HAZY

a brief introduction to CLOUDY 80.06
Introduction and Commands

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CLOUDY 80.06

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1 INTRODUCTION

This is a brief synopsis of the input, output, and assumptions for the radiative-collisional equilibrium program CLOUDY. It fully defines the commands used to drive the program and the output it generates. The methods, approximations, and assumptions used by CLOUDY are outlined, although this part, like CLOUDY itself, is still under construction.

1.1 Overview

Many environments are encountered in which dilute gas is heated and ionized by the radiation field of a central object. Under these circumstances it is possible to predict the physical conditions (that is, the run of ionization, density, and temperature) of the gas, and its resulting emission-line spectrum, in a unique and self-consistent manner. This is done by simultaneously solving the equations of statistical and thermal equilibrium, equations which balance ionization-neutralization processes, and heating-cooling processes, respectively. Osterbrock (1988) and Aller (1984) provide definitive synopses of the basic physics governing such environments, with particular emphasis on low-density nebulae ionized by relatively soft radiation (i.e., starlight), while Davidson and Netzer (1979), Halpern and Grindlay (1980), Kallman and McCray (1982), Kwan and Krolik (1981), Wills, Netzer, and Wills (1985), and Ferland and Shields (1985) provide additional details of effects of high-energy radiation and line transfer.

1.2 What Must be Specified

One powerful asset of photoionization analysis is the large number of observables resulting from only a few input parameters. Intensities of roughly 500 emission lines are predicted by CLOUDY (many of these are of negligible intensity at any one time, of course) and these result from the specification of only a) the shape and intensity of the incident continuum, b) the chemical composition of the gas, and c) the geometry of the gas, including its radial extent and the dependence of density on radius. The following subsections describe the general philosophy of the specification of each.

1.2.1 Incident Continuum

Both the shape and intensity of the incident continuum must be specified.

The shape of the continuum should be specified between an energy of 1.001×10^{-5} Ryd ($\lambda \sim 1$ cm) and an energy of 100 MeV ($\sim 7.354 \times 10^{6}$ Ryd). (In much of the following discussion energy will be given in Rydbergs. The ionization potential of

hydrogen is nearly 1 Rydberg. See section 14.9 below for an exact definition.) A physically motivated continuum spanning the full energy range should be specified, if possible. The continuum can be specified as a fundamental form (such as blackbody emission, optically thin bremsstrahlung emission, or a power-law with optional exponential cutoff), interpolated from tables of points, or a continuum predicted by previous calculations with CLOUDY. Additionally, a set of "built-in" continua (for instance, some of the Mihalas 1972 and Kurucz 1979 model atmospheres, the observed Crab Nebula continuum, or several "typical" AGN continua) can be specified.

The intensity of the continuum must also be specified in some manner. In general, the continuum can be specified as a flux (energy or photon) per unit area of cloud, in which case the inner radius of the cloud need not be specified (a plane parallel geometry will be assumed if the inner radius is not specified), or the continuum can be specified as a luminosity (energy or photon) radiated by the central object into 4π sr, in which case the inner radius of the cloud must be specified. In the first case the predicted emission-line spectrum will give the line intensity (energy radiated per unit area of cloud) and in the second case, the total line luminosity. The intensity of the continuum can be set by specifying the flux of photons, a flux density, or a luminosity, at arbitrary energies, or by giving the absolute visual or bolometric magnitude of the continuum source.

Up to ten continua of any form can be blended. If more than one continuum is entered, then there must be exactly the same number of shape and luminosity specifications. The code will stop if there are not.

1.2.2 Chemical Composition

The program considers hydrogen, helium, carbon, nitrogen, oxygen, neon, magnesium, aluminum, silicon, sulfur, argon, calcium, and iron, in detail. All stages of ionization are treated, and all published charge exchange, radiative recombination, and dielectronic recombination processes are included as recombination mechanisms. Photoionization from valence and inner shells and many excited states, as well as collisional ionization by both thermal and supra-thermal electrons, are included as ionization mechanisms. The default composition is close to a solar mixture, several other standard mixtures can easily be specified, and an arbitrary composition can be entered.

1.2.3 Geometry

The geometry is always spherical, but can be made effectively plane parallel by making the inner radius much larger than the thickness of the cloud. The default is for the gas to be constant density and fully fill its volume, but several other pressure laws and

models with only part of the volume filled can be computed as well.

CLOUDY normally assumes an "open" geometry, or one in which the gas has a very small covering factor (these terms are defined in section 2 below). This can be changed with the "SPHERE" command, which sets the covering factor to a large enough value for continuous radiation escaping the cloud in the direction towards the central object to always interact with gas on the other side. Line photons which cross the central hole interact with gas on the other side if "SPHERE STATIC" is set, but do not interact (because of a Doppler shift due to expansion) if "SPHERE EXPANDING" is set (this case is the default when "SPHERE" is specified).

1.2.4 Velocity Structure

Normally, CLOUDY assumes only thermal broadening of lines, the absence of any sort of internal velocity structure, and that the gas covering factor is so small that photons escaping the computed ionization structure do not interact with other emitting gas (i.e., an open geometry is assumed).

These assumptions can be changed in several ways. A component of microturbulence can be added with the "TURBULENCE" command. A "WIND" model, in which case a Sobolev (large velocity gradient) model is assumed, can be computed.

1.3 What is Computed and Printed

CLOUDY is driven by a set of command lines which are four letter keywords (either upper or lower case) followed by free format numbers which may be mixed with letters. Normally CLOUDY is executed as a stand-alone program. In this case fortran unit 5 is read for input, and unit 6 is used for output. It is also possible for a larger program to drive CLOUDY directly.

The program begins by echoing the input commands (with the exception of lines beginning with an "#", "%", or "*", these line have no effect). The input stream ends with either a blank line or the end-of-file. Some properties of the incident radiation field, such as luminosity and number of photons in certain frequency ranges, are then printed.

CLOUDY works by dividing a spherical nebula into a set of thin concentric shells. The shells are chosen to have thicknesses which are small enough for the physical conditions to be nearly constant within; the physical thicknesses of the shells are continuously adjusted to ensure this. Each of these shells is referred to as a "zone", and typically $\sim$ 100–200 zones are computed in a optically thick model. The physical conditions in the first and last zones are always printed and intermediate zones may be printed if needed (this is governed by the "PRINT EVERY" command). The print-out

for each zone begins with a line giving the zone number, its temperature, the distance from the center of the spherical nebula to the center of the zone, and some other properties of the solution. The next line gives some intensities of selected emission lines, while the following line gives the relative contributions of various emission lines to the radiation pressure, if this amounts to more than 5% of the gas pressure. The next lines give the ionization fraction and level populations of hydrogen excited states (2s and 2p are printed separately), and the remaining lines give the relative populations of ionization stages of the remaining elements. Many details about the conditions within the zone are intermixed with these relative populations.

After the zone calculations are complete and the model is finished, some warnings, cautions, or notes about the calculation may follow. The code is designed to check that its range of validity is not exceeded, and to complain if this occurs, or if it feels that some parameter has been mis-set. Next, optional plots of the incident and emergent continua, gas opacities, or heating-cooling curves, etc, may follow.

The final printout begins with a recapitulation of the commands, followed by the predicted emission-line spectrum. The first two columns of the emission-line spectrum give the ion and wavelength, the third column is the log of the luminosity or intensity of the emission line, and the last column gives its intensity relative to the reference line, which is usually Hβ (others can be chosen with the "NORMALIZE" command). The third column will be either the luminosity (energy radiated by a shell of gas covering Ω sr of the central object), if the continuum luminosity is specified as energy radiated into 4π sr, or the line intensity (energy emitted per square centimeter of the gas slab) if the incident continuum is specified as a flux. If the geometry is spherical, but the continuum is specified per unit area, then the line intensities will be expressed relative to the inner radius. Only the strongest emission lines are printed; the relative intensity of the weakest line to print is adjusted with the "FAINT" command.

Finally, the last page of the printout gives some averages of the ionization fractions over the slab, the optical depths in various lines and continua, the intensity of the continuum emerging from the cloud, and other properties of the nebula.

1.4 Acknowledgements

CLOUDY's development has been added by conversations with far too many people to list here. The roles of Peter G. Martin and Hagai Netzer were special, however. Peter added several of the commands which deal with ordering of supplemental line lists and the luminosity option on the blackbody command, insisted that CLOUDY run on a VAX, and provided access to the University of Toronto VAX 11/780 at a crucial time. Hagai and I have spent countless hours arguing over methods, assumptions, and just whose code had the bug. These comparisons are the only way to debug codes as large as CLOUDY or ION. My collaborators, J. Baldwin, R. Boyd, E. Capriotti, R. Carswell,

S. Cota, M. Elitzur, A. Fabian, C. Gaskell, R. Johnstone, K. Korista, D. Lambert, W. Mathews, J. Mihalszki, R. Mushotzky, S. Persson, M. Rees, G. Shields, and J. Truran contributed to the development of various parts of CLOUDY. Portions of the code were written by R.F. Carswell, S.A. Cota, and P.G. Martin. Sections of the code are taken from published work of Hummer (1988) and Press et al. (1986). Significant problems or suggestions which led to the improvement of CLOUDY were discovered/made by M. Diaz, B. Espey, M. Gaskell, R. Johnstone, S. Morris, and G. Perola.

Finally, the development of CLOUDY would not have been possible without the continued support of The National Science Foundation, through grants AST 80-2522, 83-05094, 85-12414, 87-19607, and most recently AST 90-19692. A generous allotment of time on the Ohio Supercomputer Center CRAY Y-MP is also gratefully acknowledged.

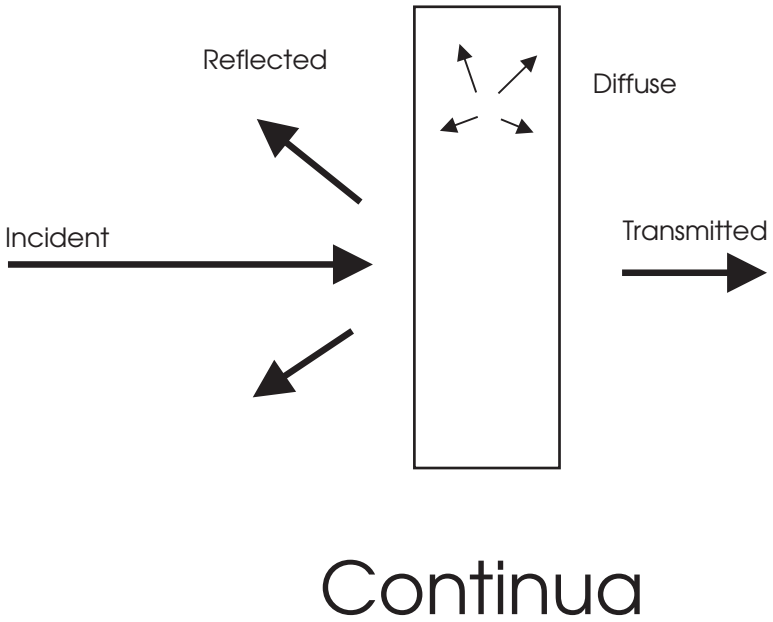

Figure 1: This figure illustrates several of the continua which enter in the calculations. Individual continua can be output by use of the "punch" command. continua

2 DEFINITIONS

2.1 Continua

Figure 1 shows several of the continua computed in the calculation.

Incident continuum The incident continuum is the external continuum emitted by the central object and striking the illuminated face of the cloud. It is usually specified in the initial conditions for the calculation. Usually absorption of the incident continuum is the only energy source for the cloud. Within the cloud the incident continuum is diminished by extinction.

Diffuse continuum The diffuse continuum (often referred to as the diffuse field) is the radiation field emitted by gas within the nebula. Examples include the Lyman,

Balmer, or two-photon continua emitted by hydrogen. These fields are very nearly isotropic, and can be significant sources of ionizing radiation under some circumstances.

The main difference between the calculation of a stellar atmosphere and a model nebula is in the treatment of the diffuse fields. In a nebula they are by definition much weaker than the attenuated incident continuum, and the gas albedo is generally small. By contrast, in a stellar atmosphere the local mean intensity is often dominated by the diffuse field. As a result the diffuse fields can be treated by lower order approximations in a nebula than in a stellar atmosphere.

Transmitted continuum The transmitted continuum is the net continuum emergent from the shielded face of the cloud. It includes both the attenuated incident continuum and the transferred diffuse continuum.

Reflected continuum The reflected continuum is the continuum emitted from the illuminated face of the cloud in the direction towards (i.e., within 2π sr of) the source of the incident continuum. This is only computed for an open geometry (defined below).

2.2 Geometry

The geometry is always spherical, but can be changed to effectively plane parallel by making the inner radius much larger than the thickness of the cloud. In addition, it is possible to make the geometry nearly cylindrical, or a wind. The summary at the end of the calculation will say whether the geometry was plane parallel (i.e., the thickness over the inner radius, $\delta r/r_{in} < 0.1$), a thick shell ($\delta r/r_{in} < 3$), or spherical ($\delta r/r_{in} \geq 3$).

Illuminated and shielded faces of the cloud. The side of the cloud in the direction towards the source of ionizing radiation is referred to as the illuminated face of the cloud while the opposite side of the cloud is referred to as the shielded face of the cloud.

Covering factor The covering factor is the fraction of 4π sr covered by gas, as viewed by the central source of ionizing radiation. It is normally written as $\Omega/4\pi$ (Osterbrock 1988), has the limits $0 \leq \Omega/4\pi \leq 1$, and is the fraction of the radiation field emitted by the central object which actually strikes nebular gas. Many of the predicted luminosities are for a shell covering Ω sr, while line intensities are per unit area.

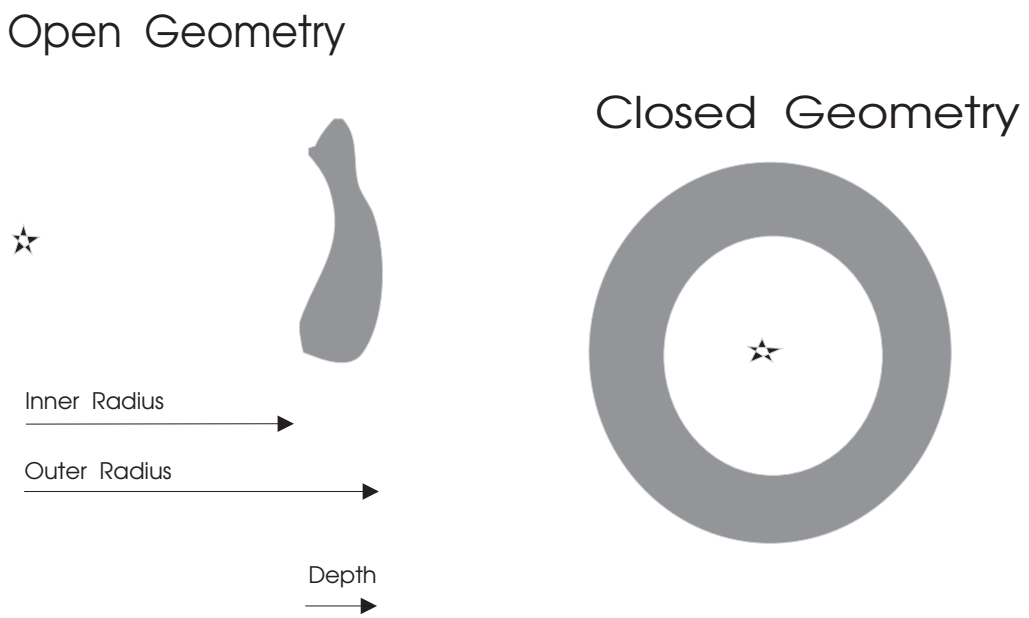

Figure 2: This figure shows the two limiting geometries which can be assumed in the calculations. The hatched area represents nebular gas. An open geometry is the default, and a closed geometry will be computed if the "sphere" command is entered. geometry

2.2.1 Open vs closed geometry

Two limiting cases can be identified for the geometry and its influence upon the ionization calculations. Here, they are referred to as "open" and "closed" geometries. Figure 2 shows examples of both. Which is the best approximation depends on the gas covering factor. The choice largely affects the calculation of the diffuse fields. These are defined in the following.

Open geometry An "open" geometry is one in which the covering factor of the gas is small and all radiation which escapes from the illuminated face of the cloud, towards the source of continuous radiation, then escapes from the system without further interaction with the gas. This is thought to be the case in, for example, the broad-line region of active nuclei or filaments in the Crab Nebula. In this case Lyβ and higher lines can escape from the nebula, and the "on-the-spot" assumption cannot be used for the innermost regions of the nebula. This geometry is the default condition for the code, and will be assumed if the "SPHERE" command (described below) is not specified.

Closed geometry Here, emission-line gas covers $\sim 4\pi$ sr as seen by the central star. If the star is small relative to the nebula, then all diffuse fields emitted by the nebula, which escape from the illuminated face of the nebula towards the star, then go on to strike the other side of the nebula. This geometry is implicitly assumed in most calculations of planetary nebulae and H II regions. Here, the "on-the-spot" assumption provides an excellent description of the hydrogen ionization balance (see, for example, Van Blerkom and Hummer 1967; Bässgen et al. 1988; Osterbrock 1988). This geometry will be assumed if the "SPHERE" command is entered.

Static vs expanding The SPHERE command has two optional arguments, "STATIC" and "EXPANDING", which determine how line photons from either side of the shell interact. The "STATIC" option causes the code to assume that the shell is stationary, so that all lines interact across the nebula. In this case, Lyman line interaction should ensure that case B emissivity is reached. If $\Omega/4\pi \sim 1$ but the nebula is expanding then the diffuse fields interact across the nebula, but the expansion velocity of the shell ensures that diffuse line photons do not; in this case the "EXPANDING" option should be set. This second case is the default when SPHERE is specified with no options.

These geometrical considerations make differences in the predicted emission-line spectrum at the $\sim$10% level, largely because of the different treatments of the diffuse fields and line optical depths.

Matter-bounded The nebula is said to be matter-bounded if the outer limit to the emission-line region is marked by the outer edge of the cloud. In this case the cloud is optically thin to the incident continuum.

Radiation-bounded The nebula is said to be radiation-bounded if the outer limit to the emission-line region is marked by an ionization front. In this case nearly all of the incident continuum has been absorbed by the cloud.

3 LIMITS, ASSUMPTIONS, AND RELIABILITY

This section outlines some of the assumptions and limits which define the range of validity of CLOUDY. The code is designed to check that the limits of its validity are not exceeded during a calculation. CLOUDY should print a warning after the last zone results if any aspects of the calculation are on thin ice.

3.1 Time Steady

Although it is possible to follow the time-dependent recombination and cooling of an optically thin cell of gas following the rapid extinction of the radiation field with the "TIME" command, steady-state is generally assumed. Various time scales characterize the approach to equilibrium of an ionized gas (see Spitzer, 1962, and Ferland 1979 for a specific application); generally, the longest is the recombination time scale,

$$T_{rec} \approx \frac{1}{\alpha(T_e)\ N_e} \approx 1.15\ {t_4}^{0.8}\ N_9 \quad hours \tag{1}$$

where t_4 is the temperature in units of 10^4K, and N_9 is the density in units of 10^9 cm^{-3}. CLOUDY is not appropriate for the treatment of situations where conditions change more rapidly than this.

3.2 Atomic Database

By its nature, the electron temperature of a photoionized gas is low compared with the ionization temperature of the mixture of atoms and ions, as defined by the Saha equation (if the two were comparable, the gas would be collisionally ionized). Because of this, the rate coefficients describing collisional effects, such as the production of cooling emission lines, are often dominated by the cross section near threshold. This is where laboratory experiments are difficult and *ab initio* quantum theory must often be used. As a result, the collision strengths undergo constant revision, hopefully towards better and more reliable values. To cite one extreme example, the collision strength for transitions within the ^{3}P ground term of Ne^{+4} has undergone three revisions between 1984 and 1991, each by a factor of 10, because of theoretical uncertainties in positions of autoionizing states which have not been observed (Lennon and Burke 1991). The intensities of all emission lines can be affected by major changes in the atomic data for only one line for some conditions. This is because (in this case) the infrared fine structure lines of Ne^{+4} can be important coolants in low-density high-ionization gasses such as planetary nebulae, and changing their cooling rate alters the thermal structure

of the entire nebula. Such changes often give even models of time-steady objects such as planetary nebulae certain time-dependent characteristics.

At present, there are fairly reliable calculations of collision strengths and transition probabilities for the majority of the important coolants in moderate ionization nebulae. This is not the case for photoionization cross sections, recombination coefficients, and charge transfer rate coefficients. Photoionization cross sections for inner electron removal by high energy radiation are fairly well known; the uncertainties are in the valence cross sections. To cite one extreme example, the cross sections for removal of outer electrons of atoms and ions of sulfur have been calculated by Chapman and Henry (1971) and by Reilman and Manson (1979). The Chapman and Henry results are consistently larger than those of Reilman and Manson, often by factors approaching 10. Similarly, low-temperature (through low-lying autoionizing states) dielectronic recombination rate coefficients have not been computed for most third row elements and iron. Extensions to the Opacity Project (Seaton 1987) should soon correct this situation. These differences result in a factor of four difference in the predicted intensity of [S II] 6731 in certain H II region calculations, where valence shell photoionization is especially important. The differences are smaller for planetary nebulae or active galactic nuclei where inner electrons are energetically accessible (because the radiation field is much harder). CLOUDY uses unpublished cross-sections of Mendoza; these are intermediate between the two published extremes. Fortunately, the photoionization-recombination cross section database will improve dramatically with the completion of the Opacity Project and its extension to recombination processes, in a few years.

Another uncertainty in the atomic/molecular data base is the rate coefficients for charge transfer. This process is often the dominant neutralization mechanism for singly or doubly ionized heavy elements. At present some charge exchange rate coefficients are the result of Landau-Zenner calculations using semi-empirical potential curves; these are thought to be accurate to better than a factor of three. Even the best quantal calculations of charge transfer rate coefficients are not thought to have an accuracy much better than 50 percent. Unpublished tests suggest that these uncertainties affect many line intensities at the $\sim 20\%$ level, and some by more than this. These uncertainties underscore the importance of atomic/molecular theory for the interpretation of astrophysical spectroscopy.

3.3 Continuous Opacity

All significant continuous opacity sources are treated for the energy range considered by the code, 1.001×10^{-5} Ryd to 7.354×10^{6} Ryd. These opacity sources include inverse bremsstrahlung, grains (when present), H^- absorption, electron scattering, the damping wings of hydrogen Lyman lines (i.e., Rayleigh scattering), pair production,

photoelectric absorption by the ground and excited states of the 13 elements included in the calculation, and photoabsorption by molecules. This treatment should be adequate as long as the optical depths to electron scattering are not large; CLOUDY is not now designed to model Compton-thick regimes.

A warning will be issued after the last zone calculation if the nebula is optically thick to an opacity source which is not fully treated.

3.4 Temperature Range

CLOUDY assumes that the electrons are non-relativistic, which limits it to temperatures below roughly 10^9 K. Tests (see section 20.3 below) show that CLOUDY goes to the Compton temperature of the radiation field to great accuracy in the limit of very high levels of ionization for blackbody radiation fields between 3K and 10^{10}K. There is no formal lower temperature limit to its validity, but the approximations used for ionic recombination coefficients (Pequignot and Aldrovandi 1986) were not intended for temperatures below 10K, (gas this cold is generally molecular, however) and the approximations for most charge transfer rate coefficients were not intended to be used below temperatures between 10^2K to 10^3K. The free-free gaunt factors, taken from Hummer (1988), do not extend above $\sim 10^8$ K or below $\sim 10^3$ K.

The present range of validity of the code is now approximately from 10K to 10^9K. Temperatures outside this range can still be treated, although with greater uncertainty. (This applies to ions, atoms, and hydrogen molecules over the stated temperature range; work on heavy element molecules is still in progress.)

3.5 Density Range

There is no formal lower limit to the density which CLOUDY can treat. The set of heavy element fine structure lines, which dominate cooling at low densities, is complete for low and moderate stages of ionization, and fine structure optical depth and maser effects are fully treated using the escape probability formalism. Note that for very low density models ($N_H \leq 10^{-1}$ cm^{-3}) with "typical" values of the ionization parameter (defined below) it is usually necessary to also consider diffuse sources of radiation such as the cosmic x-ray background, diffuse interstellar starlight, and the cosmic ray background. These must be specified independently as part of the incident continuum.

There is no formal high density limit, other than the (inexact) treatment of radiative transfer (see Avrett and Loeser 1988) and the approximate treatment of the collisional-radiative ionization processes for excited levels of the heavy elements. Hydrogen and atoms and ions of helium are treated as 10-level atoms, including all of the physical processes which allow the approach to LTE (see, for example, Mihalas 1978). Tests with a hydrogen density of 10^{19} cm^{-3} show that CLOUDY's hydrogen

and helium atoms do go to LTE at high densities; thus there is no formal high density limit to its validity. The treatment of Stark broadening for hydrogen lines follows Puetter (1981), so radiative transfer is treated correctly (in the context of the escape probability formalism) for densities above $\sim 10^{10}$ cm^{-3}. The treatment of the other 11 elements is presently not as complete as hydrogen and helium, but 3-body recombination is included as a general recombination process, so the treatment of these elements is approximately correct at high densities.

CLOUDY has been tested at densities of 10^{-4} cm^{-3} and 10^{19} cm^{-3} on 32-bit machines. The numerical (not physical) limit to the density will actually be set by the limits to the range of the floating point numbers allowed by the machine in use (densities of 10^{-6} cm^{-3} and 10^{20} cm^{-3} don't work on IEEE 32-bit machines for this reason). The physics incorporated in the code imposes no lower limit to the density. The physical high-density limit is probably now set by the approximate treatment of three-body recombination–collisional ionization for the heavy elements ($\geq 10^{13}$ cm^{-3}), and the approximate treatment of line transfer (i.e., escape probabilities). Non-LTE ionization, thermal equilibria, and line transfer at high densities is an area of on-going research.

3.6 Radiative Transfer

Line intensities are computed with stellar atmosphere conditions in mind. This means that radiative transfer effects, including possible maser emission, are treated. Collisional effects, including excitation and de-excitation, continuum florescence, recombination, etc, are all included as general line excitation mechanisms, and "nebular" approximations, such as the approximation that all atoms are in the ground state, are not made. The treatment of level populations is designed to go to LTE in the high density case.

Line and continuum transfer is currently treated using escape probabilities. This is probably the weakest assumption in the present prediction of the line intensities. Work is now underway to begin the conversion to formally correct transport methods. There is no way to judge the error introduced by the escape probability approximation, although it is known to be exact if the conditions do not vary across the line forming region (Elitzur 1982).

3.7 Hydrogen

Hydrogen is treated as a ten level (plus continuum) atom. The $2s$ and $2p$ states are treated separately, so Lyα and 2-photon emission are computed properly in low-density nebulae. Quantum numbers between 3 and 6 are treated assuming full l-mixing, as in Seaton (1959), but with all collisional and radiative transfer effects included. Levels

between 7 and 100 are treated by substituting three pseudo-states with properties chosen to mimic these high-n states. Tests show that the hydrogen line emissivity predicted by CLOUDY agrees with all of Seaton's results to $\sim 0.1\%$, and with Hummer and Storey's (1987) case B Hβ emissivity predictions to $\sim 1\%$ for $N_H \leq 10^{10}$ cm^{-3}.

Although the Hβ emissivity is predicted by CLOUDY with great precision for all densities, this is not true of the infrared hydrogen lines at low densities. The intensities of these lines are somewhat sensitive to the degree of l-mixing of the upper levels. They are predicted with precision in the context of the *full l-mixing* approximation, but this approximation is not valid for low densities. The differences can be judged by comparing Seaton's (1959) calculation (which CLOUDY reproduces to three significant figures) with the l-state calculations presented by Pengelly (1964). One of the worst cases is Paschen α, for which Seaton predicts intensities 21% smaller than Pengelly. Beware.

The full set of hydrogen level balance equations are solved by working with LTE departure coefficients. As a result, the departure coefficient of the ground state diverges for very low temperatures when the gas is ionized yet cold, so it is not possible to treat hydrogen line transfer in detail for temperatures below 1000K on 32-bit machines. For very low temperatures CLOUDY uses a special set of approximations (fitted to the results of Martin 1988) to solve for the hydrogen ionization balance and predict emissivities. The intensities of these lines are reliable for temperatures above $\sim 10^2$ K as long as radiative transfer and optical depth effects are not important. (It is unlikely that significant HII emission will occur for gas colder than this 10^2K limit.) If such low temperatures occur, and the matrix solution is not used, then a comment is printed after the last zone calculation.

Finally, the hydrogen density used by CLOUDY is the *total* hydrogen density, usually referred to by the label "HDEN", and is given by

$$N(H) = N(H^o) + N(H^+) + N(H^-) + 2N(H_2) + 2N(H_2^+) + 3N(H_3^+) \quad . \qquad (2)$$

3.8 Helium

Model atoms. Helium is treated as three separate atoms/ions; ionized helium (a ten level atom), the singlets (a ten level atom), and the triplets (presently a five level atom). The treatment of the three ions is entirely analogous to that of hydrogen; it goes to LTE in the limits of large photon or particle densities. The low-temperature limit to the matrix treatment of the He^o singlets and He$^+$ are 1000K and 1500K respectively. Below these temperatures approximations to case B results are used.

As with hydrogen, these model singlet and He$^+$ atoms assume complete l-mixing for levels $3 \leq n \leq 100$. As mentioned above, this is not a good approximation for low densities. For instance, the intensity of λ4686 is exact at high densities, but differs by

nearly 40 percent from low density case B predictions. For the time being, it is probably better to use the case B predictions, rather than the results of the 10-level atom calculations, for HeII line emission at low densities, when line transfer and collisional excitation are not important. The predictions of the ten-level atom are better when either process is important, or the density is high enough for complete l-mixing to be a good approximation.

Helium Radiative Transfer. The helium line and continuum transfer problem is one whose importance in determining the intensities of many ultraviolet lines is generally underestimated (see, for example, the discussion by Netzer and Ferland 1984). Recombinations to the He^+ ground and first excited state, and HeII Lyα, all ionize hydrogen, and the He II Lyα line undergoes Bowen fluorescence (Osterbrock 1988; Netzer, Elitzur, and Ferland 1985). Unfortunately these continua, and especially the Bowen lines, can be the main source of photoelectric heating in the He^{++} zone of some high-ionization nebulae. Fundamental uncertainties in the treatment of the Bowen problem introduce substantial uncertainties in the local heating rate, and hence in the intensities of some ultraviolet lines, such as C III] λ 1909 and C IV λ1549, because these lines are very temperature sensitive. My experience is that minor changes in the treatment of the Bowen problem typically results in $\sim 20\%$ changes in the intensities of these ultraviolet lines in certain low density nebulae, and in the near ultraviolet [Ne V] lines.

3.9 Atoms and Ions of the Heavy Elements

Most heavy elements are treated as two level systems (ground term and continuum) although photoionization from excited states is included for those cases where it is sometimes important (O^{++} and N^+ are two examples). All published charge transfer, radiative and dielectronic recombination, collisional ionization, and three body recombination processes are included in the ionization balance.

The treatment of the heavy element ionization balance should be exact in the nebular limit, but approximate for very high photon or particle densities because of the two-level treatment.

3.10 Molecules

At the present time a major effort is being made to complete the treatment of the heavy-element molecular equilibria and cooling in the code. The treatment of the hydrogen molecules/ions H^-, H_2, H_2^+, H_3^+, and HeH^+ is now fairly complete. The equilibrium of the heavy-element molecules is now treated with various levels of approximation. The predictions are thought to be correct for nebular ($N < 10^8$ cm^{-3})

conditions, but do not now go to LTE in the high nucleon-photon limits, and do not go to the fully molecular limit.

3.11 Reliability

There are several issues to address in regards to the general question of reliability of the code. The first is the effects of the bugs which surely must exist in a code the size of CLOUDY. I have seldom found bugs in sections of the code older than roughly $\sim 2-3$ years. Younger sections of the code sometimes contain bugs that only manifest themselves in exceptional situations. It is my belief that the issue of reliability in the face of complexity will increasingly be the single major problem limiting the development of large-scale numerical simulations. New methods of writing code will have to be developed if we are to take full advantage of the power of future machines. Machines are getting faster more quickly than people are getting smarter.

Test cases which are designed to exercise the code in certain well-posed limits are presented in sections 25 and 24 below. Calculations of certain standard nebulae are also shown there. The code is well-behaved in these simple limits, and agrees well with predictions of similar codes when applied to "nebular" situations.

The second issue is the validity of the numerical methods used to simulate conditions in the nebulae. Fundamental uncertainties arise for cases where the density is high (N$\gg 10^{10}$ cm^{-3}). The radiative transfer techniques used by CLOUDY are approximate (see the discussion by Avrett and Loeser 1988). Unfortunately, no definitive calculation now exists for the complete non-LTE equilibrium and emission for an intermediate density ($\sim 10^{10}$ cm^{-3}) cloud. For less extreme conditions (N$\ll 10^{10}$ cm^{-3}) nebular approximations are valid, and the comparisons presented below (section 24) shows good agreement with other codes designed to work in this limit.

Uncertainties in the atomic data base are a third concern. A great deal of progress will result over the next few years with the completion of the Opacity Project (Seaton 1987), although charge transfer, a process normally treated on a molecular basis, will remain an uncertainty.

In the end the uncertainties can probably best be judged by looking at both the dispersion among the various photoionization calculations presented in section 24 and the changes that have occurred in the predictions made by CLOUDY itself over the past few years. Much of the dispersion is due to changes in the atomic data base, changes which are likely to settle down with the completion of the Opacity Project.

3.12 The Future

The eventual goal is for CLOUDY to give reliable results for all extremes of conditions between and including the intergalactic medium and stellar atmospheres. I estimate

that the code is now well over half–way complete.

Current work centers on making the code formally correct in the optically thin limit for all extremes of radiation and matter densities. Much has already been done, and present efforts center on helium, molecules, and the heavy elements.

Line transfer is now treated with escape probabilities, an approximation which is not formally correct when conditions vary across the line forming region (see, for instance, Avrett and Loeser 1988). A major change, to be completed within the next year, is to transfer Lyα correctly, using the proper mixture of redistribution functions, using an approach similar to that of Hummer and Kunasz (1980).

By the time this work is complete, the Opacity Project (Seaton 1987) should also be finished, and attention will return to the heavy elements. An approach similar to that now used for hydrogen and helium (employing several pseudo-states to allow the model atom to correctly approach LTE) will be used to ensure that the treatment of the heavy elements is correct for all densities and temperatures.

The two major remaining concerns will be the continuum transport (especially in the infrared) and line transfer (complete redistribution is a good approximation for most lines). Both can be treated in a straightforward manner using standard radiative transfer techniques.

4 COMMANDS

This section summarizes the commands which drive CLOUDY. They are grouped together by purpose, and individual commands are discussed after examples of their use.

4.1 Default Conditions

CLOUDY is designed to be easy to use, so that a minimum number of commands are needed to drive it. The general philosophy is for a reasonable set of initial conditions to be assumed by default. These default conditions are summarized in Table 1. The code is also designed to check that its assumptions are not violated, and to complain if problems occur, if its limits are exceeded, or if the input parameters are misused.

Table 1: Default Conditions

Variable	Value	Section	Quantity
rdfalt	10^{25} cm	4.8.4	default inner radius
router	10^{30} cm	4.8.4	default outer radius
telow	10K	4.10.9	lowest temperature allowed by code
tehigh	10^{10}K	-	highest allowed temperature
tend	4000K	4.11.7	lowest temperature to allow in model
thlo	1000K	4.9.7	lowest temperature in H^o matrix
the1lo	1000K	-	lowest temperature in He^o singlet matrix
the2lo	1500K	-	lowest temperature in He^+ matrix
flxfnt	10^{-10}	4.14.6	relative flux of high energy to consider
cylind	10^{35} cm	4.8.2	half-thickness of cylinder in geometry
toler	0.02	4.10.15	tolerance in heating-cooling match
faint	10^{-4}	4.12.1	relative intensity of faintest line to print
emm	1.001×10^{-5} Ryd	-	low energy limit to radiation field
egamry	7.354×10^{6} Ryd	-	high energy limit to radiation field
nend	300	4.11.9	limiting number of zones
colend	10^{30} cm^{-2}	4.11.2	limiting total hydrogen column density
colpls	10^{30} cm^{-2}	4.11.2	limiting ionized hydrogen column density
colnut	10^{30} cm^{-2}	4.11.2	limiting neutral hydrogen column density
grains?	no grains	4.9.5	grain mixture
abundances	"solar"	4.6.1	default composition

4.2 Command Format

When executed as a stand-alone program, CLOUDY reads Fortran unit 5 for input and produces output on unit 6. The code is also designed to be used as a subroutine of other, much larger, programs. In this case the input stream is entered using the subroutine calls described in section 10 below. In either case, this input stream must contain the commands used to drive the program. The commands used to set the initial conditions in code are described next.

All commands are entered as free format lines, beginning with a four character key word specifying the purpose of the command, and usually followed by one or more numbers or keywords. Up to 100 separate commands may be entered; this is limited by the variable NKRD which appears in several parameter statements throughout the code. Most commands use cgs units. The command lines can be in any order, and can be up to 80 characters long, in either lower or upper case. The end of each line is marked either by column 80, the end-of-line, a colon ":", a semi-colon ";", or a percentage sign "%". The input stream ends with either a blank line or the end-of-file. In the following examples the individual command keywords are shown extending beyond column 4, and these extra characters are completely ignored (except for some special commands which use optional keywords).

4.2.1 Example formats

Sections describing each of the commands are introduced by examples of their use. In these examples optional parameters are shown surrounded by square brackets ("[" and "]"). Examples are shown below.

```
*following needs flux density, but frequency is optional
f(nu) = -12.456 [at .1824 Ryd]
*the luminosity command has several optional keywords
luminosity 38.3 [solar, range, linear]
*the phi(h) command has the range option
phi(h) = 12.867 [range ...]
```

These indicate only that the parameters are optional, and the brackets need not be input on the command line.

Most commands require four character matches to be recognized. In some cases the leading character is a blank, which is indicated by an underscore ("_", an example is the keyword "_LTE"). Other examples are shown below. The underscore should not be typed, only a space character.

```
*blackbody with T=50,000, in strict TE
```

```
blackbody 50,000 lte
* use nlr abundances
abundances nlr
```

4.2.2 The continue option

It is sometimes not possible to enter all the required values on a single line for the "INTERPOLATE" and "ABUNDANCES" commands. In these two cases the original command line can be continued on following lines with a series of lines beginning with the keyword "CONTINUE". The format on a "CONTINUE" line is unchanged, and there is no limit to the number of "CONTINUE" lines which can be included.

4.2.3 Numerical input

Numbers are entered in free-format, and exponential notation cannot be used. For instance, the entry "1E20" will be interpreted as the numbers 1 and 20, and no error message will result. Generally, CLOUDY avoids exponential notation on input by entering numbers as logs, so "1E20" is usually entered as "20.0". Commas can be freely embedded in input numbers and they may be preceded or followed by characters to increase readability (i.e., "T=1,000,000K" and "1000000", and usually "T=6", are equivalent, but T=1E6 is not). A period or full stop (".") by itself is interpreted as a character, not numeral or number. Default values are often available. As an example, the "POWER LAW" command has three parameters, the last two being optional. The following are all acceptable (but not equivalent) forms of the command;

```
power law, slope=-1.4, exponential cutoffs at 9 Ryd and 0.01 Ryd
powe -1.0 5
power law, slope=-1.4 .
```

The last version uses the default cutoffs, i.e, none. Note that implicit negative signs (for instance, for the slope of the power law) *do not* occur in any of the following commands.

4.2.4 Comments

Comments may be entered among the input data in several ways. Anything on a line which occurs after a colon, semi-colon, or percentage sign is completely ignored; this can be used to document parameters on a line. Any line beginning with a "#", "%", or a "*" is totally ignored; it is not even printed. A line beginning with "c_" is ignored, but printed (note that there was a space after the c). There is also a "TITLE" command, to enter a title for the model, as described below.

4.2.5 Some systematics

An attempt has been made to beep the input quantities as logical as possible. Most quantities are entered as the log of the number, but some are linear. Many commands have the sub-keywords "_log" and "linear" to force one or the other interpretation to be used. The following outlines some systematics of how these are entered.

Temperature CLOUDY will interpret a temperature as a log if the number is less than or equal to 10, and linear if greater than 10. Many commands have the optional keyword "linear" to force temperatures below 10K to be interpreted as the linear quantity rather than the log.

Linear vs log for other parameters The pattern for other quantities is not as clear as for the case of temperature. Generally, quantities are interpreted as logs if negative, but may be linear or logs if positive (depending on the command).

4.2.6 An example

Specific commands to describe the continuum (luminosity and shape), and geometrical details are discussed next. As a minimum, the hydrogen density, continuum shape, continuum luminosity or intensity, and possibly the starting radius, must be specified. As an example, a simple model of a planetary nebula could be computed by entering;

```
title - this is the input stream for a simple planetary nebula
* this is the temperature and total luminosity of the central star
black body, temperature = 100,000K, luminosity=38;[log(L)- ergs/s]
radius 17   ;log of starting radius in cm
hden 4      ;log of hydrogen density - cm^-3
filling factor 0.3 ;set a filling factor of 30 percent
sphere ; tell cloudy this is a sphere with large covering factor
```

4.3 Combinations of Continua

The continuum shape can be set by interpolating on tables of points, read in from predictions of previous calculations, and/or by specifying fundamental forms such as blackbody, power law, or bremsstrahlung emission. It is possible to combine up to 10 continua of any shape.[1] When more than one continuum is entered, the series of

[1]Restrictions on the number of tables which could be entered existed in CLOUDY versions 73 and before, but have been lifted. Restrictions on which types of continua could be combined existed in CLOUDY versions 67 and before, but have been lifted.

luminosity and shape commands must be in the same order (i.e., map one to one). There must always be exactly the same number of continuum luminosity and shape specifications; CLOUDY will stop if there are not.

As an example, the following would be a rough approximation of an accretion disk and boundary layer around a white dwarf:

```
black body, temp=500,000K
luminosity (total) 37
power law, slope=1.333, cutoff=0.6 Ryd; this is a rising power law
luminosity (total) 37
```

CLOUDY will stop if more than 10 continua are entered. This limit is set by the variable LIMSPC which occurs in several PARAMETER statements throughout the code. Increase LIMSPC everywhere if more than 10 continua are required.

4.4 Continuum Luminosity

The commands setting the intensity or luminosity of the continuum are described here. CLOUDY actually works with continuum fluxes in units similar to "photons cm^{-2} s^{-1} Ryd^{-1}", to avoid single-precision floating-point exponent limits on 32-bit IEEE machines. The intensity of the incident continuum can be set by specifying a luminosity, the number of photons, a flux density f_ν, or the absolute visual or bolometric magnitude. These can be the quantity emitted by the central object into 4π sr (with units s^{-1}) or the surface flux at the illuminated face of the cloud (with units $cm^{-2}\,s^{-1}$). The intensity of the predicted emission lines will be either a intensity (energy radiated per unit area of cloud), or the luminosity radiated by a shell covering Ω sr, where Ω is the angular coverage of the nebula and $\Omega/4\pi$ is the covering factor. Which is predicted depends on how the incident continuum was specified.

4.4.1 Continuum Normalization

For many luminosity or flux commands there is no ambiguity as to whether the incident continuum is specified as per unit area of cloud surface, or the continuum radiated into 4π sr. Examples include the "IONIZATION PARAMETER" command (continuum per unit area) and the "LUMINOSITY" command. For other commands there may be an ambiguity. In these cases CLOUDY assumes that the quantity is specified as the total radiated into 4π sr if the ionization parameter deduced by assuming that the continuum is per unit area is greater than U= 10^{10}, while the ionization parameter deduced by assuming that the continuum is into 4π sr is greater than U= 10^{-15}. The continuum is assumed to be per unit area otherwise.

4.4.2 The RANGE Option

For most of the luminosity commands the default is for the quantity entered to be the number of photons or luminosity *in ionizing radiation* (13.6 eV $\leq h\nu \leq$ 100 MeV). Other energy intervals can be specified with the "RANGE" option, an optional keyword on the "LUMINOSITY", "Q(H)", and "PHI(H)" commands.

The range option appears on the line specifying the luminosity and is invoked by entering the keyword "RANGE". When "RANGE" is specified there are an additional two parameters, the low and high energy limits to the energy range in Rydbergs. These appear as the second and third numbers on the line. The position of the keyword "RANGE" on the command line does not matter, but the order of the numbers on the line does. If the first optional number is negative or the keyword "_log" appears then *both* of the extra numbers are interpreted as logs. If either parameter is zero then the low (1.001×10^{-5} Ryd) or high (7.354×10^{6} Ryd) energy limit of the continuum will be substituted. If both energies are specified then the second number must be larger than the first (unless the second is zero). If only one parameter appears then only the lower limit of the range will be changed, and the high energy limit will be left at its default of 7.354×10^{6} Ryd. If the keyword "TOTAL" (equivalent to "RANGE TOTAL") appears with no parameters then the full energy range considered by the program will be used.

The following are some examples of the use of the range option in modifying the range on the "LUMINOSITY" command. The default condition on the "LUMINOSITY" command is for the single parameter to be the log of the luminosity (erg s^{-1}) in ionizing (1 Ryd $\leq$ hν <7.354×10^{6} Ryd) radiation.

```
* this will use the default range, only ionizing radiation
luminosity 38 ;log of luminosity in erg/sec

* either will be the total luminosity
luminosity total 38
luminosity range total 33.4

* this will be the luminosity in visible light
luminosity 37.8 range .15 to .23 Ryd

* the luminosity in radiation more energetic than 0.1 Ryd
luminosity 38.1 range -1

* this will be the luminosity in non-ionizing radiation
luminosity 39.8 range 0 1
```

4.4.3 absolute [visual, bolometric] magnitude -2.3

It is possible to specify the luminosity in "magnitudes", a quaint unit of historical interest. One of the keywords "bolometric" or "visual" must also appear. The absolute bolometric magnitude M_{bol} is related to the total luminosity by

$$L_{total} = 3.826 \times 10^{33} \times 10^{(4.72-M_{bol})/2.5} \ erg\ s^{-1} \ . \tag{3}$$

The absolute visual magnitude M_V is approximately related to the flux at 5550Å by

$$\nu F_\nu(5550\mathring{A}) \approx 3.086 \times 10^{33} \times 10^{(4.79-M_V)/2.5} \ erg\ Hz^{-1}\ s^{-1} \ . \tag{4}$$

The conversion between flux and absolute visual magnitude is approximate, with typical errors of roughly a percent, because CLOUDY assumes that the V filter has an isophotal wavelength of 5550Å, and does not actually integrate over the incident continuum using a V-filter transmission function.

The starting radius for the calculation must be specified since this command specifies the luminosity radiated into 4π sr.

4.4.4 f(nu) = -12.456 [at .1824 Ryd]

This command allows the flux density f_ν to be specified. The first number is the log of either the specific luminosity radiated by the central object into 4π sr (erg s^{-1} Hz^{-1}) or the surface flux density at the illuminated face of the cloud (erg s^{-1} Hz^{-1} cm^{-2}). In the second case the number is $4\pi J_\nu$, where J_ν is the mean intensity of the incident continuum.

The optional second number is the frequency in Rydbergs where f_ν is specified; the default is 1 Ryd, and in the example above the continuum is specified at 0.1824 Ryd = 5000Å. The frequency can be any within the energy band considered by the code, presently 1.001×10^{-5} Ryd to 7.354×10^{6} Ryd. If the energy is less than or equal to zero then it is interpreted as the log of the energy in Rydbergs, and the linear energy itself if positive.

It is not necessary to also specify the starting radius if f_ν is specified (per unit area) using this command.

4.4.5 ionization parameter = -1.984

The ionization parameter is the dimensionless ratio of photon to hydrogen densities, and is defined as

$$U \equiv \frac{Q(H)}{4\pi r^2\ N_H\ c} \equiv \frac{\phi(H)}{N_H\ c} \tag{5}$$

where r is the separation between the source of ionizing radiation and the cloud, N_H is the total hydrogen density (ionized, neutral, and molecular), c is the speed of light,

and $Q(H)$ is the number of hydrogen-ionizing photons emitted by the central object (s^{-1}).[2] In this expression ϕ(H) is the surface flux of ionizing photons (cm^{-2} s^{-1}). The number entered is the log of the ionization parameter. The ionization parameter is a useful quantity in plane parallel constant-density models, because of homology relations between models with different photon and gas densities but the same ionization parameter (see Davidson 1977).

It is not necessary to also specify a starting radius since the ionization parameter and hydrogen density together uniquely determine the flux of ionizing photons. If the starting radius is not specified, it is automatically set to 10^{25} cm to produce an effectively plane parallel model. The predicted emission-line intensities will be given as intensities (energy per unit area of emitting gas) unless a starting radius is also specified, in which case a luminosity is predicted.

4.4.6 luminosity 38.3 [solar, range, linear]

The number is either the log of the luminosity emitted by the central object into 4π sr, (erg s^{-1})

$$L = 4\pi\, R_{star}^2 \int_{\nu_1}^{\nu_2} \pi F_\nu \, d\nu \quad , \tag{6}$$

the surface energy flux (erg cm^{-2} s^{-1}) at the inner face of the cloud

$$L = \int_{\nu_1}^{\nu_2} 4\pi\, J_\nu \, d\nu \quad , \tag{7}$$

or the log of the total luminosity in solar units, if the "SOLAR" keyword is specified. The number is interpreted as the luminosity itself, rather than a log, if the optional keyword "LINEAR" appears on the line.

The default range is over hydrogen-ionizing energies (1 Ryd $\leq h\nu \leq 7.354 \times 10^6$ Ryd). The "RANGE" option can be used to adjust the values of ν_1 and ν_2. If the integrated mean intensity (equation 7) at the illuminated face of the cloud is specified then the predicted emission-line intensities will also be per unit area of gas. If the continuum intensity is specified as the total luminosity emitted by the central object into 4π sr, the emission lines will be the luminosity radiated by a shell covering Ω sr.

If the optional keyword "SOLAR" appears, the number is interpreted as the log of the *total* luminosity, relative to the luminosity of the sun (unless the "LINEAR" keyword is also used, in which case the quantity will be the relative luminosity itself). The range option cannot be used if the luminosity is specified in solar units (it will be ignored if it appears). The emission-line intensities will be the luminosity radiated by a shell covering Ω sr.

[2] Before version 65 of the code the electron density was used rather than the hydrogen density. Before version 75 N_H was the atomic/ionic hydrogen density, and did not include molecules.

The following are examples of the luminosity command.

```
*log of luminosity (erg/s) in ionizing radiation
luminosity 36

* roughly the eddington limit for one solar mass
luminosity total 38

* both are a total luminosity 1000 times solar
luminosity solar 3
luminosity linear solar 1000

* this will be the luminosity in visible light
luminosity 37.8 range .15 to .23 Ryd
```

It may or may not be necessary to specify a starting radius, depending on whether the luminosity or flux is specified.

4.4.7 nuf(nu) = 43.456 [at .1824 Ryd]

This command allows the flux density νf_ν to be specified. The first number is the log of either the specific luminosity radiated by the central object into 4π sr (erg s^{-1}) or the surface flux density at the illuminated face of the cloud (erg s^{-1} cm^{-2}). Either can be at an arbitrary frequency. In the second case the number is $4\pi\nu J_\nu$, where J_ν is the mean intensity of the incident continuum.

The optional second number is the frequency in Rydbergs where f_ν is specified; the default is 1 Ryd, and in the example above the continuum is specified at 0.1824 Ryd = 5000Å. The frequency can be any within the energy band considered by the code, presently 1.001×10^{-5} Ryd to 7.354×10^{6} Ryd. If the energy is less than or equal to zero, it is interpreted as the log of the energy in Rydbergs, and the linear energy if positive.

It may or may not be necessary to specify a starting radius, depending on whether the luminosity or flux is specified.

4.4.8 phi(h) = 12.867 [range ...]

This command is used to specify ϕ(H), the log of the surface flux of hydrogen-ionizing photons (cm^{-2} s^{-1}) striking the inner face of the cloud. It is defined as

$$\phi(H) \equiv \frac{Q(H)}{4\pi r_{inner}^2} \equiv \frac{R_{star}^2}{r_{inner}^2} \int_{\nu_1}^{\nu_2} \frac{\pi F_\nu}{h\nu}\, d\nu \ , \tag{8}$$

as in Ferland, Netzer, and Shields (1979), and is proportional to the optical depth in excited lines, such as the Balmer lines. The RANGE option can be used to change the default energy range in equation 8.

The inner radius need not be specified if this command is used since this command specifies the photon flux (i.e., per unit area).

4.4.9 Q(H) = 56.789 [range ...]

The log of the total number of ionizing photons emitted by the central object (with units s^{-1}) can be specified rather than the luminosity;

$$Q(H) = 4\pi R_{star}^2 \int_{\nu_1}^{\nu_2} \frac{\pi F_\nu}{h\nu}\, d\nu \qquad (9)$$

where the default value for ν_1 is 1 Ryd, and the default value for ν_2 is the high energy limit to the code, presently 7.354×10^6 Ryd. The RANGE option can be used to change the energy bounds ν_1 and ν_2. The photon flux (per unit area of cloud surface) can be specified with the "PHI(H)" command, described above.

It is necessary to specify a starting radius if this command is used.

4.5 Continuum Shape

The continuum should be specified between an energy of 1.001×10^{-5} Ryd ($\lambda \simeq 1$ cm; the low-energy continuum is important for Compton cooling, photoionization from excited states of hydrogen and helium, free-free heating, H^- heating, and grain heating) and 100 MeV $\simeq 7.354 \times 10^6$ Ryd (where the Klein-Nishina electron-scattering cross section is small, pair production is a competitive heating and opacity source, and the hard continuum is usually well rolled-over). CLOUDY will complain, but compute the model if possible, if the continuum is not specified over the full energy range. An intensity of zero will be assumed for missing portions of the continuum.

4.5.1 background, z=1.825, [f=100; no fireball]

This command will specify a continuum shape and intensity chosen to mimic the cosmic radio–X-ray background, as described by Ostriker and Ikeuchi (1983) and Ikeuchi and Ostriker (1986). Their ultraviolet continuum shape is a $\alpha = -1$ power-law, with a mean intensity J_ν at 912Å given by

$$4\pi J_v(912\mathring{A}, z) = 4\pi \times 10^{-21} \left\{\frac{1+z}{3.5}\right\}^4 f\ erg\ Hz^{-1}\ cm^{-2}\ s^{-1} \qquad (10)$$

where z is the redshift and f the an optional scale factor entered as the second parameter. Its default value is $f = 1$, and $z = 0$ (i.e., now) is assumed if no redshift is

entered. Judging from Bechtold et al. (1987) and Bajtlik, Duncan, and Ostriker (1988), f is within a factor of 10 of unity. This command specifies *both* the shape and intensity of the continuum.

Primordial fireball radiation is included in the generated background. This radiation field is assumed to be a blackbody radiation field, in strict thermodynamic equilibrium, with temperature given by

$$T_{fireball} = 2.756\,(1+z)\,^{o}K \tag{11}$$

where the redshift dependence is from Peebles (1971) and the present temperature of the background is assumed to be $T_{fireball} = 2.756 \pm 0.016$K (Wilkinson 1987). This background can be an important source of Compton cooling for low density clouds. If the optional keyword "NO FIREBALL" appears on the line then the background due to the primordial fireball radiation will not be included.

Thermal background radiation can also be specified independently with the "FIREBALL" command, described below.

If a starting radius is not specified, then a value of 10^{25} cm will be assumed. Some objects, such as Lyα forest clouds, may be very large. Note that for the geometry to be plane parallel it is necessary to make sure that $\delta r/r \ll 1$ (if $\delta r/r \geq 1$ then the incident continuum will be attenuated by the r^{-2} geometric factor). It may be necessary to specify a larger starting radius in some circumstances.

4.5.2 blackbody t=100,000 [linear;luminosity;radius;density; lte]

The continuum will be a blackbody with temperature given by the input number, the temperature in degrees Kelvin. The temperature may be entered directly, or as a log. The number is assumed to be a log if it is less than or equal to 10 and linear if greater than 10. (As a result, temperatures less than or equal to 10K are entered as logs, i.e., 5K = 0.69897, 10K = 1). Temperatures lower than 10K will be interpreted as the linear quantity rather than as a log if the keyword "LINEAR" appears. Embedded commas can improve readability, such as

```
black body, Temp=1,000,000K
```

which is equivalent to

```
black body t=6  .
```

Blackbody luminosity options. The luminosity of the black body can also be specified with options which may occur on this command line. (This option was added by P.G. Martin.) If the luminosity is specified with any of these options, then it must not also be specified with another luminosity command for this continuum source. The keywords which can appear on the line are as follows:

blackbody 5, luminosity = 38 If the keyword "LUMINOSITY" appears then the second number is the log of the *total* luminosity (erg s^{-1}) of the black body, $4\pi\, R_{star}^2 \sigma\, T_{eff}^4$. This example would be a 10^5 K planetary nebula nucleus at the Eddington limit.

blackbody 5, radius = 10 The log of the radius of the blackbody R_{star} (in cm) is used to set the total luminosity when the keyword "RADIUS" appears. The total luminosity is $4\pi\, R_{star}^2 \sigma\, T_{eff}^4$. This example is also typical of a planetary nebula nucleus.

blackbody 50,000K, energy density = 500K The energy density of the blackbody radiation field, expressed as the equivalent blackbody temperature T_u in degrees K, is used to set the luminosity when the "ENERGY DENSITY" keyword appears anywhere on the line. The energy density temperature is defined from Stefan's law and the actual energy density of the radiation field u (erg cm^{-3}):

$$T_u \equiv \left(\frac{u}{a}\right)^{1/4} \tag{12}$$

where a is the Stefan's radiation density constant.

The second number is assumed to be a log if it is less than or equal to 10 and linear otherwise. Numbers smaller than 10K will be interpreted as the linear temperature rather than as a log if the keyword "LINEAR" appears. (Note that if the linear option is used, then the blackbody temperature must also be linear since the key triggers both.) Note also that microwave background radiation should also be included if $T_u \leq 2.8$K. CLOUDY will complain, but compute the model, if the energy density of the incident continuum corresponds to a temperature less than the present energy density temperature of the universe.

blackbody, t=50,000K, _lte The keyword "_LTE" (note the leading space) with no second number is equivalent to the "ENERGY DENSITY" option with T_u set to the color temperature of the radiation field. This is a quick way to check that ionization and level populations go to LTE in the high radiation field limit. (This corresponds to strict thermodynamic equilibrium, not LTE, of course.)

blackbody, t=100,000K, dilution factor = -14 Here the second parameter is the dilution factor W, defined as

$$W \equiv \frac{J_\nu}{B_\nu} \approx \frac{\pi R_{star}^2}{4\pi R_{inner}^2} \tag{13}$$

where R_{star} is the radius of the star and R_{inner} is the separation between the illuminated face of the cloud and the center of the star. The approximation on the RHS assumes that $R_{star} \ll R_{inner}$. The dilution factor can be entered either directly or as a log (if the latter, then it will be negative). The example above is a rough approximation of the radiation field within a typical planetary nebula.

Starting radius If the radiation field is normalized by specifying the equivalent energy density T_u, either explicitly or with the "_LTE" option, or by setting a dilution factor, then it is not necessary to also specify the starting radius since the intensity of the incident continuum is uniquely determined. An inner radius of 10^{25} cm will be assumed if the inner radius is not set; this usually will result in a plane parallel geometry. It *is* necessary to set a starting radius for the luminosity or radius options, however, since these specify luminosity and not intensity.

4.5.3 bremsstrahlung, temp = 8

The continuum will be (approximately) characteristic of optically thin hydrogen bremsstrahlung emission. The assumed form is given by;

$$f_\nu \propto \nu^{-0.2} \exp(-h\nu/kT) \quad . \tag{14}$$

The temperature may be entered directly, or as a log. In this example the temperature would be 10^8 K. The argument is assumed to be the log of the temperature if it is less than or equal to 10, and linear otherwise. The form of the continuum is only approximate since a simple power-law gaunt factor is assumed, and the emission from an optically thin gas with cosmic abundances is actually characterized by hundreds of overlapping emission lines (see, for example, Kato 1976).

4.5.4 extinguish column dens=23, leak=0.05, low=4 Ryd

After the continuum has been fully generated and normalized to the correct intensity, this command will modify the shape by extinguishing ionizing energies by photoelectric absorption by a cold neutral slab with column density N f dr (cm^{-2}) given by the first argument (entered as a log; f is the filling factor). The form of the extinction is a simple single power-law fit to the absorption curves calculated by Cruddace et al. (1974);

$$f'_\nu(\nu \geq 1\ Ryd) = f_\nu \left\{ \eta + (1-\eta) \exp\left(6.22 \times 10^{-18}\, \nu_{Ryd}^{-2.43}\, N', f\, dr \right) \right\} \tag{15}$$

where f_ν and f'_ν are the incident and attenuated continua, $Nf\,dr$ is the column density, ν_{Ryd} is the frequency in Rydbergs, and η is the leakage. The non-ionizing (h$\nu < 1$ Ryd) continuum is not extinguished by this command.

The second optional number is the fractional leakage through the absorber η (see Ferland and Mushotzky 1982), which has a default value of 10^{-4}. This second number is interpreted as a log if it is negative and linear otherwise. A warning is printed if the leakage is zero, since it is possible that there will be no ionizing radiation in this case. If temperature failures occur or the solutions seem unphysical when the "EXTINGUISH" command is given then it is likely that nearly all ionizing radiation has been attenuated. A plot of the generated continuum (with the "PLOT CONTINUUM" command) may prove interesting.

The third optional number is the lowest energy for the absorption to occur. It must be greater than 1 Ryd (the default) and is entered as linear Rydbergs. The continuum with energies below this will be unaffected by the absorption. The optional arguments may be omitted from right to left.

The command acts by first generating the continuum shape, neglecting extinction. The continuum is then normalized using any of the luminosity commands (i.e., "Q(H)", "IONIZATION PARAMETER", "LUMINOSITY", etc.), *then* the continuum is extinguished. The continuum which actually strikes the illuminated face of the cloud *does not* have the ionization parameter or luminosity actually entered. (These values would be correct were the extinction not present.) Physically, the luminosity of the central object is not changed by the presence of an absorbing cloud along the line of sight.

4.5.5 fireball [redshift = 2000]

This command generates a blackbody radiation field in strict thermodynamic equilibrium (i.e., $T_{color} = T_u$, where u is the energy density). The optional argument is the redshift z; if it is not entered then $z = 0$ is assumed. The temperature of the blackbody is given by

$$T_{fireball} = 2.756\,(1+z)\,^{o}K \tag{16}$$

where the redshift dependence is from Peebles (1971) and the present temperature of the background is assumed to be $T_{fireball} = 2.756 \pm 0.016$K (Wilkinson (1987). This command specifies *both* the shape and intensity of the radiation field. A starting radius of 10^{25} cm will be assumed if no starting radius is specified.

4.5.6 interpolate [ν(Ryd) or log ν(hz)], log(f_ν)

Under most circumstances the continuum will actually be entered as a table of points. CLOUDY interpolates upon this table using straight lines in log-log space. Up to 100 ordered pairs of points can be entered, with "CONTINUE" lines used to continue entering values after the initial "INTERPOLATE" line is filled. The first of each pair of points is *either* the energy in Rydbergs (either linear or as a log) *or* the log of the

frequency (in Hertz); the second number of each pair is the log of the relative flux density per unit energy interval (f_ν) at that energy. CLOUDY assumes that the log of the energy in Rydbergs was entered if the first number is negative; that the log of the frequency was entered if the first number is greater than 5; and linear Rydbergs otherwise. Any of the three styles can be chosen, but must be used consistently within the command. If the first energy is entered as zero then it is interpreted as the low energy limit of the code. In this case the remaining energies will be interpreted as linear Rydbergs if the second number is positive, and the log of the energies in Rydbergs if negative. An energy of zero Ryd is not allowed (except for the first), and the energies must be in increasing order. The luminosity of the continuum is then set by any one of the luminosity commands.

The INTERPOLATE command can be freely mixed with other continuum shape commands, and a total of up to 10 INTERPOLATE and TABLE (see below) commands can be entered.[3] Note that "TABLE" and "INTERPOLATE" are actually two forms of the same command. The total number of "TABLE" and "INTERPOLATE" commands entered together cannot exceed 10, the current value of the variable LIMSPC, which occurs in parameter statements throughout the code.

As an example, the following approximates a metal-poor 45,000K stellar atmosphere; the energies are entered in Rydbergs:

```
* following is 45000k atmosphere from Shields and Searle
interpolate (0.00001 -11.106) (.58 -1.5792) (.99 -1.44) (1.01 -1.7018)
continue (1.8 -1.905) (1.81 -1.939) (2.57 -2.208) (2.59 -2.247)
continue (3 -2.3994) (3.02 -2.8193) (3.49 -2.9342) (3.51 -4.143)
continue (3.99 -5.582) (4.01 -6.3213) (6 -9.9) (10 -17.3) (20 -30)
continue (10,000,000 -30)
q(h) = 52.778151
```

Note that the continuum should be specified between 1.001×10^{-5} Ryd and 7.354×10^{6} Ryd even if the intensity is small; if it is not fully specified then a warning will be issued and a model computed with the unspecified continuum set to zero intensity, if this is possible. As a further note, it is important that the continuum be physically correct. For instance, stellar model atmospheres emit almost no X-rays, while real OB stars *are* X-ray sources (although neglecting X-rays for these stars is generally a safe approximation).

CLOUDY will stop if more than 100 frequency points are entered. The maximum number of frequency points allowed is set by the variable NTERP which occurs in several PARAMETER statements throughout the code. NTERP is presently 100. If

[3]Limits to the use of the INTERPOLATE command existed in versions 73 and before, but have been lifted.

more points are needed then NTERP should be increased everywhere this parameter occurs in the code.

4.5.7 laser, frequency = 3.5Ryd

The intensity of the continuum will be very small, except within $\pm 5\%$ of the specified energy, where it will be very large.[4] The energy is specified in Rydbergs, and it is interpreted as a log if it is negative. This is a useful way to check on the computation of the photoionization rate integrals.

4.5.8 power law, slope=-1.4 [high cut=60 Ryd [low cut=.001]]

N.B. IT IS VERY DANGEROUS TO USE THIS COMMAND. The continuum will be a power-law, with optional low and high energy exponential cutoffs, parameterized by the cut-off frequencies $\nu_{high\ cut}$ and $\nu_{low\ cut}$, expressed in Rydbergs. The form of the continuum is

$$f_\nu = \nu^{+\alpha} \exp(-\nu/\nu_{high\ cut})\ \exp(-\nu_{low\ cut}/\nu) \quad . \tag{17}$$

The first number on the command line is the slope α. Note that there is no implicit negative sign in this exponent; typical AGN have $\alpha_{ox} \sim -1.4$, (Zamorani et al. 1981). The second (optional) number is the high energy cutoff $\nu_{high\ cut}$ expressed in Rydbergs. The default value of $\nu_{high\ cut}$ is 10^{10} Ryd$\sim 10^{11}$ eV. The third optional number is the low energy cutoff $\nu_{low\ cut}$; the default value is 0 eV.

It is generally a *very bad* idea to use this command. CLOUDY treats the entire continuum between *very* low and *very* high energies. Extrapolating "reasonable" continua past the optical-ultraviolet region into microwave or γ-ray energies will have unexpected effects. Power law continua with slopes smaller than -1 will have unphysically large photon occupation numbers and brightness temperatures at very low energies, probably producing catastrophic Compton cooling and free-free heating. Continua with slopes greater than -1 will be dominated by the radiation field at energies of many MeV, resulting in large Compton heating and pair production rates. A further problem is that the exponential cutoffs can drive the continuum to zero intensity when either argument in the exponential becomes large. This is unphysical, and can cause numerical problems.

It is *much* better to use the "'INTERPOLATE"' command, and enter physically reasonable low and high energy continua. There is a special version of the command, "TABLE POWER LAW" (see below) for entering a well behaved $f_\nu \propto \nu^{-1}$ power law continuum.

[4] The luminosity normalization for this command was not exact before version 74.

Table 2: AGN Continuum

ν(Ryd)	log(F_ν)	slope
1.00(-5)	-3.388	+2.50
9.12(-3)	4.0115	-1.00
0.206	2.6576	-0.50
1.743	2.194	-1.00
4.130	1.819	-3.00
26.84	-0.6192	-0.70
7.35(+3)	-2.326	-1.67
7.40(+6)	-7.34	

4.5.9 table, [agn, akn120, ...]

Any of several default continuum shapes, which are stored as a permanent part of the code in BLOCK DATA SCALAR, can be entered with this command. This is a special version of the "INTERPOLATE" command, described above. The same interpolation on a table of input frequencies and fluxes described there is done when this command is entered. The TABLE command can be freely mixed with other shape commands, and a total of up to ten TABLE and INTERPOLATE commands can be entered.

table_agn If the keyword "_AGN" appears (note the presence of a leading space), then a continuum similar to that deduced by Mathews and Ferland (1987) will be used. The continuum is meant to be similar to "typical" radio quiet active galaxies. The points used to describe this continuum are given in Table 2. This continuum differs from the Mathews and Ferland (1987) continuum only in that the continuum is assumed to have a sub-millimeter break at 10 microns. For wavelengths longer than 100μm the continuum is assumed to have a slope $f_\nu \sim \nu^{+2.5}$, appropriate for a self-absorbed synchrotron continuum (Rybicki and Lightman 1979). Note that this is the observed continuum, and may not be directly related to the continuum actually striking BLR gas.

The energy of the sub-millimeter break is not well determined observationally, but has a major impact on certain models, as discussed by Ferland and Persson (1989). The energy of the break can be adjusted with the "BREAK" keyword. The break can be adjusted between the limits of 0.2 Rydberg and 1.001×10^{-5} Ryd by entering the keyword "BREAK", followed by a number specifying the energy of the break. The number is interpreted as the log of the energy in Rydbergs if it is negative, as linear Rydbergs if positive, and as the (linear) wavelength of the break in microns if a second keyword "MICRONS" appears. If no number appears, but the keywords "NO BREAK" does, then a break at an energy of 1.001×10^{-5} Ryd is assumed. The

Table 3: Power Law Continuum

ν(Ryd)	log(F_ν)	slope
1.00(-5)	-5.	+2.50
9.115(-3)	-0.5604	-1.00
3676.	-6.166	-2.
7.40(+6)	-12.77	

following shows equivalent ways of generating a continuum with a break at 10 microns;

```
table agn break .00912  ; energy in Ryd
table agn break -2.04   ; log of energy in Ryd
table agn break 10 microns ; wavelength in microns
table agn no break      ; no sub-millimeter break
```

Note that the nature of the continuum in AGN is still an open question. The continuum given here is very simplistic, and quite uncertain in the ionizing ultraviolet. Recent work suggests this continuum may not be correct for low redshift Seyfert galaxies (Binette et al. 1989; Clavel and Santos-Lleo 1990).

table power law [spectral index -1.4, low=.01, hi=20] This option produces a power law continuum which is well-behaved at both the high and low energy ends. The default condition (when no numbers occur on the input line) is for the form $f_\nu \propto \nu^\alpha$ with $\alpha = -1$ between 10 microns and 50 keV, and has slopes $\alpha = \nu^{5/2}$ at lower energy, and $\alpha = \nu^{-2}$ at higher energies. The spectral mid-range spectral index (for the region from 10 microns to 50 keV) has a default of $\alpha = -1$. Table 3 summarizes the default continuum.

Three optional numbers may appear on the command line. The first number sets the slope of the mid-range spectral component (infrared to X-ray) and has a default of -1. Note that implicit negative signs are never used in CLOUDY. The second optional number is the energy (in Rydbergs) of the infrared break; the default is 10 microns. If this second number is zero then the low energy limit to the continuum (1.001×10^{-5} Ryd) will be used. The number is interpreted as the log of the energy in Rydbergs if it is negative, and linear otherwise. The third optional number is the energy of the break in the X-ray continuum. The default is 50 keV, and if it is zero then the high energy limit of the continuum (7.354×10^6 Ryd) is used. The number is interpreted as a log if the energy of the infrared break is entered as a log and linear otherwise. The numbers may be omitted from right to left.

Table 4: Crab Continuum

ν(Ryd)	f_ν
1.0(-5)	3.77E-21
5.2(-4)	1.38E-21
1.5(-3)	2.10E-21
0.11	4.92E-23
0.73	1.90E-23
7.3	2.24E-24
73.	6.42E-26
7.3(+3)	4.02E-28
1.5(+6)	2.08E-31
7.4(+6)	1.66E-32

table crab If the keyword "CRAB" appears then the continuum summarized by Davidson and Fesen (1985) is generated. The luminosity of the continuum *is not* specified by this command. This is the net observed continuum, originating in both the pulsar and nebula, and not the pulsar continuum alone. The continuum is entered in the block data as the observed flux at Earth (erg cm^{-2} s^{-1} Hz^{-1}) and is given in Table 4.

According to Davidson and Fesen, the total luminosity of the Crab is $L_{tot} = 10^{38.14}$ erg s^{-1}, so the Crab continuum could be generated by the commands

```
luminosity (total) 38.14
table Crab
```

table akn120 If the keyword "AKN120" appears then the continuum summarized by Peterson et al. (in preparation) is used. This is the net continuum, as observed with a small beam, and may not be the continuum actually striking emitting gas. The continuum is described by the observed flux at Earth (erg cm^{-2} s^{-1} Hz^{-1}) and is given in Table 5.

According to Peterson the specific luminosity at 1320Å is $\nu L_\nu = 1.84 \times 10^{44}\ h^{-2}$ erg s^{-1}, where $h \equiv H_o/100$ km s^{-1} mpc^{-1}, so, setting $h = 0.75$, the AKN120 continuum could be generated by the commands

```
nuf(nu) = 44.514 at 0.6906 Ryd
table akn120
```

table star Kurucz; Mihalas Emergent continua from several stellar atmosphere calculations are also available. These are accessed with the keyword "STAR", followed

Table 5: Akn120 Continuum

ν(Ryd)	f_ν
1.0(-5)	1.5(-26)
1.9(-5)	1.6(-26)
3.0(-4)	1.4(-23)
2.4(-2)	8.0(-25)
0.15	1.6(-25)
0.30	1.8(-25)
0.76	7.1(-26)
2.0	7.9(-27)
76.	1.1(-28)
7.6(+2)	7.1(-30)
7.4(+6)	1.3(-34)

Table 6: Mihalas (1972) Continua

T_*	log(g)
30,000	4.0
32,500	4.0
35,000	4.0
37,500	4.0
40,000	4.0
45,000	4.0
50,000	4.0
55,000	4.0

by a sub-keyword ("Mihalas" or "Kurucz") to indicate which set of atmospheres is to be used. At present subsets of the Mihalas (1972) non-LTE OB stellar atmospheres and the Kurucz (1979; with supplements) line-blanketed LTE atmospheres are available. Both are static plane-parallel atmospheres. The parameters of the models now included are summarized in Tables 6 and 7. The temperature and author of the calculation (presently Kurucz or Mihalas) must be specified; these can be in any order.

Any temperature between the lowest and highest temperatures listed in the tables can be interpolated, but only the listed gravities and metalicities can be generated at present. If the specified temperature is within a tenth of a percent of one of the temperatures listed in Tables 6 or 7 then exactly the published continuum will be used, otherwise a linear interpolation in temperature — magnitude (Mihalas) or log(f_ν) (Kurucz) space will be done. Extrapolation is not performed; the temperature must be

Table 7: Kurucz (1979) Continua

T_*	log(g)	[Z]	Reference
30,000	4.0	0.0	Kurucz (1979)
35,000	4.5	0.0	private communication
40,000	4.5	0.0	private communication
45,000	4.5	0.0	Kurucz (1979)
50,000	4.5	0.0	Kurucz (1979)

between the lowest and highest values.

The following would roughly correspond to θ^1 C Ori, the ionizing star in the Orion Nebula;

```
table star Kurucz 39,000
q(h) 49    .
```

Note that these stellar atmospheres emit little energy above 4 Ryd, while real OB stars are actually X-ray sources. Sciortino et al. (1990) find a correlation the X-ray and bolometric luminosities which can be fitted by

$$\log L_x = 1.08\,(+0.06/-0.22)\log L_{bol} - 9.38\,(+2.32/-0.83)\,, \qquad (18)$$

i.e., the X-ray luminosity is typically 6.3 dex fainter than the bolometric luminosity. A source temperature of 0.5 kev is quoted by Sciortino et al. This X-ray continuum must be explicitly added as an independent continuum source. Tests show that the high energy light has little effect on conditions in the HII region, but *does* affect the ionization in the PDR.

table_ism [factor = 0.7] The local interstellar radiation field is generated with the keyword "_ISM". This uses Figure 2 of Black (1987) to represent the *unextinguished* local interstellar radiation field. This command specifies *both* the shape and luminosity of the radiation field. The continuum generated by CLOUDY is exactly that given by Black, except that the radiation field between 1 and 4 Ryd is interpolated from the observed/inferred values. Actually, it is thought that this part of the radiation field is heavily absorbed by gas in the ISM, so that little 1–4 Ryd radiation exists, at least in the galactic plane. Such absorption can be introduced with the "EXTINGUISH" command, described elsewhere. The TABLE ISM command also specifies the luminosity of the incident radiation field, since this is also directly observed. There is an optional parameter, specifying a scale factor for the intensity of the entire radiation field. It is the log of the scale factor if less than or equal to zero, and the scale factor

Table 8: Local Interstellar Radiation Field

$\log(\nu)$	$\log(\nu f_\nu)$	$\log(\nu)$	$\log(\nu f_\nu)$
9.00	-7.93	14.14	-2.30
10.72	-2.96	14.38	-1.79
11.00	-2.47	14.63	-1.79
11.23	-2.09	14.93	-2.34
11.47	-2.11	15.08	-2.72
11.55	-2.34	15.36	-2.55
11.85	-3.66	15.54	-2.62
12.26	-2.72	16.25	-5.68
12.54	-2.45	17.09	-6.45
12.71	-2.57	18.00	-6.30
13.10	-3.85	23.00	-11.30
13.64	-3.34		

itself if positive. The default is zero (i.e., Black's radiation field). The actual numbers used by CLOUDY to interpolate on Black's table are given in Table 8. The frequencies are in Hz, and the product νf_ν in erg cm^{-2} s^{-1}.

The actual ISM radiation field incident on a typical region in the galactic plane would be generated by:

```
table ism
extinguish by 22  .
```

table read [fortran unit 8] This command is used to read in the continuum predicted from previous calculations using CLOUDY. Here, the initial calculation is used to predict the continuum transmitted through a cloud. This command is then used in subsequent calculations, in which the transmitted continuum from the first calculation is to be included in the incident radiation field of the second calculation. The file containing the previously computed continuum must have been produced by the current version of CLOUDY by including the "PUNCH TRANSMITTED CONTINUUM" command in the initial calculation. This PUNCH command is described elsewhere, and produces a file containing the frequency (in Rydbergs) and the transmitted flux νf_ν. This continuum is the sum of the attenuated incident continuum and the fraction of the diffuse emission from the cloud which is emitted and transmitted in the outward direction.

This table can be freely mixed with all of the other continuum shape commands, but only one table can be read in using this command. If more than one "TABLE READ" command occurs, only the last will be honored. The default is for the file

Table 9: Solar Composition

Atom	Solar	Old Solar
Key	default	OSOLar
He	0.098	0.10
C	3.63(-4)	4.7(-4)
N	1.12(-4)	9.8(-5)
O	8.51(-4)	8.3(-4)
Ne	1.23(-4)	1.0(-4)
Mg	3.80(-5)	4.2(-5)
Al	2.95(-6)	2.7(-6)
Si	3.55(-5)	4.3(-5)
S	1.62(-5)	1.7(-5)
Ar	3.63(-6)	3.8(-6)
Ca	2.29(-6)	2.3(-6)
Fe	4.68(-5)	3.3(-5)
grains?	no	no

containing the continuum points to be FORTRAN I/O unit 7 (i.e., named "fort.7" on UNIX machines, or "assigned" with the ASSIGN NAME FOR007 statement on VMS machines). The I/O unit number is changed with the optional argument on the line.

When this command is used, punch output (using the "PUNCH" command) must not also be produced on the same Fortran I/O unit number; the input file will be overwritten if this occurs. The first two lines of the input file contain header information, and are skipped. They should not be deleted.

4.6 Chemical Composition

The composition will be "solar" (defined in Table 9; these are taken from Grevesse and Anders 1989) unless a different mixture is specified. Abundances are always specified by number relative to hydrogen, not by mass.

4.6.1 abundances he c n o ne mg al si s ar ca fe

The chemical composition is entered with a line beginning with the command "ABUNDANCES", followed by: a) a set of 12 abundances; b) a single number to set all of the abundances, or c) a second keyword to select one of several stored abundance sets. Abundances are always by number relative to the total hydrogen density (the sum of atomic, ionic, and molecular).

Arbitrary abundances. An arbitrary abundance set can be specified by entering all twelve abundances with the "ABUNDANCES" command. The elements must be in exactly the same order as indicated above, and all twelve abundances must be specified. Abundances of zero are not allowed; CLOUDY will stop. The code may crash due to floating point underflow, followed by division by zero, if an abundance is made too small (i.e., such that the volume number density (cm^{-3}) of the element underflows to zero). The composition can be specified on several lines with "CONTINUE" lines following the initial "ABUNDANCES" line.

The best way to enter abundances is as the log of the abundance by number relative to hydrogen;

```
abundances he=-1 c=-4.3 n=-5 o=-2.3 ne=-1.2 mg=-8 al=-8
continue   si=-8 s=-8 ar=-8 ca=-8 fe=-8 ; (deplete Fe, 3rd row).
```

The abundances can also be entered as a set of scale factors indicating the desired abundances relative to solar;

```
abundances he=1 c=1 n=10 o=1 ne=1.2 mg=1 al=.93
continue   si=1 s=1 ar=1 ca=1 fe=0.00001 ; (deplete iron)
```

In general it is better to use the first style since the default solar composition changes from time to time. The code decides which type is used by checking the sign of each number. The numbers are interpreted as linear scale factors relative to solar if *all* are positive, and as logs of the abundance relative to hydrogen if *any* are negative. Be sure to check the abundances listed in the header to confirm that the composition has been entered correctly.

Setting all at once. If exactly one number is entered on the "ABUNDANCES" line then all of the elements heavier than hydrogen are given this abundance; the number can be either the relative abundance or its log. The number will be interpreted as a log if it is less than or equal to zero, and as the abundance if positive. Either of the following commands will give all elements between and including helium and iron an abundance of 10^{-10} by number relative to hydrogen:

```
abundances -10
abundances 0.000,000,000,1
```

This is useful for debugging the hydrogen atom. The "METALS" command, described below, is useful for changing abundances of all elements heavier than helium.

Table 10: Stored Abundance Sets

Atom	H II Region	Planetary	Nova	Cameron	Primordial	NLR
key	HII, H II	PLANetary	NOVA	CAMEron	PRIMordial	_NLR
He	0.095	0.10	0.10	0.0677	0.072	0.10
C	3(-4)	7.8(-4)	9.4(-3)	4.22(-4)	1.0(-10)	5.0(-4)
N	7(-5)	1.8(-4)	9.8(-3)	8.72(-5)	1.0(-10)	1.1(-4)
O	4(-4)	4.4(-4)	1.7(-2)	6.93(-4)	1.0(-10)	7.9(-4)
Ne	1.1(-4)	1.1(-4)	2.0(-3)	9.77(-5)	1.0(-10)	9.5(-5)
Mg	3(-6)	1.6(-7)	4.2(-5)	3.98(-5)	1.0(-10)	4.0(-5)
Al	2(-7)	2.7(-7)	2.7(-6)	3.20(-6)	1.0(-10)	1.0(-7)
Si	3(-6)	1.0(-5)	4.3(-5)	3.76(-5)	1.0(-10)	1.0(-7)
S	1(-5)	1.0(-5)	1.7(-5)	1.88(-5)	1.0(-10)	2.2(-5)
Ar	3(-6)	2.7(-6)	3.8(-6)	3.99(-6)	1.0(-10)	4.9(-6)
Ca	2(-8)	1.2(-8)	2.3(-6)	2.35(-6)	1.0(-10)	1.0(-7)
Fe	3(-6)	5.0(-7)	3.3(-5)	3.38(-5)	1.0(-10)	1.0(-7)
grains?	Orion	PN	no	no	no	Orion

Stored abundance sets. Table 10 lists the abundance sets which are stored as a permanent part of the code. These sets are entered if there are no numbers on the line, but a keyword occurs, as in the following examples. The four character part of the keyword which must be matched for the key to be recognized is capitalized in the table.

```
abundances Cameron
abundances hii region [no grains]
abundances h ii region [no grains]
abundances nova
abundances planetary nebula [no grains]
abundances primordial
abundances NLR
```

The assumed abundances are from a variety of sources, and their present values are given in Table 10, by number relative to hydrogen. The default "solar" abundance used pre-1990 (Table 9) can be entered by using the "OSOLAR" keyword.

"CAMERON" abundances are from Cameron (1982; note that the helium abundance is *very* low, either it or the Big Bang is wrong). The "HII region" abundances are a subjective mean of the Orion Nebula abundances determined by Baldwin et al. (1991), Rubin et al. (1991), and Osterbrock et al. (1991).

Some mixtures have certain elements, especially Si, Ca, Al, Mg, and Fe in H II regions and planetary nebulae, with gas-phase compositions reduced by depletion onto

grains. Specifying "H II REGION", "_NLR", or "PLANETARY NEBULA" will invoke grains and the mixtures given in Table 10. Grains set in this manner will have the properties appropriate for the type of grains indicated (see bottom line of the Table, and the section on grains, 21 below). Grains can also be specified separately with the "GRAINS" command. If grains are set by both the "GRAINS" and "ABUNDANCE" commands then the parameters set by the "GRAINS" command are used.

In some circumstances, it is interesting to explore the effects of grain-free mixtures, with the opacity/thermal effects of the grains suppressed, but with the (depleted) gas-phase abundances unchanged. The optional keyword "NO GRAINS" can be placed in the "ABUNDANCES" line. In this case grains will not be included in the calculation, but the observed (depleted) gas-phase abundances will still be used.[5]

4.6.2 metals 0.05 [_log, linear]

This command multiplies the entire mixture of metals (elements heavier than helium) by the scale factor entered on the line. This is useful when the effects of global enrichments or depletions are to be investigated. If the number is zero or negative then it is assumed to be the log of the number; if positive then a linear scale factor. If the "LINEAR" keyword appears then the number is interpreted as linear (unless negative). If the "_LOG" keyword appears then the number is interpreted as the log of the metal abundance, no matter what sign the number has.

Combinations such as

```
abundances planetary nebula
metals 3
```

or

```
metals 3
abundances planetary nebula
```

would multiply the planetary nebula gas phase mixture by three,[6] while

```
metals -10
```

would multiply the default solar mixture by 10^{-10}.

The depletion factor is stored as the variable DMETAL, in the common block of the same name. The default is unity. The "METALS" command has no effect on the grain abundance. Physically, the two should scale together in some manner.

[5] In versions 77 and before, the abundances of depleted elements were set to solar values when "no grains" was set.

[6] Limits to the ordering of the ABUNDANCES and METALS commands existed before version 72 but have been lifted.

4.7 Density Laws

Several commands specify the run of hydrogen density with radius. The default condition is constant density, with the total hydrogen density (atomic, ionic, and molecular) given by the command "HDEN". Power law and sinusoidal density distributions, as well as constant gas pressure, constant total (gas and radiation) pressure models, or an arbitrary density law, can also be computed.

4.7.1 constant density, pressure, gas pressure

This command has several optional keywords, depending on what is to be held constant. These are described next.

4.7.2 constant density

This is the default. The hydrogen density, the sum

$$HDEN \equiv N(H^o) + N(H^+) + N(H^-) + 2N(H_2) + 2N(H_2^+) + 3N(H_3^+) \; , \qquad (19)$$

is kept constant. This is not quite an isochoric density law because the total particle density is not constant. This is because the electron and molecular fraction varies with the run of ionization. I prefer this type of model because the homology relations with the ionization parameter (Davidson 1977) are preserved. The hydrogen nucleon density is set with the "HDEN" command, which has as an option a power-law dependence on radius.

4.7.3 constant gas pressure [index=-1]

An isobaric density law is specified with this command. The gas pressure

$$P_{gas} = N_{tot}\, k\, T_e \quad , \qquad (20)$$

where N_{tot} is the total particle density, is kept constant. This type of model is trendy today in active nuclei, but not really warranted since the ionizing continuum is seldom constant over the sound travel time across a typical cloud. (The latter is several months for "standard" BLR clouds, and constant pressure is really only approached after conditions have been stable for several sound travel times.) The optional index α will force the pressure to change as a power-law of the radius;

$$P_{gas}(r) = P_o \left(\frac{r}{r_o} \right)^{\alpha} \qquad (21)$$

where P_o is the pressure at the inner radius.

The results of this command are not exact; the actual gas pressure will vary from zone to zone with an rms scatter of typically 0.7 percent.

4.7.4 constant pressure [no continuum]

If you are holding the pressure constant, you really should hold the total pressure, particle and radiation, constant. This option turns on the physics discussed by Ferland and Elitzur (1984), and Elitzur and Ferland (1986).

The pressure is the *total* pressure, the sum of the gas and radiation pressure;

$$P(r) = P(r_o) + \int a_{rad}\,\rho\,dr = P_{gas} + P_{lines} \qquad (22)$$

where a_{rad} is the radiative acceleration due to the incident continuum (see equation 176) and ρ is the density (gm cm^{-3}). This pressure law includes thermal gas pressure (P_{gas}), the nearly isotropic pressure due to trapped emission lines (P_{lines}), and the outward force due to the attenuation of the incident radiation field (the integral; this can be turned off by specifying the "no continuum" option on the command line).

CLOUDY will stop if the internal line radiation pressure builds up to more than half of the total pressure, since such clouds would be unstable unless they are self-gravitating. It is necessary to do at least a second iteration when radiation pressure is important since the total line optical depths must be known to compute line widths, escape probabilities, and level populations, reliably. If more than one iteration is to be done then the radiation pressure will not be allowed to exceed the gas pressure on any except the last iteration.

The results of this command are not exact; the actual total pressure will vary from zone to zone with an rms scatter of typically 0.7 percent. It is not possible to specify the optional power-law index for this pressure law.

4.7.5 dlaw p1, p2, p4 ... p10

An arbitrary density law, specified by the user, is used. There are up to ten parameters, which are stored as a vector in the common block "DLAW". A new function "FUNCTION FABDEN(R1)" must be provided, and the version of FABDEN already in CLOUDY must be deleted. The code will stop if the initial version of FABDEN is not replaced. The argument is the radius in centimeters, and the function returns the hydrogen density (cm^{-3}). The code provided in the function must use the ten or fewer parameters in COMMON/DLAW/ DLAW(10) to compute the density at R1. Both the vector DLAW and argument to the function are double precision, although the function value is single precision.

Note that it is not consistent to specify the density with both this command and others, such as "HDEN", "CONSTANT PRESSURE", etc. There is no telling what will happen if this is done.

4.7.6 fluctuations log(period), log(max den), log(min den)

This command specifies a model in which the density varies as a sine wave. This is useful to check on the effects of inhomogeneities upon the emission-line spectrum. The first number is the log of the period of the sine wave, in centimeters. The second two numbers are the logs of the largest and smallest hydrogen densities over the sine wave. (See Mihalszki and Ferland 1983).

4.7.7 globule [density=2, radius=16, power=3]

The density law will be appropriate for a power-law density gradient, irradiated from the outside. The total hydrogen density $N(r)$ is given by

$$N(r) = N_o \left(\frac{R}{R - \delta r} \right)^{\alpha} \tag{23}$$

where N_o is the background density outside the cloud, with default value 1 cm^{-3}, and δr is the depth into the cloud, measured from the illuminated face. The log of N_o is the optional first number on the command line. R is the radius of the cloud, and has a default of one parsec, $R = 3.086 \times 10^{18}$ cm. Other radii are specified by the optional second parameter, which must be entered as a log, in cm. The optional third argument is the index α, which has the default $\alpha = 2$. The arguments can be omitted from right to left.

4.7.8 hden = 5.6, [proportional to R -2, ...]

Hydrogen density The first number is the log of the total (ionic, atomic, and molecular) hydrogen density. This is the sum

$$HDEN = N(H^o) + N(H^+) + N(H^-) + 2N(H_2) + 2N(H_2^+) + 3N(H_3^+)\ cm^{-3}. \tag{24}$$

If the optional keyword "LINEAR" appears the number is the density itself and not its log.

For situations where the hydrogen atom is close to LTE and the gas is hot, there is a problem in defining the neutral hydrogen density because of the well-known divergence of the partition function, as discussed, for instance, by Mihalas (1978). To avoid this difficulty, the present version of CLOUDY defines the atomic hydrogen density as the total population in $n \leq 6$, while ionized hydrogen (which contributes to the free electron sum) includes all hydrogen atoms in $n \geq 7$ states. In most circumstances (i.e., $N_H \ll 10^{13}$cm^{-3} and $T \leq 10^4$ K) the ambiguity is much less than 1%.

Power-law radial dependence The second (optional) number is the exponent α for a radial density dependence, i.e.,

$$N(r) = N_o(r_o) \left(\frac{r}{r_o} \right)^{\alpha} \quad . \tag{25}$$

If the second number is -2, as in the example above, the density will be proportional to the inverse square of the distance to the central object, and spherical models will tend to have the same ionization parameter (and hence physical conditions) across the ionized zone.

For an inverse square law density dependence, there is a critical value of the number of ionizing photons emitted by the central object,

$$Q_{crit}(H) = \alpha_B(T_e)\, N_o^2\, 4\pi R_o^3 \quad , \tag{26}$$

where $\alpha_B(T_e)$ is the hydrogen case B recombination coefficient, and N_o and R_o are the inner density and radius respectively, such that an ionization front will not be present (and the model will extend to infinite radius) when $Q(H) \geq Q_{crit}(H)$. Generally, an ionization front will not be present if the density falls off faster than an inverse square law, but rather the level of ionization will tend to *increase* with radius. In either case, if a reasonable outer radius is not set, the calculation will extend to very large radii, an unphysically small density will result, and usually the code will crash due to floating point underflow, followed by division by zero. It is usually necessary to set an outer radius when the density falls off with an index $\alpha \leq -2$, since, for most circumstances, the cloud will remain hot and ionized to infinite radius.

Power-law dependence on depth The density will depend on the depth into the cloud rather than the radius if both the optional exponent *and* the keyword "DEPTH" appears. The depth is the distance (in cm) between the point in question and the illuminated face of the cloud. Here the density is given by

$$N(r) = N_o(r_o) \left(1 + \frac{depth}{r_{scale}} \right)^{\alpha} \tag{27}$$

where r_{scale} is the scale depth. The scale depth is entered as the third number on line, and is the log of the depth in centimeters.

Power-law dependence on column density The density will depend on the column density if both the optional exponent *and* the keyword "COLUMN" appears. Here the density is given by

$$N(r) = N_o(r_o) \left(1 + \frac{col}{col_{scale}} \right)^{\alpha} \quad . \tag{28}$$

where *col* is the column density from the illuminated face to the point in question, and col_{scale} is the scale column density. The scale column density is entered as the third number on line, and is the log of the column density (cm^{-2}).

4.8 Geometry

The geometry is always spherical, but can be made effectively plane parallel by making the radius much greater than the thickness of the nebula. It is also possible to compute a model in which the emission-line region is almost a disk.

4.8.1 covering factor 0.3

This command sets a covering factor $\Omega/4\pi$ for the emission-line region. The argument is interpreted as the log of the covering factor if less than or equal to zero, and the covering factor itself if positive. It is impossible to specify a covering factor of zero. The covering factor can also be set as an optional argument on the "SPHERE" command.

The covering factor affects both the luminosity and the radiative transfer of lines and continua. If a covering factor is set and the line or continua are predicted as luminosities, then the luminosities will be for a shell covering Ω sr, where $\Omega/4\pi$ is the covering factor. The covering factor does not affect the line intensities, (the emission per unit area) if these are predicted rather than luminosity. This covering factor is referred to as the geometric covering factor, and is stored as the variable COVGEO in the common block COVER. A second covering factor, COVRT, affects the transfer of lines and continua. Both covering factors are set by the number on this command line.

If no covering factor is entered and SPHERE is not set then the default is for a geometric covering factor of unity (the shell fully covers the continuum source) but a radiative covering factor of zero (i.e., an open geometry).

4.8.2 cylinder log(semithickness)=9.12

The model will be spherical, but truncated so as to simulate a cylinder (See Ferland et al. 1982). The inner and outer radii of the cylinder are set by the "RADIUS" command described elsewhere in this section. This command sets the full height of the cylinder to twice the number entered on the command. The argument is the log of the semi-height in cm.

The effective volume element used to compute the emissivity is given by

$$dV = 4\pi r_{in}^2 \left(\frac{r}{r_{in}}\right) \left(\frac{\min(r, h_{cyl})}{r_{in}}\right) f(r)\, dr \qquad (29)$$

where r_{in} is the inner radius, h_{cyl} is the cylinder half-height, and $f(r)$ is the filling factor. The half-height h_{cyl} is stored as CYLIND, the sole element of the common block with the same name. The default value is $h_{cyl} = 10^{35}$ cm.

4.8.3 filling factor = 0.05 [index=-1]

The first number is the filling factor for a clumpy model. It can be either the filling factor itself (which is greater than zero and less than or equal to one) or the log of the filling factor (in which case it will be less than or equal to zero). The second number is optional, and is the index α for a power law variation of the filling factor f(r), i.e.,

$$f(r) = f(r_o) \left(\frac{r}{r_o} \right)^{\alpha} \tag{30}$$

where $f(r_o)$ and r_o are the filling factor and inner radius of the cloud.

The filling factor is used in two ways; first to modify the volume emissivity of the cloud,

$$dI = 4\pi \, j \, f(r) \, dV \; \Omega/4\pi \tag{31}$$

where $\Omega/4\pi$ is the covering factor, and second to modify the optical depth scale

$$d\tau = \alpha_{lu} \left(N_l - N_u \frac{g_l}{g_u} \right) \, f(r) \, dr \tag{32}$$

(see Osterbrock and Flather 1959). Filling factors greater than unity are not allowed; CLOUDY will set a filling factor of unity if a value greater than one is entered.

4.8.4 radius log{r(inner)} [log{r(out;dr); parsec; linear}]

The first number is the log of the inner radius. The second number sets a stopping radius and is optional. This can be either the log of the outer radius (if it is larger than the first number) or the log of the thickness of the cloud (if it is less than or equal to the first number).

The numbers are normally interpreted as the log of the quantity. If the optional keyword "LINEAR" appears on the line then the numbers are interpreted as the numbers themselves and not their log. The default units are centimeters, but the arguments will be interpreted as the log of the radii in parsecs if the keyword "PARSECS" appears anywhere on the line. Arguments will be interpreted as linear parsecs if both keywords appear. The following gives examples of its use.

```
radius 19.5      ; log of inner radius in cm
radius 19.5 18.5 ; as above, but a thickness of approx 3x10^18 cm
```

```
radius 19.5 20   ; inner radius as above, outer radius 10^20 cm
radius 100 linear; inner radius of 100 cm
radius 0 parsecs ; log of radius in parses, so inner radius 1 pc
radius 1 to 3 linear parsecs ; inner radius 1pc, outer 3pc
```

The default value for the outer radius is effectively infinite (actually 10^{30} cm). If the "RADIUS" command is not entered and the surface flux or ionizing radiation field is set in some unambiguous manner (for instance, with the ionization parameter or energy density temperature), then a radius of 10^{25} cm will be set by default. Under most circumstances this radius will result in an effectively plane parallel geometry.

4.8.5 sphere [expanding ; static; covering factor=.4]

CLOUDY normally assumes that the gas covering factor is small, as is the case in the BLR of AGNs. The "SPHERE" command should be included if the covering factor of the gas is large and the model spherical. This command tells CLOUDY to take into account ionization by the diffuse emission in the H and He Lyman continua and He Lyα lines produced in the far side of the nebula (i.e., from beyond the central object), and not to attenuate the ionizing continuum by pure scattering opacities, such as electron scattering, backscattering by grains, or Rayleigh scattering.

This option should be set when the geometry is spherical and gas nearly fully covers the continuum source. It should not be set when the covering factor is small, and emission from a cloud is unlikely to encounter another cloud. This latter case is the default. In the language of Van Blerkom and Hummer (1967), "SPHERE" causes CLOUDY to assume the "symmetric case" (their equation 2.14), rather than the default "zero case" (their equation 2.13) for diffuse continua. Here these are referred to as "closed" and "open" geometries, respectively.

Two optional keywords "EXPANDING" and "STATIC" determine how line transfer is handled. If "EXPANDING" (the default when "SPHERE" is entered) is set then CLOUDY assumes that line photons escaping from the illuminated face of the cloud do not interact with absorbing material on the outer side. This is the case if the expansion velocity exceeds the Doppler-width by large amounts. If "STATIC"[7] is set then line photons do interact on both sides, so that the escape probability at the illuminated face of the cloud is small for optically thick lines. It is necessary to iterate at lease one time when the "STATIC" option is used, since the total line optical depths are not known on the first iteration. The optical depths for all lines are determined self-consistently on second and further iterations. Lyα radiation pressure in the H^+ zones will probably be significant if "SPHERE STATIC" is set.

[7]Sphere static did not work correctly in versions 74 and before.

The optional number on the line is the covering factor for the emission-line region. It is interpreted as the log of the covering factor if it is less than or equal to zero, and the covering factor itself if positive. The covering factor can also be set using the "COVERING FACTOR" command. The effects of the covering factor are described further below.

When a covering factor of unity is set the specific effects of SPHERE are; a) the total continuous optical depths are assumed to be twice the computed optical depths, and the initial optical depth is half the total, b) all diffuse reemission (bremsstrahlung, free-bound, etc.) is counted in the outward beam rather than only half, c) scattering opacities are not considered in the attenuation of the incident radiation field, d) when STATIC is set, the optical depth in Lyα in the inner direction is set to 10^5 on the first iteration; otherwise it is 10^{-20}, and e) include ionization by HeI and HeII lines from the other side of the nebula. At the end of the iteration, all inward optical depths are set to half of the total value computed from the previous iteration. The diffuse continua are transferred using methods described in later sections.

4.8.6 wind v=300 km/sec [mass=1.4]

The model will be a large velocity gradient ($v \sim R$ Sobolev approximation) wind. The line widths and escape probabilities are modified in the appropriate manner, i.e., the effective optical depth is given by

$$\tau_{lu}(R) = \sigma_{lu}\, R \left(N_l - N_u \frac{g_l}{g_u} \right) \left(\frac{v_{thermal}}{v_{expansion}} \right) \tag{33}$$

where $v_{thermal}$ and $v_{expansion}$ are the thermal and expansion velocities respectively, and R is the radius.

The first parameter on the command line is the expansion velocity v_o at the inner edge of the cloud. It must be greater than zero, and is entered in km/sec. The density at the illuminated face of the cloud is entered with the "HDEN" command, and the density is varied across the model to conserve mass flux (i.e., the product $\rho(r)\, r^2\, v(r)$ is kept constant). Because of this, a filling factor would not make physical sense and should not be used. The optional second parameter is the mass of the central star in solar units; its default value is one solar mass.

The equations of motion of the gas are solved. Acceleration due to the opacity of roughly ten absorption lines, the continuous opacity of the gas, and the gradient of the radiation pressure due to ~ 10 lines, and deceleration due to the gravity of the central object, are included. The calculation will stop if the gas comes to rest, or if any of the other stopping criteria are met. Further details are presented in a section below. Really, something like 10^6 lines are needed for a realistic calculation (see, for example, Abbott 1982).

4.9 Optical Depths and Radiative Transfer

In some classes of nebulae, such as H II regions and planetary nebulae, line transfer is relatively unimportant. In other objects, such as nova shells and the broad-line region of active nuclei, excited states of hydrogen have significant populations and subordinate lines become optically thick (see Ferland and Netzer 1979; Weisheit et al 1981; Kwan and Krolik 1981; Canfield and Puetter 1980). The present version of CLOUDY treats line radiative transfer in the escape probability formalism (Hummer 1968; Hummer and Kunasz 1980; Elitzur 1982; Netzer, Elitzur, and Ferland 1985). Further details are given in section 15 below.

CLOUDY is fairly fast, so there is no reason not to iterate at least one time when line transfer is important. The default is for a single pass through the cloud, and this is often adequate for low-density nebulae such as planetary nebulae or H II regions. A second iteration is usually enough to establish a fairly accurate line optical depth scale for most transitions, so that the proper escape probabilities can be computed, when line transfer is important. If Lyα or Hα optical depths change by more than $\sim$ 20% on the last iteration then a warning that the model has not converged will be printed at the end of the last iteration.

Line radiation pressure cannot be computed accurately until the total line optical depths are known, so this quantity is meaningful only after at least one iteration. CLOUDY will stop if the radiation pressure exceeds half of the surface gas pressure in a constant pressure model, since such a geometry is unstable unless it is self-gravitating. On the initial iterations of a multi-iteration constant pressure model, the radiation pressure is constrained to never exceed half the gas pressure; this is to prevent the calculation from stopping when the optical depth scale is not yet well converged.

4.9.1 case b [tau ly alpha = 9;Hummer and Storey]

With no options, this command sets the inner optical depth for hydrogen and helium Lyα to 10^9, so that even a one-zone model will be close to case B. The optional number is $\log(\tau_{Ly\alpha})$, so it is possible to change this assumption. One-sided escape probabilities are used in this case, so the total escape probability is simply that for the inward direction. The "CASE B" command also suppresses optical depths in excited states, in keeping with the case B approximation. This is useful for checking the behavior of the hydrogen and helium atoms in the low density limit.

Normally, the treatment of the hydrogen and helium atoms includes all collisions between the ten levels considered for each atom/ion. Case B does not define the population of the ground or first excited state, so a true comparison with case B results should have collisions from these levels turned off. This is done with the "Hummer and Storey" option, to allow comparison with their 1987 paper. Collisions from the ground and first excited states *are* included if this second option is not

specified. Collisions between $n \geq 3$ levels *are* always included unless the "HYDROGEN COLLISIONS OFF" command is given. Collisions between the 2s and 2p states are always included unless the "NO 2S2P" command is given.

4.9.2 diffuse fields on!off

This command turns Λ-iteration calculation of the diffuse fields off or on. If turned on, the diffuse fields are computed with the Λ-iteration method on second and latter iterations. This approximation is only formally correct when the model is plane parallel. This command has not been carefully debugged in the past few years, and should not be used except in experimental situations. A test case presented in the appendices shows that the approximations normally used by CLOUDY reproduces the Van Blerkom and Hummer (1967) exact results with great precision (much better than 1%, see 25 below).

N.B.; this command has not been carefully debugged in some time, and will soon be removed.

4.9.3 double optical depths

This command simulates a geometry in which ionizing radiation strikes the plane parallel cloud from both sides, such as a Lyα forest cloud. At the end of the iteration, the total line and continuum optical depths are set to twice the computed optical depth. The computed model is then one half of the cloud, and the other half of the cloud is assumed to be a mirror image of the first half. Doubling the total line and continuum optical depths at the end of the iteration is the *only* effect of this command. Physical quantities such as the dimension, column densities, or line emission *are not* affected.

These approximations only make sense if the cloud is optically thick in lines, but optically thin (or nearly so) in the continua. Lines such as the Lyα transitions of HeI and HeII can be important sources of ionizing radiation; their transport will be handled correctly in this limit when this command is used. Continuum transport out of the cloud will also be treated correctly, but attenuation of the incident continuum will *not* be if the cloud is optically thick in the continuum.

4.9.4 escape __K2; incomplete; [emit; destroy]

This command specifies how line escape probabilities are to be handled. One of the keywords "__K2" or "INCOmplete" must appear. If no other keywords appear then both the emission and destruction probabilities are set to either of the specified cases. If either keyword "EMIT" or "DESTroy" appear, then only the emission or destruction probability is changed.

Table 11: Grain Populations

Index	Type	Property
1	graphite	ISM
2	silicate	ISM
3	graphite	Orion
4	silicate	Orion
5	silicate	0.01 micron
6	silicate	0.1 micron
7	silicate	Volk PN silicate

4.9.5 grains [-2; planetary; orion; no heating...]

The effects of grains can be included, either with this command, or by using an abundance mixture which includes grains by default. The "GRAINS" command takes precedence over the default grains set with the "ABUNDANCES" command.

The treatment of grains was developed in close collaboration with P.G. Martin. Details are provided in section 21 below, and in Baldwin et al. (1991). Seven populations of grains, summarized in Table 11, are presently incorporated in the code.

The temperature, potential, and drift velocity of the grains are determined using standard assumptions, as described, for instance, by Martin (1979) or Spitzer (1948; 1978), and section 21 below. Heating by direct absorption of the continuum, Lyα, and all other lines and continua included in the OTS fields, and gas collisions, are included as heating mechanisms in the calculation of the grain temperature. Gas heating by grain photoionization, and cooling by free particle capture onto the grain surface, is also included. The grain potential is determined by solving the photoionization-recombination balance equation, and heating/cooling of the gas by grain photoionization-recombination is determined self-consistently.

The default condition for the code is no grains, and when grains are enabled the default grain mixture has ISM properties. The optional keyword "ORION" makes the grains more similar to the large-R grains in the Orion Nebula, which have a fairly grey ultraviolet extinction. The two grain populations marked Orion in Table 11 are used in this case. The keyword "PLANETARY" makes the grains more similar to those observed in planetary nebulae; the silicate population marked "PN" and ISM graphite are then used.

The abundances of the grain populations can be changed with the optional number on the command line. This is a scale factor used to multiply the stored grain opacities. The scale factor is the log of the opacity relative to the standard value if less than or equal to zero, and the scale factor itself if positive (i.e., both "GRAINS -2"

and "GRAINS .01" would use ISM grains with each of the two constituents having only 1 percent of the standard abundance).

It is also possible to turn on each species independently. If two numbers occur on the line then the first is interpreted as the abundance, and the second is a pointer to the grain type. The other grain types are not turned off by this option, so it is possible to turn on several grain types with successive "GRAINS" commands.

The optional keyword "NO HEATING" turns off photoelectric heating of the gas by grain photoionization. The optional keyword "NO COOLING" turns off free particle recombination cooling of the gas by grain collisions.

The following are some examples;

```
*ism grains with ism abundance
grains

*orion grains with half their standard abundance
grains orion .5

*turn on ism graphite and orion silicate
grains abundance=1, type=1
grains abundance=1, type=4

*only include opacity effects of ism grains
grains no heating, no cooling
```

For a closed geometry, in which the SPHERE option is set, the predicted emission-line spectrum will be the *intrinsic* spectrum of the nebula. Photon destruction by all background opacity sources (including grains) is fully treated using escape probabilities (i.e., Hummer 1968), and the predicted intrinsic intensities include this physics. The intensities *do not* include the reddening effects of any external grains which lie outside the line-forming region, however. For an open geometry, the full intrinsic emission-line spectrum is again printed, following the predicted emergent line intensities. In this case the first set of lines is the observed spectrum, including absorption and scattering by grains, as observed from the illuminated face of the cloud.

In no case is the possible presence of large amounts of grains within cold neutral regions outside the computed structure taken into account.

4.9.6 helium collisions; radiation...

helium collisions off This turns off collisions within the helium singlets and helium ion.

4.9.7 hydrogen ; redistribution ; data

This allows some details of the treatment of the hydrogen atom to be changed. Unlike the vast majority of the commands, the entire keyword "HYDROGEN" must match for this command to be recognized.

hydrogen redistribution.. Lyα transfer can be treated with either complete or incomplete redistribution (see, for example, Hummer 1962); the default is incomplete redistribution, and can be changed by entering

```
hydrogen redistribution complete
hydrogen redistribution incomplete  .
```

There is at present a fundamental uncertainty in the computation of the line radiation pressure for transitions such as Lyα. For a simple two-level atom with incomplete redistribution, it has long been known that the line-width is proportional to $(a\tau)^{1/3}$ (Adams 1972, Harrington 1973; a is the damping constant). It is also easily shown that for complete redistribution and a frequency independent source function that the line width would be determined by inverting the Voigt function, and hence proportional to $(a\tau)^{1/2}$. This may be the case for Lyα in practice because of "line interlocking", whereby scattered Balmer line radiation broadens the upper level of Lyα (Hubbard and Puetter 1985), or when the density is high enough for distant collisions to broaden the line. The difference in radiation pressure and emergent flux is major (factors of several) for Lyα, which can easily have an optical depth of 10^7–10^9, when Balmer lines are also optically thick. This command determines which approximation is used. The default condition is incomplete redistribution, which minimizes the line width and radiation pressure. This issue is discussed further in Elitzur and Ferland (1986).

hydrogen lowest temp 200 Normally the level populations are determined by solving the equations of statistical equilibrium using departure coefficients. These diverge at low temperatures when hydrogen is ionized, in which case fits to Martin's (1988) results are used. The lowest temperature considered by the 10–level hydrogen atom is machine dependent, and can be altered with this command. There is a single argument, and the number is interpreted as the log of the temperature if it is less than or equal to 10. The default value of the lowest temperature is 1000K. Tests show that numerical instabilities in the matrix inversion routine limit the lowest temperature to only slightly below the default value, even with 64 bit words. There is no lower limit to the temperature on a CRAY Y-MP when double precision is enabled on the compile step, so the lowest temperature can be made arbitrarily low.

hydrogen data ... The collision data set can be changed from the default, which uses quantal calculations where possible, supplemented by data from Vriens and Smeet (1980). The commands

```
hydrogen data Vriens and Smeet
hydrogen data Johnson
```

will change between the Vriems and Smeets values and those of Johnson (1972). These collision cross sections differ by factors $\sim 2-3$ for *high-n* states; this is also, at present, a fundamental uncertainly, although the Vriems and Smeets data are based on more recent experimental results.

hydrogen collisions off Collisions within the hydrogen atom can be turned off with this command. All collisions *except* 2*s*-2*p* are turned off by this command. (These are turned off for H and He with the "NO 2S2P" command.)

hydrogen stimulated emission off Stimulated emission is turned off with this command.

hydrogen induced processes off Induced recombination and induced Compton heating are turned off with this command. Both processes (stimulated emission and induced recombination) are turned off with the command

```
no induced processes
```

described below.

hydrogen damping off Continuum scattering due to the extreme damping wings of Lyman lines (i.e., Rayleigh scattering) can be turned off with the "DAMPING OFF" option. Rayleigh scattering is a significant opacity source is very large column density clouds.

4.9.8 iterate [2 times]

This command specifies the number of iterations to be performed. The default is a single pass through the model. A second iteration should be performed in order to establish the correct optical depth scale when line transfer or radiation pressure is important. Two iterations are often sufficient, and will be done if no numbers are entered on the command line. No more than 10 iterations can be performed because of the present limits to the sizes of several vectors used to store information. A comment will be printed after the last iteration if the total optical depth scale has not converged and another iteration is needed.

iterate to convergence [max=7, error=.05] This is a special form of the "ITERATE" command, in which the code will continue to iterate until the line optical depth scale has converged, or ten iterations have been computed. The optional first number on the line is the maximum number of iterations to perform, and the default is 10. It is not possible to specify more than ten iterations. The second optional number is the convergence criterion. Normally, it is that the Hα optical depth has not changed by more than 10 percent on the next-to-last iteration. The optional numbers may be omitted from right to left. The iterations will stop when the changes in the Hα optical depth are less than the second number, unless Hα is optically thin, in which case only a second iteration is performed.

4.9.9 no scattering opacity

This command turns off several pure scattering opacities. These include scattering by grains, electron scattering, and the extreme damping wings of Lyman lines (Rayleigh scattering). When scattering opacity is included and an open geometry is to be computed, the scattering opacity is assumed to attenuate the incident radiation field as $(1+0.5\tau_{scat})^{-1}$ rather than $\exp(-\tau)$ (Schuster 1905).

Scattering should be neglected in a spherical geometry with gas fully covering the source of ionizing radiation, since photons absorbed by a pure scattering process are not really lost, but continue to diffuse out with (perhaps) a slight shift in energy. Electron scattering is generally the most important scattering opacity in a grain-free mixture. If $\tau_{scat} \leq 1$ then it is reasonable to consider electron scattering as a heating and cooling process, but not as an absorption mechanism, if the energy shifts are not large (i.e., $h\nu \ll mc^2$) and the geometry spherical (this is not correct for γ-ray energies, of course). CLOUDY is not now designed to work in environments which are quite Compton thick, but the approximation of neglecting electron scattering opacity for spherical geometries should work well for nebulae where the electron scattering optical depths are less than or of order unity. (Grain scattering has no direct effect on the gas, of course.) If this command is given then Compton energy exchange and recoil ionization are still included as heating, cooling, and ionization processes, but not as opacity sources. (Thermal and ionization effects of Compton scattering are turned off with the "NO COMPTON" command.) The "NO SCATTERING OPACITY" command is automatically generated when "SPHERE" is specified.

4.9.10 turbulence = 100 km/sec

The input number is the turbulent velocity (assumed to be microturbulence) expressed in kilometers per second. This velocity field affects the line-width and optical depth scale through the Doppler width $v = \sqrt{v_{th}^2 + v_{turb}^2}$, where $v_{th} = \sqrt{2kT/m}$ is the

projected line-width due to thermal motions of particles of mass m, and the turbulent line-width v_{turb} is normally zero.

4.10 Thermal Solutions

This section describes options which affect the thermal solution. These deal with the accuracy of the solution (changes in the tolerance, or permitting more or fewer temperature failures), or with additional sources of heat, such as cosmic rays or turbulence.

4.10.1 cextra -14.231 [temp to the 1.5 power]

It is possible to add an "extra" source of cooling (due to some unspecified physical process) with this command. The first number is the log of the cooling rate in erg cm^{-3} s^{-1}. The second number is an optional exponent to specify a temperature dependence. The cooling will be given by

$$\Lambda = 10^{c_1} \times \left(\frac{T_e}{10^4 K}\right)^{c_2} \quad erg\ cm^{-3}\ s^{-1} \tag{34}$$

where c_1 and c_2 are the two numbers entered with this command. If the second optional argument c_2 is not specified then zero (i.e., constant cooling) is assumed.

4.10.2 constant temperature, t=10,000K [linear]

A constant temperature calculation will be performed. The number can be either the electron temperature itself, or the log of the temperature (the latter is assumed if the argument is less than or equal to 10). If the optional keyword "LINEAR" appears on the line then the number is always interpreted as the temperature itself, and not its log.

Collisional ionization of all atoms and ions is included, so this option can produce clouds in coronal or collisional equilibrium. For technical reasons, the photon array must be defined for all energies which contribute to photoionization of all stages of ionization with significant abundances. For instance, to do models of the solar corona it is necessary to include both the cool blackbody from the solar photosphere (important for excited state induced recombination, photoionization, and Compton cooling) as well as a weak $\sim 10^8$ K bremsstrahlung continuum to define the photon array at all possible coronal energies (see the "CORONAL EQUILIBRIUM" command, described below).

If this command is used, then it is usually necessary to specify other stopping criteria. Many calculations stop when the electron temperature falls below some lowest value, set with the "STOP TEMPERATURE" command and with the default value 4000K. This cannot happen with a constant temperature model. For instance, a

constant temperature model of a planetary nebula will continue until the limit to the number of zones (now 300) is reached. The *vast* majority of the model will consist of predominantly neutral gas well outside the Strömgren sphere, and this gas will have an small ambient level of ionization and emission due to collisional ionization. The resulting emission-line spectrum would be surprising since the neutral gas contributes significant emission. A solution would be to use the "STOP EDEN" command to stop the calculation when the hydrogen ionization front is reached.

4.10.3 coronal equilibrium, T=10,000,000K

A model in coronal equilibrium, in which the gas is mainly collisionally ionized, will be computed. The number is either the temperature or the log of the temperature (the argument is interpreted as a log if it is less than or equal to 10). This calculation is very similar to those presented by, for instance, Raymond, Cox, and Smith (1976) or Gaetz and Salpeter (1983).

The command in the example above actually issues the following commands;

```
constant temperature t=10,000,000K
stop zone 1
drmax = 0
drmin = 0
stop lyman continuum optical depth = -6
brems, t=8
ionization parameter -7
```

4.10.4 cosmic rays, background, density=1.2 [index=-2, temp=7.3]

This command turns on energy deposition and ionization due to relativistic particles, as described by Ferland and Mushotzky (1984) and section 22.1 below. The first number is the log of the cosmic ray density (N_{cr}, cm^{-3}). The second optional number is a power-law index α, describing the variation of the cosmic ray density with radius, i.e.,

$$N(cr,\, r) = N(cr,\, r_o) \left(\frac{r}{r_o} \right)^{\alpha} \quad . \tag{35}$$

The default value of the index is $\alpha = 0$, or constant density. The third optional number is the log of the temperature of the fast electrons, if they are not relativistic. If this third number is specified then expressions from Balbus and McKee (1982) will be used to evaluate the electron heating rates. The options can be omitted from right to left.

Collective effects are not included in the heating and ionization rates, but they may not be important either (Rephaeli 1987).

If no numbers appear on the line, but the keyword "BACKGROUND" does, then a constant cosmic ray density of $N_{cr} = 10^{-9}$ cm^{-3} will be used. This density will produce a neutral hydrogen ionization rate of $\sim 10^{-17}$ s^{-1}, the value quoted by Spitzer (1978) for the galactic cosmic ray ionization rate. *This value is quite uncertain.* If cosmic rays are not included in the calculation, but the neutral hydrogen ionization rate falls below 10^{-17} s^{-1}, the code will print a comment stating that the ionization rate fell below the galactic background rate.

4.10.5 failures 100 times

A temperature failure occurs when the heating-cooling balance is not within a certain tolerance, set by the "TOLERANCE" command, after 20 tries. Normally CLOUDY will punt after an excessive number of temperature failures (presently 20) occur. This command increases the number of allowed failures to the value entered as a parameter.

When CLOUDY stops because of excessive failures it first produces a map of heating-cooling space to give an indication of where the equilibrium temperature should have been. Section 8 below describes thermal failures in more detail, and describes the output produced before the program stops.

Failures occur most often when the code needs to "jump over" the peaks in the cooling function which occur near 2000K and 10^5K, or if it "trips" over an ionization front because the zones are too large. Increasing the number of allowed failures is permissible as long as the global energy balance is preserved. A warning will be issued at the end of the calculation if there is a discrepancy in the global heating–cooling balance.

The default limit to the number of failures is 20, which is stored as the variable LIMFAL.

4.10.6 force temperature to 3400K

This command forces the initial estimate of the temperature of the first zone to the value entered. The temperature is interpreted as a log if it is less than or equal to 10 and the linear temperature if greater than 10. This command is useful if more than one temperature solution is possible. It forces the first guess of the temperature to the specified value, but *does not* hold the temperature constant; the temperature is determined by energy balance thereafter. (Constant temperature is set with the "CONSTANT TEMPERATURE" command.)

4.10.7 hextra -14 [scale r=18]

This command turns on "extra" heating due to some unspecified energy source, such as dissipation of turbulence. The first number is the log of the volume heating rate (erg cm^{-3} s^{-1}). The second number is the log of the scale radius r_{scale}, such that the extra heating rate varies as $\exp(-r_{scale}/(r-r_o))$, where r_o is the inner radius. The default, when r_{scale} is not specified, is constant extra heating.

4.10.8 high temperature approach

This command tells the code to search for the first temperature by approaching the thermal solution from the high temperature extreme of 10^6K. Normally the approach is from low temperatures. This can be useful when more than one thermal solution is possible.

4.10.9 lowest temperature = 300K [linear]

The search for the temperature of the first zone can find temperatures as low as TELOW, which has a default value of 10K. CLOUDY will not allow initial temperatures below the value of TELOW, although after the first zone the temperature can fall to values as low as TEND, which has a default value of 4000K. This command can be used to change the value of TELOW. The argument is interpreted as a log if it is less than or equal to 10, otherwise as the temperature itself. There is an optional "LINEAR" keyword to force all values to be linear, rather than logs. The number is the sole element of common block "TELOW". (TEND is changed with the "STOP TEMPERATURE" command.)

4.10.10 magnetic field, log(B) = 5

The argument is the log of the magnetic field strength in Gauss. Magnetic effects are not normally included; when this is specified, cooling due to cyclotron emission, using equations from Fabian, Pringle, and Rees (1976; these assume optically thin emission) are included. The volume cooling rate is given by

$$\Lambda_{cyclotron} = N_e \frac{B^2}{8\pi} \frac{4}{3} \sigma_T \, c \left(\frac{v}{c}\right)^2 = 4.5433 \times 10^{-25} B^2 T_e \quad erg\ cm^{-3}\ s^{-1} \tag{36}$$

where σ_T is the Thomson cross-section and

$$v_e = \left(\frac{8kT_e}{\pi m_e}\right)^{1/2} = 6.2124 \times 10^5 \, T_e^{1/2} cm\ s^{-1} \tag{37}$$

is the mean electron speed. See, however, Masters, Pringle, Fabian, and Rees (1977). They show that this emission process is likely to be optically thick under some circumstances. Cyclotron optical depth effects are not now included.

Cosmic rays should not be included when a magnetic field is specified, since the effects of a field on cosmic ray transport are not now included. A warning will be printed if both are included.

4.10.11 map 4 [range 2000, 5000]

This command tells the code to compute a heating-cooling map of the specified zone. This is a useful way to check for the existence of more than one thermal solution. If no zone is specified, or if the zone is less than or equal to 0, then only a thermal map is produced for the illuminated face of the cloud, and no zone calculations are performed.

The optional keyword "RANGE" specifies the temperature range of the map. If this option is specified then the first number on the line must be the zone for the map, zero if only a map of the first zone, and the next two numbers must be the lower and upper limits to the map. These temperatures will be interpreted as logs if less than or equal to 10.

The code is left in a disturbed state after a map is computed. It is best to begin a calculation over again after a map is computed, rather than try to continue with the current model. This can be done with the "STOP ZONE" command.

4.10.12 neutrons -2 [efficiency=-2]

This command adds energy deposition and ionization by secondaries, due to the fast neutrons proposed by Sikora, Begelman, and Rudak (1989). The argument is the luminosity in fast neutrons, expressed as a fraction of the *total* photon luminosity of the incident continuum. It is interpreted as a log if less than or equal to zero, and a linear scale factor if positive.

The second argument is optional, and is the heating–ionization efficiency of the neutrons. Its default is unity. Both quantities are interpreted as logs if less than or equal to zero, and linear if greater than zero.

4.10.13 print coolants, zone 135

This turns on an option to print out the emission-line cooling arrays for the specified zone. If no zone number or 0 appears on the line then the coolants for *all* zones will be printed. The numbers printed are the log of the cooling per unit volume. Significant ($\geq 5\%$ of the total) coolants are marked by a sharp sign (#).

4.10.14 time dependent model of zone 3

A time-dependent model of the specified zone is performed, as discussed by Ferland and Truran (1981). The model follows the recombination and cooling after the ionizing radiation is instantaneously cut off. The initial conditions are those appropriate for the zone specified as the argument. Collisional ionization is included, so this calculation is somewhat like a shock.

This command does not now work, and will not function again until development work on helium is complete.

4.10.15 tolerance 0.001

The equilibrium temperature is set by balancing the heating and cooling rates. This command is used to change the error tolerance in the heating-cooling match. The default tolerance is 0.02 (or 2%). This will be the error in the heating-cooling balance allowed in each zone; the total error or energy conservation mismatch over a model will be much smaller, usually of order ten times smaller than the tolerance specified.

The tolerance is given by the variable "TOLER", which is the sole variable in the common block "TOLER".

4.11 Stopping Criteria

In some nebulae ionized by starlight, such as certain planetary nebulae or H II regions, the outer limit of the cloud is well-defined by an ionization front (the nebula is said to be radiation-bounded), and setting an outer limit is not necessary. In these cases the model stops because nearly all ionizing radiation has been attenuated, and the temperature falls below 4000K, the default lowest allowed electron temperature. This choice of lowest temperature was made with optical emission lines in mind; if lines with very low ionization and excitation potentials (i.e., the [CII] or [OI] infrared lines) are of interest, then it is probably necessary to lower this ending temperature with the "STOP TEMPERATURE" command.

In other circumstances, particularly X-ray ionized nebulae, the gas is optically thin to hard radiation and an outer limit must be specified. In other situations, optically thin models, or ones in which only part of the Strömgren sphere is present, must be computed (in this case the nebula is said to be matter-bounded). In these cases stopping criteria must be specified. More than one stopping criteria can be specified, and the calculation will stop as soon as the first one is met. CLOUDY will say why it stopped after the last zone calculation is printed.

If no stopping criteria are set, then the calculation will usually stop because the default lowest temperature (4000K) or the default greatest number of zones (300) was reached.

4.11.1 radius inner=18 [thickness=16; parsecs; linear]

The "RADIUS" command is discussed above. The optional second number is the log of the thickness of the cloud (if the second number is less than the first) or the log of the outer radius (if the second number is greater than the first). The default outer radius is 10^{30} cm. The default units are centimeters, but the arguments will be interpreted as the log of the radius and thickness in parsecs if the keyword "PARSECS" appears anywhere on the line. The numbers are interpreted as logs unless the optional keyword "LINEAR" appears. If both keys appear then linear parsecs result.

4.11.2 stop column density=23 [neutral; ionized; total; ...]

This command causes the calculation to stop when the specified hydrogen column density (cm^{-2}) is reached. There are several optional keywords, which determine whether the column density is the total (the default), the ionized hydrogen column density, the neutral hydrogen column density, or the effective column density (defined below). For all cases the default stopping column density is 10^{30} cm^{-2}.

stop column density=23 The number is the log of the total hydrogen column density (atomic, ionic, and molecular hydrogen), defined as the integral

$$\int \left\{ N(H^\circ) + N(H^+) + N(H^-) + 2N(H_2) + 2N(H_2^+) + 3N(H_3^+) \right\} f(r)\, dr \qquad (38)$$

where $f(r)$ is the filling factor.

stop neutral column density=23 The number is the log of the neutral (atomic) hydrogen column density, i.e.,

$$\int N(H^\circ) f(r)\, dr \quad . \qquad (39)$$

stop ionized column density=23 The number is the log of the ionized hydrogen (H^+) column density, i.e.,

$$\int N(H^+) f(r)\, dr \quad . \qquad (40)$$

stop effective column density=23 This command is actually a form of the "STOP OPTICAL DEPTH" command. Usually, low energy cutoffs in X-ray spectra are parameterized by the equivalent column density of a cold neutral absorber with cosmic abundances. Actually, what is measured is an optical depth at some energy, generally around 1.0 keV. If the gas is ionized then a much larger column density will

be needed to produce the observed absorption, and the difference is often more than an order of magnitude. Using this command, it is possible to stop the calculation when the incident continuum has been attenuated by the appropriate absorption at 1.0 keV. The calculation will stop when the absorption optical depth at 1.0 keV (neglecting all scattering) reaches a value of

$$\tau_{abs}(1.0\,keV) = N_{effec}\ 2.14 \times 10^{-22} \tag{41}$$

at 73.5 Ryd. The absorption cross section per proton for cold neutral gas is taken from Morrison and McCammon (1983). Scattering opacities *are not* included in this optical depth. In general, the actual column density will be much greater than the "effective" column density.

4.11.3 stop eden 3 [linear]

The model will stop if the electron density falls below the indicated value. The number is entered as a log; in this case the model will stop if $N_e < 10^3$ cm^{-3}. There is an optional keyword "LINEAR" which will force the argument to be interpreted as the quantity itself, not its log. This command is a useful way to stop constant temperature models. For instance the calculation can be forced to stop at the H^+-H^o ionization front by setting the stopping electron density of approximately half of the hydrogen density.

The following examples show a case which will stop near the He^{2+}-He^+ ionization front (for solar abundances) and a case which will stop hear the H^+-H^o ionization front.

```
* stop at the He++ - He+ ionization front
hden 9
stop eden 9.06 ;stop when helium (10 percent by number) is He+

* stop at H+ - Ho ionization front
hden 5
stop eden 4.5 ;stop when electron density falls below hydrogen density
```

The default is an electron density of -10^{30} cm^{-3}. (The negative sign is not a typo.) It is stored as the variable ENDEDN, the sole variable in common block "ENDEDN".

4.11.4 stop efrac=1.05

The model will stop when the electron fraction, defined as the ratio of electron to hydrogen densities, falls below the indicated value. This is another way to stop calculations at ionization fronts, and is useful if the hydrogen density there is not

known (this occurs in constant pressure calculations, for instance). The argument is the fraction itself if it is greater than zero, and the log of the fraction if less than or equal to zero.

The default is an electron fraction of -10^{37} cm^{-3}. (The negative sign is not a typo.) It is stored as the variable EFREND, the sole variable in common block "EFREND".

4.11.5 stop line 6300 reaches 0.1 relative to 5007

The model will stop when the emission line with the wavelength given by the first number exceeds an intensity given by the second number, relative to a second emission line with wavelength given by the third number, in this example $[O\ III]$ λ5007. If a third number is not entered, this second emission line will be Hβ (not the default normalization line). This command is useful for stopping matter-bounded models. This results of this command are not exact; the final intensity ratio will be slightly larger than the ratio specified.

4.11.6 stop optical depth -1 at 2.3 ryd

This command stops the calculation at an arbitrary *absorption* optical depth. The first number is the log of the optical depth, and the second number is the energy in Rydbergs. The optical depth is always a log, and the optical depth does not include scattering opacities. The second number is interpreted as a log if it is negative, linear Rydbergs if positive, and must be within the energy bounds considered by the code (presently 1.001×10^{-5} Ryd to 7.354×10^{6} Ryd). At present, only one stopping optical depth can be specified; if more than one is entered then only the last is honored.

It is traditional in X-ray astronomy to characterize low-energy cut-offs as the equivalent *completely neutral* column density. This is not correct when the gas is ionized, since the high energy absorption opacity is diminished, often by more than an order of magnitude. The deduced column density is underestimated by the same amount. It is better to convert the deduced column density back into an optical depth at 0.5 or 1 keV (this is actually the observed quantity), and use this optical depth and energy as the stopping criteria, than to use the deduced column density as a stopping criteria. Either this command, or the "STOP EFFECTIVE COLUMN DENSITY" command (which is actually a form of the "STOP OPTICAL DEPTH" command) can be used to stop the calculation at an X-ray optical depth corresponding to a certain low-energy absorption.

The optical depth used in this command is the absorption optical depth, and does not include scattering opacities. The most important scattering opacity in grain-free environments is usually electron scattering, which is grey when $h\nu \ll mc^2$. As a result

this scattering opacity does not affect the usual X-ray analysis. In general, the effects of scattering opacities are much more geometry dependent than absorption.

stop Balmer optical depth = -.3 This command is a special case of the "STOP OPTICAL DEPTH" command, in which the energy does not need to be specified, but the keyword "BALMER" is given. It will cause CLOUDY to stop when the log of the absorption optical depth at the Balmer edge ($\nu = 0.250$ Ryd) reaches the specified value. The default is $\tau_{Bac} = 10^{20}$, and the optical depth is always interpreted as a log. This is the *total absorption* optical depth at the Balmer edge, and includes all computed opacity sources such as grains or free-free absorption.

stop Lyman optical depth = 5 This is a special case of the STOP OPTICAL DEPTH command, in which the energy does not need to be specified. In this case the model will stop at an absorption optical depth of 10^5 in the Lyman continuum. The number entered is the log of the Lyman limit optical depth, τ_{912}. The default value is $\tau_{912} = 10^{20}$. The stopping criterion is *really* the total 912Å absorption optical depth, and *not* the hydrogen Lyman limit optical depth at 912Å. These are not exactly the same, especially when grains are present or the abundances of the heavy elements are enhanced.

4.11.7 stop temperature=1,000K [linear]

The model will stop if the electron temperature drops below T_{low}, the argument of this command. The temperature is interpreted as a log if the argument is less than or equal to 10K, and linear if greater than 10, or the "LINEAR" keyword appears. The default value is $T_{low} = 4000$K. Gas cooler than this produces little optical emission, but may be a strong emitter of infrared lines such as the [Ne II] 12.8 μm, [CII] 158 μm, or the [OI] ^{3}P lines. The lowest temperature allowed, T_{low}, should be adjusted so that $h\nu \gg kT_{low}$ for the lowest excitation potential ($h\nu$) transition to be considered. Note that more than one temperature is sometimes possible when T$\sim 10^3$ K, so thermal stability problems may develop if T_{low} is lowered below a few thousand degrees Kelvin. If stability problems occur then it may be necessary to increase the number of thermal failures allowed, with the "FAILURES" command. This is discussed further in section 8 below. The lowest temperature allowed is stored as the variable "TELOW", the sole variable in common block "TELOW".

4.11.8 stop thickness 9.3 [parsecs; linear]

This command sets an upper limit to the thickness of the model. The argument is interpreted as the log of the thickness unless the keyword "LINEAR" appears. The

default units are centimeters, but it will be interpreted as the log of the thickness in parsecs if the keyword "PARSECS" appears on the line. The "STOP THICKNESS" command has the same effect as the optional second number on the "RADIUS" command. This command makes it possible to set a thickness when the inner radius is not specified, such as when the ionization parameter is given.

4.11.9 stop zone 123 [21 on sec iteration, ...]

In this example the calculation will stop after computing 123 zones. The default value is 300. Up to ten numbers may be entered, each being the ending zone for consecutive iterations. If fewer numbers are entered than iterations performed, then the last number will be used for all further iterations.

4.12 Output

CLOUDY is capable of keeping a printer going for hours. Several commands vary the printer's mass-loss rate, and are described here. A description of the meaning of the output follows in section 3.

4.12.1 faintest line to print -2 [_off]

CLOUDY will normally print the intensities of all emission lines with intensities greater than 10^{-4} of the reference line, usually Hβ. This command changes the limit to the relative intensity of the weakest line to be printed. The argument is either the log (if less than or equal to zero) or the linear value of the intensity of the weakest line to print (if positive), relative to the reference line. The reference line is usually Hβ, and can be changed with the "NORMALIZE" command. In the case shown here, only lines with intensities greater than 1% of Hβ will be printed.

If no numbers are entered, but the keyword "_OFF" appears, then all lines are printed, even those with zero intensity.

4.12.2 line 1909

The relative intensities of a few selected lines are given for every printed zone. It is possible to have one extra emission-line intensity printed by entering this command, whose argument is the wavelength of the extra line. This is a useful way to follow the buildup of a line across a model.

4.12.3 normalize to 1216 [scale factor = 100]

Emission-line intensities are usually listed relative to the intensity of Hβ. This command changes the reference line to any of the other predicted lines. The entire emission-line spectrum will have its relative intensity normalized to the intensity of the line whose wavelength is given by the argument.

The optional second number is a scale factor for the relative intensity array. If it is equal to 100, as in this example, then all intensities will be relative to a reference line intensity of 100. The default value is 1. The example given above will cause the intensities to be expressed relative to a Lyα intensity of 100.

4.12.4 pall

This command tells the code to print many emission lines whose intensities are simply scaled from lines usually printed, such as the higher Balmer lines, and many helium lines. These assume case B emissivities, and are not reliable at high densities, or when lines are optically thick. This option was added by P.G Martin.

4.12.5 plot continuum map opacity [Emin=.1, Emax=10, trace]

A plot of any of several properties of the calculation can be made. One of the keywords described below (continuum, map, or opacity) must appear on the command line. Up to ten plots can be generated; this limit is set by the variable NDPLOT which appears in several parameter statements throughout the code. The keyword "TRACE" will turn on a great deal of information concerning the mechanics of generating the plot.

Publication quality plots can be produced using the "PUNCH" commands (described below) to produce a file which can then be post-processed using plotting software.

4.12.6 plot continuum [Emin=1, Emax=4, _raw, trace]

If "CONTINUUM" is entered then the continuum (usually 1.001×10^{-5} Ryd $\leq h\nu \leq 7.354 \times 10^{6}$ Ryd) is plotted, unless the range is altered by entering the two optional numbers. The default is for both the incident continuum (in units of νf_ν) entering the cloud (plotted as .'s) and that transmitted through the cloud (the o's) to be plotted.

Plot continuum keywords It is also possible to plot specific components of the continuum. If the keyword "DIFFUSE" appears then the diffuse emission per unit volume, for the last computed zone, will be plotted. This continuum is only that emitted by the gas and grains in the optically thin limit and unity filling factor. If the

keyword "EMITTED" appears, then the net integrated continuum produced by the cloud is plotted. This is the sum of the continuum emitted in the inward and outward directions from the computed ionization structure, and does not include the incident continuum. If the keyword "REFLECTED" appears, then only the continuum emitted from the illuminated face of the cloud is plotted. This includes the back-scattered portion of the incident continuum, along with diffuse emission from the cloud. This is meaningful only for non-spherical geometries. If the option "_RAW" is specified, then the continuum in units actually used inside CLOUDY (cm^{-2} s^{-1} $cell^{-1}$) will be plotted. If the keyword "PHOTON" appears, then the units of the plotted continuum will be photons cm^{-2} s^{-1} Ryd^{-1}).

4.12.7 plot opacity [absorption, scattering, total min=1 max=4]

If the keyword "OPACITY" is entered then the opacity of the first and last zones (per hydrogen atom) is plotted. The continuum between 1.001×10^{-5} Ryd$\leq h\nu \leq$ 7.354×10^{6} Ryd is usually plotted, unless this is adjusted by entering the optional energy range. There are three optional keywords; "absorption" "scattering" or "total", to change which opacity is plotted. If none appear, then the total opacity is plotted.

plot range options For the OPACITY and CONTINUUM options, there is a further option to specify the energy range of the plot. If one number occurs on the command line then it is interpreted as the lowest energy (in Rydbergs) on the plot. If the first number is zero, then it is interpreted as the lowest energy in the continuum, presently 1.001×10^{-5} Ryd. The optional second number is interpreted as the highest energy shown on the plot. If the second number is omitted or zero, then it is interpreted as the high energy limit of the code, presently 7.354×10^{6} Ryd. If either number is negative then both are interpreted as the log of the energy, otherwise they are assumed to be the linear energy in Rydbergs. If the first number is zero (i.e., interpreted as the lowest energy considered by the code) then the second number is interpreted as the energy of the upper limit to the plot, and not its log.

4.12.8 plot map [Tmin=3,000K, Tmax=20,000K, linear]

If the keyword "_MAP" (note the leading space) appears then a plot of the heating and cooling rates as a function of temperature will be made. This will follow the last zone calculated, and will be appropriate for the attenuated continuum and physical conditions in that zone.

plot map range options The high and low temperatures on the map can be changed by entering one or two optional numbers. If no numbers appear then a range

of 10K to 10^9K is assumed. If only one number appears then only the lower temperature limit is changed. If two numbers appear then both lower and upper limits are changed.

If the first number is less than or equal to ten then both numbers are interpreted as logs of the temperature. If the first number is greater than ten then both numbers are interpreted as the temperature itself. If the keyword "LINEAR" appears then both numbers are interpreted as the temperature itself no matter how large or small they may be.

4.12.9 print every 1000 [5 37 93]

CLOUDY will always print the results for the first and last zone. This command can be used to vary the number of zones printed in between. In the example above, it will print every 1000 zones on the first iteration, every 5 zones on the second iteration, etc. Normally about 100 - 200 zones are computed per model, so printing every five or ten zones on the last iteration may be useful. If there are fewer numbers entered than iterations performed, then the last number entered will be used for all further iterations. The default value is to print only the first and last zones.

4.12.10 print arrays

This option tells the code to print the ionization balance arrays for all elements heavier than helium. The first line is the vector of ionization rates, in units s^{-1}. The second line is the vector of recombination rates, also s^{-1}. These lines are the two diagonals of the bi-diagonal matrix used in the solution of the ionization balance equation, and include *all* ionization and recombination processes.

4.12.11 print coolants, zone 135

This turns on an option to print out the emission-line cooling arrays for the specified zone. If no zone number or 0 appears on the line then the coolants for *all* zones will be printed. The numbers printed are the log of the cooling per unit volume. Significant ($\geq 5\%$ of the total) coolants are marked by a sharp sign (#).

4.12.12 print departure coefficients

This command tells the code to print departure coefficients in addition to the relative populations for the lowest seven of the ten levels of hydrogen, H^-, helium, and some molecules.

4.12.13 print heat

This tells the code to print out the relative heating due to each stage of ionization or physical process. The number is the fraction of the total heating due to this particular stage of ionization, and is printed directly below the relative abundance of that stage.

4.12.14 print last

Normally, results for every iteration are printed as they are computed. If this command is entered then only results for the last iteration will be printed.

4.12.15 print only [header, zones]

The keyword "ONLY" shortens the printout somewhat by stopping the calculation prematurely. If it appears, then another keyword, presently "HEADER" or "ZONES", must also appear. The command "PRINT ONLY HEADER" will cause the code to stop after printing the header information. The command "PRINT ONLY ZONES" will cause the code to stop after printing the zone results on the first iteration.

4.12.16 print short

The detailed final printout is shortened when the "SHORT" keyword appears. Only the emission lines, and a short summary of some thermal properties of the model, will be printed.

4.12.17 print starting at 61

This option turns off *all* printout *until* the specified zone is reached.

4.12.18 punch option [unit=8]

Punch (output on an arbitrary output unit) any of several possible pieces of information. This command is a primary output mechanism for CLOUDY. The options are many; physical quantities such as temperature, ionization, density, for each zone are produced for some options, for other cases the continuum or other quantities predicted by the code can be output. In all cases, the general idea is for the file produced by this command (called "fort.n" in UNIX, where n is the integer on the command line) to then be post-processed by other plotting programs to produce final plots.

The current options are summarized in Table 12, and one of these keywords must appear. Only one keyword per line is recognized. The four character key which must be matched is capitalized. This command causes a subroutine called "PUNCHR" to be

called after every zone calculation. If "SPECial" is specified then a portion of the subroutine will be used, which can be changed to fit the circumstances.

The optional number on the line is the FORTRAN I/O unit number used for the output. Up to ten PUNCH commands, with or without different output numbers, can be entered. Unit 7 will be used for the first file if no number appears on the line. If no I/O unit number appears on subsequent "PUNCH" commands the unit number will be incremented by one on each call i.e., the second file will be fort.8). This is to ensure that no more than one PUNCH command writes to a given file.

Normally the results are produced for every iteration. Only results from the last iteration will be produced if the "LAST" keyword appears on the line.

Note that CLOUDY uses FORTRAN logical unit 6 for output, and unit 5 for input. These units cannot also be used for punch output, and the same logical output unit cannot be used for more than one punch option.

punch continuum This command is the primary mechanism for printing out the continuum predicted by the code. The first column is the energy in Rydbergs. The second column is the incident continuum (νF_ν, erg cm^{-2} s^{-1}) at the illuminated face of the cloud, and the third column is the transmitted portion of the incident continuum, in the same units. The 4th column is the continuum emitted by the computed structure, and includes a covering factor if one was specified. The 5th column gives the net transmitted continuum, the sum of the attenuated incident and diffuse continua. This would be the observed continuum is the nebula fully covers the continuum source. The 6th column is the reflected continuum. All continua are the flux (erg cm^{-2} s^{-1}) and are relative to the inner radius of the clouds (i.e., the specific luminosity would be the predicted quantity multiplied by $4\pi r_{inner}^2$).

punch lines, structure This option on the PUNCH LINES command tells the code to punch the emissivity of up to ten emission lines as a function of depth into the cloud. The emission lines are specified on the following input lines, and end with a line with the keyword "END" in columns 1-3. The label used by CLOUDY to identify each line (see section 6) must appear in column 1-4 of the line, and the integer used to identify the line wavelength appears as a free-format number in later columns. The line labels and wavelengths are then punched. The depth into the cloud, and the volume emissivity (erg cm^{-3} s^{-1}, for unit filling factor) is then punched for each line. This information can then be used to reconstruct the surface brightness distribution of a resolved emission-line object.

The following illustrates its use;

```
punch lines, structure
totl 4861
```

Table 12: Punch Options

Keyword	Output
CALCium	NSTEP, CA(1, 2, 3, 4)
CARBon	NSTEP, radius, depth, CARB(1-7)
CONTinuum	ν_R, νF$_\nu$(inc), trans, diffuse, sum, reflect
EMITted CONTinuum	ν_R, νF$_\nu$(emitted both sides)
DIFFuse CONTinuum	ν_R, νF$_\nu$(unit vol)
IONIzing CONTinuum	ν_R, $\nu^2\phi$
REFLected CONTinuum	ν_R, νF_ν reflected
TRANsmitted CONTinuum	ν_R, νF_ν, raw
_DR_	logic behind choice of zone thickness
GRAIN OPACity	nu, extinction, absorption, scattering
GRAIN PHYSical	te, potential, drift velocity, frac heat
GAUNt factors	ν(Ryd), free-free gaunt factor
HELIum	NSTEP, radius, depth, HeI, HeII, HeIII
HYDRogen	NSTEP, TE, HDEN, EDEN, (HI, HII, H2, H2+, H3+, H-)/HDEN
IRON	NSTEP, -log10(rel ioniz)*100
LINEs STRUcture	DEPTH, line emission per unit vol
LYMAn alpha	$\tau(Ly\alpha)$, N(2p)/N(1s), T(excitation)
_MAP	Te, heating, cooling
MOLEcules	H2/HDEN, CO/H, H2O/H, OH/H, CH/H
OPTIcal depths	nu, total, absorption, scattering optical depths
OPACities	nu, opacity(nu), albedo
_OTS	nu, flux, otscon, otslin, outcon
_QS_	nu, qabs, qscat
OXYGen	NSTEP, oxy(1,2,3,4)
PHYSical cond	NSTEP, R-R$_o$, TE, HDEN, EDEN, rad accel
PRESsure	NZONE, depth, P(gas), P(rad), Pinteg
RADIus	NZONE, R, R-Ro, dr
RECOmbin effic	τ(912), rec effic to n=1
SOURce function	nu(R), diffus, opacity, source fcn, black body ratio
SPECial	Specially defined
TEMPerature	NZONE, T, dT/dr
WIND	Radius, thickness, velocity, acceleration, force multiplier

```
o  3 5007
totl 3727
o  1 6300
end of lines
```

punch transmitted continuum This command is used to save the transmitted (attenuated incident and outward component of diffuse) continuum at the end of the calculation. This punch file can then be used as part of the continuum in a later calculation, by reading in this file with the "TABLE READ" command.

Three cautions when reading this file as an input continuum: a) if the keyword "last" does not appear on the line then the continuum from each iteration will be punched. Probably results from only the last iteration are needed, so either the "last" option should the used, or the file must be edited after the initial calculation to leave only the last computed continuum; b) on the second calculation punch output should not be created on the same FORTRAN unit number as the input file. It will overwritten if this occurs; c) the program expects the first two lines to contain header information and skips them. They should not be deleted from the input file.

4.12.19 quiet

This command sets CLOUDY's quiet mode, in which nothing is printed at all. Specifically, it sets the variable TALK in common block CALLED to false. Printing can be started at a particular zone by combining this command with the "PRINT STARTING AT" command described above.

4.12.20 sort

This option causes the output spectrum to be sorted by wavelength rather than by ion. It was added by P.G. Martin. It doesn't work.

4.12.21 title This is a title

The argument is a title for the calculation, and can be useful for organizing the models in some manner. The title is reprinted several times.

4.12.22 trace zone 94 [iteration 2;hydrogen;helium;carbon;...]

This command turns on trace printout beginning *after* the zone given by the first number on the line. The trace follows the logical flow within CLOUDY, and is a useful

Table 13: Trace Keywords and Effects

keyword	variable	Trace
CARBon	CARBUG	carbon ionization equilibrium
Compton	COMBUG	Compton heating, cooling, and ionization
CONTinuum	CONBUG	prints out photon arrays, pointers
DIFFuse fields	TRDIFF	sum of recombination coef in DIFFEM
_DR_	DRBUG	choice of next zone thickness
GRAIN	DSTBUG	details dealing with grain treatment
EDEN	NEBUG	changes in electron density
GAUNt	TRGANT	the free-free gaunt factors
IRON	FEBUG	Fe Auger - fluorescence K-alpha problem
HEATing	HEATBG	heating agents
HELIum	HEBUG	helium ionization equilibrium
HELIum IONIzed	HE2BG	helium ionization equilibrium
HELIum SINGlet	HE1BG	helium ionization equilibrium
HELIum TRIPlet	HE3BG	helium ionization equilibrium
HYDRogen	HBUG	hydrogen ionization equilibrium
Ly BETA	TR8446	Lyβ - OI 8446 pumping problem
OPACities	OPCBUG	continuous opacities, zone by zone
OPTIcal depths	OPTBUG	inner, outer optical depths in STARTR
MOLEcules	TRMOLE	rate coefficients for molecules
NEON	NEONBG	recombination, ionization for neon
THREe body	BD3BUG	three-body recombination rates for metals
TWO photon	BUG2NU	induced two photon processes

way to follow the internal decisions CLOUDY makes. CLOUDY uses adaptive logic to control many choices, such as the run of zone thickness with radius. This command allows these decisions to be followed in detail. If the zone is zero, or if no numbers occur on the line, then the trace is turned on at the beginning of the calculation. The second (optional with default=1) number is the iteration on which the trace should be started. It should be set to 2 to turn on the trace for the second iteration. Table 13 lists the trace keywords (column 1; the four character part of the key which must be matched is capitalized), the logical variable in CLOUDY which is affected (column 2; these are variables in the common block of the same name), and the purpose of each.

Table 14: Commands with "Vary" Option

Command	quantity varied	Min	Max	Increment
BLACKBODY	temperature	def	def	0.5
BREMSSTRAHLUNG	temperature	def	def	0.5
FILLING FACTOR	filling factor	def	0	0.5
HDEN	hydrogen density	def	def	1.0
IONIZATION PARAMETER	ionization parameter	def	def	0.5
LUMINOSITY	luminosity of source	def	def	0.5
METALS	log of metalicity	def	def	0.5
PHI(H)	log of photon flux	def	def	0.5
Q(H)	log of total number of photons	def	def	0.5
RADIUS	inner radius	def	def	0.5
STOP COLUMN DENSITY	column density	def	def	0.5
TABLE STAR KURUCZ	temperature	4.477	4.699	0.1
TABLE STAR MIHALAS	temperature	4.477	4.740	0.1

4.13 The Optimize Command

The OPTIMIZE command and its keywords tell the code to vary two or more of the initial parameters to try to find an optimal set of parameters to fit a specified emission-line spectrum, line flux or luminosity, and/or a set of column densities. The method was first implemented in CLOUDY by R.F. Carswell, who wrote most of the code for the present version. It uses the downhill simplex algorithm (Press et al. 1988) to obtain a best fit to a set of observed quantities. The desired emission-line spectrum, line flux or luminosity, and/or column densities, are specified by a series of "OPTIMIZE" commands. A keyword "VARY" can appear on several of the commands used to specify initial conditions (Table 14) to indicate which parameters are to be varied.

At a minimum, a desired emission-line spectrum, line flux, or column density, and a specification of which parameters are to be varied, must be given. The parameters to be varied during the optimization are specified by a keyword "VARY" which may appear on any of the commands listed in Table 14. Up to 20 parameters may be varied at a time; this limit is set by the variable LIMPAR which appears in several PARAMETER statements throughout the code. The quantities being varied are actually entered as logs within the code, and increments to the initial guess are also logarithmic. More than one parameter must be varied because of limitations in the current optimization algorithm. It simply cannot find a solution with only a single variable parameter.

An example of the "VARY" option in action is given in an sample input stream in

section 25 below. A typical input stream follows:

```
blackbody, 50,000K
hden 4 vary
ionization parameter -2 vary
stop zone 1
*
* the following specifies observed emission lines, order is
* label, wavelength, intensity relative to H-beta, tolerance
optimize lines
O  3 5007 intensity=13.8 error=1.
totl 3727 < 2.1 (only upper limit)
end of lines
*
* following are elements, stage of ionization, log col density
optimize column densities
carbon 4 17.4
silicon 3 14.6
end of column densities
```

Information concerning the optimization process is fed to the code as a series of keywords on the "OPTIMIZE" command; these are described next. Only one keyword will be recognized per "OPTIMIZE" command.

4.13.1 optimize, column density

This tells the code to try to reproduce a set of column densities. A series of column densities, ending with a line with the keyword "END" in columns 1–3, will be read in from subsequent lines. One column density is entered per line, and up to 100 may be specified. Columns 1 to 4 of the column density lines must contain the first four characters of the name of the element, spelled as in the output from the zone results. The first number on the line is the ionization stage, 1 indicates Atom I, 3 indicates Atom III, etc. The second number on the line is the log of the column density (cm^{-2}), and the last optional number is the relative uncertainty. It has a default of 0.05 (5 percent). A column density can be specified as an upper limit by entering "<" anywhere on the line. If "<" appears then the column density is only included in the optimization if the predicted value exceeds the upper limit.

The following gives some examples of its use;

```
optimize column densities
hydrogen 1  < 17 ;make sure optically thin in lyman continuum
```

```
carbon 4 17.4 error=.001
silicon 3 14.6
end of column densities
```

4.13.2 optimize, increment = 0.5 dex

The increments are the amounts by which each variable is changed in the first step away from the initial parameter. The default increments preset in the code were chosen with "typical" conditions in mind. The increments are logarithmic quantities which will be added to or subtracted from the initial guess. It may be necessary to increase these if the process is unable to identify a solution. If a zero is entered as an increment, then the default increment will not be changed.

The increments entered with this command affect *only* the previously selected "VARY" command. The following gives some examples of changing the increments.

```
hden 4 vary
optimize increments .1 ;this sets .1 dex changes in hden
brems 6 vary           ;increments left at default
radius 13.6 vary
optimize increments .05; this sets changes in radius
```

The increments are stored in the vector variable VINCR.

4.13.3 optimize, (intensity, luminosity)=36.425 [error=0.1]

The code will try to make the predicted intensity or luminosity of the normalization line (usually Hβ) match the entered value. The sub-keyword is either "intensity" or "luminosity", and both have exactly the same effect. The number is the log of either the intensity or luminosity of the line, in the same units as found in the final print out. The second (optional) number is the fractional tolerance allowed for the fit between the observed and computed values. If a tolerance is not specified, then 0.05 (five percent uncertainty) is assumed.

4.13.4 optimize, iterations=75

The upper limit to the number of iterations to be performed is specified with this command. The maximum number of iterations is stored as the variable ITOPTM, which has the default of 20. It is probably a good idea to reduce the number of iterations if the initial guess is far from the solution. It may be necessary to increase the limit if the process is still making progress at the end of the calculation. The limit to the number of iterations should really be some function of the number of parameters being varied.

4.13.5 optimize, lines

This command tells the code to try to reproduce a set of relative emission-line intensities, and to begin reading a list of observed lines. Up to 100 lines may be entered; the limit is stored as the variable NOBSLM which appears in several PARAMETER statements throughout the code.

One emission line is specified per input line, and the line must contain information in the following order: columns 1 to 4 of the line must list the label CLOUDY uses to identify the line; this must then be followed by the wavelength, a free format integer. Both must exactly match the identifications used inside CLOUDY and printed as line labels in the output; the code will stop if this is not the case. Section 6 below gives the emission line or continuum labels and wavelengths. The third quantity on the line is the desired relative intensity of the line. This will be in the same units as the relative intensities normally printed at the end of the calculation. Intensities are normally relative to Hβ, but can be changed to other reference lines with the "NORMALIZE'" command (described elsewhere). The last (optional) number is the fractional tolerance allowed for the fit between the observed and computed values. If a tolerance is not specified, then 0.05 (five percent uncertainty) is assumed. A line can be specified as an upper limit by entering "<" anywhere on the line. If "<" appears then the line is only included in the optimization if the predicted value exceeds the upper limit.

The series of emission lines ends with a line which has the keyword "END" in columns 1 to 3. If this "end" does not appear correctly then the code will continue reading lines until the end-of-file is encountered.

4.13.6 optimize, punch=9

At the end of the optimization process the optimal input parameters are entered into a file for later use. Normally this is Fortran "punch" unit 7 (i.e., fort.7 in Unix). The unit number can be changed with this command. Using this file, it is possible to make later calculations in which various quantities are also punched for plotting. Also, it is generally a good idea to confirm that a single run with CLOUDY does reproduce the final results from the many calls of the code made by the optimization method. The two should agree exactly, but would not if the code became corrupted during the many calls made during the process (this could happen if a pointer went astray, for example).

Be careful that the unit specified with this command is not the same as one of those used by the "PUNCH" command. The files will overlap if the same unit is used.

4.13.7 optimize, range -2.3 to 3.9

It is possible to establish limits to the allowed range over which parameters are to be varied. The limits which are preset in the code are indicated in Table 14. The entry

"def" indicates the default limits of -1×10^{37} and 1×10^{37}.

It is sometimes necessary to establish physical limits to parameters which are varied. For instance, metalicities may be limited to the range $-1 \leq \log(Z) \leq 0$ by observations or physical plausibility. The optimization driver doesn't know this, but can be told a set of bounds with this command. The arguments are ordered pairs of limits, which are the log of the lower and upper limits to the allowed range of variation of the previous command with "vary" specified. In this way the command is similar to the "OPTIMIZE INCREMENTS" command described above. The default limits are -1E37 and +1E37 respectively. Examples follow.

```
hden 4 vary
optimize range from 3 to 5 ;this sets limits to range of density
brems 6 vary               ;no range for this one
radius 13.6 vary
optimize range from 13 to 14; this sets limits to radius
```

The optimizer does not actually know about the range limit; a residual of 10^{37} is returned if a parameter outside the allowed range is used. The limits to the range are stored in the vectors VARANG(1,n) (lower limit) and VARANG(2,n) (upper limit).

4.13.8 optimize, tolerance = 0.2

The tolerance, a measure of the overall agreement between the observed and specified spectra, intensity, and/or column density, is set with this command. The tolerance is stored as the variable VTOLER, with the default value 0.10.

4.13.9 Convergence criteria

The sum of residuals

$$\sum \left[\frac{(observed - model)}{model \times \delta} \right]^2 \tag{42}$$

is accumulated over all relative intensities, line intensities or luminosities, and column densities, and minimized. In this expression "observed" and "model" are the observed and computed quantities. If the model prediction is zero then a residual of 10^{37} is returned. The uncertainty δ is specified when the observed quantities are read in and has a default value of 0.05 (5 percent). For column densities and relative line fluxes the linear quantity is used to form the residuals. To avoid floating point problems on 32-bit IEEE machines, the log of the line flux or luminosity is used. The process stops when the sum of residuals is smaller than the variable entered with the "OPTIMIZE TOLERANCE" command, which has the default of 0.10.

4.13.10 Notes concerning commands with "vary" option

The keyword "VARY" can appear on the commands in Table 14. Notes concerning these follow.

Blackbody It is not possible to specify the luminosity of the blackbody by using the keywords on the blackbody command when the VARY option is used. It is necessary to enter the luminosity using some other command, such as "LUMINOSITY" or "IONIZATION PARAMETER".

Filling factor Only the filling factor itself can be varied. It is possible to specify the optional power law for a radial dependence but it is not possible to vary it.

HDEN It is possible to specify the exponent for the optional power law density dependence upon radius or thickness. It is not possible to vary this additional parameter; only the initial hydrogen density is varied.

LUMINOSITY It is possible to specify all of the options on the luminosity command, but it is only possible to vary the luminosity itself.

PHI(H) and Q(H) It is possible to use the "RANGE" option, but only the log of the photon number will be varied.

RADIUS It is possible to specify the stopping radius on the line, but it is not possible to vary it. Only the starting radius is varied.

STOP COLUMN DENSITY All of the optional keywords (neutral, effective, etc) are recognized.

4.13.11 Notes concerning the optimization process.

Use physically motivated initial conditions. The algorithm will not be able to find a solution if one is not physically possible. For instance, an observed HeII λ4686/Hβ ratio of 0.5 cannot be produced by a a 20,000K blackbody, no matter how many other parameters are varied (it produces no He^+ ionizing radiation). It is probably necessary to start with parameters in the general area of the successful model. When far from the solution, it is also a good idea to limit the number of iterations the optimizer can perform (using the "OPTIMIZE ITERATIONS" command) to stop it from over-optimizing a bad solution.

Change the increment size The initial increment will be the largest step ever taken during the optimization process. If the initial parameters are far from the solution then it may be wise to increase the increments.

Set physically motivated limits to the variable quantities. The optimizer driver uses a pure "brute force" method, and understands surprisingly little modern astrophysics. For instance, while trying to reproduce an observed HeII λ4686/Hβ intensity ratio of 0.5 by varying the temperature of a black body radiator, the algorithm is likely to examine the consequences of photoionization by a 100K radiation field. Physically, it is known that HeII emission only occurs for stars hotter than $\sim$50,000K (Osterbrock 1988), so there is little purpose in examining temperatures lower than this. Also, the code may crash if radiation fields which produce *no* ionizing radiation are entered. The process will converge more quickly if reasonable bounds to the range of the varied quantities are set using the "OPTIMIZE RANGE" command.

Don't give up! My experience is that this process works about a quarter of the time. The problem is that the algorithm can easily "home-in" on a local minimum, which is actually a very bad solution. When this occurs, the best idea is to restart the optimization process with a different set of initial conditions. Better yet is to start the process with parameters which give answers known to be close to the solution. In order to avoid wasting time, it is also a good idea to limit the number of iterations with the "OPTIMIZE ITERATIONS" command.

4.14 Miscellaneous Commands

Several commands are useful for changing basic physical processes or internal parameters in CLOUDY. These options were largely intended to help "fine-tune" or debug CLOUDY, or to identify the importance of individual physical processes. These commands are not normally used.

4.14.1 dielectronic recombination [10]

At present rate coefficients for dielectronic recombination through low-lying autoionizing states have not been computed for most elements on the third row and higher. For the four lowest stages of ionization, the code uses the means of the rate coefficients for C, N, and O; these are $3 \pm 2 \times 10^{-13}$, $3 \pm 2 \times 10^{-12}$, $1.5 \pm 0.5 \times 10^{-11}$, and $2.5 \pm 1.4 \times 10^{-11}$, cm^3 s^{-1}, for the successive stages of ionization. Because no better can be done at present, these are used for those ions which have no rate coefficients. These rate coefficients can be turned off, or the values changed by a scale factor, by entering this command. If a number is entered on the line then it is the scale

factor to multiply all the above rate coefficients; if no number is entered then zero is assumed and the effect is turned off. This is a useful way to check on the importance of this recombination mechanism for specific calculations. The Opacity Project (Seaton 1987) should soon produce all needed recombination rate coefficients.

4.14.2 drive [fread, gaunts, pointers, ...

This command causes CLOUDY to enter a special debug mode, in which the program requests information and responds with deduced quantities. A flag is set when the commands are entered. Parameters for the entire model (density, continuum, and luminosity) must still be specified. This mode is entered after the last command is specified and the input stream ends with a blank line or the end-of-file.

drive escape probabilities The command causes the code to enter a debug mode in which the user enters the log of a one-sided optical depth, the code queries three of the escape probability functions, (complete redistribution with damping wings; incomplete redistribution, and complete redistribution with only the Doppler core), and responds with the one-sided escape probabilities. A null line exits the driver.

drive fread This command causes the code to enter a debug mode in which the free format input reader, subroutine FREAD, reads the input stream and prints the interpreted number. The program will request an input line, and print the interpreted number, until a line with the number zero is entered.

drive gaunts This command enters a CLOUDY debug mode in which a driver requests temperature and photon energies, queries the free-free gaunt factor routine, and responds with the returned gaunt factor. The gaunt factor routine was written by David Hummer, and is described in Hummer (1988).

drive molecules Here it is possible to change individual molecular abundances within the iteration loop.

drive pointers This command allows the user to interrogate the frequency array. After the continuum is generated, the driver will ask for energies in Rydbergs (interpreted as a log if negative) and respond with the cell pointer, frequency, cell width, boundaries, and the phase space factor $2h\nu^3/c^2$. Once complete, the calculation will continue as usual.

4.14.3 drmax 11.2

This command sets the largest allowed zone thickness. The argument is the log of the thickness in cm, and the default is 10^{30} cm. It is possible to force the zones to have a specific thickness by combining the "DRMAX" and "DRMIN" commands.

4.14.4 drmin 11.2

The number is the log of the minimum zone thickness (in cm). It may be necessary to specify this if CLOUDY starts to oscillate near an ionization front in a constant pressure model. If this happens and "DRMIN" is not set then the zones become smaller and smaller, as CLOUDY tries to damp out the oscillations. If this occurs, then, at the end of the calculation, the code will suggest using this command to establish a smallest zone size The default value is 10^{-20} cm.

4.14.5 eden -2

This command allows an "extra" component of free electrons to be added to the gas. The argument is the log of the electron density (cm^{-3}). This command is used to test the behavior of CLOUDY in the limit of very low Compton temperatures. When $T_{color} \ll 10^4$K, the gas is almost entirely neutral, and free electrons must be artificially added to test the Compton energy exchange problem in the strict TE limit. (Remember, charge conservation is a horrible thing to violate.)

4.14.6 flxfnt -20

The highest continuum frequency which needs to be considered in equilibrium calculations is lower for relatively soft continua, such as H II regions, than for x-ray continua, such as AGNs. The criterion used to choose the highest energy ν_{high} to be considered is that $\nu f_\nu(\nu_{high})/\nu f_\nu(\nu_{peak}) <$ FLXFNT, where ν_{peak} is the frequency where the continuum reaches its maximum νf_ν. FLXFNT is normally 10^{-10}. This command changes the value of FLXFNT. The argument is the log of the value.

4.14.7 fudge factors 4.59678 [12.3 34.5 958 ...]

The numbers appearing on the line can be communicated to any part of the code which calls the function "FUDGE". This has a single integer argument which points to the numbers entered on the command line. In the example given above, a call to FUDGE(2) would return the value 12.3. Up to ten numbers can be entered on the command line. Extra numbers are ignored.

This option is not normally used, but can be a useful way to pass numbers to temporary or trial parts of the code. All elements of "FUDGE" are initially zeroed in

the large BLOCK DATA. The function "FUDGE" is a permanent part of CLOUDY, and a warning is given at the end of the calculation if this function is ever evaluated. Also, the function checks that the pointer to the array of stored values is not larger than the number of values entered in the command line; the code will stop if too few values are entered.

4.14.8 increments 0.05 .05 [scale factor = 2]

This command adjusts the two variables used to choose the zone thickness. The thickness of the first zone is chosen so that the largest continuous optical depth through it is equal to the first number on the line. The default is 0.1. Thereafter, the zone thickness is continuously adjusted by checking that the relative ionization of hydrogen, helium, carbon, oxygen, and iron do not change by more than a factor related to the second number. The default is 0.15. If only one number appears on the line then it is interpreted as a scale factor used to multiply the default values. If any number is less than or equal to zero, then it is interpreted as the log of the quantity, and linear if greater than zero.

4.14.9 no . . .

It is possible to disable physical processes as a test of their importance. If a physical process is turned off, then the logical variable "PHYSOK" in the common block of the same name is set to false to indicate that the treatment of physical processes is not ok. A warning is then printed at the end of the calculation, as a reminder that the results of the calculation are not to be trusted.

4.14.10 no (2p2s;2s2p) collisions

This command turns off 2s–2p collisions in the hydrogen atom and helium singlets and ion; it is mainly used for debugging the hydrogen and helium atoms. The keyword can be either "2s2p" or "2p2s".

4.14.11 no Auger effect

This command turns off the Auger effect.

4.14.12 no Compton effect

This command turns off Compton heating and cooling of free electrons, and Compton recoil ionization of bound electrons. Electron scattering opacity *is not* turned off.

4.14.13 no fine structure line optical depths

Fine structure lines, such as the ^{3}P 52, 88 μm lines of O^{+2}, can become optically thick under certain high-luminosity conditions (see, for example, Rubin 1983). Radiative transfer effects, including stimulated and maser emission, are fully treated by CLOUDY for all fine structure lines, using escape probabilities. This command turns off the treatment of optical depths and line transfer for these lines.

4.14.14 no free free heating

Free free heating is turned off with this command. It sets the logical variable "FREEON" in the common block of the same name to false.

4.14.15 no induced processes

This command turns off induced recombination and stimulated emission for hydrogen and helium.

4.14.16 no ir pumping

This command turns off continuum pumping of infrared fine structure lines. This process can be an important heating mechanism for cool gas irradiated by a powerful infrared continuum.

4.14.17 no molecules

CLOUDY does a molecule formation network, initially based on Black (1978) and Hollenbach and McKee (1979) (see section 17.3. It includes H^+, H^o, H^-, H_2, H_2^+, HeH^+, and OH. A very brief description of the network and some results are given in Ferland (1980b). The "NO MOLECULES" command turns the network off.

4.14.18 no on the spot

This command turns on all ground state recombination coefficients, and turns off ionization by helium resonance lines. Specifically, it sets all hydrogen recombination efficiencies (in the vector HREFF(n,2)) to unity, and sets OTSMIN to 1. This last variable is then used to deduce the ionization efficiency of lines and continua; the effect of this command is to turn off such ionizations.

4.14.19 no radiation pressure

This command turns radiation pressure completely off. Radiation pressure due to trapped lines will be counted in the total pressure when the "CONSTANT PRESSURE" option is used; the default is for a constant density model. Radiation pressure is not included if constant gas pressure is specified. Acceleration due to the gradient of the radiation pressure is always included in the calculation of the radiative acceleration in "WIND" models, however, and this option turns off the extra acceleration due to trapped lines.

4.14.20 no recoil ionization

This command turns off Compton recoil ionization of hydrogen, helium, and heavy elements. Compton heating and cooling of free electrons is included, but is the only electron scattering thermal effect remaining. Bound electron scattering opacity is still included when this command is issued.

4.14.21 no secondary ionizations

This command will turn off the effects of knock-on supra-thermal electrons. Normally these are treated as in Spitzer and Tomasko (1968), Bergeron and Collin-Souffrin (1971), Shull (1979), and Shull and van Steenberg (1985). This command will make X-rays contribute 100% heat, and produce no secondary ionizations or Lyα excitations.

4.14.22 no Stark broadening

Stark broadening (important for densities larger than $\sim 10^{10}$ cm^{-3}) is treated for hydrogen lines using escape probabilities from Puetter (1981). This turns Stark broadening off.

4.14.23 no three body recombination

This turns off three body recombination for the heavy elements. It is not possible to turn off three body recombination for hydrogen or helium.

5 OUTPUT

This section defines the output produced by CLOUDY.

5.1 Header Information

Several lines of output echo the input commands and outline some properties of the initial continuum.

5.1.1 Initial Information

This begins with the version number of CLOUDY. Major revisions, which have noticeable effects on the emission-line spectrum or which reflect significant improvements in the physics, are denoted by integer increases in the version number, while minor changes increment the revision number by 0.01. In a static version of the code, changes (usually bug fixes) are denoted by letters (i.e., .02a). The following line gives the date this version was created.

All of the input command lines, with the exception of those starting with a "#", "%", or "*", are echoed before the calculation begins, and the first twelve lines are saved to be reprinted after the calculation is completed. The input information is followed by the chemical composition of the gas. The numbers are the number density of the elements, relative to hydrogen.

5.1.2 Properties of the Continuum

This section gives a synopsis of the incident continuum. These quantities are evaluated at the illuminated face of the cloud, not in the center of the first zone. The first line gives the number of numerical frequency cells in the continuum, followed by the energy (in Ryd) of the cell with the largest flux density per unit energy interval (f_ν). Next are the energies of the low and high energy limit of the continuum, both in Ryd and cm or MeV. The last two numbers are the energies of the high energy limit of the present version of the code, in Ryd and keV.

The second line gives the log of the energy (erg s^{-1} cm^{-2} or erg s^{-1}, depending on whether a flux or luminosity was specified) in the hydrogen ionizing continuum (1 Ryd $\leq h\nu <$ 100 MeV), and the average energy of the hydrogen ionizing continuum, in Ryd, weighted by photon number;

$$\langle h\nu \rangle = \frac{\int_{1Ryd}^{\infty} 4\pi J_\nu \, d\nu}{\int_{1Ryd}^{\infty} 4\pi J_\nu / h\nu \, d\nu} \quad . \tag{43}$$

The log of the energy in the "X-ray" continuum (20.6 Ryd $\leq \nu \leq$ 7676 Ryd), the log of the energy (erg s^{-1} cm^{-2} or erg s^{-1}), and the number of photons (cm^{-2} s^{-1} or s^{-1}) in the Balmer continuum (0.25 Ryd – 1.0 Ryd) is then printed.

The third line gives the log of the number of photons (cm^{-2} s^{-1} or s^{-1}) in four frequency bins (1.0 Ryd $\leq \nu <$ 1.807 Ryd, 1.807 Ryd$\leq \nu <$4.0 Ryd, 4.0 Ryd$\leq \nu <$20.6 Ryd, and 20.6 Ryd$\leq \nu <$ 7676 Ryd). The last number is the flux of hydrogen ionizing photons;

$$\phi(H) = \frac{Q(H)}{4\pi r^2}\ cm^{-2}\ s^{-1} \quad . \tag{44}$$

In this equation Q(H) is the total number of hydrogen-ionizing photons emitted by the central object (s^{-1}), and r is the separation between the center of the central object and the inner face of the cloud. Unlike the majority of the quantities printed in the header, ϕ(H) (per unit area) is always printed, never Q(H) (into 4π sr).

The fourth line of the header gives some information about the low and high energy portions of the incident continuum. The first number is the log of the luminosity in the gamma-ray (h$\nu >$ 7676 Ryd $\sim$ 100 keV) continuum. The second number on the line is the log of the number of photons over this energy range. The third number is the log of the luminosity in the continuum between 0.25 Ryd and the lowest energy considered, presently an energy of 1.001×10^{-5} Ryd. All of these entries are either per unit area, or radiated into 4π sr, depending on how the continuum was specified. The next entry is the spectral index α_{ox}, defined as in Zamorani et al. (1981), except for the difference in sign convention. This is the spectral index which would describe the continuum between 2 keV and 2500Å if the continuum could be described as a single power-law. The definition of α_{ox} used here is slightly different from that of Zamorani et al. since implicit negative signs are *never* used by CLOUDY. Typical AGN have $\alpha_{ox} \sim -1.4$. If no X-rays are present then $\alpha_{ox} = 0$. The last number on the line is the log of the total energy in the continuum between 1.001×10^{-5} Ryd and 100 MeV; it is given as either erg cm^{-2} s^{-1} or erg s^{-1}, depending on how the continuum was defined. If the continuum is specified per unit area, then this number is 4π times the integrated intensity of the incident continuum. If it is specified as the total luminosity radiated into 4π sr, then the quantity is the luminosity.

The next line is optional, depending on whether the continuum is specified as the total luminosity or photon number radiated into 4π sr, or as an incident surface flux. If the continuum is specified in absolute terms, i.e., the luminosity or photon number radiated into 4π sr, then this optional line is generated. The first quantity is the log of the total luminosity in the continuum, in solar units. The absolute bolometric magnitude, absolute V magnitude, and the bolometric correction, are then given, followed by the log of the continuum specific luminosity (νF_ν) at Hβ (νF_ν(Hβ); erg s^{-1}).

The next line begins with two ionization parameters. The first is the dimensionless ratio of ionizing photon to hydrogen densities, defined as

$$U \equiv \frac{\phi(H)}{N_H\, c} \tag{45}$$

where N_H is the total hydrogen density. The second number is defined in a similar way, but the numerator is the number of photons with energies greater than 4 Ryd (i.e., helium-ionizing). The third number is the equivalent black body temperature corresponding to the energy density u at the illuminated face of the cloud [from the incident continuum and Stefan's radiation density constant a; $T_u \equiv (L/4\pi r^2 ac)^{1/4}$], and the next quantity is the Compton temperature of the incident radiation field[8]. The last number on the line is $4\pi\nu J_\nu(912\text{Å})$, the flux at 912Å (erg cm^{-2} s^{-1}). In this equation J_ν is the mean intensity of the incident continuum as defined by Mihalas (1978).

The next two lines give the incident continuum photon occupation numbers $\eta(\nu)$, defined as

$$\eta(\nu) \equiv J_\nu \left(\frac{2h\nu^3}{c^2}\right)^{-1} \quad , \tag{46}$$

and the incident continuum brightness temperature $T_b(\nu)$, (^{o}K), defined as

$$T_b(\nu) \equiv J_\nu \left(\frac{2k\nu^2}{c^2}\right)^{-1} \quad , \tag{47}$$

for five energies. These energies correspond to the lowest frequency considered (presently an energy of 1.001×10^{-5} Ryd); the ionization potential of the $n = 6$ level of hydrogen (1/36 Ryd); an energy of one Rydberg; four Rydbergs, and the high energy limit of the incident continuum (this depends on the continuum shape; the energy is given by the fifth number on the first line of the continuum output).

Finally, if grains are present, then the last line gives the total grain extinction (scattering and absorption) cross section (cm^{-2}) per unit column density of hydrogen at several energies (Pα, Bα, Mg II, 1 Ryd, 4 Ryd).

5.2 Zone Results

The results of calculations for the first and last zones are always printed. Results for intermediate zones can be printed if desired (see the "PRINT EVERY" command above). The following is a line-by-line description of the output produced for each printed zone.

[8]For a blackbody radiation field $T_{Compton}$ is roughly 4% lower than the blackbody color temperature T_{color} when the energy density temperature T_u is $\ll T_{color}$. Only when $T_u \equiv T_{color}$ does induced Compton heating cause $T_{Compton} \equiv T_{color}$. If $T_u > T_{color}$ then $T_{Compton} > T_{color}$ because of induced Compton heating. All of the relevant physics is included in the Compton temperature printed here.

5.2.1 Line 1

The line begins with five "#" characters, to make it easy to locate with an editor. The zone number is the first number, followed by the temperature of the zone ("Te"). A lower case "u" will appear before the "Te" if the temperature solution is possibly thermally unstable (i.e., the derivative of the net cooling with respect to temperature is negative. See section 20.2 below). The total hydrogen ("Hden") and electron ("Ne") densities (cm^{-3}) follow. The next number ("R") is the distance to the center of the zone, from the center of the central object. The depth, the distance between the illuminated face of the cloud and the center of the zone, $(r - r_o)$, and the width of the zone dr, (all are in cm), follow. The inner edge of the zone is $(r - r_o) - dr/2$ from the illuminated face of the cloud. The line ends with a number indicating how many iterations were needed for this zone to converge ("NTR"), followed by the total heating[9] ("Htot"; photoelectric and otherwise, erg cm^{-3} s^{-1}), and the optical depth between the *inner* face of the cloud and the *outer* edge of the zone at the Lyman limit ("T912"; the number is the *total absorption* optical depth at 912Å, and *not* the hydrogen Lyman limit optical depth).

5.2.2 Line 2 - Emission-line strengths

The first number is the log of the surface brightness in Hβ (erg cm^{-2} s^{-1}). The remainder of the numbers are ordered pairs, with the first being the wavelength of an emission line, and the second its intensity relative to Hβ. All of these are the intensities accumulated so far, with the present zone included. The selection of lines is arbitrary, and the last can be changed with the "LINE" command. This information is useful when dealing with a matter-bounded geometry, in which the emission-line intensities are set by the thickness of the cloud.

5.2.3 [Optional] wind parameters

A line describing the velocity and acceleration of the zone is printed if the "WIND" option is used. The numbers are the wind velocity at the inner edge of the zone (km s^{-1}), inward gravitational acceleration (cm s^{-2}), total outward radiative acceleration, and the fraction of this acceleration caused by the incident continuum, line driving, and the gradient of the radiation pressure. The solution is probably not realistic for grain-free environments, since $\sim 10^6$ lines need to be included to do radiative acceleration properly (Abbott 1982).

[9] CLOUDY defines heating as the energy input by the freed photoelectron, or $h\nu - IP$, where IP is the ionization potential of the atom or ion, and $h\nu$ is the energy of the photon. See Osterbrock (1988) for more details.

5.2.4 [Optional] radiation pressure

If the ratio of line radiation to gas pressure, P(radiation)/P(gas), is greater than 5%, then a line describing the source of the radiation pressure is generated. The printed line is the vector which contains the contributors to P_{rad}, and are in the order (1)=Lyα, (2)=Mg II λ2798, (3)=C III λ1909, (4)=Fe II UV lines, (5)=C IV λ1549, (6)=C II λ1335, (7)=$n > 2$ Lyman lines, (8)=Balmer lines, (9)=He I λ10830, (10)=HeII Lyα, (11)=HeI Ly α, (12)=N III λ1750, (13)=O III λ1666, (14)=SI III λ1207, (15)=SI III λ1895, (16)=SI IV λ1397, (17)=S III λ1198, (18)=O VI λ1035, and (19)=N V λ1240. The numbers are the fraction of the total radiation pressure contributed by each line. Usually, the majority of the line radiation pressure comes from Lyα, C IV λ1549, Mg II λ 2798, or the Fe II UV lines.

5.2.5 Line 3 - Hydrogen I

The line begins with the abundance of neutral and ionized hydrogen relative to all atomic-ionic hydrogen (i.e., the ratios $H^o/(H^o+H^+)$ and $H^+/(H^o+H^+)$. If "PRINT DEPARTURE COEFFICIENTS" has been specified then departure coefficients are also printed on the following line. Neutral hydrogen H^o is defined to be the total population of atomic hydrogen in the $1 \leq n \leq 6$ states. Ionic hydrogen includes the sum over higher levels and protons. Next comes the ratio "H+-/Hden", the ratio of the density of hydrogen in atomic or ionic form to the total hydrogen density in all forms (including molecular).

The following five numbers are abundances of the negative hydrogen ion and several molecules (H^-, H_2, H_2^+, and HeH^+) relative to the total hydrogen abundance. The total hydrogen density is usually referred to by the label HDEN, and is the sum $H^o + H^+ + H^- + 2H_2 + 2H_2^+ + 3H_2^+$. Note that, with the definition of HDEN given here, a fully molecular gas will have H_2/HDEN=0.5. These molecular abundances are also expressed as departure coefficients if this option is set. The last number on the line is the total hydrogen column density (cm^{-2}).

5.2.6 Line 4 - Hydrogen II

The first two numbers are the populations of the H^o $2s$ and $2p$ levels relative to the ionized hydrogen density. The next four numbers are populations of levels 3 to 6, again relative to the ionized hydrogen density. The latter are computed assuming full l-mixing. The populations of three pseudo-states, chosen to represent the actual levels 7 – 100, are also computed, but not printed. All of these populations usually are relative to the ionized hydrogen density, but can also be printed as LTE departure coefficients if the "PRINT DEPARTURE COEFFICIENTS" command is given. The

excitation temperature T_{exc} of Lyα, defined as

$$\frac{N(2p)/g(2p)}{N(1s)/g(1s)} = \exp\left(-h\nu/kT_{exc}\right) \quad , \tag{48}$$

is given. This is followed by the temperature corresponding to the energy of the attenuated incident continuum ("T(contn)"), and the "diffuse" continua ("T(diffs)". This includes all trapped lines and diffuse continuous emission.

5.2.7 Line 5 - Helium

The first three numbers are the total populations of the three ionization stages of helium, relative to the total helium abundance. The population of atomic helium is the sum of the total population in the triplets and singlets, including the population of the lowest six levels of each. These populations can also be expressed as departure coefficients if this option is set with the "PRINT DEPARTURE COEFFICIENTS" command. The population of He^o 2^3S, relative to the total helium abundance, follows. The Compton heating and cooling rates (both erg cm^{-3} s^{-1}) are next, followed by the gas filling factor. The last number is the fraction of the total hydrogen ionizations which are caused by photoionization from the ground state.

5.2.8 Line 6 - Atomic Helium

The first group are the level populations of the 2s, 2p, and n=3–6 levels of the He^o singlets. The next group consists of populations of the 2s, 2p, and n=3s,p,d levels of the He^o triplets. Both sets of populations are relative to He^+. Departure coefficients are also printed if requested.

5.2.9 Line 7 - Ionized Helium

The populations of the 2s, 2p, and n=3–6 levels are indicated. There are relative to He^{++}; departure coefficients are also printed if requested. The ratio of radiation pressure to gas pressure follows.

5.2.10 Optional Grains

If grains are present, then lines giving some properties of the grain populations are printed. Each line gives the results of calculations for a specific type of grain. Normally, a type of graphite and silicate are included when grains are present. The line for each type gives the equilibrium temperature of the grain, the potential in volts, the charge, the drift velocity, followed by the gas heating (erg cm^{-3} s^{-1}) due to grain photoionization, and the dimensionless fraction of the total gas heating due to grain photoionization.

5.2.11 Pressure

Some information concerning the pressure is now printed. The gas equation of state includes thermal gas pressure, the radiation pressure due to trapped line emission, and the radiation pressure due to absorption of the incident continuum. The first number is the gas pressure $N_{gas}T_{gas}$ (cm^{-3} K) , followed by the total pressure (dynes cm^{-2}), followed by the gas pressure in dynes cm^{-2}. The radiation pressure follows. The second to last number is the radiative acceleration (cm s^{-2}) at the inner edge of this zone. The radiative acceleration is computed with all continuous scattering and absorption opacities included, and opacities of roughly ten lines treated in the escape probability formalism. (Work on OB winds suggests that this result is a serious underestimate for grain-free environments. See, for instance, Abbott 1982.) The last number is a "force multiplier", defined as in Tarter and McKee (1973), and is the ratio of total opacity to electron scattering opacity.

5.2.12 Molecules

A line giving relative abundances of some molecules is printed if there is a significant molecular fraction. All molecular abundances are relative to either the total carbon or total oxygen abundance (this is indicated in the label for each). In order, the molecules are CH, CH^+, CO, CO^+, H_2O, and OH.

5.2.13 Carbon

The abundances of the seven stages of ionization of carbon relative to the total carbon abundance begin the line. The relative abundance of H_2O^+ and OH^+ (relative to the total oxygen abundance) follows.

5.2.14 Nitrogen

The relative populations of the eight ionization stages of nitrogen are printed first. The relative abundance of O_2 and O_2^+ (relative to the total oxygen abundance) follows.

5.2.15 Oxygen

The oxygen ionization stages are followed by the "extra" heat added at this zone (erg cm^{-3} s^{-1}); due to cosmic rays, turbulence, etc, and the log of the effective hydrogen recombination coefficient (cm^3 s^{-1}).

5.2.16 Neon

The neon ionization balance is printed across the line.

5.2.17 Magnesium to Iron

There are too many ionization stages to print across the line. Although all stages with non-trivial abundances are computed, only the highest twelve stages of ionization are printed. The first number is an integer indicating how many stages are "off the page to the left". If the number is 2, then the first printed stage of ionization is twice ionized, i.e., Fe $^{+2}$.

5.3 Calculation stopped because ...

A series of messages appear after the printout of the last zone.

The first will say why the calculation stopped. In a valid calculation the model will stop because one of the specified stopping criteria specified were met. If no other criteria are specified, then the calculation usually stops when the default lowest temperature of 4000K is reached. If the code stops because of a probably unintended reason (i.e., internal errors, or the default limit to the number of zones) then a note is printed saying that the calculation may have halted prematurely.

The first line explains why the calculation stopped. Only one stopping criterion message will be printed. The possible messages, and their interpretations, are:

5.3.1 ... because of radiation pressure

The default density law is for a constant density. If constant pressure is specified instead (with the "CONSTANT PRESSURE" command), then CLOUDY will try to keep the total pressure, particle and radiation, constant. The radiation pressure is small at the boundaries of the cloud, so the cloud will be unstable if the ratio of radiation to total pressure exceeds 0.5. The calculation stops, and this message is generated, if this occurs on the last iteration.

5.3.2 ... because lowest EDEN reached.

The calculation can be forced to stop when the electron density ("EDEN") falls below a certain value, as set by the "STOP EDEN" command, described above. This can be used to stop the calculation at an ionization front. The default lowest electron density is negative, so this stopping criterion applies only when the command is entered.

5.3.3 ... because low electron fraction.

The calculation can be forced to stop when the ratio of electron to hydrogen densities falls below a certain value, as set by the "STOP EFRAC" command, described above. This can be used to stop the calculation at an ionization front when the hydrogen

density there is not known (for instance, in a constant pressure model). The default lowest electron density is negative, so this stopping criterion applies only when the command is entered.

5.3.4 ... because wind velocity < 0

The code can perform a simple wind calculation (see section 22.4) which includes the outward force due to radiation pressure and the inward force of gravity. This message is printed if the gas comes to rest.

5.3.5 ... because DRAD small - set DRMIN

The Strömgren radius of the H^+ zone is estimated at the start of the calculation, and the smallest allowed zone thickness is then set as a very small fraction of this. The calculation will stop if the zone thickness falls below this smallest thickness. This can occur because of any of several logical errors within CLOUDY (adaptive logic is used to continuously adjust the zone thickness), although it can rarely occur for physical reasons as well. The smallest thickness can be reset to any number with the "DRMIN" command, see above.

5.3.6 ... because DR small rel to thick.

The depth into the cloud is stored as the double precision variable DEPTH and the zone thickness is stored as the double precision variable DRAD . If the zone size becomes too small relative to the depth (DRAD/DEPTH$< 10^{-14}$) then the depth variable will underflow such that DEPTH+DRAD=DEPTH. The calculation will stop in this case and give the above reason. This is a fundamental numerical problem with no clear solution.

5.3.7 ... because optical depth reached.

The default value of the largest allowed continuous optical depth is unphysically large, and can be reset with the "STOP OPTICAL DEPTH ..." command. The command specifies both the optical depth, and the energy at which it is to be evaluated. All absorption opacity sources included in the calculation contribute to the computed optical depths. If the calculation stops because the largest continuum optical depth is reached, then this line is printed. This line is also printed if the "STOP EFFECTIVE COLUMN DENSITY" command is used to stop the calculation, since this command is actually a form of the "STOP OPTICAL DEPTH" command.

5.3.8 ... because outer radius reached.

The default outer radius is unphysically large, but can be changed with the "RADIUS" or "STOP THICKNESS" commands. If the calculation stops because the outer radius set by one of these commands is reached, then this line is printed.

5.3.9 ... because column dens reached.

The default values of the largest allowed neutral, ionized, and total hydrogen column densities are unphysically large. They can be reset with the commands "STOP COLUMN DENSITY", "STOP NEUTRAL COLUMN DENSITY", or "STOP IONIZED COLUMN DENSITY". This message will be printed if one of these criteria stops the calculation.

5.3.10 ... because lowest Te reached.

The default value of the lowest temperature allowed is 4000K. This is reasonable when only optical emission lines are of interest. The limit can be changed with the "STOP TEMPERATURE" command. This message is printed if the calculation stops because the lowest temperature is reached.

5.3.11 ... because NZONE reached.

The default condition is for up to 300 zones to be computed. This can be reset with the "STOP ZONE" command. This message is printed if the calculation stops because the limiting number of zones is reached. A comment will be printed at the end of the calculation if it stops because it hits the default limit to the number of zones allowed, presently 300, since this was probably not intended.

5.3.12 ... because line ratio reached.

It is possible to set a limit to the largest value of an emission-line intensity ratio with the "STOP LINE" command. This message is printed if the calculation stops because the largest value of the ratio is reached.

5.3.13 ... because internal error - DR.

An internal logical error caused this message to be printed. Send the command lines, and the version number of CLOUDY to me. My internet address is gary@bowen.mps.ohio-state.edu.

5.4 Geometry

After saying why the calculation stopped, CLOUDY will say whether the geometry is plane parallel ($\delta r/r_{in} < 0.1$), a thick shell ($\delta r/r_{in} < 3$), or spherical ($\delta r/r_{in} \geq 3$), where r_{in} is the inner radius and δr is the thickness of the cloud.

5.5 Warnings, Cautions, Surprises, and Notes

The next, optional, messages fall into four categories: warnings, which begin with "W-"; cautions, which begin with "C-"; surprising results which begin with an explanation mark ("!"), and notes. CLOUDY tries to check that its range of validity was not exceeded in the calculation. Warnings are issued to indicate that the program has not treated an important process correctly. For instance, warnings occur if the temperature was high enough for the electrons to be relativistic or if the global heating — cooling balance is off by more than 20%. Cautions are less severe, and indicate that CLOUDY is on thin ice. Examples are when the optical depths in excited states of hydrogen change during the last iteration. Surprises begin with "!" and indicate that, while the physical process has been treated correctly, the result is surprising. An example is when induced Compton heating is more that 5 percent of the total Compton heating. Notes indicate interesting features about the model, such as maser effects in lines or continua, or if the fine structure lines are optically thick. The messages are usually self explanatory.

5.6 Optional Plot

If any of the optional plots are requested with the "PLOT xxx" command then they will appear next. The quantities plotted are described in the section of HAZY where the command is defined.

5.7 Final Printout

5.7.1 Emission-Line Spectrum

The final printout begins by reprinting the input commands. The box surrounding it gives both the version number of CLOUDY (at the top) and the log of the ionization parameter (the ratio of ionizing photon to hydrogen densities) at the bottom.

The line following the box summarizes some properties of the model and output. The first part of the line indicates whether the energy in the emission lines is given as the luminosity radiated by a spherical shell covering Ω sr (erg s^{-1}; $\Omega/4\pi$ is the covering factor) or the intensity produced by a unit area of gas (erg s^{-1} cm^{-2}). Which of the two choices is printed is determined by whether the luminosity of the continuum was

specified as the luminosity radiated by the central object into 4π sr or the intensity of the incident continuum (erg cm^{-2} s^{-1}) at the illuminated face of the cloud. If the model is spherical and the incident continuum specified per unit area, then the emergent emission-line spectrum will be per unit area in units of the inner radius (that is, the total line luminosity radiated by a shell covering 4π sr will be the listed intensity $4\pi j$ times $4\pi r_{inner}^2$). The second part of this line indicates the density structure of the model (i.e., wind, constant density, constant pressure, constant gas pressure, power-law density distribution, etc). The next section tells whether the geometry was open or closed. The last part indicates which iteration this is.

The computed emission-line spectrum follows. Emission lines are divided into two groups. The first includes the effects of grain scattering and absorption, and is indicated by the header "Emergent Line Intensities". This first group is only printed if grains are present and the geometry is open (i.e., "SPHERE" not set). The intensities are the *total* intensities observed from the illuminated face, including both absorption and scattering by grains. The second group of lines is always printed, is usually the intrinsic intensity of the lines, and does not include the reddening effects of internal grains due to the photon's passage out of the nebula. This second group usually gives the total intrinsic intensity of the lines. Although reddening effects of internal (or external) dust are not taken into account, although photon destruction by background opacity sources during the transfer process is.

The spectrum is sorted into four large groups of columns, with each large group sub-divided into four smaller sub-columns. The first sub-column is either the spectroscopic designation of the ion producing the line or an indication of how the line is formed. The second sub-column is the line wavelength, with a 0 to indicate a continuum. The third sub-column is the log of the power in the line, in the units given in the header (4π sr or cm^{-2}). The last sub-column is the intensity of the line relative to the reference line, usually Hβ, unless this is reset with the "NORMALIZE" command.

The following sections give overviews of the general treatment of line formation. A description of the entire line array, and a formal definition of how CLOUDY works, follows in latter sections.

Heating and cooling The total photoelectric heating, due to photoionization of hydrogen, is given by "BF H". The following entries, "BFHe", and "TotM", are the heating due to helium and metal photoionization. "ComH" and "H-H ", indicate the heating due to Compton scattering and absorption by the H$^-$ ion. "Comp 0" is the total cooling due to Compton scattering, and "eeff 0" is the electron-electron bremsstrahlung cooling. "H FB" and "H FF" are the free-bound and free-free cooling of hydrogen.

Hydrogen lines The first two entries are the total intensities of Hβ and Lyα, as predicted by the 10-level H atom. These intensities are the results of calculations which include all collisional, radiative, and optical depth effects. The next ("CA B 4861") is the case B intensity of Hβ, computed from the actual model ionization and temperature structure, but assuming that Hβ emits with its case B emissivity. "DU B 4861" is the case B intensity of Hβ modified for grain destruction of Lyman lines, as described by Cota and Ferland (1988). For models of dusty low-density gas, such as an H II region, where collisional and radiative transfer effects are not important, this entry should be more reliable than the results of the ten level atom calculation when case B is a good assumption. The two may differ at the $\sim 2\%$ level. The entry "Q(H) 4861" is the intensity of Hβ predicted from the total number of ionizing photons, Q(H), assuming that each hydrogen-ionizing photon produces one hydrogen atom recombination (see, for example, Osterbrock 1988). "Q(H) 1216" indicates the Lyα intensity produced if each hydrogen ionizing photon results in one Lyα photon in the high density limit (i.e., no two-photon emission).

The lines starting with "TOTL" are the total intensities of the indicated lines, predicted by the 10-level atom, including all physical processes. A few of the entries suggest different contributions to the "TOTL" hydrogen lines. "LA X 1216" is an estimate of the intensity of Lyα produced by excitation of $n = 2$ by suprathermal electrons. "C 13 6563" and "C 14 4861" are the intensities of these Balmer lines produced by collisional excitation from the ground state. "CION 0" is the net cooling due to collisional ionization of hydrogen, and "2 NU 0" is the total two photon emission. The lines beginning "Strk" and "e sc" are the contributions to the lines from Stark broadening and electron scattering. "nFnu 4861" is the total diffuse continuous emission $\nu f_\nu(4861\text{Å})$ at the wavelength of Hβ. This continuum includes two-photon, free-free, and free-bound emission from the nebula. "BA C 0" and "PA C 0" are the integrated intensities of the Balmer and Paschen continua respectively. The entries beginning with "rest" and "COOL" are indications of the cooling due to various sets of H lines. Entries marked "INWD" indicate the intensity of the fraction of the line emitted in the inward direction (that is, towards the source of ionizing radiation). This is only meaningful on second or later iterations.

Molecular cooling "H2 l 2" is the intensity of the H_2 lines near 2 μm, and "H2 d" is the cooling due to collisional dissociation of H_2. "H-FB" and "H-FF" are the free-bound and free-free continua of the H^- ion. "H2+ " and "HEH+" are the cooling due to formation of H_2^+ and HeH^+.

Helium lines Ionized and singlet helium are each treated as ten-level atoms. Triplet helium is currently treated as an five level atom.

"HE I 4471" is the case B intensity of this He I line. "TOTL 5876" is the intensity of this line, as predicted by the model helium atom. "Ca B 5876" is the case B intensity of this line. This second entry is generally smaller than the "TOTL" intensity because of collisional excitation from 2^3S. "TOTL10830", "TOTL 3889", and "TOTL 7065" are the intensities of these lines, predicted by the model helium atom. "C HE 0" is the total cooling due to collisional excitation within the helium atom. "He I 2" and "DevB 2" are intensities of the $2\mu m$ He I line. The first is the case B prediction, and the second is the actual intensity. This was computed using expressions from Cota (1987; PhD Thesis). "He I-DevB" etc are sets of lines, the first being the case B intensity, and the second the actual intensity (the deviation from case B included). "HE2C 304" and "ESC r 304" are the produced and emitted intensities of the He II Lyα. "HeII 1640", 4686 are intensities from case B calculations. In general, case B is probably more accurate for HeII emission than the results of the present 10-level atom, because of the assumption of complete l-mixing. The entries marked "TOTL" are more accurate at high densities (N$\gg 10^8$ cm^{-3} or when collisional or transfer effects are important.

Heavy elements A few notes on deciphering the heavy element lines follow. A more complete discussion is presented in section 6. In cases where the notation is unclear a careful examination of subroutine "LINES" (which enters the line fluxes into the arrays) or "COOLR" (which actually calculates the line intensities) should clarify the meaning. In general, the line wavelengths are given in Å, although the infrared fine structure lines are an exception. Often these IR lines have their wavelength given in microns (for instance, [O III] $\lambda 88\ \mu m$), but sometimes it is given in microns or tenths of microns (this is because the wavelengths are integers). Notes on specific iso-electronic sequences follow.

$Li-sequence$. Examples include $C\ IV$ λ1549, $O\ VI$ λ1034, $Mg\ II$ λ2798, etc. A two level atom, with full treatment of optical depths and collisional excitation, is used. The intensity is the sum of both lines in the doublet.

$Be-sequence$. Examples include $C\ III]$ λ1909, $O\ V]$ λ1215, $Si\ III]$ 1895, etc. A four level atom, solving for populations of the individual ^3P_j states, is used. The first printed intensity is the total intensity of the multiplet (both j=0,1 decays), and this is followed by the intensities of individual lines. The intensity of the permitted ^1P_o–^1S transition is also calculated. Optical depth and collisional effects on both the permitted and intercombination lines are included.

$B-sequence$. Examples include $C\ II$ and $O\ IV$. The ground term is treated as a two level atom, with optical depth and collisional effects included. The ^4P–^2P_o lines are also predicted with a two level atom. The intensity printed is the total intensity of the multiplet.

$^3P-ground\ \ term$. Examples include $[O\ III]$ and $[O\ I]$. The infrared fine

structure lines are computed with full treatment of collisional and optical depth effects. A comment is printed at the end of the model if these lines mase or become optically thick. The populations of ^1D and ^1S are computed with a three-level atom. The intensity of the $^1D - ^3P$ transition is only that of the individual line (i.e. 5007), not the doublet.

$^4S^o - ground\ \ term$. Examples include $[O\ II]$ and $[S\ II]$. They are treated as a five level atom. Intensities of all individual lines, as well as co-added multiplets, are given.

5.7.2 Page two

Cooling: This line indicates the fraction of the total cooling (defined here as in Osterbrock 1988; that is, the energy of the freed photoelectron) carried by the indicated emission lines. The designation of the line is given as in the emission-line spectrum, and this is followed by the ratio of the energy in the line to the total cooling. This is an important indication of the fundamental power-losses governing conditions in the model.

Heating: This line indicates the fraction of the total heating produced by various processes.

IONIZE PARMET to He/Ha The first line begins with the log of the two ionization parameters defined in the header. The next number is the log of an ionization parameter which is often used in spherical geometries, such as H II regions or planetary nebulae. It is defined as

$$U_{sph} = \frac{Q(H)}{4\pi R_s^2 N_H c} \tag{49}$$

where R_s is the Strömgren radius, defined as the point where the hydrogen neutral fraction falls to $H^o/H_{tot} = 0.5$. If no ionization front is present, then U_{sph} is evaluated at the outer edge of the computed structure. The next two numbers are the log of the number of hydrogen ionizing photons ($h\nu \geq 1$ Ryd) exiting the nebula, and the log of the energy in this ionizing continuum. The last two numbers are the equivalent quantities, for non-ionizing (hν <1 Ryd) radiation. These are either per unit area or by a shell covering 4π sr. These have been corrected for the r^{-2} dilution if per unit area, are so are directly comparable with the numbers given at the start of the calculation.

The second line gives an indication of the energy budget of the nebula. The first number is the log of the total heating (in ergs s^{-1}, but again either into 4π sr or cm^{-2}). The second number is the total cooling, in the same units. Cooling, as defined in Osterbrock (1988), is the total energy in collisionally excited lines and part of the

recombination energy, but *does not* include recombination lines. The percentage error in the heating–cooling match follows. The next number is the total Compton heating, in the same units as the heating-cooling balance. The number indicated by "WorkF" is an indication of the "work function" (that is, the energy needed to remove bound electrons from the atom or ion) of the cloud. (The "work function" and the total cooling do not add up to the total energy absorbed from the incident continuum because some recombination lines of helium and heavy elements contribute to both.) The next number ("F-F H") is the amount of energy deposited by free-free heating, and the last number (PRADMX) is the largest value of the ratio of radiation to gas pressure which occurred in the calculation.

The third line lists the column densities (cm^{-2}) of some ions and molecules. The first number ("H12") is the total hydrogen column density (both H^o and H^+). The following two numbers are the column densities in H^+ and H^o only. The last four numbers are column densities in four ion–molecules (H^-, H_2, H_2^+, and HeH^+). The first number on the next line is the column density in OH, and the second is the "effective" column density; that needed to attenuate the incident continuum by the calculated amount at 1.0 keV, if the absorber were cold neutral gas.

The 5th line gives some average quantities. The first is the mean hydrogen density (cm^{-3}). The next number is the mean electron temperature, weighted by the H^+ density. The third number is the mean temperature of the O^{2+} zone. This is useful because it can be compared directly with the temperature indicated by the [O III] lines. The 4th number is the mean electron density, and is followed by the sound travel time (seconds) across the nebula. The 6th number is the emission measure, the integral over radius of the product $N_e\ N_p\ f\ dr$, where f is the filling factor. The last two numbers on this line are the mean electron temperature and electron density, weighted with respect to the C^{2+} density.

The next line mainly gives some quantities "deduced" from the predicted emission-line spectrum. The first ("He/Ha") number is the apparent helium abundance He/H, measured from the emission-line intensities using techniques similar to those described in Osterbrock (1988). The second number (i.e., "1.07*true"), is the ratio of this deduced abundance to the true abundance. The next two numbers are the apparent N/O abundance (deduced from the [N II] and [O II] spectra, as described by Wilkes et al. 1981) and the ratio of this to the true N/O abundance. The fifth number is the electron temperature of the [O III] zone, as indicated by the [O III] 5007/4363 ratio assuming emissivities at the low-density limit. The next number is the wavelength (in cm) where the nebula becomes optically thin to bremsstrahlung absorption. The last two numbers are the mean temperature and electron density of the S^+ zone.

The next line gives mean temperatures and electron densities for the He^+ and O^+ zones. The next number is the average number of iterations needed to converge each zone. The next two numbers are the lowest and highest electron temperatures which

occurred in the model. The last number is related to the number of iterations needed to converge each zone.

The next line of the block gives the mean radiative acceleration, if the geometry is a wind model, followed by some timescales. The first is the time scale (s) to photoerode Fe (Boyd and Ferland 1987; this number is 0s if the γ-ray flux is zero). The next two are the Compton equilibrium timescale, and the thermal cooling timescale. Both are in seconds. The density weighted mean temperature, radius weighted mean density (gm cm^{-3}), and mean molecular weight follow.

The next line gives the mean Jeans length (cm) and Jeans mass (in solar units), followed by the smallest Jeans length and mass which occurred in the calculation. The last quantity is the spectral index α_{ox}, defined as in the header, but for the transmitted continuum (attenuated incident continuum plus emitted continuum produced by the cloud).

The next, optional, lines give some information concerning grains in the calculation. These lines give the mean temperature, drift velocity, and potential, for all of the grain populations included in the calculation.

Optical Depths The first two lines give the optical depth of the nebula in various continua. These are the total optical depths, including the correction for stimulated emission, and will be negative if maser action occurs. The labels, and their interpretation, follows: COMP, Thomson scattering; H-, negative hydrogen ion at maximum cross section; R(1300), Rayleigh scattering at 1300Å; H2$^+$, H_2^+; HeTri, helium triplets. These are total optical depths, including, for instance, grain opacity if grains are present. The next line gives total optical depths for various hydrogen and helium ionization edges and lines. The next two large blocks are sets of optical depths in various emission lines, and the last set of lines are optical depths in the infrared fine structure lines.

Hydrogen and helium optical depths in continua and $n \rightarrow n-1$ α transitions follow. The first two lines are the optical depths assumed at the start of the present iteration, and the second pair of lines gives the newly computed total optical depths. Negative optical depths indicate maser action. For each of the pairs of lines, the first line is the optical depth at thresholds of the first seven levels of hydrogen. The second line gives optical depths in the first seven n-α transitions of hydrogen or helium.

Mean Ionization The two large blocks of output give the mean ionization, averaged over volume, and over radius. The numbers printed are the log of the mean ionization fraction in the various stages.

X-Ray Continuum The next line gives the photon fluxes (cm^{-2} s^{-1}) in various X-ray bands, if the continuum extends to X-ray energies. The units of the energy bands are keV. The numbers are the numbers of photons exiting the cloud, integrated over the energy bands. This is the net continuum, that is, the incident continuum, less attenuation, with diffuse re-emission from the cloud added on.

Normalized Continuum This block is a set of ordered pairs giving the emergent Balmer continuum, relative to the continuum which entered the cloud. The first number of each pair is the frequency in Rydbergs. The second is the ratio of the emergent continuum to the incident continuum (i.e., that which went into the cloud). In the absence of optical depth or diffuse emission effects, this block will be equal to 1.000 throughout.

Emergent Continuum This block gives ordered pairs of energy (in Rydbergs) and the emergent continuum. It is expressed as photon fluxes (phot Ryd^{-1} cm^{-2}) corrected for r^{-2}, so as to be directly comparable with the continuum which went into the cloud.

Lyman continuum The last block of information gives the intensities of some of the emergent diffuse fields, and is only printed for open geometries. The first part is the energy in Rydbergs and the log of the product νf_ν for the Lyman continuum emerging from the illuminated face of the cloud (the side towards the central source of ionizing radiation). The number of Lyman continuum photons and the total energy in the Lyman continuum is then given. The end of the block gives the inward and outward diffuse fields in the Lyman, Balmer, and Paschen continua. These numbers are only meaningful for a plane parallel geometry.

6 THE EMISSION LINES

This section gives a complete list of all emission lines predicted by CLOUDY. In the following, the first column gives the four character label printed in the final array listing and the second column gives the wavelength of the line. The latter is usually in Å, although some fine structure lines are given in microns or tenths of microns, and continua are usually indicated by a wavelength of zero. The next item indicates whether the entry is a heat source (indicated by "h"), a coolant ("c"), or an intensity entered for information only ("i"). The last column of the table gives a brief description of the meaning of the line prediction. More information about individual lines can usually be had by examining the comments associated with the actual calculation of the line strength (in subroutine COOLR) or in subroutine LINES, where the line intensity is entered into the storage array.

The Emission Lines

Label	λ		Description
TOTL	4861	i	total H-beta from 10-level atom
TOTL	1216	i	total Ly-a from 10-level atom
TotH	0	i	total heating, all forms, information since individuals added later
BFH1	0	h	hydrogen photoionization heating, ground state only
BFHx	0	h	hydrogen photoionization heating, all excited states
BFHe	0	h	total helium photoionization heating, all stages
TotM	0	h	total heavy element photoionization heating, all stages
FF H	0	h	total free-free heating
ComH	0	h	Compton heating
H- H	0	h	H- heating
H-Hc	0	c	induced H- cooling
GraH	0	h	gas heating by grain photoionization
GraC	0	c	gas cooling by grain collisions
extH	0	h	"extra" heat added to this zone, from HEXTRA command
extC	0	c	"extra" cooling added to this zone, from CEXTRA command
pair	0	h	heating due to pair production
CA B	4861	i	H beta recombination, assuming case B
CA B	1216	i	case b intensity of Ly-alpha, no two photon
DU B	4861	i	simple H-beta, corrected as per Cota and Ferland 1987
Q(H)	4861	i	H-beta computed from Q(H) and specified covering factor
Q(H)	1216	i	Ly-alpha from Q(H), high-dens lim, specified covering factor
TOTL	6563	i	H-alpha emission from 10-level atom
TOTL	4861	i	H-beta emission from 10-level atom
TOTL	4340	i	H-gamma emission from 10-level atom
TOTL	4102	i	H-delta emission from 10-level atom

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TOTL 18751 i   P-alpha emission from 10-level atom
TOTL 12818 i   P-beta emission from 10-level atom
TOTL 10938 i   P-gamma emission from 10-level atom
TOTL 40512 i   5-4 emission from 10-level atom
TOTL 26252 i   6-4 emission from 10-level atom

TOTL 74578 i   6-5 emission from 10-level atom
2 NU     0 i   2-photon emission from 10-level atom
TOTL  1216 i   Ly-alpha from 10-level atom
TOTL  1026 i   Lyman beta is special because of OI fluorescense
TOTL   973 i   Ly-gamma emission from 10-level atom

TOTL   950 i   Ly-delta emission from 10-level atom
TOTL   938 i   Ly-epsilon emission from 10-level atom
LA X  1216 i   la contribution from suprathermal secondaries
Ind2  1216 i   "Ly alpha" produced by induced two photon
C13c  6563 c   H-alpha collision cooling from ground state

C13h  6563 h   H-alpha collision heating from ground state
C14c  4861 c   H-beta collision cooling from ground state
C14h  4861 h   H-beta collision heating from ground state
CION     0 c   collision ionization cooling of hydrogen
3bHt     0 h   this is the heating due to 3-body recombination

INWD  1216 i   inward escaping Ly-alpha
INWD  6563 i   inward escaping Balmer-alpha
INWD  4861 i   inward escaping Balmer-beta
INWD 18751 i   inward escaping Paschen alpha
Strk  1216 i   Stark broadening contribution to line

Strk  6563 i   Stark broadening contribution to line
Strk  4861 i   Stark broadening contribution to line
Strk 18751 i   Stark broadening contribution to line
Strk 40512 i   Stark broadening contribution to line
Dest  1216 i   portion of line lost due to absorp by background opacity

Dest  6563 i   portion of line lost due to absorp by background opacity
Dest 40516 i   portion of line lost due to absorp by background opacity
Dest  4861 i   portion of line lost due to absorp by background opacity
Dest 18751 i   portion of line lost due to absorp by background opacity
e sc  1216 i   electron scattering escape contribution to line

e sc  6563 i   electron scattering escape contribution to line
e sc  4861 i   electron scattering escape contribution to line
e sc 18751 i   electron scattering escape contribution to line
e sc 40512 i   electron scattering escape contribution to line
e-e+   511 i   511keV annihilation line

nFnu  4861 i   diffuse cont-nu.fnu(4861) due to all computed emission processes
nFnu  1216 i   diffuse cont-nu.fnu(1216) due to all computed emission processes
Inci  4861 i   incident continuum at H-beta, no attenuation
Inci  1216 i   incident continuum at Ly-alpha, no attenuation
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BA C     0 i   integrated Balmer continuum emission

PA C     0 i   Paschen continuum emission
Grai     0 i   total grain reradiation, both lines and incident continuum
Grai  1216 i   part of grain heating due to destruction of Ly alpha
H FF     0 c   H brems (free-free) cooling
FF X     0 i   part of H brems, in x-ray beyond 0.5KeV

ComC     0 c   total Compton cooling
Expn     0 c   expansion cooling, only non-zero for wind
eeff     0 c   electron - electron brems
H FB     0 c   H recombination cooling
Hind     0 c   cooling due to induced rec of hydrogen

He3i     0 c   cooling due to induced rec of fully ionized helium
Cycn     0 c   cyclotron cooling
Cool  1216 c   collisionally excited La cooling
Heat  1216 h   collisionally de-excited La heating
Crst   960 c   cooling due to n>2 Lyman lines

Hrst   960 h   heating due to n>2 Lyman lines
Cool  6563 c   cooling due to collisional excitation of Balmer alpha
Heat  6563 h   heating due to collisional de-excitation of Balmer alpha
Crst  4861 c   cooling due to n>3 Balmer lines
Hrst  4861 h   heating due to n>3 Balmer lines

Cool 18751 c   cooling due to collisional excitation of Paschen alpha
Heat 18751 h   heating due to collisional de-excitation of Paschen alpha
Crst     0 c   cooling due to higher Paschen lines
Hrst     0 h   heating due to higher Paschen lines
H2 l     2 c   H2 rotation lines from Lepp and Shull ApJ 270, 578.

H2 d     0 c   H2 dissociation by H atoms (not e)
H-FB     0 c   neg H ion free-bound emission
H2+      0 c   H+ + H => H2+ + photon continuum cooling
HEH+     0 c   HeH+ formation cooling
HeFF     0 c   He brems emission

HeIn     0 c   He ionization cooling
HeFB     0 c   He recombination cooling
MeFB     0 c   heavy element recombination cooling
MeFF     0 c   metal brems emission
ToFF     0 i   total brems emission

HeIC   584 c   Helium I 584, collisional excitation only
esc    584 i   Ly alpha escaping cloud, at present includes 626
He2p   910 i   He I two photon emission from 10 level atom
He I   504 i   emission from recombination to grnd state
He I  4471 i   HeI 4471 recombination only, fit to Brocklehurst '72

TOTL  5876 i   total 5876, from n-level atom
Ca B  5876 i   He I 5876 REC, simple fit to Brocklehurst
TOTL 10830 i   10830 from n-level atom
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INWD 10830 i   inward escaping HeI 10830
TOTL  3889 i   3889 from n-level atom

TOTL  7065 i   7065 from n-level atom
CcHE     0 c   total collisional He I cooling, from n-level atom
ChHE     0 h   total collisional de-exec He I heating, from n-level atom
He I     2 i   case B He I 2.06 micron
DevB     2 i   corrected He I 2.06 micron

He I  5016 i   case B emission
DevB  5016 i   case B corrected for Lyman line destruction
He I  3965 i   case B emission
DevB  3965 i   case B corrected for Lyman line destruction
He I  3614 i   case B emission

DevB  3614 i   case B corrected for Lyman line destruction
He I  3448 i   case B emission
DevB  3448 i   case B corrected for Lyman line destruction
HeII   228 i   Lyman continuum
HE2C   304 c   He II 304 collisionally excited

ESC    304 i   He II 304 escaping from cloud
He2C   911 i   He II Balmer continuum escaping from cloud
TOTL  1640 i   1640 predicted by 10-level atom
TOTL  4686 i   4686 predicted by 10-level atom, only valid at high densities
TOTL  1216 i   1216 predicted by 10-level atom, only valid at high densities

Ca B  1640 i   He II 1640, case B corrected for density
DevB  1640 i   He II 1640, corrected for density, deviations from case B
Ca B  4686 i   He II 4686, case B
DevB  4686 i   He II 4686, corrected for deviations from case B
Mion     0 c   cooling due to collisional ionization of heavy elements

C  1  1656 c   Carbon I 1656, collision strength from van Regemoter
REC   1656 i   C I 1656 recomb; n.b. coll deexcitation not included
C  I  9850 c   C I 9850, both of doublet; like 5007+4959
C  1  8727 c   C I 8727; equivalent to 4363
C  1  4621 c   1S - 3P

C  1   610 c   C I 610 micron, only H0, H2 included in excitation
C  1   370 c   C I 370 micron, only H0, H2 included in excitation
C  2   158 c   C II 158 micron, both e- and H0, H2 included in excitation
C  2  2326 c   make correction for Balmer absorption
INWD  2326 i   inward escaping C II 2326

Phot  2326 i   photoproduction, Helfand and Trefftz
C  2  1335 c   CII 1335
REC   1335 i   1335 recombination, coef from Ferland et al
C II  3134 c   intercombination line with same upper state as 1335
C  2  4267 i   C II 4267, rate from Ferland et al.

TOTL   977 i   total CIII] 1909, recombination + collisional excitation
C3 C   977 c   collisionally excited C III] 1909
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C3 R   977 i   recombination contribution to C III] 1909
TOTL  1909 c   CIII  1909 collision
INWD  1909 i   inward escaping CIII] 1909

C  3  1907 i   j-2 to ground
C  3  1909 i   j-1 to ground
C3 R  1909 i   C III 1909 recombination from Storey
Phot  1909 i   C III] 1909 following relax following inner shell photoionization
C  3  2297 i   C III 2297, diel rec coef from Stickland et al

C  3  4187 i   C III 4187
C  3  4649 i   diel contr from Nussbaumer and Storey, Ast Ap in press ('84)
C  4  1549 c   C IV 1550
INWD  1549 i   inward part of C IV 1549
DEST  1549 i   part of line destroyed by photoionization of Balmer continuum

C4 r     1 i   recombination CIV 1549 from CV
C  4  4659 i   C IV 4659, recombination
C  5    40 c   C V 40.3 A, collisionally excited, g-bar approx
C  6    34 c   C VI 33.7 A, collisionally excited, g-bar approx
C 6r    34 i   K-alpha due to recombination of stripped ion

N  1  5200 c   Nitrogen I 5200
REC   5200 i   5200 rec, both rad+di, 1/3 of total to doublets
N  1  1200 c   collisionally excited part
N  2  6584 c   N II 6584 alone
N  2  6548 c   N II 6548 alone

REC   6584 i   N II 6584 alone, recombination contribution
N  2  5755 c   N II 5755 from Seaton 75
N  2   122 c   N II fine structure line
N  2   203 c   N II fine structure line
N  2  4239 i   N II 4239 recombination, effective rec coef from Williams et al

N  2  5680 i   N II 5680 recombination
N  2  2140 c   N II 2140 intercombination line
N  2  1084 c   N II 1084, CS guess from g-bar
N  3  1750 c   N III 1750, collisionally excited
N  3    57 c   N III 57 micron fine structure line

N  3   990 c   N III 989.8, collisionally excited
N  4  1486 c   N IV 1486, collisionally excited
N  4   765 c   N IV 765, collisionally excited
N  4  1718 i   N IV 1718, diel rec coef from Stickland et al
N  5  1240 c   N V 1240, collisionally excited

N  6    29 c   N VI 29A, collisionally excited
N  7    25 c   N VII 25A, collisionally excited
N 7r    25 i   recombination K-alpha from fully stripped ion
O  1  6300 c   Oxygen I  6300
O  1  6363 c   Oxygen I  6363

O  1  5577 c   auroral OI
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O  1   630 c   O I fine structure line
O  1  1470 c   O I fine structure line
O  1  7774 i   estimate of rec coef, 50% of total  O I rec
T OI     0 c   total collisional cooling due to 6-level OI atom

6lev  8446 i   OI 8446 from six level atom
6lev  1304 i   OI 1304 from six level atom
6lev  1039 i   OI 1039 from six level atom
6lev  4368 i   OI 4368 from six level atom
6lev    13 i   OI 1.3 micron from six level atom

6lev    11 i   OI 1.1 micron from six level atom
6lev    29 i   OI 2.9 micron from six level atom
6lev    46 i   OI 4.6 micron from six level atom
TOTL  3727 c   O II 3727, all lines of multiplet together
TOTL  7325 c   O II 7325, all lines of multiplet together

IONZ  3727 i   line produced by photoionization of Oo; already included in TOTL
IONZ  7325 i   line produced by photoionization of Oo; already included in TOTL
O II  3729 i   five level atom calculations; D5/2 - S3/2
O II  3726 i   D3/2 - S3/2 transition
O II  2471 c   both 2P 1/2 and 3/2 to ground

O II  7323 i   P1/2-D5/2 and P3/2-D5/2 together
O II  7332 i   P1/2-D3/2 and P3/2-D3/2 together
O II   834 c   O II 833.8 coll excit
O  2  4651 i   O II 4651 recombination, coef from Williams et al
O  3  1663 c   O III 1661+1666

Phot  1663 i   contribution to OIII 1664 due to inner shell (2s^2) ionization
Augr  1663 i   contribution to OIII 1664 due to K-shell ionization
Rec   1663 i   upper limit to rate coefficient for dielectronic recomb, NS84
O  3  5007 c   O III  5007 alone, collisions, tot OIII is this times 1.333
O  3  4959 c   O III  4959 alone, collisions, tot OIII is this times 4

LOST  5007 i   O III 5007 lost through excit photo
TOTL  4363 c   O III 4363,collisions from five level atom
Rec   4363 i   O III 4363 recombination, coef from Burgess and Seaton
O  3  2321 c   collisional excitation of 2321, 5-level atom
C EX  4363 i   charge exchange, Dalgarno+Sternberg ApJ Let 257, L87.

C EX  5592 i   charge exchange rate, D+S
O  3   880 c   O III fine structure line, collisions only
O  3   520 c   O III fine structure line, collisions only
O  3   834 c   O III 834A, collisions only
O  3  3341 i   Burgess and Seaton O III RECOMB, 3341+3312+3299

O  4    26 c   O IV 26 micron
O  4  1402 c   O IV 1402, collisions
CONT  1401 i   inner shell photoionization, relaxation
O  4   789 c   O IV 789A
O  4  3412 i   Burgess-Seaton O IV 3412 (whole multiplet twice as strong)
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O  5   630 c   O V 630, collisional excitation
TOTL  1218 c   O V 1214, collisional excitation
O  5  1218 i   j=1 to ground
O  5  1214 i   the other line
O  5  5112 i   BS O V 5112, recombination

O  6  1035 c   O VI 1035, collisional excitation
O  7    22 c   O VII 21.6A, collisional excitation, g-bar
O  8    19 c   O VIII 18.97A, collisional excitation, g-bar
O 8r    19 i   recombination from fully stripped ion
Ne 2   128 c   Neon II 12.8 micron

Ne 3   156 c   Ne III fine structure line
Ne 3   361 c   Ne III fine structure line
Ne 3  3869 c   Ne III  3869, of 3968+3869 doublet
Ne 3  3968 c   Ne III  3968, of 3968+3869 doublet
Ne 3  3343 c   NeIII auroral line

Ne 3  1815 c   NeIII auroral line
Ne 4  2424 c   Ne IV 2424, collisional excitation
Ne 4  4720 c   Ne IV N=3 lines, three level atom approx
Ne 4  1602 c   Ne IV N=3 lines, three level atom approx
Ne 5  3426 c   Ne V 3426 of 3426, 3346 doublet

Ne 5  3346 c   Ne V 3346 of 3426, 3346 doublet
Ne 5  2976 c   auroral line
Ne 5  1575 c   collisionally excited
Ne 5   242 c   Ne V 24.2, 14.3 micron
Ne 5   143 c   Ne V 24.2, 14.3 micron

Ne 5  1134 c   both components of 5S-3P 1140, 1131 doublet
Ne 6    76 c   Ne VI fine structure lines
Ne 6  1007 c   Ne VI] 1007, collisionally excited
Ne 7   895 c   Ne VII 895, collisionally excited
Ne 8   774 c   Ne VIII 774, collisionally excited

Ne 9    13 c   Ne 9 13.5A, collisionally excited
Ne10    12 c   Ne 10 12.13A, collisionally excited
NeLr    12 i   Ne Ly-alpha recombination from fully stripped ion
Mg 1  4571 c   Magnesium I 4571, O I data for coll strength and trans prob
Emis  2798 c   Mg II 2800 tot intensity, corrected for photoionization loss

Cool  2798 c   total cooling, including absorbed photons
phot  2798 i   fraction lost due to photoionization of upper level by Balm cont
Mg 4     4 c   Mg IV 4.5 micron
Mg 5    13 c   Mg V  13.5 micron emission
Mg 5    56 c   Mg V 5.6 micron emission

Mg 5  2751 c   (Mg 7) 2571, 2893
Mg 6  1806 c   MG VI
Mg 7  2629 c   (Mg 7) 2510, 2629
Mg 7   433 c   Mg 7 433
Mg 8   435 c   Mg 8 435
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Mg 8     3 c   Mg 8 3.03 micron
Mg 9   705 c   Mg 9 704.5
Mg 9   368 c   Mg 9 368,1
Mg10   615 c   Mg 10 614.9
Mg11     9 c   Mg 11 9.17A

Mg12     7 c   Mg 12 7.11A
MgLr     7 i   recombination from fully stripped ion
Al 3  1860 c   Aluminum; the line
AlLr     6 i   recombination from fully stripped ion
Si 2    35 c   Silicon II 35 micron

Si 2  2335 c   SI II] 2336,
Si 2  1808 c   SI II 1808, permitted resonance line, collisionally excited
Si 3  1207 c   SI III 1207, collisionally excited
Si 3  1895 c   Si III) 1895, collisionally excited
PHOT  1895 i   photoproduction by inner shell removal

Si 4  1397 c   Si IV 1397, collisionally excited
Si 6    19 c   SI VI 1.96 micron, collisionally excited
Si 7  2148 c   SI VII, 2148, O III like, collisionally excited
Si 7    25 c   Si VII 2.48, 6.49 micron, collisionally excited
Si 7    65 c   Si VII 2.48, 6.49 micron, collisionally excited

Si 8  1446 c   SI VIII 1446, OIII like, collisionally excited
Si 8    61 c   SI 8, 61.0A, collisionally excited
Si 9  1985 c   SI IX 1985, 2150, collisionally excited
Si 9   949 c   collisionally excited
Si 9  1815 c   collisionally excited

Si 9     3 c   SI 9, 3.86, 2.84 3P fine structure lines
Si 9     2 c   SI 9, 3.86, 2.84 3P fine structure lines
Si 9   691 c   both components of 5S-3P doublet
Si 9    55 c   SI 9 55.3A, collisionally excited
Si10   606 c   SI 10 606A, actually group of 4 intercombination lines.

Si10 14300 c   SI 10 1.43 micron, collisionally excited
Si11   583 c   SI XI 582.9, collisionally excited
Si11    44 c   SI XI 43.7A, collisionally excited
Si12    41 c   SI XII 40.9A, collisionally excited
Si13     7 c   SI XIII 6.7A, collisionally excited

Si14     6 c   SI XIV 6.17A, collisionally excited
SiLr     6 i   recombination from fully stripped ion
S 1R  1807 i   this is to check whether photoexcit of S II is ever important
S  2  6720 c   S II 6731 + 6716 together
S  2  4074 c   S II 4070 +4078 together

S  2 10330 c   S II N=3 lines, all four lines together
S II  6731 i   individual line from five level atom
S II  6716 i   individual line from five level atom
S II  4070 i   individual line from five level atom
```

```
S II  4078 i   individual line from five level atom

S II 10323 i   individual line from five level atom
S II 10289 i   individual line from five level atom
S II 10373 i   individual line from five level atom
S II 10339 i   individual line from five level atom
S II  1256 c   resonance line near NV, collisionally excited

S  3    18 c   S III fine structure 18.7
S  3    34 c   S III fine structure 34
S  3  9532 c   [S III] 9532 alone
S  3  9069 c   [S III] 9069 alone
S  3  6312 c   [S III] 6312, transauroral temperature sensitive

S  3  3722 c   [S III] 3722, same upper level as 6312
S  3  1198 c   WL, other data, from Ho + Henry Ap.J. 1984
S  3  1729 c   S III intercombination line with no atomic data (wild guess)
S  4   105 c   S IV 10.5 micron, collisionally excited
S  4  1406 c   S IV 1406, collisionally excited

S  5  1198 c   S V 1198, collisionally excited
S  5   786 c   S V 786.5, collisionally excited
S  6   933 c   S VI 933+944, collisionally excited
S  9  1715 c   S IX 1715, 1987, collisionally excited
S 10  1213 c   S X 1213, 1197, collisionally excited

S 11  1826 c   S XI 1615, 1826, collisionally excited
S 12   520 c   S XII 520, group of four intercombination lines all together
S 12  7611 c   S XII 7625, WL from Moore NBS, collisionally excited
S 13   488 c   S XIII 488.4, 1909 like, collisionally excited
S LR     5 i   S 16 4.7A Ly a recombination from fully stripped ion

Ar 2     7 c   Argon II 7 micron
Ar 3  7135 c   Argon III 7136
Ar 3  7751 c   Argon III 7751
Ar 3    22 c   Argon III 21.8, 9 micron lines
Ar 3     9 c   Argon III 21.8, 9 micron lines

Ar 4  4740 c   Argon IV 4711 + 4740 together, 4740=90%
Ar 4  7335 c   [AvIV] auroral line
Ar 5  7007 c   Argon V, 3P lines, 7007, collisionally excited
Ar 5  6435 c   Argon V, 3P lines, 6435, collisionally excited
Ar 5   131 c   Argon V fine structure lines, 13.09, 7.903 micron line

Ar 5    79 c   Argon V fine structure lines, 13.09, 7.903 micron line
Ar 6     4 c   Ar VI 4.53 micron
Ar14  4413 c   Ar XIV 4413, predicted lambda, not observed(??)
Ar15   409 c   collisionally excited
ArRr     4 i   Ar 18 ly a recombination 3.7A from fully stripped ion

Ca 2  3933 c   coll excit calcium k+h
Ca 2  8579 c   infrared triplet
Ca 2  7306 c   forbidden line
```

```
Phot  3933 i   fraction H Ly-alpha destruction of excited levels
Phot  7306 i   fraction H Ly-alpha destruction of excited levels

Ca2K  3934 i   individual lines from five level atom
Ca2H  3969 i   individual lines from five level atom
Ca2X  8498 i   individual lines from five level atom
Ca2Y  8542 i   individual lines from five level atom
Ca2Z  8662 i   individual lines from five level atom

CaF1  7291 i   individual lines from five level atom
CaF2  7324 i   individual lines from five level atom
Rec   3933 i   reccombination contribution to CaII emission
Ca 4    32 c   Ca IV 3.2 micron
Ca 5     4 c   Ca V 4.16, 11.47 micron

Ca 5    11 c   Ca V 4.16, 11.47 micron
Ca 5  6087 c   Ca V optical and uv lines, collisional excitation, 3-level atom
Ca 5  5311 c   Ca V optical and uv lines, collisional excitation, 3-level atom
Ca 5  2414 c   Ca V optical and uv lines, collisional excitation, 3-level atom
Ca 5  3997 c   Ca V optical and uv lines, collisional excitation, 3-level atom

CaLr     3 i   Calcium Ly a recombination from fully stripped ion
Fe 2    48 i   emission from Netzer's 3-level atom
Fe 2     7 i   emission from Netzer's 3-level atom
Emis     3 i   emission from Netzer's 3-level atom
Cool     3 i   net cooling due to UV lines

TOT      0 c   total of all UV+optical FE II cooling
FEIR     0 c   sum of all IR cooling from 6D ground state
Fe 3     0 c   sum of 3p and 3g states together
Fe 3  5270 c   Fe III 5270, predictions cop-out from garstang et al 78
Fe 3  4658 c   Fe III 5270, predictions cop-out from garstang et al 78

Fe 3  1122 c   FeIII 1122 entire multiplet
Fe 5  3892 c   Fe V  3892+3839
Fe 6     0 c   all of 2G lines together first
Fe 6  5177 c   Fe VI 5177, approximate correct
Fe 7  6087 c   FE VII 6087

Fe 9   171 c   FE 9 171.1
Fe 9   245 c   FeIX 245 j=1 fast decay
Fe 9   242 c   FeIX 242 j=1 slower decay
Fe10   352 c   FE 10 352.1
Fe10  6374 i   total (coll, pumped)

Coll  6374 c   collisional contribution
Pump  6374 i   pumped by continuum fluorescense
 352  6374 c   collisions of E1 line
Fe11  7892 i   total intensity of line
Coll  7892 c   contribution from collisional excitation

Pump  7892 i   contribution from continuum fluorescense
Fe11     6 c   IR fine structure line
```

```
Fe11  2649 c   collisional excitation
Fe11  1467 c   collisional excitation
Fe11   354 c   Fe 11 353.8

Fe12  1242 c   Fe 12, 1242, 1349 together, collisional excitation
Fe12  2170 c   Fe 12, 2170, 2406 together, collisional excitation
Fe12  2568 c   Fe12 2904, 2567, 3567, 3073 together, collisional excitation
Fe12   357 c   Fe 12 357.3, collisional excitation
Fe13   363 c   Fe 13 363.3, collisional excitation

Fe14   347 c   Fe 14 262.3, 347, collisional excitation
Fe14   262 c   Fe 14 262.3, 347, collisional excitation
Fe14  5303 i   total intensity of line
Coll  5303 c   contribution from collisional excitation
Pump  5303 i   continuum fluorescense

 347  5303 c   collisional excitation of E1 line
Fe15   284 c   Fe 15 284.1, collisional excitation
Fe16   343 c   Fe 16 343.5, collisional excitation
Fe17    17 c   2p5 3s 17.096, 17.051, 16.775A
Fe17    15 c   2p5 3d 15.451, 15.261, 15.013A

Fe18   975 c   Fe XVIII 974.A, collisional excitation
Fe18   104 c   lines from Kato, collisional excitation
Fe19   108 c   lines from Kato, collisional excitation
Fe19   592 c   fe19 from loulergue et al '85
Fe19  7082 c   fe19 from loulergue et al '85

Fe19  1118 c   fe19 from loulergue et al '85
Fe19  1328 c   fe19 from loulergue et al '85
Fe20   120 c   fe19 from loulergue et al '85
Fe21   142 c   triplet at 129, 142, 146A, collisional excitation
Fe21  1354 c   next two 3p ground state lines, collisional excitation

Fe21  2304 c   collisional excitation
Fe22   130 c   collisional excitation
Fe22   149 c   collisional excitation
Fe23   133 c   collisional excitation
Fe22   846 c   Fe 22 845.6A

Fe23   263 c   Fe 23 1909-like 262.6
Fe24   255 c   Fe 24 255, 192 doublet all in one, collisional excitation
Fe25     2 c   Fe 25, He like, 1.85A, collisional excitation
Fe26     2 c   Fe 26, H like, 1.79A, collisional excitation
Totl     2 i   total intensity of K-alpha line

FeLr     2 i   recombination from fully stripped ion
TotH     2 i   total hot iron Ka; Auger "hot" iron, plus recom
AugC     2 i   Auger production of "cold" iron, less than or 17 times ionized
```

7 MACHINE ENVIRONMENT

CLOUDY is designed to run in single precision on IEEE 32-bit computers such as SUNs, Decstations, 80X86 or 680X0-derivative machines, as well as VAXs. It has been developed with double precision disabled, indefinites set, and stack memory enabled, on The Ohio Supercomputer Center (OSC) CRAY Y-MP, and has been tested on a VAX 8650, Sun Sparcstation, Decstation 3100, and Northgate 486 PC. Calculations on all machines produce essentially identical results.

The floating point environment should be set to ignore floating point underflow but crash on any other floating point error. Floating point underflow is an unavoidable consequence of the attenuation of radiation as a beam of light is extinguished by an absorbing medium; underflow error-checking should be disabled. This is the default condition for most UNIX machines and VAXs, and code is included in the driver for CLOUDY to disable underflow error-checking on IBM, CDC, SUN, and UNIX machines.

Floating point overflow or division by zero *must never* occur, nor should library function domain errors (i.e., the log of a negative number); I would appreciate hearing about these errors; I can't fix it if I don't know it is broken. My internet address is gary@bowen.mps.ohio-state.edu; please send the input file and version number.

VAX A problem can arise when running CLOUDY on a VAX, and this makes the use of the "/g_floating" option on the DEC FORTRAN compiler necessary. Several portions of CLOUDY having to do with determining the ionization balance of the elements are written in double precision. The neutral fraction can become very small when the gas is highly ionized, and it is necessary to have exponents which extend beyond the conventional $10^{\pm 38}$ range of these machines. This portion of the code is written in double precision, which by the IEEE convention also has an increased exponent size. A VAX does not obey this convention (they were developed before it was) unless the "/g_floating" option is used on the compile step. CLOUDY checks to see that the double precision is working correctly and will print a note if it is not. On some VAXs the "g_floating" option brings a severe time penalty. If this is the case, then it is not necessary to use the "g_floating" option, but CLOUDY will not work for many conditions. Floating point overflow may or may not occur if "/g_floating" is not specified.

CRAY It is not necessary to use double precision on a Cray. The double precision disable option can safely be set on the compile step. The code has been tested with both stack memory and indefinites enabled on the Ohio Supercomputer Center (OSC) CRAY Y-MP.

SUN Unix The code has been extensively tested on a Sun Sparcstation IPC. The Sun Fortran compiler cannot compile the entire code in a single pass. It is necessary to break the code up into a half-dozen or more large pieces (being careful to divide the files to keep subprograms together), with each piece of length $\ll 10^4$ lines. If each piece is called "part1.f", "part2.f", etc, then they can be compiled separately with compile commands

```
f77 -fnonstd -c part1.f
f77 -fnonstd -c part2.f
f77 -fnonstd -c part3.f
f77 -fnonstd -c part4.f
```

and then linked with the command

```
f77 -fnonstd -o c.out part1.o part2.o part3.o part4.out
```

where "c.out" is the name of the executable file.

The execution-time warning messages saying that IEEE exceptions underflow and inexact occurred and have not been cleared are normal for Suns' implementation of IEEE arithmetic. Overflow or division by zero must not occur.

It is *essential* that the "-fnonstd" option be specified on both the compile and link steps. This option enables the correct error handling for underflow, division by zero, overflow, and operand range error. Besides setting a mode where the code will crash upon performing an illegal operation, it will speed up the execution time by factors of from three to ten.

Decstation The test cases presented in section 25 have been computed on a Decstation 3100. The agreement with results of other machines was good, although testing on this machine has not been as extensive as on the others mentioned above.

8 PROBLEMS

8.1 Floating Point Errors

CLOUDY has been tested on machines ranging from 386 PCs to CRAY Y-MPs. *Floating point errors do not occur.* The logic within the code is designed to identify problems, and complain, but not fail. The logic is only as good as the tests they were designed to pass. It is inevitable that circumstances will occur for which the logic now in the code is not sufficient. It is possible that the code will fail when these circumstances occur. I would be grateful for reports of any such failures, since they inevitably identify shortcomings in the code, and lead to its improvement. My e-mail address is gary@bowen.mps.ohio-state.edu.

8.2 No Temperature Convergence

A temperature failure occurs when the heating-cooling balance is not within a certain tolerance, set by the "TOLERANCE" command, after 20 tries. Normally CLOUDY will punt after an excessive number of temperature failures occur. The limit to the number of failures is reset with the "FAILURES" command, which sets the variable LIMFAL. The default value is 20. (When CLOUDY stops because of excessive failures it first produces a map of heating-cooling space to give an indication of where the equilibrium temperature should have been.)

It has been my experience that temperature failures most often occur for temperatures near 1–4 $\times 10^3$ K, and near 10^5–10^6K, where the cooling function permits more that one thermal solution (see, for example, Williams 1967). Figure 3 shows a typical cooling function, computed for parameters given in an example shown in section 25 below. A peak is reached at a temperature near 10^3K. This occurs because the fine-structure lines are major coolants and have Boltzmann factors near unity. As a result their cooling rate is proportional to the Coulomb focusing factor $T^{-1/2}$, and the cooling rate *decreases* until the temperature is high enough for optical forbidden lines to become important coolants. A similar phenomenon occurs if the solution needs to jump over the $\sim 10^5$–10^6 K peak in the cooling function.

When failures occur because more than one temperature solution is possible, the reported failures are a physical (not numerical) problem. CLOUDY will try to deal with this problem by forcing the temperature to values below the peak in the cooling function. Increasing the number of allowed failures (with the "FAILURES" command) to prevent the code from stopping prematurely is permissible as long as the global energy balance is preserved. A warning will be issued at the end of the calculation if the heating-cooling balance is not preserved.

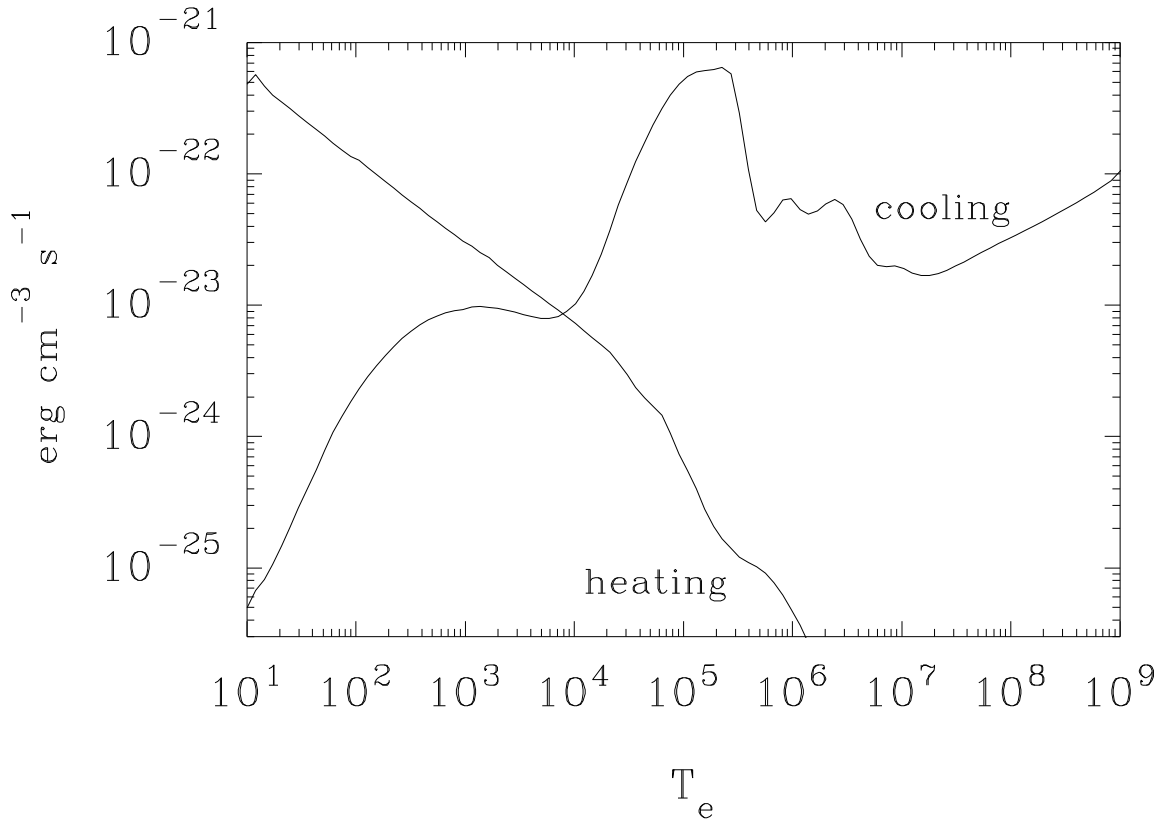

Figure 3: This figure shows a typical cooling function for low density gas. The temperature is shown on the x-axis, and the cooling rate (erg cm^{-3} s^{-1}) is indicated by the dashed line, and the heating (same units) by the solid line. The map was produced using one of the examples given in section 25 below. cooling

8.3 Map Output

If an excessive number of temperature failures occur (the default limit is 20) then the program stops and produces a map of the heating and cooling as a function of temperature. The limit to the number of failures is reset with the "FAILURES" command. The map is described here.

The programs steps through increasing temperatures and prints the heating, cooling, and ionization of the gas. From this information it should be possible to determine the temperature where the equilibrium thermal solution should have been. Each solution is completely self-consistent. Both the attenuated radiation field and collisional ionization contribute to the ionization balance at each temperature. All processes contribute to the thermal balance, including collisional ionization. The map is at constant density.

The first column gives the temperature. Column 2 and 5 give the volume heating and cooling, both in units erg s^{-1} cm^{-3}. Columns 3 and 6 are pointers to the main source of heating and cooling, and columns 4 and 7 give the fraction of the total heating or cooling due to these agents. Column 8 gives the cooling derivative, 9 is the electron density (cm^{-3}) and the remaining columns give the hydrogen and helium ionization fractions.

8.4 Thermal Stability

Note also that the thermal solution may be unstable when the temperature derivative of the net cooling function is negative. Possibly unstable solutions are indicated by a "u" just before the equilibrium temperature in the zone printout. (The temperature derivative is for isochoric, not isobaric, conditions.) Comments are printed at the end of the calculation if possibly unstable thermal solutions are present in the calculation.

8.5 Negative Populations of H, He

It is possible that the code will stop because negative level populations were predicted for atoms or ions of hydrogen and helium. This is not supposed to occur, but sometimes happens because of numerical instabilities in the matrix inversion routine.

8.6 I can't fix it if I don't know its broken.

Machines are grower faster much more rapidly than people are getting smarter. Reliability in the face of complexity is the major challenge to the development of any large-scale computer code. There can be little doubt that CLOUDY contains bugs. The code is well tested in many simple limits, and behaves in the correct manner.

Simulations of HII regions, planetary nebulae, and other simple objects, are in good agreement with predictions of other photoionization codes.

Bugs can be discovered by strange behavior in situations where the code has not been tested. The discovery of the existence of these bugs is itself a major challenge. If problems arise or the code crashes then it is likely that a problem has been isolated. I would appreciate learning about such problems since they identify shortcomings which usually lead to improvements in the code (or the documentation). My e-mail address is gary@bowen.mps.ohio-state.edu.

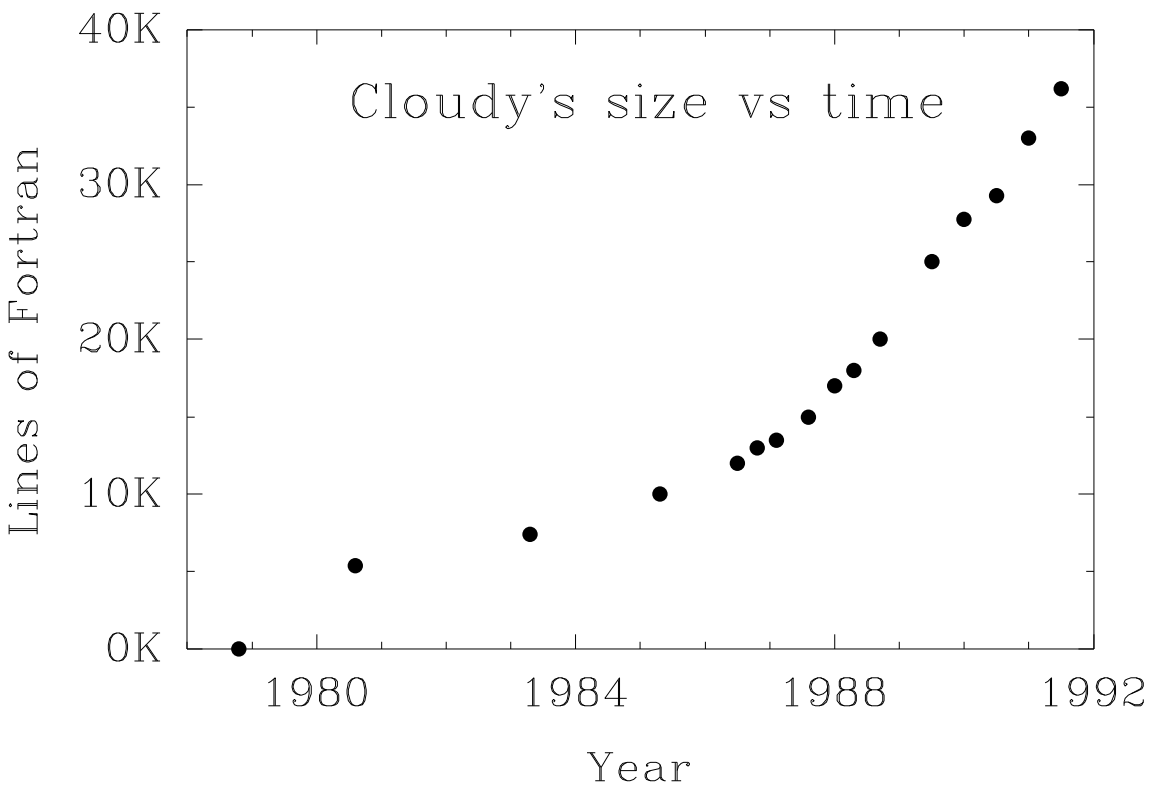

Figure 4: This figure shows the size of the code, indicated by the number of lines of FORTRAN, as a function of time. size

9 MAJOR REVISIONS TO CLOUDY

This section outlines some of the major versions of CLOUDY, and gives an indication of the direction development will take in the next few years. Its development began in August of 1978, at the Institute of Astronomy, Cambridge, and has been continued at The University of Kentucky and The Ohio State University. Figure 4 shows the evolution of the code, as indicated by its size as a function of time.

9.1 Major Past Versions

67 August 1987. Hydrogen atom goes to LTE in limit of large electron densities. Many small bugs uncovered as result of careful comparison with Netzer's ION.

68 Cambridge, Fall 1987. Development work in progress.

69 December 1987. Hydrogen atom goes to LTE in limit of large photon densities. Ferland and Rees (1988).

70 September 1988. He II Lyα transfer improved. Improved form of escape probabilities with explicit damping constants. H^- and improved free-free heating. Many high excitation metal lines transferred. (Rees, Netzer, and Ferland 1989; Ferland and Persson 1989).

71 December 1988. Photon array rewritten, now Compton exchange problem is exact for black bodies with temperatures between 2.7 K and 10^{10} K. He II Lyα radiation pressure included.

72 January 1989. Static version, minor bug fixes.

73 1989. Major rewrite of helium treatment. Dust changed to two populations, scattering and absorption included. Default radius and thickness increased by ten orders of magnitude. He^+ goes to LTE. Development work on getting helium to go to LTE. IR power law for default AGN continuum now $\nu^{+2.5}$ below 100 micron break. No ANUMM array, all continuum one array. TABLE STAR. COOLR broken up. Helium to LTE for high electron density.

74 1990 January. Hydrogen double precision, many bug fixes. 10 tables among the continua. Kurucz (1989) atmospheres. Improved dust treatment, including photoionization and charge.

75 1990, JILA. Cosmic abundances changed to Grevesse and Angers. Major bug in constant pressure for HII regions, PNs, etc; did not affect BLR. Calculation of $\nu f_\nu(H\beta)$ was incorrect. Molecules at low temperatures. HDEN now $N(H^o) + N(H^+) + N(H^-) + 2N(H_2) + 2N(H_2^+)$. Improved Rayleigh scattering treatment. Dielectronic recombination for sulphur (guess). Many changes in dust; Orion paper (Baldwin et al. 1990).

76 1990, static version from end of JILA visit.

77 through Nov 1990. OPTIMIZE option added using Bob Carswell's code. Gaunt factor for brems input spectrum. Reflected continuum predicted. Frequency partition adjusted. X-ray optical depth now at 0.5 kev. Read in table of points from previous calculation. OPSAV deleted, now single pointer OPSV for all opacities. Numerical array to 100MeV. Hummer Ly-alpha escape destruction prob. TAUTOT arrays now both in and outward directions. Bound compton included for all ionization levels. Mean ionization arrays rewritten to make sense. Bug in wind velocity fixed, result now exact. C, O outward diffuse fields changed to OTS.

78 Through May 91. Continuum escape probability formal H-only opacity. H rec, cooling over wide range of temp. "ABUNDANCES NO DUST" no longer

changes abundances of depleted elements. OI-Lyβ treatment is now six-level atom. Default table AGN changed. Continuum normalization rewritten. Milne relation for diffuse fields of H, all He. Fe Ka divided into hot and cold. Beams paper (Ferland, Peterson, Horne, et al.) Many high ionization lines included as OTS and outward ionization sources.

79 Summer 91. H molecules completed, C, N, O molecules included. Continuum binning changed for Ca, Fe L-shell ionization potentials. Extensive testing.

80.05, 80.06 July 91, static versions. Version 80.06 included several small bug fixes, and the new [NeV] IR collision strengths.

81 Yet newer collision strengths for [NeV] IR lines (10x larger).

9.2 Future Improvements

- Helium atom goes to LTE for high radiation densities.
- Helium collision data update.
- Define departure coefficients for helium as in Mihalas.
- Hydrogen and helium transition probabilities as a function of temperature and density.
- Molecule network goes to LTE for all temperatures.
- Transfer Lyα correctly (incomplete redistribution).
- Transfer other hydrogen lines correctly (complete redistribution).
- Opacity Project photoionization cross sections, recombination rate coefficients.
- Heavy elements go to LTE via psuedo states.
- Include all hydrogen, helium lines in radiative acceleration.

9.3 Known Modes for CLOUDY 80.06

- Gaunt factors taken from Hummer subroutine, not defined in very far IR.
- HeII 10-level atom predictions do not agree with case B at low density. (l-mixing not a good assumption.)
- HeII line radiation pressure not reliable.

- 2s level of hydrogen not exactly unity in radiation-LTE limit. Induced two-photon emission.

9.4 Making a Revision

- Compile with array bounds checking on Cray. Run all test cases on Cray, VAX, Sun, and PC. Confirm no differences.
- Compile line list from LINES.
- Compile index.
- Pass HAZY through spelling checker.
- Update all comparison tables; confirm OK.
- Change labels in HAZY.
- Confirm table of contents ok.
- Check that driver and main subroutine in HAZY are still accurate.
- Compile sample driver, check that results agree with sample input stream.
- Summarize changes from VERSION, for "past major revisions" above.

10 CLOUDY AS A SUBROUTINE

CLOUDY is designed to also be used as a subroutine of other, much larger, codes. When used this way, a series of subroutine calls, described next, are used to initialize the code, specify the initial conditions, drive the code, and examine the predictions.

It is also possible to drive the code by accessing its common blocks directly. In fact, this was the preferred method before version 80. The major problem with this approach, besides its inconvenience, is that the code and its common blocks are constantly changing, so that the main driver code will also have to be changed to keep up with CLOUDY. The following subroutines access the common blocks themselves, and (it is hoped) their use will not change with time.

10.1 Initializing the Code

Several variables must be initialized at the beginning of the calculation. This is done by calling subroutine CDINIT.

```
      CALL CDINIT
```

CDINIT must be called every time a new calculation is to be performed, *before* calling any of the following subroutines.

10.2 Entering Commands

The input stream used to specify the initial conditions for the calculation consists of a series of 80 character free format command lines. They must start in column 1, and contain meaningful information across all 80 columns. These command lines are entered by successive calls to routine CDREAD.

```
      CHARACTER*80 LINE
      WRITE(LINE,'(''constant pressure'')')
      CALL CDREAD( LINE , NLEFT )
*
      HDEN = 3.5
      WRITE(LINE,'(''hden='',F5.1)') HDEN
      CALL CDREAD( LINE , NLEFT )
```

The first argument of CDREAD is the line image, an eighty character variable. The line image it stores must obey all the rules for normal command lines. It is assumed to end with column 80 or one of the special characters outlined in the section on command line format. The second integer variable in the call to CDREAD is the

number of command lines which can still be entered. It is not now possible to read in more than 100 command lines because of limits to the size of the character arrays used to store them. This limit is stored as the variable NKRD which occurs in several parameter statements throughout the code. If more than 100 lines are read in by calling CDREAD then CDREAD will stop after explaining why. It will be necessary to increase NKRD throughout the code if more than 100 command lines are needed.

10.3 Controlling Output

CLOUDY normally speaks what's on its mind. However, it does have a quiet mode in which nothing at all is printed. This quiet mode is set by the logical argument to subroutine CDTALK.

```
*     set no output at all
      CALL CDTALK( .FALSE. )
*     have the code produce the normal printout
      CALL CDTALK( .TRUE. )
```

The default is for CLOUDY to produce output, and CDTALK does not have to be called if this is desired. However, it does need to be called with the logical variable false if the quiet mode is desired.

10.4 Calling the Code

CDDRIV is a subroutine with a single logical variable. The following shows an example of its use.

```
      LOGICAL OK
      CALL CDDRIV( OK )
```

If the calculation was successful then the logical variable (in this example given the name "OK") is set .TRUE. by the code. If problems occurred and the results cannot be trusted then the variable is set .FALSE.. If output was turned off (with CDTALK) then it will probably be necessary to turn output on and recompute the model to find out what went wrong.

10.5 Reading the Emission-Line Array

The predicted line intensities or luminosities are stored within a set of common blocks which also contain the line identifiers, a four character label and integer wavelength. These are normally printed at the end of the calculation. It is also possible to obtain the line formation by calling subroutine CDLINE.

```
      CHARACTER*4 LABEL
      LOGICAL OK
*
      LABEL = 'TOTL'
      LENGTH = 1216
      CALL CDLINE( LABEL , LENGTH , RELINT , ABSINT , OK )
```

The first variable is the line label, the four character string usually used to identify the line. The second integer variable gives the wavelength of the line. Both of these must exactly match the label and wavelength used by CLOUDY to identify the line (see Section 6). If CDLINE finds the line then the logical variable which is the last argument in the call to CDLINE is set to .TRUE., and this variable is set to .FALSE. if the line is not found. The third variable (RELINT in the above example) is the relative intensity of the line (relative to the normalization line, usually Hβ). The log of the intensity (erg cm^{-2} s^{-1}) or luminosity (erg s^{-1}) of the line is returned as the next variable (ABSINT in the above example).

10.6 Reading the Column Density Array

The predicted column densities can be accessed by calling the subroutine CDCOLM.

```
      CHARACTER*4 LABEL
*
      LABEL = 'CARB'
      ION = 3
      CALL CDCOLM( LABEL , ION , COLUM )
```

where COLUM is the predicted column density. The label must agree with the first four characters used in the printout. The integer variable ION is the spectroscopic designation of the level of ionization, i.e., 1 indicates CI, 3 indicates CIII, etc.

10.7 Example Call as a Subroutine

The following is an example of a very simple call as a subroutine. The normal output will be produced on Fortran unit 6.

```
      PROGRAM MAIN
      LOGICAL OK
      CHARACTER*80 LINE
*
*     initialize the code
```

```
      CALL CDINIT
*
*     write a series of command lines into character variable LINE,
*     then feed into code with CDREAD
      WRITE(LINE,'(''hden 4 '')')
      CALL CDREAD(LINE , NLEFT )
      WRITE(LINE,'(''black 5 '')')
      CALL CDREAD(LINE , NLEFT )
      WRITE(LINE,'(''stop zone 1 '')')
      CALL CDREAD(LINE , NLEFT )
      WRITE(LINE,'(''ionization -2 '')')
      CALL CDREAD(LINE , NLEFT )
*
*     now call the main driver, output will be produced
      CALL CDDRIV( OK )
*
      STOP
      END
```

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12 GLOSSARY OF SYMBOLS

As far as possible, the notation used by HAZY follows standard texts (Osterbrock 1988; Mihalas 1978). This is a summary of some of the symbols used.

Symbol	Description	Units	Page
A	radiative rate	s^{-1}	
b_n	departure coefficient	-	
C	collisional rate	s^{-1}	
D_{ul}	line destruction probability	-	
f(r)	filling factor	-	
g_i	statistical weight	-	
G	energy gains, heating	erg cm^3 s^{-1}	
I	intensity	erg s^{-1} sr^{-1}	
J	mean intensity	erg s^{-1} sr^{-1}	
N(cr)	cosmic ray density	cm^{-3}	
q	collisional rate coefficient	cm^3 s^{-1}	
P*(x)	LTE relative population	cm^3	
P_{ul}	line escape probability	-	
P_c	continuum escape probability	-	
T_u	energy density temperature	K	
T_{color}	color temperature	K	
U_g	grain potential	volt	
Q_{abs}	grain absorption efficiency	-	
Q(H)	hydrogen ionizing photons	s^{-1}	
v	velocity	cm s^{-1}	
V_g	grain potential	eV	
α(T)	recombination coefficient	cm^3 s^{-1}	
α_ν	continuous absorption cross section	cm^{-2}	
α_{lu}	line absorption cross section	cm^{-2}	
β	recombination cooling coef	cm^3 s^{-1}	
η	photon occupation number	-	
γ	one sided escape probability		
Γ	photoionization rate	s^{-1}	
κ	opacity	cm^{-1}	
Λ	energy loss, cooling	erg cm^3 s^{-1}	
ϕ	photon flux	cm^{-2} s^{-1}	
σ	scattering cross section	cm^{-2}	
Σ	projected grain area	cm^2	
τ	optical depth	-	
ν	frequency	Hz	

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HAZY

a brief introduction to CLOUDY 80.06
Computational Methods and Test Cases

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CLOUDY 80.06

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13 INTRODUCTION

This section outlines the computational methods used in version 80.06 of CLOUDY. Parts are modified from Ferland and Mushotzky (1984), Ferland and Rees (1988), Ferland and Persson (1989), Rees, Netzer, and Ferland (1989), Baldwin et al. (1991), and Fabian and Ferland (1991). The code has been designed to be as general as possible (but limited to non-relativistic regimes which are not Compton-thick) while remaining computationally expedient. Similar discussions of hydrogen line formation, focusing on the density range $N \leq 10^{11}$ cm^{-3} appropriate to quasar emission-line clouds, can be found, for instance, in Mathews, Blumenthal, and Grandi (1980) and Drake and Ulrich (1980). Discussions of line formation and ionization and thermal equilibria are presented by Osterbrock (1988), Davidson and Netzer (1979), Kwan and Krolik (1981), Halpern and Grindlay (1980), Weisheit, Shields, and Tarter (1981), Kallman and McCray (1982), Hubbard and Puetter (1985), Vernazza, Avrett, and Loeser (1981), and Avrett and Loeser (1988).

14 THE CONTINUUM

Under most circumstances the continuum produced by the central object is the only source of heat and ionization for the emission-line clouds. Supplemental heating due to cosmic rays, dissipation of turbulence, neutrons, or an arbitrary heat source can also be added, however. This section describes how this continuum, and continuous opacities, are treated.

14.1 Continuum Range

The energy interval 1.001×10^{-5} Ryd— 7.354×10^{6} Ryd is divided into ~ 500 energy bins with nearly logarithmically increasing widths. The low energy limit to the continuum is stored as the variable EMM and the high energy limit as EGAMRY. These are the two elements of the common block BOUNDS.

14.2 Continuum Pointers

The function IPOINT converts energy (Rydberg) into pointers to the cell containing the specified energy. It has a single argument, the energy in Rydberg, and returns the pointer to the appropriate cell. IPOINT will stop if the energy does not lie within the continuum bounds of the code.

14.3 Continuum Arrays

Several vectors deal with aspects of the attenuated incident and diffuse continua. All store these fluxes in units photons cm^{-2} s^{-1} $cell^{-1}$ and they all map one-to-one with one another.

ANU The energy (in Rydbergs) of the center of each cell is stored in the vector ANU.

WIDFLX The width of each cell (Rydbergs) is stored in the vector WIDFLX.

FLUX The attenuated incident continuum is stored in the vector FLUX.

OTSCON and OTSLIN Two vectors, OTSCON and OTSLIN, store the local on-the-spot (OTS) photon fluxes for continua and lines. Both are totally local rates, and are reevaluated for every zone.

DIFFUS The diffuse continuum (total local emission due to all processes, *per unit volume* with no filling factor) is stored in DIFFUS.

REFLEC The "reflected" continuum (defined elsewhere) is stored as REFLEC. The reflected continuum is updated for each zone, and the contents of REFLEC is the integrated quantity.

CONDIF The vector CONDIF stores the outward diffuse continuum which is not included in the evaluation of the photon heating rates. These are largely fields which are treated as sources of ionizing radiation in other ways.

OUTCON OUTCON stores the many lines and continua which are carried outward and treated as sources of ionizing radiation. Only weak sources of ionizing radiation are carried in this array; strong continuum sources are treated by more exact methods, and their OTS fluxes stored in OTSCON or OTSLIN.

CONEMS CONEMS is the outward continuum which is carried without further interaction with the gas. This is not a directly observed quantity.

CORIND Boltzmann factors, the ratio $\exp(-h\nu/kT)$, are stored in the vector CORIND, which is evaluated in routine BOLTGN.

14.4 Continuous Opacities

The cloud is divided into a large number of concentric shells (zones) and the attenuated and diffuse continua and physical conditions are then determined within each.

A correction must be made to account for the attenuation of the continuum across the zone (Netzer and Ferland 1983). Assuming that the continuum varies across the zone as

$$\frac{I(\nu, dr)}{I_o(\nu)} = \exp(-\kappa(\nu) f(r)\, dr) \tag{50}$$

then the intensity averaged over a zone with thickness dr is

$$\left\langle \frac{I(\nu, dr)}{I_o(\nu)} \right\rangle = \frac{1 - \exp(-\kappa(\nu) f(r)\, dr)}{\kappa(\nu) f(r)\, dr} \tag{51}$$

where $\kappa(\nu)$ is the absorption opacity and f is the filling factor. The coefficients giving this ratio as a function of energy are stored in the vector TAUMN, and are evaluated in subroutine RADINC. The continuum stored in FLUX is multiplied by these factors in the same subroutine.

The main opacity sources in the ultraviolet continuum are generally photoelectric and free-free (inverse brems) absorption, electron scattering (of both bound and free electrons), and the damping wings of Lyman lines (Rayleigh scattering). The main reemission mechanisms are generally free-free (brems), free-bound, and two photon emission. Grains can also be added as an option. Continuous absorption and reemission by all ground states, and many excited states, of all 166 ionization stages of the 13 elements in the calculation are explicitly included. Great care is taken to ensure that each absorption mechanism is balanced by a reemission process, and vice versa, so that energy balance in the strict thermodynamic limit can be achieved.

14.4.1 Rayleigh scattering

Clouds with neutral hydrogen column densities greater than $\sim 10^{23}$ cm^{-2} are optically thick to Rayleigh scattering at wavelengths near Lyα, and this process is a major scattering opacity source at short wavelengths for grain-free environments.

Rayleigh scattering cross sections given by Gavrila (1967) are used, joined with expressions for the radiative damping wings of Lyman lines (Mihalas 1978). For wavelengths longward of 1410Å a power-law fit to the Gavrila's quantal calculations is used;

$$\sigma_{Ray} = 8.41 \times 10^{-25}\epsilon^4 + 3.37 \times 10^{-24}\epsilon^6 + 4.71 \times 10^{-22}\epsilon^{14}\ cm^2 \tag{52}$$

where $\epsilon \equiv \nu / cR_\infty$ is the photon energy in Rydbergs. This fit is accurate to typically a percent, with occasional errors as large as 4 percent.

For wavelengths between 1410Å and the Lyman limit radiative broadening of the Lyman lines is assumed (Mihalas 1978);

$$\sigma_{Ray} = \sum_{i=2}^{4} \left(\frac{e^2 f_{1,i}}{mc} \right) \frac{\Gamma/4\pi}{(\nu - \nu_{1,i})^2}\ cm^2 \tag{53}$$

where Γ is the reciprocal lifetime of the upper level i and the sum is over the first four Lyman lines. This expression gives cross sections in excellent agreement with Gavrila (1967) for these wavelengths.

14.4.2 Free-free opacity

The main opacity source in the infrared-radio spectral region for many conditions is free-free opacity with a cross section given by

$$\alpha_\nu(ff) = 3.69 \times 10^8\, \bar{g}_{III}(\nu, T)\, f(r)\, \nu^{-3}\, T^{-1/2}\, \{1 - \exp(-h\nu/kT)\} \sum_A \sum_z z^2\ N_A^{+z}\ \ cm^2 \tag{54}$$

(see, for example, Mihalas 1978). The sum is over all ions N^{+z} of element A. The temperature averaged gaunt factor $\bar{g}_{III}(\nu, T)$ is taken from Hummer (1988; see also Karzas and Latter 1961). H^- free-free opacities are included as well (see below).

14.4.3 Bound-free opacity

Continuum optical depths for photoabsorption from level n are given by

$$d\tau_n(\nu) = \alpha_\nu(n)\ N_n\,[1 - \exp(-h\nu/kT)/b_n]\ \ f(r)\ dr \quad , \tag{55}$$

where b_n is the departure coefficient for level n and α_ν is the absorption cross section.

14.5 Attenuation of the Incident Continuum

Continuous opacities are stored in two vectors which map one-to-one with FLUX and ANU. The vector SCATOP stores the scattering opacity, while the vector OPAC stores the absorption opacity. Continuous optical depths accumulated up to the current zone are stored in three vectors which map one-to-one with FLUX and ANU. The vectors TAU, TAUABS, and TAUSCT store the total continuous optical depths, absorption optical depth, and scattering optical depths, respectively.

In an open geometry scattering is assumed to attenuate the incident continuum as

$$I = I_o\,(1 + 0.5\ d\tau_{scat})^{-1} \quad . \tag{56}$$

Scattering does not affect the continuum in a closed geometry. Absorption is assumed to attenuate the incident continuum as

$$I = I_o \exp\,(-d\tau_{abs}) \tag{57}$$

for both geometries.

14.6 Recombination Equilibrium

A modified version of the "on-the-spot" (OTS) approximation is used in the treatment of sources of diffuse ionizing radiation. Were no other opacity sources present, then, for a closed geometry which is optically thick in the Lyman continuum, all recombinations of hydrogen or helium to the ground state would produce ionizing photons which would be quickly absorbed by other atoms of the recombined species. In this case OTS is an excellent approximation (Van Blerkom and Hummer 1967; Bässgen, Bässgen, and Grewing 1988). However, other opacity sources are present, and these compete in absorbing protons produced by recombinations, making the recombination process more efficient than the OTS approximation would suggest.

The recombination coefficients for all states of hydrogen and helium are modified by the presence of other opacity sources, such as grains, free-free or H^- absorption, and the heavy element opacities, in the following manner. The net effective recombination rate coefficient ($cm^3\ s^{-1}$) to level n, $\hat{\alpha}(T_e, n)$, is written in terms of the spontaneous radiative recombination rate coefficient $\alpha(T_e,\ n)$, the escape probability for continuum photons described above, and the opacities (cm^{-1}) κ_n and κ_o for the level n and other opacity sources respectively, as

$$\hat{\alpha}(T_e, n) = \alpha(T_e, n)\left\{P_c(n) + [1 - P_c(n)]\left(\frac{\kappa_o}{\kappa_o + \kappa_n}\right)\right\} \quad , \tag{58}$$

and $P_c(n)$ is the continuum escape probability defined below (equation 71). In general, $P_c(n)$ varies between 0 and 0.5 for an optically thick open geometry (see, for example Davidson 1977), $P_c(n) \sim 1$ if the gas is optically thin, and $P_c(n) \sim 0$ for ground states if the gas is optically thick and the geometry is closed. All computed opacity sources are included in κ_o.

These recombination continua produce a flux of on-the-spot photons, ϕ_{OTS} ($cm^{-2}\ s^{-1}$). The OTS photoabsorption rate Γ_{OTS} (s^{-1}), used to determine the ionization or heating rate for the gas or grain constituents, is then $\Gamma_{OTS} = \alpha\phi_{OTS}$ where α is the photoabsorption cross section for the individual species. The OTS flux is related to the spontaneous recombination rate coefficient by

$$\phi_{OTS} = \alpha(T_e,\ n) N_e N_{ion} \left[\frac{1 - P_c(\tau)}{\kappa_o + \kappa_n}\right] \quad cm^{-2}\ s^{-1} \tag{59}$$

where N_{ion} is the ion in question. These are stored in the vectors OTSCON and OTSLIN.

14.7 Continuum Normalization

The continuum renormalization is performed in routine CONORM. The incident continuum can either be specified as a luminosity radiated into 4π sr, or as a surface flux, per unit area of cloud at the illuminated face. In most cases there is no ambiguity. For those where there is, the continuum is assumed to be the relevant quantity radiated into 4π sr if the resulting ionization parameter lies between 10^{10} and 10^{-15}, and a surface flux otherwise.

14.8 Continuum Generation

The continuum is generated by the function "FFUN". FFUN has a single argument, the energy in Rydbergs, and it returns the number of photons per unit area, time, and

Rydberg, at that energy. FFUN sums over all the specified continua and applies the appropriate normalization factors. Another function, FFUN1, evaluates each individual continuum, and is normally called by FFUN.

The units, and their conversion to other measures of the continuum, are

$$\phi_\nu(\nu) = FFUN(\nu) \quad photons\ cm^{-2}\ s^{-1}\ Ryd^{-1} \tag{60}$$

$$FLUX(\nu) = \phi_\nu(\nu)\,\delta\nu_i = FFUN(\nu) \times WIDFLX(\nu) \quad photons\ cm^{-2}\ s^{-1} \tag{61}$$

$$f_\nu(\nu) = FFUN(\nu)\,h\left(\frac{\nu}{\nu_{912}}\right) \quad erg\ cm^{-2}\ s^{-1}\ Hz^{-1} \quad . \tag{62}$$

14.9 Energy Units; The Rydberg

Continuum energies are usually given in Rydbergs. One Rydberg is approximately equal to the ionization potential of hydrogen, which is

$$R_H \equiv 2.178728 \times 10^{-11}\ erg = 13.59842eV = 911.76340\mathring{A}\ = 109677.576\,cm^{-1}\ . \tag{63}$$

This was the Rydberg unit used by CLOUDY before 1988, and *is not* the more commonly used R_∞, for infinite mass nuclei.

At present the energy scale is being converted to R_∞. In this unit, the wavenumber corresponding to R_∞ is

$$R_\infty = \frac{2\pi^2 m_e e^4}{ch^3} = 109737.312\ cm^{-1}\ , \tag{64}$$

the wavelength in vacuum is

$$1/R_\infty = 911.26708\mathring{A}\ , \tag{65}$$

the frequency is

$$c\,R_\infty = 3.289842 \times 10^{15}\ s^{-1}\ , \tag{66}$$

and this corresponds to an energy

$$1\ Ryd = chR_\infty = 2.17992 \times 10^{-11}\ erg = 13.60583\,eV\ \ . \tag{67}$$

Thus the ionization potential of hydrogen is actually 0.99946 Ryd. This difference is significant since it enters as the third power in the photon phase-space conversion factor $2h\nu^3/c^2$.

Another commonly used unit is the "atomic unit", also called the Hartree, which is equal to *two* Rydbergs (i.e., $2R_\infty$).

Table 15: Continuum Conversion Factors

To convert from	Code Variable	to	multiply by
photons/s/cm^2	FLUX	f_ν	ν_{Ryd} hν_1(erg)
photons/Ryd/s/cm^2	FLUX/WIDFLX	νf_ν	$\nu_{Ryd}^2\, h\nu_1$(erg)
energy, T	ANU, TE	$h\nu/kT$	1.57890(5)*ANU/TE

14.10 Conversion Factors

Table 15 gives conversion factors between various common units of continuous emission.

15 LINE AND CONTINUUM TRANSFER

Optical depths and escape probabilities are computed for *all* permitted and intercombination lines which are significant coolants. The cooling is usually distributed among many lines in high density models, and these lines are usually optically thick.

15.1 Thermalization Length

Radiative transfer will affect the thermal equilibrium of the gas when the collision timescale approaches an effective lifetime $\tau \sim (A_{ul}/N_{scat})^{-1}$, where A_{ul} is the transition probability and N_{scat} is the number of scatterings a line photon undergoes before escape. For permitted metal lines (which often have optical depths $\sim 10^4$ – 10^6) line thermalization becomes important at densities $N > 10^{15}/\tau \sim 10^{10}$ cm^{-3}. These effects are important for hydrogen at considerably lower densities. Additionally, continuum transfer affects the ionization and thermal equilibrium of the gas at all densities.

15.2 Optical Depths

The line center optical depth for a transition $u - n$, where u is the upper level, is given by (Mihalas 1978)

$$d\tau_{n,u} = \alpha_\nu \left(N_n - N_u g_n/g_u\right)\ f(r)\ dr \tag{68}$$

where $f(r)$ is the filling factor. The absorption cross section α_ν is related to the oscillator strength f by

$$\alpha_\nu = \frac{\pi^{1/2} e^2 \lambda f}{m_e c v} \phi_\nu \tag{69}$$

with

$$v^2 = 2kT/m_A + v_{turb}^2 \tag{70}$$

the line-width (cm s^{-1}), as determined by the local electron temperature. The micro-turbulent velocity v_{turb} is assumed to be zero unless it is reset with the "TURBULENCE" command.

15.3 Mean vs Line Center Optical Depths

CLOUDY tries to work with line center optical depths throughout (see, for example, Mihalas 1978). In many places routines or approximations using *mean* optical depths are encountered (eg, Hummer and Kunasz 1980). The line center optical depth is $\pi^{1/2}$ times smaller than the mean optical depth.

15.4 The Continuum Escape Probability Function

Recombination to level n_o produces radiation capable of ionizing levels $n \geq n_o$. The transport of this radiation can be treated with variations of the "on-the-spot" approximation (Van Blerkom and Hummer 1967; 1968; Davidson and Netzer 1979; Netzer and Ferland 1984; Osterbrock 1988; Bassgen et al. 1988). If hydrogen is the dominant opacity and the photoelectric cross section varies as $(\nu/\nu_o)^{-3}$, then the probability of escape of a photon is given by

$$P_c(\tau, h\nu_o/kT) = \frac{\int_1^\infty x^{-1} E_2\left(\tau_o x^{-3}\right) \exp\left(-h\nu_o(x-1)/kT\right)\, dx}{\int_1^\infty x^{-1} \exp\left(-h\nu_o(x-1)/kT\right)\, dx} \tag{71}$$

where τ_o is the optical depth at threshold, which has energy hν_o, and $x \equiv h\nu/h\nu_o$. No simple approximation is obvious, and the function is integrated numerically.

Figure 5 shows P_c. The escape probability decreases as the optical depth increases in the expected nearly exponential manner. It also decreases with decreasing $h\nu_o/kT$. Physically, as the gas temperature increases relative to the threshold energy, recombining photons are created further from threshold, where the optical depth of the gas is smaller. For small $h\nu/kT$ and large optical depths, the escape probability is several orders of magnitude larger than that suggested by the optical depth at threshold alone. For large $h\nu/kT$ the escape probability is nearly $E_2(\tau)$, as expected.

15.5 The Line Escape Probability Function

At low densities, line scattering for a two level atom is coherent in the atom's reference frame, and the line profile function is described by the incomplete redistribution function. At high densities the Stark effect can broaden the line, while, when the radiation density is high, scattering within excited states can broaden resonance lines such as Lyβ (line interlocking), destroying the coherence of the scattering process. In these cases complete redistribution more closely describes the scattering process. CLOUDY uses two escape probability functions to take these processes into account.

Line transfer can be described by either complete or partial redistribution. Which is the case is determined by the detailed processes affecting the level populations and line transport. In this work the lines are divided into two groups; strong resonance lines which are treated with partial redistribution with a Voigt profile, and subordinate lines, which are treated with complete redistribution in a Doppler core.

15.5.1 Background opacity

The ratio of continuous to line opacity is parameterized as

$$X_c = \frac{\kappa_c N_c}{\kappa_l N_l + \kappa_c N_c} \tag{72}$$

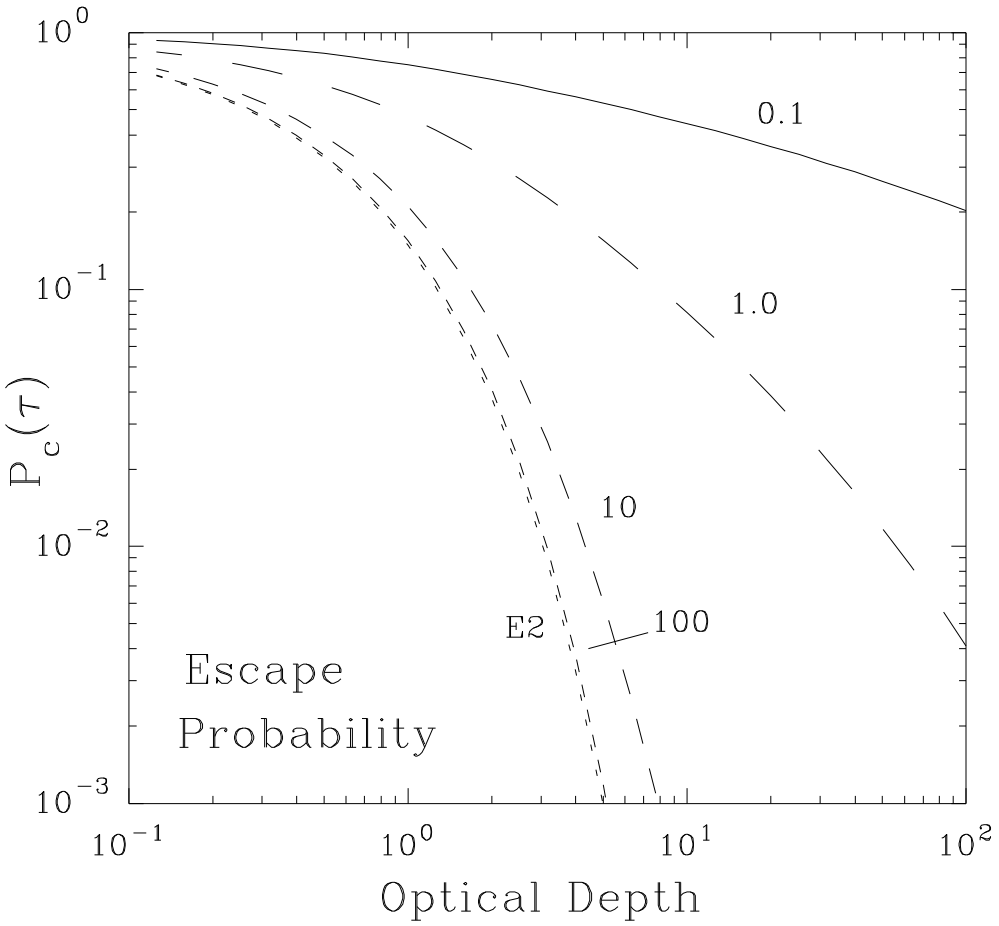

Figure 5: Continuum escape probability function. The continuum escape probability P_c is shown as a function of the optical depth at threshold, for a variety of values of the ratio $h\nu/kT$, where $h\nu$ is the energy at threshold. For small $h\nu/kT$ recombining photons are emitted far from threshold and escape freely, even for large optical depth. conesc

where κ is the opacity and the N's the number of absorbers.

15.5.2 Incomplete redistribution

Incomplete redistribution is assumed for resonance transitions such as C IV λ1549 and the Lyα transitions of hydrogen and helium. Two studies of line formation using this approximation are those of Bonilha et al. (1979) and Hummer and Kunasz (1980). Both studies suggest escape probabilities of the form

$$P_l(\tau) = \{1 + b(\tau)\tau\}^{-1} \quad , \tag{73}$$

but there is substantial disagreement in the form and value of the factor $b(\tau)$, sometimes by more than a factor of 2. (This is after due allowance for the different definitions of line opacities in the two papers.) CLOUDY uses the Hummer and Kunasz results.

The damping constant a is given by

$$a = \frac{\Gamma}{4\pi\Delta\nu_D} = \frac{\lambda \sum A}{4\pi v_{Dop}} \tag{74}$$

where Γ is the sum of the A's from the upper level, and $\Delta\nu_D$ is the Doppler width in frequency units (Mihalas 1978) and v_{Dop} is the Doppler width in cm^{-1}. The code stores the ratio $\Gamma\lambda/4\pi$ in the vectors DAMPLN, HDAMP, HE1DMP, and HE2DMP. The a's are then evaluated in the routines deriving the escape probabilities.

The escape and destruction probability functions used for HI, HeI, and HeII Lyα and strong resonance lines such as CIV λ1549 is that described by Hummer and Kunasz (1980). Their tabulated values were fitted by interpolation.

15.5.3 Complete redistribution

Lines arising from excited states (hydrogen Balmer, Paschen, etc.) and Lyman lines with $n_{upper} > 2$ are treated assuming complete redistribution in a Doppler core (i.e., the damping constant a is assumed to be zero). In this case, if the total optical depth of the slab is T, then the escape probability at a depth τ from the illuminated face is given by;

$$P_l(\tau, T, X_c) = [1 - X_c F(X_c)] \frac{1}{2} [K_2(\tau, X_c) + K_2(T - \tau, X_c)] \quad , \tag{75}$$

and the destruction probability is

$$D_l(X_c) = X_c F(X_c) \quad . \tag{76}$$

The function

$$F(X_c) = \int_{-\infty}^{+\infty} \frac{\phi(x)}{X_c + \phi(x)}\, dx \quad , \tag{77}$$

where $\phi(x) \approx \pi^{-1/2} \exp(-x^2)$ is the Voigt function, is interpolated from the tables presented by Hummer (1968). The function

$$K_2(\tau,\, X_c) \equiv \frac{1}{1 - X_c F(X_c)} \int_{-\infty}^{+\infty} \frac{\phi^2(x)}{X_c + \phi(x)} E_2\left[(X_c + \phi(x))\,\tau\right]\, dx \tag{78}$$

is evaluated numerically.

15.5.4 Level populations and emission

The radiative line de-excitation rate is given by

$$\left(\frac{dN_u}{dt}\right)_{rad} = N_u A_{u,l}\,(P_l + D_l) - N_l A_{u,l} \eta \gamma_{u,l} \tag{79}$$

where η is the photon occupation number of the external radiation field and $\gamma_{u,l}$ is the escape probability described by Castor (1970).

The emission from a transition between the level n to a lower level l is then simply

$$4\pi j(nl) = N_n\ A_{nl}\ h\nu_{nl}\ P_l(\tau_{nl})\ f(r) \tag{80}$$

where $P_l(\tau_{nl})$ is the line escape probability (Elitzur et al. 1983; Elitzur 1984). The local cooling rate due to the line is related to the volume emissivity of the line by

$$\Lambda_{ul} = 4\pi j(h\nu) = N_u A_{u,l} f(r)\, P_l(\tau,\, T,\, X_c)\, h\nu = (N_l C_{l,u} - N_u C_{u,l})\ f(r)\, h\nu \tag{81}$$

and the local flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) of "on-the-spot" (OTS) photons caused by line loss (used to compute heating or photoionization rates for the sources of the background opacity) is

$$\phi_{\mathrm{OTS}} = \frac{N_u A_{u,l}\, D_l(X_c)}{\kappa_c N(c)} \quad . \tag{82}$$

The ratio of inward to total line intensity is then given by

$$\frac{4\pi j(in)}{4\pi j(total)} = \frac{K_2(\tau, X_c)}{[K_2(\tau, X_c) + K_2(T - \tau,\, X_c)]} \tag{83}$$

15.5.5 Stark broadening

Distant collisions with charged particles broaden the upper level of lines, and in the limit of very high densities this will make the scattering process completely non-coherent even for Lyα (i.e., complete redistribution obtains). CLOUDY closely follows the treatment of Puetter (1981) in treating Stark broadening. For transitions described by incomplete redistribution a total escape probability $P_{l,\,tot}$ given by

$$P_{l,\,tot} = \min\left(P_{inc} + P_{Stark}\ ,\ P_{com}\right) \tag{84}$$

is defined, where the escape probabilities are those for incomplete, Stark, and complete redistribution respectively. The total effective escape probability is not allowed to exceed the complete redistribution value for $\tau > a^{-1}$.

15.5.6 Net escape probability

If τ is the optical depth in the direction towards the source of ionizing radiation and T is the total optical depth then the escape probability entering the balance equations is

$$P_l(\tau, T) = \left\{P_l(\tau) + P_l(T-\tau)\right\}/2 \quad . \tag{85}$$

In general the total optical depth T is only known after the first iteration, so more than one iteration must be performed when radiative transfer is important. The optical depth scale is usually well defined after the first iteration, so that reliable results are often obtained in two iterations, but more iterations may be required under some circumstances. A warning will be printed after the last zone calculation if the optical depth scale has not yet converged.

15.6 The Optical Depth Arrays

The terms open and closed geometry are defined in section 2.2 above. The treatment of transfer in these two limits is described here.

15.6.1 Open geometry

This is the default. During the first iteration the escape probability is defined using only optical depths accumulated in the inward direction. This optical depth is initialized to TAUMIN, a very small number, at the start of the calculation. At the end of the first iteration the total optical depth is set to the optical depth accumulated in the inward direction. At the end of subsequent iterations the total optical depth is defined as a mean of the new and old inward optical depths.

15.6.2 Closed expanding geometry

This is the default if the "SPHERE" command is entered. In this case it is assumed that line photons do not interact with the "other" side of the expanding spherical nebula. The treatment of the optical depths is entirely analogous to that described for an open geometry, since the presence of the distant material has no effect on line transfer.

15.6.3 Closed static geometry

This is assumed if the "SPHERE STATIC" command is entered. In this case line photons from all parts of the spherical shell do interact. As a result, the optical depth scale is poorly defined on the first iteration, and more than one iteration is required. On second and later iterations the total line optical depth is set to twice the optical depth of the computed structure, and the optical depth at the illuminated face of the shell is set to half of this. The optical depth scale is only reliably defined after at least a second iteration.

15.6.4 Wind

The model is a large velocity gradient ($v \sim R$ Sobolev approximation) wind. The effective optical depth is given by;

$$\tau_{lu}(R) = \kappa_{lu} \left(N_l - N_u \frac{g_l}{g_u} \right) R \frac{v_{thermal}}{v_{expansion}} \tag{86}$$

where $v_{thermal}$ and $v_{expansion}$ are the thermal and expansion velocities respectively. Iteration is often not required in this type of model since the line optical depth is entirely defined locally. Iteration will be required if the geometry is optically thin in the ionizing continuum (matter bounded), since the code assumes that the cloud will be radiation bounded on the first iteration. A comment will be printed at the end of the calculation if another iteration is needed.

15.6.5 Hydrogen

Several arrays are defined to store information related to the hydrogen optical depth scale and escape probabilities. The escape probability for the transition u—l is stored as the element HESC(u,l), while the effective transition rate (the spontaneous rate multiplied by the escape probability) is stored in HESC(l,u). The optical depth for the center of the zone is stored in HTNEXT(u,l); this includes corrections for stimulated emission so it may be negative. (A comment is printed if a level inversion occurs.) The fraction of the escapes which occur in the inward direction is stored in HFRCIN(u,l).

The Stark contribution to the total escape probability is stored in PESTRK(u,l); PESTRK(l,u) contains this escape probability multiplied by the spontaneous transition rate for the u—l transition. The array HDEST contains the corresponding arrays of destruction rates.

15.6.6 Helium

The treatment of singlet and ionized helium is entirely analogous to that of hydrogen. Many of the variables have similar names.

15.6.7 The heavy elements

The arrays defining the heavy element optical depths, escape probabilities, and inward escaping fractions, are stored in common block TAU. Each emission line is represented by a vector with dimension four. The first element of the vector is the optical depth in the inward direction (i.e., towards the illuminated face of the cloud), and is incremented in subroutine TAUINC. The second element is the total optical depth through the cloud, computed in the previous iteration. The third element of the vector is the escape probability for the line, and the last element is the fraction of the line escaping in the inward direction. The escape probabilities are evaluated in METESC.

The correction for stimulated emission is neglected in the optical depth scale for UV lines of heavy elements. As a result the optical depths must be greater than zero, and the escape probability must be less than unity. This approximation is reasonable for ultraviolet transitions at nebular temperatures.

15.6.8 Fine structure lines

The vector FSTAUS contains information concerning the "fine structure" lines; defined here as lines arising within levels of split ground terms. These forbidden lines may become optically thick, and may mase under some circumstances. The first element in FSTAUS is the optical depth in the inner direction. The second element is the total optical depth, as computed in the previous iteration. Both include the correction for stimulated emission, and can be negative. The third element is the escape probability evaluated by the function ESCFS,

$$P_l(\tau) = \frac{1 - \exp(-\tau)}{\tau} \tag{87}$$

which will be greater than unity if a population inversion occurs and $\tau < 0$. The next element of the array is the opacity in the transition, as computed by the section of the code which does level populations. This opacity includes the correction for stimulated emission and will be negative if a population inversion occurs. The last element is a

pointer to the line frequency. This is used to take continuum pumping into account. The escape probabilities are evaluated in METESC.

16 THE MODEL HYDROGEN ATOM

CLOUDY is designed to model environments which range from the low density limit to LTE. Hydrogen is treated as a ten-level atom. Level $2s$ and $2p$ are treated separately, while $3 \leq n \leq 6$ are treated assuming full l-mixing. The atom is completed with three supplemental levels chosen to mimic the average properties (averaged over level population assuming LTE at $T_e \sim 10^4$ K) of levels 7–10, 11–20, and 21–100 respectively; inclusion of these levels is necessary because recombination (both collisional and radiative) to high-n levels can eventually populate the lower levels which produce the observed lines. The atomic data for the upper three levels are given in Cota (1987).

Tests in the low-density, or nebular, limit show that the model atom predicts level populations and emissivities which are in much better than 1% agreement with Seaton (1959), who also assumed a well l-mixed hydrogen atom but considered many more levels. The three pseudo-states are well-coupled to the continuum for many conditions of interest; their main effect is to increase the populations of low levels by radiative and collisional deexcitation, and hence affect the ionization balance.

Pressure shielding lowers the ionization potential of the atom to include typical energies within the level representing $21 \leq n \leq 100$ when the density is greater than $N_e \sim 6 \times 10^{14} \, (T/10^5 K)$ cm^{-3} (Mihalas 1978). As a result the population of the highest level will be overestimated, and hence the neutral hydrogen density, by a small amount. This effect is compensated for by not counting the three pseudo-states in the summation over level populations to determine the neutral hydrogen fraction in the charge-conservation equation.

Departure coefficients, rather than actual level populations, are used in the solution of the hydrogen level populations. The LTE relative population density for level n is stored in the vector PLTE and is given by

$$P_n^* = \frac{N_n^*}{N_e N_p} = \frac{g_n}{g_e g_p} \left(\frac{h^2}{2\pi m k T} \right)^{3/2} \exp(\chi_n) \tag{88}$$

$$= \frac{g_n}{g_e g_p} 4.14158 \times 10^{-16} \, T^{-3/2} \exp(\chi_n) \; cm^3 \tag{89}$$

where $g_e = 2$, $g_p = 1$, and $g_n = 2n^2$ are the statistical weights, N_n^* is the LTE population of level n (cm^{-3}), and the other symbols have their usual meaning. Here

$$\chi_n = \frac{I_n}{kT} = \frac{15.789 \times 10^4 \, Z^2}{n^2 T} \tag{90}$$

where I_n is the ionization threshold for level n and Z is the nuclear charge. The departure coefficients are stored in the vector HBN and are related to the LTE relative

population density by

$$b_n = N_n / P_n^* N_e N_p \tag{91}$$

where N_n is the actual population of the level.

Boltzmann factors for transitions between levels are stored in the array

$$HLBOLT(l,u) \equiv \exp(\chi_u - \chi_l) \tag{92}$$

which is evaluated in subroutine HCOLST. Boltzmann factors for levels relative to the continuum are stored in the vector

$$HCBOLT(n) \equiv \exp(-\chi_n) \quad . \tag{93}$$

16.1 Recombination Rates and Cooling

State specific rates for radiative recombination and radiative recombination cooling are needed for the temperature range $10\text{K} \leq T_e \leq 10^{10}\text{K}$. The methods and assumptions used to derive these for hydrogenic ions is described here.

16.1.1 Formalism

The Milne relation for the state-specific radiative recombination rate coefficient (cm^3 s^{-1}) to a level n can be expressed as (Brown and Mathews 1974; Gould 1978; Mihalas 1978);

$$\alpha_n(T) = \left(\frac{2\pi m k}{h^2}\right)^{-3/2} \frac{8\pi}{c^2} \frac{g_n}{g_e\, g_{ion}} T^{-3/2} \int_{h\nu_o}^{\infty} \nu^2 \alpha_\nu(n) \exp\left(-h\left(\nu - \nu_o\right)/kT\right) d\nu \tag{94}$$

$$= 4.12373 \times 10^{11} \frac{g_n}{g_e\, g_{ion}} T^{-3/2} \int_{h\nu_o}^{\infty} \nu^2 \alpha_\nu(n) \exp\left(-h\left(\nu - \nu_o\right)/kT\right) d\nu_{Ryd} \tag{95}$$

where the g's are the statistical weights of the constituents, $h\nu_{Ryd}$ is the photon energy in Rydbergs, $h\nu_o \sim z^2/n^2$ is the ionization potential in Rydbergs, $\alpha_\nu(n)$ is the photoionization cross section, and the other symbols have their usual meanings.

In implementing this formalism the fact that, for hydrogen, the energy scale is shifted by the ratio of the reduced mass of the nucleus to an infinite mass was explicitly taken into account. If the energy of level n of hydrogen is n^{-2} R_H, then the coefficient appearing in the exponential is 157807, not the commonly quoted 157890. This does affect the results slightly since the energy scale enters as an exponential in equation 94.

Hydrogenic photoionization cross sections are required over a very wide range of energy since recombination coefficients over a wide range of temperature are needed.

Cross sections $\alpha_\nu(n)$ were calculated using a program based on routines developed by Hummer (1988) and Storey and Hummer (1990, and private communication). The program generates the cross section values at arbitrary photon energies for all hydrogenic (n,l) states, as well as for the total n, employing analytic expressions and some very accurate expansions and numerical procedures. The calculations were carried out at a number of different mesh sizes to check for convergence. The results are typically accurate to better than 0.1 percent.

The recombination cooling rate coefficient (erg cm^3 s^{-3}) is given by

$$kT\beta(T,n) = \left(\frac{2\pi m k}{h^2}\right)^{-3/2} \frac{8\pi}{c^2} \frac{g_n}{g_e\, g_{ion}} T^{-3/2} \int_{h\nu_o}^{\infty} \nu^2\, \sigma_\nu(n)\, h\,(\nu - \nu_o)\, \exp\left(-h\,(\nu - \nu_o)\,/kT\right)\, d\nu \tag{96}$$

Again, the integration is carried out numerically.

16.1.2 Results

The numerical results are presented in Tables 16 and 17. The first column of the table gives the log of the temperature, columns 2 through 7 give the total recombination coefficient for $1 \leq n \leq 6$ summed over l states. Columns 8, 9 and 10 give the total recombination coefficient for levels 7–10, 11–20, and 21–1000 respectively. The last column gives the case B sum, $2 \leq n \leq 1000$. A very large temperature range is considered for completeness; actually, at very low temperatures three-body recombination predominates for most densities (Bates et al. 1963), while at very high temperatures other processes (i.e, Compton scattering, collisions) dominate the balance and the neutral fraction is vanishingly small.

Table 16: Hydrogen recombination coefficients

State Specific and Case B Recombination Coefficients[1]

log(T_e)	1	2	3	4	5	6	7–10	11–20	21—	case B
0.5	9.258-12	5.087-12	3.512-12	2.684-12	2.172-12	1.825-12	5.303-12	7.495-12	2.950-11	5.758-11
1.0	5.206-12	2.860-12	1.974-12	1.508-12	1.220-12	1.025-12	2.974-12	4.176-12	1.335-11	2.909-11
1.5	2.927-12	1.608-12	1.109-12	8.465-13	6.842-13	5.737-13	1.658-12	2.285-12	5.638-12	1.440-11
2.0	1.646-12	9.028-13	6.216-13	4.732-13	3.811-13	3.183-13	9.081-13	1.193-12	2.173-12	6.971-12
2.5	9.246-13	5.055-13	3.460-13	2.613-13	2.084-13	1.720-13	4.753-13	5.656-13	7.476-13	3.282-12
3.0	5.184-13	2.805-13	1.888-13	1.395-13	1.085-13	8.717-14	2.260-13	2.316-13	2.273-13	1.489-12
3.5	2.890-13	1.517-13	9.779-14	6.884-14	5.099-14	3.912-14	9.264-14	8.016-14	6.177-14	6.430-13
4.0	1.582-13	7.699-14	4.555-14	2.965-14	2.053-14	1.487-14	3.203-14	2.381-14	1.535-14	2.588-13
4.5	8.255-14	3.461-14	1.812-14	1.076-14	6.953-15	4.775-15	9.492-15	6.277-15	3.568-15	9.456-14
5.0	3.882-14	1.316-14	6.059-15	3.314-15	2.022-15	1.331-15	2.495-15	1.517-15	7.897-16	3.069-14
5.5	1.545-14	4.196-15	1.736-15	8.918-16	5.219-16	3.335-16	5.999-16	3.444-16	1.690-16	8.793-15
6.0	5.058-15	1.146-15	4.392-16	2.160-16	1.229-16	7.694-17	1.347-16	7.434-17	3.510-17	2.245-15
6.5	1.383-15	2.760-16	1.005-16	4.807-17	2.685-17	1.660-17	2.854-17	1.535-17	7.088-18	5.190-16
7.0	3.276-16	6.031-17	2.129-17	1.000-17	5.523-18	3.385-18	5.756-18	3.044-18	1.399-18	1.107-16
7.5	7.006-17	1.227-17	4.251-18	1.976-18	1.083-18	6.606-19	1.115-18	5.836-19	2.709-19	2.221-17
8.0	1.398-17	2.377-18	8.139-19	3.759-19	2.052-19	1.248-19	2.097-19	1.090-19	5.179-20	4.267-18
8.5	2.665-18	4.455-19	1.515-19	6.970-20	3.796-20	2.303-20	3.862-20	2.000-20	9.743-21	7.960-19
9.0	4.940-19	8.175-20	2.769-20	1.271-20	6.913-21	4.190-21	7.015-21	3.625-21	1.819-21	1.457-19
9.5	9.001-20	1.481-20	5.005-21	2.294-21	1.247-21	7.552-22	1.263-21	6.518-22	3.382-22	2.636-20
10.0	1.623-20	2.662-21	8.985-22	4.116-22	2.235-22	1.354-22	2.263-22	1.167-22	6.267-23	4.737-21

[1] The entry 9.258-12 indicates a rate coefficient of 9.258×10^{-12} cm^3 s^{-1}.

Table 17: Recombination cooling coefficients

State Specific and Case B Recombination Cooling Coefficients[1]

log(T_e)	1	2	3	4	5	6	7–10	11–20	21—	case B
0.5	4.025-27	2.211-27	1.527-27	1.167-27	9.441-28	7.929-28	2.303-27	3.245-27	1.076-26	2.295-26
1.0	7.158-27	3.932-27	2.713-27	2.072-27	1.676-27	1.406-27	4.072-27	5.667-27	1.442-26	3.595-26
1.5	1.273-26	6.985-27	4.815-27	3.671-27	2.962-27	2.479-27	7.119-27	9.559-27	1.755-26	5.514-26
2.0	2.262-26	1.239-26	8.507-27	6.451-27	5.171-27	4.293-27	1.203-26	1.481-26	1.870-26	8.236-26
2.5	4.015-26	2.184-26	1.483-26	1.107-26	8.708-27	7.074-27	1.872-26	1.958-26	1.689-26	1.187-25
3.0	7.099-26	3.785-26	2.488-26	1.784-26	1.341-26	1.039-26	2.480-26	2.081-26	1.296-26	1.629-25
3.5	1.241-25	6.245-26	3.796-26	2.505-26	1.740-26	1.255-26	2.632-26	1.776-26	8.745-27	2.082-25
4.0	2.094-25	9.195-26	4.856-26	2.845-26	1.795-26	1.198-26	2.236-26	1.277-26	5.443-27	2.395-25
4.5	3.234-25	1.112-25	4.923-26	2.557-26	1.483-26	9.305-27	1.600-26	8.219-27	3.240-27	2.376-25
5.0	4.173-25	1.056-25	3.990-26	1.891-26	1.034-26	6.240-27	1.022-26	4.955-27	1.882-27	1.981-25
5.5	4.149-25	7.981-26	2.698-26	1.208-26	6.389-27	3.771-27	6.026-27	2.839-27	1.071-27	1.390-25
6.0	3.121-25	4.961-26	1.572-26	6.827-27	3.549-27	2.073-27	3.273-27	1.523-27	5.885-28	8.316-26
6.5	1.843-25	2.616-26	8.015-27	3.429-27	1.768-27	1.028-27	1.614-27	7.468-28	3.080-28	4.307-26
7.0	9.016-26	1.204-26	3.628-27	1.541-27	7.917-28	4.591-28	7.194-28	3.321-28	1.547-28	1.967-26
7.5	3.847-26	4.978-27	1.487-27	6.296-28	3.229-28	1.870-28	2.928-28	1.350-28	7.626-29	8.109-27
8.0	1.490-26	1.897-27	5.644-28	2.385-28	1.222-28	7.077-29	1.107-28	5.104-29	3.799-29	3.092-27
8.5	5.397-27	6.811-28	2.023-28	8.541-29	4.375-29	2.533-29	3.962-29	1.826-29	1.924-29	1.115-27
9.0	1.867-27	2.346-28	6.959-29	2.937-29	1.504-29	8.706-30	1.362-29	6.274-30	1.006-29	3.872-28
9.5	6.261-28	7.849-29	2.327-29	9.820-30	5.028-30	2.910-30	4.551-30	2.097-30	5.410-30	1.316-28
10.0	2.057-28	2.575-29	7.633-30	3.220-30	1.649-30	9.543-31	1.492-30	6.876-31	2.978-30	4.436-29

[1] The entry 4.025-27 indicates a rate coefficient of 4.025×10^{-27} erg cm^3 s^{-1}.

As tests, these predictions of the recombination rate coefficients are compared with those of Seaton (1959), Ferland (1980), Hummer and Storey (1987), and Martin (1988). (Note that the total recombination rate given by Hummer and Storey is the sum of radiative and net three-body recombination. For this comparison their results for a density of 10^2 cm^{-3} were used to minimize the contribution of the second process.) The agreement with all of these results is good, usually much better than 1 percent. Seaton (1959) calculates the recombination cooling coefficients. The present results agree with his to better than 5 percent. Figure 6 shows the recombination cooling coefficient for several states.

16.1.3 Rational approximations

It is not numerically expedient to compute these rate coefficients on-the-fly in large scale ionization/thermal structure calculations. The rate coefficients were fitted with a high-order rational approximation. The recombination rate coefficient is expressed as

$$\alpha(T,n) = 10^{F(T,n)}\ T^{-1} \tag{97}$$

with

$$F(T,n) = \frac{a_n + c_n x + e_n x^2 + g_n x^3 + i_n x^4}{1 + b_n x + d_n x^2 + f_n x^3 + h_n x^4} \tag{98}$$

and $x \equiv log(T)$. The coefficients are listed in Table 18. These approximations reproduce the numerical results with a mean error well below 0.1 percent. For levels below $n = 20$ the largest error is also under 0.1 percent, although errors as large as 1.4 percent occur for the highest sum at temperatures below 100K.

Recombination cooling coefficients were fitted to equations of the form

$$kT\beta(T,n) = 10^{F(T,n)} \tag{99}$$

where F(T,n) is given above, and the fitting coefficients are listed in Table 19. The errors in fitting these coefficients is larger, typically 0.5 percent, but sometimes as large as several percent.

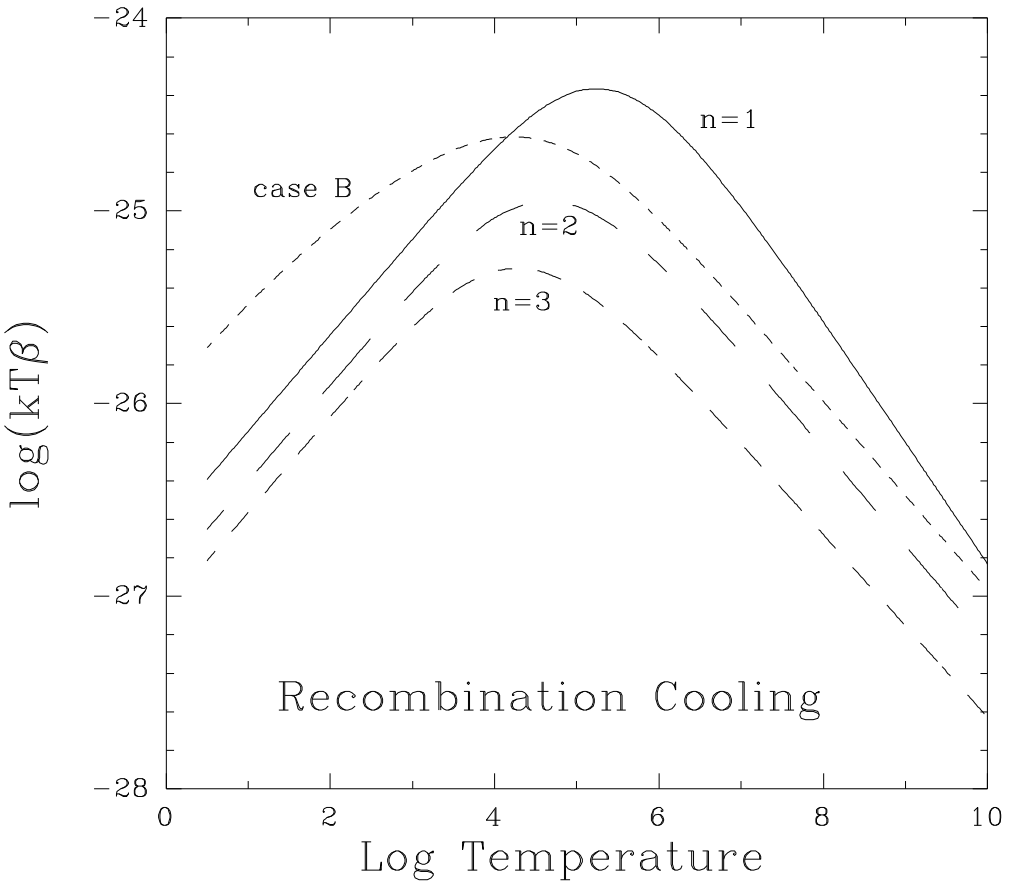

Figure 6: The recombination cooling for several states is shown as a function of temperature. recool

Table 18: Expansion for recombination coefficients

n	a	b	c	d	e	f	g	h	i
1	-10.7815	-0.388896	4.68469	0.0640438	-0.874235	-5.10248-03	0.081411	2.47761-04	-3.87713-03
2	-11.0434	-0.393514	4.84334	0.0692118	-0.956856	-5.49930-03	0.092159	3.06273-04	-5.02483-03
3	-11.2031	-0.424576	5.25370	0.0819237	-1.126131	-6.81708-03	0.114221	4.11653-04	-6.77511-03
4	-11.3145	-0.439393	5.45398	0.0853755	-1.166601	-7.40060-03	0.118057	4.03664-04	-6.48848-03
5	-11.4062	-0.436467	5.46028	0.0863856	-1.184309	-7.37118-03	0.119145	4.12342-04	-6.75160-03
6	-11.4846	-0.442457	5.56951	0.0899756	-1.241026	-7.54870-03	0.125443	4.48713-04	-7.53579-03
7	-11.0213	-0.442776	5.37057	0.0943866	-1.252699	-7.44688-03	0.125435	4.88629-04	-8.30273-03
8	-10.8751	-0.450383	5.39988	0.1022072	-1.341072	-7.17252-03	0.129801	5.52029-04	-9.92535-03
9	-10.2096	-0.048286	0.85490	0.0453455	-0.474956	-1.01818-03	0.0	0.0	0.0

Table 19: Expansion for recombination cooling coefficients

n	a	b	c	d	e	f	g	h	i
1	-26.6447	-0.405110	11.2923	0.0672574	-1.991084	-5.08026-03	0.166268	2.05287-04	-7.13575-03
2	-26.9067	-0.416447	11.7104	0.0763838	-2.268984	-5.84929-03	0.196781	2.75885-04	-9.96306-03
3	-27.0620	-0.458344	12.8931	0.0899256	-2.651639	-7.48544-03	0.242675	3.39807-04	-1.17865-02
4	-27.1827	-0.491379	13.8557	0.1022522	-3.023330	-8.56775-03	0.282237	4.14455-04	-1.46965-02
5	-27.2784	-0.519318	14.6735	0.1110161	-3.294623	-9.30673-03	0.310205	4.64233-04	-1.67032-02
6	-27.3596	-0.549712	15.5609	0.1195189	-3.566337	-9.84556-03	0.335160	5.12181-04	-1.88737-02
7	-26.9011	-0.562123	15.6545	0.1207284	-3.563036	-9.75175-03	0.332549	5.16213-04	-1.91249-02
8	-26.7582	-0.536972	14.9208	0.1093810	-3.253752	-8.32192-03	0.293805	4.56629-04	-1.75719-02
9	-26.1477	-0.467188	12.6143	0.0821541	-2.411906	-8.17803-03	0.272395	5.99744-04	-2.00967-02

16.2 The Collisional Rate Equations

Considering only collisional terms, the departure coefficient for level n is given by

$$\frac{db_n}{dt} = \sum_l b_l\, C_{nl} + \sum_u \frac{P_u^*}{P_n^*}\, b_u\, C_{un} - b_n \left\{ \sum_l C_{nl} + \sum_u \frac{P_u^*}{P_n^*}\, C_{un} + C_{n\kappa} \left(1 - b_n^{-1}\right) \right\} \quad (100)$$

where the sums are over upper and lower levels. The collision rates (s^{-1}) are denoted by C_{ij}. The first term on the RHS represents collisional excitation to n from lower levels, the second is collisional deexcitation to n from higher levels, and the last term accounts for destruction processes. These include collisions to lower levels, upper levels, and the continuum. The factor multiplying the collisional ionization rate $C_{n\kappa}$ accounts for collisional ionization less three-body recombination. Note that this is often a net recombination process for the atom since, under many circumstances, $b_n < 1$.

Figure 7 shows a test case where collisional processes are dominant. All of the radiative processes discussed below are actually included, but the intensity of the external continuum is set to a very low (and hence negligible) value. As a result collisional and spontaneous radiative processes are dominant. The electrons are given a temperature of 50,000K, and the level populations and ionization of the gas are determined by solving the full set of equations of statistical equilibrium. The model is of a very thin cell of gas which is optically thin in the lines and continuum. Departure coefficients for the ground state, $2s$, $2p$, and 4 are shown.

As is well-known, the ground state is overpopulated relative to its LTE value when upward collisional processes are much slower than downward radiative processes; it is only when the collisional rates approach the radiative rates that b_1 approaches unity. The $2s$ level also has a large overpopulation for much the same reason; it is highly metastable and accumulates a large overpopulation until $2s - 2p$ collisions become fast enough to mix the two l levels. The more highly excited levels ($n \geq 3$) have a behavior very similar to that of $n = 4$, which is shown in the figure; they are underpopulated relative to their LTE value when radiative decays to lower levels are competitive with collisional processes. It is only at a density of $N_H > 10^{18}$ cm^{-3} that collisional processes completely dominate the rate equations, and the atom reaches LTE. The mean departure coefficient at a density of 10^{19} cm^{-3} is $\bar{b_i} = 1.0007 \pm 0.0022$ for the entire ten-level atom, and the largest single deviation from unity is 0.7% (for the ground state).

16.3 The Radiative Rate Equations

The photoionization rate (s^{-1}) from level n, stored in the vector HGAMNC(n), is given by

$$\Gamma_n = 4\pi \int_{\nu_o}^{\infty} \frac{J_\nu}{h\nu}\, \alpha_\nu\, d\nu \quad (101)$$

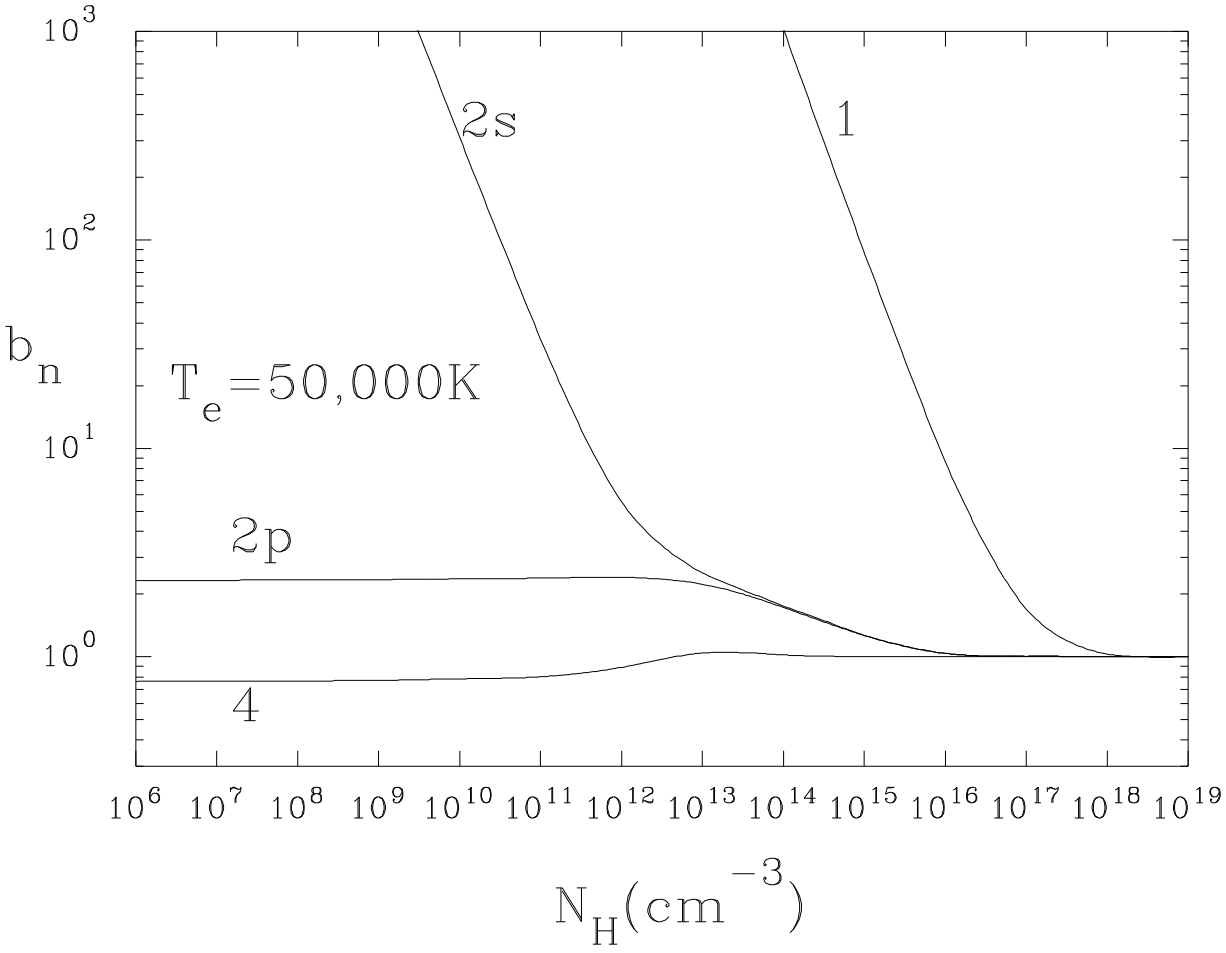

Figure 7: The equilibrium populations of the ground state and levels $2s$, $2p$, and 4 of the ten level hydrogen atom are shown as a function of the total hydrogen density N_H. The radiation field is set to a very low intensity, and the column density is kept small enough for optical depth effects to be negligible. A constant electron temperature of 5×10^4K is assumed, so the gas is primarily collisionally ionized and excited. Levels $2s$ and $2p$ do not mix until a density of nearly 10^{14} cm^{-3} is reached, and do not come into LTE until the density is nearly 100 times higher. The entire atom is nearly in LTE at densities greater than 10^{18} cm^{-3}. hbnvsn

and the induced recombination rate coefficient ($cm^3\ s^{-1}$) by

$$\alpha(ind) = P_n^*\ 4\pi\ \int_{\nu_o}^{\infty} \frac{J_\nu}{h\nu}\ \alpha_\nu\ \exp(-h\nu/kT)\ d\nu \quad . \tag{102}$$

This is evaluated at each zone by direct integration over the numerically binned continuum. Under most circumstances the population of the highest two pseudo-states is completely controlled by collisions; photoionization from these is neglected.

Spontaneous radiative recombination rate coefficients are computed as described above. The rate coefficients are evaluated in subroutine HTRANS and are stored in HREC(n,1) and have units $cm^3\ s^{-1}$. These recombinations produce ionizing radiation, and a recombination efficiency is defined to take this into account. These efficiencies are stored in the array HREC(n,i). Elements HREC(n,3) are the escape probabilities, computed including only the single-flight absorption due to the geometry, while the escape probabilities stored in HREC(n,2) include both this as well as destruction by the background absorbing continuum.

The full set of radiative balance equations can be written as

$$\frac{db_n}{dt} = \sum_l\ \frac{P_l^*}{P_n^*}\ b_l\ A_{nl}\frac{g_n}{g_l}\ \eta_{nl}\ \gamma_{nl}\ +\ \sum_u\ \frac{P_u^*}{P_n^*}\ b_u\ (A_{un}P_{un} + A_{un}\eta_{un}\gamma_{un})$$

$$+(\alpha(rad) + \alpha(ind))\,/P_n^* - b_n\left(\sum_l (A_{nl}P_{nl} + A_{nl}\eta_{nl}\gamma_{nl}) + \sum_u\ A_{un}\frac{g_u}{g_n}\eta_{un}\gamma_{un} + \Gamma_n\right) \tag{103}$$

where the continuum occupation number in the transition ij is given by

$$\eta_{ij} \equiv J_\nu(ij)/(2h\nu_{ij}^3/c^2) = (\exp(h\nu/kT_{ex}) - 1)^{-1} \quad . \tag{104}$$

Here $J_\nu(ij)$ is the mean intensity of the net continuum at the line frequency, and T_{ex} is the excitation temperature of the continuum at the level frequency.

Two escape probabilities enter in equation 103. The first is the two-sided function which accounts for line scattering and escape

$$P(\tau, T) = (P\,(\tau) + P\,(T - \tau))\ /\ 2 \tag{105}$$

where τ is the optical depth at the center of the zone and T is the total optical depth. The second escape probability $\gamma_{ij}(\tau)$ accounts for the fraction of the primary continuum which penetrates to an optical depth τ and induces transitions between levels i and j (Castor 1970; Elitzur et al. 1983; Elitzur 1984). The terms in equation 103 correspond to induced upward transitions from lower levels, spontaneous and induced downward transitions from higher levels, spontaneous and induced capture to the level from the continuum, and destruction of the level by radiative transitions and photoionization.

The product $A_{ul}\,P_l$ is stored in the array HEMIS(u,l). The continuum occupation number is stored in HJBAR(u,l), which is evaluated in HEVAL. The term $\eta A\gamma$ is stored as HCONT(u,l). The term $\sum_u\ A_{un}\,(g_u/g_n)\,\eta_{un}\gamma_{un}$ is stored in HBUL(n).

Figure 8 shows a test case which, in contrast with that shown in Figure 7, is dominated by radiative transitions. Again, the full set of equations coupling the levels are solved, but spontaneous and induced processes are more important than collisions for many values of the radiation density. The model is of a very thin cell of gas, so that all lines and continua are optically thin, has a density of $\mathrm{N}_H = 10^{10}$ cm^{-3}, and an electron temperature of 5×10^4K. The gas is exposed to a black body continuum with a color temperature of $T_{color} = 5 \times 10^4$K, but the intensity of this continuum is varied. This intensity is parameterized by an energy density temperature defined by $T_u \equiv (u/a)^{1/4}$ where u and a are, respectively, the actual radiation energy density and Stefan's radiation density constant.

A radiation field given by Planck's law (i.e., $T_u \equiv T_{color}$) forces the ionization and level population of an atom or ion to LTE in much the same way that high electron densities do. As Figure 8 shows, at very low values of T_u (low photon densities) the ground and $n = 2$ states are overpopulated for much the same reason that this occurs at low electron densities; the downward spontaneous radiative rates are fast relative to the induced (upward and downward) rates. At very low T_u (< 500K), $n \geq 3$ levels are underpopulated since they decay at a rate much faster than the induced rates (for $T_e = 5 \times 10^4$K these levels have $h\nu \ll kT$, so induced processes will be fast relative to spontaneous rates when $T_u = T_{color}$ and the atom is in LTE). As T_u increases, fluorescence from the ground state over-populates excited states (because the ground state is itself overpopulated) and b_4 exceeds unity. Finally, in the limit where $T_u = T_{color}$, the departure coefficients reach unity and the atom goes to LTE. (The actual mean departure coefficient for the entire 10-level atom is $\bar{b}_i = 1.013 \pm 0.029$). Note that the vast majority of the neutral hydrogen population is in excited states when the atom approaches LTE at these temperatures.

16.4 Thermal Emission

16.4.1 Continuous emission

Diffuse emission (free-free and free-bound) by the model hydrogen atom is computed using the stored photoabsorption cross sections and detailed balance (i.e., the Milne relation; see Mihalas 1978).

Free-bound continua of $1 \leq n \leq 9$ levels of hydrogen and helium are treated as follows. The Milne relation for the emissivity 4πj (erg cm^3 Hz^{-1} s^{-1}) can be expressed

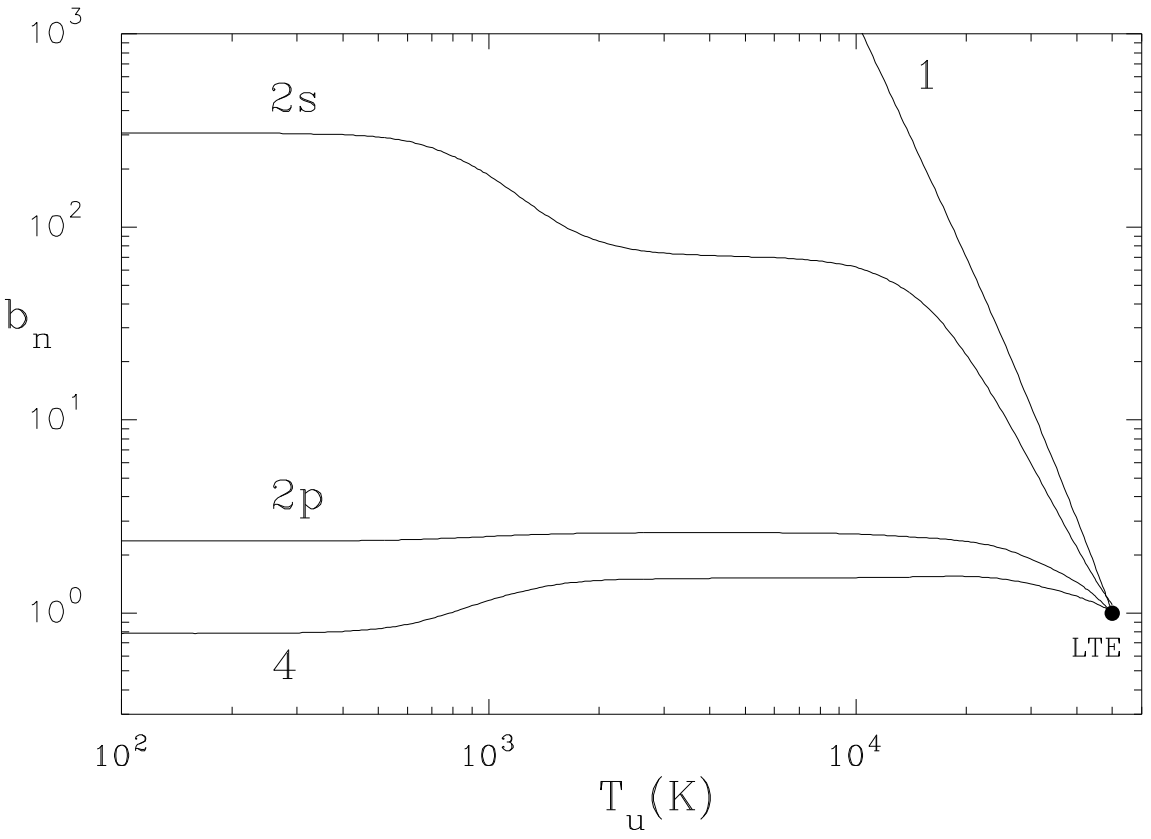

Figure 8: The calculations are for a constant temperature ($T_e = 5 \times 10^4$K) optically thin gas exposed to black body radiation with a color temperature of $T_{color} = 5 \times 10^4$K, but with various values of the energy density, parameterized as $T_u = (u/a)^{1/4}$, where u is the actual radiation density. The hydrogen density ($N = 10^{10}$ cm^{-3}) is low enough for radiation to be the main agent affecting level populations for most values of T_u. Fluorescence from the ground state drives the population of $n = 4$ above its LTE value for many radiation densities. Induced processes, mainly transitions between adjacent levels, drive the atom to LTE when T_u reaches 5×10^4K. hbnvsu

as (Brown and Mathews 1970)

$$4\pi j = h\nu \left(\frac{2\pi mk}{h^2}\right)^{-3/2} \frac{8\pi}{c^2} \frac{g_n}{g_e\, g_{ion}} T^{-3/2}\, \nu^2\, \alpha_\nu(n)\, \exp\left(-h\left(\nu-\nu_o\right)/kT\right) \qquad (106)$$

where the statistical weight of level n is $g_n = 2n^2$ for H^o and He^+, and $g_n = n^2$ for helium singlets.

The code actually works with units similar to photons Ryd^{-1} s^{-1} cm^{-2}. The photon emissivity (photons cm^3 s^{-1} Ryd^{-1}) is then

$$\begin{aligned} \phi(T,n) &= \left(\frac{2\pi mk}{h^2}\right)^{-3/2} \frac{8\pi}{c^2} \frac{g_n}{g_e\, g_{ion}} T^{-3/2}\, \nu^2\, \alpha_\nu(n)\, \exp\left(-h\left(\nu-\nu_o\right)/kT\right) & (107) \\ &= 4.12373\times 10^{11} \frac{g_n}{g_e\, g_{ion}} T^{-3/2}\, \nu_{Ryd}^2\, \alpha_\nu(n)\, \exp\left(-h\left(\nu-\nu_o\right)/kT\right) & (108) \end{aligned}$$

where the g's are the statistical weights of the constituents, ν_{Ryd} is the photon energy in Rydbergs, $h\nu_o \sim z^2/n^2$ is the ionization potential in Rydbergs, $\alpha_\nu(n)$ is the photoionization cross section, and the other symbols have their usual meanings. Equation 107 is evaluated directly using the stored photoionization cross sections. A similar approach is used for other absorption opacities, such as brems and H^-. Detailed balancing between absorption and emission mechanisms is necessary if LTE is to be achieved.

Free-free emission is computed for all energies considered by the code, and free-bound emission for energies greater than ~0.009 Ryd (the ionization edge of the n=7 pseudo-state). This emission per unit volume (erg s^{-1} cm^{-3}) is stored in the array DIFFUS, and this diffuse continuum is carried outward in the array CONDIF.[10]

A test case with a hydrogen gas at a temperature of 10^4K and a density of 10^7 cm^{-3} (to suppress two photon emission) was computed, and is shown in Figure 9. The input stream used to derive the figure is given as one of the examples in section 25. As can be seen from the figure, the predicted diffuse continuum is generally within 10 percent of the exact value (Ferland 1980). The main source of error is the treatment of highly excited states in the model hydrogen atom.

Figure 10 shows another series of test cases in which a very high density gas with cosmic abundances is irradiated with a 50,000K blackbody radiation field in strict thermodynamic equilibrium. The input stream used to derive the figure is as follows;

```
title test hydrogen atom emission in LTE limit
black 50,000 lte
constant temper 50,000
```

[10]The total transmitted/emitted continuum can be output by use of the "PUNCH CONTINUUM" command.

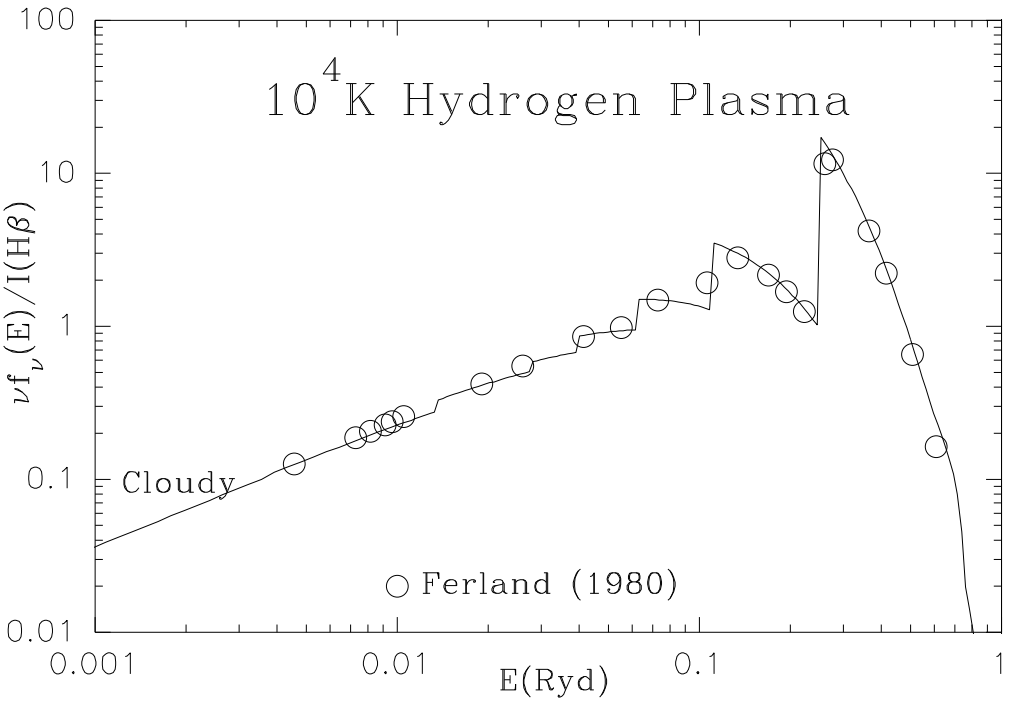

Figure 9: The predicted thermal emission from the 10-level hydrogen atom is shown as the computed flux divided by the intensity of Hβ. The gas is optically thin and contains only hydrogen. The circles indicate the filter-averaged continuum predicted by Ferland (1980). The input stream used to derive the figure is shown in section 25. hemis

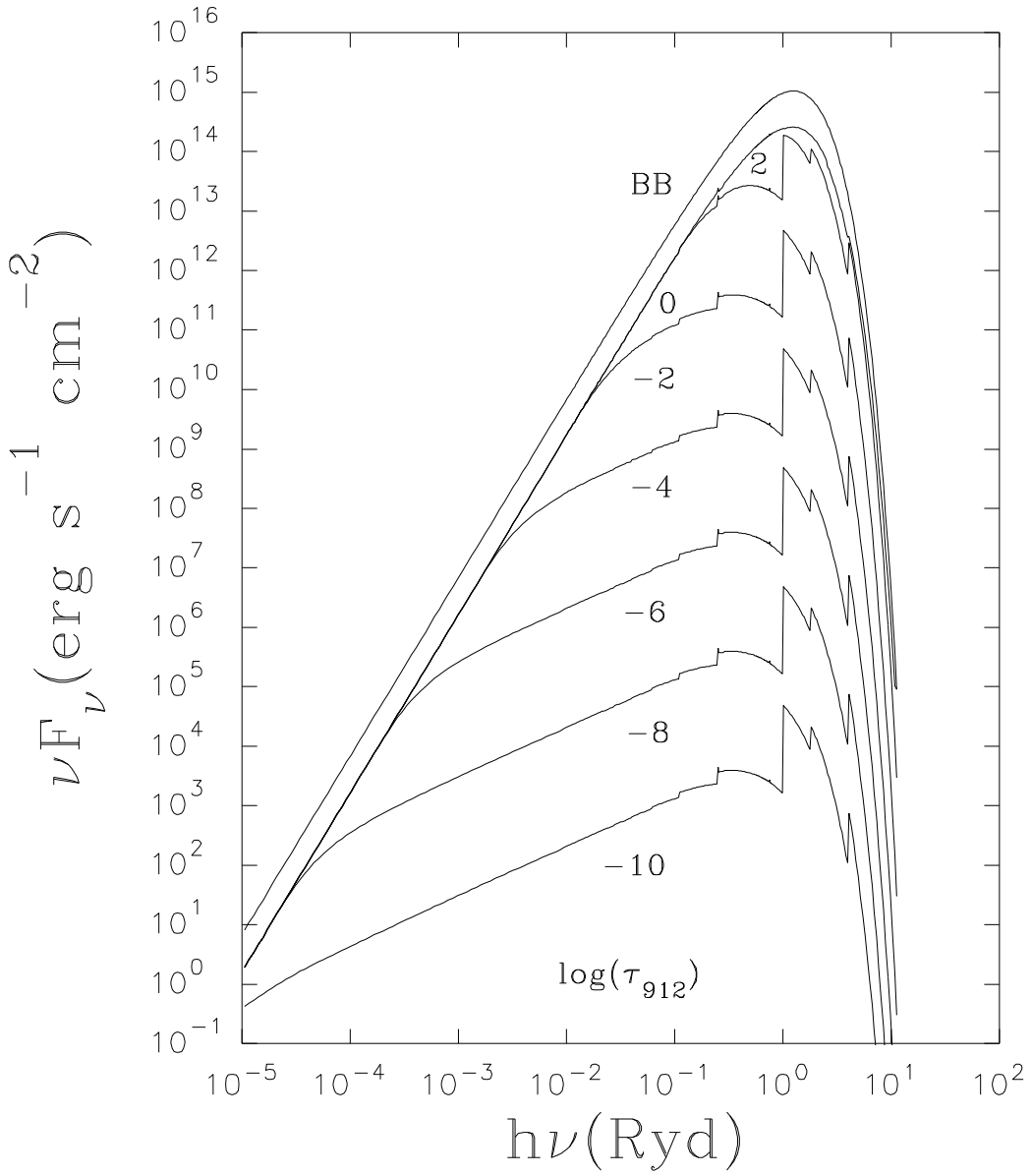

Figure 10: The emission from a dense slab of gas with cosmic abundances is shown as a function of the optical depth at the Lyman limit. The log of this optical depth is indicated on the figure. The top curve is for emission given by Planck's law. The continuous emission goes to the blackbody limit in the case of large continuum optical depths. conlte

```
hden 20
stop lyman optical depth -2   ;stop at Lyman contin tau
print short
punch reflected continuum ;output the reflected continuum
```

As can be seen from the figure, the predicted continuum goes to the blackbody limit.

17 H^- AND MOLECULES

An ion-molecule network, initially based on Black (1978) but heavily revised (Hollenbach and McKee 1979; 1989), is included in CLOUDY. The network presently includes H^-, H_2, H_2^+, H_3^+, HeH^+, OH, OH^+, CH, CH^+, O_2, O_2^+, CO, CO^+, H_2O, H_2O^+, H_3O^+, and CH_2^+.

17.1 The H^- Balance; Radiative Processes

Although only a trace amount of hydrogen is in the form of H^-, the opacity provided by this ion is large, and helps couple energy in the near infrared continuum to moderately ionized gas. The methods and approximations employed to include heating and cooling by H^- are described here. Other discussions can be found in Lambert and Pagel (1968), Vernazza, Avrett, and Loeser (1981), and Lites and Mihalas (1984).

The equilibrium density of H^- is determined by assuming statistical equilibrium, and balancing production and destruction mechanisms. Great care is taken in including both forward and back reactions, to ensure that the present treatment of H^- is capable to going to LTE in the limit of high radiation or particle densities.

In much of the following discussion comparison will be made between the predicted H^- population and its LTE value. The LTE relative population density of H^- is

$$P^*(H^-) = \frac{N^*_{H^-}}{N_e N_{H^\circ}} = \frac{g_{H^-}}{g_{H^\circ} g_e} \left(\frac{h^2}{2\pi m k T} \right)^{3/2} \exp(\chi_{H^-}/kT) \ \ (cm^3) \ , \qquad (109)$$

where g_i is the statistical weight of the constituents, ($g_{H^-} = 1$; $g_{H^\circ} = 2$; and $g_e = 2$), $\chi_{H^-} = 0.055502$ Ryd is the binding energy of the negative hydrogen ion, and other constants have their usual meaning.

17.1.1 Radiative attachment

This is the most important creation mechanism for H^- at low densities, when three-body processes are negligible;

$$H^\circ + e^- \Rightarrow H^- + \gamma \quad . \qquad (110)$$

For temperatures greater than 10^4K the rate coefficient is evaluated by numerically integrating the photodetachment cross section over frequency;

$$\alpha_{rad}(T) = P^*(H^-) \int_{\nu_\circ}^{\infty} \alpha\nu \, \frac{8\pi\nu^2}{c^2} \, \exp(-h\nu/kT) \, d\nu \quad (cm^3 \, s^{-1}) \qquad (111)$$

where cross sections computed by Wishart (1979) and spline interpolation are used. These cross sections are in excellent agreement with the velocity operator bound-free

cross sections tabulated by Doughty et al. (1966). The energy interval between the photodetachment threshold at 0.055502 Ryd and ~ 1.8 Ryd is divided into roughly 100 cells with logarithmically increasing width, and the integration is carried out as a straightforward sum.

This method is not numerically expedient for very low temperatures, where the energy bandwidth of the integral is small, and a much finer frequency grid would be required. Rather, the integration was carried out using spline interpolation and 32 point gaussian quadrature, integrating over factors of two in hν/kT. The results were then fitted with a set of power-laws. The rate coefficients ($\mathrm{cm}^{-3}\ \mathrm{s}^{-1}$) can be approximated by:

$$\alpha(T_e) = \begin{cases} 8.934 \times 10^{-18} T_e^{0.505} & 1K \leq T_e < 31.62K \\ 5.159 \times 10^{-18} T_e^{0.664} & 31.62K \leq T_e < 90K \\ 2.042 \times 10^{-18} T_e^{0.870} & 90K \leq T_e < 1200K \\ 8.861 \times 10^{-18} T_e^{0.663} & 1200K \leq T_e < 3800K \\ 8.204 \times 10^{-17} T_e^{0.393} & 3800K \leq T_e \leq 10^4 K \end{cases} \tag{112}$$

These approximations fit the exact numerical results with a mean deviation of 0.7 percent, and the largest error of 2.05 percent, over the indicated temperature range.

Tests show that the numerical radiative attachment rates computed here are in very good agreement with the approximation given by Hutchings (1976), who used the cross sections computed by Doughty et al. (1966), for temperatures $500K \leq T \leq 2500K$. (Notice that there is a typographical error in the approximation for the radiative attachment rate given by Palla, Salpeter, and Stahler 1983.) It is also within 10% of the value given by Dalgarno and Kingston (1963), which was based on earlier calculations of the photodetachment cross section.

Continuum occupation numbers can be large in the infrared. The induced radiative attachment rate coefficient is

$$\alpha_{ind}(T) = P^*(H^-) \int_{\nu_o}^{\infty} \alpha_\nu(bf)\, \frac{4\pi J_\nu(\tau)}{h\nu}\, \exp(-h\nu/kT)\, d\nu \quad (cm^3\ s^{-1}) \tag{113}$$

where the mean intensity of the depth-dependent continuum is $J_\nu(\tau)$. This expression is used for all temperatures.

17.1.2 Photodetachment

Photodetachment,

$$H^- + \gamma \Rightarrow H^o + e^- \tag{114}$$

is the dominant H^- destruction mechanism for many conditions. The rate is evaluated in the standard manner;

$$\Gamma(H^-) = \int_{\nu_o}^{\infty} \alpha_\nu(bf)\, \frac{4\pi J_\nu(\tau)}{h\nu}\, d\nu \quad (s^{-1}) \ . \tag{115}$$

The integral is evaluated as a sum over the numerically binned continuum. The incident continuum is then attenuated by optical depth increments

$$d\tau_{H^-} = \alpha_\nu (bf)\, N_{H^-}\, \{1 - \exp(-h\nu/kT)/b_{H^-}\}\; f\; dr \tag{116}$$

where b_{H^-} is the departure coefficient for H^-, $b_{H^-} \equiv N(H^-)/N^*(H^-)$, f is the filling factor, and $N^*(H^-)$ is the LTE H^- density.

17.1.3 Photodetachment by hard photons

The H^- photoabsorption cross section increases above $\sim 3/4$ Ryd, energies where excitation of $n \geq 2$ levels is possible. Cross sections which include this process are taken from Broad and Reinhardt (1976). These calculations do not extend to high energies, so we scale high-energy hydrogen cross sections by the ratio of H^- to H^o cross sections at 18Å in order to take absorption of x- and γ- rays into account.

The cross section for (γ,2e$^-$) absorption is much smaller than (γ, e$^-$) (Broad and Reinhardt 1976), and this latter process is neglected.

17.1.4 The approach to LTE; high radiation densities

As a test of the assumptions and methods, the approach to LTE under conditions determined by radiative attachment (spontaneous and induced) and photodetachment are first considered. Tests in which gas with temperature T_e is exposed to black body radiation fields with color temperature T_{color} are computed. The color and gas temperatures are set equal, $T_e = T_{color}$, and the intensity of the radiation field is varied up to the black body limit. The intensity of the radiation field is parameterized by the equivalent energy density temperature $T_u = (u/a)^{1/4}$, where u is the energy density (erg cm^{-3}; see above) and a is the Stefan's radiation density constant. The equilibrium population of H^- was computed, including all process mentioned below, but with the hydrogen density small enough (typically $\sim 10^5$ cm^{-3}) for radiative processes to be most important. The H^- population is expressed as a departure coefficient, and the results are shown in Figure 11, for tests in which $T_{color} = 0.5$, 1, and 2 $\times 10^4$ K. When $T_u = T_{color}$, and the radiation field is in strict thermodynamic equilibrium, radiative processes must hold H^- in LTE and departure coefficients of unity are expected. The computed departure coefficients for the three temperatures are 0.9998, 0.9996, and 1.0030, respectively. As the Figure shows, when T_u is lowered below T_{color}, the intensity of the radiation field falls below its thermodynamic equilibrium value, and the population of H^- increases. This is because the photodetachment rate (which is proportional to the intensity of the radiation field) is no longer in balance with the radiative attachment rate (which is proportional only to the electron density).

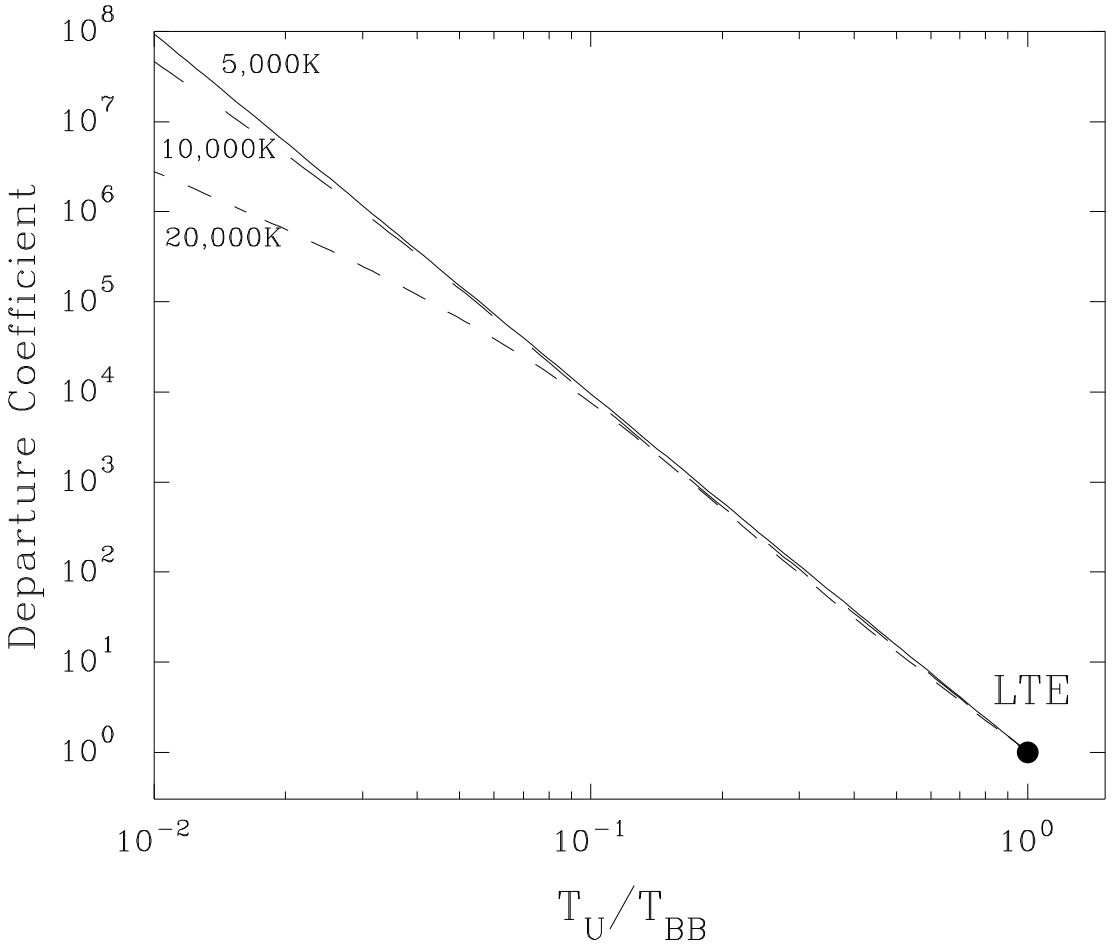

Figure 11: Departure coefficients for H^- are shown. The figure shows tests in which the hydrogen density was held fixed at a low density (typically $N_H \sim 10^5$ cm^{-3}), and the gas irradiated by black bodies with color temperatures of 5, 10, and 20 $\times 10^3$K. Gas temperature and color temperatures were equal. The intensity, characterized by the energy density temperature T_u. was varied up to its LTE limit. The H^- departure coefficient is within 0.2% of unity when $T_u = T_{color}$. hmivsu

17.2 The H⁻ Balance; Collisional Processes

17.2.1 Associative detachment

The most important H_2 formation mechanism in grain-free environments, and a significant H^- destruction mechanism, is associative detachment,

$$H^- + H^o \rightleftharpoons H_2 + e^- \tag{117}$$

where rate coefficients from Bieniek and Dalgarno (1979) are used. The reverse reaction rate coefficient C_R, for electron collisional dissociation of H_2, is related to the forward rate coefficient C_F by detailed balance;

$$C_R = C_F \frac{P^*(H^-)}{P^*(H_2)} \quad . \tag{118}$$

17.2.2 Electron collisional detachment

For typical BLR temperatures and ionization fractions, the process

$$H^- + e^- \rightleftharpoons H + 2e^- \tag{119}$$

is a competitive H^- destruction mechanism. Rates taken from the compendium of Janev et al. (1987) are used. The reverse process, electron three-body recombination with neutral hydrogen, is included via detailed balance;

$$C_R = C_F \, P^*(H^-) \quad . \tag{120}$$

17.2.3 Collisional ionization by suprathermal electrons

The total suprathermal collisional ionization rate is computed using approximations from Shull and Van Steenberg (1985). Ionization of H^- by suprathermal electrons is scaled from the H^o rates using cross sections at 20 eV given by Janev et al. (1987). This energy was chosen as representative of the mean energy of the secondary electron shower. The majority of these collisions are of the form $e^- + H^- \Rightarrow H(1s) + 2e^-$, although $e^- + H^- \Rightarrow H^+ + 3e^-$ collisions occur roughly 1% of the time.

17.2.4 Mutual neutralization

Neutral hydrogen can charge transfer with the negative ion through

$$H^- + H^+ \rightleftharpoons H + H^* \quad . \tag{121}$$

The rate coefficients given in Janev et al. (1987) are used. By far the largest rate coefficients are for collisions which populate hydrogen in the $n = 3$ level. These rates

are based on both experimental and theoretical data (see, for example, Peart et al. 1985).

The reverse reaction is included using detailed balance; if the rate coefficient for the forward reaction is C_F then the reverse reaction rate, and its rate coefficient C_R, are given by

$$H(1s)\,N(i)\,C_R = b_i\,P^*(H^-)\,N_e N_p\,C_F \tag{122}$$

where N(i) and b_i are the population and departure coefficient of hydrogen in the ith level.

17.2.5 Charge neutralization with heavy elements

The process

$$H^- + A^+ \rightleftharpoons H^o + A^o \tag{123}$$

is considered by Dalgarno and McCray (1973), who give rate coefficients for very low temperatures and ionization levels. Judging from the curves given by Peterson et al. (1971), upon which the Dalgarno and McCray rates are based, the approximation they give should still be valid (although very uncertain) at temperatures of general interest ($\sim 0.5 - 1.0 \times 10^4$ K). Here A^+ is all singly ionized species, which are assumed to be neutralized at the same rate.

17.2.6 Neglected processes

Collisional detachment by protons ($p^+ + H^- \Rightarrow H + p^+ + e^-$), which has a negligible rate coefficient according to Janev et al. (1987), is neglected, as is collisional detachment by atomic hydrogen ($H^- + H \Rightarrow 2H + e^-$), which has no reliable rate coefficient according to Lites and Mihalas (1984).

17.2.7 The approach to LTE; high hydrogen densities

A series of models in collisional equilibrium were computed. Radiative processes were also included, but the incident radiation field, a 10^4 K blackbody, was given a negligible intensity (an ionization parameter of U = 10^{-12}). Three temperatures, 0.5, 1, and 2 $\times 10^4$ K, were considered to span the temperature range typical of regions with significant H^- population. The hydrogen density was varied between 10^8 and 10^{18} cm^{-3} to confirm the approach to LTE at high densities. The results of these calculations are shown in Figure 12. For the majority of the calculations hydrogen is largely neutral, and for the smaller temperatures a significant fraction of the hydrogen was in the molecular form (H_2 and H_2^+). The calculation confirms that the departure coefficients are within 2% of unity at the highest densities computed.

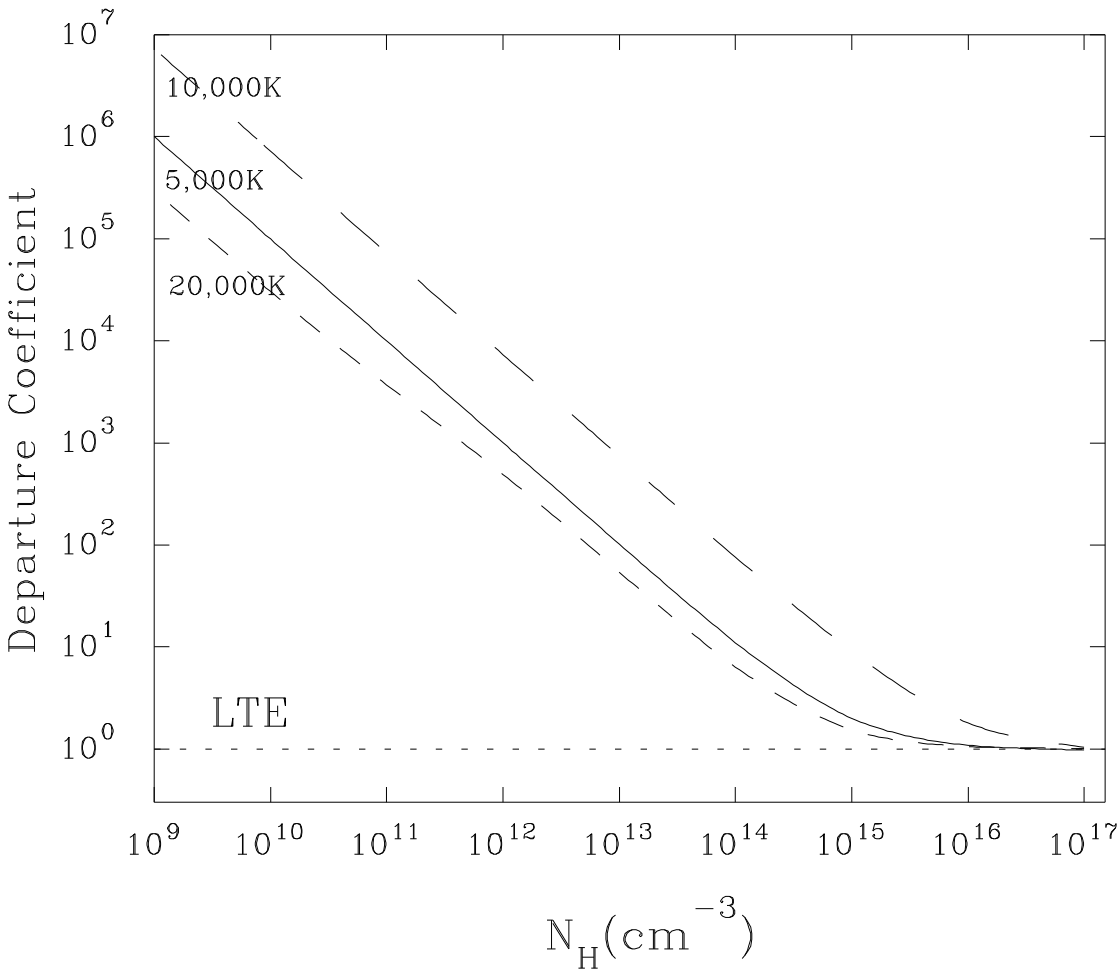

Figure 12: Departure coefficients for H^- are shown. These are tests in which the radiation density was low, but the total hydrogen density varied. Three gas temperatures, spanning typical temperatures where H^- is significant, are shown. Collisions bring H^- to LTE at high densities. hmivsn

17.3 Hydrogen Molecules

A complete ion-molecule network, initially based on Black (1978) but since heavily revised (see, for example, Hollenbach and McKee 1989; Lenzuni, Chernoff, and Salpeter 1991), is included in CLOUDY. The network includes H^-, H_2, H_2^+, and HeH^+, and its solution is performed in subroutine HMOLE. The set of balance equations for the first three species are solved simultaneously, using the matrix:

$$\begin{pmatrix} H\ conservation \\ H^-\ balance \\ H_2\ balance \\ H_2^+\ balance \\ H_3^+\ balance \end{pmatrix} \begin{pmatrix} N(H^o) \\ N(H^-) \\ N(H_2) \\ N(H_2^+) \\ N(H_3^+) \end{pmatrix} = \begin{pmatrix} N(H^o) \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{124}$$

17.4 The heavy elements

The heavy element molecule network described by Hollenbach and McKee (1989) has been incorporated into CLOUDY. The network should now be exact for situations where the heavy element molecular fraction is small. The heavy element molecules are not now included in the atomic abundances, so the treatment is approximate for predominantly molecular situations.

$$\begin{pmatrix} C\ conservation \\ O\ conservation \\ CH\ balance \\ CH^+\ balance \\ OH\ balance \\ OH^+\ balance \\ CH_2^+\ balance \\ C^+\ balance \\ CO\ balance \\ CO^+\ balance \\ H_2O\ balance \\ H_2O^+\ balance \\ H_3O^+\ balance \\ O_2\ balance \\ O_2^+\ balance \end{pmatrix} \begin{pmatrix} C^o \\ O^o \\ CH \\ CH^+ \\ OH \\ OH^+ \\ CH_2^+ \\ C^+ \\ CO \\ CO^+ \\ H_2O \\ H_2O^+ \\ H_3O^+ \\ O_2 \\ O_2^+ \end{pmatrix} = \begin{pmatrix} C_{total} \\ O_{total} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{125}$$

18 HELIUM

The helium atom is presently under construction. The following outlines the treatments of the various ions.

18.1 The Helium Ion

He^+ is treated as a ten level atom, entirely analogous to the hydrogen atom. Full l-mixing is assumed, and 2s and 2p are treated independently.

18.2 The Helium Singlets

The He singlets are treated as a ten level atom, entirely analogous to the hydrogen atom. Full l-mixing is assumed, and 2s and 2p are treated independently.

18.3 The Helium Triplets

The helium triplets are presently treated as a five level atom.

18.4 Ionization Equilibria

The ionization equilibria of the various ions/atoms is accurate for all photon and electron densities. The balance goes to LTE in the high photon-electron density limit.

18.5 Line Emission

Line intensities predicted by the 10-level atoms are indicated by the label "TOTL". These include all optical depth and collisional effects. The model atoms describing the ion and singlets assume complete l-mixing among the sublevels. The predictions are exact in the context of this approximation, but this approximation is not valid at low densities. The greatest problem is HeII 4686, for which the complete l-mixing assumption results in an intensity much smaller than the low density limit approximation.

For now the line emissivities predicted by the atoms are probably not as accurate as simple case B assumptions for low density conditions where optical depth and collision effects are not important. Case B predictions are labeled "Ca b". At high densities ($N_e \geq 10^6$ cm^{-3}) the predictions of the 10-level atom are probably better than case B predictions.

19 THE HEAVY ELEMENTS

The treatment of the ionization equilibrium of the other 11 elements is fairly conventional (see, for instance, Halpern and Grinday 1980; Kallman and McCray 1982). The treatment of the metals is presently more approximate than that of hydrogen and helium when high densities ($N_H > 10^{10}\mathrm{cm}^{-3}$) are considered. The majority of the heavy elements are treated considering only the ground term and continuum for each ionization stage. In all cases, collisional ionization from ground (using data from Shull and van Steenberg 1982) and a net three-body recombination coefficient (see, for example, Burgess and Summers 1976) are included. Photoionization rates are modified for induced recombination as described by equation 102. All published charge transfer rate coefficients are also included (e.g., Butler, Heil, and Dalgarno 1980; Butler and Dalgarno 1980).

This treatment is approximate at high densities for two reasons. First, net radiative recombination coefficients, which have been summed over all levels (Aldrovandi and Pequignot 1972; Aldrovandi and Pequignot 1974; Gould 1978), are used. These sums are correct only in the low density limit; at high densities levels can undergo collisional ionization before radiative decays to the ground state occur. A second problem is that substantial populations can build up in highly excited states when the density and temperature are high. When this occurs the partition function of the atom or ion is no longer equal to the statistical weight of the ground state. As a result the ionization equilibrium of the heavy elements is approximate at high densities (N $\gg 10^{10}$ cm^{-3}), with uncertainties probably at the ~ 0.5 dex level.

19.1 Ionization Potentials

Figure 13 shows the ionization potentials of the heavy elements included in the calculations. The upper panel shows energy range of interest for photoionization by stars. The dotted lines show the ionization potentials of hydrogen, atomic, and ionic, helium. The lower panel shows the energy range of interest for photoionization by X-ray continua.

19.2 Low Temperature Dielectronic Recombination

Dielectronic recombination through low-lying autoionizing states is known for be the dominant recombination mechanism for many ions of second-row elements (i.e., Nussbaumer and Storey 1983). Unfortunately, these have not been computed for most third-row elements or iron. This constitutes a major uncertainty in understanding the ionization balance of these elements. For those elements where a dielectronic

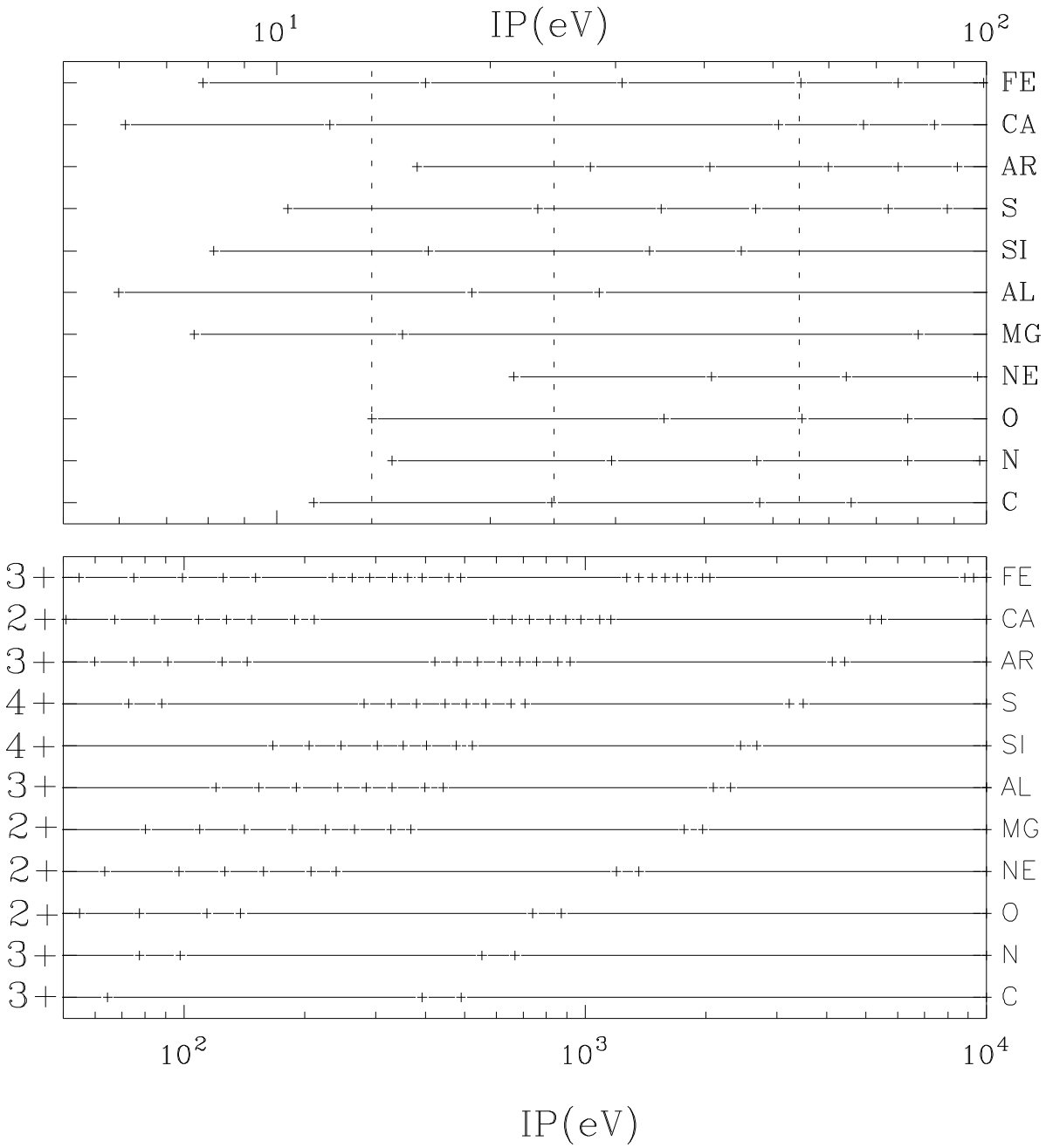

Figure 13: The ionization potentials of the heavy elements considered by the code are shown. The ionization potentials of hydrogen and helium are indicated by the dotted lines. The upper panel shows the energy range of interest for conventional nebulae, and the lower panel shows the energy range of interest for relatively hard continua. ionpot

recombination rate coefficient has not been computed, the mean of the rate coefficient for C, N, O, and Ne is used instead.

19.3 Carbon

Low temperature dielectronic recombination rate coefficients are taken from Nussbaumer and Storey (1983).

19.4 Nitrogen

Low temperature dielectronic recombination rate coefficients are taken from Nussbaumer and Storey (1983).

19.5 Oxygen

Low temperature dielectronic recombination rate coefficients are taken from Nussbaumer and Storey (1983).

19.5.1 The O I Model atom

A partial Grotrian diagram for the O I atom considered in the Lyβ–O I fluorescence problem is shown in Figure 14. Rates for fluorescence between the two transitions are computed as in Netzer et al. (1985).

19.6 Neon

Low temperature dielectronic recombination rate coefficients are taken from Nussbaumer and Storey (1987).

19.7 Magnesium

Low temperature dielectronic recombination rate coefficients for recombination to the atom are taken from Nussbaumer and Storey (1986). Rate coefficients have not been computed for recombination to the ions.

19.8 Aluminum

Low temperature dielectronic recombination rate coefficients for recombination to the atom and first ion are taken from Nussbaumer and Storey (1986). Rate coefficients have not been computed for recombination to other ions.

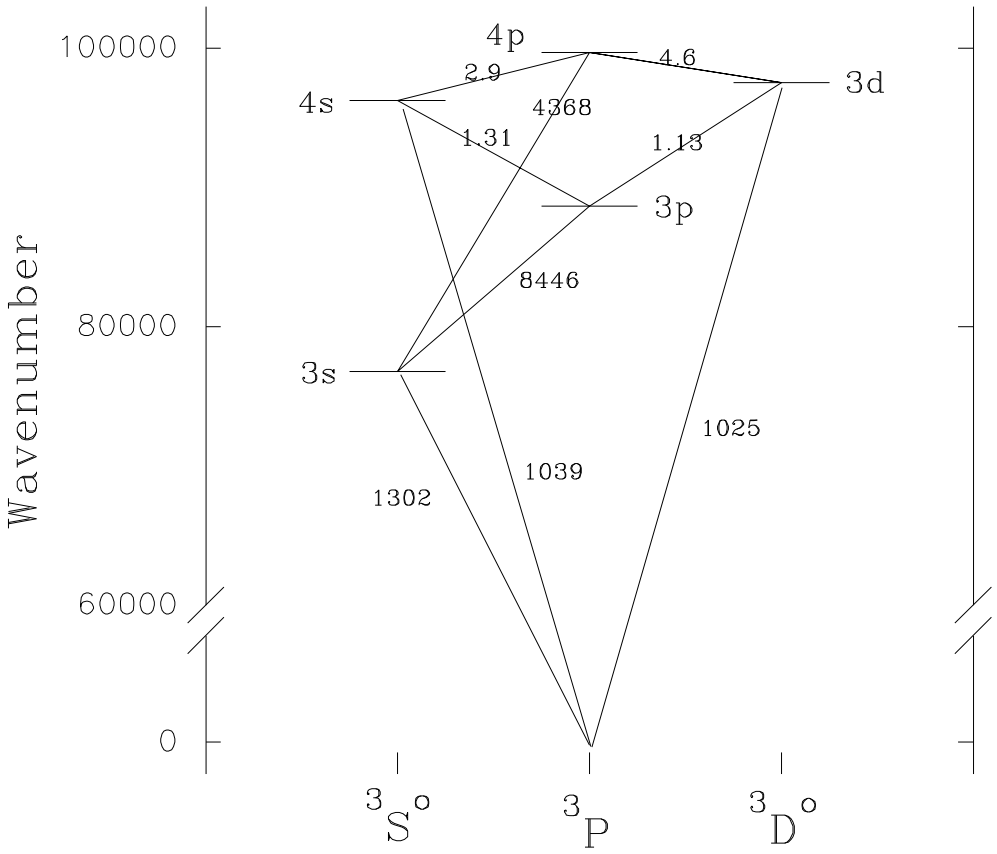

Figure 14: The levels of O^o included in the calculation of the OI– Lyβ pumping problem are shown. oigrot

19.9 Silicon

Low temperature dielectronic recombination rate coefficients for recombination to the atom and first two ions are taken from Nussbaumer and Storey (1986). Rate coefficients have not been computed for recombination to other ions.

19.10 Sulphur

Low temperature dielectronic recombination rate coefficients have not been computed for this element.

19.11 Argon

Low temperature dielectronic recombination rate coefficients have not been computed for this element.

19.12 Calcium

Low temperature dielectronic recombination rate coefficients have not been computed for this element.

19.12.1 The Ca II Model atom

The Ca II ion is treated as a five–level atom plus continuum. The model atom is shown in Figure 15, and is similar to that described by Shine and Linsky (1974). Collision strengths for j-mixing collisions are from Saraph (1970). Collision and radiative data for the 4s - 4p transition are taken from the compendium of Mendoza (1983), and all other collision data are from Chidichimo (1981) and Saraph (1970). Radiative data for the 3d - 4p and 4s - 3d transitions are from Black, Weisheit, and Laviana (1972); these are in good agreement with the calculations of Osterbrock (1951). The compendium by Shine and Linsky (1974) provides photoionization cross sections for excited levels, which are adopted here. Recombination contributions to the population of individual levels are included by dividing the excited state recombination coefficient among the excited levels considered, according to their statistical weight and the rules of LS coupling.

All Ca II transitions (including the forbidden lines) can become quite optically thick. Radiative transfer is treated with the escape probability formalism, assuming incomplete redistribution, including destruction by background opacities.

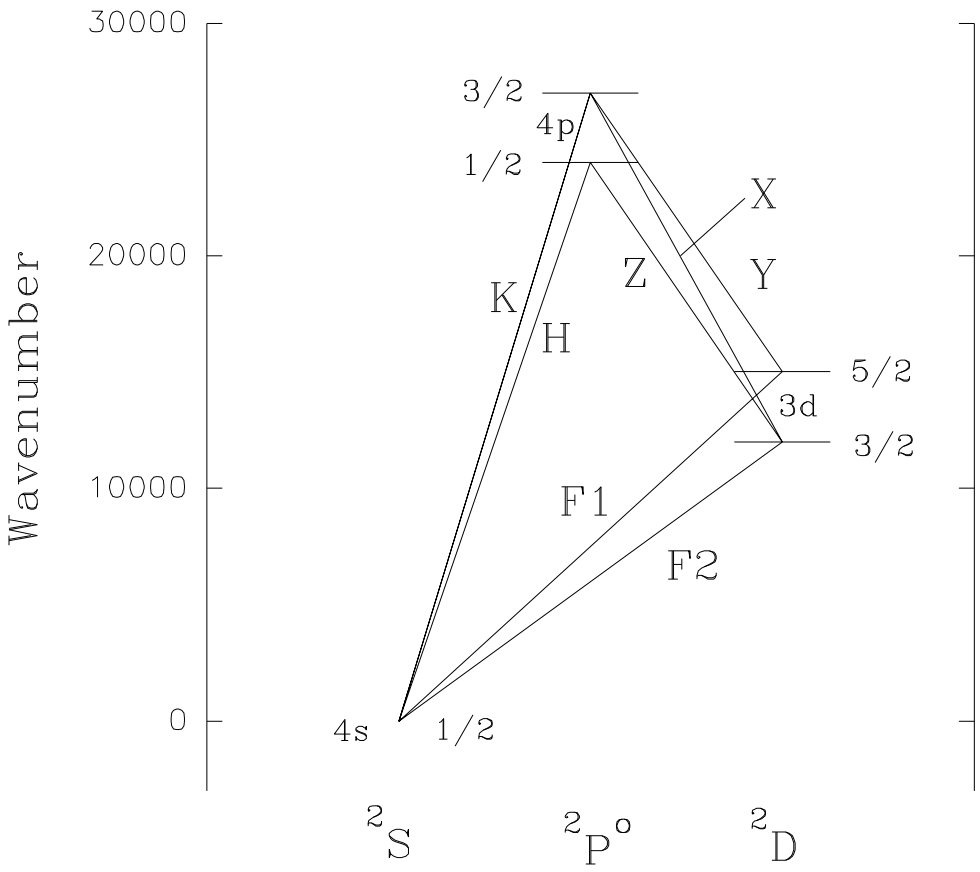

Figure 15: The five levels of Ca^+ included in the calculations are shown. The wavelengths of the predicted lines are K (3934), H (3969), X (8498), Y (8542), Z (8662), F1 (7291), and F2 (7324). ca2grot

19.13 Iron

Low temperature dielectronic recombination rate coefficients have not been computed for this element.

19.13.1 Fe Kα Emission

The intensity of the Fe Kα line is predicted including both recombination and fluorescence. Figure 16 show the assumed fluorescence yield and Kα energy. The line predictions are separated into "cold" iron (iron with M-shell electrons present) and "hot" iron (those ionization states producing lines with energies greater than $\sim$6.4 keV). This includes the recombination and collisional contribution. The "TOTL" Kyα is the sum of the two.

19.14 Heavy Element Opacities

Figure 17 shows a calculation of the opacity of a solar gas with very low ionization.

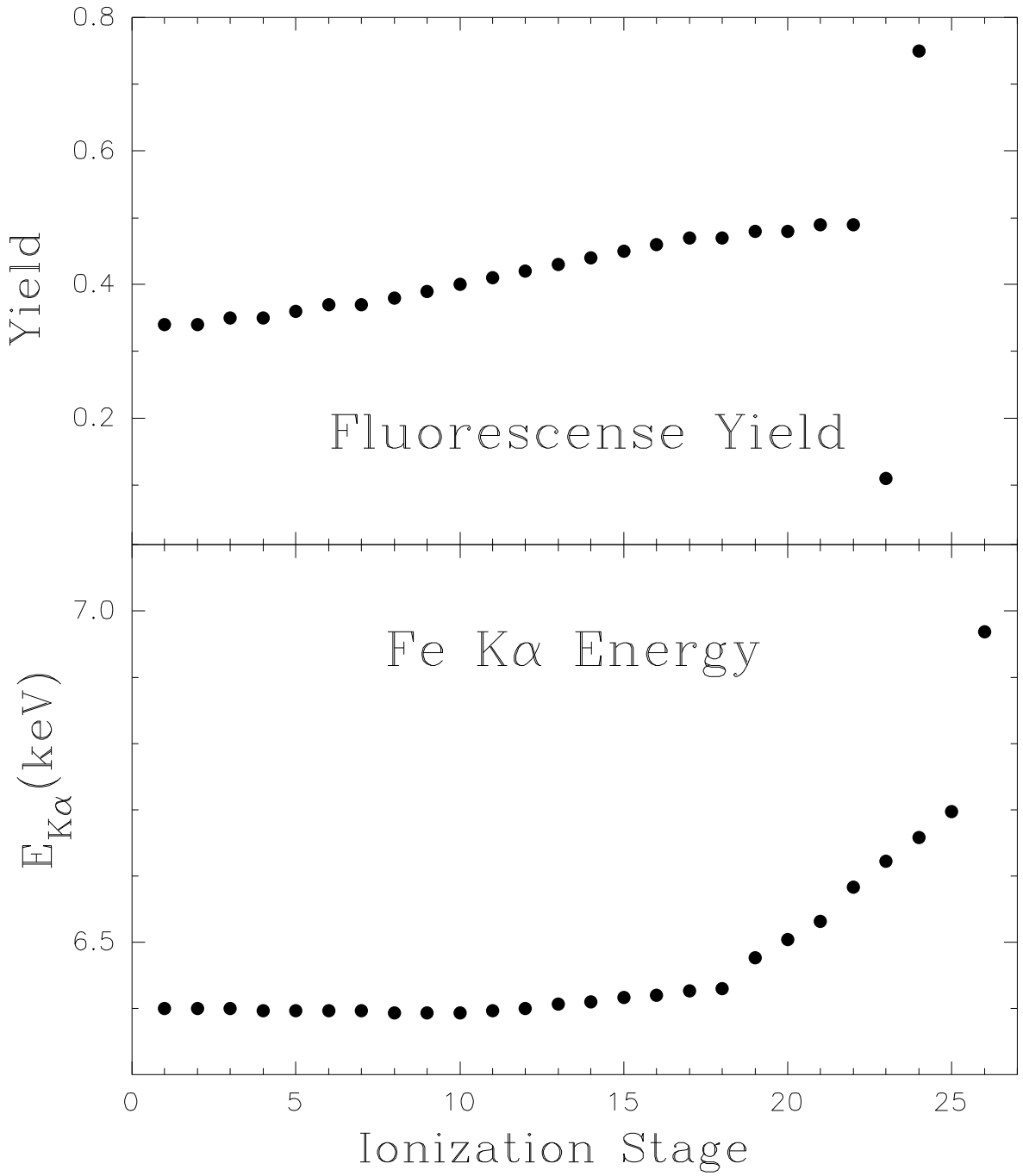

Figure 16: The fluorescence yield and energy of the emitted Fe Kα photon are shown as a function of ionization stage. feka

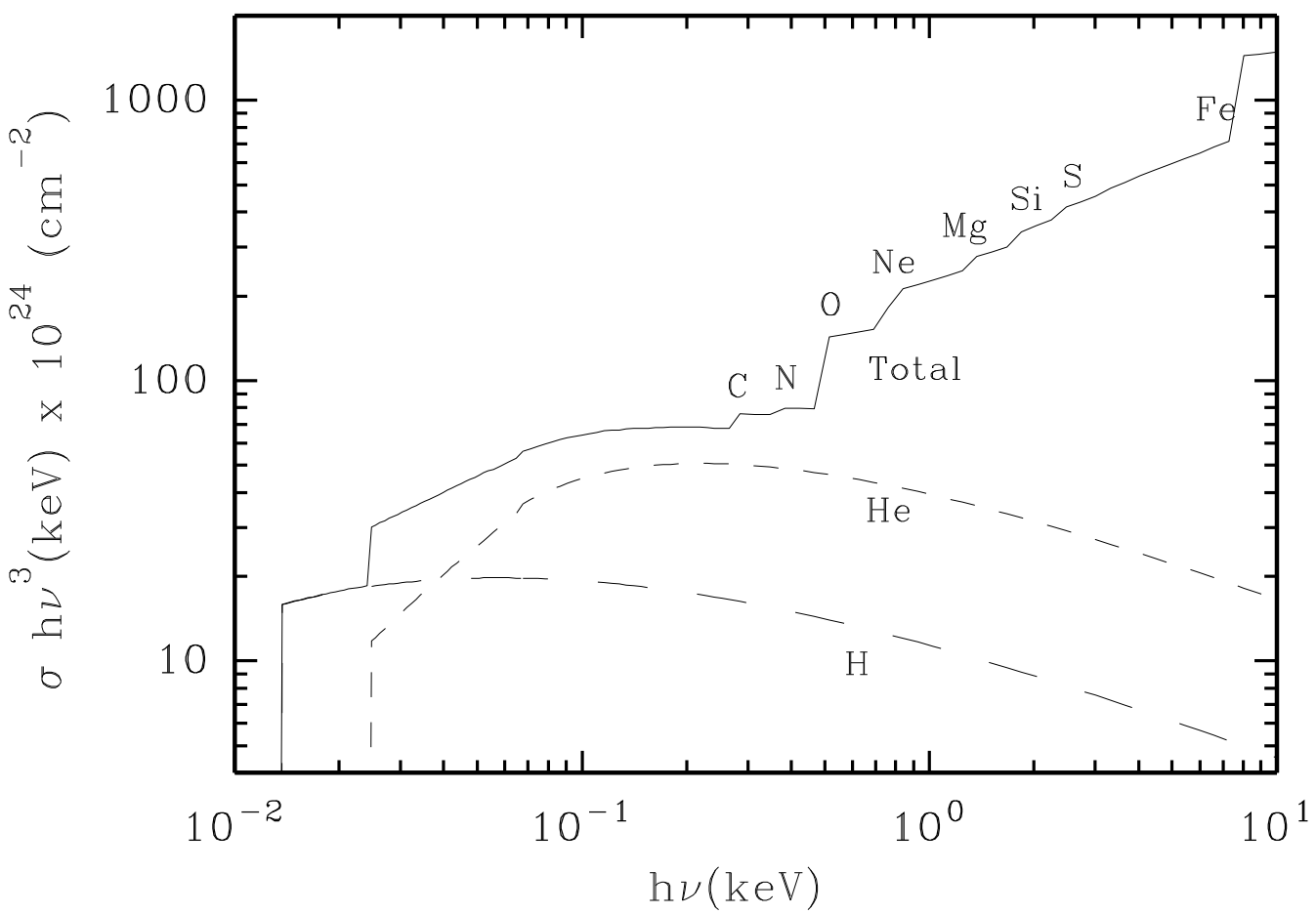

Figure 17: The opacity of a neutral gas with solar abundances is shown as a function of energy. The curve is scaled to allow direct comparison with conventional calculations of opacity at X-ray energies (i.e., Morrison and McGammon 1983). hevopc

20 THERMAL EQUILIBRIUM

20.1 Introduction

Strict thermodynamic equilibrium (TE) is reached when all heating and cooling processes are in detailed balance. The approach to this equilibrium as T_u and N increase is discussed here.

Heating or cooling can be defined relative to either the ground state or continuum, and this difference has caused some confusion in the literature. CLOUDY defines heating and cooling relative to the continuum, as in Osterbrock (1988). Note that, in this scheme of bookkeeping, photoionization contributes an amount of heat given by $h(\nu - \nu_o)$, where $h\nu_o$ is the ionization potential of the atom or ion, and emission of a recombination line *does not* constitute a cooling process. Heating and cooling rates are computed in cgs units (ergs, not Rydbergs) throughout CLOUDY.

20.2 Thermal Stability

The criterion for thermal stability used by CLOUDY is that the net cooling (i.e., cooling minus heating) have a positive temperature derivative (Field 1965). This can be expressed as

$$\frac{d\,(\Lambda - G)}{dT} > 0. \qquad (126)$$

The code will print a "u" next to the temperature in the zone results, and make a comment in the end, if possibly thermally unstable solutions were found.

The criterion used by the code is that the derivative *at constant density* (isochoric) be positive. The more traditional criterion is that the derivative *at constant pressure* (isobaric) be positive (Field 1965).

20.3 Compton Energy Exchange

The net volume heating rate (erg s^{-1} cm^{-3}) due to Compton energy exchange is given by

$$G_{Comp} - \Lambda_{Comp} = \frac{4\pi N_e}{mc^2}\left\{\int \sigma_h \; J_\nu h\nu\,[1+\eta_\nu] \; d\nu - 4kT\int \sigma_c J_\nu \; d\nu\right\} \qquad (127)$$

(see, for instance, Levich and Sunyaev 1970; and Krolik, McKee, and Tarter 1981). The two terms in braces are the heating and cooling terms respectively, while the factor in brackets in the first term accounts for heating due to both spontaneous and stimulated Compton scattering. Induced Compton heating is important when η_ν is large at frequencies where $h\nu \geq kT$; in fact it is, at most, a few percent effect in most circumstances.

The terms σ_h and σ_c appearing in equation 127 are the effective energy exchange (scattering) cross section for energy exchange, and differ from the Thomson cross section for energies $h\nu \sim m_e c^2$, where the Klein-Nishina cross section must be used. The numerical fits to Winslow's (1975) results, as used by Krolik, McKee, and Tarter (1981) and kindly provided by Dr. C.B. Tarter, were used. Defining

$$\alpha = \left\{1 + \nu_R \left(1.1792 \times 10^{-4} + 7.084 \times 10^{-10} \nu_R\right)\right\}^{-1} \tag{128}$$

and

$$\beta = \left\{1 - \alpha\nu_R(1.1792 \times 10^{-4} + 2 \times 7.084 \times 10^{-10}\nu_R)/4\right\} \quad , \tag{129}$$

where ν_R is the photon frequency in Rydbergs, the Compton energy-exchange rate coefficients are then $\sigma_h = \sigma_T \alpha$ and $\sigma_c = \sigma_T \alpha\beta$. Tests show that these are in excellent (much better than 1 %) agreement with Guilbert's (1986) calculations for $h\nu < 10$ MeV, the energies where Guilbert's calculations are valid.

The total Compton heating-cooling rates are evaluated zone by zone in subroutine HIGHEN. The coefficients for the heating and cooling terms, i.e., α and the product $\alpha\beta$, are calculated in subroutine PNTSET at the beginning of the calculation and stored in the vectors CSIGH(ν) and CSIGC(ν). The heating is determined by summing over the continuum;

$$G_{Comp} = \frac{N_e}{mc^2}\,\sigma_T\,(h\nu_{Ryd})^2 \sum \alpha_i\,\phi_i\,\nu_i^2\,(1+\eta_i) \tag{130}$$

where ϕ_i is the photon flux, stored in the vector variable FLUX, η_i is the photon occupation number, σ_T is the Thomson cross section, and ν_i is the photon energy in Rydbergs, stored in the vector variable ANU. The heating and cooling rates are stored as the variables CMHEAT and CMCOOL.

Tests in which Compton energy exchange was the dominant physical process affecting the temperature were made, and the results are shown in Figure 18. A series of models in which the gas was irradiated by black body continua in strict thermodynamic equilibrium (i.e., $T_u = T_{color}$) and various hydrogen densities, were computed. Over the temperature range 3 K $\leq T_{color} \leq 10^{10} K$ the computed equilibrium electron temperature equaled the color temperature within much better than 1% ($\langle T_e - T_{color}\rangle / T_{color} = -0.00073 \pm 0.0019$).

The input stream for the two limiting cases (temperatures of 10^{10}K and 3K respectively) follow;

```
title Compton limit; high temperature limit
blackbody 9.5 lte            % lte sets blackbody in strict T.E.
hden 10                      % low enough for Compton to dominate
stop zone 1
```

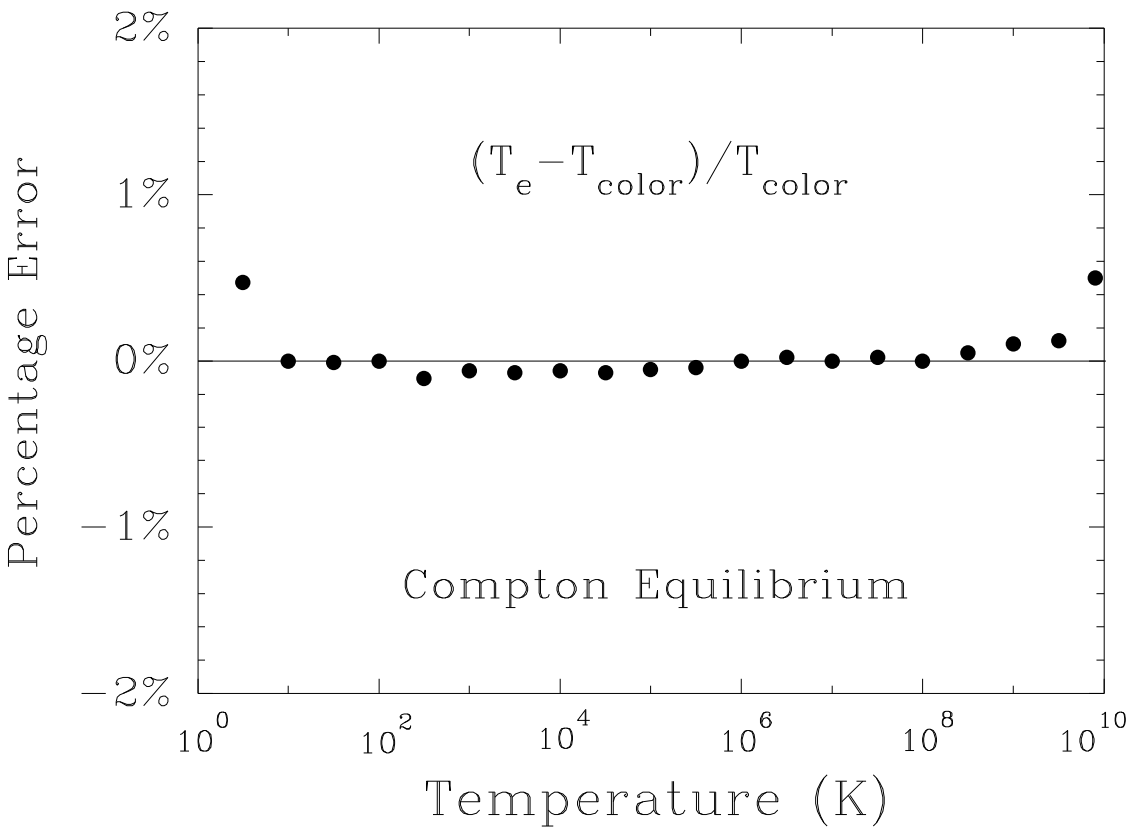

Figure 18: Thermal equilibria in the Compton Limit. These calculations are for blackbody continua of various temperatures, given as T_{color} along the x-axis. The energy density temperature T_u is set equal to T_{color} so that strict thermodynamic equilibrium is expected. The hydrogen density is adjusted to maintain ionization parameters $U \sim 10^{10}$, so that the thermal equilibrium equations are dominated by the Compton exchange problem. The deviation of the computed equilibrium temperature T_e from the asymptotic Compton temperature T_{color} is shown. The code gives reliable results (errors $\ll 1\%$) within its intended temperature bounds of 10 K and 10^9 K. compton

```
print short
tolerance 0.0001              % set fine tolerance to check temp exactly


title Compton limit; low temperature limit
black linear 3 lte            %  set to 3K
lowest temperature linear 2K % allow equil temp below 10K
brems 5                       % must have some ionizing radiation
ionization parameter -5       % but not too much
hden -10                      % set HDEN but does not matter
eden -2                       % add some free electrons
stop zone 1
print short
tolerance 0.0001
```

For a blackbody radiation field with $T_u \neq T_{color}$ the Compton temperature will not be exactly equal to T_{color} because induced scattering will not contribute the required amount of heating-cooling. Note also that when $T_u > T_{color}$ induced Compton heating drives T_e *above* T_{color}. The intended temperature range of validity for CLOUDY is 10 – 10^9K. Over this more limited range the computed Compton temperature, for conditions in which strict TE is expected, is generally equal to the color temperature within three significant figures (see figure 18). At temperatures $\gg 10^9$ K the electrons become relativistic; CLOUDY was not intended for these conditions. For temperatures $T \ll 10$K the computed temperature fails high because the energy bandwidth of the continuum array does not extend below 1.001×10^{-5} Ryd. As a further test, the models presented by Krolik, McKee, and Tarter (1981) were recomputed with excellent agreement (typically within 3%) with their computed Compton temperatures.

20.4 Free-free Heating-Cooling

The volume free-free heating rate is given by

$$G_{ff} = 4\pi \int_{\nu_l}^{\infty} N_e \ \alpha_\nu(ff) J_\nu \ d\nu \qquad (131)$$

where the free-free cross section $\alpha_\nu(ff)$ is given by equation 54 and ν_l is the low energy limit of the code (1.001×10^{-5} Ryd). The continuum J_ν is the sum of the attenuated incident radiation field and the OTS line fields. Diffuse reemission, mainly free-free emission, *is not* included in this integral, as discussed below. The heating rate is evaluated in routine FREEHT.

The cooling by free-free emission, and the subsequent absorption of this radiation, must also be treated. These diffuse continua are treated by defining a critical

frequency ν_c as follows. Gas at a depth R into the cloud is transparent to photons with energies above a critical frequency ν_c such that

$$\tau_c = \int \kappa(\nu_c)\, dr = \int_0^R \alpha_\nu(ff,\, \nu_c)\; N_e\; dr = 1 \tag{132}$$

and optically thick at lower frequencies. The critical frequency ν_c is evaluated in routine TAUFF; the energy in Rydbergs is stored as TFF, while the variable NTFF points to the cell in the continuum array.

The free-free cooling rate is then given by

$$\Lambda_{ff}(\tau) = \int_{\nu_c}^{\infty} N_e \alpha_\nu(ff)\; 4\pi B_\nu(T_e)\; d\nu = \Lambda_{ff}(0) \times \exp(-h\nu_c/kT) \tag{133}$$

where $\Lambda_{ff}(0)$ is the optically thin cooling rate and $B_\nu(T_e)$ is Planck's function. This is equivalent to assuming that, for $\nu < \nu_c$, where the cloud is optically thick, free-free heating and cooling exactly balance, as suggested by Kirchhoff's law and detailed balance considerations. The rate is evaluated in routine COOLR and is stored as the variable HBREMS.

20.5 Photoelectric Heating, Recombination Cooling

The net heating rate due to photoelectric heating less spontaneous and induced recombination cooling of level n is given by

$$G_\kappa = G_{n,\kappa} - \Lambda_{ind,n} - \Lambda_{spon,n} \tag{134}$$

where the volume heating rate due to photoionization is

$$G_{n,\kappa} = N_n \int_{\nu_o}^{\infty} \frac{4\pi J_\nu}{h\nu} \alpha_\nu\; h\,(\nu - \nu_o)\; d\nu \quad , \tag{135}$$

the volume cooling rate due to induced recombination is

$$\Lambda_{ind,n} = N_e\; N_p\; 4\pi\; P_n^* \int_{\nu_o}^{\infty} \frac{J_\nu}{h\nu} \alpha_\nu\; \exp(-h\nu/kT)\; h(\nu - \nu_o)\; d\nu \quad , \tag{136}$$

and the cooling rate due to spontaneous radiative recombination is

$$\Lambda_{spon,n} = N_e\; N_p kT \beta(T, n) \quad . \tag{137}$$

The cooling rate coefficient $\beta(T, n)$ is evaluated as described above (see also Hummer and Seaton 1963).

20.6 Collisional Ionization - Three-Body Recombination

The net volume heating rate due to collisional ionization less three-body recombination is approximately given by

$$G_{n\kappa} - \Lambda_{n\kappa} = \sum_n P_n^* N_e N_p C_{n\kappa}\ h\nu_o\ \ (1 - b_n) \tag{138}$$

where $C_{u\kappa}$ is the collisional ionization rate. This equation is approximate since the energy of the freed electron is ignored relative to the ionization potential χ_n of the level. This approximation is reasonable since the term $(1 - b_n)$ is only large for very low levels, in which $\chi_n > kT$. Far from thermodynamic equilibrium this is usually a net cooling process since departure coefficients for excited states are ~ 1 while the ground and $n = 2$ states often have $b_n \gg 1$.

20.7 Line Cooling

The net heating due to line collisional deexcitation less excitation is given by

$$G_{line} - \Lambda_{line} = \sum_{n=1}^{9} \sum_{u=n+1}^{10} P_n^* N_e N_p C_{un}\ h\nu_{un}\ \ (b_u - b_n) \tag{139}$$

where C_{un} is the downward collision rate. Far from thermodynamic equilibrium collisions involving the ground state tend to cool the gas (since $b_1 \gg 1$) and those between levels with $n \geq 3$ tend to heat the gas (since b_n tends to increase with n).

20.8 H^- Heating and Cooling

The calculation of the heating and cooling rates due to H^- are described here.

20.8.1 H^- bound-free

The volume heating rate due to spontaneous absorption (photodissociation) is

$$G_{H^-} = N(H^-) \int_{\nu_o}^{\infty} \frac{4\pi J_\nu}{h\nu}\, \alpha_\nu\, h(\nu - \nu_o)\, d\nu\ \ (ergs\ s^{-1}\ cm^{-3}) \tag{140}$$

where symbols have their usual meaning. The volume cooling rate due to induced radiative attachment is

$$\Lambda_{ind,H^-} = N_e N_{H^\circ}\, P^*(H^-) \int_{\nu_o}^{\infty} \alpha_\nu\, \frac{4\pi J_\nu}{h\nu} \exp(-h\nu/kT)\, h(\nu - \nu_o)\, d\nu\ \ (ergs\ s^{-1}\ cm^{-3})\ , \tag{141}$$

while the volume cooling rate for spontaneous radiative attachment is

$$\Lambda_{spon,H^-} = N_e N_{H^\circ} 8\pi\, P^*(H^-) \int_{\nu_o}^{\infty} \alpha_\nu\, \frac{\nu^2}{c^2} \exp(-h\nu/kT)\, h(\nu - \nu_o)\, d\nu\quad . \tag{142}$$

20.8.2 H^- free-free

Free-free heating and cooling by H^- is also significant, although less so than bound-free heating. This is included, making the appropriate correction for stimulated emission, using the cross sections given by Vernazza et al. (1981; see also Bates et al. 1975).

Under most circumstances H^- bound-free heating and cooling is much more important than H^- free-free processes. This is surprising at first sight, since standard opacity curves comparing bound-free and free-free opacities (Bates et al.1975; Mihalas 1978) show that the two are comparable. These curves are for strict thermodynamic equilibrium, with H^- departure coefficients of unity. Like the ground state of hydrogen, the departure coefficient for H^- is often many orders of magnitude larger than unity, so that the H^- bound-free opacity and the resulting heating greatly exceeds the H^- free-free opacity.

20.9 Equilibrium Calculations

Figure 19 shows the results of a series of calculations in which the full set of statistical and thermal equilibrium equations are solved for thin cells of hydrogen gas with various densities. The ionizing continuum is, in all cases, a black body with $T_{color} = 5 \times 10^4 K$, and the energy density of the radiation field is varied, up to the thermodynamic equilibrium limit, $T_u = T_{color}$.

Although the gas temperature in the thermodynamic equilibrium limit does not depend on the gas density, the physical processes which drive the gas to this temperature do. Thermal equilibria calculations were performed with three densities chosen to span a fairly wide range. For low densities ($N_H = 10^5$ cm^{-3}) the gas remains highly ionized for all values of T_u shown and the temperature in thermodynamic equilibrium is set by the balance between Compton and inverse-Compton scattering. The intermediate density case ($N_H = 10^{10}$ cm^{-3}) reaches thermodynamic equilibrium with $\sim 3/4$ of the heating-cooling set by Compton scattering and the remainder due to free-free and free-bound processes. The high density ($N_H = 10^{15}$ cm^{-3}) case reaches its thermodynamic equilibrium temperature with a balance between free-free (1/3 of the total) and free-bound (2/3 of the total) processes. In all cases the level populations and electron temperature are within $\sim$1% of their expected thermodynamic equilibrium values when $T_u = T_{color}$.

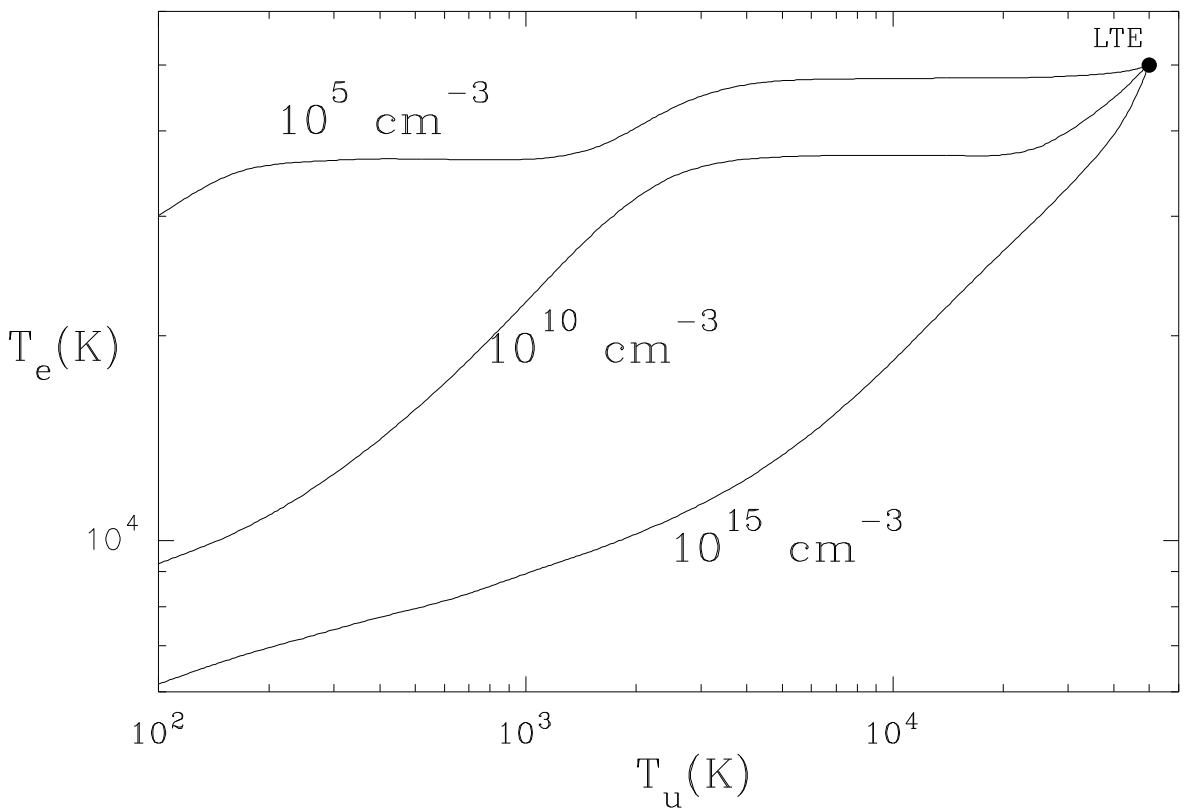

Figure 19: Thermal equilibrium calculations for an optically thin gas with various hydrogen densities are shown as a function of the energy density in the radiation field, parameterized as T_u. Ionization is by a $5 \times 10^4 K$ black body. A combination of Compton scattering, free-free, and free-bound transitions drive the gas to thermodynamic equilibrium when T_u reaches 5×10^4 K. hlte

21 GRAIN PHYSICS

The following discussion outlines some physical processes relating to grains. It is adopted from Baldwin et al. (1991), and was written in collaboration with P.G. Martin.

Several grain populations, types of graphite and "astronomical silicates", are available. Usually one of each type, for a total of two, are selected. Optical properties like opacity of the species are based on a realistic power-law size distribution. Other properties (like potential and temperature) are computed for a mean grain size rather than calculated for each individual size.

21.1 Grain Opacity

Grains are not normally included in the calculation. When enabled with the "grain" command, the default mixture has interstellar medium (ISM) properties. Grains more similar to those seen in Orion or planetary nebulae are also available.

21.1.1 ISM grains

The optical constants for the default (ISM) grain species are from the calculations of Martin and Rouleau (1990), which extend the work of Draine and Lee (1984) to ionizing energies where the grains are strongly absorbing. These opacity calculations were based on the Mathis, Rumpl, and Nordsieck (1977) power law size distribution to simulate interstellar extinction in diffuse clouds.

21.1.2 Orion grains

Grains within the Orion Nebula have a relatively large ratio of total to selective extinction and an exceptionally grey opacity in the ultraviolet, both indicative of a deficiency in small grains and a larger mean grain size. To account for this, a second set of opacity functions are included, the Orion group. For this the value of the smallest size (a_-) in the Mathis et al. (1977) size distribution was increased from 0.0025μm to 0.03μm. While this simple adjustment of the size distribution is not entirely adequate for explaining the details of the visible and near ultraviolet Orion extinction curve (Mathis and Wallenhorst 1981), it should be an improvement for the ionizing ultraviolet portion, which is most important.

The Orion extinction curve is designed to simulate the large R grains observed in this HII region. Relative to ISM standard grains the total amount of grain material was preserved, so that σ_a in the infrared and in the EUV and x-ray regions remains unchanged. The main differential effect is to lower the cross section through a broad peak at 1 Ryd.

21.1.3 PN grains

Infrared opacities for the silicate component are taken from unpublished work by K. Volk. Ultraviolet silicate cross sections, and the graphite constituent, are standard ISM.

21.1.4 Extinction

The ISM extinction properties, both effective scattering (subscript s) and absorption (subscript a), are shown in Figure 20. The quantities plotted are cross sections (cm^2) per H nucleon: $\sigma = \kappa / N_{\mathrm{H}}$, where κ (cm^{-1}) is the opacity due to grains and N_{H} (cm^{-3}) is the local density of H in any form. Rather than the total scattering cross section σ_s an effective scattering cross section $\sigma_{eff} = \sigma_s(1-g)$ is plotted; this discounts the radiation scattered near the forward direction; the asymmetry parameter g approaches unity at high and low energies, particularly for larger grains, so that σ_{eff} becomes much less than σ_a.

The optical depth τ is σ times the hydrogen column density (or κ integrated over the path). Absorption attenuates the incident radiation field as $\exp(-\tau_{abs})$. The effects of scattering are more difficult to model. In an open geometry, scattering attenuates approximately as $(1+0.5\,d\tau_{s_e})^{-1}$. However, in a closed geometry, to within factors of order unity, the scattered light is not lost from the beam, and the scattering opacity can be ignored. In either case, τ_{eff} is generally fairly small through the ionized nebula at ionizing energies.

21.2 Photoelectric Emission

As discussed below, photoelectric emission from grains contributes directly to heating the gas and, through the grain potential U_g established, affects radiative and collisional heating of the grains and the grain drift velocity.

The photoionization rate of a grain, per unit projected area, is

$$\Gamma_g = \int_{\nu_o}^{\infty} Q_{abs} \frac{4\pi J}{h\nu} \hat{Y}\, d\nu, \tag{143}$$

where $\hat{Y}$ is the effective photoelectric yield per absorbed photon, Q_{abs} is the absorption efficiency factor, and $4\pi J/h\nu$ symbolizes the photon flux of direct, diffuse, and OTS radiation fields. For the OTS line component, the integral is of course just a sum over the line photons that are sufficiently energetic. The threshold for photoemission, to be determined self-consistently, is given by $h\nu_o = \max\{\, V_n + V_g,\, V_n \,\}$, where V_n is the photoelectric threshold for a neutral grain and $V_g = eU_g$.

V_g will depend on grain size through Q_{abs} and $\hat{Y}$. In the present implementation, a typical V_g is defined for each species by using Q_{abs} averaged over the size distribution:

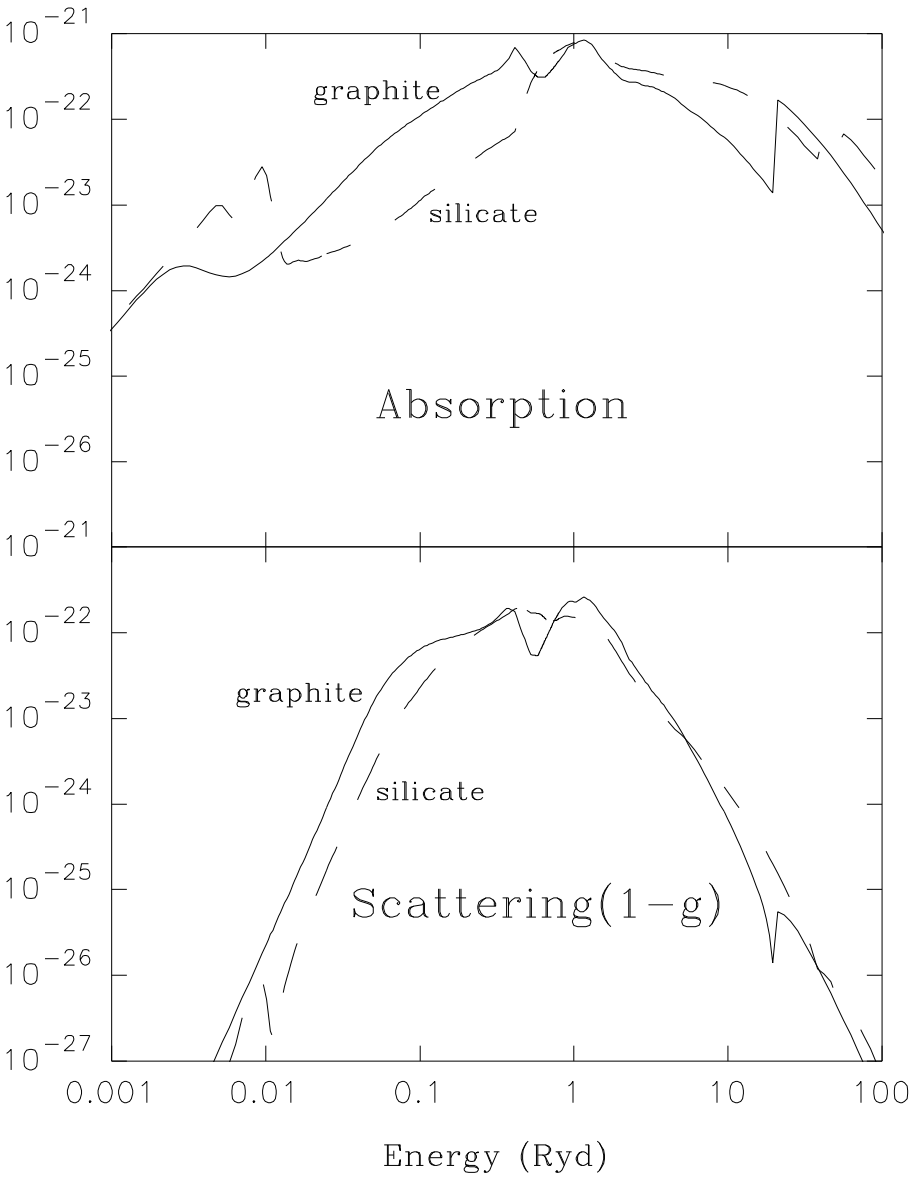

Figure 20: The absorption and scattering cross sections (cm^2 per hydrogen nucleon) for the two ISM grain populations, graphite and silicate, are shown. The effective scattering cross section is the scattering cross section multiplied by $1-g$, where g is the asymmetry parameter. grainop

$Q_{abs} = \sigma_a/\Sigma = \kappa_a/N_{\rm H}\Sigma$. The projected grain area per H, Σ, is similar for each species: 2.1×10^{-22} cm^2 for graphite and 2.4×10^{-22} cm^2 for silicates.

$\hat{Y}$ is constructed as follows. The basic laboratory data measure the yield (per absorbed photon) for a neutral surface, Y_n. For each incident photon energy $h\nu$, the photoelectrons emerging from the neutral surface have varying energies E, with a probability distribution $p_n(E)$. To account for electron escape from finite sized grains, yields measured for semi-infinite sheets in the laboratory have to be corrected by a factor $f(E)$ (which introduces a size dependence). Such a correction would change the shape of the probability distribution as well as increase the integrated emission from a neutral surface (Draine 1978 gives an approximate expression for the overall increase). Then, formally

$$\hat{Y} = Y_n \int_{E_o}^{(h\nu - V_n)} f p_n dE, \tag{144}$$

where $E_0 = \max\{0, V_g\}$ introduces the fact that the lowest energy photoelectrons do not escape from positively charged grains.

The form adopted is

$$Y_n = \min\{\, Y_0\,(1 - V_n/h\nu)\,,\, Y_1\,\} \tag{145}$$

for $h\nu \geq V_n$, and $V_n = 8$ eV and $Y_0 = 0.5$ is assumed for both grain populations; according to Draine (1978) this combination gives about the right amount of photoelectric emission to heat neutral H I clouds in interstellar space ($h\nu \leq 13.6$ eV). For the higher energies a cap at $Y_1 = 0.2$ is introduced, which is suggested by experimental data. For p_n a simple form which is independent of E (Draine 1978) is adopted:

$$p_n = (h\nu - V_n)^{-1}. \tag{146}$$

While only approximate, this induces the physically correct response (decrease) in $\hat{Y}$ (and the photoelectric heating) when the grain is positively charged. Because the form of $f(E)$ is highly uncertain $f = 1$ is assumed (this again avoids a size dependency). Extension of the flat cap in Y_n to high energies also addresses this issue to some degree. With these assumptions, $\hat{Y}$ is known in analytic form:

$$\hat{Y} = Y_n \min\{\, 1, 1 - V_g/(h\nu - V_n)\,\}. \tag{147}$$

21.3 Collisional Charging of a Grain

Per unit projected area of a grain, collisions with particles of space density N, mass m, and charge Z ($Z = -1$ for electrons) give an effective recombination rate

$$\alpha(gr) = -N\,\bar{v}\,S Z\,\eta, \tag{148}$$

where $\bar{v} = \sqrt{8kT/\pi m}$ is the mean particle speed. In this expression, and for other collisional rates involving N below, it is implicit that there is a sum of similar terms over all species in the gas. For electrons S is the sticking probability which we take to be 1 (Spitzer 1948; Watson 1972; Draine 1978). For positively charged nuclei, SZ is the charge transfer efficiency, taken to be Z here. The last factor η, the correction for Coulomb interactions between the grain and the recombining particles of charge Z, is given in terms of $\psi = ZV_g/kT_e$ by

$$\eta = \begin{cases} 1-\psi & \text{if} \quad \psi \le 0 \\ \exp(-\psi) & \text{if} \quad \psi > 0. \end{cases} \tag{149}$$

Terms for positively charged nuclei are included, but are usually small relative to the contribution from free electrons.

21.4 Grain Potential

The steady state grain potential is determined for each grain species independently by requiring charge balance: $\alpha_{gr} = \Gamma_{gr}$. Because of the many dependencies on V_g, this is carried out numerically.

21.5 Grain Drift Velocity

The grain drift velocity is determined by balancing the radiative acceleration due to the direct attenuated radiation field with the drag forces given by equations 1–6 of Draine and Salpeter (1979). The equations are solved numerically for the drift velocity, including interactions with electrons and all ions present in the gas.

21.6 Radiative Heating and Cooling of a Grain

Once the grain potential is known, the radiative rate of heating of the grain per unit projected area is

$$G_{grain}(rad) = \int_0^{\nu_o} Q_{abs} 4\pi J \, d\nu + \int_{\nu_o}^{\infty} Q_{abs} \frac{4\pi J}{h\nu} (h\nu - \widehat{EY}) \, d\nu. \tag{150}$$

The last term represents the portion of the photon energy that does not heat the grain, but rather passes to the escaping electrons:

$$\widehat{EY} = Y_n \int_{E_o}^{(h\nu - V_n)} E \, f p_n dE. \tag{151}$$

With the above approximations for f and p_n this is given analytically by

$$\widehat{EY} = 0.5\, Y_n \min\{\,(h\nu - V_n), \left[(h\nu - V_n)^2 - V_g^2\right]/(h\nu - V_n)\,\}. \tag{152}$$

The cooling of a grain by radiative losses, per unit projected area, is given by

$$\Lambda_{grain}(rad) = \int_0^\infty Q_{abs} 4\pi B_\nu(T_g)\, d\nu \tag{153}$$

where $B_\nu(T_g)$ is the Planck function for the grain temperature.

21.7 Collisional Heating of a Grain

Collisions with electrons, ions, and neutral particles also heat the grains. Per unit projected area of the grain, this heating rate may be written as

$$G_{grain}(col) = N\,\bar{v}\,S\,(2kT_e\xi - ZV_g\eta + I\eta - 2kT_g\eta). \tag{154}$$

The first term corresponds to kinetic energy extracted from the gas. The factor ξ makes adjustment for Coulomb interactions and is given by

$$\xi = \begin{cases} 1 - \psi/2 & \text{if} \quad \psi \le 0 \\ (1 + \psi/2)\exp(-\psi) & \text{if} \quad \psi > 0. \end{cases} \tag{155}$$

The second term in $G_{grain}(col)$ allows for the change of the particle's energy in the grain potential. In the third term, the product $I\eta$ is the average chemical energy released per impact; here it is assumed that when impinging ions recombine the ionization energy released is deposited as heat in the grain (there is then no corresponding term for heating the gas in Λ_g below). The last term describes the effect of thermal evaporation of neutralized ions and thermally accommodated neutral particles (there is no corresponding term for electrons).

In implementing the above processes, S for electrons is again the sticking probability. For positively charged nuclei, S is the energy transfer efficiency, taken here to be unity (this process should be evaluated consistently with that for charge transfer). For neutral particles of mass m striking a grain whose typical atom has mass M, the accommodation coefficient $S \simeq 2mM/(m+M)^2$ (Draine 1978).

21.8 Grain Temperature

The equilibrium grain temperature is determined by the balance between cooling (L) and heating (G) by radiative and collisional processes. For the radiative terms, Q_{abs} averaged over the size distribution is used to obtain a typical temperature for each species.

As a test of the bandwidth of the code, and its behavior in a well-defined limit, tests where computed in which the grains were irradiated by black body radiation in strict thermodynamic equilibrium (i.e., the color and energy density temperatures were equal). Radiation temperatures between 10K and 10^9K, the temperature limits to the code, were used. These tests showed that the deduced grain equilibrium temperature was within much better than 1 percent of the blackbody temperature.

21.9 Photoelectric Heating of the Gas

Heating of the gas by photoemission from grains can be an important process in ionized regions (Oliveira and Maciel 1986). For charged grains this heating rate (erg cm^{-3} s^{-1}) is given by

$$G_{gas} = \int_{\nu_o}^{\infty} \kappa_a \frac{4\pi J}{h\nu} \left(\widehat{EY} - V_g \hat{Y}\right) d\nu. \tag{156}$$

The first term describes the energy of the photoelectrons as they leave the surface, balancing the similar term in $G_{grain}(rad)$. The second term compensates for the grain potential, and can be seen to balance the related term in $G_g(col)$ when charge balance holds.

21.10 Collisional Cooling of the Gas

The gas is cooled as the gas particles hit the cooler grain surface. Per unit volume, this cooling rate may be written as

$$\Lambda_{gas} = N\, N_{\rm H} \sigma\, \bar{v}\, S\, (2kT_e\xi - 2kT_g\eta), \tag{157}$$

the individual terms consistently balancing the corresponding ones in $G_g(col)$.

22 OTHER PHYSICAL PROCESSES

22.1 Cosmic Ray Interactions

Synchrotron radio sources are usually modeled in terms of an interaction between a magnetic field and a relativistic gas with a typical energy per electron of a few hundred MeV (see Pacholczyk 1970; Longair 1981). The spectral index of the radio emission for radio-loud active galaxies is usually ~ -0.7, and this suggests that the electrons, which make the dominant contribution to synchrotron emission, have a density (per unit energy interval) given by $N(cr,\, E) \sim E^{-2.4}$ (Kellerman 1966). The total relativistic electron density is sensitive to the lower bound of the energy distribution, which is typically of order 10—100 MeV, corresponding to relativistic factor of $\gamma \sim$ 10–100 (Lee and Holman 1978).

The cosmic ray density used by CLOUDY is defined as

$$N(cr) = \int_{E_{min}}^{E_{max}} N(cr,\, E)\, dE \tag{158}$$

with the lower bound set to $E_{min} = 5$ MeV, corresponding to $\gamma \approx 10$. The density is only weakly sensitive to the upper limit $E_{max} \approx 10$ GeV because of the strong convergence of the electron density function, although uncertainties in the lower energy bound introduce a fundamental uncertainty. Cosmic ray protons should have much smaller affects than the electrons, so the total cosmic ray electron density N(cr) is the only parameter.

The code assumes that the gas is "optically thin" to the energetic electrons. Serious and fundamental uncertainties afflict detailed treatments of the penetration of energetic particles into gas, particularly if magnetic fields are present. In the simplest case penetration is impeded only by ionization and heating losses resulting from two-body collisions. In this case the ability to heat an entire cloud is determined by the range of a particle, or the column density of gas required to stop it (see Rossi 1952). Relativistic electrons have a range that is given to within 15% by (Berger and Seltzer 1965)

$$R_e = 10^{25} \left(\frac{E}{100\ MeV} \right)^{0.8} \quad cm^{-2} \tag{159}$$

for a gas composed of neutral hydrogen. The range of a 100 MeV electron in a fully ionized gas, in which bremsstrahlung and Coulomb losses are more important than ionization, would be some 10 times smaller.

The relativistic particles both heat and ionize the gas. The main concern is for the rate with which energy is transferred to the cold gas (Lea and Holman 1978; Ginzberg and Syrovatskii 1964). In the H^+ zone the main interaction will be with free electrons.

Kinetic energy is passed to the cold electrons at a rate

$$G_{cr} = 8.5 \times 10^{-19}\ N_e N(cr)\ ergs\ cm^{-3}\ s^{-1} \tag{160}$$

by direct Coulomb interactions (Jackson 1975; Spitzer 1962; Ginzburg and Syrovatskii 1964; Pacholczyk 1970). Here N_e is the thermal electron density, and we have integrated over the electron distribution given above.

In the H^o zone the main interaction between thermal and relativistic gases is through ionization of the cold gas. For large neutral fractions very little of the energy of secondary electrons goes into actually heating the gas (Rossi 1952; Spitzer and Tomasko 1968); calculations show that secondary electrons have typical energies of ~40 eV, and that there is roughly one ionization per 15 eV deposited. Using the Bethe-Bloch approximation (Ginzburg and Syrovatskii 1964) the neutral heating rate is

$$G_{cr} = 3.7 \times 10^{-20}\ N(H^o) N(cr)\ ergs\ cm^{-3}\ s^{-1} \tag{161}$$

and the H^o ionization rate is

$$\Gamma = 1.5 \times 10^{-8}\ N(cr)\ N(H^o)\ cm^{-3}\ s^{-1} \quad . \tag{162}$$

This ionization rate was scaled through Lotz's (1967) curves to include collisional ionization of heavy elements in the calculation of heavy element ionization equilibria.

If cosmic rays are not included, and the hydrogen ground state photoionization rate falls below the galactic background cosmic ray ionization rate, then a comment will be generated warning that the cosmic ray background should perhaps be included. According to Spitzer (1978), the background cosmic ray ionization rate is very uncertain, but of the order of 10^{-17} s^{-1} for neutral hydrogen. According to the equations above, this rate corresponds to a cosmic ray density of $\sim 10^{-9}$ cm^{-3}, the value used as the "background" cosmic ray density for the COSMIC RAY command.

The discussion above, as well as the code, includes only two-body Coulomb interactions, and *does not* include collective effects, such as those discussed by Scott et al. (1980). Rephaeli (1987) notes that collective effects may not be important in most circumstances.

22.2 Line Radiation Pressure

Line radiation pressure was implemented in CLOUDY in collaboration with Moshe Elitzur. The following was written in collaboration with Moshe, and is adopted from Elitzur and Ferland (1986).

For radiation intensity I_ν, the standard expression for the radiation pressure per unit frequency, P_ν, is (e.g. Schwarzchild 1965)

$$P_\nu = \frac{1}{c} \int I_\nu \mu^2 d\Omega \quad , \tag{163}$$

where $\mu = \cos\theta$ and θ is the direction of propagation of the radiation. When the radiation field is isotropic, its pressure and energy density,

$$U_\nu = \frac{1}{c}\int I_\nu \Omega \quad , \tag{164}$$

are related by the familiar expression

$$P_\nu = \frac{1}{3}U_\nu \quad . \tag{165}$$

This relation holds for a rather wide range of circumstances. If the angular distribution of I_ν is expanded in a power series in μ, then only powers higher than the second will lead to violations of equation 165. However, the successive coefficients of this expansion are decreasing approximately like the optical depth (e.g. Schwarzchild 1965, p 40), so deviations from equation 165 will only be proportional to $1/\tau^2$. Hence, when the medium is optically thick at the frequency ν equation 165 is an excellent approximation for the radiation pressure.

The only radiative quantity we need to know in order to calculate the radiation pressure is the angle-averaged flux, J_ν, since

$$U_\nu = \frac{1}{c}4\pi J_\nu \quad . \tag{166}$$

The integrated radiation pressure is then

$$P(\nu) = \frac{4\pi}{3c}\int J_\nu \, d\nu \quad . \tag{167}$$

Introducing the line-width, defined by

$$\Delta\nu = \frac{1}{\bar{J}}\int J_\nu \, d\nu \quad , \tag{168}$$

where

$$\bar{J} = \int J_\nu \Phi(\nu)\, d\nu \tag{169}$$

is the integrated mean intensity in the line and $\Phi(\nu)$ is the normalized line profile $[\int \Phi(\nu)\, d\nu = 1]$. The quantity $\bar{J}$ is readily available in the escape probability approximation because it is related directly to the source function S by

$$\bar{J} = S(1 - P_l) \tag{170}$$

where P_l is the photon escape probability. The line source function S is simply $B_\nu(T_{exc})$, the Planck function of the line excitation temperature. The final expression for the pressure due to a line at frequency ν is therefore

$$P(\nu) = \frac{4\pi}{3c}B_\nu(T_{exc})\,\Delta\nu\,(1 - P_e) \quad . \tag{171}$$

The line width is a crucial parameter in the calculations since the line radiation pressure is directly proportional to it. For lines with a moderate optical depth (i.e., $\tau \leq 10^4$) the damping wings are optically thin, and the line emission profile is essentially identical to the absorption profile. In this case $\Phi(\nu)$ is simply described by the Doppler profile $\pi^{1/2} \exp(-x^2)$, where $x = (\nu - \nu_o)/\Delta\nu_d$ is the dimensionless frequency shift from line center and $\Delta\nu_d = (2kT/m)^{1/2}\nu_o/c$ is the Doppler width. The line width is then

$$\Delta\nu = \Delta\nu_D \times 2(\ln\tau)^{1/2} \tag{172}$$

for $\tau \gg 1$.

The situation when the line optical depth exceeds $\sim 10^4$ is much more complicated because scattering in the damping wings becomes significant, and the frequency dependence of the emission profile is not known before the entire radiative transfer problem is solved. In general, it is known that, for Lyα (generally the most important source of line radiation pressure) and large optical depths, the line width (in dimensionless units) is

$$x = k(a\tau)^{1/3} \ , \tag{173}$$

(Adams 1972; Harrington 1973; Bonilha et al. 1979). In this expression a is the damping constant ($a \sim 4.7 \times 10^{-4}$ for Lyα), τ is the line center optical depth, and k is a number of order unity.

The frequency width required here is the value that will provide a rectangular profile with the same area as the proper integral of the source function. The results of Adams (1972) are adopted, and the resulting expression for the full line width in the case of large optical depths ($a\tau \gg 1$) is

$$\Delta\nu = \Delta\nu_D \, 2.3 \, (a\tau)^{1/3} \tag{174}$$

An important point, evident from the plots provided by Adams for the source function as a function of frequency (his Fig 3), is that the width of the frequency distribution varies very little with position in the slab. This is also evident from the mean intensity plots of Harrington, as mentioned above, and is a result of the strong coupling between distant regions caused by scattering in the line wings. The expression provided in equation 174 for all locations in the slab, with τ being half the total slab thickness.

Background opacity is included in the determination of the level populations using the formalism outlined in the section on line radiative transfer. Its main effect is to lower the line excitation temperature by providing a second "escape" (actually destruction) route for trapped photons. This is assumed to be the only effect background opacity has on radiation pressure. Balmer continuous absorption typically has an optical depth of order unity, while the line optical depths are many orders of magnitude larger. Absorption in the Balmer continuum can only compete with line

scattering in the extreme wings, at frequency shifts exceeding $\sim (a\tau)^{1/2}$, which are much larger than the line width predicted by equation 174.

Collisional de-excitation can also break the assumption of pure scattering because a photon will be lost to the thermal pool before the radiative process can take place. This will happen when the density is high enough that the rate for collisional de-excitation, C_{ul}, exceeds the probability for the effective rate for the transition, $P_l A_{ul}$, where P_l is the line escape probability and A_{ul} is the Einstein coefficient. Because at large optical depths P_l is essentially equal to τ^{-1}, the "effectively thin" assumption breaks down when

$$\tau \sim A_{ul}/C_{ul} \quad . \tag{175}$$

Once the line optical depth exceeds $\sim A/C$, a "thermalization limit" is encountered, and the assumption of a purely scattering nebula does not apply anymore. Therefore, in evaluating the optical depth for the line width expression (equation 174) the minimum of the actual line optical depth and the one prescribed by A/C is used. this is a conservative estimate of the effect of collisions on photon scattering. This is probably the most poorly understood part of the calculation of the line radiation pressure.

22.3 Radiative Acceleration

The radiative acceleration (cm s^{-2}) due to the direct attenuated continuum flux F_ν, for density ρ, is given by

$$a_{rad} = \frac{1}{\rho c} \int F_\nu \hat{\kappa}_\nu \, d\nu + \frac{1}{\rho c} \sum_l F_\nu(l) \kappa_l \gamma_l. \tag{176}$$

Here $\hat{\kappa}$ is the effective continuous opacity; it includes the usual photoelectric, and free-free absorption in the gas, and Compton and Rayleigh scattering. In addition it includes $\kappa_a + (1-g)\kappa_s$ for the grain contributions if grains are present. The integral is over all energies considered by the code (from $\lambda \approx 1$ cm to $h\nu \approx 100$ MeV). The second term is a sum is over roughly a dozen strong ultraviolet and optical resonance lines; κ_l is the line opacity, B_l is the Einstein coefficient, and γ_l is the escape probability in the direction towards the source of ionizing radiation (Ferland and Rees 1988).

Really, something like 10^6 lines are needed for a realistic calculation of the radiative acceleration (Abbott 1982). The approximations used here will underestimate the actual radiative acceleration by as much as a factor of two, depending on the level of ionization of the gas and form of the incident continuum.

When the pressure is held constant (with the "CONSTANT PRESSURE" command) the pressure law is given by

$$P(r) = P_{gas}(r_o) + \int a_{rad} \, \rho \, dr = P_{gas}(r) + P_{line}(r) \tag{177}$$

where

$$P_{gas}(r_o) = N_{tot} kT \tag{178}$$

is the gas pressure at the illuminated face of the cloud, N_{tot} is the total particle density, and r is the radius in question. The gas pressure is stored as the variable PGAS and is evaluated in routine PTOT. The line radiation pressure is evaluated as described above, and its total is stored as the variable PRAD which is also evaluated in PTOT. Finally, the integrated radiative force on the gas is evaluated in routine RADINC and is stored as the variable PINTEG.

22.4 Wind Geometry

CLOUDY will do a simple wind geometry if the "WIND" command is specified. The effective acceleration is written as $a_{eff} = a_{rad} - g_{grav}$, where a_{rad} is computed as above, and g_{grav} is the inward gravitational acceleration due to the central object. The default is one solar mass. The velocity is computed assuming that the acceleration is constant across the zone. In this case the velocity v at the outer edge of a zone of thickness dr will be

$$v = \frac{v_o + \sqrt{v_o^2 + 4\, a_{eff}\, dr}}{2} \tag{179}$$

where v_o is the velocity at the inner edge. The calculation will stop if the velocity ever falls below zero.

The density at the illuminated face of the cloud is entered with the "HDEN" command, and the density is varied across the model to conserve mass flux (i.e., the product $\rho(r)\, r^2\, v(r)$ is kept constant). Because of this, a filling factor would not make physical sense, and should not be used. Note also that it is usually necessary to set an outer radius when a wind model is computed to stop the calculation from extending to infinity.

A simple Sobolev approximation is used for line transfer when a wind is computed. The effective optical depth is given by;

$$\tau_{lu}(R) = \alpha_{lu} \left(N_l - N_u \frac{g_l}{g_u} \right) R \frac{v_{thermal}}{v_{expansion}} \tag{180}$$

where R is the radius and $v_{thermal}$ and $v_{expansion}$ are the thermal and expansion velocities respectively.

Figure 21 shows a test case in which a wind is driven in the plane parallel electron scattering limit. As can be seen the numerical solution is in excellent agreement with the analytically predicted result.

The cooling (erg cm^{-3} s^{-1}) due to the hydrodynamic expansion of the gas is given by

$$\Lambda_{exp} = -kT \frac{dN}{dt} = N \left[\frac{a}{v} + \frac{2v}{R} \right] \tag{181}$$

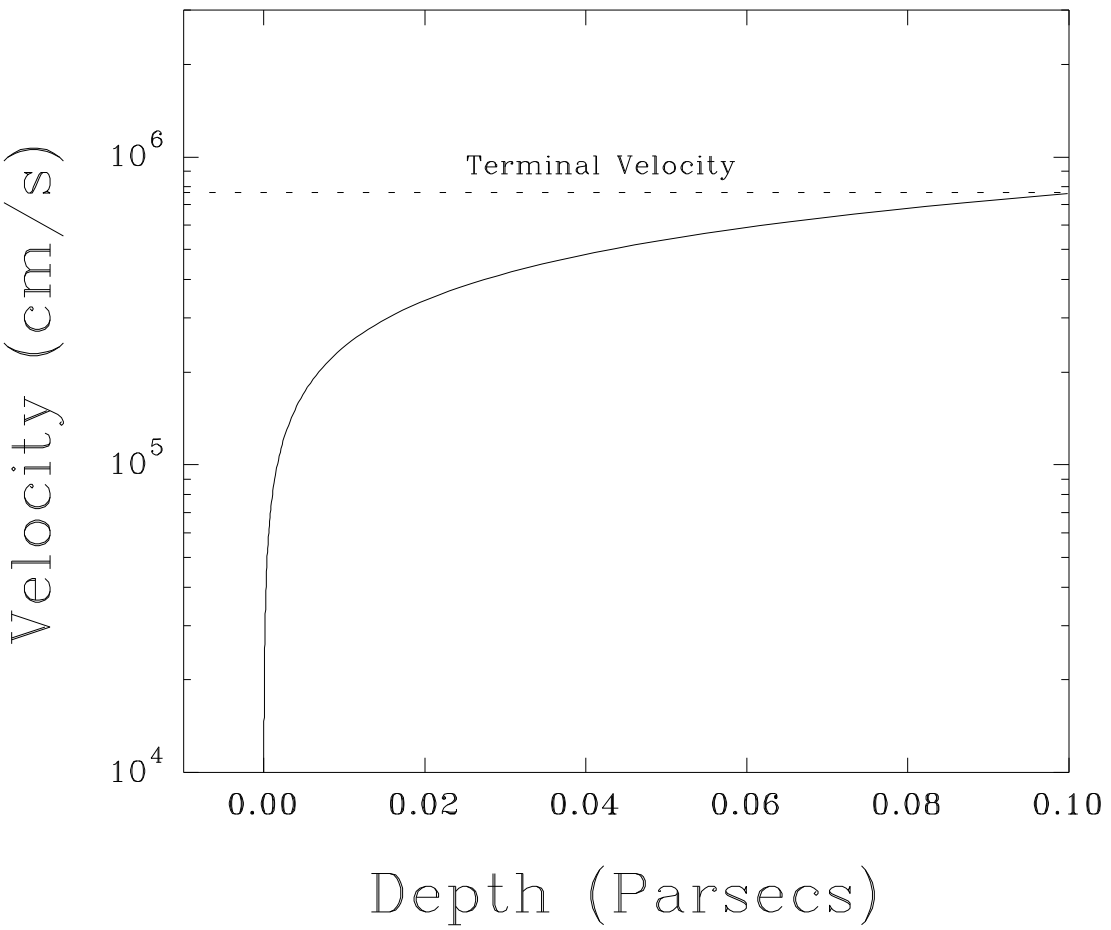

Figure 21: The wind velocity is computed using the input stream shown in one of the test cases in section 25. Parameters were chosen to have a readily computed final velocity. The velocity at the outer edge of the slab is within 1 percent of its expected value. wind

where N, a, v, and R are the total particle density, acceleration, wind velocity, and radius respectively.

22.5 Secondary Ionization

Secondary ionizations by supra-thermal electrons are treated following Shull and van Steenberg (1985). All sources of energetic electrons, including both Auger and primary electrons, are considered in the initial input of high-energy electrons into the gas. The resulting flux of non-thermal electrons is stored as the variable CSUPRA, which has units cm^{-2} s^{-1}. A typical energy of an electron in the non-thermal shower is ~ 20 eV; this energy is used to evaluate collisional ionization and excitation cross sections. Secondary ionization is included among the general ionization processes considered for all species.

22.6 Jeans Length and Mass

The Jeans length and mass are computed for each zone in the calculation. The smallest computed Jeans length and mass are saved, and a note is printed at the end of the calculation if the computed structure is Jeans unstable.

The expression for the Jeans length is

$$\lambda_J = \left(\frac{\pi kT}{\mu m_H G\rho}\right)^{1/2} = 6.257 \times 10^7 \left(\frac{T}{\mu\rho}\right)^{1/2} \quad cm \tag{182}$$

where μ is the mean molecular weight of the gas (referred to as the variable WMOLE) and ρ is the density of the gas (gm, referred to as the variable DENSTY). Both are computed in routine PTOT.

The Jeans mass is then given by

$$M_J = \frac{4\pi}{3}\rho\left(\frac{\lambda_J}{2}\right)^3 \quad gm \tag{183}$$

where the mass is that of a sphere with radius $\lambda_J/2$.

23 OTHER DETAILS

23.1 Geometry

This section defines the internal variables used to describe the geometry. The geometry is always spherical, but can be made effectively plane parallel by making the inner radius of the cloud much larger than its thickness.

Most variables having to do with the geometry are set and incremented in routine NEWRAD.

RINNER This is the separation between the center of symmetry (i.e., the center of the central object) and the inner edge of the cloud. It remains constant throughout the calculation. If an inner radius is not specified then it is given the default value of 10^{25} cm. This will usually result in a plane parallel geometry.

DRAD This is the thickness of the current zone. Note that the zone size changes continuously throughout the calculation. Upper or lower limits to DRAD can be set with the DRMAX and DRMIN commands, described above.

RADIUS This is the distance between the center of symmetry and the *outer* edge of the current zone. For the first zone, RADIUS has the value RINNER+DRAD/2.

DEPTH This is the distance between the inner edge of the cloud and the *outer* edge of the current zone. For the first zone, RADIUS has the value DRAD/2.

ROUTER This is the limit to the outer radius of the structure, as set before the calculation begins. The default value is effectively infinite, actually 10^{30} cm.

R1R0SQ This is the sphericity ratio

$$R1R0SQ = \left(\frac{distance\ to\ center\ of\ zone}{inner\ radius} \right)^2 = \left(\frac{RADIUS - DRAD/2}{RINNER} \right)^2 \qquad (184)$$

A problem can arise under certain extreme circumstances. The depth variable DEPTH must be increased for every zone, by adding the zone thickness DRAD. Both variables are double precision. If the radio DRAD/DEPTH falls below $\sim 10^{-14}$ then the depth cannot be updated on most machines. The problem is that the sum DEPTH+DRAD will be equal to DEPTH because of numerical underflow. If this occurs (i.e., the zone thickness DRAD falls below DEPTH/10^{14}) the code will stop, with the comment than the zone thickness is too small relative to the depth. There is no obvious solution to this problem.

PIRSQ This is the log of the inner area ($4\pi r_{inner}^2$).

DREFF This is the effective radius, $dr_{eff} = dr \times f(r)$ where $f(r)$ is the filling factor.

DVEFF This is the effective volume relative to the inner radius.

24 COMPARISON CALCULATIONS

This section presents comparisons between the current predictions of the code, and results from other independent calculations. The "other" calculations are from the compendium resulting from the Meudon (1985) meeting on model nebulae edited by Daniel Pequignot.

The scatter among the calculations, as well as the changes that have occurred in the predictions made by CLOUDY, are in some sense an indication of the stability and reliability of these types of extreme non-LTE calculations. The largest discrepancies between current predictions made by CLOUDY and the other models (which were computed in 1985) are due to changes which have occurred in the atomic data base between 1985 and the present. In general, the strongest lines are in very good agreement (as they must because of energy conservation) while weak lines (which are very sensitive to changes in the computed temperature and ionization structure) scatter by nearly a factor of two.

24.1 Paris Planetary Nebula

This compares current predictions of the code with those of other participants at the Meudon meeting on photoionization calculations, for the case of ionization by a very hot black body. The input used to generate this model planetary nebula is shown in the sample input section. The model results are very sensitive to the detailed transfer of HeII Lyα; this line is the dominant heat source across the model nebula. The parameters were chosen to be roughly similar to NGC 7027, a very well studied object.

Table 20: Paris Meeting Planetary Nebula

Line		Harrington	Netzer	Pequignot	Mean
Hβ	erg/s	2.64E35	2.51E35	2.67E35	2.60 ± 0.09E35
He I	5876	0.097	0.11	0.11	0.106±0.008
He II	4686	0.336	0.350	0.316	0.334±0.017
C II	2326	0.498	0.310	0.323	0.377±0.105
C III]	1909	1.67	1.73	1.70	1.70±0.03
C IV	1549	1.70	1.19	2.02	1.64±0.42
[N I]	5200	0.020	0.010	0.017	0.016±0.005
[N II]	6584	1.12	1.10	1.03	1.08±0.05
N III]	1749	0.118	0.090	0.112	0.107±0.015
N IV]	1487	0.116	0.090	0.160	0.122±0.035
N V	1240	0.079	0.040	0.148	0.089±0.55
[O I]	6300	0.117	0.112	0.101	0.110±0.008
[O II]	3727	2.28	2.24	2.18	2.23±0.05
[O III]	5007	16.12	16.84	17.28	16.74±0.58
[O III]	4363	0.159	0.150	0.156	0.155±0.005
[O III]	52μm	1.44	1.42	1.43	1.43±0.01
O IV]	1403	0.149	0.070	0.179	0.132±0.56
O V]	1218	0.073	0.030	0.178	0.094±0.076
[Ne II]	12.8μm	0.023	0.030	0.032	0.0285±0.004
[Ne III]	15.5μm	2.56	2.44	2.54	2.51±0.06
[Ne III]	3869	2.05	1.92	1.98	1.98±0.06
Ne IV]	2423	0.62	0.43	0.62	0.556±0.110
[Ne V]	3426	0.48	0.44	0.69	0.535±0.132
[Ne V]	24.2μm	1.58	1.85	1.58	1.67 ±0.16
Mg II	2798	1.46	1.00	1.97	1.48±0.49
Mg IV	4.5μm	0.074	-	0.099	0.086±0.018
Si II	34.8μm	-	0.12	0.15	0.133±0.018
Si II	2335	-	0.10	0.126	0.113±0.018
Si III	1892	0.198	0.13	0.262	0.197±0.067
Si IV	1397	0.142	0.11	0.203	0.152±0.047
S II	6720	0.456	0.33	0.385	0.390±0.063
S II	4070	0.078	0.06	0.0642	0.0674±0.009
S III	18.7μm	0.493	0.52	0.446	0.486±0.037
S III	9532	1.36	1.70	1.37	1.48±0.206
S IV	10.5μm	2.21	1.66	1.88	1.92±0.277

24.2 Paris HII Region

This compares current predictions of the code with those of other participants at the Meudon meeting on photoionization calculations for the case of a simple spherical HII region. The input used to generate this model HII region is shown in the sample input section.

Table 21: Paris Planetary vs CLOUDY

Line		Mean	74.23	76.03	80.06
Hβ	erg/s	2.60 ± 0.09E35	2.57E35	2.66E35	2.52E35
He I	5876	0.106±0.008	0.11	0.11	0.107
He II	4686	0.334±0.017	0.294	0.319	0.354
C II	2326	0.377±0.105	0.359	0.352	0.373
C III]	1909	1.70±0.03	1.572	1.48	1.72
C IV	1549	1.64±0.42	2.237	2.76	2.48
[N I]	5200	0.016±0.005	0.009	0.009	0.009
[N II]	6584	1.08±0.05	1.06	1.05	1.08
N III]	1749	0.107±0.015	0.097	0.081	0.096
N IV]	1487	0.122±0.035	0.164	0.119	0.109
N V	1240	0.089±0.055	0.142	0.093	0.061
[O I]	6300	0.110±0.008	0.112	0.111	0.119
[O II]	3727	2.23±0.05	2.24	2.19	2.35
[O III]	5007	16.74±0.58	15.94	15.81	15.30
[O III]	4363	0.155±0.005	0.142	0.125	0.149
[O III]	52μm	1.43±0.01	1.40	1.35	1.37
[O IV]	26μm	-	-	-	3.42
O IV]	1403	0.132±0.056	0.187	0.215	0.105
O V]	1218	0.094±0.076	0.169	0.109	0.067
[Ne II]	12.8μm	0.0285±0.004	0.033	0.034	0.034
[Ne III]	15.5μm	2.51±0.06	2.77	2.70	2.67
[Ne III]	3869	1.98±0.06	2.41	2.26	2.43
Ne IV]	2423	0.556±0.110	0.62	0.514	0.513
[Ne V]	3426	0.535±0.132	0.48	0.404	0.401
[Ne V]	24.2μm	1.67 ±0.16	0.241	0.247	1.007
Mg II	2798	1.48±0.49	0.830	1.82	1.96
Mg IV	4.5μm	0.086±0.018	0.116	0.130	0.135
Si II	34.8μm	0.133±0.018	0.156	0.162	0.162
Si II	2335	0.113±0.018	0.150	0.144	0.158
Si III	1892	0.197±0.067	0.322	0.417	0.419
Si IV	1397	0.152±0.047	0.168	0.240	0.222
S II	6720	0.390±0.063	0.382	0.679	0.662
S II	4070	0.0674±0.009	0.0647	0.121	0.118
S III	18.7μm	0.486±0.037	0.580	0.706	0.673
S III	9532	1.48±0.19	1.69	2.11	2.07
S IV	10.5μm	1.92±0.28	1.64	1.32	1.53

Table 22: Paris Meeting HII Region

Line		Harrington	Rubin	Netzer	Pequignot	Mean
Hβ	erg/s	2.04E37	2.07E37	2.09E37	2.03E37	2.06 ± 0.03E37
Lyα	1216	-	-	21.9	23.5	22.7 ± 1.1
He I	5876	0.116	-	0.120	0.113	0.116 ± 0.004
C II	2326	0.169	-	0.18	0.149	0.166 ± 0.016
C II	1335	0.080	-	0.080	0.079	0.080 ± 0.0006
C III]	1909	0.059	-	0.04	0.0551	0.051 ± 0.0099
[N II]	6584	0.538	0.565	0.51	0.569	0.546 ± 0.027
[O I]	6300	0.0056	0.0095	0.007	0.0062	0.0072 ± 0.0017
[O II]	7330	0.0283	0.0347	0.026	0.0266	0.0289 ± 0.0040
[O II]	3727	2.03	2.29	1.73	2.00	2.01 ± 0.23
[O III]	52μm	1.11	1.07	1.22	1.00	1.10 ± 0.092
[O III]	5007	1.53	1.46	1.49	1.62	1.525 ± 0.069
[O III]	4363	0.0035	0.0033	0.003	0.0033	0.0033 ± 0.0002
[O IV]	26μm	0.0008	-	0.002	0.0019	0.0016 ± 0.0007
[Ne II]	12.8μm	0.182	0.226	0.18	0.24	0.207 ± 0.031
[Ne III]	15.5μm	0.465	0.451	0.42	0.415	0.438 ± 0.024
[Ne III]	3869	0.077	0.0716	0.069	0.069	0.072 ± 0.004
[S II]	6725	0.152	0.161	0.1	0.150	0.141 ± 0.028
[S II]	4070	0.0067	0.0076	0.006	0.0064	0.0067 ± 0.0007
[S III]	18.7μm	0.556	0.577	0.54	0.510	0.546 ± 0.028
[S III]	9532	0.87	0.91	0.99	0.99	0.940 ± 0.061
[S IV]	10.5μm	0.411	0.326	0.43	0.410	0.394 ± 0.046

Table 23: Paris HII Region vs CLOUDY

Line		Mean	76.03	80.06
Hβ	erg/s	2.06 ± 0.03E37	2.06E37	2.04E37
Lyα	1216	22.7 ± 1.1	23.3	23.4
He I	5876	0.116 ± 0.004	0.116	0.116
C II	2326	0.166 ± 0.016	0.237	0.166
C II	1335	0.080 ± 0.0006	0.0926	0.107
C III]	1909	0.051 ± 0.0099	0.060	0.108
[N II]	6584	0.546 ± 0.027	0.578	0.602
[O I]	6300	0.0072 ± 0.0017	0.0080	0.0081
[O II]	7330	0.0289 ± 0.0040	0.0348	0.0368
[O II]	3727	2.01 ± 0.23	2.287	2.43
[O III]	52μm	1.10 ± 0.092	1.15	1.09
[O III]	5007	1.525 ± 0.069	1.829	1.62
[O III]	4363	0.0033 ± 0.0002	0.0044	0.0041
[O IV]	26μm	0.0016 ± 0.0007	0.0009	0.0007
[Ne II]	12.8μm	0.207 ± 0.031	0.219	0.230
[Ne III]	15.5μm	0.438 ± 0.024	0.469	0.450
[Ne III]	3869	0.072 ± 0.004	0.0938	0.089
[S II]	6725	0.141 ± 0.028	0.267	0.291
[S II]	4070	0.0067 ± 0.0007	0.0124	0.0136
[S III]	18.7μm	0.546 ± 0.028	0.542	0.528
[S III]	9532	0.940 ± 0.061	1.04	1.04
[S IV]	10.5μm	0.394 ± 0.046	0.0852	0.108

24.3 Paris NLR Model

This compares current predictions of the code with those of other participants at the Meudon meeting on photoionization calculations, for a model similar to the NLR of active nuclei.

Table 24: Paris Meeting NLR Model

Line		Netzer	Pequignot	Binette	Kraemer	Mean
Hβ	erg/s/cm^2	0.129	0.134	0.124	0.12	0.127±0.006
Hβ	4861	1.00	1.00	1.00	1.00	1.00
Lyα	1216	35.3	33.1	-	24.0	30.8±6.0
He I	5876	0.095	0.098	0.092	0.090	0.094±0.004
He II	4686	0.36	0.32	0.38	0.37	0.358±0.026
C II	2326	0.96	0.77	1.70	1.06	1.12±0.40
C II	1335	0.14	0.14	0.20	0.08	0.14±0.05
C III]	1909	4.59	4.99	6.50	4.91	5.25±0.85
C IV	1549	7.03	7.20	5.30	7.20	6.68±0.93
[N I]	5200	0.31	0.33	0.82	0.37	0.46±0.24
[N II]	6548	2.68	1.52	1.77	1.63	1.90±0.53
N III]	1749	0.40	0.40	0.43	0.48	0.428±0.038
N IV]	1487	0.45	0.43	0.51	0.48	0.468±0.035
N V	1240	0.32	0.30	0.32	0.28	0.305±0.019
[O I]	63.2 μm	-	0.62	0.14	0.10	0.29±0.29
[O I]	6300	1.32	0.90	1.62	1.04	1.22±0.32
[O II]	7325	0.11	0.094	0.16	0.10	0.116±0.03
[O II]	3727	3.4	2.62	4.41	2.73	3.29±0.82
[O III]	52μm	2.5	2.54	2.31	2.65	2.50±0.14
[O III]	5007	27.36	27.36	23.28	27.76	26.44±2.11
[O III]	4363	0.42	0.41	0.44	0.44	0.428±0.015
O III]	1663	0.97	0.95	0.92	1.01	0.963±0.038
[O IV]	25.9μm	5.69	5.19	5.49	-	5.46±0.25
O IV]	1403	0.53	0.44	0.51	0.66	0.534±0.092
O V]	1218	0.33	0.32	0.45	0.24	0.335±0.086
O VI	1035	0.17	0.17	0.22	0.10	0.165±0.049
[Ne II]	12.8μm	0.28	0.18	0.48	0.13	0.268±0.155
[Ne III]	15.5μm	2.8	2.62	1.83	1.25	2.13±0.72
[Ne III]	3869	2.70	2.59	2.27	1.67	2.31±0.46
Ne IV]	2423	0.82	0.79	1.03	1.12	0.94±0.16
[Ne V]	24.2μm	3.54	2.64	3.54	-	3.24 ±0.52
[Ne V]	3426	1.17	1.02	1.13	1.05	1.095±0.066
Mg II	2798	1.58	1.43	1.51	1.10	1.40±0.21
Si II	34.8μm	1.73	0.97	0.51	-	1.07±0.62
Si II	2335	0.21	0.17	0.09	-	0.16±0.06
Si III	1892	0.15	0.19	0.69	0.14	0.29±0.26
Si IV	1397	0.21	0.14	0.02	0.13	0.13±0.08
S II	6720	1.00	0.62	1.29	0.37	0.82±0.41
S II	4070	0.07	0.04	0.078	0.03	0.055±0.023
S III	18.7μm	0.75	0.49	0.68	0.65	0.64±0.11
S III	9532	2.25	1.38	1.73	1.62	1.74±0.37
S IV	10.5μm	1.39	0.73	0.94	1.57	1.16±0.39

25 SAMPLE INPUT

25.1 Limiting Cases

The following examples all have readily predictable answers, and demonstrate the behavior of the code in the appropriate limits.

```
title case A
c Seaton 1959 results; 4pi j (beta) = 5.56E-26
c for this model log totl H-beta = 4.745
c b(2)=3.73E-3 (3)=3.69E-2 (4)=0.0910 (5)=0.145 (6)=0.193
c n.b. very different results if not l-mixed
no induced processes ;  N.B. case A is a fiction; no induced transitions
hydrogen collisions off ; must turn off all collisions except 2s-2p
stop Lyman optical depth -6
constant temperature = 10,000K
print departure coef
stop zone 1
black body, T=50,000K
ionization parameter -2
hden = 15 ; must be high density to mix 2s, 2p
drmax 0
drmin 0
abundances -10
print short
```

Case A is a mathematical fiction; when the Lyman lines are optically thin continuum pumping must be important if the gas is ionized. Fluorescense is turned off with the "NO INDUCED PROCESSES" command. The density is set to a very high value (10^{15} cm^{-3}) so that the 2s-2p states are well *l-mixed*, in keeping with standard casee A assumptions. As a result, collisional excitation would dominate the level populations, and hydrogen collisions must be turned off with the "hydrogen collisions off" command. The Lyman continuum optical depth is set to a small value to force the outward Lyα optical depth to a small value. The pair of DRMAX and DRMIN commands set the zone thickness to 1 cm. The abundances are set to a very small value so that the electron density is equal to the hydrogen density.

Checks:

- departure coefficients for H, He levels
- neutral fractions
- Hβ emissivity

```
title case B
c this is a test of the 10-level H atom
c this input will predict the Hb emissivity per
c unit vol; the answer should be 1.24E-25 (Seaton 1959)
c b(3) = 0.116; (4)=0.201; (5)=0.276; (6)=0.335
print departure coefficients
case b
constant temperature = 4
stop zone 1
black body, T=50,000K
ionization parameter -2
hden = 0
abundances -10
drmax 0
drmin 0
print short
```

This test case compares the predictions of the ten level hydrogen atom with the Seaton (1959) results. The pair of DRMAX and DRMIN commands set the zone thickness to 1 cm. The "case b" command sets Lyman line optical depths to very large values.

Checks:

- departure coefficients for H, He levels
- neutral fractions
- Hβ emissivity

```
title hydrogen ionization in optically thin limit
c H cross sec=2.09E-18 cm^2, rec coef(A)=4.18E-13
c answer is neutral fraction of 2.00E-4
laser 1.5 Ryd
hden 1
phi(h) = 10
iterate
print last iteration
stop lyman optical depth -6
constant temperature = 10,000K
stop zone 1
drmax 0
drmin 0
abundances -10
print short
```

This checks the calculation of the hydrogen photoionization equilibrium. The continuum is a "laser" peaked at 1.5 Ryd, where the hydrogen photoioinzation cross section is 2.09×10^{-18} cm^{-2}.

Checks:

- hydrogen neutral fraction is 2.00×10^{-4}

```
title Compton limit, test continuum partition
c test of thermal equil in compton limit; temp should EXACTLY equal 2E5K
c check continuum partition;
c energy range, photon densities, luminosities, follow
c 0.25-1.  Q=26.6470 L=15.8190     c 1-1.807  Q=26.8867 L=16.3766
c 1.807-4  Q=27.3042 L=17.0948     c 4-20     Q=27.2041 L=17.3179
c 20 --    Q=22.9038 L=22.9038     c total lumin 17.5597
c nufnu(912A) = 1.8029E+16
black body t=200,000K lte
grains -5 no heating, no cooling
hden = 6
stop zone 1
faint .1
print last short
metals -10
iterate
stop lyman continuum optical depth = -6
print departure coef
drmax 0
drmin 0
tolerance 0.0001 %decrease tolerance on heating cooling match
```

This tests the behaviour of the code in the Compton limit. The incident continuum is a blackbody in strict thermodynamic equilibrium. Strict thermodynamic equilibrium is expected for all constituents of the gas. The input stream also lists the expected photon fluxes for the incident continuum; this tests the normalization of the continuum, and its distribution. Grains are included to test confirm their behaviour in the LTE limit. The pair of DRMAX and DRMIN commands set the zone thickness to 1 cm.

Checks:

- luminosity, photon flux, over various energy intervals, 4πJ at 912Å.
- Electron temperature *exactly* 2×10^5 K.
- Grain temperature forced to 2×10^5K by radiative processes.

```
Title, Martin Gaskell's funny model
c used to test that electron density convergence is OK
c hydrogen line spectrum strongly pumped by continuum
black 4000
lumin 27.2
constant temper 5500
faint -3
radius 15
hden 5.13
abundances 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000
stop zone 1
print short
drmax 0
drmin 0
```

This is mainly a test of the ability of the code to converge a model with a *very strange* electron density. The electrons are mainly contributed by heavy elements, and the gas is only slightly ionized.

Checks:

- Electron density is correct.
- Hydrogen line spectrum strongly pumped by continuum.

```
title high electron density approach to lte
c test from Ferland and Rees 88, collisions drive H to LTE
c collisions should drive all departure coef to unity
constant temperature = 50,000
print departure coefficients
stop zone 1
stop lyman optical depth -6
black body t=50,000
ionization parameter -5
hden = 19
abundances -10
iterate
print last short
drmax 0
drmin 0
```

This model is a test of the behaviour of hydrogen and helium in the high density, collision dominated, limit. The temperature is preset, the hydrogen density is set to a very high value, and the ionization parameter is very low. The resulting model is collision dominated, so this case checks that the collision physics occurs in detailed balance. The predicted departure coefficients should all equal unity. The pair of DRMAX and DRMIN commands set the zone thickness to 1 cm.

Checks:

- Hydrogen departure coefficients *exactly* unity. (Density not high enough to bring helium departure coefficients to unity.)

```
title const temper black body limit from Ferland and Rees 1988
c tests whether departure coef are forced to unity by induced processes
constant temper 50,000
stop zone 1
grains -5 no heating no cooling
hden 10
stop lyman continuum optical depth -6
black body, t=50,000 lte
metals -10
print departure coef
faint -1
print short last
iterate
drmax 0
drmin 0
```

This example tests whether induced processes force level populations of hydrogen and helium to LTE when they are irradiated by a blackbody in strict thermodynamic equilibrium. The density is low enough value for radiation to dominate the rate equations coupling levels with each other and the continuum. The expectation is for all departure coefficents to equal unity. A small amount of grains are included to check that the grain thermal balance is handled properly in this radiation dominated limit.

Checks:

- Departure ceofficients *exactly* unity.
- Grain temperature *exactly* 5×10^4 K.

```
title therm equil black body limit from Ferland and Rees 1988
c this tests whether thermal processes go to lte
stop zone 1
hden 10
stop lyman optical depth -6
black body, t=50,000 lte
abundances -10
print departure coef
print last short
iterate
drmax 0
drmin 0
```

This is the ultimate test of the bahaviour of the code in the strict thermodynamic equilibrium limit. The temperature is not held constant, so the resulting equilibrium temperature determines whether cooling processes are treated properly in the detailed balance limit. The equilibrium temperature should be exactly 5×10^4K, and all departure coefficients should equal unity. A small amount of grains are included to check that the grain thermal balance is handled properly in this limit.

Checks:

- Electron temperature *exactly* 5×10^4 K.
- Departure coefficients unity.

```
title check pure hydrogen sphere
c  the answer is R(Stromgren) =  4.16e+17
hden 4
sphere static
radius 16
blackbody 50,000k
q(h) 49
stop eden 3.
constant temperature 7500
abundances -10
print short
```

This is a test of the conservation of photon number across a sperical model. The estimate of the Strömgren radius comes from arguments similar to those given in Osterbrock's book. The low temperature ensures that collisional ionization and excitation are unimportant. The "STOP EDEN" command is used to stop the code near the hydrogen ionization front.

Checks:

- Strömgren radius exactly 4.16×10^{17} cm.
- Compare predicted, case B, and Q(H), Hβ luminosity.

```
title test against Van Blerkom and Hummer, Fig 4
c  tests hydrogen grd state rec effic against vb+h exact results
c  this is their case e) - "Zero contition"
c  their answer for H0/Htot at the illuminated edge is approx 5.8E-4,
c  and a Stromgren radius of roughly 7.8E16 cm
hden 4
blackbody 50,000k
phi(h) 12.30103
stop eden 3.5
constant temperature 4
abundances -10
print only zones
```

This is a test of the treatment of the diffuse fields, their transfer, and their effects on the ionization stucture of a nebula. The comparison is made against the exact calculation published by Van Blerkom and Hummer (1967). The geometry is open, that is, similar to that assumed in most BLR calculations.

Checks:

- Neutral fraction at illuminated face 5.8×10^{-4}.
- Location of ionization front at 7.8×10^{16} cm.
- "TOTL 4861" and "ca b 4861" agree; both slightly lower than "Q(H) 4861".

```
title test hydrogen atom emissivity
black 5
ionization parameter -2
sphere static            ;want full outward flux
constant temperature 4
abundances -10           ;pure hydrogen
hden 7                   ;suppress two-photon emission
stop eden 6              ;stop model at H ionization front
print short
hydrogen collisions off  ;make sure no collisional excitation
punch emitted continuum  ;output the predicted continuum
```

This checks that the predicted hydrogen continuum is in good agreement with exact results in the optically thin nebular limit. It was used to generate Figure 9 in HAZY.

Checks:

- Continuum relatve to Hβ should agree with Ferland (1980) filter averaged results.

```
title test of equations of motion in a wind
c test of wind code
c radiative acceleration (e- only) is 9.54E-7 cm s^-2
c terminal velocity (e- only) is 7.68 km s^-1
hden 4
table agn
luminosiy (total) 45
radius (parsecs) 1
stop thickness (parsecs) -1
no radiation pressure
wind 0.1
constant temperature 8
print only zones
```

This tests the management of the radiative acceleration of an electron scattering wind, and the resulting velocity. The parameters were chosen so that electron scattering is the dominant opacity source, so that the equations can be solved both numerically (in the example) and analytically (the expected solution given above). The actual acceleration is slightly below that due to Thomson scattering alone because the gas opacity at high energies is slightly below Thomson.

Checks:

- Terminal velocity should be ~ 7.68 cm s^{-1}.

```
title map of heating vs cooling
hden 0
table agn
ionization parameter -2.5
plot map
stop zone 1
print short
```

This is a test of the continuity of the code over a very large range of temperature. It was used to produce the thermal map shown in HAZY (Figure 3).

Checks:

- No breaks in heating-cooling curves where various approximations change.

25.2 Nebulae

The following examples establish "standard" models, useful to check whether (and how) the predictions of the code change with time.

```
title final F+P BLR model table 3
abundances osolar
stop column density 25.5
iterate 3 times
print last
ionization parameter -0.5
hden 9.5
table agn
plot continuum
stop zone 400
```

This calculation was presented by Ferland and Persson (1989). The differences between the present predictions and those given by FP are largely due to improved treatment of Balmer line escape and destruction. The cloud is quite thick, so that the default number of zones must be increased.

```
title "conventional" BLR model
constant pressure
ionization parameter -2
stop column density 23
table agn
print last iteration
iterate
hden 9.5
```

This is an example of a "conventional" BLR calculation. Notice that the Lyα/Hβ ratio is much larger than observed.

```
title Kwan+Krolick Ap.J. 250, 478 BLR model
constant gas pressure
f(nu) -7.32148
abundances he-1 c-3.699 n-4 o-3.1549 ne-4 mg-4.5229
continue al-10 si-4.4229 s-10 ar-10 ca-10 fe-4.5229
stop column density 23
interpolate (0 -5) (.05 -5) (.1 0) (1 -0.5) (7.353 -2.233)
continue (735 -3.233) (800 -015) (8,000,000 -15)
print last iteration
normalise 1216 100
iterate
plot continuum -3
hden 9.60206
```

This is the "standard" BLR model presented by Kwan and Krolick (1981).

```
title (roughly) Ferland et al. DQ Her model
c model of ice cold ionized cloud arund old nova DQ Her
c roughly that of Ferland et al. 1984 Ap.J. 281, 194.
c tests behaviour of code at very low temperatures
stop temp = 100
c flat continuum, followed by nu^-2 power law
interpolate (0, 0) (0.3, 0) (8,000,000 -14.8)
luminosity 34
hden = 2.
filling factor 0.667
covering factor 0.667
radius 16.5682, thickness=16.14613
abundances 2 20 200 50 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
grains
iterate
faint .05
print last
```

This is a test of the behaviour of the code in the extreme limit posed by the nebula surrounding DQ Her. A first cut at this model was published by Ferland et al. (1984).

```
title Ly alpha forest
c ionized by AGN power law plus cosmic background
background, z=2  ;this includes thermal and AGN background
double       ; mimic two-sided photoionization
hden -2
stop neutral column density 15
metals -1.5  ;reduce all heavy elements by 1.5 dex
faint -1
iterate      ; must iterate since optically thin
print last
```

This example demonstrates the behaviour of the code in the low density limit. The ionizing source is the cosmic background at a redshift of $z = 2$. The cloud is assumed to be optically thin to ionizing radiation, in keeping with the Gunn-Peterson test, so the "DOUBLE" command is included, and an iteration is performed.

```
title interstellar cloud irradiated by ism background
table ism
extinguish by a column of 22
cosmic rays, background
hden 0
abundances hii region  ;this turns on Orion grains by default
grains ism ;this over rides above default, forcing ism grains
sphere ;set this since matter in all directions
stop temperature linear 10
stop thickness 0.1 linear parsecs
iterate
print last
faint .1
```

This is a test of the behaviour of the code in the extreme of photoionization by a relatively hard continuum, at low densities. The continuum is the galactic background, attenuated by a column density of 10^{22} cm^{-2}. This example checks whether the ionization balance, thermal balance, and electron density sum, are performed correctly in this limit.

```
title conditions similar to Orion nebula blister
sphere
table star kurucz 39,700K
phi(h) 13.0
turbulence 8 km/sec
hden 4
abundances hii region
constant pressure
iterate
print last iteration
```

This is a model similar in spirit to the blister geometry HII region model commputed by Baldwin et al. (1991). Orion grains are turned on with the abundances command. The constant pressure command does a hydrostatic equilibrium structure.

```
title liner model
c a constant pressure (gas+radiation) model of a liner cloud
c in the spirit of Ferland and Netzer 83
table agn
metals 0.3
constant pressure
iterate ;must iterate to get radiation pressure correctly
hden 6
stop column density 23
ionization parameter -3
print last
```

This is a model somewhat like the Liner parameters proposed by Ferland and Netzer (1983). A second iteration is performed to allow the calculation of the line radiation pressure.

```
title "New" Paris meeting Planetary nebula
c recompute "standard" PN model of the Pequignot Meudon Conferance
sphere
black body, T=150,000K radius = 10
hden = 3.4771213
radius = 17
abund -1 C-3.523 N-4. O-3.222 ne-3.824 mg-4.523 al=-7
continue si-4.523 s-4.824 ar-9 ca=-7 fe-7
plot continuum 0.1
```

This is one of the "standard" models computed at the Paris meeting on photoionization and shock calculations. Table 20 compares the predictions of the current version of CLOUDY with predictions of a few of the other codes.

```
title "New" Paris meeting HII region
c "standard" HII region model of the Pequignot Meudon Conferance
sphere
black body, T=40,000K radius = 12.113943
hden = 2
radius = 18.477121
abund -1 C-3.6576 N-4.39794 O-3.481146 ne-4.30103 mg-8 al=-8
continue si-8 s-5.04576 ar-8 ca=-8 fe-8
plot continuum .1
iterate ; must iterate since fine structure lines optically thick
print last
```

This is one of the "standard" models computed at the Paris meeting on photoionization and shock calculations. Table 22 compares the predictions of the current version of CLOUDY with predictions of a few of the other codes. It is necessary to iterate since some fine structure lines are optically thick.

```
title paris meeting NLR model
interpolate (0 -10) (0.073 -10) (0.074 1) (7352 -4)
continue (7400 -15) (7,353,000 -20)
stop lyman continuum optical depth 4
hden 3
abund -1 C-3.5229 N-4. O-3.22185 ne-3.82391 mg-4.5229 al=-8
continue si-4.5229 s-4.82391 ar-8 ca=-8 fe-7
ionization parameter -2
```

This is the NLR model presented in the Meudon meeting on model nebulae.

```
title test of optimization driver
optimize intensity -1 ;want H-bet flux of .1 erg cm^-2 s^-1
*
optimize column density ;read in sets of desired column densities
hydrogen 2  21.3
end of column dens
*
optimize lines ; read in sets of desired relative line intensities
O  3 5007 3.1415
end of lines
*
hden 3 vary  ;vary the density, ionization parameter, and bb temp
black 5 vary
ionizat -2 vary
```

Vary three parameters to try to reproduce a desired Hβ intensity, ionized hydrogen column density, and 5007/Hβ intensity ratio.

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27 GLOSSARY OF SYMBOLS

As far as possible, the notation used by HAZY follows standard texts (Osterbrock 1988; Mihalas 1978). This is a summary of some of the symbols used.

Symbol	Description	Units	Page
A	radiative rate	s^{-1}	
b_n	departure coefficient	-	
C	collisional rate	s^{-1}	
D_{ul}	line destruction probability	-	
f(r)	filling factor	-	
g_i	statistical weight	-	
G	energy gains, heating	erg cm^3 s^{-1}	
I	intensity	erg s^{-1} sr^{-1}	
J	mean intensity	erg s^{-1} sr^{-1}	
N(cr)	cosmic ray density	cm^{-3}	
q	collisional rate coefficient	cm^3 s^{-1}	
P*(x)	LTE relative population	cm^3	
P_{ul}	line escape probability	-	
P_c	continuum escape probability	-	
T_u	energy density temperature	K	
T_{color}	color temperature	K	
U_g	grain potential	volt	
Q_{abs}	grain absorption efficiency	-	
Q(H)	hydrogen ionizing photons	s^{-1}	
v	velocity	cm s^{-1}	
V_g	grain potential	eV	
α(T)	recombination coefficient	cm^3 s^{-1}	
α_ν	continuous absorption cross section	cm^{-2}	
α_{lu}	line absorption cross section	cm^{-2}	
β	recombination cooling coef	cm^3 s^{-1}	
η	photon occupation number	-	
γ	one sided escape probability		
Γ	photoionization rate	s^{-1}	
κ	opacity	cm^{-1}	
Λ	energy loss, cooling	erg cm^3 s^{-1}	
ϕ	photon flux	cm^{-2} s^{-1}	
σ	scattering cross section	cm^{-2}	
Σ	projected grain area	cm^2	
τ	optical depth	-	
ν	frequency	Hz	

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28 SAMPLE OUTPUT

Tests were computed with the Ohio Supercomputer CRAY Y-MP, a micro-VAX II, a SUN Sparcstation, and a Northgate 486, with essentially identical results. Tests were also computed on a Decstation 3100, and the results were similar but not identical. The following output is from models computed on the Cray.

```
**************************************91Aug03***************************************
*                                                                                  *
* title final F+P BLR model table 3                                                *
* stop column density 25.5                                                         *
* iterate 3 times                                                                  *
* print last                                                                       *
* ionization parameter -0.5                                                        *
* hden 9.5                                                                         *
* table agn                                                                        *
* plot continuum                                                                   *
* stop zone 400                                                                    *
* c blr.in                                                                         *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

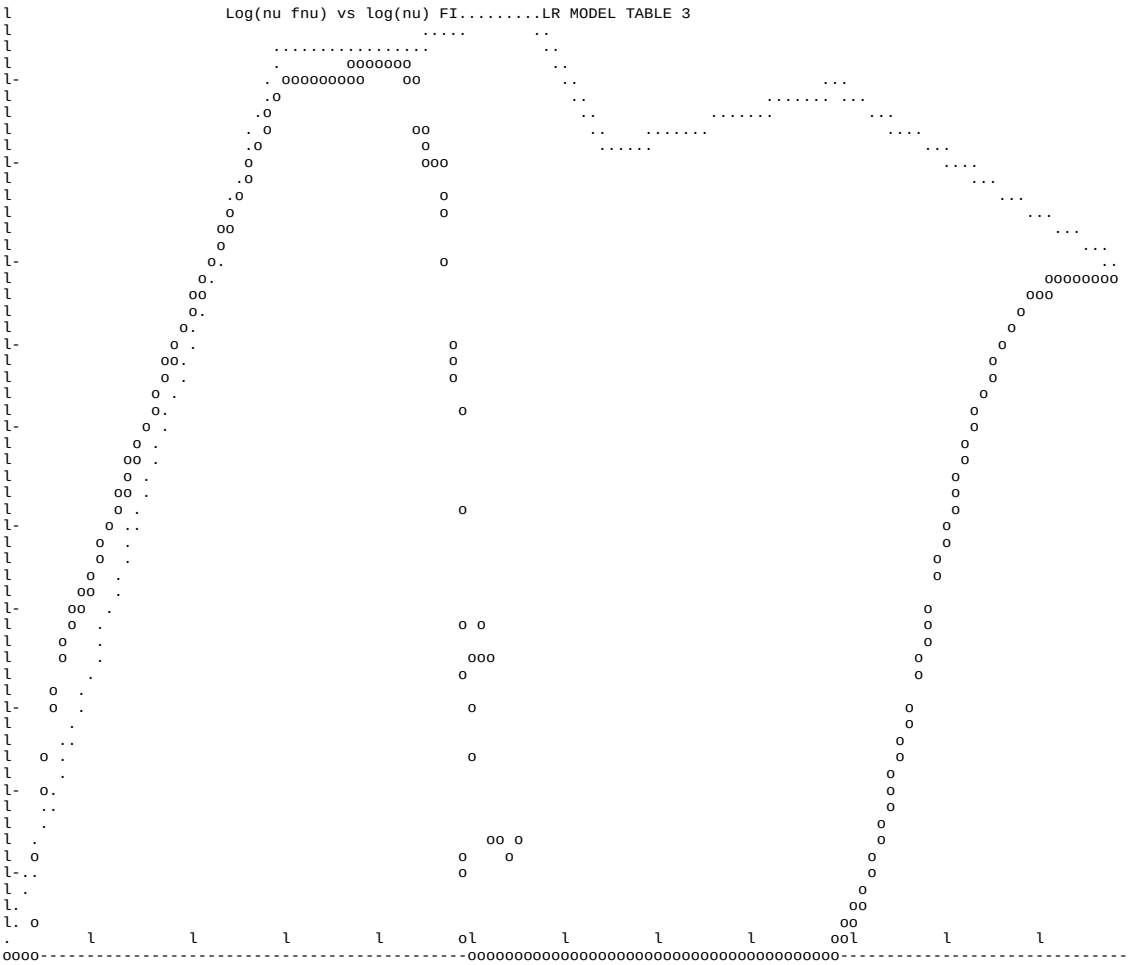
Chemical composition

He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

```
          546Cell Peak1.78E+00   Lo 1.00E-05=0.9101cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   9.2980   Average nu:3.038E+00   P( X-ray):   8.4693   P(BalC):   8.8023     Q(Balmer C):  19.7651
          Q(1.0-1.8):  19.1738   Q(1.8-4.0):  19.0661   Q(4.0-20):  18.5287   Q(20--):  16.7913     Ion pht flx:3.001E+19
          L(gam ray):   8.2078   Q(gam ray):  14.6227   L(Infred):   9.0163   Alf(ox):  -1.4120     Total lumin:   9.5633
          U(1.0----):3.165E-01   U(4.0----):3.628E-02   T(En-Den):2.004E+03   T(Comp):1.327E+07     nuJnu(912A):6.342E+08
          Occ(FarIR):5.638E+01   Occ(H n=6):2.126E-02   Occ(1Ryd):2.924E-08   Occ(4R):1.499E-10      Occ (Nu-hi):2.089E-38
          Tbr(FarIR):9.380E+01   Tbr(H n=6):9.439E+01   Tbr(1Ryd):4.619E-03   Tbr(4R):9.484E-05      Tbr (Nu-hi):2.306E-26

#####  1 Te:2.208E+04 Hden:3.162E+09 Ne:3.806E+09 R:1.000E+25 R-R0:1.432E+08 dR:2.864E+08 NTR:  1 Htot:7.009E-05 T912: 5.368E-05###
  2.25 4686  1.72 5876  0.00 1909  0.06 1549 38.66 6584  0.00 2326  0.00 3727  0.00 6300  0.00 2798  0.00 1035 39.16
Hydrogen    9.416E-06 1.000E+00 H+0/Hden: 1.000E+00 1.474E-17 H-     H2 7.808E-17 2.386E-14 H2+  HeH+ 2.470E-17 H col den 9.057E+17
H 2SP 3-6   6.402E-11 1.125E-11 8.395E-12 1.127E-11 1.588E-11 2.138E-11 Texc(La); 8.028E+03 T(contn): 2.004E+03 T(diffs): 8.404E+03
Helium      2.312E-08 1.768E-03 9.982E-01 He I 2S3  1.646E-09 Comp H, C 7.872E-08 1.310E-10 Fill Fact 1.000E+00 Gam 1/tot 9.095E-01
He singlet  2.147E-08 1.552E-13 1.984E-15 2.827E-15 4.203E-15 6.210E-15 He triplt 1.645E-09 9.014E-13 8.930E-15 2.479E-14 6.279E-15
HeII        1.768E-03 9.584E-10 4.051E-12 5.586E-12 8.030E-12 1.137E-11 9.559E-11 1.242E-09 1.614E-07 PRAD/GAS; 1.675E-02
Pressure    NgasTgas; 1.610E+14 P(total): 2.261E-02 P( gas ): 2.223E-02 P(Radtn): 3.724E-04 Rad accel 1.624E+00 Force Mul 3.918E+01
Carbon      0.000E+00 5.256E-07 9.219E-04 1.096E-01 7.964E-01 9.143E-02 1.636E-03 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 1.458E-04 1.629E-02 1.961E-01 7.591E-01 2.825E-02 2.031E-04 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 1.150E-04 1.820E-02 1.858E-01 4.472E-01 3.471E-01 1.652E-03 0.000E+00 Hex(tot): 0.000E+00 A:-12.803
Neon        0.000E+00 0.000E+00 7.219E-05 1.204E-02 2.898E-01 6.226E-01 6.442E-02 9.901E-03 1.080E-03 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 1.845E-05 1.715E-03 2.367E-02 2.785E-01 5.064E-01 1.718E-01 1.677E-02 1.044E-03 4.213E-05 0.000E+00
Aluminium 0 0.000E+00 1.104E-07 2.641E-05 1.658E-03 1.867E-02 2.094E-01 5.099E-01 2.349E-01 2.428E-02 1.143E-03 4.154E-05 0.000E+00
Silicon   0 0.000E+00 0.000E+00 1.424E-05 1.038E-03 1.504E-02 1.625E-01 4.295E-01 3.213E-01 6.590E-02 4.456E-03 1.746E-04 0.000E+00
Sulphur   1 0.000E+00 2.300E-05 8.290E-04 7.498E-03 1.163E-01 4.269E-01 3.250E-01 1.083E-01 1.423E-02 8.465E-04 3.019E-05 7.951E-07
Argon     3 7.265E-04 1.620E-02 5.076E-02 2.499E-01 3.382E-01 2.932E-01 4.648E-02 4.368E-03 1.713E-04 4.042E-06 8.701E-08 1.511E-09
Calcium   0 0.000E+00 0.000E+00 2.241E-07 2.198E-05 4.989E-04 1.786E-02 1.640E-01 4.137E-01 3.018E-01 7.991E-02 2.107E-02 1.114E-03
Iron      1 0.000E+00 0.000E+00 0.000E+00 3.544E-05 4.726E-03 9.636E-02 5.009E-01 2.704E-01 1.050E-01 1.997E-02 2.408E-03 2.312E-04
#####307 Te:4.954E+03 Hden:3.162E+09 Ne:7.727E+07 R:1.000E+25 R-R0:9.969E+15 dR:6.273E+13 NTR:  8 Htot:6.272E-09 T912: 1.813E+08###
  7.26 4686  0.12 5876  0.22 1909  4.19 1549 10.83 6584  0.00 2326  0.07 3727  0.00 6300  0.09 2798  0.44 1035  1.63
Hydrogen    9.761E-01 2.385E-02 H+0/Hden: 1.000E+00 4.788E-11 H-     H2 1.702E-07 2.993E-08 H2+  HeH+ 3.996E-09 H col den 3.162E+25
H 2SP 3-6   1.746E-07 5.238E-07 1.226E-08 3.143E-09 1.083E-09 5.073E-10 Texc(La); 6.138E+03 T(contn): 1.101E+03 T(diffs): 1.086E+03
Helium      9.974E-01 2.605E-03 0.000E+00 He I 2S3  8.584E-09 Comp H, C 1.853E-12 5.844E-14 Fill Fact 1.000E+00 Gam 1/tot 2.512E-02
He singlet  9.974E-01 3.757E-13 1.411E-15 4.922E-16 6.132E-16 8.212E-16 He triplt 8.310E-09 2.680E-10 5.488E-12 2.223E-14 1.152E-12
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 2.156E-03
Pressure    NgasTgas; 1.893E+13 P(total): 2.960E-03 P( gas ): 2.614E-03 P(Radtn): 3.467E-04 Rad accel 8.999E-05 Force Mul 1.171E+00
Carbon      5.329E-01 4.671E-01 3.909E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.825E-01 1.752E-02 2.146E-10 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.792E-01 2.077E-02 3.439E-10 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.555
```

```
Neon        9.992E-01 8.319E-04 7.708E-08 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 8.144E-03 9.918E-01 4.256E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 7.461E-05 9.999E-01 7.036E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.876E-03 9.981E-01 1.734E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.982E-04 9.996E-01 6.820E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 9.989E-01 1.140E-03 2.484E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 3.856E-04 1.057E-01 8.939E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 8.951E-02 9.104E-01 1.065E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because column dens reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached  83.3 percent of the total rate out.
  Photoionization of He 2TriS reached  94.6 percent of the total rate out.
 !The largest continuum occupation number was 5.638E+01 at 1.054E-05 Ryd.
 !The largest continuum brightness temperature was 2.683E+03K at 8.642E-03 Ryd.
  Hydrogen self ionization by alpha transitions reached   12.8% of the destruction rate for level 4.
  Some excited state HeI lines are thick.
  Some excited state HeII lines are thick.
  Some fine struc lines are optically thick, largest=7.12E+02
  Continuum occupation number reached  4.09E+02 for some fine structure transitions.
  Some fine structure lines were a heat source.
  Induced recombination was  11.4% of the total for H level 6
  Stimulated emission was  80.8% of the total for H transition 7 - 6
  Timescale-photoerosion of Fe=8.17E+06yr
  Free-free heating was  1.6% of the total.
C-Free-free heating significant and frequency out of range of gaunt factor routine.
  H- absorption heating was  2.3% of the total.
  Balmer continuum optical depth is  9.96E+00
  Balmer continuum stimulated emission correction to optical depths reached  0.16
  Paschen cont optical depth=  1.06E+00
  Continuum optical depth at low nu ( 1.054E-05 Ryd) was  1.752E+05
  The optical depth to Rayleigh scattering at 1300A is 1.93E+02
  The optical depth to the H2+ molecular ion is 4.68E+00
  Optical depth to negative hydrogen ion is  9.69E-02
  The ratio of radiation to gas pressure reached  2.48E+00.  Caused by Lyman alpha.
C-Model thick to e-scat; tau= 1.90E+00
C-This is the last iteration and H(a) optical depth changed by  11.1% (was  5.18E+05). Try another iteration
  Line radiation pressure capped by thermalization length.
```




```
**********> CLOUDY 80.08  <**********
* title final F+P BLR model table 3
* stop column density 25.5
* iterate 3 times
* print last
* ionization parameter -0.5
* hden 9.5
* table agn
* plot continuum
* stop zone 400
* c blr.in
* c cray
**********> LOG(U): -0.50 <**********
>>>>>>>>>> Cautions are present.
>>>>>>>>>> Another iteration is suggested.
```

Emission Line Spectrum. Constant Density Model. Open geometry. Iteration 3 of 3.
Intensity (erg/s/cm^2)

TOTL 4861	7.257	1.0000	Heat18751	5.100	0.0070	N 2 4239	4.229	0.0009	PHOT 1895	4.915	0.0046
TOTL 1216	8.523	18.4833	Crst 0	6.733	0.2998	N 2 5680	4.750	0.0031	Si 4 1397	7.252	0.9900
TotH 0	9.085	67.3834	H-FB 0	7.420	1.4573	N 2 2140	5.578	0.0210	Si 6 19	4.804	0.0035
BFH1 0	8.571	20.6380	H2+ 0	7.116	0.7229	N 2 1084	3.659	0.0003	Si 7 2148	5.219	0.0092
BFHx 0	8.210	8.9850	HEH+ 0	4.526	0.0019	N 3 1750	7.156	0.7934	Si 7 25	4.525	0.0019
BFHe 0	8.227	9.3361	HeFF 0	7.077	0.6613	N 3 990	5.469	0.0163	Si 8 1446	4.085	0.0007
TotM 0	8.288	10.7512	HeFB 0	7.192	0.8616	N 4 1486	6.949	0.4927	Si 9 1985	4.110	0.0007
FF H 0	7.286	1.0711	MeFB 0	5.990	0.0542	N 4 765	5.066	0.0064	S 1R 1807	5.035	0.0060
ComH 0	7.071	0.6516	MeFF 0	6.185	0.0848	N 4 1718	4.586	0.0021	S 2 6720	4.570	0.0021
H- H 0	7.441	1.5307	ToFF 0	8.385	13.4409	N 5 1240	7.008	0.5641	S 2 4074	6.017	0.0576
pair 0	4.751	0.0031	esc 584	6.439	0.1522	N 7r 25	3.381	0.0001	S 210330	5.818	0.0364
CA B 4861	8.460	15.9714	He I 504	7.398	1.3850	O 1 6300	6.226	0.0932	S II 6731	4.412	0.0014
CA B 1216	9.977	524.7340	He I 4471	6.355	0.1254	O 1 6363	5.749	0.0311	S II 6716	4.054	0.0006
DU B 4861	8.460	15.9695	TOTL 5876	6.590	0.2155	O 1 5577	5.853	0.0395	S II 4070	5.937	0.0479
Q(H) 4861	7.154	0.7895	Ca B 5876	6.795	0.3452	O 1 7774	5.716	0.0288	S II 4078	5.246	0.0098
Q(H) 1216	8.688	26.9934	TOTL10830	6.411	0.1429	6lev 8446	5.801	0.0350	S II10323	5.434	0.0150
TOTL 6563	7.496	1.7359	INWD10830	6.395	0.1376	6lev 1304	6.694	0.2736	S II10289	5.305	0.0112
TOTL 4861	7.257	1.0000	TOTL 3889	5.424	0.0147	6lev 13	3.686	0.0003	S II10373	4.776	0.0033
TOTL 4340	6.895	0.4350	TOTL 7065	6.761	0.3197	6lev 11	5.885	0.0425	S II10339	5.096	0.0069
TOTL 4102	6.515	0.1813	CcHE 0	6.095	0.0689	TOTL 3727	3.347	0.0001	S 3 9532	3.875	0.0004
TOTL18751	6.419	0.1453	He I 2	6.174	0.0828	TOTL 7325	4.705	0.0028	S 3 9069	3.459	0.0002
TOTL12818	6.388	0.1354	DevB 2	5.860	0.0401	O II 2471	4.617	0.0023	S 3 6312	4.095	0.0007
TOTL10938	6.128	0.0744	He I 5016	6.127	0.0743	O II 7323	4.457	0.0016	S 3 3722	3.866	0.0004
TOTL40512	5.502	0.0176	DevB 5016	6.004	0.0558	O II 7332	4.342	0.0012	S 3 1198	4.689	0.0027
TOTL26252	5.545	0.0194	He I 3965	5.838	0.0381	O 2 4651	5.440	0.0153	S 3 1729	5.192	0.0086
TOTL74578	4.803	0.0035	DevB 3965	5.600	0.0220	O 3 1663	7.413	1.4334	S 4 105	3.482	0.0002
2 NU 0	7.377	1.3202	He I 3614	5.554	0.0198	Augr 1663	3.413	0.0001	S 4 1406	6.439	0.1524
TOTL 1216	8.523	18.4833	DevB 3614	5.412	0.0143	Rec 1663	5.810	0.0357	S 5 1198	5.519	0.0183
TOTL 1026	6.107	0.0709	He I 3448	5.335	0.0120	O 3 5007	5.659	0.0253	S 5 786	3.908	0.0004
TOTL 973	6.482	0.1681	DevB 3448	5.109	0.0071	O 3 4959	5.182	0.0084	S 6 933	5.637	0.0240
TOTL 950	5.988	0.0538	HeII 228	7.330	1.1835	LOST 5007	4.824	0.0037	S 9 1715	3.970	0.0005
TOTL 938	5.572	0.0207	ESC 304	6.388	0.1354	TOTL 4363	5.896	0.0436	Ar 3 7135	3.941	0.0005
LA X 1216	7.622	2.3220	He2C 911	6.672	0.2604	O 3 2321	5.269	0.0103	Ar 3 7751	3.311	0.0001
Ind2 1216	4.782	0.0034	TOTL 1640	7.247	0.9787	O 3 834	5.935	0.0477	Ar 4 4740	3.485	0.0002
C13c 6563	3.934	0.0005	TOTL 4686	6.336	0.1200	O 3 3341	4.402	0.0014	Ar 4 7335	4.507	0.0018
C13h 6563	4.899	0.0044	TOTL 1216	6.693	0.2732	O 4 1402	6.791	0.3423	Ca 2 3933	6.408	0.1419
C14h 4861	3.556	0.0002	Ca B 1640	7.047	0.6177	CONT 1401	5.140	0.0076	Ca 2 8579	6.814	0.3609
CION 0	8.438	15.1899	DevB 1640	7.046	0.6164	O 4 789	5.971	0.0518	Ca 2 7306	6.212	0.0903
INWD 1216	8.523	18.4833	Ca B 4686	6.157	0.0795	O 4 3412	4.768	0.0032	Phot 7306	5.185	0.0085
INWD 6563	7.475	1.6550	DevB 4686	6.153	0.0788	O 5 630	5.870	0.0410	Ca2K 3934	6.112	0.0717

```
     INWD 4861  7.234   0.9504      REC  1656  6.757   0.3164      TOTL 1218  7.204   0.8867      Ca2H 3969  6.103   0.0702
     INWD18751  6.342   0.1218      C  I 9850  5.080   0.0067      O  5 1218  7.204   0.8866      Ca2X 8498  6.315   0.1143
     Strk 1216  5.075   0.0066      C  1 8727  6.338   0.1205      O  5 5112  4.020   0.0006      Ca2Y 8542  6.364   0.1282
     Strk 6563  6.771   0.3271      C  2 2326  6.117   0.0725      O  6 1035  7.469   1.6308      Ca2Z 8662  6.330   0.1185
     Strk 4861  6.494   0.1729      INWD 2326  6.112   0.0716      Ne 3  156  3.520   0.0002      CaF1 7291  5.958   0.0503
     Strk18751  5.853   0.0395      Phot 2326  6.280   0.1057      Ne 3 3869  5.680   0.0265      CaF2 7324  5.859   0.0400
     Strk40512  4.913   0.0045      C  2 1335  5.294   0.0109      Ne 3 3968  5.167   0.0081      Rec  3933  4.989   0.0054
     Dest 1216  7.888   4.2801      REC  1335  6.776   0.3309      Ne 3 3343  4.834   0.0038      Ca 4   32  3.669   0.0003
     Dest 6563  7.566   2.0399      C II 3134  3.590   0.0002      Ne 3 1815  4.973   0.0052      Fe 2   48  7.141   0.7656
     Dest40516  4.222   0.0009      C  2 4267  5.087   0.0068      Ne 4 4720  3.486   0.0002      Fe 2    7  7.141   0.7668
     Dest 4861  7.025   0.5871      TOTL  977  6.965   0.5112      Ne 4 1602  4.102   0.0007      Emis    3  6.261   0.1010
     Dest18751  6.037   0.0603      C3 C  977  6.764   0.3218      Ne 5 3426  4.781   0.0033      Cool    3  7.154   0.7903
     e-e+  511  4.691   0.0027      C3 R  977  6.534   0.1894      Ne 5 3346  4.349   0.0012      TOT     0  7.507   1.7782
     nFnu 4860  8.519  18.3131      TOTL 1909  7.879   4.1923      Ne 5 2976  3.956   0.0005      FEIR    0  4.941   0.0048
     nFnu 1215  7.032   0.5958      INWD 1909  7.643   2.4355      Ne 5 1575  4.432   0.0015      Fe 3    0  4.577   0.0021
     Inci 4861  8.459  15.9411      C  3 1907  4.335   0.0012      Ne 5 1134  5.754   0.0314      Fe 3 5270  3.897   0.0004
     Inci 1216  8.740  30.4218      C  3 1909  7.879   4.1911      Ne 6 1007  5.465   0.0161      Fe 3 4658  4.141   0.0008
     BA C    0  8.213   9.0540      C3 R 1909  6.119   0.0728      Ne 7  895  4.335   0.0012      Fe 3 1122  4.051   0.0006
     PA C    0  8.227   9.3494      Phot 1909  5.994   0.0547      Ne 8  774  3.736   0.0003      Fe 6    0  4.069   0.0006
     H FF    0  8.360  12.6948      C  3 2297  6.039   0.0606      Mg 1 4571  4.452   0.0016      Fe 6 5177  3.618   0.0002
     ComC    0  3.838   0.0004      C  3 4187  4.184   0.0008      Emis 2798  6.899   0.4393      Fe 7 6087  4.101   0.0007
     H FB    0  8.308  11.2629      C  3 4649  4.970   0.0052      Cool 2798  7.158   0.7979      Fe10 6374  5.202   0.0088
     Hind    0  5.242   0.0097      C  4 1549  8.291  10.8298      Mg 5 2751  4.206   0.0009      Coll 6374  5.179   0.0084
     Cool 1216  5.401   0.0139      INWD 1549  8.160   8.0027      Mg 6 1806  3.755   0.0003      Pump 6374  3.906   0.0004
     Heat 1216  7.548   1.9581      DEST 1549  5.949   0.0493      Mg 7 2629  5.252   0.0099      Fe11 7892  4.303   0.0011
     Crst  960  3.638   0.0002      C4 r 1549  5.629   0.0236      Mg 8    3  3.464   0.0002      Coll 7892  4.256   0.0010
     Hrst  960  3.420   0.0001      C  4 4659  3.979   0.0005      Al 3 1860  6.274   0.1040      Pump 7892  3.313   0.0001
     Cool 6563  6.380   0.1327      C 6r   34  4.646   0.0025      Si 2   35  3.334   0.0001      Fe11 2649  3.801   0.0004
     Heat 6563  6.774   0.3292      N  1 5200  3.381   0.0001      Si 2 2335  5.758   0.0317      Fe12 2170  3.647   0.0002
     Crst 4861  5.722   0.0292      N  2 6584  4.589   0.0021      Si 2 1808  4.583   0.0021      Totl    2  6.589   0.2150
     Hrst 4861  5.163   0.0081      N  2 6548  4.112   0.0007      Si 3 1207  5.792   0.0343      AugC    2  6.589   0.2150
     Cool18751  6.306   0.1122      N  2 5755  4.588   0.0021      Si 3 1895  6.963   0.5091
Lines with negative intensities;  205 T OI    0  255 Ne 2  128  361 Ar 2    7
```

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                          FINAL F+P BLR MODEL TABLE 3
Cooling:  CION    0:0.224  H FF    0:0.187  H FB    0:0.166  TOTL 1909:0.062  C  4 1549:0.160
Heating:  BFH1    0:0.306  BFHx    0:0.133  BFHe    0:0.139  TotM    0:0.160

IONIZE PARMET:  U(1-) -0.4996  U(4-): -1.4403  U(sp): -0.50  Q(ion):   10.707  L(ion):   6.205 Q(low): 20.82    P(low)  8.52
ENERGY BUDGET:  Heat:   9.085  Coolg:   9.087  Error:  0.5%  Compt H:   7.071  WorkF:   11.742 F-F  H  7.286    PRADMX:2.48E+00
Column density  H12:3.162E+25  H II:2.821E+24  HI:2.880E+25  H-:    2.487E+15  H2:   3.009E+18 H2+:6.693E+17    He H+:7.380E+16
                OH: 0.000E+00  Heff:3.367E+25
<NH>:3.162E+09  <Tp>:5.78E+03  <TO3>:1.31E+04  Ne:3.484E+09  ti(snd):1.62E+10  NeN+dl:1.59E+33 <T(C3)>:1.27E+04 <E(C3)>:3.47E+09
He/Ha:1.69E-01  =   1.72*true  N/Oap:0.00E+00  =   0.00true  T(O3R):1.000E+01  L THIN:3.14E-03 <T(S2)>:5.48E+03 <E(S2)>:2.71E+08
T He+:1.06E+04  EHe+:2.43E+09  T(O+):5.40E+03  EO+:4.26E+08  iter/zn:   2.287  Te-low:4.30E+03 Te-high:2.21E+04  Hlu/zn:3.07E+00
  <a>:0.00E+00  erdeFe2.5E+14  Tcompt1.91E-07  Tthr3.32E+02  <Tden>: 5.51E+03  <dens>:7.45E-15 <Mol>:1.20E+00
Mean Jeans      l(cm)4.79E+16  M(sun)2.16E+02  smallest:     len(cm):4.54E+16  M(sun):1.84E+02 Alf(ox-tran):  -244.3771

Optical Depths: CONTN; COMP: 1.90E+00    H-: 9.69E-02 R(1300): 1.93E+02 H2+ 4.68E+00  HeTri:6.54E+00
 Pfa:1.93E+00   Pa:2.05E+00   Ba:2.52E+00   Hb:2.22E+00  La:4.80E+03   1r:1.813E+08  1.8:5.83E+07  4.:9.077E+06  21R:1.043E+05
10830: 3.18E+04  3889: 1.39E+03  5876: 1.68E+03  7065: 9.24E+02
 1550: 1.24E+06  2800: 2.21E+09   774: 1.45E+02  1240: 1.52E+04  1035: 8.93E+04  1335: 1.21E+09   977: 9.62E+06  1397: 8.41E+05
  789: 1.31E+05  1207: 1.04E+06  1085: 1.66E+07  1194: 3.15E+03  1909: 3.83E+00  1895: 2.78E+01  2326: 6.03E+02  1666: 3.54E+01
 1750: 1.46E-01  1025: 3.03E+08   352: 1.03E+02   347: 1.00E-20  1860: 8.38E+04   630: 2.52E+05   834: 4.62E+08   835: 1.72E+06
 1808: 1.92E+09  1256: 3.04E+07    -3: 9.79E+07   -48: 4.65E+02  3934: 2.25E+07  3969: 1.14E+07  8498: 3.39E+04  8542: 3.02E+05
 8662: 1.72E+05   353: 1.48E+01  1304: 1.04E+09  1122: 9.94E+04   990: 6.42E+05  1402: 1.74E+00  1214: 1.36E+00  1486: 1.07E+00
 2335: 4.59E+03  1406: 2.61E+01  1656: 7.36E+08  9830: 1.23E-01  8727: 1.99E+00  6300: 2.75E+00  5577: 1.48E+00  7291: 1.71E+00
 7324: 1.18E+00  1039: 1.47E+08 -8446: 1.49E+04 -4368: 5.73E+01  -132: 1.66E+02  -113: 7.31E+02   -29: 9.60E-01   -46: 1.85E+01
 -245: 1.68E+00   765: 6.51E+05 -1198: 1.02E+01   786: 3.05E+04
 C157: 5.57E+01  N122: 3.95E+00  N205: 5.35E+00   N57: 7.48E-02  O146: 2.36E+02   O63: 7.12E+02   O88: 4.54E-01   O52: 7.62E-01
  O26: 7.32E-02  NE13: 4.07E-01  NE16: 1.76E-01  NE16: 5.47E-01   MG4: 3.29E-03  MG14: 1.73E-03   MG6: 1.02E-03  SI35: 6.49E+01
  S19: 2.81E-02   S34: 1.33E-02   S11: 7.34E-02   AR7: 4.49E-02   AR9: 1.04E-02  AR22: 3.04E-03  AR13: 1.27E-04   AR8: 2.43E-04
  CA3: 9.79E-03  CA12: 4.23E-05   CA4: 1.78E-04  Ne14: 8.67E-03  Ne24: 4.28E-03   Si3: 1.55E-03   Si4: 1.47E-02   Fe7: 3.32E-06
 Fe61:-1.72E-01  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 3.35E-03 Si6.5: 1.01E-03  C610: 8.57E+00  C370: 5.96E+00

Old hydro optical depths:    1 1.81E+08    2 9.43E+00    3 1.06E+00    4 5.67E-01    5 2.90E-01    6 1.51E-01    7 1.49E-01
                    Lines:  2-1 2.26E+12  3-2 5.18E+05  4-3 8.07E+04  5-4 7.50E+04  6-5 6.02E+04  7-6 4.90E+03  8-7 5.84E+03
New hydro optical depths:    1 1.81E+08    2 9.96E+00    3 1.06E+00    4 5.17E-01    5 2.60E-01    6 1.35E-01    7 1.38E-01
                    Lines:  2-1 2.30E+12  3-2 4.61E+05  4-3 8.05E+04  5-4 7.14E+04  6-5 5.77E+04  7-6 4.73E+03  8-7 5.92E+03

Old He Is optical depths:    1 5.87E+07    2 4.67E+00    3 2.01E-07    4-1.02E-07    5-2.71E-07    6-4.64E-07    7-4.03E-06
                    Lines:  2-1 1.53E+11  3-2 3.49E+00  4-3 1.57E-01  5-4 4.59E-02  6-5-1.41E-02  7-6 1.86E-01  8-7 2.78E+00
New HE Is optical depths:    1 5.83E+07    2 4.11E+00    3 2.45E-07    4-1.09E-07    5-2.95E-07    6-5.07E-07    7-4.38E-06
                    Lines:  2-1 1.57E+11  3-2 3.98E+00  4-3 1.87E-01  5-4 5.38E-02  6-5-1.27E-02  7-6 2.05E-01  8-7 3.07E+00

Old He II optical depths:    1 9.11E+06    2 1.82E+08    3 2.43E-07    4-1.96E-08    5-4.47E-08    6-7.72E-08    7-7.59E-07
                    Lines:  2-1 2.51E+08  3-2 8.04E+01  4-3 3.49E-02  5-4 8.09E-04  6-5-3.67E-04  7-6 3.32E-03  8-7 4.93E-02
New HE II optical depths:    1 9.08E+06    2 1.81E+08    3 2.80E-07    4-1.94E-08    5-4.47E-08    6-7.74E-08    7-7.60E-07
                    Lines:  2-1 3.35E+08  3-2 8.83E+01  4-3 4.01E-02  5-4 8.73E-04  6-5-3.26E-04  7-6 3.34E-03  8-7 4.96E-02

Hydrogen  -0.041 -1.050                        Log10 Mean Ionisation (over volume)
Helium    -0.003 -2.208 -3.637
Carbon    -0.375 -0.241 -2.509 -2.963 -3.807 -5.006 -6.944
Nitrogen  -0.062 -0.894 -2.513 -2.987 -4.143 -3.876 -5.571 -7.850
Oxygen    -0.036 -1.123 -2.428 -3.670 -4.067 -4.112 -4.486 -6.964
Neon      -0.002 -2.985 -2.407 -4.533 -3.936 -4.046 -5.244 -6.055 -7.108
Magnesium -2.322 -0.016 -1.513 -4.478 -4.514 -4.050 -4.086 -4.729 -5.822 -7.050 -8.525
Aluminum  -4.397 -0.002 -3.054 -2.483 -4.446 -4.067 -4.040 -4.573 -5.683 -7.043 -8.554
Silicon   -2.708 -0.003 -3.143 -2.732 -2.776 -3.998 -4.029 -4.395 -5.247 -6.503 -7.940
Sulphur   -3.268 -0.002 -2.987 -2.575 -3.256 -4.126 -3.965 -4.341 -4.999 -6.012 -7.315 -8.867-13.643
Argon     -0.003 -2.841 -3.041 -2.501 -4.456 -4.222 -4.122 -4.298 -4.498 -5.451 -6.596 -8.087-12.393-14.603-16.364
Calcium   -3.642 -0.866 -0.064 -3.100 -4.783 -4.336 -4.125 -4.142 -4.504 -5.184 -5.855 -7.206
Iron      -1.166 -0.033 -3.045 -2.403 -4.613 -4.388 -4.182 -3.993 -4.512 -5.025 -5.829 -6.801 -7.862
```

```
          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.041 -1.050                          Log10 Mean Ionisation (over radius)
Helium    -0.003 -2.208 -3.637
Carbon    -0.375 -0.241 -2.509 -2.963 -3.807 -5.006 -6.944
Nitrogen  -0.062 -0.894 -2.513 -2.987 -4.143 -3.876 -5.571 -7.850
Oxygen    -0.036 -1.123 -2.428 -3.670 -4.067 -4.112 -4.486 -6.964
Neon      -0.002 -2.985 -2.407 -4.533 -3.936 -4.046 -5.244 -6.055 -7.108
Magnesium -2.322 -0.016 -1.513 -4.478 -4.514 -4.050 -4.086 -4.729 -5.822 -7.050 -8.525
Aluminum  -4.397 -0.002 -3.054 -2.483 -4.446 -4.067 -4.040 -4.573 -5.683 -7.043 -8.554
Silicon   -2.708 -0.003 -3.143 -2.732 -2.776 -3.998 -4.029 -4.395 -5.247 -6.503 -7.940
Sulphur   -3.268 -0.002 -2.987 -2.575 -3.256 -4.126 -3.965 -4.341 -4.999 -6.012 -7.315 -8.867-13.643
Argon     -0.003 -2.841 -3.041 -2.501 -4.456 -4.222 -4.122 -4.298 -4.498 -5.451 -6.596 -8.087-12.393-14.603-16.364
Calcium   -3.642 -0.866 -0.064 -3.100 -4.783 -4.336 -4.125 -4.142 -4.504 -5.184 -5.855 -7.206
Iron      -1.166 -0.033 -3.045 -2.403 -4.613 -4.388 -4.182 -3.993 -4.512 -5.025 -5.829 -6.801 -7.862

0.5-1.0KEV:0.00E+00 1.0-1.5:******** 1.5-2.0:2.89-618 2.0-2.5:2.37-386 2.5-3:1.66-254 3-5:5.43E-72 5-7.5:4.61E+01 7.5-10:1.60E-19


                                              Normalised continuum
  0.25 0.114   0.27 0.094   0.30 0.074   0.33 0.056   0.36 0.042   0.39 0.037   0.43 0.036   0.47 0.032   0.51 0.016   0.56 0.002
  0.62 0.000   0.67 0.000   0.74 0.000   0.81 0.000   0.88 0.000   0.97 0.000   0.98 0.000   0.99 0.000   1.00 0.000


Inward continua (nuFnu) at head of Balmer, Lyman series;  5.59E+08  4.27E+08


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  3.50E+07  0.00E+00

                                          Emergent continuum - phot/ryd/cm2 (r in)
  0.26 2.48E+19  1.00 0.00E+00     3.9 0.00E+00    17.3 0.00E+00    75.3 0.00E+00    1.26E+03 4.85E-03    3.24E+05 3.36E+04
  0.29 1.52E+19  1.01 0.00E+00     4.0 0.00E+00    19.5 0.00E+00    81.6 0.00E+00    1.88E+03 2.02E+00    4.81E+05 3.71E+04
  0.33 8.86E+18  1.02 0.00E+00     4.2 0.00E+00    22.0 0.00E+00    88.3 0.00E+00    2.79E+03 1.15E+01    7.16E+05 3.13E+04
  0.37 5.21E+18  1.10 0.00E+00     4.7 0.00E+00    24.8 0.00E+00    95.71.53-1574    4.14E+03 1.75E+01    1.06E+06 2.11E+04
  0.42 3.94E+18  1.24 0.00E+00     5.3 0.00E+00    27.9 0.00E+00   103.75.25-1369    6.16E+03 1.97E+01    1.58E+06 1.19E+04
  0.47 2.94E+18  1.40 0.00E+00     5.9 0.00E+00    31.5 0.00E+00   112.35.32-1110    9.15E+03 1.95E+01    2.35E+06 5.87E+03
  0.53 8.81E+17  1.57 2.70E+07     6.7 0.00E+00    35.5 0.00E+00   121.6 3.81-900    1.36E+04 2.16E+01    3.49E+06 2.61E+03
  0.60 1.11E+16  1.78 0.00E+00     7.5 0.00E+00    40.0 0.00E+00   131.7 5.31-730    2.02E+04 3.49E+01    5.19E+06 1.07E+03
  0.67 8.63E+15  2.00 4.25E+09     8.5 0.00E+00    45.0 0.00E+00   142.7 5.50-651    3.00E+04 8.41E+01
  0.76 2.11E+09  2.25 2.10E+09     9.5 0.00E+00    50.5 0.00E+00   173.9 7.94-387    4.46E+04 2.76E+02
  0.86 1.63E+15  2.54 0.00E+00    10.7 0.00E+00    54.7 0.00E+00   258.5 1.41-157    6.64E+04 1.04E+03
  0.97 0.00E+00  2.86 0.00E+00    12.1 0.00E+00    59.3 0.00E+00   384.3 1.02E-56    9.86E+04 3.68E+03
  0.99 0.00E+00  3.22 0.00E+00    13.6 0.00E+00    64.2 0.00E+00   571.2 1.37E-38    1.47E+05 1.05E+04
  0.99 0.00E+00  3.63 0.00E+00    15.4 0.00E+00    69.5 0.00E+00   849.0 1.54E-11    2.18E+05 2.22E+04
```

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                                          CLOUDY 80.08

                ************************************91Aug03*************************************
                *                                                                                 *
                * title case A                                                                    *
                * c Seaton 1959 results; 4pi j(beta) 5.56E-26                                     *
                * c for this model total H-beta=4.745                                             *
                * c b(2)=3.73E-3 (3)=3.69E-2 (4)=0.091 (5)=0.145 (6)=0.193                        *
                * c n.b. very different results if not l-mixed                                    *
                * no induced processes ;N.B. case A is a fiction; no incuded transitions          *
                * hydrogen collisions off ; must turn off all collisions except 2s-2p             *
                * stop lyman optical depth -6                                                     *
                * constant temperature = 10,000K                                                  *
                * print departure coefficients                                                    *
                * stop zone 1                                                                     *
                * black body, T=50,000K                                                           *
                * ionization parameter -2                                                         *
                * hden = 15; must be high to mix 2s, 2p                                           *
                * drmax 0                                                                         *
                * drmin 0                                                                         *
                * abundances -10                                                                  *
                * print short                                                                     *
                * c casea.in                                                                      *
                * c cray                                                                          *
                *                                                                                 *
                ***********************************************************************************


                                             Chemical composition
He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  12.9889   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  12.8421     Q(Balmer C):  23.7181
          Q(1.0-1.8):  23.3840   Q(1.8-4.0):  22.7615   Q(4.0-20):  20.3654   Q(20--):   0.0000     Ion pht flx:3.001E+23
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  11.4994   Alf(ox):   0.0000     Total lumin:  13.2308
          U(1.0----):1.001E-02   U(4.0----):7.736E-06   T(En-Den):1.655E+04   T(Comp):4.787E+04     nuJnu(912A):1.157E+13
          Occ(FarIR):0.000E+00   Occ(H n=6):0.000E+00   Occ(1Ryd):0.000E+00   Occ(4R):0.000E+00     Occ (Nu-hi):0.000E+00
          Tbr(FarIR):0.000E+00   Tbr(H n=6):0.000E+00   Tbr(1Ryd):0.000E+00   Tbr(4R):0.000E+00     Tbr (Nu-hi):0.000E+00

#####  1 Te:1.000E+04 Hden:1.000E+15 Ne:9.995E+14 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:2.455E+06 T912: 2.971E-06###
  4.74 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 2326  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    4.824E-04 9.995E-01 H+0/Hden: 1.000E+00 3.356E-11 H-     H2 2.633E-13 6.132E-12 H2+  HeH+ 1.216E-20 H col den 1.000E+15
Hydrogen    1.587E-04 1.000E+00 H+0/Hden: 1.000E+00 2.804E-01 H-     H2 6.060E-02       H2+ 1.474E+00     He H+ 1.216E-20
H 2SP 3-6   8.037E-08 2.409E-07 7.897E-07 1.598E-06 2.798E-06 4.433E-06 Texc(La); 1.363E+04 T(contn): 1.655E+04 T(diffs): 1.680E+03
H 2SP 3-6   3.749E-03 3.745E-03 3.667E-02 8.991E-02 1.438E-01 1.919E-01
Helium      6.463E-03 9.918E-01 1.786E-03 He I 2S3  1.673E-05 Comp H, C 3.654E-01 7.633E-02 Fill Fact 1.000E+00 Gam 1/tot 9.964E-01
Helium      4.943E-08 5.004E-19 1.000E+00 He I 2S3  1.040E-01 Comp H, C 3.654E-01 7.633E-02 Fill Fact 1.000E+00 Gam 1/tot 9.964E-01
He singlet  6.427E-03 1.032E-06 3.532E-06 4.147E-06 4.760E-06 5.709E-06 He triplt 8.070E-06 6.754E-06 2.894E-07 7.535E-07 8.586E-07
He singlet  4.943E-08 4.849E-02 6.616E-01 9.414E-01 9.866E-01 9.965E-01 He triplt 1.040E-01 1.094E-01 1.076E-01 1.305E-01 9.635E-02
HeII        9.918E-01 1.835E-08 1.009E-07 2.310E-07 1.699E-07 1.381E-07 5.139E-07 2.371E-06 2.518E-04 PRAD/GAS; 1.048E-08
HeII        5.004E-19 8.593E-07 1.360E-02 3.771E-01 7.350E-01 8.977E-01 9.945E-01 9.999E-01 1.000E+00 8.713E-07 PRAD/GAS; 1.048E-08
Pressure    NgasTgas; 2.000E+19 P(total): 2.761E+03 P( gas ): 2.761E+03 P(Radtn): 2.892E-05 Rad accel 2.307E+05 Force Mul 1.015E+03
Carbon      8.757E-05 2.276E-01 7.701E-01 2.236E-03 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.467E-04 2.981E-01 6.988E-01 2.893E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.712E-04 4.886E-01 5.105E-01 7.755E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.380
Neon        1.030E-03 6.812E-01 3.175E-01 1.866E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 8.967E-04 2.409E-01 7.582E-01 1.640E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.760E-04 4.799E-01 5.101E-01 9.568E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 7.157E-05 1.758E-01 8.101E-01 1.409E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
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Sulphur   0 3.285E-05 1.707E-01 8.228E-01 6.464E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 7.254E-05 3.459E-01 6.501E-01 3.966E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 1.318E-02 5.175E-01 4.687E-01 6.508E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 3.546E-06 4.034E-02 6.679E-01 2.916E-01 2.118E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because optical depth reached
  Geometry is plane-parallel.
C-Density greater than 10**13
  Photoionization of He 2TriS reached   4.1 percent of the total rate out.
W-A physical process has been disabled.
W-Heating - cooling mismatch =  1.19E+00 Whats wrong????
  Frequency out of range of free-free gaunt factor routine.
  Continuum optical depth at low nu ( 1.053E-05 Ryd) was  5.952E+01
```

```
**********************************> CLOUDY 80.08  <**********************************
* title case A                                                                       *
* c Seaton 1959 results; 4pi j(beta) 5.56E-26                                        *
* c for this model total H-beta=4.745                                                *
* c b(2)=3.73E-3 (3)=3.69E-2 (4)=0.091 (5)=0.145 (6)=0.193                           *
* c n.b. very different results if not l-mixed                                       *
* no induced processes ;N.B. case A is a fiction; no incuded transitions             *
* hydrogen collisions off ; must turn off all collisions except 2s-2p                *
* stop lyman optical depth -6                                                        *
* constant temperature = 10,000K                                                     *
* print departure coefficients                                                       *
* stop zone 1                                                                        *
* black body, T=50,000K                                                              *
* ionization parameter -2                                                            *
* hden = 15; must be high to mix 2s, 2p                                              *
* drmax 0                                                                            *
* drmin 0                                                                            *
* abundances -10                                                                     *
* print short                                                                        *
* c casea.in                                                                         *
* c cray                                                                             *
**********************************> LOG(U): -2.00 <**********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                                                Intensity (erg/s/cm^2)

TOTL 4861  4.740   1.0000      Q(H) 1216 12.688*********      TOTL74578  3.082   0.0220      Strk18751  2.182   0.0028
TOTL 1216  6.388  44.4709      TOTL 6563  5.022   1.9175      TOTL 1216  6.388  44.4709      nFnu 4860  5.355   4.1223
TotH    0  6.390  44.7176      TOTL 4861  4.740   1.0000      TOTL 1026  5.928  15.4447      nFnu 1215  3.374   0.0431
BFH1    0  6.386  44.2523      TOTL 4340  4.510   0.5893      TOTL  973  5.620   7.5891      Inci 4861 11.600*********
BFHx    0  3.340   0.0398      TOTL 4102  4.319   0.3800      TOTL  950  5.382   4.3925      Inci 1216 12.930*********
FF H    0  4.368   0.4254      TOTL18751  4.182   0.2769      TOTL  938  5.188   2.8099      BA C    0  5.717   9.4915
CA B 4861  5.093   2.2540      TOTL12818  3.979   0.1736      INWD 1216  6.078  21.8041      PA C    0  5.204   2.9140
CA B 1216  6.626  77.0445      TOTL10938  3.796   0.1140      Strk 1216  4.392   0.4489      H FF    0  5.243   3.1868
DU B 4861  5.093   2.2537      TOTL40512  3.568   0.0674      Strk 6563  3.022   0.0192      H FB    0  5.651   8.1480
Q(H) 4861 11.154*********      TOTL26252  3.412   0.0471      Strk 4861  2.740   0.0100      ToFF    0  5.243   3.1868
```

```
                        CASE A
Cooling:  H FF    0:0.281  H FB    0:0.719
Heating:  BFH1    0:0.990

IONIZE PARMET:  U(1-) -1.9996  U(4-): -5.1115  U(sp): -2.00  Q(ion):   23.477  L(ion):  12.989 Q(low): 23.79    P(low) 12.86
ENERGY BUDGET:  Heat:   6.390  Coolg:   5.794  Error: 74.7%  Compt H:  -0.437  WorkF:    6.979 F-F  H  4.368    PRADMX:1.05E-08
Column density  H12:1.000E+15  H II:9.995E+14  HI:4.824E+11  H-:    3.356E+04  H2:   2.633E+02 H2+:6.132E+03    He H+:1.216E-05
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+15  <Tp>:1.00E+04  <TO3>:1.00E+04  Ne:9.995E+14  ti(snd):7.76E-07  NeN+dl:9.99E+29 <T(C3)>:1.00E+04 <E(C3)>:1.00E+15
He/Ha:2.97E-10  =   2.97*true  N/Oap:0.00E+00  =   0.00true  T(O3R):1.000E+01  L THIN:1.00E+30 <T(S2)>:1.00E+04 <E(S2)>:1.00E+15
T He+:1.00E+04  EHe+:1.00E+15  T(O+):1.00E+04  EO+:1.00E+15  iter/zn:   1.000  Te-low:1.00E+04 Te-high:1.00E+04  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.65E-15  Tthr6.65E-03  <Tden>: 1.00E+04  <dens>:1.66E-09 <Mol>:5.00E-01
Mean Jeans      l(cm)2.17E+14  M(sun)4.47E+00  smallest:     len(cm):2.17E+14  M(sun):4.47E+00 Alf(ox-tran):     0.0000
```

```
                                        CLOUDY 80.08

                ************************************91Aug03*************************************
                *                                                                              *
                * title case B                                                                 *
                * c this is a test of the 10-level H atom                                      *
                * c this input will predict the Hb emissivity per                              *
                * c unit vol; the answer should be 1.24E-25 (Seaton 1959)                      *
                * c b(3) = 0.116; (4)=0.201; (5)=0.276; (6)=0.335                              *
                * print departure coefficients                                                 *
                * case b                                                                       *
                * constant temperature = 4                                                     *
                * stop zone 1                                                                  *
                * black body, T=50,000K                                                        *
                * ionization parameter -2                                                      *
                * hden = 0                                                                     *
                * abundances -10                                                               *
                * drmax 0                                                                      *
                * drmin 0                                                                      *
                * print short                                                                  *
                * c caseb.in                                                                   *
                * c cray                                                                       *
                *                                                                              *
                ********************************************************************************


                                        Chemical composition
He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  -2.0111   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  -2.1579     Q(Balmer C):   8.7181
          Q(1.0-1.8):   8.3840   Q(1.8-4.0):   7.7615   Q(4.0-20):   5.3654   Q(20--):   0.0000     Ion pht flx:3.001E+08
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  -3.5006   Alf(ox):   0.0000     Total lumin:  -1.7692
          U(1.0----):1.001E-02   U(4.0----):7.736E-06   T(En-Den):2.943E+00   T(Comp):4.787E+04     nuJnu(912A):1.157E-02
          Occ(FarIR):3.607E-13   Occ(H n=6):1.295E-16   Occ(1Ryd):5.334E-19   Occ(4R):3.849E-23     Occ (Nu-hi):2.802E-33
          Tbr(FarIR):5.999E-13   Tbr(H n=6):5.749E-13   Tbr(1Ryd):8.425E-14   Tbr(4R):2.435E-17     Tbr (Nu-hi):5.037E-27

#####  1 Te:1.000E+04 Hden:1.000E+00 Ne:9.996E-01 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:1.980E-24 T912: 1.242E-20###
-24.91 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
P(LINES): 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    3.849E-04 9.996E-01 H+0/Hden: 1.000E+00 5.662E-16 H-     H2 1.340E-18 2.766E-17 H2+  HeH+ 8.342E-21 H col den 1.000E+00
Hydrogen    1.293E+11 1.000E+00 H+0/Hden: 1.000E+00 5.927E+09 H-     H2 4.842E+08       H2+ 1.044E+10     He H+ 8.342E-21
H 2SP 3-6   9.907E-15 2.016E-13 2.496E-21 3.577E-21 5.385E-21 7.823E-21 Texc(La); 5.265E+03 T(contn): 2.943E+00 T(diffs): 2.734E+02
H 2SP 3-6   4.620E+05 3.135E+06 1.159E-01 2.013E-01 2.767E-01 3.385E-01
Helium      6.713E-04 8.817E-01 1.176E-01 He I 2S3  2.233E-10 Comp H, C 3.654E-31 7.634E-32 Fill Fact 1.000E+00 Gam 1/tot 9.998E-01
Helium      5.806E+06 6.755E-06 1.000E+00 He I 2S3  3.236E+09 Comp H, C 3.654E-31 7.634E-32 Fill Fact 1.000E+00 Gam 1/tot 9.998E-01
He singlet  6.713E-04 2.091E-15 5.464E-22 7.203E-22 1.084E-21 1.574E-21 He triplt 2.233E-10 1.322E-20 3.125E-22 2.249E-21 6.212E-22
He singlet  5.806E+06 2.984E-03 1.151E-01 1.839E-01 2.526E-01 3.089E-01 He triplt 3.236E+09 2.408E-01 1.306E-01 4.379E-01 7.840E-02
HeII        8.817E-01 4.338E-16 1.165E-22 1.763E-22 2.792E-22 4.250E-22 3.689E-21 4.020E-20 8.035E-18 PRAD/GAS; 3.883E+04
HeII        6.755E-06 1.483E-09 2.382E-04 4.369E-03 1.834E-02 4.196E-02 1.084E-01 2.574E-01 4.846E-01 1.238E+00 PRAD/GAS; 3.883E+04
Pressure    NgasTgas; 2.000E+04 P(total): 1.072E-07 P( gas ): 2.761E-12 P(Radtn): 1.072E-07 Rad accel 1.877E-10 Force Mul 8.261E+02
Carbon      8.400E-06 3.524E-02 9.055E-01 5.918E-02 3.281E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.027E-05 2.968E-02 9.099E-01 6.038E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.204E-05 5.837E-02 9.118E-01 2.983E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.472
Neon        5.841E-05 6.776E-02 9.250E-01 7.226E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 2.348E-02 9.761E-01 4.406E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 8.098E-02 6.308E-01 2.882E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 1.758E-02 6.955E-01 2.831E-01 3.865E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 1.552E-02 8.364E-01 1.471E-01 9.894E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
```

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Argon     0 4.726E-06 3.715E-02 8.487E-01 1.139E-01 3.008E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 5.666E-02 9.143E-01 2.905E-02 2.337E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 4.066E-04 8.936E-02 8.677E-01 4.243E-02 5.715E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
  Photoionization of He 2TriS reached  86.4 percent of the total rate out.
W-Heating - cooling mismatch =  1.17E+00 Whats wrong????
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations   2 times.
 !Incident radiation field < 10*Habing diffuse ISM field.  Is this OK?
  The ratio of radiation to gas pressure reached  3.88E+04.  Caused by Lyman alpha.
C-The Lyman continuum is thin, and I assumed that it was thick.  Try another iteration.
```

```
**********************************> CLOUDY 80.08  <**********************************
* title case B                                                                       *
* c this is a test of the 10-level H atom                                           *
* c this input will predict the Hb emissivity per                                   *
* c unit vol; the answer should be 1.24E-25 (Seaton 1959)                           *
* c b(3) = 0.116; (4)=0.201; (5)=0.276; (6)=0.335                                   *
* print departure coefficients                                                      *
* case b                                                                            *
* constant temperature = 4                                                          *
* stop zone 1                                                                       *
* black body, T=50,000K                                                             *
* ionization parameter -2                                                           *
* hden = 0                                                                          *
* abundances -10                                                                    *
* drmax 0                                                                           *
* drmin 0                                                                           *
* print short                                                                       *
* c caseb.in                                                                        *
* c cray                                                                            *
**********************************> LOG(U): -2.00 <**********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                                              Intensity (erg/s/cm^2)

TOTL 4861-24.910   1.0000      TOTL 6563-24.478   2.7068      TOTL74578-26.671   0.0174      nFnu 1215-26.626   0.0193
TOTL 1216-23.641  18.5924      TOTL 4861-24.910   1.0000      2 NU    0-23.876  10.8299      Inci 4861 -3.400*********
TotH    0-23.703  16.1011      TOTL 4340-25.206   0.5066      TOTL 1216-23.641  18.5924      Inci 1216 -2.070*********
BFH1    0-23.703  16.1009      TOTL 4102-25.434   0.2995      INWD 1216-23.942   9.2962      BA C    0-24.283   4.2391
CA B 4861-24.907   1.0067      TOTL18751-25.468   0.2769      Dest 1216-24.219   4.9083      PA C    0-24.796   1.3014
CA B 1216-23.374  34.4095      TOTL12818-25.736   0.1492      e sc 1216-27.558   0.0022      H FF    0-24.757   1.4233
DU B 4861-24.907   1.0067      TOTL10938-25.957   0.0898      e sc18751-25.468   0.2771      H FB    0-24.465   2.7860
Q(H) 4861 -3.846*********      TOTL40512-26.147   0.0579      e sc40512-26.147   0.0580      Cool 1216-26.856   0.0113
Q(H) 1216 -2.312*********      TOTL26252-26.341   0.0371      nFnu 4860-24.385   3.3524      ToFF    0-24.757   1.4233
```

```
                        CASE B
Cooling:  H FF    0:0.337  H FB    0:0.660
Heating:  BFH1    0:1.000

IONIZE PARMET:  U(1-) -1.9996  U(4-): -5.1115  U(sp): -2.00  Q(ion):    8.477  L(ion):  -2.011 Q(low):  8.79    P(low) -2.14
ENERGY BUDGET:  Heat: -23.703  Coolg: -24.285  Error: 73.8%  Compt H: -30.437  WorkF:  -20.000 F-F  H-29.743    PRADMX:3.88E+04
Column density  H12:1.000E+00  H II:9.996E-01  HI:3.849E-04  H-:    5.662E-16  H2:   1.340E-18 H2+:2.766E-17    He H+:8.342E-21
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+00  <Tp>:1.00E+04  <TO3>:1.00E+04  Ne:9.996E-01  ti(snd):7.76E-07  NeN+dl:9.99E-01 <T(C3)>:1.00E+04 <E(C3)>:1.00E+00
He/Ha:9.32E-11  =   0.93*true  N/Oap:3.26E-01  =   0.33true  T(O3R):9.854E+03  L THIN:1.00E+30 <T(S2)>:1.00E+04 <E(S2)>:1.00E+00
T He+:1.00E+04  EHe+:1.00E+00  T(O+):1.00E+04  EO+:1.00E+00  iter/zn:   1.000  Te-low:1.00E+04 Te-high:1.00E+04  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.65E+15  Tthr7.98E+12  <Tden>: 1.00E+04  <dens>:1.66E-24 <Mol>:5.00E-01
Mean Jeans      l(cm)6.87E+21  M(sun)1.41E+08  smallest:     len(cm):6.87E+21  M(sun):1.41E+08 Alf(ox-tran):     0.0000
```

```
                                    CLOUDY 80.08

************************************91Aug03*************************************
*                                                                              *
* title Compton limit, test continuum partition                                *
* c test of thermal equil in compton limit; temp should EXACTLY equal 2E5K     *
* c check continuum partition;                                                 *
* c energy range, photon densities, luminosities, follow                       *
* c 0.25-1.  Q=26.6470 L=15.8190     c 1-1.807  Q=26.8867 L=16.3766            *
* c 1.807-4  Q=27.3042 L=17.0948     c 4-20     Q=27.2041 L=17.3179            *
* c 20 --    Q=22.9038 L=22.9038     c total lumin 17.5597                      *
* c nufnu(912A) = 1.8029E+16                                                   *
* black body t=200,000K lte                                                    *
* grains -5 no heating no cooling                                              *
* hden = 6                                                                     *
* stop zone 1                                                                  *
* faint .1                                                                     *
* print last short                                                             *
* metals -10                                                                   *
* iterate                                                                      *
* stop lyman continuum optical depth = -6                                      *
* print departure coef                                                         *
* drmax 0                                                                      *
* drmin 0                                                                      *
* tolerance .0001  % decrease tolerance on heat-cool match                     *
* c compton.in                                                                 *
* c cray                                                                       *
*                                                                              *
********************************************************************************

                                  Chemical composition
He:.098 C:3.63E-14 N:1.12E-14 O:8.51E-14 Ne:1.23E-14 Mg:3.80E-15 Al:3.0E-16 Si:3.55E-15 S:1.62E-15 A:3.6E-16 Ca:2.3E-16 Fe:4.68E-15

          378Cell Peak4.95E+00   Lo 1.00E-05=0.9105cm   Hi-Con:4.43E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  17.5517   Average nu:3.727E+00   P( X-ray):  13.4506   P(BalC):  15.8197     Q(Balmer C):  26.6477
          Q(1.0-1.8):  26.8874   Q(1.8-4.0):  27.3043   Q(4.0-20):  27.2042   Q(20--):  22.7730     Ion pht flx:4.387E+27
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  14.1236   Alf(ox):   0.0000     Total lumin:  17.5599
          U(1.0----):1.463E+11   U(4.0----):5.338E+10   T(En-Den):2.000E+05   T(Comp):1.999E+05     nuJnu(912A):1.805E+16
          Occ(FarIR):1.202E+05   Occ(H n=6):4.463E+01   Occ(1Ryd):8.331E-01   Occ(4R):4.426E-02      Occ (Nu-hi):1.074E-15
          Tbr(FarIR):1.999E+05   Tbr(H n=6):1.982E+05   Tbr(1Ryd):1.316E+05   Tbr(4R):2.800E+04      Tbr (Nu-hi):7.396E-09
          Grain(Pal):4.423E-28   Grain(Bal):1.783E-27   Grain Mg2:4.381E-27   Grain R:1.527E-26     Grain(HeII):5.214E-27

#####  1 Te:1.999E+05 Hden:1.000E+06 Ne:1.196E+06 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:3.892E-05 T912: 2.527E-20###
-14.48 4686  2.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
P(LINES): 0.000 0.000 0.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    5.500E-16 1.000E+00 H+0/Hden: 1.000E+00 0.000E+00 H-     H2 0.000E+00 0.000E+00 H2+  HeH+ 0.000E+00 H col den 1.000E+06
Hydrogen    1.013E+00 1.000E+00 H+0/Hden: 1.000E+00 1.000E+00 H-     H2 6.747E-04       H2+ 5.009E+09     He H+ 0.000E+00
H 2SP 3-6   8.139E-18 2.043E-17 5.662E-17 9.616E-17 1.471E-16 2.092E-16 Texc(La); 1.982E+05 T(contn): 2.000E+05 T(diffs): 1.948E+02
H 2SP 3-6   1.205E+00 1.008E+00 1.040E+00 1.032E+00 1.028E+00 1.026E+00
Helium      1.075E-29 7.477E-16 1.000E+00 He I 2S3  3.503E-31 Comp H, C 3.892E-05 3.892E-05 Fill Fact 1.000E+00 Gam 1/tot 3.522E-01
Helium      1.158E+01 9.952E-01 1.000E+00 He I 2S3  1.505E+00 Comp H, C 3.892E-05 3.892E-05 Fill Fact 1.000E+00 Gam 1/tot 3.522E-01
He singlet  4.839E-32 1.738E-31 5.507E-31 1.339E-30 2.812E-30 5.475E-30 He triplt 6.169E-33 3.564E-33 6.104E-32 2.562E-31 2.337E-32
He singlet  1.158E+01 2.805E+01 5.409E+01 7.689E+01 1.052E+02 1.436E+02 He triplt 1.505E+00 3.097E-01 1.762E+01 2.506E+01 1.377E+00
HeII        1.300E-16 5.023E-17 7.261E-17 1.105E-16 1.613E-16 2.231E-16 1.779E-15 1.445E-14 1.936E-12 PRAD/GAS; 5.113E+03
HeII        9.952E-01 9.820E-01 1.025E+00 1.023E+00 1.026E+00 1.024E+00 1.046E+00 1.035E+00 1.040E+00 1.167E+00 PRAD/GAS; 5.113E+03
Gra-ISM     Dust temp 2.001E+05 Pot(Volt) 4.377E+02 Nelectron 9.119E+04 drft cm/s 1.790E+12  Heating: 0.000E+00 Frac(tot) 0.000E+00
Sil-ISM     Dust temp 2.001E+05 Pot(Volt) 4.273E+02 Nelectron 8.903E+04 drft cm/s 2.102E+12  Heating: 0.000E+00 Frac(tot) 0.000E+00
Pressure    NgasTgas; 4.585E+11 P(total): 3.238E-01 P( gas ): 6.331E-05 P(Radtn): 3.237E-01 Rad accel 4.197E+06 Force Mul 1.007E+00
```

```
Carbon      0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.713E-13 3.361E-05 1.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.343E-18 4.031E-04 9.996E-01 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.655E-26 1.661E-13 1.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-13.426
Neon        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.940E-21 5.618E-11 1.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.016E-15 1.372E-07 1.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.374E-11 8.677E-06 1.000E+00
Silicon   1 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.940E-08 1.522E-04 9.998E-01
Sulphur   1 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.322E-06 8.677E-03 9.913E-01
Argon     0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.825E-09 6.202E-04 9.994E-01
Calcium   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.378E-21 1.682E-10 1.000E+00 0.000E+00
Iron      5 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 5.080E-08 3.008E-04 9.997E-01
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
  Photoionization of He 2TriS reached 100.0 percent of the total rate out.
 !The largest continuum occupation number was 1.202E+05 at 1.053E-05 Ryd.
  The continuum occupation number fell below 1 at  1.033E+03 Angstroms.
 !The largest continuum brightness temperature was 1.999E+05K at 1.053E-05 Ryd.
  The continuum brightness temperature fell below 10,000K at  5.745E+00 Ryd.
W-A physical process has been disabled.
  Continuum occupation number reached  8.37E+03 for some fine structure transitions.
  Induced recombination was  94.8% of the total for H level 7
  Stimulated emission was  99.4% of the total for H transition 7 - 6
  Population of H n=2 reached  3.30E+00 relative to the ground state.
  Compton heating was100.0% of the total.
W-Maximum tempertaure of grain  Gra-ISM   was  2.00E+05, above sublimation temperature?
W-Maximum tempertaure of grain  Sil-ISM   was  2.00E+05, above sublimation temperature?
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  5.11E+03.  Caused by line number  7
```

```
*********************************> CLOUDY 80.08  <*********************************
* title Compton limit, test continuum partition                                     *
* c test of thermal equil in compton limit; temp should EXACTLY equal 2E5K          *
* c check continuum partition;                                                      *
* c energy range, photon densities, luminosities, follow                            *
* c 0.25-1.  Q=26.6470 L=15.8190     c 1-1.807  Q=26.8867 L=16.3766                 *
* c 1.807-4  Q=27.3042 L=17.0948     c 4-20     Q=27.2041 L=17.3179                 *
* c 20 --    Q=22.9038 L=22.9038     c total lumin 17.5597                          *
* c nufnu(912A) = 1.8029E+16                                                        *
* black body t=200,000K lte                                                         *
* grains -5 no heating no cooling                                                   *
* hden = 6                                                                          *
* stop zone 1                                                                       *
* faint .1                                                                          *
* print last short                                                                  *
* metals -10                                                                        *
* iterate                                                                           *
* stop lyman continuum optical depth = -6                                           *
* print departure coef                                                              *
* drmax 0                                                                           *
* drmin 0                                                                           *
* tolerance .0001  % decrease tolerance on heat-cool match                          *
* c compton.in                                                                      *
* c cray                                                                            *
*********************************> LOG(U): 11.17 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.

Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                Intensity (erg/s/cm^2)

                                    Emergent line intensities
TOTL 4861-14.482   1.0000      TOTL 6563-14.123   2.2854      TOTL 4340-14.770   0.5145      TOTL18751-15.039   0.2772
TOTL 1909-35.000   0.0000      C  4 1549-35.000   0.0000      N  2 6584-35.000   0.0000      N  2 6548-35.000   0.0000
O  1 6300-35.000   0.0000      O  1 6363-35.000   0.0000      TOTL 3727-35.000   0.0000      O  3 5007-35.000   0.0000
O  3 4959-35.000   0.0000      TOTL 4363-35.000   0.0000      Emis 2798-35.000   0.0000      S  2 6720-35.000   0.0000
S  3 9532-35.000   0.0000

                                    Intrinsic line intensities
TOTL 4861-14.481   1.0000      TOTL 6563-14.122   2.2844      e sc 6563-14.724   0.5714      Hind    0-12.364 130.6723
TOTL 1216-12.680  63.2397      TOTL 4861-14.481   1.0000      e sc 4861-14.480   1.0015      He3i    0-13.072  25.6150
TotH    0 -4.410*********      TOTL 4340-14.769   0.5146      nFnu 4860 -6.388*********      HeFF    0-12.373 128.0286
BFH1    0-12.200 190.6821      TOTL 4102-15.006   0.2980      nFnu 1215 -4.043*********      HeFB    0-12.644  68.6153
BFHx    0-12.605  75.0747      TOTL18751-15.038   0.2769      Inci 4861 14.226*********      ToFF    0-11.823 454.6321
BFHe    0-12.199 191.3468      TOTL12818-15.300   0.1516      Inci 1216 15.930*********      HeII  228-11.901 380.0344
FF H    0-11.818 460.1147      TOTL 1216-12.680  63.2397      BA C    0-13.259  16.6518      He2C  911-12.975  32.0131
ComH    0 -4.410*********      TOTL  973-13.600   7.5891      PA C    0-13.910   3.7232      TOTL 1640-13.215  18.4318
CA B 4861-14.199   1.9118      TOTL  950-13.897   3.8357      Grai    0 -2.907*********      TOTL 4686-14.179   2.0005
CA B 1216-12.539  87.4564      TOTL  938-14.138   2.2030      Grai 1216-14.479   1.0029      TOTL 1216-13.622   7.2220
DU B 4861-14.373   1.2809      INWD 1216-12.974  32.1294      H FF    0-11.967 326.6035      Ca B 1640-13.025  28.5197
Q(H) 4861 15.319*********      Dest 1216-14.479   1.0029      ComC    0 -4.410*********      Ca B 4686-14.144   2.1686
Q(H) 1216 16.853*********      e sc 1216-12.680  63.2397      H FB    0-12.148 215.1410      DevB 4686-14.488   0.9824
```

COMPTON LIMIT, TEST CONTINUUM PARTITION
Cooling: ComC   0:1.000
Heating: ComH   0:1.000

IONIZE PARMET: U(1-) 11.1654 U(4-): 10.7274 U(sp): 11.17 Q(ion):   27.642 L(ion): 17.552 Q(low): 26.68   P(low) 15.83
ENERGY BUDGET: Heat: -4.410 Coolg: -4.410 Error: 0.0% Compt H: -4.410 WorkF: -11.272 F-F H-11.818   PRADMX:5.11E+03
Column density H12:1.000E+06 H II:1.000E+06 HI:5.500E-10 H-:   0.000E+00 H2:   0.000E+00 H2+:0.000E+00   He H+:0.000E+00
                OH: 0.000E+00 Heff:0.000E+00
<NH>:1.000E+06 <Tp>:2.00E+05 <TO3>:0.00E+00 Ne:0.000E+00 ti(snd):1.91E-07 NeN+dl:1.20E+12 <T(C3)>:0.00E+00 <E(C3)>:0.00E+00
He/Ha:1.56E-01 =   1.59*true N/Oap:0.00E+00 =   0.00true T(O3R):0.000E+00 L THIN:1.00E+30 <T(S2)>:0.00E+00 <E(S2)>:0.00E+00
T He+:2.00E+05 EHe+:1.20E+06 T(O+):0.00E+00 EO+:0.00E+00 iter/zn: 1.000 Te-low:2.00E+05 Te-high:2.00E+05 Hlu/zn:1.00E+00
  <a>:0.00E+00 erdeFe0.0E+00 Tcompt2.58E-10 Tthr2.44E+00 <Tden>: 2.00E+05 <dens>:2.31E-18 <Mol>:6.07E-01
Mean Jeans   l(cm)2.36E+19 M(sun)8.02E+06 smallest: len(cm):2.36E+19 M(sun):8.02E+06 Alf(ox-tran):   0.0000
  L(dust):-2.907E+00
           Gra-ISM   Sil-ISM   Gra-Ori   Sil-Ori   Sil-0.01 Sil-0.1   SilicatPN
  <Tdust>: 2.001E+05 2.001E+05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Vel D>: 3.579E+12 4.204E+12 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Pot D>: 4.377E+02 4.273E+02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CLOUDY 80.08

**********91Aug03**********
*   *
* title test that energy is conserved   *
* hden 1.0   *
* constant pressure   *
* iterate   *
* print last iteration   *
* black body, temp=5.5   *
* luminostity total -4   *
* stop temperature 3 linear   *
* radius 25   *
* c conserv.in   *
* c cray   *
*   *
****

Chemical composition
He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

          398Cell Peak7.74E+00   Lo 1.00E-05=0.9105cm   Hi-Con:6.88E+01 Ryd   E(hi):7.35E+06Ryd   E(hi):   100.01 MeV
          P(nu>1ryd): -4.0022   Average nu:5.628E+00   P(X-ray): -6.0827   P(BalC): -6.2859   Q(Balmer C):   4.5377
          Q(1.0-1.8):   4.8343   Q(1.8-4.0):   5.3839   Q(4.0-20):   5.6985   Q(20--):   3.2209   Ion pht flx:8.115E+05
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred): -8.0210   Alf(ox):   0.0000   Total lumin: -3.9999
          U(1.0----):2.707E-06   U(4.0----):1.672E-06   T(En-Den):8.149E-01   T(Comp):3.028E+05   nuJnu(912A):1.478E-06
          Occ(FarIR):8.382E-18   Occ(H n=6):3.124E-21   Occ(1Ryd):6.821E-23   Occ(4R):6.913E-24   Occ (Nu-hi):7.530E-38
          Tbr(FarIR):1.394E-17   Tbr(H n=6):1.387E-17   Tbr(1Ryd):1.077E-17   Tbr(4R):4.373E-18   Tbr (Nu-hi):8.093E-31

Pressure not converged; zone 18 Te: 1.19E+03 Hden: 3.04E+01 current Pres: 5.58E-12 Corr Pres 1.32E-11
Pressure not converged; zone 19 Te: 7.17E+02 Hden: 5.45E+01 current Pres: 5.99E-12 Corr Pres 1.32E-11
Pressure not converged; zone 20 Te: 5.17E+02 Hden: 9.76E+01 current Pres: 7.50E-12 Corr Pres 1.32E-11
Pressure not converged; zone 21 Te: 3.85E+02 Hden: 1.75E+02 current Pres: 9.92E-12 Corr Pres 1.32E-11
1 Te:6.567E+03 Hden:1.000E+01 Ne:2.730E+00 R:1.000E+25 R-R0:1.013E+15 dR:2.026E+15 NTR: 6 Htot:8.049E-23 T912: 9.904E-02###
 -8.54 4686 0.04 5876 0.21 1909 0.00 1549 0.00 6584 2.04 5007 0.00 3727 1.80 6300 2.04 2798 1.38 1035 0.00
Hydrogen   7.762E-01 2.238E-01 H+0/Hden: 1.000E+00 3.050E-08 H-   H2 9.256E-06 3.167E-08 H2+ HeH+ 9.917E-08 H col den 2.026E+16
H 2SP 3-6   4.868E-14 3.056E-16 1.432E-20 1.865E-20 2.682E-20 3.803E-20 Texc(La); 3.108E+03 T(contn): 8.139E-01 T(diffs): 2.911E+02
Helium   5.211E-01 4.625E-01 1.636E-02 He I 2S3 2.907E-09 Comp H, C 3.550E-32 7.700E-34 Fill Fact 1.000E+00 Gam 1/tot 9.643E-01
He singlet 5.211E-01 3.959E-15 1.060E-21 1.413E-21 2.150E-21 3.151E-21 He triplt 2.907E-09 2.408E-20 5.241E-22 3.999E-21 1.265E-21
HeII   4.625E-01 2.126E-16 5.735E-23 8.778E-23 1.406E-22 2.161E-22 1.901E-21 2.025E-20 4.039E-18 PRAD/GAS; 2.648E-06
Pressure   NgasTgas; 9.496E+04 P(total): 1.311E-11 P(gas): 1.311E-11 P(Radtn): 3.472E-17 Rad accel 2.337E-10 Force Mul 9.091E+05
Carbon   5.723E-01 4.173E-01 1.039E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen   6.244E-01 3.755E-01 1.214E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen   7.974E-01 2.025E-01 9.431E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.334
Neon   2.008E-01 5.223E-01 2.769E-01 1.477E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.284E-02 8.026E-01 1.845E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 4.568E-01 4.711E-01 6.435E-02 7.710E-03 4.288E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 3.451E-01 6.542E-01 5.756E-04 7.085E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 7.537E-02 8.860E-01 3.868E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon   0 2.921E-01 4.366E-01 2.714E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 9.143E-01 8.505E-02 6.875E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron   0 2.022E-02 9.735E-01 6.251E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Pressure not converged; zone 17 Te: 1.09E+03 Hden: 3.15E+01 current Pres: 5.32E-12 Corr Pres 1.31E-11
Pressure not converged; zone 18 Te: 6.93E+02 Hden: 5.64E+01 current Pres: 5.83E-12 Corr Pres 1.31E-11
Pressure not converged; zone 19 Te: 4.95E+02 Hden: 1.01E+02 current Pres: 7.41E-12 Corr Pres 1.31E-11
Pressure not converged; zone 20 Te: 3.71E+02 Hden: 1.81E+02 current Pres: 9.89E-12 Corr Pres 1.31E-11
#####184 Te:2.888E+00 Hden:4.029E+04 Ne:1.296E-01 R:1.000E+25 R-R0:3.948E+17 dR:6.933E+14 NTR: 9 Htot:3.001E-24 T912: 5.099E+03###
 -6.21 4686 0.02 5876 1.16 1909 0.00 1549 0.00 6584 0.53 5007 0.00 3727 0.38 6300 0.81 2798 0.31 1035 0.00

```
Hydrogen    1.000E+00 4.529E-06 H+0/Hden: 3.582E-01 3.600E-14 H-     H2 3.207E-01 5.150E-14 H2+  HeH+ 8.523E-13 H col den 6.725E+20
H 2SP 3-6   2.373E-13 1.301E-13 2.610E-19 1.105E-19 1.117E-19 1.392E-19 Texc(La); 2.746E+03 T(contn): 2.174E-01 T(diffs): 3.886E-01
Helium      1.000E+00 8.718E-07 0.000E+00 He I 2S3  4.158E-13 Comp H, C 1.440E-35 8.913E-41 Fill Fact 1.000E+00 Gam 1/tot 4.626E-02
He singlet  1.000E+00 1.367E-19 2.286E-25 9.683E-26 9.784E-26 1.219E-25 He triplt 4.158E-13 4.812E-24 5.996E-27 1.109E-25 6.219E-25
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 7.403E-06
Pressure    NgasTgas; 9.471E+04 P(total): 1.308E-11 P( gas ): 1.308E-11 P(Radtn): 9.683E-17 Rad accel 1.716E-14 Force Mul 1.062E+09
Molecules   CH/Ctot ; 2.249E-05 CH+/Ctot: 2.782E-10 CO/Ctot : 2.975E-03 CO+/Ctot: 1.188E-09 H2O/Otot: 1.731E-05 OH/Ototl: 1.874E-05
Carbon      9.994E-01 5.819E-04 2.857E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 1.682E-09 OH+/Ototl 3.423E-10
Nitrogen    1.000E+00 3.278E-05 3.632E-12 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 6.890E-08 O2+/Otot: 2.047E-11
Oxygen      1.000E+00 6.034E-11 3.048E-13 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-10.170
Neon        9.999E-01 8.127E-05 1.859E-12 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 9.990E-01 9.640E-04 6.227E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 9.901E-01 9.875E-03 4.525E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 9.822E-01 1.783E-02 8.967E-11 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 9.700E-01 2.996E-02 1.606E-08 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 9.996E-01 4.448E-04 2.061E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 9.997E-01 2.557E-04 2.104E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 9.979E-01 2.081E-03 2.751E-13 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest Te reached.
  Geometry is plane-parallel.
  Derivative of cooling negative and so thermally unstable in   6 zones.
  Some fine struc lines are optically thick, largest=2.11E+01
  Ratio of computed diffuse emission to  case B reached 8.62E+00
W-Temperature fell below 100K, this calculation is tentative.
  Compton cooling equilibrium timescale is longer than Hubble time, =  6.80E+17s
C-Cloud thicker than smallest Jeans length=2.56E+17cm; stability problems? (smallest Jeans mass=4.20E-01Mo)
  Sum of gas+line rad pressure ranged from  5.32E-12 to   1.33E-11 in a constant pressure model.
  Temperature out of range of free-free gaunt factor routine.
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations 181 times.
C-3 body rec coef outside range   1
 !Incident radiation field energy density is less than 2.7K.  Include background with FIREBALL command.
 !Incident radiation field < 10*Habing diffuse ISM field.  Is this OK?
  Ionization rate fell below background cosmic ray ionization rate.  Should this be included?
  A large amount of the hydrogen is molecular, fraction reached  66.7%
  The carbon molecular fraction reached 3.18E-01%
  Temp too low and matrix not used for H in some zones. Low-density Case B assumed.  167 THLO= 1.000E+03
  Temp too low and matrix not used for He singlets in some zones. Low-density Case B assumed.  167 THE1LO= 1.000E+03
  Temp too low and matrix not used for He ion in some zones. Low-density Case B assumed.  168 THE2LO= 1.500E+03
```

```
**********************************> CLOUDY 80.08  <**********************************
* title test that energy is conserved                                                 *
* hden 1.0                                                                            *
* constant pressure                                                                   *
* iterate                                                                             *
* print last iteration                                                                *
* black body, temp=5.5                                                                *
* luminostity total -4                                                                *
* stop temperature 3 linear                                                           *
* radius 25                                                                           *
* c conserv.in                                                                        *
* c cray                                                                              *
**********************************> LOG(U): -5.57 <**********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.

                Emission Line Spectrum.  Constant  Pressure Model.    Open geometry.  Iteration 2 of 2.
                                              Intensity (erg/s/cm^2)

   TOTL 4861 -6.205   1.0000      Cool 1216 -8.177   0.0107      C  1  370 -5.750   2.8571      Si 2 2335 -8.318   0.0077
   TOTL 1216 -4.777  26.8389      H2 l    2 -6.098   1.2802      C  2  158 -5.456   5.6109      Si 2 1808 -9.984   0.0002
   TotH    0 -4.321  76.6107      H-FB    0 -7.547   0.0456      C  2 2326 -7.997   0.0161      PHOT 1895 -9.087   0.0013
   BFH1    0 -4.631  37.5097      H2+     0 -7.962   0.0175      INWD 2326 -8.298   0.0081      S 1R 1807 -6.982   0.1674
   BFHe    0 -4.636  37.1006      HEH+    0 -7.574   0.0428      Phot 2326 -8.753   0.0028      S  2 6720 -5.760   2.7906
   TotM    0 -5.905   1.9993      HeFF    0 -7.375   0.0678      REC  1335 -8.685   0.0033      S  2 4074 -7.535   0.0468
   H- H    0 -9.509   0.0005      HeFB    0 -7.088   0.1311      Phot 1909 -8.768   0.0027      S  210330 -7.708   0.0314
   CA B 4861 -6.227   0.9506      MeFB    0 -8.601   0.0040      N  1 5200 -7.009   0.1573      S II 6731 -6.152   1.1311
   CA B 1216 -4.652  35.8045      MeFF    0 -9.079   0.0013      REC  5200 -9.171   0.0011      S II 6716 -5.985   1.6595
   DU B 4861 -6.228   0.9504      ToFF    0 -6.708   0.3144      N  2 6584 -6.478   0.5340      S II 4070 -7.659   0.0352
   Q(H) 4861 -6.414   0.6186      esc   584 -7.759   0.0279      N  2 6548 -6.955   0.1780      S II 4078 -8.141   0.0116
   Q(H) 1216 -4.880  21.1511      He2p  910 -8.315   0.0078      N  2 5755 -9.037   0.0015      S II10323 -8.162   0.0111
   TOTL 6563 -5.533   4.7029      He I  504 -6.653   0.3566      N  2  122 -6.954   0.1784      S II10289 -8.291   0.0082
   TOTL 4861 -6.205   1.0000      He I 4471 -6.944   0.1826      N  2  203 -6.825   0.2402      S II10373 -8.611   0.0039
   TOTL 4340 -6.565   0.4366      TOTL 5876 -6.142   1.1561      N  2 2140 -9.501   0.0005      S II10339 -8.291   0.0082
   TOTL 4102 -6.816   0.2451      Ca B 5876 -6.143   1.1541      O  1 6300 -6.298   0.8072      S  3   18 -7.330   0.0751
   TOTL18751 -6.763   0.2769      TOTL10830 -6.263   0.8768      O  1 6363 -6.776   0.2691      S  3   34 -6.990   0.1641
   TOTL12818 -7.096   0.1286      INWD10830 -6.549   0.4535      O  1 5577 -9.009   0.0016      S  3 9532 -7.385   0.0662
   TOTL10938 -7.339   0.0735      TOTL 3889 -6.875   0.2138      O  1  630 -5.152  11.3034      S  3 9069 -7.801   0.0254
   TOTL40512 -7.507   0.0499      TOTL 7065 -7.681   0.0335      O  1 1470 -6.489   0.5200      S  3 6312 -9.767   0.0003
   TOTL26252 -7.723   0.0303      CcHE    0 -9.720   0.0003      O  1 7774 -9.232   0.0009      S  3 3722 -9.996   0.0002
   TOTL74578 -8.053   0.0142      He I    2 -7.205   0.1002      6lev 8446 -9.929   0.0002      Ar 2    7 -7.354   0.0710
   2 NU    0 -5.205  10.0131      DevB    2 -7.401   0.0637      6lev 1304 -9.183   0.0011      Ar 3 7135 -7.705   0.0317
   TOTL 1216 -4.777  26.8389      He I 5016 -7.345   0.0726      6lev   11-10.091   0.0001      Ar 3 7751 -8.334   0.0074
   TOTL 1026-10.167   0.0001      DevB 5016 -7.436   0.0589      TOTL 3727 -6.625   0.3808      Ar 3   22 -8.450   0.0057
   TOTL  973-10.130   0.0001      He I 3965 -7.678   0.0337      TOTL 7325 -9.004   0.0016      Ar 3    9 -7.305   0.0795
   TOTL  950-10.072   0.0001      DevB 3965 -7.860   0.0222      IONZ 3727 -7.778   0.0268      Ca 2 3933 -7.381   0.0668
   TOTL  938-10.015   0.0002      He I 3614 -7.962   0.0175      IONZ 7325 -8.377   0.0067      Ca 2 8579 -8.126   0.0120
   LA X 1216 -4.873  21.5142      DevB 3614 -8.070   0.0137      O II 3729 -6.877   0.2130      Ca 2 7306 -6.208   0.9950
   INWD 1216 -4.777  26.7921      He I 3448 -8.180   0.0106      O II 3726 -7.056   0.1411      Ca2K 3934 -7.590   0.0413
   INWD 6563 -5.834   2.3515      DevB 3448 -8.348   0.0072      O II 2471 -9.106   0.0013      Ca2H 3969 -7.799   0.0255
   INWD 4861 -6.506   0.5000      HeII  228 -6.733   0.2967      O II 7323 -9.262   0.0009      Ca2X 8498 -9.257   0.0009
   INWD18751 -7.064   0.1384      ESC   304 -7.405   0.0631      O II 7332 -9.352   0.0007      Ca2Y 8542 -8.299   0.0081
   Dest 1216 -5.436   5.8841      He2C  911 -8.492   0.0052      Phot 1663-10.018   0.0002      Ca2Z 8662 -8.719   0.0031
   e sc 6563 -9.761   0.0003      TOTL 1640 -6.940   0.1843      O  3 5007 -9.833   0.0002      CaF1 7291 -6.433   0.5923
   e sc 4861 -9.361   0.0007      TOTL 4686 -7.902   0.0201      O  3  880 -9.308   0.0008      CaF2 7324 -6.600   0.4027
   e sc18751 -6.763   0.2771      TOTL 1216 -7.345   0.0726      O  3  520 -9.563   0.0004      Fe 2   48 -9.616   0.0004
   e sc40512 -7.506   0.0500      Ca B 1640 -6.819   0.2437      Ne 2  128 -6.090   1.3049      Fe 2    7 -6.283   0.8373
   nFnu 4860 -5.948   1.8087      DevB 1640 -6.857   0.2231      Ne 3  156 -6.009   1.5719      Emis    3 -6.712   0.3115
   nFnu 1215 -9.809   0.0002      Ca B 4686 -7.545   0.0458      Ne 3  361 -7.083   0.1325      Cool    3 -6.712   0.3115
   Inci 4861 -7.919   0.0193      DevB 4686 -7.578   0.0424      Ne 3 3869 -7.428   0.0600      TOT     0 -6.145   1.1492
```

```
Inci 1216 -6.176   1.0700      C  1 1656 -9.331   0.0007      Ne 3 3968 -7.941   0.0184      FEIR    0 -5.528   4.7624
BA C    0 -5.795   2.5725      REC  1656 -7.283   0.0837      Mg 1 4571 -9.893   0.0002      Fe 3    0 -9.287   0.0008
PA C    0 -6.266   0.8700      C  I 9850 -5.539   4.6431      Emis 2798 -6.714   0.3103      Fe 3 5270 -9.967   0.0002
H FF    0 -6.816   0.2454      C  1 8727 -6.986   0.1658      Cool 2798 -6.714   0.3103      Fe 3 4658 -9.723   0.0003
H FB    0 -6.546   0.4564      C  1  610 -5.337   7.3813      Si 2   35 -4.797  25.6395
```

```
                          TEST THAT ENERGY IS CONSERVED
Cooling:  C  I 9850:0.060  C  1  610:0.096  C  2  158:0.073  O  1  630:0.147  Si 2   35:0.333  FEIR    0:0.062
Heating:  BFH1    0:0.490  BFHe    0:0.484

IONIZE PARMET:  U(1-) -5.5676  U(4-): -5.7769  U(sp): -9.17  Q(ion):    2.765  L(ion):  -6.577 Q(low):  4.34    P(low) -6.62
ENERGY BUDGET:  Heat:  -4.321  Coolg:  -4.320  Error:  0.4%  Compt H: -14.041  WorkF:   -4.154 F-F  H-11.380    PRADMX:1.98E-03
Column density  H12:6.725E+20  H II:6.016E+17  HI:3.950E+20  H-:    1.509E+11  H2:   1.382E+20 H2+:9.618E+11    He H+:6.427E+11
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.702E+03  <Tp>:4.84E+03  <TO3>:5.72E+03  Ne:2.364E+00  ti(snd):2.86E+12  NeN+dl:1.29E+18 <T(C3)>:5.52E+03 <E(C3)>:2.27E+00
He/Ha:8.56E-01  =   8.73*true  N/Oap:1.41E-01  =   1.07true  T(O3R):5.980E+03  L THIN:1.00E+30 <T(S2)>:1.28E+02 <E(S2)>:8.72E-01
T He+:4.88E+03  EHe+:2.12E+00  T(O+):5.41E+03  EO+:2.22E+00  iter/zn:   4.897  Te-low:2.89E+00 Te-high:6.57E+03  Hlu/zn:7.03E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt6.80E+17  Tthr2.62E+11  <Tden>: 4.48E+01  <dens>:4.00E-21 <Mol>:1.60E+00
Mean Jeans      l(cm)1.01E+18  M(sun)2.57E+01  smallest:     len(cm):2.56E+17  M(sun):4.20E-01 Alf(ox-tran):     0.0000

Optical Depths: CONTN; COMP: 5.14E-07    H-: 5.88E-06 R(1300): 2.65E-03 H2+ 6.73E-06  HeTri:9.80E-06
 Pfa:5.14E-07   Pa:5.16E-07   Ba:6.00E-06   Hb:5.13E-06  La:6.13E-01   1r:5.099E+03  1.8:1.48E+03  4.:2.175E+02  21R:2.381E+00
10830: 4.70E-02  3889: 2.00E-03  5876: 3.19E-13  7065: 1.76E-13
 1550: 1.00E-20  2800: 2.95E+04   774: 1.00E-20  1240: 1.00E-20  1035: 1.00E-20  1335: 2.52E+03   977: 3.04E+00  1397: 6.52E-03
  789: 1.00E-20  1207: 6.15E-02  1085: 1.08E+01  1194: 5.07E-02  1909: 1.21E-06  1895: 1.65E-06  2326: 1.26E-03  1666: 5.71E-08
 1750: 3.14E-10  1025: 2.38E+05   352: 1.00E-20   347: 1.00E-20  1860: 6.00E+00   630: 1.00E-20   834: 9.79E+01   835: 2.78E-03
 1808: 1.72E+05  1256: 5.24E+03    -3: 1.38E+03   -48: 1.73E-11  3934: 1.61E+01  3969: 8.13E+00  8498: 6.92E-09  8542: 6.16E-08
 8662: 3.51E-08   353: 1.00E-20  1304: 8.15E+05  1122: 2.71E-02   990: 1.38E-03  1402: 1.00E-20  1214: 1.00E-20  1486: 1.00E-20
 2335: 4.10E-01  1406: 1.00E-20  1656: 1.27E+06  9830: 2.11E-04  8727: 4.39E-11  6300: 2.16E-03  5577: 1.64E-13  7291: 4.19E-05
 7324: 2.90E-05  1039: 1.16E+05 -8446: 7.55E-13 -4368: 2.86E-15  -132: 2.87E-17  -113: 4.51E-17   -29: 1.07E-20   -46: 1.07E-16
 -245: 1.00E-20   765: 1.00E-20 -1198: 1.00E-20   786: 1.00E-20
 C157: 6.86E-03  N122: 1.06E-05  N205: 2.09E-03   N57: 2.42E-08  O146: 1.06E-05   O63: 4.22E+00   O88: 5.30E-07   O52: 1.33E-09
  O26: 1.00E-20  NE13: 1.37E-03  NE36:-5.07E-09  NE16: 2.17E-04   MG4: 1.00E-20  MG14: 1.00E-20   MG6: 1.00E-20  SI35: 2.65E-02
  S19: 1.41E-08   S34: 4.26E-05   S11: 1.00E-20   AR7: 2.35E-05   AR9: 4.41E-06  AR22:-3.84E-11  AR13: 1.00E-20   AR8: 1.00E-20
  CA3: 1.00E-20  CA12: 1.00E-20   CA4: 1.00E-20  Ne14: 1.00E-20  Ne24: 1.00E-20   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.00E-20 Si6.5: 1.00E-20  C610: 2.30E-01  C370: 2.11E+01

Old hydro optical depths:    1 5.04E+03    2 2.82E-06    3 5.59E-06    4 1.58E-06    5 5.54E-16    6 1.36E-15    7 8.23E-15
                    Lines:  2-1 9.81E+08  3-2 6.67E-07  4-3 4.61E-13  5-4 2.97E-13  6-5 2.70E-13  7-6 3.99E-13  8-7 4.14E-13
New hydro optical depths:    1 5.10E+03    2 2.98E-06    3 5.89E-06    4 1.67E-06    5 5.41E-16    6 1.33E-15    7 8.02E-15
                    Lines:  2-1 9.89E+08  3-2 6.27E-07  4-3 4.38E-13  5-4 2.83E-13  6-5 2.57E-13  7-6 3.83E-13  8-7 4.24E-13

Old He Is optical depths:    1 1.46E+03    2 1.89E-06    3 2.20E-20    4 1.80E-20    5 1.89E-20    6 2.23E-20    7-2.04E-19
                    Lines:  2-1 1.12E+08  3-2 2.17E-08  4-3 7.97E-14  5-4 5.75E-14  6-5 5.62E-14  7-6 8.52E-14  8-7 3.95E-14
New HE Is optical depths:    1 1.48E+03    2 1.99E-06    3 2.16E-20    4 1.75E-20    5 1.79E-20    6 2.06E-20    7-2.16E-19
                    Lines:  2-1 1.14E+08  3-2 2.11E-08  4-3 7.66E-14  5-4 5.56E-14  6-5 5.45E-14  7-6 8.31E-14  8-7 4.17E-14

Old He II optical depths:    1 2.15E+02    2 5.04E+03    3 9.65E-21    4 9.15E-21    5 8.34E-21    6 7.11E-21    7-2.14E-20
                    Lines:  2-1 9.07E+03  3-2 1.92E-11  4-3 2.84E-18  5-4-1.37E-18  6-5-1.60E-17  7-6 4.46E-17  8-7 6.36E-16
New HE II optical depths:    1 2.17E+02    2 5.10E+03    3 9.64E-21    4 9.10E-21    5 8.25E-21    6 6.96E-21    7-2.30E-20
                    Lines:  2-1 9.40E+03  3-2 1.97E-11  4-3 2.90E-18  5-4-1.49E-18  6-5-1.68E-17  7-6 4.65E-17  8-7 6.64E-16

Hydrogen  -0.001 -2.818                          Log10 Mean Ionisation (over volume)
Helium    -0.001 -2.644 -4.210
Carbon    -0.002 -2.340 -4.541
Nitrogen  -0.001 -2.883 -6.682
Oxygen     0.000 -3.149 -6.731
Neon      -0.004 -2.174 -2.798 -7.837
Magnesium -0.022 -1.317 -2.834
Aluminum  -0.049 -0.972 -3.144 -3.818 -6.167
Silicon   -0.095 -0.706 -5.873 -6.370
Sulphur   -0.168 -0.493 -3.636
Argon     -0.003 -2.266 -3.049
Calcium   -0.007 -1.808 -4.543
Iron      -0.024 -1.272 -4.967
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          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.001 -2.818                          Log10 Mean Ionisation (over radius)
Helium    -0.001 -2.644 -4.210
Carbon    -0.002 -2.340 -4.541
Nitrogen  -0.001 -2.883 -6.682
Oxygen     0.000 -3.149 -6.731
Neon      -0.004 -2.174 -2.798 -7.837
Magnesium -0.022 -1.317 -2.834
Aluminum  -0.049 -0.972 -3.144 -3.818 -6.167
Silicon   -0.095 -0.706 -5.873 -6.370
Sulphur   -0.168 -0.493 -3.636
Argon     -0.003 -2.266 -3.049
Calcium   -0.007 -1.808 -4.543
Iron      -0.024 -1.272 -4.967

0.5-1.0KEV:7.08E-01 1.0-1.5:0.00E+00 1.5-2.0:0.00E+00 2.0-2.5:0.00E+00 2.5-3:0.00E+00 3-5:0.00E+00 5-7.5:0.00E+00 7.5-10:0.00E+00


                                              Normalised continuum
  0.25******   0.2773.254   0.3045.456   0.3332.698   0.3628.435   0.3923.702   0.4320.881   0.4718.581   0.5116.424   0.5614.095
  0.62 7.225   0.67 6.008   0.74 1.980   0.81 0.637   0.88 0.029   0.97 0.045   0.98 0.049   0.99 0.050   1.00 0.051


Inward continua (nuFnu) at head of Balmer, Lyman series;  3.38E-06  2.52E-06


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  3.38E-06  0.00E+00

                                            Emergent continuum - phot/ryd/cm2 (r in)
  0.26 2.37E+06  0.67 3.08E+05     1.0 0.00E+00     2.5 1.32-283     5.3 1.24E-44    1.36E+01 4.63E+00    3.54E+01 6.91E-01
  0.29 1.26E+06  0.76 3.07E+04     1.1 0.00E+00     2.9 2.75-210     5.9 1.84E-31    1.54E+01 2.45E+01    3.99E+01 8.07E-02
  0.33 8.77E+05  0.86 1.61E+03     1.2 0.00E+00     3.2 6.03-156     6.7 1.17E-21    1.73E+01 5.87E+01    4.50E+01 9.80E-03
  0.37 7.93E+05  0.97 3.16E+03     1.4 0.00E+00     3.6 3.23-115     7.5 1.79E-14    1.95E+01 7.62E+01    5.05E+01 9.08E-04
  0.42 7.26E+05  0.99 3.52E+03     1.6 7.56E-03     3.9 3.59E-97     8.5 2.57E-09    2.20E+01 4.95E+01    5.47E+01 1.35E-04
  0.47 6.92E+05  0.99 3.65E+03     1.8 0.00E+00     4.0 1.02E-88     9.5 1.32E-05    2.48E+01 2.87E+01    5.92E+01 1.73E-05
  0.53 6.51E+05  1.00 0.00E+00     2.0 5.36E-02     4.2 1.01E-79    10.8 5.35E-03    2.79E+01 1.15E+01    6.41E+01 1.77E-06
  0.60 3.38E+05  1.01 0.00E+00     2.3 1.46E-03     4.7 3.63E-60    12.1 3.24E-01    3.15E+01 3.21E+00
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                                          CLOUDY 80.08

                                    ***********************************91Aug03***********************************
                                    *                                                                           *
                                    * title (roughly) Ferland et al. DQ Her model                               *
                                    * c model of ice cold ionized cloud arund old nova DQ Her                   *
                                    * c roughly that of Ferland et al. 1984 Ap.J. 281, 194.                     *
                                    * c tests behaviour of code at very low temperatures                       *
                                    * stop temp = 100                                                          *
                                    * c flat continuum, followed by nu^-2 power law                            *
                                    * interpolate (0, 0) (0.3, 0) (8,000,000 -14.8)                            *
                                    * luminosity total 34                                                      *
                                    * hden = 2.                                                               *
                                    * filling factor 0.667                                                    *
                                    * covering factor 0.667                                                   *
                                    * radius 16.5682, thickness=16.14613                                      *
                                    * abundances 2 20 200 50 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                    *
                                    * grains                                                                  *
                                    * iterate                                                                 *
                                    * faint .05                                                               *
                                    * print last                                                              *
                                    * c dqher.in                                                              *
                                    * c cray                                                                  *
                                    *                                                                         *
                                    *****************************************************************************


                                                Chemical composition
He:.196 C:7.26E-03 N:2.24E-02 O:4.26E-02 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

          546Cell Peak2.45E-01   Lo 1.00E-05=0.9120cm   Hi-Con:7.33E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  33.1814   Average nu:2.007E+00   P( X-ray):  31.8794   P(BalC):  33.6366     Q(Balmer C):  44.6874
          Q(1.0-1.8):  43.3814   Q(1.8-4.0):  42.9280   Q(4.0-20):  42.3236   Q(20--):  40.9296     Ion pht flx:2.019E+09
          L(gam ray):  29.3554   Q(gam ray):  35.8610   L(Infred):  33.6184   Alf(ox):  -1.9930     Total lumin:  34.0001
          L/Lsolar:     0.4173   Abs bol mg:   3.6767   Abs V mag:   4.9271   Bol cor:  -1.2505     nuFnu(Bbet):  33.4932
          U(1.0----):6.734E-04   U(4.0----):4.249E-05   T(En-Den):7.116E+00   T(Comp):6.503E+04     nuJnu(912A):8.762E-02
          Occ(FarIR):3.833E-02   Occ(H n=6):2.005E-12   Occ(1Ryd):4.038E-18   Occ(4R):3.957E-21     Occ (Nu-hi):2.710E-52
          Tbr(FarIR):6.364E-02   Tbr(H n=6):8.901E-09   Tbr(1Ryd):6.378E-13   Tbr(4R):2.503E-15     Tbr (Nu-hi):2.990E-40
          Grain(Pal):4.422E-23   Grain(Bal):1.782E-22   Grain Mg2:4.380E-22   Grain R:1.527E-21     Grain(HeII):5.214E-22

#####  1 Te:3.331E+02 Hden:1.000E+02 Ne:1.176E+02 R:3.770E+16 R-R0:7.000E+14 dR:1.400E+15 NTR:  2 Htot:6.284E-19 T912: 4.403E-02###
 -5.02 4686  0.01 5876  0.89 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.98 6300  0.00 2798  0.00 1035  0.00
Hydrogen    7.452E-02 9.255E-01 H+0/Hden: 1.000E+00 2.575E-10 H-     H2 1.297E-09 2.003E-10 H2+  HeH+ 8.332E-09 H col den 9.338E+16
H 2SP 3-6   1.250E-11 3.325E-15 5.348E-18 4.615E-18 5.638E-18 7.368E-18 Texc(La); 3.707E+03 T(contn): 6.677E+00 T(diffs): 3.341E+00
Helium      1.882E-01 7.823E-01 2.953E-02 He I 2S3  2.779E-06 Comp H, C 1.994E-27 1.021E-29 Fill Fact 6.670E-01 Gam 1/tot 1.000E+00
He singlet  1.882E-01 2.747E-12 4.185E-18 3.612E-18 4.412E-18 5.766E-18 He triplt 2.779E-06 3.868E-17 2.400E-19 2.845E-18 2.798E-18
HeII        7.823E-01 1.056E-13 9.874E-21 8.521E-21 1.041E-20 1.360E-20 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 2.241E-03
Gra-ISM     Dust temp 3.838E+01 Pot(Volt)-9.775E-03 Nelectron-2.036E+00 drft cm/s 1.622E+05  Heating: 3.072E-22 Frac(tot) 4.888E-04
Sil-ISM     Dust temp 3.462E+01 Pot(Volt)-8.168E-03 Nelectron-1.702E+00 drft cm/s 1.026E+05  Heating: 3.890E-22 Frac(tot) 6.190E-04
Pressure    NgasTgas; 7.950E+04 P(total): 1.100E-11 P( gas ): 1.098E-11 P(Radtn): 2.459E-14 Rad accel 1.800E-07 Force Mul 5.661E+04
Carbon      1.088E-02 6.347E-01 3.521E-01 2.313E-03 3.081E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.722E-02 7.861E-01 1.917E-01 4.992E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      8.308E-02 6.776E-01 2.367E-01 2.577E-03 1.137E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-11.422
Neon        4.585E-02 5.824E-01 3.615E-01 1.021E-02 1.586E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.532E-02 5.982E-01 3.506E-01 5.795E-03 1.782E-05 2.888E-08 1.515E-11 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 7.709E-03 7.795E-01 1.961E-01 1.657E-02 8.380E-05 1.167E-07 4.989E-11 1.382E-14 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 6.683E-03 8.912E-01 9.495E-02 7.044E-03 1.258E-04 1.992E-07 9.818E-11 3.020E-14 6.926E-18 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 3.958E-03 6.496E-01 3.447E-01 1.693E-03 7.372E-05 9.093E-07 1.232E-08 5.087E-12 7.249E-16 1.356E-19 1.357E-23 0.000E+00
Argon     1 5.523E-01 4.367E-01 6.663E-03 6.628E-05 1.975E-06 1.144E-08 1.687E-10 4.912E-13 5.009E-17 4.201E-21 3.241E-25 2.068E-29
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Calcium   0 2.056E-01 6.614E-01 1.293E-01 3.588E-03 1.512E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.132E-03 4.638E-01 4.051E-01 1.240E-01 5.951E-03 5.280E-05 1.191E-07 2.316E-10 2.016E-13 0.000E+00 0.000E+00 0.000E+00
##### 11uTe:6.478E+02 Hden:1.000E+02 Ne:1.111E+02 R:5.029E+16 R-R0:1.329E+16 dR:6.173E+14 NTR:  1 Htot:3.569E-19 T912: 5.236E-01###
 -4.02 4686  0.01 5876  0.81 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  1.17 6300  0.00 2798  0.00 1035  0.00
Hydrogen    1.118E-01 8.882E-01 H+0/Hden: 1.000E+00 8.096E-10 H-     H2 6.618E-09 1.277E-09 H2+  HeH+ 1.300E-08 H col den 9.070E+17
H 2SP 3-6   7.313E-12 4.353E-16 3.019E-18 2.871E-18 3.600E-18 4.735E-18 Texc(La); 3.439E+03 T(contn): 6.036E+00 T(diffs): 2.460E+00
Helium      2.512E-01 7.310E-01 1.776E-02 He I 2S3  1.352E-06 Comp H, C 9.578E-28 9.687E-30 Fill Fact 6.670E-01 Gam 1/tot 1.000E+00
He singlet  2.512E-01 1.435E-12 2.201E-18 2.094E-18 2.625E-18 3.453E-18 He triplt 1.352E-06 2.816E-17 1.498E-19 1.731E-18 1.187E-18
HeII        7.310E-01 3.839E-14 3.342E-21 3.179E-21 3.985E-21 5.242E-21 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 1.877E-03
Gra-ISM     Dust temp 3.414E+01 Pot(Volt)-8.148E-02 Nelectron-1.697E+01 drft cm/s 6.941E+04  Heating: 1.282E-22 Frac(tot) 3.593E-04
Sil-ISM     Dust temp 3.039E+01 Pot(Volt)-7.873E-02 Nelectron-1.640E+01 drft cm/s 3.960E+04  Heating: 1.630E-22 Frac(tot) 4.568E-04
Pressure    NgasTgas; 1.514E+05 P(total): 2.095E-11 P( gas ): 2.091E-11 P(Radtn): 4.024E-14 Rad accel 9.219E-08 Force Mul 5.954E+04
Carbon      1.635E-02 7.055E-01 2.775E-01 6.447E-04 2.365E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    3.171E-02 8.982E-01 6.920E-02 9.355E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.527E-01 7.529E-01 9.411E-02 3.019E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-11.615
Neon        6.714E-02 6.257E-01 3.042E-01 2.994E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 6.043E-02 6.257E-01 3.119E-01 1.915E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.003E-02 8.057E-01 1.672E-01 1.696E-02 9.250E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 9.619E-03 9.604E-01 2.617E-02 3.752E-03 1.986E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 8.168E-03 7.060E-01 2.853E-01 5.589E-04 2.526E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 6.556E-03 5.271E-01 4.638E-01 2.496E-03 2.633E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 2.455E-01 6.462E-01 1.063E-01 1.989E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 2.672E-03 7.625E-01 2.102E-01 2.358E-02 9.818E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because outer radius reached.
  Geometry is a thick shell.
  Derivative of cooling negative and so thermally unstable in   5 zones.
  Temperature out of range of free-free gaunt factor routine.
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations   2 times.
  The ratio of radiation to gas pressure reached  2.94E+00.  Caused by Lyman alpha.
  Temp too low and matrix not used for H in some zones. Low-density Case B assumed.   11 THLO= 1.000E+03
  Temp too low and matrix not used for He singlets in some zones. Low-density Case B assumed.   11 THE1LO= 1.000E+03
  Temp too low and matrix not used for He ion in some zones. Low-density Case B assumed.   11 THE2LO= 1.500E+03
```

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**********************************> CLOUDY 80.08  <**********************************
* title (roughly) Ferland et al. DQ Her model                                       *
* c model of ice cold ionized cloud arund old nova DQ Her                           *
* c roughly that of Ferland et al. 1984 Ap.J. 281, 194.                             *
* c tests behaviour of code at very low temperatures                                *
* stop temp = 100                                                                   *
* c flat continuum, followed by nu^-2 power law                                     *
* interpolate (0, 0) (0.3, 0) (8,000,000 -14.8)                                     *
* luminosity total 34                                                               *
* hden = 2.                                                                         *
* filling factor 0.667                                                              *
* covering factor 0.667                                                             *
* radius 16.5682, thickness=16.14613                                                *
* abundances 2 20 200 50 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                             *
* grains                                                                            *
* iterate                                                                           *
* faint .05                                                                         *
* print last                                                                        *
* c dqher.in                                                                        *
* c cray                                                                            *
**********************************> LOG(U): -3.17 <**********************************

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                          Luminosity (erg/s) emitted by shell with a covering factor of  66.7%.

    TOTL 4861 30.212   1.0000      INWD 1216 31.503  19.5182      TOTL10830 30.021   0.6438      N  2  122 31.107   7.8525
    TOTL 1216 31.825  40.9534      INWD 6563 30.542   2.1380      INWD10830 29.715   0.3178      N  2  203 30.409   1.5728
    TotH    0 31.836  42.0279      INWD 4861 29.911   0.5000      TOTL 3889 29.474   0.1826      N  2 5680 29.016   0.0636
    BFH1    0 31.496  19.1959      INWD18751 29.354   0.1384      He I    2 29.117   0.0803      N  3   57 30.935   5.2814
    BFHe    0 31.206   9.8626      Dest 1216 29.683   0.2958      DevB    2 29.060   0.0704      O  1  630 28.923   0.0513
    TotM    0 31.324  12.9272      e sc18751 29.315   0.1266      He I 5016 28.985   0.0592      O  1 7774 29.200   0.0971
    CA B 4861 30.298   1.2179      nFnu 4860 30.369   1.4345      DevB 5016 28.966   0.0566      6lev 1304 28.954   0.0552
    CA B 1216 31.795  38.2751      Inci 4861 33.4931909.1455      HeII  228 30.066   0.7131      TOTL 3727 30.279   1.1666
    DU B 4861 30.298   1.2172      Inci 1216 33.3021229.7086      ESC   304 29.586   0.2363      IONZ 3727 30.279   1.1666
    Q(H) 4861 31.042   6.7457      BA C    0 30.630   2.6136      He2C  911 29.067   0.0716      IONZ 7325 29.643   0.2696
    Q(H) 1216 32.575 230.6365      PA C    0 30.179   0.9252      TOTL 1640 29.121   0.0809      O  3  880 31.298  12.1676
    TOTL 6563 30.844   4.2759      Grai    0 30.126   0.8188      Ca B 1640 29.945   0.5398      O  3  520 31.308  12.4655
    TOTL 4861 30.212   1.0000      Grai 1216 29.681   0.2941      DevB 1640 29.936   0.5287      O  4   26 29.797   0.3844
    TOTL 4340 29.832   0.4167      H FB    0 29.394   0.1518      Ca B 4686 29.429   0.1646      Ne 3  156 29.089   0.0752
    TOTL 4102 29.560   0.2224      esc   584 30.060   0.7041      DevB 4686 29.414   0.1592      Si 2   35 29.981   0.5862
    TOTL18751 29.655   0.2769      He2p  910 29.329   0.1308      REC  1656 29.007   0.0623      S  3   34 29.269   0.1138
    TOTL12818 29.302   0.1228      He I  504 30.649   2.7316      C  2  158 30.103   0.7769      FEIR    0 29.297   0.1215
    TOTL10938 29.036   0.0667      He I 4471 29.365   0.1420      REC  1335 28.977   0.0582
    2 NU    0 31.225  10.2808      TOTL 5876 30.121   0.8091      Phot 1909 29.292   0.1202
    TOTL 1216 31.825  40.9534      Ca B 5876 30.074   0.7270      REC  5200 29.372   0.1445
Lines with negative intensities;  205 T OI    0
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                          (ROUGHLY) FERLAND ET AL. DQ HER MODEL
Cooling:  N  2  122:0.188  N  3   57:0.126  O  3  880:0.291  O  3  520:0.298
Heating:  BFH1    0:0.457  BFHe    0:0.235  TotM    0:0.308

IONIZE PARMET:  U(1-) -3.1718  U(4-): -4.3717  U(sp): -3.44  Q(ion):   43.390  L(ion):  33.056 Q(low): 45.91    P(low) 33.93
ENERGY BUDGET:  Heat:  31.836  Coolg:  31.833  Error:  0.6%  Compt H:  23.280  WorkF:   32.292 F-F  H 22.471    PRADMX:2.94E+00
Column density  H12:9.070E+17  H II:8.242E+17  HI:8.281E+16  H-:    4.231E+08  H2:   3.109E+09 H2+:3.373E+08    He H+:9.686E+09
                OH: 0.000E+00  Heff:2.757E+19
<NH>:1.000E+02  <Tp>:4.75E+02  <TO3>:4.51E+02  Ne:1.147E+02  ti(snd):5.28E+10  NeN+dl:9.41E+19 <T(C3)>:4.69E+02 <E(C3)>:1.14E+02
He/Ha:5.98E-01  =   3.05*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:4.78E+02 <E(S2)>:1.14E+02
T He+:4.74E+02  EHe+:1.14E+02  T(O+):4.79E+02  EO+:1.14E+02  iter/zn:   3.500  Te-low:3.33E+02 Te-high:6.48E+02  Hlu/zn:3.50E+00
  <a>:0.00E+00  erdeFe1.1E+28  Tcompt2.68E+10  Tthr2.67E+07  <Tden>: 4.76E+02  <dens>:4.77E-22 <Mol>:1.19E+00
Mean Jeans      l(cm)5.69E+19  M(sun)2.31E+04  smallest:     len(cm):4.82E+19  M(sun):1.40E+04 Alf(ox-tran):    -1.9936
  L(dust): 3.013E+01
           Gra-ISM   Sil-ISM   Gra-Ori   Sil-Ori   Sil-0.01  Sil-0.1   SilicatPN
  <Tdust>: 3.643E+01 3.321E+01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Vel D>: 1.586E+05 8.775E+04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Pot D>:-3.287E-02-2.941E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

Optical Depths: CONTN; COMP: 6.89E-07    H-: 1.65E-08 R(1300): 5.56E-07 H2+ 2.36E-09  HeTri:7.40E-04
 Pfa:1.27E-05   Pa:5.54E-05   Ba:2.78E-04   Hb:3.80E-04  La:1.21E-03   1r:5.240E-01  1.8:4.80E-01  4.:4.967E-01  21R:9.670E-03
10830: 2.41E+00  3889: 1.03E-01  5876: 4.50E-11  7065: 2.48E-11
 1550: 4.83E+00  2800: 1.40E+02   774: 1.00E-20  1240: 1.00E-20  1035: 1.00E-20  1335: 2.77E+03   977: 2.92E+03  1397: 3.57E-01
  789: 5.55E+00  1207: 1.08E+01  1085: 2.14E+03  1194: 1.32E-01  1909: 1.16E-03  1895: 2.90E-04  2326: 1.39E-03  1666: 1.16E-02
 1750: 1.77E-04  1025: 1.90E+02   352: 1.00E-20   347: 1.00E-20  1860: 2.40E+00   630: 3.84E-02   834: 2.16E+04   835: 5.65E+02
 1808: 1.78E+02  1256: 2.05E+00    -3: 6.40E+00   -48: 1.00E-20  3934: 1.25E+01  3969: 6.31E+00  8498: 1.41E-19  8542: 1.04E-18
 8662: 6.76E-19   353: 1.00E-20  1304: 6.51E+02  1122: 3.60E+00   990: 7.80E+02  1402: 7.40E-05  1214: 2.07E-07  1486: 8.30E-05
 2335: 4.25E-04  1406: 1.56E-06  1656: 4.72E+01  9830: 7.87E-09  8727: 1.00E-20  6300: 1.72E-06  5577: 1.00E-20  7291: 8.38E-07
 7324: 5.80E-07  1039: 9.24E+01 -8446: 6.70E-12 -4368: 2.56E-14  -132: 5.86E-14  -113: 9.23E-14   -29: 1.00E-20   -46: 2.19E-13
 -245: 2.59E-16   765: 5.05E+01 -1198: 1.32E-07   786: 3.92E-04
 C157: 2.29E-03  N122: 1.57E-02  N205: 1.94E-02   N57: 1.06E-02  O146:-1.90E-05   O63: 1.98E-02   O88: 4.98E-02   O52: 1.20E-02
  O26: 2.40E-04  NE13: 2.21E-04  NE36:-3.44E-08  NE16: 1.81E-04   MG4: 4.33E-07  MG14: 1.95E-15   MG6: 3.99E-10  SI35: 1.81E-04
  S19: 4.14E-06   S34: 1.01E-04   S11: 1.25E-07   AR7: 7.89E-06   AR9: 9.58E-06  AR22:-2.43E-11  AR13: 3.65E-09   AR8: 1.91E-13
  CA3: 2.68E-08  CA12: 3.41E-20   CA4: 2.62E-11  Ne14: 1.43E-11  Ne24: 3.91E-09   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 4.39E-16 Si6.5: 1.00E-20  C610: 1.77E-05  C370: 7.36E-04

Old hydro optical depths:    1 4.63E-01    2 2.84E-04    3 1.16E-04    4 5.54E-05    5 2.73E-05    6 1.48E-05    7 5.02E-06
                     Lines:  2-1 2.08E+04  3-2 1.87E-05  4-3 1.47E-11  5-4 1.48E-11  6-5 1.71E-11  7-6 3.05E-11  8-7 1.00E-20
New hydro optical depths:    1 5.24E-01    2 3.09E-04    3 1.26E-04    4 6.01E-05    5 2.96E-05    6 1.61E-05    7 5.45E-06
                     Lines:  2-1 2.25E+04  3-2 1.85E-05  4-3 1.44E-11  5-4 1.46E-11  6-5 1.70E-11  7-6 3.04E-11  8-7 1.00E-20

Old He Is optical depths:    1 4.34E-01    2 4.07E-04    3 2.84E-18    4 3.43E-18    5 5.29E-18    6 8.48E-18    7 1.00E-20
                     Lines:  2-1 6.82E+03  3-2 1.75E-06  4-3 4.74E-12  5-4 4.77E-12  6-5 5.51E-12  7-6 9.83E-12  8-7 1.00E-20
New HE Is optical depths:    1 4.80E-01    2 4.42E-04    3 2.90E-18    4 3.52E-18    5 5.45E-18    6 8.75E-18    7 1.00E-20
                     Lines:  2-1 7.19E+03  3-2 1.74E-06  4-3 4.64E-12  5-4 4.71E-12  6-5 5.47E-12  7-6 9.82E-12  8-7 1.00E-20

Old He II optical depths:    1 4.56E-01    2 4.63E-01    3 1.53E-20    4 1.64E-20    5 1.99E-20    6 2.58E-20    7 1.00E-20
                     Lines:  2-1 1.75E+04  3-2 1.31E-08  4-3 2.26E-15  5-4 2.27E-15  6-5 2.61E-15  7-6 4.65E-15  8-7 1.00E-20
New HE II optical depths:    1 4.97E-01    2 5.24E-01    3 1.54E-20    4 1.66E-20    5 2.01E-20    6 2.63E-20    7 1.00E-20
                     Lines:  2-1 1.83E+04  3-2 1.30E-08  4-3 2.21E-15  5-4 2.23E-15  6-5 2.59E-15  7-6 4.63E-15  8-7 1.00E-20

Hydrogen  -1.031 -0.042                          Log10 Mean Ionisation (over volume)
Helium    -0.628 -0.129 -1.672
Carbon    -1.852 -0.169 -0.512 -2.920 -4.593
Nitrogen  -1.603 -0.066 -0.943 -2.654
Oxygen    -0.912 -0.138 -0.827 -3.028 -6.065
Neon      -1.231 -0.213 -0.490 -2.269 -5.921
Magnesium -1.345 -0.205 -0.483 -2.493 -5.870 -8.660-11.941
Aluminum  -2.073 -0.100 -0.743 -1.788 -4.077 -8.054-11.423-14.981
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Silicon   -2.188 -0.028 -1.292 -2.307 -4.284 -7.822-11.129-14.641-18.281
Sulphur   -2.470 -0.164 -0.509 -3.024 -4.383 -7.162 -9.031-12.415-16.261-19.989-23.988
Argon     -2.260 -0.264 -0.350 -2.398 -4.406 -6.825 -9.063-10.894-13.430-17.421-21.498-25.610-29.805
Calcium   -0.697 -0.170 -0.921 -2.574 -5.941
Iron      -2.704 -0.194 -0.527 -1.230 -2.588 -4.691 -8.045-10.756-13.817
           1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -1.040 -0.042                          Log10 Mean Ionisation (over radius)
Helium    -0.633 -0.128 -1.661
Carbon    -1.861 -0.171 -0.507 -2.891 -4.588
Nitrogen  -1.617 -0.069 -0.920 -2.618
Oxygen    -0.925 -0.140 -0.806 -2.981 -5.932
Neon      -1.239 -0.214 -0.486 -2.242 -5.787
Magnesium -1.351 -0.206 -0.481 -2.468 -5.736 -8.527-11.807
Aluminum  -2.078 -0.101 -0.739 -1.789 -4.082 -7.920-11.289-14.847
Silicon   -2.197 -0.030 -1.262 -2.293 -4.243 -7.688-10.995-14.507-18.147
Sulphur   -2.491 -0.166 -0.505 -2.999 -4.360 -7.029 -8.897-12.281-16.127-19.855-23.855
Argon     -2.269 -0.263 -0.352 -2.376 -4.386 -6.692 -8.929-10.760-13.296-17.288-21.364-25.477-29.672
Calcium   -0.701 -0.169 -0.917 -2.562 -5.808
Iron      -2.721 -0.205 -0.513 -1.193 -2.549 -4.642 -7.911-10.623-13.683

0.5-1.0KEV:1.09E+06 1.0-1.5:2.19E+05 1.5-2.0:7.17E+04 2.0-2.5:3.41E+04 2.5-3:2.04E+04 3-5:2.65E+04 5-7.5:8.59E+03 7.5-10:3.19E+03


                                          Normalised continuum
  0.25 1.038   0.27 0.997   0.30 0.997   0.33 0.998   0.36 0.999   0.39 0.999   0.43 1.000   0.47 1.002   0.51 1.003   0.56 1.005
  0.62 1.006   0.67 1.006   0.74 0.998   0.81 0.995   0.88 0.994   0.97 0.994   0.98 0.994   0.99 0.994   1.00 0.994


Inward continua (nuFnu) at head of Balmer, Lyman series;  1.24E-03  2.84E-06


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  1.04E-03  0.00E+00

                                         Emergent continuum - phot/ryd/cm2 (r in)
  0.26 1.71E+11  1.00 2.24E+09     3.9 5.06E+07    17.3 7.74E+05    75.3 9.54E+03    1.26E+03 2.09E+00    3.24E+05 1.28E-07
  0.29 1.51E+11  1.01 2.21E+09     4.0 3.42E+07    19.5 5.43E+05    81.6 7.52E+03    1.87E+03 6.37E-01    4.81E+05 3.90E-08
  0.33 1.12E+11  1.02 2.18E+09     4.2 3.59E+07    22.0 3.78E+05    88.3 5.92E+03    2.78E+03 1.94E-01    7.15E+05 1.19E-08
  0.37 7.81E+10  1.10 1.89E+09     4.7 2.81E+07    24.8 2.65E+05    95.7 4.67E+03    4.14E+03 5.94E-02    1.06E+06 3.64E-09
  0.42 5.46E+10  1.24 1.48E+09     5.3 2.12E+07    27.9 1.86E+05   103.7 3.68E+03    6.15E+03 1.81E-02    1.58E+06 1.11E-09
  0.47 3.82E+10  1.40 1.17E+09     5.9 1.73E+07    31.5 1.29E+05   112.3 2.90E+03    9.15E+03 5.54E-03    2.35E+06 3.39E-10
  0.53 2.68E+10  1.57 9.37E+08     6.7 1.25E+07    35.5 9.03E+04   121.6 2.28E+03    1.36E+04 1.69E-03    3.49E+06 1.04E-10
  0.60 1.87E+10  1.78 5.97E+08     7.5 8.92E+06    40.0 6.21E+04   131.7 1.80E+03    2.02E+04 5.16E-04    5.19E+06 3.17E-11
  0.67 1.31E+10  2.00 3.32E+08     8.5 6.35E+06    45.0 4.38E+04   142.7 1.41E+03    3.00E+04 1.58E-04
  0.76 9.04E+09  2.25 2.27E+08     9.5 4.51E+06    50.5 3.12E+04   173.8 7.85E+02    4.46E+04 4.81E-05
  0.86 6.31E+09  2.54 1.71E+08    10.8 3.18E+06    54.7 2.47E+04   258.3 2.40E+02    6.63E+04 1.47E-05
  0.97 4.40E+09  2.86 1.06E+08    12.1 2.24E+06    59.2 1.95E+04   383.9 7.32E+01    9.86E+04 4.49E-06
  0.99 4.13E+09  3.22 7.95E+07    13.6 1.57E+06    64.2 1.53E+04   570.6 2.24E+01    1.47E+05 1.37E-06
  0.99 4.03E+09  3.63 6.03E+07    15.4 1.10E+06    69.5 1.21E+04   848.1 6.83E+00    2.18E+05 4.19E-07
```

```
                    ************************************91Aug03***************************************
                    *                                                                                *
                    * title Martin Gaskell's funny model                                             *
                    * c used to test that electron density convergence is ok                         *
                    * c hydrogen line spectrum strongly pumped by continuum                          *
                    * black 4000                                                                     *
Is T(star)=  4.00E+03 correct???
                    * lumin 27.2                                                                    *
                    * constant temper 5500                                                          *
                    * faint -3                                                                      *
                    * radius 15                                                                     *
                    * hden 5.13                                                                     *
                    * abundances 1000 1000 1000 1000 1000 1000 1000 1000                            *
                    * continue 1000 1000 1000 1000 1000 1000                                        *
Is a helium abundance of 9.800E+01 reasonable?
Is an abundance of 3.630E-01 for element  2 reasonable?
Is an abundance of 1.120E-01 for element  3 reasonable?
Is an abundance of 8.510E-01 for element  4 reasonable?
Is an abundance of 1.230E-01 for element  5 reasonable?
                    * stop zone 1                                                                  *
                    * print short                                                                  *
                    * drmax 0                                                                      *
                    * drmin 0                                                                      *
                    * c eden.in                                                                    *
                    * c cray                                                                       *
                    *                                                                              *
                    ********************************************************************************


                                          Chemical composition
He:**** C:3.63E-01 N:1.12E-01 O:8.51E-01 Ne:1.23E-01 Mg:3.80E-02 Al:3.0E-03 Si:3.55E-02 S:1.62E-02 A:3.6E-03 Ca:2.3E-03 Fe:4.68E-02

          263Cell Peak9.90E-02   Lo 1.00E-05=0.9105cm   Hi-Con:1.80E+00 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  27.2025   Average nu:1.027E+00   P( X-ray):   0.0000   P(BalC):  38.3567     Q(Balmer C):  49.5708
          Q(1.0-1.8):  37.8529   Q(1.8-4.0):   0.0000   Q(4.0-20):   0.0000   Q(20--):   0.0000     Ion pht flx:5.671E+06
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  40.3304   Alf(ox):   0.0000     Total lumin:  40.3350
          L/Lsolar:     6.7522   Abs bol mg: -12.1605   Abs V mag: -11.3684   Bol cor:  -0.7921     nuFnu(Bbet):  39.7854
          U(1.0----):1.402E-09   U(4.0----):0.000E+00   T(En-Den):1.660E+03   T(Comp):3.835E+03     nuJnu(912A):4.627E-03
          Occ(FarIR):7.124E+01   Occ(H n=6):1.460E-02   Occ(1Ryd):2.105E-19   Occ(4R):0.000E+00     Occ (Nu-hi):1.270E-32
          Tbr(FarIR):1.185E+02   Tbr(H n=6):6.481E+01   Tbr(1Ryd):3.325E-14   Tbr(4R):0.000E+00     Tbr (Nu-hi):3.542E-27

#####  1 Te:5.500E+03 Hden:1.349E+05 Ne:4.652E+04 R:1.000E+15 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:9.513E-16 T912: 1.092E-12###
-15.90 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  6.84 5007  0.00 3727  1.10 6300****** 2798****** 1035  0.00
Hydrogen    9.985E-01 1.497E-03 H+0/Hden: 1.000E+00 6.383E-15 H-     H2 1.326E-11 6.545E-11 H2+  HeH+ 1.284E-09 H col den 1.349E+05
H 2SP 3-6   1.006E-10 1.685E-11 8.938E-14 1.809E-14 1.040E-14 8.650E-15 Texc(La); 3.650E+03 T(contn): 1.660E+03 T(diffs): 3.049E+01
Helium      1.000E+00 0.000E+00 0.000E+00 He I 2S3  0.000E+00 Comp H, C 1.371E-16 1.967E-16 Fill Fact 1.000E+00 Gam 1/tot 8.289E-01
He singlet  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 He triplt 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 4.434E-07
Pressure    NgasTgas; 7.489E+10 P(total): 1.034E-05 P( gas ): 1.034E-05 P(Radtn): 4.584E-12 Rad accel 1.890E-05 Force Mul 1.002E+00
Carbon      4.473E-01 5.527E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.985E-01 1.454E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.987E-01 1.306E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.258
Neon        1.000E+00 8.137E-13 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 7.100E-04 9.993E-01 6.772E-07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.115E-06 1.000E+00 7.487E-12 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.471E-04 9.999E-01 1.862E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.445E-02 9.856E-01 4.763E-16 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
```

```
Argon     0 1.000E+00 2.885E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 7.089E-05 9.992E-01 7.586E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 9.221E-04 9.991E-01 1.252E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
 !The largest continuum occupation number was 7.124E+01 at 1.053E-05 Ryd.
W-Heating - cooling mismatch =  2.00E+00 Whats wrong????
  Continuum occupation number reached  4.95E+00 for some fine structure transitions.
  Induced recombination was   1.7% of the total for H level 7
  Stimulated emission was   8.1% of the total for H transition 7 - 6
  Compton heating was 14.4% of the total.
  Energy density of radiation field was greater than the Compton temperature. Is this physical?
  Frequency out of range of free-free gaunt factor routine.
  H- absorption heating was  3.7% of the total.
C-The Lyman continuum is thin, and I assumed that it was thick.  Try another iteration.
```

```
*********************************> CLOUDY 80.08  <*********************************
* title Martin Gaskell's funny model                                                 *
* c used to test that electron density convergence is ok                             *
* c hydrogen line spectrum strongly pumped by continuum                              *
* black 4000                                                                         *
* lumin 27.2                                                                         *
* constant temper 5500                                                               *
* faint -3                                                                           *
* radius 15                                                                          *
* hden 5.13                                                                          *
* abundances 1000 1000 1000 1000 1000 1000 1000 1000                                 *
* stop zone 1                                                                        *
* print short                                                                        *
* drmax 0                                                                            *
* drmin 0                                                                            *
* c eden.in                                                                          *
* c cray                                                                             *
*********************************> LOG(U): -8.85 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                            Luminosity (erg/s) emitted by shell with full coverage.

TOTL 4861 15.198   1.0000      TOTL  938 14.560   0.2299      N  2 5755 13.755   0.0360      S II 6731 18.073 748.6573
TOTL 1216 19.766*********      INWD 1216 19.766*********      N  2  122 13.269   0.0118      S II 6716 17.723 334.8413
TotH    0 16.078   7.5730      Dest 1216 15.467   1.8545      N  2  203 12.283   0.0012      S II 4070 17.989 617.1406
BFH1    0 13.489   0.0195      e sc18751 12.268   0.0012      N  2 2140 12.988   0.0062      S II 4078 17.499 199.6309
BFHx    0 12.746   0.0035      nFnu 4860 16.152   8.9969      O  1 6300 18.6903099.8769      S II10323 17.486 193.7774
TotM    0 15.999   6.3244      Inci 4861 39.786*********      O  1 6363 18.2131033.2923      S II10289 17.357 143.9799
FF H    0 12.505   0.0020      Inci 1216 32.551*********      O  1 5577 15.930   5.3953      S II10373 17.028  67.6201
ComH    0 15.236   1.0917      BA C    0 13.948   0.0562      O  1  630 18.033 683.1214      S II10339 17.348 141.3086
H- H    0 14.318   0.1318      PA C    0 13.457   0.0181      O  1 1470 16.489  19.5166      Ar 2    7 13.301   0.0127
CA B 4861 13.395   0.0157      H FF    0 13.178   0.0095      O  1 7774 13.715   0.0329      Ca 2 3933 18.037 689.5098
CA B 1216 14.909   0.5132      ComC    0 15.393   1.5658      T OI    0 13.761   0.0366      Ca 2 8579 16.465  18.4953
DU B 4861 13.388   0.0155      H FB    0 13.583   0.0242      6lev 1304 13.761   0.0365      Ca 2 7306 19.0577231.0594
Q(H) 4861 25.530*********      Cool 1216 13.317   0.0131      TOTL 3727 15.239   1.0993      Ca2K 3934 17.852 450.4940
Q(H) 1216 27.063*********      H-FB    0 14.449   0.1783      TOTL 7325 14.424   0.1681      Ca2H 3969 17.577 239.0158
TOTL 6563 16.481  19.1627      MeFB    0 15.779   3.8043      O II 3729 14.614   0.2602      Ca2X 8498 15.285   1.2202
TOTL 4861 15.198   1.0000      MeFF    0 15.544   2.2182      O II 3726 15.122   0.8390      Ca2Y 8542 16.243  11.0833
TOTL 4340 14.485   0.1935      ToFF    0 15.546   2.2277      O II 2471 14.322   0.1329      Ca2Z 8662 15.990   6.1918
TOTL 4102 14.014   0.0655      REC  1656 16.621  26.4660      O II 7323 14.166   0.0927      CaF1 7291 18.8324298.5488
TOTL18751 14.641   0.2769      C  I 9850 18.7223340.5012      O II 7332 14.075   0.0753      CaF2 7324 18.6662932.5105
TOTL12818 13.954   0.0570      C  1 8727 17.998 630.3314      Mg 1 4571 13.759   0.0364      Fe 2   48 13.801   0.0401
TOTL10938 13.491   0.0196      C  1  610 13.415   0.0165      Emis 2798 18.2271067.7718      Fe 2    7 18.6442792.1011
TOTL40512 13.543   0.0221      C  1  370 14.313   0.1303      Cool 2798 18.2271067.7718      Emis    3 18.123 841.0212
TOTL26252 13.107   0.0081      C  2  158 16.101   8.0019      Si 2   35 17.756 361.0007      Cool    3 18.123 841.0212
TOTL74578 12.777   0.0038      C  2 2326 16.985  61.1770      Si 2 2335 16.508  20.3813      TOT     0 18.7593633.1624
2 NU    0 13.536   0.0217      C  2 1335 13.879   0.0479      Si 2 1808 14.769   0.3724      FEIR    0 18.6062555.5387
TOTL 1216 19.766*********      N  1 5200 17.117  82.8697      S 1R 1807 14.987   0.6143      Fe 3    0 13.324   0.0134
TOTL 1026 16.938  54.9398      REC  5200 12.415   0.0016      S  2 6720 18.2331083.4986      Fe 3 5270 12.644   0.0028
TOTL  973 15.711   3.2593      N  2 6584 16.033   6.8367      S  2 4074 18.110 816.7716      Fe 3 4658 12.888   0.0049
TOTL  950 15.020   0.6632      N  2 6548 15.556   2.2789      S  210330 17.936 546.6860
```

```
                          MARTIN GASKELL'S FUNNY MODEL
Cooling:  C  I 9850:0.123  O  1 6300:0.115  Ca 2 7306:0.267  TOT     0:0.134  FEIR    0:0.094
Heating:  TotM    0:0.835  ComH    0:0.144

IONIZE PARMET:  U(1-) -8.8531  U(4-):-37.0000  U(sp): -8.85  Q(ion):   37.853  L(ion):  27.203 Q(low): 52.16    P(low) 40.33
ENERGY BUDGET:  Heat:  16.078  Coolg:  19.631  Error:*****%  Compt H:  15.236  WorkF:   17.632 F-F  H 12.505    PRADMX:4.43E-07
Column density  H12:1.349E+05  H II:2.019E+02  HI:1.347E+05  H-:    8.611E-10  H2:   1.789E-06 H2+:8.829E-06    He H+:1.732E-04
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.349E+05  <Tp>:5.50E+03  <TO3>:0.00E+00  Ne:0.000E+00  ti(snd):3.02E-06  NeN+dl:9.39E+06 <T(C3)>:0.00E+00 <E(C3)>:0.00E+00
He/Ha:0.00E+00  =   0.00*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:5.50E+03 <E(S2)>:4.65E+04
T He+:0.00E+00  EHe+:0.00E+00  T(O+):5.50E+03  EO+:4.65E+04  iter/zn:   1.000  Te-low:5.50E+03 Te-high:5.50E+03  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt2.81E-02  Tthr4.50E+06  <Tden>: 5.50E+03  <dens>:9.42E-17 <Mol>:4.16E+00
Mean Jeans      l(cm)2.34E+17  M(sun)3.19E+02  smallest:     len(cm):2.34E+17  M(sun):3.19E+02 Alf(ox-tran):     0.0000
```

```
**************************************91Aug03***************************************
*                                                                                  *
* title test hydrogen atom continuous emissivity                                   *
* black 5                                                                          *
* ionization parameter -2                                                          *
* sphere static            ;want full outward flux                                 *
* constant temperature 4                                                           *
* abundances -10           ;pure hydrogen                                          *
* hden 7                   ;suppress two-photon emission                           *
* stop eden 6              ;stop model at H ionization front                       *
* print short                                                                      *
* punch emitted continuum  ;output the predicted continuum                         *
* hydrogen collisions off                                                          *
* c hemis.in                                                                       *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

Chemical composition

He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

```
          356Cell Peak2.46E+00   Lo 1.00E-05=0.9105cm   Hi-Con:2.30E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   5.1532   Average nu:2.177E+00   P( X-ray):  -5.0583   P(BalC):   4.2200     Q(Balmer C):  15.0617
          Q(1.0-1.8):  15.1279   Q(1.8-4.0):  15.1711   Q(4.0-20):  14.2441   Q(20--):   4.2804     Ion pht flx:3.001E+15
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):   2.6360   Alf(ox):   0.0000     Total lumin:   5.2023
          U(1.0----):1.001E-02   U(4.0----):5.851E-04   T(En-Den):1.628E+02   T(Comp):9.574E+04     nuJnu(912A):3.960E+04
          Occ(FarIR):4.222E-07   Occ(H n=6):1.550E-10   Occ(1Ryd):1.827E-12   Occ(4R):1.261E-14     Occ (Nu-hi):2.090E-27
          Tbr(FarIR):7.022E-07   Tbr(H n=6):6.882E-07   Tbr(1Ryd):2.886E-07   Tbr(4R):7.980E-09     Tbr (Nu-hi):7.463E-21

#####  1 Te:1.000E+04 Hden:1.000E+07 Ne:9.995E+06 R:1.000E+25 R-R0:1.502E+12 dR:3.004E+12 NTR:  1 Htot:2.621E-10 T912: 9.991E+07###
  1.57 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
P(LINES): 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    5.290E-04 9.995E-01 H+0/Hden: 1.000E+00 2.443E-12 H-     H2 1.398E-14 1.448E-13 H2+  HeH+ 1.316E-21 H col den 3.004E+19
H 2SP 3-6   5.962E-10 1.372E-09 2.636E-14 3.590E-14 5.389E-14 7.824E-14 Texc(La); 8.473E+03 T(contn): 1.619E+02 T(diffs): 5.437E+02
Helium      4.227E-05 1.155E-01 8.845E-01 He I 2S3  9.675E-08 Comp H, C 6.842E-17 7.146E-18 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  4.217E-05 7.126E-12 2.016E-16 3.864E-16 7.010E-16 1.143E-15 He triplt 9.675E-08 5.114E-14 4.996E-16 3.068E-15 8.329E-16
HeII        1.155E-01 4.739E-10 3.767E-15 7.774E-15 1.415E-14 2.346E-14 2.266E-13 3.055E-12 1.199E-09 PRAD/GAS; 2.806E+01
Pressure    NgasTgas; 1.999E+11 P(total): 8.022E-04 P( gas ): 2.761E-05 P(Radtn): 7.746E-04 Rad accel 1.659E-03 Force Mul 7.797E+02
Carbon      2.293E-06 6.108E-03 3.263E-01 6.019E-01 6.571E-02 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.005E-06 2.612E-03 3.117E-01 6.352E-01 5.010E-02 3.321E-04 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      7.177E-07 2.714E-03 3.052E-01 6.519E-01 4.007E-02 8.037E-05 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.588
Neon        8.613E-07 2.169E-03 4.195E-01 5.582E-01 2.014E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.236E-07 1.184E-02 6.430E-01 3.403E-01 4.829E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.159E-07 2.505E-02 3.691E-01 6.019E-01 3.867E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 6.567E-03 2.409E-01 5.874E-01 1.651E-01 1.630E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 5.213E-03 4.032E-01 4.925E-01 8.923E-02 9.812E-03 8.505E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 8.609E-07 4.140E-03 2.610E-01 5.543E-01 1.787E-01 1.910E-03 2.121E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 9.366E-06 2.665E-02 3.042E-01 5.297E-01 1.256E-01 1.375E-02 9.167E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 6.433E-06 2.800E-03 1.319E-01 4.620E-01 3.899E-01 1.332E-02 1.790E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
##### 88 Te:1.000E+04 Hden:1.000E+07 Ne:9.809E+05 R:1.000E+25 R-R0:1.405E+14 dR:1.134E+12 NTR:  1 Htot:1.031E-11 T912: 9.991E+07###
  3.12 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    9.207E-01 7.930E-02 H+0/Hden: 1.000E+00 1.540E-08 H-     H2 2.962E-07 8.610E-09 H2+  HeH+ 1.786E-16 H col den 1.411E+21
H 2SP 3-6   2.272E-09 6.389E-09 2.200E-14 4.858E-15 6.273E-15 8.794E-15 Texc(La); 5.277E+03 T(contn): 9.318E+01 T(diffs): 2.514E+02
Helium      6.263E-01 3.498E-01 2.393E-02 He I 2S3  1.911E-06 Comp H, C 2.371E-19 8.016E-20 Fill Fact 1.000E+00 Gam 1/tot 4.389E-01
He singlet  6.263E-01 1.304E-10 6.258E-17 1.192E-16 2.154E-16 3.495E-16 He triplt 1.911E-06 6.245E-14 3.160E-16 1.186E-15 2.971E-16
HeII        3.498E-01 1.322E-11 1.022E-17 2.107E-17 3.827E-17 6.325E-17 6.063E-16 7.782E-15 2.759E-12 PRAD/GAS; 1.030E-02
```

```
Pressure    NgasTgas; 1.105E+11 P(total): 1.546E-05 P( gas ): 1.525E-05 P(Radtn): 2.075E-07 Rad accel 3.319E-05 Force Mul 1.480E+03
Carbon      2.426E-04 9.884E-01 1.136E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    5.915E-02 9.407E-01 1.162E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.287E-01 7.130E-02 1.247E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.588
Neon        1.092E-01 4.307E-01 4.601E-01 1.916E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.962E-03 5.675E-01 4.305E-01 2.115E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 2.434E-04 7.453E-01 1.805E-01 7.293E-02 1.086E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.048E-04 9.986E-01 1.196E-03 8.100E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 3.091E-05 9.758E-01 2.422E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 4.986E-01 4.487E-01 5.266E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 7.153E-04 1.975E-02 9.790E-01 5.201E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.254E-02 9.795E-01 7.980E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest EDEN reached.
  Geometry is plane-parallel.
  Photoionization of He 2TriS reached  86.1 percent of the total rate out.
W-A physical process has been disabled.
W-Heating - cooling mismatch =  1.76E+00 Whats wrong????
  Continuum occupation number reached  9.81E-01 for some fine structure transitions.
C-I must iterate when SPHERE STATIC is set.
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  2.81E+01.  Caused by Lyman alpha.
C-This is the last iteration and H(a) optical depth changed by  91.3% (was  2.32E+01). Try another iteration
```

```
*********************************> CLOUDY 80.08  <*********************************
* title test hydrogen atom continuous emissivity                                    *
* black 5                                                                           *
* ionization parameter -2                                                           *
* sphere static            ;want full outward flux                                  *
* constant temperature 4                                                            *
* abundances -10           ;pure hydrogen                                           *
* hden 7                   ;suppress two-photon emission                            *
* stop eden 6              ;stop model at H ionization front                        *
* print short                                                                       *
* punch emitted continuum  ;output the predicted continuum                          *
* hydrogen collisions off                                                           *
* c hemis.in                                                                        *
* c cray                                                                            *
*********************************> LOG(U): -2.00 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Constant  Density Model.  Closed geometry.  Iteration 1 of 1.
                                                Intensity (erg/s/cm^2)

TOTL 4861  3.124   1.0000      Q(H) 1216  4.688  36.5957      TOTL74578  1.418   0.0197      BA C    0  3.798   4.7204
TOTL 1216  4.706  38.1728      TOTL 6563  3.621   3.1404      2 NU    0  2.193   0.1172      PA C    0  3.286   1.4492
TotH    0  4.895  58.9393      TOTL 4861  3.124   1.0000      TOTL 1216  4.706  38.1728      H FF    0  3.324   1.5849
BFH1    0  4.895  58.9290      TOTL 4340  2.851   0.5332      LA X 1216  1.341   0.0165      H FB    0  3.457   2.1525
BFHx    0  1.013   0.0077      TOTL 4102  2.633   0.3227      INWD 1216  4.706  38.1724      H-FB    0  0.580   0.0029
H- H    0  0.490   0.0023      TOTL18751  2.663   0.3454      Dest 1216  1.197   0.0118      H2+     0  0.227   0.0013
CA B 4861  3.174   1.1210      TOTL12818  2.361   0.1725      nFnu 4860  3.440   2.0707      ToFF    0  3.324   1.5849
CA B 1216  4.708  38.3170      TOTL10938  2.132   0.1018      nFnu 1215  1.456   0.0214
DU B 4861  3.174   1.1210      TOTL40512  1.950   0.0670      Inci 4861  2.738   0.4107
Q(H) 4861  3.154   1.0704      TOTL26252  1.748   0.0420      Inci 1216  4.328  15.9710
```

```
                          TEST HYDROGEN ATOM CONTINUOUS EMISSIVITY
Cooling:  H FF    0:0.424  H FB    0:0.575
Heating:  BFH1    0:1.000

IONIZE PARMET:  U(1-) -1.9996  U(4-): -3.2328  U(sp): -2.00  Q(ion):   11.624  L(ion):   1.857 Q(low): 15.11    P(low)  4.23
ENERGY BUDGET:  Heat:   4.895  Coolg:   3.697  Error: 93.7%  Compt H:  -2.239  WorkF:    4.832 F-F  H -1.698    PRADMX:2.81E+01
Column density  H12:1.411E+21  H II:1.251E+21  HI:1.601E+20  H-:    3.453E+12  H2:   3.505E+13 H2+:1.581E+12    He H+:2.392E+04
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+07  <Tp>:1.00E+04  <TO3>:1.00E+04  Ne:9.852E+06  ti(snd):1.13E+08  NeN+dl:1.20E+28 <T(C3)>:1.00E+04 <E(C3)>:9.58E+06
He/Ha:5.18E-11  =   0.52*true  N/Oap:0.00E+00  =   0.00true  T(O3R):1.000E+01  L THIN:1.00E+30 <T(S2)>:1.00E+04 <E(S2)>:4.49E+06
T He+:1.00E+04  EHe+:7.28E+06  T(O+):1.00E+04  EO+:7.13E+06  iter/zn:   1.000  Te-low:1.00E+04 Te-high:1.00E+04  Hlu/zn:1.41E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt3.52E+01  Tthr1.00E+06  <Tden>: 1.00E+04  <dens>:1.66E-17 <Mol>:5.41E-01
Mean Jeans      l(cm)1.61E+18  M(sun)1.84E+04  smallest:     len(cm):1.61E+18  M(sun):1.84E+04 Alf(ox-tran):     0.0000
```

```
**************************************91Aug03***************************************
*                                                                                  *
* title high electron density approach to lte                                      *
* c test from Ferland and Rees 88, collisions drive H to LTE                       *
* c collisions should drive all departure coef to unity                            *
* constant temperature = 50,000                                                    *
* print departure coefficients                                                     *
* stop zone 1                                                                      *
* stop lyman optical depth -6                                                      *
* black body t=50,000                                                              *
* ionization parameter -5                                                          *
* hden = 19                                                                        *
* abundances -10                                                                   *
* iterate                                                                          *
* print last short                                                                 *
* drmax 0                                                                          *
* drmin 0                                                                          *
* c highn.in                                                                       *
* c cray                                                                           *
*                                                                                  *
************************************************************************************


Is this value of the H-density reasonable?
                                        Chemical composition
He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  13.9889   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  13.8421     Q(Balmer C):  24.7181
          Q(1.0-1.8):  24.3840   Q(1.8-4.0):  23.7615   Q(4.0-20):  21.3654   Q(20--):   0.0000     Ion pht flx:3.001E+24
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  12.4994   Alf(ox):   0.0000     Total lumin:  14.2308
          U(1.0----):1.001E-05   U(4.0----):7.736E-09   T(En-Den):2.943E+04   T(Comp):4.812E+04     nuJnu(912A):1.157E+14
          Occ(FarIR):3.607E+03   Occ(H n=6):1.295E+00   Occ(1Ryd):5.334E-03   Occ(4R):3.849E-07     Occ (Nu-hi):2.802E-17
          Tbr(FarIR):5.999E+03   Tbr(H n=6):5.749E+03   Tbr(1Ryd):8.425E+02   Tbr(4R):2.435E-01     Tbr (Nu-hi):5.037E-11

#####  1 Te:5.000E+04 Hden:1.000E+19 Ne:9.553E+18 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:1.746E+13 T912: 4.946E-01###
 10.38 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 2326  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    4.472E-02 9.553E-01 H+0/Hden: 1.000E+00 4.712E-06 H-     H2 2.359E-07 7.176E-09 H2+  HeH+ 4.439E-18 H col den 1.000E+19
Hydrogen    1.001E+00 1.000E+00 H+0/Hden: 1.000E+00 9.996E-01 H-     H2 4.505E-01       H2+ 2.619E-03     He H+ 4.439E-18
H 2SP 3-6   7.793E-04 2.338E-03 4.523E-03 6.897E-03 1.004E-02 1.391E-02 Texc(La); 4.994E+04 T(contn): 2.793E+04 T(diffs): 2.864E+04
H 2SP 3-6   1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00
Helium      3.813E-02 9.539E-01 7.942E-03 He I 2S3  5.781E-03 Comp H, C 3.511E+04 3.648E+04 Fill Fact 1.000E+00 Gam 1/tot 2.897E-04
Helium      1.042E+00 1.109E+00 1.000E+00 He I 2S3  9.933E-01 Comp H, C 3.511E+04 3.648E+04 Fill Fact 1.000E+00 Gam 1/tot 2.897E-04
He singlet  2.316E-02 7.508E-04 1.079E-03 1.645E-03 2.394E-03 3.317E-03 He triplt 7.600E-04 1.751E-03 3.884E-04 1.090E-03 1.792E-03
He singlet  1.042E+00 1.010E+00 1.001E+00 1.000E+00 1.000E+00 1.000E+00 He triplt 9.933E-01 9.948E-01 9.944E-01 9.948E-01 9.964E-01
HeII        9.532E-01 2.644E-04 1.029E-04 9.902E-05 1.164E-04 1.437E-04 9.825E-04 7.350E-03 9.457E-01 PRAD/GAS; 4.051E-08
HeII        1.109E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 1.000E+00 PRAD/GAS; 4.051E-08
Pressure    NgasTgas; 9.776E+23 P(total): 1.350E+08 P( gas ): 1.350E+08 P(Radtn): 5.468E+00 Rad accel 5.583E+07 Force Mul 2.572E+04
Carbon      9.460E-05 1.776E-01 8.221E-01 2.028E-04 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.719E-04 8.449E-01 1.541E-01 1.679E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      2.308E-02 9.435E-01 3.339E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.983
Neon        7.358E-03 8.307E-01 1.619E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 3.143E-06 9.884E-03 9.901E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.837E-05 9.218E-02 7.162E-01 1.916E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.036E-04 2.126E-01 7.539E-01 3.339E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.037E-05 1.079E-01 8.826E-01 9.429E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
```

```
Argon     0 4.921E-05 9.993E-02 8.989E-01 1.113E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 5.505E-07 3.343E-03 9.941E-01 2.595E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 4.675E-05 4.540E-02 8.963E-01 5.826E-02 1.851E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because optical depth reached
  Geometry is plane-parallel.
W-Density greater than 10**15
 !The largest continuum occupation number was 3.607E+03 at 1.053E-05 Ryd.
 !The largest continuum brightness temperature was 5.999E+03K at 1.053E-05 Ryd.
W-Heating - cooling mismatch =  1.65E+00 Whats wrong????
  Continuum occupation number reached  1.99E-01 for some fine structure transitions.
  Some fine structure lines were a heat source.
  Induced recombination was  49.8% of the total for H level 7
  Stimulated emission was  90.9% of the total for H transition 7 - 6
  Population of H n=2 reached  3.74E-01 relative to the ground state.
  Induced recombination cooling was  7.6% of the total.
  Free-free heating was 46.9% of the total.
C-Free-free heating significant and frequency out of range of gaunt factor routine.
  Balmer continuum optical depth is  5.03E-01
  Lyman continuum stimulated emission correction to optical depths reached  0.04
  Paschen cont optical depth=  1.78E+00
  Continuum optical depth at low nu ( 1.053E-05 Ryd) was  5.692E+08
  Line radiation pressure capped by thermalization length.
```

```
*********************************> CLOUDY 80.08  <*********************************
* title high electron density approach to lte                                      *
* c test from Ferland and Rees 88, collisions drive H to LTE                       *
* c collisions should drive all departure coef to unity                            *
* constant temperature = 50,000                                                    *
* print departure coefficients                                                     *
* stop zone 1                                                                      *
* stop lyman optical depth -6                                                      *
* black body t=50,000                                                              *
* ionization parameter -5                                                          *
* hden = 19                                                                        *
* abundances -10                                                                   *
* iterate                                                                          *
* print last short                                                                 *
* drmax 0                                                                          *
* drmin 0                                                                          *
* c highn.in                                                                       *
* c cray                                                                           *
*********************************> LOG(U): -5.00 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.

                    Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                                 Intensity (erg/s/cm^2)

     TOTL 4861 10.379   1.0000      TOTL18751  9.799   0.2631      INWD 4861 10.060   0.4800      BA C    0 13.110 537.9006
     TOTL 1216 12.375  99.0903      TOTL12818  9.525   0.1399      INWD18751  9.481   0.1264      PA C    0 12.555 149.8258
     TotH    0 13.242 729.6163      TOTL10938  9.304   0.0841      Strk 1216 12.359  95.5367      H FF    0 13.5811590.9079
     BFH1    0 12.612 170.9720      TOTL40512  9.104   0.0531      Strk 6563 10.761   2.4088      H FB    0 13.6451843.3791
     BFHx    0 12.711 214.8266      TOTL26252  8.894   0.0328      Strk 4861 10.355   0.9468      Hind    0 12.120  55.1043
     FF H    0 12.913 342.2061      TOTL74578  8.560   0.0152      Strk18751  9.797   0.2621      Cool 1216 13.161 605.3822
     H- H    0 10.586   1.6108      TOTL 1216 12.375  99.0903      Strk40512  9.103   0.0530      Crst  960 11.437  11.4252
     CA B 4861 12.362  96.1266      TOTL 1026 10.530   1.4145      Dest 1216 10.485   1.2753      Cool 6563 12.789 257.1106
     CA B 1216 13.9633840.0487      TOTL  973 11.325   8.8350      Dest 6563  9.926   0.3528      Crst 4861 12.286  80.7343
     DU B 4861 12.358  95.3853      TOTL  950 11.103   5.2945      Dest40516  9.163   0.0608      Cool18751 13.032 449.8266
     Q(H) 4861 12.154  59.5680      TOTL  938 10.976   3.9570      Dest 4861  9.947   0.3702      Crst    0 12.017  43.5010
     Q(H) 1216 13.6882036.6283      C13c 6563 11.990  40.8341      Dest18751  9.491   0.1294      H-FB    0 11.311   8.5443
     TOTL 6563 10.764   2.4294      C14c 4861 10.832   2.8403      nFnu 4860 13.259 758.2635      H2+     0 10.909   3.3890
     TOTL 4861 10.379   1.0000      CION    0 13.7772498.6938      nFnu 1215 13.367 972.2584      ToFF    0 13.5811590.9079
     TOTL 4340 10.113   0.5426      INWD 1216 12.057  47.6666      Inci 4861 12.600 166.5390      Mion    0  7.735   0.0023
     TOTL 4102  9.936   0.3606      INWD 6563 10.446   1.1670      Inci 1216 13.9303557.6206
Lines with negative intensities;  255 Ne 2  128  361 Ar 2    7  389 Ca 4   32
```

```
                              HIGH ELECTRON DENSITY APPROACH TO LTE
Cooling:  CION    0:0.324  H FF    0:0.206  H FB    0:0.239  Cool 1216:0.078  Cool18751:0.058
Heating:  BFH1    0:0.234  BFHx    0:0.294  FF H    0:0.469

IONIZE PARMET:  U(1-) -4.9996  U(4-): -8.1115  U(sp): -5.00  Q(ion):   24.337  L(ion):  13.870 Q(low): 24.68    P(low) 13.81
ENERGY BUDGET:  Heat:  13.242  Coolg:  14.267  Error:957.9%  Compt H:   4.545  WorkF:   16.239 F-F  H 12.913    PRADMX:4.05E-08
Column density  H12:1.000E+19  H II:9.553E+18  HI:4.472E+17  H-:    4.712E+13  H2:   2.359E+12 H2+:7.176E+10    He H+:4.439E+01
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+19  <Tp>:5.00E+04  <TO3>:5.00E+04  Ne:9.553E+18  ti(snd):3.51E-07  NeN+dl:9.13E+37 <T(C3)>:5.00E+04 <E(C3)>:9.55E+18
He/Ha:1.34E-08  = 134.41*true  N/Oap:0.00E+00  =   0.00true  T(O3R):1.000E+01  L THIN:1.00E+30 <T(S2)>:5.00E+04 <E(S2)>:9.55E+18
T He+:5.00E+04  EHe+:9.55E+18  T(O+):5.00E+04  EO+:9.55E+18  iter/zn:   1.000  Te-low:5.00E+04 Te-high:5.00E+04  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.72E-20  Tthr5.99E-07  <Tden>: 5.00E+04  <dens>:1.66E-05 <Mol>:5.11E-01
Mean Jeans      l(cm)4.80E+12  M(sun)4.84E-01  smallest:     len(cm):4.80E+12  M(sun):4.84E-01 Alf(ox-tran):     0.0000
```

CLOUDY 80.08

```
*************************************91Aug03*************************************
*                                                                              *
* title test of H ionization is optically thin limit                           *
* c H cross section is 2.09E-18 cm^2, rec coef is 4.18E-14                     *
* c answer is neutral fraction 2.00E-4                                         *
* laser 1.5 Ryd                                                                *
* phi(h) 10                                                                    *
* hden 1                                                                       *
* constant temperature = 4                                                     *
* iterate                                                                      *
* stop zone 1                                                                  *
* abundances -10                                                               *
* drmax 0                                                                      *
* drmin 0                                                                      *
* print last                                                                   *
* print short                                                                  *
* c hion.in                                                                    *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

Chemical composition

He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

```
          263Cell Peak1.53E+00   Lo 1.00E-05=0.9112cm   Hi-Con:1.81E+00 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  -0.4860   Average nu:1.499E+00   P( X-ray):   0.0000   P(BalC): -30.0000     Q(Balmer C): -24.2981
          Q(1.0-1.8):  10.0000   Q(1.8-4.0):   0.0000   Q(4.0-20):   0.0000   Q(20--):   0.0000     Ion pht flx:1.000E+10
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred): -36.3400   Alf(ox):   0.0000     Total lumin:  -0.4860
          U(1.0----):3.336E-02   U(4.0----):0.000E+00   T(En-Den):6.160E+00   T(Comp):5.918E+04     nuJnu(912A):1.462E-35
          Occ(FarIR):6.090E-42   Occ(H n=6):8.537E-49   Occ(1Ryd):6.746E-52   Occ(4R):4.206E-53     Occ (Nu-hi):2.136E-52
          Tbr(FarIR):1.012E-41   Tbr(H n=6):3.791E-45   Tbr(1Ryd):1.066E-46   Tbr(4R):2.661E-47     Tbr (Nu-hi):5.996E-47

#####  1 Te:1.000E+04 Hden:1.000E+01 Ne:9.998E+00 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:4.502E-22 T912: 2.246E-20###
-23.24 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    1.980E-04 9.998E-01 H+0/Hden: 1.000E+00 1.744E-12 H-     H2 5.832E-14 2.441E-12 H2+  HeH+ 1.418E-22 H col den 1.000E+01
H 2SP 3-6   5.869E-14 2.684E-21 8.734E-21 1.672E-20 2.880E-20 4.538E-20 Texc(La); 2.962E+03 T(contn): 6.160E+00 T(diffs): 3.936E+02
Helium      1.000E+00 0.000E+00 0.000E+00 He I 2S3  0.000E+00 Comp H, C 8.672E-29 1.465E-29 Fill Fact 1.000E+00 Gam 1/tot 9.999E-01
He singlet  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 He triplt 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 1.395E-06
Pressure    NgasTgas; 2.000E+05 P(total): 2.761E-11 P( gas ): 2.761E-11 P(Radtn): 3.852E-17 Rad accel 2.733E-09 Force Mul 6.265E+02
Carbon      1.431E-04 9.999E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.720E-05 9.999E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      5.674E-05 9.999E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.380
Neon        6.480E-04 9.994E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 3.916E-05 6.186E-03 9.938E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 5.605E-05 1.771E-02 9.822E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 4.281E-06 5.654E-03 9.943E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.136E-04 9.998E-01 2.068E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 3.433E-05 1.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 3.794E-03 2.941E-02 9.668E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.641E-05 1.343E-02 9.866E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
W-Heating - cooling mismatch =  1.51E+00 Whats wrong????
```

```
*********************************> CLOUDY 80.08  <*********************************
* title test of H ionization is optically thin limit                           *
* c H cross section is 2.09E-18 cm^2, rec coef is 4.18E-14                     *
* c answer is neutral fraction 2.00E-4                                         *
* laser 1.5 Ryd                                                                *
* phi(h) 10                                                                    *
* hden 1                                                                       *
* constant temperature = 4                                                     *
* iterate                                                                      *
* stop zone 1                                                                  *
* abundances -10                                                               *
* drmax 0                                                                      *
* drmin 0                                                                      *
* print last                                                                   *
* print short                                                                  *
* c hion.in                                                                    *
* c cray                                                                       *
*********************************> LOG(U): -1.48 <*********************************
>>>>>>>>> Warnings exist, this calculation is suspect.
```

Emission Line Spectrum. Constant Density Model. Open geometry. Iteration 2 of 2.
Intensity (erg/s/cm^2)

```
TOTL 4861-23.240   1.0000      TOTL 4861-23.240   1.0000      TOTL 1216-21.759  30.2723      e sc40512-24.418   0.0664
TOTL 1216-21.759  30.2723      TOTL 4340-23.477   0.5797      TOTL 1026-22.094  14.0095      nFnu 4860-22.473   5.8554
TotH    0-21.347  78.3174      TOTL 4102-23.670   0.3717      TOTL  973-22.392   7.0539      nFnu 1215-24.626   0.0412
BFH1    0-21.347  78.3173      TOTL18751-23.798   0.2769      TOTL  950-22.623   4.1480      BA C    0-22.283   9.0724
CA B 4861-22.907   2.1544      TOTL12818-24.008   0.1708      TOTL  938-22.812   2.6791      PA C    0-22.796   2.7853
CA B 1216-21.373  73.6431      TOTL10938-24.193   0.1115      INWD 1216-21.862  23.8954      H FF    0-22.757   3.0461
DU B 4861-22.907   2.1544      TOTL40512-24.419   0.0663      INWD 6563-23.235   1.0134      H FB    0-22.349   7.7882
Q(H) 4861 -2.323*********      TOTL26252-24.578   0.0460      INWD 4861-23.542   0.5000      Cool 1216-25.145   0.0125
Q(H) 1216 -0.789*********      TOTL74578-24.907   0.0215      INWD18751-24.099   0.1384      ToFF    0-22.757   3.0461
TOTL 6563-22.934   2.0267      2 NU    0-22.103  13.7278      e sc18751-23.798   0.2771
```

TEST OF H IONIZATION IS OPTICALLY THIN LIMIT

```
Cooling:  H FF    0:0.281  H FB    0:0.718
Heating:  BFH1    0:1.000

IONIZE PARMET:  U(1-) -1.4768  U(4-):-37.0000  U(sp): -1.48  Q(ion):   10.000  L(ion):  -0.486 Q(low):-19.29    P(low)-30.03
ENERGY BUDGET:  Heat: -21.347  Coolg: -22.205  Error: 86.1%  Compt H: -28.062  WorkF:  -20.000 F-F  H-27.335    PRADMX:7.50E-04
Column density  H12:1.000E+01  H II:9.998E+00  HI:1.980E-03  H-:    1.744E-11  H2:   5.832E-13 H2+:2.441E-11    He H+:1.418E-21
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+01  <Tp>:1.00E+04  <TO3>:0.00E+00  Ne:0.000E+00  ti(snd):7.76E-07  NeN+dl:1.00E+02 <T(C3)>:0.00E+00 <E(C3)>:0.00E+00
He/Ha:0.00E+00  =   0.00*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:1.00E+04 <E(S2)>:1.00E+01
T He+:0.00E+00  EHe+:0.00E+00  T(O+):1.00E+04  EO+:1.00E+01  iter/zn:   1.000  Te-low:1.00E+04 Te-high:1.00E+04  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.50E+13  Tthr6.64E+11  <Tden>: 1.00E+04  <dens>:1.66E-23 <Mol>:5.00E-01
Mean Jeans      l(cm)2.17E+21  M(sun)4.47E+07  smallest:     len(cm):2.17E+21  M(sun):4.47E+07 Alf(ox-tran):     0.0000
```

CLOUDY 80.08

```
*************************************91Aug03*************************************
*                                                                              *
* title thermal equil black body limit from Ferland and Rees 1988              *
* c this tests whether thermal processes go to lte                             *
* stop zone 1                                                                  *
* hden 10                                                                      *
* stop lyman optical depth -6                                                  *
* black body, t=50,000 lte                                                     *
* abundances -10                                                               *
* print departure coef                                                         *
* print last short                                                             *
* iterate                                                                      *
* drmax 0                                                                      *
* drmin 0                                                                      *
* c hlte.in                                                                    *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

Chemical composition

```
He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  14.9097   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  14.7629     Q(Balmer C):  25.6389
          Q(1.0-1.8):  25.3048   Q(1.8-4.0):  24.6823   Q(4.0-20):  22.2862   Q(20--):   0.0000     Ion pht flx:2.501E+25
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  13.4202   Alf(ox):   0.0000     Total lumin:  15.1516
          U(1.0----):8.341E+04   U(4.0----):6.446E+01   T(En-Den):5.000E+04   T(Comp):4.997E+04     nuJnu(912A):9.638E+14
          Occ(FarIR):3.006E+04   Occ(H n=6):1.079E+01   Occ(1Ryd):4.445E-02   Occ(4R):3.207E-06     Occ (Nu-hi):2.335E-16
          Tbr(FarIR):4.999E+04   Tbr(H n=6):4.791E+04   Tbr(1Ryd):7.020E+03   Tbr(4R):2.029E+00     Tbr (Nu-hi):4.197E-10

#####  1 Te:5.038E+04 Hden:1.000E+10 Ne:1.000E+10 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:4.290E-04 T912: 5.527E-19###
 -5.60 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 2326  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    4.928E-11 1.000E+00 H+0/Hden: 1.000E+00 4.826E-24 H-     H2 2.458E-32 1.867E-24 H2+  HeH+ 2.433E-41 H col den 1.000E+10
Hydrogen    1.030E+00 1.000E+00 H+0/Hden: 1.000E+00 8.968E-01 H-     H2 3.927E+01       H2+ 5.685E+08     He H+ 2.433E-41
H 2SP 3-6   8.934E-13 2.428E-12 4.793E-12 7.287E-12 1.057E-11 1.457E-11 Texc(La); 4.975E+04 T(contn): 5.000E+04 T(diffs): 1.067E+03
H 2SP 3-6   1.110E+00 1.006E+00 1.024E+00 1.020E+00 1.016E+00 1.011E+00
Helium      6.276E-18 1.207E-07 1.000E+00 He I 2S3  1.687E-18 Comp H, C 3.180E-04 3.206E-04 Fill Fact 1.000E+00 Gam 1/tot 3.622E-01
Helium      1.182E+00 1.158E+00 1.000E+00 He I 2S3  2.669E+00 Comp H, C 3.180E-04 3.206E-04 Fill Fact 1.000E+00 Gam 1/tot 3.622E-01
He singlet  3.335E-18 1.071E-19 1.507E-19 2.248E-19 3.248E-19 4.466E-19 He triplt 2.663E-19 1.561E-19 1.742E-19 9.467E-19 1.439E-19
He singlet  1.182E+00 1.027E+00 1.066E+00 1.042E+00 1.034E+00 1.026E+00 He triplt 2.669E+00 6.790E-01 3.407E+00 6.595E+00 6.107E-01
HeII        1.206E-07 3.728E-11 1.451E-11 1.390E-11 1.627E-11 1.979E-11 1.432E-10 9.583E-10 1.235E-07 PRAD/GAS; 1.158E-15
HeII        1.158E+00 1.096E+00 1.088E+00 1.080E+00 1.073E+00 1.057E+00 1.117E+00 9.984E-01 1.000E+00 1.112E+00 PRAD/GAS; 1.158E-15
Pressure    NgasTgas; 1.006E+15 P(total): 1.389E-01 P( gas ): 1.389E-01 P(Radtn): 1.609E-16 Rad accel 1.894E+04 Force Mul 1.000E+00
Carbon      0.000E+00 0.000E+00 1.719E-10 1.751E-04 9.998E-01 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 3.506E-05 4.791E-02 9.521E-01 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 6.859E-04 7.278E-01 2.707E-01 7.840E-04 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.910
Neon        0.000E+00 0.000E+00 0.000E+00 7.477E-03 9.488E-01 4.370E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 3.220E-05 1.569E-01 8.318E-01 1.126E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 1.370E-07 5.863E-01 4.137E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 0.000E+00 2.578E-12 7.219E-06 1.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.657E-06 9.938E-03 9.901E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.327E-04 2.392E-02 9.581E-01 1.790E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 8.046E-05 1.218E-01 8.263E-01 5.184E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.016E-07 9.191E-03 8.414E-01 1.494E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
```

```
  Photoionization of He 2TriS reached 100.0 percent of the total rate out.
 !The largest continuum occupation number was 3.006E+04 at 1.053E-05 Ryd.
  The continuum occupation number fell below 1 at  4.101E+03 Angstroms.
 !The largest continuum brightness temperature was 4.999E+04K at 1.053E-05 Ryd.
  The continuum brightness temperature fell below 10,000K at  1.065E+03 Angstroms.
  Continuum occupation number reached  2.09E+03 for some fine structure transitions.
  Some fine structure lines were a heat source.
  Induced recombination was  85.8% of the total for H level 7
  Stimulated emission was  97.7% of the total for H transition 7 - 6
  Population of H n=2 reached  4.19E-01 relative to the ground state.
  Compton heating was 74.1% of the total.
  Induced recombination cooling was  1.6% of the total.
  Free-free heating was 10.1% of the total.
C-Free-free heating significant and frequency out of range of gaunt factor routine.
```

```
                    **********************************> CLOUDY 80.08  <**********************************
                    * title thermal equil black body limit from Ferland and Rees 1988                     *
                    * c this tests whether thermal processes go to lte                                    *
                    * stop zone 1                                                                         *
                    * hden 10                                                                             *
                    * stop lyman optical depth -6                                                         *
                    * black body, t=50,000 lte                                                            *
                    * abundances -10                                                                      *
                    * print departure coef                                                                *
                    * print last short                                                                    *
                    * iterate                                                                             *
                    * drmax 0                                                                             *
                    * drmin 0                                                                             *
                    * c hlte.in                                                                           *
                    * c cray                                                                              *
                    **********************************> LOG(U):  4.92 <**********************************
                    >>>>>>>>>> Cautions are present.

                  Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                                 Intensity (erg/s/cm^2)

    TOTL 4861 -5.601   1.0000      TOTL 6563 -5.194   2.5518      TOTL  950 -5.040   3.6392      Inci 4861 13.521*********
    TOTL 1216 -3.604  99.2126      TOTL 4861 -5.601   1.0000      TOTL  938 -5.295   2.0252      Inci 1216 14.851*********
    TotH    0 -3.368 171.1970      TOTL 4340 -5.912   0.4883      CION    0 -8.406   0.0016      BA C    0 -4.790   6.4772
    BFH1    0 -4.427  14.9292      TOTL 4102 -6.163   0.2739      INWD 1216 -3.906  49.6063      PA C    0 -5.377   1.6748
    BFHx    0 -4.522  11.9963      TOTL18751 -6.159   0.2769      INWD 6563 -5.495   1.2759      H FF    0 -4.378  16.7045
    FF H    0 -4.361  17.3623      TOTL12818 -6.443   0.1438      INWD 4861 -5.902   0.5000      ComC    0 -3.495 127.7448
    ComH    0 -3.498 126.9092      TOTL10938 -6.687   0.0821      INWD18751 -6.460   0.1384      H FB    0 -4.227  23.6657
    CA B 4861 -5.602   0.9981      TOTL40512 -6.854   0.0558      Strk 1216 -8.225   0.0024      Hind    0 -5.171   2.6945
    CA B 1216 -3.999  39.9575      TOTL26252 -7.071   0.0339      Strk 6563 -8.034   0.0037      ToFF    0 -4.378  16.7045
    DU B 4861 -5.605   0.9904      TOTL74578 -7.400   0.0159      Strk 4861 -8.171   0.0027
    Q(H) 4861 13.075*********      TOTL 1216 -3.604  99.2126      nFnu 4860 -4.703   7.9149
    Q(H) 1216 14.609*********      TOTL  973 -4.721   7.5891      nFnu 1215 -4.593  10.1817
Lines with negative intensities;  283 Mg 4    4
```

```
                          THERMAL EQUIL BLACK BODY LIMIT FROM FERLAND AND REES 1988
Cooling:  H FF    0:0.098  ComC    0:0.748  H FB    0:0.139
Heating:  BFH1    0:0.087  BFHx    0:0.070  FF H    0:0.101  ComH    0:0.741

IONIZE PARMET:  U(1-)  4.9212  U(4-):  1.8093  U(sp):  4.92  Q(ion):   25.398  L(ion):  14.910 Q(low): 25.71    P(low) 14.78
ENERGY BUDGET:  Heat:  -3.368  Coolg:  -3.369  Error:  0.2%  Compt H:  -3.498  WorkF:   -3.572 F-F  H -4.361    PRADMX:1.27E-01
Column density  H12:1.000E+10  H II:1.000E+10  HI:4.928E-01  H-:    4.826E-14  H2:   2.458E-22 H2+:1.867E-14    He H+:2.433E-31
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+10  <Tp>:5.04E+04  <TO3>:0.00E+00  Ne:0.000E+00  ti(snd):3.46E-07  NeN+dl:1.00E+20 <T(C3)>:5.04E+04 <E(C3)>:1.00E+10
He/Ha:2.64E-10  =   2.64*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:0.00E+00 <E(S2)>:0.00E+00
T He+:5.04E+04  EHe+:1.00E+10  T(O+):0.00E+00  EO+:0.00E+00  iter/zn:   1.000  Te-low:5.04E+04 Te-high:5.04E+04  Hlu/zn:1.00E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.98E-12  Tthr4.87E+02  <Tden>: 5.04E+04  <dens>:1.66E-14 <Mol>:5.00E-01
Mean Jeans      l(cm)1.54E+17  M(sun)1.60E+04  smallest:     len(cm):1.54E+17  M(sun):1.60E+04 Alf(ox-tran):     0.0000
```

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                                        CLOUDY 80.08

                ************************************91Aug03*************************************
                *                                                                              *
                * title constant temper black body limit from Ferland and Rees 1988            *
                * c tests whether departure coef are forced to unity by induced processes      *
                * constant temper 50,000                                                       *
                * stop zone 1                                                                  *
                * grains -5 no heating no cooling                                              *
                * hden 10                                                                      *
                * stop lyman continuum optical depth -6                                        *
                * black body, t=50,000 lte                                                     *
                * metals -10                                                                   *
                * print departure coef                                                         *
                * faint -1                                                                     *
                * print short last                                                             *
                * iterate                                                                      *
                * drmax 0                                                                      *
                * drmin 0                                                                      *
                * c induc.in                                                                   *
                * c cray                                                                       *
                *                                                                              *
                ********************************************************************************


                                        Chemical composition
He:.098 C:3.63E-14 N:1.12E-14 O:8.51E-14 Ne:1.23E-14 Mg:3.80E-15 Al:3.0E-16 Si:3.55E-15 S:1.62E-15 A:3.6E-16 Ca:2.3E-16 Fe:4.68E-15

         333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
         P(nu>1ryd):  14.9097   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  14.7629     Q(Balmer C):  25.6389
         Q(1.0-1.8):  25.3048   Q(1.8-4.0):  24.6823   Q(4.0-20):  22.2862   Q(20--):   0.0000     Ion pht flx:2.501E+25
         L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  13.4202   Alf(ox):   0.0000     Total lumin:  15.1516
         U(1.0----):8.341E+04   U(4.0----):6.446E+01   T(En-Den):5.000E+04   T(Comp):4.997E+04     nuJnu(912A):9.638E+14
         Occ(FarIR):3.006E+04   Occ(H n=6):1.079E+01   Occ(1Ryd):4.445E-02   Occ(4R):3.207E-06     Occ (Nu-hi):2.335E-16
         Tbr(FarIR):4.999E+04   Tbr(H n=6):4.791E+04   Tbr(1Ryd):7.020E+03   Tbr(4R):2.029E+00     Tbr (Nu-hi):4.197E-10
         Grain(Pal):4.423E-28   Grain(Bal):1.783E-27   Grain Mg2:4.381E-27   Grain R:1.527E-26     Grain(HeII):5.214E-27

#####  1 Te:5.000E+04 Hden:1.000E+10 Ne:1.196E+10 R:1.000E+25 R-R0:5.000E-01 dR:1.000E+00 NTR:  1 Htot:5.845E-04 T912: 1.534E-16###
 -5.52 4686  3.31 5876  0.00 1909  0.00 1549  0.00 6584  0.00 2326  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    5.933E-11 1.000E+00 H+0/Hden: 1.000E+00 6.958E-24 H-     H2 2.931E-32 2.234E-24 H2+  HeH+ 3.446E-32 H col den 1.000E+10
Hydrogen    1.007E+00 1.000E+00 H+0/Hden: 1.000E+00 8.890E-01 H-     H2 3.182E+01       H2+ 4.635E+08     He H+ 3.446E-32
H 2SP 3-6   1.075E-12 2.922E-12 5.769E-12 8.773E-12 1.273E-11 1.756E-11 Texc(La); 4.976E+04 T(contn): 5.000E+04 T(diffs): 4.230E+02
H 2SP 3-6   1.102E+00 9.981E-01 1.019E+00 1.016E+00 1.013E+00 1.008E+00
Helium      9.037E-18 1.449E-07 1.000E+00 He I 2S3  2.433E-18 Comp H, C 3.803E-04 3.805E-04 Fill Fact 1.000E+00 Gam 1/tot 3.620E-01
Helium      1.135E+00 1.068E+00 1.000E+00 He I 2S3  2.636E+00 Comp H, C 3.803E-04 3.805E-04 Fill Fact 1.000E+00 Gam 1/tot 3.620E-01
He singlet  4.797E-18 1.540E-19 2.167E-19 3.238E-19 4.682E-19 6.442E-19 He triplt 3.836E-19 2.251E-19 2.510E-19 1.365E-18 2.080E-19
He singlet  1.135E+00 1.015E+00 1.056E+00 1.035E+00 1.028E+00 1.021E+00 He triplt 2.636E+00 6.724E-01 3.379E+00 6.551E+00 6.080E-01
HeII        1.448E-07 4.474E-11 1.739E-11 1.668E-11 1.953E-11 2.377E-11 1.721E-10 1.157E-09 1.491E-07 PRAD/GAS; 1.032E-15
HeII        1.068E+00 1.070E+00 1.072E+00 1.068E+00 1.064E+00 1.049E+00 1.111E+00 9.983E-01 1.000E+00 1.084E+00 PRAD/GAS; 1.032E-15
Gra-ISM     Dust temp 5.002E+04 Pot(Volt) 5.313E+01 Nelectron 1.107E+04 drft cm/s 1.904E+09  Heating: 0.000E+00 Frac(tot) 0.000E+00
Sil-ISM     Dust temp 5.002E+04 Pot(Volt) 5.566E+01 Nelectron 1.160E+04 drft cm/s 1.795E+09  Heating: 0.000E+00 Frac(tot) 0.000E+00
Pressure    NgasTgas; 1.147E+15 P(total): 1.584E-01 P( gas ): 1.584E-01 P(Radtn): 1.635E-16 Rad accel 1.655E+04 Force Mul 1.017E+00
Carbon      0.000E+00 0.000E+00 2.466E-10 2.097E-04 9.998E-01 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 5.040E-05 5.739E-02 9.426E-01 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 8.605E-04 7.624E-01 2.362E-01 5.650E-04 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.908
Neon        0.000E+00 0.000E+00 0.000E+00 9.042E-03 9.544E-01 3.656E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 4.484E-05 1.826E-01 8.083E-01 9.059E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 1.760E-07 6.292E-01 3.708E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 0.000E+00 3.690E-12 8.643E-06 1.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
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Sulphur   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.629E-06 1.205E-02 9.879E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.894E-04 2.852E-02 9.564E-01 1.488E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.167E-04 1.454E-01 8.125E-01 4.191E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.518E-07 1.139E-02 8.621E-01 1.265E-01 1.066E-05 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
  Photoionization of He 2TriS reached 100.0 percent of the total rate out.
 !The largest continuum occupation number was 3.006E+04 at 1.053E-05 Ryd.
  The continuum occupation number fell below 1 at  4.101E+03 Angstroms.
 !The largest continuum brightness temperature was 4.999E+04K at 1.053E-05 Ryd.
  The continuum brightness temperature fell below 10,000K at  1.065E+03 Angstroms.
W-A physical process has been disabled.
C-Heating - cooling mismatch =  5.9%. Whats wrong?
  Continuum occupation number reached  2.09E+03 for some fine structure transitions.
  Some fine structure lines were a heat source.
  Induced recombination was  85.8% of the total for H level 7
  Stimulated emission was  97.7% of the total for H transition 7 - 6
  Population of H n=2 reached  3.85E-01 relative to the ground state.
  Compton heating was 65.1% of the total.
W-Maximum tempertaure of grain  Gra-ISM   was  5.00E+04, above sublimation temperature?
W-Maximum tempertaure of grain  Sil-ISM   was  5.00E+04, above sublimation temperature?
  Induced recombination cooling was  1.4% of the total.
  Free-free heating was 12.5% of the total.
C-Free-free heating significant and frequency out of range of gaunt factor routine.
```

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                                  ********************************> CLOUDY 80.08  <********************************
                                  * title constant temper black body limit from Ferland and Rees 1988               *
                                  * c tests whether departure coef are forced to unity by induced processes         *
                                  * constant temper 50,000                                                         *
                                  * stop zone 1                                                                    *
                                  * grains -5 no heating no cooling                                                *
                                  * hden 10                                                                        *
                                  * stop lyman continuum optical depth -6                                          *
                                  * black body, t=50,000 lte                                                       *
                                  * metals -10                                                                     *
                                  * print departure coef                                                           *
                                  * faint -1                                                                       *
                                  * print short last                                                               *
                                  * iterate                                                                        *
                                  * drmax 0                                                                        *
                                  * drmin 0                                                                        *
                                  * c induc.in                                                                     *
                                  * c cray                                                                         *
                                  ********************************> LOG(U):  4.92 <********************************
                                  >>>>>>>>>> Warnings exist, this calculation is suspect.

                               Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                                     Intensity (erg/s/cm^2)

                                                                Emergent line intensities
     TOTL 4861 -5.522   1.0000      TOTL 6563 -5.115   2.5518      TOTL 4340 -5.833   0.4883      TOTL18751 -6.079   0.2769
     TOTL 1909-22.453   0.0000      C  4 1549-15.507   0.0000      N  2 6584-35.000   0.0000      N  2 6548-35.000   0.0000
     O  1 6300-35.000   0.0000      O  1 6363-35.000   0.0000      TOTL 3727-35.000   0.0000      O  3 5007-35.000   0.0000
     O  3 4959-35.000   0.0000      TOTL 4363-35.000   0.0000      Emis 2798-35.000   0.0000      S  2 6720-35.000   0.0000
     S  3 9532-35.000   0.0000

                                                                Intrinsic line intensities
     TOTL 4861 -5.520   1.0000      TOTL 6563 -5.114   2.5508      INWD18751 -6.379   0.1384      HeFF    0 -4.709   6.4833
     TOTL 1216 -3.524  99.1318      TOTL 4861 -5.520   1.0000      nFnu 4860 -3.074 279.4284      HeFB    0 -4.704   6.5475
     TotH    0 -3.233 193.7339      TOTL 4340 -5.832   0.4884      nFnu 1215 -1.129*********      ToFF    0 -4.158  23.0224
     BFH1    0 -4.347  14.9127      TOTL 4102 -6.083   0.2741      Inci 4861 13.521*********      HeII  228 -3.543  94.9844
     BFHx    0 -4.442  11.9930      TOTL18751 -6.078   0.2769      Inci 1216 14.851*********      He2C  911 -4.511  10.2274
     BFHe    0 -4.301  16.5903      TOTL12818 -6.362   0.1439      BA C    0 -4.710   6.4657      TOTL 1640 -3.836  48.4009
     FF H    0 -4.137  24.1733      TOTL 1216 -3.524  99.1318      PA C    0 -5.297   1.6730      TOTL 4686 -5.001   3.3094
     ComH    0 -3.420 126.0645      TOTL  973 -4.640   7.5891      Grai    0 -1.108*********      TOTL 1216 -4.443  11.9472
     CA B 4861 -5.521   0.9993      TOTL  950 -4.959   3.6403      H FF    0 -4.302  16.5391      Ca B 1640 -4.659   7.2752
     CA B 1216 -3.919  39.9211      TOTL  938 -5.214   2.0263      ComC    0 -3.420 126.1371      DevB 1640 -4.669   7.0995
     DU B 4861 -5.695   0.6696      INWD 1216 -3.825  49.5659      H FB    0 -4.149  23.4943      Ca B 4686 -5.640   0.7596
     Q(H) 4861 13.075*********      INWD 6563 -5.415   1.2754      Hind    0 -5.091   2.6911      DevB 4686 -5.656   0.7320
     Q(H) 1216 14.609*********      INWD 4861 -5.821   0.5000      He3i    0 -5.643   0.7543
Lines with negative intensities;  283 Mg 4    4
```

CONSTANT TEMPER BLACK BODY LIMIT FROM FERLAND AND REES 1988
Cooling: H FF   0:0.091 ComC   0:0.691 H FB   0:0.129
Heating: BFH1   0:0.077 BFHx   0:0.062 BFHe   0:0.086 FF H   0:0.125 ComH   0:0.651

IONIZE PARMET: U(1-) 4.9212 U(4-): 1.8093 U(sp): 4.92 Q(ion):   25.398 L(ion): 14.910 Q(low): 25.71   P(low) 14.78
ENERGY BUDGET: Heat: -3.233 Coolg: -3.259 Error: 5.7% Compt H: -3.420 WorkF: -0.639 F-F H -4.137   PRADMX:1.11E-01
Column density H12:1.000E+10 H II:1.000E+10 HI:5.933E-01 H-:   6.958E-14 H2:   2.931E-22 H2+:2.234E-14   He H+:3.446E-22
                OH: 0.000E+00 Heff:0.000E+00
<NH>:1.000E+10 <Tp>:5.00E+04 <TO3>:0.00E+00 Ne:0.000E+00 ti(snd):3.82E-07 NeN+dl:1.20E+20 <T(C3)>:5.00E+04 <E(C3)>:1.20E+10
He/Ha:2.58E-01 =   2.63*true N/Oap:0.00E+00 =   0.00true T(O3R):0.000E+00 L THIN:1.00E+30 <T(S2)>:0.00E+00 <E(S2)>:0.00E+00
T He+:5.00E+04 EHe+:1.20E+10 T(O+):0.00E+00 EO+:0.00E+00 iter/zn: 1.000 Te-low:5.00E+04 Te-high:5.00E+04 Hlu/zn:1.00E+00
  <a>:0.00E+00 erdeFe0.0E+00 Tcompt1.65E-12 Tthr4.31E+02 <Tden>: 5.00E+04 <dens>:2.31E-14 <Mol>:6.07E-01
Mean Jeans   l(cm)1.18E+17 M(sun)1.00E+04 smallest: len(cm):1.18E+17 M(sun):1.00E+04 Alf(ox-tran):   0.0000
  L(dust):-1.108E+00
           Gra-ISM   Sil-ISM   Gra-Ori   Sil-Ori   Sil-0.01 Sil-0.1   SilicatPN
  <Tdust>: 5.002E+04 5.002E+04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Vel D>: 3.807E+09 3.590E+09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Pot D>: 5.313E+01 5.566E+01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CLOUDY 80.08

```
**************************************91Aug03**************************************
*                                                                                  *
* title interstellar cloud irradiated by ism background                            *
* table ism                                                                        *
* extinguish by a column of 22                                                     *
* cosmic rays, background                                                          *
* hden 0                                                                           *
* abundances hii region; this turns on Orion grains by default                     *
* grains ism ;this over rides above default, forcing ism grains                    *
* sphere ;set sphere since matter in all directions                                *
* stop temperature linear 10                                                       *
* stop thickness 0.1 linear parsecs                                                *
* iterate                                                                          *
* print last                                                                       *
* faint .1                                                                         *
* c ism.in                                                                         *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

Chemical composition
He:.095 C:3.00E-04 N:7.00E-05 O:4.00E-04 Ne:1.10E-04 Mg:3.00E-05 Al:2.0E-07 Si:3.00E-06 S:1.00E-05 A:3.0E-06 Ca:2.0E-08 Fe:3.00E-06

```
          546Cell Peak5.62E-05   Lo 1.00E-05=0.9105cm   Hi-Con:7.33E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  -6.0706   Average nu:3.498E+01   P( X-ray):  -6.0947   P(BalC):  -2.5136     Q(Balmer C):   8.5139
          Q(1.0-1.8):   2.9599   Q(1.8-4.0):   1.7594   Q(4.0-20):   0.2544   Q(20--):   2.1588     Ion pht flx:1.115E+03
          L(gam ray):  -7.7247   Q(gam ray):  -1.2176   L(Infred):  -1.4664   Alf(ox):  -2.4590     Total lumin:  -1.4290
          U(1.0----):3.720E-08   U(4.0----):4.868E-09   T(En-Den):3.580E+00   T(Comp):4.398E+03     nuJnu(912A):9.999E-08
          Occ(FarIR):1.080E+00   Occ(H n=6):1.419E-13   Occ(1Ryd):4.603E-24   Occ(4R):1.009E-28     Occ (Nu-hi):3.721E-55
          Tbr(FarIR):1.796E+00   Tbr(H n=6):6.301E-10   Tbr(1Ryd):7.271E-19   Tbr(4R):6.383E-23     Tbr (Nu-hi):4.105E-43
          Grain(Pal):4.423E-23   Grain(Bal):1.782E-22   Grain Mg2:4.379E-22   Grain R:1.527E-21     Grain(HeII):5.214E-22

#####  1 Te:8.808E+01 Hden:1.000E+00 Ne:2.220E-02 R:1.000E+25 R-R0:8.121E+15 dR:1.624E+16 NTR:  1 Htot:2.770E-26 T912: 1.786E+00###
-10.60 4686  0.00 5876  0.04 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    9.782E-01 2.176E-02 H+0/Hden: 1.000E+00 9.792E-12 H-     H2 3.372E-07 2.845E-12 H2+  HeH+ 7.061E-10 H col den 1.624E+16
H 2SP 3-6   5.284E-15 6.823E-18 2.924E-21 2.065E-21 2.391E-21 3.083E-21 Texc(La); 2.663E+03 T(contn): 3.580E+00 T(diffs): 1.495E-01
Helium      9.991E-01 9.387E-04 1.338E-09 He I 2S3  2.206E-12 Comp H, C 1.606E-33 3.216E-35 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  9.991E-01 1.714E-18 2.718E-24 1.920E-24 2.223E-24 2.866E-24 He triplt 2.206E-12 2.245E-23 1.208E-25 1.668E-24 2.659E-24
HeII        9.387E-04 2.235E-24 2.421E-31 1.710E-31 1.980E-31 2.553E-31 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 4.939E-06
Gra-ISM     Dust temp 1.973E+01 Pot(Volt) 2.933E-01 Nelectron 6.111E+01 drft cm/s 3.722E+03  Heating: 6.542E-27 Frac(tot) 2.361E-01
Sil-ISM     Dust temp 1.595E+01 Pot(Volt) 3.231E-01 Nelectron 6.732E+01 drft cm/s 1.131E+03  Heating: 7.669E-27 Frac(tot) 2.768E-01
Pressure    NgasTgas; 9.757E+01 P(total): 1.347E-14 P( gas ): 1.347E-14 P(Radtn): 6.654E-20 Rad accel 1.065E-10 Force Mul 1.346E+04
Carbon      1.031E-03 9.989E-01 9.524E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.894E-01 1.065E-02 9.087E-09 4.449E-10 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.994E-01 5.834E-04 2.896E-08 2.725E-12 1.537E-15 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 5.975E-29 A:-11.111
Neon        9.965E-01 3.515E-03 7.142E-06 5.022E-11 8.311E-15 3.593E-17 3.517E-21 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 3.675E-03 9.961E-01 2.662E-04 9.744E-09 1.911E-12 5.302E-15 6.751E-19 1.288E-21 1.038E-25 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.228E-04 9.996E-01 9.483E-05 1.816E-06 8.044E-11 6.251E-13 1.549E-17 8.531E-20 9.007E-25 3.573E-27 0.000E+00 0.000E+00
Silicon   0 2.185E-04 9.998E-01 4.497E-07 1.525E-08 1.628E-15 7.279E-15 7.103E-21 1.149E-21 1.116E-27 7.675E-29 6.320E-35 0.000E+00
Sulphur   1 9.995E-01 2.234E-04 2.441E-09 2.735E-13 2.001E-15 9.428E-20 4.114E-22 9.464E-27 2.568E-29 4.644E-34 9.953E-37 1.069E-41
Argon     3 2.306E-09 2.036E-13 2.209E-15 1.609E-19 1.359E-21 5.746E-26 1.450E-28 1.663E-33 3.896E-36 4.032E-41 8.009E-44 7.393E-49
Calcium   0 3.810E-03 3.226E-01 6.736E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 8.261E-03 9.917E-01 1.525E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
##### 11 Te:1.023E+02 Hden:1.000E+00 Ne:1.272E-02 R:1.000E+25 R-R0:2.917E+17 dR:1.683E+16 NTR:  3 Htot:1.807E-26 T912: 3.544E+00###
 -9.58 4686  0.00 5876  0.06 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    9.877E-01 1.225E-02 H+0/Hden: 1.000E+00 6.528E-12 H-     H2 3.568E-07 8.780E-13 H2+  HeH+ 1.063E-09 H col den 3.001E+17
```

```
H 2SP 3-6   2.686E-15 1.234E-18 1.447E-21 1.047E-21 1.220E-21 1.576E-21 Texc(La); 2.532E+03 T(contn): 3.580E+00 T(diffs): 2.808E-01
Helium      9.987E-01 1.272E-03 2.649E-08 He I 2S3  1.527E-12 Comp H, C 9.501E-34 2.210E-35 Fill Fact 1.000E+00 Gam 1/tot 9.917E-01
He singlet  9.987E-01 1.164E-18 1.823E-24 1.319E-24 1.538E-24 1.986E-24 He triplt 1.527E-12 1.547E-23 8.837E-26 1.200E-24 1.808E-24
HeII        1.272E-03 2.230E-23 2.373E-30 1.717E-30 2.001E-30 2.585E-30 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 4.569E-06
Gra-ISM     Dust temp 1.973E+01 Pot(Volt) 5.107E-01 Nelectron 1.064E+02 drft cm/s 2.749E+03  Heating: 5.660E-27 Frac(tot) 3.132E-01
Sil-ISM     Dust temp 1.595E+01 Pot(Volt) 5.515E-01 Nelectron 1.149E+02 drft cm/s 8.658E+02  Heating: 6.516E-27 Frac(tot) 3.606E-01
Pressure    NgasTgas; 1.125E+02 P(total): 1.553E-14 P( gas ): 1.553E-14 P(Radtn): 7.126E-20 Rad accel 1.052E-10 Force Mul 2.320E+04
Carbon      5.259E-04 9.994E-01 9.239E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.957E-01 4.333E-03 6.685E-09 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.995E-01 4.983E-04 2.713E-08 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 4.982E-29 A:-11.140
Neon        9.951E-01 4.865E-03 1.486E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.860E-03 9.979E-01 2.427E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.660E-04 9.997E-01 1.421E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.115E-04 9.999E-01 2.164E-07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.527E-04 9.995E-01 3.146E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 8.798E-01 1.201E-01 1.243E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 1.111E-03 1.863E-01 8.126E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 4.190E-03 9.958E-01 1.026E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because outer radius reached.
  Geometry is plane-parallel.
 !The largest continuum occupation number was 1.080E+00 at 1.053E-05 Ryd.
W-Temperature fell below 100K, this calculation is tentative.
  Local grain-gas photoelectric heating rate reached  67.4% of the total.
  Gloal grain photoelectric heating of gas was 59.2% of the total.
  Grain photoelectric heating is VERY important.
  Temperature out of range of free-free gaunt factor routine.
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations   1 times.
  Temp too low and matrix not used for H in some zones. Low-density Case B assumed.   11 THLO= 1.000E+03
  Temp too low and matrix not used for He singlets in some zones. Low-density Case B assumed.   11 THE1LO= 1.000E+03
  Temp too low and matrix not used for He ion in some zones. Low-density Case B assumed.   11 THE2LO= 1.500E+03
```

```
                    *********************************> CLOUDY 80.08  <*********************************
                    * title interstellar cloud irradiated by ism background                            *
                    * table ism                                                                        *
                    * extinguish by a column of 22                                                     *
                    * cosmic rays, background                                                          *
                    * hden 0                                                                           *
                    * abundances hii region; this turns on Orion grains by default                     *
                    * grains ism ;this over rides above default, forcing ism grains                   *
                    * sphere ;set sphere since matter in all directions                                *
                    * stop temperature linear 10                                                      *
                    * stop thickness 0.1 linear parsecs                                               *
                    * iterate                                                                         *
                    * print last                                                                       *
                    * faint .1                                                                        *
                    * c ism.in                                                                        *
                    * c cray                                                                          *
                    *********************************> LOG(U): -7.43 <*********************************
                    >>>>>>>>>> Warnings exist, this calculation is suspect.

                 Emission Line Spectrum.   Constant  Density Model.  Closed geometry.  Iteration 2 of 2.
                                                Intensity (erg/s/cm^2)

    TOTL 4861 -9.577   1.0000      DU B 4861 -9.543   1.0822      2 NU    0 -8.576  10.0320      Inci 1216 -2.637*********
    TOTL 1216 -7.975  40.0415      Q(H) 4861 -9.276   2.0005      TOTL 1216 -7.975  40.0415      BA C    0 -9.254   2.1059
    TotH    0 -8.173  25.3316      Q(H) 1216 -7.742  68.3975      INWD 1216 -8.218  22.8366      PA C    0 -9.700   0.7527
    BFH1    0 -8.579   9.9570      TOTL 6563 -8.841   5.4428      INWD 6563 -9.142   2.7214      Grai    0 -6.4791253.5774
    BFHe    0-10.234   0.2205      TOTL 4861 -9.577   1.0000      INWD 4861 -9.878   0.5000      REC  1656-10.280   0.1984
    TotM    0-10.567   0.1025      TOTL 4340 -9.985   0.3907      INWD18751-10.436   0.1384      C  2  158 -8.176  25.1774
    GraH    0 -8.401  14.9875      TOTL 4102-10.265   0.2051      e sc18751-10.134   0.2771      Si 2   35-10.545   0.1076
    CA B 4861 -9.543   1.0823      TOTL18751-10.135   0.2769      nFnu 4860 -9.431   1.3989
    CA B 1216 -7.977  39.7777      TOTL12818-10.516   0.1151      Inci 4861 -2.138*********
Lines with negative intensities;  205 T OI    0
```

INTERSTELLAR CLOUD IRRADIATED BY ISM BACKGROUND

```
Cooling:  C  2  158:0.987
Heating:  BFH1    0:0.393  GraH    0:0.592

IONIZE PARMET:  U(1-) -7.4295  U(4-): -8.3126  U(sp): -7.43  Q(ion):    2.664  L(ion):  -6.079 Q(low): 12.99    P(low) -1.43
ENERGY BUDGET:  Heat:  -8.173  Coolg:  -8.170  Error:  0.7%  Compt H: -15.391  WorkF:   -7.831 F-F  H-14.997    PRADMX:4.44E-03
Column density  H12:3.001E+17  H II:4.970E+15  HI:2.951E+17  H-:    2.558E+06  H2:   1.039E+11 H2+:4.998E+05    He H+:2.525E+08
                OH: 0.000E+00  Heff:2.684E+17
<NH>:1.000E+00  <Tp>:9.38E+01  <TO3>:9.46E+01  Ne:1.708E-02  ti(snd):3.82E+12  NeN+dl:8.76E+13 <T(C3)>:9.46E+01 <E(C3)>:1.71E-02
He/Ha:4.31E-02  =   0.45*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:9.47E+01 <E(S2)>:1.70E-02
T He+:9.53E+01  EHe+:1.67E-02  T(O+):9.44E+01  EO+:1.72E-02  iter/zn:   5.571  Te-low:8.81E+01 Te-high:1.04E+02  Hlu/zn:1.04E+01
  <a>:0.00E+00  erdeFe7.6E+30  Tcompt7.10E+12  Tthr7.48E+11  <Tden>: 9.47E+01  <dens>:2.32E-24 <Mol>:1.25E+00
Mean Jeans      l(cm)3.57E+20  M(sun)2.77E+04  smallest:     len(cm):3.45E+20  M(sun):2.51E+04 Alf(ox-tran):    -2.4590
  L(dust):-6.479E+00
            Gra-ISM   Sil-ISM   Gra-Ori   Sil-Ori   Sil-0.01  Sil-0.1   SilicatPN
  <Tdust>: 1.973E+01 1.595E+01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Vel D>: 6.041E+03 1.861E+03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  <Pot D>: 3.963E-01 4.322E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

Optical Depths: CONTN; COMP: 1.70E-09    H-: 4.99E-11 R(1300): 1.98E-06 H2+ 3.50E-12  HeTri:2.33E-04
 Pfa:3.80E-06   Pa:1.73E-05   Ba:8.76E-05   Hb:1.20E-04  La:4.23E-04   1r:1.772E+00  1.8:5.47E-01  4.:8.285E-02  21R:9.449E-04
10830: 7.62E-07  3889: 3.25E-08  5876: 4.72E-18  7065: 2.61E-18
 1550: 1.00E-20  2800: 1.30E+02   774: 1.00E-20  1240: 1.00E-20  1035: 1.00E-20  1335: 1.25E+02   977: 2.72E-02  1397: 3.65E-09
  789: 5.26E-12  1207: 3.81E-06  1085: 4.08E-02  1194: 5.13E-05  1909: 1.08E-08  1895: 1.02E-10  2326: 6.23E-05  1666: 1.40E-11
 1750: 2.54E-14  1025: 1.12E+01   352: 1.00E-20   347: 1.00E-20  1860: 7.87E-05   630: 1.65E-14   834: 1.11E-01   835: 6.79E-07
 1808: 1.18E+01  1256: 1.36E+00    -3: 4.85E-01   -48: 1.00E-20  3934: 1.00E-20  3969: 1.00E-20  8498: 1.00E-20  8542: 1.00E-20
 8662: 1.00E-20   353: 1.00E-20  1304: 3.83E+01  1122: 6.82E-07   990: 1.12E-07  1402: 7.02E-17  1214: 9.91E-20  1486: 1.88E-15
 2335: 2.82E-05  1406: 9.30E-14  1656: 7.88E-02  9830: 1.31E-11  8727: 1.00E-20  6300: 1.01E-07  5577: 1.00E-20  7291: 1.98E-09
 7324: 1.37E-09  1039: 5.43E+00 -8446: 2.19E-20 -4368: 1.01E-20  -132: 1.27E-20  -113: 1.43E-20   -29: 1.00E-20   -46: 2.01E-20
 -245: 1.00E-20   765: 1.14E-09 -1198: 2.03E-17   786: 6.04E-14
 C157: 1.00E-03  N122: 2.29E-09  N205: 8.93E-06   N57: 1.97E-12  O146: 1.31E-11   O63: 1.16E-03   O88: 1.31E-10   O52: 2.46E-15
  O26: 2.37E-16  NE13: 9.90E-07  NE36: 1.78E-19  NE16: 3.83E-09   MG4: 1.00E-20  MG14: 1.00E-20   MG6: 1.14E-17  SI35: 1.56E-05
  S19: 1.65E-14   S34: 4.43E-08   S11: 1.00E-20   AR7: 1.00E-20   AR9: 1.43E-09  AR22: 1.00E-20  AR13: 2.08E-18   AR8: 1.00E-20
  CA3: 1.00E-20  CA12: 1.00E-20   CA4: 1.00E-20  Ne14: 1.00E-20  Ne24: 6.38E-19   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.00E-20 Si6.5: 1.00E-20  C610: 2.41E-09  C370: 1.37E-06

Old hydro optical depths:    1 1.69E+00    2 9.27E-05    3 3.77E-05    4 1.81E-05    5 8.90E-06    6 4.83E-06    7 1.64E-06
                     Lines:  2-1 1.64E+05  3-2 1.00E-10  4-3 1.22E-16  5-4 9.93E-17  6-5 1.02E-16  7-6 1.56E-16  8-7 1.00E-20
New hydro optical depths:    1 1.77E+00    2 9.74E-05    3 3.96E-05    4 1.90E-05    5 9.35E-06    6 5.07E-06    7 1.72E-06
                     Lines:  2-1 8.98E+04  3-2 5.06E-11  4-3 6.20E-17  5-4 5.05E-17  6-5 5.19E-17  7-6 7.92E-17  8-7 5.00E-21

Old He Is optical depths:    1 2.60E-01    2 6.60E-05    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                     Lines:  2-1 1.01E+04  3-2 3.67E-13  4-3 1.29E-18  5-4 1.05E-18  6-5 1.08E-18  7-6 1.65E-18  8-7 1.00E-20
New HE Is optical depths:    1 2.87E-01    2 7.27E-05    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                     Lines:  2-1 1.10E+04  3-2 3.91E-13  4-3 1.37E-18  5-4 1.12E-18  6-5 1.15E-18  7-6 1.76E-18  8-7 1.00E-20

Old He II optical depths:    1 3.94E-02    2 8.43E-01    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                     Lines:  2-1 8.99E+00  3-2 1.12E-18  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20
New HE II optical depths:    1 4.34E-02    2 9.29E-01    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                     Lines:  2-1 8.96E+00  3-2 1.26E-18  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20

Hydrogen  -0.007 -1.781                          Log10 Mean Ionisation (over volume)
Helium     0.000 -2.984 -7.804
Carbon    -3.125  0.000 -4.016
Nitrogen  -0.003 -2.153 -8.110-10.618
Oxygen     0.000 -3.267 -7.552-12.831-16.080
Neon      -0.002 -2.379 -4.972-11.566-15.347-17.711-21.720
Magnesium -2.574 -0.001 -3.593 -9.278-12.985-15.542-19.437-22.157-26.250
Aluminum  -3.628  0.000 -3.916 -7.007-11.361-13.471-18.076-20.336-25.312-27.714
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Silicon   -3.799  0.000 -6.494 -9.083-16.055-15.405-21.415-22.206-28.219-29.382-35.466
Sulphur   -3.664  0.000 -3.568 -9.879-13.830-15.965-20.292-22.652-27.290-29.857-34.600-37.269-42.238
Argon     -0.062 -0.875 -3.960 -9.367-13.415-15.922-20.060-22.133-26.507-29.105-34.046-36.676-41.661-41.954-41.954
Calcium   -2.656 -0.603 -0.126
Iron      -2.222 -0.003 -5.899
           1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.007 -1.781                          Log10 Mean Ionisation (over radius)
Helium     0.000 -2.984 -7.804
Carbon    -3.125  0.000 -4.016
Nitrogen  -0.003 -2.153 -8.110-10.618
Oxygen     0.000 -3.267 -7.552-12.831-16.080
Neon      -0.002 -2.379 -4.972-11.566-15.347-17.711-21.720
Magnesium -2.574 -0.001 -3.593 -9.278-12.985-15.542-19.437-22.157-26.250
Aluminum  -3.628  0.000 -3.916 -7.007-11.361-13.471-18.076-20.336-25.312-27.714
Silicon   -3.799  0.000 -6.494 -9.083-16.055-15.405-21.415-22.206-28.219-29.382-35.466
Sulphur   -3.664  0.000 -3.568 -9.879-13.830-15.965-20.292-22.652-27.290-29.857-34.600-37.269-42.238
Argon     -0.062 -0.875 -3.960 -9.367-13.415-15.922-20.060-22.133-26.507-29.105-34.046-36.676-41.661-41.954-41.954
Calcium   -2.656 -0.603 -0.126
Iron      -2.222 -0.003 -5.899

0.5-1.0KEV:6.18E+00 1.0-1.5:2.50E+01 1.5-2.0:2.38E+01 2.0-2.5:1.88E+01 2.5-3:1.60E+01 3-5:3.16E+01 5-7.5:1.24E+01 7.5-10:4.64E+00


                                                Normalised continuum
  0.25 1.000   0.27 1.000   0.30 1.000   0.33 1.000   0.36 1.000   0.39 1.000   0.43 1.000   0.47 1.000   0.51 1.000   0.56 1.000
  0.62 1.000   0.67 1.000   0.74 1.000   0.81 1.000   0.88 1.000   0.97 1.000   0.98 1.000   0.99 1.000   1.00 1.000

                                              Emergent continuum - phot/ryd/cm2 (r in)
  0.26 2.78E+09  1.00 7.13E+02     3.9 1.74E+00    17.3 9.66E-03    75.3 5.14E-01    1.26E+03 3.07E-03    3.24E+05 1.82E-10
  0.29 1.62E+09  1.01 7.08E+02     4.0 1.43E+00    19.5 6.82E-03    81.6 6.00E-01    1.87E+03 9.37E-04    4.81E+05 5.53E-11
  0.33 9.40E+08  1.02 7.03E+02     4.2 1.17E+00    22.0 4.82E-03    88.3 6.64E-01    2.78E+03 2.85E-04    7.15E+05 1.68E-11
  0.37 5.67E+08  1.10 6.29E+02     4.7 6.37E-01    24.8 3.40E-03    95.7 7.04E-01    4.14E+03 8.69E-05    1.06E+06 5.13E-12
  0.42 4.80E+08  1.24 4.72E+02     5.3 3.26E-01    27.9 2.40E-03   103.7 7.20E-01    6.15E+03 2.65E-05    1.58E+06 1.56E-12
  0.47 4.06E+08  1.40 3.19E+02     5.9 2.15E-01    31.5 1.71E-03   112.3 7.14E-01    9.15E+03 8.06E-06    2.35E+06 4.75E-13
  0.53 3.44E+08  1.57 2.03E+02     6.7 1.53E-01    35.5 1.48E-03   121.6 6.91E-01    1.36E+04 2.45E-06    3.49E+06 1.45E-13
  0.60 2.91E+08  1.78 1.16E+02     7.5 1.09E-01    40.0 4.04E-03   131.7 6.56E-01    2.02E+04 7.47E-07    5.19E+06 4.41E-14
  0.67 2.46E+08  2.00 5.46E+01     8.5 7.72E-02    45.0 1.95E-02   142.7 6.12E-01    3.00E+04 2.28E-07
  0.76 1.81E+08  2.25 3.09E+01     9.5 5.47E-02    50.5 6.52E-02   173.9 4.89E-01    4.46E+04 6.93E-08
  0.86 1.12E+08  2.54 1.70E+01    10.8 3.87E-02    54.7 1.24E-01   258.5 2.72E-01    6.63E+04 2.11E-08
  0.97 5.62E+07  2.86 9.15E+00    12.1 2.74E-02    59.3 2.07E-01   383.9 1.05E-01    9.86E+04 6.43E-09
  0.99 4.96E+07  3.22 4.84E+00    13.6 1.93E-02    64.2 3.06E-01   570.6 3.28E-02    1.47E+05 1.96E-09
  0.99 4.75E+07  3.63 2.53E+00    15.4 1.37E-02    69.5 4.12E-01   848.1 1.01E-02    2.18E+05 5.96E-10
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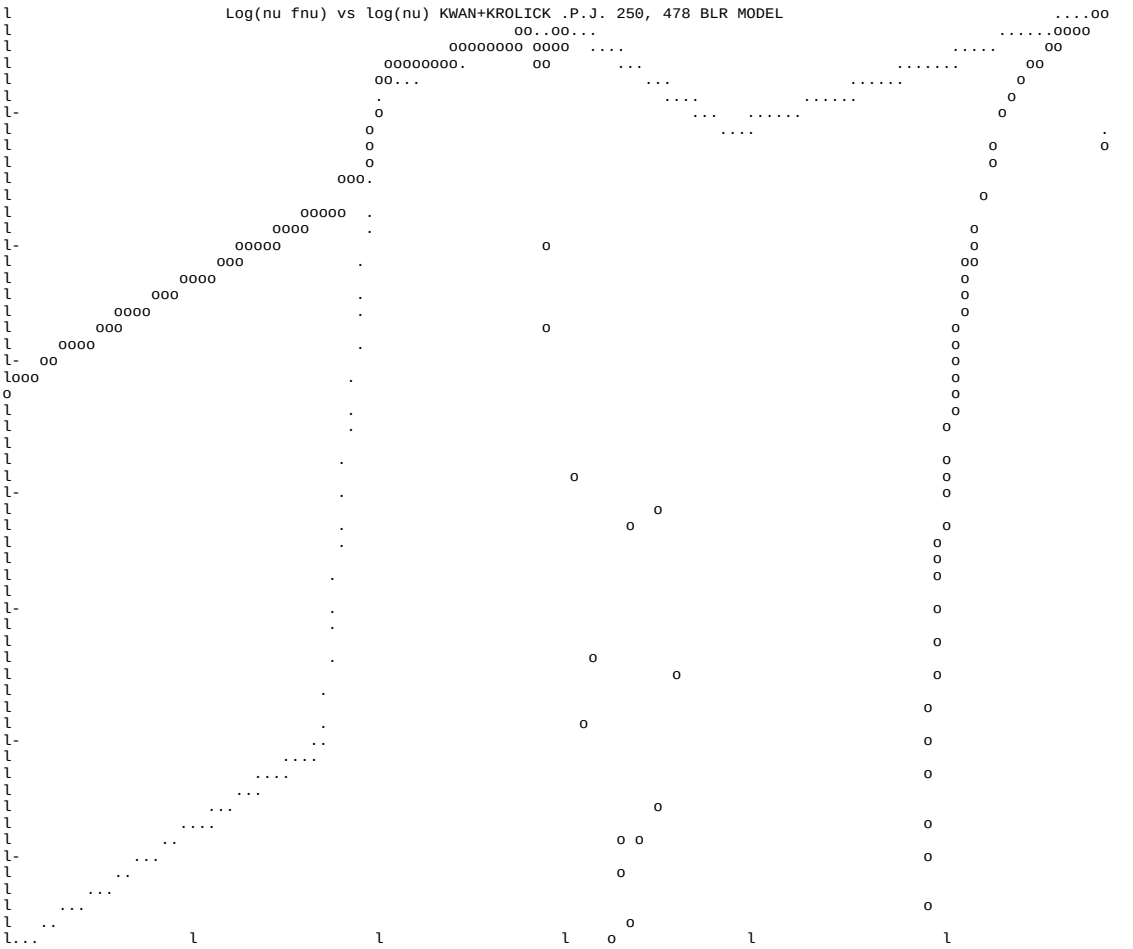
**************************************91Aug03***************************************
*                                                                                  *
* title Kwan+Krolick Ap.J. 250, 478 BLR model                                      *
* constant gas pressure                                                            *
* f(nu) -7.32148                                                                   *
* abundances he-1 c-3.699 n-4 o-3.1549 ne-4 mg-4.5229                              *
* continue al-10 si-4.4229 s-10 ar-10 ca-10 fe-4.5229                              *
* stop column density 23                                                           *
* interpolate (0 -5) (.05 -5) (.1 0) (1 -0.5) (7.353 -2.233)                       *
* CONTINUE (735 -3.233) (800 -015) (8,000,000 -15)                                 *
* print last iteration                                                             *
* normalise 1216 100                                                               *
* iterate                                                                          *
* plot continuum -3                                                                *
* hden 9.60206                                                                     *
* c kk.in                                                                          *
* c cray                                                                           *
*                                                                                  *
************************************************************************************


                                        Chemical composition
He:.100 C:2.00E-04 N:1.00E-04 O:7.00E-04 Ne:1.00E-04 Mg:3.00E-05 Al:1.0E-10 Si:3.78E-05 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:3.00E-05

          455Cell Peak6.96E+02   Lo 1.00E-05=0.9120cm   Hi-Con:8.92E+02 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   8.7170   Average nu:6.338E+00   P( X-ray):   8.5529   P(BalC):   8.1955     Q(Balmer C):  19.1584
          Q(1.0-1.8):  18.3979   Q(1.8-4.0):  17.9425   Q(4.0-20):  17.4232   Q(20--):  17.1248     Ion pht flx:3.774E+18
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):   7.7816   Alf(ox):  -1.0009     Total lumin:   8.8684
          U(1.0----):3.147E-02   U(4.0----):3.321E-03   T(En-Den):1.343E+03   T(Comp):5.487E+06     nuJnu(912A):1.568E+08
          Occ(FarIR):1.969E+02   Occ(H n=6):1.030E-08   Occ(1Ryd):7.228E-09   Occ(4R):7.013E-12     Occ (Nu-hi):3.736E-32
          Tbr(FarIR):3.270E+02   Tbr(H n=6):4.573E-05   Tbr(1Ryd):1.142E-03   Tbr(4R):4.437E-06     Tbr (Nu-hi):5.011E-24

#####  1 Te:2.109E+04 Hden:4.000E+09 Ne:4.802E+09 R:1.000E+25 R-R0:8.393E+07 dR:1.679E+08 NTR:  2 Htot:1.543E-04 T912: 3.213E-04###
  2.39 4686  0.87 5876  0.01 1909  2.21 1549 58.54 6584  0.00 2326  0.01 3727  0.00 6300  0.00 2798  0.00 1035  6.62
Hydrogen    7.603E-05 9.999E-01 H+0/Hden: 1.000E+00 6.253E-16 H-     H2 1.512E-14 7.930E-13 H2+  HeH+ 3.274E-14 H col den 6.715E+17
H 2SP 3-6   1.272E-10 7.225E-11 1.864E-11 2.113E-11 2.815E-11 3.713E-11 Texc(La); 7.905E+03 T(contn): 1.343E+03 T(diffs): 6.167E+03
Helium      1.030E-05 4.123E-02 9.588E-01 He I 2S3  8.947E-08 Comp H, C 8.557E-09 3.289E-11 Fill Fact 1.000E+00 Gam 1/tot 9.294E-01
He singlet  1.021E-05 7.990E-12 7.859E-14 1.067E-13 1.572E-13 2.242E-13 He triplt 8.941E-08 5.423E-11 4.374E-13 9.717E-13 2.638E-13
HeII        4.123E-02 9.318E-10 3.398E-12 5.159E-12 8.225E-12 1.256E-11 1.140E-10 1.648E-09 2.105E-07 PRAD/GAS; 1.696E-02
Pressure    NgasTgas; 1.932E+14 P(total): 2.712E-02 P( gas ): 2.667E-02 P(Radtn): 4.523E-04 Rad accel 1.774E+00 Force Mul 2.127E+02
Carbon      0.000E+00 9.111E-04 1.007E-01 5.378E-01 3.020E-01 5.686E-02 1.753E-03 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 3.295E-04 6.316E-02 3.147E-01 3.226E-01 2.806E-01 1.834E-02 2.405E-04 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 2.137E-04 5.100E-02 3.722E-01 3.166E-01 1.817E-01 7.753E-02 6.623E-04 0.000E+00 Hex(tot): 0.000E+00 A:-12.764
Neon        0.000E+00 3.101E-05 1.350E-02 1.464E-01 5.172E-01 3.009E-01 1.607E-02 5.345E-03 5.784E-04 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 1.590E-05 2.770E-03 2.668E-02 7.608E-02 3.370E-01 4.057E-01 1.318E-01 1.805E-02 1.732E-03 1.016E-04 0.000E+00
Aluminium 0 0.000E+00 1.435E-04 2.935E-03 1.595E-02 4.579E-02 2.418E-01 4.349E-01 2.235E-01 3.240E-02 2.427E-03 1.312E-04 0.000E+00
Silicon   0 0.000E+00 2.388E-05 2.645E-03 1.474E-02 2.728E-02 1.615E-01 3.641E-01 3.206E-01 9.777E-02 1.066E-02 6.410E-04 2.916E-05
Sulphur   0 0.000E+00 7.256E-05 1.010E-02 3.044E-02 4.012E-02 1.687E-01 2.674E-01 2.908E-01 1.550E-01 3.390E-02 3.347E-03 1.912E-04
Argon     1 2.897E-05 2.995E-03 1.598E-02 3.291E-02 1.028E-01 2.076E-01 2.543E-01 2.862E-01 8.295E-02 1.326E-02 8.861E-04 3.404E-05
Calcium   0 0.000E+00 2.191E-05 1.646E-03 1.062E-02 2.319E-02 1.272E-01 2.843E-01 2.988E-01 1.662E-01 6.469E-02 2.123E-02 2.092E-03
Iron      1 0.000E+00 1.502E-05 1.071E-03 9.922E-03 1.022E-01 2.860E-01 3.886E-01 1.232E-01 6.809E-02 1.739E-02 3.098E-03 4.275E-04
#####154 Te:7.137E+03 Hden:2.288E+10 Ne:1.368E+09 R:1.000E+25 R-R0:5.647E+12 dR:1.377E+11 NTR:  6 Htot:7.758E-06 T912: 5.053E+05###
  6.57 4686  0.06 5876  0.11 1909  3.26 1549 15.03 6584  0.00 2326  0.42 3727  0.00 6300  0.01 2798  2.77 1035  0.45
Hydrogen    9.408E-01 5.916E-02 H+0/Hden: 1.000E+00 2.262E-09 H-     H2 3.600E-07 5.901E-09 H2+  HeH+ 1.503E-09 H col den 1.000E+23
H 2SP 3-6   8.096E-07 2.429E-06 1.135E-07 1.837E-08 5.364E-09 2.080E-09 Texc(La); 7.044E+03 T(contn): 1.085E+03 T(diffs): 8.310E+02
Helium      9.982E-01 1.841E-03 2.687E-07 He I 2S3  9.035E-09 Comp H, C 1.545E-09 1.397E-12 Fill Fact 1.000E+00 Gam 1/tot 1.013E-02
He singlet  9.982E-01 6.924E-13 3.077E-15 3.727E-15 5.717E-15 8.647E-15 He triplt 8.767E-09 2.659E-10 1.004E-12 9.345E-14 1.045E-12
```

```
HeII        1.841E-03 2.516E-16 5.041E-19 7.793E-19 1.332E-18 2.208E-18 2.350E-17 6.330E-16 8.996E-14 PRAD/GAS; 2.053E-02
Pressure    NgasTgas; 1.914E+14 P(total): 2.697E-02 P( gas ): 2.643E-02 P(Radtn): 5.427E-04 Rad accel 1.300E-02 Force Mul 7.244E+01
Carbon      1.105E-04 9.995E-01 4.191E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.918E-01 8.082E-01 1.682E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.475E-01 5.250E-02 3.155E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.537
Neon        8.949E-01 8.514E-02 2.000E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.820E-04 7.559E-01 2.436E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 5.673E-05 9.591E-01 3.191E-02 8.695E-03 1.816E-04 4.742E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 5.155E-05 9.997E-01 2.662E-04 2.277E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.957E-05 9.624E-01 3.761E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 7.621E-01 2.363E-01 1.573E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 7.906E-05 2.844E-02 9.714E-01 7.463E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.245E-03 9.969E-01 1.795E-03 7.731E-06 2.430E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because column dens reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached  34.8 percent of the total rate out.
  Photoionization of He 2TriS reached  67.4 percent of the total rate out.
 !The largest continuum occupation number was 1.969E+02 at 1.052E-05 Ryd.
  Hydrogen self ionization by alpha transitions reached    1.8% of the destruction rate for level 3.
  Some excited state HeII lines are thick.
  Some fine struc lines are optically thick, largest=1.06E+00
  Continuum occupation number reached  3.25E+02 for some fine structure transitions.
  Frequency out of range of free-free gaunt factor routine.
  Balmer continuum optical depth is  5.47E-01
  Balmer continuum stimulated emission correction to optical depths reached  0.08
  Continuum optical depth at low nu ( 1.052E-05 Ryd) was  5.332E+03
  The optical depth to Rayleigh scattering at 1300A is 5.39E-01
  Optical depth to negative hydrogen ion is  1.12E-02
  The ratio of radiation to gas pressure reached  8.17E-01.  Caused by Lyman alpha.
C-This is the last iteration and H(a) optical depth changed by  15.7% (was  2.54E+04). Try another iteration
  Line radiation pressure capped by thermalization length.
```




```
**********> CLOUDY 80.08  <**********
* title Kwan+Krolick Ap.J. 250, 478 BLR model
* constant gas pressure
* f(nu) -7.32148
* abundances he-1 c-3.699 n-4 o-3.1549 ne-4 mg-4.5229
* stop column density 23
* interpolate (0 -5) (.05 -5) (.1 0) (1 -0.5) (7.353 -2.233)
* print last iteration
* normalise 1216 100
* iterate
* plot continuum -3
* hden 9.60206
* c kk.in
* c cray
**********> LOG(U): -1.50 <**********
>>>>>>>>>> Cautions are present.
>>>>>>>>>> Another iteration is suggested.
```

Emission Line Spectrum. Constant Pressure Model. Open geometry. Iteration 2 of 2.
Intensity (erg/s/cm^2)

TOTL	4861	6.566	6.3673	H-FB	0	6.104	2.1945	C 4	4659	2.663	0.0008	Ne 4	1602	4.087	0.0211
TOTL	1216	7.762	100.0000	H2+	0	5.777	1.0349	C 6r	34	3.993	0.0170	Ne 5	3426	3.963	0.0159
TotH	0	8.409	443.5726	HEH+	0	2.840	0.0012	N 1	1200	2.663	0.0008	Ne 5	3346	3.530	0.0059
BFH1	0	7.603	69.2160	HeFF	0	5.995	1.7076	N 2	6584	3.320	0.0036	Ne 5	2976	3.200	0.0027
BFHx	0	6.907	13.9554	HeFB	0	6.080	2.0755	N 2	6548	2.843	0.0012	Ne 5	1575	3.675	0.0082
BFHe	0	7.805	110.2877	MeFB	0	4.521	0.0574	N 2	5755	3.789	0.0106	Ne 5	1134	5.095	0.2151
TotM	0	8.156	247.3015	MeFF	0	4.930	0.1472	N 2	4239	2.834	0.0012	Ne 6	76	1.827	0.0001
FF H	0	4.288	0.0335	ToFF	0	7.196	27.1215	N 2	5680	3.333	0.0037	Ne 6	1007	4.451	0.0489
ComH	0	4.487	0.0530	HeIC	584	2.842	0.0012	N 2	2140	5.483	0.5252	Ne 7	895	3.218	0.0029
H- H	0	6.156	2.4771	esc	584	5.539	0.5975	N 2	1084	3.950	0.0154	Ne 8	774	3.022	0.0018
CA B	4861	7.006	17.5164	He I	504	6.363	3.9865	N 3	1750	6.392	4.2567	Mg 1	4571	2.877	0.0013
CA B	1216	8.537	594.6159	He I	4471	5.026	0.1833	N 3	990	5.274	0.3243	Emis	2798	7.009	17.6452
DU B	4861	7.006	17.5158	TOTL	5876	5.605	0.6965	N 4	1486	6.451	4.8791	Cool	2798	7.122	22.8991
Q(H)	4861	6.253	3.0974	Ca B	5876	5.456	0.4938	N 4	765	5.183	0.2631	Mg 4	4	2.823	0.0011
Q(H)	1216	7.787	105.8999	TOTL	10830	6.219	2.8619	N 4	1718	3.902	0.0138	Mg 5	56	2.619	0.0007
TOTL	6563	7.061	19.8636	INWD	10830	6.037	1.8794	N 5	1240	6.321	3.6149	Mg 5	2751	3.641	0.0076
TOTL	4861	6.566	6.3673	TOTL	3889	4.926	0.1456	N 7r	25	3.089	0.0021	Mg 6	1806	2.942	0.0015
TOTL	4340	6.099	2.1699	TOTL	7065	5.484	0.5272	O 1	6300	4.454	0.0491	Mg 7	2629	4.402	0.0436
TOTL	4102	5.745	0.9595	CcHE	0	6.217	2.8462	O 1	6363	3.977	0.0164	Mg 8	3	2.679	0.0008
TOTL	18751	6.021	1.8143	He I	2	4.866	0.1269	O 1	5577	4.549	0.0612	Mg 9	705	1.939	0.0002
TOTL	12818	5.903	1.3820	DevB	2	4.380	0.0415	O 1	7774	4.178	0.0260	Si 2	2335	6.105	2.1993
TOTL	10938	5.623	0.7246	He I	5016	4.826	0.1157	6lev	8446	4.707	0.0880	Si 2	1808	5.003	0.1742
TOTL	40512	5.189	0.2672	DevB	5016	4.640	0.0754	6lev	1304	6.366	4.0129	Si 3	1207	6.178	2.6039
TOTL	26252	5.225	0.2903	He I	3965	4.540	0.0599	6lev	1039	1.894	0.0001	Si 3	1895	6.926	14.5666
TOTL	74578	4.532	0.0589	DevB	3965	4.190	0.0268	6lev	4368	3.531	0.0059	PHOT	1895	3.892	0.0135
2 NU	0	6.115	2.2527	He I	3614	4.256	0.0312	6lev	13	3.725	0.0092	Si 4	1397	6.916	14.2384
TOTL	1216	7.762	100.0000	DevB	3614	4.039	0.0189	6lev	11	5.491	0.5352	Si 6	19	4.050	0.0194
TOTL	1026	5.677	0.8221	He I	3448	4.038	0.0188	6lev	29	2.722	0.0009	Si 7	2148	4.592	0.0675
TOTL	973	4.946	0.1524	DevB	3448	3.690	0.0085	TOTL	3727	1.808	0.0001	Si 7	25	3.822	0.0115
TOTL	950	4.531	0.0586	HeII	228	6.122	2.2896	TOTL	7325	3.522	0.0058	Si 7	65	2.013	0.0002
TOTL	938	4.388	0.0422	HE2C	304	2.253	0.0003	O II	2471	3.435	0.0047	Si 8	1446	3.671	0.0081
LA X	1216	6.221	2.8769	ESC	304	5.772	1.0223	O II	7323	3.275	0.0033	Si 9	1985	4.010	0.0177
Ind2	1216	2.647	0.0008	He2C	911	5.685	0.8373	O II	7332	3.160	0.0025	Si 9	949	2.511	0.0006
C13c	6563	5.144	0.2405	TOTL	1640	6.263	3.1684	O II	834	4.081	0.0208	Si 9	3	2.040	0.0002
C14c	4861	4.130	0.0233	TOTL	4686	5.325	0.3654	O 2	4651	4.063	0.0200	Si 9	2	2.135	0.0002
CION	0	7.736	94.1725	TOTL	1216	5.780	1.0412	O 3	1663	7.027	18.3905	Si 9	691	2.351	0.0004
INWD	1216	7.762	99.8228	Ca B	1640	6.077	2.0622	Phot	1663	2.260	0.0003	Si1014300		2.992	0.0017
INWD	6563	6.992	16.9750	DevB	1640	6.076	2.0589	Augr	1663	4.547	0.0609	Ca 2	3933	1.979	0.0002

```
     INWD 4861  6.492   5.3602      Ca B 4686  5.181   0.2619      Rec  1663  4.826   0.1158      Ca2K 3934  1.799   0.0001
     INWD18751  5.944   1.5201      DevB 4686  5.177   0.2598      O  3 5007  4.355   0.0392      Fe 2   48  7.143  24.0210
     Strk 1216  4.488   0.0531      Mion    0  2.220   0.0003      O  3 4959  3.878   0.0131      Fe 2    7  5.215   0.2838
     Strk 6563  6.368   4.0362      C  1 1656  2.251   0.0003      LOST 5007  4.002   0.0173      Emis    3  6.744   9.5829
     Strk 4861  5.806   1.1064      REC  1656  5.097   0.2161      TOTL 4363  4.858   0.1246      Cool    3  6.984  16.6429
     Strk18751  5.294   0.3400      C  2 2326  6.193   2.6975      O  3 2321  4.231   0.0294      TOT     0  7.311  35.3703
     Strk40512  4.424   0.0459      INWD 2326  5.978   1.6437      C EX 5592  2.697   0.0009      FEIR    0  2.250   0.0003
     Dest 1216  6.415   4.4967      C  2 1335  5.400   0.4339      O  3  834  6.021   1.8115      Fe 3    0  3.378   0.0041
     Dest 6563  6.267   3.1941      REC  1335  5.140   0.2387      O  3 3341  3.394   0.0043      Fe 3 5270  2.698   0.0009
     Dest40516  2.487   0.0005      C II 3134  2.966   0.0016      O  4 1402  6.445   4.8099      Fe 3 4658  2.943   0.0015
     Dest 4861  5.495   0.5405      C  2 4267  3.488   0.0053      CONT 1401  4.898   0.1366      Fe 3 1122  4.140   0.0238
     Dest18751  4.068   0.0202      TOTL  977  6.639   7.5298      O  4  789  5.978   1.6440      Fe 5 3892  3.068   0.0020
     nFnu 4860  7.302  34.6297      C3 C  977  6.625   7.2933      O  4 3412  3.793   0.0107      Fe 6    0  3.780   0.0104
     nFnu 1215  6.226   2.9081      C3 R  977  5.136   0.2365      O  5  630  5.041   0.1897      Fe 6 5177  3.329   0.0037
     Inci 4861  7.832 117.3445      TOTL 1909  7.079  20.7397      TOTL 1218  6.250   3.0713      Fe 7 6087  3.252   0.0031
     Inci 1216  8.133 234.6889      INWD 1909  6.781  10.4319      O  5 1218  6.250   3.0711      Fe10 6374  4.335   0.0373
     BA C    0  7.351  38.7734      C  3 1907  3.108   0.0022      O  5 1214  2.162   0.0003      Coll 6374  4.330   0.0369
     PA C    0  7.069  20.2496      C  3 1909  7.079  20.7374      O  5 5112  2.678   0.0008      Pump 6374  2.385   0.0004
     H FF    0  7.165  25.2667      C3 R 1909  4.644   0.0762      O  6 1035  6.217   2.8451      Fe11 7892  3.625   0.0073
     H FB    0  7.208  27.9180      Phot 1909  4.424   0.0459      Ne 2  128  2.679   0.0008      Coll 7892  3.621   0.0072
     Cool 1216  6.669   8.0544      C  3 2297  4.621   0.0721      Ne 3  156  2.254   0.0003      Fe11 2649  3.215   0.0028
     Heat 1216  6.264   3.1750      C  3 4187  2.753   0.0010      Ne 3 3869  4.373   0.0408      Fe12 1242  2.357   0.0004
     Crst  960  4.635   0.0745      C  3 4649  3.598   0.0069      Ne 3 3968  3.860   0.0125      Fe12 2170  3.329   0.0037
     Cool 6563  6.860  12.5157      C  4 1549  7.743  95.6785      Ne 3 3343  3.816   0.0113      Fe12 2568  1.856   0.0001
     Crst 4861  5.929   1.4656      INWD 1549  7.521  57.3062      Ne 3 1815  3.955   0.0156      Totl    2  6.087   2.1128
     Cool18751  6.247   3.0488      DEST 1549  5.365   0.4000      Ne 4 2424  2.195   0.0003      AugC    2  6.087   2.1128
     Crst    0  6.089   2.1199      C4 r 1549  4.304   0.0348      Ne 4 4720  3.472   0.0051
Lines with negative intensities;  205 T OI    0
```

```
                              KWAN+KROLICK AP.J. 250, 478 BLR MODEL
Cooling:  CION    0:0.212  H FF    0:0.057  H FB    0:0.063  C  4 1549:0.215  Cool 2798:0.051  TOT     0:0.080
Heating:  BFH1    0:0.156  BFHe    0:0.249  TotM    0:0.558

IONIZE PARMET:  U(1-) -1.5021  U(4-): -2.4787  U(sp): -2.26  Q(ion):   16.182  L(ion):   8.138 Q(low): 19.46    P(low)  8.25
ENERGY BUDGET:  Heat:   8.409  Coolg:   8.411  Error:  0.3%  Compt H:   4.487  WorkF:   10.635 F-F  H  4.288    PRADMX:8.17E-01
Column density  H12:1.000E+23  H II:1.974E+22  HI:8.028E+22  H-:    2.876E+14  H2:   3.010E+16 H2+:7.289E+14    He H+:1.106E+14
                OH: 0.000E+00  Heff:8.517E+22
<NH>:1.750E+10  <Tp>:1.04E+04  <TO3>:1.73E+04  Ne:5.599E+09  ti(snd):6.92E+06  NeN+dl:8.00E+31 <T(C3)>:1.65E+04 <E(C3)>:5.65E+09
He/Ha:8.53E-02  =   0.85*true  N/Oap:0.00E+00  =   0.00true  T(O3R):1.000E+01  L THIN:1.62E-02 <T(S2)>:7.35E+03 <E(S2)>:3.03E+09
T He+:1.69E+04  EHe+:5.52E+09  T(O+):7.52E+03  EO+:3.52E+09  iter/zn:   3.040  Te-low:7.14E+03 Te-high:2.38E+04  Hlu/zn:4.23E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt8.64E-06  Tthr1.31E+02  <Tden>: 7.94E+03  <dens>:4.09E-14 <Mol>:1.10E+00
Mean Jeans      l(cm)2.20E+16  M(sun)1.50E+02  smallest:     len(cm):2.09E+16  M(sun):1.28E+02 Alf(ox-tran):    -1.6107

Optical Depths: CONTN; COMP: 1.36E-02    H-: 1.12E-02 R(1300): 5.39E-01 H2+ 5.10E-03  HeTri:2.39E-01
 Pfa:1.42E-02   Pa:1.66E-02   Ba:4.93E-02   Hb:3.23E-02  La:1.33E+01   1r:5.053E+05  1.8:1.69E+05  4.:2.749E+04  21R:3.003E+02
10830: 5.24E+02  3889: 2.42E+01  5876: 7.97E+01  7065: 4.39E+01
 1550: 3.58E+04  2800: 2.50E+06   774: 1.57E+01  1240: 2.39E+03  1035: 3.31E+03  1335: 2.96E+06   977: 1.56E+05  1397: 2.82E+04
  789: 9.72E+03  1207: 6.31E+04  1085: 2.61E+05  1194: 3.29E-03  1909: 6.23E-02  1895: 1.69E+00  2326: 1.48E+00  1666: 9.52E-01
 1750: 3.68E-03  1025: 6.05E+05   352: 1.26E+01   347: 1.00E-20  1860: 5.28E-01   630: 2.04E+04   834: 1.73E+06   835: 4.63E+04
 1808: 5.30E+06  1256: 4.69E-01    -3: 1.73E+05   -48: 4.79E+00  3934: 6.21E-01  3969: 3.13E-01  8498: 1.62E-03  8542: 1.47E-02
 8662: 8.23E-03   353: 3.00E+00  1304: 2.07E+06  1122: 1.56E+03   990: 1.62E+04  1402: 1.30E-01  1214: 1.10E-01  1486: 4.21E-02
 2335: 1.27E+01  1406: 2.61E-06  1656: 5.06E+02  9830: 8.43E-08  8727: 2.50E-06  6300: 5.49E-03  5577: 8.16E-03  7291: 5.08E-08
 7324: 3.52E-08  1039: 2.94E+05 -8446: 4.33E+02 -4368: 1.67E+00  -132: 6.13E+00  -113: 2.70E+01   -29: 2.95E-02   -46: 6.45E-01
 -245: 1.15E-01   765: 2.56E+04 -1198: 1.01E-06   786: 3.01E-03
 C157: 1.01E-01  N122: 4.46E-02  N205: 6.01E-02   N57: 1.44E-03  O146: 3.53E-01   O63: 1.06E+00   O88: 9.36E-03   O52: 1.58E-02
  O26: 4.14E-03  NE13: 1.00E-01  NE36: 1.16E-02  NE16: 3.69E-02   MG4: 1.74E-03  MG14: 3.91E-04   MG6: 2.27E-04  SI35: 1.32E-01
  S19: 3.35E-08   S34: 1.59E-08   S11: 5.68E-09   AR7: 4.02E-07   AR9: 1.65E-08  AR22: 4.84E-09  AR13: 8.77E-10   AR8: 1.68E-09
  CA3: 1.24E-08  CA12: 1.12E-09   CA4: 4.60E-09  Ne14: 1.12E-03  Ne24: 5.51E-04   Si3: 1.04E-03   Si4: 8.91E-03   Fe7: 6.51E-07
 Fe61:-3.40E-02  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 6.06E-04 Si6.5: 1.90E-04  C610: 4.53E-06  C370: 3.01E-06

Old hydro optical depths:    1 5.13E+05    2 6.53E-01    3 6.44E-02    4 1.68E-02    5 5.20E-03    6 2.26E-03    7 2.03E-03
                    Lines:  2-1 5.62E+09  3-2 2.54E+04  4-3 4.37E+03  5-4 1.85E+03  6-5 1.10E+03  7-6 6.76E+01  8-7 6.63E+01
New hydro optical depths:    1 5.05E+05    2 5.47E-01    3 5.76E-02    4 1.57E-02    5 5.03E-03    6 2.25E-03    7 2.18E-03
                    Lines:  2-1 5.55E+09  3-2 2.14E+04  4-3 3.88E+03  5-4 1.73E+03  6-5 1.05E+03  7-6 6.62E+01  8-7 6.99E+01

Old He Is optical depths:    1 1.71E+05    2 2.66E-01    3 3.14E-10    4-3.42E-09    5-7.28E-09    6-1.16E-08    7-5.44E-08
                    Lines:  2-1 4.17E+08  3-2 6.83E-02  4-3 9.51E-04  5-4 3.15E-04  6-5-1.45E-03  7-6 6.03E-03  8-7 9.88E-02
New HE Is optical depths:    1 1.69E+05    2 2.24E-01    3 7.91E-10    4-4.52E-09    5-9.71E-09    6-1.53E-08    7-6.66E-08
                    Lines:  2-1 4.14E+08  3-2 1.08E-01  4-3 1.48E-03  5-4 4.62E-04  6-5-2.03E-03  7-6 8.34E-03  8-7 1.37E-01

Old He II optical depths:    1 2.77E+04    2 5.13E+05    3 1.12E-09    4-2.25E-09    5-4.60E-09    6-7.74E-09    7-7.28E-08
                    Lines:  2-1 9.54E+06  3-2 3.08E+00  4-3 2.56E-04  5-4 2.56E-05  6-5-8.70E-05  7-6 3.31E-04  8-7 5.08E-03
New HE II optical depths:    1 2.75E+04    2 5.05E+05    3 3.51E-09    4-2.21E-09    5-4.68E-09    6-7.94E-09    7-7.50E-08
                    Lines:  2-1 1.21E+07  3-2 4.78E+00  4-3 5.59E-04  5-4 4.37E-05  6-5-7.50E-05  7-6 3.43E-04  8-7 5.23E-03

Hydrogen  -0.095 -0.705                          Log10 Mean Ionisation (over volume)
Helium    -0.026 -1.280 -2.180
Carbon    -3.716 -0.026 -1.488 -1.684 -2.497 -3.364 -4.912
Nitrogen  -0.977 -0.076 -1.502 -1.783 -2.398 -2.482 -3.773 -5.660
Oxygen    -0.088 -0.892 -1.355 -2.154 -2.574 -2.954 -3.361 -5.441
Neon      -0.105 -0.897 -1.135 -2.139 -2.207 -2.681 -3.964 -4.420 -5.375
Magnesium -3.265 -0.296 -0.326 -2.067 -2.526 -2.334 -2.401 -2.914 -3.756 -4.742 -5.949
Aluminum  -3.982 -0.042 -1.309 -1.585 -2.369 -2.276 -2.275 -2.629 -3.470 -4.565 -5.804
Silicon   -4.078 -0.025 -1.791 -1.677 -2.396 -2.293 -2.265 -2.427 -2.966 -3.913 -5.101 -6.444
Sulphur   -4.353 -0.040 -1.279 -1.810 -2.498 -2.226 -2.369 -2.421 -2.731 -3.389 -4.372 -5.586
Argon     -0.135 -0.683 -1.704 -1.863 -2.551 -2.132 -2.308 -2.302 -2.370 -2.926 -3.736 -4.894 -6.305
Calcium   -3.792 -1.469 -0.029 -2.044 -2.421 -2.209 -2.324 -2.434 -2.753 -3.167 -3.654 -4.629
Iron      -2.652 -0.029 -2.073 -1.509 -2.275 -2.085 -2.348 -2.446 -2.979 -3.238 -3.819 -4.541 -5.371
```

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          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.095 -0.705                          Log10 Mean Ionisation (over radius)
Helium    -0.026 -1.280 -2.180
Carbon    -3.716 -0.026 -1.488 -1.684 -2.497 -3.364 -4.912
Nitrogen  -0.977 -0.076 -1.502 -1.783 -2.398 -2.482 -3.773 -5.660
Oxygen    -0.088 -0.892 -1.355 -2.154 -2.574 -2.954 -3.361 -5.441
Neon      -0.105 -0.897 -1.135 -2.139 -2.207 -2.681 -3.964 -4.420 -5.375
Magnesium -3.265 -0.296 -0.326 -2.067 -2.526 -2.334 -2.401 -2.914 -3.756 -4.742 -5.949
Aluminum  -3.982 -0.042 -1.309 -1.585 -2.369 -2.276 -2.275 -2.629 -3.470 -4.565 -5.804
Silicon   -4.078 -0.025 -1.791 -1.677 -2.396 -2.293 -2.265 -2.427 -2.966 -3.913 -5.101 -6.444
Sulphur   -4.353 -0.040 -1.279 -1.810 -2.498 -2.226 -2.369 -2.421 -2.731 -3.389 -4.372 -5.586
Argon     -0.135 -0.683 -1.704 -1.863 -2.551 -2.132 -2.308 -2.302 -2.370 -2.926 -3.736 -4.894 -6.305
Calcium   -3.792 -1.469 -0.029 -2.044 -2.421 -2.209 -2.324 -2.434 -2.753 -3.167 -3.654 -4.629
Iron      -2.652 -0.029 -2.073 -1.509 -2.275 -2.085 -2.348 -2.446 -2.979 -3.238 -3.819 -4.541 -5.371

0.5-1.0KEV:4.25E+06 1.0-1.5:2.56E+12 1.5-2.0:9.80E+13 2.0-2.5:4.37E+14 2.5-3:9.95E+14 3-5:5.04E+15 5-7.5:5.13E+15 7.5-10:3.41E+15


                                          Normalised continuum
  0.25 1.398   0.27 1.259   0.30 1.142   0.33 1.060   0.36 1.008   0.39 0.979   0.43 0.965   0.47 0.965   0.51 0.962   0.56 0.956
  0.62 0.926   0.67 0.859   0.74 0.020   0.81 0.789   0.88 0.830   0.97 0.730   0.98 0.737   0.99 0.738   1.00 0.740


Inward continua (nuFnu) at head of Balmer, Lyman series;  5.46E+07  4.31E+07


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  6.09E+07  0.00E+00

                                       Emergent continuum - phot/ryd/cm2 (r in)
  0.26 7.51E+19  0.86 7.90E+18     1.6 2.97E+09     4.2 0.00E+00    13.7 0.00E+00    4.50E+01 7.68E-10    1.04E+02 1.44E+11
  0.29 5.43E+19  0.97 5.57E+18     1.8 1.24E-16     4.7 0.00E+00    15.4 1.20-288    5.05E+01 2.89E-03    1.12E+02 5.58E+11
  0.33 4.08E+19  0.99 5.44E+18     2.0 1.92E+07     5.3 0.00E+00    17.3 5.79-195    5.47E+01 2.46E-01    1.22E+02 1.63E+12
  0.37 3.20E+19  0.99 5.39E+18     2.3 1.13E+14     5.9 0.00E+00    19.5 1.34-131    5.93E+01 2.24E+02    1.32E+02 3.78E+12
  0.42 2.59E+19  1.00 0.00E+00     2.5 4.43E-24     6.7 4.57E+06    22.0 7.55E-94    6.42E+01 2.13E+03    1.43E+02 4.83E+12
  0.47 2.16E+19  1.01 4.73E-09     2.9 3.18E-27     7.5 0.00E+00    24.8 1.68E-60    6.95E+01 3.16E+05    1.74E+02 1.63E+13
  0.53 1.79E+19  1.02 3.96E-09     3.2 9.22E-31     8.5 4.38E+06    27.9 2.47E-37    7.53E+01 1.72E+07    2.59E+02 3.57E+13
  0.60 1.45E+19  1.10 6.08E-10     3.6 1.83E+06     9.5 0.00E+00    31.5 8.96E-24    8.16E+01 4.18E+08    3.84E+02 3.31E+13
  0.67 1.12E+19  1.24 2.51E-11     3.9 0.00E+00    10.8 0.00E+00    35.5 4.78E-12    8.83E+01 5.35E+09    5.71E+02 2.02E+13
  0.76 3.63E+16  1.40 7.00E-13     4.0 0.00E+00    12.1 0.00E+00    40.0 2.10E-19    9.57E+01 4.08E+10    8.49E+02 2.34E+01
```

```
                                          CLOUDY 80.08

                ************************************91Aug03*************************************
                *                                                                                *
                * title Ly alpha forest cloud                                                    *
                * c ionized by AGN power law plus cosmic background                              *
                * background, z=2 ; this includes both black body and AGN parts                  *
                * double  ; mimic two-siced photoionization                                      *
                * hden -2                                                                        *
                * stop neutral column density 15                                                 *
                * metals -1.5  ;reduce all heavy elements by 1.5 dsex                            *
                * faint -1                                                                       *
                * iterate  ; must iterate since optically thin                                   *
                * print last                                                                     *
                * c lalpha.in                                                                    *
                * c cray                                                                         *
                *                                                                                *
                **********************************************************************************


                                       Chemical composition
He:.098 C:1.15E-05 N:3.54E-06 O:2.69E-05 Ne:3.89E-06 Mg:1.20E-06 Al:9.3E-08 Si:1.12E-06 S:5.12E-07 A:1.1E-07 Ca:7.2E-08 Fe:1.48E-06

         546Cell Peak2.03E-04   Lo 1.00E-05=0.9106cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
         P(nu>1ryd):  -3.4516   Average nu:1.584E+01   P( X-ray):  -3.8828   P(BalC):  -4.5096     Q(Balmer C):   6.4875
         Q(1.0-1.8):   5.6607   Q(1.8-4.0):   5.4919   Q(4.0-20):   5.3137   Q(20--):   4.6992     Ion pht flx:1.024E+06
         L(gam ray):  -3.8090   Q(gam ray):   2.1572   L(Infred):   0.0267   Alf(ox):  -1.0000     Total lumin:   0.0269
         U(1.0----):3.417E-03   U(4.0----):8.537E-04   T(En-Den):8.276E+00   T(Comp):2.248E+04     nuJnu(912A):2.231E-05
         Occ(FarIR):4.574E+00   Occ(H n=6):1.648E-15   Occ(1Ryd):1.029E-21   Occ(4R):3.997E-24     Occ (Nu-hi):4.305E-49
         Tbr(FarIR):7.606E+00   Tbr(H n=6):7.317E-12   Tbr(1Ryd):1.625E-16   Tbr(4R):2.529E-18     Tbr (Nu-hi):4.753E-37

#####  1 Te:2.138E+04 Hden:1.000E-02 Ne:1.183E-02 R:1.000E+25 R-R0:8.762E+17 dR:1.752E+18 NTR:  2 Htot:6.190E-28 T912: 1.661E-04###
-10.66 4686  0.54 5876  0.01 1909  1.23 1549  1.30 6584  0.01 5007  1.15 3727  0.06 6300  0.00 2798  0.01 1035  0.02
Hydrogen    1.506E-03 9.985E-01 H+0/Hden: 1.000E+00 3.136E-11 H-     H2 2.670E-12 2.227E-11 H2+  HeH+ 1.028E-11 H col den 1.752E+16
H 2SP 3-6   1.847E-16 9.555E-23 3.606E-23 3.619E-23 4.601E-23 5.895E-23 Texc(La); 2.611E+03 T(contn): 8.276E+00 T(diffs): 2.489E+02
Helium      2.528E-04 1.229E-01 8.768E-01 He I 2S3  1.611E-12 Comp H, C 1.269E-31 1.207E-31 Fill Fact 1.000E+00 Gam 1/tot 6.005E-01
He singlet  2.528E-04 1.750E-18 3.798E-25 5.117E-25 7.382E-25 1.031E-24 He triplt 1.611E-12 1.235E-23 3.388E-25 2.148E-24 4.498E-25
HeII        1.229E-01 2.715E-17 8.352E-24 1.127E-23 1.596E-23 2.211E-23 1.699E-22 1.167E-21 2.230E-19 PRAD/GAS; 5.846E-06
Pressure    NgasTgas; 4.820E+02 P(total): 6.655E-14 P( gas ): 6.655E-14 P(Radtn): 3.890E-19 Rad accel 1.544E-11 Force Mul 1.280E+00
Carbon      1.636E-04 5.293E-02 6.110E-01 2.728E-01 6.024E-02 2.817E-03 1.925E-05 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    2.931E-05 1.840E-02 4.243E-01 4.225E-01 8.817E-02 4.633E-02 3.360E-04 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.251E-05 1.157E-02 4.000E-01 4.276E-01 1.339E-01 2.226E-02 4.655E-03 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.622
Neon        1.904E-06 1.450E-03 1.724E-01 4.034E-01 3.550E-01 6.659E-02 1.027E-03 1.435E-04 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 5.486E-05 3.550E-03 1.288E-01 2.618E-01 1.752E-01 2.948E-01 1.220E-01 1.316E-02 6.067E-04 2.095E-05 0.000E+00 0.000E+00
Aluminium 0 7.842E-04 8.028E-02 4.639E-02 1.825E-01 1.635E-01 3.114E-01 1.847E-01 2.917E-02 1.218E-03 2.896E-05 0.000E+00 0.000E+00
Silicon   0 1.453E-04 1.648E-02 2.170E-01 1.005E-01 1.276E-01 2.742E-01 2.026E-01 5.624E-02 5.104E-03 1.673E-04 0.000E+00 0.000E+00
Sulphur   0 2.316E-05 4.995E-02 4.039E-01 1.900E-01 9.689E-02 1.146E-01 1.047E-01 3.444E-02 5.232E-03 3.168E-04 8.832E-06 0.000E+00
Argon     1 1.228E-02 2.273E-01 2.136E-01 1.264E-01 1.645E-01 1.377E-01 7.289E-02 4.195E-02 3.277E-03 1.448E-04 2.634E-06 2.865E-08
Calcium   0 1.846E-04 7.850E-03 7.713E-02 1.472E-01 9.252E-02 2.602E-01 2.570E-01 1.216E-01 2.985E-02 5.475E-03 8.916E-04 2.256E-05
Iron      0 0.000E+00 1.234E-05 2.037E-03 2.165E-02 6.407E-02 3.058E-01 3.787E-01 2.015E-01 2.157E-02 4.209E-03 3.605E-04 2.420E-05
#####  5 Te:2.140E+04 Hden:1.000E-02 Ne:1.182E-02 R:1.000E+25 R-R0:4.979E+19 dR:3.292E+19 NTR:  1 Htot:6.224E-28 T912: 6.296E-03###
 -9.18 4686  0.51 5876  0.01 1909  1.53 1549  1.60 6584  0.01 5007  1.43 3727  0.07 6300  0.00 2798  0.02 1035  0.03
Hydrogen    1.511E-03 9.985E-01 H+0/Hden: 1.000E+00 3.215E-11 H-     H2 2.682E-12 2.234E-11 H2+  HeH+ 1.021E-11 H col den 6.625E+17
H 2SP 3-6   1.613E-16 4.255E-22 2.481E-23 2.670E-23 3.800E-23 5.179E-23 Texc(La); 2.700E+03 T(contn): 8.276E+00 T(diffs): 2.439E+02
Helium      2.531E-04 1.241E-01 8.756E-01 He I 2S3  1.614E-12 Comp H, C 1.269E-31 1.208E-31 Fill Fact 1.000E+00 Gam 1/tot 5.993E-01
He singlet  2.531E-04 1.705E-18 3.535E-25 4.954E-25 7.277E-25 1.026E-24 He triplt 1.614E-12 1.236E-23 3.399E-25 2.150E-24 4.485E-25
HeII        1.241E-01 2.044E-17 5.428E-24 8.007E-24 1.238E-23 1.839E-23 1.504E-22 1.185E-21 2.227E-19 PRAD/GAS; 2.632E-05
Pressure    NgasTgas; 4.875E+02 P(total): 6.731E-14 P( gas ): 6.730E-14 P(Radtn): 1.771E-18 Rad accel 1.545E-11 Force Mul 1.281E+00
Carbon      1.628E-04 5.263E-02 6.127E-01 2.717E-01 6.001E-02 2.807E-03 1.918E-05 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
```

```
Nitrogen    2.906E-05 1.826E-02 4.260E-01 4.214E-01 8.781E-02 4.617E-02 3.349E-04 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.235E-05 1.140E-02 4.015E-01 4.268E-01 1.335E-01 2.218E-02 4.640E-03 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.622
Neon        1.833E-06 1.425E-03 1.730E-01 4.034E-01 3.545E-01 6.648E-02 1.026E-03 1.432E-04 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 5.498E-05 3.562E-03 1.292E-01 2.619E-01 1.750E-01 2.945E-01 1.219E-01 1.315E-02 6.063E-04 2.094E-05 0.000E+00 0.000E+00
Aluminium 0 7.818E-04 8.027E-02 4.639E-02 1.826E-01 1.635E-01 3.114E-01 1.847E-01 2.917E-02 1.218E-03 2.897E-05 0.000E+00 0.000E+00
Silicon   0 1.432E-04 1.647E-02 2.166E-01 1.010E-01 1.275E-01 2.741E-01 2.026E-01 5.623E-02 5.104E-03 1.673E-04 0.000E+00 0.000E+00
Sulphur   0 2.147E-05 4.968E-02 4.029E-01 1.910E-01 9.678E-02 1.148E-01 1.048E-01 3.447E-02 5.236E-03 3.171E-04 0.000E+00 0.000E+00
Argon     0 7.314E-06 1.205E-02 2.258E-01 2.145E-01 1.264E-01 1.649E-01 1.379E-01 7.303E-02 4.202E-02 3.283E-03 1.451E-04 0.000E+00
Calcium   0 1.852E-04 7.882E-03 7.751E-02 1.474E-01 9.248E-02 2.601E-01 2.567E-01 1.215E-01 2.983E-02 5.470E-03 8.910E-04 2.254E-05
Iron      0 0.000E+00 1.223E-05 2.024E-03 2.176E-02 6.418E-02 3.059E-01 3.786E-01 2.014E-01 2.156E-02 4.207E-03 3.605E-04 2.420E-05
  Calculation stopped because column dens reached.
  Geometry is plane-parallel.
 !The largest continuum occupation number was 4.574E+00 at 1.053E-05 Ryd.
  Continuum occupation number reached  5.94E-02 for some fine structure transitions.
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations  10 times.
```

```
                  ********************************> CLOUDY 80.08  <********************************
                  * title Ly alpha forest cloud                                                     *
                  * c ionized by AGN power law plus cosmic background                              *
                  * background, z=2 ; this includes both black body and AGN parts                  *
                  * double  ; mimic two-siced photoionization                                     *
                  * hden -2                                                                       *
                  * stop neutral column density 15                                                *
                  * metals -1.5  ;reduce all heavy elements by 1.5 dsex                           *
                  * faint -1                                                                      *
                  * iterate  ; must iterate since optically thin                                  *
                  * print last                                                                    *
                  * c lalpha.in                                                                   *
                  * c cray                                                                        *
                  ********************************> LOG(U): -2.47 <********************************

               Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                         Intensity (erg/s/cm^2)

TOTL 4861 -9.177   1.0000      TOTL  973 -8.966   1.6257      Cool 1216 -7.700  29.9987      C  3 1907 -9.212   0.9233
TOTL 1216 -7.455  52.7726      TOTL  950 -9.099   1.1959      Crst  960 -9.709   0.2938      C  3 1909 -9.397   0.6034
TotH    0 -7.386  61.8612      TOTL  938 -9.231   0.8829      HeFF    0 -9.135   1.1019      C  4 1549 -8.972   1.6043
BFH1    0 -7.869  20.3217      C13c 6563 -9.199   0.9510      HeFB    0 -8.972   1.6026      INWD 1549 -9.189   0.9731
BFHe    0 -7.564  41.0106      CION    0 -8.614   3.6537      ToFF    0 -8.554   4.1979      N  4 1486-10.086   0.1233
TotM    0 -9.465   0.5157      INWD 1216 -7.546  42.7599      esc   584 -9.626   0.3560      O  3 1663 -9.853   0.2109
CA B 4861 -9.327   0.7077      INWD 6563 -8.921   1.8055      He I  504 -9.389   0.6146      O  3 5007 -9.023   1.4255
CA B 1216 -7.763  25.9810      INWD 4861 -9.478   0.5000      HeII  228 -7.594  38.3187      O  3 4959 -9.500   0.4752
DU B 4861 -9.327   0.7077      INWD18751-10.036   0.1384      He2C  911 -8.500   4.7501      O  3  880-10.048   0.1347
Q(H) 4861 -6.313 731.6663      e sc 6563 -9.992   0.1533      TOTL 1640 -8.492   4.8449      O  4   26 -9.330   0.7033
Q(H) 1216 -4.779*********      e sc 4861 -9.708   0.2946      TOTL 4686 -9.469   0.5108      O  4 1402 -9.869   0.2033
TOTL 6563 -8.620   3.6111      e sc18751 -9.735   0.2771      TOTL 1216 -8.911   1.8440      TOTL 1218-10.136   0.1101
TOTL 4861 -9.177   1.0000      nFnu 4860 -8.334   6.9654      Ca B 1640 -8.459   5.2312      Ne 4 2424 -9.947   0.1700
TOTL 4340 -9.510   0.4644      nFnu 1215 -8.888   1.9443      DevB 1640 -8.461   5.1983      Ne 5 3426-10.075   0.1265
TOTL 4102 -9.774   0.2529      Inci 4861 -4.652*********      Ca B 4686 -9.356   0.6631      Ne 5  242 -9.942   0.1717
TOTL18751 -9.735   0.2769      Inci 1216 -4.652*********      DevB 4686 -9.363   0.6514      Ne 5  143-10.008   0.1475
TOTL12818-10.041   0.1368      BA C    0 -8.612   3.6777      TOTL  977 -9.547   0.4271      Si 3 1895 -9.844   0.2153
2 NU    0 -7.829  22.2846      PA C    0 -9.158   1.0463      C3 C  977 -9.549   0.4250      S  3 9532-10.173   0.1009
TOTL 1216 -7.455  52.7726      H FF    0 -8.687   3.0945      TOTL 1909 -8.993   1.5267
TOTL 1026 -8.718   2.8813      H FB    0 -8.387   6.1710      INWD 1909 -9.294   0.7634
```

LY ALPHA FOREST CLOUD
Cooling: CION   0:0.059 H FF   0:0.050 H FB   0:0.100 Cool 1216:0.486
Heating: BFH1   0:0.329 BFHe   0:0.663

IONIZE PARMET: U(1-) -2.4664 U(4-): -3.0687 U(sp): -2.47 Q(ion):   6.009 L(ion): -3.452 Q(low): 14.53   P(low) 0.03
ENERGY BUDGET: Heat: -7.386 Coolg: -7.387 Error: 0.2% Compt H: -11.075 WorkF: -6.928 F-F H-14.178   PRADMX:7.98E-05
Column density H12:6.625E+17 H II:6.615E+17 HI:1.000E+15 H-:   2.124E+07 H2:   1.775E+06 H2+:1.479E+07   He H+:6.754E+06
                OH: 0.000E+00 Heff:2.528E+16
<NH>:1.000E-02 <Tp>:2.14E+04 <TO3>:2.14E+04 Ne:1.182E-02 ti(snd):3.88E+13 NeN+dl:7.82E+15 <T(C3)>:2.14E+04 <E(C3)>:1.18E-02
He/Ha:4.75E-02 =   0.48*true N/Oap:1.29E-01 =   0.98true T(O3R):2.047E+04 L THIN:1.00E+30 <T(S2)>:2.14E+04 <E(S2)>:1.18E-02
T He+:2.14E+04 EHe+:1.18E-02 T(O+):2.14E+04 EO+:1.18E-02 iter/zn: 1.000 Te-low:2.14E+04 Te-high:2.14E+04 Hlu/zn:1.00E+00
  <a>:0.00E+00 erdeFe3.7E+25 Tcompt3.71E+11 Tthr1.73E+14 <Tden>: 2.14E+04 <dens>:2.31E-26 <Mol>:6.11E-01
Mean Jeans   l(cm)7.70E+22 M(sun)2.78E+09 smallest: len(cm):7.70E+22 M(sun):2.78E+09 Alf(ox-tran):   -1.0001

Optical Depths: CONTN; COMP: 5.21E-07   H-: 8.28E-10 R(1300): 6.71E-09 H2+ 1.04E-10 HeTri:5.21E-07
 Pfa:5.21E-07   Pa:5.21E-07   Ba:5.22E-07   Hb:5.22E-07 La:6.89E-07   1r:6.296E-03 1.8:1.32E-03 4.:1.275E-02 21R:1.245E-04
10830: 9.74E-08 3889: 4.15E-09 5876: 4.63E-19 7065: 2.60E-19
 1550: 1.68E-01 2800: 2.73E-03   774: 1.56E-05 1240: 1.19E-02 1035: 1.68E-02 1335: 3.69E-02   977: 9.68E-01 1397: 2.36E-02
  789: 1.45E-01 1207: 1.41E-01 1085: 7.83E-04 1194: 5.77E-04 1909: 3.86E-07 1895: 3.76E-06 2326: 1.85E-08 1666: 1.97E-06
 1750: 1.03E-08 1025: 1.37E-06   352: 3.04E-05   347: 1.00E-20 1860: 2.06E-03   630: 2.53E-01   834: 2.33E-02   835: 9.58E-02
 1808: 1.07E-02 1256: 5.09E-04   -3: 4.33E-07   -48: 1.49E-19 3934: 4.94E-04 3969: 2.49E-04 8498: 1.18E-14 8542: 1.06E-13
 8662: 5.99E-14   353: 2.38E-06 1304: 4.69E-06 1122: 7.92E-05   990: 4.55E-02 1402: 1.94E-06 1214: 1.36E-06 1486: 2.35E-07
 2335: 2.55E-08 1406: 9.74E-07 1656: 9.59E-05 9830: 1.60E-14 8727: 1.78E-18 6300: 1.24E-14 5577: 1.13E-20 7291: 3.30E-11
 7324: 2.29E-11 1039: 6.66E-07 -8446: 1.00E-20 -4368: 1.00E-20 -132: 1.00E-20 -113: 1.00E-20   -29: 1.00E-20   -46: 1.00E-20
 -245: 7.76E-07   765: 1.43E-01 -1198: 9.63E-07   786: 2.87E-03
 C157: 2.98E-07 N122: 5.52E-12 N205: 1.72E-07   N57: 7.99E-07 O146:-1.99E-16   O63: 1.43E-10   O88: 1.85E-05   O52: 1.24E-10
  O26: 6.55E-06 NE13: 1.77E-09 NE36:-3.03E-14 NE16: 3.24E-07   MG4: 1.10E-07 MG14:-4.93E-16   MG6: 1.10E-07 SI35: 1.41E-08
  S19: 1.06E-12   S34: 4.99E-07   S11: 7.81E-08   AR7: 5.95E-10   AR9: 1.66E-08 AR22:-5.96E-16 AR13: 3.71E-08   AR8: 6.40E-16
  CA3: 4.81E-09 CA12:-1.06E-17   CA4: 4.48E-09 Ne14: 1.20E-12 Ne24: 2.48E-06   Si3: 1.01E-18   Si4: 1.21E-08   Fe7: 7.15E-13
 Fe61:-2.34E-17 Fe23: 1.00E-20 Fe13: 1.00E-20 Si2.5: 2.53E-08 Si6.5:-3.80E-18 C610: 8.80E-17 C370: 1.69E-09

Old hydro optical depths: 1 6.30E-03   2 4.08E-10   3 8.07E-10   4 2.28E-10   5 1.52E-20   6 2.12E-20   7 5.99E-20
                    Lines: 2-1 8.07E+01 3-2 8.43E-11 4-3 2.01E-17 5-4 1.63E-17 6-5 2.89E-17 7-6 8.07E-17 8-7 9.70E-16
New hydro optical depths: 1 6.30E-03   2 4.19E-10   3 8.29E-10   4 2.34E-10   5 1.40E-20   6 1.85E-20   7 4.77E-20
                    Lines: 2-1 4.05E+01 3-2 3.70E-11 4-3 8.99E-18 5-4 7.60E-18 6-5 1.39E-17 7-6 3.23E-17 8-7 3.85E-16

Old He Is optical depths: 1 2.68E-03   2 5.43E-10   3 2.00E-20   4 2.00E-20   5 2.00E-20   6 2.00E-20   7 2.00E-20
                    Lines: 2-1 9.89E-01 3-2 2.10E-13 4-3 6.93E-20 5-4 9.27E-20 6-5 1.59E-19 7-6 3.65E-19 8-7 4.16E-18
New HE Is optical depths: 1 1.32E-03   2 2.79E-10   3 1.00E-20   4 1.00E-20   5 1.00E-20   6 1.00E-20   7 9.99E-21
                    Lines: 2-1 4.22E-01 3-2 7.49E-14 4-3 2.32E-20 5-4 2.43E-20 6-5 2.64E-20 7-6 1.31E-19 8-7 1.55E-18

Old He II optical depths: 1 2.97E-02   2 1.26E-02   3 2.00E-20   4 2.00E-20   5 2.00E-20   6 1.99E-20   7 1.93E-20
                    Lines: 2-1 3.77E+02 3-2 6.03E-13 4-3 1.28E-19 5-4 8.46E-20 6-5-8.57E-20 7-6 1.41E-18 8-7 1.87E-17
New HE II optical depths: 1 1.27E-02   2 6.30E-03   3 1.00E-20   4 9.99E-21   5 9.99E-21   6 9.98E-21   7 9.76E-21
                    Lines: 2-1 1.62E+02 3-2 2.33E-13 4-3 4.99E-20 5-4 2.53E-20 6-5-5.17E-20 7-6 5.77E-19 8-7 7.55E-18

Hydrogen -2.821 -0.001   Log10 Mean Ionisation (over volume)
Helium   -3.598 -0.908 -0.057
Carbon   -3.787 -1.278 -0.213 -0.565 -1.221 -2.551 -4.717
Nitrogen -4.535 -1.737 -0.371 -0.375 -1.056 -1.335 -3.475
Oxygen   -4.906 -1.941 -0.397 -0.370 -0.874 -1.654 -2.333
Neon   -5.731 -2.844 -0.762 -0.394 -0.450 -1.177 -2.989 -3.844
Magnesium -4.260 -2.449 -0.889 -0.582 -0.757 -0.531 -0.914 -1.881 -3.217 -4.679
Aluminum -3.106 -1.095 -1.334 -0.739 -0.787 -0.507 -0.734 -1.535 -2.914 -4.538
Silicon   -3.842 -1.783 -0.664 -0.996 -0.894 -0.562 -0.693 -1.250 -2.292 -3.776
Sulphur   -4.657 -1.303 -0.394 -0.720 -1.014 -0.940 -0.980 -1.463 -2.281 -3.499 -6.631
Argon   -5.133 -1.916 -0.645 -0.669 -0.898 -0.783 -0.861 -1.137 -1.377 -2.484 -3.839 -7.157 -9.120
Calcium   -3.733 -2.104 -1.111 -0.832 -1.034 -0.585 -0.590 -0.915 -1.525 -2.262 -3.050 -4.647
Iron   -30.000 -4.911 -2.693 -1.663 -1.193 -0.514 -0.422 -0.696 -1.666 -2.376 -3.443 -4.616

---

          1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17

Hydrogen -2.821 -0.001   Log10 Mean Ionisation (over radius)
Helium   -3.598 -0.908 -0.057
Carbon   -3.787 -1.278 -0.213 -0.565 -1.221 -2.551 -4.717
Nitrogen -4.535 -1.737 -0.371 -0.375 -1.056 -1.335 -3.475
Oxygen   -4.906 -1.941 -0.397 -0.370 -0.874 -1.654 -2.333
Neon   -5.731 -2.844 -0.762 -0.394 -0.450 -1.177 -2.989 -3.844
Magnesium -4.260 -2.449 -0.889 -0.582 -0.757 -0.531 -0.914 -1.881 -3.217 -4.679
Aluminum -3.106 -1.095 -1.334 -0.739 -0.787 -0.507 -0.734 -1.535 -2.914 -4.538
Silicon   -3.842 -1.783 -0.664 -0.996 -0.894 -0.562 -0.693 -1.250 -2.292 -3.776
Sulphur   -4.657 -1.303 -0.394 -0.720 -1.014 -0.940 -0.980 -1.463 -2.281 -3.499 -6.631
Argon   -5.133 -1.916 -0.645 -0.669 -0.898 -0.783 -0.861 -1.137 -1.377 -2.484 -3.839 -7.157 -9.120
Calcium   -3.733 -2.104 -1.111 -0.832 -1.034 -0.585 -0.590 -0.915 -1.525 -2.262 -3.050 -4.647
Iron   -30.000 -4.911 -2.693 -1.663 -1.193 -0.514 -0.422 -0.696 -1.666 -2.376 -3.443 -4.616

0.5-1.0KEV:1.36E+04 1.0-1.5:4.80E+03 1.5-2.0:2.25E+03 2.0-2.5:1.37E+03 2.5-3:1.01E+03 3-5:1.80E+03 5-7.5:9.19E+02 7.5-10:4.86E+02

Normalised continuum
  0.25 1.000   0.27 1.000   0.30 1.000   0.33 1.000   0.36 1.000   0.39 1.000   0.43 1.000   0.47 1.000   0.51 1.000   0.56 1.001
  0.62 1.001   0.67 1.000   0.74 1.000   0.81 1.000   0.88 1.000   0.97 1.000   0.98 1.000   0.99 1.000   1.00 1.000

Inward continua (nuFnu) at head of Balmer, Lyman series; 6.19E-09 6.89E-08

Outwrd continua (nuFnu) at head of Balmer, Lyman series; 6.19E-09 7.01E-08

Emergent continuum - phot/ryd/cm2 (r in)
  0.26 1.54E+07 1.00 1.02E+06   3.9 6.77E+04   17.3 3.41E+03   75.3 1.81E+02   1.26E+03 6.44E-01   3.24E+05 9.76E-06
  0.29 1.21E+07 1.01 1.00E+06   4.0 6.31E+04   19.5 2.68E+03   81.6 1.54E+02   1.88E+03 2.91E-01   4.82E+05 4.42E-06
  0.33 9.51E+06 1.02 9.88E+05   4.2 5.82E+04   22.0 2.11E+03   88.3 1.31E+02   2.79E+03 1.32E-01   7.16E+05 2.00E-06
  0.37 7.48E+06 1.10 8.46E+05   4.7 4.67E+04   24.8 1.67E+03   95.7 1.12E+02   4.14E+03 5.97E-02   1.06E+06 9.05E-07
  0.42 5.89E+06 1.24 6.66E+05   5.3 3.69E+04   27.9 1.31E+03   103.7 9.53E+01   6.16E+03 2.70E-02   1.58E+06 4.09E-07
  0.47 4.63E+06 1.40 5.30E+05   5.9 2.91E+04   31.5 1.03E+03   112.3 8.12E+01   9.15E+03 1.22E-02   2.35E+06 1.85E-07
  0.53 3.65E+06 1.57 4.13E+05   6.7 2.29E+04   35.5 8.14E+02   121.6 6.92E+01   1.36E+04 5.54E-03   3.49E+06 8.39E-08
  0.60 2.87E+06 1.78 3.24E+05   7.5 1.81E+04   40.0 6.41E+02   131.7 5.90E+01   2.02E+04 2.51E-03   5.19E+06 3.80E-08
  0.67 2.26E+06 2.00 2.56E+05   8.5 1.43E+04   45.0 5.05E+02   142.7 5.03E+01   3.01E+04 1.13E-03
  0.76 1.77E+06 2.25 2.02E+05   9.5 1.12E+04   50.5 4.02E+02   173.9 3.39E+01   4.47E+04 5.14E-04
  0.86 1.40E+06 2.54 1.59E+05   10.8 8.85E+03   54.7 3.42E+02   258.5 1.53E+01   6.64E+04 2.32E-04
  0.97 1.10E+06 2.86 1.25E+05   12.1 6.97E+03   59.3 2.92E+02   384.2 6.94E+00   9.87E+04 1.05E-04
  0.99 1.05E+06 3.22 9.85E+04   13.7 5.49E+03   64.2 2.49E+02   571.0 3.14E+00   1.47E+05 4.76E-05
  0.99 1.04E+06 3.63 7.76E+04   15.4 4.33E+03   69.5 2.12E+02   848.8 1.42E+00   2.18E+05 2.16E-05

```
**************************************91Aug03***************************************
*                                                                                  *
* title check that equilibrium works at very low densities                         *
* hden = -1, proportional to radius to the -2                                      *
* stop eden -5                                                                     *
* filling factor -5                                                                *
* radius 15                                                                        *
* blackbody, t=5                                                                   *
* luminosity 38                                                                    *
* sphere                                                                           *
* c ldl.in                                                                         *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

Chemical composition

He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

```
          356Cell Peak2.46E+00   Lo 1.00E-05=0.9105cm   Hi-Con:2.30E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  38.0001   Average nu:2.177E+00   P( X-ray):  27.7886   P(BalC):  37.0669     Q(Balmer C):  47.9086
          Q(1.0-1.8):  47.9748   Q(1.8-4.0):  48.0180   Q(4.0-20):  47.0910   Q(20--):  37.1273     Ion pht flx:1.679E+17
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  35.4829   Alf(ox):   0.0000     Total lumin:  38.0492
          L/Lsolar:     4.4664   Abs bol mg:  -6.4461   Abs V mag:  -0.0356   Bol cor:  -6.4105     nuFnu(Bbet):  35.5847
          U(1.0----):5.599E+07   U(4.0----):3.273E+06   T(En-Den):4.452E+02   T(Comp):9.574E+04     nuJnu(912A):2.215E+06
          Occ(FarIR):2.362E-05   Occ(H n=6):8.670E-09   Occ(1Ryd):1.022E-10   Occ(4R):7.057E-13     Occ (Nu-hi):1.169E-25
          Tbr(FarIR):3.928E-05   Tbr(H n=6):3.850E-05   Tbr(1Ryd):1.614E-05   Tbr(4R):4.464E-07     Tbr (Nu-hi):4.175E-19

#####  1 Te:9.567E+04 Hden:7.901E-02 Ne:9.523E-02 R:1.062E+15 R-R0:6.250E+13 dR:1.250E+14 NTR:  1 Htot:3.647E-23 T912: 9.991E+07###
-18.93 4686  1.99 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.01
P(LINES): 0.971 0.000 0.000 0.000 0.000 0.000 0.029 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    9.214E-15 1.000E+00 H+0/Hden: 1.000E+00 4.570E-32 H-     H2 5.117E-41 1.271E-30 H2+  HeH+ 1.271E-43 H col den 9.877E+07
H 2SP 3-6   1.174E-16 2.956E-23 2.388E-23 3.063E-23 4.106E-23 5.313E-23 Texc(La); 5.731E+03 T(contn): 3.958E+02 T(diffs): 4.073E+02
Helium      4.106E-25 2.155E-12 1.000E+00 He I 2S3  3.136E-26 Comp H, C 3.647E-23 3.644E-23 Fill Fact 1.000E-05 Gam 1/tot 9.947E-01
He singlet  3.770E-25 2.248E-27 4.934E-34 8.533E-34 1.498E-33 2.517E-33 He triplt 3.136E-26 5.930E-34 2.086E-35 1.007E-34 1.206E-35
HeII        2.155E-12 9.118E-17 2.997E-23 3.495E-23 4.518E-23 5.863E-23 4.146E-22 2.140E-21 3.217E-19 PRAD/GAS; 4.301E+05
Pressure    NgasTgas; 1.742E+04 P(total): 1.035E-06 P( gas ): 2.405E-12 P(Radtn): 1.035E-06 Rad accel 1.011E-04 Force Mul 1.000E+00
Carbon      0.000E+00 0.000E+00 2.278E-19 1.152E-09 1.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 1.988E-17 3.781E-09 1.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.782E-14 3.102E-07 1.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-13.492
Neon        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.113E-04 2.832E-02 9.715E-01 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.011E-07 1.946E-03 2.856E-01 7.125E-01 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.270E-06 2.437E-02 8.150E-01 1.606E-01 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.722E-07 1.562E-02 9.145E-01 6.990E-02 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.074E-10 1.785E-01 8.215E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.321E-12 9.650E-07 1.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.559E-05 1.207E-02 9.879E-01 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.678E-06 1.396E-01 6.990E-01 1.603E-01 1.123E-03
#####177 Te:9.566E+04 Hden:7.799E-06 Ne:9.399E-06 R:1.105E+17 R-R0:1.095E+17 dR:5.400E+15 NTR:  1 Htot:2.808E-31 T912: 9.991E+07###
-17.92 4686  2.07 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.01
P(LINES): 0.972 0.000 0.000 0.000 0.000 0.000 0.028 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    1.083E-14 1.000E+00 H+0/Hden: 1.000E+00 4.109E-36 H-     H2 7.885E-41 1.637E-30 H2+  HeH+ 2.242E-43 H col den 9.469E+08
H 2SP 3-6   1.212E-20 2.956E-27 2.356E-27 3.041E-27 4.081E-27 5.283E-27 Texc(La); 3.940E+03 T(contn): 4.053E+01 T(diffs): 4.035E+02
Helium      1.097E-26 2.696E-12 1.000E+00 He I 2S3  8.616E-27 Comp H, C 2.807E-31 2.805E-31 Fill Fact 1.000E-05 Gam 1/tot 1.000E+00
He singlet  2.358E-27 1.898E-31 2.381E-38 5.679E-38 1.158E-37 2.126E-37 He triplt 8.616E-27 7.321E-38 2.575E-39 1.243E-38 1.489E-39
HeII        2.696E-12 9.489E-21 3.150E-27 3.647E-27 4.686E-27 6.052E-27 4.254E-26 2.112E-25 3.176E-23 PRAD/GAS; 4.666E+05
Pressure    NgasTgas; 1.719E+00 P(total): 1.108E-10 P( gas ): 2.374E-16 P(Radtn): 1.108E-10 Rad accel 7.884E-09 Force Mul 1.000E+00
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Carbon      0.000E+00 0.000E+00 4.821E-19 1.458E-09 1.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 4.231E-17 4.782E-09 1.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.642E-13 3.925E-07 1.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-13.492
Neon        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.301E-04 3.556E-02 9.640E-01 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.040E-07 3.640E-03 3.353E-01 6.610E-01 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.321E-06 4.006E-02 8.512E-01 1.088E-01 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.227E-06 2.442E-02 9.272E-01 4.838E-02 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.226E-10 2.156E-01 7.844E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.003E-12 1.221E-06 1.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.525E-05 1.928E-02 9.806E-01 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.847E-05 2.285E-01 6.782E-01 9.286E-02 3.873E-04
  Calculation stopped because lowest EDEN reached.
  Geometry is spherical.
  Photoionization of He 2TriS reached 100.0 percent of the total rate out.
  Compton heating was100.0% of the total.
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  4.35E+06.  Caused by Lyman alpha.
C-The HeII continuum is thin and I assumed that it was thick.  Try another iteration.
C-The HeI continuum is thin and I assumed that it was thick.  Try another iteration.
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*********************************> CLOUDY 80.08  <*********************************
* title check that equilibrium works at very low densities                        *
* hden = -1, proportional to radius to the -2                                     *
* stop eden -5                                                                    *
* filling factor -5                                                               *
* radius 15                                                                       *
* blackbody, t=5                                                                  *
* luminosity 38                                                                   *
* sphere                                                                          *
* c ldl.in                                                                        *
* c cray                                                                          *
*********************************> LOG(U):  7.75 <*********************************
>>>>>>>>>> Cautions are present.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Power Law Density Model.  Closed geometry.  Iteration 1 of 1.
                                Luminosity (erg/s) emitted by shell with full coverage.

TOTL 4861 13.179   1.0000      TOTL 1216 14.783  40.1138      TOTL 1640 14.577  25.0031      Si 9 1815 11.404   0.0168
TOTL 1216 14.783  40.1138      TOTL  973 13.787   4.0521      TOTL 4686 13.495   2.0697      Si 9    3 13.136   0.9041
TotH    0 18.732*********      TOTL  950 13.538   2.2812      TOTL 1216 14.053   7.4717      Si 9    2 12.782   0.4007
BFH1    0 14.540  22.9457      TOTL  938 13.358   1.5085      Ca B 1640 14.303  13.2771      Si 9  691 13.056   0.7518
BFHx    0 11.639   0.0288      INWD 1216 14.783  40.1138      DevB 1640 14.300  13.2104      Fe 9  171 13.504   2.1097
BFHe    0 14.601  26.3754      Dest 1216 10.364   0.0015      Ca B 4686 13.257   1.1950      Fe 9  245 11.939   0.0574
TotM    0 14.685  32.0293      e sc 1216 13.411   1.7029      DevB 4686 13.250   1.1764      Fe 9  242 10.678   0.0032
ComH    0 18.732*********      e sc 6563 13.237   1.1413      C4 r 1549 13.015   0.6843      Fe10  352 14.864  48.3380
CA B 4861 13.231   1.1269      e sc 4861 13.089   0.8120      C  4 4659 11.111   0.0085      Fe10 6374 22.460*********
CA B 1216 14.861  48.0141      e sc18751 12.622   0.2771      O  6 1035 11.153   0.0094      Coll 6374 14.316  13.6946
DU B 4861 13.231   1.1265      e sc40512 11.893   0.0517      Ne 7  895 12.221   0.1101      Pump 6374 22.460*********
Q(H) 4861 36.001*********      nFnu 4860 14.613  27.1389      Ne 8  774 15.012  67.9799       352 6374 13.088   0.8101
Q(H) 1216 37.535*********      nFnu 1215 14.900  52.5638      Mg 7 2629 12.424   0.1757      Fe11 7892 21.323*********
TOTL 6563 13.658   3.0118      Inci 4861 35.585*********      Mg 7  433 12.351   0.1483      Coll 7892 13.538   2.2809
TOTL 4861 13.179   1.0000      Inci 1216 37.175*********      Mg 8  435 13.903   5.2899      Pump 7892 21.323*********
TOTL 4340 12.834   0.4517      BA C    0 14.107   8.4649      Mg 8    3 13.593   2.5929      Fe11    6 12.104   0.0841
TOTL 4102 12.556   0.2380      PA C    0 13.489   2.0384      Mg 9  705 14.810  42.7330      Fe11 2649 13.355   1.4973
TOTL18751 12.622   0.2769      H FF    0 14.914  54.2111      Mg 9  368 14.508  21.3030      Fe11 1467 12.435   0.1802
TOTL12818 12.304   0.1331      ComC    0 18.732*********      Si 7 2148 12.754   0.3753      Fe11  354 14.430  17.8147
TOTL10938 12.033   0.0714      H FB    0 14.442  18.3243      Si 7   25 12.202   0.1054      Fe12 1242 11.756   0.0378
TOTL40512 11.892   0.0516      HeFF    0 14.507  21.2508      Si 7   65 11.001   0.0066      Fe12 2170 12.080   0.0796
TOTL26252 11.649   0.0295      HeFB    0 14.384  16.0128      Si 8 1446 14.790  40.7597      Fe12 2568 11.255   0.0119
TOTL74578 11.319   0.0138      MeFF    0 13.669   3.0876      Si 9 1985 13.351   1.4849      Fe12  357 12.333   0.1425
2 NU    0 14.368  15.4465      ToFF    0 15.075  78.5495      Si 9  949 12.410   0.1701
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                          CHECK THAT EQUILIBRIUM WORKS AT VERY LOW DENSITIES
Cooling:  ComC    0:0.999
Heating:  ComH    0:1.000

IONIZE PARMET:  U(1-)  7.7481  U(4-):  6.5150  U(sp):  7.77  Q(ion):   48.248  L(ion):  37.924 Q(low): 47.88    P(low) 37.00
ENERGY BUDGET:  Heat:  18.732  Coolg:  18.732  Error:  0.0%  Compt H:  18.732  WorkF:   16.227 F-F  H  8.285    PRADMX:4.35E+06
Column density  H12:9.469E+08  H II:9.469E+08  HI:1.002E-05  H-:    1.563E-23  H2:   6.950E-32 H2+:1.476E-21    He H+:2.008E-34
                OH: 0.000E+00  Heff:0.000E+00
<NH>:8.437E-04  <Tp>:9.57E+04  <TO3>:0.00E+00  Ne:0.000E+00  ti(snd):3.12E+05  NeN+dl:3.48E+07 <T(C3)>:9.57E+04 <E(C3)>:3.30E-02
He/Ha:1.61E-01  =   1.65*true  N/Oap:0.00E+00  =   0.00true  T(O3R):0.000E+00  L THIN:1.00E+30 <T(S2)>:0.00E+00 <E(S2)>:0.00E+00
T He+:9.57E+04  EHe+:3.55E-02  T(O+):0.00E+00  EO+:0.00E+00  iter/zn:   2.045  Te-low:9.56E+04 Te-high:9.57E+04  Hlu/zn:2.04E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt5.22E+07  Tthr9.88E+10  <Tden>: 9.57E+04  <dens>:1.99E-27 <Mol>:6.16E-01
Mean Jeans      l(cm)5.75E+24  M(sun)9.21E+11  smallest:     len(cm):5.72E+22  M(sun):9.15E+09 Alf(ox-tran):     0.0000

Optical Depths: CONTN; COMP: 3.79E-16    H-: 5.00E-21 R(1300): 6.73E-29 H2+ 1.03E-38  HeTri:3.79E-16
 Pfa:3.79E-16   Pa:3.79E-16   Ba:3.79E-16   Hb:3.79E-16  La:3.79E-16   1r:4.995E+07  1.8:1.15E+07  4.:1.715E+06  21R:3.176E+04
10830: 1.00E-20  3889: 1.00E-20  5876: 1.00E-20  7065: 1.00E-20
 1550: 1.88E-17  2800: 1.00E-20   774: 8.07E-11  1240: 1.35E-17  1035: 6.20E-15  1335: 1.00E-20   977: 1.00E-20  1397: 1.00E-20
  789: 1.00E-20  1207: 1.00E-20  1085: 1.00E-20  1194: 1.00E-20  1909: 1.00E-20  1895: 1.00E-20  2326: 1.00E-20  1666: 1.00E-20
 1750: 1.00E-20  1025: 1.00E-20   352: 1.07E-10   347: 1.00E-20  1860: 1.00E-20   630: 1.51E-20   834: 1.00E-20   835: 1.00E-20
 1808: 1.00E-20  1256: 1.00E-20    -3: 1.00E-20   -48: 1.00E-20  3934: 1.00E-20  3969: 1.00E-20  8498: 1.00E-20  8542: 1.00E-20
 8662: 1.00E-20   353: 1.73E-11  1304: 1.00E-20  1122: 1.00E-20   990: 1.00E-20  1402: 1.00E-20  1214: 1.00E-20  1486: 1.00E-20
 2335: 1.00E-20  1406: 1.00E-20  1656: 1.00E-20  9830: 1.00E-20  8727: 1.00E-20  6300: 1.00E-20  5577: 1.00E-20  7291: 1.00E-20
 7324: 1.00E-20  1039: 1.00E-20 -8446: 1.00E-20 -4368: 1.00E-20  -132: 1.00E-20  -113: 1.00E-20   -29: 1.00E-20   -46: 1.00E-20
 -245: 1.41E-13   765: 1.00E-20 -1198: 1.00E-20   786: 1.00E-20
 C157: 1.00E-20  N122: 1.00E-20  N205: 1.00E-20   N57: 1.00E-20  O146: 1.00E-20   O63: 1.00E-20   O88: 1.00E-20   O52: 1.00E-20
  O26: 1.00E-20  NE13: 1.00E-20  NE36: 1.00E-20  NE16: 1.00E-20   MG4: 1.00E-20  MG14: 1.00E-20   MG6: 1.00E-20  SI35: 1.00E-20
  S19: 1.00E-20   S34: 1.00E-20   S11: 1.00E-20   AR7: 1.00E-20   AR9: 1.00E-20  AR22: 1.00E-20  AR13: 1.00E-20   AR8: 1.00E-20
  CA3: 1.00E-20  CA12: 1.00E-20   CA4: 1.00E-20  Ne14: 1.00E-20  Ne24: 1.00E-20   Si3: 1.00E-20   Si4: 2.82E-15   Fe7: 5.20E-18
 Fe61: 9.42E-21  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 5.45E-17 Si6.5: 1.00E-20  C610: 1.00E-20  C370: 1.00E-20

Old hydro optical depths:    1 9.99E+07    2 1.00E-20    3 1.00E-20    4 1.00E-20    5 1.00E-20    6 1.00E-20    7 1.00E-20
                    Lines:  2-1 9.96E+09  3-2 1.30E+03  4-3 1.30E+01  5-4 6.48E-01  6-5 9.97E-02  7-6 9.97E-03  8-7 9.97E-04
New hydro optical depths:    1 5.00E+07    2 5.00E-21    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 5.00E-01  3-2 8.47E-21  4-3 5.00E-21  5-4 5.00E-21  6-5 5.00E-21  7-6 5.00E-21  8-7 5.00E-21

Old He Is optical depths:    1 4.15E+05    2 0.00E+00    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 9.96E+09  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 0.00E+00
New HE Is optical depths:    1 6.39E-24    2 5.00E-21    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 1.00E+00  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20

Old He II optical depths:    1 4.15E+05    2 4.15E+05    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 9.96E+09  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 0.00E+00
New HE II optical depths:    1 1.93E-22    2 5.03E-21    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 1.00E+00  3-2 1.03E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20

Hydrogen -13.970  0.000                          Log10 Mean Ionisation (over volume)
Helium   -25.099-11.569  0.000
Carbon   -30.000-30.000-18.344 -8.836  0.000
Nitrogen -30.000-30.000-30.000-16.396 -8.320  0.000
Oxygen   -30.000-30.000-30.000-30.000-12.807 -6.406  0.000
Neon     -30.000-30.000-30.000-30.000-30.000-30.000 -3.386 -1.449 -0.016
Magnesium-30.000-30.000-30.000-30.000-30.000-30.000 -6.554 -2.458 -0.475 -0.180
Aluminum -30.000-30.000-30.000-30.000-30.000-30.000 -5.516 -1.416 -0.071 -0.948
Silicon  -30.000-30.000-30.000-30.000-30.000-30.000 -5.681 -1.629 -0.033 -1.303
Sulphur  -30.000-30.000-30.000-30.000-30.000-30.000 -9.206 -0.666 -0.105
Argon    -30.000-30.000-30.000-30.000-30.000-30.000-30.000-11.177 -5.913  0.000
Calcium  -30.000-30.000-30.000-30.000-30.000-30.000-30.000-30.000-30.000 -4.062 -1.734 -0.008
Iron     -30.000-30.000-30.000-30.000-30.000-30.000-30.000-30.000 -4.776 -0.661 -0.166 -1.006 -3.360
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          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen -13.975  0.000                          Log10 Mean Ionisation (over radius)
Helium   -24.267-11.578  0.000
Carbon   -30.000-30.000-18.434 -8.846  0.000
Nitrogen -30.000-30.000-30.000-16.487 -8.330  0.000
Oxygen   -30.000-30.000-30.000-30.000-12.896 -6.416  0.000
Neon     -30.000-30.000-30.000-30.000-30.000-30.000 -3.467 -1.458 -0.016
Magnesium-30.000-30.000-30.000-30.000-30.000 -6.697 -2.532 -0.481 -0.176
Aluminum -30.000-30.000-30.000-30.000-30.000 -5.653 -1.488 -0.077 -0.889
Silicon  -30.000-30.000-30.000-30.000-30.000 -5.788 -1.691 -0.034 -1.254
Sulphur  -30.000-30.000-30.000-30.000-30.000 -9.222 -0.674 -0.103
Argon    -30.000-30.000-30.000-30.000-30.000-30.000-11.268 -5.923  0.000
Calcium  -30.000-30.000-30.000-30.000-30.000-30.000-30.000-30.000 -4.212 -1.805 -0.007
Iron     -30.000-30.000-30.000-30.000-30.000-30.000-30.000 -4.934 -0.738 -0.158 -0.912 -3.175


                                          Normalised continuum
  0.25 0.839   0.27 0.839   0.30 0.839   0.33 0.839   0.36 0.839   0.39 0.839   0.43 0.839   0.47 0.839   0.51 0.839   0.56 0.839
  0.62 0.839   0.67 0.839   0.74 0.839   0.81 0.839   0.88 0.839   0.97 0.839   0.98 0.839   0.99 0.839   1.00 0.839

                                       Emergent continuum - phot/ryd/cm2 (r in)
  0.26 4.94E+16  0.60 8.49E+16     1.0 9.69E+16     1.8 7.58E+16     3.9 1.22E+16    7.51E+00 1.48E+14    1.73E+01 1.49E+08
  0.29 5.42E+16  0.67 8.92E+16     1.0 9.69E+16     2.0 6.63E+16     4.0 1.04E+16    8.46E+00 4.19E+13    1.95E+01 5.94E+06
  0.33 5.92E+16  0.76 9.28E+16     1.0 9.69E+16     2.3 5.56E+16     4.2 8.87E+15    9.53E+00 9.78E+12    2.20E+01 1.53E+05
  0.37 6.43E+16  0.86 9.54E+16     1.1 9.65E+16     2.5 4.45E+16     4.7 5.16E+15    1.07E+01 1.84E+12
  0.42 6.96E+16  0.97 9.68E+16     1.2 9.43E+16     2.9 3.37E+16     5.3 2.58E+15    1.21E+01 2.72E+11
  0.47 7.49E+16  0.99 9.69E+16     1.4 9.01E+16     3.2 2.40E+16     5.9 1.14E+15    1.36E+01 3.07E+10
  0.53 8.00E+16  0.99 9.69E+16     1.6 8.40E+16     3.6 1.59E+16     6.7 4.44E+14    1.54E+01 2.54E+09
```

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                                          CLOUDY 80.08

                ************************************91Aug03***************************************
                *                                                                                   *
                * title liner model                                                                 *
                * c a constant pressure (gas+radiation) model of a liner cloud                      *
                * c in the spirit of Ferland and Netzer 1983                                        *
                * table agn                                                                         *
                * metals 0.3                                                                        *
                * constant pressure                                                                 *
                * iterate ;must iterate to get radiation pressure correctly                         *
                * hden 6                                                                            *
                * stop column density 23                                                           *
                * ionization parameter -3                                                           *
                * print last                                                                        *
                * c liner.in                                                                        *
                * c cray                                                                            *
                *                                                                                   *
                *************************************************************************************


                                          Chemical composition
He:.098 C:1.09E-04 N:3.36E-05 O:2.55E-04 Ne:3.69E-05 Mg:1.14E-05 Al:8.9E-07 Si:1.07E-05 S:4.86E-06 A:1.1E-06 Ca:6.9E-07 Fe:1.40E-05

          546Cell Peak1.78E+00   Lo 1.00E-05=0.9101cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   3.2980   Average nu:3.038E+00   P( X-ray):   2.4693   P(BalC):   2.8023     Q(Balmer C):  13.7651
          Q(1.0-1.8):  13.1738   Q(1.8-4.0):  13.0661   Q(4.0-20):  12.5287   Q(20--):  10.7913     Ion pht flx:3.001E+13
          L(gam ray):   2.2078   Q(gam ray):   8.6227   L(Infred):   3.0163   Alf(ox):  -1.4120     Total lumin:   3.5633
          U(1.0----):1.001E-03   U(4.0----):1.147E-04   T(En-Den):6.338E+01   T(Comp):1.327E+07     nuJnu(912A):6.342E+02
          Occ(FarIR):5.638E-05   Occ(H n=6):2.126E-08   Occ(1Ryd):2.924E-14   Occ(4R):1.499E-16     Occ (Nu-hi):2.089E-44
          Tbr(FarIR):9.380E-05   Tbr(H n=6):9.439E-05   Tbr(1Ryd):4.619E-09   Tbr(4R):9.484E-11     Tbr (Nu-hi):2.306E-32

#####  1 Te:1.473E+04 Hden:1.000E+06 Ne:1.154E+06 R:1.000E+25 R-R0:8.769E+11 dR:1.754E+12 NTR:  3 Htot:4.613E-12 T912: 5.557E-02###
 -0.46 4686  0.24 5876  0.04 1909  1.95 1549  0.50 6584  0.02 5007  3.48 3727  0.01 6300  0.00 2798  0.93 1035  0.00
Hydrogen    5.034E-03 9.950E-01 H+0/Hden: 1.000E+00 1.601E-10 H-     H2 1.911E-11 6.657E-11 H2+  HeH+ 1.394E-10 H col den 1.754E+18
H 2SP 3-6   2.937E-10 4.733E-12 6.178E-15 5.944E-15 7.505E-15 9.719E-15 Texc(La); 5.405E+03 T(contn): 6.315E+01 T(diffs): 2.609E+02
Helium      2.510E-03 3.811E-01 6.164E-01 He I 2S3  1.439E-06 Comp H, C 2.387E-17 2.650E-20 Fill Fact 1.000E+00 Gam 1/tot 8.651E-01
He singlet  2.509E-03 1.107E-10 1.979E-16 2.598E-16 3.884E-16 5.551E-16 He triplt 1.439E-06 1.335E-13 5.363E-16 2.231E-15 3.266E-16
HeII        3.811E-01 4.136E-10 5.417E-16 8.101E-16 1.269E-15 1.912E-15 1.635E-14 1.721E-13 4.348E-11 PRAD/GAS; 1.392E-03
Pressure    NgasTgas; 3.262E+10 P(total): 4.510E-06 P( gas ): 4.504E-06 P(Radtn): 6.268E-09 Rad accel 2.967E-04 Force Mul 7.366E+03
Carbon      5.021E-04 1.348E-01 7.545E-01 1.078E-01 2.325E-03 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    3.334E-04 1.136E-01 7.478E-01 1.353E-01 2.884E-03 9.031E-05 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      4.783E-04 1.039E-01 8.033E-01 8.975E-02 2.536E-03 3.496E-05 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.601
Neon        7.740E-05 2.300E-02 8.259E-01 1.469E-01 4.140E-03 2.654E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 9.819E-04 1.066E-01 8.076E-01 8.304E-02 1.762E-03 6.852E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.532E-03 5.038E-01 3.487E-01 1.406E-01 5.116E-03 1.785E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 7.663E-05 1.128E-01 6.966E-01 1.753E-01 1.469E-02 5.160E-04 4.587E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 8.726E-06 1.202E-01 8.010E-01 7.541E-02 2.564E-03 7.892E-04 2.080E-05 8.329E-08 2.757E-10 0.000E+00 0.000E+00 0.000E+00
Argon     0 2.109E-04 1.086E-01 7.626E-01 1.226E-01 5.327E-03 7.016E-04 2.665E-05 1.155E-06 3.717E-08 7.257E-11 1.424E-13 0.000E+00
Calcium   0 9.275E-04 2.508E-02 7.380E-01 2.235E-01 1.078E-02 1.666E-03 6.119E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 8.552E-06 3.686E-03 1.690E-01 4.526E-01 2.623E-01 1.058E-01 6.552E-03 1.226E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00
#####170 Te:3.978E+03 Hden:7.430E+06 Ne:4.552E+04 R:1.000E+25 R-R0:3.958E+14 dR:7.521E+12 NTR:  2 Htot:1.639E-14 T912: 9.752E+03###
  1.15 4686  0.12 5876  0.16 1909  2.51 1549  0.31 6584  0.13 5007  4.52 3727  0.04 6300  0.34 2798  3.46 1035  0.00
Hydrogen    9.946E-01 5.435E-03 H+0/Hden: 9.997E-01 5.210E-09 H-     H2 1.451E-04 5.566E-08 H2+  HeH+ 8.030E-09 H col den 1.698E+21
H 2SP 3-6   4.275E-10 7.585E-10 2.926E-16 3.947E-16 6.127E-16 9.225E-16 Texc(La); 4.332E+03 T(contn): 5.518E+01 T(diffs): 1.796E+02
Helium      9.946E-01 5.435E-03 4.141E-06 He I 2S3  1.145E-07 Comp H, C 9.657E-19 1.611E-22 Fill Fact 1.000E+00 Gam 1/tot 1.085E-01
He singlet  9.946E-01 1.953E-12 3.586E-19 4.789E-19 7.447E-19 1.114E-18 He triplt 1.145E-07 1.813E-15 2.510E-19 3.674E-18 4.973E-19
HeII        5.435E-03 9.339E-16 2.750E-22 4.393E-22 7.256E-22 1.150E-21 1.094E-20 1.433E-19 4.516E-17 PRAD/GAS; 1.030E-04
Pressure    NgasTgas; 3.297E+10 P(total): 4.552E-06 P( gas ): 4.552E-06 P(Radtn): 4.744E-10 Rad accel 1.640E-07 Force Mul 1.330E+03
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Carbon      8.020E-04 9.989E-01 2.845E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.918E-01 8.225E-03 5.574E-07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.953E-01 4.655E-03 7.190E-07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.268
Neon        8.467E-01 1.427E-01 1.062E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 2.753E-03 9.939E-01 3.355E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.941E-04 9.876E-01 9.062E-03 2.872E-03 2.463E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 4.660E-04 9.995E-01 9.809E-07 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.673E-04 9.890E-01 1.081E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 8.342E-01 1.649E-01 8.430E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 1.913E-03 2.126E-01 7.855E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 7.991E-03 9.920E-01 7.791E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest Te reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached   6.9 percent of the total rate out.
  Photoionization of He 2TriS reached  14.3 percent of the total rate out.
  Frequency out of range of free-free gaunt factor routine.
  The optical depth to Rayleigh scattering at 1300A is 1.04E-02
```

```
**********************************> CLOUDY 80.08  <**********************************
* title liner model                                                                   *
* c a constant pressure (gas+radiation) model of a liner cloud                        *
* c in the spirit of Ferland and Netzer 1983                                          *
* table agn                                                                           *
* metals 0.3                                                                          *
* constant pressure                                                                   *
* iterate ;must iterate to get radiation pressure correctly                           *
* hden 6                                                                              *
* stop column density 23                                                              *
* ionization parameter -3                                                             *
* print last                                                                          *
* c liner.in                                                                          *
* c cray                                                                              *
**********************************> LOG(U): -3.00 <**********************************
```

Emission Line Spectrum. Constant Pressure Model.   Open geometry. Iteration 2 of 2.
Intensity (erg/s/cm^2)

TOTL 4861	1.145	1.0000	He2p 910	-1.649	0.0016	N 3 990	-1.268	0.0039	Si 2 2335	0.428	0.1918
TOTL 1216	2.880	54.3167	He I 504	1.011	0.7340	N 4 1486	-0.645	0.0162	Si 2 1808	-0.499	0.0227
TotH 0	2.854	51.1067	He I 4471	-0.232	0.0419	N 4 765	-2.707	0.0001	Si 3 1207	0.105	0.0911
BFH1 0	2.702	35.9808	TOTL 5876	0.341	0.1570	N 5 1240	-2.278	0.0004	Si 3 1895	1.067	0.8343
BFHe 0	2.301	14.2984	Ca B 5876	0.205	0.1148	O 1 6300	0.674	0.3380	PHOT 1895	-1.568	0.0019
TotM 0	1.050	0.8031	TOTL10830	1.494	2.2338	O 1 6363	0.197	0.1127	Si 4 1397	0.122	0.0947
ComH 0	-2.459	0.0002	INWD10830	1.411	1.8446	O 1 5577	-0.969	0.0077	S 2 6720	-0.327	0.0337
H- H 0	-0.617	0.0173	TOTL 3889	0.105	0.0911	O 1 630	-0.445	0.0257	S 2 4074	0.575	0.2686
CA B 4861	1.131	0.9683	TOTL 7065	0.118	0.0939	O 1 1470	-2.006	0.0007	S 210330	0.391	0.1758
CA B 1216	2.675	33.8848	CcHE 0	1.480	2.1590	O 1 7774	-2.329	0.0003	S II 6731	-0.485	0.0234
DU B 4861	1.131	0.9682	He I 2	-0.410	0.0278	T OI 0	-1.302	0.0036	S II 6716	-0.842	0.0103
Q(H) 4861	1.154	1.0198	DevB 2	-1.199	0.0045	6lev 1304	-1.306	0.0035	S II 4070	0.469	0.2108
Q(H) 1216	2.688	34.8654	He I 5016	-0.456	0.0250	TOTL 3727	-0.239	0.0412	S II 4078	-0.093	0.0578
TOTL 6563	1.624	3.0122	DevB 5016	-0.814	0.0110	TOTL 7325	0.952	0.6407	S II10323	-0.034	0.0662
TOTL 4861	1.145	1.0000	He I 3965	-0.745	0.0129	IONZ 7325	-1.617	0.0017	S II10289	-0.163	0.0492
TOTL 4340	0.845	0.5009	DevB 3965	-1.317	0.0034	O II 3729	-0.881	0.0094	S II10373	-0.563	0.0196
TOTL 4102	0.613	0.2935	He I 3614	-1.029	0.0067	O II 3726	-0.353	0.0317	S II10339	-0.243	0.0409
TOTL18751	0.596	0.2825	DevB 3614	-1.452	0.0025	O II 2471	0.853	0.5097	S II 1256	-2.068	0.0006
TOTL12818	0.317	0.1485	He I 3448	-1.248	0.0040	O II 7323	0.696	0.3551	S 3 18	-1.126	0.0054
TOTL10938	0.091	0.0883	DevB 3448	-1.857	0.0010	O II 7332	0.601	0.2856	S 3 34	-2.193	0.0005
TOTL40512	-0.094	0.0576	HeII 228	1.303	1.4377	O II 834	-1.373	0.0030	S 3 9532	0.757	0.4091
TOTL26252	-0.293	0.0365	ESC 304	1.048	0.7996	O 2 4651	-1.780	0.0012	S 3 9069	0.342	0.1571
TOTL74578	-0.623	0.0171	He2C 911	0.493	0.2226	O 3 1663	0.783	0.4339	S 3 6312	0.066	0.0832
2 NU 0	0.833	0.4873	TOTL 1640	1.204	1.1444	Phot 1663	-2.479	0.0002	S 3 3722	-0.164	0.0491
TOTL 1216	2.880	54.3167	TOTL 4686	0.232	0.1221	Augr 1663	-2.323	0.0003	S 3 1198	-1.293	0.0036
TOTL 1026	-1.590	0.0018	TOTL 1216	0.790	0.4407	Rec 1663	-1.638	0.0016	S 3 1729	-0.608	0.0177
TOTL 973	-1.653	0.0016	Ca B 1640	1.236	1.2323	O 3 5007	1.801	4.5245	S 4 105	-1.500	0.0023
TOTL 950	-1.622	0.0017	DevB 1640	1.233	1.2239	O 3 4959	1.324	1.5082	S 4 1406	-1.381	0.0030
TOTL 938	-1.577	0.0019	Ca B 4686	0.377	0.1706	LOST 5007	-2.453	0.0003	Ar 2 7	-0.758	0.0125
LA X 1216	0.949	0.6355	DevB 4686	0.370	0.1676	TOTL 4363	0.740	0.3934	Ar 3 7135	0.308	0.1453
C13c 6563	0.527	0.2406	Mion 0	-2.634	0.0002	Rec 4363	-2.702	0.0001	Ar 3 7751	-0.322	0.0341
C14c 4861	-0.533	0.0210	C 1 1656	-1.532	0.0021	O 3 2321	0.113	0.0928	Ar 3 22	-2.321	0.0003
CION 0	0.771	0.4225	REC 1656	-1.334	0.0033	C EX 4363	-2.483	0.0002	Ar 3 9	-0.705	0.0141
INWD 1216	2.879	54.0894	C I 9850	-2.017	0.0007	C EX 5592	-2.394	0.0003	Ar 4 4740	-1.159	0.0050
INWD 6563	1.355	1.6210	C 1 8727	-1.290	0.0037	O 3 880	-2.396	0.0003	Ar 4 7335	-1.404	0.0028
INWD 4861	0.851	0.5082	C 2 158	-2.473	0.0002	O 3 520	-1.382	0.0030	Ar 5 7007	-2.372	0.0003
INWD18751	0.295	0.1412	C 2 2326	1.086	0.8723	O 3 834	-0.866	0.0097	Ar 5 6435	-2.739	0.0001
Dest 1216	0.309	0.1458	INWD 2326	0.791	0.4422	O 4 26	-1.764	0.0012	Ca 2 3933	-0.637	0.0165
Dest 6563	-2.018	0.0007	C 2 1335	0.092	0.0884	O 4 1402	-0.798	0.0114	Ca 2 8579	-0.963	0.0078
Dest 4861	-2.741	0.0001	REC 1335	-0.264	0.0390	CONT 1401	-0.889	0.0092	Ca 2 7306	0.275	0.1349

```
    e sc18751 -2.500   0.0002      C  2 4267 -1.996   0.0007      O  4  789 -1.994   0.0007      Ca2K 3934 -0.837   0.0104
    nFnu 4860  1.594   2.8123      TOTL  977  0.317   0.1484      TOTL 1218 -2.285   0.0004      Ca2H 3969 -1.068   0.0061
    nFnu 1215  0.579   0.2711      C3 C  977  0.306   0.1449      O  5 1218 -2.364   0.0003      Ca2X 8498 -2.086   0.0006
    Inci 4861  2.459  20.5900      C3 R  977 -1.308   0.0035      Ne 2  128  0.187   0.1100      Ca2Y 8542 -1.174   0.0048
    Inci 1216  2.740  39.2935      TOTL 1909  1.545   2.5087      Ne 3  156  0.120   0.0943      Ca2Z 8662 -1.471   0.0024
    BA C    0  1.789   4.3964      INWD 1909  1.244   1.2547      Ne 3  361 -1.415   0.0028      CaF1 7291  0.051   0.0804
    PA C    0  1.264   1.3142      C  3 1907  0.267   0.1323      Ne 3 3869  1.224   1.1971      CaF2 7324 -0.118   0.0545
    H FF    0  1.466   2.0899      C  3 1909  1.521   2.3764      Ne 3 3968  0.710   0.3673      Ca 4   32 -1.198   0.0045
    H FB    0  1.570   2.6572      C3 R 1909 -1.469   0.0024      Ne 3 3343 -1.069   0.0061      Fe 2   48 -0.724   0.0135
    Cool 1216  2.383  17.3008      Phot 1909 -0.513   0.0220      Ne 3 1815 -0.929   0.0084      Fe 2    7  1.003   0.7210
    Crst  960 -0.036   0.0658      C  3 2297 -1.826   0.0011      Ne 4 2424 -0.859   0.0099      Emis    3  1.368   1.6687
    Cool 6563 -1.904   0.0009      C  4 1549  0.641   0.3132      Ne 4 4720 -1.336   0.0033      Cool    3  1.368   1.6699
    Crst 4861 -2.813   0.0001      INWD 1549  0.484   0.2180      Ne 4 1602 -0.720   0.0136      TOT     0  1.526   2.4034
    H2 l    2 -2.214   0.0004      DEST 1549 -2.736   0.0001      Ne 5 3426 -1.709   0.0014      FEIR    0  0.082   0.0865
    H-FB    0 -0.225   0.0426      N  1 5200 -1.624   0.0017      Ne 5 3346 -2.141   0.0005      Fe 3    0  0.713   0.3693
    H2+     0 -0.592   0.0183      N  1 1200 -2.401   0.0003      Ne 5  143 -2.806   0.0001      Fe 3 5270  0.033   0.0772
    HEH+    0 -1.548   0.0020      N  2 6584  0.253   0.1282      Mg 1 4571 -2.517   0.0002      Fe 3 4658  0.277   0.1354
    HeFF    0  0.663   0.3293      N  2 6548 -0.224   0.0427      Emis 2798  1.684   3.4589      Fe 3 1122 -1.086   0.0059
    HeFB    0  0.825   0.4783      N  2 5755 -0.046   0.0643      Cool 2798  1.684   3.4593      Fe 5 3892  0.002   0.0718
    MeFB    0 -1.980   0.0007      N  2 5680 -2.428   0.0003      Mg 4    4 -1.009   0.0070      Fe 6    0 -0.943   0.0082
    MeFF    0 -1.287   0.0037      N  2 2140  0.011   0.0734      Mg 5   56 -1.959   0.0008      Fe 6 5177 -1.394   0.0029
    ToFF    0  1.530   2.4230      N  2 1084 -1.213   0.0044      Mg 5 2751 -2.809   0.0001      Fe 7 6087 -2.293   0.0004
    HeIC  584 -2.775   0.0001      N  3 1750  0.372   0.1685      Al 3 1860 -0.202   0.0449      Totl    2 -2.388   0.0003
    esc   584  0.385   0.1738      N  3   57 -2.597   0.0002      Si 2   35 -0.864   0.0098      AugC    2 -2.388   0.0003
```

```
                          LINER MODEL
Cooling:  H FB    0:0.052  Cool 1216:0.337  O  3 5007:0.088  Emis 2798:0.067  Cool 2798:0.067
Heating:  BFH1    0:0.704  BFHe    0:0.280

IONIZE PARMET:  U(1-) -2.9996  U(4-): -3.9403  U(sp): -3.87  Q(ion):   10.540  L(ion):   2.639 Q(low): 15.31    P(low)  3.22
ENERGY BUDGET:  Heat:   2.854  Coolg:   2.856  Error:  0.6%  Compt H:  -2.459  WorkF:    3.106 F-F  H -3.856    PRADMX:8.19E-02
Column density  H12:1.698E+21  H II:1.488E+20  HI:1.549E+21  H-:    1.558E+13  H2:   6.477E+16 H2+:5.133E+13    He H+:2.594E+13
                OH: 0.000E+00  Heff:7.947E+20
<NH>:4.250E+06  <Tp>:1.25E+04  <TO3>:1.42E+04  Ne:1.094E+06  ti(snd):5.60E+08  NeN+dl:1.42E+26 <T(C3)>:1.38E+04 <E(C3)>:1.09E+06
He/Ha:1.26E-01  =   1.28*true  N/Oap:3.73E+00  =  28.36true  T(O3R):4.370E+04  L THIN:1.00E+30 <T(S2)>:5.23E+03 <E(S2)>:1.10E+05
T He+:1.18E+04  EHe+:9.04E+05  T(O+):1.06E+04  EO+:8.17E+05  iter/zn:   2.890  Te-low:3.98E+03 Te-high:1.51E+04  Hlu/zn:3.87E+00
  <a>:0.00E+00  erdeFe2.5E+20  Tcompt6.31E+02  Tthr1.46E+06  <Tden>: 5.75E+03  <dens>:9.79E-18 <Mol>:1.21E+00
Mean Jeans      l(cm)1.02E+18  M(sun)4.75E+03  smallest:     len(cm):8.44E+17  M(sun):2.73E+03 Alf(ox-tran):    -1.4353

Optical Depths: CONTN; COMP: 1.11E-04    H-: 6.07E-04 R(1300): 1.04E-02 H2+ 3.59E-04  HeTri:7.66E-04
 Pfa:1.11E-04   Pa:1.11E-04   Ba:6.66E-04   Hb:5.43E-04  La:2.56E-01   1r:9.752E+03  1.8:3.01E+03  4.:4.760E+02  21R:4.919E+00
10830: 1.13E+02  3889: 4.80E+00  5876: 3.08E-04  7065: 1.70E-04
 1550: 5.52E+01  2800: 3.57E+04   774: 1.00E-20  1240: 2.18E-01  1035: 1.00E-02  1335: 3.30E+04   977: 2.60E+03  1397: 6.62E+01
  789: 1.51E+01  1207: 7.72E+02  1085: 1.72E+02  1194: 4.02E+00  1909: 1.04E-03  1895: 2.07E-02  2326: 1.65E-02  1666: 6.86E-03
 1750: 3.18E-05  1025: 5.09E+03   352: 1.00E-20   347: 1.00E-20  1860: 6.50E+01   630: 2.06E+00   834: 2.81E+03   835: 3.33E+02
 1808: 3.08E+04  1256: 4.70E+02    -3: 1.64E+03   -48: 2.61E-04  3934: 7.13E+02  3969: 3.59E+02  8498: 1.90E-02  8542: 1.70E-01
 8662: 9.68E-02   353: 1.00E-20  1304: 1.74E+04  1122: 3.55E+01   990: 1.40E+02  1402: 2.01E-04  1214: 1.11E-05  1486: 6.06E-05
 2335: 7.34E-02  1406: 6.23E-04  1656: 3.91E+01  9830: 6.52E-09  8727: 1.22E-07  6300: 4.62E-05  5577: 1.33E-06  7291: 4.78E-05
 7324: 3.31E-05  1039: 2.48E+03 -8446: 4.88E-09 -4368: 1.85E-11  -132: 7.28E-13  -113: 7.27E-12   -29: 1.67E-11   -46: 1.09E-11
 -245: 1.00E-20   765: 3.69E+01 -1198: 3.16E-05   786: 9.40E-02
 C157: 1.69E-03  N122: 3.48E-05  N205: 4.25E-05   N57: 1.72E-05  O146: 4.20E-03   O63: 1.63E-02   O88: 8.05E-05   O52: 1.64E-04
  O26: 1.12E-05  NE13: 1.09E-02  NE36:-1.84E-04  NE16: 1.73E-03   MG4: 2.57E-05  MG14:-6.96E-08   MG6: 5.45E-07  SI35: 1.34E-03
  S19: 7.66E-05   S34: 2.34E-05   S11: 2.54E-06   AR7: 5.35E-04   AR9: 4.46E-05  AR22:-2.55E-06  AR13: 8.43E-08   AR8: 1.57E-07
  CA3: 5.71E-06  CA12:-2.77E-08   CA4: 2.31E-07  Ne14: 2.68E-07  Ne24: 6.53E-08   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.72E-11 Si6.5:-2.32E-13  C610: 1.06E-06  C370: 8.52E-08

Old hydro optical depths:    1 1.06E+04    2 3.19E-04    3 6.27E-04    4 1.77E-04    5 9.66E-11    6 2.22E-10    7 9.84E-10
                    Lines:  2-1 1.43E+08  3-2 7.73E-02  4-3 1.45E-07  5-4 9.19E-08  6-5 7.33E-09  7-6 9.97E-07  8-7 1.31E-05
New hydro optical depths:    1 9.75E+03    2 3.09E-04    3 6.08E-04    4 1.72E-04    5 9.76E-11    6 2.24E-10    7 9.93E-10
                    Lines:  2-1 1.30E+08  3-2 5.78E-02  4-3 1.88E-07  5-4 1.06E-07  6-5 1.46E-08  7-6 1.02E-06  8-7 1.34E-05

Old He Is optical depths:    1 3.28E+03    2 6.66E-04    3-1.18E-14    4-4.92E-14    5-1.02E-13    6-1.82E-13    7-2.06E-12
                    Lines:  2-1 8.90E+06  3-2 4.39E-03  4-3 5.34E-09  5-4 3.41E-09  6-5 1.96E-09  7-6 3.70E-08  8-7 4.82E-07
New HE Is optical depths:    1 3.01E+03    2 6.26E-04    3-1.22E-14    4-5.07E-14    5-1.05E-13    6-1.87E-13    7-2.13E-12
                    Lines:  2-1 8.06E+06  3-2 4.07E-03  4-3 5.47E-09  5-4 3.50E-09  6-5 2.01E-09  7-6 3.81E-08  8-7 4.95E-07

Old He II optical depths:    1 5.20E+02    2 1.06E+04    3-1.80E-14    4-4.69E-14    5-9.17E-14    6-1.59E-13    7-1.71E-12
                    Lines:  2-1 4.30E+05  3-2 3.32E-04  4-3 2.30E-10  5-4-1.34E-11  6-5-9.22E-10  7-6 3.65E-09  8-7 5.16E-08
New HE II optical depths:    1 4.76E+02    2 9.75E+03    3-1.76E-14    4-4.61E-14    5-9.00E-14    6-1.56E-13    7-1.67E-12
                    Lines:  2-1 3.90E+05  3-2 3.05E-04  4-3 2.27E-10  5-4-1.43E-11  6-5-9.15E-10  7-6 3.61E-09  8-7 5.10E-08

Hydrogen  -0.040 -1.057                        Log10 Mean Ionisation (over volume)
Helium    -0.044 -1.083 -1.867
Carbon    -2.840 -0.026 -1.268 -2.516 -4.360
Nitrogen  -0.068 -1.009 -1.358 -2.433 -4.258 -5.673
Oxygen    -0.039 -1.422 -1.330 -2.819 -4.428 -6.340
Neon      -0.183 -0.628 -0.979 -2.500 -4.101 -6.376
Magnesium -2.541 -0.032 -1.181 -2.645 -4.370 -5.792
Aluminum  -3.237 -0.023 -1.414 -1.938 -3.544 -5.189
Silicon   -3.380 -0.022 -1.402 -2.020 -3.237 -4.684 -8.324
Sulphur   -3.989 -0.038 -1.105 -2.383 -3.968 -4.388 -6.111-10.065-12.546
Argon     -0.163 -0.618 -1.183 -2.212 -3.794 -4.448 -6.045 -8.924-10.416-13.125-15.833
Calcium   -2.313 -0.645 -0.118 -2.196 -3.732 -4.511 -6.035
Iron      -1.997 -0.035 -1.532 -1.517 -2.278 -2.804 -4.046 -5.780
```

```
          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.040 -1.057                          Log10 Mean Ionisation (over radius)
Helium    -0.044 -1.083 -1.867
Carbon    -2.840 -0.026 -1.268 -2.516 -4.360
Nitrogen  -0.068 -1.009 -1.358 -2.433 -4.258 -5.673
Oxygen    -0.039 -1.422 -1.330 -2.819 -4.428 -6.340
Neon      -0.183 -0.628 -0.979 -2.500 -4.101 -6.376
Magnesium -2.541 -0.032 -1.181 -2.645 -4.370 -5.792
Aluminum  -3.237 -0.023 -1.414 -1.938 -3.544 -5.189
Silicon   -3.380 -0.022 -1.402 -2.020 -3.237 -4.684 -8.324
Sulphur   -3.989 -0.038 -1.105 -2.383 -3.968 -4.388 -6.111-10.065-12.546
Argon     -0.163 -0.618 -1.183 -2.212 -3.794 -4.448 -6.045 -8.924-10.416-13.125-15.833
Calcium   -2.313 -0.645 -0.118 -2.196 -3.732 -4.511 -6.035
Iron      -1.997 -0.035 -1.532 -1.517 -2.278 -2.804 -4.046 -5.780

0.5-1.0KEV:9.02E+09 1.0-1.5:5.49E+09 1.5-2.0:3.06E+09 2.0-2.5:2.05E+09 2.5-3:1.62E+09 3-5:3.21E+09 5-7.5:1.88E+09 7.5-10:1.11E+09


                                          Normalised continuum
  0.25 1.332   0.27 1.277   0.30 1.216   0.33 1.165   0.36 1.129   0.39 1.094   0.43 1.068   0.47 1.069   0.51 1.048   0.56 1.033
  0.62 1.022   0.67 1.013   0.74 0.925   0.81 0.997   0.88 0.992   0.97 0.992   0.98 0.992   0.99 0.992   1.00 0.992


Inward continua (nuFnu) at head of Balmer, Lyman series;  1.04E+02  2.59E+02


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  1.04E+02  0.00E+00

                                       Emergent continuum - phot/ryd/cm2 (r in)
  0.26 2.94E+14  1.00 0.00E+00     3.9 1.74-200    17.3 1.97E+06    75.3 1.86E+08    1.26E+03 1.81E+06    3.24E+05 3.70E+00
  0.29 2.29E+14  1.01 8.58E-14     4.0 2.72-183    19.5 1.51E+07    81.6 1.68E+08    1.88E+03 9.24E+05    4.81E+05 1.28E+00
  0.33 1.81E+14  1.02 6.28E-14     4.2 1.39-168    22.0 4.67E+07    88.3 1.50E+08    2.79E+03 4.71E+05    7.16E+05 4.46E-01
  0.37 1.45E+14  1.10 2.27E-15     4.7 1.86-131    24.8 1.03E+08    95.7 1.34E+08    4.14E+03 2.40E+05    1.06E+06 1.55E-01
  0.42 1.16E+14  1.24 8.09E-18     5.3 1.30E-97    27.9 1.68E+08   103.7 1.19E+08    6.16E+03 1.22E+05    1.58E+06 5.37E-02
  0.47 9.66E+13  1.40 1.42E-20     5.9 1.41E-68    31.5 2.44E+08   112.3 1.05E+08    9.15E+03 5.05E+04    2.35E+06 1.86E-02
  0.53 7.87E+13  1.57 2.06E+06     6.7 3.31E+03    35.5 3.06E+08   121.6 9.26E+07    1.36E+04 1.75E+04    3.49E+06 6.47E-03
  0.60 6.46E+13  1.78 3.10E-27     7.5 6.42E-31    40.0 2.69E+08   131.7 8.15E+07    2.02E+04 6.09E+03    5.19E+06 2.25E-03
  0.67 5.33E+13  2.00 7.01E+04     8.5 3.17E+03    45.0 2.85E+08   142.7 7.15E+07    3.00E+04 2.11E+03
  0.76 3.88E+13  2.25 1.29E+07     9.5 6.34E-11    50.5 2.80E+08   173.9 5.18E+07    4.46E+04 7.34E+02
  0.86 3.66E+13  2.54 0.00E+00    10.7 6.05E-05    54.7 2.60E+08   258.5 2.67E+07    6.64E+04 2.55E+02
  0.97 3.05E+13  2.86 0.00E+00    12.1 9.95E-01    59.3 2.45E+08   384.3 1.36E+07    9.86E+04 8.84E+01
  0.99 2.95E+13  3.22 3.44-294    13.6 8.57E+02    64.2 2.23E+08   571.2 6.96E+06    1.47E+05 3.07E+01
  0.99 2.91E+13  3.63 1.93E-21    15.4 8.65E+04    69.5 2.05E+08   849.0 3.55E+06    2.18E+05 1.07E+01
```

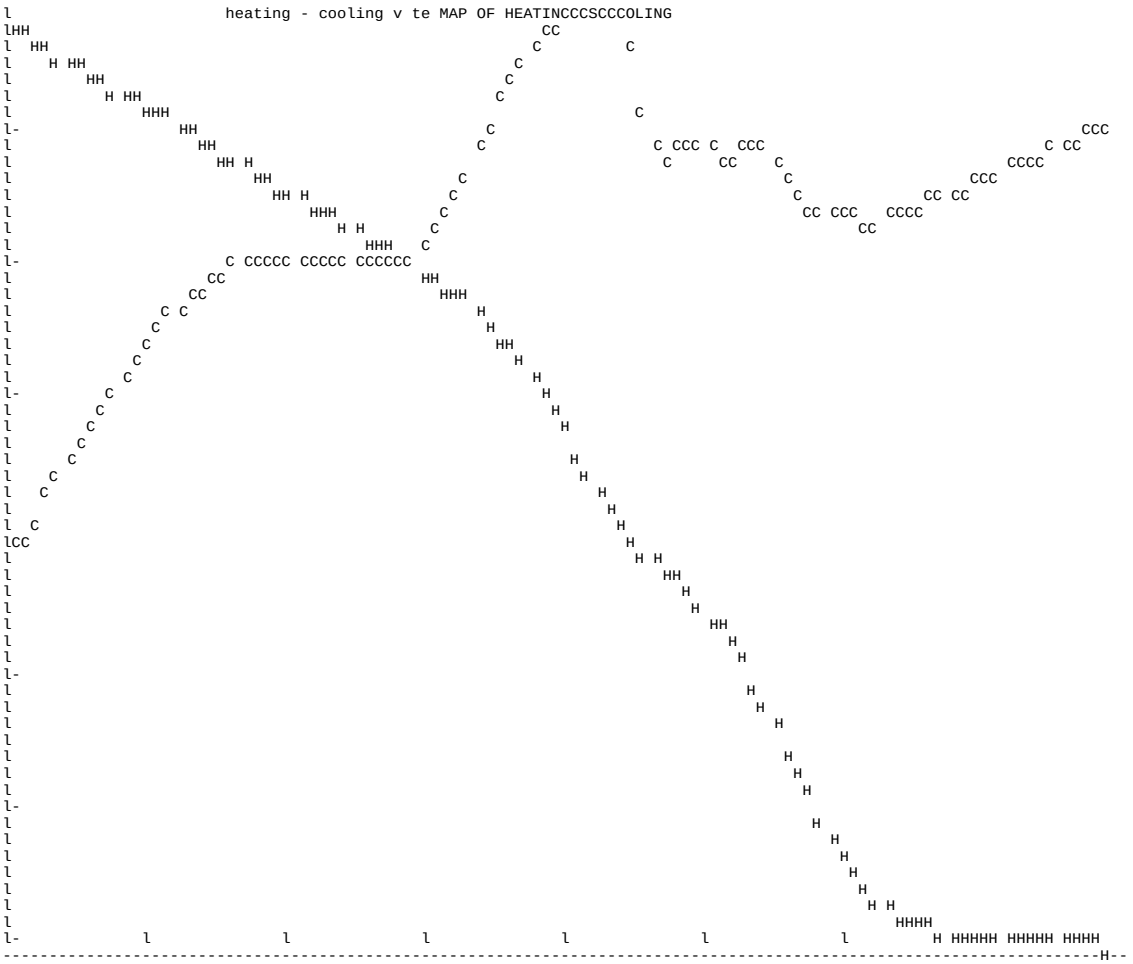
```
                                        CLOUDY 80.08

                    ************************************91Aug03*************************************
                    *                                                                              *
                    * title map of heating vs cooling                                              *
                    * hden 0                                                                       *
                    * table agn                                                                    *
                    * ionization parameter -2.5                                                    *
                    * c change plot to punch to generate plot for hazy                             *
                    * plot map                                                                     *
                    * stop zone 1                                                                  *
                    * print short                                                                  *
                    * c map.in                                                                     *
                    * c cray                                                                       *
                    *                                                                              *
                    ********************************************************************************


                                          Chemical composition
He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

          546Cell Peak1.78E+00   Lo 1.00E-05=0.9101cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  -2.2020   Average nu:3.038E+00   P( X-ray):  -3.0307   P(BalC):  -2.6977     Q(Balmer C):   8.2651
          Q(1.0-1.8):   7.6738   Q(1.8-4.0):   7.5661   Q(4.0-20):   7.0287   Q(20--):   5.2913     Ion pht flx:9.489E+07
          L(gam ray):  -3.2922   Q(gam ray):   3.1227   L(Infred):  -2.4837   Alf(ox):  -1.4120     Total lumin:  -1.9367
          U(1.0----):3.165E-03   U(4.0----):3.628E-04   T(En-Den):2.673E+00   T(Comp):1.327E+07     nuJnu(912A):2.006E-03
          Occ(FarIR):1.783E-10   Occ(H n=6):6.724E-14   Occ(1Ryd):9.248E-20   Occ(4R):4.741E-22     Occ (Nu-hi):6.607E-50
          Tbr(FarIR):2.966E-10   Tbr(H n=6):2.985E-10   Tbr(1Ryd):1.461E-14   Tbr(4R):2.999E-16     Tbr (Nu-hi):7.291E-38

#####  1 Te:7.535E+03 Hden:1.000E+00 Ne:1.173E+00 R:1.000E+25 R-R0:1.362E+18 dR:2.723E+18 NTR:  2 Htot:8.617E-24 T912: 4.640E-02###
 -6.05 4686  0.31 5876  0.02 1909  0.04 1549  0.01 6584  0.03 5007  2.65 3727  0.08 6300  0.00 2798  0.03 1035  0.00
Hydrogen    2.707E-03 9.973E-01 H+0/Hden: 1.000E+00 7.847E-11 H-     H2 7.958E-12 4.252E-11 H2+  HeH+ 3.629E-11 H col den 2.723E+18
H 2SP 3-6   2.415E-14 1.789E-18 8.022E-21 9.639E-21 1.289E-20 1.721E-20 Texc(La); 3.281E+03 T(contn): 2.663E+00 T(diffs): 2.612E+02
Helium      8.385E-04 2.410E-01 7.582E-01 He I 2S3  6.676E-10 Comp H, C 7.689E-29 4.367E-32 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  8.385E-04 8.130E-16 2.155E-22 2.979E-22 4.440E-22 6.323E-22 He triplt 6.676E-10 5.510E-21 1.210E-22 9.188E-22 2.867E-22
HeII        2.410E-01 4.108E-15 1.108E-21 1.694E-21 2.711E-21 4.167E-21 3.664E-20 3.914E-19 7.837E-17 PRAD/GAS; 2.279E-04
Pressure    NgasTgas; 1.636E+04 P(total): 2.259E-12 P( gas ): 2.259E-12 P(Radtn): 5.148E-16 Rad accel 5.702E-10 Force Mul 4.463E+03
Carbon      8.033E-05 5.753E-02 6.333E-01 2.906E-01 1.846E-02 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    4.139E-05 2.384E-02 5.596E-01 3.884E-01 2.721E-02 9.220E-04 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      4.556E-05 2.461E-02 5.896E-01 3.626E-01 2.240E-02 6.692E-04 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.377
Neon        1.391E-05 8.911E-03 6.151E-01 3.441E-01 3.152E-02 3.427E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.623E-04 3.168E-02 6.174E-01 3.194E-01 2.916E-02 2.177E-03 2.773E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.240E-04 9.459E-02 5.161E-01 3.513E-01 3.541E-02 2.435E-03 3.698E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 4.593E-05 9.329E-02 4.935E-01 3.502E-01 5.874E-02 4.085E-03 7.227E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 3.645E-06 4.143E-02 7.184E-01 2.169E-01 1.707E-02 5.880E-03 2.783E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 2.664E-05 3.564E-02 5.505E-01 3.553E-01 5.303E-02 4.991E-03 4.770E-04 2.020E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 2.040E-02 1.275E-01 4.135E-01 3.636E-01 5.967E-02 1.429E-02 9.481E-04 3.556E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 2.831E-04 2.203E-02 2.347E-01 3.841E-01 3.181E-01 3.946E-02 1.334E-03 1.243E-05 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because NZONE reached.
  Geometry is plane-parallel.
  Frequency out of range of free-free gaunt factor routine.
  OI negative level populations   3 times.
 !Incident radiation field < 10*Habing diffuse ISM field.  Is this OK?
C-The Lyman continuum is thin, and I assumed that it was thick.  Try another iteration.
C-The HeII continuum is thin and I assumed that it was thick.  Try another iteration.
C-The HeI continuum is thin and I assumed that it was thick.  Try another iteration.
```




```
**********************************> CLOUDY 80.08  <**********************************
* title map of heating vs cooling                                                     *
* hden 0                                                                              *
* table agn                                                                           *
* ionization parameter -2.5                                                           *
* c change plot to punch to generate plot for hazy                                    *
* plot map                                                                            *
* stop zone 1                                                                         *
* print short                                                                         *
* c map.in                                                                            *
* c cray                                                                              *
**********************************> LOG(U): -2.50 <**********************************
>>>>>>>>>> Cautions are present.
>>>>>>>>>> Another iteration is suggested.

          Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                                        Intensity (erg/s/cm^2)

TOTL 4861 -6.046   1.0000      HeFB    0 -6.458   0.3871      N  2 6548 -7.990   0.0114      PHOT 1895 -8.533   0.0033
TOTL 1216 -4.459  38.5697      HeFF    0 -8.314   0.0054      N  2  122 -8.414   0.0043      Si 6   19 -8.984   0.0012
TotH    0 -4.630  26.0688      ToFF    0 -6.196   0.7075      N  2  203 -8.265   0.0060      S  2 6720 -7.184   0.0728
BFH1    0 -4.962  12.1214      esc   584 -6.923   0.1327      N  3 1750 -8.901   0.0014      S  2 4074 -8.707   0.0022
BFHe    0 -4.953  12.3919      He2p  910 -8.012   0.0108      N  3   57 -6.630   0.2604      S  210330 -8.881   0.0015
TotM    0 -5.854   1.5552      He I  504 -6.554   0.3105      TOTL 3727 -7.158   0.0773      S II 6731 -7.575   0.0295
CA B 4861 -6.293   0.5656      He I 4471 -8.228   0.0066      O II 3729 -7.380   0.0463      S II 6716 -7.410   0.0432
CA B 1216 -4.767  19.0184      TOTL 5876 -7.737   0.0204      O II 3726 -7.558   0.0307      S II 4070 -8.830   0.0016
DU B 4861 -6.293   0.5656      Ca B 5876 -7.761   0.0192      O  2 4651 -8.743   0.0020      S  3   18 -6.425   0.4174
Q(H) 4861 -4.346  50.0773      TOTL10830 -7.559   0.0307      O  3 1663 -8.611   0.0027      S  3   34 -6.130   0.8241
Q(H) 1216 -2.8121712.1424      TOTL 3889 -7.924   0.0132      Rec  1663 -7.430   0.0412      S  3 9532 -6.183   0.7293
TOTL 6563 -5.537   3.2289      TOTL 7065 -8.596   0.0028      O  3 5007 -5.622   2.6516      S  3 9069 -6.599   0.2800
TOTL 4861 -6.046   1.0000      He I    2 -8.427   0.0042      O  3 4959 -6.099   0.8839      S  3 6312 -8.167   0.0076
TOTL 4340 -6.392   0.4501      He I 5016 -8.486   0.0036      TOTL 4363 -8.294   0.0057      S  3 3722 -8.396   0.0045
TOTL 4102 -6.657   0.2445      DevB 5016 -8.935   0.0013      Rec  4363 -8.306   0.0055      S  4  105 -6.251   0.6235
TOTL18751 -6.603   0.2769      He I 3965 -8.782   0.0018      O  3 2321 -8.921   0.0013      Ar 2    7 -8.847   0.0016
TOTL12818 -6.923   0.1326      HeII  228 -5.099   8.8416      C EX 4363 -8.746   0.0020      Ar 3 7135 -7.274   0.0592
TOTL10938 -7.181   0.0733      ESC   304 -6.916   0.1347      C EX 5592 -8.675   0.0023      Ar 3 7751 -7.903   0.0139
TOTL40512 -7.334   0.0515      He2C  911 -5.971   1.1873      O  3  880 -5.553   3.1098      Ar 3   22 -8.340   0.0051
TOTL26252 -7.565   0.0303      TOTL 1640 -5.596   2.8134      O  3  520 -5.807   1.7319      Ar 3    9 -7.207   0.0690
TOTL74578 -7.894   0.0142      TOTL 4686 -6.559   0.3068      O  3 3341 -8.688   0.0023      Ar 4 4740 -7.618   0.0267
2 NU    0 -5.055   9.7971      TOTL 1216 -6.001   1.1077      O  4   26 -5.084   9.1662      Ar 5 7007 -8.494   0.0036
TOTL 1216 -4.459  38.5697      Ca B 1640 -5.532   3.2625      CONT 1401 -7.431   0.0412      Ar 5 6435 -8.861   0.0015
TOTL 1026 -7.430   0.0413      DevB 1640 -5.535   3.2444      Ne 2  128 -8.363   0.0048      Ar 5  131 -8.387   0.0046
TOTL  973 -7.444   0.0400      Ca B 4686 -6.328   0.5218      Ne 3  156 -6.108   0.8667      Ar 5   79 -8.473   0.0037
TOTL  950 -7.408   0.0434      DevB 4686 -6.335   0.5132      Ne 3  361 -7.173   0.0745      Ca 2 3933 -7.572   0.0298
TOTL  938 -7.339   0.0509      C  2  158 -6.991   0.1135      Ne 3 3869 -6.842   0.1599      Ca 2 7306 -6.879   0.1469
INWD 1216 -4.459  38.5697      C  2 2326 -8.165   0.0076      Ne 3 3968 -7.355   0.0490      Ca2K 3934 -7.755   0.0195
Dest 1216 -8.919   0.0013      REC  1335 -7.131   0.0822      Ne 4 2424 -7.949   0.0125      Ca2H 3969 -8.036   0.0102
e sc 6563 -8.921   0.0013      C  2 4267 -8.971   0.0012      Ne 5 3426 -8.413   0.0043      CaF1 7291 -7.104   0.0875
e sc 4861 -8.570   0.0030      TOTL  977 -7.309   0.0546      Ne 5 3346 -8.845   0.0016      CaF2 7324 -7.272   0.0595
e sc18751 -6.603   0.2771      C3 R  977 -7.309   0.0546      Ne 5  242 -6.696   0.2238      Ca 4   32 -7.620   0.0266
e sc40512 -7.333   0.0516      TOTL 1909 -7.488   0.0361      Ne 5  143 -6.780   0.1842      Ca 5    4 -8.604   0.0028
nFnu 4860 -5.626   2.6311      C  3 1907 -7.707   0.0218      Emis 2798 -7.645   0.0251      Fe 3    0 -8.273   0.0059
nFnu 1215 -7.802   0.0175      C  3 1909 -7.891   0.0143      Cool 2798 -7.645   0.0251      Fe 3 5270 -8.953   0.0012
Inci 4861 -3.0411011.1165      C3 R 1909 -7.471   0.0376      Mg 4    4 -7.001   0.1108      Fe 3 4658 -8.709   0.0022
Inci 1216 -2.7601929.5989      Phot 1909 -7.595   0.0283      Mg 5   13 -7.863   0.0152      Fe 5 3892 -7.211   0.0683
BA C    0 -5.700   2.2145      C  3 2297 -7.816   0.0170      Mg 5   56 -7.071   0.0944      Fe 6    0 -7.523   0.0333
PA C    0 -6.202   0.6973      C  3 4649 -8.988   0.0011      Al 3 1860 -9.040   0.0010      Fe 6 5177 -7.974   0.0118
H FF    0 -6.320   0.5312      C  4 1549 -8.116   0.0085      Si 2   35 -6.799   0.1765      Fe 7 6087 -8.401   0.0044
H FB    0 -5.984   1.1515      C4 r 1549 -8.555   0.0031      Si 2 2335 -8.696   0.0022
```

```
HeFF    0 -6.813   0.1709      N  2 6584 -7.513   0.0341      Si 3 1895 -7.891   0.0143
```

```
                              MAP OF HEATING VS COOLING
Cooling:  O  3 5007:0.103  O  3  880:0.120  O  3  520:0.067  O  4   26:0.354
Heating:  BFH1    0:0.465  BFHe    0:0.475  TotM    0:0.060

IONIZE PARMET:  U(1-) -2.4996  U(4-): -3.4403  U(sp): -2.50  Q(ion):    7.965  L(ion):  -2.213 Q(low):  9.81    P(low) -2.28
ENERGY BUDGET:  Heat:  -4.630  Coolg:  -4.633  Error:  0.8%  Compt H:  -9.679  WorkF:   -4.065 F-F  H-11.088    PRADMX:1.84E+03
Column density  H12:2.723E+18  H II:2.716E+18  HI:7.372E+15  H-:    2.137E+08  H2:   2.167E+07 H2+:1.158E+08    He H+:9.882E+07
                OH: 0.000E+00  Heff:2.147E+18
<NH>:1.000E+00  <Tp>:7.53E+03  <TO3>:7.53E+03  Ne:1.173E+00  ti(snd):2.78E+12  NeN+dl:3.19E+18 <T(C3)>:7.53E+03 <E(C3)>:1.17E+00
He/Ha:3.90E-02  =   0.40*true  N/Oap:1.26E-01  =   0.96true  T(O3R):9.114E+03  L THIN:1.00E+30 <T(S2)>:7.53E+03 <E(S2)>:1.17E+00
T He+:7.53E+03  EHe+:1.17E+00  T(O+):7.53E+03  EO+:1.17E+00  iter/zn:   3.000  Te-low:7.53E+03 Te-high:7.53E+03  Hlu/zn:1.07E+02
  <a>:0.00E+00  erdeFe7.8E+25  Tcompt1.96E+14  Tthr4.01E+11  <Tden>: 7.53E+03  <dens>:2.36E-24 <Mol>:6.24E-01
Mean Jeans      l(cm)4.51E+21  M(sun)5.70E+07  smallest:     len(cm):4.48E+21  M(sun):5.57E+07 Alf(ox-tran):    -1.4125
```

CLOUDY 80.08

```
*************************************91Aug03*************************************
*                                                                              *
* title "conventional" BLR model                                               *
* constant pressure                                                            *
* ionization parameter -2                                                      *
* stop column density 23                                                       *
* table agn                                                                    *
* print last iteration                                                         *
* iterate                                                                      *
* hden 9.5                                                                     *
* c oldblr.in                                                                  *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

Chemical composition

He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

```
          546Cell Peak1.78E+00   Lo 1.00E-05=0.9101cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   7.7980   Average nu:3.038E+00   P( X-ray):   6.9693   P(BalC):   7.3023     Q(Balmer C):  18.2651
          Q(1.0-1.8):  17.6738   Q(1.8-4.0):  17.5661   Q(4.0-20):  17.0287   Q(20--):  15.2913     Ion pht flx:9.489E+17
          L(gam ray):   6.7078   Q(gam ray):  13.1227   L(Infred):   7.5163   Alf(ox):  -1.4120     Total lumin:   8.0633
          U(1.0----):1.001E-02   U(4.0----):1.147E-03   T(En-Den):8.451E+02   T(Comp):1.327E+07     nuJnu(912A):2.006E+07
          Occ(FarIR):1.783E+00   Occ(H n=6):6.724E-04   Occ(1Ryd):9.248E-10   Occ(4R):4.741E-12      Occ (Nu-hi):6.607E-40
          Tbr(FarIR):2.966E+00   Tbr(H n=6):2.985E+00   Tbr(1Ryd):1.461E-04   Tbr(4R):2.999E-06      Tbr (Nu-hi):7.291E-28

#####  1 Te:1.628E+04 Hden:3.162E+09 Ne:3.774E+09 R:1.000E+25 R-R0:9.508E+07 dR:1.902E+08 NTR:  1 Htot:6.556E-05 T912: 1.832E-03###
  2.45 4686  0.64 5876  0.01 1909  2.21 1549 23.38 6584  0.00 2326  0.03 3727  0.00 6300  0.00 2798  0.18 1035  0.05
Hydrogen    4.841E-04 9.995E-01 H+0/Hden: 1.000E+00 2.949E-14 H-     H2 3.760E-13 5.683E-12 H2+  HeH+ 1.050E-12 H col den 6.013E+17
H 2SP 3-6   2.924E-10 3.682E-10 2.653E-11 2.732E-11 3.395E-11 3.633E-11 Texc(La); 7.789E+03 T(contn): 8.450E+02 T(diffs): 4.018E+03
Helium      4.528E-05 7.000E-02 9.300E-01 He I 2S3  2.279E-07 Comp H, C 2.470E-09 3.030E-12 Fill Fact 1.000E+00 Gam 1/tot 9.514E-01
He singlet  4.505E-05 1.870E-11 1.208E-13 1.706E-13 2.524E-13 3.657E-13 He triplt 2.278E-07 7.915E-11 5.879E-13 1.446E-12 3.583E-13
HeII        7.000E-02 1.218E-09 3.301E-12 5.034E-12 8.119E-12 1.265E-11 1.183E-10 1.874E-09 2.380E-07 PRAD/GAS; 1.996E-02
Pressure    NgasTgas; 1.177E+14 P(total): 1.657E-02 P( gas ): 1.625E-02 P(Radtn): 3.243E-04 Rad accel 1.476E+00 Force Mul 1.136E+03
Carbon      1.698E-06 4.552E-03 2.221E-01 6.379E-01 1.353E-01 2.143E-04 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    6.630E-07 2.126E-03 2.095E-01 5.899E-01 1.807E-01 1.784E-02 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      3.923E-07 1.578E-03 1.877E-01 6.264E-01 1.715E-01 1.231E-02 4.154E-04 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.644
Neon        2.833E-07 6.272E-04 1.483E-01 5.411E-01 2.942E-01 1.575E-02 5.592E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 9.135E-06 3.303E-03 2.197E-01 5.249E-01 1.964E-01 5.337E-02 2.286E-03 2.727E-05 3.303E-07 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.948E-05 2.377E-02 2.518E-01 5.081E-01 1.700E-01 4.371E-02 2.453E-03 3.020E-05 2.068E-07 1.381E-09 0.000E+00 0.000E+00
Silicon   0 1.686E-06 4.711E-03 2.085E-01 4.915E-01 2.342E-01 5.744E-02 3.485E-03 6.466E-05 5.369E-07 3.461E-09 1.843E-11 0.000E+00
Sulphur   1 6.431E-03 3.833E-01 4.166E-01 1.149E-01 6.978E-02 8.877E-03 1.638E-04 1.740E-06 1.142E-08 6.375E-11 2.705E-13 1.005E-15
Argon     3 4.654E-01 2.905E-01 3.789E-02 9.496E-03 6.604E-04 8.181E-05 5.594E-07 2.698E-09 1.002E-11 2.960E-14 9.430E-17 2.219E-19
Calcium   0 7.216E-05 1.133E-02 1.287E-01 3.767E-01 2.435E-01 1.954E-01 4.114E-02 3.106E-03 1.487E-04 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 1.995E-06 8.073E-04 3.162E-02 1.686E-01 5.227E-01 2.458E-01 2.989E-02 5.619E-04 2.197E-05 0.000E+00 0.000E+00
#####193 Te:5.422E+03 Hden:2.216E+10 Ne:1.204E+08 R:1.000E+25 R-R0:5.066E+12 dR:4.638E+11 NTR:  4 Htot:9.555E-08 T912: 6.162E+05###
  5.52 4686  0.17 5876  0.20 1909  7.15 1549 18.68 6584  0.00 2326  0.47 3727  0.00 6300  0.06 2798  5.75 1035  0.01
Hydrogen    9.953E-01 4.736E-03 H+0/Hden: 1.000E+00 1.242E-09 H-     H2 1.578E-06 3.949E-09 H2+  HeH+ 1.937E-09 H col den 1.001E+23
H 2SP 3-6   1.271E-06 3.812E-06 4.933E-09 8.040E-11 8.671E-12 5.348E-12 Texc(La); 6.251E+03 T(contn): 7.171E+02 T(diffs): 3.848E+02
Helium      9.982E-01 1.767E-03 0.000E+00 He I 2S3  1.123E-08 Comp H, C 7.634E-11 1.684E-14 Fill Fact 1.000E+00 Gam 1/tot 3.072E-02
He singlet  9.982E-01 4.959E-13 2.960E-16 3.811E-16 5.923E-16 8.958E-16 He triplt 1.122E-08 3.031E-12 1.024E-14 3.443E-15 2.880E-14
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 1.499E-03
Pressure    NgasTgas; 1.330E+14 P(total): 1.839E-02 P( gas ): 1.836E-02 P(Radtn): 3.057E-05 Rad accel 6.239E-04 Force Mul 1.999E+02
Carbon      9.397E-05 9.999E-01 6.084E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.014E-01 9.865E-02 1.164E-08 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.959E-01 4.131E-03 2.471E-08 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.384
```

```
Neon        9.913E-01 7.636E-03 1.099E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 3.815E-04 9.817E-01 1.789E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.953E-05 9.964E-01 2.860E-03 7.054E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 4.400E-05 1.000E+00 5.422E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.601E-05 9.974E-01 2.612E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 9.745E-01 2.542E-02 4.806E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 2.814E-05 2.819E-02 9.718E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 7.983E-04 9.992E-01 3.662E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because column dens reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached  22.5 percent of the total rate out.
  Photoionization of He 2TriS reached  58.1 percent of the total rate out.
 !The largest continuum occupation number was 1.783E+00 at 1.054E-05 Ryd.
  Hydrogen self ionization by alpha transitions reached    0.1% of the destruction rate for level 3.
  Some fine struc lines are optically thick, largest=2.21E+00
  Continuum occupation number reached  1.50E+02 for some fine structure transitions.
  Stimulated emission was   6.7% of the total for H transition 7 - 6
  Timescale-photoerosion of Fe=2.58E+08yr
  Sum of gas+line rad pressure ranged from  1.65E-02 to   1.87E-02 in a constant pressure model.
  Frequency out of range of free-free gaunt factor routine.
  Balmer continuum optical depth is  6.98E-02
  Continuum optical depth at low nu ( 1.054E-05 Ryd) was  2.115E+02
  The optical depth to Rayleigh scattering at 1300A is 6.57E-01
  Line radiation pressure capped by thermalization length.
```

```
*********************************> CLOUDY 80.08  <*********************************
* title "conventional" BLR model                                                   *
* constant pressure                                                                *
* ionization parameter -2                                                          *
* stop column density 23                                                           *
* table agn                                                                        *
* print last iteration                                                             *
* iterate                                                                          *
* hden 9.5                                                                         *
* c oldblr.in                                                                      *
* c cray                                                                           *
*********************************> LOG(U): -2.00 <*********************************

                Emission Line Spectrum.  Constant  Pressure Model.    Open geometry.  Iteration 2 of 2.
                                          Intensity (erg/s/cm^2)
```

TOTL 4861	5.519	1.0000	HEH+ 0	2.945	0.0027	N 2 2140	4.164	0.0441	PHOT 1895	3.353	0.0068
TOTL 1216	7.203	48.3003	HeFF 0	5.175	0.4528	N 2 1084	3.144	0.0042	Si 4 1397	5.893	2.3639
TotH 0	7.346	67.0768	HeFB 0	5.311	0.6187	N 3 1750	5.401	0.7613	Si 6 19	2.649	0.0013
BFH1 0	7.150	42.7253	MeFB 0	3.311	0.0062	N 3 990	3.948	0.0268	S 1R 1807	2.284	0.0006
BFHx 0	5.237	0.5221	MeFF 0	4.010	0.0310	N 4 1486	5.360	0.6926	S 2 6720	2.149	0.0004
BFHe 0	6.750	17.0097	ToFF 0	6.083	3.6582	N 4 765	3.504	0.0097	S 2 4074	3.658	0.0138
TotM 0	6.319	6.3014	esc 584	4.823	0.2014	N 4 1718	2.700	0.0015	S 210330	3.458	0.0087
FF H 0	3.057	0.0035	He I 504	5.531	1.0267	N 5 1240	4.568	0.1118	S II 6731	1.991	0.0003
ComH 0	3.203	0.0048	He I 4471	4.231	0.0515	O 1 6300	4.265	0.0556	S II 6716	1.634	0.0001
H- H 0	4.825	0.2021	TOTL 5876	4.824	0.2017	O 1 6363	3.788	0.0185	S II 4070	3.577	0.0114
CA B 4861	5.637	1.3105	Ca B 5876	4.664	0.1395	O 1 5577	3.785	0.0184	S II 4078	2.886	0.0023
CA B 1216	7.184	46.2181	TOTL10830	5.675	1.4297	O 1 630	1.687	0.0001	S II10323	3.074	0.0036
DU B 4861	5.637	1.3104	INWD10830	5.575	1.1356	O 1 7774	2.144	0.0004	S II10289	2.945	0.0027
Q(H) 4861	5.654	1.3630	TOTL 3889	4.203	0.0483	6lev 8446	3.949	0.0269	S II10373	2.416	0.0008
Q(H) 1216	7.188	46.6025	TOTL 7065	4.693	0.1493	6lev 1304	5.328	0.6434	S II10339	2.736	0.0016
TOTL 6563	6.293	5.9365	CcHE 0	5.659	1.3799	6lev 11	4.386	0.0735	S II 1256	2.360	0.0007
TOTL 4861	5.519	1.0000	He I 2	4.062	0.0349	TOTL 7325	2.679	0.0014	S 3 9532	2.457	0.0009
TOTL 4340	5.117	0.3956	DevB 2	3.274	0.0057	O II 2471	2.592	0.0012	S 3 9069	2.041	0.0003
TOTL 4102	4.817	0.1983	He I 5016	4.019	0.0316	O II 7323	2.432	0.0008	S 3 6312	2.793	0.0019
TOTL18751	5.399	0.7582	DevB 5016	3.661	0.0138	O II 7332	2.317	0.0006	S 3 3722	2.564	0.0011
TOTL12818	4.997	0.3005	He I 3965	3.731	0.0163	O II 834	3.119	0.0040	S 3 1198	3.806	0.0194
TOTL10938	4.645	0.1336	DevB 3965	3.160	0.0044	O 2 4651	3.380	0.0072	S 3 1729	4.146	0.0423
TOTL40512	4.674	0.1429	He I 3614	3.448	0.0085	O 3 1663	6.023	3.1856	S 4 1406	4.639	0.1316
TOTL26252	4.441	0.0836	DevB 3614	3.024	0.0032	Augr 1663	2.958	0.0027	S 5 1198	3.339	0.0066
TOTL74578	4.106	0.0386	He I 3448	3.229	0.0051	Rec 1663	4.133	0.0411	S 5 786	1.784	0.0002
2 NU 0	5.210	0.4899	DevB 3448	2.621	0.0013	O 3 5007	3.786	0.0185	S 6 933	3.002	0.0030
TOTL 1216	7.203	48.3003	HeII 228	5.722	1.5947	O 3 4959	3.309	0.0062	Ar 2 7	1.826	0.0002
TOTL 1026	4.571	0.1125	ESC 304	5.218	0.4997	LOST 5007	3.495	0.0095	Ar 3 7135	2.473	0.0009
TOTL 973	3.737	0.0165	He2C 911	5.060	0.3474	TOTL 4363	4.140	0.0418	Ar 3 7751	1.843	0.0002
TOTL 950	3.594	0.0119	TOTL 1640	5.714	1.5652	O 3 2321	3.513	0.0099	Ar 4 7335	2.476	0.0009
TOTL 938	3.472	0.0090	TOTL 4686	4.751	0.1703	C EX 5592	2.417	0.0008	Ar 5 7007	1.601	0.0001
LA X 1216	5.219	0.5009	TOTL 1216	5.295	0.5962	O 3 834	4.525	0.1013	Ca 2 3933	3.975	0.0285
Ind2 1216	1.609	0.0001	Ca B 1640	5.527	1.0185	O 3 3341	2.715	0.0016	Ca 2 8579	4.115	0.0394
C13c 6563	4.579	0.1146	DevB 1640	5.526	1.0153	O 4 1402	5.220	0.5023	Ca 2 7306	3.280	0.0058
C14c 4861	3.524	0.0101	Ca B 4686	4.656	0.1371	CONT 1401	4.343	0.0667	Phot 7306	2.400	0.0008
CION 0	5.491	0.9359	DevB 4686	4.651	0.1354	O 4 789	4.254	0.0542	Ca2K 3934	3.715	0.0157
INWD 1216	7.203	48.2772	C 1 1656	1.930	0.0003	O 4 3412	2.735	0.0016	Ca2H 3969	3.629	0.0129
INWD 6563	6.274	5.6798	REC 1656	4.173	0.0450	O 5 630	2.661	0.0014	Ca2X 8498	3.695	0.0150
INWD 4861	5.513	0.9849	C 2 2326	5.187	0.4656	TOTL 1218	4.601	0.1208	Ca2Y 8542	3.609	0.0123
INWD18751	5.353	0.6809	INWD 2326	5.082	0.3655	O 5 1218	4.601	0.1208	Ca2Z 8662	3.601	0.0121
Strk 1216	3.718	0.0158	C 2 1335	4.698	0.1507	O 6 1035	3.533	0.0103	CaF1 7291	3.047	0.0034
Strk 6563	4.908	0.2445	REC 1335	4.639	0.1318	Ne 2 128	2.096	0.0004	CaF2 7324	2.898	0.0024
Strk 4861	3.851	0.0215	C 2 4267	2.931	0.0026	Ne 3 156	1.746	0.0002	Rec 3933	2.316	0.0006

Strk18751	3.668	0.0141	TOTL 977	5.557	1.0903	Ne 3 3869	3.816	0.0198	Ca 4 32	1.876	0.0002
Strk40512	2.749	0.0017	C3 C 977	5.490	0.9348	Ne 3 3968	3.303	0.0061	Ca 5 5311	1.882	0.0002
Dest 1216	5.544	1.0593	C3 R 977	4.711	0.1555	Ne 3 3343	3.093	0.0037	Ca 5 2414	1.605	0.0001
Dest 6563	4.121	0.0399	TOTL 1909	6.374	7.1474	Ne 3 1815	3.233	0.0052	Fe 2 48	5.534	1.0348
Dest 4861	2.634	0.0013	INWD 1909	6.073	3.5804	Ne 4 4720	2.497	0.0009	Fe 2 7	4.883	0.2311
nFnu 4860	6.143	4.1985	C 3 1907	2.427	0.0008	Ne 4 1602	3.113	0.0039	Emis 3	5.692	1.4872
nFnu 1215	5.217	0.4987	C 3 1909	6.374	7.1465	Ne 5 3426	2.778	0.0018	Cool 3	5.699	1.5113
Inci 4861	6.959	27.5214	C3 R 1909	4.304	0.0609	Ne 5 3346	2.345	0.0007	TOT 0	5.960	2.7582
Inci 1216	7.240	52.5214	Phot 1909	4.147	0.0424	Ne 5 2976	1.717	0.0002	FEIR 0	2.467	0.0009
BA C 0	6.255	5.4434	C 3 2297	4.194	0.0473	Ne 5 1575	2.193	0.0005	Fe 3 0	3.072	0.0036
PA C 0	5.775	1.8029	C 3 4187	2.336	0.0007	Ne 5 1134	3.342	0.0066	Fe 3 5270	2.392	0.0007
H FF 0	6.021	3.1744	C 3 4649	3.138	0.0042	Ne 6 1007	1.665	0.0001	Fe 3 4658	2.636	0.0013
H FB 0	6.090	3.7173	C 4 1549	6.791	18.6806	Emis 2798	6.279	5.7519	Fe 3 1122	3.485	0.0092
Cool 1216	6.323	6.3662	INWD 1549	6.559	10.9493	Cool 2798	6.293	5.9340	Fe 5 3892	2.345	0.0007
Heat 1216	4.976	0.2863	DEST 1549	4.311	0.0619	Mg 4 4	2.229	0.0005	Fe 6 0	3.027	0.0032
Crst 960	4.033	0.0327	C4 r 1549	3.266	0.0056	Mg 5 56	1.874	0.0002	Fe 6 5177	2.576	0.0011
Cool 6563	5.546	1.0640	C 4 4659	1.654	0.0001	Mg 5 2751	2.680	0.0014	Fe 7 6087	2.288	0.0006
Crst 4861	4.655	0.1367	N 2 6584	2.418	0.0008	Al 3 1860	5.123	0.4013	Totl 2	4.349	0.0676
Cool18751	4.220	0.0502	N 2 6548	1.941	0.0003	Si 2 2335	4.866	0.2219	AugC 2	4.349	0.0676
Crst 0	3.373	0.0071	N 2 5755	2.629	0.0013	Si 2 1808	3.965	0.0279			
H-FB 0	4.805	0.1928	N 2 4239	2.077	0.0004	Si 3 1207	5.096	0.3773			
H2+ 0	4.453	0.0858	N 2 5680	2.585	0.0012	Si 3 1895	5.987	2.9357			

Lines with negative intensities; 205 T OI   0

"CONVENTIONAL" BLR MODEL
Cooling: H FB   0:0.055 Cool 1216:0.095 TOTL 1909:0.107 C 4 1549:0.278 Emis 2798:0.086 Cool 2798:0.088
Heating: BFH1   0:0.637 BFHe   0:0.254 TotM   0:0.094

IONIZE PARMET: U(1-) -1.9996 U(4-): -2.9403 U(sp): -2.85 Q(ion):   14.360 L(ion):   7.036 Q(low): 19.81   P(low) 7.69
ENERGY BUDGET: Heat: 7.346 Coolg: 7.346 Error: 0.0% Compt H: 3.203 WorkF: 9.805 F-F H 3.057   PRADMX:4.67E-01
Column density H12:1.001E+23 H II:2.211E+21 HI:9.791E+22 H-:   1.531E+14 H2:   1.113E+17 H2+:4.485E+14   He H+:2.544E+14
                OH: 0.000E+00 Heff:1.066E+23
<NH>:1.890E+10 <Tp>:1.21E+04 <TO3>:1.49E+04 Ne:3.110E+09 ti(snd):8.13E+06 NeN+dl:4.89E+30 <T(C3)>:1.47E+04 <E(C3)>:3.14E+09
He/Ha:1.62E-01 =   1.66*true N/Oap:0.00E+00 =   0.00true T(O3R):1.000E+01 L THIN:7.06E-02 <T(S2)>:5.79E+03 <E(S2)>:1.65E+08
T He+:1.33E+04 EHe+:2.69E+09 T(O+):6.70E+03 EO+:5.83E+08 iter/zn: 3.221 Te-low:5.42E+03 Te-high:1.70E+04 Hlu/zn:4.58E+00
  <a>:0.00E+00 erdeFe7.8E+15 Tcompt6.10E-06 Tthr3.59E+02 <Tden>: 5.92E+03 <dens>:4.42E-14 <Mol>:1.27E+00
Mean Jeans   l(cm)1.87E+16 M(sun)8.89E+01 smallest: len(cm):1.79E+16 M(sun):7.79E+01 Alf(ox-tran):   -2.2323

Optical Depths: CONTN; COMP: 1.64E-03   H-: 5.97E-03 R(1300): 6.57E-01 H2+ 3.14E-03 HeTri:3.42E-02
 Pfa:1.65E-03   Pa:1.64E-03   Ba:7.33E-03   Hb:6.07E-03 La:1.62E+01   1r:6.162E+05 1.8:1.92E+05 4.:2.953E+04 21R:3.331E+02
10830: 4.85E+02 3889: 2.12E+01 5876: 2.20E+01 7065: 1.21E+01
 1550: 2.05E+04 2800: 6.55E+06   774: 1.00E-20 1240: 2.26E+02 1035: 6.55E+01 1335: 6.34E+06   977: 7.70E+04 1397: 9.88E+03
  789: 2.87E+03 1207: 1.85E+04 1085: 7.06E+04 1194: 1.33E+02 1909: 3.07E-02 1895: 4.94E-01 2326: 3.17E+00 1666: 3.51E-01
 1750: 1.16E-03 1025: 9.94E+05   352: 1.40E-03   347: 1.00E-20 1860: 4.14E+03   630: 2.44E+03   834: 1.25E+05   835: 1.70E+04
 1808: 5.88E+06 1256: 9.21E+04   -3: 3.20E+05   -48: 2.49E+00 3934: 1.14E+04 3969: 5.76E+03 8498: 2.11E+01 8542: 1.80E+02
 8662: 1.07E+02   353: 1.00E-20 1304: 3.40E+06 1122: 3.09E+02   990: 5.12E+03 1402: 3.83E-02 1214: 1.32E-02 1486: 1.76E-02
 2335: 1.40E+01 1406: 1.63E-01 1656: 5.34E+02 9830: 8.89E-08 8727: 1.66E-06 6300: 9.02E-03 5577: 5.94E-03 7291: 8.80E-04
 7324: 6.09E-04 1039: 4.83E+05 -8446: 1.22E+02 -4368: 4.64E-01 -132: 1.82E-01 -113: 8.13E-01   -29: 4.18E-06   -46: 4.49E-03
 -245: 1.84E-04   765: 1.07E+04 -1198: 3.76E-02   786: 1.12E+02
 C157: 2.74E-01 N122: 1.50E-02 N205: 2.02E-02   N57: 5.09E-04 O146: 7.33E-01   O63: 2.21E+00   O88: 3.94E-03   O52: 6.64E-03
  O26: 1.50E-03 NE13: 4.56E-02 NE36: 3.89E-03 NE16: 1.25E-02   MG4: 5.37E-04 MG14: 8.84E-05   MG6: 5.22E-05 SI35: 1.87E-01
  S19: 1.43E-03   S34: 6.88E-04   S11: 3.99E-04   AR7: 4.88E-03   AR9: 2.06E-04 AR22: 6.12E-05 AR13: 7.74E-06   AR8: 1.48E-05
  CA3: 1.25E-04 CA12: 3.58E-06   CA4: 1.51E-05 Ne14: 1.74E-04 Ne24: 8.67E-05   Si3: 6.35E-12   Si4: 1.28E-10   Fe7: 1.00E-20
 Fe61: 1.00E-20 Fe23: 1.00E-20 Fe13: 1.00E-20 Si2.5: 2.05E-06 Si6.5: 6.09E-07 C610: 5.97E-06 C370: 4.07E-06

Old hydro optical depths: 1 6.16E+05   2 7.05E-02   3 6.26E-03   4 1.67E-03   5 5.03E-06   6 9.06E-06   7 4.02E-05
                    Lines: 2-1 7.61E+09 3-2 3.00E+03 4-3 3.86E+01 5-4 2.48E+00 6-5 2.57E-01 7-6 4.72E-02 8-7 5.54E-01
New hydro optical depths: 1 6.16E+05   2 6.98E-02   3 6.38E-03   4 1.71E-03   5 7.27E-06   6 1.07E-05   7 4.49E-05
                    Lines: 2-1 7.62E+09 3-2 2.98E+03 4-3 3.66E+01 5-4 3.29E+00 6-5 5.11E-01 7-6 7.03E-02 8-7 6.62E-01

Old He Is optical depths: 1 1.92E+05   2 3.10E-02   3-8.41E-11   4-8.99E-10   5-1.87E-09   6-3.07E-09   7-2.10E-08
                    Lines: 2-1 4.77E+08 3-2 2.80E-02 4-3 1.68E-04 5-4 6.16E-05 6-5-2.54E-04 7-6 1.22E-03 8-7 1.96E-02
New HE Is optical depths: 1 1.92E+05   2 3.08E-02   3-8.62E-11   4-9.70E-10   5-2.01E-09   6-3.31E-09   7-2.24E-08
                    Lines: 2-1 4.78E+08 3-2 2.95E-02 4-3 1.84E-04 5-4 6.68E-05 6-5-2.81E-04 7-6 1.33E-03 8-7 2.14E-02

Old He II optical depths: 1 2.95E+04   2 6.16E+05   3-2.90E-10   4-8.94E-10   5-1.73E-09   6-2.89E-09   7-2.75E-08
                    Lines: 2-1 3.63E+06 3-2 1.87E-01 4-3 1.11E-05 5-4-1.93E-06 6-5-4.39E-05 7-6 1.15E-04 8-7 1.79E-03
New HE II optical depths: 1 2.95E+04   2 6.16E+05   3-2.65E-10   4-8.92E-10   5-1.74E-09   6-2.90E-09   7-2.76E-08
                    Lines: 2-1 3.89E+06 3-2 3.07E-01 4-3 1.43E-05 5-4-1.07E-06 6-5-4.32E-05 7-6 1.15E-04 8-7 1.80E-03

Hydrogen -0.010 -1.656   Log10 Mean Ionisation (over volume)
Helium   -0.008 -1.812 -2.685
Carbon   -4.003 -0.006 -2.074 -2.231 -3.703 -6.525
Nitrogen -0.095 -0.740 -2.078 -2.253 -3.512 -4.423
Oxygen   -0.009 -2.155 -1.905 -2.813 -3.625 -4.798 -6.254
Neon   -0.025 -1.454 -1.733 -2.809 -3.252 -4.558 -6.994
Magnesium -3.396 -0.033 -1.155 -2.753 -3.373 -3.955 -5.297 -7.205-11.702
Aluminum -4.325 -0.009 -1.900 -2.111 -3.208 -3.869 -5.108 -7.010-11.906-14.081
Silicon   -4.351 -0.006 -2.306 -2.130 -2.822 -3.633 -4.873 -6.611-10.944-13.682-15.956
Sulphur   -4.607 -0.009 -1.882 -2.249 -3.172 -3.501 -4.473 -6.178-10.013-12.618-14.872-17.789-20.219
Argon   -0.029 -1.295 -2.125 -2.185 -3.220 -3.633 -4.633 -5.533 -6.691-10.514-12.829-15.677-18.208-21.247-23.875
Calcium   -4.528 -1.644 -0.012 -2.445 -3.318 -3.513 -4.257 -5.360 -6.677
Iron   -3.031 -0.007 -2.889 -1.947 -3.111 -2.963 -3.397 -4.331 -6.026 -7.447

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          1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17

Hydrogen -0.010 -1.656   Log10 Mean Ionisation (over radius)
Helium   -0.008 -1.812 -2.685
Carbon   -4.003 -0.006 -2.074 -2.231 -3.703 -6.525
Nitrogen -0.095 -0.740 -2.078 -2.253 -3.512 -4.423
Oxygen   -0.009 -2.155 -1.905 -2.813 -3.625 -4.798 -6.254
Neon   -0.025 -1.454 -1.733 -2.809 -3.252 -4.558 -6.994
Magnesium -3.396 -0.033 -1.155 -2.753 -3.373 -3.955 -5.297 -7.205-11.702
Aluminum -4.325 -0.009 -1.900 -2.111 -3.208 -3.869 -5.108 -7.010-11.906-14.081
Silicon   -4.351 -0.006 -2.306 -2.130 -2.822 -3.633 -4.873 -6.611-10.944-13.682-15.956
Sulphur   -4.607 -0.009 -1.882 -2.249 -3.172 -3.501 -4.473 -6.178-10.013-12.618-14.872-17.789-20.219
Argon   -0.029 -1.295 -2.125 -2.185 -3.220 -3.633 -4.633 -5.533 -6.691-10.514-12.829-15.677-18.208-21.247-23.875
Calcium   -4.528 -1.644 -0.012 -2.445 -3.318 -3.513 -4.257 -5.360 -6.677
Iron   -3.031 -0.007 -2.889 -1.947 -3.111 -2.963 -3.397 -4.331 -6.026 -7.447

0.5-1.0KEV:1.93E+02 1.0-1.5:2.52E+09 1.5-2.0:2.73E+11 2.0-2.5:2.04E+12 2.5-3:5.19E+12 3-5:3.53E+13 5-7.5:4.07E+13 7.5-10:2.54E+13

Normalised continuum
  0.25 1.241   0.27 1.207   0.30 1.167   0.33 1.131   0.36 1.102   0.39 1.075   0.43 1.053   0.47 1.051   0.51 1.029   0.56 1.007
  0.62 0.966   0.67 0.871   0.74 0.010   0.81 0.774   0.88 0.553   0.97 0.595   0.98 0.605   0.99 0.607   1.00 0.610

Inward continua (nuFnu) at head of Balmer, Lyman series; 3.23E+06 8.02E+06

Outwrd continua (nuFnu) at head of Balmer, Lyman series; 3.08E+06 0.00E+00

Emergent continuum - phot/ryd/cm2 (r in)
  0.26 8.70E+18 1.00 0.00E+00   3.9 0.00E+00   17.3 3.08-209   75.3 2.74E+03   1.26E+03 5.15E+10   3.24E+05 1.15E+05
  0.29 6.93E+18 1.01 0.00E+00   4.0 0.00E+00   19.5 1.34-141   81.6 1.43E+05   1.88E+03 2.68E+10   4.81E+05 4.01E+04
  0.33 5.55E+18 1.02 0.00E+00   4.2 0.00E+00   22.0 1.83-107   88.3 3.42E+06   2.79E+03 1.38E+10   7.16E+05 1.40E+04
  0.37 4.48E+18 1.10 0.00E+00   4.7 0.00E+00   24.8 7.60E-71   95.7 4.34E+07   4.14E+03 7.04E+09   1.06E+06 4.86E+03
  0.42 3.63E+18 1.24 0.00E+00   5.3 0.00E+00   27.9 2.69E-45   103.7 1.73E+08   6.16E+03 3.60E+09   1.58E+06 1.69E+03
  0.47 3.00E+18 1.40 0.00E+00   5.9 0.00E+00   31.5 1.59E-30   112.3 9.97E+08   9.15E+03 1.49E+09   2.35E+06 5.87E+02
  0.53 2.44E+18 1.57 3.37E+11   6.7 0.00E+00   35.5 1.99E-17   121.6 4.01E+09   1.36E+04 5.19E+08   3.49E+06 2.04E+02
  0.60 1.95E+18 1.78 0.00E+00   7.5 0.00E+00   40.0 2.44E-27   131.7 1.21E+10   2.02E+04 1.81E+08   5.19E+06 7.08E+01
  0.67 1.45E+18 2.00 6.58E+09   8.5 0.00E+00   45.0 3.81E-16   142.7 1.87E+10   3.00E+04 6.33E+07
  0.76 1.78E+15 2.25 2.37E+12   9.5 0.00E+00   50.5 1.93E-08   173.9 9.13E+10   4.46E+04 2.21E+07
  0.86 1.02E+18 2.54 0.00E+00   10.7 0.00E+00   54.7 7.05E-07   258.5 2.46E+11   6.64E+04 7.74E+06
  0.97 5.88E+17 2.86 0.00E+00   12.1 0.00E+00   59.3 3.07E-03   384.3 2.62E+11   9.86E+04 2.71E+06
  0.99 5.79E+17 3.22 0.00E+00   13.6 0.00E+00   64.2 4.28E-02   571.2 1.52E+11   1.47E+05 9.46E+05
  0.99 5.76E+17 3.63 0.00E+00   15.4 0.00E+00   69.5 1.98E+01   849.0 9.47E+10   2.18E+05 3.30E+05

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                                                    OPTIMIZATION  DRIVER
                                                        CLOUDY 80.08

                        ***************************************91Aug03*************************************
                        *                                                                                  *
                        * title test of optimization driver                                                *
                        * optimize iterations 30 ; increase limit to number of iterations                  *
                        * optimize luminostiy -1 ;want H-bet flux of .1 erg cm^-2 s^-1                     *
                        * optimize column density ;read in sets of desired column densities                *
                        * hydrogen 2  21.3                                                                 *
                        * end of column dens                                                               *
                        * optimize lines ; read in sets of desired relative line intensities               *
                        * O  3 5007 3.1415                                                                 *
                        * end of lines                                                                     *
                VARY>>> * hden 3 vary  ;vary the density, ionization parameter, and bb temp               *
                        * optimze increment 1                                                              *
                VARY>>> * black 5 vary                                                                     *
                        * optimize increment .5                                                            *
                VARY>>> * ionizat -2 vary                                                                  *
                        * optimize increment .5                                                            *
                        * c optim.in                                                                       *
                        * c cray                                                                           *
                        *                                                                                  *
                        ************************************************************************************


Up to   30 iterations will be performed,
and the final version of the input file will be written on Fortran I/O unit  7

  3 parameters will be varied.  The first lines, and the increments are:

HDEN=  3.00000
Initial increment is 1.000, the limits are -1.00E+37 to   1.00E+37

BLACKbody=  5.00000
Initial increment is 0.500, the limits are -1.00E+37 to   1.00E+37

IONIZATION PARAMETER= -2.00000
Initial increment is 0.500, the limits are -1.00E+37 to   1.00E+37
**************************************************
HDEN=  3.00000
BLACKbody=  5.00000
IONIZATION PARAMETER= -2.00000
 ID              Model    Observed       error      chi**2     Type
O  3  5007    13.93833     3.14150     0.05000    4.72E+03 Relative intensity
HYDR     2  8.8892E+20  1.9953E+21     0.05000   122.98053 Column density
TOTL  4861    -0.87555    -1.00000     0.05000    2.48E+01 Line intensity
Iteration   1 Chisq=  4.87E+03
**************************************************
HDEN=  4.00000
BLACKbody=  5.00000
IONIZATION PARAMETER= -2.00000
 ID              Model    Observed       error      chi**2     Type
O  3  5007    18.14175     3.14150     0.05000    9.12E+03 Relative intensity
HYDR     2  9.3809E+20  1.9953E+21     0.05000   112.29203 Column density
TOTL  4861     0.11618    -1.00000     0.05000    3.41E+02 Line intensity
Iteration   2 Chisq=  9.57E+03
**************************************************
HDEN=  3.00000
```

```
BLACKbody=  5.50000
IONIZATION PARAMETER= -2.00000
 ID              Model    Observed       error      chi**2     Type
O  3  5007    19.40824     3.14150     0.05000    1.07E+04 Relative intensity
HYDR     2  1.5823E+21  1.9953E+21     0.05000    17.13797 Column density
TOTL  4861    -0.84828    -1.00000     0.05000    3.48E+01 Line intensity
Iteration   3 Chisq=  1.08E+04
**************************************************
HDEN=  3.00000
BLACKbody=  5.00000
IONIZATION PARAMETER= -1.50000
 ID              Model    Observed       error      chi**2     Type
O  3  5007    15.80766     3.14150     0.05000    6.50E+03 Relative intensity
HYDR     2  2.8449E+21  1.9953E+21     0.05000    72.53675 Column density
TOTL  4861    -0.37613    -1.00000     0.05000    2.32E+02 Line intensity
Iteration   4 Chisq=  6.81E+03
**************************************************
HDEN=  3.66667
BLACKbody=  4.50000
IONIZATION PARAMETER= -1.66667
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.62268     3.14150     0.05000    6.55E+03 Relative intensity
HYDR     2  1.6313E+21  1.9953E+21     0.05000    13.31223 Column density
TOTL  4861     0.13413    -1.00000     0.05000    3.43E+02 Line intensity
Iteration   5 Chisq=  6.90E+03
**************************************************
HDEN=  2.44444
BLACKbody=  4.66667
IONIZATION PARAMETER= -1.44444
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.02937     3.14150     0.05000    1.20E+02 Relative intensity
HYDR     2  2.4727E+21  1.9953E+21     0.05000    22.89984 Column density
TOTL  4861    -0.82611    -1.00000     0.05000    4.35E+01 Line intensity
Iteration   6 Chisq=  1.87E+02
**************************************************
HDEN=  1.66667
BLACKbody=  4.50000
IONIZATION PARAMETER= -1.16667
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.00180     3.14150     0.05000    1.22E+09 Relative intensity
HYDR     2  6.4053E+17  1.9953E+21     0.05000   399.74322 Column density
TOTL  4861    -4.67149    -1.00000     0.05000    8.81E+09 Line intensity
Iteration   7 Chisq=  1.00E+10
**************************************************
HDEN=  1.96296
BLACKbody=  5.27778
IONIZATION PARAMETER= -1.62963
 ID              Model    Observed       error      chi**2     Type
O  3  5007    15.93528     3.14150     0.05000    6.63E+03 Relative intensity
HYDR     2  2.5225E+21  1.9953E+21     0.05000    27.93300 Column density
TOTL  4861    -1.57887    -1.00000     0.05000    3.12E+03 Line intensity
Iteration   8 Chisq=  9.78E+03
**************************************************
HDEN=  3.24074
BLACKbody=  4.69444
IONIZATION PARAMETER= -1.65741
 ID              Model    Observed       error      chi**2     Type
O  3  5007     4.82630     3.14150     0.05000    1.15E+02 Relative intensity
HYDR     2  1.6666E+21  1.9953E+21     0.05000    10.85559 Column density
TOTL  4861    -0.26470    -1.00000     0.05000    2.66E+02 Line intensity
```

```
Iteration   9 Chisq=  3.92E+02
************************************************
HDEN=  2.79012
BLACKbody=  4.57407
IONIZATION PARAMETER= -1.90123
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.95346     3.14150     0.05000    2.11E+03 Relative intensity
HYDR     2  9.3401E+20  1.9953E+21     0.05000   113.16092 Column density
TOTL  4861    -0.94653    -1.00000     0.05000    5.37E+00 Line intensity
Iteration  10 Chisq=  2.23E+03
************************************************
HDEN=  2.65021
BLACKbody=  4.29012
IONIZATION PARAMETER= -1.33539
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.00097     3.14150     0.05000    4.23E+09 Relative intensity
HYDR     2  2.9591E+21  1.9953E+21     0.05000    93.34197 Column density
TOTL  4861    -0.53810    -1.00000     0.05000    1.71E+02 Line intensity
Iteration  11 Chisq=  4.23E+09
************************************************
HDEN=  2.91255
BLACKbody=  4.82253
IONIZATION PARAMETER= -1.83385
 ID              Model    Observed       error      chi**2     Type
O  3  5007     7.36194     3.14150     0.05000    7.22E+02 Relative intensity
HYDR     2  1.1983E+21  1.9953E+21     0.05000    63.81360 Column density
TOTL  4861    -0.76589    -1.00000     0.05000    6.95E+01 Line intensity
Iteration  12 Chisq=  8.55E+02
************************************************
HDEN=  2.94170
BLACKbody=  4.88169
IONIZATION PARAMETER= -1.38923
 ID              Model    Observed       error      chi**2     Type
O  3  5007    11.07777     3.14150     0.05000    2.55E+03 Relative intensity
HYDR     2  3.3930E+21  1.9953E+21     0.05000   196.29044 Column density
TOTL  4861    -0.31400    -1.00000     0.05000    2.52E+02 Line intensity
Iteration  13 Chisq=  3.00E+03
************************************************
HDEN=  2.82802
BLACKbody=  4.65098
IONIZATION PARAMETER= -1.77323
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.35474     3.14150     0.05000    4.47E+01 Relative intensity
HYDR     2  1.2192E+21  1.9953E+21     0.05000    60.52031 Column density
TOTL  4861    -0.78182    -1.00000     0.05000    6.24E+01 Line intensity
Iteration  14 Chisq=  1.68E+02
************************************************
HDEN=  2.76292
BLACKbody=  4.51886
IONIZATION PARAMETER= -1.41621
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.36990     3.14150     0.05000    2.25E+04 Relative intensity
HYDR     2  2.7488E+21  1.9953E+21     0.05000    57.05494 Column density
TOTL  4861    -0.50413    -1.00000     0.05000    1.85E+02 Line intensity
Iteration  15 Chisq=  2.27E+04
************************************************
HDEN=  2.87514
BLACKbody=  4.74661
IONIZATION PARAMETER= -1.72944
 ID              Model    Observed       error      chi**2     Type
```

```
O  3  5007     4.98990     3.14150     0.05000    1.38E+02 Relative intensity
HYDR     2  1.4313E+21  1.9953E+21     0.05000    31.96007 Column density
TOTL  4861    -0.69381    -1.00000     0.05000    1.02E+02 Line intensity
Iteration  16 Chisq=  2.73E+02
************************************************
HDEN=  2.19100
BLACKbody=  4.68173
IONIZATION PARAMETER= -1.64067
 ID              Model    Observed       error      chi**2     Type
O  3  5007     1.72537     3.14150     0.05000    2.69E+02 Relative intensity
HYDR     2  1.5279E+21  1.9953E+21     0.05000    21.94485 Column density
TOTL  4861    -1.27547    -1.00000     0.05000    3.14E+02 Line intensity
Iteration  17 Chisq=  6.05E+02
************************************************
HDEN=  2.97830
BLACKbody=  4.69127
IONIZATION PARAMETER= -1.65322
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.90665     3.14150     0.05000    2.37E+01 Relative intensity
HYDR     2  1.6384E+21  1.9953E+21     0.05000    12.79641 Column density
TOTL  4861    -0.51797    -1.00000     0.05000    1.80E+02 Line intensity
Iteration  18 Chisq=  2.16E+02
************************************************
HDEN=  2.62537
BLACKbody=  4.59266
IONIZATION PARAMETER= -1.51783
 ID              Model    Observed       error      chi**2     Type
O  3  5007     0.98777     3.14150     0.05000    1.90E+03 Relative intensity
HYDR     2  2.1413E+21  1.9953E+21     0.05000     2.14345 Column density
TOTL  4861    -0.72513    -1.00000     0.05000    8.80E+01 Line intensity
Iteration  19 Chisq=  1.99E+03
************************************************
HDEN=  2.81270
BLACKbody=  4.70812
IONIZATION PARAMETER= -1.67654
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.78199     3.14150     0.05000    1.66E+01 Relative intensity
HYDR     2  1.5402E+21  1.9953E+21     0.05000    20.80618 Column density
TOTL  4861    -0.70500    -1.00000     0.05000    9.72E+01 Line intensity
Iteration  20 Chisq=  1.35E+02
************************************************
HDEN=  2.41180
BLACKbody=  4.65925
IONIZATION PARAMETER= -1.60959
 ID              Model    Observed       error      chi**2     Type
O  3  5007     1.71173     3.14150     0.05000    2.79E+02 Relative intensity
HYDR     2  1.6959E+21  1.9953E+21     0.05000     9.00657 Column density
TOTL  4861    -1.02186    -1.00000     0.05000    1.07E+00 Line intensity
Iteration  21 Chisq=  2.89E+02
************************************************
HDEN=  2.83668
BLACKbody=  4.68326
IONIZATION PARAMETER= -1.64231
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.28331     3.14150     0.05000    8.15E-01 Relative intensity
HYDR     2  1.6476E+21  1.9953E+21     0.05000    12.14774 Column density
TOTL  4861    -0.64540    -1.00000     0.05000    1.25E+02 Line intensity
Iteration  22 Chisq=  1.38E+02
************************************************
HDEN=  3.20715
```

```
BLACKbody=  4.69491
IONIZATION PARAMETER= -1.95028
 ID              Model    Observed       error      chi**2     Type
O  3  5007     4.24748     3.14150     0.05000    4.96E+01 Relative intensity
HYDR     2  8.6052E+20  1.9953E+21     0.05000   129.37612 Column density
TOTL  4861    -0.58697    -1.00000     0.05000    1.51E+02 Line intensity
Iteration  23 Chisq=  3.30E+02
************************************************
HDEN=  2.63512
BLACKbody=  4.67373
IONIZATION PARAMETER= -1.57090
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.51548     3.14150     0.05000    2.48E+01 Relative intensity
HYDR     2  1.9106E+21  1.9953E+21     0.05000     0.72024 Column density
TOTL  4861    -0.76372    -1.00000     0.05000    7.04E+01 Line intensity
Iteration  24 Chisq=  9.59E+01
************************************************
HDEN=  2.69498
BLACKbody=  4.72576
IONIZATION PARAMETER= -1.48660
 ID              Model    Observed       error      chi**2     Type
O  3  5007     4.12979     3.14150     0.05000    3.96E+01 Relative intensity
HYDR     2  2.4176E+21  1.9953E+21     0.05000    17.92258 Column density
TOTL  4861    -0.62602    -1.00000     0.05000    1.33E+02 Line intensity
Iteration  25 Chisq=  1.91E+02
************************************************
HDEN=  2.79476
BLACKbody=  4.66967
IONIZATION PARAMETER= -1.70158
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.72381     3.14150     0.05000    9.41E+00 Relative intensity
HYDR     2  1.4129E+21  1.9953E+21     0.05000    34.07983 Column density
TOTL  4861    -0.74746    -1.00000     0.05000    7.78E+01 Line intensity
Iteration  26 Chisq=  1.21E+02
************************************************
HDEN=  2.65837
BLACKbody=  4.68442
IONIZATION PARAMETER= -1.65703
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.75824     3.14150     0.05000    7.72E+00 Relative intensity
HYDR     2  1.5542E+21  1.9953E+21     0.05000    19.54576 Column density
TOTL  4861    -0.83596    -1.00000     0.05000    3.96E+01 Line intensity
Iteration  27 Chisq=  6.69E+01
************************************************
HDEN=  2.56922
BLACKbody=  4.68500
IONIZATION PARAMETER= -1.66439
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.51664     3.14150     0.05000    2.47E+01 Relative intensity
HYDR     2  1.5078E+21  1.9953E+21     0.05000    23.87486 Column density
TOTL  4861    -0.93138    -1.00000     0.05000    8.54E+00 Line intensity
Iteration  28 Chisq=  5.71E+01
************************************************
HDEN=  2.52004
BLACKbody=  4.64415
IONIZATION PARAMETER= -1.61471
 ID              Model    Observed       error      chi**2     Type
O  3  5007     1.62071     3.14150     0.05000    3.52E+02 Relative intensity
HYDR     2  1.6940E+21  1.9953E+21     0.05000     9.11687 Column density
TOTL  4861    -0.92144    -1.00000     0.05000    1.10E+01 Line intensity
```

```
Iteration  29 Chisq=  3.72E+02
************************************************
HDEN=  2.73953
BLACKbody=  4.69213
IONIZATION PARAMETER= -1.66108
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.18776     3.14150     0.05000    8.67E-02 Relative intensity
HYDR     2  1.5651E+21  1.9953E+21     0.05000    18.59250 Column density
TOTL  4861    -0.76067    -1.00000     0.05000    7.18E+01 Line intensity
Iteration  30 Chisq=  9.05E+01
************************************************
HDEN=  2.50116
BLACKbody=  4.69757
IONIZATION PARAMETER= -1.56267
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.72126     3.14150     0.05000    9.54E+00 Relative intensity
HYDR     2  1.9427E+21  1.9953E+21     0.05000     0.27746 Column density
TOTL  4861    -0.88813    -1.00000     0.05000    2.06E+01 Line intensity
Iteration  31 Chisq=  3.04E+01
************************************************
HDEN=  2.35436
BLACKbody=  4.71151
IONIZATION PARAMETER= -1.49322
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.78743     3.14150     0.05000    6.45E+00 Relative intensity
HYDR     2  2.2585E+21  1.9953E+21     0.05000     6.96386 Column density
TOTL  4861    -0.96615    -1.00000     0.05000    2.25E+00 Line intensity
Iteration  32 Chisq=  1.57E+01
************************************************
HDEN=  2.47362
BLACKbody=  4.71871
IONIZATION PARAMETER= -1.64155
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.07107     3.14150     0.05000    2.10E-01 Relative intensity
HYDR     2  1.6325E+21  1.9953E+21     0.05000    13.21916 Column density
TOTL  4861    -0.99880    -1.00000     0.05000    3.04E-03 Line intensity
Iteration  33 Chisq=  1.34E+01
************************************************
HDEN=  2.39287
BLACKbody=  4.74119
IONIZATION PARAMETER= -1.67688
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.38859     3.14150     0.05000    2.47E+00 Relative intensity
HYDR     2  1.5358E+21  1.9953E+21     0.05000    21.21164 Column density
TOTL  4861    -1.11195    -1.00000     0.05000    3.46E+01 Line intensity
Iteration  34 Chisq=  5.83E+01
************************************************
HDEN=  2.19193
BLACKbody=  4.71802
IONIZATION PARAMETER= -1.53836
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.52734     3.14150     0.05000    2.36E+01 Relative intensity
HYDR     2  2.0157E+21  1.9953E+21     0.05000     0.04186 Column density
TOTL  4861    -1.16974    -1.00000     0.05000    9.15E+01 Line intensity
Iteration  35 Chisq=  1.15E+02
************************************************
HDEN=  2.60263
BLACKbody=  4.69860
IONIZATION PARAMETER= -1.63040
 ID              Model    Observed       error      chi**2     Type
```

```
O  3  5007     2.96916     3.14150     0.05000    1.35E+00 Relative intensity
HYDR     2  1.6613E+21  1.9953E+21     0.05000    11.20731 Column density
TOTL  4861    -0.86339    -1.00000     0.05000    2.91E+01 Line intensity
Iteration  36 Chisq=  4.17E+01
************************************************
HDEN=  2.38452
BLACKbody=  4.73421
IONIZATION PARAMETER= -1.51239
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.39501     3.14150     0.05000    2.60E+00 Relative intensity
HYDR     2  2.2239E+21  1.9953E+21     0.05000     5.25276 Column density
TOTL  4861    -0.95575    -1.00000     0.05000    3.75E+00 Line intensity
Iteration  37 Chisq=  1.16E+01
************************************************
HDEN=  2.29217
BLACKbody=  4.75881
IONIZATION PARAMETER= -1.43639
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.90052     3.14150     0.05000    2.34E+01 Relative intensity
HYDR     2  2.6860E+21  1.9953E+21     0.05000    47.93817 Column density
TOTL  4861    -0.97296    -1.00000     0.05000    1.46E+00 Line intensity
Iteration  38 Chisq=  7.27E+01
************************************************
HDEN=  2.20570
BLACKbody=  4.74435
IONIZATION PARAMETER= -1.46771
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.29647     3.14150     0.05000    9.73E-01 Relative intensity
HYDR     2  2.4549E+21  1.9953E+21     0.05000    21.22705 Column density
TOTL  4861    -1.08645    -1.00000     0.05000    1.94E+01 Line intensity
Iteration  39 Chisq=  4.16E+01
************************************************
HDEN=  2.30493
BLACKbody=  4.73291
IONIZATION PARAMETER= -1.50838
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.12345     3.14150     0.05000    1.34E-02 Relative intensity
HYDR     2  2.1941E+21  1.9953E+21     0.05000     3.97098 Column density
TOTL  4861    -1.03382    -1.00000     0.05000    2.62E+00 Line intensity
Iteration  40 Chisq=  6.61E+00
************************************************
HDEN=  2.42102
BLACKbody=  4.74570
IONIZATION PARAMETER= -1.61500
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.66977     3.14150     0.05000    1.13E+01 Relative intensity
HYDR     2  1.7661E+21  1.9953E+21     0.05000     5.27461 Column density
TOTL  4861    -1.02695    -1.00000     0.05000    1.64E+00 Line intensity
Iteration  41 Chisq=  1.82E+01
************************************************
HDEN=  2.37102
BLACKbody=  4.72006
IONIZATION PARAMETER= -1.52366
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.01091     3.14150     0.05000    7.52E-01 Relative intensity
HYDR     2  2.1254E+21  1.9953E+21     0.05000     1.70288 Column density
TOTL  4861    -0.98138    -1.00000     0.05000    7.05E-01 Line intensity
Iteration  42 Chisq=  3.16E+00
************************************************
HDEN=  2.23336
```

```
BLACKbody=  4.73942
IONIZATION PARAMETER= -1.38807
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.30335     3.14150     0.05000    1.06E+00 Relative intensity
HYDR     2  2.9335E+21  1.9953E+21     0.05000    88.44898 Column density
TOTL  4861    -0.98045    -1.00000     0.05000    7.75E-01 Line intensity
Iteration  43 Chisq=  9.03E+01
************************************************
HDEN=  2.41356
BLACKbody=  4.72388
IONIZATION PARAMETER= -1.57818
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.14357     3.14150     0.05000    1.73E-04 Relative intensity
HYDR     2  1.8904E+21  1.9953E+21     0.05000     1.10506 Column density
TOTL  4861    -0.99433    -1.00000     0.05000    6.74E-02 Line intensity
Iteration  44 Chisq=  1.17E+00
************************************************
HDEN=  2.34182
BLACKbody=  4.71703
IONIZATION PARAMETER= -1.56109
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.80069     3.14150     0.05000    5.92E+00 Relative intensity
HYDR     2  1.9519E+21  1.9953E+21     0.05000     0.18913 Column density
TOTL  4861    -1.04332    -1.00000     0.05000    4.40E+00 Line intensity
Iteration  45 Chisq=  1.05E+01
************************************************
HDEN=  2.35250
BLACKbody=  4.72132
IONIZATION PARAMETER= -1.54892
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.95900     3.14150     0.05000    1.52E+00 Relative intensity
HYDR     2  2.0050E+21  1.9953E+21     0.05000     0.00957 Column density
TOTL  4861    -1.02444    -1.00000     0.05000    1.34E+00 Line intensity
Iteration  46 Chisq=  2.87E+00
************************************************
HDEN=  2.45312
BLACKbody=  4.71060
IONIZATION PARAMETER= -1.59213
 ID              Model    Observed       error      chi**2     Type
O  3  5007     2.87724     3.14150     0.05000    3.37E+00 Relative intensity
HYDR     2  1.8115E+21  1.9953E+21     0.05000     3.39280 Column density
TOTL  4861    -0.96875    -1.00000     0.05000    1.93E+00 Line intensity
Iteration  47 Chisq=  8.69E+00
************************************************
HDEN=  2.34198
BLACKbody=  4.72733
IONIZATION PARAMETER= -1.52932
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.05680     3.14150     0.05000    3.07E-01 Relative intensity
HYDR     2  2.0733E+21  1.9953E+21     0.05000     0.61152 Column density
TOTL  4861    -1.02086    -1.00000     0.05000    9.69E-01 Line intensity
Iteration  48 Chisq=  1.89E+00
************************************************
HDEN=  2.36766
BLACKbody=  4.72830
IONIZATION PARAMETER= -1.58061
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.13919     3.14150     0.05000    2.17E-04 Relative intensity
HYDR     2  1.8785E+21  1.9953E+21     0.05000     1.36883 Column density
TOTL  4861    -1.04215    -1.00000     0.05000    4.15E+00 Line intensity
```

```
Iteration  49 Chisq=  5.52E+00
**************************************************
HDEN=  2.37018
BLACKbody=  4.72212
IONIZATION PARAMETER= -1.53790
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.04302     3.14150     0.05000    4.19E-01 Relative intensity
HYDR     2  2.0606E+21  1.9953E+21     0.05000     0.42951 Column density
TOTL  4861    -0.99661    -1.00000     0.05000    2.42E-02 Line intensity
Iteration  50 Chisq=  8.73E-01
**************************************************
HDEN=  2.39798
BLACKbody=  4.72757
IONIZATION PARAMETER= -1.54802
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.18737     3.14150     0.05000    8.53E-02 Relative intensity
HYDR     2  2.0246E+21  1.9953E+21     0.05000     0.08669 Column density
TOTL  4861    -0.97949    -1.00000     0.05000    8.51E-01 Line intensity
Iteration  51 Chisq=  1.02E+00
**************************************************
HDEN=  2.44584
BLACKbody=  4.72171
IONIZATION PARAMETER= -1.58008
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.14899     3.14150     0.05000    2.28E-03 Relative intensity
HYDR     2  1.8896E+21  1.9953E+21     0.05000     1.12210 Column density
TOTL  4861    -0.96290    -1.00000     0.05000    2.68E+00 Line intensity
Iteration  52 Chisq=  3.81E+00
**************************************************
HDEN=  2.36794
BLACKbody=  4.72593
IONIZATION PARAMETER= -1.54201
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.12202     3.14150     0.05000    1.56E-02 Relative intensity
HYDR     2  2.0526E+21  1.9953E+21     0.05000     0.33019 Column density
TOTL  4861    -1.00213    -1.00000     0.05000    9.69E-03 Line intensity
Iteration  53 Chisq=  3.55E-01
**************************************************
HDEN=  2.34385
BLACKbody=  4.72653
IONIZATION PARAMETER= -1.50710
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.07674     3.14150     0.05000    1.77E-01 Relative intensity
HYDR     2  2.2183E+21  1.9953E+21     0.05000     4.99726 Column density
TOTL  4861    -0.98995    -1.00000     0.05000    2.09E-01 Line intensity
Iteration  54 Chisq=  5.38E+00
**************************************************
HDEN=  2.39613
BLACKbody=  4.72454
IONIZATION PARAMETER= -1.56041
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.14055     3.14150     0.05000    3.67E-05 Relative intensity
HYDR     2  1.9657E+21  1.9953E+21     0.05000     0.08789 Column density
TOTL  4861    -0.99403    -1.00000     0.05000    7.45E-02 Line intensity
Iteration  55 Chisq=  1.62E-01
**************************************************
HDEN=  2.35819
BLACKbody=  4.72083
IONIZATION PARAMETER= -1.54553
 ID              Model    Observed       error      chi**2     Type
```

```
O  3  5007     2.96393     3.14150     0.05000    1.44E+00 Relative intensity
HYDR     2  2.0205E+21  1.9953E+21     0.05000     0.06396 Column density
TOTL  4861    -1.01553    -1.00000     0.05000    5.30E-01 Line intensity
Iteration  56 Chisq=  2.03E+00
**************************************************
HDEN=  2.38803
BLACKbody=  4.72588
IONIZATION PARAMETER= -1.54740
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.16515     3.14150     0.05000    2.27E-02 Relative intensity
HYDR     2  2.0289E+21  1.9953E+21     0.05000     0.11349 Column density
TOTL  4861    -0.98841    -1.00000     0.05000    2.78E-01 Line intensity
Iteration  57 Chisq=  4.14E-01
**************************************************
HDEN=  2.39789
BLACKbody=  4.72878
IONIZATION PARAMETER= -1.56198
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.20199     3.14150     0.05000    1.48E-01 Relative intensity
HYDR     2  1.9637E+21  1.9953E+21     0.05000     0.10020 Column density
TOTL  4861    -0.99348    -1.00000     0.05000    8.87E-02 Line intensity
Iteration  58 Chisq=  3.37E-01
**************************************************
HDEN=  2.38661
BLACKbody=  4.72696
IONIZATION PARAMETER= -1.56220
 ID              Model    Observed       error      chi**2     Type
O  3  5007     3.17330     3.14150     0.05000    4.10E-02 Relative intensity
HYDR     2  1.9605E+21  1.9953E+21     0.05000     0.12131 Column density
TOTL  4861    -1.00519    -1.00000     0.05000    5.79E-02 Line intensity
Iteration  59 Chisq=  2.20E-01
Amoeba exceeding maximum iterations.
**************************************************
**************************************************
**************************************************

Cloudy was called   59 times.

Optimal command: HDEN=  2.39613
 Smallest value:  1.67E+00 Largest value:  4.00E+00 Allowed range  -1.00E+37 to   1.00E+37
Optimal command: BLACKbody=  4.72454
 Smallest value:  4.29E+00 Largest value:  5.50E+00 Allowed range  -1.00E+37 to   1.00E+37
Optimal command: IONIZATION PARAMETER= -1.56041
 Smallest value: -2.00E+00 Largest value: -1.17E+00 Allowed range  -1.00E+37 to   1.00E+37
**************************************************
HDEN=  2.39613
BLACKbody=  4.72454
IONIZATION PARAMETER= -1.56041
```

```
**************************************91Aug03***************************************
*                                                                                  *
* title test of optimization driver                                                *
* optimize iterations 30 ; increase limit to number of iterations                  *
* optimize luminostiy -1 ;want H-bet flux of .1 erg cm^-2 s^-1                     *
* optimize column density ;read in sets of desired column densities                *
* optimize lines ; read in sets of desired relative line intensities               *
* HDEN=  2.39613                                                                   *
* optimze increment 1                                                              *
* BLACKbody=  4.72454                                                              *
* optimize increment .5                                                            *
* IONIZATION PARAMETER= -1.56041                                                   *
* optimize increment .5                                                            *
* c optim.in                                                                       *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

Chemical composition

He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

```
          335Cell Peak1.31E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.23E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   0.8355   Average nu:1.529E+00   P( X-ray):   0.0000   P(BalC):   0.6195     Q(Balmer C):  11.4912
          Q(1.0-1.8):  11.2051   Q(1.8-4.0):  10.6528   Q(4.0-20):   8.4244   Q(20--):   0.0000     Ion pht flx:2.056E+11
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  -0.7514   Alf(ox):   0.0000     Total lumin:   1.0488
          U(1.0----):2.754E-02   U(4.0----):3.560E-05   T(En-Den):1.490E+01   T(Comp):5.077E+04     nuJnu(912A):7.263E+00
          Occ(FarIR):1.988E-10   Occ(H n=6):7.154E-14   Occ(1Ryd):3.349E-16   Occ(4R):4.123E-20     Occ (Nu-hi):1.414E-30
          Tbr(FarIR):3.306E-10   Tbr(H n=6):3.177E-10   Tbr(1Ryd):5.291E-11   Tbr(4R):2.608E-14     Tbr (Nu-hi):2.699E-24

#####  1 Te:5.033E+03 Hden:2.490E+02 Ne:2.808E+02 R:1.000E+25 R-R0:1.815E+15 dR:3.631E+15 NTR:  1 Htot:3.212E-19 T912: 1.567E-03###
 -4.09 4686  0.13 5876  0.08 1909  0.00 1549  0.00 6584  0.00 5007  0.56 3727  0.01 6300  0.00 2798  0.00 1035  0.00
Hydrogen    2.753E-04 9.997E-01 H+0/Hden: 1.000E+00 1.997E-12 H-     H2 2.330E-14 2.168E-12 H2+  HeH+ 2.101E-12 H col den 9.039E+17
H 2SP 3-6   6.668E-12 1.468E-17 2.183E-18 2.632E-18 3.612E-18 4.986E-18 Texc(La); 3.736E+03 T(contn): 1.490E+01 T(diffs): 2.683E+02
Helium      5.117E-04 7.256E-01 2.739E-01 He I 2S3  6.012E-07 Comp H, C 7.171E-26 7.108E-27 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  5.111E-04 1.283E-12 3.006E-19 4.084E-19 5.872E-19 8.194E-19 He triplt 6.012E-07 5.963E-18 1.086E-19 8.707E-19 3.118E-19
HeII        7.256E-01 4.802E-13 1.305E-19 2.018E-19 3.274E-19 5.104E-19 4.587E-18 4.978E-17 1.044E-14 PRAD/GAS; 5.633E-03
Pressure    NgasTgas; 2.747E+06 P(total): 3.813E-10 P( gas ): 3.792E-10 P(Radtn): 2.136E-12 Rad accel 1.131E-07 Force Mul 9.524E+02
Carbon      2.168E-06 1.706E-02 8.579E-01 1.248E-01 2.649E-04 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    2.071E-06 9.732E-03 7.966E-01 1.936E-01 7.742E-05 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      2.461E-06 2.471E-02 8.482E-01 1.270E-01 3.088E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.245
Neon        1.171E-05 2.824E-02 9.534E-01 1.835E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.030E-05 1.125E-02 9.864E-01 2.377E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.657E-06 1.201E-02 4.572E-01 5.308E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 9.590E-07 4.584E-03 4.752E-01 4.993E-01 2.094E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 3.000E-07 5.495E-03 6.580E-01 3.290E-01 7.468E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 8.008E-07 1.297E-02 6.790E-01 3.049E-01 3.141E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 9.028E-05 2.577E-02 8.736E-01 1.002E-01 3.357E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 6.436E-05 3.080E-02 8.264E-01 1.421E-01 6.040E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
##### 73 Te:3.641E+03 Hden:2.490E+02 Ne:2.010E+01 R:1.000E+25 R-R0:7.959E+18 dR:1.697E+15 NTR:  3 Htot:8.465E-21 T912: 1.005E+02###
 -0.99 4686  0.00 5876  0.16 1909  0.03 1549  0.00 6584  0.11 5007  3.14 3727  0.37 6300  0.01 2798  0.07 1035  0.00
P(LINES): 0.032 0.000 0.000 0.000 0.000 0.000 0.000 0.760 0.208 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    9.420E-01 5.799E-02 H+0/Hden: 1.000E+00 2.596E-09 H-     H2 3.922E-09 7.936E-10 H2+  HeH+ 1.153E-07 H col den 1.982E+21
H 2SP 3-6   9.930E-13 6.485E-14 2.937E-19 4.679E-19 8.041E-19 1.338E-18 Texc(La); 3.454E+03 T(contn): 1.176E+01 T(diffs): 3.004E+02
Helium      7.744E-01 2.256E-01 0.000E+00 He I 2S3  1.769E-08 Comp H, C 1.132E-27 1.567E-28 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  7.744E-01 2.268E-14 6.203E-21 8.317E-21 1.288E-20 1.916E-20 He triplt 1.769E-08 2.688E-16 1.010E-20 2.082E-19 9.607E-21
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 7.049E-02
```

```
Pressure    NgasTgas; 1.186E+06 P(total): 1.923E-10 P( gas ): 1.637E-10 P(Radtn): 2.860E-11 Rad accel 1.407E-09 Force Mul 4.270E+02
Carbon      3.293E-05 9.937E-01 6.221E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.459E-01 5.408E-02 2.277E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.502E-01 4.982E-02 4.052E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.244
Neon        5.012E-01 4.222E-01 7.664E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.607E-04 9.906E-01 9.216E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 2.721E-05 9.952E-01 4.799E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 2.674E-05 1.000E+00 7.116E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 8.821E-06 9.875E-01 1.250E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 7.406E-01 2.104E-01 4.909E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 5.533E-06 1.067E-02 9.893E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 4.953E-04 9.994E-01 1.133E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest Te reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached   5.6 percent of the total rate out.
  Photoionization of He 2TriS reached  20.5 percent of the total rate out.
  Some fine struc lines are optically thick, largest=2.13E+00
C-This is the last iteration and the fine structure optical depths changed.  Try another iteration.
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  1.13E+01.  Caused by Lyman alpha.
```

```
********************************> CLOUDY 80.08  <********************************
* title test of optimization driver                                             *
* optimize iterations 30 ; increase limit to number of iterations               *
* optimize luminostiy -1 ;want H-bet flux of .1 erg cm^-2 s^-1                  *
* optimize column density ;read in sets of desired column densities             *
* hydrogen 2  21.3                                                              *
* end of column dens                                                            *
* optimize lines ; read in sets of desired relative line intensities            *
* O  3 5007 3.1415                                                              *
* end of lines                                                                  *
* HDEN=  2.39613                                                                *
* optimze increment 1                                                           *
* BLACKbody=  4.72454                                                           *
* optimize increment .5                                                         *
* IONIZATION PARAMETER= -1.56041                                                *
* optimize increment .5                                                         *
* c optim.in                                                                    *
* c cray                                                                        *
********************************> LOG(U): -1.56 <********************************
>>>>>>>>>> Cautions are present.
>>>>>>>>>> Another iteration is suggested.

          Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                                  Intensity (erg/s/cm^2)

TOTL 4861 -0.994   1.0000      He2p  910 -2.392   0.0400      N  2 6548 -2.412   0.0382      S  2 6720 -2.198   0.0625
TOTL 1216  0.366  22.9100      He I  504 -1.118   0.7523      REC  6584 -3.797   0.0016      S  2 4074 -3.565   0.0027
TotH    0  0.349  22.0437      He I 4471 -2.306   0.0488      N  2 5755 -3.998   0.0010      S  210330 -3.738   0.0018
BFH1    0  0.296  19.4907      TOTL 5876 -1.801   0.1561      N  2  122 -3.261   0.0054      S II 6731 -2.537   0.0286
BFHe    0 -0.666   2.1277      Ca B 5876 -1.821   0.1488      N  2  203 -3.950   0.0011      S II 6716 -2.464   0.0339
TotM    0 -1.365   0.4252      TOTL10830 -1.552   0.2767      N  2 4239 -4.419   0.0004      S II 4070 -3.689   0.0020
CA B 4861 -0.989   1.0118      TOTL 3889 -2.372   0.0419      N  2 5680 -3.838   0.0014      S II 4078 -4.169   0.0007
CA B 1216  0.527  33.2202      TOTL 7065 -2.307   0.0487      N  2 2140 -4.057   0.0009      S II10323 -4.192   0.0006
DU B 4861 -0.989   1.0118      CcHE    0 -2.372   0.0418      N  3 1750 -3.978   0.0010      S II10289 -4.321   0.0005
Q(H) 4861 -1.010   0.9632      He I    2 -2.511   0.0304      N  3   57 -1.301   0.4929      S II10373 -4.640   0.0002
Q(H) 1216  0.524  32.9317      DevB    2 -2.763   0.0170      O  1 6300 -3.278   0.0052      S II10339 -4.319   0.0005
TOTL 6563 -0.570   2.6574      He I 5016 -2.576   0.0262      O  1 6363 -3.755   0.0017      S  3   18 -1.106   0.7725
TOTL 4861 -0.994   1.0000      DevB 5016 -2.665   0.0213      O  1  630 -3.827   0.0015      S  3   34 -0.961   1.0790
TOTL 4340 -1.281   0.5165      He I 3965 -2.875   0.0132      O  1 1470 -4.876   0.0001      S  3 9532 -1.065   0.8496
TOTL 4102 -1.501   0.3109      DevB 3965 -3.066   0.0085      O  1 7774 -4.707   0.0002      S  3 9069 -1.481   0.3262
TOTL18751 -1.551   0.2772      He I 3614 -3.158   0.0068      TOTL 3727 -1.421   0.3738      S  3 6312 -3.214   0.0060
TOTL12818 -1.812   0.1522      DevB 3614 -3.259   0.0054      TOTL 7325 -3.291   0.0051      S  3 3722 -3.443   0.0036
TOTL10938 -2.024   0.0932      He I 3448 -3.377   0.0041      IONZ 3727 -3.748   0.0018      S  3 1729 -4.986   0.0001
TOTL40512 -2.223   0.0591      DevB 3448 -3.548   0.0028      IONZ 7325 -4.348   0.0004      S  4  105 -1.013   0.9562
TOTL26252 -2.409   0.0385      HeII  228 -2.785   0.0162      O II 3729 -1.703   0.1954      Ar 2    7 -3.571   0.0026
TOTL74578 -2.738   0.0180      ESC   304 -4.097   0.0008      O II 3726 -1.747   0.1766      Ar 3 7135 -2.061   0.0857
2 NU    0  0.016  10.2312      He2C  911 -3.267   0.0053      O II 2471 -3.391   0.0040      Ar 3 7751 -2.691   0.0201
TOTL 1216  0.366  22.9100      TOTL 1640 -2.828   0.0147      O II 7323 -3.548   0.0028      Ar 3   22 -2.949   0.0111
TOTL 1026 -3.333   0.0046      TOTL 4686 -3.785   0.0016      O II 7332 -3.640   0.0023      Ar 3    9 -1.806   0.1543
TOTL  973 -3.386   0.0041      TOTL 1216 -3.228   0.0058      O  2 4651 -3.270   0.0053      Ar 4 4740 -3.125   0.0074
TOTL  950 -3.403   0.0039      Ca B 1640 -2.760   0.0171      O  3 1663 -3.759   0.0017      Ca 2 3933 -4.415   0.0004
TOTL  938 -3.405   0.0039      DevB 1640 -2.761   0.0171      Rec  1663 -4.902   0.0001      Ca 2 8579 -3.297   0.0050
INWD 1216  0.366  22.9100      Ca B 4686 -3.522   0.0030      O  3 5007 -0.497   3.1405      Ca 2 7306 -2.174   0.0660
Dest 1216 -1.512   0.3037      DevB 4686 -3.526   0.0029      O  3 4959 -0.974   1.0468      Ca2K 3934 -4.720   0.0002
e sc18751 -1.551   0.2773      REC  1656 -4.646   0.0002      TOTL 4363 -3.377   0.0041      Ca2H 3969 -4.712   0.0002
e sc40512 -2.609   0.0242      C  2  158 -3.124   0.0074      O  3 2321 -4.004   0.0010      Ca2X 8498 -4.479   0.0003
nFnu 4860 -0.613   2.4052      C  2 2326 -2.894   0.0126      O  3  880 -0.579   2.5983      Ca2Y 8542 -3.521   0.0030
nFnu 1215 -4.134   0.0007      C  2 1335 -4.768   0.0002      O  3  520 -0.326   4.6509      Ca2Z 8662 -3.770   0.0017
Inci 4861 -0.650   2.2070      REC  1335 -1.669   0.2113      O  4   26 -2.511   0.0304      CaF1 7291 -2.400   0.0393
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Inci 1216  0.711  50.7209      C  2 4267 -3.527   0.0029      Ne 2  128 -2.240   0.0568      CaF2 7324 -2.567   0.0267
BA C    0 -0.424   3.7191      TOTL  977 -2.771   0.0167      Ne 3  156 -0.674   2.0912      Ca 4   32 -3.630   0.0023
PA C    0 -0.919   1.1893      C3 R  977 -2.771   0.0167      Ne 3  361 -1.748   0.1763      Fe 2   48 -4.457   0.0003
H FF    0 -1.136   0.7213      TOTL 1909 -2.566   0.0268      Ne 3 3869 -1.758   0.1723      Fe 2    7 -2.612   0.0241
H FB    0 -0.881   1.2987      C  3 1907 -2.786   0.0161      Ne 3 3968 -2.271   0.0529      Emis    3 -2.495   0.0316
Cool 1216 -3.054   0.0087      C  3 1909 -2.967   0.0106      Emis 2798 -2.124   0.0741      Cool    3 -2.495   0.0316
H-FB    0 -4.946   0.0001      C3 R 1909 -2.933   0.0115      Cool 2798 -2.124   0.0741      TOT     0 -2.246   0.0560
HeFF    0 -2.142   0.0712      Phot 1909 -2.522   0.0296      Al 3 1860 -4.188   0.0006      FEIR    0 -2.913   0.0121
HeFB    0 -1.916   0.1196      C  3 2297 -3.273   0.0053      Si 2   35 -1.926   0.1169      Fe 3    0 -2.455   0.0346
MeFB    0 -4.861   0.0001      C  3 4649 -4.483   0.0003      Si 2 2335 -3.402   0.0039      Fe 3 5270 -3.135   0.0072
MeFF    0 -3.320   0.0047      C  4 1549 -4.931   0.0001      Si 2 1808 -4.656   0.0002      Fe 3 4658 -2.891   0.0127
ToFF    0 -1.092   0.7972      N  1 5200 -4.346   0.0004      Si 3 1895 -3.048   0.0088
esc   584 -1.929   0.1161      N  2 6584 -1.935   0.1145      PHOT 1895 -3.351   0.0044
```

```
                          TEST OF OPTIMIZATION DRIVER
Cooling:  H FB    0:0.059  O  3 5007:0.142  O  3  880:0.118  O  3  520:0.210  Ne 3  156:0.095
Heating:  BFH1    0:0.884  BFHe    0:0.097

IONIZE PARMET:  U(1-) -1.5600  U(4-): -4.4486  U(sp): -1.56  Q(ion):    6.175  L(ion):  -3.950 Q(low): 11.56    P(low)  0.64
ENERGY BUDGET:  Heat:   0.349  Coolg:   0.350  Error:  0.3%  Compt H:  -6.477  WorkF:    0.824 F-F  H -5.717    PRADMX:1.13E+01
Column density  H12:1.982E+21  H II:1.966E+21  HI:1.597E+19  H-:    1.223E+11  H2:   9.929E+10 H2+:7.875E+10    He H+:1.856E+12
                OH: 0.000E+00  Heff:0.000E+00
<NH>:2.490E+02  <Tp>:6.26E+03  <TO3>:6.16E+03  Ne:2.739E+02  ti(snd):9.11E+12  NeN+dl:5.37E+23 <T(C3)>:6.23E+03 <E(C3)>:2.74E+02
He/Ha:1.15E-01  =   1.18*true  N/Oap:4.47E-02  =   0.34true  T(O3R):6.682E+03  L THIN:1.00E+30 <T(S2)>:7.50E+03 <E(S2)>:2.21E+02
T He+:6.26E+03  EHe+:2.73E+02  T(O+):7.26E+03  EO+:2.66E+02  iter/zn:   3.082  Te-low:3.64E+03 Te-high:8.90E+03  Hlu/zn:3.88E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt9.45E+09  Tthr1.79E+09  <Tden>: 6.26E+03  <dens>:5.87E-22 <Mol>:6.48E-01
Mean Jeans      l(cm)1.87E+20  M(sun)1.01E+06  smallest:     len(cm):1.43E+20  M(sun):4.48E+05 Alf(ox-tran):     0.0000

Optical Depths: CONTN; COMP: 1.44E-03    H-: 4.77E-06 R(1300): 1.07E-04 H2+ 5.51E-07  HeTri:2.09E-03
 Pfa:1.44E-03   Pa:1.44E-03   Ba:1.44E-03   Hb:1.44E-03  La:4.25E-03   1r:1.005E+02  1.8:2.75E+01  4.:5.799E+01  21R:1.000E-20
10830: 2.05E+02  3889: 8.75E+00  5876: 1.26E-06  7065: 6.96E-07
 1550: 5.18E+03  2800: 6.68E+03   774: 1.00E-20  1240: 1.89E-02  1035: 1.00E-20  1335: 6.54E+03   977: 2.50E+05  1397: 1.51E+04
  789: 4.84E+01  1207: 6.42E+04  1085: 3.74E+02  1194: 1.88E+02  1909: 9.96E-02  1895: 1.72E+00  2326: 3.27E-03  1666: 7.88E-01
 1750: 3.75E-03  1025: 1.32E+02   352: 1.00E-20   347: 1.00E-20  1860: 4.34E+03   630: 3.05E-02   834: 2.92E+04   835: 3.83E+04
 1808: 6.96E+03  1256: 4.87E+01    -3: 9.48E+01   -48: 6.59E-08  3934: 4.92E+02  3969: 2.48E+02  8498: 6.61E-05  8542: 5.88E-04
 8662: 3.36E-04   353: 1.00E-20  1304: 4.51E+02  1122: 6.31E+02   990: 1.65E+04  1402: 6.46E-04  1214: 1.65E-07  1486: 6.68E-03
 2335: 1.66E-02  1406: 2.01E-01  1656: 1.22E+00  9830: 2.03E-10  8727: 9.76E-11  6300: 1.20E-06  5577: 1.40E-10  7291: 3.29E-05
 7324: 2.28E-05  1039: 6.41E+01 -8446: 1.83E-13 -4368: 7.12E-16  -132: 3.62E-15  -113: 5.79E-15   -29: 2.78E-16   -46: 1.36E-14
 -245: 1.00E-20   765: 4.06E+03 -1198: 3.85E-03   786: 1.15E+01
 C157: 3.05E-03  N122: 2.81E-03  N205: 2.64E-03   N57: 2.14E-01  O146:-1.67E-04   O63: 1.35E-02   O88: 2.13E+00   O52: 9.80E-01
  O26: 1.98E-03  NE13: 1.46E-02  NE36:-9.92E-04  NE16: 3.06E-01   MG4: 2.56E-06  MG14: 1.00E-20   MG6: 1.00E-20  SI35: 6.45E-03
  S19: 1.08E-02   S34: 1.24E-01   S11: 1.59E-02   AR7: 3.34E-04   AR9: 1.01E-02  AR22:-1.15E-05  AR13: 1.24E-06   AR8: 7.71E-10
  CA3: 1.31E-04  CA12:-1.06E-12   CA4: 1.93E-08  Ne14: 1.00E-20  Ne24: 1.00E-20   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.00E-20 Si6.5: 1.00E-20  C610: 4.33E-07  C370: 1.90E-05

Old hydro optical depths:    1 9.99E+07    2 1.00E-20    3 1.00E-20    4 1.00E-20    5 1.00E-20    6 1.00E-20    7 1.00E-20
                    Lines:  2-1 9.96E+09  3-2 1.59E-03  4-3 1.59E-05  5-4 7.93E-07  6-5 1.22E-07  7-6 1.22E-08  8-7 1.22E-09
New hydro optical depths:    1 1.01E+02    2 2.52E-06    3 4.77E-06    4 1.35E-06    5 5.57E-13    6 1.44E-12    7 5.14E-12
                    Lines:  2-1 1.12E+06  3-2 4.87E-03  4-3 8.90E-10  5-4 3.40E-10  6-5-1.69E-09  7-6 1.14E-08  8-7 1.55E-07

Old He Is optical depths:    1 8.30E+05    2 0.00E+00    3 1.00E-20    4 1.00E-20    5 1.00E-20    6 1.00E-20    7 1.00E-20
                    Lines:  2-1 9.96E+09  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 0.00E+00
New HE Is optical depths:    1 2.75E+01    2 6.47E-04    3-2.80E-16    4-8.32E-16    5-1.65E-15    6-2.87E-15    7-3.15E-14
                    Lines:  2-1 4.87E+04  3-2 3.19E-04  4-3 5.86E-11  5-4 1.77E-11  6-5-6.13E-11  7-6 5.09E-10  8-7 6.89E-09

Old He II optical depths:    1 8.30E+05    2 8.30E+05    3 1.00E-20    4 1.00E-20    5 1.00E-20    6 1.00E-20    7 1.00E-20
                    Lines:  2-1 9.96E+09  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 0.00E+00
New HE II optical depths:    1 5.80E+01    2 1.01E+02    3-4.59E-18    4-1.13E-17    5-2.20E-17    6-3.83E-17    7-4.13E-16
                    Lines:  2-1 1.33E+06  3-2 2.17E-07  4-3 2.87E-14  5-4-3.33E-14  6-5-2.59E-13  7-6 6.14E-13  8-7 9.10E-12

Hydrogen  -2.094 -0.004                          Log10 Mean Ionisation (over volume)
Helium    -2.262 -0.003 -2.712
Carbon    -4.888 -1.245 -0.047 -1.337 -5.721
Nitrogen  -2.445 -1.262 -0.057 -1.185 -6.131
Oxygen    -2.138 -1.058 -0.044 -3.125 -7.075
Neon      -2.783 -1.151 -0.033 -3.833
Magnesium -4.388 -1.270 -0.024 -4.490
Aluminum  -5.281 -1.149 -0.253 -0.431
Silicon   -5.730 -1.167 -0.248 -0.446 -2.044
Sulphur   -6.553 -1.530 -0.124 -0.663 -2.679
Argon     -2.539 -1.385 -0.105 -0.770 -4.651
Calcium   -3.907 -1.339 -0.031 -1.657 -5.679
Iron      -4.269 -1.765 -1.010 -0.053 -3.059 -5.583
```

```
          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -2.094 -0.004                          Log10 Mean Ionisation (over radius)
Helium    -2.262 -0.003 -2.712
Carbon    -4.888 -1.245 -0.047 -1.337 -5.721
Nitrogen  -2.445 -1.262 -0.057 -1.185 -6.131
Oxygen    -2.138 -1.058 -0.044 -3.125 -7.075
Neon      -2.783 -1.151 -0.033 -3.833
Magnesium -4.388 -1.270 -0.024 -4.490
Aluminum  -5.281 -1.149 -0.253 -0.431
Silicon   -5.730 -1.167 -0.248 -0.446 -2.044
Sulphur   -6.553 -1.530 -0.124 -0.663 -2.679
Argon     -2.539 -1.385 -0.105 -0.770 -4.651
Calcium   -3.907 -1.339 -0.031 -1.657 -5.679
Iron      -4.269 -1.765 -1.010 -0.053 -3.059 -5.583


                                          Normalised continuum
  0.25 3.502   0.27 2.394   0.30 1.782   0.33 1.488   0.36 1.371   0.39 1.297   0.43 1.262   0.47 1.242   0.51 1.229   0.56 1.212
  0.62 1.189   0.67 1.142   0.74 1.032   0.81 0.999   0.88 0.999   0.97 0.999   0.98 0.999   0.99 0.999   1.00 0.999


Inward continua (nuFnu) at head of Balmer, Lyman series;  1.10E+00  4.75E+00


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  1.10E+00  2.17E-06

                                         Emergent continuum - phot/ryd/cm2 (r in)
  0.26 1.12E+12  0.53 5.57E+11     1.0 3.38E+11     1.2 8.37E+01     2.5 8.87E+04    4.18E+00 2.37E-11    8.45E+00 4.05E+00
  0.29 7.43E+11  0.60 5.41E+11     1.0 3.35E+11     1.4 1.66E+00     2.9 3.76E+05    4.66E+00 1.63E-09    9.52E+00 1.66E+00
  0.33 6.03E+11  0.67 5.02E+11     1.0 2.70E+05     1.6 2.52E+03     3.2 1.61E+06    5.25E+00 2.27E-05    1.07E+01 2.16E-01
  0.37 5.69E+11  0.76 4.16E+11     1.0 2.04E+05     1.8 6.84E+01     3.6 1.04E+06    5.91E+00 1.47E-02    1.21E+01 1.43E-02
  0.42 5.60E+11  0.86 3.86E+11     1.0 1.54E+05     2.0 1.03E+03     3.9 1.41E+06    6.66E+00 5.01E-01
  0.47 5.60E+11  0.97 3.46E+11     1.1 8.09E+03     2.3 7.59E+03     4.0 2.41E-10    7.51E+00 2.93E+00
 ID             Model    Observed       error      chi**2     Type
O  3  5007     3.14055     3.14150     0.05000    3.67E-05 Relative intensity
HYDR     2  1.9657E+21  1.9953E+21     0.05000     0.08789 Column density
TOTL  4861    -0.99403    -1.00000     0.05000    7.45E-02 Line intensity
Iteration  60 Chisq=  1.62E-01
```

CLOUDY 80.08

```
************************************91Aug03***************************************
*                                                                              *
* title conditions similar to Orion nebula blister                             *
* sphere                                                                       *
* table star kurucz 39,700K                                                    *
* phi(h) 13.0                                                                  *
* turbulence 8 km/sec                                                          *
* hden 4                                                                       *
* abundances hii region                                                        *
* constant pressure                                                            *
* iterate                                                                      *
* print last iteration                                                         *
* c orion.in                                                                   *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

Chemical composition

He:.095 C:3.00E-04 N:7.00E-05 O:4.00E-04 Ne:1.10E-04 Mg:3.00E-05 Al:2.0E-07 Si:3.00E-06 S:1.00E-05 A:3.0E-06 Ca:2.0E-08 Fe:3.00E-06

```
          293Cell Peak9.37E-01   Lo 1.01E-05=0.9025cm   Hi-Con:3.99E+00 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   2.4800   Average nu:1.385E+00   P( X-ray):   0.0000   P(BalC):   2.8173     Q(Balmer C):  13.6996
          Q(1.0-1.8):  12.9496   Q(1.8-4.0):  12.0419   Q(4.0-20):   0.0000   Q(20--):   0.0000     Ion pht flx:1.001E+13
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):   1.4996   Alf(ox):   0.0000     Total lumin:   2.9957
          U(1.0----):3.338E-02   U(4.0----):0.000E+00   T(En-Den):4.571E+01   T(Comp):3.542E+04     nuJnu(912A):5.336E+02
          Occ(FarIR):2.609E-08   Occ(H n=6):1.204E-11   Occ(1Ryd):2.456E-14   Occ(4R):0.000E+00     Occ (Nu-hi):6.473E-22
          Tbr(FarIR):4.375E-08   Tbr(H n=6):5.348E-08   Tbr(1Ryd):3.879E-09   Tbr(4R):0.000E+00     Tbr (Nu-hi):4.050E-16
          Grain(Pal):5.037E-23   Grain(Bal):1.960E-22   Grain Mg2:3.617E-22   Grain R:5.706E-22     Grain(HeII):3.532E-22

#####  1 Te:8.609E+03 Hden:1.000E+04 Ne:1.097E+04 R:1.000E+25 R-R0:2.573E+15 dR:5.145E+15 NTR:  3 Htot:2.969E-16 T912: 4.824E+01###
 -0.56 4686  0.00 5876  0.04 1909  0.09 1549  0.00 6584  0.01 5007  1.59 3727  0.09 6300  0.00 2798  0.01 1035  0.00
Hydrogen    1.249E-04 9.999E-01 H+0/Hden: 1.000E+00 2.403E-12 H-     H2 4.772E-15 6.261E-13 H2+  HeH+ 1.025E-12 H col den 5.145E+19
H 2SP 3-6   2.408E-10 3.462E-14 1.732E-16 1.582E-16 1.850E-16 2.178E-16 Texc(La); 5.120E+03 T(contn): 4.515E+01 T(diffs): 4.101E+01
Helium      5.908E-04 9.994E-01 0.000E+00 He I 2S3  4.042E-06 Comp H, C 1.726E-22 4.195E-23 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  5.867E-04 1.000E-10 8.420E-18 1.160E-17 1.828E-17 2.616E-17 He triplt 4.042E-06 1.713E-15 8.030E-18 6.301E-17 1.022E-17
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 1.134E-02
Gra-Ori     Dust temp 1.825E+02 Pot(Volt) 2.367E+00 Nelectron 4.932E+02 drft cm/s 1.744E+04  Heating: 2.559E-17 Frac(tot) 8.619E-02
Sil-Ori     Dust temp 1.417E+02 Pot(Volt) 2.509E+00 Nelectron 5.228E+02 drft cm/s 1.468E+04  Heating: 3.160E-17 Frac(tot) 1.064E-01
Pressure    NgasTgas; 1.774E+08 P(total): 2.476E-08 P( gas ): 2.449E-08 P(Radtn): 2.777E-10 Rad accel 1.229E-05 Force Mul 1.182E+03
Carbon      9.104E-07 1.797E-02 9.817E-01 2.949E-04 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    2.520E-06 2.095E-02 9.787E-01 3.093E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      8.256E-06 1.515E-01 8.485E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.430
Neon        2.232E-04 5.837E-01 4.161E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.660E-06 8.217E-03 9.918E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.007E-06 1.779E-02 5.674E-01 4.148E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.241E-07 6.151E-03 7.650E-01 2.288E-01 6.719E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 6.597E-03 9.101E-01 8.333E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 9.205E-07 2.267E-02 9.699E-01 7.433E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 9.758E-05 1.372E-02 9.861E-01 5.298E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 1.545E-04 7.461E-02 9.252E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
##### 98 Te:3.877E+03 Hden:8.261E+04 Ne:1.412E+03 R:1.000E+25 R-R0:1.160E+17 dR:9.146E+11 NTR:  7 Htot:4.837E-17 T912: 9.646E+01###
  0.49 4686  0.00 5876  0.13 1909  0.70 1549  0.00 6584  0.54 5007  3.60 3727  1.49 6300  0.01 2798  0.21 1035  0.00
Hydrogen    9.833E-01 1.673E-02 H+0/Hden: 1.000E+00 5.137E-09 H-     H2 4.838E-08 1.419E-09 H2+  HeH+ 6.165E-11 H col den 1.528E+21
H 2SP 3-6   2.658E-10 2.145E-13 1.002E-16 1.595E-16 2.846E-16 4.720E-16 Texc(La); 3.445E+03 T(contn): 3.408E+01 T(diffs): 4.136E+01
Helium      1.000E+00 0.000E+00 0.000E+00 He I 2S3  0.000E+00 Comp H, C 5.682E-24 9.087E-25 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 He triplt 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
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HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 2.425E-03
Gra-Ori     Dust temp 1.259E+02 Pot(Volt) 2.210E+00 Nelectron 4.605E+02 drft cm/s 1.566E+04  Heating: 1.261E-17 Frac(tot) 2.607E-01
Sil-Ori     Dust temp 1.024E+02 Pot(Volt) 2.263E+00 Nelectron 4.714E+02 drft cm/s 1.328E+04  Heating: 1.456E-17 Frac(tot) 3.009E-01
Pressure    NgasTgas; 3.921E+08 P(total): 5.433E-08 P( gas ): 5.413E-08 P(Radtn): 2.033E-10 Rad accel 3.330E-06 Force Mul 6.637E+04
Carbon      4.039E-05 9.998E-01 2.079E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.656E-01 3.436E-02 7.416E-16 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.857E-01 1.432E-02 5.933E-16 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.216
Neon        9.520E-01 4.801E-02 2.156E-11 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.821E-04 9.993E-01 4.728E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 2.664E-05 9.993E-01 6.348E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 2.901E-05 1.000E+00 2.268E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.058E-05 9.946E-01 5.421E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 9.199E-01 8.012E-02 3.351E-14 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 7.468E-06 1.345E-02 9.865E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 5.286E-04 9.995E-01 1.587E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest Te reached.
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached   3.3 percent of the total rate out.
  Photoionization of He 2TriS reached  30.2 percent of the total rate out.
  Sum of gas+line rad pressure ranged from  2.48E-08 to   5.46E-08 in a constant pressure model.
  Local grain-gas photoelectric heating rate reached  56.2% of the total.
  Gloal grain photoelectric heating of gas was 10.7% of the total.
  Local grain-gas cooling of gas rate reached  37.4% of the total.
  Frequency out of range of free-free gaunt factor routine.
  Balmer continuum optical depth is  1.04E+00
  Balmer continuum stimulated emission correction to optical depths reached  0.14
  Paschen cont optical depth=  4.80E-01
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*********************************> CLOUDY 80.08  <*********************************
* title conditions similar to Orion nebula blister                                   *
* sphere                                                                             *
* table star kurucz 39,700K                                                          *
* phi(h) 13.0                                                                        *
* turbulence 8 km/sec                                                                *
* hden 4                                                                             *
* abundances hii region                                                              *
* constant pressure                                                                  *
* iterate                                                                            *
* print last iteration                                                               *
* c orion.in                                                                         *
* c cray                                                                             *
*********************************> LOG(U): -1.48 <*********************************
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Emission Line Spectrum. Constant Pressure Model. Closed geometry. Iteration 2 of 2.
Intensity (erg/s/cm^2)

TOTL 4861	0.487	1.0000	BA C 0	1.081	3.9313	C 3 1909	0.021	0.3425	Si 2 1808	-3.233	0.0002
TOTL 1216	1.248	5.7728	PA C 0	0.570	1.2124	Phot 1909	-1.495	0.0104	Si 3 1207	-2.609	0.0008
TotH 0	1.775	19.4001	Grai 0	2.493	101.5280	N 2 6584	0.217	0.5372	Si 3 1895	-0.982	0.0340
BFH1 0	1.689	15.9133	Grai 1216	1.992	32.0084	N 2 6548	-0.260	0.1791	PHOT 1895	-3.015	0.0003
BFHe 0	0.598	1.2914	H FF 0	0.583	1.2491	REC 6584	-2.609	0.0008	Si 4 1397	-3.067	0.0003
TotM 0	-0.442	0.1178	H FB 0	0.802	2.0684	N 2 5755	-1.406	0.0128	S 2 6720	-0.850	0.0460
H- H 0	-3.337	0.0001	Cool 1216	-0.587	0.0843	N 2 122	-2.928	0.0004	S 2 4074	-1.009	0.0319
GraH 0	0.804	2.0774	Crst 960	-3.252	0.0002	N 2 4239	-3.156	0.0002	S 210330	-1.183	0.0214
GraC 0	0.485	0.9948	H-FB 0	-3.262	0.0002	N 2 5680	-2.609	0.0008	S II 6731	-1.018	0.0313
CA B 4861	0.463	0.9474	HeFF 0	-0.463	0.1122	N 2 2140	-1.326	0.0154	S II 6716	-1.344	0.0148
CA B 1216	1.995	32.2256	HeFB 0	-0.318	0.1565	N 2 1084	-3.144	0.0002	S II 4070	-1.132	0.0240
DU B 4861	0.456	0.9304	MeFB 0	-2.712	0.0006	N 3 1750	-1.113	0.0252	S II 4078	-1.617	0.0079
Q(H) 4861	0.677	1.5492	MeFF 0	-1.991	0.0033	N 3 57	-1.074	0.0275	S II10323	-1.635	0.0075
Q(H) 1216	2.211	52.9687	ToFF 0	0.622	1.3647	O 1 6300	-1.756	0.0057	S II10289	-1.764	0.0056
TOTL 6563	0.934	2.7990	He I 4471	-0.890	0.0419	O 1 6363	-2.233	0.0019	S II10373	-2.087	0.0027
TOTL 4861	0.487	1.0000	TOTL 5876	-0.400	0.1297	O 1 630	-2.786	0.0005	S II10339	-1.767	0.0056
TOTL 4340	0.186	0.5001	Ca B 5876	-0.443	0.1174	O 1 7774	-2.711	0.0006	S 3 18	0.031	0.3503
TOTL 4102	-0.047	0.2927	TOTL10830	0.213	0.5327	TOTL 3727	0.661	1.4940	S 3 34	-0.736	0.0599
TOTL18751	-0.064	0.2810	INWD10830	-0.078	0.2727	TOTL 7325	0.006	0.3301	S 3 9532	0.695	1.6152
TOTL12818	-0.343	0.1480	TOTL 3889	-1.072	0.0276	IONZ 3727	-2.459	0.0011	S 3 9069	0.279	0.6201
TOTL10938	-0.569	0.0879	TOTL 7065	-0.628	0.0767	IONZ 7325	-2.648	0.0007	S 3 6312	-0.966	0.0352
TOTL40512	-0.754	0.0574	CcHE 0	0.489	1.0060	O II 3729	0.064	0.3773	S 3 3722	-1.195	0.0208
TOTL26252	-0.953	0.0363	He I 2	-1.088	0.0266	O II 3726	0.534	1.1156	S 3 1198	-3.215	0.0002
TOTL74578	-1.283	0.0170	DevB 2	-1.408	0.0127	O II 2471	-0.096	0.2613	S 3 1729	-2.049	0.0029
2 NU 0	1.244	5.7231	He I 5016	-1.141	0.0235	O II 7323	-0.252	0.1823	S 4 105	-0.708	0.0639
TOTL 1216	1.248	5.7728	DevB 5016	-1.259	0.0179	O II 7332	-0.343	0.1479	Ar 2 7	-1.530	0.0096
TOTL 1026	-1.621	0.0078	He I 3965	-1.434	0.0120	O 2 4651	-2.389	0.0013	Ar 3 7135	-0.131	0.2412
TOTL 973	-1.704	0.0064	DevB 3965	-1.672	0.0069	O 3 1663	-1.289	0.0167	Ar 3 7751	-0.761	0.0566
TOTL 950	-1.691	0.0066	He I 3614	-1.718	0.0062	O 3 5007	1.043	3.5994	Ar 3 22	-1.543	0.0093
TOTL 938	-1.652	0.0073	DevB 3614	-1.852	0.0046	O 3 4959	0.566	1.1998	Ar 3 9	-0.316	0.1576
C13c 6563	-2.638	0.0008	He I 3448	-1.937	0.0038	TOTL 4363	-1.235	0.0190	Ar 4 4740	-2.924	0.0004
CION 0	-2.592	0.0008	DevB 3448	-2.159	0.0023	O 3 2321	-1.862	0.0045	Ca 2 3933	-2.780	0.0005
INWD 1216	1.243	5.7059	REC 1656	-2.851	0.0005	O 3 880	-1.167	0.0222	Ca 2 7306	-2.324	0.0015
INWD 6563	0.633	1.3988	C I 9850	-3.275	0.0002	O 3 520	-0.256	0.1806	Ca2K 3934	-2.962	0.0004
INWD 4861	0.186	0.4996	C 2 158	-3.032	0.0003	Ne 2 128	0.365	0.7561	Ca2H 3969	-3.243	0.0002
INWD18751	-0.366	0.1405	C 2 2326	-0.363	0.1413	Ne 3 156	-0.093	0.2633	CaF1 7291	-2.549	0.0009
Dest 1216	1.973	30.6246	INWD 2326	-0.664	0.0706	Ne 3 361	-1.286	0.0169	CaF2 7324	-2.718	0.0006
Dest 6563	-0.834	0.0477	C 2 1335	-1.622	0.0078	Ne 3 3869	-0.410	0.1268	Fe 2 7	-1.795	0.0052
Dest 4861	-2.615	0.0008	REC 1335	-0.329	0.1527	Ne 3 3968	-0.923	0.0389	Emis 3	-1.518	0.0099
e sc18751	-1.466	0.0112	C 2 4267	-2.135	0.0024	Ne 3 1815	-3.380	0.0001	Cool 3	-1.477	0.0109
e sc40512	-2.698	0.0007	TOTL 977	-2.018	0.0031	Emis 2798	-0.194	0.2083	TOT 0	-1.328	0.0153

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nFnu 4860	0.881	2.4768	C3 C 977	-2.021	0.0031	Cool 2798	0.165	0.4770	FEIR 0	-2.631	0.0008
nFnu 1215	-1.268	0.0176	TOTL 1909	0.333	0.7009	Al 3 1860	-2.277	0.0017	Fe 3 0	-1.085	0.0268
Inci 4861	1.608	13.2183	INWD 1909	0.030	0.3490	Si 2 35	-2.647	0.0007	Fe 3 5270	-1.765	0.0056
Inci 1216	2.919	270.6663	C 3 1907	0.041	0.3585	Si 2 2335	-2.157	0.0023	Fe 3 4658	-1.521	0.0098

CONDITIONS SIMILAR TO ORION NEBULA BLISTER

```
Cooling:  GraC    0:0.051  H FF    0:0.064  H FB    0:0.106  CcHE    0:0.052  TOTL 3727:0.077  O  3 5007:0.185  S  3 9532:0.083
Heating:  BFH1    0:0.820  BFHe    0:0.067  GraH    0:0.107

IONIZE PARMET:  U(1-) -1.4765  U(4-):-37.0000  U(sp): -2.39  Q(ion):    7.012  L(ion):  -3.411 Q(low): 13.47    P(low)  2.49
ENERGY BUDGET:  Heat:   1.775  Coolg:   1.775  Error:  0.1%  Compt H:  -4.819  WorkF:    2.292 F-F  H -9.396    PRADMX:2.55E-02
Column density  H12:1.528E+21  H II:1.521E+21  HI:7.533E+18  H-:    1.532E+11  H2:   2.631E+11 H2+:6.702E+10    He H+:5.312E+10
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.317E+04  <Tp>:9.46E+03  <TO3>:9.07E+03  Ne:1.350E+04  ti(snd):1.05E+11  NeN+dl:2.24E+25 <T(C3)>:9.39E+03 <E(C3)>:1.45E+04
He/Ha:9.59E-02  =   1.01*true  N/Oap:1.05E-01  =   0.60true  T(O3R):9.269E+03  L THIN:1.00E+30 <T(S2)>:9.83E+03 <E(S2)>:1.59E+04
T He+:9.42E+03  EHe+:1.46E+04  T(O+):9.84E+03  EO+:1.60E+04  iter/zn:   2.900  Te-low:3.88E+03 Te-high:1.06E+04  Hlu/zn:3.86E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt1.99E+06  Tthr1.37E+08  <Tden>: 9.45E+03  <dens>:3.05E-20 <Mol>:6.39E-01
Mean Jeans      l(cm)1.25E+19  M(sun)9.71E+04  smallest:     len(cm):7.98E+18  M(sun):2.55E+04 Alf(ox-tran):     0.0000
  L(dust): 2.493E+00
            Gra-ISM   Sil-ISM   Gra-Ori   Sil-Ori   Sil-0.01  Sil-0.1   SilicatPN
  <Tdust>: 0.000E+00 0.000E+00 1.572E+02 1.227E+02 0.000E+00 0.000E+00 0.000E+00
  <Vel D>: 0.000E+00 0.000E+00 5.985E+04 4.910E+04 0.000E+00 0.000E+00 0.000E+00
  <Pot D>: 0.000E+00 0.000E+00 1.527E+00 1.615E+00 0.000E+00 0.000E+00 0.000E+00

Optical Depths: CONTN; COMP: 5.52E-04    H-: 2.99E-06 R(1300): 5.05E-05 H2+ 4.69E-07  HeTri:1.17E+00
 Pfa:2.39E-02   Pa:1.12E-01   Ba:5.67E-01   Hb:7.55E-01  La:1.24E+00   1r:4.847E+01  1.8:6.21E+01  4.:1.000E-20  21R:1.000E-20
10830: 5.12E+02  3889: 2.18E+01  5876: 5.70E-05  7065: 3.14E-05
 1550: 1.80E+00  2800: 1.24E+03   774: 1.00E-20  1240: 1.00E-20  1035: 1.00E-20  1335: 2.71E+03   977: 5.29E+04  1397: 6.40E+01
  789: 1.00E-20  1207: 1.42E+03  1085: 1.85E+02  1194: 2.38E+01  1909: 2.11E-02  1895: 3.80E-02  2326: 1.36E-03  1666: 4.62E-02
 1750: 5.37E-04  1025: 1.02E+01   352: 1.00E-20   347: 1.00E-20  1860: 6.45E+01   630: 1.00E-20   834: 1.90E+04   835: 2.25E+03
 1808: 1.07E+02  1256: 7.59E+00    -3: 8.36E-01   -48: 8.43E-08  3934: 5.93E-01  3969: 2.99E-01  8498: 9.53E-06  8542: 8.54E-05
 8662: 4.84E-05   353: 1.00E-20  1304: 3.48E+01  1122: 1.61E+01   990: 2.37E+03  1402: 1.00E-20  1214: 1.00E-20  1486: 1.20E-06
 2335: 2.55E-04  1406: 3.20E-03  1656: 5.44E-01  9830: 9.07E-11  8727: 2.52E-09  6300: 9.22E-08  5577: 1.61E-09  7291: 3.97E-08
 7324: 2.75E-08  1039: 4.94E+00 -8446: 3.08E-13 -4368: 1.90E-15  -132: 1.59E-13  -113: 2.52E-13   -29: 7.45E-15   -46: 5.95E-13
 -245: 1.00E-20   765: 7.32E-01 -1198: 1.00E-20   786: 1.00E-20
 C157: 8.63E-05  N122: 6.12E-05  N205: 2.63E-05   N57: 3.00E-03  O146:-6.13E-05   O63: 4.17E-04   O88: 1.82E-03   O52: 1.25E-02
  O26: 1.00E-20  NE13: 3.23E-02  NE36:-6.69E-04  NE16: 7.98E-03   MG4: 1.00E-20  MG14: 1.00E-20   MG6: 1.00E-20  SI35: 7.33E-06
  S19: 2.26E-03   S34: 6.81E-04   S11: 1.59E-04   AR7: 1.37E-04   AR9: 1.37E-03  AR22:-5.39E-05  AR13: 1.00E-20   AR8: 1.00E-20
  CA3: 9.99E-11  CA12: 1.00E-20   CA4: 1.00E-20  Ne14: 1.00E-20  Ne24: 1.00E-20   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.00E-20 Si6.5: 1.00E-20  C610: 8.45E-07  C370: 3.91E-06

Old hydro optical depths:    1 4.82E+01    2 5.29E-01    3 2.44E-01    4 1.20E-01    5 5.84E-02    6 3.10E-02    7 1.00E-02
                    Lines:  2-1 4.06E+05  3-2 5.54E-02  4-3 2.78E-08  5-4 2.08E-08  6-5 3.32E-09  7-6 2.16E-07  8-7 2.84E-06
New hydro optical depths:    1 4.82E+01    2 5.20E-01    3 2.40E-01    4 1.18E-01    5 5.74E-02    6 3.05E-02    7 9.87E-03
                    Lines:  2-1 2.04E+05  3-2 2.78E-02  4-3 1.53E-08  5-4 1.14E-08  6-5 2.58E-09  7-6 1.09E-07  8-7 1.44E-06

Old He Is optical depths:    1 3.07E+01    2 2.93E-01    3-1.95E-15    4-6.96E-15    5-1.41E-14    6-2.48E-14    7-2.78E-13
                    Lines:  2-1 1.58E+05  3-2 1.07E-02  4-3 8.24E-10  5-4 3.93E-10  6-5-5.33E-11  7-6 6.14E-09  8-7 8.08E-08
New HE Is optical depths:    1 3.13E+01    2 2.82E-01    3-1.97E-15    4-7.02E-15    5-1.42E-14    6-2.50E-14    7-2.80E-13
                    Lines:  2-1 1.62E+05  3-2 1.07E-02  4-3 8.30E-10  5-4 3.97E-10  6-5-9.78E-11  7-6 6.17E-09  8-7 8.13E-08

Old He II optical depths:    1 9.43E+01    2 2.41E+01    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 1.00E+00  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20
New HE II optical depths:    1 8.71E+01    2 2.41E+01    3 5.00E-21    4 5.00E-21    5 5.00E-21    6 5.00E-21    7 5.00E-21
                    Lines:  2-1 1.00E-20  3-2 1.00E-20  4-3 1.00E-20  5-4 1.00E-20  6-5 1.00E-20  7-6 1.00E-20  8-7 1.00E-20

Hydrogen  -2.307 -0.002                          Log10 Mean Ionisation (over volume)
Helium    -1.306 -0.022-30.000
Carbon    -4.603 -0.982 -0.048 -4.109
Nitrogen  -2.899 -0.785 -0.078 -4.092
Oxygen    -2.314 -0.304 -0.302
Neon      -2.297 -0.075 -0.816
Magnesium -3.648 -1.212 -0.028
Aluminum  -4.482 -0.871 -0.175 -0.707
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Silicon   -5.235 -1.201 -0.079 -0.984 -4.809
Sulphur   -5.895 -1.384 -0.034 -1.460
Argon     -2.604 -0.906 -0.060 -2.662
Calcium   -2.840 -1.385 -0.019 -4.876
Iron      -3.989 -1.783 -0.541 -0.158
           1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -2.307 -0.002                          Log10 Mean Ionisation (over radius)
Helium    -1.306 -0.022-30.000
Carbon    -4.603 -0.982 -0.048 -4.109
Nitrogen  -2.899 -0.785 -0.078 -4.092
Oxygen    -2.314 -0.304 -0.302
Neon      -2.297 -0.075 -0.816
Magnesium -3.648 -1.212 -0.028
Aluminum  -4.482 -0.871 -0.175 -0.707
Silicon   -5.235 -1.201 -0.079 -0.984 -4.809
Sulphur   -5.895 -1.384 -0.034 -1.460
Argon     -2.604 -0.906 -0.060 -2.662
Calcium   -2.840 -1.385 -0.019 -4.876
Iron      -3.989 -1.783 -0.541 -0.158
```

Normalised continuum

```
  0.25 1.100   0.27 0.915   0.30 0.784   0.33 0.707   0.36 0.657   0.39 0.622   0.43 0.590   0.47 0.551   0.51 0.497   0.56 0.448
  0.62 0.420   0.67 0.404   0.74 0.381   0.81 0.387   0.88 0.401   0.96 0.414   0.98 0.416   0.99 0.417   1.00 0.417
```

Emergent continuum - phot/ryd/cm2 (r in)

```
  0.26 6.49E+13  0.47 4.24E+13     0.9 2.30E+13     1.0 3.52E+07     1.6 4.68E+06    2.86E+00 2.29E-02
  0.29 5.39E+13  0.53 3.65E+13     1.0 1.97E+13     1.0 2.71E+07     1.8 9.80E+07    3.22E+00 1.39E-01
  0.33 4.93E+13  0.60 3.24E+13     1.0 1.23E+13     1.1 2.00E+06     2.0 9.93E+00    3.63E+00 3.04E-01
  0.37 4.72E+13  0.67 2.92E+13     1.0 1.06E+13     1.2 5.56E+04     2.3 6.67E-01    3.89E+00 8.14E-01
  0.42 4.49E+13  0.76 2.55E+13     1.0 4.57E+07     1.4 3.34E+04     2.5 2.64E-02
```

CLOUDY 80.08

```
************************************91Aug03*************************************
*                                                                              *
* title "New" Paris meeting HII region                                         *
* c "standard" HII region model of the Pequignot Meudon Conferance             *
* sphere                                                                       *
* black body, T=40,000K radius = 12.113943                                     *
* hden = 2                                                                     *
* radius = 18.477121                                                           *
* abund -1 C-3.6576 N-4.39794 O-3.481146 ne-4.30103 mg-8 al=-8                 *
* continue si-8 s-5.04576 ar-8 ca=-8 fe-8                                      *
* plot continuum .1                                                            *
* iterate   ; must iterate since fine structure lines are opticall thick       *
* print last                                                                   *
* c parishii.in                                                                *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

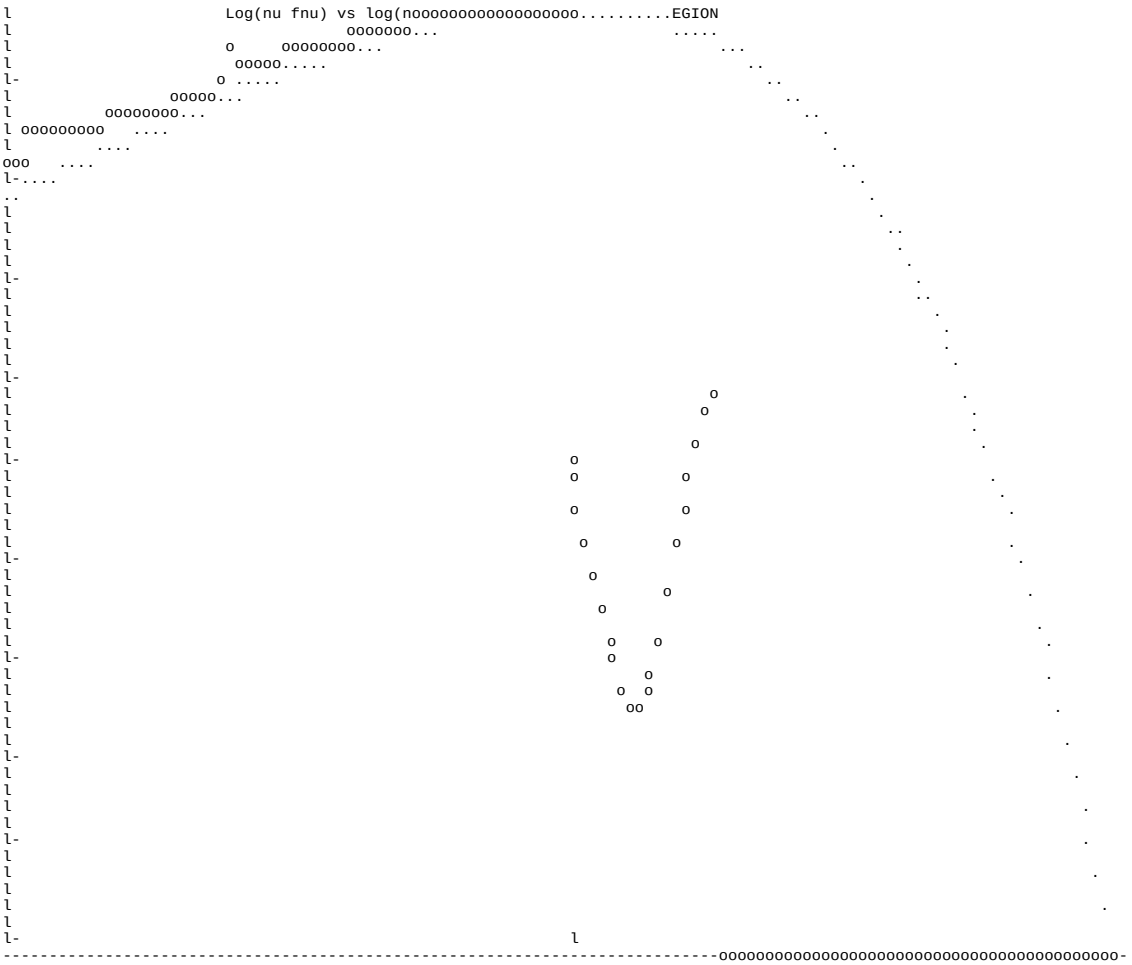
Chemical composition

He:.100 C:2.20E-04 N:4.00E-05 O:3.30E-04 Ne:5.00E-05 Mg:1.00E-08 Al:1.0E-08 Si:1.00E-08 S:9.00E-06 A:1.0E-08 Ca:1.0E-08 Fe:1.00E-08

```
          326Cell Peak9.65E-01   Lo 1.00E-05=0.9105cm   Hi-Con:9.38E+00 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  39.1048   Average nu:1.370E+00   P( X-ray):   0.0000   P(BalC):  39.2323     Q(Balmer C):  50.1283
          Q(1.0-1.8):  49.5803   Q(1.8-4.0):  48.6622   Q(4.0-20):  45.5292   Q(20--):   0.0000     Ion pht flx:3.770E+11
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  38.0134   Alf(ox):   0.0000     Total lumin:  39.4890
          L/Lsolar:     5.9062   Abs bol mg: -10.0455   Abs V mag:  -6.3924   Bol cor:  -3.6531     nuFnu(Bbet):  38.1136
          U(1.0----):1.258E-01   U(4.0----):9.976E-06   T(En-Den):1.862E+01   T(Comp):3.830E+04     nuJnu(912A):2.006E+01
          Occ(FarIR):1.129E-09   Occ(H n=6):4.006E-13   Occ(1Ryd):9.248E-16   Occ(4R):6.369E-21      Occ (Nu-hi):6.544E-30
          Tbr(FarIR):1.877E-09   Tbr(H n=6):1.779E-09   Tbr(1Ryd):1.461E-10   Tbr(4R):4.029E-15      Tbr (Nu-hi):9.547E-24

#####  1 Te:6.512E+03 Hden:1.000E+02 Ne:1.115E+02 R:3.004E+18 R-R0:3.795E+15 dR:7.591E+15 NTR:  3 Htot:2.611E-20 T912: 4.023E+01###
 -4.68 4686  0.08 5876  0.10 1909  0.01 1549  0.00 6584  0.00 5007  1.14 3727  0.01 6300  0.00 2798  0.00 1035  0.00
Hydrogen    2.968E-05 1.000E+00 H+0/Hden: 1.000E+00 2.747E-15 H-     H2 9.992E-17 5.027E-14 H2+  HeH+ 5.753E-14 H col den 7.591E+17
H 2SP 3-6   2.090E-12 2.632E-18 6.672E-19 7.923E-19 1.089E-18 1.503E-18 Texc(La); 3.797E+03 T(contn): 1.854E+01 T(diffs): 2.626E+02
Helium      1.703E-04 8.650E-01 1.349E-01 He I 2S3  2.421E-07 Comp H, C 5.224E-26 8.883E-27 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  1.701E-04 5.103E-13 1.399E-19 1.813E-19 2.526E-19 3.457E-19 He triplt 2.421E-07 4.584E-18 4.872E-20 4.317E-19 1.165E-19
HeII        8.650E-01 8.047E-14 2.180E-20 3.347E-20 5.389E-20 8.337E-20 7.416E-19 8.133E-18 1.687E-15 PRAD/GAS; 1.088E-02
Pressure    NgasTgas; 1.358E+06 P(total): 1.895E-10 P( gas ): 1.875E-10 P(Radtn): 2.040E-12 Rad accel 3.261E-08 Force Mul 1.133E+02
Carbon      0.000E+00 5.129E-03 9.118E-01 8.304E-02 2.792E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    2.156E-07 5.877E-03 8.882E-01 1.059E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      2.760E-07 2.011E-02 9.379E-01 4.196E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.437
Neon        4.023E-06 3.303E-02 9.630E-01 4.001E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.532E-07 2.222E-03 9.976E-01 1.311E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 1.981E-03 3.068E-01 6.912E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 7.070E-04 4.022E-01 5.813E-01 1.585E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 1.292E-03 6.060E-01 3.878E-01 4.902E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 6.215E-03 7.313E-01 2.619E-01 6.110E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 1.102E-05 4.082E-03 9.517E-01 4.414E-02 1.955E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 1.286E-05 2.084E-02 9.308E-01 4.834E-02 1.723E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
#####110 Te:3.810E+03 Hden:1.000E+02 Ne:5.469E+00 R:1.463E+19 R-R0:1.163E+19 dR:6.607E+14 NTR:  4 Htot:3.095E-22 T912: 8.044E+01###
 -0.74 4686  0.00 5876  0.12 1909  0.11 1549  0.00 6584  0.60 5007  1.62 3727  2.43 6300  0.01 2798  0.00 1035  0.00
Hydrogen    9.456E-01 5.444E-02 H+0/Hden: 1.000E+00 7.555E-09 H-     H2 3.703E-08 2.186E-09 H2+  HeH+ 7.418E-11 H col den 1.163E+21
H 2SP 3-6   3.118E-13 2.143E-16 9.240E-20 1.498E-19 2.589E-19 4.333E-19 Texc(La); 2.955E+03 T(contn): 7.380E+00 T(diffs): 3.255E+02
Helium      1.000E+00 0.000E+00 0.000E+00 He I 2S3  0.000E+00 Comp H, C 4.610E-29 7.081E-30 Fill Fact 1.000E+00 Gam 1/tot 1.000E+00
He singlet  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 He triplt 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
HeII        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 PRAD/GAS; 2.186E-02
```

```
Pressure    NgasTgas; 4.958E+05 P(total): 7.083E-11 P( gas ): 6.845E-11 P(Radtn): 2.376E-12 Rad accel 2.035E-10 Force Mul 5.839E+02
Carbon      7.026E-05 9.985E-01 1.478E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    9.711E-01 2.887E-02 2.597E-15 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.532E-01 4.682E-02 7.083E-15 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.215
Neon        8.562E-01 1.438E-01 1.116E-10 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 2.988E-04 9.974E-01 2.328E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 4.590E-05 9.978E-01 2.159E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 4.808E-05 9.999E-01 6.979E-06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.800E-05 9.826E-01 1.737E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 7.679E-01 2.321E-01 6.940E-13 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 2.146E-05 2.294E-02 9.770E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 8.460E-04 9.991E-01 5.424E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest Te reached.
  Geometry is spherical.
  Photoionization of He 2TriS reached   2.9 percent of the total rate out.
  Some fine struc lines are optically thick, largest=7.02E-01
  Frequency out of range of free-free gaunt factor routine.
```




```
 ********************************> CLOUDY 80.08  <********************************
 * title "New" Paris meeting HII region                                            *
 * c "standard" HII region model of the Pequignot Meudon Conferance                *
 * sphere                                                                          *
 * black body, T=40,000K radius = 12.113943                                        *
 * hden = 2                                                                        *
 * radius = 18.477121                                                              *
 * abund -1 C-3.6576 N-4.39794 O-3.481146 ne-4.30103 mg-8 al=-8                    *
 * plot continuum .1                                                               *
 * iterate   ; must iterate since fine structure lines are opticall thick          *
 * print last                                                                      *
 * c parishii.in                                                                   *
 * c cray                                                                          *
 ********************************> LOG(U): -0.90 <********************************
```

Emission Line Spectrum. Constant Density Model. Closed geometry. Iteration 2 of 2.
Luminosity (erg/s) emitted by shell with full coverage.

TOTL	4861	37.310	1.0000	PA C	0	37.407	1.2508	C 2	1335	34.916	0.0040	O 3	5007	37.518	1.6163
TOTL	1216	38.679	23.4002	H FF	0	37.334	1.0577	REC	1335	36.324	0.1032	O 3	4959	37.041	0.5388
TotH	0	38.499	15.4491	H FB	0	37.507	1.5756	C 2	4267	34.490	0.0015	TOTL	4363	34.921	0.0041
BFH1	0	38.460	14.1209	Cool	1216	36.286	0.0946	TOTL	977	34.292	0.0010	O 3	2321	34.294	0.0010
BFHe	0	37.405	1.2447	Crst	960	33.560	0.0002	C3 R	977	34.273	0.0009	O 3	880	37.383	1.1839
TotM	0	36.230	0.0833	H-FB	0	33.758	0.0003	TOTL	1909	36.344	0.1081	O 3	520	37.346	1.0880
H- H	0	33.535	0.0002	H2+	0	33.478	0.0001	INWD	1909	36.035	0.0532	O 4	26	34.166	0.0007
CA B	4861	37.313	1.0067	HeFF	0	36.205	0.0786	C 3	1907	36.125	0.0653	Ne 2	128	36.672	0.2301
CA B	1216	38.839	33.8374	HeFB	0	36.387	0.1194	C 3	1909	35.941	0.0428	Ne 3	156	36.963	0.4500
DU B	4861	37.313	1.0067	MeFB	0	33.963	0.0005	C3 R	1909	34.111	0.0006	Ne 3	361	35.896	0.0385
Q(H)	4861	37.307	0.9926	MeFF	0	34.577	0.0019	Phot	1909	35.135	0.0067	Ne 3	3869	36.261	0.0894
Q(H)	1216	38.840	33.9366	ToFF	0	37.366	1.1381	C 3	2297	33.767	0.0003	Ne 3	3968	35.748	0.0274
TOTL	6563	37.739	2.6838	He I	4471	35.900	0.0390	C 4	1549	33.333	0.0001	Emis	2798	33.534	0.0002
TOTL	4861	37.310	1.0000	TOTL	5876	36.375	0.1163	N 1	5200	34.463	0.0014	Cool	2798	33.534	0.0002
TOTL	4340	37.018	0.5110	Ca B	5876	36.364	0.1133	REC	5200	33.455	0.0001	Si 2	35	33.350	0.0001
TOTL	4102	36.793	0.3045	TOTL	10830	36.631	0.2094	N 2	6584	37.089	0.6014	S 2	6720	36.774	0.2910
TOTL	18751	36.752	0.2769	INWD	10830	36.111	0.0633	N 2	6548	36.612	0.2005	S 2	4074	35.441	0.0135
TOTL	12818	36.487	0.1506	TOTL	3889	36.130	0.0662	REC	6584	33.922	0.0004	S	210330	35.268	0.0091
TOTL	10938	36.270	0.0913	TOTL	7065	35.676	0.0232	N 2	5755	35.178	0.0074	S II	6731	36.407	0.1250
TOTL	40512	36.076	0.0584	CcHE	0	35.765	0.0285	N 2	122	35.814	0.0319	S II	6716	36.530	0.1661
TOTL	26252	35.886	0.0377	He I	2	35.700	0.0245	N 2	203	35.347	0.0109	S II	4070	35.318	0.0102
TOTL	74578	35.556	0.0176	DevB	2	35.620	0.0204	N 2	5680	33.862	0.0004	S II	4078	34.835	0.0034
2 NU	0	38.335	10.5888	He I	5016	35.641	0.0214	N 2	2140	35.223	0.0082	S II	10323	34.815	0.0032
TOTL	1216	38.679	23.4002	DevB	5016	35.614	0.0202	N 3	1750	34.513	0.0016	S II	10289	34.686	0.0024
TOTL	1026	35.176	0.0074	He I	3965	35.345	0.0109	N 3	57	36.516	0.1608	S II	10373	34.365	0.0011
TOTL	973	35.116	0.0064	DevB	3965	35.277	0.0093	O 1	6300	35.216	0.0081	S II	10339	34.685	0.0024
TOTL	950	35.102	0.0062	He I	3614	35.062	0.0057	O 1	6363	34.739	0.0027	S 3	18	37.041	0.5381
TOTL	938	35.096	0.0061	DevB	3614	35.034	0.0053	O 1	630	34.467	0.0014	S 3	34	37.273	0.9192
C13c	6563	34.187	0.0008	He I	3448	34.843	0.0034	O 1	1470	33.438	0.0001	S 3	9532	37.327	1.0417
CION	0	34.184	0.0007	DevB	3448	34.792	0.0030	O 1	7774	34.024	0.0005	S 3	9069	36.912	0.3999
INWD	1216	38.640	21.3947	TOTL	1640	34.337	0.0011	6lev	1304	33.367	0.0001	S 3	6312	35.474	0.0146
INWD	6563	37.437	1.3410	TOTL	4686	33.376	0.0001	TOTL	3727	37.695	2.4298	S 3	3722	35.245	0.0086
INWD	4861	37.009	0.5000	TOTL	1216	33.933	0.0004	TOTL	7325	35.876	0.0368	S 3	1729	34.141	0.0007
INWD	18751	36.451	0.1385	Ca B	1640	34.401	0.0012	IONZ	3727	34.748	0.0027	S 4	105	36.343	0.1079
Dest	1216	35.519	0.0162	DevB	1640	34.401	0.0012	IONZ	7325	34.079	0.0006	Ar 3	7135	33.895	0.0004
e sc	18751	36.753	0.2772	Ca B	4686	33.621	0.0002	O II	3729	37.450	1.3805	Ar 3	9	33.924	0.0004
e sc	40512	36.077	0.0585	DevB	4686	33.619	0.0002	O II	3726	37.330	1.0466	Ca 2	3933	33.870	0.0004
nFnu	4860	37.777	2.9328	REC	1656	34.207	0.0008	O II	2471	35.774	0.0291	Ca 2	7306	34.431	0.0013
nFnu	1215	35.066	0.0057	C I	9850	34.379	0.0012	O II	7323	35.618	0.0203	Ca2K	3934	33.684	0.0002
Inci	4861	38.114	6.3672	C 2	158	36.152	0.0695	O II	7332	35.527	0.0165	Ca2H	3969	33.411	0.0001
Inci	1216	39.299	97.5993	C 2	2326	36.529	0.1656	O 2	4651	34.375	0.0012	CaF1	7291	34.207	0.0008

```
BA C    0 37.912   3.9988      INWD 2326 36.228   0.0828      O  3 1663 34.690   0.0024      CaF2 7324 34.037   0.0005
```

```
                          "NEW" PARIS MEETING HII REGION
Cooling:  H FF    0:0.068  H FB    0:0.102  TOTL 3727:0.157  O  3 5007:0.105  O  3  880:0.077  O  3  520:0.070  S  3 9532:0.067
Heating:  BFH1    0:0.914  BFHe    0:0.081

IONIZE PARMET:  U(1-) -0.9004  U(4-): -5.0011  U(sp): -2.27  Q(ion):   44.552  L(ion):  34.128 Q(low): 50.22    P(low) 39.26
ENERGY BUDGET:  Heat:  38.499  Coolg:  38.499  Error:  0.1%  Compt H:  31.699  WorkF:   39.074 F-F  H 32.553    PRADMX:1.97E-01
Column density  H12:1.163E+21  H II:1.157E+21  HI:6.387E+18  H-:    1.571E+11  H2:   2.938E+11 H2+:6.519E+10    He H+:2.089E+10
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+02  <Tp>:7.64E+03  <TO3>:7.22E+03  Ne:1.101E+02  ti(snd):1.18E+13  NeN+dl:1.26E+23 <T(C3)>:7.45E+03 <E(C3)>:1.10E+02
He/Ha:8.60E-02  =   0.86*true  N/Oap:4.96E-02  =   0.41true  T(O3R):7.686E+03  L THIN:1.00E+30 <T(S2)>:8.82E+03 <E(S2)>:9.82E+01
T He+:7.42E+03  EHe+:1.10E+02  T(O+):8.46E+03  EO+:1.06E+02  iter/zn:   2.296  Te-low:3.81E+03 Te-high:1.01E+04  Hlu/zn:2.94E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt7.38E+09  Tthr1.11E+10  <Tden>: 7.65E+03  <dens>:2.34E-22 <Mol>:6.46E-01
Mean Jeans      l(cm)3.25E+20  M(sun)2.11E+06  smallest:     len(cm):2.29E+20  M(sun):7.42E+05 Alf(ox-tran):     0.0000

Optical Depths: CONTN; COMP: 4.19E-04    H-: 3.06E-06 R(1300): 4.29E-05 H2+ 4.56E-07  HeTri:9.77E-04
 Pfa:8.38E-04   Pa:8.38E-04   Ba:8.43E-04   Hb:8.42E-04  La:1.94E-03   1r:4.022E+01  1.8:1.16E+02  4.:4.314E+01  21R:1.000E-20
10830: 4.01E+01  3889: 1.71E+00  5876: 2.04E-08  7065: 1.12E-08
 1550: 4.09E+02  2800: 1.23E+00   774: 1.00E-20  1240: 1.00E-20  1035: 1.00E-20  1335: 5.92E+03   977: 7.50E+04  1397: 1.05E+00
  789: 4.45E+00  1207: 1.29E+01  1085: 3.14E+02  1194: 6.29E+01  1909: 2.99E-02  1895: 3.45E-04  2326: 2.96E-03  1666: 1.20E-01
 1750: 6.15E-04  1025: 2.10E+01   352: 1.00E-20   347: 1.00E-20  1860: 9.21E+00   630: 1.00E-20   834: 2.37E+04   835: 5.82E+03
 1808: 1.22E+00  1256: 3.08E+01    -3: 1.58E-02   -48: 7.26E-12  3934: 1.55E+00  3969: 7.82E-01  8498: 1.25E-07  8542: 1.12E-06
 8662: 6.36E-07   353: 1.00E-20  1304: 7.20E+01  1122: 2.42E-01   990: 2.71E+03  1402: 5.93E-05  1214: 1.00E-20  1486: 2.70E-04
 2335: 2.91E-06  1406: 2.47E-02  1656: 2.58E+00  9830: 4.31E-10  8727: 1.24E-10  6300: 1.91E-07  5577: 1.60E-11  7291: 1.04E-07
 7324: 7.18E-08  1039: 1.02E+01 -8446: 1.24E-14 -4368: 5.49E-17  -132: 1.69E-15  -113: 2.68E-15   -29: 8.23E-17   -46: 6.33E-15
 -245: 1.00E-20   765: 1.64E+02 -1198: 1.95E-04   786: 5.82E-01
 C157: 5.52E-03  N122: 3.52E-03  N205: 7.74E-03   N57: 4.22E-02  O146:-1.26E-05   O63: 2.17E-03   O88: 7.02E-01   O52: 8.88E-02
  O26: 1.93E-04  NE13: 1.75E-02  NE36:-5.75E-05  NE16: 4.41E-02   MG4: 2.44E-11  MG14: 1.00E-20   MG6: 1.00E-20  SI35: 1.39E-06
  S19: 1.54E-03   S34: 4.89E-02   S11: 1.97E-03   AR7: 2.38E-06   AR9: 1.43E-05  AR22:-6.51E-09  AR13: 4.40E-10   AR8: 1.05E-13
  CA3: 5.58E-08  CA12:-3.94E-17   CA4: 1.66E-12  Ne14: 1.00E-20  Ne24: 1.00E-20   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.00E-20 Si6.5: 1.00E-20  C610: 2.78E-07  C370: 4.39E-05

Old hydro optical depths:    1 4.02E+01    2 2.96E-06    3 5.82E-06    4 1.64E-06    5 1.10E-13    6 2.74E-13    7 1.01E-12
                   Lines:  2-1 4.17E+05  3-2 8.89E-04  4-3 1.59E-10  5-4 8.30E-11  6-5-2.16E-10  7-6 2.00E-09  8-7 2.69E-08
New hydro optical depths:    1 4.02E+01    2 3.04E-06    3 5.98E-06    4 1.69E-06    5 1.10E-13    6 2.73E-13    7 1.01E-12
                   Lines:  2-1 2.08E+05  3-2 4.44E-04  4-3 7.95E-11  5-4 4.18E-11  6-5-1.07E-10  7-6 9.98E-10  8-7 1.34E-08

Old He Is optical depths:    1 5.74E+01    2 6.94E-05    3-2.03E-17    4-6.34E-17    5-1.26E-16    6-2.20E-16    7-2.43E-15
                   Lines:  2-1 5.46E+05  3-2 4.74E-05  4-3 9.80E-12  5-4 3.58E-12  6-5-8.42E-12  7-6 8.48E-11  8-7 1.14E-09
New HE Is optical depths:    1 5.90E+01    2 7.00E-05    3-2.02E-17    4-6.30E-17    5-1.26E-16    6-2.19E-16    7-2.42E-15
                   Lines:  2-1 5.63E+05  3-2 4.73E-05  4-3 9.77E-12  5-4 3.60E-12  6-5-8.32E-12  7-6 8.44E-11  8-7 1.13E-09

Old He II optical depths:    1 2.15E+01    2 2.01E+01    3-2.27E-19    4-5.71E-19    5-1.11E-18    6-1.94E-18    7-2.10E-17
                   Lines:  2-1 3.88E+05  3-2 2.39E-08  4-3 3.31E-15  5-4-2.91E-15  6-5-2.55E-14  7-6 6.62E-14  8-7 9.70E-13
New HE II optical depths:    1 2.16E+01    2 2.01E+01    3-2.27E-19    4-5.69E-19    5-1.11E-18    6-1.93E-18    7-2.09E-17
                   Lines:  2-1 3.73E+05  3-2 2.37E-08  4-3 3.28E-15  5-4-2.84E-15  6-5-2.51E-14  7-6 6.56E-14  8-7 9.60E-13

Hydrogen  -1.900 -0.006                          Log10 Mean Ionisation (over volume)
Helium    -0.569 -0.137 -3.901
Carbon    -3.767 -0.539 -0.151 -2.412 -7.706
Nitrogen  -2.041 -0.367 -0.255 -2.336
Oxygen    -1.889 -0.267 -0.351 -4.444
Neon      -1.860 -0.231 -0.399 -5.340
Magnesium -3.306 -0.869 -0.063 -6.601
Aluminum  -4.150 -0.587 -0.185 -1.054
Silicon   -4.831 -0.815 -0.109 -1.161 -3.426
Sulphur   -5.528 -0.931 -0.071 -1.467 -4.127
Argon     -2.220 -0.434 -0.215 -1.775 -6.237
Calcium   -2.441 -0.987 -0.050 -2.864 -8.095
Iron      -3.220 -1.273 -0.292 -0.362 -4.376 -8.462
```

```
          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -2.260 -0.002                          Log10 Mean Ionisation (over radius)
Helium    -0.903 -0.059 -2.933
Carbon    -4.070 -0.796 -0.082 -1.951 -6.727
Nitrogen  -2.410 -0.626 -0.127 -1.861
Oxygen    -2.260 -0.470 -0.183 -3.475
Neon      -2.208 -0.409 -0.219 -4.380
Magnesium -3.654 -1.152 -0.032 -5.656
Aluminum  -4.475 -0.850 -0.184 -0.689
Silicon   -5.177 -1.110 -0.120 -0.788 -2.788
Sulphur   -5.886 -1.205 -0.072 -1.050 -3.448
Argon     -2.595 -0.694 -0.126 -1.326 -5.267
Calcium   -2.752 -1.194 -0.031 -2.399 -7.109
Iron      -3.590 -1.610 -0.486 -0.188 -3.409 -7.471


                                                Normalised continuum
  0.25 2.551   0.27 1.992   0.30 1.632   0.33 1.427   0.36 1.325   0.39 1.260   0.43 1.227   0.47 1.210   0.51 1.201   0.56 1.192
  0.62 1.177   0.67 1.140   0.74 1.035   0.81 1.000   0.88 1.000   0.97 1.000   0.98 1.000   0.99 1.000   1.00 1.000

                                               Emergent continuum - phot/ryd/cm2 (r in)
  0.26 4.16E+12  0.53 2.22E+12     1.0 9.46E+11     1.2 4.74E+04     2.5 2.92E-03    4.18E+00 8.32E-10    8.45E+00 1.48E-02
  0.29 3.18E+12  0.60 2.06E+12     1.0 9.31E+11     1.4 3.88E+04     2.9 4.61E-05    4.66E+00 6.51E-07
  0.33 2.71E+12  0.67 1.82E+12     1.0 1.60E+07     1.6 2.13E+06     3.2 3.46E-07    5.25E+00 1.06E-04
  0.37 2.51E+12  0.76 1.42E+12     1.0 1.24E+07     1.8 2.67E+07     3.6 1.99E-06    5.91E+00 4.36E-03
  0.42 2.40E+12  0.86 1.21E+12     1.0 9.68E+06     2.0 1.75E+00     3.9 5.02E-05    6.66E+00 2.77E-02
  0.47 2.32E+12  0.97 9.86E+11     1.1 8.69E+05     2.3 9.45E-02     4.0 3.07E-11    7.50E+00 3.92E-02
```

```
                                          CLOUDY 80.08

                                    ***********************************91Aug03***********************************
                                    *                                                                           *
                                    * title paris meeting NLR model                                             *
                                    * iterate                                                                   *
                                    * print last iteration                                                      *
                                    * interpolate (0 -10) (0.073 -10) (0.074 1) (7352 -4)                       *
                                    * CONTINUE (7400 -15) (7,353,000 -20)                                       *
                                    * stop lyman continuum optical depth 4                                      *
                                    * hden 3                                                                    *
                                    * abund -1 C-3.5229 N-4. O-3.22185 ne-3.82391 mg-4.5229 al=-8               *
                                    * continue si-4.5229 s-4.82391 ar-8 ca=-8 fe-7                              *
                                    * ionization parameter -2                                                   *
                                    * c parisnlr.in                                                             *
                                    * c cray                                                                    *
                                    *                                                                           *
                                    *****************************************************************************


                                                Chemical composition
He:.100 C:3.00E-04 N:1.00E-04 O:6.00E-04 Ne:1.50E-04 Mg:3.00E-05 Al:1.0E-08 Si:3.00E-05 S:1.50E-05 A:1.0E-08 Ca:1.0E-08 Fe:1.00E-07

         478Cell Peak1.57E+02   Lo 1.00E-05=0.9120cm   Hi-Con:8.70E+03 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
         P(nu>1ryd):   1.7642   Average nu:8.888E+00   P( X-ray):   1.5829   P(BalC):   0.9577     Q(Balmer C):  11.9548
         Q(1.0-1.8):  11.1278   Q(1.8-4.0):  10.9587   Q(4.0-20):  10.7803   Q(20--):  10.1653     Ion pht flx:3.001E+11
         L(gam ray):  -0.9305   Q(gam ray):   5.8744   L(Infred):   0.9013   Alf(ox):  -1.0006     Total lumin:   1.8759
         U(1.0----):1.001E-02   U(4.0----):2.499E-03   T(En-Den):2.399E+01   T(Comp):1.914E+07     nuJnu(912A):6.540E+00
         Occ(FarIR):3.514E-11   Occ(H n=6):1.838E-21   Occ(1Ryd):3.015E-16   Occ(4R):1.171E-18     Occ (Nu-hi):5.951E-43
         Tbr(FarIR):5.835E-11   Tbr(H n=6):8.161E-18   Tbr(1Ryd):4.763E-11   Tbr(4R):7.408E-13     Tbr (Nu-hi):7.784E-34

#####  1 Te:1.581E+04 Hden:1.000E+03 Ne:1.199E+03 R:1.000E+25 R-R0:6.851E+15 dR:1.370E+16 NTR:  2 Htot:9.534E-18 T912: 4.541E-02###
 -2.55 4686  0.35 5876  0.00 1909  2.06 1549  9.82 6584  0.01 5007  2.43 3727  0.02 6300  0.00 2798  0.00 1035  0.27
Hydrogen    5.265E-04 9.995E-01 H+0/Hden: 1.000E+00 6.113E-12 H-     H2 4.303E-13 6.269E-12 H2+  HeH+ 8.723E-13 H col den 1.370E+19
H 2SP 3-6   1.577E-11 2.540E-15 5.930E-18 5.981E-18 7.434E-18 9.454E-18 Texc(La); 4.356E+03 T(contn): 2.394E+01 T(diffs): 2.548E+02
Helium      4.202E-05 4.978E-02 9.502E-01 He I 2S3  5.410E-08 Comp H, C 7.242E-22 5.980E-25 Fill Fact 1.000E+00 Gam 1/tot 9.715E-01
He singlet  4.197E-05 3.206E-13 2.514E-20 3.406E-20 4.883E-20 6.715E-20 He triplt 5.410E-08 6.583E-18 3.616E-20 2.134E-19 3.172E-20
HeII        4.978E-02 2.932E-12 7.846E-19 1.168E-18 1.819E-18 2.723E-18 2.298E-17 2.278E-16 4.159E-14 PRAD/GAS; 7.285E-03
Pressure    NgasTgas; 3.551E+07 P(total): 4.938E-09 P( gas ): 4.902E-09 P(Radtn): 3.571E-11 Rad accel 4.636E-07 Force Mul 5.468E+02
Carbon      1.868E-06 4.103E-03 1.929E-01 5.223E-01 2.531E-01 2.710E-02 4.342E-04 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    3.210E-07 9.353E-04 1.073E-01 3.647E-01 3.026E-01 2.176E-01 6.784E-03 4.097E-05 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      1.408E-07 5.399E-04 8.715E-02 4.006E-01 3.087E-01 1.569E-01 4.597E-02 1.612E-04 0.000E+00 Hex(tot): 0.000E+00 A:-12.624
Neon        0.000E+00 6.212E-05 2.628E-02 1.977E-01 5.383E-01 2.291E-01 7.055E-03 1.513E-03 9.476E-05 0.000E+00 0.000E+00
Magnesium 0 2.470E-07 5.261E-05 5.304E-03 4.293E-02 1.008E-01 3.868E-01 3.677E-01 8.839E-02 7.611E-03 4.013E-04 1.247E-05 0.000E+00
Aluminium 0 7.793E-07 1.009E-03 5.493E-03 2.914E-02 7.210E-02 3.115E-01 4.179E-01 1.491E-01 1.317E-02 5.210E-04 1.335E-05 0.000E+00
Silicon   0 0.000E+00 2.186E-04 8.186E-03 2.927E-02 4.741E-02 2.293E-01 3.869E-01 2.450E-01 5.015E-02 3.378E-03 1.086E-04 0.000E+00
Sulphur   0 0.000E+00 5.210E-04 2.650E-02 5.876E-02 5.632E-02 2.276E-01 3.111E-01 2.290E-01 7.905E-02 1.058E-02 5.914E-04 1.763E-05
Argon     1 1.344E-04 8.416E-03 3.735E-02 6.014E-02 1.516E-01 2.522E-01 2.351E-01 2.154E-01 3.606E-02 3.428E-03 1.249E-04 2.281E-06
Calcium   0 0.000E+00 1.967E-04 2.679E-03 1.493E-02 2.811E-02 1.542E-01 3.260E-01 3.007E-01 1.273E-01 3.650E-02 8.888E-03 4.422E-04
Iron      1 0.000E+00 2.775E-05 1.345E-03 1.107E-02 1.214E-01 3.421E-01 4.040E-01 8.556E-02 2.937E-02 4.622E-03 4.981E-04 4.084E-05
#####100 Te:9.406E+03 Hden:1.000E+03 Ne:1.649E+02 R:1.000E+25 R-R0:3.164E+18 dR:1.502E+17 NTR:  5 Htot:8.789E-19 T912: 1.001E+04###
 -0.86 4686  0.24 5876  0.10 1909  6.14 1549  9.64 6584  2.31 5007 25.00 3727  3.08 6300  1.07 2798  2.67 1035  0.12
Hydrogen    8.515E-01 1.485E-01 H+0/Hden: 1.000E+00 3.245E-09 H-     H2 1.171E-07 6.778E-09 H2+  HeH+ 4.926E-08 H col den 3.239E+21
H 2SP 3-6   6.738E-12 2.789E-13 5.526E-19 6.638E-19 9.901E-19 1.436E-18 Texc(La); 3.726E+03 T(contn): 2.140E+01 T(diffs): 2.468E+02
Helium      8.480E-01 1.485E-01 3.569E-03 He I 2S3  4.549E-08 Comp H, C 1.017E-22 3.104E-26 Fill Fact 1.000E+00 Gam 1/tot 6.553E-02
He singlet  8.480E-01 8.513E-14 1.598E-20 2.093E-20 3.135E-20 4.521E-20 He triplt 4.549E-08 3.558E-16 2.375E-20 4.254E-19 1.935E-20
HeII        1.485E-01 2.235E-15 5.963E-22 9.018E-22 1.423E-21 2.155E-21 1.861E-20 1.935E-19 4.488E-17 PRAD/GAS; 2.180E-02
Pressure    NgasTgas; 1.218E+07 P(total): 1.739E-09 P( gas ): 1.681E-09 P(Radtn): 5.772E-11 Rad accel 1.677E-08 Force Mul 2.266E+02
Carbon      1.748E-04 8.811E-01 1.185E-01 1.114E-04 7.142E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
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Nitrogen    3.065E-01 6.927E-01 6.522E-04 1.389E-04 1.400E-07 2.274E-05 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      8.649E-01 1.345E-01 6.662E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.565
Neon        2.720E-02 2.589E-01 7.137E-01 1.514E-04 3.816E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 1.910E-03 6.500E-01 3.479E-01 1.347E-04 9.646E-06 1.231E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 7.034E-05 6.335E-01 1.727E-01 1.065E-01 4.042E-02 3.298E-02 1.168E-02 2.017E-03 1.662E-04 0.000E+00 0.000E+00 0.000E+00
Silicon   0 6.545E-05 9.969E-01 2.076E-03 8.597E-04 8.358E-07 6.355E-05 3.752E-05 1.240E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.099E-05 6.073E-01 3.921E-01 3.338E-04 4.732E-05 1.400E-04 4.422E-05 3.191E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 8.037E-02 7.427E-01 1.760E-01 2.431E-04 4.941E-05 1.895E-04 1.360E-04 1.331E-04 1.033E-04 3.022E-05 0.000E+00 0.000E+00
Calcium   0 1.769E-03 5.795E-02 9.069E-01 1.053E-02 3.932E-04 9.923E-03 5.176E-03 4.690E-03 1.754E-03 7.442E-04 2.066E-04 0.000E+00
Iron      0 6.536E-03 9.651E-01 1.506E-02 4.929E-04 4.803E-03 3.689E-03 2.616E-03 1.196E-03 3.574E-04 1.340E-04 0.000E+00 0.000E+00
  Calculation stopped because optical depth reached
  Geometry is plane-parallel.
  FeII-MgII photoionization of H N=2 reached  10.8 percent of the total rate out.
  Photoionization of He 2TriS reached  14.5 percent of the total rate out.
C-Continuum not defined at gamma-ray energies - pair production and Compton scattering OK?
  Some fine struc lines are optically thick, largest=8.54E-01
  Frequency out of range of free-free gaunt factor routine.
  The optical depth to Rayleigh scattering at 1300A is 1.07E-02
```

```
**********************************> CLOUDY 80.08  <**********************************
* title paris meeting NLR model                                                      *
* iterate                                                                            *
* print last iteration                                                               *
* interpolate (0 -10) (0.073 -10) (0.074 1) (7352 -4)                                *
* stop lyman continuum optical depth 4                                               *
* hden 3                                                                             *
* abund -1 C-3.5229 N-4. O-3.22185 ne-3.82391 mg-4.5229 al=-8                        *
* ionization parameter -2                                                            *
* c parisnlr.in                                                                      *
* c cray                                                                             *
**********************************> LOG(U): -2.00 <**********************************
>>>>>>>>>> Cautions are present.

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 2 of 2.
                                                Intensity (erg/s/cm^2)

TOTL 4861 -0.860   1.0000      He I    2 -2.514   0.0221      O  1 6363 -1.308   0.3559      Mg 7 2629 -1.831   0.1067
TOTL 1216  0.683  34.9131      DevB    2 -3.289   0.0037      O  1 5577 -2.701   0.0144      Mg 8    3 -2.158   0.0503
TotH    0  1.235 124.3059      He I 5016 -2.560   0.0199      O  1  630 -1.323   0.3440      Al 3 1860 -4.609   0.0002
BFH1    0  0.679  34.6054      DevB 5016 -2.913   0.0089      O  1 1470 -2.447   0.0259      Si 2   35 -0.833   1.0627
BFHe    0  0.901  57.6624      He I 3965 -2.849   0.0103      O  1 7774 -4.429   0.0003      Si 2 2335 -1.520   0.2186
TotM    0  0.645  32.0009      DevB 3965 -3.412   0.0028      T OI    0 -2.875   0.0097      Si 2 1808 -2.548   0.0205
ComH    0 -2.946   0.0082      He I 3614 -3.132   0.0053      6lev 1304 -2.880   0.0095      Si 3 1207 -2.318   0.0348
H- H    0 -2.565   0.0197      DevB 3614 -3.548   0.0020      TOTL 3727 -0.372   3.0760      Si 3 1895 -1.206   0.4505
CA B 4861 -0.866   0.9856      He I 3448 -3.351   0.0032      TOTL 7325 -1.810   0.1122      PHOT 1895 -3.350   0.0032
CA B 1216  0.680  34.6504      DevB 3448 -3.948   0.0008      IONZ 3727 -3.257   0.0040      Si 4 1397 -1.525   0.2160
DU B 4861 -0.866   0.9856      HeII  228 -0.532   2.1282      IONZ 7325 -3.817   0.0011      Si 6   19 -1.676   0.1526
Q(H) 4861 -0.846   1.0319      ESC   304 -0.891   0.9315      O II 3729 -0.695   1.4597      Si 7 2148 -2.420   0.0275
Q(H) 1216  0.688  35.2817      He2C  911 -1.251   0.4064      O II 3726 -0.652   1.6123      Si 7   25 -1.528   0.2149
TOTL 6563 -0.397   2.9032      TOTL 1640 -0.499   2.2947      O II 2471 -1.909   0.0892      Si 7   65 -2.773   0.0122
TOTL 4861 -0.860   1.0000      TOTL 4686 -1.473   0.2437      O II 7323 -2.066   0.0621      Si 8 1446 -3.039   0.0066
TOTL 4340 -1.163   0.4972      TOTL 1216 -0.915   0.8797      O II 7332 -2.160   0.0501      Si 9 1985 -3.434   0.0027
TOTL 4102 -1.398   0.2897      Ca B 1640 -0.445   2.5996      O II  834 -4.010   0.0007      Si 9    3 -3.014   0.0070
TOTL18751 -1.416   0.2775      DevB 1640 -0.447   2.5870      O  2 4651 -3.404   0.0029      Si 9    2 -4.144   0.0005
TOTL12818 -1.694   0.1466      Ca B 4686 -1.310   0.3545      O  3 1663 -0.859   1.0020      Si1014300 -3.543   0.0021
TOTL10938 -1.921   0.0869      DevB 4686 -1.316   0.3497      Phot 1663 -3.814   0.0011      S  2 6720 -0.695   1.4603
TOTL40512 -2.105   0.0569      C  1 1656 -4.753   0.0001      Augr 1663 -2.719   0.0138      S  2 4074 -1.858   0.1003
TOTL26252 -2.305   0.0359      REC  1656 -3.649   0.0016      Rec  1663 -2.291   0.0371      S  210330 -2.031   0.0674
TOTL74578 -2.635   0.0168      C  I 9850 -3.524   0.0022      O  3 5007  0.538  24.9979      S II 6731 -1.025   0.6835
2 NU    0  0.349  16.1707      C  1 8727 -4.593   0.0002      O  3 4959  0.061   8.3326      S II 6716 -0.969   0.7768
TOTL 1216  0.683  34.9131      C  2  158 -2.048   0.0649      TOTL 4363 -1.228   0.4280      S II 4070 -1.982   0.0754
TOTL 1026 -3.614   0.0018      C  2 2326 -0.913   0.8840      Rec  4363 -3.344   0.0033      S II 4078 -2.463   0.0249
TOTL  973 -3.557   0.0020      INWD 2326 -1.208   0.4481      O  3 2321 -1.855   0.1010      S II10323 -2.485   0.0237
TOTL  950 -3.525   0.0022      C  2 1335 -2.135   0.0531      C EX 4363 -3.872   0.0010      S II10289 -2.614   0.0176
TOTL  938 -3.471   0.0024      REC  1335 -1.888   0.0936      C EX 5592 -3.801   0.0011      S II10373 -2.933   0.0084
LA X 1216 -0.756   1.2701      C  2 4267 -3.630   0.0017      O  3  880 -0.896   0.9208      S II10339 -2.613   0.0176
C13c 6563 -1.697   0.1456      TOTL  977 -1.169   0.4909      O  3  520 -0.483   2.3803      S II 1256 -4.537   0.0002
C14c 4861 -2.765   0.0124      C3 C  977 -1.251   0.4057      O  3  834 -2.416   0.0278      S  3   18 -1.122   0.5467
CION    0 -1.553   0.2027      C3 R  977 -1.930   0.0852      O  3 3341 -3.704   0.0014      S  3   34 -1.053   0.6402
INWD 1216  0.646  32.0066      TOTL 1909 -0.071   6.1439      O  4   26 -0.114   5.5681      S  3 9532 -0.636   1.6743
INWD 6563 -0.695   1.4628      INWD 1909 -0.365   3.1217      O  4 1402 -1.276   0.3839      S  3 9069 -1.052   0.6428
INWD 4861 -1.160   0.5005      C  3 1907 -0.294   3.6768      CONT 1401 -1.787   0.1183      S  3 6312 -2.135   0.0531
INWD18751 -1.718   0.1387      C  3 1909 -0.468   2.4670      O  4  789 -2.309   0.0356      S  3 3722 -2.364   0.0313
Dest 1216 -1.626   0.1714      C3 R 1909 -2.091   0.0587      O  4 3412 -3.233   0.0042      S  3 1198 -3.526   0.0022
Dest 6563 -4.214   0.0004      Phot 1909 -2.196   0.0461      O  5  630 -3.536   0.0021      S  3 1729 -2.760   0.0126
e sc18751 -1.526   0.2158      C  3 2297 -2.449   0.0258      TOTL 1218 -1.455   0.2540      S  4  105 -0.942   0.8282
e sc40512 -2.673   0.0154      C  3 4187 -4.306   0.0004      O  5 1218 -1.868   0.0981      S  4 1406 -2.560   0.0199
nFnu 4860 -0.126   5.4180      C  3 4649 -3.509   0.0022      O  5 1214 -1.667   0.1558      S  5 1198 -3.117   0.0055
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    nFnu 1215 -1.177   0.4812      C  4 1549  0.125   9.6448      O  5 5112 -4.308   0.0004      S  5  786 -4.851   0.0001
    Inci 4861  0.816  47.3946      INWD 1549 -0.087   5.9222      O  6 1035 -1.774   0.1217      S  6  933 -2.792   0.0117
    Inci 1216  0.816  47.3575      DEST 1549 -3.056   0.0064      Ne 2  128 -1.800   0.1147      S  9 1715 -3.850   0.0010
    BA C    0 -0.203   4.5382      C4 r 1549 -2.518   0.0220      Ne 3  156 -0.393   2.9273      Ar 3 7135 -4.191   0.0005
    PA C    0 -0.729   1.3501      C  4 4659 -4.116   0.0006      Ne 3  361 -1.461   0.2506      Ar 3 7751 -4.821   0.0001
    H FF    0 -0.501   2.2826      C 6r   34 -3.319   0.0035      Ne 3 3869 -0.343   3.2865      Ar 3    9 -4.497   0.0002
    H FB    0 -0.407   2.8376      N  1 5200 -1.888   0.0936      Ne 3 3968 -0.856   1.0083      Ar 4 4740 -4.387   0.0003
    Cool 1216  0.285  13.9681      REC  5200 -4.309   0.0004      Ne 3 3343 -2.829   0.0107      Ar 6    4 -4.600   0.0002
    Crst  960 -2.289   0.0373      N  1 1200 -4.042   0.0007      Ne 3 1815 -2.690   0.0148      Ca 2 3933 -4.045   0.0007
    H-FB    0 -2.528   0.0215      N  2 6584 -0.496   2.3113      Ne 4 2424 -0.828   1.0745      Ca 2 7306 -3.671   0.0015
    H2+     0 -2.920   0.0087      N  2 6548 -0.973   0.7704      Ne 4 4720 -2.513   0.0222      Ca2K 3934 -4.230   0.0004
    HEH+    0 -4.137   0.0005      REC  6584 -3.955   0.0008      Ne 4 1602 -1.897   0.0919      Ca2H 3969 -4.503   0.0002
    HeFF    0 -1.168   0.4913      N  2 5755 -2.231   0.0425      Ne 5 3426 -0.649   1.6247      CaF1 7291 -3.894   0.0009
    HeFB    0 -0.980   0.7580      N  2  122 -2.149   0.0513      Ne 5 3346 -1.082   0.6000      CaF2 7324 -4.067   0.0006
    MeFB    0 -4.119   0.0005      N  2  203 -2.812   0.0112      Ne 5 2976 -3.121   0.0055      Ca 4   32 -4.740   0.0001
    MeFF    0 -2.485   0.0237      N  2 4239 -4.574   0.0002      Ne 5 1575 -2.646   0.0164      Fe 2    7 -3.169   0.0049
    ToFF    0 -0.413   2.7976      N  2 5680 -4.060   0.0006      Ne 5  242 -0.289   3.7223      Emis    3 -2.849   0.0103
    esc   584 -2.427   0.0271      N  2 2140 -2.037   0.0665      Ne 5  143 -0.287   3.7402      Cool    3 -2.848   0.0103
    He2p  910 -2.729   0.0135      N  2 1084 -3.583   0.0019      Ne 5 1134 -2.421   0.0274      TOT     0 -2.679   0.0152
    He I  504 -1.173   0.4855      N  3 1750 -1.277   0.3823      Ne 6   76 -1.324   0.3435      FEIR    0 -3.731   0.0013
    He I 4471 -2.337   0.0333      N  3   57 -1.555   0.2018      Ne 6 1007 -3.319   0.0035      Fe 3    0 -4.239   0.0004
    TOTL 5876 -1.864   0.0991      N  3  990 -2.856   0.0101      Emis 2798 -0.434   2.6658      Fe 3 4658 -4.675   0.0002
    Ca B 5876 -1.902   0.0907      N  4 1486 -1.242   0.4151      Cool 2798 -0.434   2.6665      Fe 5 3892 -3.961   0.0008
    TOTL10830 -1.087   0.5920      N  4  765 -3.175   0.0048      Mg 4    4 -1.865   0.0987      Fe 6    0 -4.175   0.0005
    INWD10830 -1.293   0.3691      N  4 1718 -3.192   0.0047      Mg 5   13 -1.857   0.1005      Fe 6 5177 -4.626   0.0002
    TOTL 3889 -2.143   0.0521      N  5 1240 -1.470   0.2456      Mg 5   56 -1.126   0.5412      Fe 7 6087 -4.231   0.0004
    TOTL 7065 -2.218   0.0438      N 7r   25 -4.765   0.0001      Mg 5 2751 -2.142   0.0523
    CcHE    0 -1.206   0.4504      O  1 6300 -0.831   1.0677      Mg 6 1806 -2.185   0.0472
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                              PARIS MEETING NLR MODEL
Cooling:  Cool 1216:0.112  C  4 1549:0.077  O  3 5007:0.200  O  3 4959:0.067
Heating:  BFH1    0:0.278  BFHe    0:0.464  TotM    0:0.257

IONIZE PARMET:  U(1-) -1.9996  U(4-): -2.6021  U(sp): -2.00  Q(ion):    9.713  L(ion):   1.486 Q(low): 12.57    P(low)  1.23
ENERGY BUDGET:  Heat:   1.235  Coolg:   1.236  Error:  0.3%  Compt H:  -2.946  WorkF:    1.212 F-F  H -5.860    PRADMX:3.43E-01
Column density  H12:3.239E+21  H II:1.648E+21  HI:1.591E+21  H-:    8.267E+12  H2:   1.220E+14 H2+:6.642E+12    He H+:1.155E+14
                OH: 0.000E+00  Heff:2.290E+21
<NH>:1.000E+03  <Tp>:1.33E+04  <TO3>:1.39E+04  Ne:1.117E+03  ti(snd):3.15E+12  NeN+dl:1.50E+24 <T(C3)>:1.24E+04 <E(C3)>:7.71E+02
He/Ha:9.22E-02  =   0.92*true  N/Oap:3.98E-01  =   2.39true  T(O3R):1.392E+04  L THIN:1.00E+30 <T(S2)>:9.95E+03 <E(S2)>:2.53E+02
T He+:1.23E+04  EHe+:7.84E+02  T(O+):1.04E+04  EO+:3.69E+02  iter/zn:   2.092  Te-low:9.41E+03 Te-high:1.66E+04  Hlu/zn:2.60E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt3.09E+08  Tthr8.09E+08  <Tden>: 1.16E+04  <dens>:2.36E-21 <Mol>:8.92E-01
Mean Jeans      l(cm)1.32E+20  M(sun)1.43E+06  smallest:     len(cm):1.19E+20  M(sun):1.04E+06 Alf(ox-tran):    -1.0450

Optical Depths: CONTN; COMP: 1.25E-03    H-: 3.22E-04 R(1300): 1.07E-02 H2+ 4.65E-05  HeTri:1.95E-03
 Pfa:1.25E-03   Pa:1.25E-03   Ba:1.54E-03   Hb:1.48E-03  La:2.65E-01   1r:1.001E+04  1.8:3.06E+03  4.:6.628E+02  21R:7.467E+00
10830: 1.23E+02  3889: 5.25E+00  5876: 9.73E-07  7065: 5.37E-07
 1550: 1.26E+04  2800: 4.91E+04   774: 4.26E+00  1240: 8.62E+02  1035: 1.27E+03  1335: 6.57E+04   977: 8.79E+04  1397: 2.20E+03
  789: 3.11E+03  1207: 5.57E+03  1085: 4.38E+03  1194: 1.15E+02  1909: 3.50E-02  1895: 1.49E-01  2326: 3.28E-02  1666: 1.60E-01
 1750: 7.24E-04  1025: 8.84E+03   352: 1.05E-02   347: 1.00E-20  1860: 4.97E+00   630: 7.71E+03   834: 4.45E+04   835: 7.76E+03
 1808: 7.92E+04  1256: 6.59E+02    -3: 1.01E+01   -48: 1.68E-08  3934: 3.14E+00  3969: 1.58E+00  8498: 1.60E-06  8542: 1.44E-05
 8662: 8.13E-06   353: 1.40E-03  1304: 3.03E+04  1122: 7.27E-01   990: 3.20E+03  1402: 4.15E-02  1214: 4.16E-02  1486: 1.10E-02
 2335: 1.89E-01  1406: 4.58E-02  1656: 1.58E+01  9830: 2.63E-09  8727: 3.21E-09  6300: 8.02E-05  5577: 3.59E-08  7291: 2.10E-07
 7324: 1.45E-07  1039: 4.30E+03 -8446: 9.08E-09 -4368: 3.44E-11  -132:-5.69E-14  -113: 1.73E-13   -29: 7.15E-13   -46: 1.37E-13
 -245: 1.54E-04   765: 6.70E+03 -1198: 4.38E-02   786: 1.30E+02
 C157: 2.80E-02  N122: 3.58E-02  N205: 3.56E-02   N57: 2.88E-02  O146:-3.11E-02   O63: 8.54E-01   O88: 2.23E-01   O52: 1.85E-01
  O26: 1.10E-01  NE13: 4.19E-02  NE36:-1.38E-03  NE16: 3.31E-01   MG4: 3.47E-03  MG14:-1.56E-06   MG6: 3.28E-03  SI35: 7.46E-02
  S19: 6.40E-03   S34: 7.61E-02   S11: 3.50E-03   AR7: 1.22E-05   AR9: 1.12E-05  AR22:-1.81E-08  AR13: 3.19E-06   AR8: 6.11E-09
  CA3: 1.92E-06  CA12:-2.23E-10   CA4: 9.23E-07  Ne14: 6.39E-03  Ne24: 1.13E-01   Si3: 1.33E-08   Si4: 3.36E-03   Fe7: 4.21E-10
 Fe61:-1.14E-09  Fe23: 1.00E-20  Fe13: 1.00E-20 Si2.5: 1.80E-03 Si6.5:-2.64E-08  C610: 3.50E-05  C370: 1.41E-05

Old hydro optical depths:    1 1.00E+04    2 1.49E-04    3 2.94E-04    4 8.29E-05    5 9.21E-13    6 2.12E-12    7 9.21E-12
                    Lines:  2-1 9.45E+07  3-2 9.03E-03  4-3 1.22E-09  5-4 9.10E-10  6-5 2.82E-10  7-6 9.51E-09  8-7 1.24E-07
New hydro optical depths:    1 1.00E+04    2 1.63E-04    3 3.23E-04    4 9.11E-05    5 9.26E-13    6 2.13E-12    7 9.24E-12
                    Lines:  2-1 9.45E+07  3-2 8.67E-03  4-3 1.27E-09  5-4 9.38E-10  6-5 3.01E-10  7-6 9.61E-09  8-7 1.25E-07

Old He Is optical depths:    1 3.05E+03    2 6.51E-04    3-9.54E-17    4-3.90E-16    5-8.08E-16    6-1.45E-15    7-1.66E-14
                    Lines:  2-1 5.64E+06  3-2 4.17E-04  4-3 4.05E-11  5-4 2.82E-11  6-5 2.45E-11  7-6 2.76E-10  8-7 3.54E-09
New HE Is optical depths:    1 3.06E+03    2 6.70E-04    3-9.77E-17    4-3.97E-16    5-8.24E-16    6-1.48E-15    7-1.69E-14
                    Lines:  2-1 5.66E+06  3-2 4.24E-04  4-3 4.10E-11  5-4 2.87E-11  6-5 2.54E-11  7-6 2.78E-10  8-7 3.57E-09

Old He II optical depths:    1 6.60E+02    2 1.00E+04    3-3.55E-16    4-9.28E-16    5-1.82E-15    6-3.15E-15    7-3.41E-14
                    Lines:  2-1 3.41E+06  3-2 2.74E-05  4-3 4.45E-12  5-4 2.70E-13  6-5-1.53E-11  7-6 6.85E-11  8-7 9.56E-10
New HE II optical depths:    1 6.63E+02    2 1.00E+04    3-3.53E-16    4-9.25E-16    5-1.81E-15    6-3.14E-15    7-3.40E-14
                    Lines:  2-1 3.43E+06  3-2 2.74E-05  4-3 4.44E-12  5-4 2.90E-13  6-5-1.52E-11  7-6 6.83E-11  8-7 9.53E-10

Hydrogen  -0.309 -0.293                         Log10 Mean Ionisation (over volume)
Helium    -0.336 -0.406 -0.835
Carbon    -3.839 -0.300 -0.485 -0.875 -1.461 -2.478 -4.310
Nitrogen  -0.881 -0.294 -0.760 -0.925 -1.405 -1.555 -3.139 -5.415
Oxygen    -0.301 -0.856 -0.620 -1.145 -1.495 -1.875 -2.424 -4.908
Neon      -2.033 -0.912 -0.176 -1.083 -1.047 -1.550 -3.098 -3.745 -4.979
Magnesium -3.303 -0.446 -0.412 -1.263 -1.447 -1.075 -1.188 -1.853 -2.934 -4.210 -5.860
Aluminum  -4.502 -0.464 -0.819 -0.922 -1.112 -0.846 -0.906 -1.425 -2.489 -4.065 -5.787
Silicon   -4.799 -0.194 -1.292 -1.247 -1.580 -1.135 -1.032 -1.301 -2.033 -3.229 -4.731
Sulphur   -5.664 -0.513 -0.404 -1.296 -1.599 -1.094 -1.121 -1.306 -1.811 -2.711 -3.992 -5.630
Argon     -1.544 -0.401 -0.594 -1.401 -1.677 -1.167 -1.154 -1.208 -1.299 -2.091 -3.127 -4.630 -8.015
Calcium   -3.063 -1.284 -0.218 -1.172 -1.640 -1.100 -1.100 -1.217 -1.630 -2.147 -2.755 -4.197
Iron      -2.496 -0.228 -1.384 -0.950 -1.372 -1.166 -1.161 -1.248 -1.956 -2.425 -3.255 -4.229 -5.344
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          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15     16     17

Hydrogen  -0.309 -0.293                          Log10 Mean Ionisation (over radius)
Helium    -0.336 -0.406 -0.835
Carbon    -3.839 -0.300 -0.485 -0.875 -1.461 -2.478 -4.310
Nitrogen  -0.881 -0.294 -0.760 -0.925 -1.405 -1.555 -3.139 -5.415
Oxygen    -0.301 -0.856 -0.620 -1.145 -1.495 -1.875 -2.424 -4.908
Neon      -2.033 -0.912 -0.176 -1.083 -1.047 -1.550 -3.098 -3.745 -4.979
Magnesium -3.303 -0.446 -0.412 -1.263 -1.447 -1.075 -1.188 -1.853 -2.934 -4.210 -5.860
Aluminum  -4.502 -0.464 -0.819 -0.922 -1.112 -0.846 -0.906 -1.425 -2.489 -4.065 -5.787
Silicon   -4.799 -0.194 -1.292 -1.247 -1.580 -1.135 -1.032 -1.301 -2.033 -3.229 -4.731
Sulphur   -5.664 -0.513 -0.404 -1.296 -1.599 -1.094 -1.121 -1.306 -1.811 -2.711 -3.992 -5.630
Argon     -1.544 -0.401 -0.594 -1.401 -1.677 -1.167 -1.154 -1.208 -1.299 -2.091 -3.127 -4.630 -8.015
Calcium   -3.063 -1.284 -0.218 -1.172 -1.640 -1.100 -1.100 -1.217 -1.630 -2.147 -2.755 -4.197
Iron      -2.496 -0.228 -1.384 -0.950 -1.372 -1.166 -1.161 -1.248 -1.956 -2.425 -3.255 -4.229 -5.344

0.5-1.0KEV:1.29E+09 1.0-1.5:1.02E+09 1.5-2.0:5.74E+08 2.0-2.5:3.71E+08 2.5-3:2.81E+08 3-5:5.14E+08 5-7.5:2.66E+08 7.5-10:1.41E+08


                                              Normalised continuum
  0.25 1.207   0.27 1.202   0.30 1.189   0.33 1.181   0.36 1.179   0.39 1.180   0.43 1.188   0.47 1.228   0.51 1.236   0.56 1.245
  0.62 1.247   0.67 1.212   0.74 0.976   0.81 0.998   0.88 1.038   0.97 0.995   0.98 0.995   0.99 0.995   1.00 0.995


Inward continua (nuFnu) at head of Balmer, Lyman series;  1.40E+00  2.38E+00


Outwrd continua (nuFnu) at head of Balmer, Lyman series;  1.40E+00  0.00E+00

                                         Emergent continuum - phot/ryd/cm2 (r in)
  0.26 5.47E+12  0.97 3.21E+11     2.0 9.57E+02     5.9 3.69E+01    22.0 1.18E+06    6.95E+01 3.48E+07    2.58E+02 4.37E+06
  0.29 4.23E+12  0.99 3.07E+11     2.3 2.07E+07     6.7 4.45E+02    24.8 6.22E+06    7.53E+01 3.32E+07    3.84E+02 2.01E+06
  0.33 3.30E+12  0.99 3.02E+11     2.5 8.06E-25     7.5 8.42E-42    27.9 1.86E+07    8.16E+01 3.09E+07    5.71E+02 9.13E+05
  0.37 2.59E+12  1.00 0.00E+00     2.9 3.23E-27     8.5 4.93E+02    31.5 3.06E+07    8.83E+01 2.83E+07    8.49E+02 4.14E+05
  0.42 2.05E+12  1.01 2.47E-13     3.2 5.51E+01     9.5 6.98E-20    35.5 4.80E+07    9.57E+01 2.56E+07    1.26E+03 1.88E+05
  0.47 1.67E+12  1.02 2.16E-13     3.6 1.20E+02    10.8 5.63E+01    40.0 2.40E+07    1.04E+02 2.24E+07    1.88E+03 8.49E+04
  0.53 1.33E+12  1.10 5.12E-14     3.9 1.84E-23    12.1 1.14E-05    45.0 3.33E+07    1.12E+02 1.99E+07    2.79E+03 3.84E+04
  0.60 1.05E+12  1.24 4.46E-15     4.0 3.01E-09    13.7 4.93E+02    50.5 3.97E+07    1.22E+02 1.76E+07    4.14E+03 1.74E+04
  0.67 8.04E+11  1.40 2.88E-16     4.2 1.04E-08    15.4 7.10E+02    54.7 4.19E+07    1.32E+02 1.54E+07    6.16E+03 7.87E+03
  0.76 4.58E+11  1.57 1.60E+04     4.7 5.35E+01    17.3 1.40E+04    59.3 4.26E+07    1.43E+02 1.32E+07
  0.86 4.09E+11  1.78 3.89E-19     5.3 1.11E+03    19.5 2.95E+05    64.2 3.56E+07    1.74E+02 9.31E+06
```

```
                                        CLOUDY 80.08

                ************************************91Aug03*************************************
                *                                                                              *
                * title "New" Paris meeting Planetary nebula                                   *
                * c recompute "standard" PN model of the Pequignot Meudon Conferance           *
                * sphere                                                                       *
                * black body, T=150,000K radius = 10                                           *
                * hden = 3.4771213                                                             *
                * radius = 17                                                                  *
                * abund -1 C-3.523 N-4. O-3.222 ne-3.824 mg-4.523 al=-7                        *
                * continue si-4.523 s-4.824 ar-9 ca=-7 fe-7                                    *
                * plot continuum .1                                                            *
                * c parispn.in                                                                 *
                * c cray                                                                       *
                *                                                                              *
                ********************************************************************************

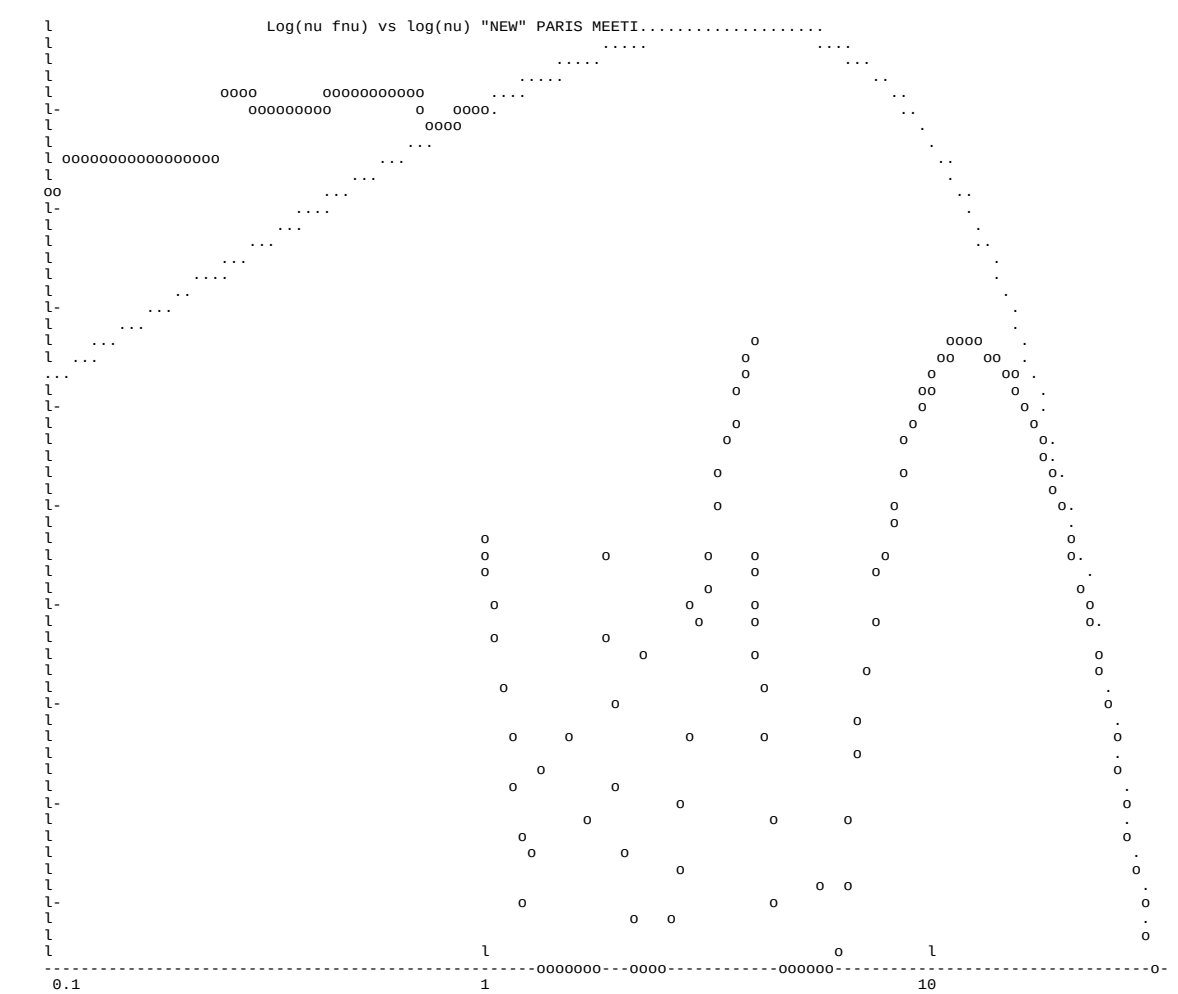

                                          Chemical composition
He:.100 C:3.00E-04 N:1.00E-04 O:6.00E-04 Ne:1.50E-04 Mg:3.00E-05 Al:1.0E-07 Si:3.00E-05 S:1.50E-05 A:1.0E-09 Ca:1.0E-07 Fe:1.00E-07

          369Cell Peak3.74E+00   Lo 1.00E-05=0.9105cm   Hi-Con:3.38E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  37.5397   Average nu:2.935E+00   P( X-ray):  31.4677   P(BalC):  36.1444     Q(Balmer C):  46.9767
          Q(1.0-1.8):  47.1615   Q(1.8-4.0):  47.4535   Q(4.0-20):  47.0523   Q(20--):  40.7978     Ion pht flx:4.313E+12
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  34.4848   Alf(ox):   0.0000     Total lumin:  37.5572
          L/Lsolar:     3.9744   Abs bol mg:  -5.2161   Abs V mag:   2.4664   Bol cor:  -7.6825     nuFnu(Bbet):  34.5868
          U(1.0----):4.795E-02   U(4.0----):9.981E-03   T(En-Den):3.354E+01   T(Comp):1.436E+05     nuJnu(912A):2.909E+01
          Occ(FarIR):2.254E-10   Occ(H n=6):8.337E-14   Occ(1Ryd):1.342E-15   Occ(4R):3.747E-17     Occ (Nu-hi):1.382E-30
          Tbr(FarIR):3.749E-10   Tbr(H n=6):3.702E-10   Tbr(1Ryd):2.120E-10   Tbr(4R):2.371E-11     Tbr (Nu-hi):7.278E-24

#####  1 Te:1.447E+04 Hden:3.000E+03 Ne:3.612E+03 R:1.062E+17 R-R0:6.250E+15 dR:1.250E+16 NTR:  3 Htot:5.540E-17 T912: 9.991E+07###
 -1.78 4686  0.65 5876  0.00 1909  0.12 1549  5.60 6584  0.00 5007  0.26 3727  0.00 6300  0.00 2798  0.00 1035  0.21
Hydrogen    1.293E-04 9.999E-01 H+0/Hden: 1.000E+00 2.228E-12 H-     H2 3.911E-14 1.338E-12 H2+  HeH+ 9.890E-15 H col den 3.750E+19
H 2SP 3-6   2.646E-11 8.762E-16 8.772E-18 1.145E-17 1.596E-17 2.169E-17 Texc(La); 4.411E+03 T(contn): 2.969E+01 T(diffs): 2.448E+02
Helium      7.307E-07 5.877E-03 9.941E-01 He I 2S3  1.314E-08 Comp H, C 6.683E-23 6.733E-24 Fill Fact 1.000E+00 Gam 1/tot 9.955E-01
He singlet  7.176E-07 1.710E-13 5.433E-21 8.457E-21 1.361E-20 2.039E-20 He triplt 1.314E-08 1.981E-18 1.678E-20 5.907E-20 1.400E-20
HeII        5.877E-03 1.024E-11 2.777E-18 4.161E-18 6.523E-18 9.833E-18 8.345E-17 7.756E-16 1.388E-13 PRAD/GAS; 8.650E-04
Pressure    NgasTgas; 9.343E+07 P(total): 1.291E-08 P( gas ): 1.290E-08 P(Radtn): 1.116E-11 Rad accel 1.213E-06 Force Mul 3.729E+02
Carbon      0.000E+00 3.625E-05 1.107E-02 3.113E-01 6.776E-01 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 6.086E-06 5.346E-03 1.656E-01 5.011E-01 3.279E-01 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 5.610E-06 6.676E-03 2.449E-01 5.757E-01 1.669E-01 5.838E-03 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.722
Neon        0.000E+00 2.456E-06 6.231E-03 2.180E-01 7.032E-01 7.243E-02 8.327E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 2.811E-05 1.382E-02 3.035E-01 4.946E-01 1.867E-01 1.379E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 1.003E-06 1.109E-03 3.160E-02 4.393E-01 4.392E-01 8.817E-02 6.046E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 9.291E-05 1.247E-02 1.983E-01 6.992E-01 8.952E-02 3.948E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 1.561E-05 4.747E-03 4.619E-02 1.216E-01 5.082E-01 3.192E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 7.470E-06 2.800E-03 7.449E-02 4.712E-01 2.324E-01 2.046E-01 1.429E-02 1.689E-04 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 6.320E-06 2.875E-04 8.712E-03 5.360E-02 4.141E-01 4.504E-01 7.164E-02 1.281E-03 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 9.373E-05 4.862E-03 1.728E-01 5.957E-01 2.237E-01 2.915E-03 0.000E+00 0.000E+00 0.000E+00
#####172 Te:3.679E+03 Hden:3.000E+03 Ne:1.467E+02 R:3.971E+17 R-R0:2.971E+17 dR:1.496E+14 NTR:  4 Htot:4.289E-19 T912: 9.991E+07###
  0.30 4686  0.23 5876  0.11 1909  1.72 1549  2.48 6584  1.07 5007 15.28 3727  2.35 6300  0.12 2798  1.96 1035  0.01
Hydrogen    9.636E-01 3.638E-02 H+0/Hden: 1.000E+00 1.100E-08 H-     H2 3.895E-06 1.504E-08 H2+  HeH+ 8.046E-08 H col den 8.916E+20
H 2SP 3-6   3.351E-12 3.681E-13 9.184E-19 1.331E-18 2.091E-18 3.172E-18 Texc(La); 3.584E+03 T(contn): 7.511E+00 T(diffs): 2.477E+02
Helium      8.800E-01 1.197E-01 3.456E-04 He I 2S3  6.768E-08 Comp H, C 1.501E-27 1.782E-28 Fill Fact 1.000E+00 Gam 1/tot 7.131E-01
He singlet  8.800E-01 1.001E-13 2.512E-20 3.365E-20 5.230E-20 7.805E-20 He triplt 6.768E-08 5.927E-16 3.446E-20 6.925E-19 3.763E-20
HeII        1.197E-01 3.823E-16 1.026E-22 1.599E-22 2.608E-22 4.079E-22 3.715E-21 4.286E-20 1.116E-17 PRAD/GAS; 1.292E-02
Pressure    NgasTgas; 1.407E+07 P(total): 1.990E-09 P( gas ): 1.942E-09 P(Radtn): 4.778E-11 Rad accel 3.227E-09 Force Mul 9.685E+03
Carbon      1.059E-03 9.965E-01 2.448E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
```

Nitrogen		9.758E-01	2.421E-02	3.612E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	O2/Ototl: 0.000E+00	O2+/Otot: 0.000E+00
Oxygen		9.689E-01	3.114E-02	9.389E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	Hex(tot): 0.000E+00 A:-12.244
Neon		5.334E-01	3.949E-01	7.175E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Magnesium	0	4.832E-03	9.648E-01	3.041E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Aluminium	0	1.177E-03	9.656E-01	2.734E-02	5.918E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Silicon	0	9.818E-04	9.990E-01	6.961E-06	2.604E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Sulphur	0	2.324E-04	9.853E-01	1.447E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Argon	0	8.117E-01	1.693E-01	1.898E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Calcium	0	4.823E-03	2.491E-01	7.461E-01	3.157E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00
Iron	0	1.561E-02	9.843E-01	5.519E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 0.000E+00

Calculation stopped because lowest Te reached.
Geometry is a thick shell.
FeII-MgII photoionization of H N=2 reached 7.3 percent of the total rate out.
Photoionization of He 2TriS reached 15.6 percent of the total rate out.
Frequency out of range of free-free gaunt factor routine.
The ratio of radiation to gas pressure reached 1.16E+00. Caused by Lyman alpha.



```
*********************************> CLOUDY 80.08  <*********************************
* title "New" Paris meeting Planetary nebula                                       *
* c recompute "standard" PN model of the Pequignot Meudon Conferance               *
* sphere                                                                           *
* black body, T=150,000K radius = 10                                               *
* hden = 3.4771213                                                                 *
* radius = 17                                                                      *
* abund -1 C-3.523 N-4. O-3.222 ne-3.824 mg-4.523 al=-7                            *
* plot continuum .1                                                                *
* c parispn.in                                                                     *
* c cray                                                                           *
*********************************> LOG(U): -1.32 <*********************************
```

Emission Line Spectrum. Constant Density Model. Closed geometry. Iteration 1 of 1.
Luminosity (erg/s) emitted by shell with full coverage.

TOTL 4861	35.402	1.0000	DevB 2	32.830	0.0027	O 1 630	33.658	0.0180	Mg 5 2751	33.740	0.0218
TOTL 1216	36.842	27.5419	He I 5016	33.707	0.0202	O 1 1470	32.420	0.0010	Mg 6 1806	32.302	0.0008
TotH 0	37.206	63.7683	DevB 5016	33.260	0.0072	O 1 7774	31.823	0.0003	Al 3 1860	32.646	0.0018
BFH1 0	37.061	45.6144	He I 3965	33.416	0.0103	T OI 0	32.611	0.0016	Si 2 35	34.610	0.1616
BFHe 0	36.599	15.7628	DevB 3965	32.741	0.0022	6lev 1304	32.613	0.0016	Si 2 2335	34.599	0.1576
TotM 0	35.780	2.3897	He I 3614	33.133	0.0054	TOTL 3727	35.773	2.3502	Si 2 1808	33.592	0.0155
H- H 0	32.512	0.0013	DevB 3614	32.605	0.0016	TOTL 7325	34.622	0.1662	Si 3 1207	33.696	0.0197
CA B 4861	35.404	1.0043	He I 3448	32.914	0.0033	IONZ 3727	33.319	0.0083	Si 3 1895	35.023	0.4182
CA B 1216	36.942	34.7218	DevB 3448	32.182	0.0006	IONZ 7325	32.839	0.0027	PHOT 1895	33.321	0.0083
DU B 4861	35.404	1.0043	TOTL 1640	35.738	2.1705	O II 3729	35.299	0.7890	Si 4 1397	34.747	0.2215
Q(H) 4861	35.411	1.0209	TOTL 4686	34.767	0.2320	O II 3726	35.593	1.5529	Si 6 19	32.936	0.0034
Q(H) 1216	36.945	34.9046	TOTL 1216	35.325	0.8374	O II 2471	34.522	0.1320	S 2 6720	35.222	0.6607
TOTL 6563	35.843	2.7638	Ca B 1640	35.796	2.4798	O II 7323	34.365	0.0920	S 2 4074	34.474	0.1182
TOTL 4861	35.402	1.0000	DevB 1640	35.794	2.4681	O II 7332	34.272	0.0742	S 210330	34.301	0.0794
TOTL 4340	35.104	0.5033	Ca B 4686	34.950	0.3535	O II 834	31.761	0.0002	S II 6731	35.002	0.3979
TOTL 4102	34.873	0.2958	DevB 4686	34.943	0.3482	O 2 4651	32.881	0.0030	S II 6716	34.821	0.2627
TOTL18751	34.845	0.2777	C 1 1656	32.276	0.0007	O 3 1663	34.756	0.2260	S II 4070	34.350	0.0887
TOTL12818	34.573	0.1484	REC 1656	32.130	0.0005	Rec 1663	33.927	0.0335	S II 4078	33.870	0.0294
TOTL10938	34.350	0.0887	C I 9850	33.520	0.0131	O 3 5007	36.586	15.2764	S II10323	33.847	0.0279
TOTL40512	34.162	0.0576	C 1 8727	32.549	0.0014	O 3 4959	36.109	5.0921	S II10289	33.718	0.0207
TOTL26252	33.966	0.0366	C 2 158	32.855	0.0028	TOTL 4363	34.575	0.1490	S II10373	33.400	0.0100
TOTL74578	33.636	0.0171	C 2 2326	34.973	0.3727	Rec 4363	32.905	0.0032	S II10339	33.720	0.0208
2 NU 0	36.418	10.3838	C 2 1335	33.722	0.0209	O 3 2321	33.948	0.0352	S II 1256	31.641	0.0002
TOTL 1216	36.842	27.5419	REC 1335	34.385	0.0962	C EX 4363	32.171	0.0006	S 3 18	35.229	0.6720
TOTL 1026	31.681	0.0002	C 2 4267	32.610	0.0016	C EX 5592	32.242	0.0007	S 3 34	34.878	0.2991
TOTL 973	32.620	0.0017	TOTL 977	34.470	0.1170	O 3 880	34.845	0.2778	S 3 9532	35.719	2.0746
TOTL 950	32.690	0.0019	C3 C 977	33.911	0.0323	O 3 520	35.538	1.3700	S 3 9069	35.303	0.7964
TOTL 938	32.757	0.0023	C3 R 977	34.330	0.0847	O 3 834	32.472	0.0012	S 3 6312	34.184	0.0606
LA X 1216	32.275	0.0007	TOTL 1909	35.637	1.7180	O 3 3341	32.540	0.0014	S 3 3722	33.955	0.0358
C13c 6563	33.958	0.0360	C 3 1907	35.403	1.0038	O 4 26	35.935	3.4133	S 3 1198	32.491	0.0012
C14c 4861	32.893	0.0031	C 3 1909	35.255	0.7142	O 4 1402	34.423	0.1050	S 3 1729	33.413	0.0103
CION 0	34.095	0.0493	C3 R 1909	34.168	0.0584	CONT 1401	34.273	0.0743	S 4 105	35.584	1.5221
INWD 1216	36.842	27.5419	Phot 1909	34.147	0.0557	O 4 789	32.966	0.0037	S 4 1406	33.546	0.0139
Dest 1216	34.637	0.1720	C 3 2297	33.814	0.0258	O 4 3412	32.959	0.0036	S 5 1198	32.686	0.0019
Dest 6563	31.966	0.0004	C 3 4187	31.968	0.0004	TOTL 1218	34.225	0.0666	S 6 933	32.399	0.0010
e sc18751	34.227	0.0670	C 3 4649	32.717	0.0021	O 5 1218	33.816	0.0260	Ca 2 3933	33.471	0.0117
e sc40512	32.994	0.0039	C 4 1549	35.796	2.4784	O 5 1214	34.010	0.0406	Ca 2 8579	32.976	0.0038
nFnu 4860	36.017	4.1282	DEST 1549	33.019	0.0041	O 6 1035	33.187	0.0061	Ca 2 7306	34.087	0.0484
nFnu 1215	34.752	0.2240	C4 r 1549	33.640	0.0173	Ne 2 128	33.938	0.0344	Ca2K 3934	33.243	0.0069
Inci 4861	34.587	0.1532	C 4 4659	32.060	0.0005	Ne 3 156	35.829	2.6744	Ca2H 3969	33.082	0.0048
Inci 1216	36.254	7.1168	N 1 5200	33.368	0.0092	Ne 3 361	34.732	0.2140	Ca2X 8498	31.854	0.0003
BA C 0	36.045	4.4007	N 1 1200	31.497	0.0001	Ne 3 3869	35.787	2.4287	Ca2Y 8542	32.812	0.0026
PA C 0	35.526	1.3321	N 2 6584	35.432	1.0732	Ne 3 3968	35.274	0.7451	Ca2Z 8662	32.357	0.0009

H FF 0	35.652	1.7784	N 2 6548	34.955	0.3577	Ne 3 3343	33.099	0.0050	CaF1 7291	33.868	0.0293
H FB 0	35.751	2.2344	REC 6584	32.326	0.0008	Ne 3 1815	33.239	0.0069	CaF2 7324	33.684	0.0192
Cool 1216	35.911	3.2277	N 2 5755	33.776	0.0237	Ne 4 2424	35.111	0.5115	Ca 4 32	32.610	0.0016
Crst 960	33.371	0.0093	N 2 122	32.947	0.0035	Ne 4 4720	33.314	0.0082	Ca 5 4	31.919	0.0003
H-FB 0	32.837	0.0027	N 2 203	32.011	0.0004	Ne 4 1602	33.930	0.0338	Ca 5 5311	31.715	0.0002
H2+ 0	32.454	0.0011	N 2 4239	31.719	0.0002	Ne 5 3426	35.004	0.4001	Fe 2 7	32.494	0.0012
HeFF 0	34.977	0.3759	N 2 5680	32.251	0.0007	Ne 5 3346	34.571	0.1478	Emis 3	32.884	0.0030
HeFB 0	35.197	0.6241	N 2 2140	33.988	0.0386	Ne 5 2976	32.313	0.0008	Cool 3	32.884	0.0030
MeFB 0	31.907	0.0003	N 2 1084	32.418	0.0010	Ne 5 1575	32.788	0.0024	TOT 0	33.033	0.0043
MeFF 0	33.532	0.0135	N 3 1750	34.381	0.0954	Ne 5 242	35.404	1.0045	FEIR 0	31.799	0.0002
ToFF 0	35.738	2.1678	N 3 57	34.397	0.0988	Ne 5 143	35.526	1.3308	Fe 3 0	32.260	0.0007
He I 4471	33.947	0.0351	N 3 990	32.332	0.0009	Ne 5 1134	32.863	0.0029	Fe 3 5270	31.581	0.0002
TOTL 5876	34.431	0.1070	N 4 1486	34.439	0.1090	Ne 6 76	33.516	0.0130	Fe 3 4658	31.825	0.0003
Ca B 5876	34.386	0.0965	N 4 765	31.979	0.0004	Mg 1 4571	31.465	0.0001	Fe 5 3892	31.973	0.0004
TOTL10830	35.327	0.8427	N 4 1718	32.947	0.0035	Emis 2798	35.694	1.9592	Fe 6 0	31.976	0.0004
TOTL 3889	34.063	0.0459	N 5 1240	34.184	0.0606	Cool 2798	35.694	1.9592	Fe 6 5177	31.525	0.0001
TOTL 7065	34.127	0.0531	O 1 6300	34.476	0.1186	Mg 4 4	34.532	0.1351	Fe 7 6087	31.666	0.0002
CcHE 0	35.252	0.7081	O 1 6363	33.999	0.0395	Mg 5 13	34.168	0.0584			
He I 2	33.757	0.0227	O 1 5577	32.658	0.0018	Mg 5 56	34.906	0.3195			

"NEW" PARIS MEETING PLANETARY NEBULA
Cooling: Cool 1216:0.050 O 3 5007:0.238 O 3 4959:0.079 O 4   26:0.053
Heating: BFH1   0:0.715 BFHe   0:0.247

IONIZE PARMET: U(1-) -1.3192 U(4-): -2.0008 U(sp): -2.50 Q(ion):   43.550 L(ion): 33.879 Q(low): 47.01   P(low) 36.15
ENERGY BUDGET: Heat: 37.206 Coolg: 37.209 Error: 0.6% Compt H: 30.129 WorkF: 37.422 F-F H 30.480   PRADMX:1.16E+00
Column density H12:8.916E+20 H II:8.589E+20 HI:3.274E+19 H-:   7.708E+11 H2:   4.568E+13 H2+:4.323E+11   He H+:4.103E+12
                OH: 0.000E+00 Heff:0.000E+00
<NH>:3.000E+03 <Tp>:1.24E+04 <TO3>:1.14E+04 Ne:3.355E+03 ti(snd):2.38E+11 NeN+dl:2.95E+24 <T(C3)>:1.14E+04 <E(C3)>:3.31E+03
He/Ha:9.72E-02 =   0.97*true N/Oap:1.83E-01 =   1.10true T(O3R):1.130E+04 L THIN:1.00E+30 <T(S2)>:1.02E+04 <E(S2)>:2.22E+03
T He+:1.10E+04 EHe+:3.17E+03 T(O+):1.11E+04 EO+:2.81E+03 iter/zn: 2.000 Te-low:3.68E+03 Te-high:1.45E+04 Hlu/zn:2.53E+00
  <a>:0.00E+00 erdeFe0.0E+00 Tcompt8.11E+07 Tthr3.81E+08 <Tden>: 1.23E+04 <dens>:7.07E-21 <Mol>:6.44E-01
Mean Jeans   l(cm)7.43E+19 M(sun)7.63E+05 smallest: len(cm):4.07E+19 M(sun):1.25E+05 Alf(ox-tran):   0.0000

Optical Depths: CONTN; COMP: 3.32E-04   H-: 1.50E-05 R(1300): 2.20E-04 H2+ 3.03E-06 HeTri:5.87E-04
 Pfa:3.32E-04   Pa:3.32E-04   Ba:3.46E-04   Hb:3.43E-04 La:3.07E-03   1r:4.995E+07 1.8:1.15E+07 4.:1.715E+06 21R:3.170E+04
10830: 1.17E+02 3889: 5.00E+00 5876: 2.94E-06 7065: 1.62E-06
 1550: 1.09E+04 2800: 3.84E+03   774: 1.00E-20 1240: 1.14E+03 1035: 6.01E+02 1335: 2.91E+03   977: 2.74E+04 1397: 4.30E+03
  789: 3.59E+03 1207: 6.24E+03 1085: 2.03E+02 1194: 2.65E+01 1909: 1.09E-02 1895: 1.67E-01 2326: 1.45E-03 1666: 8.69E-02
 1750: 3.93E-04 1025: 1.76E+02   352: 1.00E-20   347: 1.00E-20 1860: 2.19E+01   630: 1.18E+04   834: 6.10E+03   835: 4.22E+03
 1808: 4.88E+03 1256: 4.82E+01   -3: 2.96E-01   -48: 4.13E-09 3934: 1.79E+01 3969: 9.01E+00 8498: 6.18E-05 8542: 5.69E-04
 8662: 3.14E-04   353: 1.00E-20 1304: 6.04E+02 1122: 4.03E-01   990: 1.74E+03 1402: 4.79E-02 1214: 6.35E-02 1486: 9.91E-03
 2335: 1.17E-02 1406: 7.74E-02 1656: 1.51E+01 9830: 2.52E-09 8727: 2.03E-08 6300: 1.60E-06 5577: 3.87E-09 7291: 1.20E-06
 7324: 8.28E-07 1039: 8.58E+01 -8446: 2.36E-11 -4368: 8.95E-14 -132: 6.08E-15 -113: 4.02E-14   -29: 8.33E-14   -46: 6.33E-14
 -245: 9.69E-07   765: 6.03E+03 -1198: 5.12E-02   786: 1.52E+02
 C157: 3.26E-04 N122: 3.30E-04 N205: 4.72E-05   N57: 7.45E-03 O146:-1.20E-03   O63: 1.55E-02   O88: 2.55E-02   O52: 6.54E-02
  O26: 8.62E-02 NE13: 2.04E-03 NE36:-1.78E-03 NE16: 6.25E-02   MG4: 5.60E-03 MG14:-5.27E-06   MG6: 3.49E-03 SI35: 1.64E-03
  S19: 3.86E-03   S34: 4.91E-03   S11: 5.35E-03   AR7: 3.10E-08   AR9: 3.78E-07 AR22:-4.18E-09 AR13: 1.01E-06   AR8: 6.29E-09
  CA3: 1.48E-05 CA12:-9.24E-09   CA4: 1.17E-05 Ne14: 9.62E-03 Ne24: 5.21E-02   Si3: 1.00E-20   Si4: 1.00E-20   Fe7: 1.00E-20
 Fe61: 1.00E-20 Fe23: 1.00E-20 Fe13: 1.00E-20 Si2.5: 1.79E-07 Si6.5:-8.17E-12 C610: 3.07E-05 C370: 2.78E-05

Old hydro optical depths: 1 9.99E+07   2 1.00E-20   3 1.00E-20   4 1.00E-20   5 1.00E-20   6 1.00E-20   7 1.00E-20
                    Lines: 2-1 9.96E+09 3-2 3.34E-02 4-3 3.33E-04 5-4 1.66E-05 6-5 2.56E-06 7-6 2.56E-07 8-7 2.56E-08
New hydro optical depths: 1 5.00E+07   2 7.76E-06   3 1.50E-05   4 4.26E-06   5 1.07E-12   6 2.48E-12   7 1.07E-11
                    Lines: 2-1 1.04E+06 3-2 4.94E-03 4-3 1.18E-09 5-4 9.44E-10 6-5 8.33E-11 7-6 1.12E-08 8-7 1.47E-07

Old He Is optical depths: 1 4.15E+05   2 0.00E+00   3 5.00E-21   4 5.00E-21   5 5.00E-21   6 5.00E-21   7 5.00E-21
                    Lines: 2-1 9.96E+09 3-2 1.00E-20 4-3 1.00E-20 5-4 1.00E-20 6-5 1.00E-20 7-6 1.00E-20 8-7 0.00E+00
New HE Is optical depths: 1 2.56E+01   2 2.54E-04   3-9.73E-17   4-3.44E-16   5-7.04E-16   6-1.26E-15   7-1.42E-14
                    Lines: 2-1 6.59E+04 3-2 9.77E-04 4-3 6.06E-11 5-4 4.05E-11 6-5 3.21E-11 7-6 4.23E-10 8-7 5.46E-09

Old He II optical depths: 1 4.15E+05   2 4.15E+05   3 5.00E-21   4 5.00E-21   5 5.00E-21   6 5.00E-21   7 5.00E-21
                    Lines: 2-1 9.96E+09 3-2 1.00E-20 4-3 1.00E-20 5-4 1.00E-20 6-5 1.00E-20 7-6 1.00E-20 8-7 0.00E+00
New HE II optical depths: 1 3.38E+01   2 1.03E+02   3-7.69E-16   4-1.98E-15   5-3.88E-15   6-6.72E-15   7-7.27E-14
                    Lines: 2-1 1.09E+06 3-2 1.08E-04 4-3 1.73E-11 5-4-1.16E-12 6-5-6.90E-11 7-6 2.77E-10 8-7 3.89E-09

Hydrogen -1.104 -0.036   Log10 Mean Ionisation (over volume)
Helium   -1.423 -0.173 -0.536
Carbon   -2.976 -0.795 -0.303 -0.555 -1.209
Nitrogen -1.413 -0.747 -0.377 -0.555 -1.151 -1.876
Oxygen   -1.132 -0.850 -0.248 -0.818 -1.210 -2.235 -4.004
Neon   -1.899 -1.370 -0.153 -0.797 -1.103 -2.597 -5.971
Magnesium -2.960 -0.702 -0.245 -0.754 -1.305 -2.206 -4.644
Aluminum -3.625 -0.473 -0.518 -0.501 -1.384 -2.572 -5.054
Silicon   -4.214 -0.545 -0.585 -0.481 -0.916 -2.398 -5.148
Sulphur   -4.983 -0.785 -0.317 -0.611 -1.286 -1.333 -1.978
Argon   -1.507 -1.138 -0.302 -0.560 -0.985 -1.870 -2.309 -3.703 -5.813
Calcium   -1.893 -0.711 -0.335 -0.766 -1.251 -1.113 -1.621 -2.790 -4.774
Iron   -2.698 -0.882 -0.821 -0.375 -1.237 -0.843 -1.080 -2.043 -4.267

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          1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17

Hydrogen -1.435 -0.016   Log10 Mean Ionisation (over radius)
Helium   -1.764 -0.364 -0.259
Carbon   -3.291 -1.097 -0.445 -0.411 -0.764
Nitrogen -1.761 -1.051 -0.507 -0.445 -0.751 -1.329
Oxygen   -1.474 -1.144 -0.368 -0.555 -0.779 -1.670 -3.341
Neon   -2.252 -1.684 -0.316 -0.560 -0.687 -2.039 -5.249
Magnesium -3.282 -0.991 -0.369 -0.504 -0.876 -1.640 -3.975
Aluminum -3.945 -0.732 -0.601 -0.349 -0.973 -2.004 -4.366
Silicon   -4.550 -0.836 -0.710 -0.411 -0.588 -1.888 -4.490
Sulphur   -5.330 -1.091 -0.465 -0.532 -0.985 -0.859 -1.390
Argon   -1.856 -1.425 -0.493 -0.492 -0.621 -1.355 -1.685 -3.007 -5.054
Calcium   -2.205 -0.965 -0.498 -0.733 -0.987 -0.715 -1.097 -2.163 -4.070
Iron   -3.041 -1.214 -1.084 -0.527 -1.158 -0.602 -0.685 -1.503 -3.619

Normalised continuum
  0.2552.710   0.2738.477   0.3026.227   0.3318.318   0.3613.548   0.3910.272   0.43 8.203   0.47 8.120   0.51 6.544   0.56 5.419
  0.62 4.468   0.67 3.363   0.74 1.527   0.81 1.014   0.88 1.023   0.97 0.999   0.98 0.999   0.99 0.999   1.00 0.999

Emergent continuum - phot/ryd/cm2 (r in)
  0.26 2.66E+13 0.60 4.86E+12   1.0 5.47E+07   1.8 1.70E-01   3.9 2.74E+08   7.51E+00 1.75E+05   1.73E+01 2.92E+06
  0.29 1.75E+13 0.67 3.69E+12   1.0 4.15E+07   2.0 5.43E+04   4.0 1.80E+06   8.47E+00 2.15E+06   1.95E+01 5.17E+05
  0.33 1.19E+13 0.76 1.21E+12   1.0 3.14E+07   2.3 8.35E+05   4.2 1.47E+05   9.54E+00 1.53E+07   2.20E+01 5.19E+04
  0.37 8.80E+12 0.86 1.25E+12   1.1 1.58E+06   2.5 3.06E+02   4.7 9.80E+01   1.07E+01 3.56E+07   2.48E+01 4.33E+03
  0.42 6.92E+12 0.97 1.32E+12   1.2 1.21E+04   2.9 7.34E+04   5.3 6.29E-02   1.21E+01 4.25E+07   2.79E+01 2.35E+02
  0.47 6.99E+12 0.99 1.33E+12   1.4 1.11E+02   3.2 4.67E+06   5.9 4.88E+00   1.36E+01 2.68E+07   3.14E+01 7.68E+00
  0.53 5.76E+12 0.99 1.33E+12   1.6 2.65E+05   3.6 7.61E+07   6.7 2.40E+03   1.54E+01 1.10E+07

CLOUDY 80.08

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************************************91Aug03***************************************
*                                                                                *
* title check pure hydrogen Stromgren sphere                                     *
* c the answer is R(Stromgren) = 4.16E17 cm                                      *
* hden 4                                                                         *
* sphere static                                                                  *
* radius 16                                                                      *
* blackbody 50,000k                                                              *
* q(h) 49                                                                        *
* stop eden 3.                                                                   *
* constant temper 7500                                                           *
* abundances -10                                                                 *
* print short                                                                    *
* c strom.in                                                                     *
* c cray                                                                         *
*                                                                                *
**********************************************************************************
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Chemical composition

He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

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          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  38.5118   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):  38.3651     Q(Balmer C):  49.2411
          Q(1.0-1.8):  48.9070   Q(1.8-4.0):  48.2845   Q(4.0-20):  45.8883   Q(20--):   0.0000     Ion pht flx:7.962E+15
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  37.0224   Alf(ox):   0.0000     Total lumin:  38.7538
          L/Lsolar:     5.1710   Abs bol mg:  -8.2075   Abs V mag:  -3.9048   Bol cor:  -4.3027     nuFnu(Bbet):  37.1233
          U(1.0----):2.656E+01   U(4.0----):2.053E-02   T(En-Den):2.112E+02   T(Comp):4.787E+04     nuJnu(912A):3.069E+05
          Occ(FarIR):9.570E-06   Occ(H n=6):3.435E-09   Occ(1Ryd):1.415E-11   Occ(4R):1.021E-15     Occ (Nu-hi):7.434E-26
          Tbr(FarIR):1.592E-05   Tbr(H n=6):1.525E-05   Tbr(1Ryd):2.235E-06   Tbr(4R):6.460E-10     Tbr (Nu-hi):1.336E-19

#####  1 Te:7.500E+03 Hden:1.000E+04 Ne:1.000E+04 R:1.062E+16 R-R0:6.250E+14 dR:1.250E+15 NTR:  1 Htot:1.943E-16 T912: 9.991E+07###
 -1.64 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
P(LINES): 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    1.423E-07 1.000E+00 H+0/Hden: 1.000E+00 1.824E-20 H-     H2 6.133E-26 4.542E-21 H2+  HeH+ 3.619E-30 H col den 1.250E+19
H 2SP 3-6   7.412E-11 1.293E-12 3.229E-17 4.672E-17 7.114E-17 1.045E-16 Texc(La); 9.310E+03 T(contn): 1.878E+02 T(diffs): 8.489E+02
Helium      1.032E-09 3.448E-03 9.966E-01 He I 2S3  7.155E-13 Comp H, C 9.700E-20 1.520E-20 Fill Fact 1.000E+00 Gam 1/tot 9.992E-01
He singlet  1.031E-09 2.438E-14 7.371E-21 1.417E-20 2.586E-20 4.227E-20 He triplt 7.154E-13 2.311E-18 1.439E-20 1.085E-19 3.335E-20
HeII        3.448E-03 2.585E-11 4.783E-18 9.943E-18 1.821E-17 3.030E-17 2.924E-16 3.687E-15 9.719E-13 PRAD/GAS; 2.514E+05
Pressure    NgasTgas; 1.500E+08 P(total): 5.207E-03 P( gas ): 2.071E-08 P(Radtn): 5.207E-03 Rad accel 7.869E-06 Force Mul 1.305E+00
Carbon      0.000E+00 0.000E+00 2.900E-03 4.203E-01 5.768E-01 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 4.714E-03 8.128E-01 1.822E-01 2.896E-04 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 2.294E-07 8.502E-03 8.611E-01 1.304E-01 1.096E-05 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.486
Neon        0.000E+00 1.794E-06 5.482E-02 9.337E-01 1.144E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 0.000E+00 4.341E-06 4.365E-01 5.627E-01 7.554E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 0.000E+00 0.000E+00 8.686E-04 9.990E-01 1.748E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 0.000E+00 0.000E+00 2.839E-05 2.804E-02 9.719E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 0.000E+00 0.000E+00 7.647E-05 3.555E-02 6.486E-01 3.134E-01 2.375E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 0.000E+00 0.000E+00 3.234E-04 1.194E-01 8.509E-01 2.922E-02 2.092E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 0.000E+00 0.000E+00 3.730E-03 2.988E-01 6.255E-01 7.191E-02 3.847E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 0.000E+00 0.000E+00 0.000E+00 2.141E-03 2.609E-01 7.311E-01 5.871E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
#####127 Te:7.500E+03 Hden:1.000E+04 Ne:9.627E+02 R:4.168E+17 R-R0:4.068E+17 dR:1.182E+14 NTR:  1 Htot:1.763E-17 T912: 9.991E+07###
  3.56 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    9.218E-01 7.823E-02 H+0/Hden: 1.000E+00 4.087E-09 H-     H2 9.931E-09 3.091E-09 H2+  HeH+ 2.128E-16 H col den 4.068E+21
H 2SP 3-6   1.867E-11 2.427E-12 6.208E-18 7.247E-18 1.146E-17 1.787E-17 Texc(La); 3.903E+03 T(contn): 2.645E+01 T(diffs): 3.035E+02
Helium      5.330E-01 4.367E-01 3.028E-02 He I 2S3  7.132E-07 Comp H, C 1.329E-24 3.822E-25 Fill Fact 1.000E+00 Gam 1/tot 8.834E-01
He singlet  5.330E-01 2.605E-12 9.476E-20 1.821E-19 3.322E-19 5.424E-19 He triplt 7.132E-07 2.268E-17 2.123E-19 1.440E-18 4.359E-19
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HeII        4.367E-01 8.337E-14 1.480E-20 3.082E-20 5.645E-20 9.391E-20 9.062E-19 1.141E-17 2.969E-15 PRAD/GAS; 2.544E-02
Pressure    NgasTgas; 8.269E+07 P(total): 1.207E-08 P( gas ): 1.142E-08 P(Radtn): 6.501E-10 Rad accel 7.071E-08 Force Mul 4.954E+02
Carbon      5.134E-05 9.833E-01 1.668E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    1.620E-01 8.379E-01 1.003E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      9.302E-01 6.983E-02 1.310E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.486
Neon        1.598E-01 4.710E-01 3.692E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 5.269E-04 9.184E-01 8.106E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 4.975E-05 9.895E-01 1.011E-02 3.235E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 2.827E-05 9.995E-01 4.417E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 1.195E-05 9.720E-01 2.799E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 6.600E-01 3.197E-01 2.023E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 1.218E-04 1.785E-02 9.819E-01 1.646E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.464E-03 9.954E-01 3.165E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest EDEN reached.
  Geometry is spherical.
  Photoionization of He 2TriS reached 100.0 percent of the total rate out.
W-Heating - cooling mismatch =  1.61E+00 Whats wrong????
C-I must iterate when SPHERE STATIC is set.
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  2.51E+05.  Caused by Lyman alpha.
```

```
*********************************> CLOUDY 80.08  <*********************************
* title check pure hydrogen Stromgren sphere                                       *
* c the answer is R(Stromgren) = 4.16E17 cm                                        *
* hden 4                                                                           *
* sphere static                                                                    *
* radius 16                                                                        *
* blackbody 50,000k                                                                *
* q(h) 49                                                                          *
* stop eden 3.                                                                     *
* constant temper 7500                                                             *
* abundances -10                                                                   *
* print short                                                                      *
* c strom.in                                                                       *
* c cray                                                                           *
*********************************> LOG(U):  1.42 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Constant  Density Model.  Closed geometry.  Iteration 1 of 1.
                                Luminosity (erg/s) emitted by shell with full coverage.

TOTL 4861 36.661   1.0000      Q(H) 1216 38.211  35.5014      TOTL26252 35.254   0.0392      Inci 4861 37.123   2.9030
TOTL 1216 38.112  28.2669      TOTL 6563 37.105   2.7823      TOTL74578 34.924   0.0183      Inci 1216 38.453  62.0146
TotH    0 38.021  22.9116      TOTL 4861 36.661   1.0000      2 NU    0 37.471   6.4625      BA C    0 37.263   4.0035
BFH1    0 38.021  22.9092      TOTL 4340 36.377   0.5203      TOTL 1216 38.112  28.2669      PA C    0 36.761   1.2602
BFHx    0 33.933   0.0019      TOTL 4102 36.157   0.3136      INWD 1216 38.112  28.2664      H FF    0 36.645   0.9639
CA B 4861 36.673   1.0298      TOTL18751 36.129   0.2941      Dest 1216 34.056   0.0025      H FB    0 36.835   1.4930
CA B 1216 38.197  34.3612      TOTL12818 35.856   0.1569      e sc18751 34.716   0.0114      Cool 1216 34.363   0.0050
DU B 4861 36.673   1.0298      TOTL10938 35.638   0.0950      nFnu 4860 37.006   2.2141      ToFF    0 36.645   0.9639
Q(H) 4861 36.677   1.0384      TOTL40512 35.445   0.0609      nFnu 1215 33.852   0.0016
```

```
                          CHECK PURE HYDROGEN STROMGREN SPHERE
Cooling:  H FF    0:0.391  H FB    0:0.606
Heating:  BFH1    0:1.000

IONIZE PARMET:  U(1-)  1.4242  U(4-): -1.6877  U(sp): -1.81  Q(ion):   44.701  L(ion):  34.682 Q(low): 49.31    P(low) 38.38
ENERGY BUDGET:  Heat:  38.021  Coolg:  37.052  Error: 89.3%  Compt H:  31.595  WorkF:   38.320 F-F  H 31.989    PRADMX:2.51E+05
Column density  H12:4.068E+21  H II:4.035E+21  HI:3.378E+19  H-:    2.344E+11  H2:   3.443E+11 H2+:2.046E+11    He H+:5.083E+03
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+04  <Tp>:7.50E+03  <TO3>:7.50E+03  Ne:9.988E+03  ti(snd):3.65E+11  NeN+dl:4.02E+25 <T(C3)>:7.50E+03 <E(C3)>:9.97E+03
He/Ha:9.00E-11  =   0.90*true  N/Oap:1.34E+00  =   1.34true  T(O3R):7.791E+03  L THIN:1.00E+30 <T(S2)>:7.50E+03 <E(S2)>:6.86E+03
T He+:7.50E+03  EHe+:9.90E+03  T(O+):7.50E+03  EO+:9.30E+03  iter/zn:   1.000  Te-low:7.50E+03 Te-high:7.50E+03  Hlu/zn:1.25E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt6.21E+03  Tthr8.10E+08  <Tden>: 7.50E+03  <dens>:1.66E-20 <Mol>:5.03E-01
Mean Jeans      l(cm)4.42E+19  M(sun)3.76E+05  smallest:     len(cm):4.42E+19  M(sun):3.76E+05 Alf(ox-tran):     0.0000
```

CLOUDY 80.08

```
**************************************91Aug03*************************************
*                                                                              *
* title test against Van Blerkom and Hummer, fig 4                             *
* c tesest hydrogen grd state rec effic against vb+h exact results             *
* c this is their case e) - "zero condition"                                   *
* c their answer for H0/Htot at the illuminated edge is approx 5.8E-4,         *
* c and a Stromgren radius of roughly 7.8E16 cm                                *
* hden 4                                                                       *
* blackbody 50,000k                                                            *
* phi(h) 12.30103                                                              *
* stop eden 3.5                                                                *
* constant temper 4                                                            *
* abundances -10                                                               *
* print short                                                                  *
* c vbhum.in                                                                   *
* c cray                                                                       *
*                                                                              *
********************************************************************************
```

Chemical composition

He:.000 C:1.00E-10 N:1.00E-10 O:1.00E-10 Ne:1.00E-10 Mg:1.00E-10 Al:1.0E-10 Si:1.00E-10 S:1.00E-10 A:1.0E-10 Ca:1.0E-10 Fe:1.00E-10

```
          333Cell Peak1.24E+00   Lo 1.00E-05=0.9105cm   Hi-Con:1.16E+01 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):   1.8129   Average nu:1.491E+00   P( X-ray):   0.0000   P(BalC):   1.6661     Q(Balmer C):  12.5421
          Q(1.0-1.8):  12.2081   Q(1.8-4.0):  11.5855   Q(4.0-20):   9.1894   Q(20--):   0.0000     Ion pht flx:2.001E+12
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):   0.3234   Alf(ox):   0.0000     Total lumin:   2.0548
          U(1.0----):6.675E-03   U(4.0----):5.159E-06   T(En-Den):2.660E+01   T(Comp):4.787E+04     nuJnu(912A):7.712E+01
          Occ(FarIR):2.405E-09   Occ(H n=6):8.633E-13   Occ(1Ryd):3.557E-15   Occ(4R):2.567E-19     Occ (Nu-hi):1.868E-29
          Tbr(FarIR):4.000E-09   Tbr(H n=6):3.834E-09   Tbr(1Ryd):5.618E-10   Tbr(4R):1.624E-13     Tbr (Nu-hi):3.359E-23

#####  1 Te:1.000E+04 Hden:1.000E+04 Ne:9.994E+03 R:1.000E+25 R-R0:1.370E+15 dR:2.739E+15 NTR:  1 Htot:1.988E-16 T912: 9.995E-02###
 -1.17 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    5.797E-04 9.994E-01 H+0/Hden: 1.000E+00 1.319E-11 H-     H2 4.718E-13 7.839E-12 H2+  HeH+ 1.758E-20 H col den 2.739E+19
H 2SP 3-6   1.073E-10 2.758E-14 5.979E-17 7.101E-17 9.362E-17 1.234E-16 Texc(La); 4.757E+03 T(contn): 2.638E+01 T(diffs): 2.877E+02
Helium      1.724E-03 9.168E-01 8.145E-02 He I 2S3  3.767E-06 Comp H, C 2.436E-23 5.089E-24 Fill Fact 1.000E+00 Gam 1/tot 9.997E-01
He singlet  1.720E-03 8.819E-11 5.003E-18 8.344E-18 1.267E-17 1.798E-17 He triplt 3.767E-06 8.890E-16 6.766E-18 2.815E-17 7.210E-18
HeII        9.168E-01 1.124E-11 4.870E-18 4.670E-18 5.423E-18 6.668E-18 4.660E-17 2.075E-16 4.445E-14 PRAD/GAS; 6.794E-04
Pressure    NgasTgas; 1.999E+08 P(total): 2.762E-08 P( gas ): 2.760E-08 P(Radtn): 1.875E-11 Rad accel 1.884E-06 Force Mul 1.244E+03
Carbon      1.905E-05 5.321E-02 9.087E-01 3.804E-02 1.391E-05 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    2.348E-05 4.664E-02 9.138E-01 3.949E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      3.113E-05 8.956E-02 8.925E-01 1.788E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.472
Neon        1.298E-04 9.984E-02 8.955E-01 4.505E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 7.654E-05 3.502E-02 9.646E-01 2.726E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 2.683E-05 1.117E-01 6.817E-01 2.065E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.464E-06 2.943E-02 7.634E-01 2.053E-01 1.832E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 2.203E-07 2.449E-02 8.754E-01 9.966E-02 4.264E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 1.099E-05 5.734E-02 8.684E-01 7.413E-02 1.251E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 2.404E-03 8.364E-02 8.951E-01 1.883E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 2.731E-07 9.193E-04 1.343E-01 8.376E-01 2.712E-02 2.365E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
##### 48 Te:1.000E+04 Hden:1.000E+04 Ne:3.118E+03 R:1.000E+25 R-R0:7.777E+16 dR:1.819E+14 NTR:  1 Htot:1.100E-16 T912: 9.999E+01###
 -0.02 4686  0.00 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
Hydrogen    7.432E-01 2.568E-01 H+0/Hden: 1.000E+00 1.969E-08 H-     H2 7.968E-08 7.561E-09 H2+  HeH+ 1.257E-16 H col den 7.786E+20
H 2SP 3-6   1.170E-10 5.957E-12 1.176E-17 1.300E-17 1.943E-17 2.845E-17 Texc(La); 4.224E+03 T(contn): 2.151E+01 T(diffs): 2.625E+02
Helium      2.774E-01 6.806E-01 4.195E-02 He I 2S3  1.971E-06 Comp H, C 1.895E-24 7.196E-25 Fill Fact 1.000E+00 Gam 1/tot 3.280E-01
He singlet  2.774E-01 2.083E-11 3.490E-19 6.598E-19 1.190E-18 1.924E-18 He triplt 1.971E-06 1.637E-16 1.407E-18 6.579E-18 1.713E-18
HeII        6.806E-01 7.102E-13 2.462E-19 2.773E-19 3.723E-19 5.162E-19 4.184E-18 3.522E-17 7.478E-15 PRAD/GAS; 3.400E-02
```

```
Pressure    NgasTgas; 1.331E+08 P(total): 1.908E-08 P( gas ): 1.838E-08 P(Radtn): 7.019E-10 Rad accel 3.234E-07 Force Mul 1.599E+03
Carbon      3.254E-04 9.313E-01 6.839E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    4.649E-02 9.526E-01 9.115E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      7.639E-01 2.357E-01 3.322E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 Hex(tot): 0.000E+00 A:-12.588
Neon        5.788E-02 3.763E-01 5.659E-01 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Magnesium 0 4.459E-03 9.133E-01 8.220E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Aluminium 0 3.426E-04 9.848E-01 1.477E-02 1.297E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Silicon   0 1.117E-04 9.951E-01 4.767E-03 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Sulphur   0 3.198E-05 9.308E-01 6.917E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Argon     0 4.769E-01 4.635E-01 5.960E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Calcium   0 6.508E-03 1.107E-01 8.824E-01 4.389E-04 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
Iron      0 1.548E-02 9.529E-01 3.157E-02 1.595E-05 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  Calculation stopped because lowest EDEN reached.
  Geometry is plane-parallel.
  Photoionization of He 2TriS reached  40.8 percent of the total rate out.
W-Heating - cooling mismatch =  1.42E+00 Whats wrong????
  Frequency out of range of free-free gaunt factor routine.
  The ratio of radiation to gas pressure reached  2.27E+00.  Caused by Lyman alpha.
C-The HeII continuum is thin and I assumed that it was thick.  Try another iteration.
```

```
*********************************> CLOUDY 80.08  <*********************************
* title test against Van Blerkom and Hummer, fig 4                                   *
* c tesest hydrogen grd state rec effic against vb+h exact results                   *
* c this is their case e) - "zero condition"                                         *
* c their answer for H0/Htot at the illuminated edge is approx 5.8E-4,               *
* c and a Stromgren radius of roughly 7.8E16 cm                                      *
* hden 4                                                                             *
* blackbody 50,000k                                                                  *
* phi(h) 12.30103                                                                    *
* stop eden 3.5                                                                      *
* constant temper 4                                                                  *
* abundances -10                                                                     *
* print short                                                                        *
* c vbhum.in                                                                         *
* c cray                                                                             *
********************************> LOG(U): -2.18 <*********************************
>>>>>>>>>> Warnings exist, this calculation is suspect.
>>>>>>>>>> Another iteration is suggested.

                Emission Line Spectrum.   Constant  Density Model.    Open geometry.  Iteration 1 of 1.
                                              Intensity (erg/s/cm^2)

TOTL 4861 -0.016   1.0000      TOTL 4861 -0.016   1.0000      TOTL 1216  1.447  29.0388      nFnu 1215 -1.748   0.0185
TOTL 1216  1.447  29.0388      TOTL 4340 -0.314   0.5033      TOTL 1026 -2.660   0.0023      Inci 4861  0.424   2.7579
TotH    0  1.341  22.7791      TOTL 4102 -0.545   0.2962      TOTL  973 -2.666   0.0022      Inci 1216  1.754  58.9147
BFH1    0  1.341  22.7785      TOTL18751 -0.571   0.2784      TOTL  950 -2.634   0.0024      BA C    0  0.595   4.0797
CA B 4861 -0.030   0.9688      TOTL12818 -0.844   0.1486      TOTL  938 -2.591   0.0027      PA C    0  0.082   1.2525
CA B 1216  1.504  33.1156      TOTL10938 -1.067   0.0889      C13c 6563 -2.500   0.0033      H FF    0  0.121   1.3698
DU B 4861 -0.030   0.9688      TOTL40512 -1.255   0.0576      CION    0 -2.474   0.0035      H FB    0  0.298   2.0597
Q(H) 4861 -0.022   0.9865      TOTL26252 -1.451   0.0367      INWD 1216  1.447  29.0387      Cool 1216 -0.426   0.3891
Q(H) 1216  1.512  33.7268      TOTL74578 -1.781   0.0172      e sc18751 -1.799   0.0165      ToFF    0  0.121   1.3698
TOTL 6563  0.424   2.7569      2 NU    0  0.807   6.6543      nFnu 4860  0.416   2.7016
```

```
                          TEST AGAINST VAN BLERKOM AND HUMMER, FIG 4
Cooling:  H FF    0:0.356  H FB    0:0.536  Cool 1216:0.101
Heating:  BFH1    0:1.000

IONIZE PARMET:  U(1-) -2.1755  U(4-): -5.2875  U(sp): -2.18  Q(ion):    9.044  L(ion):  -1.047 Q(low): 12.61    P(low)  1.69
ENERGY BUDGET:  Heat:   1.341  Coolg:   0.569  Error: 83.1%  Compt H:  -5.894  WorkF:    1.659 F-F  H -4.878    PRADMX:2.27E+00
Column density  H12:7.786E+20  H II:7.627E+20  HI:1.589E+19  H-:    4.100E+11  H2:   8.589E+11 H2+:1.553E+11    He H+:1.763E+03
                OH: 0.000E+00  Heff:0.000E+00
<NH>:1.000E+04  <Tp>:1.00E+04  <TO3>:1.00E+04  Ne:9.966E+03  ti(snd):6.07E+10  NeN+dl:7.54E+24 <T(C3)>:1.00E+04 <E(C3)>:9.92E+03
He/Ha:1.16E-10  =   1.16*true  N/Oap:1.08E+00  =   1.08true  T(O3R):9.978E+03  L THIN:1.00E+30 <T(S2)>:1.00E+04 <E(S2)>:8.47E+03
T He+:1.00E+04  EHe+:9.83E+03  T(O+):1.00E+04  EO+:9.51E+03  iter/zn:   1.000  Te-low:1.00E+04 Te-high:1.00E+04  Hlu/zn:1.37E+00
  <a>:0.00E+00  erdeFe0.0E+00  Tcompt2.47E+07  Tthr7.97E+08  <Tden>: 1.00E+04  <dens>:1.66E-20 <Mol>:5.05E-01
Mean Jeans      l(cm)5.60E+19  M(sun)7.69E+05  smallest:     len(cm):5.60E+19  M(sun):7.69E+05 Alf(ox-tran):     0.0000
```

CLOUDY 80.08

```
**************************************91Aug03***************************************
*                                                                                  *
* title test of equations of motion in a wind                                      *
* c test of wind code                                                              *
* c radiative acceleration (e- only) is 9.54E-7 cm s^-2                            *
* c terminal velocity (e- only) is 7.6 km s^-1                                     *
* hden 4                                                                           *
* table agn                                                                        *
* luminosiy (total) 45                                                             *
* radius (parsecs) 1                                                               *
* stop thickness (parsecs) -1                                                      *
* no radiation pressure                                                            *
* wind 0.1                                                                         *
* constant temperature 8                                                           *
* print only zones                                                                 *
* c wind.in                                                                        *
* c cray                                                                           *
*                                                                                  *
************************************************************************************
```

Chemical composition

He:.098 C:3.63E-04 N:1.12E-04 O:8.51E-04 Ne:1.23E-04 Mg:3.80E-05 Al:3.0E-06 Si:3.55E-05 S:1.62E-05 A:3.6E-06 Ca:2.3E-06 Fe:4.68E-05

```
          546Cell Peak1.78E+00   Lo 1.00E-05=0.9101cm   Hi-Con:7.34E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.01 MeV
          P(nu>1ryd):  44.7349   Average nu:3.038E+00   P( X-ray):  43.9062   P(BalC):  44.2392     Q(Balmer C):  55.2020
          Q(1.0-1.8):  54.6108   Q(1.8-4.0):  54.5031   Q(4.0-20):  53.9656   Q(20--):  52.2283     Ion pht flx:6.858E+14
          L(gam ray):  43.6447   Q(gam ray):  50.0597   L(Infred):  44.4533   Alf(ox):  -1.4120     Total lumin:  45.0003
          L/Lsolar:    11.4175   Abs bol mg: -23.8237   Abs V mag: -21.2231   Bol cor:  -2.6006     nuFnu(Bbet):  43.8959
          U(1.0----):2.287E+00   U(4.0----):2.622E-01   T(En-Den):1.386E+02   T(Comp):1.327E+07     nuJnu(912A):1.449E+04
          Occ(FarIR):1.288E-03   Occ(H n=6):4.859E-07   Occ(1Ryd):6.683E-13   Occ(4R):3.426E-15     Occ (Nu-hi):4.775E-43
          Tbr(FarIR):2.144E-03   Tbr(H n=6):2.157E-03   Tbr(1Ryd):1.056E-07   Tbr(4R):2.167E-09     Tbr (Nu-hi):5.269E-31

#####  1 Te:1.000E+08 Hden:1.000E+04 Ne:1.210E+04 R:3.086E+19 R-R0:1.084E+12 dR:2.168E+12 NTR:  1 Htot:6.351E-18 T912: 1.790E-12###
 -9.52 4686  0.89 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
WIND; V:1.000E-01km/s G:-1.393E-13 Accel: 9.401E-07 Fr(cont): 1.000 Fr(line): 0.000 Fr(dP): 0.000
P(LINES): 0.008 0.000 0.000 0.000 0.000 0.000 0.992 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    1.313E-11 1.000E+00 H+0/Hden: 1.000E+00 0.000E+00 H-     H2 0.000E+00 0.000E+00 H2+  HeH+ 0.000E+00 H col den 2.168E+16
H 2SP 3-6   1.346E-14 5.391E-22 3.735E-22 4.052E-22 5.236E-22 6.695E-22 Texc(La); 4.729E+03 T(contn): 1.386E+02 T(diffs): 3.940E+02
Helium      1.537E-18 4.185E-10 1.000E+00 He I 2S3  6.001E-20 Comp H, C 5.720E-18 4.312E-17 Fill Fact 1.000E+00 Gam 1/tot 2.922E-01
He singlet  1.477E-18 1.706E-22 2.009E-29 4.319E-29 8.746E-29 1.601E-28 He triplt 6.001E-20 5.614E-27 1.355E-29 1.556E-29 4.130E-30
HeII        4.185E-10 7.577E-15 2.303E-22 2.081E-22 2.765E-22 3.659E-22 2.591E-21 1.950E-20 2.381E-18 PRAD/GAS; 0.000E+00
Pressure    NgasTgas; 2.309E+12 P(total): 3.188E-04 P( gas ): 3.188E-04 P(Radtn): 0.000E+00 Rad accel 9.401E-07 Force Mul 9.878E-01
Carbon      0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.378E-10 1.841E-05 1.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.749E-09 5.524E-05 9.999E-01 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.654E-08 1.460E-04 9.999E-01 Hex(tot): 0.000E+00 A:-16.938
Neon        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.127E-07 7.675E-04 9.992E-01
Magnesium 1 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 5.126E-06 2.952E-03 9.970E-01
Aluminium 2 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.353E-04 7.257E-03 9.925E-01
Silicon   3 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.538E-05 9.344E-03 9.906E-01
Sulphur   5 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.628E-07 3.255E-04 2.585E-02 9.738E-01
Argon     7 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.643E-06 3.752E-03 6.127E-02 9.350E-01
Calcium   9 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.945E-05 6.421E-03 1.304E-01 8.632E-01
Iron     15 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.211E-05 4.345E-03 2.428E-01 4.476E-01 3.052E-01
#####153 Te:1.000E+08 Hden:1.312E+02 Ne:1.587E+02 R:3.116E+19 R-R0:3.015E+17 dR:6.349E+15 NTR:  1 Htot:7.743E-20 T912: 1.982E-09###
 -6.85 4686  0.93 5876  0.00 1909  0.00 1549  0.00 6584  0.00 5007  0.00 3727  0.00 6300  0.00 2798  0.00 1035  0.00
WIND; V:7.476E+00km/s G:-1.366E-13 Accel: 9.103E-07 Fr(cont): 1.000 Fr(line): 0.000 Fr(dP): 0.000
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P(LINES): 0.000 0.000 0.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
Hydrogen    1.720E-12 1.000E+00 H+0/Hden: 1.000E+00 0.000E+00 H-     H2 0.000E+00 0.000E+00 H2+  HeH+ 0.000E+00 H col den 7.856E+19
H 2SP 3-6   2.250E-16 2.113E-23 1.778E-23 1.928E-23 2.315E-23 2.797E-23 Texc(La); 4.512E+03 T(contn): 1.379E+02 T(diffs): 4.379E+02
Helium      1.515E-19 3.015E-10 1.000E+00 He I 2S3  1.169E-20 Comp H, C 7.358E-20 5.546E-19 Fill Fact 1.000E+00 Gam 1/tot 9.069E-01
He singlet  1.398E-19 2.029E-24 2.866E-31 5.516E-31 1.009E-30 1.738E-30 He triplt 1.169E-20 1.552E-29 1.279E-31 1.468E-31 1.154E-32
HeII        3.015E-10 1.308E-16 1.640E-23 1.685E-23 1.994E-23 2.395E-23 1.511E-22 2.536E-22 3.121E-20 PRAD/GAS; 0.000E+00
Pressure    NgasTgas; 3.062E+10 P(total): 4.227E-06 P( gas ): 4.227E-06 P(Radtn): 0.000E+00 Rad accel 9.103E-07 Force Mul 9.860E-01
Carbon      0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.518E-10 1.499E-05 1.000E+00 H2O+/Otot 0.000E+00 OH+/Ototl 0.000E+00
Nitrogen    0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.967E-09 4.406E-05 1.000E+00 O2/Ototl: 0.000E+00 O2+/Otot: 0.000E+00
Oxygen      0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.142E-08 1.148E-04 9.999E-01 Hex(tot): 0.000E+00 A:-16.938
Neon        0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.476E-07 5.727E-04 9.994E-01
Magnesium 1 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.989E-06 2.125E-03 9.979E-01
Aluminium 2 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.636E-05 4.249E-03 9.957E-01
Silicon   3 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.025E-05 6.052E-03 9.939E-01
Sulphur   5 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.136E-04 1.513E-02 9.848E-01
Argon     7 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.084E-06 1.306E-03 3.544E-02 9.633E-01
Calcium   9 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.836E-06 1.773E-03 7.338E-02 9.248E-01
Iron     15 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.699E-06 7.743E-04 5.809E-02 3.313E-01 6.098E-01
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