

## Addenda to version 07.02.01 of Cloudy

This is a bug-fix roll up of version C07.02 of Cloudy. In the past no new features have been included in a bug fix roll up. However this release is different. There are two significant differences between C07.02.01 and C07.02.00 (the original release of C07.02).

### 1.1. Dielectronic recombination

A number of studies have appeared in the past two years that have greatly expanded the dielectronic-recombination data base. These new generation DR rates are referred to as the Badnell data. DR is the dominant recombination mechanism for most heavy elements (Osterbrock & Ferland 2006; section 2.7 and Appendix 4). There are several changes in the treatment of DR in C07.02.01.

The Badnell DR rates were available in C06.02 but were not used by default. They were enabled with the **set recombination** commands. These are used by default in C07.02. These result in significant changes in some predicted quantities.

*The guessed DR rates* The DR database is still very incomplete. Most ions do not have calculated or measured rate coefficients. It is better to use a guess of a DR rate than to assume that the rate is zero (Ali et al. 1991). Starting in C06.02 the guesses of the DR rates have come from the mean of the existing DR rates for that charge state. That is, the guess for the DR recombination rate for ions with a particular charge will be the mean of all known rates for ions with that charge. The method of determining this mean has changed in C07.02.01. In versions C06.02 through C07.02.00 a straight linear average was taken. In C07.02.01 the average of the logs of the rates is used instead. This is better due to the large dispersion in rate coefficients. Some of the asserted values in the test suite changed as a result. All of this is an uncertainty of course.

The **set atomic data** command now has the option **sulphur DR** to change the treatment of S dielectronic recombination. Accurate DR rates do not now exist for low stages of ionization of S at photoionization temperatures. The [S III] / [S II] ratio is an important diagnostic indicator of conditions in many nebulae. This ratio depends on the DR rates chosen. This command changes the DR rates assumed for the lowest four ionization stages of S. The default, which can also be set with the keyword **\_mix**, is to use the larger of the Badnell (1991) or guessed rates. The keyword **pure** says to use only the Badnell rates. The keyword **scale** says to use scaled oxygen DR rates. In this case one to four scale factors, one for each ionization stage, will be parsed off the command line. If fewer than four numbers occur then the last number entered will be used for the missing scale factors. The DR rate for ions of S will be equal to the DR rate for the same ionization stage of O multiplied by its scale factor.

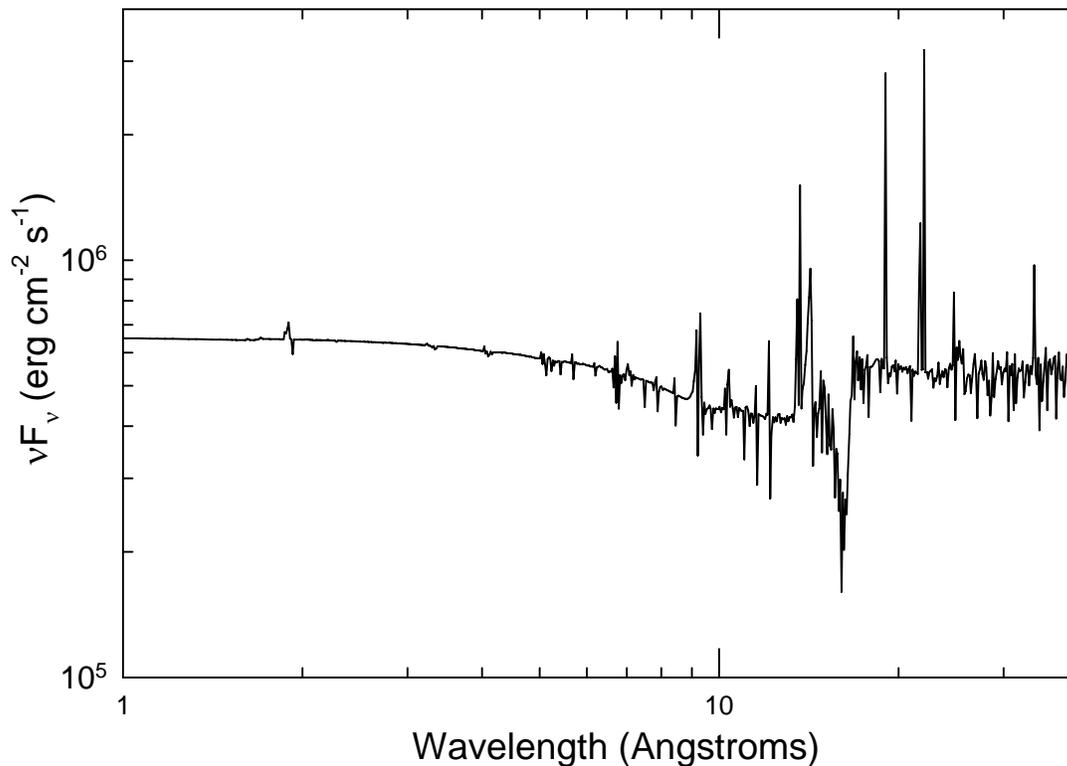
Versions before C07.02 used pure guesses. Version C07.02.00 assumed the **pure** case. Version C07.02.01 uses the **\_mix** case. One result of these changes is that the [S III] / [S II] balance will be different in C07.02.01 than it was in C07.02.00 and will be more similar to C06.02.

## 1.2. Absorption lines in the continuum

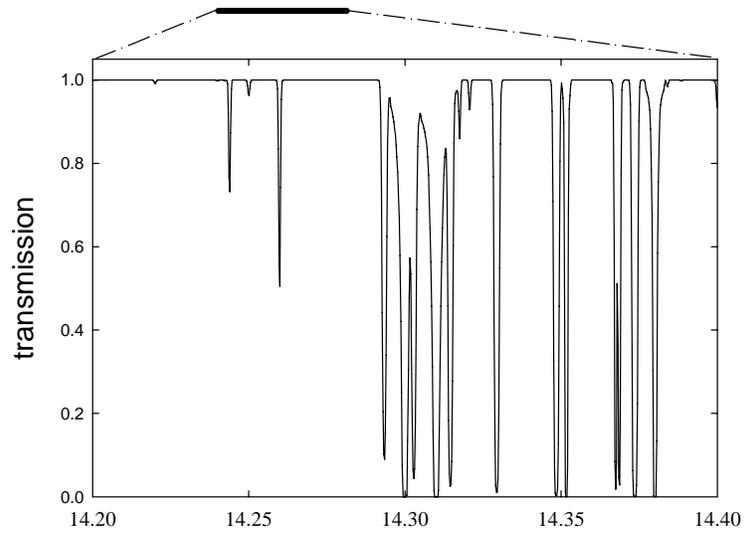
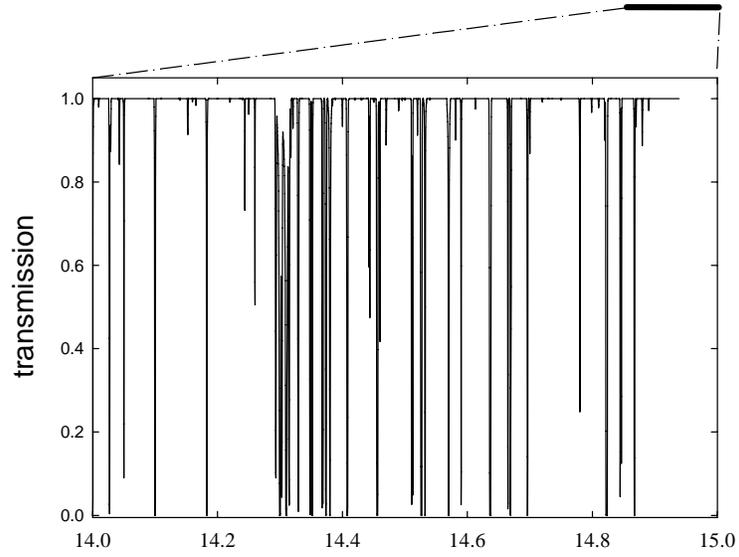
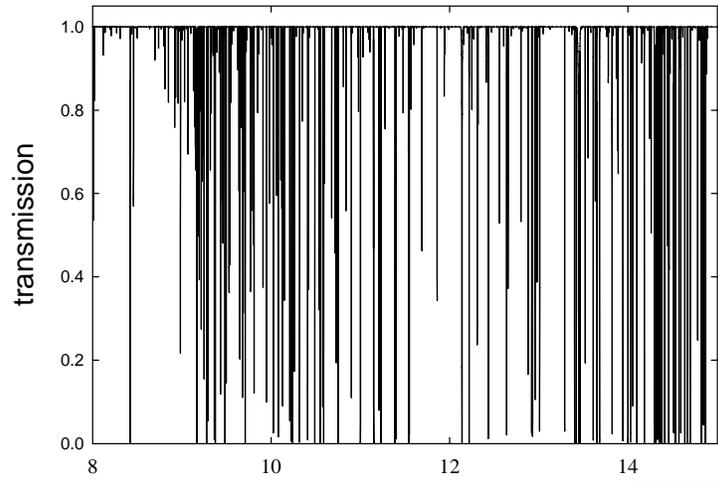
The code uses multi-grid methods to do the continuum radiative transfer on a coarse grid, to save time, and line transfer, including overlap, on a fine continuum. This was introduced in C05 and is described in Shaw et al. (2005).

The effects of line absorption were not shown in **punch continuum** output in version C07.02.00 and before although they were included in the calculations. The fine-continuum transmission coefficients are propagated into the punch output in version C07.02.01. The only change is in the coarse continuum output with these punch commands.

The figure below shows a portion of the coarse X-ray continuum for the *agn\_warm\_absorber.in* test case. This is the predicted continuum from the “total” column of the **punch continuum** output.



The fine continuum can be accessed with the **punch fine continuum** command. This gives transmission coefficients for a very fine energy mesh. The following figure shows part of the fine continuum for the *agn\_warm\_absorber.in* test case. This corresponds to a small part of the coarse continuum shown in the previous figure. Each panel shows a small portion of the panel above it. The lowest panel does not reveal the full resolution of the fine continuum since three energy bins were co-added to save disk space.



Wavelength (Angstroms)

### 1.3. References

- Ali, B., Blum, R. D., Bumgardner, T. E., Cranmer, S. R., Ferland, G. J., Haefner, R. I., & Tiede, G. P. 1991, *PASP*, 103, 1182
- Badnell, N. 1991; *ApJ*, 379, 356
- Osterbrock, D.E. & Ferland, G.J. 2006, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*, 2nd edition (AGN3)
- Shaw, G. Ferland, G.J. Abel, N.P. Stancil, P.C. & van Hoof, P.A.M. 2005, *ApJ*, 624, 794, (astro-ph/0501485)