THE NEBULATOM COOKBOOK

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RESUMEN

Este documento incluye las tareas del taller NEBULATOM

ABSTRACT

This is the exercises document for the NEBULATOM workshop. It can be see as a heavy FAQ document, to which the answers are given in a set of python programs.

Key Words: H II regions — ISM: planetary nebulae

This cookbook was prepared for hands-on activities on nebular and atomic physics for NEBULATOM, a capacity development workshop for Latin American astronomers on emission-line objects in the Universe, Choroni 4–16 March 2013. Many theoretical aspects treated during this workshop can be found for example in the fundamental books by in Spitzer ***, Osterbrock & Ferland (2006), Dopita & Sutherland (2003) and in the articles by Stasińska (2004) and Stasińska (2009).

The exercises presented here are meant to familiarize the student with the various concepts involved in the study of emission-line nebulae. They also serve to introduce the students to Cloudy, the most widely used public photoionization code (Ferland et al. 1998) and to Xstar, another public photoionization code (Kallman 1999) as well as to new tools developed in python for an easy interpretation of nebular spectra, which are pyNeb (Luridiana et al. 2012) and pyCloudy (Morisset 2012).

The solutions to the exercises, proposed as series of codes written in python, can be downloaded from `http://132.248.1.104/PyNeb/Choroni/`. It is actually not expected from the students to produce similar codes by themselves, but to run the proposed codes, paying attention to the way the problems are treated, exploring alternative solutions, and keeping a critical eye on the results.

These codes are also meant to be convenient starting points for further exploration of problems dealing with emission line nebulae.

Note: The exercises should be made in the proposed order, as they may use tools developed in previous steps.

[1]XXX.
[2]YYY.
[3]ZZZ.

1. LINE EMISSIVITIES

These exercises make use of the pyNeb software (Luridiana et al. 2012)[4].

For any line, the word ‘emissivity’ is taken to be the energy per emitting ion and per electron emitted in all directions for the corresponding transition. In CGS units it is expressed in erg s^{-1} cm^3 .

1.1. Emissivities of lines from O III

1.1.1.

Find all the lines emitted by the O III ion. Examine from what levels they are issued. For lines issued from the same level, which are the ones which will be the strongest?

1.1.2.

Compute the emissivities of all these lines between 1000 and 30000 K, at a density of n_e= 100 cm^{-3}, and plot them. Which are the strongest lines at T_e= 3000 K ? at T_e= 10000 K ? at T_e= 30000 K ? Why?

1.1.3.

Do the same for n_e= 10^5 cm^{-3}. What are the differences? How do they relate to the critical densities of the levels?

1.1.4.

Check the sources of atomic data that are used in the computations of the line emissivities.

1.1.5.

Change artificially all the transition probabilities by a factor of 5. Plot the line emissivities for n_e= 100 cm^{-3} and

[4]To install pyNeb, see Appendix A.

$n_e = 10^5$ cm^{-3}. In what case are the emissivities most changed? Why? Write the expression of a line emissivity in the case of a 2-level atom to better understand the behaviour of the O III line emissivities in your plot.

1.1.6.

Do the same but now changing all the collision strengths by a factor of 5.

1.1.7.

Extend the plot to temperatures down to 100 K and up to 10^7 K. What happens? Check the values of the collision strenghts at the different temperatures. Try a linear extrapolation of the collision strenghts rather that the default one in PyNeb (Chebycheff).

1.2. Energy balance in an hydrogen-oxygen nebula

We consider a nebula with constant density $n_H =$ 100 cm^{-3} composed only of hydrogen and oxygen, and ionized by a star of temperature $T_\star = 50000$ K and radiating like a blackbody.

1.2.1.

Compute the energy gain $\Gamma/n_e/n_H$ in erg s^{-1} cm^3 due to hydrogen ionization by the stellar radiation discarding the change of the spectral energy distribution of the ionizing photons within the nebula due to absorption. Plot it as a function of T_e from 0 to 30000K.

1.2.2.

Compute the energy losses due to H recombination and to H free-free radiation as a function of T_e and plot them, together with their sum, in the same diagram.

1.2.3.

Compute the energy losses in the O^{++} region of each of the oxygen line and plot them in a diagram for an oxygen abundance O/H= 3×10^{-4}.

1.2.4.

Plot in a separate diagram the energy gains, the H losses, the O^{++} losses, and the total losses. Find the resulting electron temperature.

1.2.5.

By how much does one need to change the oxygen abundance to increase the temperature by 2000 K? To decrease it by 2000 K?

1.2.6.

Alternatively, what change in $T_\star$ is needed to produce the same effect?

1.2.7.

Repeat the whole procedure for the O^+ zone.

1.2.8.

Comment on the comparison between the O^{++} and O^+ zone. In a real nebula, what changes would you expect with respect to this simple toy model?

2. PLASMA DIAGNOSTICS

2.1. A catalogue of isoratios for plasma diagnostics

Consider the following ions: C^{++}, N^+, O^+, O^{++}, Ne^{++}, S^+, S^{++}, Cl^{++}, Ar^{+++}.

2.1.1.

For each of them, find line pairs that are susceptible to be easily observed (either in the UV, the optical or the IR domain) and to give temperature and/or density diagnostics. Note: some line pairs are strictly equivalent from the point of view of the plasma diagnostics. e.g. [O III] λ4363/[O III] λ5007 and [O III] λ4363/[O III] λ4959. In that case, consider only the one involvng the strongest line, i.e., in this case [O III] λ4363/[O III] λ5007.

2.1.2.

For each of these pairs, construct an isoratio plot, and save it.

2.1.3.

Looking at these plots, for each of them find the temperature/density domain where they are useful for plasma diagnostics.

2.2. Using pyNeb for plasma diagnostics of a planetary nebula of high excitation

Analyse the planetary nebula IC 2165.

2.2.1.

Hyung, S. , 1994, ApJS, 90, 119 gives the intensities of optical lines, corrected for extinction and relative to Hβ= 100. The following table gives the ones that are important for diagnostics and abundance calculations:

```
NAME IC_2165
Ne5_3426A 55.88
O2_3726A 18.39
O2_3729A 9.36
Ne3_3869A 85.70
S2_4069A 0.87
S2_4076A 0.71
O3_4363A 20.75
Fe3_4659A 0.17
He2_4686A 63.48
Fe3_4703A 0.14
Ar4_4711A 5.33
Ar4_4740A 5.86
H1_4861A 100
O3_5007A  1158.31
Ar3_5192A 0.11
N1_5198A 0.16
N1_5200A 0.11
Cl4_5323A 0.07
Cl3_5518A 0.33
Cl3_5538A 0.37
O1_5577A 1.21
N2_5755A 0.47
O1_6300A  1.20
S3_6312A  1.32
Ar5_6435A  1.32
N2_6583A  17.12
S2_6716A  0.86
S2_6731A  1.34
Ar5_7006A 2.08
Ar3_7136A  7.12
Ar4_7170A 0.31
Ar4_7237A 0.26
Ar4_7262A 0.23
Cl4_7531A 0.34
O2_7319A+  1.14
O2_7330A+  0.96
Ar3_7751A 1.50
Cl4_8046A 0.73
Cl3_8501A 0.37
S3_9069A 5.96
```

Construct the plasma diagnostic diagram with PyNeb. Hint: to find which line ratios provide useful diagnostics, consult Tables 1.9 to 1.14 from Stasińska (2009) available from internet at `http://arxiv.org/abs/0704.0348`.

What does the plasma diagnostic diagram say about the electron density in this object? Is there evidence for zones of different densities? What does it say about the electron temperature in the low excitation region? in the high excitation region? Compare with the diagnostic diagram published by Hyung.

2.2.2.

Add information from the UV spectrum (Table 1 from Hyung 1994) into the plasma diagnostic diagram. nb: the UV data have already been dereddened and put to a common scale with the optical data using the HeII 1640/HeII 4686 ratio. The corresponding line intensities are as follows:

```
N4_1487A 32.53
Ne5_1575A 16.32
O3_1666A 21.71
N3_1754A 16.95
C3_1907A 961.7
C3_1909A 943.17
```

To find out what new diagnostics are available when including UV data do the following in pyNeb, for example for N III:

```
N3 = pn.Atom('N',3)
N3.printIonic(1e4, 100, verbose=True, printA=True)
```

Comment of the different values of the densities from different diagnostics. Did all the new data provide a diagnostic? If not, try to understand why.

2.2.3.

Infrared data have been obtained by ISO for this object (Pottasch et al, 1994, A&A 423, 593, Table 2, reproduced below).

```
 ident  lambda  Intensity
He II 9-7  2.826  0.13
H I 5-4  4.053  2.81
[Mg IV]   4.487  4.18
[Ar VI]   4.530  1.82:
[Mg V]   5.610  4.76
[Ne VI]   7.655  0.52:
[Ar V]   7.903  0.75
[Ar III]   8.993  2.27
[S IV]    10.510  27.4
[Ne II]   12.816  1.50
[Ar V]   13.103  1.25
[Mg V]   13.525  0.52
[Ne V]   14.325  24.0
[Ne III]   15.558  32.2
[S III]   18.716  5.55
[Ne V]   24.320  21.3
[O IV]  25.894  84.2
[S III]   33.485  2.40
[Ne III]   36.021  3.56
[O III]   51.854  28.4
[N III]   57.385  4.53
[O III]   88.393  8.06
```

The measured intensities are in units of 10^{-12} erg cm^{-2} s^{-1}. Add information from these lines in the plasma diagnostic diagram. Caution: put the IR observations to scale with the optical ones using the H I 5-4/Hβ ratio. We will assume that all the IR observations were done using the same $14'' \times 20''$ aperture. Comment on the new diagnostics.

2.2.4.

Redo the 3 diagnostics plots with atomic data set corresponding to "IRAF_09".

2.2.5.

If you have not done it yet, find an image of IC 2165 on the internet. Comments.

3. ABUNDANCE DERIVATIONS WITH THE DIRECT METHOD

3.1. The chemical composition of IC 2165

3.1.1.

Using the plasma diagnostics diagram for IC 2165 estimate the following parameters: n_e([O II]), n_e([Ar IV]), T_e([N II]), T_e([O III]) *from the optical data only*.

3.1.2.

Determine the ionic abundances for N, O, Ne, S, Cl, Ar ions. Comment on the abundances of the same ion as determined by different lines.

3.1.3.

Determine the abundances of N, O, Ne, S, Cl, Ar *from the optical data only* using the ionization correction factors from Kingsburgh & Barlow (1994).

3.1.4.

Add information from the UV and infrared data to determine the chemical composition of this nebula (including the carbon abundance) basing as much as possible on direct measurement of ionic abundances without using ionization correction factors. Comment on the reliability of the derived abundances using all the available information with respect to those derived from optical data only.

3.1.5.

Repeat steps 3.1.2 and 3.1.3 using the set of atomic data corresponding to “IRAF_09”

3.2. The chemical composition of giant H II regions NGC 300

Bresolin et al. 2009, have observed 20 giant H II regions in the spiral galaxy NGC 300.

3.2.1.

Take the observed line intensities from NGC300.dat at `http://132.248.1.104/PyNeb/Choroni/` , and compute the electron densities and temperatures from all the available ratios.

3.2.2.

Use Bresolin’s et al policy to derive the electron temperature in the low- and high-excitation zones of each object.

3.2.3.

Compute the ionic abundances for N, O, Ne for all the objects

3.2.4.

Compute the total abundances of N, O, Ne for all the objects using the ’classical’ formulae for the ionization correction factors: O/H= O^+/H + O^{++}/H, N/O = N^+/O^+, and Ne/O=Ne^{++}/O^{++}.

3.2.5.

Plot O/H, Ne/H, N/H as a function of the galactocentric distance (given in Bresolin et al 2009).

3.2.6.

Compute the error bars on O/H, N/O and Ne/O taking into account only the effect of the uncertainty in the electron temperature, for simplicity. What other sources of errors could be important. How should one compute the error bars properly?

4. ABUNDANCE DERIVATIONS WITH STRONG LINE METHODS

4.1. The metallicities of the giant H II regions in NGC 300 using the R_{23} indicator

Consider the same sample of giant H II regions in NGC 300 as in Sect. 3.2.

4.1.1.

Compute the values of O/H using the R_{23} indicator with the calibration fro Zaritsky et al. (1994).

4.1.2.

Compute the error bas on O/H considering only the nominal uncertainties on the observed line ratios. What other sources of error could be important?

4.1.3.

Plot the two O/H abundances against each other, including the error bars. Comments?

4.2. Comparing the results from various stron line indicators

4.2.1.

Repeat exercises from Sect. 4.1 but with the O_3N_2 index using the calibration of Pettini & Pagel (2004).

4.2.2.

Do the same with the calibration of Pilyugin & Thuan (2005). Comments?

5. FIRST STEPS WITH CLOUDY

The examples are obtained running Cloudy 10.00[5].

5.1. A simple run with Cloudy

5.1.1.

Read the instructions in c10.00/docs/QuickStart.pdf

5.1.2.

Run a simple model for an ionzing blackbody with a luminosity $10^4 L_\odot$ and an effective temperature of 50000K. The nebula is a sphere with density n= 100 cm^{-3}, solar abundances, no dust. Look at the output file.

5.1.3.

Run a second model, changing the geometry from spherical to plane parallel, but having the same ionization parameter. How did the ionization structure change? and the temperature of the O^+ and O^{++} zones. And the [O II] λ3727/Hβ and [O III] λ5007/Hβ line ratios?

6. RUNNING CLOUDY WITHIN THE PYCLOUDY ENVIRONMENT

The proposed exercises use the Cloudy code within the pyCloudy environment, developed by C. Morisset, in which many tools are available to easily make models and analyze them [6].

[5] To install Cloudy, see Appendix B.
[6] To install pyCloudy, see Appendix C.

6.1. Using Cloudy to better understand the physics of nebulae

6.1.1.

Check that L(Hβ) is a good measure of the total rate of H-ionizing photons when a dust-free nebula is ionization bounded. eg compute $L(\mathrm{H}\beta)/Q_H$ for models of various metallicities, various densities, and various temperatures of the blackbody ionizing stars.

6.1.2.

Check that the ionization structure is only a function of U when the spectral energy distribution is given. eg.. compare a spherical model with $n = 100$ cm^{-3} and filling factor ff=1 with a model with $n = 10^4$ $cm^{-3}$and filling factor ff=0.1. Repeat the exercise for various values of the effective temperature.

6.1.3.

Plot T_e, O^{++}/O, O^+/O as a function of the distance to the star in the above models.

6.1.4.

Construct a series of constant density, spherical dust-free models of density $n = 100$ cm^{-3} with average ionization parameter log $U = -2$ ionized by a star radiating as a blackbody at a temperature of 50000K, where the metallicity varies from 0.01 $Z_\odot$ to 3 $Z_\odot$ plot the following parameters, as a function of metallicity: outer radius, average temperatures and ionic fractions of O^+ and O^{++} [O II] λ3727/Hβ, [O III] λ5007/Hβ, [O III] λ88μm/Hβ. Comment.

6.1.5.

Do the same, adding dust with Orion-type grains, with a dust-to-gas ratio proportional to metallicity.

6.1.6.

Do the same, now depleting the gas abundances according to the dust content.

6.1.7.

Do the same, now taking a density $n = 10^3$ cm^{-3}.

6.2. Testing different stellar energy distributions

Consider a dust-free, spherical H II region of constant density n_H= 100 cm^{-3}, filling factor ff = 1 and half-solar abundances.

6.2.1.

Compute the value of the total rate of stellar photons with energies > 13.6 eV, $Q(\mathrm{H}^0)$, wich corresponds to an average ionization parameter $\log < U >= -2$, assuming an electron temperature $T_{\mathrm{e}} = 10^4$ K.

6.2.2.

Consider a starburst with initial mass 10^6 $\mathrm{M}_\odot$ and the Kroupa IMF with upper mass limit 100 $\mathrm{M}_\odot$, as modelled by Starburst99. Compute the spectral energy distributions corresponding to an age of 1 Myr and of 5 Myr, using the Geneva tracks with high mass-loss for $Z = 0.008$ and the Pauldrach/Hillier model atmospheres option. Name your model 'ISB_008'. Produce all the output files except .HRD, .OVI, .HIRES and .IFASPEC[7].

What is the value of $Q(\mathrm{He}^0)/Q(\mathrm{H}^0)$ for 1 Myr and 5 Myr?

6.2.3.

Compute with Cloudy in the pyCloudy environment a photoionization model having $\log < U >= -2$ and ionized why the SB99 SED at an age of 1 Myr[8].

Construct a figure with 9 panels showing the ionization structure of He and H, N, O, Ne, S, Ar, and the variations of n_{e} and n_{H}, T_{e}, and U as a function of the distance to the star.

6.2.4.

Find the temperature of the blackbody that has the same value of $Q(\mathrm{He}^0)/Q(\mathrm{H}^0)$.

6.2.5.

Repeat 6.2.3, but with such a blackbody and overplot the results on the on the previous figure.

6.2.6.

Find the temperature of a WMbasic model atmosphere with $\log g = 4$ and $\log (Z) = -0.3$ having the same value of $Q(\mathrm{He}^0)/Q(\mathrm{H}^0)$.

6.2.7.

Repeat 6.2.3, but with the WMbasic atmsosphere and overplot the results on the on the previous figure.

[7] Follow the instructions in Appendix D to run Starburst99.

[8] To use a model from Starburst 99 with Cloudy, follow the instructions in Appendix E.

6.2.8.

Construct a table giving the ionic fractions of the considered elements for each of the models.

6.2.9.

Plot the SEDS for 3, 5, 7 on the same figure. Comment the differences in ionization structure in the light of the SED plots.

6.3. Building a grid of Cloudy models to separate pure star forming galaxies in the BPT diagram

6.3.1.

When building a grid of models, one first has to ask oneself what are the lines whose intensities need to be stored. Prepare a list of lines that will be useful for the study of emission line galaxies observed in the Sloan Digital Sky Survey. Find the labels used for these lines in Cloudy. For this, first run a fake model including the following command:

```
save line labels "all_lines_C10.00.txt"
```

and look for the corresponding labels in the "all_lines_C10.00.txt" list. Caution: some lines have different labels depending on the processes that are included. e.g. O2 3727.

6.3.2.

Build a grid of plane parallel photoionization models with the following common input parameters:
open geometry, density $n_{\mathrm{H}} = 100$ cm^{-3}, no dust, ionizing radiation from starburst99 models for half solar metallicity and an age of 1 Myr (take the SB99 model from 6.2.2) and the following varying parameters:
$Z = 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.5$ $\mathrm{Z}_\odot$,
$\log U = -2, -2.3, -2.7, -3, -3.3, -3.7, -4$.

6.3.3.

Plot the observational BPT diagram (log [O III] λ5007/Hβ, vs log [N II] λ6584/Hα) for a set of emission line galaxies from the Sloan Digital Sky Survey. The relevant line intensities are given in file

`http://132.248.1.104/PyNeb/Choroni/BPT4Graz_f4.dat.`

6.3.4.

Overplot the grid of photoionization models, joining models with same metallicities by dashed lines and models with same ionization parameter by continuous lines and comment on the resulting plot.

6.3.5.

Comment on your results with respect to those of Stasińska et al. (2006).

6.4. Model-fitting of extragalactic planetary nebulae

This is an example of model-fitting with few observational constraints. Consider the planetary nebulae observed in the galaxy NGC 5128 by Walsh et al. (2012), for example objects F34 1, F34 2, F34 4, F34 7, and F34 11.

6.4.1.

For each object, try to fit an ionization bounded photoionization model to the observed data assuming a spherical geometry, constant density, a blackbody radiation, and comparing the observed line intensities with those given by the model. Before starting, think of the policy you will follow to find your best model. To analyze the goodness of your fit, use first a khi-sqare method on the line intensities, with weights inversely proportional to the line intensities. This is a widely used method. Analyze the problems of your 'best' model.

6.4.2.

Try to obtain a better model by attempting to fit each line within its error bar. Comments.

6.4.3.

Produce a new model, now relaxing the assumptions of constant density and ionization boundedness.

6.4.4.

Estimate the error bars on the O/N and N/O ratios.

6.5. Detailed model-fitting with many observational constraints

Consider the planetary nebula IC 418. A detailed photoionization model of it has been published by Morisset & Georgiev (2009). The proposed exercise is not to reproduce this model exactly but rather to show the different steps to reach an acceptable solution and keep a critical eye on the results. The following observational constraints are considered, most of them are reported in the MG09 paper:

- HST WFPC observations in Hα, [N II] λ6584 and [O III] λ5007fiters (find the 3-colour image on the internet and examine it)
- Total reddening-corrected Hβ flux
- Angular diameter
- The stellar spectrum
- A high resolution, deep optical spectrum within a slit
- Ultraviolet spectra obtained with IUE
- Infrared spectra obtained with ISO.

6.5.1.

Compute the starting model abundances using the direct method.

6.5.2.

Build a model with a density distribution reproducing the observed Hα surface brightness distribution and using the stellar model presented in Morisset & Georgiev (2009), which fits the atmospheric stellar properties.

For the fitting procedure, compare the observed line intensities with those obtained by the model *in the corresponding apertures*. Try to find a model which reproduces *all* the line intensities *within their respective error bars.*

7. MISCELLANEA

7.1. Dereddening a nebular spectrum

Consider the dereddened line fluxes of the planetary nebula NGC 2242 as given in Tables 2 and 3 of Torres-Peimbert et al. (1990).

- Redden them using the value of $C(\mathrm{H}\beta)$ given by those authors and the extinction law used by them. Deredden the obtained "observed" fluxes assuming the Fitzpatrick (1999) extinction law 1) with R_V = 2.1 and 2) with R_V = 5.0. Comments.
- Redden them, but now taking $C(\mathrm{H}\beta)$ = 0.3. Deredden the resulting fluxes again assuming the Fitzpatrick (1999) extinction law 1) with R_V = 2.1 and 2) with R_V = 5.0. Comments.

7.2. Computing line profiles

Taking the model of IC418 developped in Sec. 6.5, compute the line profile for Hbeta, [NII] and [OIII] lines in dirrefent directions. You can use a 2nd order polynomial law for the expansion velocity. Compare to the observations reported by Gesicki et al. 1996.

7.3. Plamas diagnostics for nebulae with strong condensations

Compute the Te-Ne diagnostic diagram of a 2-component gas by summing the contribution of a low density medium in which high density inclusions are present. Draw the diagrams for each componen and for the sum. The free parameters can be: Te, Ne, and mass of each component. What are the limitations of such a toy model?

7.4. A catalogue of line emissivities

Prepare an ascii catalogue of line emissivities for the more important emission lines, for easy reference or easy back-of-the envelope computations of abundances. Choose convenient temperature and density steps, eg 0.2dex in density and 200K in temperature). Do not forget to indicate in the file what were the atomic data used to build the catalogue and the version of pyneb.

7.5. Kappa distribution

7.5.1.

7.5.2.

7.6. Xstar and Cloudy

7.6.1.

7.6.2.

APPENDICES

A. INSTALLING PYNEB

To install and update PyNeb, follow the instructions on the page:
`http://132.248.1.104/PyNeb/` This is also where to find the PyNeb Manual, the Reference Manual, the Developper Reference Manual and more informations.

To check the version of PyNeb, enter the following in python:

```
print(pn.__version__)
```

B. INSTALLING CLOUDY

Download Cloudy from
`http://www.nublado.org/wiki/DownLoad` Unpack it in a safe place. Enter the source directory and change the following line in the Makefile:

```
95c95
<   CDP = $(PWD)/$SRCDIR/../data/
---
>   CDP = ./:$(PWD)/$SRCDIR/../data/
--
```

You can now compile Cloudy with the make command, following the instructions on the nublado.org web page.

C. INSTALLING PYCLOUDY

Download pyCloudy from
`https://sites.google.com/site/pycloudy/`

D. A USER-FRIENDLY INSTALLATION OF STARBURST99

Download Starburst99 on your computer from
`http://www.stsci.edu/science/starburst99/docs/default.htm`
and place it in a convenient location. After decompacting the file, rename the directory 'galaxy' as, for example, 'SB99_V6.0.4'. Enter the directory 'SB99_V6.0.4', modify the file 'Makefile' according to your needs and execute it by typing 'make' in a terminal window.

Create a directory for your SB99 model files and enter it. Go to
`https://sites.google.com/site/nebulatomtools/starburst99-tools`
and download the user-friendly driver goSB99. Modify the line starting with 'set dcode' to reflect your own installation.

Download also from
`https://sites.google.com/site/nebulatomtools/starburst99-tools`
the file ISB_008.input which is an input example.

E. MODIFYING CLOUDY TO RUN IT USING SEDS FROM STARBURST99

The version of Cloudy C10.00 reads the column containing stellar+nebular radiation instead of the one containing the stellar radiation only.

Do the following changes in source/stars.cpp:

```
1290c1290
<       double cage, cwavl, cfl1;
---
>       double cage, cwavl, cfl1, cfl2, cfl3;
1294c1294
<if( sscanf( chLine, " %le %le %le", &cage, &cwavl, &cfl1 ) != 3 )
---
>if( sscanf( chLine, " %le %le %le %le %le", &cage, &cwavl, &cfl1, &cfl2, &cfl3 ) != 5 )
1348c1348
<             fluxes[nmods][ngp] = pow( 10., cfl1 - 44.077911 );
---
>             fluxes[nmods][ngp] = pow( 10., cfl2 - 44.077911 );
```

and recompile Cloudy.

Rename the 'ISB_008.spectrum' file to a name readable by Cloudy:

```
cp ISB-008.spectrum ISB_008.stb99
```

Modify Cloudy by entering the following:

```
echo 'compile stars "ISB_008.stb99"' | cloudy.exe
```

This makes Cloudy create the file ISB_008.mod, which it is able to use as an input spectrum for computing a model.

REFERENCES

[]Bresolin F., Gieren W., Kudritzki R.-P., Pietrzyński G., Urbaneja M. A., Carraro G., 2009, ApJ, 700, 309
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