He-Like Triplet Plasma Emissivity Database Modifier

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1 Introduction

The He-like triplet lines which occur in the X-ray band from 5–42 Å are powerful diagnostics of density or photoexcitation. The APED[1], however, only contains emissivities for low density. To use triplet lines as a density diagnostic, one method is to fit the line strengths and from the ratio of the forbidden to intercombination line fluxes ("f/i"), look up the implied density from external sources.

The program used to compute APED (APEC[2]) can be used to compute emissivities for arbitrary densities, but it is not publicly available. Output for the strong He-triplets as a function of density has been available for some time as an ASCII table (Nancy Brickhouse, private communication) or a FITS table (Randall Smith, private communication), and as documents[3].

To provide better support for more direct fitting and modeling, we have

1. constructed a database of emissivity coefficients which parameterize the density dependence;
2. made very general modifications to ISIS[4] to provide APED-emissivity modifiers;
3. written an ISIS model to implement the modifier via the coefficients table; and
4. written a demonstration script and web page with examples.

[1] Astrophysical Plasma Emission Database: `http://cxc.harvard.edu/atomdb/`
[2] `http://cxc.harvard.edu/atomdb/sources_apec.html`
[3] `http://cxc.harvard.edu/atomdb/features_density.html`
[4] Interactive Spectral Interpretation System; `http://space.mit.edu/cxc/isis/`

2 Emissivity Fits

The aforementioned R. Smith documents give a prescription for fitting density dependence with a sum of exponentials. We have modified his procedure slightly by fitting a ratio of emissivities, in particular the triplet line in question to the sum of the triplet lines. Since the input data are on a rather coarse temperature grid (0.25 dex), dividing by the sum (which is rather insensitive to density), will give a better estimate when scaled by the sum at a nearby temperature. That is, we avoid errors otherwise incurred by interpolating in temperature.

The designations and APED levels for the triplet lines are given as follows:

Type	Label	upper	lower
resonance	w	7	1
intercombination	x	6	1
intercombination	y	5	1
forbidden	z	2	1

If we let $S(T, n_e) = \sum_i \epsilon_i(T, n_e)$ where i indexes the line type, then at each temperature grid point, T_j we fit

$$r_{kj} = \epsilon_k(T_j, n_e)/S(T_j, n_e) = a_0 + a_1 e^{-n_e/a2} + a_3 e^{-n_e/a4}$$

for the coefficients, a_m, over the grid of density, n_e. Here ϵ is the line emissivity in units of photons $\mathrm{cm^3 s^{-1}}$. Our input data had logarithmic grids of 16 temperatures from 5.0 to 8.75 in steps of 0.25 (dex), and 40 densities from 5.0 to 14.75 in steps of 0.25 (dex), though the grids are not filled completely over these ranges for any particular ion. Triplet data are available for He-like C, N, O, Ne, Mg, Si, and S.

The grid and coefficients are stored in a FITS binary table, `He_like_xyz_norm_coef.fits` with the structure given by

Col	Name	Type	Comment
1	elem	Int4	Element's atomic number
2	type	String[1]	Spectroscopic label, x, y, or z.
3	temp	Real8	Temperature [K]
4	a0	Real8	Coefficient, constant term
5	a1	Real8	Coefficient, amplitude of first exponential
6	a2	Real8	Coefficient, density scale for first exponential
7	a3	Real8	Coefficient, amplitude of second exponential
8	a4	Real8	Coefficient, density scale for second exponential

We did not fit the w (resonance) line, since it is not particularly density sensitive; it can be recovered as a function of density, if desired, from the three ratios and the sum for any temperature (e.g., to form the "G" ratio, $(f + i)/r$). Figure 1 shows an example of our fit to the O VII z, x, and y ratios at $\log T = 6.5$.

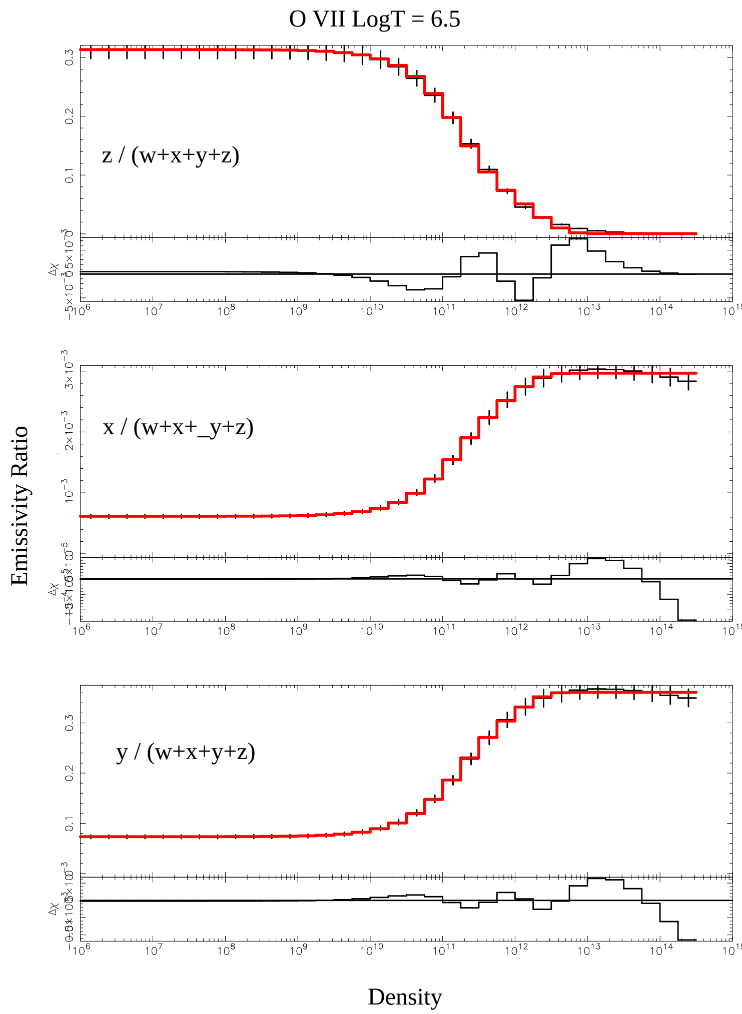

Figure 1: *Example fits for O* VII *at* $\log T = 6.5$

3 The Emissivity Modifier Function

ISIS allows an arbitrary emissivity modifier to be applied to any line in the APED database, as specified by a user-defined function which may also have adjustable fit parameters. We have used this feature to apply the parameterized density dependence when evaluating APED model spectra via the ISIS/S-Lang script, `he_modifier.sl`. This allows one to specify a plasma model in the following way:

```
isis>  require( "he_modifier.sl" ) ;
isis>  create_aped_fun( "Aped_1", default_plasma_state ) ;
isis>  fit_fun( "Aped_1( 1, He_triplets(1) )" );
```

The first line loads the source code file, which also reads the database table of coefficients. The second line creates a fit function called `Aped_1` which will be an isothermal plasma with Solar photospheric abundances, in this case. The modifier is given in the fit function specification as `He_triplets(1, He_Data)`. When we list the model parameters, we may see (after setting some parameters):

```
Aped_1( 1, He_triplets(1) )
 idx  param                 tie-to  freeze         value         min          max
  1  He_triplets(1).density    0      0     6.984294e+11       1e+08        1e+14
  2  Aped_1(1).norm            0      0      0.002563865       1e-06          0.1
  3  Aped_1(1).temperature     0      0          4474381     1584893      7943282
  4  Aped_1(1).density         0      1                1           0            0
  5  Aped_1(1).vturb           0      1                0           0            0
  6  Aped_1(1).redshift        0      1     9.359543e-05      -0.001        0.001
  7  Aped_1(1).metal_abund     0      1                1           0            0
```

Here, index 1 is our modifier parameter, giving the density ([cm^{-3}]). This *only effects the triplet lines as provided by the data table.* Parameter number 4 is given as a general parameter for the plasma database (APED), even though the current database has no density information. It is here for forward compatibility in anticipation of a density-dependent database (whose format has been specified), but *it will have no effect for APED 1.3.1.*

The modifier functionality is described in detail in the ISIS help for the function `create_aped_fun`. We have written a detailed test script, `t_he_modifier.sl`, which applies the triplet modifiers in a few different ways.

4 Obtaining Code, Data, and Examples

The programs, data, and examples (as well as this document) reside at the MIT/CXC software site, http://space.mit.edu/cxc/software/index.html under the "S-Lang Packages" category. Please navigate to http://space.mit.edu/cxc/software/slang/packages/hemodifier. The plasma modeling functions require ISIS[5] and APED[6] to run. The FITS coefficients datafile can be used independently, if desired.

5 Acknowledgements

We thank Nancy Brickhouse for providing the ASCII table of APEC triplet emissivities, and Randall Smith for providing a density-dependent test APED database with the same information. We also thank them for general advice on working with the APEC emissivity data.

[5] http://space.mit.edu/cxc/isis

[6] http://cxc.harvard.edu/atomdb