Atomic Data Unleashed

Interactive and scriptable interfaces to atomic databases

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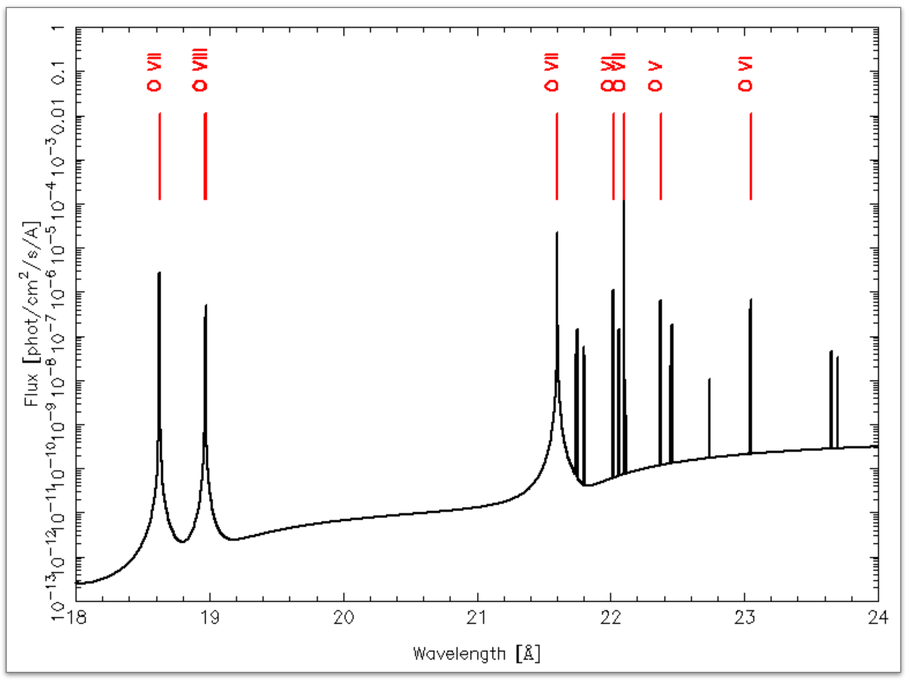
We present new software developed in **ISIS**, the Interactive Spectral Interpretation System, to provide high level access to underlying atomic data used in astrophysical plasma models. In particular, modules developed to support spectra computed from the **XSTAR** database allow for simple line or edge identification and more complex analysis requiring strengths or dependencies of specific features, such as theoretical line ratios. We will show examples for **computing diagnostics of astrophysical interest**, such as curves of growth and emissivity curves, and for **modeling multi-component photoionized plamas** (using **warmabs** and **photemis**) with newly developed ISIS modules. These software interfaces to atomic data are key to the legacy of Chandra, which has a rich and ever increasing high resolution spectroscopic dataset, requiring increasingly complex analysis.

Example 1: A single photemis model

```
% Set up the model, with fits file writing
fit_fun( "photemis2(1)" );

set_par( "photemis2(1).write_outfile", 1 );
set_par( "photemis2(1).autoname_outfile", 1 );
set_par( [3:27], 0 );
set_par( "photemis2(1).Oabund", 1 );

% Run the model
variable x1, x2;
(x1, x2) = linear_grid( 1.0, 40.0, 10000 );
variable y = eval_fun( x1, x2 );

% Load the XSTAR database from this run
variable db = rd_xstar_output( "photemis_1.fits" );

   ...

% Find the strongest lines by luminosity, 18-24 Angs
variable strongest = xstar_strong( 8, db; wmin=18.0, wmax=24.0 );

% Print a table of the strongest lines
xstar_page_group( db, strongest; sort="luminosity" );

% Mark them on the current plot
variable lstyle = line_label_default_style();
lstyle.top_frac = 0.85;
lstyle.bottom_frac = 0.7;
xstar_plot_group( db, strongest, 2, lstyle );
```

(Right) *Emission lines from a photoionized plasma. All metal abundances were set to zero, except for oxygen (1 x solar). The plotted wavelength region includes the O VII triplet.*

(Below) *The eight strongest transitions between 18 and 24 angstroms.*




```
isis> xstar_page_group( db, strongest; sort="luminosity" );
#      id    ion    lambda     A[s^-1]          f  gl  gu      tau_0       W(A) L[10^38 cgs]      type                    label
    7346    O   VII  22.1012  4.000e+01  8.784e-12   1   3  0.000e+00 -5.208e-14    8.397e+00      line     1s2.1S_0 - 1s1.2s1.3S_1
    7431    O   VII  21.6020  3.303e+12  6.930e-01   1   3  0.000e+00 -3.135e-15    4.940e-01      line     1s2.1S_0 - 1s1.2p1.1P_1
    7420    O   VII  18.6270  9.333e+11  1.456e-01   1   3  0.000e+00 -5.295e-16    7.195e-02      line     1s2.1S_0 - 1s1.3p1.1P_1
    7051    O    VI  23.0500  1.850e+11  7.365e-03   4   2  0.000e+00 -1.057e-16    1.777e-02      line 2s0.2p1.2P_3/2 - 1s1.2s2.2S_1/2
    7026    O    VI  22.0194  3.390e+12  4.926e-01   2   4  0.000e+00 -9.858e-17    1.584e-02      line   2s1.2S_1/2 - 1s1.2s1.2p1.2P_3/2
    6643    O     V  22.3740  3.150e+12  7.089e-01   1   3  0.000e+00 -8.235e-17    1.344e-02      line     2s2.1S_0 - 1s1.2s2.2p1.1P_1
    7620    O  VIII  18.9671  2.566e+12  2.767e-01   2   4  0.000e+00 -9.709e-17    1.343e-02      line   1s1.2S_1/2 - 1s0.2p1.2P_3/2
    7619    O  VIII  18.9725  2.566e+12  1.384e-01   2   2  0.000e+00 -9.278e-17    1.284e-02      line   1s1.2S_1/2 - 1s0.2p1.2P_1/2
```

The newly developed ISIS package **xstardb** provides an interface to the most recent version of XSTAR, which writes atomic data from a model run into a fits file.

To load the package in ISIS:
`require( "xstardb" );`

Basic Features

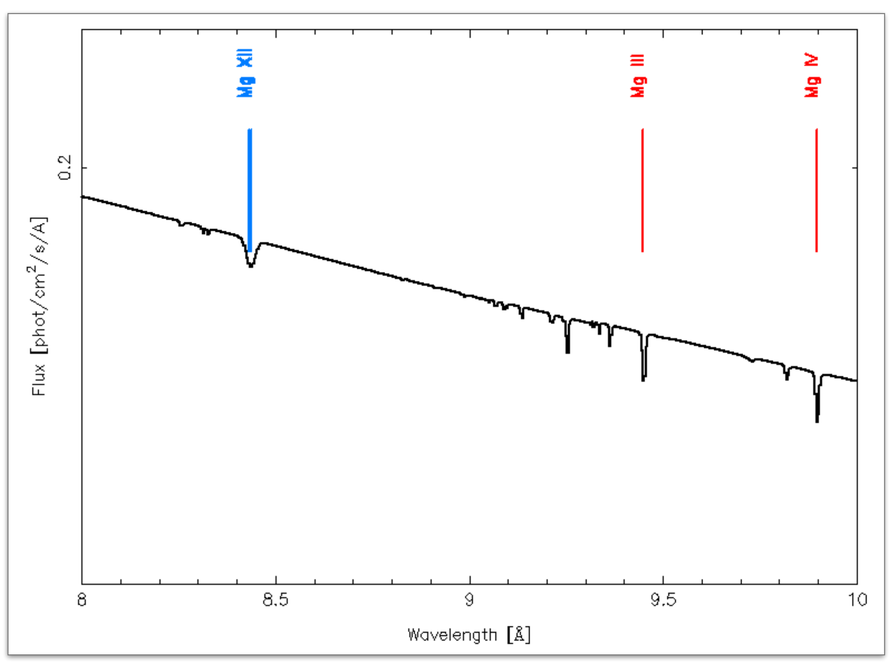
- Search databases by wavelength, element, ion, transition levels, and line strength
- Display and save search results as an ascii table
- Mark line transitions on a plot
- Manage multiple databases at once

Advanced Features

- Manage redshifts from single- and multi-component models
- Set up and run a grid of XSTAR models, with model input varied over a parameter of interest
- Manage a large number of model databses, cataloging unique transitions
- Retrieve interesting properties (e.g. luminosities, equivalent widths, and line ratios) as a function of XSTAR model parameter (e.g. rlogxi and column)

(Right) *The Mg transitions from two photoionized absorbers are disentangled. The red lines mark absorption from a z=0 absorber, and the green lines mark absorption from a fast outflow around a z=0.0077 absorber.*

Example 2: Multiple warmabs components at different redshifts




```
% See Holczer et al. (2010) ApJ 708, 981 for inspiration

fit_fun("Powerlaw(1) * ( warmabs2(1) + warmabs2(2) )" );

% Redshift should be z_obj + v_outflow/c
variable z_fast = 0.007749 - 1900.e5 / Const_c;
set_par( "warmabs2(1).Redshift", 0.0 );
set_par( "warmabs2(2).Redshift", z_fast );

    ...

% Load the files as a marged database
variable db_m = xstar_merge( ["warmabs_1.fits", "warmabs_2.fits"] );
variable z    = [ get_par("warmabs2(1).Redshift"),
                  get_par("warmabs2(2).Redshift") ];

    ...

% Find strongest lines within 8 - 10 Angs
variable lines = xstar_strong( 4, db_m; wmin=8.0, wmax=10.0, redshift=z );
variable l1 = lines[ where(db_m.origin_file[lines] == 0) ];
variable l2 = lines[ where(db_m.origin_file[lines] == 1) ];

xstar_plot_group( db_m, l1, 2, lstyle, z[0] );
xstar_plot_group( db_m, l2, 3, lstyle, z[1] );
```

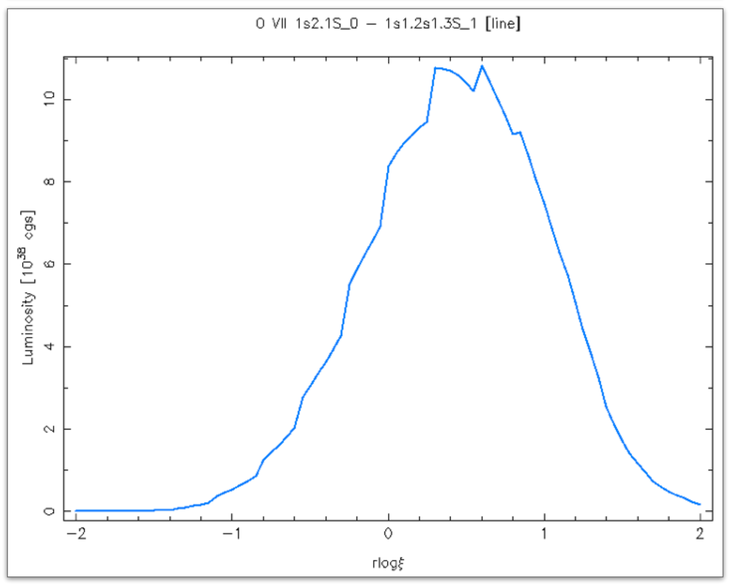
Example 3: A grid of photemis models over rlogxi

```
% 1. Set up and run the models
variable x1, x2;
(x1, x2) = linear_grid( 1.0, 40.0, 10000 );

variable model_info    = @_default_model_info;
variable model_binning = struct{ bin_lo=x1, bin_hi=x2 };

set_struct_fields( model_info, "photemis", "rlogxi", -2.0, 2.0, 0.05, model_binning );
xstar_run_model_grid( model_info,  "/my/path/ "; nstart=10 );

% 2. Load the models into a gridded database structure
variable fgrid, pe_grid;
fgrid = glob(  "/my/path/photemis_*.fits" );
fgrid = fgrid[ array_sort(fgrid) ];

pe_grid = xstar_load_tables( fgrid );

% 3. Look for the o_vii triplet
variable o_vii = where( xstar_el_ion(pe_grid.mdb, 0, 7) );
xstar_page_grid( pe_grid, o_vii );

% Track the luminosity of the forbidden line as it changes with rlogxi
variable o_vii_F = where(xstar_trans( pe_grid.mdb, 0, 7, 1, 2 ));
variable o_vii_F_lum = xstar_line_prop( pe_grid, o_vii_F, "luminosity" );
variable rlogxi  = xstar_get_grid_par( pe_grid, "rlogxi" );
```

(Above, right) *The set of unique He-like oxygen transitions from a set of photemis runs.*

(Below, right) *The luminosity of the forbidden O VII triplet line as a function of rlogxi.*

```
isis> xstar_page_grid( pe_grid, o_vii );
#         uid    ion    lambda     A[s^-1]          f  gl  gu      type                    label
   350010241    O   VII  16.7705  0.000e+00  0.000e+00   1   0 edge/rrc     1s2.1S_0 -    continuum
   350010240    O   VII  16.7805  3.103e+06  3.928e-07   1   3      line     1s2.1S_0 - 1s1.200p1.1P
   350010040    O   VII  17.3960  1.963e+11  2.671e-02   1   3      line     1s2.1S_0 - 1s1.5p1.1P_1
   350010029    O   VII  17.7680  3.867e+11  5.488e-02   1   3      line     1s2.1S_0 - 1s1.4p1.1P_1
   350010017    O   VII  18.6270  9.333e+11  1.456e-01   1   3      line     1s2.1S_0 - 1s1.3p1.1P_1
   350010007    O   VII  21.6020  3.303e+12  6.930e-01   1   3      line     1s2.1S_0 - 1s1.2p1.1P_1
   350010003    O   VII  21.8044  3.100e+04  2.209e-09   1   1      line     1s2.1S_0 - 1s1.2p1.3P_0
   350010005    O   VII  21.8044  3.100e+04  1.104e-08   1   5      line     1s2.1S_0 - 1s1.2p1.3P_2
   350010004    O   VII  21.8070  3.100e+04  6.628e-09   1   3      line     1s2.1S_0 - 1s1.2p1.3P_1
   350010002    O   VII  22.1012  4.000e+01  8.784e-12   1   3      line     1s2.1S_0 - 1s1.2s1.3S_1
```



Download the beta

space.mit.edu/ASC/analysis/xstardb/xstardb.tar

Requires developer version of XSTAR (warmabs22dev)

See examples

github.com/eblur/xstardb-tutorials

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