How to Find and Identify Weak Emission Lines in a Stellar HETG Spectrum Using *TGCat* and WebGUIDE

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1   Introduction

Most Chandra grating observations, being long exposures, are typically broken into several shorter observations. In any single observation, spectral features may be too weak to be identified. We can use the Chandra grating spectral catalog, *TGCat*, to combine the orders from a single observation – or we can combine spectra over multiple observations – to bring out weaker features in order to determine whether detailed spectral analysis is warranted.

We will use the calibration source, Capella, since there are many observations. Capella has a coronal spectrum, dominated by emission lines characteristic of a hot plasma in collisional ionization equilibrium.

While *TGCat* operation is generally straigtforward, it also has a "Help" menu (top right of every page) which can be used for additional guidance.

2   Exercise

1. Use *TGCat* (`http://tgcat.mit.edu`) to find all HETG/ACIS observations of Capella and list them sorted by descending exposure time.

2. View the summary products for the longest exposure. In particular, look at the detailed spectrum below 6 Å.

3. Make a plot (also of the longest exposure spectrum) of the MEG combined first orders in counts/bin vs wavelength from 1.7 to 5.5 Å, uniformly grouped by 4 bins, scaled linearly on both axes.

4. Select all the observations and make a plot of the combined HEG and MEG $+1$ and -1 orders in photon flux density ($\mathrm{photons/cm^2/s/Å}$), linearly scaled from 1.7–5.5 Å, binned uniformly by 1 bin, with a linear y-scale.

5. Use WebGUIDE (found on `http://www.atomdb.org`) to identify the strongest line in the 1.7–5.5 Å region. Note its temperature of maximum emissivity.

6. Given the estimate of temperature from the line, use WebGUIDE to list the strongest lines for that temperature in the 1.7–5.5 Å region.

3   Solution

1. *Use* TGCat *(`http://tgcat.mit.edu`) to find all HETG/ACIS observations of Capella and list them sorted by descending exposure time.*

   - Send your browser to `http://tgcat.mit.edu`.
   - Use the "Quick Search" menu item, and enter "capella", click "Go".

     You should get a "source table" with one entry for Capella (the only match), with basic information and links to supporting data. In the last column you can see that Capella has 43 extractions.
   - In the "Object" column, click on the name "Capella". This opens the extractions table. Sort the list by grating and exposure:

     ```
     View -> Sort -> grating -> Primary Order Asc
     ```
     followed by:
     ```
     View -> Sort -> exposure -> Secondary Order Desc
     ```
   - Mark all 19 ACIS/HETG extraction using the check-box (leftmost column), then
     ```
     Actions -> Limit
     ```
     to display only HETG/ACIS sorted by exposure.

2. *View the summary products for the longest exposure. In particular, look at the detailed spectrum below 6 Å.*

   Inspect the longest exposure observation by clicking on the "object" column name (obsid 1103, top row). This opens a new page with summary products. Inspect the ready-made flux spectrum plot showing the full spectrum, followed by detail in short wavelength intervals. We can see some weak emission lines between 3 and 6 Å (and strong ones elsewhere).

3. *Make a plot (also of the longest exposure spectrum) of the MEG combined first orders in counts/bin vs wavelength from* 1.7 *to* 5.5 Å*, uniformly grouped by 4 bins, scaled linearly on both axes.*

   To make a customized plot, use

   ```
   View -> Custom Plotting -> Open Plotter
   ```

   Use the "PLOTTING CONTROLS" pop-up menu to customize:

   - Plot Type: for flux units (choose "counts/bin")
   - X-Units: choose "A"
   - xlog, ylog: uncheck for linear scales.
   - MEG Orders: check $+1$ and -1;
   - HEG Orders: uncheck
   - Combine: check
   - Xmin, Xmax: set to 1.7 and 5.5
   - Ymin, Ymax: can be left blank
   - Bin: check
   - min-S/N: set to some ridiculously small number (like `1.e-8`), to get the effect of no dynamic grouping (otherwise, grouping will be done to achieve a minimum signal-to-noise ratio, which is not always useful for emission-line-dominated spectra).

- min-Chan: set to 4 for uniform grouping by 4 bins.

- replot: click to generate a new plot

We see (Figure 2, top) a strong feature and a weak continuum.

4. *Select all the observations and make a plot of the combined HEG and MEG $+1$ and -1 orders in photon flux density (*photons/cm^2/s/Å*), linearly scaled from* 1.7–5.5 Å*, binned uniformly by 1 bin, with a linear y-scale.*

   - Return to the "extractions table" page and select all rows by clicking the "+/-" above the 1st column. Then select

     ```
     Actions ->  Plot (Combined)
     ```
     and wait for data to be loaded and plot to be generated with default parameters (in a new window). This can take about 30 seconds since there are 76 orders – each with two response files – to be loaded. So it makes sense to become familiar with the controls (units, scales, binning, combination) on a single extraction.

   - Adjust the plot parameters to display 1.7–5.5 Å linearly in x, y, flux density ($F\gamma/\chi$), HEG, MEG, $+1$, -1 all combined, binned by 1, and replot. (HEG spectra are put on the MEG grid.)
     We can now see many lines, even including He-like Fe XXV at 1.85 Å (Figure 2, bottom).
     The strongest feature should be at a little over 5 Å – about 5.04 Å.

5. *Use WebGUIDE (found on* `http://www.atomdb.org`*) to identify the strongest line in the* 1.7–5.5 Å *region. Note its temperature of maximum emissivity.*

   Use the "List lines in wavelength region" dialog, entering the "Wavelength" of 5.04, "A" unit, and "Width" of 0.01, default "Min. Emissivity", and "Elec. Temp. Units" of "K" (the default). Click "Get Lines".

   We see that the strongest feature is S XV He-Lyman-alpha resonance line (upper levels 7, lower level 1). Notice that this forms at a peak temperature of 16 MK ($\log T = 7.2$).

6. *Given the estimate of temperature from the line, use WebGUIDE to list the strongest lines for that temperature in the* 1.7–5.5 Å *region.*

   Go back to the WebGUIDE form page, and use the "List strong lines in wavelength region at a specific temperature:" dialog to enter the central wavelength of 3.6 Å (mean of 1.7 and 5.5 Å) with (half) width of 1.9 Å. Enter the temperature noted in the previous step, and then click "Get Strong Lines".

   In the resulting table, you should be able to match the strongest lines with features seen in the plotted spectrum. These will have lower levels of 1 and upper levels less than about 50. (Upper level values > 10000 are dielectronic recombination lines.)

4   Going Further

If you liked the plot and want to save it, you can download the displayed image (a PNG file). Or if you want the plot in ASCII form (to incorporate with other data or into documents), use the plot window menu item, "`View -> Custom Plotting -> ASCII Dump`" to get the file. Note that this is not necessarily recommended for detailed analysis, but it can be used for graphics, especially for multi-wavelength applications.
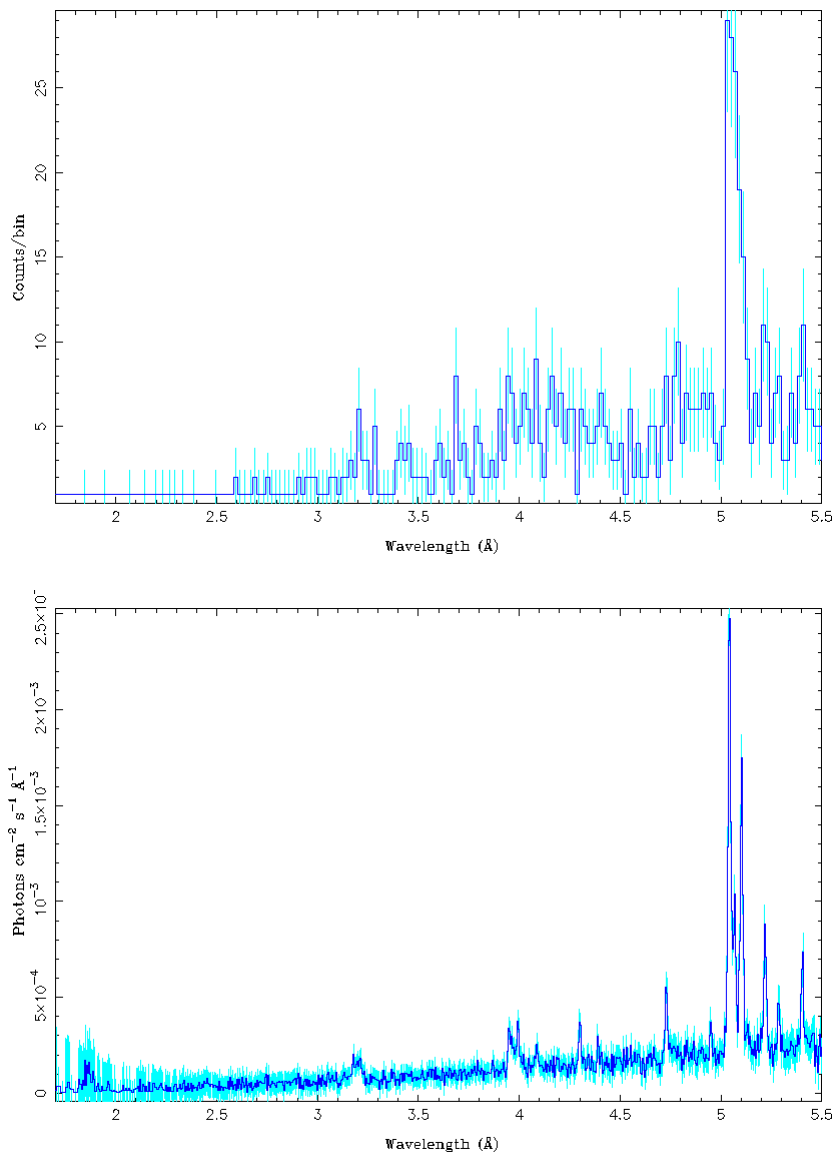
Figure 1: Capella; Top: a single obsid 1103, in count units (Step 3). Bottom: 19 observations summed, in flux units (Step 4).

If you want the actual data files for detailed analysis, go to the "extractions table", select the extractions of interest, then use the menu, "`Actions -> Download`". You will be given a choice of file types for your package.

If you want to see what tgcat does to load data and create a plot, use the

`View -> Custom Plotting -> ISIS Commands File`

menu item in the plot window. This can serve as a tutorial (with help from the ISIS manual), or as a template for customized analysis.

For going further with line-based analysis you can use ISIS, Sherpa, or Xspec to fit lines (parametrically or with plasma models). If you want to work directly with information from APED, then ISIS is the best choice; see the "Advanced Exercise" below.

5   Advanced Example - Line ID and Emissivities in ISIS

ISIS is a spectral analysis package with uses the S-Lang scripting language. While it is an extensible, modular fitting and analysis package, here we will only look at some of its unique features for accessing the atomic database, APED. This assumes both isis and the database are installed on your system (see the ISIS web page for help, http://space.mit.edu/cxc/software/isis). This brief example shows how to evaluate and isothermal APED plasma model, mark and list line idendifications, and how to form and emissivity ratio versus temperature from the atomic database. For more detail, use the isis built-in help facilities ("apropos NAME", "help NAME", or check for a usage message by omitting arguments).

```
> isis
isis> plasma( aped ) ;                          % load the atomic database
isis> create_aped_fun( "Aped_1T",
          default_plasma_state ) ;              % define a custom plasma model
isis> (w1, w2) =
      linear_grid( 1.7, 5.5, 8192 );            % define a wavelength grid
isis> t = 10^[6.0:8.0:0.1];                     % define a temperature grid
isis> fit_fun( "Aped_1T(1)" ) ;                 % specify a model fit function
isis> set_par( "Aped_1T(1).temperature", 16e6 );% set the plasma model temperature
isis> y = eval_fun( w1, w2 ) ;                  % evaluate the model
isis> ylin;                                     % linear y-axis
isis> plot( w1, y );                            % plot the model
isis> plot_group(brightest(30,where(wl(1.5, 5.5))));  % mark the brightest features
isis> page_group(brightest(30,where(wl(1.5, 5.5))));  % list the brightest features
isis> ls16 = where( trans( S, 16, [4,3], 1 ) ); % get the ID of the S XVI line
isis> ls15 = where( trans( S, 15, 7, 1 ) );     % get the ID of the S XV line
isis> r = ratio_em( ls16, ls15, t ) ;           % compute the ratio of He-like to H-like
isis> xrange( 7,7.5 );                          % set the x-range
isis> yrange(0.1); ylog;                        % set the y-range and scale
isis> plot( log10( t ), r ) ;                   % plot the line ratio vs temperature
```

What can be said about the likely plasma temperature of Capella now? Is it near the peak of emissivity for S XV? (Estimate at the ratio of S XV to S XVI in the combined data *TGCat* plot, and read $\log T$ off the plotted ratio curve for that T).
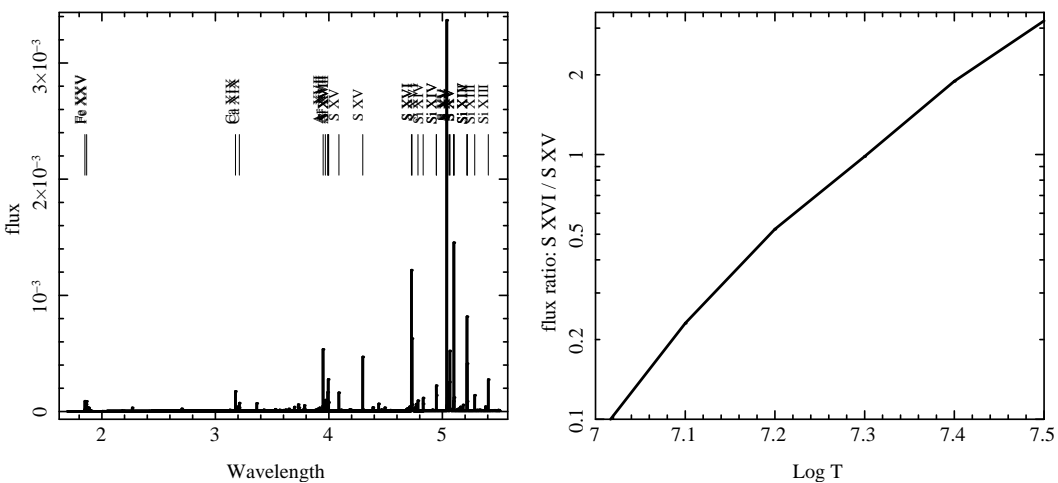

Figure 2:

Left: isothermal APED (16 MK) model photon spectrum;

Right: photon flux ratio of S XVI to S XV.