Computer exercises SPEX

AHEAD High-Resolution Spectroscopy School

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1 AGN winds

In many cases the emission from the central region around the black hole is partly absorbed by the disk and/or wind. In the file `agn.spo` we have a spectrum showing a lot of absorption lines. We set the distance to the source to 1 Mpc and the $N_{\rm H}$ to 1×10^{20} cm^{-2}. Response file: `corona.res`.

1. This spectrum is too complicated to fit in one run. Therefore start fitting with just an absorbed power-law model to get the slope and normalization right.

2. Identify the absorption lines near 17.7 Å, 18.6 Å, 19.0 Å and 21.6 Å using the SPEX line list.

3. Now add a component called `slab` to your model and free the ions which you identified in 2. You might want to increase the column density per ion to about 10^{20} (Note: the parameter in `slab` is logarithmic). Do the same for the ions C VI and N VII. Is it a good fit?

4. Near 15 Å there are a lot of lines associated with iron. Free the column density of Fe XIV to Fe XVII and fit again. Is the fit acceptable yet?

5. You can obtain a table with the optical depth of all the lines with the following command: `asc ter 1 3 tran` (replace `3` in this command with your component number for `slab`). Write down the optical depth of the O VII and O VIII edge or save the output. Where are the O VII and O VIII edge in the plot? Also save or write down the column densities of O VII and O VIII. You need those later.

6. Remove the `slab` component from your model and add a component called `xabs`, which is a more physical model. Fit the spectrum again.

7. If we zoom in on the lines, we see that they are blueshifted. Fit the parameter `zv`. Provide a reasonable starting value for `zv` first. What is the speed of the absorber?

8. Create the table with optical depths again with the command `asc ter1 3 tran` and `asc ter 1 3 col` to get the column densities for every ion. Do you see differences with the `slab` model?

9. The ionization parameter `xi` is defined as follows: $\xi = \frac{L_X}{nr^2}$. Determine the luminosity (L_X) of the source (L_X is the luminosity between 1 and 1000 Rydberg, where 1 Rydberg = 13.6 eV) and calculate the density (n) if the wind is at 1 pc from the source. Take care of units and logs.

   Usually the density is estimated from variability arguments, which then allow one to put a limit on the distance of the absorber.

10. The impact of the outflow on its environment can be assessed as follows. Assume that the outflow has constant velocity v (measured from your spectrum). The outflow is not fully spherical. Usually people assume that the solid angle sustained by the outflow $\Omega \sim 1$.

    Then the total mass loss is $\dot{M} = \Omega m_{\rm H} n r^2 v$ and the kinetic energy carried away per second is $L_{\rm K} = \frac{1}{2} v^2 \Omega m_{\rm H} n r^2 v$.

    Calculate the kinetic energy carried away and compare to the ionising luminosity (you should do this offline from SPEX, but use the numbers from your fit). Is the kinetic energy significant compared to the radiated energy?

Learning goals:
After having done this spectrum, you should know:

- How to use models for photo-ionised plasmas
- How you can get more info out of SPEX by using the "asc" commands
- Some basic parameters of black hole winds that can be derived from X-ray spectra

2 Clusters and groups

The temperature structure of the hot X-ray emitting gas in clusters of galaxies can be quite complicated, especially in cooling-core or merging clusters. The spectra that we obtain therefore contain spectral components originating from regions with different temperatures. Moreover, due to the extended nature of the source, lines are broadened in grating spectra. The temperature distribution is not exactly known and fitting all temperature components separately is rarely possible. The current approach is to assume a certain temperature distribution and reduce the number of variables of the distribution to two or three. A frequently used example of such a model is the `wdem` model. Here the Differential Emission Measure (DEM) as a function of temperature is assumed to be a power law. In addition, there is also a component to account for the spectral broadening due to the extent of the source, called `lpro`.

1. Load the spectrum in the file `ngc4649.spo` together with the `ngc4649.res` response matrix. Set up a model containing a redshift (`reds`), absorption (`abs`), and CIE (`cie`) component and plot the spectrum. Identify a few lines and guess the temperature of the plasma. *Remember to use the log save command to save your command history!*

2. Before fitting the model, it is best to guess the most important parameters like the temperature and normalisation. By plotting the spectrum, you can first try to set a value for the parameter, calculate the model (`calc`), and see in the plot window wether the model is reasonably close to the data points.

3. It is clear that the lines in the spectrum are broader than the lines in the model. This is due to the grating spectrometer. Add the `lpro` component to your model to account for the broadening. On the exercise website, there is a file called `vprof.dat`. This file contains the clusters' profile along the dispersion direction. Load this file in SPEX by issuing the command: `par 1 4 file av vprof.dat`. Does the fit improve? Adapt the scaling parameter of the lpro component if necessary.

4. Fit the spectrum and the abundances. Is it a good fit? Zoom in on the lines with the plot command. Do you see deviations? Which lines show the largest deviation? *Make sure that you save your fit parameters and command history with par write and log save!*

5. Perhaps the deviations are caused by multi-temperature structure. Remove the CIE component from your model and replace it with a `wdem` model. Fit the spectrum again using WDEM. Does the fit improve with respect to the fit with the CIE component? How do you tell?

6. Another cause of differences can be the atomic data. Load your previous fit with a CIE model again using the saved command history and fit parameters. When you have your previous fit back, we will load the new SPEXACT 3.03 database by giving the commands: `var calc new` and `ibal u16`. Give the fit command again. This time the fit takes much longer. Is the fit better?

7. Bonus: The brightest lines of Fe XVII are actually part of a triplet with forbidden, resonance and intercombination lines. The resonant line is sensitive to resonant scattering. Can you determine the ratio between the resonance and forbidden line of Fe XVII? Is it different from the expected ratio? What does that mean for the turbulence in the plasma?

Learning goals:
After having done this spectrum, you should know:

- How to use a more complex emission model.
- How to deal with line broadening for a grating spectrum of an extended source.
- How to distinguish between two different models.
- That atomic data is not complete yet. There are still improvements being made to the models.