Data Analysis Project 2

Due Fri, 20 Apr. Turn in the Python/IDL/Matlab code for all of your work.

There will be a progress check on Fri, 13 Apr. I will ask one or more of you to report on your methdology and results through section 7 (normalized co-added spectrum).

Reading assignment: Read Rieke Ch. 6 (Spectroscopy), Ch. 8 (Submillimeter and Radio Astronomy). If you have not done so already, read Rieke Ch 2.1, 2.2 (telescopes), Ch 3.1-3.6 (UV-IR detectors), Ch 4.1-4.5 (optical and infrared imaging).

UV Spectral Line Analysis on HST GHRS Data

The data that you will analyze for this problem set are UV spectra from the Hubble Space Telescope taken using the Goddard High Resolution Spectrograph (GHRS) Echelle-B grating. GHRS was replaced by the Space Telescope Imaging Spectrograph (STIS) on 14 Feb 97. For more information on the HST instruments, see `http://www.stsci.edu/hst/HST_overview/instruments`.

The spectra contain Mg II interstellar absorption lines. Heavy ions observed in absorption in the warm local interstellar medium allow characterization of ISM physical characteristics such as turbulent velocity, temperature, and column density. See, e.g., Linsky, J. L. & Redfield, S. 2002, ApJS, 139, 439, and the book by Spitzer, "Physical Processes in the Interstellar Medium."

Thanks to Jeff Linsky and Charles Danforth for their help in developing this problem set.

1) Go to the Space Telescope archive (`http://archive.stsci.edu/mast.html`) and download GHRS ECH-B spectra of the star HZ 43. What kind of a star is HZ 43? (Hint, consult SIMBAD). The GHRS dataset contains a series of .fits files. *c0f.fits contains the wavelength solutions, *c1f.fits contains the calibrated fluxes, *c2f.fits contains the uncertainties. Consult `http://www.stsci.edu/documents/dhb/pdf/GHRS.pdf` for details. There are two HST GHRS ECH-B datasets for HZ 43. Choose the one that contains the Mg II absorption lines near 2796 and 2803 Å.

2) Read the GHRS.pdf document to understand why the 16 subexposures in the dataset have four different sets of wavelength solutions (look in Section 35.6). Follow the recommended procedure and align the subexposures by cross-correlating them against the first exposure obtained, then shifting by the number of wavelength bins required to achieve maximum cross-correlation. You may want to co-add each set of 4 before cross-correlating to improve s/n.

3) Co-add (i.e., find the mean of) all aligned subexposures, using uniform weighting since presumably the each of the sub-exposures has the same integration time. Calculate the uncertainty in your co-added spectrum using the given uncertainties for the individual spectra.

4) Search for the interstellar absorption lines of Mg II (near 2796 and 2803 Å). What are the laboratory wavelengths of these lines? (See Morton, D. 1991, ApJS, 77, 119 for this and oscillator strengths (f values).)

5) What is the s/n in the continuum on either side of these lines? What is the s/n in the absorption line? If the noise is dominated by Poisson noise from photon counts, what would you expect the relationship between fractional uncertainties in the continuum and the line to be? Check to see if your s/n ratio is consistent with a Poisson distribution.

6) Fit a low order polynomial (even just a straight line and slope) to the continuum, masking out the absorption lines.

7) Normalize the spectrum by dividing by your best fit continuum polynomial or line. The continuum should now be relatively flat, with a mean value of unity in the continuum.

8) Fit each of the two absorption lines with a Gaussian. Report your best-fit values and uncertainties for the fit parameters, including the central wavelength, amplitude, and width. Are the single Gaussian fits

acceptable?

9) Calculate the central velocity for each line, and the uncertainties in the central velocities. Use the convention that a positive velocity is away from the observer (careful!). Are the central velocities of these lines consistent with each other? Test the consistency with using a differenced χ^2 consistency test, taking into account the uncertainties in the laboratory wavelengths of these lines.

10) Are the true line profiles resolved? To answer this, look up the spectral resolution of the GHRS ECH-B instrument, and estimate the LSF (line spread function) width. What would you consider to be "resolved"?

11) When the true line profile cannot be fully resolved, one instead measures the "equivalent width" W_λ, in units of wavelength, given by

$$W_\lambda = \int d\lambda \left[1 - \frac{I_\lambda}{I_\lambda(0)}\right],$$

since the equivalent width is independent of instrument resolution. (Why?) Calculate the equivalent widths for the two lines, using the normalized spectrum. You can either do this by simple analytical integration of your best fit Gaussians, or calculate a discrete integral by summing the data over some reasonable interval around the line and multiplying by the wavelength bin width $\Delta\lambda$. Try both methods. Do they agree?

12) Calculate the uncertainties in the equivalent widths for the two lines, using two different methods:

- Use the propagation of errors method, given your uncertainties in your Gaussian fit parameters.
- Calculate the equivalent width of different sections of the continuum, using the same number of data points as your line equivalent width calculation, then calculate the sample standard deviation of your results.

Do the two methods of estimating uncertainty agree? Which do you think is the most accurate uncertainty estimation method? Discuss the pros and cons of each method.

13) Are these two lines saturated? To test this, look up the oscillator strengths (f values) for the two lines in the Morton paper. In the optically thin (unsaturated) limit, the ratio of equivalent widths and oscillator strengths is given by

$$\frac{W_{\lambda_1}}{W_{\lambda_2}} = \frac{f_1\lambda_1}{f_2\lambda_2}.$$

Estimate uncertainties in your measured equivalent width ratio and $f\lambda$ ratio.

14) Estimate or put a lower limit on the column density N (units: cm^{-2}), using the relation

$$\frac{W_\lambda}{\lambda} \leq \frac{\pi e^2}{m_e c^2} N\lambda f = 8.85 \times 10^{-13} N\lambda f$$

where $N\lambda$ has units cm^{-1}, and the equality holds in the optically thin limit. Check to make sure your derived column density makes physical sense. Estimate N from the two equivalent widths, and estimate uncertainties. Do the two estimates of N agree? If not, why not? (Hint: Look up the dependence of the "curve of growth" on $Nf\lambda$.)