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Spectroscopy: Data Reduction and Analysis

1. Data Reduction

1. Construct master darks for each of the different exposure times (use the median instead of the mean to reject cosmic rays).
2. Subtract the appropriate master dark from the science spectra, the flat-fields, the arc lamp spectra, and the standard star spectra.
3. Make a median image of the flat-fields.
4. Open the median flatfield in ds9. Use the flat-field to identify the boundary of the pixel region illuminated by the slit with which you observed your target. Specify this region to be rectangular, and make sure that all contained pixels are illuminated (if the spectrum is slightly tilted, it's ok if some illuminated pixels are outside the region). Cut the flat-field, the science image, the arc spectrum, and the reference star spectrum to *only* contain the pixels from this region.
5. The flat-field in spectroscopy has a similar, but more limited, purpose as the flat-field in imaging. As in imaging, it is used to correct sensitivity variations of neighboring pixels; however, because the flat-field lamp has a distinct spectrum (it does not emit the same flux at every wavelength) it cannot be used to determine the sensitivity at (very) different wavelengths. The large-scale shape of the flat-field is therefore irrelevant. In the following, we remove the large-scale variation and normalize the flat-field, so that pixel values in the flat-field are around 1.

   (a) "Collapse" the flat-field spectrum to a 1D spectrum by averaging the counts in each column (i.e. same x-values). Plot the flat-field spectrum, i.e. the average count rate vs. x-pixel position.

   (b) Fit a low-order (second or third order should suffice) polynomial to the flat-field spectrum. The "wiggles" that you see around this fit are actual variations in the sensitivity of our spectrograph. Plot the 1D flat-field spectrum with your best-fit polynomial overlaid.

   (c) Divide the 2D flat-field by this polynomial (i.e. each row gets divided by the polynomial) - this is your actual flat-field. Open it in ds9. How does it compare to the original? Why do you think it is important that the pixel values are 1 on average?

   (d) Divide the science images, the arc lamp images, and the standard star images by the normalized 2d flat-field.

6. Open the science frame in ds9 and determine the image rows that contain flux from the target, as well as a set of image rows that contain only sky background emission. Sum the "target" image rows, and subtract the expected sky background flux to create your 1D spectrum of the target.
7. Repeat the above for the standard star spectrum. Note that the spectrum of the star can be in a different part of the slit, i.e. the target vs. background rows can be different between standard star and main target.
8. Derive the wavelength calibration from the arc lamp spectrum and/or the science spectrum (if the latter contains emission lines). Identify the lines in your image, determine their centers along the

x-axis, and make a table of x-positions and wavelength. From this table, determine the wavelength solution by fitting wavelength as function of x-position. Make a plot of wavelength vs. x-position, along with your best-fit wavelength solution.

9. Perform the wavelength calibration for both your science spectrum and your standard star spectrum. Your 1D spectrum should now be a table of wavelength with corresponding flux.
10. Recall that the spectroscopic flat-field does not map the sensitivity as function of wavelength. In order to relate the measured counts to object flux, we need to determine the sensitivity function. This is where the spectrum of the reference star comes in. Look up its temperature and assume that its true spectrum follows a blackbody curve. Compare the measured spectrum to the "true" spectrum to derive a sensitivity function, which relates measured counts to object flux (apart from an overall normalization). Note that the star has strong absorption lines, which you should mask out when you are fitting a function. Make a plot illustrating the observed spectrum, the "true" spectrum, and your derived sensitivity function.
11. Correct the science spectrum with the derived sensitivity function. Make sure to make a plot of the final spectrum (flux vs. wavelength)!

2. Data Analysis

1. To measure emission lines: fit a Gaussian profile to each emission line to determine the flux of each line. The flux is the area under the Gaussian. (What are the units?)
2. To measure absorption lines: absorption lines are measured relative to the continuum of the object.
   (a) Normalize the spectrum to its continuum. To do so, fit a low-order polynomial to the spectrum (you may need to mask strong features), and divide the spectrum by the polynomial. The continuum should now be ≈ 1.
   (b) To measure absorption line features: fit a (negative) Gaussian profile to each line. The strength of the line is quoted as equivalent width, which is the area under the Gaussian (if the continuum is normalized to 1).