PHY517 / AST443: Observational Techniques

Homework 4: Spectroscopic Data Analysis

You can complete the following in python (or R, or matlab). Note that you only need to hand in the parts marked *"Submit"* (and your answers to the questions posed), but for partial credit, you may want to document your other steps, e.g. with a jupyter notebook (python or R). The tutorial `Some spectroscopy tools` from the wiki gives you some helpful python commands; also note that some of the steps are similar to the CCD Lab.

In `/astrolab/anja/homework_spectroscopy` on spock you will find the following:

- a subdirectory `nebula` with 3 "science" exposures where the planetary nebula NGC 7662 has been placed on one of the spectrograph slits,
- a subdirectory `ref_star`, where the star Omicron Andromedae has been placed on the the same spectrograph slit,
- a subdirectory `flats` of flat-fields, taken by pointing the telescope at the dome, and switching on the dome lamps,
- 3 subdirectories of dark frames, one for 30 s darks, one for 3 min darks, and one for 10 min darks.

In each of these exposure, the x dimension is wavelength (blue to red), and the y direction is a spatial direction along the entrance slit.

1. Figure out which dark frames are required for the science exposures, the reference star exposures, and the flat fields. Construct master darks for each, and correct the nebula, reference star, and flat field exposures.
2. Make a median image of the 3 science exposures, a median image of the 3 reference star exposures, and a median image of the flat-fields.
3. Open the median science frame and the flatfield in ds9. Our spectrograph has 3 slits; identify which one contains the target. Use the flat-field to identify the boundary of the pixel region illuminated by this slit. 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 science image, the flat-field, and the star frame to *only* contain the pixels from this region.
4. 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.

(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. *Submit a plot of the 1D flat-field spectrum, and your best-fit polynomial.*

(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 frame, and the star frame, by the new flat-field.

5. 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 "nebula" image rows, and subtract the expected sky background flux to create your 1D spectrum of the nebula.

6. Repeat the above for the star frame. 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 star and nebula.

7. The planetary nebula has enough emission lines that we can use them for the wavelength calibration. A list of the lines that you should expect to see is given below. 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. Plot the residuals (i.e. the difference between measured wavelength and model wavelength) as function of wavelength to check that your fit is adequate. *Submit a plot of wavelength vs. x-position, along with your best-fit wavelength solution, and a plot of the residuals.*

8. Perform the wavelength calibration for both your nebula spectrum and your star spectrum. Your 1D spectrum should now be a table of wavelength with corresponding flux.

9. 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. *Submit a plot illustrating the observed spectrum, the "true" spectrum, and your derived sensitivity function.*

10. Make a plot of the final spectrum (flux vs. wavelength), and label the strongest emission lines. *Submit this plot.*

Nebular emission lines in the wavelength range of these spectra:

- Hγ 4341 Å
- [O III] 4363 Å
- HeII 4686 Å
- [Ar IV] 4711 Å
- [Ar IV] 4740 Å
- Hβ 4861 Å
- [O III] 4959 Å
- [O III] 5007 Å