Astronomy 3130 – Spring 2016 – Lab 5

Spectroscopy at McCormick Observatory with the 26 ½" Clark Refractor

Now that you are familiar with the operation of CCD's, have seen a research telescope in action (Fan Mountain), know how to plan a set of observations on a given night, and know the basics of how to build a spectrograph, this lab will combine all of these elements in the collection and analysis of stellar spectra using the McCormick telescope. You will process the data to generate spectra with interpretable scientific content. The CCD will be the same one that served as the imager for the pinhole camera experiment in Prelab4. The data sheet for the CCD can be found at http://www.ccd.com/alta_f9000.html .

As with all labs, *especially with this one*, you need to be prepared at the telescope. Doing so means reviewing the class notes on spectroscopy, reading the Chromey and Birney Chapters regarding spectroscopy as well as Chapter 14 of the ASTR 3130/5110 Observatory Handbook (Sections 1-6) to know how the spectrograph itself works. You will be using the 50μm slit and the 600 grooves/mm grating for all observations. The spectrograph will be configured in advance for you, and the TA will ensure that the grating is at the proper angle to disperse first order in the blaze direction onto the array covering the full visible spectrum.

You should verify that the camera lens is adjusted for best focus of the spectrum on the CCD. You should also adjust the eyepiece so that your relaxed eye sees the slit in focus. The eyepiece slides in and out. Once you have the eyepiece in the right place you can adjust the telescope focus to focus the star as seen in the eyepiece. Following this two step procedure will ensure that the star is in focus in the plane of the slit and that you can comfortably view the slit and the focused star simultaneously.

For this lab your challenge is to observe a grid of known spectral standard stars spanning the main sequence and obtain a spectrum of a "mystery star," making your best estimate of its spectral classification based on your calibration grid.

If you need a refresher on spectral classification or if you need reference spectra for comparison in order to check your results the following could be of interest in addition to the relevant sections in your textbook(s):

- Ryden and Peterson (Sections 5.6 and 14.2)
- Carroll and Ostlie, An Introduction to Modern Astrophysics or An Introduction to Modern Stellar Astrophysics (the first includes all the content in the second).
- Turnshek et al., An Atlas of Digital Spectra of Cool Stars
- Morgan et al., Revised MK Spectral Atlas for Stars Earlier than the Sun
- Jacoby et al. (1984, ApJS, 56, 257)
- Montes et al. (1999, ApJS, 123, 283)
- Jaschek & Jaschek, The Classification of Stars

- Jaschek & Jaschek, The Behavior of Chemical Elements in Stars
- Kaler, Stars and Their Spectra
- https://www.cfa.harvard.edu/~pberlind/atlas/atframes.html

Most of the books should be located in the astronomy library (unless they are out on loan). The library can be opened using your astronomy department key. Please do not remove them from the library.

At minimum obtain spectra for five stars to establish your comparison grid (not including the mystery star, so six targets minimum in total). Your best resource for selecting your targets is a page on bright spectroscopic standards mirrored on the course home page: http://faculty.virginia.edu/skrutskie/ASTR3130/users.erols.com/njastro/faas/pages/starcat.htm

Select your five "standard" stars to span a good range of spectral class from cool late-K/early M to hot B stars. Note that 3rd magnitude stars and brighter should produce high SNR spectra in modest amounts of time (less than one minute exposures). Be sure not to saturate!! Pick stars that are readily accessible during the first half of the night. If you are the cautious type you might select and "early" and "late" candidate for some of the targets to give you flexibility.

Prior to executing the lab you must lay out an observing program to observe all of the stars optimally given restrictions on airmass and transit time (like the preamble to the lab said, this lab is your opportunity to put everything together and operate as an efficient and effective observer). By choosing stars wisely (largely meaning not too far south) you can engineer a lot of flexibility into your observations.

The Mystery Star: 11:09:39.8 +44:29:54.7 (2000.0) magnitude 3.0

Resist the temptation to look this star up… Shun it if you accidentally pick it as a spectral standard and find a substitute.

The magnitudes provided should be a guide to exposure time. You may not be able to estimate integration times a priori from these magnitudes but once you have observed one star and are satisfied with the signal-to-noise level (how are you going to estimate that in real time?) you should be able to scale the integration time for the other objects. Remember that saturated data contains no useful information. Don't expose too long. Your TA should be helpful in converging to an optimal integration time.

At the beginning of the night you should acquire a random bright star on the slit (or your first "science" target) and adjust the instrument rotation so that the spectrum falls as precisely as possible along a single row or column. Doing so will help with spectral extraction later on. Note that the spectrograph is configured so that in each observation of an isolated star you obtain a spectrum of the "dark" sky and contaminating background (e.g.

mercury street lamp emission).

Consider, for "fun", the following bonus spectra if you have the time or tenacity:

1) Take a spectrum of Jupiter and interpret.

2) Take as spectrum of the illuminated portion of the Moon and interpret.

3) Choose a giant (luminosity class I, II, or III) and compare your spectrum with a dwarf (luminosity class V).

4) Try an emission line object such as a planetary nebula.

~~In addition to these stellar observations include a long-exposure (how long is up to you to decide) spectrum of the night sky near zenith and near the horizon (with the same exposure time) low on the horizon over Charlottesville.~~ Don't forget calibration lamp observations as described in the observing manual. Can they be obtained in parallel with your stellar observations? Note that the comparison lamp bulbs have a limited lifetime. Please turn them off when not needed.

Don't forget the importance of bias and dark frames of appropriate exposure time in calibrating your images prior to extracting spectra. Plan your required calibrations (dark, bias, lamp) in advance.

Work as a group to extract and wavelength-calibrate spectra and to carry out spectral classification of the mystery target. The TA's will provide the usual iPython guidance. Note that you have made no attempt to make an overall absolute calibration of the shape of the spectrum so that the overall shape of your extracted spectrum will not match the curves in the spectral atlas. Spectral classification depends on the spectral absorption lines. Use these as your guide. As part of your analysis identify elements responsible for the most prominent absorptions in the various spectra.

Write up the lab individually, again casting it as a scientific paper - this time to determine the spectral class of the mystery star (note "spectral class" here, you're not under obligation to determine the luminosity class (giant vs. dwarf) although you are welcome to try).

Post-lab activity: Your group must arrange a time with one of the class staff to visit the fiber-fed echelle spectrograph in the instrumentation laboratory. Pointing the fiber out of the window in daylight will provide the opportunity to acquire a high-resolution spectrum of the Sun. Appreciate the multi-order nature of the echelle spectrograph. The TA's will help you extract one of the orders from the solar spectrum. The order will be the one containing the sodium D lines. Having received this data your job is to wavelength calibrate this one order and make an estimate of the resolution, R, of this spectrograph. Identify lines other than sodium in your order by referring to a high resolution solar atlas such as http://bass2000.obspm.fr/download/solar_spect.pdf and compare the extraction with the simulated solar spectrum provided at http://bass2000.obspm.fr/solar_spect.php . Work as a group to accomplish these tasks and then include the results as an appendix to your individual lab write up.

Questions and tasks to motivate your lab write-up (not questions to be answered serially):

How well sampled are your observed spectra both in the spatial direction as well as in the spectral direction?

Given the focal length of the McCormick telescope, the internal optics of the spectrograph and the pixel size of the CCD (recall the reference to the manufacturer's specifications above) determine the spatial extent of a pixel perpendicular to the spectral direction. Account for CCD binning if you were instructed to use it.

Why do the spectra tend to "flare" toward the extreme ends?

What is the resolving power, R, of your spectrograph based on calibration lamps and/or airglow lines.

Which sky lines are natural (originating in the Earth's atmosphere – i.e. airglow) and which are artificial based on your sky observations at different elevations?

Wavelength calibration – identify specific lamp lines as a function of pixel number and use at least a second order fit to establish a formula linking pixel number to wavelength in nanometers.

Can you identify telluric (atmospheric) absorption lines in the spectral standards? These will be common features between the different spectra and not on the spectral atlases. Can you attribute any of these spectral features to specific atoms or molecules?

After you have completed spectral classification you can look up the spectral types of the targets to compare with your results. Can you distinguish any difference between the dwarf and giant stars? Should you expect to be able to do so based on your resolution?

What do you regard as the greatest source of uncertainty in establishing your spectral classifications relative to the "official" result.