Astronomy 3130 – Spring 2014

Lab 4 - Spectroscopy at McCormick Observatory with the 26½” Clark Refractor

Now that you are familiar with the operation of CCD’s, have seen a research telescope in action (Fan Mountain), 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 pre-lab3. 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 240 grooves/mm grating for all observations. The TA will set the grating so that a useful wavelength range is dispersed onto the detector. You will be responsible for adjusting the camera lens for best focus of the spectrum on the CCD.

If you need a refresher on spectral classification or if you need reference spectra for comparison to your results the following could be of interest:

- 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).
- Morgan et al. Revised MK Spectral Atlas for Stars Earlier than the Sun
- 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.

The table below contains the primary targets for the lab. At minimum obtain spectra for the Orion Nebula/Trapezium and four of the spectral standards. The list is not ordered in terms of the natural order of observations. The table includes RA and Dec. 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). The table provides a magnitude for each object. Spectral types have been left out of this table because it is your job to classify these stars as part of the lab, which means you should not be looking up the spectral types of the stars, only determining them from the spectra.

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 arriving at an optimal integration time.

At the beginning of the night you should acquire a random bright star on the slit 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.

Given that it is Spring and Orion is setting in the early evening your first target will naturally be the Orion Nebula and Trapezium star cluster (θ1c Ori being the brightest star in the Trapezium - It wouldn't hurt to research and understand the Trapezium in advance). You will simultaneously be able to acquire a spectrum of the brightest Trapezium star as well as surrounding nebulosity (why is that??). For the same reason, in each observation of an isolated star you obtain a spectrum of the “dark” sky and contaminating background (e.g. mercury street lamp emission). Orion is a special case where the slit is completely filled with spectral information about the target so you will need to plan an “off” observation of the sky to remove contaminating emission.

<table>
<thead>
<tr>
<th>Target Name</th>
<th>RA</th>
<th>Dec</th>
<th>V mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orion Nebula (θ1c Orionis)</td>
<td>5:35:17</td>
<td>-5:23:28</td>
<td>5.1</td>
</tr>
<tr>
<td>Betelguese (a Ori)</td>
<td>5:55:57</td>
<td>7:24:31</td>
<td>0.5</td>
</tr>
<tr>
<td>Dubhe(a UMa)</td>
<td>11:04:36</td>
<td>61:40:21</td>
<td>1.8</td>
</tr>
<tr>
<td>Procyon (a CMi)</td>
<td>7:40:03</td>
<td>5:11:13</td>
<td>0.4</td>
</tr>
<tr>
<td>Merak (b UMa)</td>
<td>11:02:42</td>
<td>56:18:16</td>
<td>2.4</td>
</tr>
<tr>
<td>Regulus (a Leo)</td>
<td>10:09:08</td>
<td>11:53:45</td>
<td>1.4</td>
</tr>
<tr>
<td>i Ori</td>
<td>5:36:08</td>
<td>-5:54:05</td>
<td>2.8</td>
</tr>
</tbody>
</table>

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. Attempt to classify to the nearest “half” classification. G0 vs. G5 vs. K0 vs. K5 etc. 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.

Answer remaining questions and of course write up the lab individually.

Fun and games: Try getting a spectrum of Jupiter if you have the time early in the evening. How does it differ from the other stellar spectra?

Post-lab activity: After classification you will note the absence of a G-type (sun-like star) on the list. If you are early for the lab you can try to get a spectrum of the twilight sky (scattered sunlight) and estimate the spectral type. More importantly 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](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](http://bass2000.obspm.fr/solar_spect.php). Work as a group to accomplish these tasks and then include the results in 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.