ASTR:4850 - Longslit Spectroscopy

1 Introduction

Spectroscopy is crucial to astronomy. It is the principal diagnostic for determining the temperature, the chemical composition, and the kinematics of stars, nebulae, and galaxies. Spectroscopy is of equal importance to physics. No experimental evidence was of more importance to the emergence of modern physics than the existence of spectral lines of different atoms and molecules. Today, spectroscopy continues to be one of the most important experimental or observational measurement in both astronomy and physics.

In optical astronomy, there are four different classes of spectrographs: slitless, longslit, multislit, and integral-field spectrographs. This course will experiment with optical spectrographs in the first two classes (slitless and longslit). In longslit spectroscopy, a narrow slit placed at the telescope's focal plane is used to prevent light sources outside the slit from entering the spectrograph, which significantly improves the S/N of the source spectra by drastically reducing the sky background. Because of the longslit, the observer has to center the target source precisely on the slit, and most times they cannot obtain spectra from more than two sources at the same time. By removing the slit, slitless spectroscopy resolves these two issues, but at the cost of (1) elevated sky background emission (which decreases S/N) and (2) spectral overlapping among sources (which limits its use to fields where the source density is low).

In this lab, we will play with a miniature computer-controlled slit spectrograph that contains all of the components that a research-grade spectrograph has (slitmask, collimator, grating, and focuser), We will connect it with a CCD camera, and later a telescope, to measure and analyze spectra of gas discharge tubes in the lab room.

2 Equipment List

The main components of the lab equipment are:

- Spectrograph: SBIG DSS-7 Deep Space Spectrograph

- Camera: SBIG ST-402 CCD camera

- Connecting cable and mounting adapter

- Telescope: Orion ShortTube 80-A with tripod (80 mm diameter, 400 mm focal length)

- PC laptop with CCDOps, DS9, and Python installed

- Tools: Allen wrenches

- Light Source: Gas spectrum tube carousel with optical fiber.
  Warning: gas spectrum tubes have short lifespans, please turn off the power when not taking data. During alignment, the Nitrogen or Air gas tube is the preferred one to use because they last the longest.
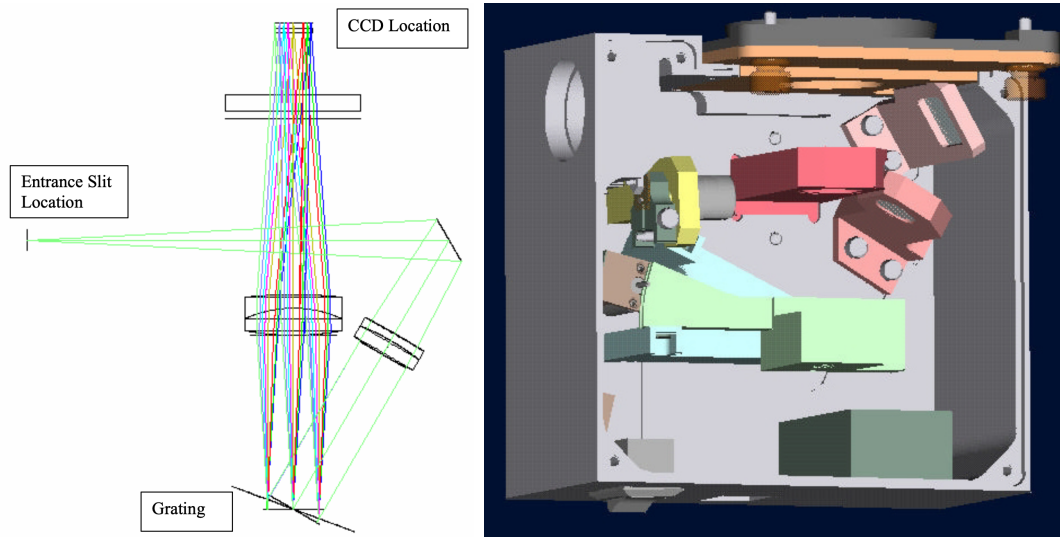
Figure 1: Spectrograph optical layout and mechanical design.

3   Spectrograph Setup & Taking Calibration Spectra

3.1   Operating the CCD Camera

You will use an ST-402 camera made by the Santa Barbara Instrumentation Group (SBIG) for this lab. One of the links above under "Reading" leads to the a description of the camera on the SBIG web site. The software we will use to control the camera and download data from the processor in the camera is called CCDOps. Download and look over the CCDOps manual; you will need it to control and analyze data from the camera. Before we attach the spectrometer, let's try out the camera.

- Connect the camera to the computer, and establish communication between them. Connect power to the camera, and run the USB cable from the camera to one of the USB ports of the computer. Bring up CCDOps on the computer.

- You now need to have the computer and the camera talk to each other. You do this by clicking on the "EstLnk" button in the CCDOps Toolbar, or in the main CCDOps window, you can select the "Camera" menu and then click on "Establish COM link". The camera should make a number of clicking sounds and flash its red LED while setting up the link. The red LED should then stay solidly on to show the camera's contentment if the link is successful.

- We'll now pretend to take an image. On the icon toolbar, click "GRAB", which controls taking an image. The GRAB function is described in the CCDOps manual. Set the exposure time to several seconds, dark frame to none, image size to full, exposure delay to 0, special processing to none, binning to 1, and then click "OK". This will open the shutter. While the shutter is open you can see the CCD chip.

Figure 2: DSS-7 spectrograph connected to the ST-402 CCD camera.

3.2 Connecting the Spectrograph

- Physically connect the spectrograph to the camera, as described in step 2 in the section "Attaching the DSS-7 to the camera" in the DSS-7 manual. There is an adapter ring, properly threaded, which connects the DSS-7 and the ST-402. Figure 2 shows what the properly assembled system should look like.

- Remove the side panel of the spectrograph with the Allen wrench. Looking inside will give you a very clear idea of how the spectrograph works. Be sure and compare what you see with Figure 1 to identify the optical components.

- Connect the phone line between the two units so the ST-402 can talk to the DSS-7. Turn on the DSS-7 with its on-off switch. The red light in the switch should glow (dimly). If it doesn't, change the 9V battery in the DSS-7. Connect the USB cable from the ST-402 to the computer, and connect power to the ST-402. Bring up CCDOps, connect to the camera, and listen for the contented clicking sounds. Both the DSS-7 spectrograph and the ST-402 camera can now be controlled by a single software, CCDOps.

- Now we will check whether the motors inside the DSS-7 move correctly when controlled by CCDOps. Start by disabling the DSS, in CCDOps do DSS/DSS Mode and make sure that the "Enable DSS" box is NOT checked. Now run through the commands that move the slit in and out of the light path and rotate the diffraction grating. This procedure is described in the section "Aligning the DSS-7 to the camera:" of the DSS-7 manual: select MOVE TELESCOPE under TRACK. Select XPLUS with a time of 0.2 seconds, and hit OK. The grating assembly should rotate clockwise (CW) to its limit. Next, select XMINUS and try it. The grating should rotate counterclockwise (CCW). Do this a couple times to make sure it moves freely. Next, select YPLUS and hit OK.
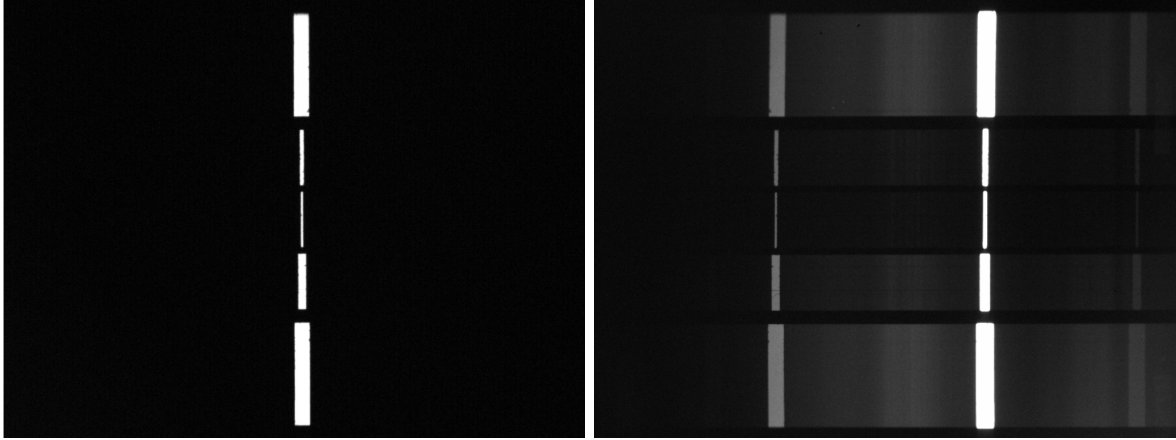
3

Figure 3: *Left*: Image of the slit mask when the CCD camera is focused, centered, and aligned. *Right*: Spectrum taken from a screen illuminated by the Hydrogen lamp.

The slit assembly should rotate into the entrance port. Select YMINUS and it should rotate out. Do this a few times to verify it works properly.

- By rotating the grating and the slit assembly, the spectrograph has three preset configurations that are controlled by commands in CCDOps:

  - VIEW SLIT: rotates the grating to the 0th order position (i.e., the imaging mode) and moves the slit assembly in the entrance port. This configuration is used to take an image of an illuminated slit.
  - GRAB SPECTRUM: rotates the grating to the 1st-order position (i.e., the spectroscopy mode) and moves the slit assembly in the entrance port. This configuration is used to take a spectrum of the illuminated slit.
  - POSITION MODE: rotates the grating to the 0th-order position (i.e., the imaging mode) and moves the slit assembly out of the entrance port. This configuration is used to take an image of the field without obstruction from the slit, useful for target acquisition.

- We will use all of the three configurations in this lab. But you probably have realized that there is one last combination that DSS-7 does not offer as a preset: the slitless spectroscopy mode, which would rotate the grating to 1st-order and move the slit out of the entrance port. This mode would make DSS-7 a slitless spectrograph (like the simple one we used in the previous lab), but this is not what it is designed to do.

- When you have checked that all of the mechanisms move properly, close the side panel on the DSS-7.

3.3   Centering and Focusing the CCD Camera

The next goal is to make sure that the internal optics of the spectrograph are focused on the slit and that the slit images are falling in the middle of the CCD chip (instead of off to the

side).

- Begin by picking DSS in the CCDOps menu, and now checking the ENABLE DSS box. This means the spectroscopic commands to the computer will move the slit and diffraction grating. The following instructions are also in the DSS-7 manual in the section "Aligning the DSS-7 to the camera".

- Choose VIEW SLIT from the DSS menu, and choose an exposure time of $\sim$1 second. The VIEW SLIT command rotates the grating to the 0th order position (i.e., the imaging mode), moves the slit assembly in the entrance port, and takes an image.

- When the slit is illuminated by ambient room light, you should see an image of the slit (see Figure 3 left panel), which is likely (1) blurry because it is out of focus, (2) offset from the center of the CCD, and (3) rotated at an angle with respect to the CCD columns. We need to correct all three of these. The slit actually consists of 5 slits of different widths. The larger the width of the slit, the poorer the spectral resolution, but the higher the signal-to-noise ratio because more light is admitted. This instrument lets you confront the trade-off, always present in astronomical spectroscopy, between high spectral resolution and high signal-to-noise ratio. For the experiment in the lab, we will use the narrowest slit that provides the highest spectral resolution.

- Focus the image of the slit on the CCD by moving the position of the focuser lens in DSS-7. Be sure and read the section in the manual entitled "Aligning the DSS-7 to the camera" for guidance on how to do this. Look at Figure 13 in the manual for an idea of what we have to do. On the side of the spectrometer opposite of the side panel that you just removed and replace, there is a pair of screws with Allen heads. Loosen the two screws on the little plate. Do not touch the other two screws. Once you have loosened them, move the little plate back and forth. This moves one of the focusing lenses in the instrument. Run the camera in focus mode. Continue adjusting the position of the sliding plate until the images of the slits are as small as possible, and the edges are crisp. Then re-tighten the screws on the slider. Tightening the screws often shifts the focus, which can make getting a really good focus a bit frustrating.

- Finally, put the narrowest slit in the middle of the CCD chip, and align it so it is parallel to the vertical direction as seen on the computer screen (i.e., the way a spectrograph slit should be). The spectrograph can be moved relative to the camera by loosening the brass thumbscrews and moving the spectrograph around. You will need to both rotate and translate the spectrograph. In the end, the image on the computer screen should look like the left panel of Figure 3, with the narrowest slit centered and vertical in the image.

Once the CCD camera is focused, centered, and aligned, we are ready to take some spectral data.

3.4   Taking Spectra from an Illuminated Screen

You will now take spectra of hydrogen, helium, and neon lamps for calibration purposes. We will need to have the lights off in the room while taking the data.

Let's take a moment to discuss the 2D spectra that we will acquire. The image of the spectrum of a hydrogen lamp should look like the right panel of Figure 3. The horizontal axis in the image below is the 'dispersion axis', i.e. the axis along which the photons are dispersed by the grating according to their wavelength. Thus, position along the horizontal axis is a measure of wavelength (which we will calibrate in detail below). The vertical axis is un-dispersed. The grating essentially acts like a mirror for reflection in this axis. Thus, the vertical axis is actually a spatial axis. A vertical slice across the spectral image through a bright spectral line will give a one-dimensional image of the source along an axis aligned with the slit. For the hydrogen lamp, the light source fills the whole slit, so one sees the whole outline of the slit in the bright lines. In contrast, a star will fill only a few pixels of the vertical extent of the slit (e.g., see Figure 5).

The following gives the suggested data taking procedure:

- The "Spectrum Tube Carousel" has several different gas discharge tubes. Make sure the power supply is off while rotating the carousel.

- Select the Hydrogen tube in the carousel and turn it on.

- Set up a white piece of paper (that we'll call the screen) and adjust the tube carousel so that the tube illuminates the screen. Adjust the DDS-7 so that it views the light from the tube on the screen. The point of the screen is to spread the light from the tube roughly uniformly over a larger area than just the tube itself. This helps in obtaining a spectrum that is uniform over the whole length of the slit.

- Acquire a spectrum (DSS/Enable DSS/GRAB SPECTRUM). The GRAB SPECTRUM command rotates the grating to the 1st-order position (i.e., the spectroscopy mode), moves the slit assembly in the entrance port, and takes an image.

- Adjust the exposure time so that the brightest pixels in the image of the narrowest slit have at least several thousand counts but are not saturated. Save the spectrum as a FITS file with an identifiable filename. You should also get into the habit of specifying the object (in this case 'H lamp') while saving so that it is written to the FITS header.

- Repeat this procedure for the helium tube and the neon tube. You might need to adjust the position of the carousel, screen, and DSS-7 for each lamp. Save the helium and neon spectra.

- Turn off the carousel.

- Check that you have a full set of spectra (hydrogen, helium, and neon) and that the brightest pixels in the image of the narrow slit for each spectrum has a decent signal but are not saturated. Go back and re-acquire any spectra that are bad.

- Now take and save 5+ bias frames at the same CCD temperature.

- When you are finished, shut down the system. Turn off the DSS-7 and shut down the ST-402.

4 Spectral Analysis

In this python analysis, we will utilize your longslit lamp spectra taken from the illuminated screen to solve for an approximately linear relation between pixels and wavelengths (i.e., wavelength calibration) and check its accuracy. This part is almost identical to the slitless spectroscopy lab, except that (1) we do not see the 0th order image in the spectrum and (2) we do not need to use its position to set the x-axis origin for wavelength calibration because the slit position is fixed in the field-of-view.

4.1 Spectral Extraction

Your spectra have been recorded by pixels on a regularized 2D (x, y) grid. This FIT file is often called the raw 2D spectrum: count vs. (x, y) pixels. But spectra are usually plotted in 1D as count vs. wavelength. So the first step of spectral analysis is to extract a 1D spectrum (count vs. x) from the 2D spectrum (count vs. (x, y)).

For simplicity, we start with the Hydrogen lamp spectrum because it shows only two prominent lines that are widely spaced.

Because the five slits have different widths, we first define the extraction region so that we extract spectra from the narrowest slit only.

- Load your best spectrum taken with the hydrogen lamp into DS9. Adjust the contrast levels to make the lines visible. It should look similar to the right panel of Fig. 3.

- If you have taken the data following the instructions, the lines should line up vertically in the CCD frame.

- Draw a horizontal rectangular region that bracket the central slit. This is the extraction region of your spectrum.

- Record the center y-position (y_0) of the extraction region and its height (h).

Next, write a python code to load the raw FITS data, build and subtract the master bias frame, and at each x position sum up the counts of pixels within the extraction region (i.e., from $y = y_0 - h/2$ to $y = y_0 + h/2$). Plot the extracted raw spectrum as count vs. x-position. The following example code from the previous lab might be useful to get started. Note that in this example, the loaded FITS file is already bias-subtracted.

```
#####################
# Spectral Extraction
#####################
# import needed extensions
import matplotlib.pyplot as plt # plotting package
import astropy.io.fits as pyfits
from numpy import *

```

```
9  # load bias-subtracted arc lamp image
10 arcfile = pyfits.open('Hydro_Setup2_bsub.fits')
11 arcimg = arcfile[0].data
12
13 # define extraction region
14 y0 = 300 # y center of extraction region
15 dy = 10 # half width of the aperture
16 (ny, nx) = shape(arcimg) # dimensions of spectral image
17
18 # find a 1-d spectrum by summing across the aperture
19 arc = zeros(nx)
20 for i in range(nx):
21     arc[i] = sum(arcimg[(y0-dy):(y0+dy+1), i])
22 # array of x positions
23 x = 1+arange(nx)
24
25 # plot raw spectrum (count vs. x-position)
26 plt.figure(2)
27 plt.xlabel('X Position (Pixel)')
28 plt.title('Raw spectrum')
29 plt.ylabel('Sum Counts (ADU)')
30 plt.plot(x, arc, '-b')
```

4.2 Wavelength Calibration

A spectrum is incomplete without wavelength information. In this section we attempt to establish an approximate empirical conversion between pixel coordinates and wavelengths. This procedure is called wavelength calibration. Because we can look up the rest-frame wavelengths of emission lines from common elements, we can obtain the pixel-to-wavelength relation by identifying emission lines in the observed spectrum of a calibration lamp, like the hydrogen gas tube we used in this lab.

First, plot the extracted spectrum of Hydrogen, and measure the x-coordinates of the peaks that correspond to the two strongest Hydrogen Balmer lines in the spectrum ($x_{H\alpha}$ for Hα at 6562.85 Å and $x_{H\beta}$ for Hβ at 4861.33 Å). Think about which line is brighter; that will help you identify which line is which.

We can now solve for the pixel-to-wavelength relation based on the CCD coordinates and the known wavelengths of the two identified lines (Hα and Hβ). Because we only use two lines, we will approximate the non-linear relation with a linear dispersion relation:

$$\lambda(x) = \lambda_c + D \cdot (x - x_c) \tag{1}$$

where three constants need to be solved: D is the dispersion in Å/pixel, and λ_c and x'_c are the wavelength and x coordinate of the reference line. It's easy to solve these constants with the two Hydrogen lines: you can first set λ_c and x_c to the wavelength and the CCD x-coordinate of Hβ, then solve for D using wavelength and the x-coordinate of Hα.

Use this relation to convert x to λ and plot the wavelength calibrated 1st-order spectrum of Hydrogen (count vs. λ). Overlay the wavelengths of Hα and Hβ in the plot as vertical dotted lines. Show this plot and report your calculated linear dispersion relation in the lab report.
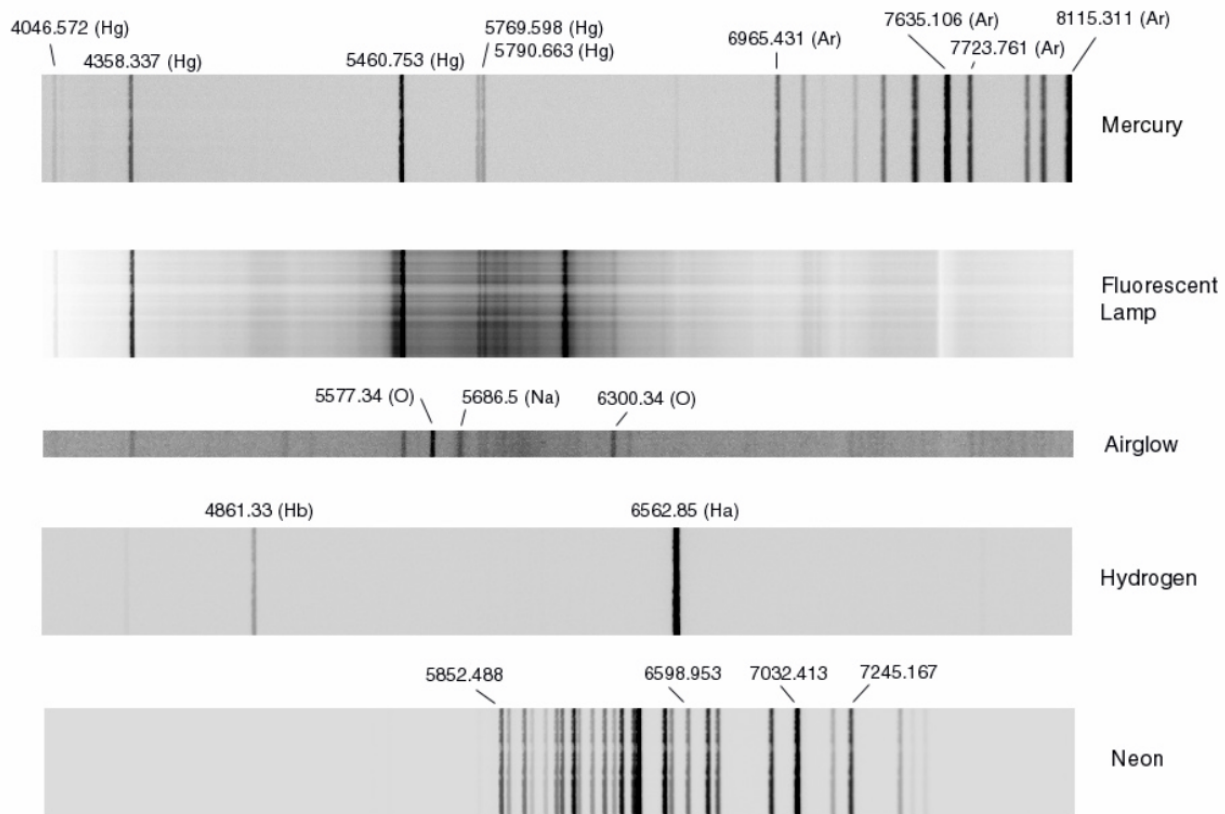
Figure 4: Example spectra with prominent emission lines identified.

The following example code might be helpful for you to get started:

```
#####################
# Wavelength Calibration
#####################

# extracted spectral data from the previous step
s1 = arc              # counts
p = 1+arange(len(s1)) # pixel numbers

# calculate centroids for each line
linec = array([    172,      485]) # approximate center of interval (pixel)
lined = array([      4,        4]) # width of interval to calculate
    centroid (pixel)
linew = array([4861.33, 6562.85]) # wavelength of lines (Ang)
centroid = 0.0*linec
for i in range(len(linec)):
  # array elements included in this line
  k = range(linec[i]-lined[i], linec[i]+lined[i]+1)
  # find statistics for this line
  centroid[i] = sum(p[k]*s1[k])/sum(s1[k])
  print 'center, range, mean = ', linec[i], lined[i], centroid[i]

```

```
21  # solve for constants in wavelength calibration
22  centralp = mean(centroid)
23  centralw = mean(linew)
24  slope = (linew[1]-linew[0])/(centroid[1]-centroid[0])
25  print 'central pixel = ', centralp
26  print 'central wavelength = ', centralw
27  print 'slope = ', slope
28
29  # plot the spectrum: Counts vs. versus wavelength
30  w = centralw + slope*(p-centralp)
31  plt.figure(3)
32  plt.title('Wavelength-Calibrated Spectrum')
33  plt.xlabel('Wavelength (Ang)')
34  plt.ylabel('Sum Counts (ADU)')
35  plt.plot(w, s1, '-b')
36  plt.show() # display the plot
```

4.3   Check the Accuracy of the Calibration

To obtain more precise wavelength calibration, 20 to 40 lines from multiple gas lamps are usually used (e.g., arc lamps of Thorium, Argon, Neon, and Iron, instead of Hydrogen). But how good is the linear approximation? To answer this question, we need to use spectra of the Helium and the Neon lamps that you took right after the Hydrogen lamp.

The National Institute of Standards and Technology (NIST) provide online tables giving the wavelengths of strong lines of Hydrogen, Helium and Neon. Note that the air wavelengths are given in Angstroms (Å). Select lines to plot only in the optical wavelength regime (4000 to 8000 Å).

Our simple testing procedure is:

- extract spectrum from the Helium lamp data;

- apply your derived wavelength calibration (Eq. 1) to convert the x-coordinates to wavelengths;

- plot count vs. wavelength (this is your wavelength calibrated spectrum of Helium);

- overlay the known wavelengths of Helium emission lines on the spectrum as dotted vertical lines;

- calculate the deviations between the vertical lines and their corresponding peaks in the spectrum (it is sufficient to do this for the only most prominent lines);

- Repeat this for Neon lamp data.

Show these figures and report the mean deviations in Å in your lab report.

4.4 Measure Spectral Resolution

A key parameter describing the capability of a spectrograph in revolving spectral features closely separated in wavelength is the spectral resolution R. Defined as $R = \lambda/\Delta\lambda$ where $\Delta\lambda$ is the full-width-at-half-maximum (FWHM) in Å of a spectral line at a wavelength of λ (also in Å), it is a dimensionless parameter that can be empirically determined by measuring the FWHM of lines in a lamp spectrum or airglow lines from the atmosphere. Spectral resolution not only depends on the grade of the grating but also on the slit width. Since the DSS-7's slit mask is made of five slits of three different widths (50, 100, 200μm), it has three different spectral resolutions. Choose two unsaturated, relatively isolated, strong emission lines in you Helium spectrum, extract three 1D spectra from the top three slits, convert pixel to wavelength using the wavelength calibration formula, and measure their central wavelengths and their FWHMs by either fitting a Gaussian or using simple interpolation method at half of the peak height (note that the baseline level may not be at zero). Now you have the data to calculate R at two wavelengths and three slit widths. Report λ, $\Delta\lambda$, and R of these six measurements in a table. How does R depend on wavelength and slit width?

5 Taking "Stellar" Spectra in the Lab

In the previous sections we have focused and aligned the spectrograph, and obtained calibration spectra. To obtain a spectrum from a celestial source, we need to place the source onto a very narrow slit ($\sim$50μm) at the focus of a telescope. The process that achieves this seemingly impossible objective is called *spectroscopic target acquisition*. It is a time consuming process even with professional telescopes (e.g., observers typically spend 5-10 min on acquisition per target field at Keck observatory). To practice this procedure in the lab room, we will mount the spectrograph on the Orion refractor, and our target is an artificial "star" created by connecting an optical fiber in front of a gas discharge tube, like what we did in the slitless spectroscopy lab.

5.1 Equipment Setup and Rough Alignment

The spectrograph was assembled in the previous class period. We will assume that this was done right and that the wavelength calibration is still valid. Follow these steps to install the optical fiber, center the telescope, and mount the spectrograph on the telescope:

- Install optical fiber adapter on the carousel.

- Install optical fiber, turn on the Nitrogen lamp and make sure you see light coming out of the fiber.

- Secure the output end of the fiber on a horizontal surface and point it at your Orion focuser (now doubled as a telescope) on the other side of the room.

- Point the telescope at the optical fiber's output end. It helps to use the finderscope and an eyepiece in this step.

- Turn on the Nitrogen lamp.

- Make sure you can see the shining bright spot at the center of the fiber through the telescope eyepiece.

- Adjust the telescope pointing until the bright spot is at the center of your field of view. For better alignment, switch to an eyepiece with higher magnification (i.e., shorter focal length). Lock the scope at this position and verify that the finderscope is pointing at the exact same position; if not, adjust the finderscope.

- Turn off the lamp.

- Install the 1.25-in nosepiece adapter on the entrance port of the DSS-7 spectrograph.

- Replace the eyepiece with the DSS-7 camera. When installing the spectrograph, try and place it so you have free access to the finder telescope and the focus knob (both will be necessary).

- Connect the phone line between the DSS-7 and ST-402, and turn on the DSS-7 with its own switch. Connect the USB cable from the ST-402 to the control computer. Connect the power unit for the ST-402.

- Bring up CCDOps and establish a link between the computer and the spectrograph. Listen for the contented clicking noises of the ST-402.

5.2 Target Acquisition

Now we are ready to acquire the artificial "star" on the slit. The procedure is detailed in the section of the DSS-7 manual entitled "Operation at the Telescope". The instructions are summarized below:

- A crucial task is to place a marker in the field of view that indicates the slit location. This will permit you to guide the star onto the slit. First, be sure the box "DSS-7 Enabled" is checked in the DSS-7 menu box. Then choose VIEW SLIT, then click POSITION MARKER. This will place a white rectangle on the screen. Change the size and reposition it so it fits right over the narrowest slit.

- Turn off light in the room and turn on the Nitrogen lamp. Make sure you see light coming out of the fiber.

- Now we need to adjust the telescope's focus so that it is on the slit mask. Click on the DSS-7 dialog box, and select "POSITION MODE". The POSITION MODE rotates the grating to the 0th-order position and moves the slit assembly out of the entrance port, so that we can take an image of the full field without the slit blocking the light. Choose a short integration time and take an image. If the image appear out of focus, adjust the telescope focus and repeat "POSITION MODE" until a sharp image of the "star" is obtained.
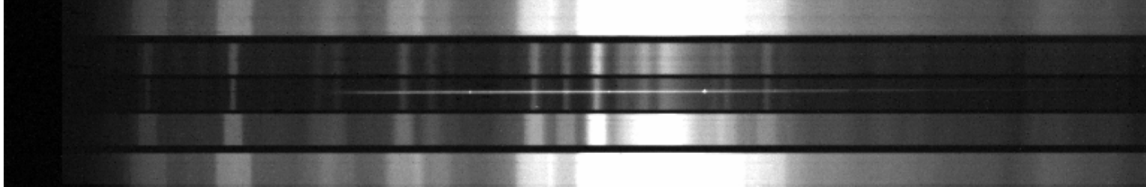
Figure 5: Example stellar spectrum from the star P Cygni. Only the horizontal trace near the center is the stellar spectra, the rest are airglow spectra from the atmosphere. Notice the bright Hydrogen Balmer emission lines in the stellar spectrum.

- Now we need to position the "star" on the slit, in preparation for measuring its spectrum. Notice the little white box which indicates the position of the slit (as if it were there). Your goal here is to move the "star" onto the white box by carefully changing the pointing of the telescope. It would make the process easier if you move one axis at a time (i.e., unlock one rotating axis while keeping the other axis locked).

- When you have the "star" on the slit (white box), bring up the dialog box, choose "GRAB SPECTRA", and take a spectrum. Start with an integration time of 10 seconds. Check the resultant spectrum to see if it is usable (i.e. not saturated, but with an adequate signal-to-noise ratio). Take a number of spectra with different exposure times.

- When saving your data file, you could also save a copy of the 2D spectrum that is "cropped". That makes it look like the spectra in your physics and astronomy textbooks, and makes the spectra easier to analyze. You can do this either in Python or use CCDOps. There is a utility in CCDOps that cuts out a 20 pixel-high ribbon that can be read by the analysis program DSS7 (referred to as SCP in the manual). In CCDOps, go to the UTILITY menu, the select CROP, then select SPECTROSCOPY. The program will pop a wide, white band on your set of spectra. Position it so it fits right on the spectrum you want to save (usually the one with the narrowest slit, and thus the highest spectral resolution). When you have positioned the CROP mask, go back to the UTILITY menu, select CROP, and under the choices, pick CROP IMAGE. Pick a name for the file that identifies it as a cropped spectrum, then save to your folder of spectra for the night.

- Save your spectra to a folder for later processing. Choose file names that tell you what star and exposure time was used.

In your lab report, show an image of the raw 2D spectrum, an image of the cropped 2D spectrum, and a plot of the 1D extracted spectrum of the Nitrogen fiber (counts vs. wavelength). Here you can use the same wavelength calibration as you obtained in Section 4.2.

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6 Take Stellar Spectrum on the Roof (Bonus Activity)

Throughout your astronomy education, you have read about stellar spectra. Now is your chance to actually take some and compare them with the spectra presented in textbooks. Completing this roof-top night-time activity during the two week period will earn up to 20 bonus points: obtaining a useful spectrum of a bright star will earn up to 10 points, and completing the analysis of the spectral data will earn an additional 10 points.

Because accurate sidereal tracking is needed for target acquisition with a longslit spectrograph, you will mount the DSS-7 spectrograph on a Celestron 8-in scope with a tracking equatorial mount or the Meade LX200GPS. If using the Celestron 8-in scope, the whole system should be assembled and turned on while there is still light to work by. We can then wait until it gets dark to take spectra.

Figure 5 shows an example spectrum. That sets the goal of this bonus activity. As for the target, you can choose any star for this exercise. For Spring Semester, the brightest star Sirius is clearly visible in the southern sky.

A summary of the procedure follows. Take spectra of a bright star, note essential information in your observing log, extract and wavelength calibrate the spectrum. Look up the star's spectral type, and compare your spectrum with the spectrum of a star with the same spectral type in the MILES stellar libraries by plotting them with Python. Identify prominent absorption features, and comment on the similarities you observe between your spectrum and the archival spectrum and the likely causes of any significant differences you notice between the two. Figures showing your wavelength calibrated spectrum and the archival spectrum of the comparison star are required.