Department of Physics and Astronomy
University of Iowa
29:137 Astronomical Laboratory
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Lab 3: Spectroscopy in the Laboratory

1 Introduction

Spectroscopy is crucial to astronomy. It is the principal diagnostic for determining the temperature and chemical composition 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 this class, we will have the pleasure of measuring and analysing spectra. We will use the same ST-402XME camera used in the previous exercises as the "detector" of our spectrograph. The equipment which actually makes up the spectrograph (slit, internal optics, and most importantly, diffraction grating) is provided by a unit which connects to the front of the ST-402XME. The instrument is called the *Deep Space Spectrograph* DSS-7. This unit is also manufactured by the Santa Barbara Instrumentation Group (SBIG). The SBIG company designed this spectrograph to be mounted on a telescope.

We will do two lab projects with this equipment. In the first (the subject of this exercise) we will set it up in the laboratory and get it working. We will then calibrate it by taking spectra of gas discharges of hydrogen, helium, etc. We can also use the calibration data to search for weak lines of these elements. We will also take a spectrum of the Sun and " Let the Sun shine in" (sounds like an easy-listening song).

In a subsequent project, we will mount the spectrographs on the Celestron 8 telescopes, and measure stellar or nebular spectra.

1.1 Reading Material

This exercise will be much more meaningful if you know what is going on. Review the description of spectrographs in your introductory astronomy textbook. Look at the discussion in the book *Astrophysical Techniques* by Kitchen. Finally, the manual for the DSS-7 spectrograph (on the course web page under "Textbooks") has much worthwhile tutorial material as well as indispensible material on the construction and operation of the DSS-7. You should particularly look at Figures 1, 5, and 7 of the DSS-7 manual. An important characteristic of the DSS-7 is its wavelength range. As stated in the manual, it is nominally 400-800 nanometers (or 4000-8000 Angstroms, in a unit more traditionally used in astronomy).

2 Equipment to be used

The following pieces of equipment will be used in this lab. We have equipment for two complete setups as described below.

- The ST-402XME CCD camera connected to a workstation running CCDOPS
- Power unit and USB cable for the ST-402XME
- The DSS-7 Deep Space Spectrograph
- A 7 inch phoneline connecting the spectrograph and the camera
- Adapter ring to connect the DSS-7 and ST-402XME
- A set of Allen wrenches, including little ones
- Gas discharge tubes of hydrogen and helium (other elements would be good, too) plus associated power supplies.

3 System Setup

1. Physically connect the spectrograph to the camera, as described in step 2 in the section "Attaching the DSS-7 to the camera". There is an adapter ring, properly threaded, which connects the DSS-7 and the ST-402XME. Figure 12 of the manual shows what the properly assembled system should look like.

2. 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 Figures 1, 5, and 7.

3. Connect the phone line between the two units so the ST-402XME can talk to the DSS-7. Turn on the DSS-7 with its on-off switch. Connect the USB cable from the ST-402XME to the workstation, and connect power to the ST-402XME. Bring up CCDOPS, connect to the camera as done in experiments 1 and 2, and listen for the contented clicking sounds.

4. To see how the spectrograph works, run through the commands that move the slit in and out of the light path, and also rotate the diffraction grating. This is done as described in the section "aligning the DSS-7 to the camera". Before carrying out these operations, be sure that you have un-checked the box **ENABLE DSS** in the DSS MODE dialog box in CCDOPS (described in the manual). At the end of this phase, close the side panel on the DSS-7.

4 Centering and Focusing on the Slit

This section is really still part of the setup phase. However, there is a lot involved, so these steps merit their own section. The goal is to make sure that the slit images are falling in the middle of the CCD chip (instead of off to the side), and that the internal optics of the spectrograph are focused on the slit.

1. 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 commands are also in the DSS-7 manual in the section "Aligning the DSS-7...".

2. Choose VIEW SLIT from the DSS menu, and choose an exposure time of 1 second. This runs the camera and spectrograph in normal camera mode, except you are taking a picture of the slit. You should see an image of the slit (see Figure 2), which is blurry (out of focus), offset

from the center, and rotated with respect to the horizontal. 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 with the highest spectral resolution.

3. First, *if it is necessary*, focus the internal optics on the slit. This is a remarkably inconvenient operation. 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 for an idea of what we have to do. On the side of the spectrometer opposite of the side panel, there is a pair of screws with Allen heads. You will see that if you loosen them, something will move. Check with the instructor before doing anything to make sure you are loosening the right screws. Once you have loosened them, move the slider 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 slider until the images of the slits are as small as possible, and the edges are crisp. Then re-tighten the screws on the slider.

4. 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 workstation 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 workstation screen should look like Figure 2 in the manual. As described in the manual, there is an additional adjustment that will be necessary before making observations of astronomical objects, but we will worry about that next time.

We are now ready to take data.

5 Data Taking and Measurements

There are two main goals of this lab exercise. The first is to calibrate the spectrograph. This means to determine the relationship between pixel number and wavelength in nanometers. The second is to take and subsequently explore a spectrum of the Sun.

1. **Note the recommendation** in the section of the manual "Capturing Calibration Spectrum". Mount a white sheet of paper and have the light source illuminate it. The spectrograph slit should be viewing the sheet of paper, which we will refer to as the screen.

2. The first thing to determine is which side of the workstation screen corresponds to the red part of the spectrum, and which is the blue side. The manual says "for a ST-402 the longest wavelengths are on the left ...", but check it out. There are light source boxes in the lab. Hook up one and illuminate the screen. To take a spectrum, click on the DSS box in CCDOPS, and select "GRAB SPECTRA". Play with the exposure time until you can see the red or blue continuum. That will tell you whether increasing pixel number corresponds to shorter or longer wavelengths. A more brutal way of doing this is to pick flashlights with red and clear covers, and studying the light recorded by the spectrograph.

3. For purposes of analysis, it is most convenient select a strip of the spectrum, i.e. the full range of pixels on the abscissa (corresponding to wavelength), but only a small range of the ordinate. The resulting spectrum will look like the ones you have seen in your astronomy and physics textbooks. The operation to cut out a portion of the CCD image is called CROP. There is a utility in CCDOPS that cuts out a 20 pixel-high ribbon that can later be read by Maxim DL. In CCDOPS, go to the UTILITY menu, then 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. It will show an image which is just the ribbon spectrum you have chosen. Pick a name for the file that identifies it as a cropped spectrum, then save to your folder of spectra. Since we will use Maxim DL for this analysis, save the file in FITS format.

4. We are now ready to take data to calibrate the spectrograph. We will do this with the gas discharge tubes in the laboratory. Place a hydrogen discharge tube so that it illuminates the screen. Take a spectrum, choosing the exposure time so that you have good measurements of at least a couple of strong lines. Save this spectrum in your working team folder for subsequent analysis with Maxim DL. Before going further, use the CCDOPS software and your brain to identify the lines you see, and measure their positions on the CCD array. On the wall of the laboratory is a nice chart showing the spectrum of hydrogen and other elements, and giving the wavelengths of the principal lines. Consult with your fellow team members, and discuss the line identification, without getting into vicious arguments.

   An additional source of information on line identification is in Table 1 and Appendix A of the manual.

5. Repeat the procedure in # 3 for helium. A third element wouldn't hurt either. The name of the game here is to get enough lines, over a wide enough wavelength range, to get a good wavelength calibration. Be sure and get the data you need now. Later, the equipment will be in use by another working team.

6. We want to take a spectrum of the Sun. Making sure that the fluorescent lights are off in the room, and open the window shades ("Let the Sun shine, let the Sun shine in ..."). Take a long enough exposure to get a high signal-to-noise ratio measurement of the solar continuum. Save the file to your working group folder.

When you are finished, **shut down the system**. Turn off the DSS-7 and shut down the ST-402XME using the CAMERA-SHUTDOWN command, and other steps in the procedure which we have previously used.

6 Analysis and Results

Data analysis should be undertaken in Maxim DL and with a data analysis program such as *LoggerPro*, or *Mathematica*.

1. First identify all spectrum lines in the hydrogen, helium, etc spectra, and collect their true wavelengths as well as raw spectrograph locations. List your data in tabular form.

2. Make a plot of wavelength versus pixel number. Fit an accurate analytic function to these data. In the best of all possible worlds, this will be a linear relationship, but if a linear fit is inadequate, use a higher order polynomial. Your final plot should include the function fit to the data as well as the data points. Your report should also include the equation for the calibration relationship.

3. Examine your discharge spectra for weaker lines that were not used in determining the calibration curve. Measure the wavelengths and intensities of several of them relative to the more prominent lines. Present your results in a table. If you are ambitious, find a line list for this element and check your values for the wavelengths. Your report should also include these spectra in line drawing format.

4. What is the wavelength resolution in your spectrum? How did you obtain this value?

5. Next work on the solar spectrum. Make a plot (line drawing or $I(\lambda)$ format) and submit with your report. Identify the wavelengths of the more prominent features. This is something you should do outside of the lab room, since you will need to do some library research. For those of you who have taken *Introduction to Astrophysics*, you should look at the book by Carroll and Ostlie for information.

6. Measure the peak in the continuum spectrum of the Sun. Use Wien's Law to obtain an estimate of the temperature of the solar photosphere. Give your value, and discuss how it agrees with the accepted value.