Optical Spectrometry

Cosmic Messengers Lab (PHY/AST-3880)

By: **Esha Sajjanhar**

Prof. Dipankar Bhattacharya
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Abstract

Optical spectroscopy is the study of the spectra of stars. This allows us to identify spectral lines due to specific elements thereby revealing the composition of the star. Obtaining stellar spectra involves using a slit and a grating in combination with the telescope and camera apparatus. In this report, we detail the method used to reduce demo data from the Asiago Observatories for the spectrum of the star AS338 and obtain a wavelength-calibrated spectrum.

1 Data and Software Used

The data used for this experiment is the demo data provided alongside the Asiago observatory's notes on spectroscopy. It was processed using NOAO's Image Reduction and Analysis Facility (IRAF) along with the image viewer SAO DS9. IRAF is composed of a variety of tasks with diverse usage. These tasks are grouped under various packages and subpackages. For the purpose of this experiment, we use subpackages and tasks contained within the `noao` package.

2 Analysis

The data are available to us in the form of FITS files. While most of these files are uncalibrated, the darks provided to us have already been bias subtracted. The images and their file names have been tabulated below. In this report, the spectrum for the star

File Name	Frame
a0019	AS338 (1 min exposure)
a0021	Lamp spectrum
a0035	BD284211 (standard star)
a0007 - a0009	Darks
a0001 - a0006	Flats
a0039 - a0043	Biases

Table 1: Filenames for each of the frames used in this experiment.

We use IRAF to reduce all the images. IRAF is ideally used within an `xgterm` terminal wherein it can be called by running the command `irafcl`. IRAF should be launched from the directory which contains the `login.cl` file. For image reduction and stacking, we use tasks within the `ccdred` package. After running any task in IRAF, we can refer to the logfile created for that directory in order to find the history of operations. This is a good tool to verify that the right tasks were run.

2.1 Image Reduction

We begin by trimming the images. The spectrum does not occupy the entire frame of the image, and thus we need to trim the 'empty' parts of the image because otherwise these would affect the statistics in our pixelwise operations.

To do so, we first create a copy of all the images we need. We create a text file called 'input-trim.txt' containing the names of all the files and the columns to be used from each (ex: 'a0019.fits[*, 10:2040]'). We similarly create a file containing the corresponding names for all the trimmed images ('output-trim.txt' with entries 'b0019.fits'). Then, we can trim the images and save the trimmed images with the command `imcopy @input-trim.txt @output-trim.txt`.

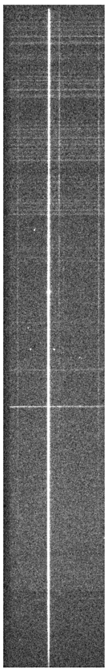

Figure 1: Unreduced image of the star AS338.

2.1.1 Preparing the Calibration Frames

We begin by creating the master bias frame. To do so, we navigate to the `noao > imred > ccdred` package. We create a file ('bias-input.txt') with the file names of all the bias frames. The parameters used in the task `zerocombine` have been given below.

input	@bias-input.txt
output	MasterBias.fits
combine	average
scale	none

Table 2: Parameters for `zerocombine`.

Now, we want to produce a master flat and a master dark by obtaining the median of all the flat and the dark frames respectively. We do this using the task `imcombine`. We need to create a file (say, 'input-flats.txt' and 'input-darks.txt') with the filenames of all the flats to be stacked. The parameters used for this task have been tabulated below.

input	@flats-input.txt / @input-darks.txt
output	MasterFlat.fits / MasterDark.fits
combine	median
scale	mode

Table 3: Parameters for `combine`.

The task `imstat` can be used to find the statistics (minimum, maximum, mean and standard deviation of pixel values). It is extremely useful to compare the statistics before and after stacking to see the effects of the stacking operations on the image. We find that averaging N bias images reduces the standard deviation of the images by a factor of $\sqrt{N}$.

At this stage, we have bias subtracted and stacked darks, and stacked flats. We now want to subtract the bias from the flats. This can be done using the task `imarith`. We can use the command `imarith MasterFlat.fits - MasterBias.fits MasterFlat-Bias.fits calctype=real pixtype=real`.

At this stage, the master flat we have obtained is strongly wavelength dependent. Due to the presence of the spectrograph, different wavelengths are directed to different parts of the sensor. However, we want the flat frame to give us only the differential response of each pixel, without any wavelength dependence. To account for this, we average over a range of columns to produce a single line which gives the wavelength-independent flat field response. We can then duplicate this column over the range of the image in order to obtain our true master flat. We do so by running the following commands.

```
blkavg MasterFlat-Bias.fits[20:310,*]
avcol_in 291 1

blkrep avcol_in avcol_out 317 1

imarith MasterFlat-Bias.fits / avcol_out
FinalMasterFlat-Bias.fits calctype=real
pixtype=real
```

We have now normalised all the bias subtracted flats to a value of 1.0, which can be verified using `imstat`. We can repeat the same blocking for 'MasterFlat.fits' which contains the bias contribution for use with the calibration spectrum and produce 'FinalMasterFlat.fits'.

2.1.2 Reduction of Light Frames

We now have bias subtracted darks and biases. We can get the bias subtracted lights using `imarith`. Here, the light frames are the trimmed images of AS338 and a standard star. We first create a text file which contains the file names of the light frames 'reduction-input.txt', and a file containing new set of names for the corresponding bias subtracted files 'bias-subtracted-sources.txt'. We now run the command `imarith @reduction-input.txt - MasterBias.fits @bias-subtracted-sources.txt calctype=real pixtype=real`. Now, we can finally perform the dark and flat correction using the task `ccdproc`. The parameters for this are given below.

Here, 'reduction-output.txt' contains the names of the final reduced images. We set zerocorrection to 'no' here because all the files we're using have already been corrected for the bias.

images	@bias-subtracted-sources.txt
output	@reduction-output.txt
trim	no
darkcorr	yes
zerocorr	no
flatcorr	yes
dark	MasterDark.fits
flat	MasterFlatG.fits

Table 4: Parameters for `ccdproc` for the star image.

Finally, we can reduce the lamp spectrum corresponding to the star image used. The lamp image has a very small exposure, and so the dark current typically does not play a major role in this frame. We can reduce it using the following parameters in `ccdproc`.

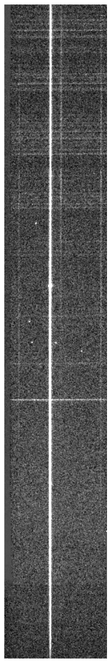

Figure 2: Reduced image of the star AS338.

images	b00221.fits
output	CAL-AS338-reduced.fits
trim	no
darkcorr	no
zerocorr	yes
flatcorr	yes
bias	MasterBias.fits
flat	FinalMasterFlat.fits

Table 5: Parameters for `ccdproc` for the lamp image.

2.2 Aperture Extraction

We now navigate to `noao > twodspec > apextract`. We want to use the task `apall` in order to extract the apertures for the star image and the lamp spectrum. We begin with the star image. If the image contains many negative values, we need to add an offset to each pixel such that all values become positive before running this task. For our image, we choose a value slightly greater than the sum of the absolute value of the minimum and the standard deviation report by `imstat`. We add the offset (here, +150) using `imarith` to produce 'AS338-reduced-offset.fits'. We now run apall with the following parameters (`epar apall`).

images	AS338-reduced-offset.fits
output	AS338.spec.fits
apertures	1
format	onedspec
interactive	yes
find	yes
recenter	yes
resize	yes
edit	yes
trace	yes
fittrace	yes
extract	yes
extras	yes
review	yes
nsum	10
lower	-4.0
upper	4.0
b_sampl	-10:-6,6:10
b_niterate	2
nfind	1
llimit	-5.0
ulimit	5.0
backgro	none
weights	variance
saturat	15500
readnoi	4.2
gain	1.2

Table 6: Parameters for `apall` for the star image.

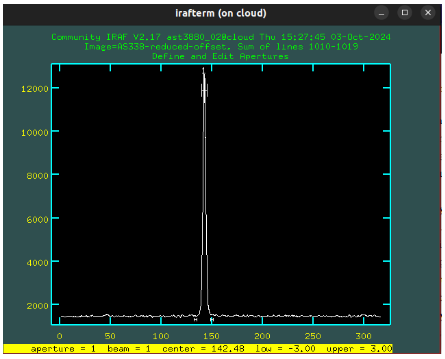

Figure 3: Extracting the aperture using `apall`.

Here, readnoise and gain are set as per values provided by the camera manufacturers. With these parameters set, we can run apall for the star image. This launches a plotting window with options to choose the aperture. There will be a default choice of aperture highlighted. We can press 'd' to delete this, and press 'n' and 'm' to place new markers at the cursor position. Once this is set, we enter background fitting by pressing 'b'. We can again delete the automatic selection using 'z'. We can now press 's' to choose multiple background regions. Once this is completed, we hit 'f' to fit the background and 'q' to quit background fitting. We hit 'q' again when prompted to change the choice of aperture. Now, we see a plot of all the points on the spectrum. The default fit plotted alongside is a linear fit. Typically, this will not be sufficient. We type `:o 3` to switch to an order 3 fit, and hot 'f' fit the new function, and 'r' to redraw the graph. Finally, once this is satisfactory, we hit 'q' to quit, and confirm by hitting 'enter' when prompted to save the aperture.

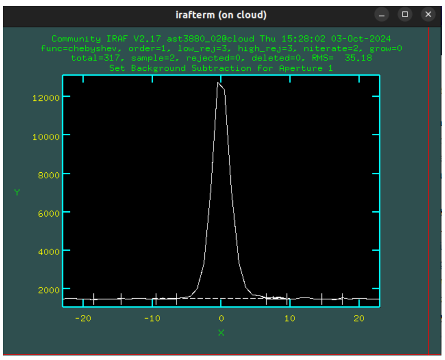

Figure 4: Background selection using `apall`.

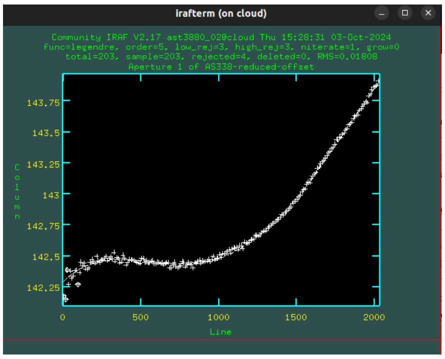

Figure 5: Fitting the background using `apall`.

We repeat this procedure for the lamp image after making a few changes to the `apall` parameters. First, we enter the name of the star image ('AS338-reduced-offset.fits') in the fields for `referen` and `profile`). Next, we change all options (except `extract`) from `interac` to `review` to 'no'. We also turn off background subtraction by setting `backgro` to 'no'. This produces a comparision spectrum for the lamp.

2.3 Wavelength Calibration

We now want to obtain a pixel to wavelength conversion for our star spectrum. To do so, we use the pixel positions of the known lines in the lamp spectrum. The wavelengths for various lines in the lamp spectrum (Helium-Neon-Argon lamp) in the demo data have been identified and marked in the Asiago manual. We use the task `identify` in the package `noao > onedspec`. We use the following parameters in the task `identify`.

images	CAL-AS338.spec.0001.fits
section	middle line
database	database
coordli	linelists$idhenear.dat
ftype	emission
fwidth	4.0

Table 7: Parameters for `identify`.

This launches a plotting window showing the various emission lines in the lamp spectrum. We use the key 'm' to enter the wavelength corresponding to each line by placing the cursor over the line. After entering the wavelength for a few lines, press 'f' to produce a preliminary fit for for the pixel to wavelength conversion. At this stage, the fit may look bad. Press 'l' to include all other lines from the database and then press 'f' again to fit all identified lines. The fit should look much better at this stage. If the fit is not satisfactory, you can add more lines and then try fitting again. Once the fit is good, use 'q' to exit. Hit enter to confirm that the fit should be saved to the database.

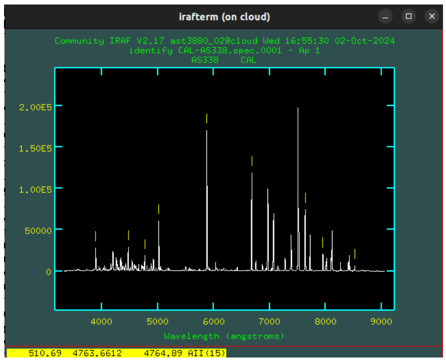

Figure 6: Marking known lines in the lamp spectrum using `identify`.

All that remains now is to apply the conversion to the star image. To do so, we first edit the header of the star image to add the lamp image as the reference for calibration. We do this by running the command `hedit AS338-spec.0001.fits refspec1 CAL-AS338.spec.0001.fits add+ ver-`. Finally, we apply the calibration to the star image by running the command, `dispcorr AS338.spec.0001.fits AS338-WavCal.spec.fits linearize=no`. We can now plot the wavelength calibrated spectrum of the star image using `splot`.

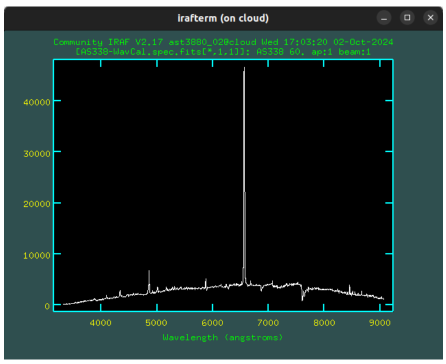

Figure 7: Wavelength calibrated spectrum for the star AS338 plotted using `splot`.

3 Discussion

We can use the spectrum of the standard star reduced earlier to perform flux calibration such that we can find the true intensity of each of the absorption lines of the star. This can be performed using IRAF after setting observatory specific parameters and accounting for atospheric lines in the spectrum. The atmospheric lines are the emission lines we see in the spectrum while the absorption lines are due to the star itself.

References

‘An introduction to analysis of single dispersion spectra with IRAF’ by Tomaz Zwitter and Ulisse Munari, Asiago Observatories, Italy.