

# ASTR 5110 Observing Lab / HW #6

## Stellar Spectroscopy

Due Date: Nov. 30, 2025

In this lab we will use the Celesteon 14" telescope + Shelyak Instruments' Lisa spectrograph (<https://www.shelyak.com/produit/spectroscope-lisa-vis/?lang=en>) and ZWO detector to gain familiarity with spectroscopy of stars and other objects. For this lab it is especially important to be prepared at the telescope, having read thoroughly the requirements of this lab.

This lab will require initiative to research outside resources to learn about spectral classification and stellar atmospheres. *The observation and analysis of stellar photospheres* by David F. Gray is a good reference (Chapters 1, 12, 13, 14), *An atlas of digital spectra of cool stars* by Turnshek et al., *The Classification of Stars* by C. Jaschek and M. Jaschek, *Revised MK Spectral Atlas for Stars Earlier than the Sun* (Morgan, Abt and Tapscott, link), Jacoby et al. (1984, ApJS, 56, 257), and Montes et al. (1999, ApJS, 123, 283). A useful reference on AGN is Osterbrock's *Astrophysics of Gaseous Nebula and Active Galactic Nuclei*. Please respectfully share these resources from the library.

### Preparations before observing:

1. Read through this assignment carefully so you are prepared at the telescopes! For observing efficiency, make sure to collect the data you need, and make note of which parts of the lab should be done early and which later.
2. **Prepare finding charts for your targets.** A good place to start is: [https://astro.swarthmore.edu/transits/finding\\_charts.cgi](https://astro.swarthmore.edu/transits/finding_charts.cgi)
3. Help yourself by preparing in advance an airmass chart for the targets you expect to observe. This lab lends itself readily to multiple groups observing in a night and sharing data, but this requires careful coordination and division of labor.

HINT: P Cygni,  $\beta$  Cephei and IC 4997 will be setting early!!

### At the telescope:

1. Every member of each observing/reduction group should share all aspects of the work equally.

2. Make sure to determine the spectrograph set-up (grating, dispersion, wavelength coverage, slit size, resolution, calibration lamps, etc.) and know the particulars (pixel pitch, format) of the detector you are using.
3. Don't forget to turn off the comparison lamps when you are not using them!
4. Because of potential flexure in the spectrograph, you should collect calibration lamp spectra for every target.
5. Make sure to keep a standard observing log for your observations — e.g., the version of the log sent to you for previous labs.
6. Do not bin the detector for this lab.

## Data reduction and analysis

1. All analysis work should be done with wavelength calibrated, one-dimensional spectra. The one dimensional spectra can be extracted from the calibrated images using aperture photometry.
2. For analyzing the extracted spectra, the `specutils` package is a good option. Examples for analyzing line profiles can be found [here](#) and [here](#).
3. `pyvista` is another python package that can be used to reduce, extract, and analyzing spectroscopic data.
4. Please label each spectrum you hand in clearly by the star name.

## Your lab write-up:

1. It should include a list of scientific objectives, and a simple description of the general procedures followed for each part of the experiment (please do not just reiterate the instructions here, but, rather, briefly explain the general idea of what was done and why).
2. Include for each part of the assignment/lab a copy of your one-dimensional spectra (suitably annotated with, e.g., line identifications – these can be done by hand in pencil if necessary), and your observing log. Of course, answer the questions posed in this handout.

## EXPERIMENT

### 1. SPECTROGRAPH PARAMETERS

From a calibration lamp exposure (in the case of the LISA spectrograph, NeAr) determine:

- the dispersion of the spectrograph in  $\text{\AA}/\text{pixel}$  around a specific, middle of the spectrum wavelength;
- the dispersion of the spectrograph in  $\text{\AA}/\text{mm}$  around a specific, middle of the spectrum wavelength;
- the size of a resolution element in both pixels and wavelength, determined from the FWHM of a specific, isolated, sharp spectral line in the middle of the spectrum;
- the resolution of the spectrograph, using the FWHM of a specific, isolated, sharp spectral line in the middle of the spectrum.

## 2. SOLAR SPECTRUM (DAYTIME SKY or MOON AS SUBSTITUTE)

Take a well-exposed, but not saturated spectrum of the twilight or daytime sky. It is easiest to obtain the daytime spectrum just around sunset when the sky is still illuminated by the sun but is not too bright. Note that the integration times you need for the daytime spectrum exposure will depend on how far into twilight you are when you begin the exposure! Make sure to take a short test exposure to evaluate the required exposure time for a good signal-to-noise spectrum.

If it is not possible to get a good spectrum of the day or twilight sky, you might try substituting a spectrum of the moon (reflected sunlight); in this case be careful not to saturate the detector!

From the extracted and wavelength-calibrated 1-D spectrum:

- Identify the most prominent lines (wavelength, element and ionization level) in your spectrum. At minimum, you should identify each Fraunhofer line visible in the spectrum (a list of the Fraunhofer lines is given in Table 1). Please mark the Fraunhofer lines by (1) their standard wavelength, element and ionization level, (2) their standard Fraunhofer letter, and (3) where relevant, the modern, common Fraunhofer-derived moniker (e.g., “Na D lines”). This will require some independent research on your part. Mark with a “terrestrial line” symbol (“ $\oplus$ ”) any Fraunhofer (or other) prominent lines that appear in your spectrum that are actually created by the atmosphere of the earth. Make sure to remember the location of these terrestrial lines when you do your spectral classification of stars later in this lab (because these are lines to “exclude” from your thinking about the spectral classification of stars).
- Using the a spectral atlas or other guide to spectral classification, estimate the approximate “spectral type” of the day time sky and justify this by the appearance (or non-appearance!) of features in the spectrum. Also explain what is expected for this.

## 3. NIGHT TIME SPECTRUM

The adjoining figure below shows a typical spectrum of the night time sky, taken with a long exposure (over an hour) using a slit spectrograph at Lick Observatory, near San Jose, California:

Table 1: Prominent Fraunhofer absorption lines in the solar spectrum.

Line	Wavelength (Å)	Element / Origin
A	7594–7621	O <sub>2</sub> (terrestrial)
B	6867–6884	O <sub>2</sub> (terrestrial)
C	6563	H $\alpha$ (Hydrogen)
D <sub>1</sub> , D <sub>2</sub>	5896, 5890	Na I (Sodium doublet)
E	5270	Fe I (Iron)
F	4861	H $\beta$ (Hydrogen)
G	4308	CH (molecular band)
H	3968	Ca II (Calcium)
K	3934	Ca II (Calcium)

- Compare this figure of the night time sky with your spectrum of the day time sky. Describe the difference in character of the day and night time sky spectrum. Explain the reason for the difference in the spectrum of the sky during the day and at night. This may require some independent research on your part.
- Note the numerous lines of neutral oxygen ([OI]) and the hydroxy molecule (OH) in the night time spectrum shown above. Why are these lines common in the night time spectrum, but not the daytime? Postulate why there are also so many lines of the element mercury (labeled with “HG”) in the night time spectrum shown.

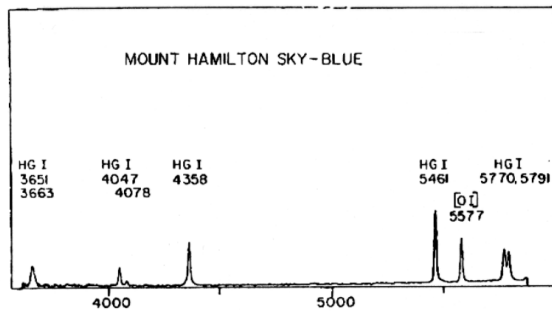


FIG. 1 — The blue region of the night-sky spectrum observed from Mount Hamilton on 1975 August 2/3. The exposure was 64 minutes centered about 23:37 PST at a mean zenith distance 19° and azimuth 130° ( $\alpha = 21^{\text{h}}22^{\text{m}}$ ,  $\delta = +25^\circ$ ;  $l = 75^\circ$ ,  $b = -18^\circ$ ). The relative flux per unit frequency interval is plotted against wavelength to the same scale as Figure 2.

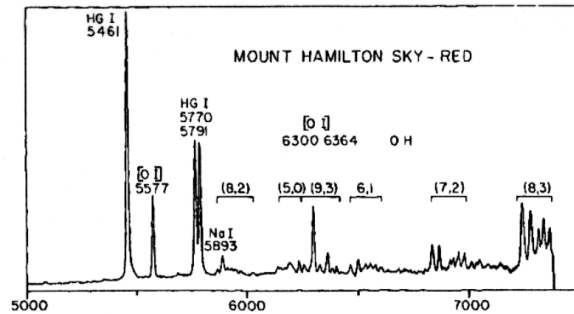


FIG. 2 — The red region of the night-sky spectrum observed from Mount Hamilton on 1975 August 2/3. The exposure was 48 minutes centered about 21:50 PST at a mean zenith distance 53° and azimuth 248° ( $\alpha = 15^{\text{h}}14^{\text{m}}$ ,  $\delta = +70^\circ$ ;  $l = 10^\circ$ ,  $b = +50^\circ$ ). The relative flux per unit frequency interval is plotted against wavelength to the same scale as Figure 1.

## 4. SPECTRAL CLASSIFICATION OF STARS

Use the same spectrograph settings as in the previous parts of the lab. Obtain a high S/N spectrum of one star from each of the following groups of stars. You only need one star per group. The class should coordinate the distribution of targets across observing teams to make sure all target groups are covered. Scale your integration times according to magnitudes

(remember that each magnitude corresponds to a factor of  $2.5\times$  in brightness!). Make sure you do not saturate anywhere along the spectra.

Please do not look up the spectral types of these stars. I want you to classify them objectively using the information taught in lecture without knowledge of the answers.

The stellar coordinates given are in equinox 2000.0.

**Group 1:**

- $\alpha$  Peg ( $\alpha = 23:04:45.6$ ,  $\delta = +15:12:19$ ,  $V = 2.49$ )
- $\delta$  Cas ( $\alpha = 01:25:48.9$ ,  $\delta = +60:14:07$ ,  $V = 2.68$ )
- $\nu$  Tau ( $\alpha = 04:03:09.4$ ,  $\delta = +05:59:21$ ,  $V = 3.91$ )

**Group 2:**

- $\gamma$  Cas ( $\alpha = 00:56:43$ ,  $\delta = +60:43:00$ ,  $V = 2.47$ )
- 48 Per ( $\alpha = 04:08:40$ ,  $\delta = +07:42:45$ ,  $V = 4.04$ )
- $\zeta$  Tau ( $\alpha = 05:37:38.7$ ,  $\delta = +21:08:33$ ,  $V = 3.03$ )

**Group 3:**

- $\beta$  Cas ( $\alpha = 00:09:10.7$ ,  $\delta = +59:08:59$ ,  $V = 2.27$ )
- $\eta$  Cas ( $\alpha = 00:49:06.3$ ,  $\delta = +57:48:55$ ,  $V = 3.44$ )
- $\xi$  Gem ( $\alpha = 06:45:17.4$ ,  $\delta = +12:53:44$ ,  $V = 3.36$ )

**Group 4:**

- $\beta$  Peg ( $\alpha = 23:03:46.5$ ,  $\delta = +28:04:58$ ,  $V = 2.42$ )
- $\beta$  And ( $\alpha = 01:09:43.9$ ,  $\delta = +35:37:14$ ,  $V = 2.06$ )
- $\alpha$  Cet ( $\alpha = 03:02:16.7$ ,  $\delta = +04:05:23$ ,  $V = 2.53$ )
- $\mu$  Gem ( $\alpha = 06:22:57.6$ ,  $\delta = +22:30:49$ ,  $V = 2.88$ )

**Group 5:**

- $\eta$  Psc ( $\alpha = 01:31:29.0$ ,  $\delta = +15:20:45$ ,  $V = 3.62$ )
- $\alpha$  Aur ( $\alpha = 05:16:41.4$ ,  $\delta = +45:59:53$ ,  $V = 0.08$ )

**Group 6:**

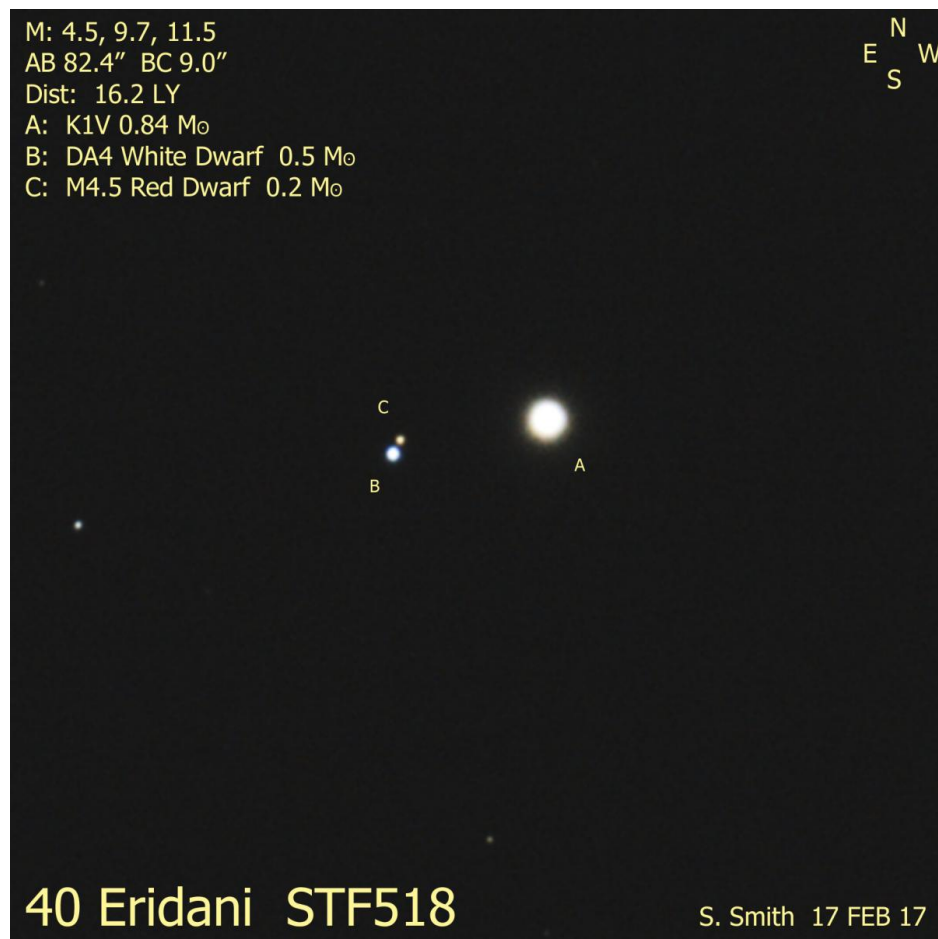
- $\nu$  And ( $\alpha = 00:49:48.8$ ,  $\delta = +41:04:44$ ,  $V = 4.53$ )
- $\xi$  Per ( $\alpha = 03:58:57.9$ ,  $\delta = +35:47:28$ ,  $V = 4.04$ )
- $\nu$  Gem ( $\alpha = 06:28:57.8$ ,  $\delta = +20:12:44$ ,  $V = 4.15$ )

**Group 7:** (Not necessary to do in 2023)

- HD4306 ( $\alpha = 00:45:27.2$ ,  $\delta = -09:32:40$ ,  $V = 9.08$ )

**Group 8:**

- $\delta$  And ( $\alpha = 00:39:19.7$ ,  $\delta = +30:51:40$ ,  $V = 3.27$ )
- $\alpha$  Cas ( $\alpha = 00:40:30.4$ ,  $\delta = +56:32:14$ ,  $V = 2.23$ )
- $\nu$  Psc ( $\alpha = 01:41:25.9$ ,  $\delta = +05:29:15$ ,  $V = 4.44$ )
- $\delta$  Aur ( $\alpha = 05:59:31.6$ ,  $\delta = +54:17:05$ ,  $V = 3.72$ )



**Group 9:** At the discretion of the teaching staff, other, unnamed sources will be set up for you to observe.

From the extracted, wavelength calibrated one-dimensional spectra identify the spectral types of the stars observed. Use any outside reference atlas or classification manual/prescription to do this (e.g., the Turnshek et al. atlas, Birney, Jaschek & Jaschek, or the Morgan, Abt & Tapscott atlas, instead of looking up the spectral types of the stars directly.

Explain the reasoning for your classification in each case. This classification should be based on the presence or absence of specific lines and not on the shape of the continuum, which can be influenced by the spectral response of the spectrograph and detector, as well as chromatic atmospheric refraction putting different wavelengths of the star in and out of the slit if the slit was not oriented along the parallactic angle. You should be able to identify the stars to at least the spectral type letter (e.g., OBAFGKM), and you should try to do better than that (to at least half a spectral type, e.g., the difference between a “G0” and “G5” star).

Identify on the spectra and in a short description any prominent lines that influenced your decisions and how. Note that due to differences in the optics transmission, quantum efficiency of the detector, and light through the slit at different wavelengths, you should not expect the mean continuum level trends of your spectra to necessarily match to those in any atlas (though, you might be able to discern trends in the slopes of the continua as a function of the temperature of stars internally within your own data set). You should be paying more attention to the number, types and relative strengths of absorption lines you see in your spectra. To accentuate the strengths of absorption lines and de-emphasize variations in the continuum strength (which may be real or artificially-induced) it is best to fit and subtract the continuum level across the spectra.

Note also anything obviously peculiar you may see in your spectra. Be warned that there are some “curveballs” I’ve deliberately thrown at you in the above list, and you should be able to find them (and hopefully explain them).

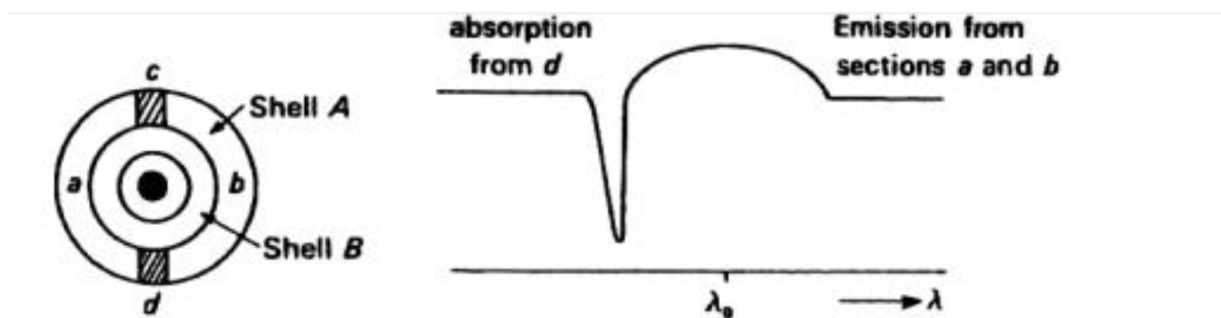
## 6. THE DOPPLER SHIFT AS SEEN IN A NOVA STAR

Novae are stars called eruptive variables. They are stars that suddenly increase greatly in brightness. It is believed that novae are evolved stars in binary systems that violently expel material hurled at them by their companion stars. The star brightens during the expulsion of the material from its surface. The nova phenomenon may be recurrent, but the timescale of the recurrence may vary greatly on a case by case basis (thus, a nova is considered recurrent if it has been seen to flare more than one time, but recurrences may be missed because they did not produce a significant enough brightness change or they may be spaced over centuries and not frequently enough to have been noticed by humans).

The escaping material is assumed to be ejected in the form of a shell. Although past novae outbursts provide much evidence that the ejected material is in the form of a nonuniform and irregular shell, for simplicity we often carry out calculations under the assumption of spherical symmetry because the degree of distortion from a sphere is not known in most cases, and the calculations are much easier to perform.

If the ejected shell is moving outward from the star at velocity  $v$ , a spectrograph on earth will reveal very broad features corresponding to a Doppler broadening of width  $\sim 2v$ . We see the shell as having a spread of velocities in the direction of the observer, because different regions of the shell have different components of  $v$  along our line of sight. All parts of the shell contribute to the emission of light with an emission line spectrum. However, that part of the shell moving along the observer’s line of sight lies directly in front of the nova star. Thus, the front edge of the gas shell along the line of sight to the observer absorbs photons from the light coming through it from behind it (from both shell gas and the stellar photosphere), and contributes an absorption line spectrum. However, since this same part of the gas shell

is also that part that has the largest negative velocity with respect to the mean velocity of the nova star, the absorption line spectrum is blueshifted with respect to the emission line spectrum. The geometry of the situation is demonstrated in the figure. The type of line profiles shown were first seen in the star P Cygni, and the shape of the line profile is therefore called a P Cygni profile. Such profiles are seen in supernovae (exploding stars) as well as eruptive nova variables (i.e., stars not exploding but expelling material that fell on them from a companion). P Cygni was first noticed from an eruption in the year 1600. Here we will observe the star P Cygni and observe the P Cygni profiles. P Cygni's coordinates (1999.5) are ( $\alpha = 20 : 17 : 46.1$ ,  $\delta = +38:01:53$ ) and it is at  $V = 4.81$ . You will compare to a star of similar spectral type, but which has no ejected shell, the  $V = 3.2$  magnitude star  $\beta$  Cephei, with coordinates ( $\alpha = 21 : 28 : 40.7$ ,  $\delta = +70 : 34 : 02$ ), or, alternatively, the  $V = 4.16$  star  $\kappa$  Cas, with coordinates ( $\alpha = 00:33:00.0$   $\delta = +62:55:54$ ). Make an airmass chart for P Cygni and  $\beta$  Cephei/ $\kappa$  Cas for the night you will observe it. Do this BEFORE observing so you know when is the optimal time to observe these stars.



**Fig. 17.8.** In the beginning of the supernova expansion the material in the outer shell (shell A) is rather dense. There is much material in section *d* in front of the star to absorb light from the deeper layers, causing a blueshifted absorption line. Sections *a* and *b* cannot contribute to the absorption line; they can only emit light, giving rise to an emission line. These sections move on average transverse to the line of sight; the emission line is therefore only broadened but not shifted. Redshifted emission lines are emitted from section *c* but are obscured by the star. The expected absorption–emission line profile is shown on the right side of the figure. These types of line profiles were first observed for the star P Cygni (which is not a supernova) and are therefore called P Cygni lines.

Take a spectrum of P Cygni and of either or both of  $\beta$  Cephei and  $\kappa$  Cas at the same exposure level. You should make sure that you can see the P Cygni profile phenomenon in some strong, clean lines of the spectrum. It is critical that your spectra, especially the emission lines in the P Cygni spectrum, do not saturate.

Extract and wavelength calibrate one-dimensional spectra from the images. Then:

- (a) Identify at least one strong example of a line exhibiting the characteristic P Cygni phenomenon and, for each P Cygni and the control star, plot high and similar resolution versions (across the same wavelength range) of this line to allow ready comparison. These plots should be included in your lab report.
- (b) Measure the equivalent width of the absorption and emission line parts of the P Cygni line plotted above (the `specutils` function has an equivalent width function: read the docs page).
- (c) Measure the half line width of the absorption and emission lines. Can you discern the expected difference in Doppler widths according to the above physical picture for P Cygni?
- (d) Using the difference in the emission line center and the absorption line center (which you can get by fitting the lines with `specutils`) for your P Cygni profiles, calculate the expansion velocity of the outer shell of P Cygni. Use at least two P Cygni lines and compare the results, explaining any differences.
- (e) Suppose P Cygni were 2000 pc away. How long, at the computed rate of expansion, would it take until the shell was resolvable to 0.2 arcseconds diameter with the Hubble Space Telescope?
- (f) Turn the previous question's logic around. Suppose there were a nova for which there existed historical records of when the last major eruption occurred. Describe a way you could obtain the distance to the nova by geometric means. Explain how this method of dynamical parallax could be used as an elementary step of the cosmic distance ladder (note: nova are visible in Local Group galaxies).