AAVSO Guide to Getting Started in Spectroscopy

Version 2.0 - December 2019

Table of contents

Introduction

This guide is intended for those who are interested in getting started with astronomical spectroscopy, and in particular for observers who already have some experience with imaging. Our hope is to familiarize our observers with what is required to acquire and work with spectroscopic data. Section 1 gives an overview of the design and principles of spectrographs, and briefly discusses the equipment required to produce a fully calibrated set of spectroscopic data; Section 2 describes the calibration data needed and how it is applied; Section 3 gives a thorough overview of processing spectroscopic data; and Section 4 briefly discusses potential data quality issues to be aware of. Excellent equipment-specific and software-specific resources are available elsewhere. For a comprehensive discussion of principles discussed in this guide, we strongly recommend Successfully Starting in Astronomical Spectroscopy by François Cochard.

It is important to note that submitting spectra to the AAVSO spectroscopic database, SpecDB, does not require all of the processing and calibration steps discussed here. After users have submitted an initial reference star spectrum for approval, subsequent spectra may be submitted to the database with minimal processing. The submission requirements (to be discussed in context below, see Section 3) are simply that the spectrum be dark-corrected, extracted into a one-dimensional spectrum, and wavelength calibrated. While many science applications require more thoroughly processed spectra, minimally processed spectra have scientific value; the AAVSO encourages observers to get started with spectroscopy. However, with tools such as the spectroscopic processing and analysis software ISIS (to be discussed below), fully processed spectra can be produced quickly and relatively easily. For more information on submitting to the database and a thorough discussion of the technical requirements, please refer to: https://www.aavso.org/apps/specdb/help

Acknowledgements

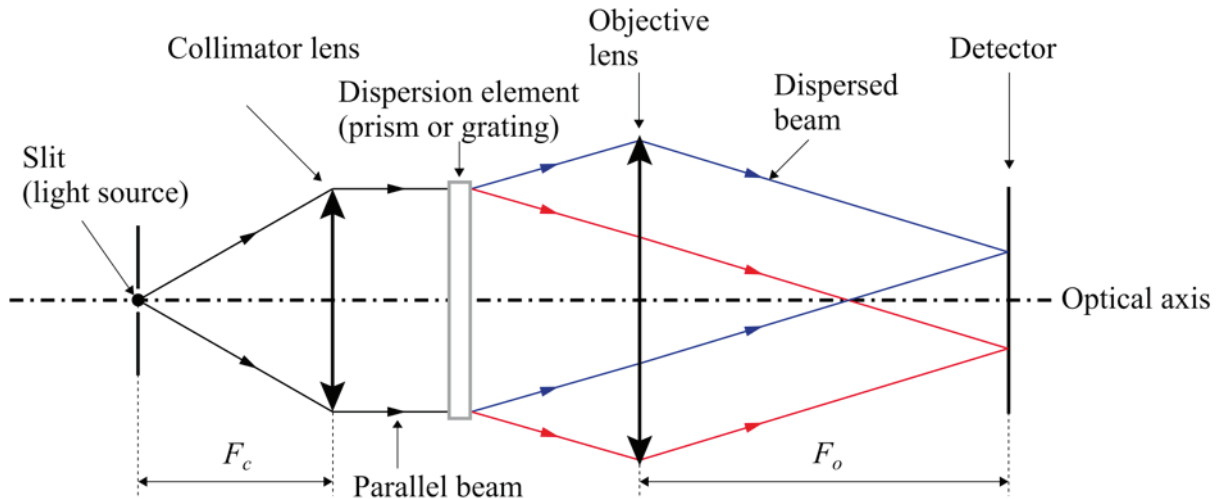# Section 1 - Equipment

1.1 Principles of Spectrographs

Figure 1.1 – Diagram of a Spectrograph (courtesy of Francois Cochard).

Components of a Spectrograph

A. The **slit** acts as the light source, restricts the angular size of the object/source (both to isolate the source and to achieve higher spectral resolution), and causes the initial dispersion through diffraction. In a fiber-fed spectrograph, the fiber acts as a slit.

B. The **collimator lens** transforms the divergent light from the slit into a collimated (parallel) beam; poor collimation will result in vignetting (loss of light from edges of the beam) which will reduce signal or even reduce wavelength coverage.

C. Dispersion Element

       a. A **prism** disperses light due to the wavelength dependence of the index of refraction; blue light is dispersed more than red. Prisms have higher throughput   than gratings but with much lower dispersion.

       b. A **diffraction grating** is a glass plate with a large number of finely-ruled grooves (typically 100s of lines per mm), each of which acts as a diffraction source; interference between light from each groove increases resolution by making each wavelength "sharper". In contrast to prisms, gratings disperse red light more than blue. Gratings also have multiple diffraction orders that can be used. Note   that while in the basic design described here a transmission grating is assumed, there are also reflection gratings.

D. The **objective lens** focuses light from the dispersion element onto the detector. Poor focus will result in decreased spectral resolution (discussed immediately below), in much the same that a poor focus with an imager results in reduced spatial resolution.

Dispersion versus Resolution

As alluded to above, there is a distinction between dispersion and resolution. Dispersion describes the extent to which the light is spread out, i.e. how much wavelengths are separated, and is usually stated in angstroms/pixel. But resolution describes the smallest spectral feature that can be clearly distinguished. The resolution is equal to the full width at half maximum (FWHM) of a "thin" spectral line (examples of thin lines are given below). Lines closer together than that are blended and not fully distinguishable. Resolution is often given in terms of the ratio of the wavelength to the resolved difference in wavelength:

$$R = \frac{\lambda}{\Delta\lambda}$$

Roughly speaking, R < 5000 is considered "low" resolution, R = 5000 to 10000 is considered "medium," and R > 10000 is considered "high."

As noted above, resolution is set in part by the size of the slit, and in part by the dispersing element. Slit spectrographs sometimes have slits of multiple sizes that can be selected; alternatively, some might have a Vernier which allows adjustment of the slit size. But resolution is also influenced by the natural random processes affecting light as it passes through the telescope and spectrograph optics. These processes give spectral lines their Gaussian profile.

The resolution is typically determined from the FWHM of emission lines in wavelength calibration spectra (Ne or Ar lamp), which are very "thin." It can also be determined using the absorption lines of a slowly rotating star, such as the Sun. Which is to say that any line profile (shape) features thinner than this will not be resolved; spectral lines in stellar atmospheres are affected by other processes, but for "weak" lines in slowly rotating stars, the observed line width and shape is set by the instrument, not the star.

It is also important to note that seeing conditions have no impact on spectral resolution. If seeing is poor, then less of the stars light passes through the slit, and so the spectrum will simply have less signal (for a given exposure time).

1.2. Other Equipment Considerations

In addition to a spectrograph, you will of course need a telescope OTA, mount, CCD, computer, control and imaging software, etc. Spectrographs do not usually require additional control software. There are no special requirements for the CCD imager, so long as the pixel size is well-matched to the resolution, and the format is large enough for the wavelength range of the spectra; it is also helpful if the sensitivity is roughly uniform over optical wavelengths. In addition, the pixel size should be well-matched to the resolution, ideally 2 to 4 pixels per "resolution element," which in the case of spectra is the FWHM of a thin spectral line (e.g., in a wavelength calibration spectrum). For comparison, in the case of photometry, a resolution element is the FWHM of the star's seeing disk (but as noted above, seeing does not influence spectral resolution). To determine the number of pixels per resolution element in your spectra, simply divide the FWHM of a thin spectral line by the dispersion.

Guiding

This is perhaps the most challenging aspect of acquiring a spectrum, as the star must remain on the slit. This could in principle be accomplished with a standard off-axis guide camera, but instead you should guide on an image of the slit itself, and in fact need a camera in this position to center the star on the slit initially. Some spectrographs, such as the popular Shelyak Lhires III, have a reflective slit, allowing the slit to be directly imaged, and furthermore allowing guiding on the target star itself.

Flat fielding

The principles of flat fielding for spectroscopy are discussed in section 2. Spectrographs often have an internal flat field lamp (typically tungsten) which can be used for this purpose. The source only needs to be spatially uniform over the slit of the spectrograph; spatially uniformity is not relevant for fiber-fed spectrographs, unless a second fiber is used to image the background sky spectrum, in which case it must be uniform over both.

Comparison Spectra

The principles of wavelength calibration of spectra are discussed in Section 2. Spectrographs often have an internal comparison spectrum lamp (typically Neon and/or Argon). The emission lines are identified and their wavelengths entered, and then a polynomial fit is applied to find the wavelength solution (this assigns wavelength units to individual pixels of the CCD). Neon and Argon are usually used since those gases have a rich emission line spectrum in the optical. In general, you should use a lamp with as many spectral lines as possible to get a good wavelength solution.

Section 2 - Calibration Data and Procedures

2.1.1 Preamble

While we do not intend to provide a tutorial on how to process data with any particular software, we will use the very popular ISIS software (written by Christian Buil) provide examples and context. The ISIS website provides thorough manuals for processing data for each of Shelyak's spectrograph models, and are a recommended resource. http://www.astrosurf.com/buil/isis/isis_en.htm

2.1.2 Introductory Notes

Spectroscopy requires the same basic calibration data as for photometry, but with a few important additions (for example, wavelength calibration spectra). Also, some of the calibration steps, while similar in purpose to the analogous ones for photometry, must be handled different (for example, flat fielding). We describe the calibration procedures here, and they are presented in order, but note that there are additional steps, and we will put all of this in the sequential context of the overall processing procedure in Section 3.

We reiterate that what follows are the data necessary to produce a fully processed spectrum, but this does not constitute the SpecDB submission requirements. The only calibration data absolutely required are darks and a wavelength comparison spectrum.

2.2 Calibration Data Dependent Only on the CCD

Calibrations dependent only on the CCD include biases and darks. Only a single set is absolutely necessary (for each CCD binning configuration) per session, even for multiple spectrograph configurations.

<u>Biases (aka Zeros)</u>

Biases are a snapshot of the CCD background level (zero exposure time), to be subtracted from all images. Best practice is to acquire a substantial number (at least 10, if not 20) and then take the median of them (pixel by pixel) to produce a master bias. If observations span many hours, consider taking a set at both the beginning and end of the night.

ISIS can be used to both produce a master bias image and apply the correction (see their manual for details); alternatively, you could first produce the master bias image using another image utility, and then simply supply that file to ISIS.

Darks

Darks are integrated exposures with the shutter closed. Due to thermal noise, extra electrons accumulate in each pixel and introduce additional electronic noise to the data; this is called dark current. It is temperature dependent, and can be minimized by cooling the CCD. Most CCDs have built in thermoelectric cooling that can cool the chip by 20 to 30 °C below ambient; it is recommended that the CCD be cooled to at least 0 °C, if feasible without requiring a large percentage of the CCD's power to maintain it. In addition, there may be "hot pixels" that accumulate charge at a higher rate. It is important to note that these might or might not scale linearly with exposure, and so are best removed by creating a hot pixel map, which can be done with ISIS.

There are two approaches to correcting this. (1) If you have a limited set of exposure times, you can simply take a substantial number of darks at each exposure time (at least 10), make a "master" dark for each (by median combining them), and then subtract the master dark from the corresponding images. This also eliminates the need for a separate bias correction. (2) If you have many different exposure lengths, then assuming that the dark current is scalable (linear) with exposure length, then take several long (30 minutes or more) dark exposures, bias subtract them, scale to the appropriate length, and subtract from the bias corrected images.

As with master bias subtraction, ISIS can be used to both create the master dark (if you did not do this with another image utility) and apply the correction; ISIS can also scale darks. Note that ISIS can also create a hot pixel map.

2.3 Calibration Data Dependent on Spectrograph Configuration

A calibration set for each of these types will be necessary for each combination of grating/ wavelength region/dispersion used.

Flats

Flats are well-exposed spectra of a continuous (thermal) source. As with biases, the best practice is to acquire a substantial number (at least 10), and average them to produce a master.

As is the case for photometry, flats are used to correct for pixel-to-pixel variations in effective detector sensitivity. This is done by fitting a polynomial curve to the flat field spectrum in the dispersion direction, in each row, and then dividing the flat by the fit to produce a "normalized" flat. All other spectra can then be divided by this normalized flat. In this way, only the pixel-to-pixel variation is removed, rather than other components of the instrumental response. After this row-by-row correction is applied, the spectrum can then be summed up in the direction perpendicular to the dispersion (i.e., by wavelength; roughly the column direction, if the CCD is well aligned).

Flats should not be used to correct for the total instrument response (which depends on the CCD sensitivity as a function of wavelength, the grating, etc.), because that assumes a uniform flux across all wavelengths. The instrument response correction will be described below.

Once again, ISIS can both produce a master flat and apply the flat field correction; you do not need to produce a normalized flat, ISIS takes care of this for you.
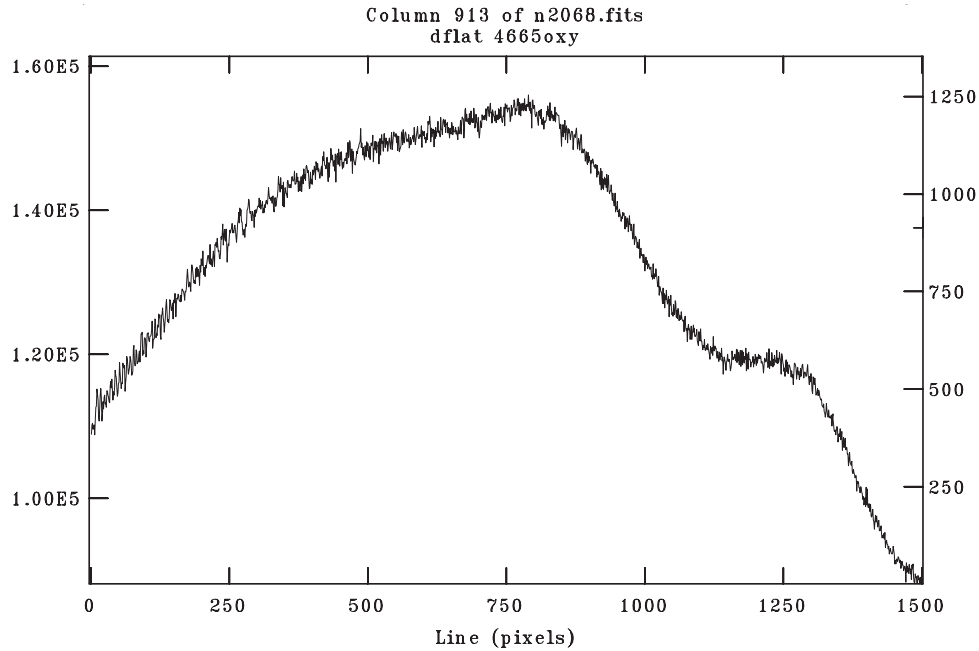
Plot along the dispersion direction, in a single row, for a raw flat-field spectrum, showing the pixel-to-pixel variation, as well as the overall and the instrumental response. The spectral range is roughly 400 angstroms. To apply the flat field correction, a polynomial is first fit to this.
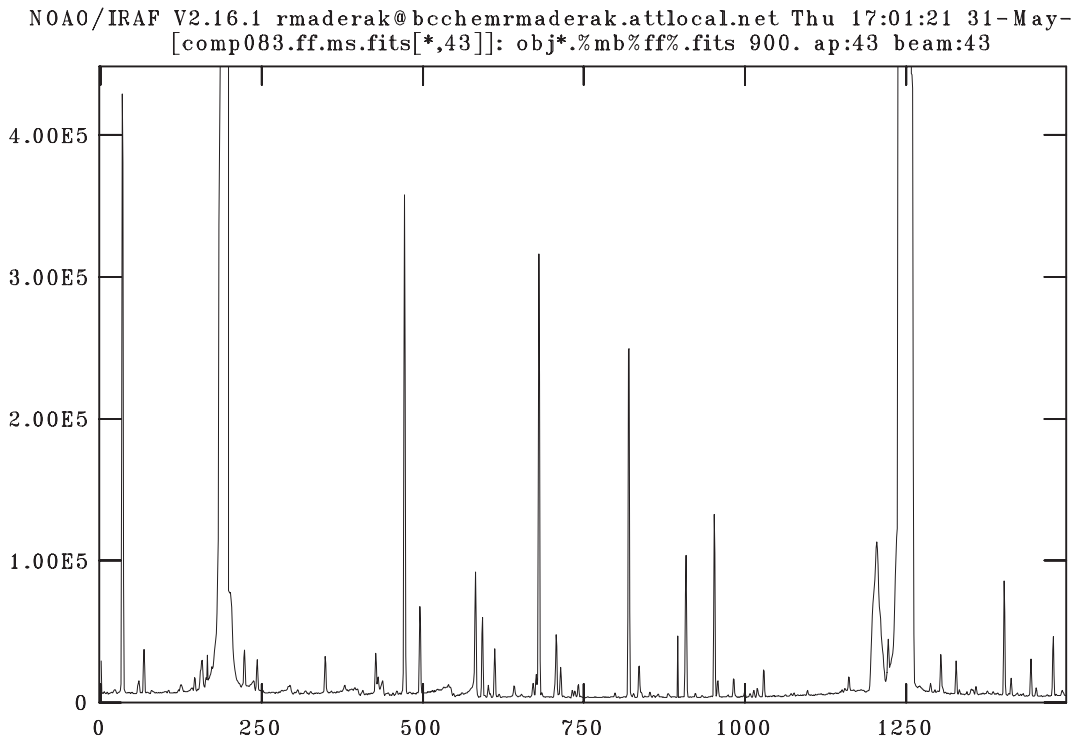
Wavelength Calibration Spectra:
A spectrum of a source with known emission line wavelengths is used to find the wavelength scale (dispersion solution) for your spectra. Only one well exposed comparison spectrum is needed, but be careful not to over expose and saturate strong lines, or else the line centers cannot be accurately determined.

The solar spectrum could be used if necessary. Simply take a spectrum of the daytime sky, which gives you the solar spectrum via scattered sunlight. Refer to a solar spectrum atlas for wavelengths of lines in the solar spectrum. Be careful to avoid using atmospheric absorption lines (aka telluric lines).

To apply the wavelength calibration in ISIS, you first supply an estimate of the dispersion and specify the order of the polynomial fit. The lowest order that fits the data well is best; even in the case where you have a large number (20 or more) of reliably identified comparison lines, a polynomial order greater than 5 – 6 is probably not appropriate. In the case where you have only a few lines, the order of the fit should be at least one degree less than the number of points (for

10

example, for 3 lines, at most order 2 should be used). For identifying lines, it may be helpful to find a comparison line atlas (see for example http://iraf.noao.edu/specatlas/). But keep in mind that relative strengths of the emission lines depends in part on the specific lamp used, so pay attention to both the strength and the spacing of the lines. Note that ISIS also has some predefined calibration routines for specific Shelyak models and for specific wavelength ranges that greatly simplify the calibration process.

NOAO/IRAF V2.16.1 rmaderak@bcchemrmaderak.attlocal.net Thu 17:01:21 31-May-
[comp083.ff.ms.fits[*,43]]: obj*.%mb%ff%.fits 900. ap:43 beam:43

Plot along the dispersion direction for a comparison spectrum (Thorium-Argon lamp, near infrared), showing emission lines.
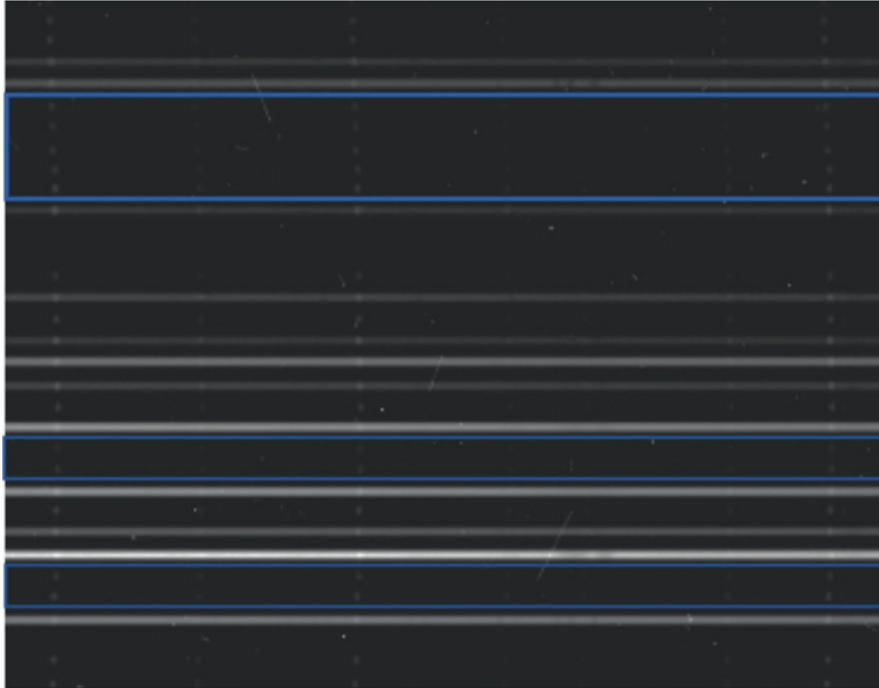
Sky Background Spectra

Spectra of the sky background should be acquired near each of your object spectra. The atmosphere produces various emission lines, and the sky might also contribute a scattered white light background, both of which should be subtracted out. For slit spectrographs, the portions of the slit not on a star, image the background sky; this is ideal as the sky background from the slit can be subtracted without additional correction.

For slit spectra, ISIS performs sky subtraction by sampling then subtracting the sky background from user-defined intervals outside of the object spectrum. In the case of fiber fed spectrographs, you must either take a second spectrum of the same exposure length away from the star, or use a second fiber to acquire a simultaneous sky (but note, if another fiber is used, you will need to

apply a throughput correction to account for the different response of the two fibers). You would then simply treat the fiber(s) with the background sky exposure as if it were an additional object spectrum, then subtract it.

Note: for short exposures of bright objects, sky subtraction might not be absolutely necessary. The contribution is significant for long exposures. Sky subtraction is important for long exposures and/or faint objects, because the sky signal will be a substantial fraction of the object signal. Also, the sky background is dependent on the observing conditions.

Raw multi-object fiber-fed image of an open star cluster, showing both object spectra and sky background spectra. Selected sky spectra are indicated by boxes. Note the bright sky emission line "dots" on both the sky background spectra and the brighter object spectra.
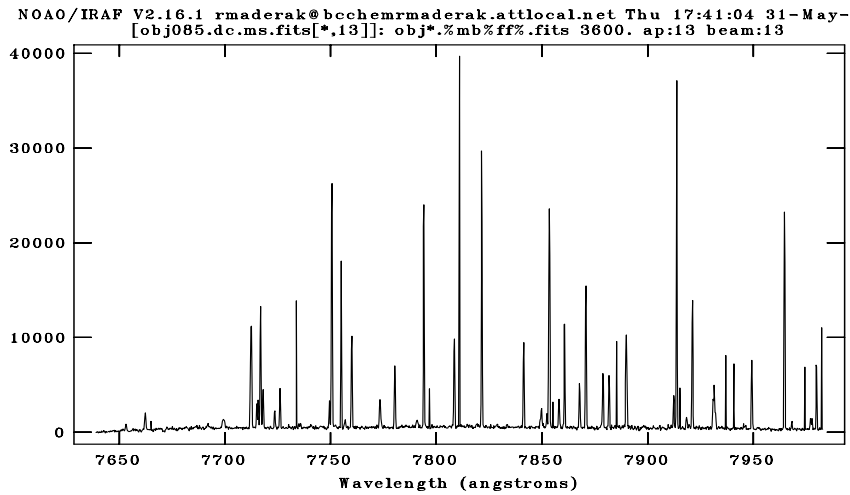
Sample sky background spectrum, showing sky emission lines.

Flux Calibration Standards

Your telescope optics, detector, and spectrograph are each not uniformly sensitive to all wavelengths. This wavelength dependent variation in sensitivity is called spectral response or instrumental response, and must be corrected for if your spectra are to be compared with others in a consistent, instrument independent way. For some stars, high quality reference spectra exist that have been carefully corrected for instrumental response and atmospheric extinction. These standards are usually very hot (early spectral types) because such stars have very few absorption lines. Dividing your spectrum by the reference spectrum (for the same star) will allow determination of your instrumental response, which can then be applied to other spectra. ISIS can both calculate the instrumental response, using a built-in library of reference spectra, and apply it automatically.

An important complication is that while the spectral response of your instrument system should be very stable, the spectral response of the atmosphere is not, and varies with airmass, humidity, etc. Observations of reference spectra should be taken with similar airmass to your target stars, and in principle should be taken every night, if not multiple times per night. In practice, except for more precise science applications, a reference spectrum taken at similar airmass is probably sufficient over multiple nights.

If you want to apply an absolute flux calibration in order to produce a spectrum completely free of atmospheric extinction (and therefore allow you to produce a spectrum in physical intensity units such as ergs/cm2) then you will need acquire a spectra of flux calibration standards at the same airmasses (or in the same airmass range) as your targets, on the same night, under photometric conditions. This method is called spectrophotometry and is necessary for precise astrophysical applications, where the physical conditions of a target are to be determined (for example, temperature). Absolute flux calibration is not commonly performed even for professionally acquired spectra. Most spectra will use a relative intensity for the y-axis values. The AAVSO does not require absolute flux calibration for submission to the SpecDB. An instrumental response in your processing steps is preferred but not required.

## 2.4 Additional Reference Data for Specific Science Objectives

Radial Velocity Standards

Spectra of stars with well-known radial velocities can be used to check your radial velocity scale, and if necessary, correct it. It is recommended that you acquire spectra of radial velocity standards if you intend to produce radial velocities on an absolute scale.

Solar Sky Spectrum

Because the atmosphere scatters sunlight, the solar spectrum can be acquired simply by taking a spectrum of a clear area of the daytime or twilight sky (all telluric absorption lines will of

course be present). A solar spectrum can also be acquired by taking the spectrum of the Moon (reflected sunlight). If you intended to perform a spectroscopic chemical abundance analysis, then a solar spectrum is recommended, because solar abundances are often used as zero points for the abundance scale.

Sun - 4/6/2018 6:04 PM - C14 LhiresIII_2400 Atik_460EX_bin2x2 - 5 x 10 s
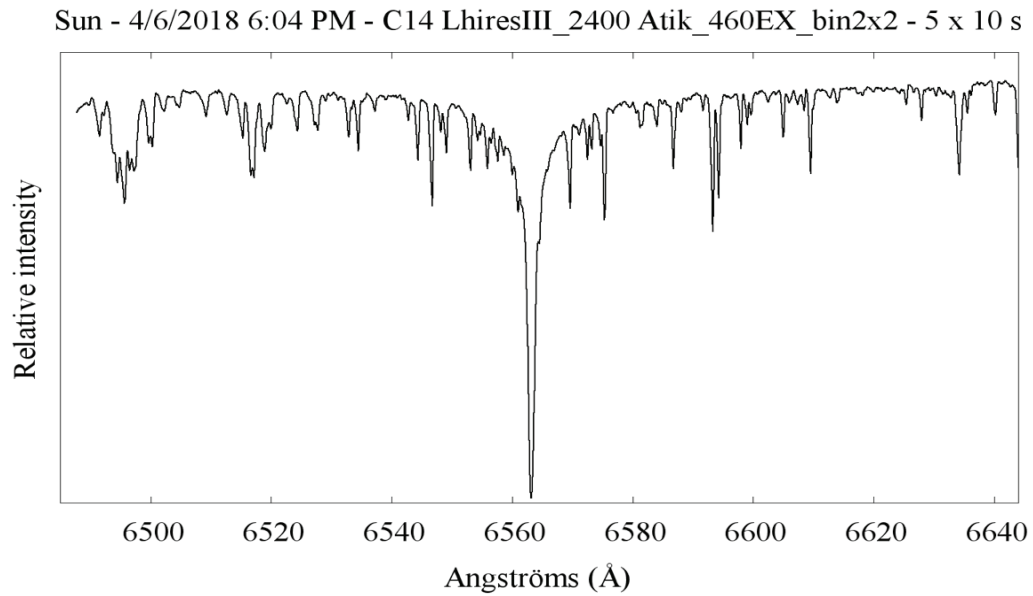
Sample daytime solar sky spectrum, in the Hα region.

Section 3 - Data Processing

We will now give a sequential list of calibration and processing steps. Those steps already described in Section 2 will simply be listed; steps being introduced here will be described.

Note that it is not advisable to co-add (stack) raw images, even if they were taken one after the other. Produce processed, wavelength calibrated spectra first, then co-add. However, a co-add of the raw spectra can be a useful "first look" to gauge data quality.

SpecDB Submission Requirements: As noted a few times above, the only strict requirements for submission to the AAVSO SpecDB are that the spectrum has been dark subtracted (assuming that this has also removed the bias), and that it has been wavelength calibrated. But, steps such as flat fielding are of course strongly recommended. For an end user's purpose, an instrument response corrected spectrum is arguably best, as it will minimize concerns about remaining instrumental effects in the data, and allow the user to make additional corrections as they see fit.

A. Bias subtraction
B. Dark subtraction
Note, as alluded to above, that a separate bias subtraction is not necessary if you are not using scaled darks (which have had the bias subtracted).
C. Flat fielding

D. Aperture Tracing and Extraction
As was discussed above in the context of flat fielding, a raw spectrum spans at least several pixels in the direction perpendicular to the dispersion. This is called the aperture. These pixels must be defined and then summed into a single one-dimensional spectrum. Defining the pixels to sum over is called aperture tracing, and summation itself is called extraction.

ISIS traces the aperture by having the user select the row closest to the center of the aperture, and then measuring the slant angle between the actual aperture and that row. This can be thought of as a linear trace. The aperture is then extracted more-or-less automatically.
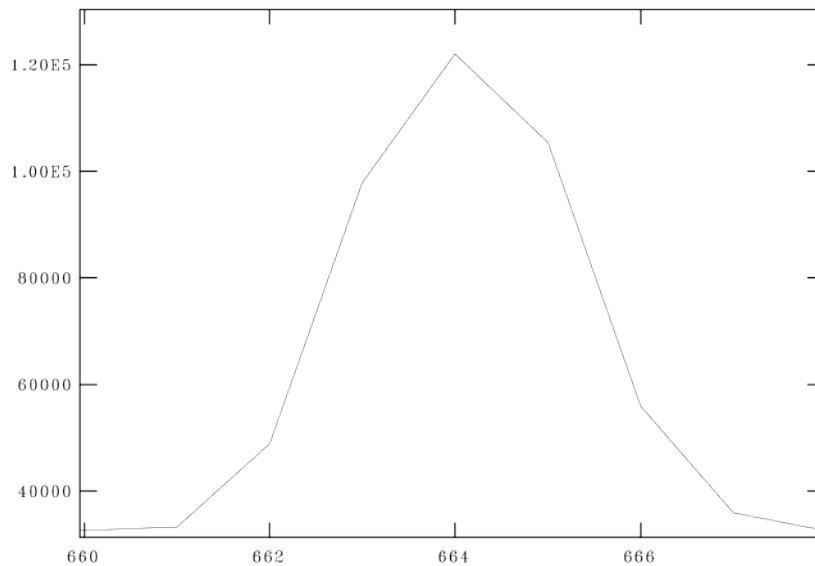
Plot perpendicular to the dispersion direction, showing the spectral aperture that must be summed over.

ISIS traces the aperture by having the user select the row or column closest to the center of the aperture, and then measuring the slant angle between the actual aperture and that row/column. This can be thought of as a linear trace. The aperture is then extracted more-or-less automatically.

In IRAF, aperture tracing is done by the routine appall, which uses polynomial traces (as always, the lowest order that gives a reasonable fit should be used). The routine apsum is then used to extract the spectrum.

E. Cosmic Ray Subtraction

Cosmic rays are familiar to anyone who has taken CCD data. They appear as bright dots or streaks in the image. ISIS can remove them as part of the aperture extraction process. There are a number of different routines in IRAF (including external user-written ones) that can be used. Cosmic ray removal typically involves replacing the affected pixels with the average value from surrounding pixels. An important caveat is that this can leave the profiles of affected spectral lines distorted, which may be an important issue depending on the science that will be done with the spectrum. It might therefore be useful to retain a version of the processed spectrum with the cosmic rays left in, to refer to if you encounter any anomalies during data reduction and analysis.

16
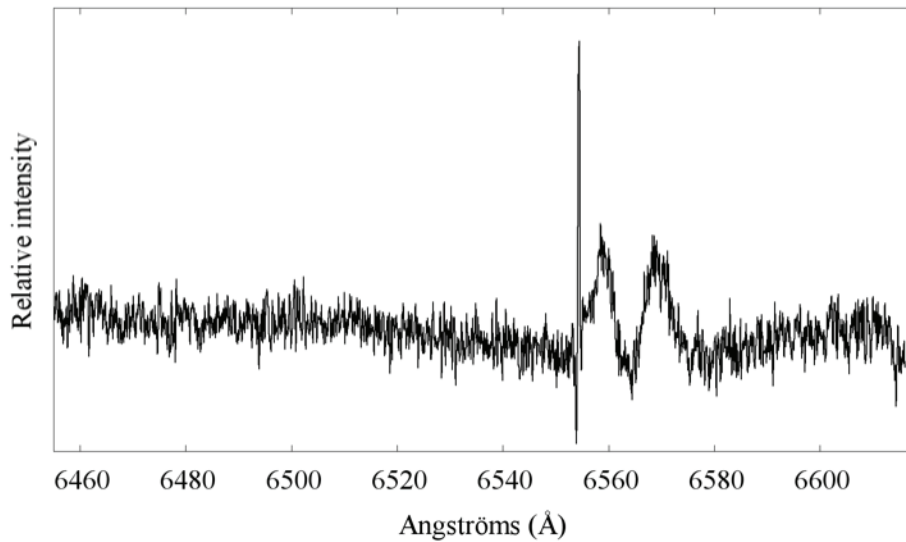
Spectrum showing a cosmic ray spike.

F. Wavelength solution (using comparison spectra)
G. Sky subtraction

H. Instrument Response; Continuum Normalization (Fitting or Scaling)
Instrumental response and absolute flux calibration were discussed in Section 2. The continuum is the "baseline" level of the spectrum, visible where there are no spectral lines. All of the methods discussed here involve "normalization" or "scaling" of the continuum, in order to produce a spectrum that can be compared to others. Unfortunately, the terms "normalized" and "scaled" are a source of much confusion to some, because they refer to similar but quite distinct concepts, and furthermore are not used in a perfectly consistent way by all spectroscopists. Particular confusion arises from the fact that professionals and amateurs use the terms somewhat differently. Normalization often means "scaling" to amateurs, but often means "continuum fitting" to professionals.

Continuum fitting, sometimes called rectification (and what "normalization" typically means to professionals), involves fitting a polynomial to the continuum across the entire spectrum and then dividing by the fit to normalize the continuum level to 1 everywhere. One of the primary purposes of continuum fitting is if you want to measure the equivalent width of a spectral line, which is a measure of the total emission or absorption. It is also useful for automated comparisons of spectra. Note that a spectrum that is to be continuum fit does not necessarily require instrumental response correction first, because the instrumental response will be lost (which is convenient in one sense, but also means that information has been lost).
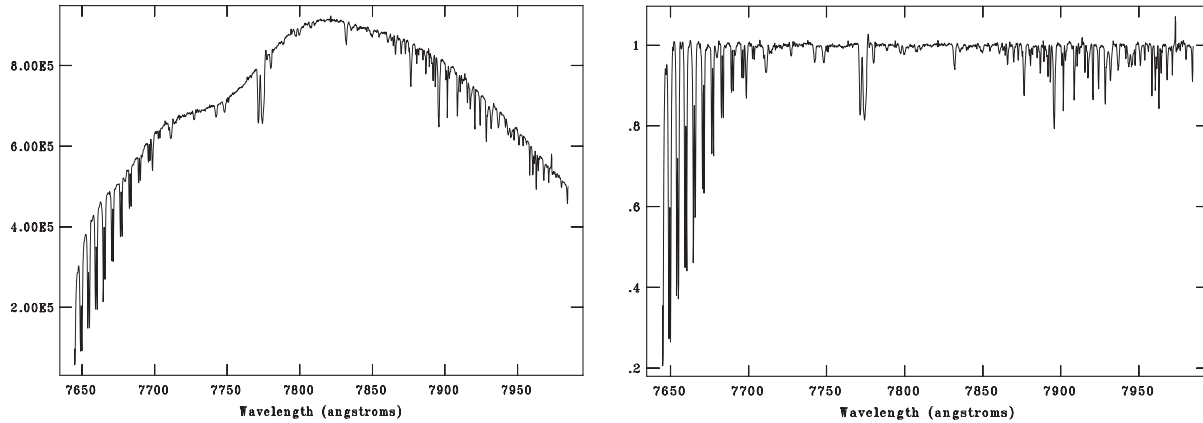
Comparison of a wavelength-calibrated spectrum before and after continuum fitting.

Relative flux normalization, also called "scaling," consists of dividing the entire spectrum by the average continuum value measured in a selected line-free wavelength range. The purpose is simply to reduce the potentially very large ADU values to smaller, more convenient units. In this case, the spectrum will be normalized to 1 (on average) only over the selected wavelength range (with values near 1 over the rest of the continuum).

For convenience, we summarize the various "normalization" terms and their meanings below:
> 1. Dividing the spectrum everywhere by a constant value = scaling = relative flux normalization = continuum normalization as meant by most amateurs
> 2. Fitting a polynominal to the continuum and dividing by it to produce a continuum value of 1 everywhere = continuum fitting = continuum normalization as meant by most professionals

No normalization is necessary for spectra submitted to SpecDB, but observers may choose to scale their spectra. Continuum fitting is not recommend, and end users should be allowed to do this themselves if they desire.

I. Heliocentric Doppler Correction

The observed radial velocities of objects depend on the Earth's orbital and rotational motions. Therefore observed radial velocities vary not only over the course of the year but also over the course of the night, and depend both on the coordinates of the object and the longitude and latitude of the observatory site. If we want to produce a radial velocity curve for an object, then we must correct for this, and place the radial velocity in the Sun's reference frame. But note that the calculation of this correction is non-trivial.

18

ISIS can automatically calculate the correction if the option is enabled, but a separate routine must be used if you wish to shift the spectrum. However, as matter of principle, if you are not the end user of your data, it is better not to apply this shift to the spectrum, and instead allow the end user to do so. We recommend that AAVSO users do not apply this shift to spectra to be submitted to SpecDB.

A convenient web utility for calculating the heliocentric correction can be found at: http://astroutils.astronomy.ohio-state.edu/exofast/barycorr.html

It is important to note that if you intend to co-add spectrum from very different observation times, then you must apply the helio-centric correction first. Also, it is recommended that should be done before any continuum fitting, normalization, or scaling has been applied.

Section 4 - Common Data Quality Problems

4.1 Raw Data Issues

The following issues occur during data acquisition, and can in principle be identified in real-time.

Saturation (and Non-Linearity)
As with photometry, saturation means irrecoverable loss in data accuracy. Indicators that your spectrum is compromised due to saturation or non-linearity include (but are not limited to):
A. Emission lines with flat tops (they should be roughly Gaussian).
B. Flattening of the spectral response (in a plot along the dispersion direction); this can usually be checked by comparison to rows away from the center of the aperture.
C. Flattening of the aperture profile in the direction perpendicular to the dispersion (this should be roughly Gaussian).
D. A perfectly uniform continuum; even a very high signal-to-noise spectrum should show some random variation (though you may have to zoom in to see it).
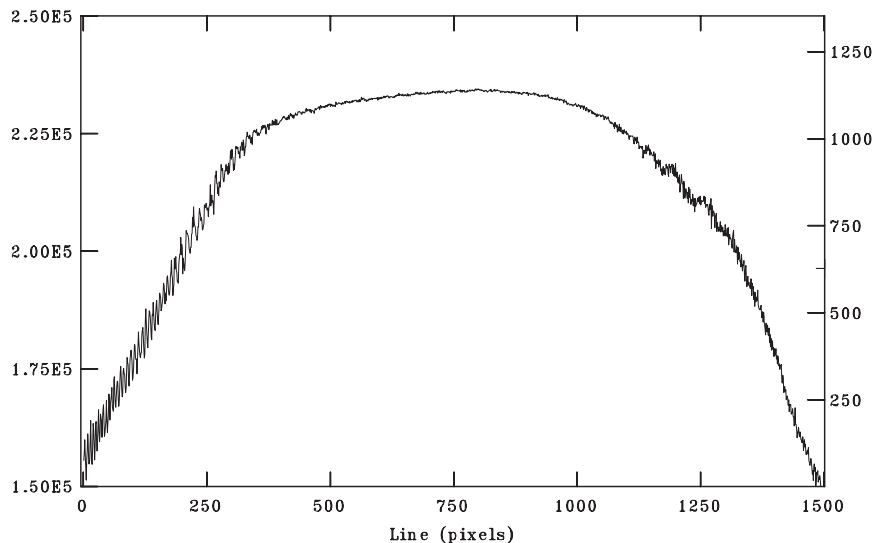

Plot in the dispersion direction for a raw flat field spectrum showing flattening of the spectral response due to saturation.

Under-Sampling

If your spectrum contains no substantial stellar spectral features, then you have probably (a) under-exposed; or (b) not centered, drifted off of, or missed your target.

A. Under-exposure: at the bare minimum, your target is underexposed if the weakest spectral

lines are not statistically distinguishable from the noise. There are rigorous criteria for this (for example, if the equivalent width of the line is less than about 3 times that of a typical noise feature), but practical indicators are that there are no spectral features that are clearly stronger than the largest noise features and/or that there are no spectral features that include the expected number of pixels for a "resolution element" (at least 2 – 4 pixels, as noted in Section 1).
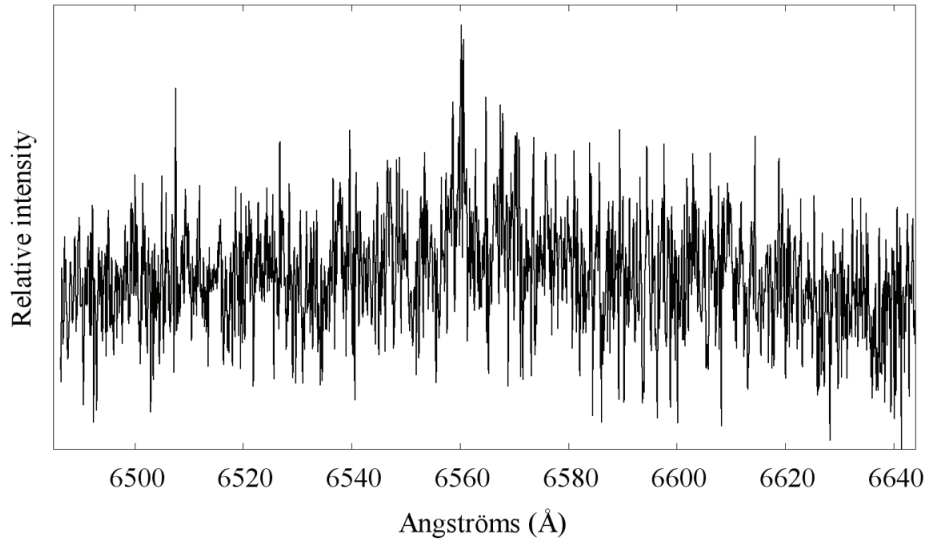
An underexposed spectrum, i.e. low signal-to-noise ratio.

B. Off-center or Missed Target: This will result in sky emission lines being disproportionately strong compared to the stellar continuum. If telluric absorption lines (due to our atmosphere) are visible in the spectrum, this is an indication that some star/object light has been received (some telluric lines, such as the A and B bands due to O2, are strong enough to be seen even a low continuum exposure).
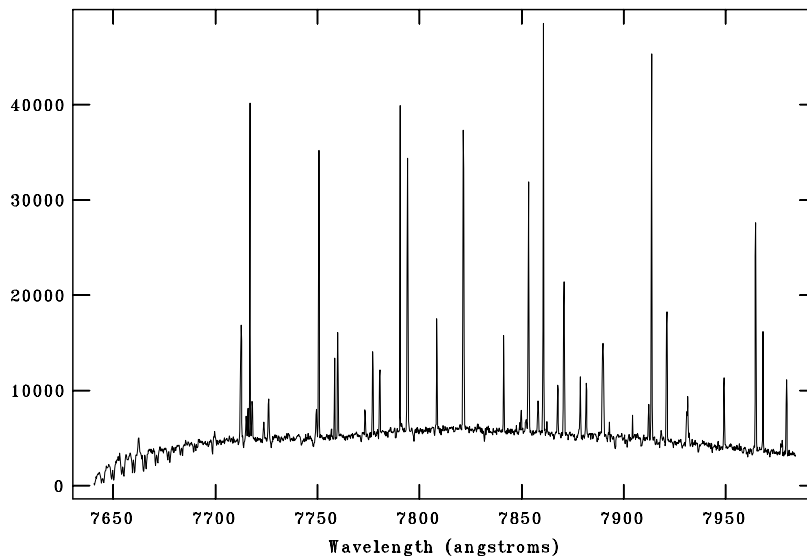

Spectrum in which the stellar continuum disproportionately dominated by sky background, indicating poor centering or a missed target

Wrong Object

If you have not observed a target before, it may not be readily obvious that you have selected the wrong star. A helpful indicator when centering the star is whether it is as bright as stars of similar magnitude; this same indicator of course applies after you have acquired the spectrum, if the continuum counts are much lower than expected (but see the above discussion of under-exposure) for a star of that magnitude. A more precise, but more difficult indicator is whether the star is of the correct spectral type. This can be gauged by comparing the spectrum to an appropriate template; broadly speaking, the absorption line strength of most elements increase with decreasing temperature, i.e. later spectral types.

For stars showing emission lines, such as spectral types Be or WR, the emission lines themselves provide an excellent indicator that you have the correct object. We also call attention to resources such as the BeSS database (for Be stars specifically), where users can easily compare their spectra to others for the same star.
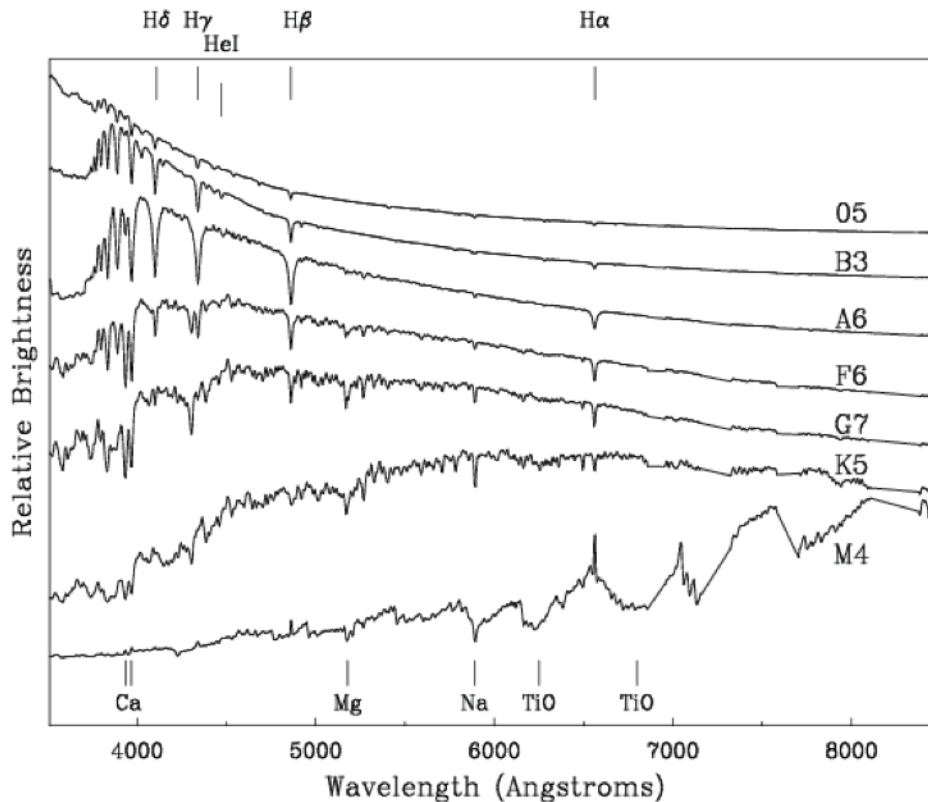

Sample stellar spectra. Note how the number and strength of absorption lines increase from O stars (hottest) to M stars (coolest).

4.2 Data Processing Issues

Poor Continuum Fitting

This occurs when the continuum has not been fit appropriately, and results in substantial variations in the normalized continuum level, which should 1 everywhere if normalized in the professional understanding of the term. A properly fit continuum should be flat. Another possible manifestation of poor continuum fitting is that if the wings of very strong lines have been over-fit, then part of the line profile will be normalized out, which can be more difficult to recognize.

If however the continuum has only been scaled (normalized in the amateur understanding of the term), then the continuum will still show some variation.
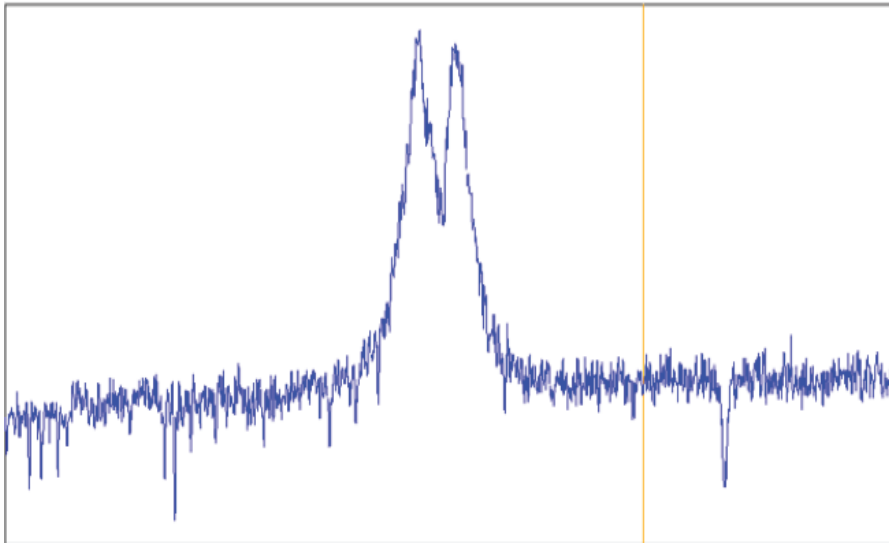
Spectrum showing imperfect continuum fitting. Note that while the continuum on the right (redward) side is relatively flat, the left (blueward) side shows a gradual change and is not at the same relatively intensity as the redward side.

Poor Wavelength Solution

This can occur if there are too few comparison lines used, or if an inappropriate fit order is used. The result is a wavelength scale that is skewed or not very uniform over some parts of the spectrum (note that this is likely to affect only parts of the spectrum, portions without many comparison lines being most susceptible). This may not be readily obvious in the finished spectra. Good indicators are that (a) lines in one part of the spectrum give radial velocities that are systematically different from other parts, or (b) the FWHM of the lines being systematically different from other parts of the spectrum (though this would be an extreme case).

#1 and #2 are most likely due to poor normalization between the object and sky spectra, but could also result, for example, if using a fiber-fed spectrograph with a sky fiber that is too close to another star. #3 is simply a wavelength solution issue.

Resources

AAVSO - https://www.aavso.org
BeSS - http://basebe.obspm.fr/basebe/
Comparison line atlas - http://iraf.noao.edu/specatlas/
IRAF - http://iraf.noao.edu
ISIS - http://www.astrosurf.com/buil/isis/isis_en.htm