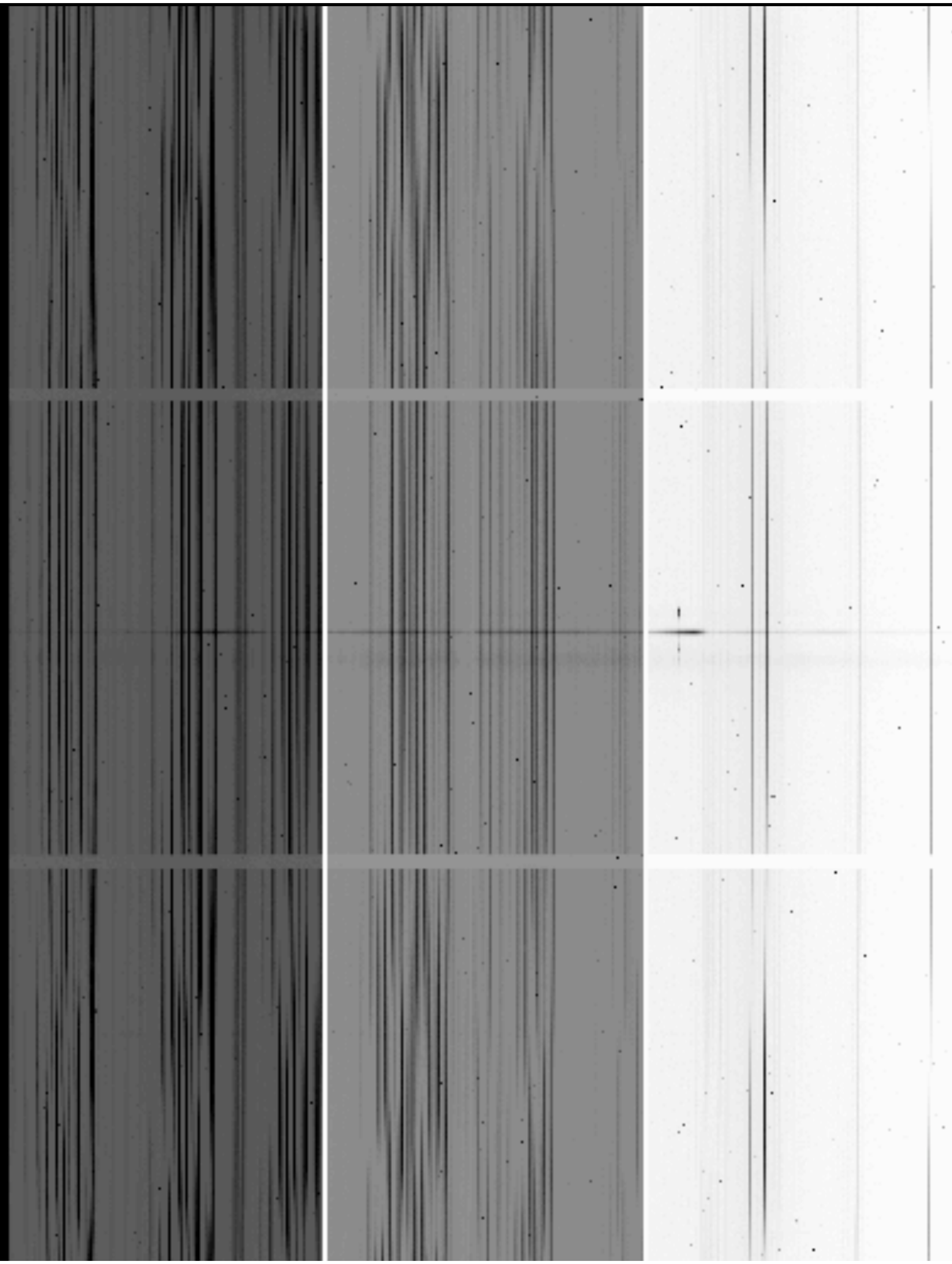
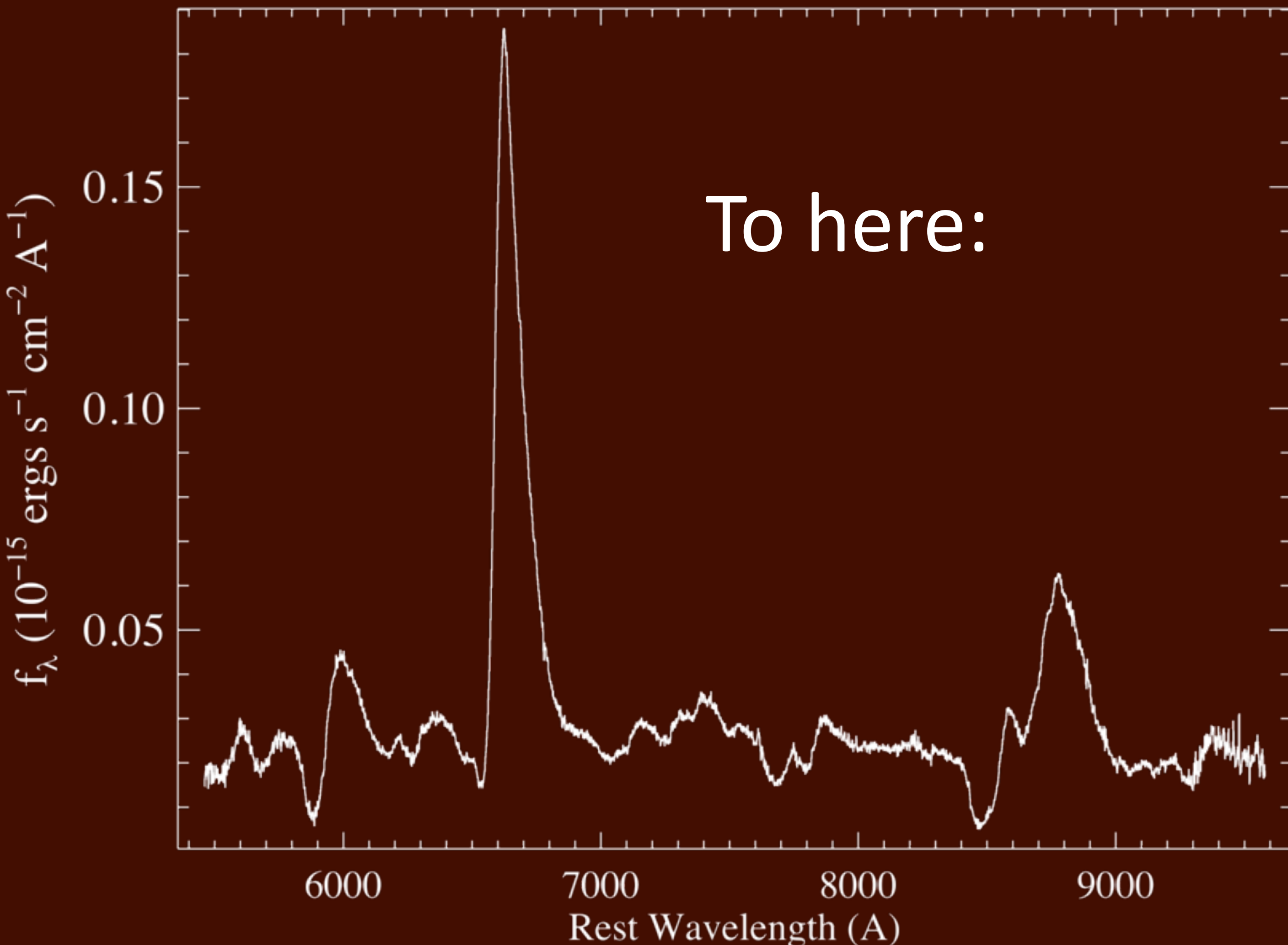
Low – Resolution Optical Spectroscopy

Tom Matheson

NOAO

How to get from here ➔




0.15
0.10
0.05
f_λ (10^{-15} ergs s^{-1} cm^{-2} A^{-1})
6000
7000
8000
9000
Rest Wavelength (A)

To here:

Why Spectroscopy?

- Composition/abundances
- Velocity (radial, dispersion, rotation curves)
- Temperature
- Excitation mechanisms
- Density/pressure
- Intervening matter

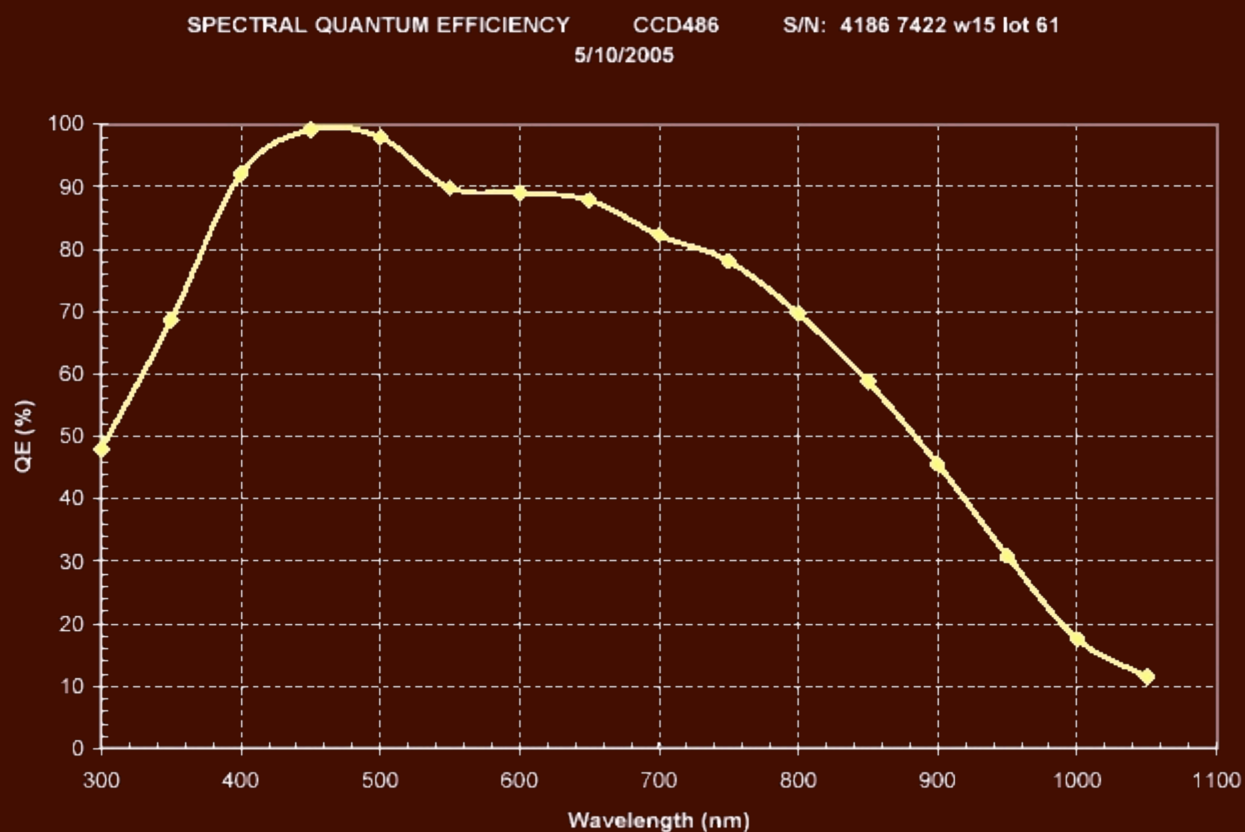
Outline

• Brief overview of the obstacles between a raw frame and the final product
• Choosing the right grating in the right spectrograph on the right telescope
• The kinds of calibrations you need and how to apply them

Things I Won't Cover (but are still important)

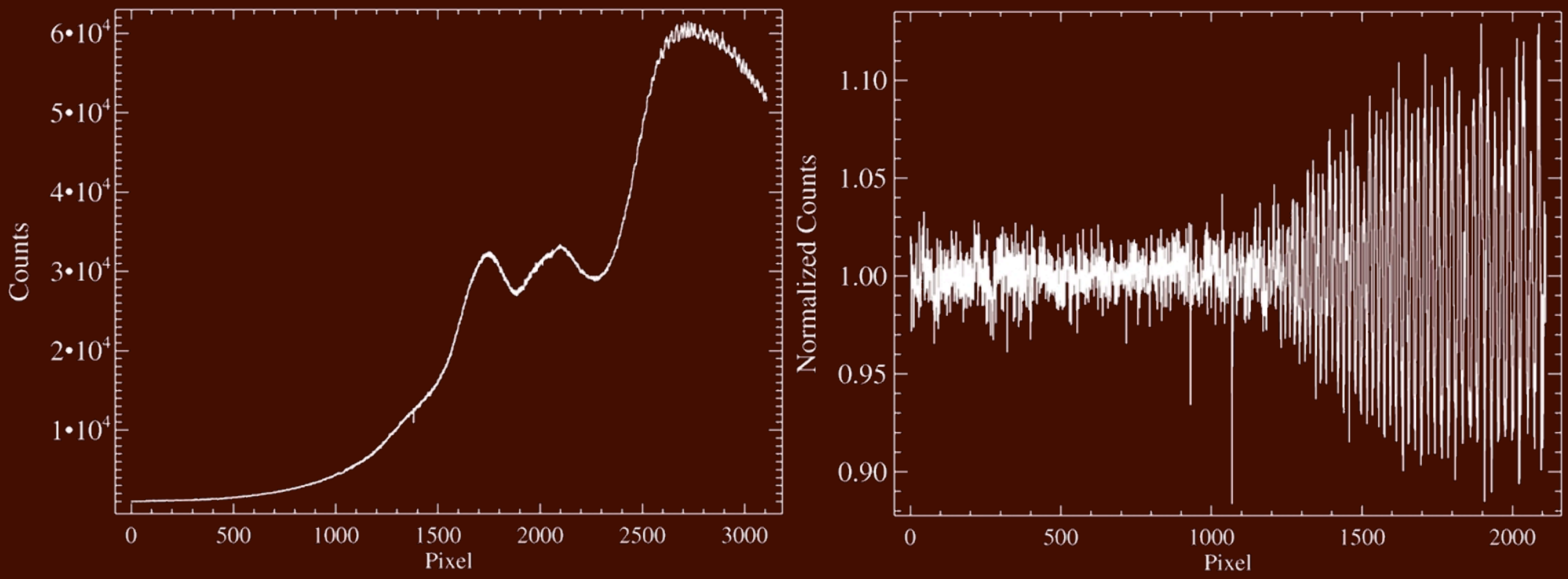
- Multi-object (see the GMOS presentations)
- Nod & Shuffle (see the GMOS presentations)
- Extended objects
- High-resolution
- Infra-red (See NIRI/NIFS presentations)
- Software/IRAF parameters (See *A User's Guide to Reducing Slit spectra with IRAF*, Massey, Valdes, & Barnes, 1992, available on the NOAO web site)

Problem #1: The CCD



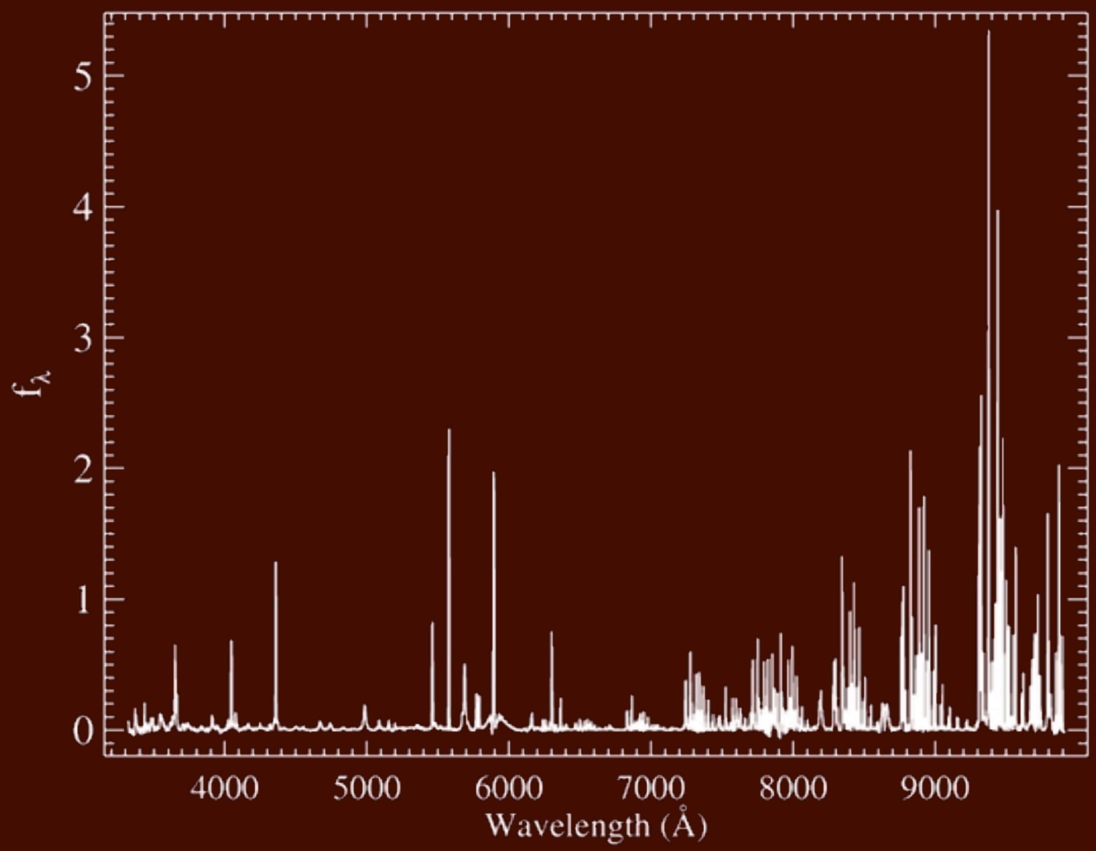
Quantum Efficiency of the Detector

Problem #1: The CCD



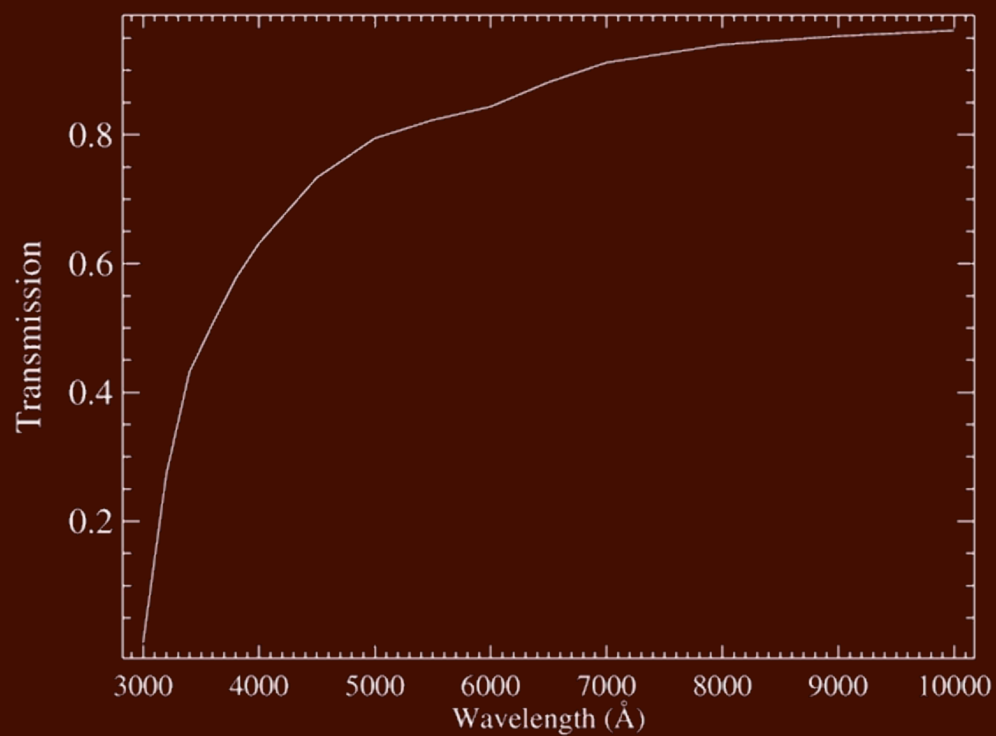
Flatfield and Fringing

Problem #2: The Sky



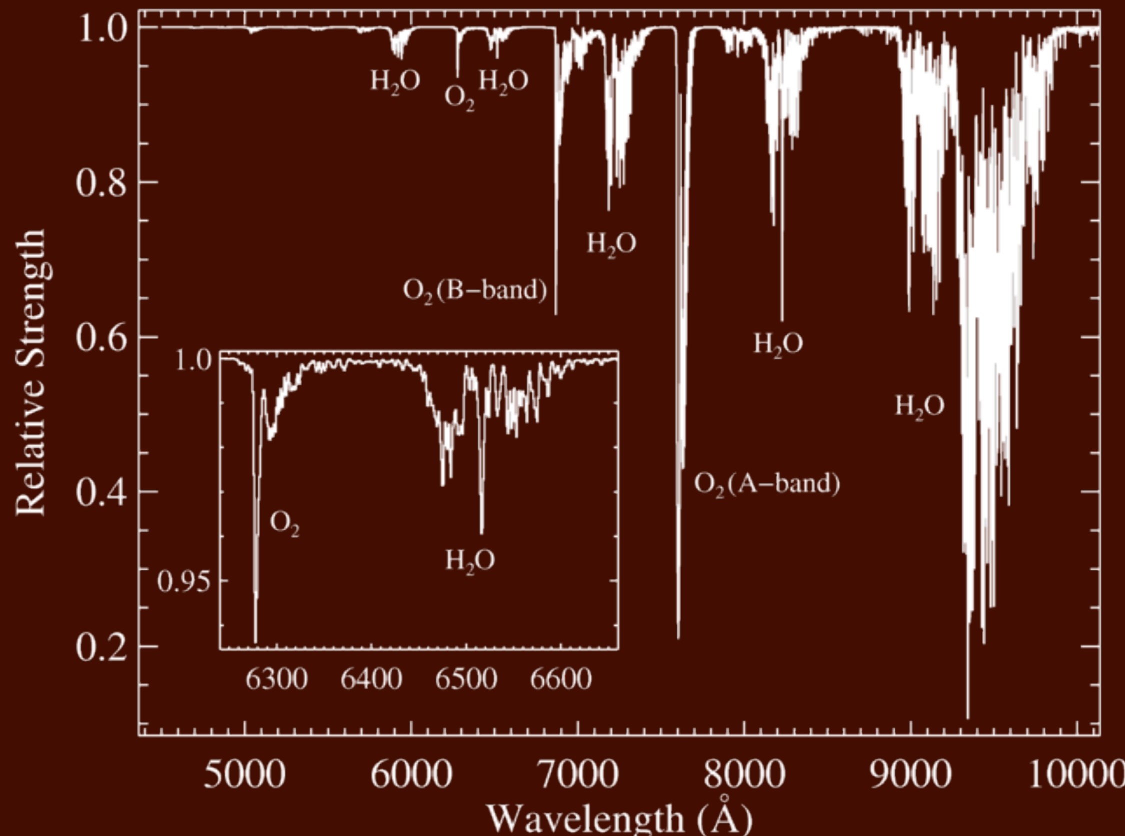
Night-Sky Emission Lines

Problem #2: The Sky



Continuous Absorption

Problem #2: The Sky



Wallace, Hinkle, & Livingston 1993, 1998)

Molecular Absorption

Other Potential Problems

- Finding the right grating for your project
- Biases, darks, overscan (CCD/electronics effects)
- Second-order light
- Parallactic angle
- Observing standard stars (flux and other)
- Getting good wavelength calibration lamps
- Extraction of the 1-D spectrum
- Wavelength calibration
- Flux calibration
- Telluric correction

Three Things to Take Away from this Presentation

1. Do no harm

Don't compromise the data
Do the minimum necessary for removal of instrumental effects and calibration

Three Things to Take Away from this Presentation

2. Look at the data

Don't expect everything to work
A misplaced bias frame or saturated flat field can lead to problems that are difficult to diagnose

Three Things to Take Away from this Presentation

3. Take all the calibration frames you need and then take all the calibration frames you don't think you need

Planning the Observation: Gratings

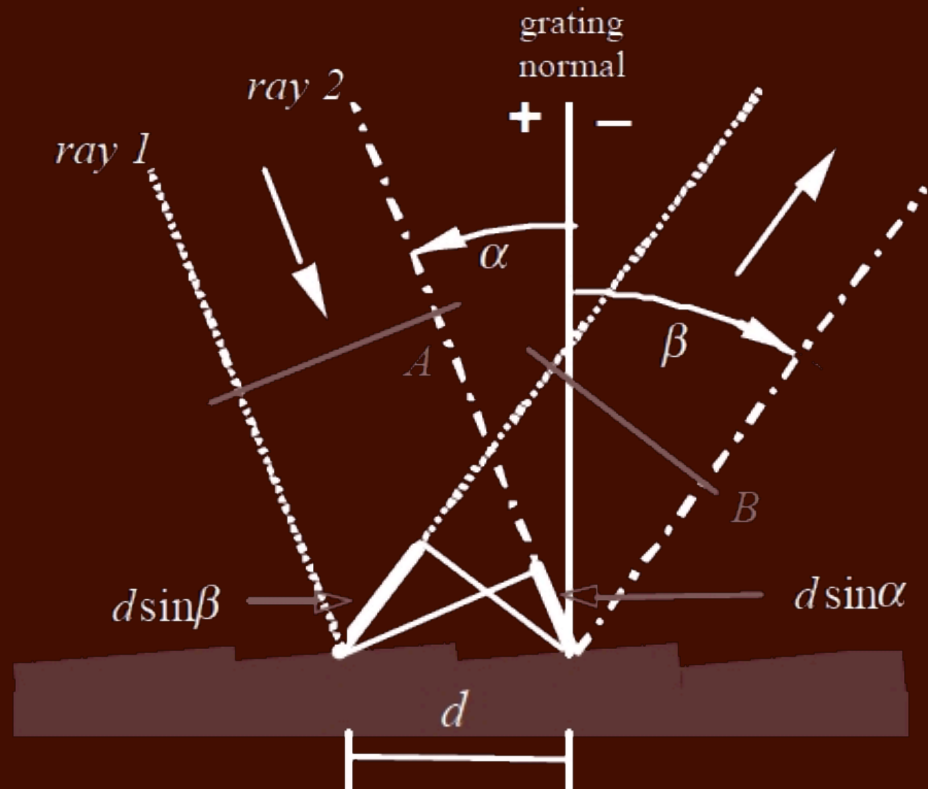
There are two basic quantities to consider:

1: Resolving Power = R = $\frac{\lambda}{\Delta\lambda}$ = Nm

Resolution a function of dispersion, detector pixel scale, slit width, and (possibly) seeing
Essentially the ability to distinguish nearby features

2: Wavelength Coverage

Limited mainly by size of detector as well as optics, telescope throughput, and detector response



$$m\lambda = d\,(\sin\alpha + \sin\beta),$$

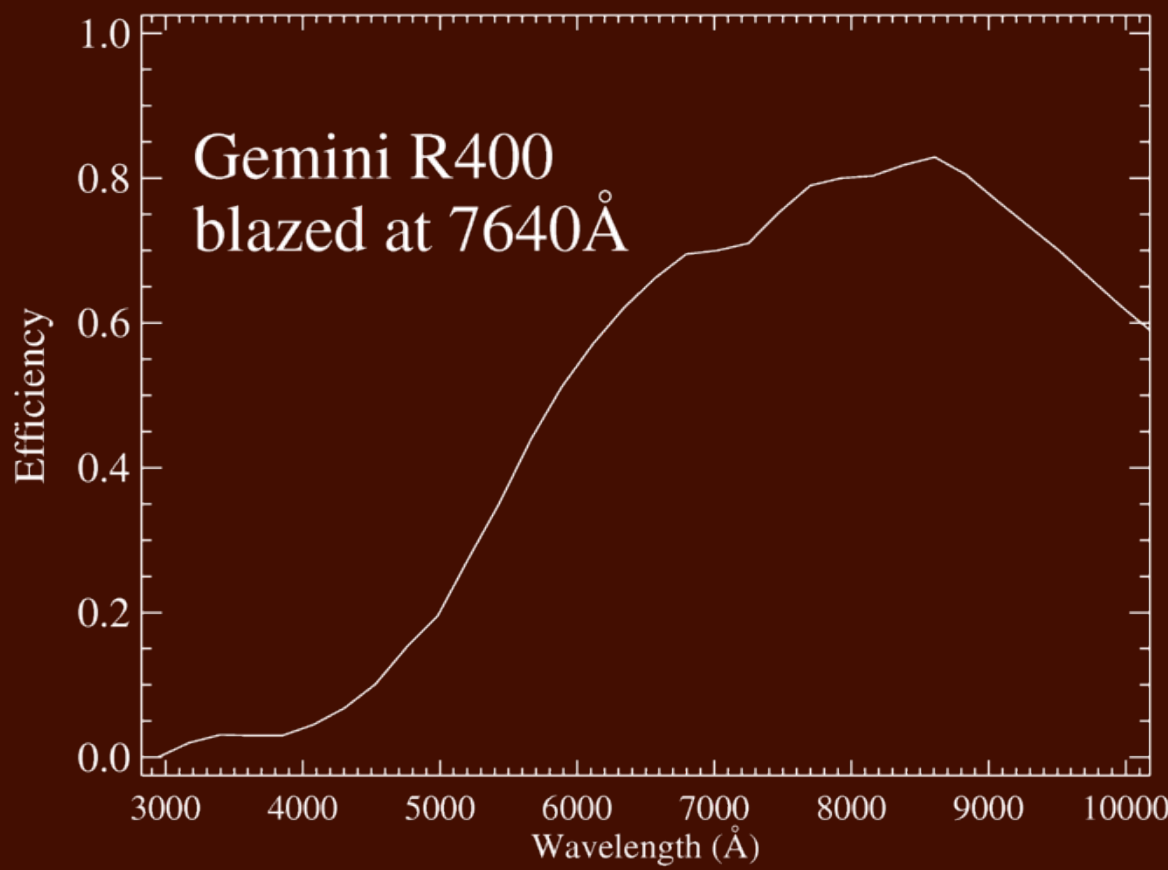
Diffraction Grating Handbook, Palmer 2005
Newport/Richardson Gratings

Planning the Observation: Gratings

In practical terms, gratings are described with a few numbers:

1. The number of lines per mm (e.g., R400, B1200) Higher numbers mean better resolution
2. The blaze wavelength, essentially the wavelength with the highest efficiency, but other effects can change this, so you should seek out the efficiency curve
3. Dispersion in Å/pixel
4. Resolution, measured with some slit width

Grating Efficiency Curve



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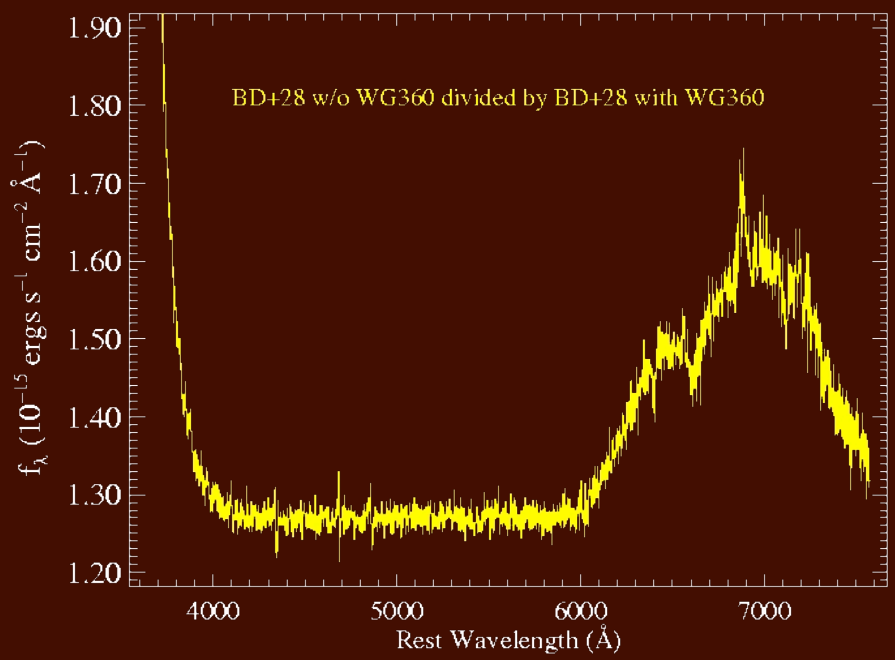
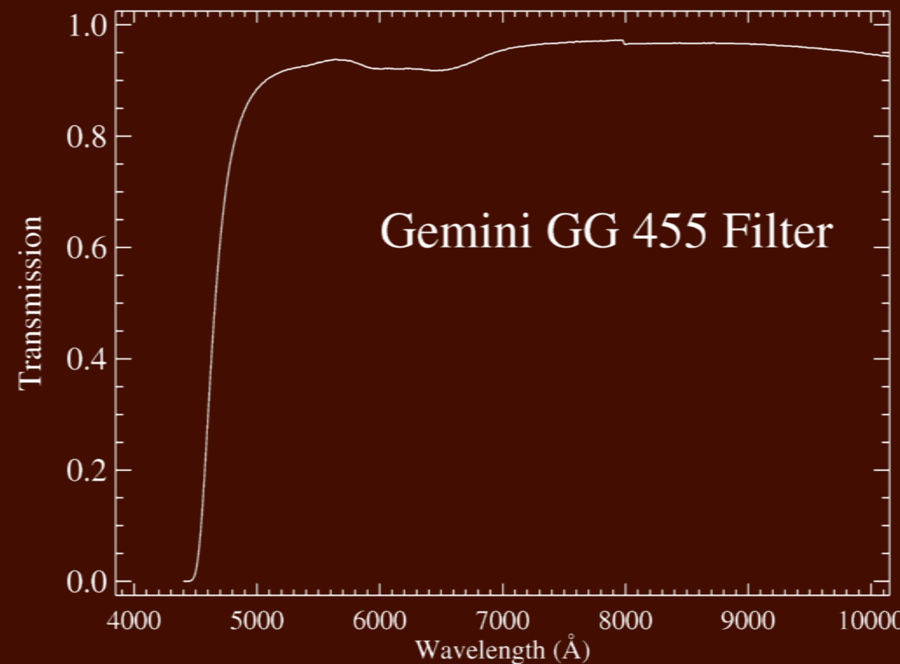
Second-order Light



Blue light in second order overlaps red light in first order

Second-order Light



Use an order-sorting filter (generally identified with the half-throughput wavelength)

Testing the CCD: Biases

Use biases and flats to determine gain and read noise (for this and a lot more detail about CCDs, see Steve Howell's talk, or his book, Handbook of CCD Astronomy)

The $\sqrt{N}$ is your friend. Do enough biases to get above the read noise

For most modern detectors, there isn't much need to subtract a bias for spectroscopic frames. As long as there isn't a pattern, any residual pedestal in the bias will be removed by sky subtraction

The real value is as a test of instrument health.

Testing the CCD: Darks

As with biases, dark current in modern optical detectors isn't usually a serious problem.

It can take a lot of time to get enough darks to be well above the read noise.

Check with the instrument scientist to see if dark current is a concern.

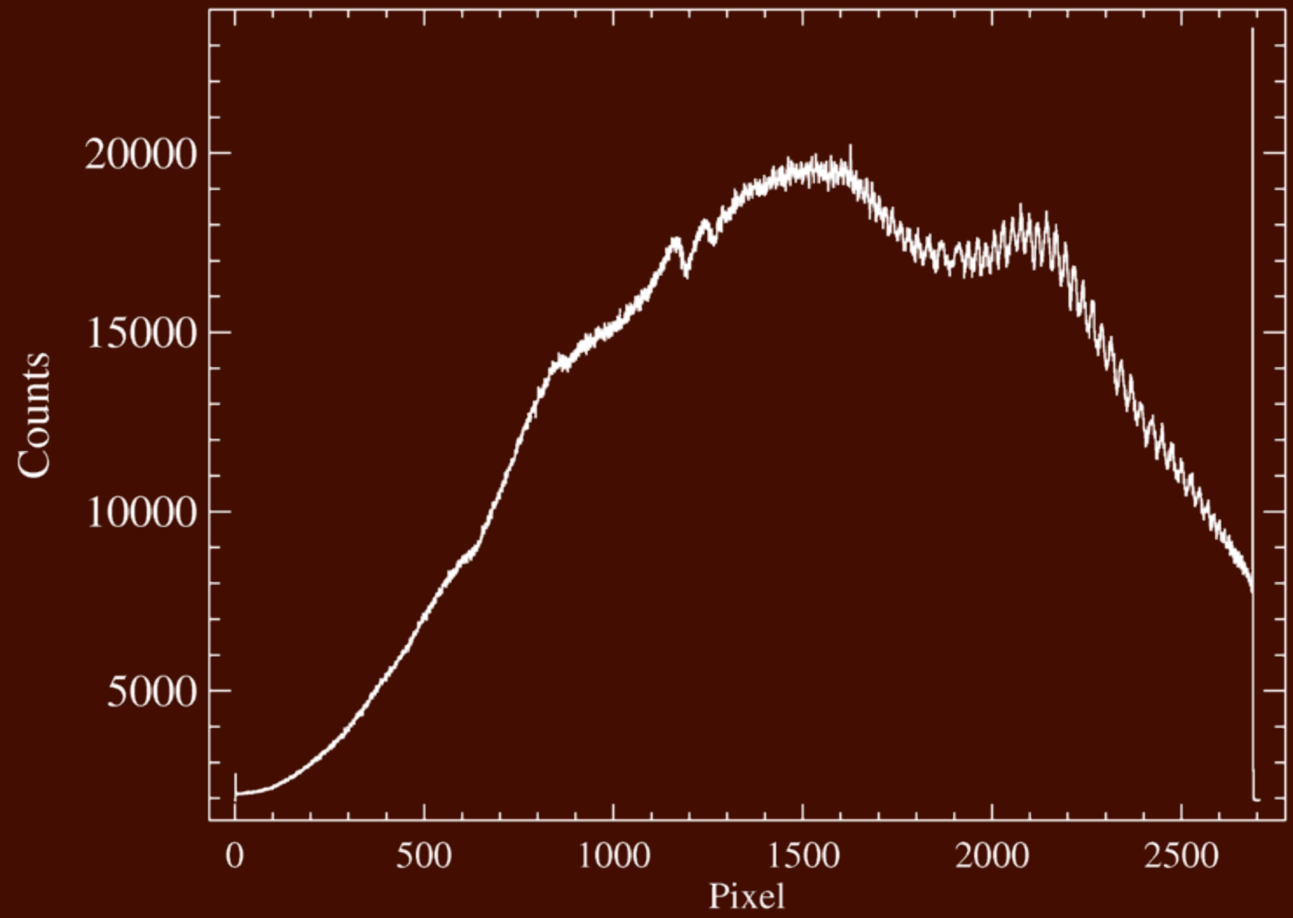
Testing the CCD: Trim & Overscan

Examine the CCD, find out about saturation and non-linearity

Determine the useful region of the CCD . If parts of the CCD don't have counts (or have too many), then that will play havoc with statistics used to scale other calibrations, so make sure you have a well-defined region of the CCD to use.

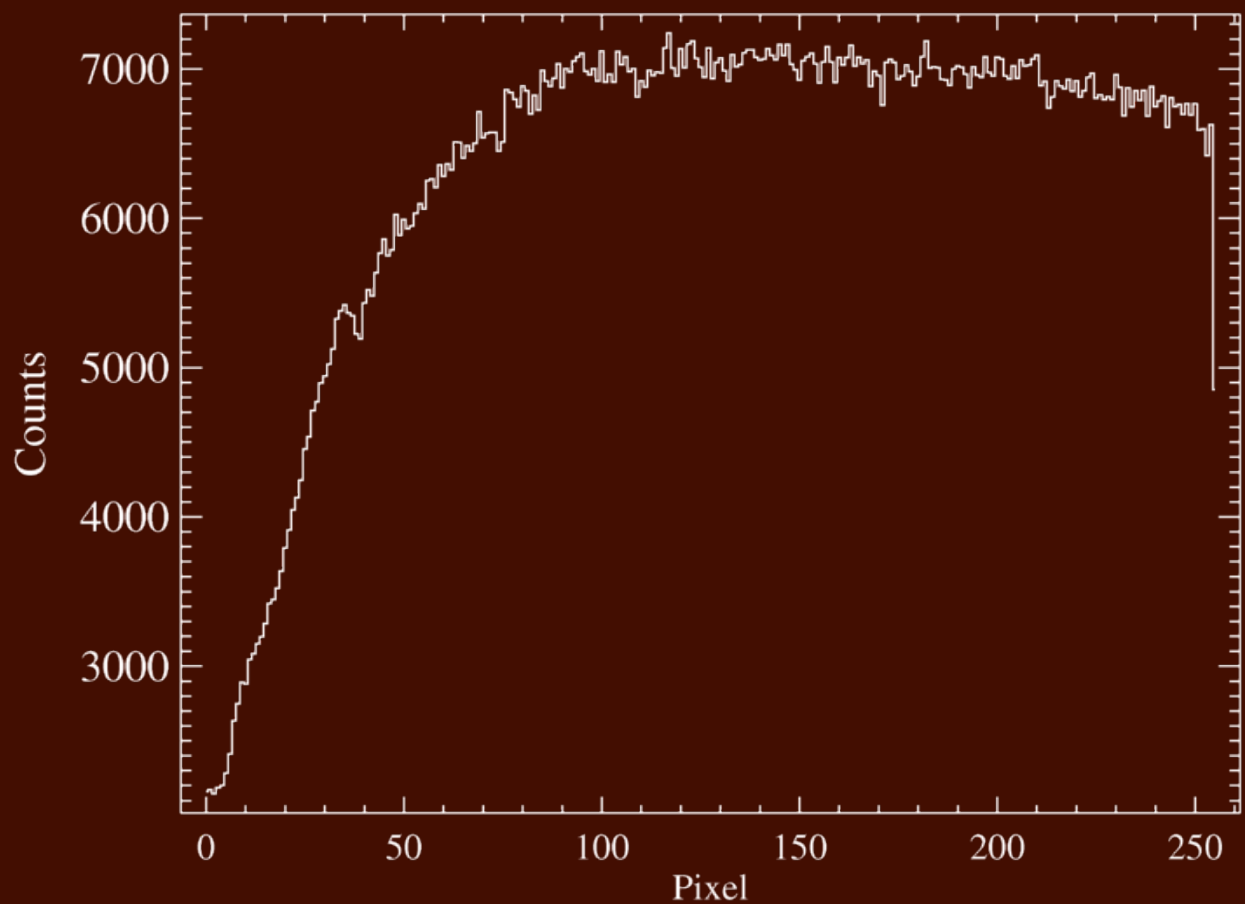
Look at the overscan in some of your biases and flats. The region defined in the headers often includes portions that aren't good. Choose a subset of the overscan that gives you an unbiased look

Cross cut of flat



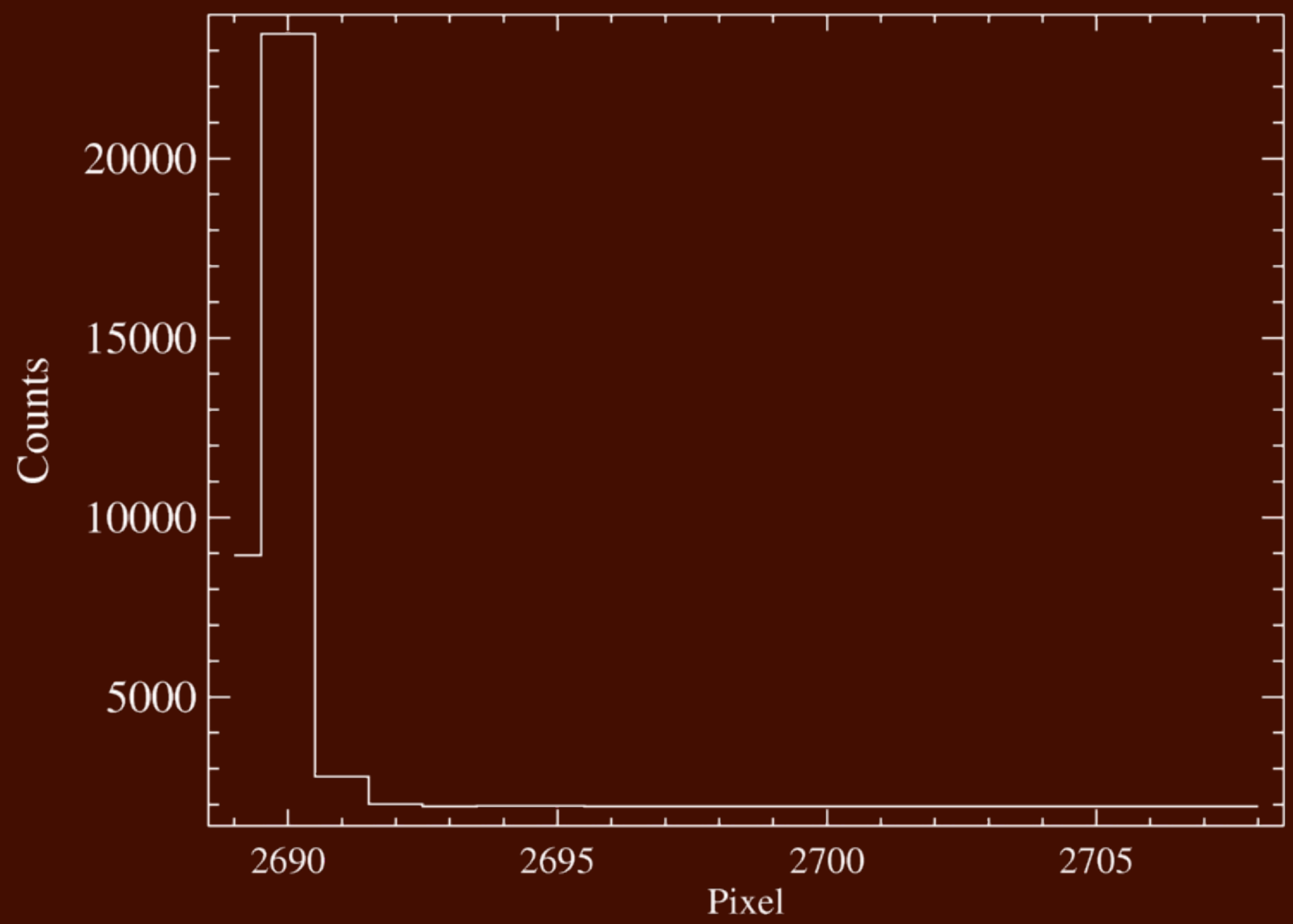
Choose regions with reasonable response

Cross cut of flat



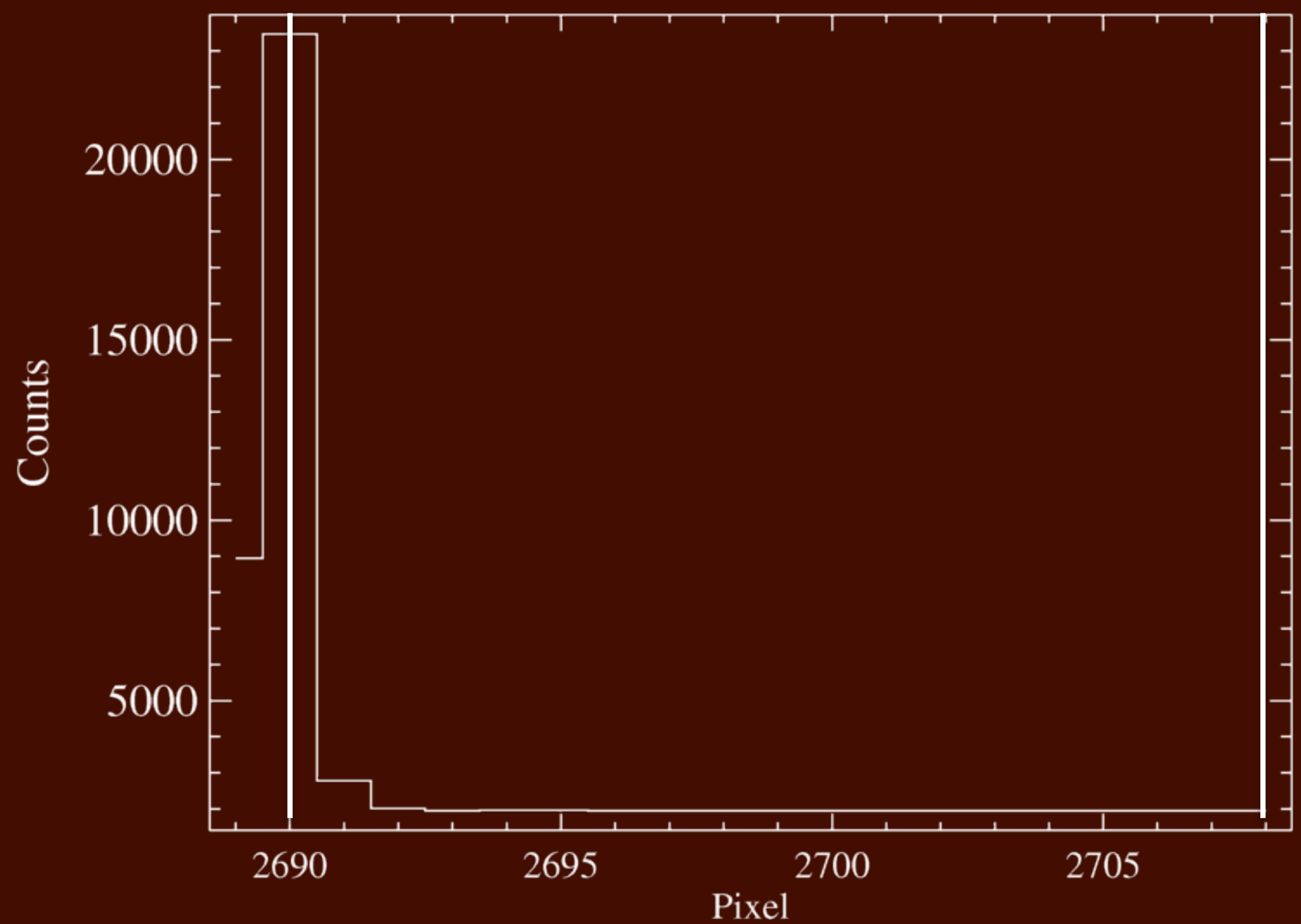
Choose regions with reasonable response

Overscan



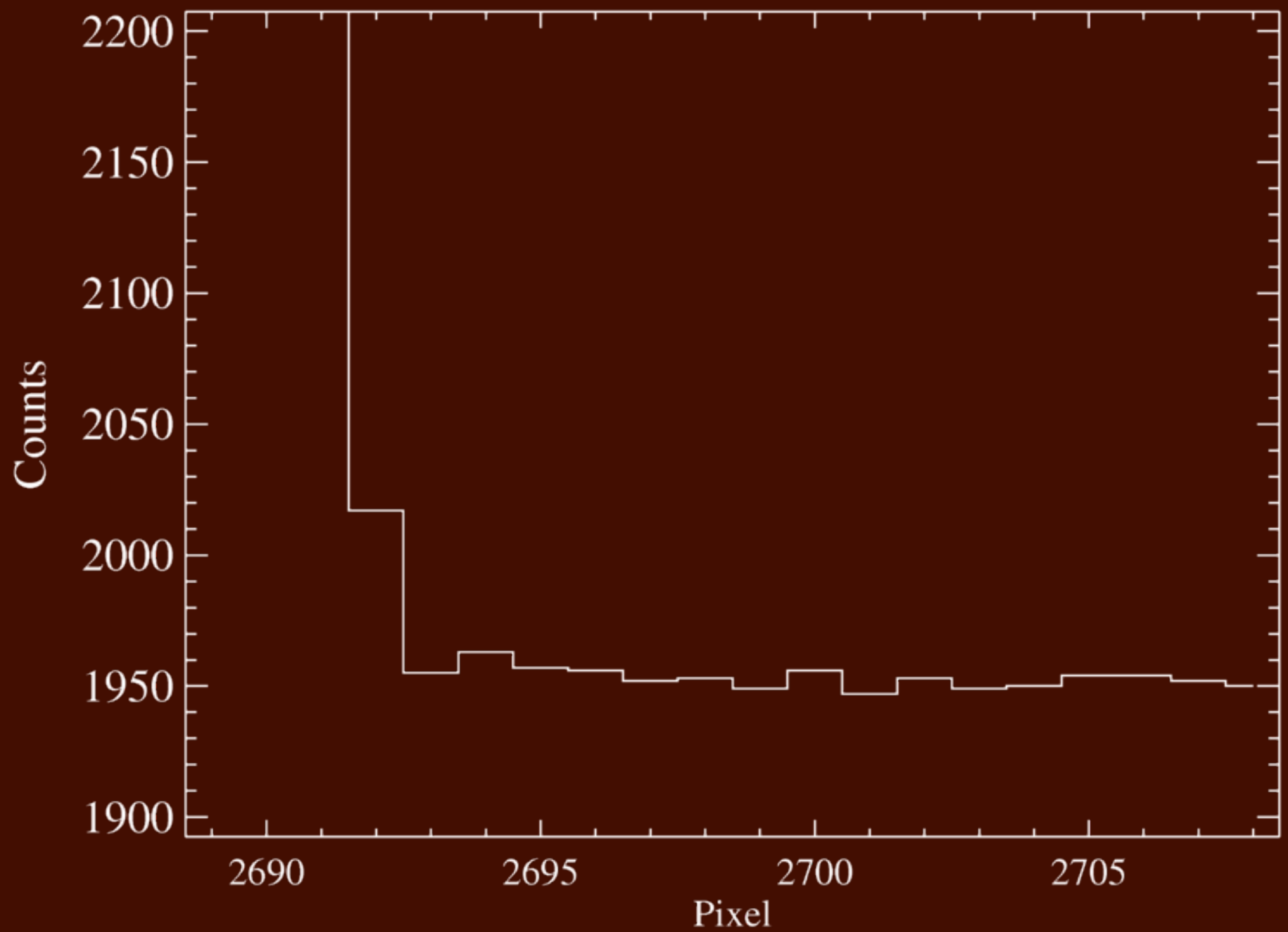
Choose regions with reasonable response

Overscan



Choose regions with reasonable response

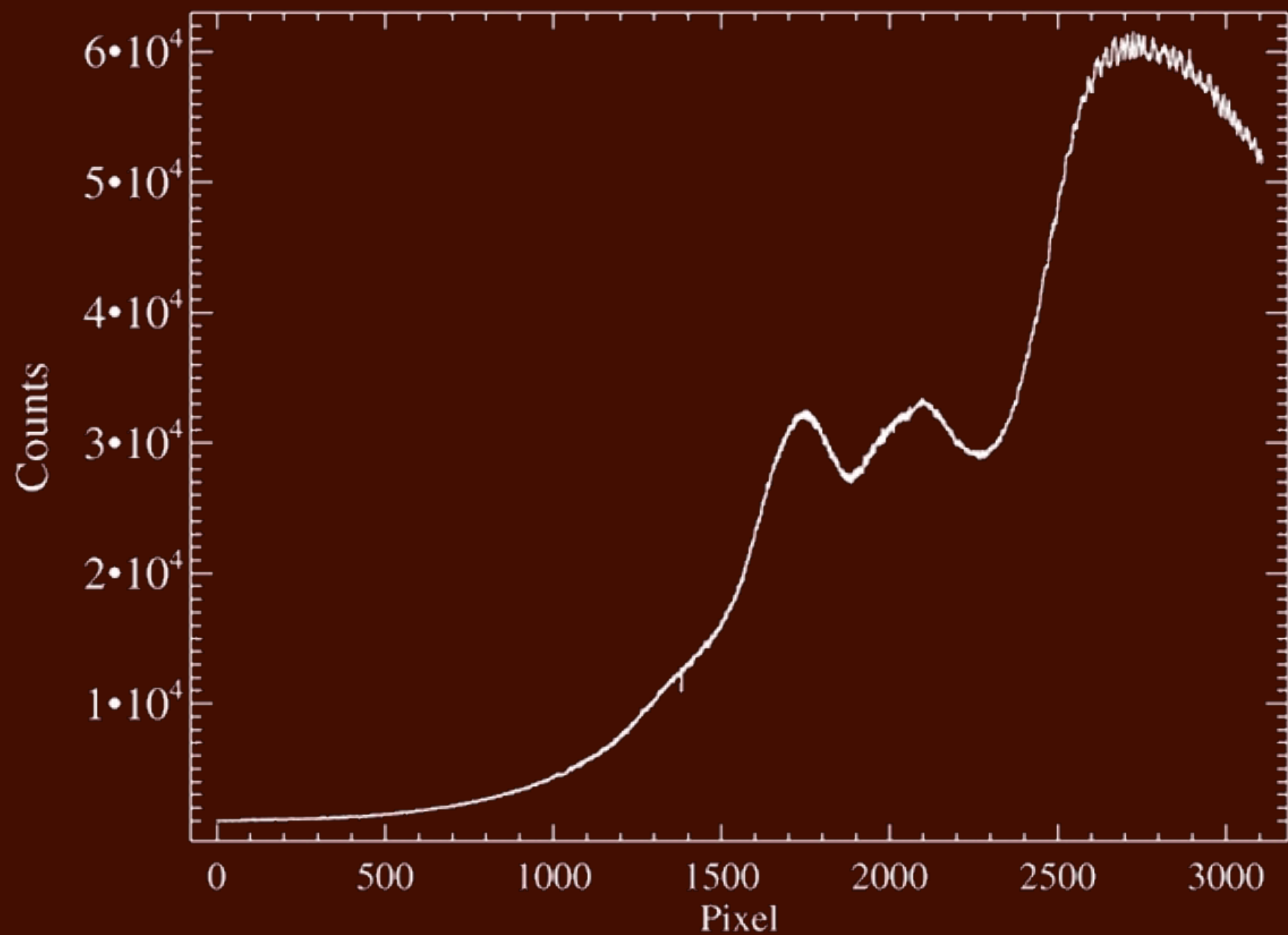
Overscan



Choose regions with reasonable response

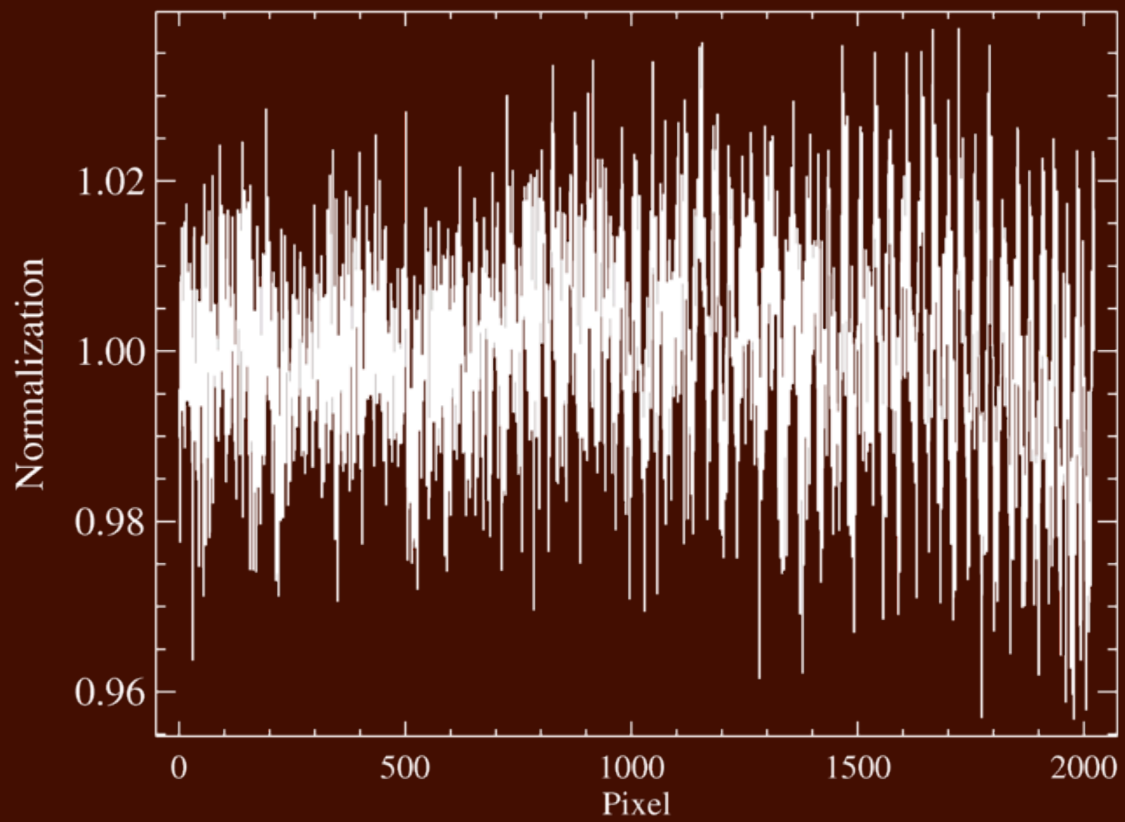
Flat Fields

- Remove pixel-to-pixel variation
- Get enough counts, 10Xobject is a good rule
- You don't want to imprint the color-temperature of the flat lamp onto your data, so you need to remove the overall trend



Remove shape with fit, typically cubic spline

Use lowest order possible to remove signature of the lamp, not the CCD



Normalized flat, fringing still present

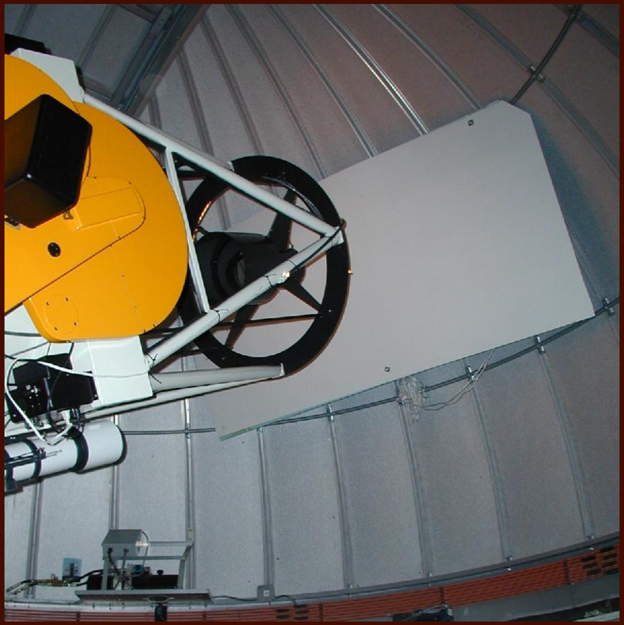
Use the same normalization for all flats in one configuration

Flat Fields

Fringing is caused by the light falling on the chip interfering with itself when the chip depth is on the same scale as the light

Depends sensitively on wavelength and chip position, so do red flats at the position of your object

Flat Field Screen



http://www.jca.umbc.edu/telescope/UsersGuides/TakingFlats.html

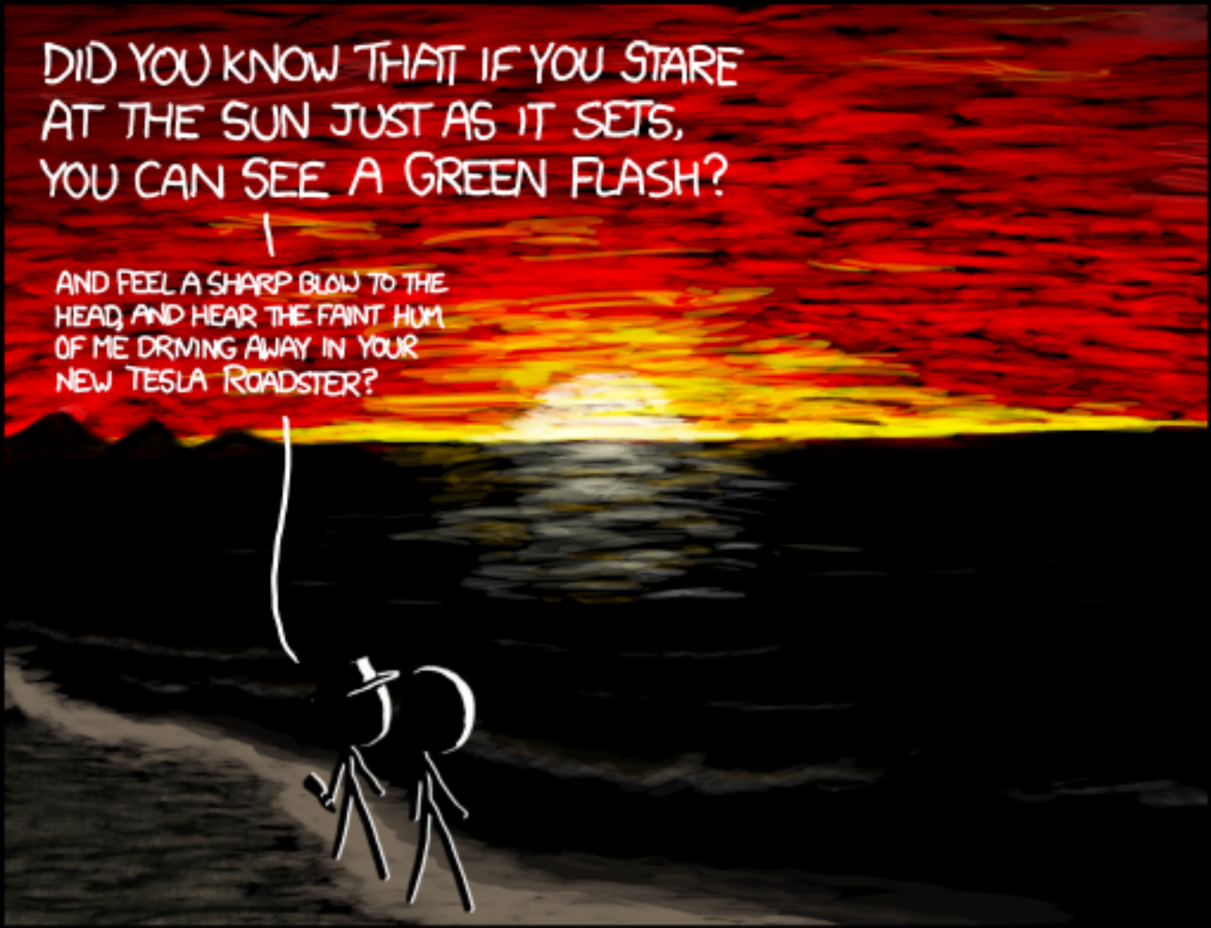
Internal lamps are another common option

Depending on flexure and the optics, this can also be effective

Atmospheric Dispersion

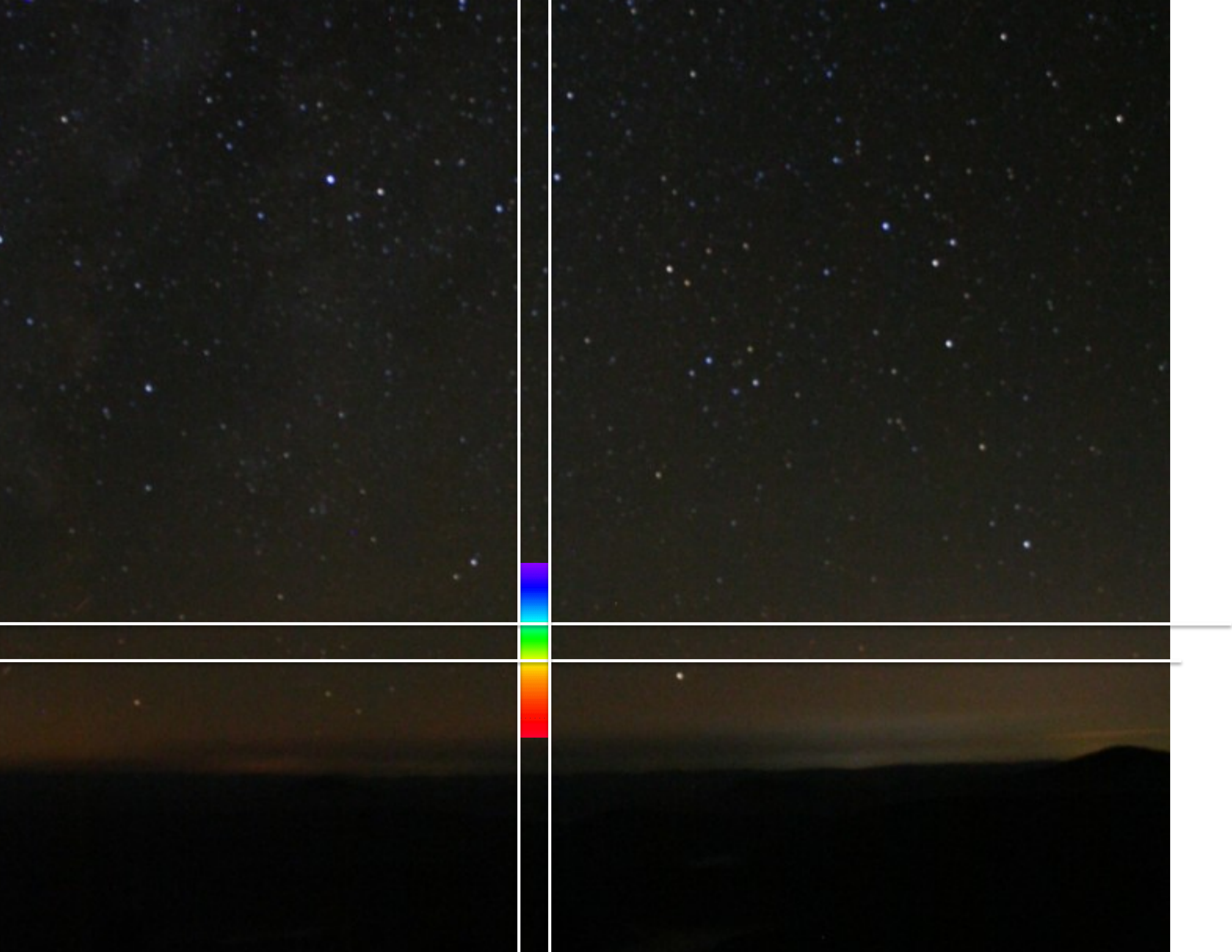
http://www.kenrockwell.com/tech/2008-01-new.htm

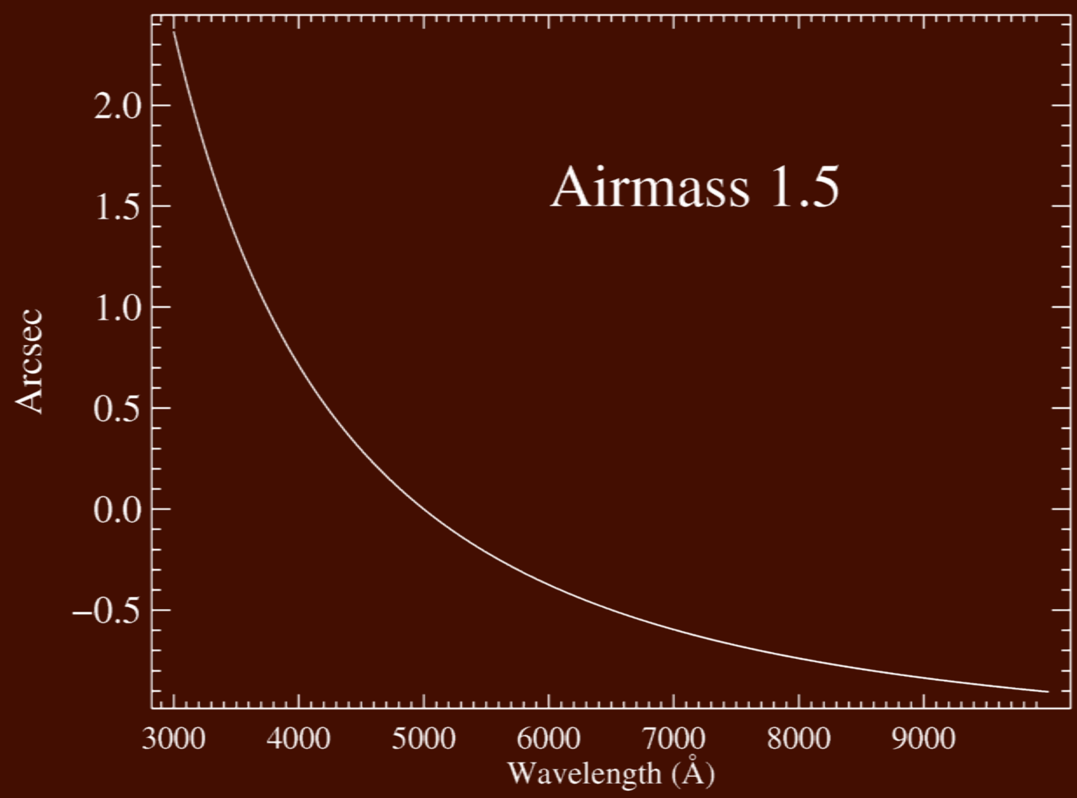
Atmospheric Dispersion



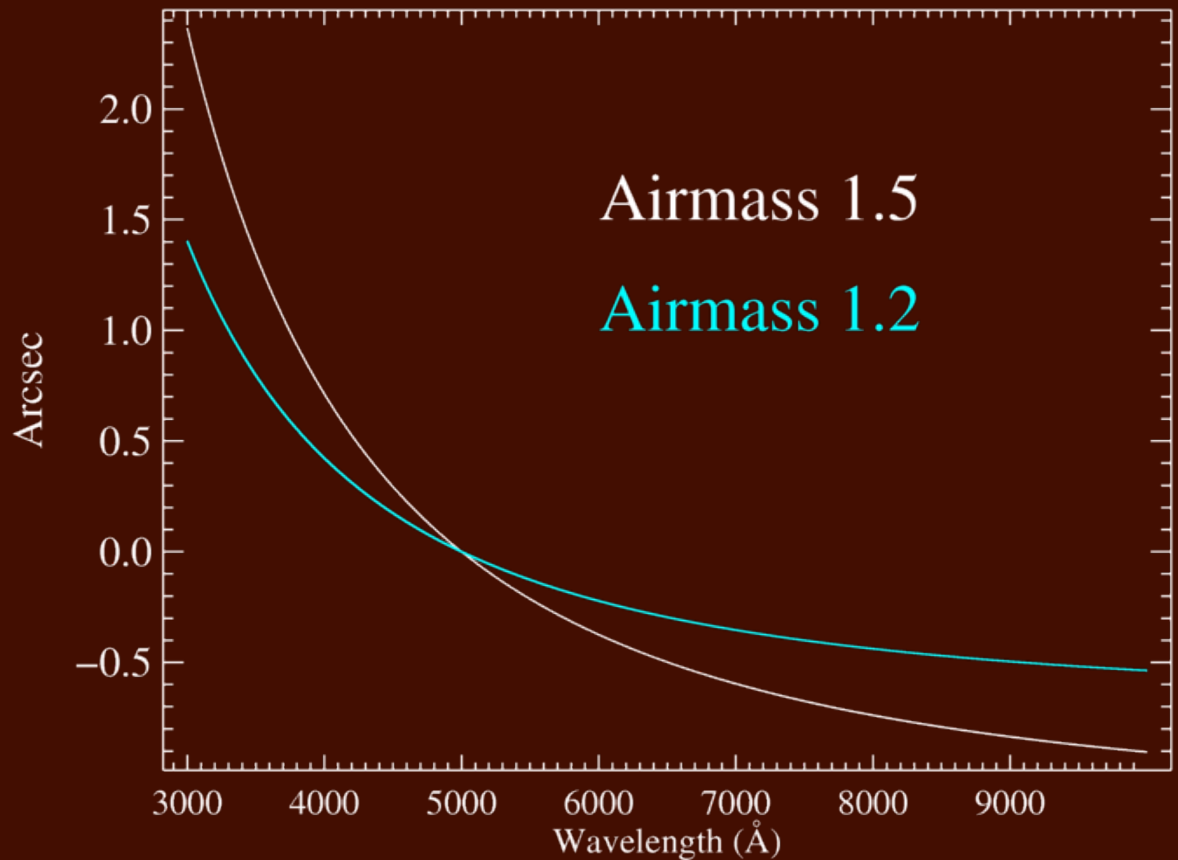
http://xkcd.com/766/

Atmospheric Dispersion



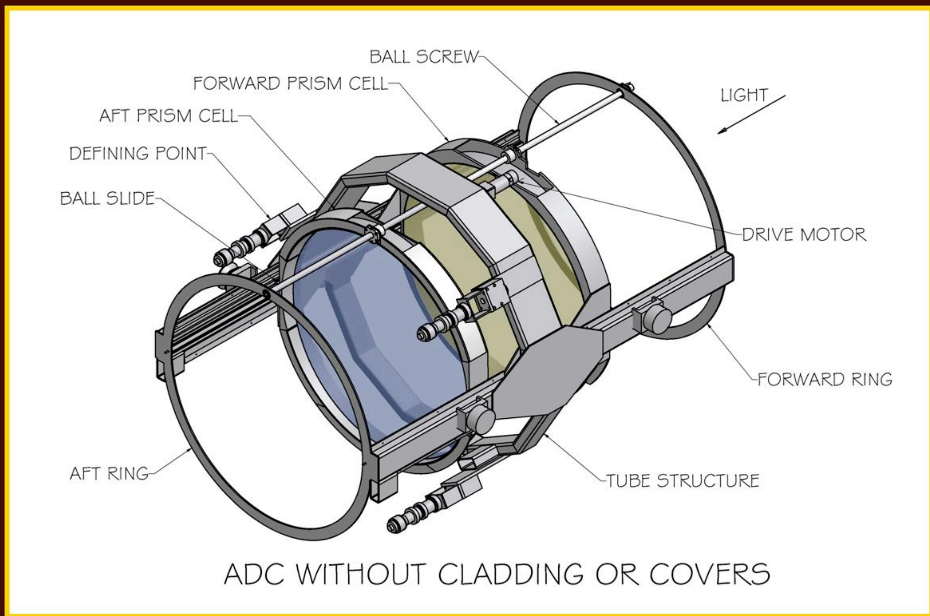


Even in the red, dispersion losses can be significant



Lower airmass can help, but still a problem in the blue

Use an ADC



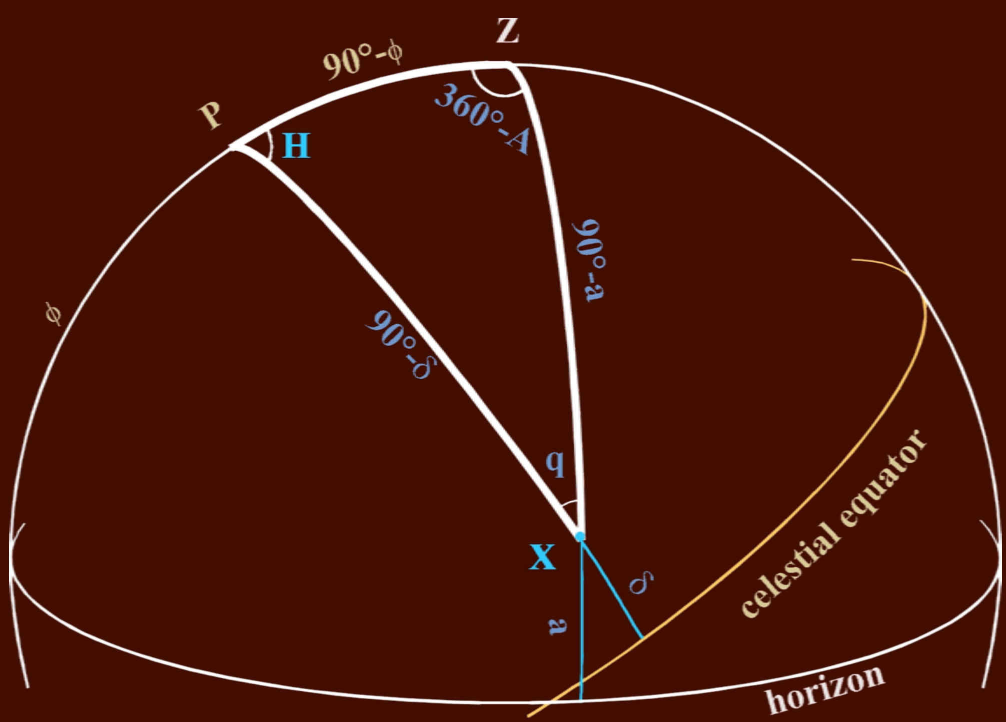
LRIS ADC design

ODI ADC under construction

Effective, but still some dispersion at high airmass

Slight throughput loss, possible distortions

Use the Parallactic Angle

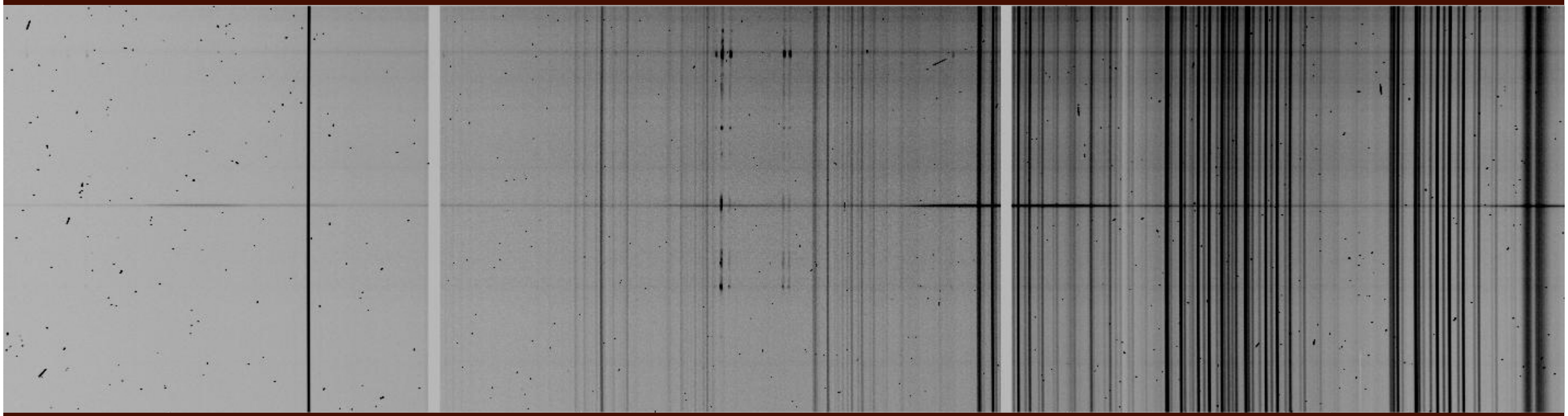


http://star-www.st-and.ac.uk/~fv/webnotes/chapter7.htm

The parallactic angle is the position angle on the sky at your current azimuth and elevation that orients the slit perpendicular to the horizon, i.e., along the dispersion direction.

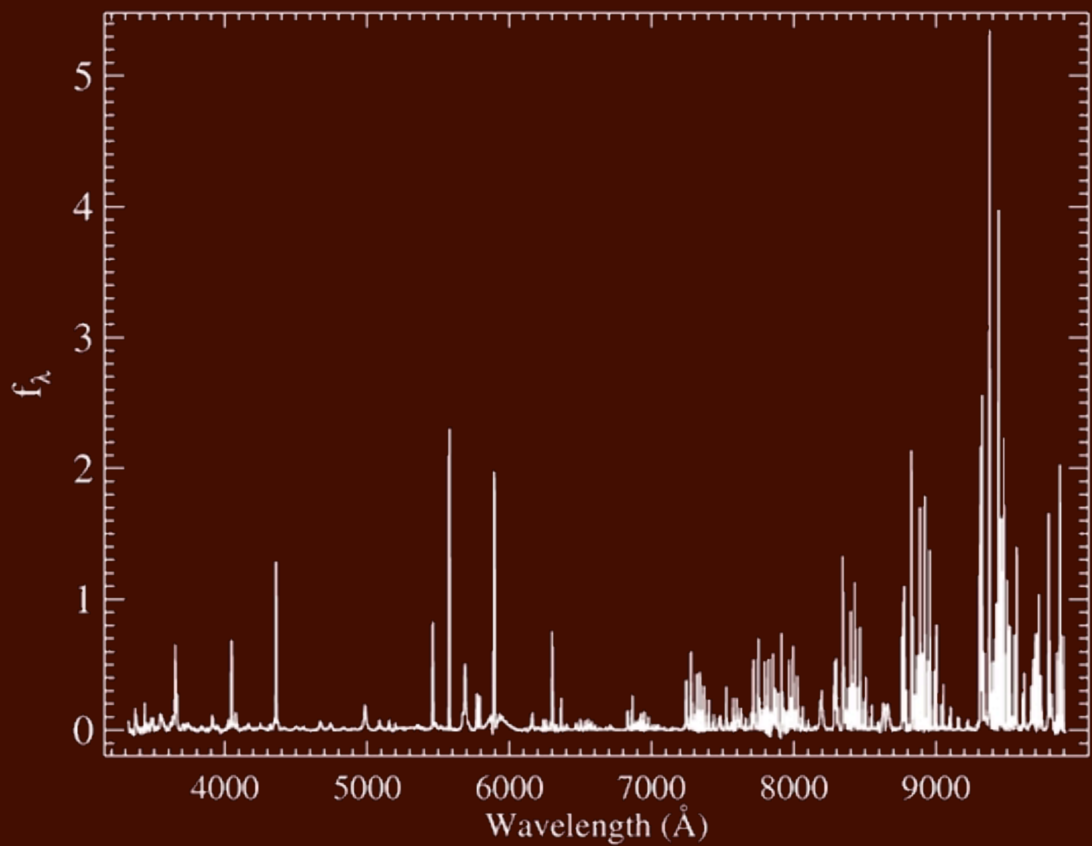
See Filippenko 1982, PASP, 94, 715

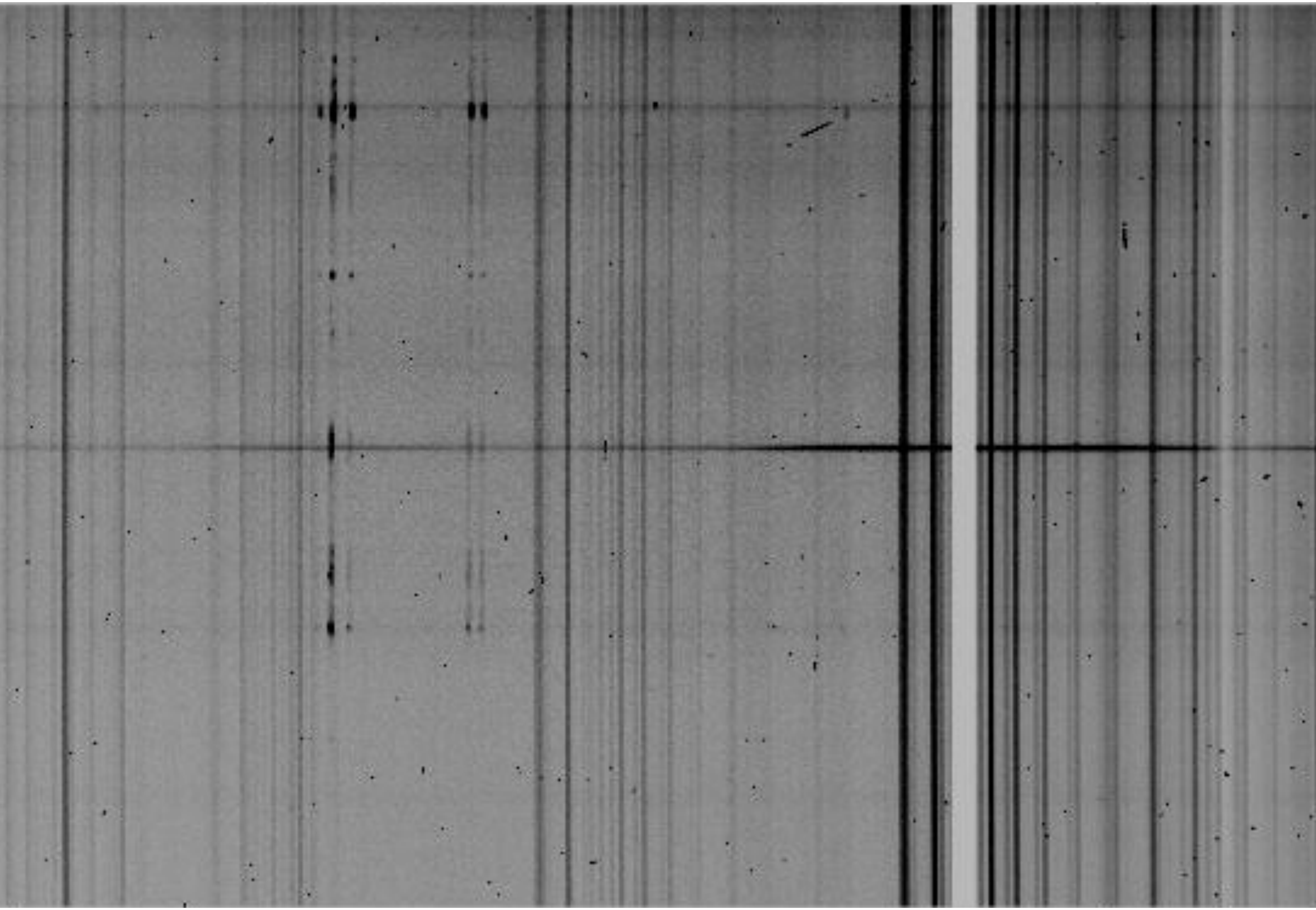
Extraction from the 2-D Frame

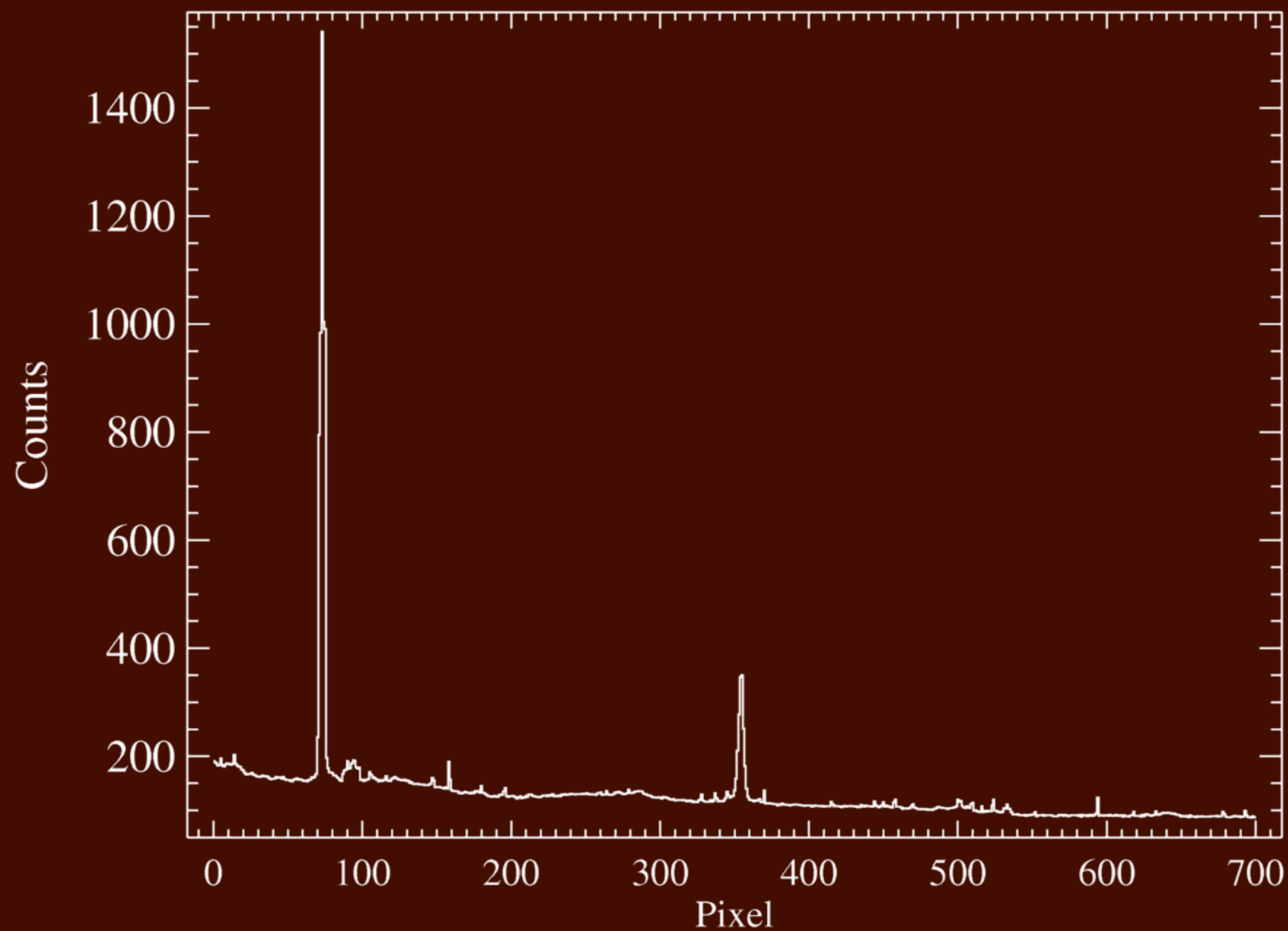


Define a profile, choose a background region to extract

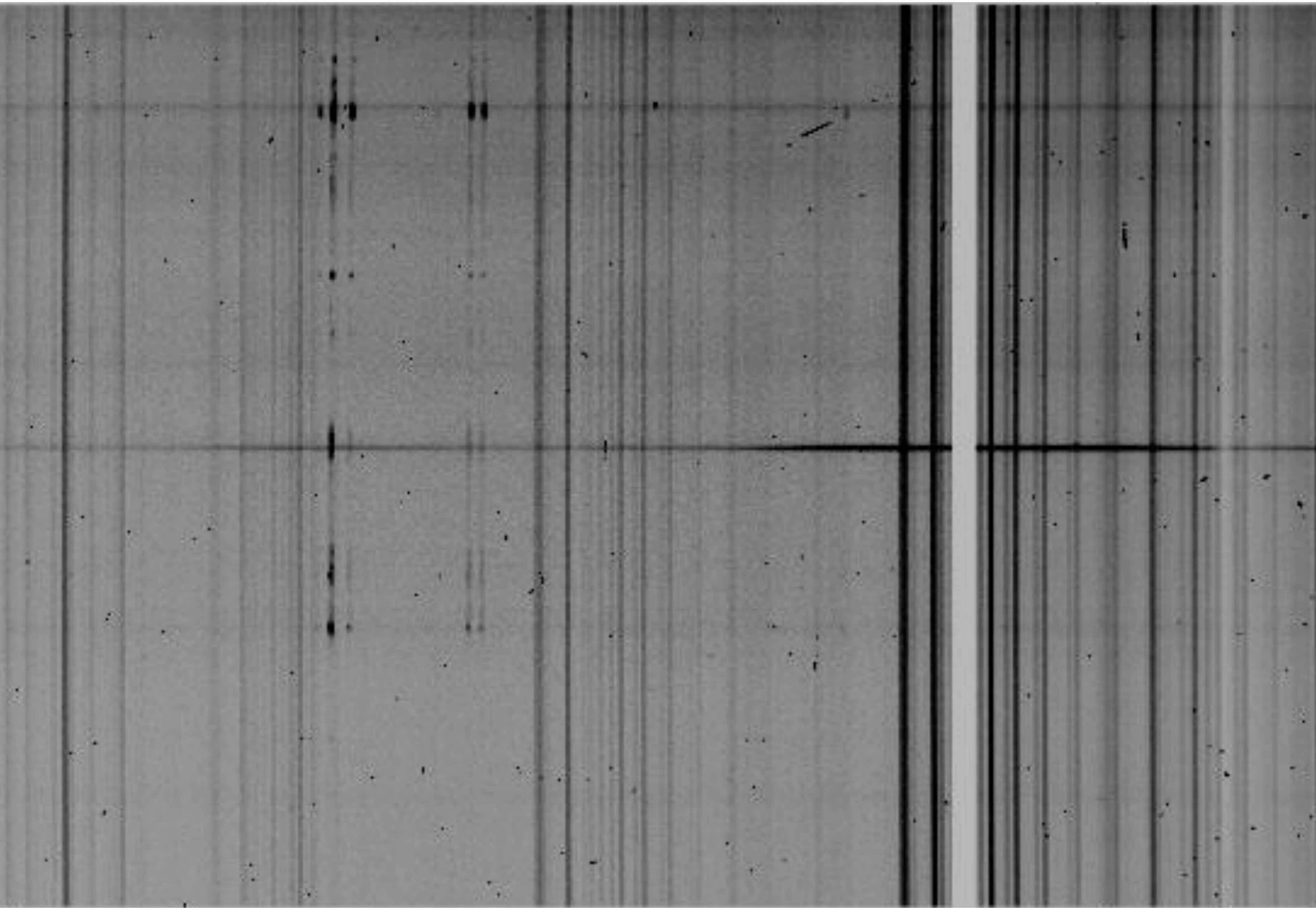
Night Sky Emission Lines

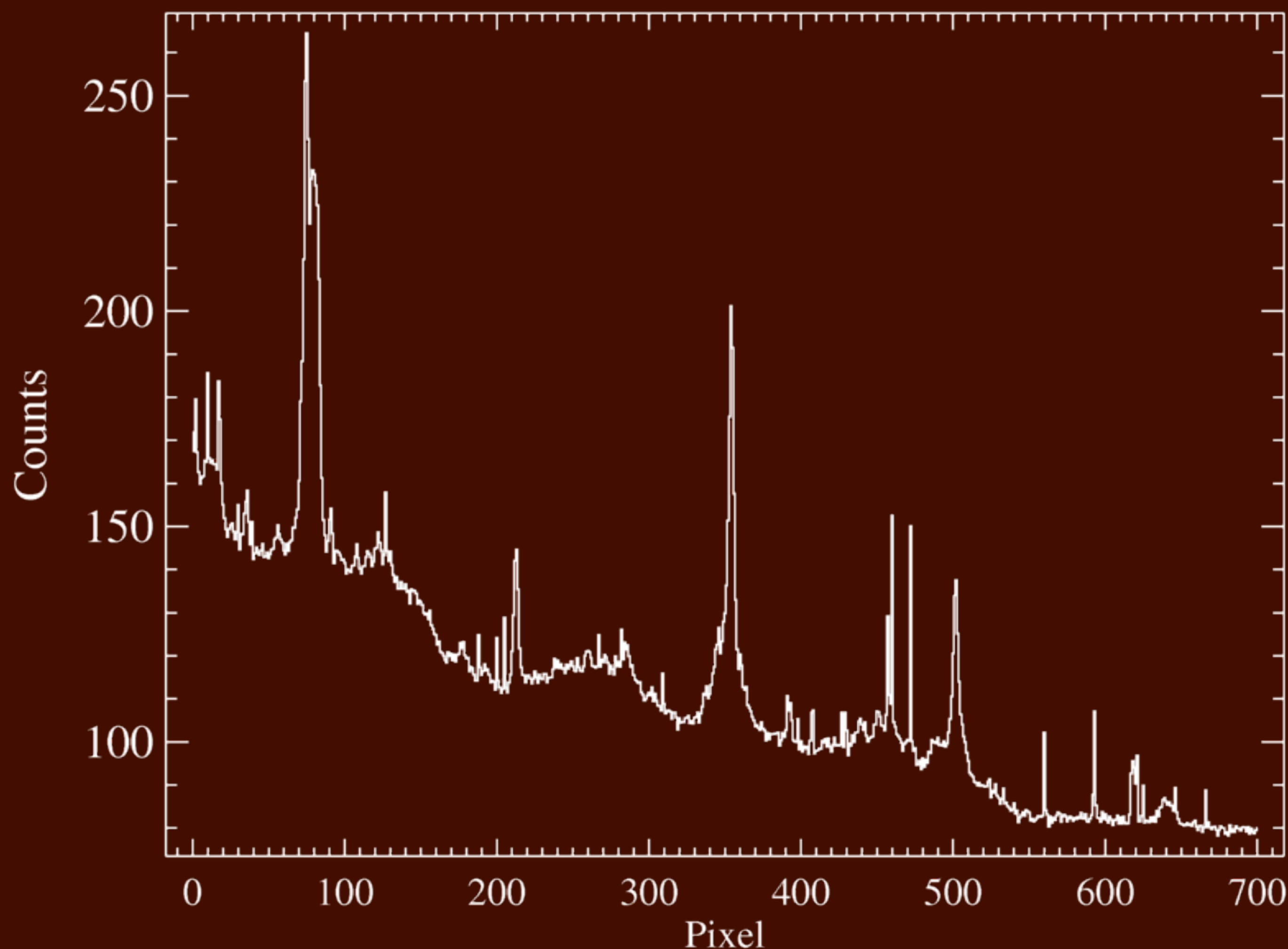






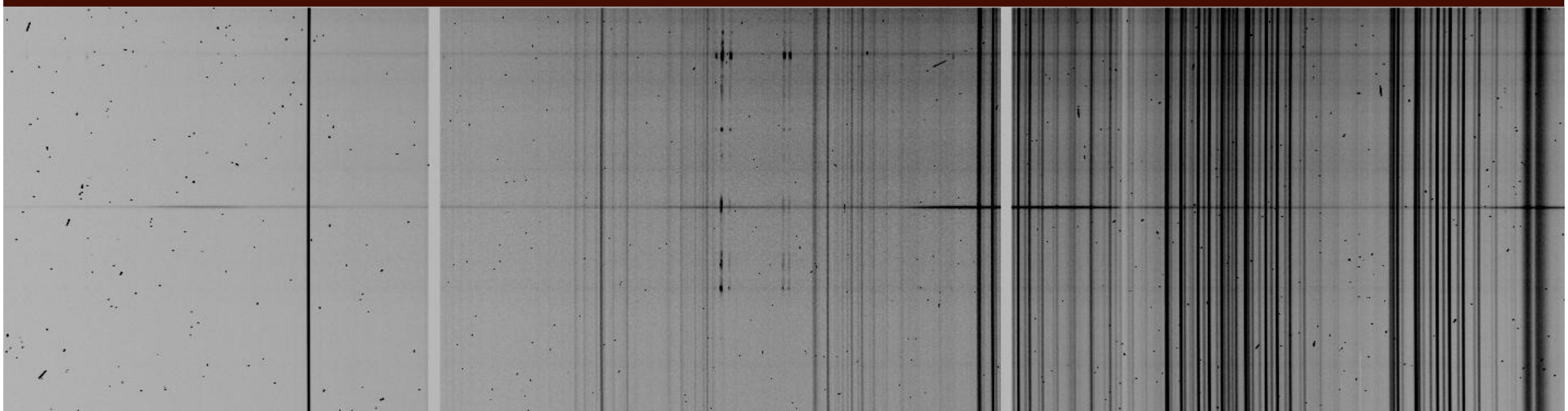
1400
1200
1000
800
600
400
200
Counts
0
100
200
300
400
500
600
700
Pixel





Make sure you know what you're extracting
Make sure you know what you're subtracting

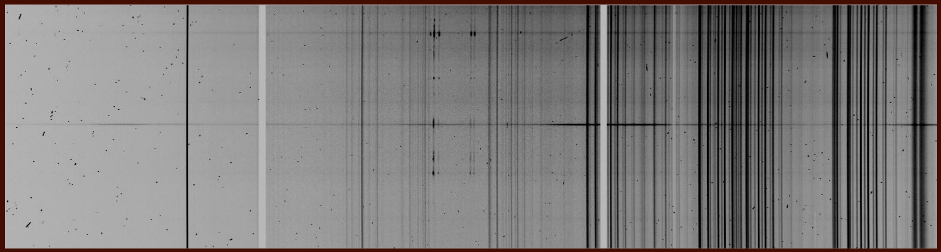
Extraction from the 2-D Frame



Trace: Locating the centroid over the dispersion axis

Use a low-order fit

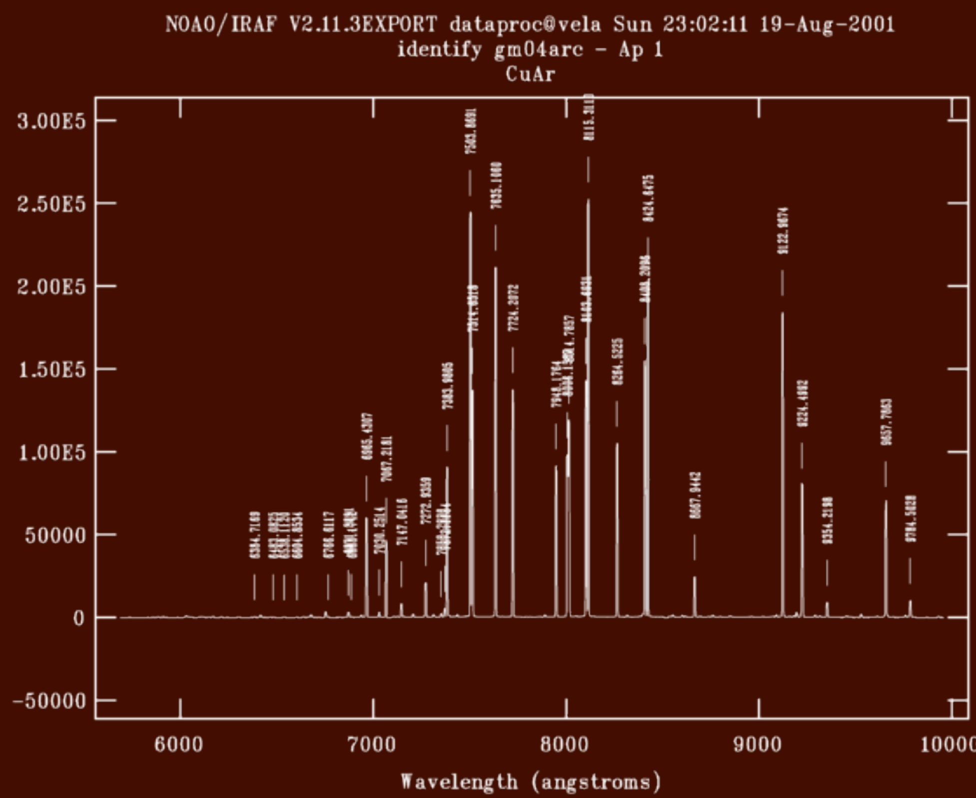
Extraction from the 2-D Frame



Standard: Sum of flux in extraction window

Optimal: Each pixel in extraction window weighted by its flux, gives actual variance estimate (Horne 1986, PASP, 98, 609) Cleans cosmic rays too

Wavelength Lamps



Wavelength Solution

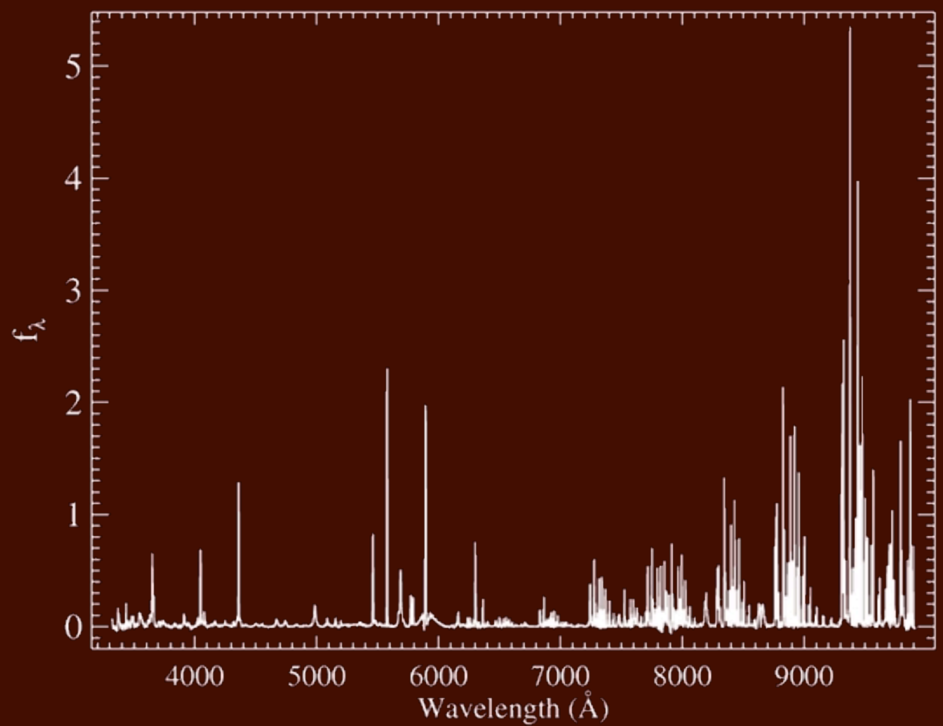
Identify calibration-lamp emission lines

Assign wavelengths to pixels, typically using a polynomial fit

Use as low-order a fit as possible

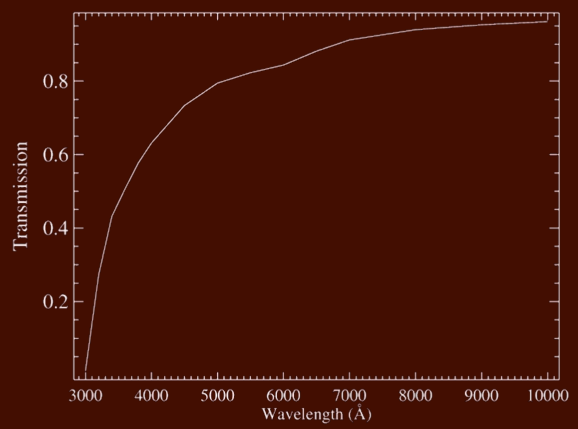
Telescope/instrument flexure may require lamps at the position of the object depending on the precision you need–check with the instrument scientist

Wavelength Solution



You always have another set of lines with known wavelengths
Even if you use calibration lamps, use sky for zero-point check

Standard Stars



The way to translate counts into flux units

Things change with position and time, so you want
a standard star as closely matched to object as possible

Standard Stars

Oke & Gunn (1983) HD19445, HD84937, BD+26 2606, BD+17 4708

Oke (1974)
Stone (1977) Feige 34, BD+28 4211
Massey et al. (1988)
Oke (1990)
Massey & Gronwall (1990)
Hamuy et al. (1994)
Bessell (1999)

Tables of AB magnitude vs. wavelength, all tied back to Vega

AB magnitude

Should be a minus sign!

magnitude for α Lyrae of $V = +0.03$. On this basis we define a monochromatic magnitude

$$AB = -2.5 \log f_\nu + 48.60,$$

where f_ν is the flux in ergs cm^{-2} s^{-1} Hz^{-1}. The constant is chosen such that $AB = V$ for an object with a flat spectrum; practically, $AB = V$ at 5480 Å for objects with relatively smooth spectra.

Oke & Gunn, 1983

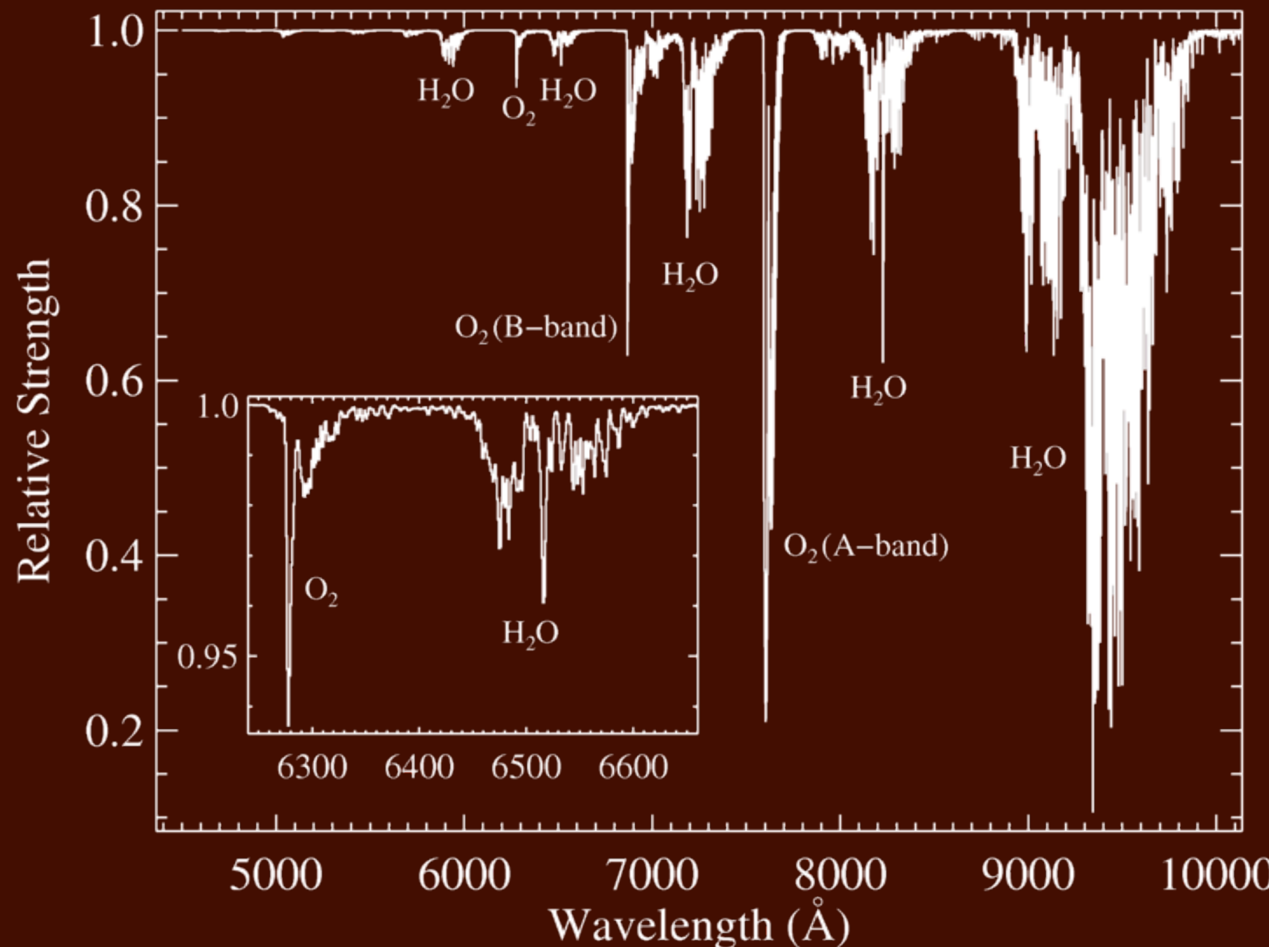
Standard Stars: Caveats

Flux is in coarse bins and often a few steps removed from Vega

Relative spectrophotometry is feasible, when all the calibrations are available

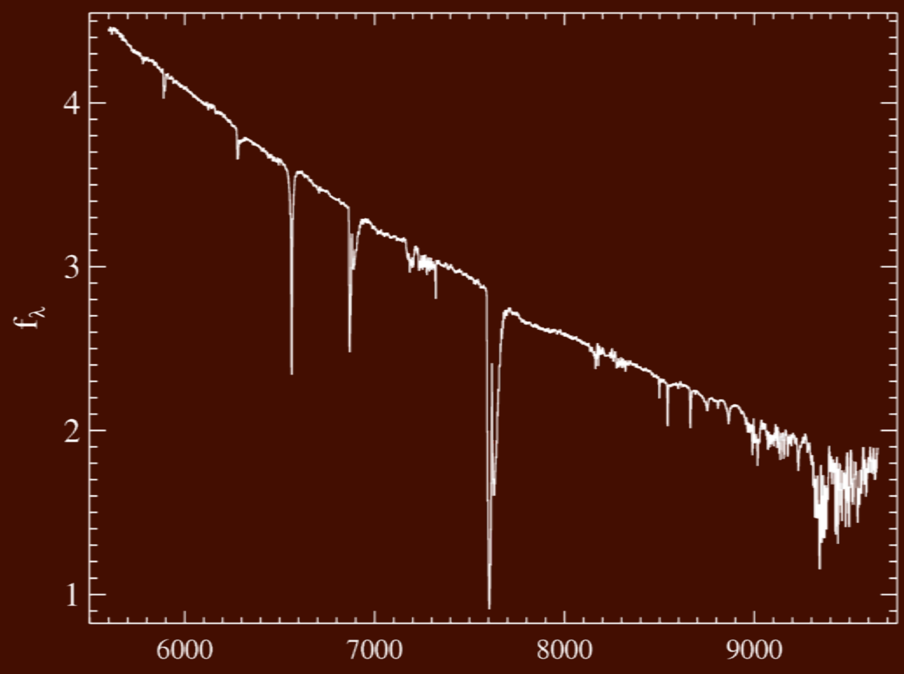
Absolute spectrophotometry is difficult, but you can do pretty well with extra effort

Telluric Absorption



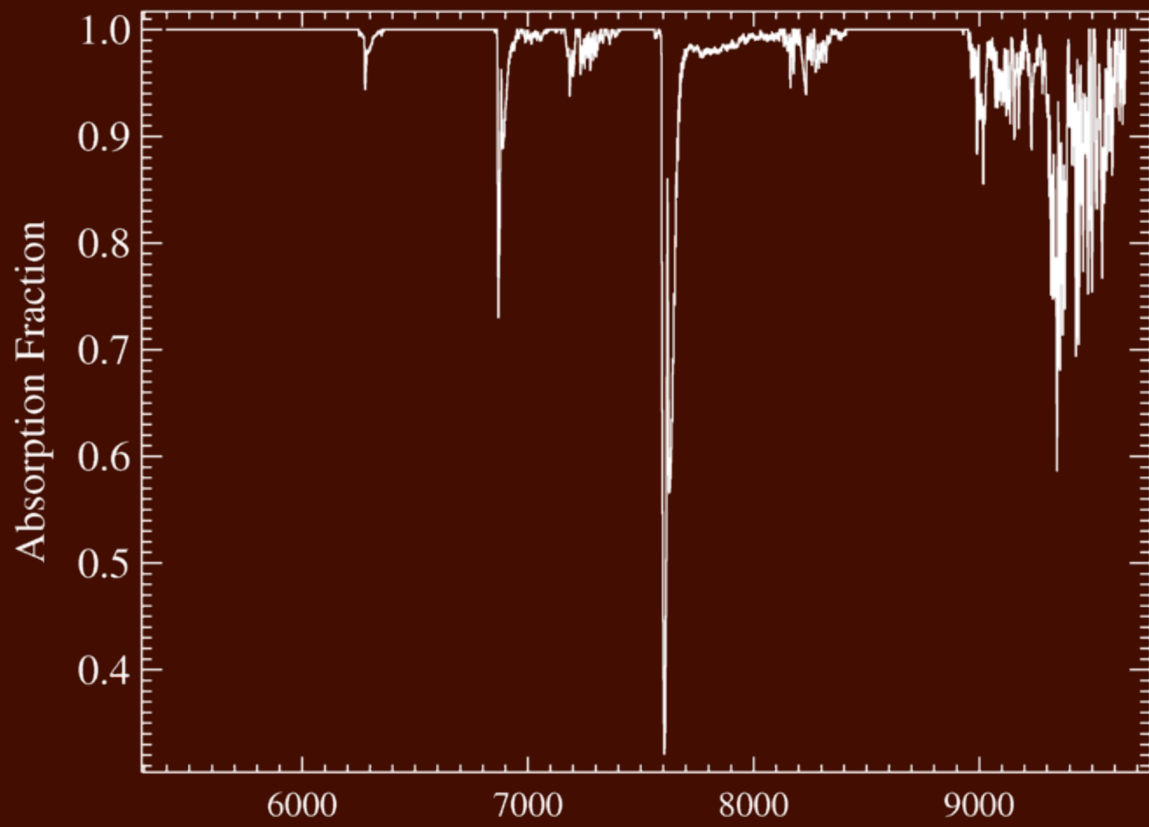
Wallace, Hinkle, & Livingston 1993, 1998)

Telluric Absorption



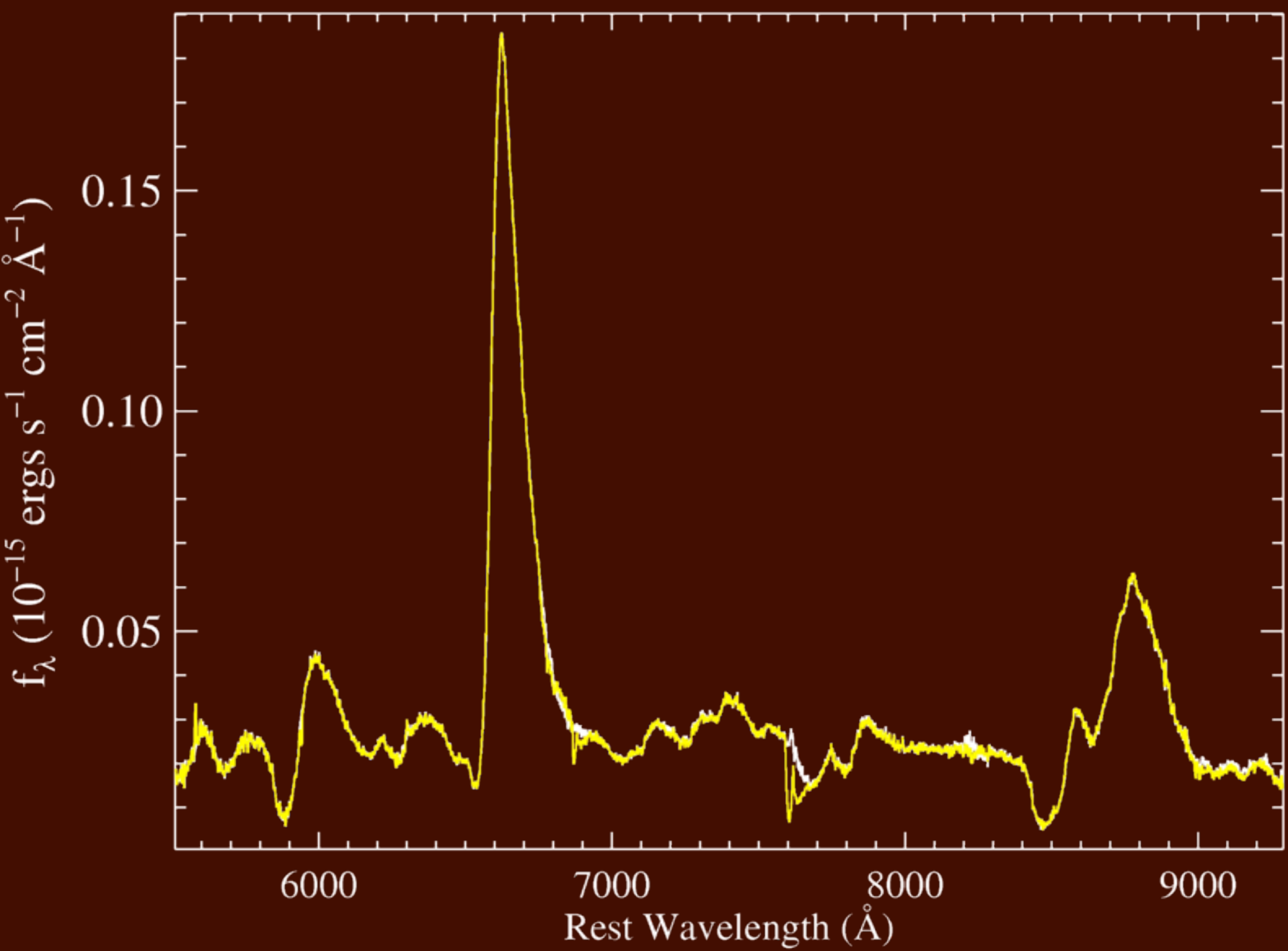
Smooth spectrum star with lots of counts, matched in airmass and resolution

Telluric Absorption

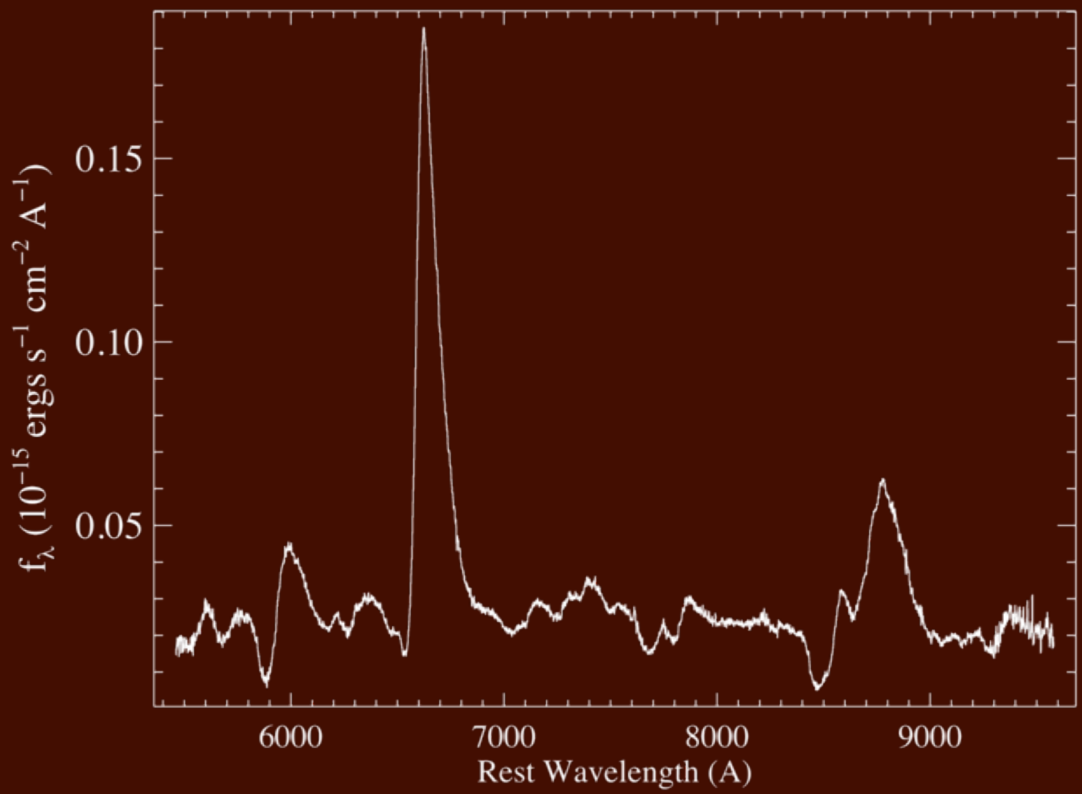


Can scale with airmass$^{0.6}$ (Wade & Horne 1988), but best to match standard to airmass of object

Telluric Absorption



The Reduced Spectrum



Not the final product. Reduction is a step, not the goal.

Final Reminder

- Do no harm
- Look at your data
- Make sure you have all the calibrations