# PHY 517 / AST 443:
# Observational Techniques in Astronomy

## Lecture 4:
## (Photometry)
## Spectroscopy

# Last Time: CCDs

*You want to take a sky image with our telescope + CCD camera. Which calibration images do need to take in order to analyze the science image? How do you take them? What do you do with them?*

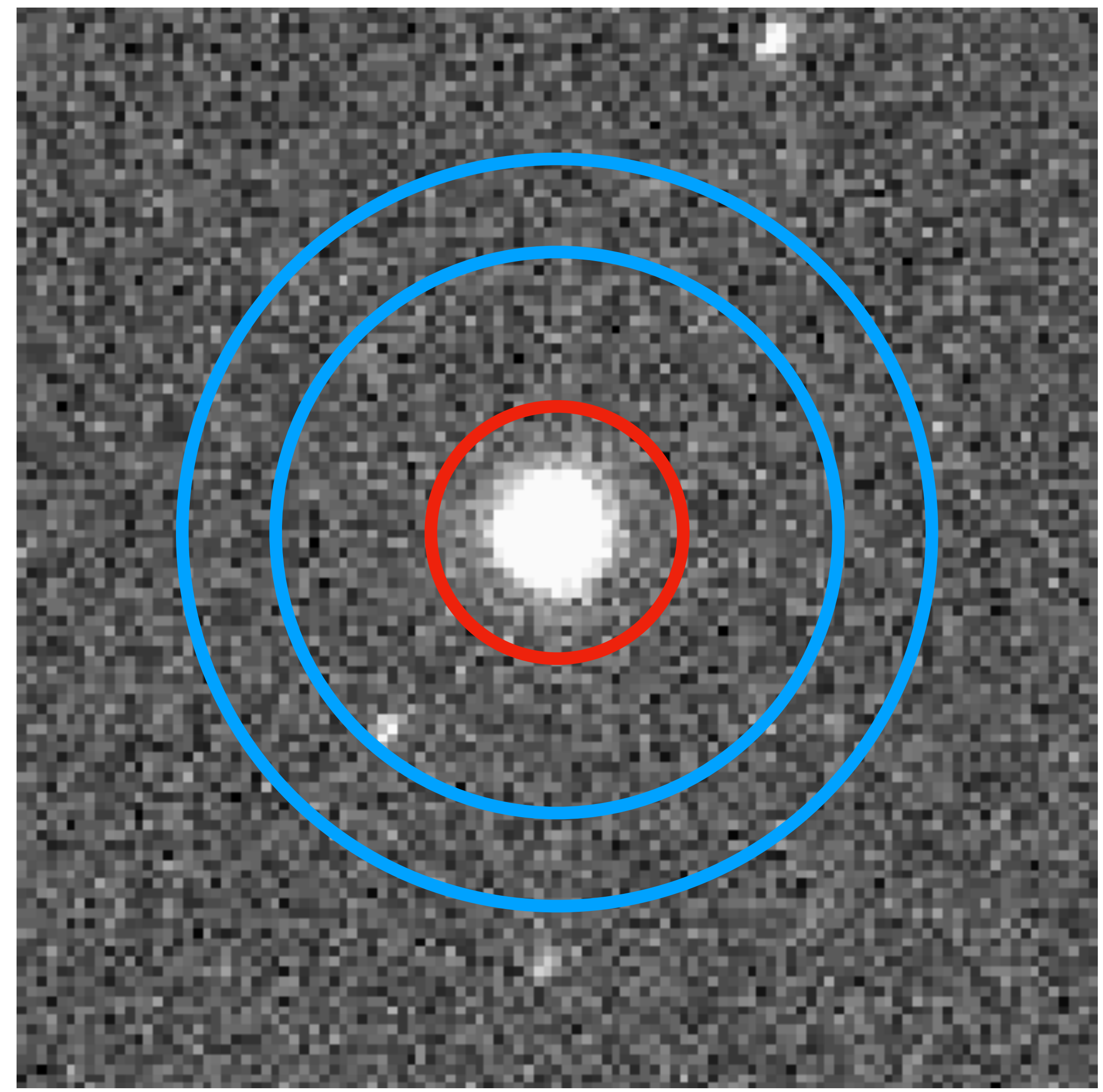
- Dark frames: same exposure time, same temperate -> measures bias + dark current
- Flat-fields: images of a uniform surface (e.g. dome), taken with the camera attached to the telescope in the same set-up as for the science image (*also needs to be dark-corrected*)

$$\text{calibrated image} = \frac{\text{science image} - \text{dark}}{\text{flatfield}}$$

# Calibrated image

Photometry: measure the brightness (also colors) of sky objects

*How would you measure the flux of this star?*



1. Sum up counts within aperture
2. Measure sky background (per pixel) from empty region of sky
3. Subtract estimated sky counts
4. Repeat for a reference star of known magnitude

$$m_1 - m_2 = -2.5 \log\left(\frac{F_1}{F_2}\right)$$

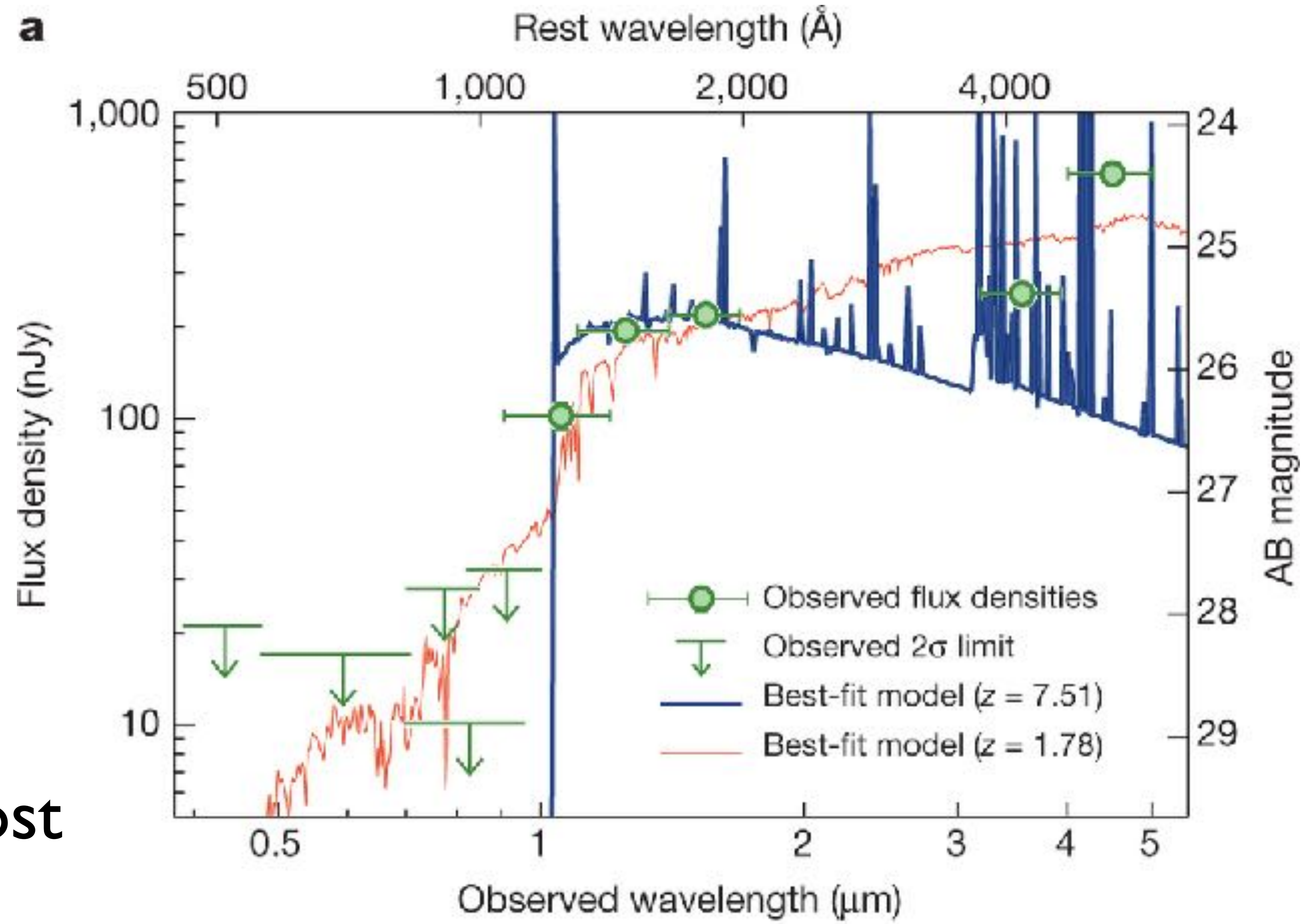
# Spectroscopy

# Motivation

photometry only measures integrated flux (over filter band)

gives some information about the object properties, but often not enough

e.g.: finding the most distant galaxies



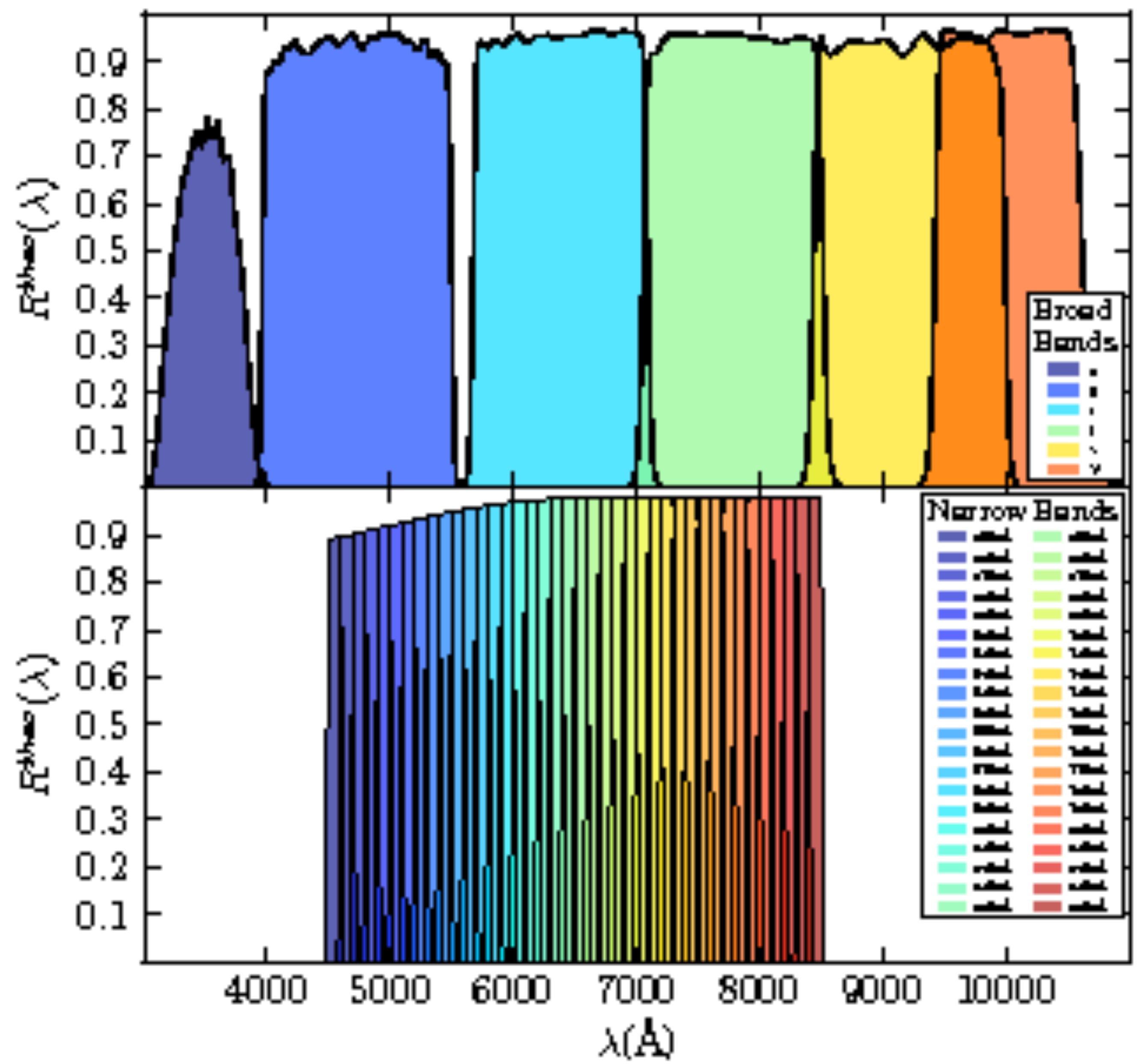

Finkelstein et al. 2013

# Narrow-band imaging

can determine spectrum of object with images in many narrow-band filters

advantage: can determine spectra of all objects in the same FOV

disadvantage: have to take a lot of images!

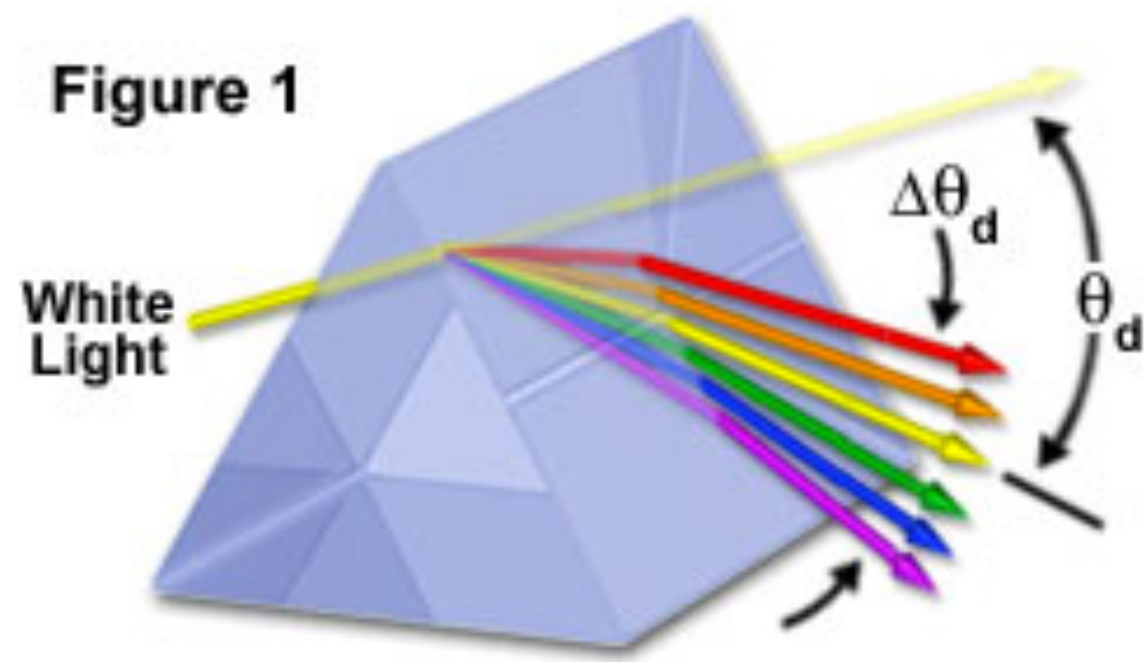



The PAU Survey

# Spectroscopy

add a dispersing element to split up the light from an object: measure the spectrum directly

e.g. a prism:

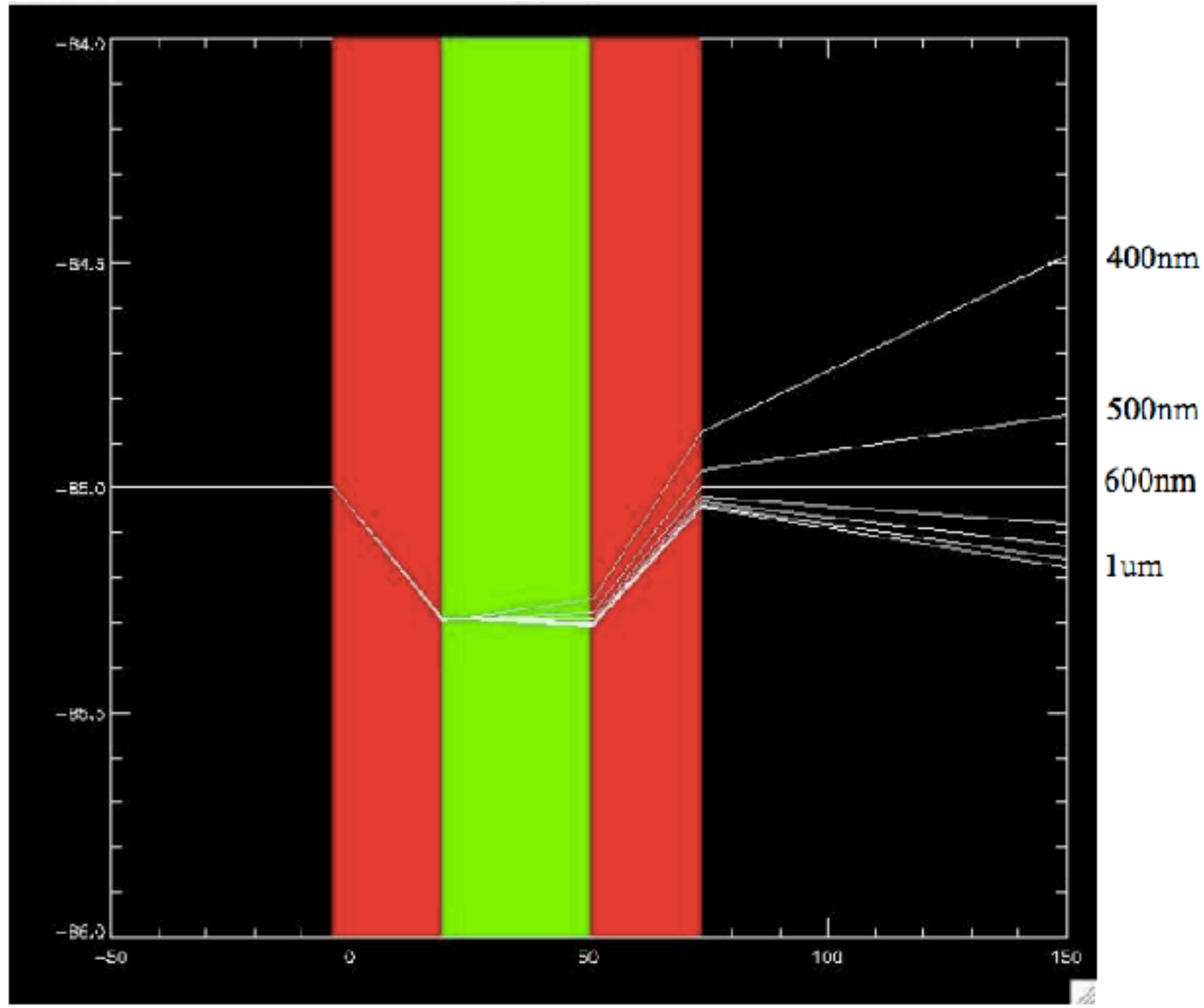



Olympus

# Prism Spectroscopy

only few astronomical spectrographs use prisms

- low dispersion (resolution)
- dispersion varies with wavelength




LDP Prism description

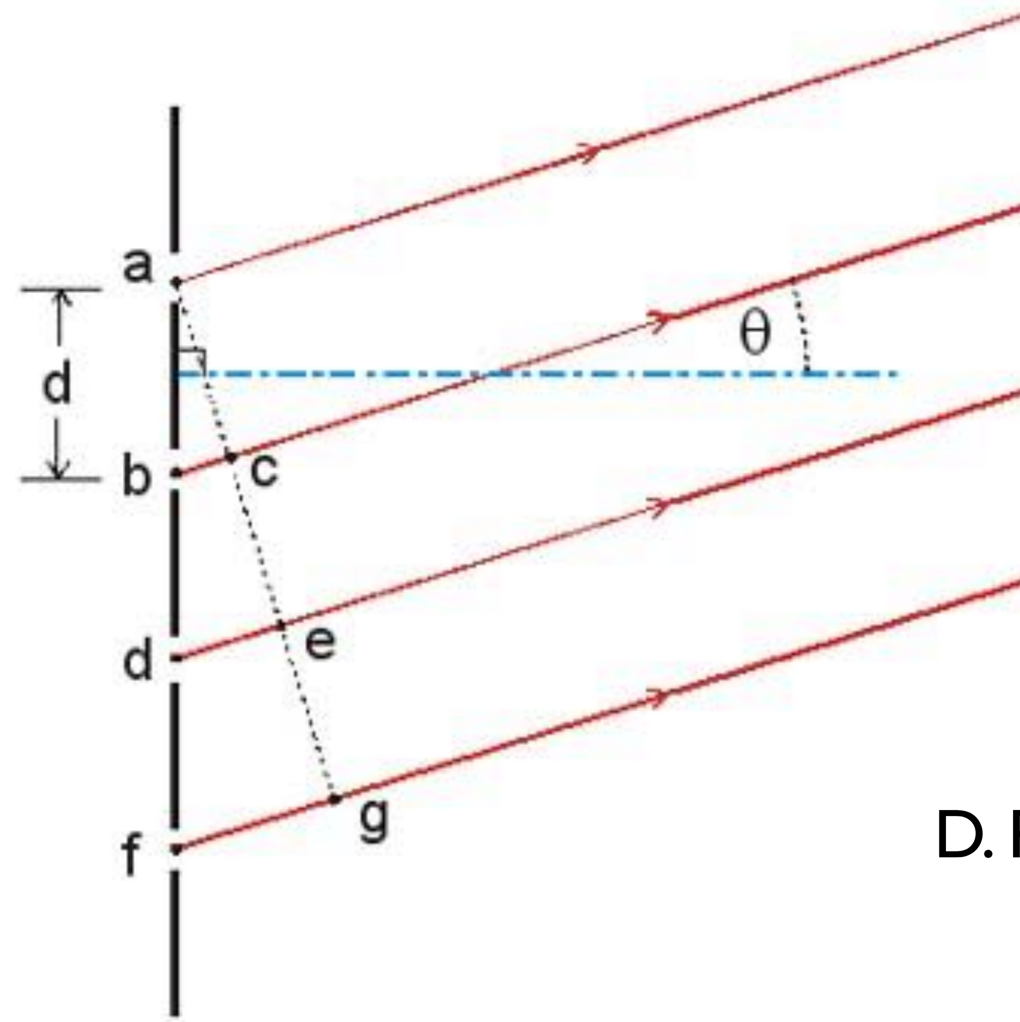
"low dispersion prism" for IMACS spectrograph on Magellan 6-m telescope; uses 3 prisms

# Diffraction gratings

make use of wave properties of light: interference

grating: many parallel lines (~500/mm)

similar to single-slit and double-slit experiments

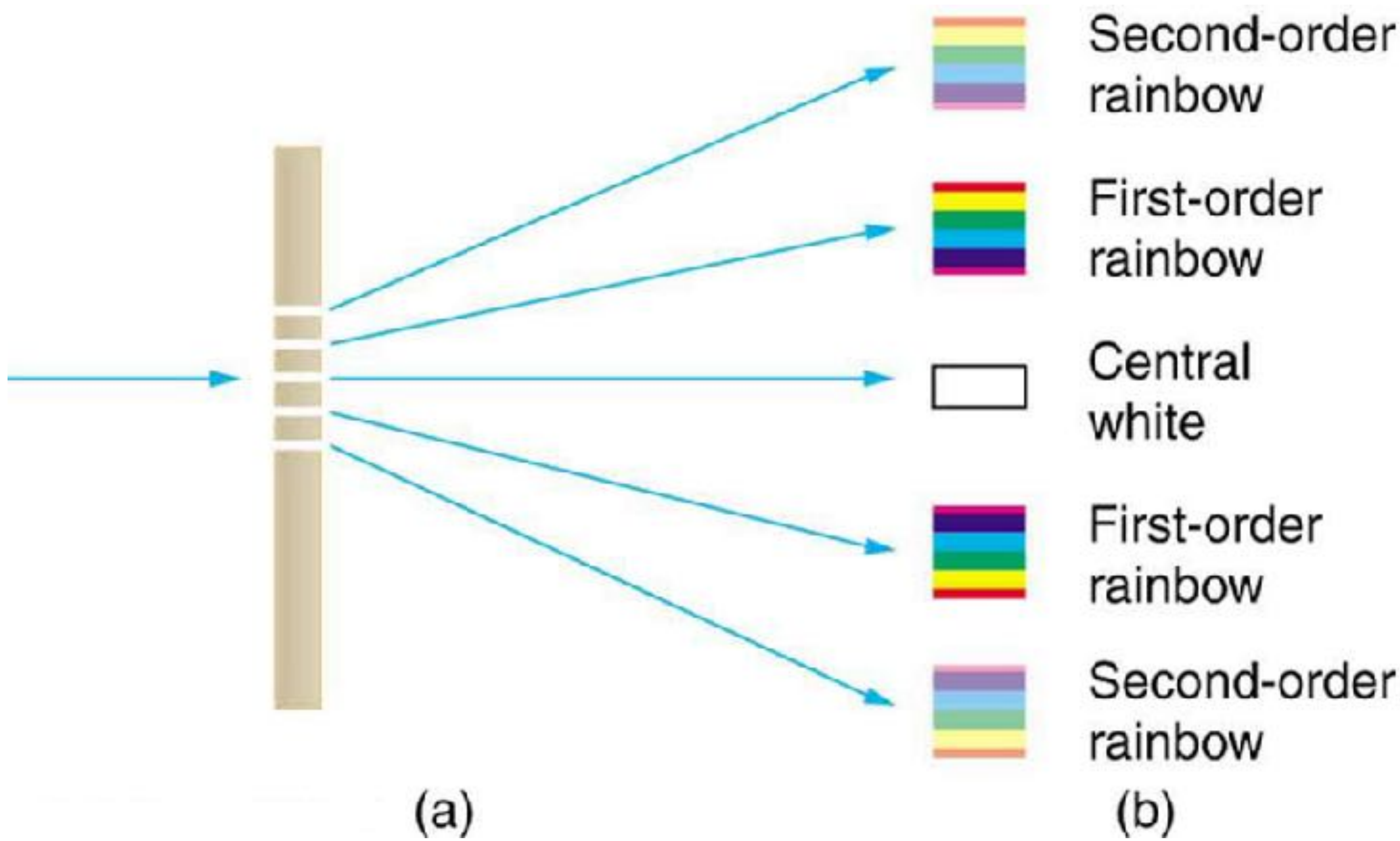



D. Pogosian

if b-c = λ: maximum at θ
and d-e = 2λ, etc.

position of *n*th order: $$n\lambda = d \sin\theta$$

# Diffraction gratings

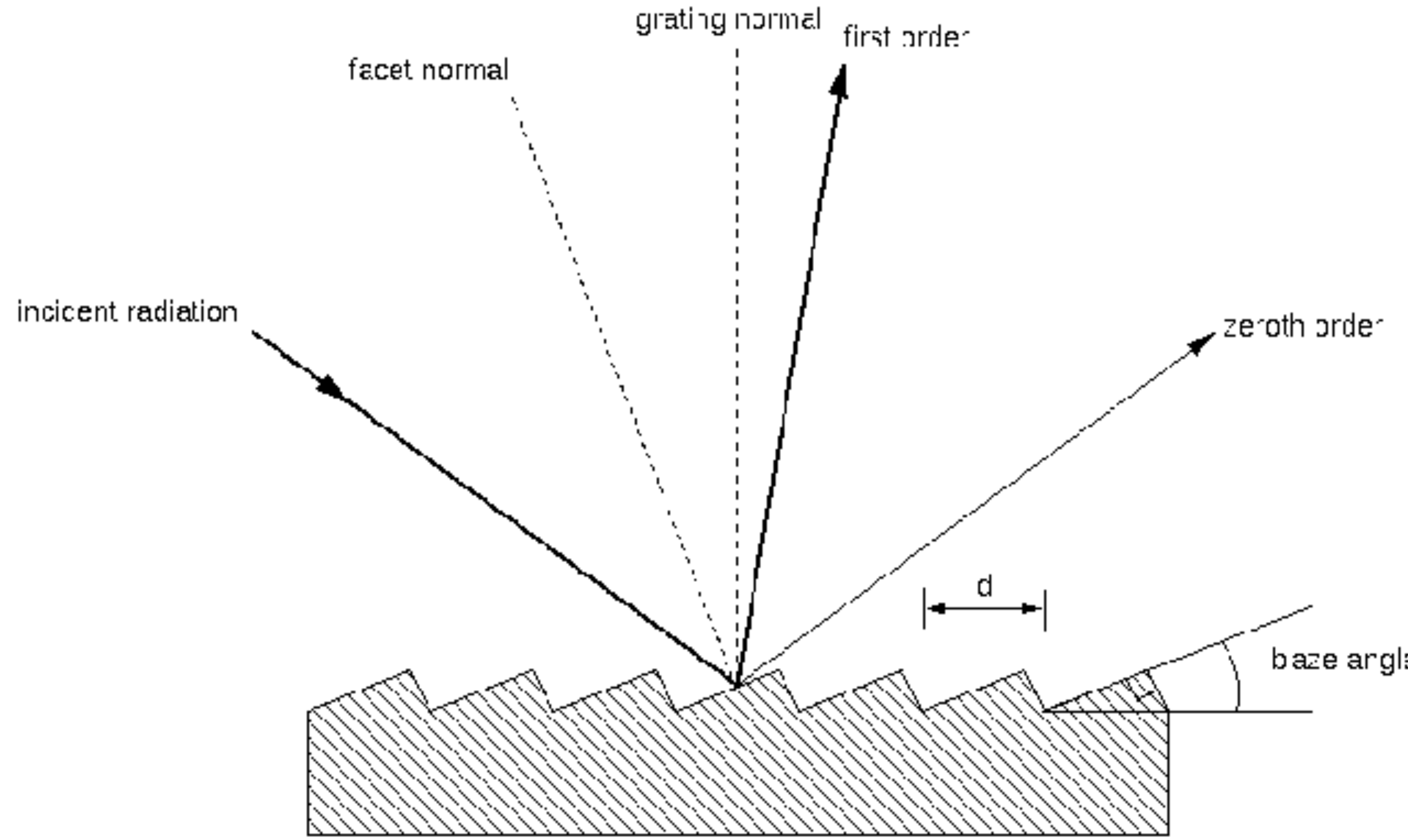



OpenStax University

# Diffraction gratings

can be transmission gratings or reflection gratings

most astronomical spectrographs use reflection gratings



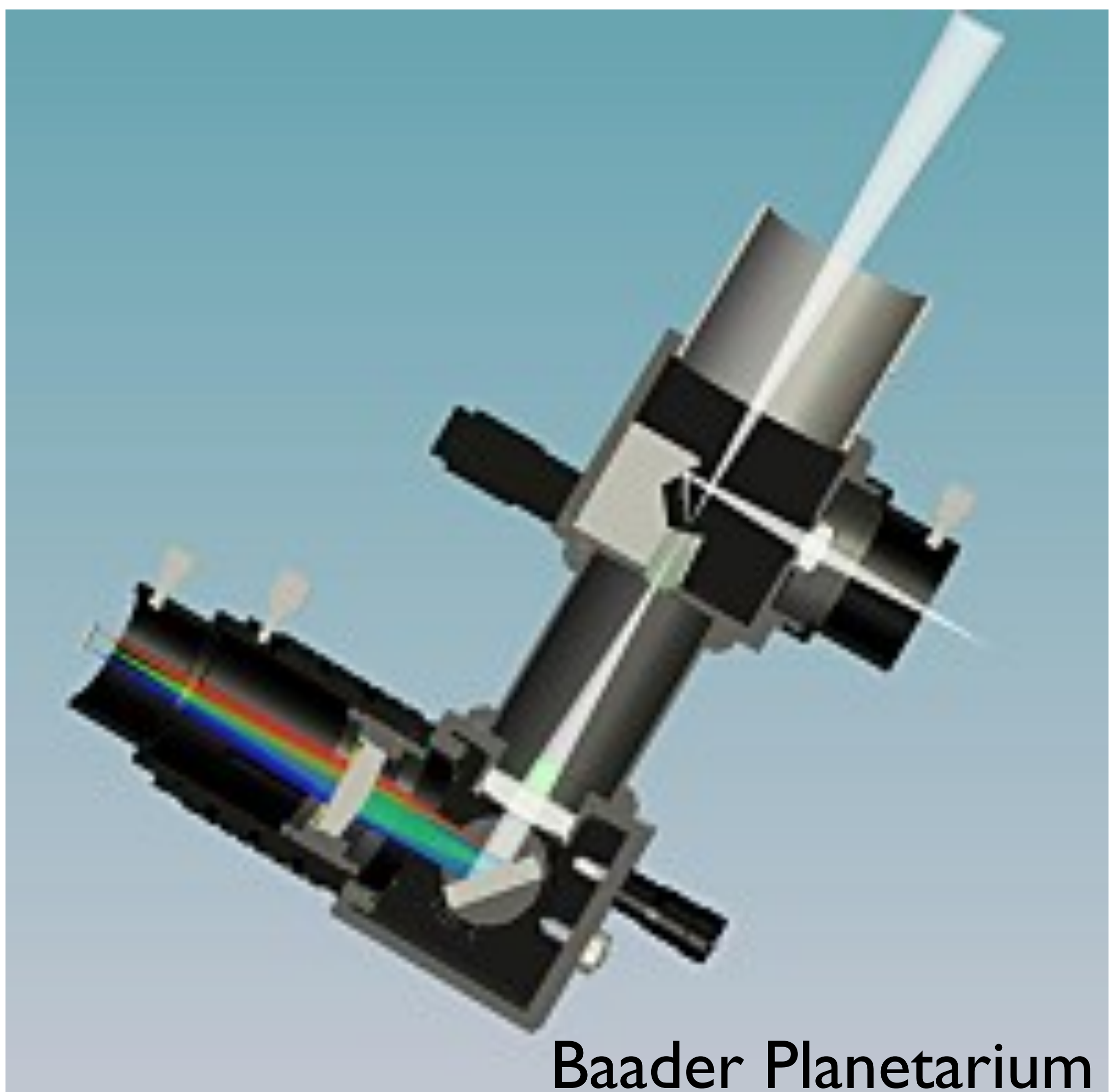

Dhillon 2012

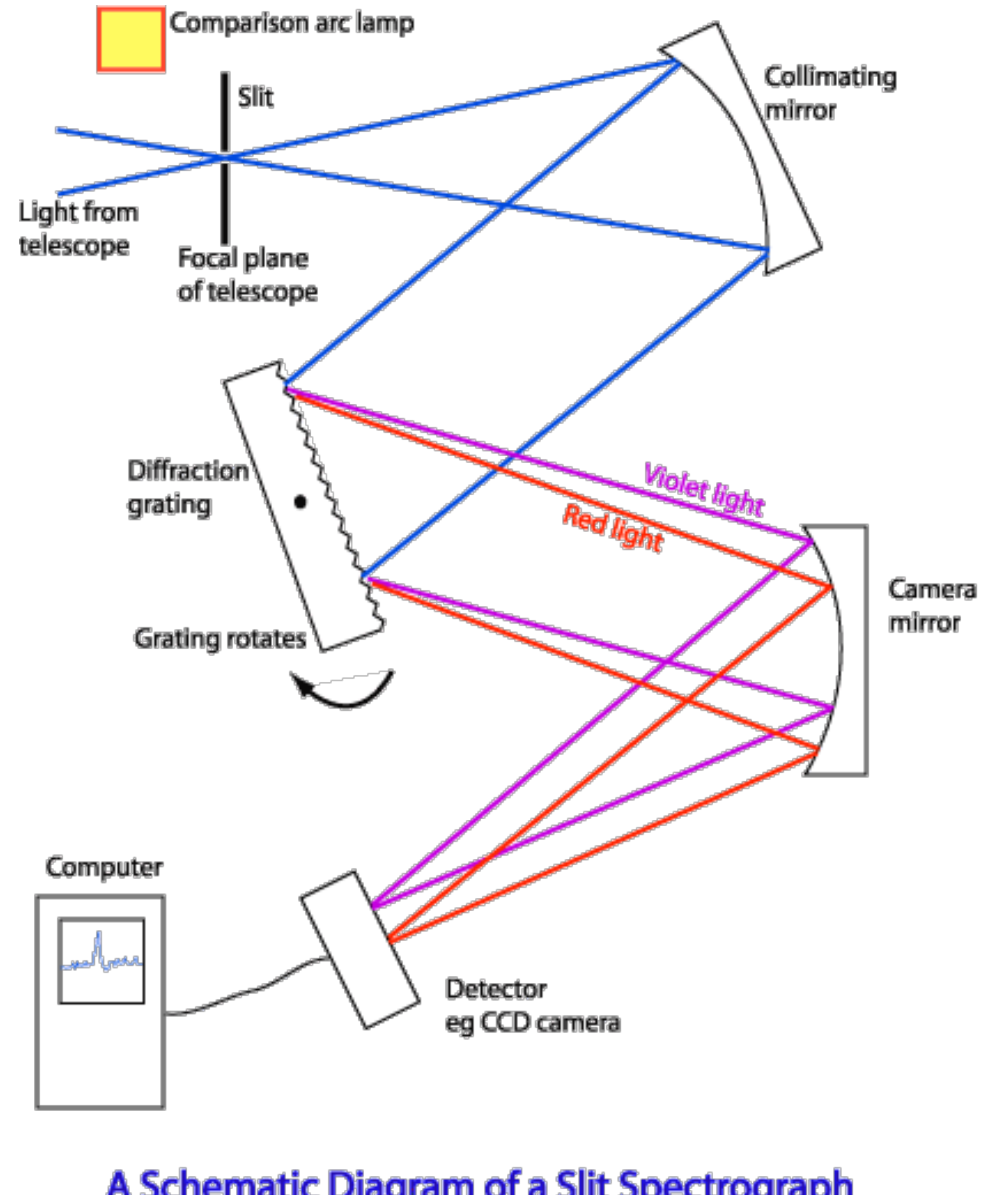
blaze wavelength: wavelength for direction of reflection coincides with desired spectral order
→ maximal efficiency

# Typical spectrograph

entrance: usually a slit, similar to seeing size

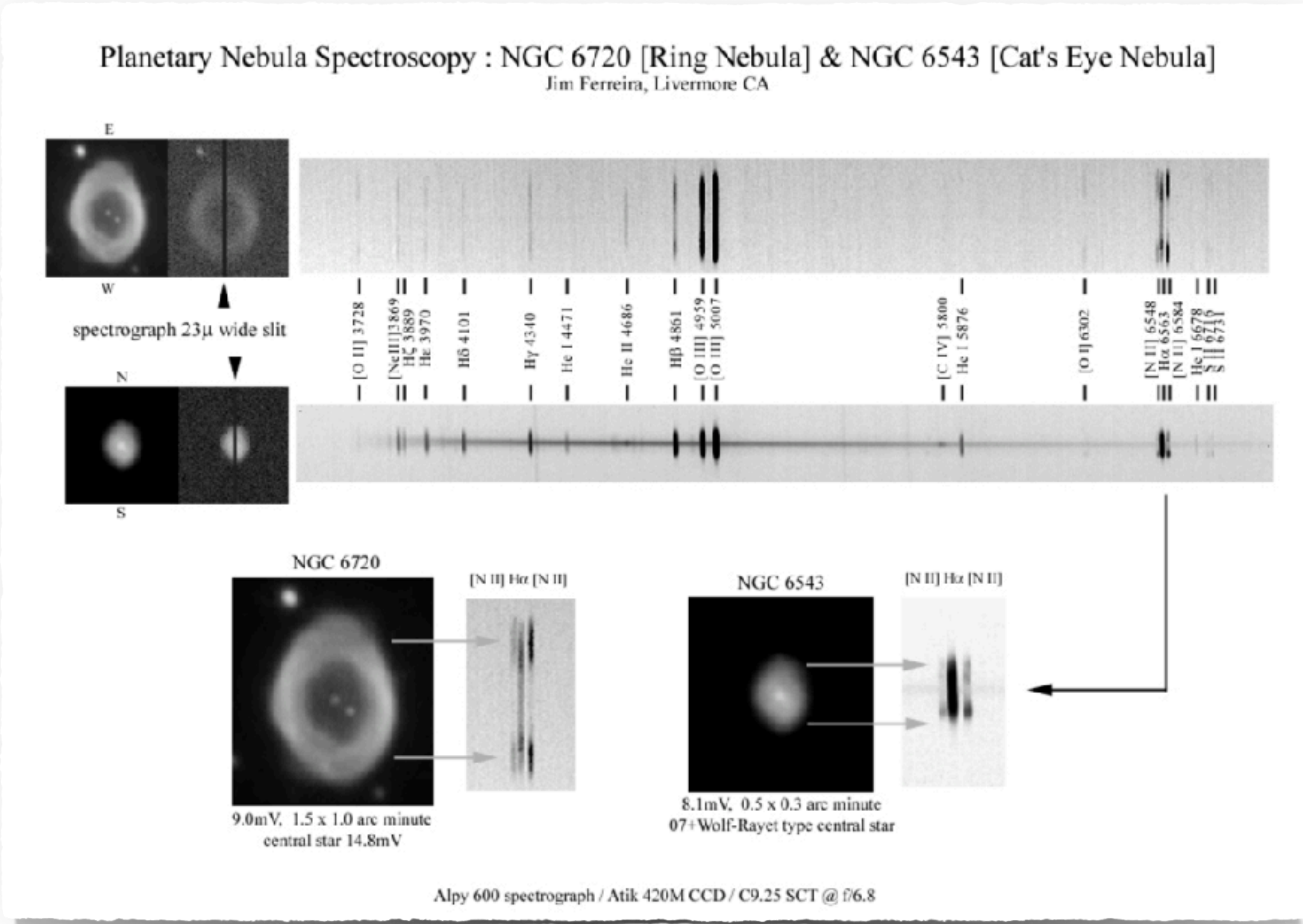
collimator: converts a diverging beam to a parallel beam



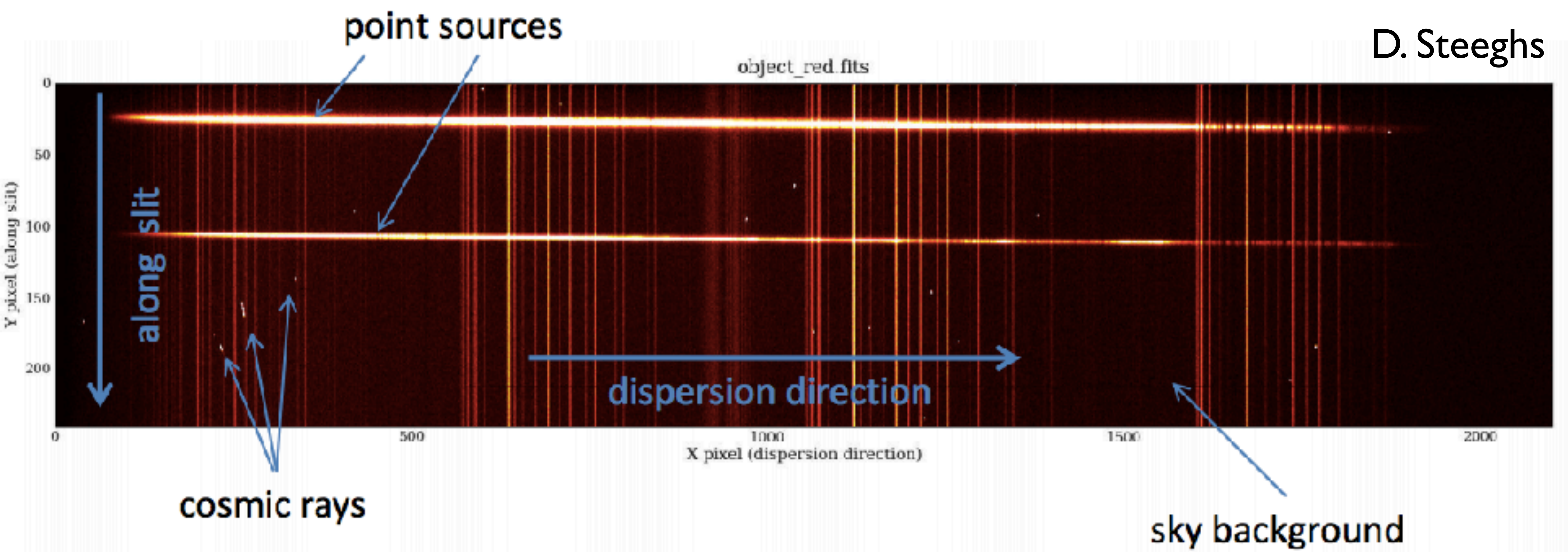




Kaler, *Stars and their Spectra*

# Long-slit observations



# Long-slit observations

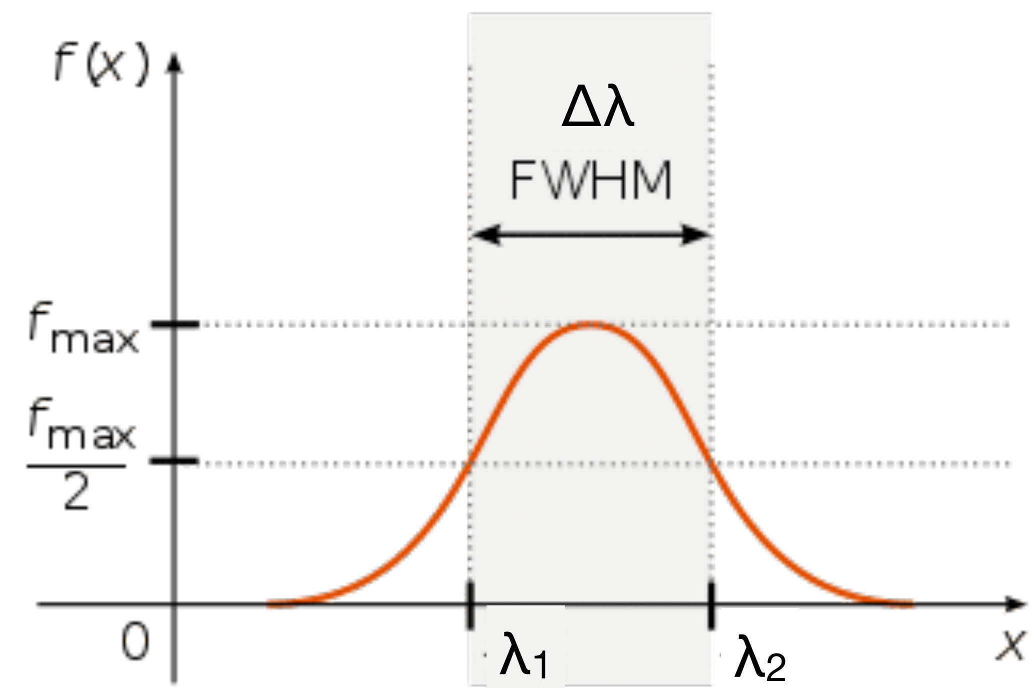



- long axis of CCD used to sample spectrum
- spatial information along slit still available: two objects, lots of sky
- sky background has a lot of emission lines!

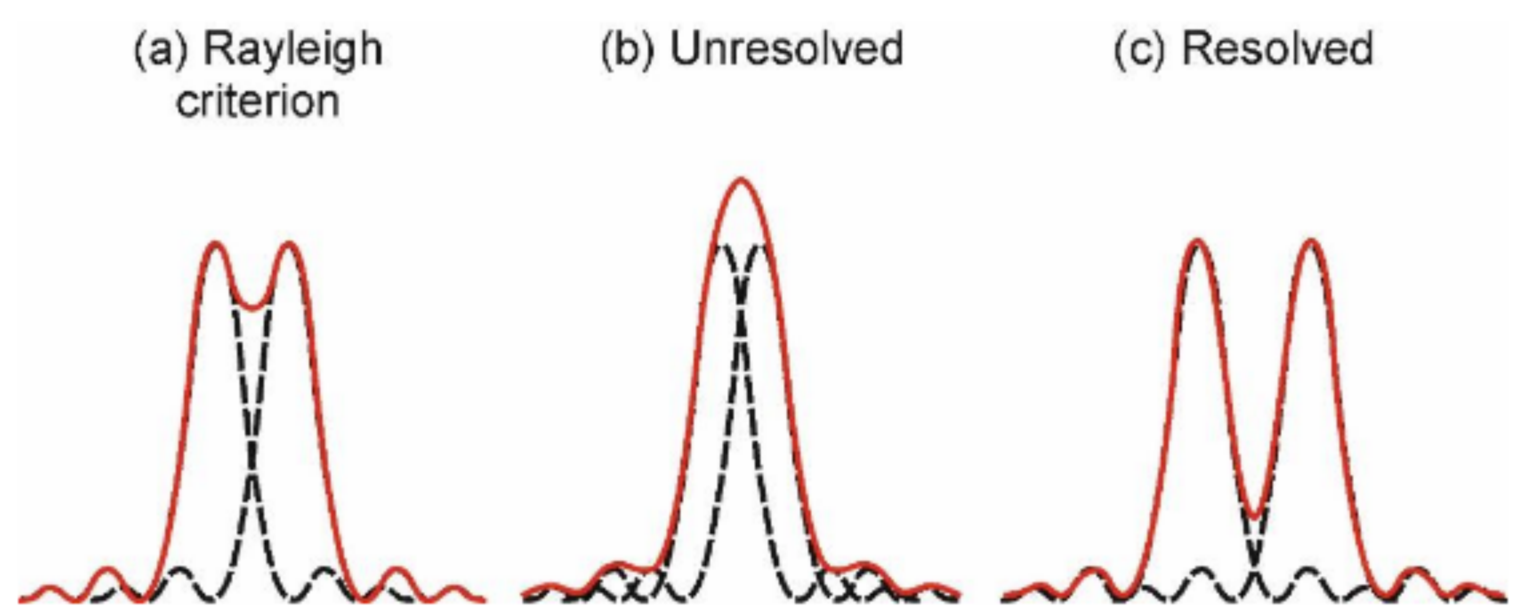
# Spectral Resolution

spectrographs have a finite resolution $\Delta\lambda$:

- FWHM of observed line width of incoming delta-function emission line




- minimum wavelength separation to resolve 2 lines




Note: very similar to the definition of *spatial* resolution of a telescope!

# Spectral Resolution

often expressed as *R*:

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

determined by:

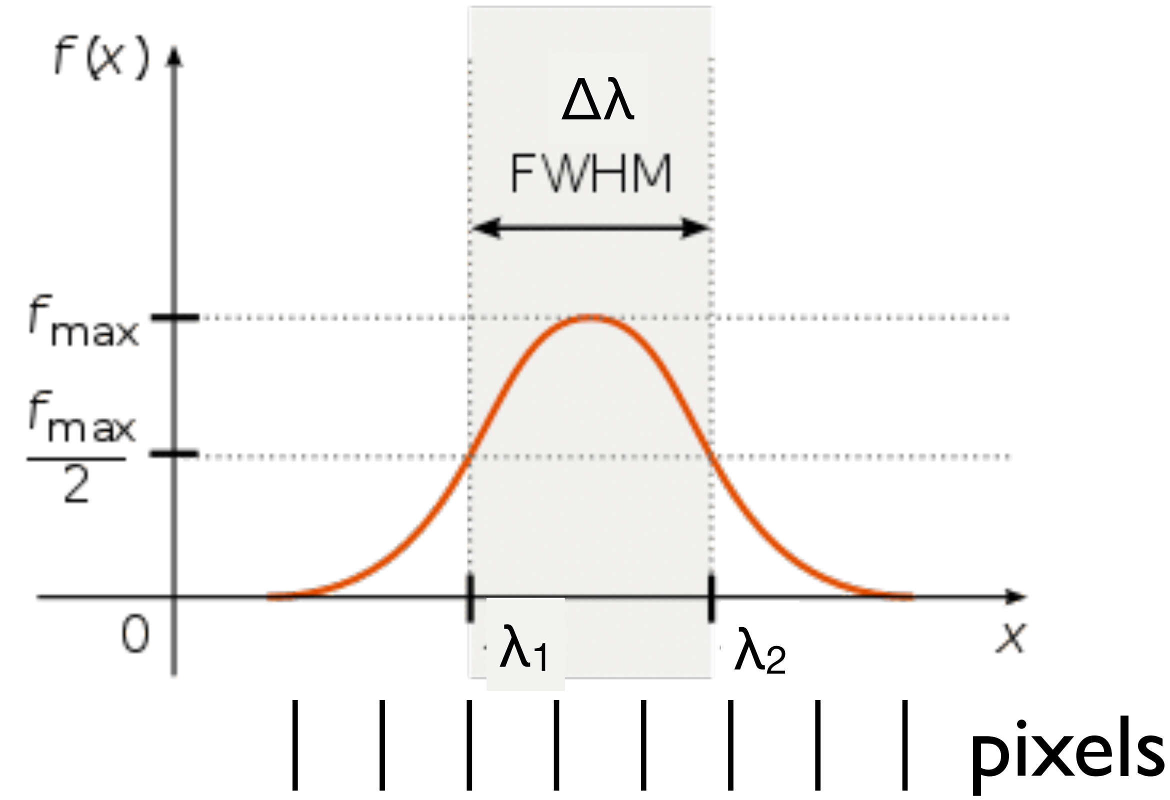
- grating (line density): more lines → higher R
- width of entrance slit: wider slit → lower R

| | | |
|---|---|---|
| R < 1000 | low-resolution | e.g. our "low-resolution" spectrograph |
| 1000 < R < 10,000 | medium-resolution | e.g. our "high-resolution" spectrograph |
| R > 10,000 | high-resolution | Echelle spectrographs |

# Spectral Dispersion

resolution: *R* or Δλ

dispersion: length Δλ' of spectrum over single pixel, [Å/px]



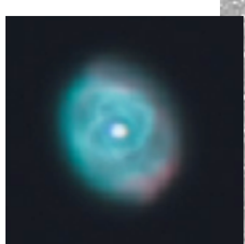

to properly sample the spectrum: $\Delta\lambda \sim 2 - 3\,\Delta\lambda'$

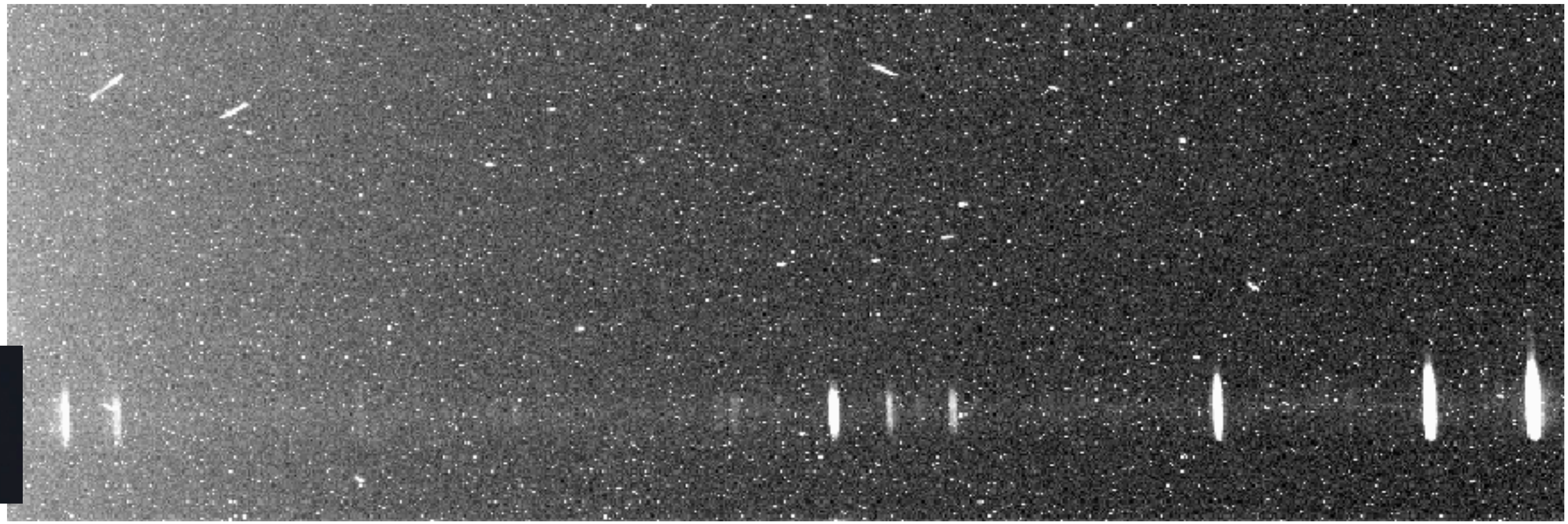
analogous to imaging: size of PSF vs. pixel scale

# Spectroscopic Calibration

- dark frames!
- flat field: use bright continuum source
  - small-scale pixel sensitivity variation
  - variations in slit width
- wavelength calibration: which position on the CCD corresponds to which wavelength?
  - use "arc" lamps with discrete emission lines
  - can also use sky emission lines
- flux calibration:
  - "spectrophotometric" standard stars: stars with known spectral shapes, smooth continua

# Spectroscopic Data Reduction

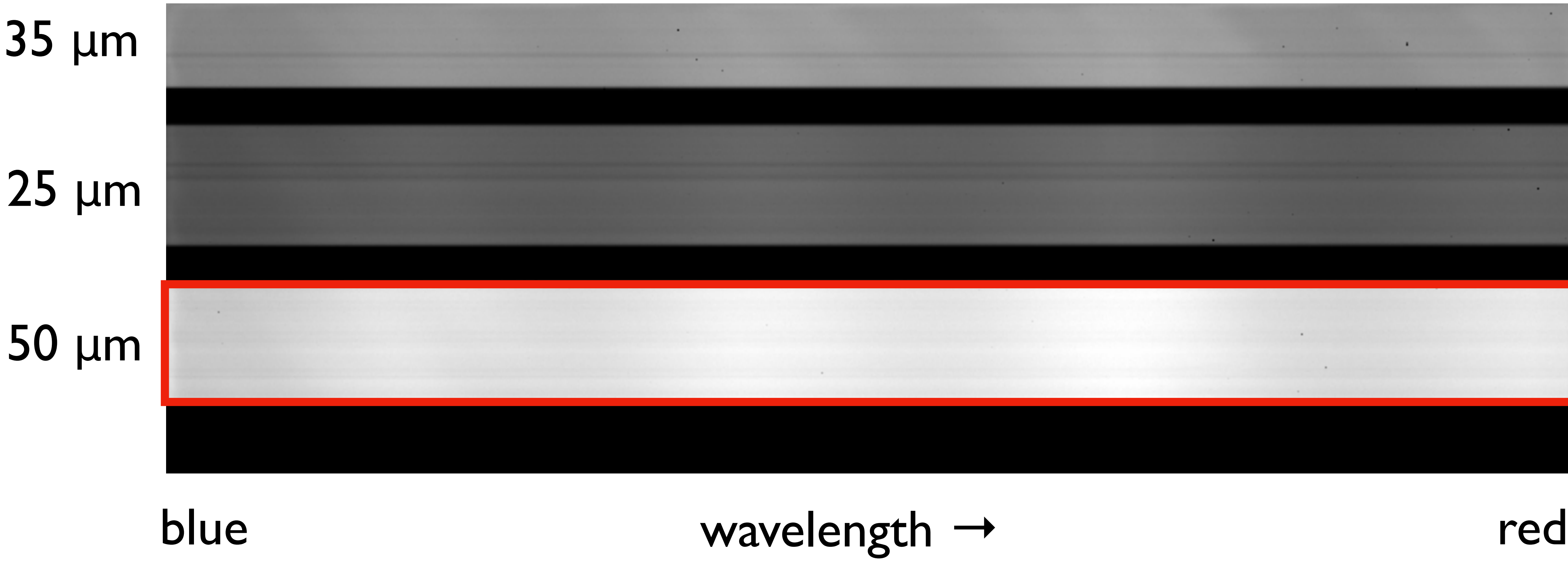




blue wavelength → red

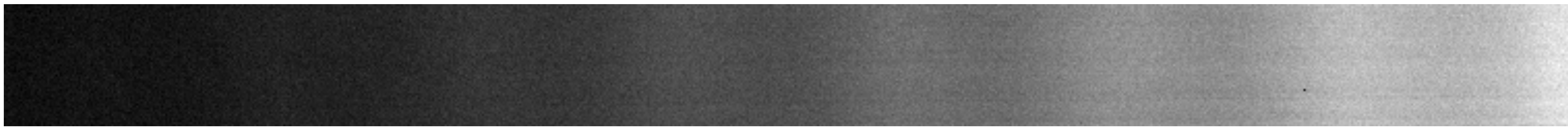
1. Subtract master dark
2. (Median-combine multiple exposures IF target always in the same place)

# Spectroscopic Flat-field

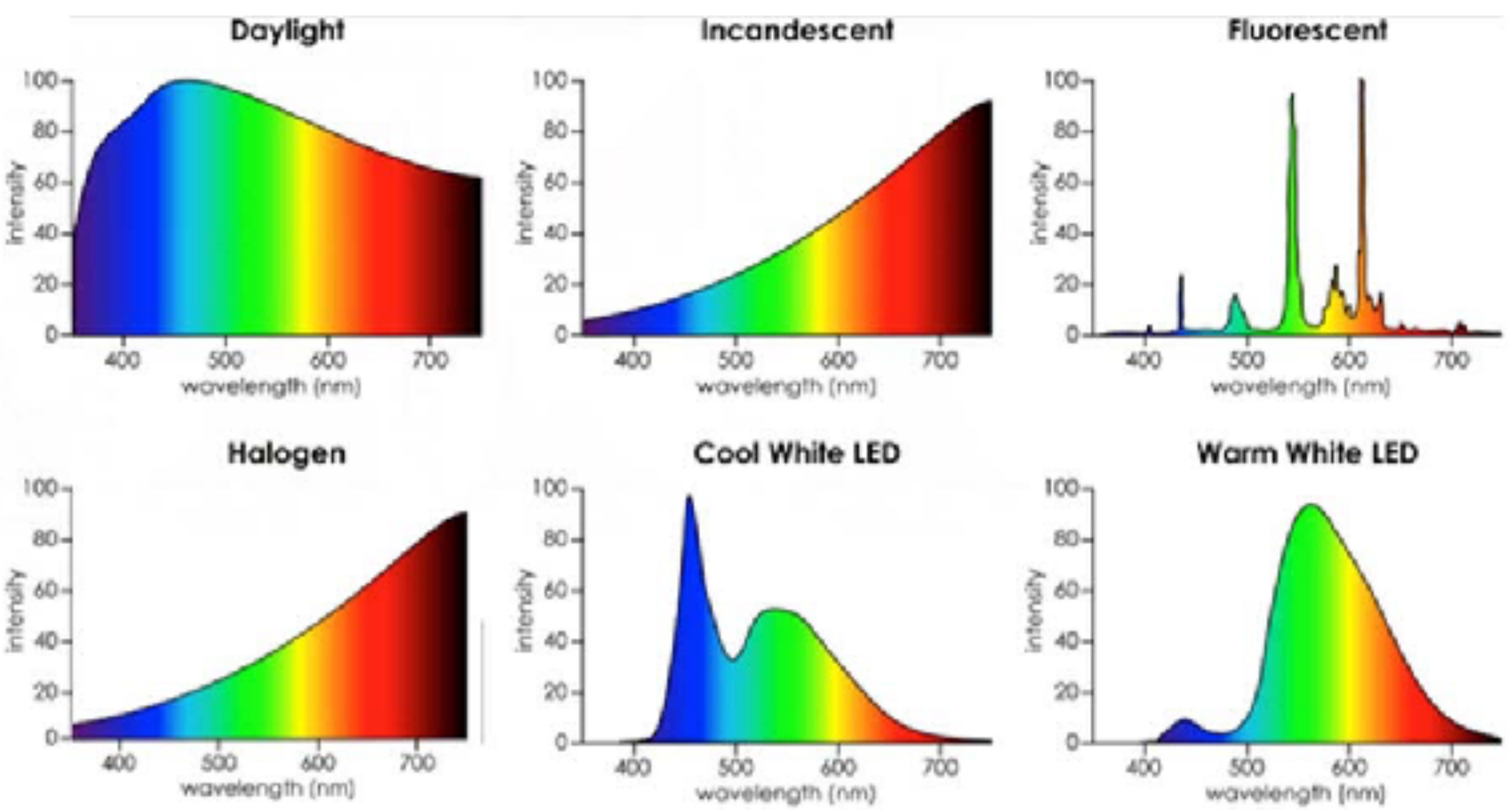



3. Use flat-field to cut all images (flat, science, arcs) to desired pixel rows (only choose rows that are fully illuminated blue-red)

# Spectroscopic Flat-field (2)



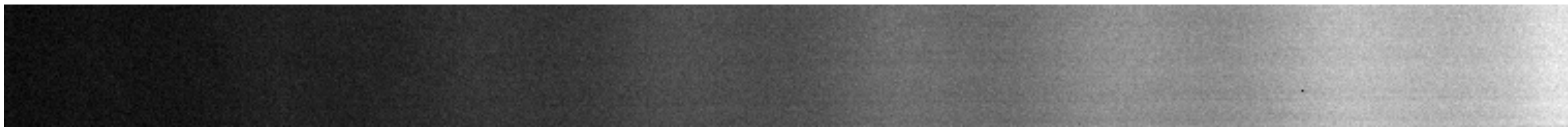
blue wavelength → red



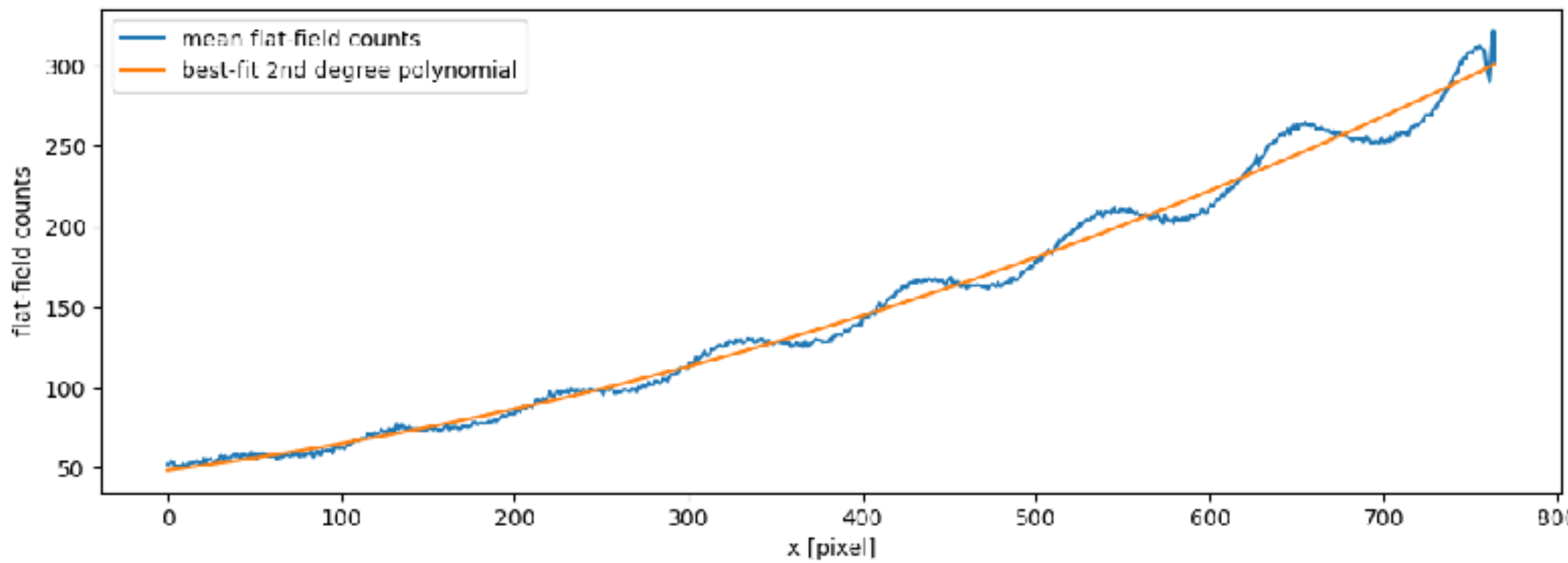

The overall shape of the spectroscopic flat-field is **not** indicative of sensitivity as fct. of wavelength.

Can still use it to correct pixel-to-pixel sensitivity variations.

4. “Collapse” 2-d flat-field to 1-d, by taking the mean (or median) of each column:

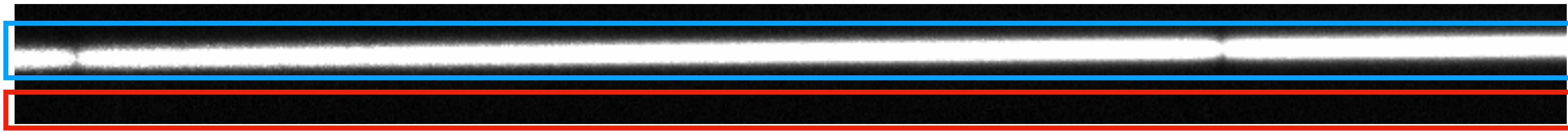


5. Fit low-order polynomial to 1-d flat-field:

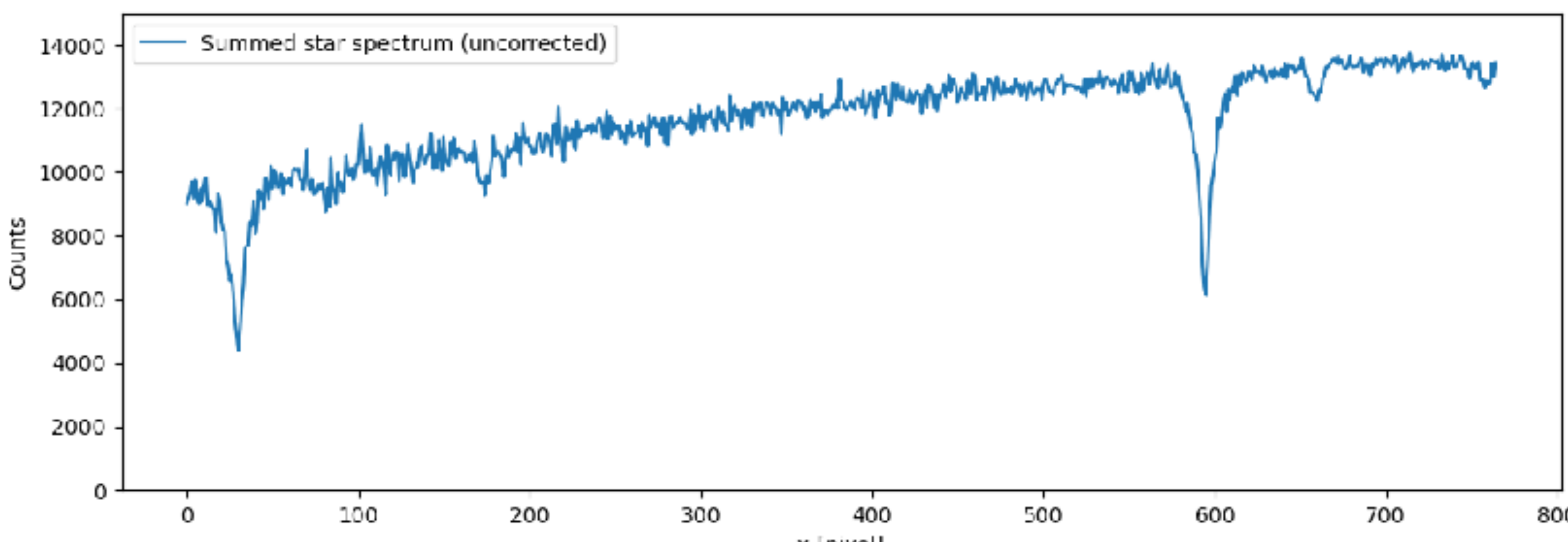



6. Normalize 2-d flat by the best-fit polynomial - **THIS** is the spectroscopic flat-field; divide science frames by it

# 2-d → 1-d spectrum + background subtraction

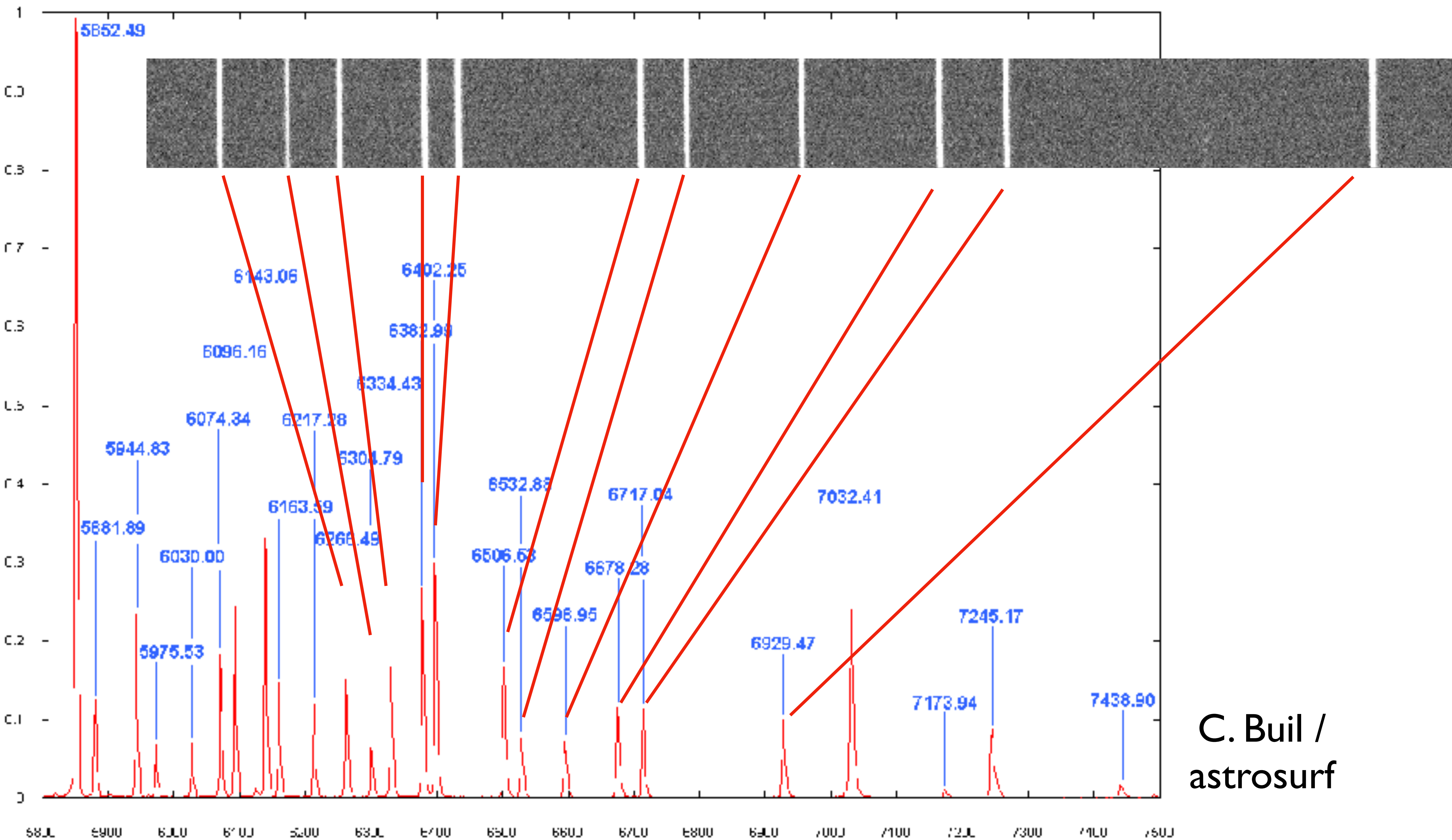


7. Define source rows: all rows with flux from object, and background rows: all empty rows.
   Estimate *background flux per pixel* at given x-position (wavelength).
   Subtract background from all rows.
   Sum over source rows.



# Wavelength Calibration

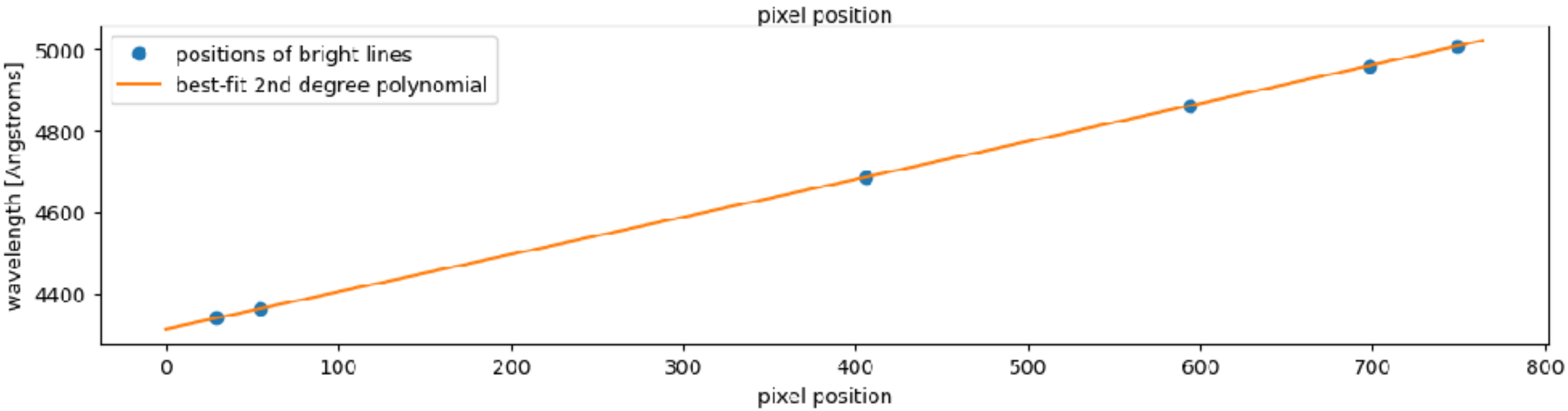
map pixel position to wavelength, using arc lamps (Ne, Hg, …) or emission lines in science spectrum




C. Buil / astrosurf

# Wavelength Calibration

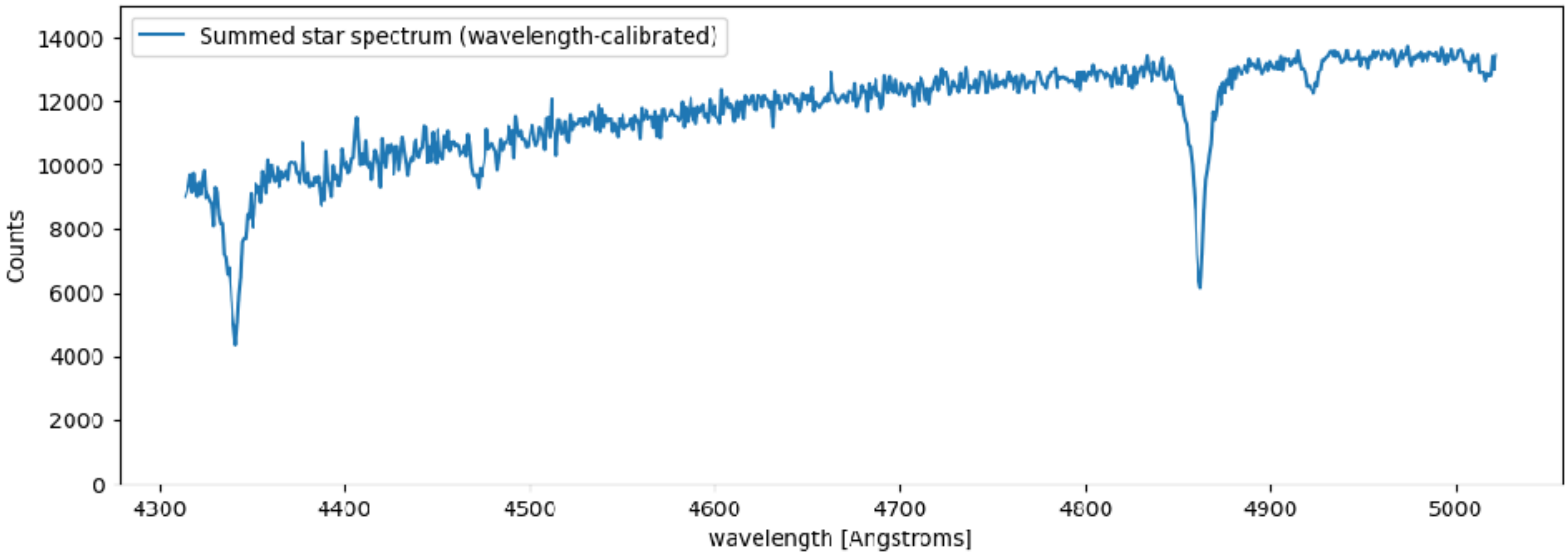
map pixel position to wavelength, using arc lamps (Ne, Hg, …) or emission lines in science spectrum



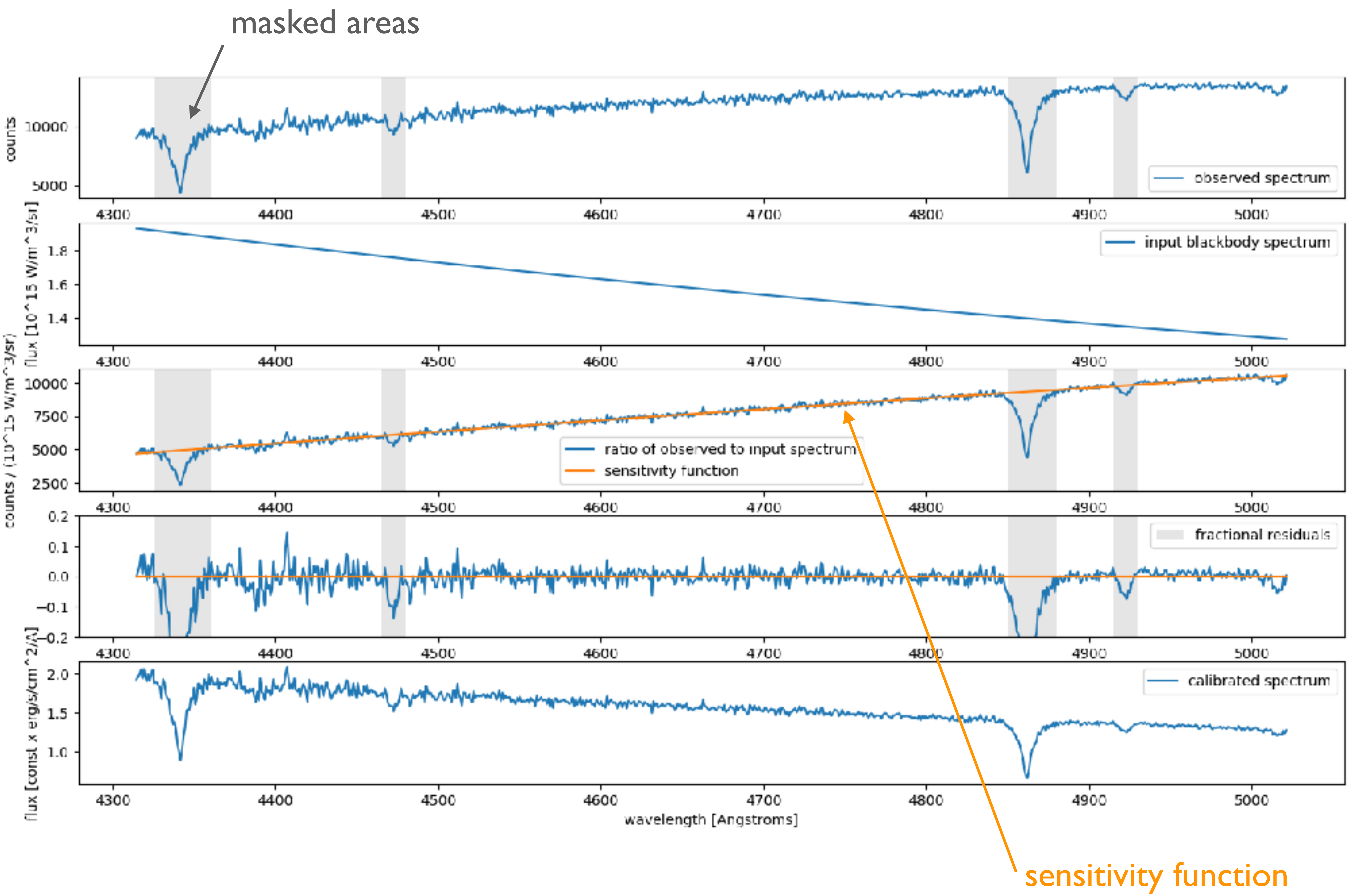

8. fit wavelength as function of pixel position → wavelength calibration

# Flux Calibration

resulting spectra are in units of ADU counts, not flux.

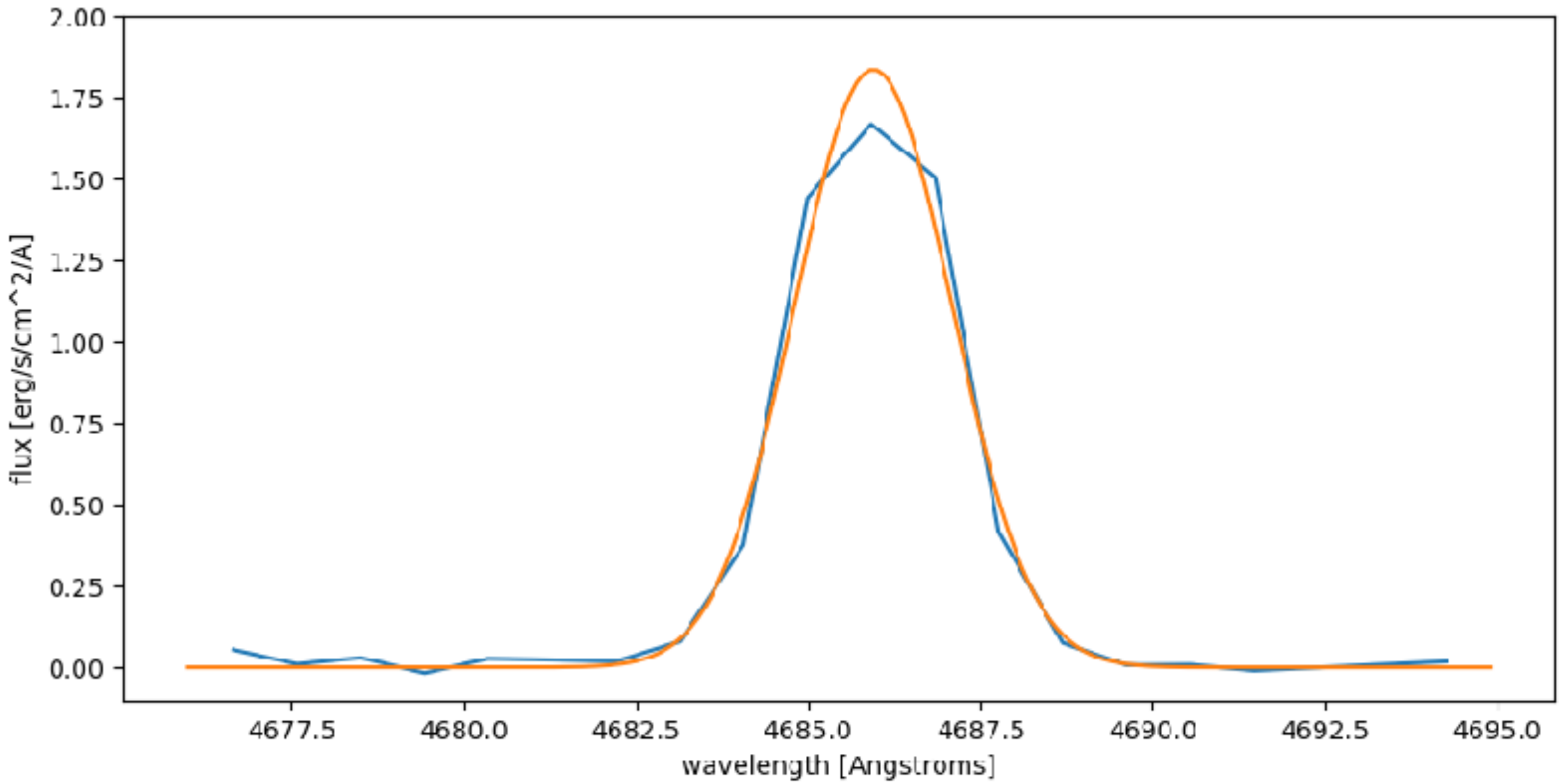



9. use observations of a star with known true spectrum to derive sensitivity function



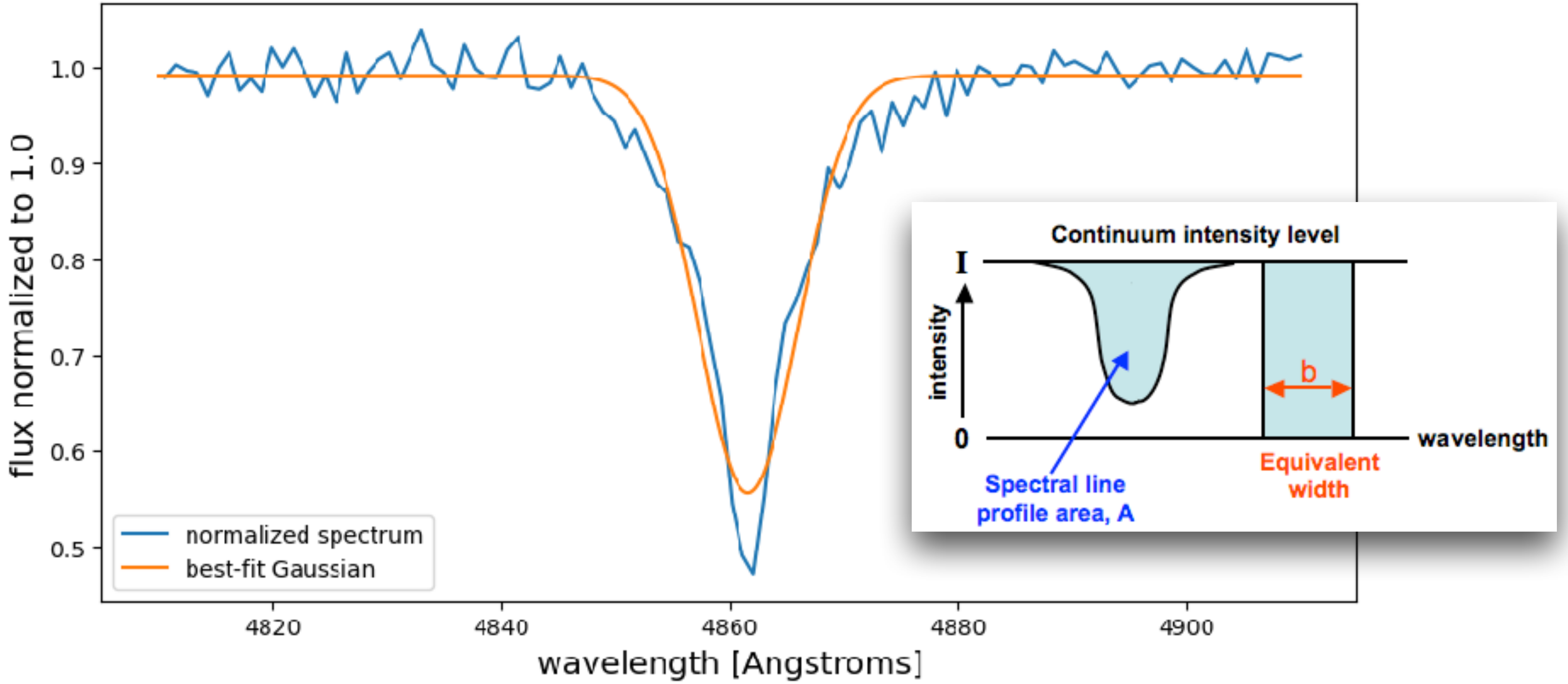
masked areas
sensitivity function
observed spectrum
input blackbody spectrum
ratio of observed to input spectrum
sensitivity function
fractional residuals
calibrated spectrum
counts
flux [10^15 W/m^3/sr]
counts / (10^15 W/m^3/sr)
flux [const x erg/s/cm^2/Å]
wavelength [Angstroms]
4300
4400
4500
4600
4700
4800
4900
5000

# Emission line measurements




- generally, spectrum has to be flux-calibrated
- fit Gaussian to emission line
  - line strength: area of Gaussian, units erg/s/cm$^2$ (or: subtract background, integrate the measured line flux)
  - line width: $\sigma$ (or FWHM) of Gaussian, units Å or km/s

# Absorption line measurements




- first, normalize by continuum
- spectrum does not need to be flux-calibrated
- fit Gaussian* to absorption line
  - line strength = "equivalent width": area of Gaussian, units Å
  - line width: σ (or FWHM) of Gaussian, units Å or km/s

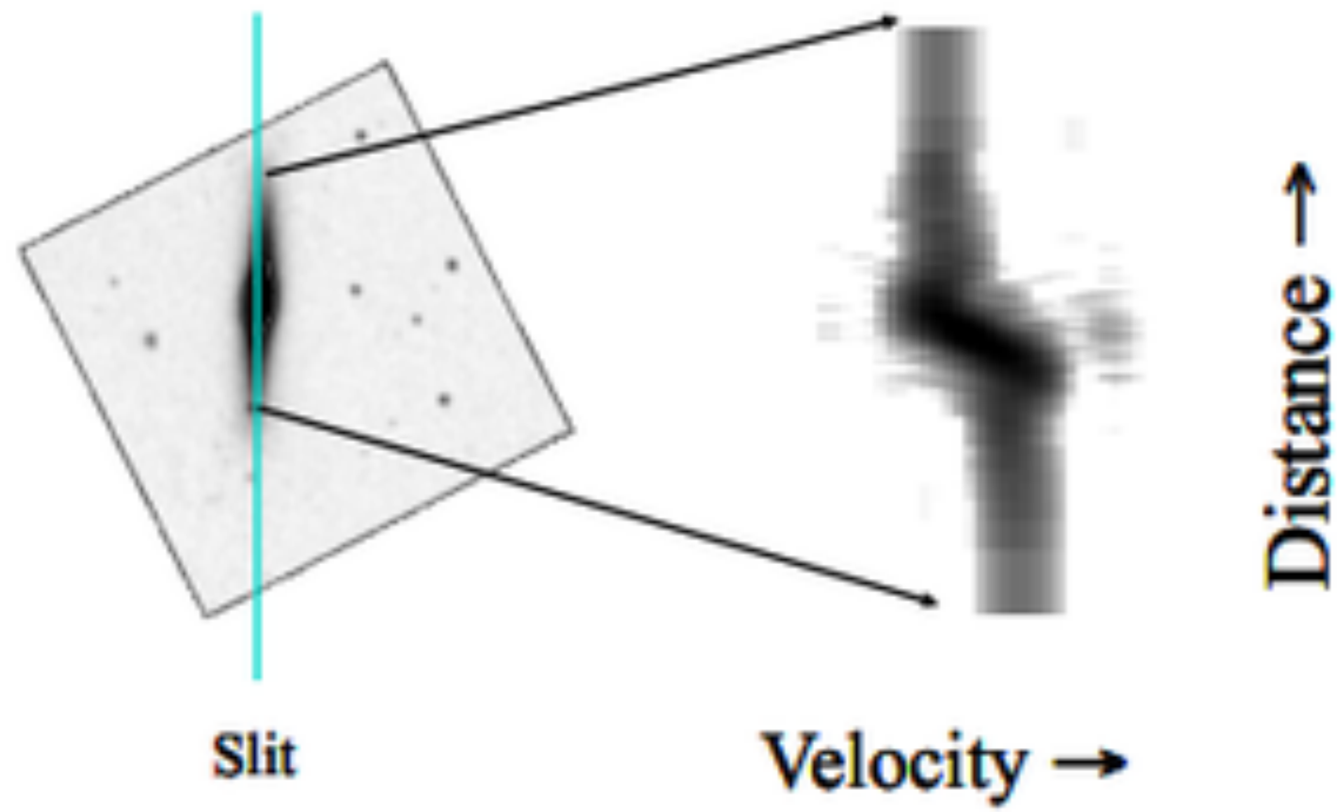
# Long-slit spectrographs

most common spectrograph

can only target one (or a few) objects

gives spatial variation

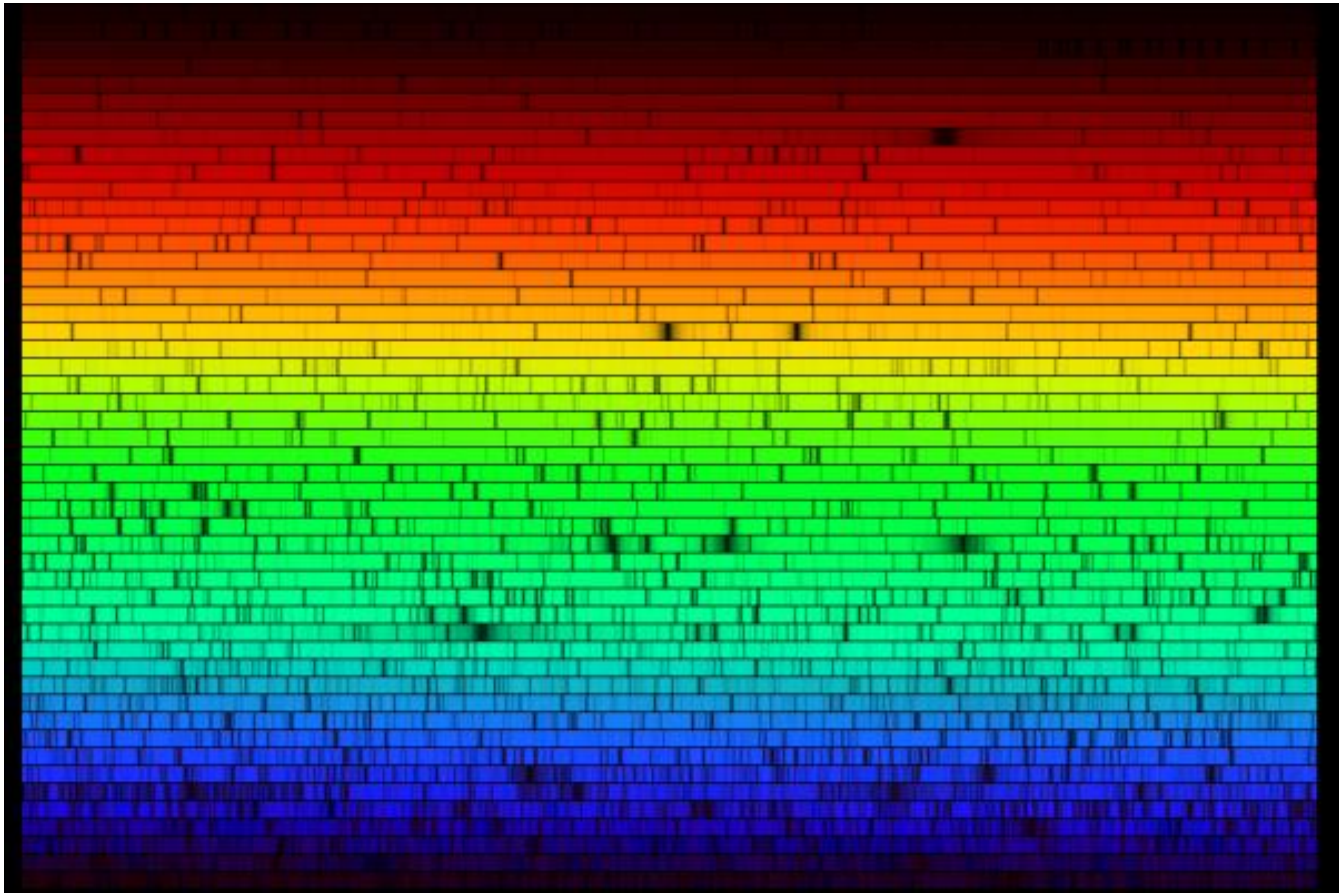
very good estimate of sky background




wikipedia

# Echelle spectrographs

- very high resolution long-slit spectrographs
- have additional elements to fit entire spectrum onto CCD
- only for bright objects

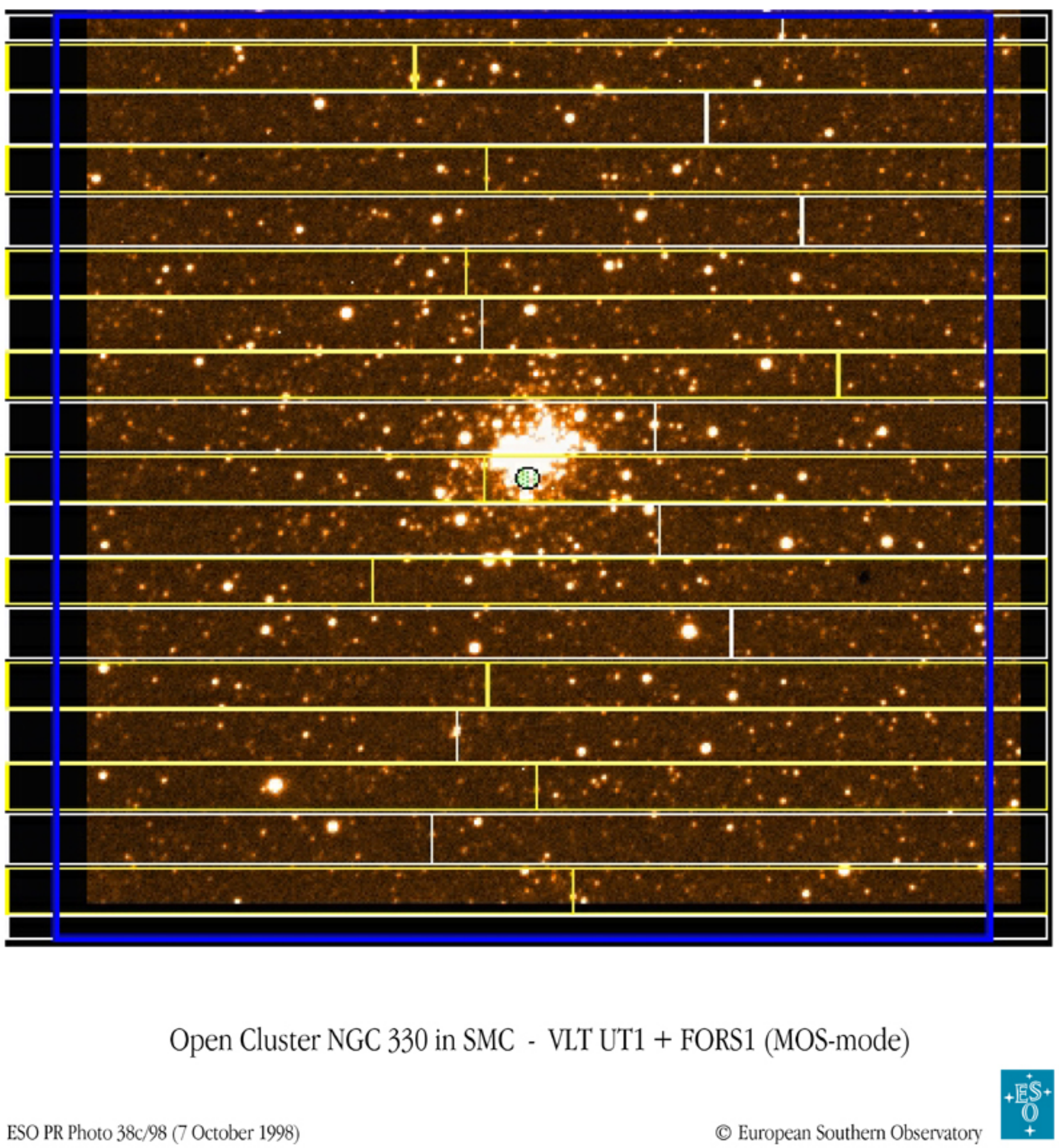


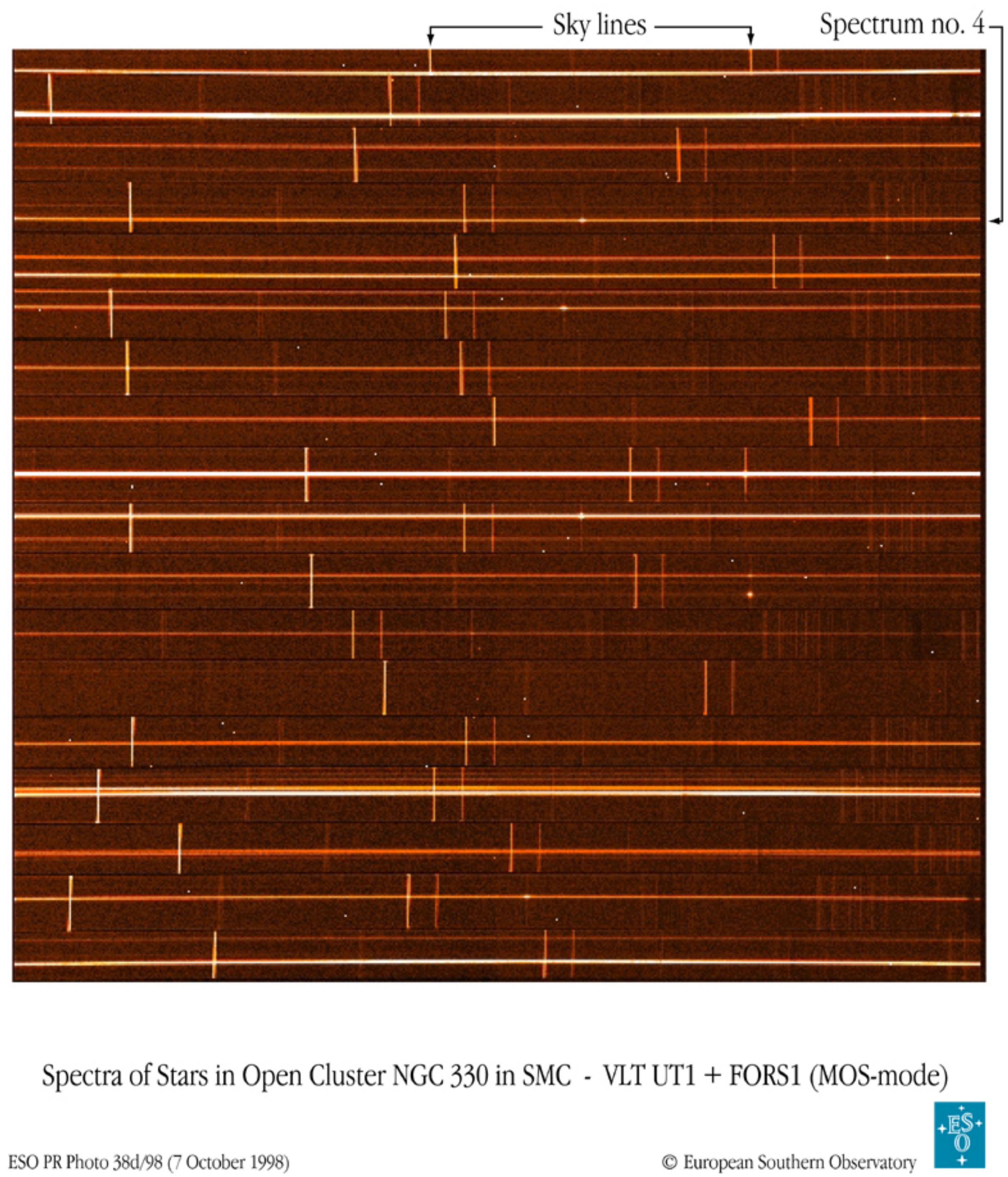
Echelle spectrum of the Sun, 4000-7000Å

NOAO

# Multi-object spectrographs

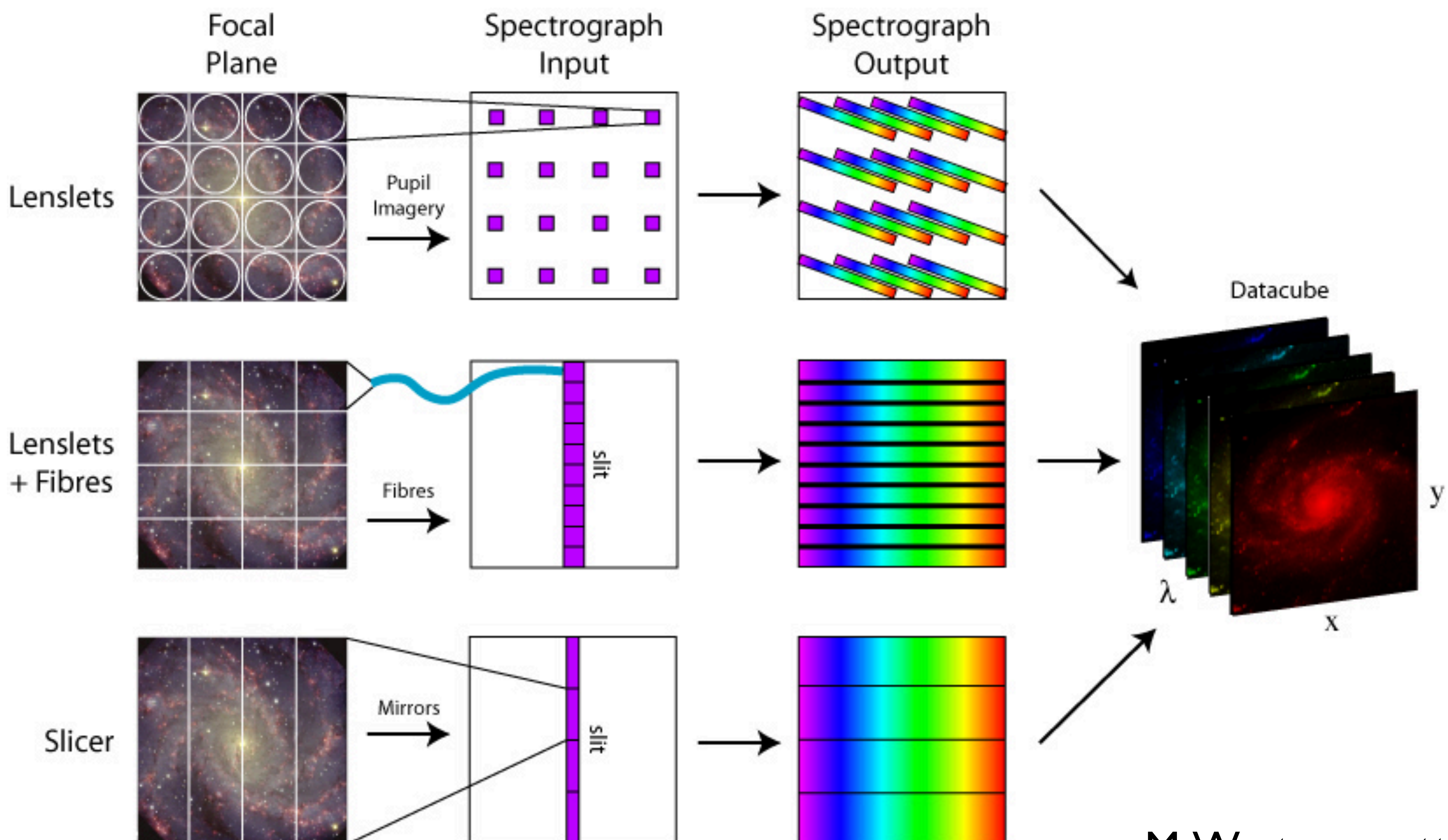
make a mask with multiple slits, one per target



# Integral-Field Units

divide image into "spaxels" (spectroscopic pixels)



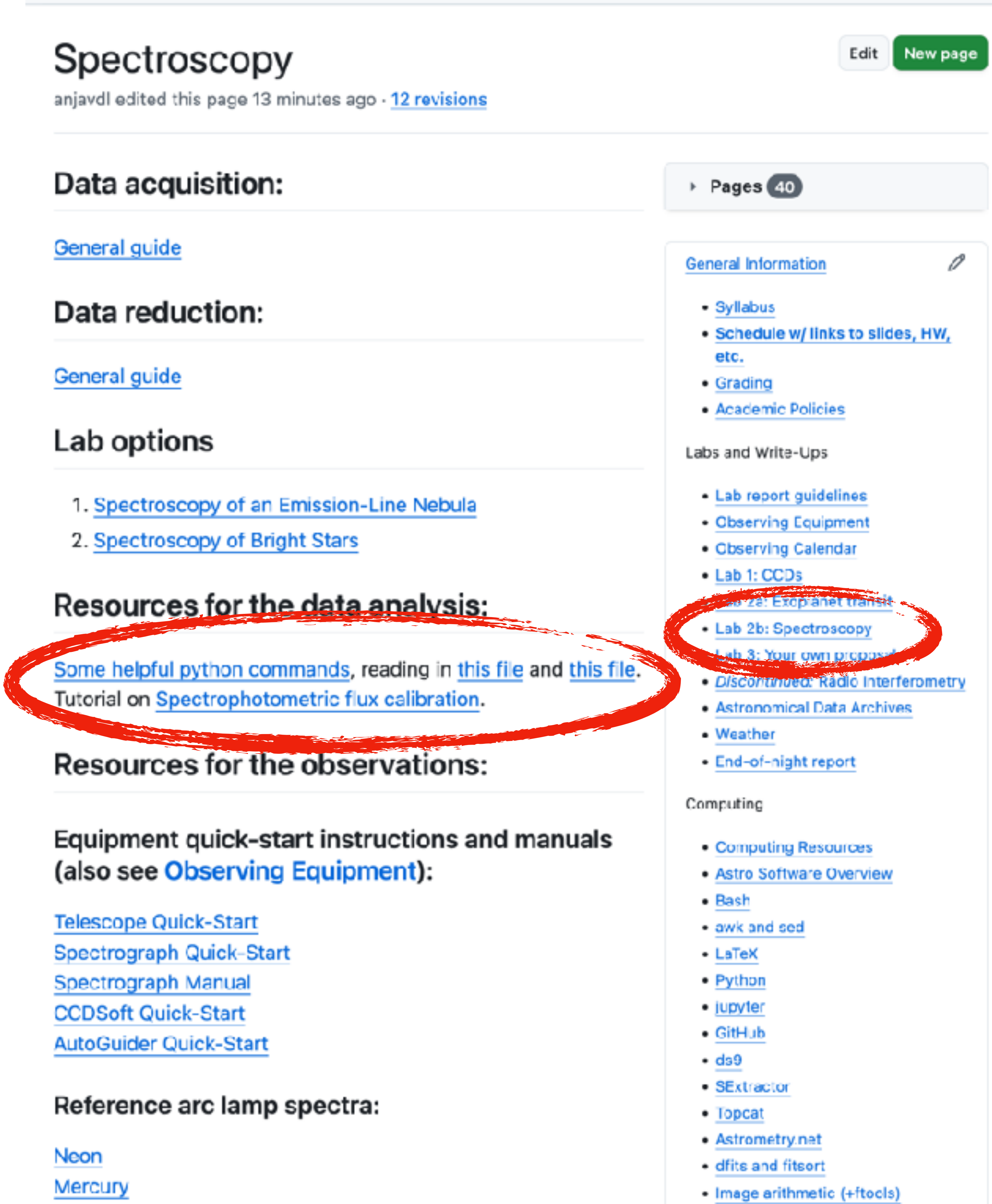

M. Westmoquette

# Today's Tutorial(s)

- finish last week's tutorials
- spectroscopy notebooks
- work with your lab partners on Lab 1

# HW4

- complete walk-through of spectroscopic data reduction (due Sept. 17)


Edit New page

# Spectroscopy

anjavdl edited this page 13 minutes ago · 12 revisions

## Data acquisition:

General guide

## Data reduction:

General guide

## Lab options

1. Spectroscopy of an Emission-Line Nebula
2. Spectroscopy of Bright Stars

## Resources for the data analysis:

Some helpful python commands, reading in this file and this file.
Tutorial on Spectrophotometric flux calibration.

## Resources for the observations:

### Equipment quick-start instructions and manuals (also see Observing Equipment):

Telescope Quick-Start
Spectrograph Quick-Start
Spectrograph Manual
CCDSoft Quick-Start
AutoGuider Quick-Start

### Reference arc lamp spectra:

Neon
Mercury

Pages 40

General Information

- Syllabus
- Schedule w/ links to slides, HW, etc.
- Grading
- Academic Policies

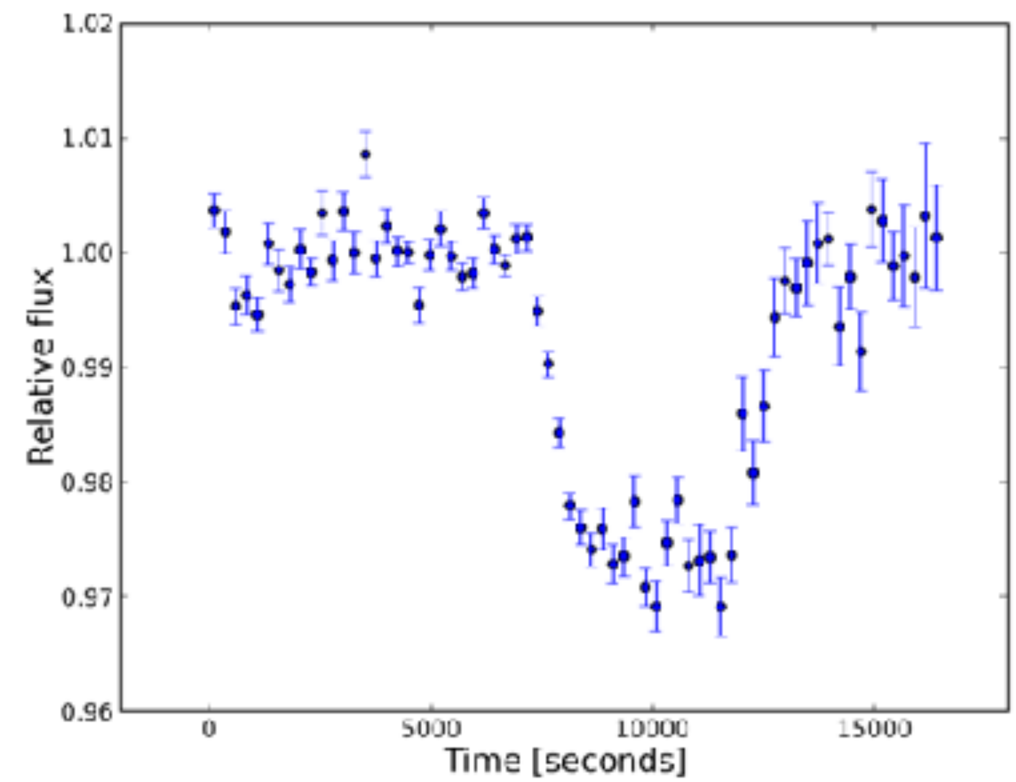
Labs and Write-Ups

- Lab report guidelines
- Observing Equipment
- Observing Calendar
- Lab 1: CCDs
- Lab 2a: Exoplanet transit
- Lab 2b: Spectroscopy
- Lab 3: Your own proposal
- *Discontinued:* Radio Interferometry
- Astronomical Data Archives
- Weather
- End-of-night report

Computing

- Computing Resources
- Astro Software Overview
- Bash
- awk and sed
- LaTeX
- Python
- jupyter
- GitHub
- ds9
- SExtractor
- Topcat
- Astrometry.net
- dfits and fitsort
- Image arithmetic (+ftools)

# Lab 2

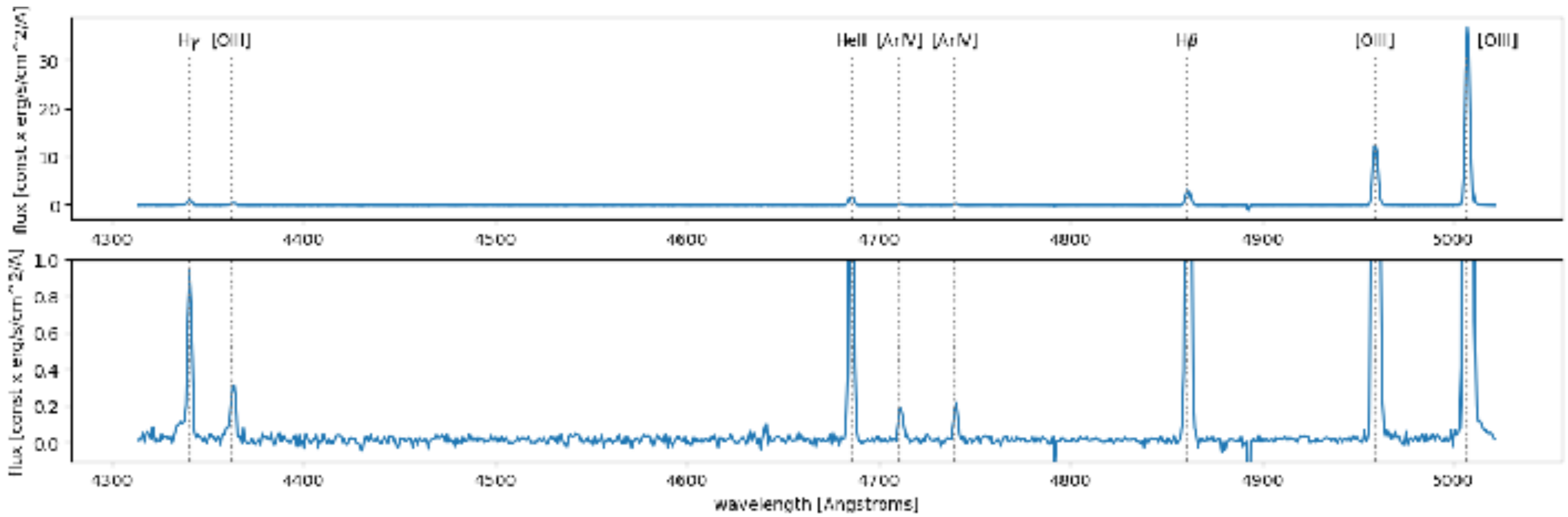



- Option A)  Exoplanet transit
  - photometry of a star that hosts an exoplanet
  - extensive lab manual
  - new camera!

  - imaging data analysis is easier (conceptually) than spectroscopic data analysis
  - involves more programming later on (we're not doing photometry by hand 😜)
  - for Lab 3, have to then use spectroscopy

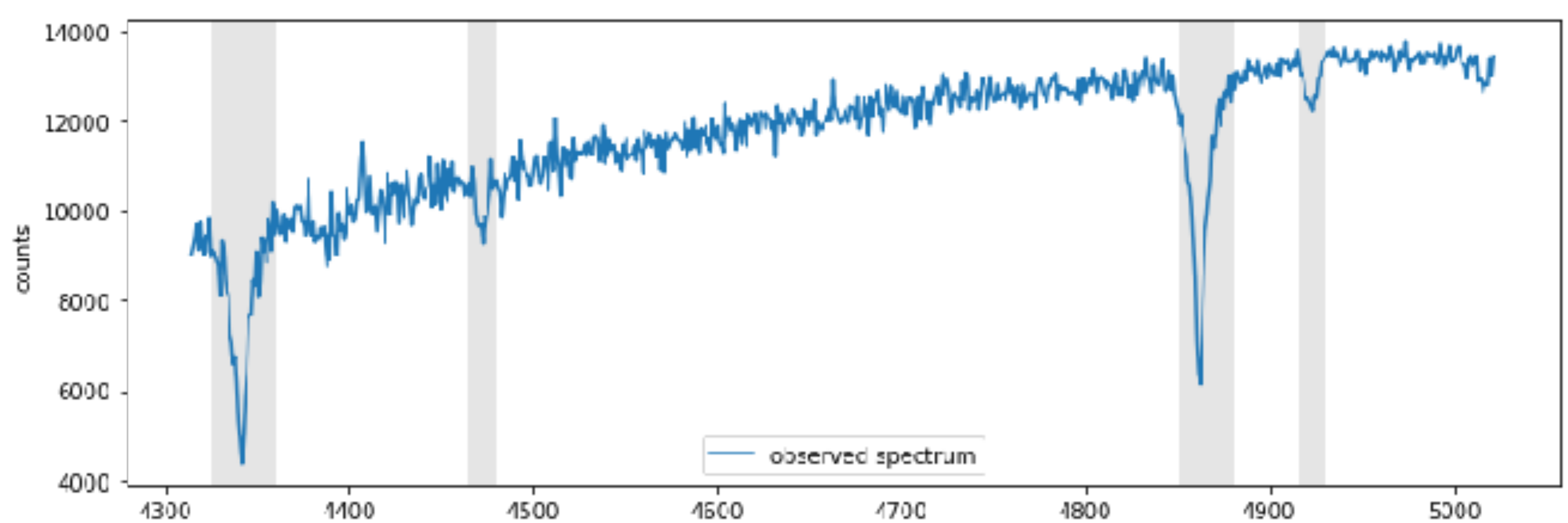
## Option B.1) Spectroscopy of an emission-line nebula

- measure density and temperature of a planetary nebula




## Option B.2) Spectroscopy of bright stars

- measure strength of absorption line features as function of temperature



# Lab 2

- spectroscopic data analysis conceptually more involved than imaging data analysis
- somewhat less programming intensive
- for Lab 3, have to then do imaging

# Lab 2

- Start discussing which Lab 2 option you want to choose
- Should have completed at least the day-time observations of Lab 1 before you decide
- Will look to scheduling these between now and Oct. 3rd

- Once you have decided, let us know. THEN: select targets according to instructions and request 3 observing nights - first come, first serve