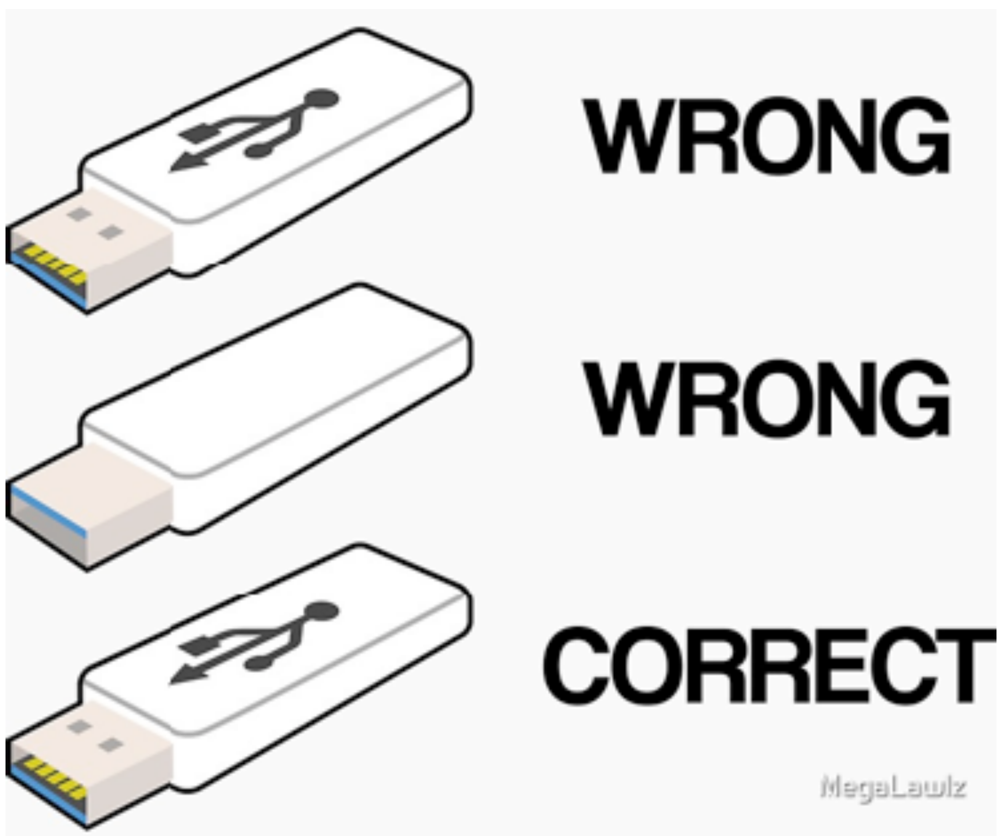
PHY 517 / AST 443: Observational Techniques in Astronomy

Lecture 4: Photometry Spectroscopy

Please be gentle with our equipment!!

Example: do not force a plug into a connector - USB-A and -B are **not** symmetric. Check with the TAs when in doubt.



For the time being, the STL-1001E camera is out of commission. Plan on using the ST-402ME camera instead.

Shut-Down Procedure

Make sure to follow the entire shut-down procedure in the manual(s).

I found the dome power still on in the daytime; there are open wires in the dome, so this is a safety hazard.

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?

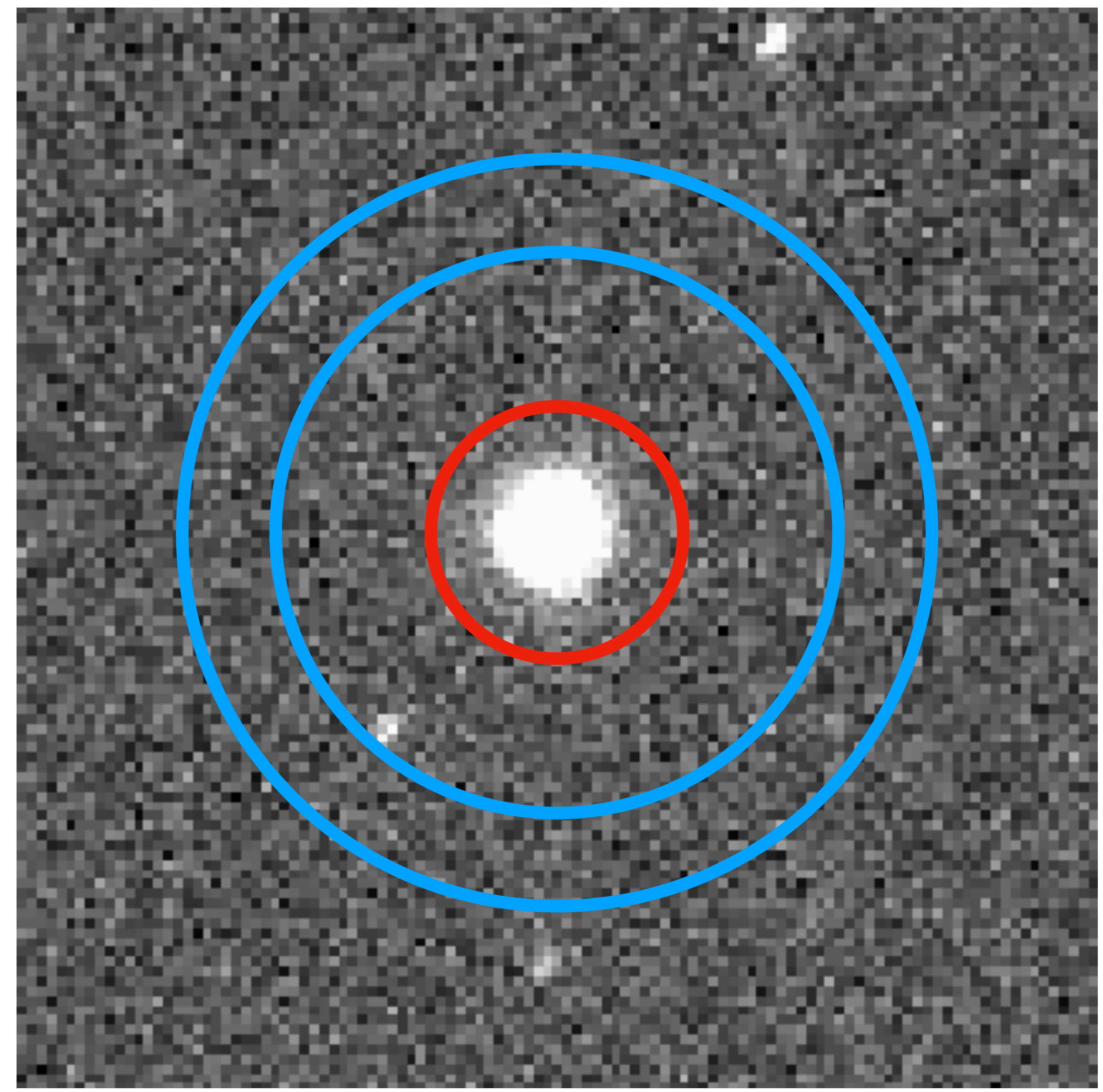
- Dark frames: same exposure time, same temperate -> measures bias + dark current
- Flat-fields: images of a uniform surface (e.g. dome), taken with the camera attached to the telescope in the same set-up as for the science image (*also needs to be dark-corrected*)

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

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

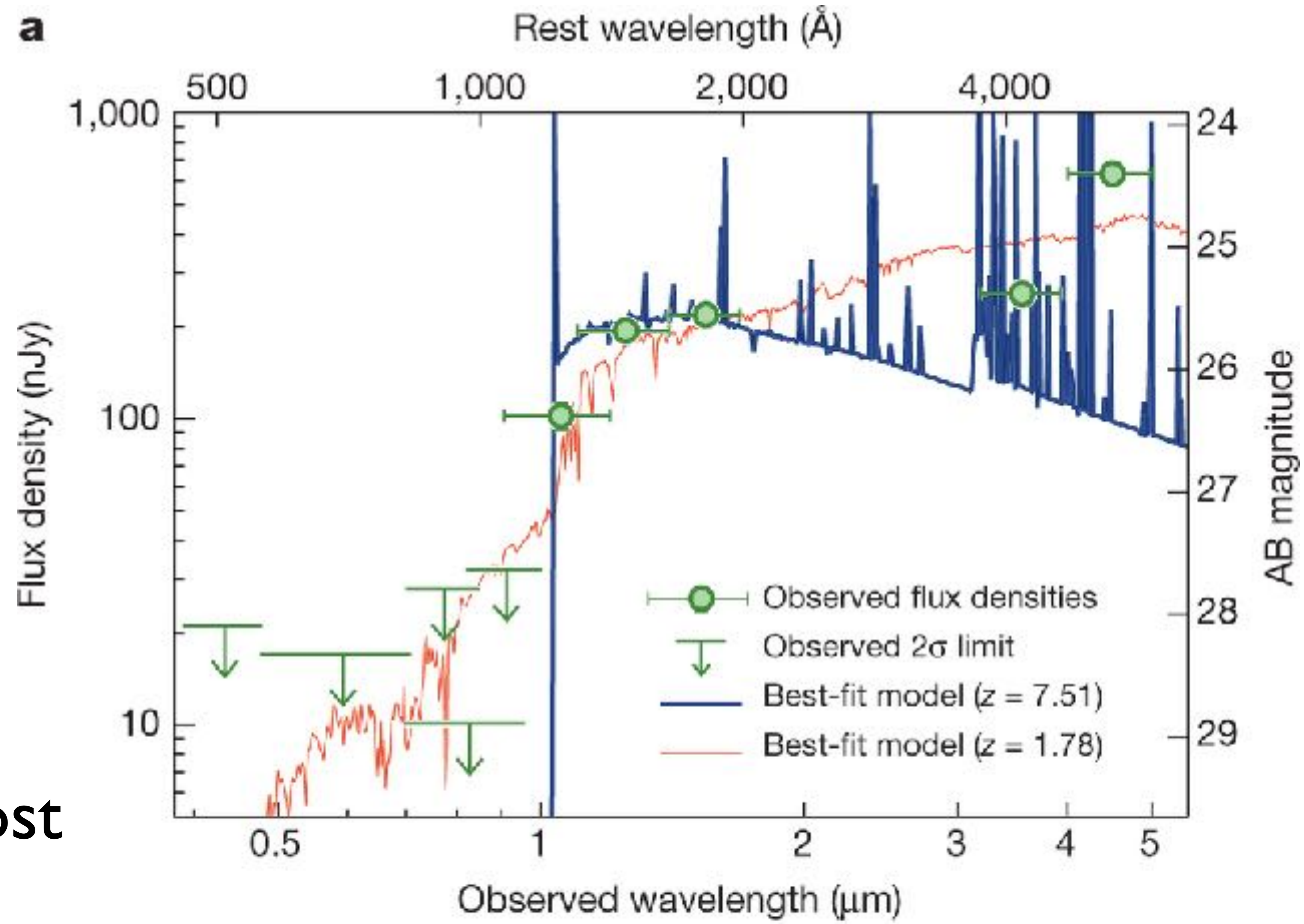
$$m_1 - m_2 = -2.5 \log \left(\frac{F_1}{F_2} \right)$$

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

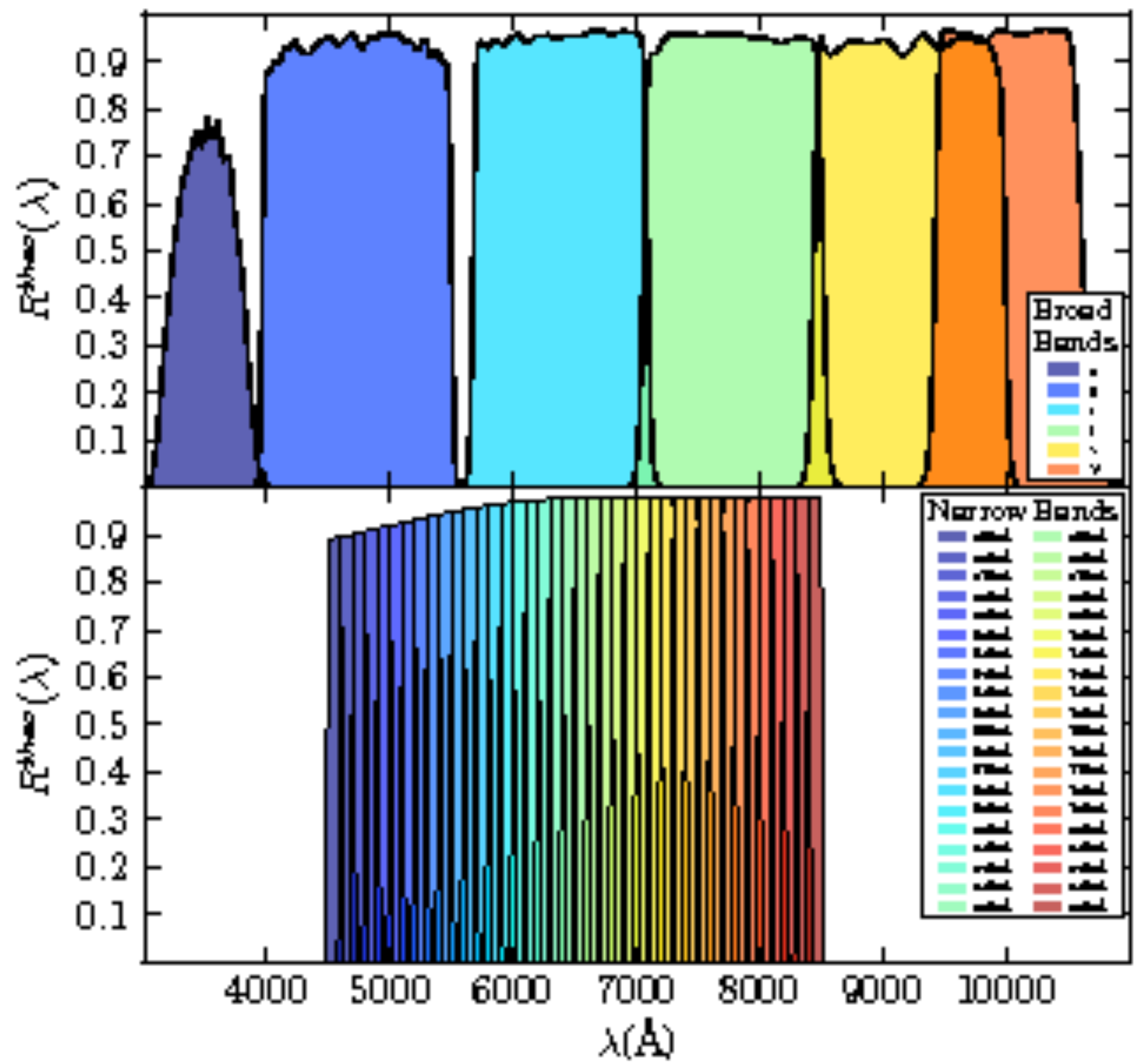
Finkelstein et al. 2013

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!

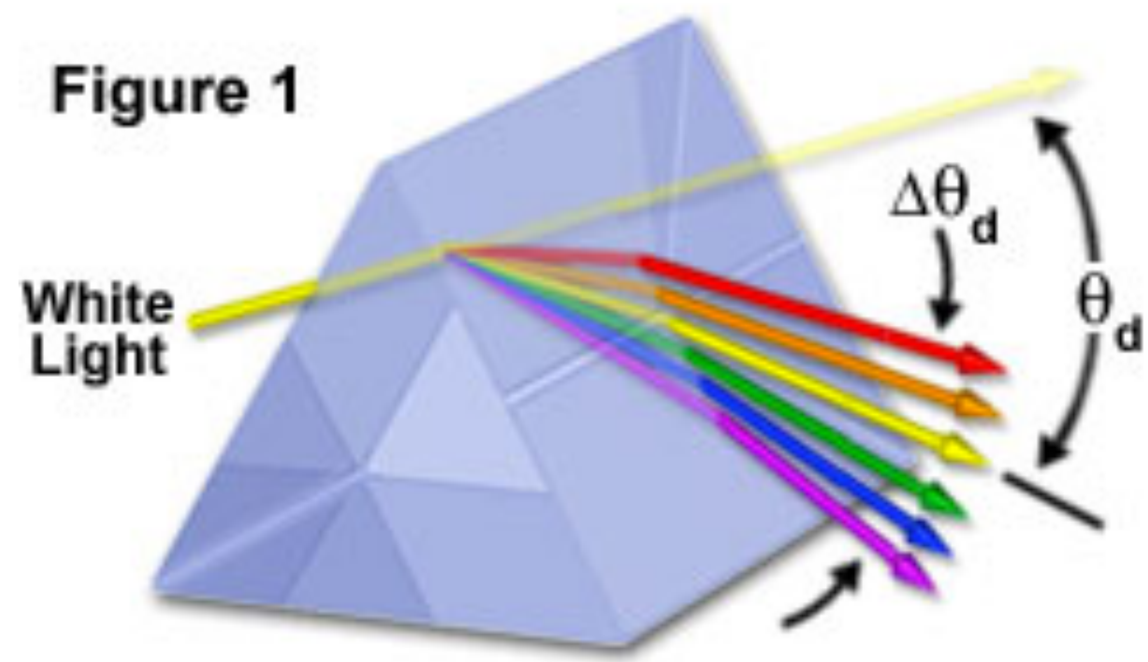


The PAU Survey

Spectroscopy

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

e.g. a prism:

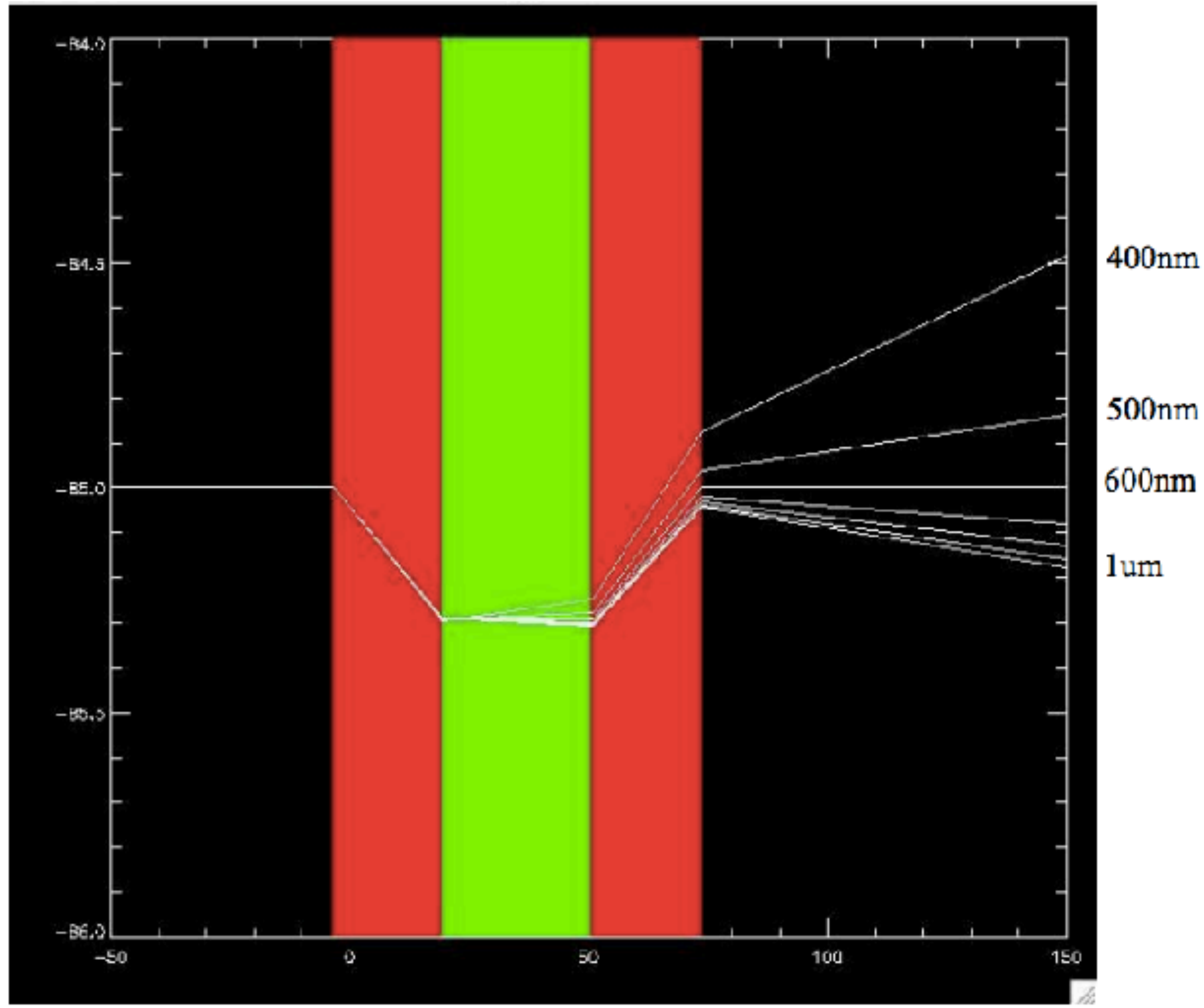


Olympus

Prism Spectroscopy

only few astronomical spectrographs use prisms

- low dispersion (resolution)
- dispersion varies with wavelength



LDP Prism description

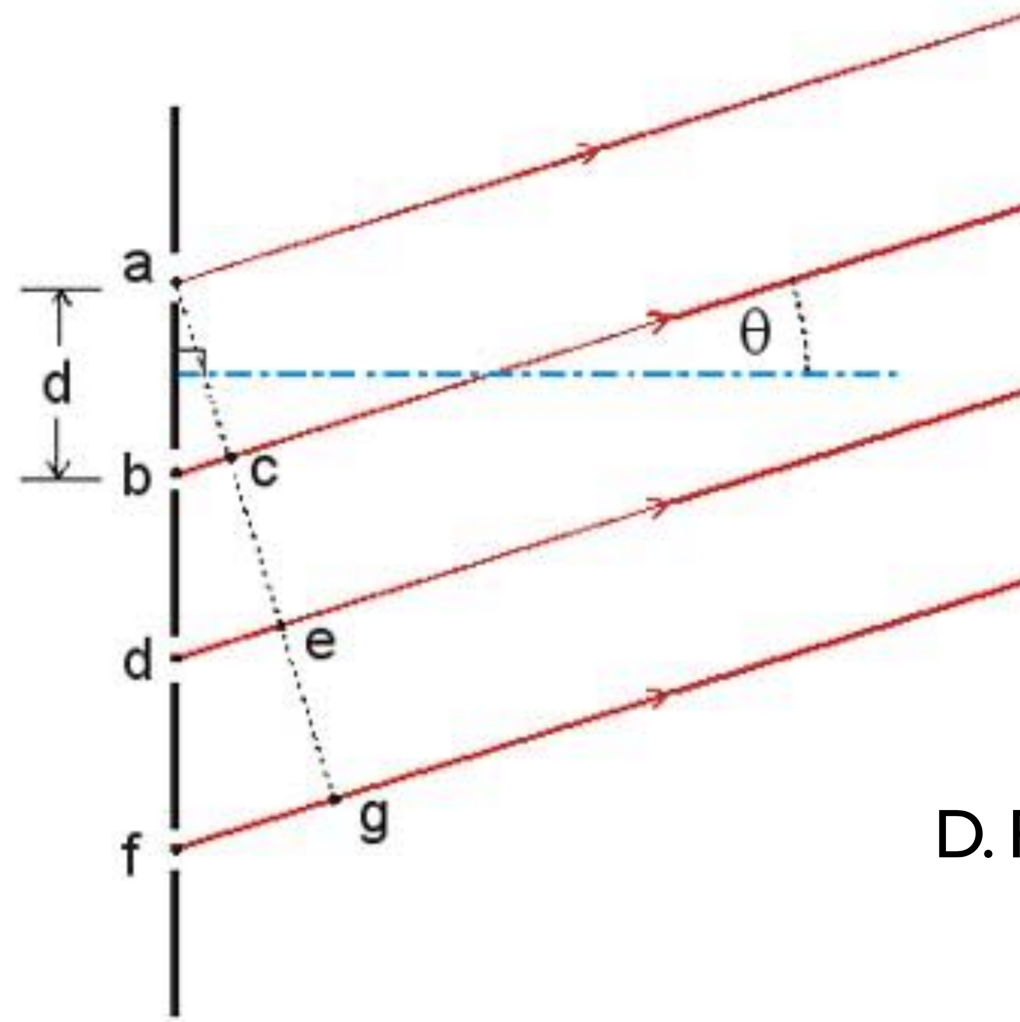
"low dispersion prism" for IMACS spectrograph on Magellan 6-m telescope; uses 3 prisms

Diffraction gratings

make use of wave properties of light: interference

grating: many parallel lines (~500/mm)

similar to single-slit and double-slit experiments

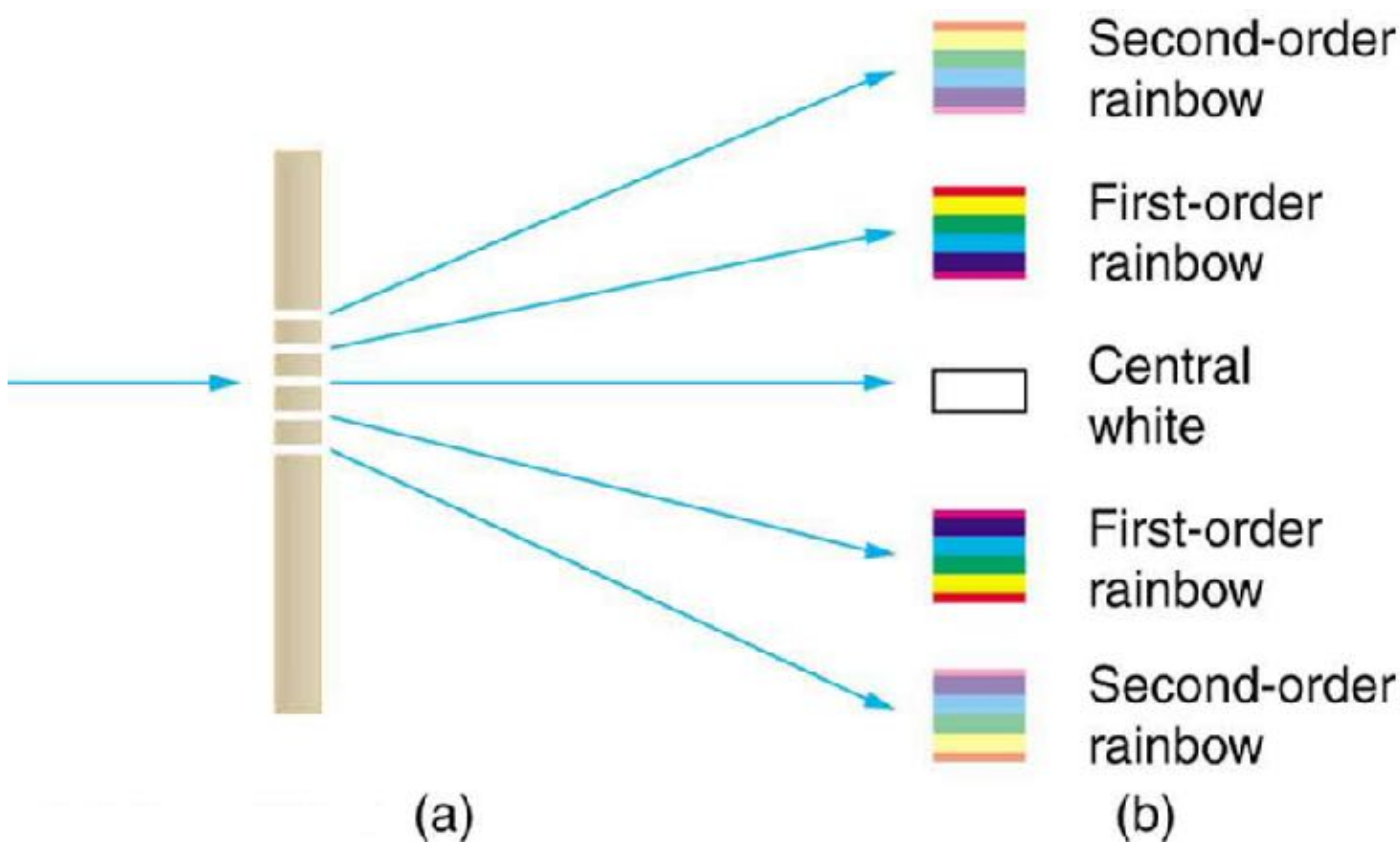


D. Pogosian

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

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

Diffraction gratings

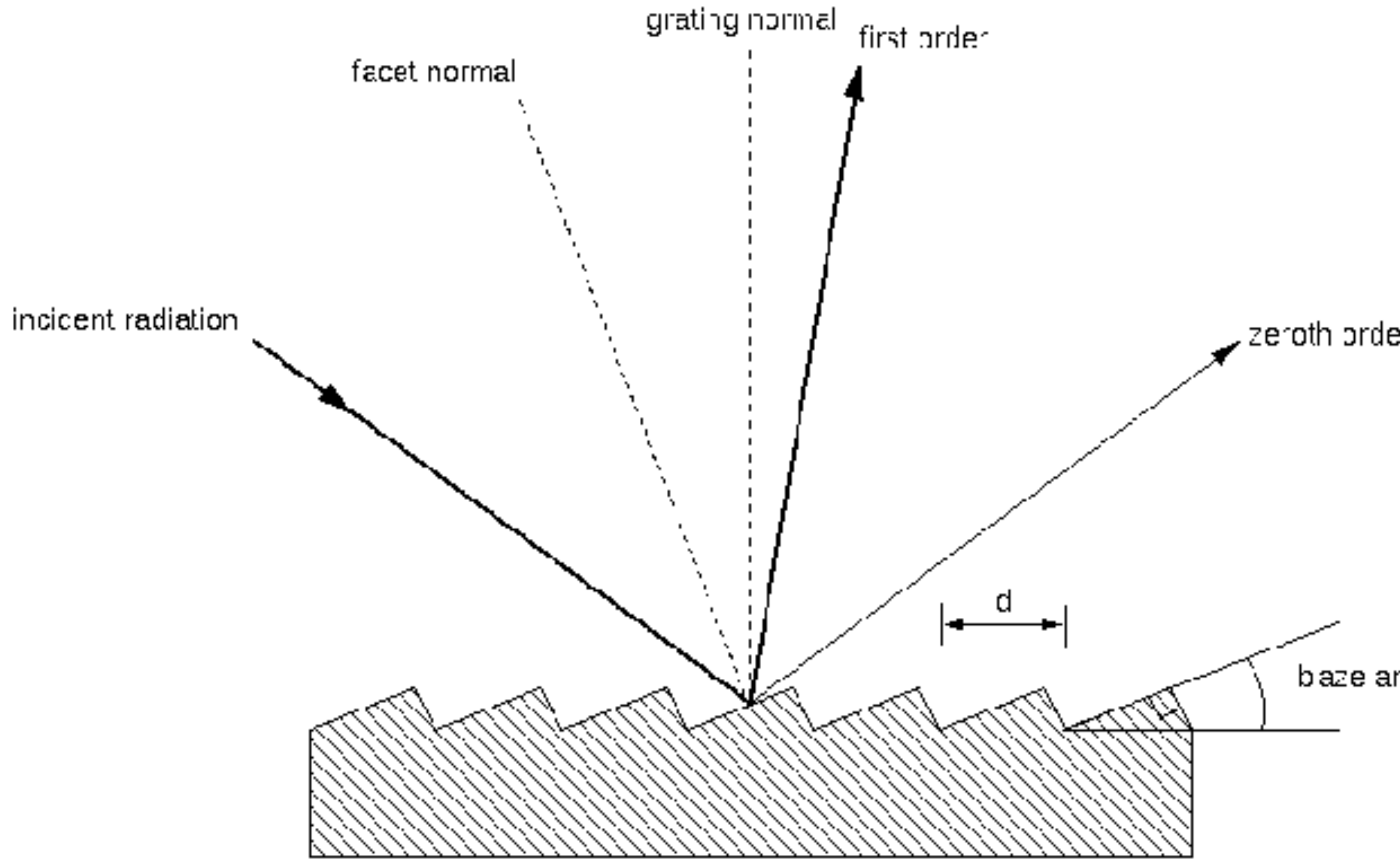


OpenStax University

Diffraction gratings

can be transmission gratings or reflection gratings

most astronomical spectrographs use reflection gratings



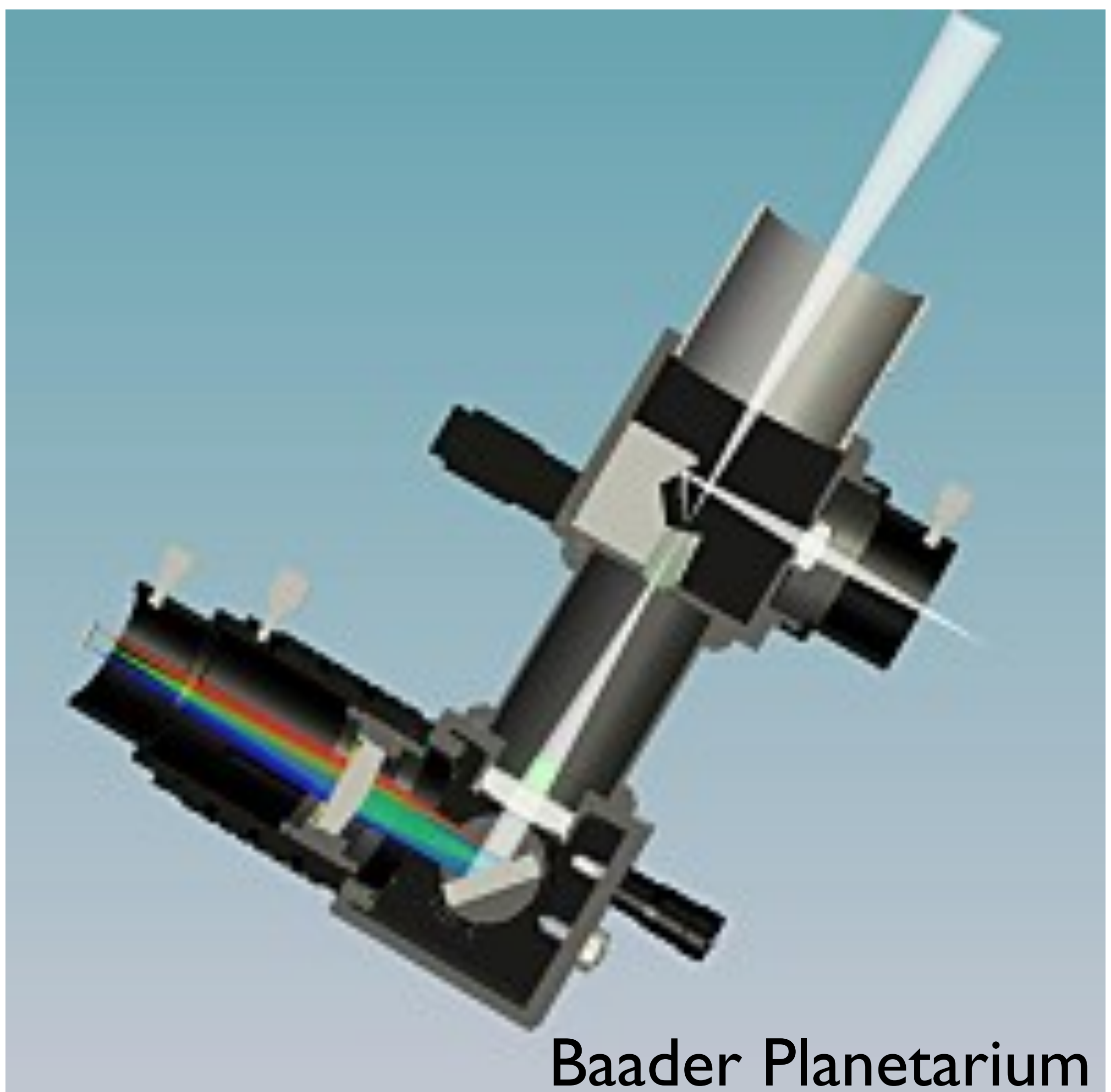
Dhillon 2012

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

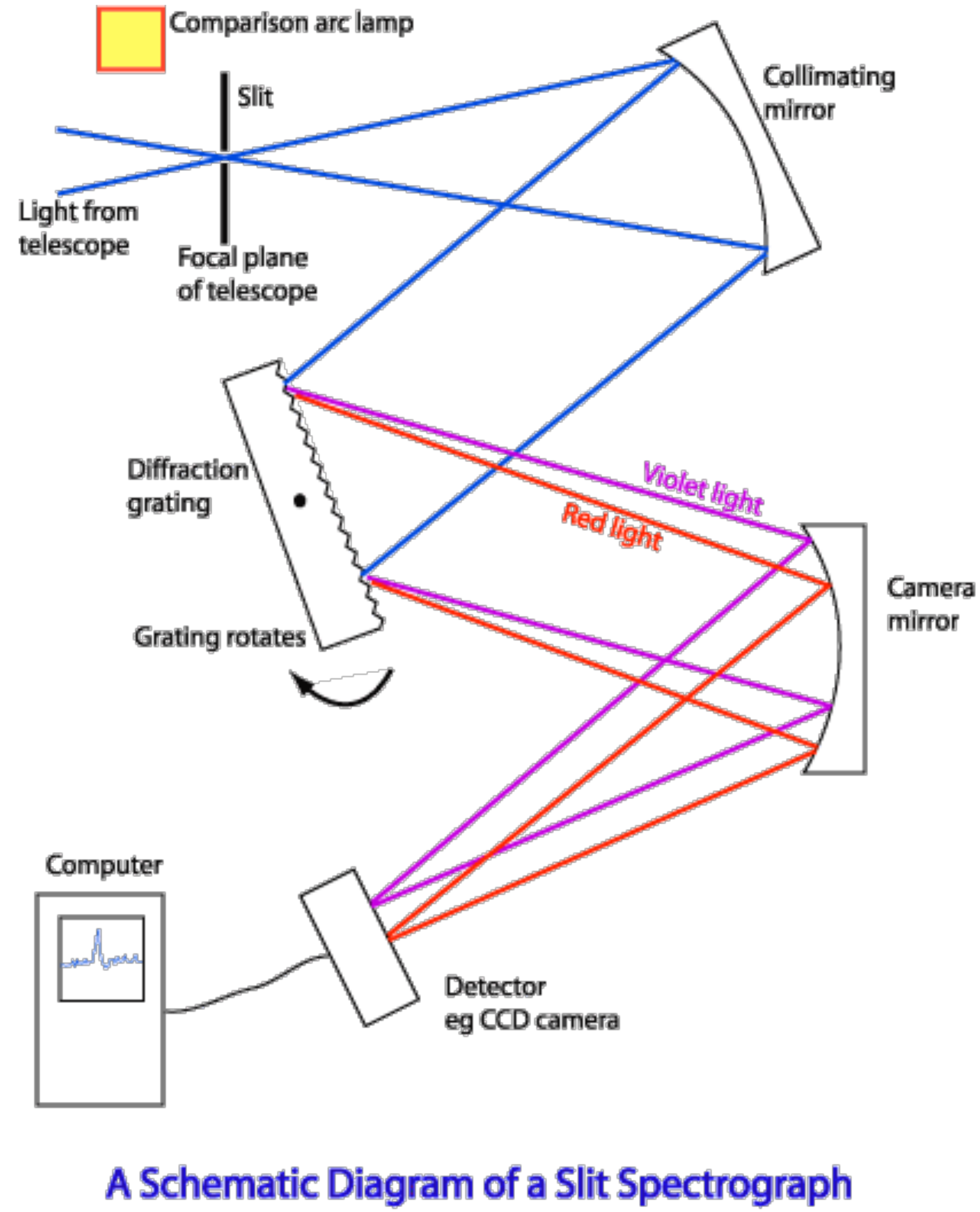
Typical spectrograph

entrance: usually a slit, similar to seeing size

collimator: converts a diverging beam to a parallel beam



Baader Planetarium



Kaler, *Stars and their Spectra*

Spectral Resolution

defined by smallest wavelength difference $\Delta\lambda$ that can be distinguished at wavelength λ

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

determined by:

- grating (line density)
- width of entrance slit
- seeing

resolution: R or $\Delta\lambda$

dispersion: length $\Delta\lambda'$ of spectrum over single pixel, [Å/px]

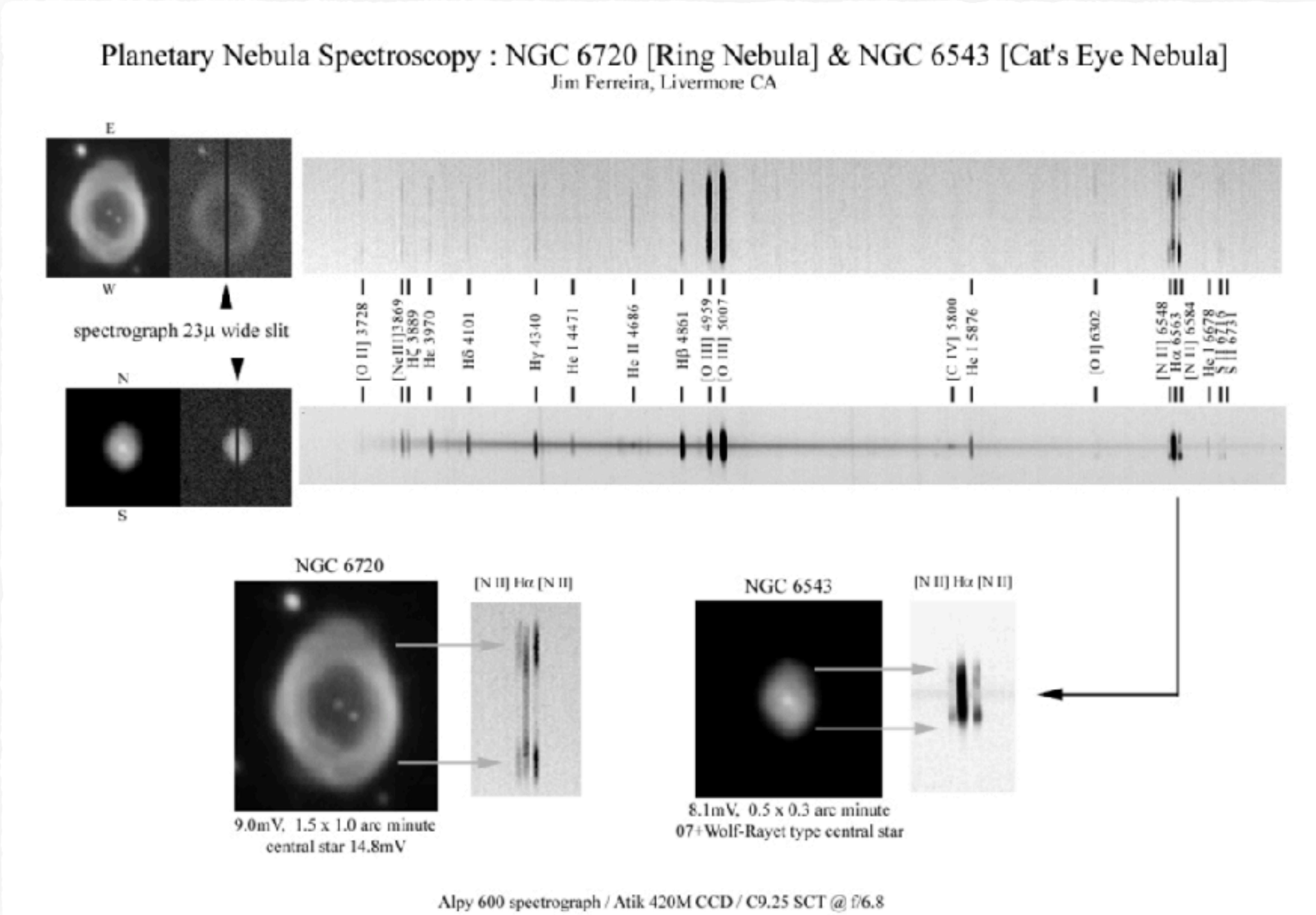
to properly sample the spectrum:

$$\Delta\lambda \sim 2 - 3\,\Delta\lambda'$$

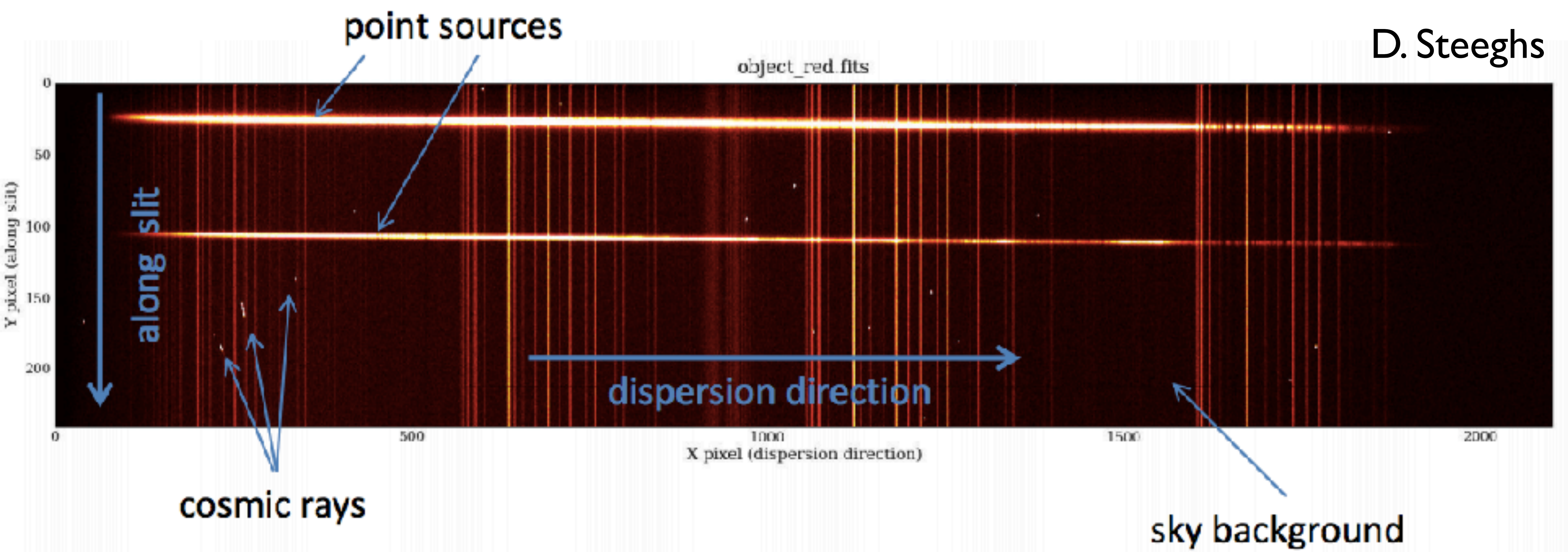
Spectral Resolution

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

Long-slit observations



Long-slit observations



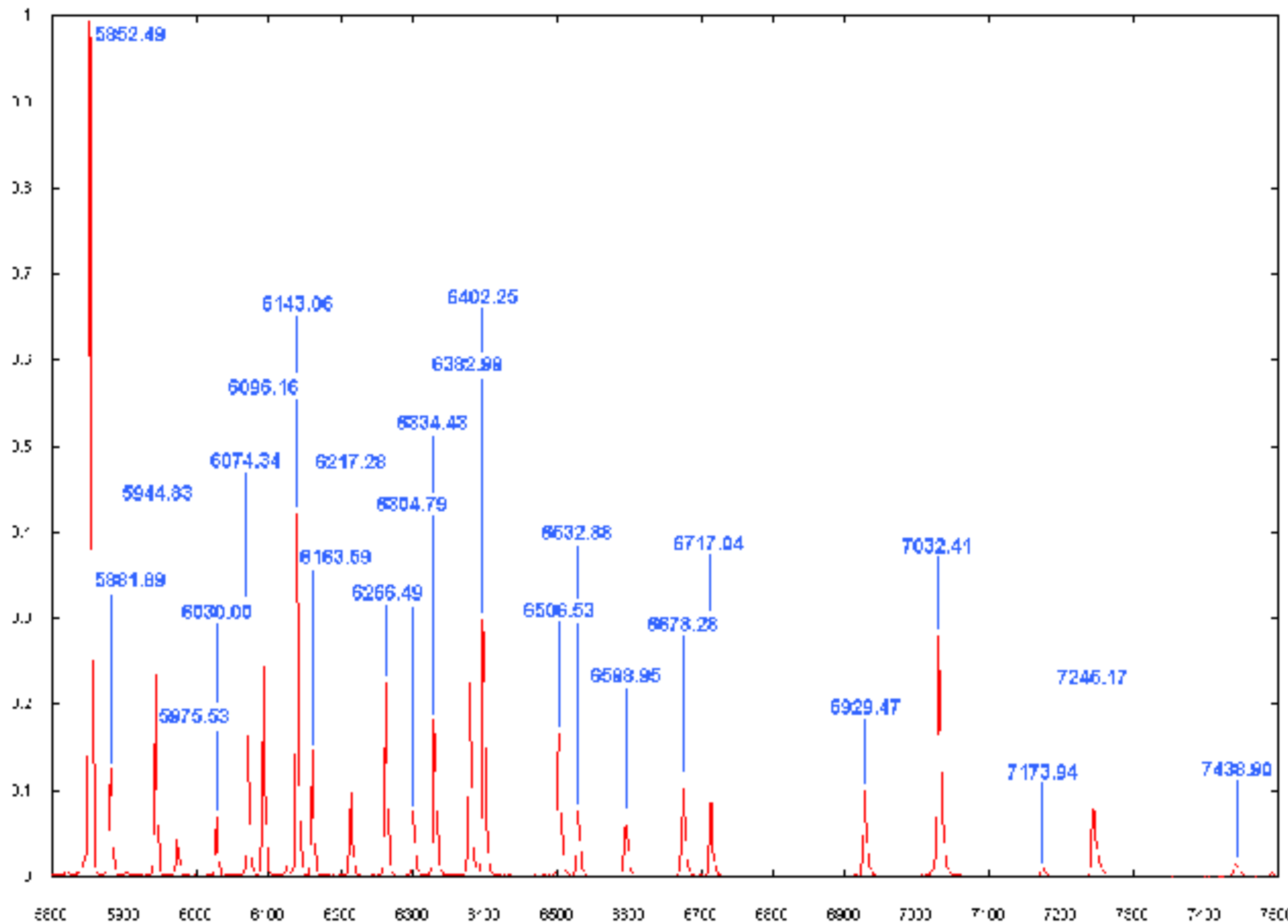
- long axis of CCD used to sample spectrum
- spatial information along slit still available: two objects, lots of sky
- sky background has a lot of emission lines!

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 Calibration

wavelength calibration: map pixel position to emission lines

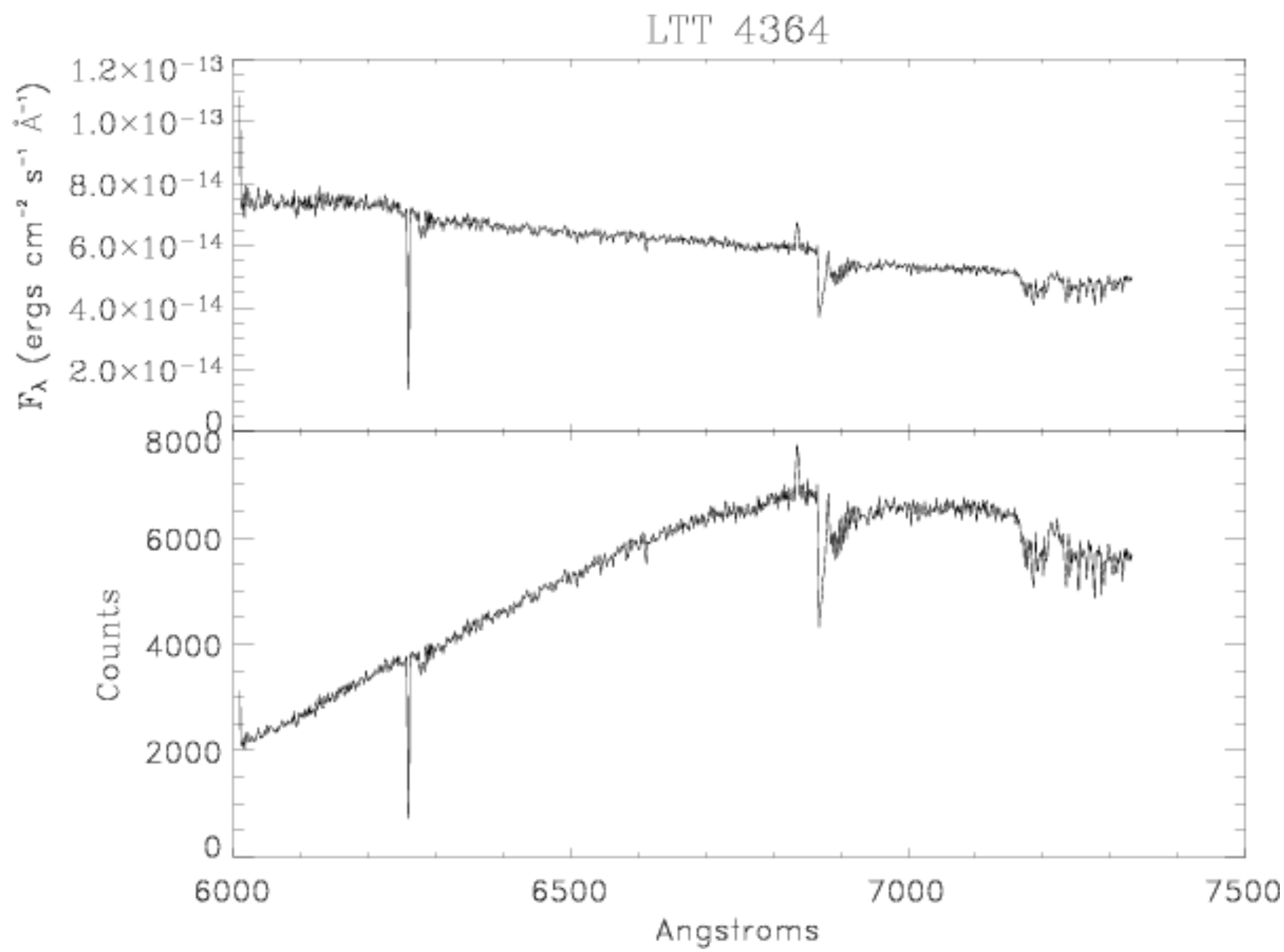


C. Buil / astrosurf

Spectroscopic Calibration

flux calibration:
observe
spectrophotometric
standard star

compare observed
spectrum (counts)
to known spectrum



F. Walter

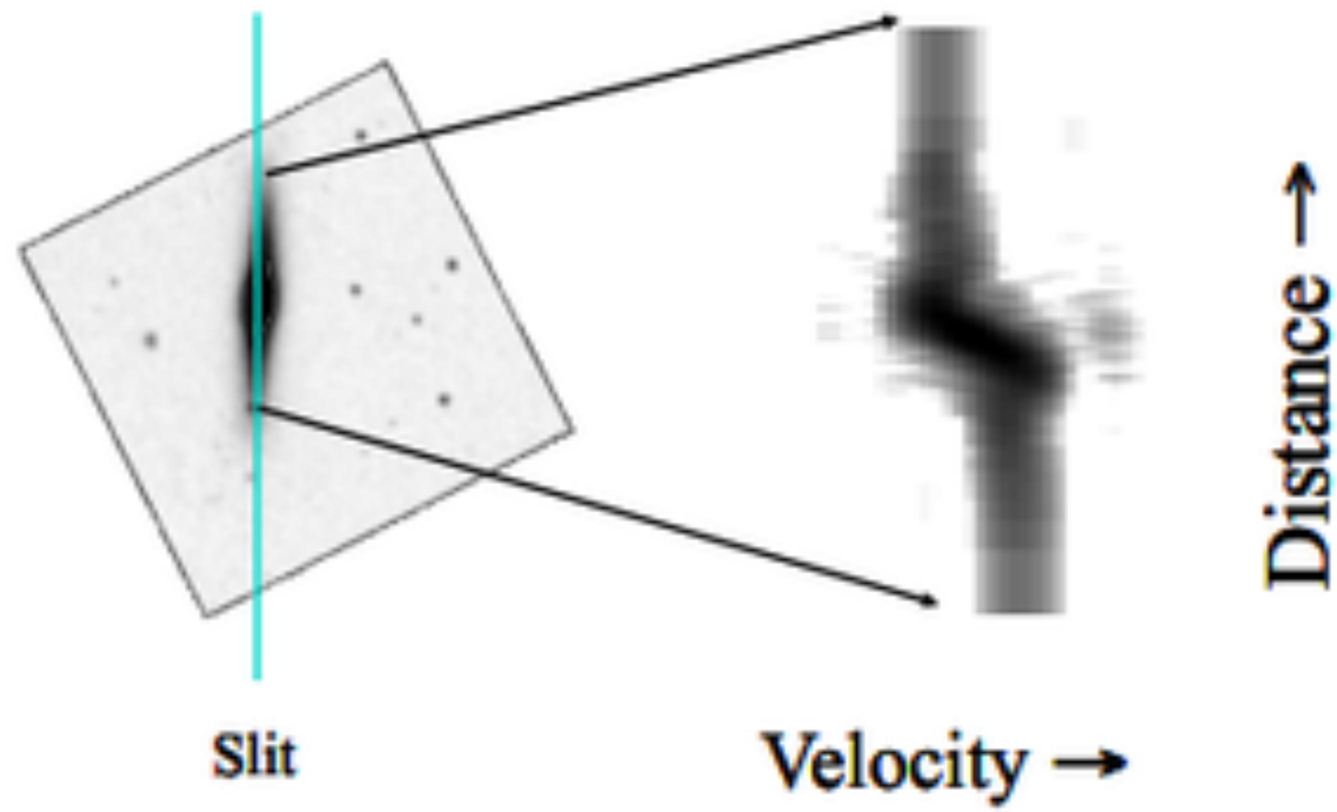
Long-slit spectrographs

most common spectrograph

can only target one (or a few) objects

gives spatial variation

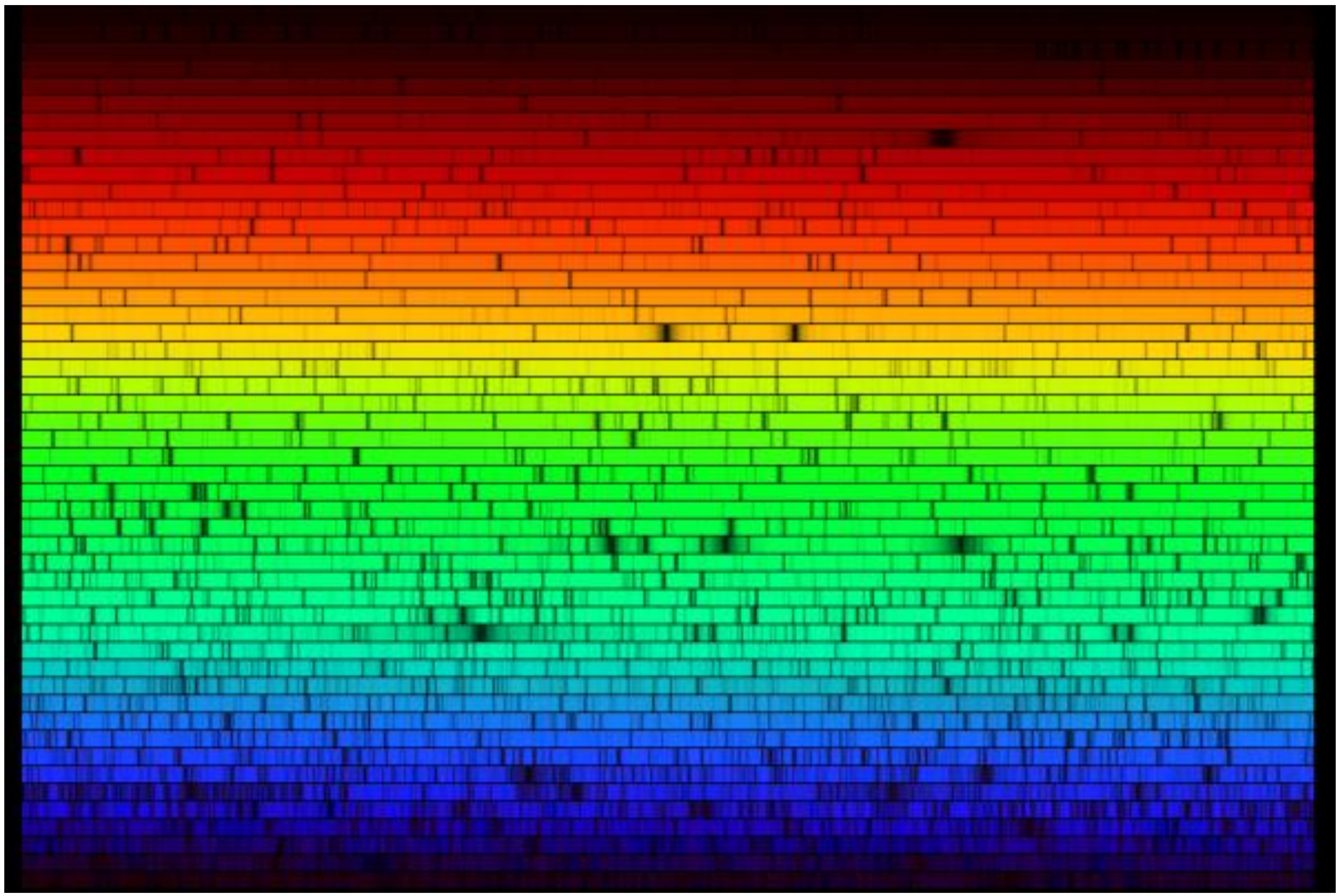
very good estimate of sky background



wikipedia

Echelle spectrographs

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

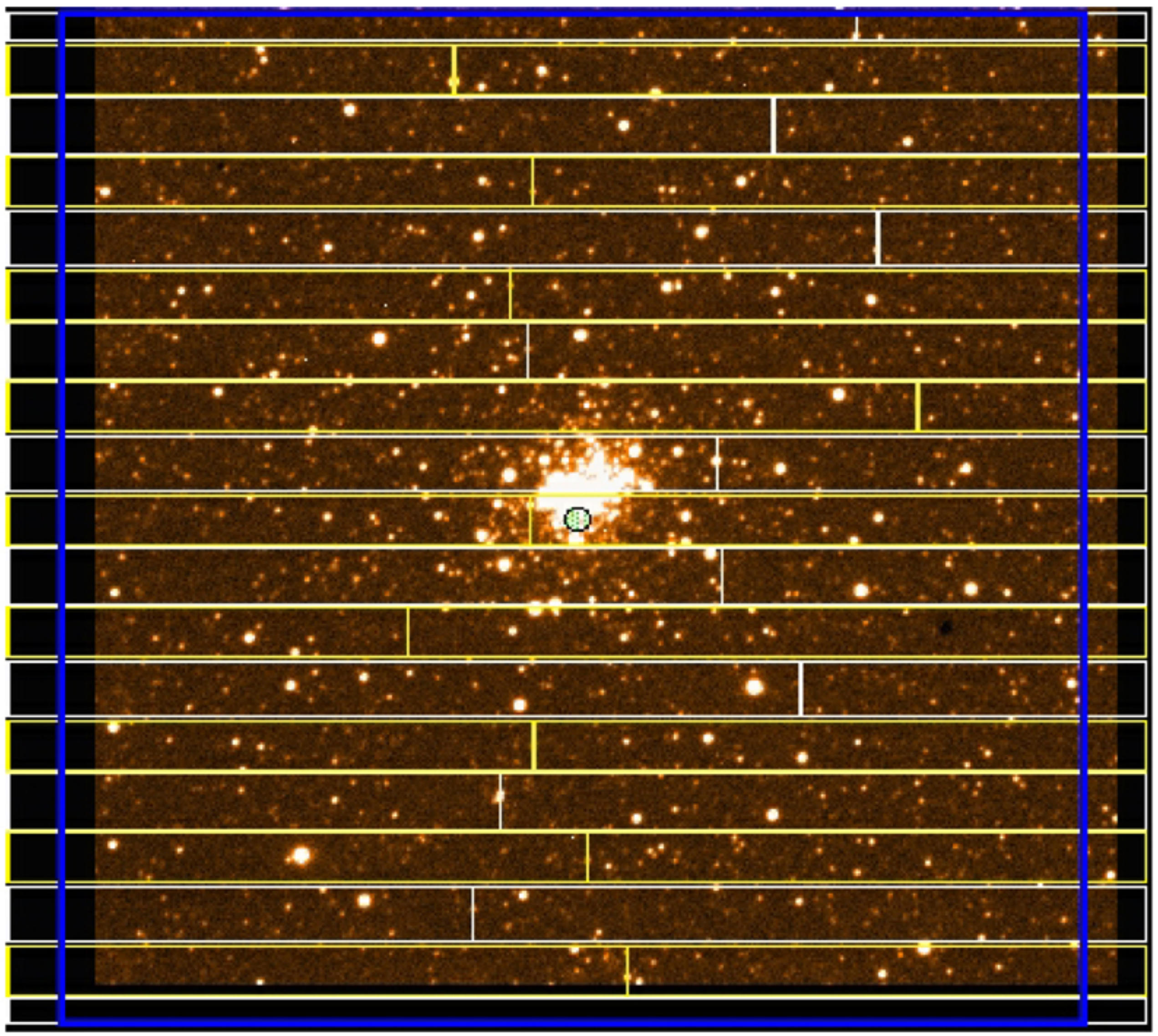


Echelle spectrum of the Sun, 4000-7000Å

NOAO

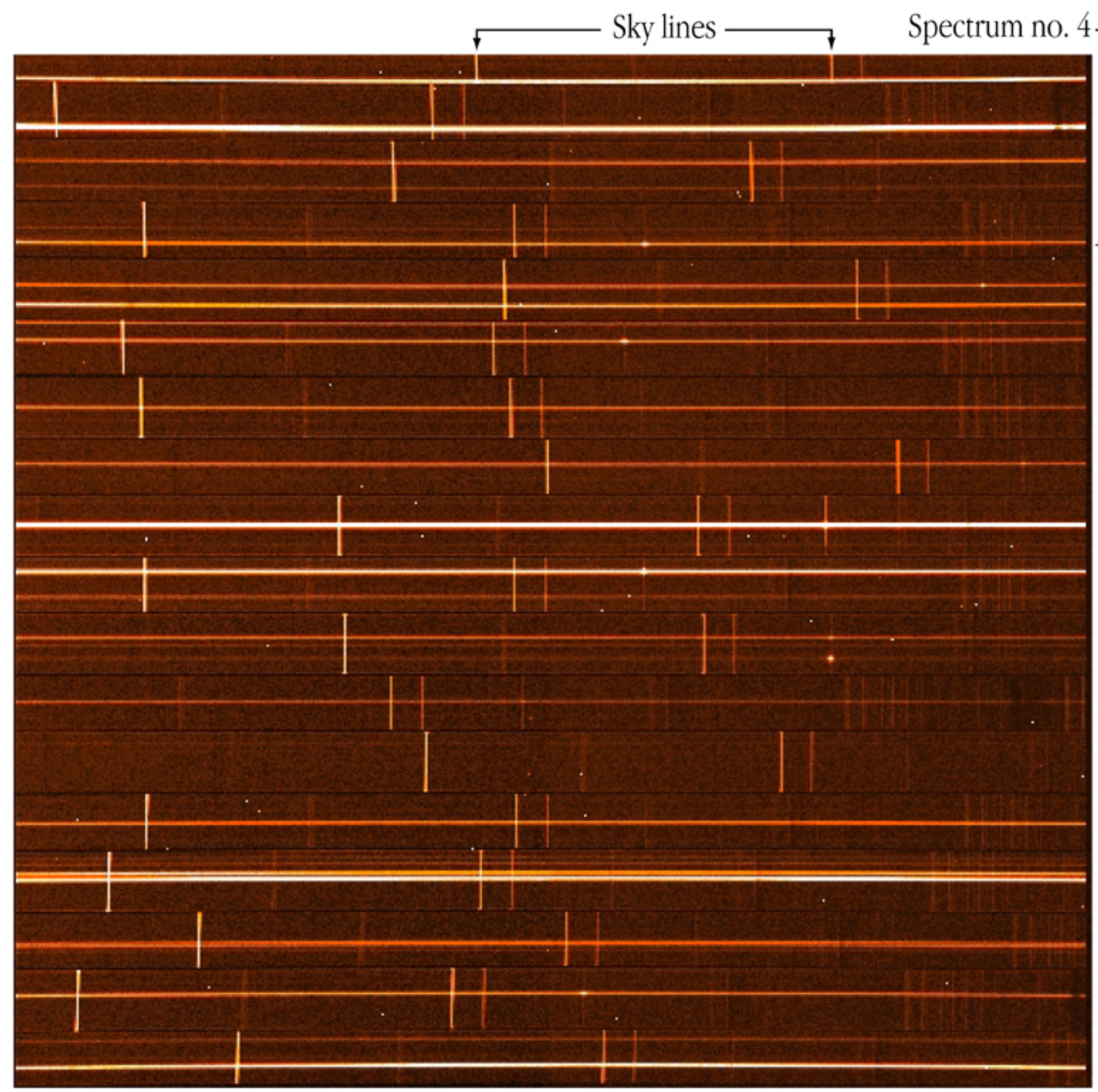
Multi-object spectrographs

make a mask with multiple slits, one per target



Open Cluster NGC 330 in SMC - VLT UT1 + FORS1 (MOS-mode)

ESO PR Photo 38c/98 (7 October 1998)

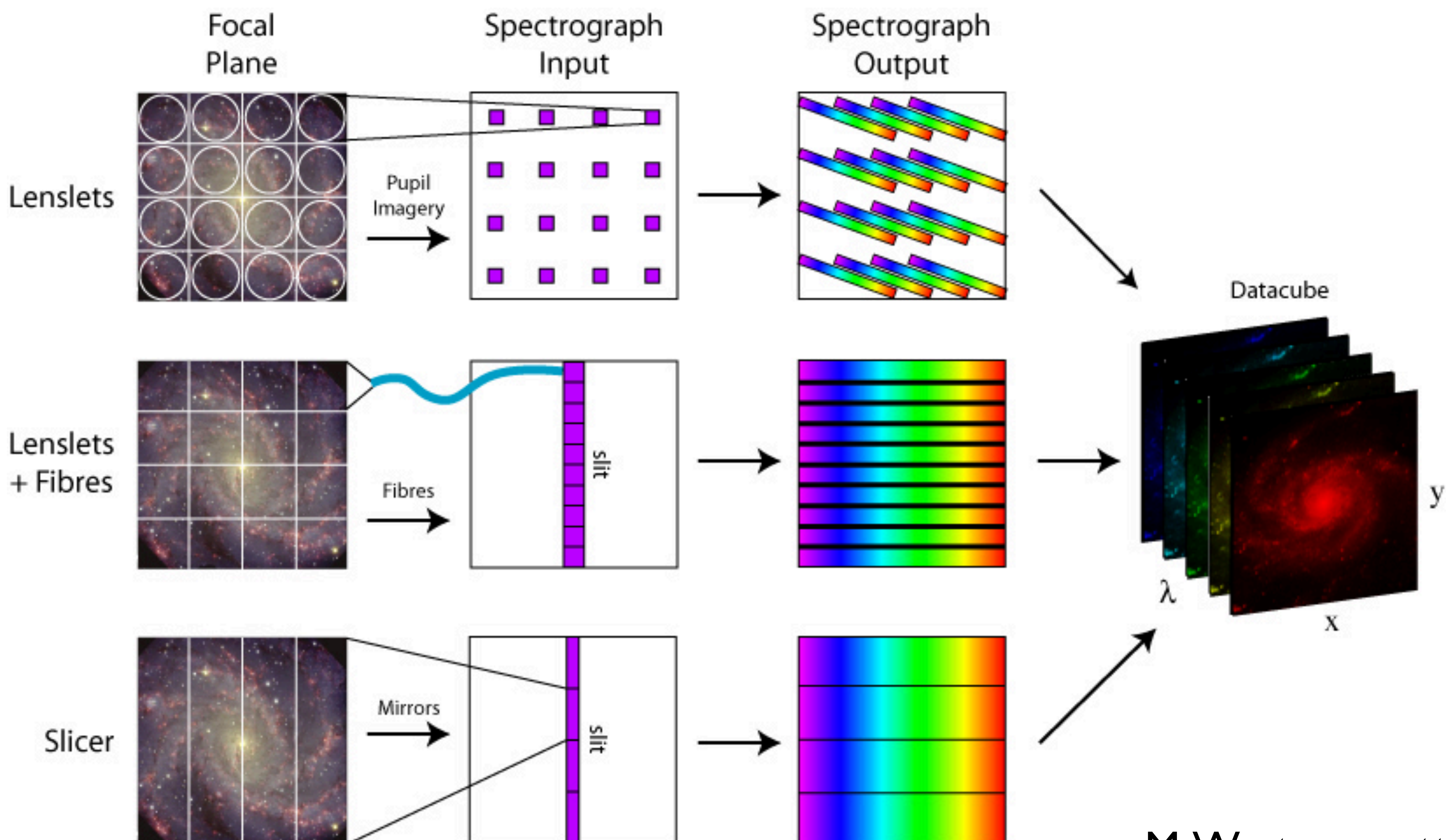


Spectra of Stars in Open Cluster NGC 330 in SMC - VLT UT1 + FORS1 (MOS-mode)

ESO PR Photo 38d/98 (7 October 1998)

Integral-Field Units

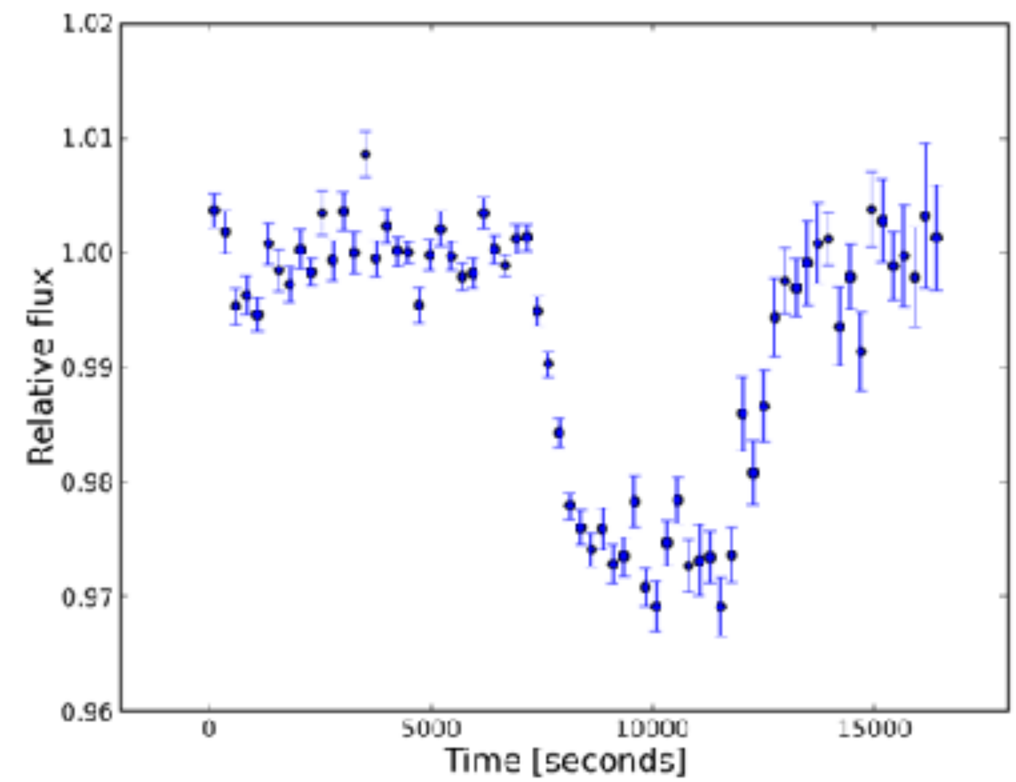
divide image into "spaxels" (spectroscopic pixels)



M. Westmoquette

Lab 2

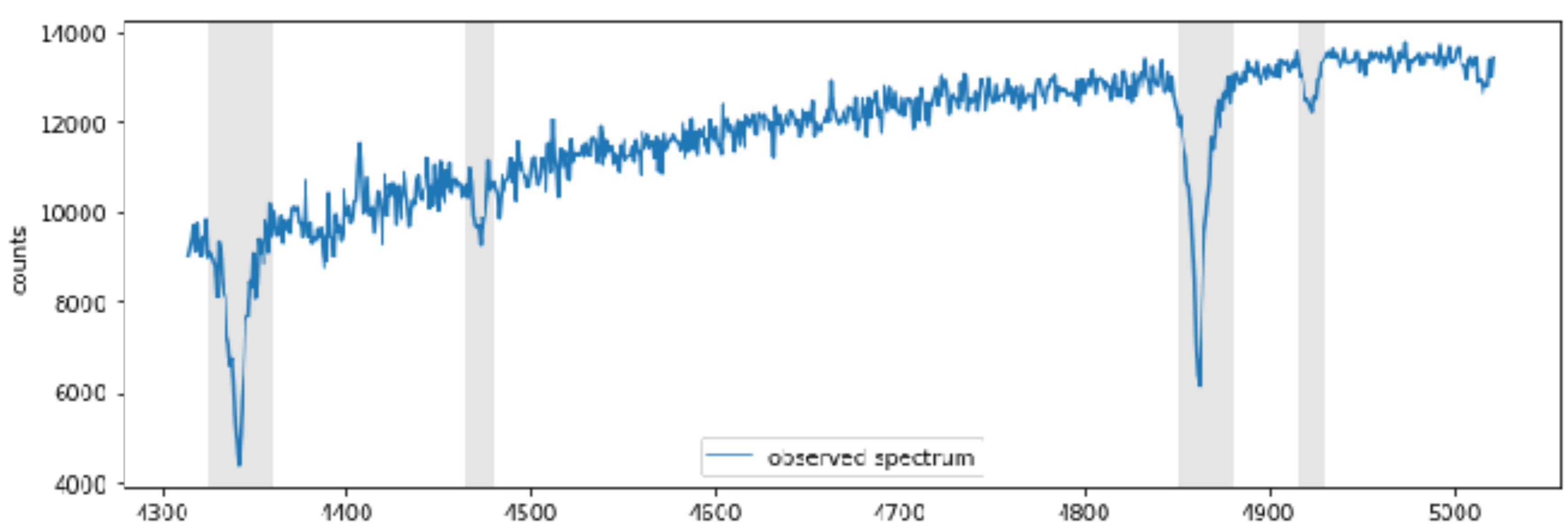
- Option A) Exoplanet transit
  - photometry of a star that hosts an exoplanet
  - extensive lab manual
  - usually done with STL-1001E …



- imaging data analysis is easier (conceptually) than spectroscopic data analysis
- involves more programming later on
- for Lab 3, have to then use spectroscopy

Lab 2

- Option B) Spectroscopy of bright stars
  - measure strength of absorption line features as function of temperature
  - lab manual still in draft form
  - 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 Feb. 14 and March 11

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