PHY 517 / AST 443:
Observational Techniques in Astronomy

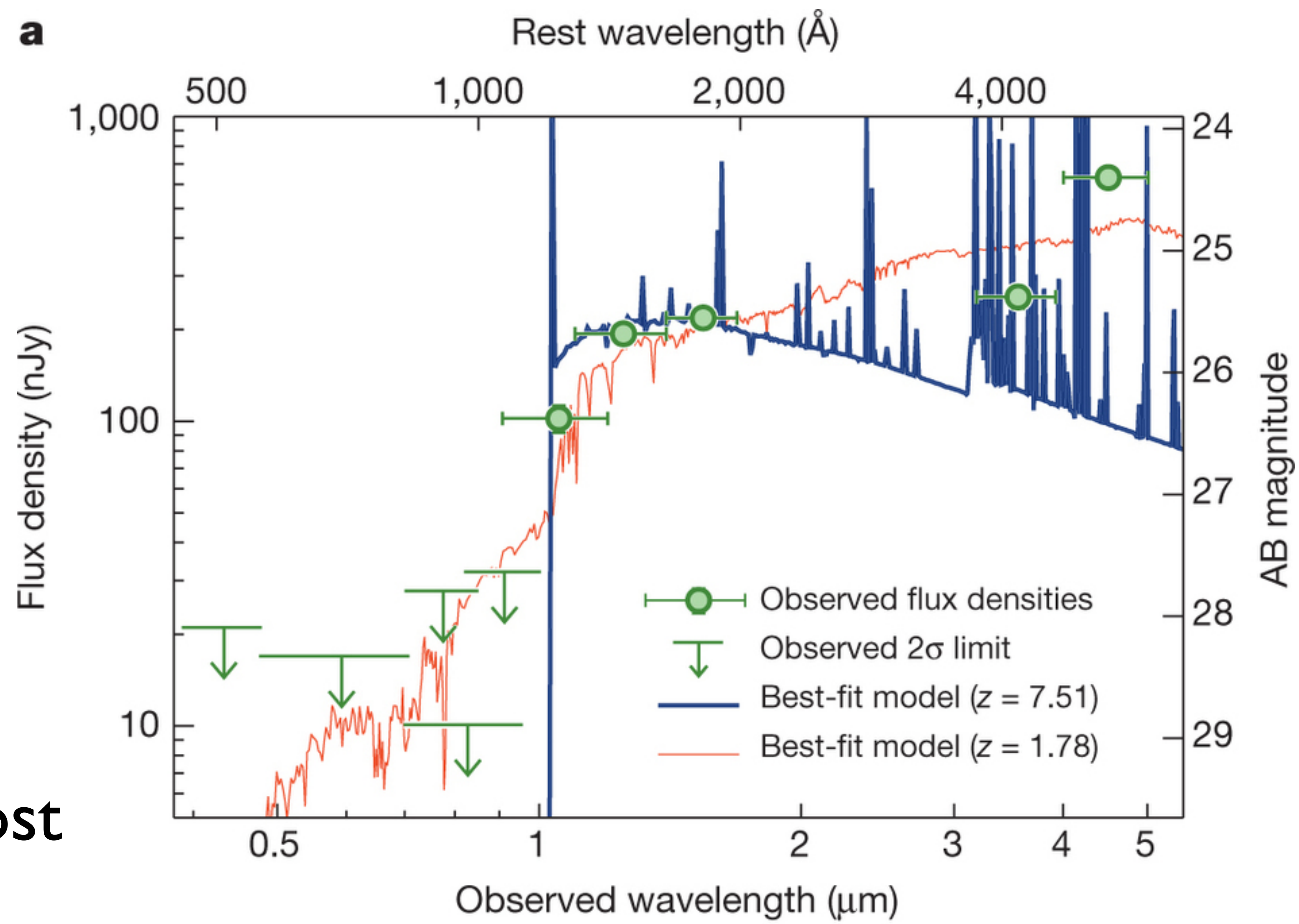
Lecture 6:
Spectroscopy

Motivation

photometry (measuring flux from images) only measures integrated flux

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

e.g.: finding the most distant galaxies



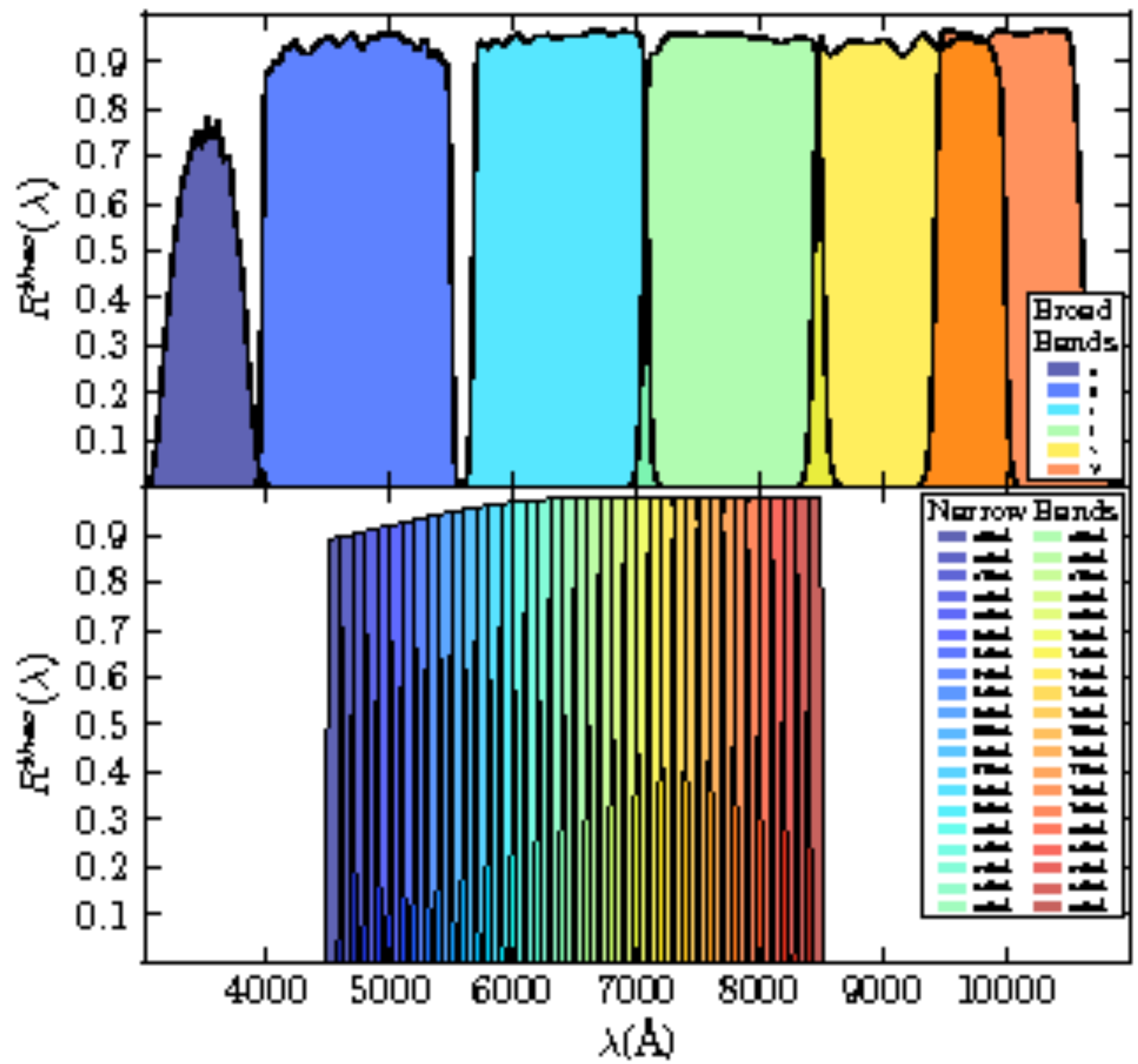
Finkelstein et al. 2013

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!

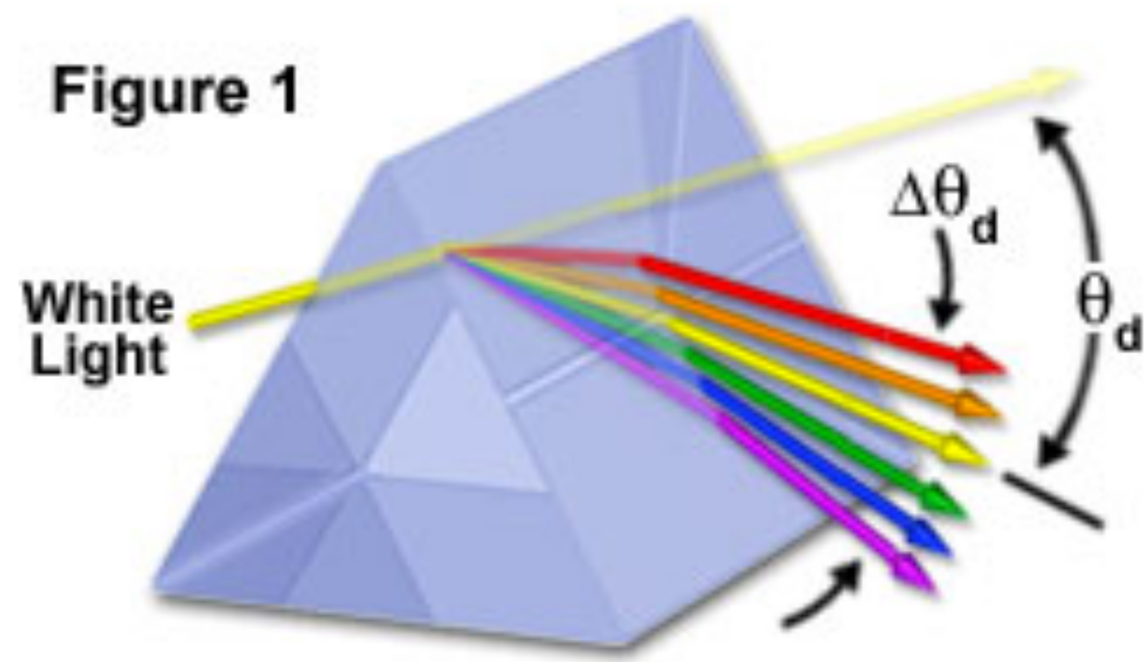


The PAU Survey

Spectroscopy

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

e.g. a prism:

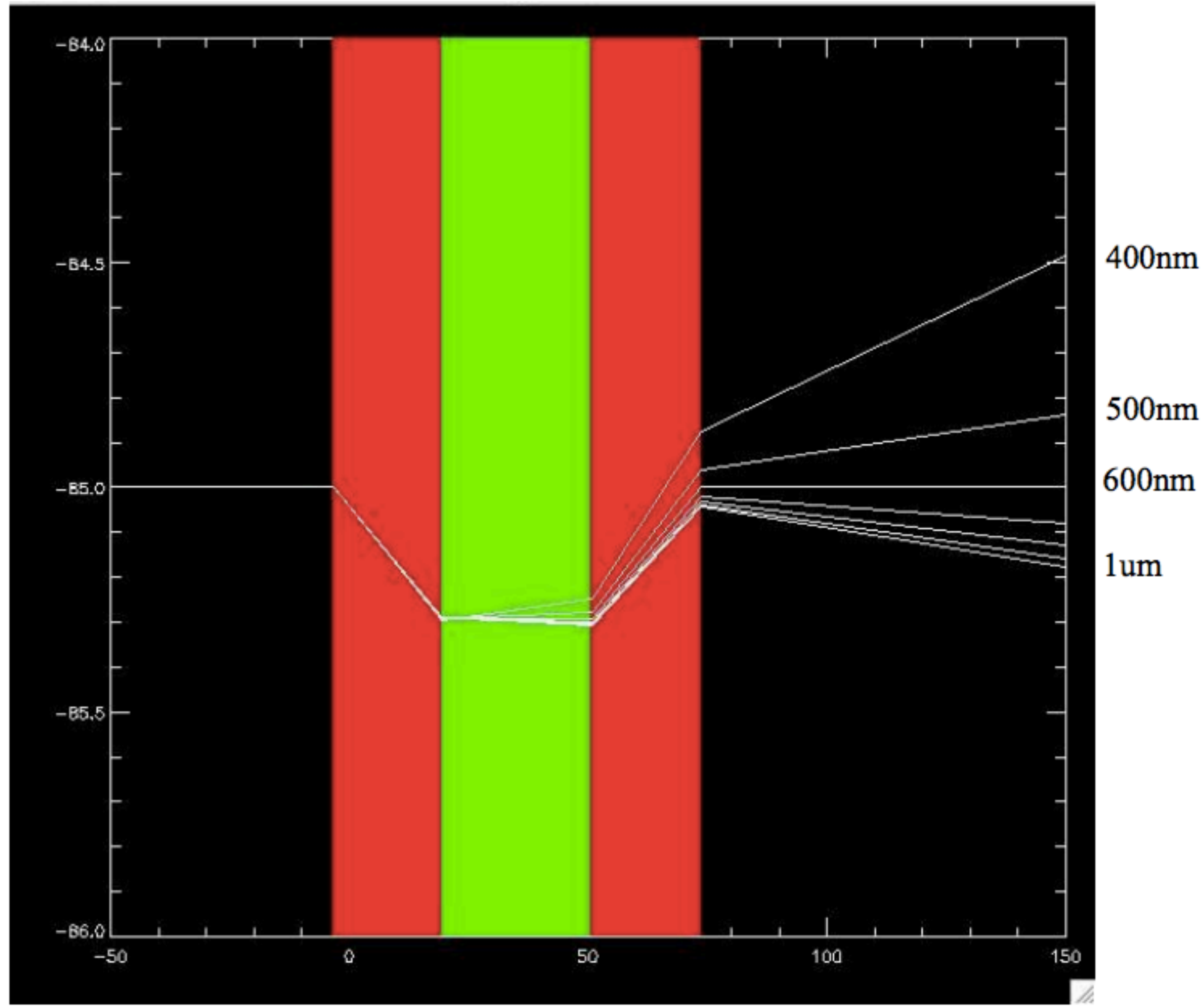


Olympus

Prism Spectroscopy

only few astronomical spectrographs use prisms

- low dispersion (resolution)
- dispersion varies with wavelength



LDP Prism description

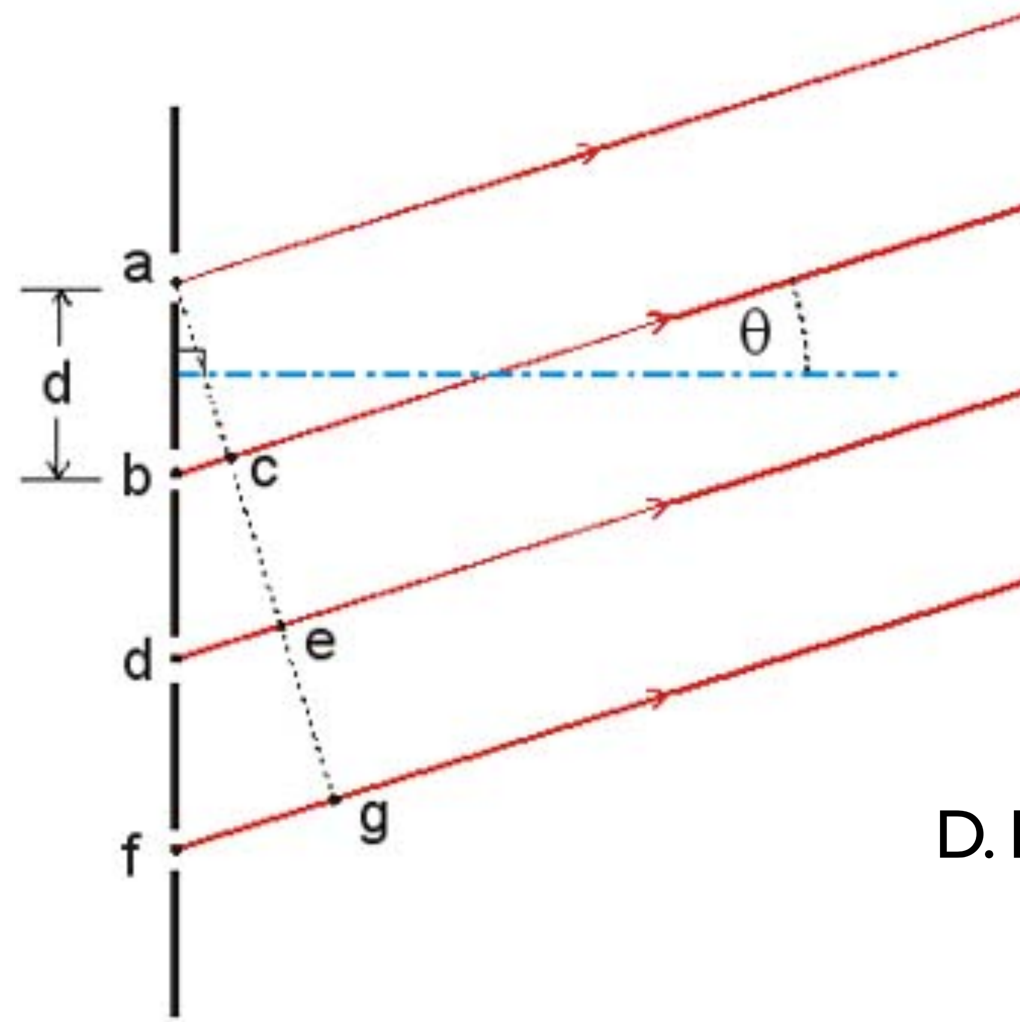
“low dispersion prism” for IMACS spectrograph on Magellan 6-m telescope; uses 3 prisms

Diffraction gratings

make use of wave properties of light: interference

grating: many parallel lines (~500/mm)

similar to single-slit and double-slit experiments

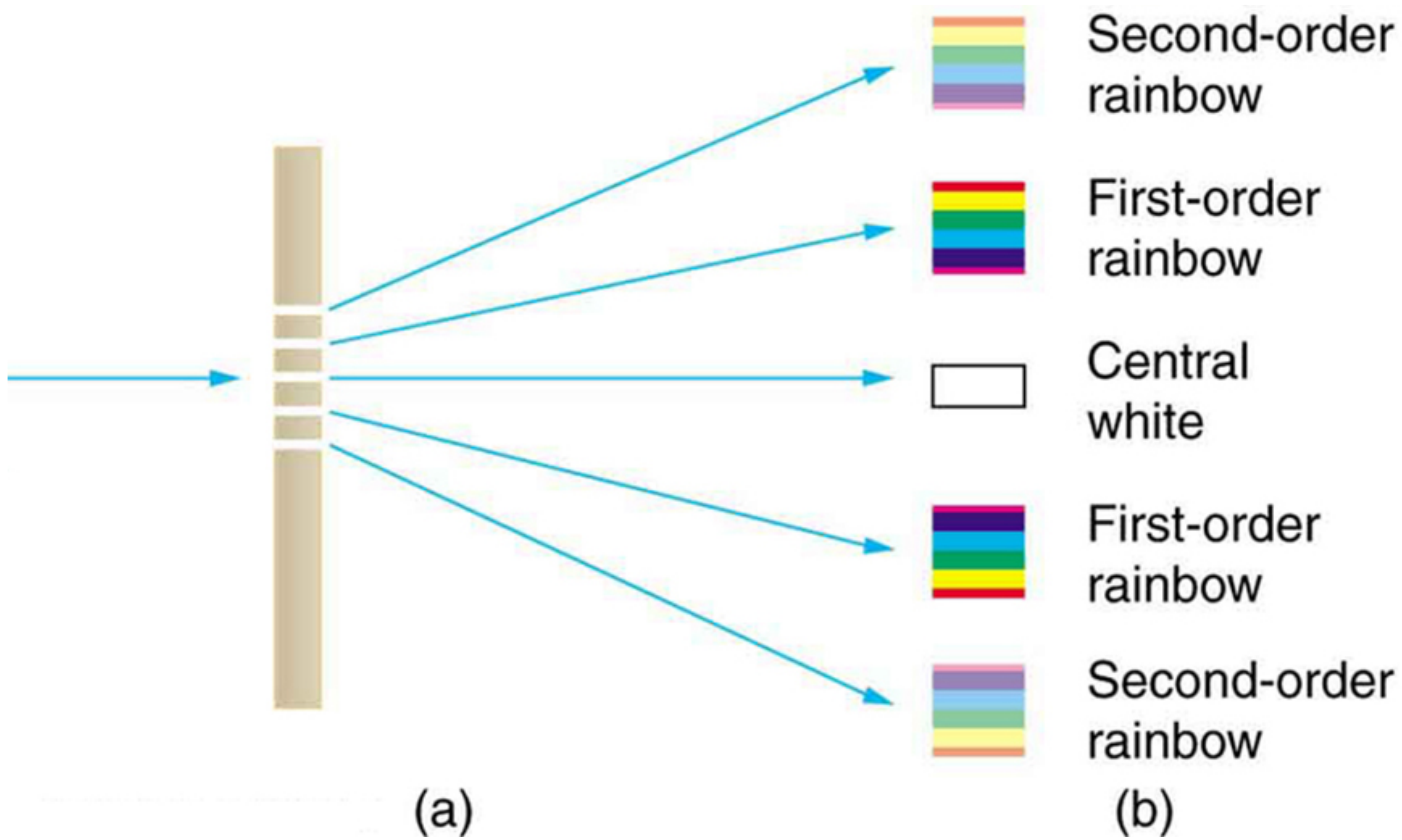


D. Pogosian

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

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

Diffraction gratings

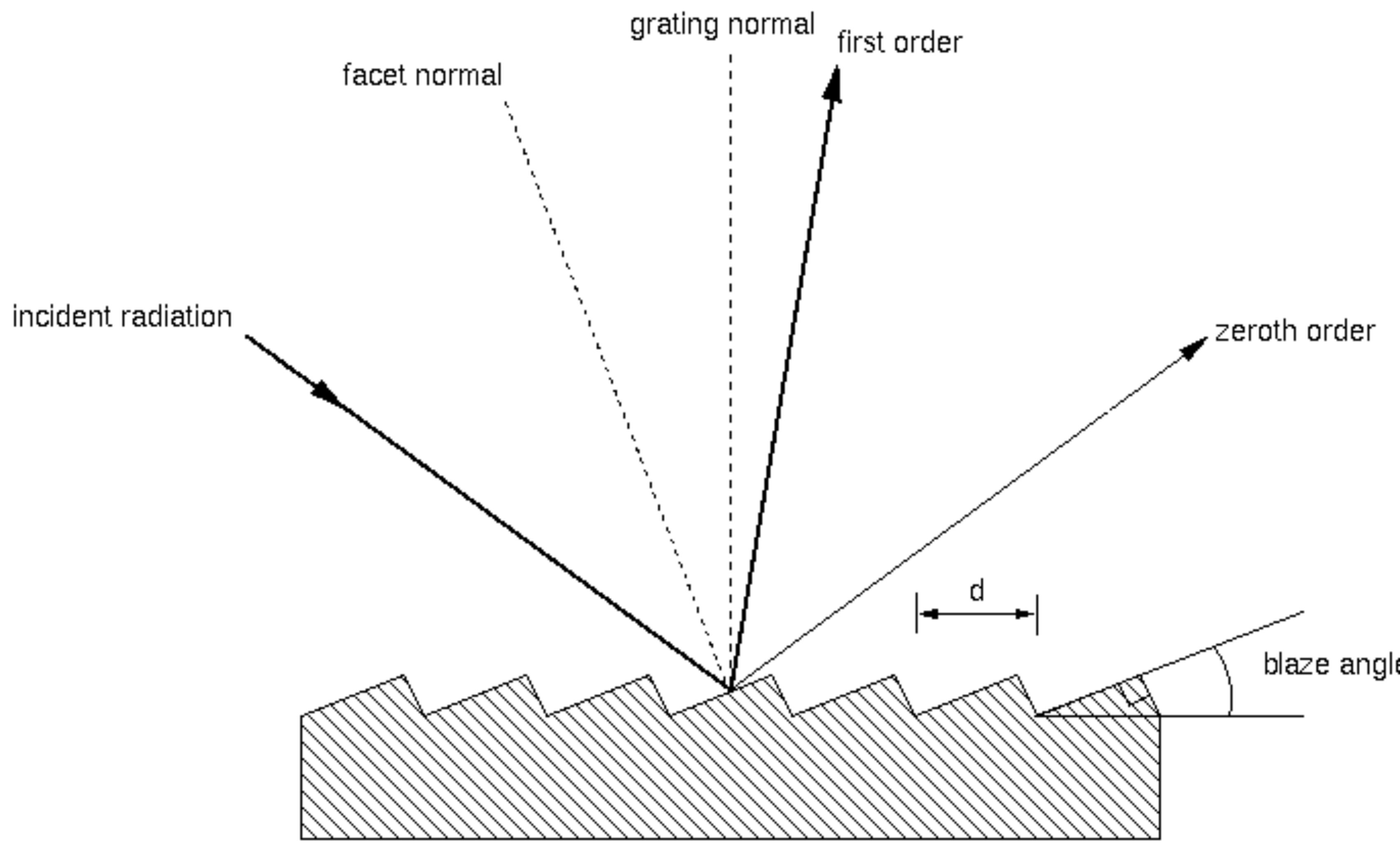


OpenStax University

Diffraction gratings

can be transmission gratings or reflection gratings

most astronomical spectrographs use reflection gratings



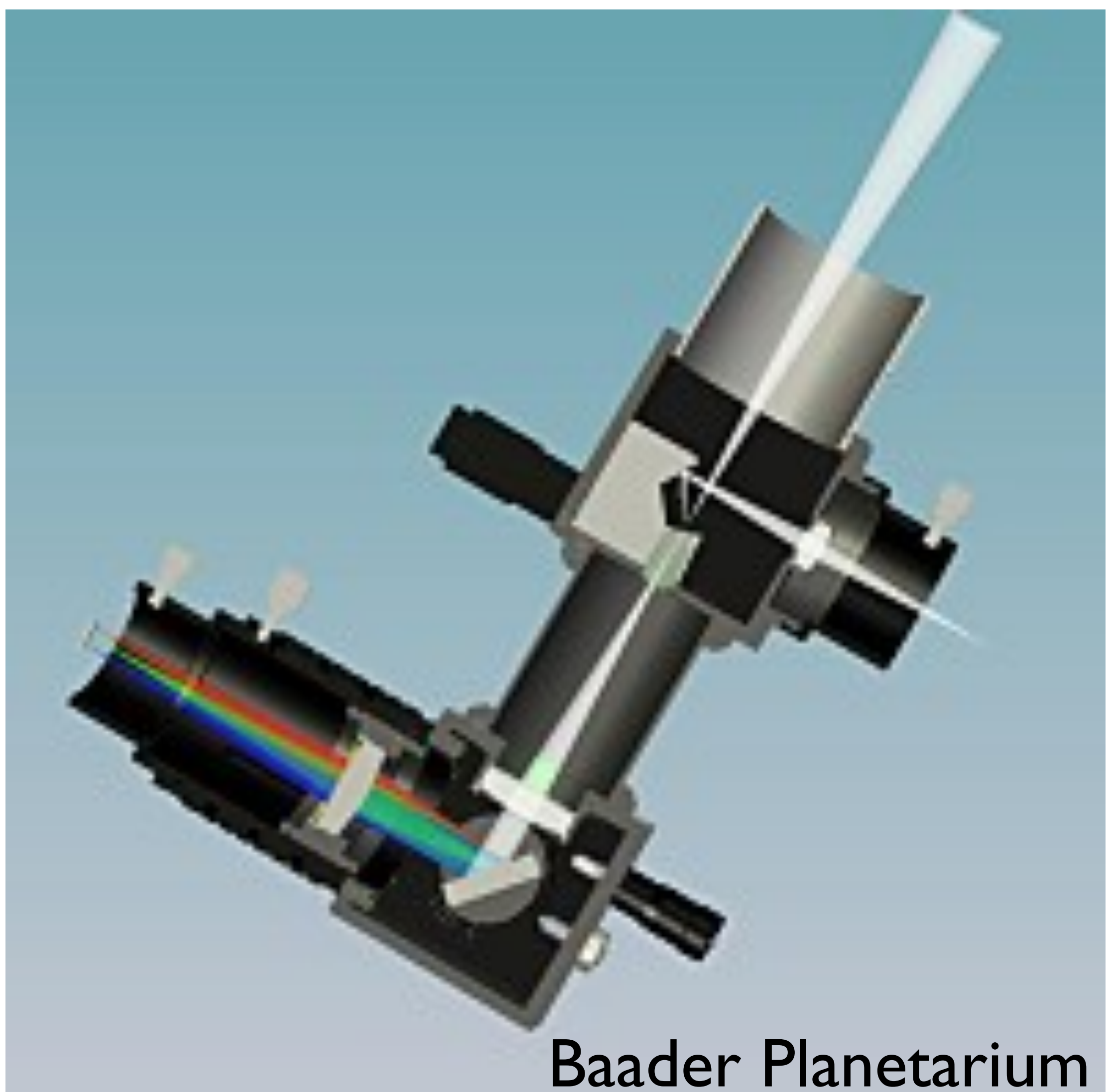
Dhillon 2012

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

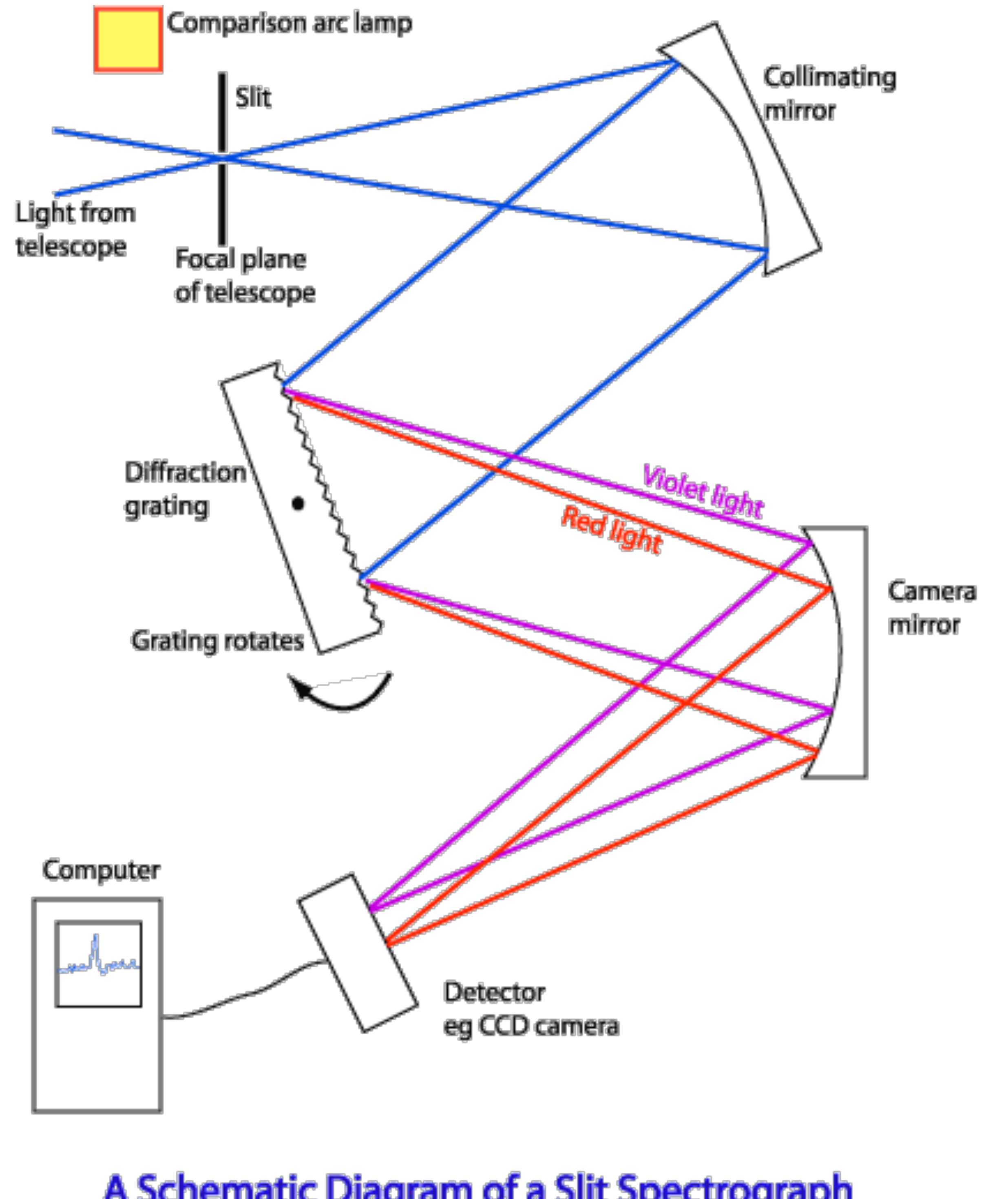
Typical spectrograph

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]

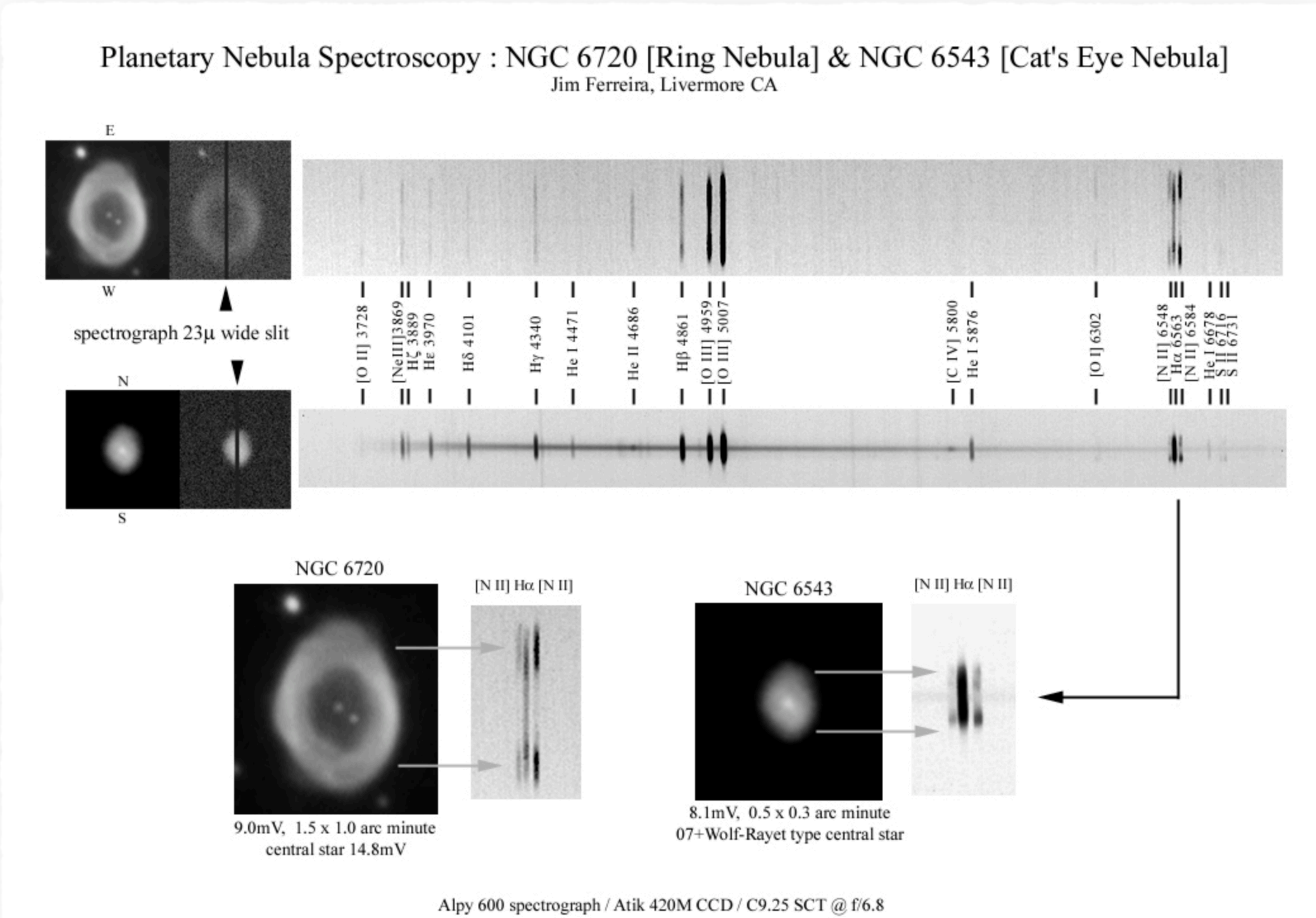
to properly sample the spectrum:

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

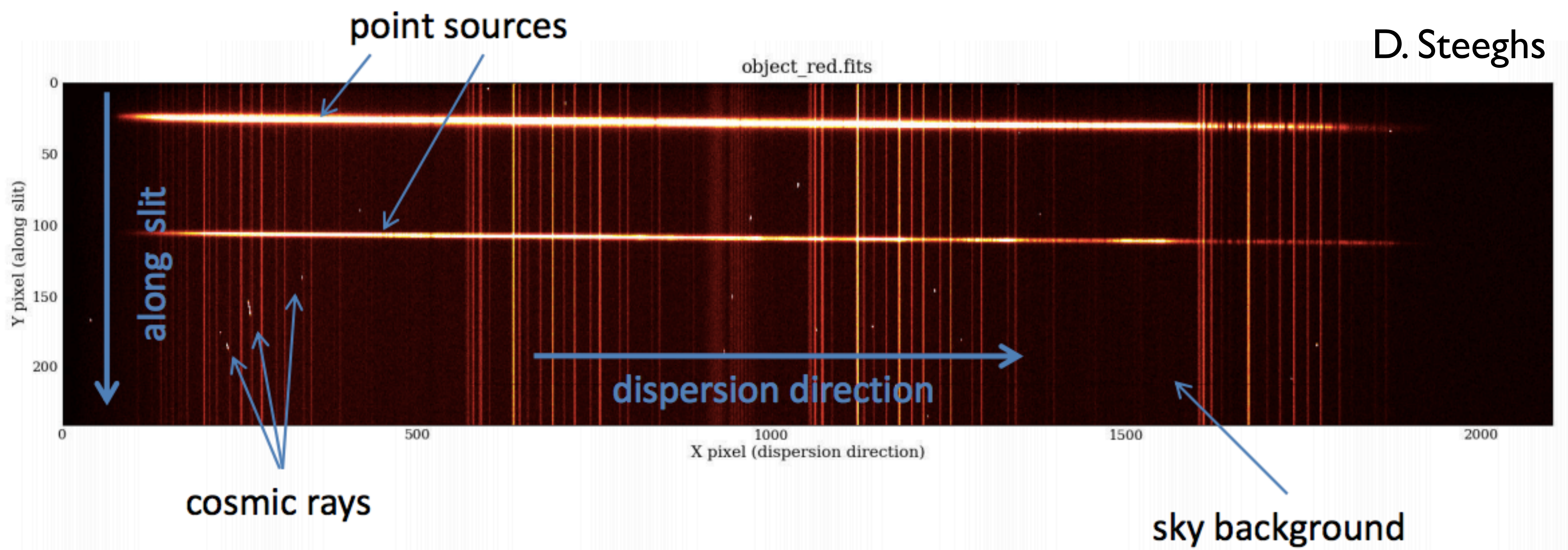
Spectral Resolution

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



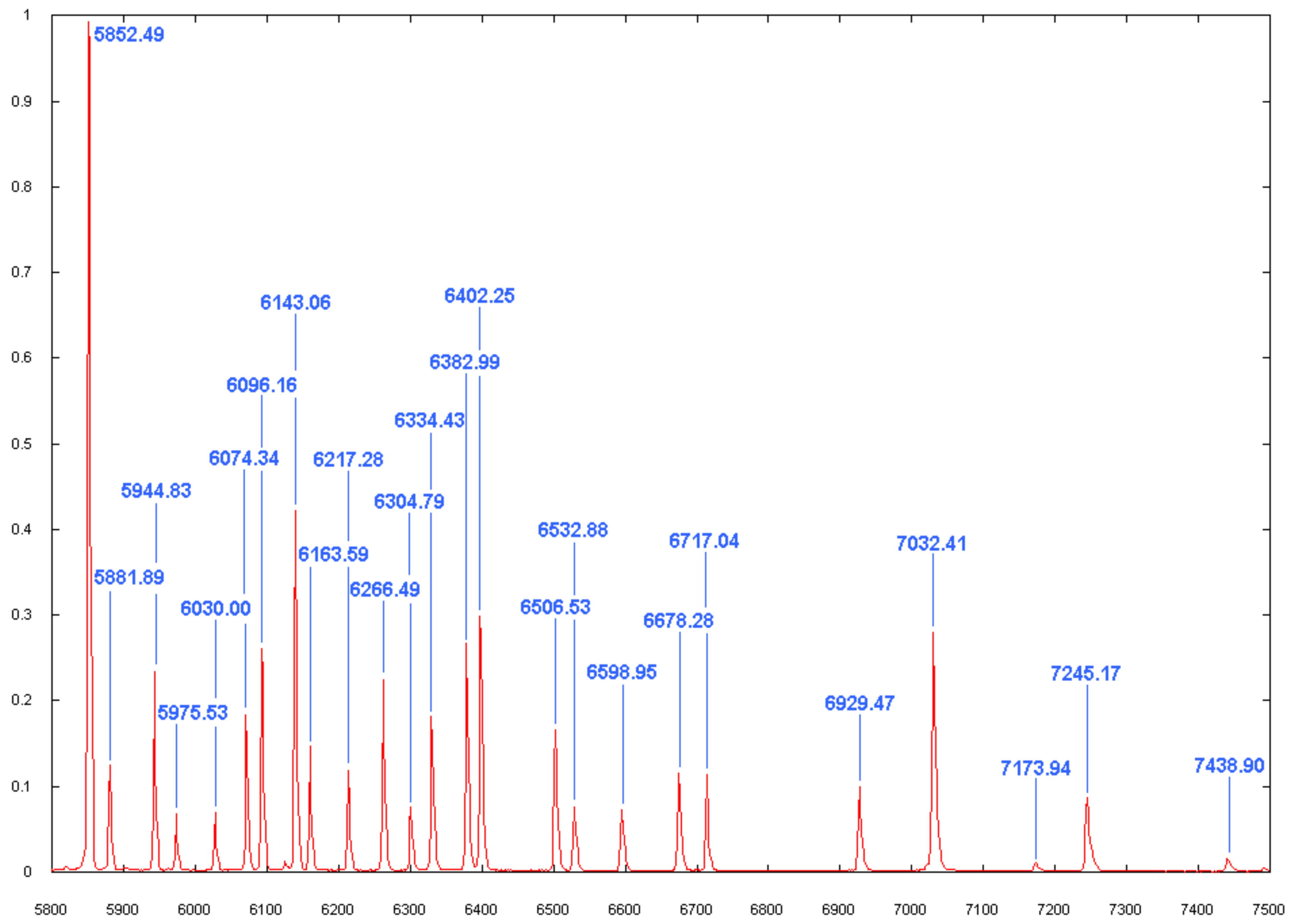
- long axis of CCD used to sample spectrum
- spatial information along slit still available: two objects, lots of sky
- sky background has a lot of emission lines!

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

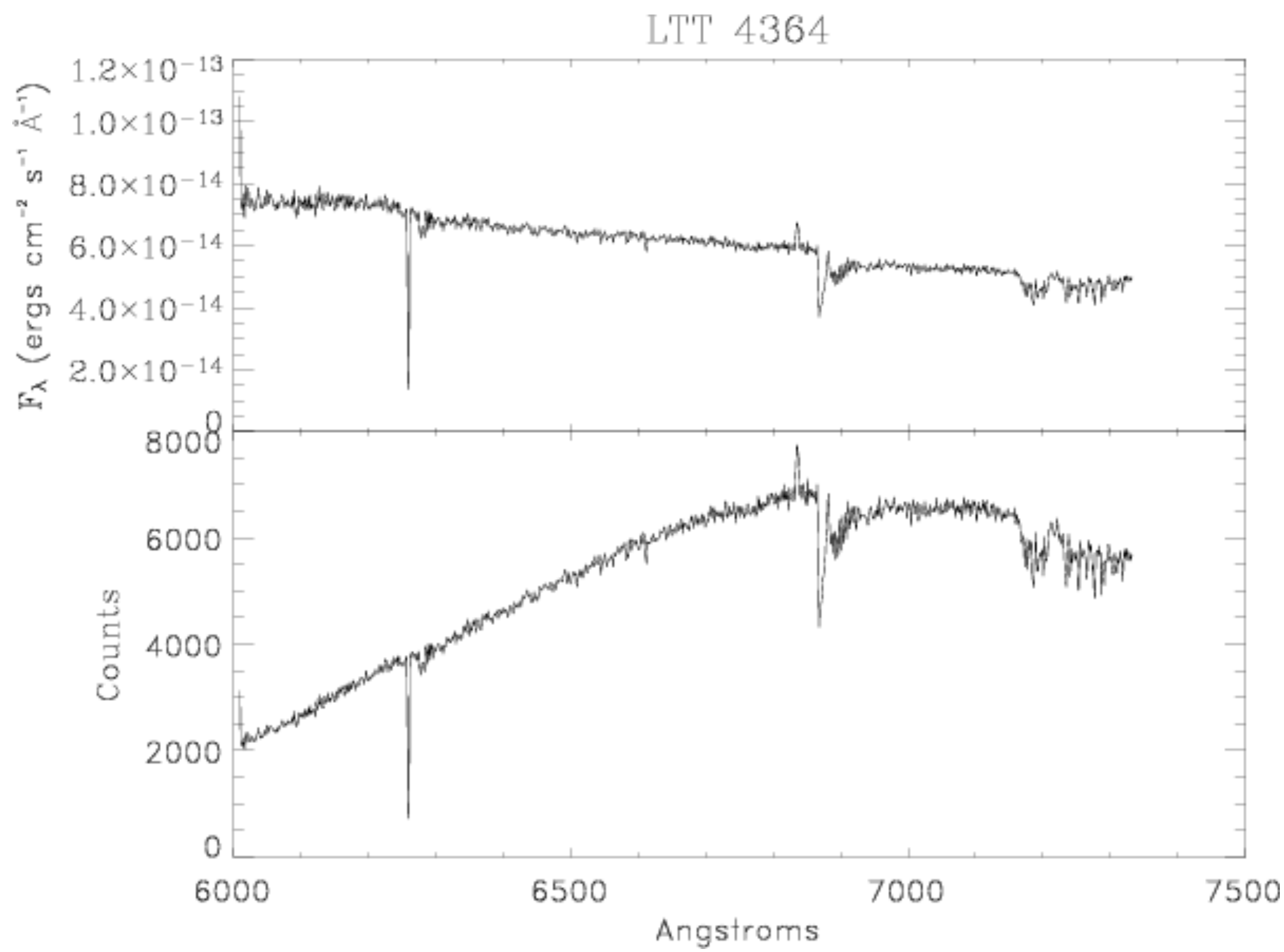


C. Buil / astrosurf

Spectroscopic Calibration

flux calibration:
observe spectrophotometric standard star

compare observed spectrum (counts) to known spectrum



F. Walter

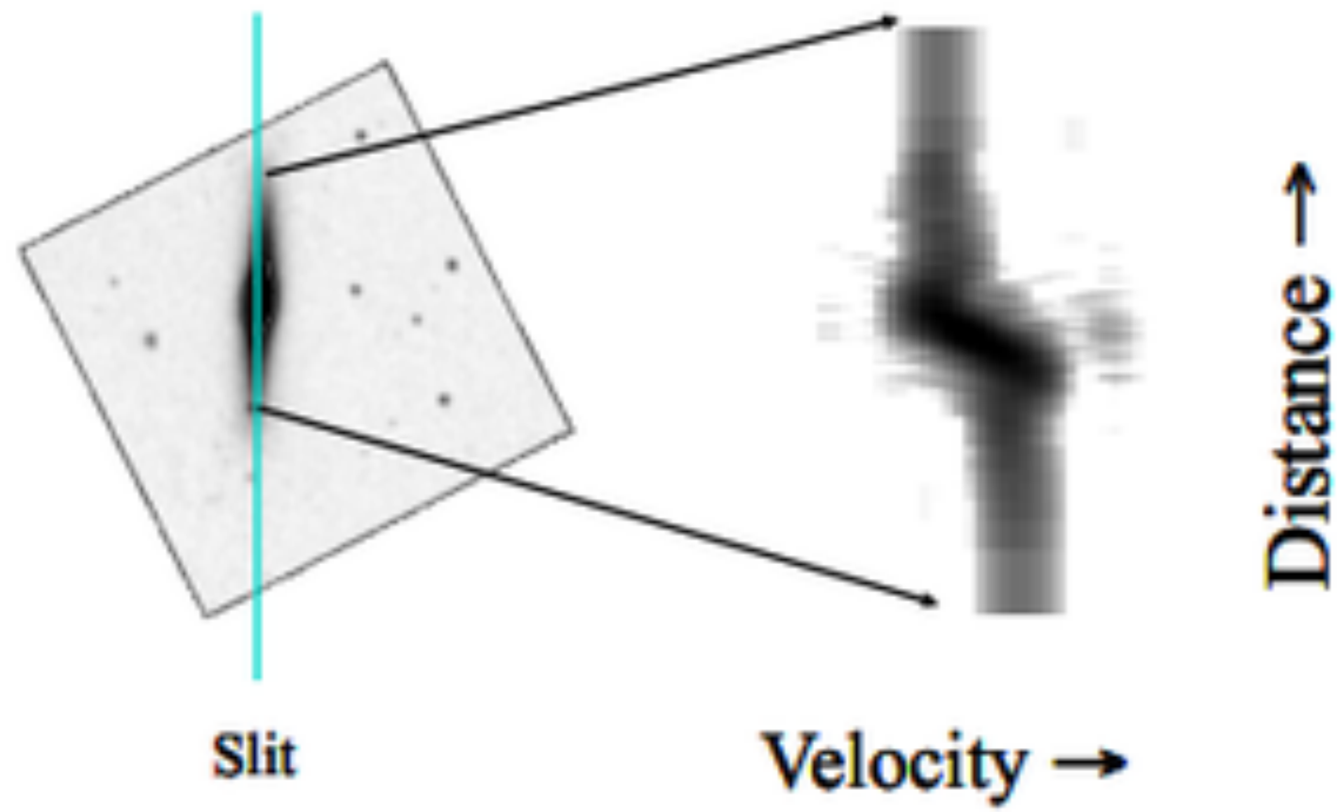
Long-slit spectrographs

most common spectrograph

can only target one (or a few) objects

gives spatial variation

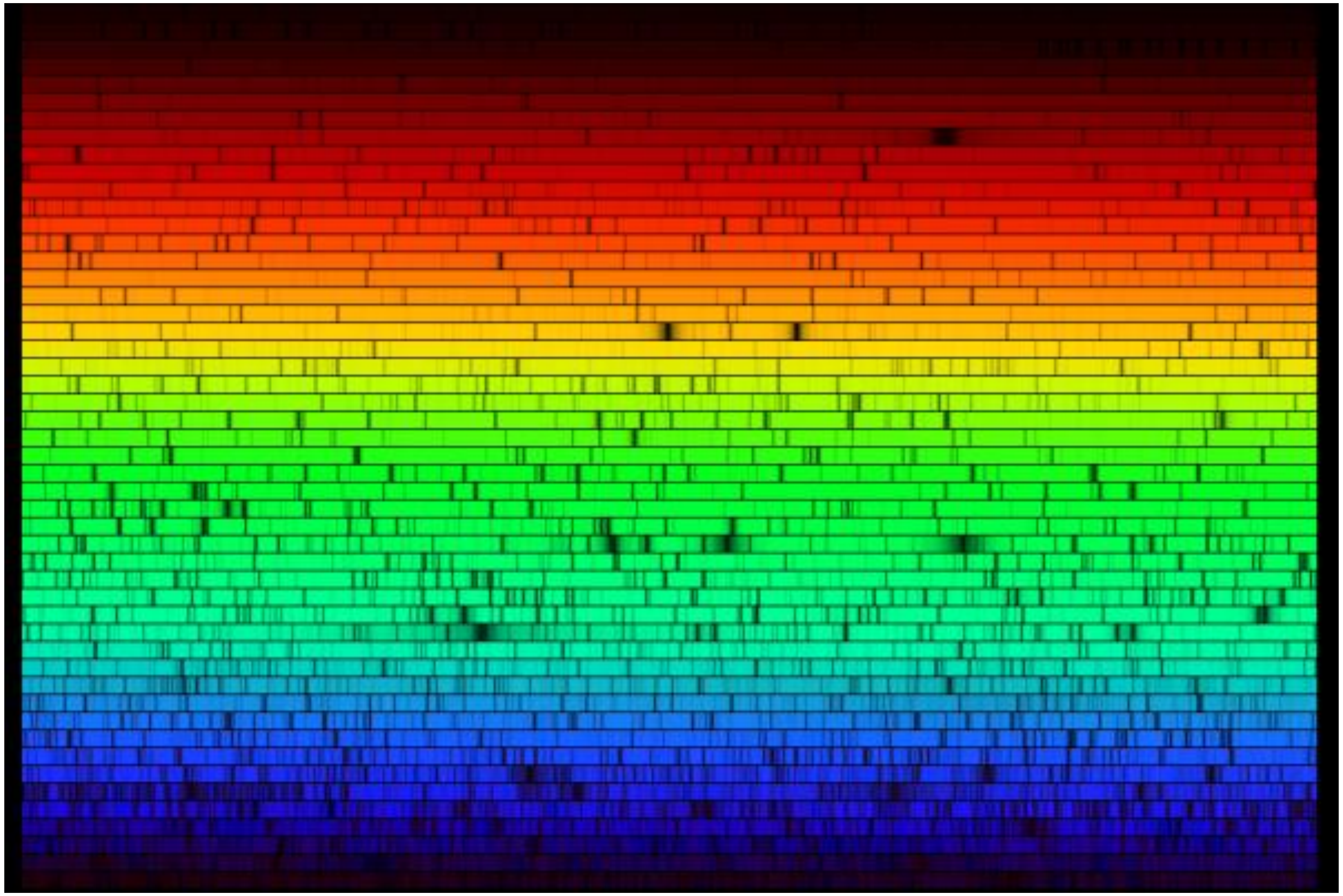
very good estimate of sky background



wikipedia

Echelle spectrographs

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

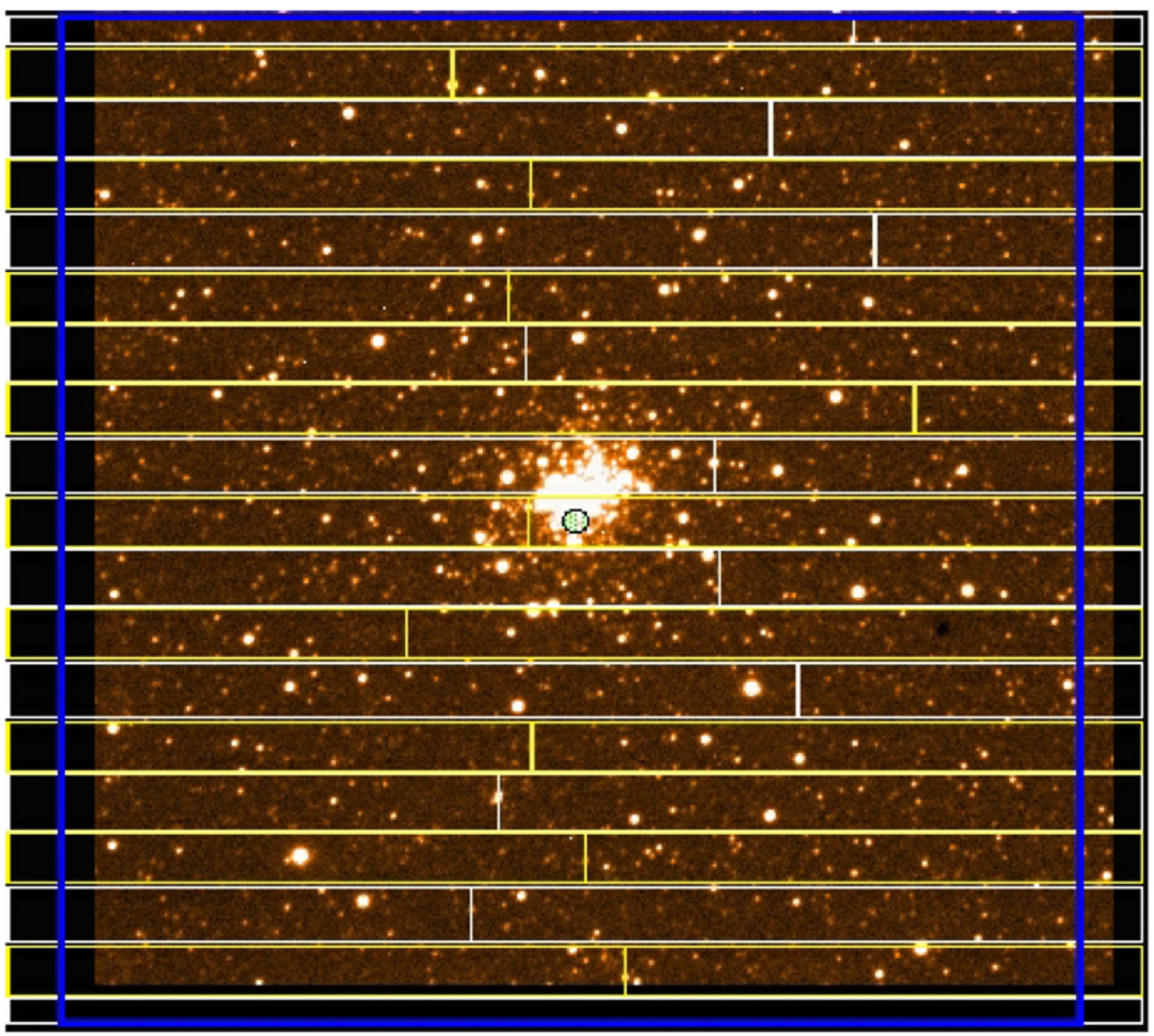


Echelle spectrum of the Sun, 4000-7000Å

NOAO

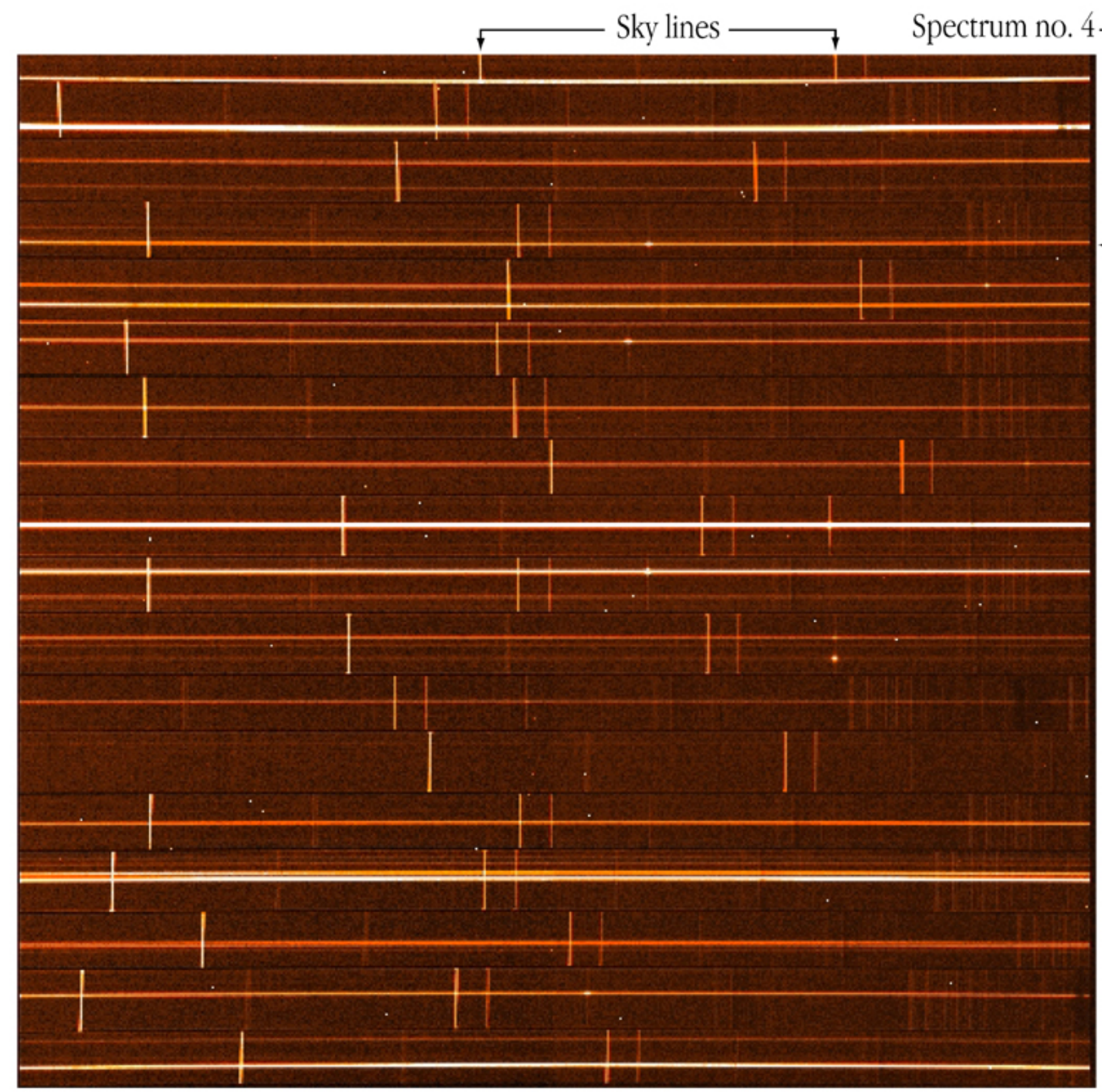
Multi-object spectrographs

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)

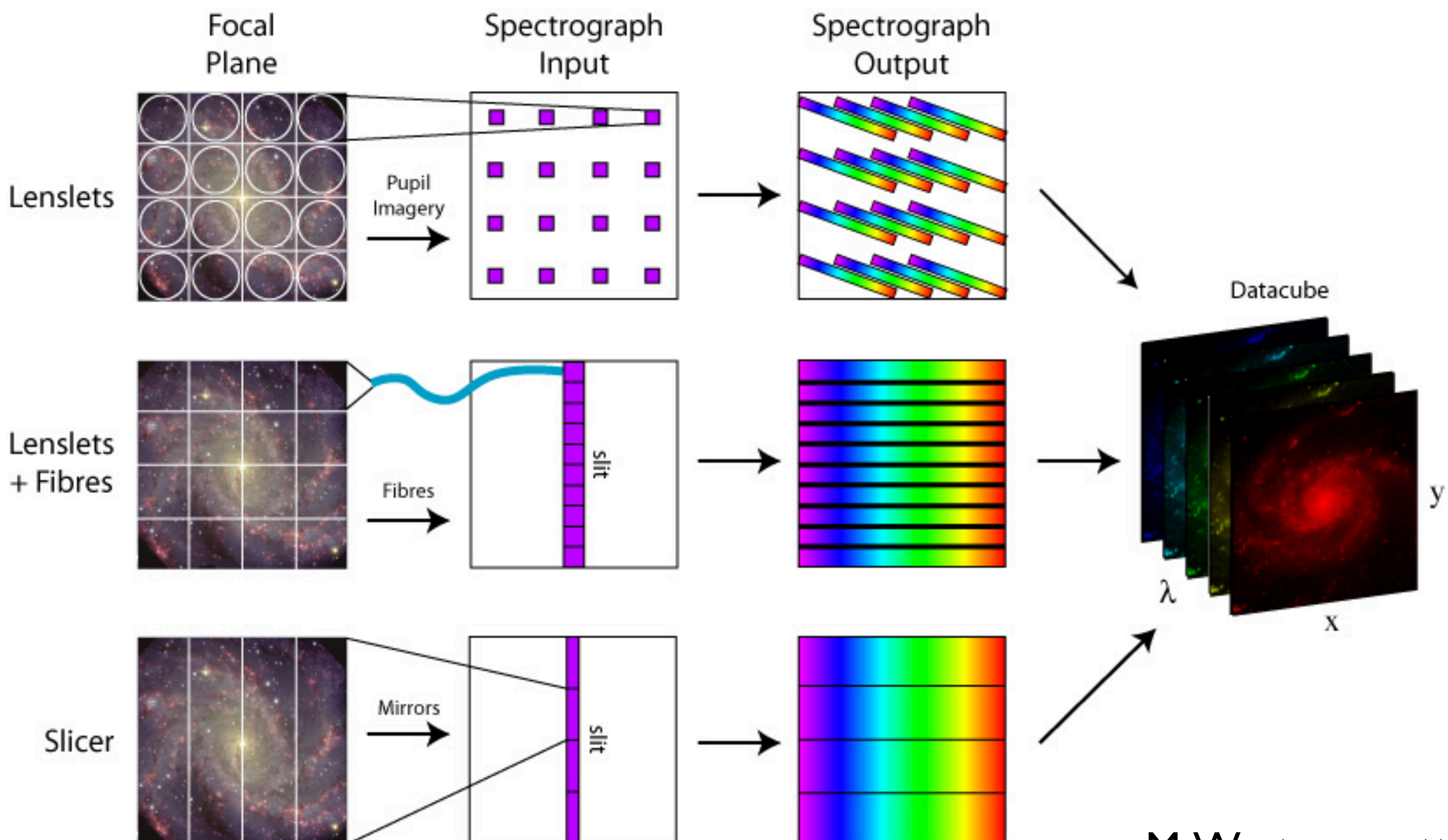


Spectra of Stars in Open Cluster NGC 330 in SMC - VLT UT1 + FORS1 (MOS-mode)

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

Integral-Field Units

divide image into "spaxels" (spectroscopic pixels)



M. Westmoquette

Spectroscopy Lab

- Option A) Spectroscopy of an emission-line nebula
  - goal: measure gas density and temperature
  - existing, detailed lab manual
  - observational challenge: it can be very difficult to find the target
- Option B) Spectroscopy of bright stars
  - measure strength of absorption line features as function of temperature
  - lab manual in draft form - help me design this lab!
  - much easier to find the targets

Spectroscopy Lab

- Figure out which lab option you plan to conduct
- Find suitable targets
- Request 3 observing dates between now and Oct. 23 (make sure the Moon is not too bright)
- With your request, submit an observing plan with a list of targets, calibration plan, and StarAlt plots