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ASTR 2401

Basic Spectroscopy

Observational Astronomy

Labs This Week

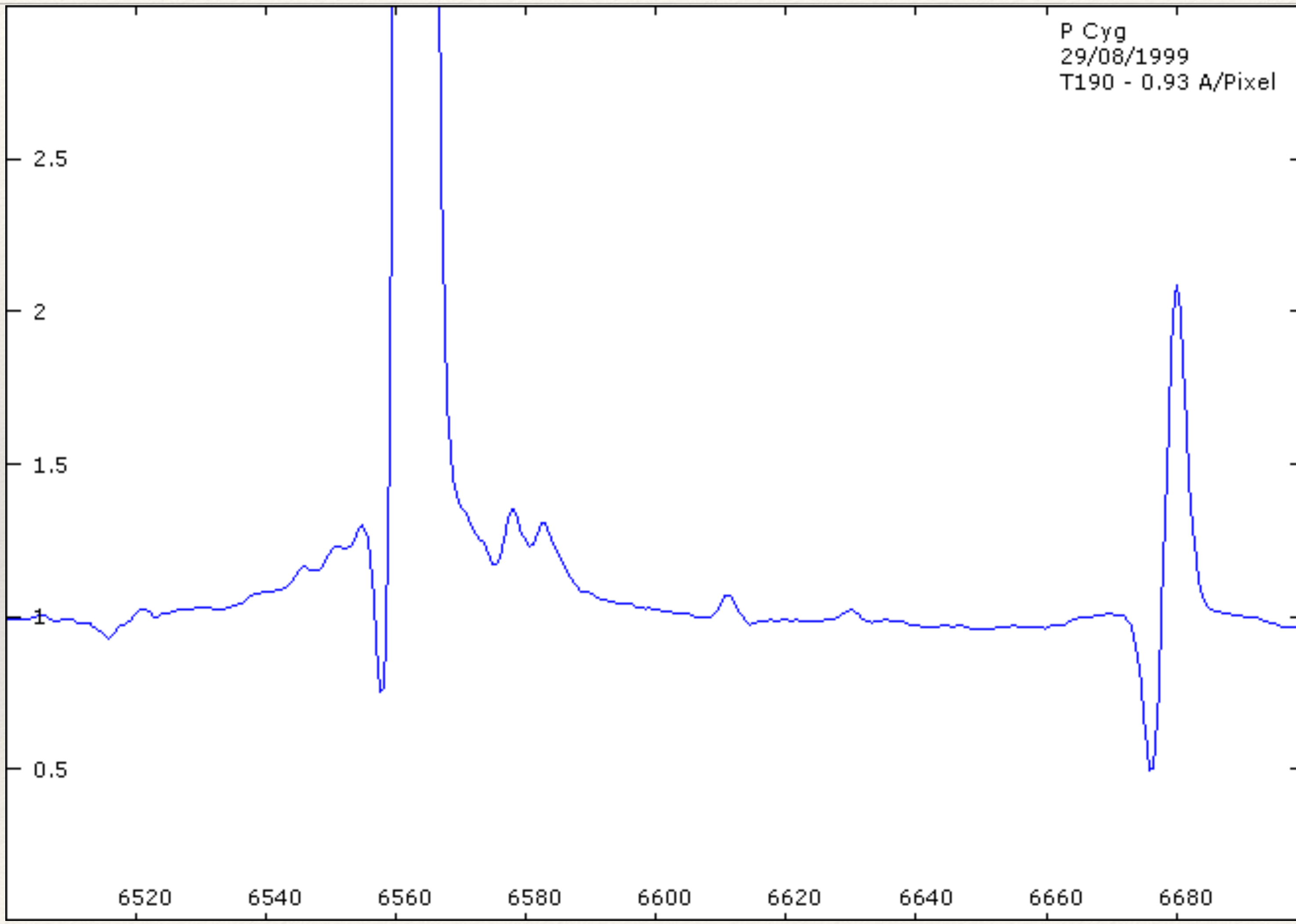
- We are done with observing for the semester.
- Lab time in evening to work on projects.
- Must come to your night, but may come to the other night for extra help.
- 8:00 (7:00?) - 10:00

Physical Applications

Spectroscopy provides a host of information not attainable from imaging, including:

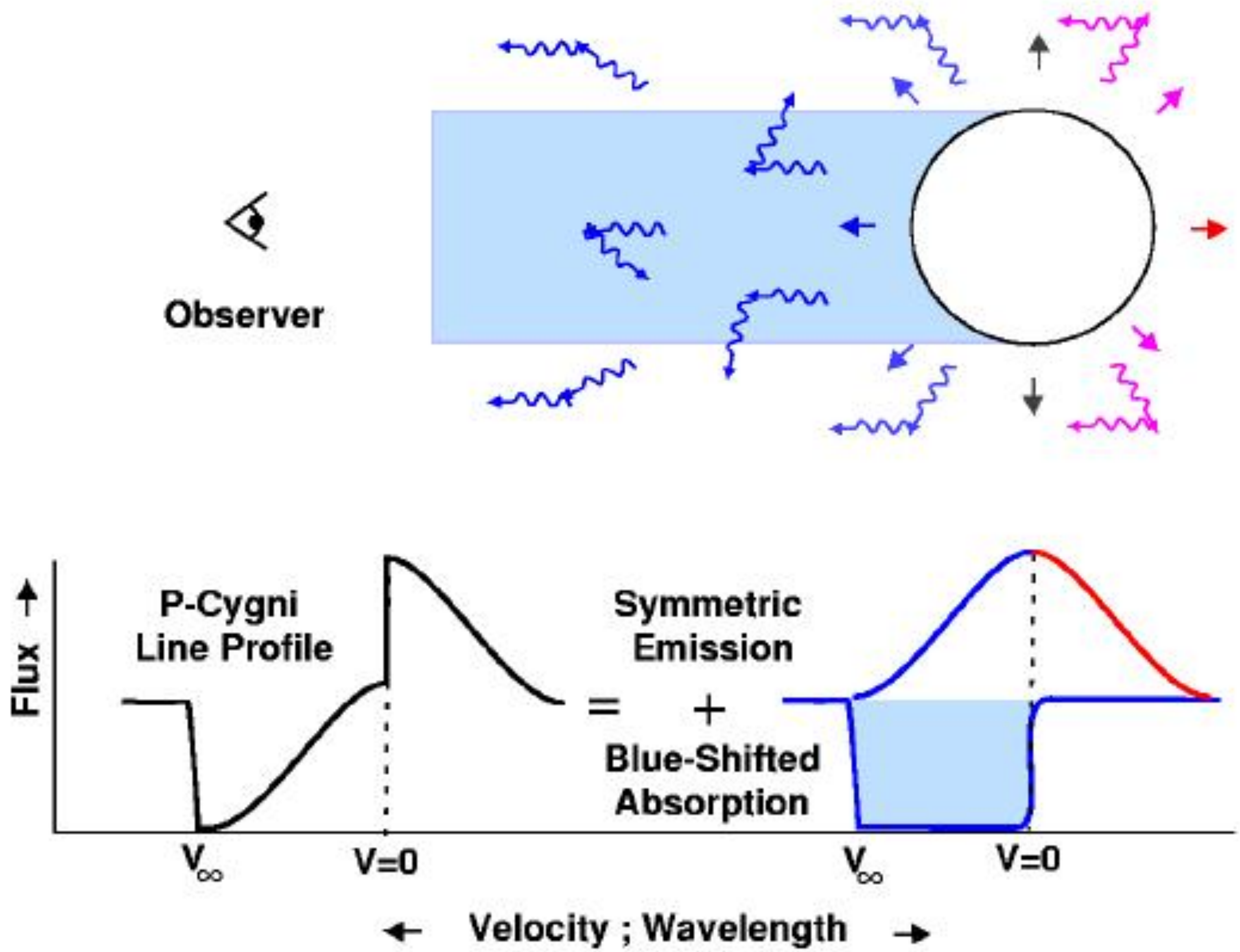
- Line profiles
  - broadening mechanisms (thermal, collisional, rotational)
  - velocity dispersions
  - outflows
- Spectral types of stars (temperature, surface gravity)
- Elemental abundances
- Radial velocities (redshifts)

P Cygni Profile



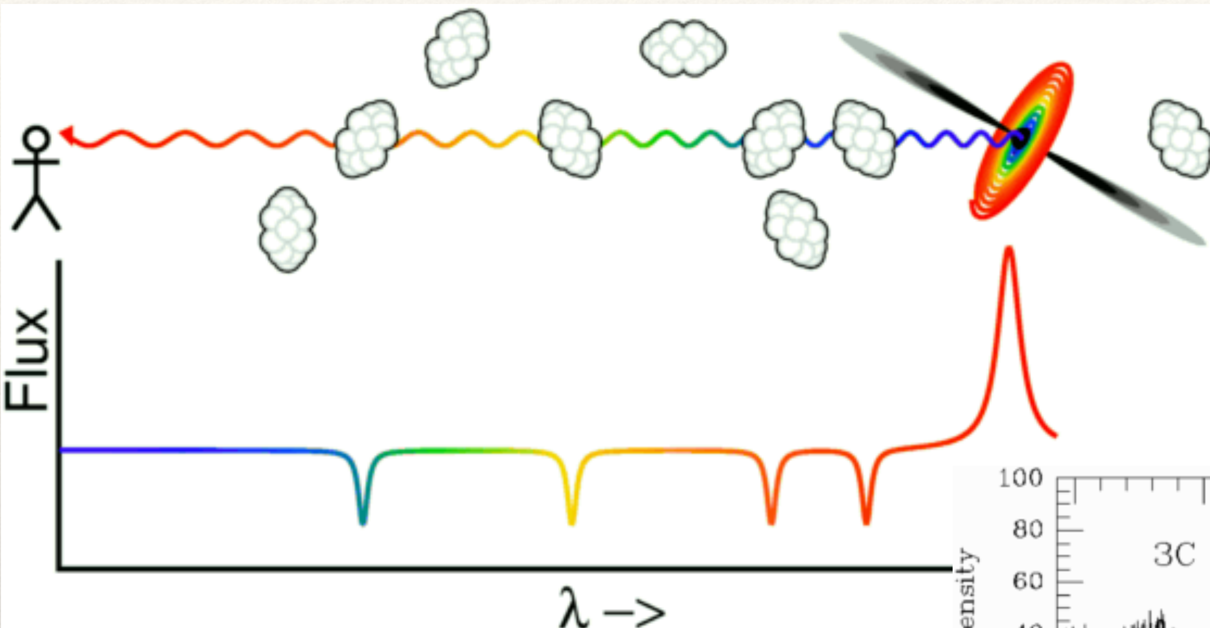
http://www.astrosurf.org/buil/us/peculiar2/pcygni.htm

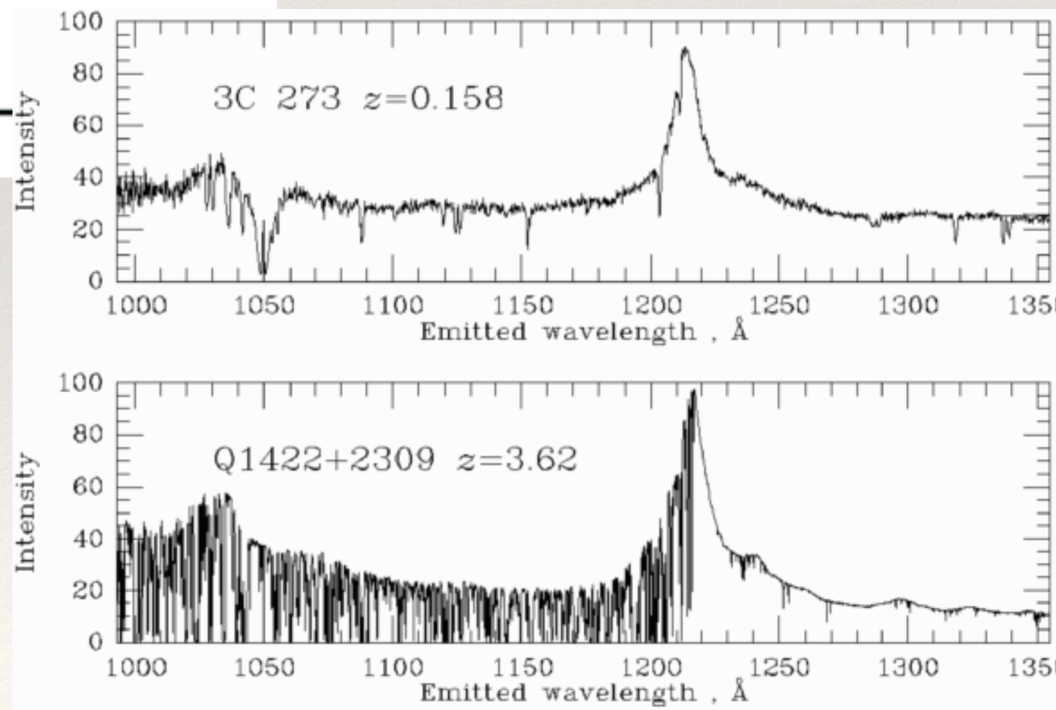
Formation of a P-Cygni Line- Profile



http://www.bartol.udel.edu/~owocki/RDOME/Swarthmore/sld025.htm

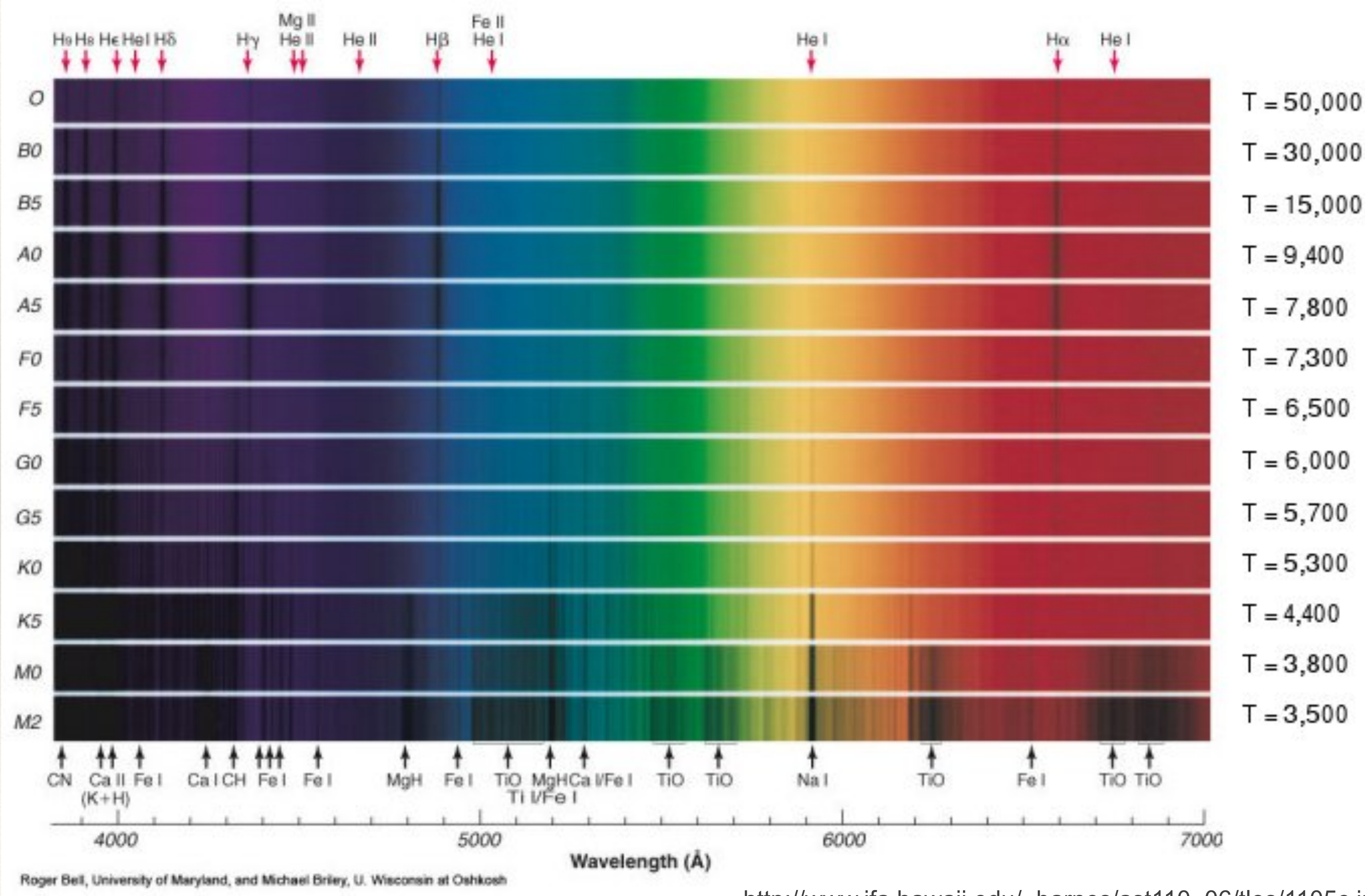
Lyman-alpha Forest





ght/Lyman-alpha-forest.html

Stellar types



http://www.ifa.hawaii.edu/~barnes/ast110_06/tlos/1105c.jpg

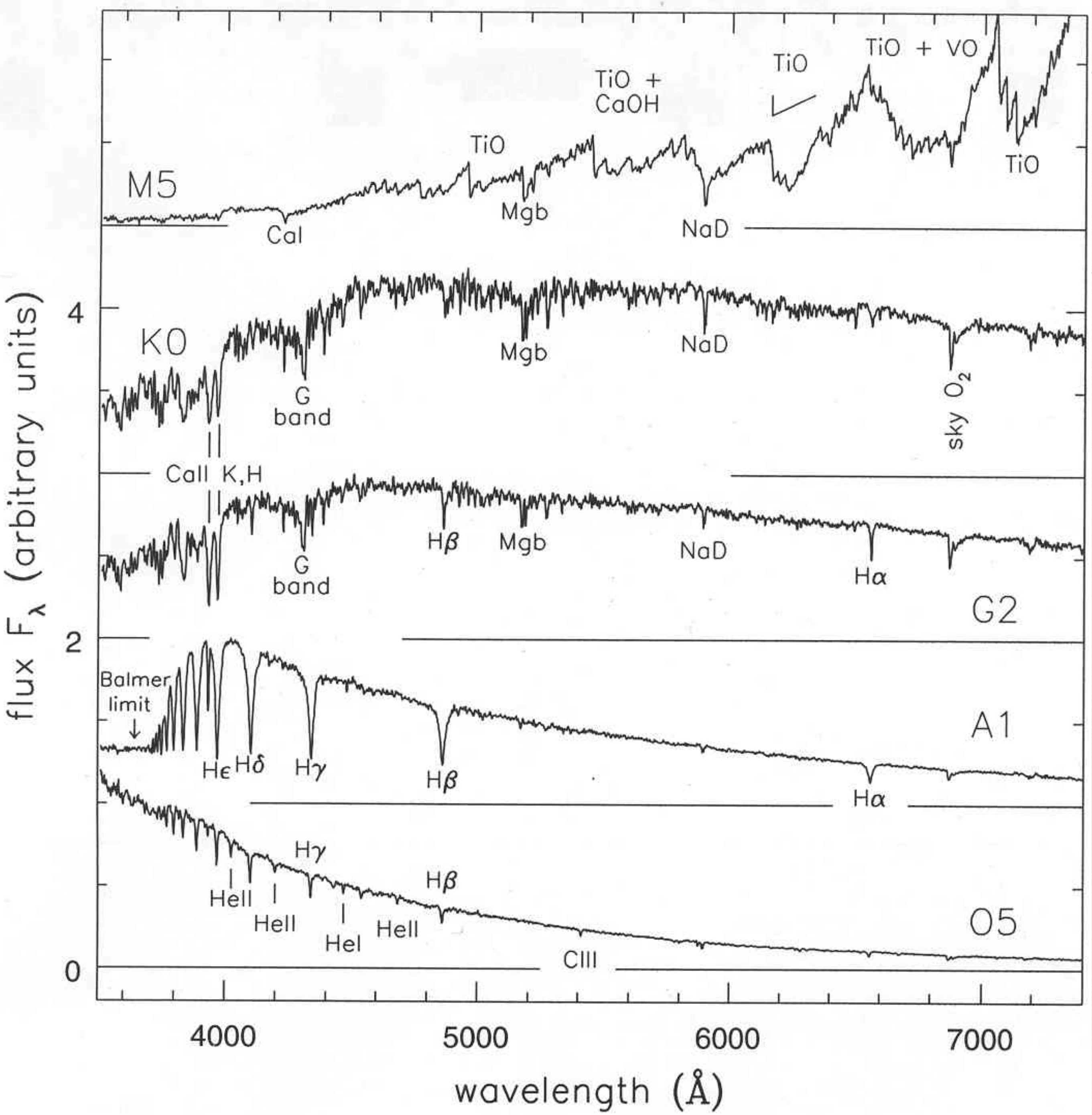
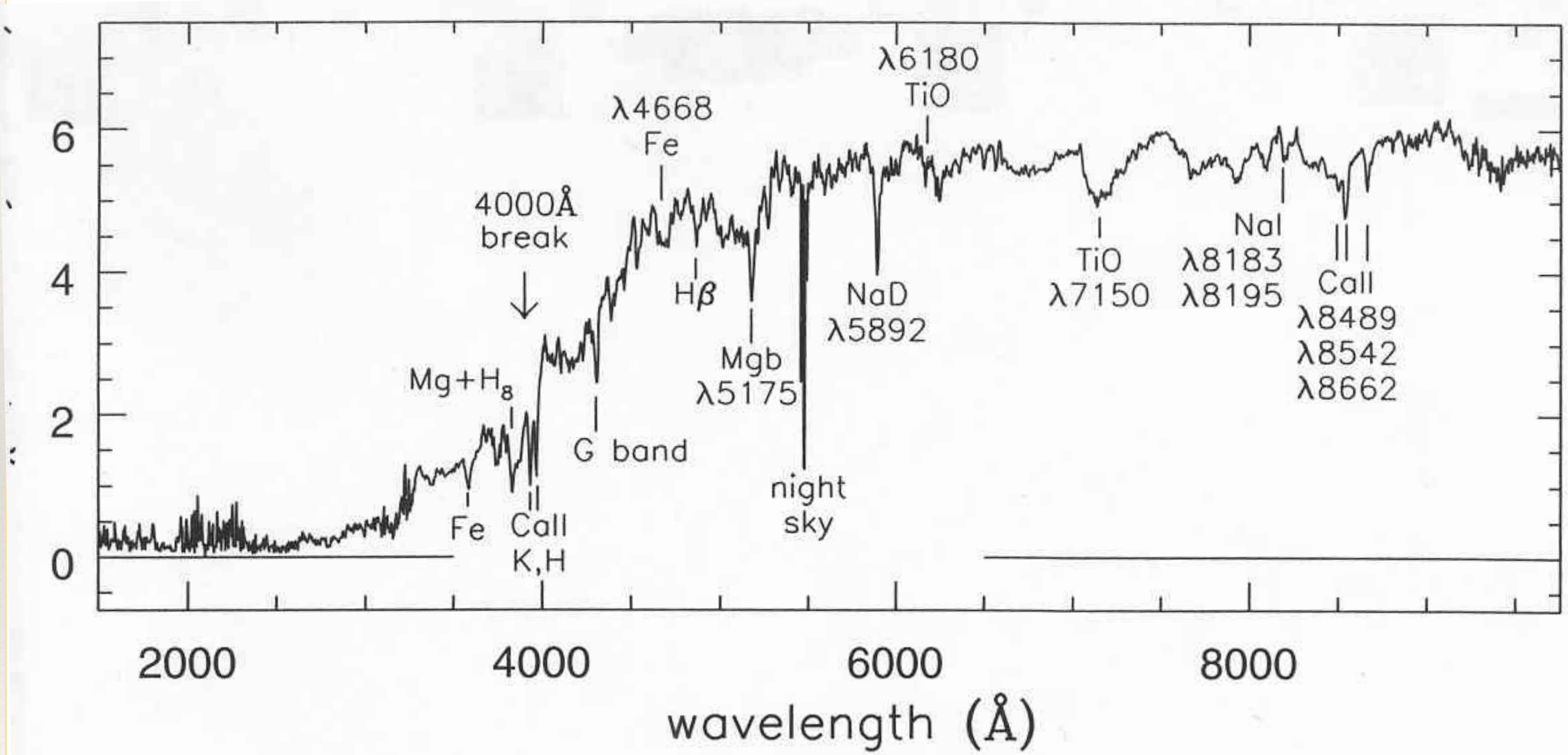


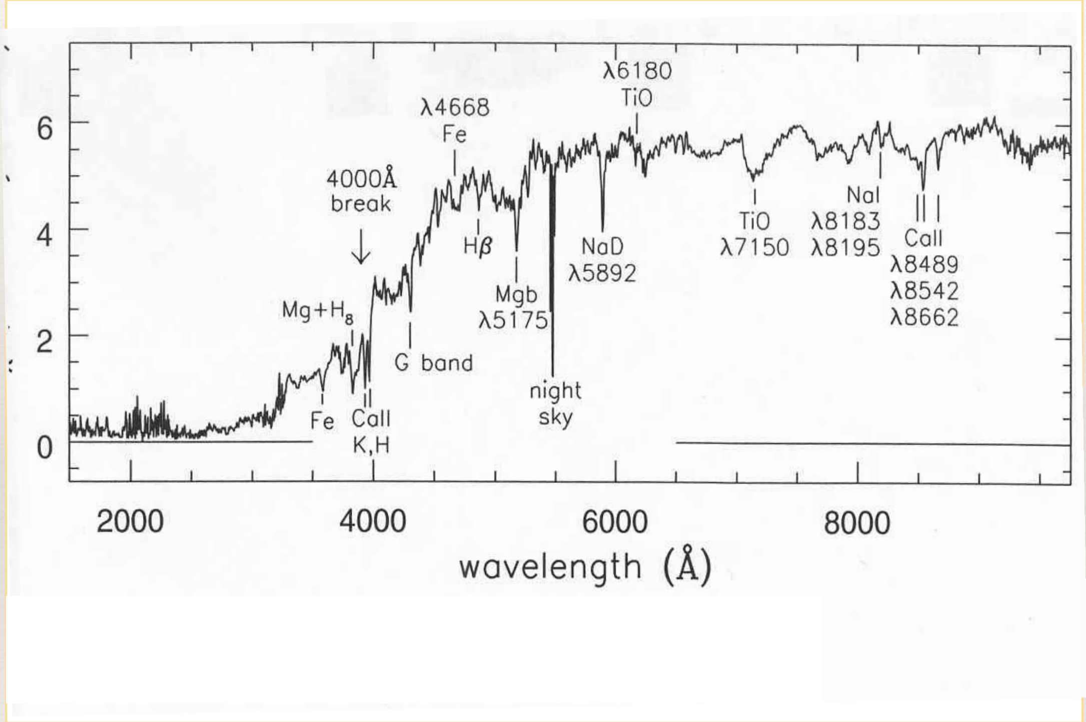
Figure 1.1 Optical spectra of main-sequence stars with roughly the solar chemical composition. From the top in order of increasing surface temperature, the stars have spectral classes M5, K0, G2, A1, and O5 – G. Jacoby *et al.*, spectral library.

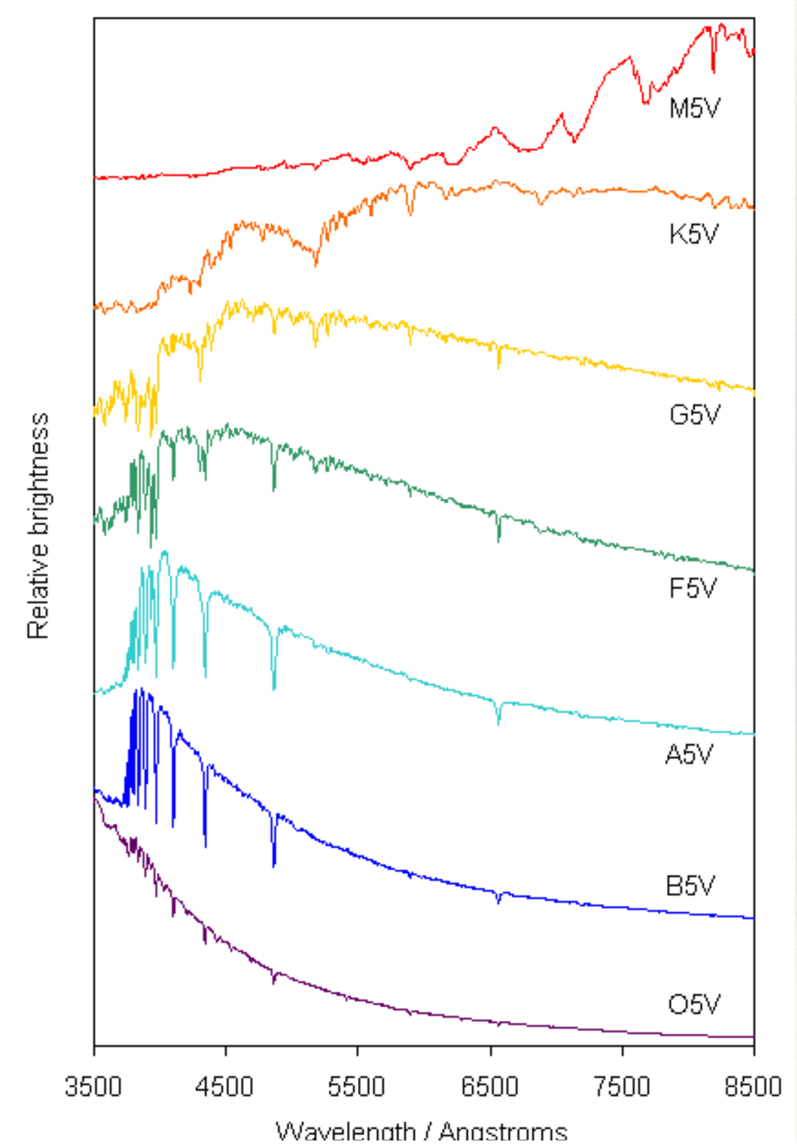
burro.astr.cwru.edu/cassie/323/jan22p6.jpg

Elliptical galaxy



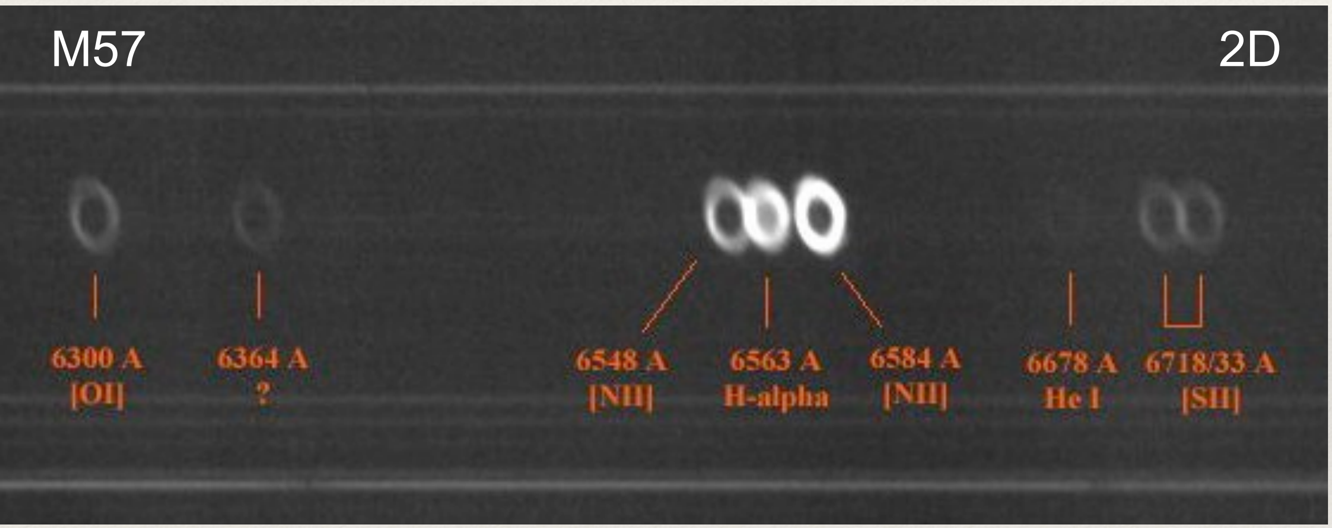
Elliptical galaxy

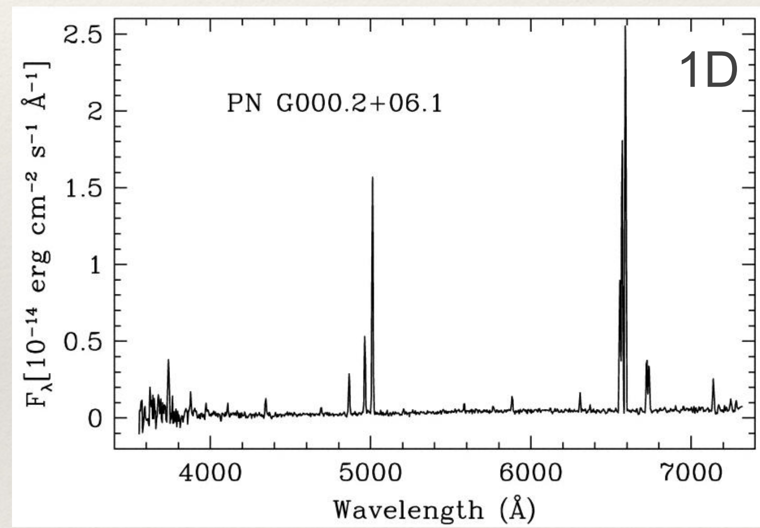




http://burro.astr.cwru.edu/cassie/323/jan22p7.jpg

Emission line source





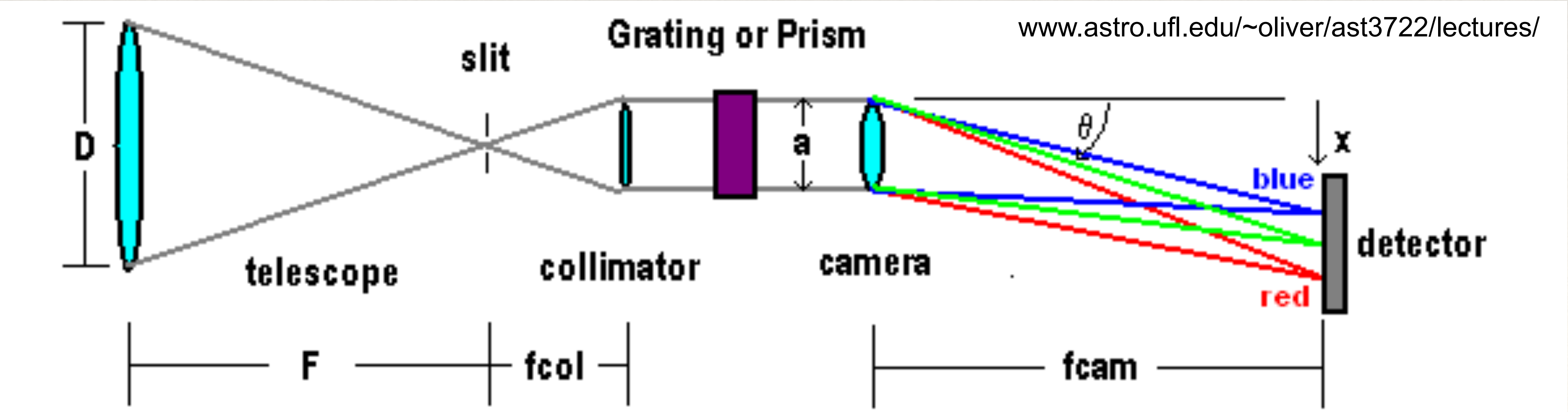
http://spiff.rit.edu/classes/phys301/lectures/spec_lines/spec_lines.html

www.astrosurf.com/buil/us/spe6/planet.htm

Basic Spectrograph

- Slit: isolates portion of sky that is imaged (not required)
- Collimator: makes the beam parallel
- Dispersive element: disperses light in wavelength
- Camera: focus light on detector, where the spectrum is recorded.

*The important characteristics of a spectrograph are the **dispersion** and **resolution**.*



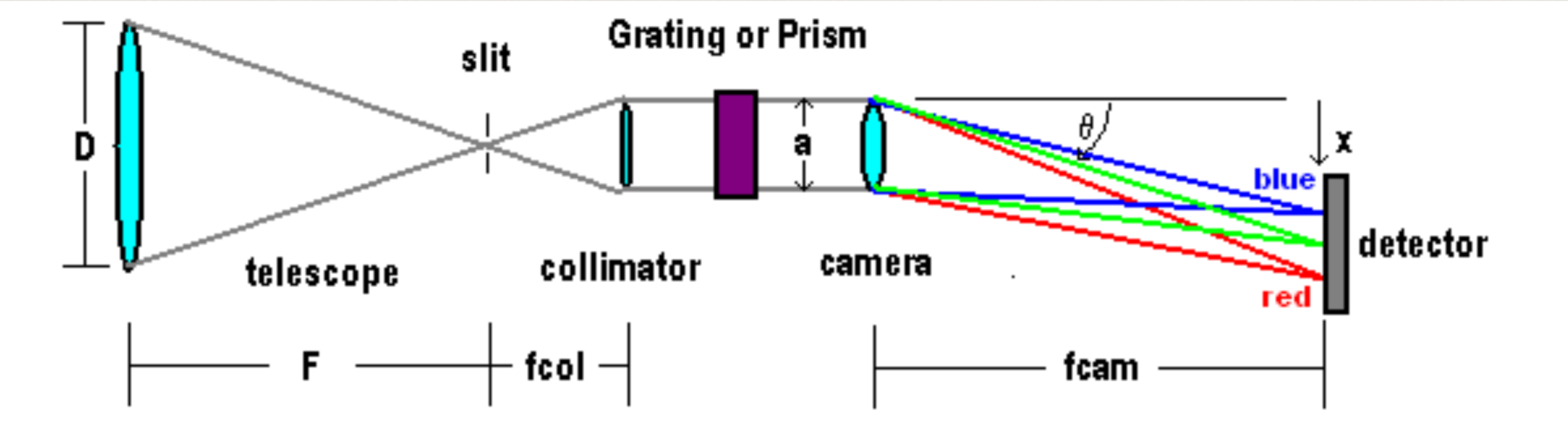
Dispersion

- Dispersion: $d\theta / d\lambda$
  - How widely the light is spread (arcsec/Å or inverse)
  - In physical detector units,

    $dx = d\theta \cdot f_{cam}$, so

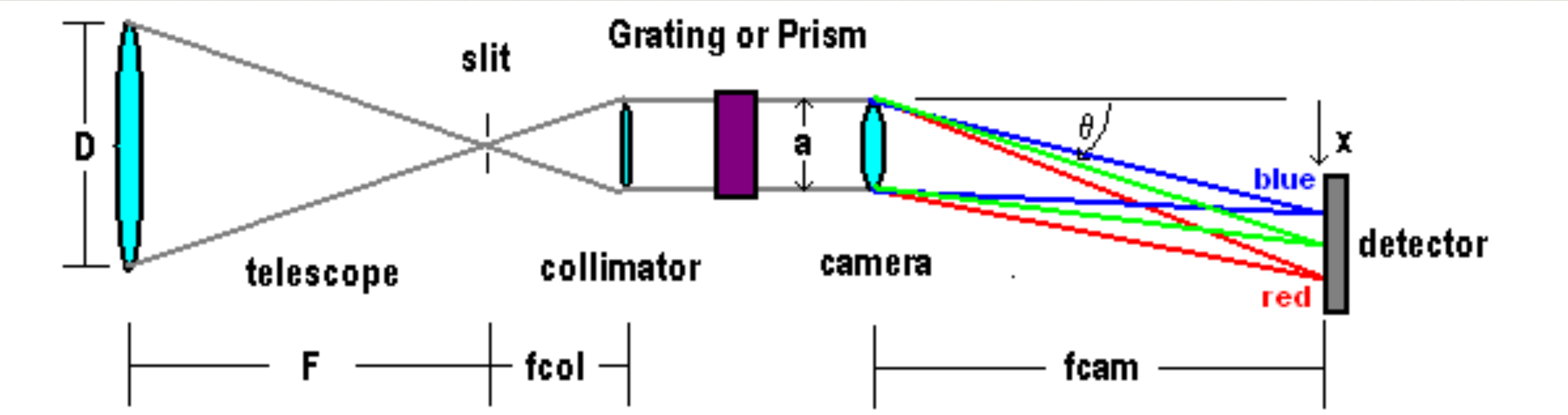
    $dx/d\lambda = d\theta/d\lambda \cdot f_{cam}$

    This is the linear dispersion of the spectrograph (mm/Å).
  - Typical to quote inverse of linear dispersion (Å /mm)



Dispersion

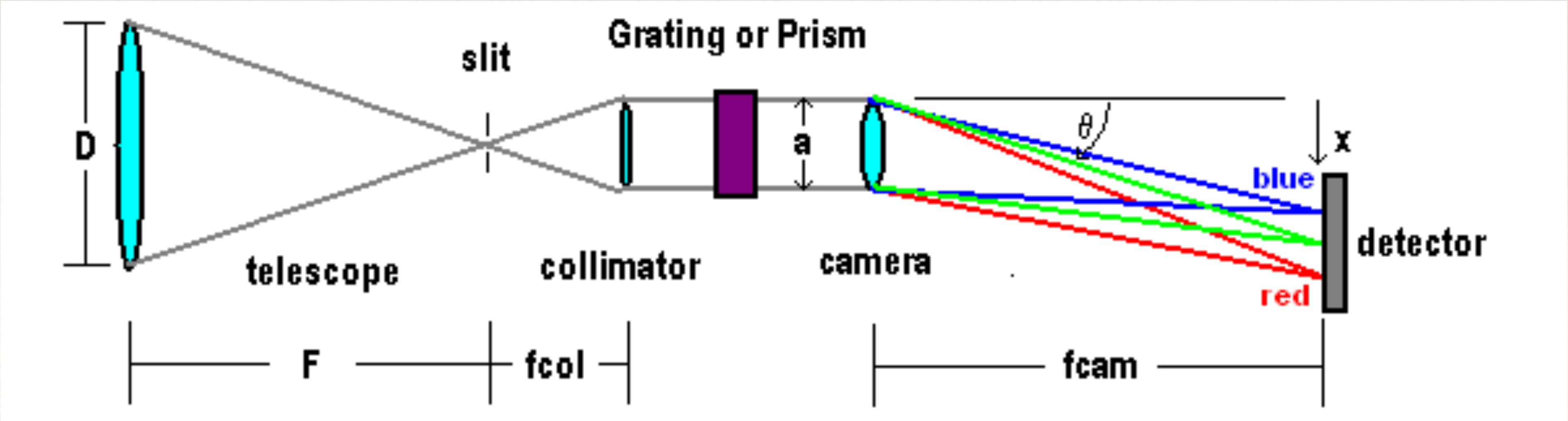
- Dispersion: $d\theta/d\lambda$
  - Typical to quote inverse of linear dispersion (Å /mm)
    - "Low" dispersion: ~50-200 Å /mm (spectral types)
    - "Medium" dispersion: ~10-50 Å /mm (radial velocities)
    - "High" dispersion: <10 Å /mm(line profiles)



Spectral Resolution

- Spectral resolution, or resolving power
  - Defined as R=λ/Δλ (you saw this before with imaging filters).
  - The optical system images the telescope focal plane on to the spectrograph detector plane.
  - If a slit is used, the ratio of image scale at the slit *vs*. the detector plane is

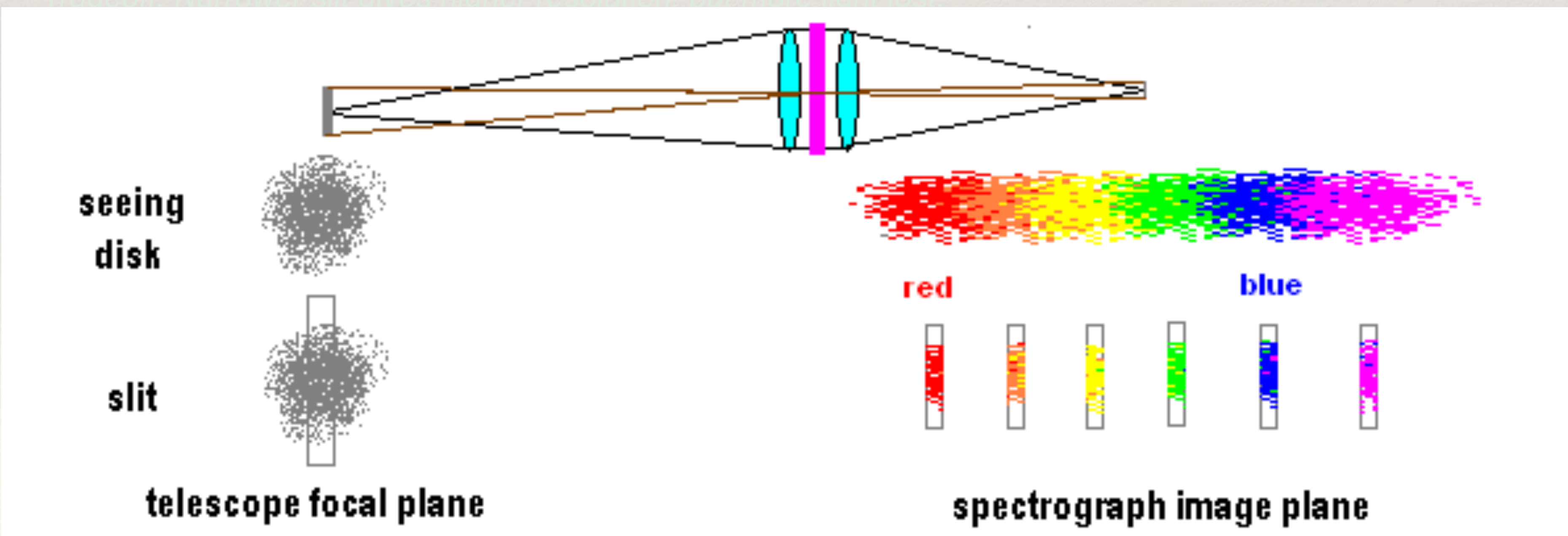
$$\frac{x_{\det}}{x_{slit}} = \frac{f_{cam}}{f_{col}}$$



Why Slits?

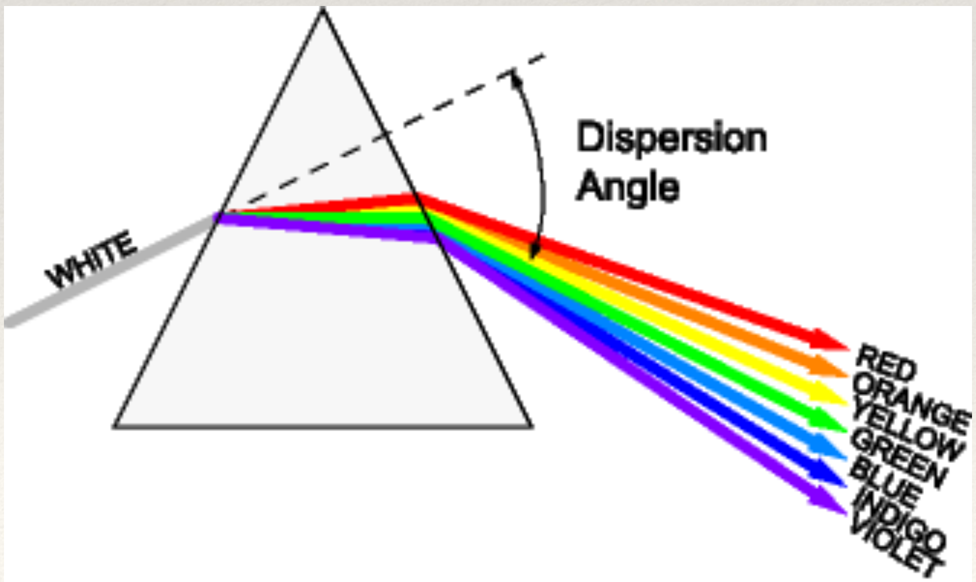
- In order to limit the spreading of light of a single wavelength in the dispersion direction, a slit is usually employed at the telescope focal plane to mask the light from the object.
- To first order the possible spectral resolution will be set by the width, ω, (in the dispersion direction) of the image or the slit, as imaged in the spectrograph.
- The wavelength resolution is thus given by $\delta\lambda = \omega \, d\lambda/dx$.
    - or $\delta\lambda = p \, d\lambda/dx$ if the pixel size of the detector, $p>\omega$.
- Must also include diffraction limit, $\theta=1.22 \, \lambda/D$
    - $\omega_{min} = f_{cam} \, \lambda/D$

Tradeoff: Narrower slit gives higher resolution, but more light lost



Dispersive Elements: Prisms

- Prisms
  - Simple dispersive elements
  - Based upon refraction (Snell's law)
    - First surface disperses the light
    - Second surface disperses further
      - At this surface different wavelengths also have different angles of incidence



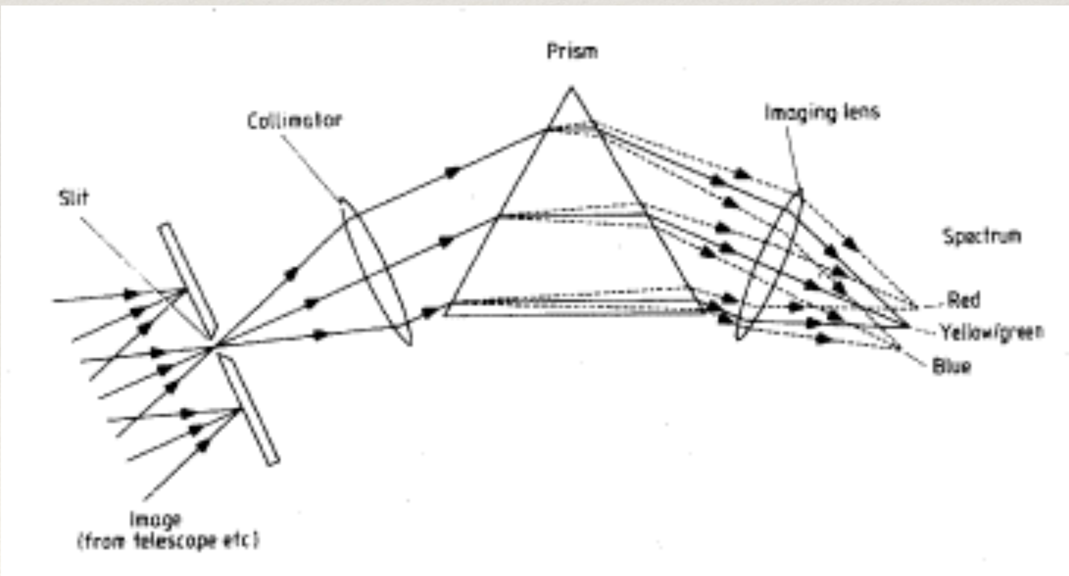
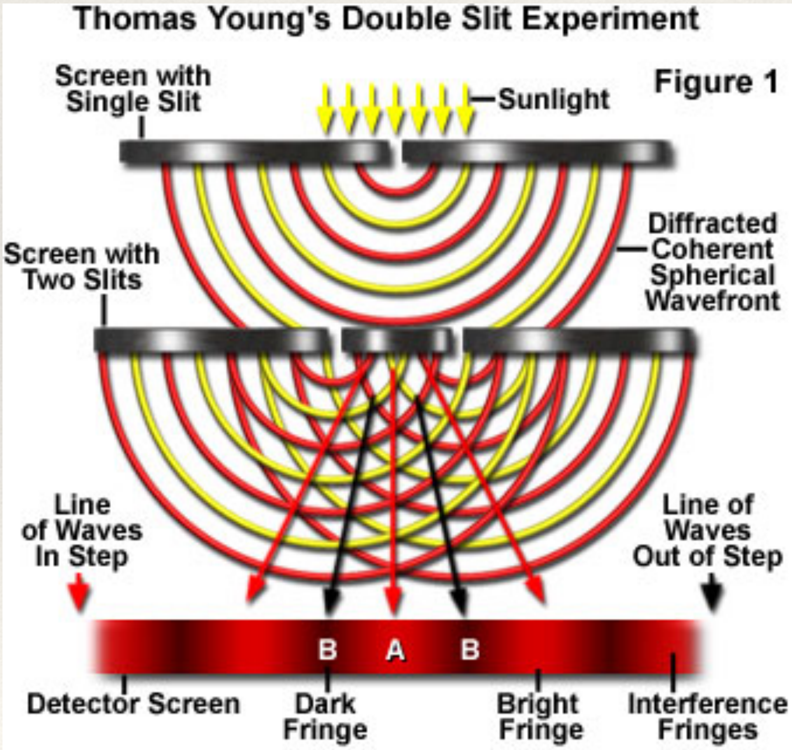


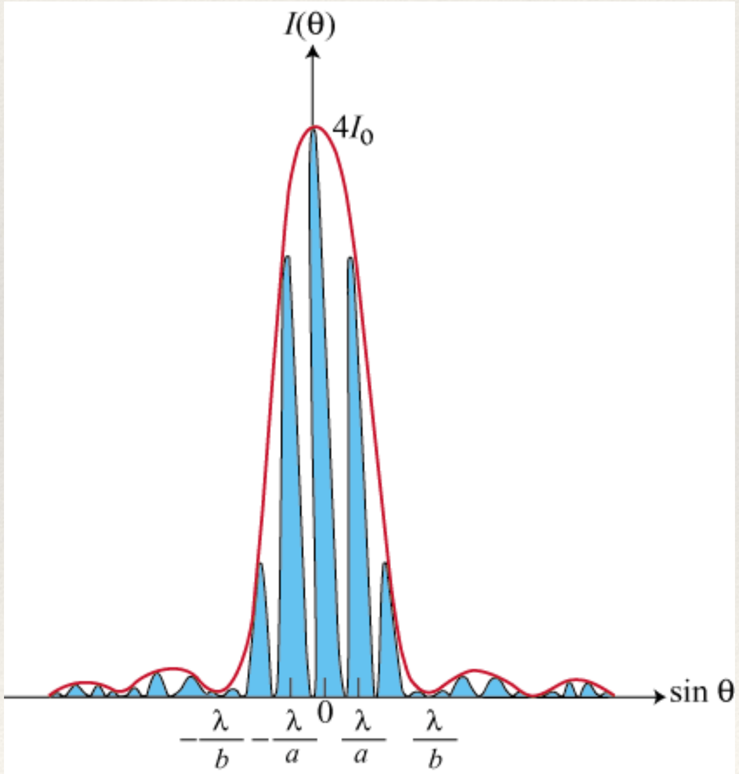
Figure 4.1.5. Basic optical arrangement of a prism spectroscope.

http://www.physics.uc.edu/~sitko/AdvancedAstro/3-Spectroscopy/SPECTROSCOPY.htm

Dispersive Elements: Gratings

- Diffraction Gratings
  - Use diffraction rather than refraction to disperse light



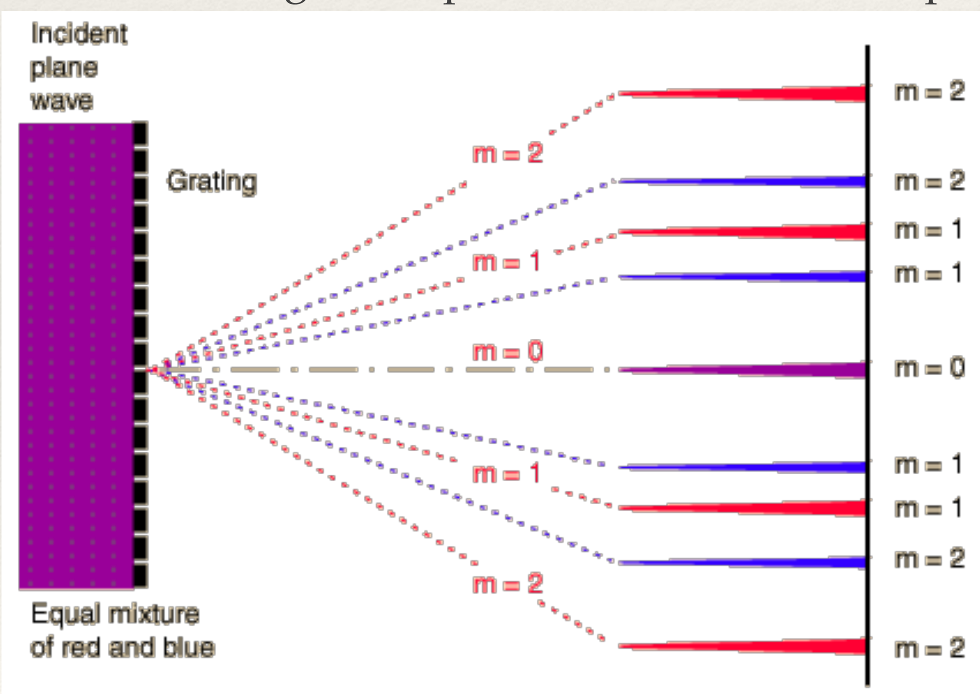


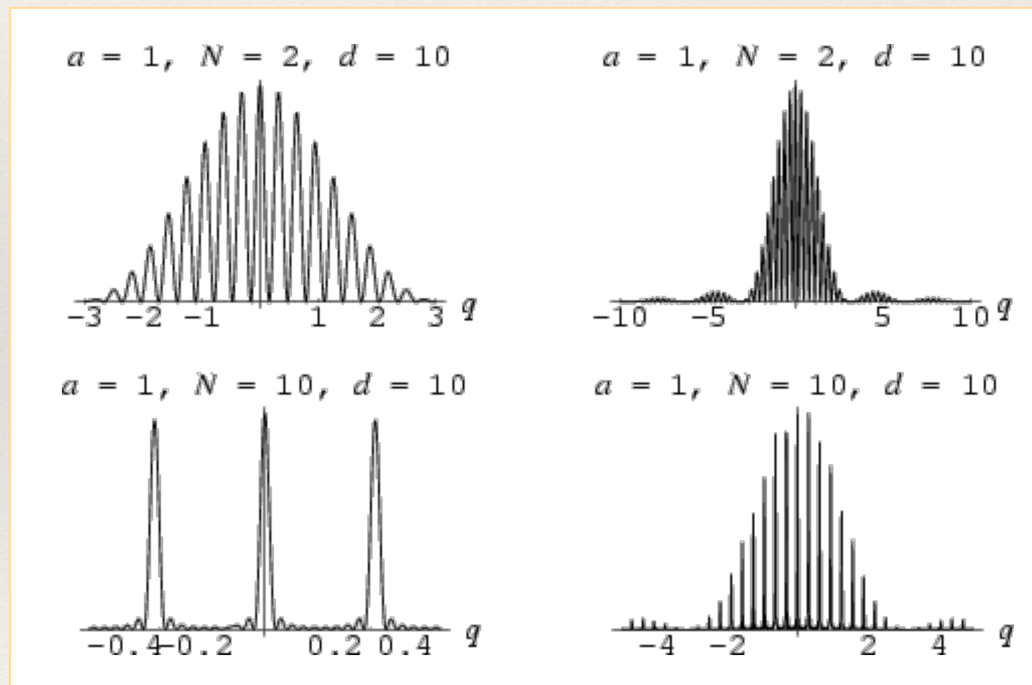
http://micro.magnet.fsu.edu/primer/java/interference/doubleslit

http://www.sparknotes.com/physics/optics/phenom/section2.rhtml

Dispersive Elements: Gratings

- Diffraction Gratings
  - Use diffraction rather than refraction to disperse light
  - Angular separation of interference peaks is wavelength dependent





N is the number of slits
d is the separation of the slits
2a is the width of the slits

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html

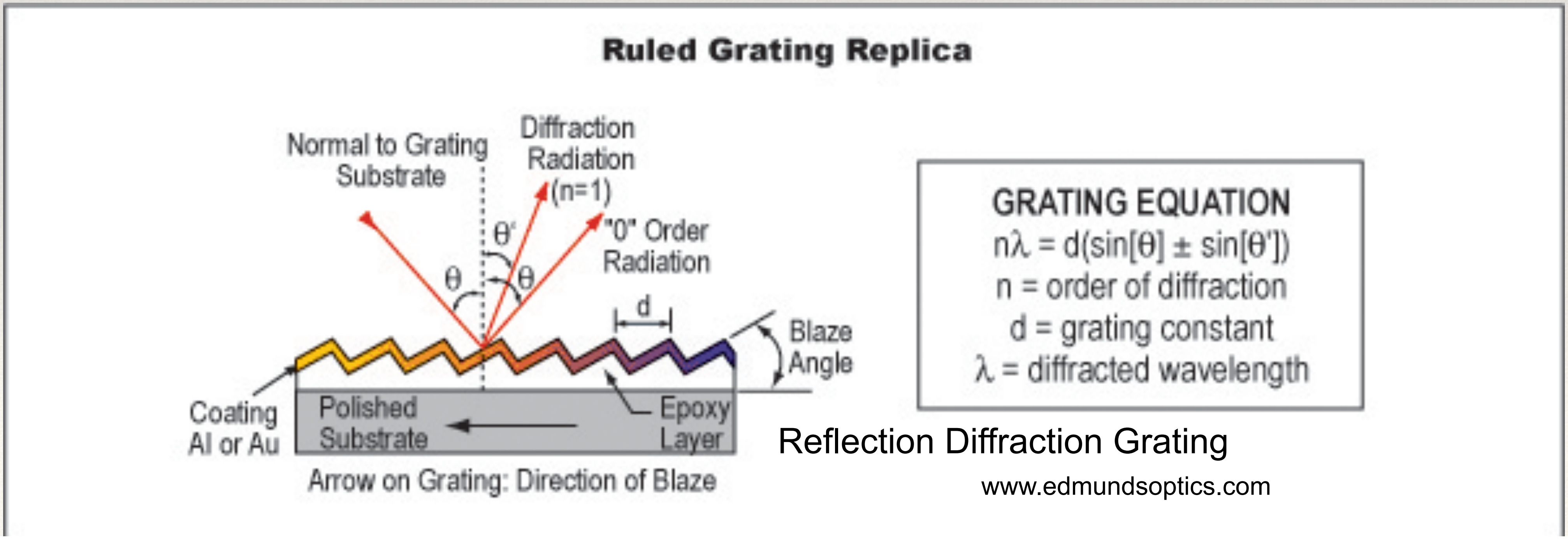
http://scienceworld.wolfram.com/physics/DiffractionGrating.html

Dispersive Elements

Transmission gratings operate in a very similar fashion to Young's slit experiment, with a large number of slits.

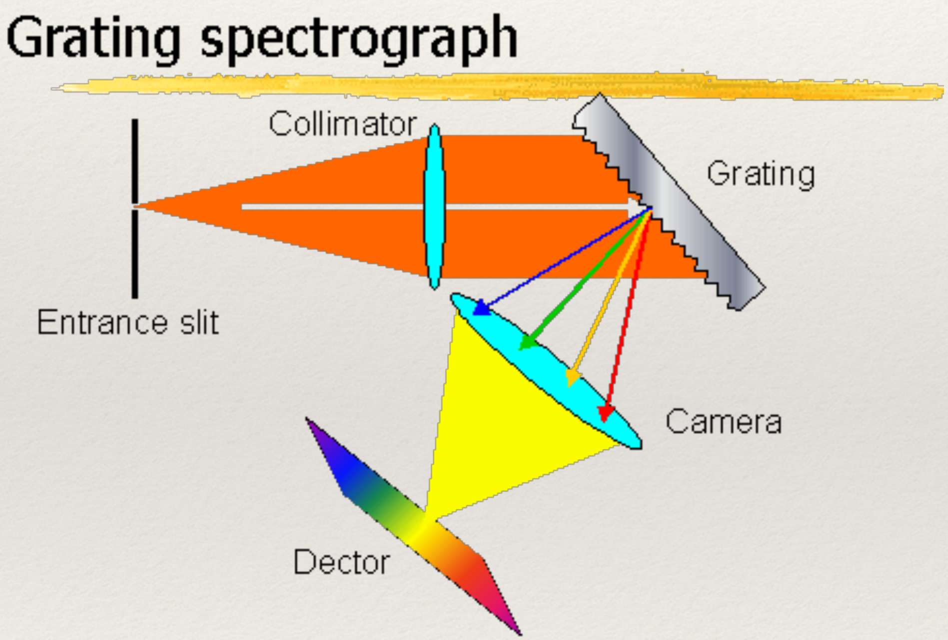
Reflection gratings consist of many closely-spaced grooves that act as parallel mirrors.

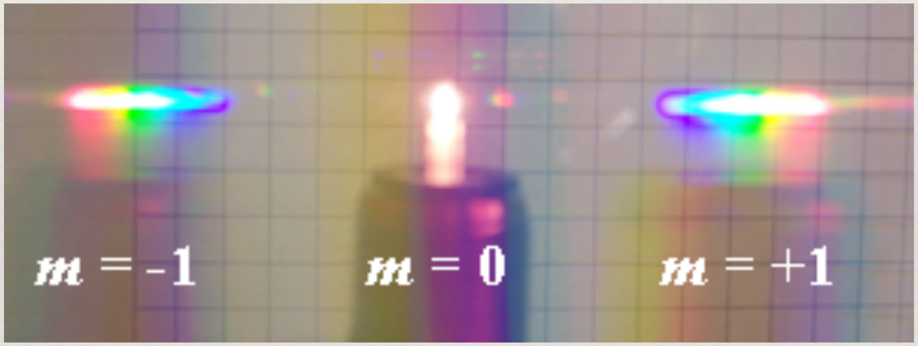
- Constructive interference occurs when the path lengths light of rays reflecting off adjacent mirrors differs by n times the wavelength, where the integer n is the "order". 0th order is undispersed (white) light.
- The grating and dispersion equations follow from the above definition.



Reflection Diffraction Grating

www.edmundsoptics.com

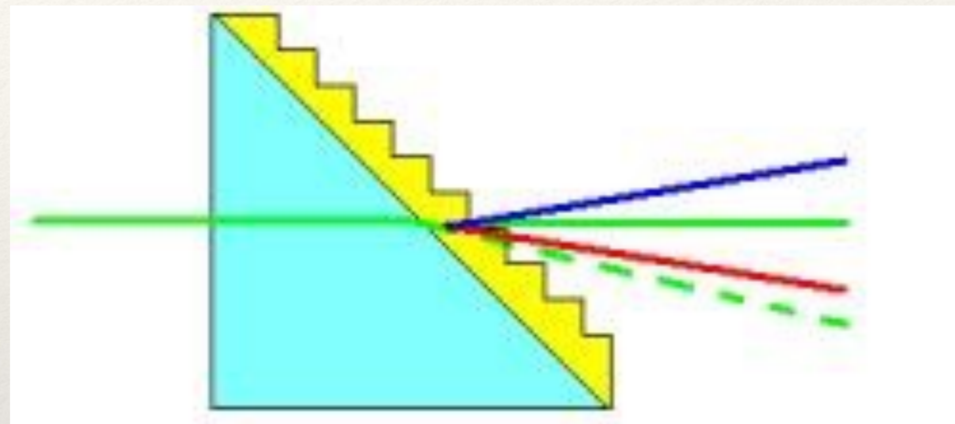


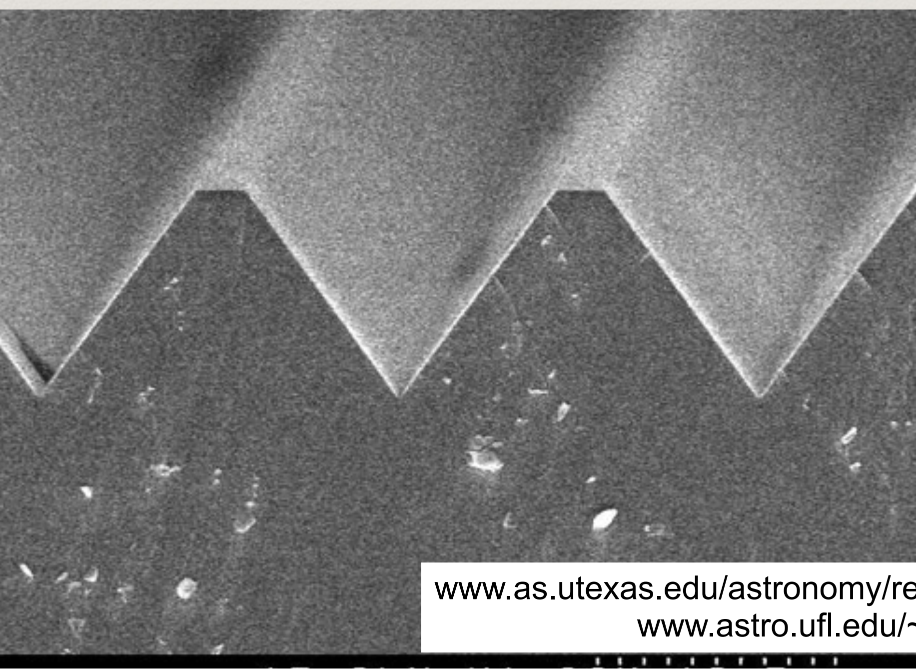


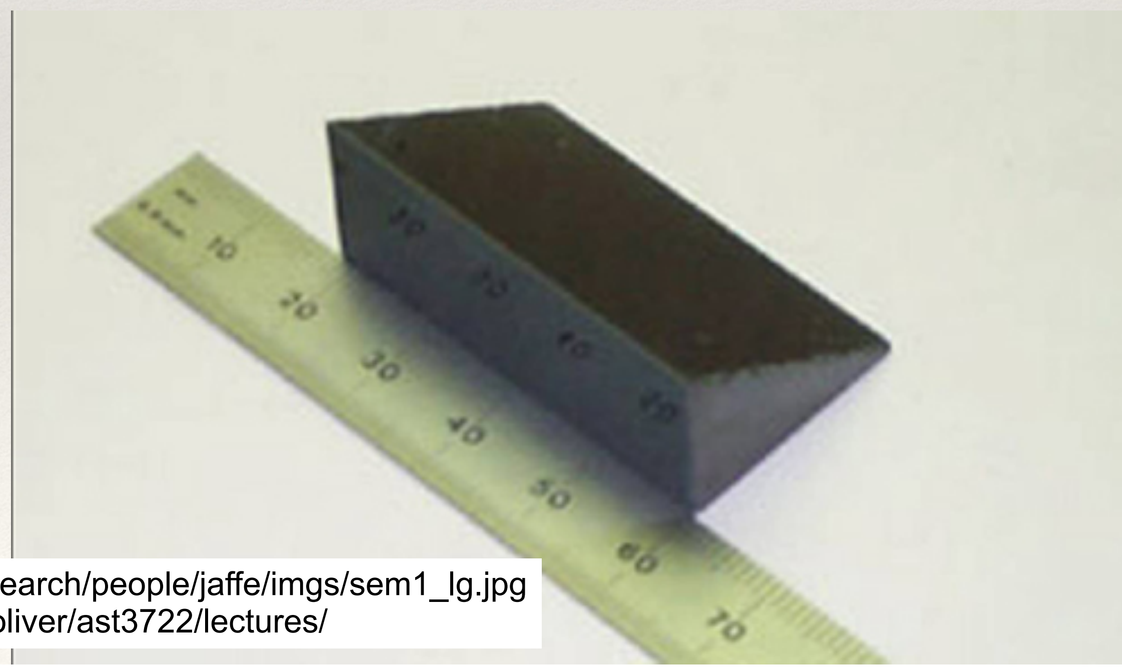
http://dtomono.freeshell.org/biblio/mos/021106_Konzil/img006.gif

Dispersive Elements: Grisms

- Grisms
  - Combination of a prism with a transmission grating.
  - Light at a chosen central wavelength passes through with no deviation in direction

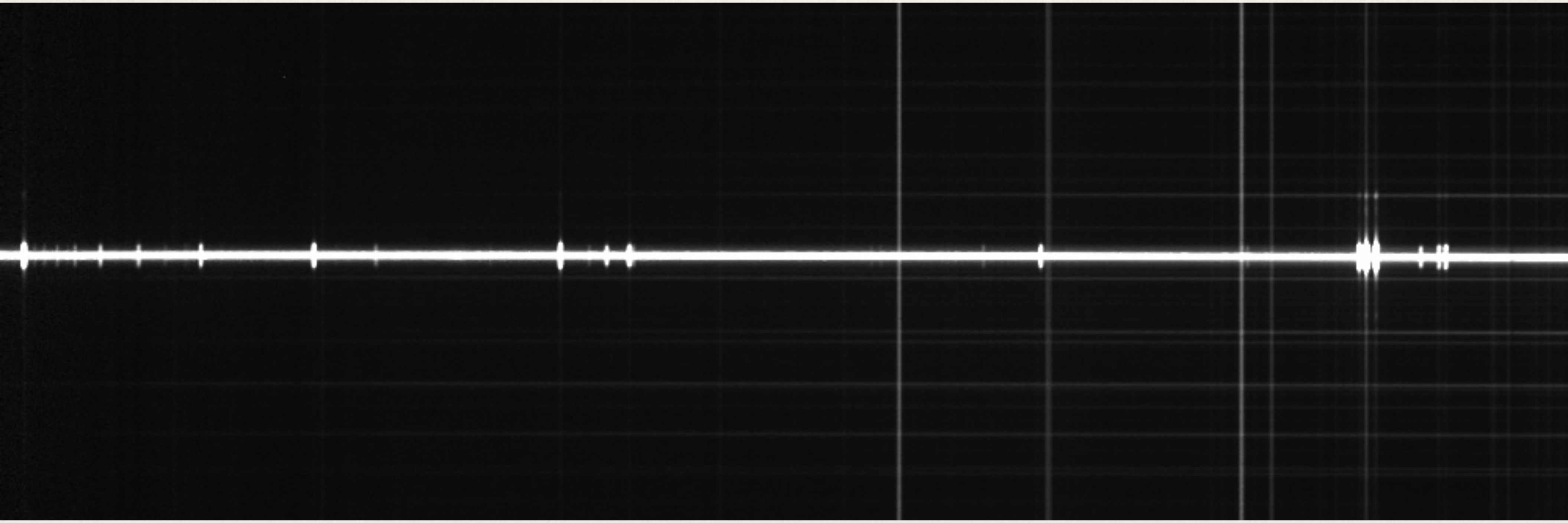






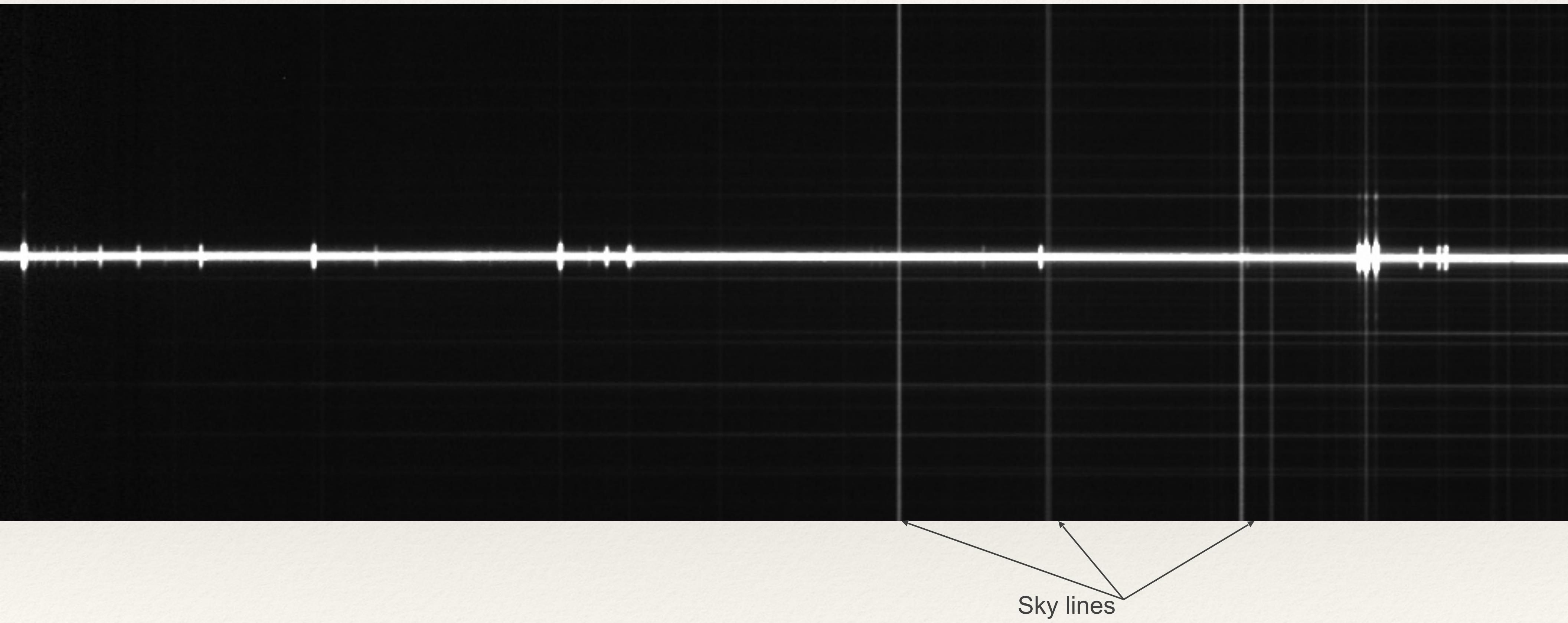
www.as.utexas.edu/astronomy/research/people/jaffe/imgs/sem1_lg.jpg
www.astro.ufl.edu/~oliver/ast3722/lectures/

Long slit spectrum



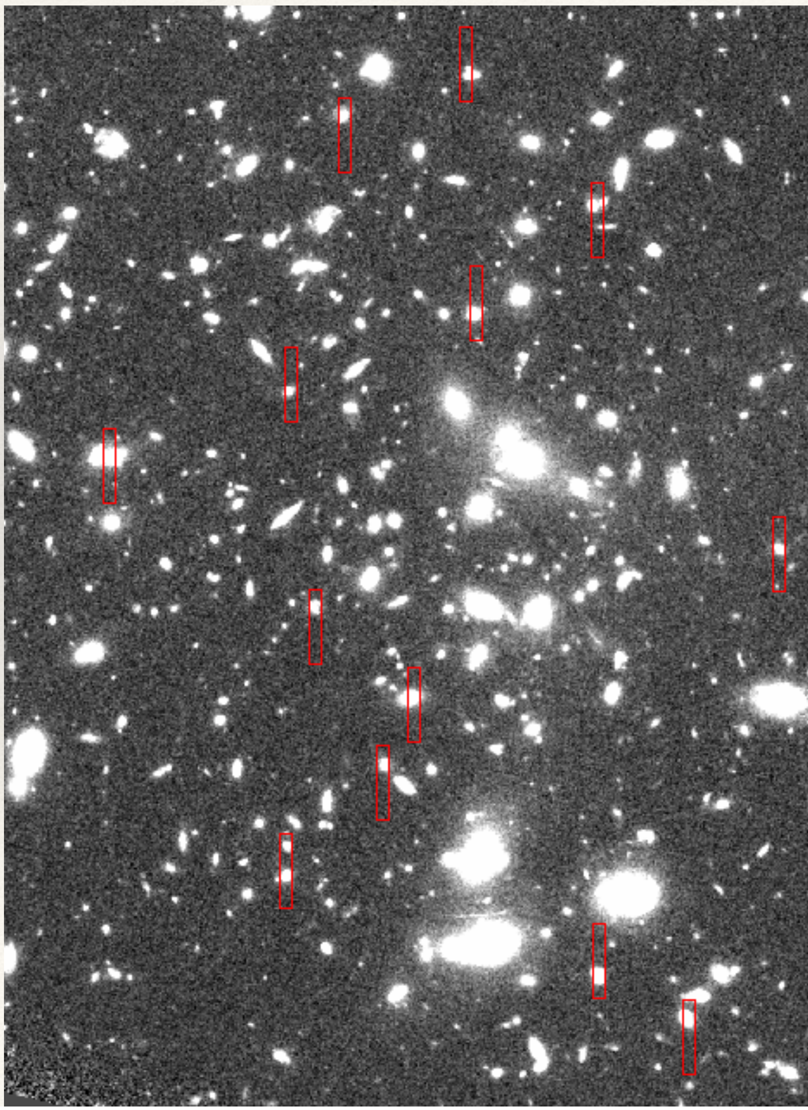
http://www.chara.gsu.edu/~cantrell/m146.htm

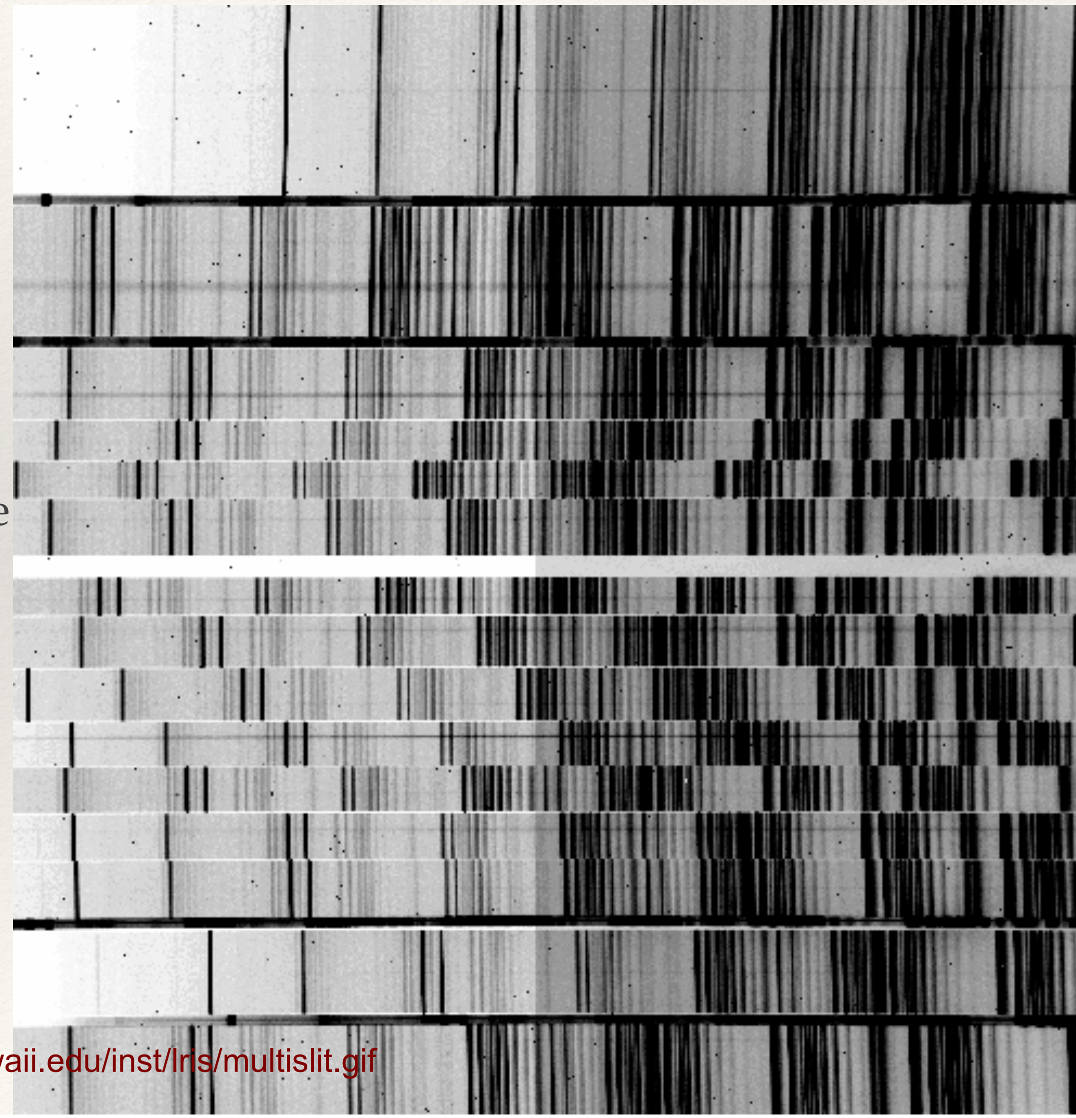
Long slit spectrum



http://www.chara.gsu.edu/~cantrell/m146.htm

Multiobject Spectrographs





- s

tiple

.hawaii.edu/inst/lris/multislit.gif

Multiobject Spectrographs

- Multifiber spectrograph
  - Place fiber optic cables at locations of objects in the focal plane.
    - Can be done either with a plate (as for multislit) or robotic positioning of the fibers
  - Each fiber then feeds the light from the object to the spectrograph.

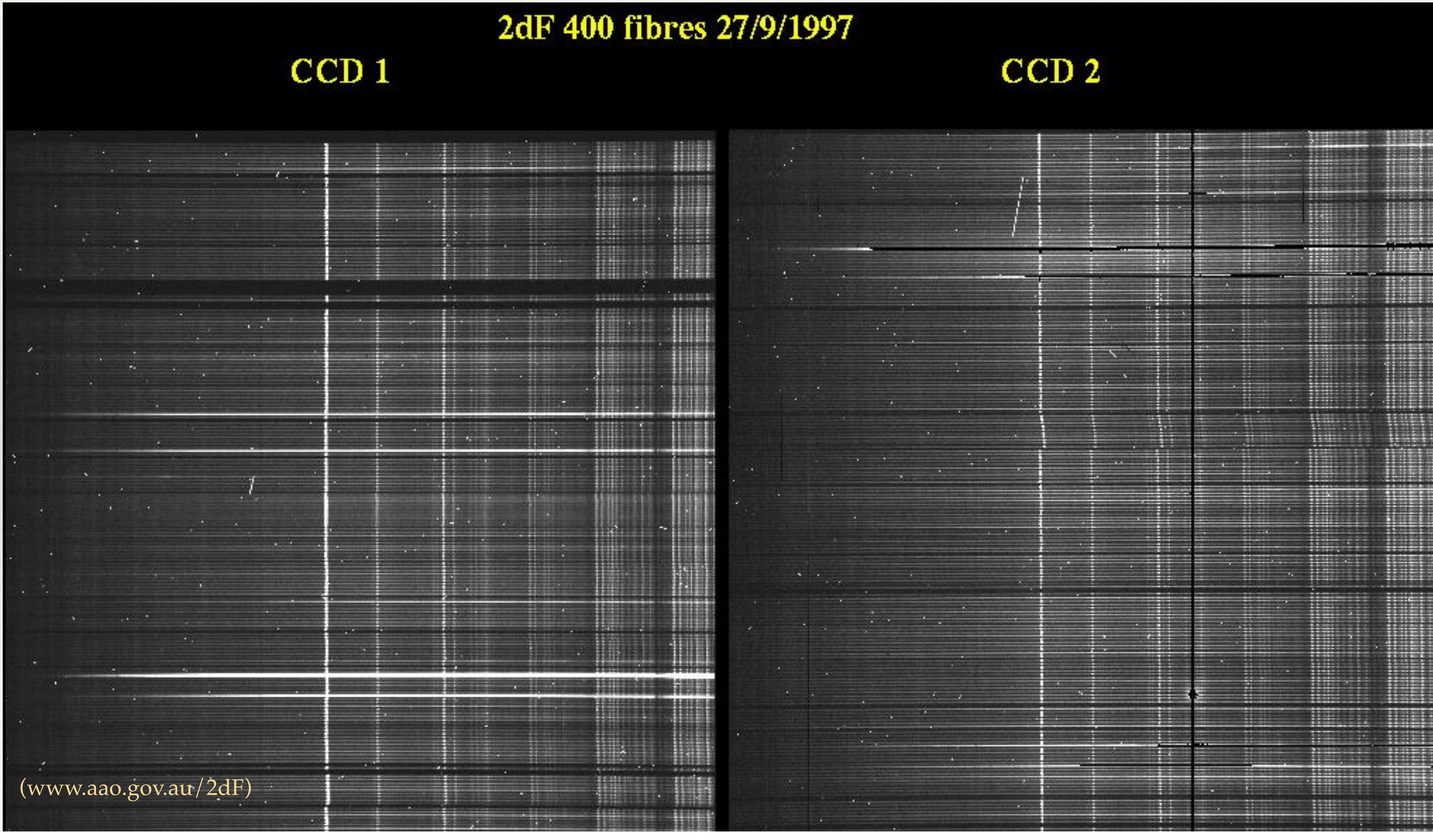
Right: 2dF spectrograph, showing fibers out the plate

(www.aao.gov.au/2dF)

Multiobject Spectrographs

Individual fibers on 2dF spectrograph.
(www.aao.gov.au/2dF)

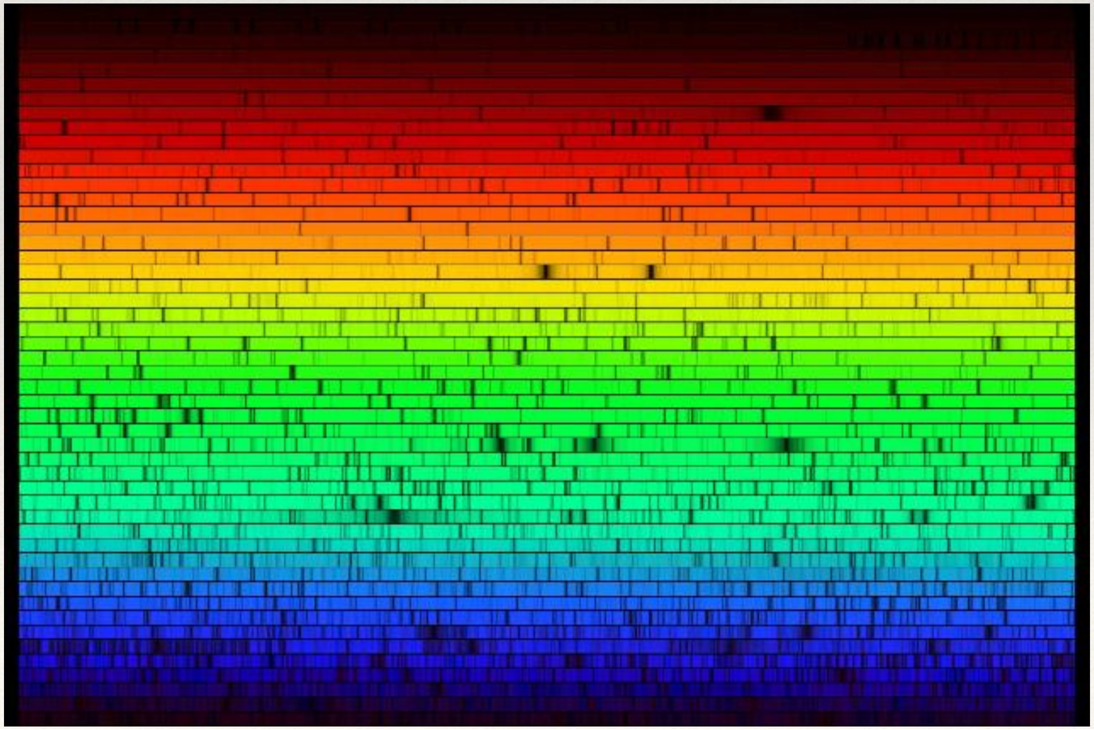
Multiobject Spectrographs



(www.aao.gov.au/2dF)

Echelle Spectrographs

- Echelle spectrographs are used for high resolution spectroscopy.
  - Typically operate with very high orders (m>50).
  - Second dispersive element is used to "cross-disperse" light.
  - Single object spectrum spread out in 2D.
  - Resolution can be very high (50-100k)

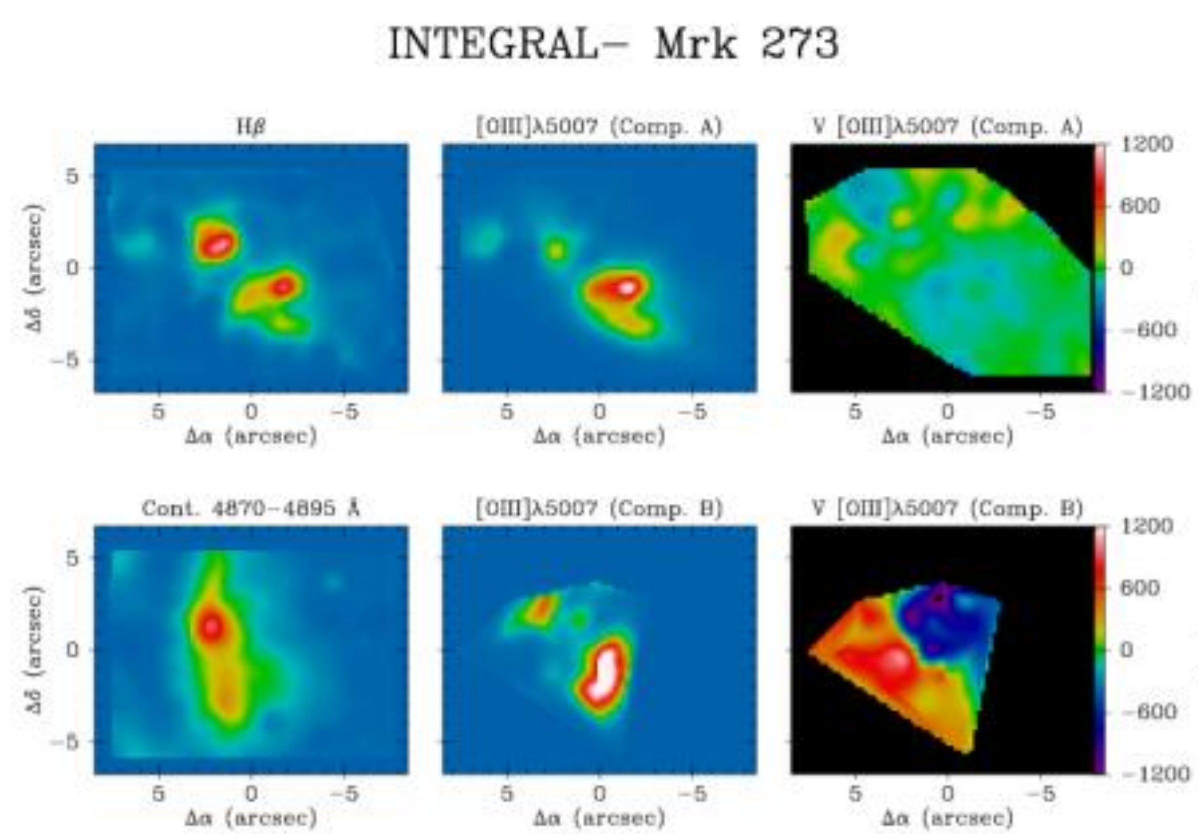


Integral Field Units

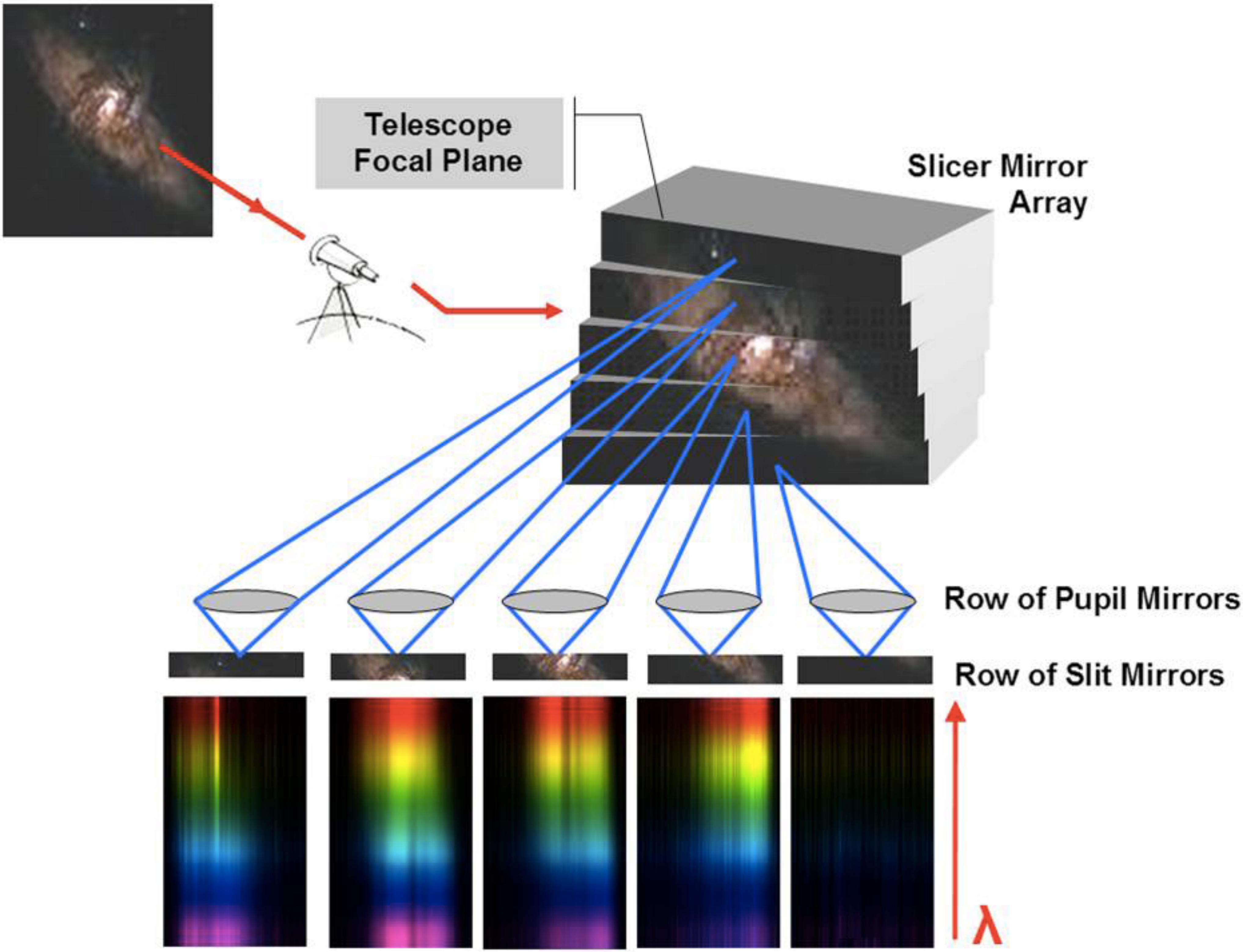
- *Combine some of the best features of imaging and spectroscopy.*
  - *Essentially get a spectrum for each pixel in the image.*

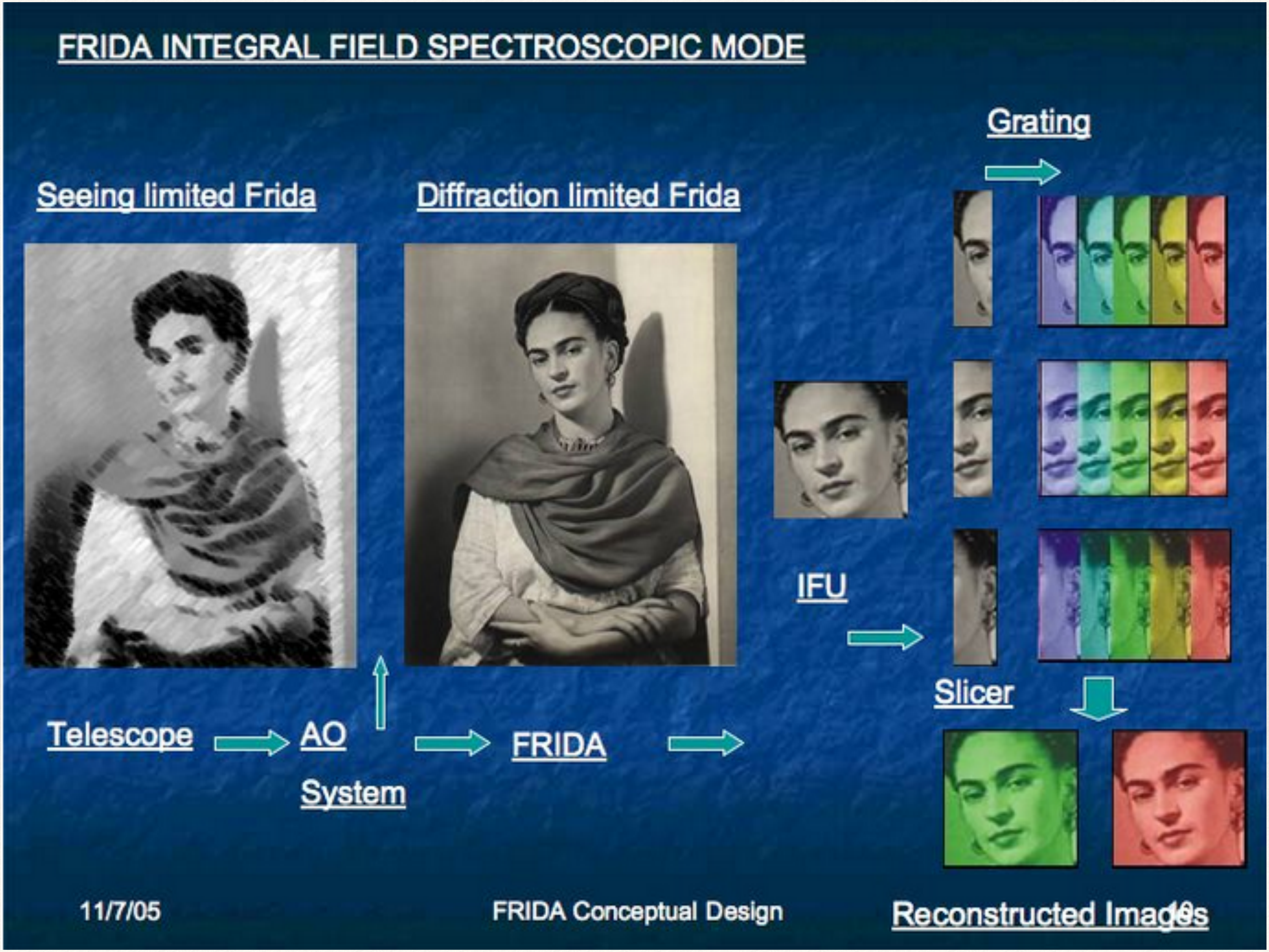
- *Certain tradeoffs...*

- *Several approaches*
  - *Fiber-fed*
  - *Image slicer*



http://www.ing.iac.es:8080/PR/newsletter/news3/mkn370s.jpg


Telescope
Focal Plane
Slicer Mirror
Array
Row of Pupil Mirrors
Row of Slit Mirrors
λ


FRIDA INTEGRAL FIELD SPECTROSCOPIC MODE
Grating
Seeing limited Frida
Diffraction limited Frida
IFU
Slicer
Telescope
AO
System
FRIDA
11/7/05
FRIDA Conceptual Design
Reconstructed Images
10