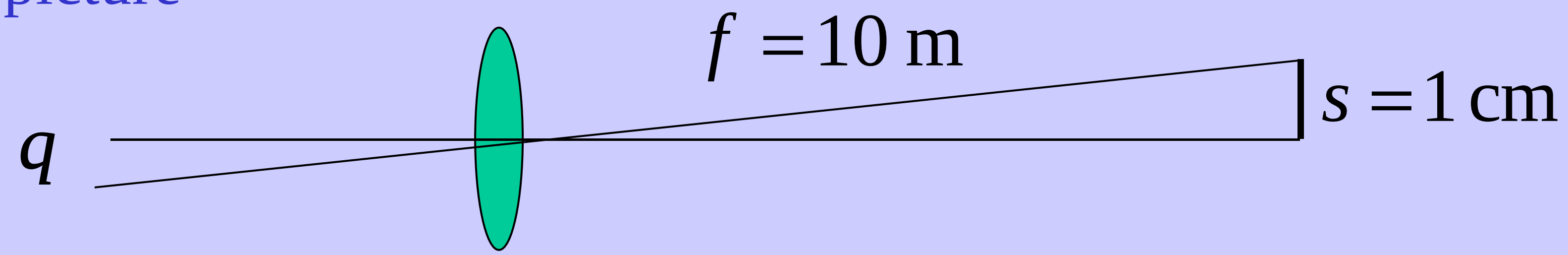
Problem Solving

picture



equation $$s = f \sin q \approx fq$$

rearrange $$q = s / f$$

check dimensions

numbers with units $$q = \frac{1\ \text{cm}}{10\ \text{m}} \times \frac{1\ \text{m}}{100\ \text{cm}} = 10^{-3}\ \text{radians}$$

calculate

factors to change units $$\times \frac{180^\circ}{p\ \text{radians}} \times \frac{60\ \text{arcmin}}{1^\circ} = 3.4\ \text{arcmin}$$

Problem Solving

1. Draw a simple picture (label with symbols)

2. Write an equation (check dimensions)

4. Re-arrange the equation

5. Insert numbers with units

6. Multiply by factors to obtain correct units

7. Does the result make sense?

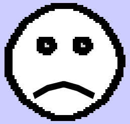
Astronomical Instruments

Measure properties of incoming light

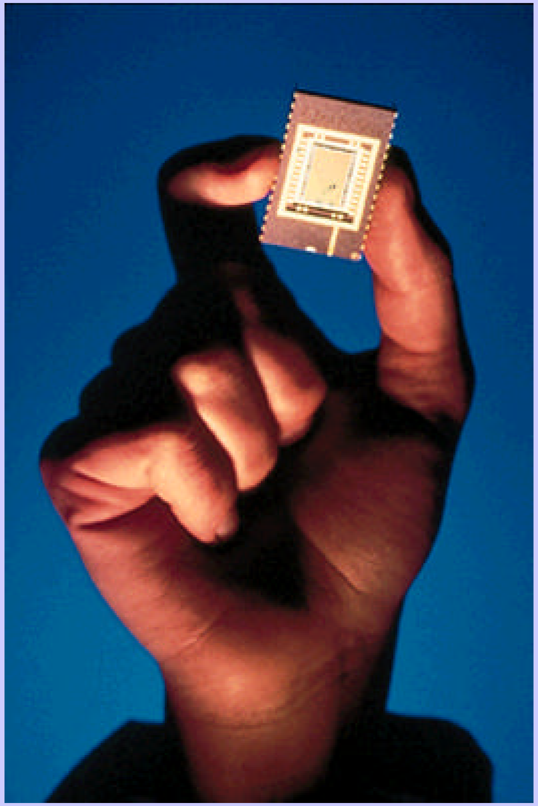
- Imaging - direction
- Photometry - brightness
- Spectroscopy - wavelengths
- Polarimetry - linear/circular polarisation
- Timing - variations in all of the above

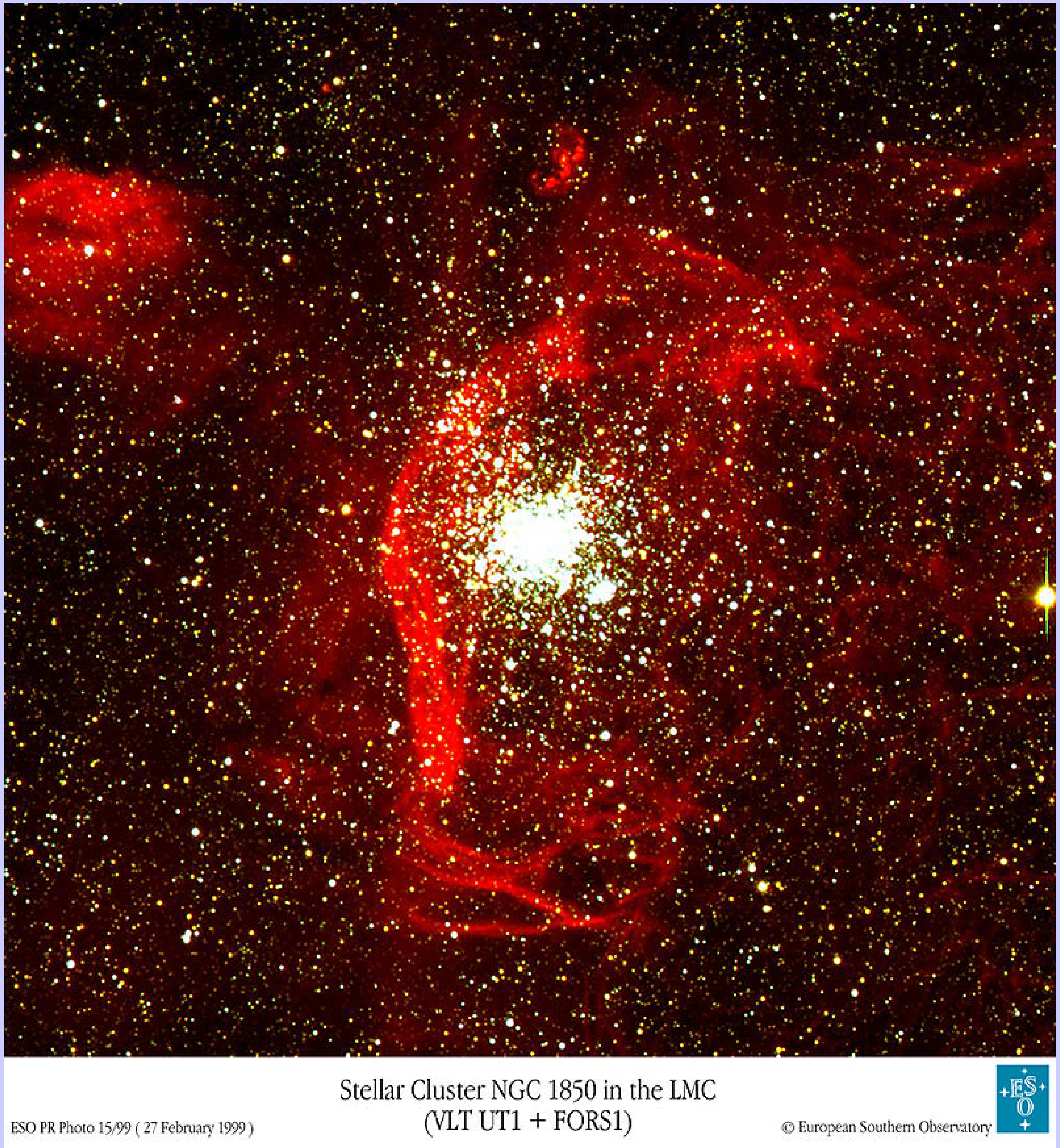
- ***<u>direct cameras</u>:*** record an image of an area of sky with stars, galaxies, …
  - Schmidt telescopes:
    f/2 - f/3, large fields 6° ´ 6°
  - photographic plates
  - reflectors: prime focus ~ f/3
    Cassegrain focus ~ f/10
    fields < 1°, better image scale
  - electronic detectors (CCDs)

- *photographic plates*
  - --glass coated on front side with photographic emulsion
  - –large area (e.g. 35 ´ 35 cm)
  - –low efficiency (1-2%)
    98% of light not recorded
  - –negatives digitized by laser scanner
  - – e.g. Palomar Digital Sky Survey
  - –UK Schmidt Telescope Survey

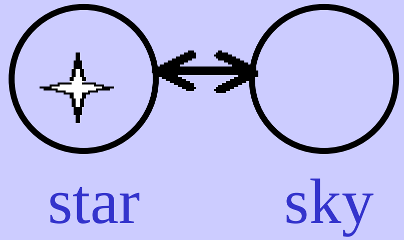
- ***<u>electronic detectors</u>***
  - Charge-Coupled Device (CCD)
  - silicon chip; array of light-sensitive squares - PIXELS (+readout electronics)
  - pixel size ~15 ´ 15 *mm*
  - format ~ 1024 ´ 1024 pixels
    up to 4096 ´ 4096 pixels
  - small area : postage stamp 
  - ~ 75-90% efficiency 
  - digital images read direct from CCD
  - expensive

A Charge-Coupled Device, CCD



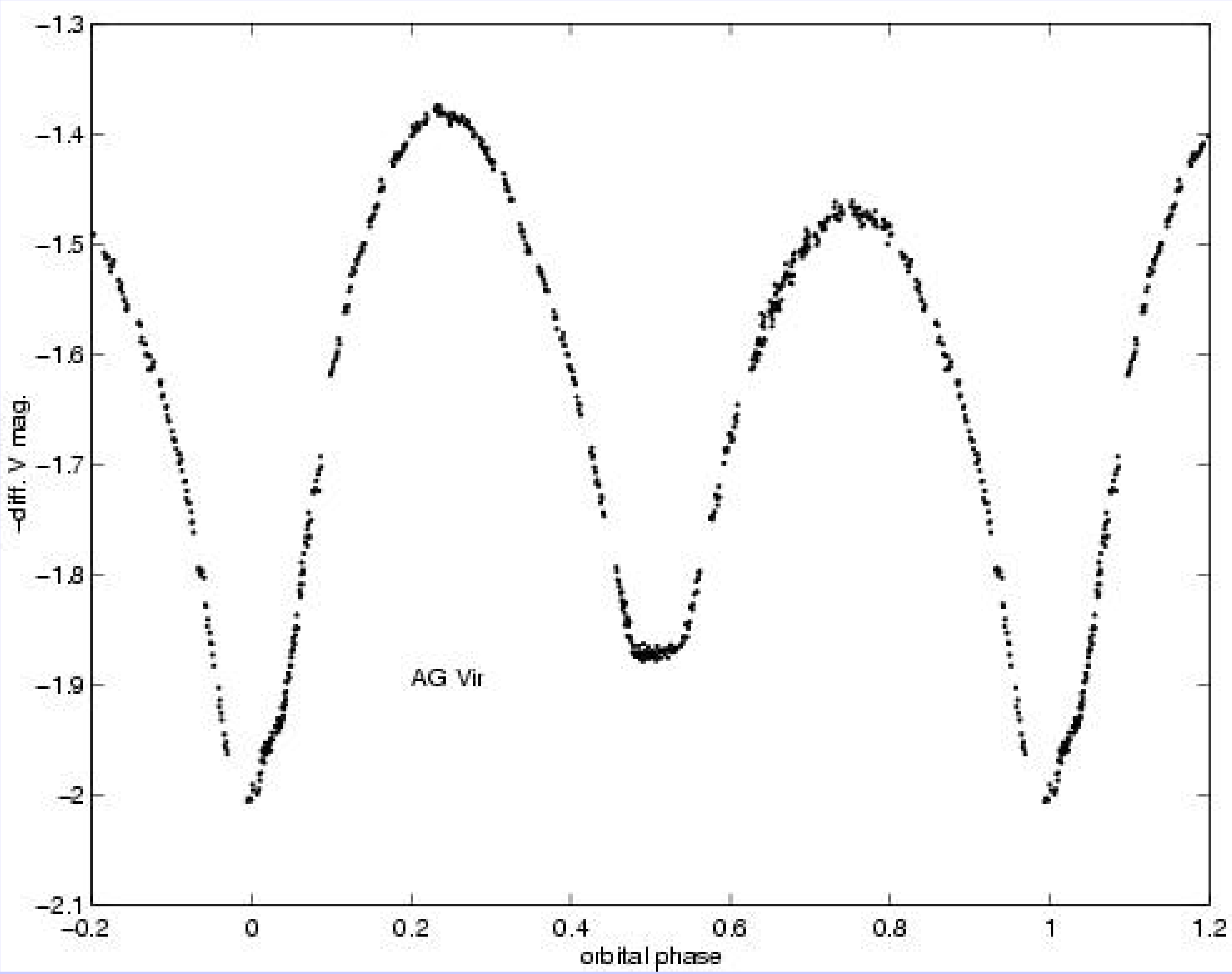

Stellar Cluster NGC 1850 in the LMC
(VLT UT1 + FORS1)
ESO PR Photo 15/99 (27 February 1999)
© European Southern Observatory

- photometry:
  - measure apparent brightnesses of sources
  - filters select a range of wavelengths
  - narrow~1 nm   broad~100 nm
- photomultiplier tube
  - ~20% efficiency
  - counts individual photons
    high speed (e.g. milliseconds)
  - one star at a time
  - (focal plane pinhole)



- CCD camera:
  - < 1% accuracy
  - >10s time resolution
  - ~10,000 sources per CCD image

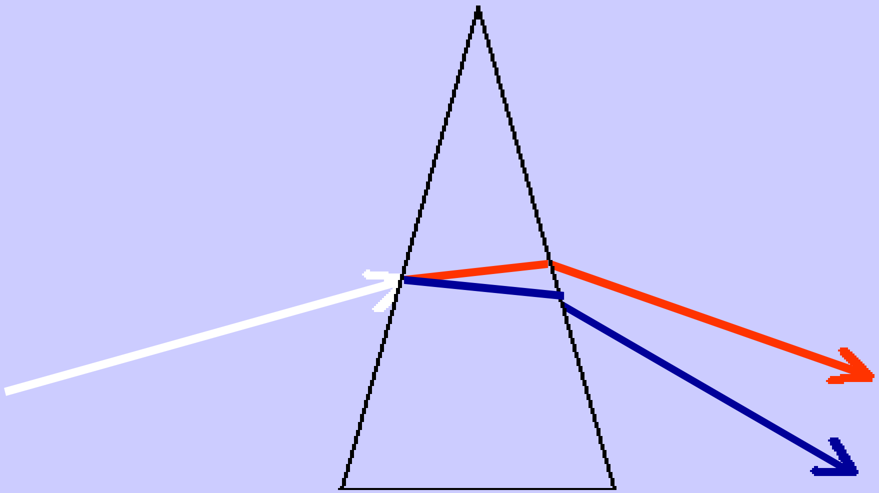
- digitized photographic plates
  - 5-10% accuracy
  - exposure time ~ hours
  - millions of sources per Schmidt plate



−1.3
−1.4
−1.5
−1.6
−1.7
−1.8
−1.9
−2
−2.1
-diff. V mag.
AG Vir
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
orbital phase

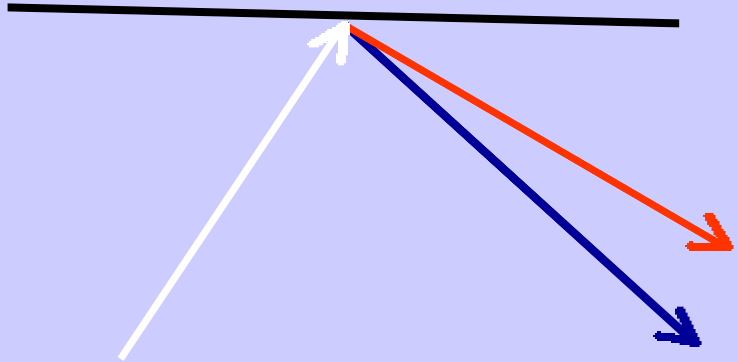
- ***spectroscopy***:
  - spectrograph / spectrometer with prism or diffraction grating to disperse light into a spectrum
  - record spectrum with a CCD
  - (***polarimetry***, ***spectropolarimetry*** use instruments together with a polariser)

Dispersing light into a spectrum

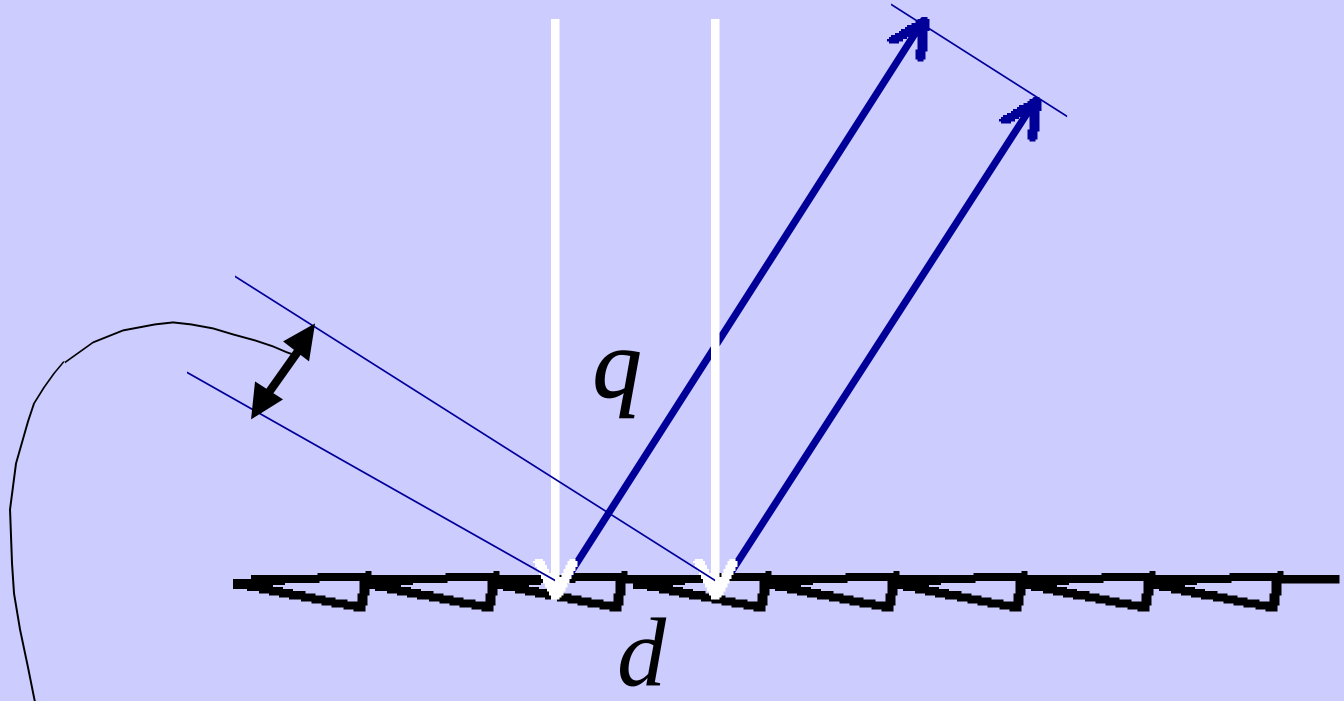


Prism

Grating



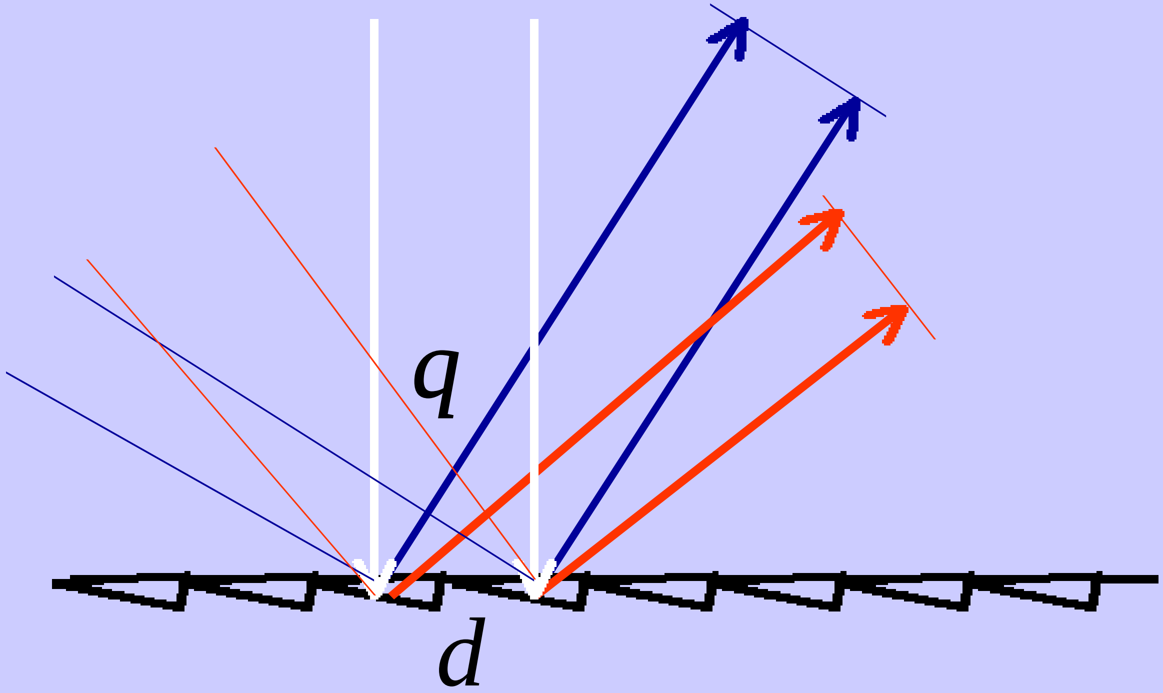
Diffraction Grating



Constructive interference if

$$\text{path difference} = d \sin\theta = m\lambda$$

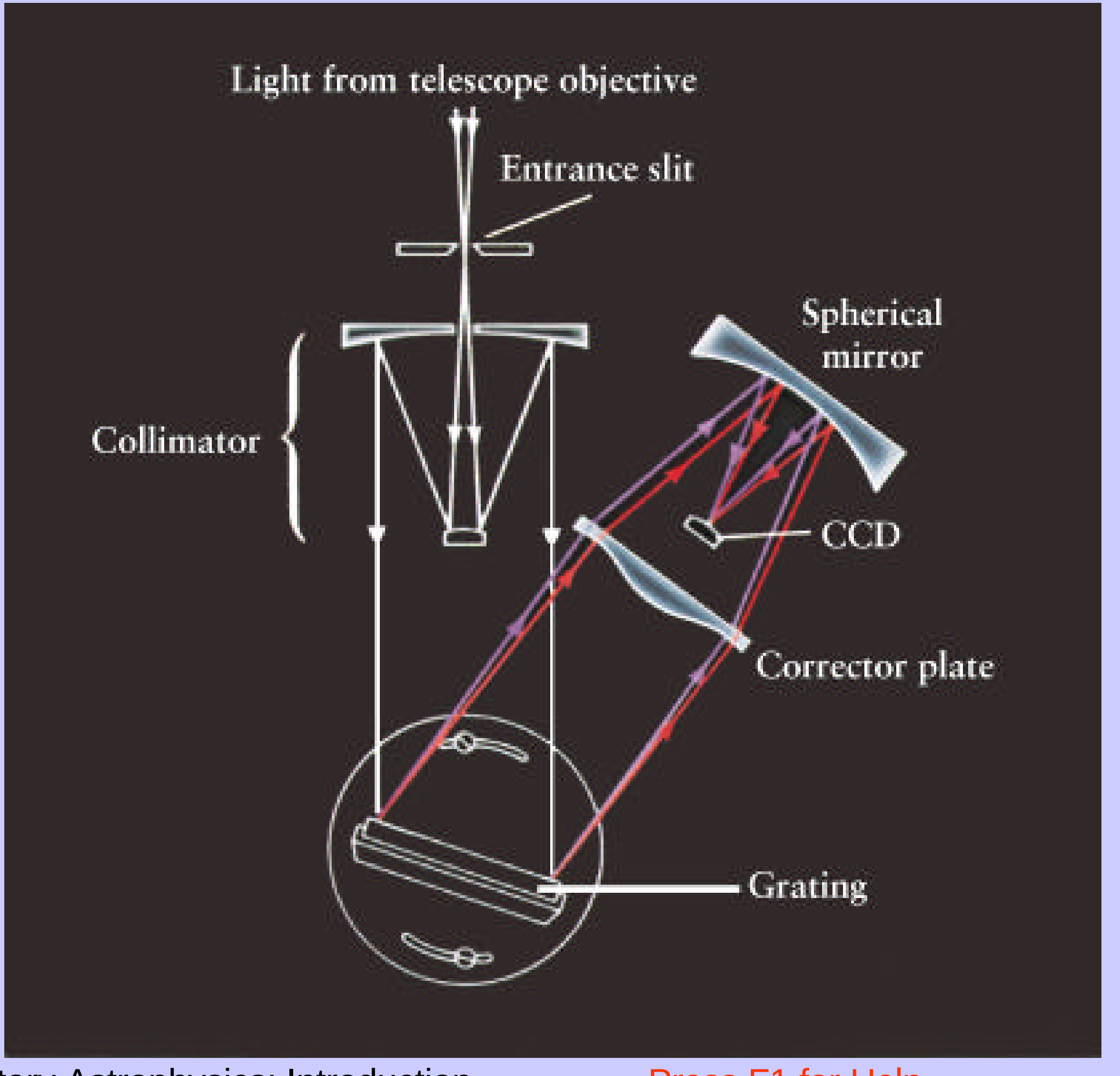
Diffraction Grating



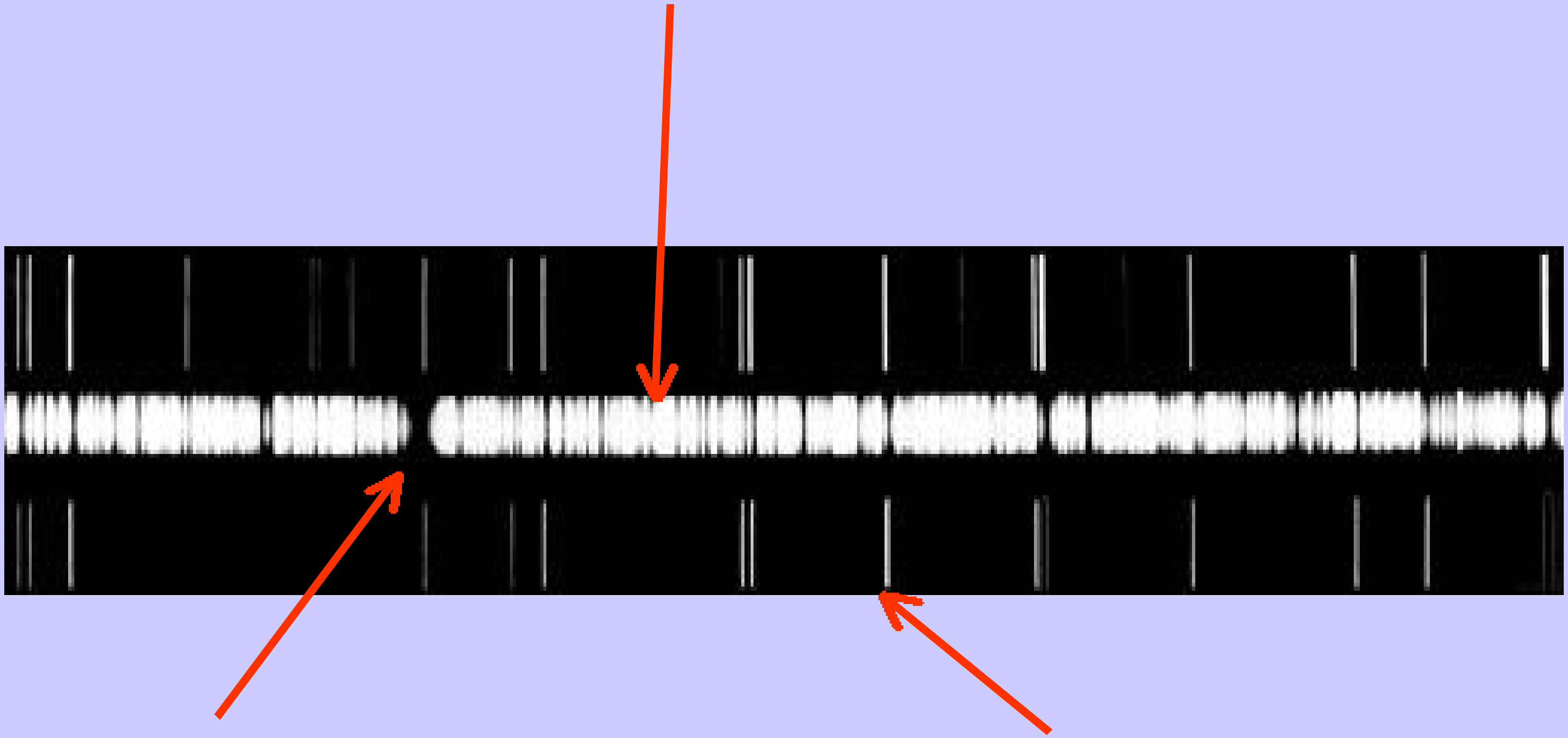
Constructive interference if

$$\text{path difference} = d \sin q = m l$$

A typical spectrograph



Spectrum of a star

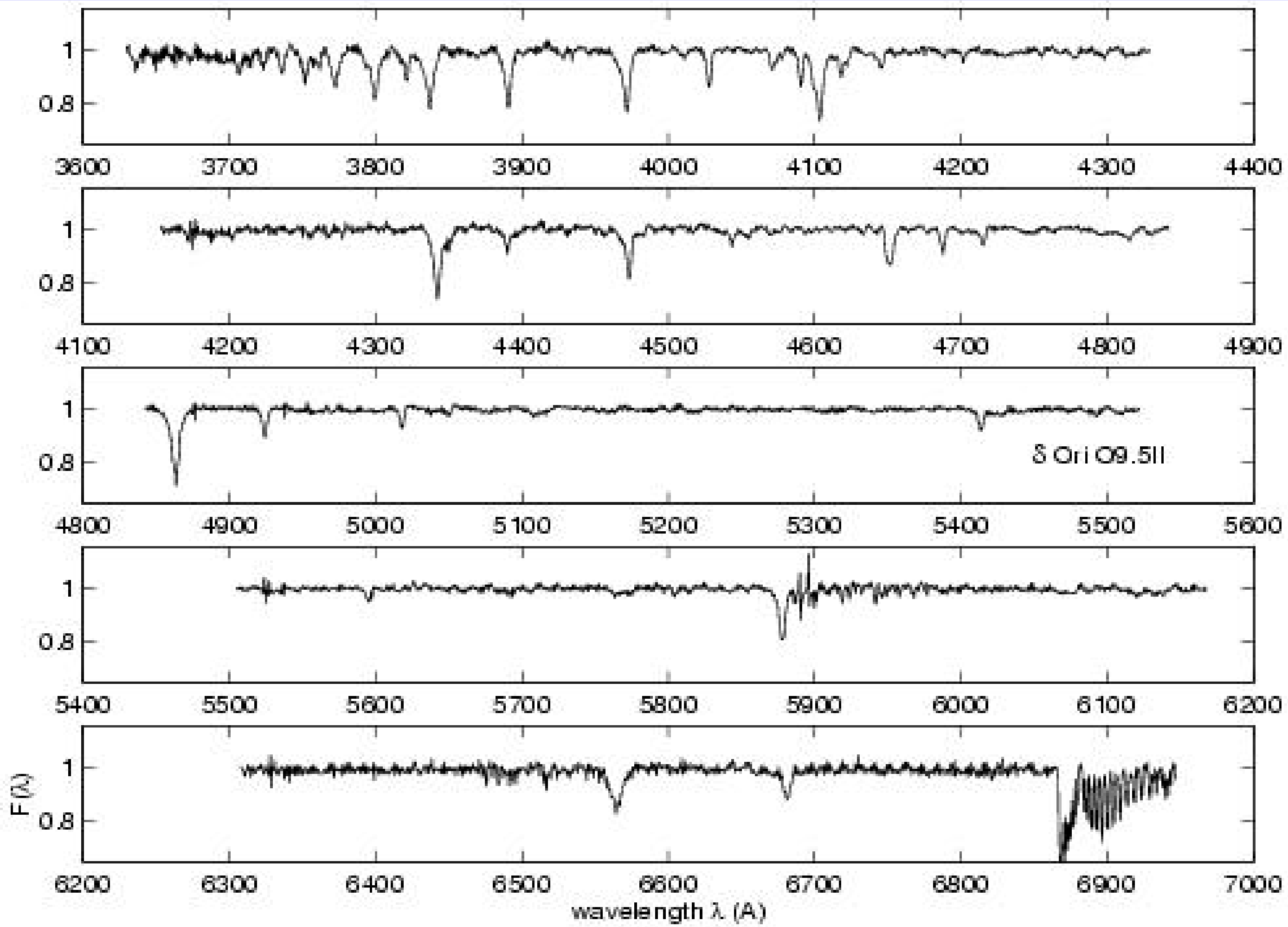


Absorption lines from star's atmosphere

emission lines from a calibration source

Spectrum of a star

blue



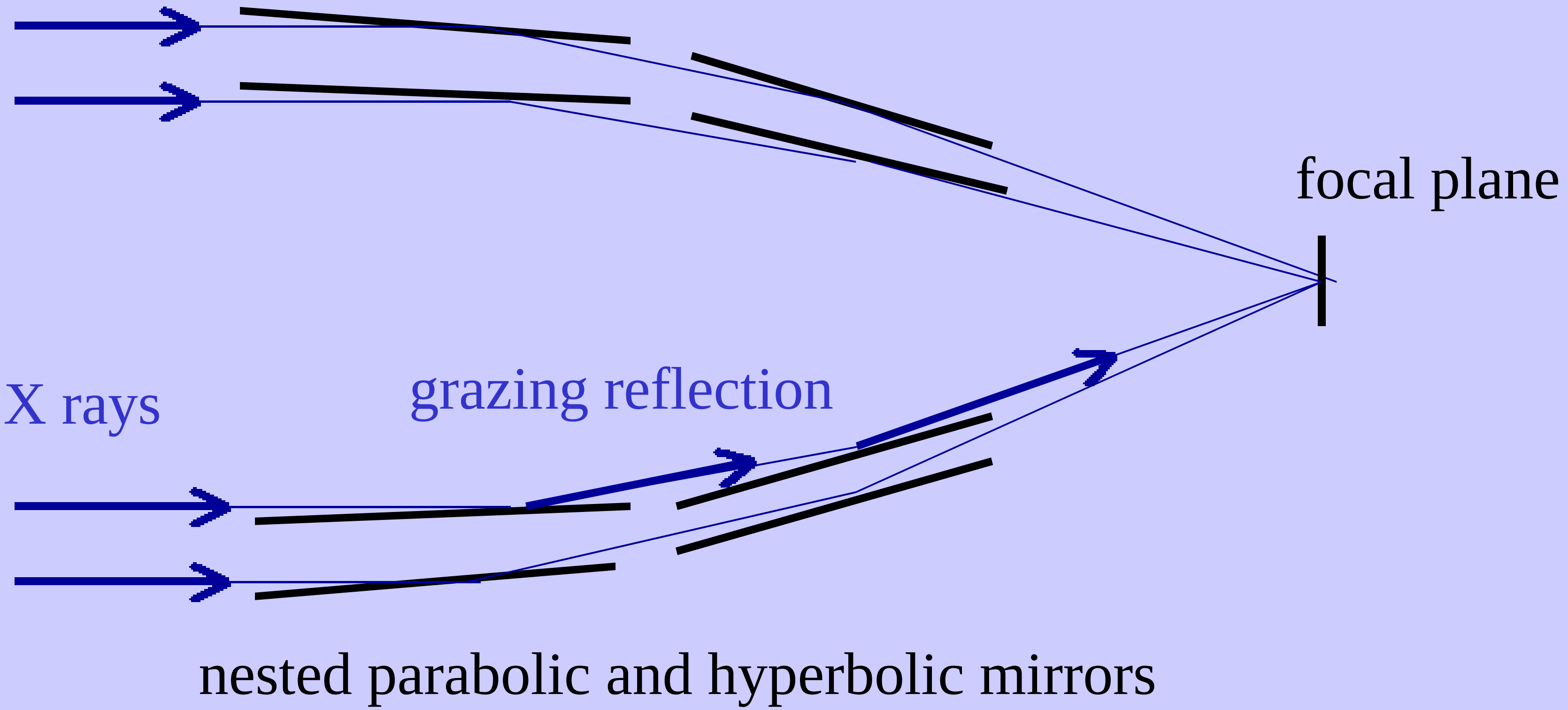
red

- Ultraviolet studies - from satellites
  - reflecting telescopes with smoother mirrors
  - CCDs not sensitive to ultraviolet, so use photon-counting electronic detectors
  - Hubble Space Telescope (HST)
  - 0.05 arcsec resolution (after repair!)
  - 2.4 metre diameter mirror
  - UV spectrometer; direct imaging
  - (also optical and infrared)
  - EUVE = Extreme UltraViolet Explorer
  - FUSE = Far UltraViolet Explorer

Telescopes and detectors for high-energy radiation

- gamma rays - **g** rays - ***l*** < 0.01 *nm* (10^{-11} *m*)
- X-rays -- hard: ***l*** ~ 0.01 - 0.1 *nm*
  soft : ***l*** ~ 0.1 - 10 *nm*
- *PROBLEM:*
  - will not reflect from ordinary mirrors
  - nested rings of highly polished mirrors using GRAZING REFLECTION

Schematic X-ray Telescope



- detectors:

g-rays

– scintillation detectors (e.g. NaI crystal)

– several layers convert **g**-rays by photoelectric effect into visible light detectable by photomultiplier

X-rays

– now mainly solid-state detectors like CCDs

– hence measurable current of electrons proportional to X-ray flux density

- recent satellites for high-energy radiation studies:

Compton gamma-ray observatory - 1991

ROSAT (Röntgen satellite) - X-ray studies - 1992

YOKHOH - X-ray studies of the Sun - 1993

RXTE (Rossi X-ray timing explorer) - 1996

Chandra - X-ray spectroscopy - 1999

XMM-Newton - X-ray imaging - 1999