# Astronomical Techniques I

## Lecture 12

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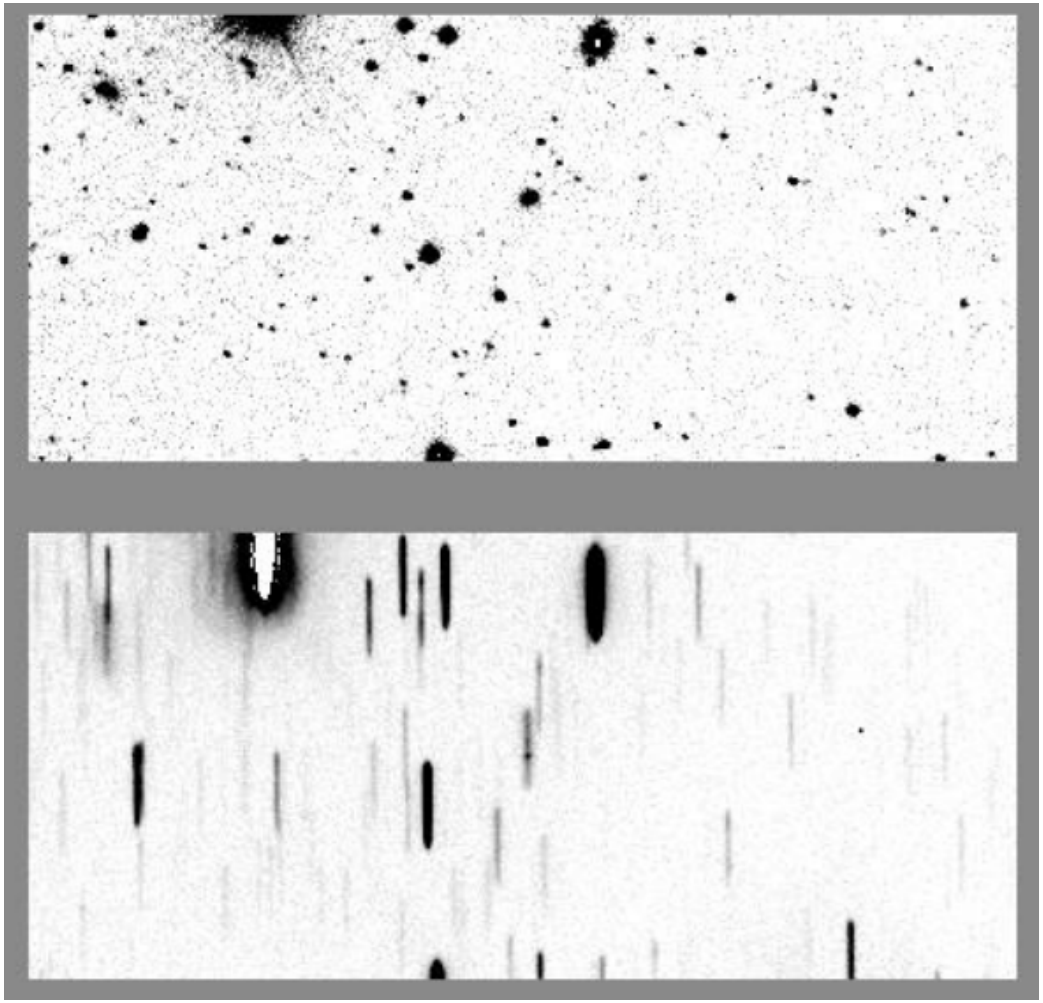
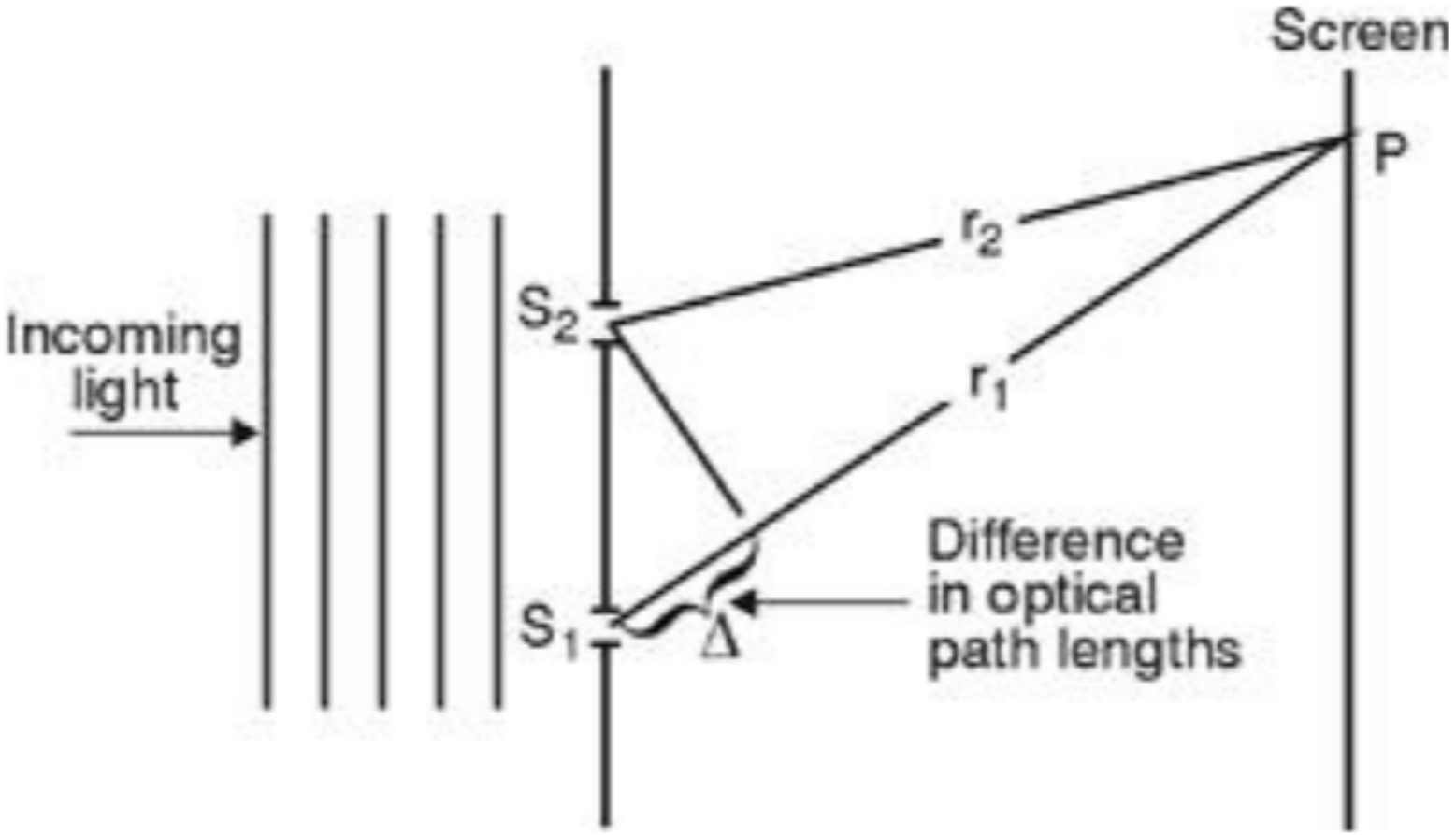
# Objective prism imagers: place prism over telescope primary

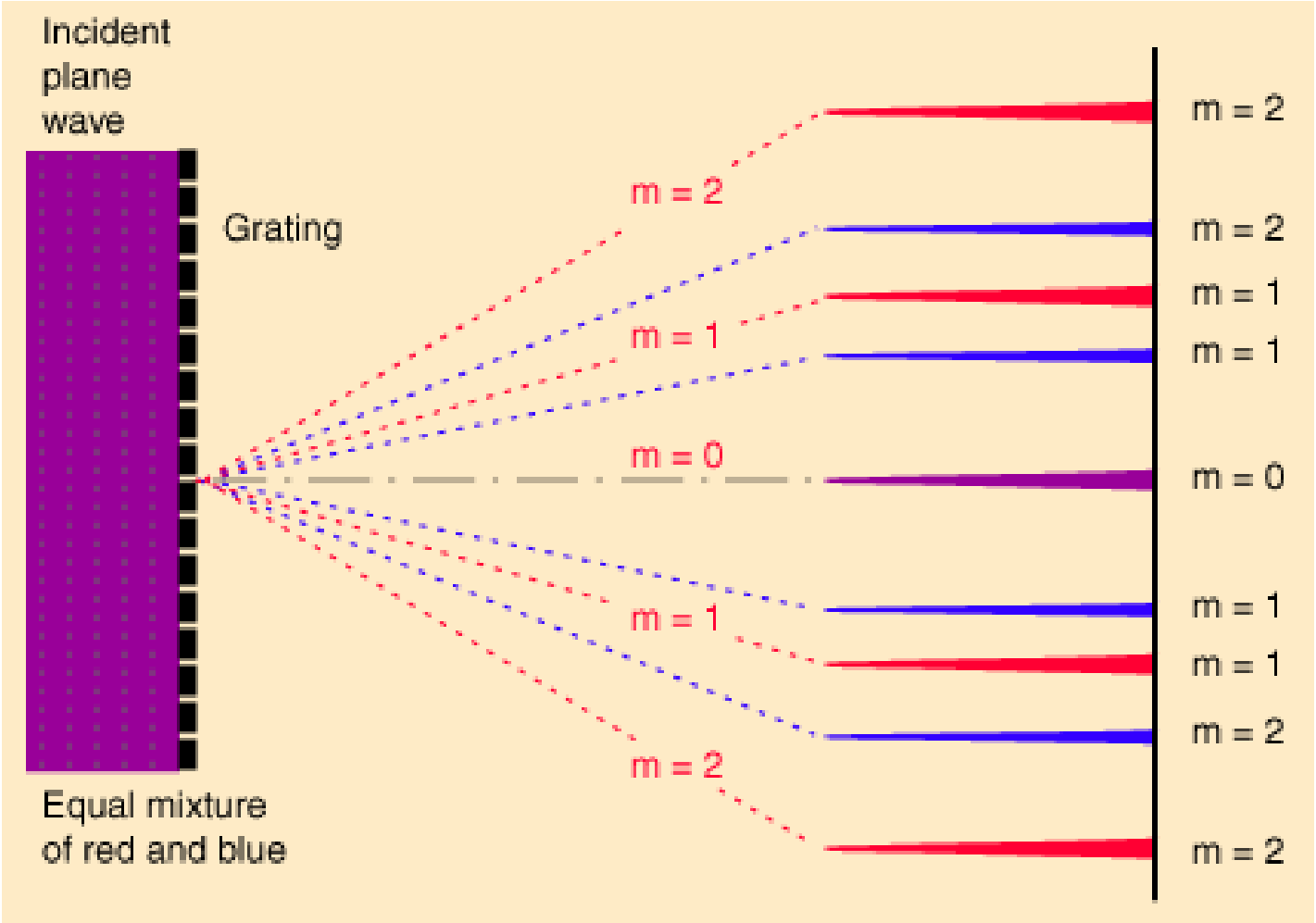


# Principle of diffraction gratings

Maxima in the output intensity occur at a sequence of angles $\sin\theta_n = n\lambda/d$.

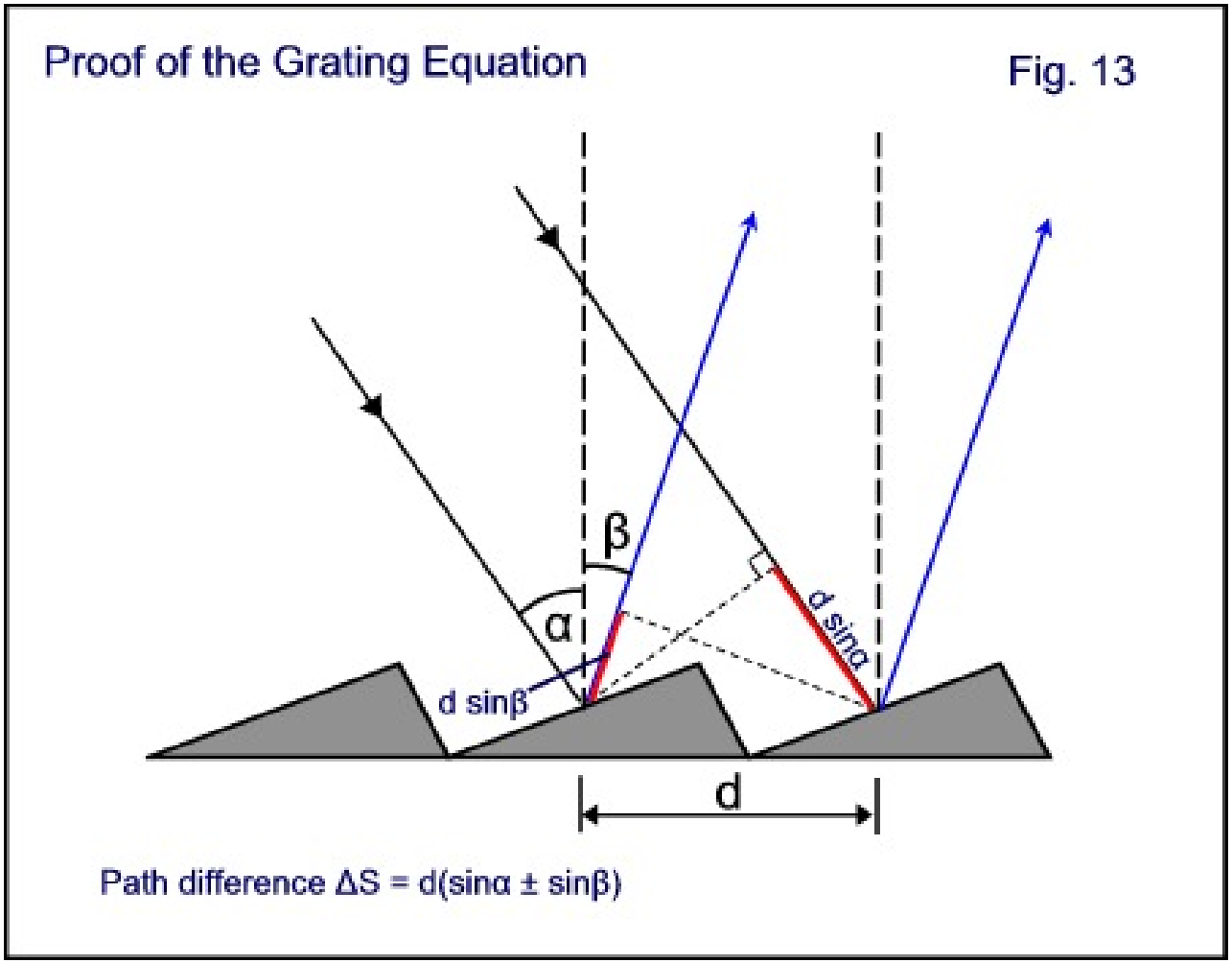


# Diffraction grating contains many slits. Order 1 onwards, separation happens!




gratings contain hundreds to thousands of grooves/mm.

# proof of grating equation with reflection grating



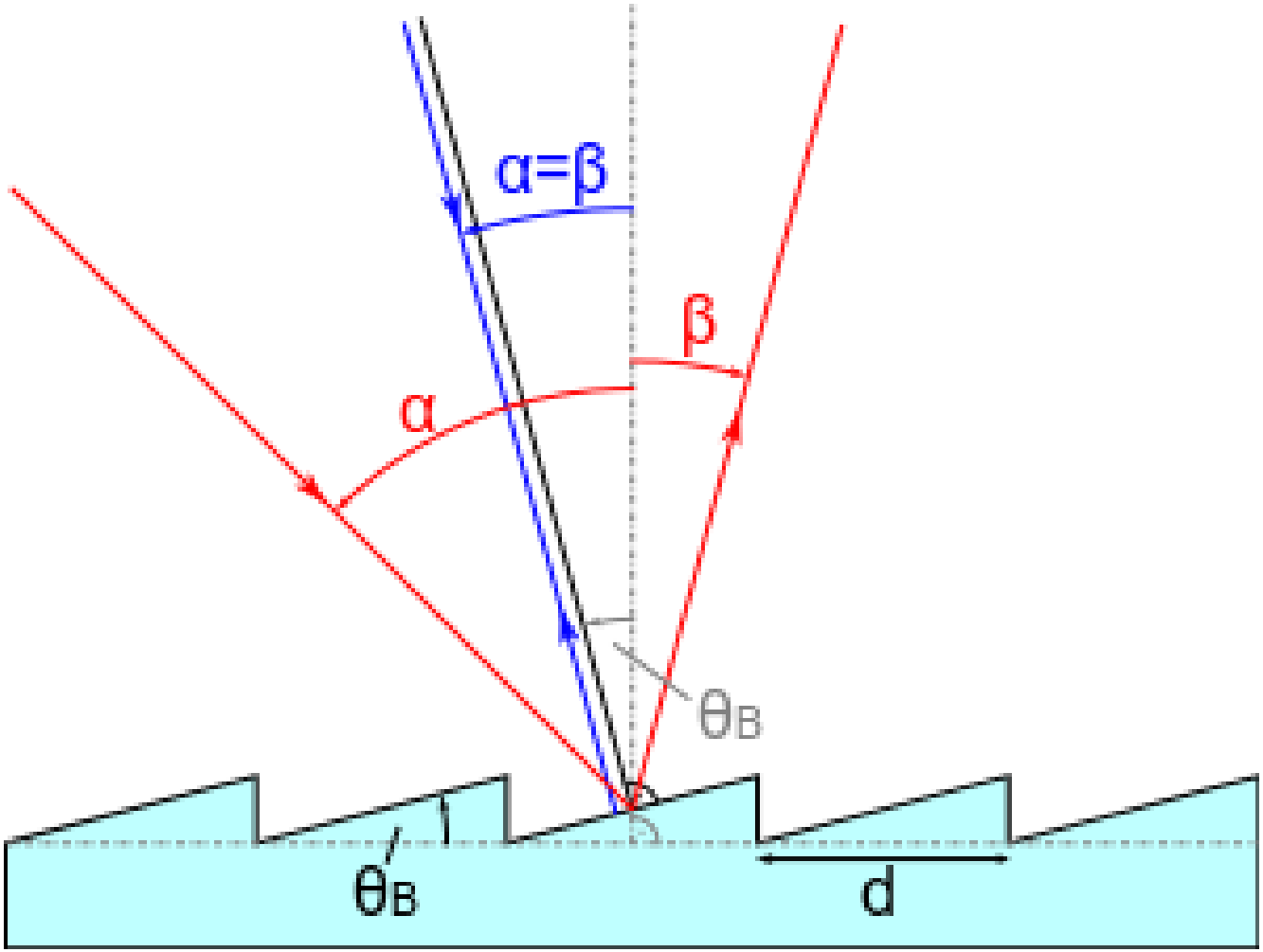

$$n\lambda = d(\sin\alpha + \sin\beta_n)$$

# reflection grating

Sign convention: $\alpha$ and $\beta$ have opposite signs if they are on opposite sides of the grating normal.

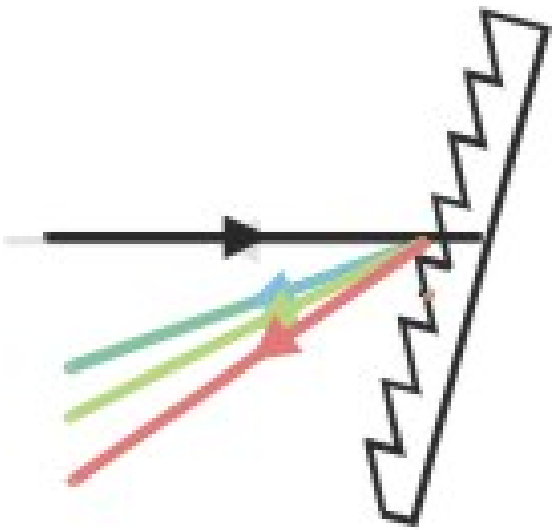
- for $m = 0$ grating acts as a mirror $\alpha = -\beta$
- for $m > 0$, $\beta > -\alpha$
- for $m < 0$ $\beta < -\alpha$

# Blazed grating -Littrow configuration

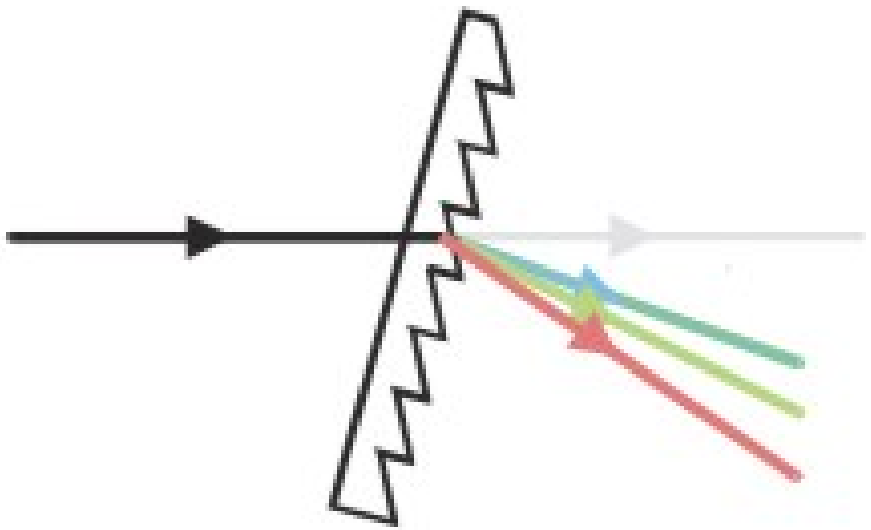



$$2d \sin \theta_B = m\lambda$$

# Reflection and transmission gratings



Reflection grating

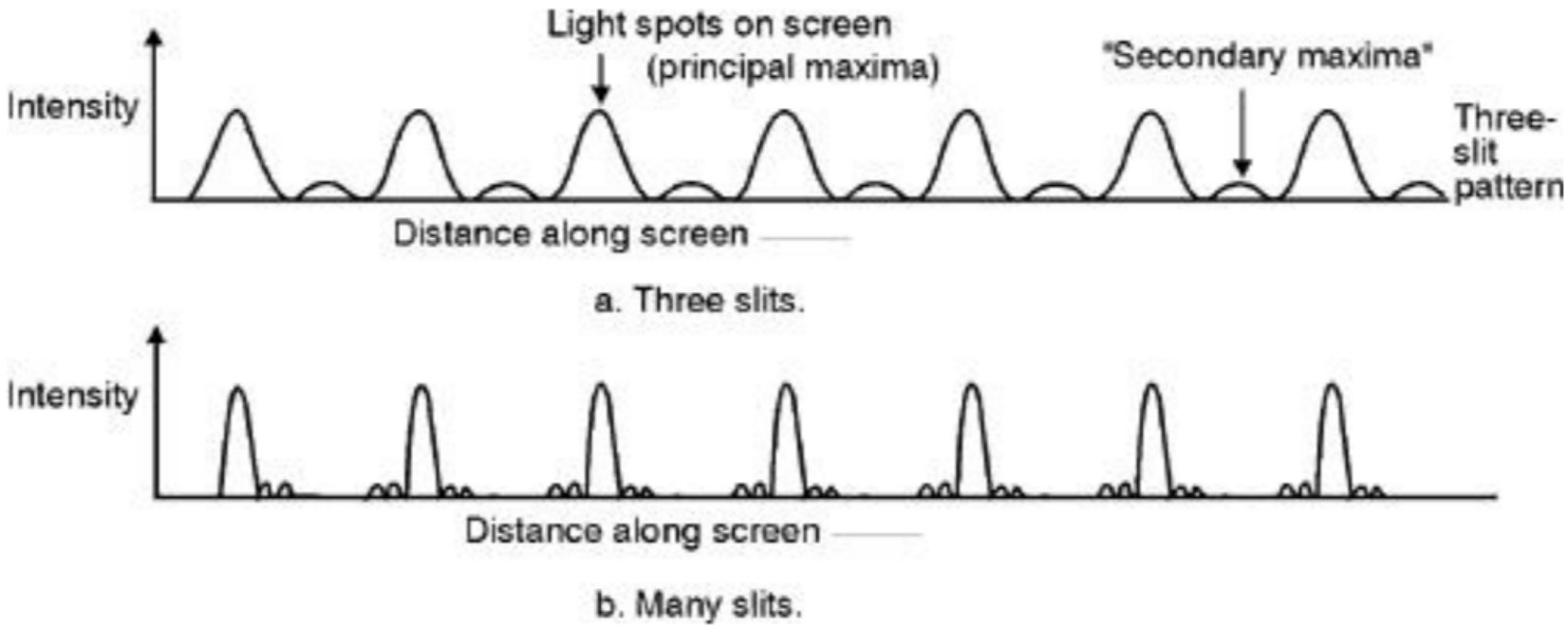


Transmission grating

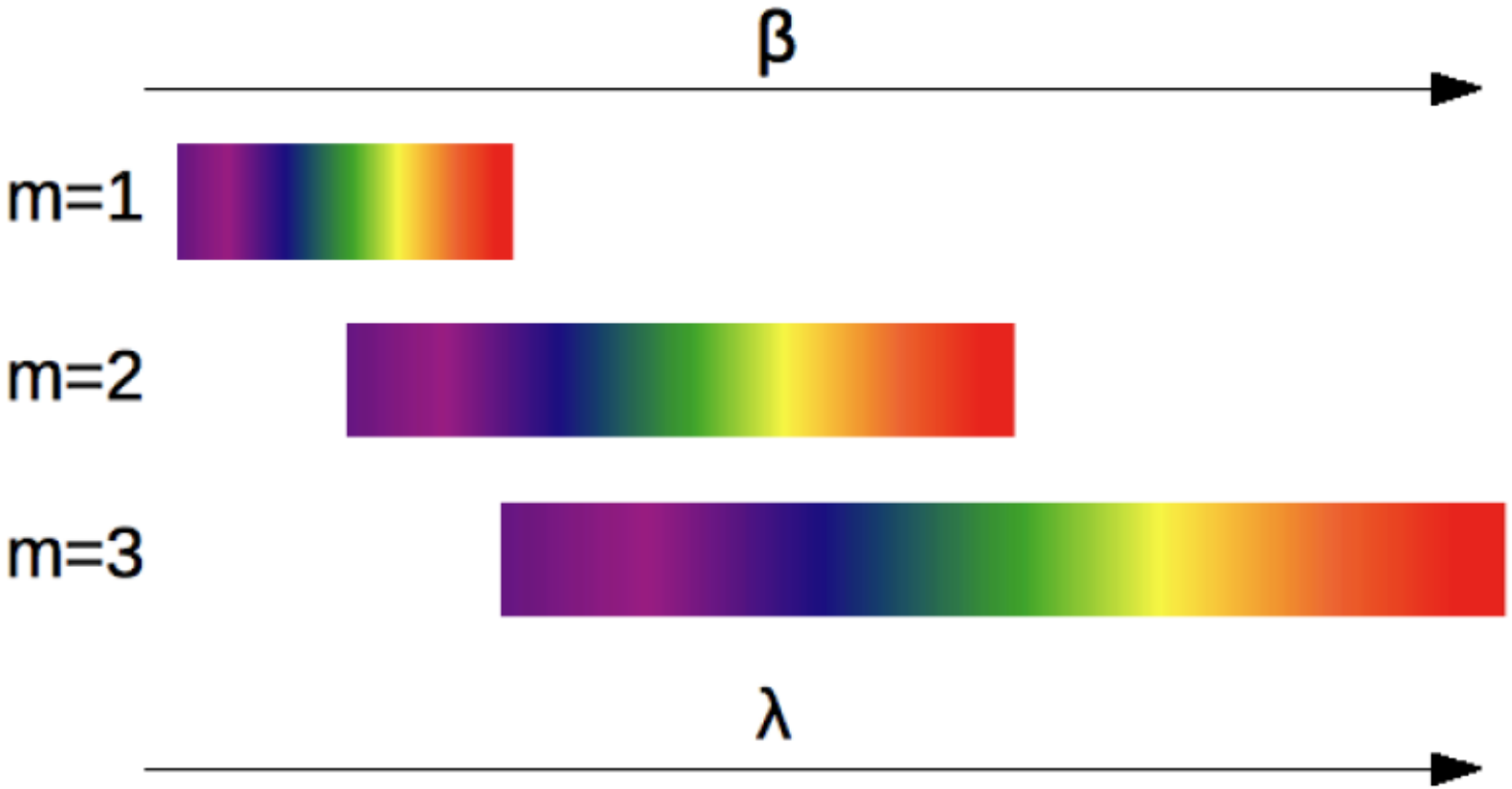
How is this transmission grating different from a prism?

# Pattern for many slits - monochromatic light

The addition of slits increases the sharpness and brightness of the peaks but leaves the locations of the orders unchanged. Of course, slight peak offset for slightly differing wavelength.



# But different orders overlap!



# Resolution of grating

If grating is illuminated by polychromatic light. In a given order, redder light is diffracted to larger angles than blue light. The maxima for adjacent wavelengths in a given order are offset slightly. Spectral resolution for order *n* is determined by the wavelength shift needed to place the diffraction pattern maximum for $\lambda + \delta\lambda$ on the first minimum in the pattern for $\lambda$. The resolution is:

$$\Re = \frac{\lambda}{\delta\lambda} = nN$$

so it depends both on the order and on the total number of slits illuminated on the grating *N*.

# Angular dispersion

in order $n$ is given by:

$$\frac{d\theta}{d\lambda} = \frac{n}{d\cos\theta}$$

Higher dispersion corresponds to larger values of this quantity. Echelles take advantage of both $n$ and $\theta$ dependence to maximize dispersion.

# Astronomers working definition of dispersion

Astronomers often use the word *dispersion* to refer to $d\lambda/dx$ in the spectrograph focal plane, usually quoted in Å per mm. This is more properly called the "linear reciprocal dispersion". It is inversely related to the angular dispersion, so lower values correspond to higher wavelength dispersion. e.g. Sloan Survey has 3 Å per pixel (24 $\mu$m).

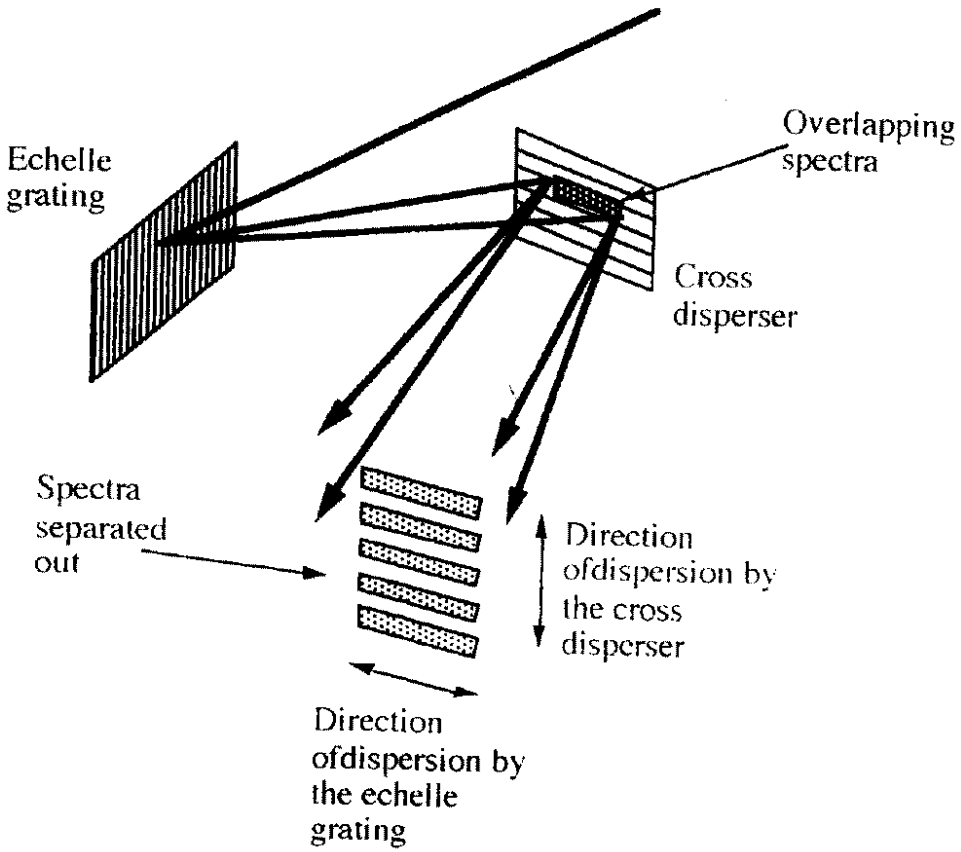
# Advantages of gratings

- Dispersion same for all wavelengths in given order
- Large dispersions/resolutions possible (large n)
- Transmission or reflection gratings available
- High UV throughputs possible (with proper reflection coating)
- Grating technology highly developed, extensive customization possible

# Disadvantages of gratings

- Size limited by capacity of ruling engine. Use of mosaic gratings with large beam telescopes possible but performance compromised.
- Order superposition: red light of a given order is spatially coincident with blue light from a higher order. In echelle spectrographs, use a second grating as a cross-disperser.
- Low efficiency: Gratings distribute light across a large number of orders (including the zeroth order, which has no dispersion). Flux decreases rapidly with order. Solution: *Blazed* reflection gratings, in which the facets of the slits are cut at an angle that places the maximum of the single-aperture pattern at a chosen wavelength and order.

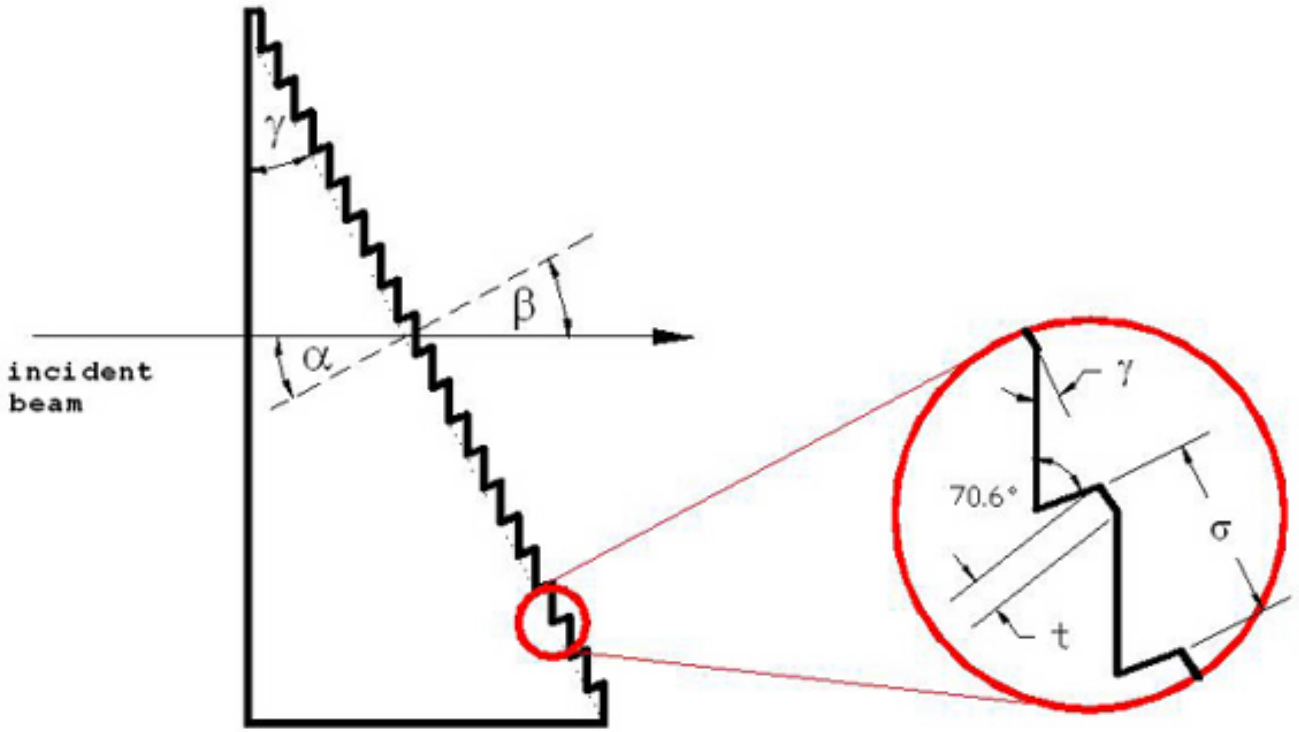
# Echelle grating and cross disperser



# How gratings are manufactured

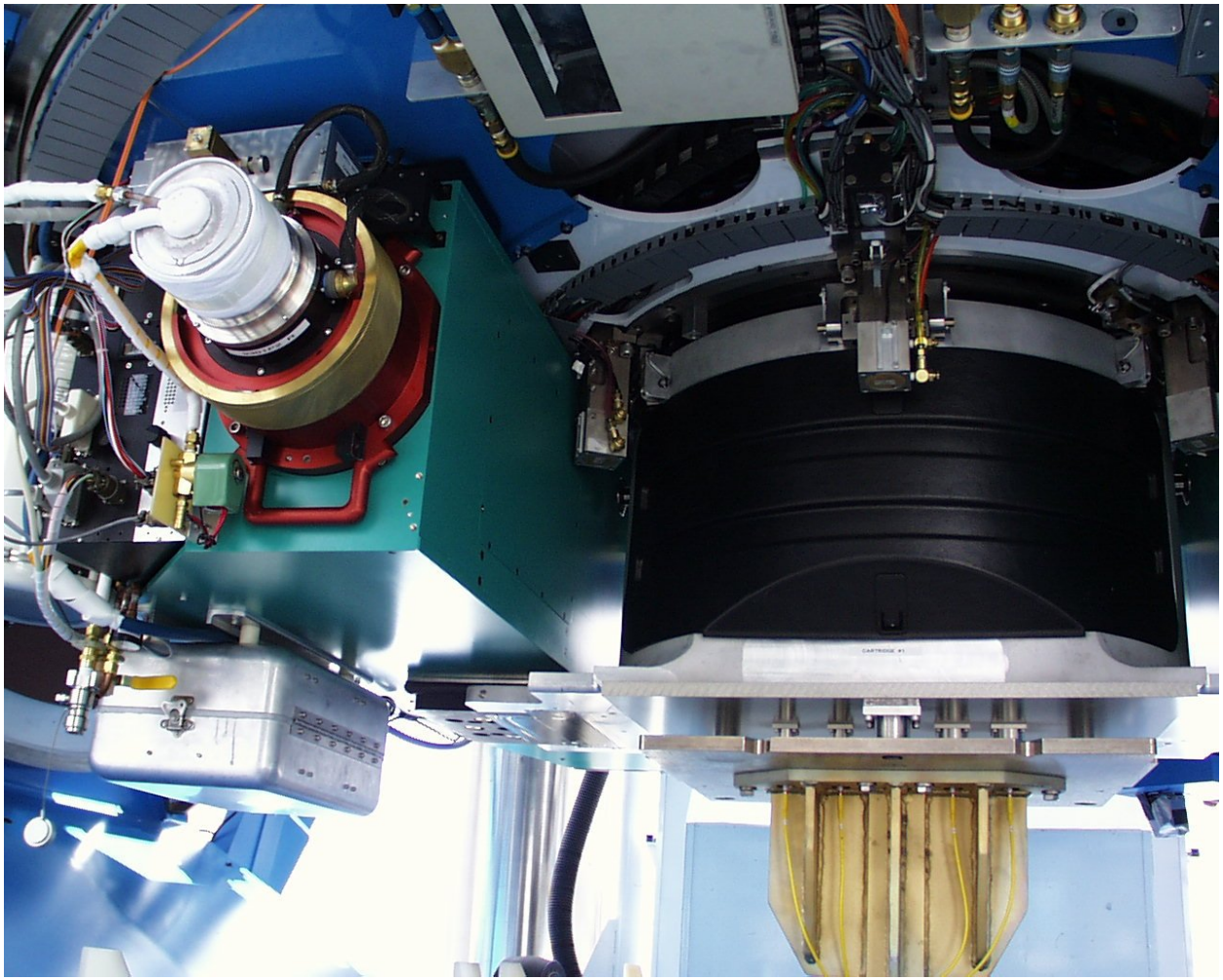
- a master is prepared with a diamond tool making closely spaced grooves on metal - high cost.
- many replicas can be made with plastic using the metal grating as master.
- these can be mounted on glass to form a transmission grating or coated with a reflective material to form reflection grating.

# Grism - Prism + Diffraction grating

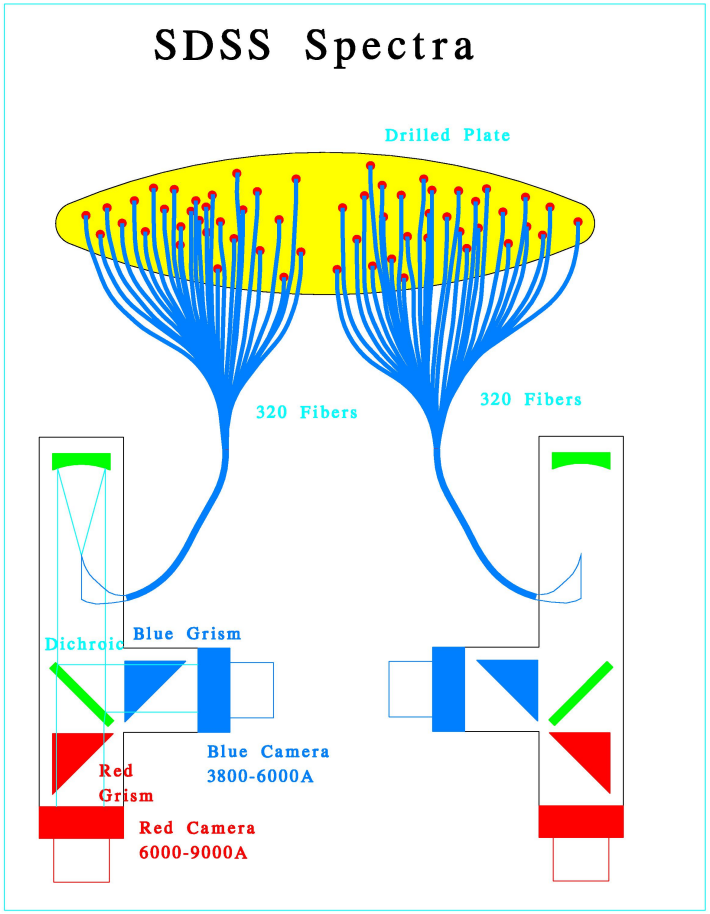



A grism is a combination of a prism and grating arranged to keep light at a chosen central wavelength undeviated as it passes through a camera.

# Spectrograph variants: Double spectrographs

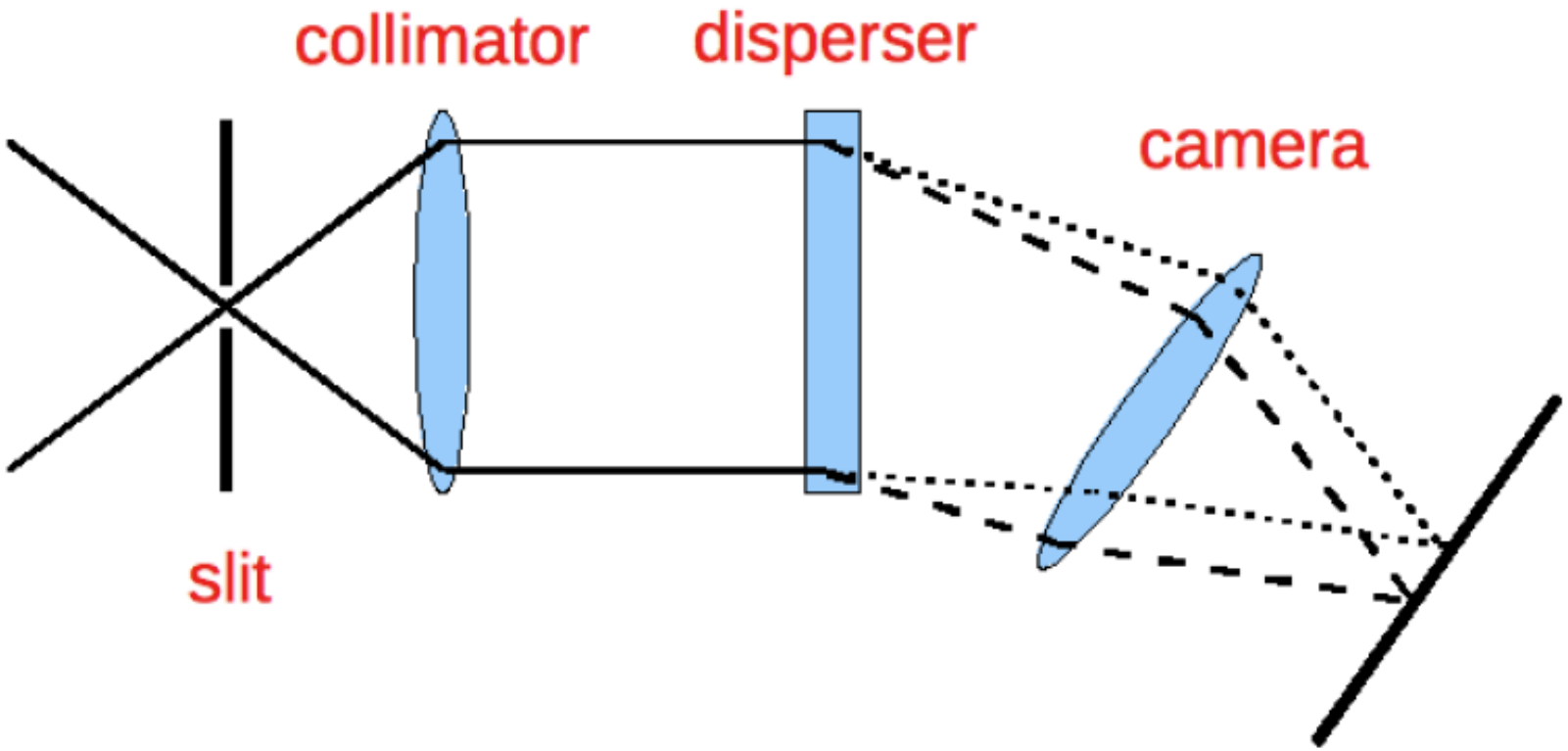


# Spectrograph variants: Fiber fed multi-object spectrographs (1D)

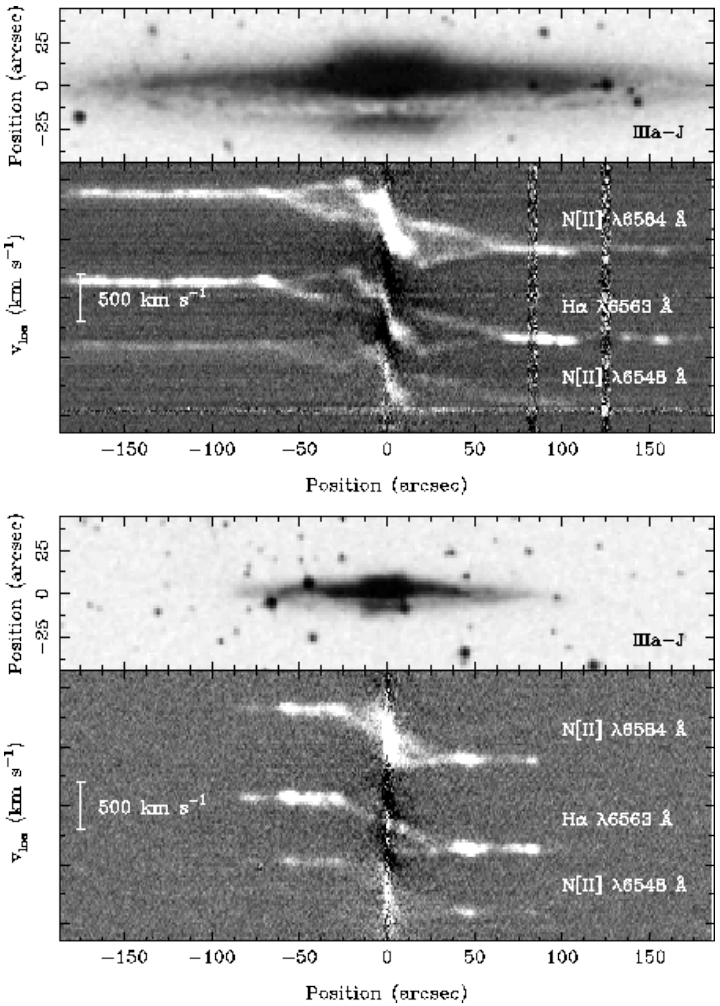


# SDSS plugplate

# Long slit spectroscopy (2D)



# Long slit spectroscopy

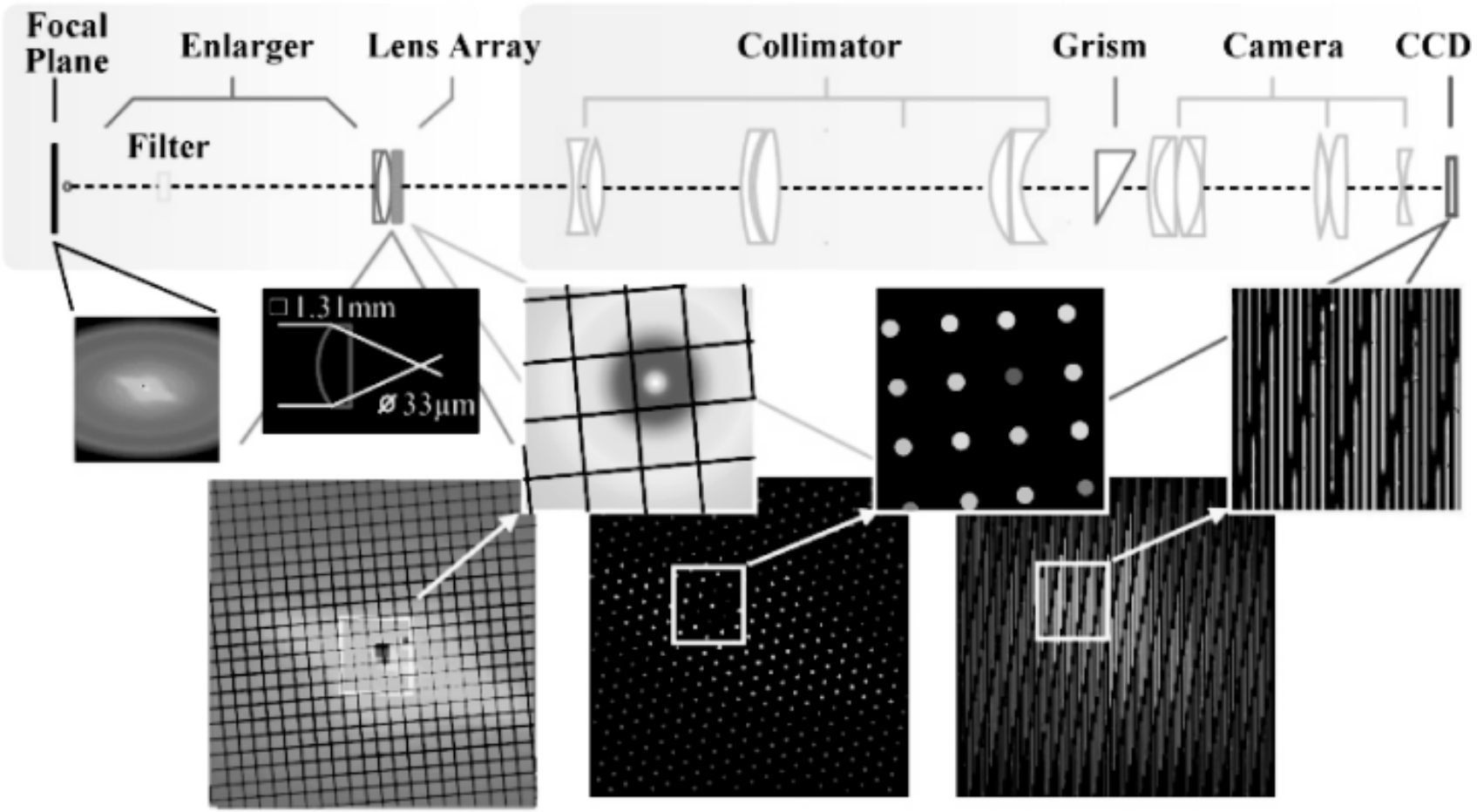



Which way is the galaxy rotating?

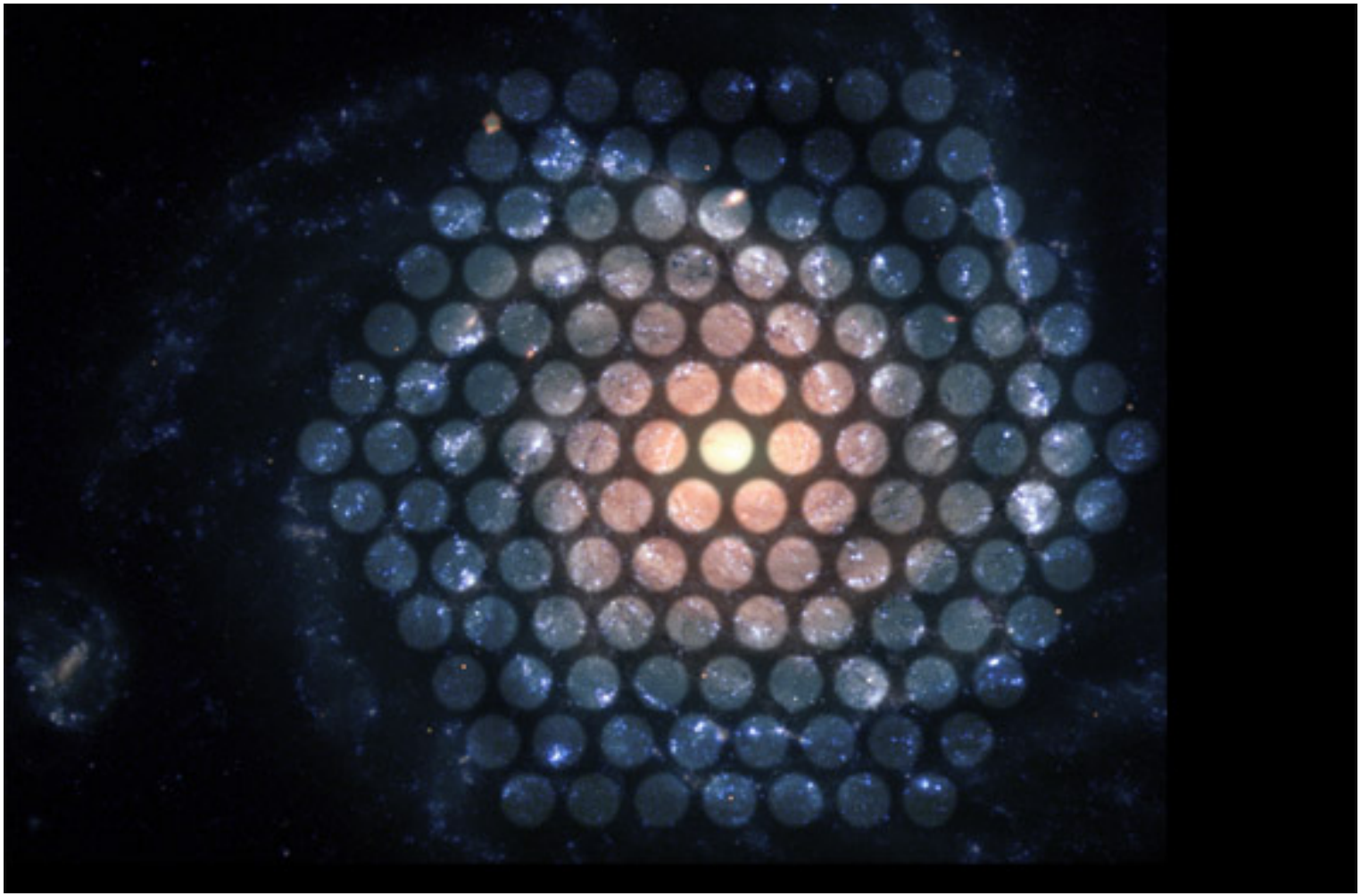
# All detector imaging steps apply for spectroscopy

Bias subtraction, Dark subtraction, flat fielding, cosmic ray removal, bad pixel interpolation etc. are required for spectroscopic data.

# Integral field spectrograph (3D)



# Tiling a galaxy with lenslets



# Integral field spectrograph