# Observational Astronomy

# SPECTROSCOPY
## and
# spectrometers

Kitchin, pp. 310-370

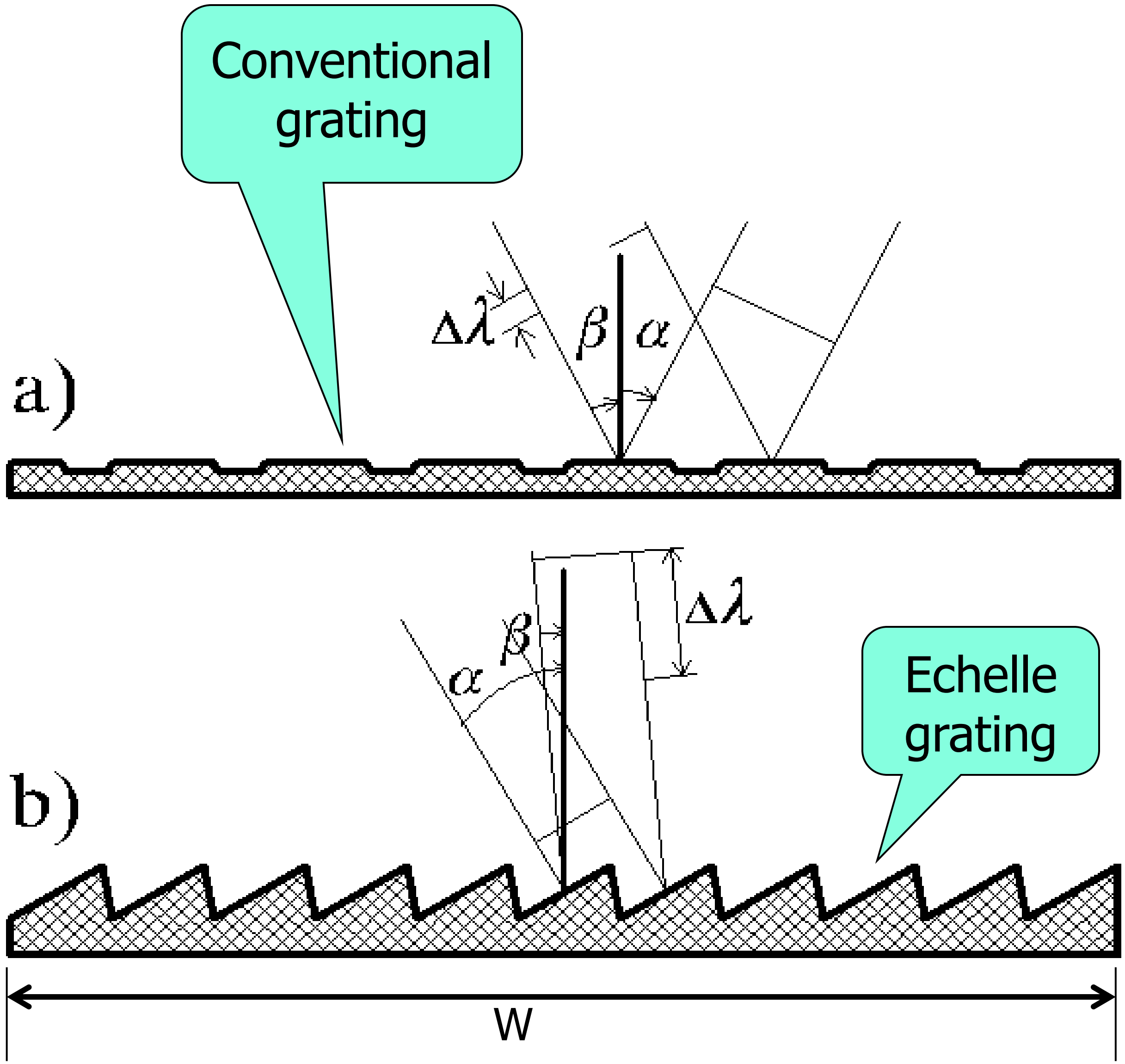
# Spectroscopic methods

- Different purposes require different instruments
- Main spectroscopic methods:
  - *Spectrophotometry*
  - *Low resolution*
  - *Long slit, high resolution*
  - *High resolution*
- Spectroscopic observations are characterized by: *dispersion/spectral resolution* and *spectral range*

# Spectrophotometry

- Typical goal: search for objects with specific spectral features
- Method 1: objective prism, telescope "sees" the source through a prism, therefore each point source looks like a small spectrum
- Method 2: narrow band filters for given spectral features. Often such filters have the possibility to change central wavelength by changing temperature/pressure. There is no slit!

# Gratin




Interference:

Grating formula: $OPD = \delta \sin\alpha + \delta \sin\beta = m\lambda$

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# A bit of math:

- Expression for angular dispersion is found by differentiating the grating eq.:

$$m d\lambda = \delta \cos\beta d\beta$$

$$\frac{d\lambda}{d\beta} = \delta \cos\beta / m$$ Angular dispersion

- Linear dispersion is readily obtained for a given focal length

$$\frac{d\lambda}{dx} = \delta \frac{\cos\beta}{m \cdot f_{\mathrm{cam}}}$$ Linear dispersion

# … and some more …

- Angular resolution. Think of a grating as a mirror, its diffraction angle is given by:

$$\Delta\beta = \lambda / (W \cdot \cos\beta)$$

Projected size of the grating

- … and combining it with the angular dispersion equation:

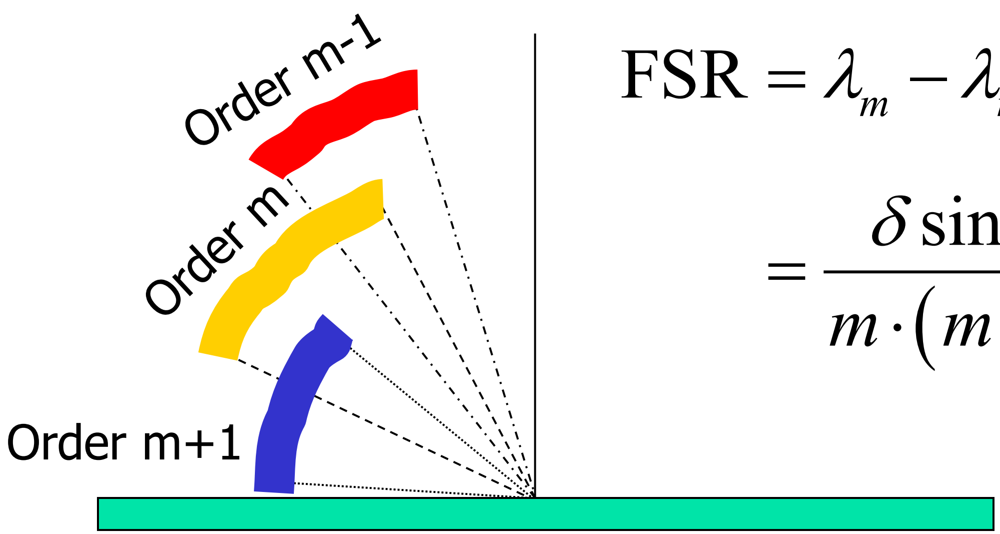
?

$$\frac{\lambda}{\Delta\lambda} \equiv R = m \cdot \frac{W}{\delta} = m \cdot N$$

- *Resolving power depends in the number of illuminated grooves!*

# Free spectral range

The free spectral range (FSR) of a diffraction grating is defined as the spectral interval in a given order which does not overlap with the wavelengths in adjacent orders.

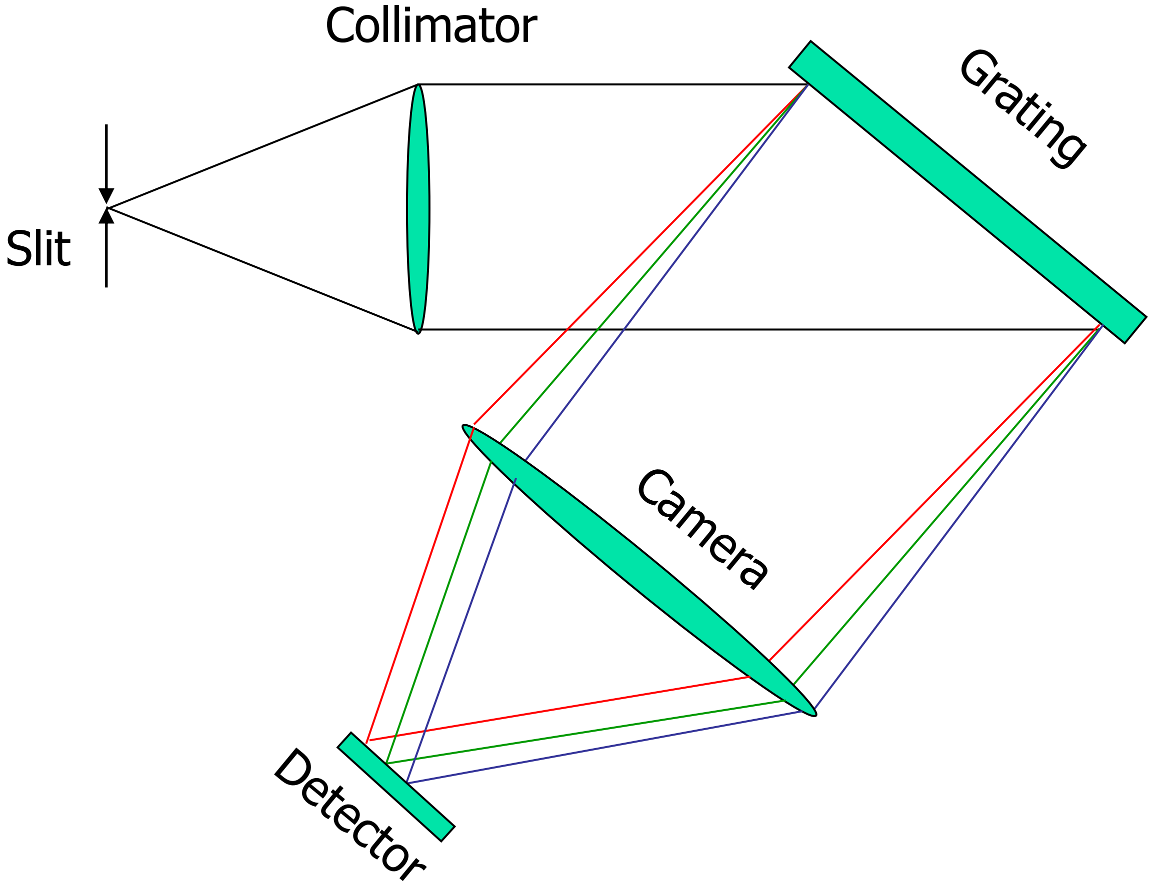



$$\mathrm{FSR} = \lambda_m - \lambda_{m+1} = \frac{\delta \sin \beta}{m} - \frac{\delta \sin \beta}{m+1} =$$

$$= \frac{\delta \sin \beta}{m \cdot (m+1)}$$

For a prism FSR is the whole sp. range!

# Grating spectrometers



# Real world: the seeing and the pixel size

- The angular slit size as seen by the grating is:

$$\Delta\alpha = s/f_{\text{coll}}$$

where $f_{\text{coll}}$ is the focal length of the collimator and $s$ is the linear width of the slit. Grating equation connects this to the angular resolution element:

$$\Delta\alpha\cos\alpha = s/f_{\text{coll}}\cos\alpha = -\Delta\beta\cos\beta$$

$$\left|\Delta\beta\right| = \frac{s\cdot\cos\alpha}{f_{\text{coll}}\cdot\cos\beta}$$

- If we try to match this to the angular resolution of the grating we end up with too narrow slit.
- In practice, we select the slit, translate this to angular resolution and select the camera focal length to match the pixel scale.

# Putting some numbers

Home work

The spectrograph for the BWT is based on a 20 cm grating with a blaze angle of 66.5º and 72 grooves per mm

- Find angular resolution of the grating at 4000 Å, 6000 Å and 8000 Å
- Find optimal slit size with collimator length of 80cm
- Take a realistic seeing (2") and the corresponding entrance slit size. Compute the resolution R and the camera focal length to achieve 3 pixel sampling of a resolution element (15 micron pixel size)
- Why is it hard to make high-resolution spectrometers for large telescopes? How the size of the primary mirror affects parameters and dimensions of a spectrometer?

# Modern concept

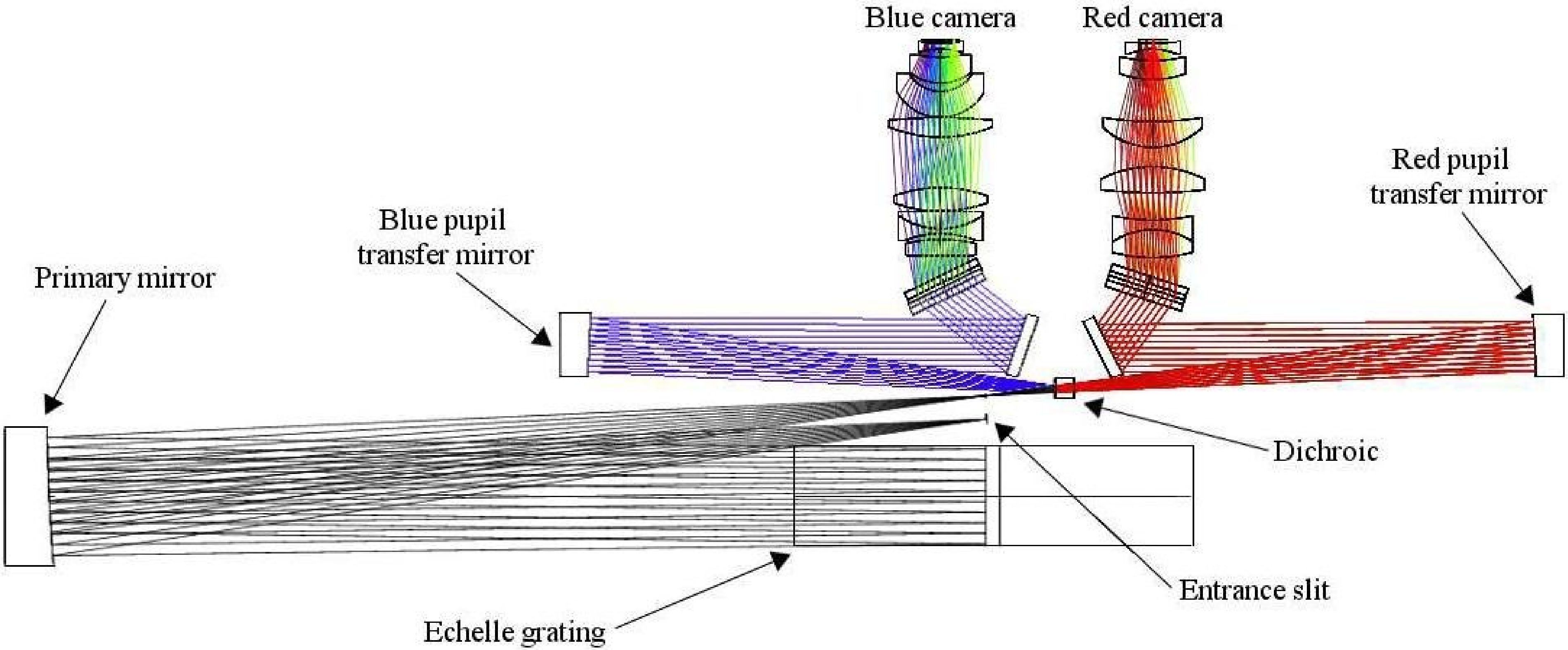
- Echelle gives high resolving power (high orders) and high efficiency (no dark stripes)
- Spectral orders overlap (maximum reflection at blaze angle) $\Rightarrow$ order selection or cross-disperser is needed (e.g. grating or prism)
- Central wavelength of order $m$ is given by:

$$\lambda_m = 2\delta \sin\theta_{\mathrm{blaze}} / m$$

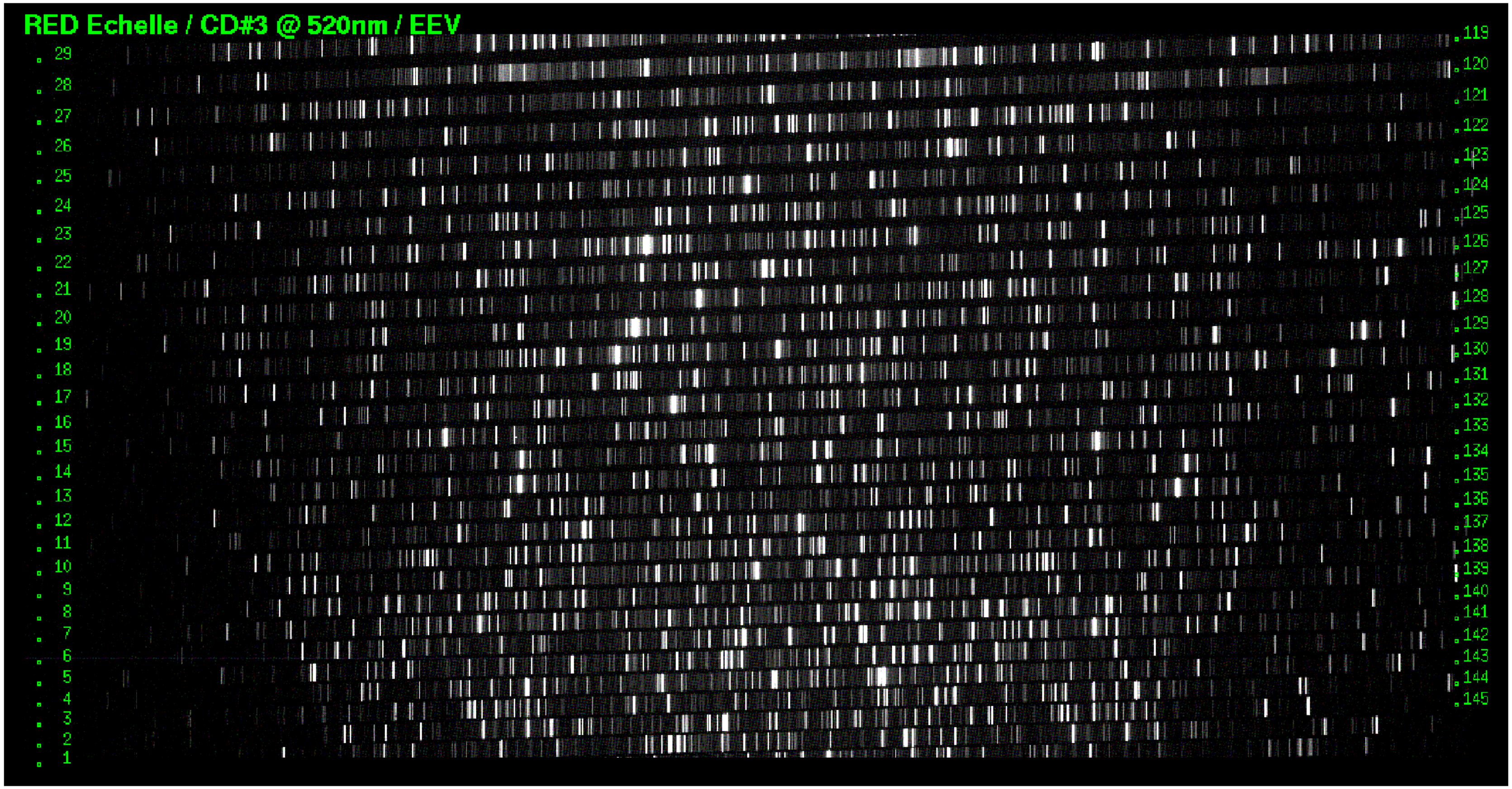
- With a cross-disperser the whole spectrum is packed in a rectangular 2D format, perfect for an electronic detector

# Spectrograph designs

Echelle, white pupil (e.g. SALT-HRS)



# Echelle focal plane layout

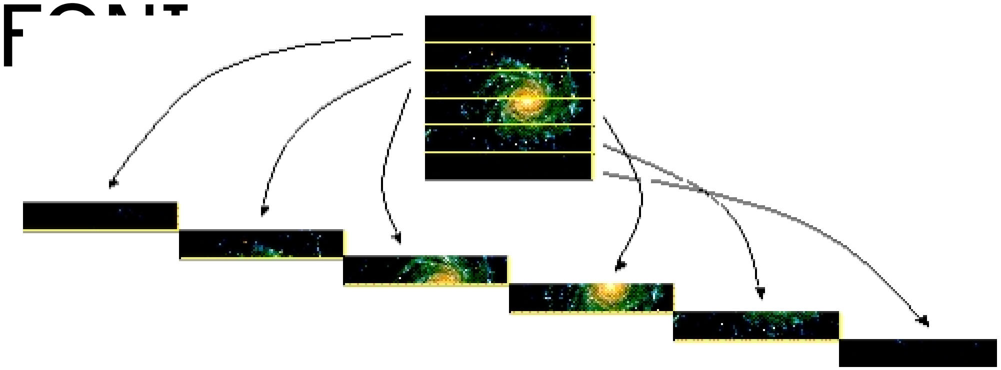


# Side effects

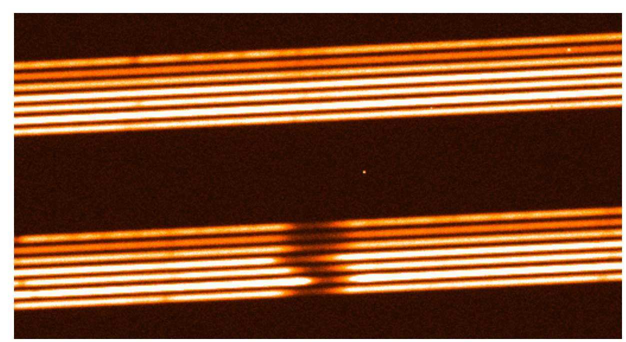
- Orders are curved
- Order spacing changes
- Short FSR
- Camera aberrations directly affect resolution
- Hard to calibrate fringing

# Other spectroscopic instruments

- IFU instruments
  2D image slices are re-arranged in 1D slit. E.g. SINFONI

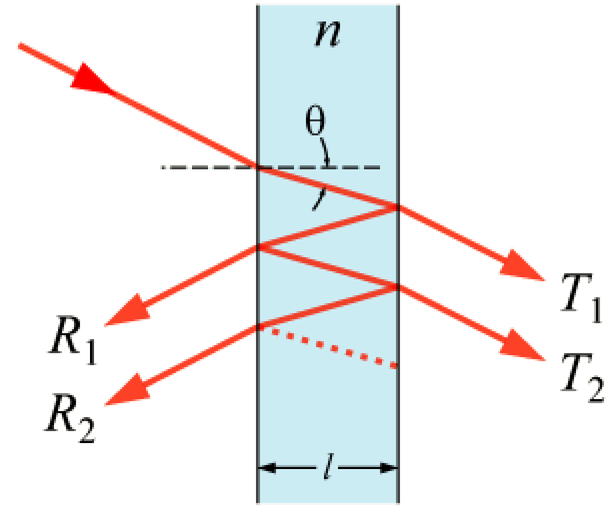


- Multi-object instruments.
  E.g. FORS, FLAMES



http://www.physik.uni-osnabrueck.de/kbetzler/sos/fabryperot.pdf

# Fabry-Perot interferometer




- The resolution is determined in the same way as for a gra
- Transmission/Reflection ratio depends on the wavelength
- The ratio between the reflection and the transmission peaks is called *finesse*
- F-P is often used as tunable filter