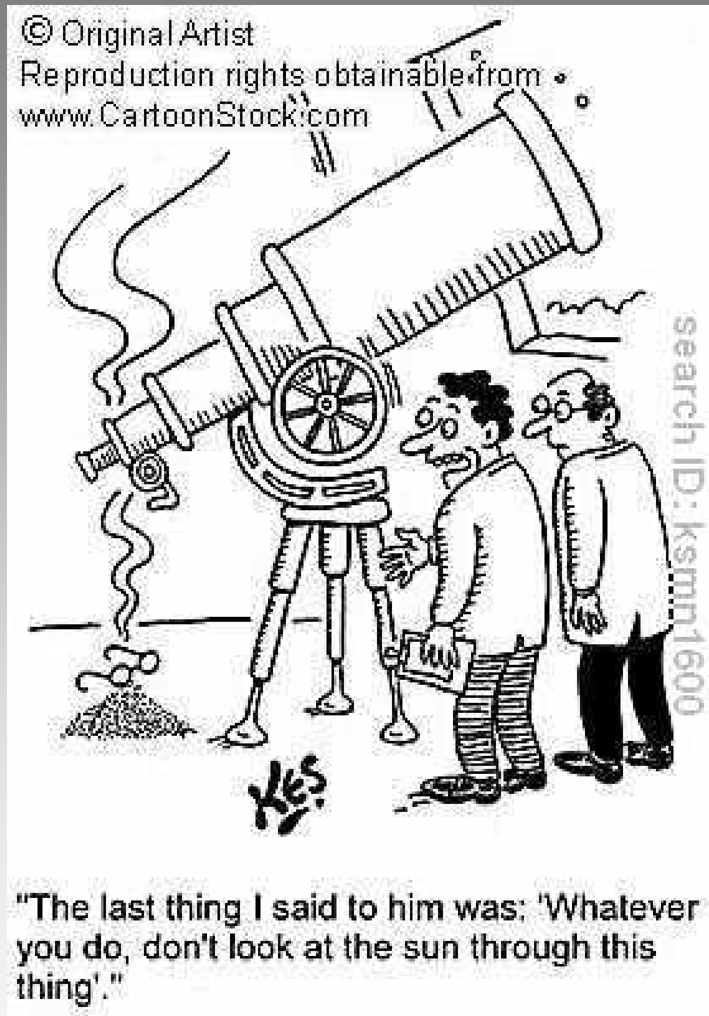
Optical/IR Observational Astronomy

Telescopes I: Telescope Basics



David Buckley, SAAO

Some other Telescope Parameters

1. Plate Scale

- This defines the scale of an image at the telescopes focal <u>surface</u>
- For a focal *plane*, with no distortion, this is just related to the *<u>focal length (F)</u>*

$$s \text{ (in radians/length unit)} = 1 / F \text{ (length unit)}$$

So,

$$s \text{ (radians/mm)} = 1 / F \text{ (mm)}$$

- *In more useful units for astronomers:*
  - Use <u>arcseconds</u> *(1 / 3600th of a degree; 2π radians = 360^o)*
  - So, 1 radian = 206,265 arcsecs

$$s \text{ (arcsec/mm)} = 206265 / F \text{ (mm)}$$

Some other Telescope Parameters

Plate Scale example:

Example: at the prime focus of a 4m telescope with an f/3 primary,

$$\text{focal length, f} = \text{f ratio} \times \text{aperture} = 12\text{m} = 12000\text{mm}$$

so,

$$\text{scale} = 206265/12000 = 17.2 \text{ arcsec/mm}$$

Homework:

What's the plate scale for SALT?

Some other Telescope Parameters

2. Light Gathering Power

- Simply defined by *collecting area*

$$area \propto radius^2 \propto diameter^2$$

- Approximated by size of mirror, but usually a little less due to *obstructions* (optical and mechanical)
- Sometimes also defined as *brightness*

3. Focal Ratio (*f/number*)

$$f/\# = focal\ length/diamter = F / D$$

- Refer to "slow" (high number) and "fast" (low number) *f*-ratios

Some other Telescope Parameters

4. Speed

- Defines how quickly an extended object is detectable, which is determined by how concentrated the image is on the detector

- Used mostly in imaging of 2D unresolved objects (galaxies, nebulae)

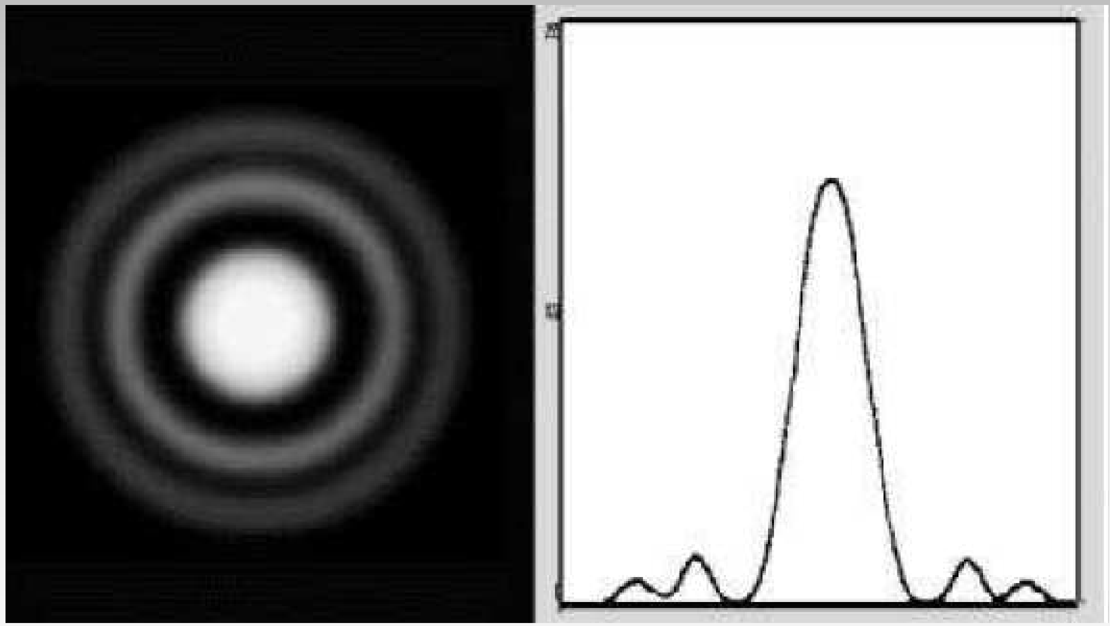
- Defined as:

$$S \sim (a/f)^2 \sim (1/F^2)$$

Some other Telescope Parameters

5. Resolving Power

- Defined by considering the ***wave*** nature of light
- Specifically diffraction at an aperture (Fraunhofer or Fresnel)
- Typically telescope apertures are ***circular***
- From interference, a ***diffraction pattern*** is produced



Some other Telescope Parameters

Airy disk:

- **Defined by the diameter of the central peak in the diffraction pattern**
- **This can be determined simply by the diameter of the first "dark ring":**

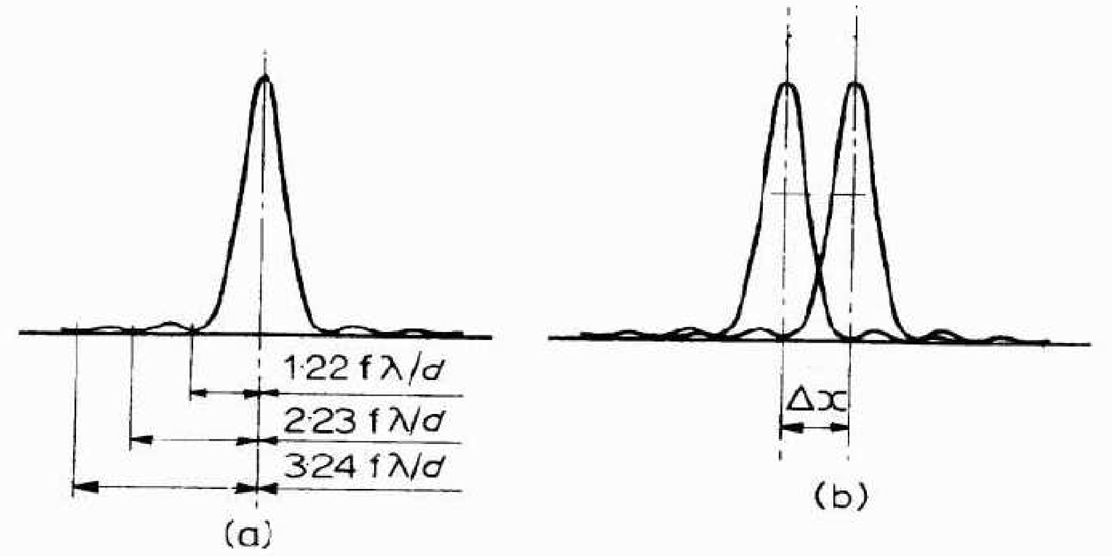
$$\theta = 1.22 \frac{\lambda}{a}$$

Question: what are the units?

Some other Telescope Parameters

Resolvability:

- **Two point sources are said to be *resolved* if the peak of the central maximum of one diffraction pattern falls onto the first dark ring of the other**
- **This is referred to as the *Rayleigh criterion***



(a) Airy disk; (b) Diffraction limit to resolution

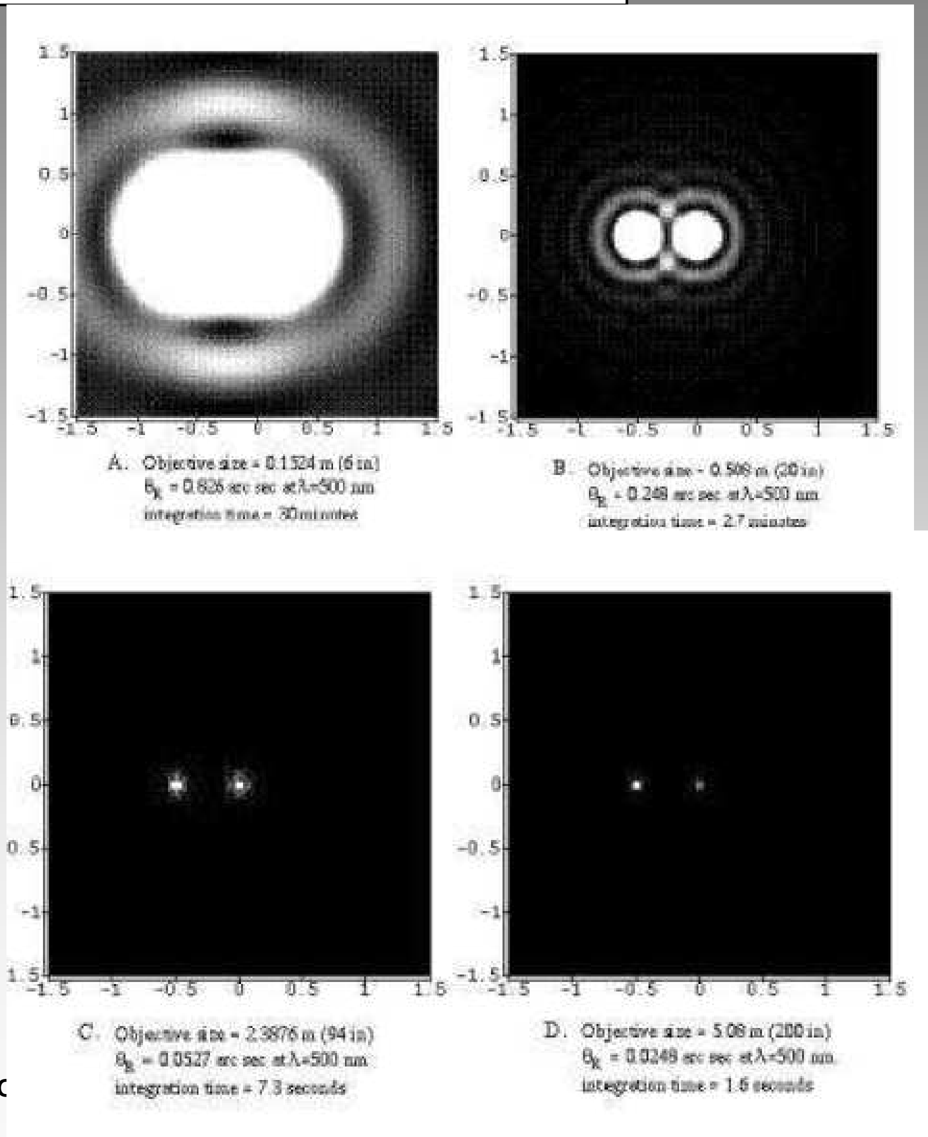
Some other Telescope Parameters

Resolvability:

- **Ignoring atmospheric effects, the resolution of an ideal telescope is just defined by its *size***
- ***Examples:***

  D = 0.13 m, 0.50 m, 2.5m

  & 5 m diameter telescopes



Some other Telescope Parameters

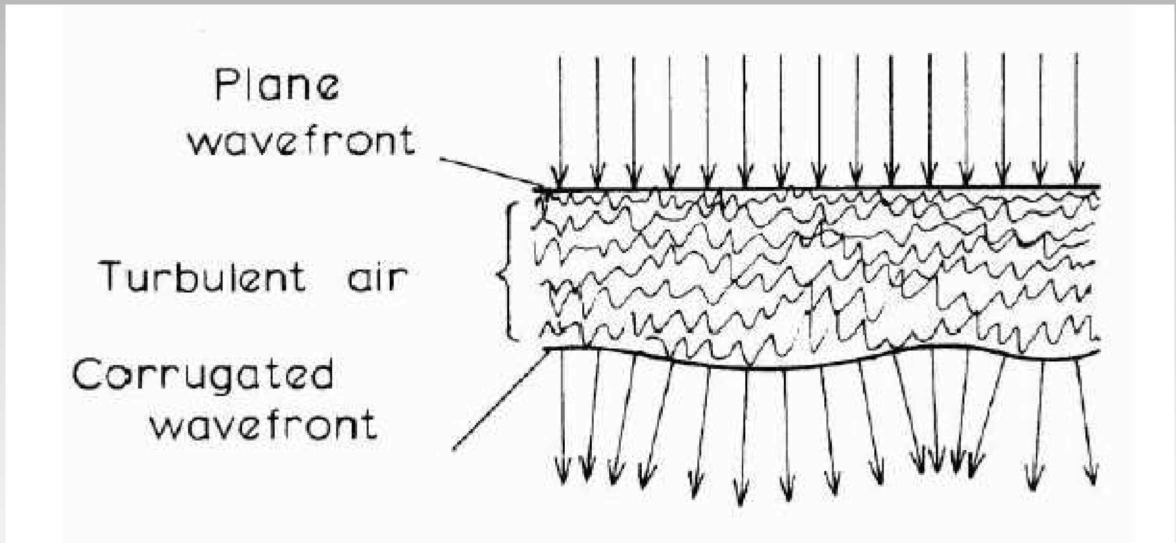
Resolvability:

- **Other effects can limit resolvabilty in *real* images**
  - **Problems associated with saturation by bright objects**
  - **Other diffraction effects**

Some other Telescope Parameters

Atmospheric seeing:

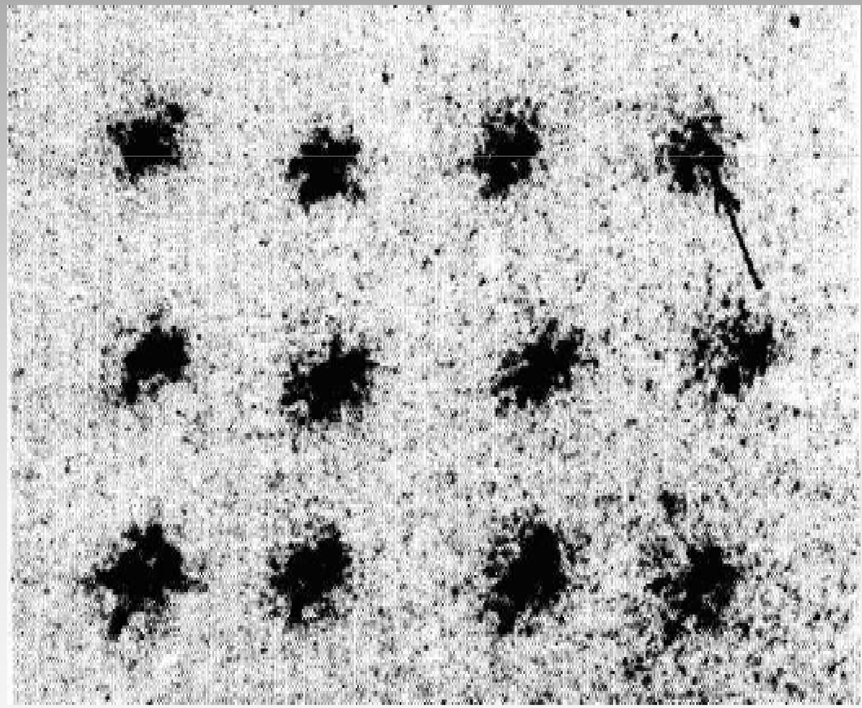
- **Also, because of the atmosphere, telescope optics are often not built to be *diffraction limited***
  - **Expensive & unnecessary, unless the atmosphere (“seeing”)can be corrected**



Some other Telescope Parameters

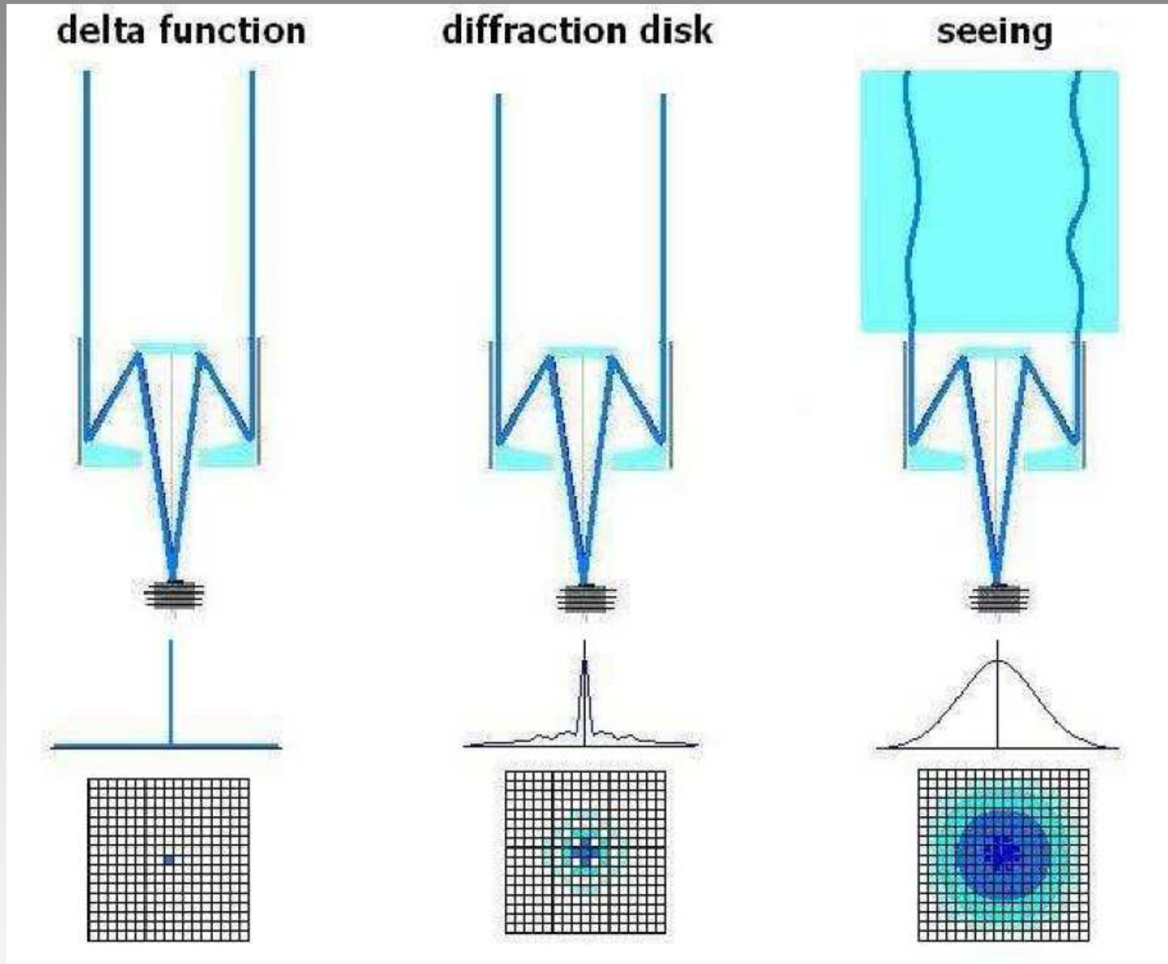
Atmospheric seeing:

- Fast phase changes cause a *scintillation* pattern.
- Only seen if exposures are short (milliseconds) as images get blurred out



Consecutive 2 ms images of a bright star

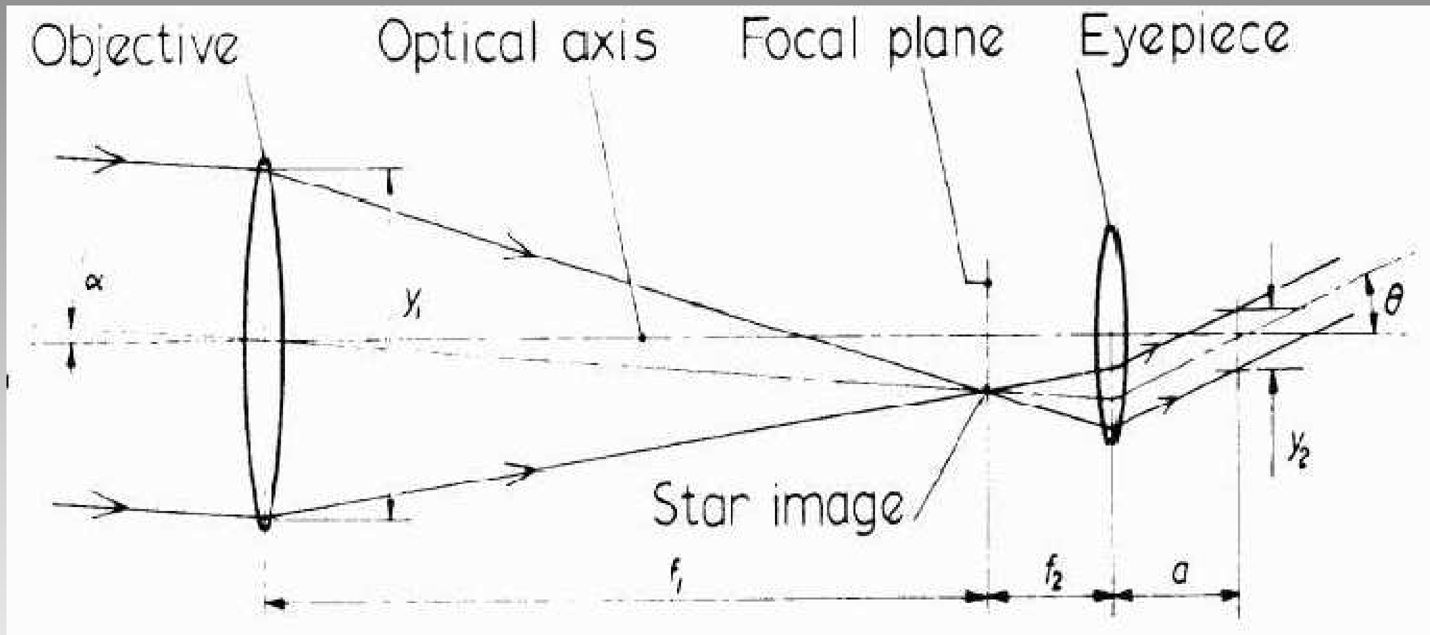
Telescope Systems for Different Assumptions



Geometric Optics Wave Optics Real Atmosphere

Telescope Configurations

1. Refractors

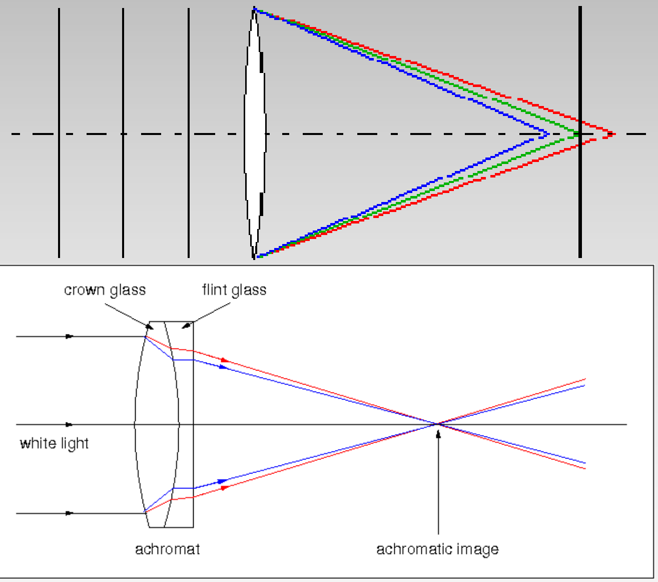


- **α = field angle (FoV); f_1 = telescope focal length; f_2 = eyepiece focal length; y_1 is the telescope aperture diameter (entrance pupil); y_2 is the exit pupil diameter (matched by eyepiece to diameter of eye pupil); magnification = $\theta/\alpha = f_1/f_2$**

Telescope Mirrors

- **The first telescopes built were refractors**
  - Lenses that bend light to a focus through refraction
  - Lens only can be supported at their outer edges
  - Limited in size to ~1-m due to sagging under their own weight
  - As refraction is wavelength dependent, certain *chromatic* aberrations occur

Yerkes refractor in 1895



Correction in an achromat

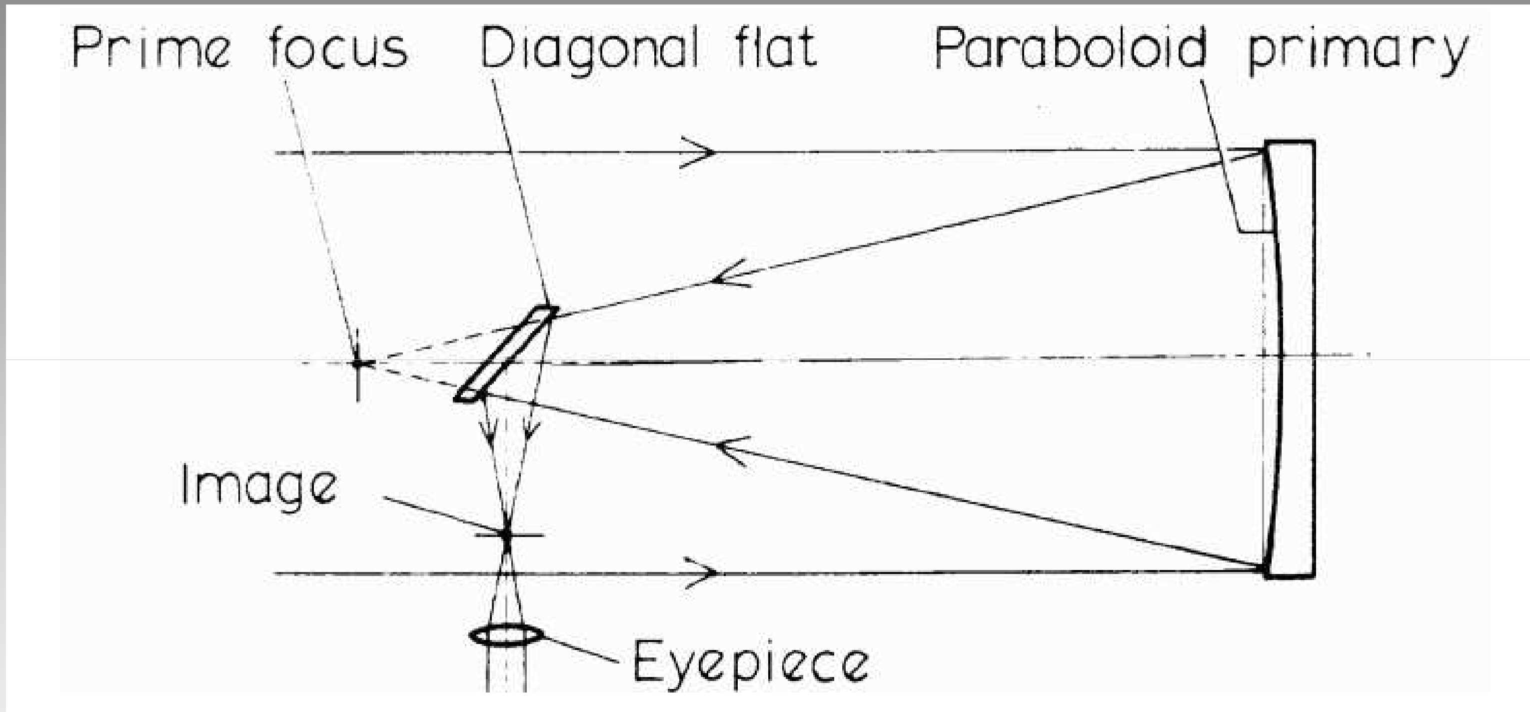
Telescope Configurations

Disadvantages of Refractors:

1. **Difficult to figure and test large lenses**
2. **Large lenses are heavy, bend and difficult to keep aligned**
3. **Glass absorbs light, particularly at short wavelength**
4. **Chromatic effects**
   - **Dispersive properties of glasses**

Telescope Configurations

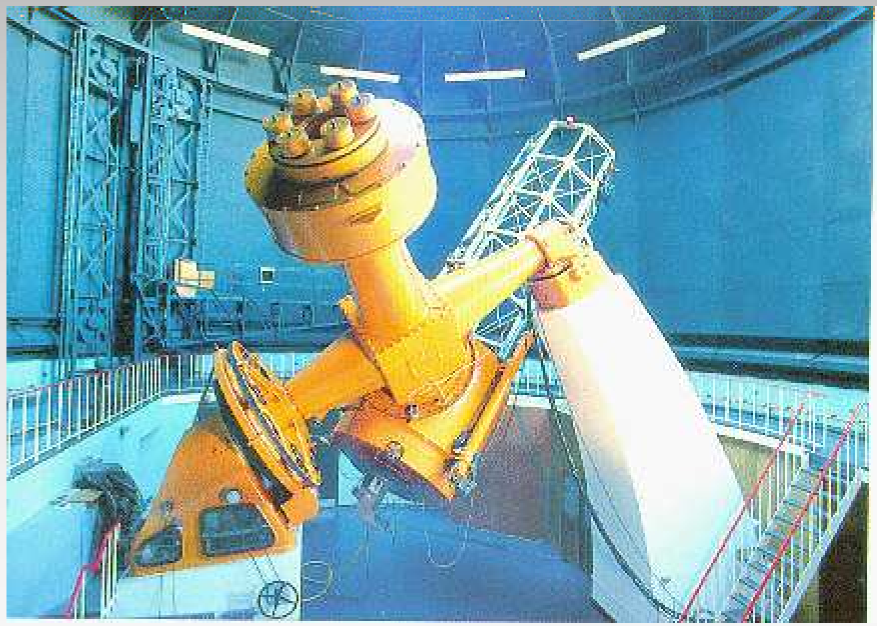
2. Reflectors



- **Example of Newtonian reflector**

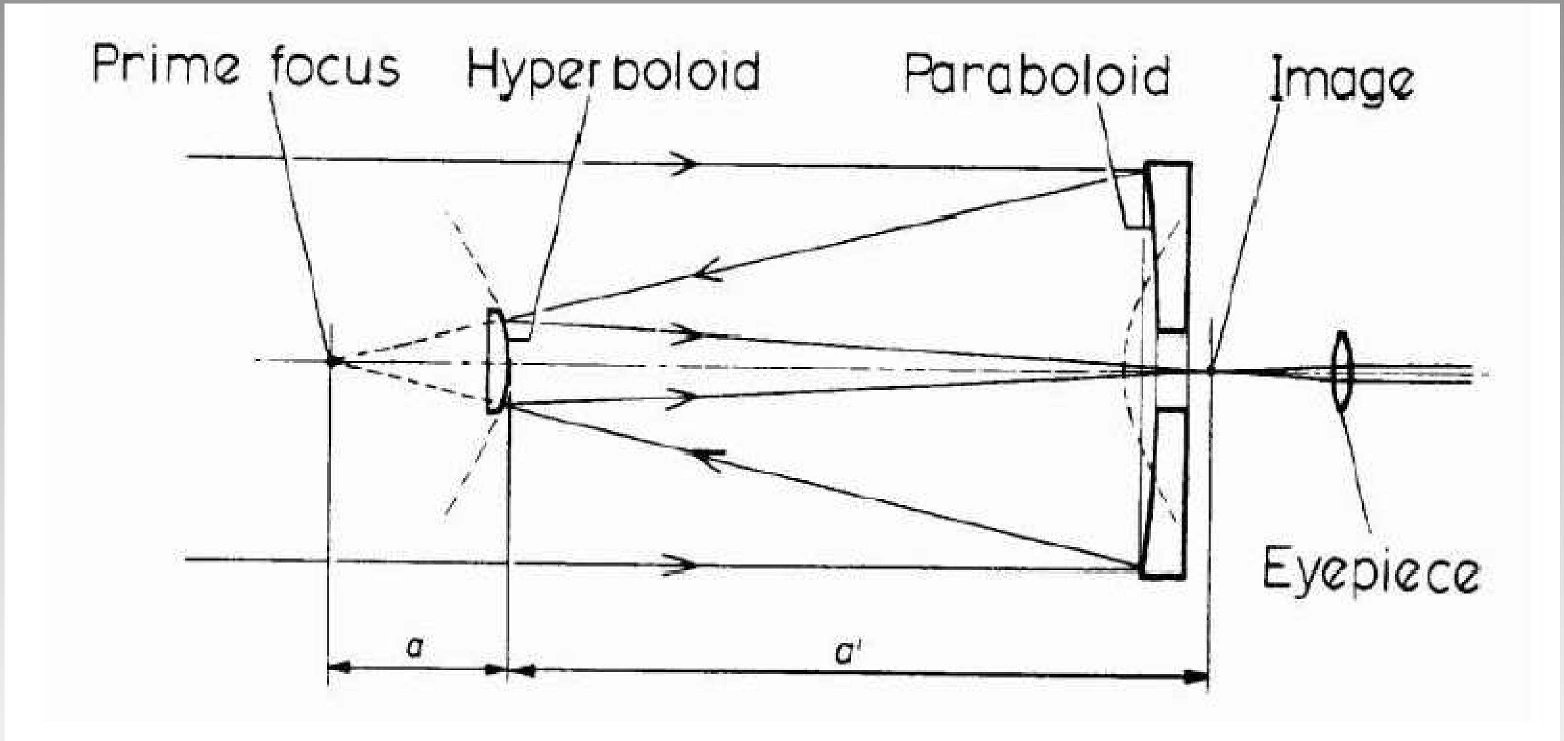
Telescope Configurations

- **Newtonian telescopes**
  - e.g. the Mt Wilson 100” Hooker telescope, completed in 1917
  - The SAAO 74” (originally called the Radcliffe reflector), completed in 1948 in Pretoria. Moved to Sutherland in 1974.



Telescope Configurations

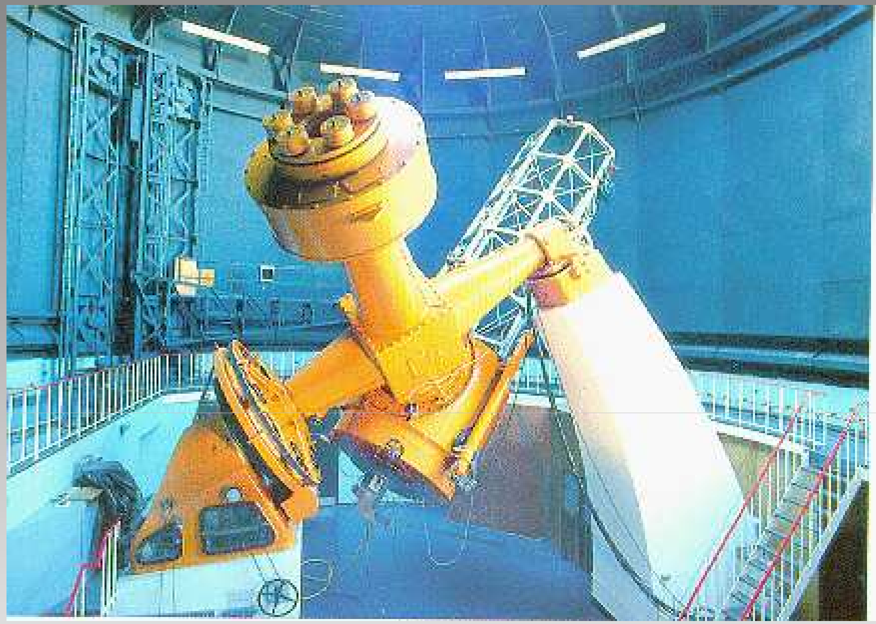
2. Reflectors



- **Example of Cassegrain reflector**

Telescope Configurations

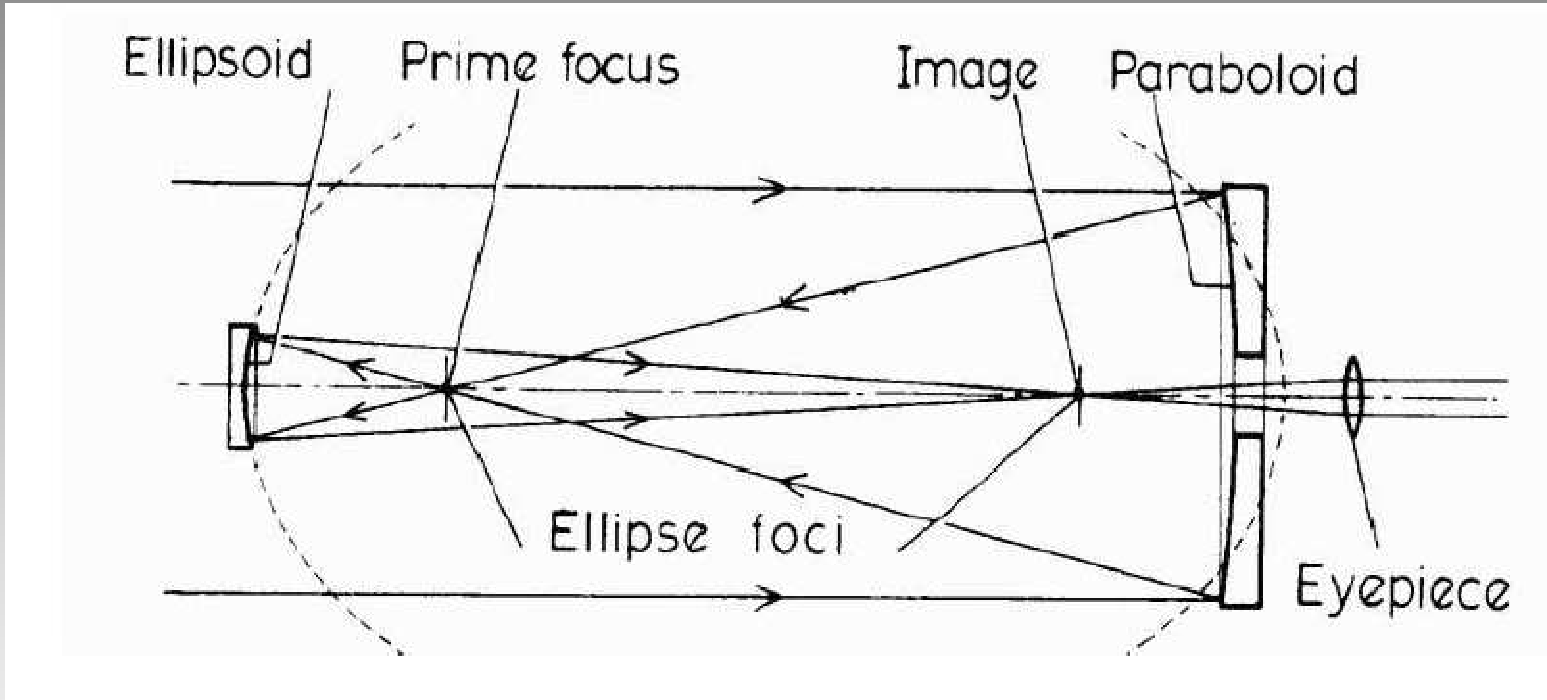
2. Reflectors



- Cassegrain reflector typically has a ***paraboloid*** primary and ***hyperboloid*** secondary
- Generally “slow” beams (~f/10-f/20)
  - SAAO 1/9-m is f/18
- Typically aberrations (primarily coma & astigmatism) limit the useable field of view
- Can correct for this using addition “corrector” optics (lenses)
- Modification of Cassegrain (Ritchey-Chretian) gives larger FoV

Telescope Configurations

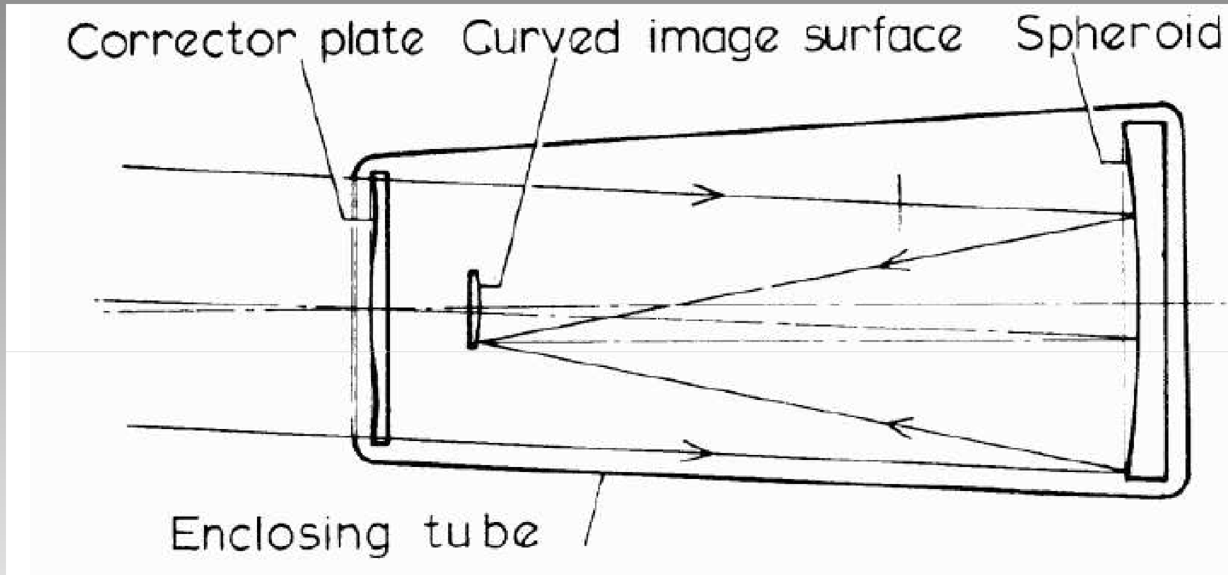
2. Reflectors



- **Example of Gregorian reflector**

Telescope Configurations

3. Schmidt Reflectors



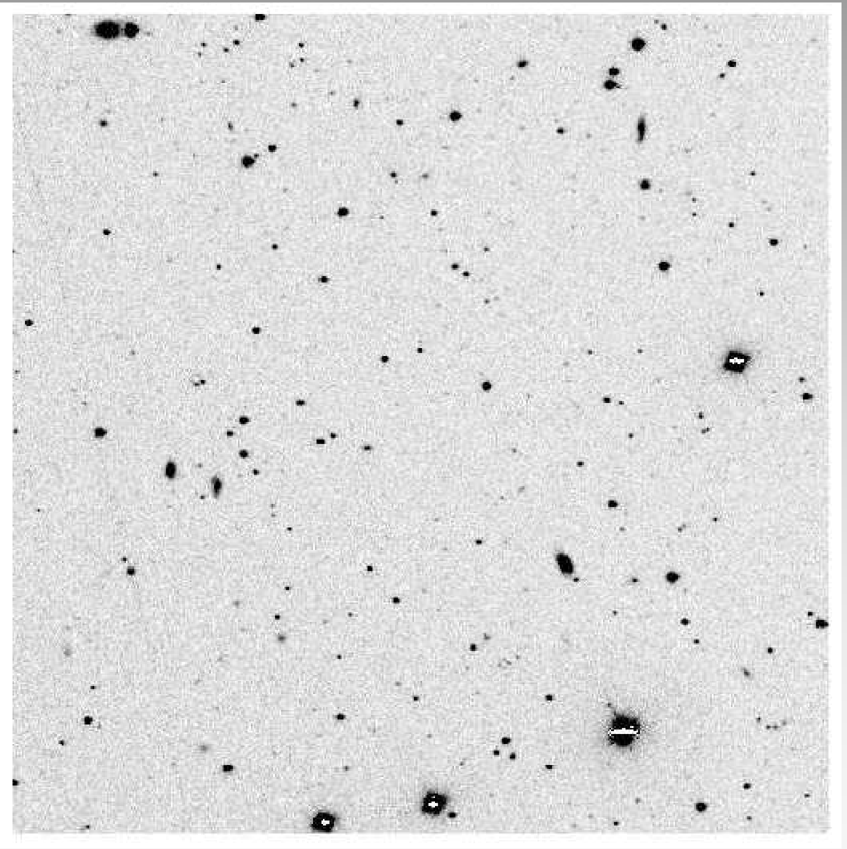
- **Clever design to "pre-aberrate" the wavefront such that a *spherical* primary will focus FoV, but on a spherical focal surface.**
- **Primary mirrors are *fast* (f/2, or less)**
- **Why? Because it can deliver a *huge* field (many degrees)**

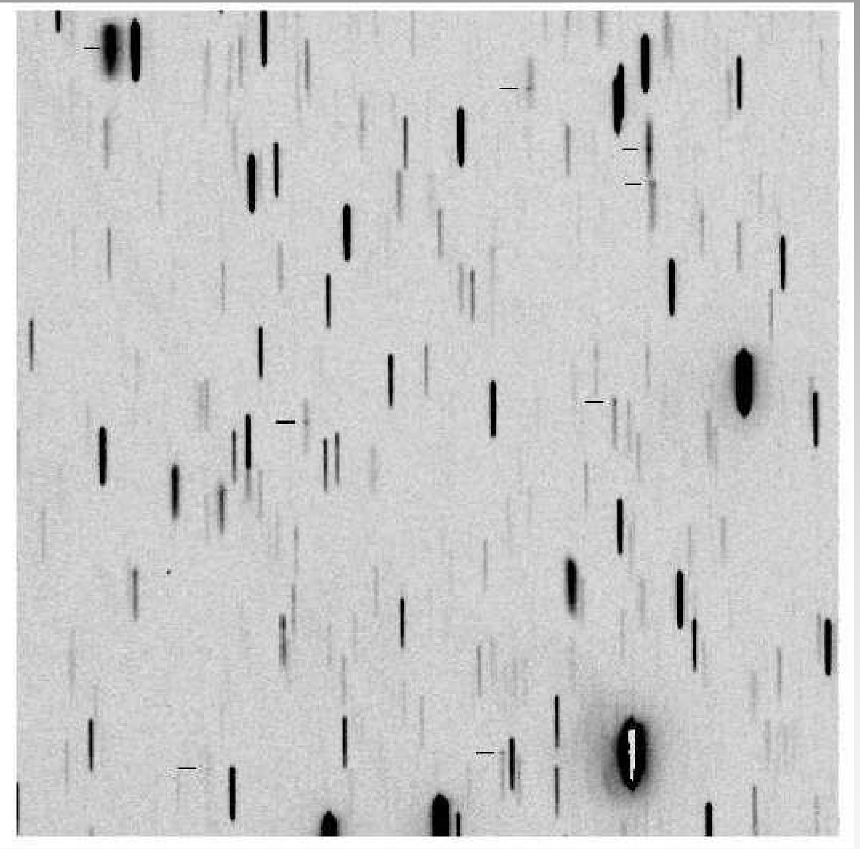
Example of a Schmidt telescope:

- **The UK Schmidt in Australia**
- **Allows wide FoV (6 degrees) imaging and spectroscopy**
- **Combined with Schmidt telescope, *objective prisms* could be used to spectroscopically survey large areas of sky**
- ***Multiplex advantage:*** **area coverage *and* wavelength information**

Example of Objective Prisms Spectra

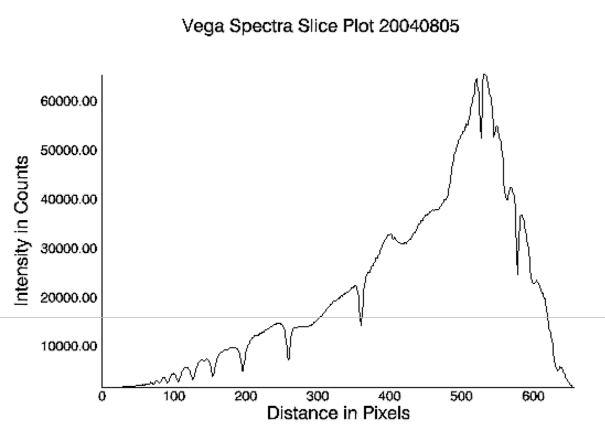
- **Search for emission line objects**
  - **e.g. star formation in galaxies**

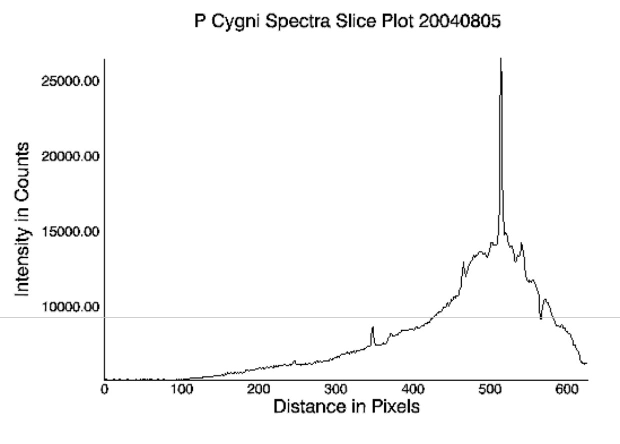


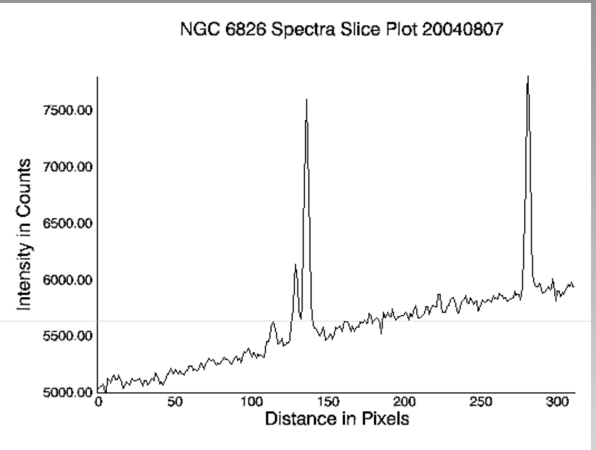


Example of Objective Prisms Spectra

- **Spectral classification**

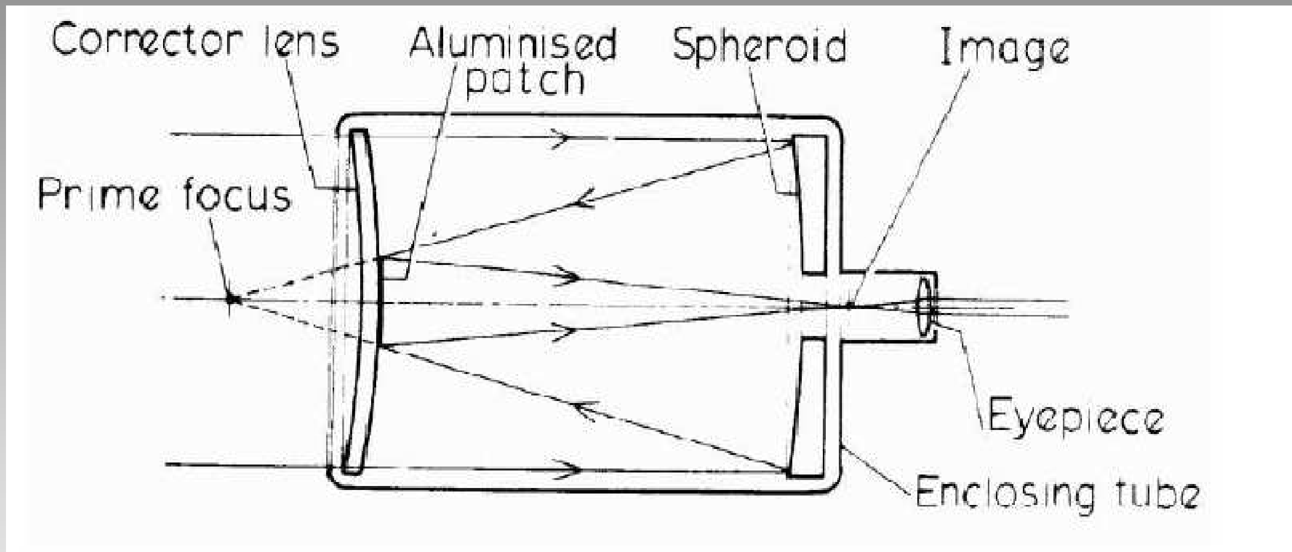






Telescope Configurations

4. Maksutov Reflectors

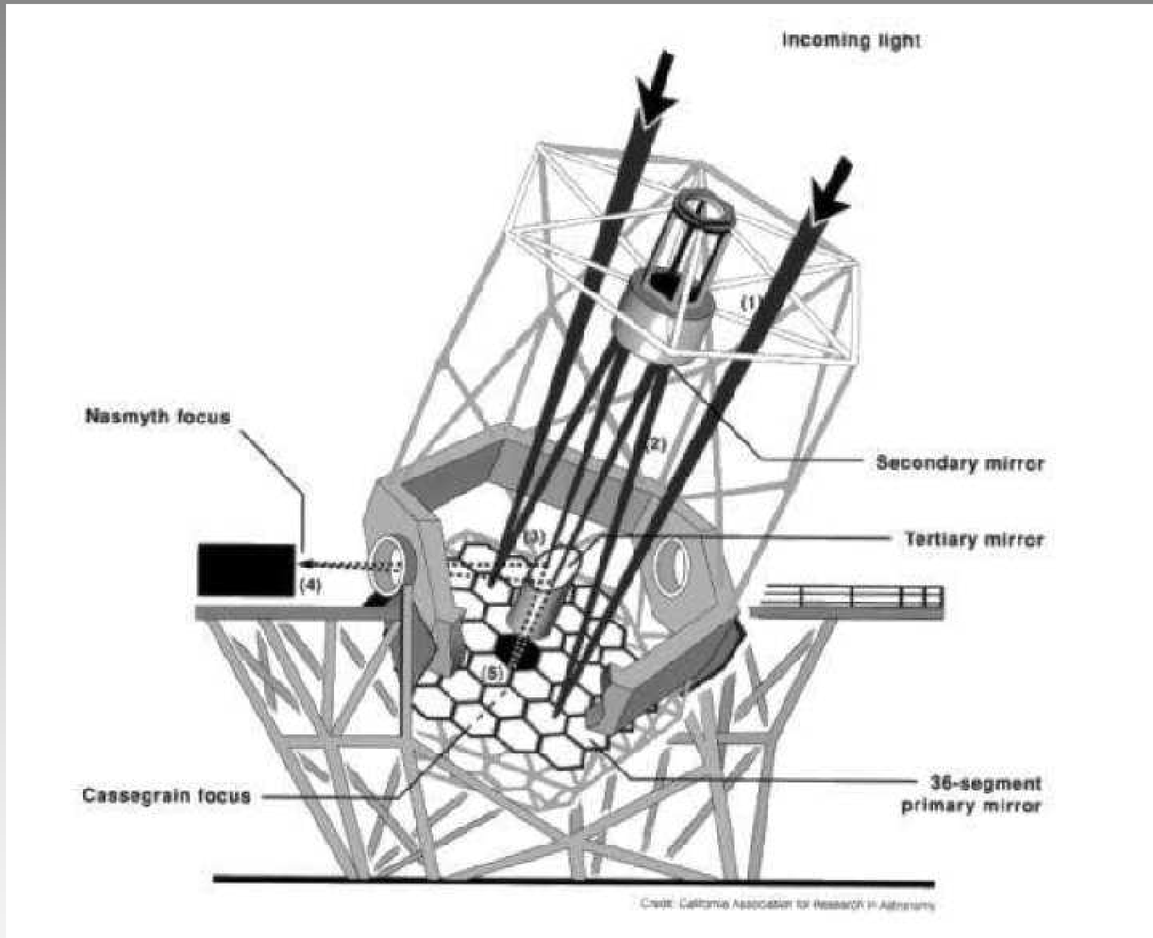


- **Like a Schmidt, but uses spherical corrector**
- **Exactly balances the spherical aberration of the primary**
- **But limited in size (meniscus corrector)**

Telescope Configurations

4. The Nasmyth focus

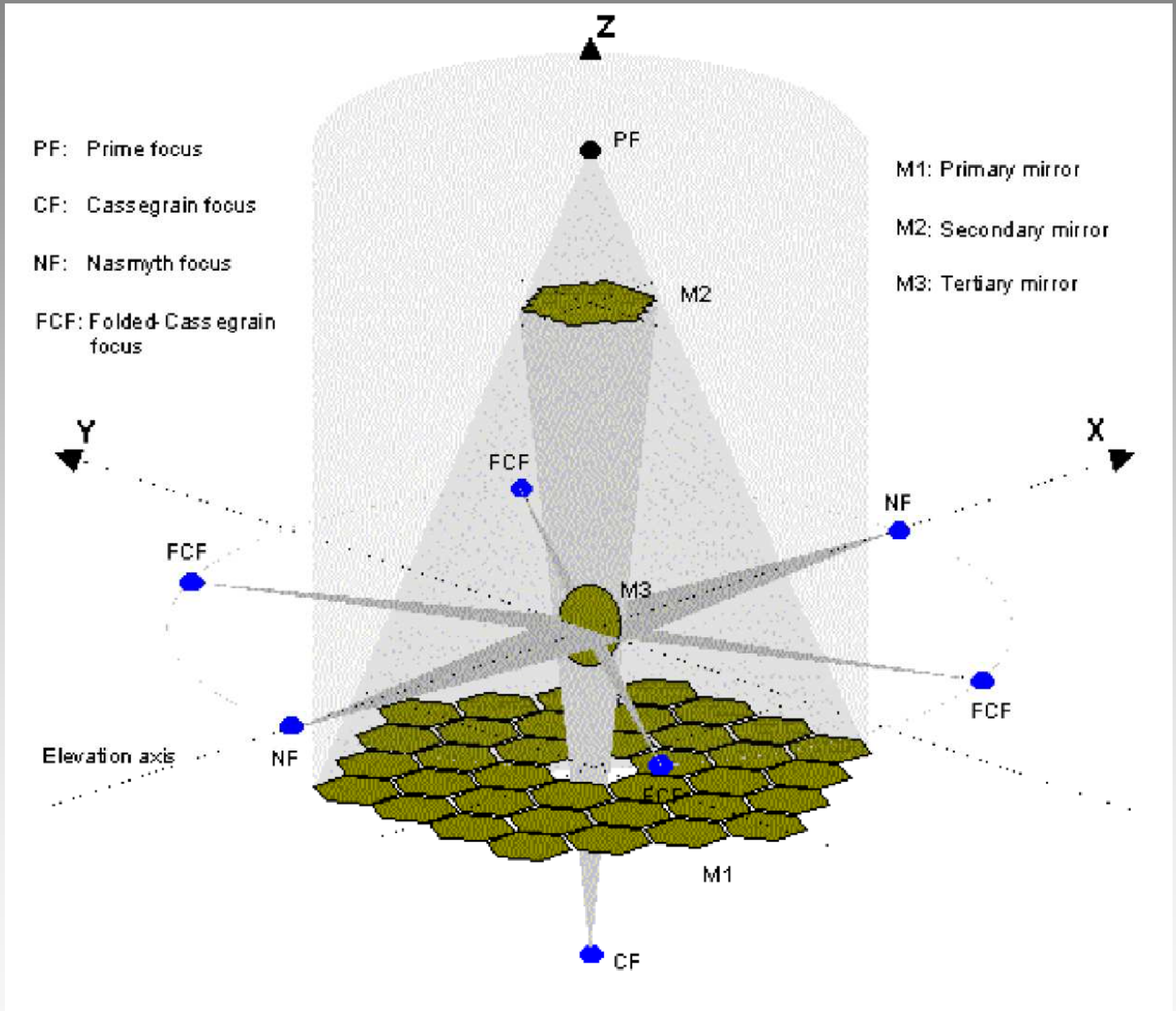
- For any reflector, can add a ***third mirror*** (tertiary flat) to deflect the beam perpendicular to optical axis
- Allows for heavy instrumentation to be easily supported



Telescope Configurations

Example: Keck Telescope

- Many foci are supported
- Multiple instruments accommodated
- Don't need to keep changing instruments



Keck Telescopes

The “Big Five”: Segmented Mirror Telescopes

- Keck I (1993) & Keck II (1996): Hawaii, USA
- HET (1999): Texas, USA
- SALT (2005): South Africa
- GRANTECAN (2009:) Canary Islands, Spain

These telescopes have the largest light grasp

Some also use *adaptive optics* to get sharper images, particularly at longer wavelengths (IR)