AS2001 Observational Techniques

Synopsis: The nitty-gritty of practical astronomy.

Telescopes:

- optical systems - images, aberrations, telescopes
- atmospheric seeing; active and adaptive optics

Instrumentation:

- optical detectors – CCDs
- optical instruments – photometers and spectrometers

Observing:

- planning your observations, rising, setting, transit times etc
- photometry, spectrophotometry, spectroscopy
- extinction through the Earth's atmosphere
- filter systems, magnitude systems (Vega and AB)

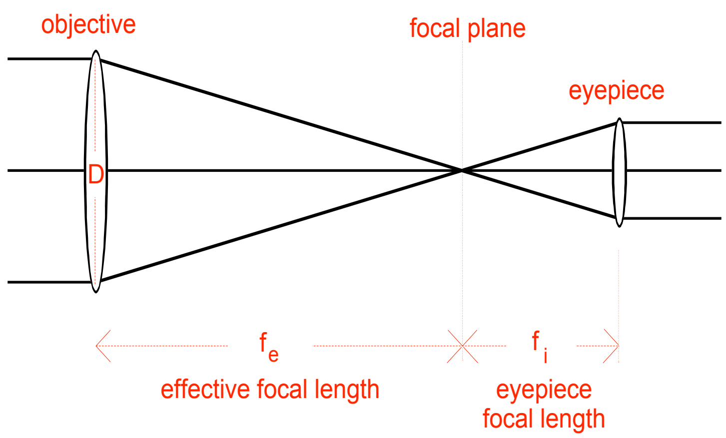
Multi-wavelength astronomy:

- infrared (IR), radio, ultraviolet, x-rays, γ-rays

Telescope case studies (final lecture student presentations!)

reminders from AS1001

- telescope basics



- focal ratio $n = f_e/D$, written as f/n

  e.g. D = 100 *cm*, f_e = 300 *cm*, f ratio is f/3

  f_e = 2000 *cm*,   f/20

  the f/ ratio measures how rapidly the beam converges to a focus

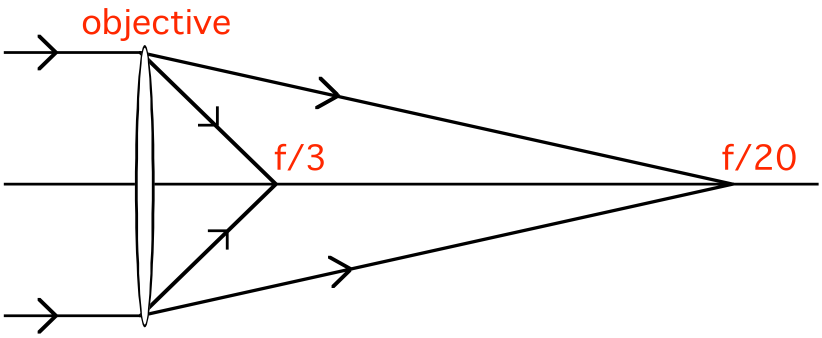


Image scale

An optical system produces an image of size $f_T \sin\alpha \approx f_T \alpha$ radians for a distant object subtending angle α radians.

$$\text{Image scale} = \frac{180 \times 3600}{\pi \times f_T} = \frac{206265}{f_T} \text{ arcsec/mm}$$

for effective focal length, f_T, in mm.

e.g. f/3 telescope of 1m diameter has
  focal length = 3000 mm
  image scale 68.75 arcsec/mm
  for a detector of size 13.8 mm field of view = 949 arcsec = 15.8 arcmin

Image brightness ("Speed")

Total flux through telescope aperture $\propto \frac{\pi D^2}{4} \propto \frac{\pi}{4}\left(\frac{f_T}{\mathrm{n}}\right)^2$

Image area at focal plane $= \frac{\pi}{4}(f_T\alpha)^2$ (4 comes from using diameter not radius)

$\therefore$ flux density in image $\propto \frac{(\pi/4)(f_T/\mathrm{n})^2}{(\pi/4)(f_T\alpha)^2} \propto \frac{1}{(\mathrm{n})^2}$

so e.g. *f*/3 (i.e., n=3) is a *fast* system, small image… *f*/20 (i.e., n=20) is a *slow* system, large image

1. Optical Systems - Telescopes

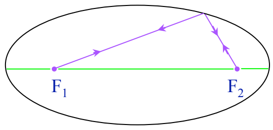
Telescope has 3 functions:

- 1. increase amount of light reaching detector (human eye via eyepiece, CCD camera)
- 2. enlarge apparent angular size of source
- 3. observe frequencies/wavelengths invisible to human eye

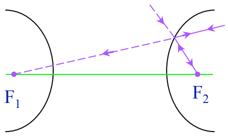
Paraxial (or first-order) optics

- first-order description using elementary geometrical optics
- basic relationships, used often
- only approximate
  - ignores diffractions and aberrations present in real optical systems.

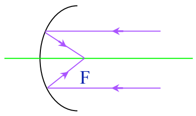
Reflection properties of conics



ellipse



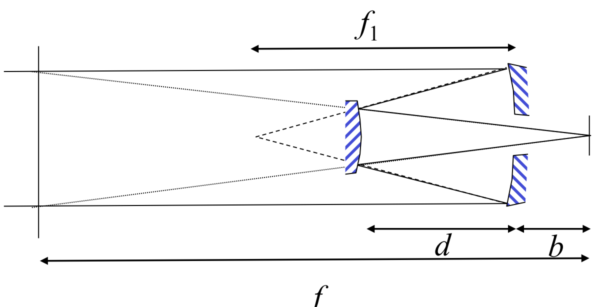
hyperbola



parabola

We see examples of these properties in astronomical telescopes

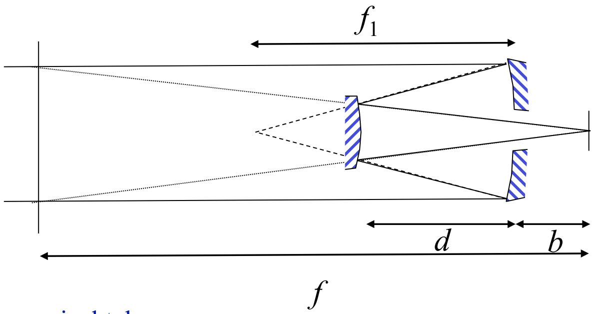
Example: Cassegrain reflecting telescope



- Concave primary mirror, focal length f_1
- Convex secondary mirror, focal length f_2
- Object distance s_o, image distance s_i (-ve if behind mirror)
- Standard thin lens/mirror equation:

for primary $$\frac{1}{s_{o1}} + \frac{1}{s_{i1}} = \frac{1}{f_1}$$ for secondary $$\frac{1}{s_{o2}} + \frac{1}{s_{i2}} = \frac{1}{f_2}$$

Example: Cassegrain telescope



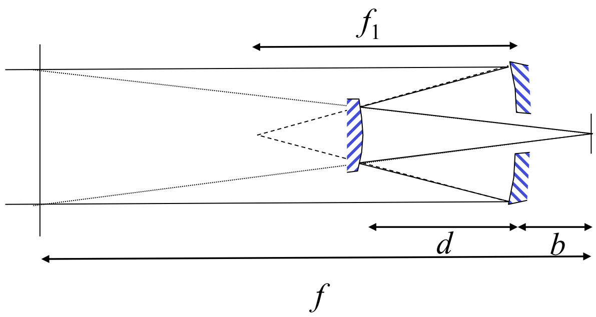
For astronomical telescope $s_{o1} \rightarrow \infty$

So for primary mirror: $s_{i1} = f_1$, and for secondary: $s_{o2} = d - s_{i1} = d - f_1$

$$\Rightarrow \frac{1}{s_{i2}} = \frac{1}{f_2} - \frac{1}{s_{o2}} = \frac{1}{f_2} - \frac{1}{d - f_1} = \frac{d - f_1 - f_2}{(d - f_1)f_2}$$

$$\Rightarrow s_{i2} = \frac{(d - f_1)f_2}{d - f_1 - f_2} = d + b$$

Important for telescope design?

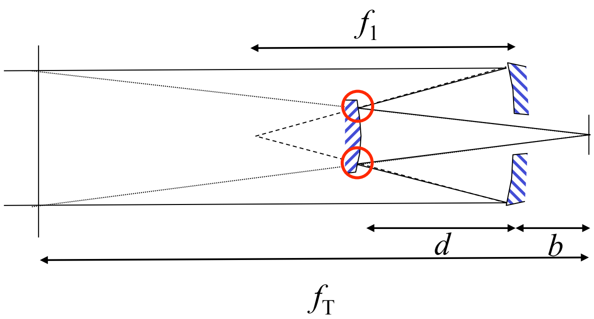


Transverse magnification of the secondary mirror is:

$$m_2 = -\frac{s_{i2}}{s_{o2}} = -\frac{(d - f_1)f_2}{d - (f_1 + f_2)} \cdot \frac{1}{(d - f_1)} = \frac{f_2}{(f_1 + f_2) - d}$$

Secondary mirror in a Cassegrain system magnifies the image formed by the primary by a factor m_2.

Secondary has virtual object at $s_{o2} < f_2$, so image is real, right way up, and magnified at s_{i2}.



The effective focal length f_T of the optical system is given by $f_T = m_2 f_1$

$$f_T = \frac{f_1 f_2}{(f_1 + f_2) - d}$$

shown in figure by extending rays in exit cone from the secondary back to where their height is equal to the incoming beam,

$$\frac{1}{s_{oT}} + \frac{1}{s_{iT}} = \frac{1}{f_T}; \; s_{oT} \rightarrow \infty; \; s_{iT} = f_T$$ as illustrated.

Paraxial region - rays, images close to *optical axis*
= axis of rotational symmetry of system

optical elements (lenses, mirrors etc) are assumed to be thin

Astronomical telescopes are used on sources with distances $\rightarrow \infty$
so incident rays $\approx$ parallel

incident rays on optical axis form images on that axis - axial images

incident rays passing through an optical system at an angle to optical axis form off-axis images