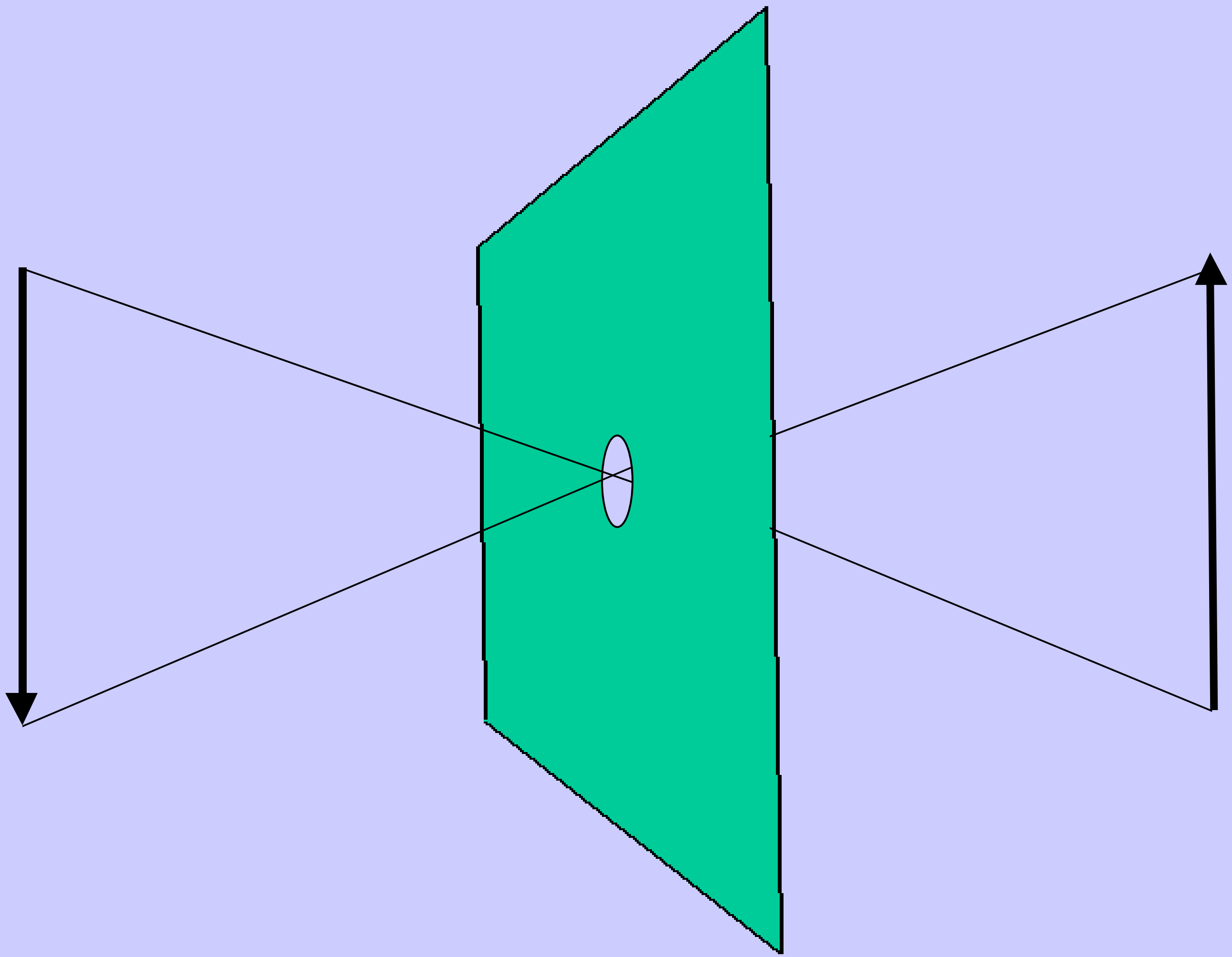
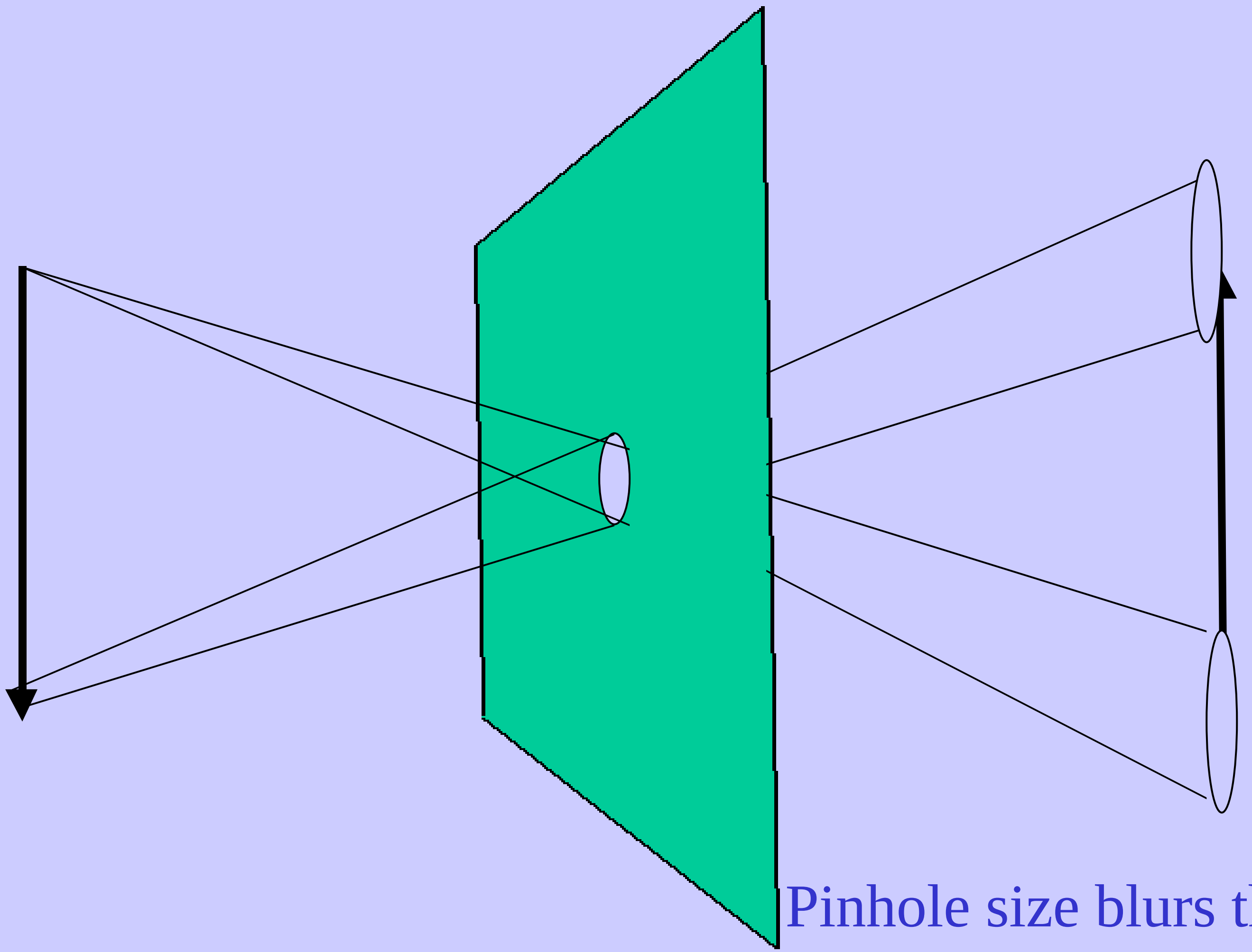
Pinhole camera images

Pinhole camera

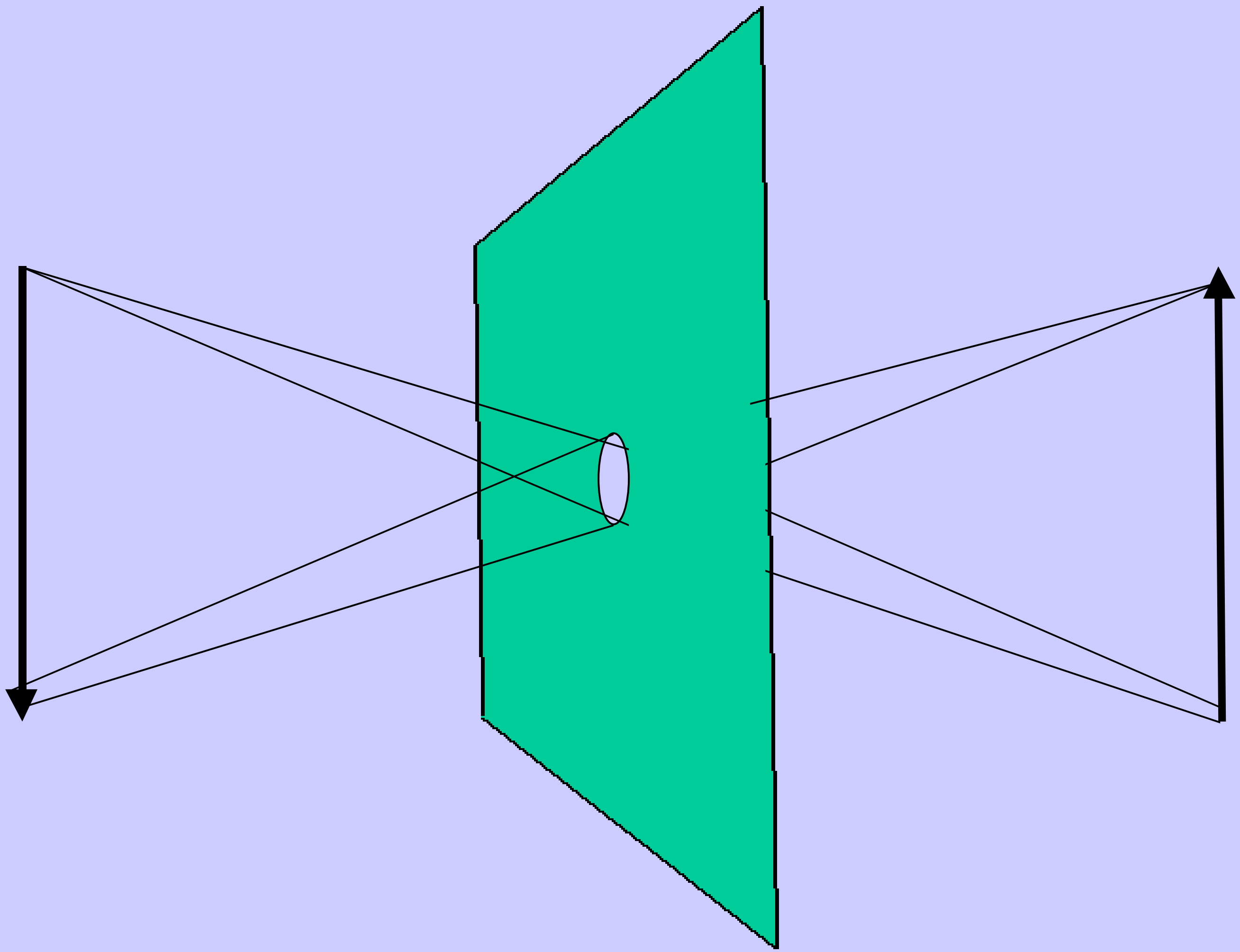


Problem with pinhole camera



Pinhole size blurs the image

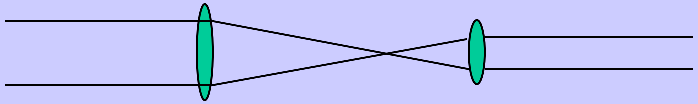
Solution: insert a lens



How a lens works

By slowing light down

REFRACTORS



objective lens

+ eyepiece

largest:

1.0 m Yerkes (1888)

now obsolete

REFLECTORS

mirror systems

or

combinations of mirrors and lenses

largest:

10.0 m Keck

(Hawaii 1992)

planned: 30m ELT

100m OWL

net result is the same:

an imaging system brings radiation from a distant source (parallel rays of light) to a focal plane where the image may be recorded directly or entered into an analysing instrument (including the eye)

Problems with Refractors

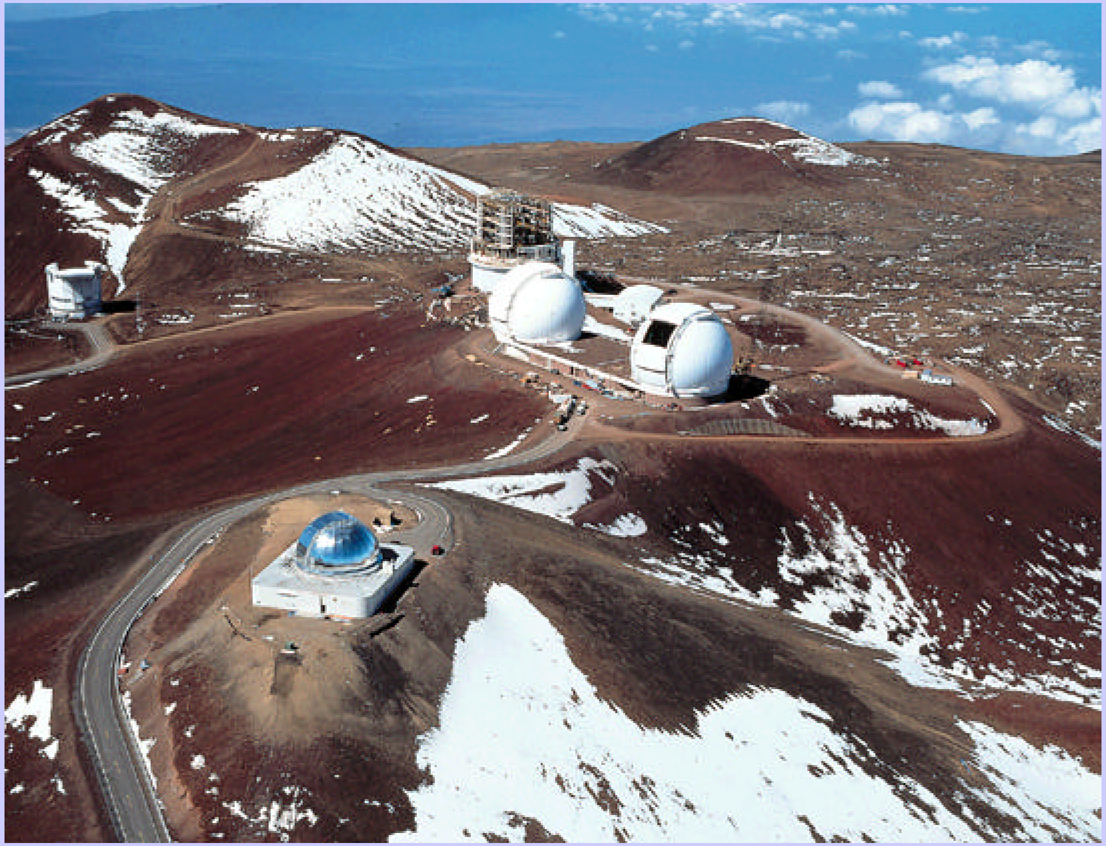
Large lenses hard to make (more expensive).

Lenses must be supported only on their rim.

Lens focal length depends on wavelength.

All large telescopes today are reflectors.

Aerial view of the summit of Mauna Kea, Hawaii

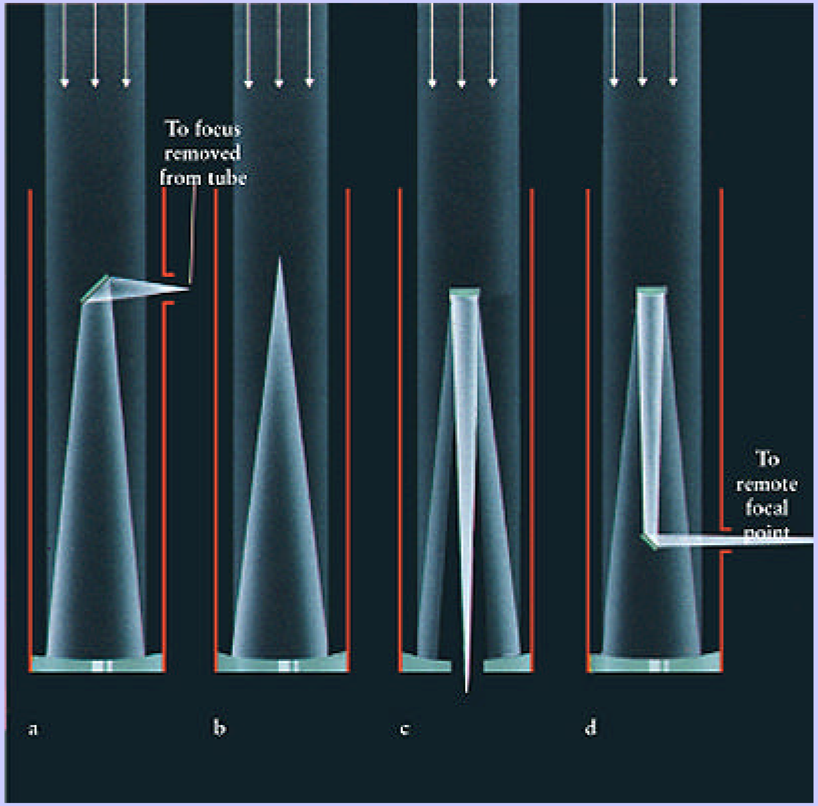


Keck 10-metre optical telescope

Various designs of reflector telescopes

prime

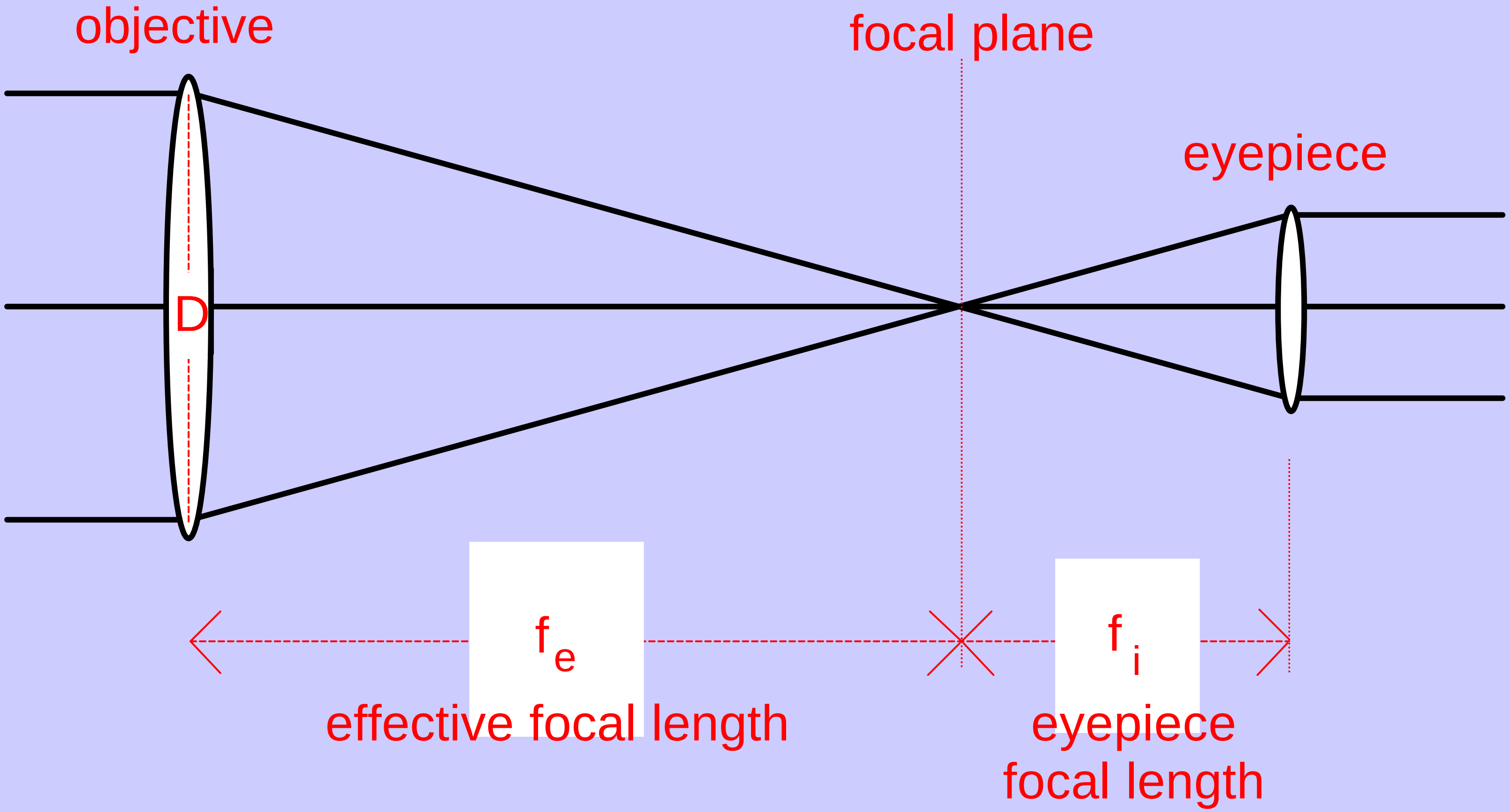
Newtonian



Neysmith or Coude

Cassegrain

Telescope Optics



telescope aperture = diameter *D* of objective

- 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

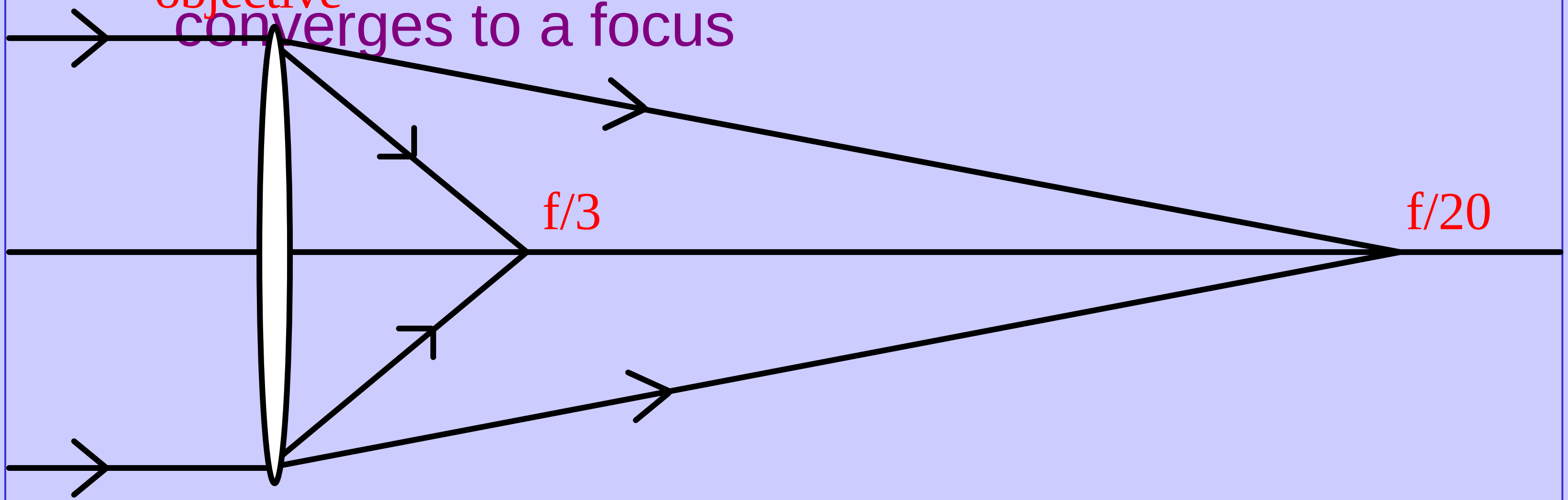


Image of an extended source

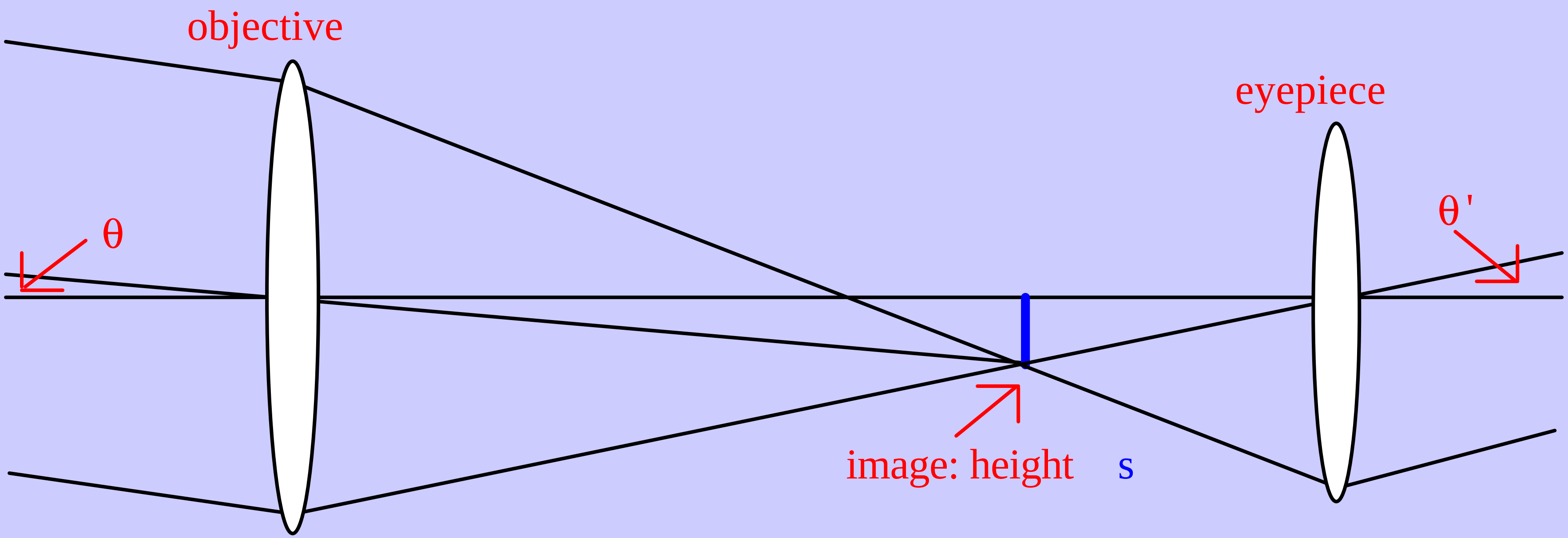
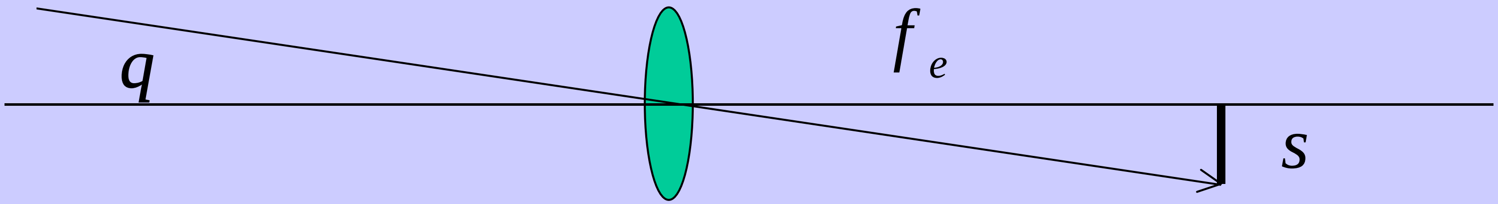


Image size



$$s = f_e \tan q \cong f_e q$$

- *example* $f_e = 300 \text{ cm}$

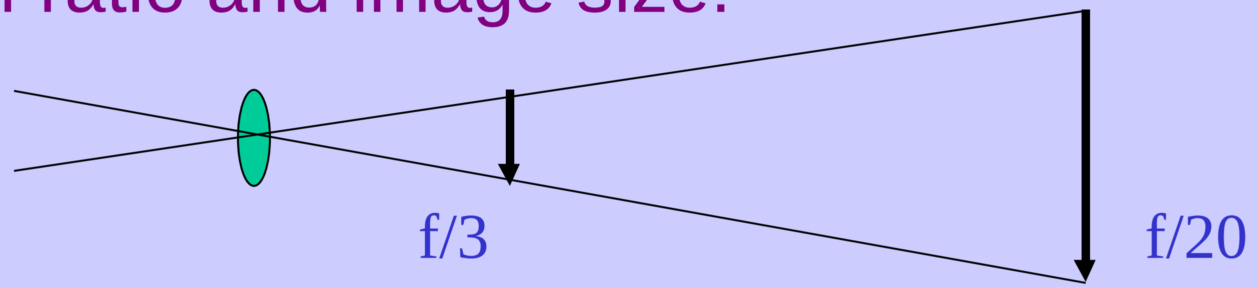
$$q = 1 \text{ arcmin} \times \frac{1^\circ}{60 \text{ arcmin}} \times \frac{\text{ð radian}}{180^\circ}$$

$$s = 300 \text{ cm} \times \frac{1^\circ}{60 \text{ arcmin}} \times \frac{\text{ð radian}}{180^\circ} = 0.087 \text{cm}$$

- *example 2*

$$f_e = 3000 \text{ cm} \quad q = 1 \text{ arcmin} \quad s = 0.87 \text{ cm}$$

- f ratio and image size:



- small f/ ⇒ small images
- large f/ ⇒ large images
- <u>Fast / Slow optical systems</u>

FAST (small f/) concentrates light into small image.

-- short exposure times

-- wide field of view

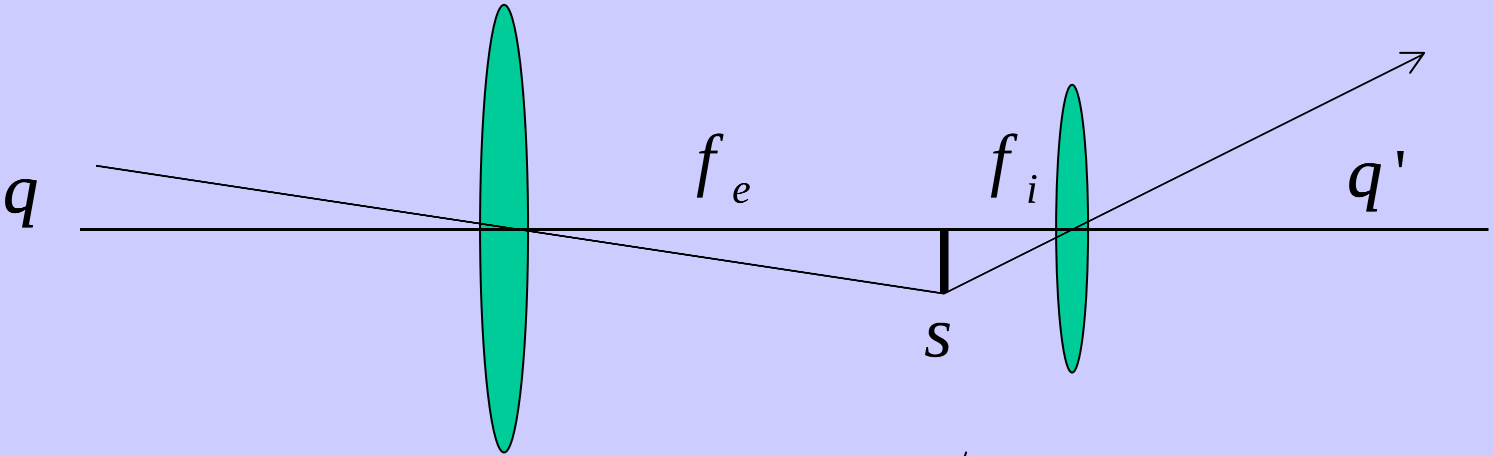
SLOW (large f/) spreads light over larger image.

-- longer exposure times needed

-- narrow field of view

Magnification

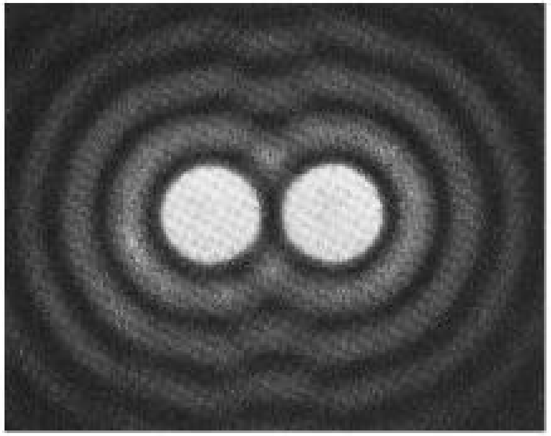
- change by changing the eyepiece



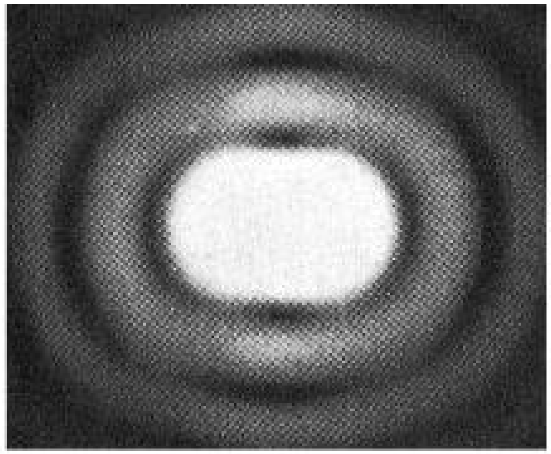
$$\text{magnification} = \frac{q'}{q} \cong \frac{s/f_i}{s/f_e} = \frac{f_e}{f_i}$$

$$= \frac{\text{effective focal length}}{\text{eyepiece focal length}}$$

Resolving a double star



a

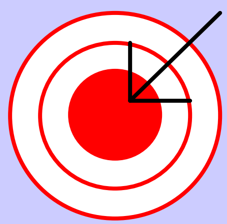


b

Angular Resolution

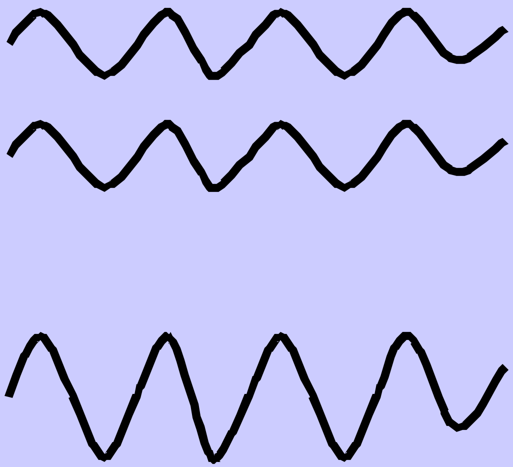
- the minimum angular separation of two sources on sky that may be seen as two separate sources in telescope
- seeing limit (e.g. 1 arcsec)
- diffraction limit (e.g. l/D radians) (caused by diffraction at edge of telescope aperture)

Airy pattern:



Interference of light waves

+

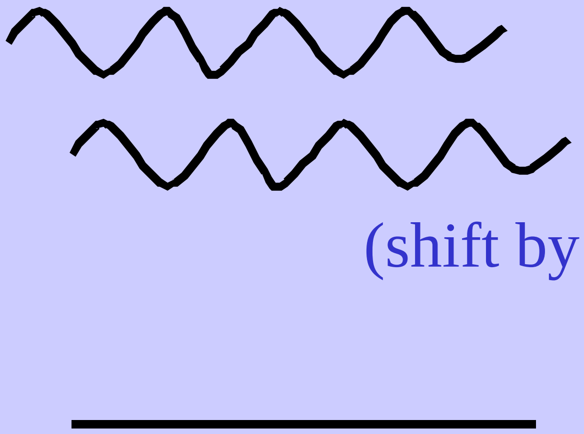


=

constructive

(double amplitude)

+



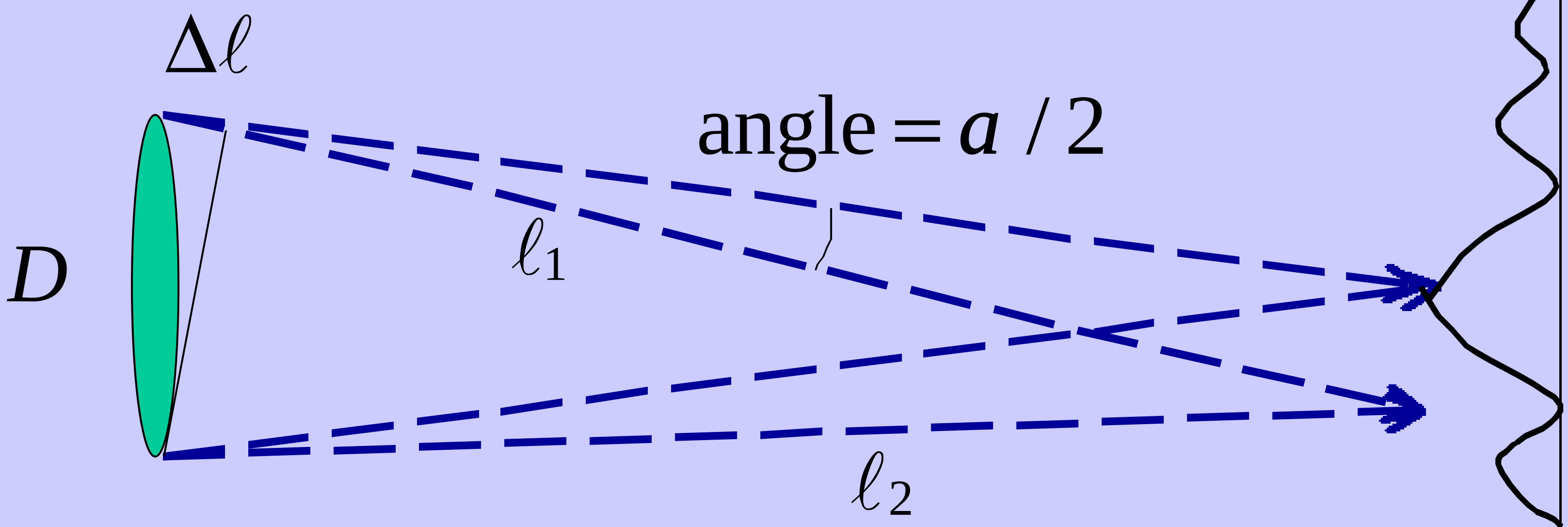
(shift by Û/2)

=

destructive

(zero amplitude)

Diffraction limit



$$\Delta\ell = \ell_1 - \ell_2 = D\sin(a / 2) \approx Da / 2$$

$$\Delta\ell = n\,l \quad \text{constructive interference}$$

$$\Delta\ell = (n + \tfrac{1}{2})\,l \quad \text{destructive}$$

$$a \approx l / D$$

- "diffraction-limited" image

  typically < 0.1 arcsec at optical wavelengths
- Rayleigh's criterion: angular resolution

$$a = 1.22\frac{l}{D}\ \text{radians} \cong 2.5\times 10^{5}\frac{l}{D}\ \text{arcsec}$$

Note: D and Û in the same units

D = diameter of aperture (main mirror) of telescope

Û X500 nm (wavelength of optical light)

Ñ ~ 1 arcsec for D~0.125 m.

X0.03 arcsec for D~4 m.

At Radio Wavelengths

λ_{radio} = 20 cm ~ 400,000 $\times$ $\lambda_{optical}$

- For 1 *arcsec* resolution,
  .   need *D* ~ 50 *km* !
  .   (not very realistic)

- Solution: INTERFEROMETRY
  .   (later)