# Thin lenses and optical instruments

SM, Phy 123, Spring 2013

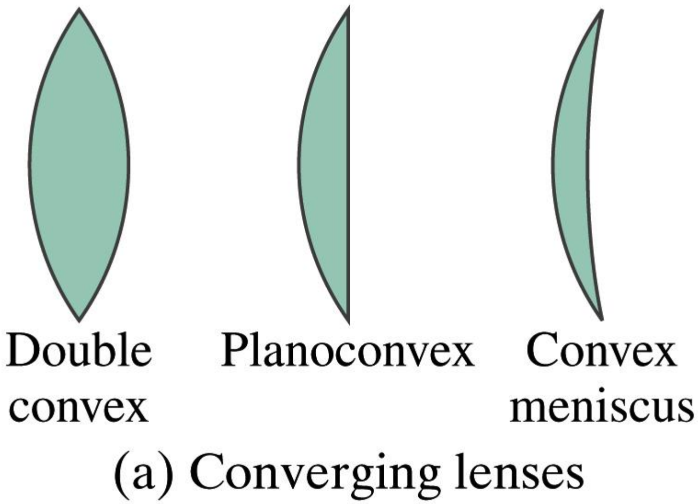
References and photo sources:

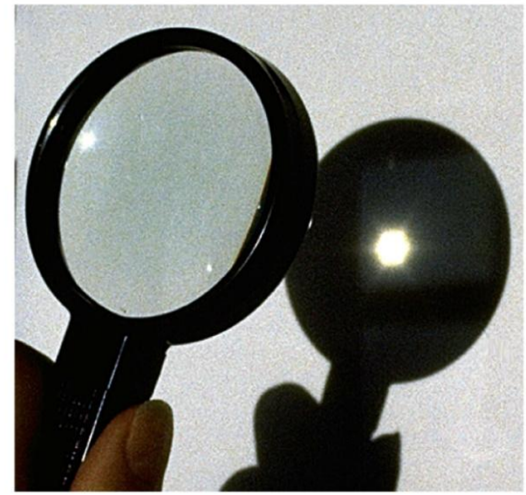
D. Giancoli, Physics for Scientists and Engineers, 3rd ed., 2000, Prentice-Hall

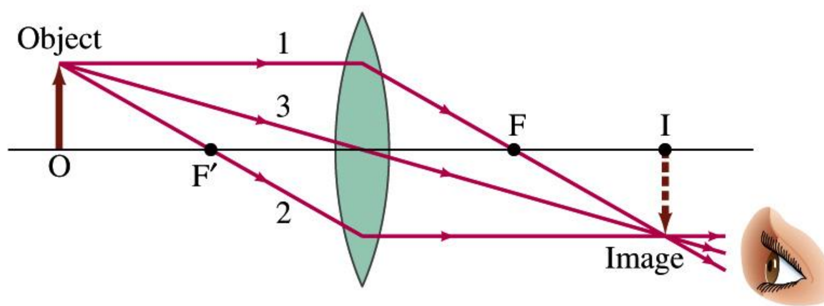
http://cvs.anu.edu.au (D. Denning and M. Kirk)

http://www.ebiomedia.com

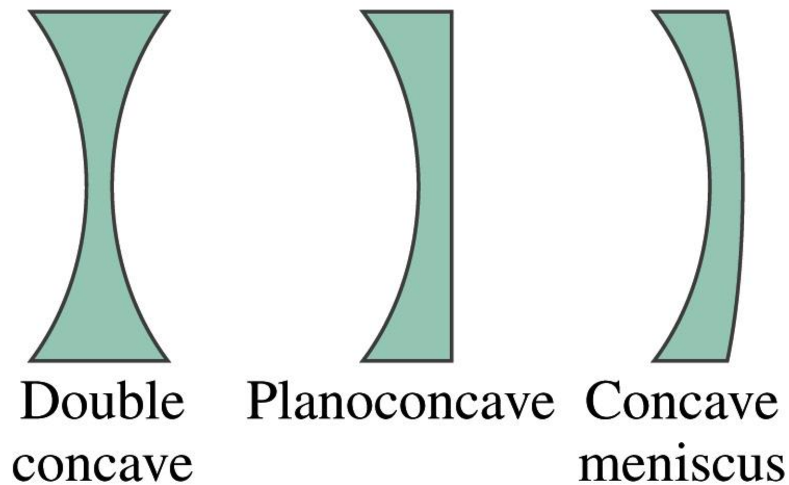
NASA



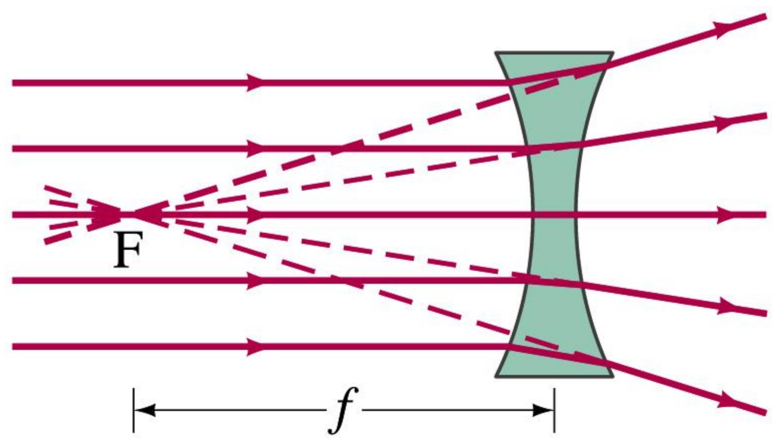



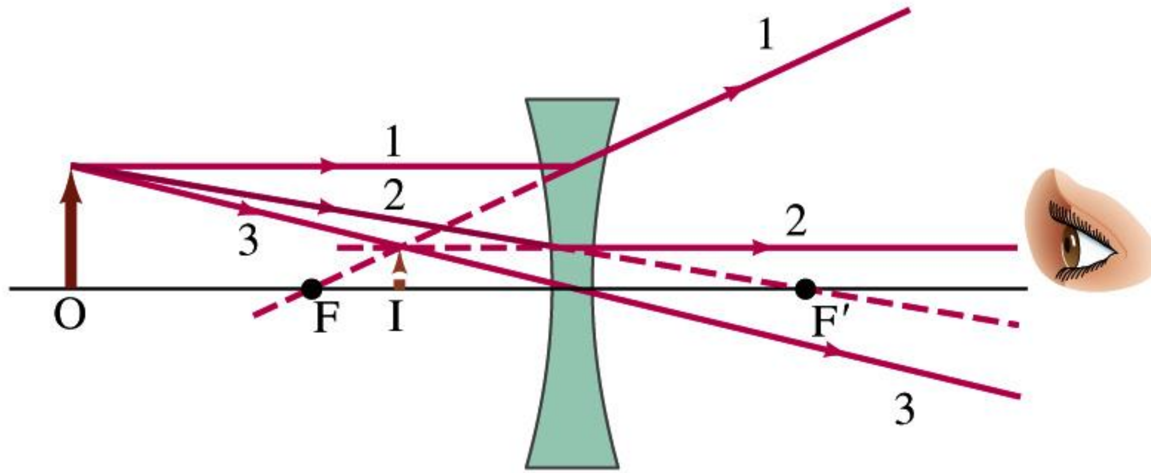



(c) Ray 3 passes straight through the center of the lens (assumed very thin).




(b) Diverging lenses

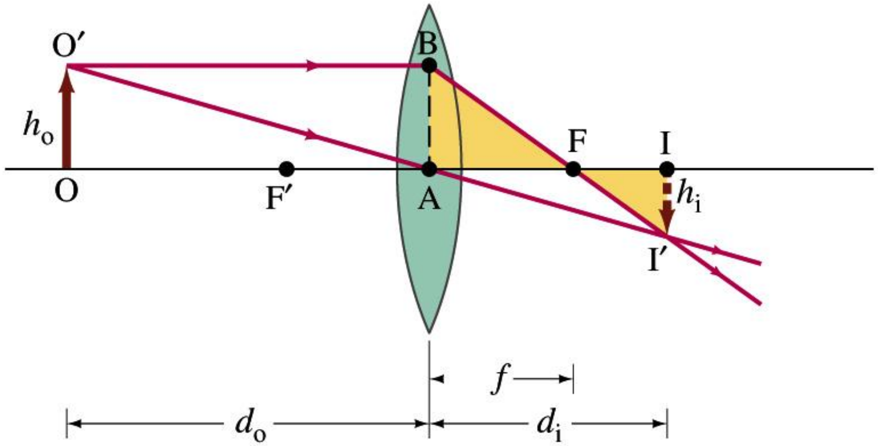



1
1
2
2
3
3
O
F
I
F′

# Power of lens measured in diopters

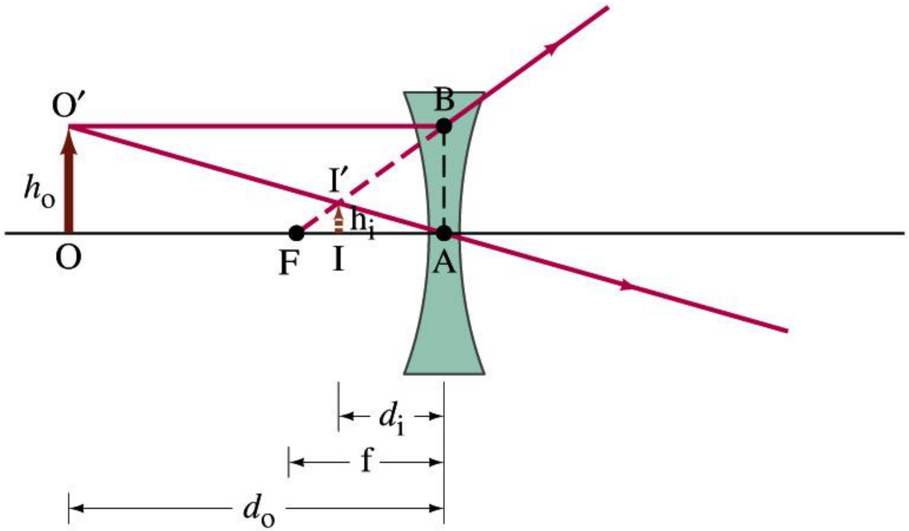
$$P = \frac{1}{f}$$ where f is focal length in meters

Power is positive for converging lenses
and negative for diverging lenses




Magnification:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$




Lens equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

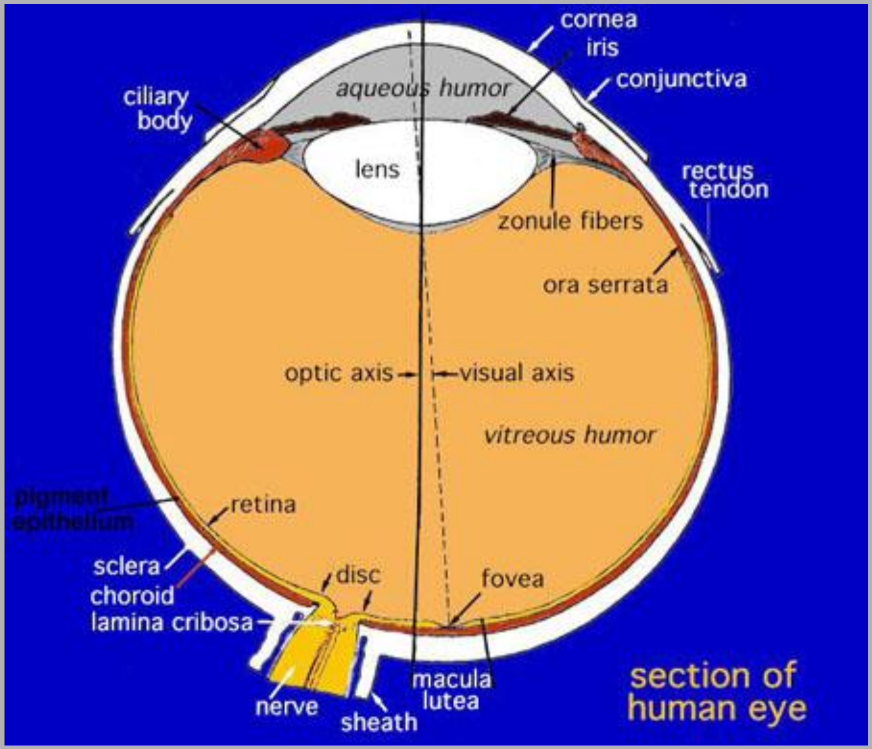
**Real image: rays actually pass thru image**

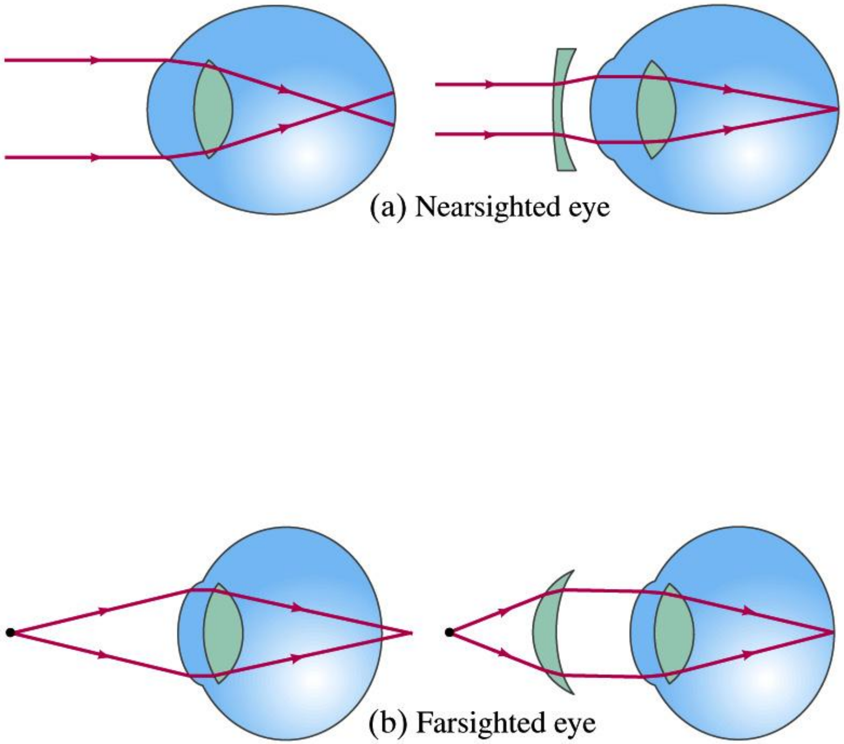
**Virtual image: rays do not actually pass thru image**

**Sign convention is the tricky part, especially in multiple lens systems**

**Convention from Giancoli p. 841:**

- **Focal length is + for converging lens and - for diverging lens**
- **Object distance is + if on the side of the lens from which the light is coming (usual, unless in multi-lens system)**
- **Image distance is + if on the opposite side of the lens from where the light is coming, if on same side, image distance is –**
- **Image distance is + for real images and – for virtual images**
- **Height of image is + if image is upright and – if image is inverted. Height of object is always taken to be +.**

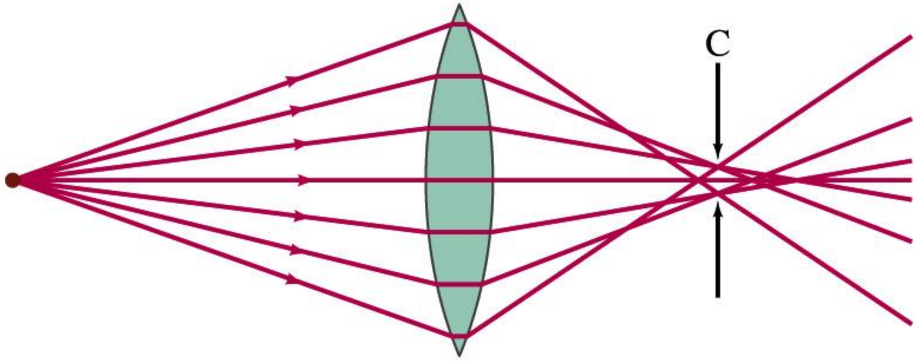


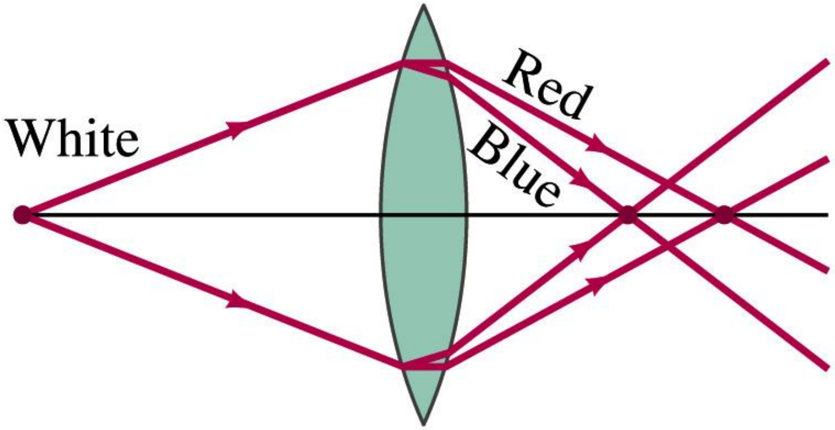
(a) Nearsighted eye

(b) Farsighted eye

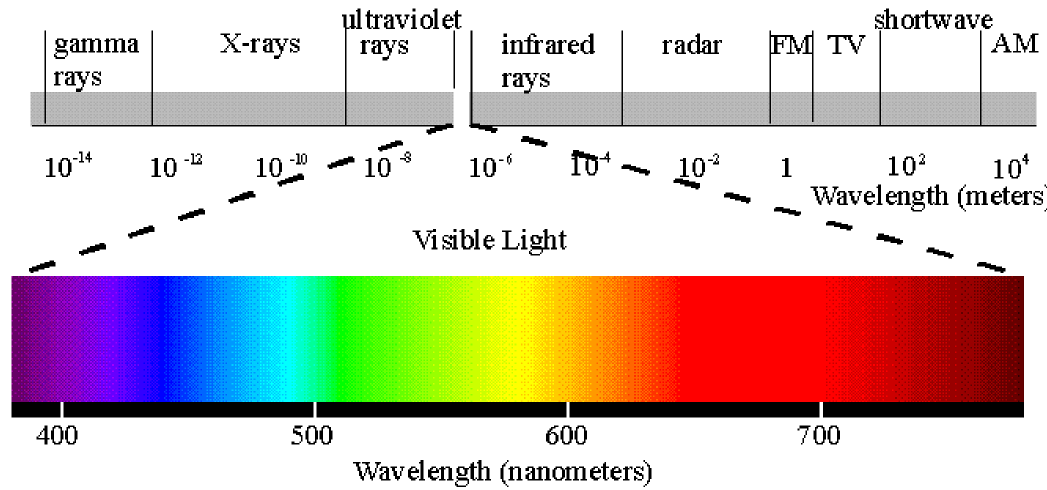
# Aberrations



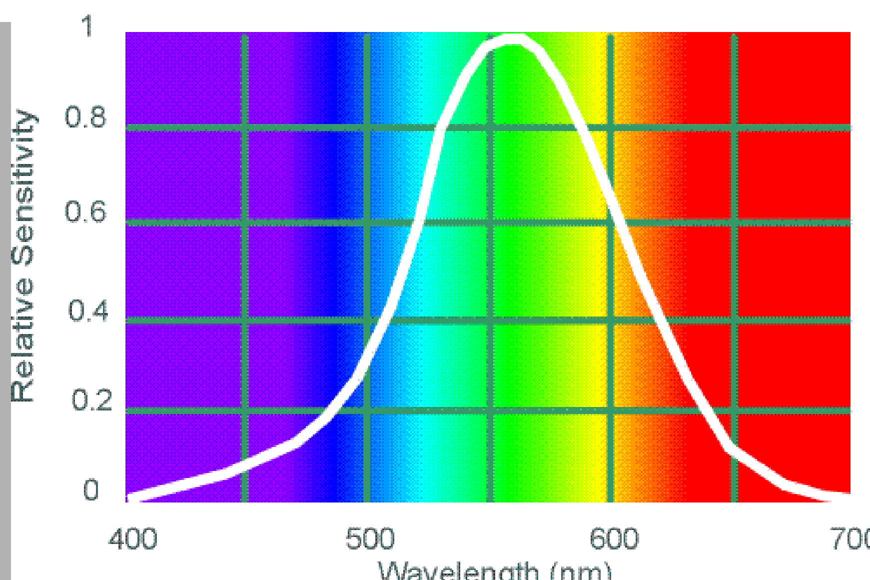

Spherical aberration

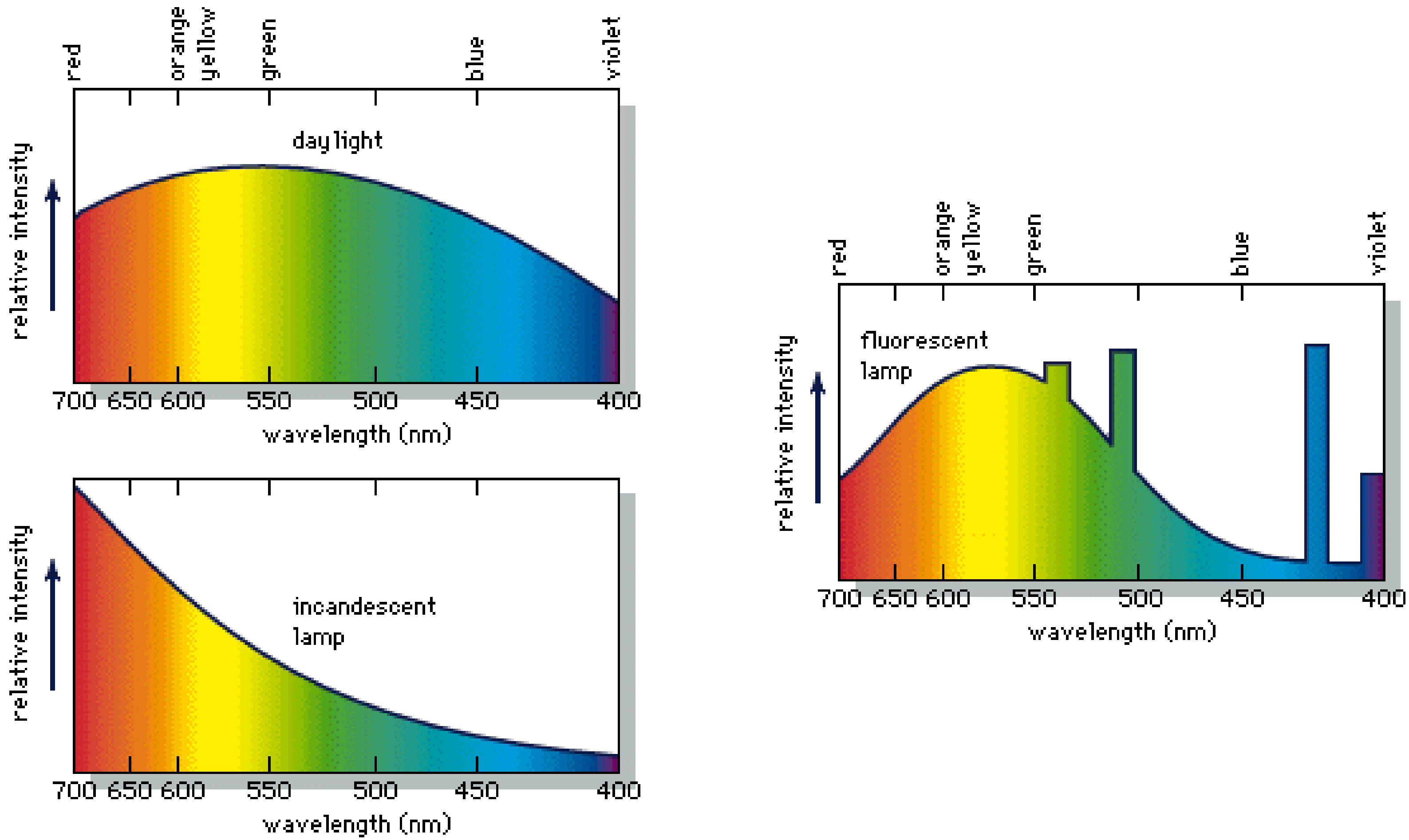



Chromatic aberration

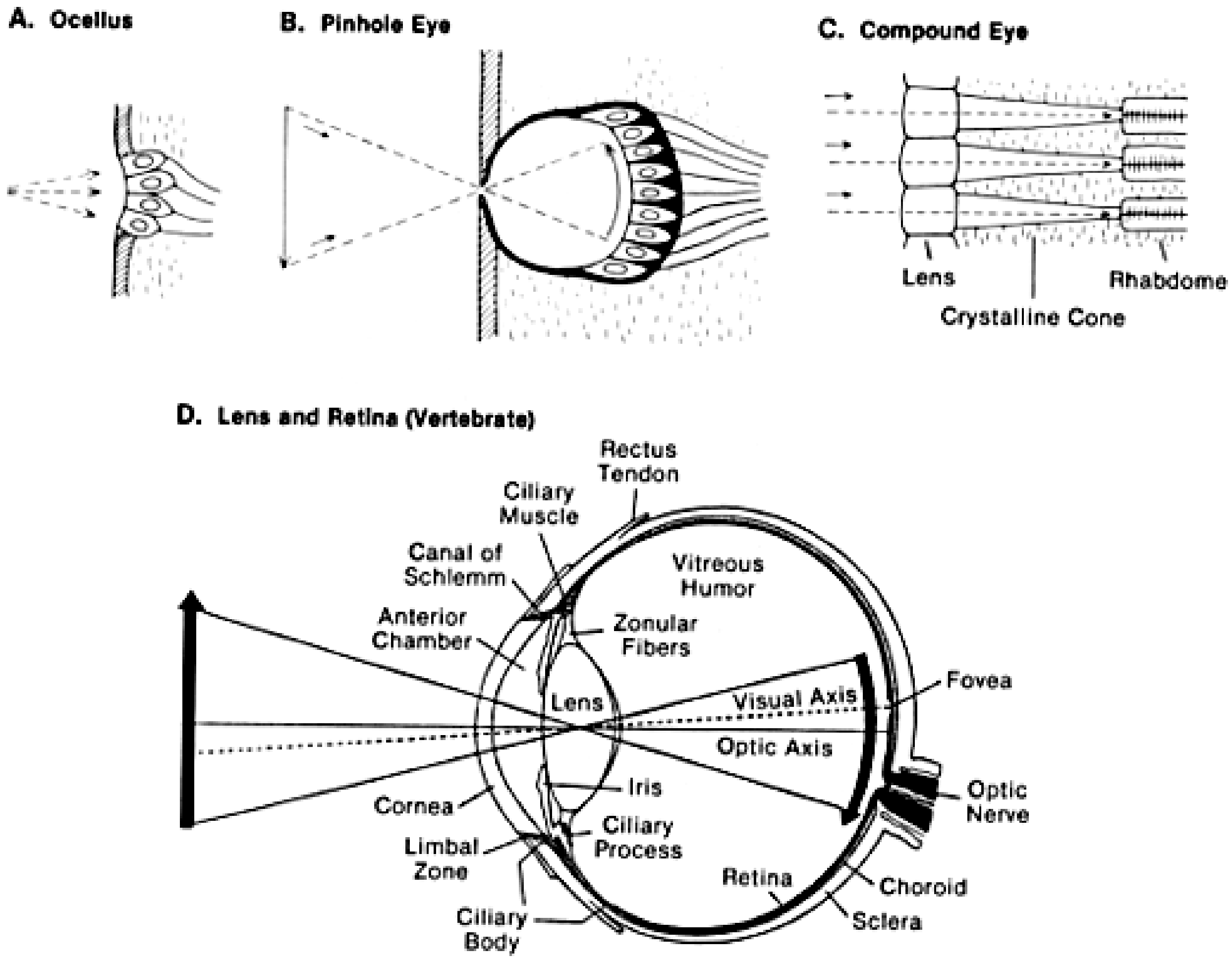


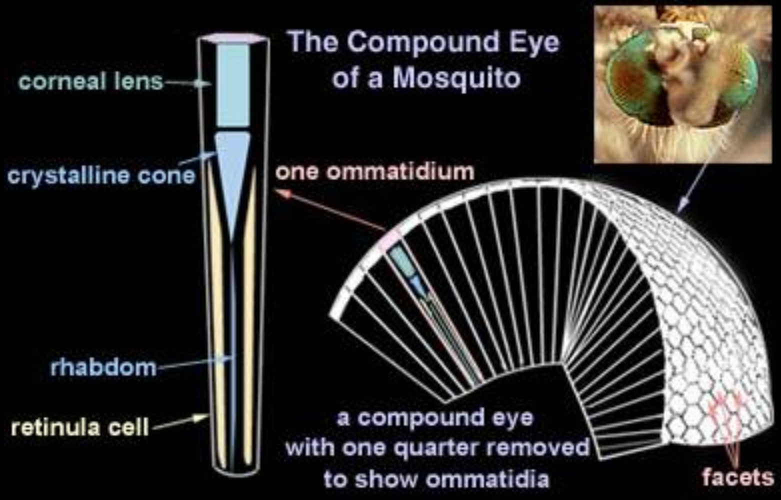

The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/eye/

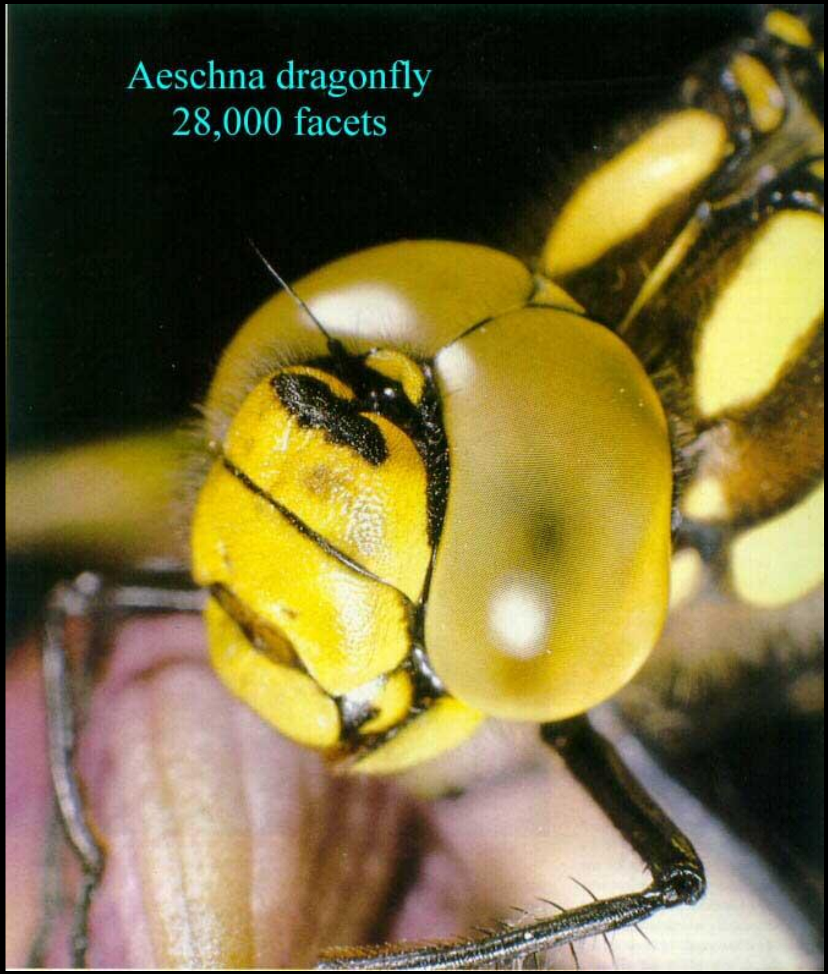



red
orange
yellow
green
blue
violet
daylight
relative intensity
700 650 600 550 500 450 400
wavelength (nm)
incandescent
lamp
relative intensity
700 650 600 550 500 450 400
wavelength (nm)
red
orange
yellow
green
blue
violet
fluorescent
lamp
relative intensity
700 650 600 550 500 450 400
wavelength (nm)

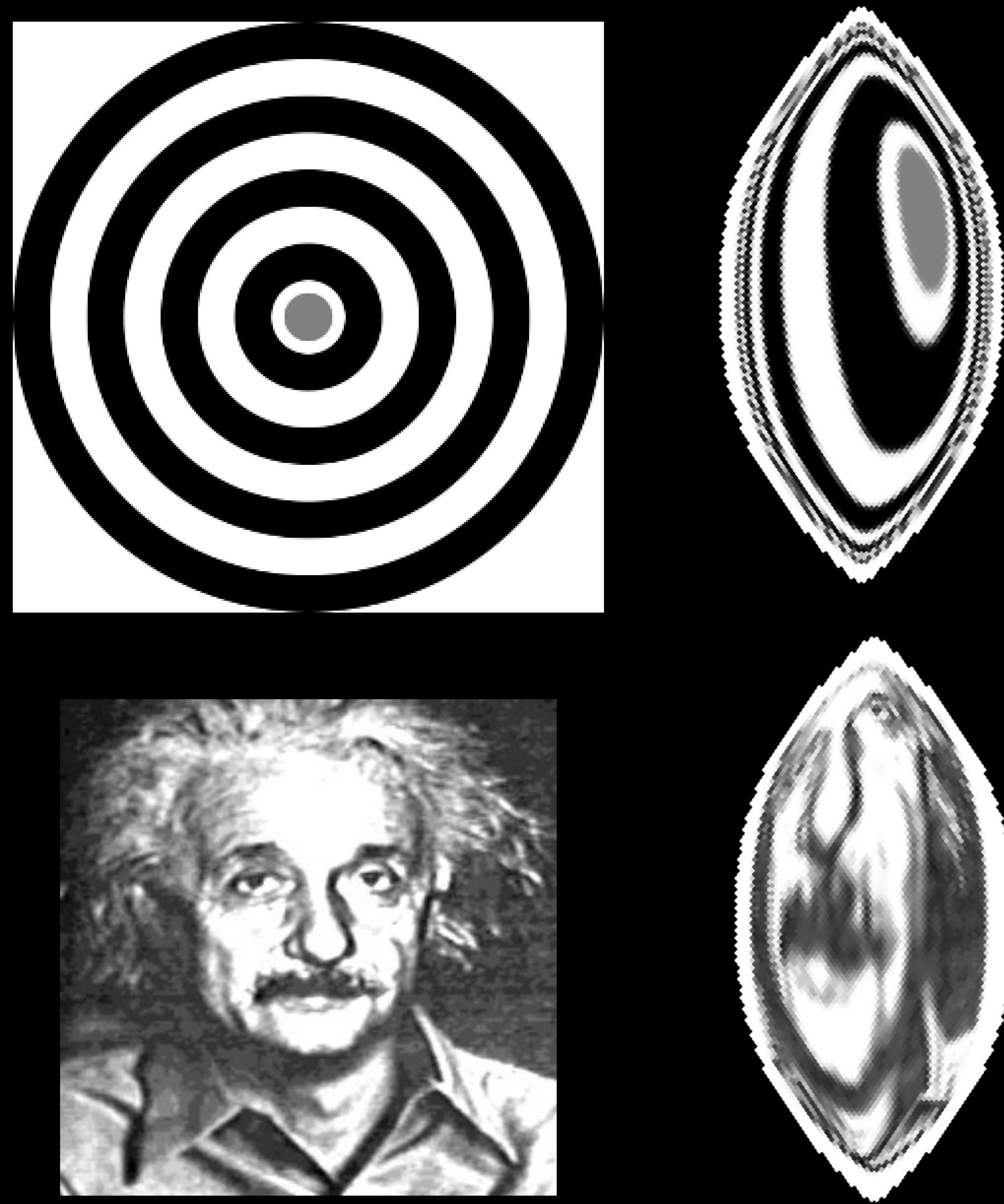
# Types of eyes in the animal kingdom




The Compound Eye
of a Mosquito
corneal lens
crystalline cone
one ommatidium
rhabdom
retinula cell
a compound eye
with one quarter removed
to show ommatidia
facets


Aeschna dragonfly
28,000 facets

## A bee’s eye view



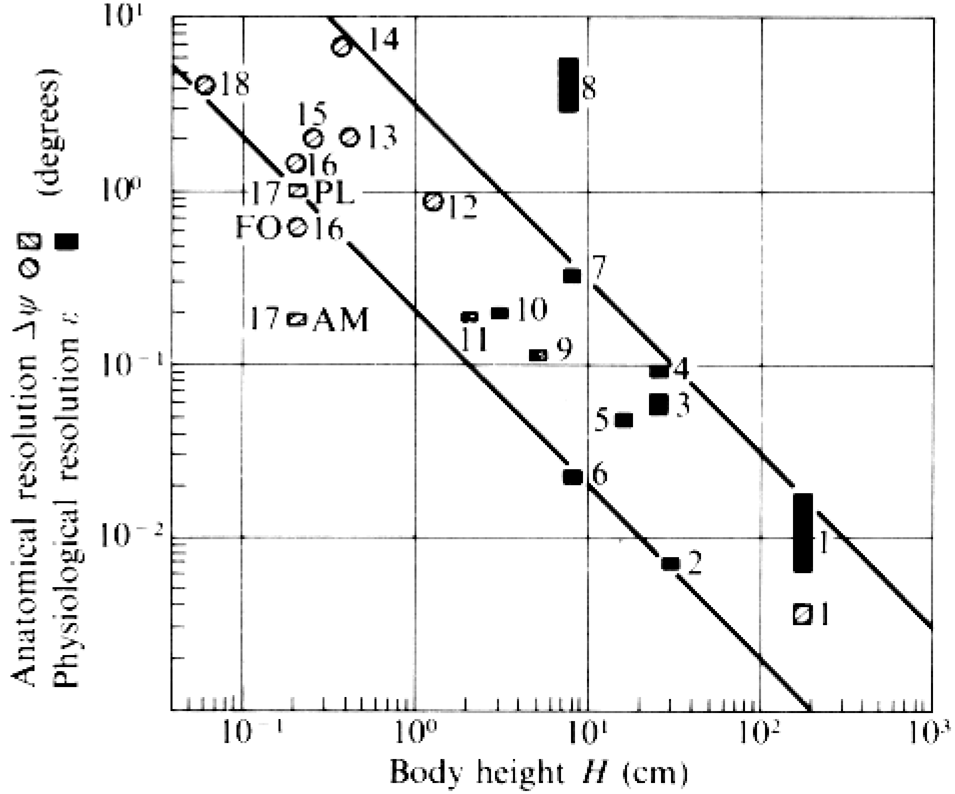
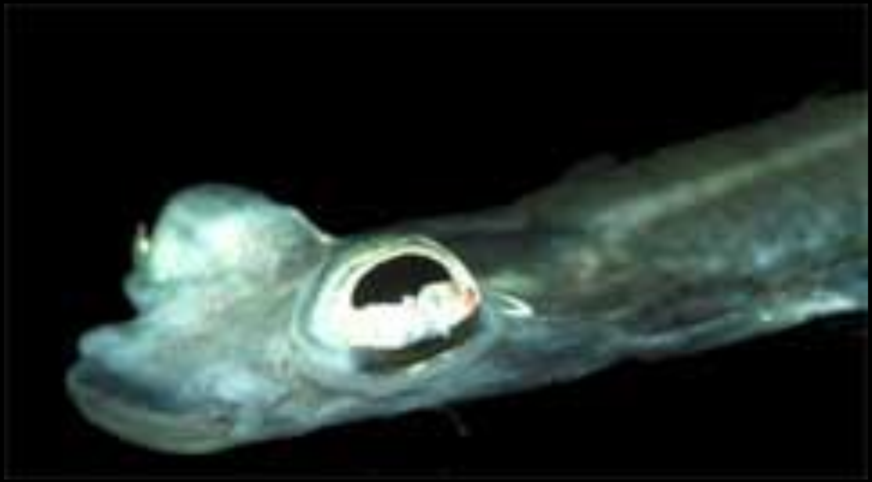
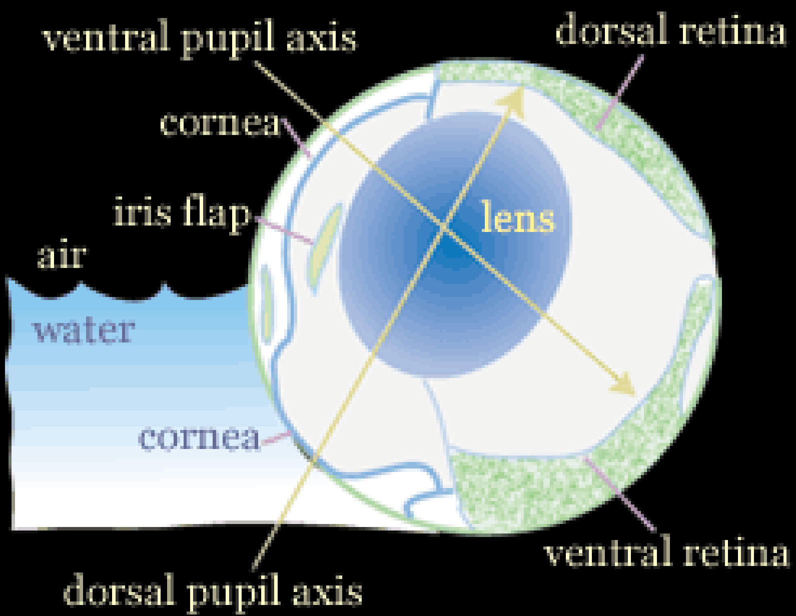



Fig. 2.9. Resolution of the eyes of various animals measured physiologically and deduced from anatomical criteria compared to body height: (1) man; (2) peregrine falcon; (3) hen; (4) cat; (5) pigeon; (6) chaffinch; (7) rat; (8) bat (*Myotis*); (9) frog; (10) lizard; (11) minnow; (12) dragonfly (*Aeschna*); (13) bee (Apis); (14) *Chlorophanus*; (15) housefly (*Musca*); (16) hover fly (*Syrrita*), frontal region FO; (17) jumping spider (*Methaphidippus*), anteromedian eye AM, postero-lateral eye PL; (18) fruit fly, *Drosophila*. (From Kirschfeld 1976.)

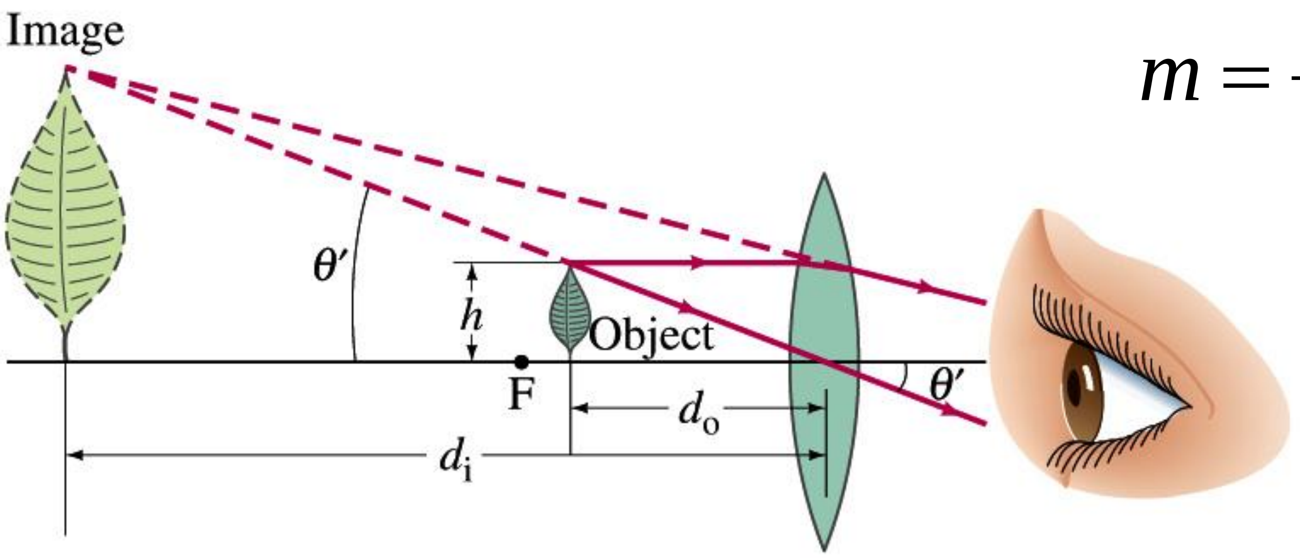
# Anableps - minnow

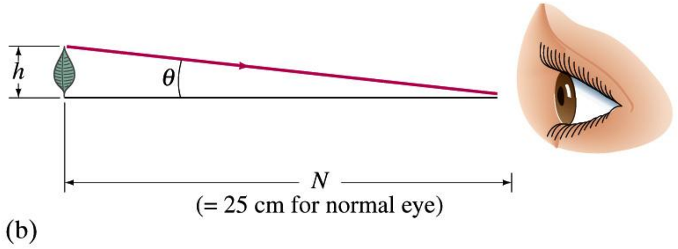


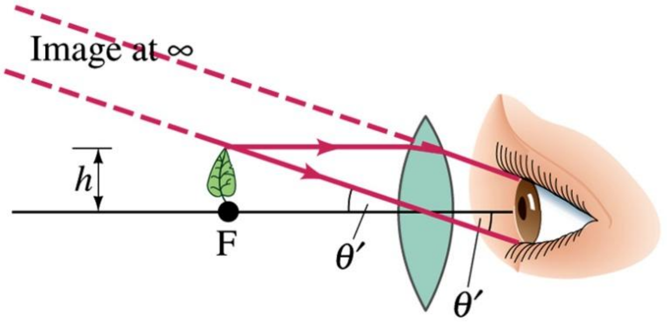


# Magnifying glass

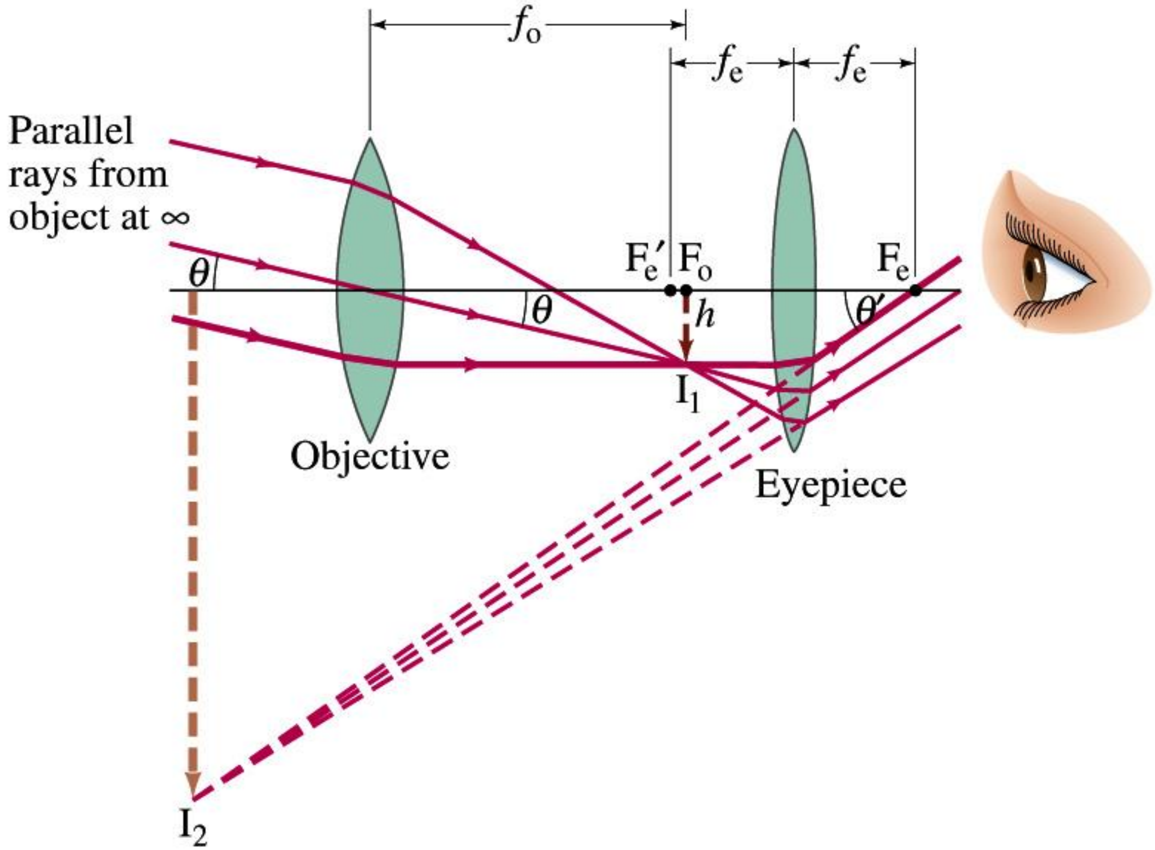
$$m = \frac{\theta'}{\theta} = \frac{N}{f}$$



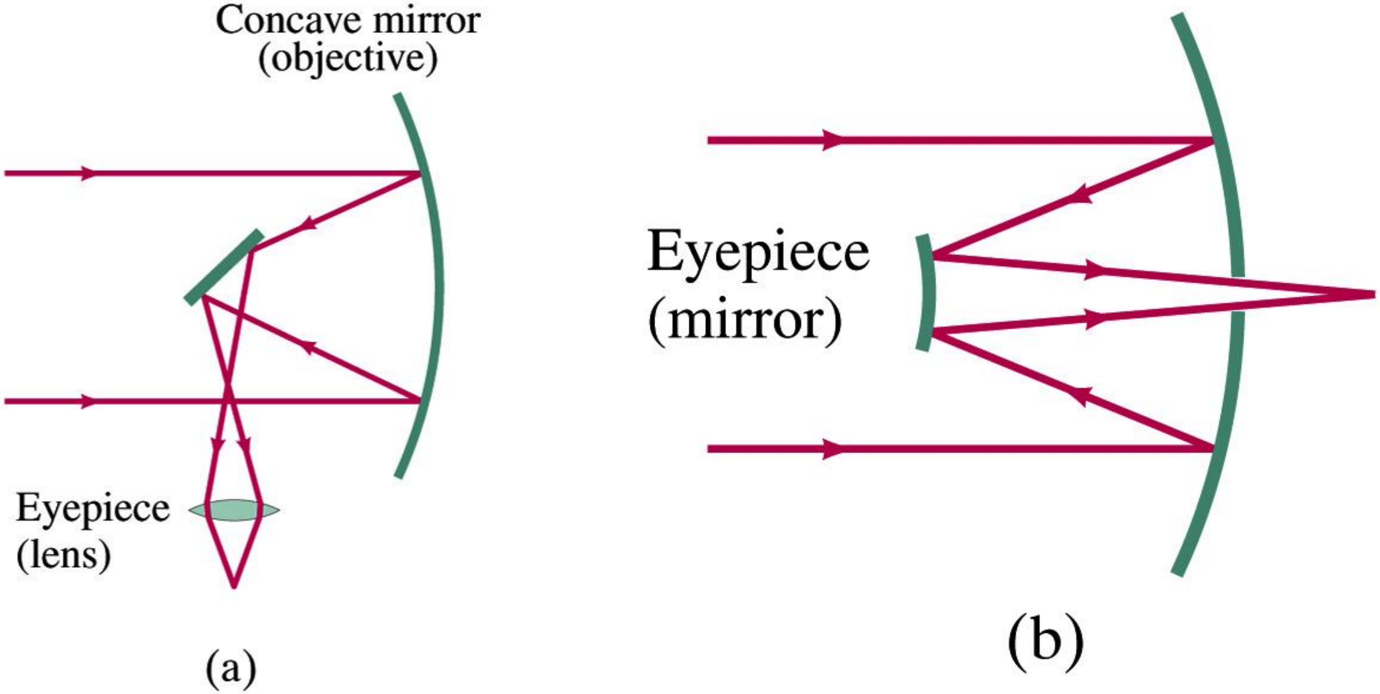



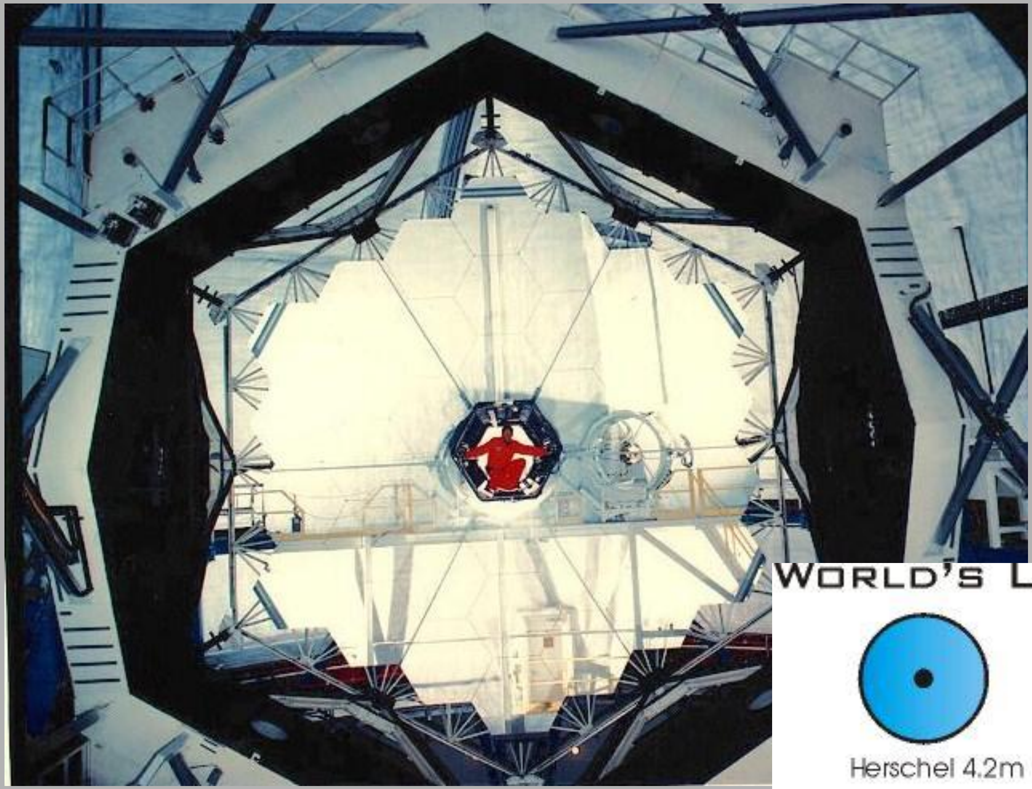
# Refracting telescope

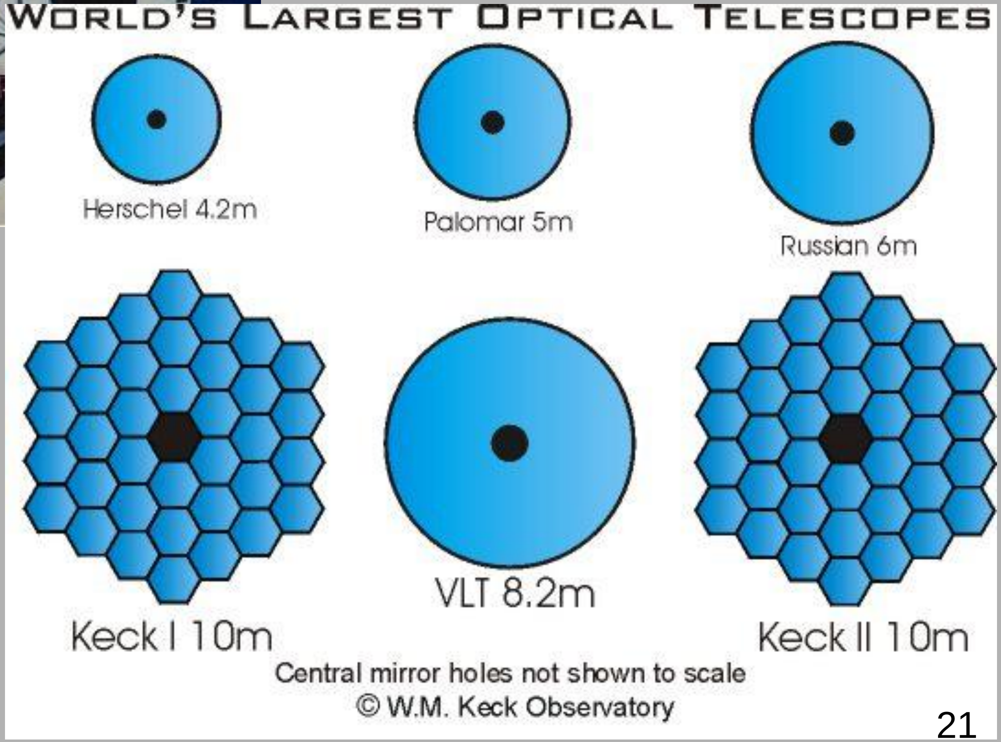



40 inch refractor – Yerkes Observatory

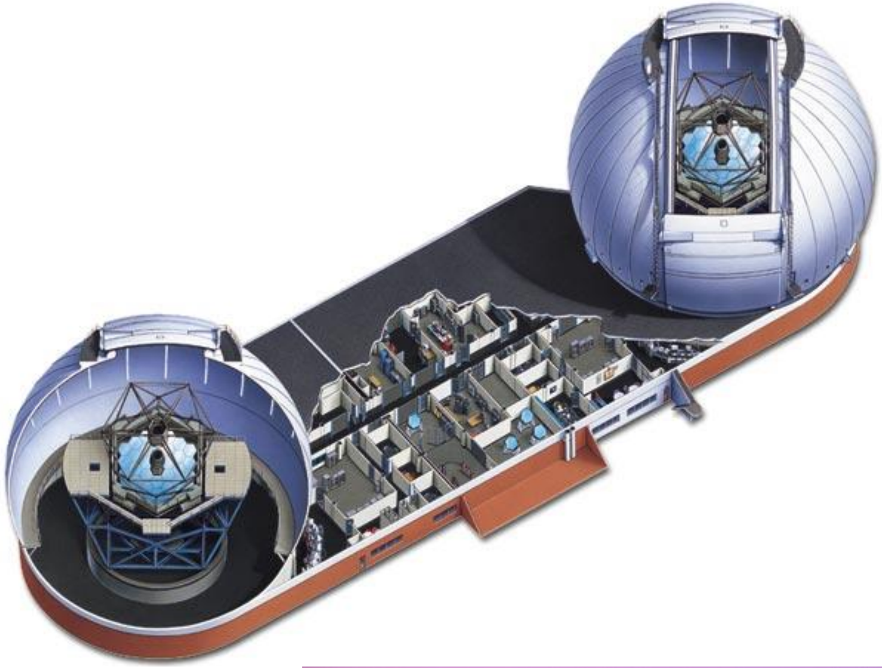
# Reflecting telescope

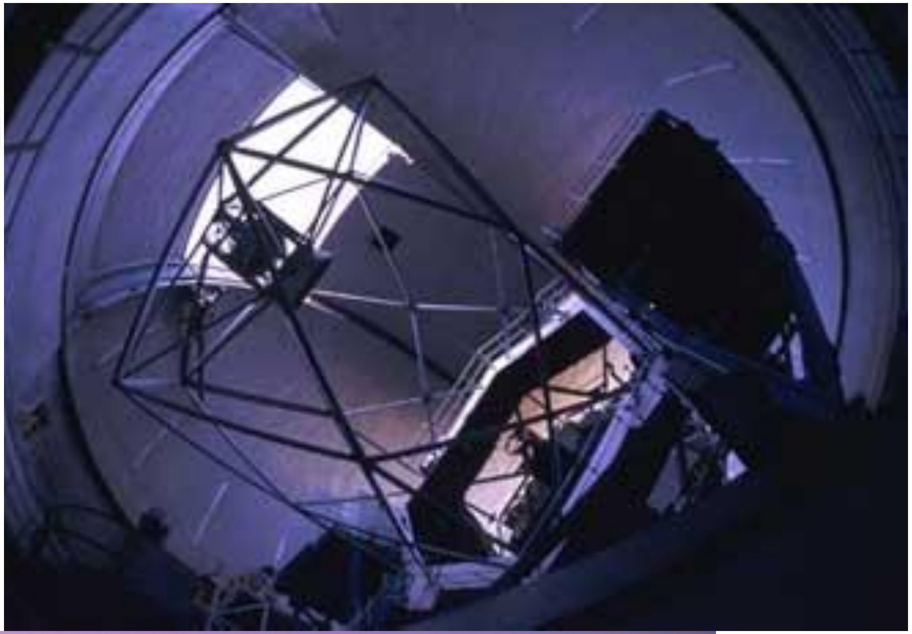






WORLD'S LARGEST OPTICAL TELESCOPES
Herschel 4.2m
Palomar 5m
Russian 6m
Keck I 10m
VLT 8.2m
Keck II 10m
Central mirror holes not shown to scale
© W.M. Keck Observatory

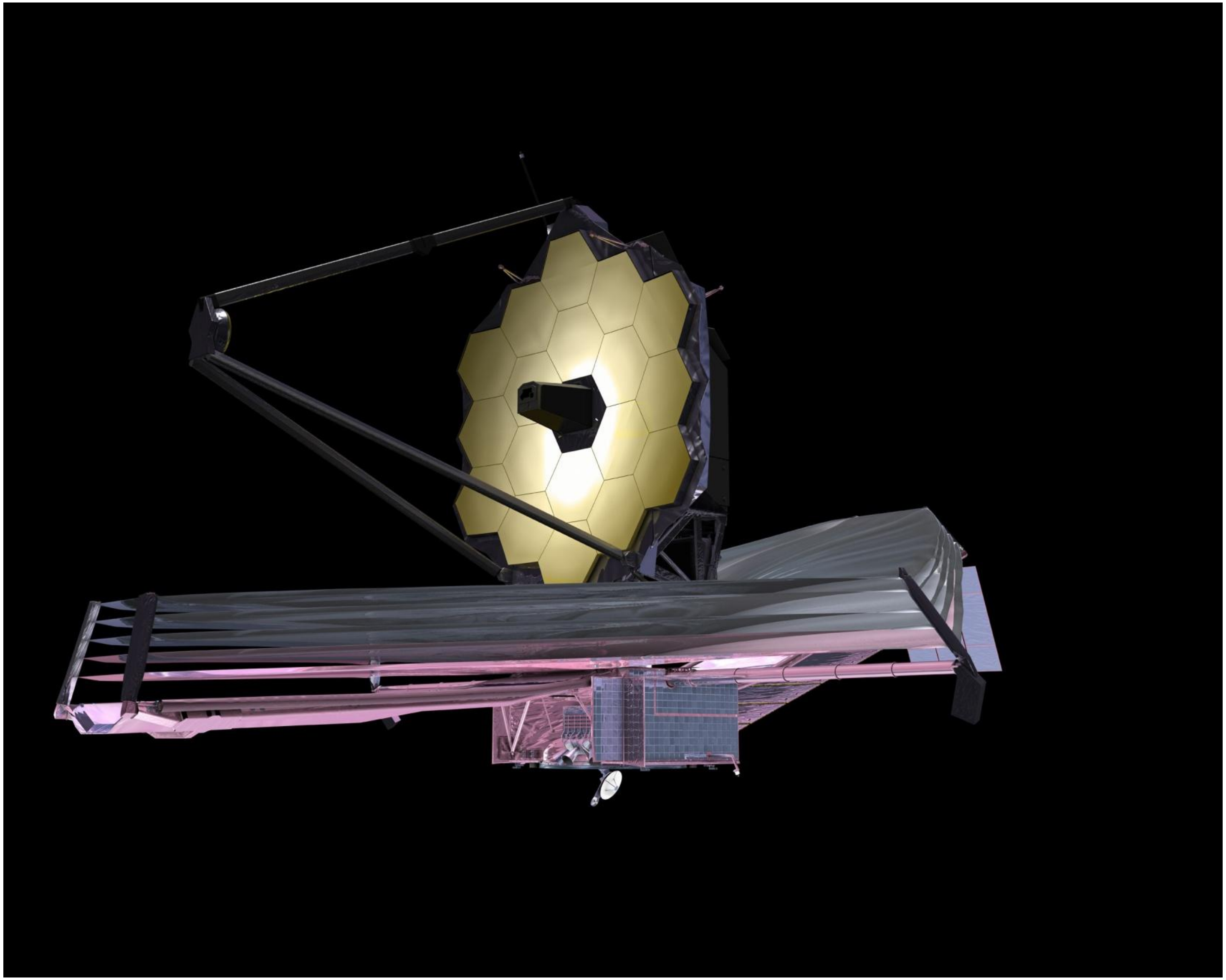




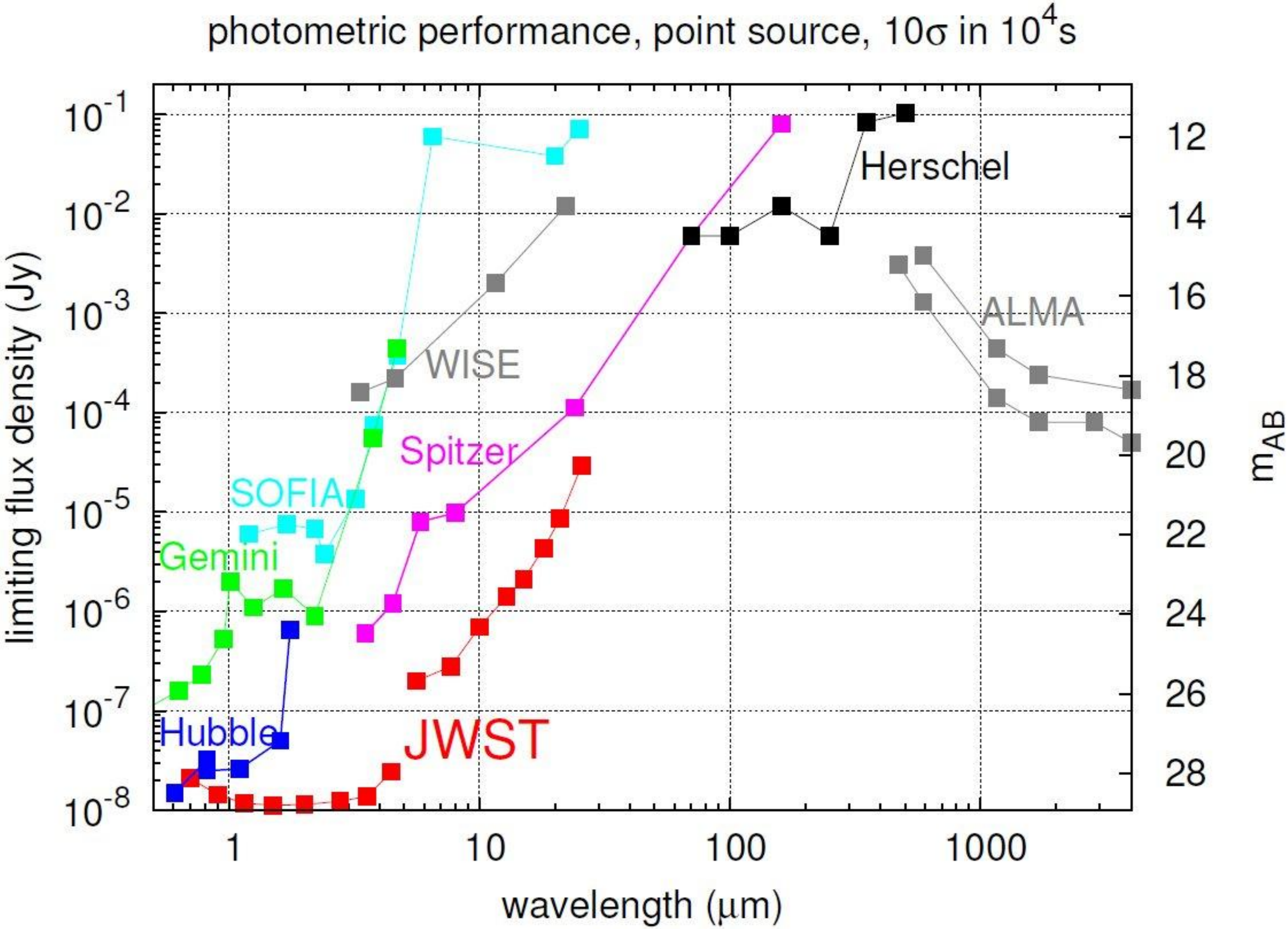
## Keck Observatory

## Hubble Space Telescope

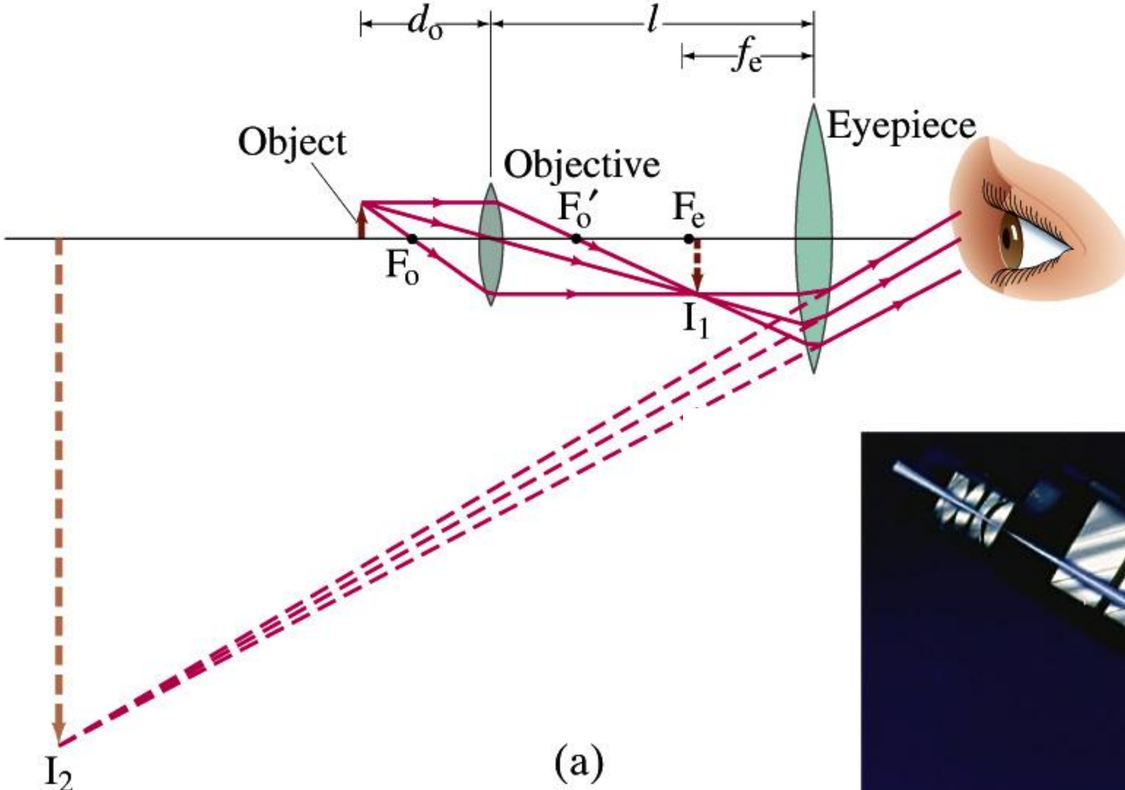
Hubble space telescope
2.4 m primary mirror
Launched in April 1990
Optics “repair” in 1993



James Webb space telescope – 6.5 meter primary mirror
Expected 2018 launch date

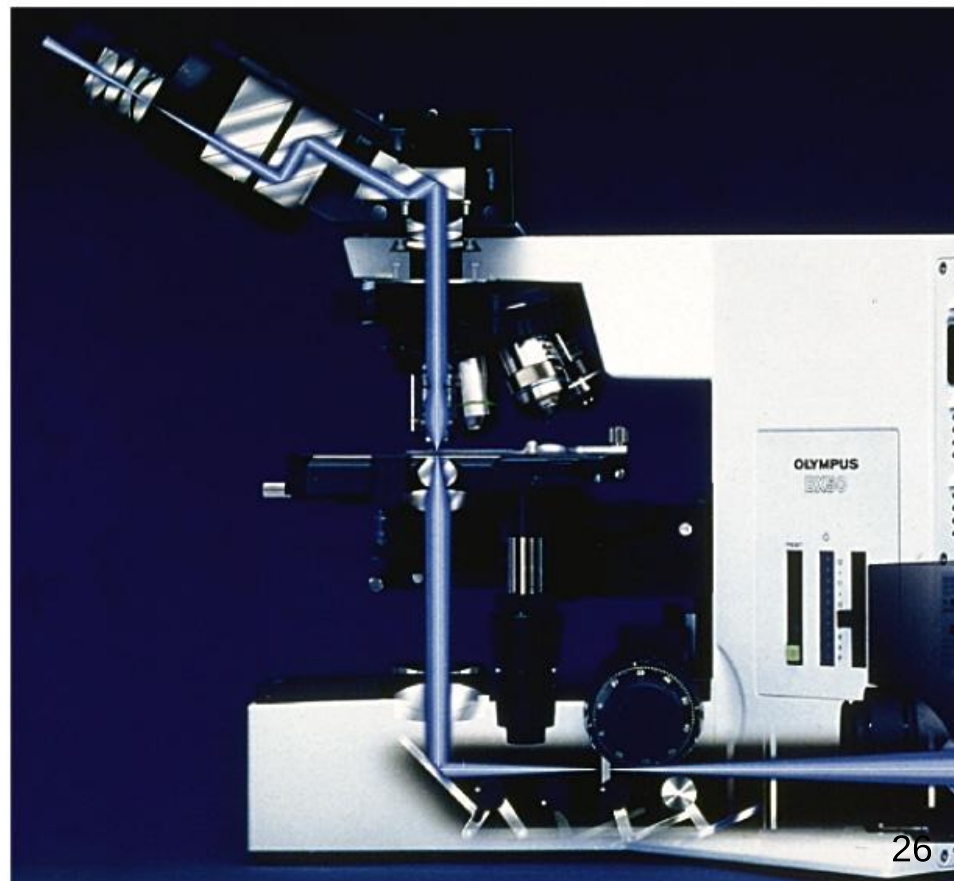



*From NASA:*
*http://www.stsci.edu/jwst/science/sensitivity*



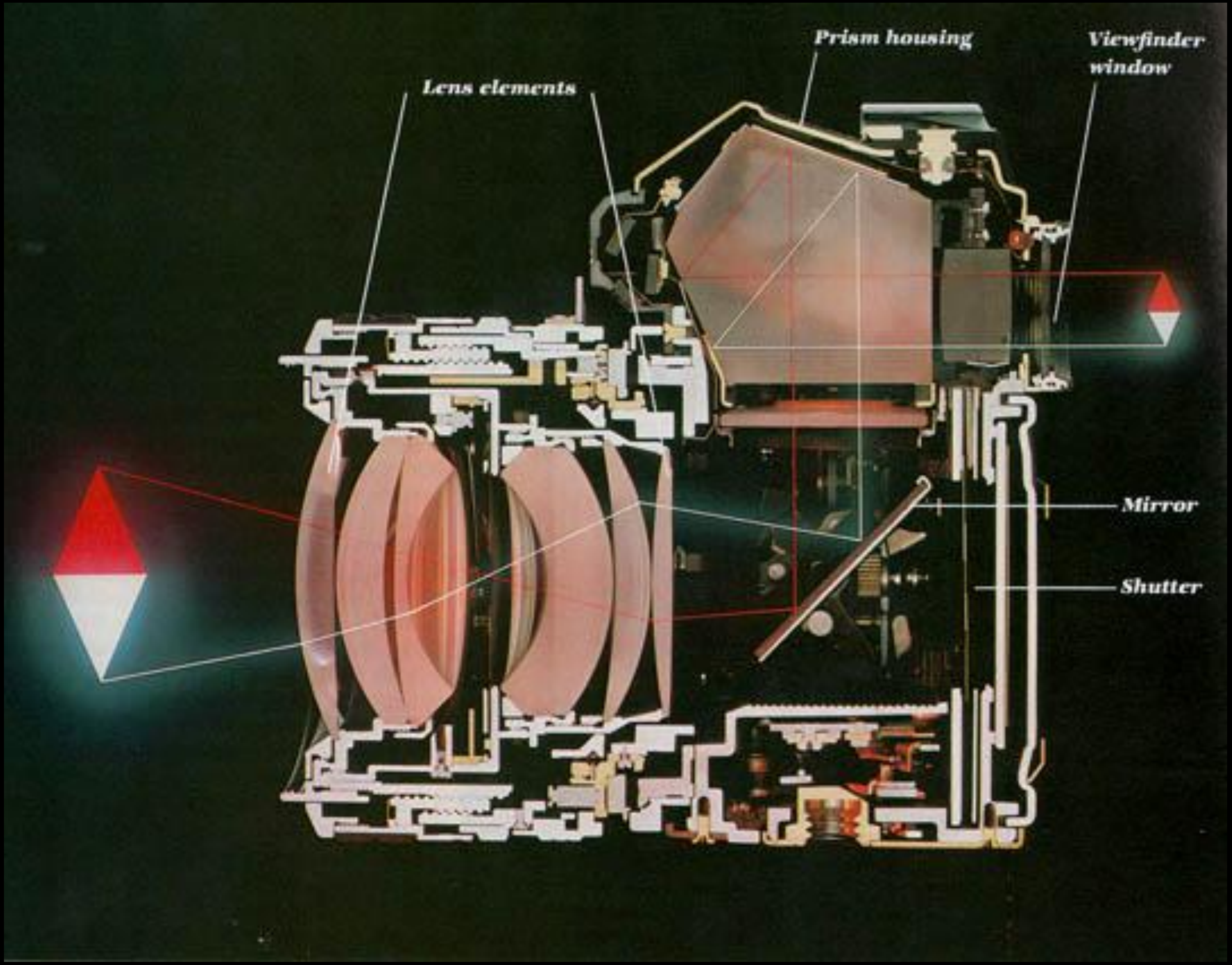

(a)

**Compound microscope**




(b)

# Camera



Prism housing
Viewfinder window
Lens elements
Mirror
Shutter

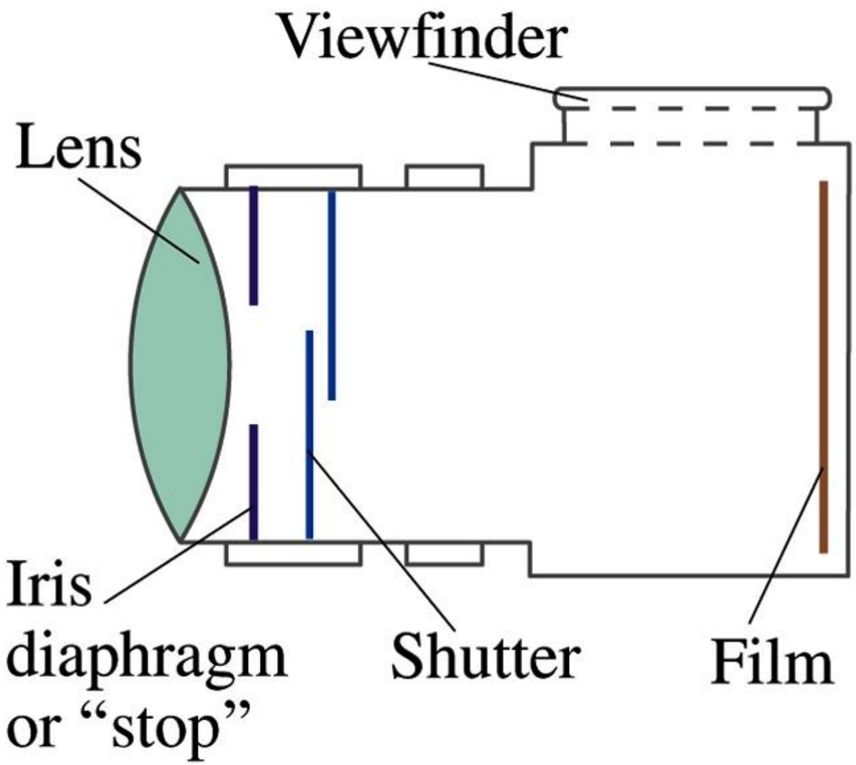
Light vs. depth of field

Shutter speed

f-stop=f/D, each f-stop=factor of 2 in light intensity

Faster the object or darker the day, need slower speed and/or larger D

Larger D means narrower depth of field

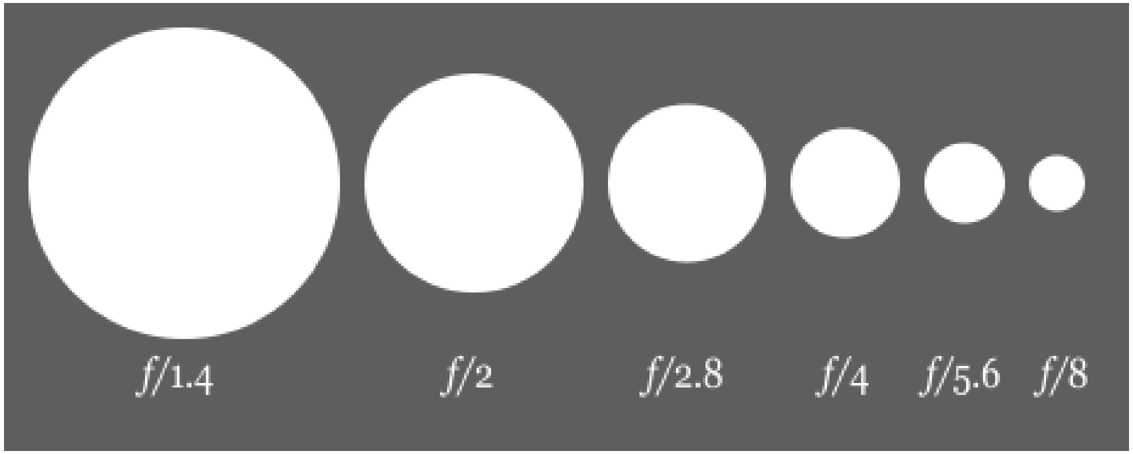



Speed limited on the low end by movement of object or support platform (hand), on high end by technology and amount of light

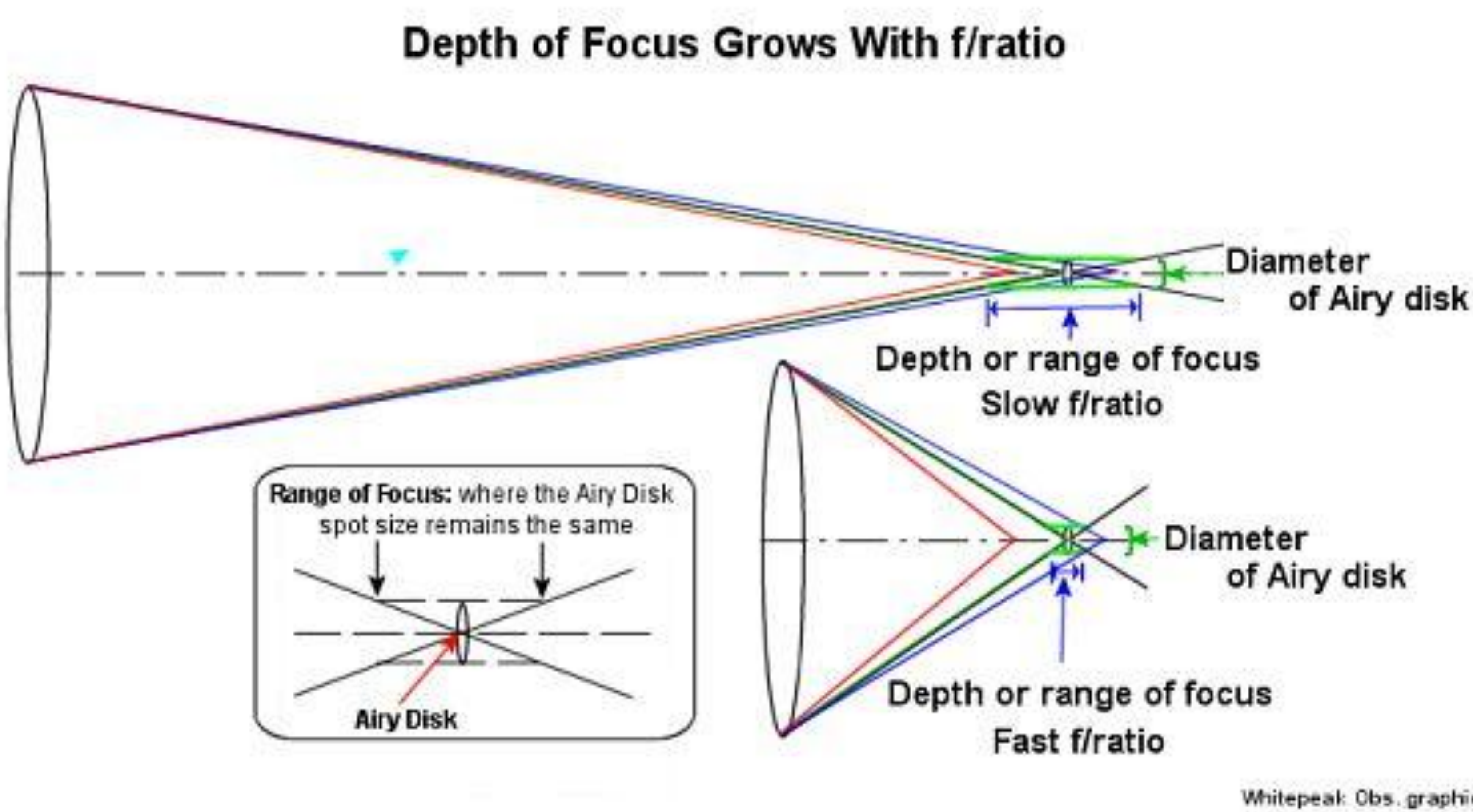
f-stop or f ratio
Each stop differs by factor of 2 in light intensity
Exposure goes as (time)(area opening)
Amount of light goes as area, goes as diameter$^2$
So, stops differ in diameter of sqrt(2)~1.4

If lens has a 10 mm focal length, an aperture of 5 mm would give f/2
Same lens with aperture of 1.8 mm would give f/5.6

Larger maximum aperture, more light, faster lens
(usually more expensive … *because more issues with controlling aberrations, I think*)




Aperture diagram for different f-stops


Depth of Focus Grows With f/ratio
Diameter
of Airy disk
Depth or range of focus
Slow f/ratio
Range of Focus: where the Airy Disk
spot size remains the same
Airy Disk
Diameter
of Airy disk
Depth or range of focus
Fast f/ratio
Whitepeak Obs. graphic

Slow exposure time
(Note hand motion)

Small opening

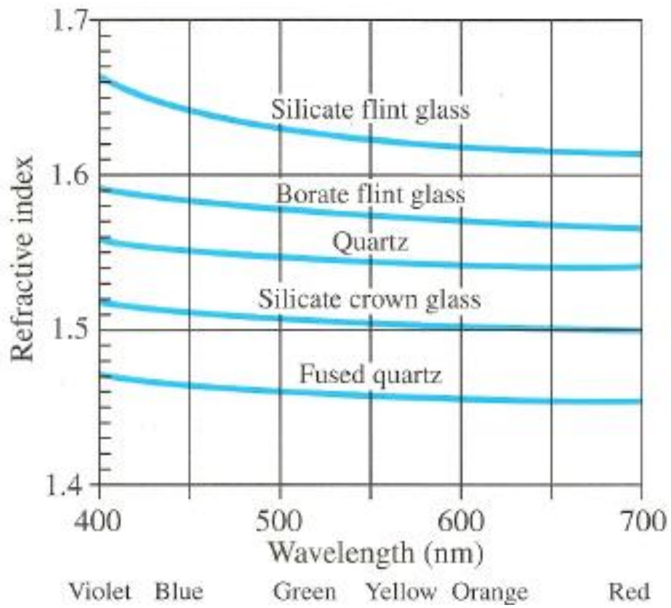
large depth of field of focus

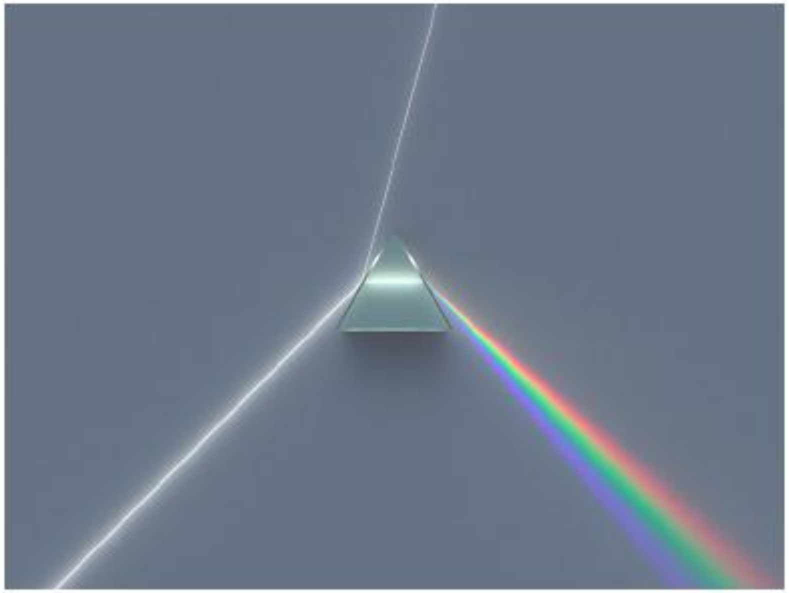
fast Time

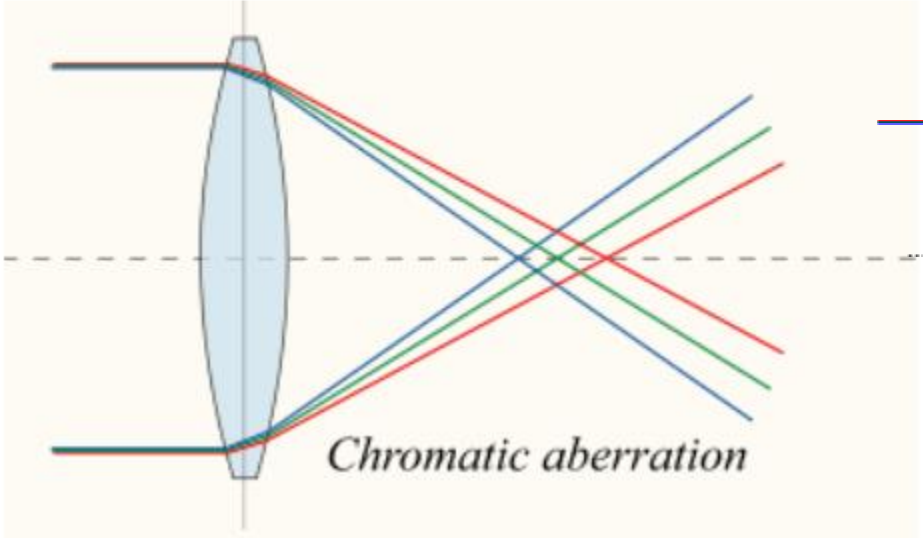
large opening

Narrow Field of focus

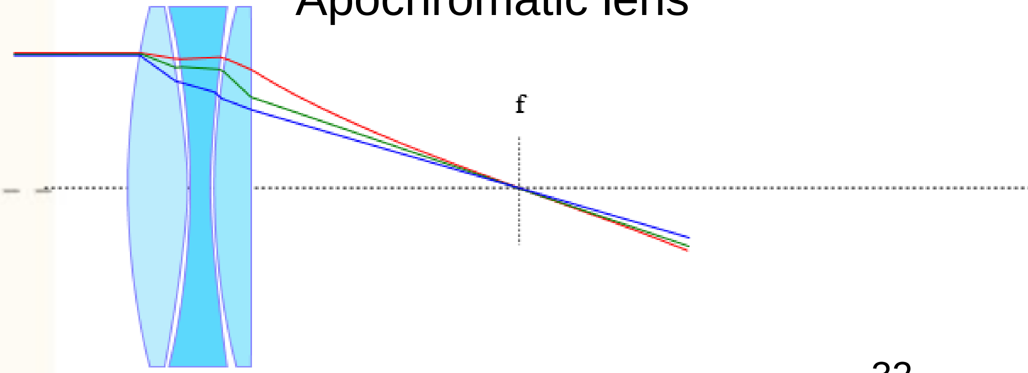
# Aberrations

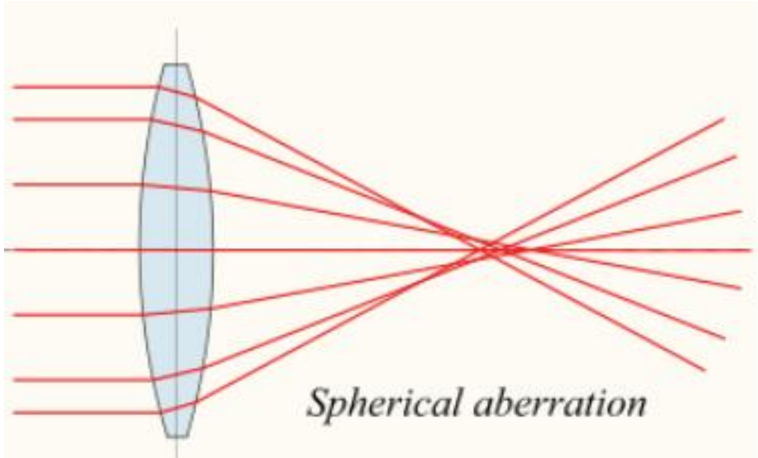


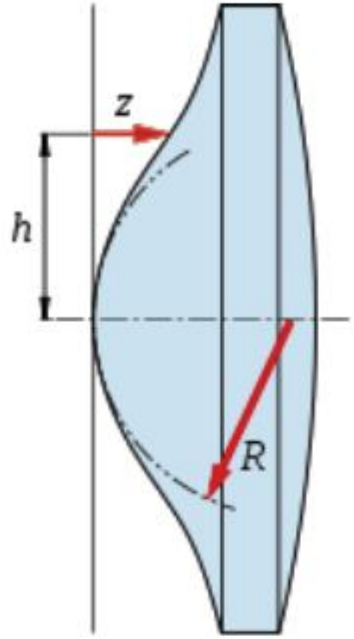






Apochromatic lens






Aspheric lens

Astigmatism