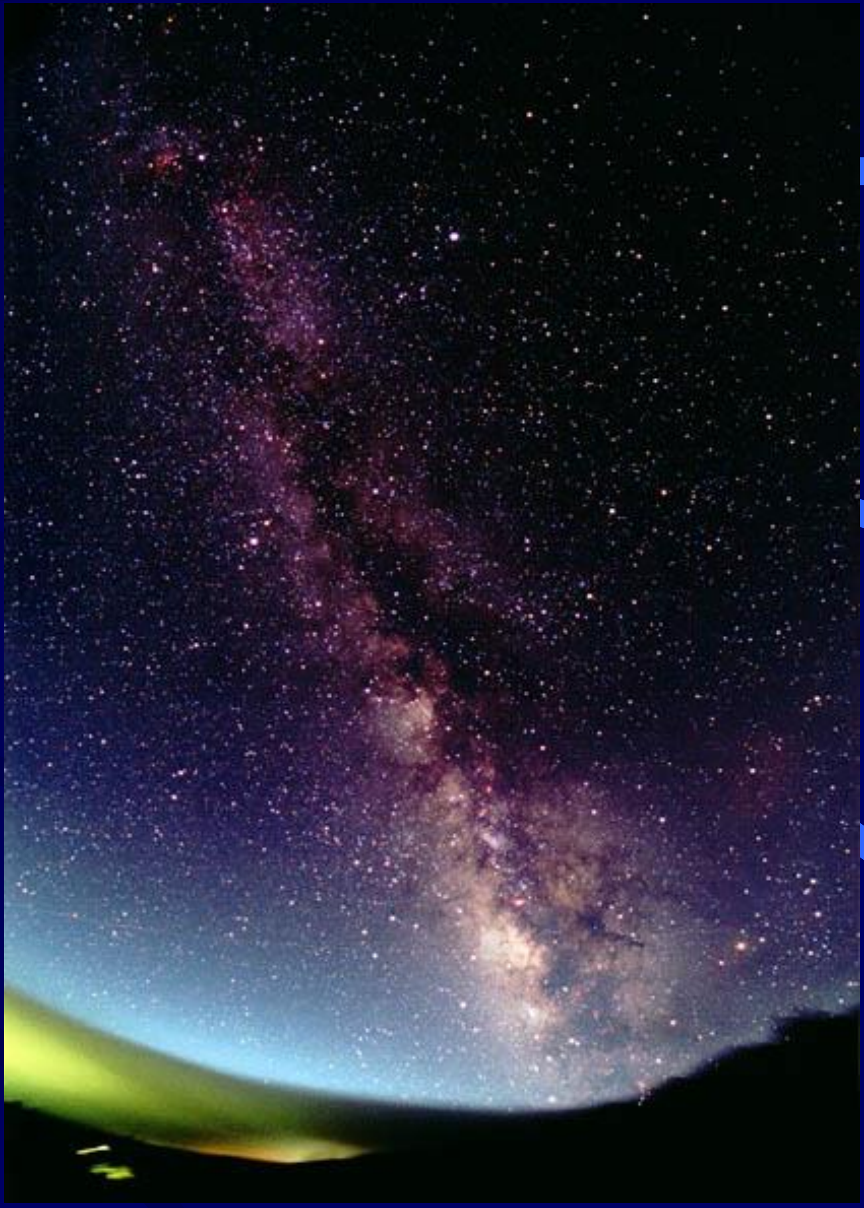
Telescopes and Electromagnetic Radiation

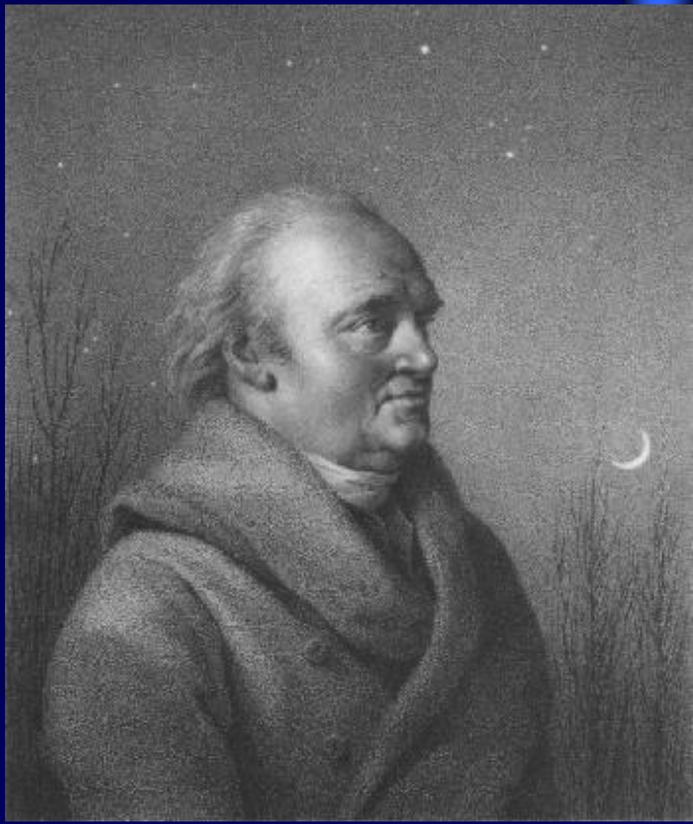
Exploring the Milky Way

- Appears as a milky band of light across the sky
- A small telescope reveals that it is composed of many stars (Galileo again!)
- Our knowledge of the Milky Way comes from a combination of observation and comparison to other galaxies



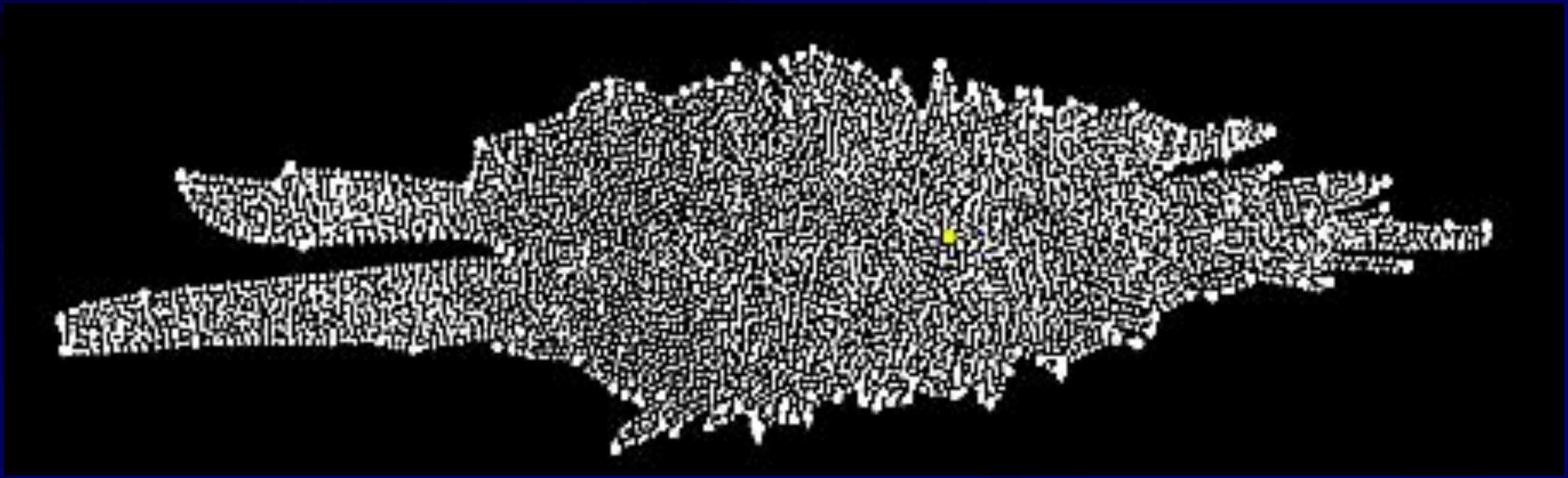
Herschel's Model of the Milky Way

- Simple model:
  - Assumed all stars have the same absolute brightness
  - Counts stars as a function of apparent magnitude
  - Brighter stars closer to us; fainter stars further away
  - Cut off in brightness corresponds to a cut off at a certain distance.
- Conclusion: there are no stars beyond a certain distance



Herschel's Findings

- Stars thinned out very fast at right angles to Milky Way
- In the plane of the Milky Way the thinning was slower and depended upon the direction in which he looked
- Flaws:
  - Observations made only in visible spectrum
  - Did not take into account absorption by interstellar gas and dust

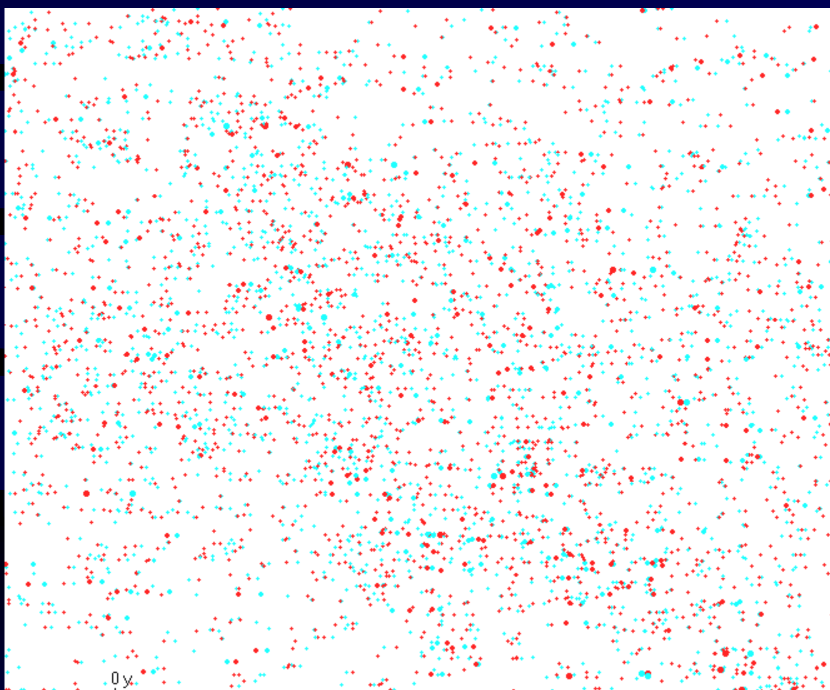


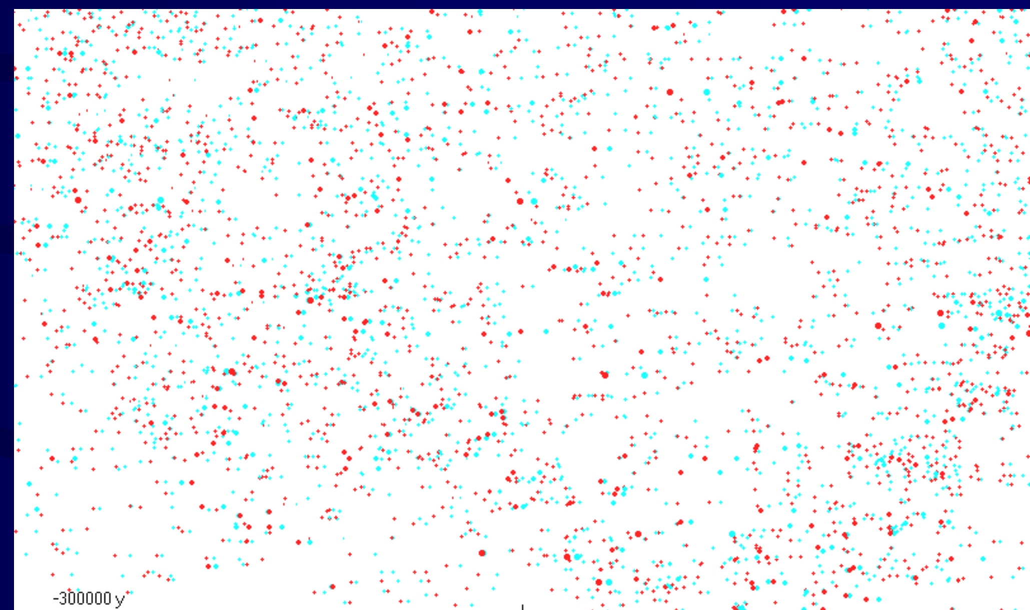
Herschel measures the Sun's velocity as it rotates around the center of the Milky Way

- Proper motion of stars is biased!
- Distribution of proper motions looks like snowflakes on the highway
- Seem to come from one point: the apex, or direction in which the sun is moving

- NOVA Video 4:23

Stars seem to drift away from the apex and towards the antapex





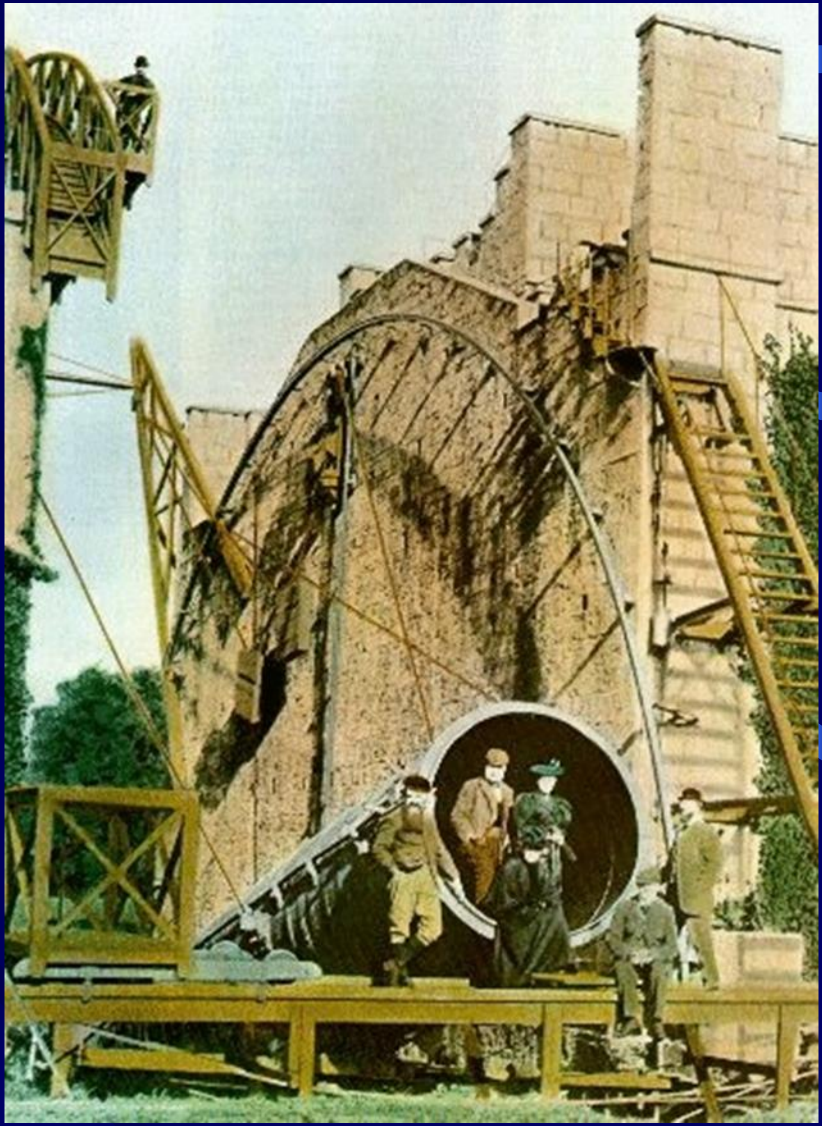
- The apex is the direction in which the sun is moving within the Milky Way (Wikipedia, Alexander Meleg)

Spiral Nebulae

- Data: Lots of nebulous spots known in the night sky
- Questions: What are they? All the same? Different things?
- Need more observations!

➔Build bigger telescopes

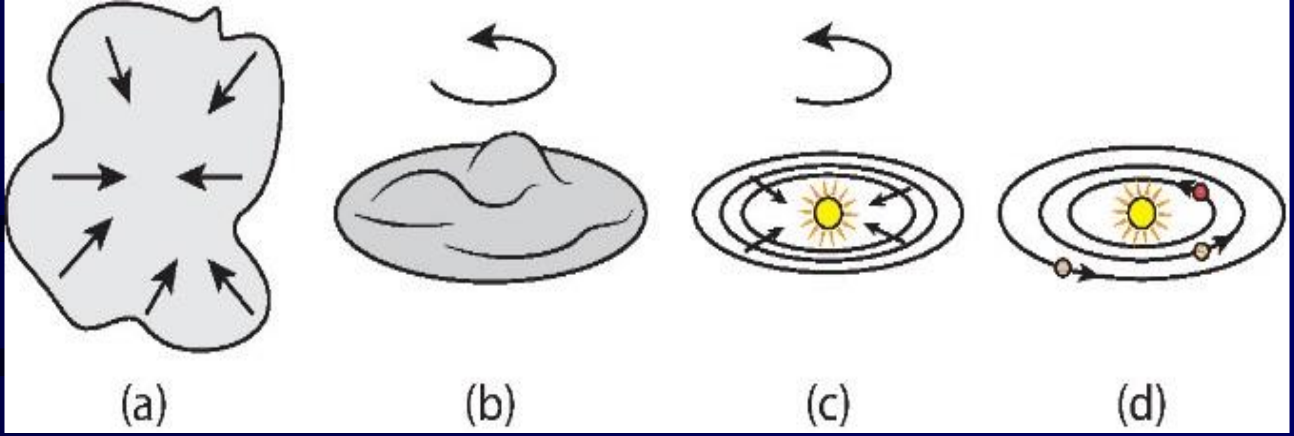
(Lord Rosse's Leviathan of Parsonstown shown, 1845. Biggest telescope until 1917)



The first nebula discovered to have spiral structure: M51 (Lord Ross 1845 vs Hubble Space Telescope)

First Toughts on the Formation of the Universe

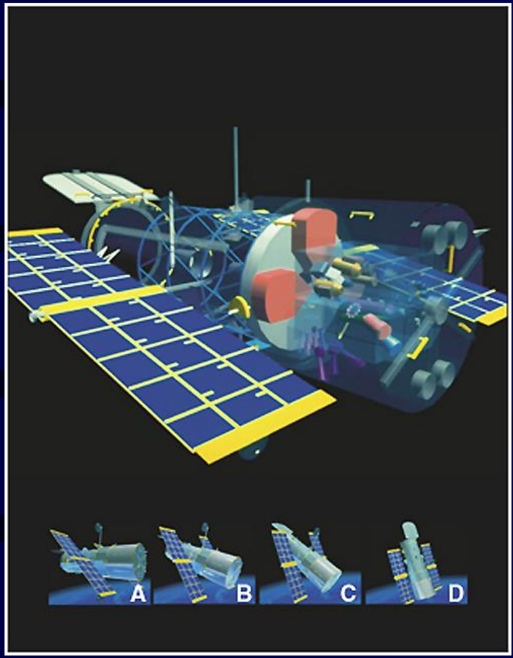
- Maybe milky way is just one of many “island universes”?
- If the cosmos is physical, let’s think about how it developed, came to be, formed
- Ideas from Thomas Wright (Milky Way is a lenticular star system), Immanuel Kant and Heinrich Lambert (rotation stabilizes a Newtonian and hierarchical universe)

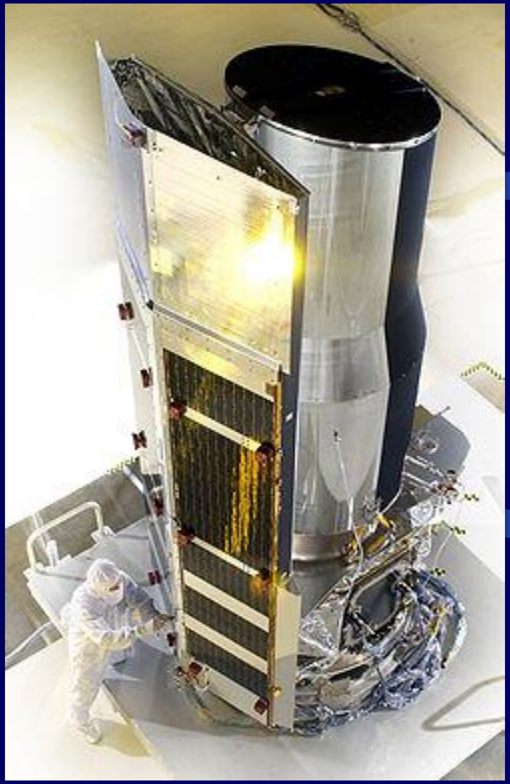


Kant's Nebular Hypothesis

- The galaxy and also the solar system may have formed from contraction and rotation of a giant gas and dust cloud
- The would explain why all planets orbit and spin counterclockwise
- Later extended by Laplace

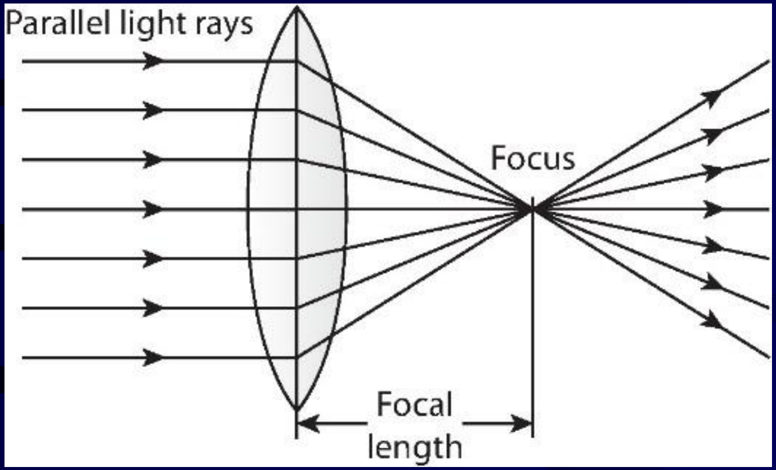
Telescopes

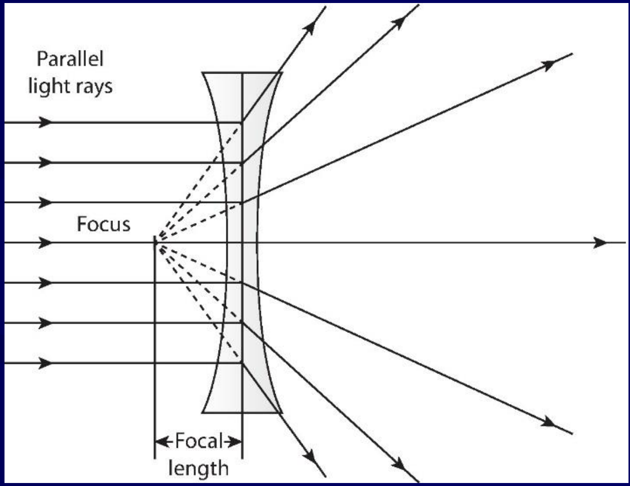


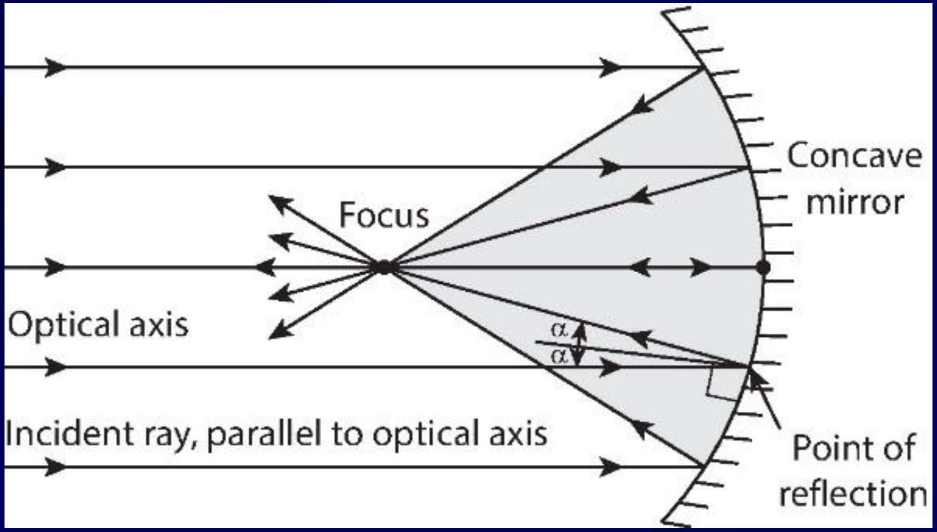


- From Galileo to Hubble, Chandra (X ray) & Spitzer (Infrared)
- Telescopes use lenses and mirrors to focus and therefore collect light

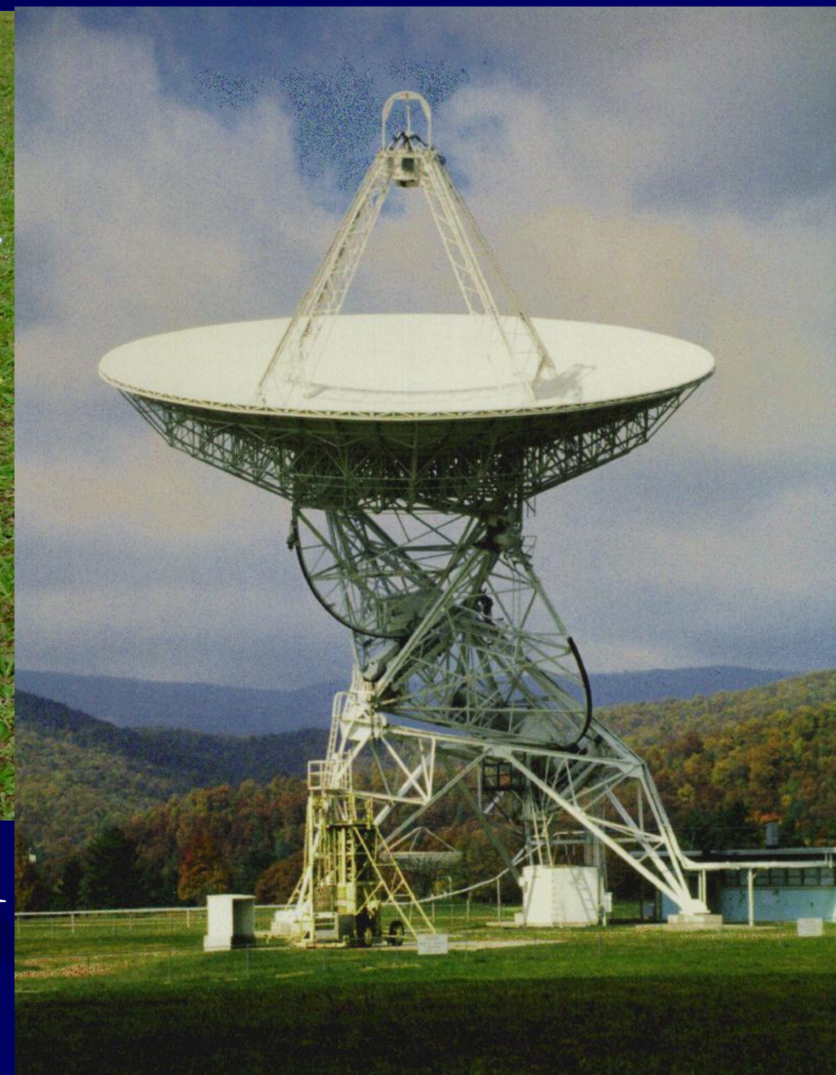
Two ways to focus light: Refraction (Lens) and Reflection (Mirror)







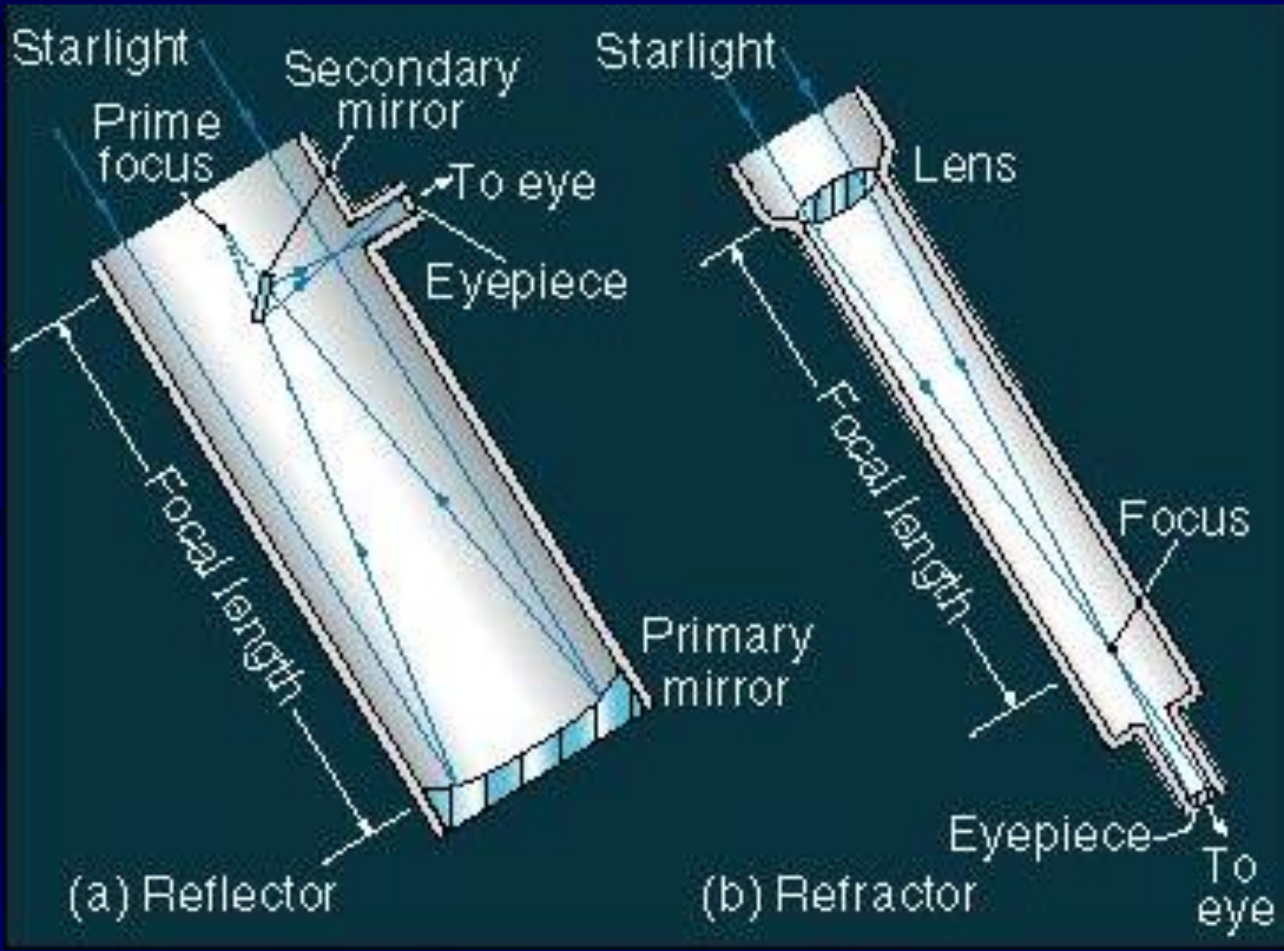
Rain analogy: Collect light as you collect rain



Rain/light collected is proportional to area of umbrella/mirror, not its diameter

Telescopes

- Light collectors
- Two types:
  - Reflectors (Mirrors)
  - Refractors (Lenses)

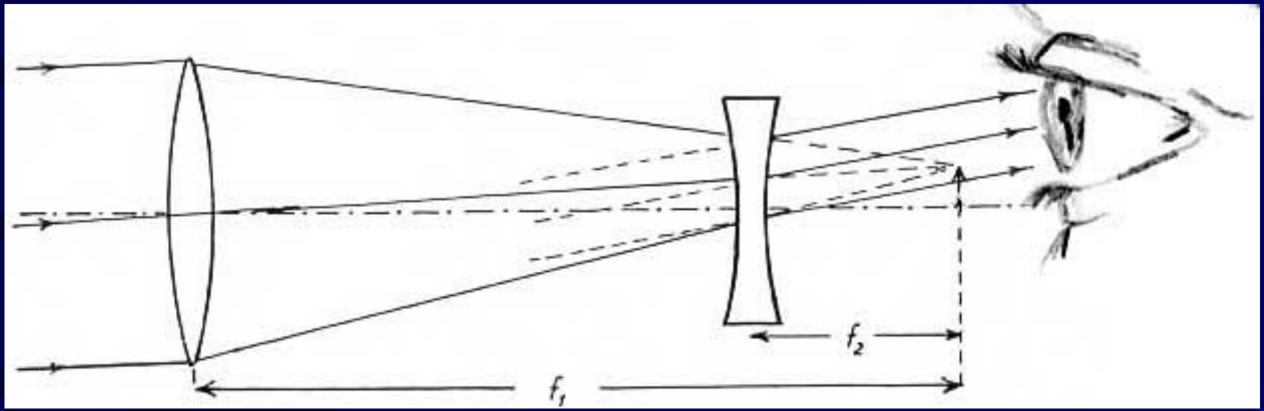


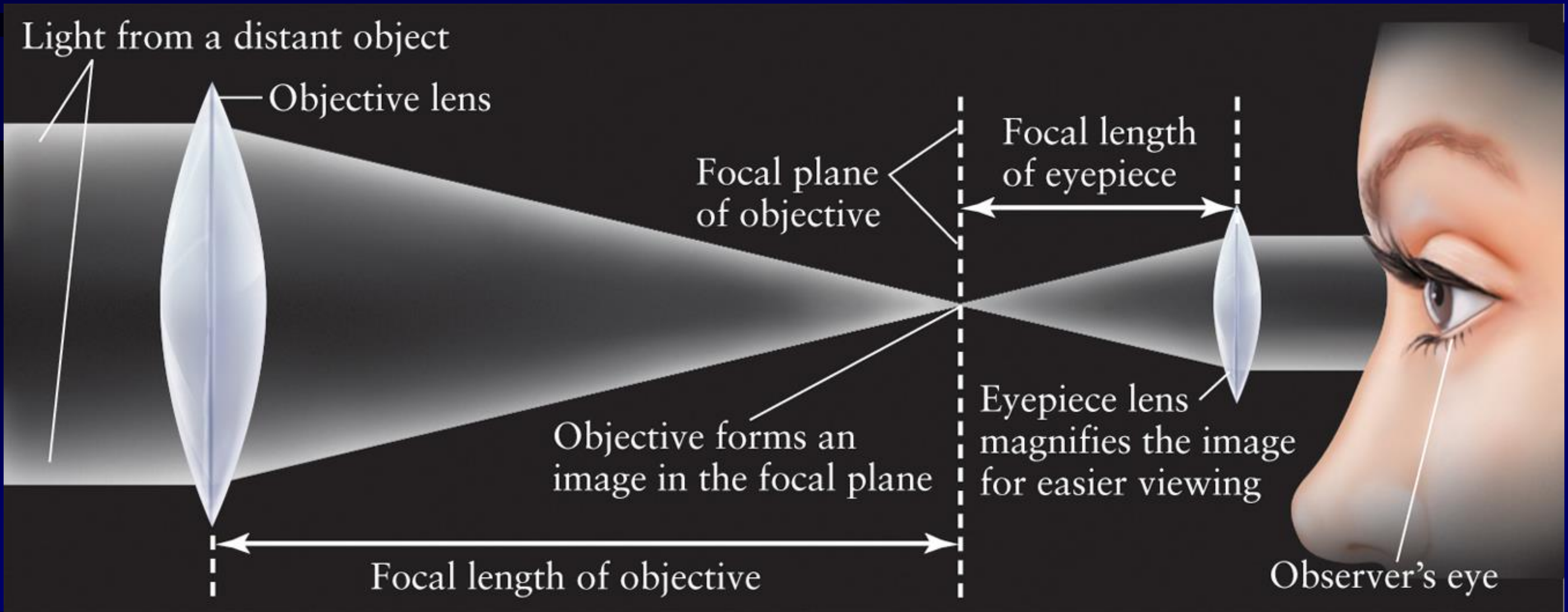
Brief History of Telescopes

- Around 1610: Galilean and Keplerian Telescopes “invented”
- 17th century: Aerial telescopes – extremely long focal length to reduce lens errors
- 1672 Newton invents the Reflector
- Around 1750: Dollond patents the achromatic lens
- Late 1700s: Herschel builds huge speculum reflectors
- 1858: Foucault invents silverized mirrors

Galilean & Keplerian telescopes

- G: converging and diverging lens, upright virtual image
- K: 2 converging lenses, inverting, real image



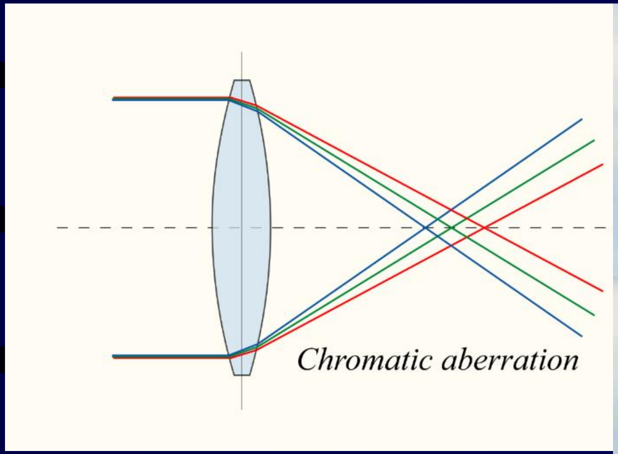


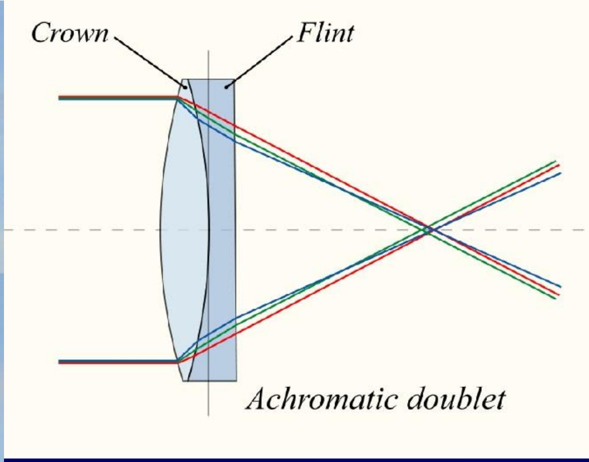
Magnification

- The magnification of a telescope can easily be changed by plugging in a different eyepiece with a different focal length
- $$M = \frac{\text{focal length of main lense or mirror}}{\text{focal length of eyepiece}}$$

Example: F= 2000mm, f = 40 mm → M= 50

Chromatic Aberration: different focus for different color light

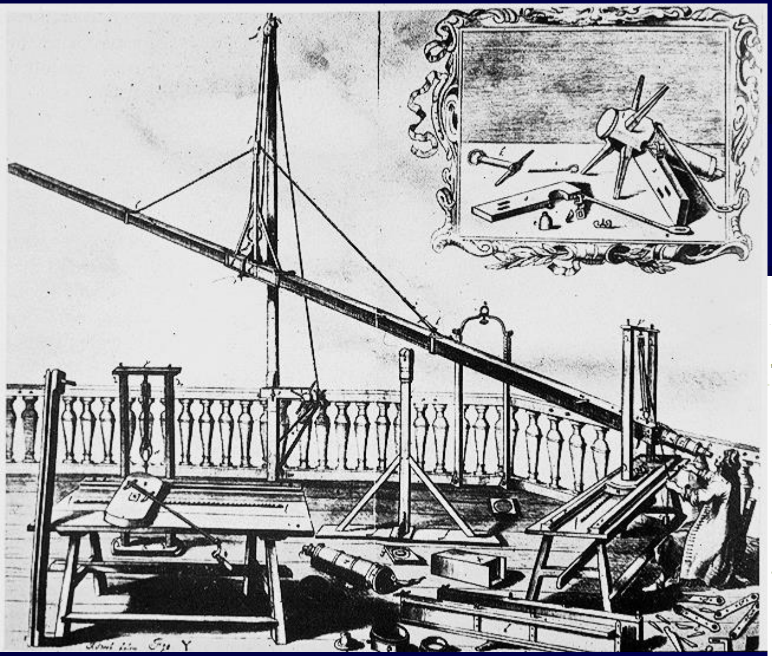


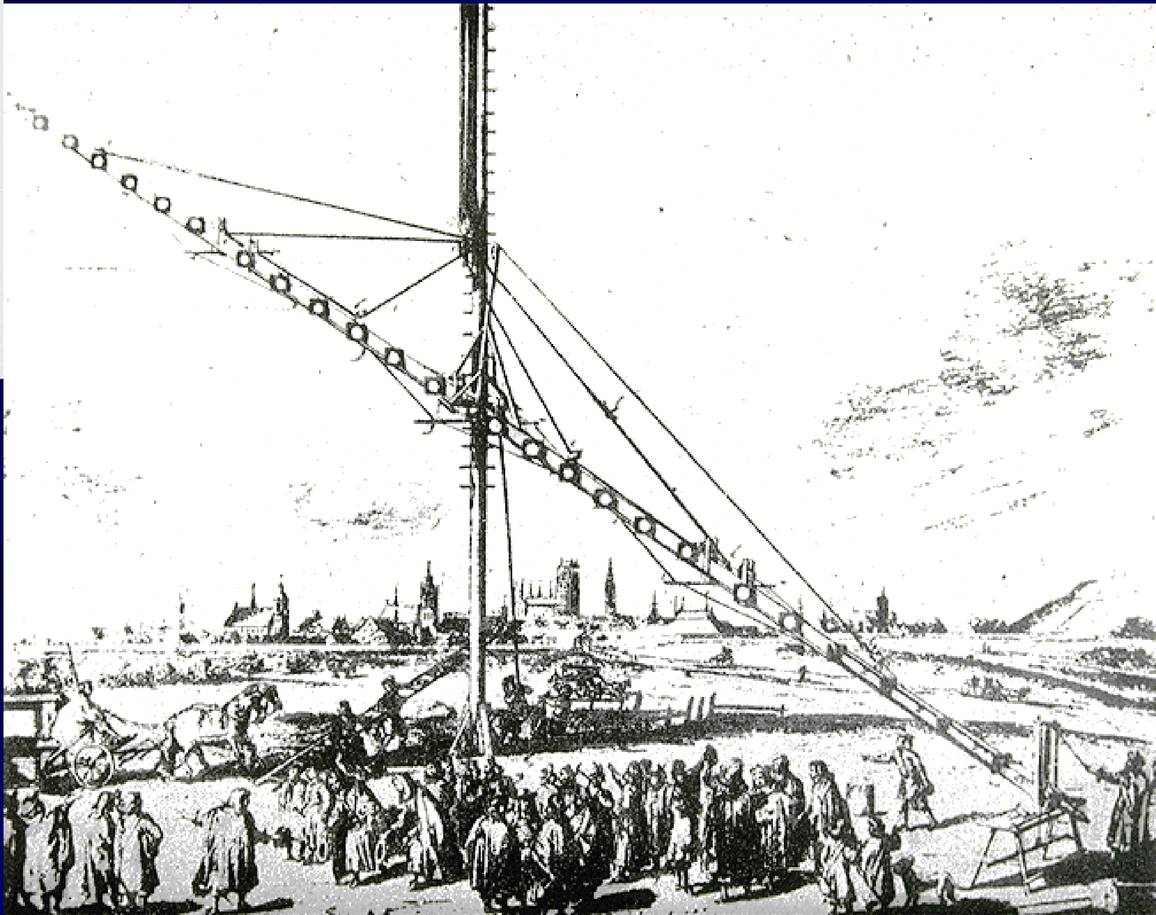


- Image is distorted and has colored edges
- The effect is diminished for very long focal lengths
- 1760s cure (Dollond): the achromatic lens, a combination of two lenses

(Images: Wikipedia; Demo: Large Lenses)

Aerial Telescopes to lessen Chromatic Aberration are unwieldy





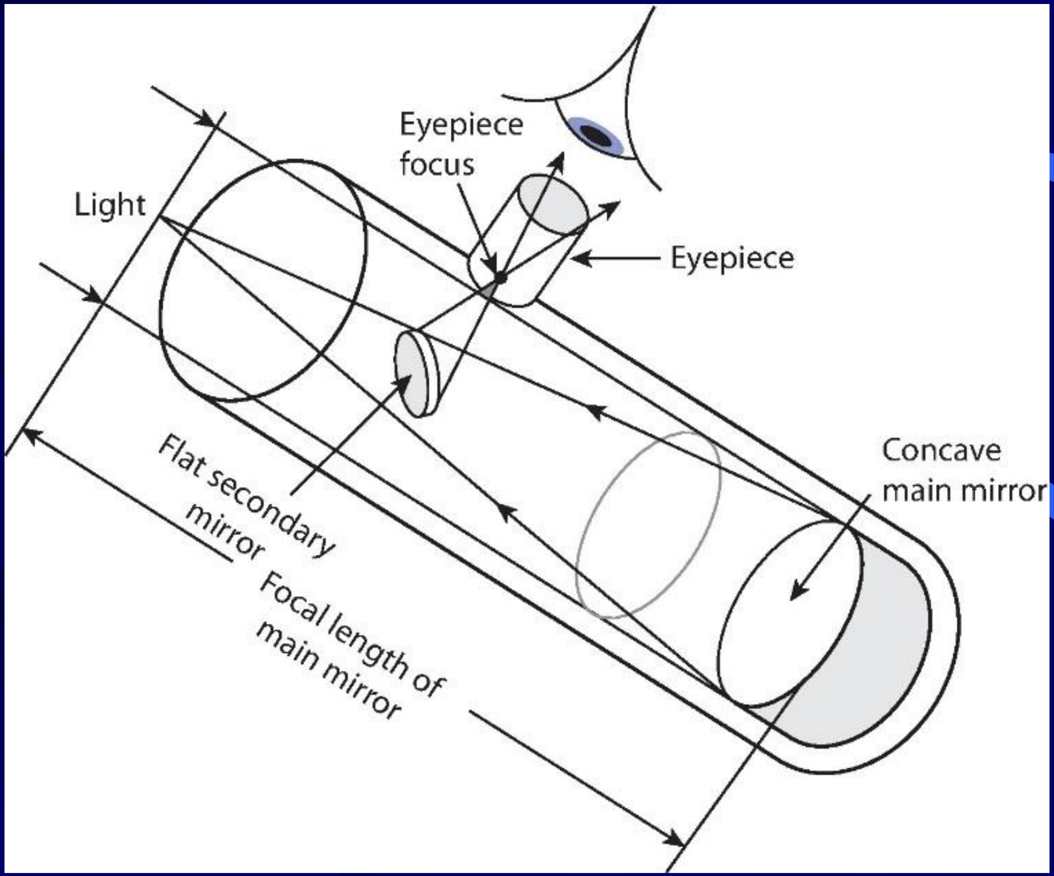
60 foot ^

140 foot ➔

Halley: useless

Newtonian Reflectors

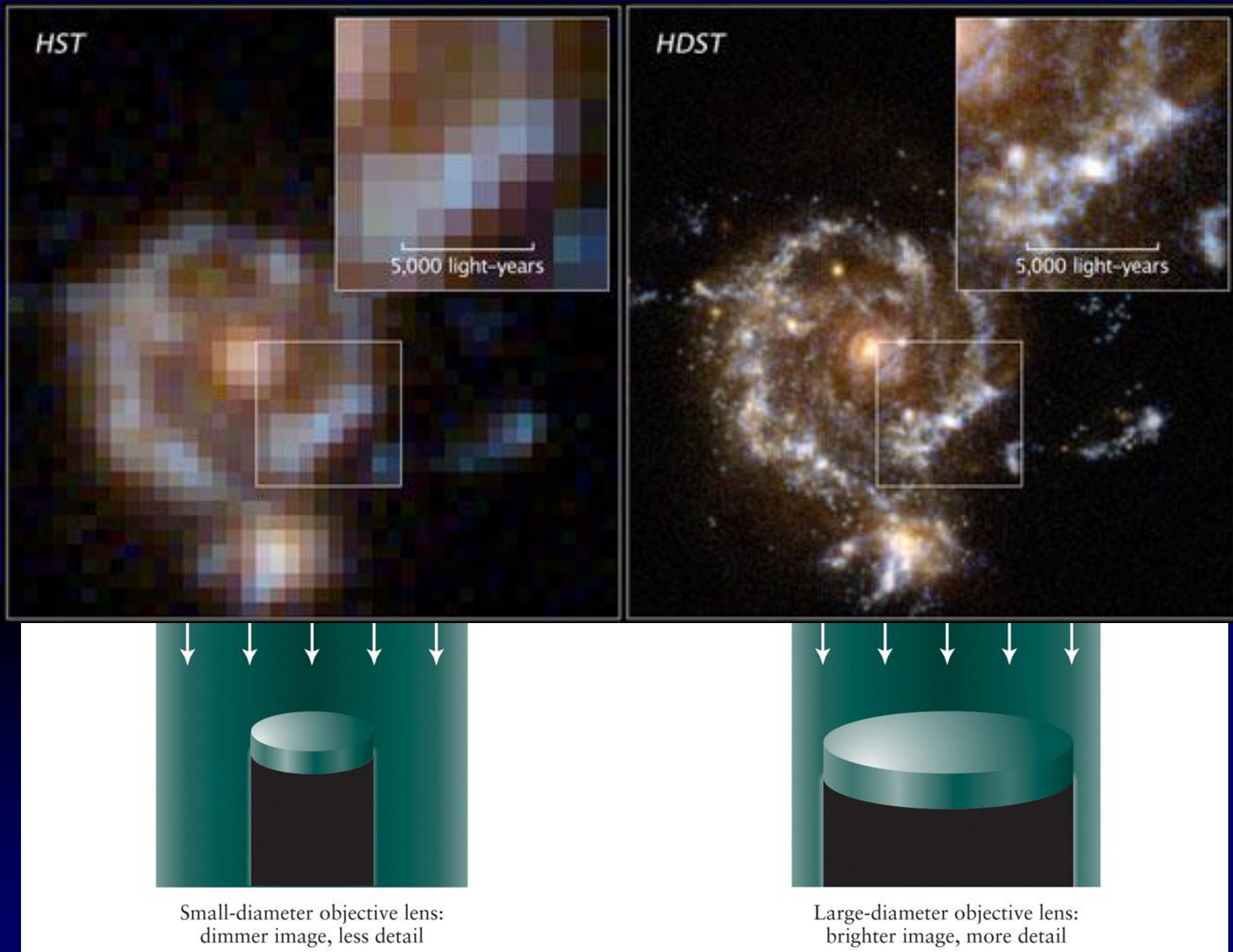
- Long tubes (approx. focal length)
- Open at front
- Eyepiece on side



Reflectors don't suffer from Chromatic Aberration!

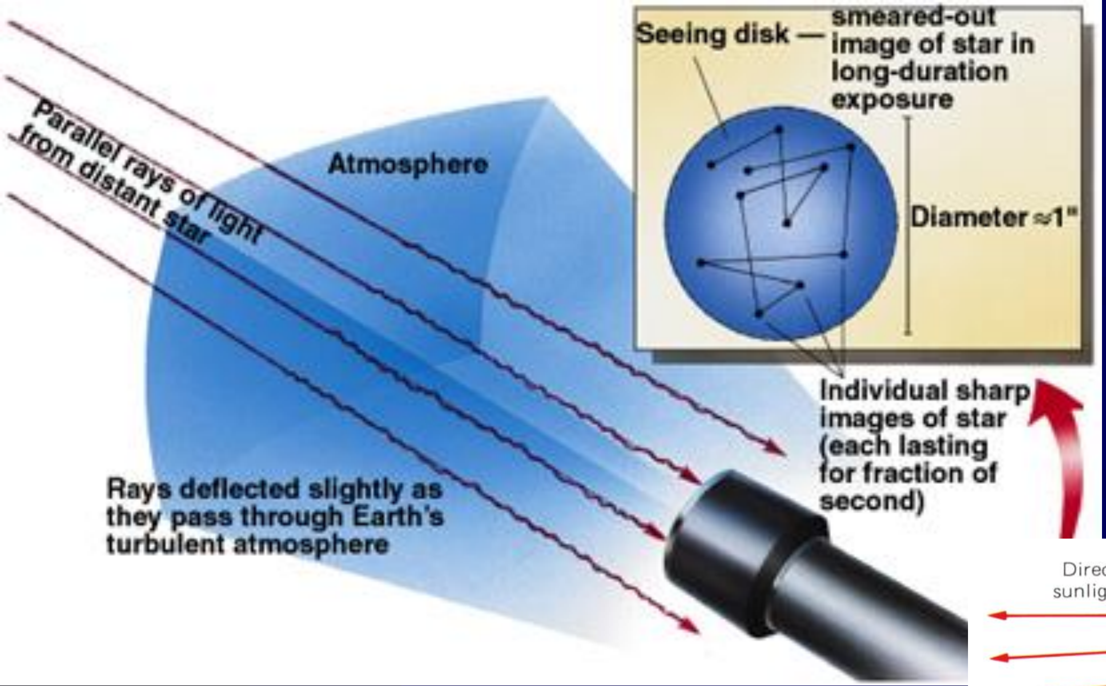
- Newton invents the Reflector
- Built around 1670
- Rather modest 2" mirror
- Disadvantage: Metal mirror! (up to 1850s)
- Speculum metal only reflects 66%

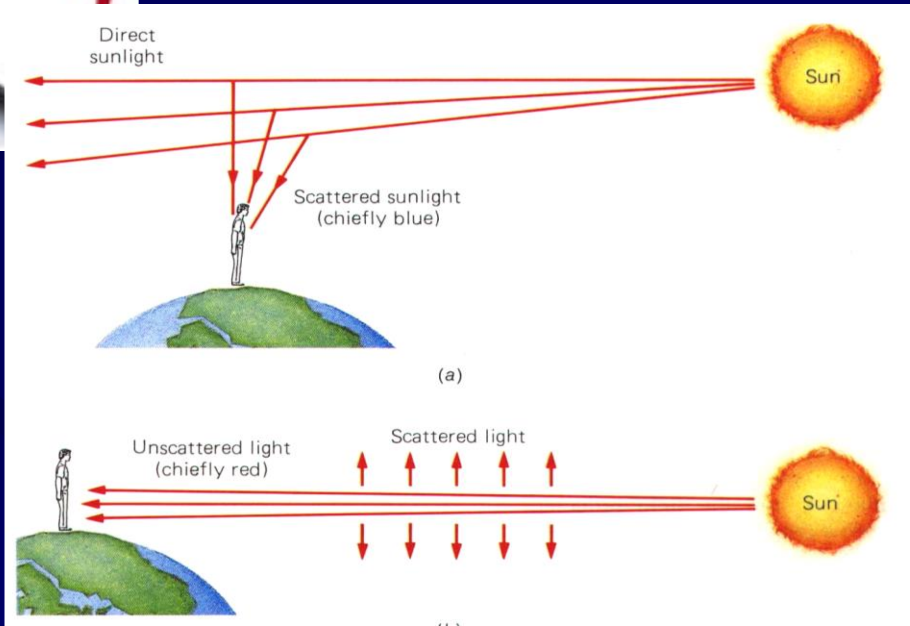
Resolving Power of Telescopes



Association of Universities for Research in Astronomy [AURA]

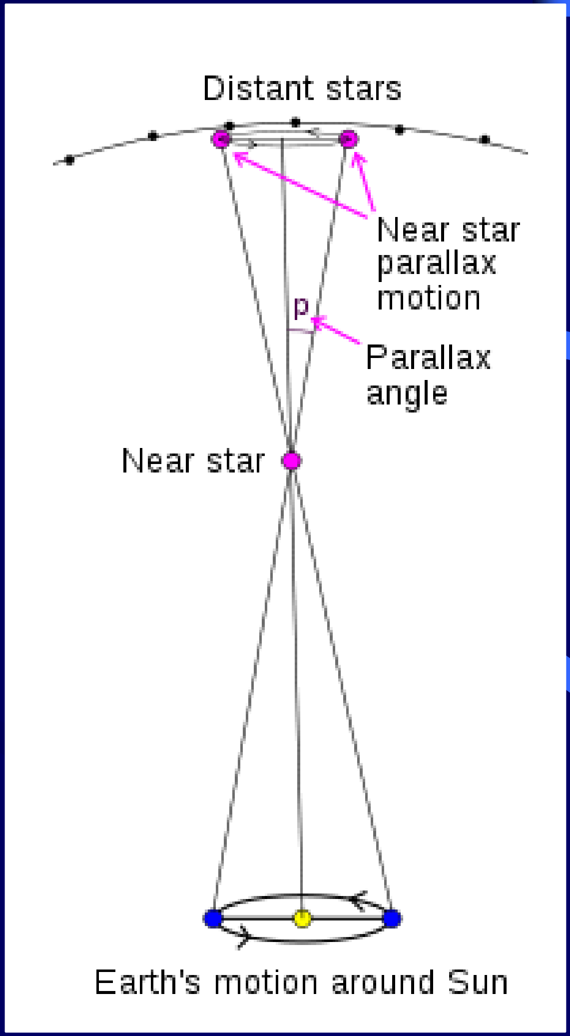
Atmospheric Limitations





The parallax is finally measured!

- Bessel in 1838 measures the parallactic angle of 61 Cygni to be p = 0.3136”
- This is 64x smaller than its aberrational motion (20”)
- Since d=1/p = 3.189 pc = 10.39 ly



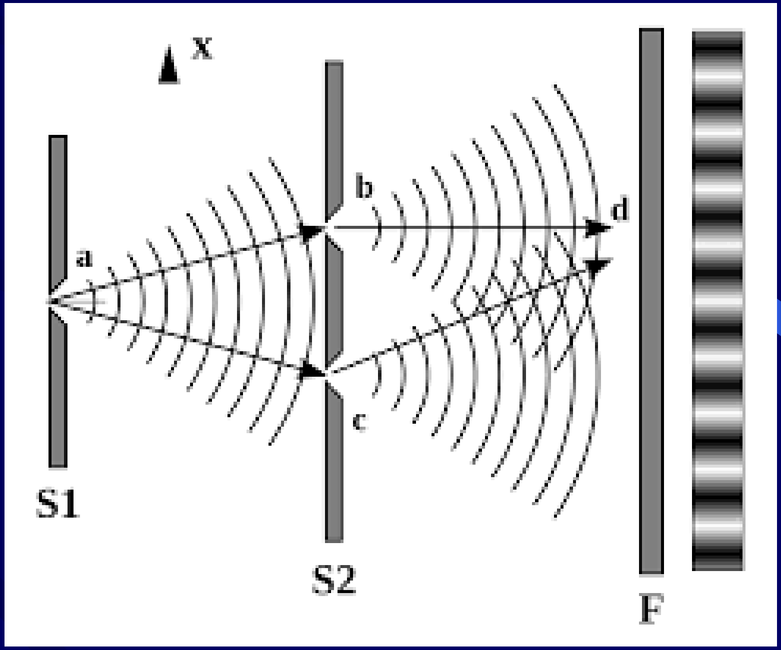
Activity: Telescopes

- Pick up a worksheet
- Form a group of 3-4 people
- Work on the questions on the sheet
- Fill out the sheet and put your name on top
- Hold on to the sheet until we've talked about the correct answers
- Hand them in at the end of the lecture or during the break
- I'll come around to help out !

Electricity + Magnetism = Electromagnetism

- Young 1801: light is wave, not a particle
  - NB: Bradley's explanation of stellar aberration assumed light is a particle
- Light interferes –
- it does not collide!
- Maxwell (1864):

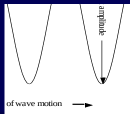
Speed of light (c) can be computed from the strength of the electric force and the strength of the magnetic force



Light is an electromagnetic wave

- The vast majority of information we have about astronomical objects comes from light they either emit or reflect
- Here, "light" stands for all sorts of electromagnetic radiation:
  - Visible light (400-700nm wavelength)
  - Infrared light (Herschel 1800, longer wavelength)
  - Ultraviolet light (Ritter 1801, shorter wavelength)
- Other forms:
  - Radiowaves: very long wavelength
  - X rays: very short wavelength
- All EM waves travel at the speed of light!

Waves

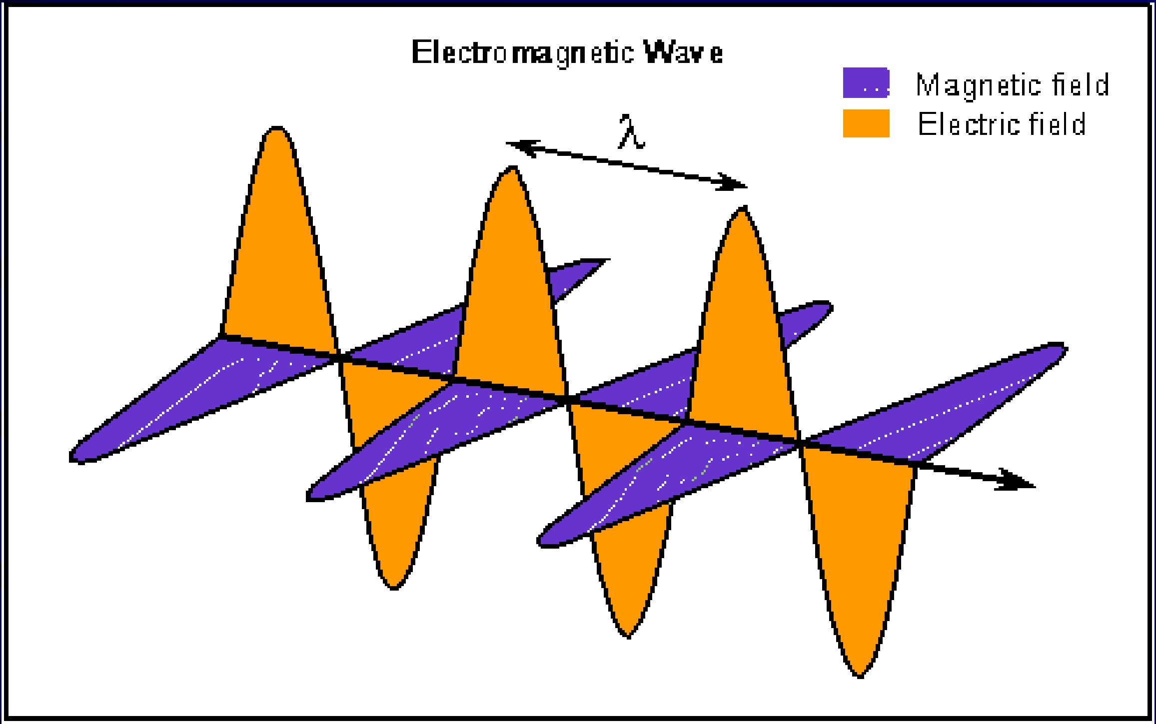


- Light is a type of wave (Demo: Slinky)
- Other common examples: ocean waves, sound
- Wave frequency: how often a crest washes over you
- Wave speed = wavelength (λ) × frequency (f)

Examples

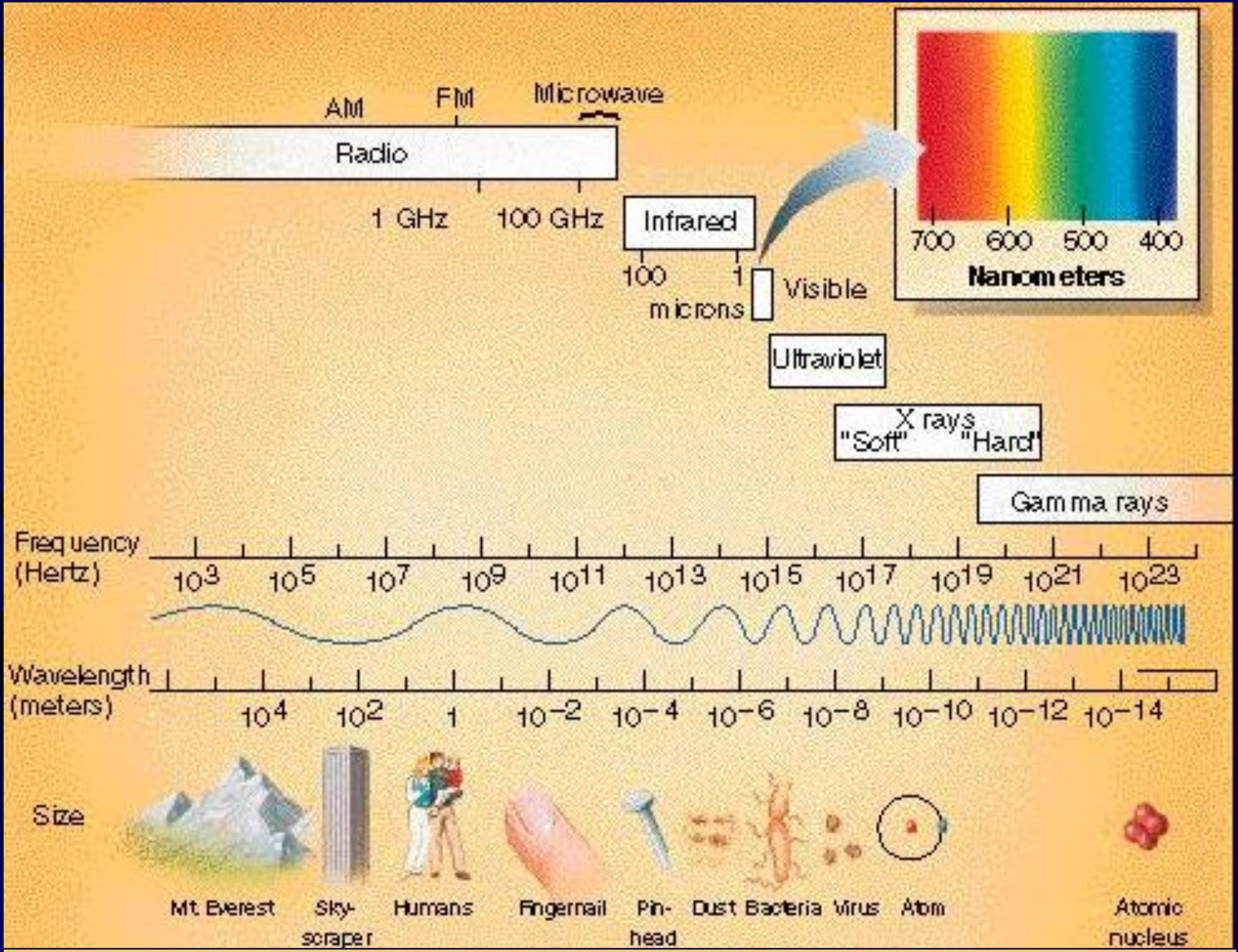
- λ= 500nm given, can compute frequency f = c/ λ = 300,000 km/s/500nm = 3/5x10$^{8-(-7)}$ 1/s = 6x10^{14} Hz
- λ= 1000nm given, can compute frequency f = c/ λ = 300,000 km/s/1000nm = 3x10$^{8-(-6)}$ 1/s = 3x10^{14}Hz
  - ➔ Twice the wavelength, therefore half the frequency!
  - ➔ Same speed (c)!
- f = 100 MHz given, can compute wavelength λ = c/f 300,000 km/s/(100x10^{6}Hz) = 3x10$^{8-8}$ m = 3m
  - ➔ A radiowave has very long wavelength, but same speed!

Electromagnetic Waves



- Medium = electric and magnetic field
- Speed = 3×10^5 km/sec = 3×10^8 m/sec
- The higher the frequency, the higher the energy of EM radiation ($E = h\,f$, where h is a constant)

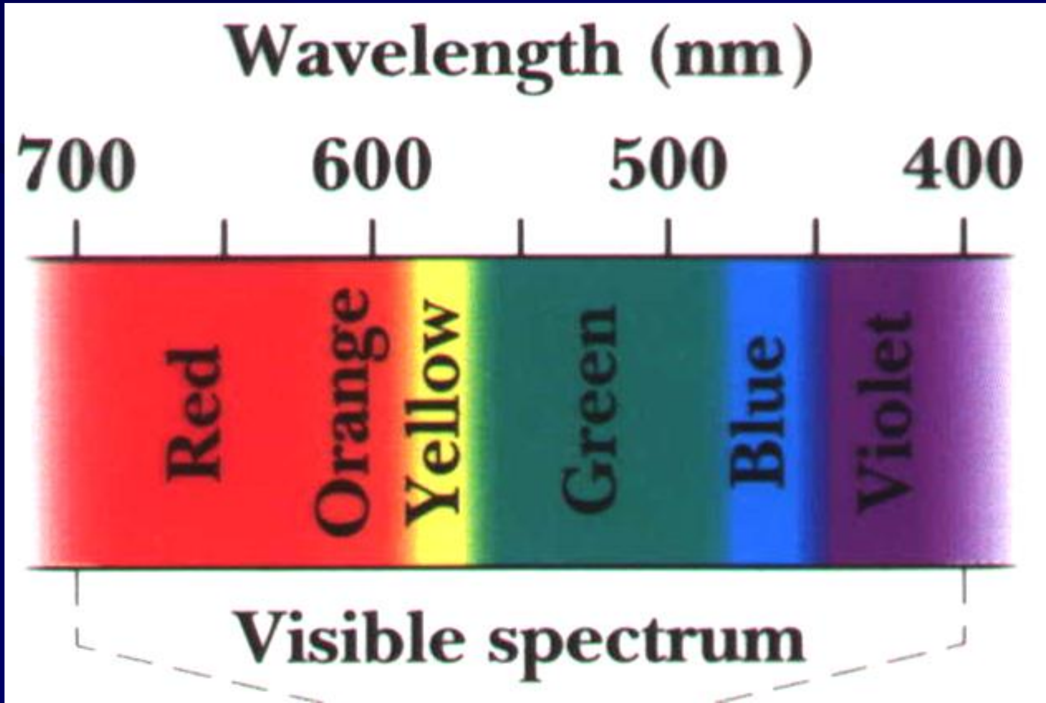
Electromagnetic Spectrum



Energy: low → medium → high

Visible Light

- Color of light determined by its wavelength
- White light is a mixture of all colors
- Can separate individual colors with a prism

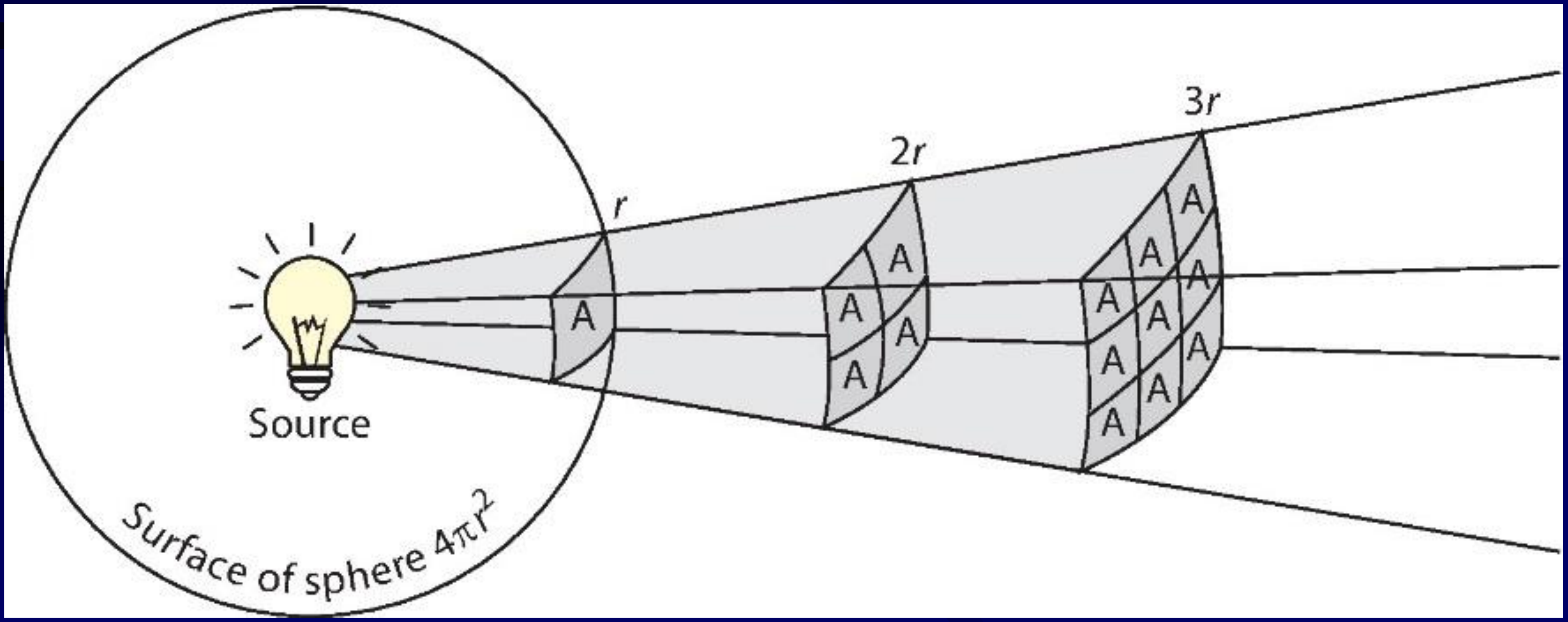


Observing Light: Brightness

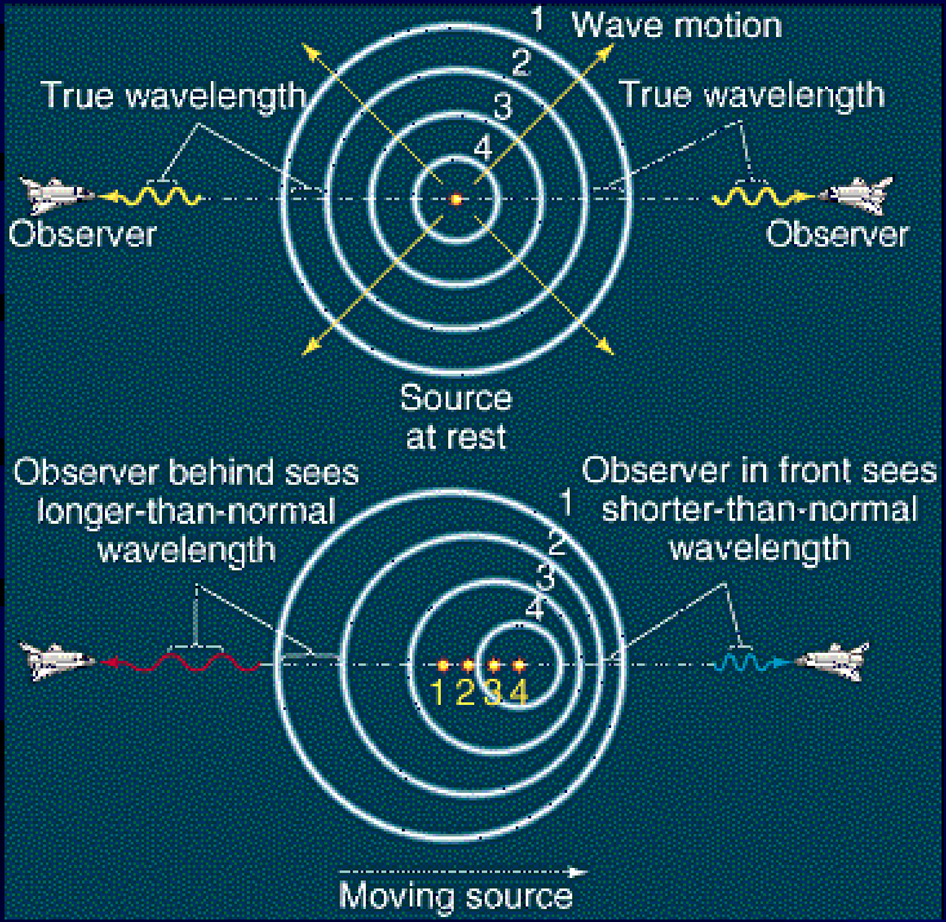
- Light spreads radially out from the source and appears dimmer from a distance r
- Brightness B falls off like inverse distance squared!
- The more light the light source sends out (luminosity L), the brighter it appears
- $B = L/(4\pi r^2)$

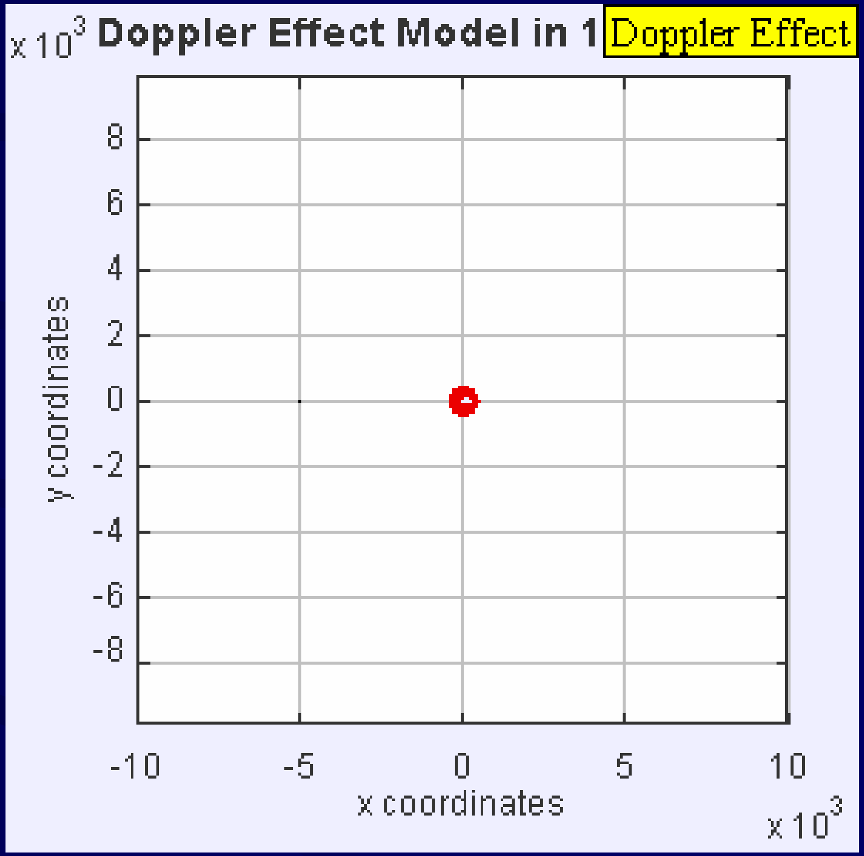
Why inverse quadratic?

- Because the influence "thins out" as the area of the sphere as the distance from the source increases (scales like area)



Observing: Doppler Effect (1842)





- Relative motion of source and observer shifts the wavelength

➔ If we observe a shifted wavelength, we can conclude that the source is moving relative to the observer! (Simulation:Wikipedia)

Use the Doppler Shift to measure Velocities

- Can use the Doppler shift to determine radial velocity of distant objects relative to us

- Transverse velocity can be measured from the motion of stars with respect to back-ground over a period of years
  - (Halley 1718: Sirius, Arcturus, Aldebaran moved since Hipparchus, 1850 years ago)