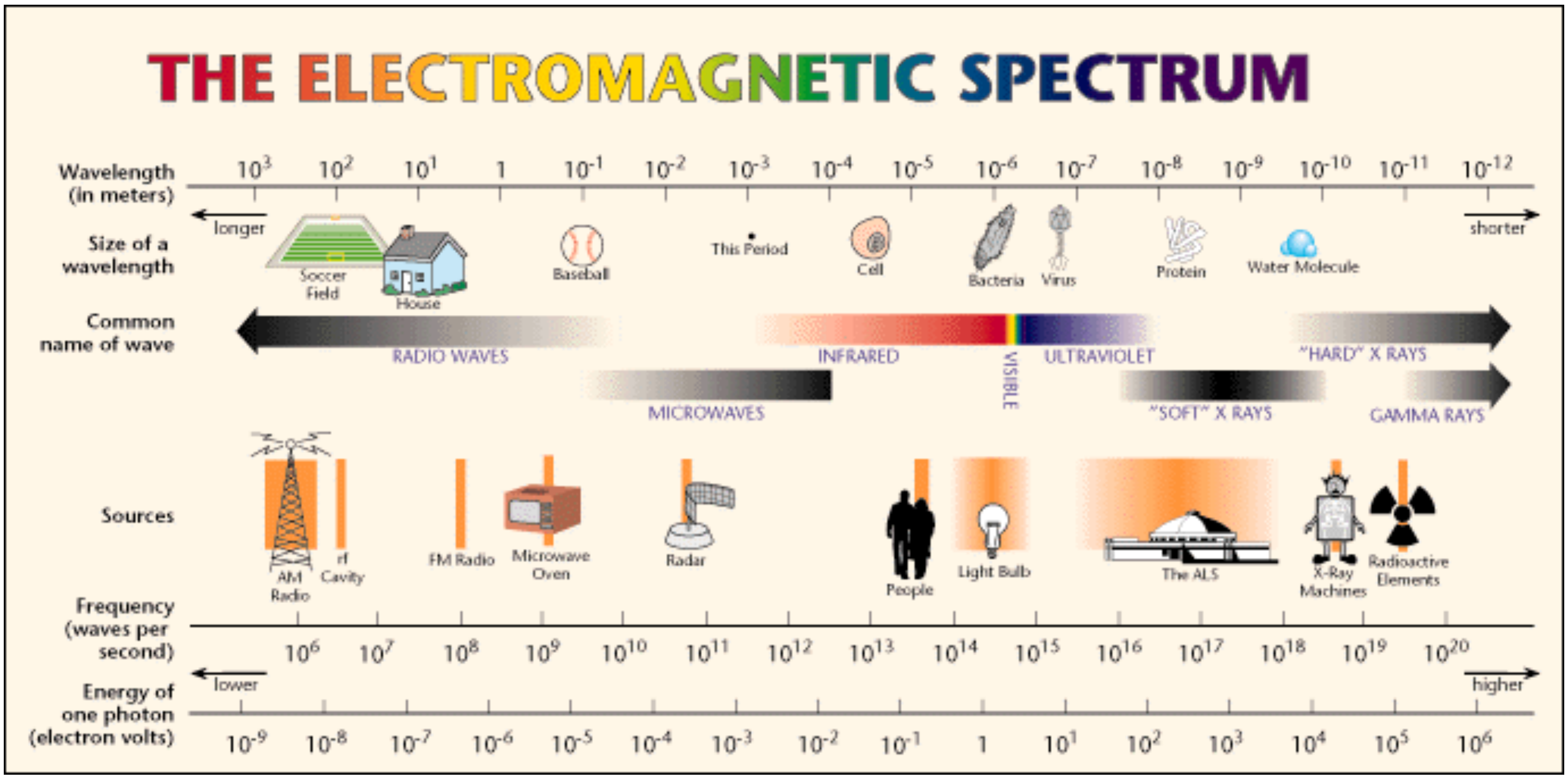
Review

- Light as both wave properties (freq. wavelength) and particle properties (photon is a discrete light unit)
- Speed of light constant in ALL rest frames – time and space "accomodates" this… (Einstein)
- Wavelength, frequency, speed: $v = \lambda \times \nu$ or
  - Speed = wavelength times frequency
- Energy: energy of a photon = constant X frequency
  - $E = h\nu$ or hc/λ, h = Plank's constant
- Spectrum: Continuous, absorption or emission
- The change of direction of light going from one medium to another is **refraction**.

Nature of Light

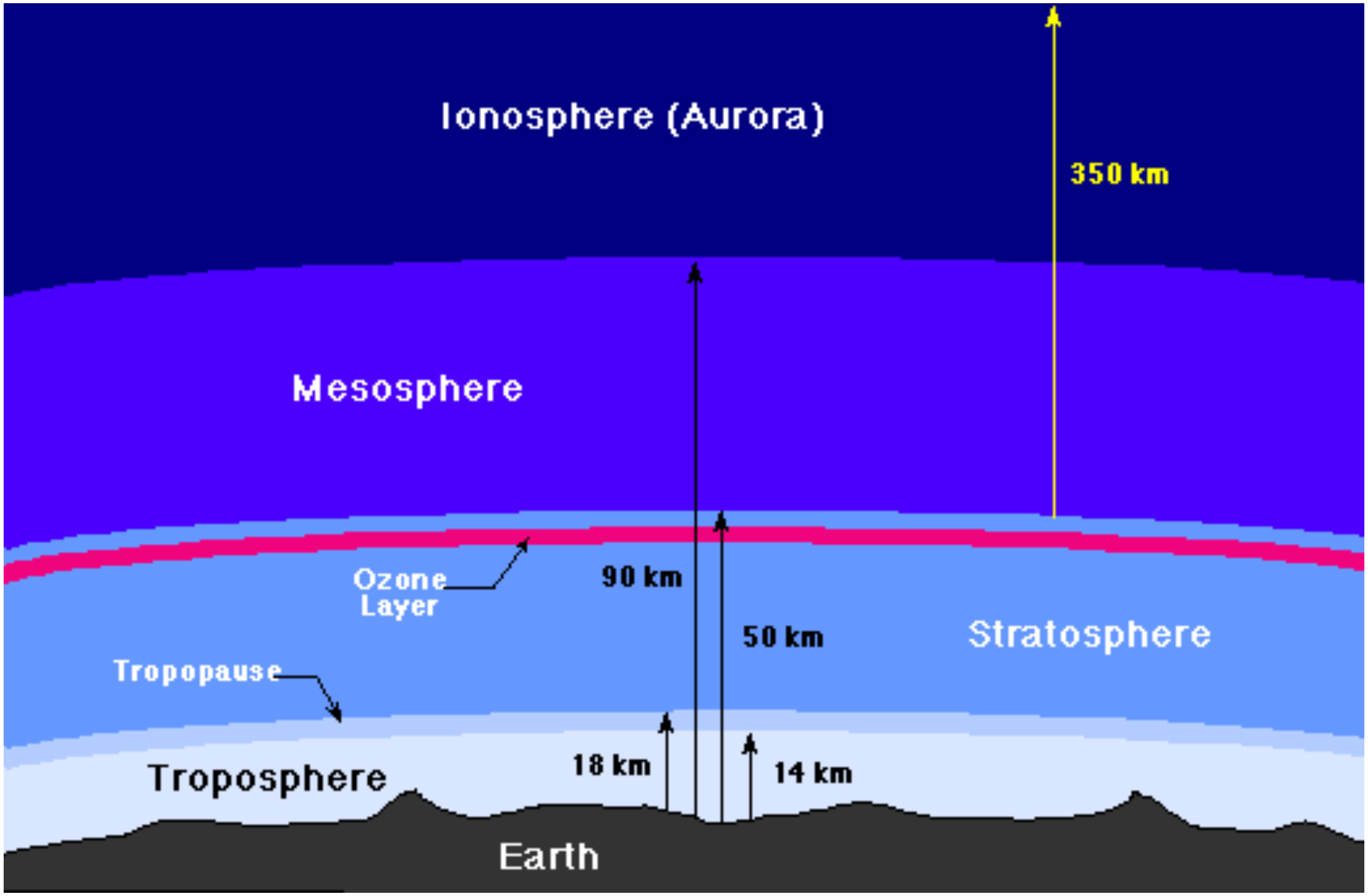
- Newton proposed that white is NOT a fundamental color and that light is composed of particles
- Light travels in quantum packets called photons, with qualities of both wave and particles. Visible light is only a small part of the electromagnetic spectrum
- Light can travel in a vacuum … fluctuations in electric and magnetic fields alternately, is its own "medium"



Light and Radiation

- Einstein proposed this "quantization" of light, with light of different energies having different frequencies
- The wavelength of a visible light photon is associated with its color. Visible light ranges from ~ 400 nm (violet) to ~ 700 nm (red).
- A blackbody "perfectly" absorbs EM radiation of ALL wavelengths. The relative intensites of emitted radiation depend only on temperature. Examples: stars, the entire Universe (Cosmic Microwave Background)
- Wein's Law: Peak wavelength emitted is inversely proportional to temperature. (Figure 3-42 in Comin).
- Stephan-Boltzmann: Hotter blackbody emits more radiation at every wavelength than does a cooler one.
- Spectra: Continuous spectrum with absorption lines and discrete spectrum with emission lines.
- Sine waves: Simpliest solution to "harmonic oscillator" problem: $F \sim \Delta x$ which is: $ma = md^2x/dt^2 \sim \Delta x$

The Atmosphere



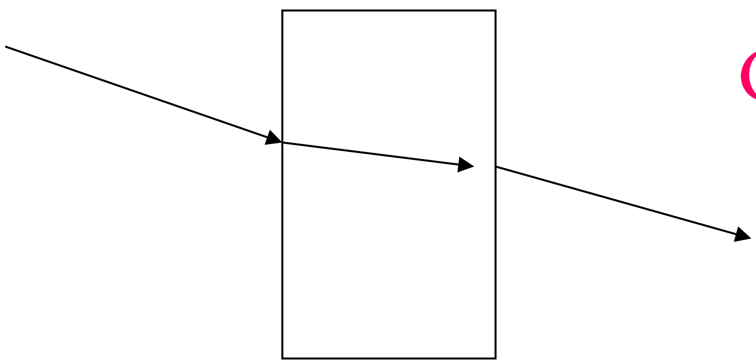
- Atoms are ionized
- Colder vs. elevation
- Airflow is mostly horizontal
- Weather (convection)

The Atmosphere (cont)

- The twinkling of the stars in a result of atmo. density fluctuations .
- Ozone layer shields from UV (lesser in the last 50 years, but has stabilized).
- Shorter ultraviolet wavelengths of light contain more energy than the infrared or visible portions of sunlight that reach Earth's surface. Because of this, UV photons can break atmospheric chemical bonds and cause complex health effects.
- UV-A (from 320 to 400 nanometers) — cause sunburn and cataracts. Yet, UV-A can also improve health by spurring the production of Vitamin D, a substance that's critical for calcium absorption in bones and that helps stave off a variety of chronic diseases.
- UV-B, (from 320 to 290 nanometers), damages DNA by tangling and distorting its ladder-like structure, causing a range of health problems such as skin cancer and diseases affecting the immune system.

Lenses, Mirrors,Telescopes

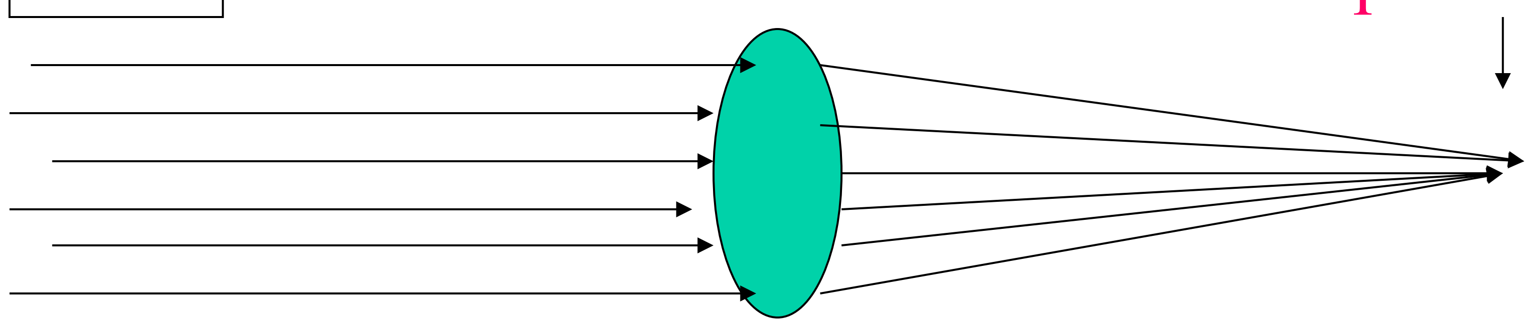
- Refraction: light is bent at the surface between two media
- Spherical (parabolic) surfaces can focus light-collect over large area and gather to small area (parabolic is better)
- Bend angle varies with color/frequency



Glass will “bend” light

Focal point changes with color

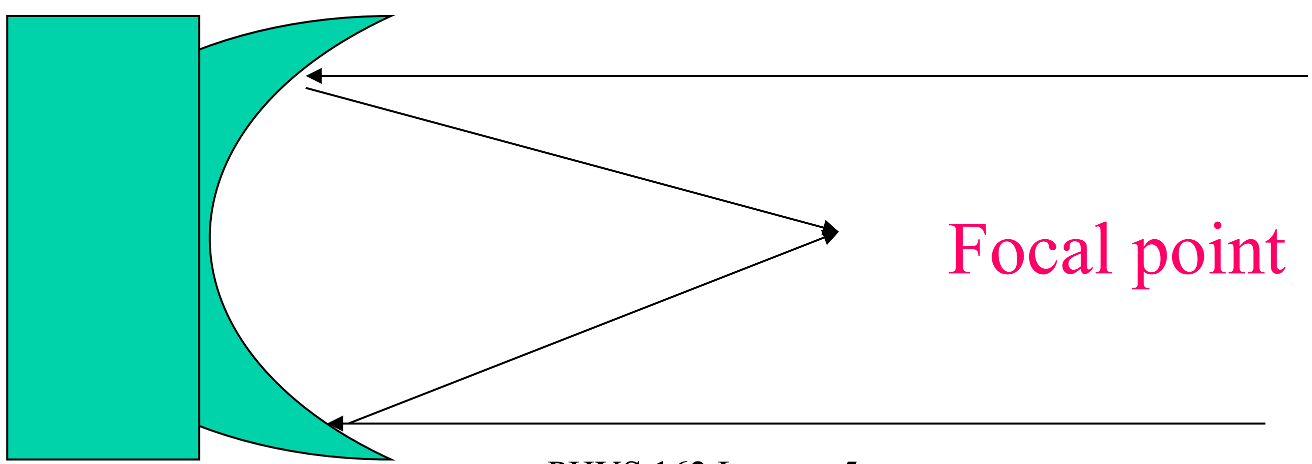
Convex lens and focal point



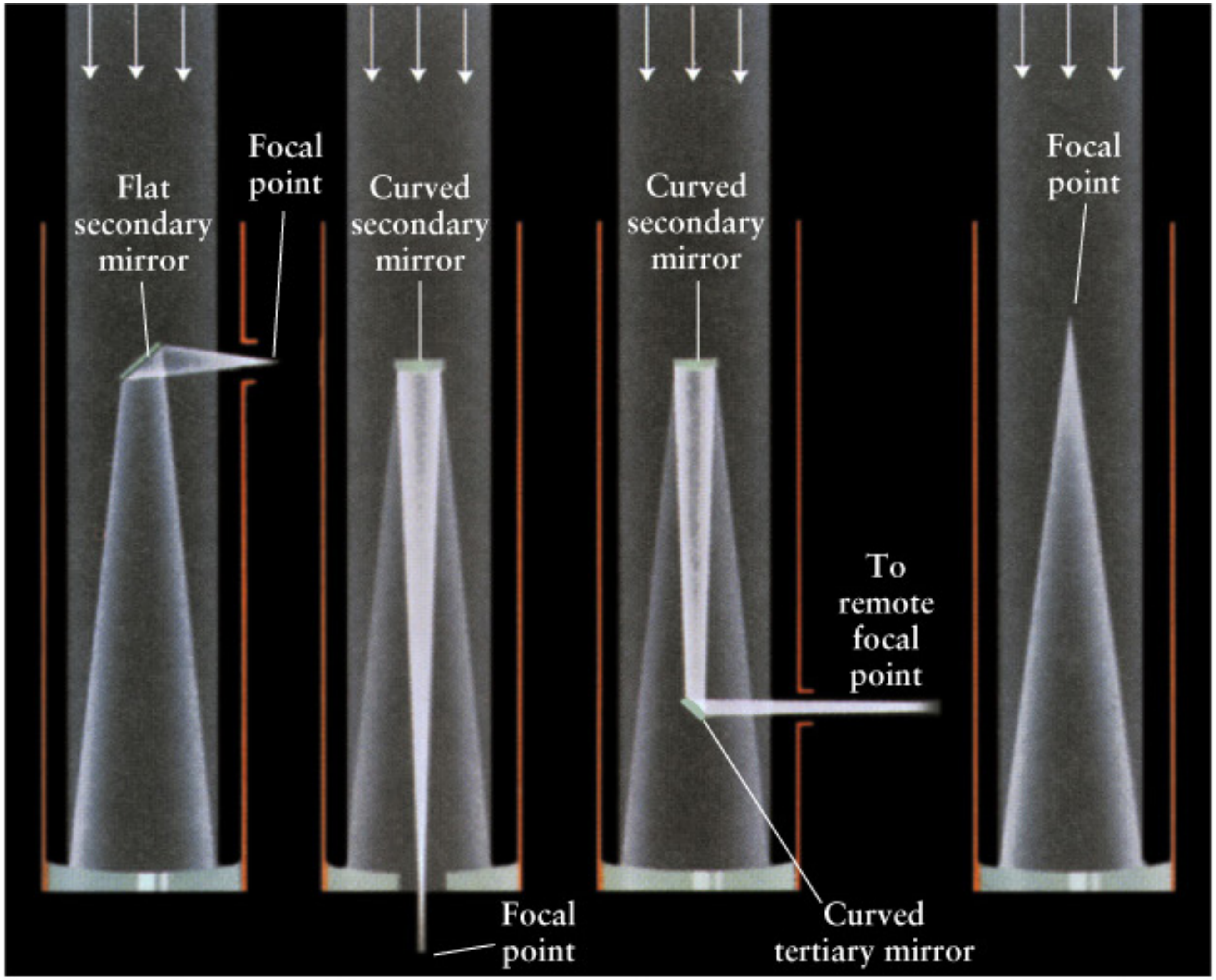
Reflecting Mirrors

Most big telescopes made from mirrors

- easier to make (especially if large up to 6 m). Only one "good" surface needed
- same focal point for all frequencies
- can make out of many (1000s) of small elements which can be computer controlled to adjust focal point (improves resolution)



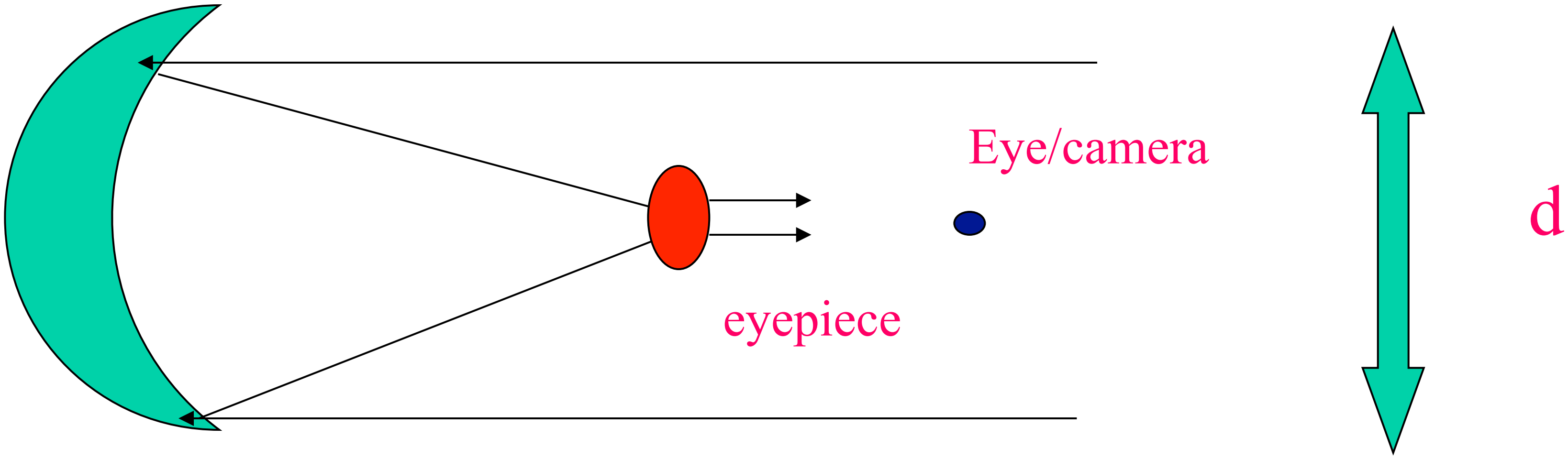
Reflecting Mirrors



a Newtonian focus
b Cassegrain focus
c Nasmyth focus or coudé focus
d Prime focus

Applications

- Collect more light. Depends on area of primary lens = $\pi(d/2)^2$
  d=aperture

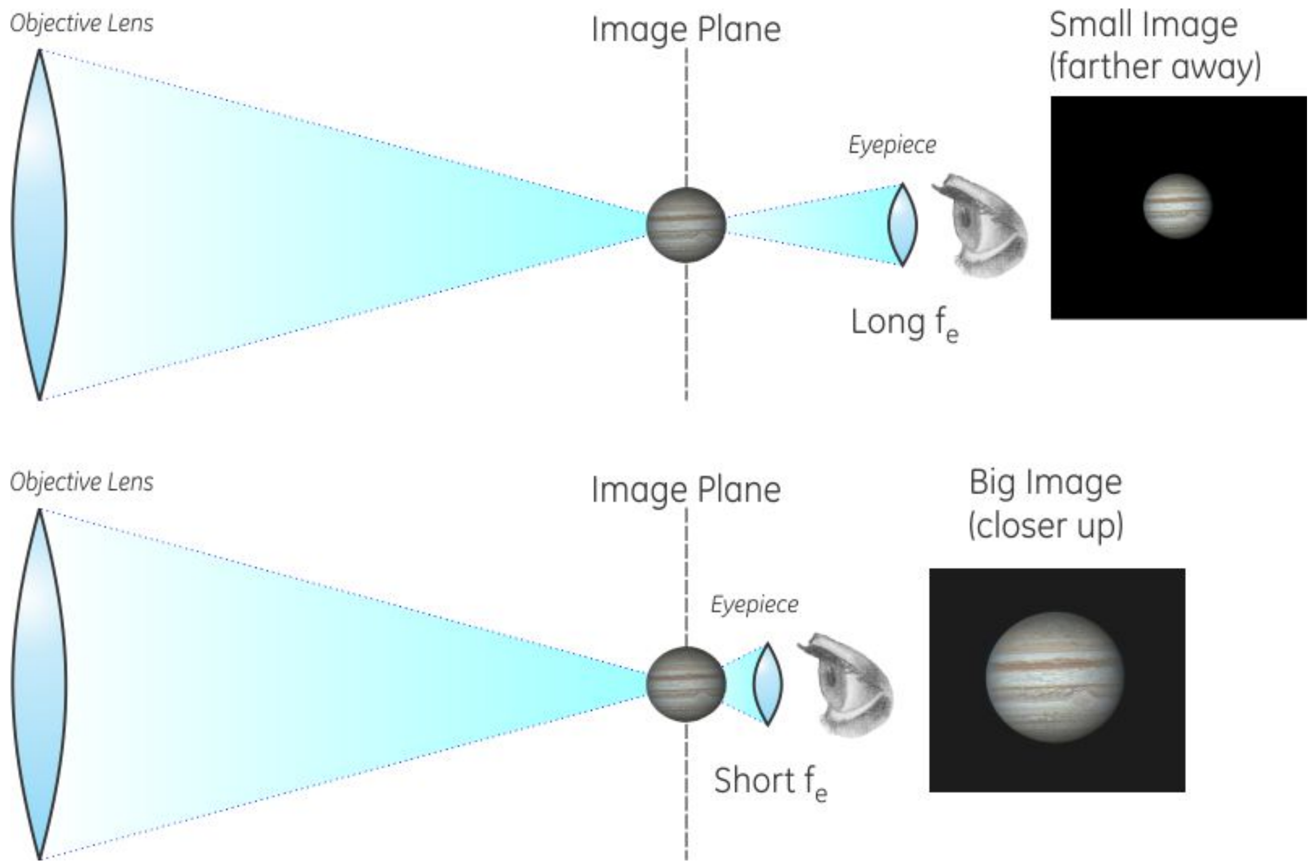


$$\text{Magnify.: Power} = \frac{\text{(focal length primary)}}{\text{(focal length eyepiece)}}$$

telescopes are mostly used to collect more light with angular resolution and aperture being crucial criteria. Magnification usually not important

Magnifying Power

The objective lens brings the image to a focus. The eyepiece, with a much shorter focal length, lets you get very close to that image to look at it, and – when you get closer, the image is bigger.



Telescope Quality

- Light gathering

  bigger mirror and/or sensitive electronic cameras

  can "see" dim objects < 10^{-9} unaided eye

- Angular Resolution (or "Vision") depends on mirror quality. atmospheric turbulence limits to

  1 arc second (1/3600 degree). But placing telescope outside the atmosphere, or using correctable lens surface or digitally correcting can reduce distortion.

Hubble Space telescope (and some on earth's surface) have 1/20 arc-second resolution

Detecting Light (not on tests)

- Human Eye

  cannot easily “save” information

  cannot collect light over long lengths of time

- Photographic Film

  - long time exposures-telescope needs to move opposite to Earth’s rotation

  - can filter to “see” different colors

- Electronic Devices (CCD, what is in video/digital cameras)

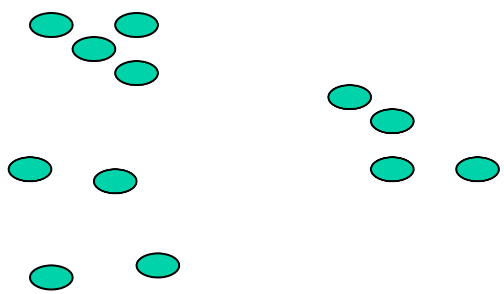
  - much more sensitive than film (~1,000,000)

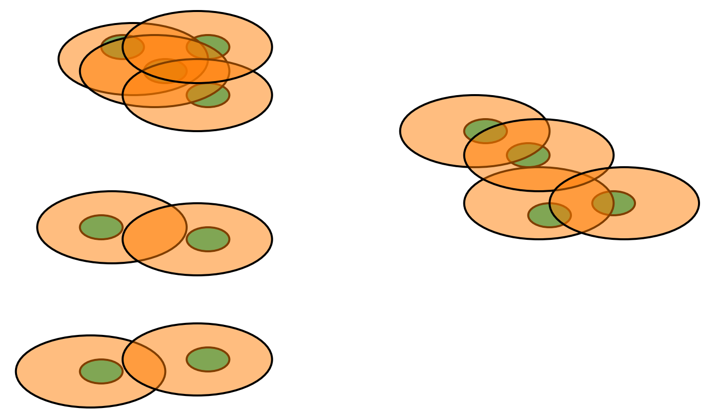
  - have amount of light versus time (instead of just sum). Can statistically remove effects of atmospheric twinkling or look for rapid variations

  -data easier to collect, to make available to others, to analyze

“Vision”

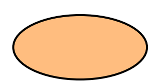
- Good angular resolution allows 2 close objects to be clearly separated. Same as good “vision”





Good resoultion.

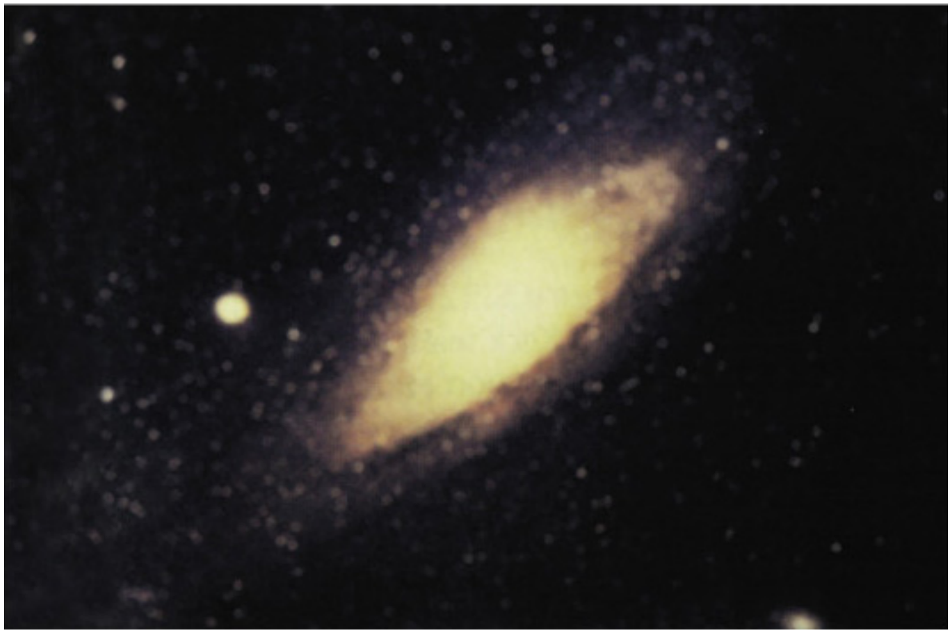
See 12 objects

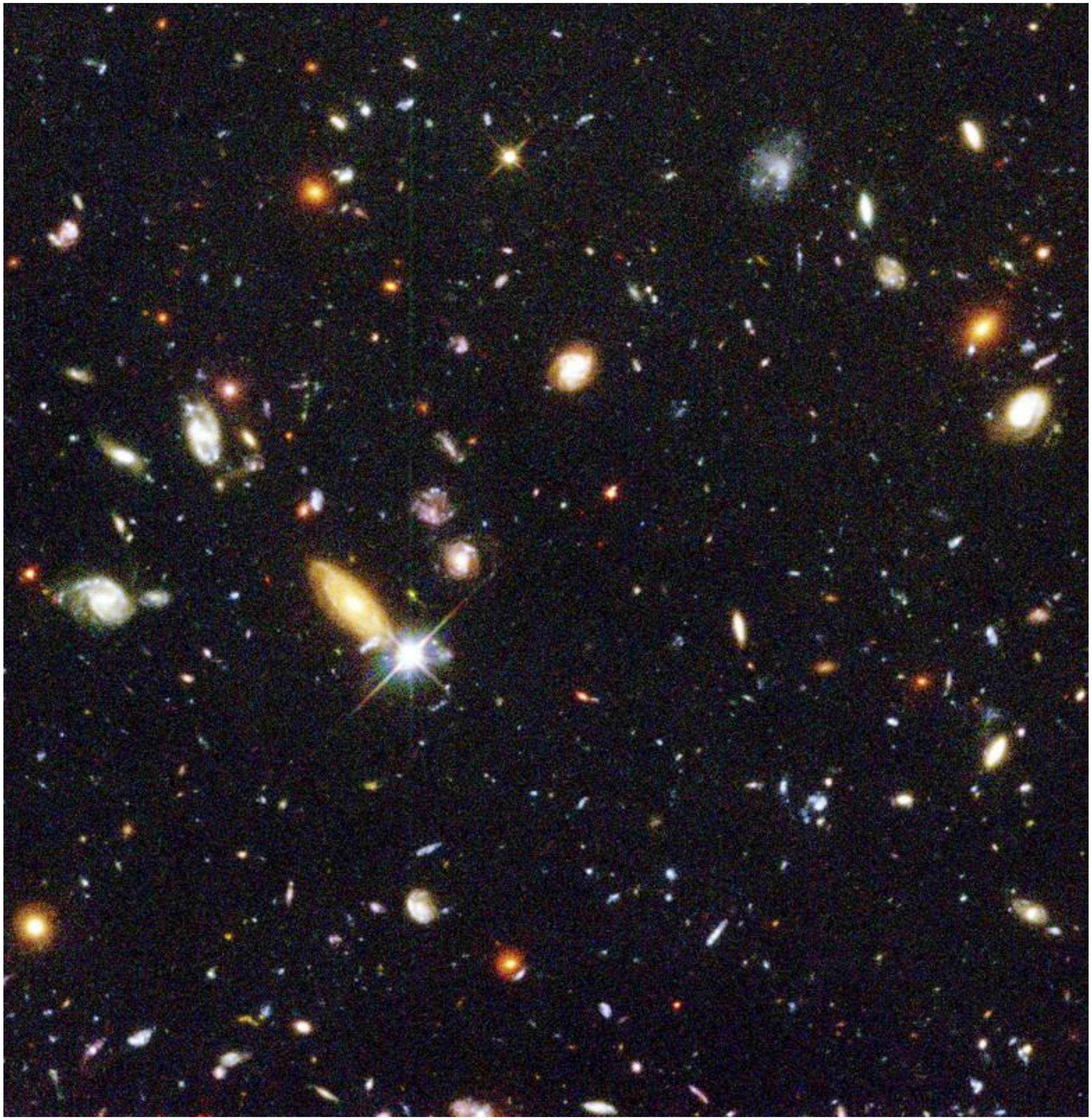


Bad Resolution 3 times

worse. Separate 4 objects

Telescope Quality – Resolution
Poor vs Good





Good Resolution plus long time exposure → deep space

images

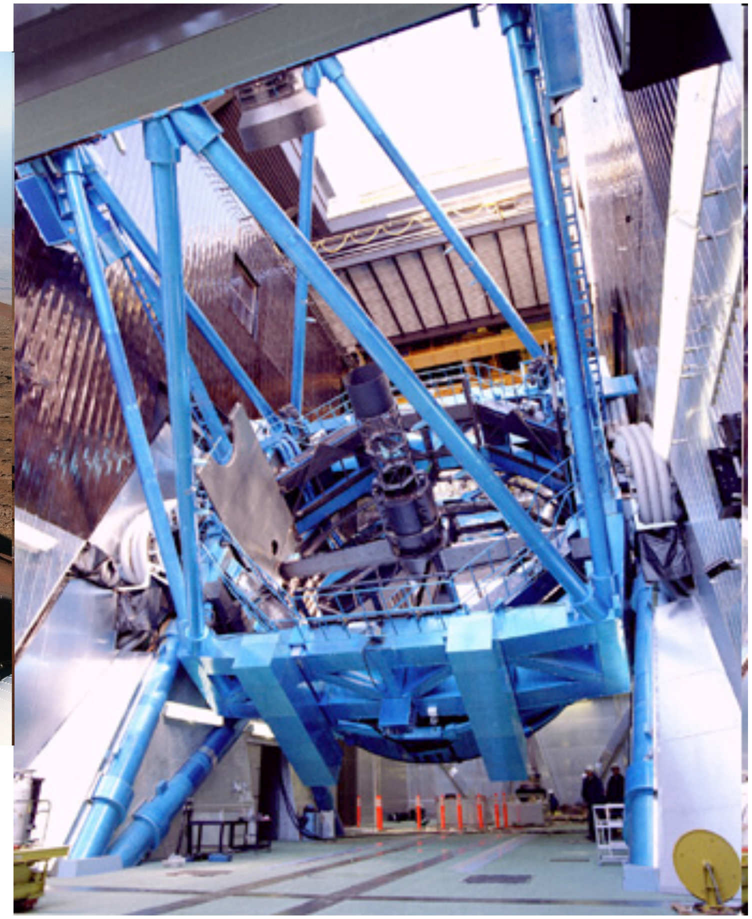
Telescope Quality

- Placed at high altitudes, away from cities, to aid in reducing atmospheric effects and light pollution (near Equator also good as can see all of the stars N/S)

twin 10 m Keck telescopes

Mauna Kea Observatory on big island in Hawaii including infrared. At 13,000 ft

Subaru Telescope – Mauna Kea



8.2 m mirror

cost about $300,000,000

Blanco Telescope – Cerro Tololo Chile

Located at 7,000 ft and in operation since 1965 by US-Chile collaboration

4 m mirror plus new 640 mega-pixel camera built at Fermilab. First data Sept 2012 Dark Energy Survey

Radio Telescopes

- Easy to make large. Atmosphere (including clouds) do not really effect
- Angular resolution is worse because the wavelength is longer. Improve by making either a large aperture or "faking" large using many dishes at same time → can get similar resolution to visible light

Very Large Baseline

Array. 27 dishes in NM

Use many spread out over

continent/world

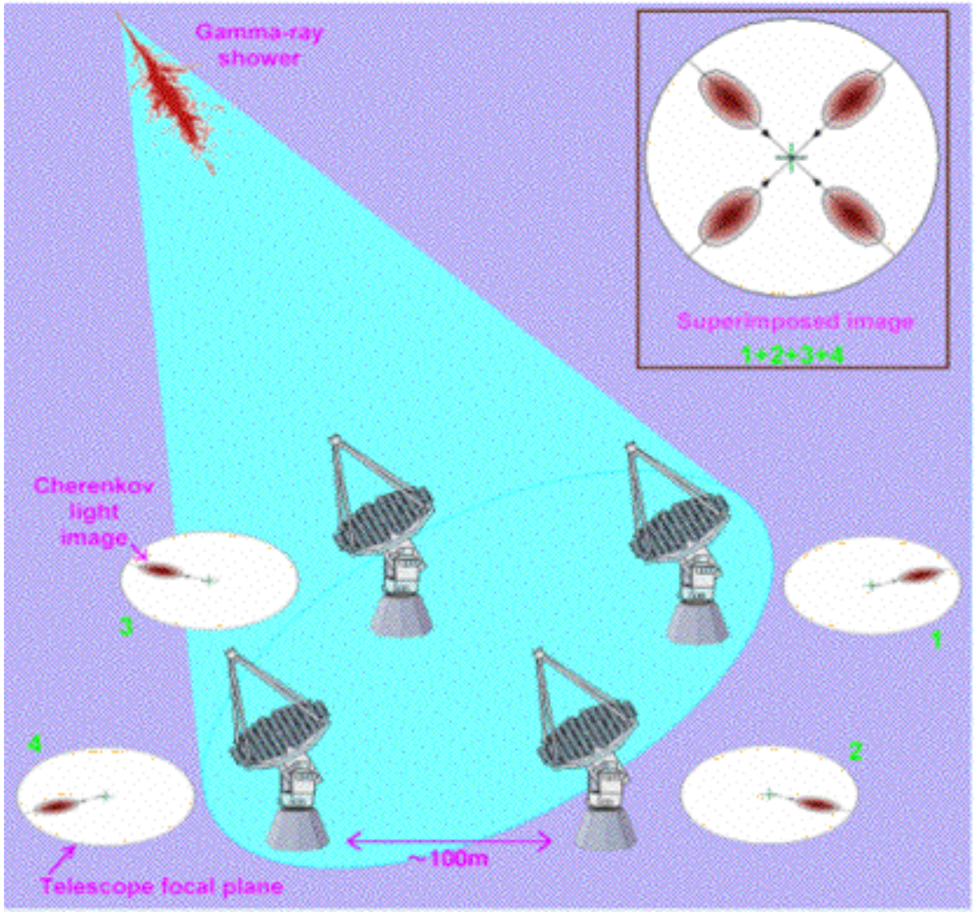
Gamma Ray Telescopes

- Gamma rays CANNOT penetrate the Earth's atmosphere. Instead, some 10-20 km overhead, an incoming gamma collides with molecules, producing energetic particles.
- These particles travel faster than the speed of light in the air producing an EM “shock wave”(analogous to a “sonic boom”) – Cherenkov radiation.
- There are many types of objects that emit gamma-rays. Typical sources are:
  - Supernova remnants
  - Emission from black hole centers of Galaxies, Pulsars and Quasars
- Two types of telescopes: satellite (GLAST, Compton Gamma Ray Observatory) and ground arrays like VERITAS

VERITAS Night Sky Time Lapse
http://vimeo.com/47127288

Veritas Project

- The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is a collection of four telescopes used to detect astrophysical sources of Very High Energy (VHE) gamma rays.
- The higher the energy, the bigger the shower.



- Combine the 4 fields of view.