Lecture #15: Plan

• Telescopes
• Atmosphere
Telescopes
Types of Telescopes

• **Refracting Telescopes or “Refractors”**
  — Use lenses to collect light

• **Reflecting Telescopes or “Reflectors”**
  — Use mirrors to collect light
Refracting Telescopes

- Disadvantages:
  - Large lenses are expensive
  - Large lenses “sag” under gravity
  - Many lens materials absorb ultraviolet
  - Chromatic aberration due to wavelength dependence of refraction
Reflecting Telescopes
Multiple Mirrors

• Reflectors can be made very large if multiple mirrors are used as the primary mirror

• Example: Keck Telescopes (diameter of 10 meters! Made of 36 x 1.8 meter hexagonal segments)
Multiple Mirrors: Future
(~20-30-40 meters)
Collecting Area

- "Light bucket": the bigger the area of the telescope, the more photons it collects

Collecting Area $\sim (\text{Diameter of telescope})^2$
Collecting Area

- **Example:** Eye (D = 5 mm) vs Keck (D = 10 m)

Collecting power (Keck) / Collecting power (eye)

\[
= \frac{D(\text{Keck})^2}{D(\text{eye})^2}
= \left[\frac{D(\text{Keck})}{D(\text{eye})}\right]^2
= \left[\frac{10}{5 \times 10^{-3}}\right]^2
= \left[2 \times 10^3\right]^2
= 4 \times 10^6
\]

Keck is 4,000,000 x more powerful than our eye.
Resolving Power

• The bigger the *size* of the telescope, the better it is at discerning fine details

Resolving power $\sim \frac{\text{(Diameter of telescope)}}{\lambda}$
Radio Telescopes are big!

(radio $\rightarrow$ longer $\lambda$, so larger $D$ is needed to get the same resolving power as optical telescopes)
Radio Telescopes: Interferometry

(Combine the signal from an array of radio telescopes to increase effective D)
Interferometers

- Resolution is equivalent to that of a single telescope with an aperture as large as the separation in the array!
Effects of Earth’s Atmosphere

1. Absorption: light is absorbed by atmosphere
2. Scattering: light is redirected by atmosphere
3. Refraction: light is bent by atmosphere
Atmospheric Absorption

- Oxygen ($O_2$) & ozone ($O_3$) absorb UV and X-rays
- Water and carbon dioxide absorb infrared
- Electrons in upper atmosphere screen out long radio wavelengths
- Atmosphere is transparent to visible and short radio waves
Atmospheric Scattering

• Redirection of light in random directions when it strikes atoms, molecules or dust particles
• The amount of scattering is larger in blue than in red
• Consequences:
  1. Sky is bright
  2. Sky is blue
  3. Sunset / sunrise are red
Refraction

- Bending of light when it moves from one medium to another
Example: Air to Water
Atmospheric Refraction: Consequences

1. Lingering, elliptical sunsets
Atmospheric Refraction: Consequences
2. Scintillation ("twinkling") of stars

Wind moves pockets of slightly cooler air across your line of sight.

Light ray shifted from side to side by refraction in air pockets.
Atmospheric Refraction: Consequences

3. Dispersion ("splitting") of light into its different colors

→ Flashing colors in twinkling stars
High–Altitude Ground–based Observatories

or Space–based Observatories
Avoid light Pollution!
Trick: Adaptive Optics (not on the exams!)

Some observatories measure the amount of atmospheric turbulence with lasers, and then adjust the mirrors in their telescopes with tiny motors to eliminate this effect.
Observatories in Space

Hubble Space Telescope (13.6 m long) – HST

Infrared radiation enters here

About 4 meters long (14.6 feet)

Spitzer Infrared Space Telescope

Herschel Space Observatory (far-infrared)

Opening is about 1.2 m (3.9 feet) in diameter

total length of satellite is about 12.2 meters (40 feet)

Chandra X-ray Telescope Satellite
Images from the Hubble Space Telescope

Sombrero Galaxy
A system of billions of stars and dark dusty interstellar matter.

Hourglass Nebula
A dying star

Disk of hot gas in the core of the galaxy NGC 4261;
a black hole may lie in the disk’s center.
Future: James Webb Space Telescope

Expected launch: end of 2018
Future: James Webb Space Telescope

JWST primary mirror (6.5 m)

Hubble primary mirror (2.4 m)