Telescopes: Portals of Discovery

All of this has been discovered and observed these last days thanks to the telescope that I have [built], after having been enlightened by divine grace.

Galileo Galilei (1564 – 1642)
Astronomer & Physicist
The Bending of Light

**Focus** – to bend all light waves coming from the same direction to a single point

Light rays from different directions converge to form an *image*. 
Angular Resolution

- Ability to distinguish two objects.

- Angle between two objects decreases as your distance to them increases.

- The smallest angle at which you can distinguish two objects is your \textit{angular resolution}. 
Two Fundamental Properties of a Telescope

1. Light-Collecting Area
   - think of the telescope as a “photon bucket”
   - its area: \( A = \pi D^2 / 4 \)
If one doubles a telescope’s diameter, by what factor does its light collection area increase?

A. 2 times

B. 4 times

C. 16 times

D. It depends on the wavelength of the light
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Two Fundamental Properties of a Telescope

1. Light-Collecting Area
   - think of the telescope as a “photon bucket”
   - its area: \( A = \pi \frac{D^2}{4} \)

2. Angular Resolution
   - smallest angle that can be seen
   - \( a = 1.2 \frac{\lambda}{D} \quad 180^\circ / \pi = 70^\circ \frac{\lambda}{D} \)
   - \( = 4" \quad (\lambda/\mu m)/(D/m) \)
   - recall angular size \( \alpha = \frac{s}{d} = \text{size/distance} \)
i-Clicker

If one doubles a telescope’s diameter, by what factor does its angular resolution change?

A. 2
B. 1/2
C. 4
D. 1/4
If one doubles a telescope’s diameter, by what factor does its angular resolution change?

A. 2

B. 1/2 \ a \sim \ 1/D

C. 4

D. 1/4
Telescope Types

- **Refractor**
  - focuses light using lenses

- **Reflector**
  - focuses light using mirrors
  - used exclusively in professional astronomy
Refractor

Yerkes 40-inch telescope; largest refractor in the world
Reflector

Gemini 8-m Telescope, Mauna Kea, Hawaii
Reflectors

MMT – Mt. Hopkins, AZ

SUBARU – Mauna Kea, HI
Reflector -- Radio

Heinrich Hertz Telescope – Mt. Graham, AZ
Imaging

- **Filters** are placed in front of a camera to allow only certain colors to be imaged.
- Single color images are superimposed to form true color images.
Spectroscopy

- The spectrograph reflects light off a **grating**: a finely ruled, smooth surface.

- Light interferes with itself and **disperses** into colors.

- This **spectrum** is recorded by a digital detector called a CCD.
Nonvisible Light

• Most light is invisible to the human eye.
• Special detectors/receivers can record such light.
• Digital images are reconstructed using false-color coding so that we can see this light.

Chandra X-ray image of the Center of the Milky Way Galaxy
Seeing Through the Atmosphere

- Earth’s atmosphere causes problems for astronomers on the ground.
- Bad weather makes it impossible to observe the night sky.
- Air turbulence in the atmosphere distorts light.
  - That is why the stars appear to “twinkle”.
  - Angular resolution is degraded.
- Man-made light is reflected by the atmosphere, thus making the night sky brighter.
  - This is called light pollution.
Adaptive Optics (AO)

- It is possible to “de-twinkle” a star.
- A star’s light rays are deformed by the atmosphere.
- By monitoring the distortions of the light from a nearby bright star (or a laser), computer can deform the secondary mirror in the opposite way.

- Angular resolution improves.
- These two stars are separated by 0.38”
- Without AO, we see only one star.

AO mirror off

AO mirror on
Atmospheric Absorption of Light

- Earth’s atmosphere absorbs most types of light.
  - good thing it does, or we would be dead!
- Only visible, radio, and certain IR and UV light make it through to the ground.

To observe the other wavelengths, we must put our telescopes in space!
Space Based Telescopes

Chandra X-ray Obs.  
Hubble Space Telescope
X-ray Telescopes

- X-rays will pass right through a mirror.
- But can be reflected/focused at shallow angles—like “skimming stones”
Radio Telescopes

• The wavelengths of radio waves are long.
• So the dishes which reflect them must be very large to achieve any reasonable angular resolution.
Interferometry

- Two (or more) radio dishes observe the same object.
- Signals are made to interfere.
- Reconstruct image with angular resolution of single dish with the size of the distance between them.
- Light-collecting area is still only the sum of the individual dish areas.
Very Large Array (VLA)
VLT (Very Large Telescope)

European Southern Observatory
Paranal Mountain, Chile