AST 101
Intro to Astronomy:
Stars & Galaxies

Imaging with our Eyes
- **pupil** – allows light to enter the eye
- **lens** – focuses light to create an image
- **retina** – detects the light and generates signals sent to brain

Telescopes and cameras work much like our eyes
Optical Telescopes of Two Types

REFRACTOR (LENSES)

REFLECTOR (MIRRORS)

World’s Largest Refractor

World’s Largest Optical Reflector

Reflecting vs Refracting

1. A mirror only needs a high-quality surface coating, the rest of the glass doesn’t matter
   - Surface can be recoated as necessary
2. Big lenses are heavy!
   - Big mirrors are heavy too but they can be supported from the back
     - Newest telescopes use multiple smaller mirrors
3. Lenses focus different colors of light at different places
Clicker Question

*Why is the largest reflector ten times larger than the largest refractor?*

A. Metal for the long tube of the refractors is too expensive.
B. Reflecting telescopes are easier to clean since their mirrors are exposed.
C. Lenses will crack if taken to high altitudes.
D. Large mirrors are easier to make accurately than large lenses.
E. Reflecting telescopes work at more wavelengths.

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**Size DOES Matter!**

1. *Light-Collecting Area*
   - Telescopes with a larger collecting area can gather a greater amount of light in a shorter time.

2. *Angular Resolution*
   - Telescopes that are larger are capable of taking images with greater detail.

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**Light Collecting Power**

- Think of telescope as a “photon bucket”
  - Bigger bucket = more photons
- Amount of light collected is directly proportional to area
  - The larger the telescope diameter, the more light rays it intercepts
    - Area \( \propto \) Diameter\(^2\)
  - To make up for light collecting power, you can just take longer images
Angular Resolution for telescopes

• The amount of fine detail that can be seen!
• Expressed as the angle between two objects that can be seen as separated
  = SMALLER angle is BETTER
  = High resolution = small angular resolution

Diffraction Limit

• Theoretical best angular resolution a telescope can get.
• Measured in arcseconds ("")
  • 1 arcsec (")
  • = 1/60 arcminute
  • = 1/3600 degree
  • 1 arcsec = angular size of a dime placed 2.5 miles away

Diffraction Limit Example

• θ = (2.5 x 10^5 arcsec) x λ / D
  = (λ is light wavelength, D is mirror diameter)
• Better (smaller angles) for shorter wavelengths, or larger telescopes

Angular resolution (arcseconds)

θ = (2.5 x 10^5 arcsec) x (5 x 10^{-7} meters) / (0.4 meters)
θ = 0.3 arcseconds
Another Diffraction Limit Example

- Keck 10 meter telescope
- Wavelength of green light
  \[= 500 \text{ nm} = 500 \times 10^{-9} \text{ m} = 5 \times 10^{-7} \text{ m}\]

Angular resolution (arcseconds)
\[\theta = (2.5 \times 10^5 \text{ arcsec}) \times (5 \times 10^{-7} \text{ meters}) / (10 \text{ meters})\]
\[\theta = 0.01 \text{ arcseconds}\]

Watch out for the units!
They must match for wavelength and size of telescope!

How many light bulbs does it take
to screw up an astronomer?

- An immediately curable pollution: simply turn the lights off!
- Several famous observatories are now useless...

Los Angeles basin view from Mt. Wilson Observatory, 1908 and 1998

Our Atmospheric screws viewing up!

- Light Pollution
  - 90% of the Earth’s population can not see the Milky Way on the average night

Other sources of disturbance:
Atmospheric turbulence

- Atmospheric Turbulence
- Very dependent on local conditions

Bad seeing
Good seeing
Sites in Hawaii, Arizona, Chile, Canary Islands…

- Mauna Kea, Big Island of Hawaii, 14,000’ elevation, middle of the Pacific
- Dry, high, dark and isolated.
- Even in the best places though, seeing is typically θ ~ 0.3-0.5 arcsec

**Adaptive Optics to the Rescue!**

- Use a laser to create an artificial star and correct for the distortion caused by earth’s atmosphere

If you bounce the incoming light off a “deformable mirror” the light comes off corrected

**Adaptive Optics to the Rescue!**

Images from the Keck Observatory courtesy of the NSF Center for Adaptive Optics
Atmospheric Absorption of “Light”

- Earth’s atmosphere absorbs most types of light (not entirely bad, or we would be dead!)
- Only visible, radio, some IR, and some UV light get through to the ground

Radiation Waves: most get through
- Thus radio telescopes are built on the ground

Weather is not an issue - radio waves come right through the clouds

But poor angular resolution
- Why?
  - VERY long wavelengths!

Interferometry

- Join multiple telescopes together to simulate one large telescope.
- Only perfected at radio wavelengths: Very Large Array (VLA) in New Mexico has 27 dishes across a 40 km valley
  - D=40 km = 4 x 10^4 m
- Recent initial success using the two Keck telescopes as an infrared interferometer.

Can we go even bigger? YES!

- Very Large Baseline Array: VLBA is an array of ten 25-meter telescopes
- Resolutions as small as 0.001 arcseconds for radio light
- Other observing campaigns use observations from around the world, synchronized by atomic clocks

Space interferometry is coming….
Infrared Telescopes

- **INFRARED** can be absorbed by molecules like H$_2$O, CO$_2$, CO, etc.

- Absorption is in specific wavebands, leaving “windows” where we can see through the atmosphere.

- Combination of ground-based, airplane, balloon, rockets, satellite.

For other wavelengths, we have to get above the atmosphere.

- UV, X-rays, Gamma Rays
  - These all have enough energy to ionize electrons in atoms or break apart molecules.
  - Heavy absorbed by the atmosphere.


Hubble Space Telescope:
**NASA’s most famous observatory**

- Launched in 1990
  - Error in mirror made blurry images.
- Corrective optics installed in 1993.
- **Small** (only 2.5 meters) but diffraction-limited.
- Low orbit accessible by Shuttle, refurbishing missions mean long lifetime (1990 to 2015+).
- $5$ billion over $20$ years = $10$-$100$ times more than ground-based telescope.
**NASA’s Great Observatories**

- **Spitzer Space Telescope**
  - Infrared
- **Hubble Space Telescope**
  - UV/Visible
- **Chandra X-Ray Observatory**
- **Compton Gamma Ray Observatory**

**X-ray telescopes**

- Difficult to focus X-rays; They penetrate or are absorbed
- Glancing angles scatter X-rays, bringing them to a focus to make an image
- **Always** false color!

**Instruments in the Focal Plane**

*How astronomers use light collected by a telescope:*

1. **Imaging**
   - use camera to take pictures (images)
   - photometry → measure amount and color (with filters) of light from object
2. **Spectroscopy**
   - use spectrograph to separate light in detail into its different wavelengths (colors)
3. **Timing**
   - measure how amount of light changes with time (sometimes in a fraction of a second)

**Imaging (Digital with CCDs)**

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

Images are combined to show full color.
Spectroscopy – analyzing the light

- **Spectrograph** reflects light off a **diffraction grating**: finely ruled, smooth surface
- Light disperses into colors
- This spectrum is recorded by **CCD detector**

**Clicker Question**

**Why Do We Put Telescopes in Space?**

A. In space we can build telescopes larger and cheaper in zero gravity
B. Earth orbit places them closer to the stars
C. The Earth’s atmosphere interferes with light coming from space
D. The cold temperatures in space reduce “noise” in telescope cameras
E. Glass (for telescope mirrors) degrade less and stay cleaner in space

**Timing**

- A light curve represents a series of brightness measurements made over a period of time

**Clicker Question**

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Clicker Question
Which of the following (hypothetical) telescope proposals is most likely to get funded?

A. A visible wavelength telescope, located on a university campus, will be used in the search for planets outside the solar system.
B. An X-ray wavelength telescope, located near the North Pole, will be used to examine the sun.
C. A ultraviolet wavelength telescope, placed on a satellite in orbit around Earth, will be used to observe a pair of binary stars located in the constellation of Ursa Major.
D. A radio wavelength telescope, with diameter 1 m, will be used to study young, hot, massive stars.
E. An infrared wavelength telescope, located in the high elevation mountains of Chile, will be used to view newly forming stars.