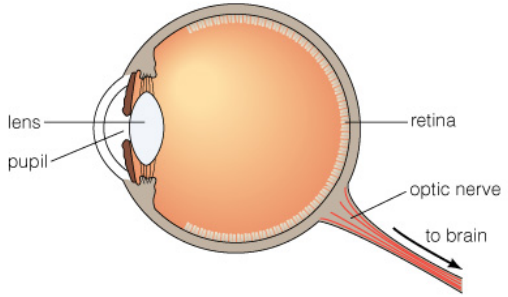
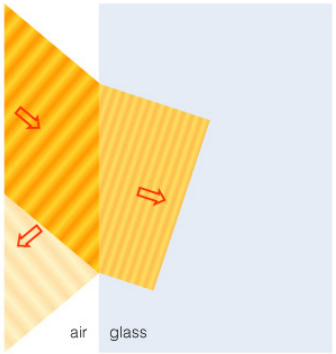
Chapter 6
Telescopes: Portals of Discovery

How does your eye form an image?

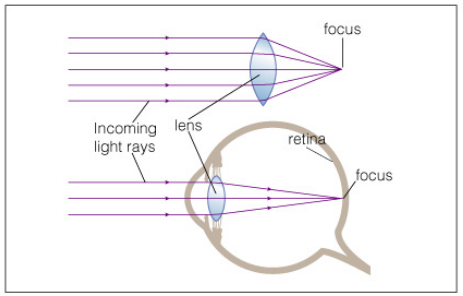


Refraction



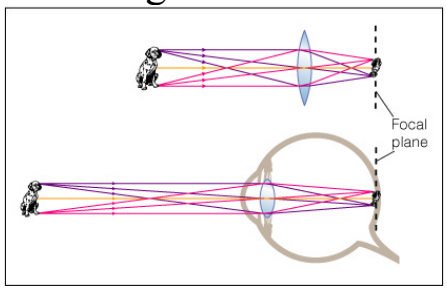
- Refraction is the bending of light when it passes from one substance into another
- Your eye uses refraction to focus light

Focusing Light



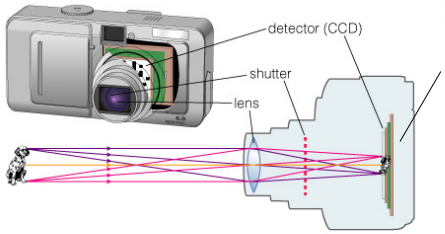
- Refraction can cause parallel light rays to converge to a focus

Image Formation



- The focal plane is where light from different directions comes into focus
- The image behind a single (convex) lens is actually upside-down!

How do we record images?



Digital cameras detect light with charge-coupled devices (CCDs)

- A camera focuses light like an eye and captures the image with a detector
- The CCD detectors in digital cameras are similar to those used in modern telescopes

What are the two most important properties of a telescope?

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.

Light Collecting Area

- A telescope's diameter tells us its light-collecting area: Area = π(diameter/2)^2
- The largest telescopes currently in use have a diameter of about 10 meters

Thought Question

How does the collecting area of a 10-meter telescope compare with that of a 2-meter telescope?

a) It's 5 times greater.
b) It's 10 times greater.
c) It's 25 times greater.

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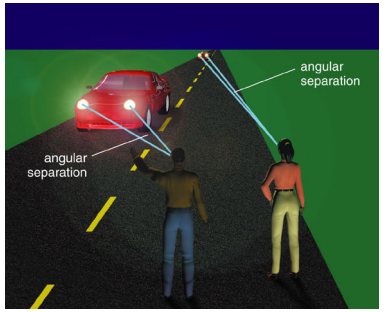
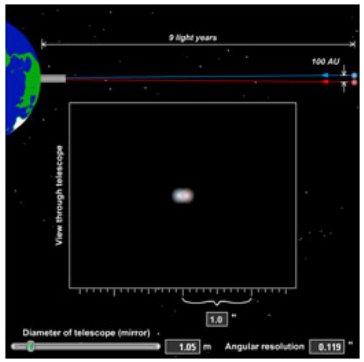
Angular Resolution

- The *minimum* angular separation that the telescope can distinguish.



Angular Resolution

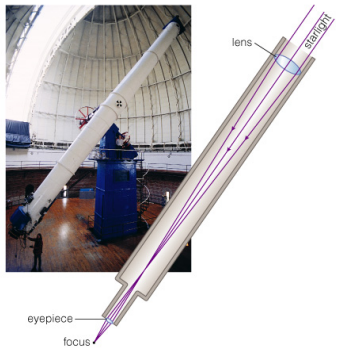


- Ultimate limit to resolution comes from interference of light waves within a telescope.
- Larger telescopes are capable of greater resolution (smaller angles) because there's less interference

What are the two basic designs of telescopes?

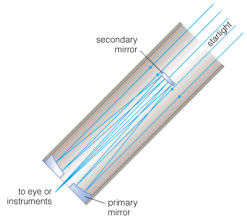
- **Refracting telescope:** Primary collector of light is a lens
- **Reflecting telescope:** Primary collector of light is a mirror

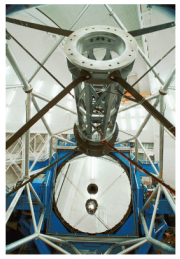
Refracting Telescope



- Refracting telescopes need to be very long, with large, heavy lenses

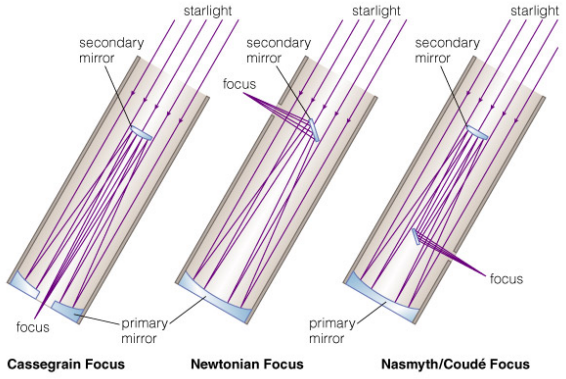
Reflecting Telescope



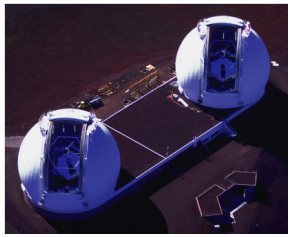


- Reflecting telescopes can have much greater diameters
- Most modern telescopes are reflectors

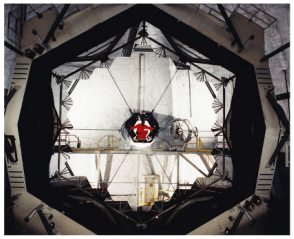
Designs for Reflecting Telescopes



Mirrors in Reflecting Telescopes



Twin Keck telescopes on Mauna Kea in Hawaii

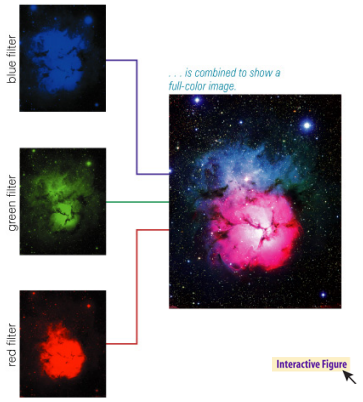


Segmented 10-meter mirror of a Keck telescope

What do astronomers do with telescopes?

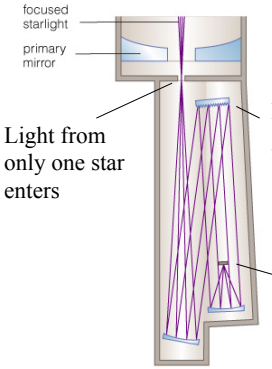
- **Imaging:** Taking pictures of the sky
- **Spectroscopy:** Breaking light into spectra
- **Timing:** Measuring how light output varies with time

Imaging



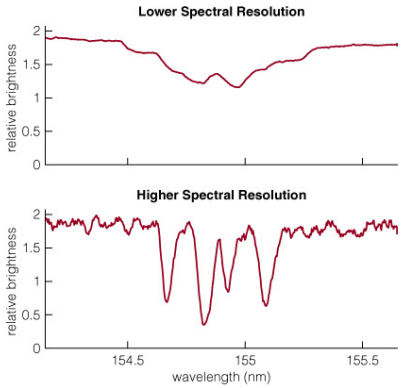
- Astronomical detectors generally record only one color of light at a time
- Several images must be combined to make full-color pictures

Spectroscopy



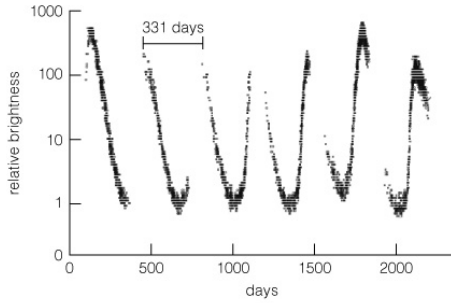
- A spectrograph separates the different wavelengths of light before they hit the detector

Spectroscopy



- Graphing relative brightness of light at each wavelength shows the details in a spectrum

Timing



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

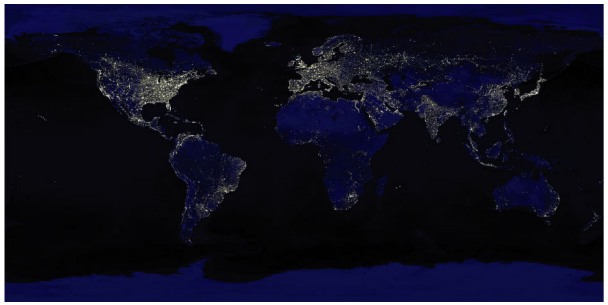
Want to buy your own telescope?

- Buy binoculars first (e.g. 7x35) - you get much more for the same money.
- Ignore magnification (sales pitch!)
- Notice: aperture size, optical quality, portability.
- Consumer research: Astronomy, Sky & Tel, Mercury. Astronomy clubs.

How does Earth's atmosphere affect ground-based observations?

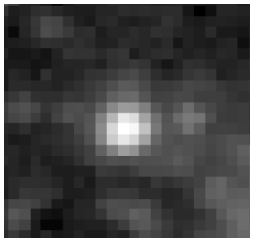
- The best ground-based sites for astronomical observing are
  - Calm (not too windy)
  - High (less atmosphere to see through)
  - Dark (far from city lights)
  - Dry (few cloudy nights)

Light Pollution

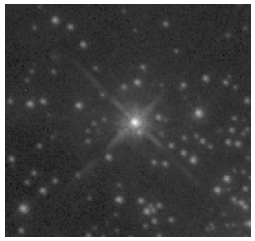


- Scattering of human-made light in the atmosphere is a growing problem for astronomy

Twinkling and Turbulence



Star viewed with ground-based telescope

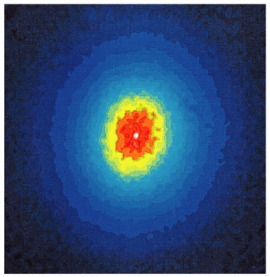


Same star viewed with Hubble Space Telescope

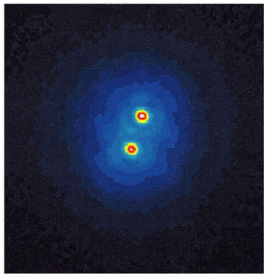
Turbulent air flow in Earth's atmosphere distorts our view, causing stars to appear to twinkle

- Without correction, resolution is limited to > 1
(same for 200-inch and 9-inch telescopes).

Adaptive Optics



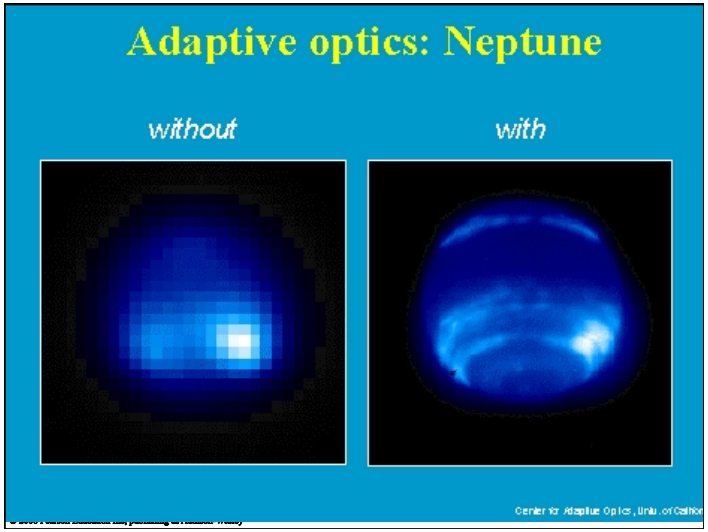
Without adaptive optics



With adaptive optics

Rapidly changing the shape of a telescope's mirror compensates for turbulence

Adaptive optics: Neptune



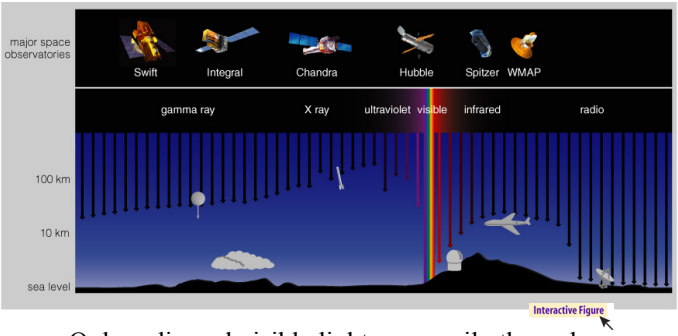
Calm, High, Dark, Dry

Summit of Mauna Kea, Hawaii

- The best observing sites are atop remote mountains

Why do we put telescopes into space?

Transmission in Atmosphere



- Only radio and visible light pass easily through Earth's atmosphere
- We need telescopes in space to observe other forms

How can we observe nonvisible light?

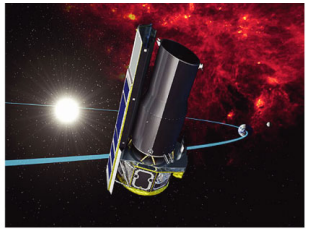
- A standard satellite dish is essentially a telescope for observing radio waves

Radio Telescopes

- A radio telescope is like a giant mirror that reflects radio waves to a focus

IR & UV Telescopes

SOFIA



Spitzer

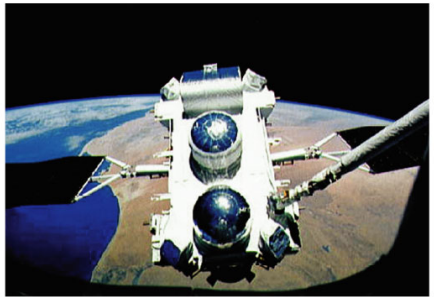
- Infrared and ultraviolet-light telescopes operate like visible-light telescopes but need to be above atmosphere to see all IR and UV wavelengths

X-Ray Telescopes

Chandra

- X-ray telescopes also need to be above the atmosphere

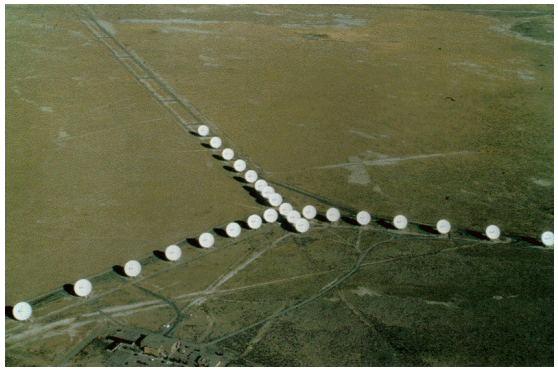
Gamma Ray Telescopes



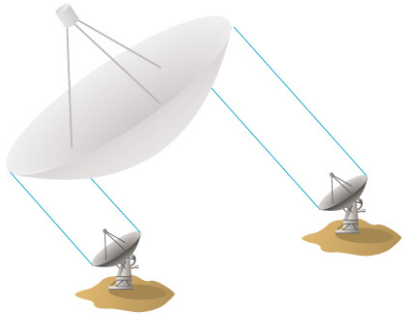
Compton Observatory

- Gamma ray telescopes also need to be in space
- Focusing gamma rays is extremely difficult

How can multiple telescopes work together?



Interferometry



- Interferometery is a technique for linking two or more telescopes so that they have the angular resolution of a single large one

Interferometry

- Easiest to do with radio telescopes
- Now becoming possible with infrared and visible-light telescopes

Very Large Array (VLA)

Georgia State University's Center for High Angular Resolution Astronomy

Mt. Wilson, California

First Science Paper from CHARA:
Size and Shape of a Blue Star - Regulus