Chapter 6
Telescopes: Portals of Discovery

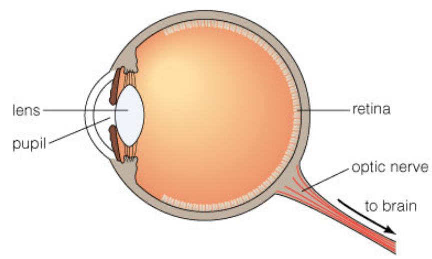
Agenda

- Announce:
  - Read S2 for Thursday
- Ch. 6 Telescopes

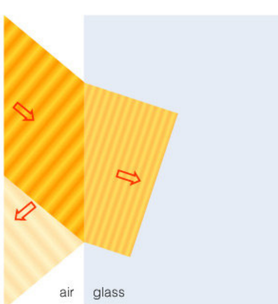
6.1 Eyes and Cameras: Everyday Light Sensors

- Our goals for learning
- How does your eye form an image?
- How do we record images?

How does your eye form an image?

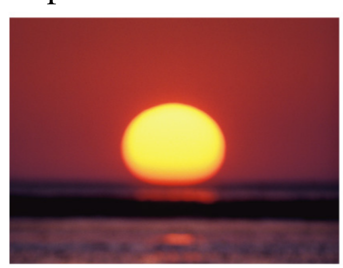


Refraction



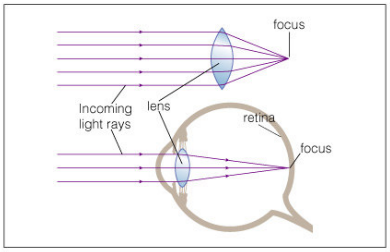
- Refraction is the bending of light when it passes from one substance into another
- Your eye uses refraction to focus light

Example: Refraction at Sunset



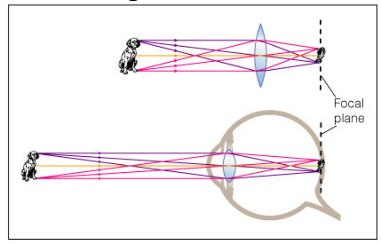
- Sun appears distorted at sunset because of how light bends in Earth's atmosphere

Focusing Light



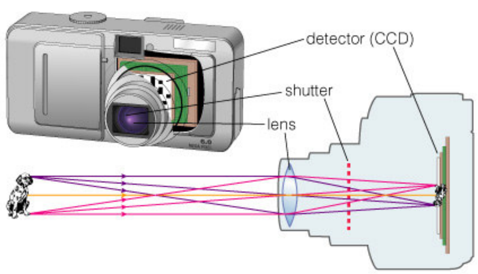
- Refraction can cause parallel light rays to converge to a focus

Image Formation

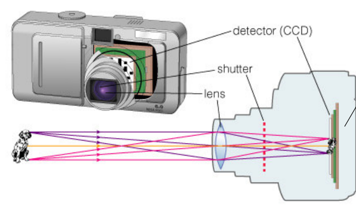


- The focal plane is where light from different directions comes into focus
- The image behind a single (convex) lens is actually upside-down!

How do we record images?



Focusing Light



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 have we learned?

- How does your eye form an image?
  - It uses refraction to bend parallel light rays so that they form an image.
  - The image is in focus if the focal plane is at the retina.
- How do we record images?
  - Cameras focus light like your eye and record the image with a detector.
  - The detectors (CCDs) in digital cameras are like those used on modern telescopes

6.2 Telescopes: Giant Eyes

- Our goals for learning
- What are the two most important properties of a telescope?
- What are the two basic designs of telescopes?
- What do astronomers do with telescopes?

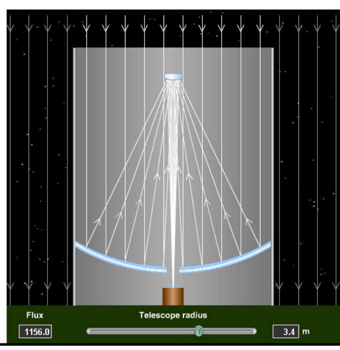
What are the two most important properties of a telescope?

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 = $\pi(\text{diameter}/2)^2$
- The largest telescopes currently in use have a diameter of about 10 meters

Bigger is better



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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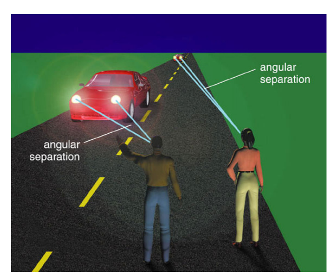
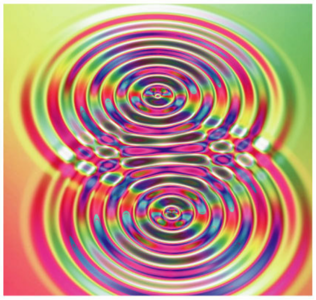
Angular Resolution

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



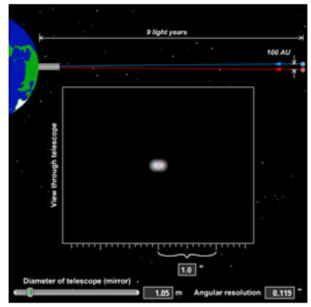
Interactive Figure

Angular Resolution



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

Angular Resolution



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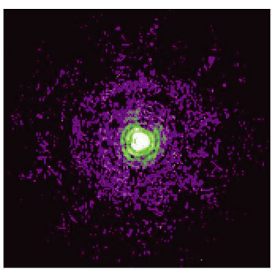
Angular Resolution



Close-up of a star from the Hubble Space Telescope

- The rings in this image of a star come from interference of light wave.
- This limit on angular resolution is known as the **diffraction limit**

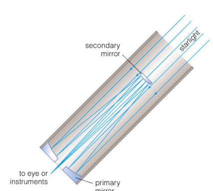
What are the two basic designs of telescopes?

- **Refracting telescope:** Focuses light with lenses
- **Reflecting telescope:** Focuses light with mirrors

Refracting Telescope

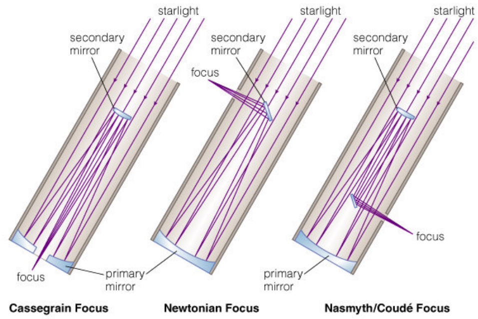
- Refracting telescopes need to be very long, with large, heavy lenses

Reflecting Telescope

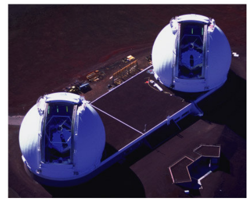


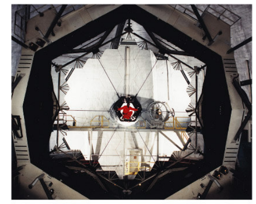
- Reflecting telescopes can have much greater diameters
- Most modern telescopes are reflectors

Designs for Reflecting Telescopes



Mirrors in Reflecting Telescopes

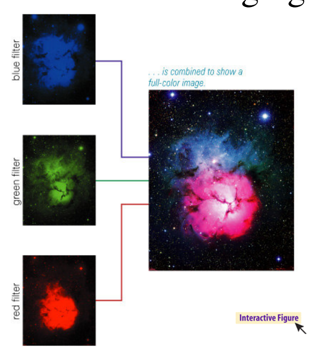

Twin Keck telescopes on Mauna Kea in Hawaii


Segmented 10-meter mirror of a Keck telescope

What do astronomers do with telescopes?

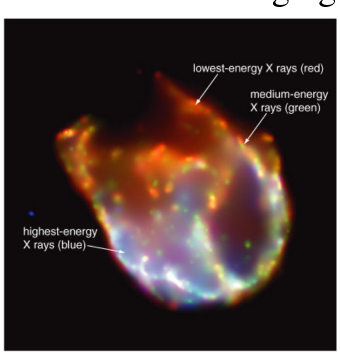
- **Imaging:** Taking pictures of the sky
- **Spectroscopy:** Breaking light into spectra
- **Timing:** Measuring how light output varies with time

Imaging



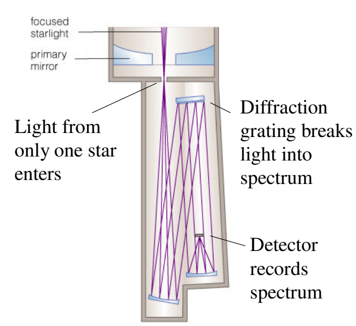
- Astronomical detectors generally record only one color of light at a time
- Several images must be combined to make full-color pictures

Imaging



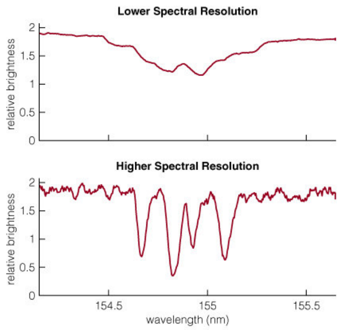
- Astronomical detectors can record forms of light our eyes can't see
- Color is sometimes used to represent different energies of nonvisible light

Spectroscopy



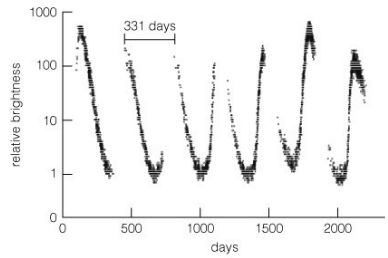
- A spectrograph separates the different wavelengths of light before they hit the detector

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

What have we learned?

- What are the two most important properties of a telescope?
  - Collecting area determines how much light a telescope can gather
  - Angular resolution is the minimum angular separation a telescope can distinguish
- What are the two basic designs of telescopes?
  - Refracting telescopes focus light with lenses
  - Reflecting telescopes focus light with mirrors
  - The vast majority of professional telescopes are reflectors

What have we learned?

- What do astronomers do with telescopes?
  - Imaging
  - Spectroscopy
  - Timing

6.3 Telescopes and the Atmosphere

- Our goals for learning
- How does Earth's atmosphere affect ground-based observations?
- Why do we put telescopes into space?

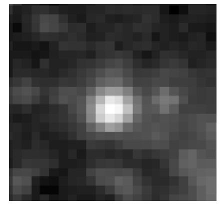
How does Earth's atmosphere affect ground-based observations?

- 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)

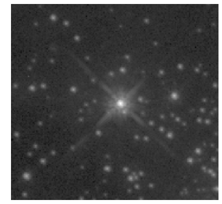
Light Pollution

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

Twinkling and Turbulence



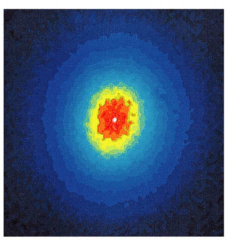
Star viewed with ground-based telescope



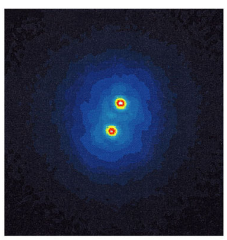
Same star viewed with Hubble Space Telescope

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

Adaptive Optics



Without adaptive optics

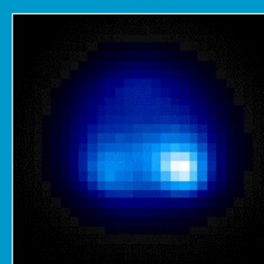


With adaptive optics

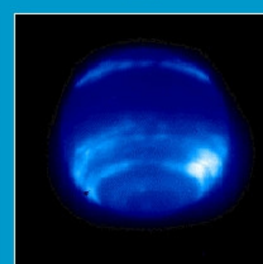
Rapidly changing the shape of a telescope's mirror compensates for some of the effects of turbulence

Adaptive optics: Neptune

without



with



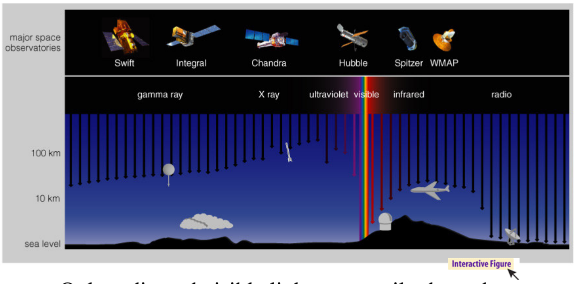
Calm, High, Dark, Dry

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

What have learned?

- How does Earth's atmosphere affect ground-based observations?
  - Telescope sites are chosen to minimize the problems of light pollution, atmospheric turbulence, and bad weather.
- Why do we put telescopes into space?
  - Forms of light other than radio and visible do not pass through Earth's atmosphere.
  - Also, much sharper images are possible because there is no turbulence.

6.4 Eyes and Cameras: Everyday Light Sensors

- Our goals for learning
- How can we observe nonvisible light?
- How can multiple telescopes work together?

How can we observe nonvisible light?

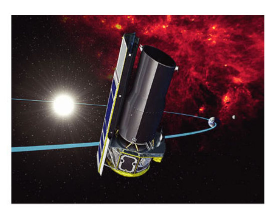
- A standard satellite dish is essentially a telescope for observing radio waves

Radio Telescopes

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

IR & UV Telescopes

SOFIA



Spitzer

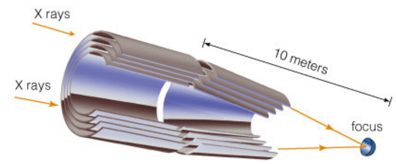
- Infrared and ultraviolet-light telescopes operate like visible-light telescopes but need to be above atmosphere to see all IR and UV wavelengths

X-Ray Telescopes

Chandra

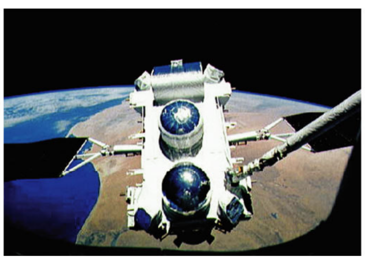
- X-ray telescopes also need to be above the atmosphere

X-Ray Telescopes



- Focusing of X-rays requires special mirrors
- Mirrors are arranged to focus X-ray photons through grazing bounces off the surface

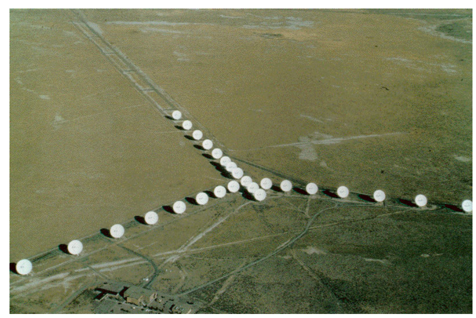
Gamma Ray Telescopes



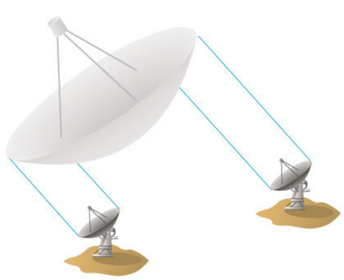
Compton Observatory

- 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

Very Large Array (VLA)

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

Future of Astronomy in Space?

- The Moon would be an ideal observing site