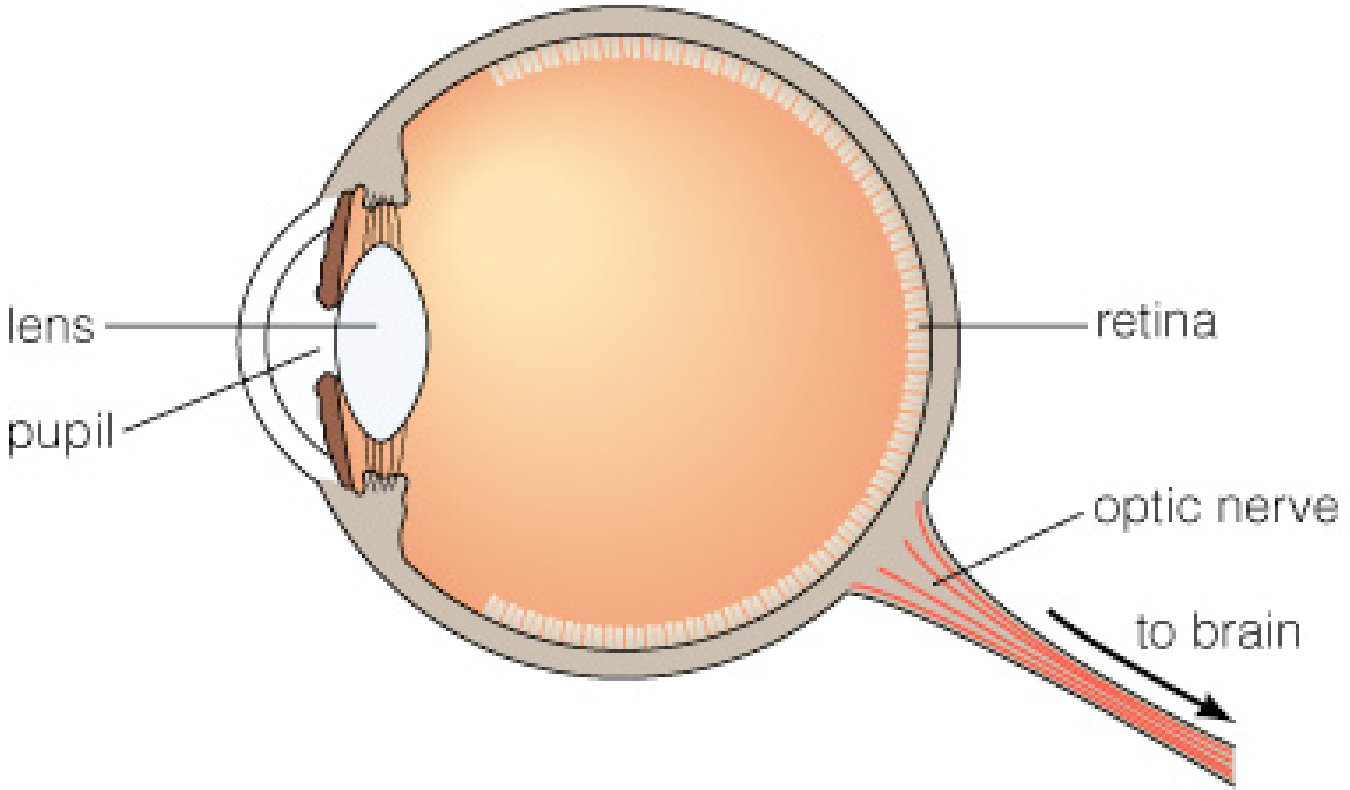
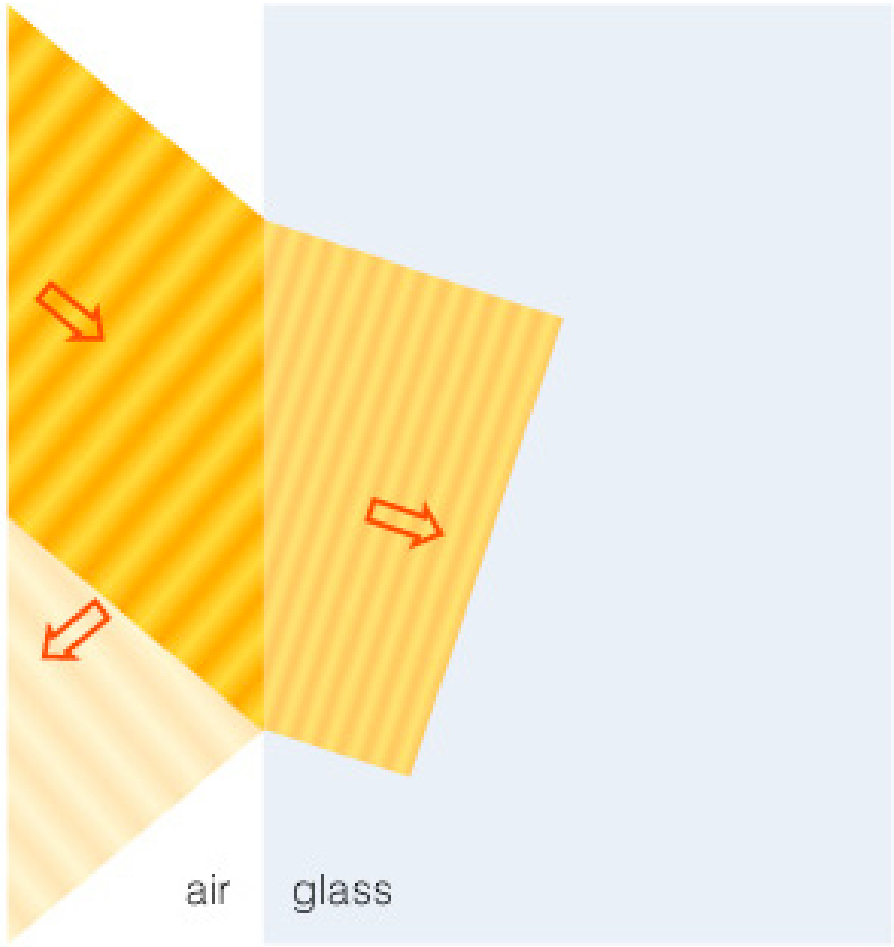
Chapter 6
Telescopes: Portals of Discovery

How does your eye form an image?



Refraction

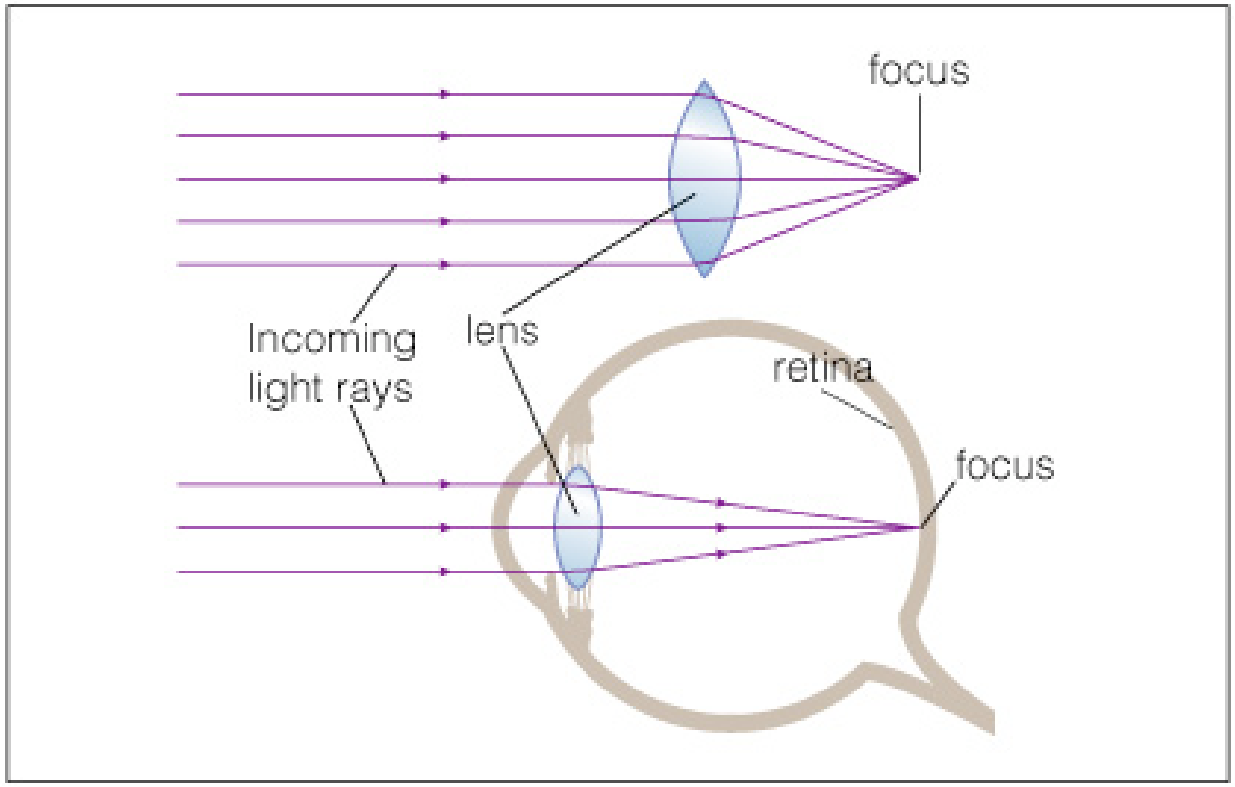


- Refraction is the bending of light when it passes from one substance into another
- Your eye uses refraction to focus light

Example: Refraction at Sunset

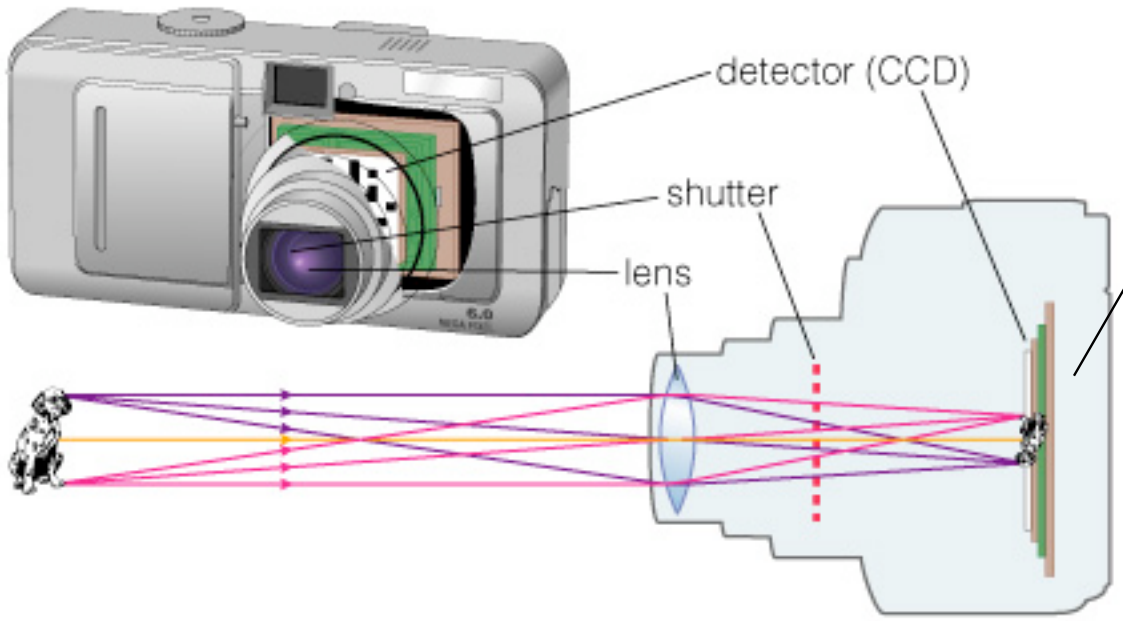
- Sun appears distorted at sunset because of how light bends in Earth's atmosphere

Focusing Light



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

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 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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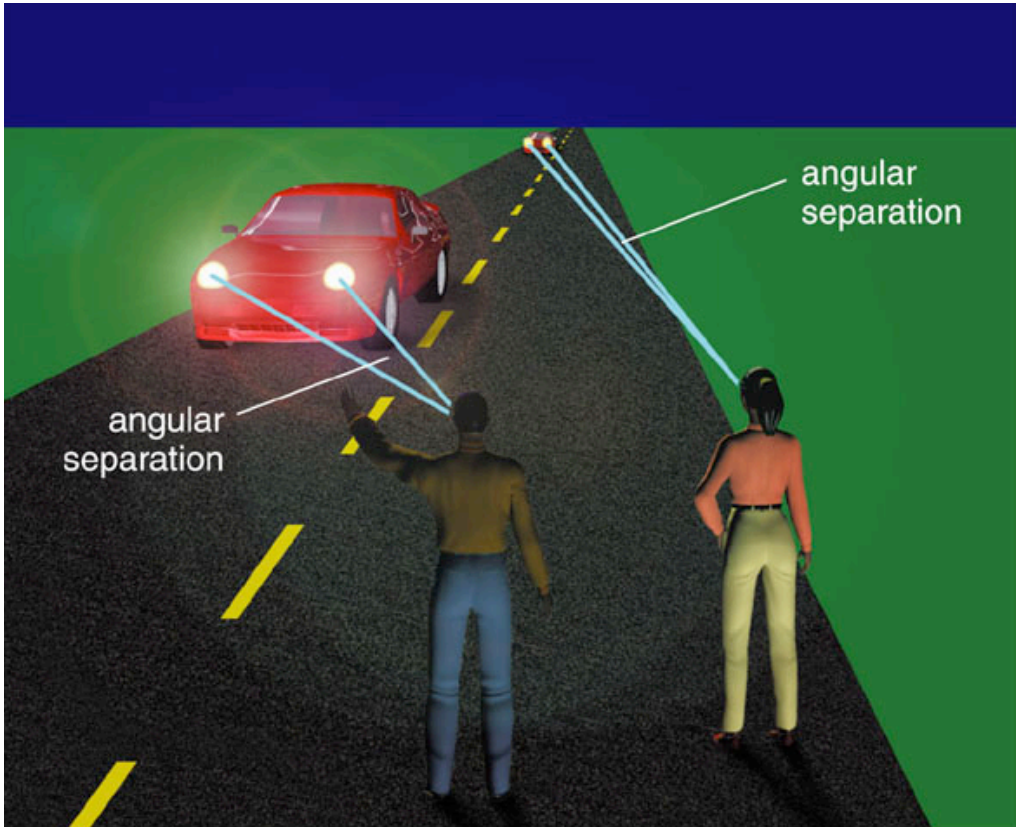
$$\text{Area} = \pi(\text{diameter}/2)^2$$

Angular Resolution

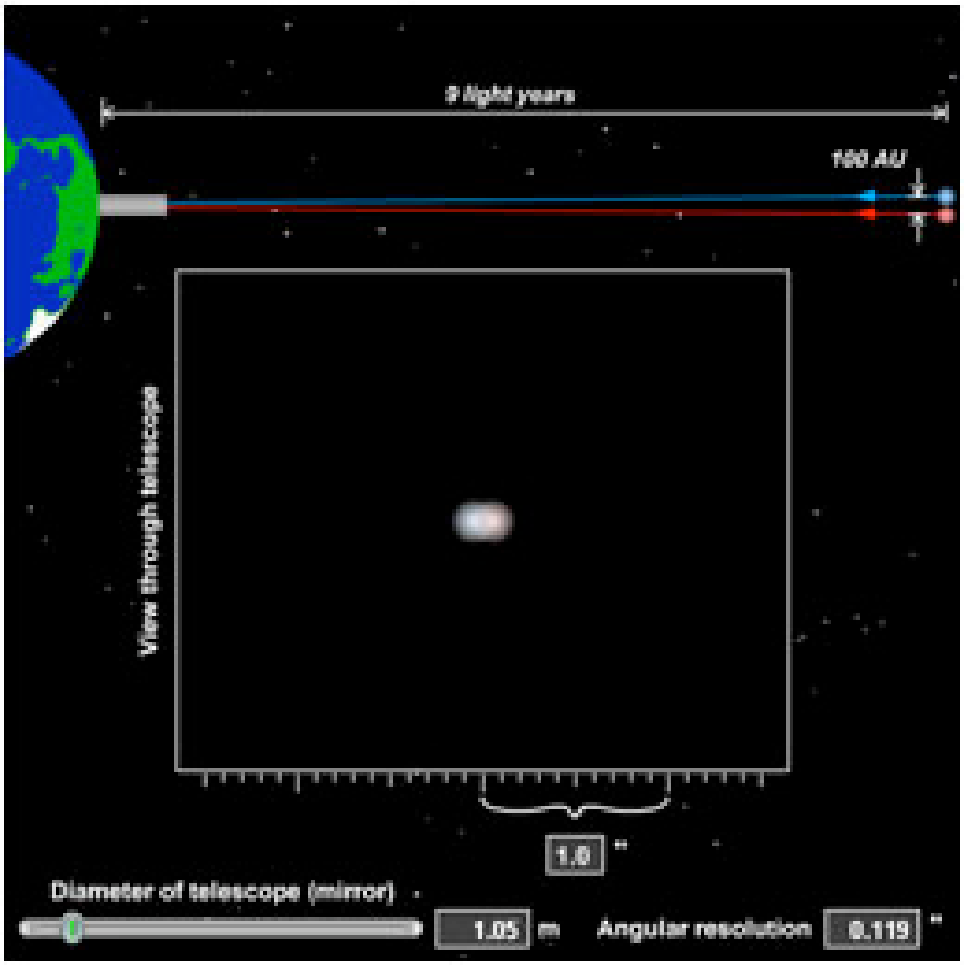
- The *minimum* angular separation that the telescope can distinguish.

- Depends on both separation and distance to us



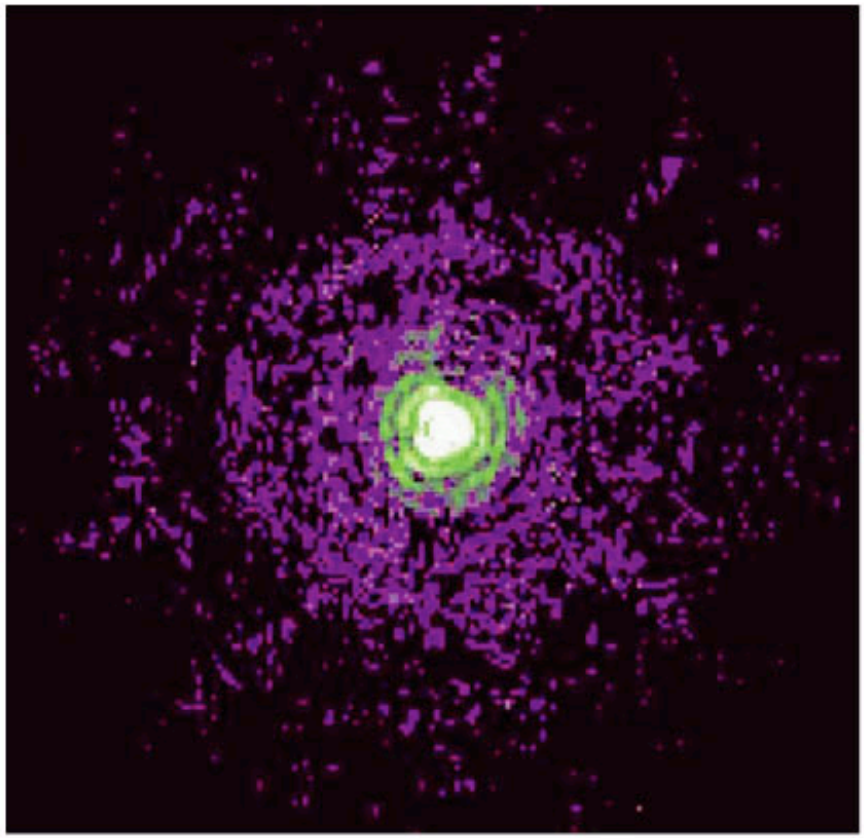
Interactive Figure

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



Close-up of a star from the Hubble Space Telescope

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

Thought Question

Suppose two stars are separated in the sky by 0.1 arc-second. If you look at them with a telescope with an angular resolution of 0.01 arc-second, what do you see?

a) Two distinct stars.
b) One point of light that is the blurred image of both stars.
c) Nothing at all.

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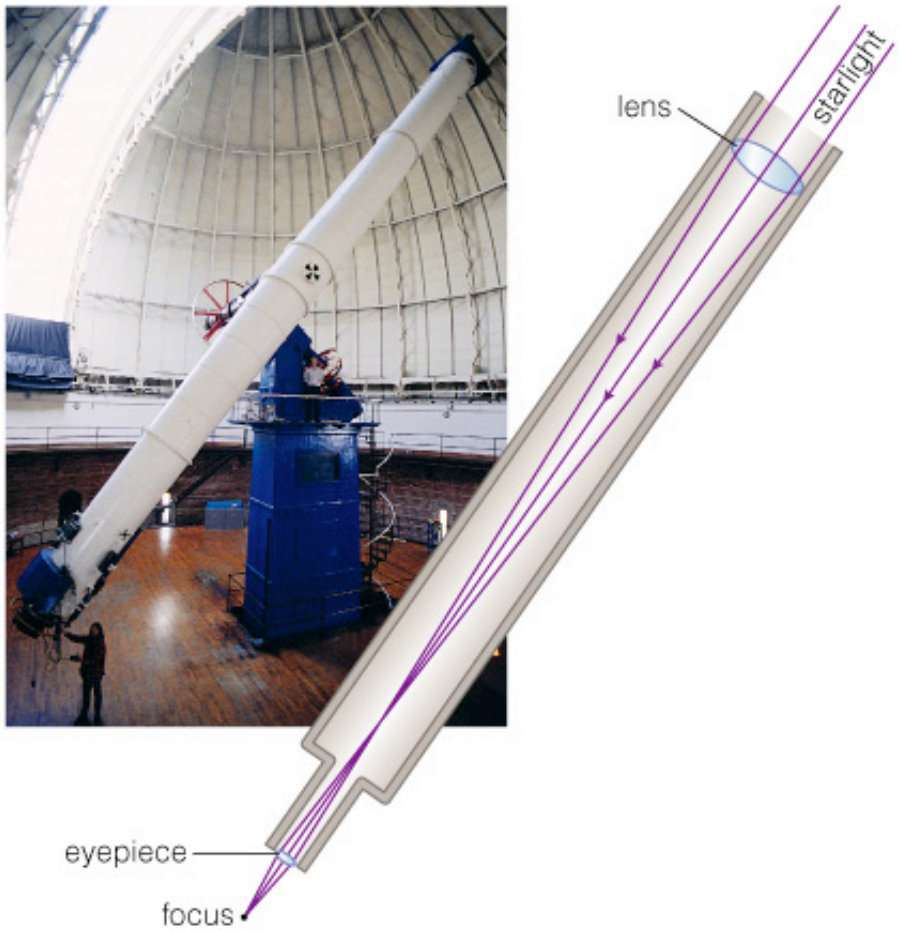
What are the two basic designs of telescopes?

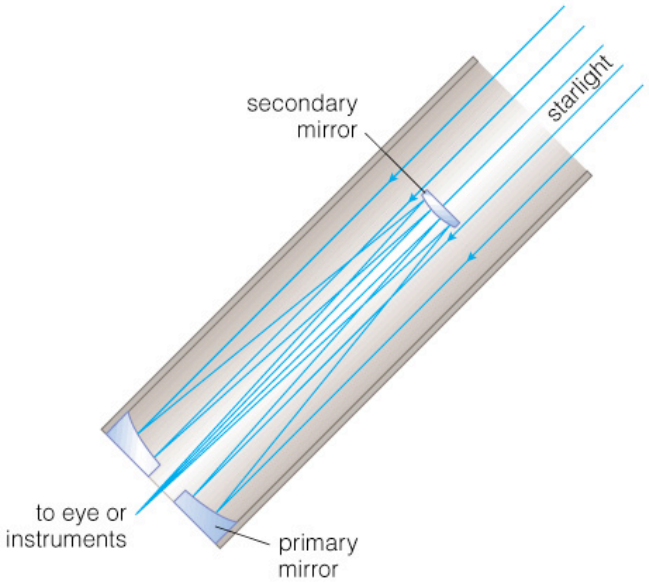
- **Refracting telescope:** Focuses light with lenses
- **Reflecting telescope:** Focuses light with mirrors

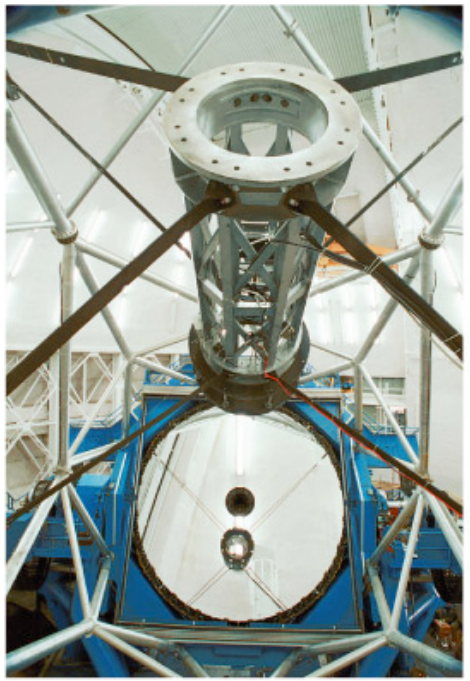
Refracting Telescope



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

Reflecting Telescope



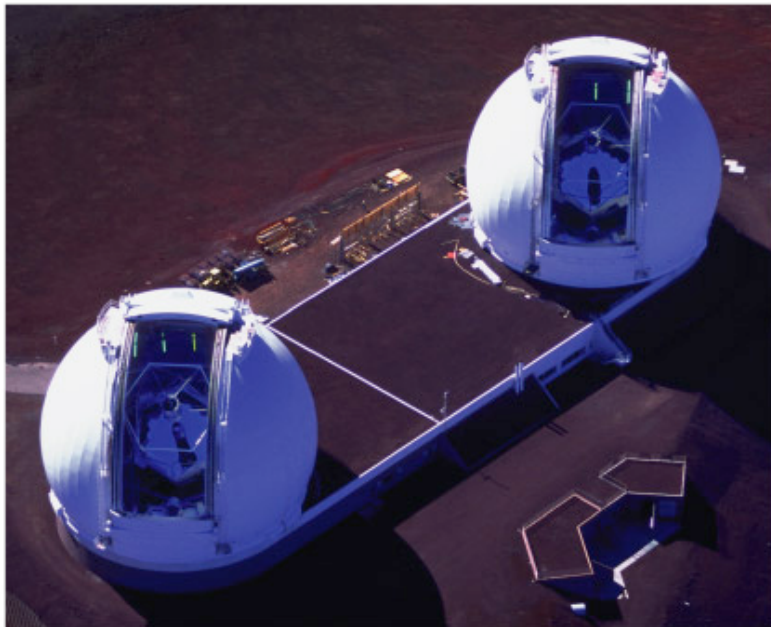


- Reflecting telescopes can have much greater diameters
- Most modern telescopes are reflectors

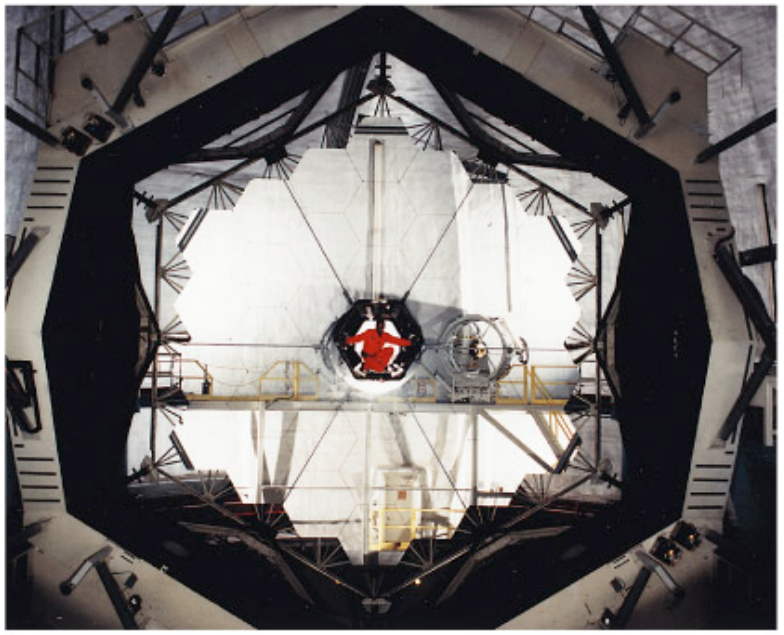
All modern telescopes are reflecting telescopes because:

- Only 1 precise surface needs polishing
  - (as opposed to two surfaces)
- Possible to support mirror on back of glass
  - (as opposed to being only held by their edges)
- Large lens at bottom of telescope
  - (as opposed to to at the top of the telescope)
- Possible to reduce chromatic aberration
  - (lenses bringing different colors of light into focus at slightly different places)

Mirrors in Reflecting Telescopes



Twin Keck telescopes on Mauna Kea in Hawaii

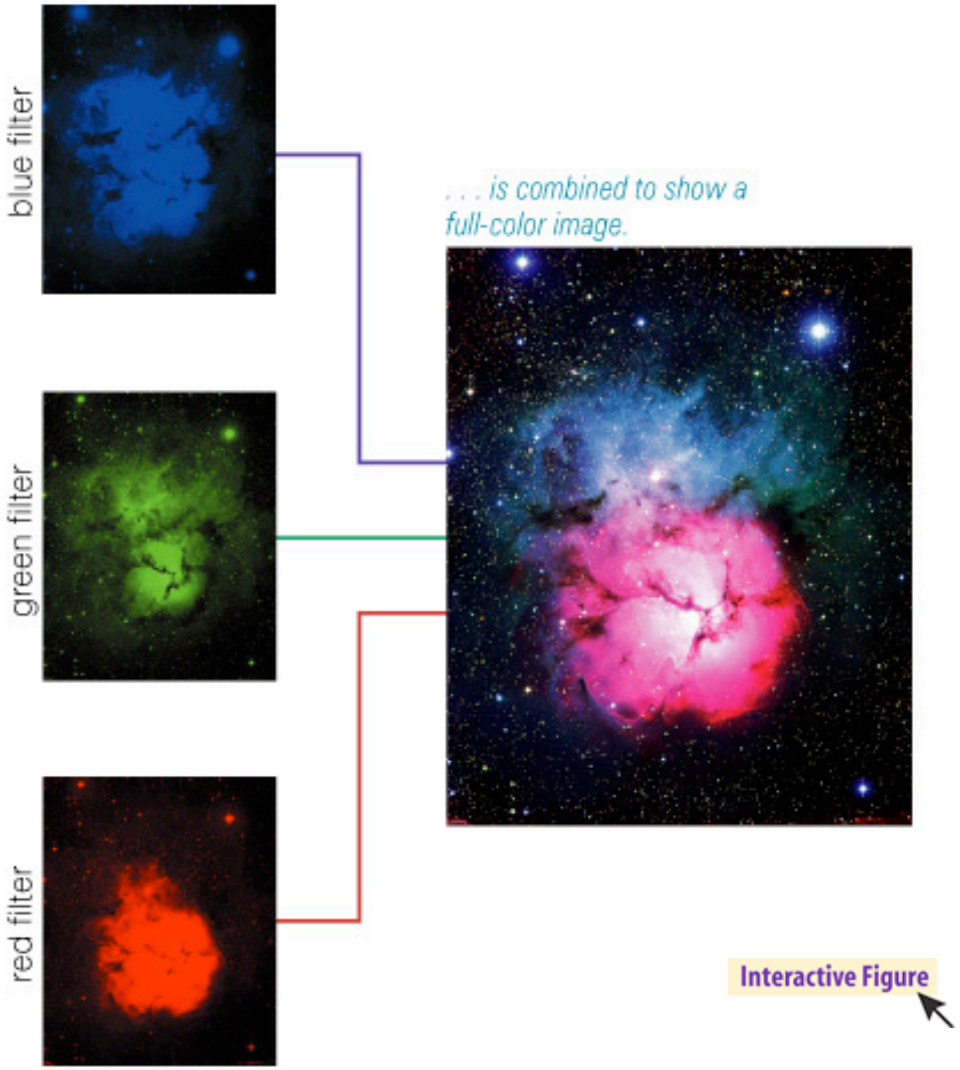


Segmented 10-meter mirror of a Keck telescope

What do astronomers do with telescopes?

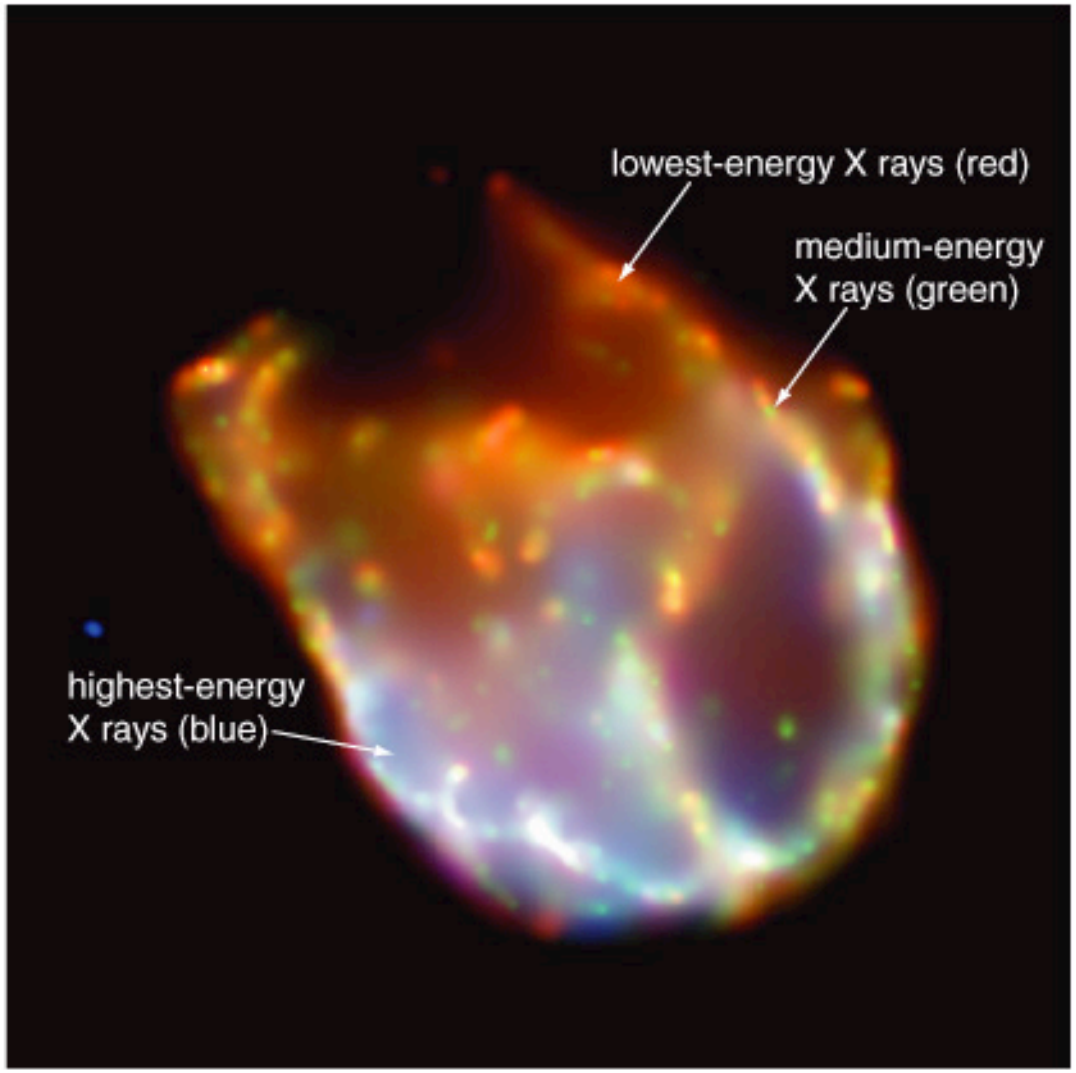
- **Imaging:** Taking pictures of the sky
- **Spectroscopy:** Breaking light into spectra
- **Timing:** Measuring how light output varies with time

Imaging



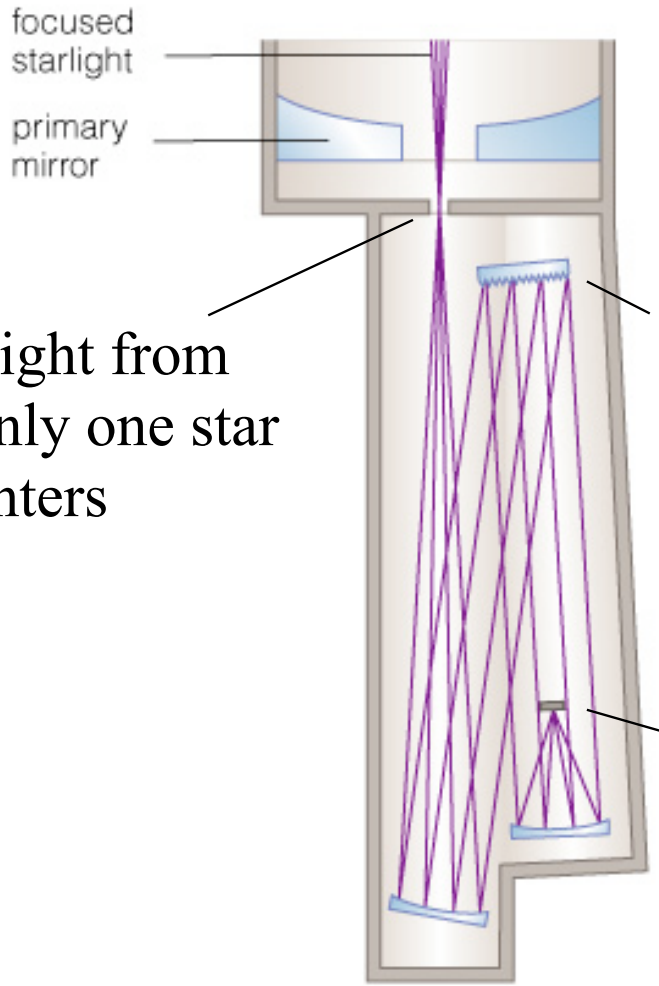
- Astronomical detectors generally record only one color of light at a time
- Several images must be combined to make full-color pictures

Imaging



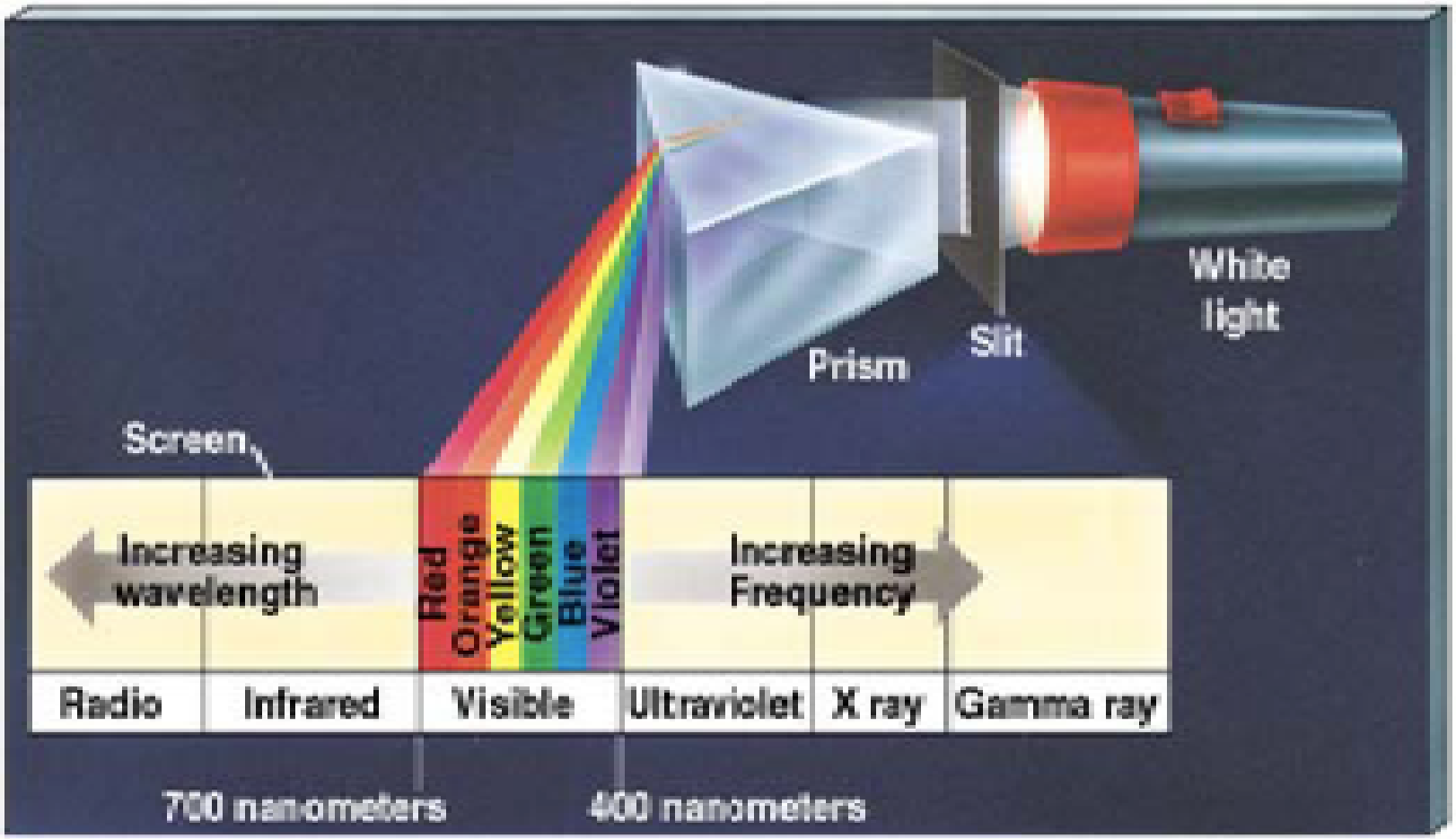
- Astronomical detectors can record forms of light our eyes can't see
- Color is sometimes used to represent different energies of nonvisible light

Spectroscopy

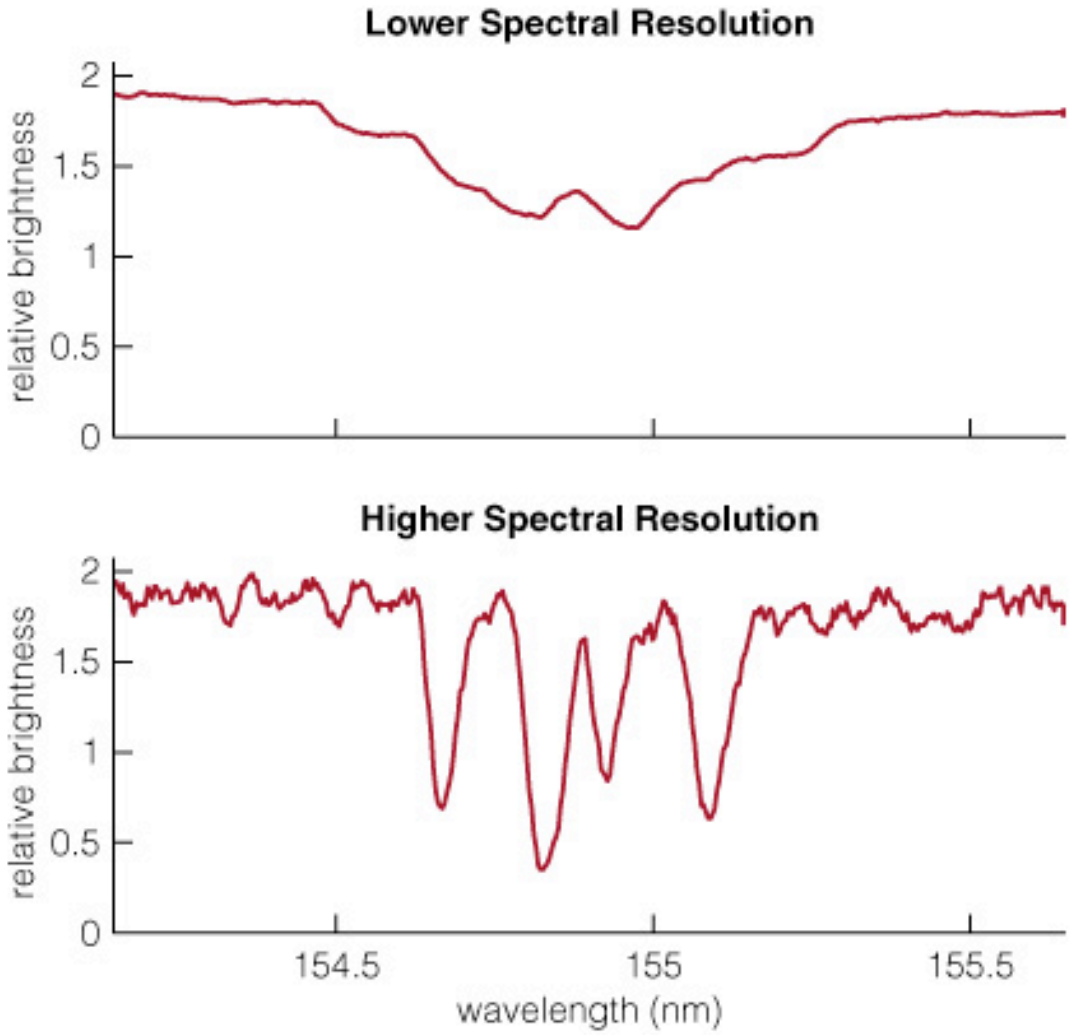


- A spectrograph separates the different wavelengths of light before they hit the detector

Just like a prism

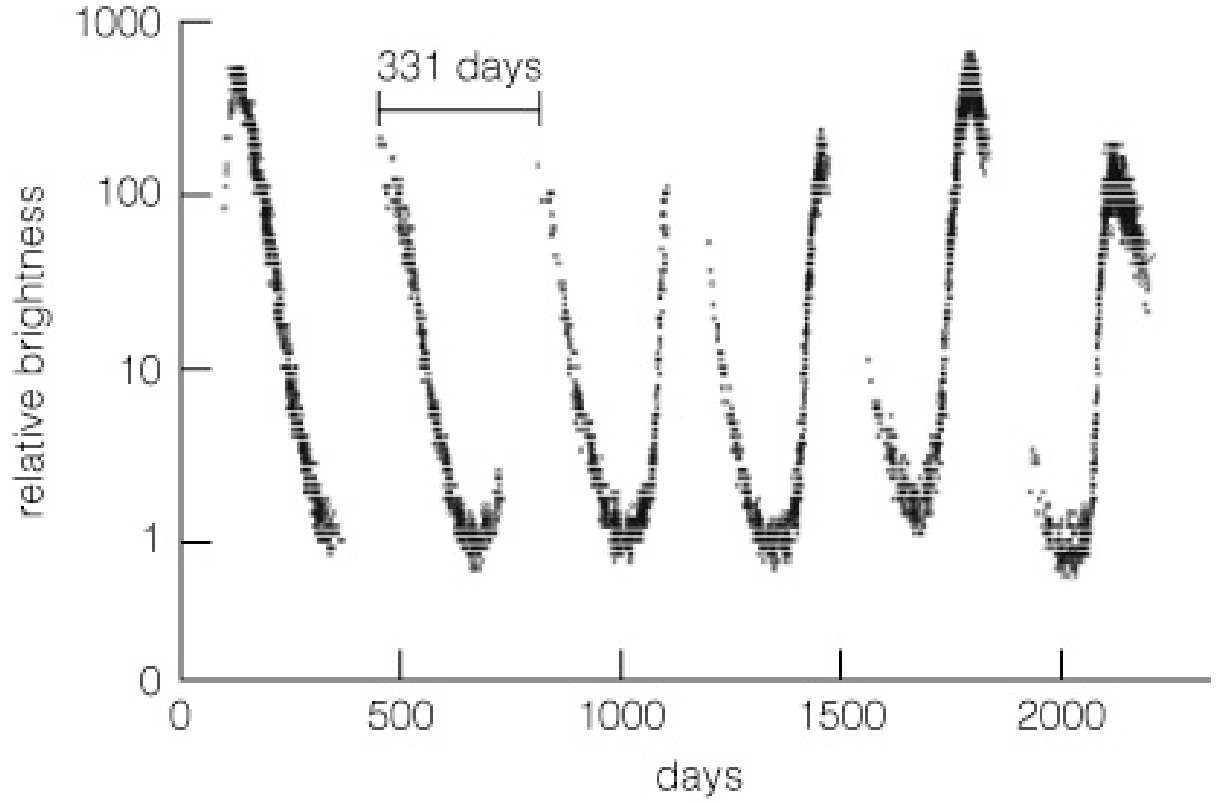


Spectroscopy



- 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

Discuss with someone near you

- What are the two most important properties of a telescope?
  - ??
  - ??
- What are the two basic designs of telescopes?
  - ??
  - ??

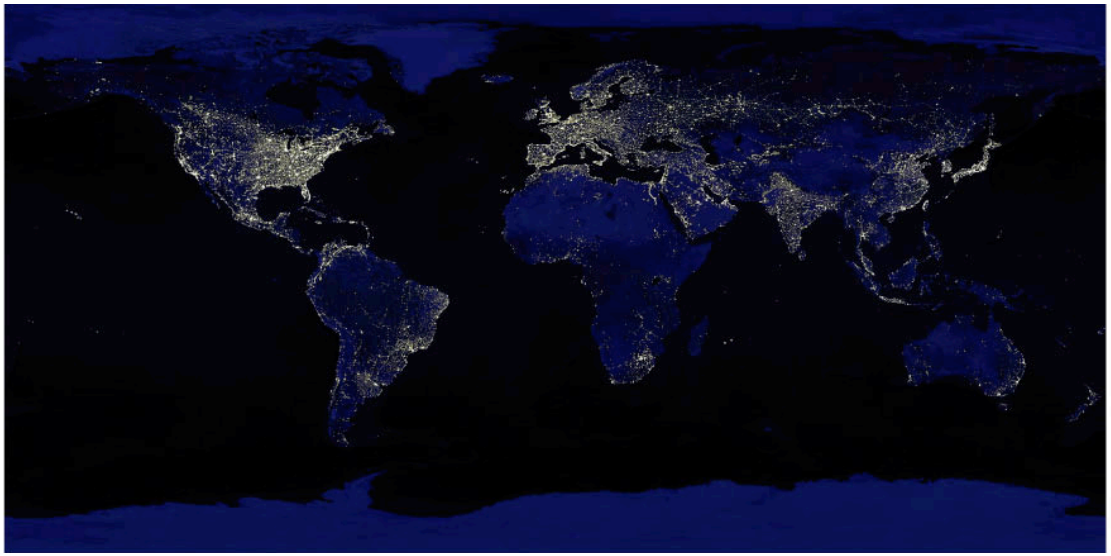
If no one is near you, move next to someone
Groups of two please

Discuss with someone near you

- 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

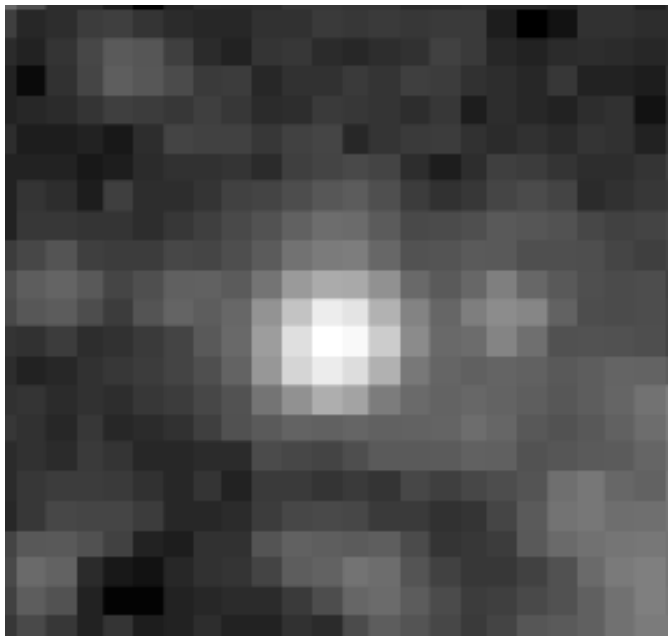
How does Earth's atmosphere affect ground-based observations?

1. Light Pollution

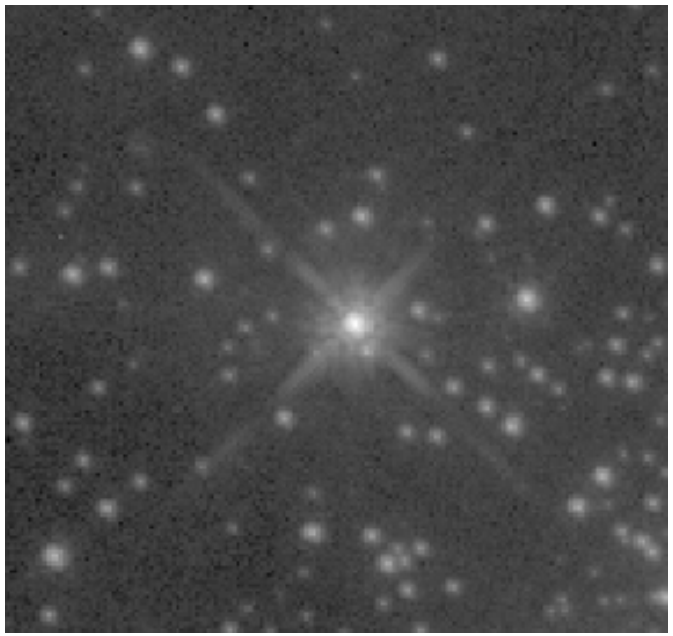


- Scattering of human-made light in the atmosphere is a growing problem for astronomy

2. Twinkling and Turbulence



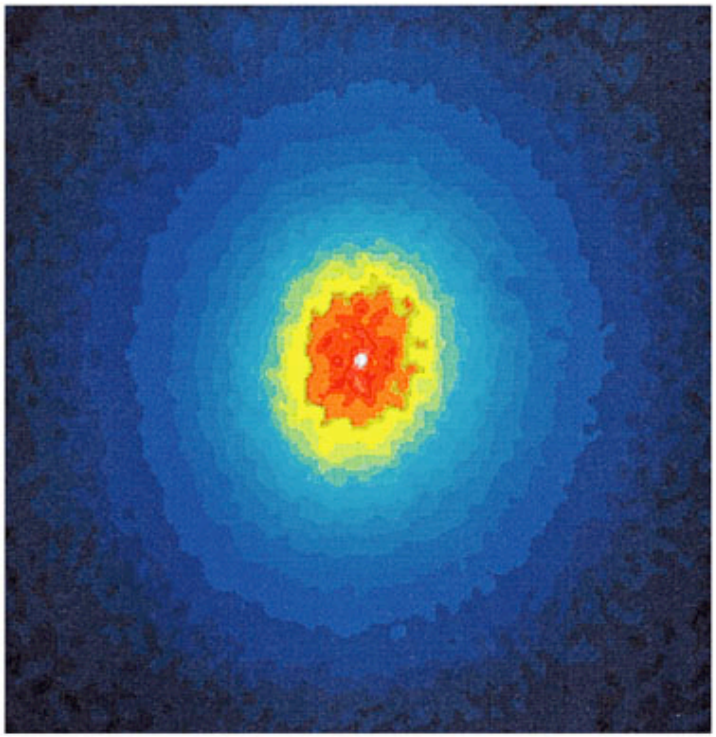
Star viewed with ground-based telescope



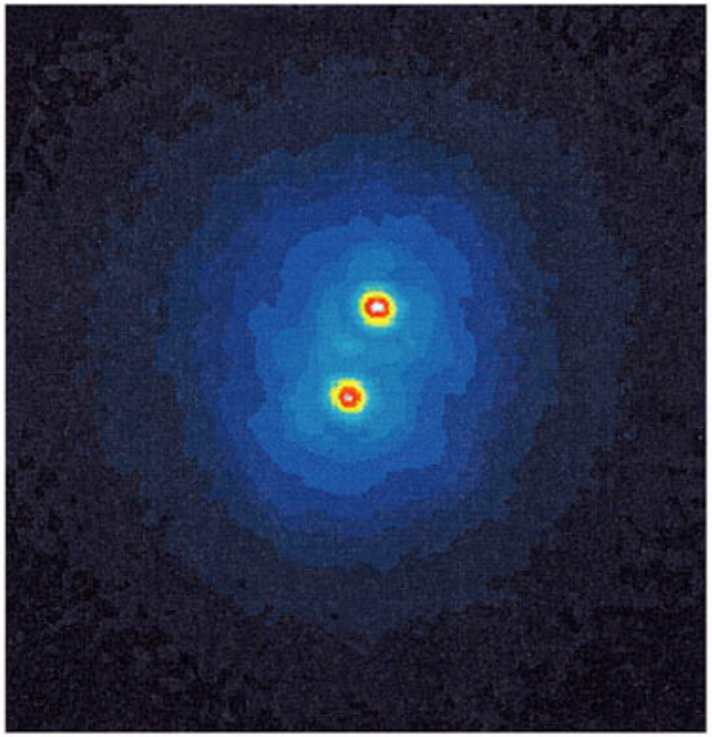
Same star viewed with Hubble Space Telescope

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

Adaptive Optics



Without adaptive optics

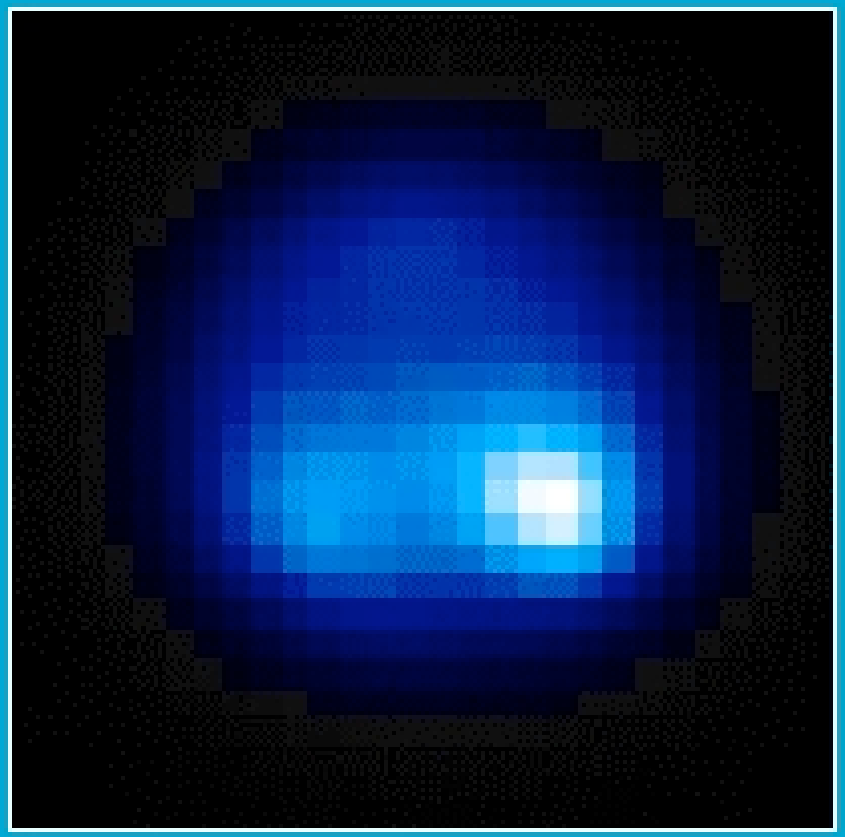


With adaptive optics

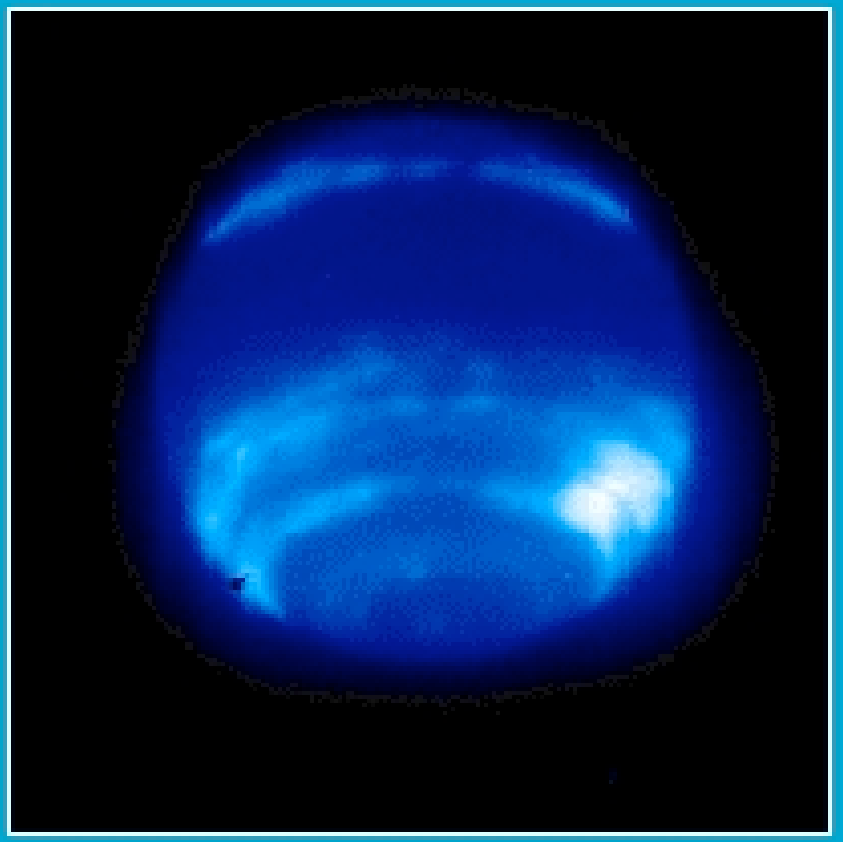
Rapidly changing the shape of a telescope's mirror compensates for some of the effects of turbulence

Adaptive optics: Neptune

without



with



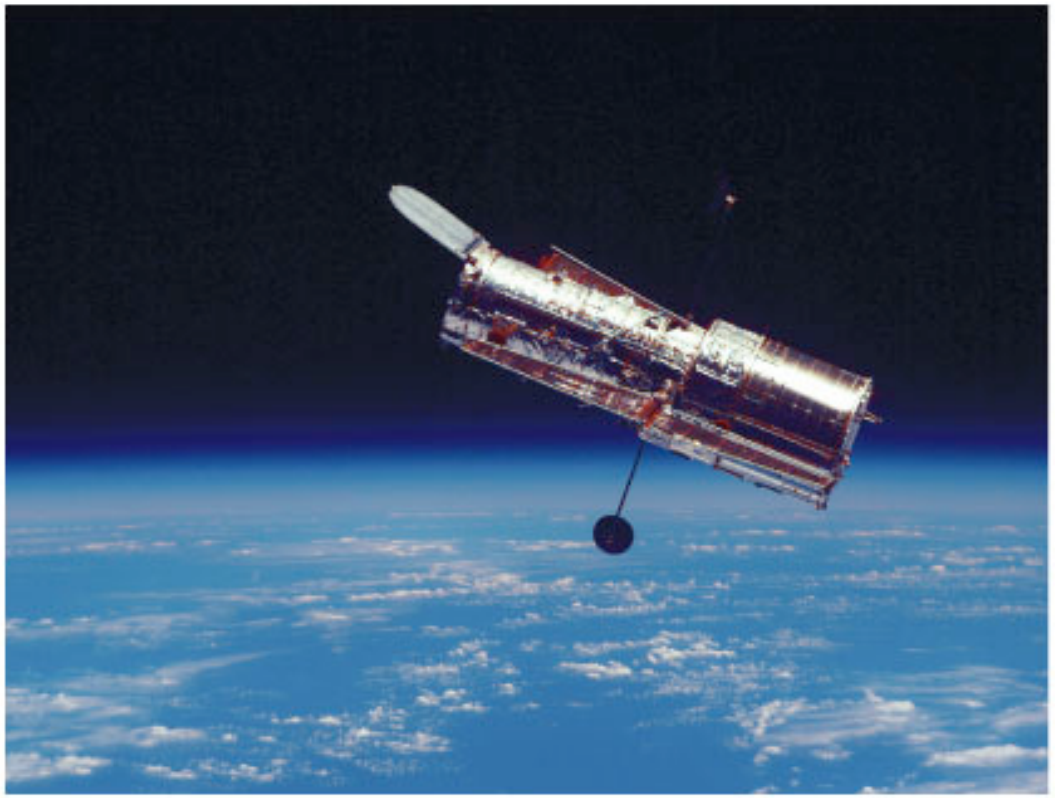
Where should we build telescopes?

- 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)

ie: atop remote mountains

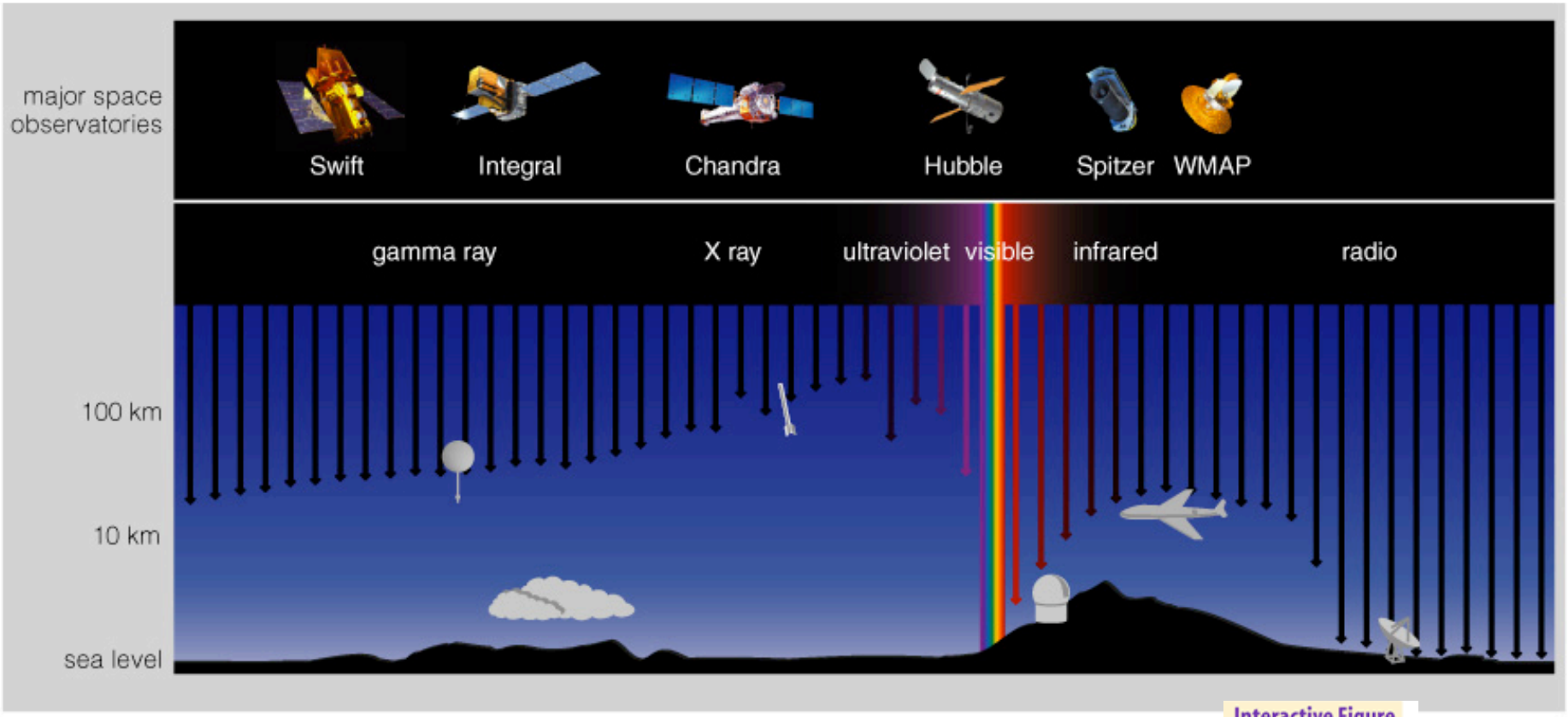
Summit of Mauna Kea, Hawaii

Why do we put telescopes into space?



- Escape from atmospheric distortion (seeing)
- Escape from atmospheric airglow and light pollution
- Observe other regions of electromagnetic spectrum

Transmission in Atmosphere



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

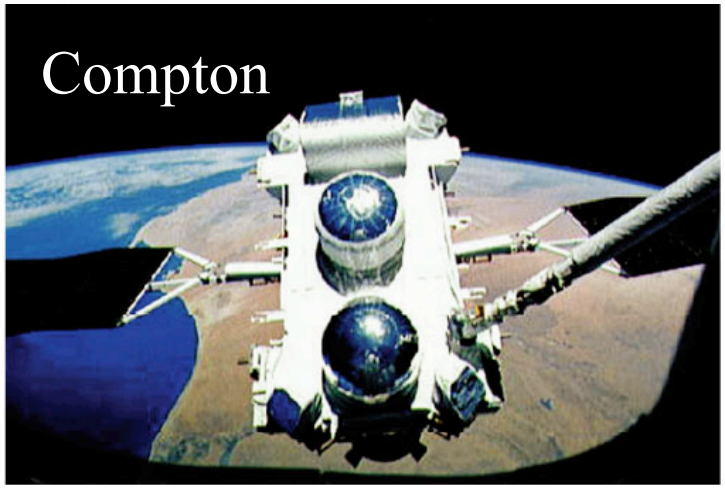
How can we observe nonvisible light?

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

Radio Telescopes

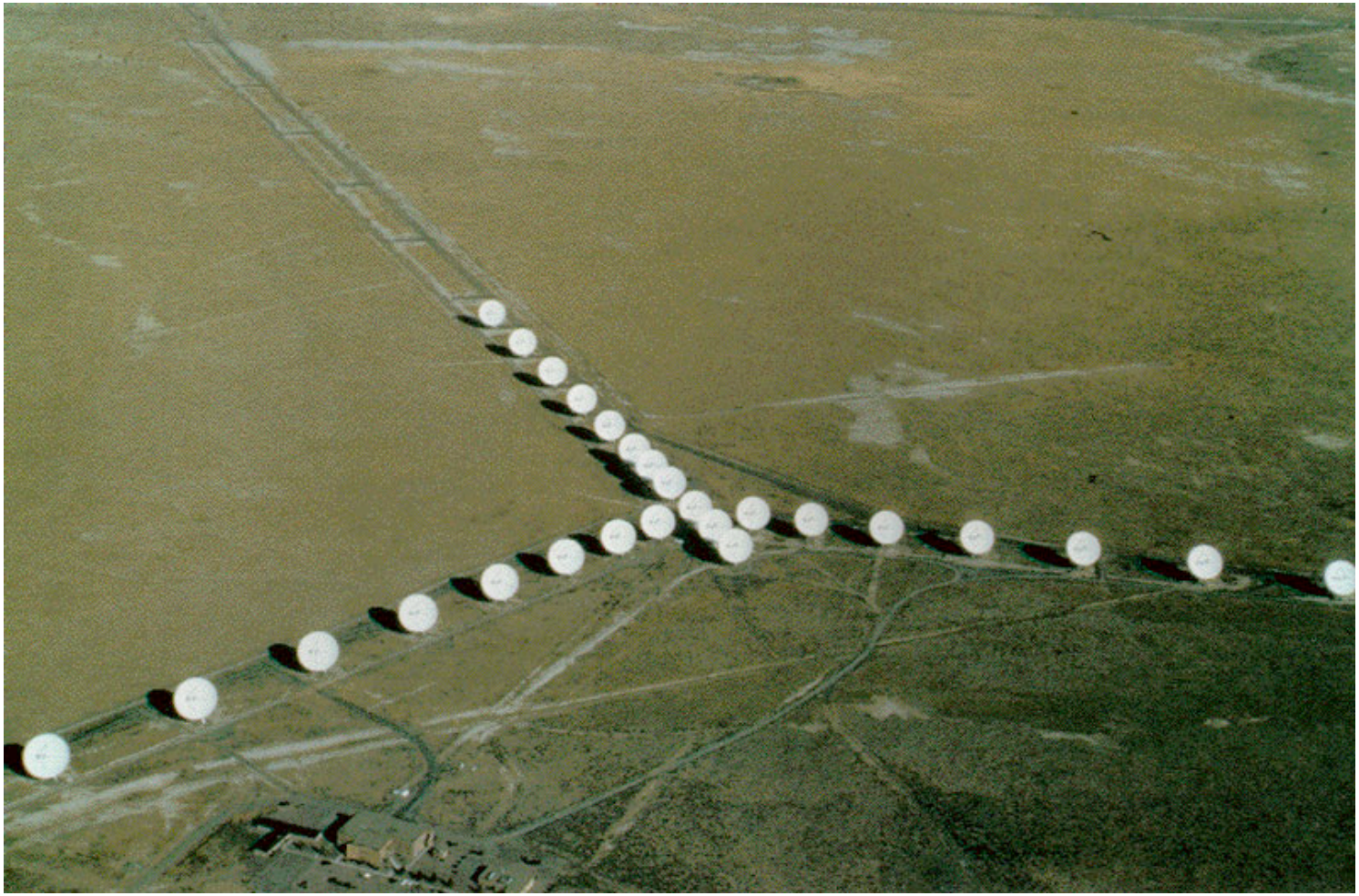
- A radio telescope is like a giant mirror that reflects radio waves to a focus
- Wavelengths of light much longer than visible light
- Irregularities should be less than 1/5 the wavelength of light being focused

X-Ray and Gamma Ray Telescopes

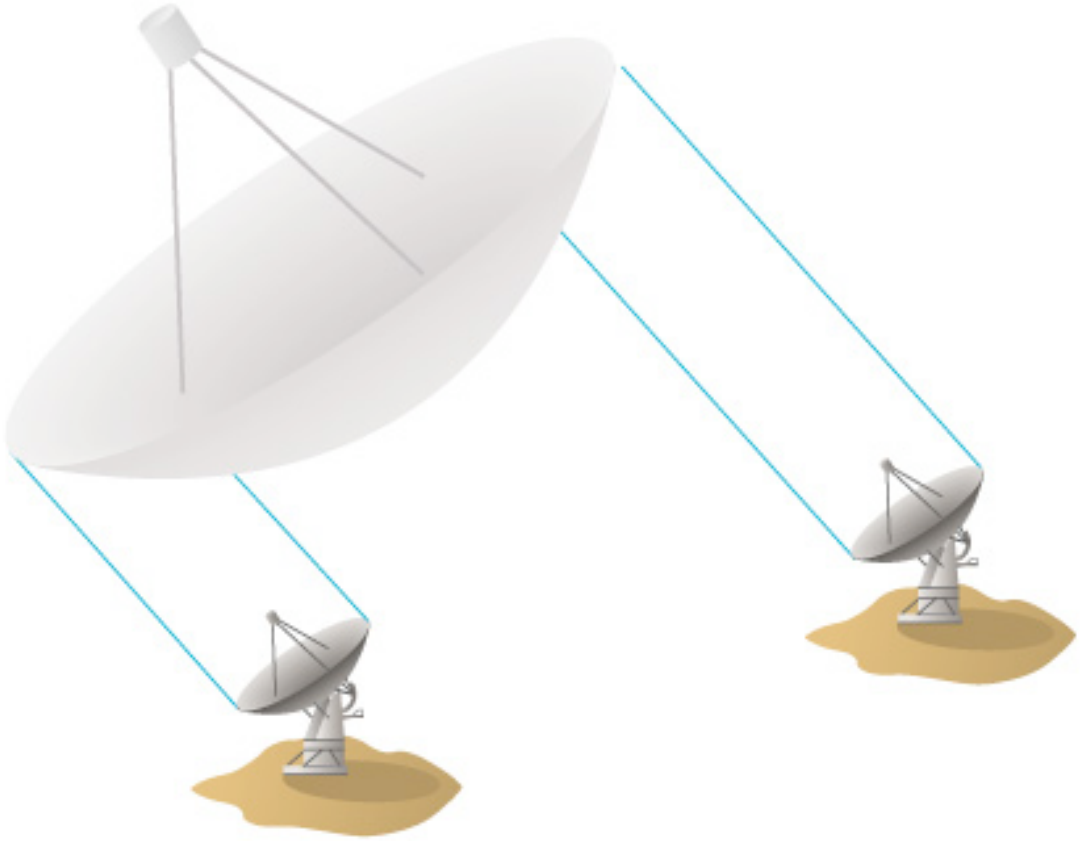


- X-ray telescopes also need to be above the atmosphere
- As do Gamma Ray telescopes

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