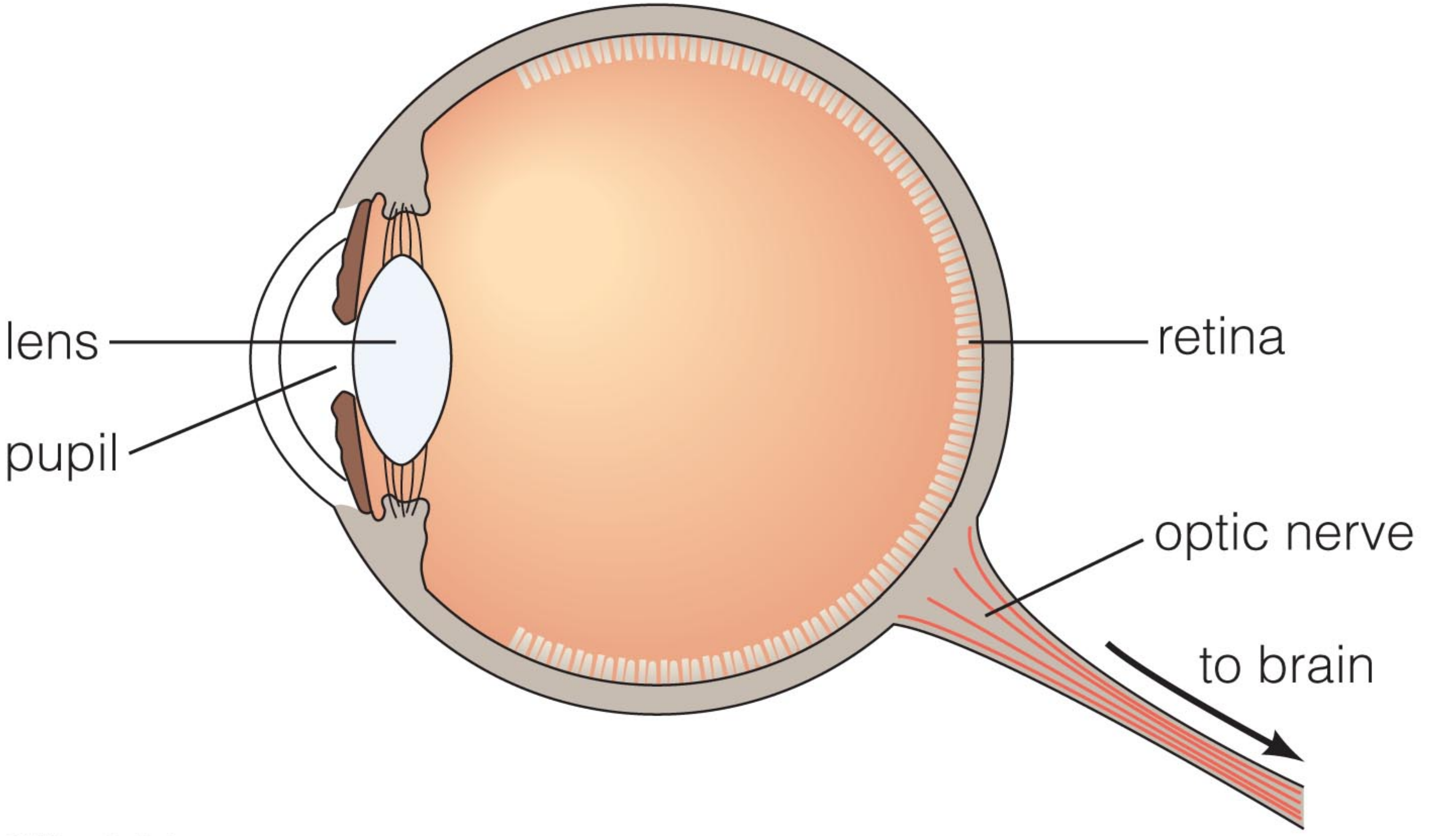
Telescopes: Portals of Discovery

6.1 Eyes and Cameras: Everyday Light Sensors

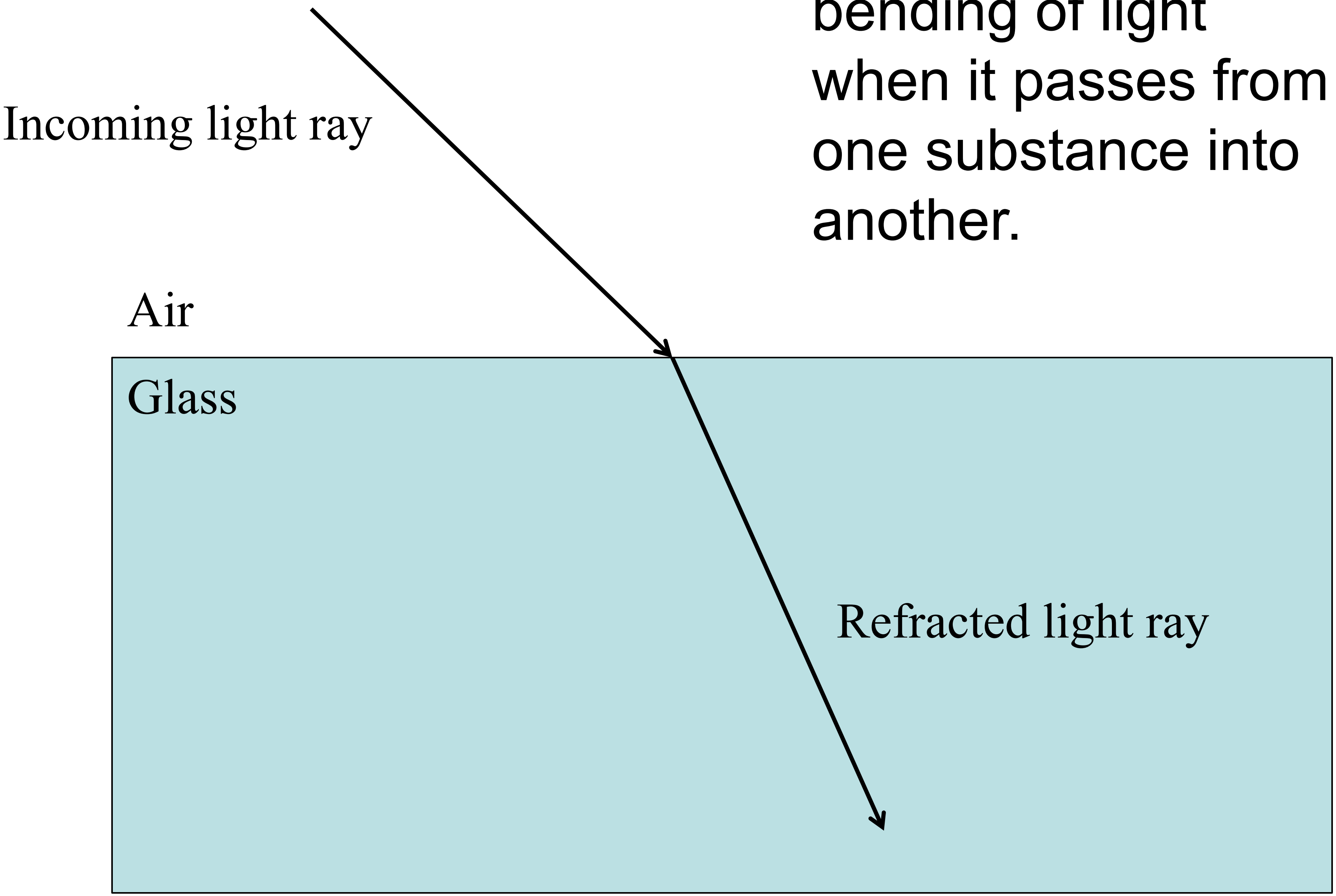
- Our goals for learning:
  - **How do eyes and cameras work?**

The Eye

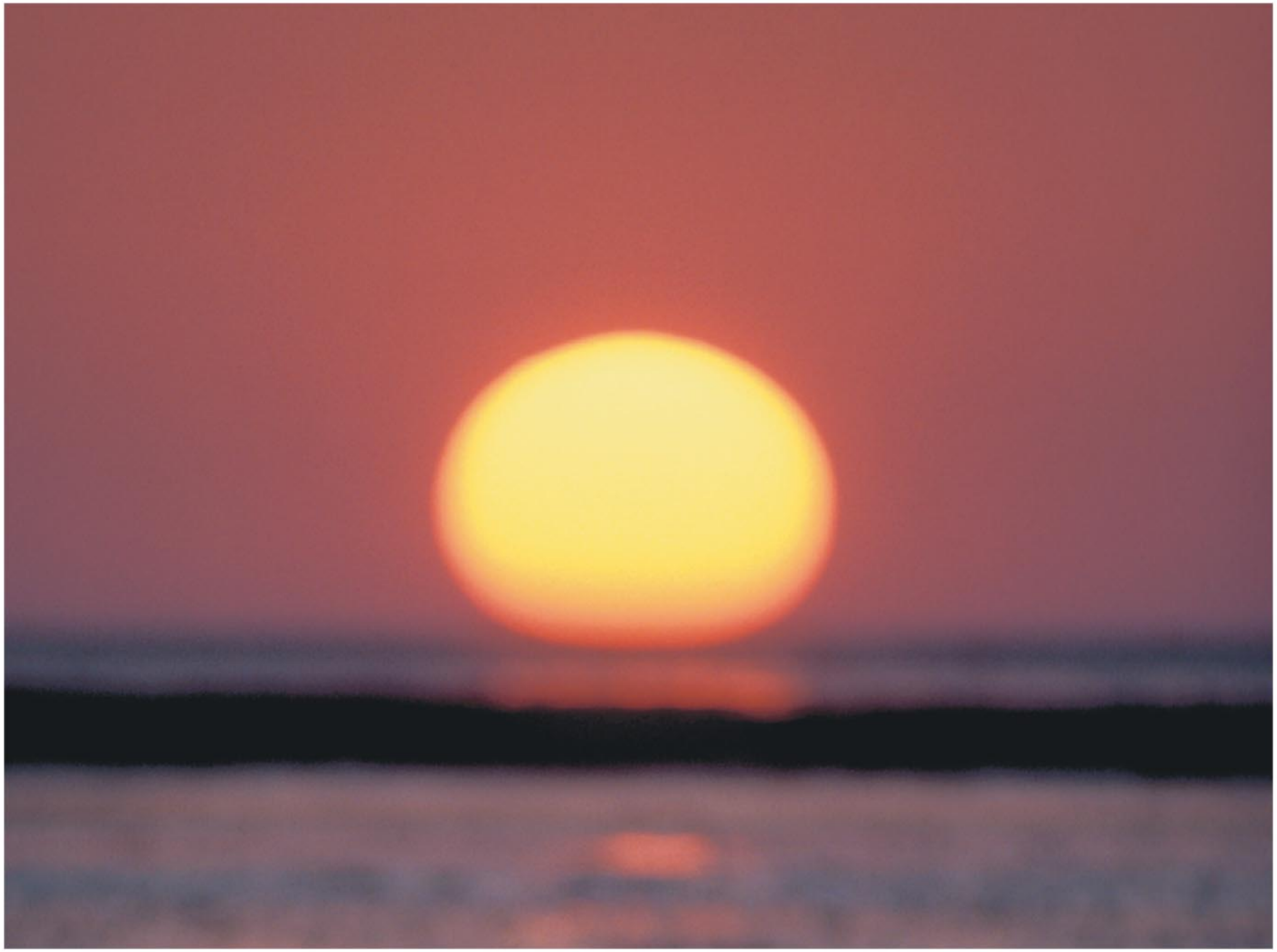


Refraction

Refraction is the bending of light when it passes from one substance into another.

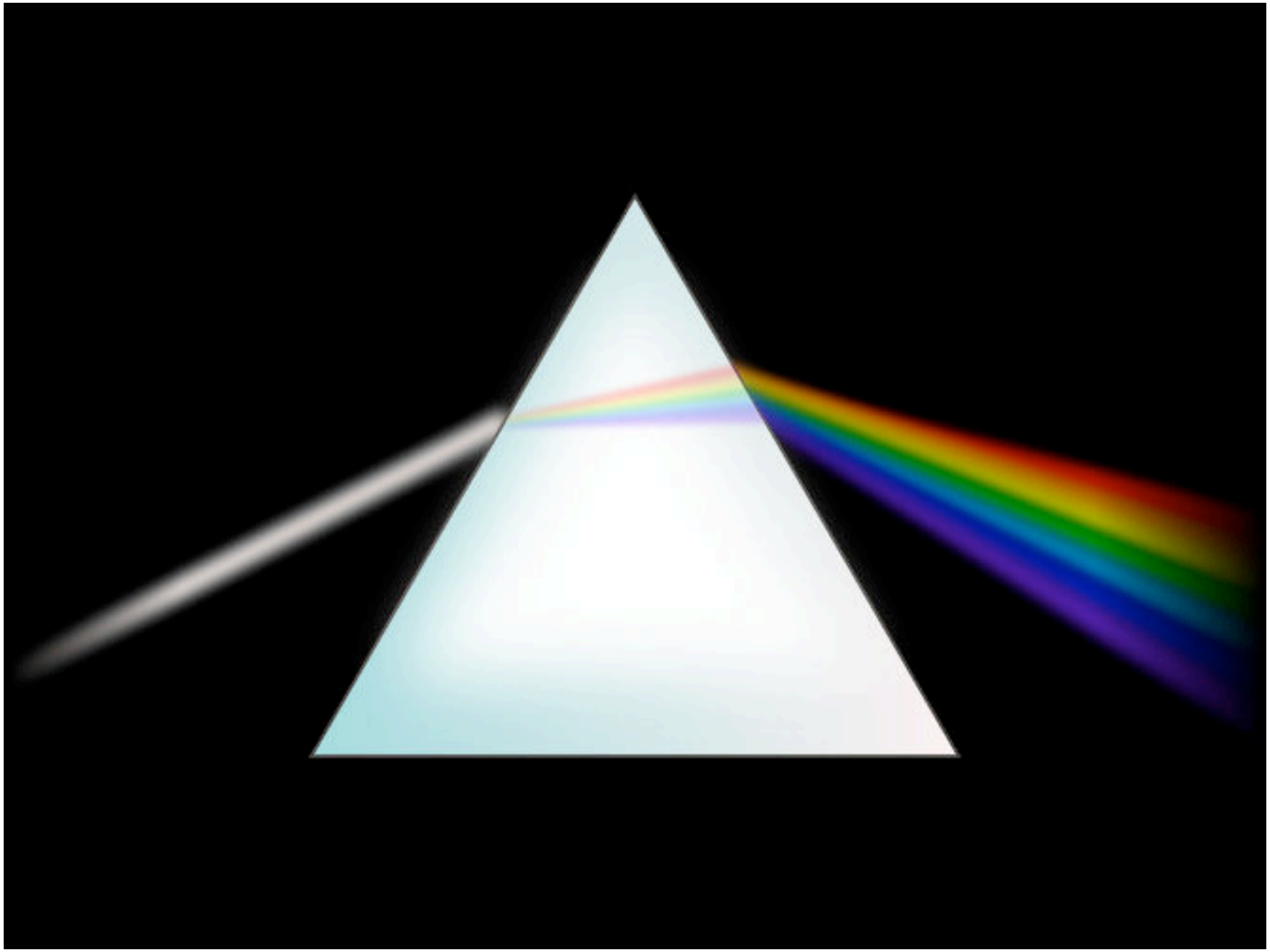


Example: Refraction at Sunset



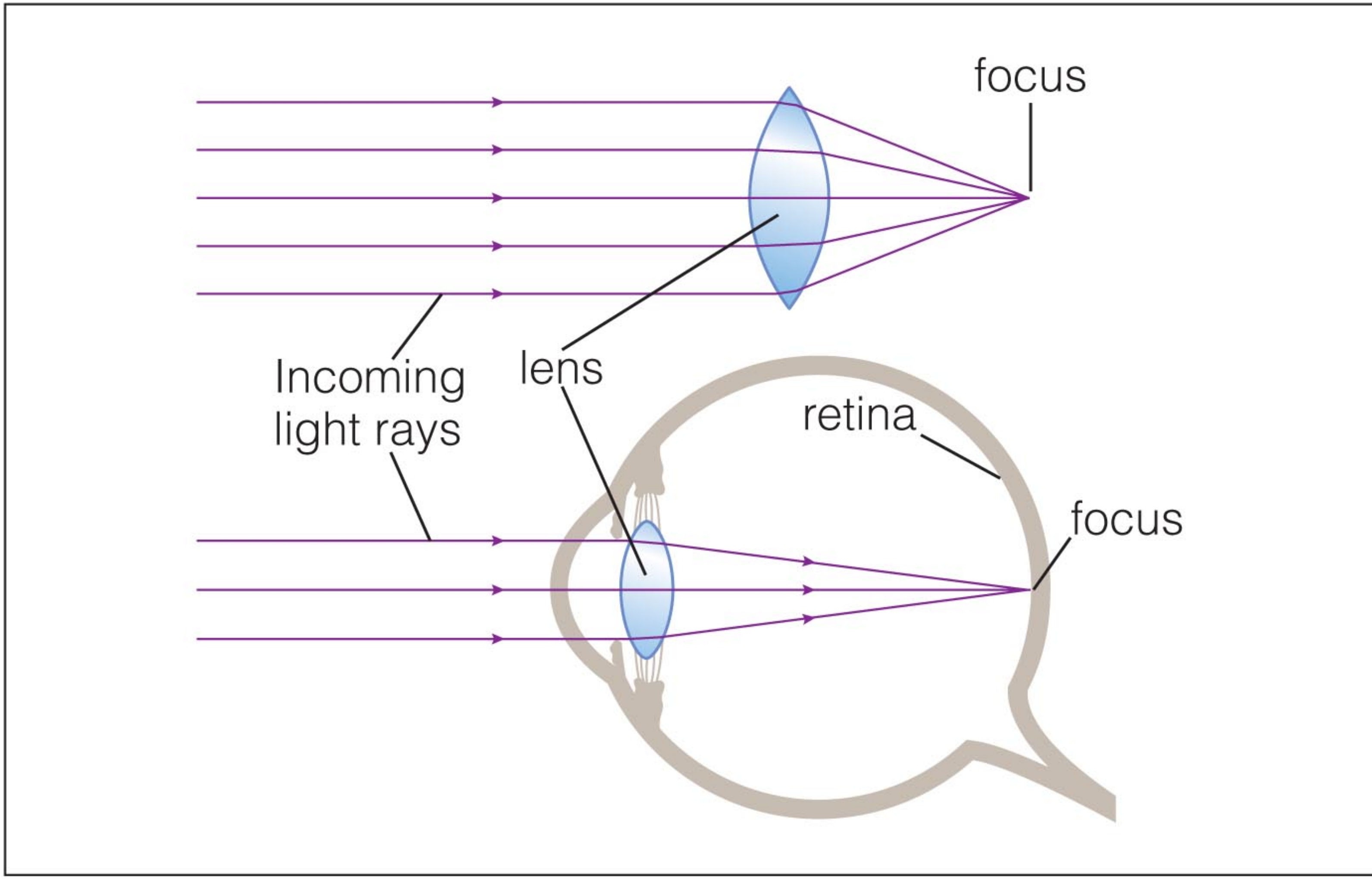
- Sun appears distorted at sunset because of how light bends in Earth's atmosphere.

Example: Prisms



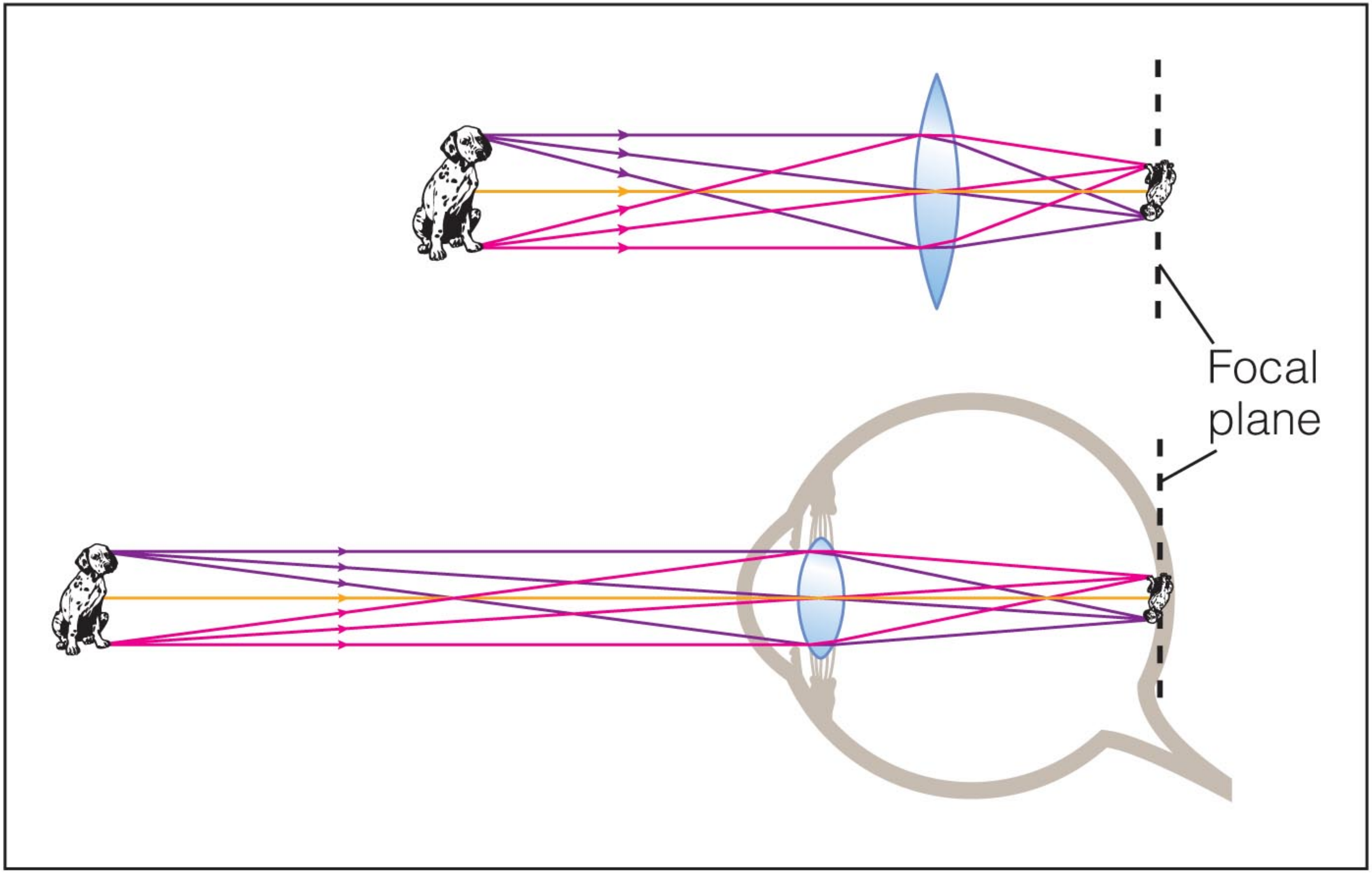
- Prism refracts light – different wavelength have different refraction angles

Focusing Light

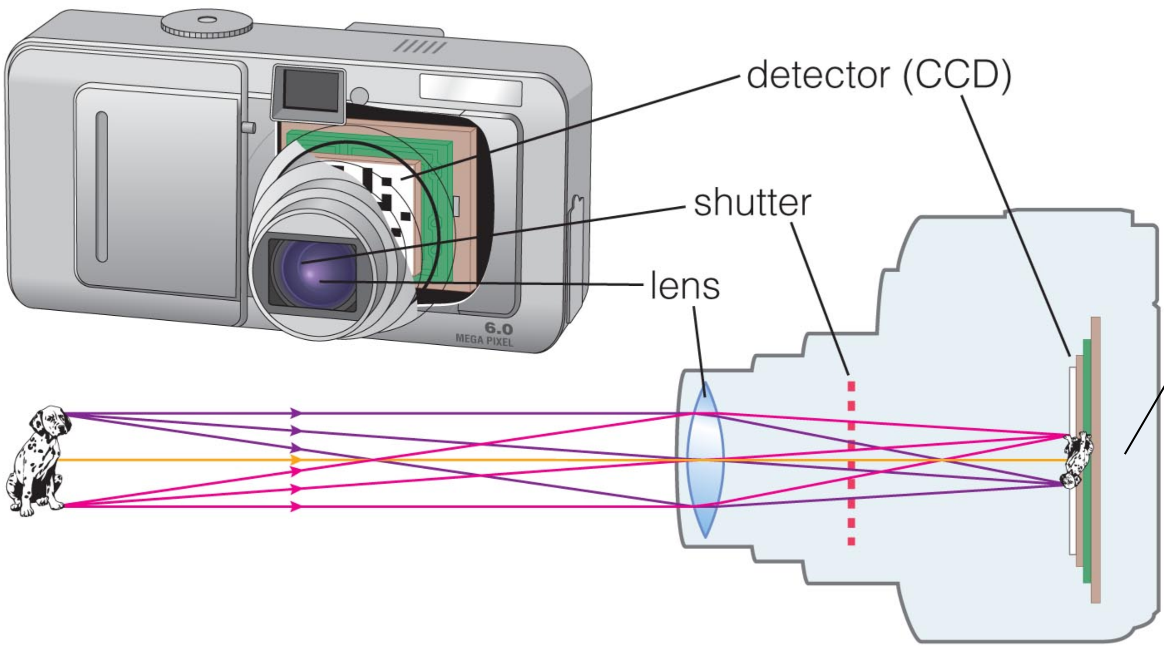


- Refraction can cause parallel light rays to converge to a focus.

Image Formation



Recording 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 have we learned?

- **How do eyes and cameras work?**
  - Eyes use 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.
  - Cameras focus light like your eye and record the image with a detector.

6.2 Telescopes: Giant Eyes

What are the two most important properties of a telescope?

What are the two basic designs of 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

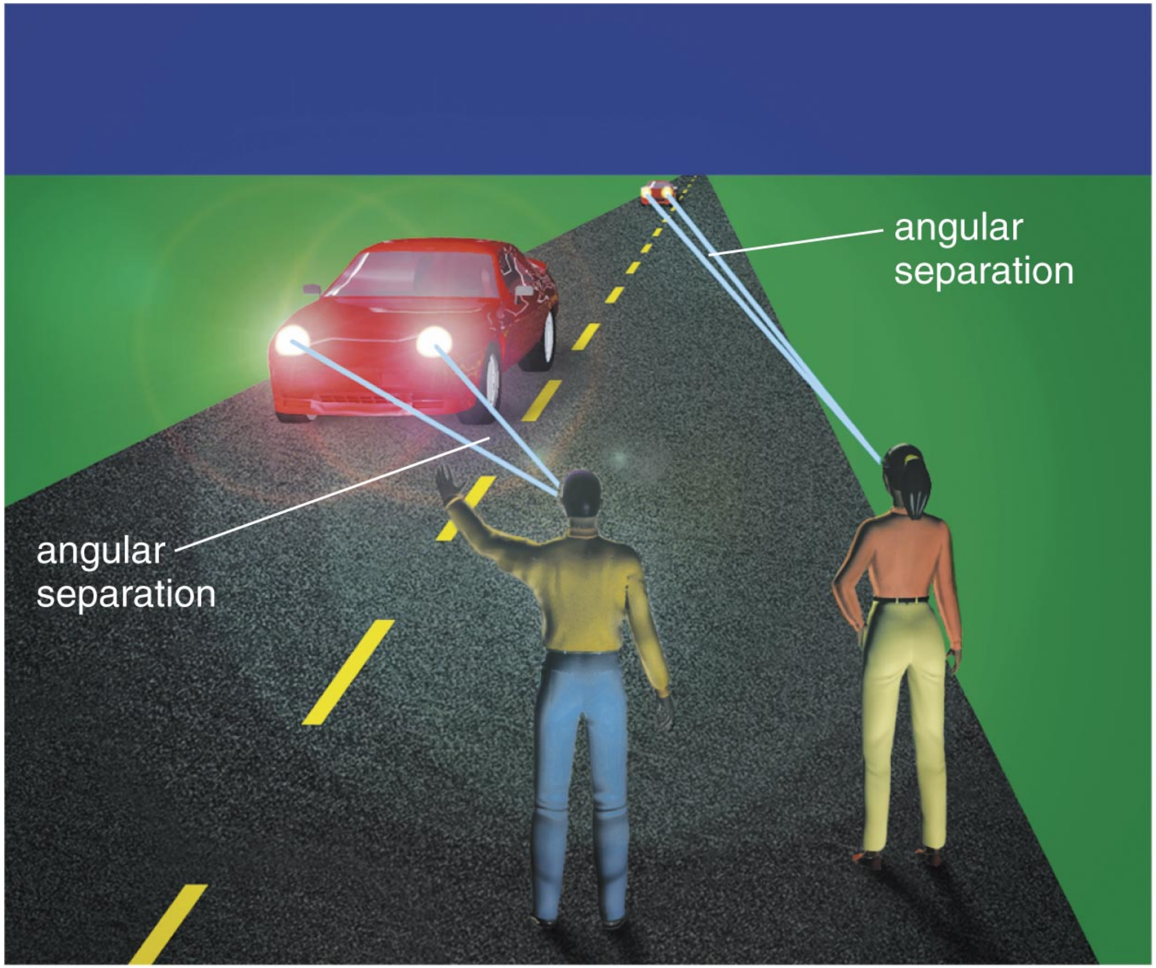
- A telescope's diameter tells us its light-collecting area *(like wider buckets collect more rain).* If the telescope has a diameter of *d*, it has a collecting area: $A = \pi(d/2)^2$

  So a 4-meter telescope has 16x the light collecting area of a 1-meter telescope.

- The largest telescopes currently in use have a diameter of about 10 meters.

Angular Resolution

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



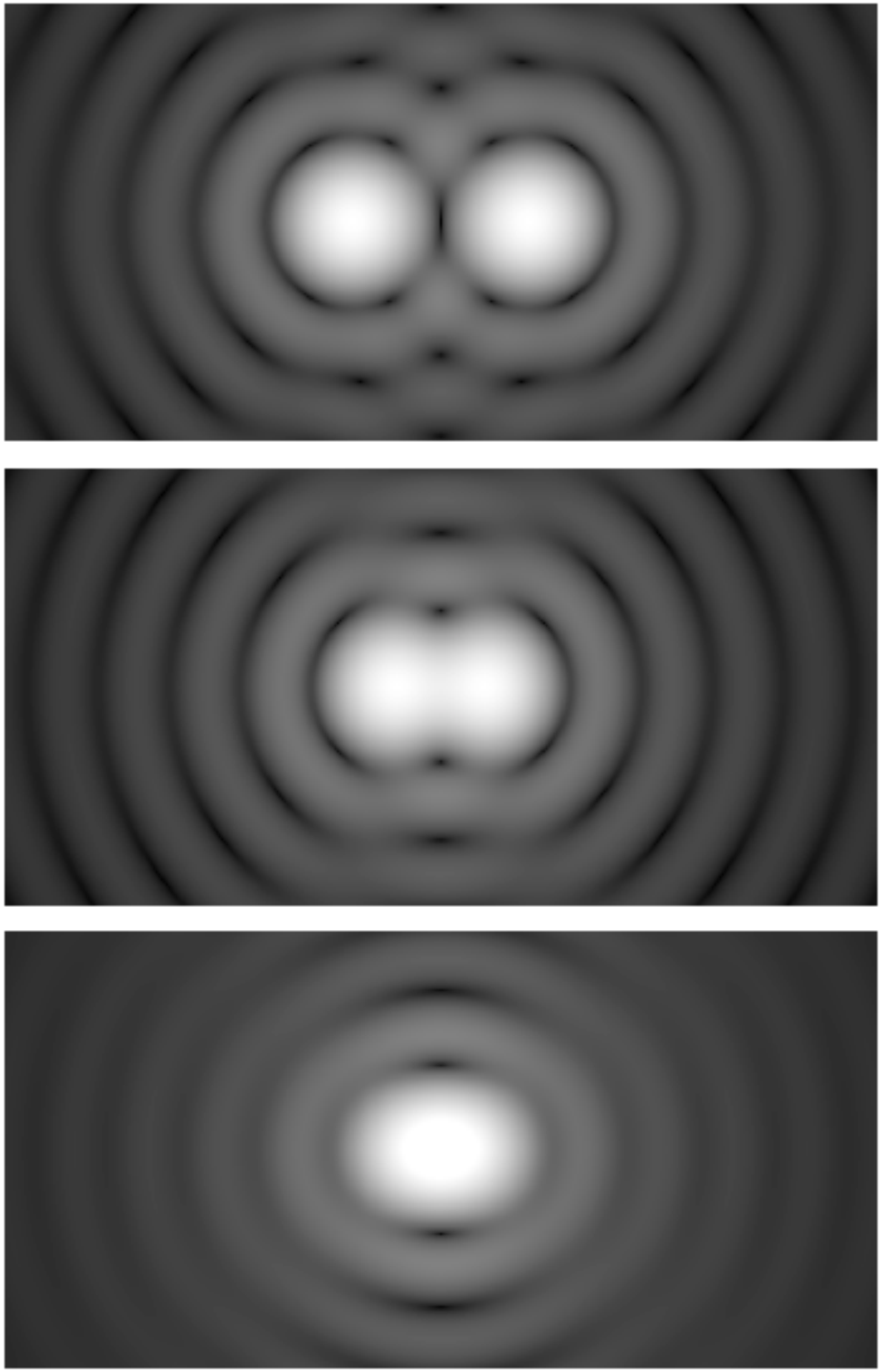
Alcor and Mizar

Angular Resolution

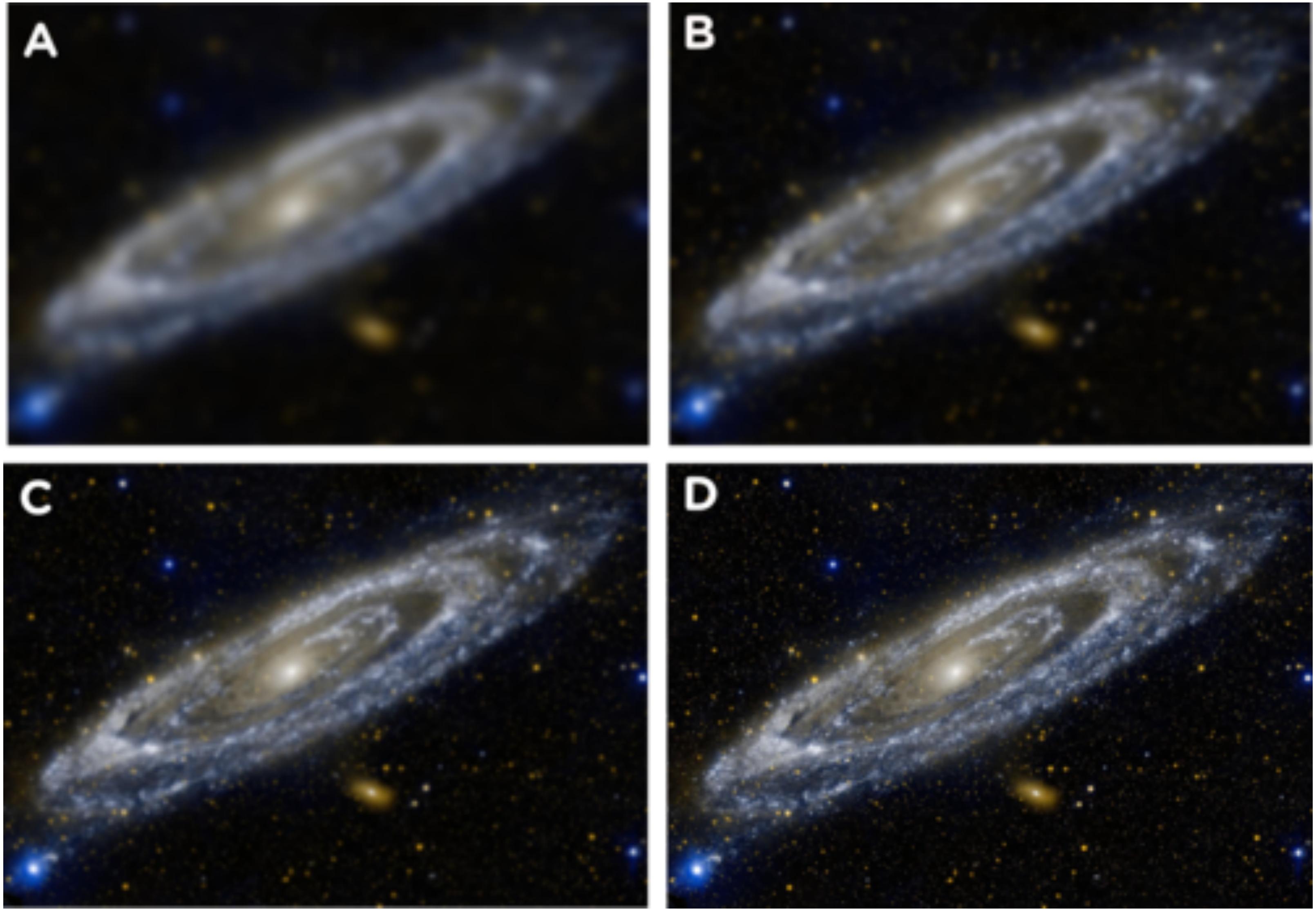
- Stars are so far away that they all look like "dots".

- But interference between light and telescope blurs these dots.

- Bigger telescopes: less interference, sharper images



Angular Resolution



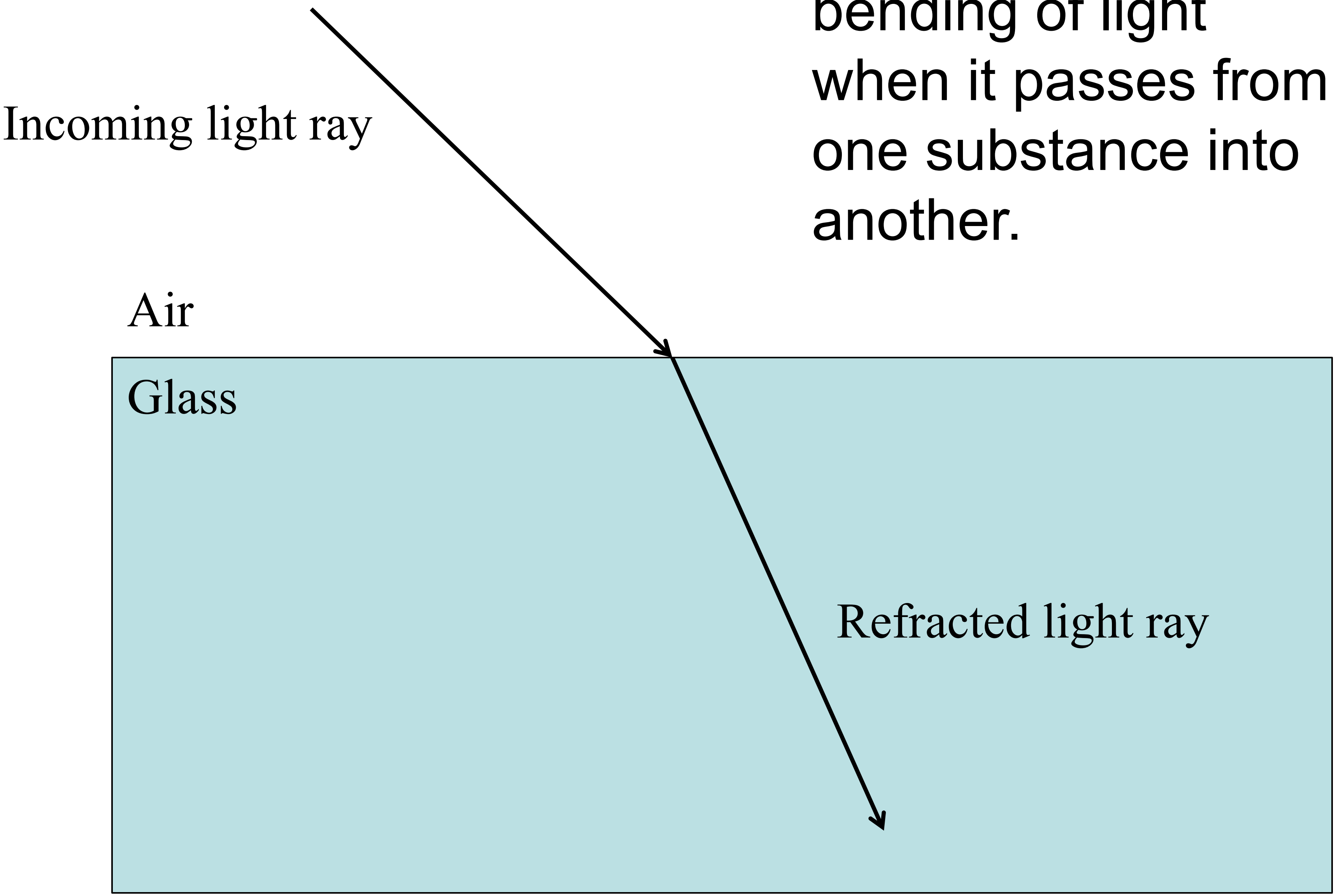
Resolution gets better from A →D: Sharper images

What are the two basic designs of telescopes?

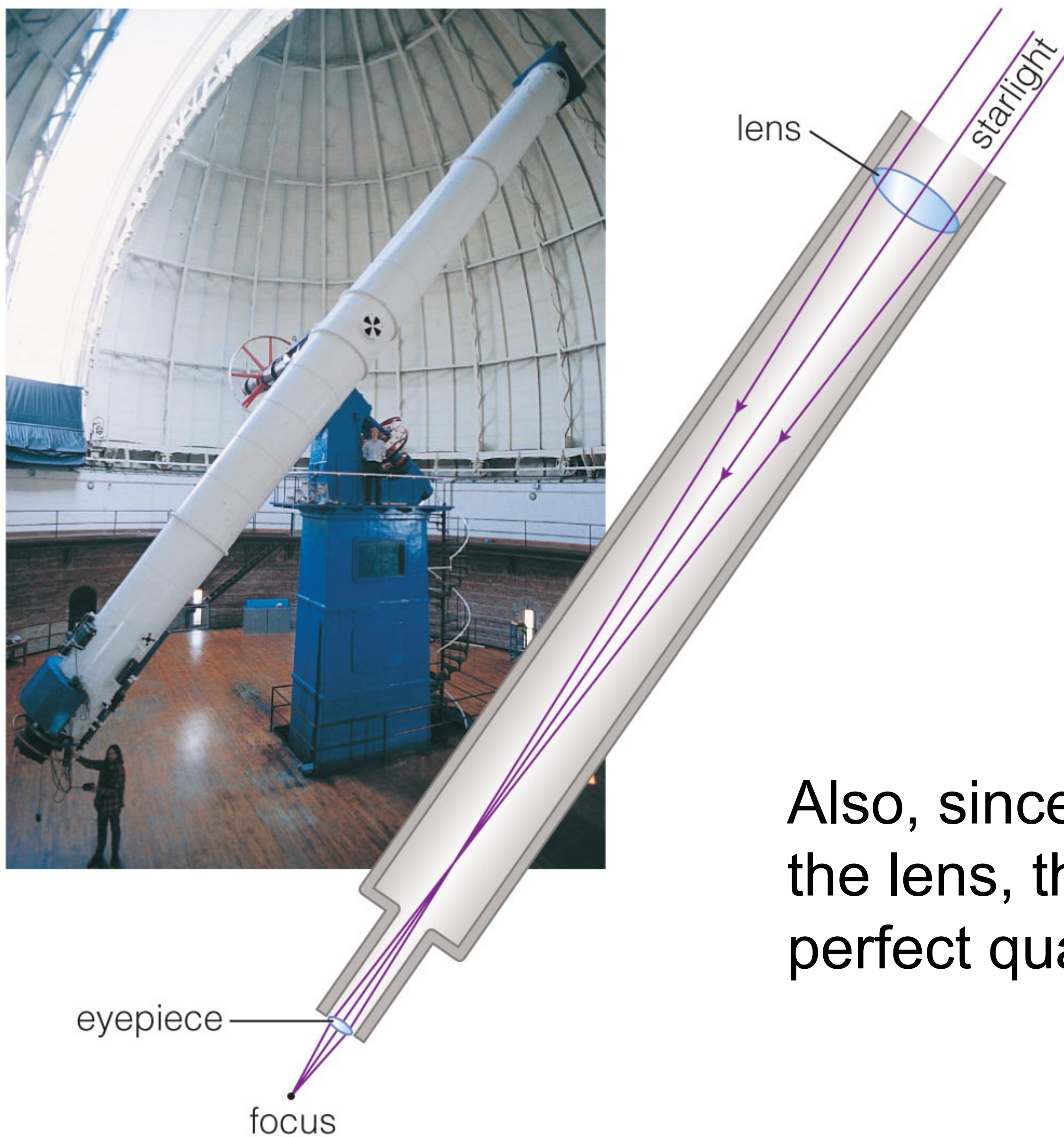
- **Refracting telescope:** focuses light with lenses
- **Reflecting telescope:** focuses light with mirrors

Refraction

Refraction is the bending of light when it passes from one substance into another.



Refracting Telescope

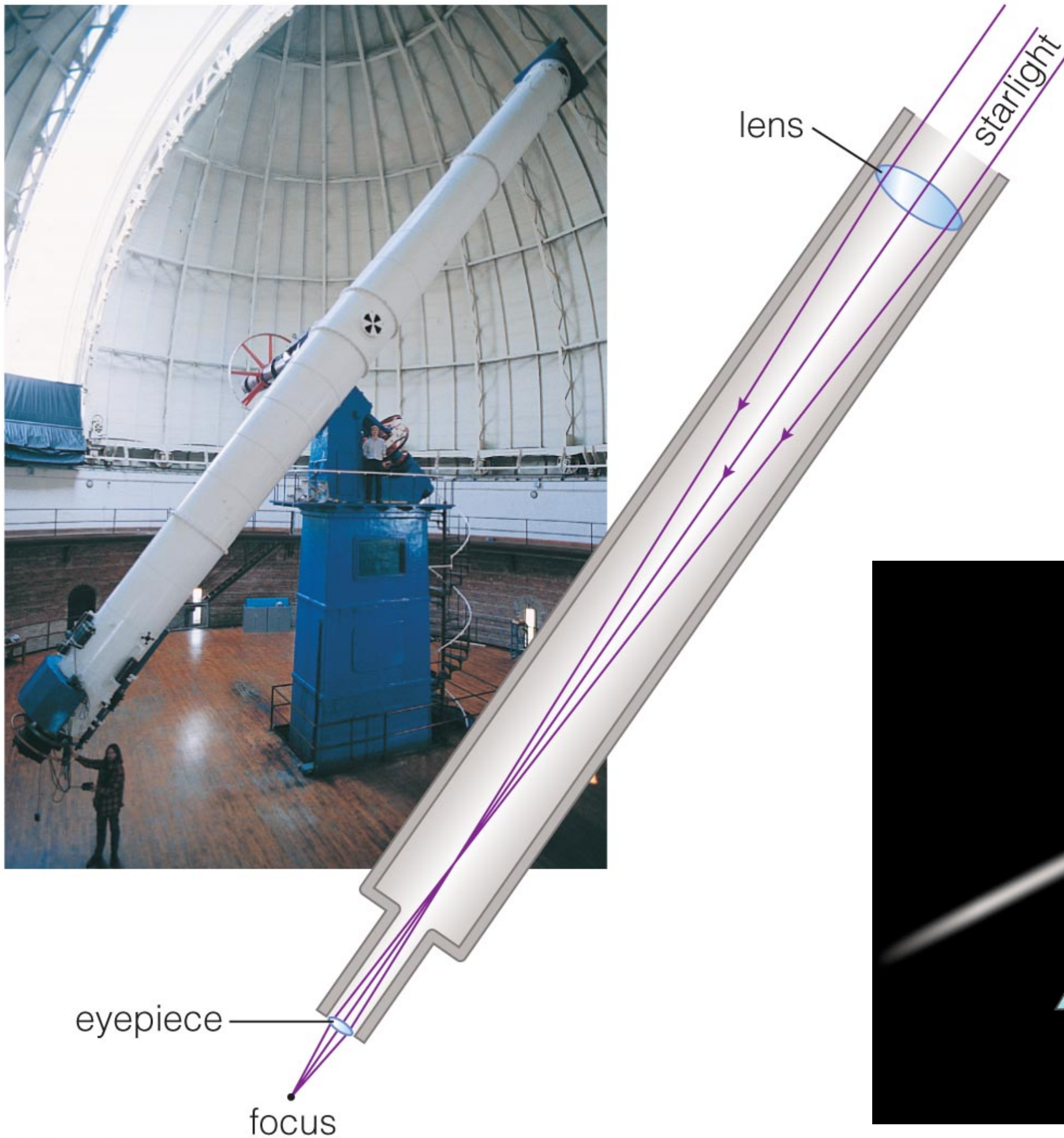


Refracting telescopes need to be very long, with large, heavy lenses.

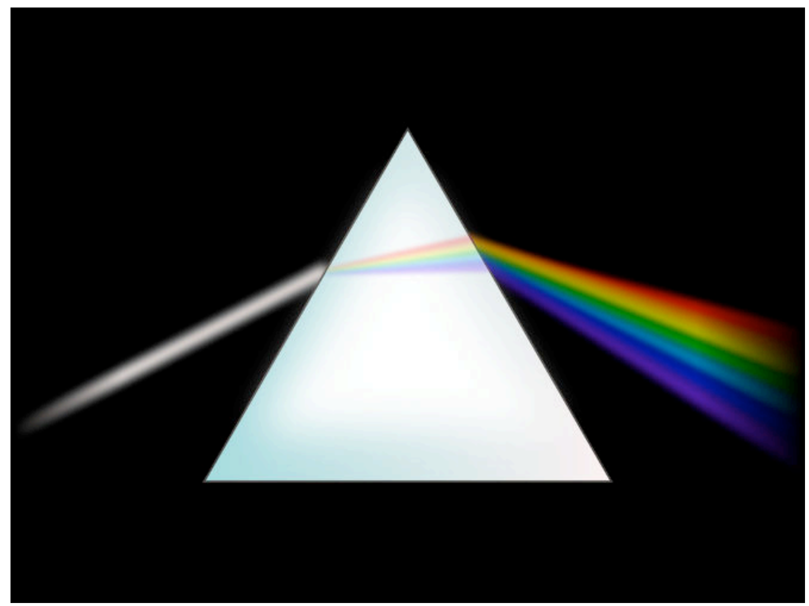
If the lenses are too big/heavy, they will sag out of shape.

Also, since light passes through the lens, the glass needs to be perfect quality

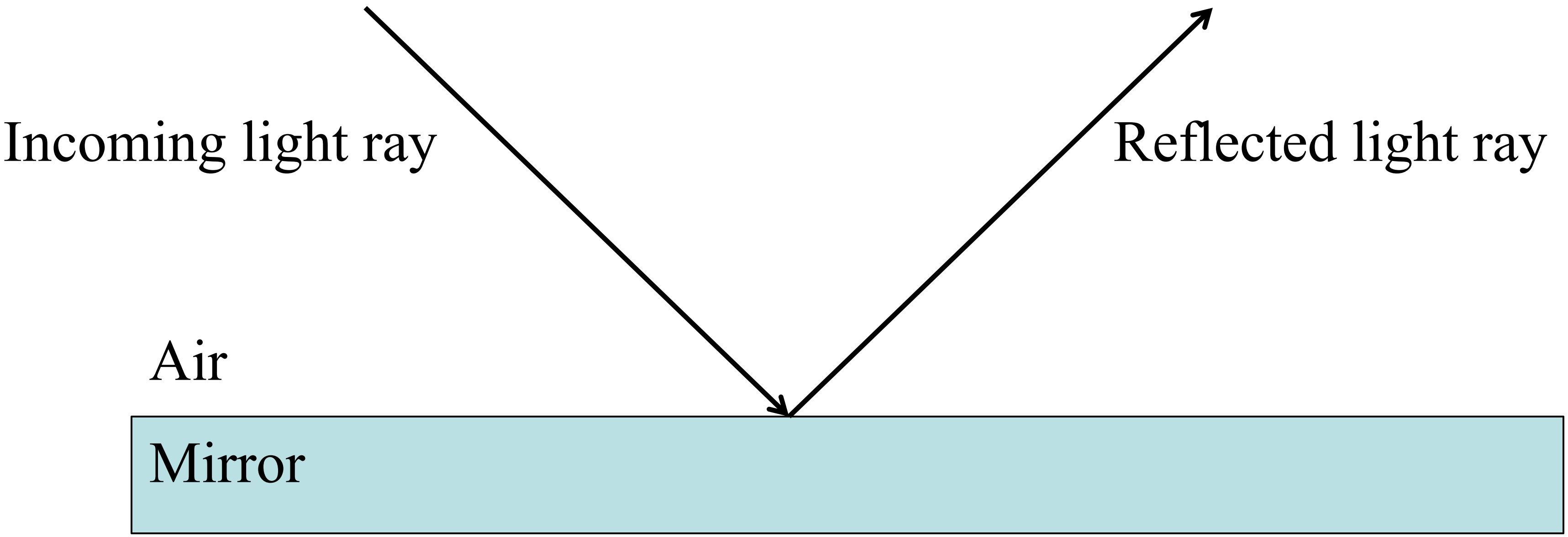
Refracting Telescope



Finally, since refraction depends on wavelength, different colors will focus differently: bad!

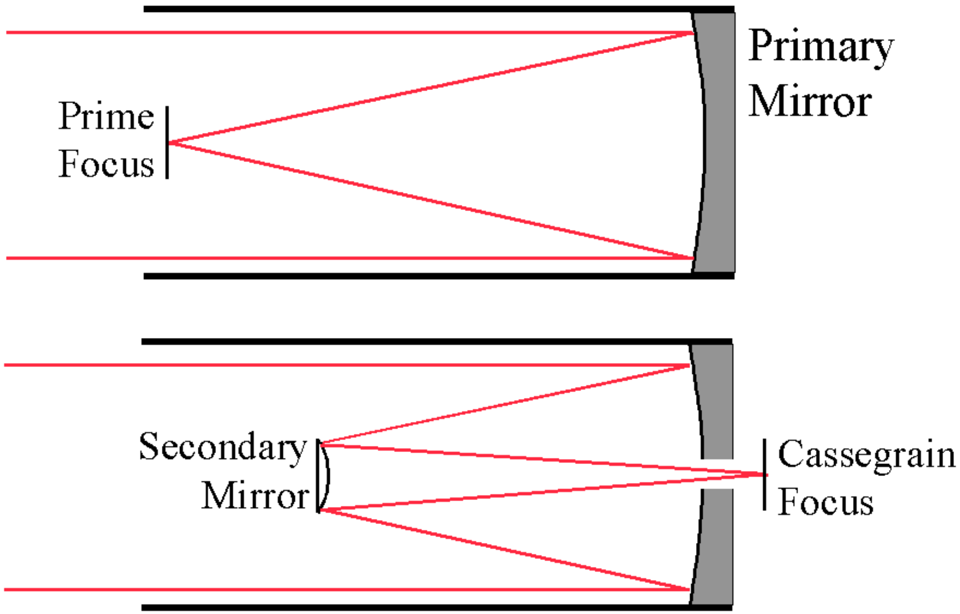


Reflection



Reflection is another way of bending light!

Reflecting Telescope



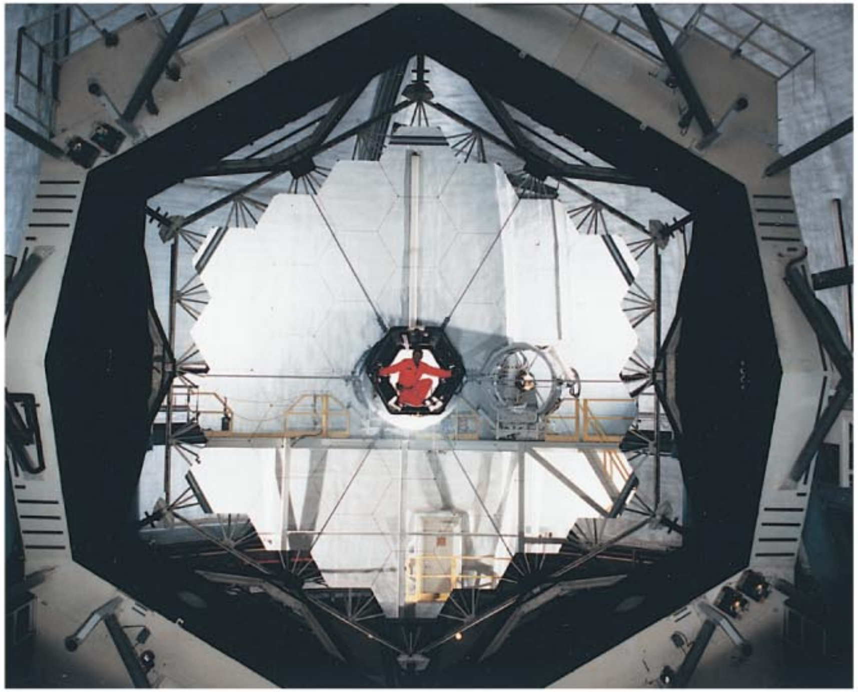
Why are reflectors better than refractors?

1. Light doesn't pass through the glass, so only the surface has to be perfect.
2. Mirrors can be supported from their back, so they don't sag when they get big.
3. Reflection doesn't depend on wavelength, so all colors focus the same.
4. In a reflector, light path is "folded" so the telescope can be shorter: cheaper to build the observatory!

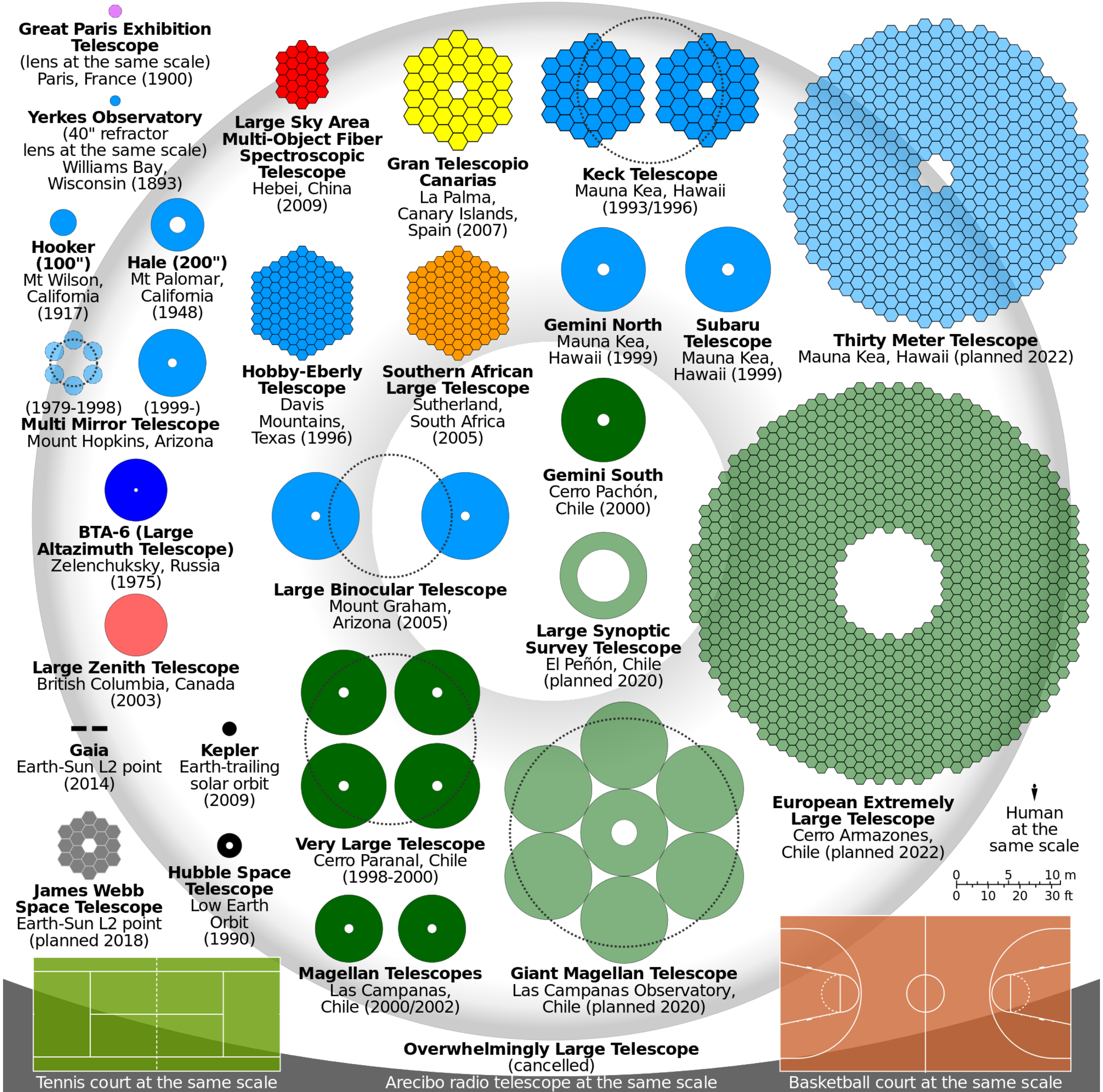
So most modern telescopes are reflectors.

Mirrors in Reflecting Telescopes

Twin Keck telescopes on Mauna Kea in Hawaii



Segmented 10-meter mirror of a Keck telescope


Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor
lens at the same scale)
Williams Bay,
Wisconsin (1893)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China
(2009)
Gran Telescopio Canarias
La Palma,
Canary Islands,
Spain (2007)
Keck Telescope
Mauna Kea, Hawaii
(1993/1996)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Hooker (100")
Mt Wilson,
California
(1917)
Hale (200")
Mt Palomar,
California
(1948)
Hobby-Eberly Telescope
Davis
Mountains,
Texas (1996)
Southern African Large Telescope
Sutherland,
South Africa
(2005)
Gemini North
Mauna Kea,
Hawaii (1999)
Subaru Telescope
Mauna Kea,
Hawaii (1999)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
Gemini South
Cerro Pachón,
Chile (2000)
BTA-6 (Large Altazimuth Telescope)
Zelenchukskу, Russia
(1975)
Large Binocular Telescope
Mount Graham,
Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile
(planned 2020)
Large Zenith Telescope
British Columbia, Canada
(2003)
Gaia
Earth-Sun L2 point
(2014)
Kepler
Earth-trailing
solar orbit
(2009)
Very Large Telescope
Cerro Paranal, Chile
(1998-2000)
European Extremely Large Telescope
Cerro Armazones,
Chile (planned 2022)
Human
at the
same scale
0 5 10 m
0 10 20 30 ft
James Webb Space Telescope
Earth-Sun L2 point
(planned 2018)
Hubble Space Telescope
Low Earth
Orbit
(1990)
Magellan Telescopes
Las Campanas,
Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

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.

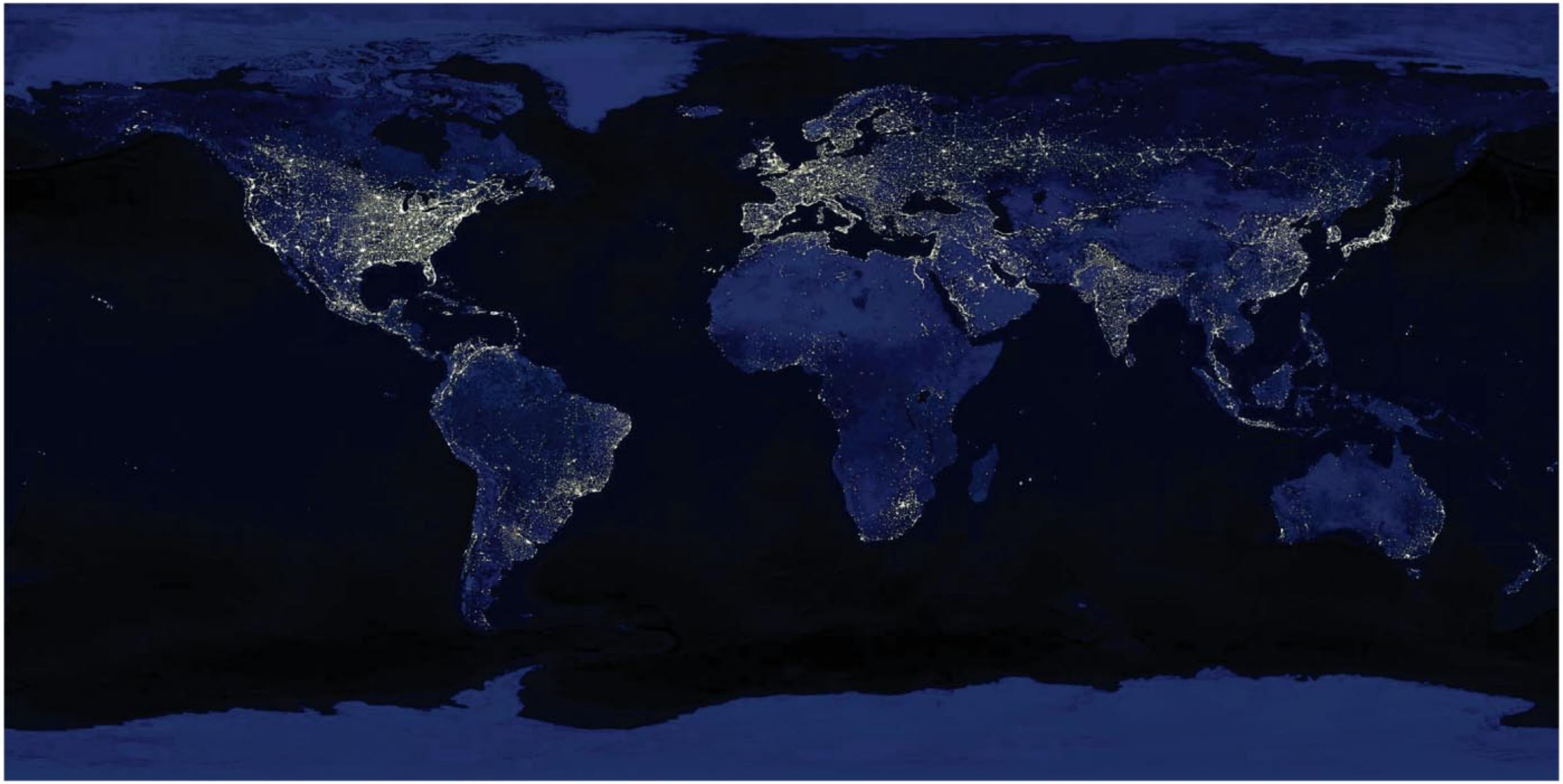
6.3 Telescopes and the Atmosphere

- 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:
  - dark (far from city lights)
  - calm (not too windy)
  - high (less atmosphere to see through)
  - dry (few cloudy nights)

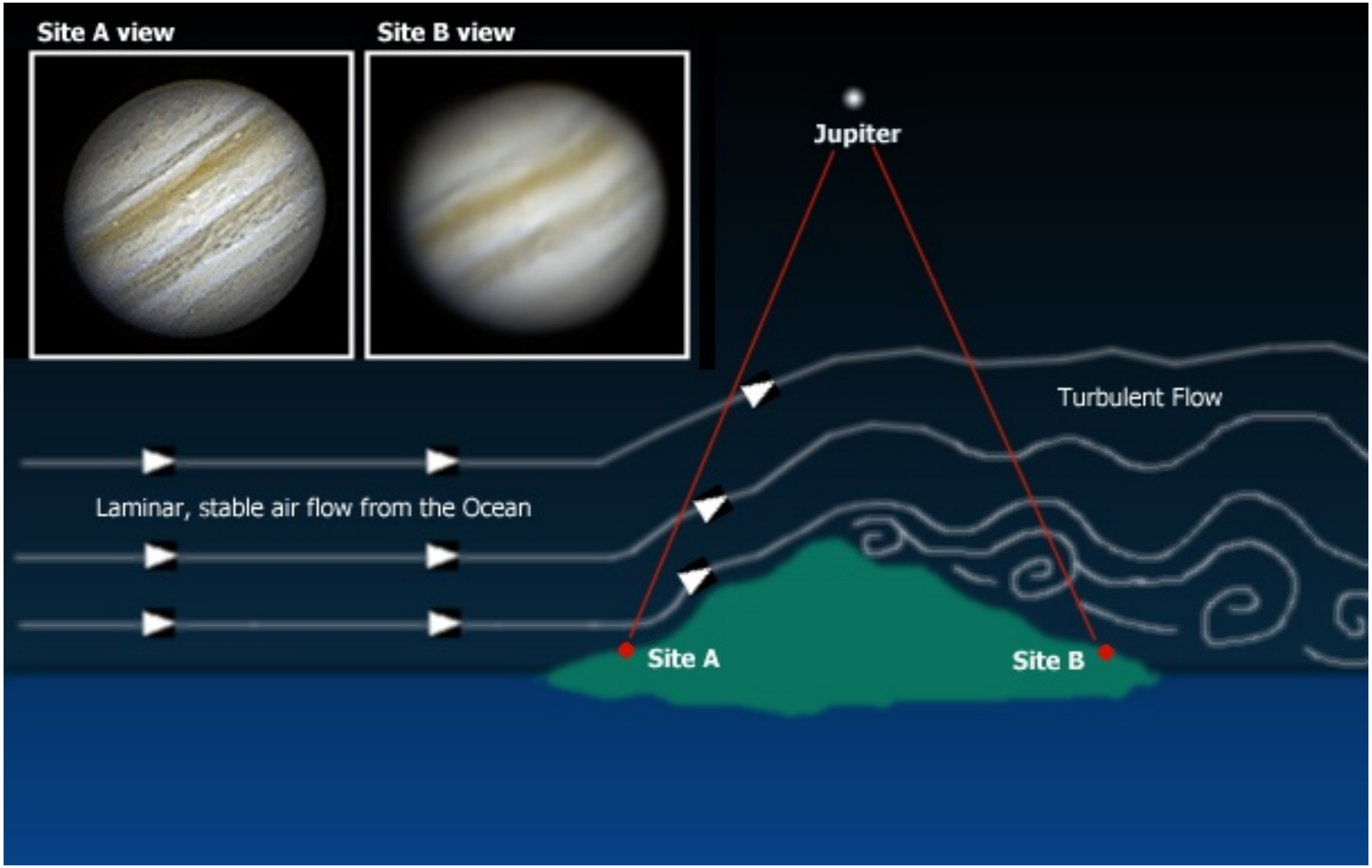
Light Pollution



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

Atmospheric "Seeing"

The atmosphere blurs our view of distant planets and stars



Top of mountains: less atmosphere to look through

Calm, High, Dark, Dry

Summit of Mauna Kea, Hawaii

The best observing sites are atop remote mountains, often in deserts.

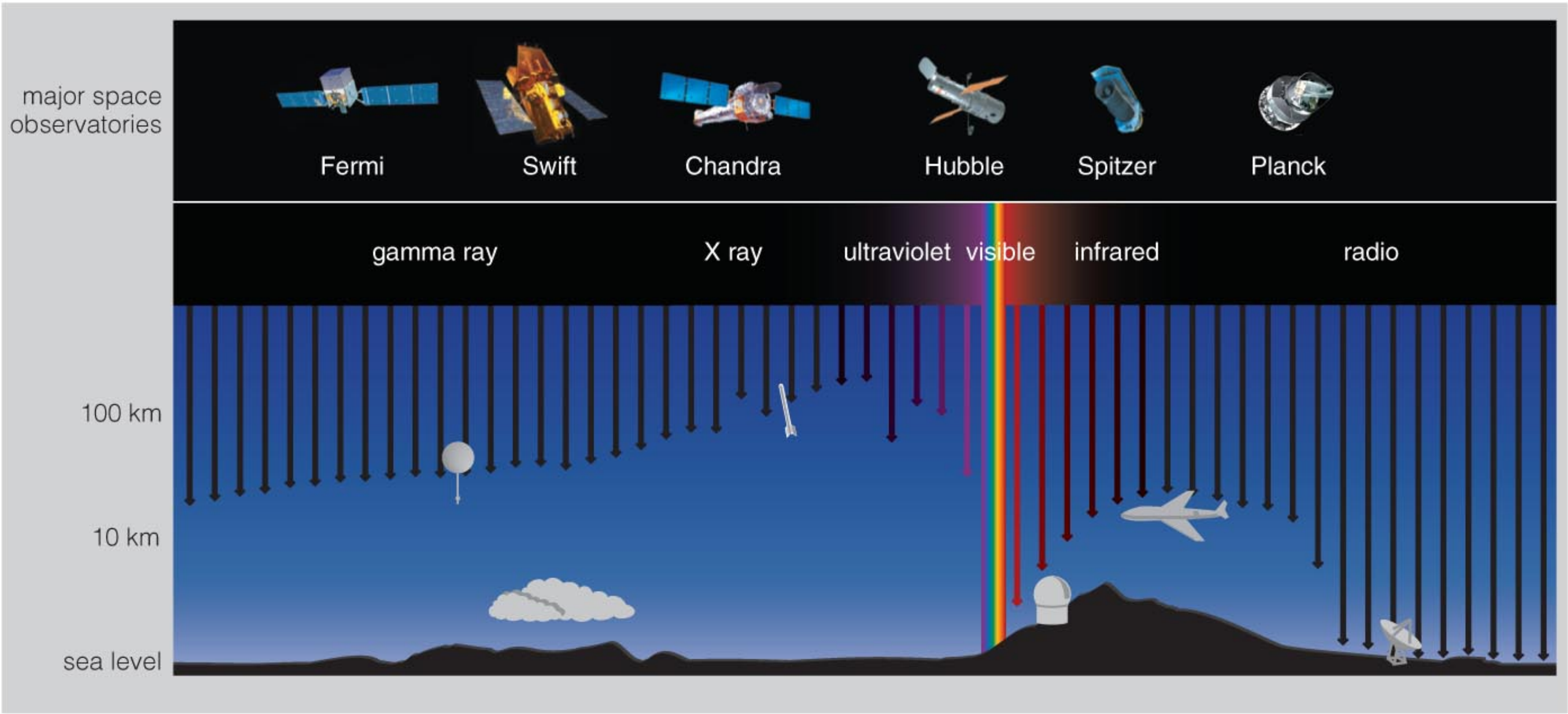
Calm, High, Dark, Dry

Summit of Kitt Peak, Arizona

The best observing sites are atop remote mountains, often in deserts.

Why do we put telescopes into space?

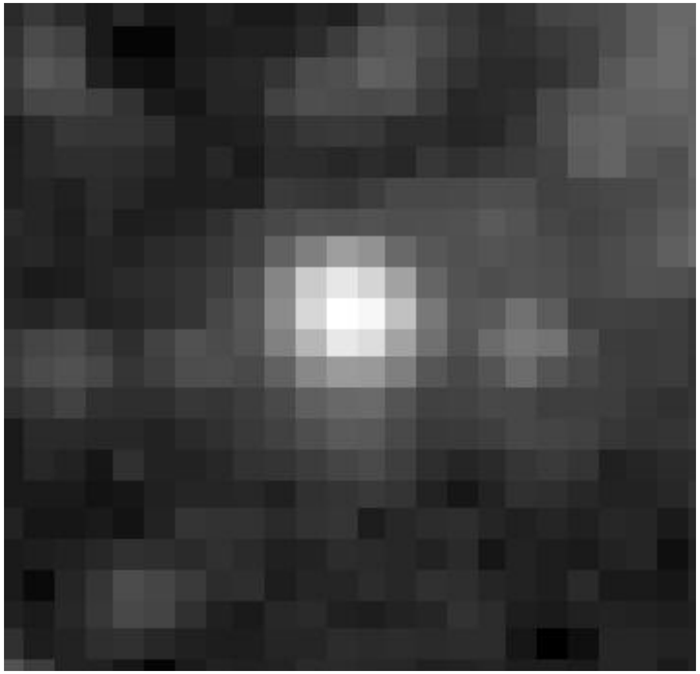
Transmission in Atmosphere



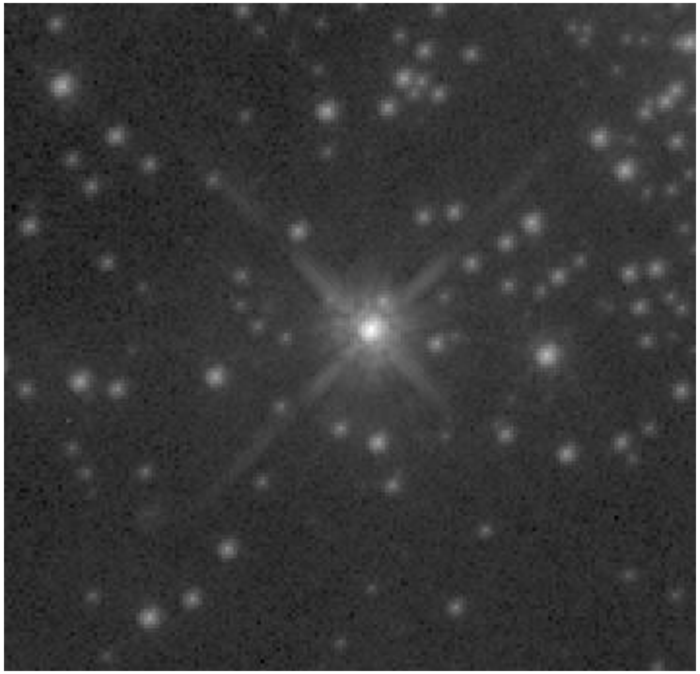
Interactive Figure

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

Twinkling and Turbulence



Bright 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.

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.

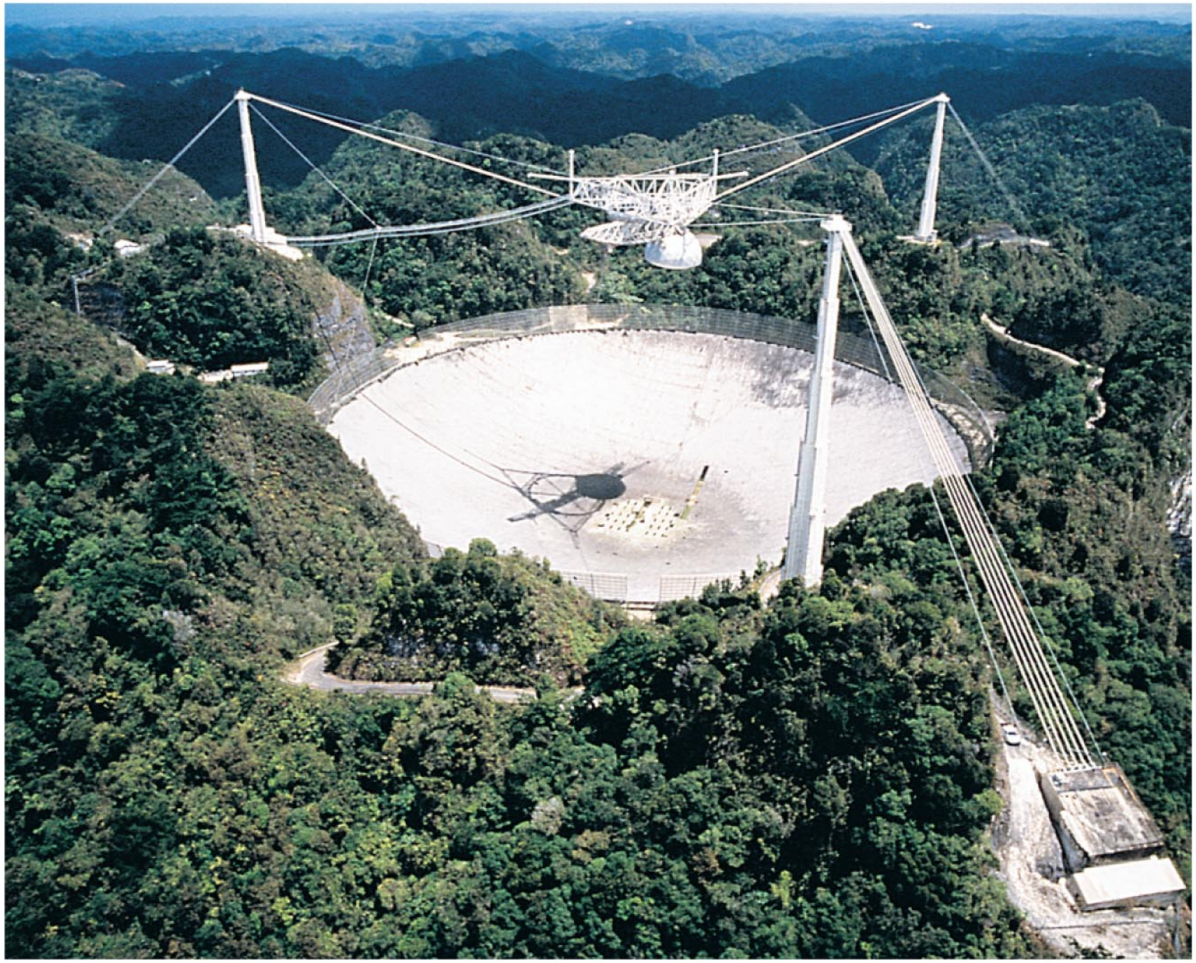
6.4 Telescopes and Technology

- Our goals for learning:
  - **How can we observe invisible light?**
  - **How can multiple telescopes work together?**

How can we observe "invisible" light?

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

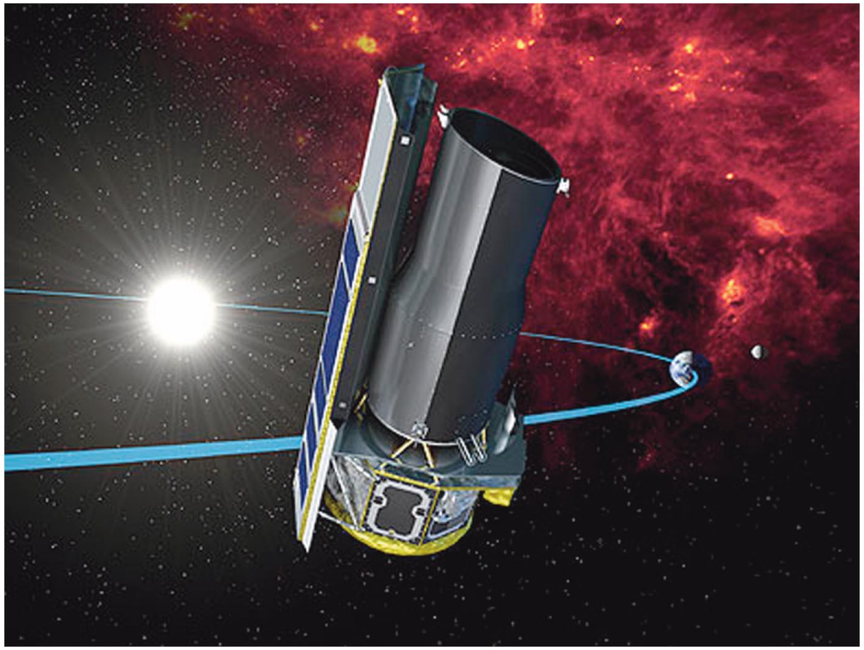
Radio Telescopes



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

Infrared and Ultraviolet Telescopes

SOFIA



Spitzer

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

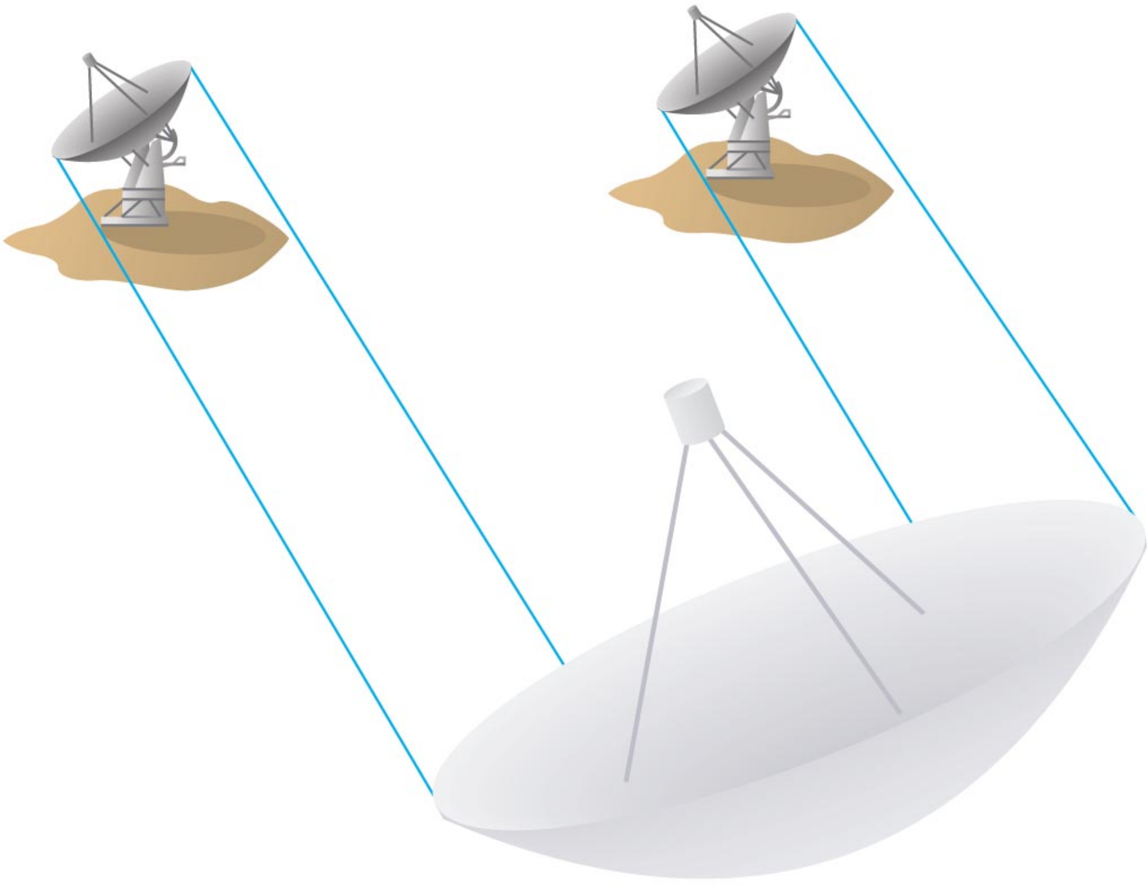
X-Ray Telescopes

Chandra X-Ray Observatory

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

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

Very Large Array (VLA)

Interferometry

Easiest to do with radio telescopes

Very Large Array (VLA)

What have learned?

- **How can we observe "invisible" light at other wavelengths?**
  - Telescopes for invisible light are usually modified versions of reflecting telescopes.
  - Many of the telescopes used for observing invisible light are in space.
- **How can multiple telescopes work together?**
  - Linking multiple telescopes using interferometry enables them to produce the angular resolution of a much larger telescope.