# Astronomy 1 – Fall 2019

One person's perspective:

*Three great events stand at the threshold of the modern age and determine its character:*
*1) the discovery of America;*
*2) the Reformation;*
*3) the invention of the telescope and the development of a new science that considers the nature of the Earth from the viewpoint of the universe'*

(Hannah Arendt, 'The Human Condition')

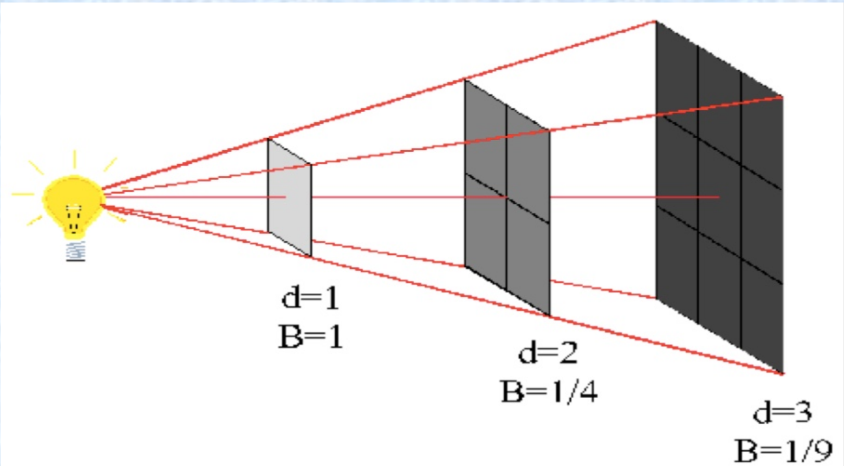


Lecture 5; October 16, 2019

# Previously on Astro-1

- The Nature of Light
  - Particles called photons
  - Waves in an electromagnetic field
  - Relation of speed to wavelength and frequency
  - Relation of energy to wavelength and frequency
- Blackbody Radiation
  - Describes the spectrum of light emitted by opaque sources
  - The temperature of the blackbody determines
    - The spectrum (Wien's Law)
    - The energy flux (Stefan-Boltzman Law)
- Kirchoff's Laws *(use for HW3 problem 5)*
  - A hot body produces a continuous spectrum
  - A hot transparent gas produces emission lines
  - Cool transparent gas in front of a hot body produces absorption lines

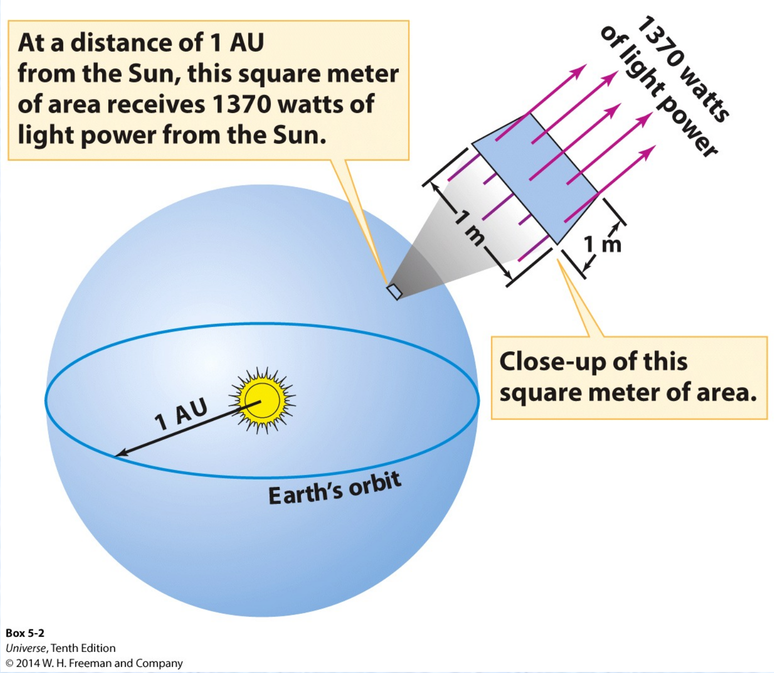
# Inverse Square Law for Radiation



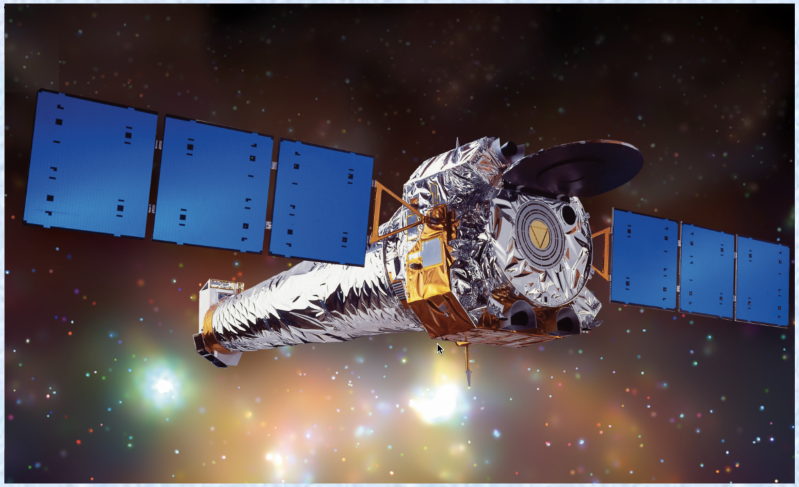

The same principle applies to the flux of the Sun on the surface of the Earth, thus

$F = L_0 / (4 \pi R^2)$

The flux measured on the screen goes down as the square of the distance from the lightbulb.



# Today on Astronomy 1



- Doppler shift
- Show how optics focus light
- Explain how telescopes work



Lecture 5;  October 6, 2016

# Doppler Shifts

The motion of the object producing the waves affects the frequency of the observed wave. Since the waves travel at a fixed speed (e.g., the sound speed for sound or c for electromagnetic radiation), the wavelength also shifts.

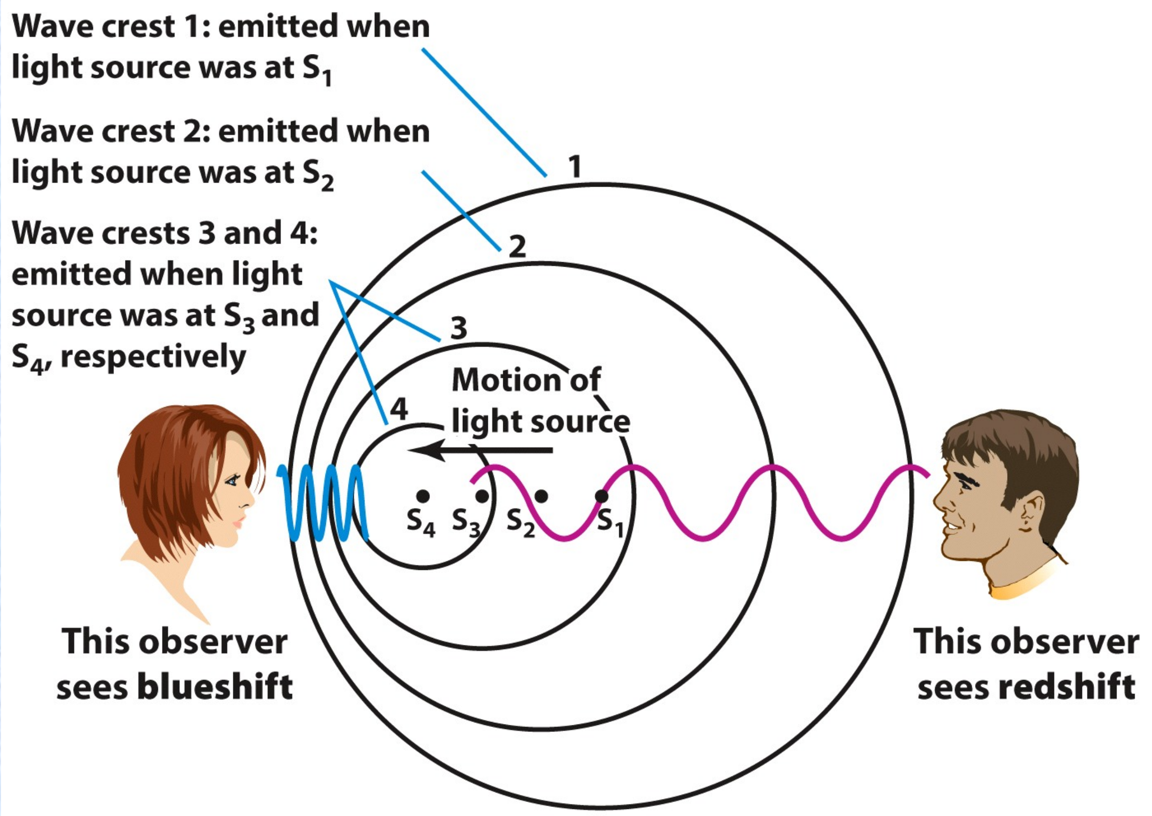



Figure 5-26
*Universe*, Tenth Edition

# Demo: Doppler Shift of Sound Waves (iclicker Question)

**A speaker is whirled around on a rope.**
**The sound from the speaker will do the following.**

A. Rise to higher frequency as the speaker moves towards the listener. Fall to lower frequency as the speaker moves away from the listener.
B. Fall to lower frequency as the speaker moves towards the listener. Rise to higher frequency as the speaker moves away from the listener.
C. Get louder as the speaker approaches the listener and get softer as the speaker moves away.
D. Get louder as the speaker moves away and get softer as the speaker moves towards the listener.
E. Both A & C

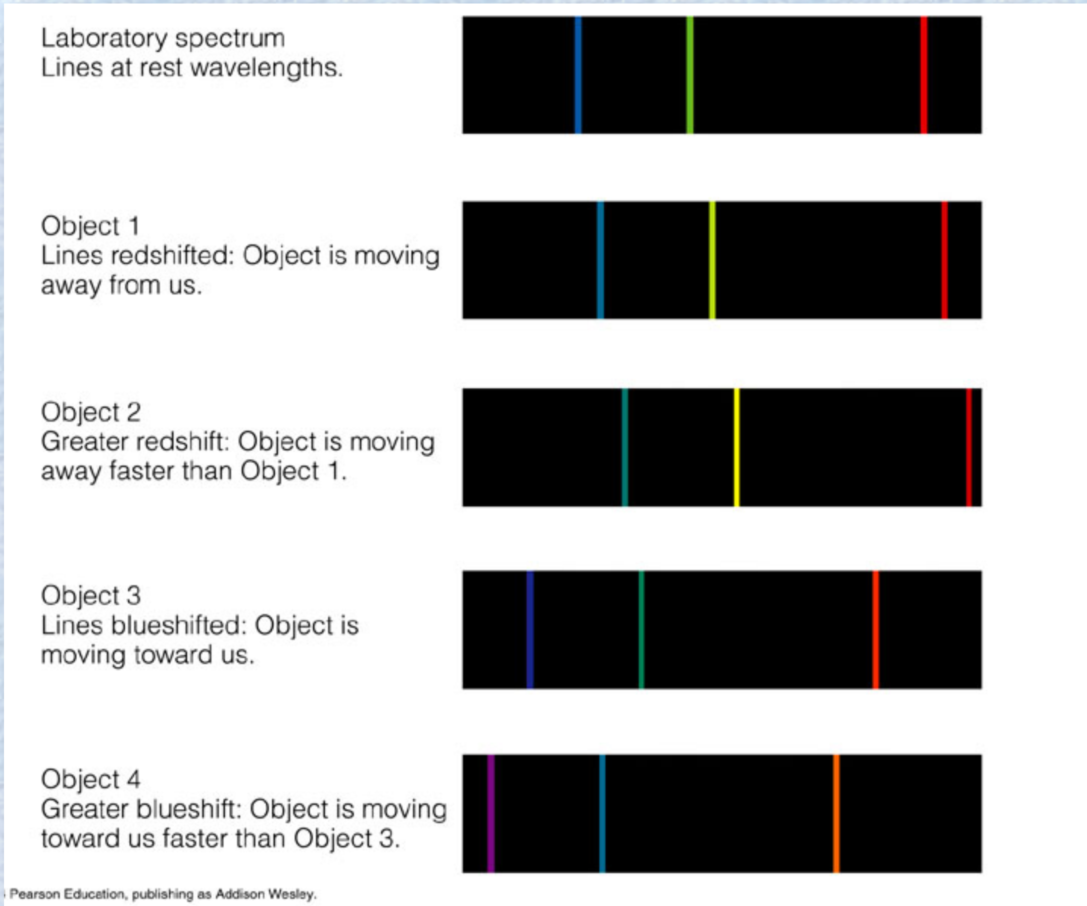
# Demo: Doppler Shift of Sound Waves (iclicker Question)

**A speaker is whirled around on a rope.**
**The sound from the speaker will do the following.**

A. **Rise to higher frequency as the speaker moves towards the listener. Fall to lower frequency as the speaker moves away from the listener.**
B. Fall to lower frequency as the speaker moves towards the listener. Rise to higher frequency as the speaker moves away from the listener.
C. Get louder as the speaker approaches the listener and get softer as the speaker moves away.
D. Get louder as the speaker moves away and get softer as the speaker moves towards the listener.
E. Both A & C

# Doppler Shift of Light

400 nm 700 nm




- You can tell how fast something is moving from the shift of its spectral lines relative to the laboratory standard.
- When v << c, then

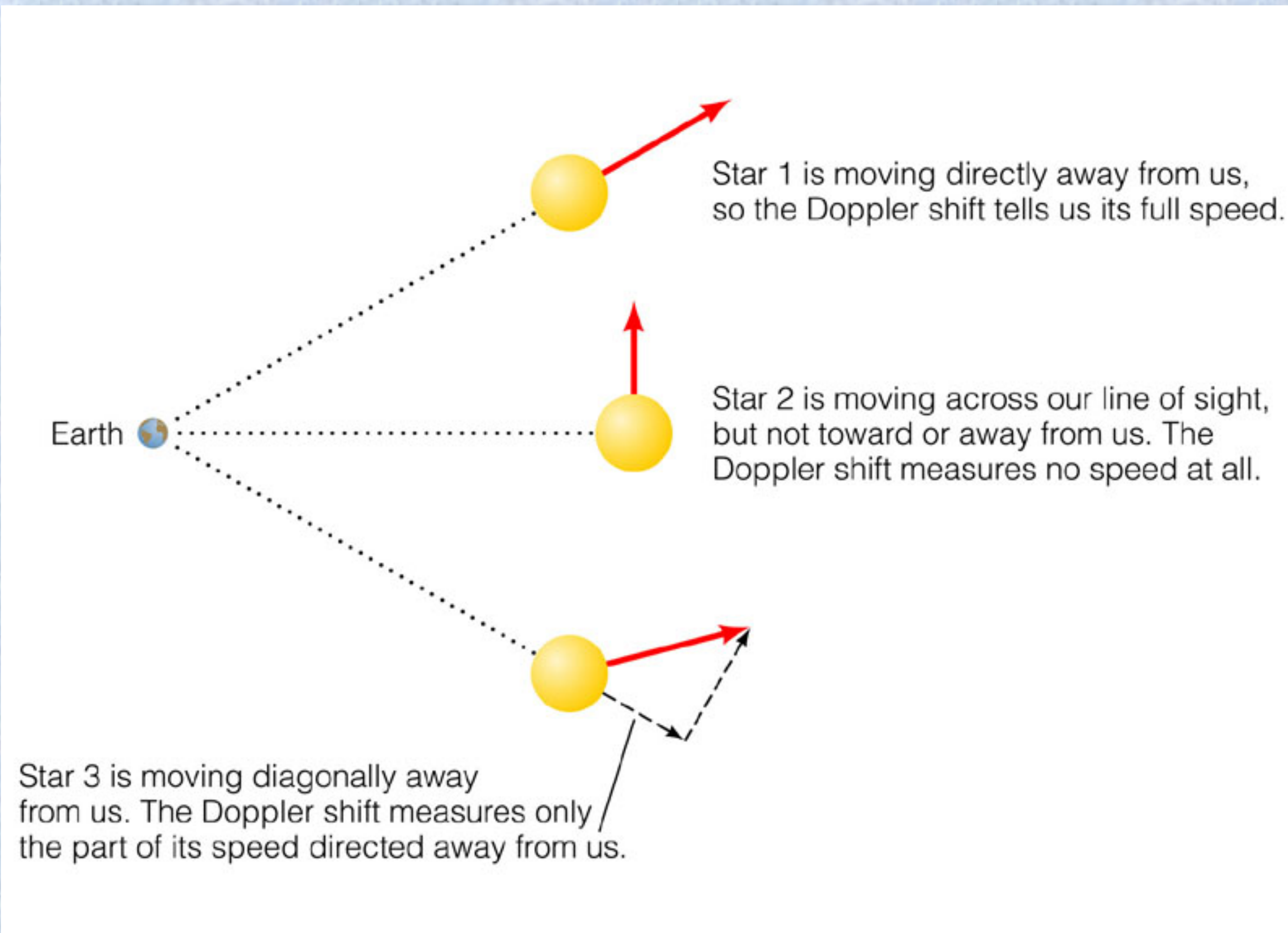
$$\Delta\lambda / \lambda = v / c$$

- Notice that the shift is generally too small to change the color of the light:

$\Delta\lambda$ =6 nm (v/3000 km/s) $\times$ ($\lambda$ / 600 nm)

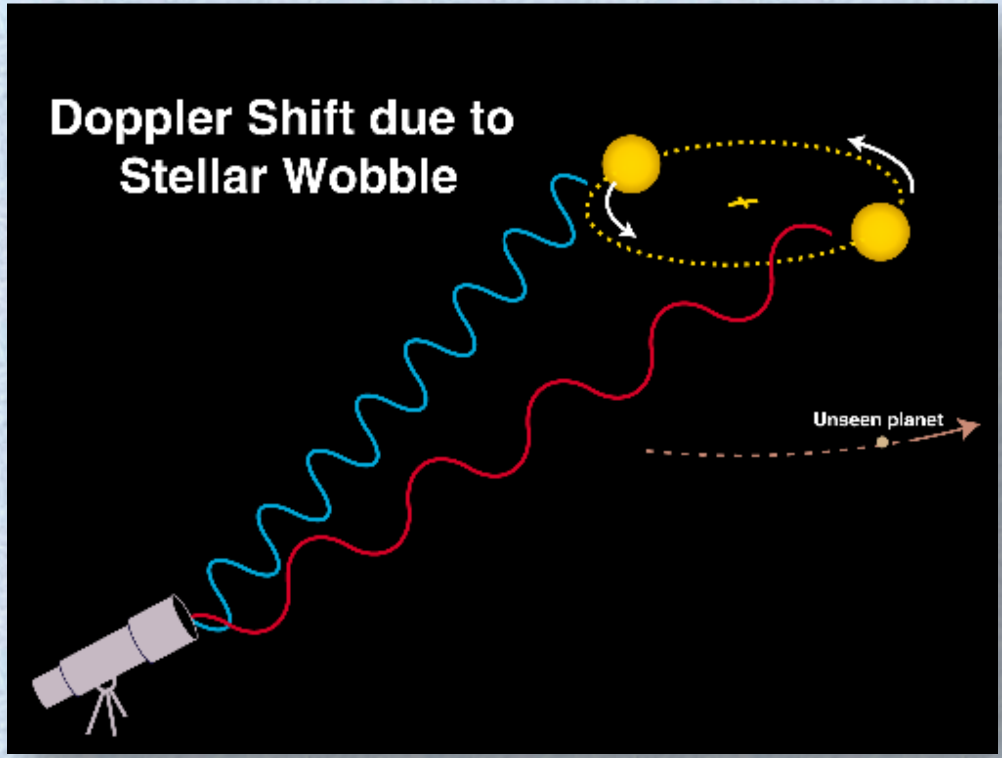
- *HW3 – speeding ticket!*

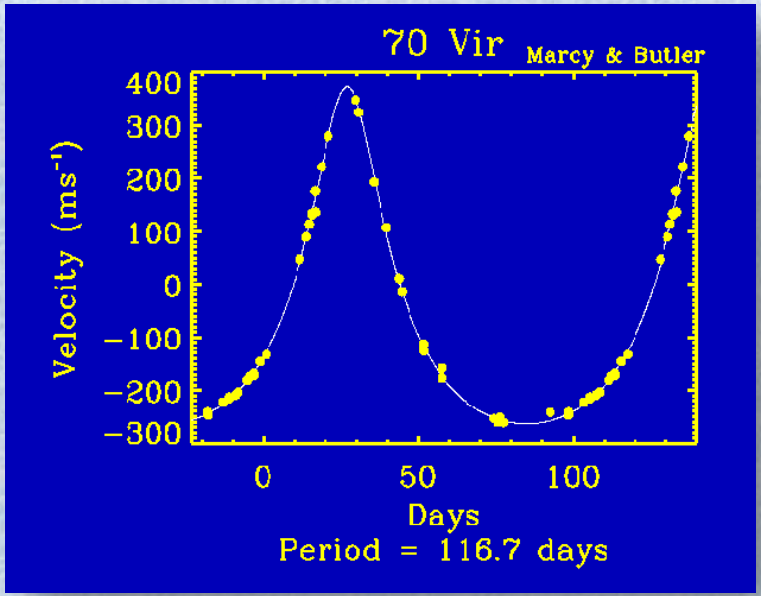
# Doppler shift measures motion directly towards/away from us



# Extra-solar Planets

Many have been discovered using Doppler shift measurements of their parent stars (since 1995)



# Spectral Lines
# (iclicker Question)

Professor Martin used a spectrograph on the Keck telescope to observe a distant galaxy.  She detected an absorption line from sodium atoms. The wavelength she measured was 0.22 nm bluer than the laboratory wavelength of 589.0 nm. What should she conclude?

A. There are cool clouds between the observer and the galaxy.
B. The gas between the galaxy and the observer is hotter than the galaxy.
C. The gas clouds are moving away from the galaxy towards the observer.
D. The gas clouds are falling into the galaxy.
E. Both A and C

# Spectral Lines (iclicker Question)

Professor Martin used a spectrograph on the Keck telescope to observe a distant galaxy. She detected an absorption line from sodium atoms. The wavelength she measured was 0.22 nm bluer than the laboratory wavelength of 589.0 nm. What should she conclude?

A. There are cool clouds between the observer and the galaxy.
B. The gas between the galaxy and the observer is hotter than the galaxy.
C. The gas clouds are moving away from the galaxy towards the observer.
D. The gas clouds are falling into the galaxy.
**E. Both A and C**

# Geometrical Optics

# The Light Rays from Distant Objects are Parallel

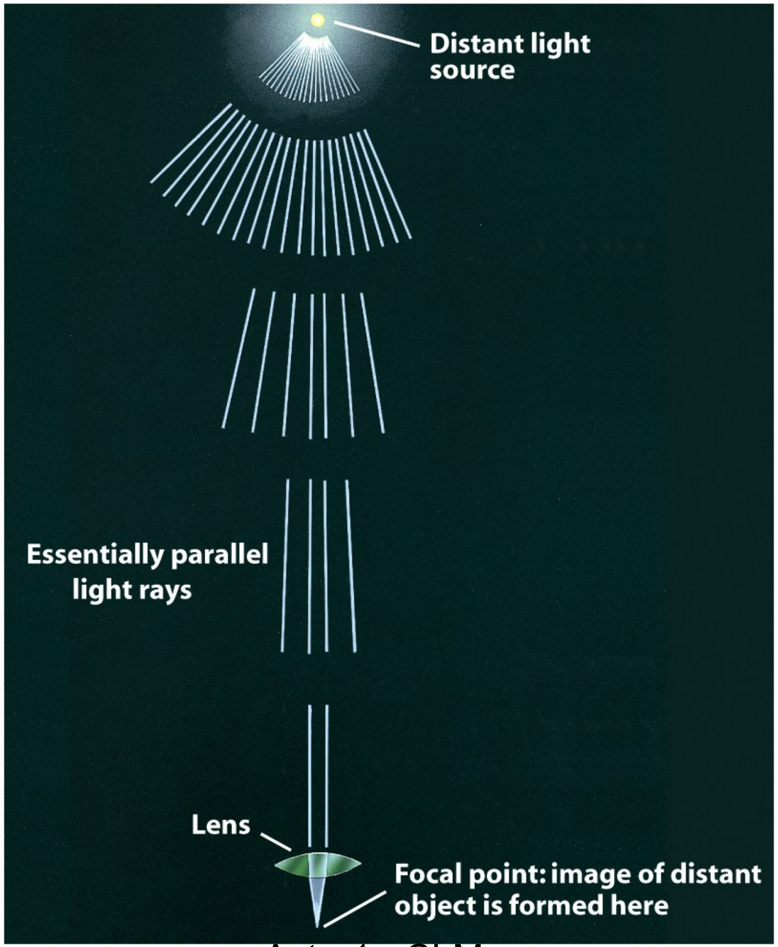



Figure 6-3
*Universe, Eighth Edition*

# Refraction:
# Change in Direction of a Light Ray

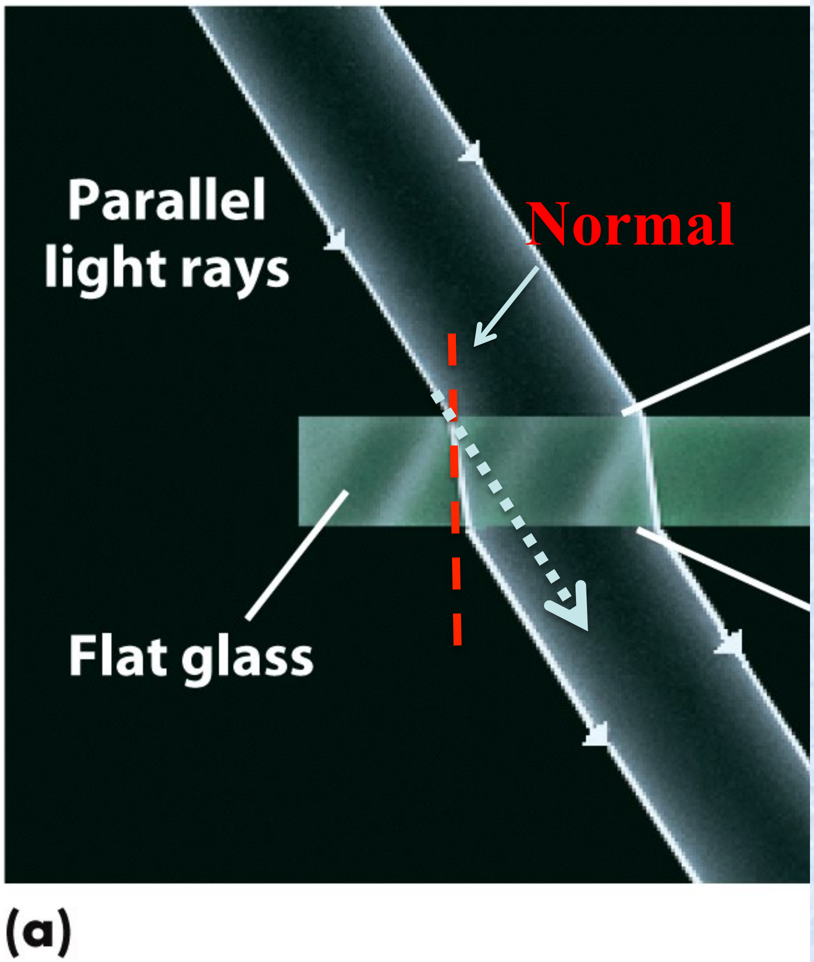



Figure 6-2
*Universe, Eighth Edition*

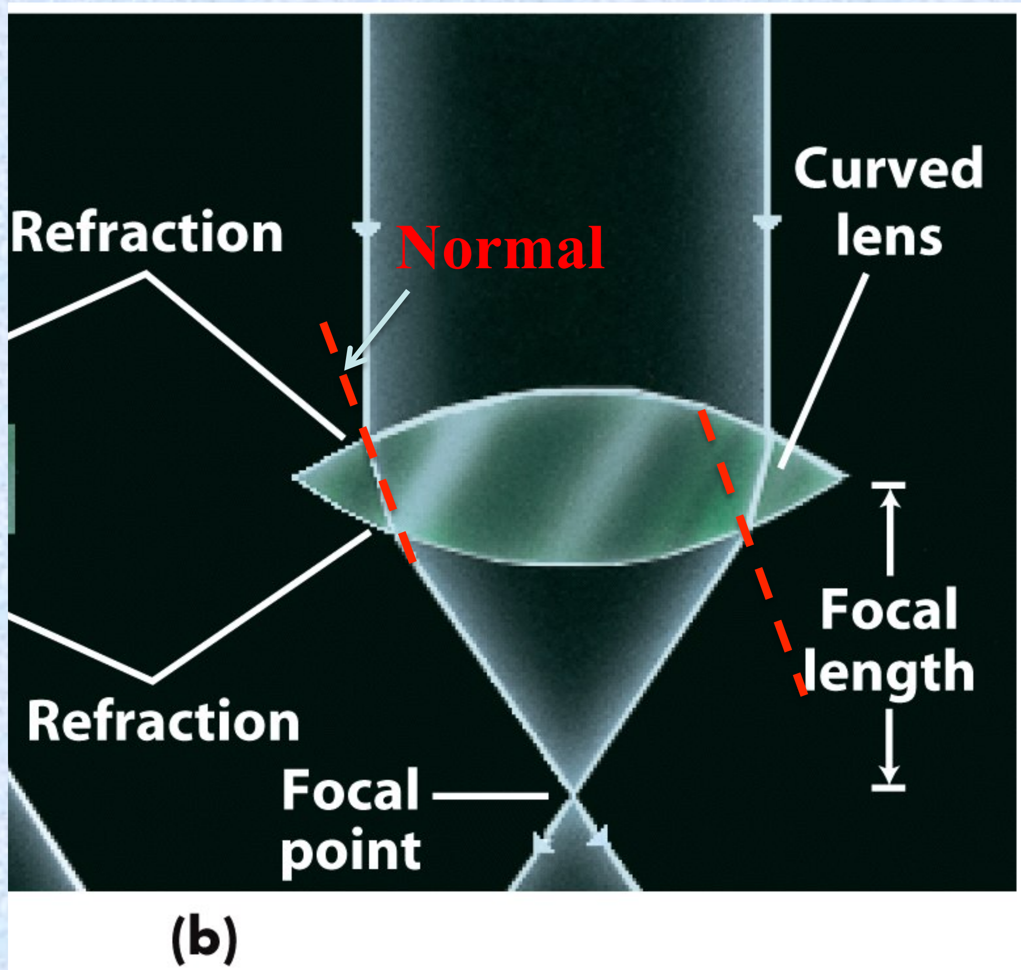

**Entering a denser medium:** Light bends towards the normal to the surface

**Entering a less dense medium:** Light bends away from the normal to the surface

# Demo:
# Use the Law of Refraction to Focus Light

**Entering a denser medium:**
Light bends towards the normal to the surface

**Entering a less dense medium:**
Light bends away from the normal to the surface



# Refraction
# Which Way Does the Path Bend?

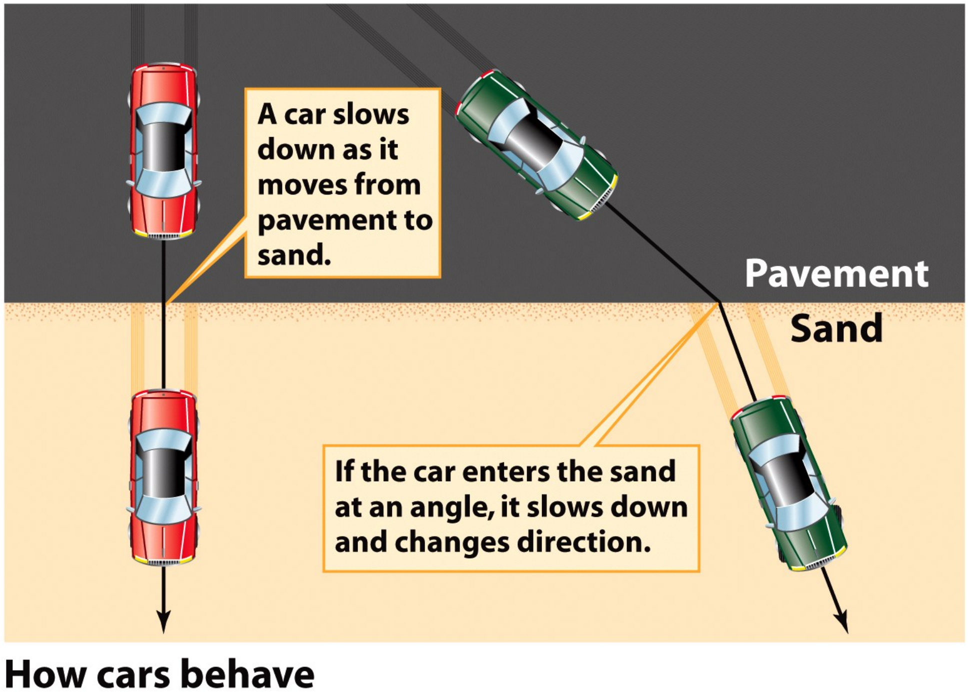



Figure 6-1a
*Universe, Eighth Edition*

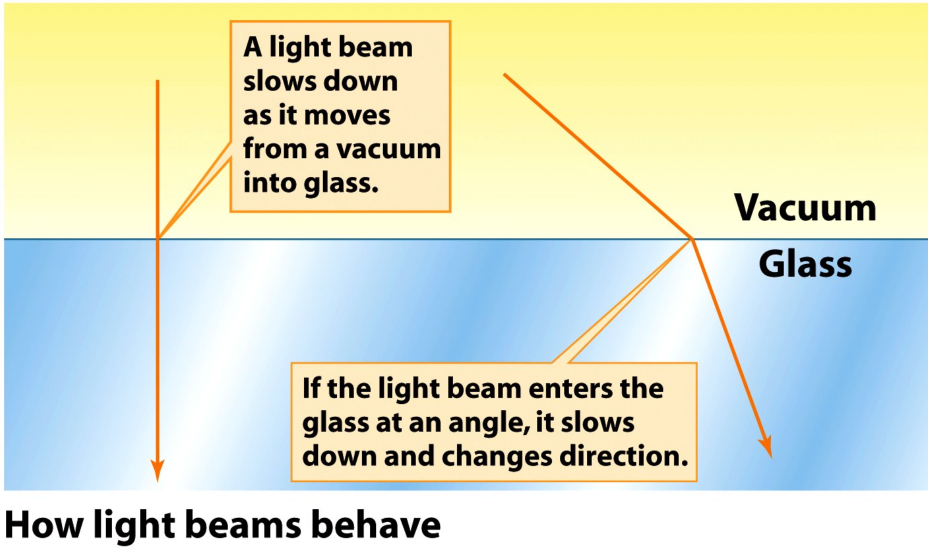




Figure 6-1b
*Universe, Eighth Edition*

# The Keplerian Telescope

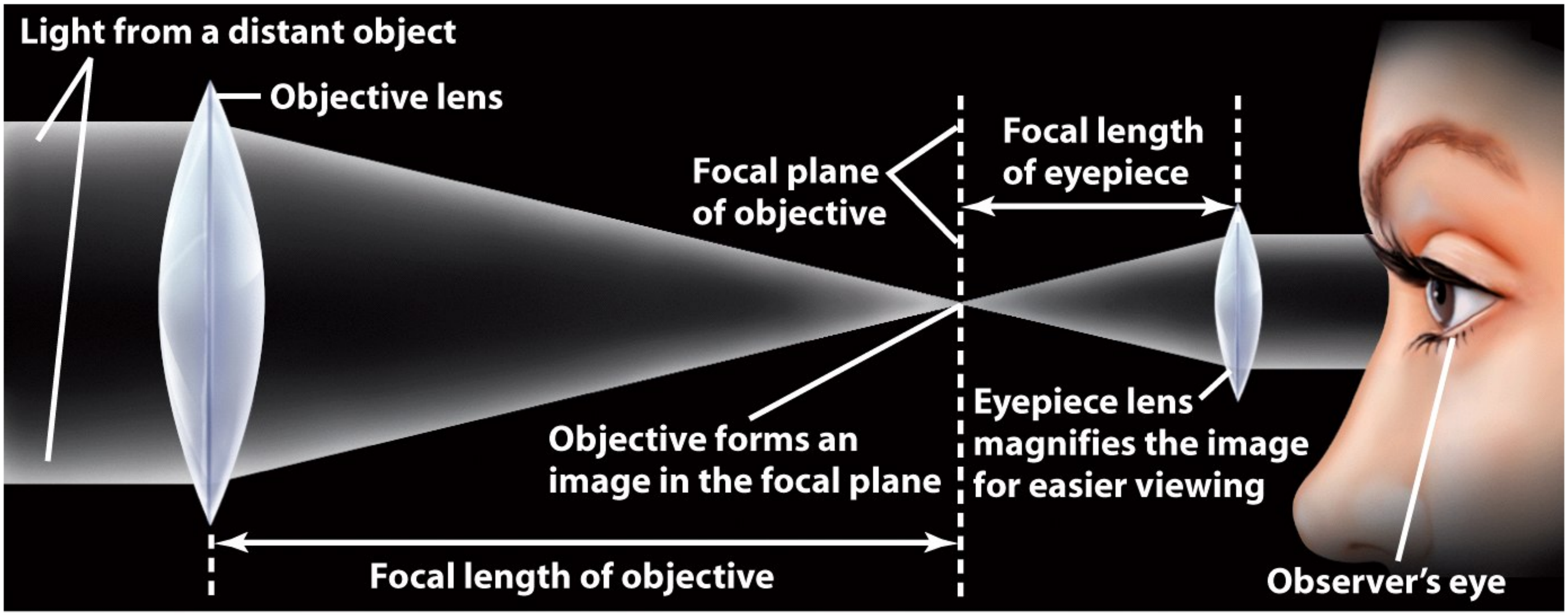


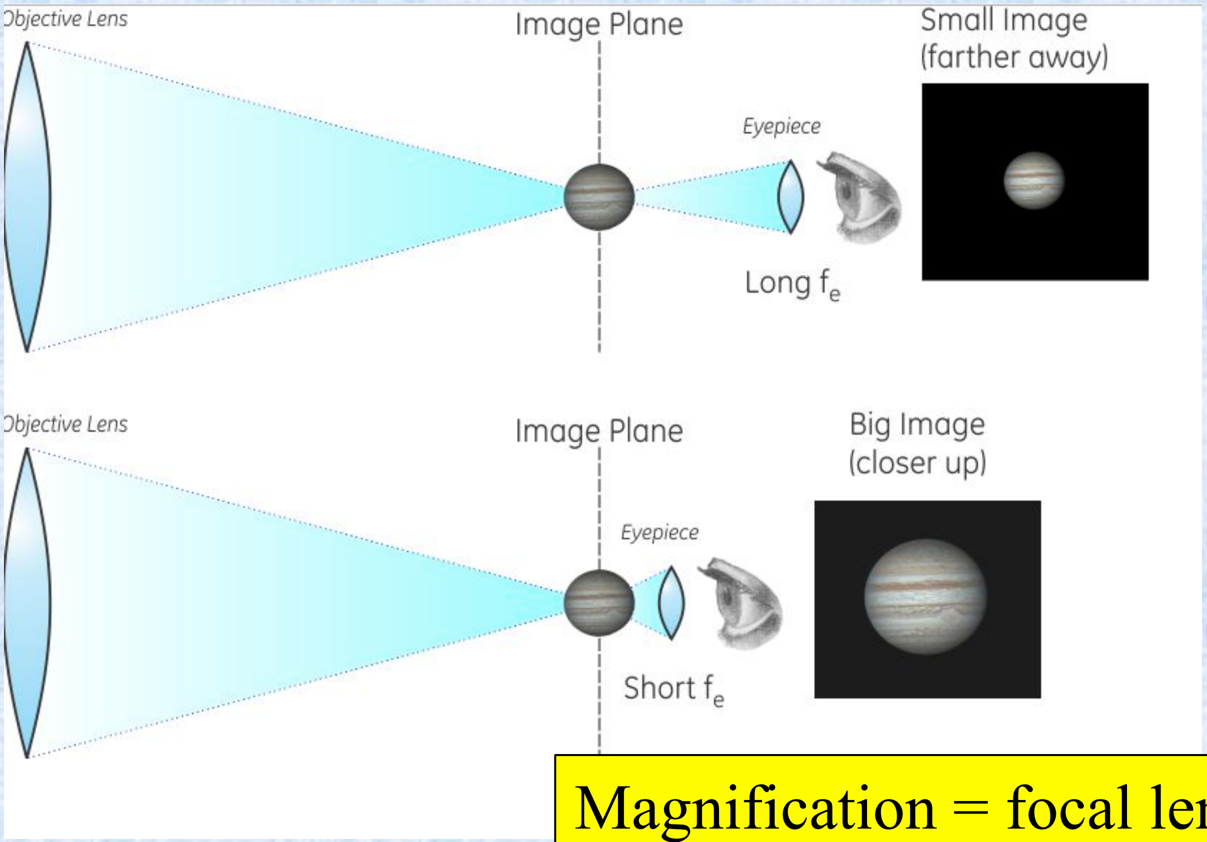

**Figure 6-5**
***Universe, Eighth Edition***


Two key properties of telescopes:

1. Light gathering power
2. Magnification

# Magnification of a Telescope

Magnification enlarges the angular size of an object.




Example:

Jupiter has a diameter of 38 arcseconds on the sky

Magnifying it be a factor of 2 makes it appear 76” acrcoss.

Magnification = focal length of objective lens / focal length of eyepiece

# Telescope Demo (iclicker Question)

The objective lens of our telescope demo has a focal length of 500 mm. Suppose we replace the 100 mm eyepiece with a 50 mm eyepiece. How will the magnification of the meter stick change?

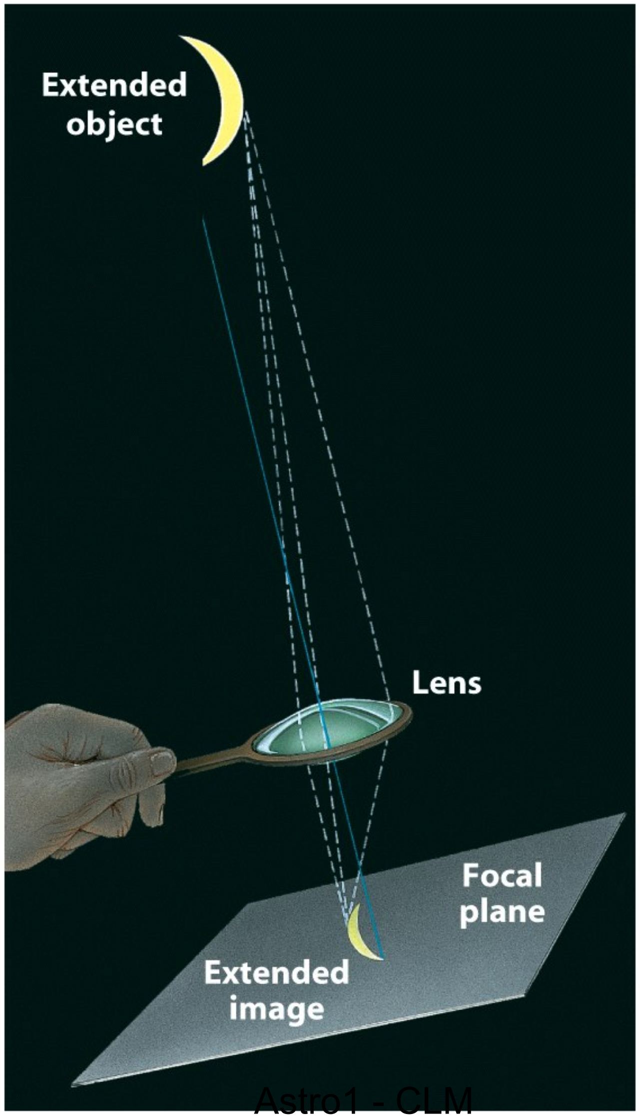
A. Decrease to 2x
B. Increase to 10x
C. Decrease to 50x
D. Increase to 50x
E. The magnification does not change.

# Telescope Demo (iclicker Question)

The objective lens of our telescope demo has a focal length of 500 mm. Suppose we replace the 250 mm eyepiece with a 50 mm eyepiece. To focus the telescope, how should we move the objective lens?

A. Move the objective lens closer to the eyepiece.
B. Move the objective lens further from the eyepiece.
C. Move the objective lens away from the optical axis.
D. There is no need to refocus the telescope.
E. Back and forth by trial and error; it cannot be predicted.

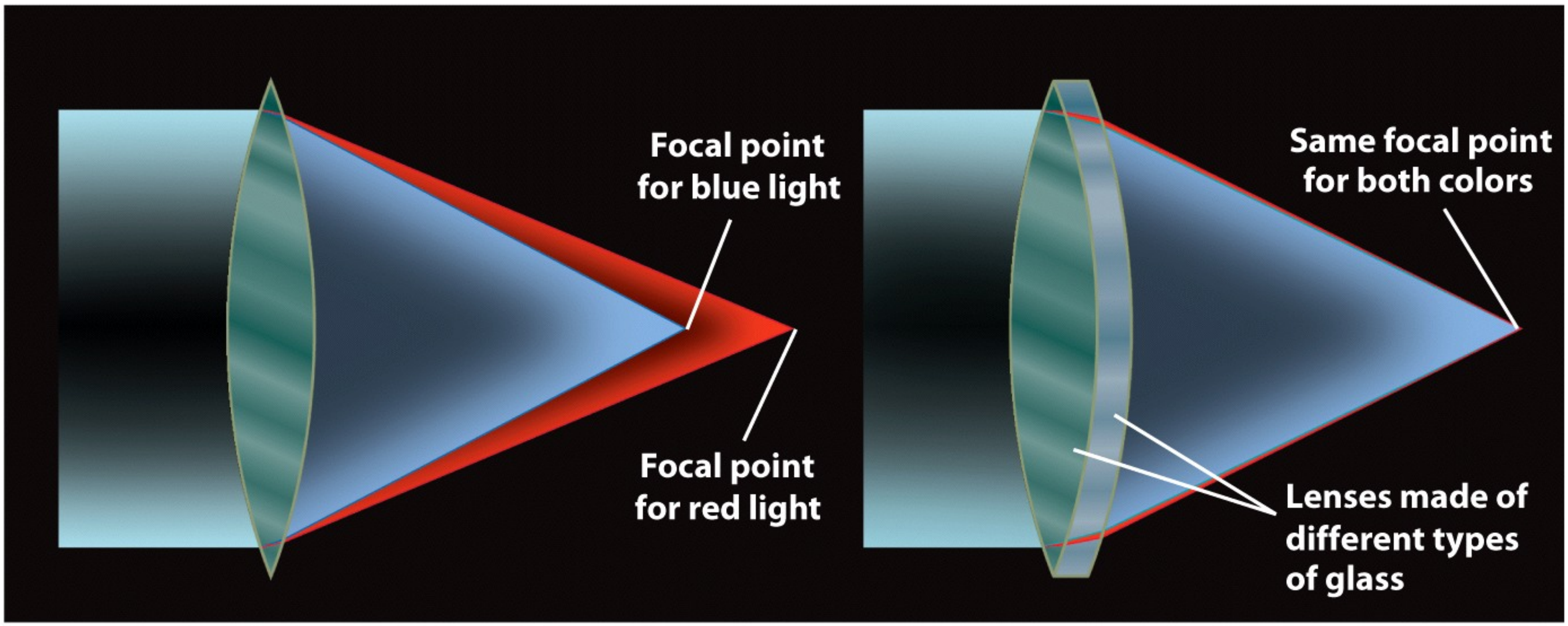
# Light from Every Point on an Extended Object Passes through Every Point in the Lens




Astro1 - CLM

**Figure 6-4**
***Universe, Eighth Edition***

# Name some shortcomings of lenses




(a) The problem: chromatic aberration (b) The solution: use two lenses

**Figure 6-7**
*Universe*, Tenth Edition

# Demo:
# Law of Reflection

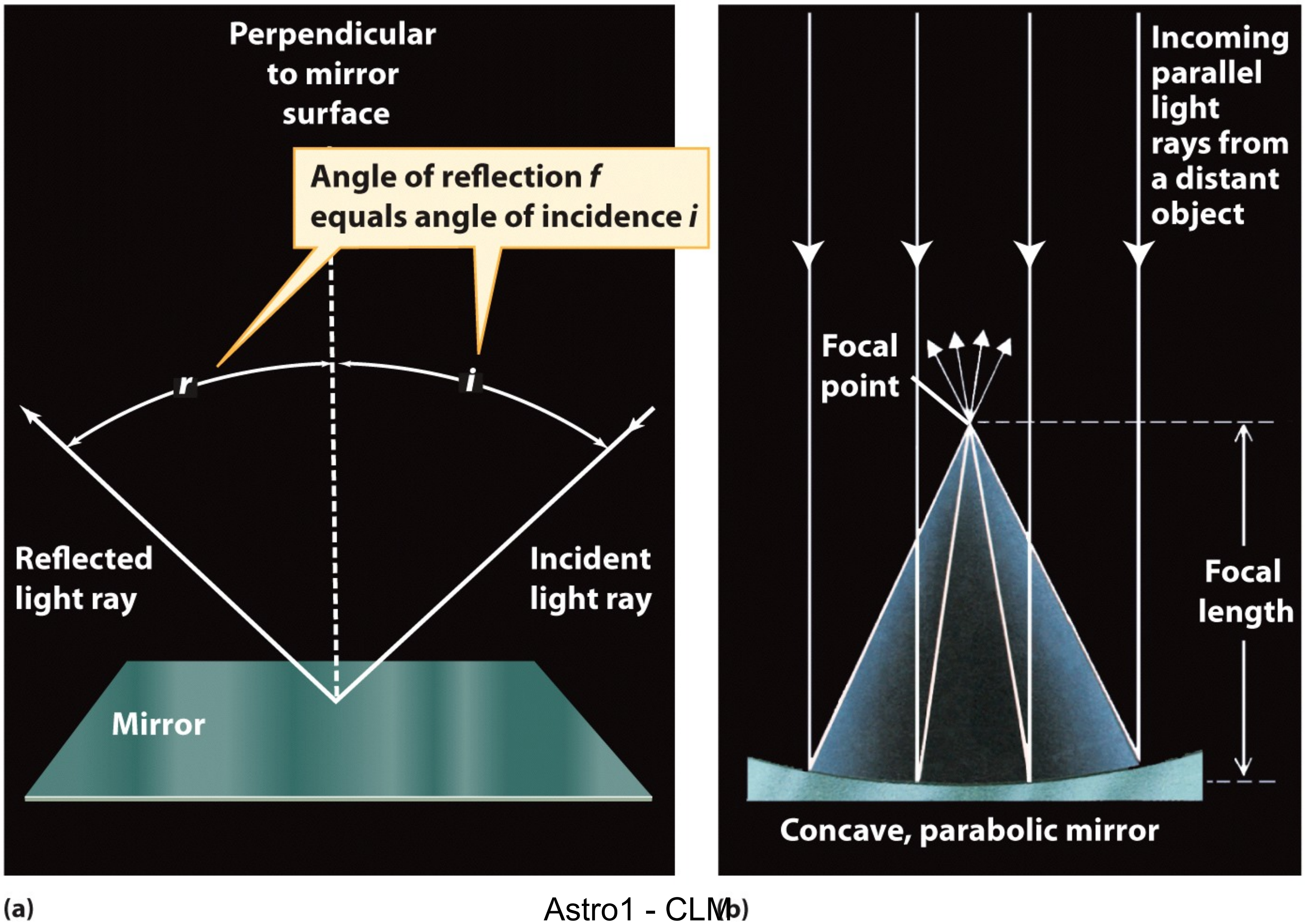



Figure 6-9
*Universe*, Tenth Edition

# Solution = Reflecting Telescopes

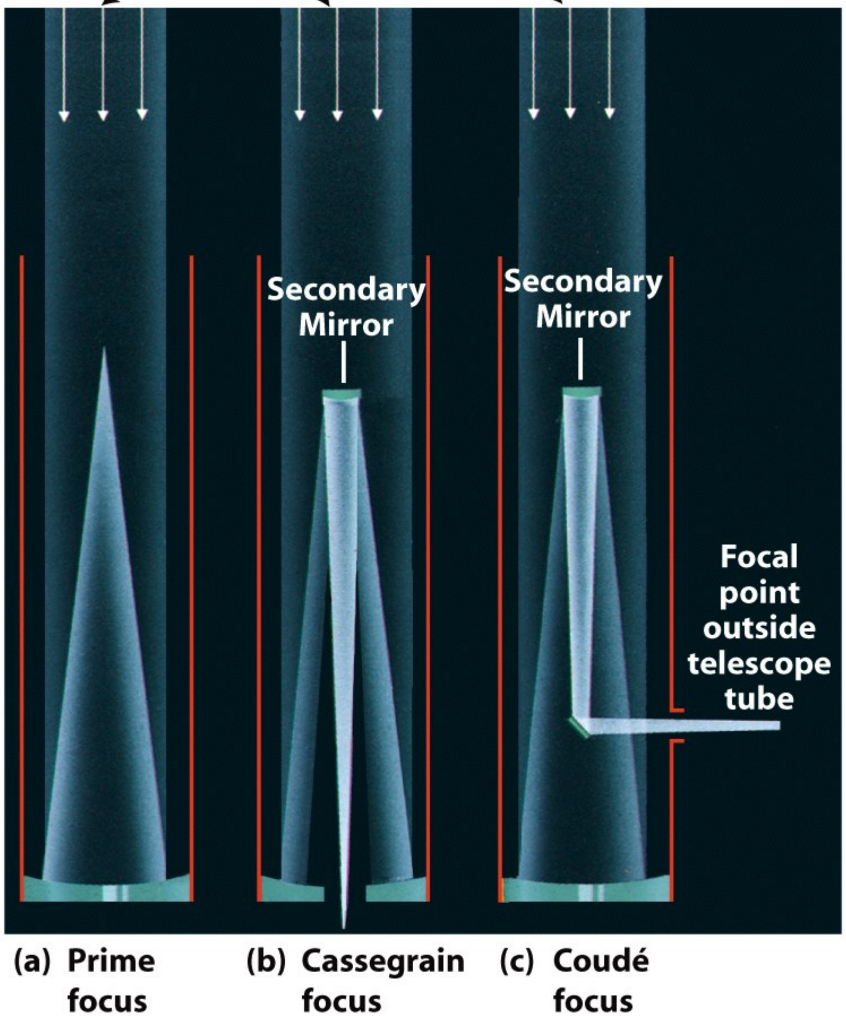



Figure 6-11
*Universe, Eighth Edition*


## Newtonian Reflector

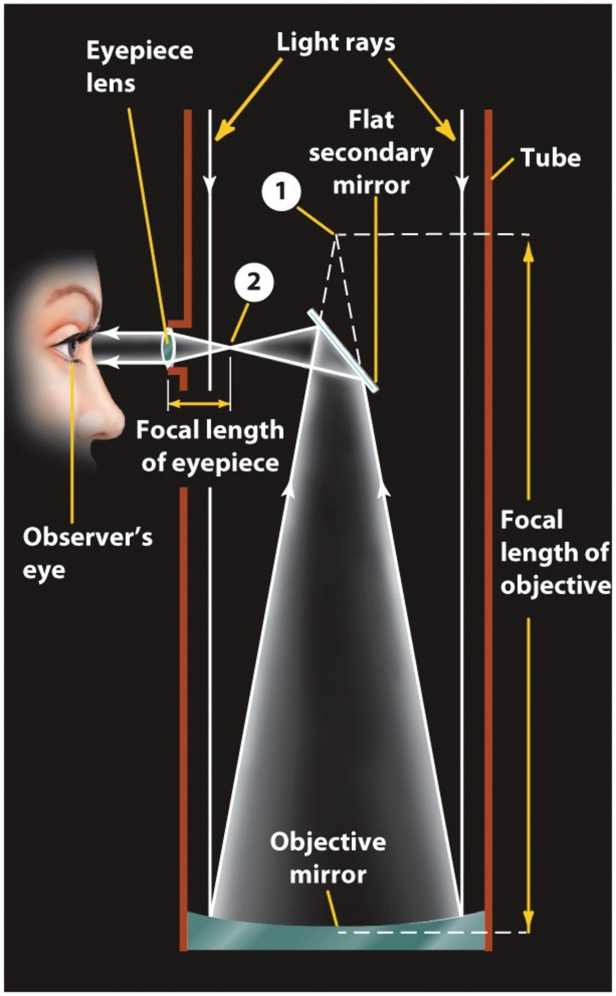
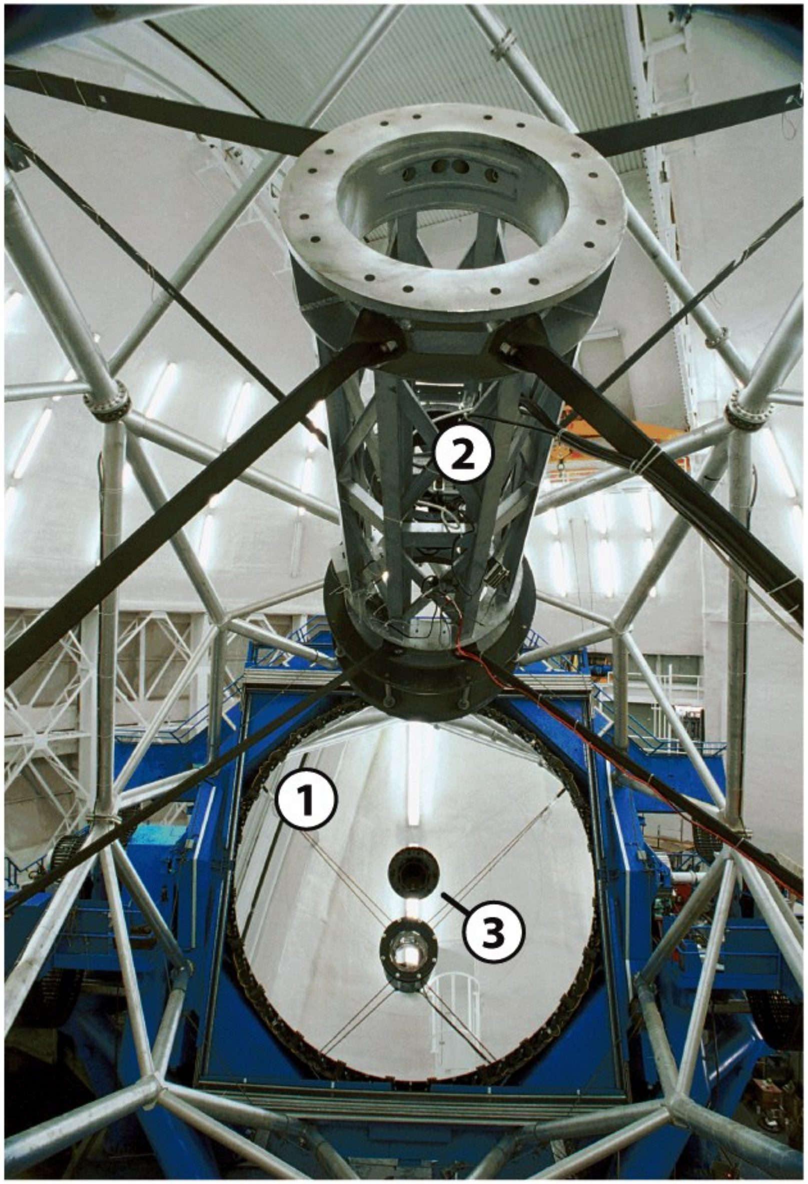



Figure 6-10a
*Universe*, Tenth Edition

# A Reflecting Telescope




**A large Cassegrain telescope**

**Figure 6-14b**
***Universe, Eighth Edition***


This view of the Gemini North telescope shows its 8.1-meter objective mirror (1). Light incident on this mirror is reflected toward the 1.0-meter secondary mirror (2), then through the hole in the objective mirror (3) to the Cassegrain focus

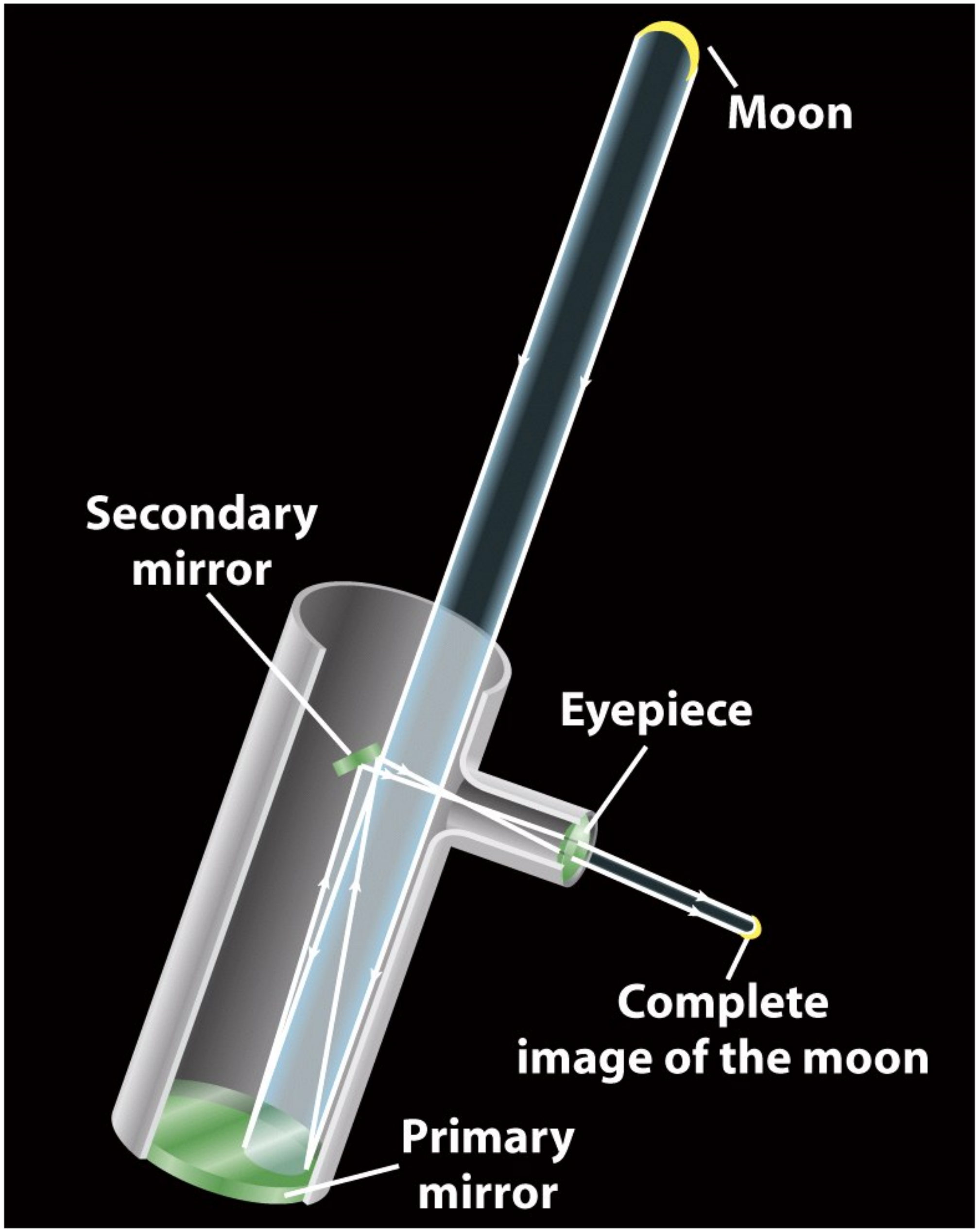



Figure 6-12
***Universe, Eighth Edition***


# The Secondary Mirror Does Not Cause a Hole in the Image

This illustration shows how even a small portion of the primary (objective) mirror of a reflecting telescope can make a complete image of the Moon. Thus, the secondary mirror does not cause a black spot or hole in the image. (It does, however, make the image a bit dimmer by reducing the total amount of light that reaches the primary mirror.)

# Telescope Performance

1. Light gathering power
2. Magnification
3. Angular resolution
4. Location (atmospheric water vapor, turbulence)

The bandpass (optical, infrared, radio, etc.) strongly affects what types of celestial objects can be seen.

# Light gathering power depends on size of objective lens or primary mirror

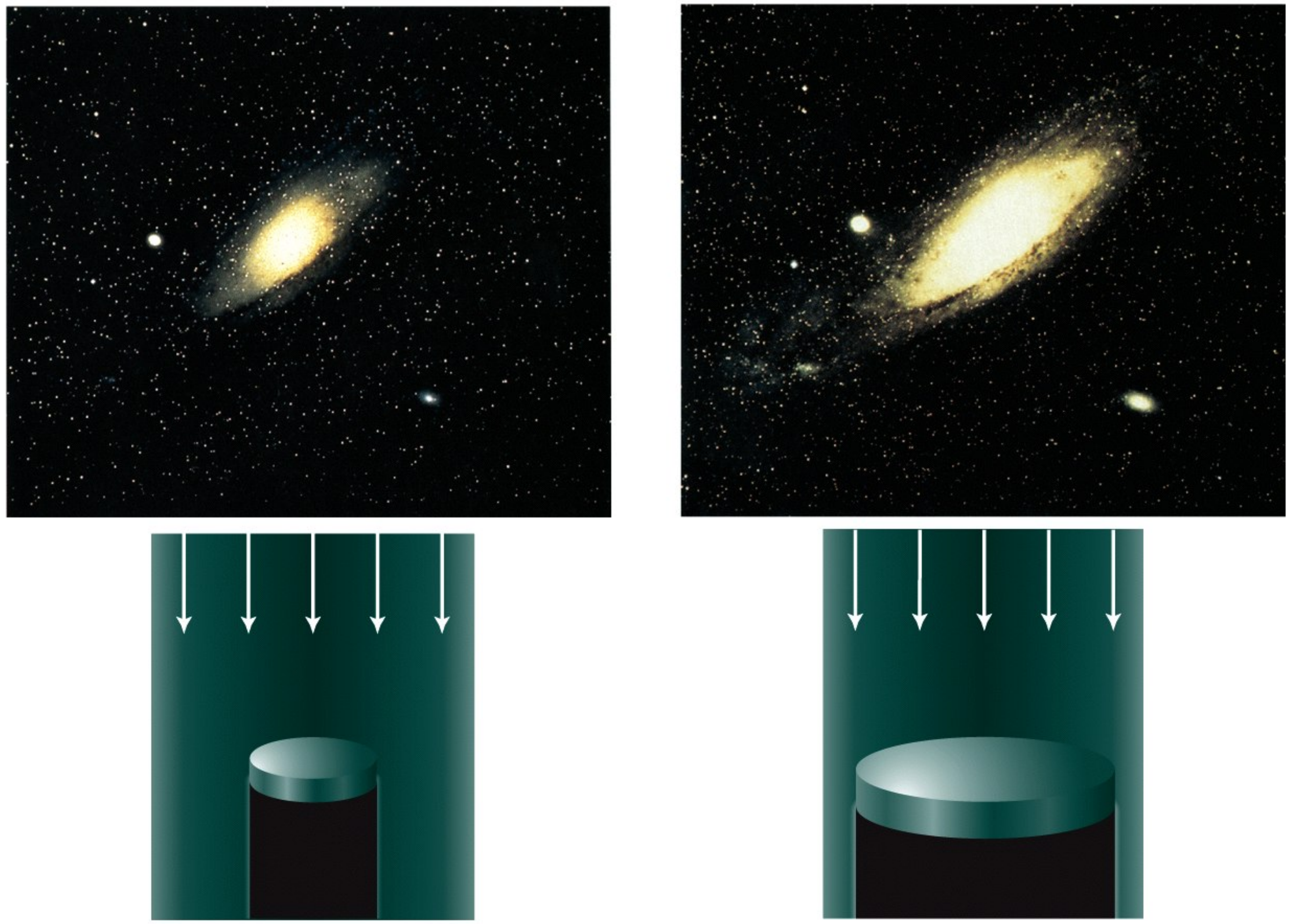
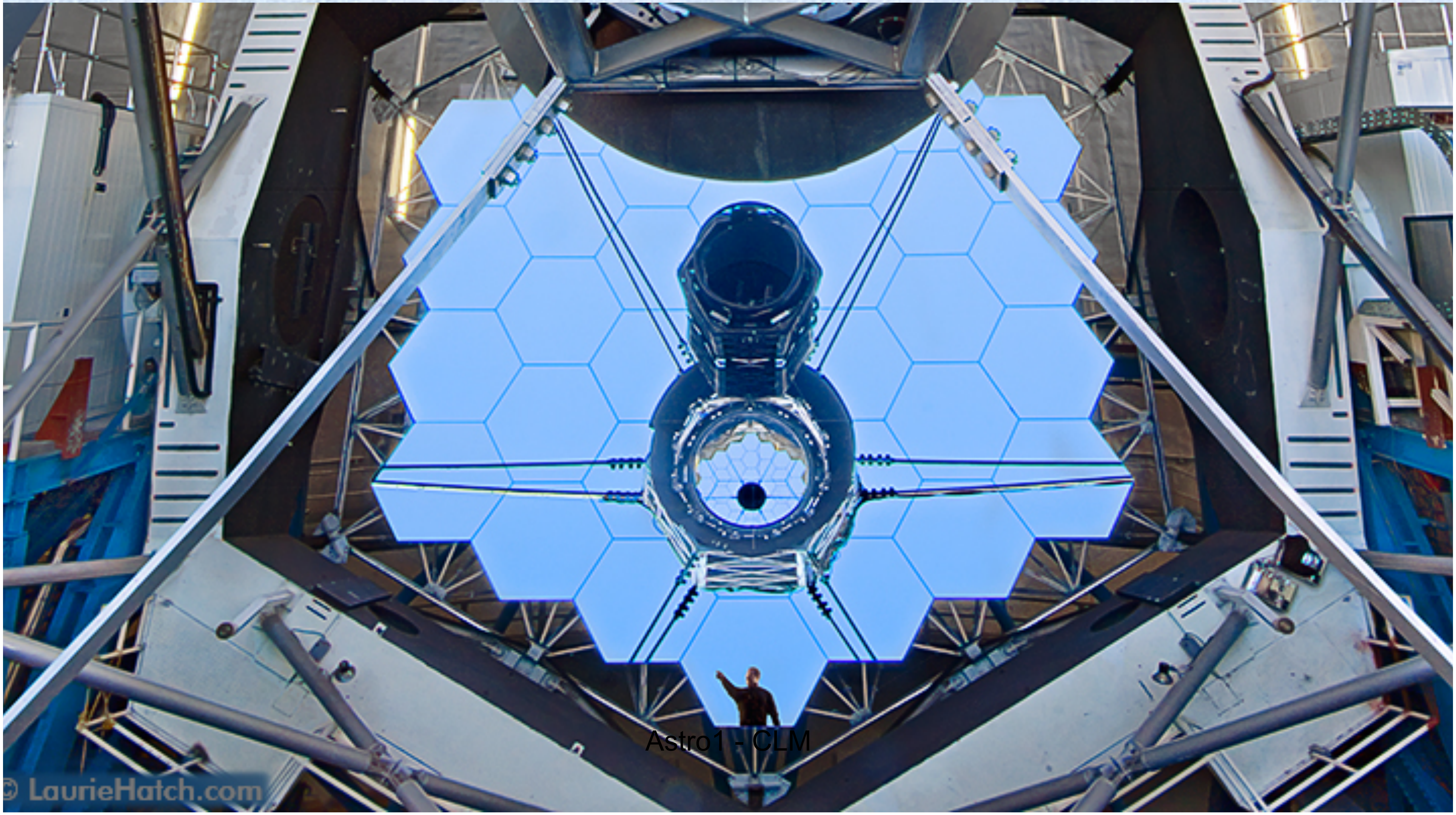



Figure 6-6
*Universe, Eighth Edition*

# How Do You Make a Lightweight 10m Diameter Mirror?

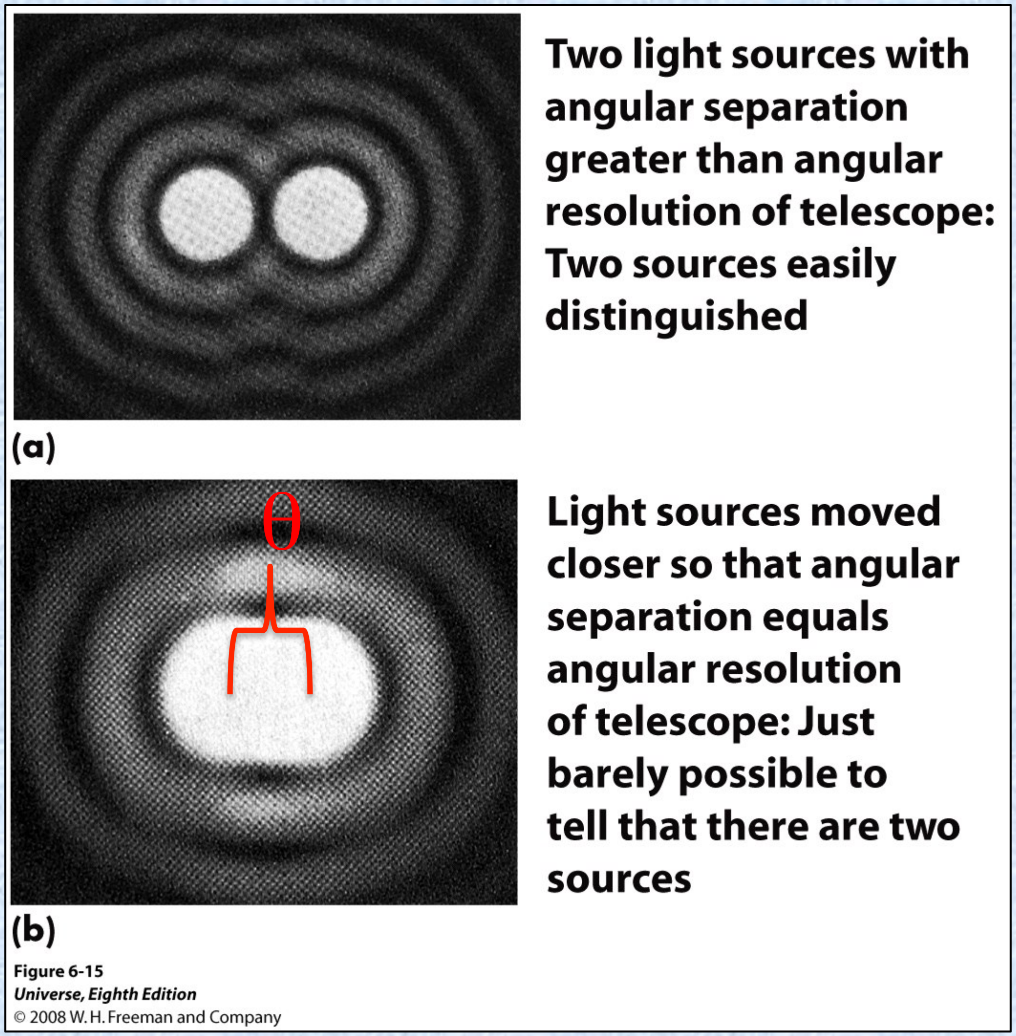


# How much more light gathering power does a 10m telescope have than an 0.5 m telescope?

Answer: The light gathering power is proportional to the square of the mirror's diameter.
$(10m)^2/(0.5m)^2 = 100m / 0.25m = 400$

So you can see objects about 400 times fainter with the 10m telescope in the same amount of time.

# Angular Resolution




Limited by:

- The quality of the optics and detector on the telescope.
- The size of the telescope primary aperture sets the "diffraction limit".
- **The diffraction limit is an angle, θ, usually given in arcseconds.**
- Blurring effects of the atmosphere ("seeing"), i.e. the twinkling of stars

# The diffraction limit

$$\theta = 2.5 \times 10^5 \frac{\lambda}{D}$$

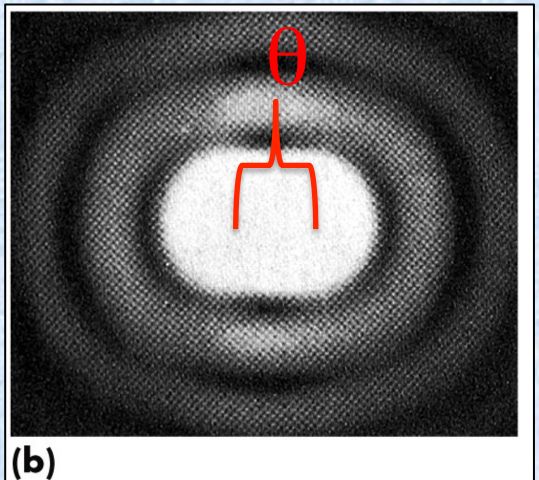



Figure 6-15
*Universe, Eighth Edition*


θ= angular resolution of the telescope (in arcseconds)

λ= wavelength of light, in meters

D = diameter of telescope objective, in meters

# iClicker Question

What is the diffraction limit for red light (640 nm = $6.4\times10^{-7}$m) for a telescope with with a 0.5m objective/primary?

A. $1.28 \times 10^{-6}$ arcseconds
B. 0.32 radians
C. 0.32 arcseconds
D. 1.28 arcminutes
E. None of the above

# iClicker Question

What is the diffraction limit for red light (640 nm = $6.4\times10^{-7}$m) for a telescope with with a 0.5m objective/primary?

A. $1.28 \times 10^{-6}$ arcseconds
B. 0.32 radians
**C. 0.32 arcseconds**
D. 1.28 arcminutes
E. None of the above

$$\theta = 2.5\times10^{5}\,\frac{\lambda}{\mathrm{D}} = 2.5\times10^{5}\,\frac{6.4\times10^{-7}\,m}{0.5\mathrm{m}} = 0.32''$$

So even if you had a perfect atmosphere and perfect optics, you couldn't resolve details finer than 0.32" with a 0.5m telescope.

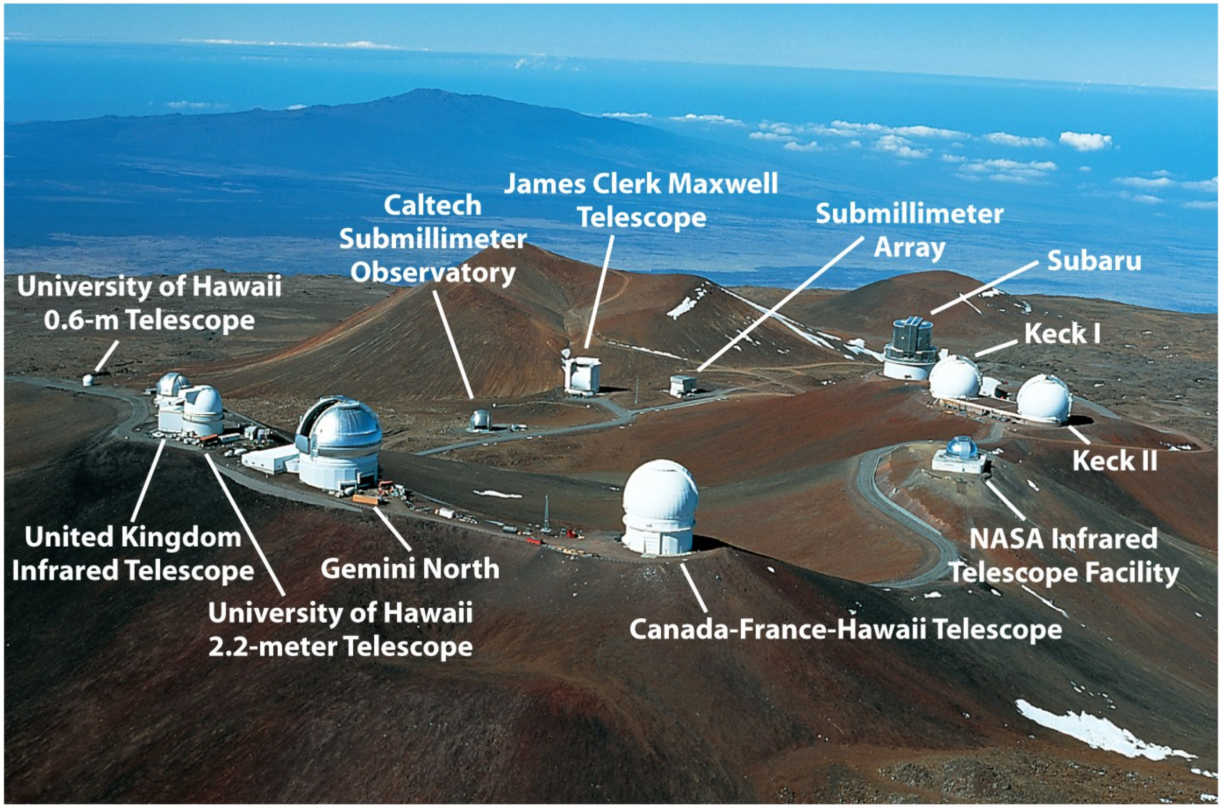



**Figure 6-16**
***Universe, Eighth Edition***


- Astronomers build telescopes at the best sites in the world.
- They may travel to the telescope to observe or observe remotely over the internet.

Mauna Kea, an extinct volcano in Hawaii that reaches 13,400 feet, is the best site in the world for optical and infrared telescopes. It has mostly clear, dark skies, little atmospheric turbulence, and is above most of the water vapor in the Earth's atmosphere. Notice the snow and lack of vegetation.

# Adaptive Optics Help Telescopes on Earth Remove the Blurring Caused by the Atmosphere

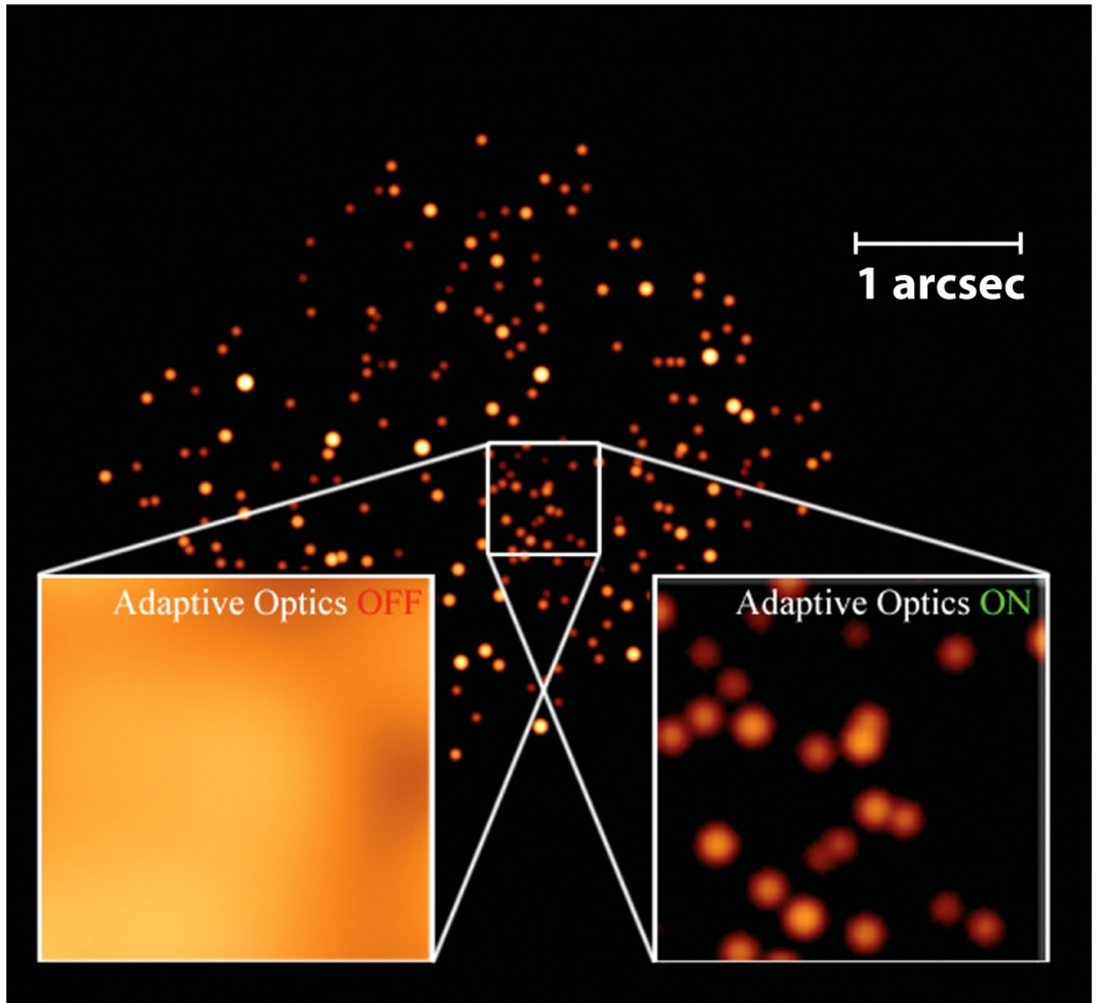
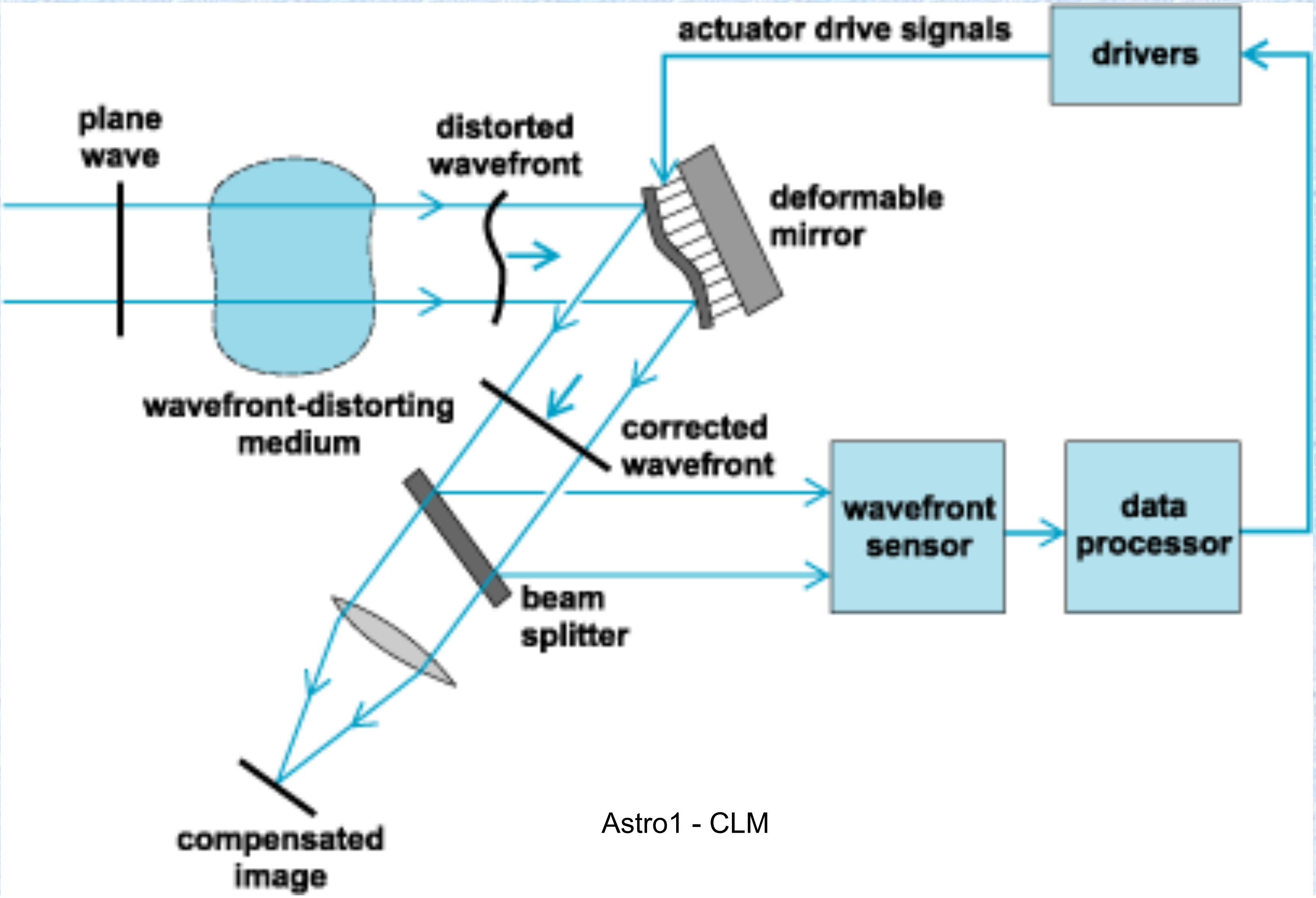


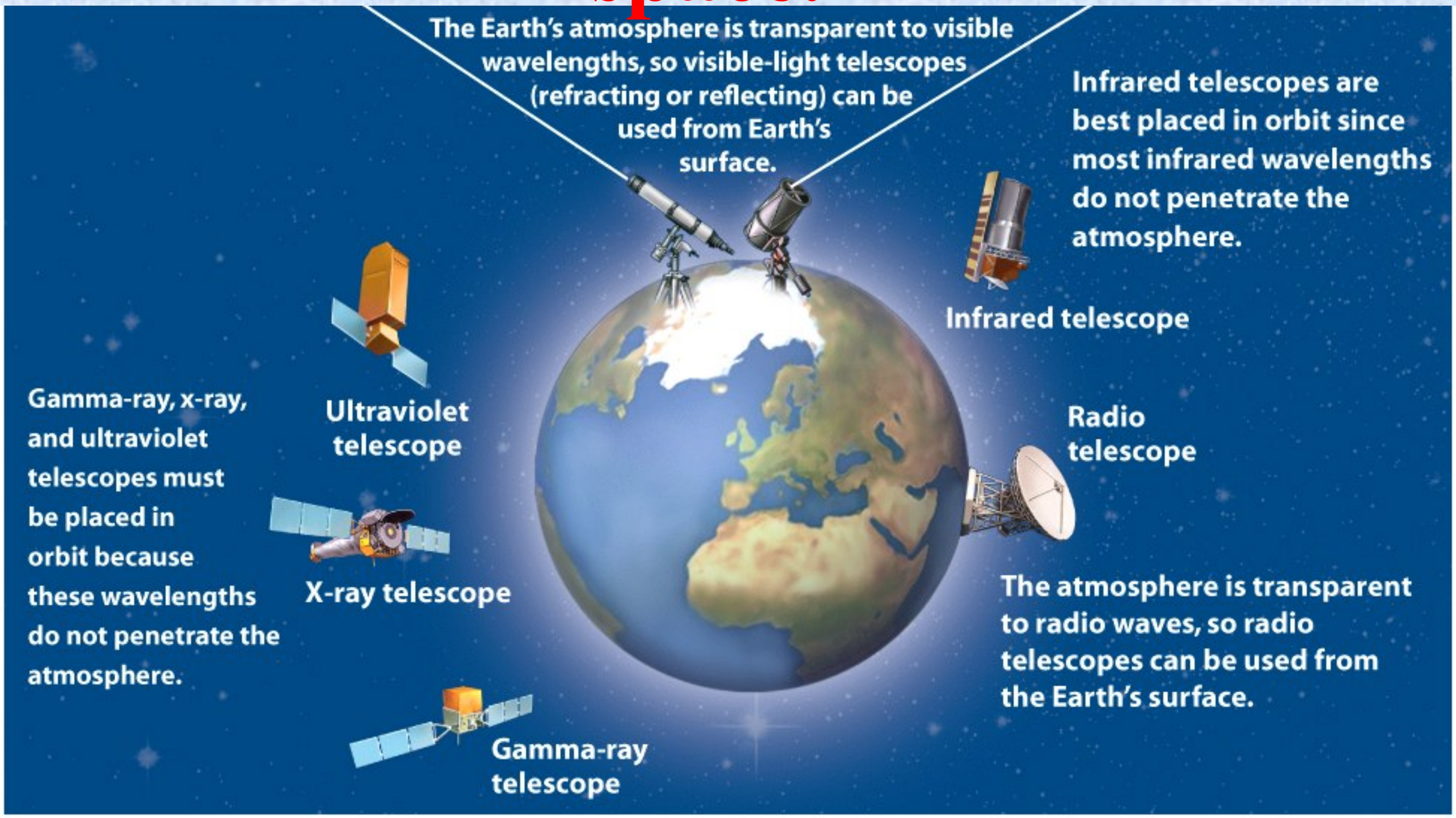

Figure 6-18
*Universe, Eighth Edition*

# Laser Beacon Makes an Artificial Star

# Adaptive Optics System



# The sky is only visible in some parts of the electromagnetic spectrum from space.




Cosmic Connections 6
*Universe, Eighth Edition*

# Transparency of Earth's Atmosphere

The transparency is high in the **optical** "window" or "bandpass".

**Near infrared** "windows" or "bandpasses".

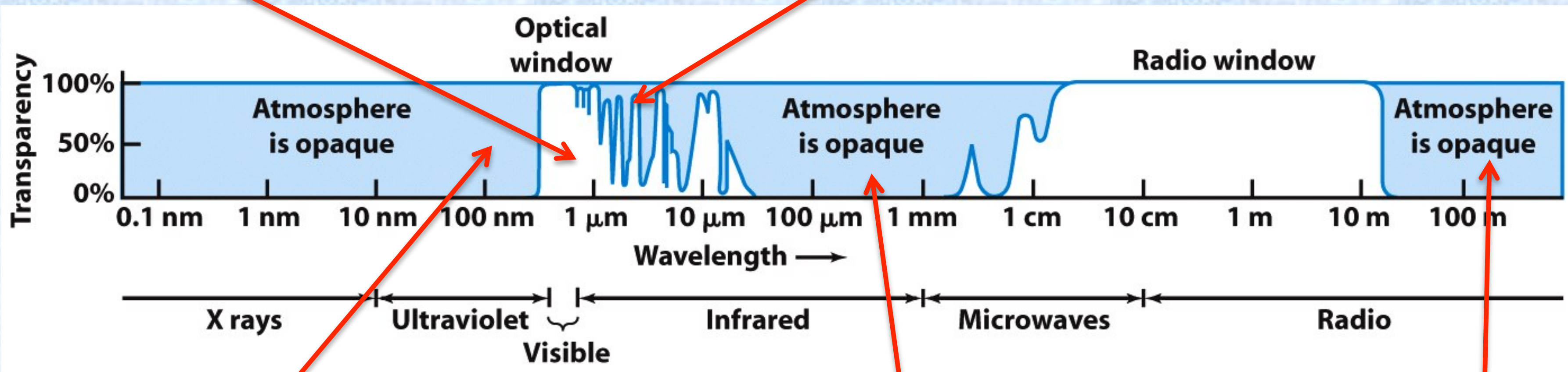



Figure 6-25
*Universe, Eighth Edition*


**Ultraviolet** radiation is absorbed by oxygen and nitrogen in the atmosphere.

Water vapor and carbon dioxide absorb light between the optical and radio bands.

Reflected

# Saturn Reflects the Sun’s Light; And It Also Emits Light as Do All Blackbodies

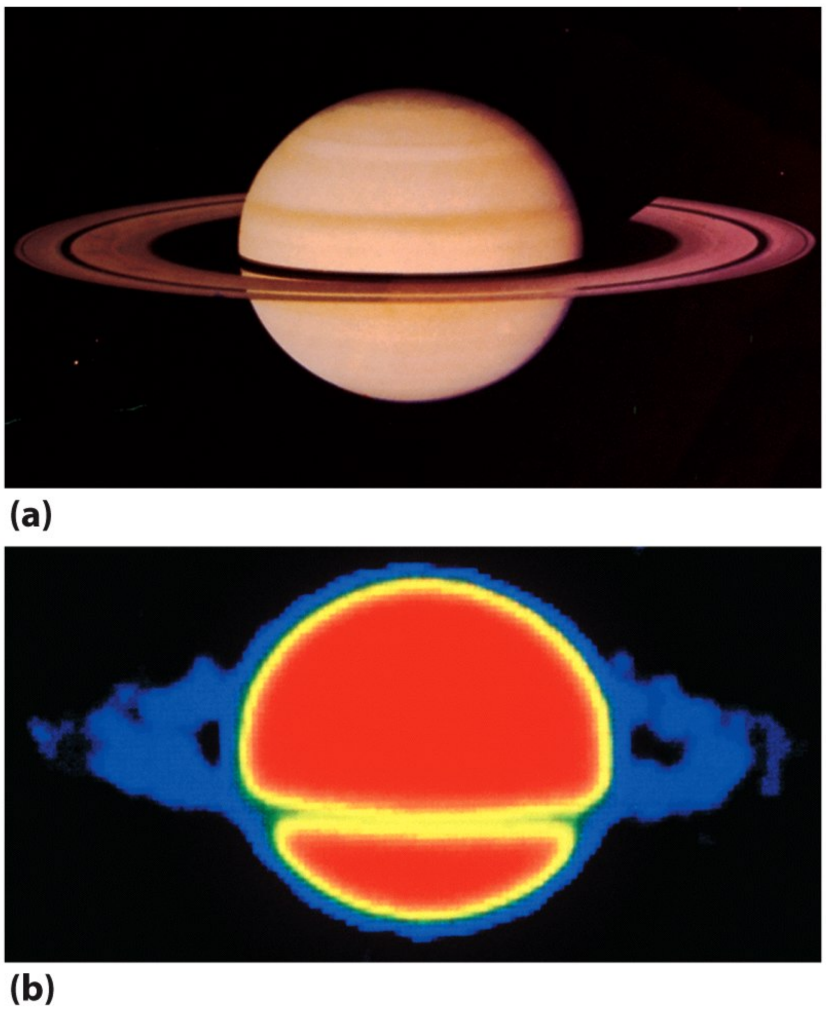
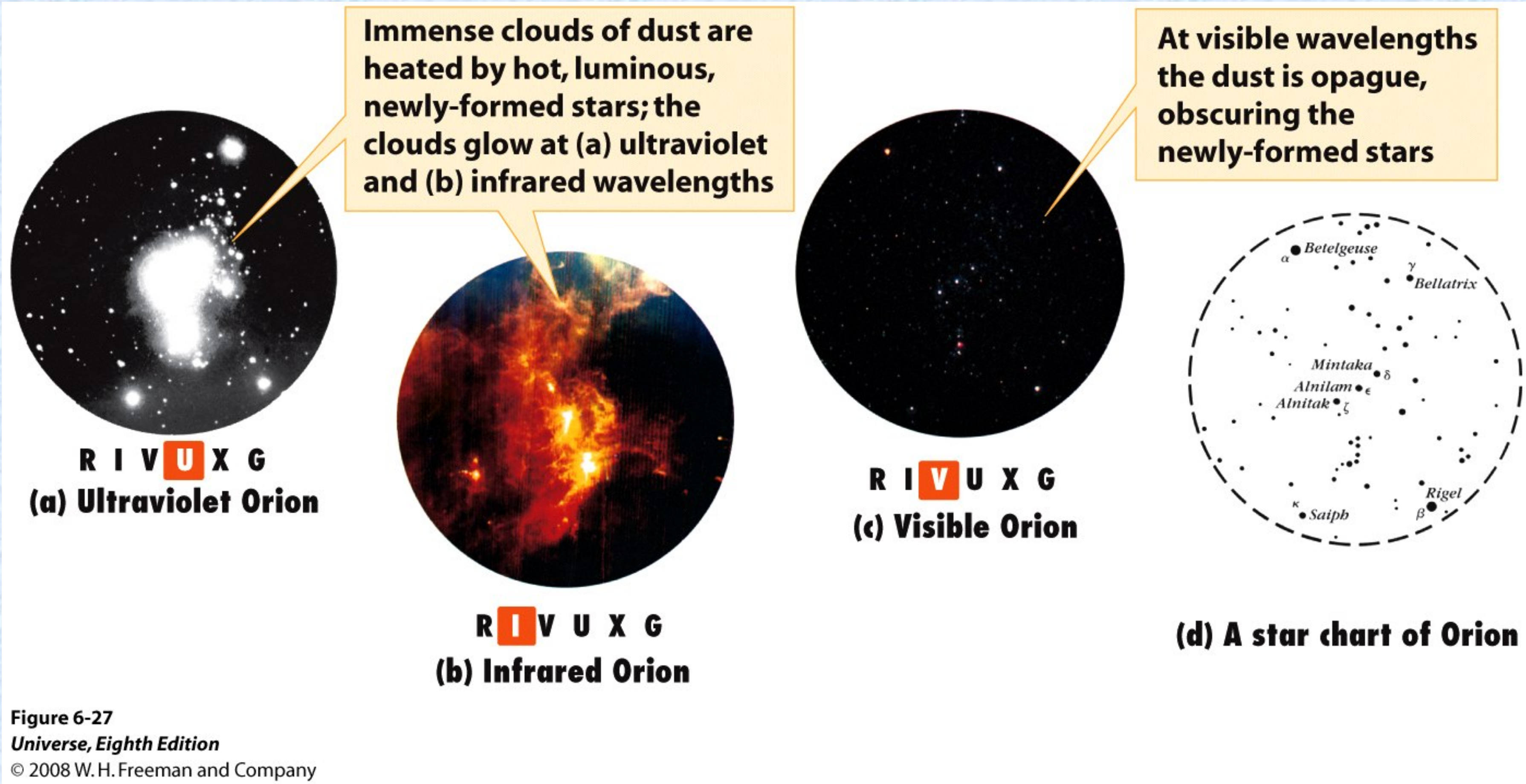



**Figure 6-24**
***Universe, Eighth Edition***


Note:
color maps intensity in this image, not temperature

# A Panchromatic View of the Orion Nebula




**Applying Wien's Law is often the first step in understanding the source of the emission.**

# A Panchromatic View of the Milky Way

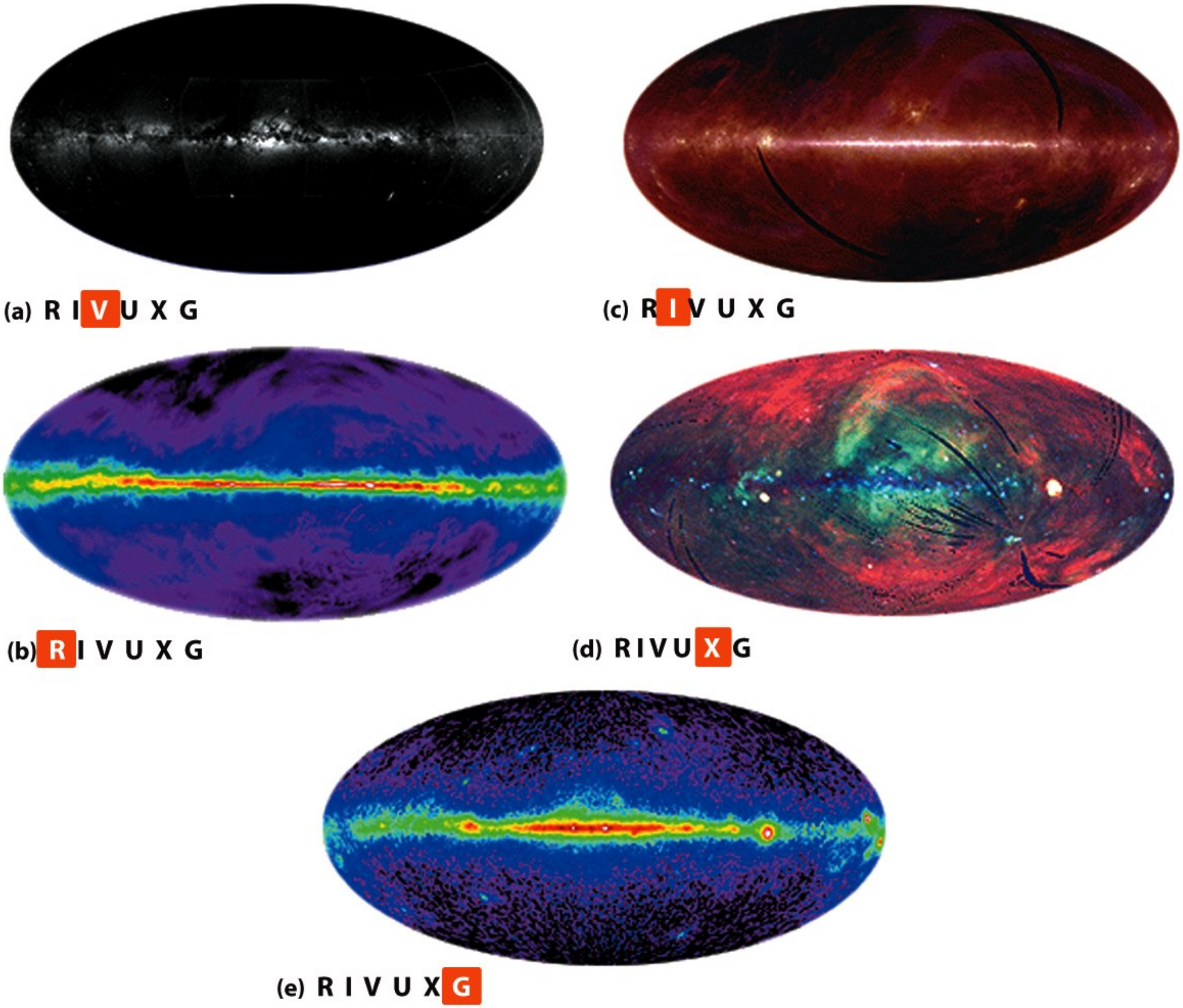
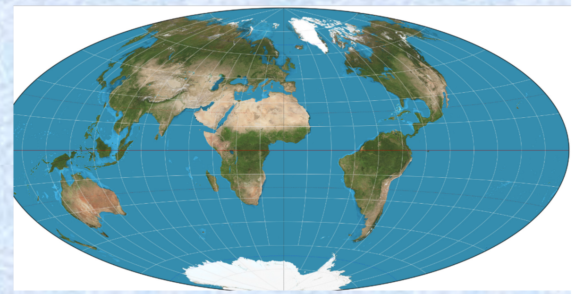



Figure 6-32
*Universe, Eighth Edition*


An Aitoff projection shows the entire sky.



Which images show the distribution of stars? [T = 3000 K to 50,000 K]

What do the other images show?

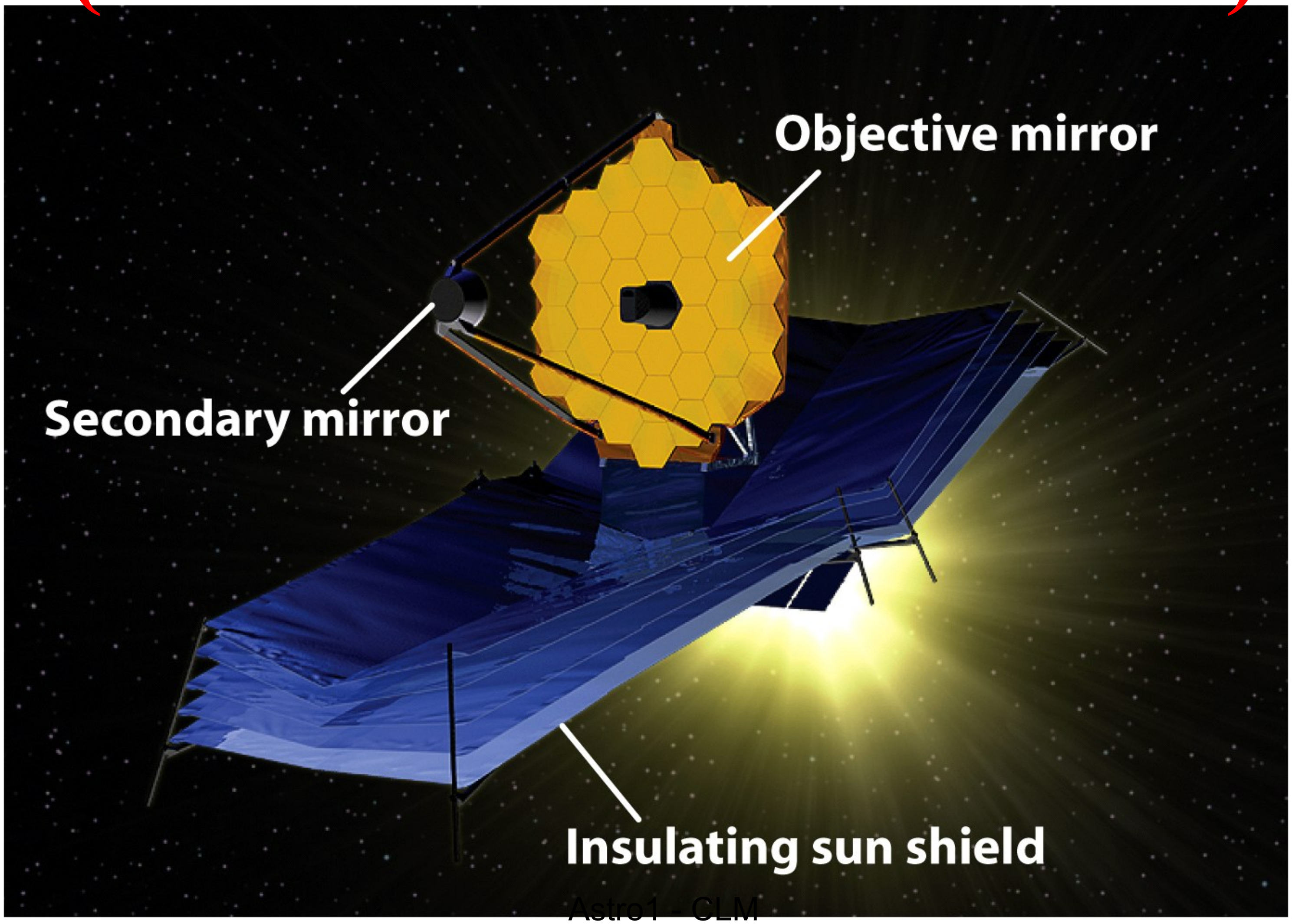
# Exploring the electromagnetic spectrum led to many discoveries

- Radio astronomy revealed the large mass of cold, interstellar gas between the stars. This material is the fuel from which new stars are made.
- X-ray astronomy probes the hot tenuous corona of the Sun, black holes, and galaxies.
- Transient bursts of gamma-rays in the sky have been shown to mark stellar explosions half-way across the universe.
- Ultraviolet and near-infrared observations probe the hottest and coldest stars, respectively. We will learn that *the hottest stars are very massive and short lived*; hence they mark recent sites of stellar birth. *The coolest stars are the most numerous* and account for most of the stellar mass in the galaxy.

# Hubble Space Telescope

**Figure 6-28**
***Universe, Eighth Edition***

# James Webb Space Telescope (see movie on class website)




Astro1 - CLM

**Figure 6-29**
***Universe, Eighth Edition***

# Summary

- The Doppler shift tells us how fast the emitting objects moves toward us or away from us.
- Geometrical optics
  - Light rays must be focused to produce an image.
  - Use the laws of Reflection & Refraction to focus light.
- Telescope performance depends on
  - Light gathering power
  - Angular resolution (or resolving power)
  - Location
- The wavelength of the light (i.e., the bandpass) determines what type of celestial objects are seen.

# Homework #3 (Due 10/18/19)

- On your own: answer all the review questions in chapter 5 & 6.s
- To TAs: answer questions
  - 5.34 (Note that Io's surface temperature is -150$^o$ C and not 2150$^o$ C), 5.37, 5.43, 5.44
  - 6.34 – What does the atmosphere do to images of the sky?
  - 6.36--Why does Hubble Space Telescope produces sharp images?
  - 6.40 – Think about observing at sub-mm wavelengths
  - 6.41– Think about absorption vs. emission lines

# Telescope Demo (iclicker Question)

Suppose the professor covers the bottom half of the objective lens. What will the class see through the telescope on the sceen?

A. The top of the ruler, and this image will be inverted left to right.
B. The bottom of the ruler because the image is inverted, and this image will be inverted left to right.
C. The top of the ruler, and this image will NOT be inverted left to right.
D. The bottom of the ruler because the image is inverted, and this image will NOT be inverted left to right.
E. The same image we saw previously.