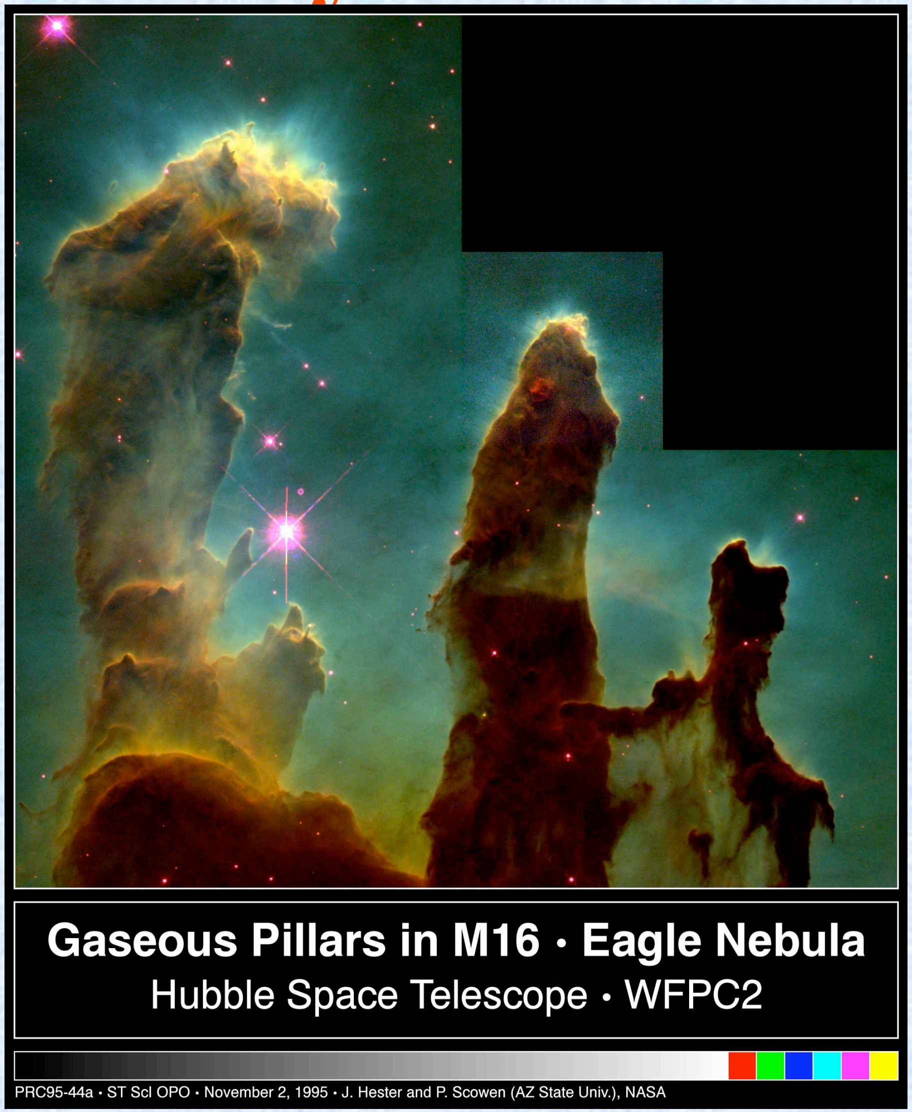
Astronomy 1 – Winter 2011



Lecture 9; January 26 2011

Homework – Due 02/02/11

- On your own: answer all the review questions in chapters 7 and 8
- To TAs: answer questions 7.22, 7.23, 7.28, 8.35, 8.37, 8.40

Previously on Astro-1

- **What are photons?**
  - light can have particle-light properties. The particles of light are called photons: $E = h\nu = hc/\lambda$
- **Why is the sky is blue and sunsets red?**
  - Interaction between light and atmosphere
- **What are stars and interstellar gas made of?**
  - The same elements we see on Earth, mostly Hydrogen, He, Oxygen, Carbon
- **What causes spectral lines?**
  - **Atomic structure**

Today on Astro-1

- **A most valuable tool: the Doppler effect**
  - **The discovery of extrasolar planets**
- **Telescopes: astronomers' tools of the trade**
  - Basic optics
  - Refractors
  - Reflectors
  - Light gathering power and resolution
- **Telescopes and the atmosphere**
  - Space Telescopes

Doppler Shift
a most useful tool for astronomy

Austrian physicist Christian Doppler explained the effect in 1842

Doppler Effect: change in frequency or wavelength of a wave as perceived by an observer moving relative to the source of the waves.

Waves from sources moving *towards* and observer have a *higher* perceived frequency (longer wavelength). If the source is moving *away*, the observed waves have a *lower* frequency.

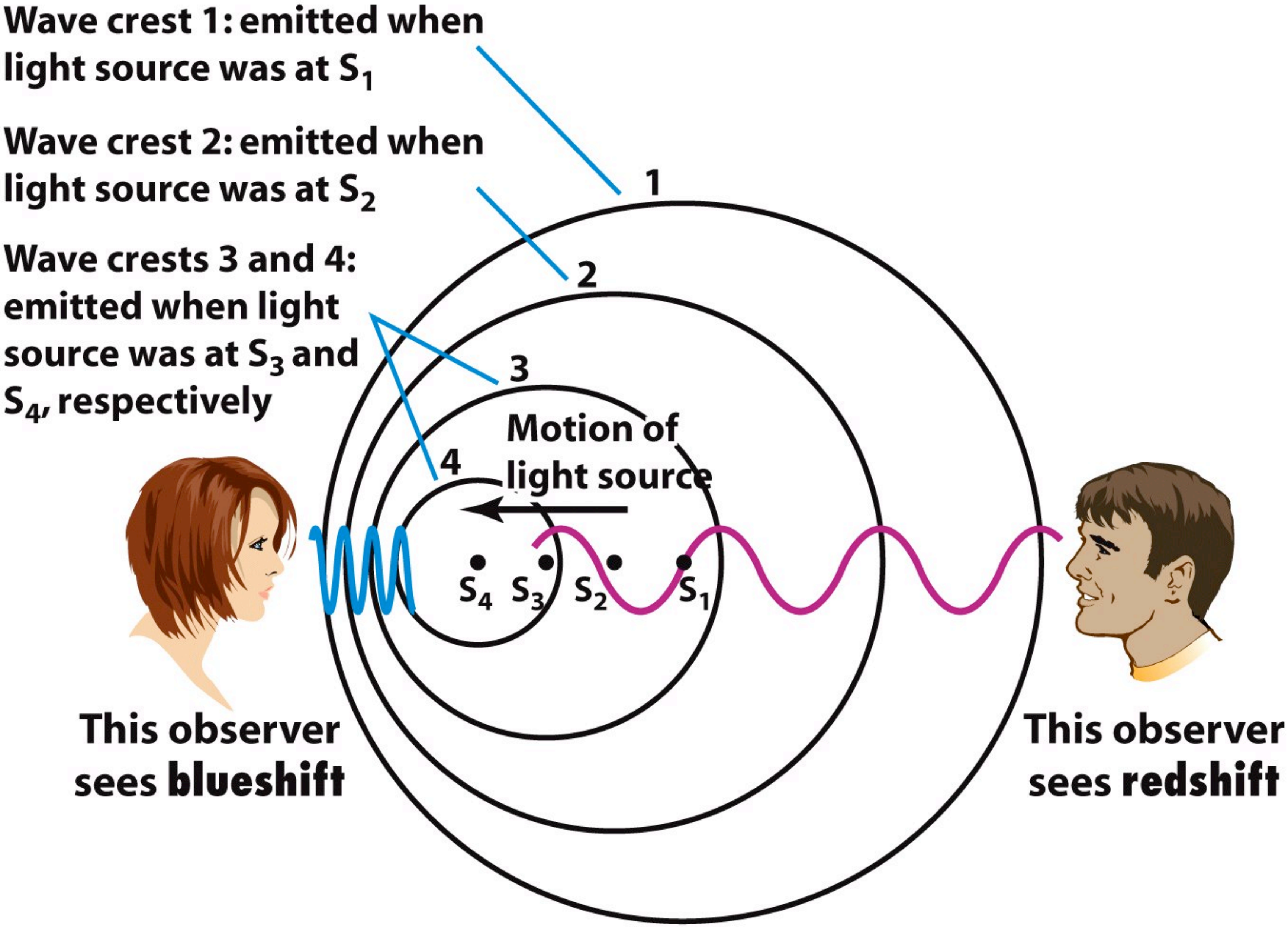


Figure 5-26
Universe, Eighth Edition

Calculating the Doppler shift

$$f_{obs} = \left(\frac{v_w}{v_w + v_s}\right) f_e$$

f_{obs}: observed frequency

f_e: emitted frequency

v_w: wave velocity

v_s: source velocity relative to observer

- **positive** if moving away
- **negative** if moving toward

Example: A scooter honks a horn with a frequency of 3900 Hz. If it approaches at 10 m/s, what shift in frequency do you hear as it passes? (The speed of sound waves is 330 m/s).

Approaching:

$$f_{obs} = \left(\frac{330}{330 - 10}\right) 3900 = 4022$$

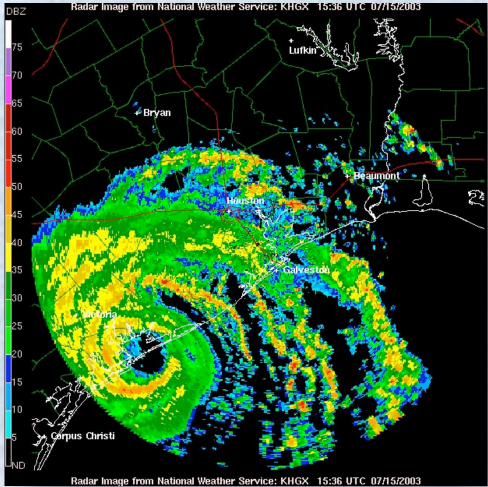
Receding:

$$f_{obs} = \left(\frac{330}{330 + 10}\right) 3900 = 3785$$

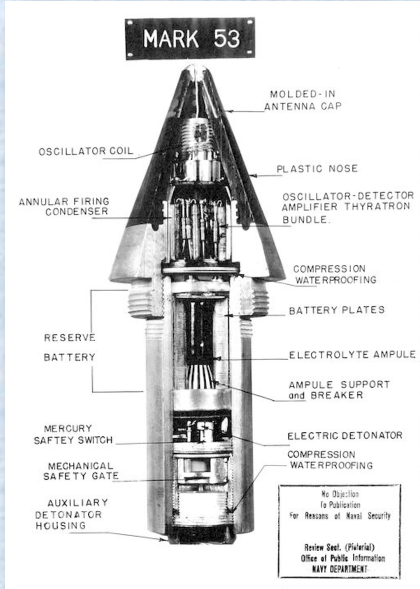
Difference: 4022-3785 = 237 Hz

Everyday applications of the Doppler effect

Radar guns

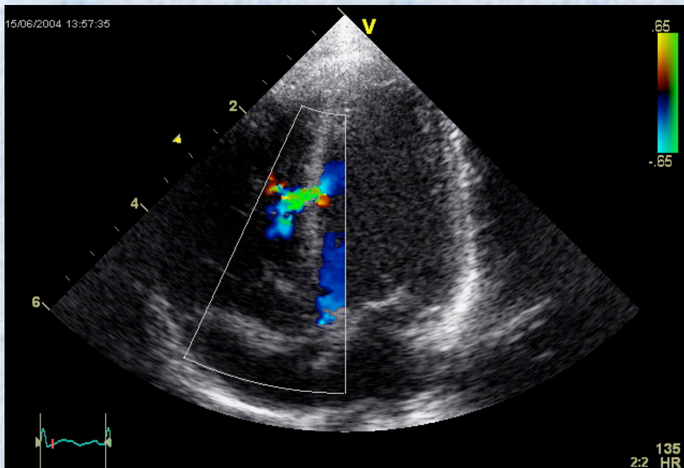


Doppler weather radar



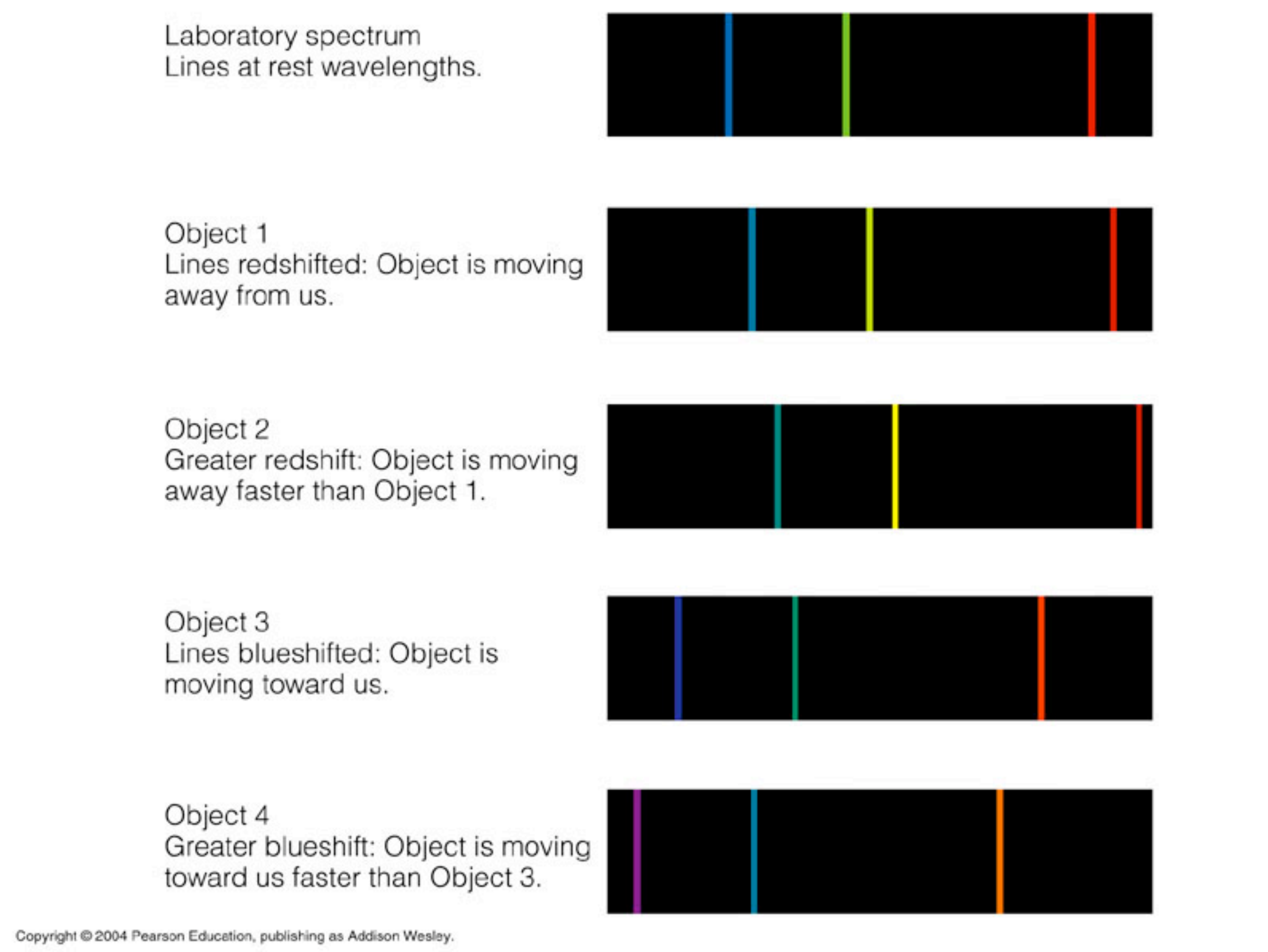
Bomb fuzes

Bat echolocation

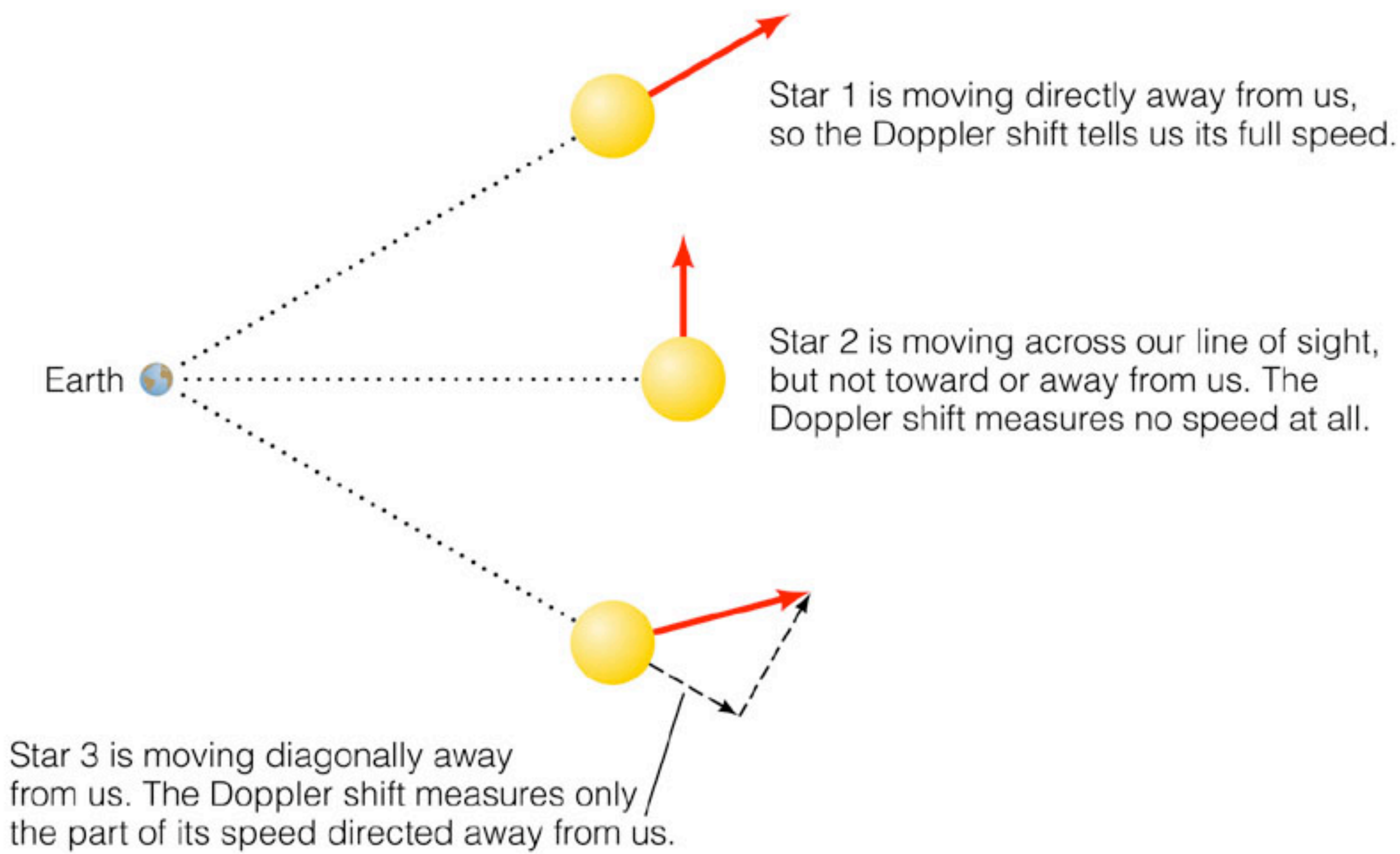


Medical imaging

Light is a wave… it is affected by motion too.



Bottom line: you can tell how fast something is moving from its spectrum… sort of


Star 1 is moving directly away from us, so the Doppler shift tells us its full speed.
Star 2 is moving across our line of sight, but not toward or away from us. The Doppler shift measures no speed at all.
Earth
Star 3 is moving diagonally away from us. The Doppler shift measures only the part of its speed directed away from us.

Doppler shift formula: Note: technically this is an approximation that only holds for for small speeds compared to the wave speed. It is almost always a good approximation in astronomy (because light waves are so fast!), but it does not work for sound.

Wavelength shift → $\Delta\lambda$; Rest wavelength → λ_0; velocity → v; speed of light → c

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

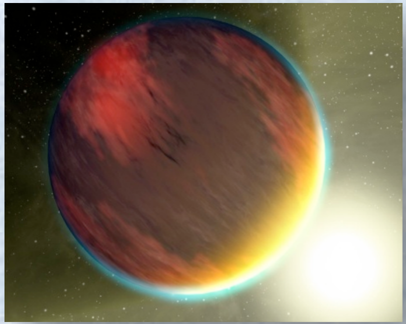
$$\Delta\lambda = \lambda - \lambda_0$$

Example: Silicon usually emits or absorbs light at 635.5 nm. During a supernova explosion, silicon atoms are seen absorbing light at 618.6 nm. How fast is this silicon gas moving?

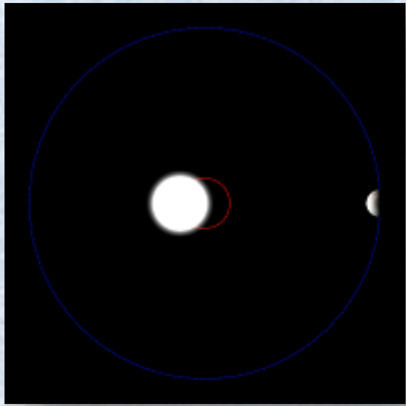
$$v = c\frac{\Delta\lambda}{\lambda_0} = 3\times10^{8}\,m/s\,\frac{618.6nm - 635.5nm}{635.5nm}$$

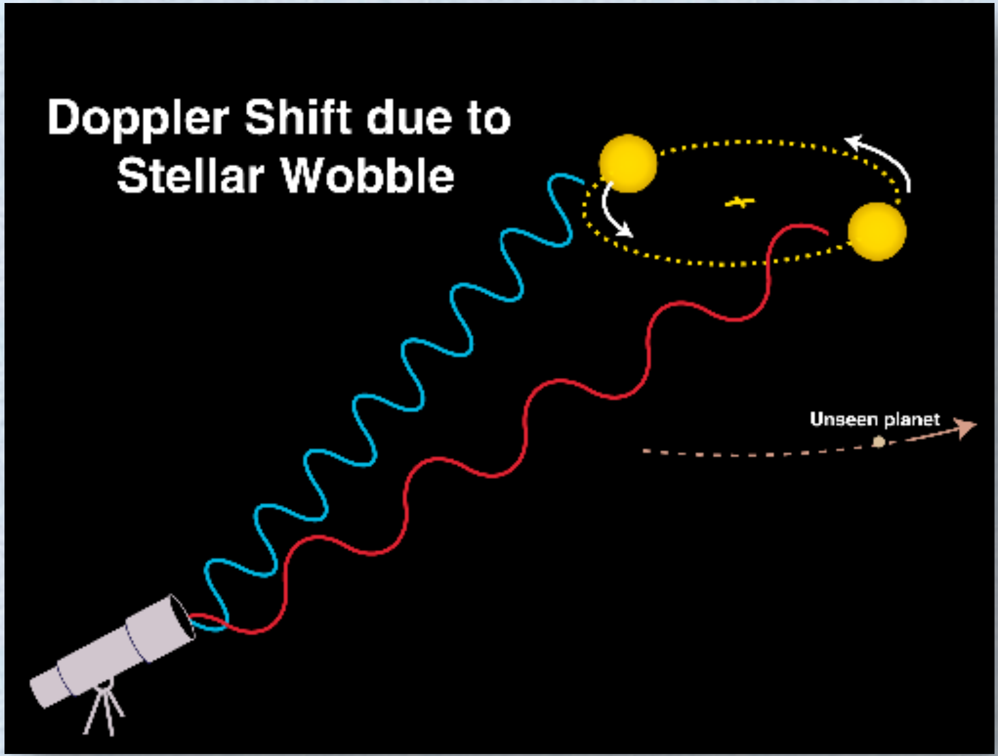
$= -7.98\times10^{6}$ m/s

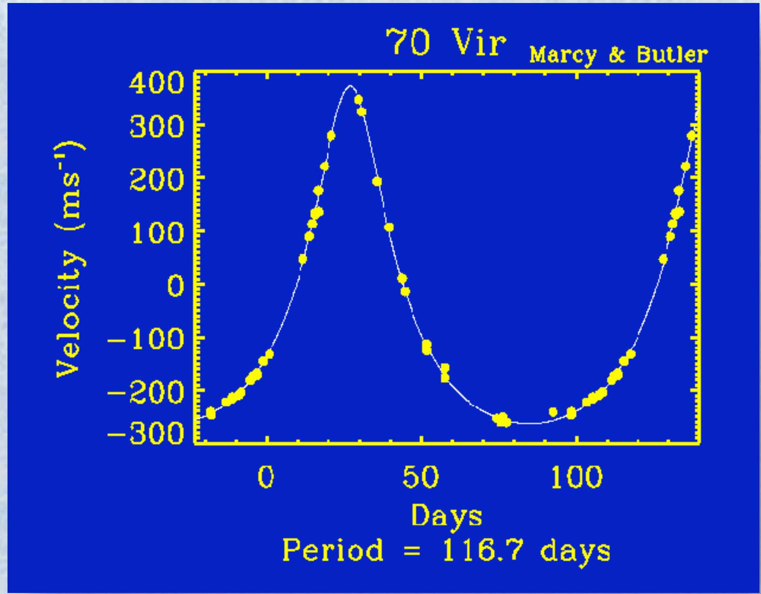
Minus sign means it is moving towards us.



Extra-solar planets: most have been discovered using Doppler shift measurements of their parent stars (since 1995)

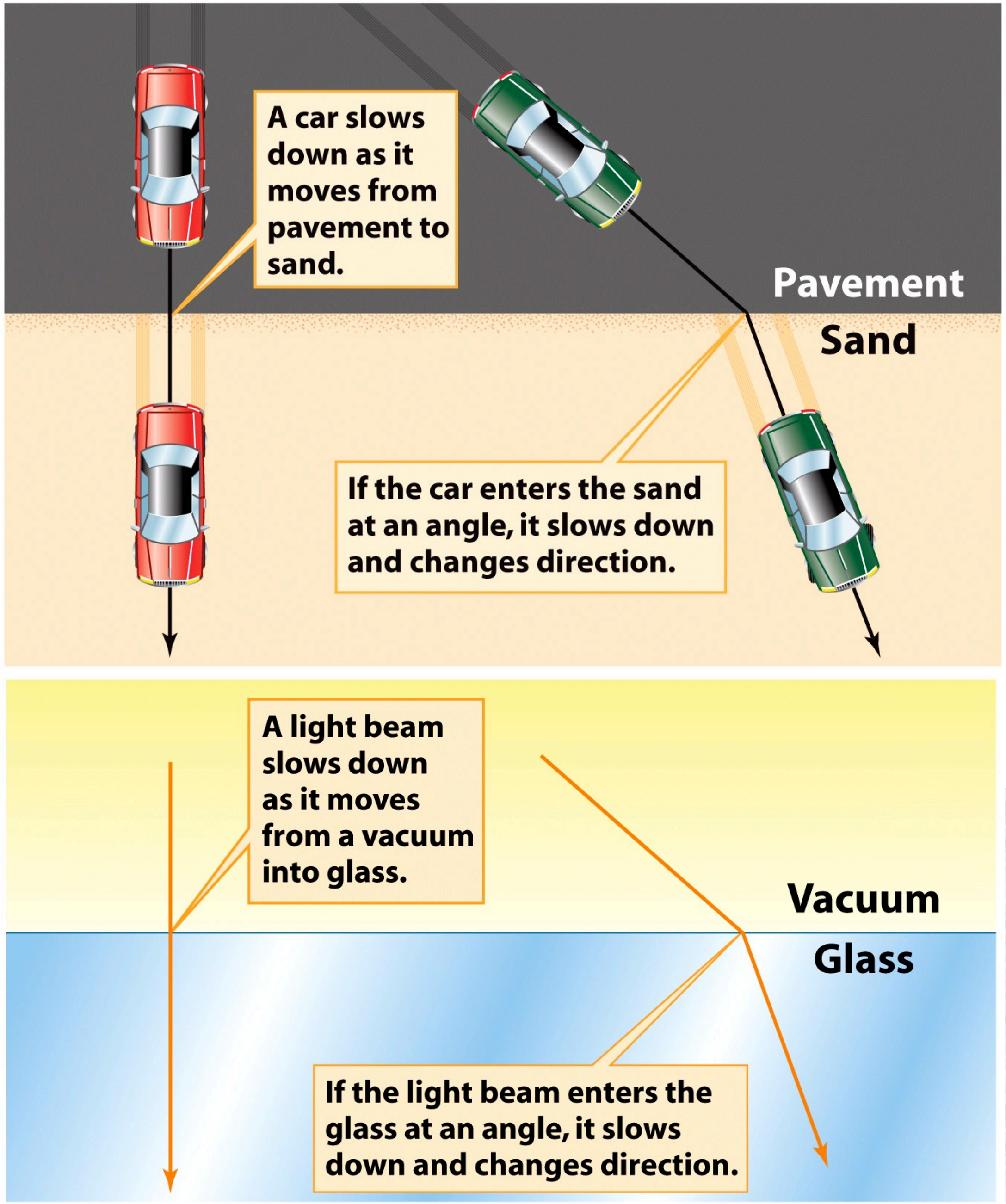






Question 9.1 (iclickers!)

- The spectrum of a star shows an equivalent set of dark absorption lines to those of the Sun, but with one exception: every line appears at slightly longer wavelength, shifted toward the red end of the spectrum. What conclusion can be drawn from this observation?
  - A) The star is moving rapidly toward Earth
  - B) A cloud of dust surrounds the star and absorbs the light
  - C) The star is moving rapidly away from Earth
  - D) The temperature of the star's surface is higher than that of the Sun.



How light beams behave

Figure 6-1b
Universe, Eighth Edition

Refraction

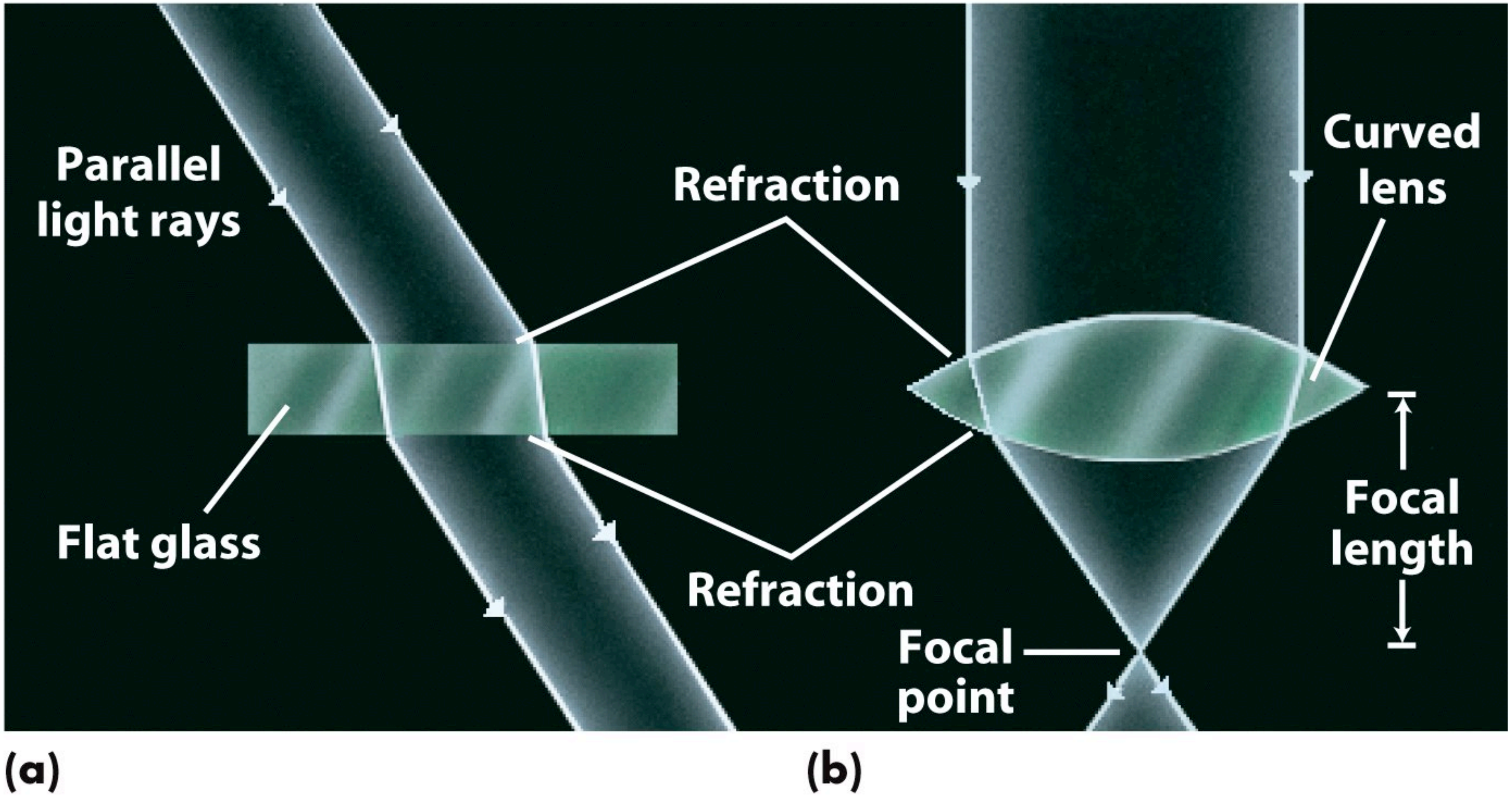


Figure 6-2
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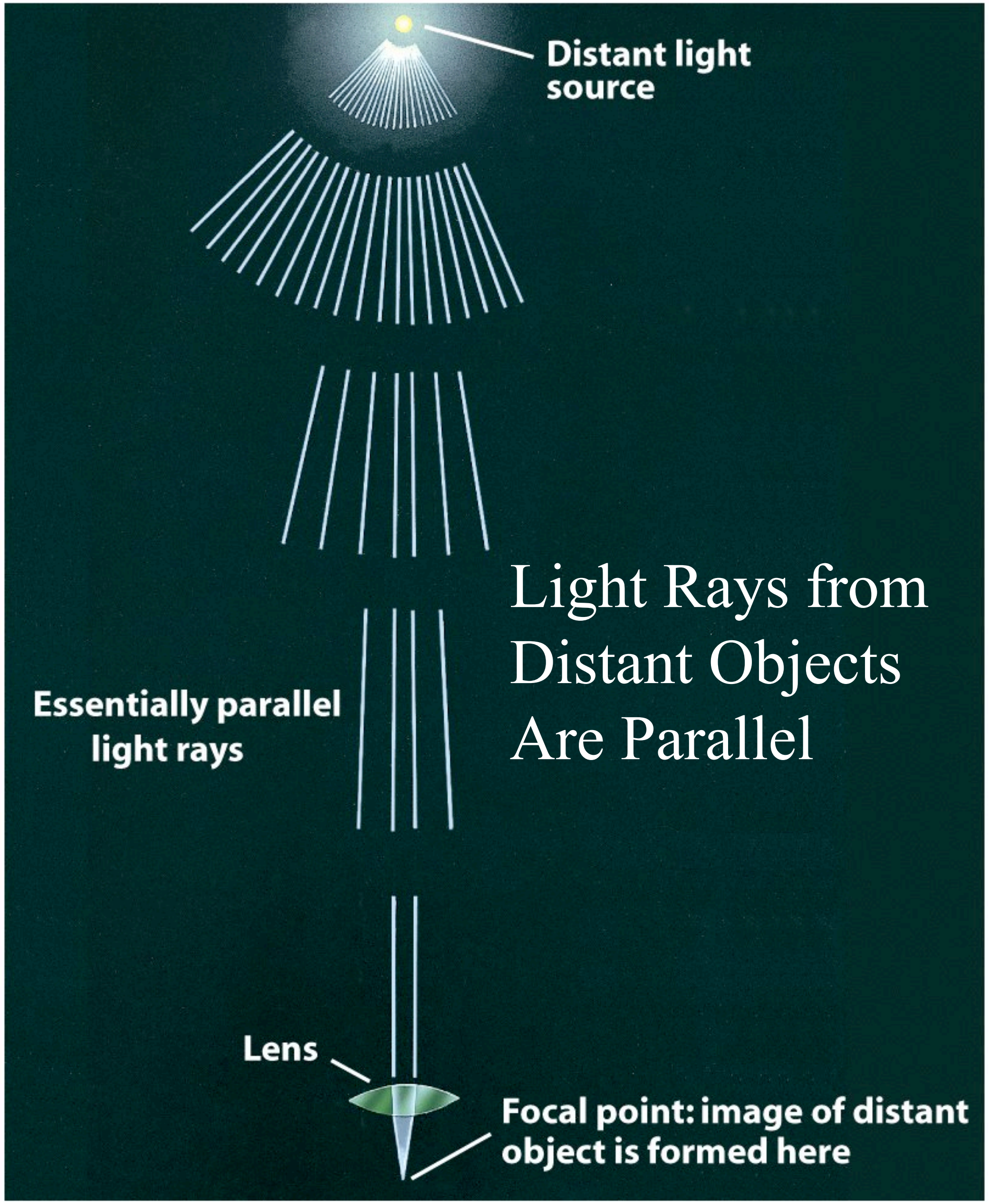
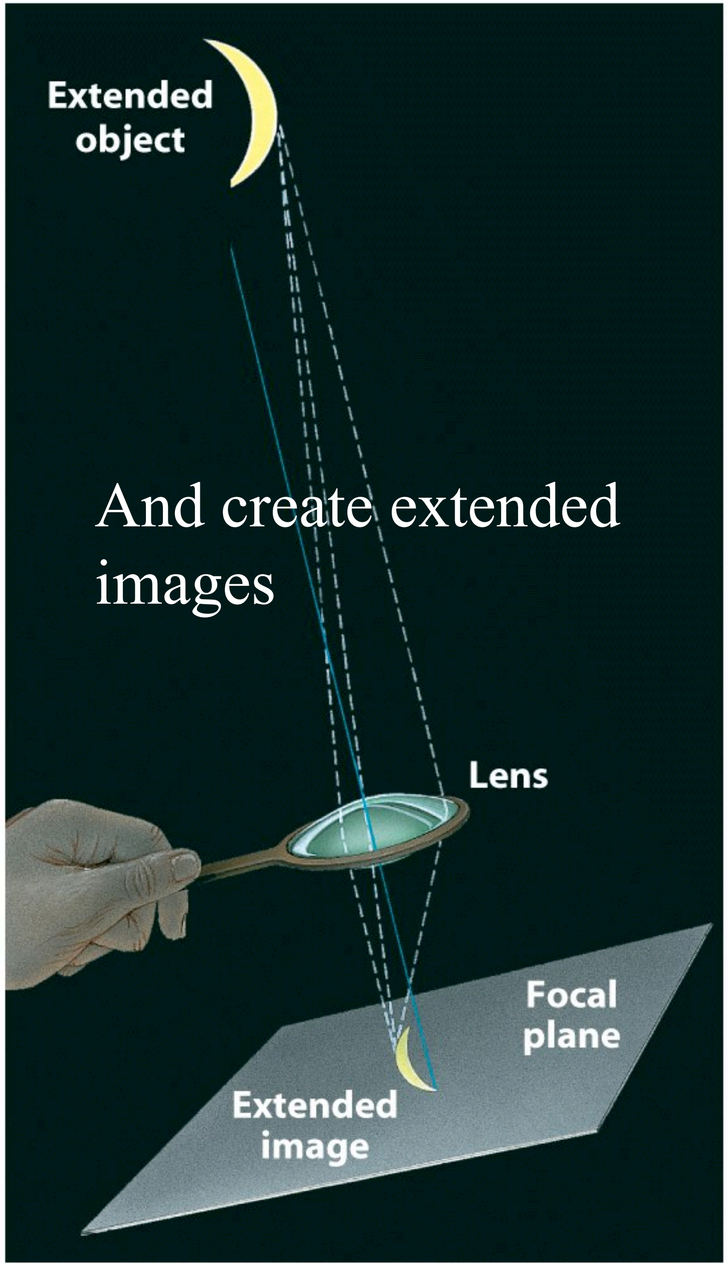


Light Rays from Distant Objects Are Parallel

Figure 6-3
Universe, Eighth Edition



And create extended images

Figure 6-4
Universe, Eighth Edition

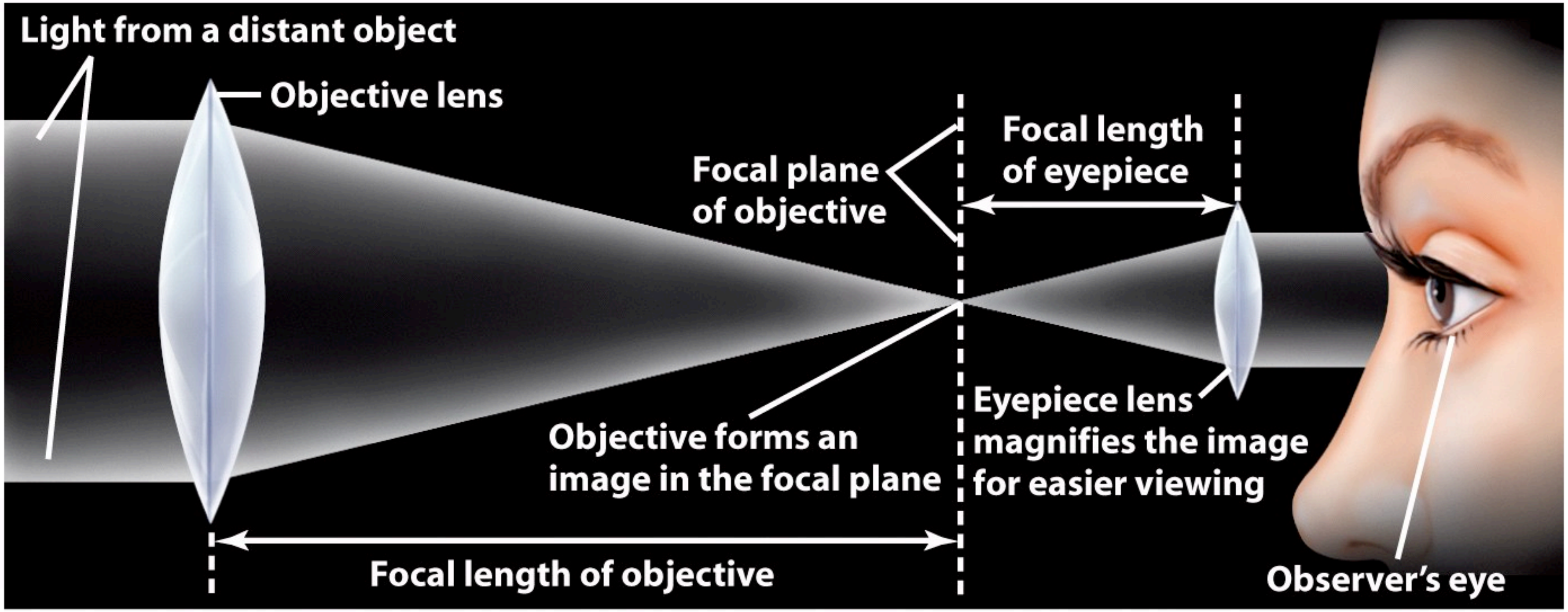
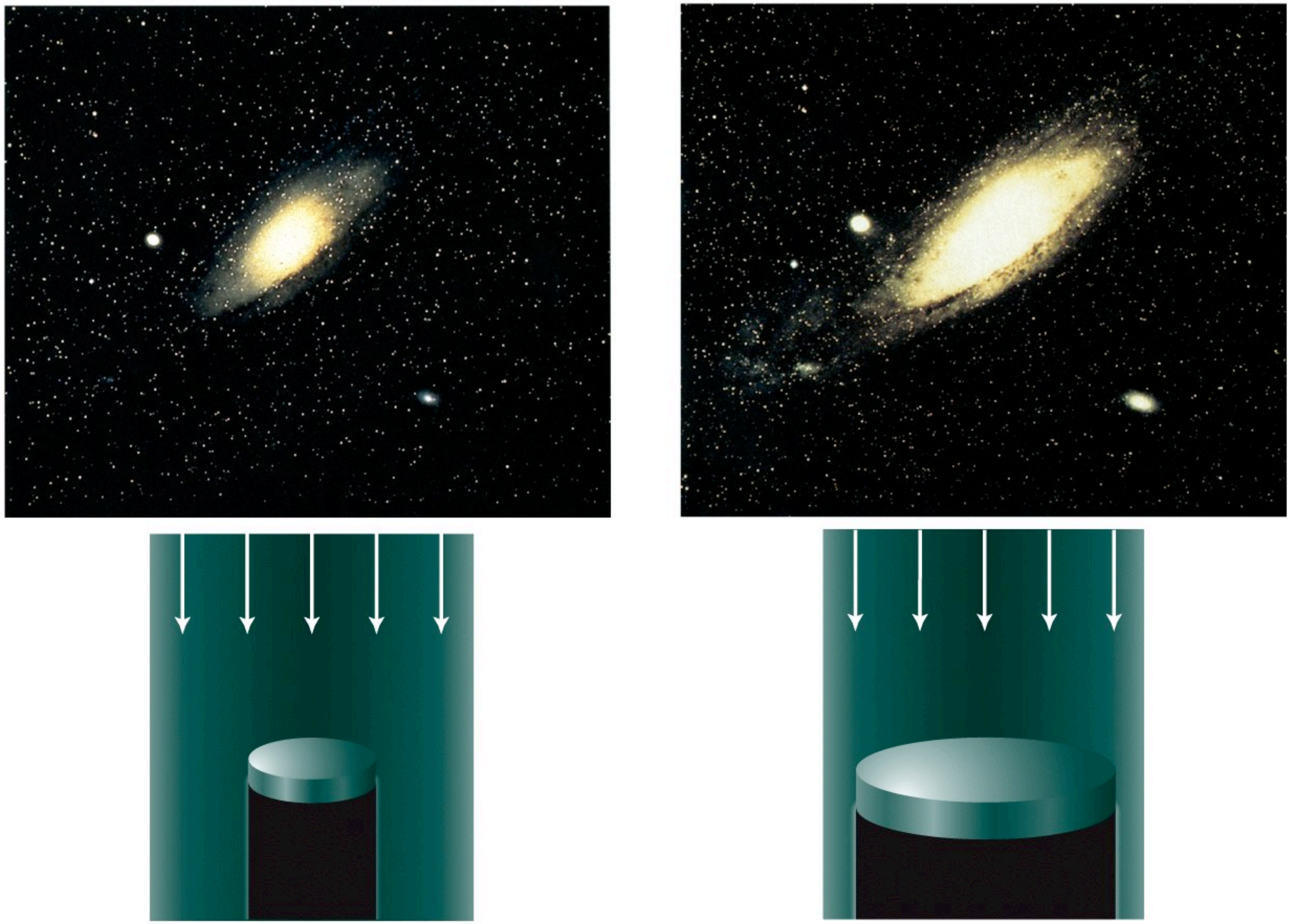


Figure 6-5
Universe, Eighth Edition

Question 9.2 (iclickers!)

- Compared to its speed in vacuum, the speed of light in glass is
  - A) much greater
  - B) slightly greater
  - C) less
  - D) exactly the same, since the speed of light cannot vary

Light gathering power



Small-diameter objective lens: dimmer image, less detail

Large-diameter objective lens: brighter image, more detail

Figure 6-6
Universe, Eighth Edition

Light gathering power depends on size of mirror or lens

The largest amateur telescopes have primary mirrors about ½ meter in diameter. The largest professional optical telescopes have a primary mirror about 10m in diameter. How much more light gathering power does the 10m telescope have?

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.

Reflection Telescopes

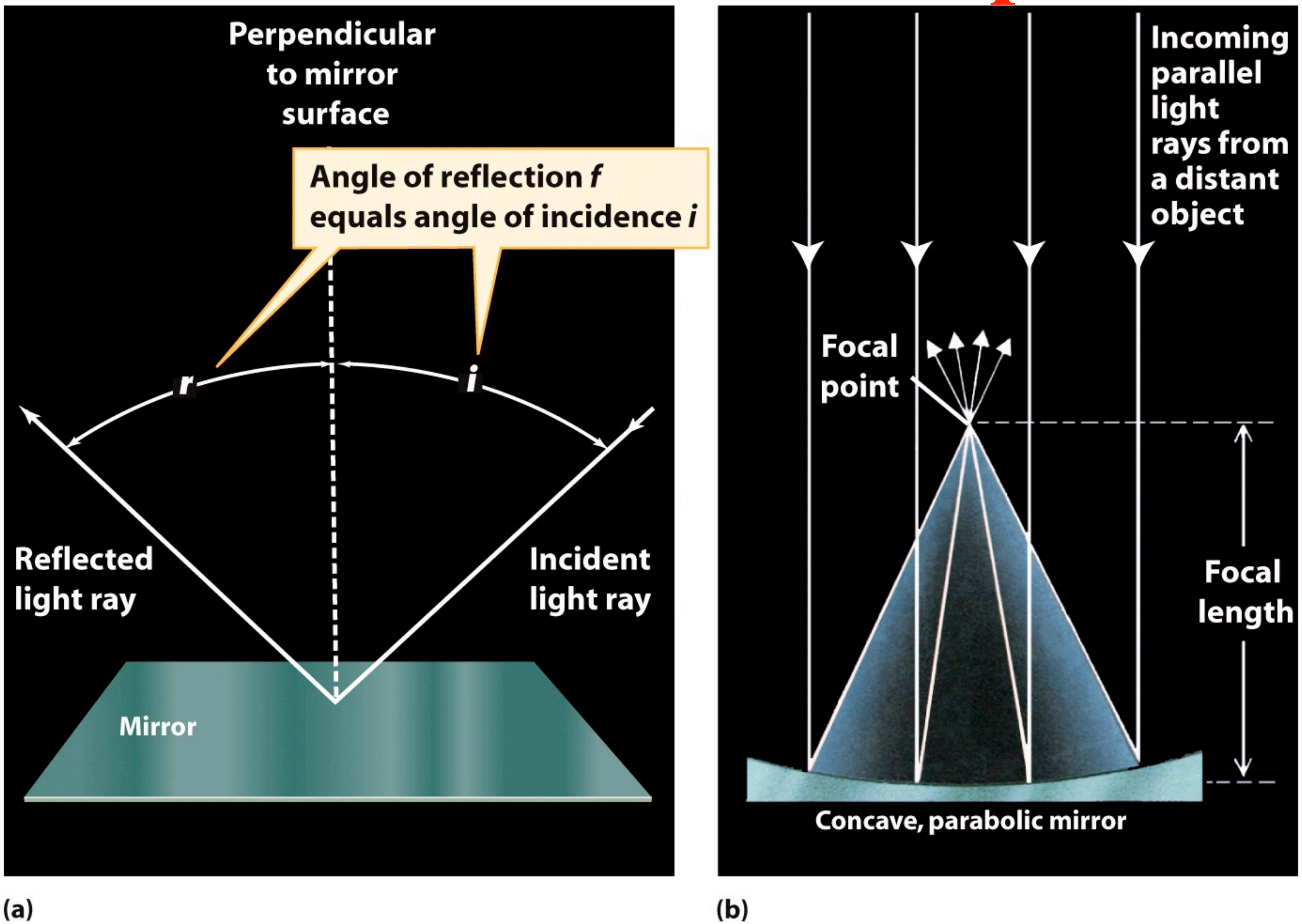


Figure 6-9
Universe, Eighth Edition

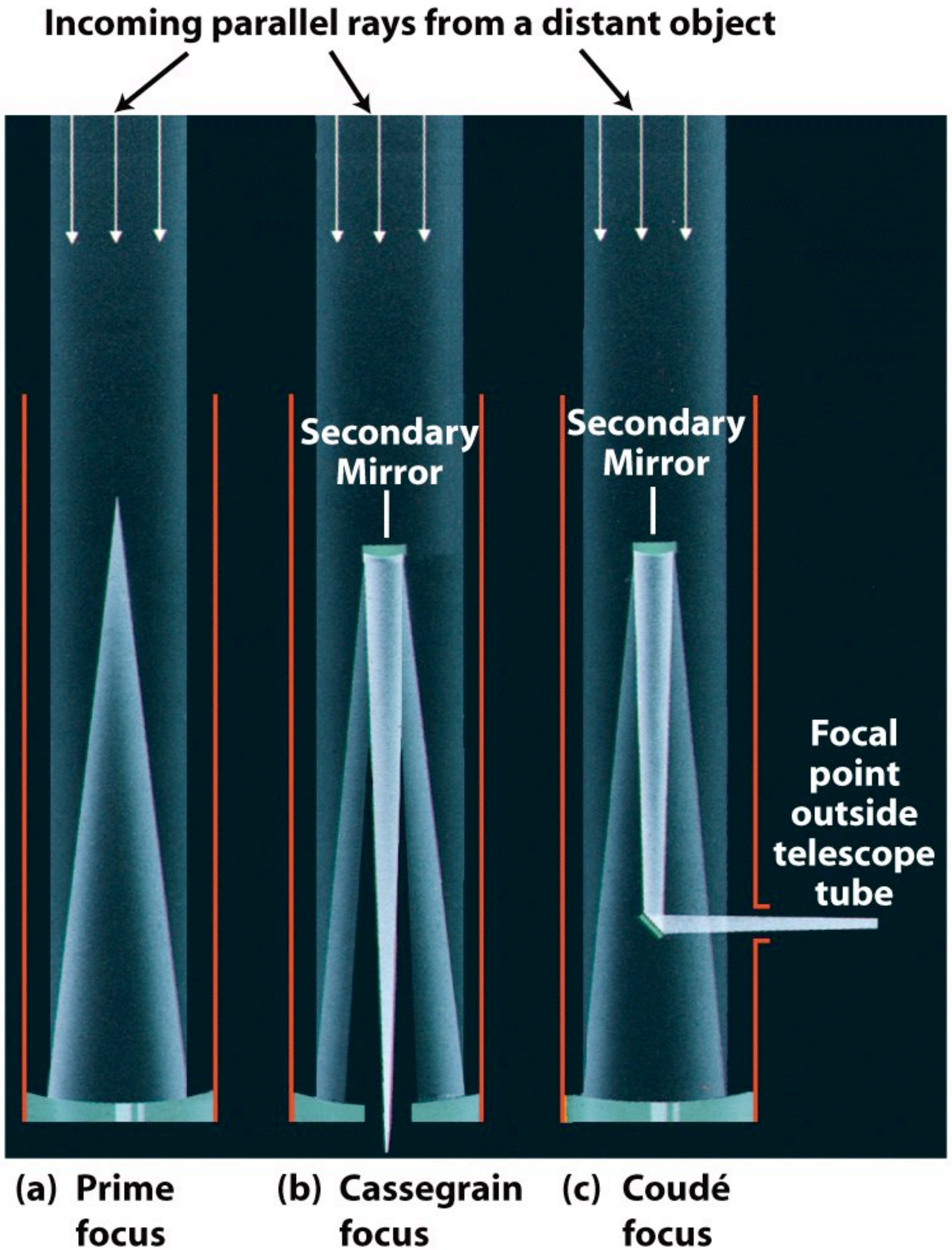


Figure 6-11
Universe, Eighth Edition

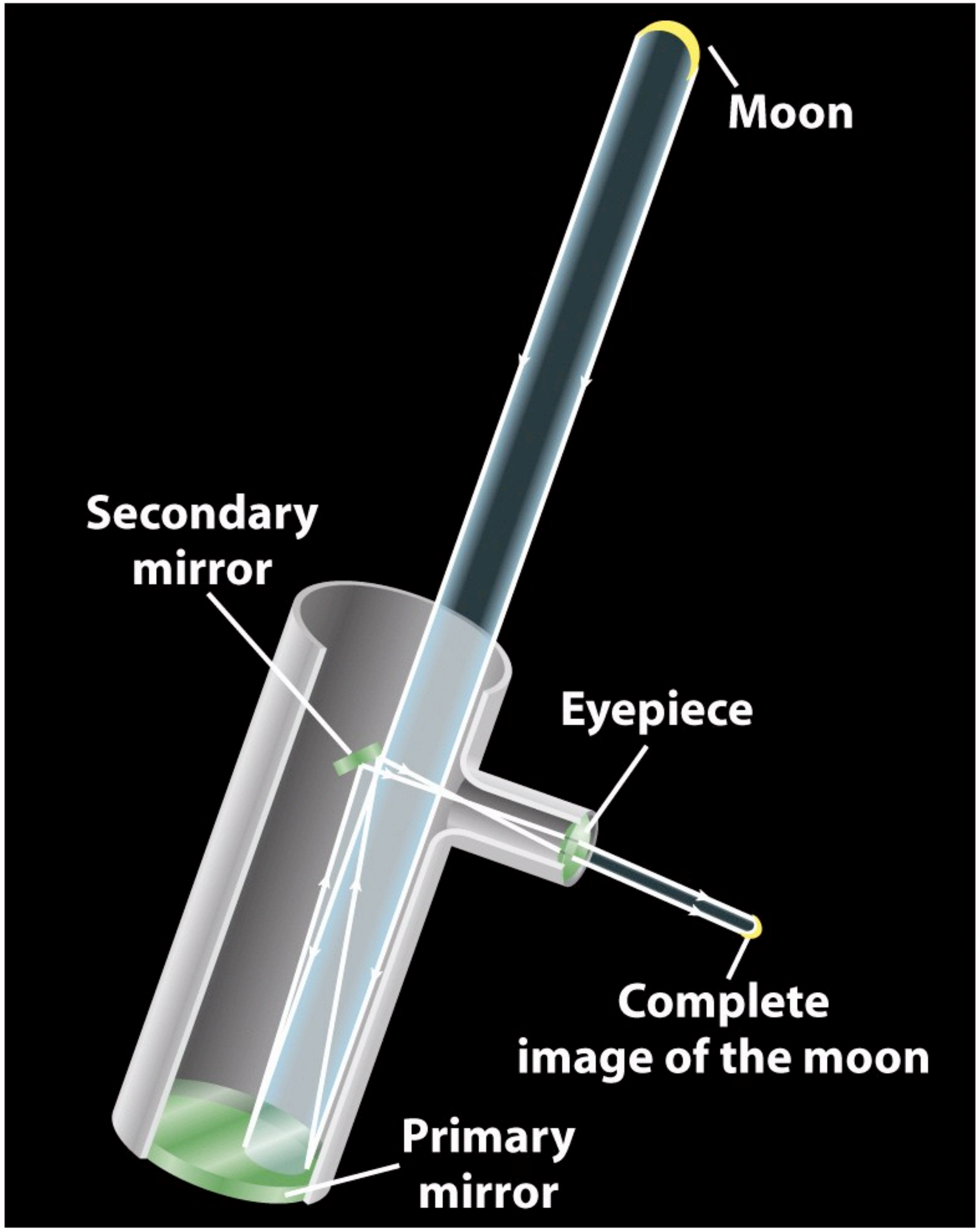
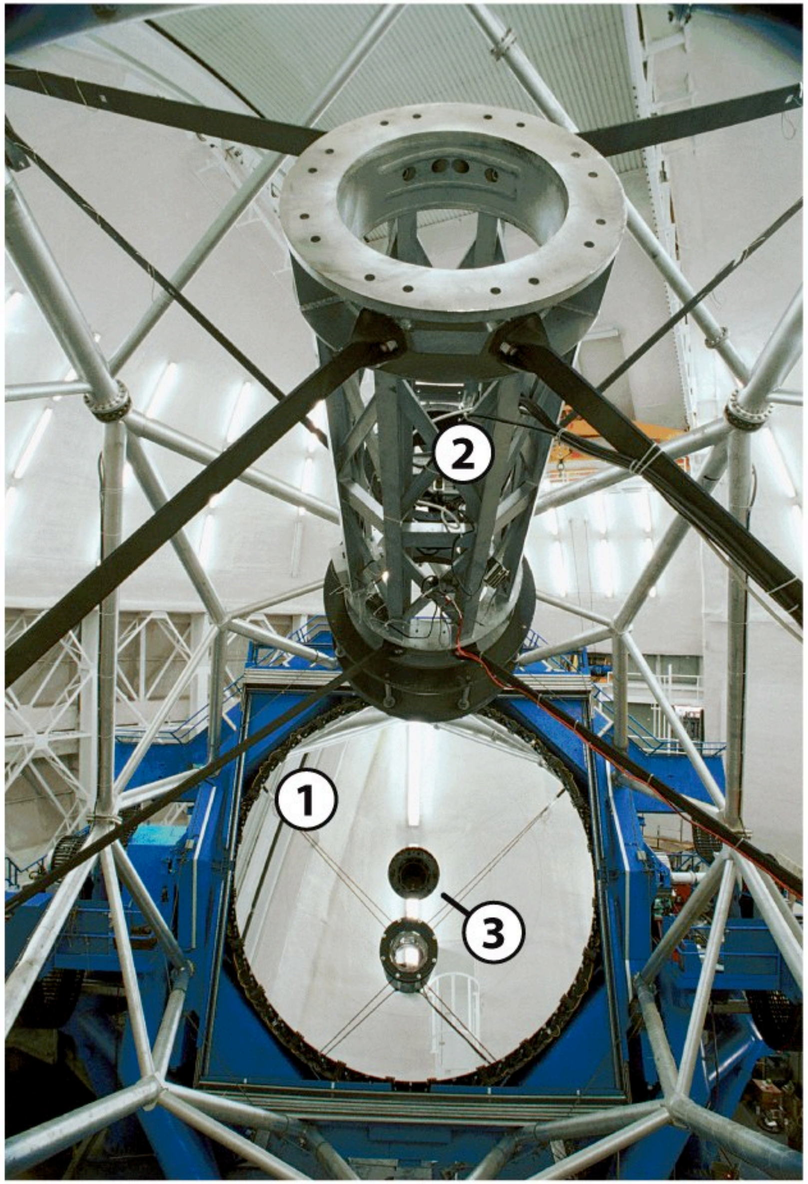


Figure 6-12
Universe, Eighth Edition

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.)



A large Cassegrain telescope

Figure 6-14b
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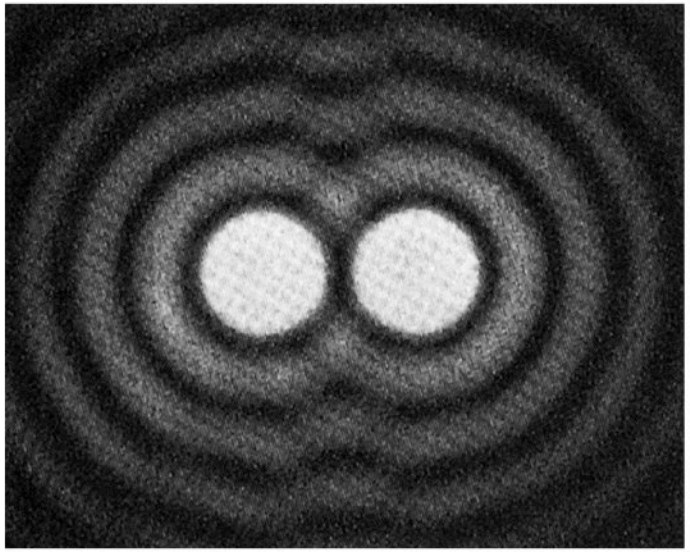
Reflecting Telescopes

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

Question 9.3 (iclickers!)

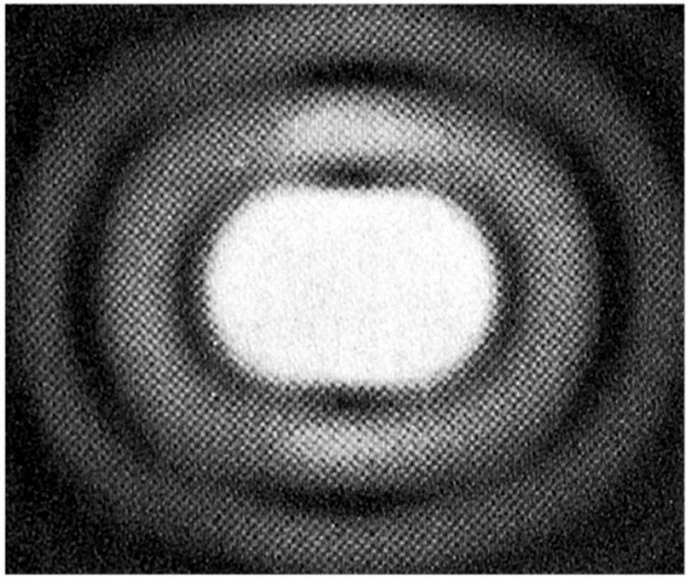
- The light gathering power of a telescope is related directly to the
  - A) image quality of its optics
  - B) area of its primary mirror or lens
  - C) focal length of its primary mirror or lens
  - D) ratio of the focal lenghts of its primary element and its eyepiece

Angular Resolution



(a)

Two light sources with angular separation greater than angular resolution of telescope: Two sources easily distinguished



(b)

Light sources moved closer so that angular separation equals angular resolution of telescope: Just barely possible to tell that there are two sources

Figure 6-15
Universe, Eighth Edition

Angular resolution of the telescope

Limited by:

- Blurring effects of the atmosphere ("seeing"), i.e. the twinking of stars

- The quality of the optics and detector on the telescope.

- The size of the telescope – the "diffraction limit."

The diffraction limit

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

θ= diffraction-limited angular resolution of the telescope, in arcseconds
λ= wavelength of light, in meters
D = diameter of telescope objective, in meters

Example: What is the diffraction limit for red light (640nm=6.4×10^{-7}m) for a telescope with with a 0.5m objective/primary.

$$\theta = 2.5 \times 10^5 \frac{\lambda}{\mathrm{D}} = 2.5 \times 10^5 \frac{6.4 \times 10^{-7} m}{0.5\mathrm{m}} = 0.32''$$

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.

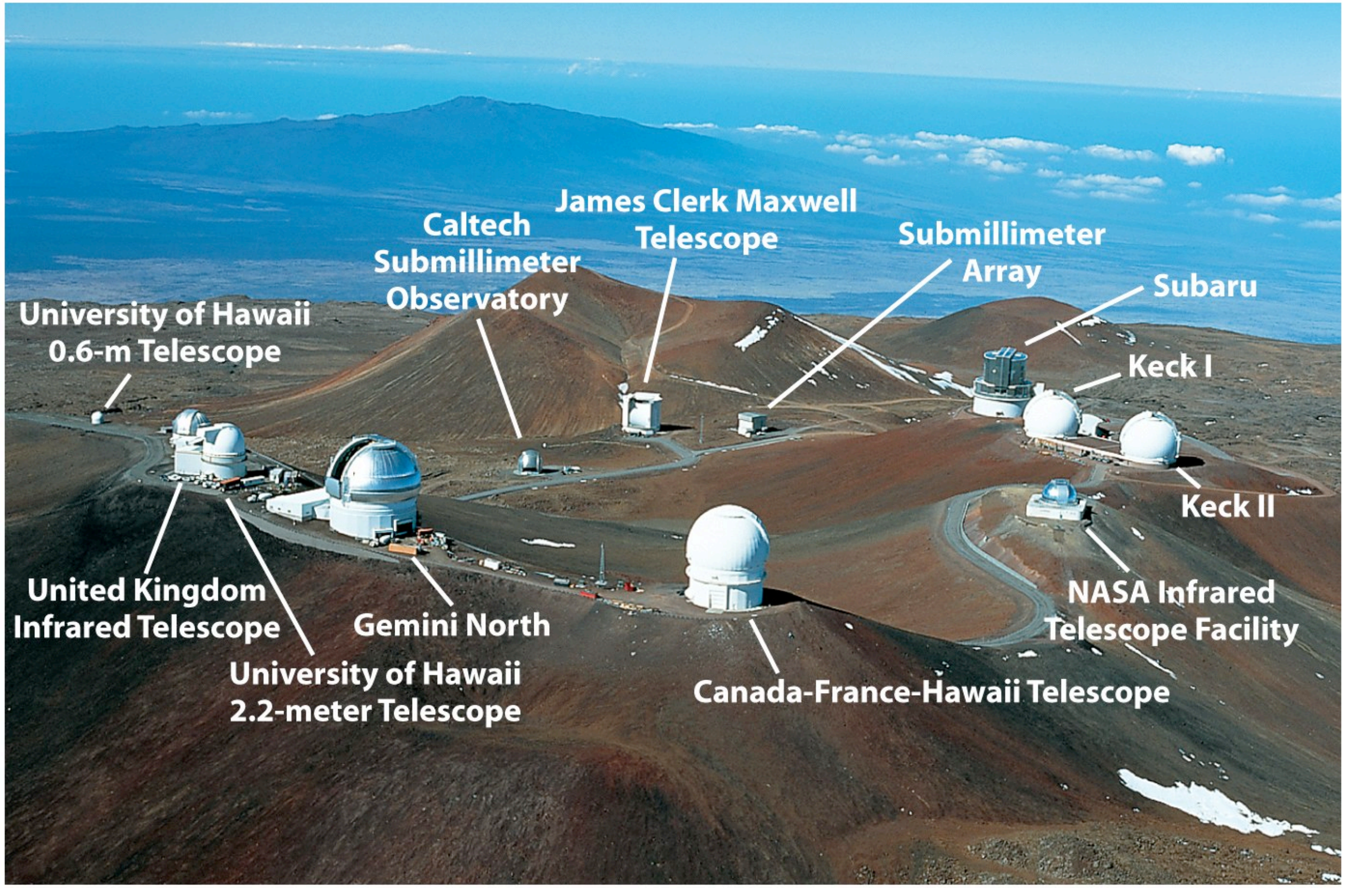


Figure 6-16
Universe, Eighth Edition

Today astronomers build telescopes at the best sites in the world, then travel to the telescope to observe, or have someone else on-site observe for them, 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.

Laser guide star adaptive optics

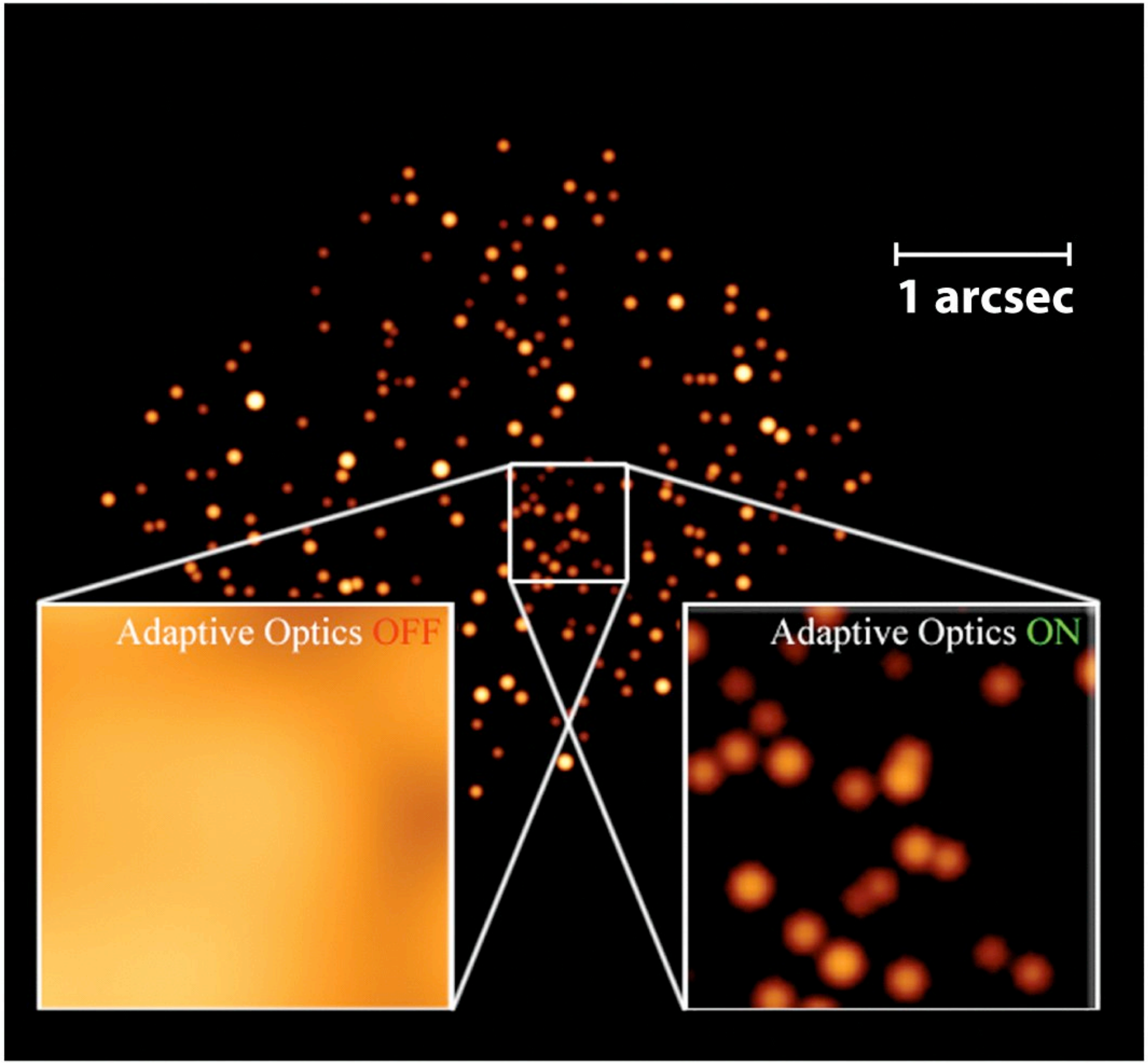


Figure 6-18
Universe, Eighth Edition

Light pollution

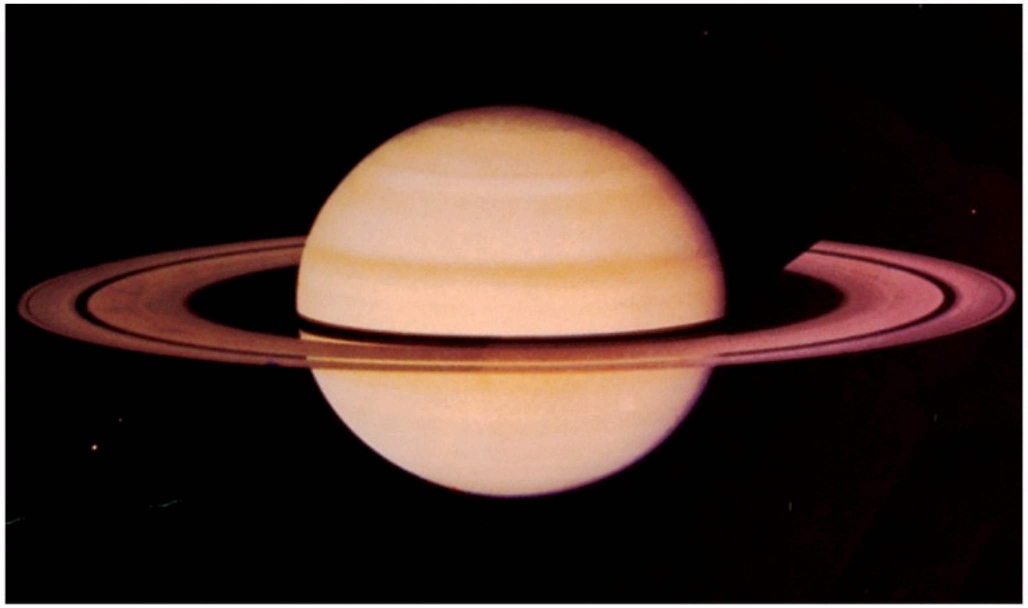
Figure 6-22
Universe, Eighth Edition

A Radio Telescope
The dish of the Parkes radio telescope in New South Wales, Australia, is 64 m (210 ft) in diameter. Radio waves reflected from the dish are brought to a focus and collected by an antenna at the focal point.

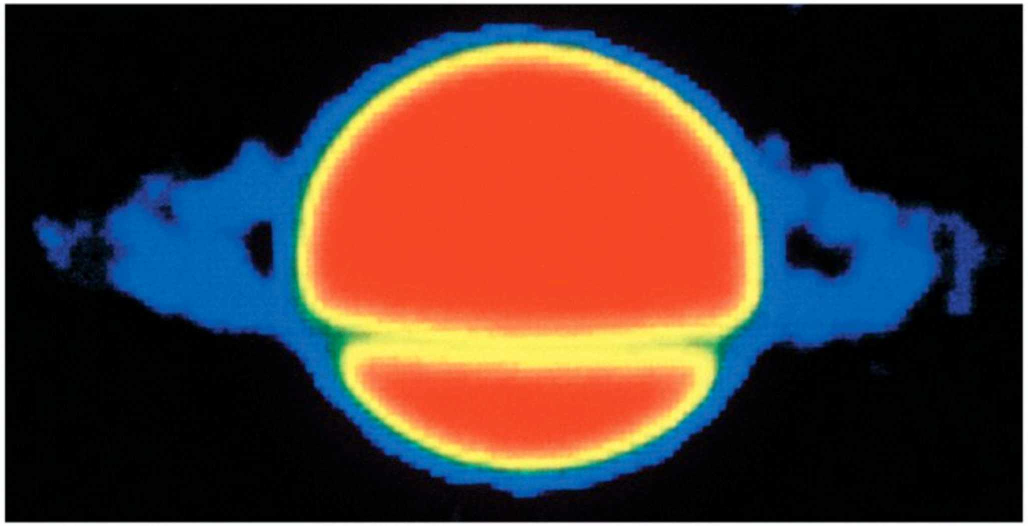
Arecibo

Very Large Array

Figure 6-23
Universe, Eighth Edition



(a)



(b)

Figure 6-24
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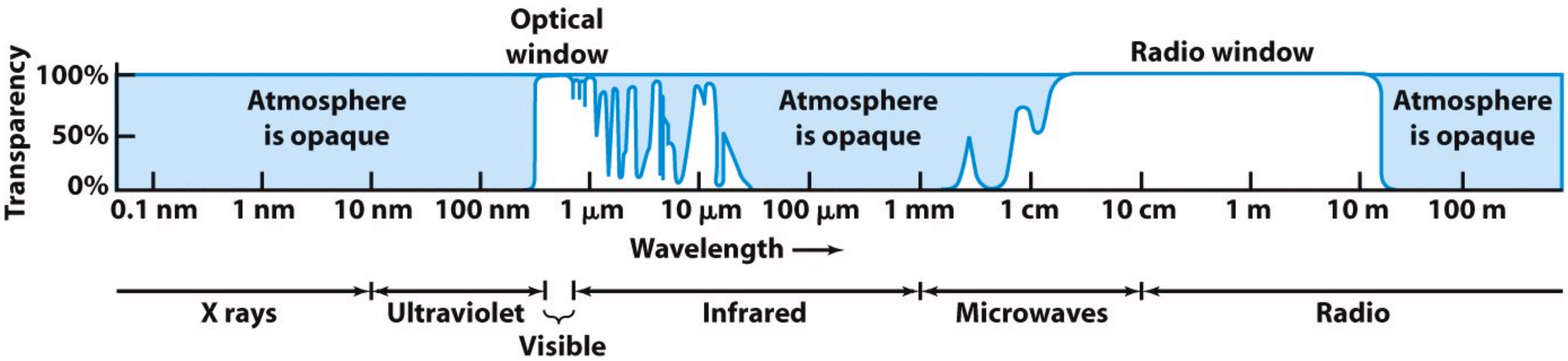

Figure 6-25
Universe, Eighth Edition

The percentage of radiation that can penetrate the Earth's atmosphere at different wavelengths. Regions in which the curve is high are called "windows," because the atmosphere is relatively transparent at those wavelengths. There are also three wavelength ranges in which the atmosphere is opaque and the curve is near zero: at wavelengths less than about 290 nm, which are absorbed by atmospheric oxygen and nitrogen; between the optical and radio windows, due to absorption by water vapor and carbon dioxide; and at wavelengths longer than about 20 m, which are reflected back into space by ionized gases in the upper atmosphere.

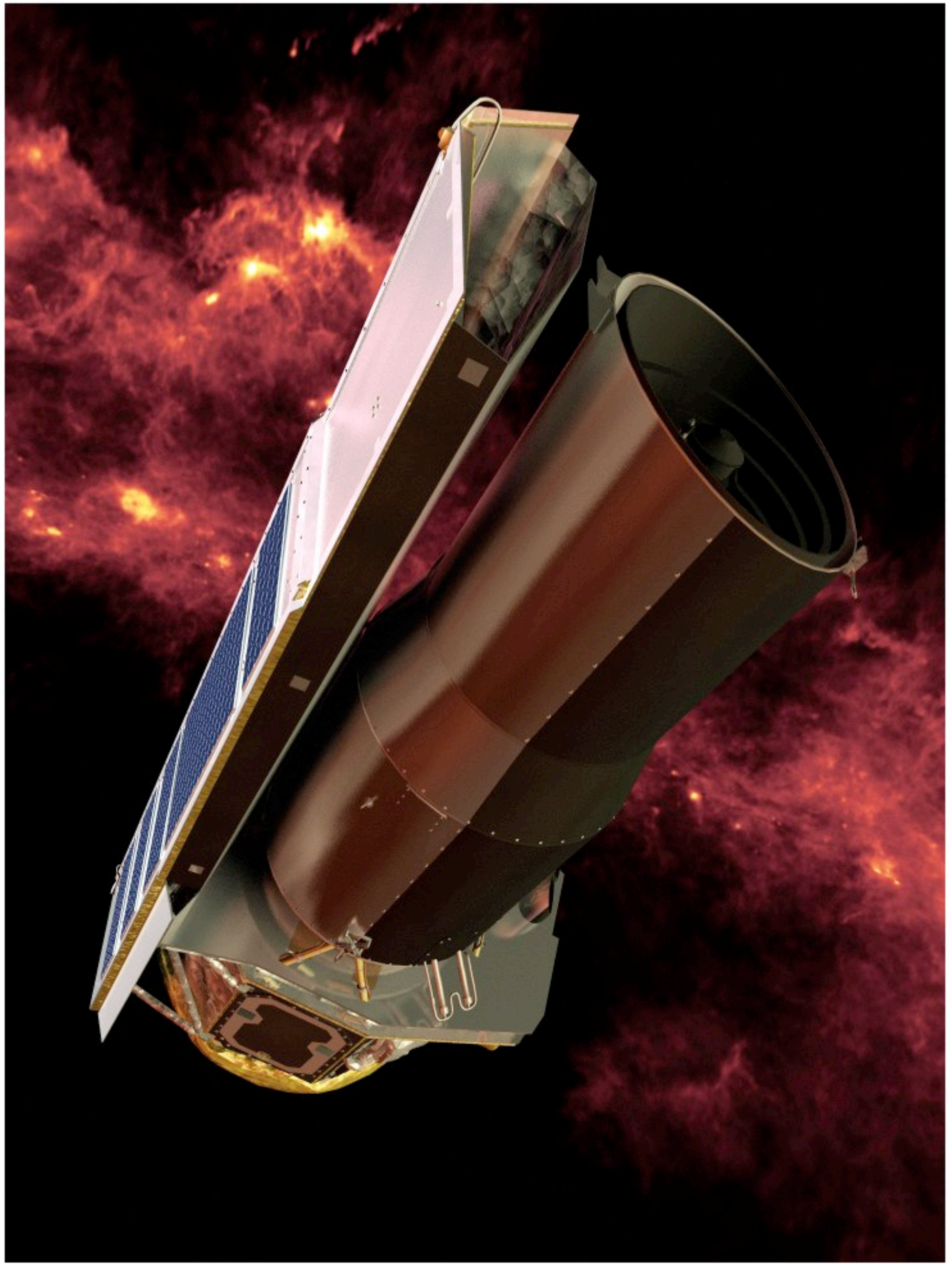

Figure 6-26
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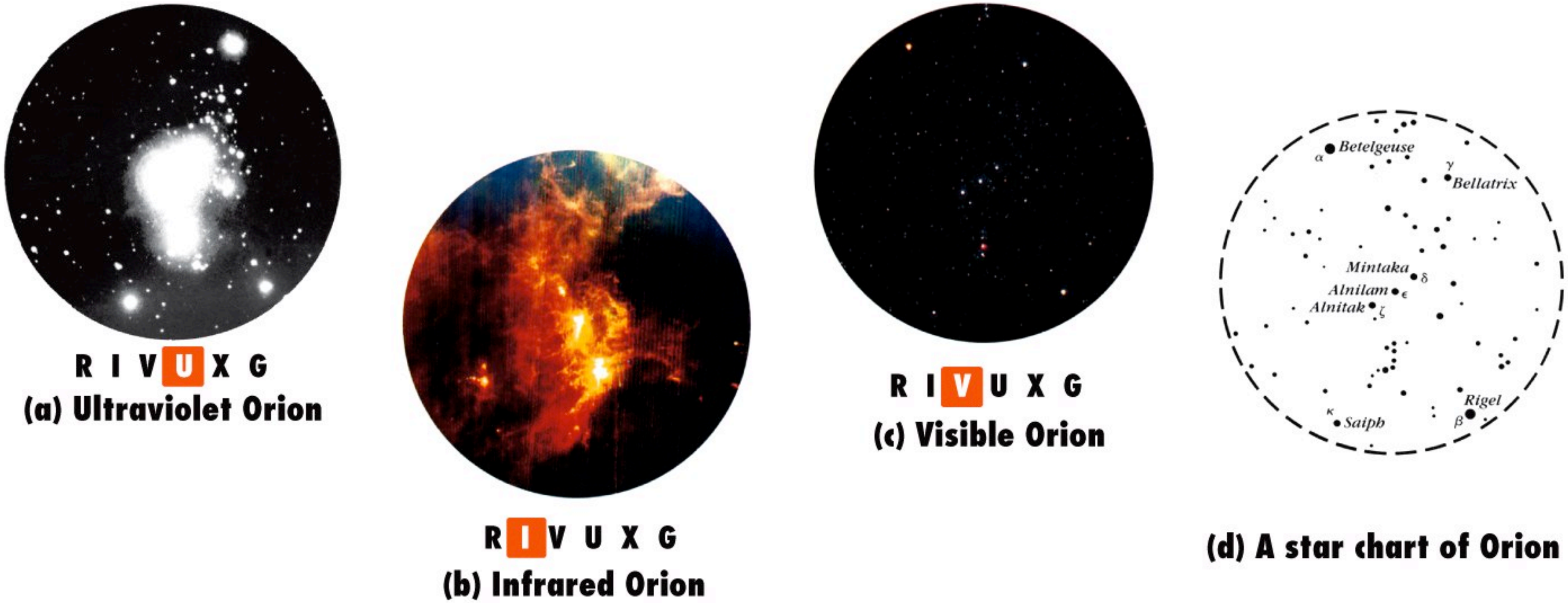

Figure 6-27
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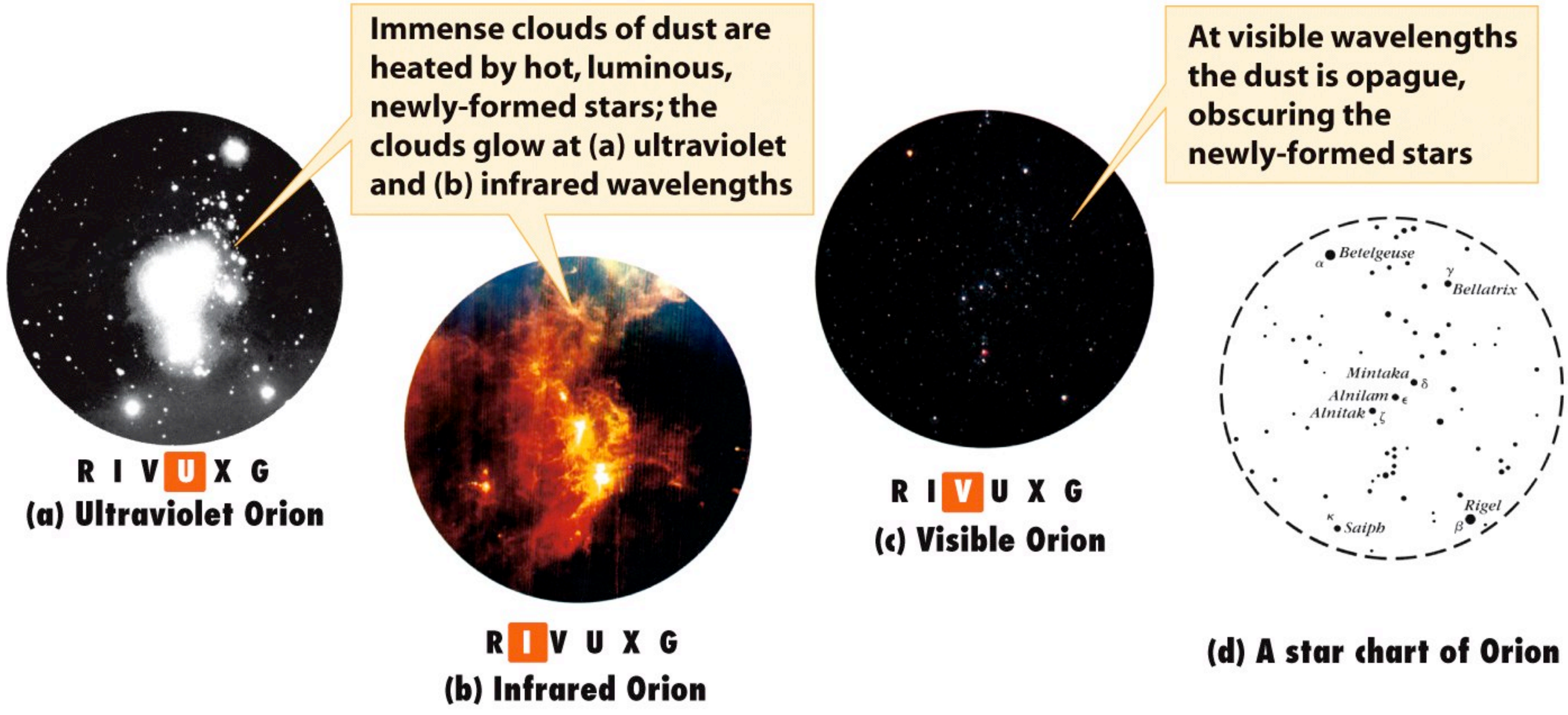

Figure 6-27
Universe, Eighth Edition

Hubble Space Telescope

Figure 6-28
Universe, Eighth Edition

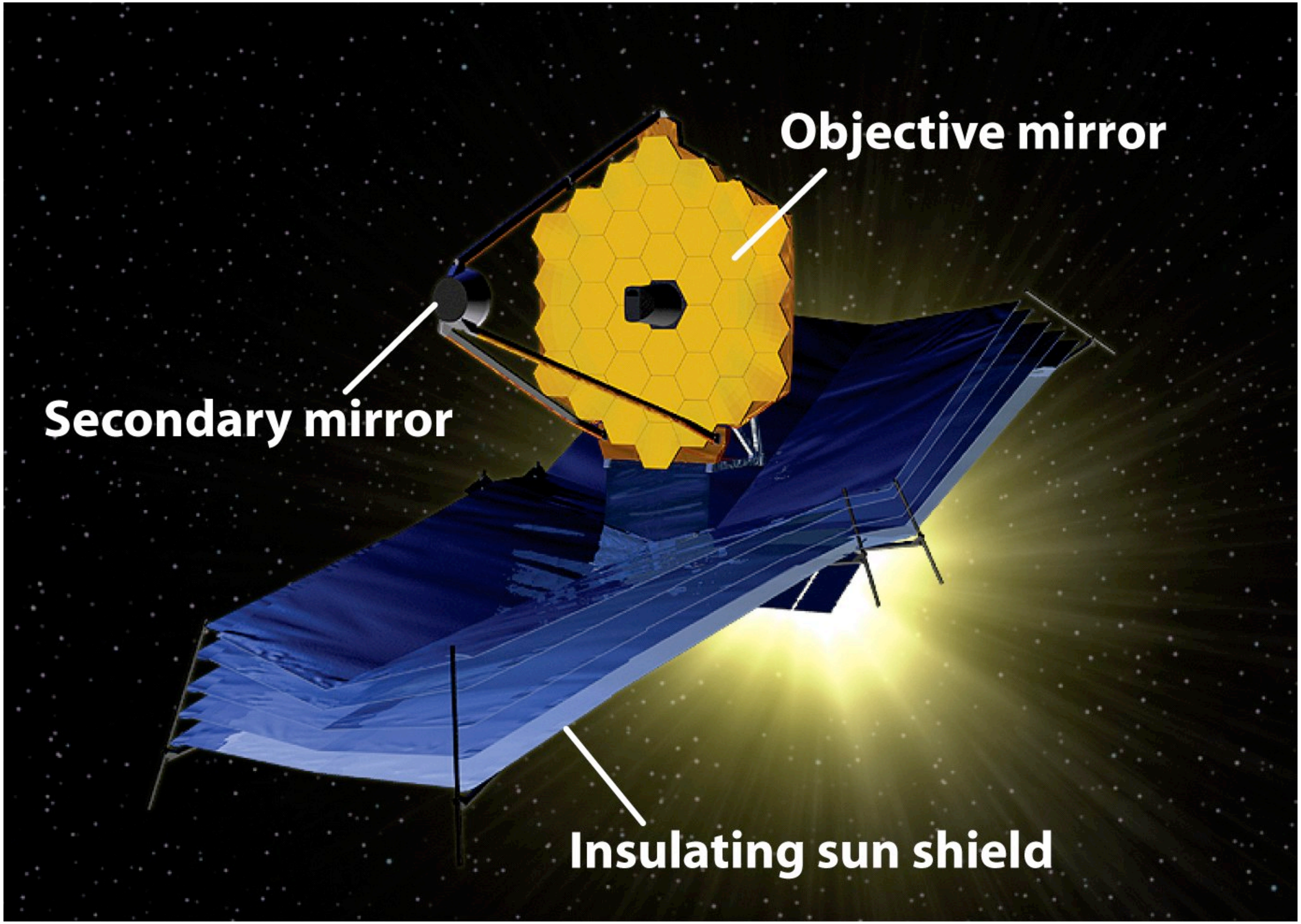

Figure 6-29
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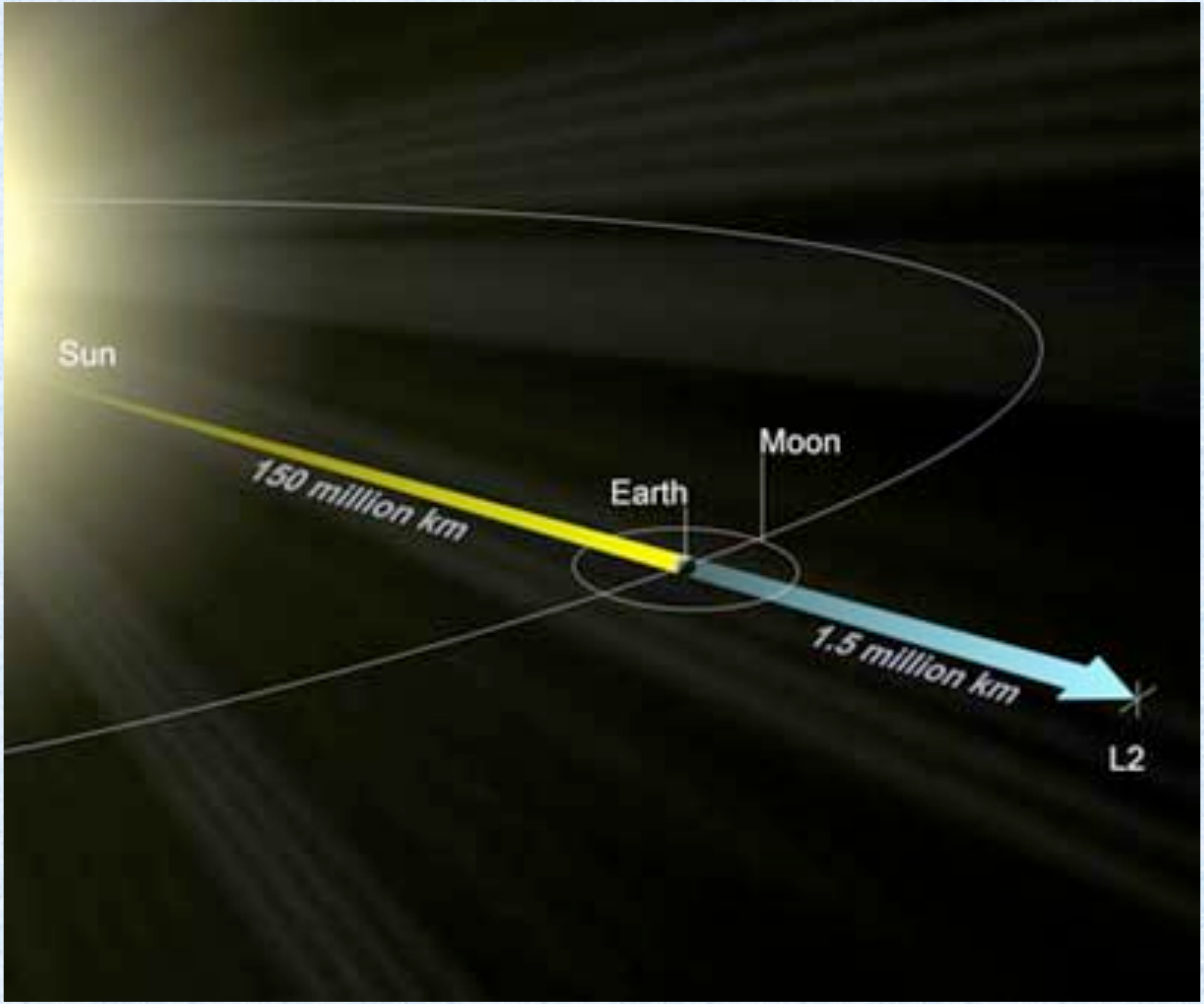
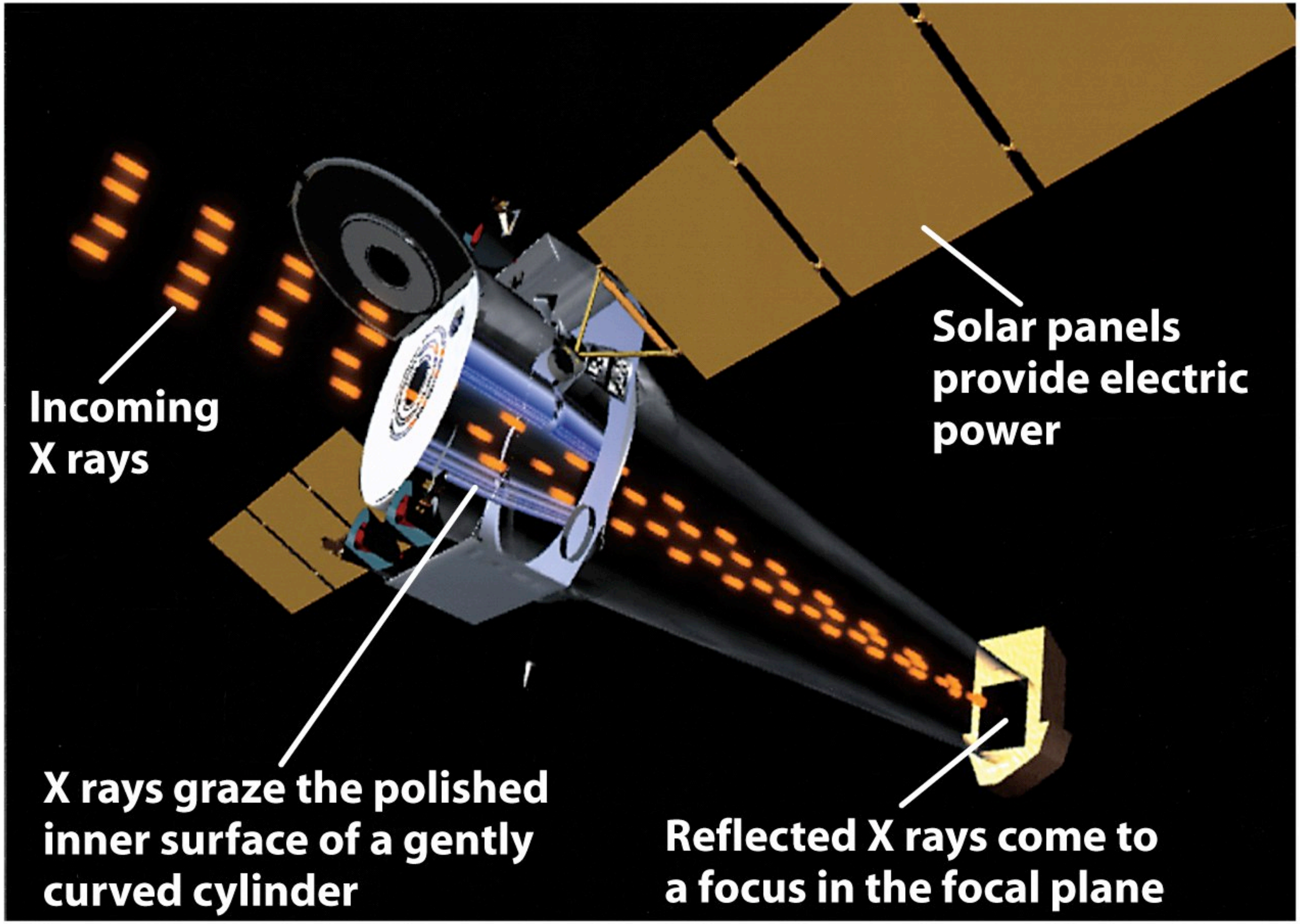

Sun
150 million km
Earth
Moon
1.5 million km
L2



Chandra X-ray Observatory

Figure 6-30a
Universe, Eighth Edition

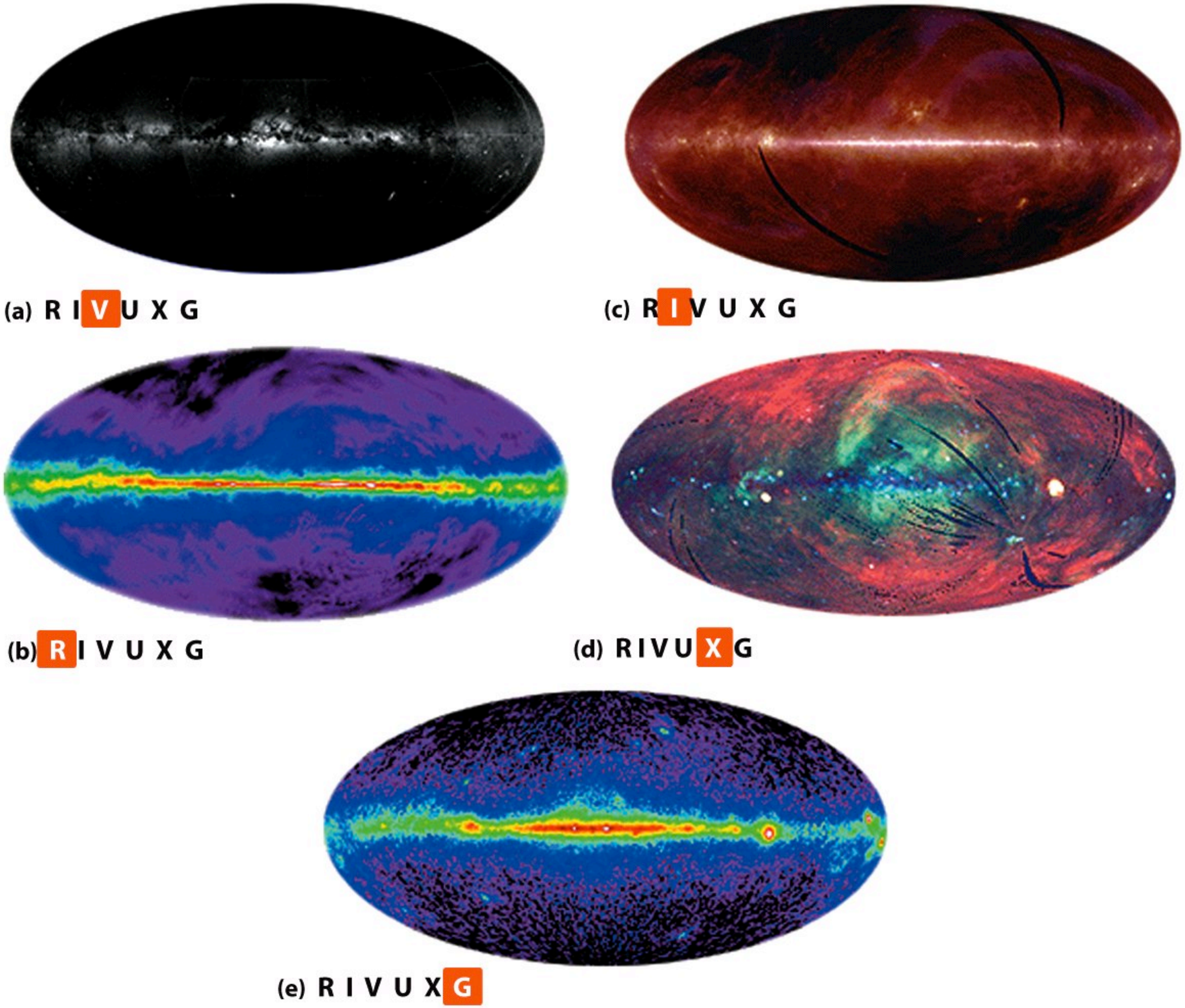
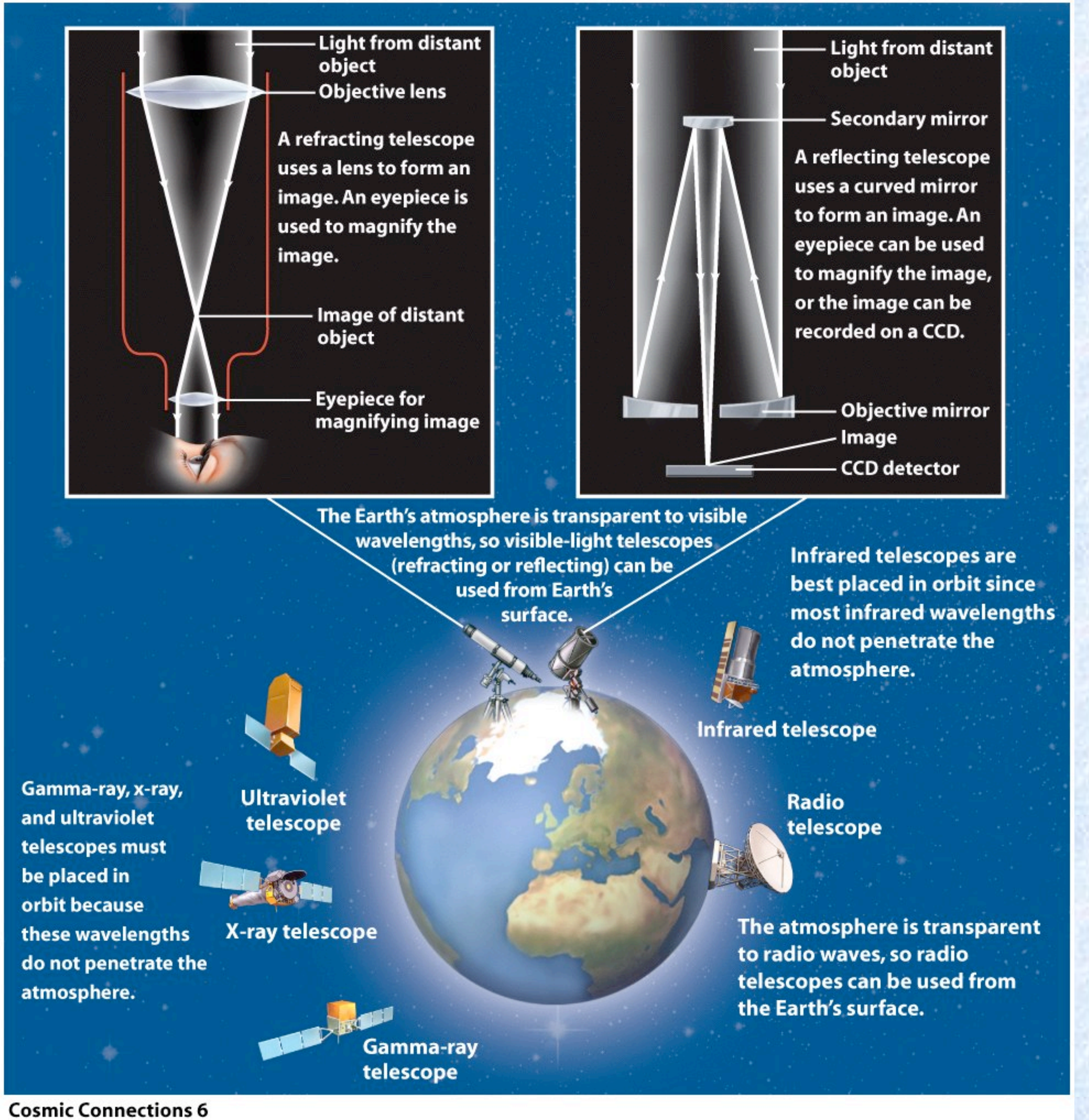


Figure 6-32
Universe, Eighth Edition



Cosmic Connections 6
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Importance of the telescope

‘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’)

Discovery	Enabled by	Year
The heavens are not perfect and unchanging; (ultimately) the Earth is not the center of the universe.	The telescope and Galileo's observations.	~1609
The sun and stars are giant balls of hydrogen undergoing fusion.	Fraunhofer's invention of the spectrograph.	1814
Our galaxy is not the center of the universe, and the universe is expanding.	Edwin Hubble and the giant Palomar 200-inch and large-format photographic plates.	1929
The universe started as a hot "Big Bang"	Penzias and Wilson using a radio "telescope," confirmed by satellites.	1965
Planets are common in the universe.	Modern charge-couple-device detectors (CCD); Iodine cell for spectrograph.	1995
Dark Energy dominates the universe.	Large-format CCD detectors; 10m Keck telescope.	1998

And there are many more involving infrared,
x-ray, ultraviolet and gamma-ray discoveries.

Summary

- **A most valuable tool: the Doppler effect**
  - **The discovery of extrasolar planets**
- **Telescopes: astronomers' tools of the trade**
  - Basic optics
  - Refractors
  - Reflectors
  - Light gathering power and resolution
- **Telescopes and the atmosphere**
  - Space Telescopes

The End

See you on Friday!