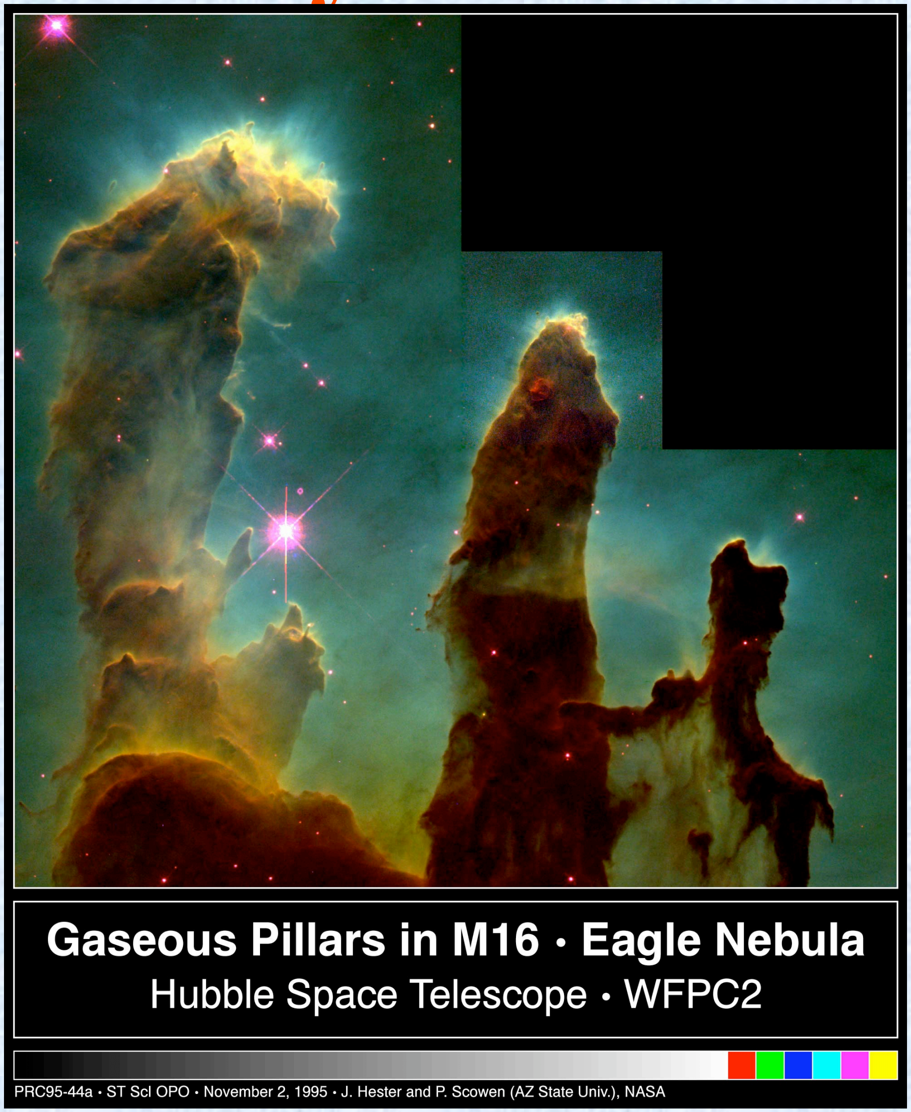
Astronomy 1 – Winter 2011



Lecture 23; March 4 2011

Previously on Astro-1

- **The late stages of stellar evolution**
- **Stellar afterlife**
  - Intermediate mass stars
  - High mass stars

Stargazing Events

- March 7/8
- 2% credit, first come first served basis, registration closes today. The TAs will let you know when/if you got in. Write ASTRO1 stargazing in the subject
- 2% Penalty if you register and don't show up!
- Bring warm clothes, and binoculars if you have them
- Meet in the lobby of Broida at 7PM
- Will let you know on Monday during lecture if weather is ok

Unregistered iclickers

- 060D060D
- 06EE23CB
- 07CFDF17
- 0959D383
- 0E2DF8DB
- 0E8A30B4
- 10067167
- 105FD29D
- 1A3B1031
- 1D1EFBF8
- 1D3DE7C7
- 1F80C45B

Today on Astro-1

- **Introduction to special relativity**
- **Introduction to general relativity**
- **Introduction to black holes, stellar and supermassive**

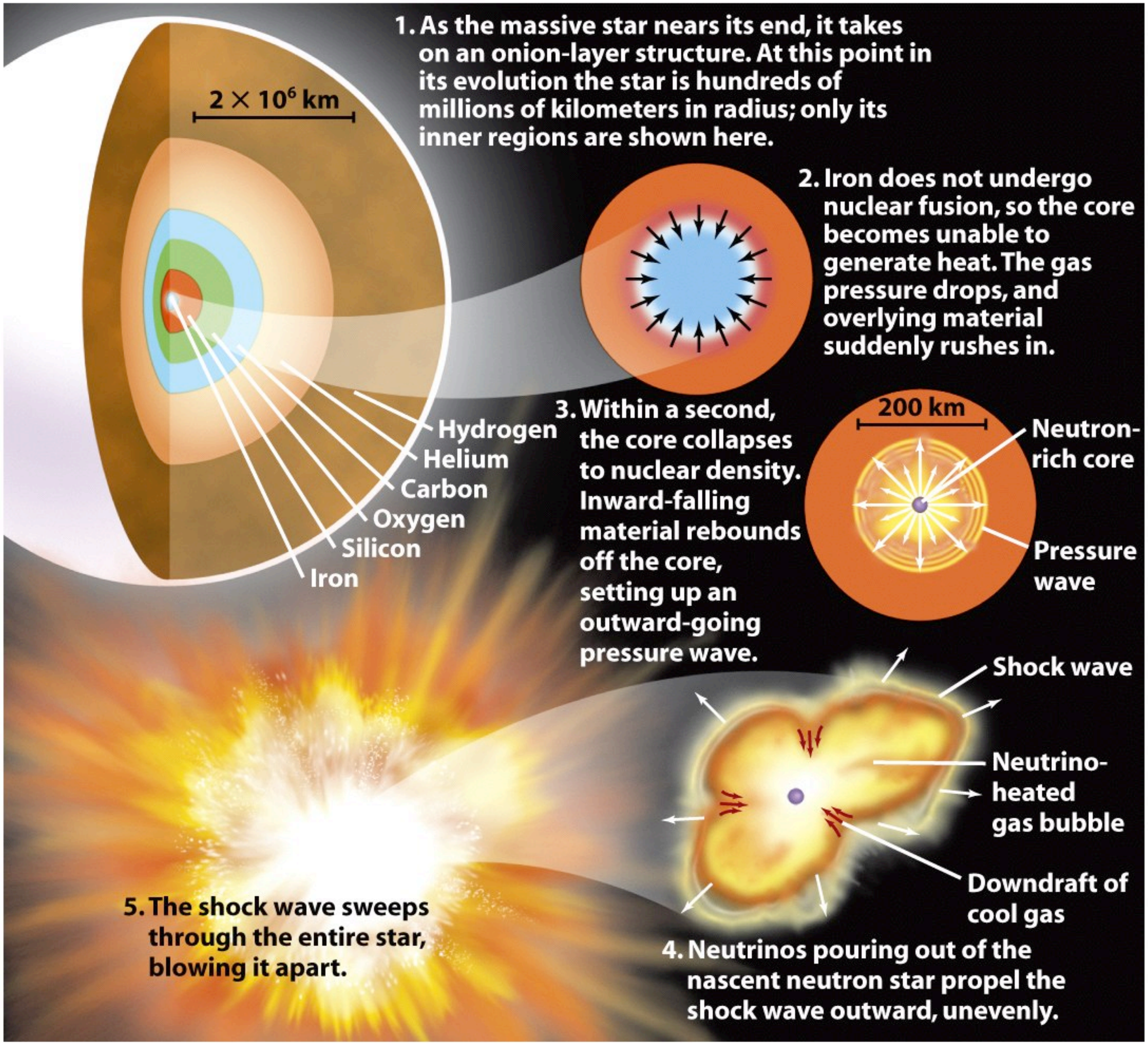


Figure 20-14
Universe, Eighth Edition

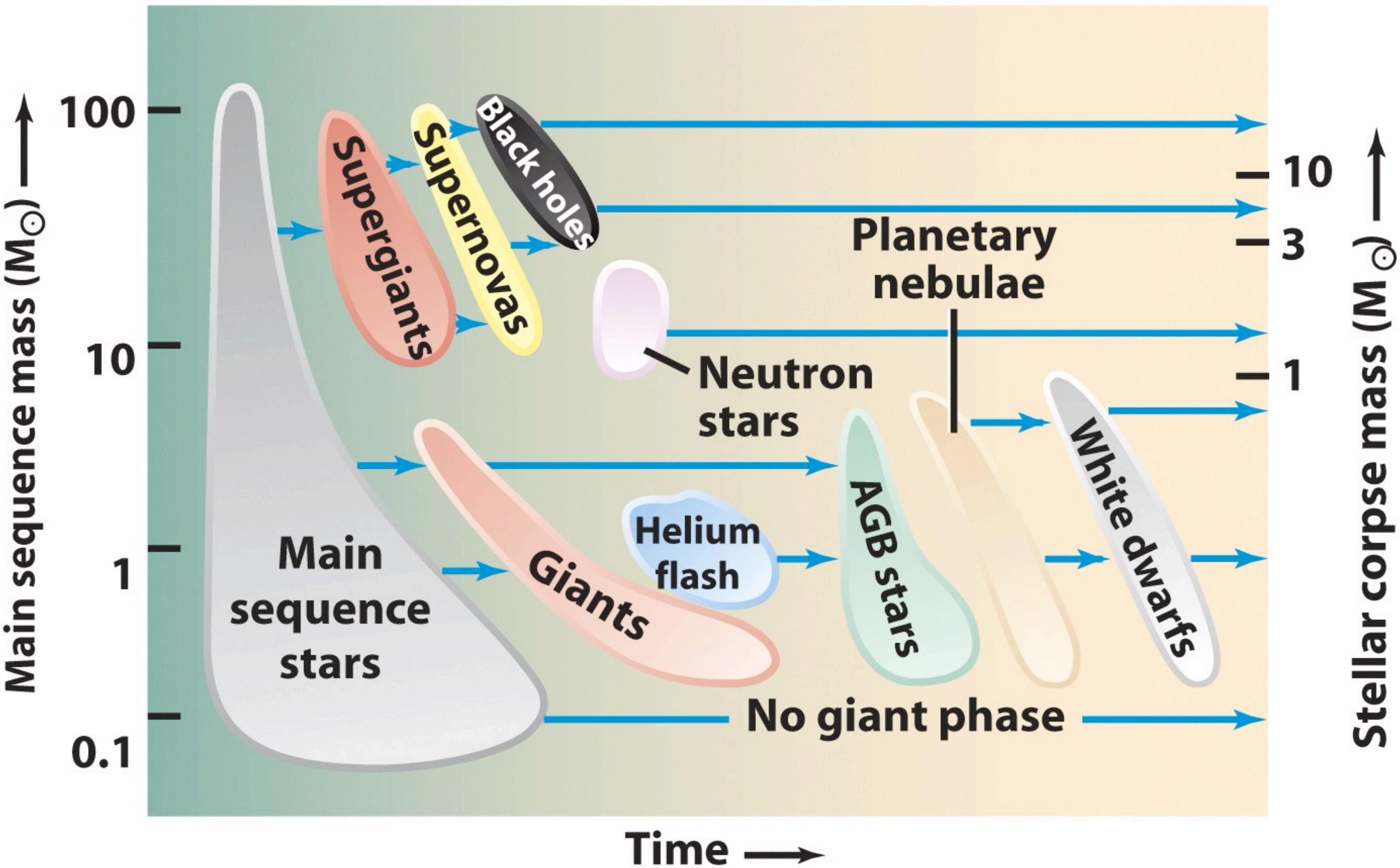


Figure 20-26a
Universe, Eighth Edition

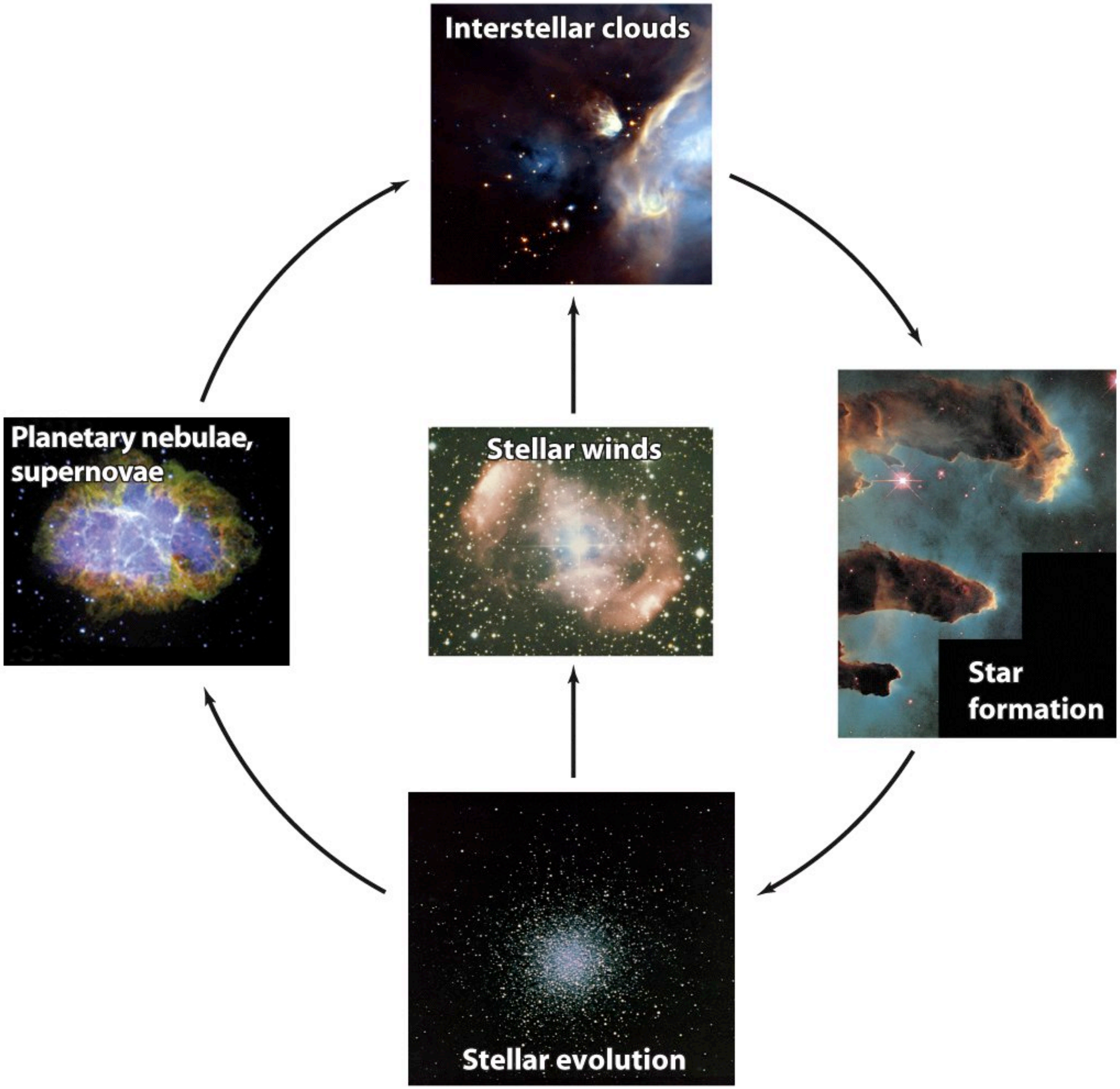


Figure 20-26b
Universe, Eighth Edition

Introduction to special relativity

Einstein's special theory of relativity (1905)

Einstein in 1905

Einstein's special theory of relativity (1905)

1. No matter what your constant velocity, the laws of physics are the same.

Einstein in 1905

Einstein's special theory of relativity (1905)

1. No matter what your constant velocity, the laws of physics are the same.
2. No matter what your constant velocity, the speed of light in a vacuum is the same

Einstein in 1905

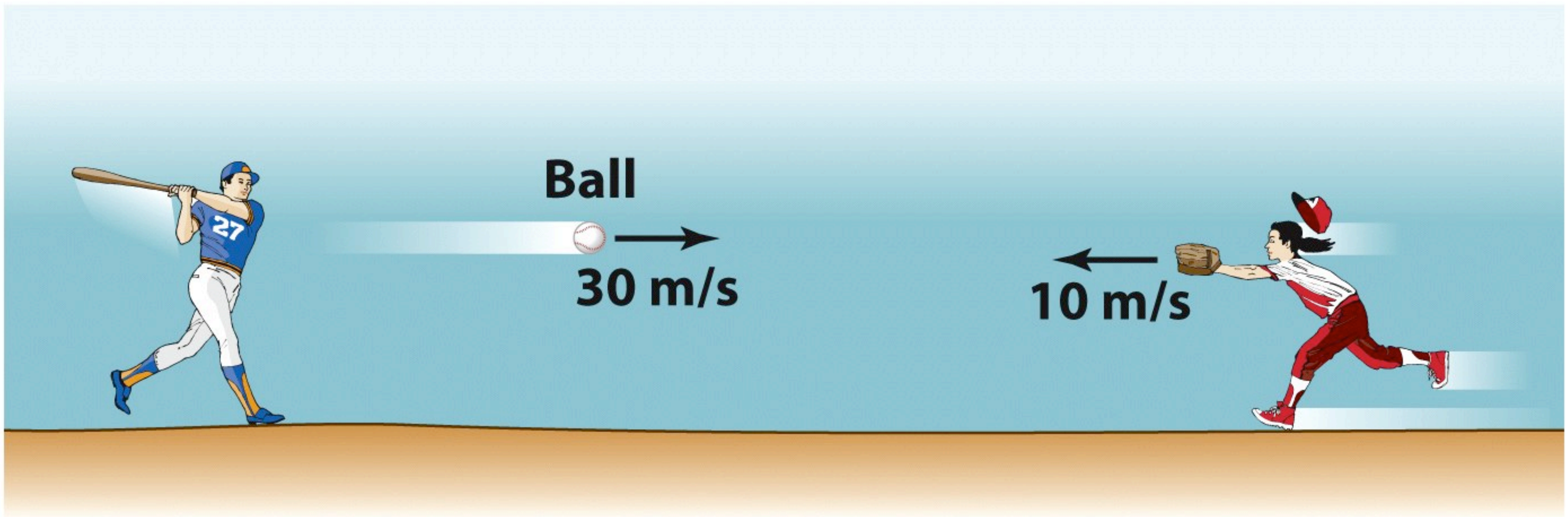


Figure 22-1a
Universe, Eighth Edition

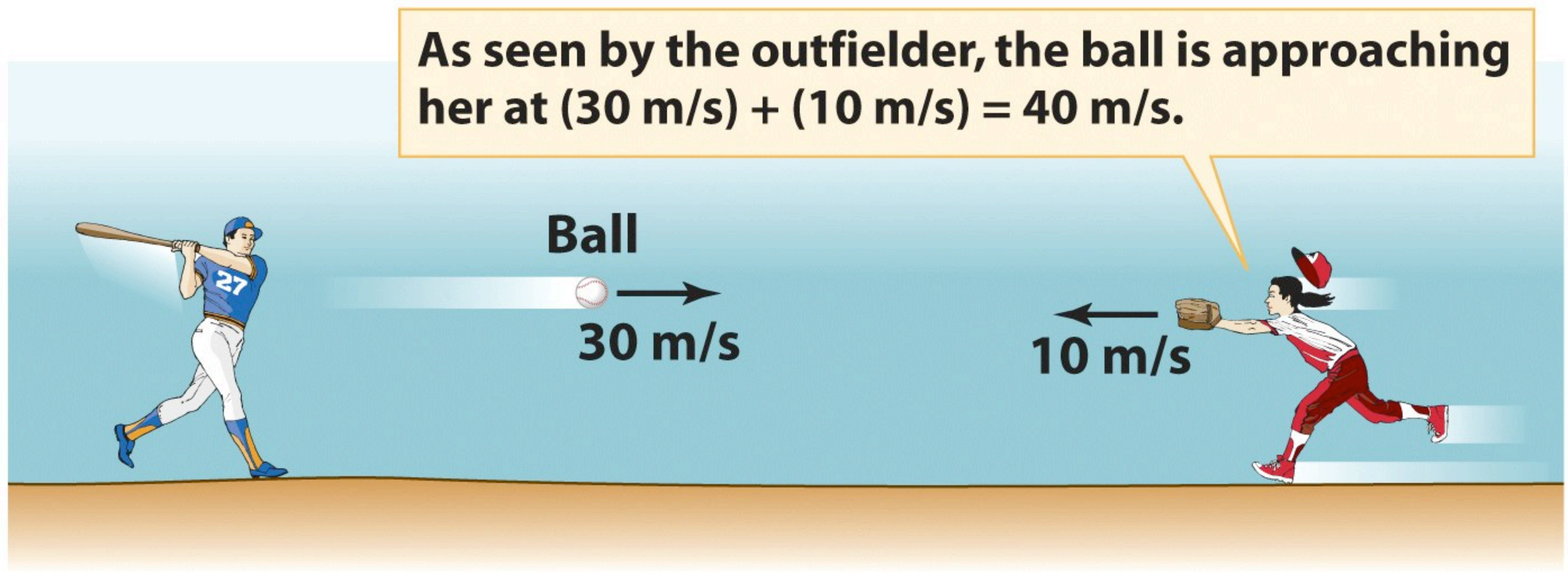


Figure 22-1a
Universe, Eighth Edition

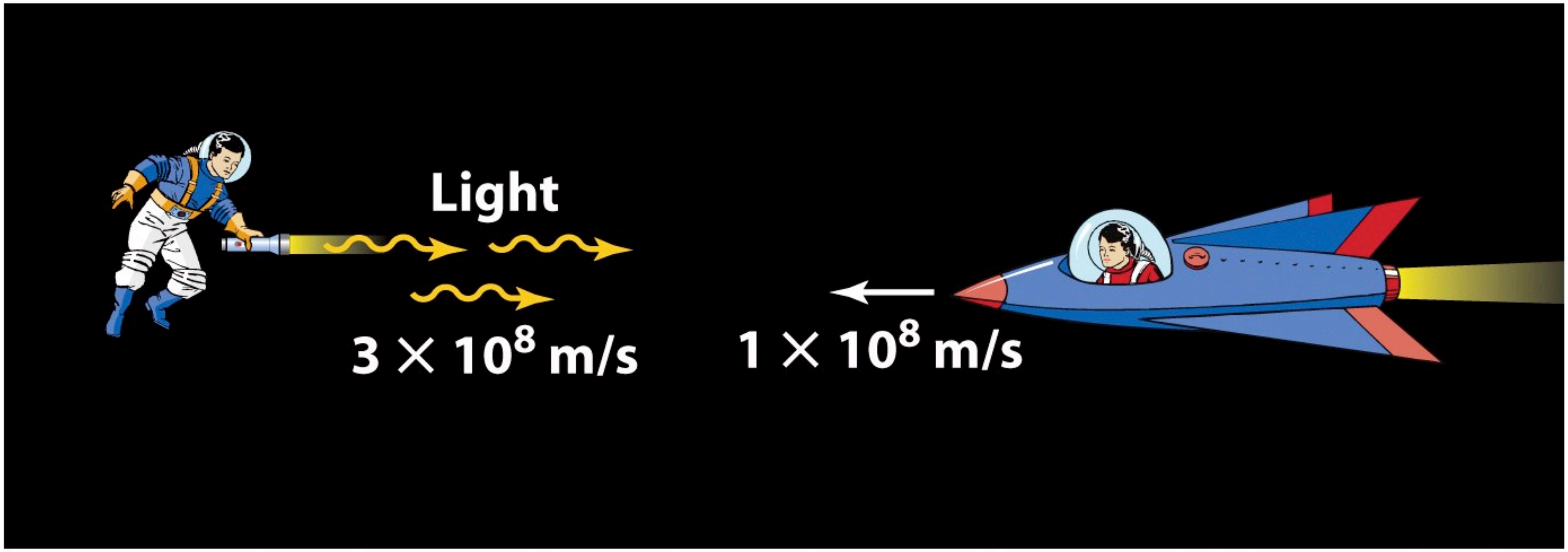


Figure 22-1b
Universe, Eighth Edition

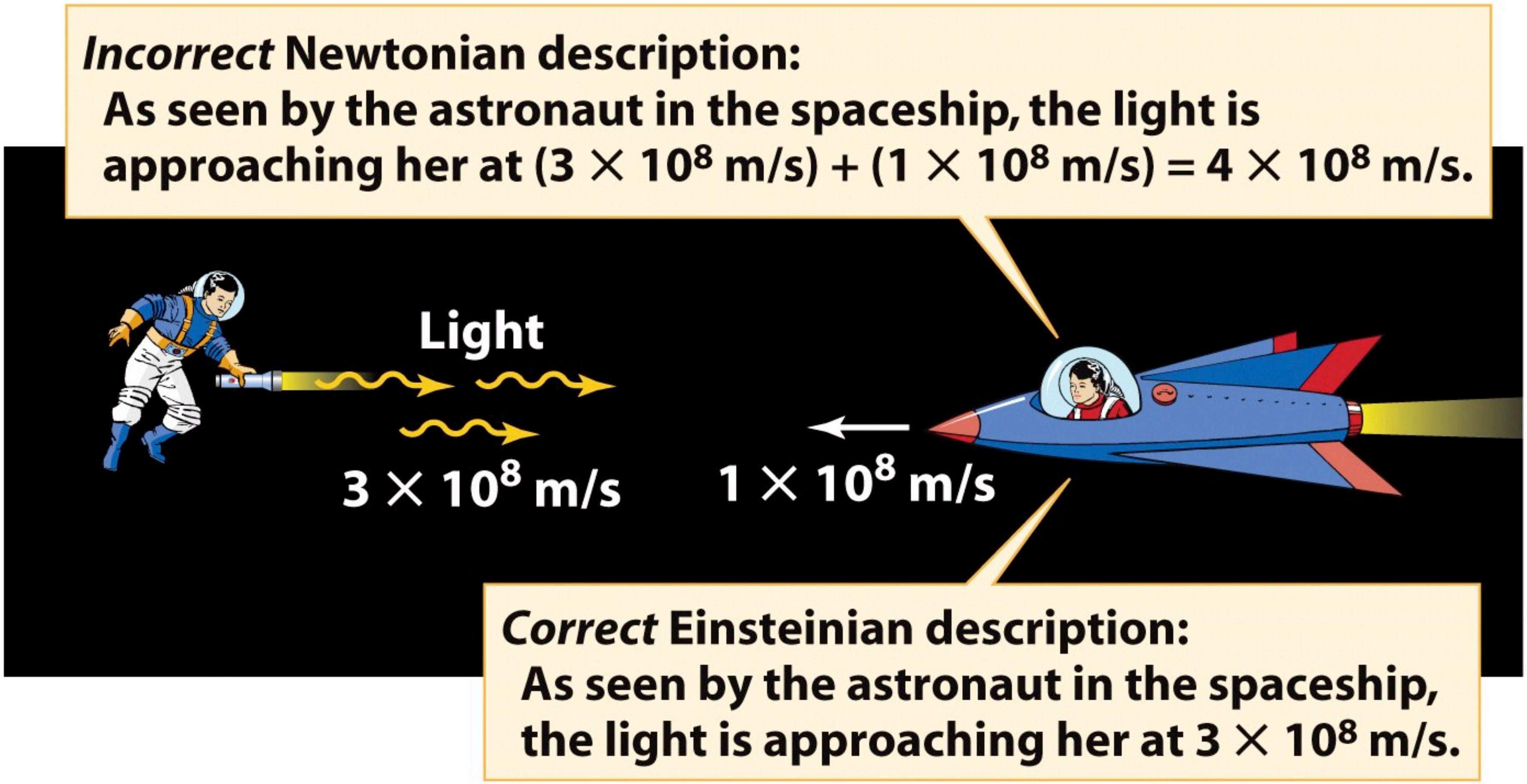


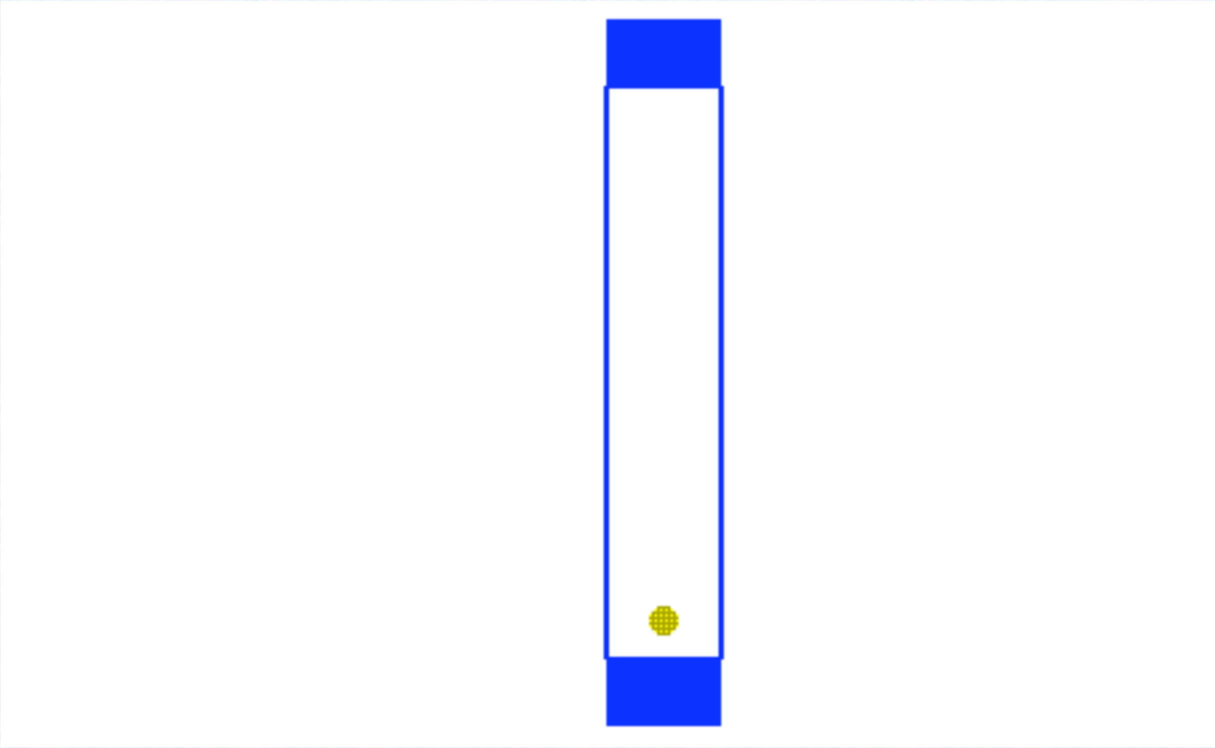
Figure 22-1b
Universe, Eighth Edition

Sound waves vs. light waves

An airplane can fly through the air faster than a sound wave …

… but nothing can fly through space faster than a light wave

Consequence: TIME DILATION

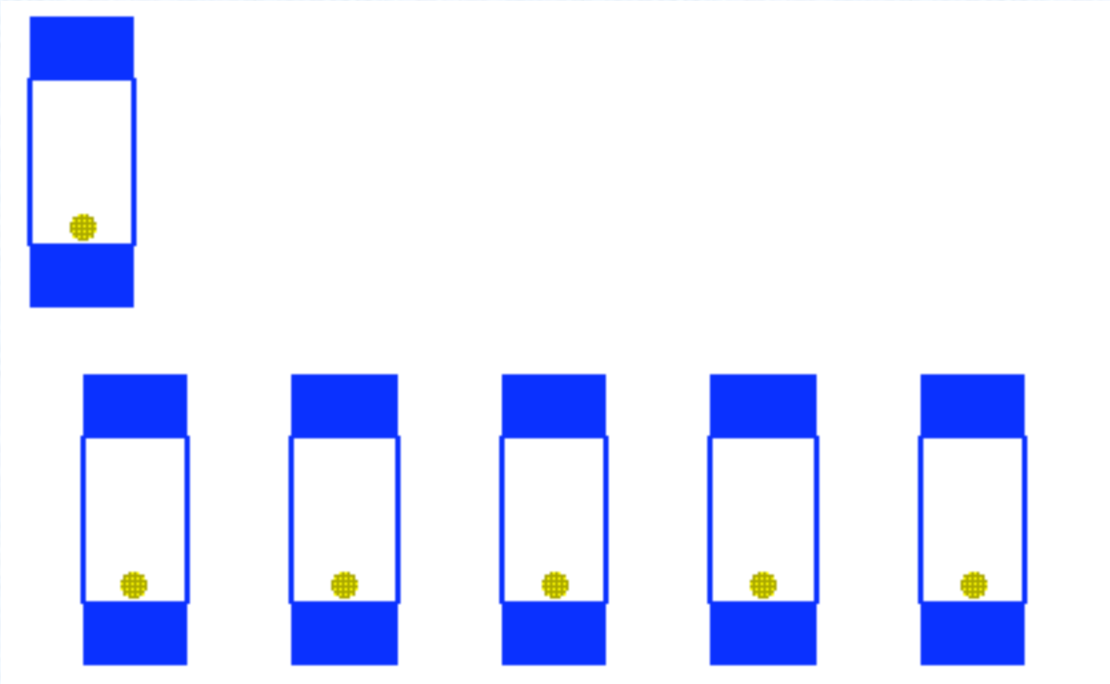


A “light clock”

Consequence: TIME DILATION

A “light clock” that’s moving

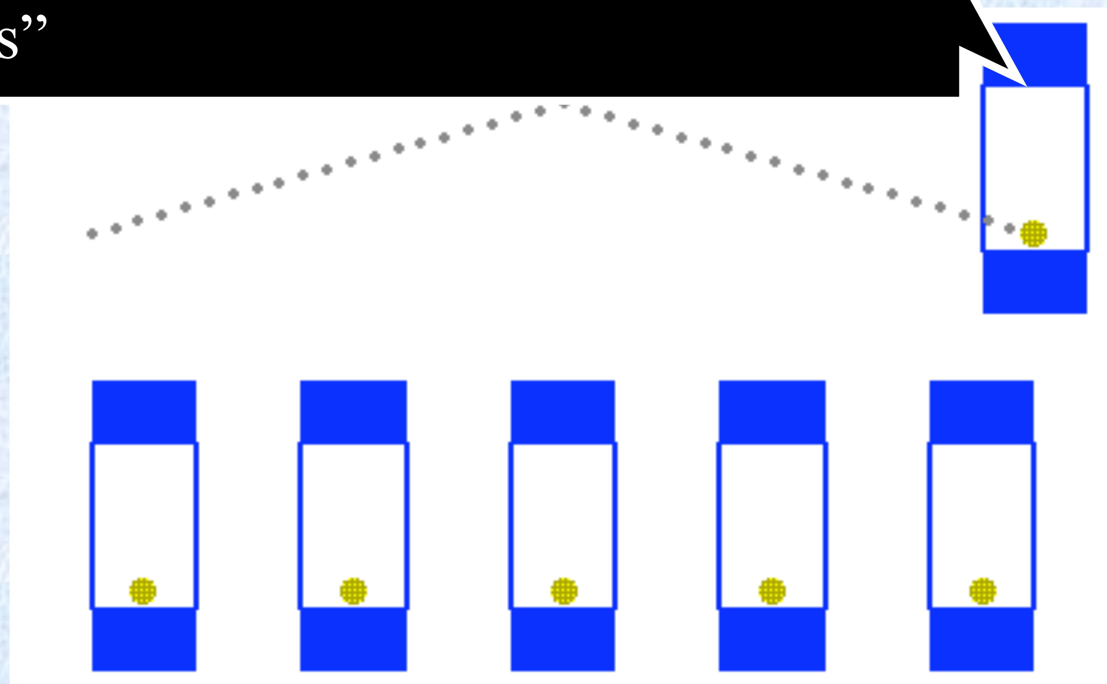
Consequence: TIME DILATION



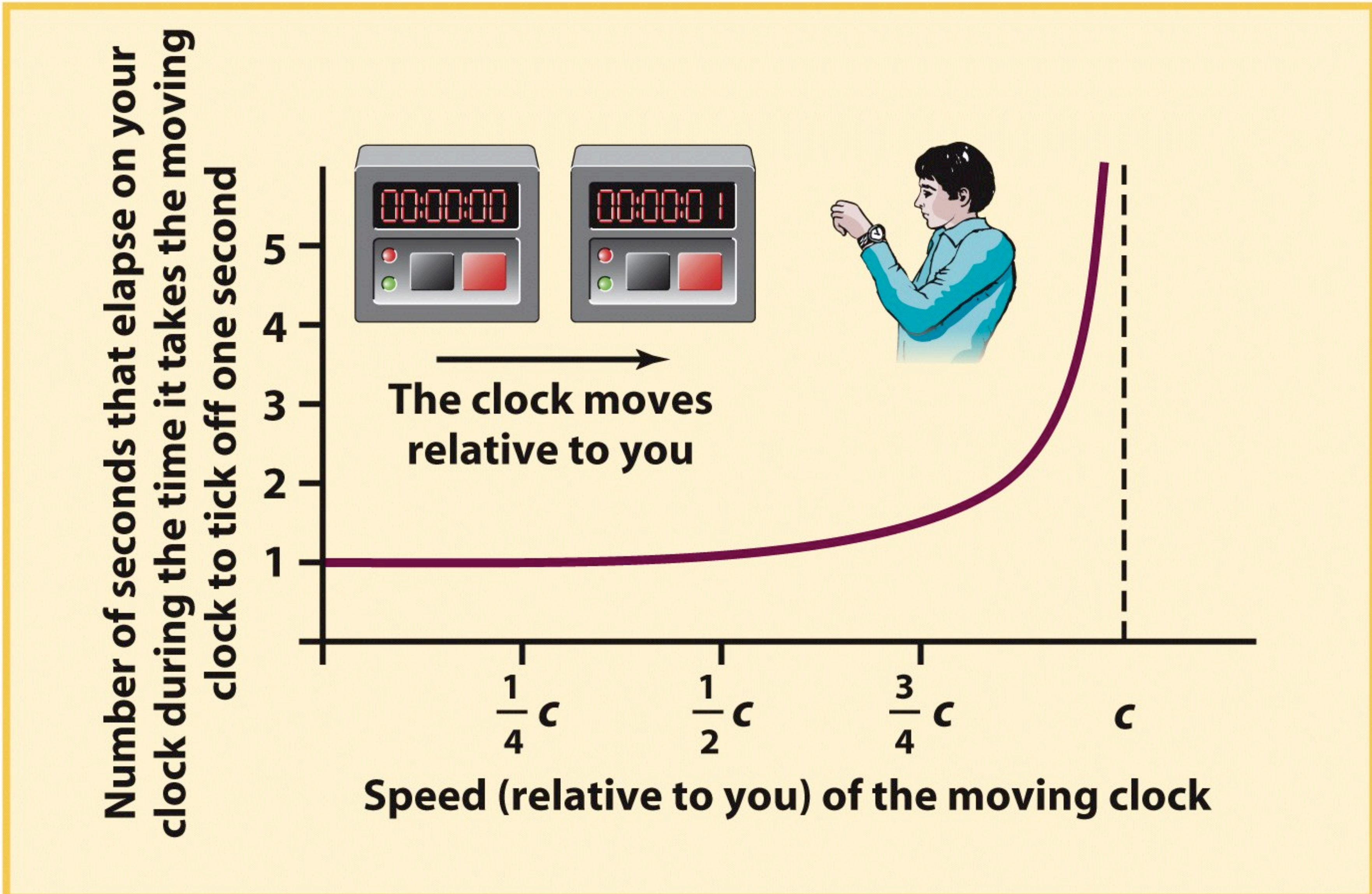
Comparing moving and stationary
“light clocks”

Consequence: TIME DILATION

Moving clock did one "tick"
during the time the stationary clocks
did two "ticks"



Comparing moving and stationary
"light clocks"



Time dilation

Figure 22-2b
Universe, Eighth Edition

Consequence: TIME DILATION

$$T = \frac{T_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

T = time interval measured by an observer moving relative to the phenomenon

T_0 = time interval measured by an observer not moving relative to the phenomenon (proper time)

v = speed of the moving observer relative to the phenomenon

c = speed of light

Consequence: Length Contraction

Question 23.1 (iclickers!)

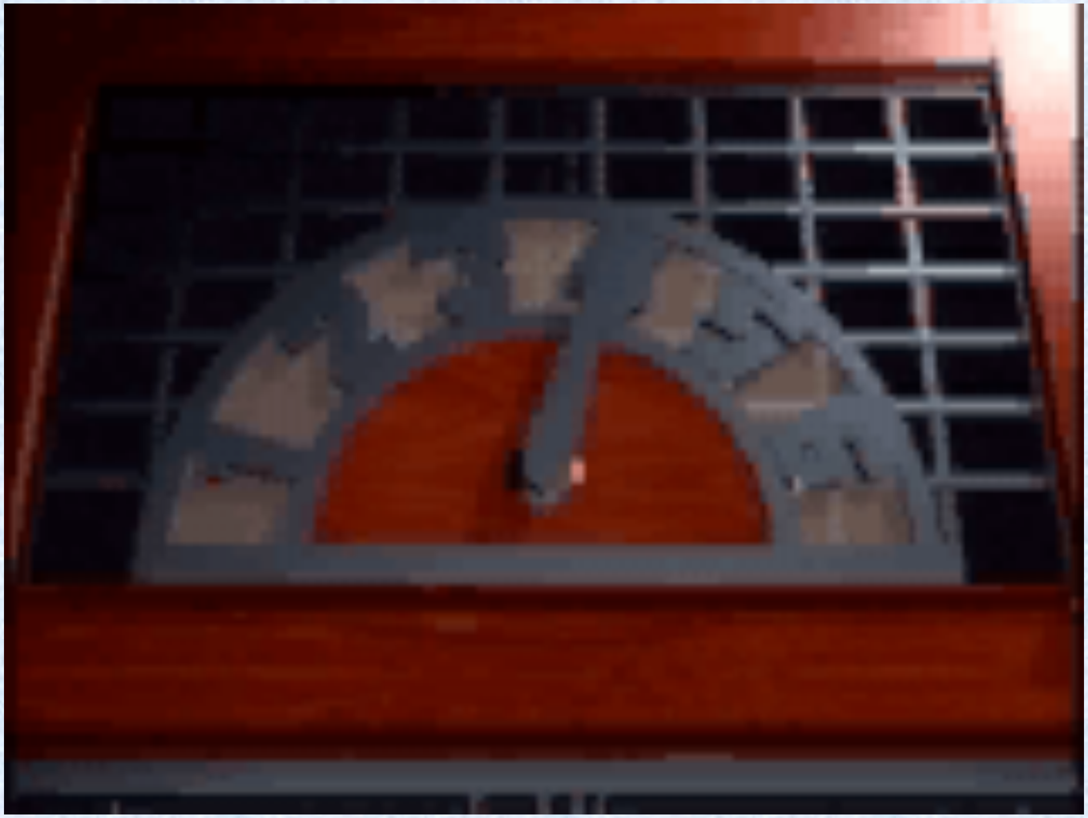
- Suppose you are in a spaceship traveling toward Earth to 95% of the speed of light. Compared when your ship was at rest on Mars, you measure the length of your ship to be:
  - A) The same as when it was on Mars
  - B) Longer than when it was on Mars
  - C) You can't tell. Your life processes have slowed down too much for you to measure the length
  - D) Shorter than when it was on Mars

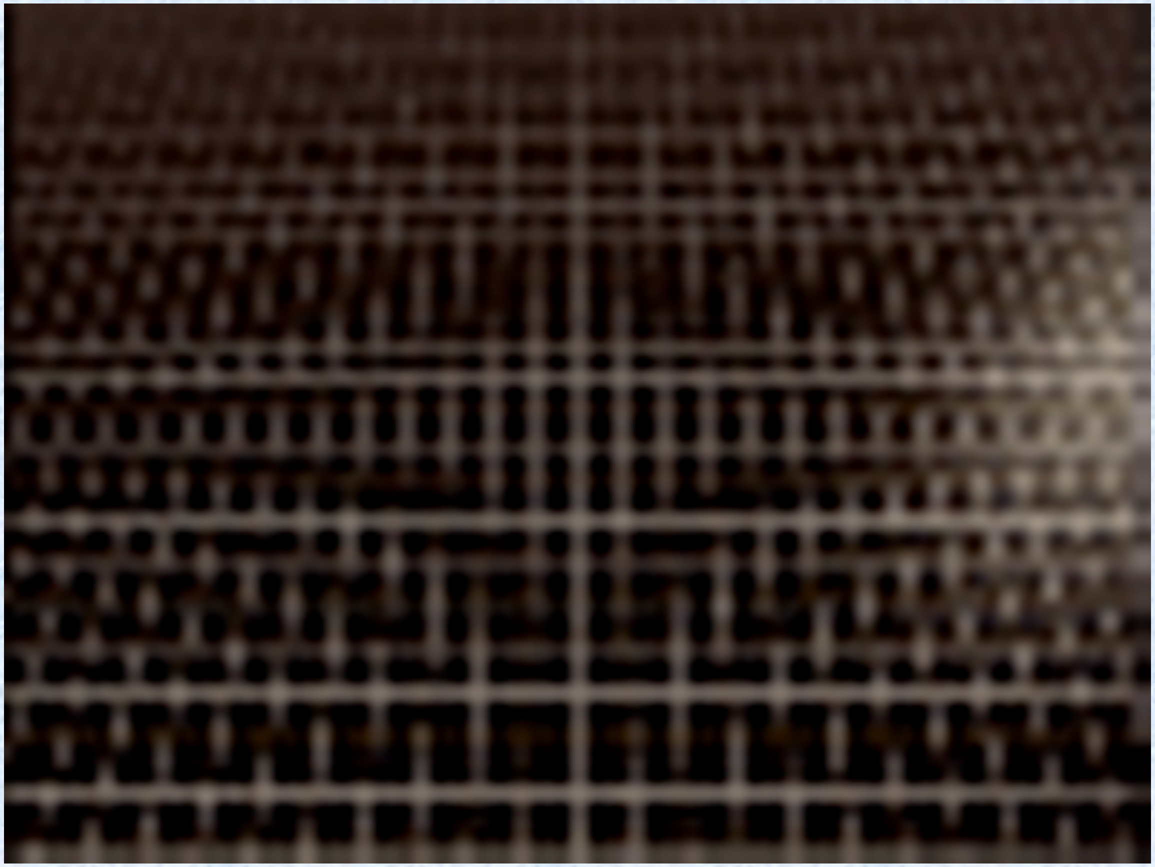
Introduction to general relativity

The Equivalence Principle (1915)

- Everything responds to gravity, independent of its mass the equivalence principle (gravitational mass = inertial mass!)
- Gravity can be described as a property of space-time!

The Equivalence Principle (1915)





A prediction of
Einstein's general theory of relativity:
Gravitational bending of light

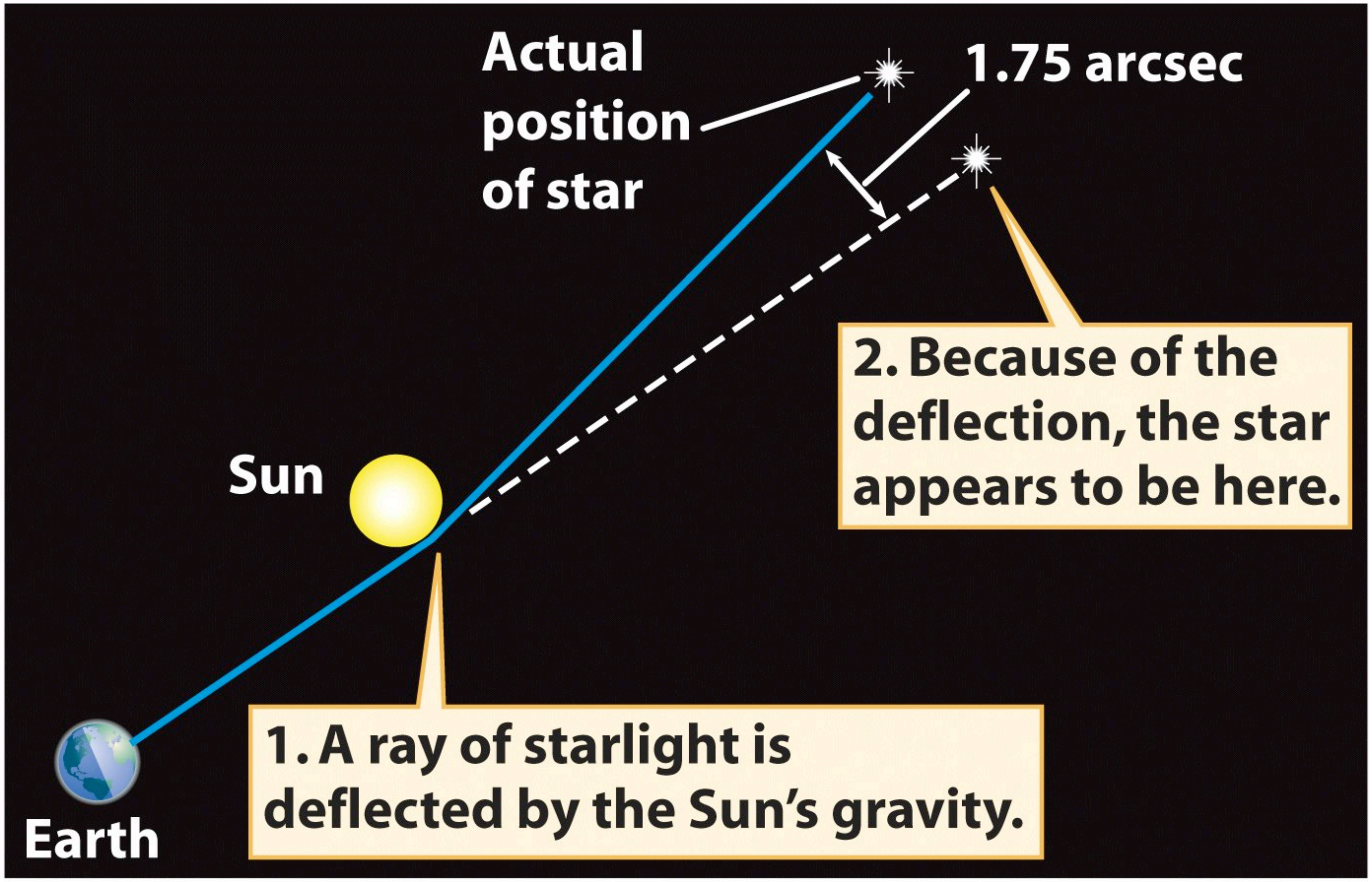
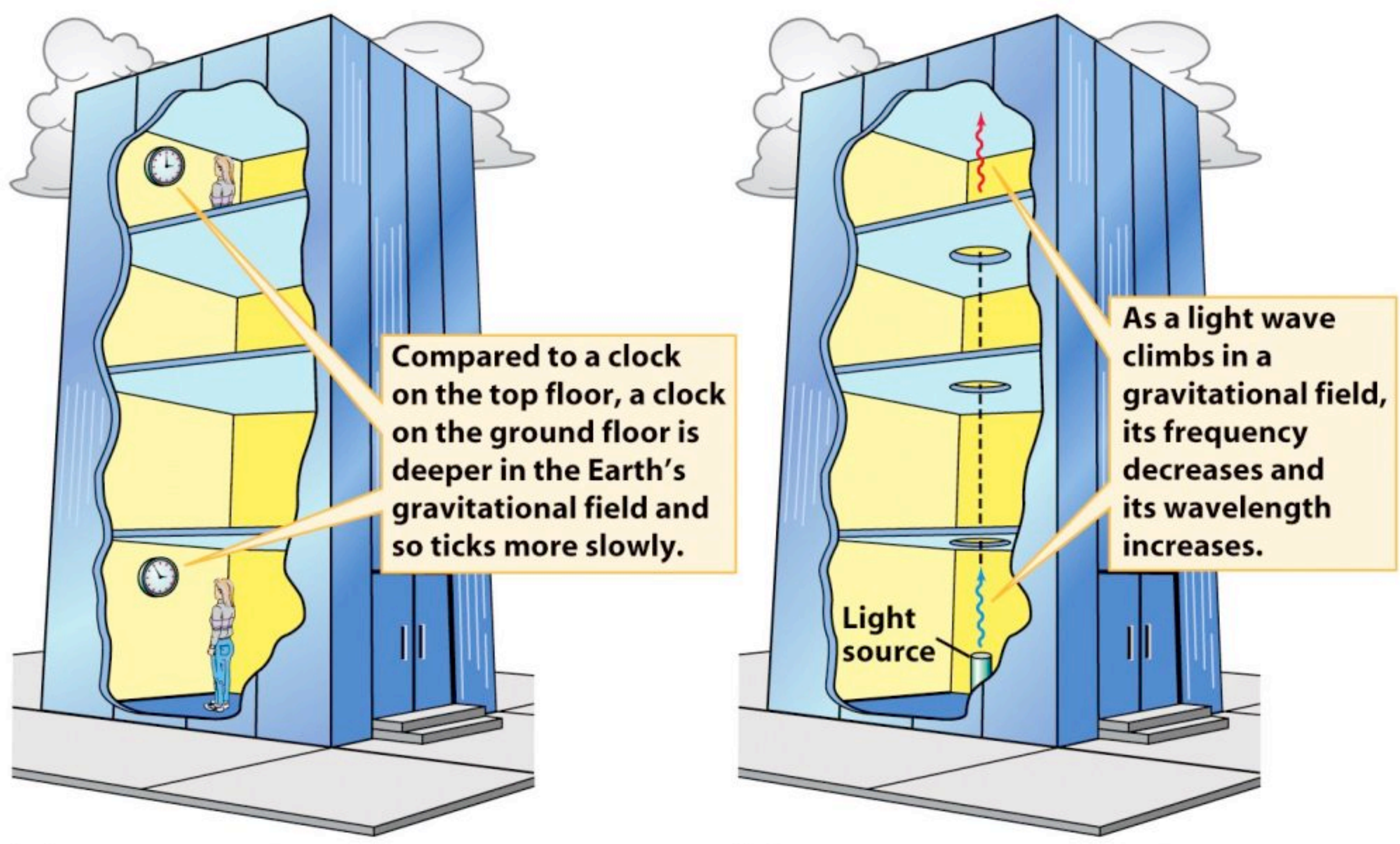


Figure 22-5
Universe, Eighth Edition

A prediction of Einstein's general theory of relativity: Gravitational time dilation

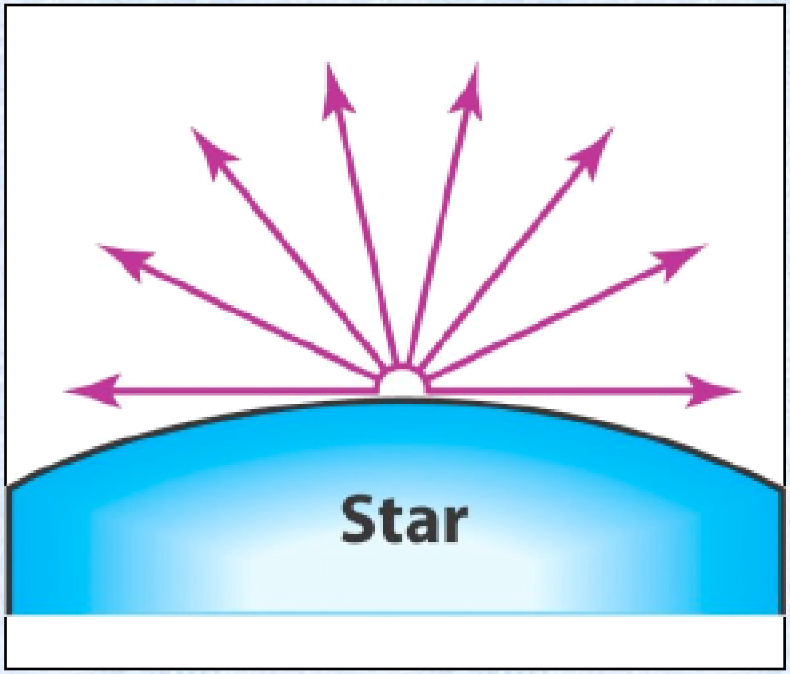


(a) The gravitational slowing of time (b) The gravitational redshift

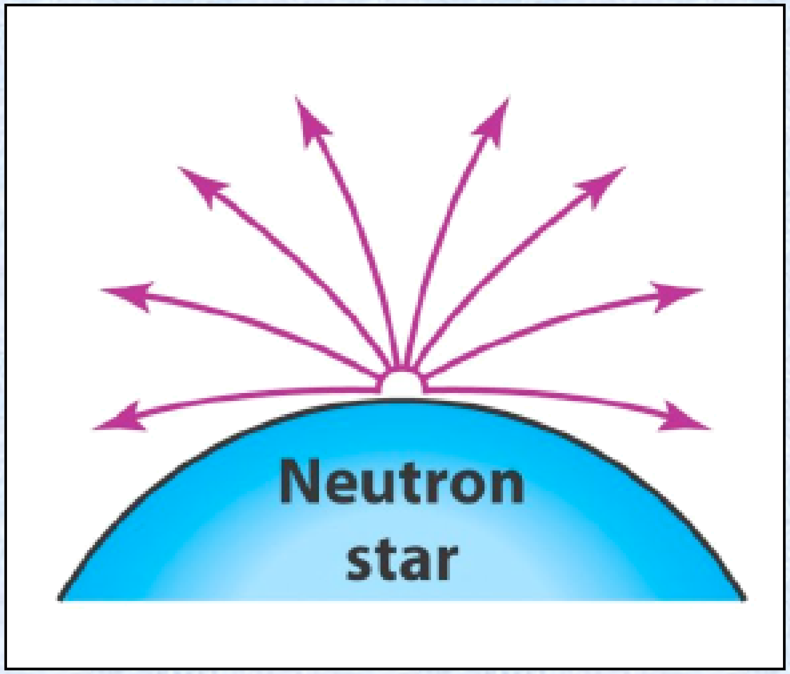
Question 23.2 (iclickers!)

- Suppose you are far from a planet that has a very strong gravitational field, and you are watching a clock on the surface of the planet. During the time in which your own clock ticks out a time of 1 hour, how much time does the clock on the planet tick out?
    - A) More than 1 hour
    - B) No time at all
    - C) Exactly 1 hour, the same as your clock
    - D) Less than 1 hour

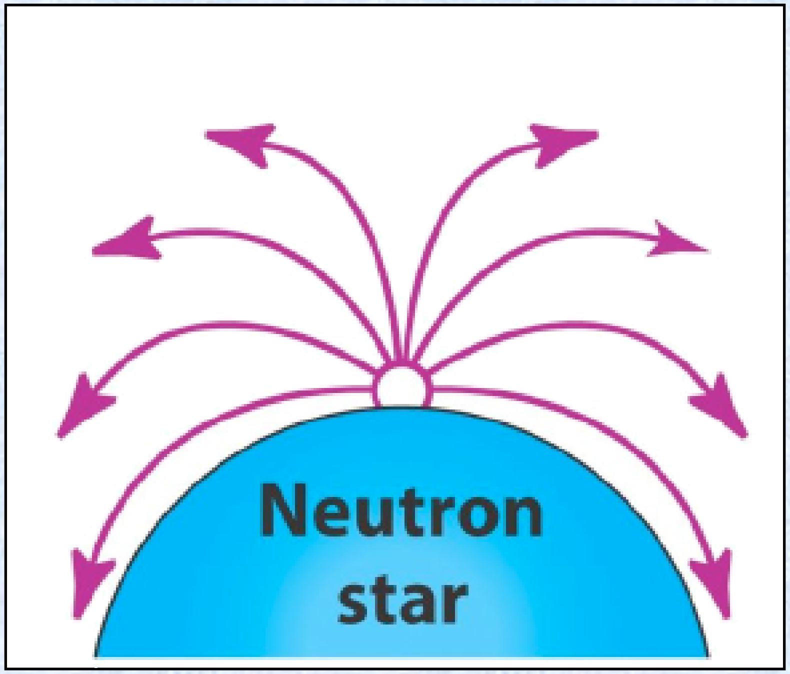
A prediction of
Einstein's general theory of relativity:
Black holes



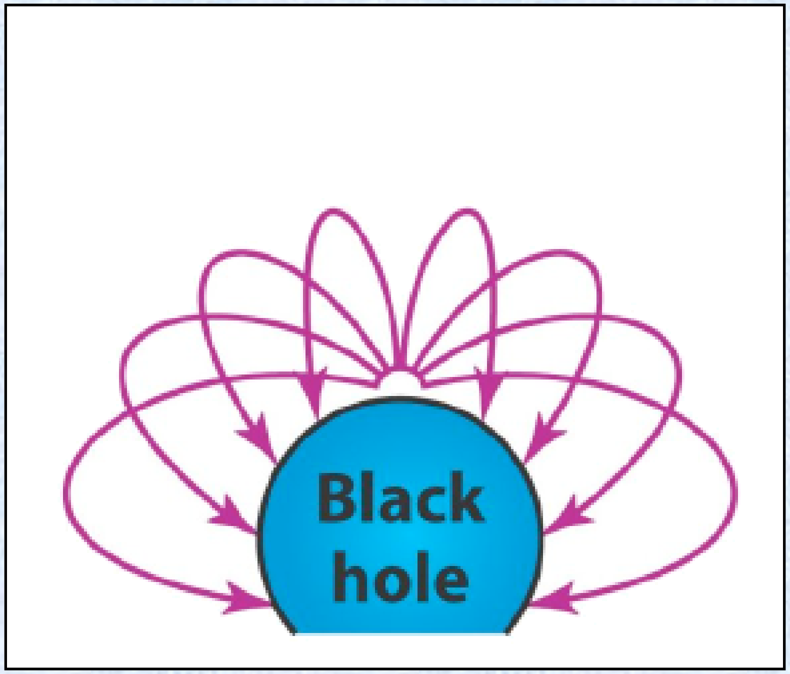
A prediction of
Einstein's general theory of relativity:
Black holes



A prediction of
Einstein's general theory of relativity:
Black holes



A prediction of
Einstein's general theory of relativity:
Black holes



Structure of a black hole

The event horizon is the point where the escape velocity equals the speed of light. It is the "point of no return."

What if you fall in?

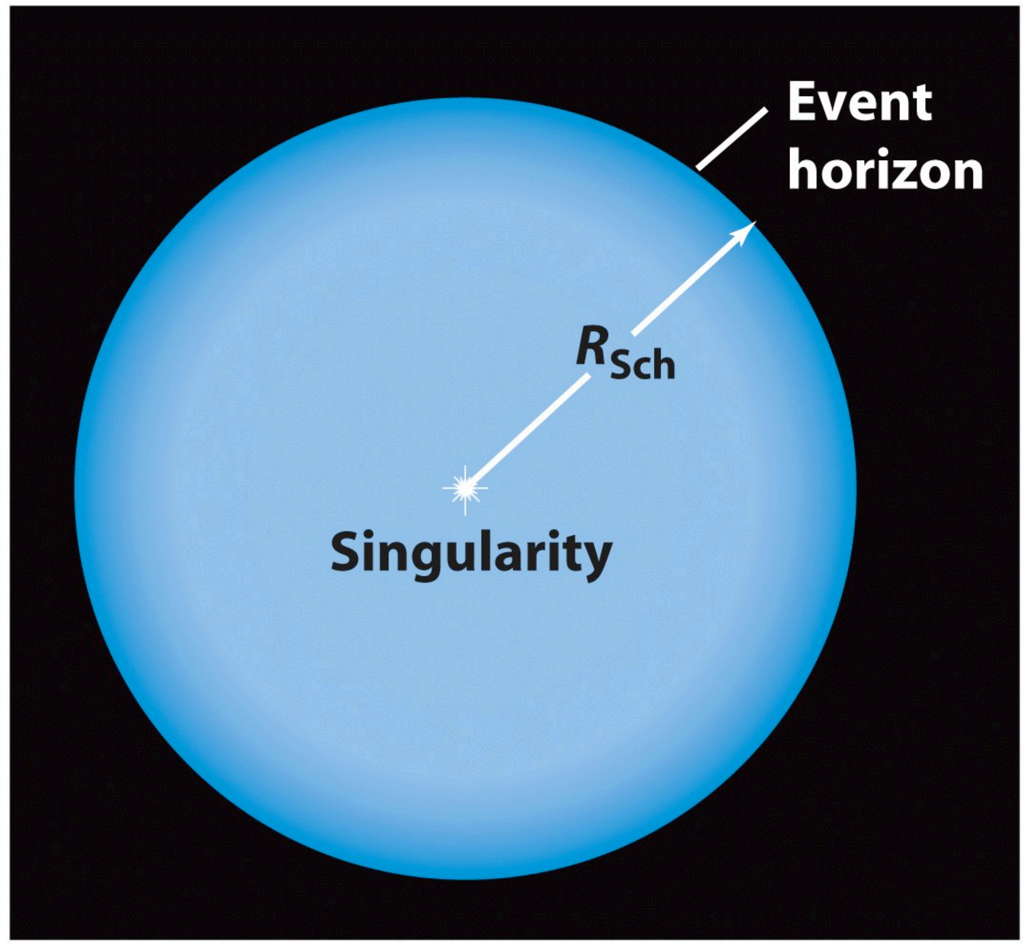
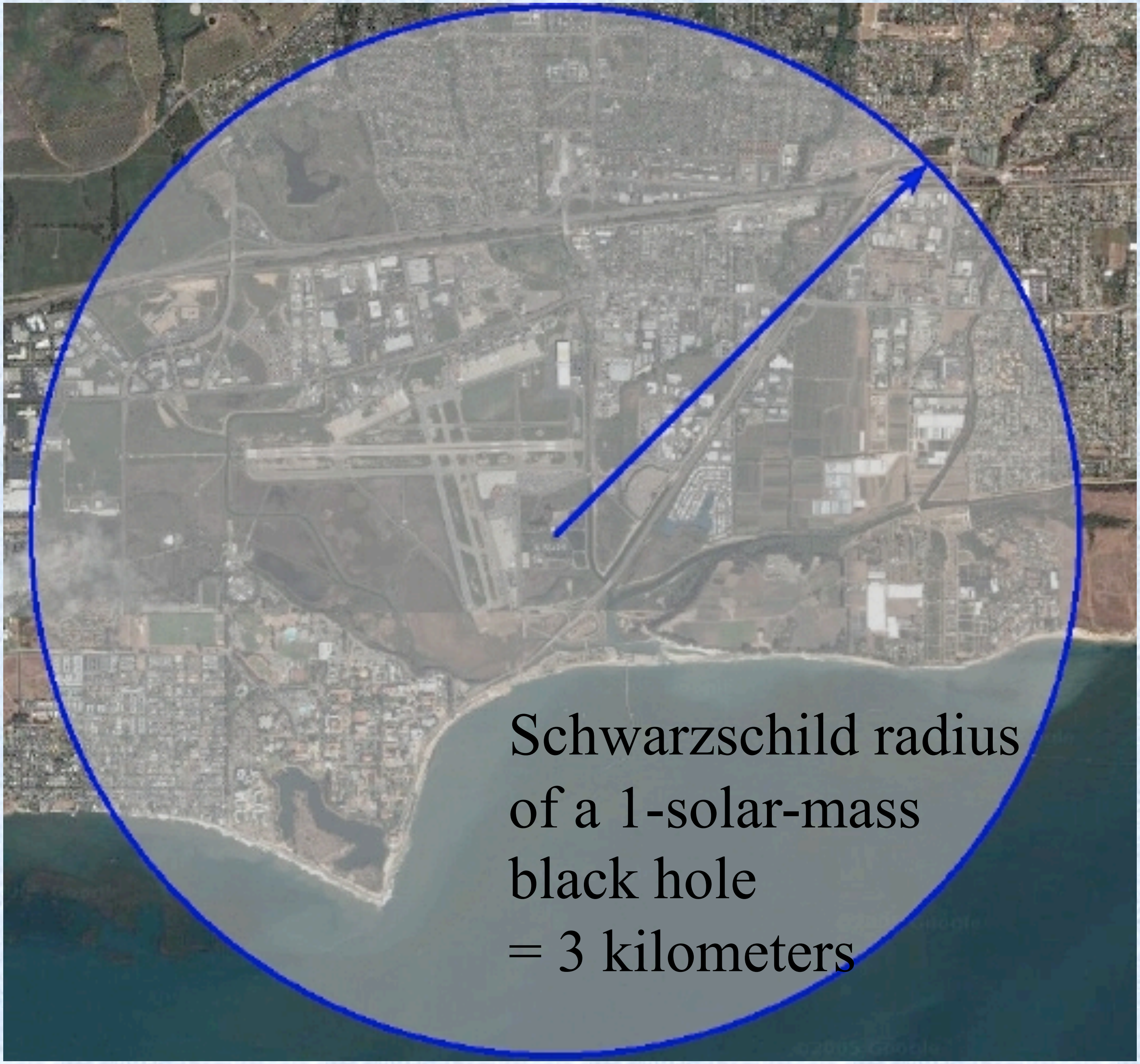
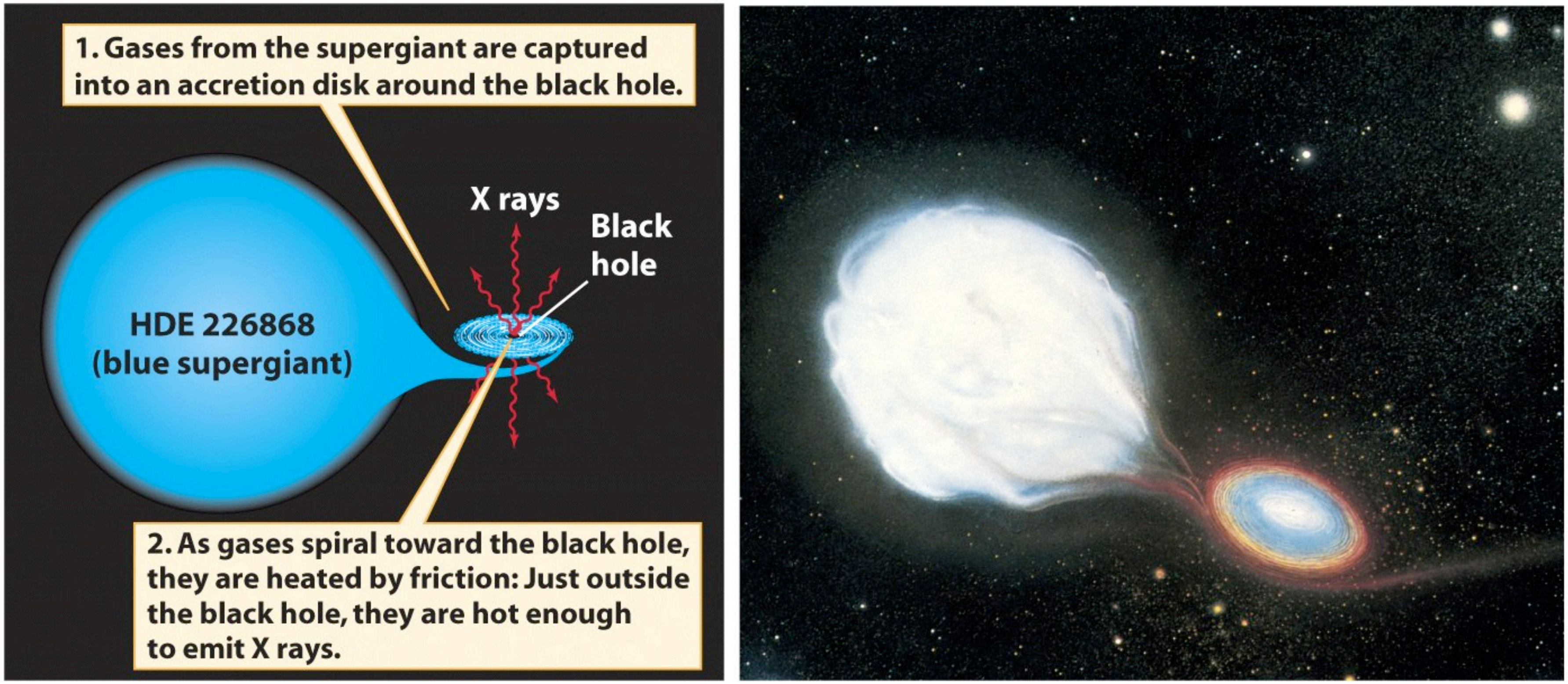


Figure 22-18
Universe, Eighth Edition

Schwarzschild radius $R_{\mathrm{Sch}} = 2GM/c^2$


Schwarzschild radius
of a 1-solar-mass
black hole
= 3 kilometers



(a) A schematic diagram of Cygnus X-1 (b) An artist's impression of Cygnus X-1

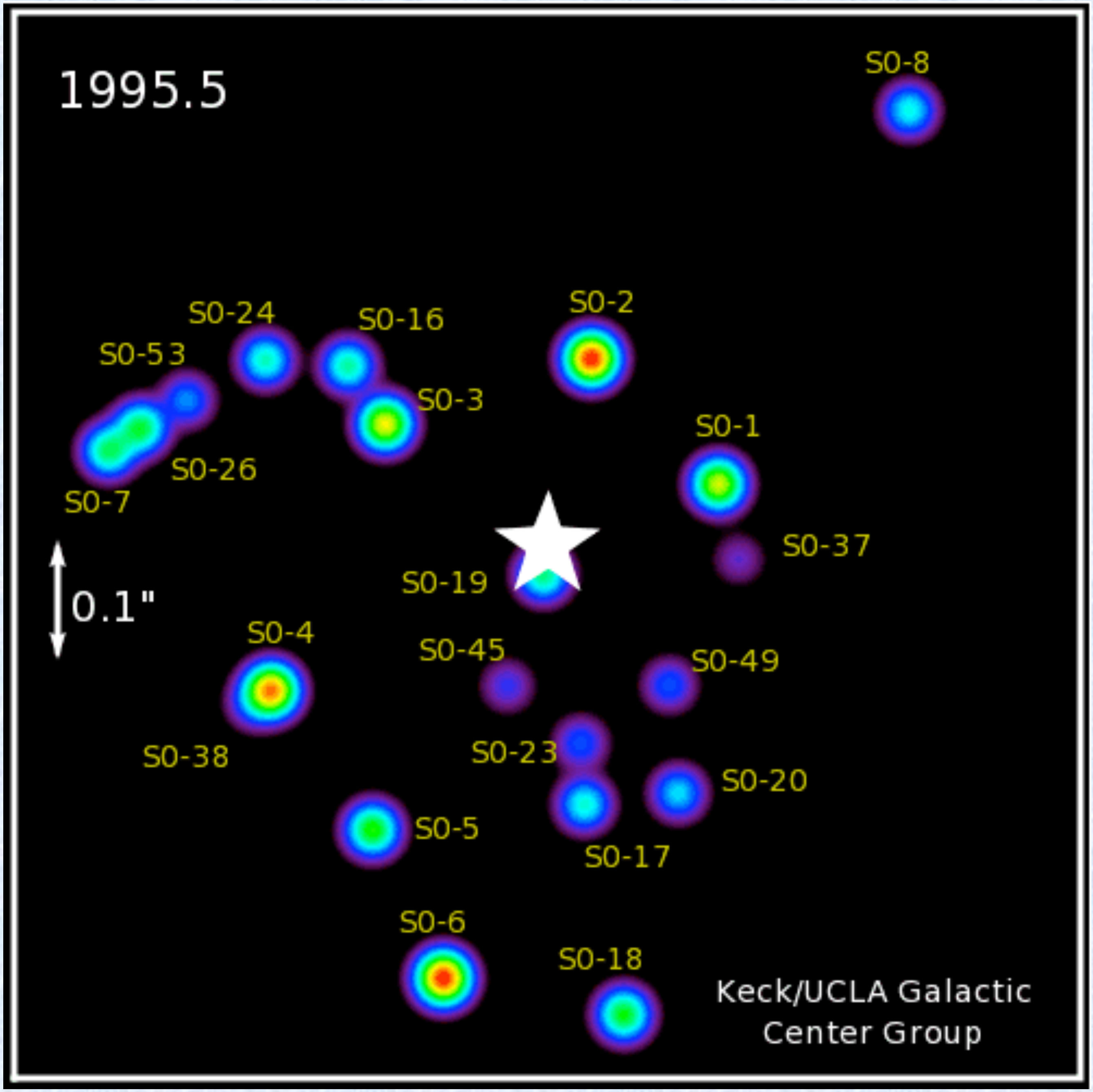
Figure 22-11
Universe, Eighth Edition

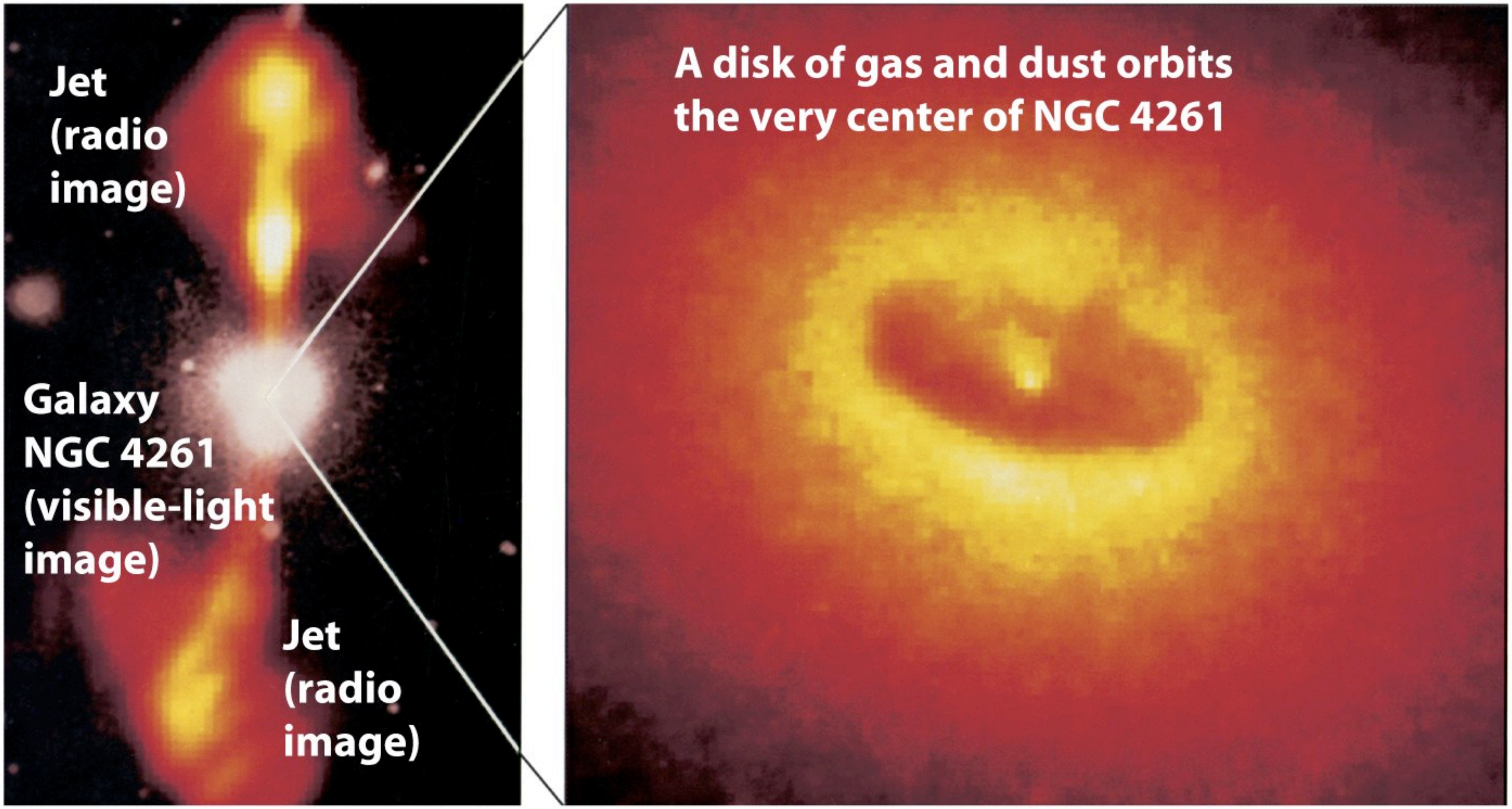
The larger member of the Cygnus X-1 system is a B0 supergiant of about 30 M. The other, unseen member of the system has a mass of at least 7 M and is probably a black hole.

Question 23.3 (iclickers!)

- Two identical 5 solar mass black holes are placed side by side. Add one solar mass of pineapples to the left-hand one and one solar mass of radioactive uranium to the the right-hand one. Afterward, how do these black holes differ
  - A) The left-hand one will smell better
  - B) The right-hand one is radioactive emitting alpha particles, electrons and gamma rays
  - C) The right-hand one has a stronger gravitational field because of the denser material inside it
  - D) They do not differ at all

Supermassive black holes


1995.5
S0-8
S0-24
S0-16
S0-2
S0-53
S0-3
S0-1
S0-26
S0-7
S0-37
S0-19
0.1"
S0-4
S0-45
S0-49
S0-38
S0-23
S0-20
S0-5
S0-17
S0-6
S0-18
Keck/UCLA Galactic
Center Group



(a) Galaxy NGC 4261 **(b)** Evidence for a supermassive black hole in NGC 4261

Figure 22-16
Universe, Eighth Edition

Gravitational energy is extracted from matter falling into the black hole ~0.1 mc^2 compared to 0.007 mc^2 from fusion. 1 marshmallow = Hiroshima

Summary

- **The Special Theory of Relativity:**
  - The laws of physics are the same in any (intertial) reference frame
  - The speed of light is the same to all observers
  - An observer will note a slowing of clocks and a shortening of rulers that are moving with respect to them.
  - Space and time are aspects of a single entity called spacetime.
- **The General Theory of Relativity:**
  - Inertial mass and gravitational mass are the same
  - Gravity = acceleration
  - Gravity is nothing but the distortion of space time by mass
  - Predicts bending of light by gravity, gravitational redshift and gravitational waves
- **Black Holes:**
  - A stellar corpse with mass greater than 3 ~$M_{\odot}$, will collapse under gravity. Will be so dense that not even light can escape.

The End

See you on monday!