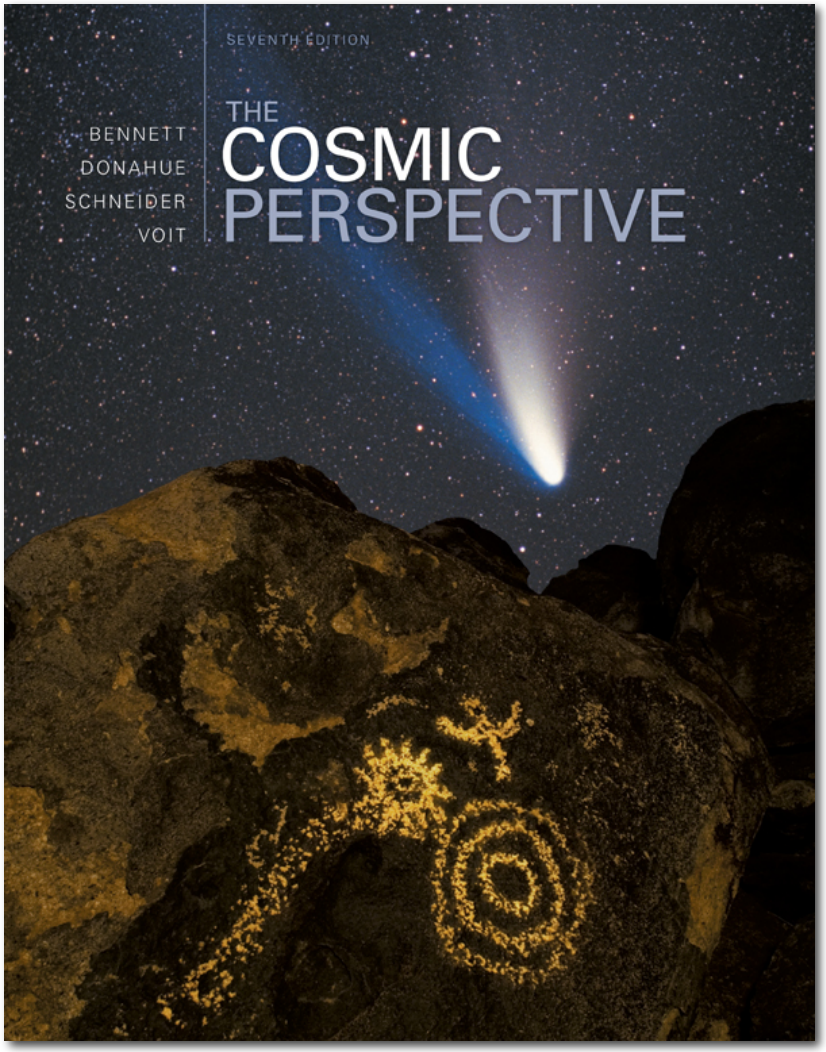
The Cosmic Perspective

Seventh Edition



Life in the Universe

© 2014 Pearson Education, Inc.

Aliens Among US?

Is there life on other planets? Is their intelligent life elsewhere in the Universe?

When and how did life begin on Earth? Could life have been triggered by complex organic compounds brought in from asteroids?

How many habitable planets are there in our galaxy?

How do we detect a habitable planet?

If there is life out there what would its basic chemistry be like?

What might alien life forms look like? Would they look like us?

Should we be sending out our coordinates into outer space? What would happen if our civilization came in contact with another civilization?

If there is intelligent life out there why haven't they contacted us yet?

Aliens Among US?

Are we Alone?

- Observable Universe: ~100 billion Galaxies with ~100 billion stars per galaxy

Are we Alone?

Recent discoveries from the study of life on Earth make it appear more likely that life may exist elsewhere:

1. From fossils we have found that **life began very early on Earth** suggesting that life would likely form quickly on other planets as well.

2. Lab experiments show that **molecules** that are predicted to have been present during the formation of the Earth **could form more complex organic molecules**.

These experiments indicate that **life may have formed through naturally occurring chemistry**. If this is the case then similar chemistry may lead to life on other planets.

3. We have discovered microscopic organisms that can survive in harsh conditions suggesting that they also could survive on other planets as well.

24.1 Life on Earth

- Our goals for learning:
  - **When did life arise on Earth?**
  - **How did life arise on Earth?**
  - **What are the necessities of life?**

© 2014 Pearson Education, Inc.

When did life arise on Earth?

We can learn about when life began by studying fossils.

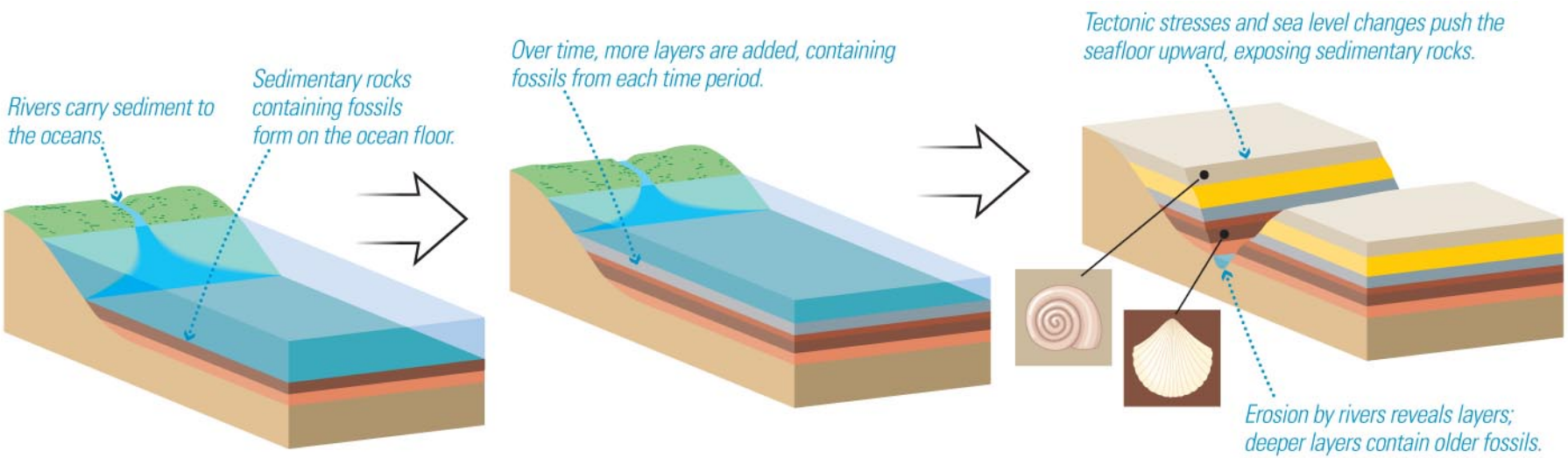
Many fossils end up at the bottom of the sea and are gradually buried by layers of sediments.

Over millions of years sediments pileup and compress the underlying layers into rocks that preserve the fossils.

Erosion or tectonic activity may expose these rocks that contain fossils (Example: the Grand Canyon).

When did life arise on Earth?

Fossils buried in deeper layers formed earlier. Radioactive dating confirms this and provides absolute ages



- Relative ages: deeper layers formed earlier
- Absolute ages: radiometric dating

Earliest Life Forms

- Life probably arose on Earth more than 3.85 billion years ago, shortly after the end of heavy bombardment.
- Evidence comes from fossils, carbon isotopes.

© 2014 Pearson Education, Inc.

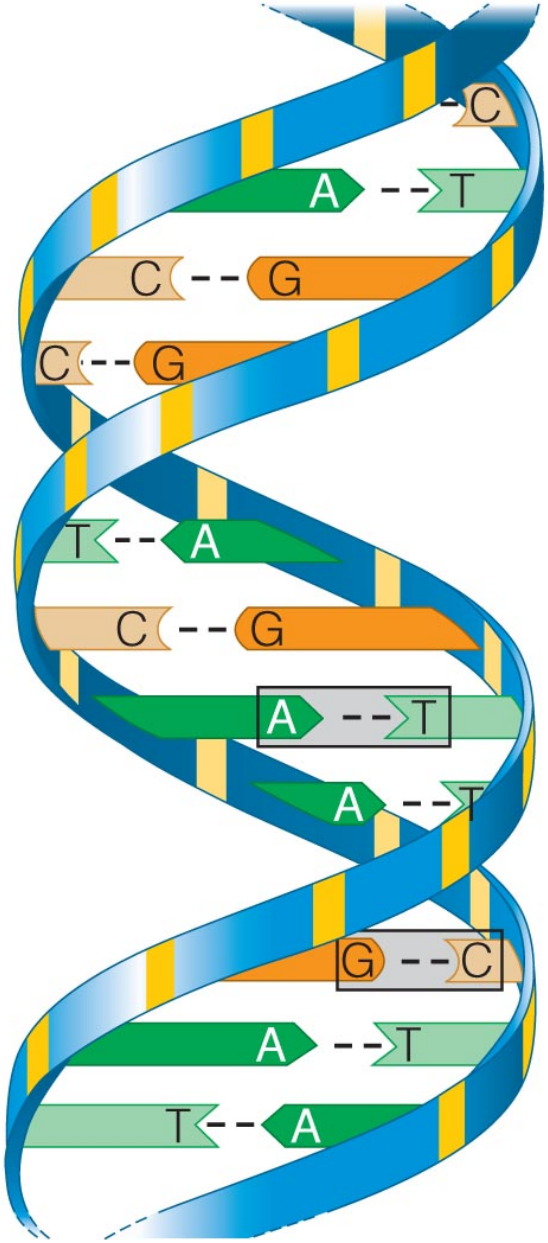
Earliest Fossils

a These knee-high mats at Shark Bay, Western Australia, are colonies of microbes known as "living stromatolites."

- The oldest fossils show that bacteria-like organisms were present over 3.5 billion years ago.
- Carbon isotope evidence dates the origin of life to more than 3.85 billion years ago.

© 2014 Pearson Education, Inc.

How did life evolve on Earth?

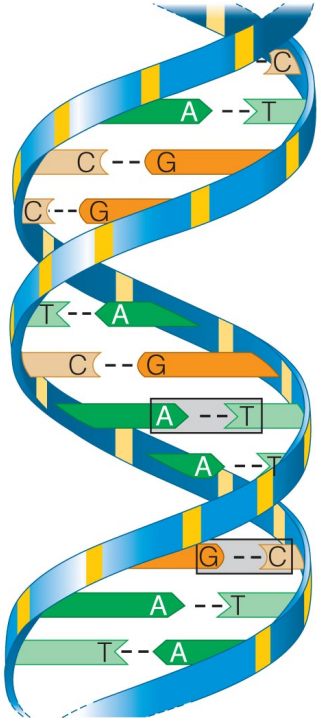


© 2014 Pearson Education, Inc.

How did life evolve on Earth?

Fossil records shows that life has gone through great changes over time.

The theory accepted by scientists to explains HOW change occurs in life over time is the **Theory of Evolution** first proposed by Darwin.



How did life arise on Earth?

Darwins theory is based on 2 main facts:
Fact 1: Overproduction can lead to competition for survival.

Fact 2: Some individuals of the same species may have different traits that make them better able to compete for vital resources.

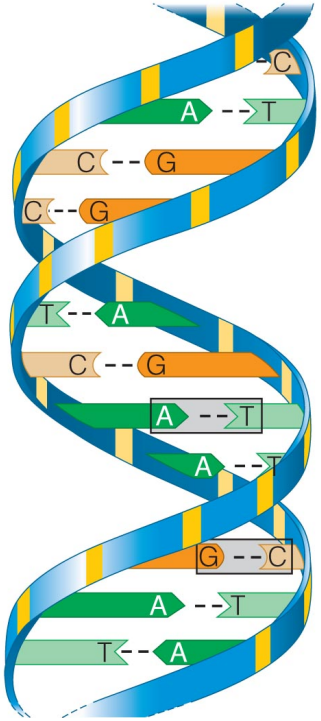
Conclusion from these facts: Evolution occurs through **natural selection**. Advantageous genetic traits will over time win out over less advantageous traits because they are most likely to be passed down through many generations.

Seven-year-old Darwin

How did life arise on Earth?

Darwins theory is supported by the **discovery of DNA.**

DNA is the genetic material that **contains all the instructions for assembling the organism that contains it.**



The information is stored in the precise order of 4 chemical bases that connect the 2 strands that make up a DNA.
The four DNA bases are:
A for adenine
T for thymine
G for guanine
C for cytosine

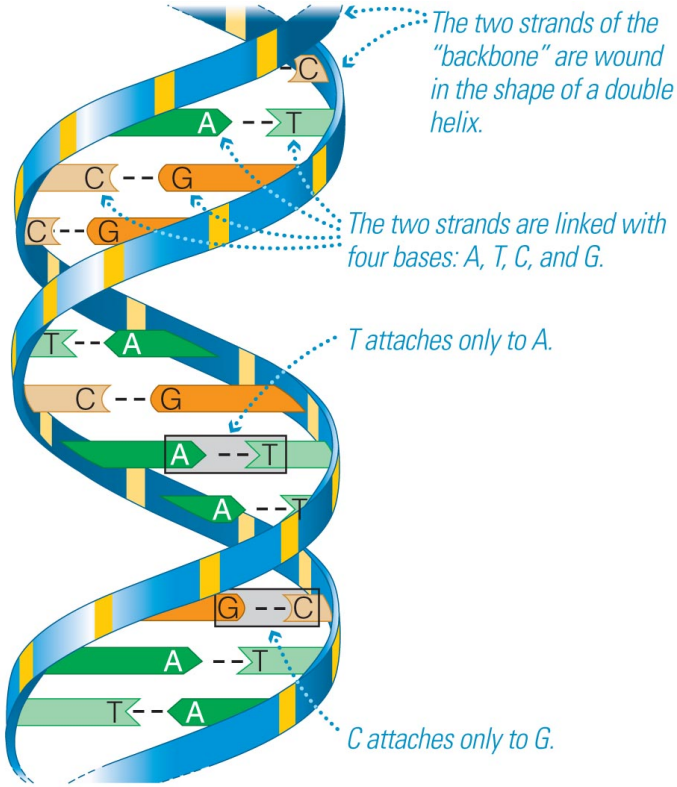
How did life arise on Earth?

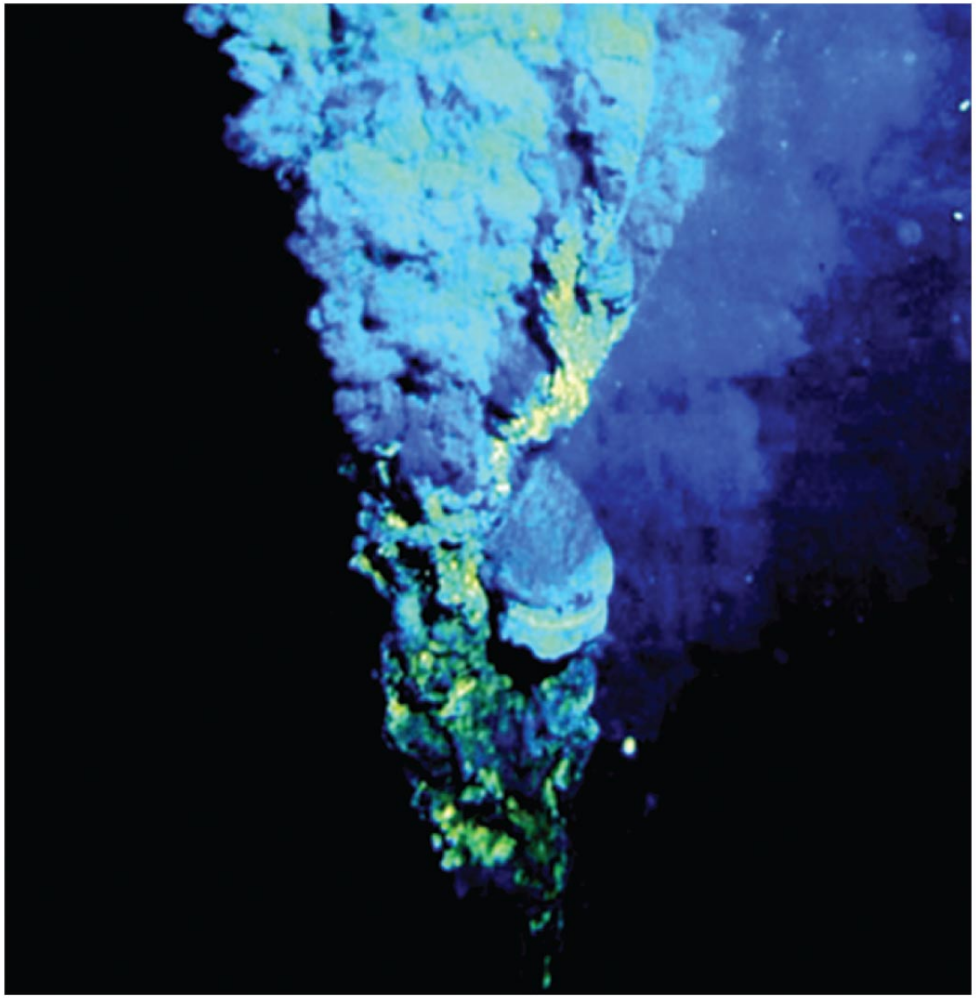
A single **DNA can reproduce** by given rise to two identical copies of itself.

EVOLUTION occurs because there are occasional errors in this copying DNA process.

Any change in a DNA during the reproduction process is called a **mutation.**

Several of the **mutations** may lead to killing the cell but some may improve the cells ability to survive and reproduce.

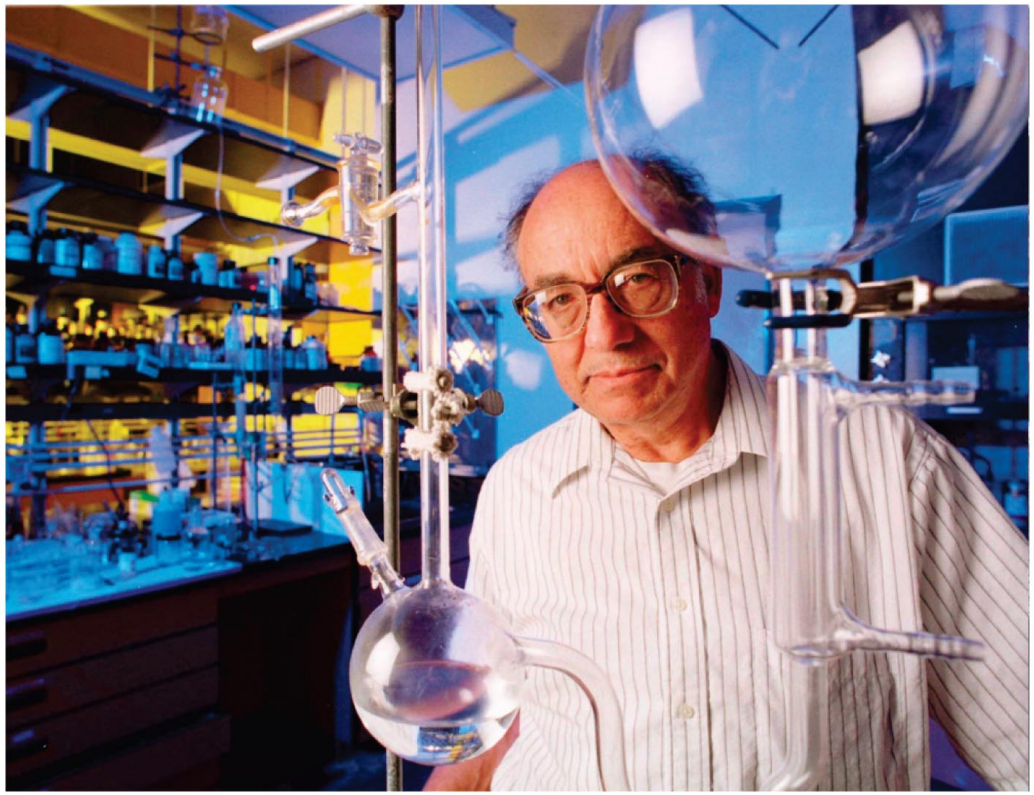




- These genetic studies suggest that the earliest life on Earth may have resembled the bacteria today found near deep ocean volcanic vents (*black smokers*).

© 2014 Pearson Education, Inc.

Laboratory Experiments



- The Miller experiment (and more recent experiments) show that the building blocks of life form easily and spontaneously under the conditions of early Earth.

© 2014 Pearson Education, Inc.

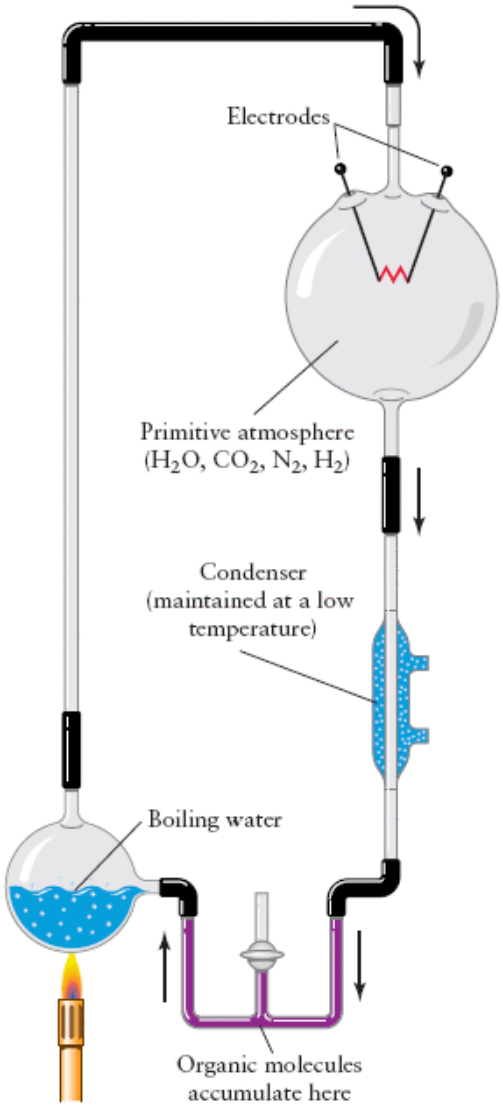
Did Life on Earth Arise from Chemical Reactions?

Earth's primordial atmosphere was composed of carbon dioxide (CO_2), nitrogen (N_2), and water vapor that outgassed from volcanoes, along with some hydrogen.

(The original Miller experiment used water, methane, ammonia and hydrogen.)

Numerous organic compounds important to life can be synthesized, with the help of a few electric sparks, from gases that were present in the Earth's primordial atmosphere.

Scientists have yet to figure out how these organic molecules gathered themselves into cells and developed systems for self-replication.



The Miller Experiment

Could life have migrated to Earth?

- Venus, Earth, Mars have exchanged tons of rock (blasted into orbit by impacts).
- Some microbes can survive years in space.

© 2014 Pearson Education, Inc.

Could life have migrated to Earth?

(a)

(b)

Ideally one would like to bring back rocks from Mars and have them tested in laboratories on Earth for the presence of life. Until then however we have the next best thing: Several meteorites that have reached Earth from Mars.

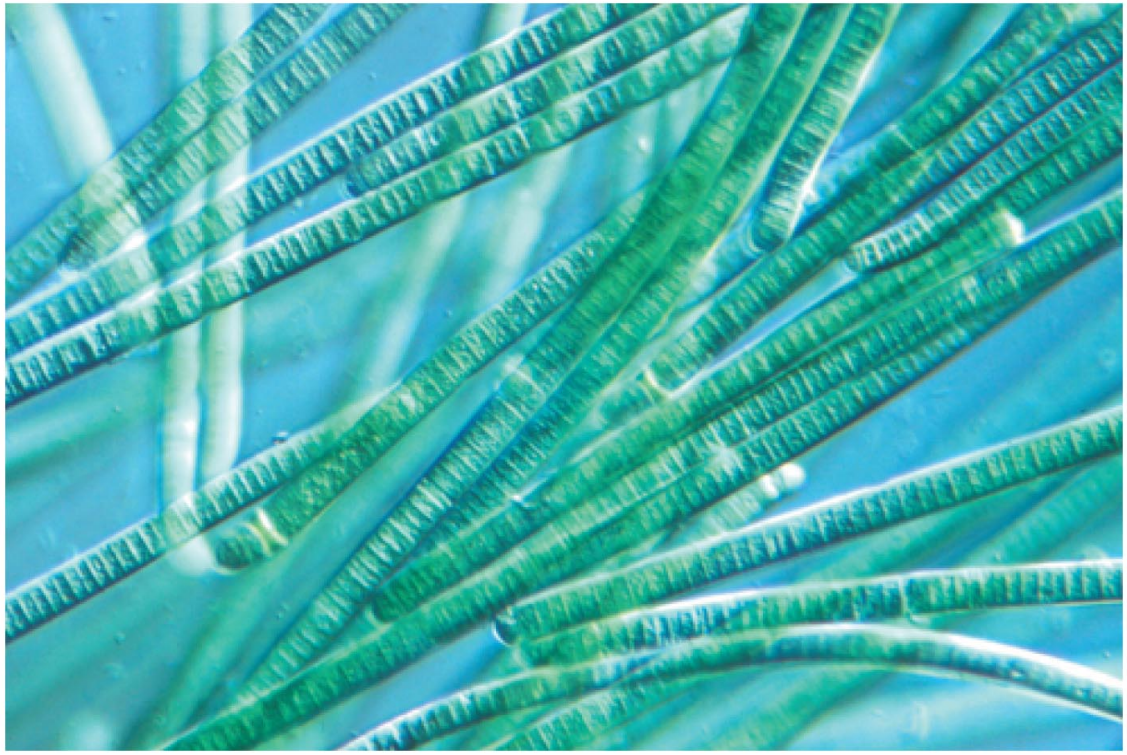
When a large asteroid impacts Mars most of the material thrown upwards returns back to the surface but a small amount can escape Mars's gravitational pull and enter an elliptical orbit.
If these orbits cross Earth's path some of the meteorites will collide with the Earth's surface. These are the SNC meteorites.

Could life have migrated to Earth?

SNC meteorite ALH 84001 has been the topic of considerable scientific debate. In 1996, David McKay and Everett Gibson analyzed ALH 84001 and reported:

ALH 84001 contains rounded grains of minerals called **carbonates**, which can form only in the presence of water. Around the carbonate grains were large numbers of elongated, tubelike structures resembling **fossilized microorganisms**.

Origin of Oxygen



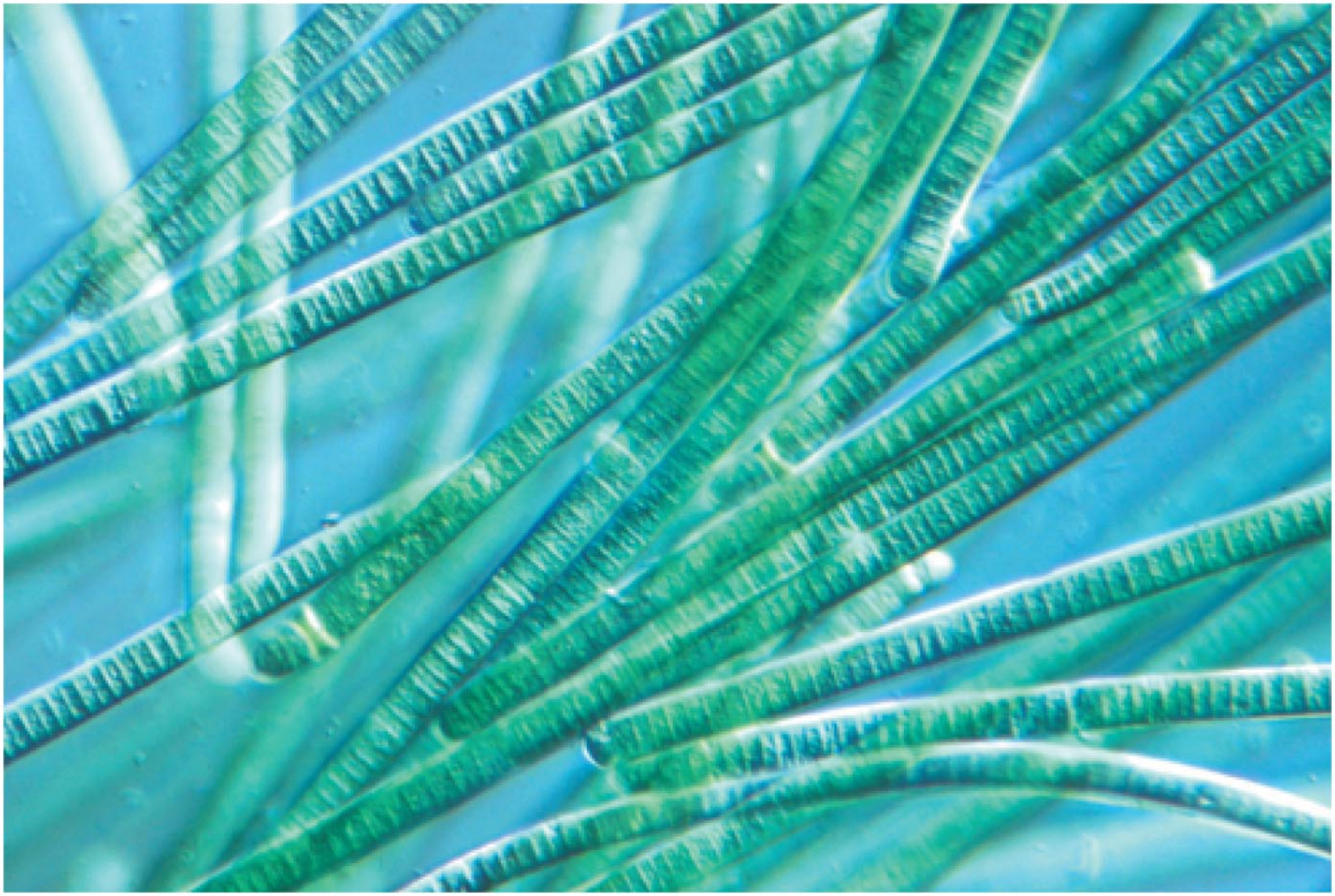
- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into atmosphere via photosynthesis.

$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$$

CarbonDioxide + Water → Sugar + Oxygen

© 2014 Pearson Education, Inc.

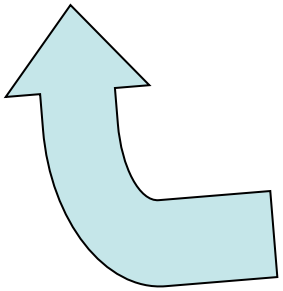
What are the necessities of life?



© 2014 Pearson Education, Inc.

Necessities for Life

- A nutrient source (atoms and molecules) from which to build cells.
- Energy (sunlight, chemical reactions, internal heat)
- Liquid water (or possibly some other liquid)



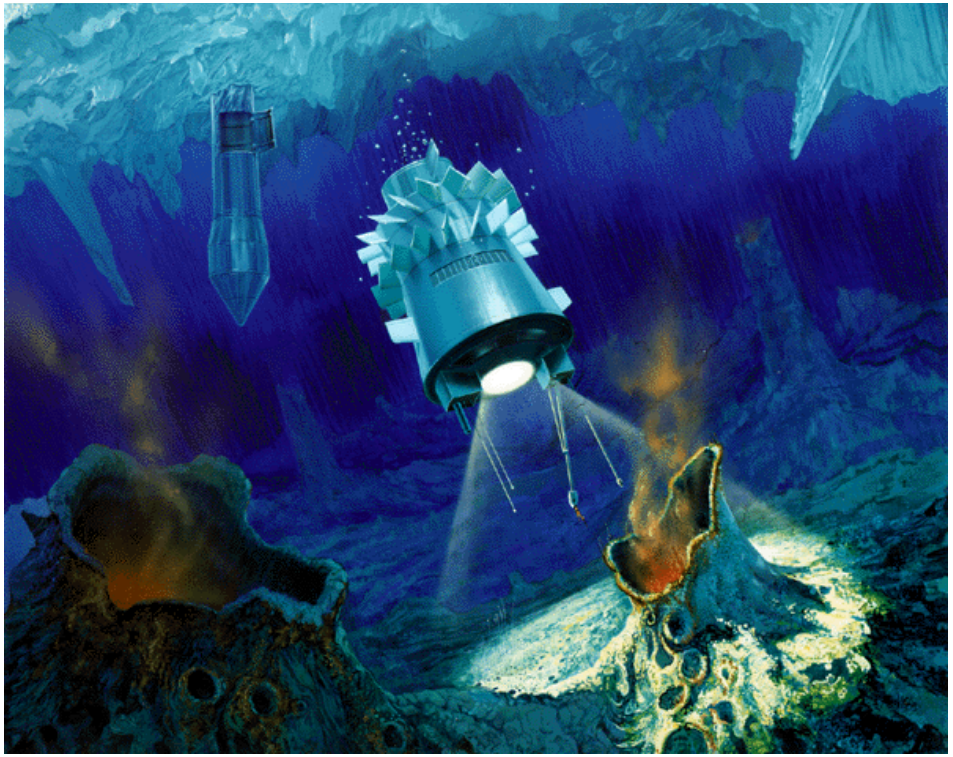
Hardest to find on other planets

© 2014 Pearson Education, Inc.

Necessities for Life

Liquid water is essential for life on Earth and might be essential for life on other alien worlds.

Other places in our solar system that have or may have contained water are Europa, Ganymede and Mars.



Submersible Probe Searching For Life on Europa.

What have we learned?

- **When did life arise on Earth?**
  - Life arose at least 3.85 billion years ago, shortly after end of heavy bombardment.
- **How did life evolve on Earth?**
  - Life evolved from a common organism through natural selection, but we do not yet know the origin of the first organism.
- **What are the necessities of life?**
  - Nutrients, energy, and liquid water.

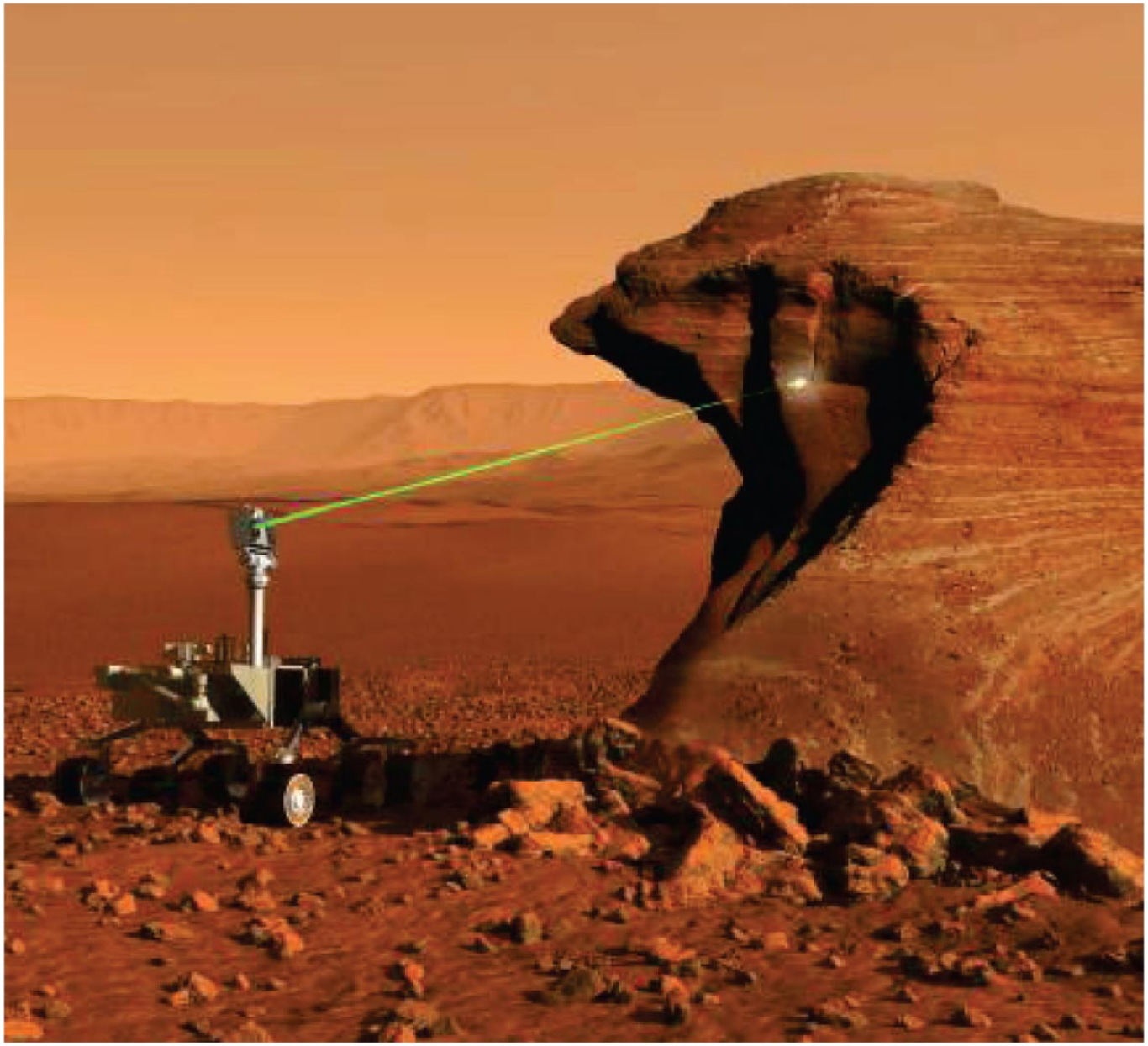
© 2014 Pearson Education, Inc.

24.2 Life in the Solar System

- Our goals for learning
  - **Could there be life on Mars?**
  - **Could there be life on Europa or other jovian moons?**

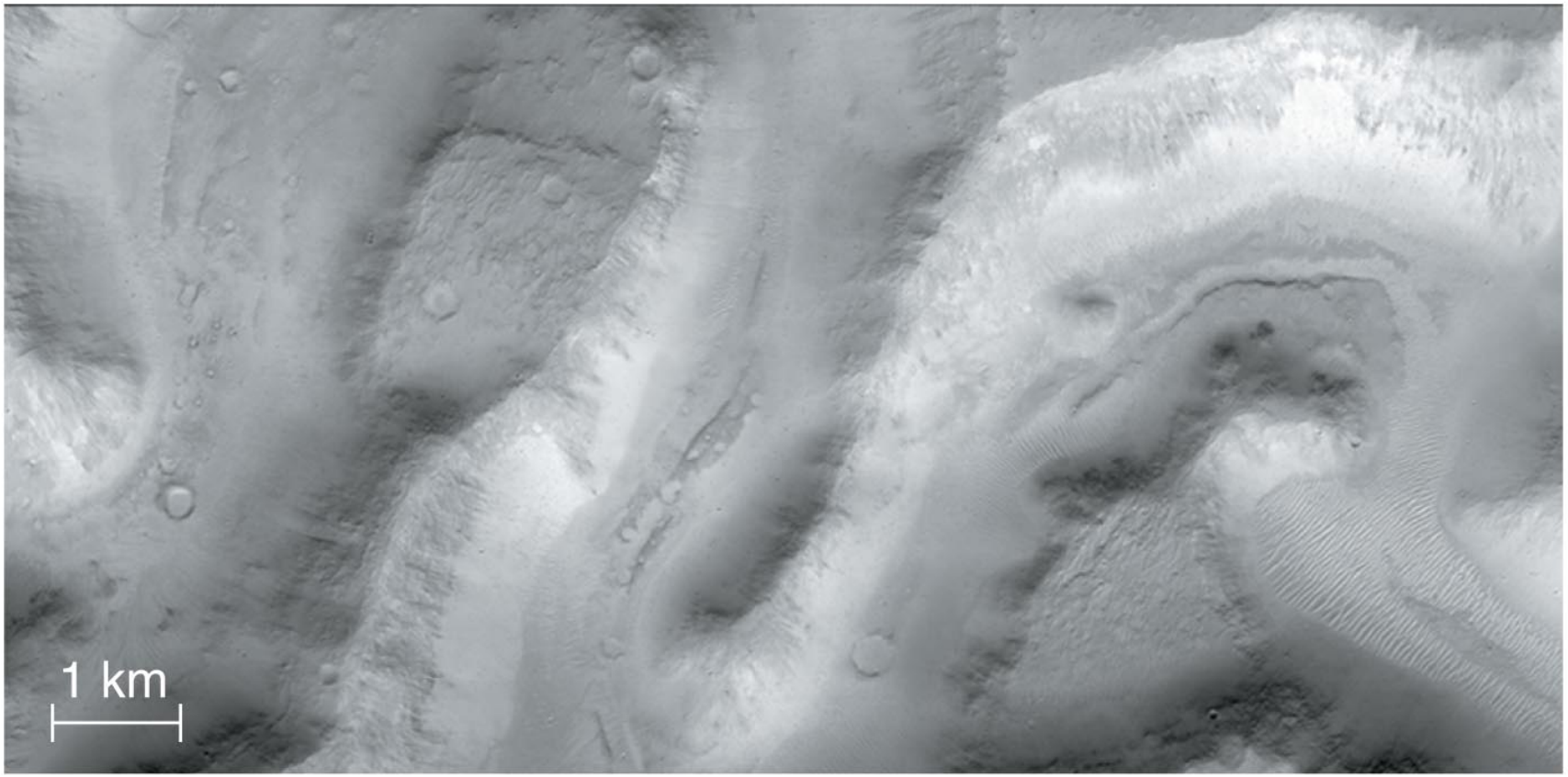
© 2014 Pearson Education, Inc.

Could there be life on Mars?



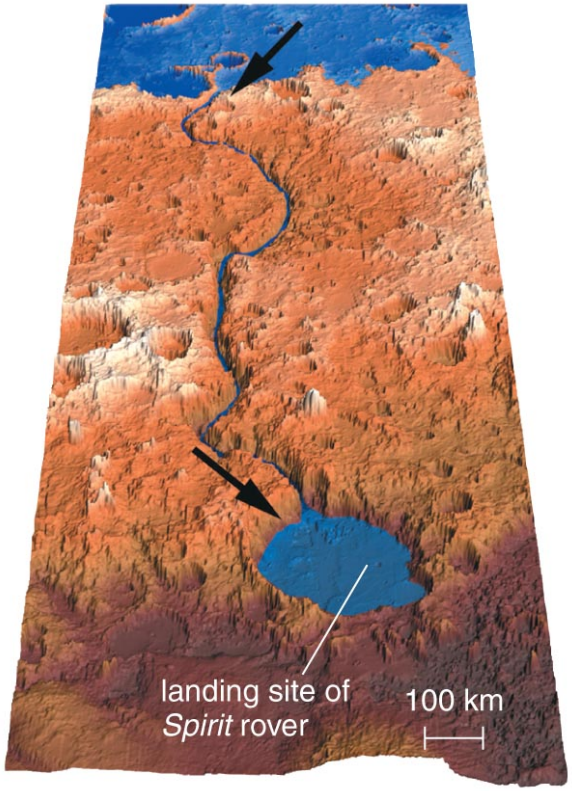
© 2014 Pearson Education, Inc.

Searches for Life on Mars



- Mars had liquid water in the distant past.
- Still has subsurface ice; possibly subsurface water near sources of volcanic heat

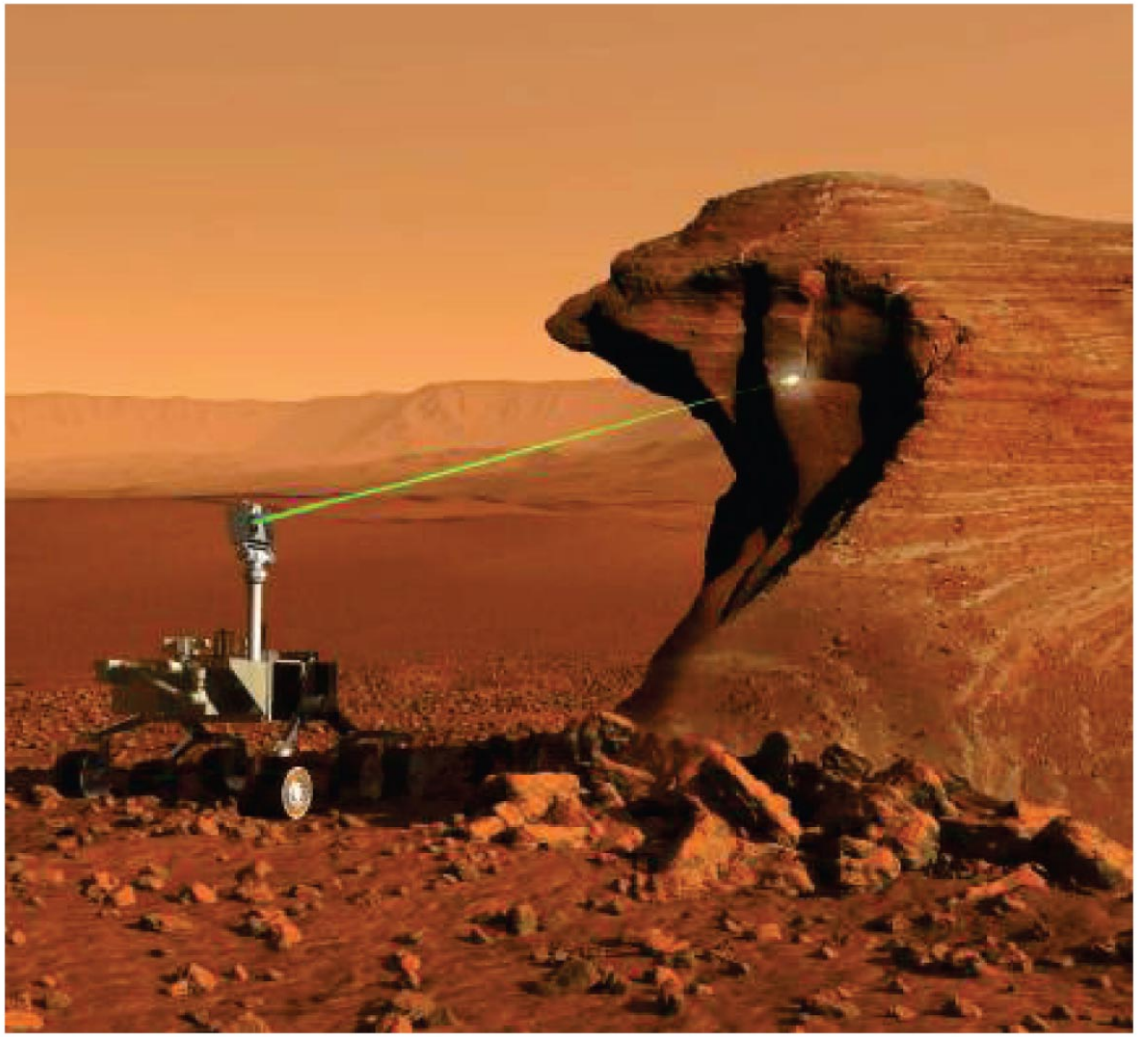
© 2014 Pearson Education, Inc.



b This computer-generated perspective view shows how a Martian valley forms a natural passage between two possible ancient lakes (shaded blue). Vertical relief is exaggerated 14 times to reveal the topography.

- In 2004, NASA *Spirit* and *Opportunity* rovers sent home new mineral evidence of past liquid water on Mars.

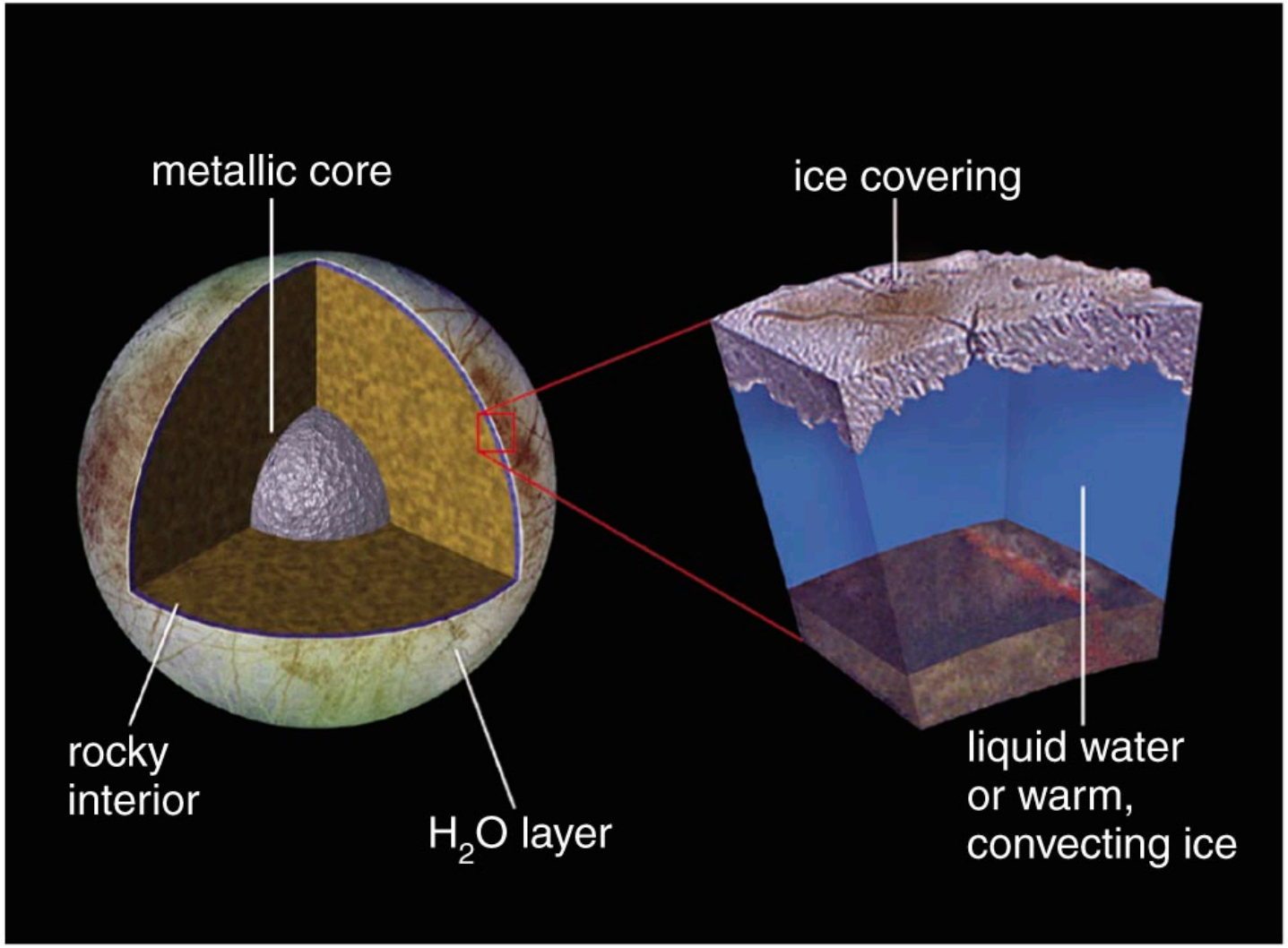
© 2014 Pearson Education, Inc.



- The *Curiosity* rover landed on Mars in 2012. It carries many instruments designed to explore the habitability of the planet.

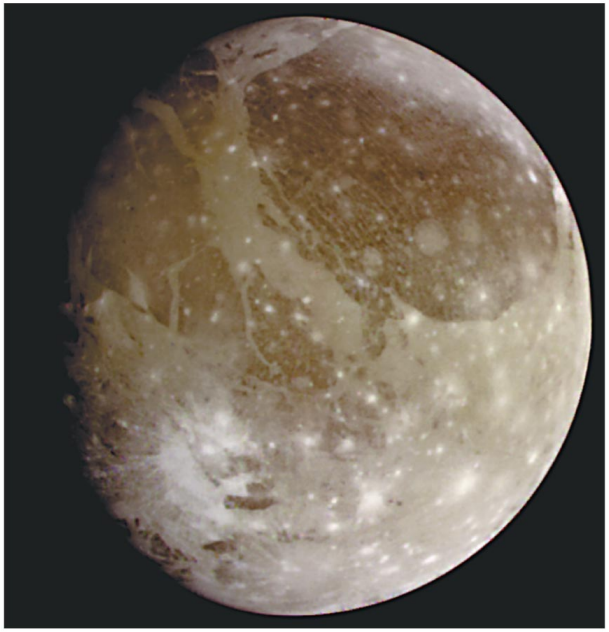
© 2014 Pearson Education, Inc.

Could there be life on Europa or other jovian moons?

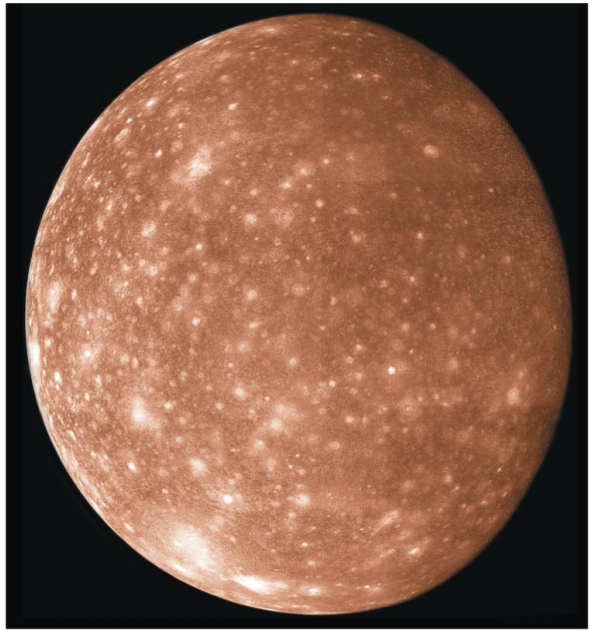


© 2014 Pearson Education, Inc.

- Ganymede, Callisto also show some evidence for subsurface oceans.
- Relatively little energy available for life, but there still may be enough.
- Intriguing prospect of THREE potential homes for life around Jupiter alone.



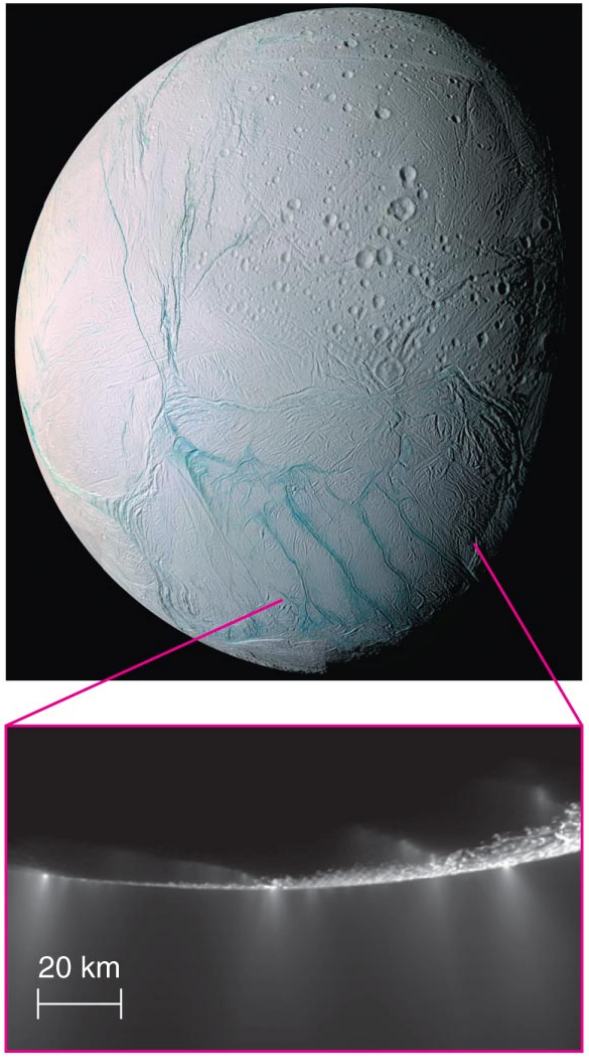
Ganymede



Callisto

© 2014 Pearson Education, Inc.

Enceladus



- Ice fountains suggest that Enceladus may have a subsurface ocean.

© 2014 Pearson Education, Inc.

What have we learned?

- **Could there be life on Mars?**
  - Evidence for liquid water in past suggests that life was once possible on Mars.
- **Could there be life on Europa or other jovian moons?**
  - Jovian moons are cold but some show evidence for subsurface water and other liquids.

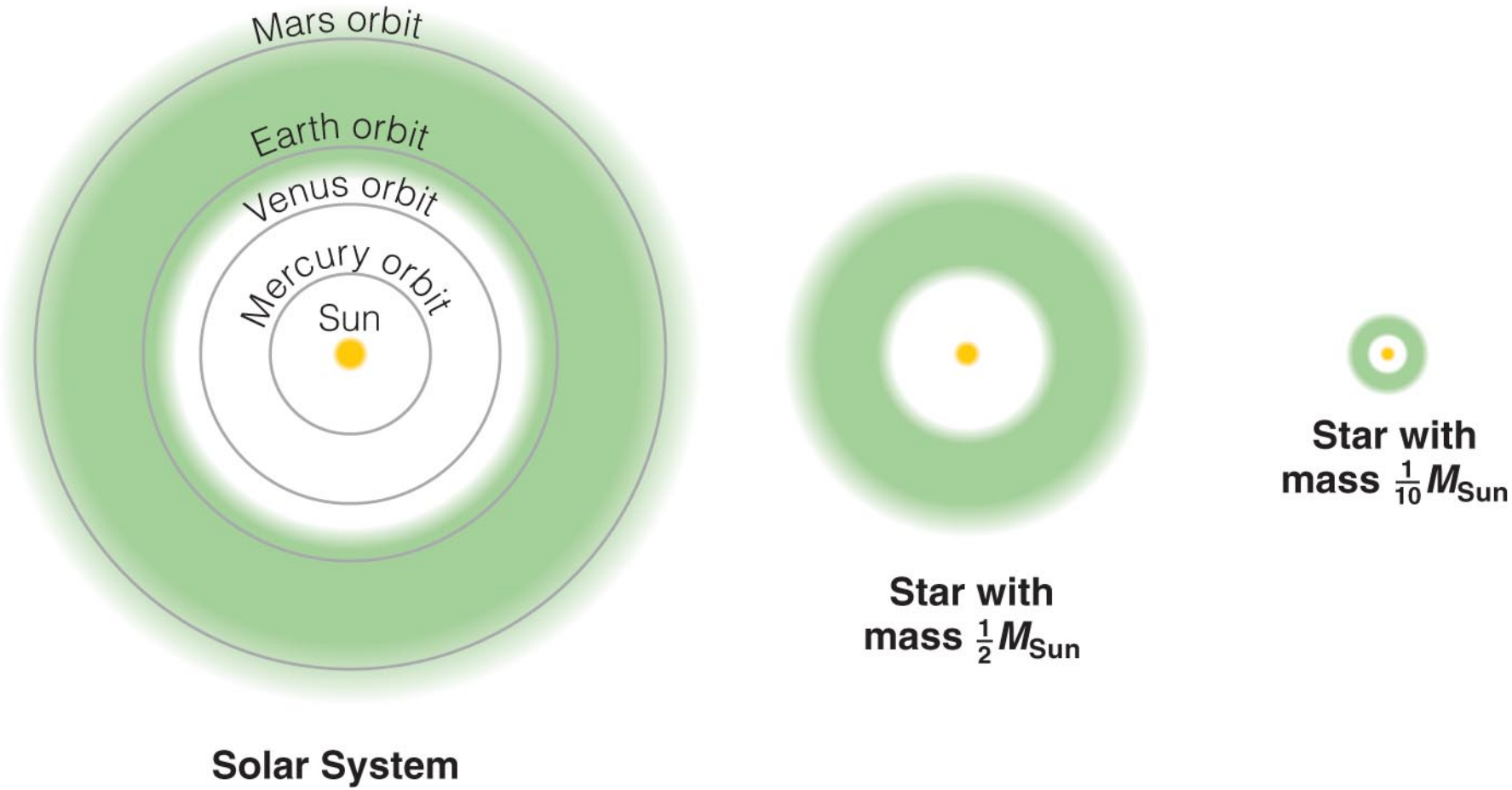
© 2014 Pearson Education, Inc.

24.3 Life around Other Stars

- Our goals for learning:
  - **What kinds of stars might have habitable planets?**
  - **Are Earth-like planets rare or common?**

© 2014 Pearson Education, Inc.

What kinds of stars might have habitable planets?



© 2014 Pearson Education, Inc.

Habitable Planets

- Definition:
  - A **habitable** world contains the basic necessities for life as we know it, including liquid water.
  - It does *not* necessarily have life.

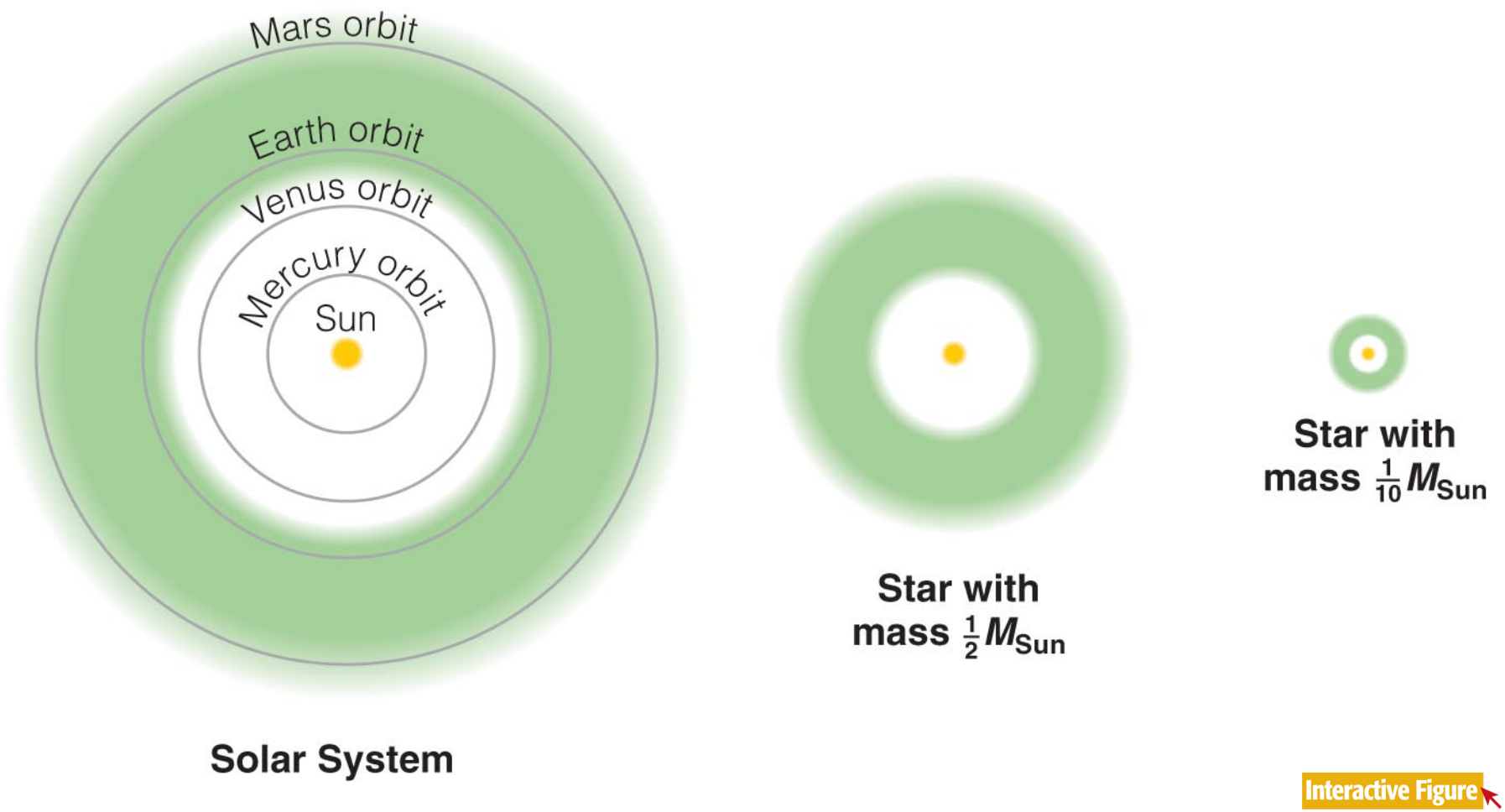
© 2014 Pearson Education, Inc.

Stars Systems with Habitable Planets

- Star system constraints:
  1) Old enough to allow time for evolution (rules out high-mass stars - 1%)
  2) Need to have stable orbits (*might* rule out binary/multiple star systems - 50%)
  3) Size of "habitable zone": region in which a planet of the *right size* could have liquid water on its surface

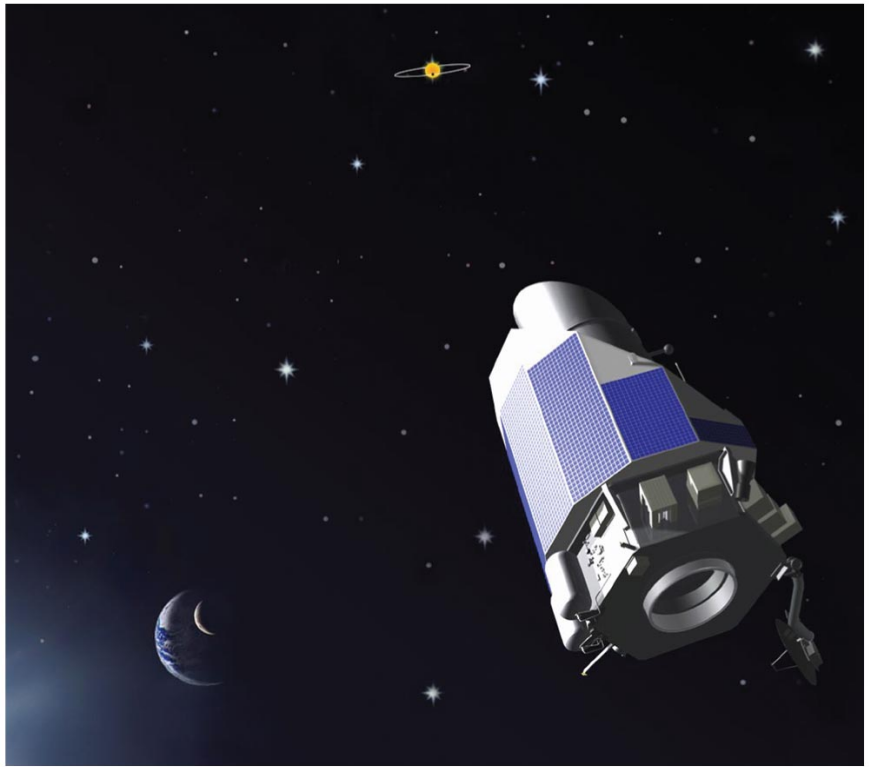
- Even with these constraints, billions of stars in the Milky Way could potentially have habitable worlds.

© 2014 Pearson Education, Inc.



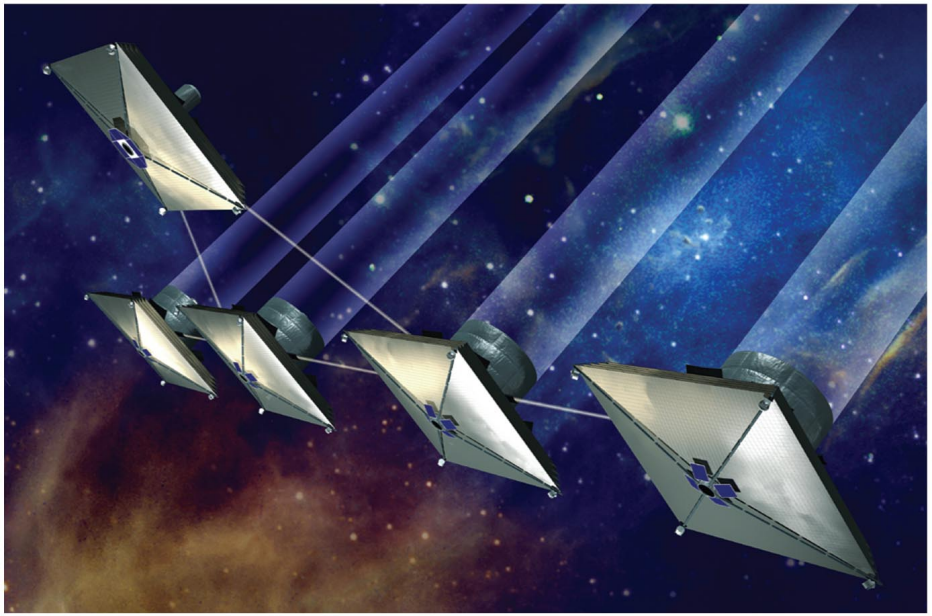
- The more massive the star, the larger its habitable zone—and the higher probability of a planet existing in this zone.

© 2014 Pearson Education, Inc.



- *Kepler* (launched in 2009) monitored ~100,000 stars for transit events for 4 years.

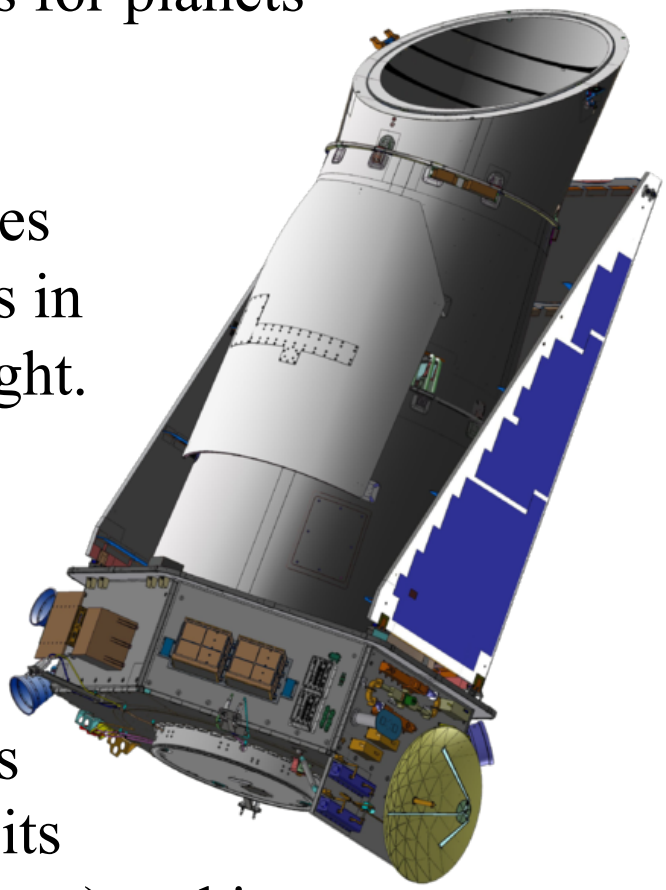
- Future interferometers may obtain spectra and crude images of Earth-size planets.



© 2014 Pearson Education, Inc.

Kepler : Searching for Earth-like planets

The Kepler mission is searching the skies for planets similar in size to Earth.



Kepler searches for dips in the light curves that occur when a transiting planet passes in front of its star and blocks some of the light.

The degree of this dip in brightness can be used to deduce the **diameter of the planet**, and the interval between transits can be used to deduce the planet's **orbital period**, from which estimates of its orbital semi-major axis (using Kepler's laws) and its temperature (using models of stellar radiation) can be calculated.

Kepler Finds Earth-Sized Planets!

- The Kepler mission has already discovered many planets in the habitable zone.
- One of the exoplanets discovered by Kepler in the middle of the habitable zone is Kepler 22b. It has a radius ~ 2× Mass_Earth and orbits a star slightly cooler than our sun.
- It is estimated that our galaxy contains about 10 billion habitable planets

© 2014 Pearson Education, Inc.

Confirming Habitability

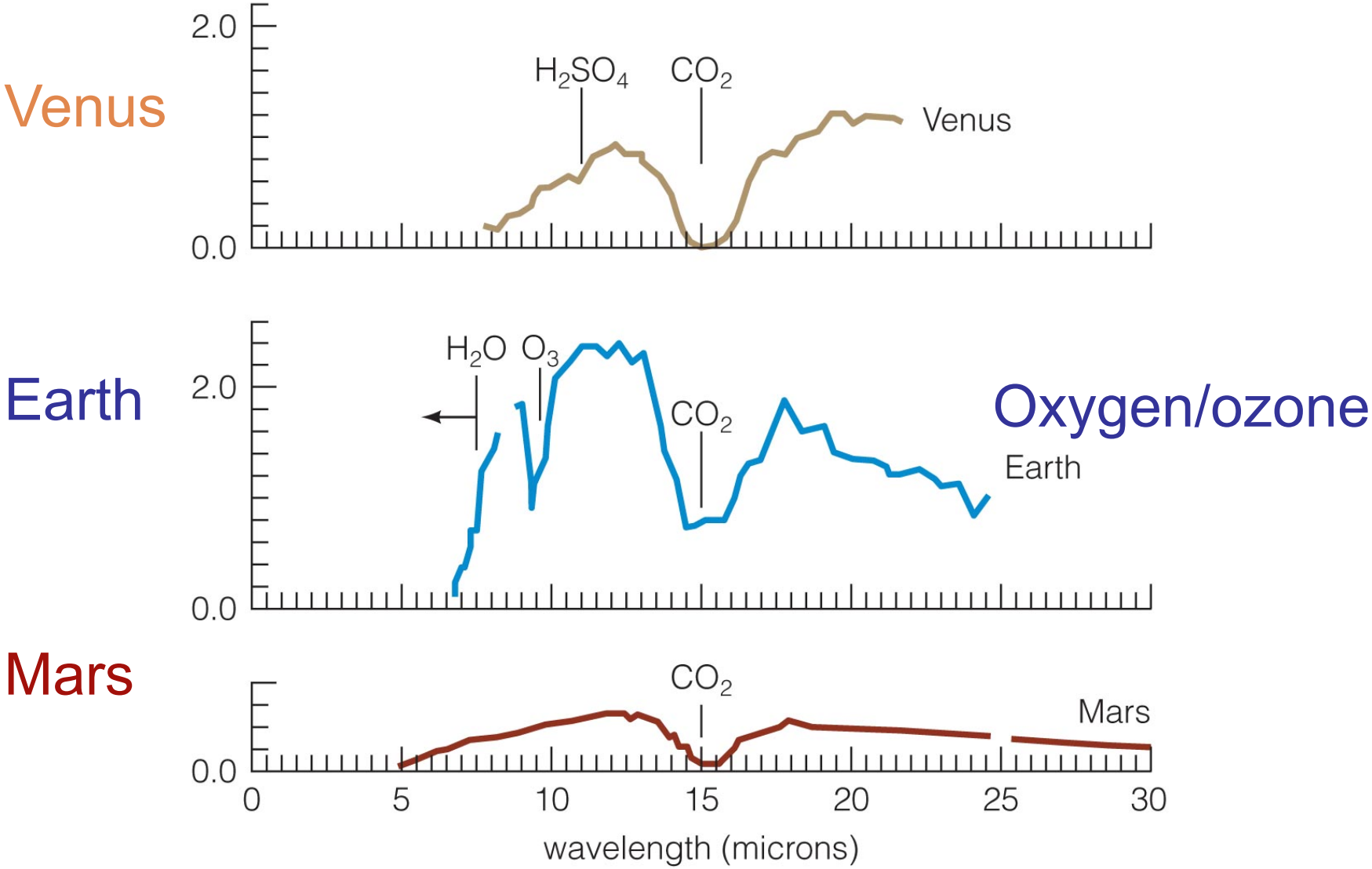
- For now we can at best say that a planet is **potentially habitable.**

- In order to confirm that a planet is habitable we need to **confirm that the surface conditions allow for liquid water**. This can be obtained from spectra.

- IR spectra can reveal the presence of many atmospheric gases including CO_2, O_3 CH_4 H_2O

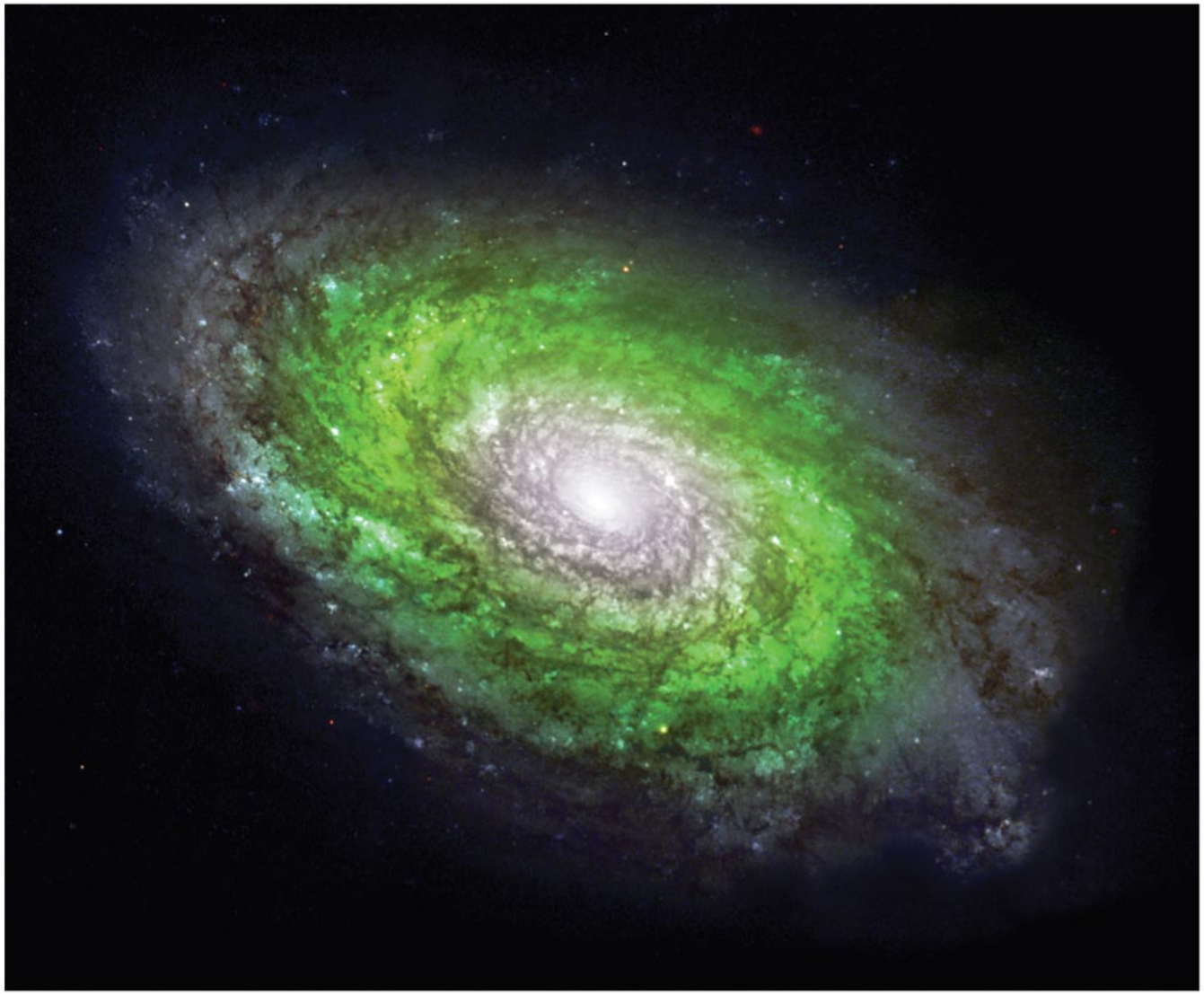
© 2014 Pearson Education, Inc.

Spectral Signatures of Life



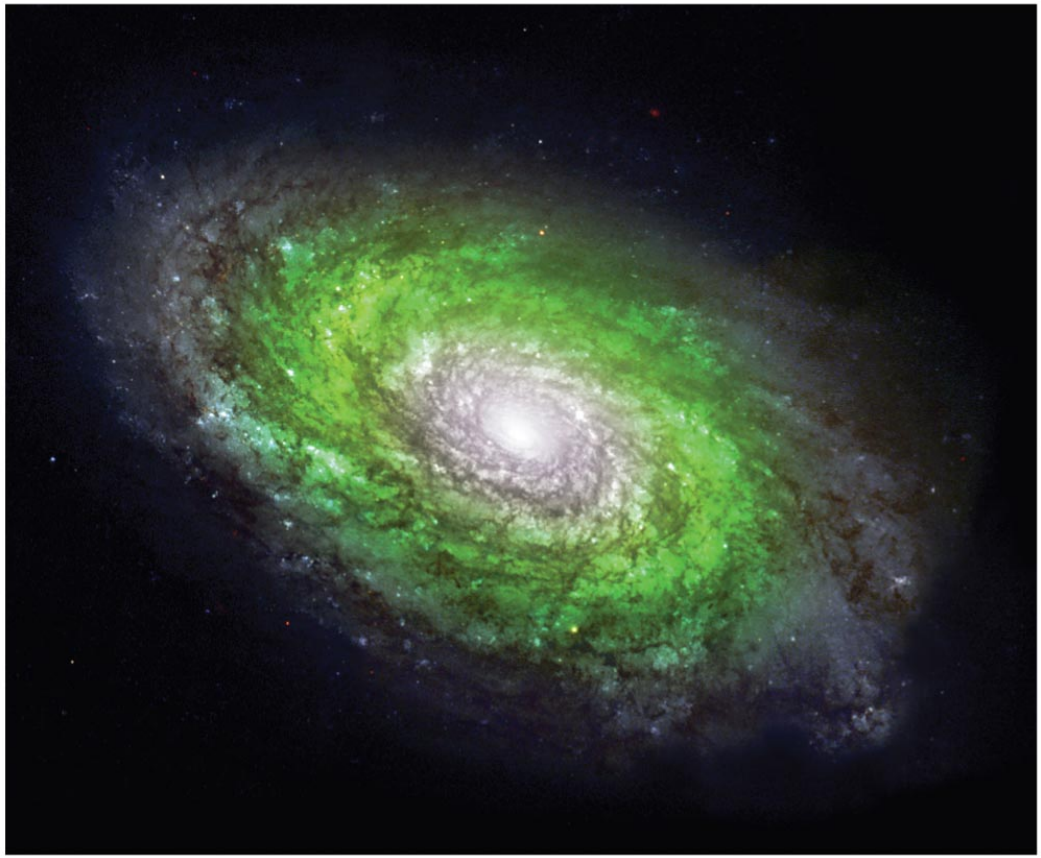
© 2014 Pearson Education, Inc.

Are Earth-like planets rare or common?



© 2014 Pearson Education, Inc.

Rare Earth Hypothesis: Low Metallicity reduces Habitability



- Some scientists argue that the proportions of heavy elements need to be just right for the formation of habitable planets.
- If so, then Earth-like planets are restricted to a **galactic habitable zone**.

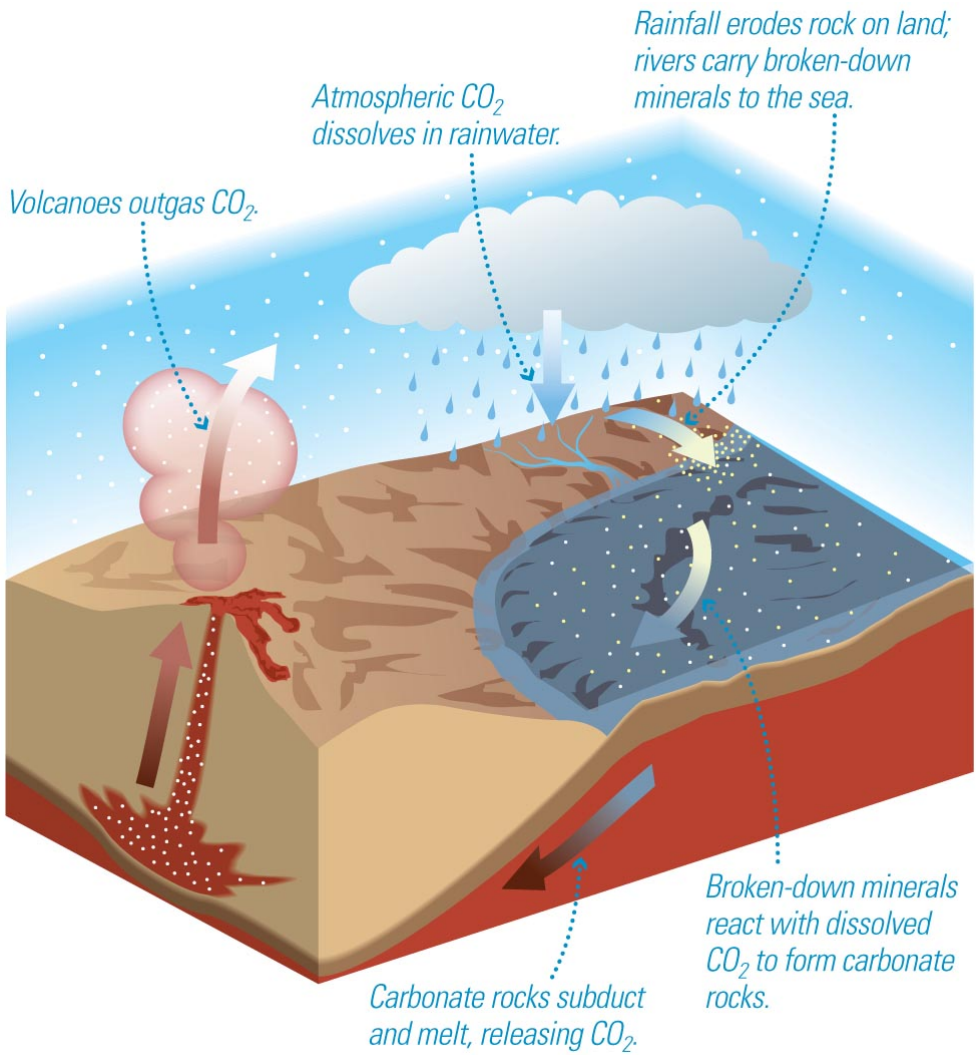
© 2014 Pearson Education, Inc.

Rare Earth Hypothesis: Impacts Reduce Habitability

- Some scientists argue that **Jupiter-like planets are necessary to reduce rate of impacts.**
- If so, then Earth-like planets are restricted to star systems with Jupiter-like planets.

© 2014 Pearson Education, Inc.

Rare Earth Hypothesis: Stable Climate Required for Habitability



- Some scientists argue that plate tectonics and/or a large moon are necessary to keep the climate of an Earth-like planet stable enough for life.

© 2014 Pearson Education, Inc.

The Bottom Line

We don't yet know how important or negligible these concerns are.

© 2014 Pearson Education, Inc.

What have we learned?

- **What kinds of stars might have habitable planets?**
  - Billions of stars have sizable habitable zones, but we don't yet know how many have terrestrial planets in those zones.
- **Are Earth-like planets rare or common?**
  - We don't yet know because we are still trying to understand all the factors that make Earth suitable for life.

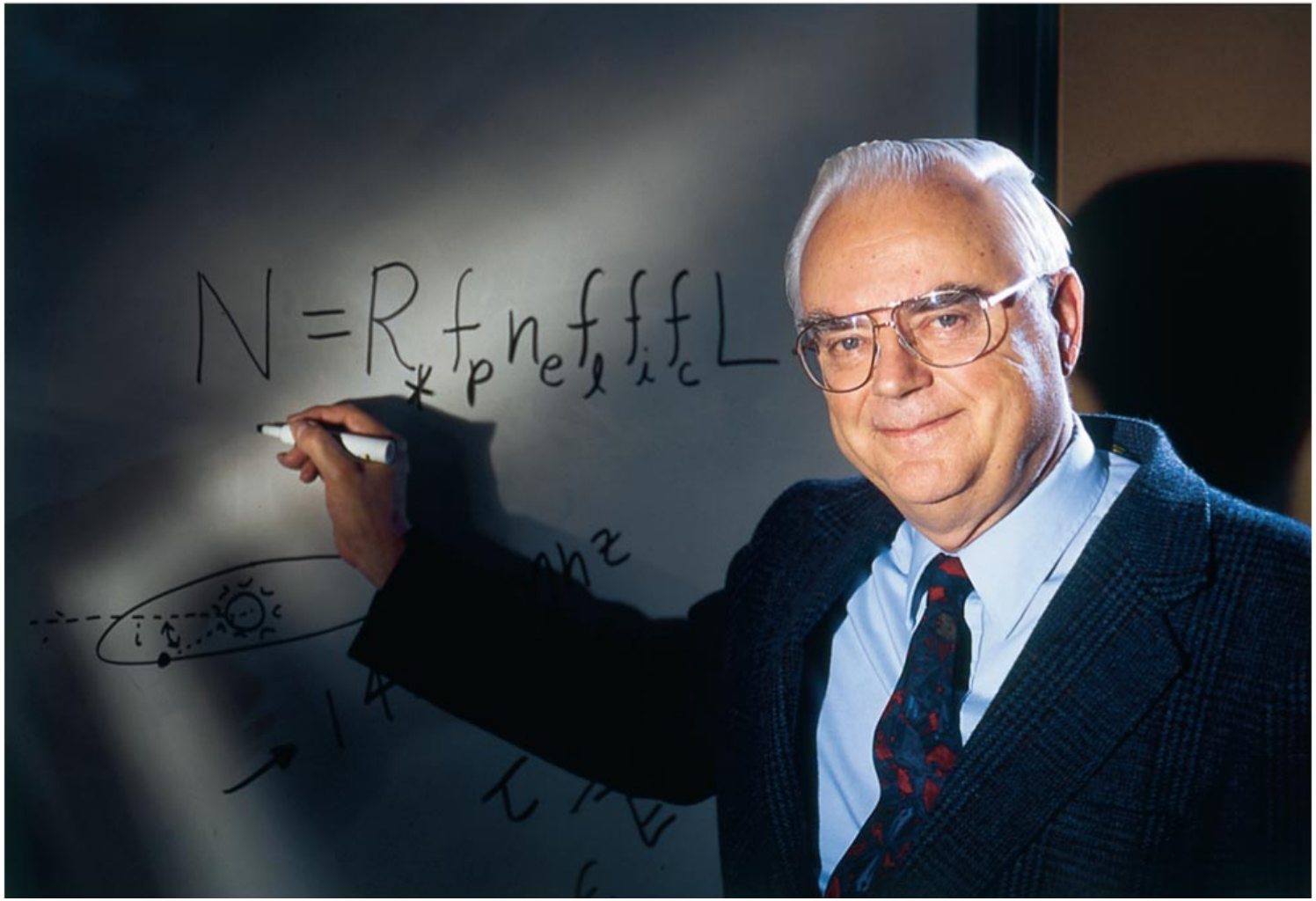
© 2014 Pearson Education, Inc.

24.4 The Search for Extraterrestrial Intelligence

- Our goals for learning:
  - **How many civilizations are out there?**
  - **How does SETI work?**

© 2014 Pearson Education, Inc.

How many civilizations are out there?



© 2014 Pearson Education, Inc.

Drake Equation : How many intelligent ET's are there in our Galaxy?

$$N = R_* f_p n_e f_{life} f_i f_c L$$

N = Number of technologically advanced civilizations in the Galaxy whose messages we might be able to detect.

R_* = the rate at which solar-type stars form in the Galaxy ~ 1 per year
f_p = the fraction of sunlike stars that have planets ~ 1
n_e = the number of planets per stellar system that are habitable ~ 2
f_{life} = the fraction of those Earthlike planets on which life actually arises~1
f_i = the fraction of those life-forms that evolve into intelligent species~1
f_c = the fraction of those species that develop adequate technology and then choose to send messages out into space~1
L = lifetime of a technologically advanced civilization~10,000 years

N = 1/year × 1 × 2 × 1 × 1 × 0.1 × 10,000 years = 2,000 technologically advanced civilizations in our Galaxy out of the hundred billion stars in it.

How does SETI work?

CONTACT

© 2014 Pearson Education, Inc.

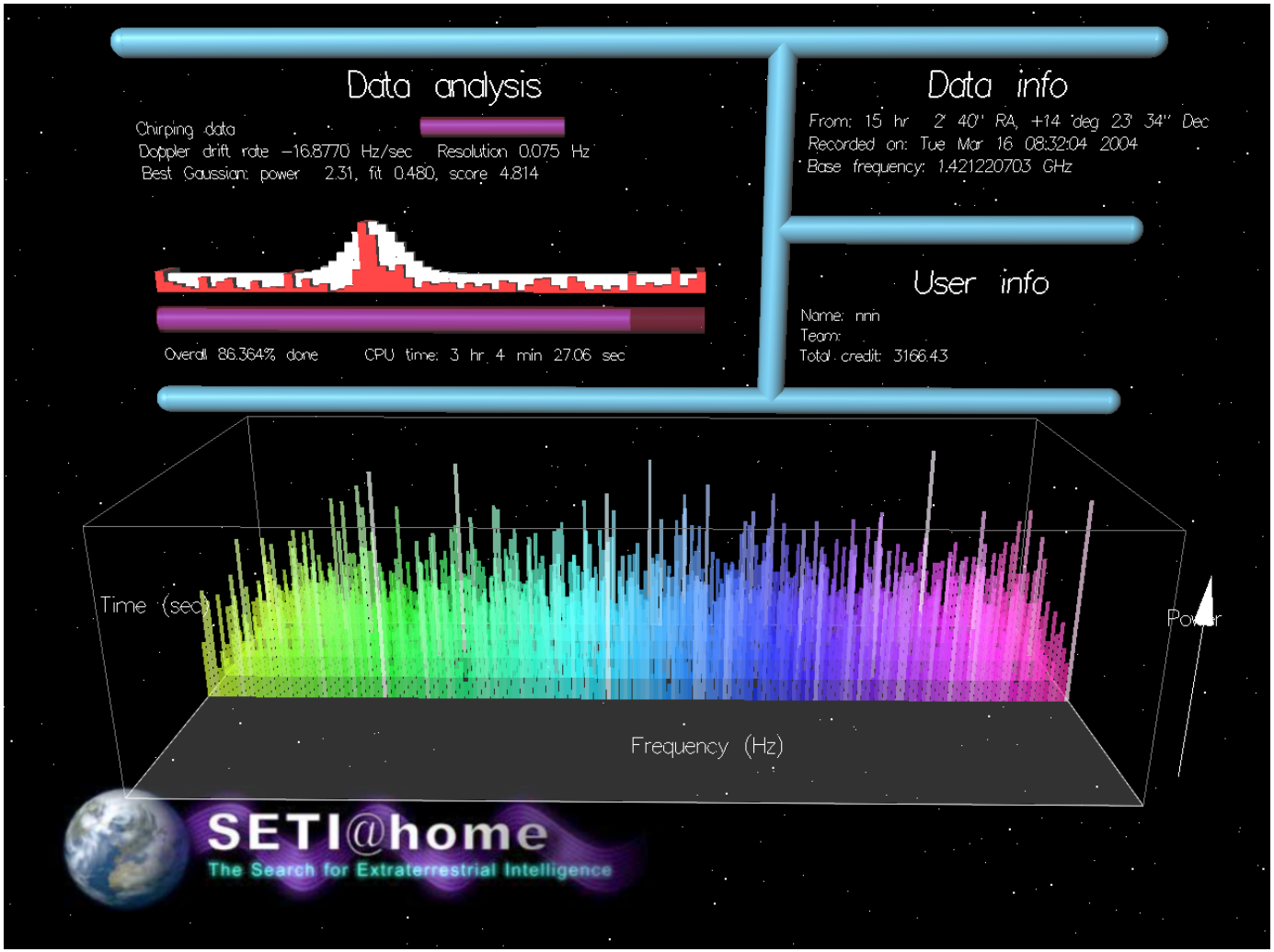
- SETI experiments look for **deliberate** signals from extraterrestrials

© 2014 Pearson Education, Inc.

- We've even sent a few signals ourselves…

- Earth to globular cluster M13: Hoping we'll hear back in about 42,000 years!

© 2014 Pearson Education, Inc.



- Your computer can help! SETI @ Home: a screensaver with a purpose

© 2014 Pearson Education, Inc.

What have we learned?

- **How many civilizations are out there?**
  - We don't know, but the Drake equation gives us a framework for thinking about the question.
- **How does SETI work?**
  - Some telescopes are looking for deliberate communications from other worlds.

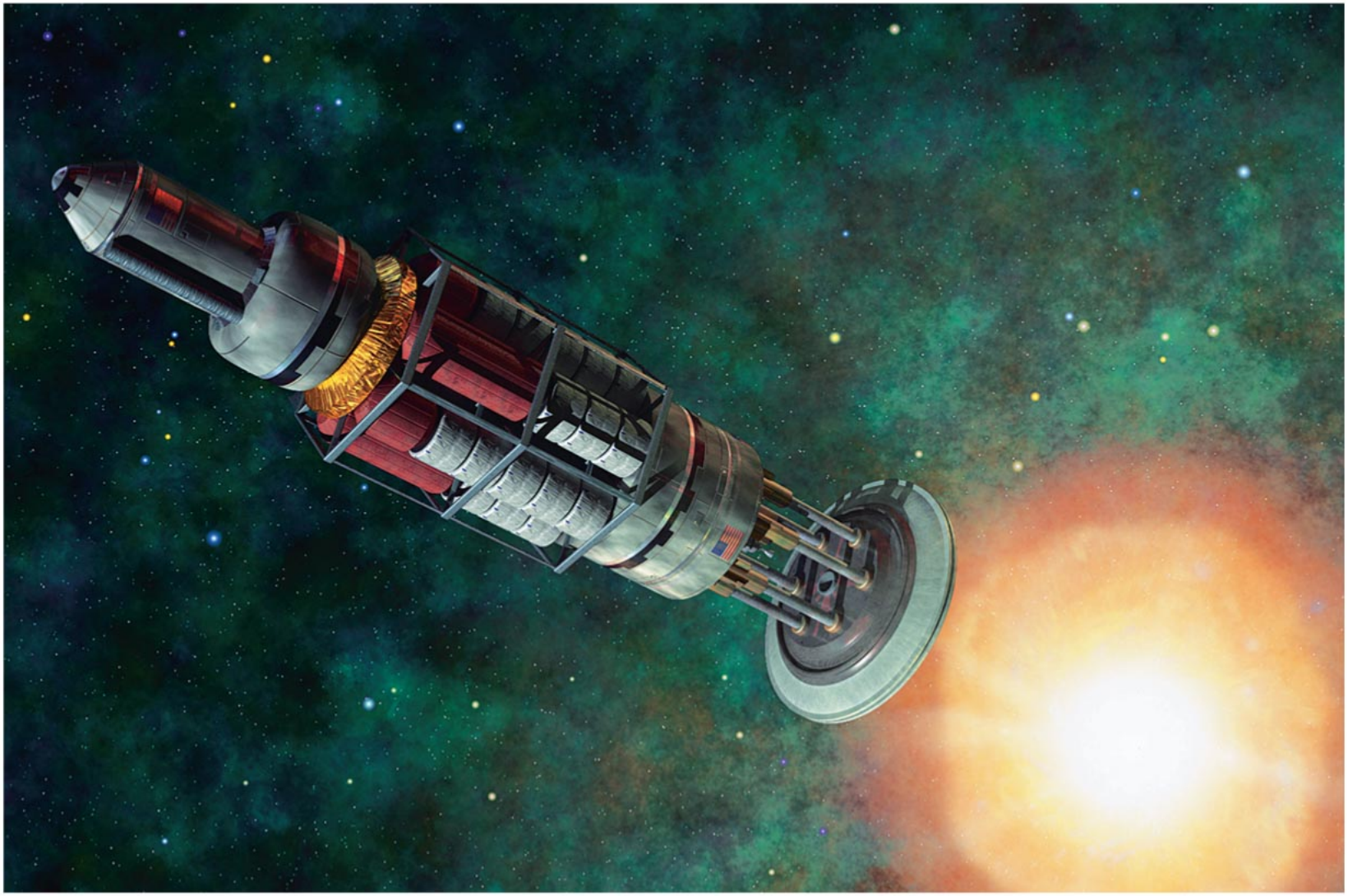
© 2014 Pearson Education, Inc.

24.5 Interstellar Travel and Its Implications to Civilization

- Our goals for learning:
  - **How difficult is interstellar travel?**
  - **Where are the aliens?**

© 2014 Pearson Education, Inc.

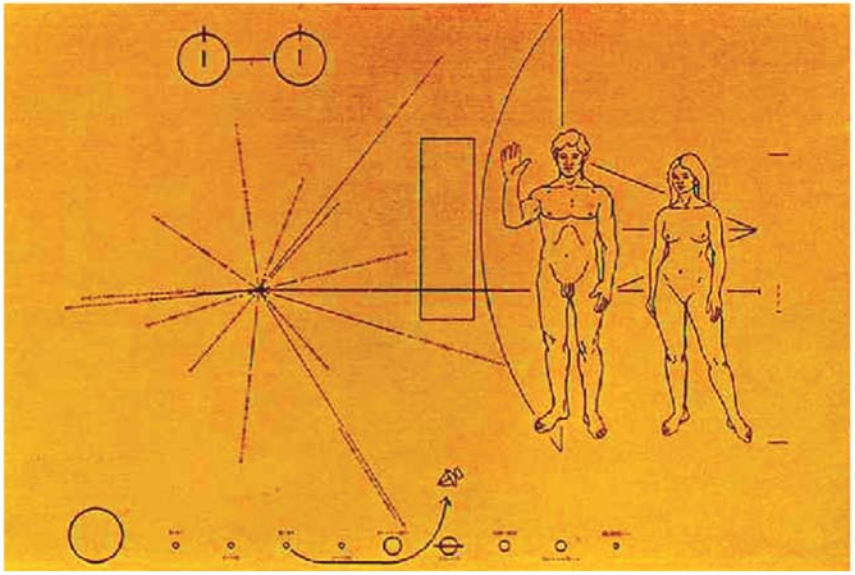
How difficult is interstellar travel?



© 2014 Pearson Education, Inc.

Current Spacecraft

- Current spacecraft travel at <1/10,000*c*; 100,000 years to the nearest stars

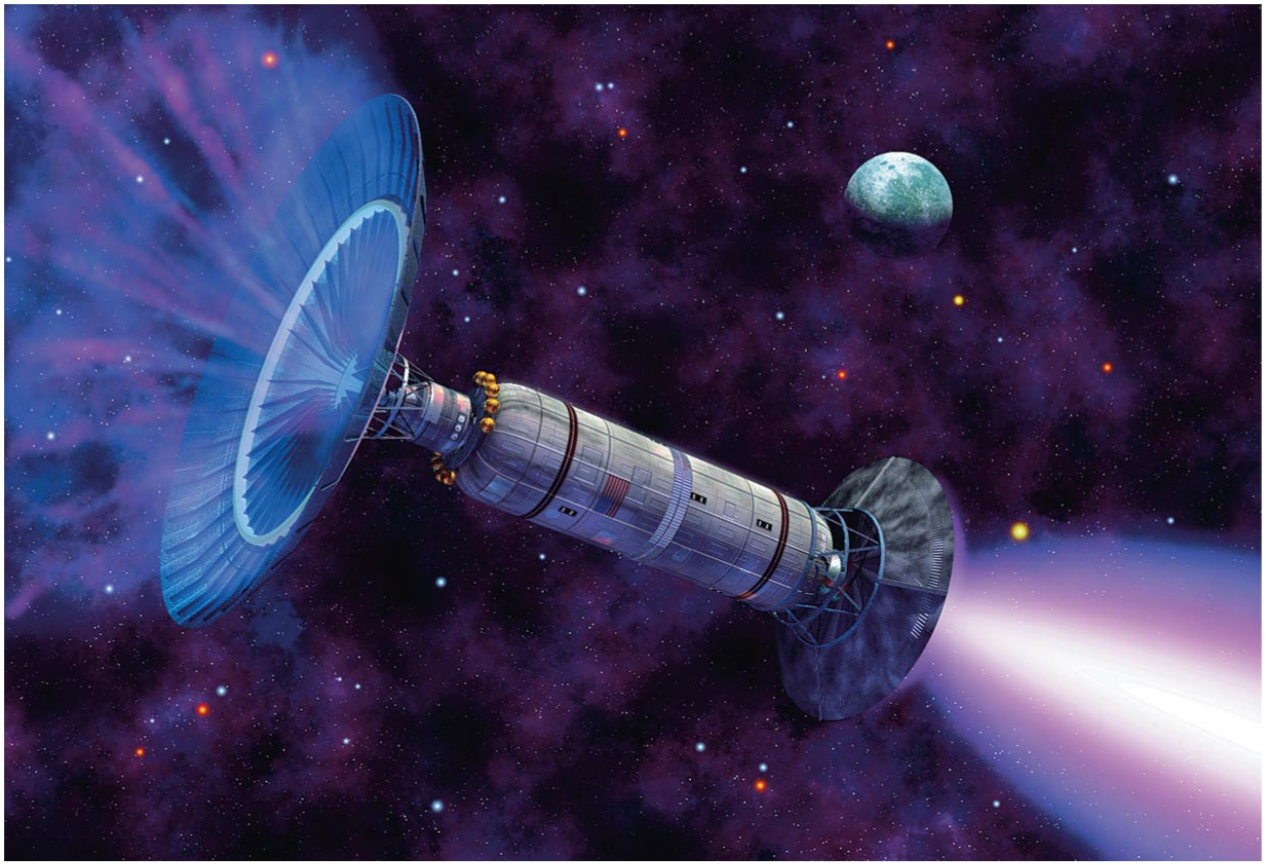


Pioneer plaque

Voyager record

© 2014 Pearson Education, Inc.

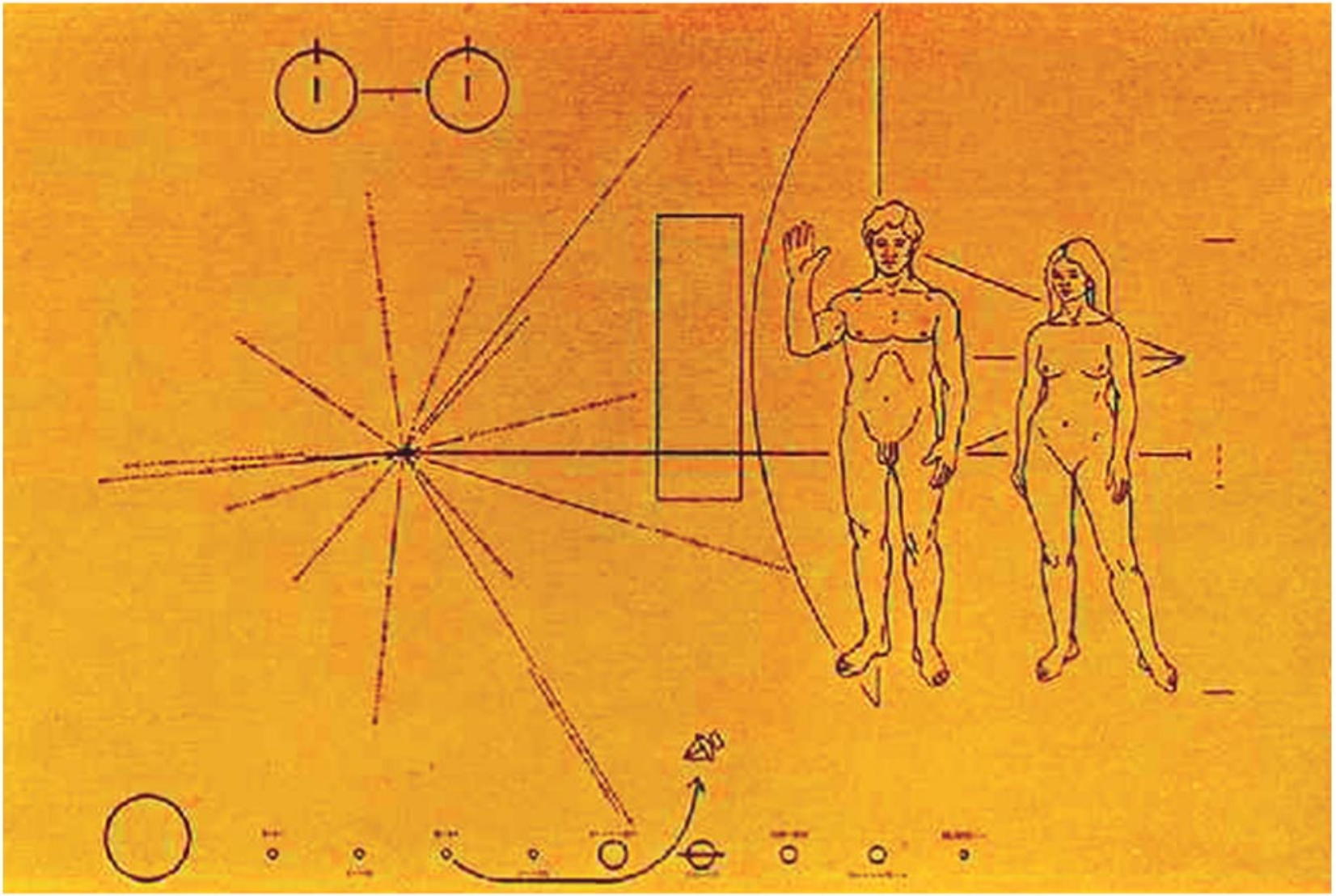
Difficulties of Interstellar Travel



- Far more efficient engines are needed.
- Energy requirements are enormous.
- Ordinary interstellar particles become like cosmic rays.
- Social complications of time dilation.

© 2014 Pearson Education, Inc.

Where are the aliens?



© 2014 Pearson Education, Inc.

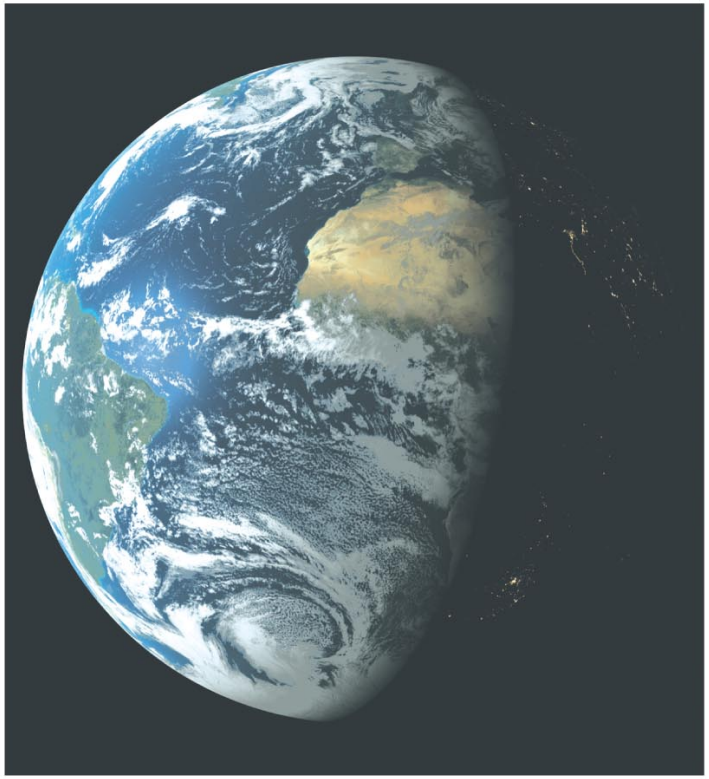
Fermi's Paradox

- Plausible arguments suggest that civilizations should be common. For example, even if only 1 in 1 million stars gets a civilization at some time $\Rightarrow$ 100,000 civilizations
- So why haven't we detected them?

© 2014 Pearson Education, Inc.

Possible solutions to the paradox

1) We are alone: life/civilization is much rarer than we might have guessed.
   - Our own planet/civilization looks all the more precious…



© 2014 Pearson Education, Inc.

Possible solutions to the paradox

2) Civilizations are common, but interstellar travel is not because:
   - interstellar travel is more difficult than we think.
   - the desire to explore is rare.
   - civilizations destroy themselves before achieving interstellar travel.

- These are all possibilities, but not very appealing…

© 2014 Pearson Education, Inc.

Possible solutions to the paradox

3) There IS a galactic civilization…
   … and some day we'll meet them.

© 2014 Pearson Education, Inc.

What have we learned?

- **How difficult is interstellar travel?**
  - Interstellar travel remains well beyond our current capabilities and poses enormous difficulties.
- **Where are the aliens?**
  - Plausible arguments suggest that if interstellar civilizations are common then at least one of them should have colonized the rest of the galaxy.
  - Are we alone? Has there been no colonization? Are the colonists hiding? We don't know yet.

© 2014 Pearson Education, Inc.