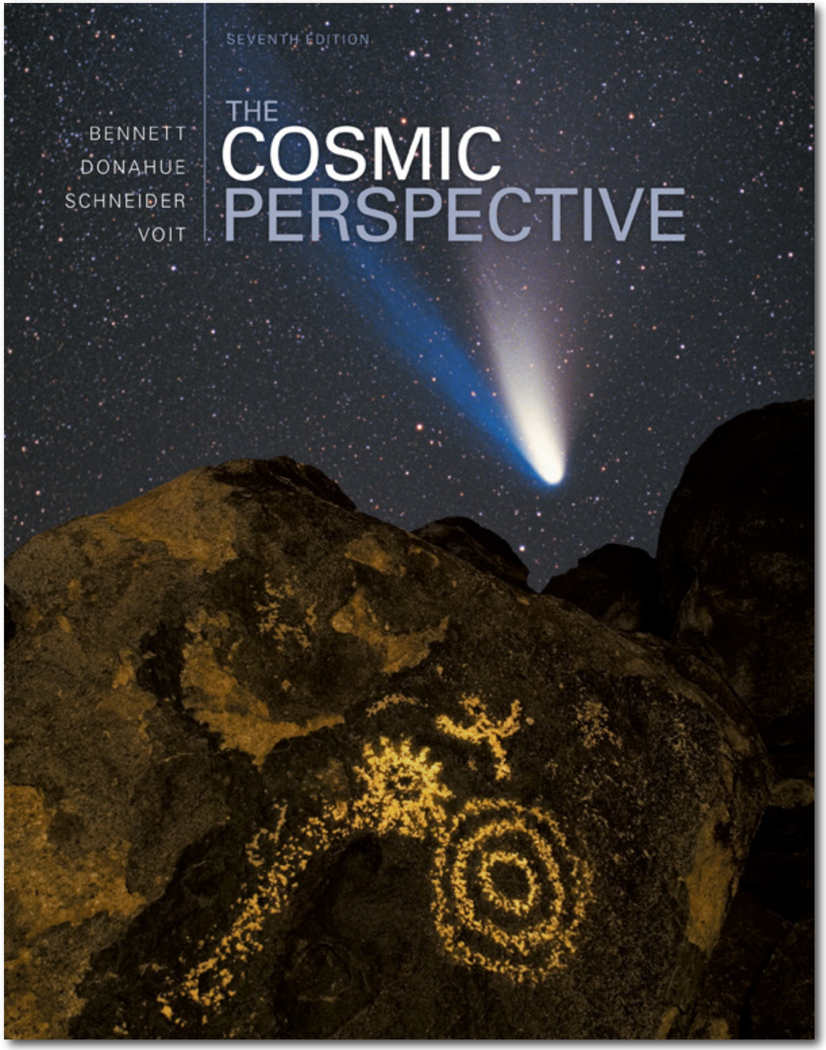
The Cosmic Perspective

Seventh Edition



Life in the Universe

Aliens Among US?

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?

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**?

Do we live in a simulation?

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.

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.

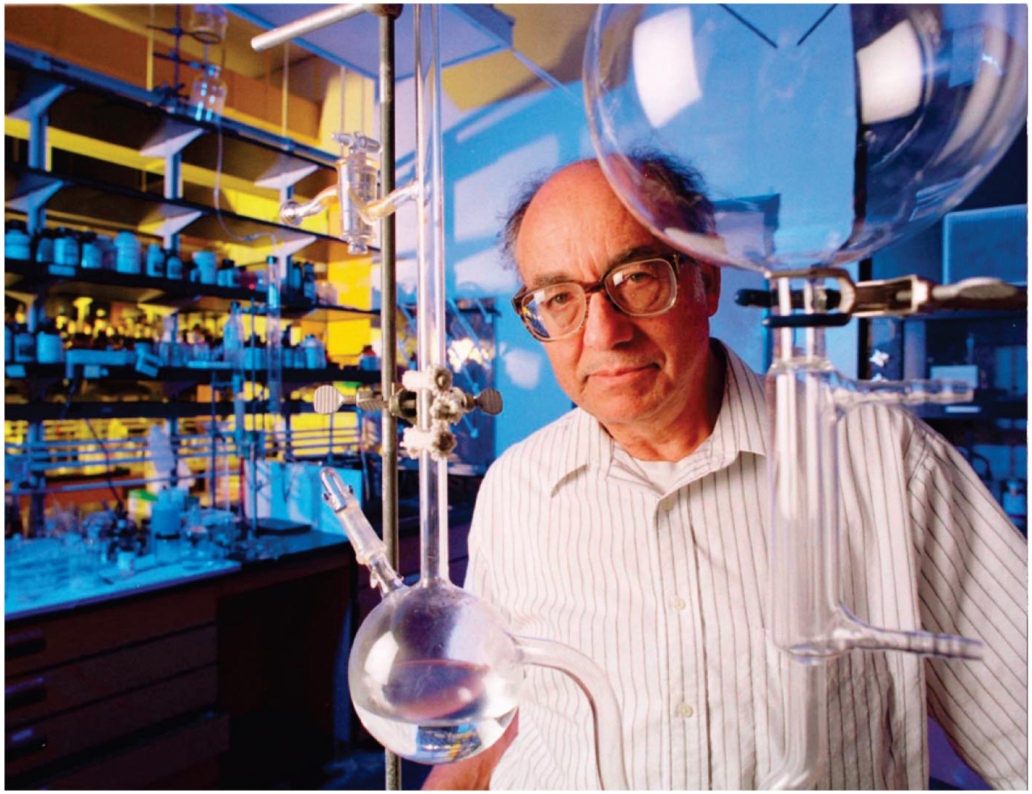
Over millions of years sediments pileup and compress the underlying layers into rocks that preserve the fossils.

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

Earliest Fossils

- The oldest fossils show that **bacteria-like organisms** were present over 3.5 billion years ago.

Laboratory Experiments



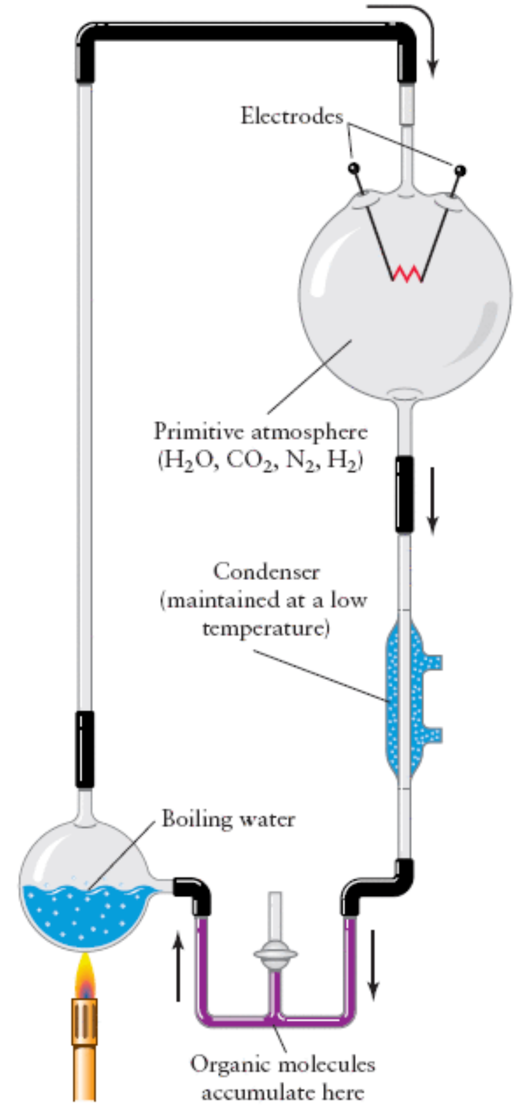
- The Miller experiment (and more recent experiments) show that the building blocks of life form easily and spontaneously under the conditions of early Earth.

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.

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.

Could life have migrated to Earth?

(a)

(b)

Several meteorites 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?

(a) (b)

The martian meteorite ALH 84001 (found in Allan Hills in Antartica) 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**.

The wider scientific community ultimately has rejected the hypothesis that the tubelike structures in ALH 84001 were made by organisms on Mars.

Necessities for Life

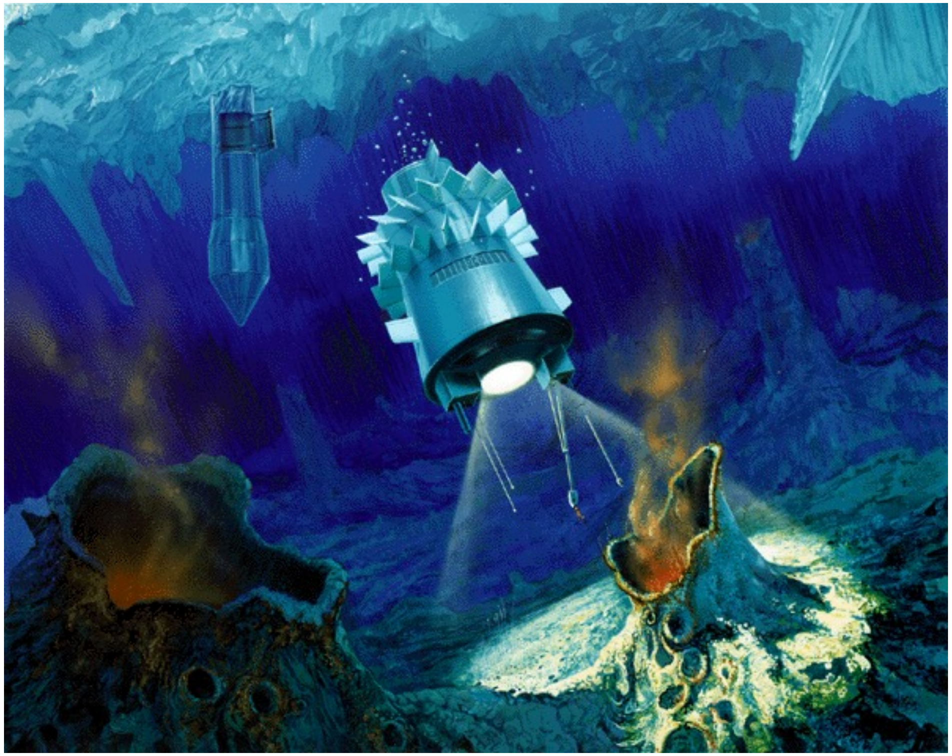
- A nutrient source from which to build cells.
- Energy (sunlight, chemical reactions, internal heat)
- Liquid water (or possibly some other liquid)

Hardest to find on other planets

Necessities for Life

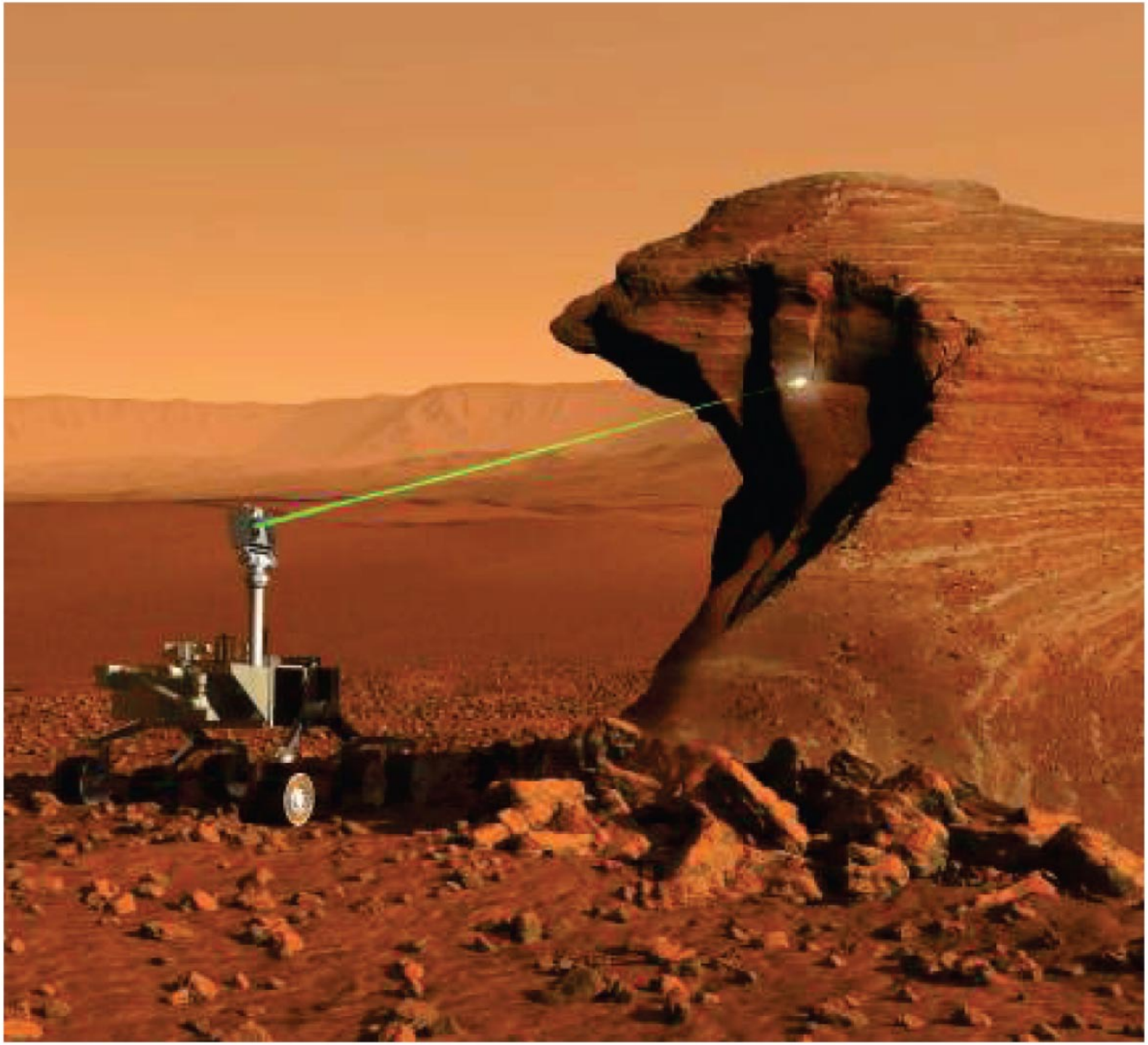
Liquid water is essential for life on Earth and might be essential for life on other alien worlds.

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

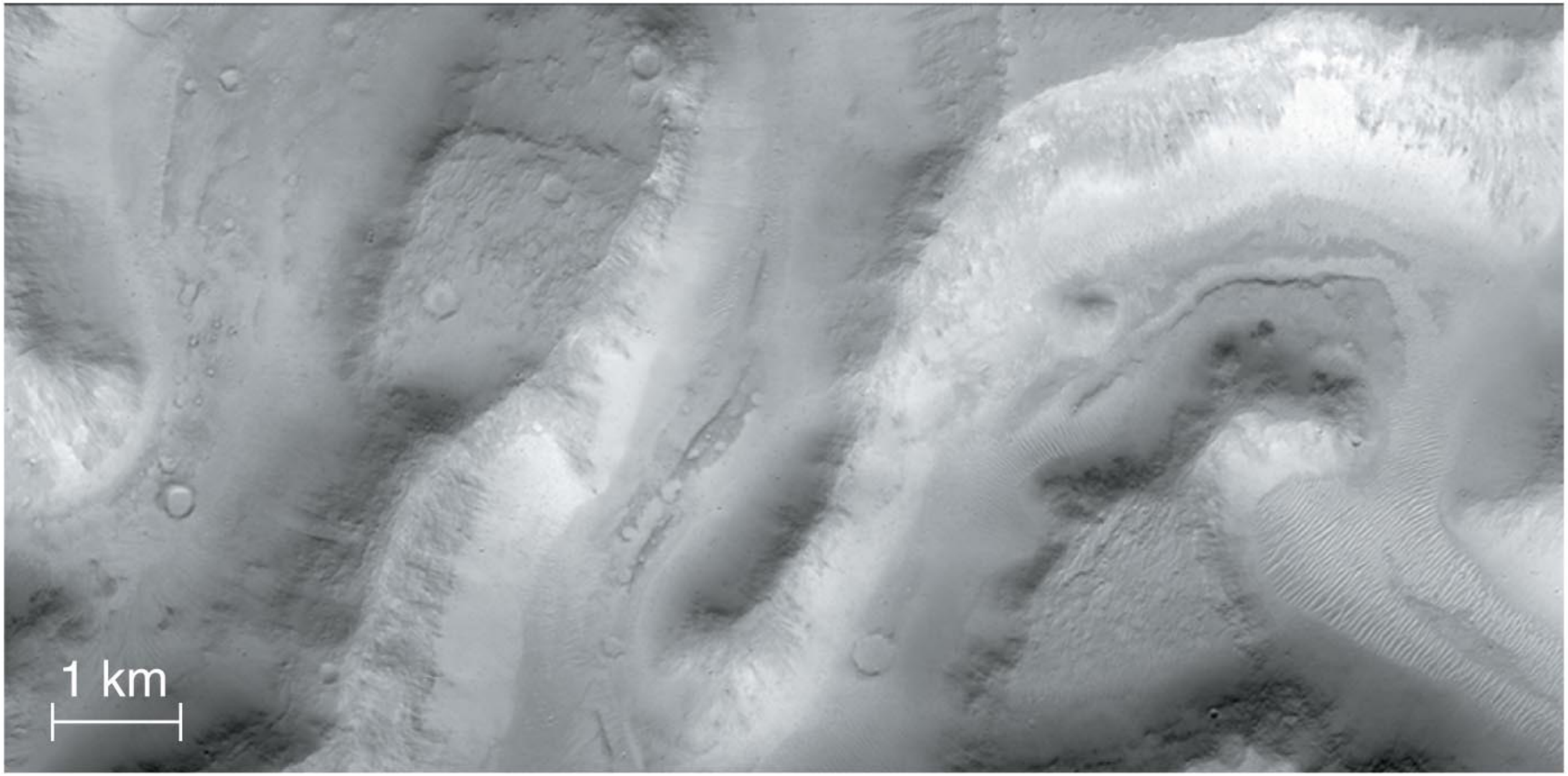


Submersible Probe Searching For Life on Europa.

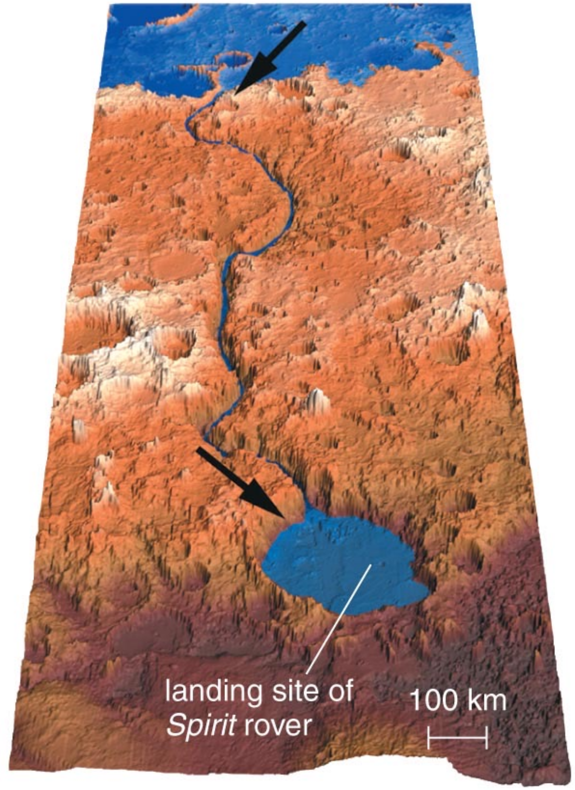
Could there be life on Mars?



Searches for Life on Mars



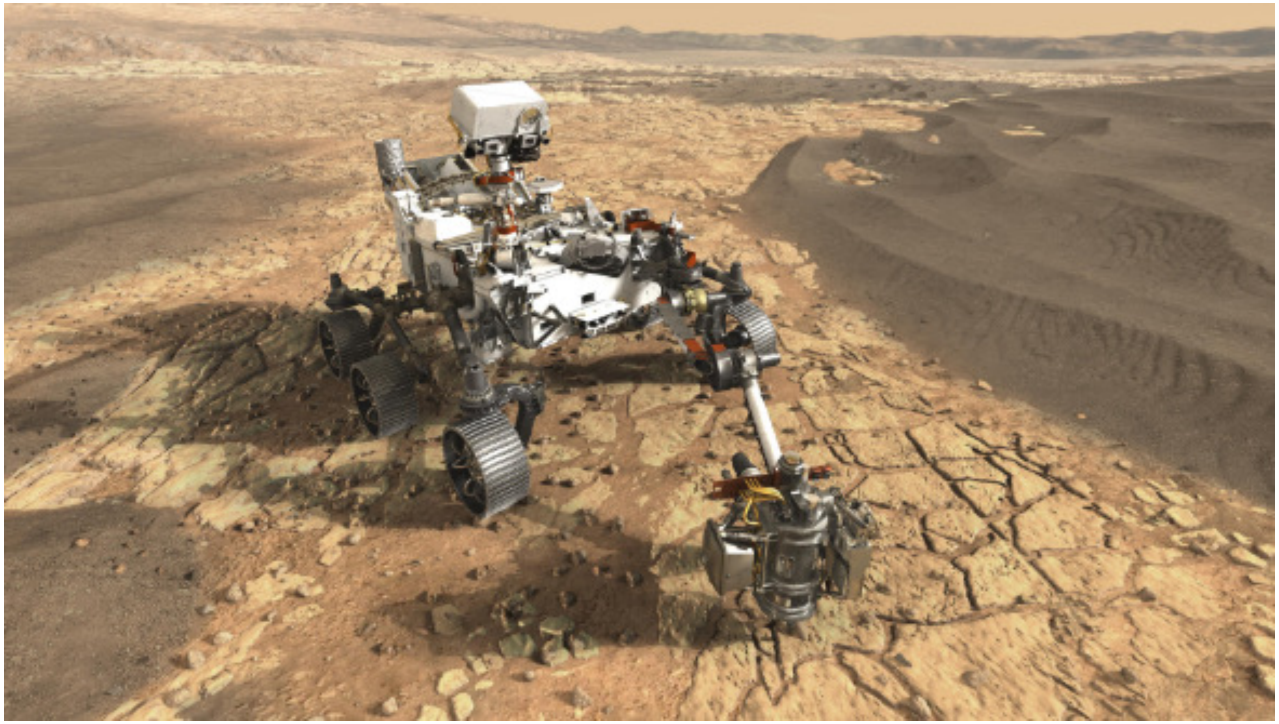
- Mars had liquid water in the distant past.
- Still has subsurface ice; possibly subsurface water near sources of volcanic heat



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.

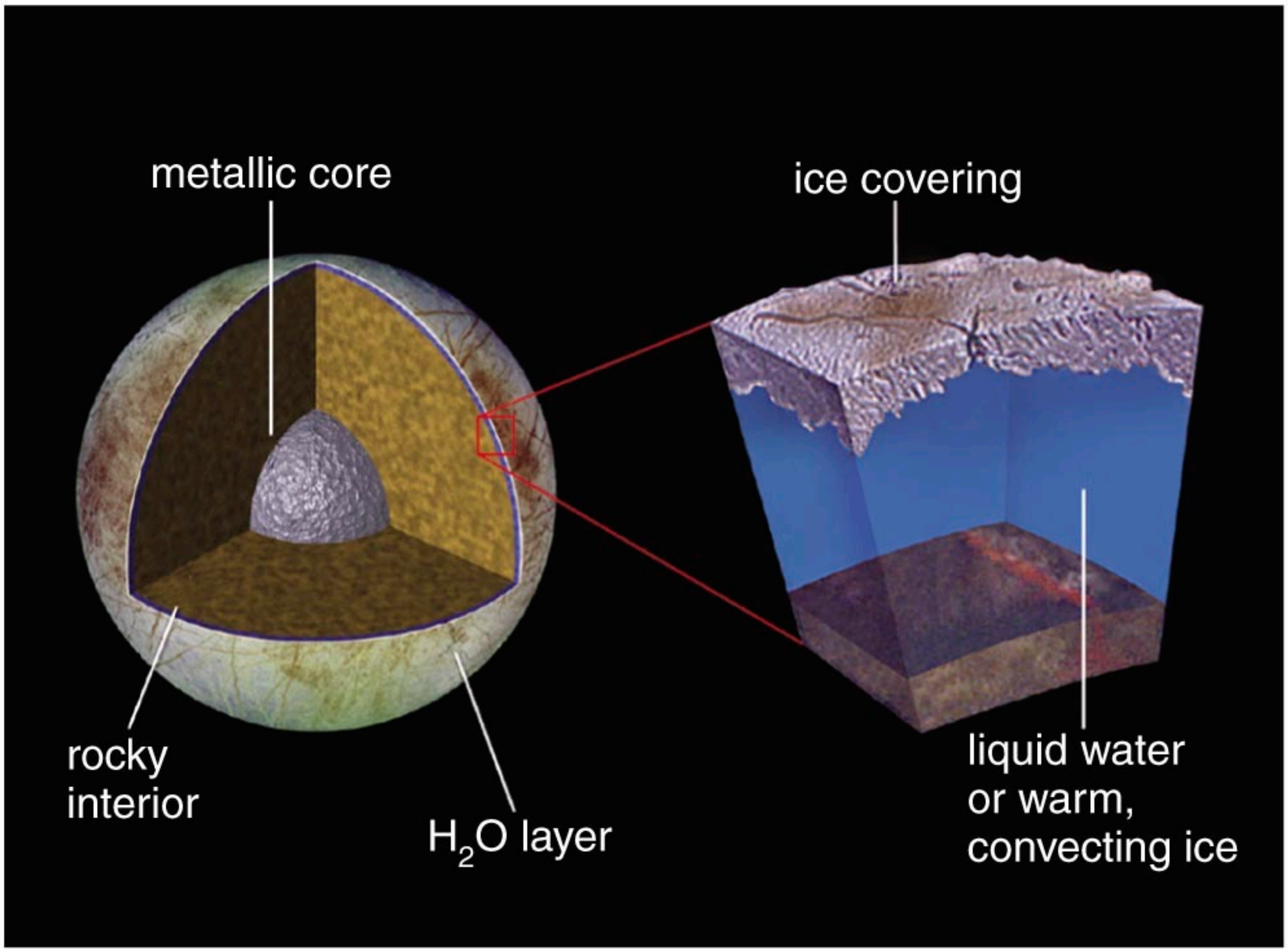
Mars Perseverance



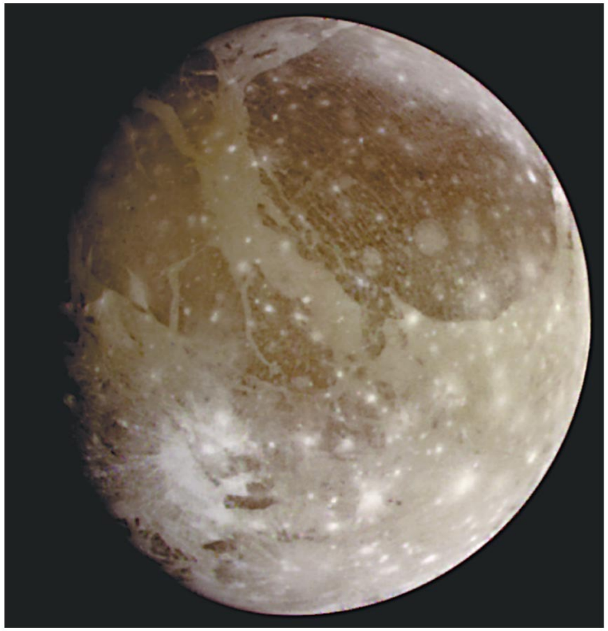
Perseverance is searching for signs of ancient life on Mars.

Perseverance is the first leg of a round trip to Mars.

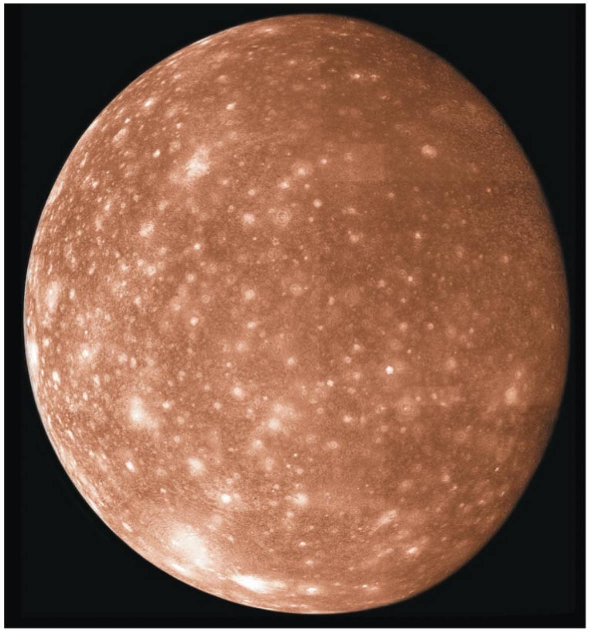
Could there be life on Europa or other jovian moons?



- Ganymede and Callisto also show some evidence for subsurface oceans.
- Intriguing prospect of THREE potential homes for life around Jupiter alone.

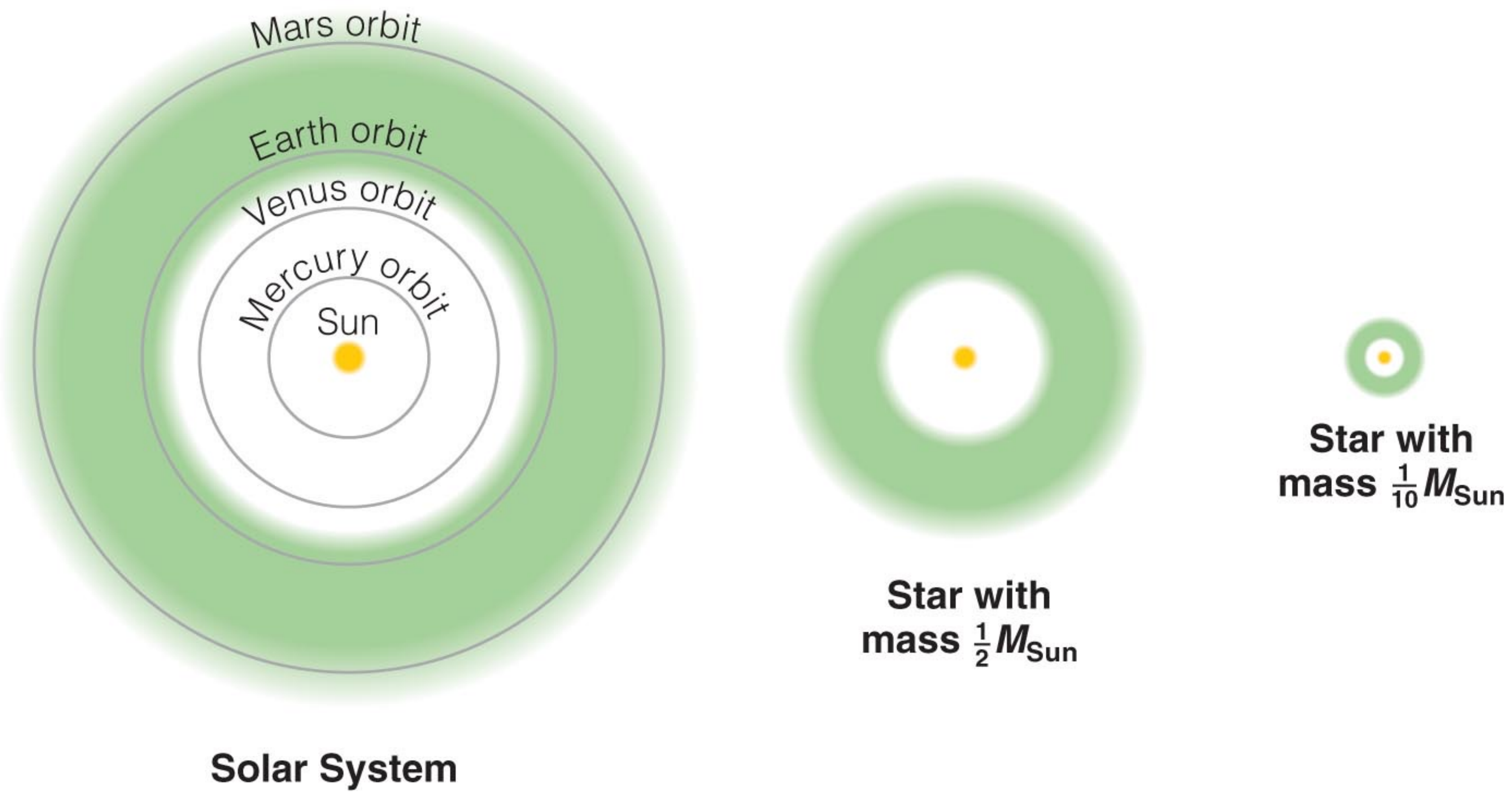


Ganymede



Callisto

What kinds of stars might have habitable planets?

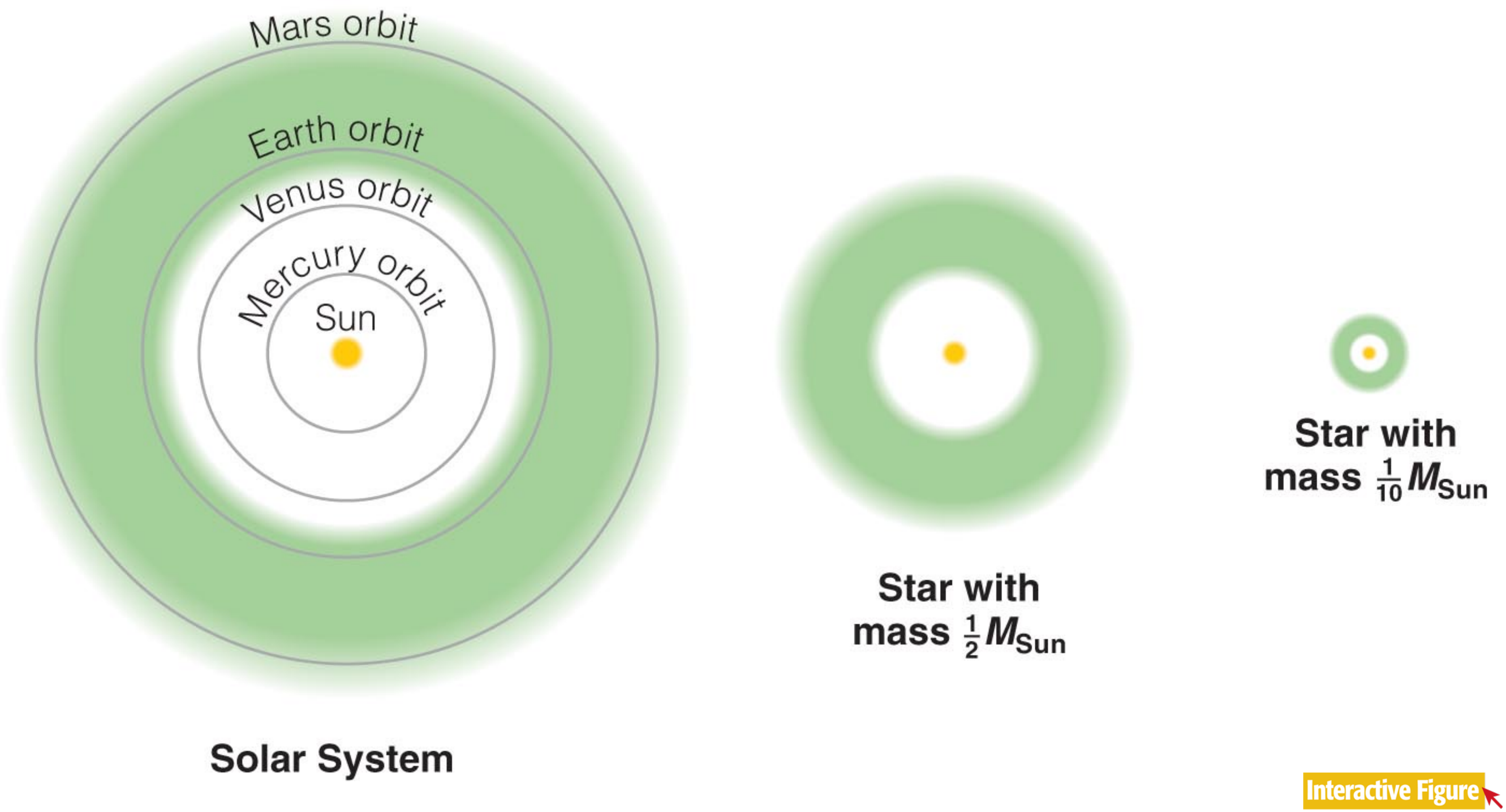


Habitable Planets

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

Stars Systems with Habitable Planets

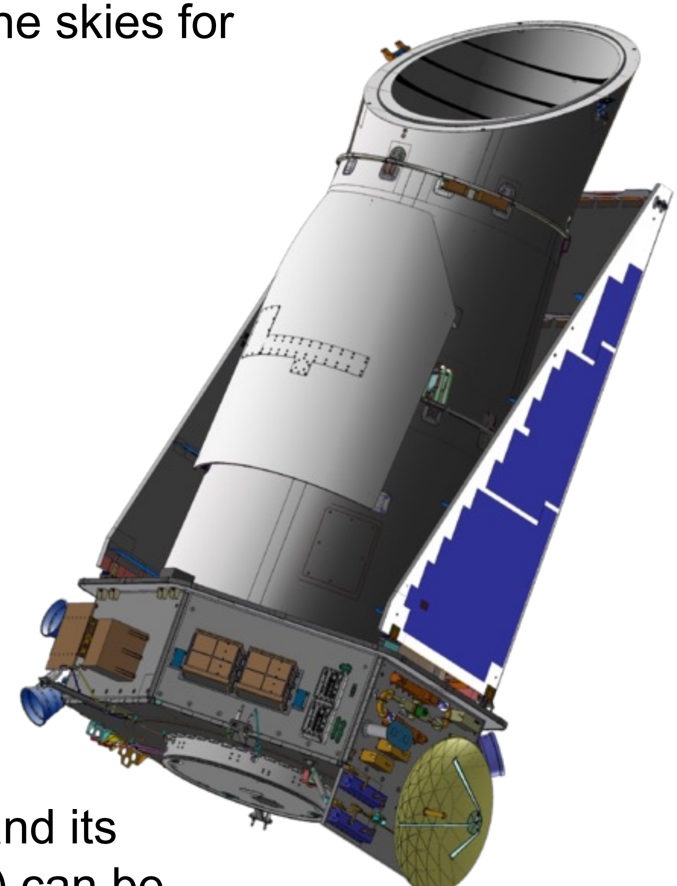
- Star system constraints:
  1) Old enough to allow time for evolution (rules out high-mass stars - 1%)
  2) Need to have stable orbits (*might* rule out binary/multiple star systems - 50%)
  3) Size of "habitable zone": region in which a planet of the *right size* could have liquid water on its surface



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

Kepler : Searching for Earth-like planets

The Kepler mission (2009 – 2018) searched the skies for planets similar in size to Earth.



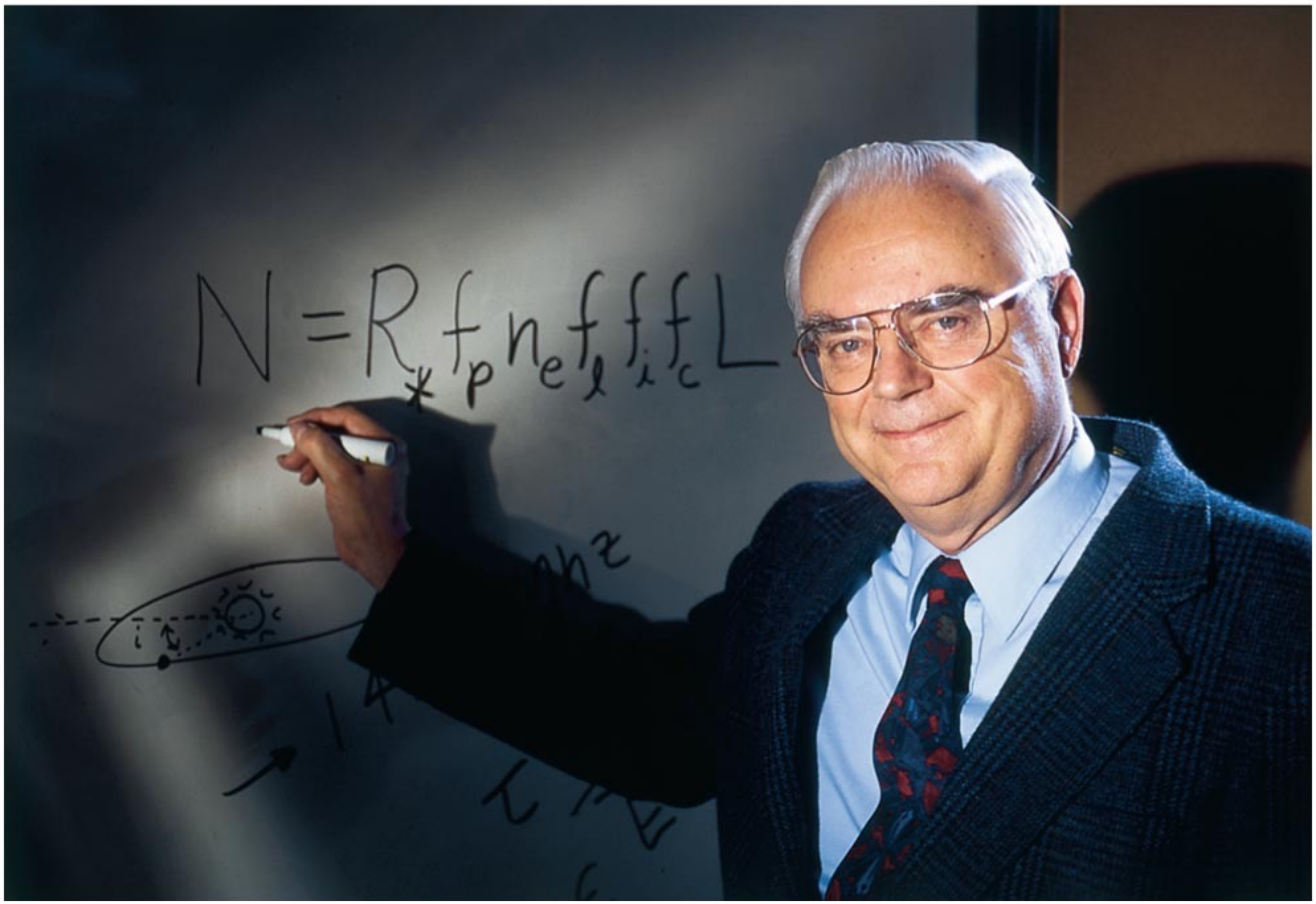
Kepler searched for dips in the light curves that occur when a transiting planet passes in front of its star and blocks some of the light.

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

How many civilizations are out there?



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~0.1
L = lifetime of a technologically advanced civilization~10,000 years

A very rough estimate:

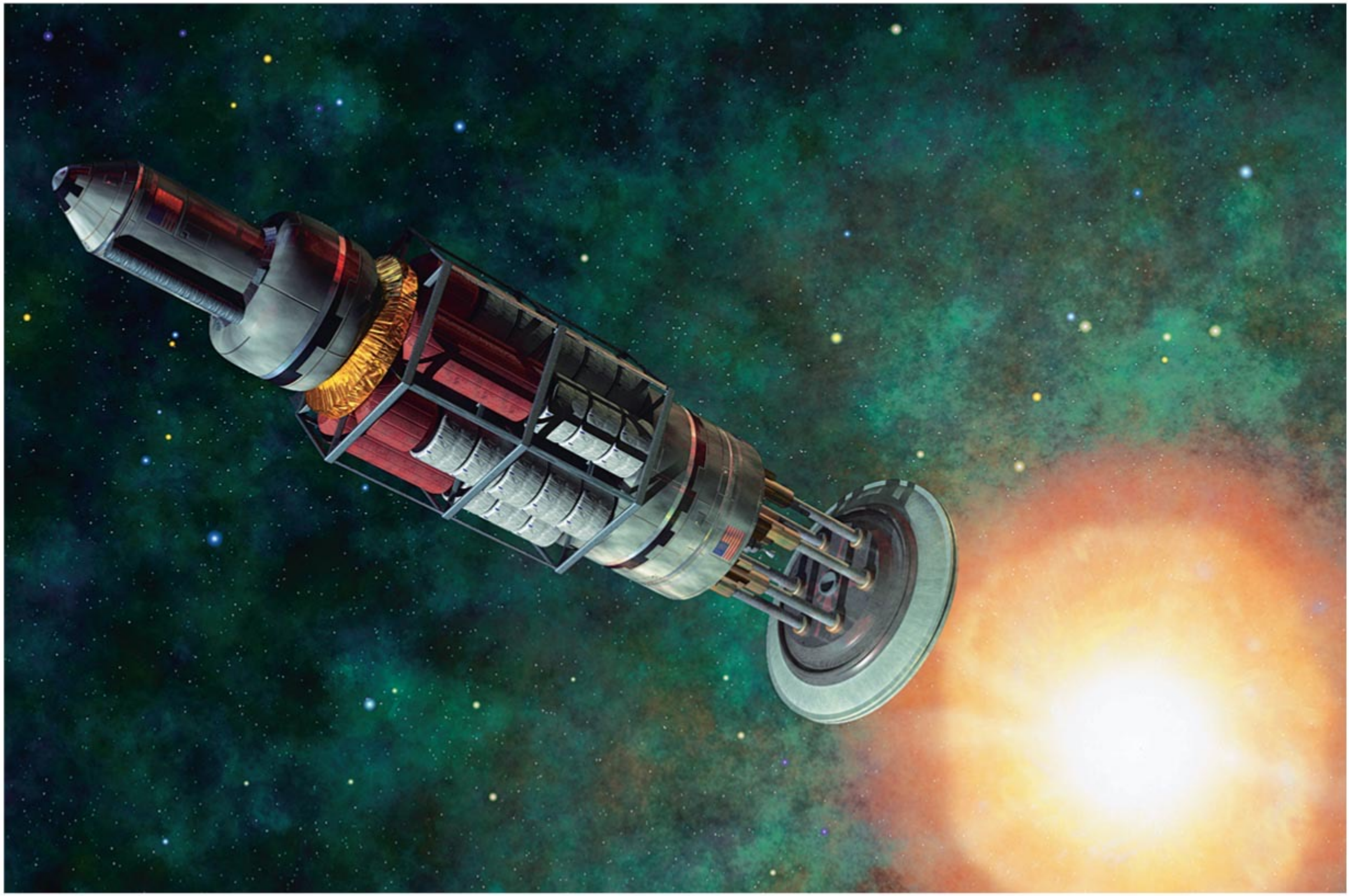
N = 1/year × 1 × 2 × 1 × 1 × 0.1 × 10,000 years = 2,000 technologically advanced civilizations in our Galaxy out of the hundred billion stars in it.

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

- We've even sent a few signals ourselves…

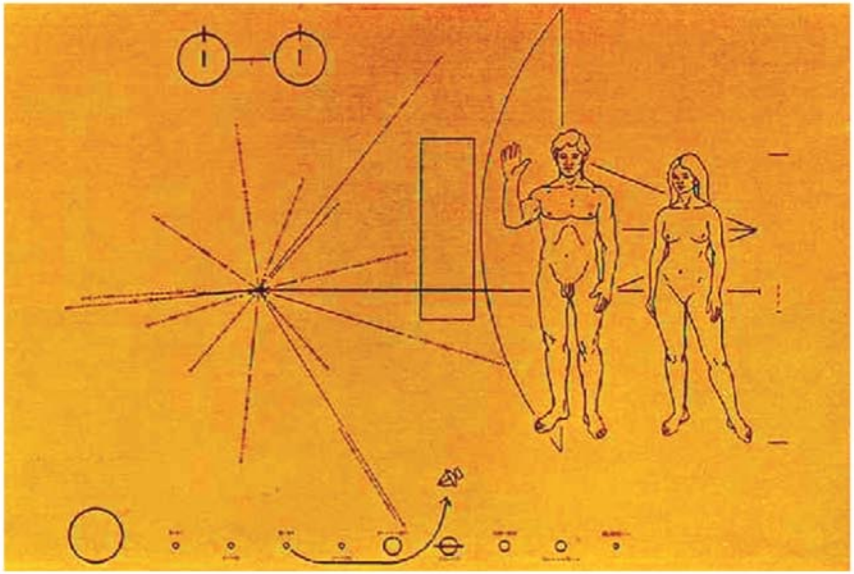
- Earth to globular cluster M13: Hoping we'll hear back in about 42,000 years!

How difficult is interstellar travel?



Current Spacecraft

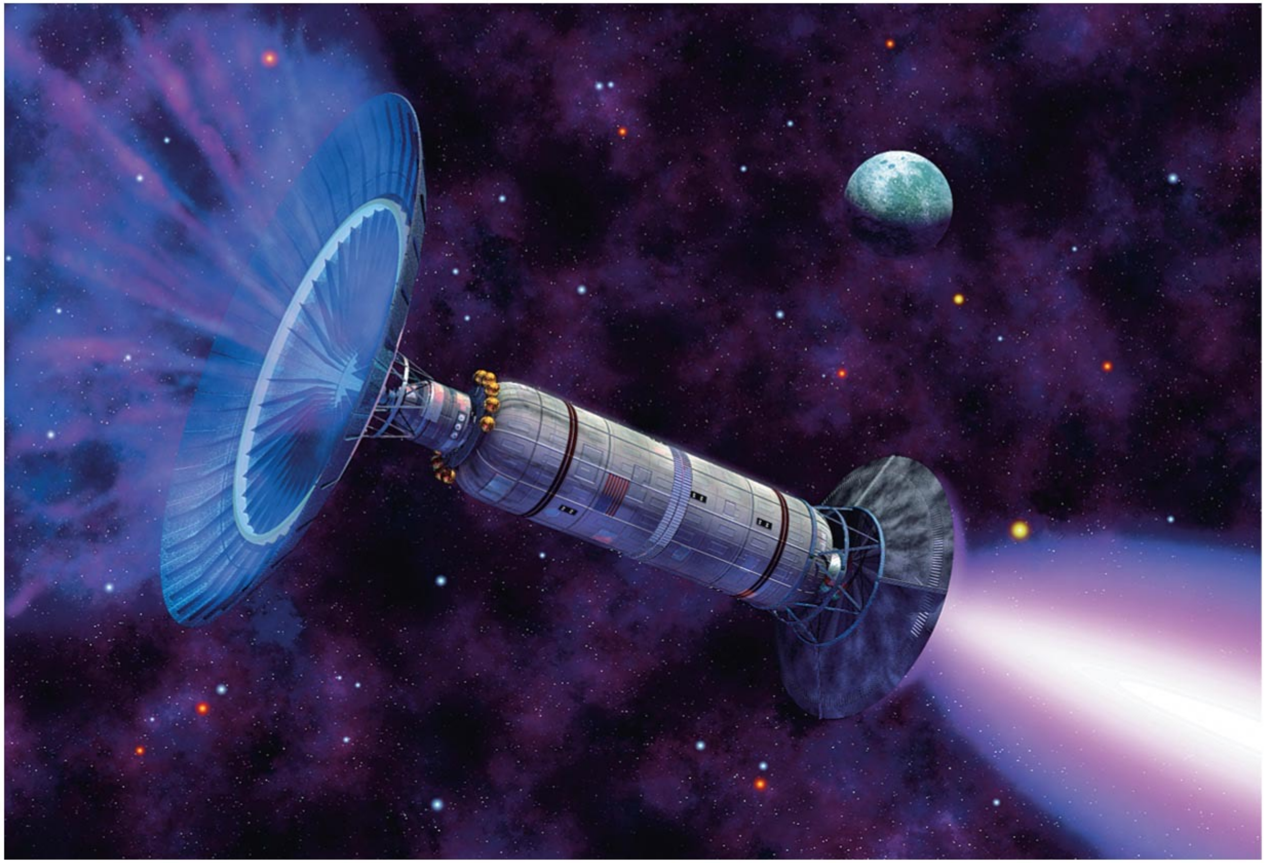
- Current spacecraft travel at <1/10,000*c*; 100,000 years to the nearest stars



Pioneer plaque

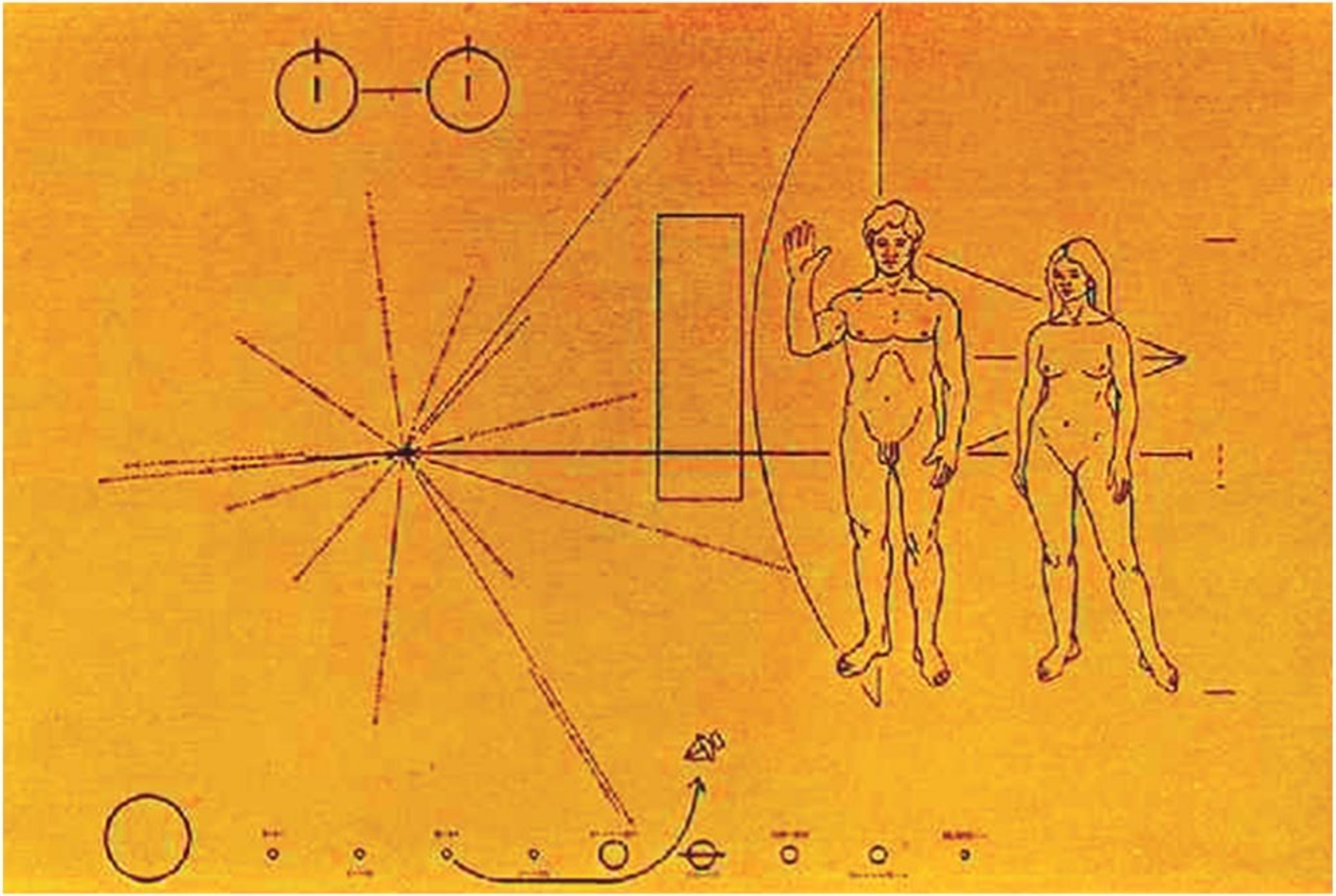
Voyager record

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.

Where are the aliens?

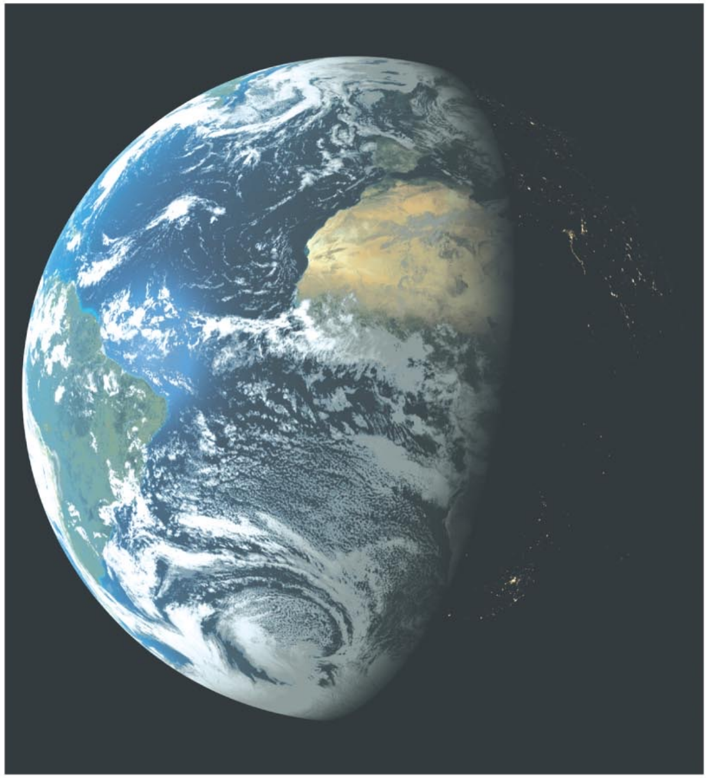


Fermi's Paradox

- 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?

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…



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…

Possible solutions to the paradox

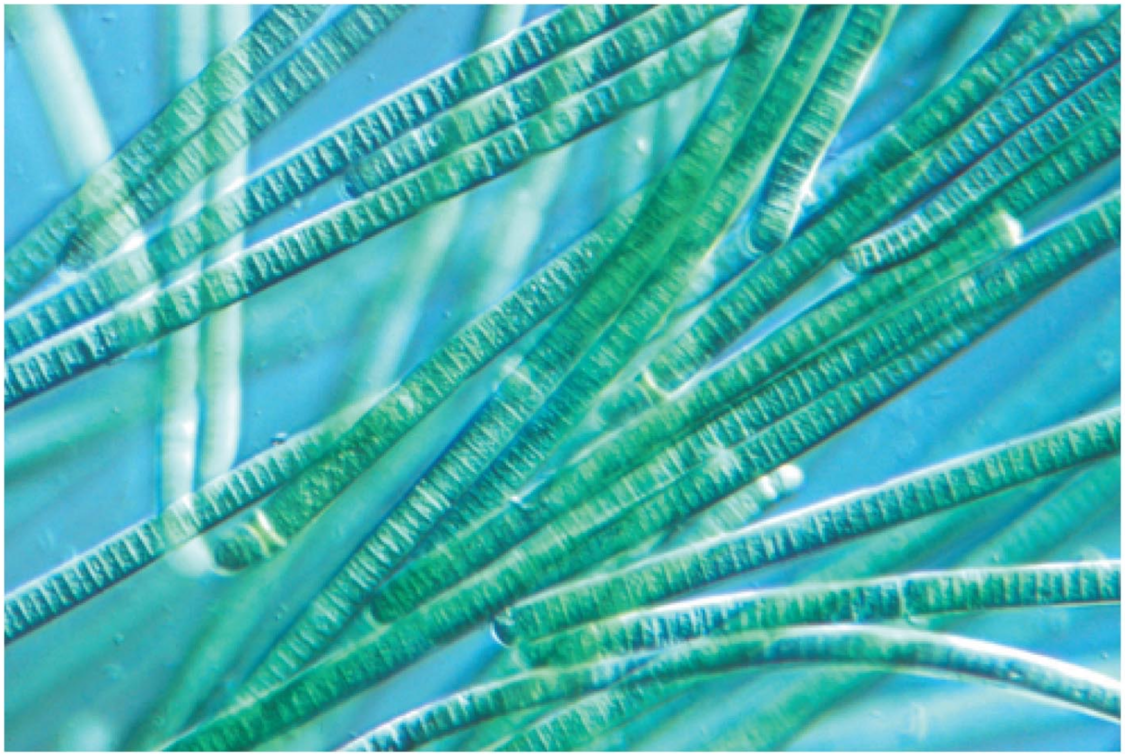
3) There IS a galactic civilization…
   … and some day we'll meet them.

Extra slides

Brief History of Life

- 4.4 billion years - early oceans form
- 3.5 billion years - cyanobacteria start releasing oxygen
- 2.0 billion years - oxygen begins building up in atmosphere
- 540–500 million years - Cambrian Explosion
- 225–65 million years - dinosaurs and small mammals (dinosaurs ruled)
- Few million years - earliest hominids

Origin of Oxygen

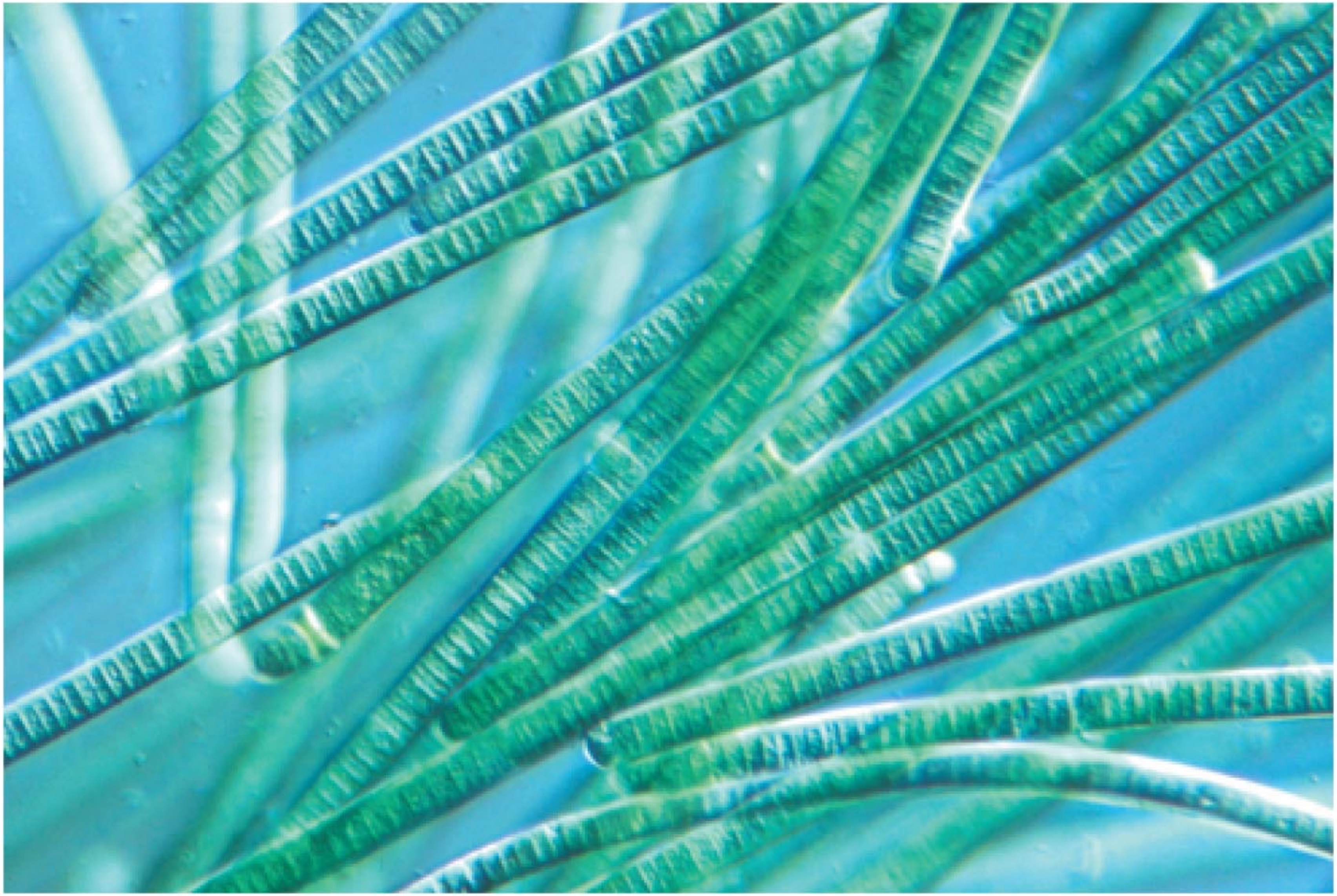


- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into atmosphere via photosynthesis.

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

CarbonDioxide + Water → Sugar + Oxygen

What are the necessities of life?



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

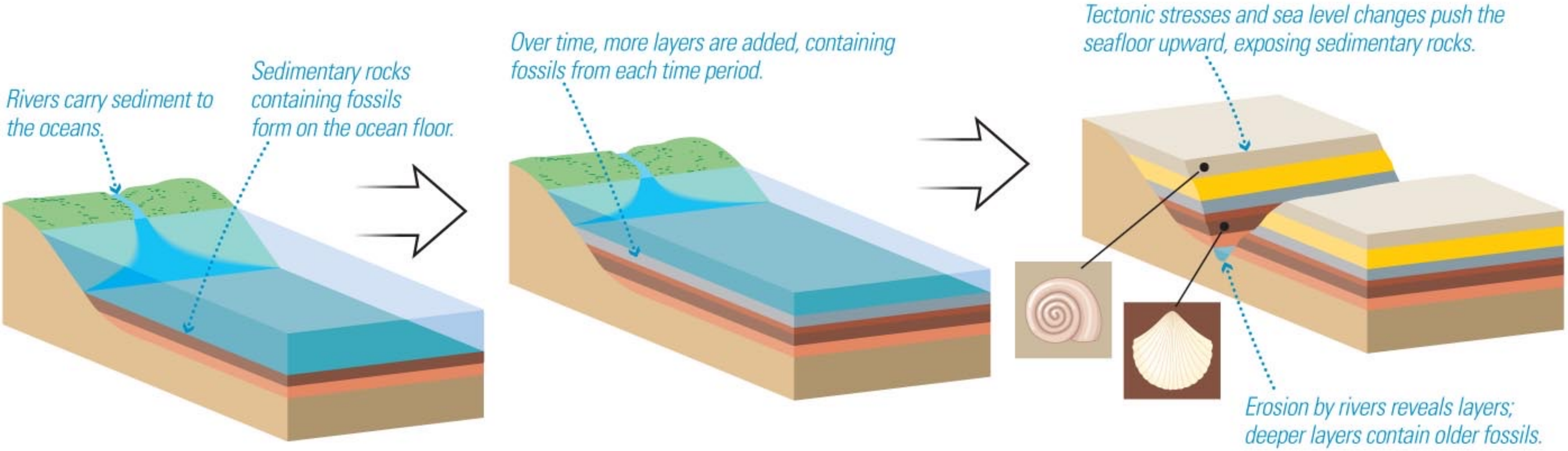
$$N = N_* f_s N_p f_e f_l f_i (L / L_{MW})$$

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

N_* = the number of stars in our Galaxy ~ 300 billion
f_s = the fraction of sunlike stars
N_p = the average number of planets per stellar system
f_e = the fraction of planets with conditions favorable for life
f_l = the fraction of those upon which life develops
f_i = the fraction of those species that develop adequate technology and then choose to send messages out into space
L = lifetime of a technologically advanced civilization
L_{MW} = the age of our Galaxy

When did life arise on Earth?

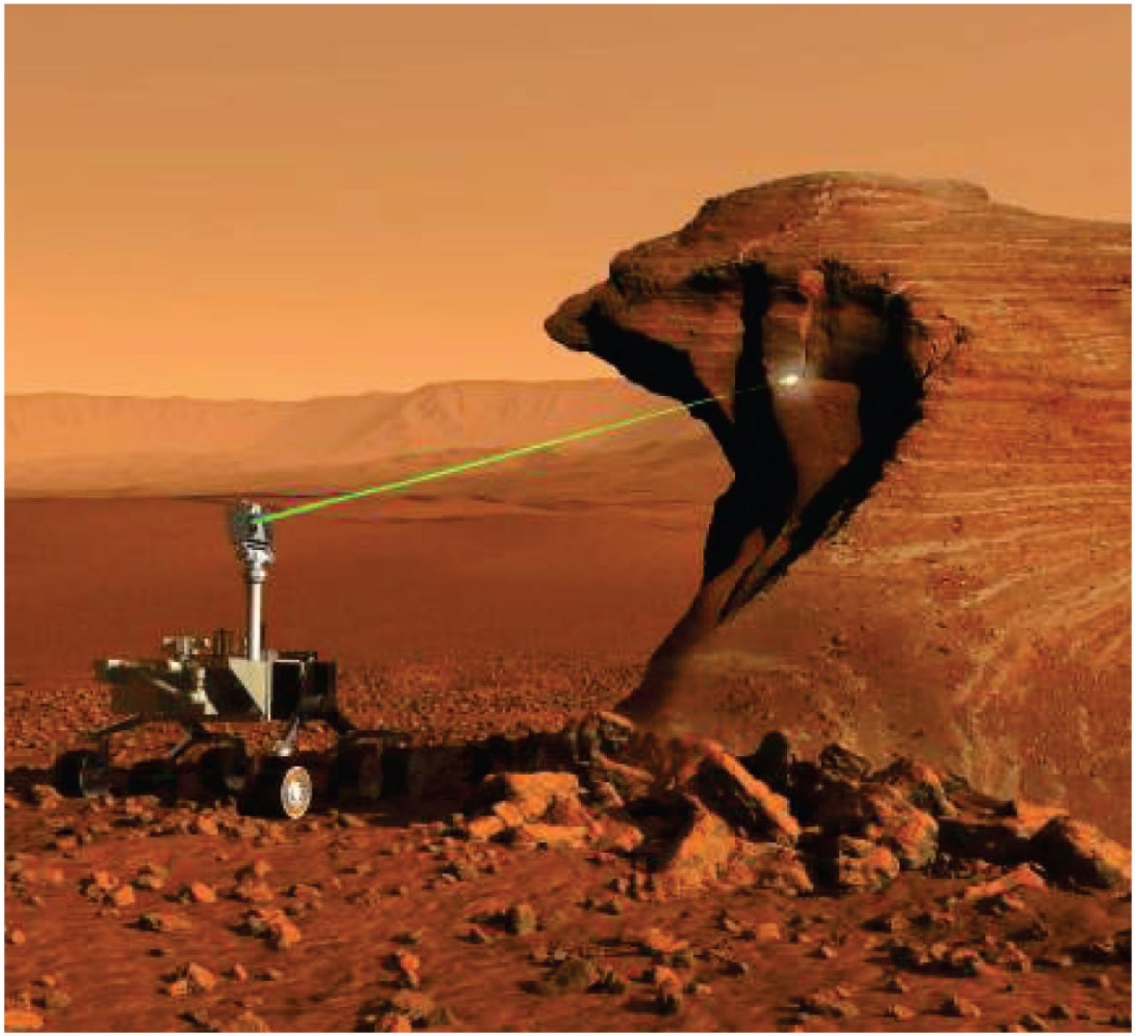
Fossils buried in deeper layers formed earlier. Radioactive dating confirms this and provides absolute ages



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

How does SETI work?

CONTACT



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

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