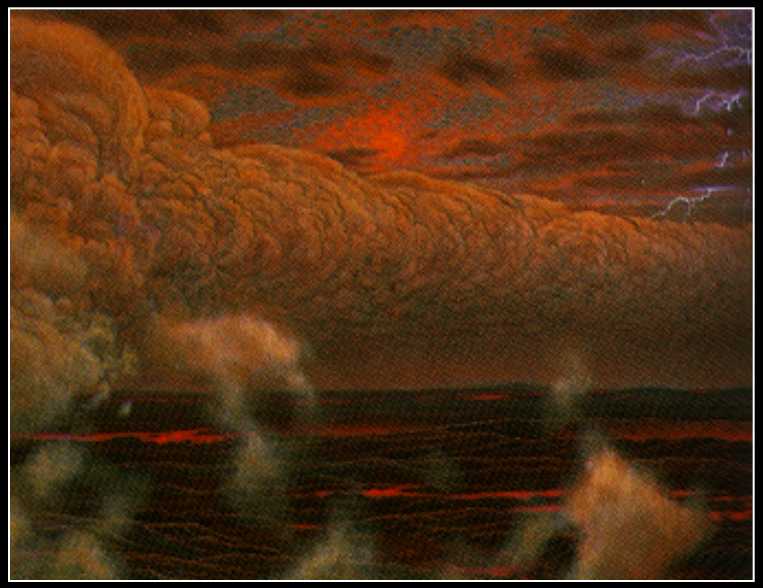
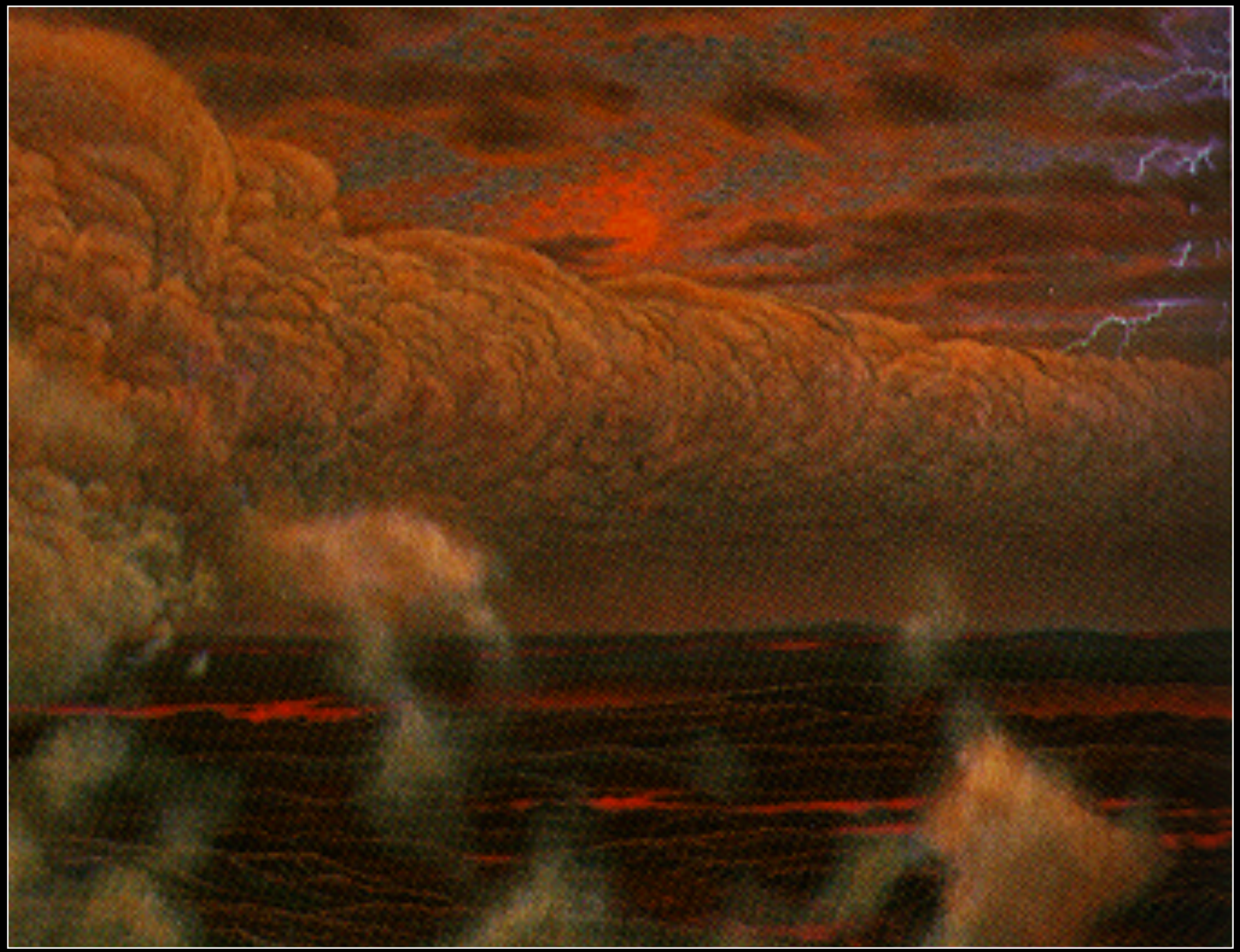
The Search for Life in the Universe

Is there life out there?

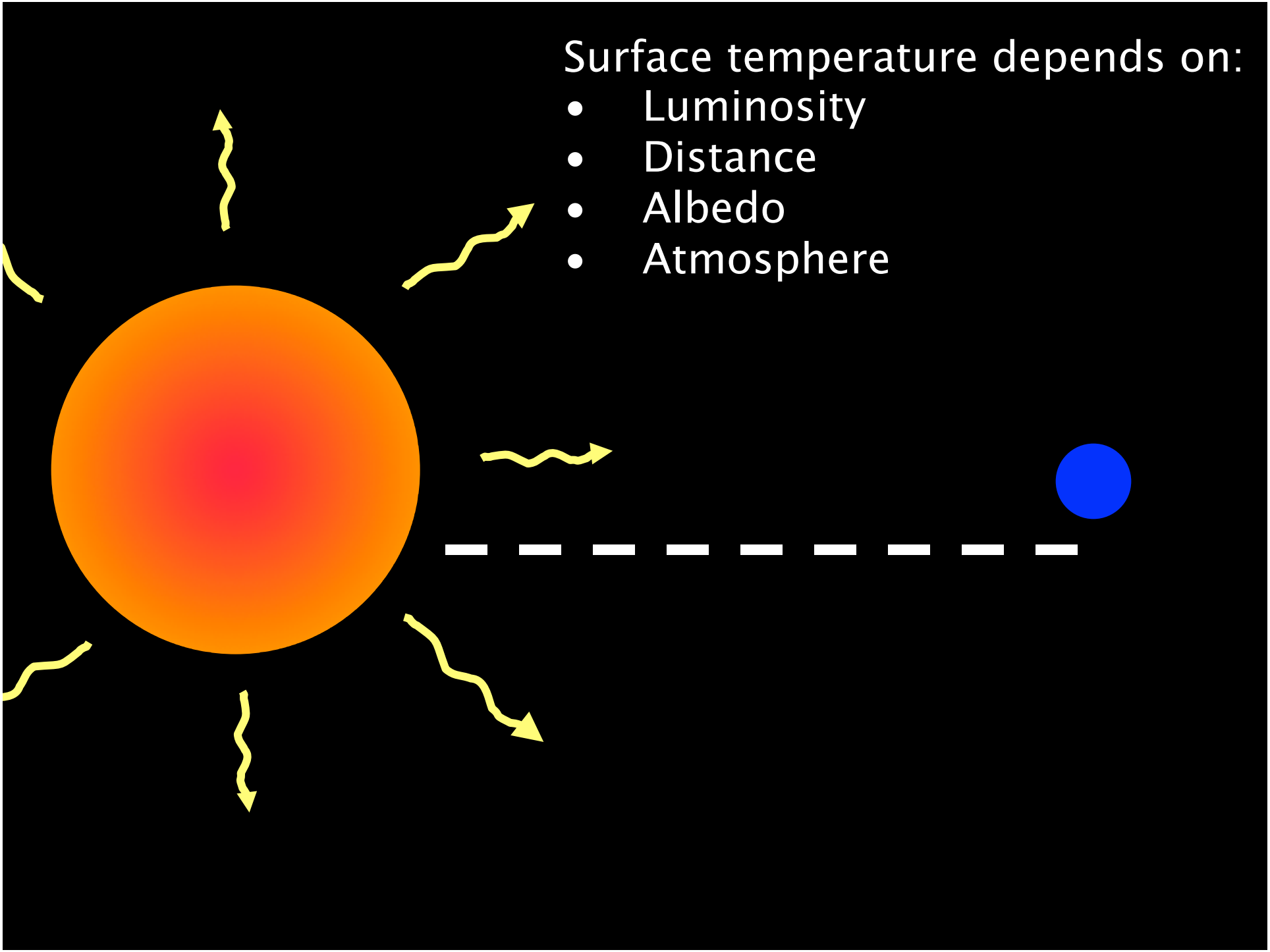
For the first time, we may be able to answer this question in our lifetimes.

What is a habitable planet?

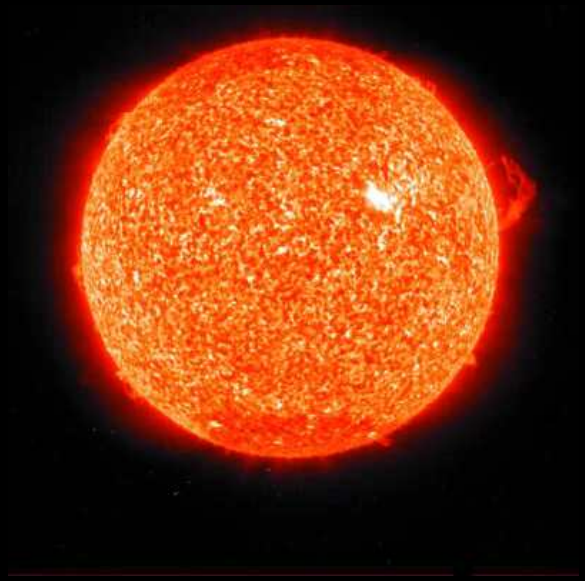


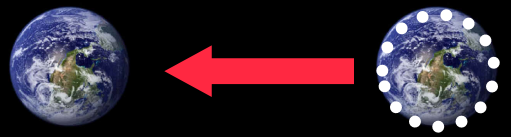


Liquid water

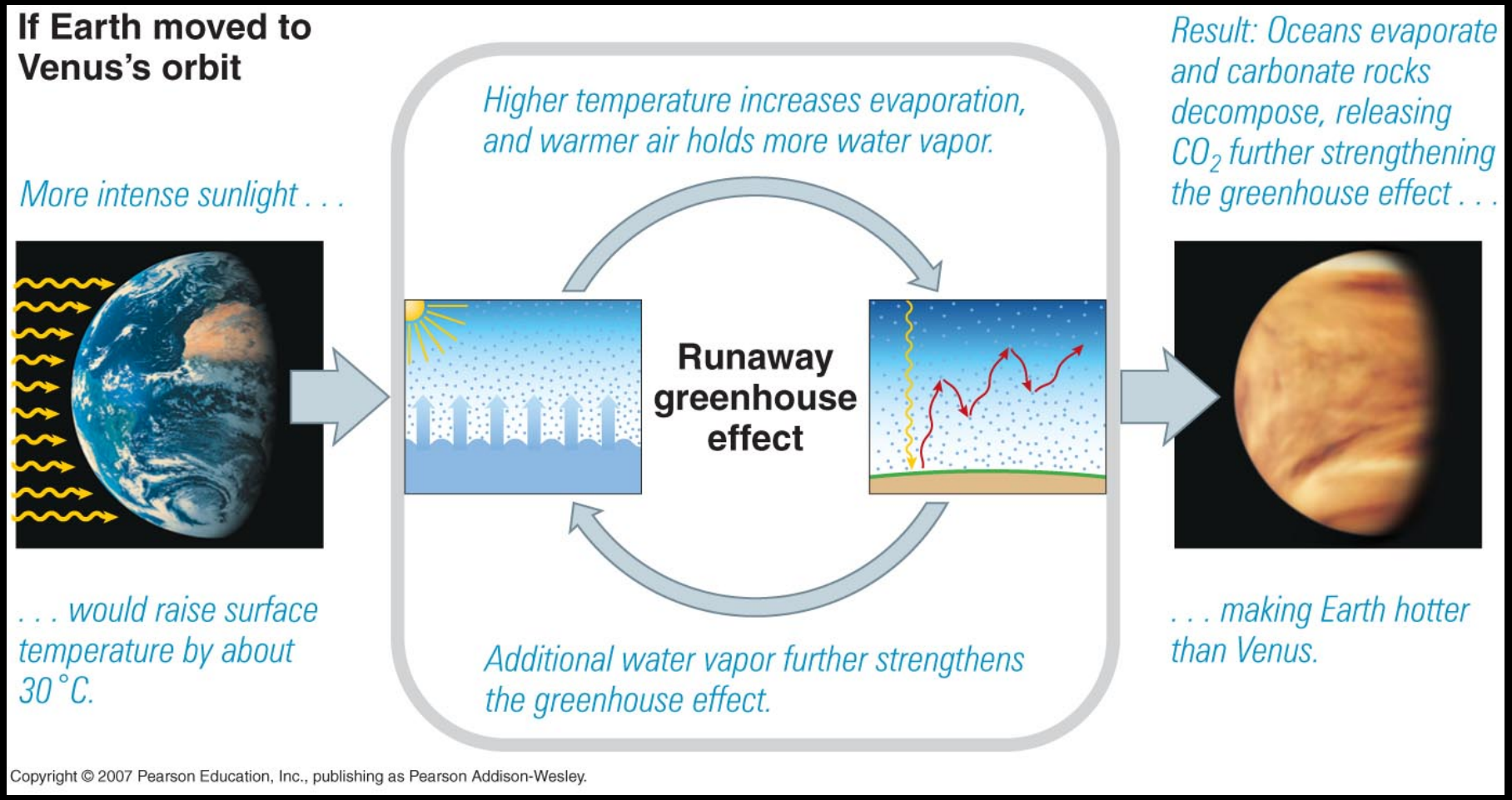

Surface temperature depends on:
• Luminosity
• Distance
• Albedo
• Atmosphere

What happens if we move the Earth close to the Sun?

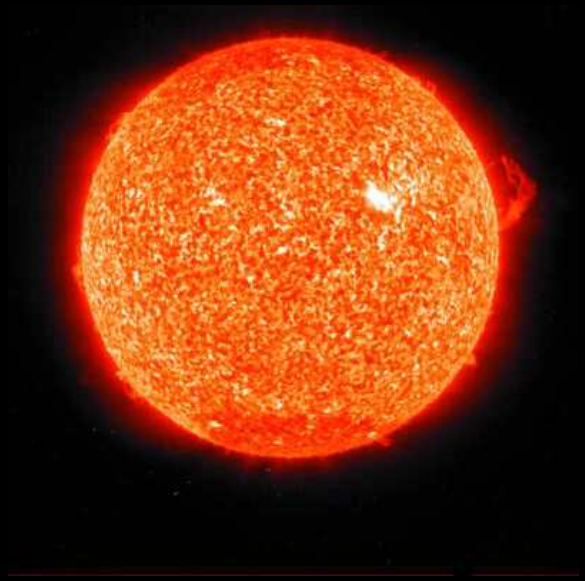


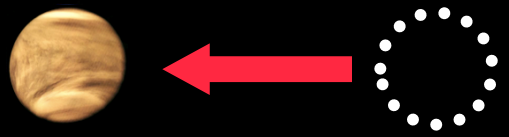


Runaway Greenhouse Effect



What happens if we move the Earth close to the Sun?

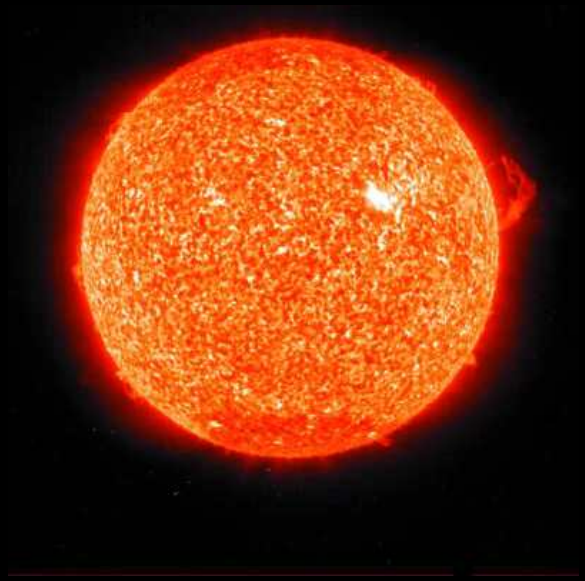


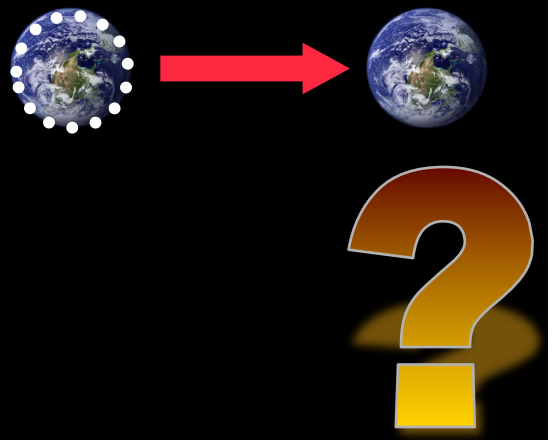


How close is too close?

- Venus (a=0.72) clearly too close.
- "Runaway Greenhouse" closer than a=0.84 AU
- Too close = certainly 0.84 AU (maybe 0.95 AU)!

What happens if we move the Earth further from the Sun?

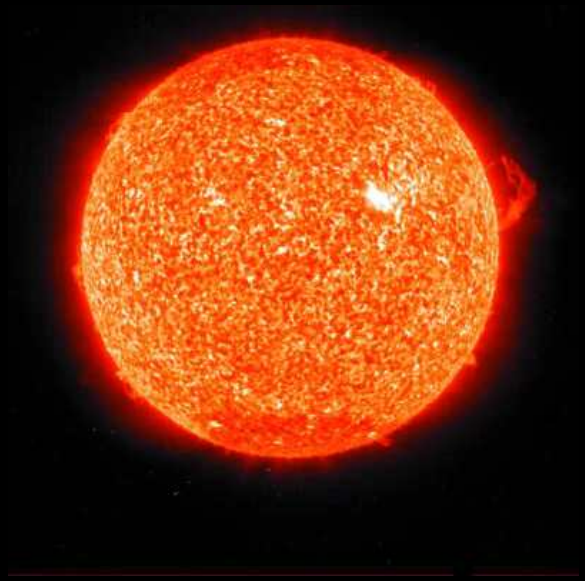


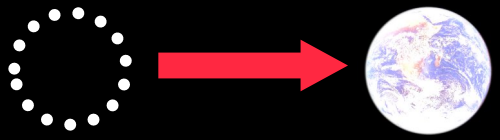


How far is too far?

- Is Mars too far?
- A thick CO_2 atmosphere *could* support liquid water to almost twice the Earth's distance (1.7AU)!
- Eventually, temperature too cold for liquid water

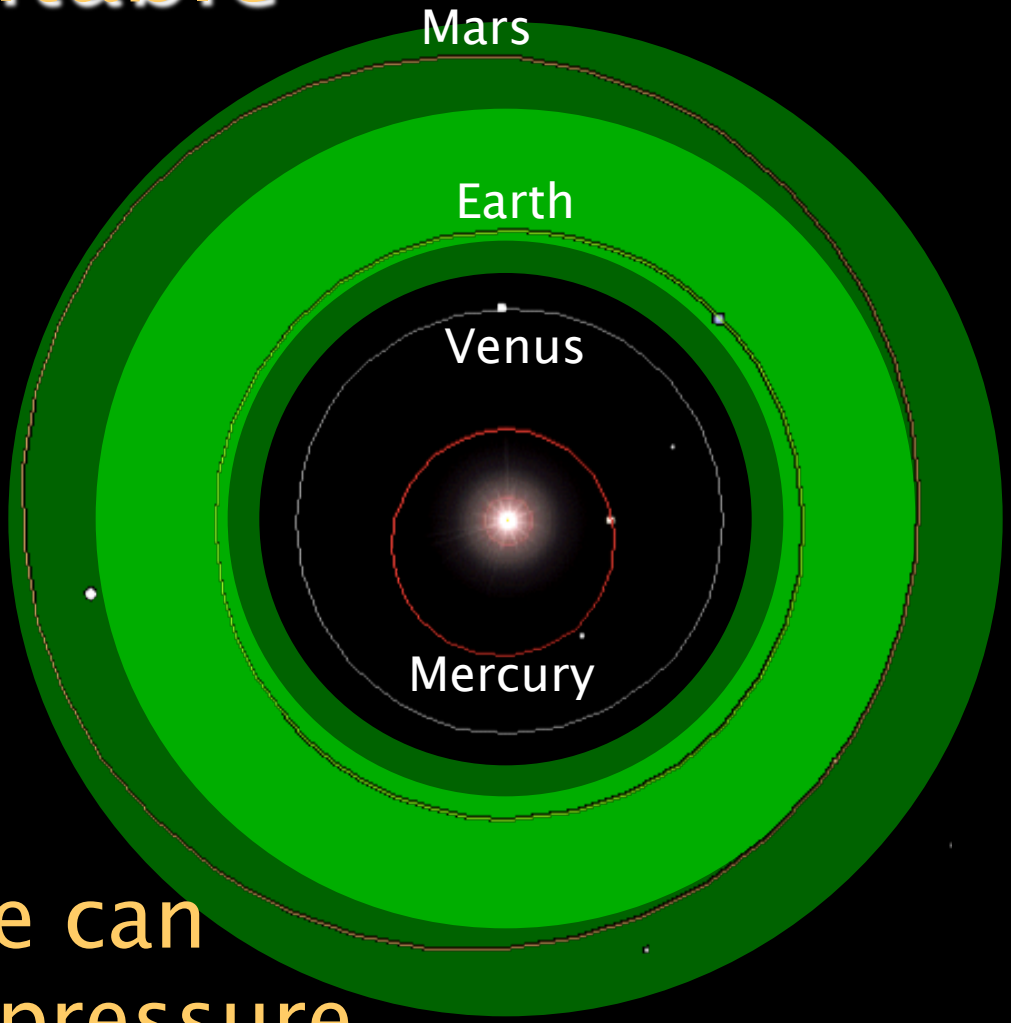
What happens if we move the Earth further from the Sun?



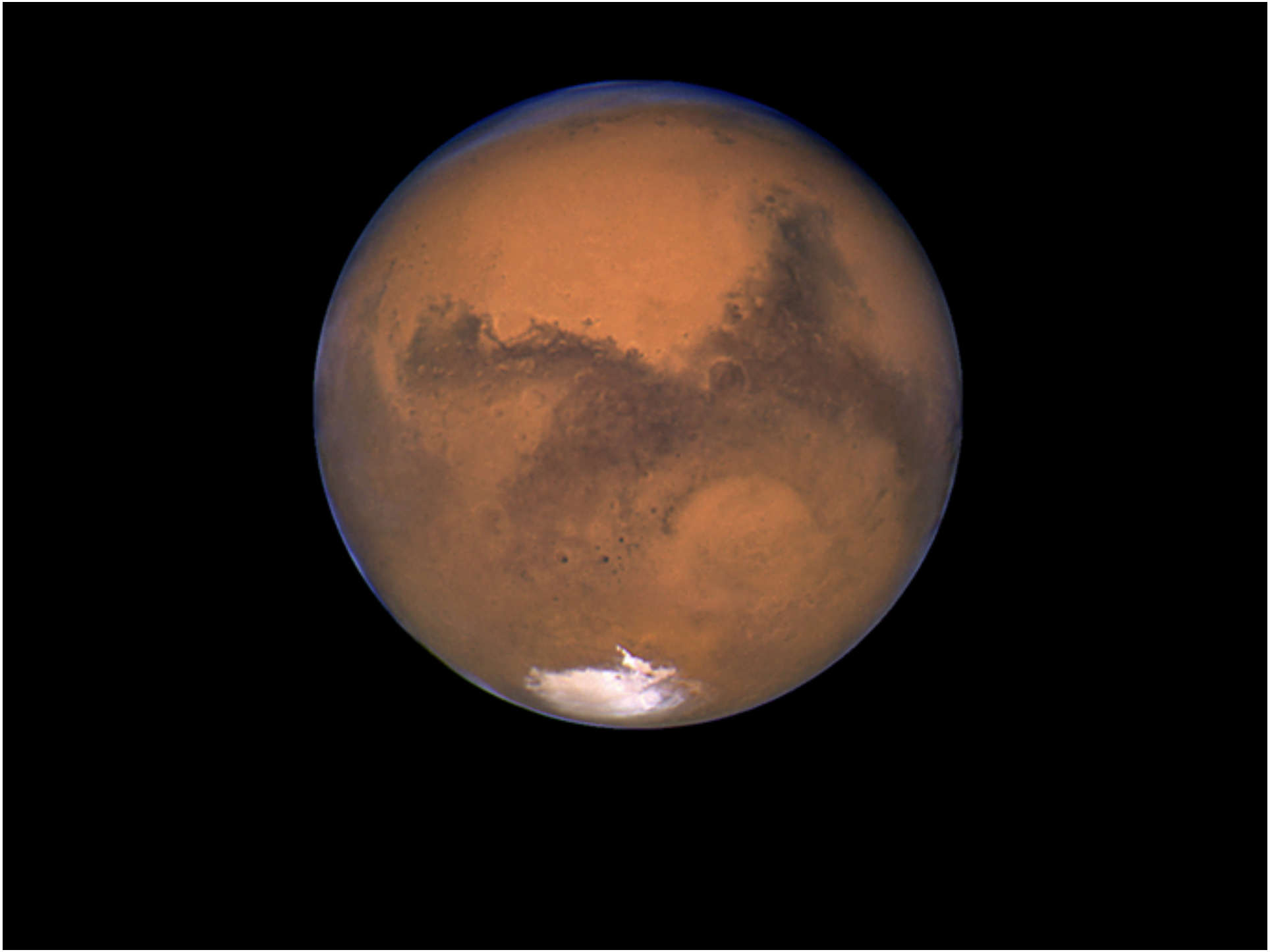


The Sun's Habitable Zone Today

- Conservative:
  0.95 – 1.4 AU
- Optimistic:
  0.84 – 1.7 AU

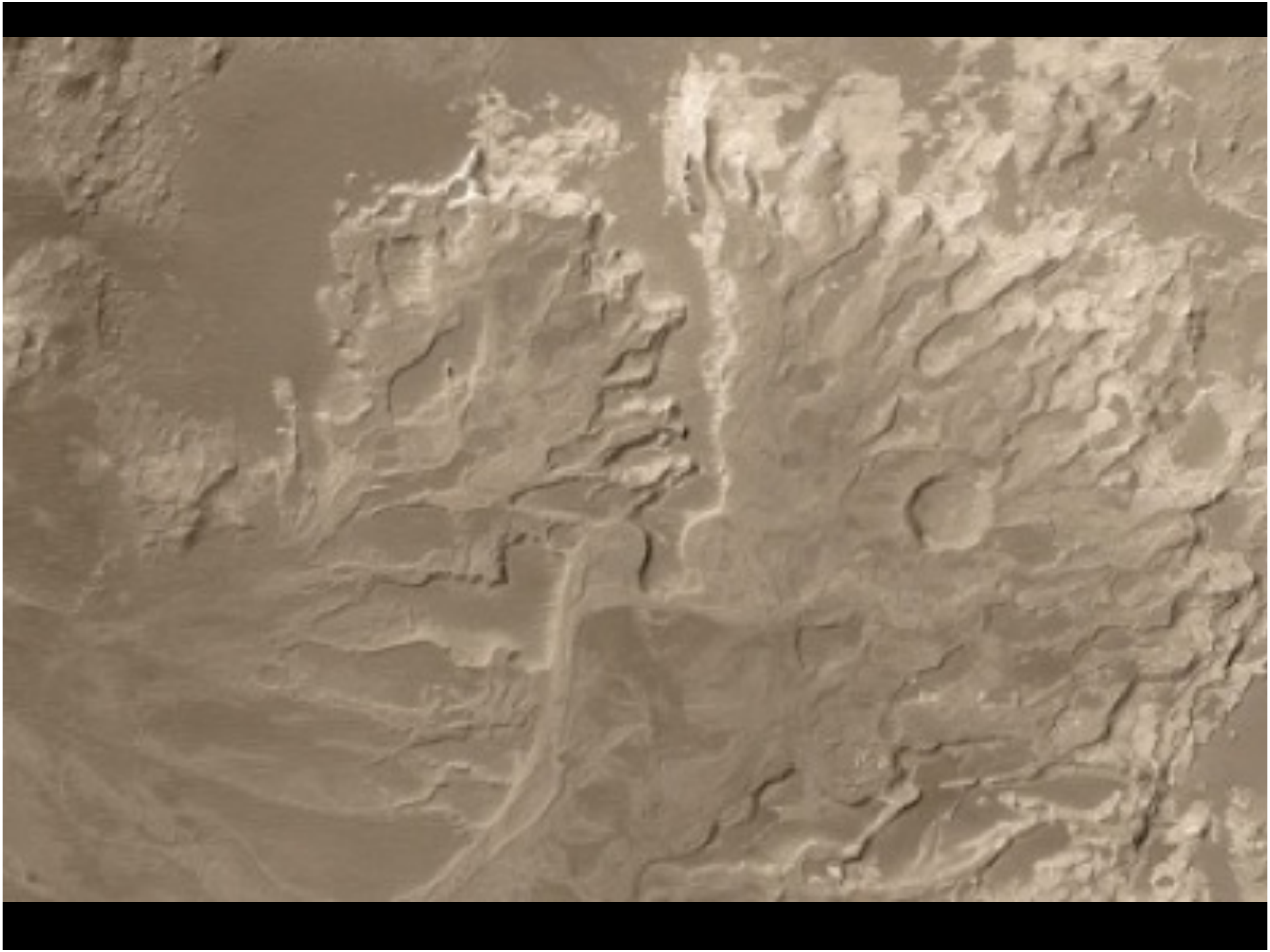


Region where there can be liquid H_2O at a pressure of 1 atm

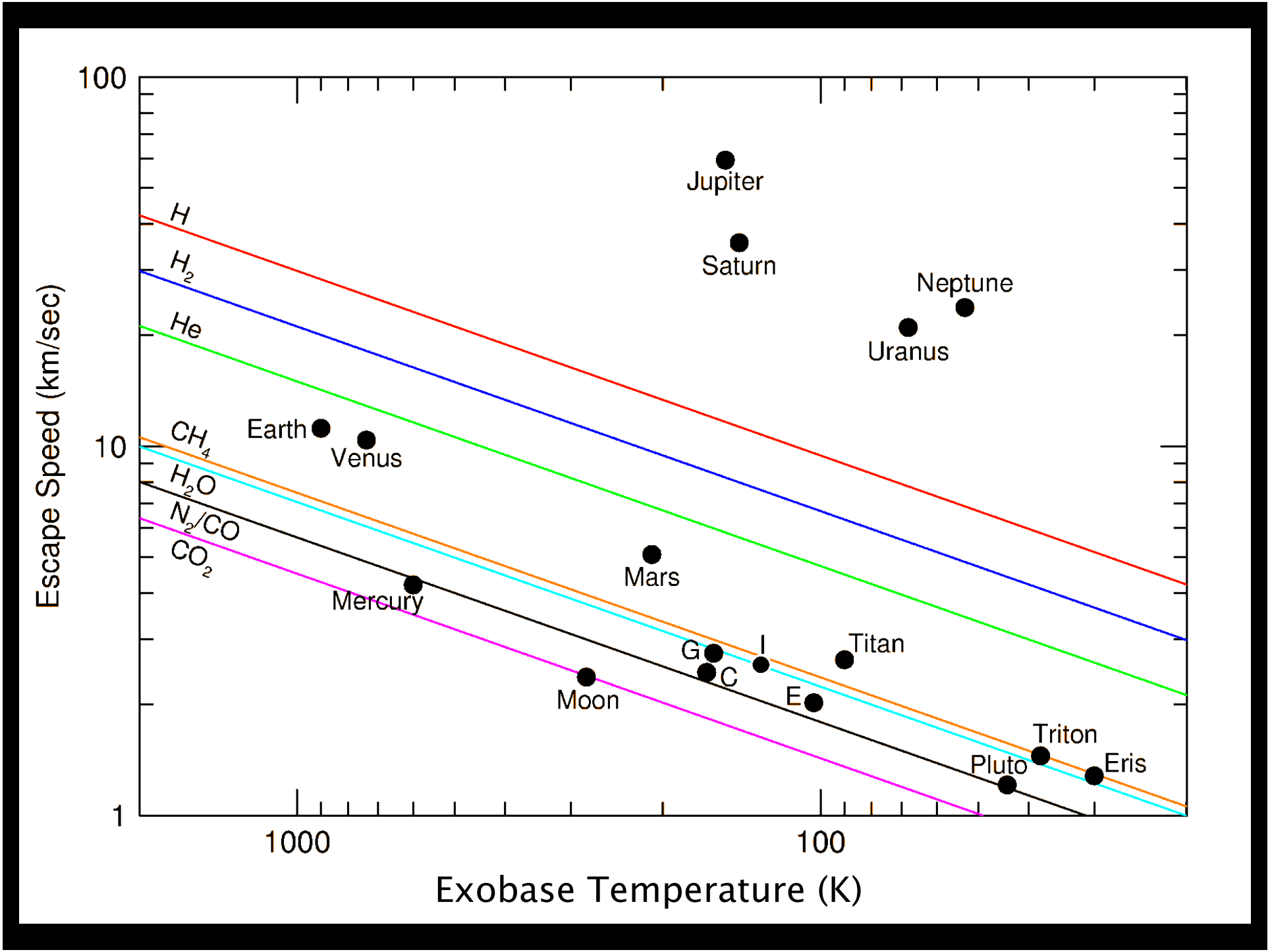


Water on Mars?

- Results from the Mars orbital surveys:
  - Evidence of water carving gullies like seen on Earth.
  - Layered terrains (e.g., like Grand Canyon)
- Mars Exploration Rovers:
  - Layered sedimentary rocks with flow patterning
  - Salt deposits laid down by evaporating water
  - Hydrated minerals like Hematite



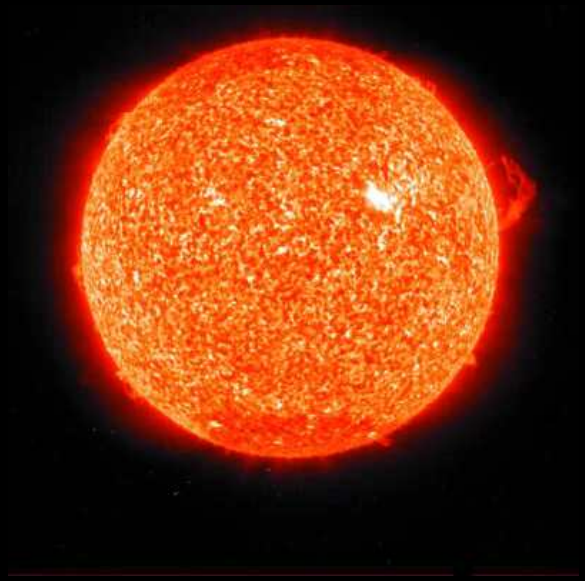

What Happened?

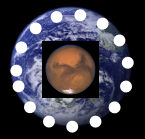

100
10
1
Escape Speed (km/sec)
1000
100
Exobase Temperature (K)
H
H2
He
CH4
H2O
N2/CO
CO2
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Mercury
Moon
G
I
C
E
Titan
Triton
Pluto
Eris

What happened?

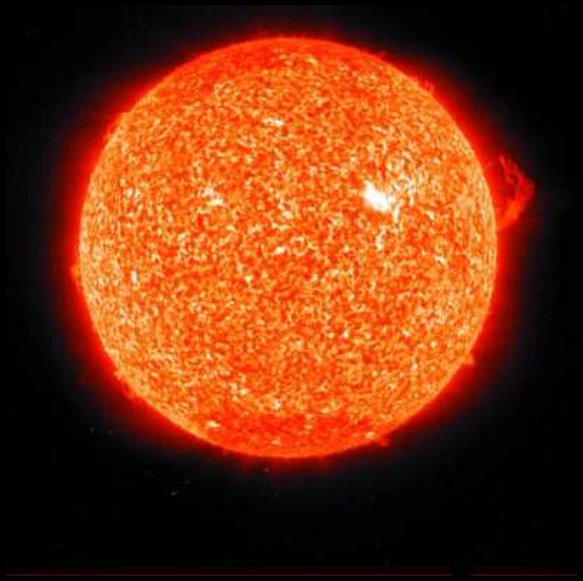
- Harder time holding onto its atmosphere.
- Cooled off:
  - No more volcanoes to resupply the atmosphere
  - No magnetic fields to protect the atmosphere.

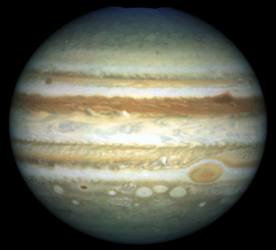
What happens if the Earth is too small?



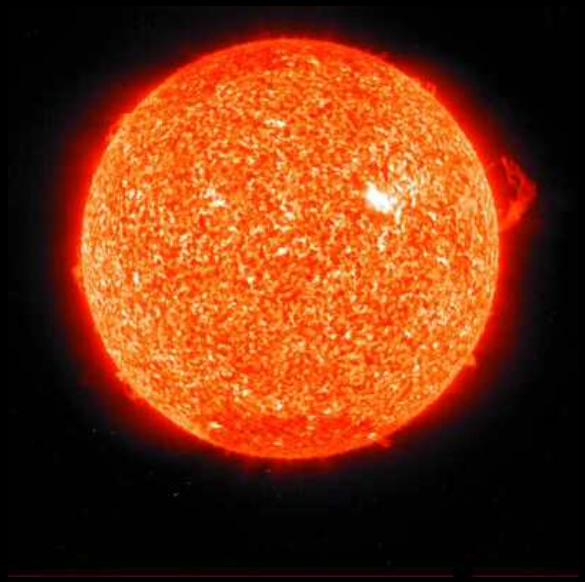


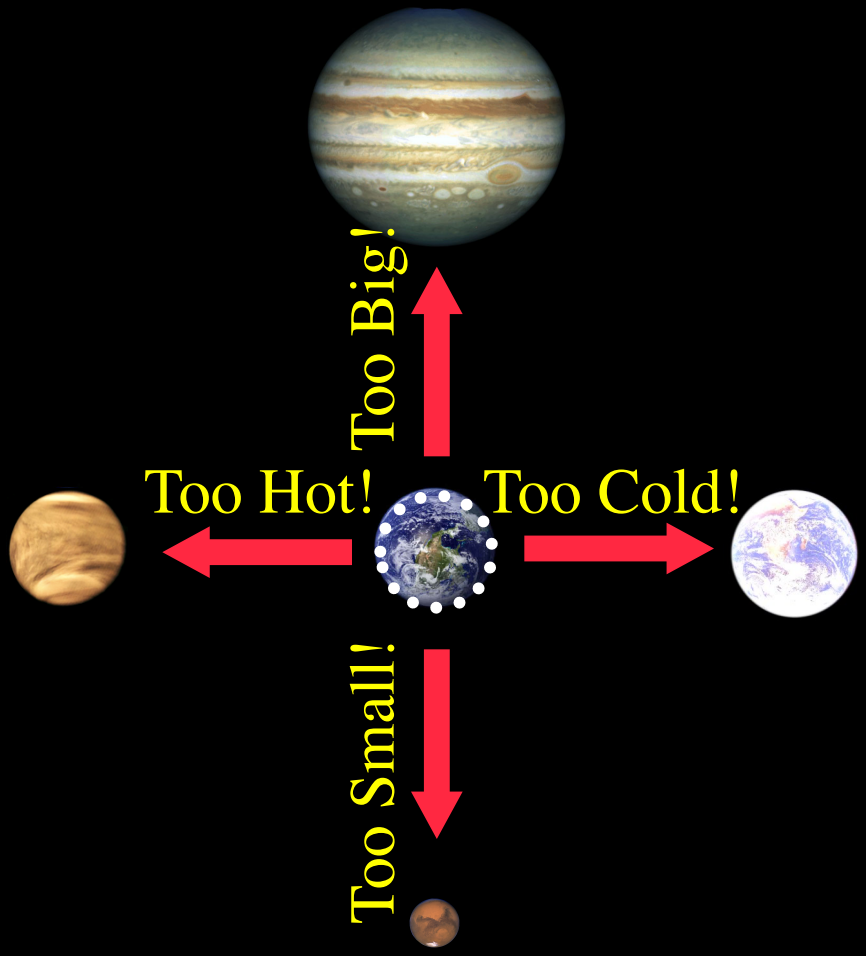
What happens if the Earth is too big?

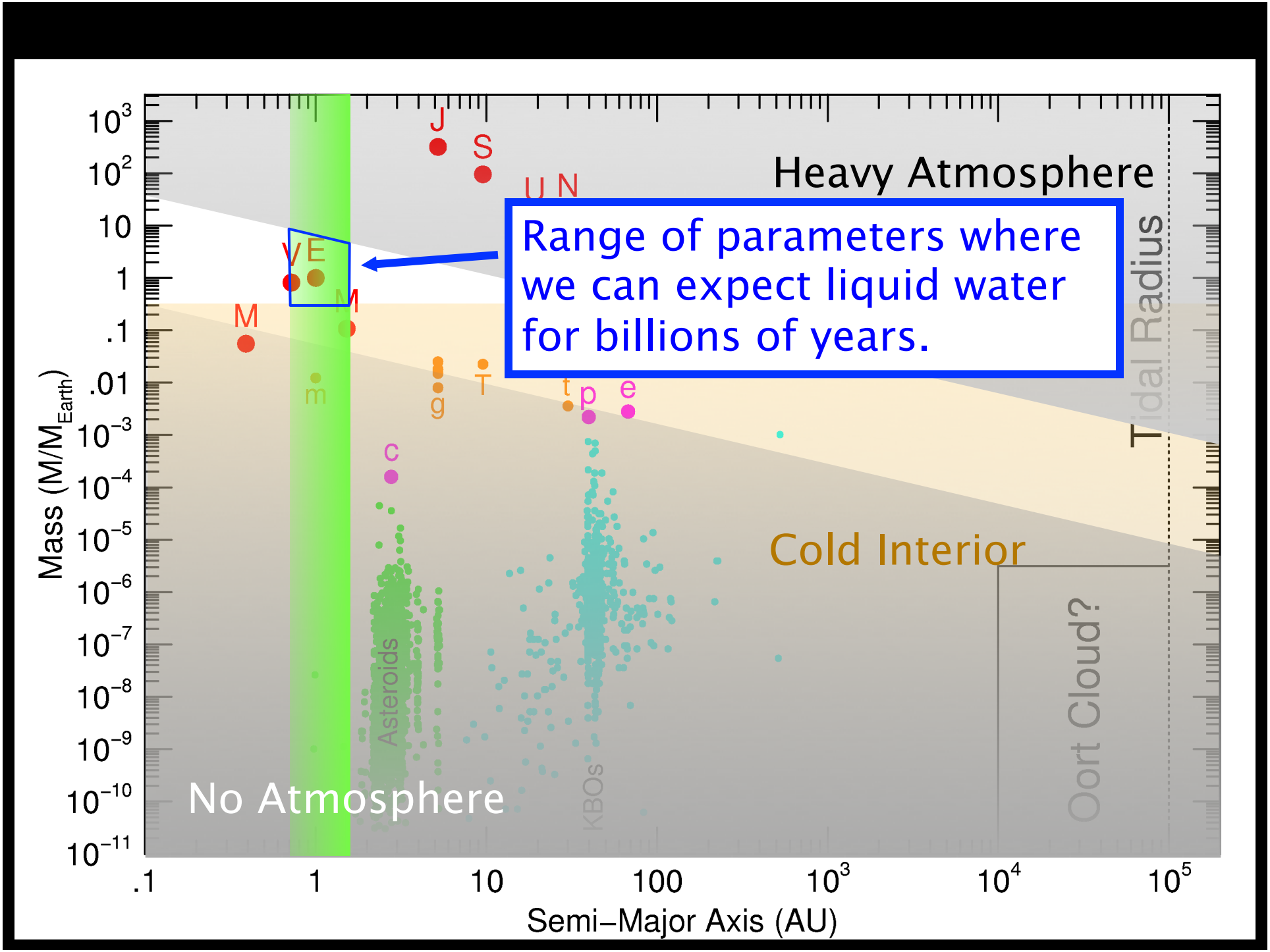




Goldilocks!

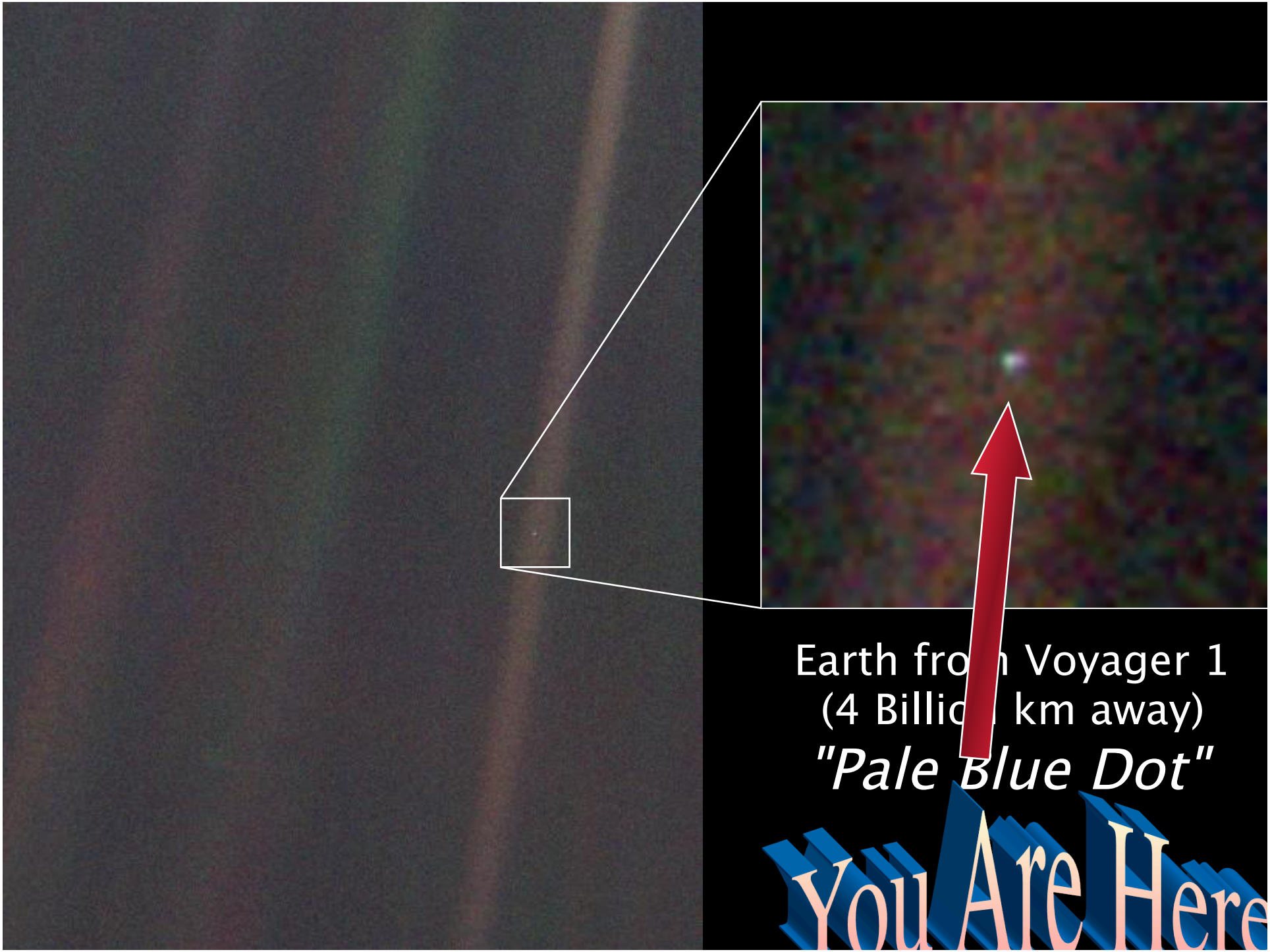





Heavy Atmosphere
Range of parameters where we can expect liquid water for billions of years.
Cold Interior
No Atmosphere
Tidal Radius
Oort Cloud?
Asteroids
KBOs
J
S
U
N
V
E
M
M
m
g
T
t
p
e
c
Mass (M/M$_{Earth}$)
Semi–Major Axis (AU)
10^{3}
10^{2}
10
1
.1
.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
.1
1
10
100
10^{3}
10^{4}
10^{5}

Which are the best places to look for life?

Stars with rocky, Earth-sized planets in their habitable zones.


Earth from Voyager 1
(4 Billion km away)
"Pale Blue Dot"
You Are Here

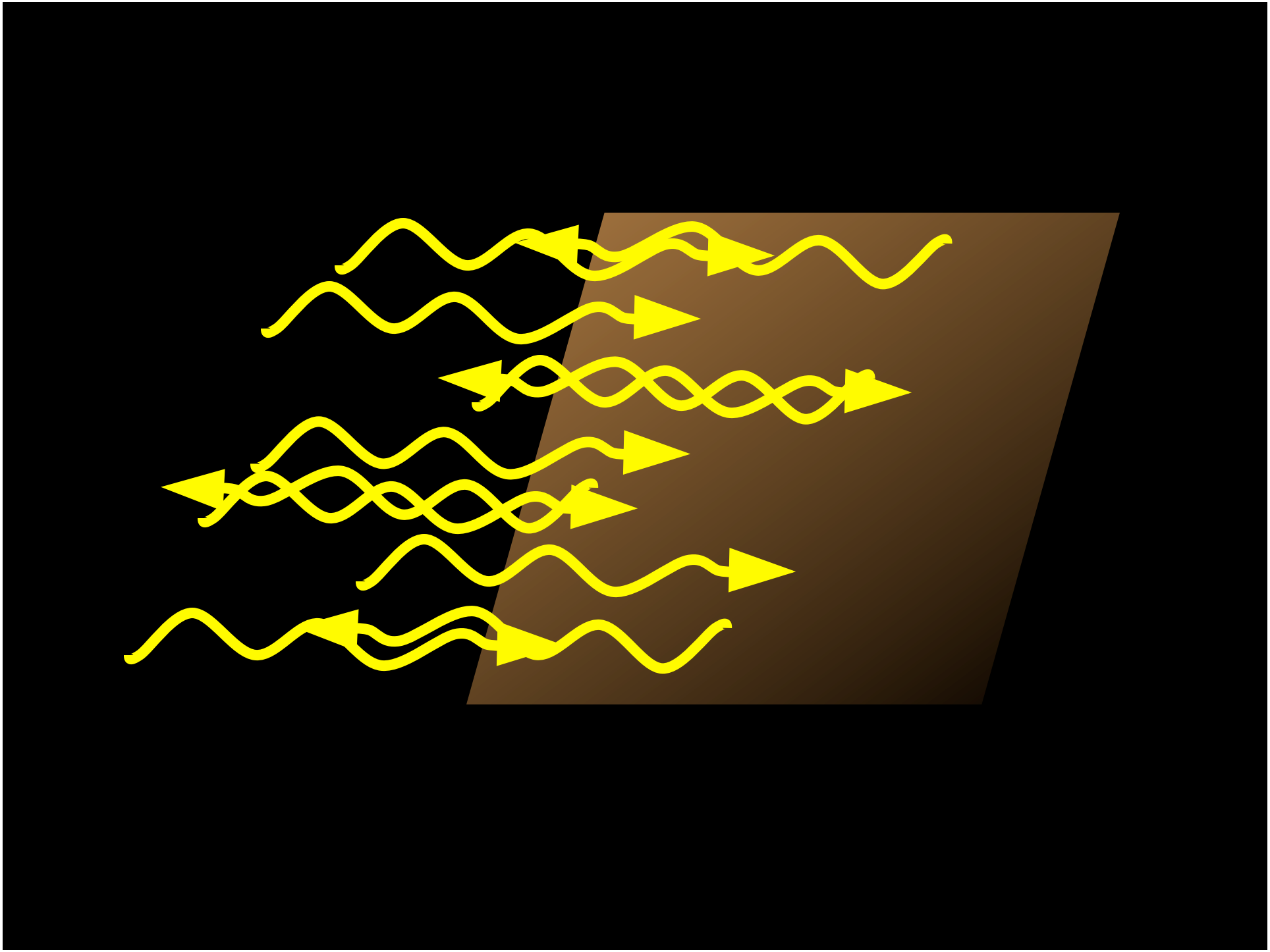
Remotely Detecting Earths

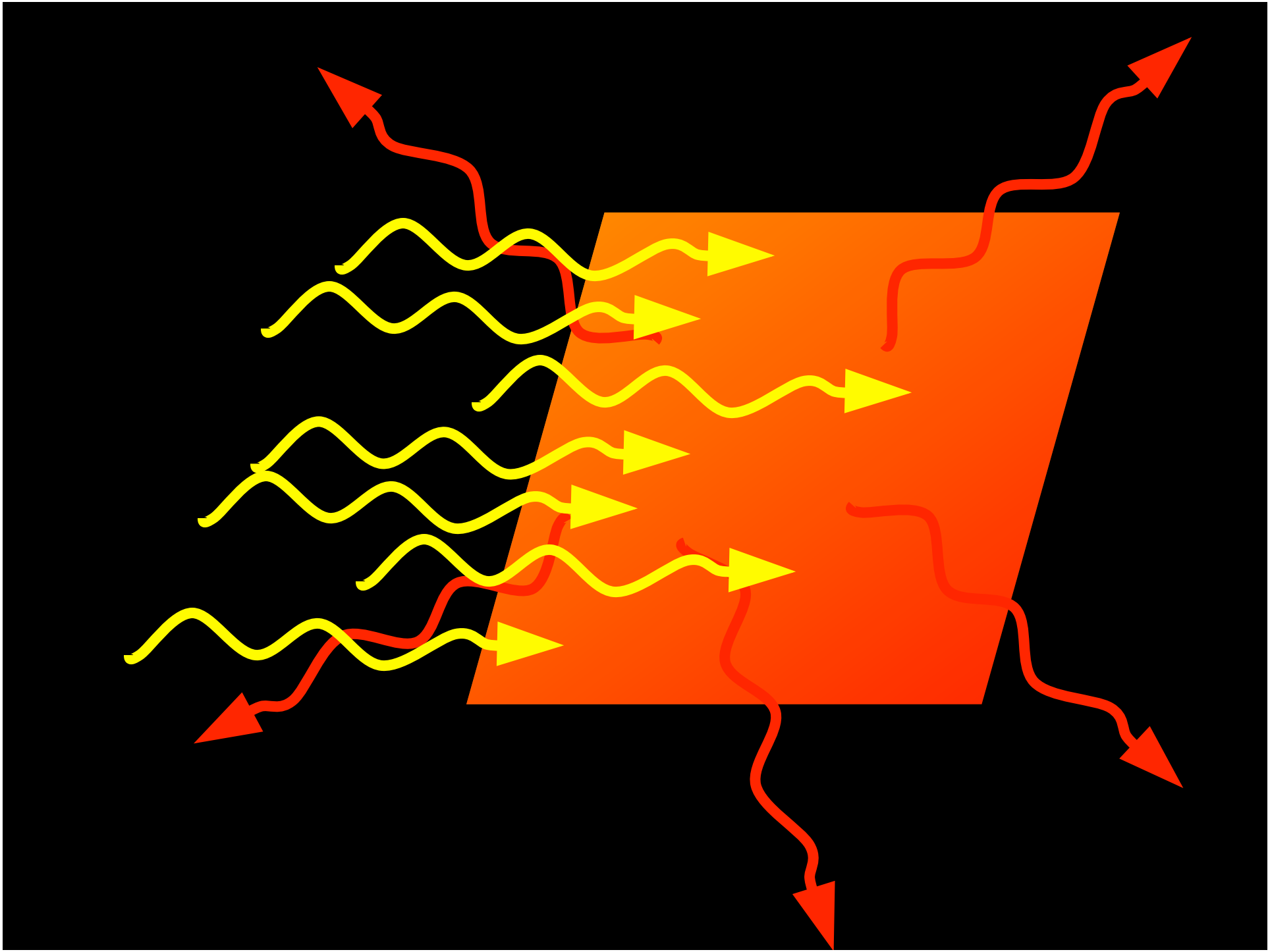
Direct detection of Earthlike planets

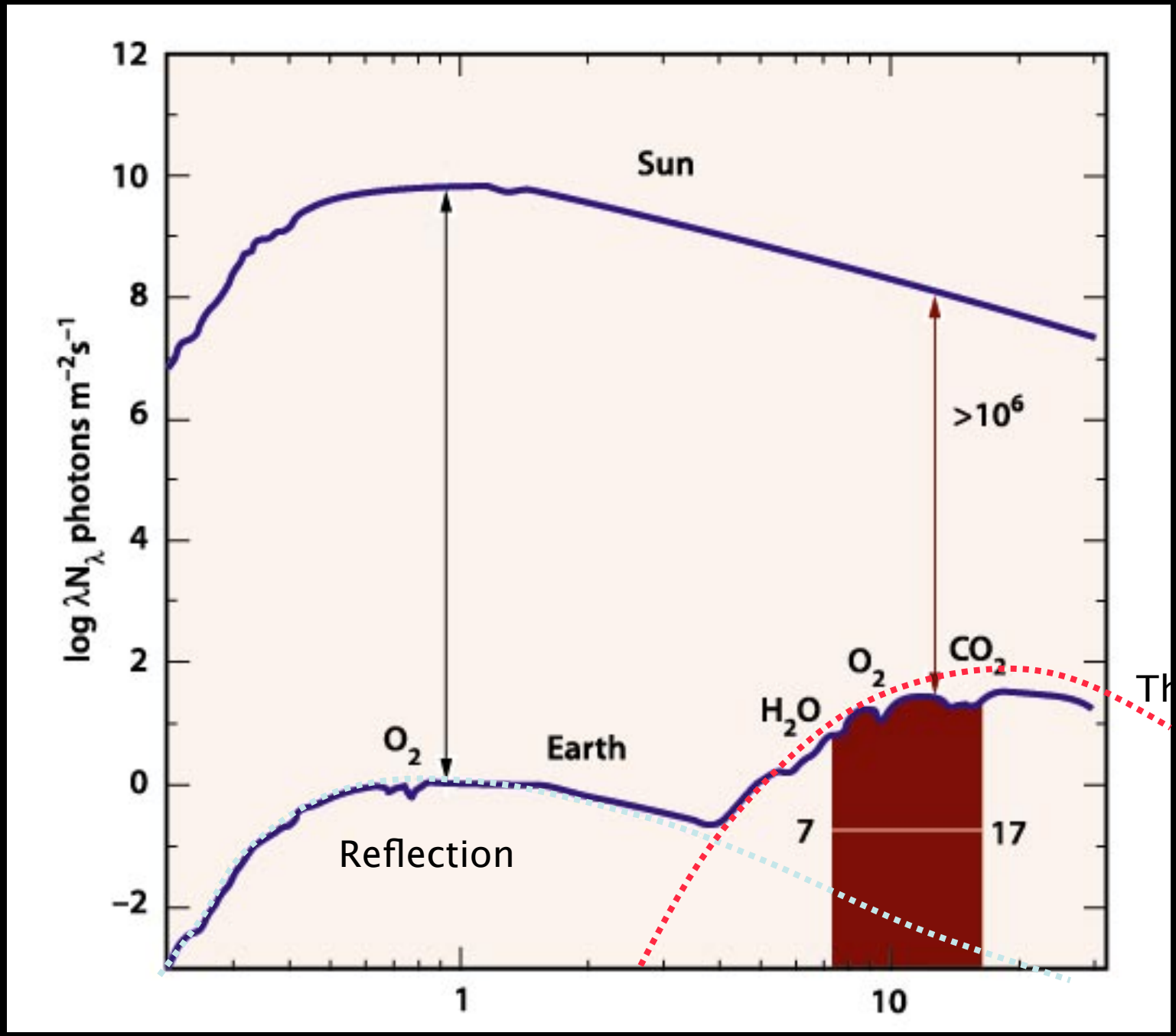
- Measurement of light is very powerful

Determining the properties of the planets

- Spectra allow detection of biomarkers
- Variability allow inference of surface properties






12
10
8
6
4
2
0
−2
log λN$_\lambda$ photons m^{-2}s^{-1}
Sun
>10^6
O$_2$
Earth
Reflection
H$_2$O
O$_2$
CO$_2$
7
17
1
10

The Earth's Spectrum

Many different features, but most important:

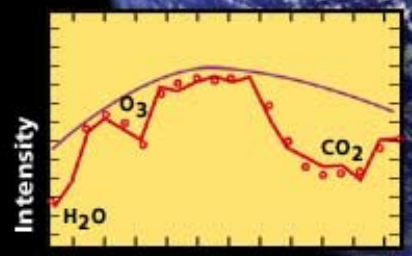
- *Water*
  - Requirement for life?
- *Oxygen*
  - On Earth, created by biological processes
- *Carbon dioxide*
  - Moderator of greenhouse effect
- *Methane*
  - On Earth, mostly produced by biological processes
  - Methanogens, and…

Oxygen?

O_3 Ozone, produced by plants, algae

Abundant Liquid Water?

H_2O Liquid water

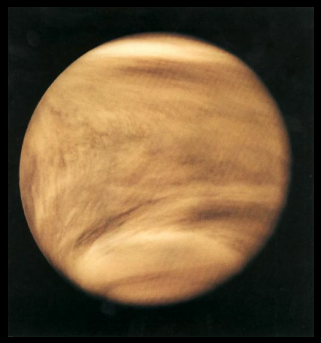


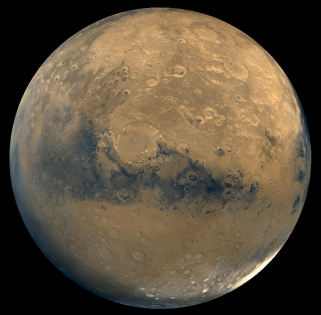
Does it have an Atmosphere?

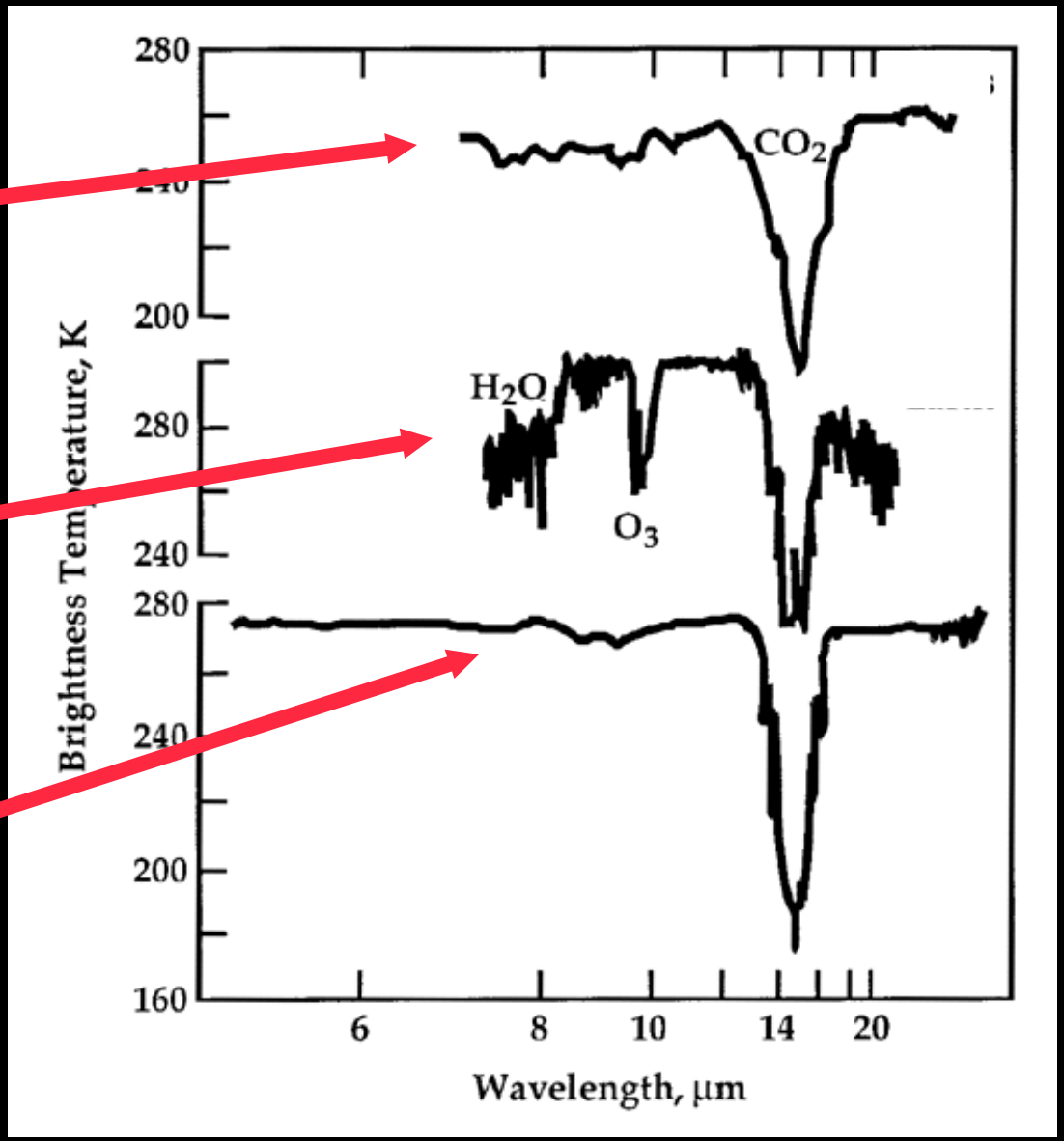
Methane produced by living organisms

Biological Activity?

Signs of Life ?

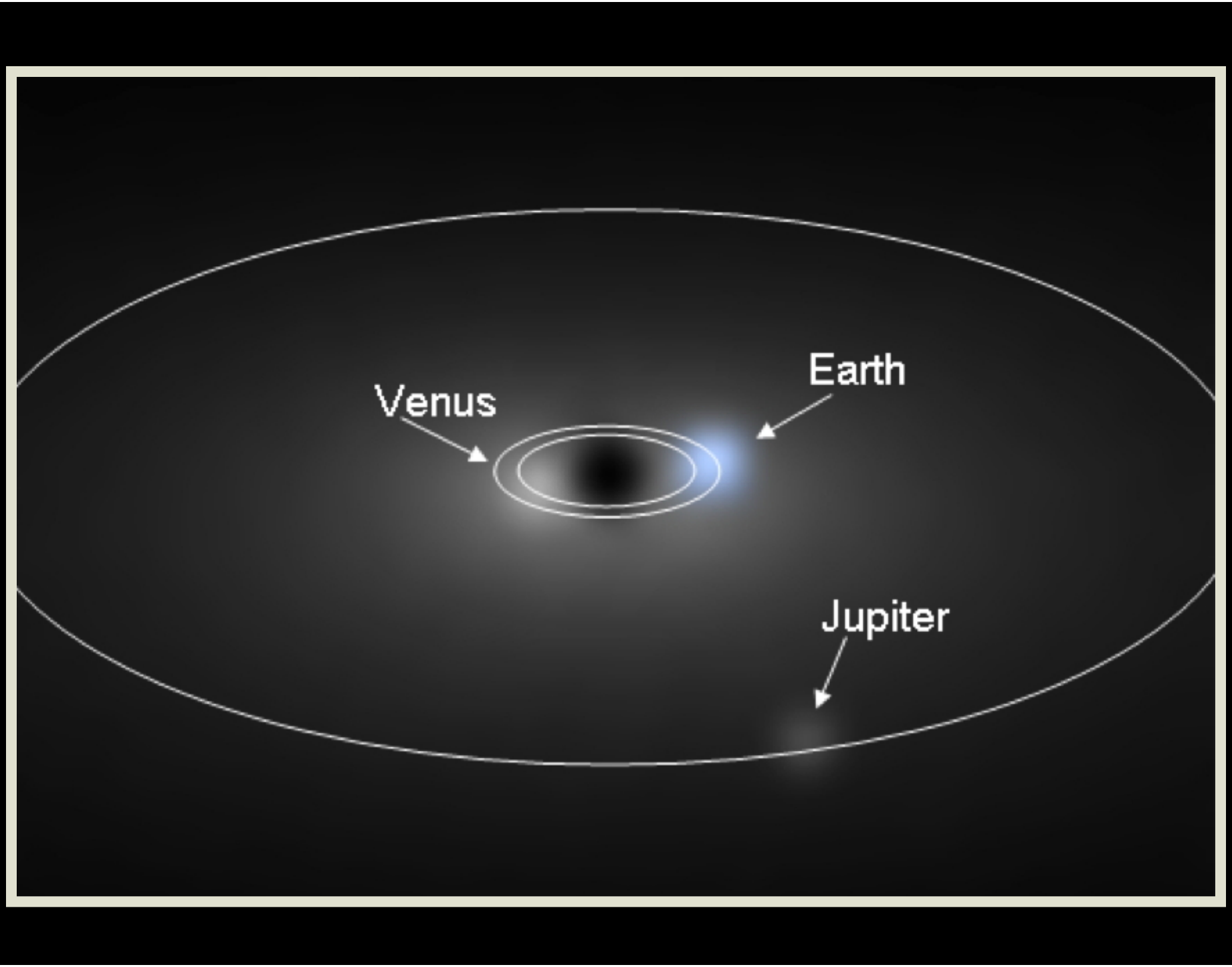






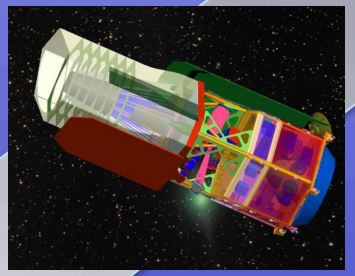
Spectrum and variability of "pale blue dots" tell us about the constituents of their atmosphere and compositions of their surfaces.

By finding and studying these system, we may hope to be able to detect signs of life!


Venus
Earth
Jupiter

Today

2020 -2030



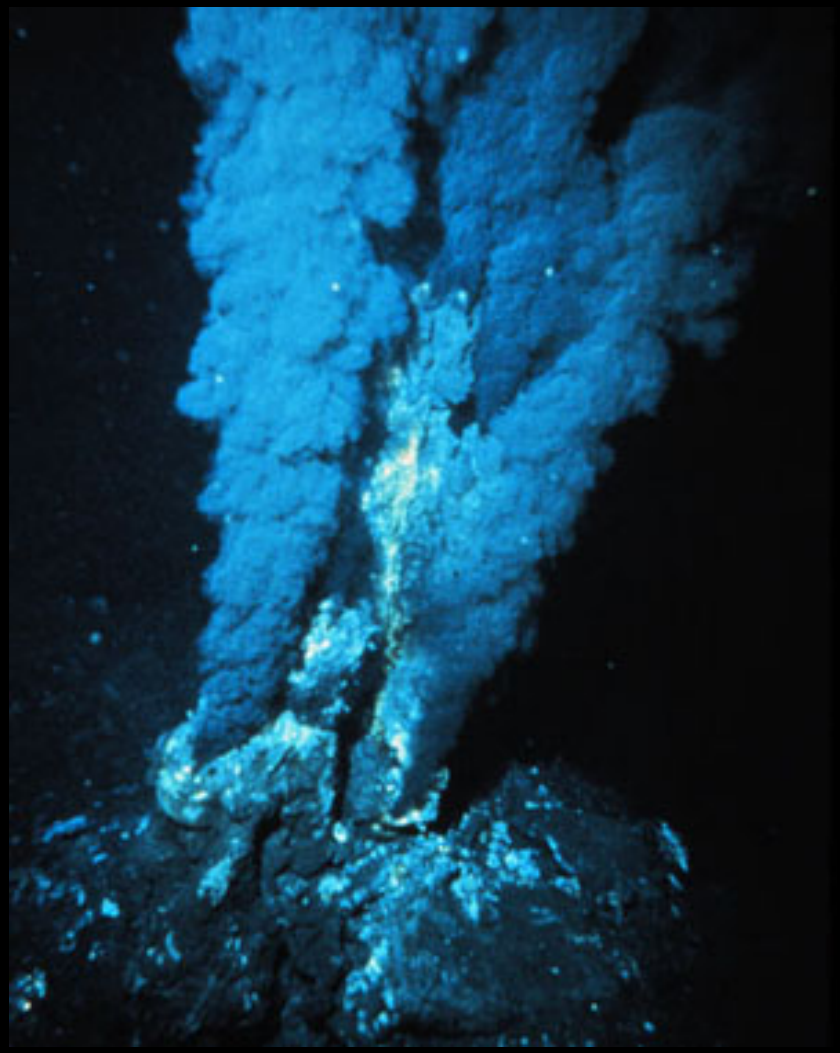
2030 -2040

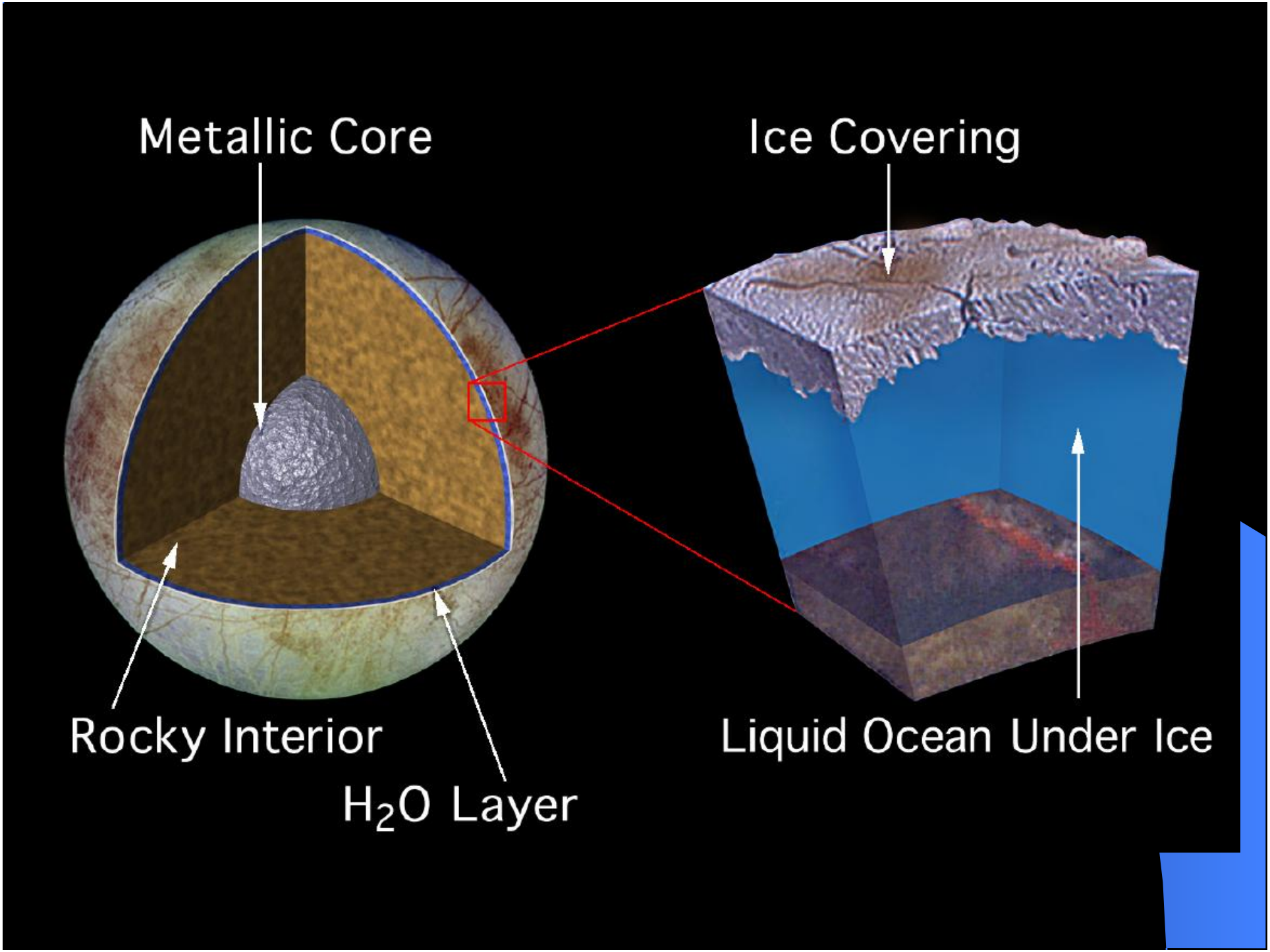
Beyond 2040

Life on Europa?

Three requirements for life:

- Liquid Water
- Energy Source
- Elements of Life




Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice

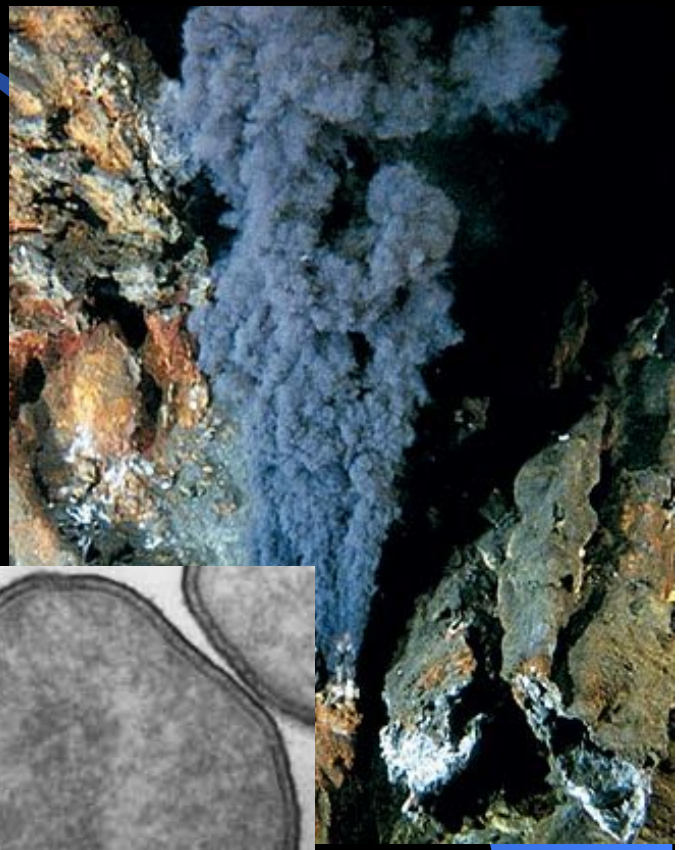
Thermophiles that thrive at high temperatures (>45°C)

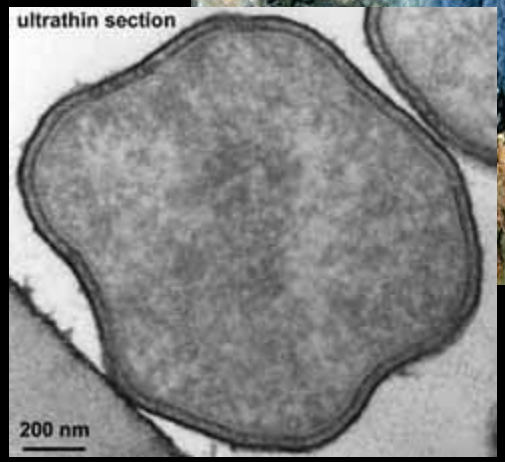
On Earth, found in hot springs and deep-sea hydrothermal vents

Have proteins & enzymes that work at high temperatures

Live by chemosynthesis (oxidation using hydrogen sulfide or methane)

Don't require sunlight!





Pyrolobus fumarii

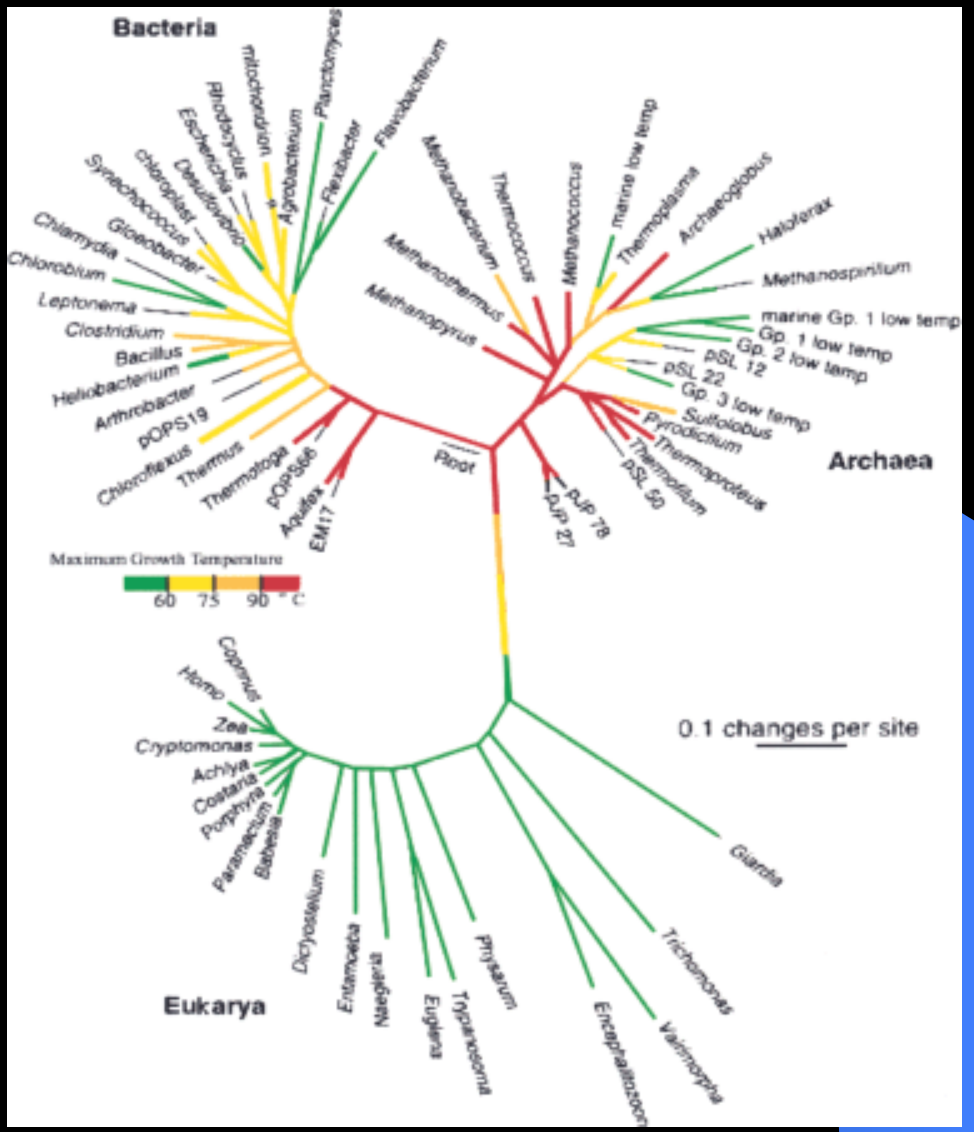
Evidence that *Thermophiles* were the first forms of life on Earth

The earliest life was *prokaryotic archaea*

Prokaryotes tend to be more heat tolerant

Deep hydrothermal vents are isolated from the harsh surface of the young Earth.

Relatively easy path for life?



Searching for Life on Europa

1. Determine if there is an ocean.
2. Drill into ice to look for life.
3. Fly through water plumes?