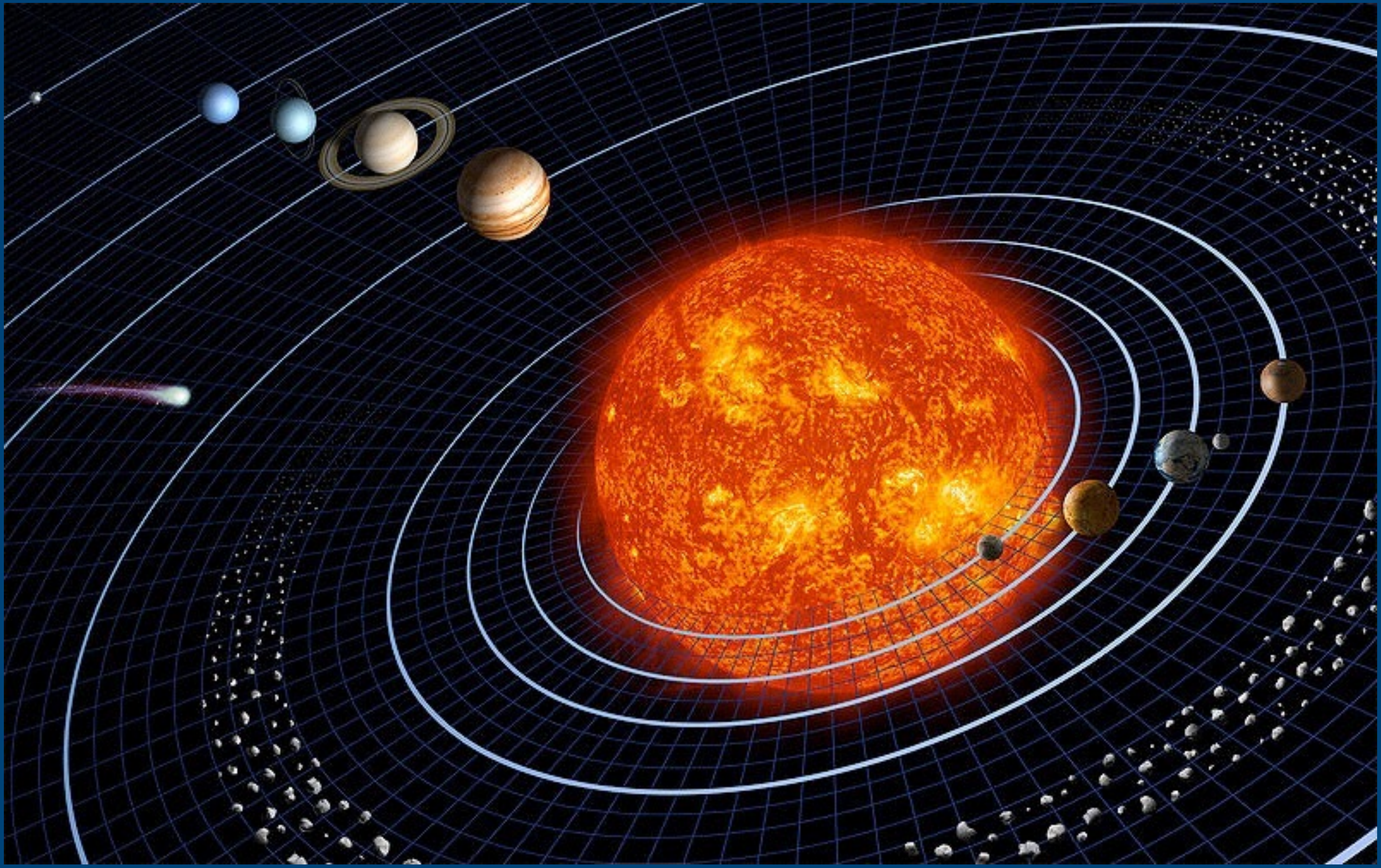
A biological tour of the Solar System



The story so far...

- Cosmological: age, size and composition of the Universe.
- Solar System: solar energy budget, physical composition of the planets.
- Earth: the impact of planetary geology on life.
- Life: signatures and requirements.
- Life on Earth: a case study, the emergence of life, the evolution of bio-signatures.

A biological tour of the Solar System

- In this lecture we will narrow down the search for life in the Solar System to a few of the most promising worlds.
- Studying the Earth has helped us to understand what are some of the basic requirements of life.
- Where in the Solar System do we see these conditions replicated?
- How are we investigating these worlds? We will look at some recent and planned missions to potential life bearing habitats.

The basic requirements of life

- Life on Earth requires liquid water, organic chemicals and energy.
- We believe that organic material is widespread throughout the Solar System.
- We can compute the amount of solar energy available to a planet or moon. In addition, we can determine whether energy might be available from tidal heating.
- Therefore can we simplify our search to look for evidence of liquid water?

Can we push the requirement for water?

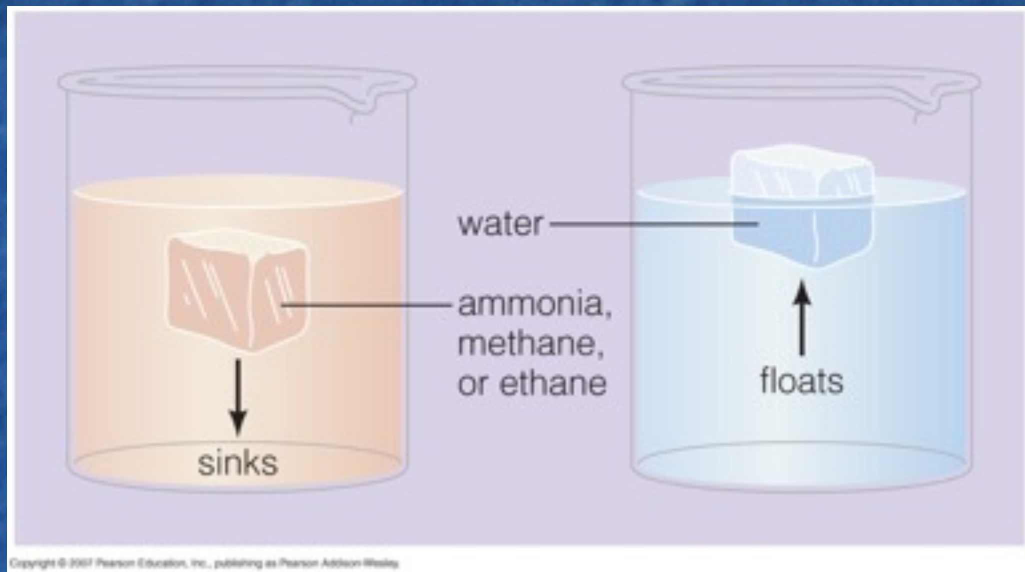
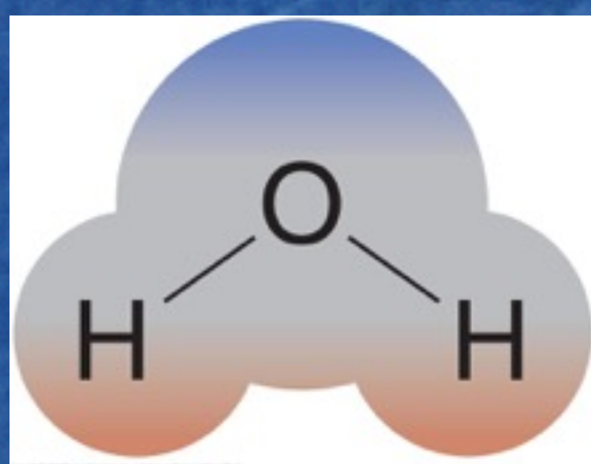


TABLE 7.1 *Potential Liquids for Life*

Freezing and boiling points (under 1 atmosphere of pressure) for common substances that may be found in liquid form in our solar system. The last column gives the width of the liquid range, found by subtracting the freezing point from the boiling point.

Substance	*Freezing Temperature*	*Boiling Temperature*	*Width of Liquid Range*
Water (H_2O)	0°C	100°C	100°C
Ammonia (NH_3)	−78°C	−33°C	45°C
Methane (CH_4)	−182°C	−164°C	18°C
Ethane (C_2H_6)	−183°C	−89°C	94°C



The Moon and Mercury

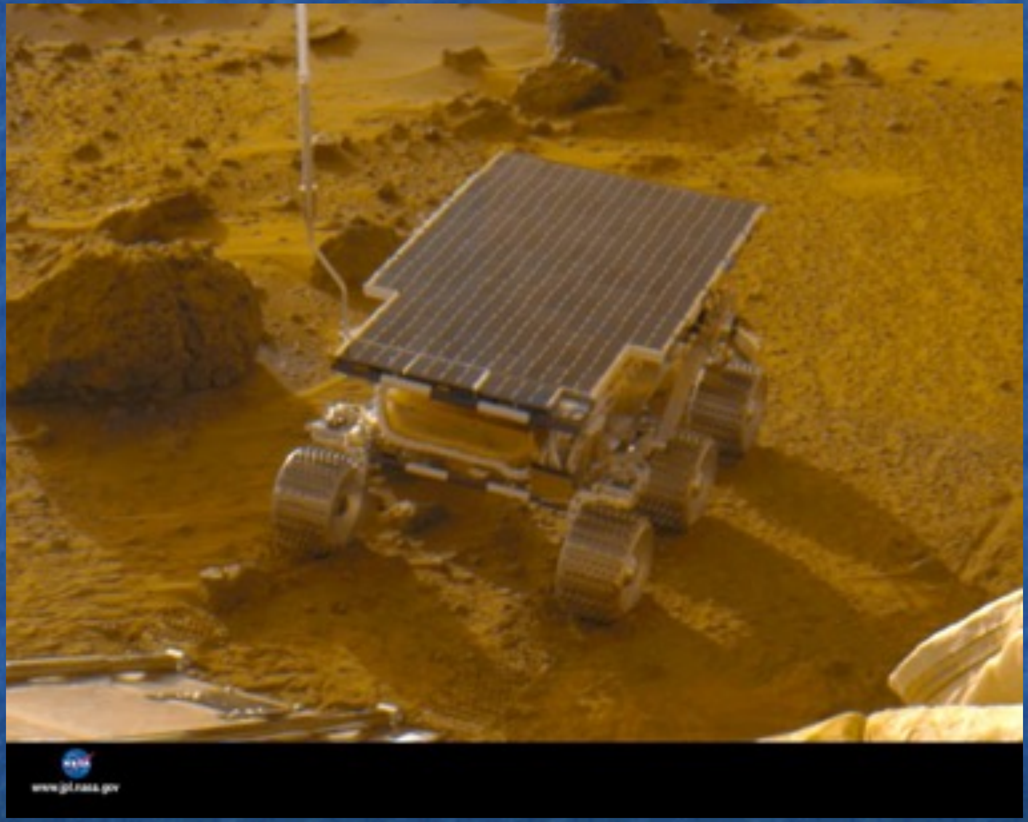
a The Moon   b Mercury

Venus

What happened on Venus?

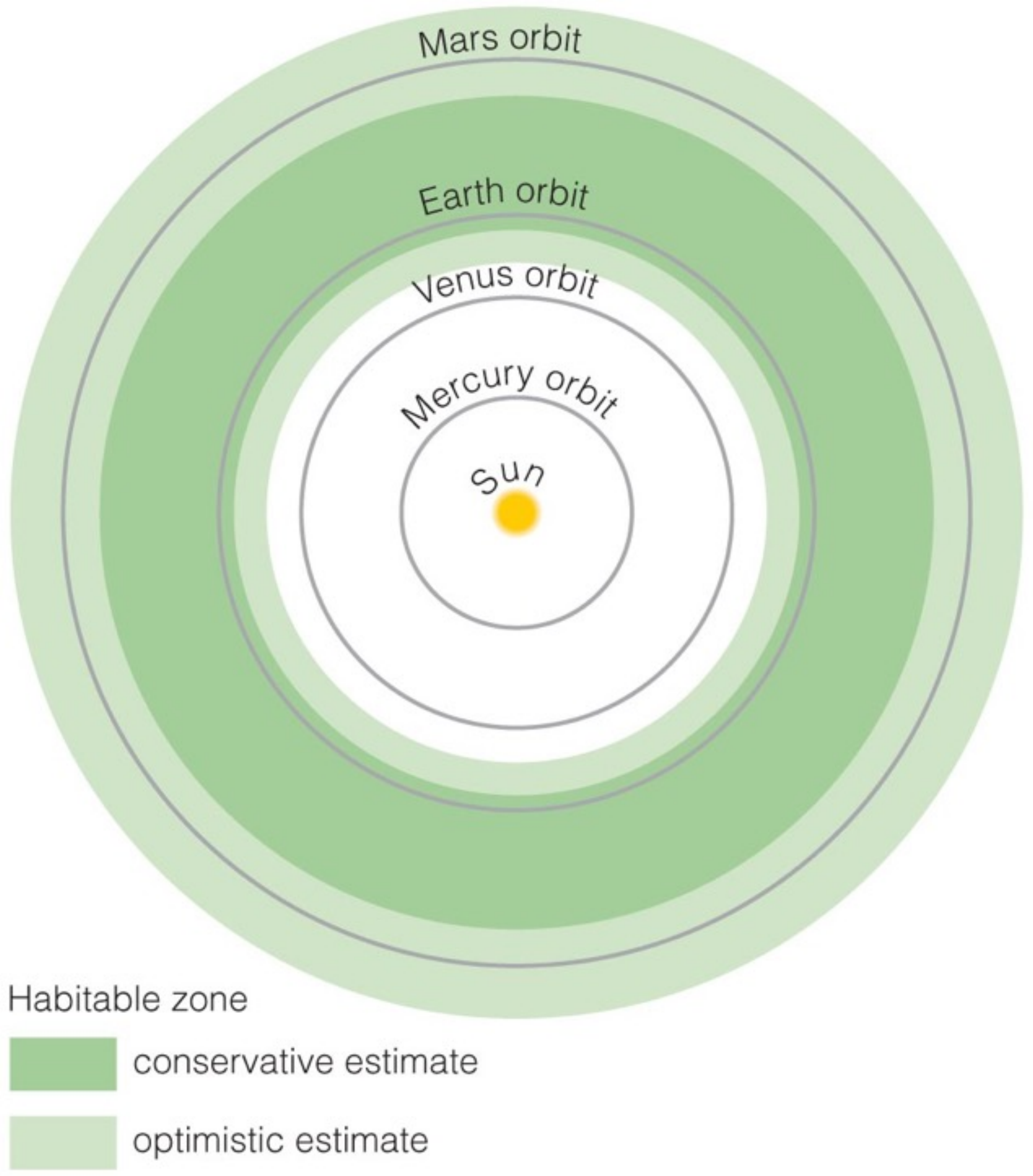
- Venus became too hot too early.
- As the young Sun brightened from an early, dim phase, Venus' CO2 atmosphere generated a strong greenhouse effect.
- Water oceans, if present, evaporated. This removed a key link in the CO2 cycle - no climate regulation.
- Warming continued to the point where water was even baked out of the rocks.
- Dry rock resulted in a thick, rigid crust.
- No subduction, no CO2-rock cycle.

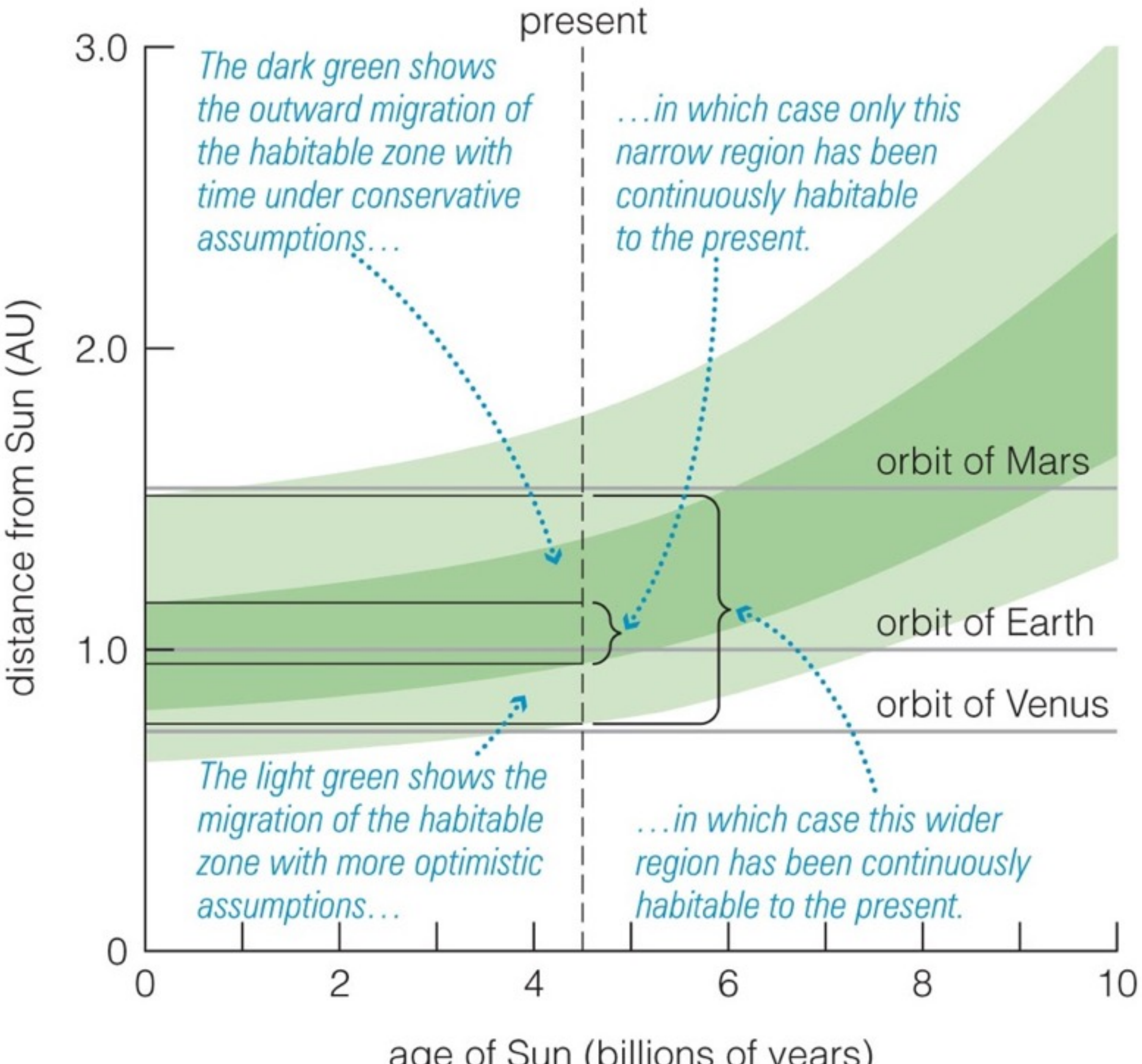
Mars



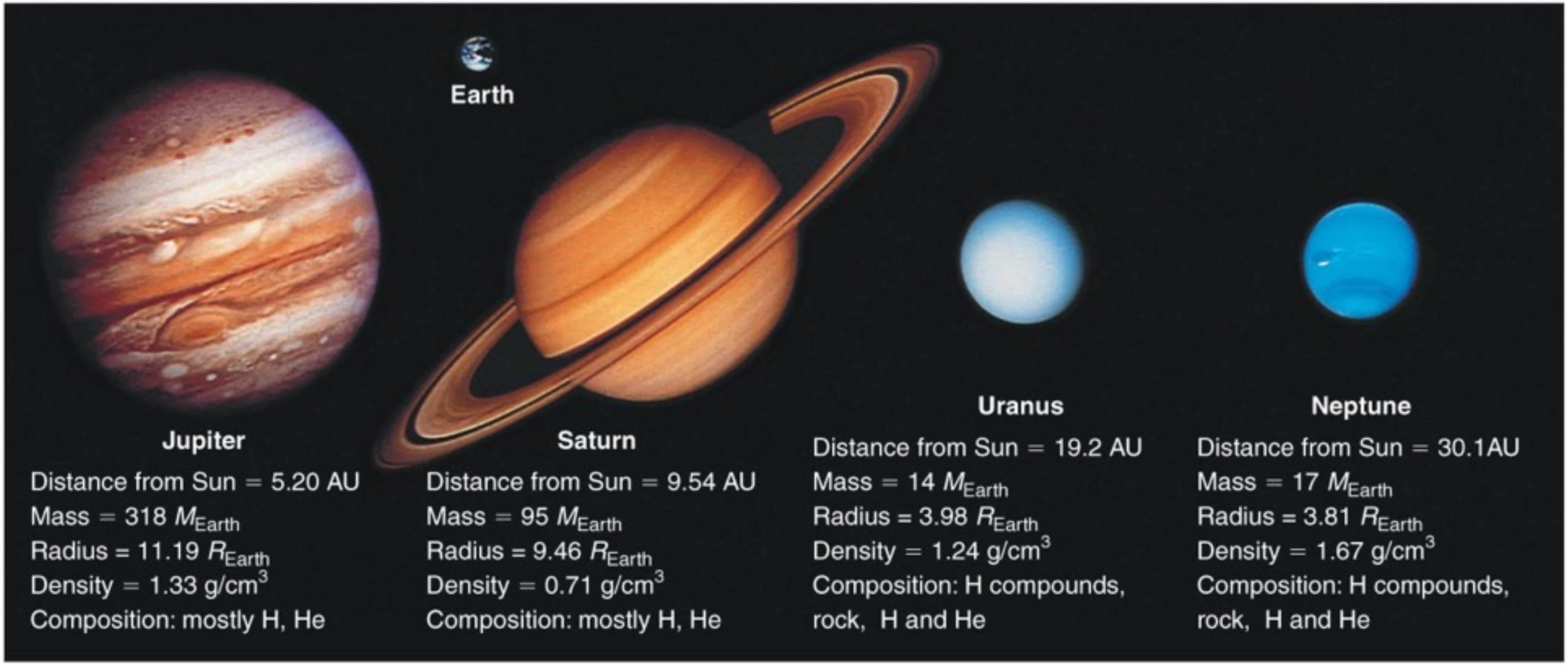
What happened on Mars?

- Mars displays evidence for past surface liquid water.
- The presence of liquid water requires an atmosphere much thicker than the present atmosphere.
- The youthful Mars possessed more internal heat than today.
- This powered volcanos and potentially a magnetic field.
- Mars could have hosted a thick atmosphere.
- However, Mars cooled faster than the Earth.
- Active geology ceased. The atmosphere was lost.
- Surface temperatures dropped. Liquid water became ice or evaporated.
- Large reservoirs of sub-surface ice remain.

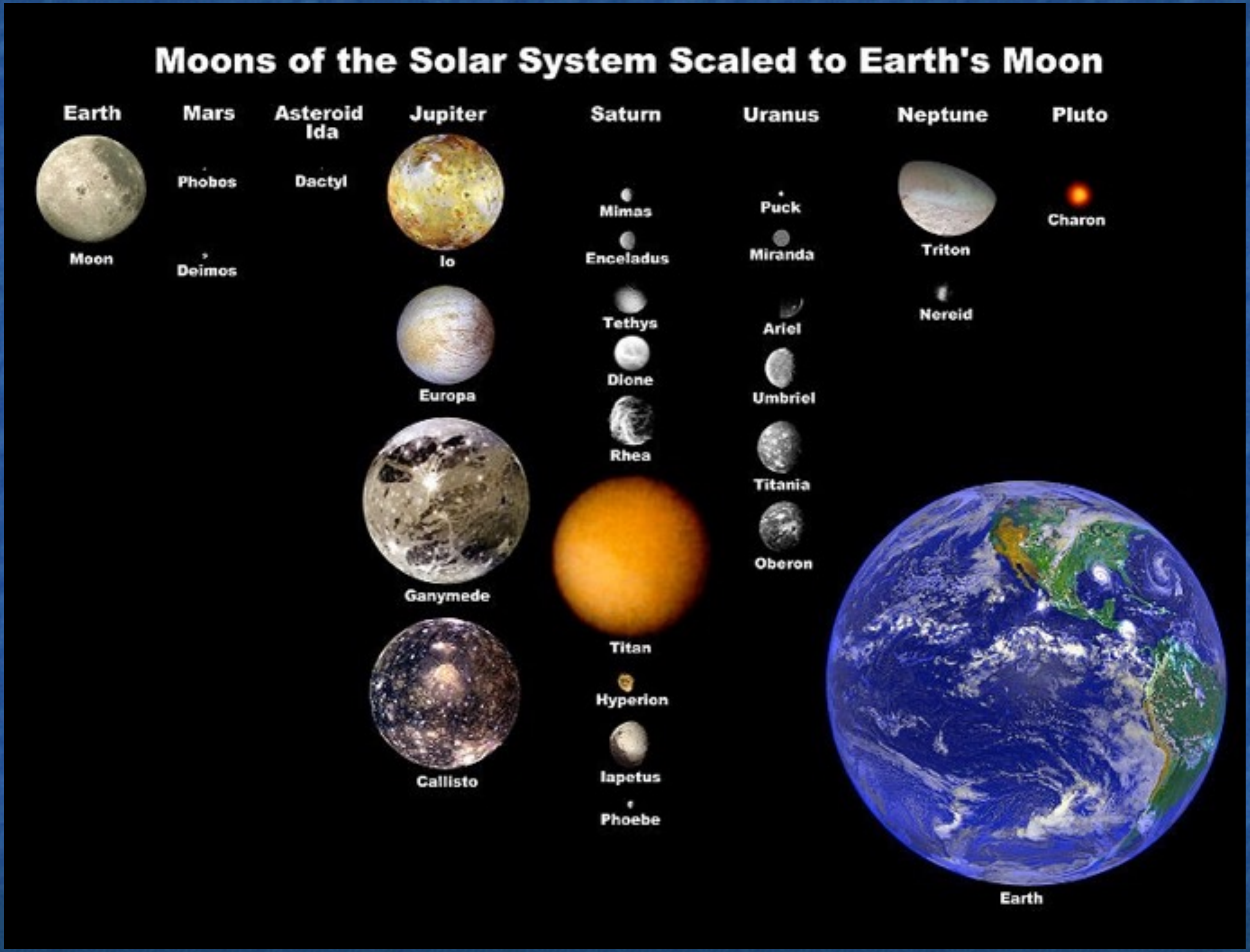

Mars orbit
Earth orbit
Venus orbit
Mercury orbit
Sun
Habitable zone
conservative estimate
optimistic estimate


present
3.0
2.0
1.0
0
distance from Sun (AU)
The dark green shows the outward migration of the habitable zone with time under conservative assumptions…
…in which case only this narrow region has been continuously habitable to the present.
orbit of Mars
orbit of Earth
orbit of Venus
The light green shows the migration of the habitable zone with more optimistic assumptions…
…in which case this wider region has been continuously habitable to the present.
0
2
4
6
8
10
age of Sun (billions of years)

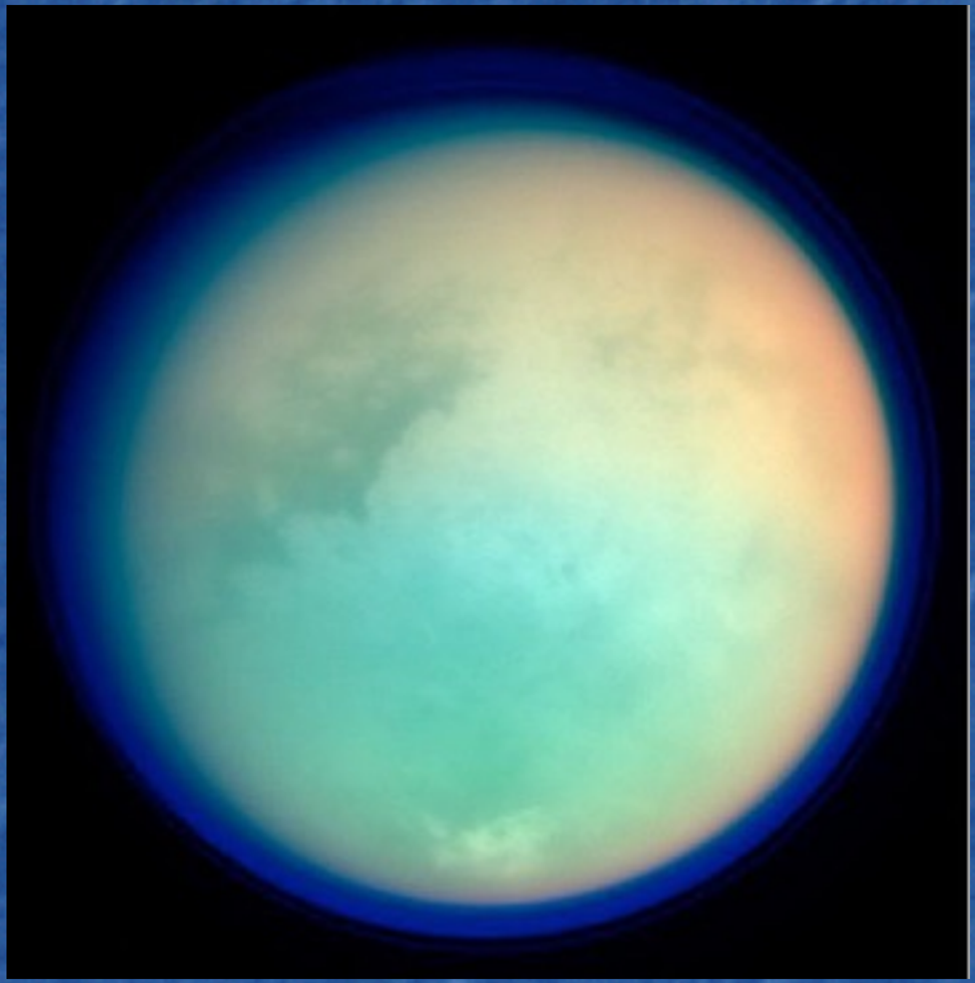
Jovian worlds

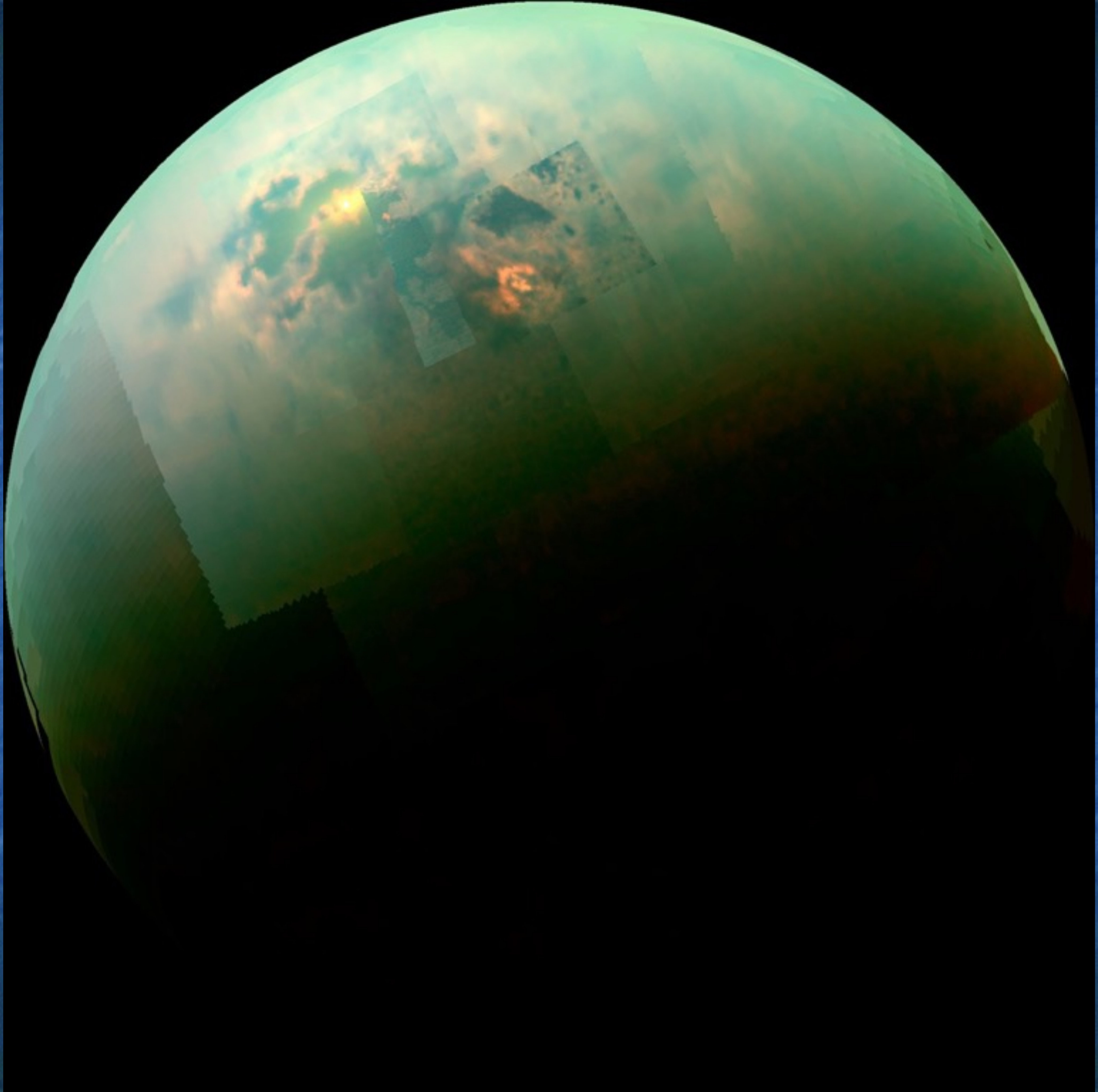


Jovian moons

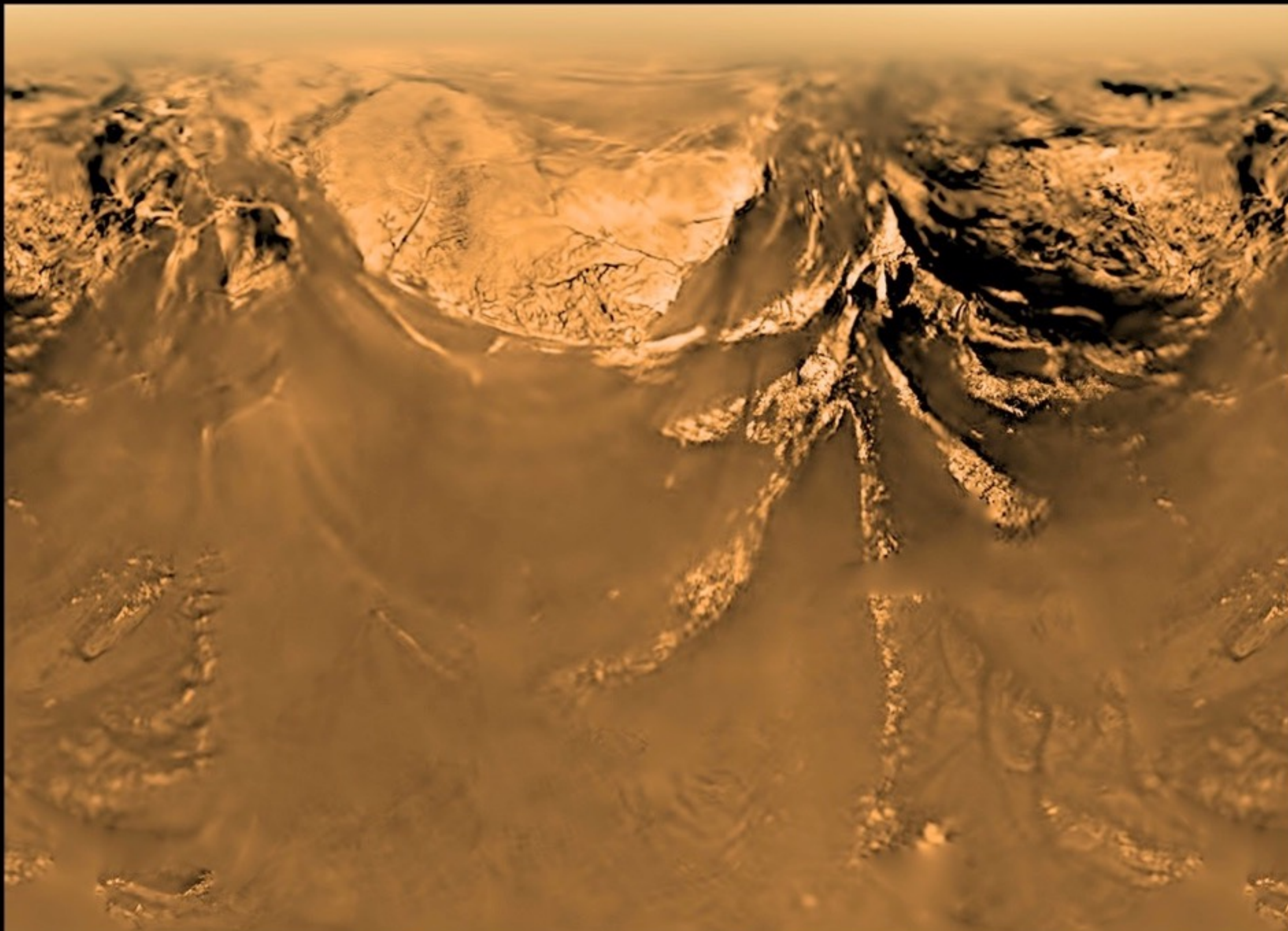


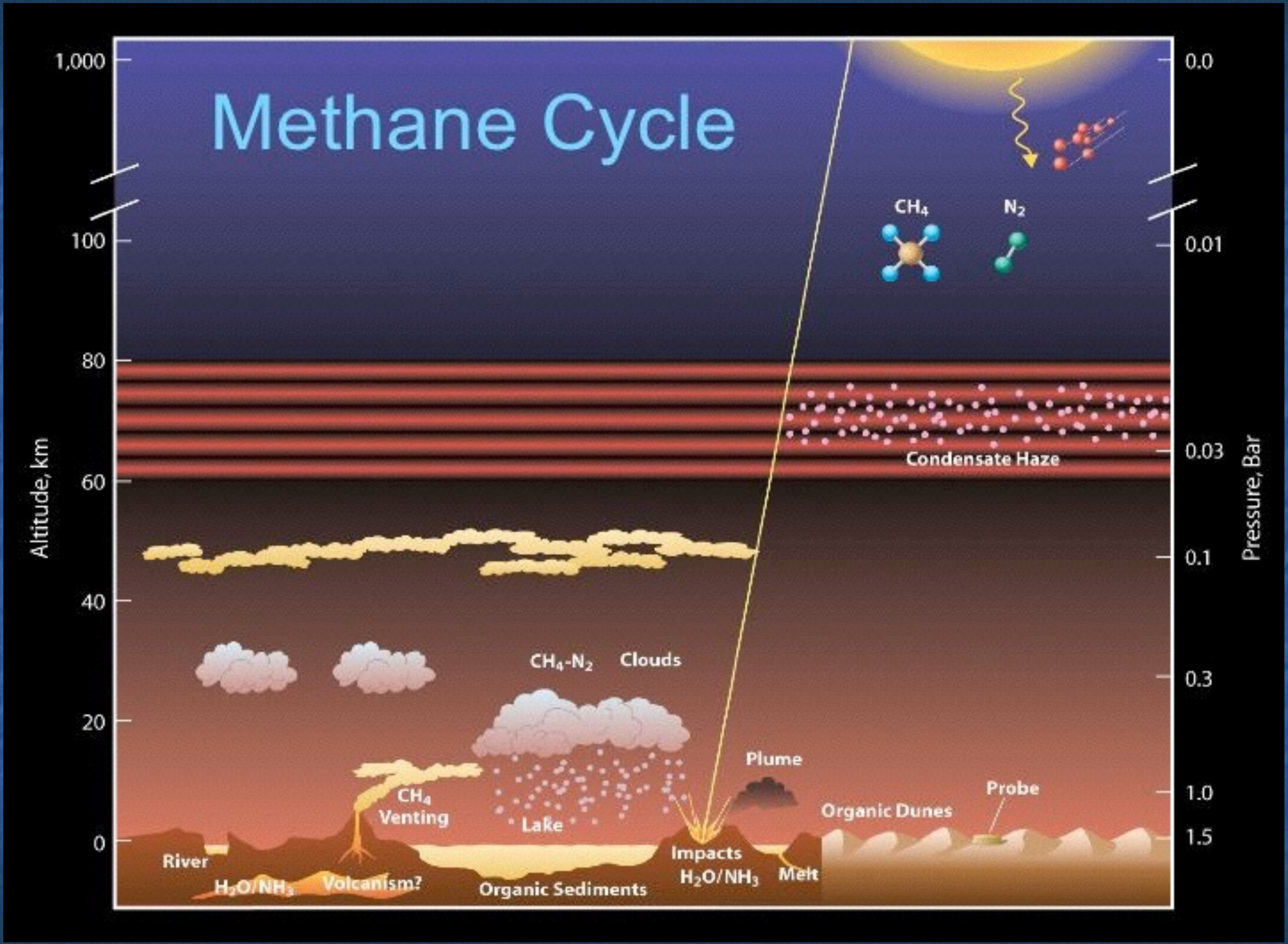
Jovian moons: Titan





Aerial View of Titan Around the Huygens Landing Site from 10 km Altitude





Methane Cycle
1,000
100
80
60
40
20
0
Altitude, km
0.0
0.01
0.03
0.1
0.3
1.0
1.5
Pressure, Bar
CH_4
N_2
Condensate Haze
CH_4-N_2 Clouds
Plume
CH_4 Venting
Lake
Probe
Organic Dunes
River
H_2O/NH_3
Volcanism?
Organic Sediments
Impacts
H_2O/NH_3
Melt

Rare Titan

Scientists have discovered liquid (H_2O) on another planet!

however;

- it is extremely corrosive to organics & inorganics

- solution concentrations will be so high as to be toxic

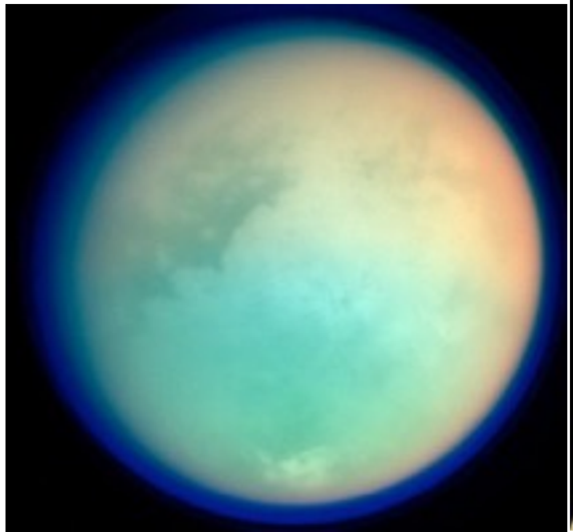
- high temperatures imply life Rx on timescale of days

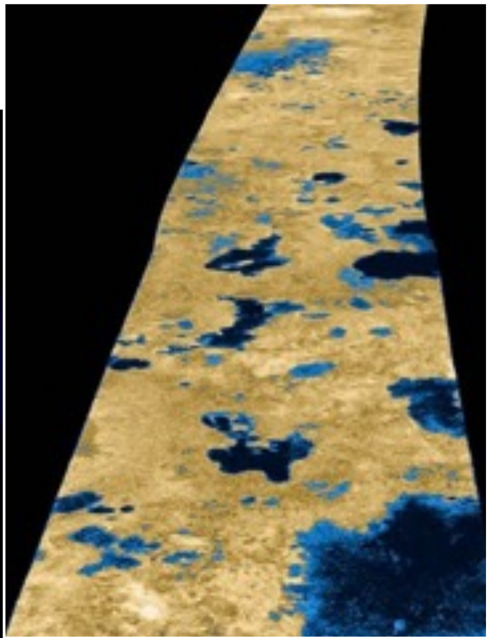
- solid phase floats; rendering the polar & winter regions uninhabitable and creating a climate feedback instability

- its photolysis product, O_2, poisons the atmosphere.

…

proving the suitability of our environment of liquid CH_4 at normal temperatures and the intelligence of its design.





Best candidates for life

World	Atmosphere	Liquids	Energy	Extremes
Mercury	✘	✘	✔	✔
Venus	✔	✘	✔	✔
Earth	✔	✔	✔	✘
Moon	✘	✘	✔	✔
Mars (today)	✘	?	✔	✘
Mars (past)	✔	✔	✔	✘
Jovian planets	✔	✘	✔	✔
Jovian moons	✔	✔	✔	✘

Space missions: past highlights

- Flyby: Voyager 2 (Jupiter, Saturn, Uranus, Neptune)
- Orbiter: Mars Global Surveyor, Cassini (Saturn)
- Lander/Probe: Spirit and Opportunity (Mars), Huygens (Titan)
- Manned/Sample return: Apollo (Moon), Stardust (Comet Wild2)

Martian rover's wild ride

The aeroshell protects the rover from fiery temperatures as it enters the Martian atmosphere. Six minutes to landing.

With the parachute deployed, three retrorockets fire their engines, suspending the lander 30–50 feet above the Martian surface.

Protected by large airbags, the lander falls away from the parachute, landing safely on Mars. The lander bounces for several minutes, traveling hundreds of meters.

After bouncing to a stop, the airbags are retracted and the lander's petals deploy, creating a ramp for the rover to descend.

The rover deploys the solar arrays, wheels, cameras, and other instruments and begins its exploration of the Martian surface.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