Fermi's Paradox and the Likelihood of Finding Another Planet Like Earth

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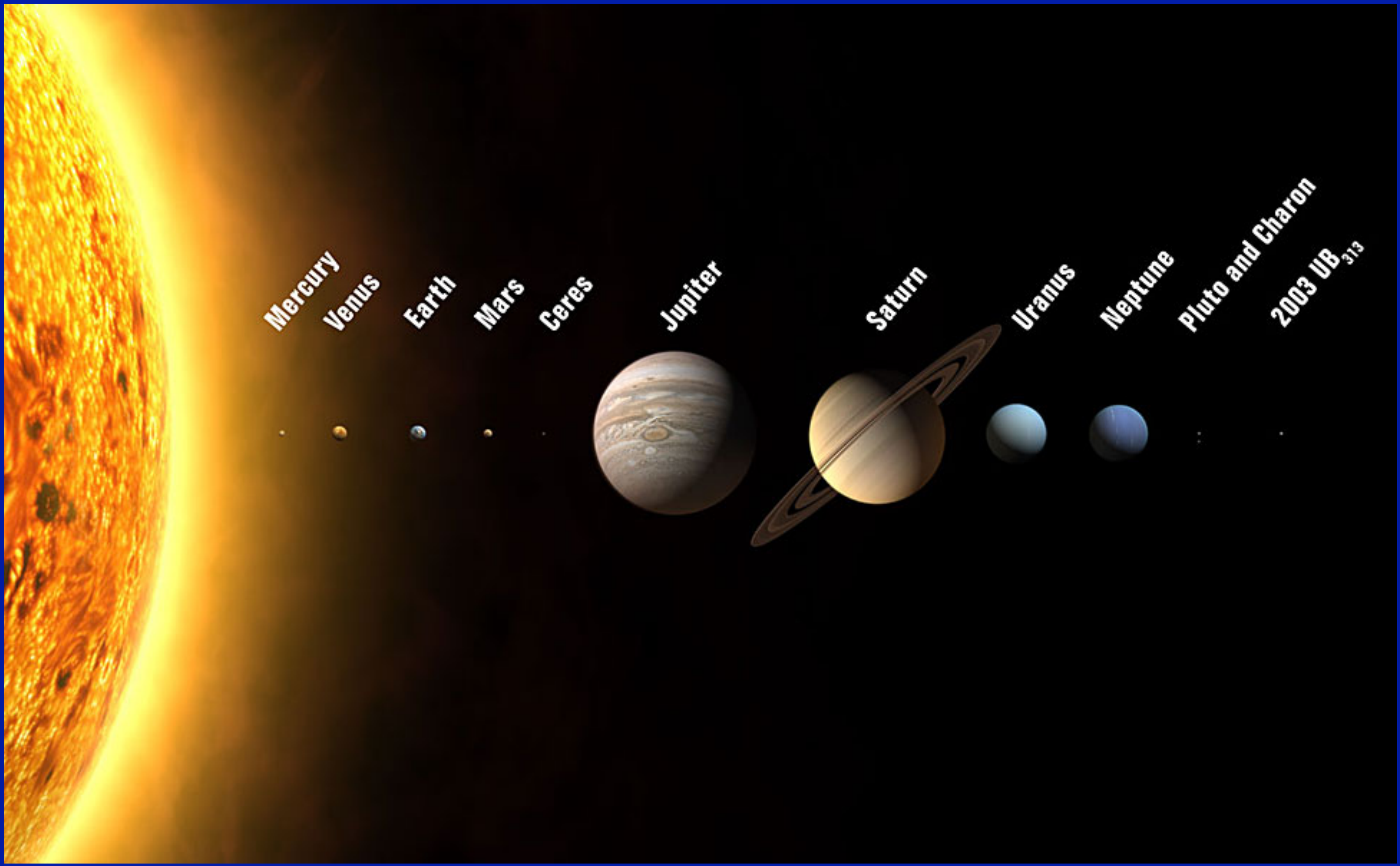
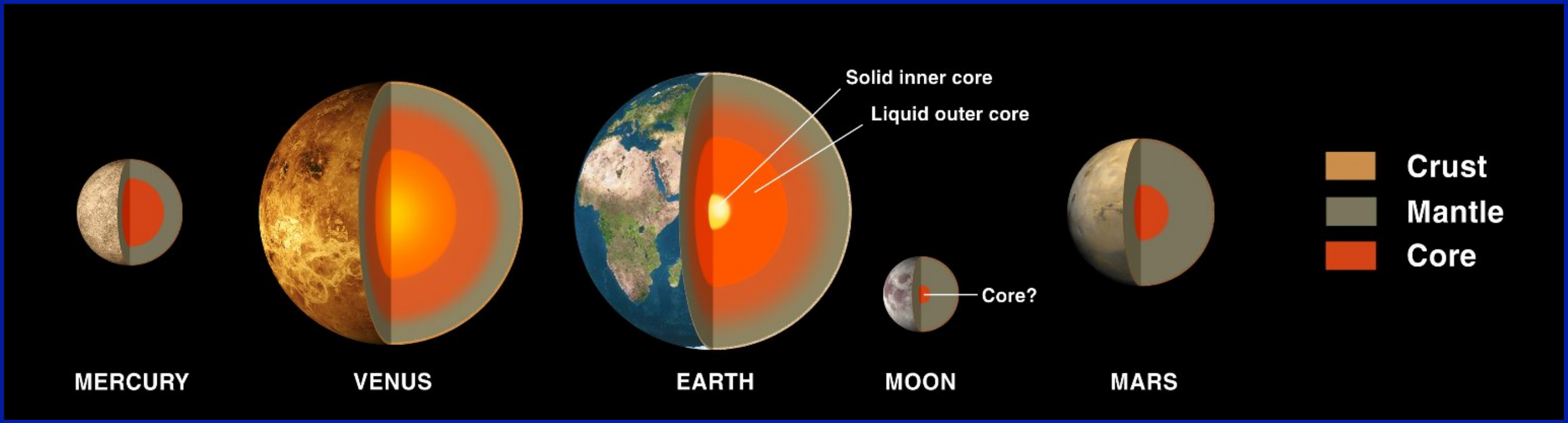


Sun is 99.85% of mass of the Solar System



Comparison of Terrestrial Planets

MERCURY

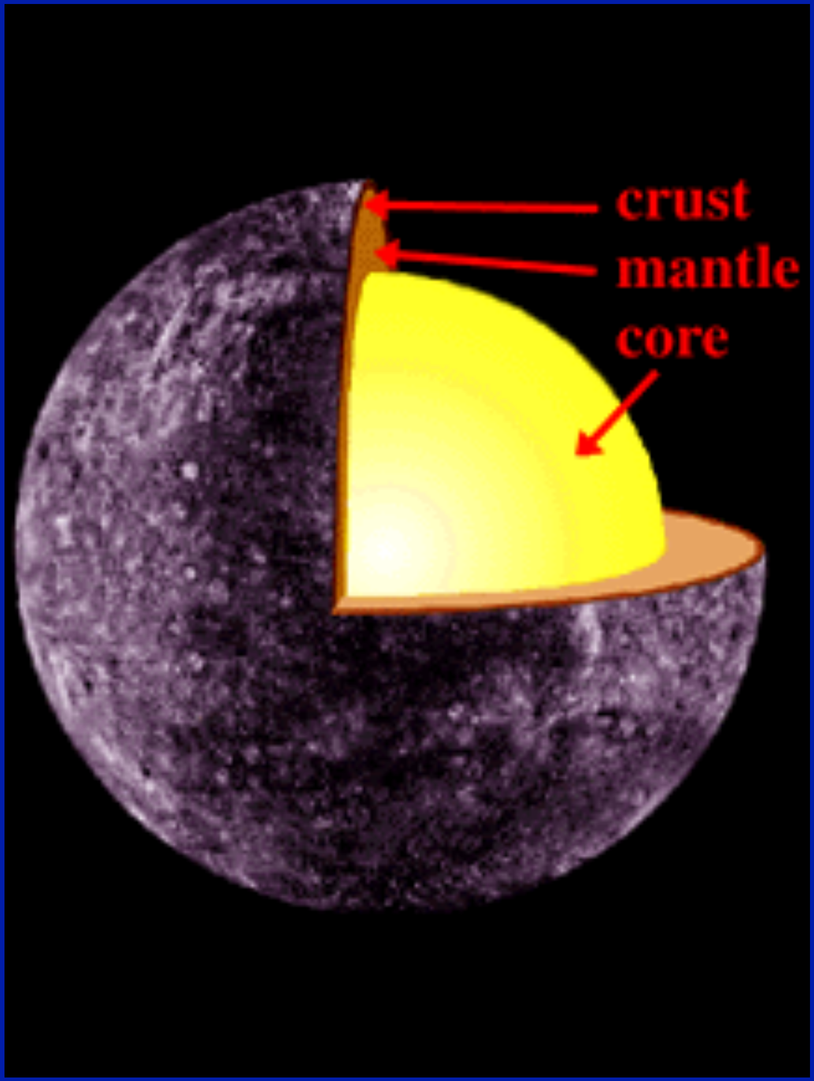
Mass = 5.5% of E

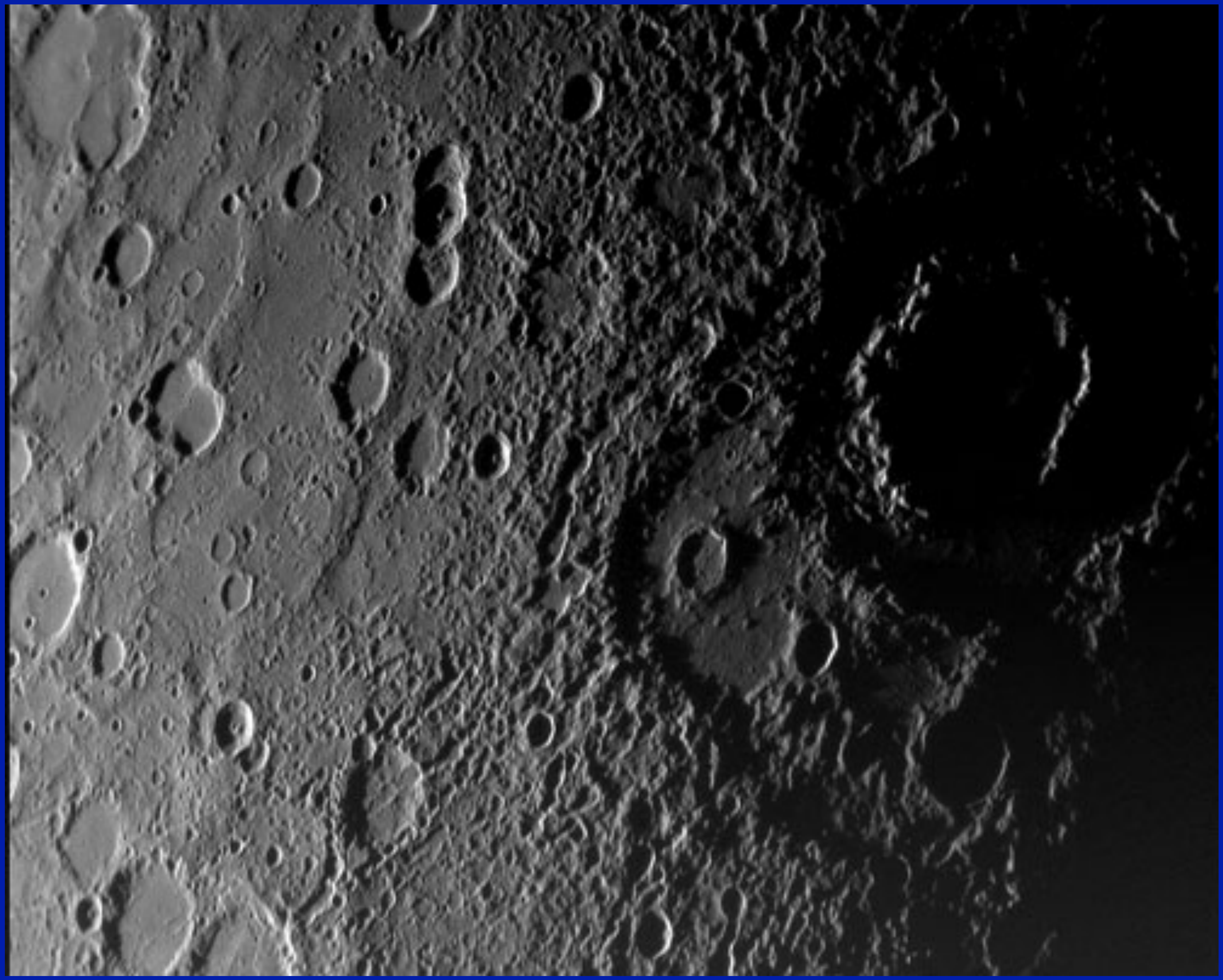
Density = 98.4% of E

R = 2440 km

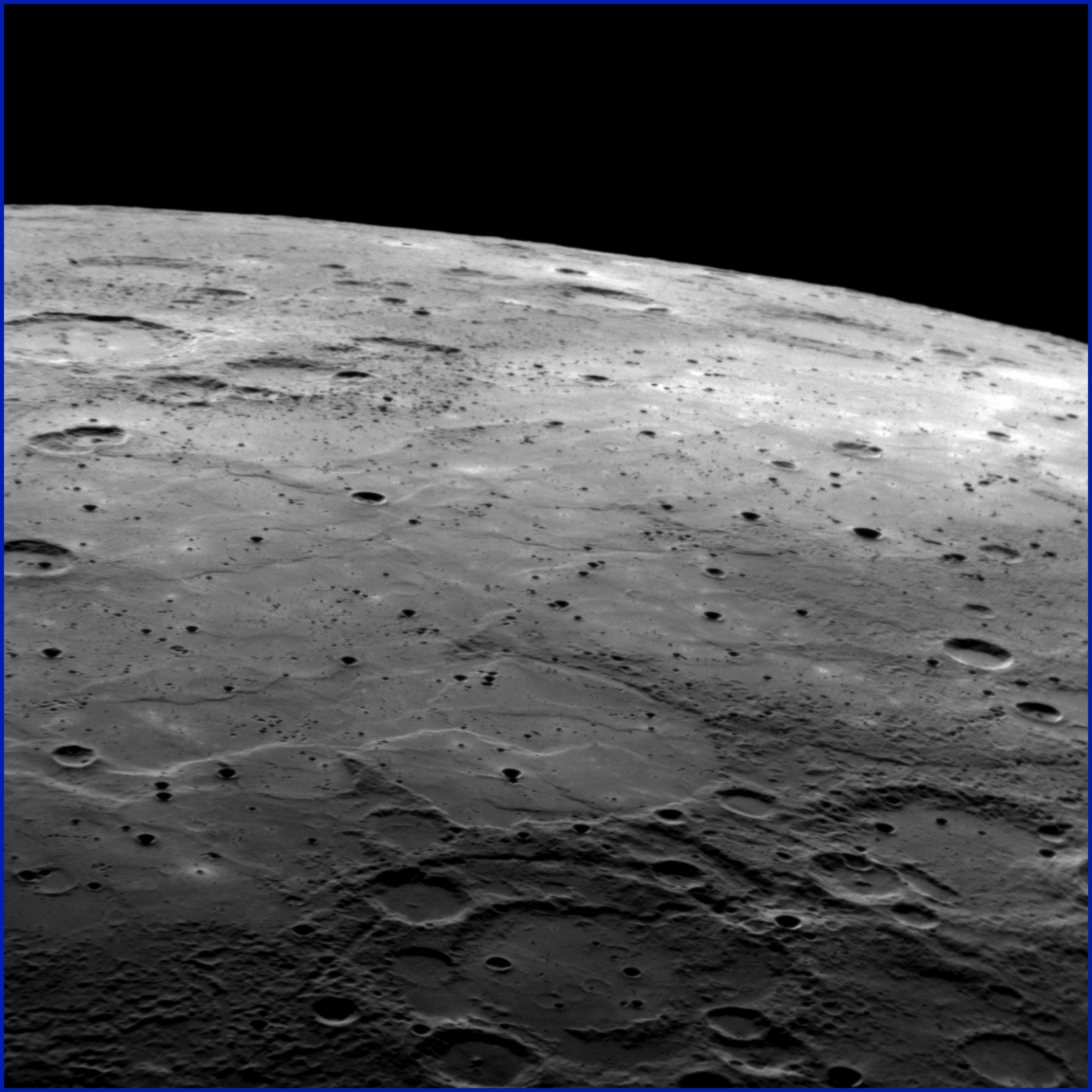
R(core) = 1800 km

g = 37.8% of E





Surface T = 80K to 700K

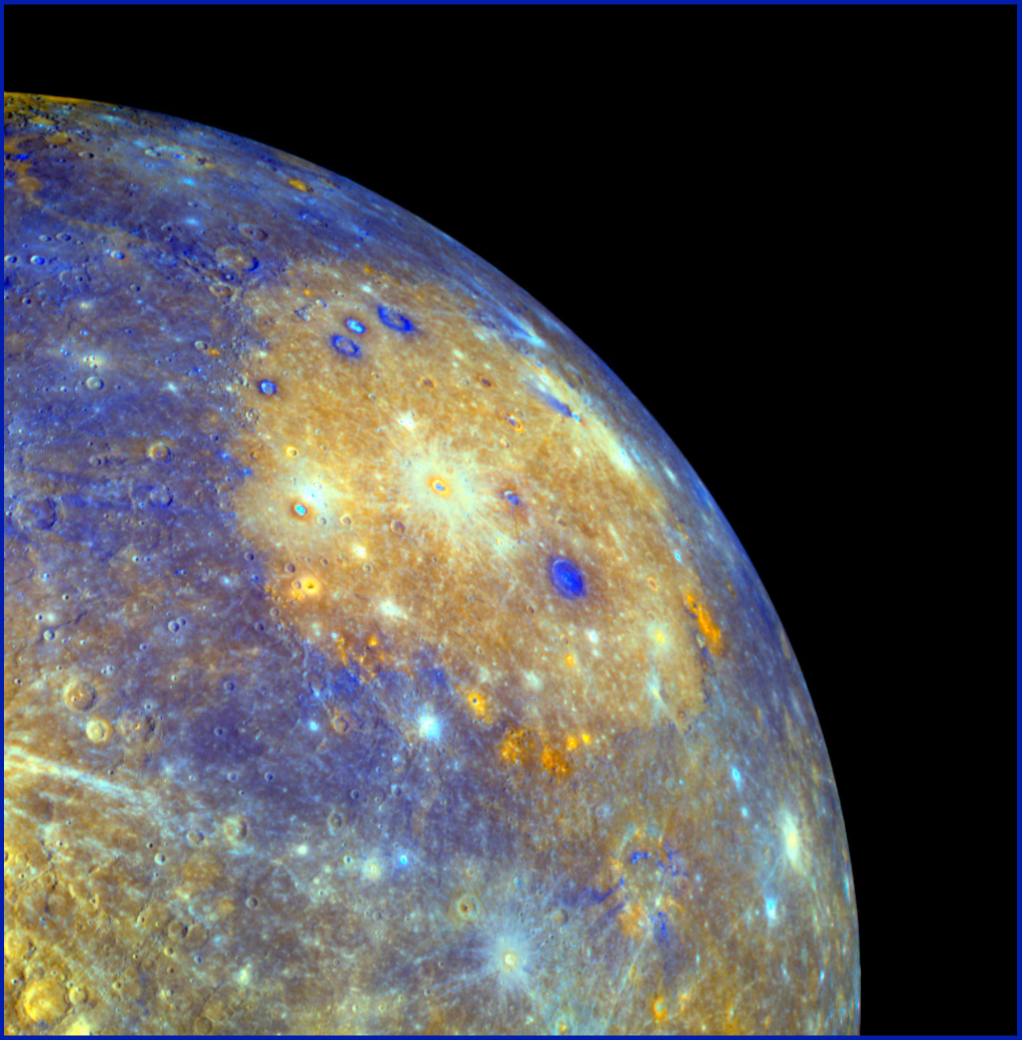


Trace water amounts may survive in permanently-shadowed craters

Evidence of volcanism

- low-Fe basaltic shield volcano, 100-km across

Shows evidence of slight exosphere (Mg, Ca, Na)



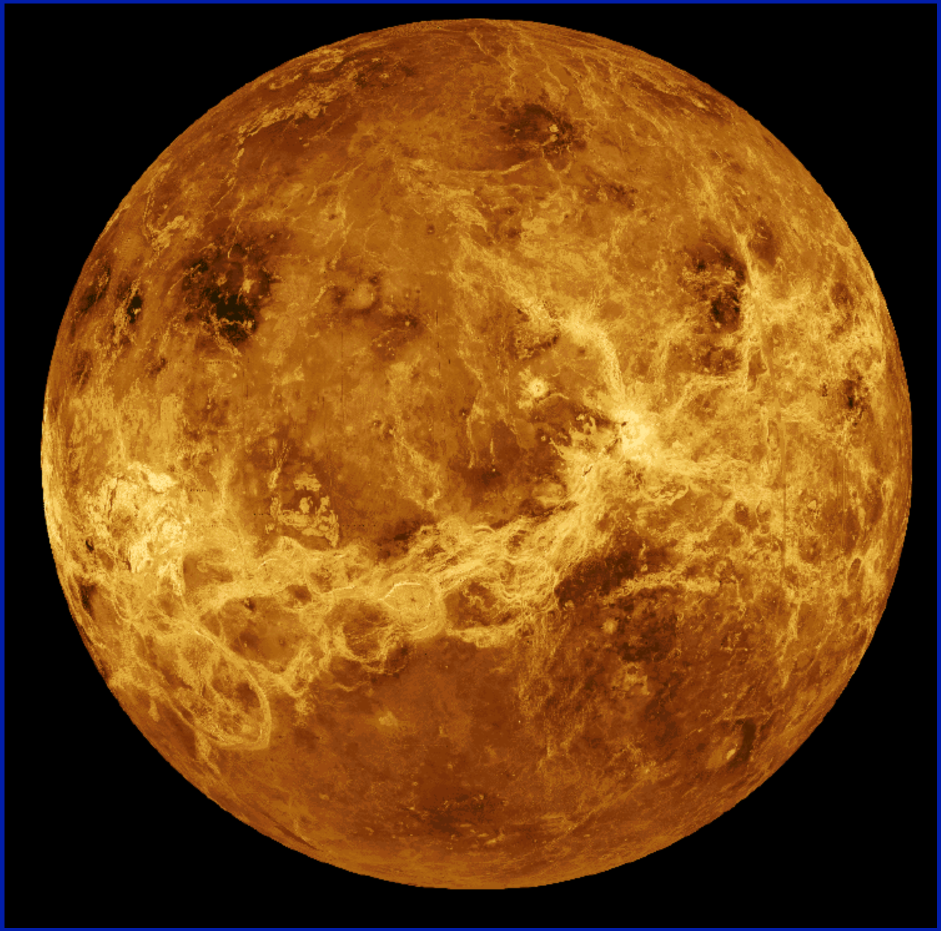
VENUS

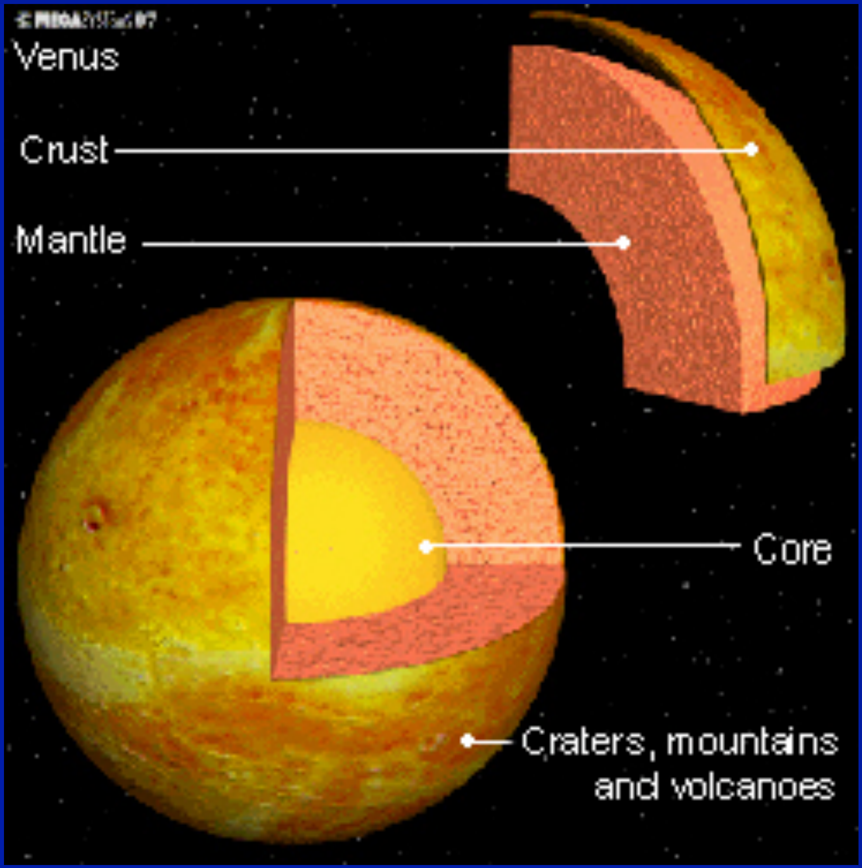
Mass = 81.5% of E

Density = 95.1% of E

R = 6052 km (95% of E)

g = 90.5% of E



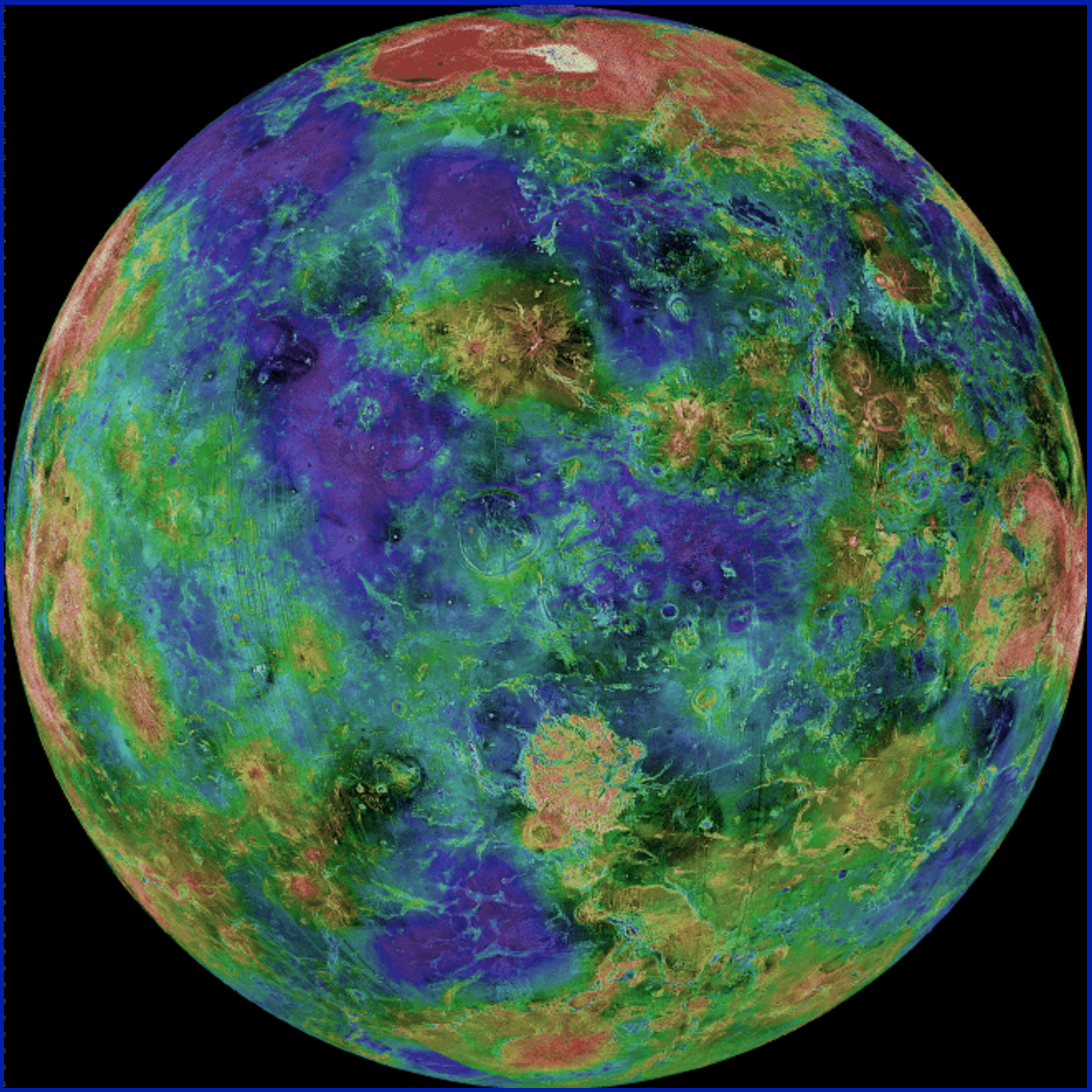


Very little rotation (backwards; 243 days) - no magnetic field

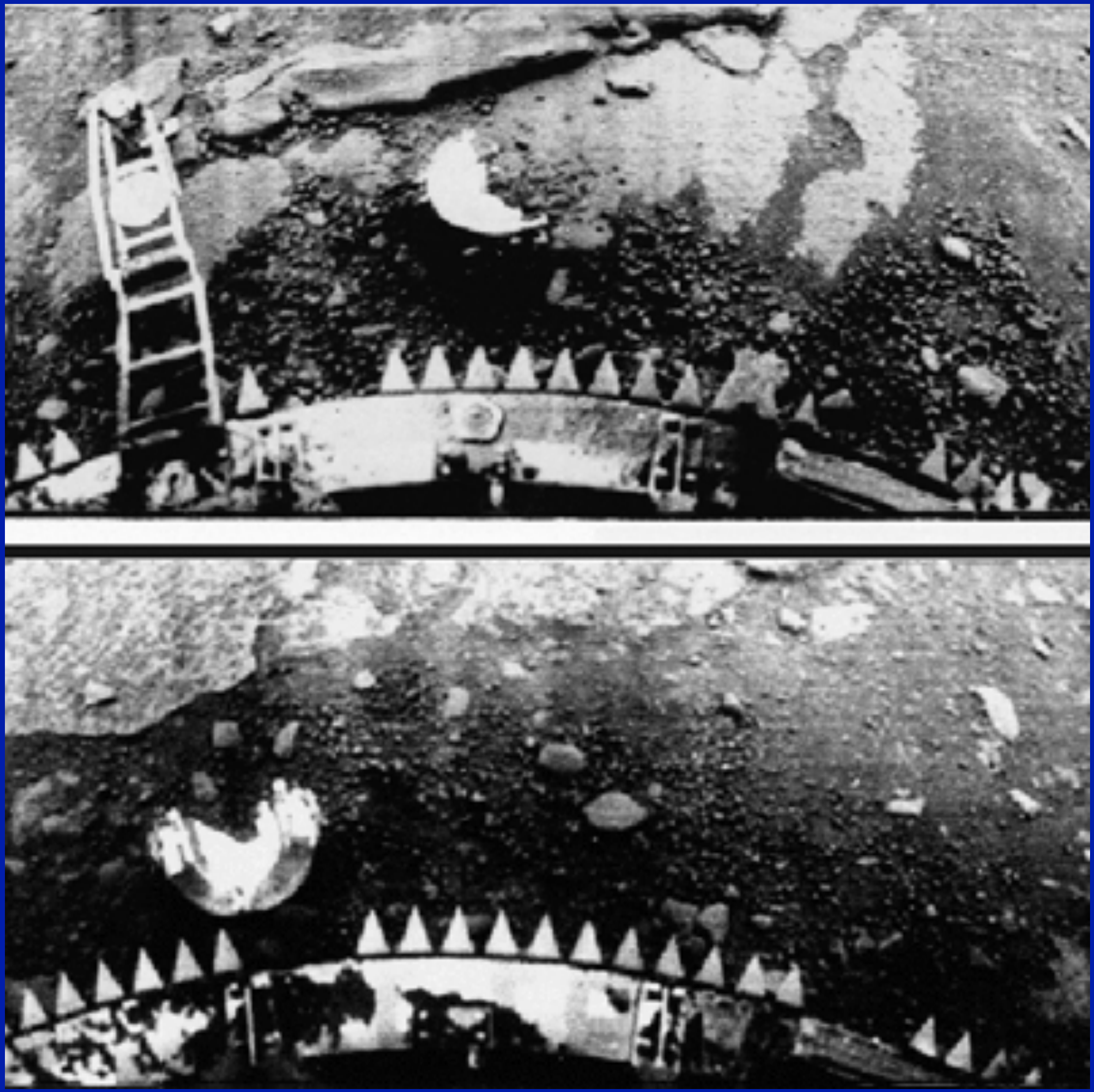
No water - no asthenosphere - no plate tectonics

Atmosphere - 92 bars; 96.5% CO_2

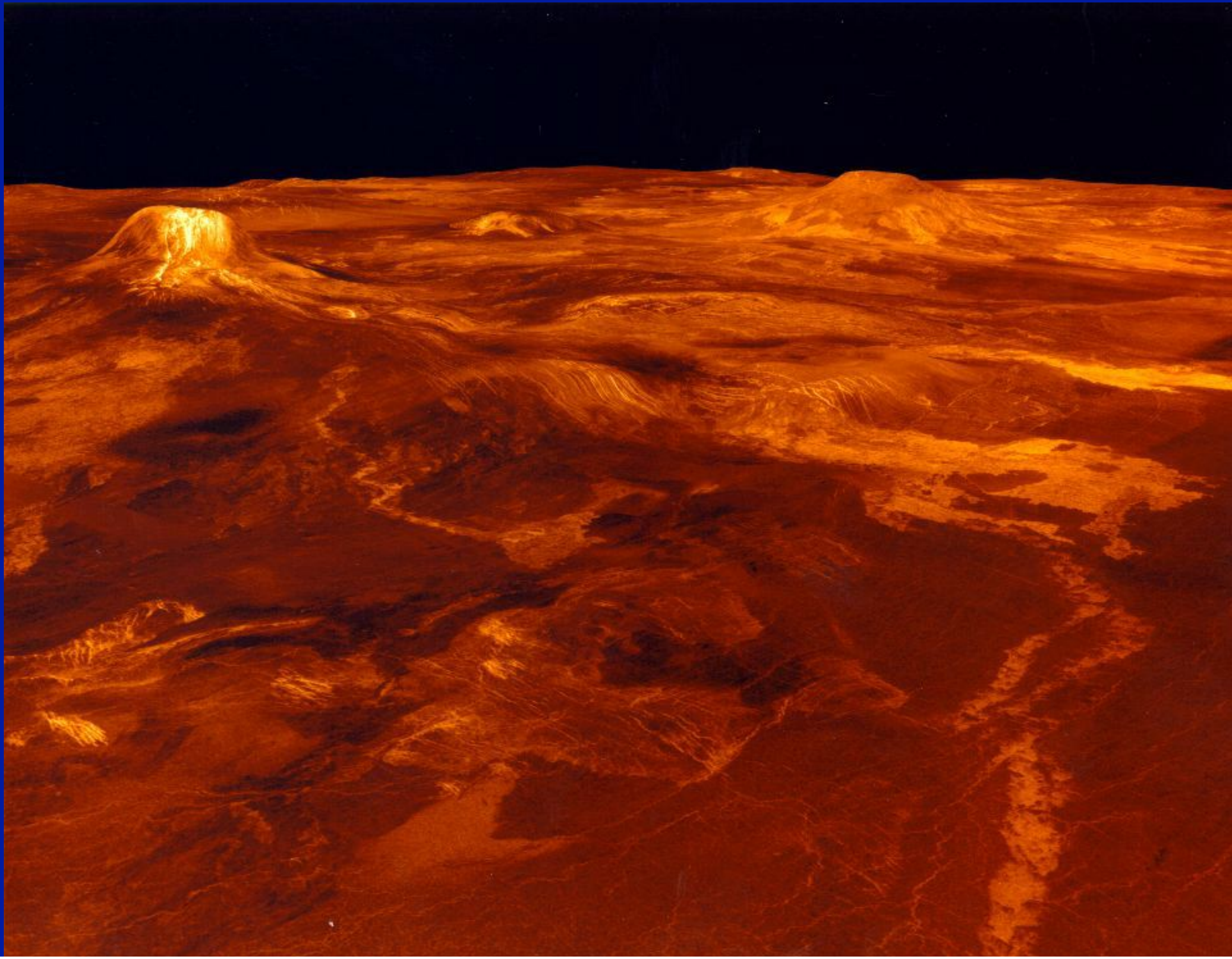
Mean T = 464ºC

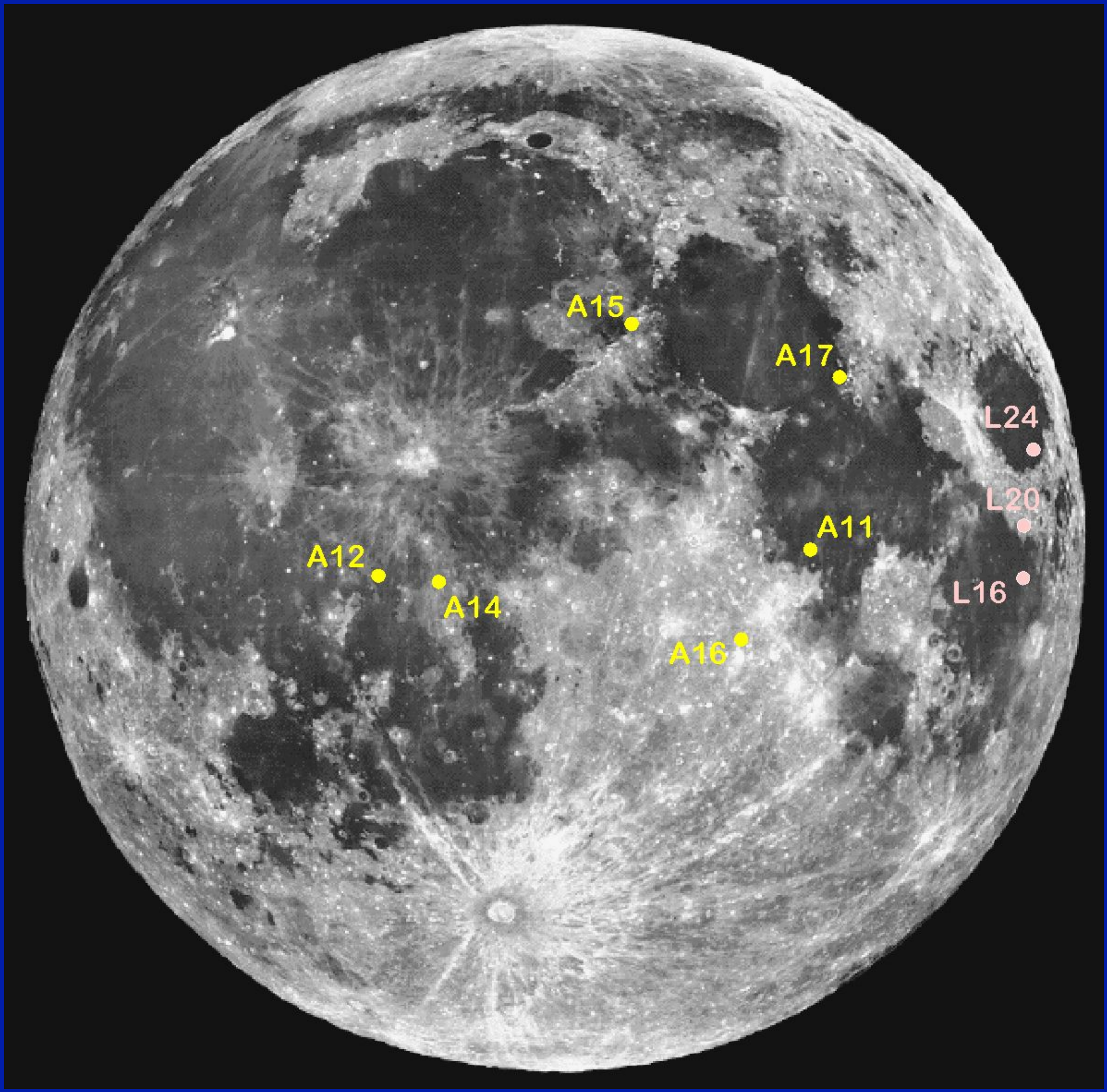


10,000’s of shield volcanoes; only 1000 craters



Venera: Blocky plate-like rocks and soils





6 Apollo missions on which samples were collected and returned:
1969 – 1972

382 kg of samples

3 Luna missions (Russia) returned samples:
1970 – 1976

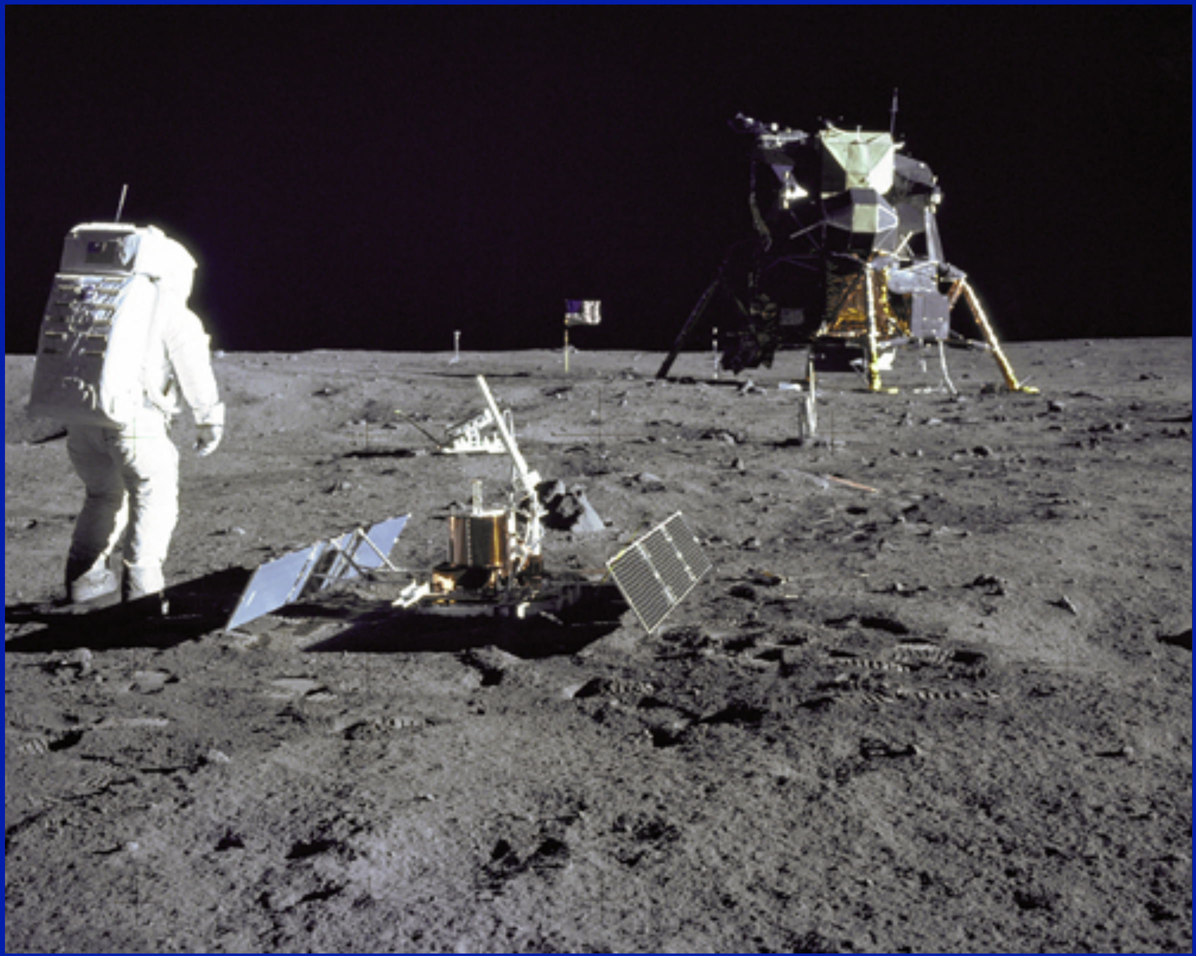
0.3 kg of samples

lunar mineralogy

Only 4 minerals account for 98+% of the Moon's crust!

	typical volume % ("mode")	
	feldspathic highlands	**maria**
plagioclase	85	36
pyroxene	10	53
olivine	5	6
ilmenite	0.3	5
total	100	100

Lunar seismometer network deployed by Apollo 12, 14, 15, 16 (1969 – 1972): Worked until they were switched off Sep., 1977

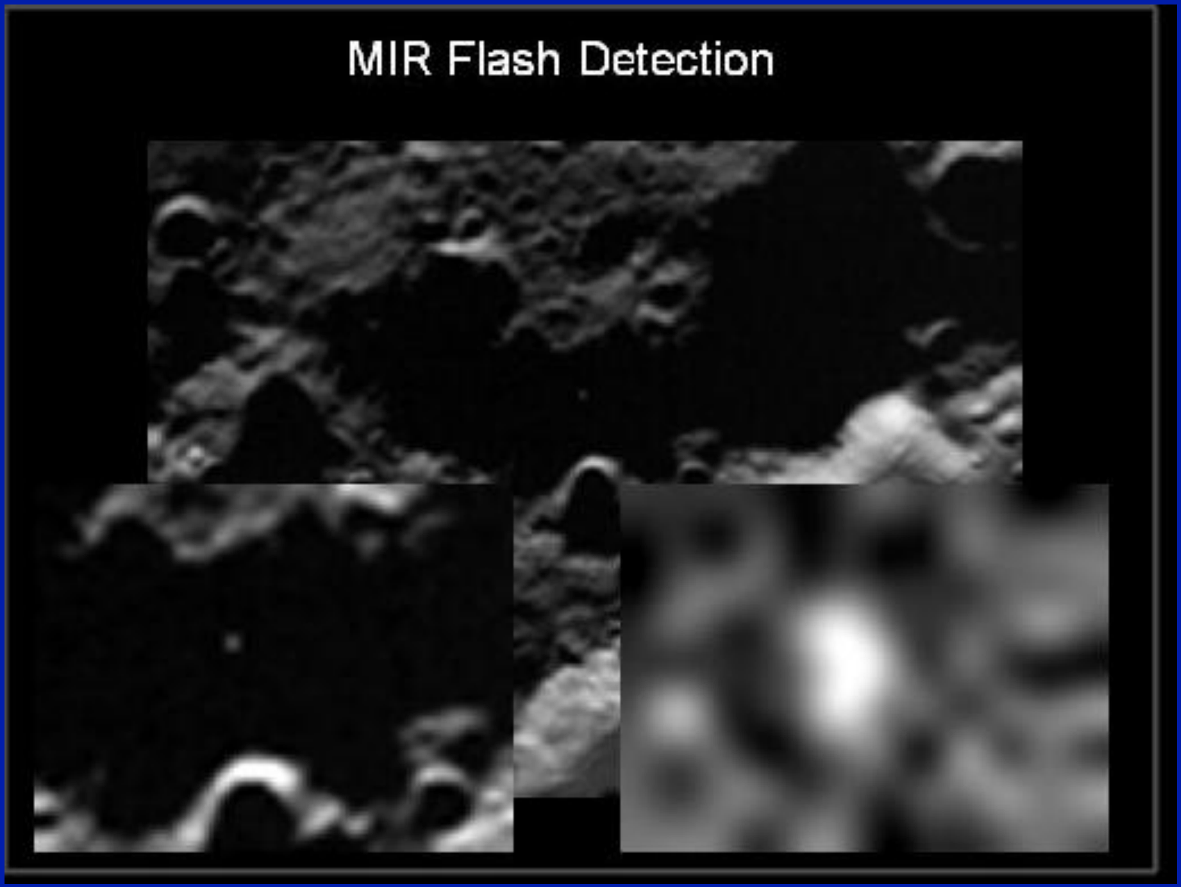


(Buzz Aldrin and the Apollo 11 seismometer, which only worked for 3 weeks)

Lunar CRater Observation and Sensing Satellite (LCROSS)

- Searching for South Pole water
- Centaur impacted on October 9, 2009

Centaur upper stage impact sodium flash detected with the mid infrared camera onboard the LCROSS Shepherding Spacecraft

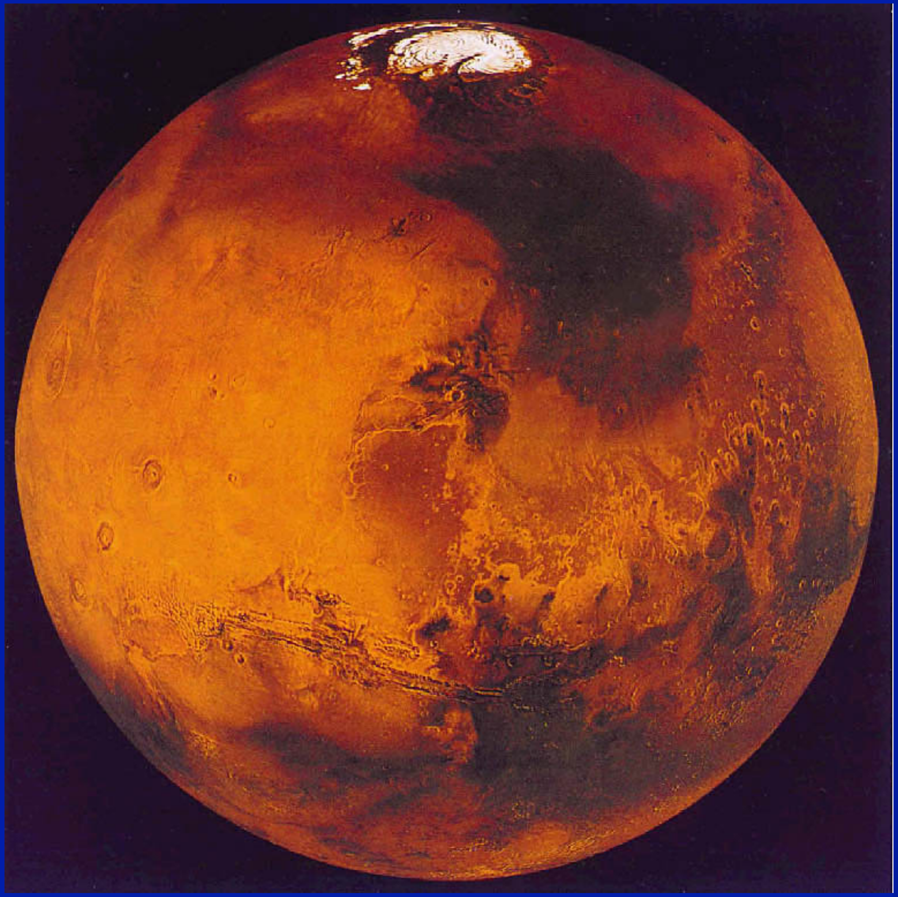


Evidence of water – perhaps ~1% of regolith there

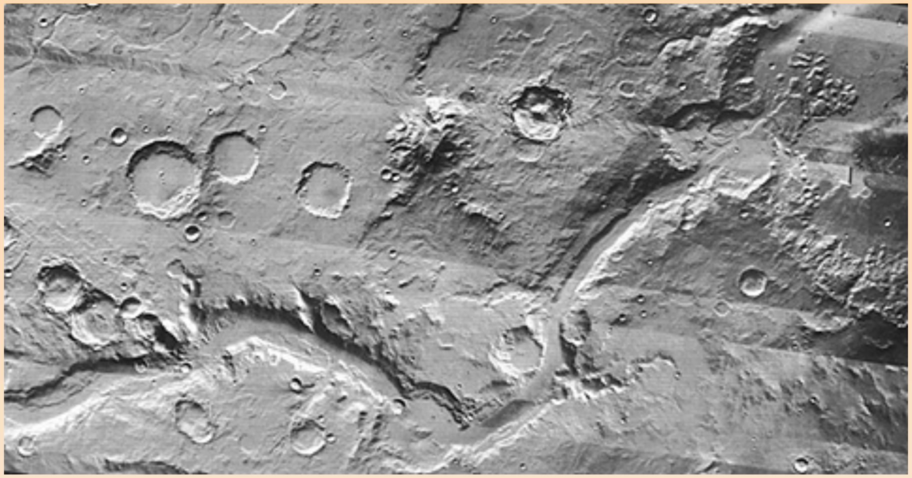
MARS
Mass = 10.7% of Earth's
Radius = 3397 km (53.2%)
g = 37.9% of Earth's
day = 24.66 hours
axis tilt = 25.2°
Atm = < 0.01 bar

Yellow-orange color of surface due to oxidized iron in regolith.

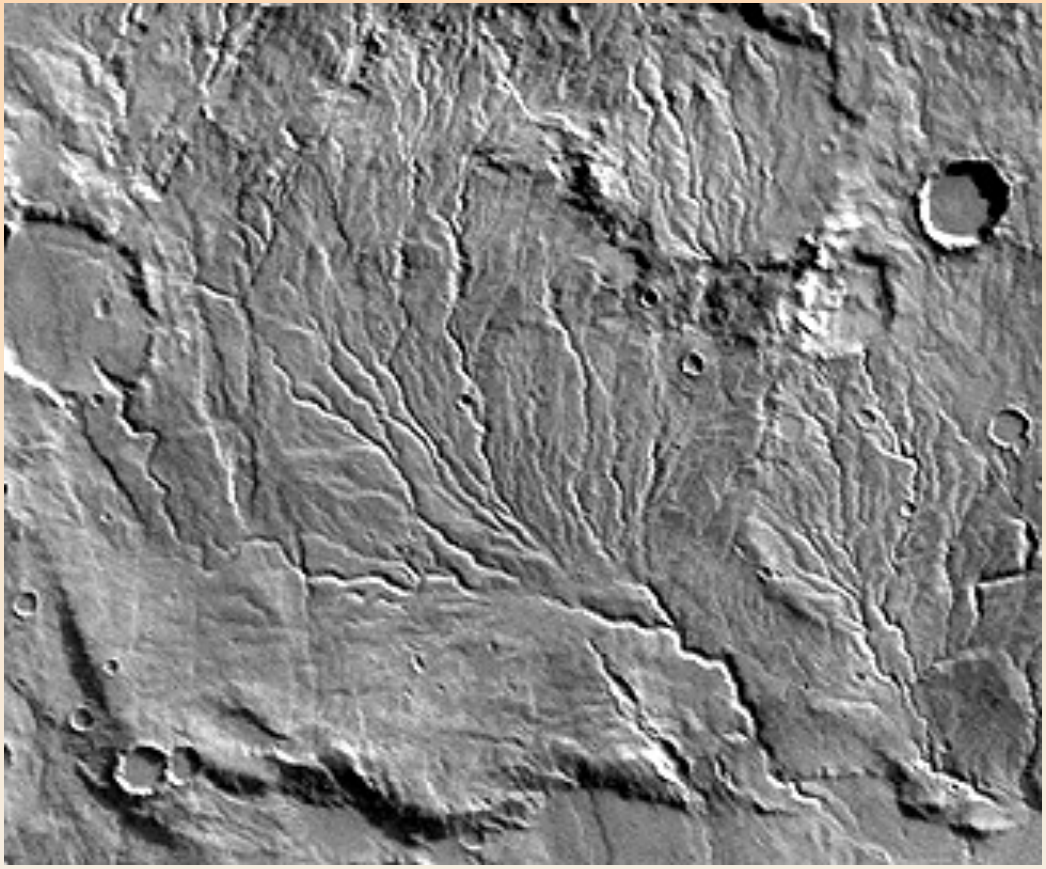
Pink-orange color of sky caused by extremely fine red dust suspended in thin atmosphere.

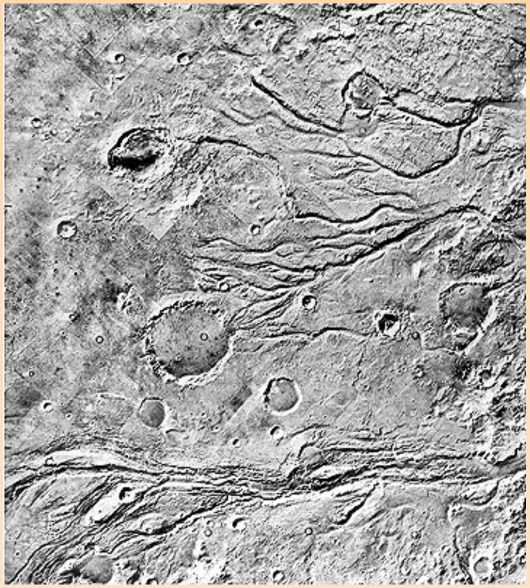


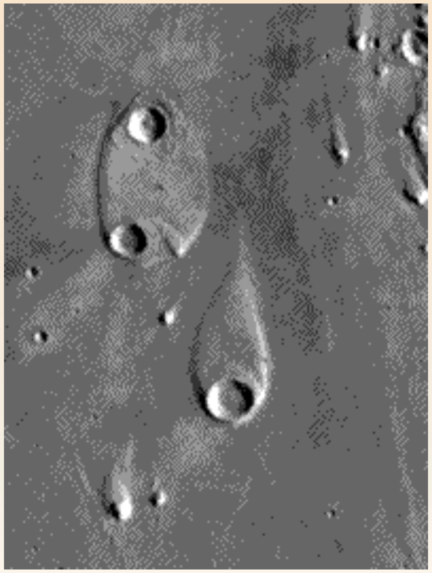
Past Water on Mars - Channels

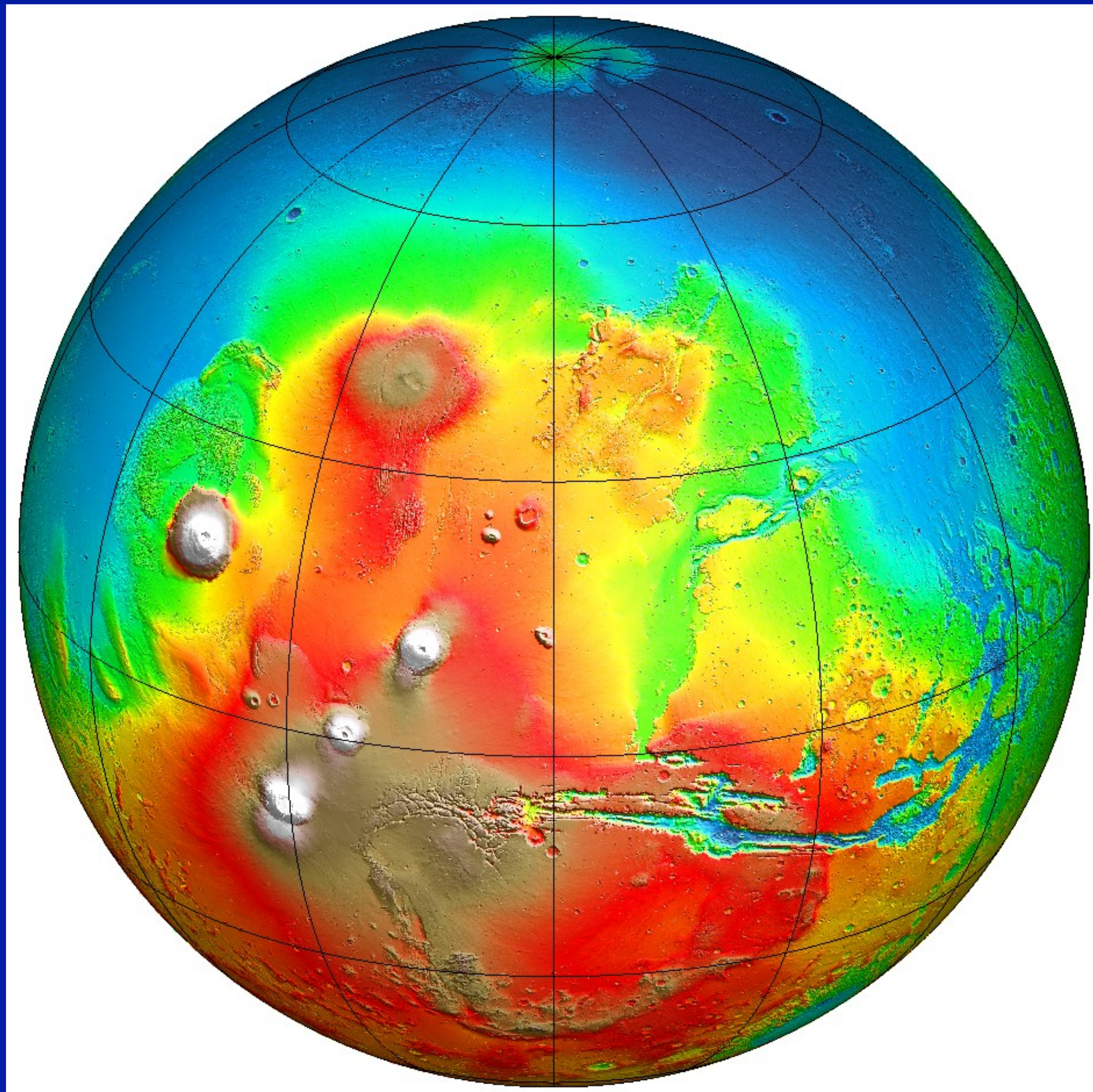


Past Water on Mars - Channels







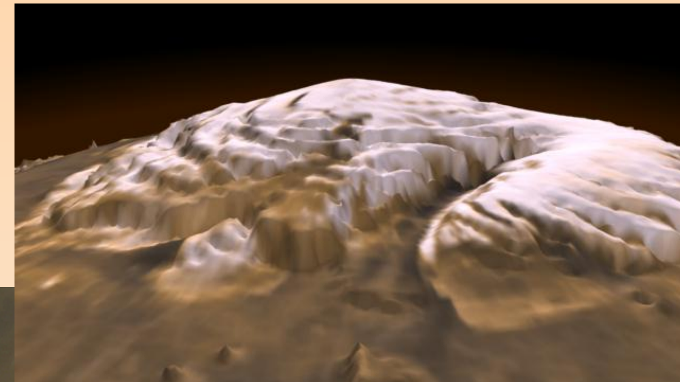


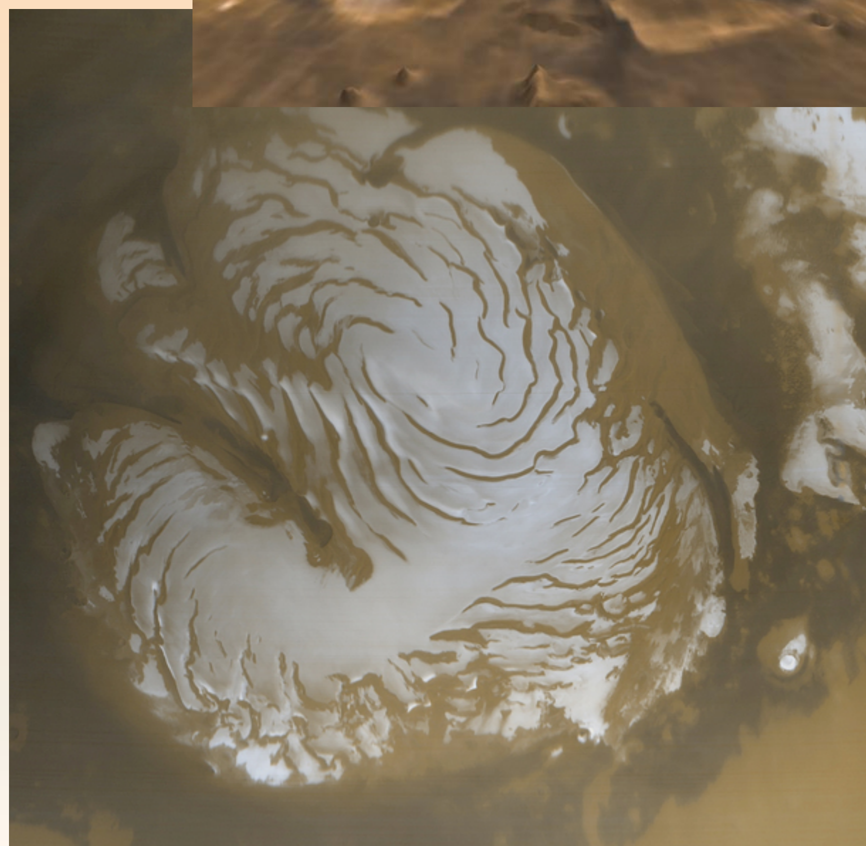
Allan Hills (Antarctica) Meteorite

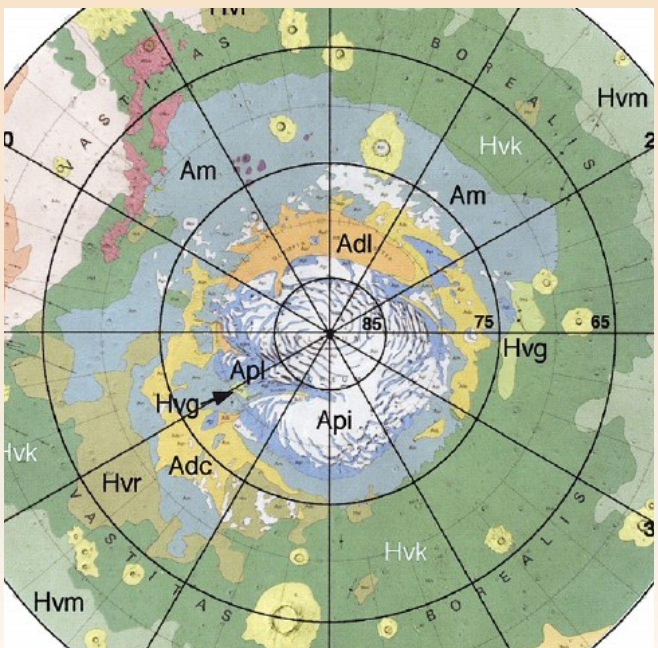
Mars’ Clouds from Opportunity

Mars' "Permanent" North Polar Cap

- Made of water ice; Young surface
- Has terraced structure; Troughs between terraces expose fine-scaled layers
- Large chasms cut into cap

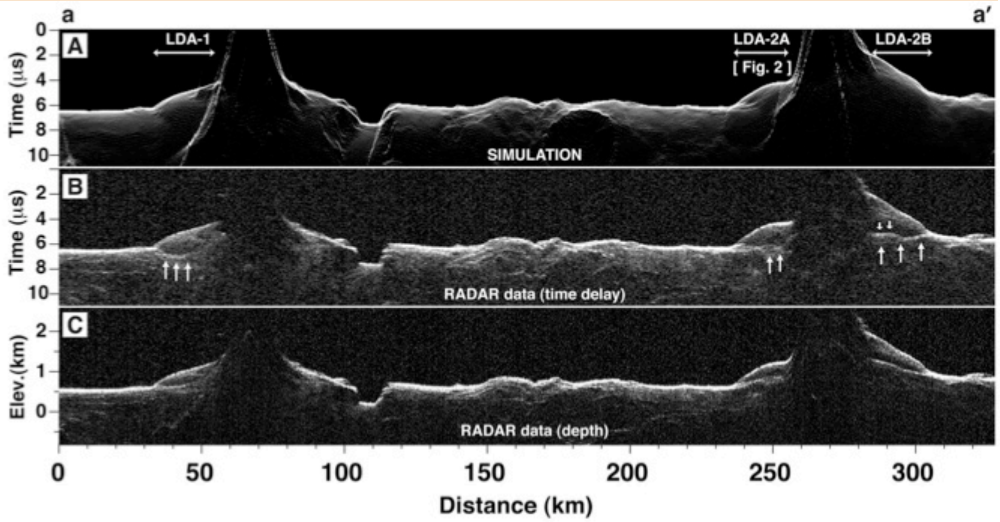


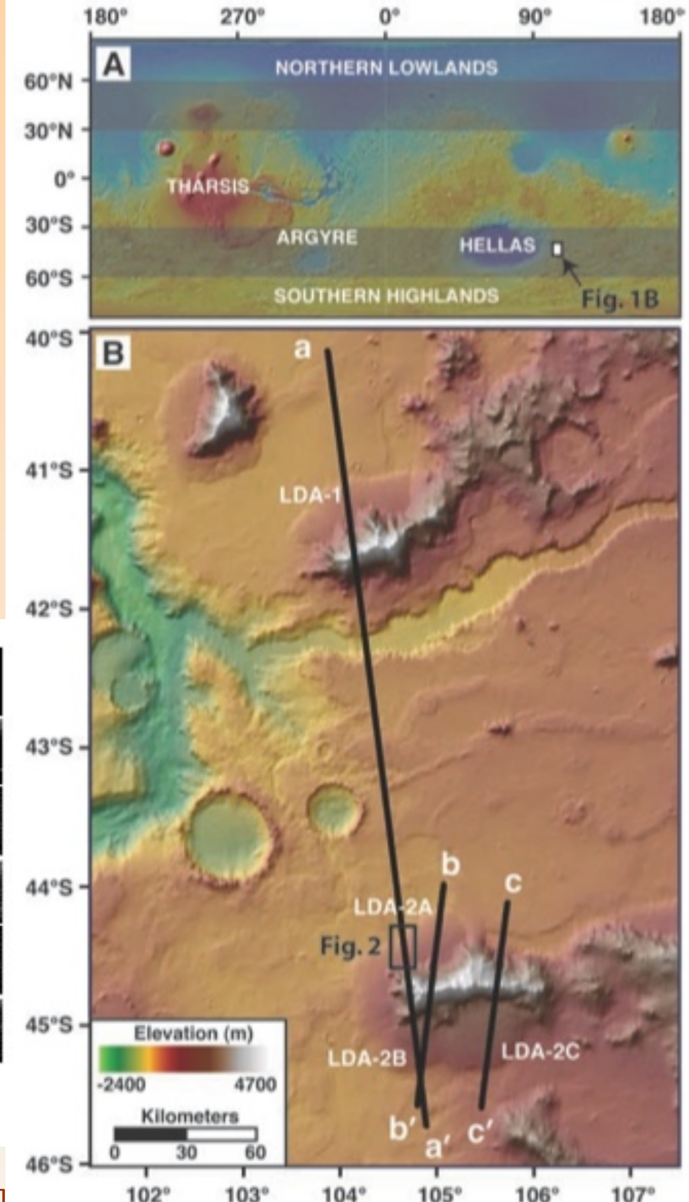




Present-Day Ice in Mid-Latitude Lobate Debris Flows

- Morphology previously suspected to be related to subsurface ice; now seen to contain massive ice
- Must have formed in a different climate
- Detected by SHARAD aboard Mars Express

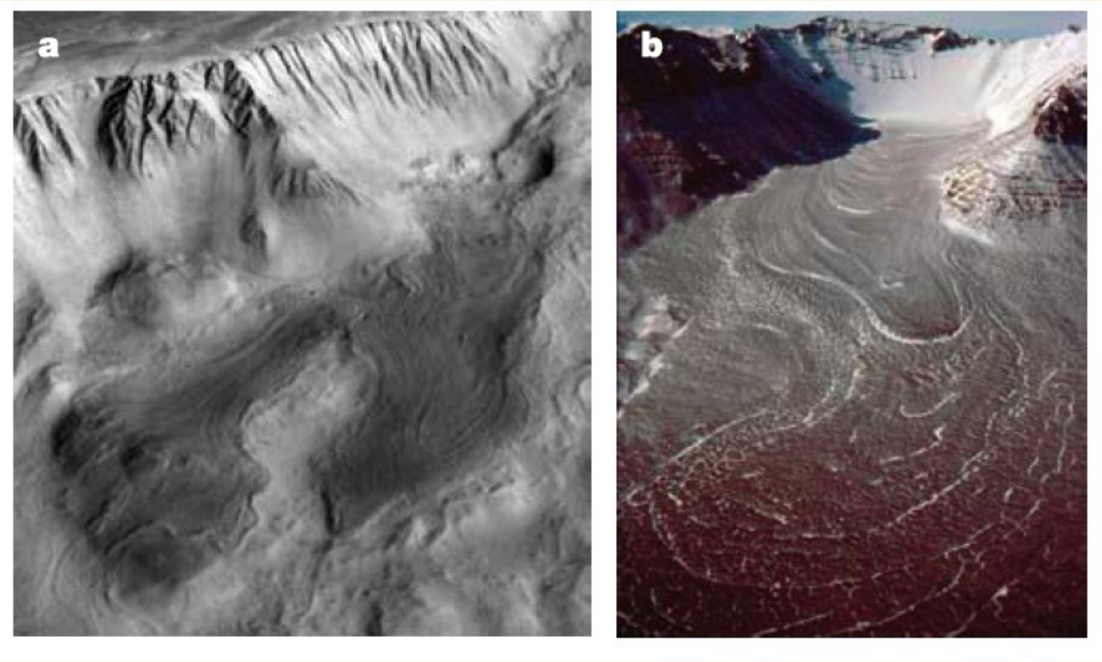




[Holt *et al.* 2008]

Equatorial Ground Ice

- Images from Viking to HRSC reveal a number of distinct features at tropical, mid, and high latitudes with morphologies suggestive of ice, including glacial-like flow patterns, lobate debris aprons, lineated valley fill, etc. Most are relatively young (10-100s of Ma)
- Orbital radars on MRO and Mars Express show that ice is present within these deposits

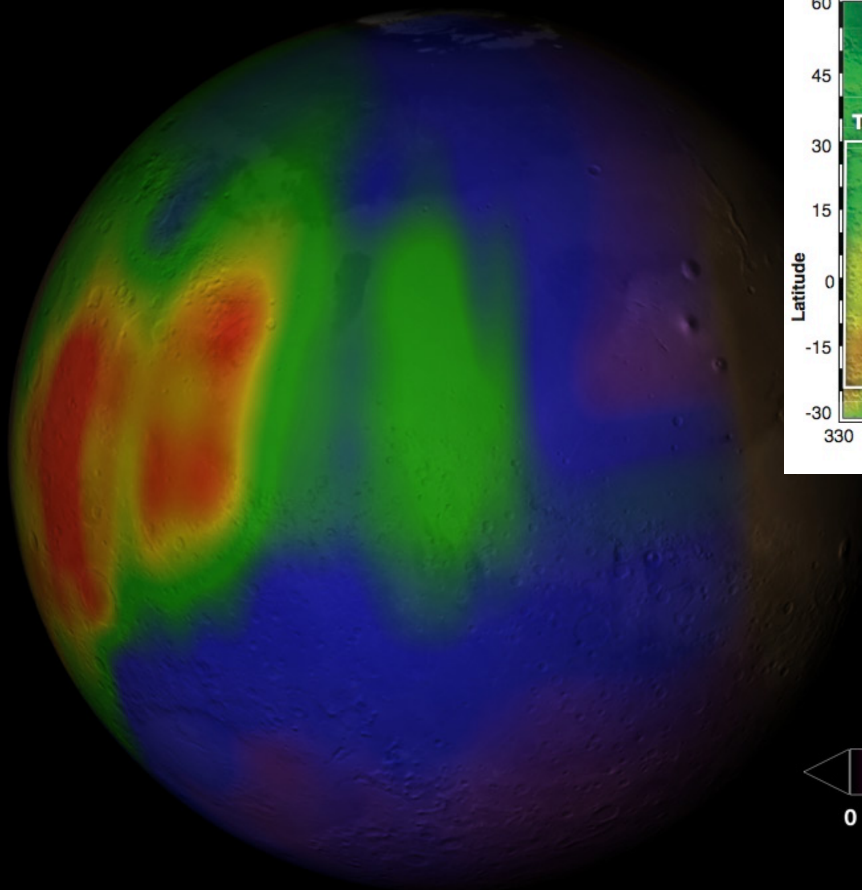


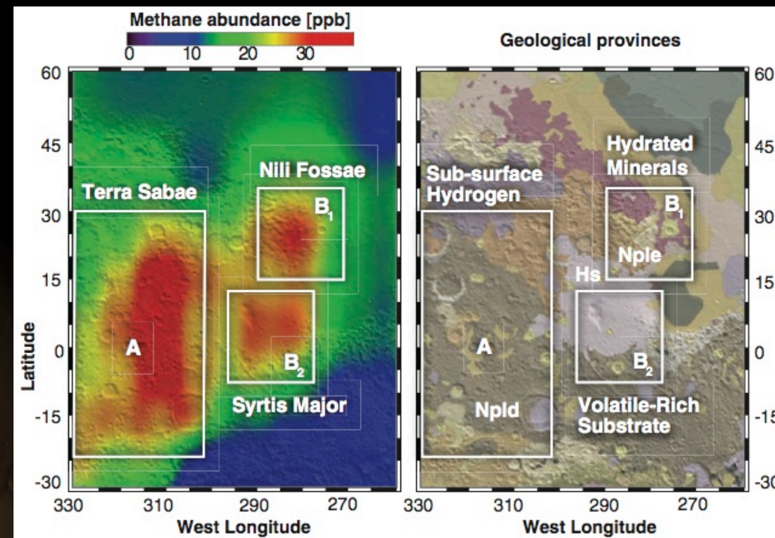
[Head *et al*. 2005]

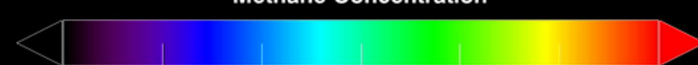
Gullies with Fans Covering Dunes

Evidence they are Recent?

Atmospheric Methane (CH_4)

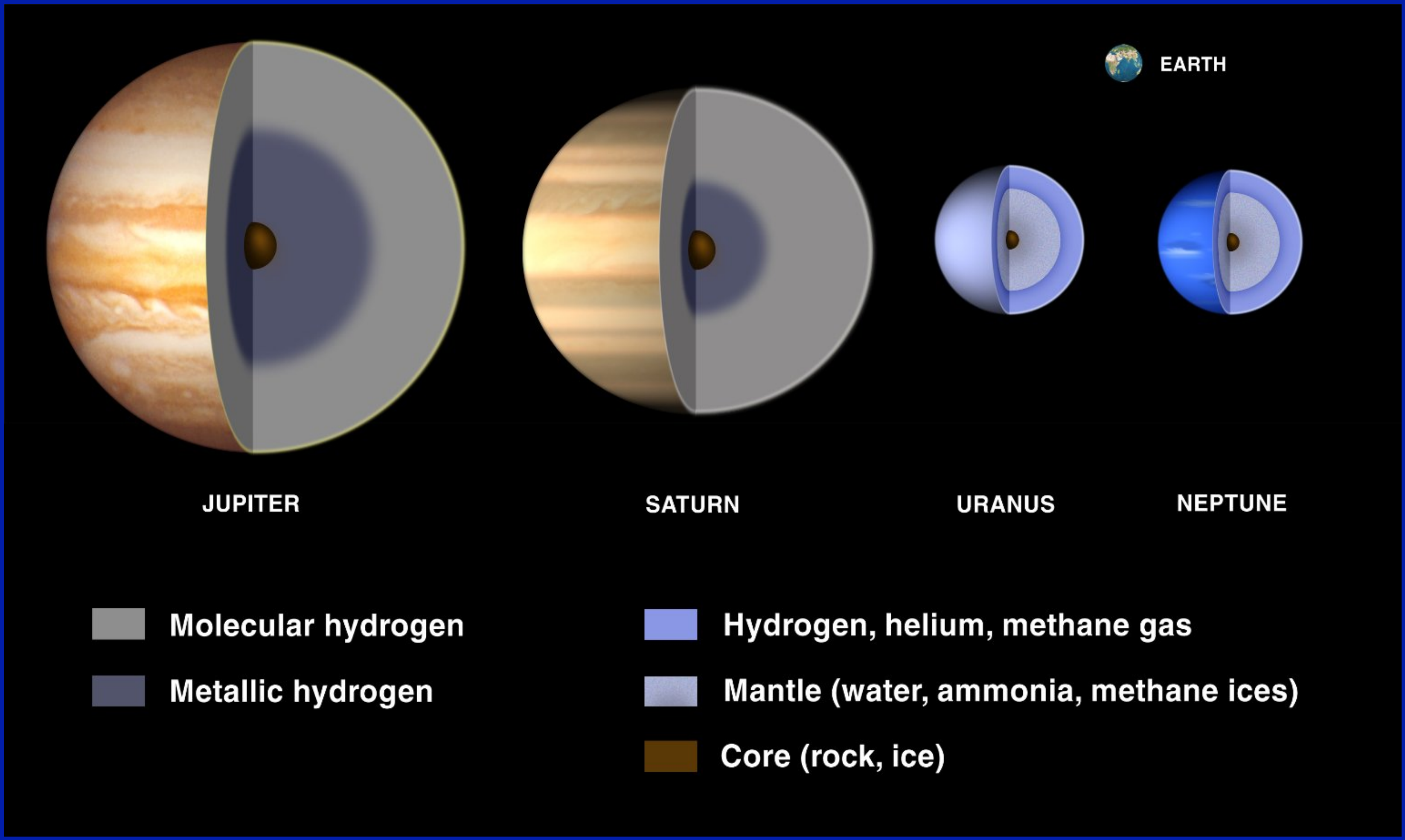






[Northern Summer; Mumma *et al.*, 2009]

Gas/Ice Giants



JUPITER: rotation, T = 9.9 hrs

SATURN: rotation, T = 10.6 hrs

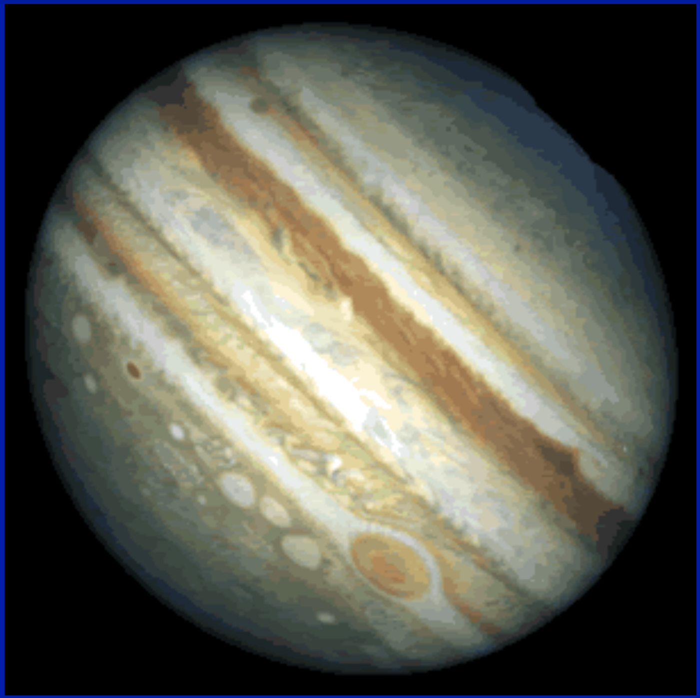
JUPITER: revolution, T = 11.86 yrs

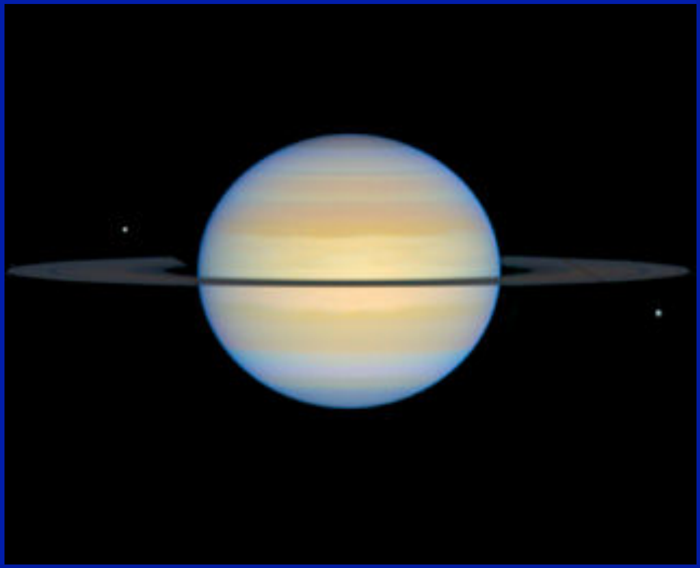
SATURN: revolution, T = 29.46 yrs

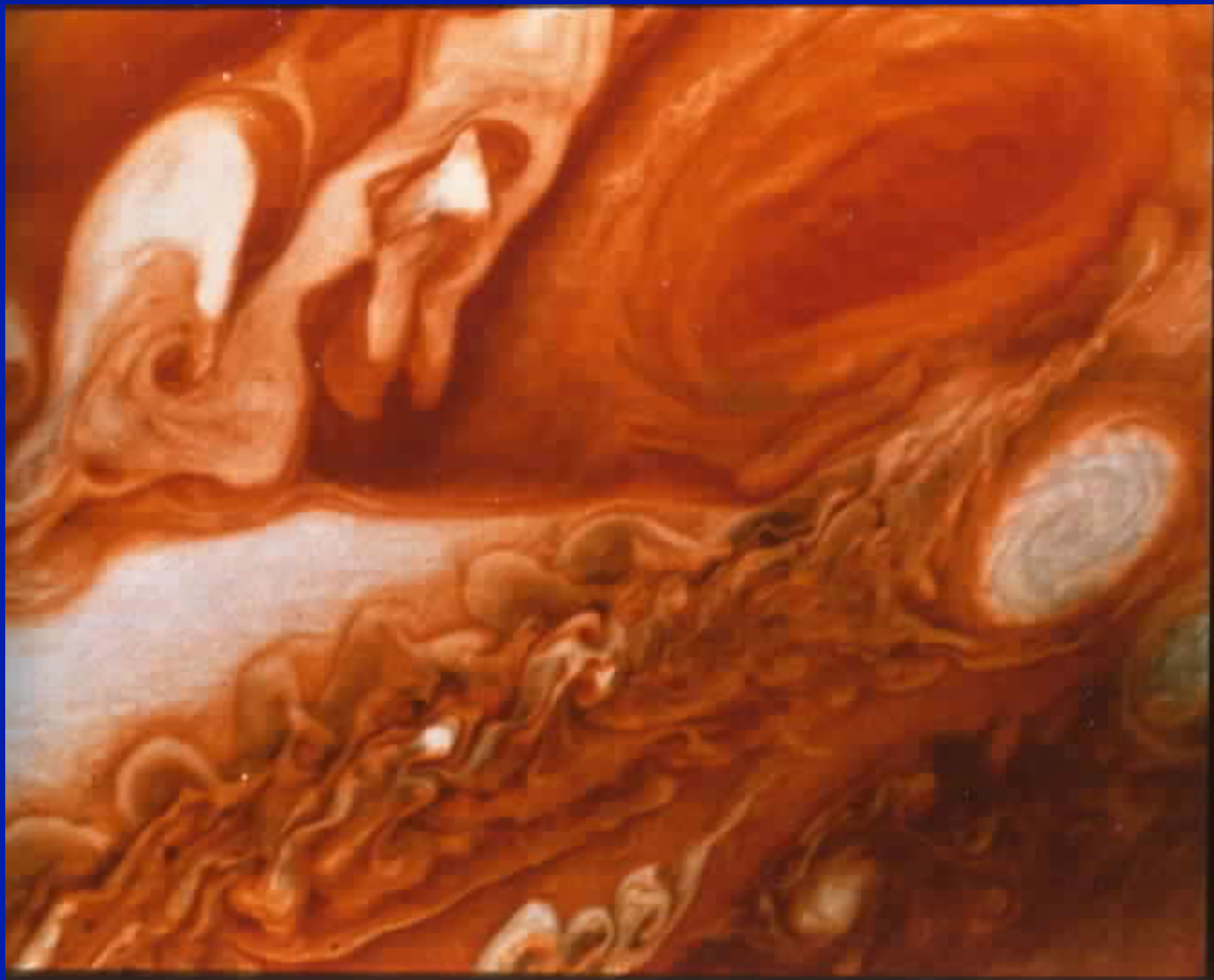
However, at some point in a 2:1 resonance

* Destabilized solar system

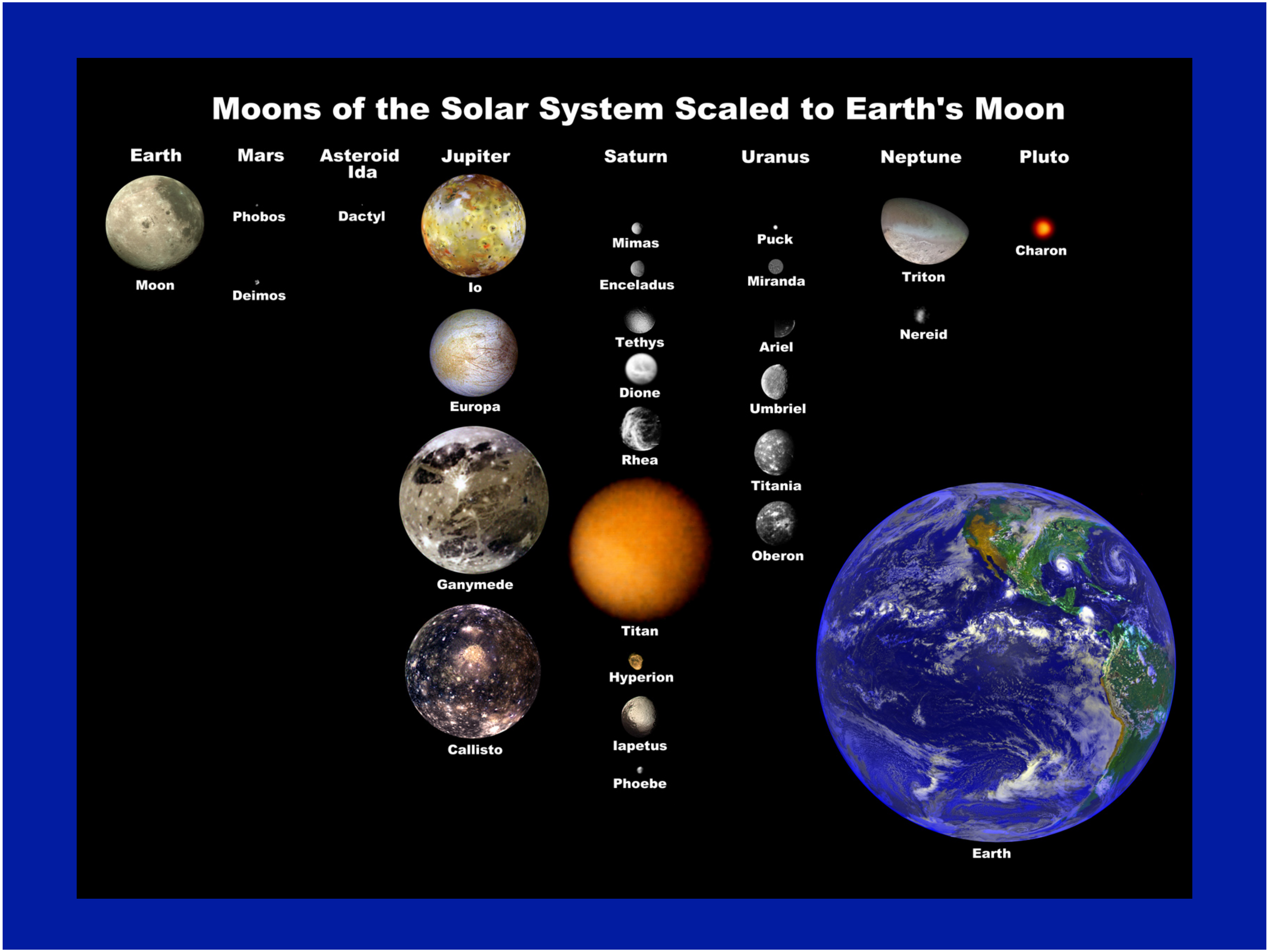
* Late Heavy Bombardment



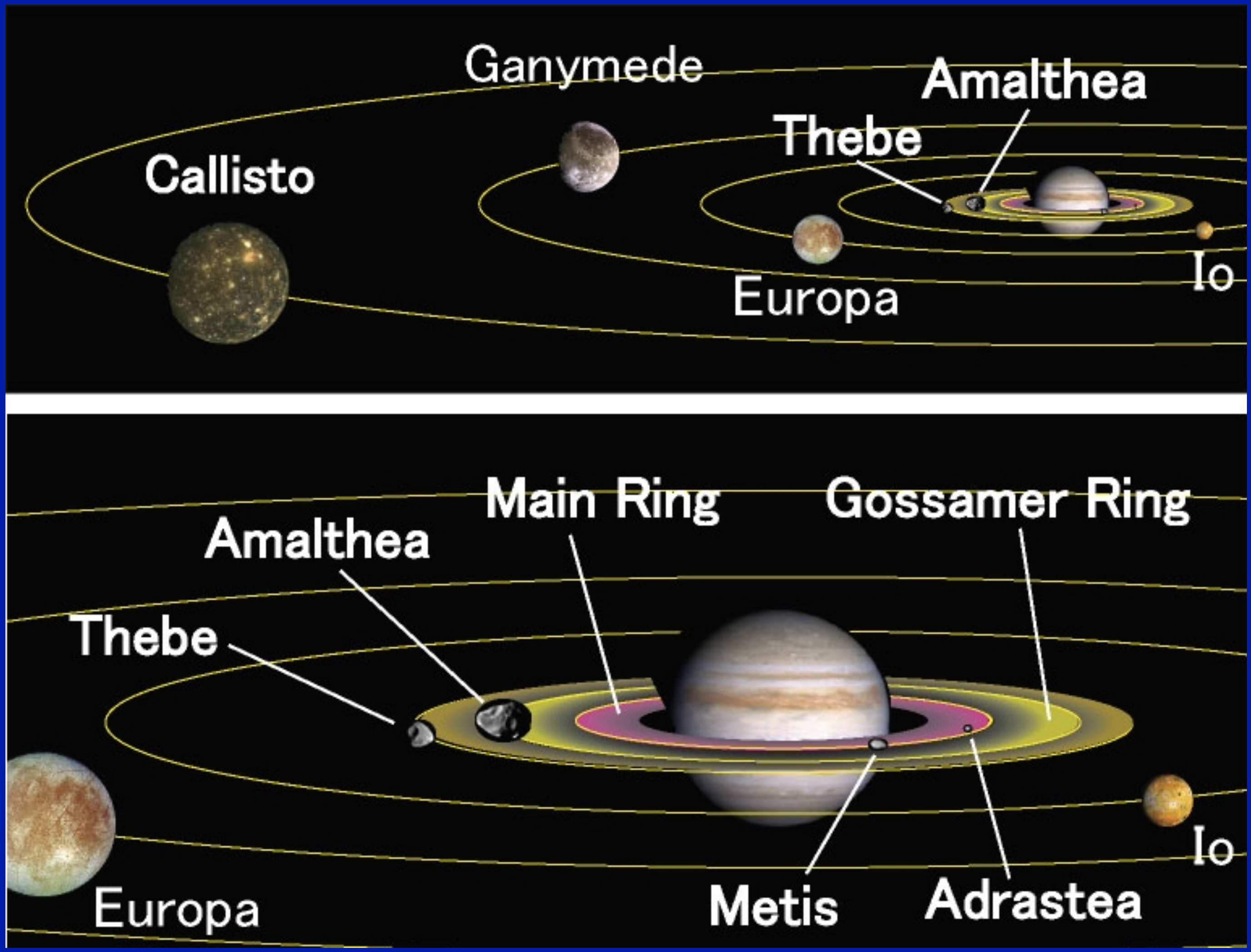




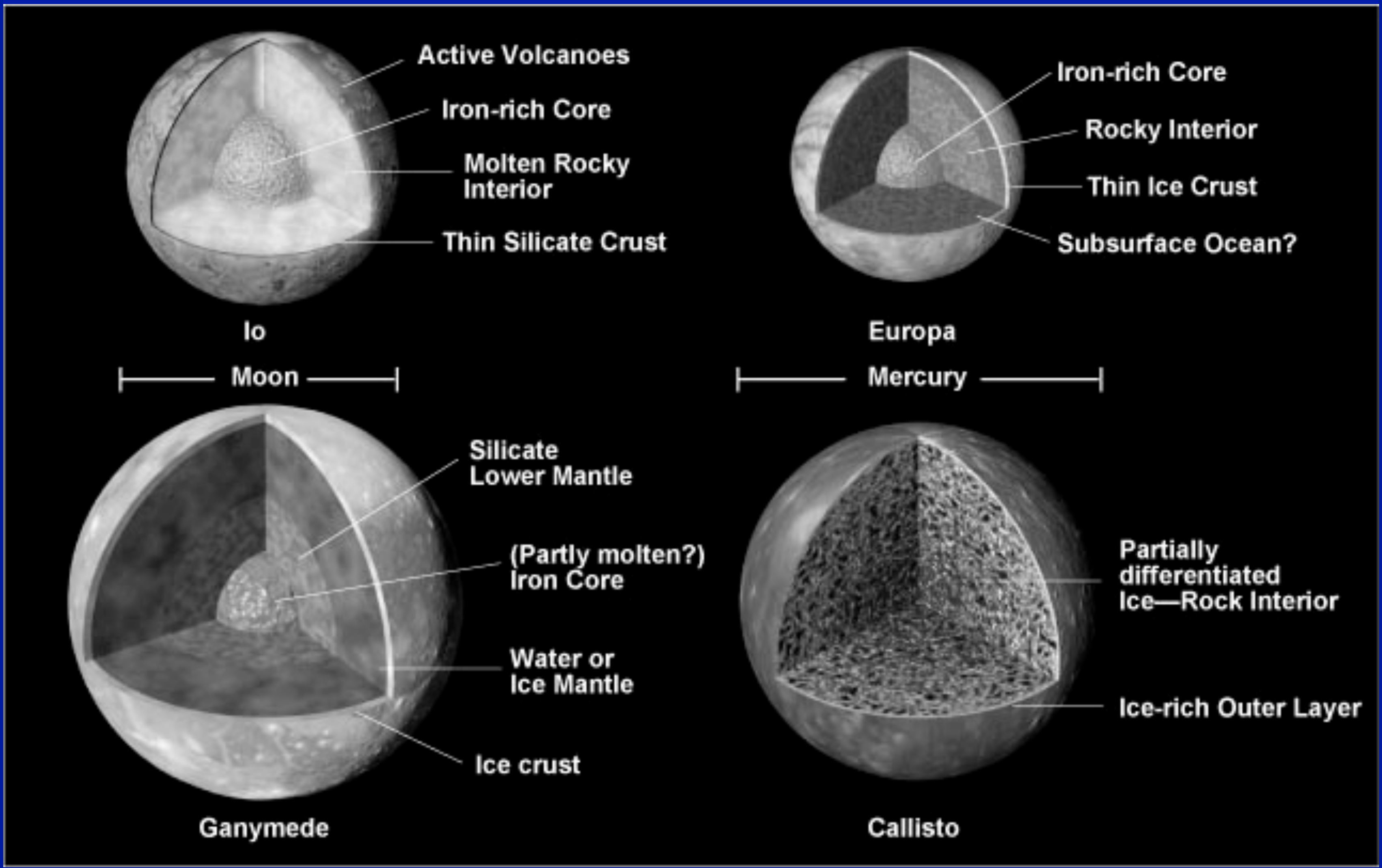
Red Spot: 23,000 km-long hurricane (at least 180 yrs old)


Moons of the Solar System Scaled to Earth's Moon
Earth
Mars
Asteroid Ida
Jupiter
Saturn
Uranus
Neptune
Pluto
Moon
Phobos
Deimos
Dactyl
Io
Europa
Ganymede
Callisto
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Triton
Nereid
Charon
Earth

Jupiter's Moons:



Io, Europa, Ganymede in 4:2:1 resonance of orbits


Active Volcanoes
Iron-rich Core
Molten Rocky Interior
Thin Silicate Crust
Io
Iron-rich Core
Rocky Interior
Thin Ice Crust
Subsurface Ocean?
Europa
Moon
Mercury
Silicate Lower Mantle
(Partly molten?) Iron Core
Water or Ice Mantle
Ice crust
Ganymede
Partially differentiated Ice—Rock Interior
Ice-rich Outer Layer
Callisto

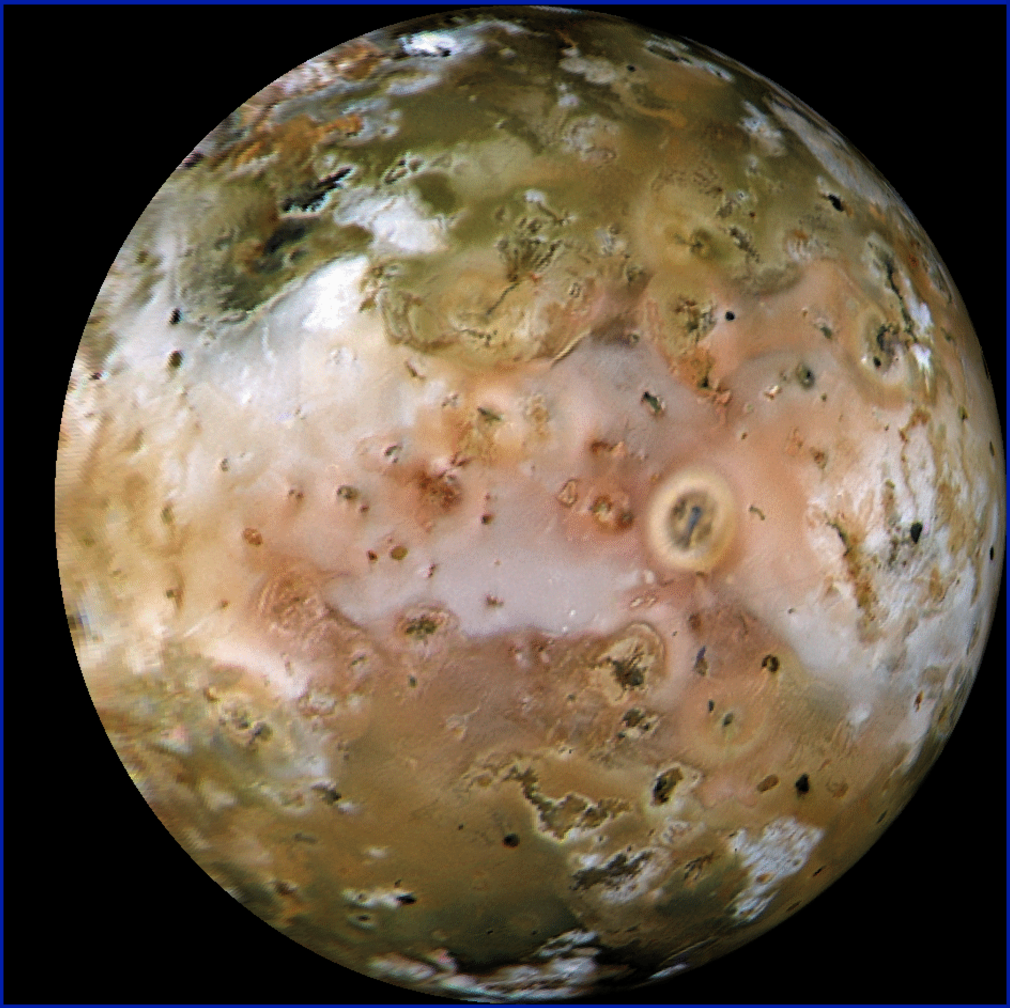
Io:

100s of volcanoes active at any time

Lava is both basalt and sulfur

Orbital resonance of moons causes their orbits to greatly fluctuate --> large tidal stresses

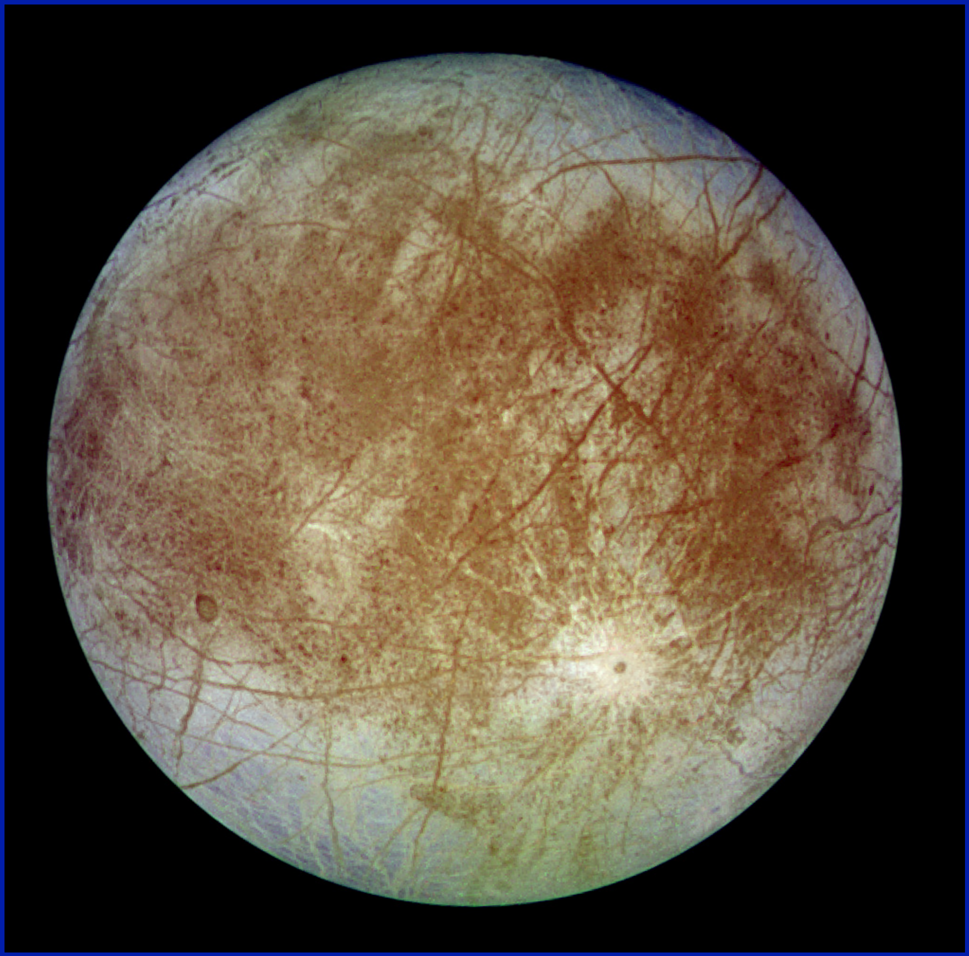
Boosaule Mons = 16.7 km high non-volcanic mountain



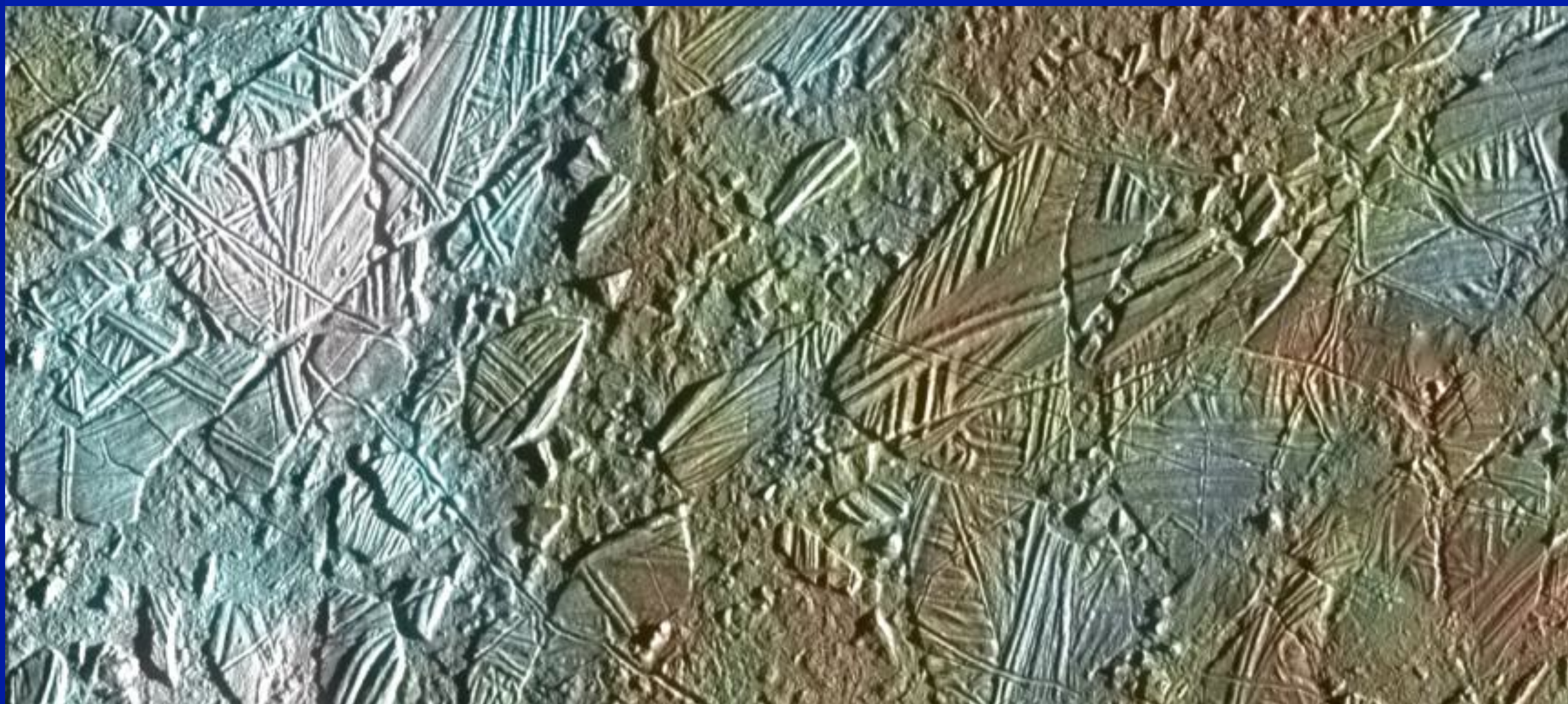
Europa

Liquid ocean >150 km thick

Very few impacts suggests that the crust is young and constantly reworked

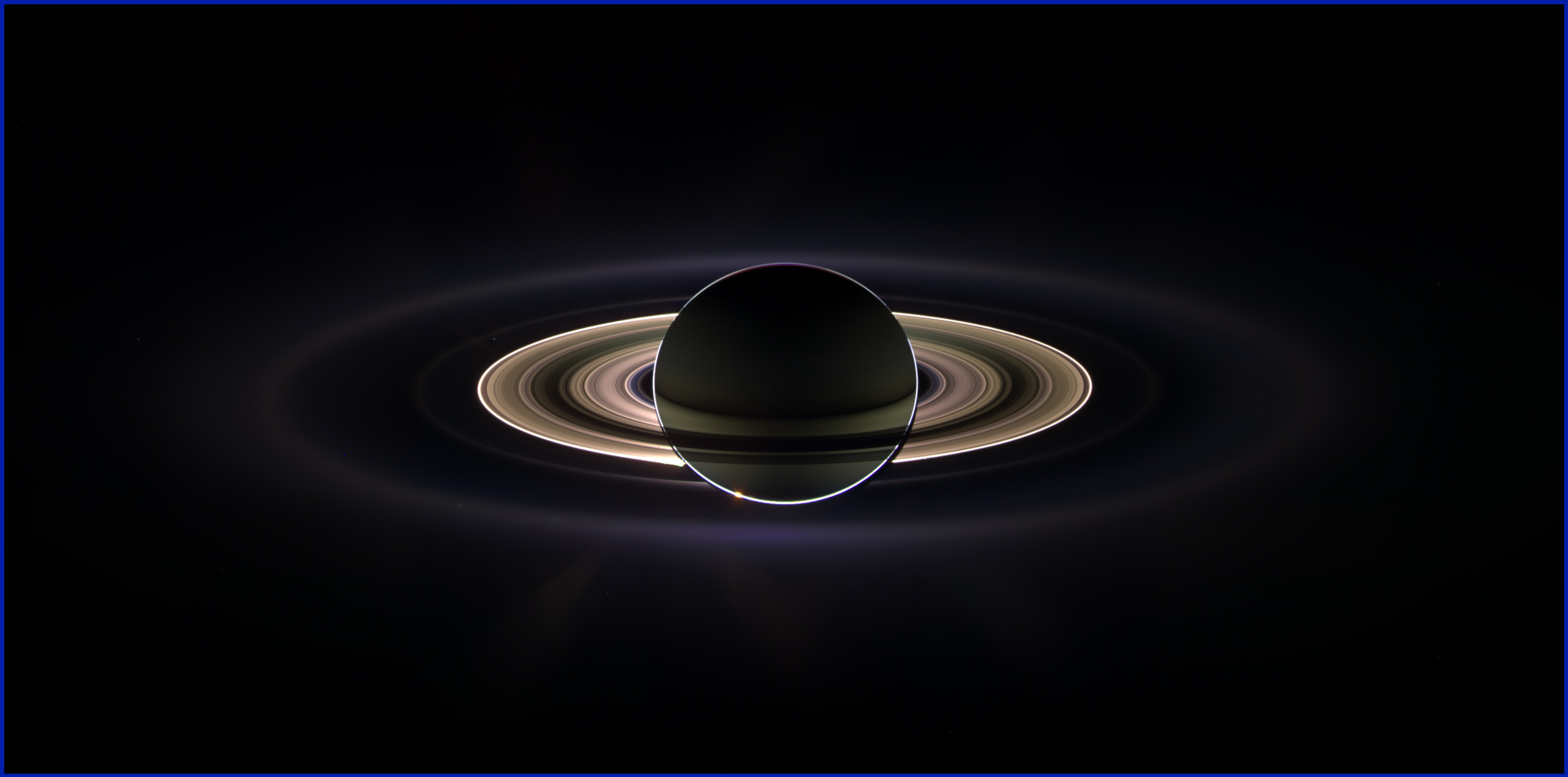


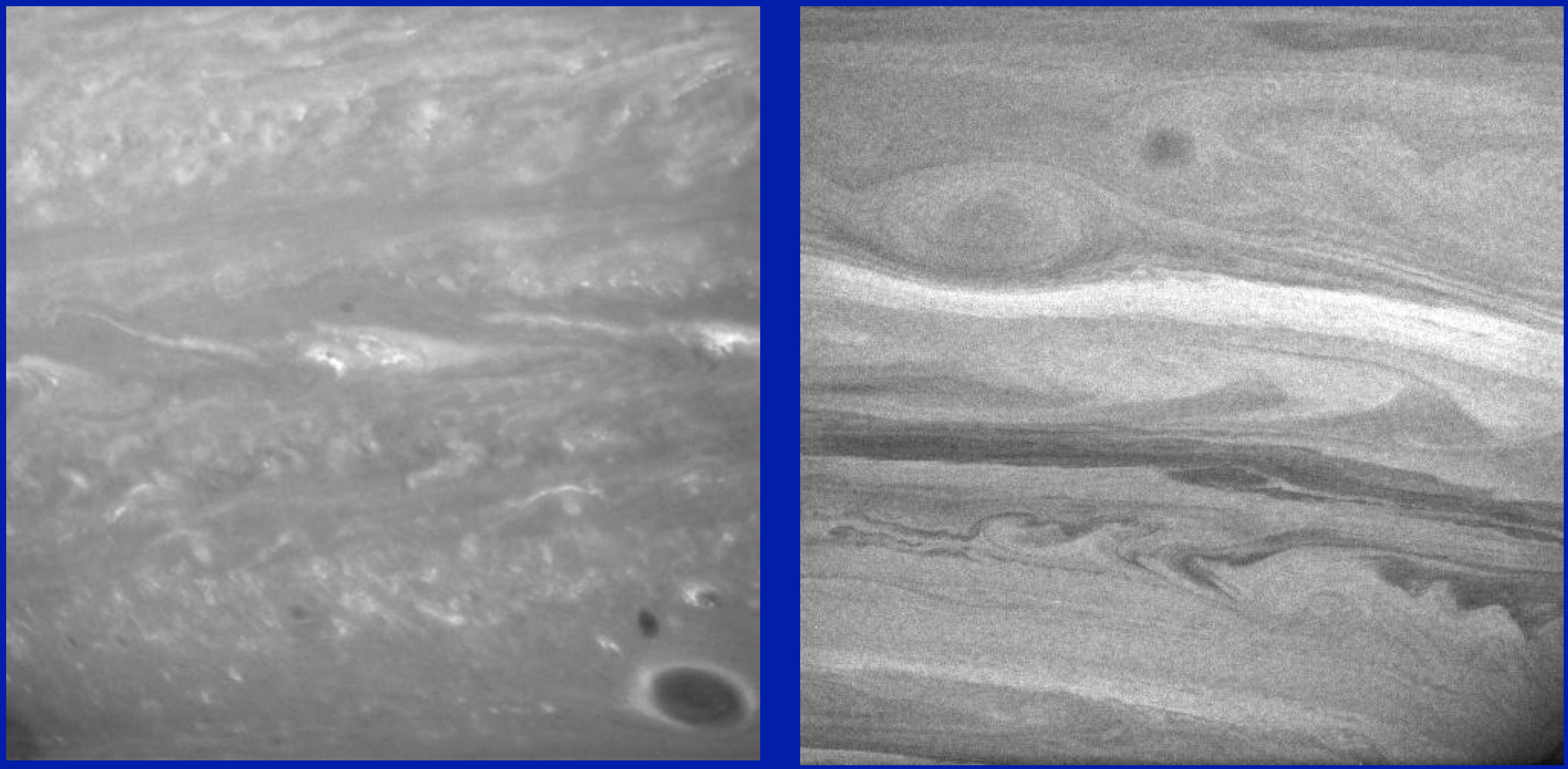
Fractures form arcs in response to Jupiter's tidal stresses; suggests icy crust is thin



New research: Europa's ocean may have lots of oxygen – enough to support 3 billion kg of animal life

Saturn eclipsing the sun (Cassini)

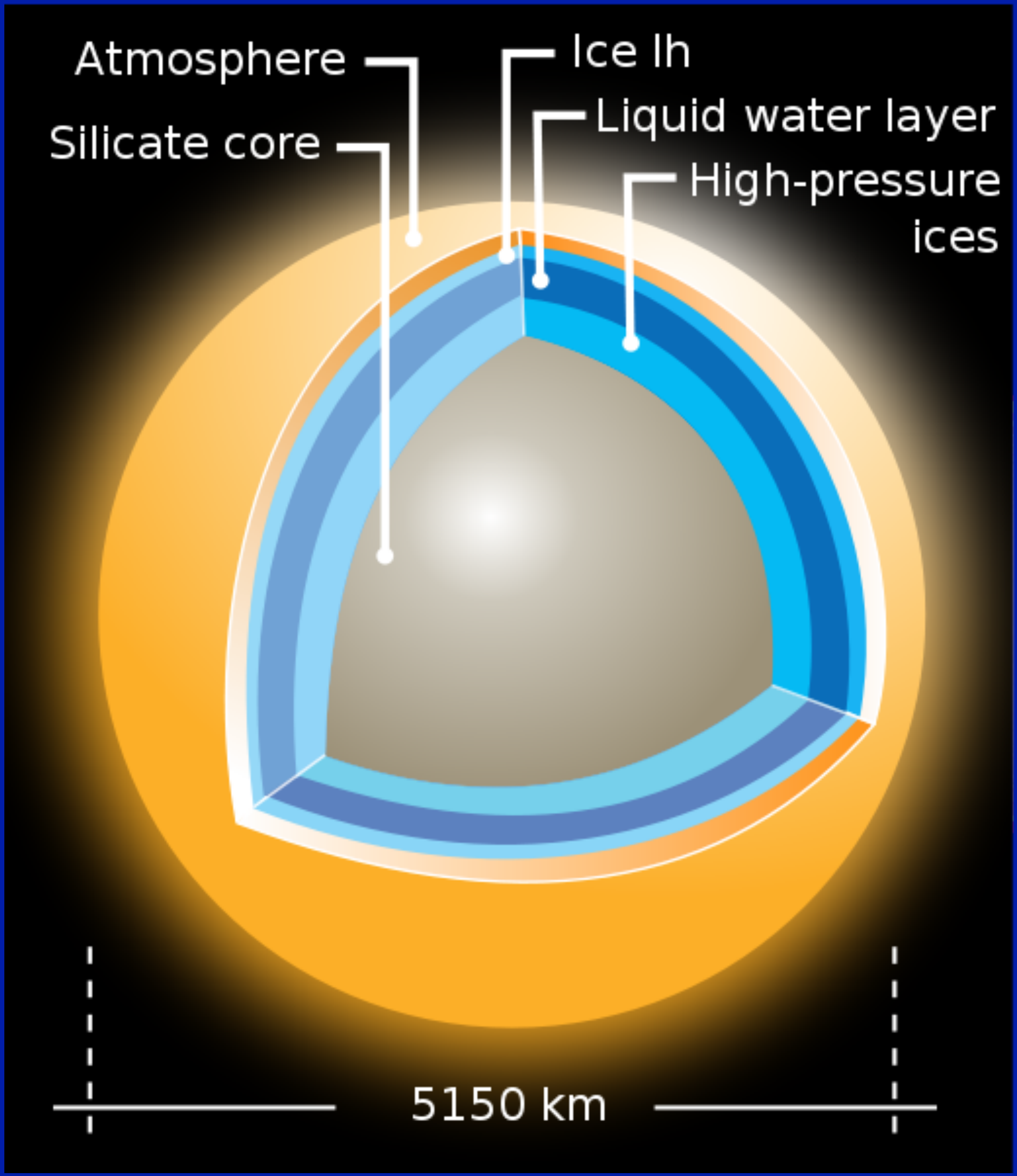




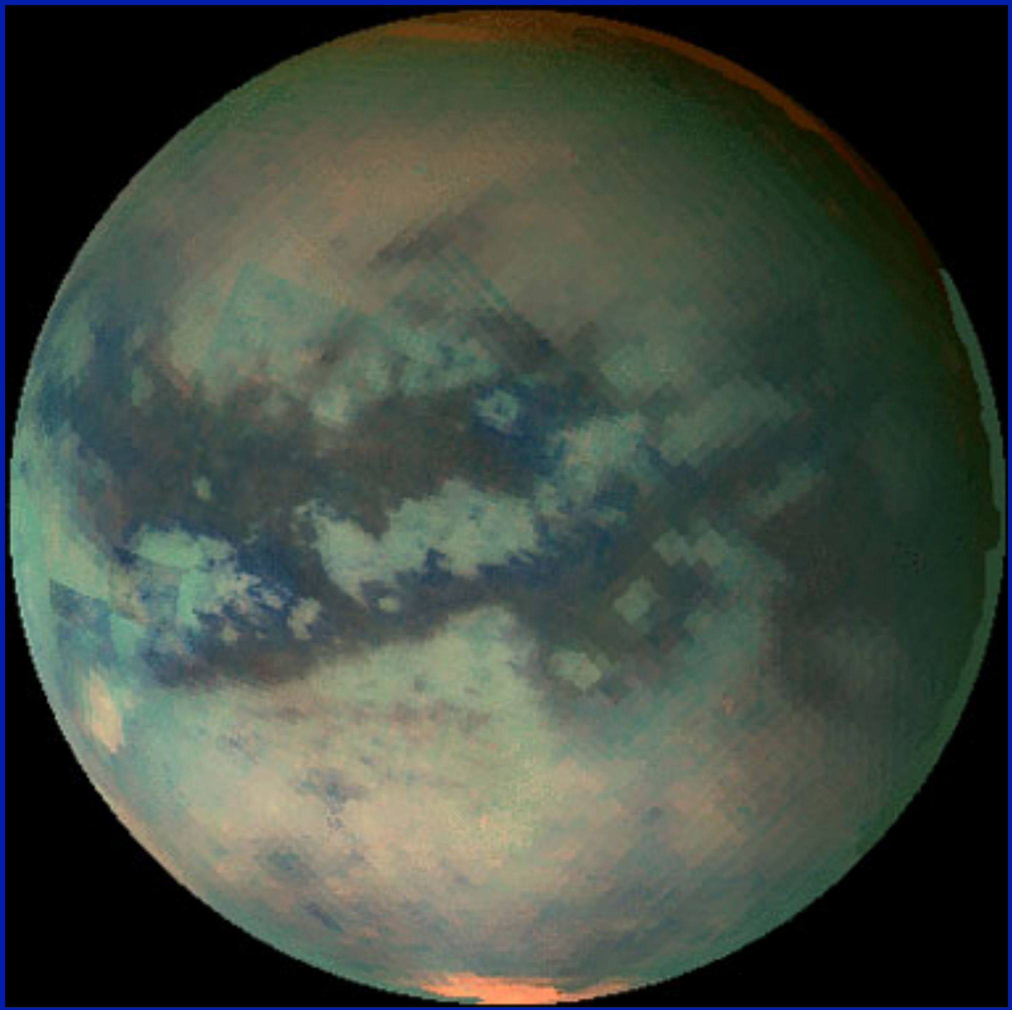
Storms on Saturn (winds > 360 km/hr; Cassini)

Cassini's voyage to Saturn's moon Titan.

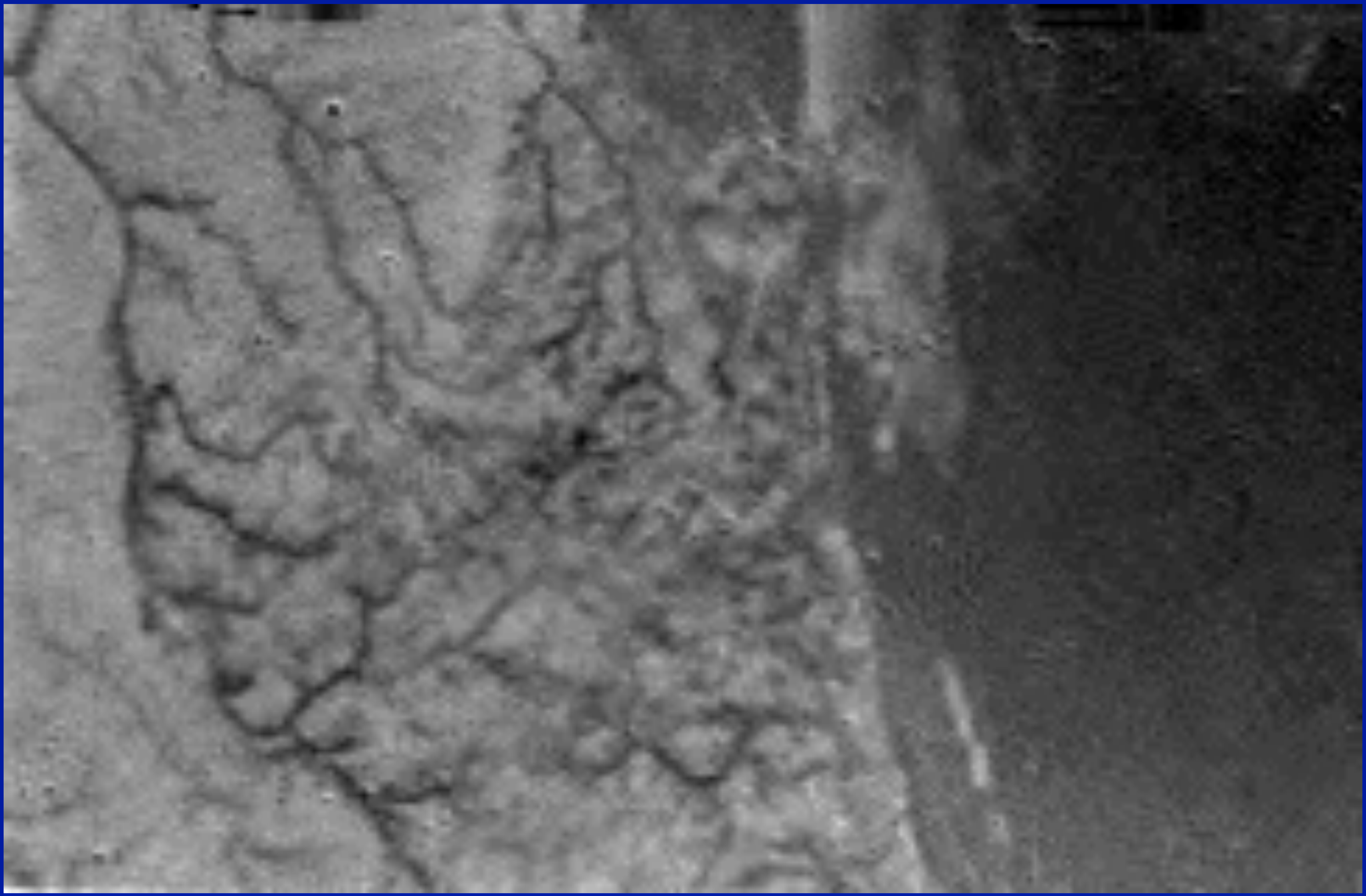
Titan


Atmosphere
Ice Ih
Liquid water layer
Silicate core
High-pressure ices
5150 km

Titan: only moon with a substantial atmosphere (nitrogen)

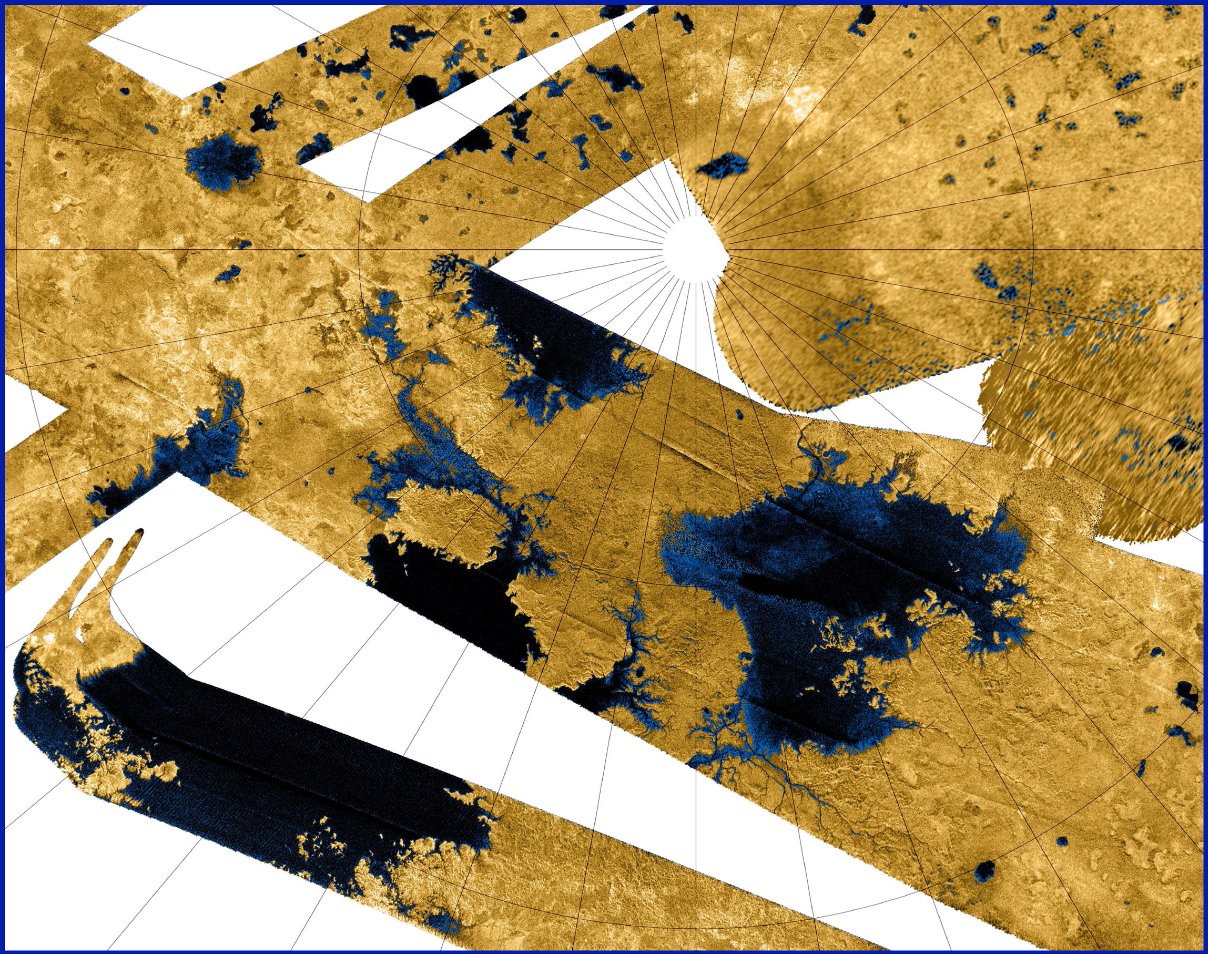


Liquid methane on a water-ice surface?

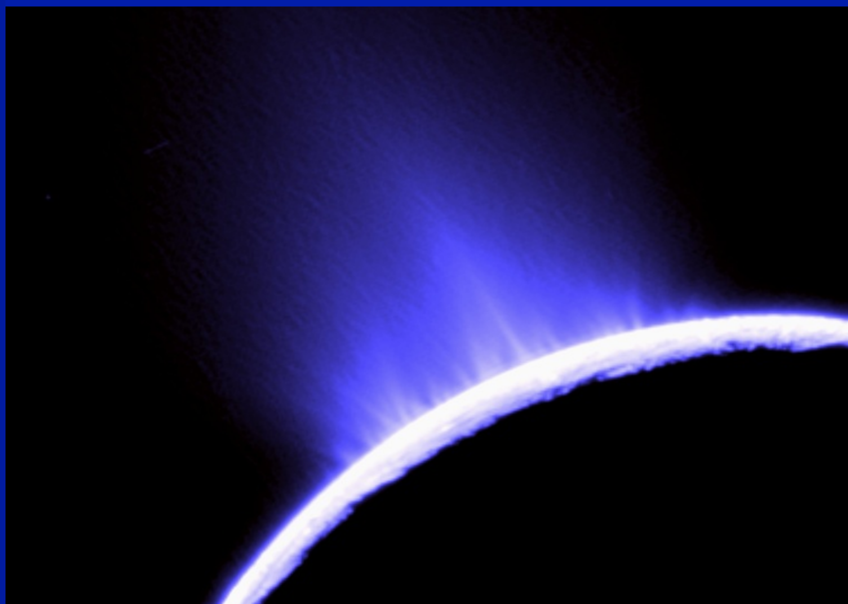


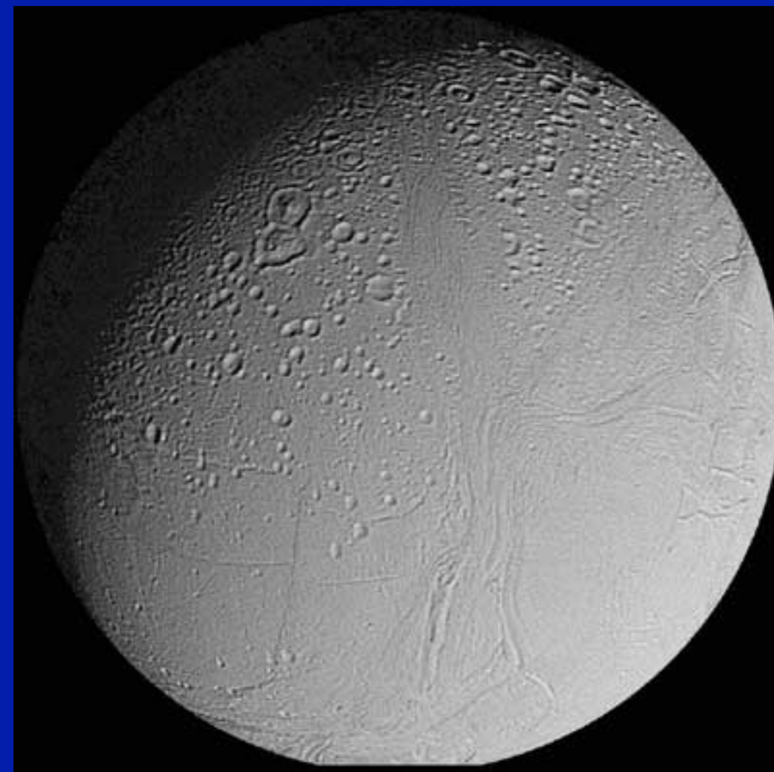
From an altitude of 16 km, Huygens photographed these drainage channels leading to a shoreline.

Lakes (liquid methane/ethane) at Titan’s north pole (Cassini)



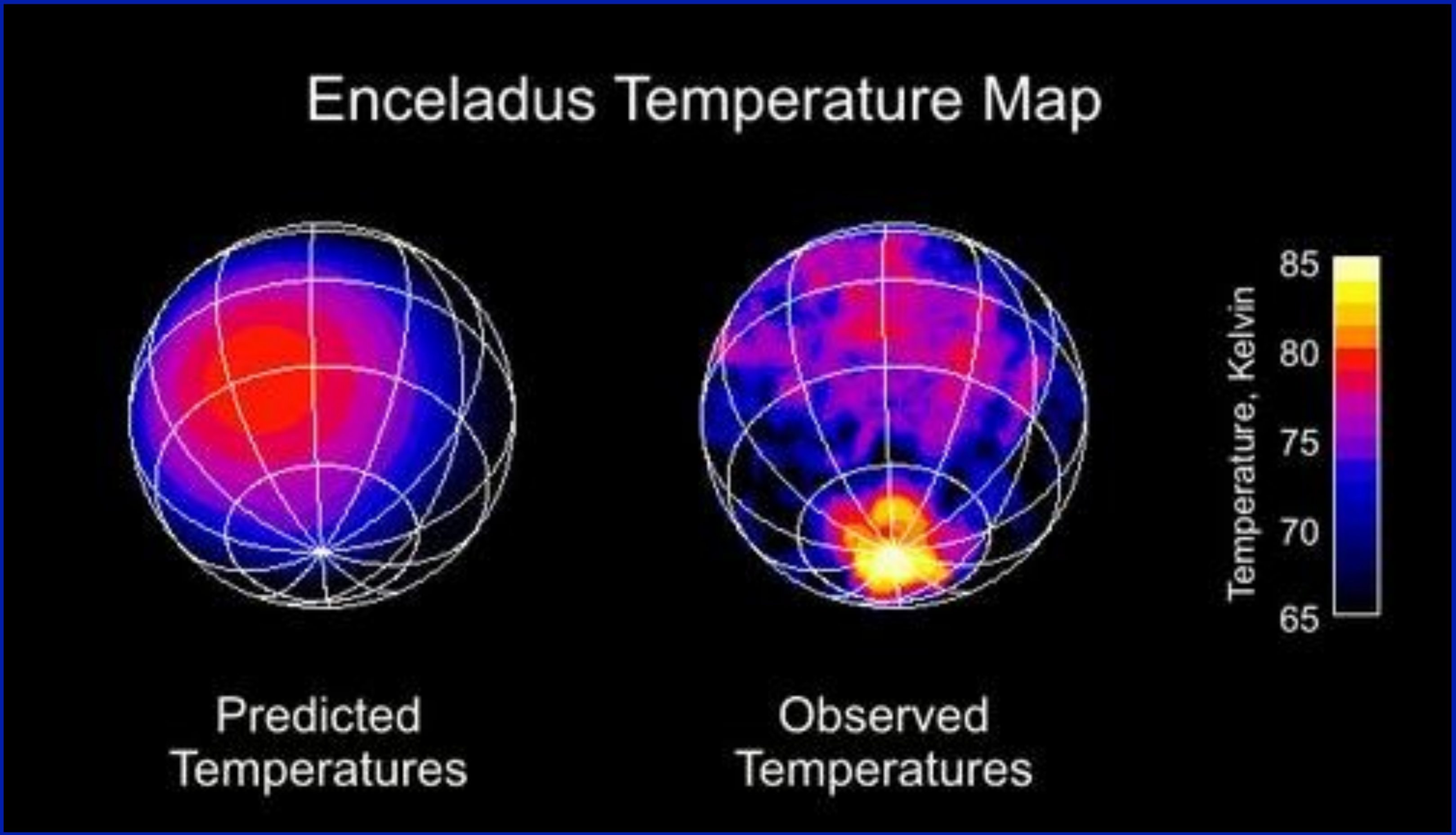
New research: Titan could support microbial life that breathes hydrogen (missing from surface) and ingests acetylene (missing from atmosphere).





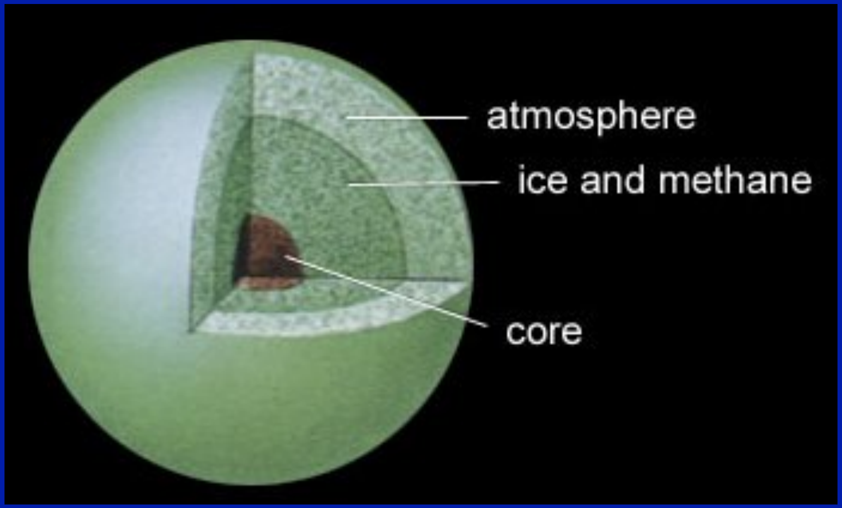
Enceladus: caught in gravitational resonance with larger Dione; large orbit swings cause large tidal heating and ice geysers

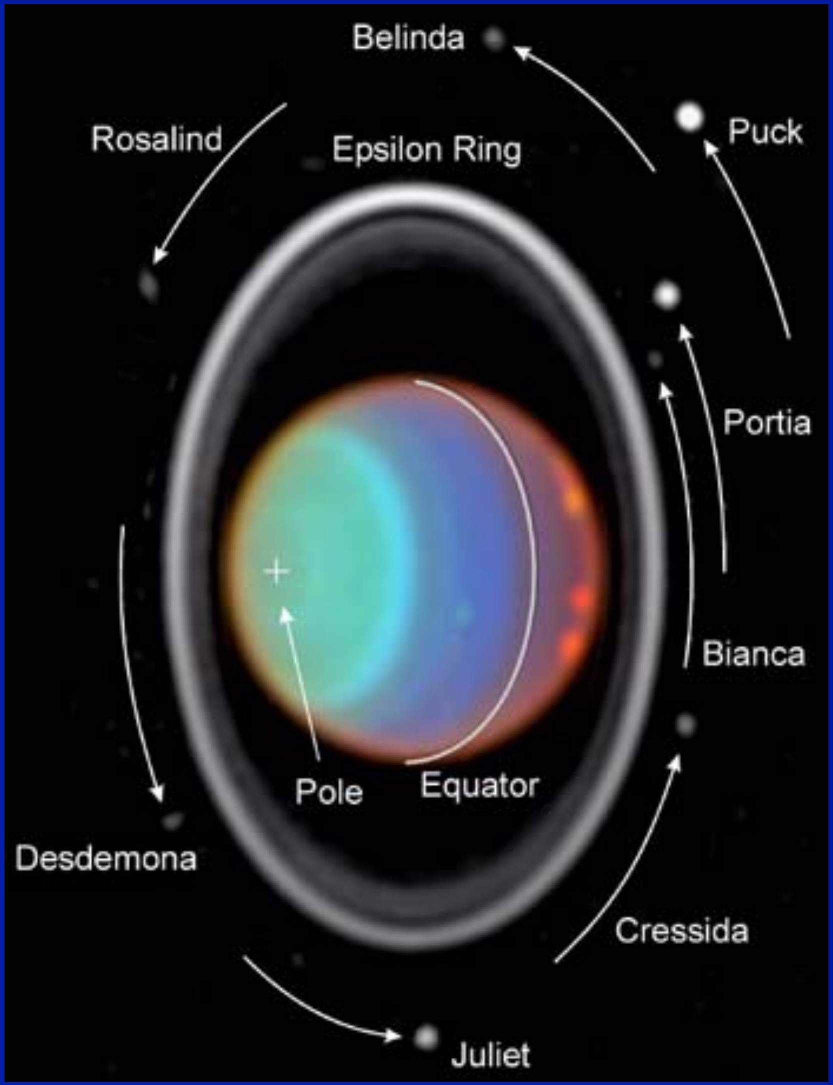
Enceladus Surface Temperature: *Internal Hot Spot at South Pole?* (Cassini)



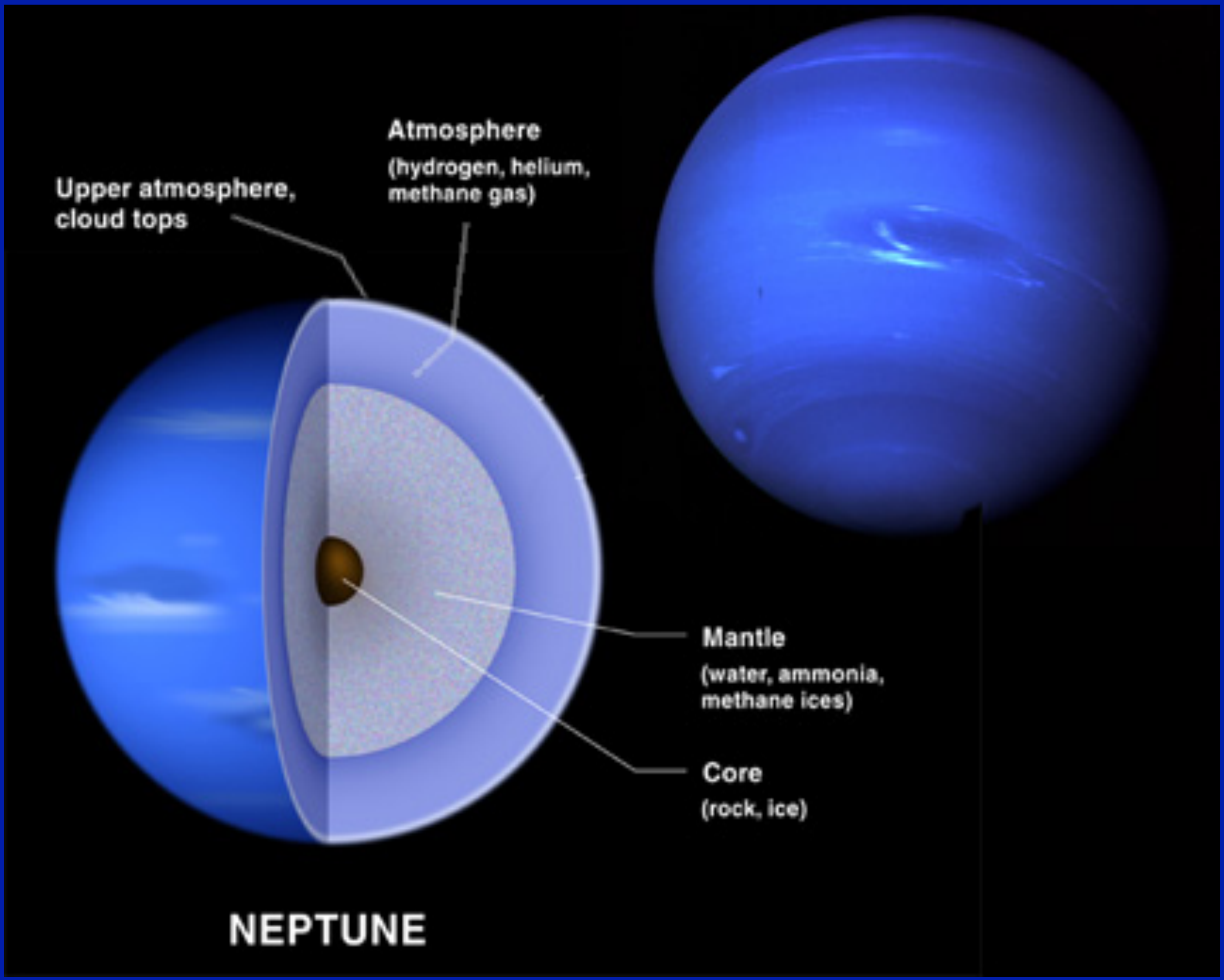
Enceladus Surface Temperature:
Internal heat leaking out of fissures?
(Cassini)

ICY GIANTS:
Uranus





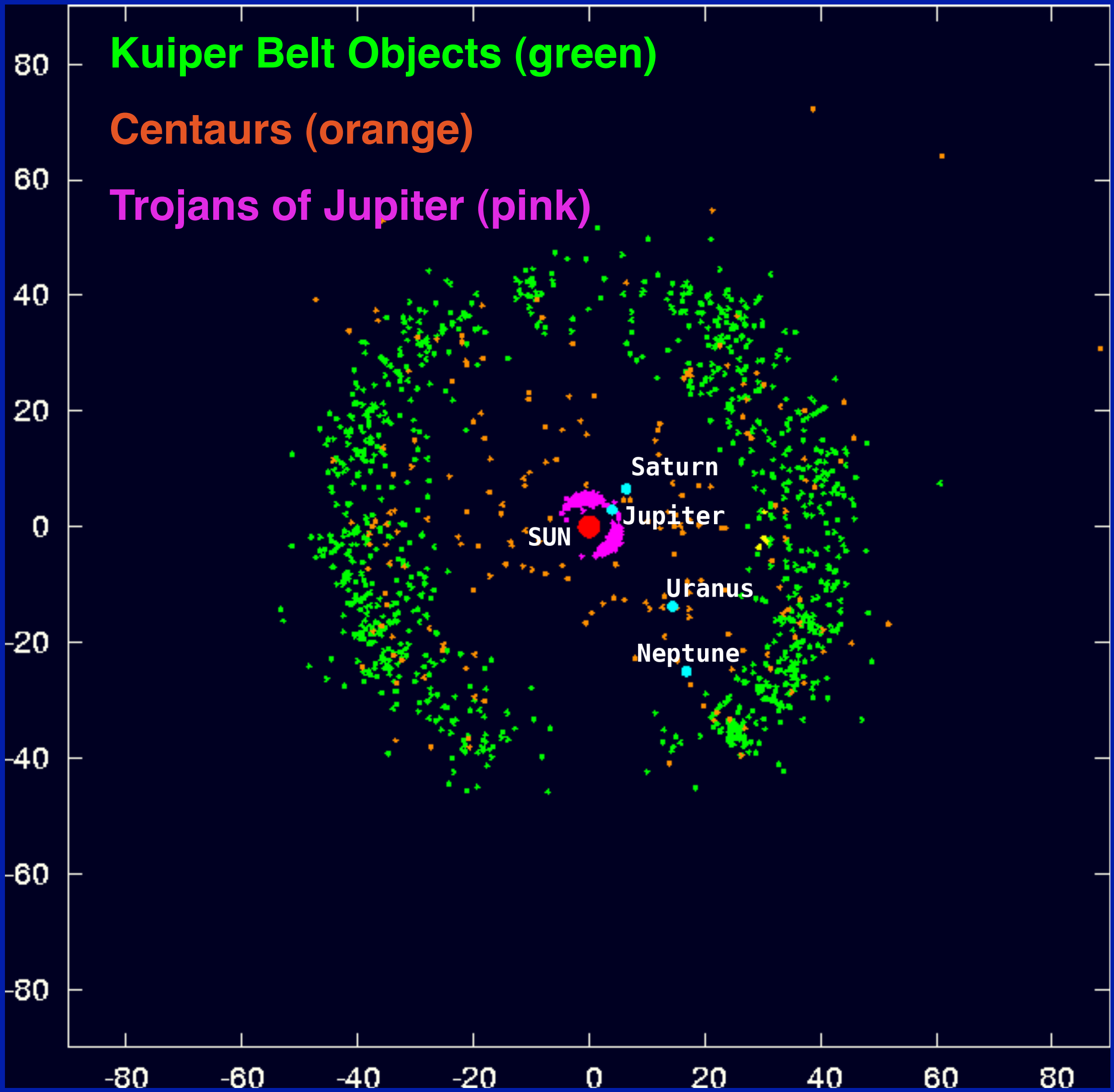
ICY GIANTS: Neptune



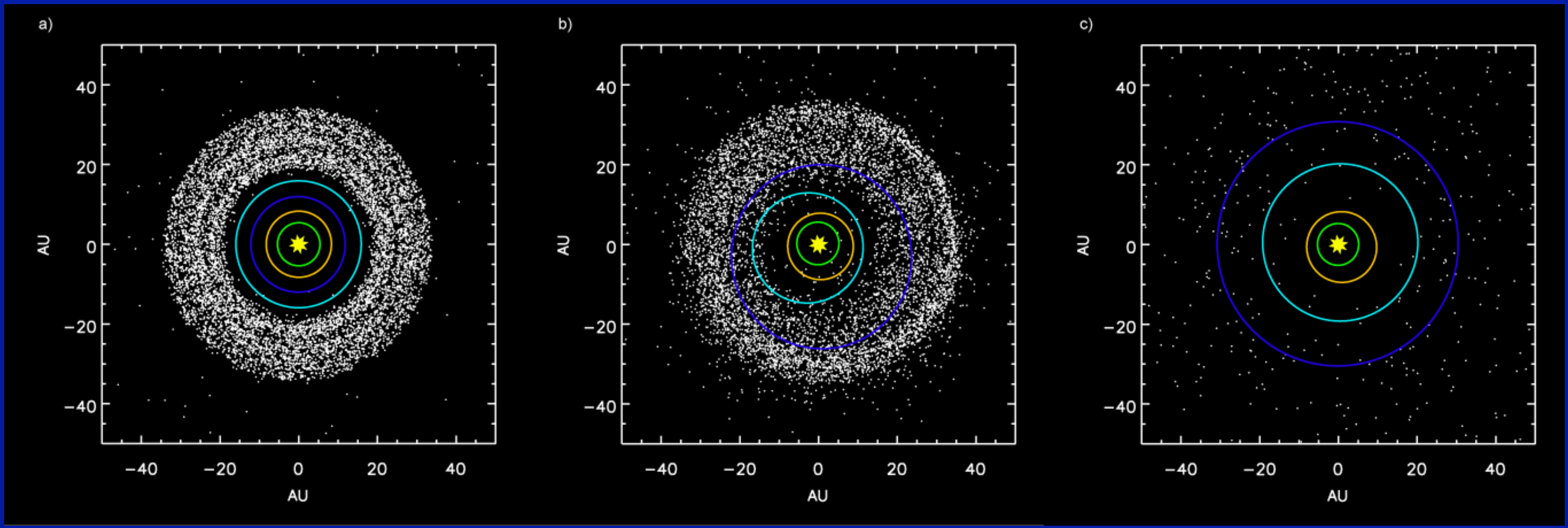
Great Dark Spot: Observed by *Voyager 2* in 1989, but was gone 5 years later (in Hubble images)

Small Solar System Bodies (SSSBs)

(Includes minor planets, asteroids, meteoroids, and comets)



KBO evolution and the Nice Model:

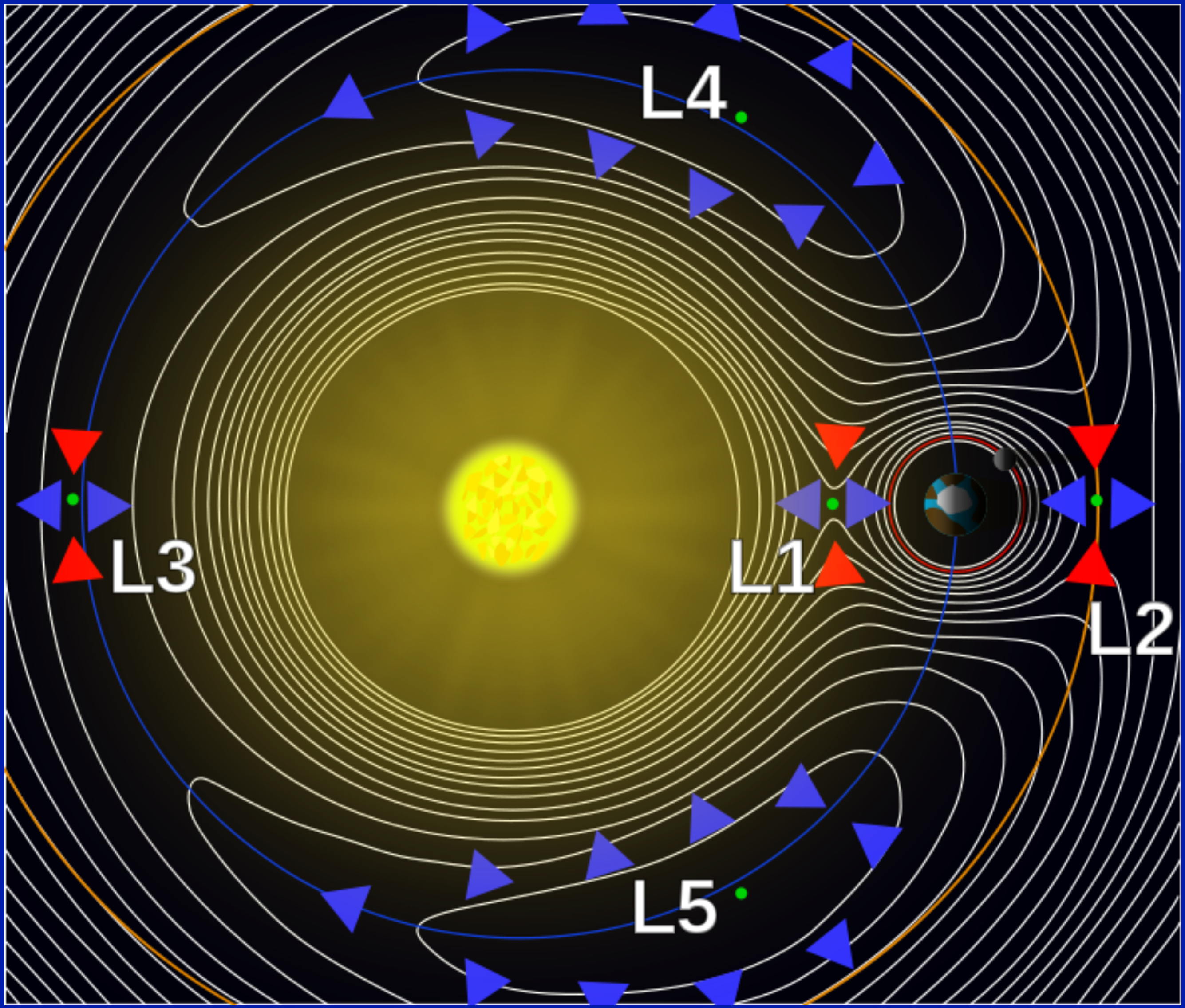


KBOs before the Jupiter/Saturn 2:1 resonance

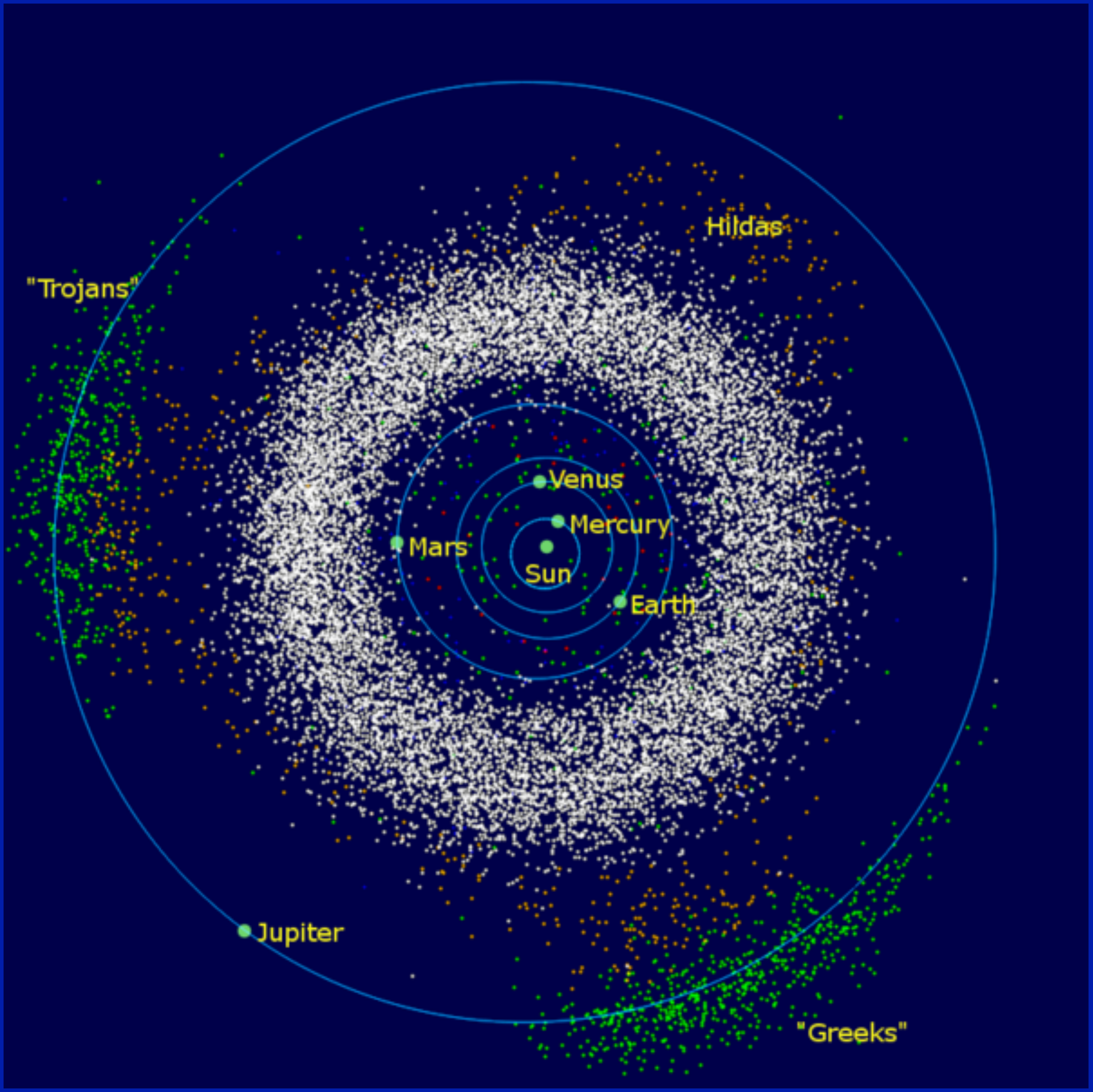
Scattering of KBOs into inner solar system after shift of Neptune

After ejection of KBOs by Jupiter

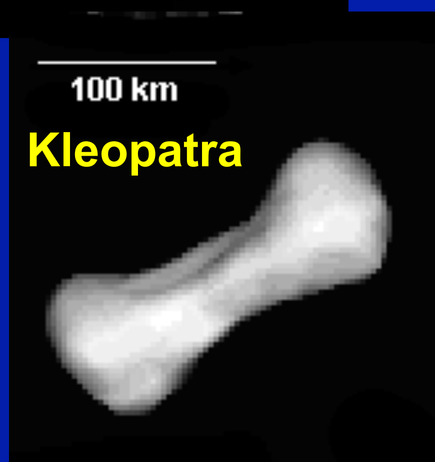
Lagrange Points:

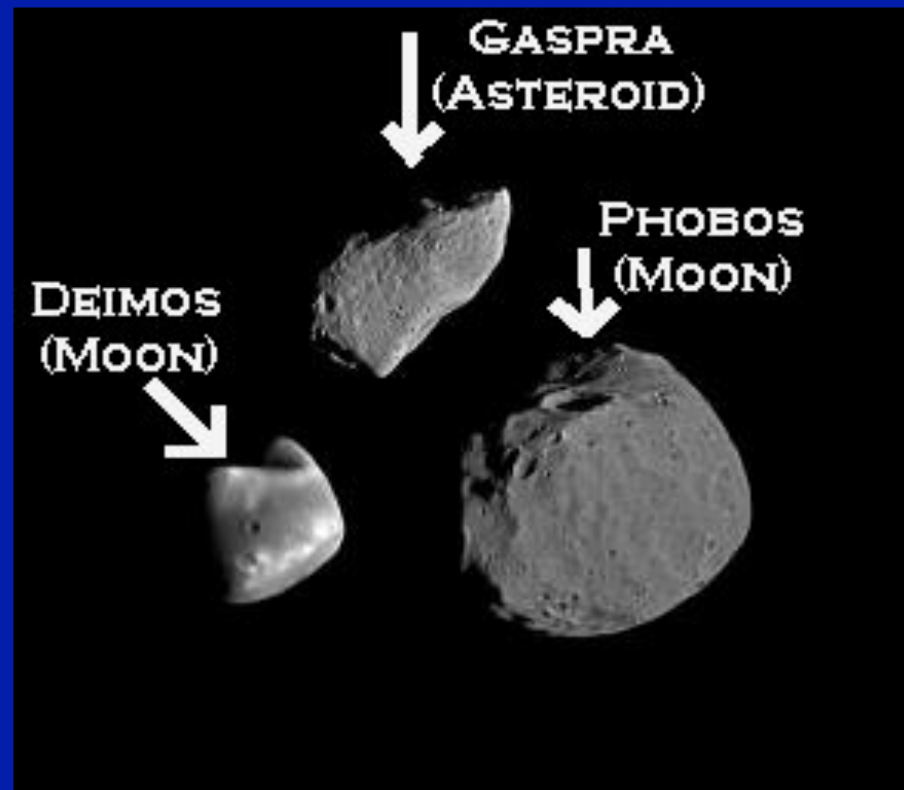


Inner Solar System Bodies



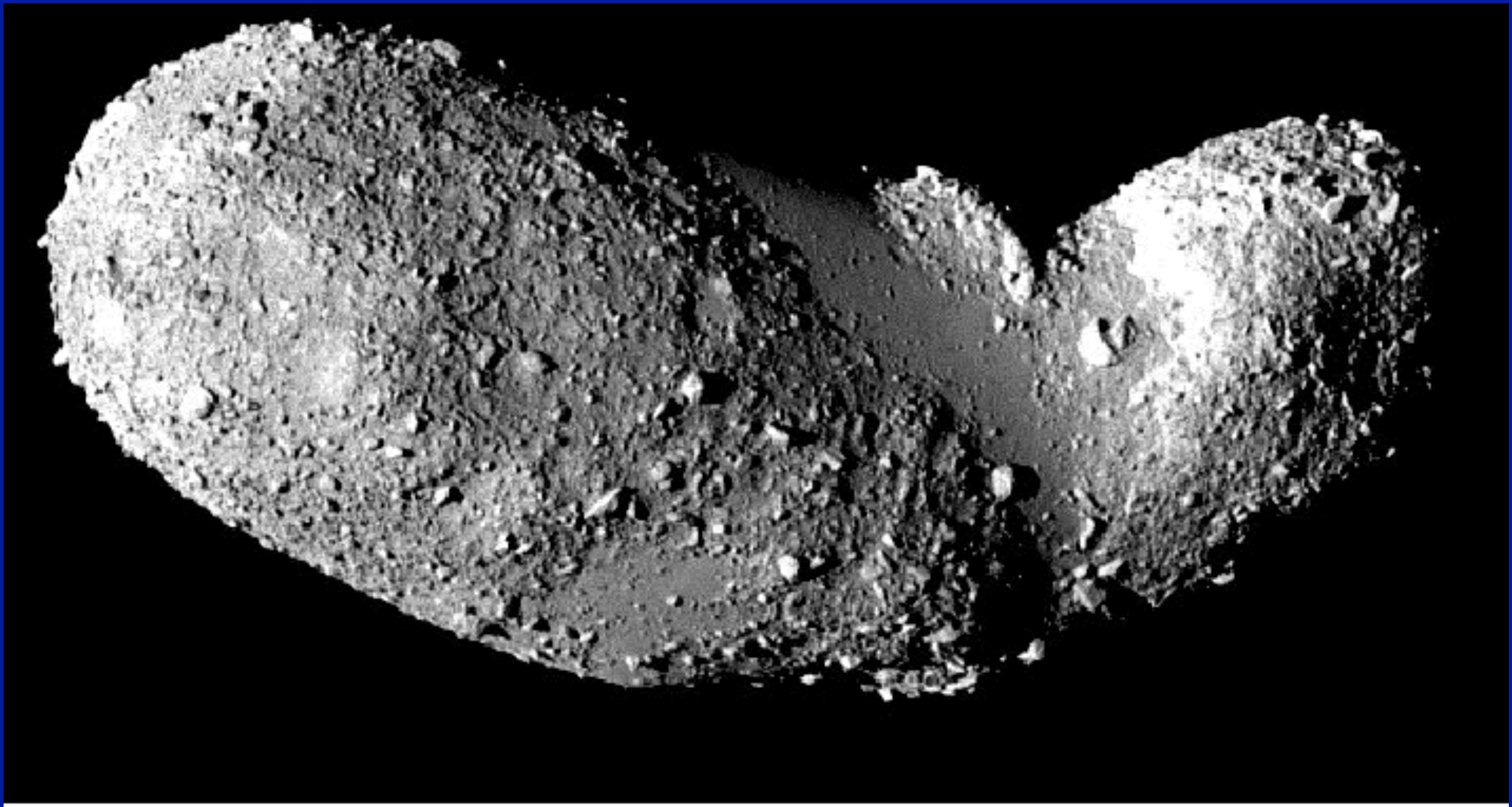
Asteroids: range from solid to rubble, and rocky to icy;
--- the line between asteroids and comets has blurred





The solar system's "snow line" could have been close to Mars, so many asteroids are probably icy

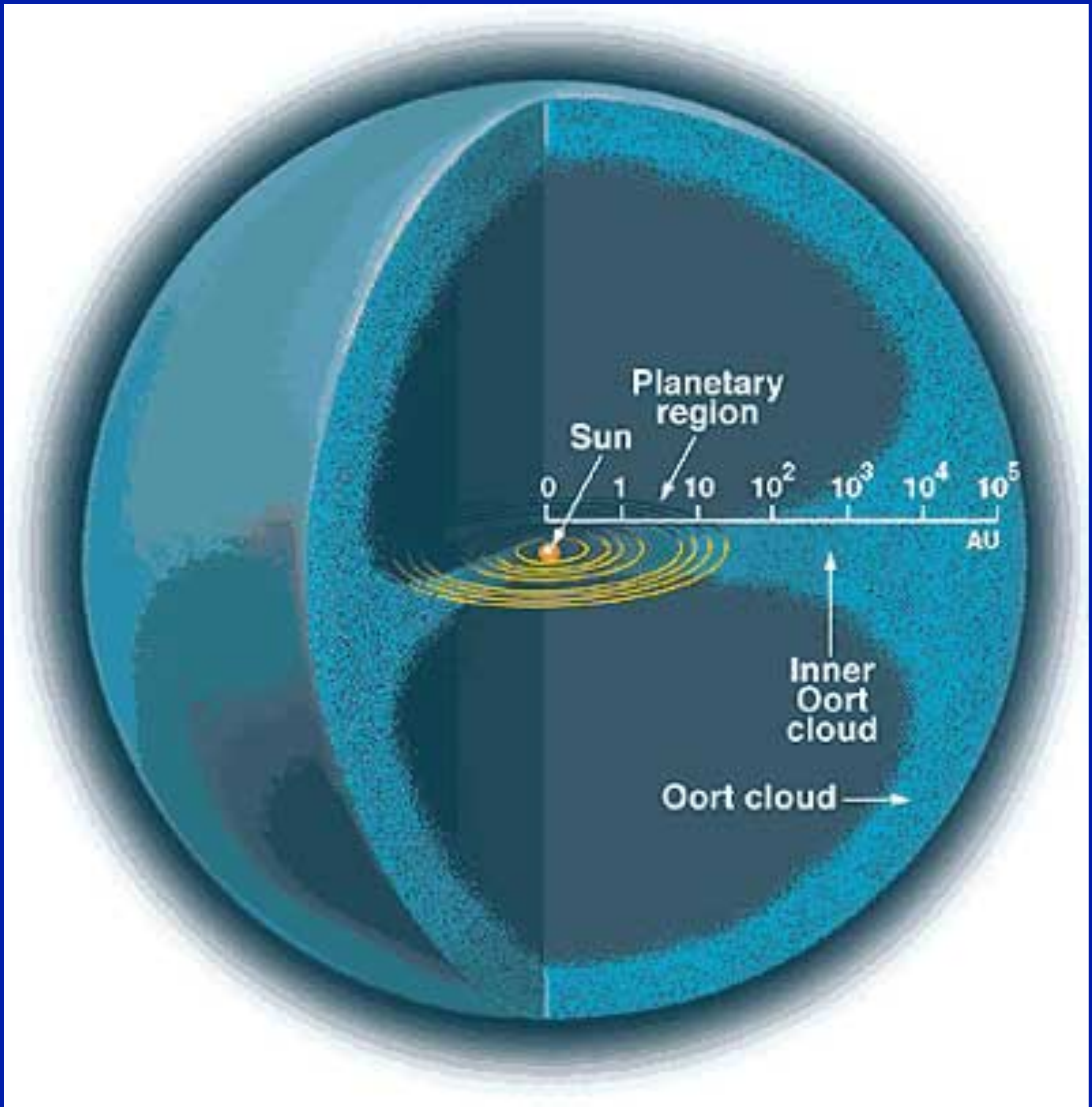
ASTEROIDS (Itokawa)



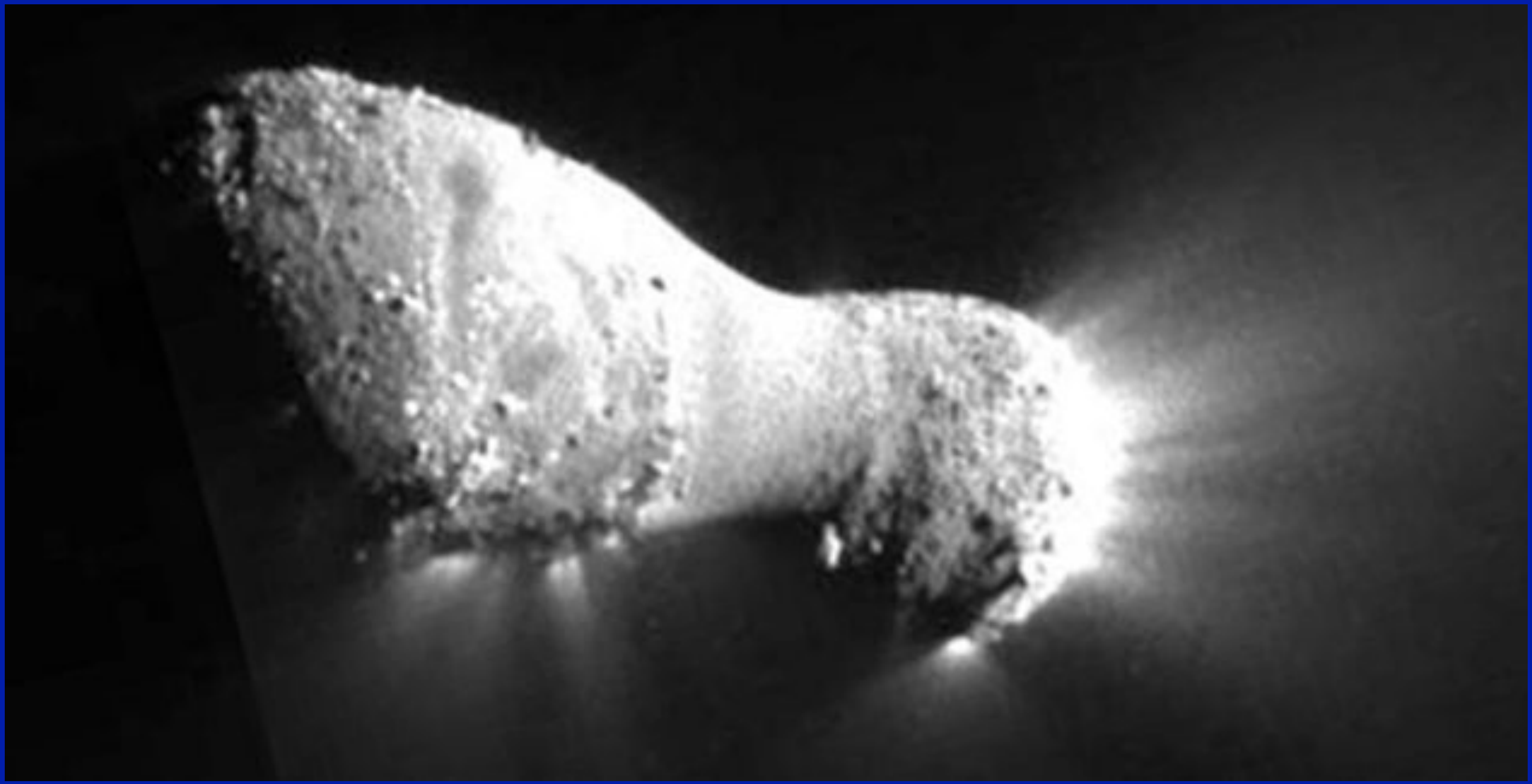
Japanese Hayabusa mission landed in 2005; sample capsule landed at Woomera, South Australia, on June 13; it is unclear if any samples were returned.

Oort Cloud:

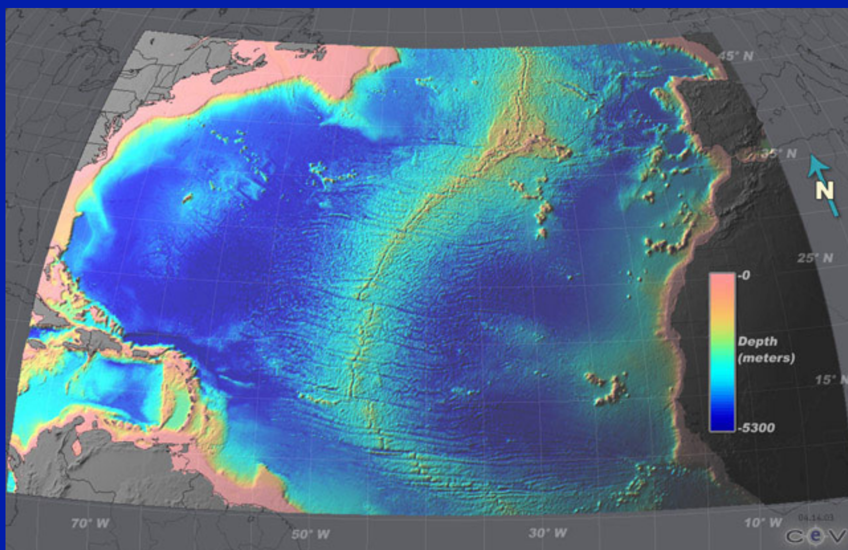
- 2000 - 50,000 AU
- trillions of comets > 1.3 km
- total mass may be ~ 5 Earth masses



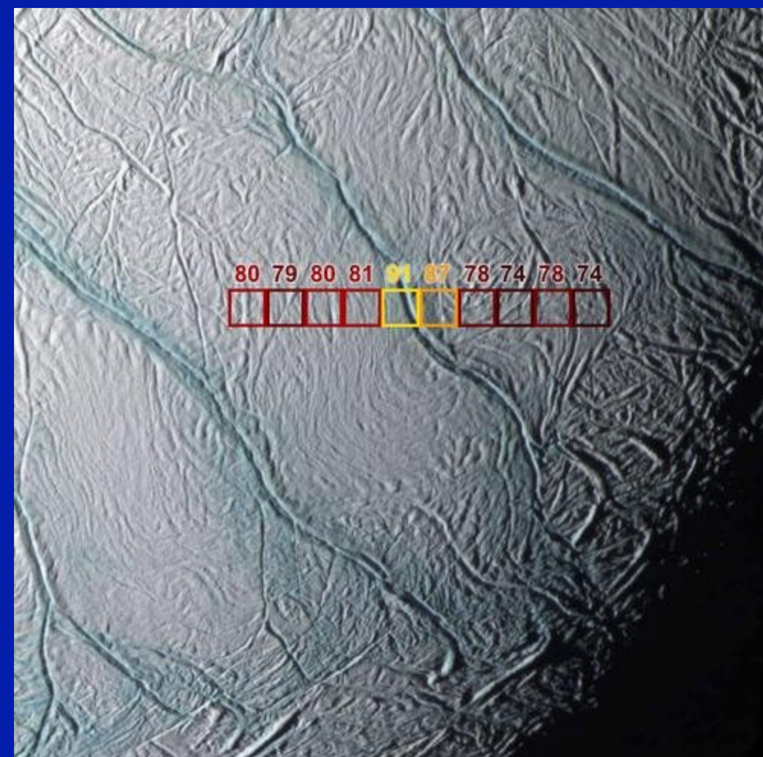
Comet Hartley 2, taken from NASA's EPOXI probe



Crustal Rift

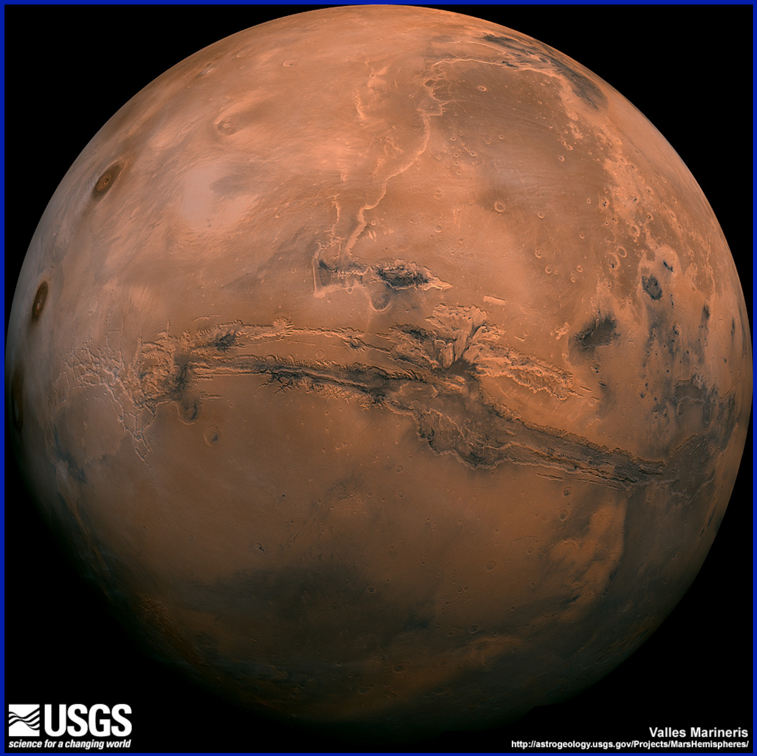


Earth



Enceladus

Valley

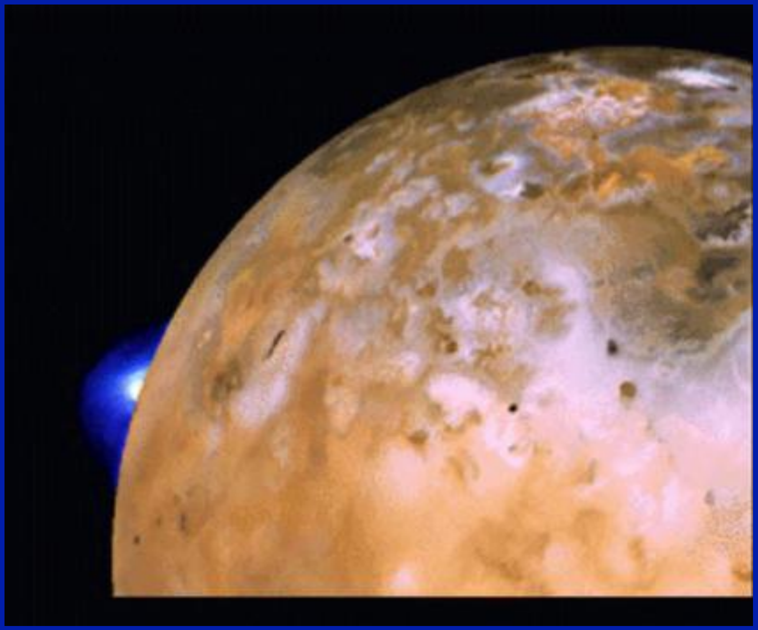


Earth

Mars

Volcanic Eruption

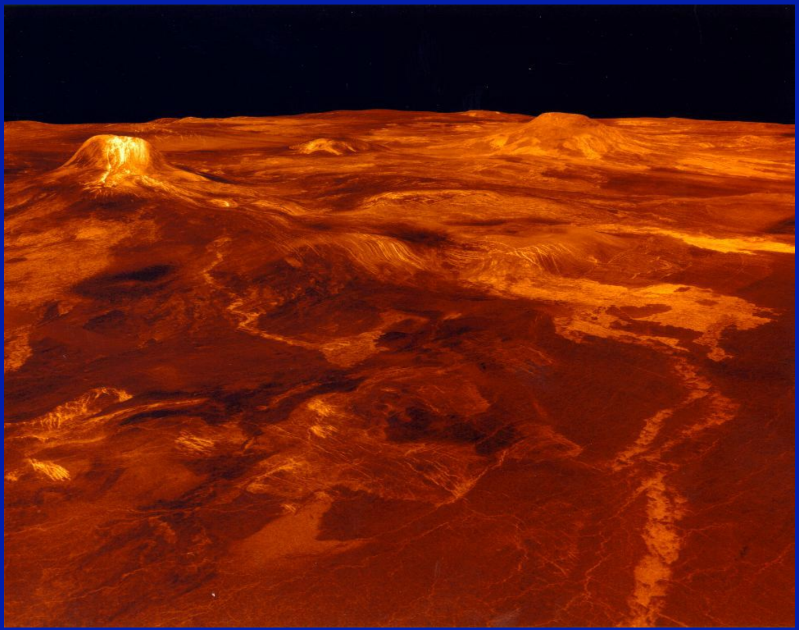
Earth



Io

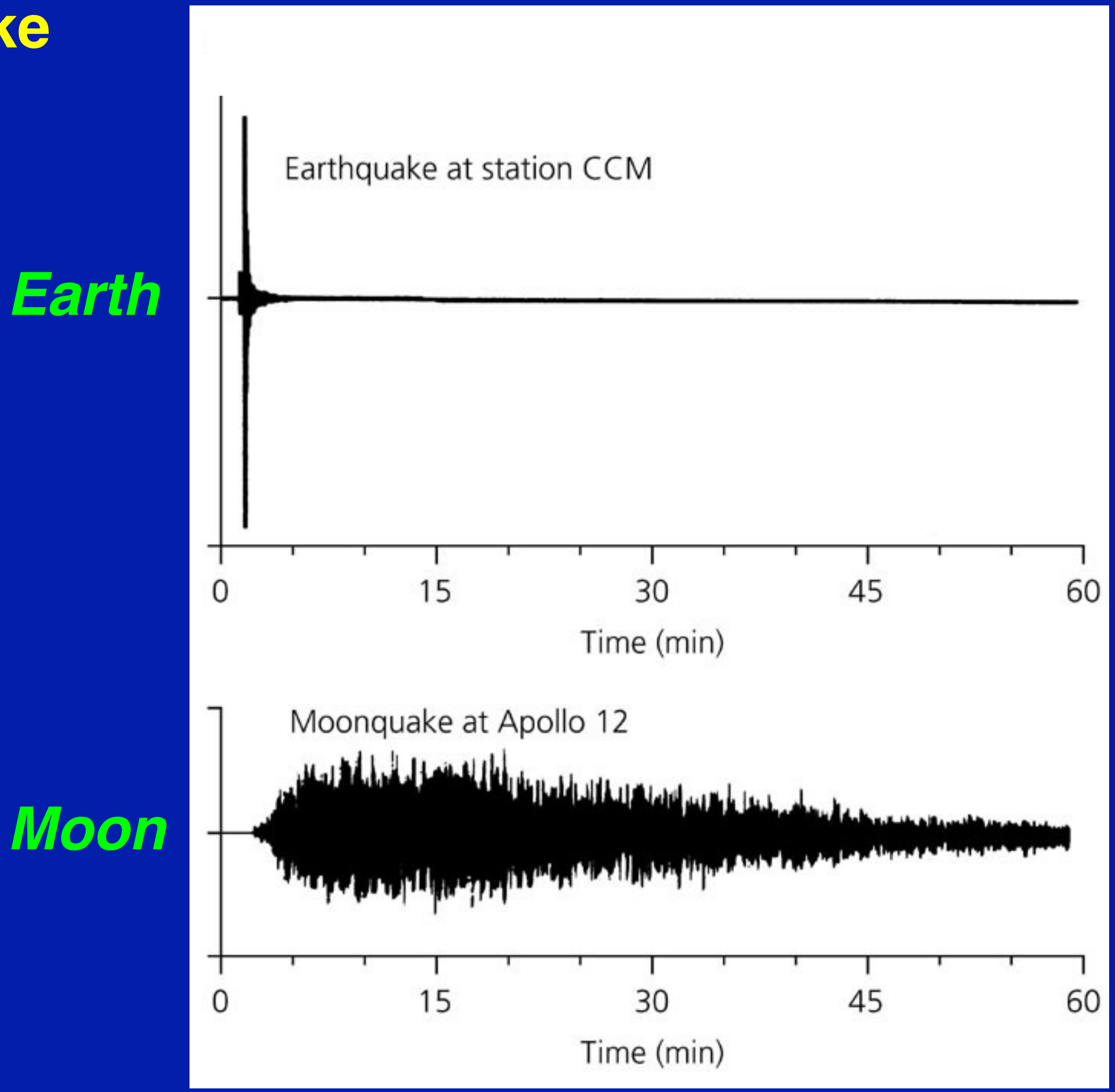
Lava Flow

Earth



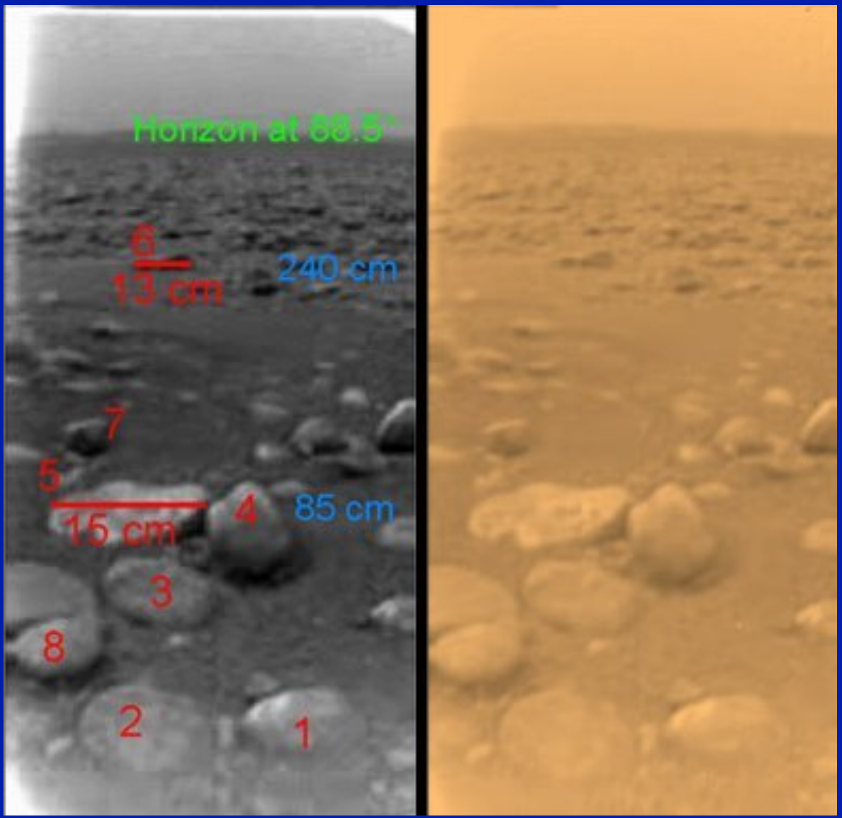
Venus

Earthquake


Earth
Moon
Earthquake at station CCM
Moonquake at Apollo 12
0
15
30
45
60
Time (min)

Weathering

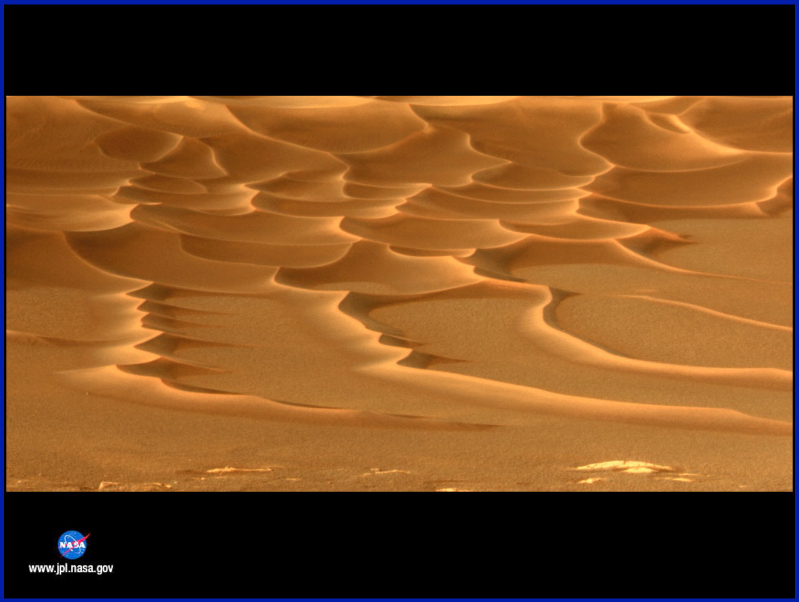
Earth



Titan

Sand Dunes

Earth



Mars

Desert Pavement

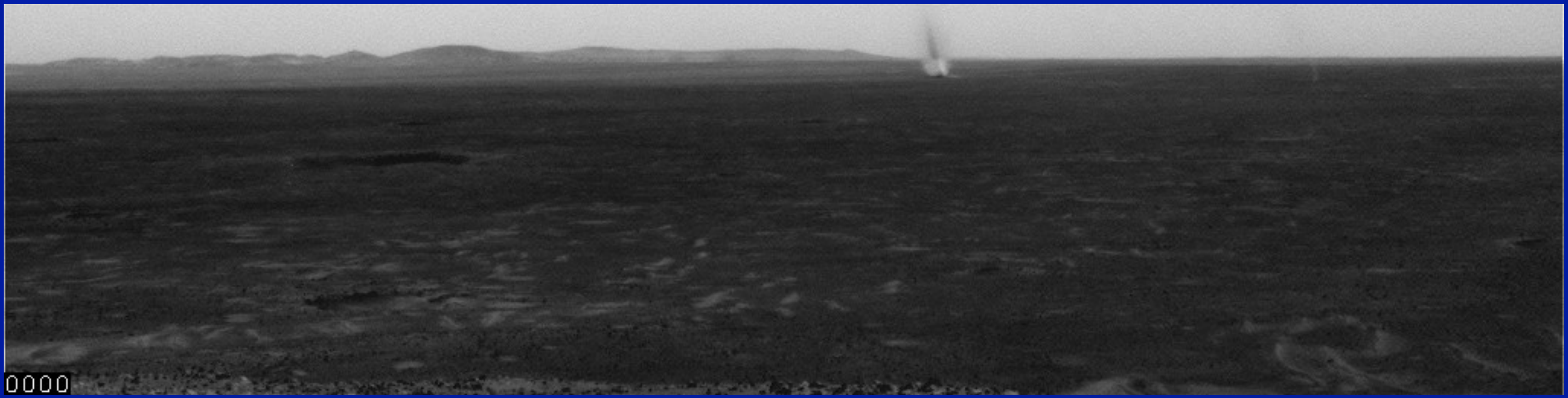
Earth

Mars

Dust Devils

Earth

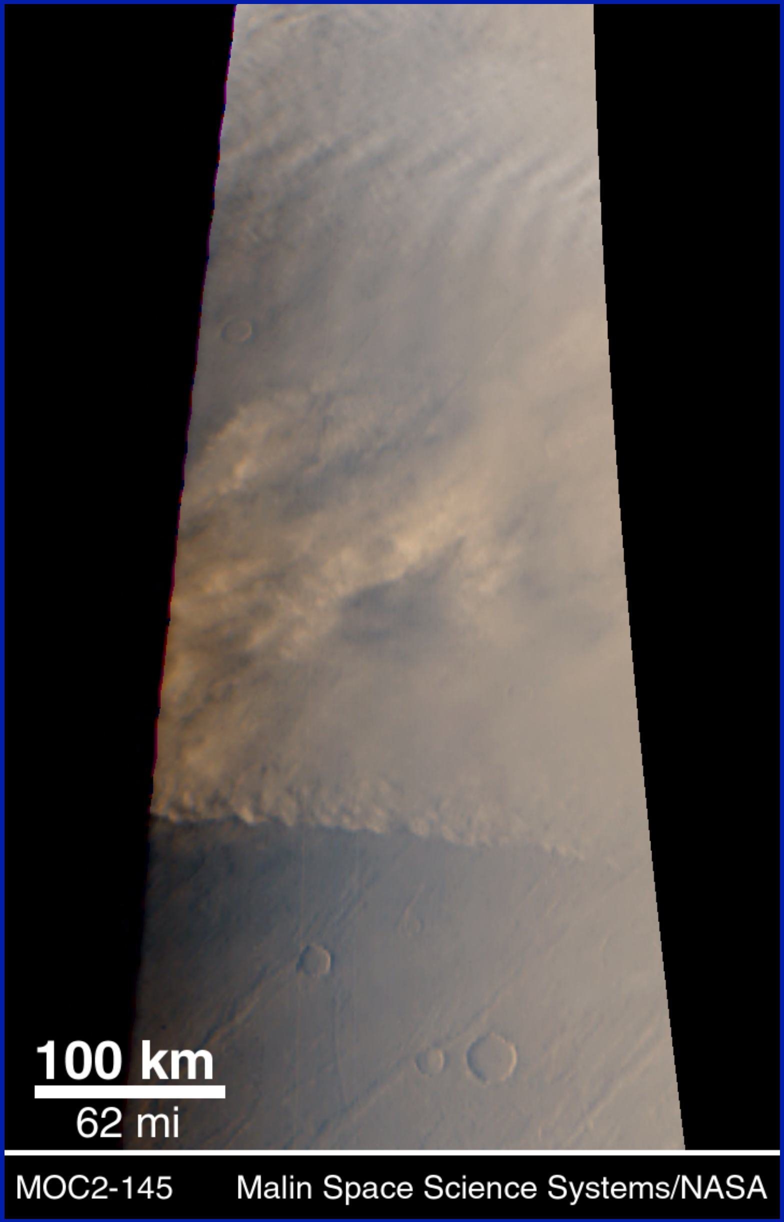
Mars



Dust Storm

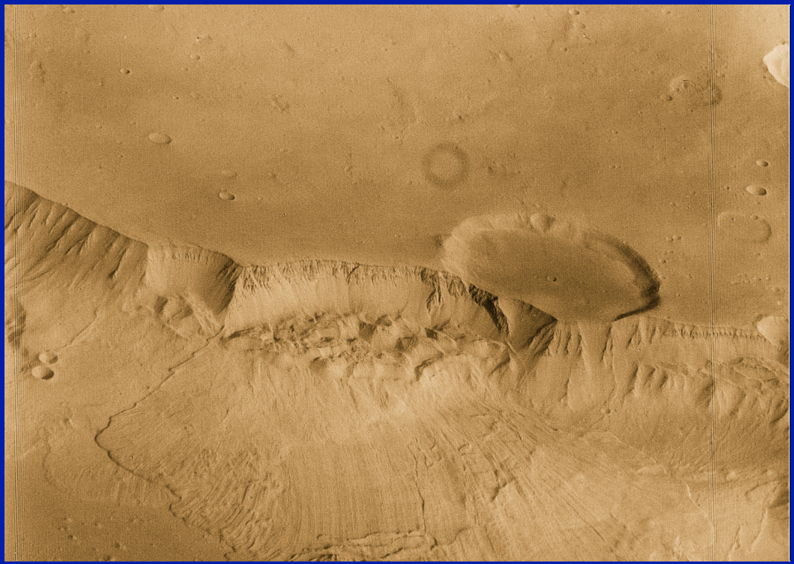
Earth

Mars



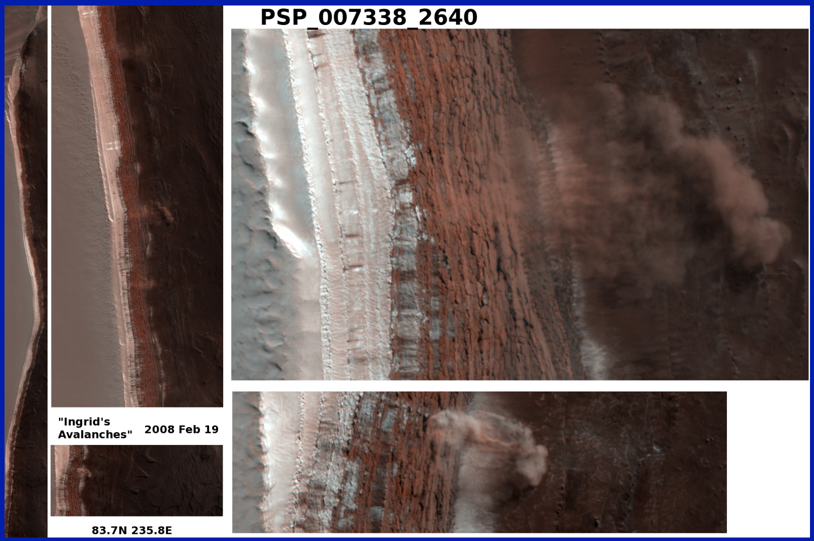
Slumping

Earth



Mars

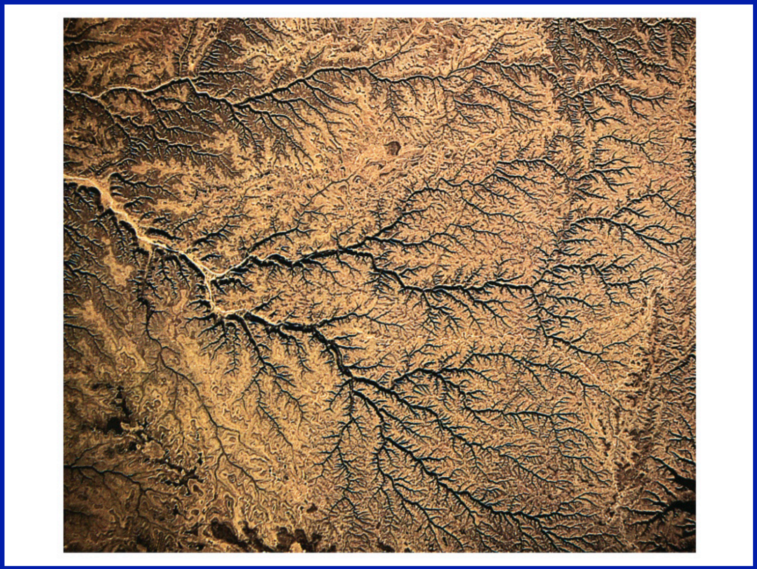
Rock Avalanche



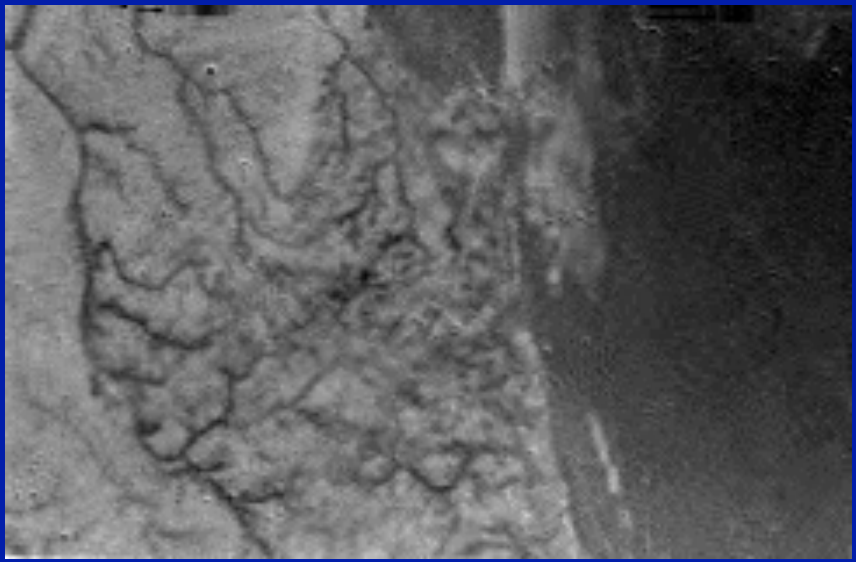
Earth

Mars

Streams



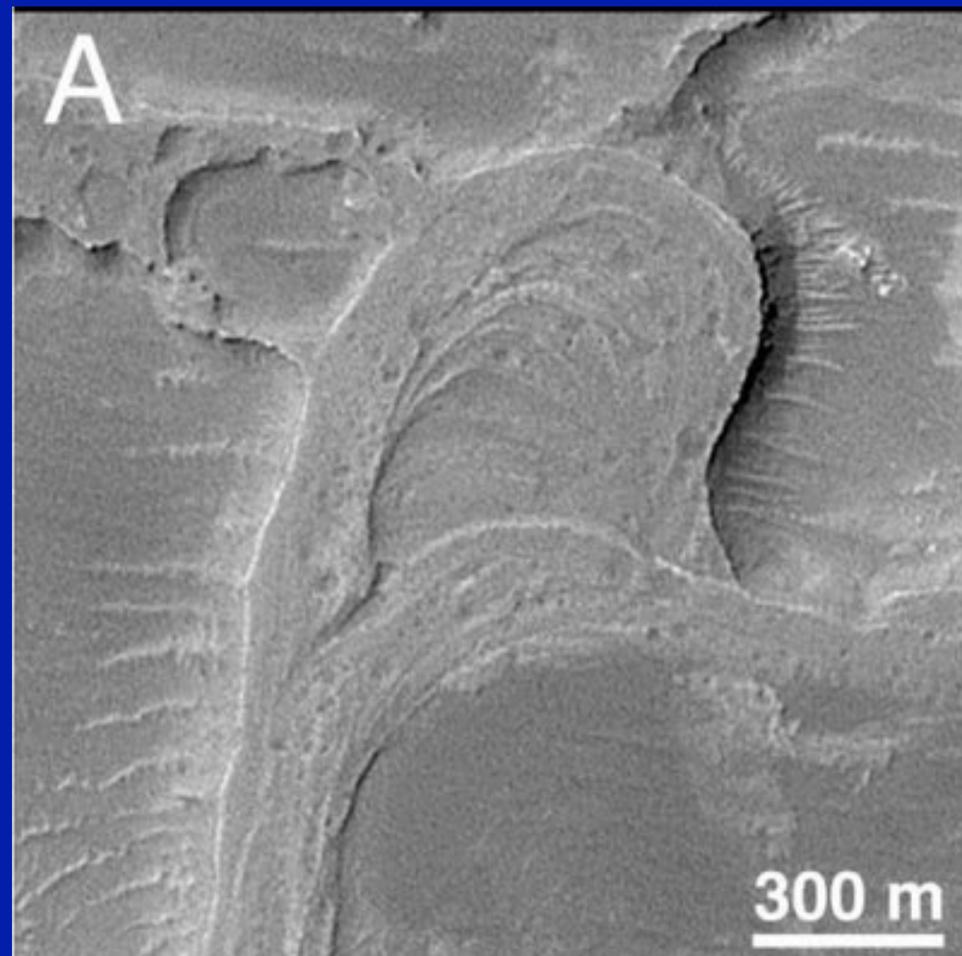
Earth



Titan

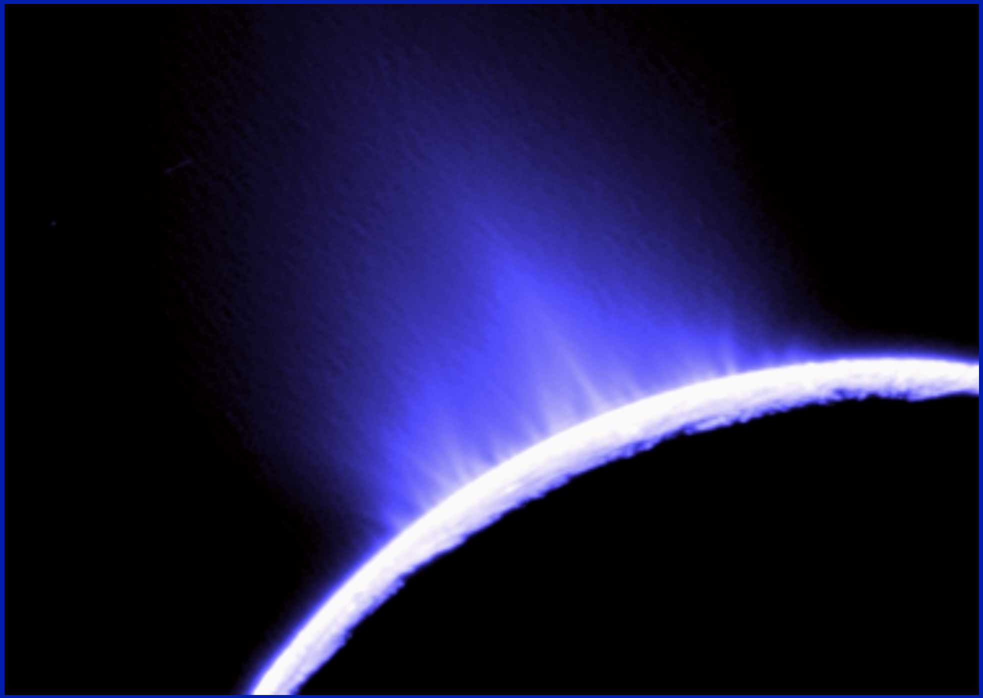
Stream Meander

Earth



Mars

Geyser



Earth

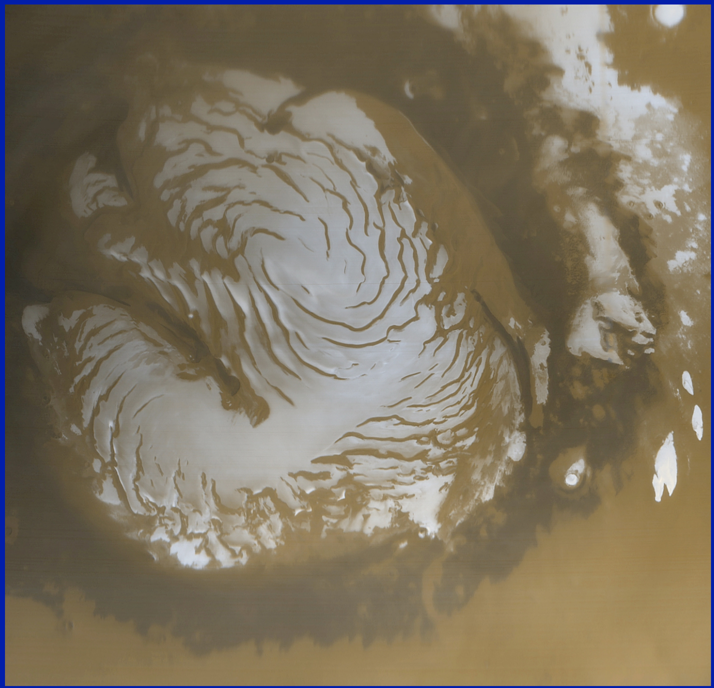
Enceladus

Lakes

Titan *Earth*

Water Ice Caps

Earth



Mars

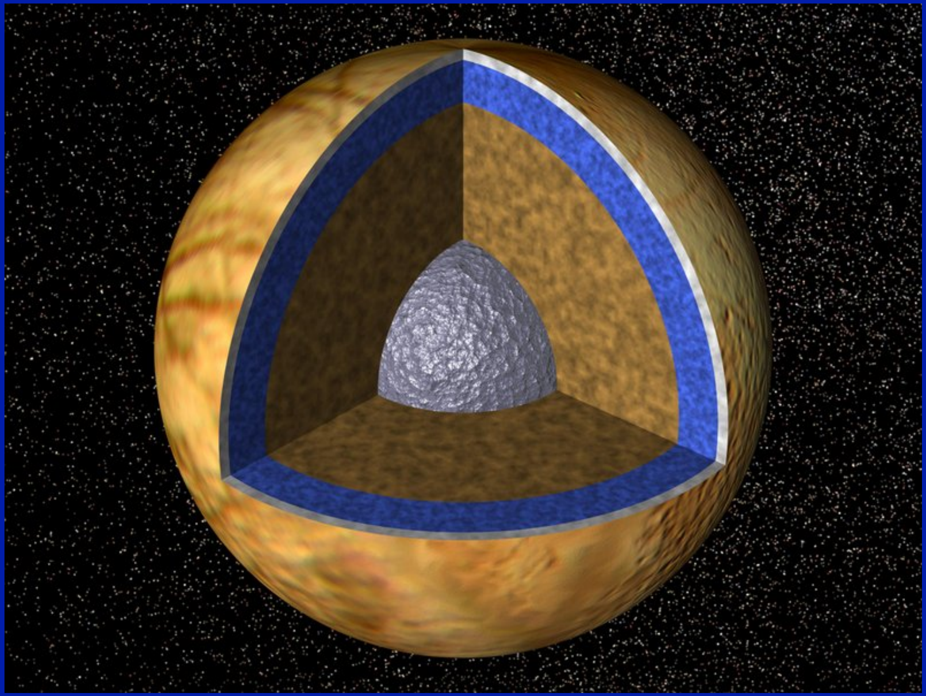
Glacial Moraine

Earth

Mars

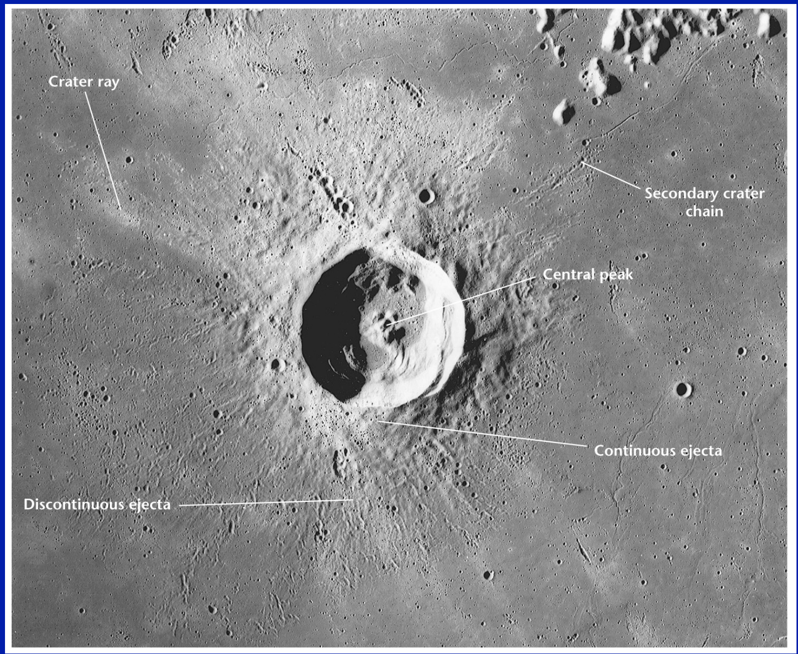
Water Ocean

Earth



Europa

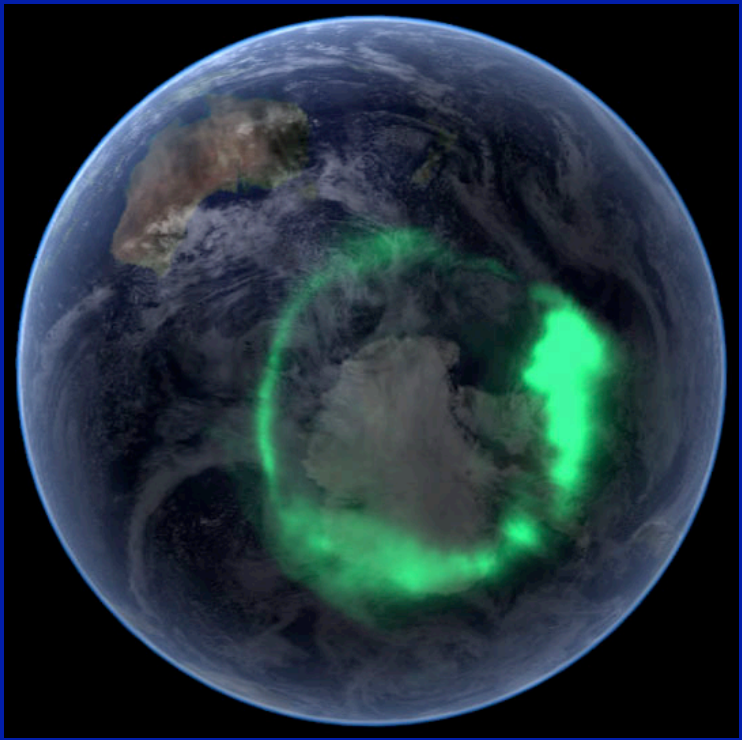
Meteor Impact Crater

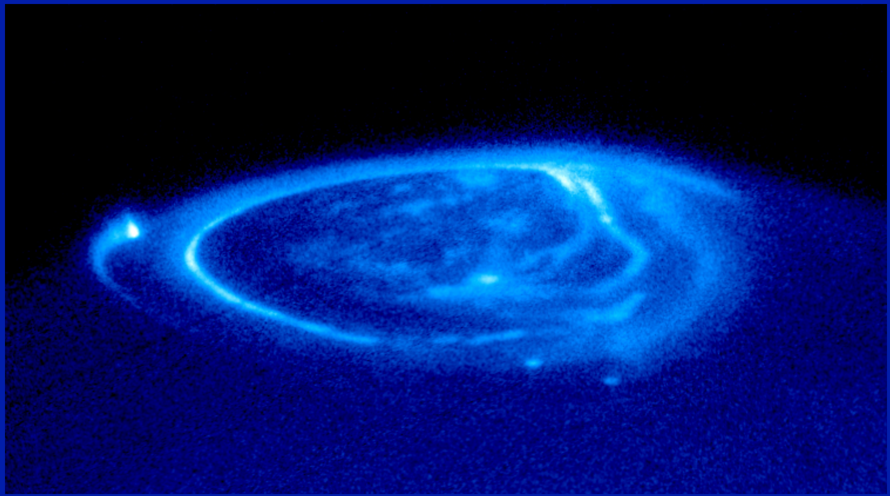


Earth

Moon

Aurora

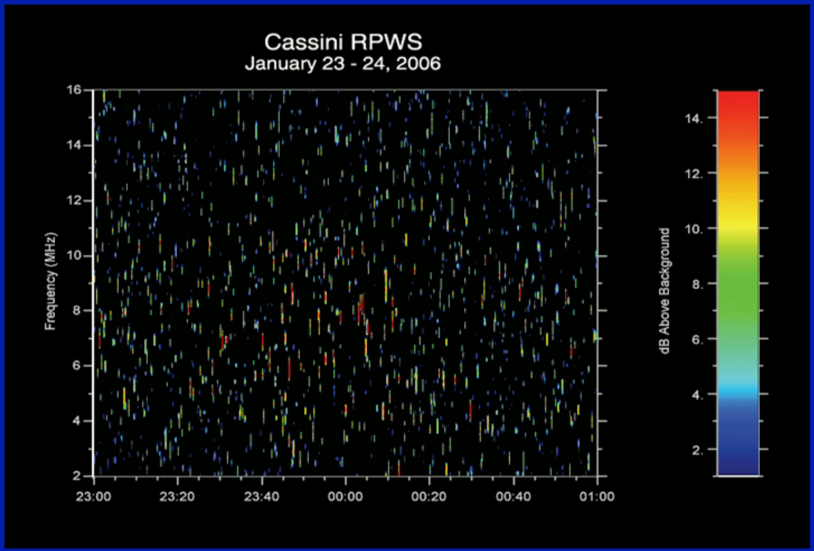




Earth

Jupiter

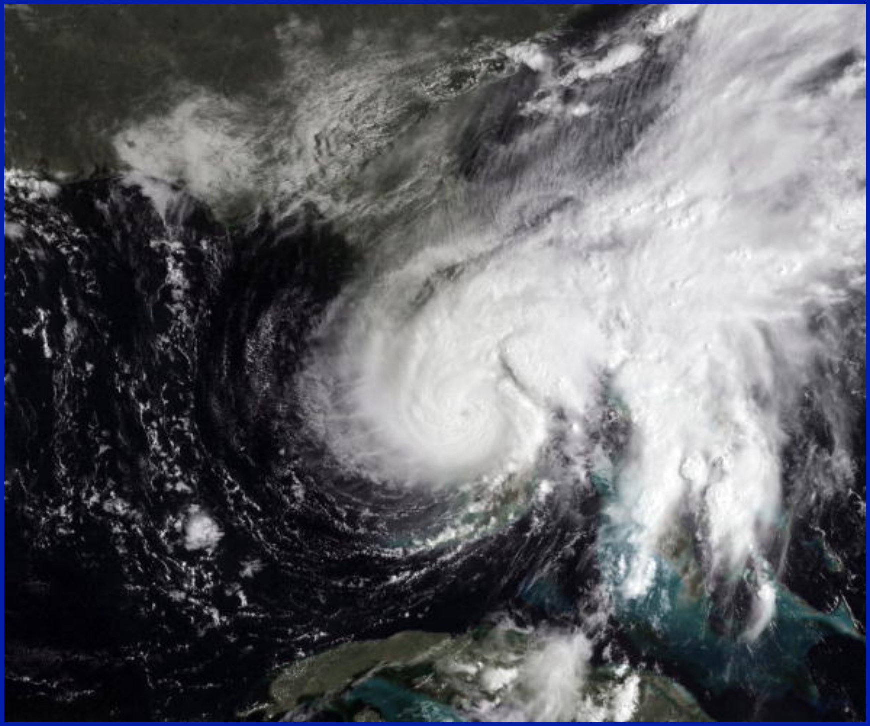
Lightning



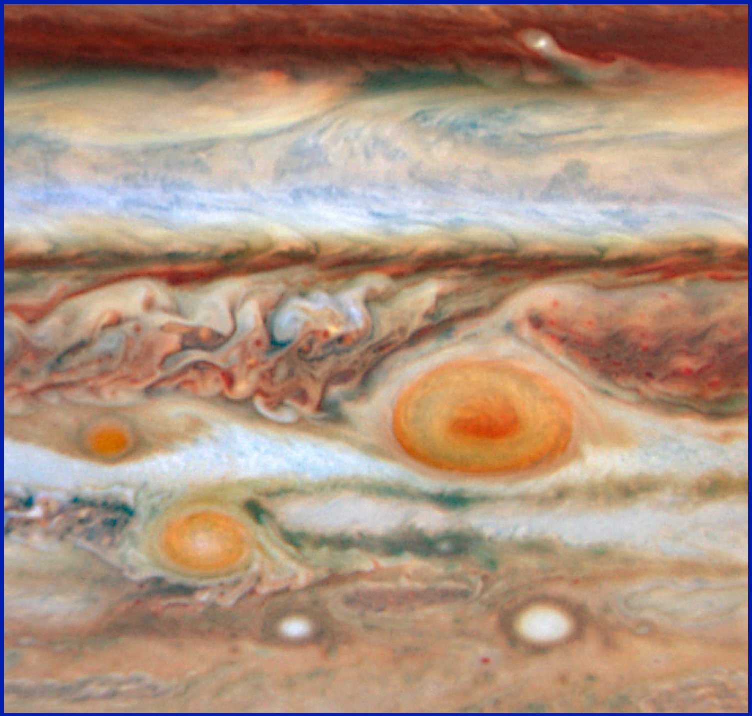
Earth

Saturn

Storms

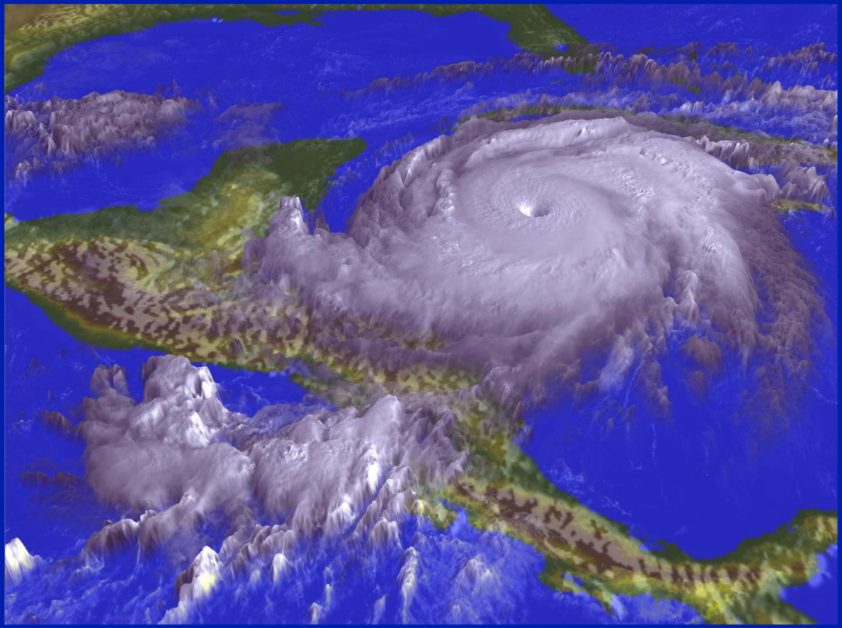


Earth

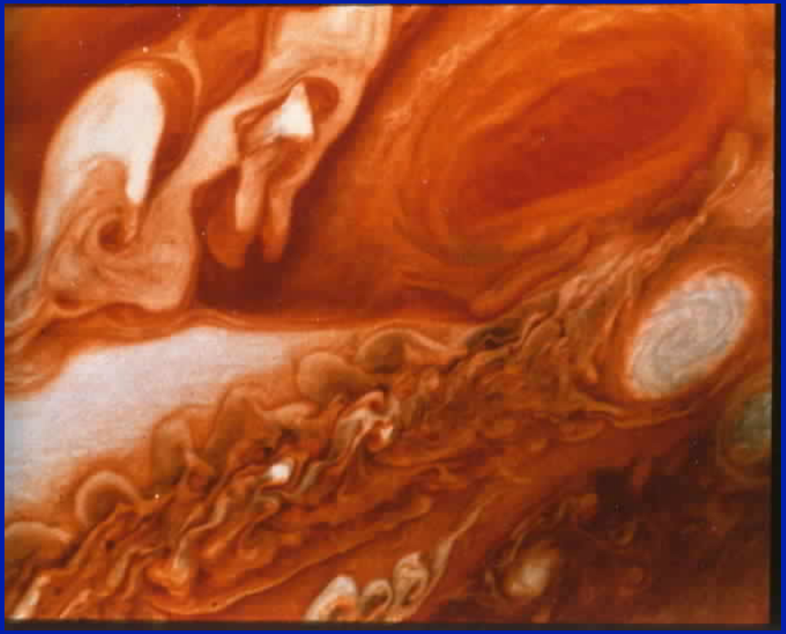


Jupiter

Hurricane

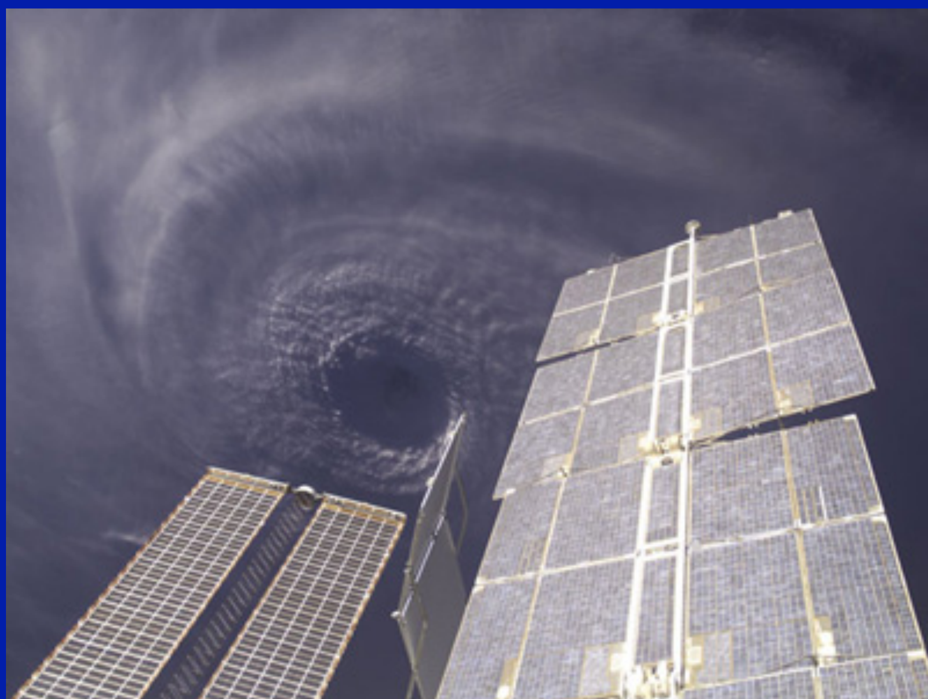


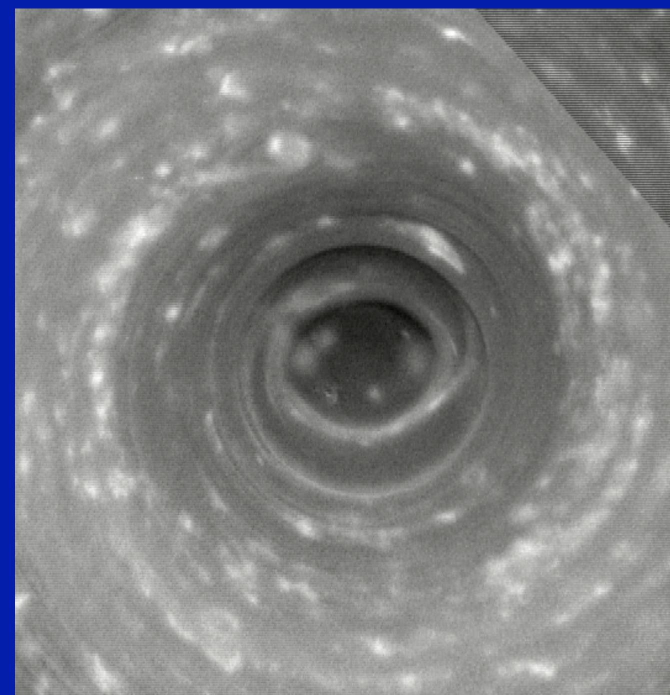
Earth



Jupiter

Hurricane "Eye"





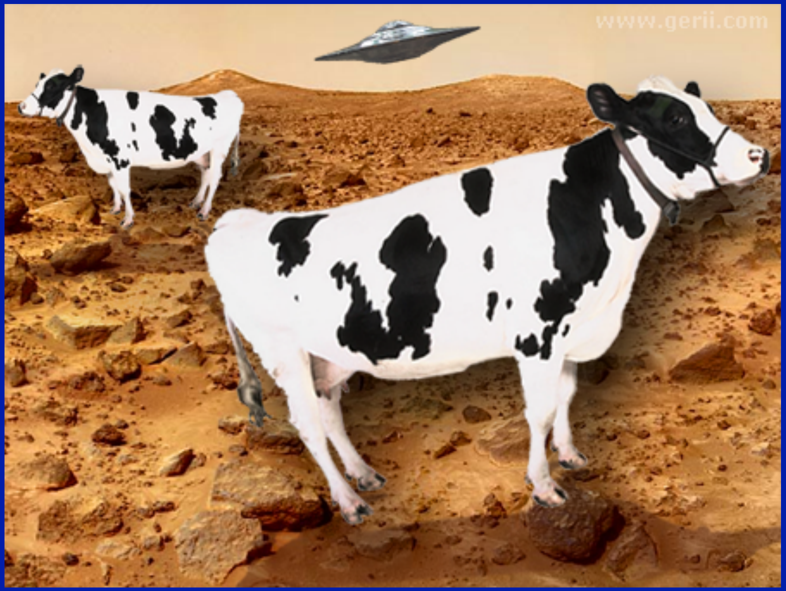
Earth

(Hurricane Ivan from ISS)

Saturn

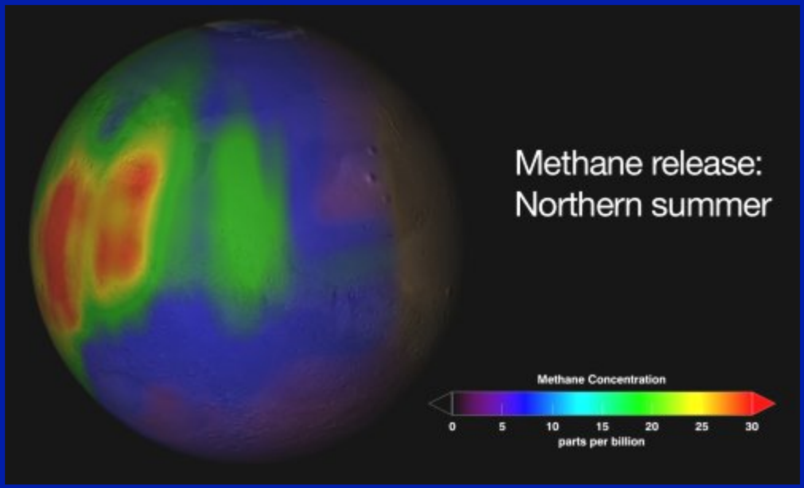
Life

Earth



Mars

Life



Earth

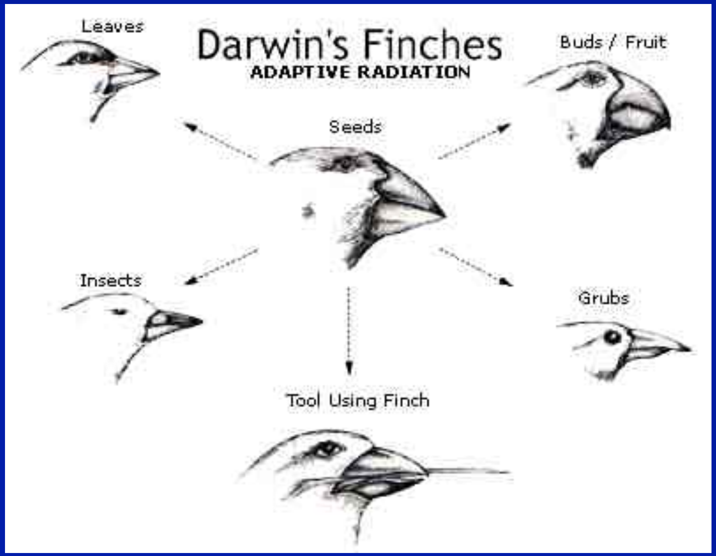
Mars???

No other planet comes close to Earth with respect to the *diversity* of its environments, and nowhere else do we see *plate tectonics*.

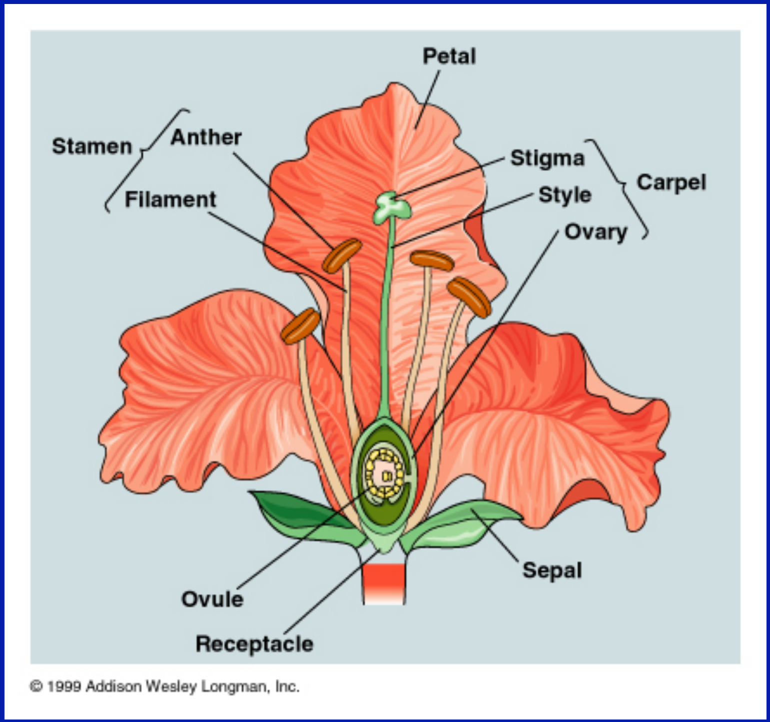

MetLife

Evolution:

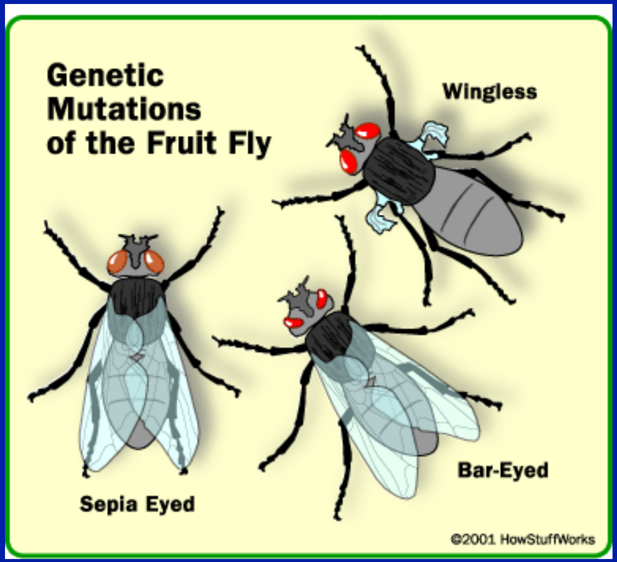
Natural Selection



Reproduction



Mutation



Adaptation to environmental change: deciduous trees.

Fall

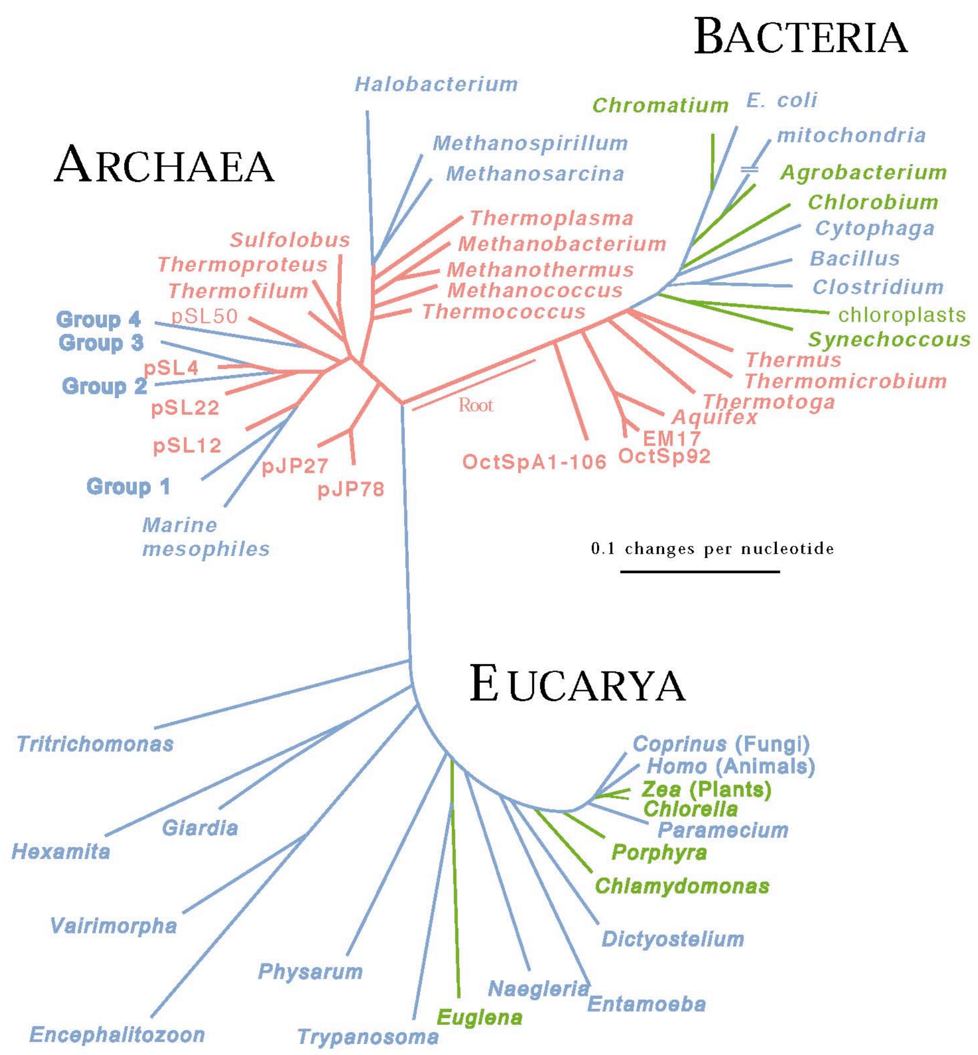
Summer

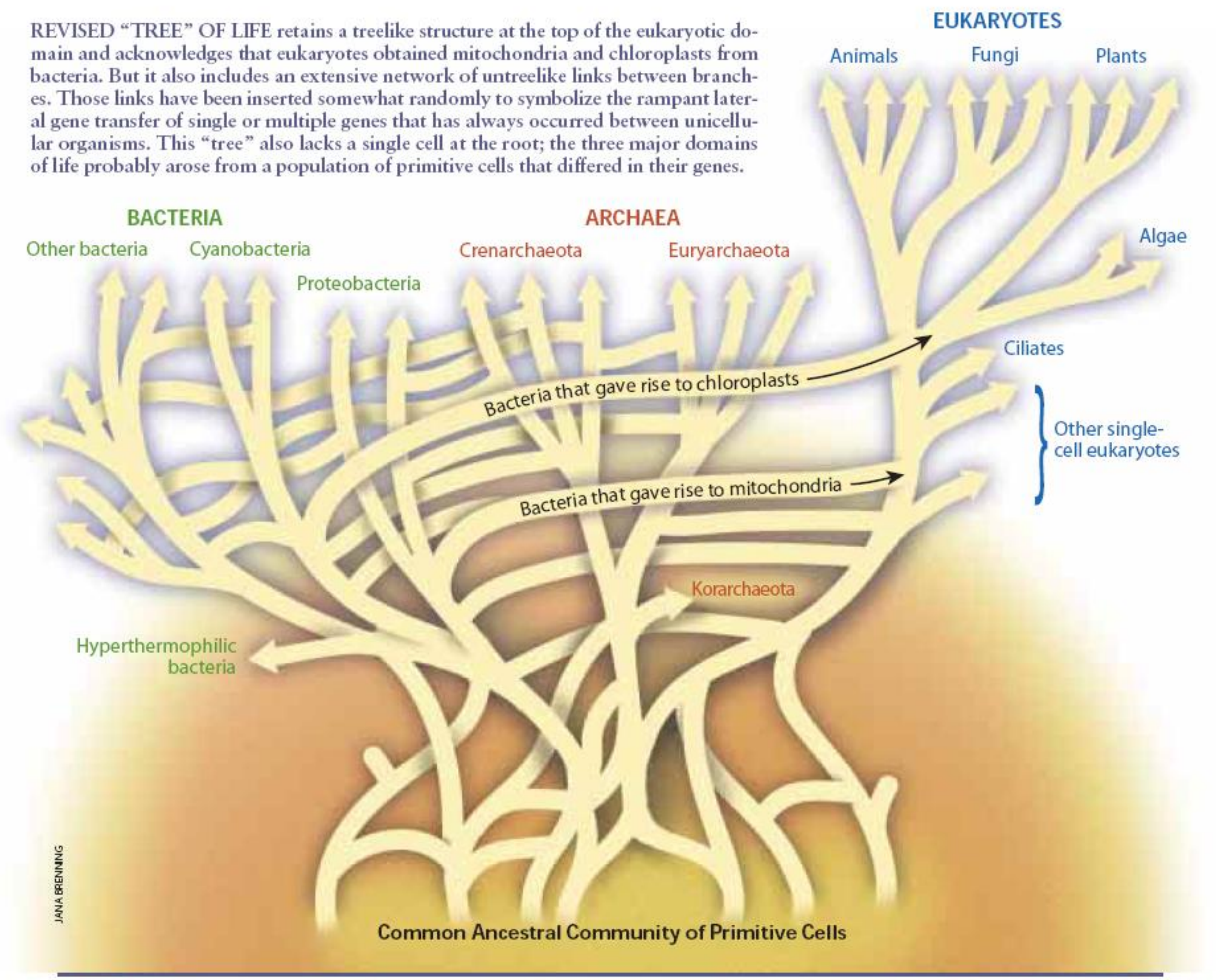
Winter

Invasion: Ex/ Kudzu

Invasion: Ex/ European Starlings

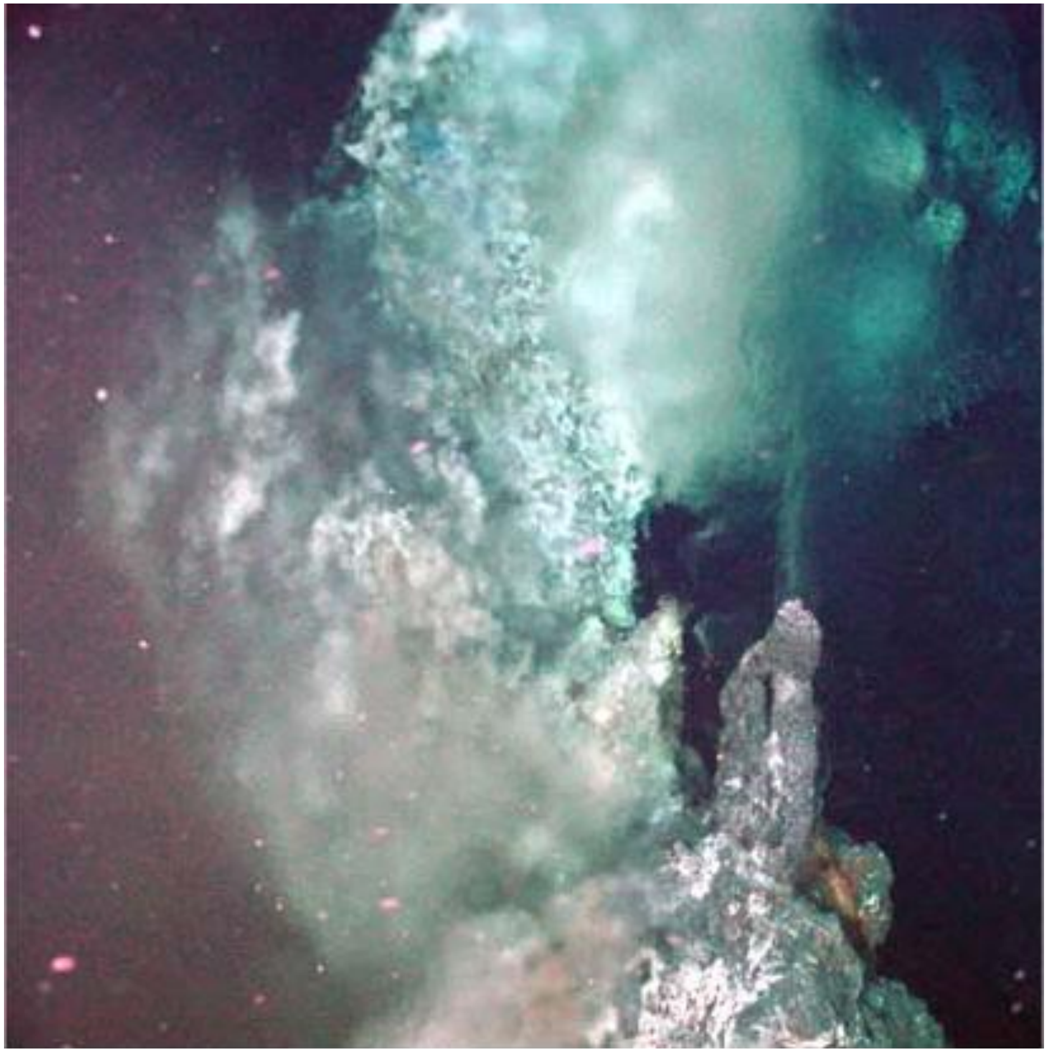
100 European Starlings brought to NY City in late 1800's. Now more than 200 million in North America.


BACTERIA
ARCHAEA
EUCARYA
Halobacterium
Methanospirillum
Methanosarcina
Thermoplasma
Methanobacterium
Methanothermus
Methanococcus
Thermococcus
Sulfolobus
Thermoproteus
Thermofilum
pSL50
Group 4
Group 3
pSL4
Group 2
pSL22
pSL12
Group 1
pJP27
pJP78
Marine mesophiles
Chromatium
E. coli
mitochondria
Agrobacterium
Chlorobium
Cytophaga
Bacillus
Clostridium
chloroplasts
Synechoccous
Thermus
Thermomicrobium
Thermotoga
Aquifex
EM17
OctSp92
OctSpA1-106
Root
0.1 changes per nucleotide
Tritrichomonas
Hexamita
Giardia
Vairimorpha
Encephalitozoon
Physarum
Trypanosoma
Euglena
Naegleria
Entamoeba
Dictyostelium
Chlamydomonas
Porphyra
Paramecium
Chlorella
Zea (Plants)
Homo (Animals)
Coprinus (Fungi)



REVISED "TREE" OF LIFE retains a treelike structure at the top of the eukaryotic domain and acknowledges that eukaryotes obtained mitochondria and chloroplasts from bacteria. But it also includes an extensive network of untreelike links between branches. Those links have been inserted somewhat randomly to symbolize the rampant lateral gene transfer of single or multiple genes that has always occurred between unicellular organisms. This "tree" also lacks a single cell at the root; the three major domains of life probably arose from a population of primitive cells that differed in their genes.

Where life may have started: Deep sea vents



The “Anthropic Principle,” or *Goldilocks Enigma*

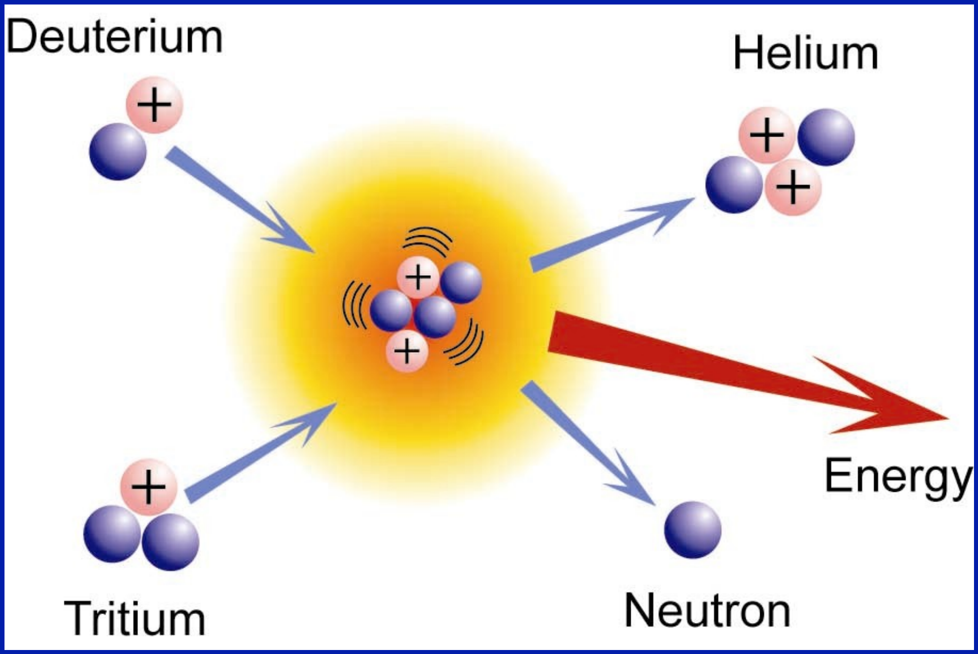
The very existence of stars and planets requires very narrow bounds on the fundamental laws of the Universe.

Four fundamental forces:

- **Gravity**
- **Electromagnetism**
- **Strong nuclear force**
- **Weak nuclear force**

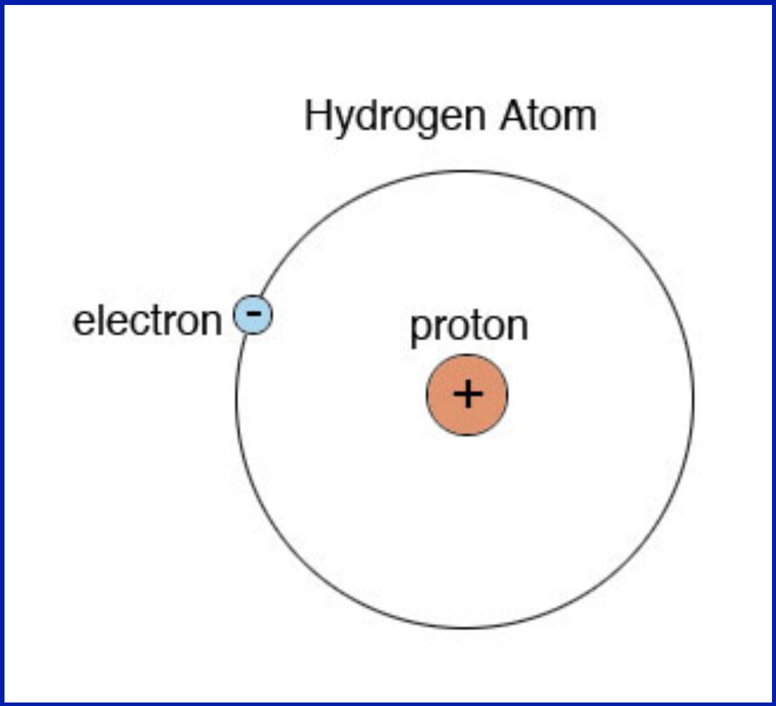
If Strong Nuclear Force slightly larger:

- All of the hydrogen in the universe would have converted to helium in the early universe
- No water!!
- No long-lived stars.



If Strong Nuclear Force slightly smaller:

- No elements greater than hydrogen.

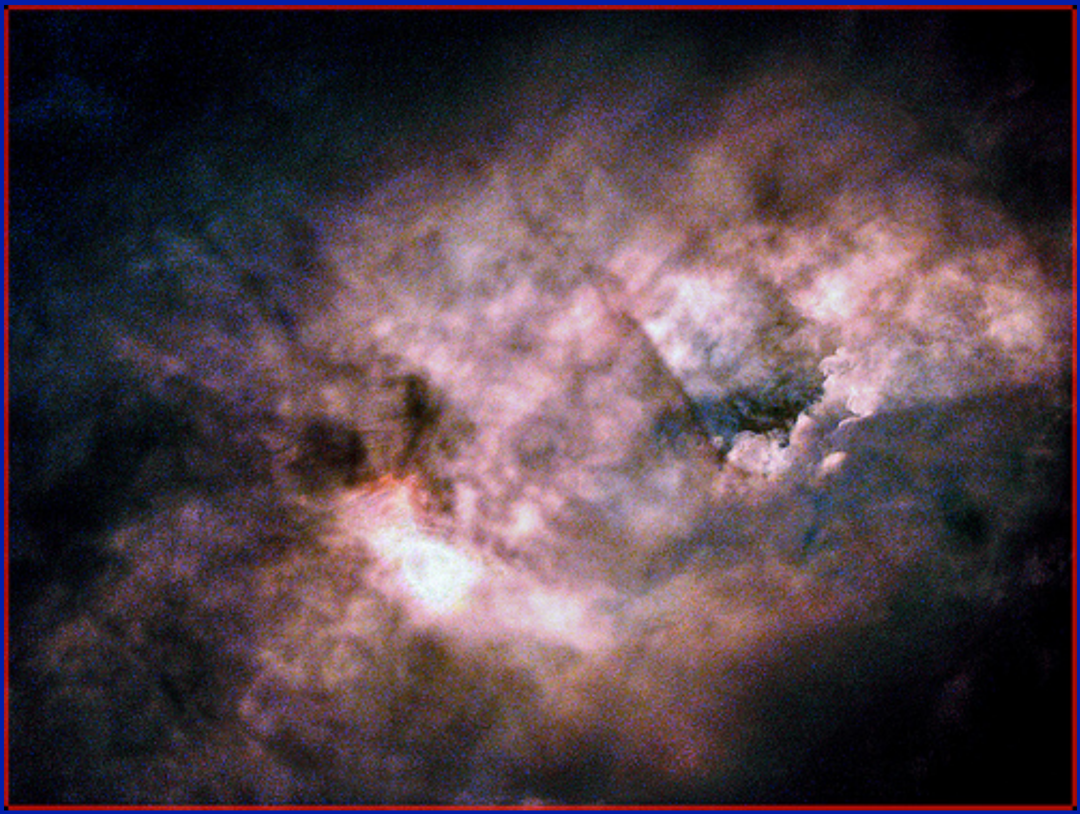


If Gravity slightly larger:

- Stars burn up fast.
- Tendency toward massive stars and black holes.

If Gravity slightly smaller:

- No stars or planets form.
- Universe is a diffuse cloud of hydrogen and helium.



Possible Solutions to the *Goldilocks Enigma*:

The Absurd Universe:

It just happens to turn out this way [by random chance].

The Unique Universe:

There is a deep underlying principle of physics that requires the universe to be this way.

Some “Theory of Everything” will explain why the various features of the Universe must have exactly the values that we see.

We just haven’t found it yet.

The Fake Universe:

We are living in a virtual reality simulation [as in the movie *The Matrix*].

The *real* world could have rules that are much simpler and more obvious.

The Designed Universe:

An intelligent Creator designed the Universe specifically to support complexity and the emergence of Intelligence.

The Multiverse:

Multiple Universes exist, maybe an infinite number.

They have all possible combinations of characteristics.

We, of course, find ourselves within the one that supports our existence.

- **Is an outcome of string theory**
- **Solves time-traveler paradox**

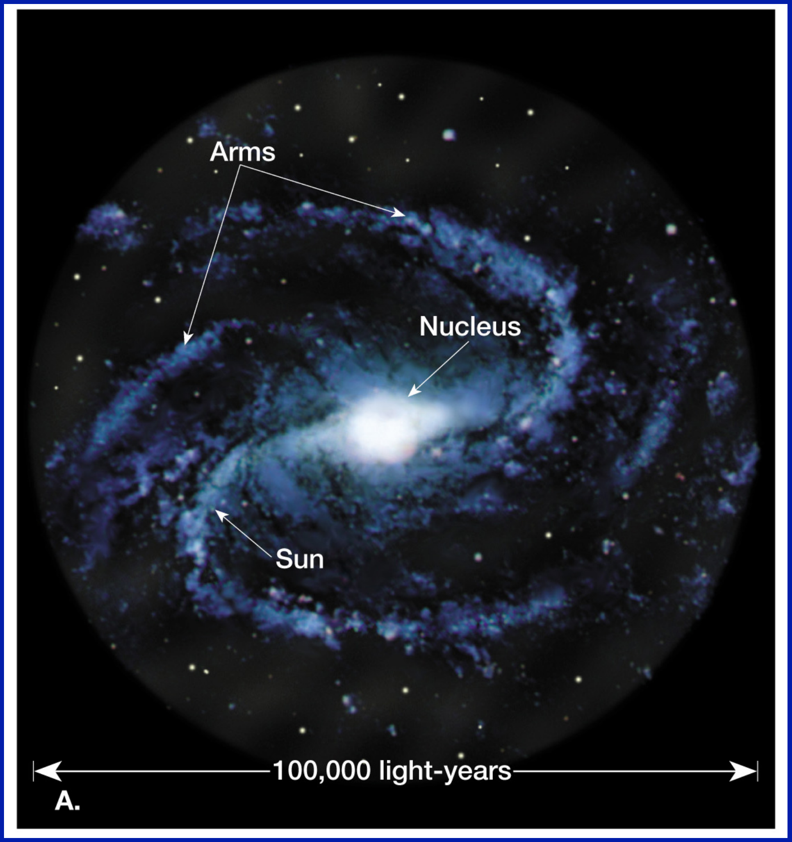
“Rare Earth” Situation:

Conditions required for intelligent life to evolve on a planet are exceedingly rare.

***Another* Goldilocks Enigma!**

We are at the right location in the right kind of galaxy:

About 5-10% of stars are in a narrow middle zone in spiral galaxies



Our Sun isn’t too small:

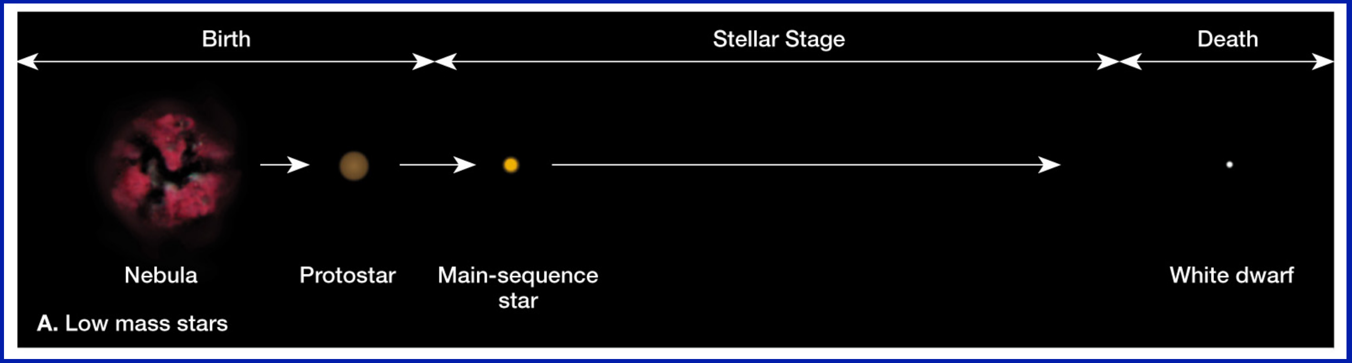
For small stars, the habitable zone is close to sun

*** Danger of solar flares**

*** Planets usually tidally locked (one side is burning, one side freezing)**

*** Small stars = ~90% of all stars**

Small Star



Our Sun isn't too large:

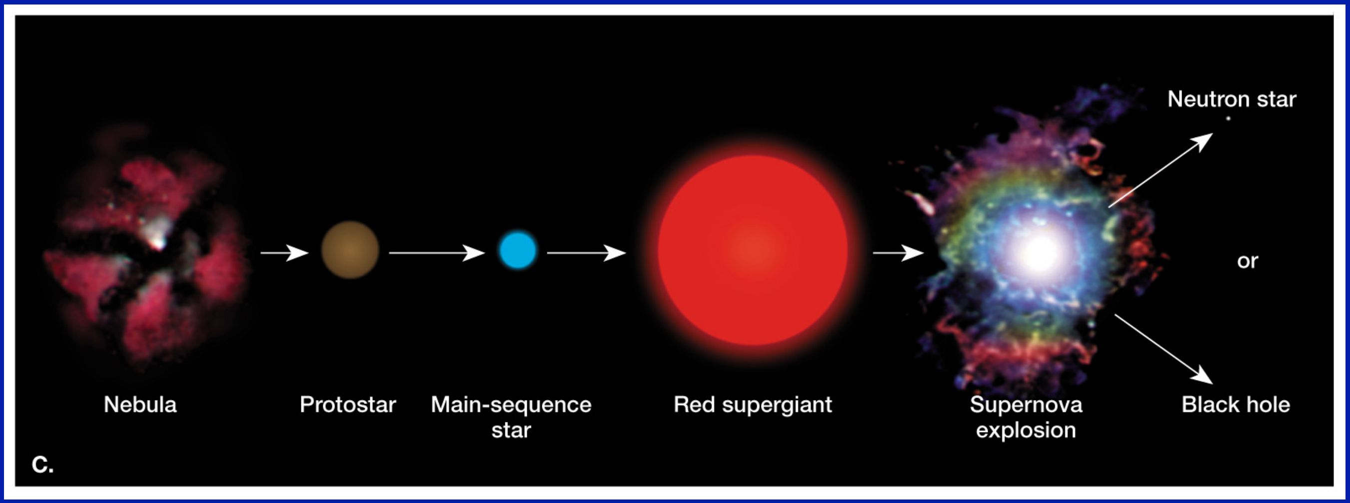
Large stars

* Burn out quickly

* Give off too much UV

* (Many stars have highly variable energy output --- changes habitable zone location!!)

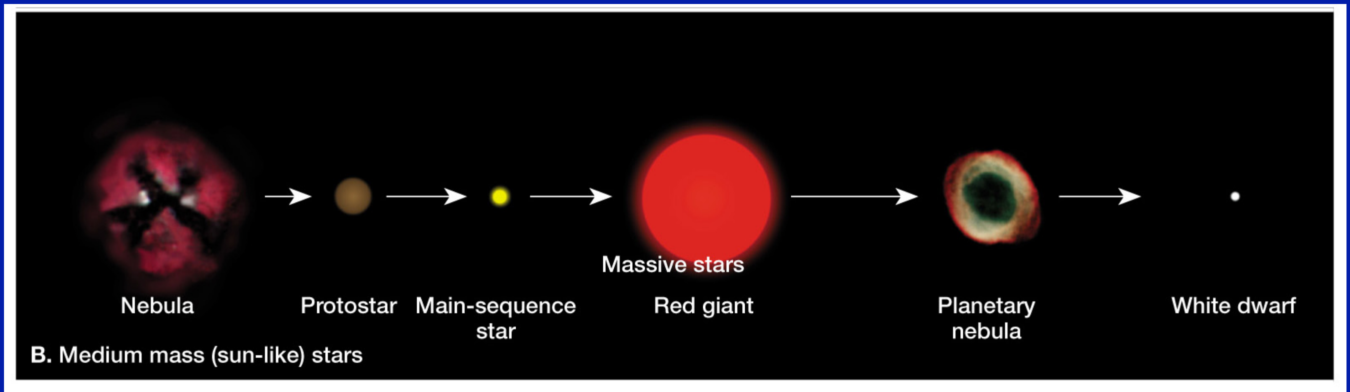
Massive Star



Our Sun is just the right size:

Stars like our sun = ~ 5% of stars

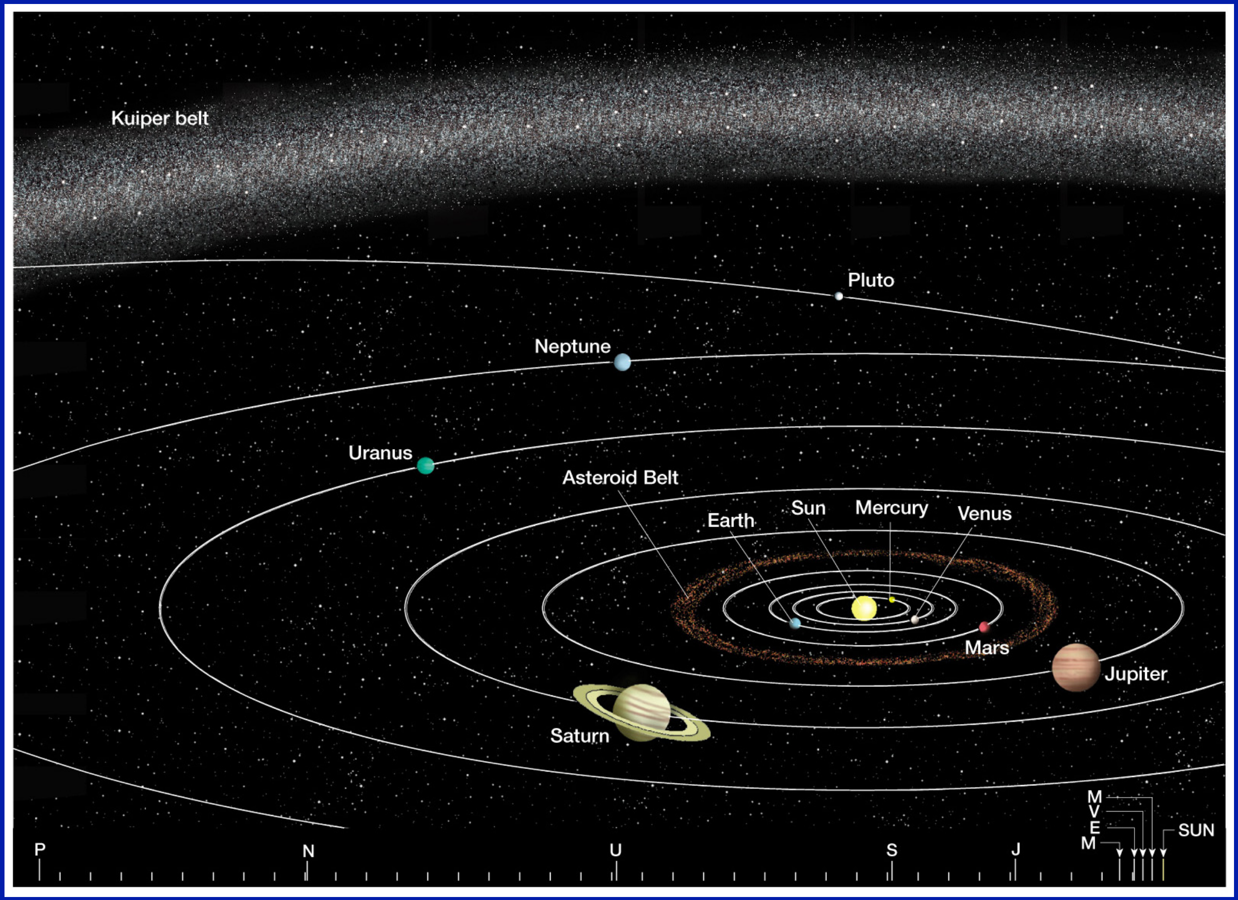
Medium-sized Star



We are the right distance from our Sun:

The Sun's habitable zone is 0.95 to 1.15 AU

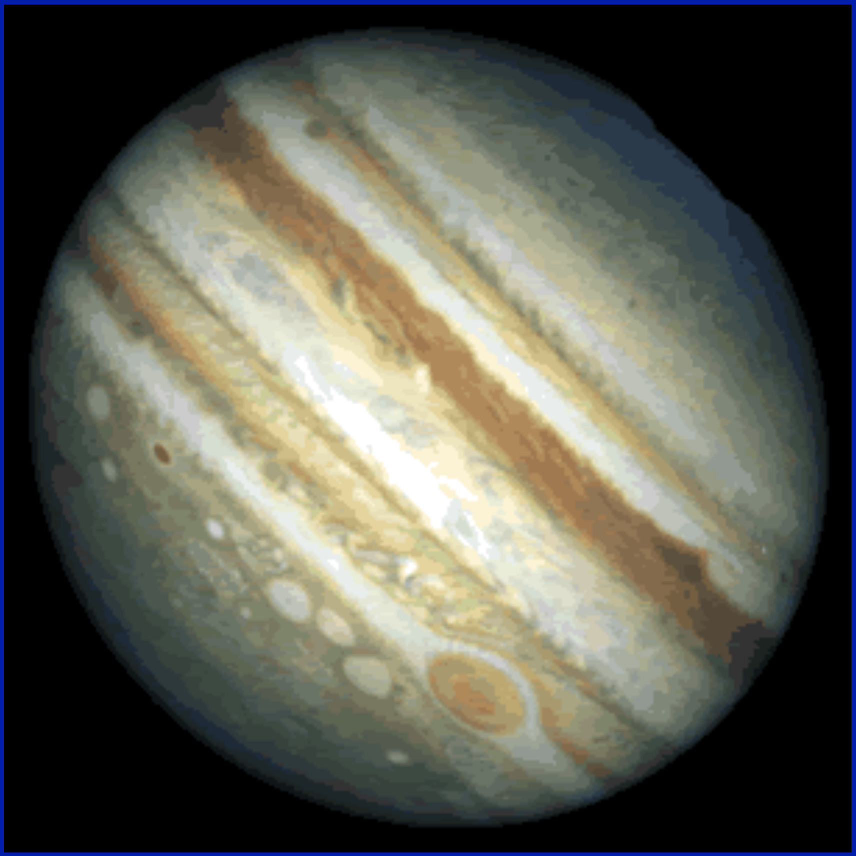
(5% closer than Earth to 15% farther)



Jupiter is (currently) just the right kind of shepherd:

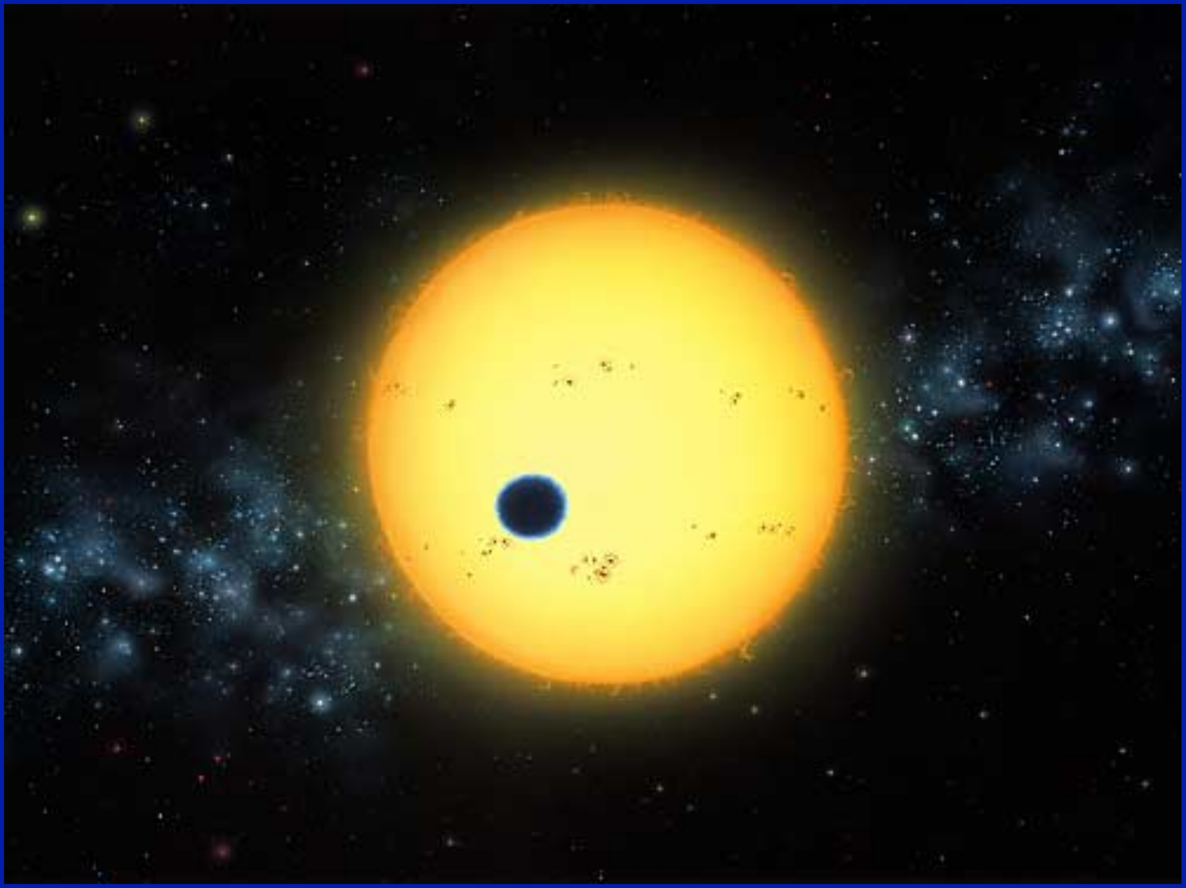
* Protects Earth from bombardment

* Not too big or orbit too elliptical



Jupiter is just the right kind of shepherd:

* Extrasolar "Jupiters" have been *bad* "Jupiters"



Earth is the right-sized planet:

* Too small, no atmosphere; too large --> all H&He

Earth is the right-sized planet:

Large planets:

*** Attract too many impactors**

*** Big "g" might level lands (single ocean would mean no land-feedback mechanism for regulating CO_2)**

Earth has the right composition:

Good balance of rock & metals & volatiles

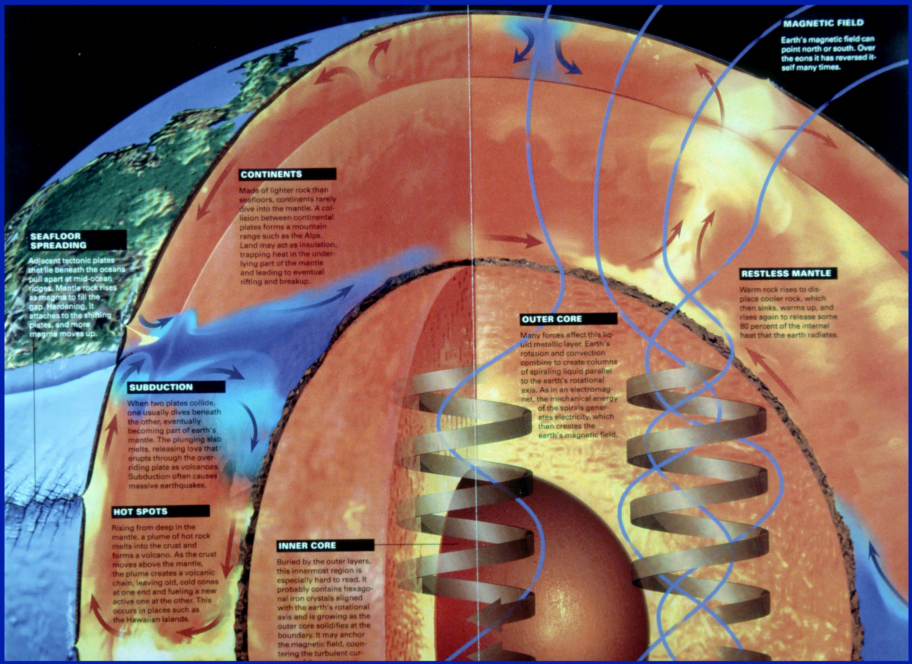
– life uses lots of different elements

Earth has the right composition:

Good good amount of radiogenic isotopes

*** Keeps Earth geologically alive, powers mantle convection, drives plate tectonics --> land, air, & water!**

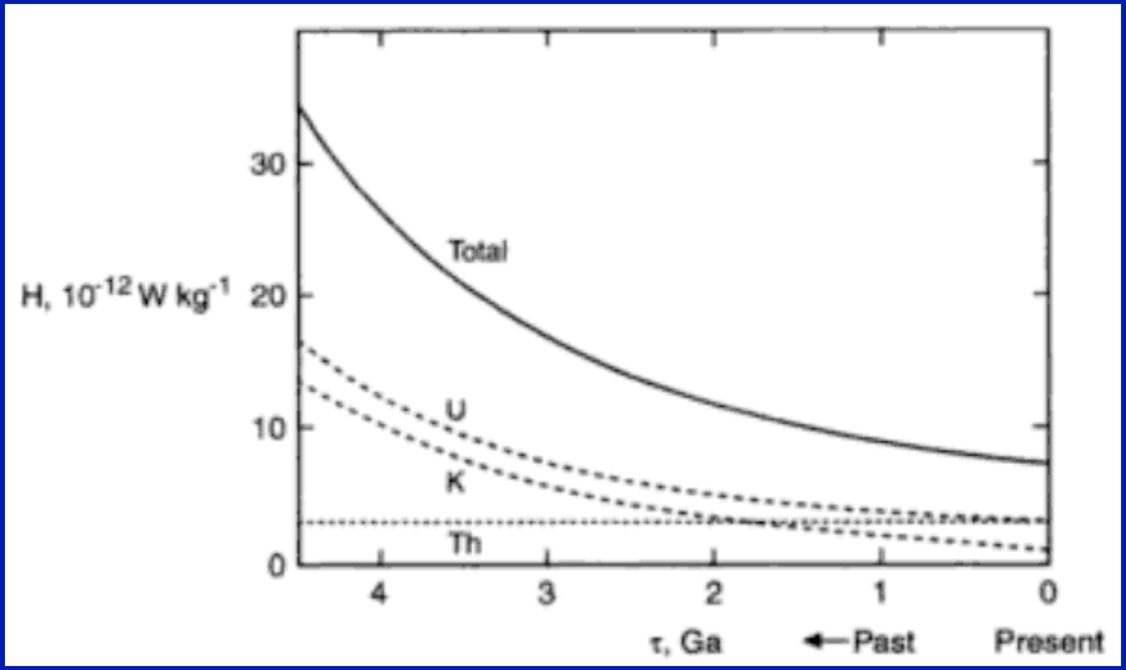
*** Creates many different ecological niches & microclimates --> promotes biodiversity!**



Earth has the right composition:

The Sun's EM output is increasing by 1% every 100 Ma (*Warming Earth*!)

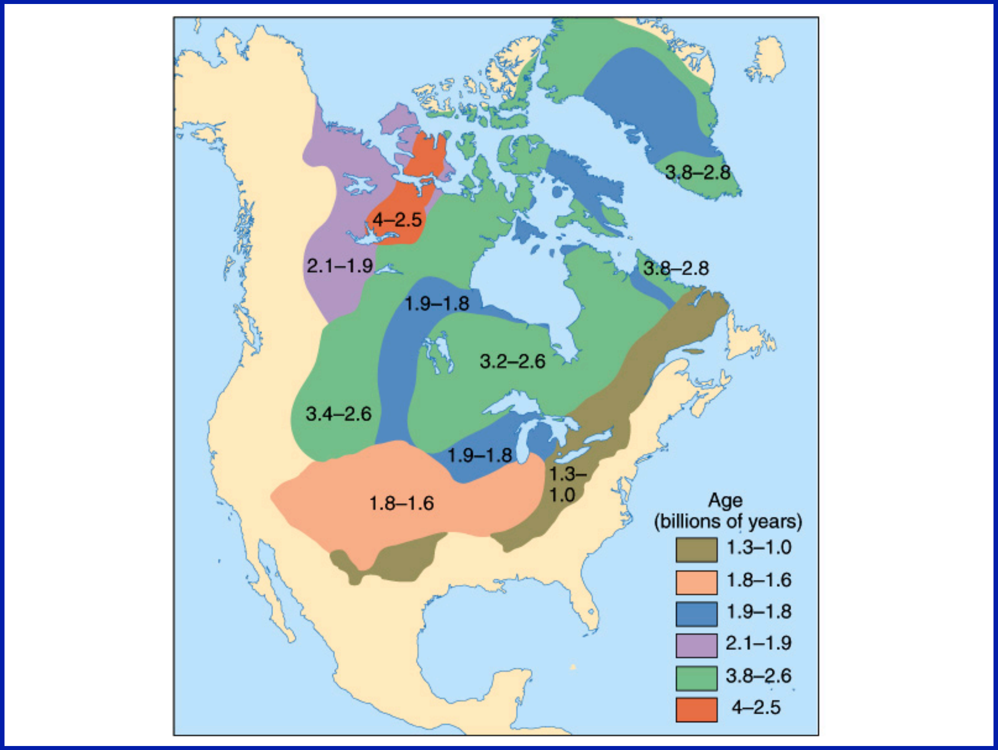
- ***But*, Earth's internal radiogenic heat production is decreasing over time! (*Cooling Earth*!)**



Earth has the right kind of plate tectonics:

The Sun's EM output is increasing by 1% every 100 Ma (*Warming Earth*!)

- ***But*, the size of continents has increased over time, replacing ocean with land (*Cooling Earth*!)**



Earth has a nearly circular orbit:

Keeps it in the habitable zone with liquid water

*** Ocean absorbs CO_2, prevents runaway Greenhouse**

Earth has a large Moon:

Moon acts like a large gyroscope

*** minimizes changes in tilt of Earth's axis**

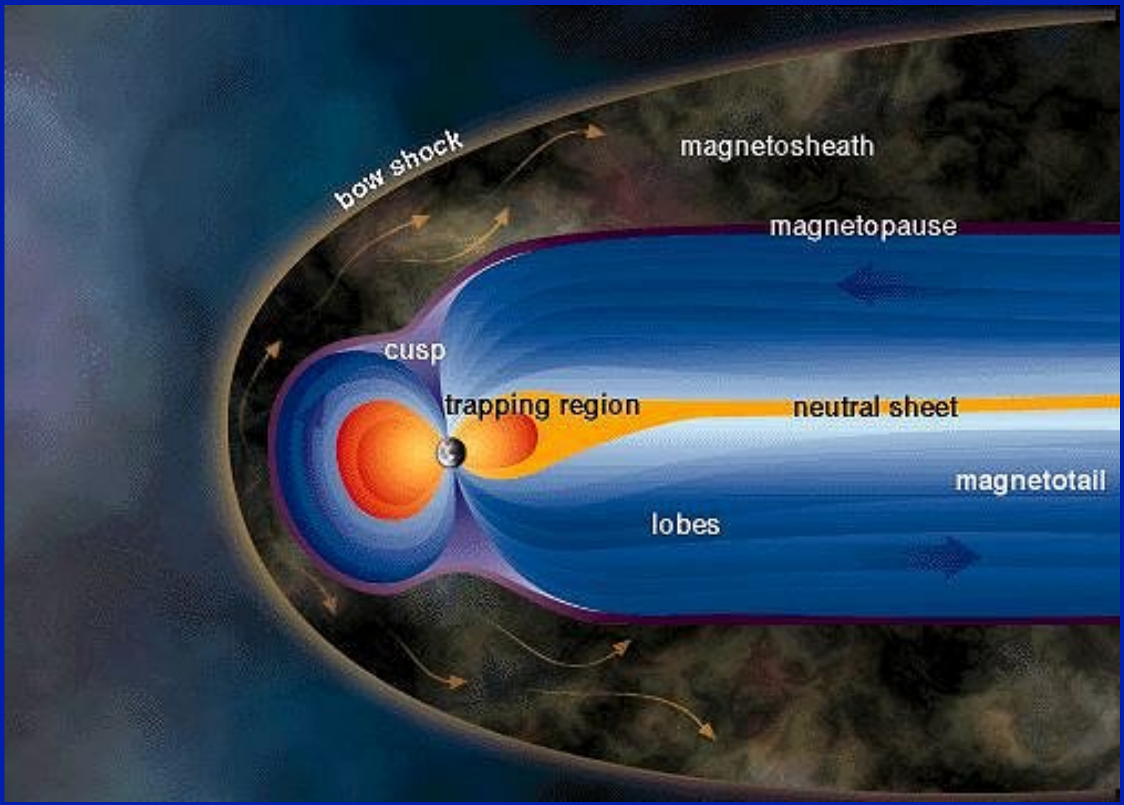
-- maintains climate stability

*** Milankovitch cycles are small compared to other planets**

Earth has a large Moon:

Protomoon impact gave Earth its large iron core

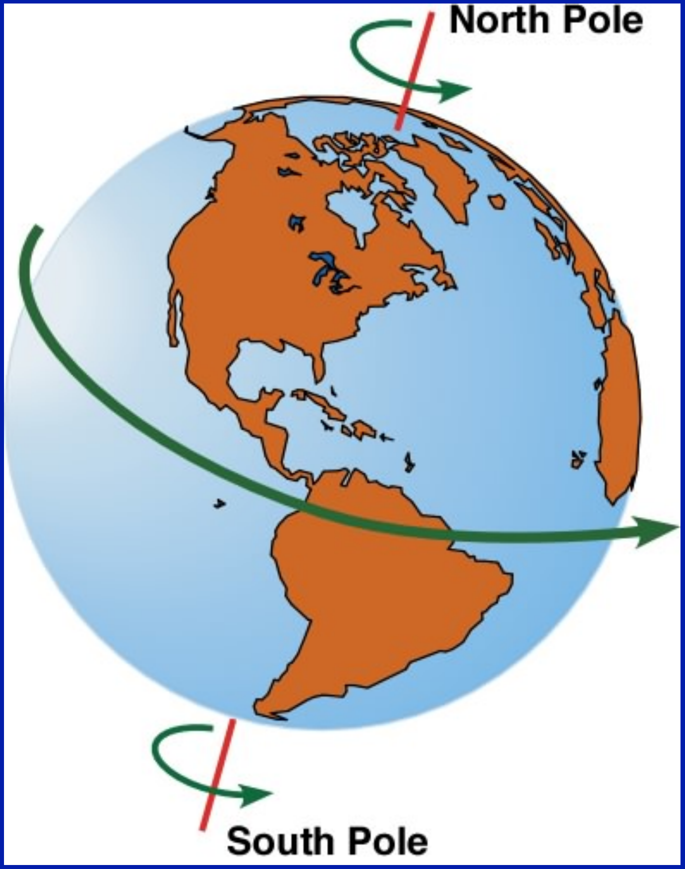
*** Large, strong geodynamo produces large magnetic field**
-- protective magnetosphere!



Earth has a fast rotation:

* Keeps day/night ΔT small

* Helps power magnetogeodynamo



This was not always viewed to be the case:

Frank Drake; Carl Sagan; SETI

Drake Equation: N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable “suns” for planetary systems	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable "suns" for planetary systems	
fp	Fraction of suitable suns with planetary systems	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable “suns” for planetary systems	
fp	Fraction of suitable suns with planetary systems	
ne	Number of planets in the Continuously Habitable Zone	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable "suns" for planetary systems	
fp	Fraction of suitable suns with planetary systems	
ne	Number of planets in the Continuously Habitable Zone	
fl	Fraction of these planets on which life actually originates	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

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R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable “suns” for planetary systems	
fp	Fraction of suitable suns with planetary systems	
ne	Number of planets in the Continuously Habitable Zone	
fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	

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fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

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fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
L	Average of mean lifetime (in years) of a communicative civilization	

Drake Equation: **$N = (R^*)(f_s)(f_p)(n_e)(f_l)(f_i)(f_c)(L)$**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	
fs	Fraction of stars that are suitable "suns" for planetary systems	
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L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable “suns” for planetary systems	
fp	Fraction of suitable suns with planetary systems	
ne	Number of planets in the Continuously Habitable Zone	
fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable "suns" for planetary systems	1/20
fp	Fraction of suitable suns with planetary systems	
ne	Number of planets in the Continuously Habitable Zone	
fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable "suns" for planetary systems	1/20
fp	Fraction of suitable suns with planetary systems	2/3
ne	Number of planets in the Continuously Habitable Zone	
fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: **$N = (R^*) (f_s) (f_p) (n_e) (f_l) (f_i) (f_c) (L)$**

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NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable "suns" for planetary systems	1/20
fp	Fraction of suitable suns with planetary systems	2/3
ne	Number of planets in the Continuously Habitable Zone	1/100
fl	Fraction of these planets on which life actually originates	
fi	Fraction of these planets on which life becomes intelligent	
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
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fi	Fraction of these planets on which life becomes intelligent	
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R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable “suns” for planetary systems	1/20
fp	Fraction of suitable suns with planetary systems	2/3
ne	Number of planets in the Continuously Habitable Zone	1/100
fl	Fraction of these planets on which life actually originates	1/10
fi	Fraction of these planets on which life becomes intelligent	1/1000
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	
L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

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fp	Fraction of suitable suns with planetary systems	2/3
ne	Number of planets in the Continuously Habitable Zone	1/100
fl	Fraction of these planets on which life actually originates	1/10
fi	Fraction of these planets on which life becomes intelligent	1/1000
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	1/2
L	Average of mean lifetime (in years) of a communicative civilization	
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: **$N = (R^*) (fs) (fp) (ne) (fl) (fi) (fc) (L)$**

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R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable “suns” for planetary systems	1/20
fp	Fraction of suitable suns with planetary systems	2/3
ne	Number of planets in the Continuously Habitable Zone	1/100
fl	Fraction of these planets on which life actually originates	1/10
fi	Fraction of these planets on which life becomes intelligent	1/1000
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	1/2
L	Average of mean lifetime (in years) of a communicative civilization	10,000,000
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	

Drake Equation: **N = (R*) (fs) (fp) (ne) (fl) (fi) (fc) (L)**

(Finds the number of intelligent civilizations able and willing to communicate with us within our galaxy)

NAME	DESCRIPTION	Estimate
R*	Average rate of star formation (per year)	6
fs	Fraction of stars that are suitable "suns" for planetary systems	1/20
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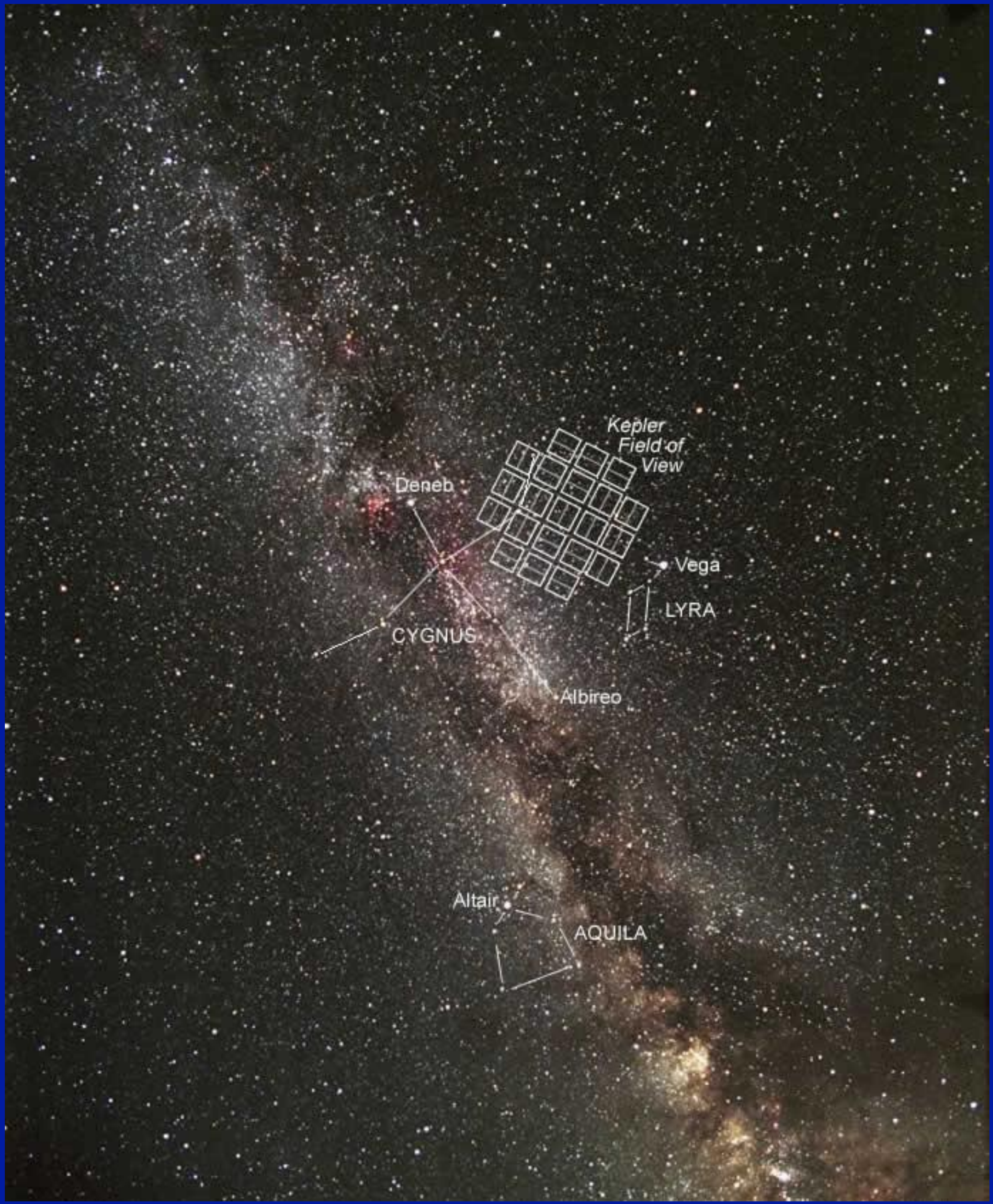
ne	Number of planets in the Continuously Habitable Zone	1/100
fl	Fraction of these planets on which life actually originates	1/10
fi	Fraction of these planets on which life becomes intelligent	1/1000
fc	Fraction of intelligent species of these planets that develop a desire to communicate with others	1/2
L	Average of mean lifetime (in years) of a communicative civilization	10,000,000
N	Number of intelligent civilizations within our galaxy able to and interested in communicating	**1 (Us!)**

NASA Kepler: Field of View

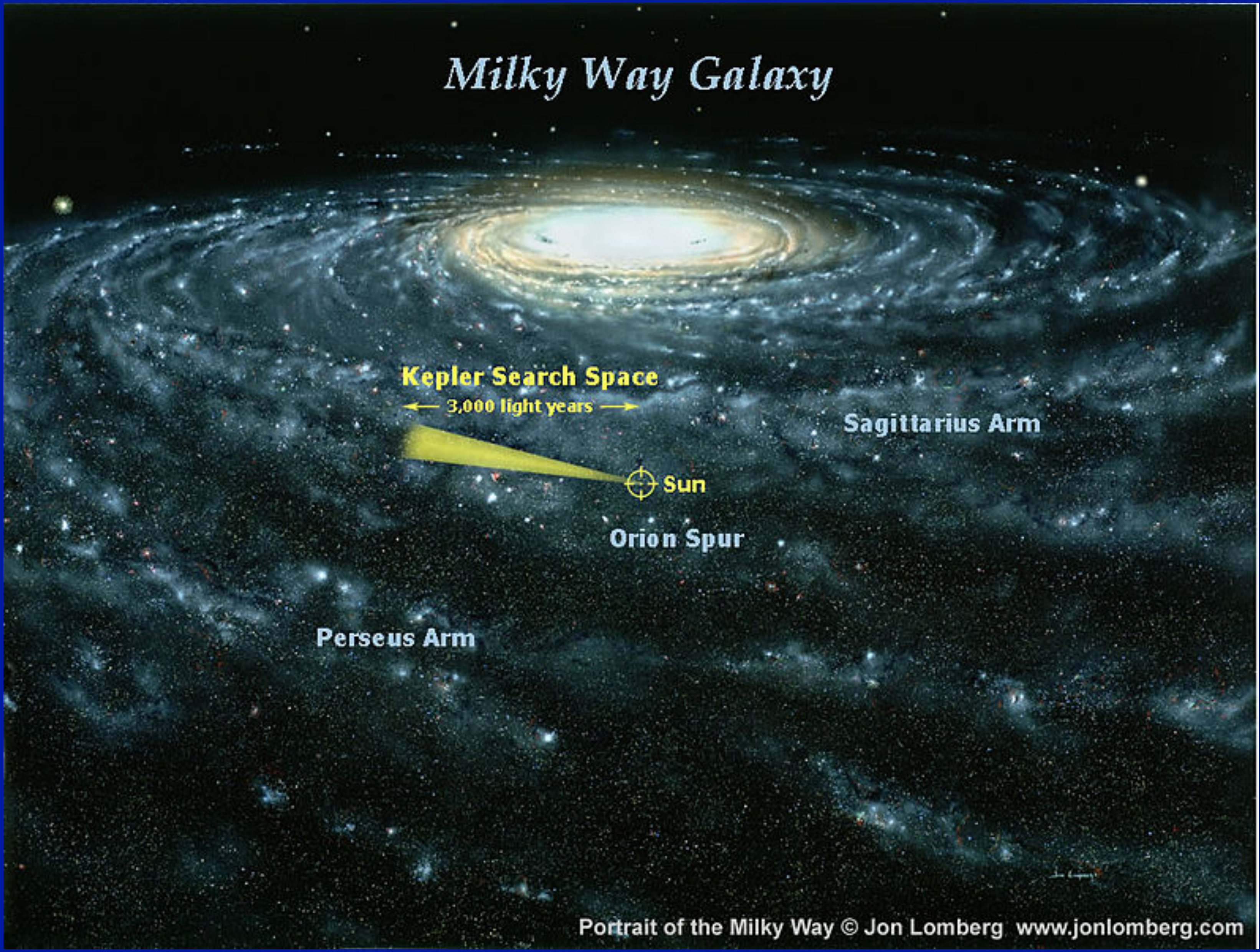
Feb, 2011: 1235 Planetary Candidates

68 were Earth-sized

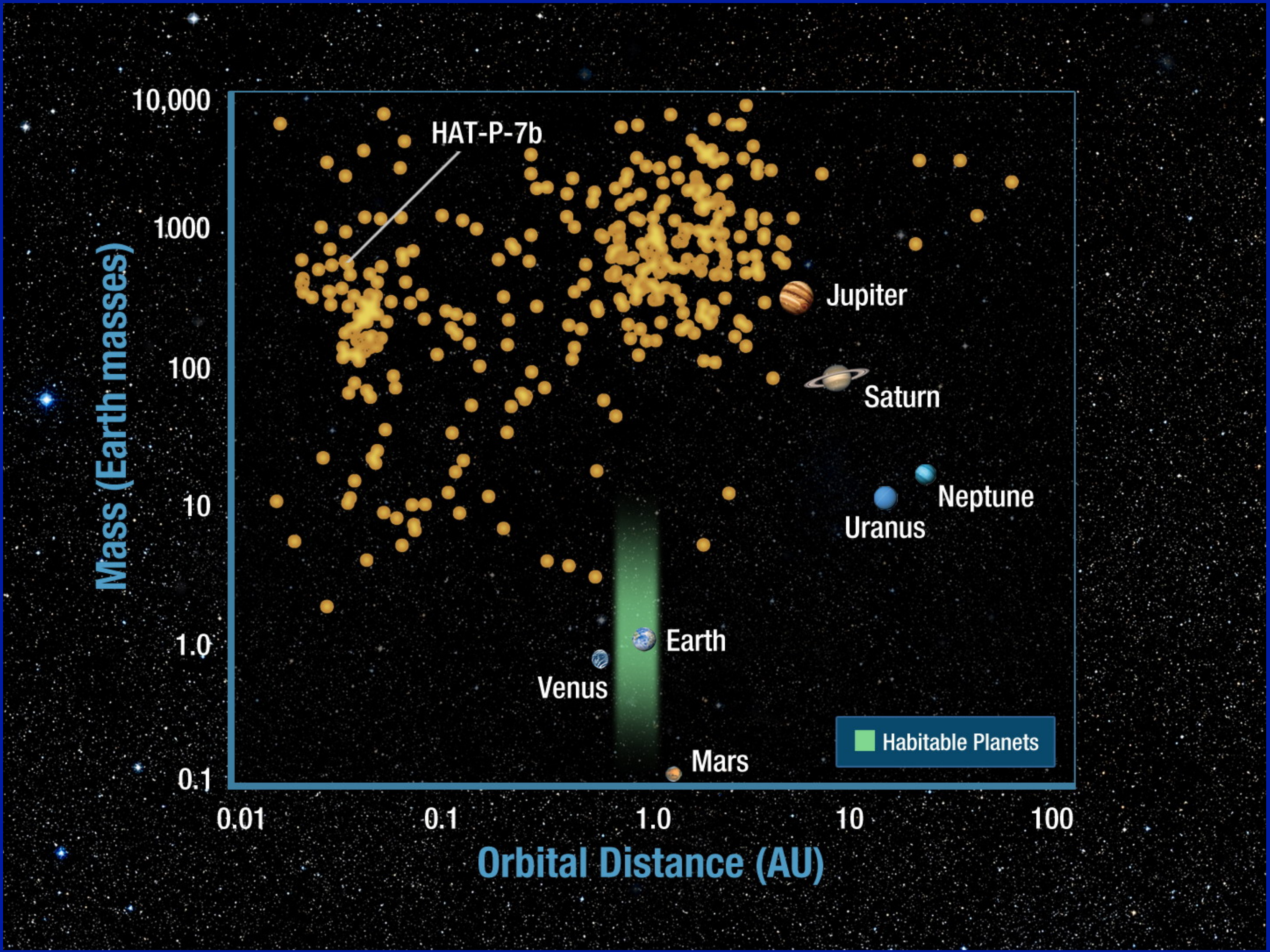
54 estimated to be within the habitable zone



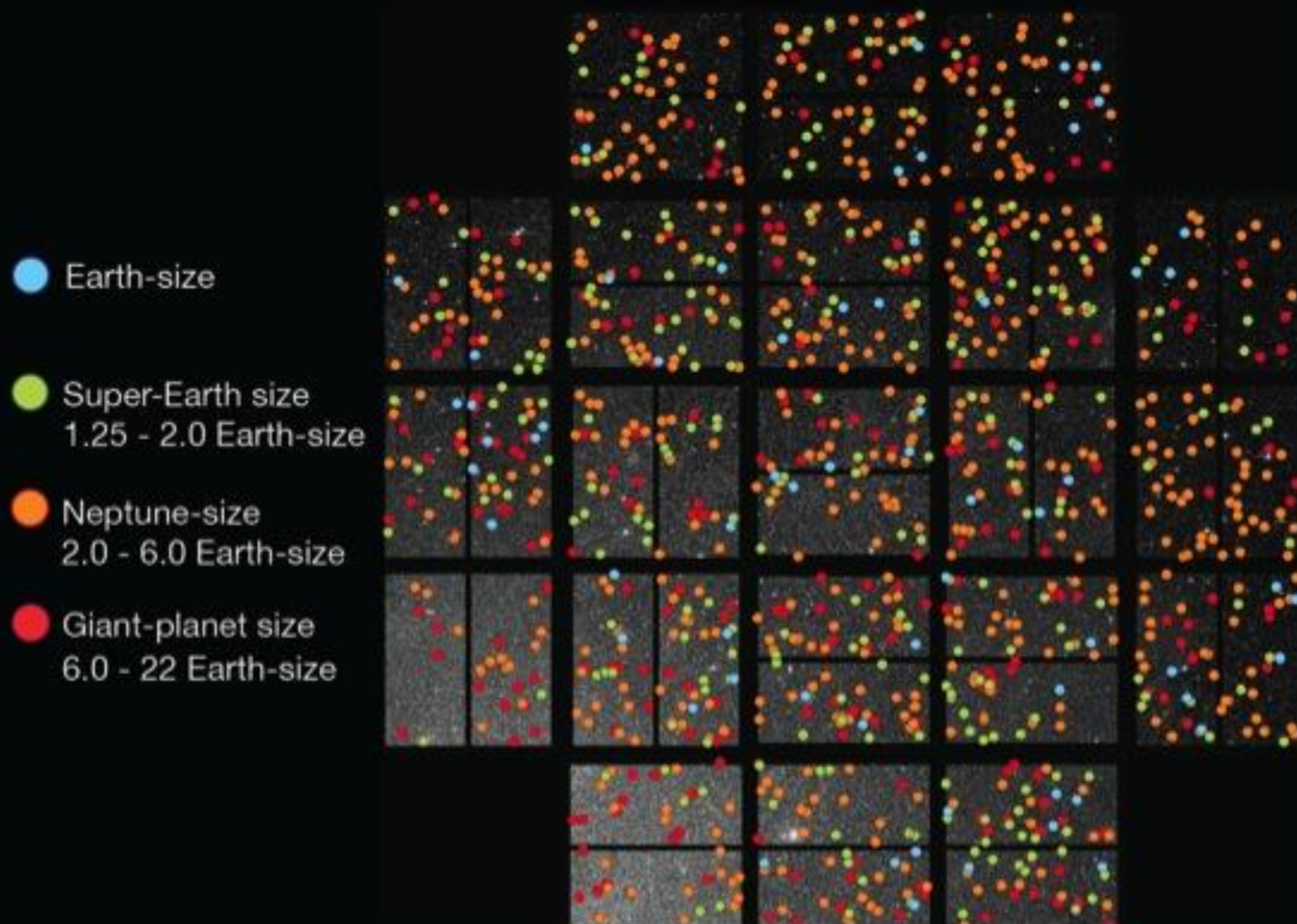
NASA Kepler: Location of View



Exoplanets Before NASA-Kepler



Locations of Kepler Planet Candidates



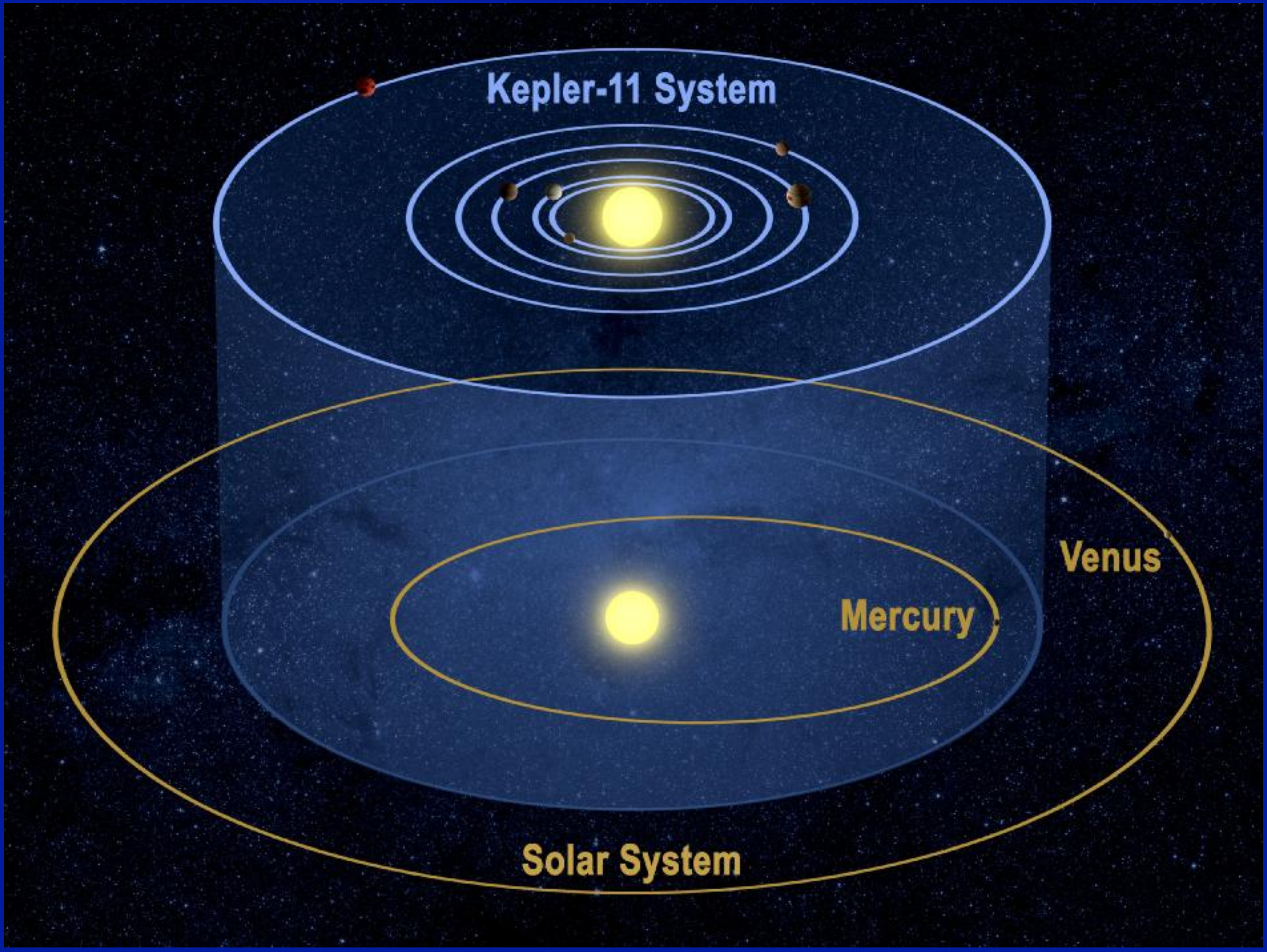
One NASA estimate: "within a thousand light-years of Earth," there are "at least 30,000” habitable planets.

Kepler team has estimated that there are "at least 50 billion planets in the Milky Way", of which "at least 500 million" are in the habitable zone.

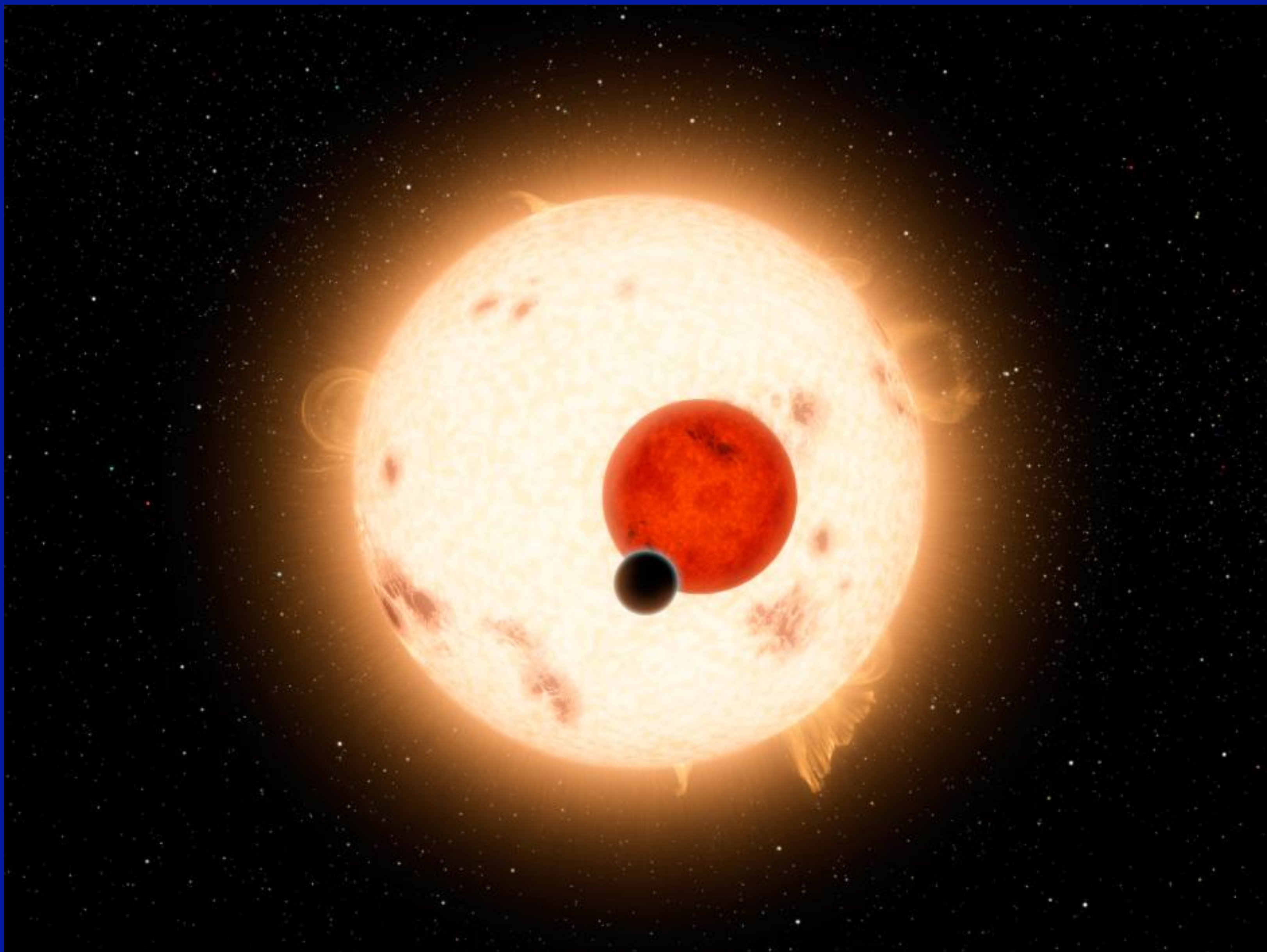
Astronomers at JPL reported that about "1.4 to 2.7%" of all sunlike stars are expected to have earthlike planets "within the habitable zones of their stars".

This means there are "two billion" of these "Earth analogs" in our own Milky Way galaxy alone.

NASA-Kepler: Kepler-11 Planetary System



Kepler 16-B: A planet orbiting two dwarf stars



Planet Tatooine (*Star Wars*)

Arthur Clarke: “Sometimes I think we’re alone in the universe, and sometimes I think we’re not. In either case, the idea is quite staggering.”

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Fermi’s Paradox: “Where is everybody?”

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Maybe these civilizations *have* tried to contact us, but we don’t recognize the signs?

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Maybe --- they're not there?