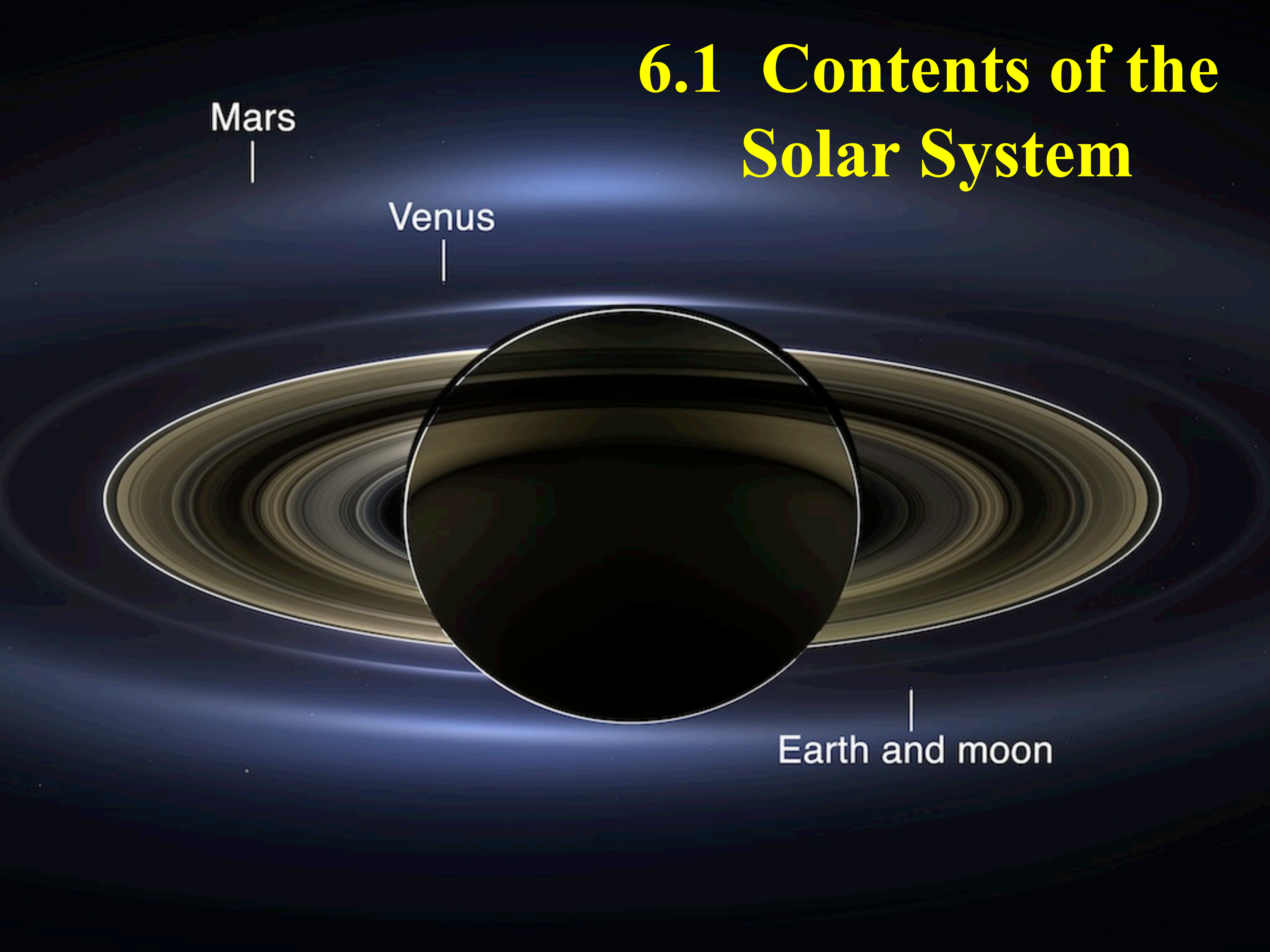
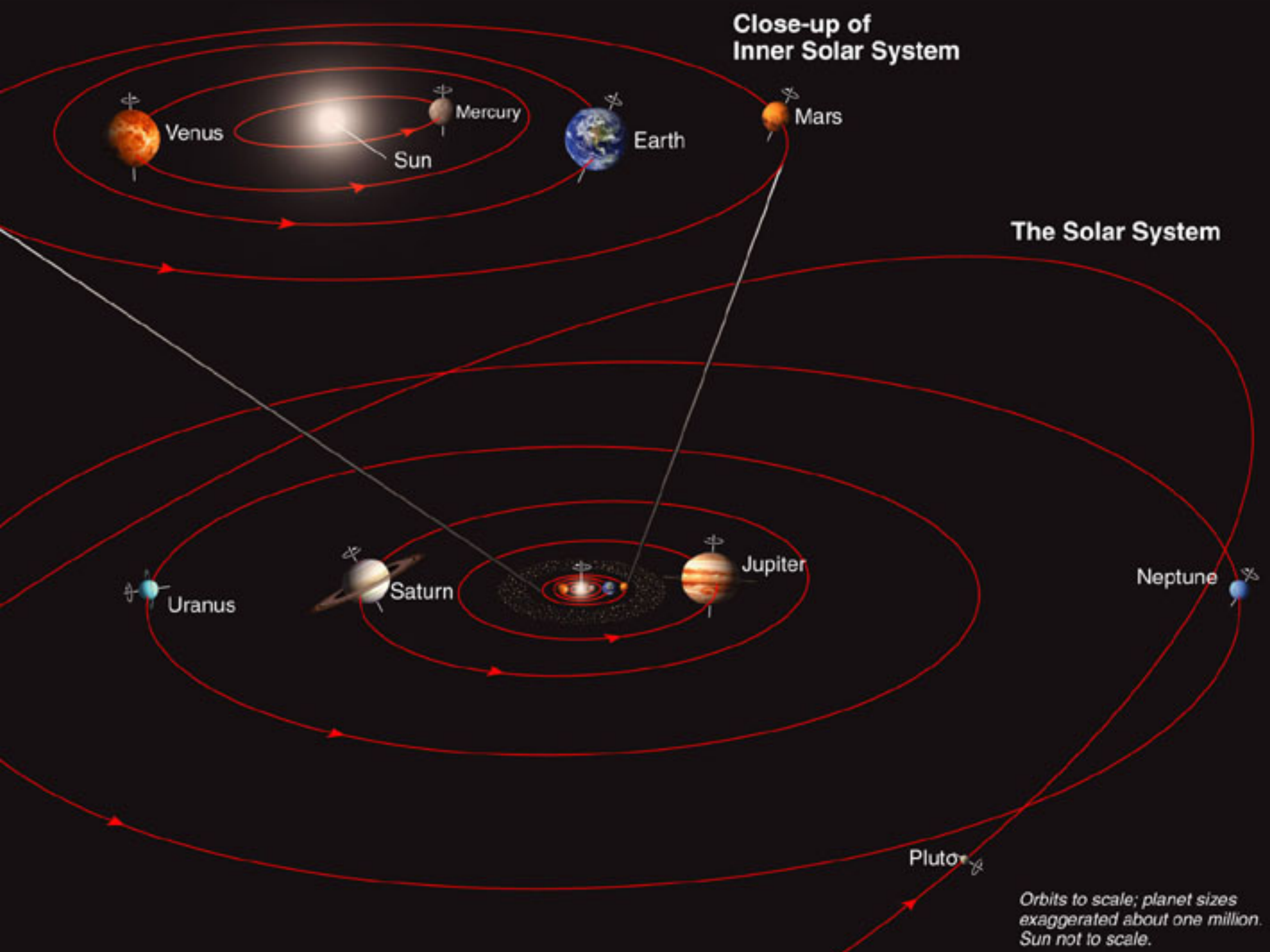

Ay 1 – Lecture 6
Other Worlds:
Our Solar System
and the Others

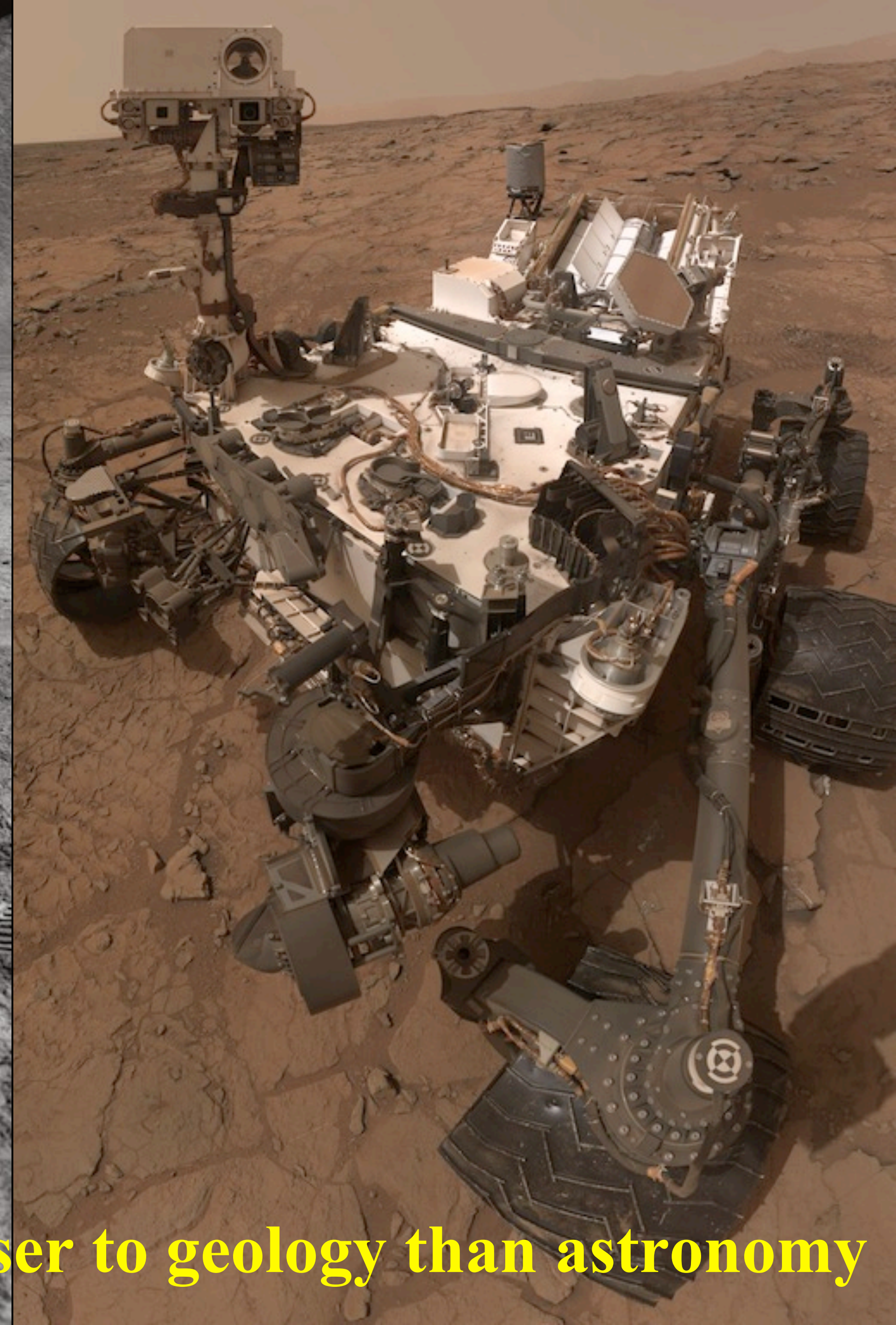
6.1 Contents of the Solar System




Close-up of
Inner Solar System
Venus
Mercury
Sun
Earth
Mars
The Solar System
Uranus
Saturn
Jupiter
Neptune
Pluto
Orbits to scale; planet sizes
exaggerated about one million.
Sun not to scale.

Planetary Demographics

Name	Distance from Sun (AU)[2]	Revolution Period (y)	Diameter (km)	Mass (10^{23} kg)	Density (g/cm^3)[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7
Uranus	19.18	84.07	51,118	866	1.3
Neptune	30.06	164.82	49,660	1030	1.6

Planetary Science: closer to geology than astronomy

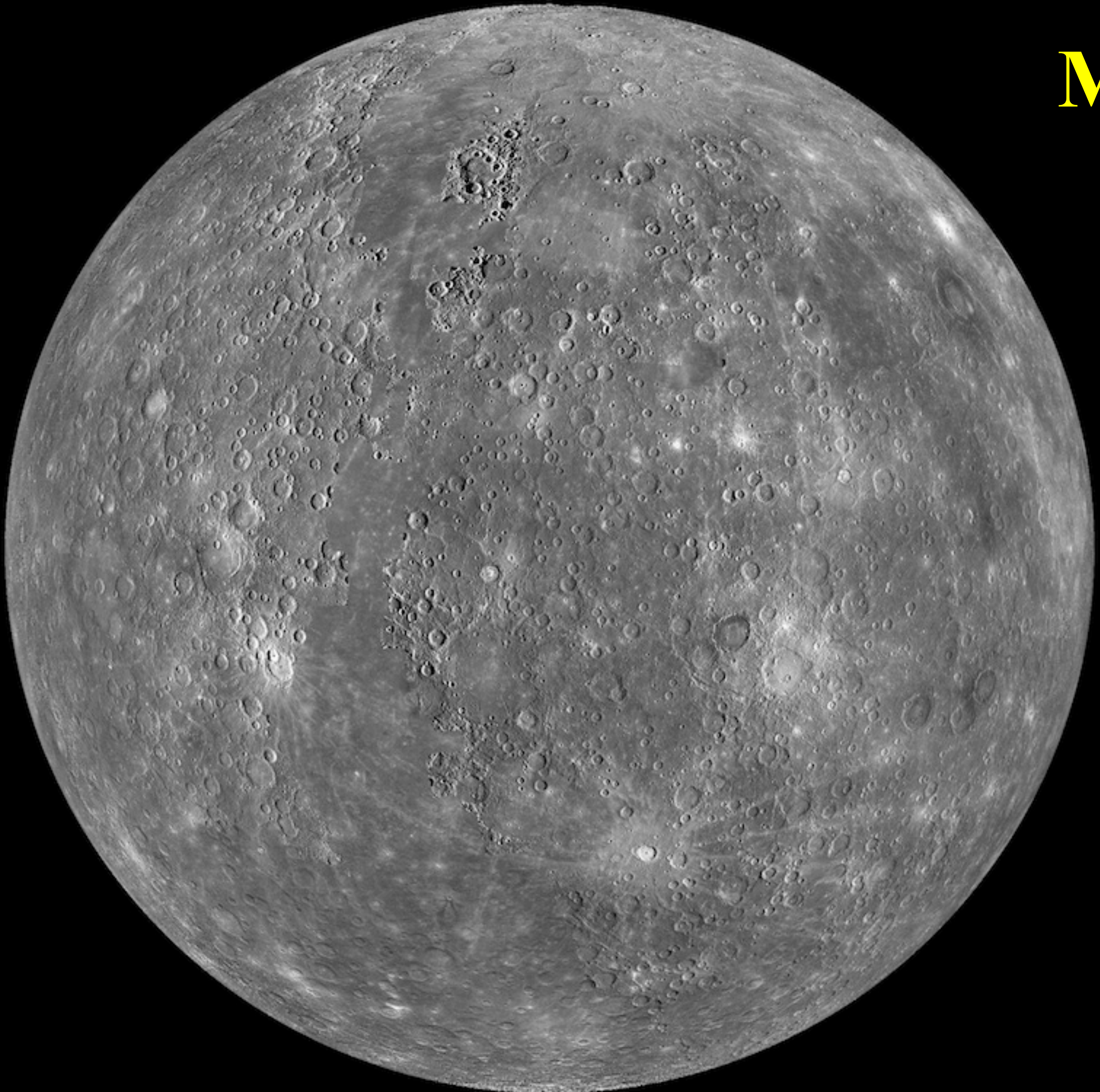
Three Kinds of Planets

- Rocky: inner Solar system, smaller, high density, composed of heavier elements
  - Mercury, Venus, Earth, Mars

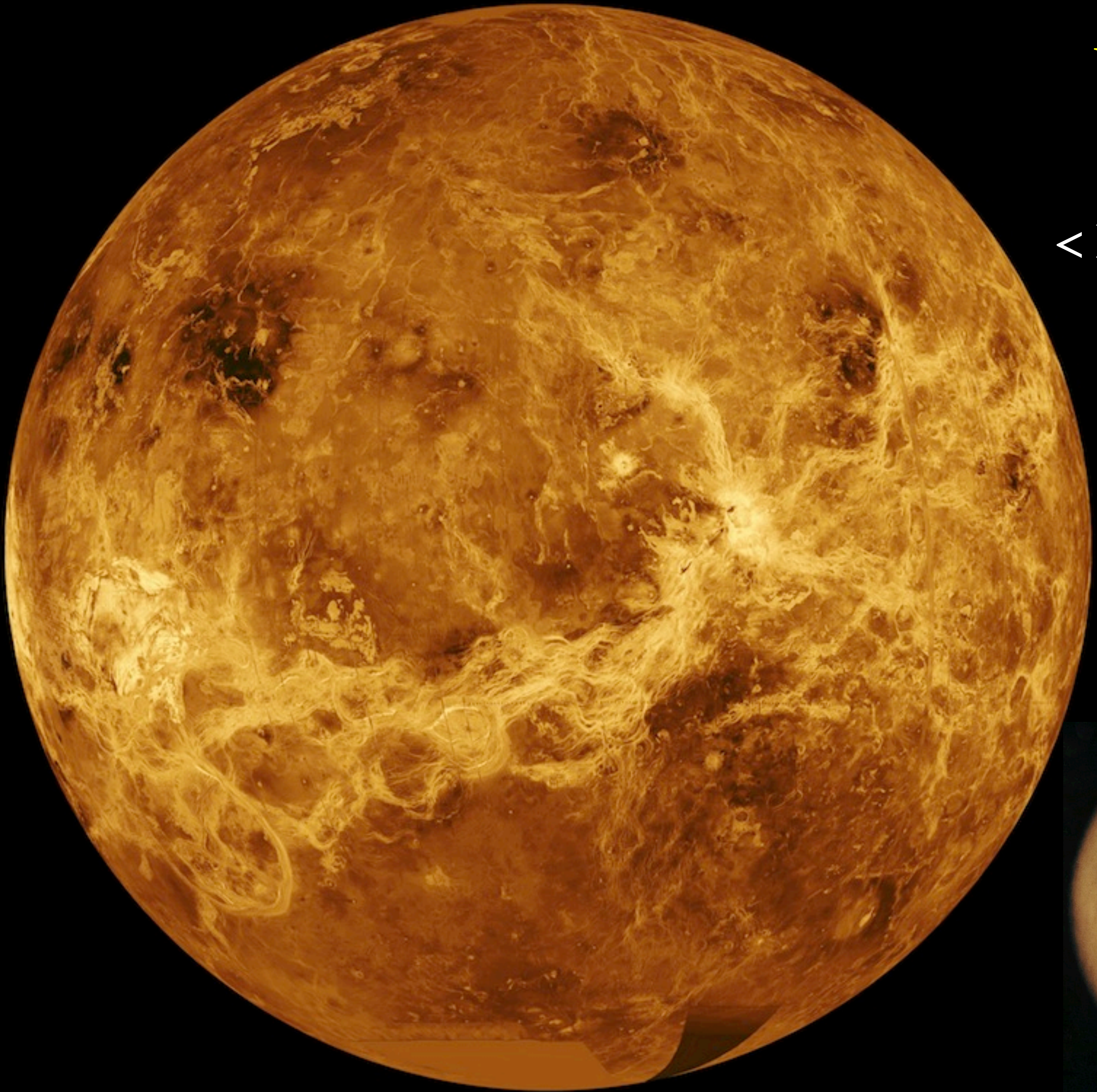
- Gas giants: Outer Solar system, large, massive, lower densities, lighter elements are abundant
  - Jupiter, Saturn, Uranus, Neptune

- Dwarf planets: Very Outer Solar system, low mass, small, icy
  - Pluto, Sedna, Eris, Makemake, Ceres, etc.

Mercury

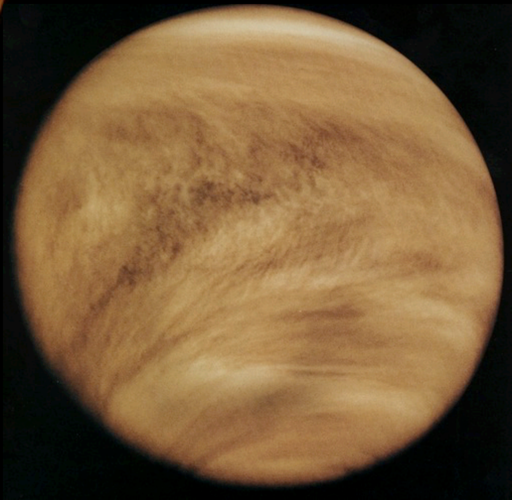


Venus

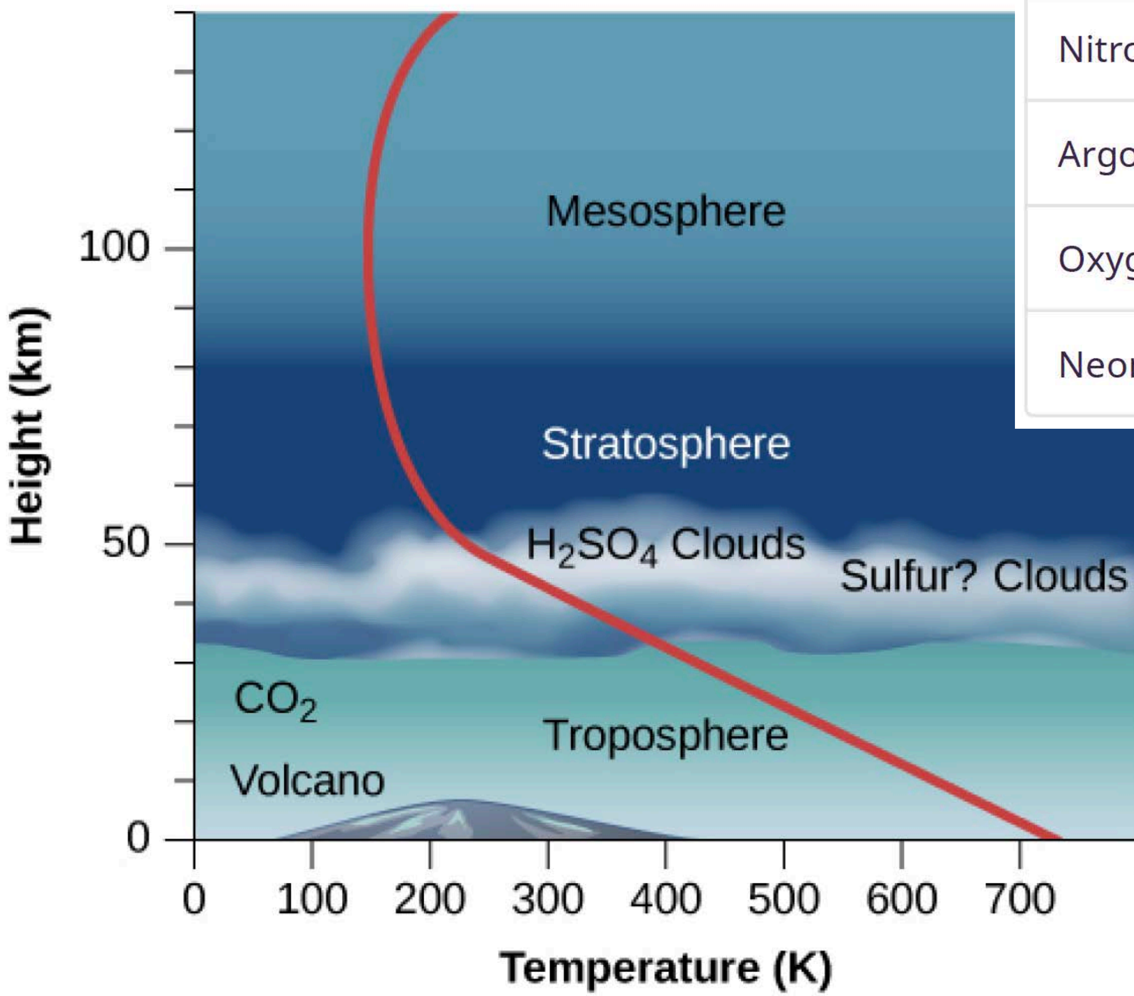


< Magellan Radar

Pioneer UV



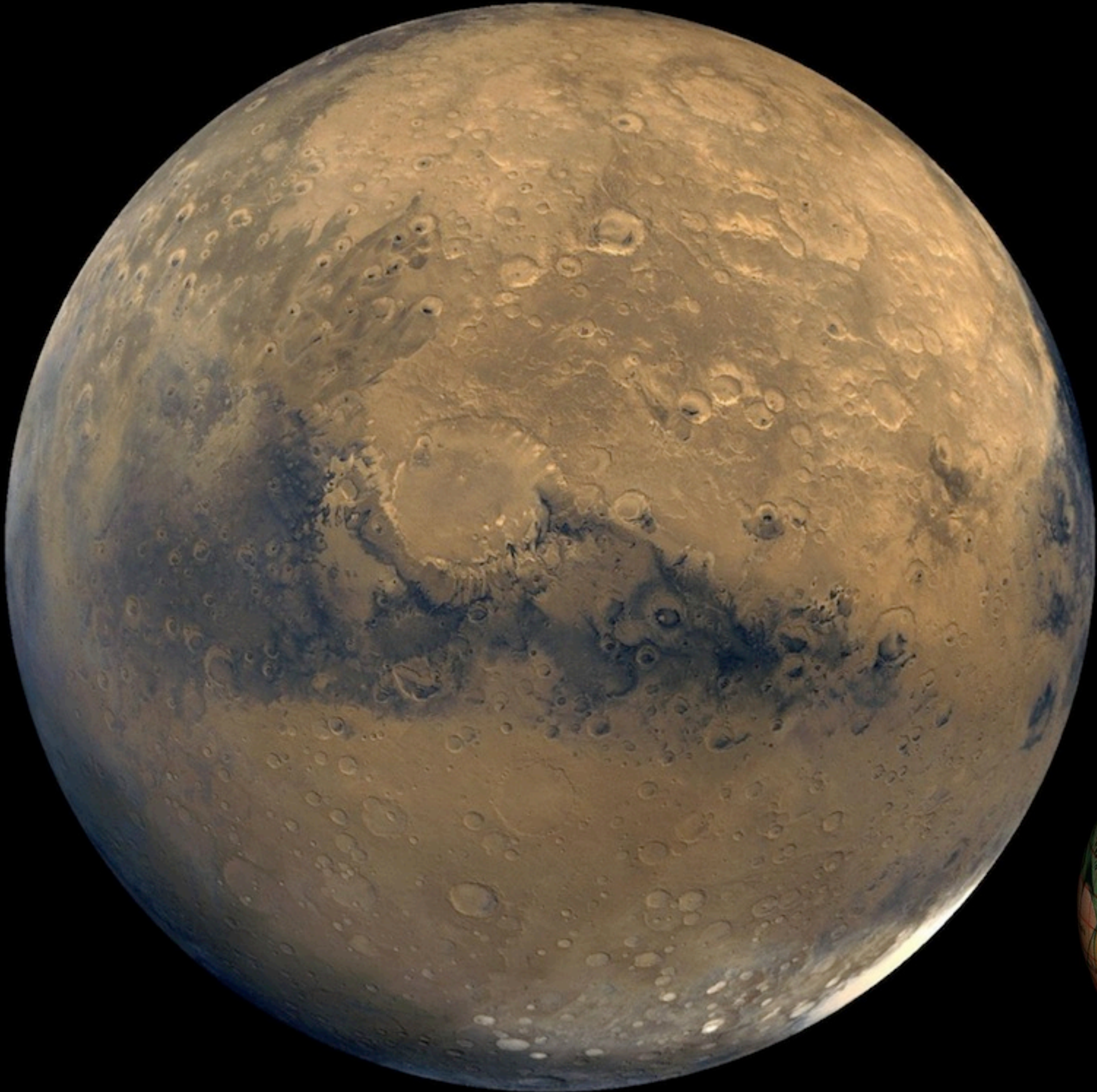
Runaway Greenhouse Effect on Venus

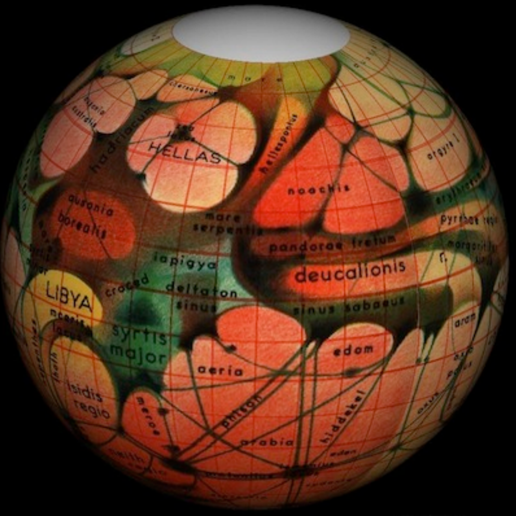


Gas	Earth	Venus
Carbon dioxide (CO_2)	0.03%	96%
Nitrogen (N_2)	78.1%	3.5%
Argon (Ar)	0.93%	0.006%
Oxygen (O_2)	21.0%	0.003%
Neon (Ne)	0.002%	0.001%

Earth's Moon

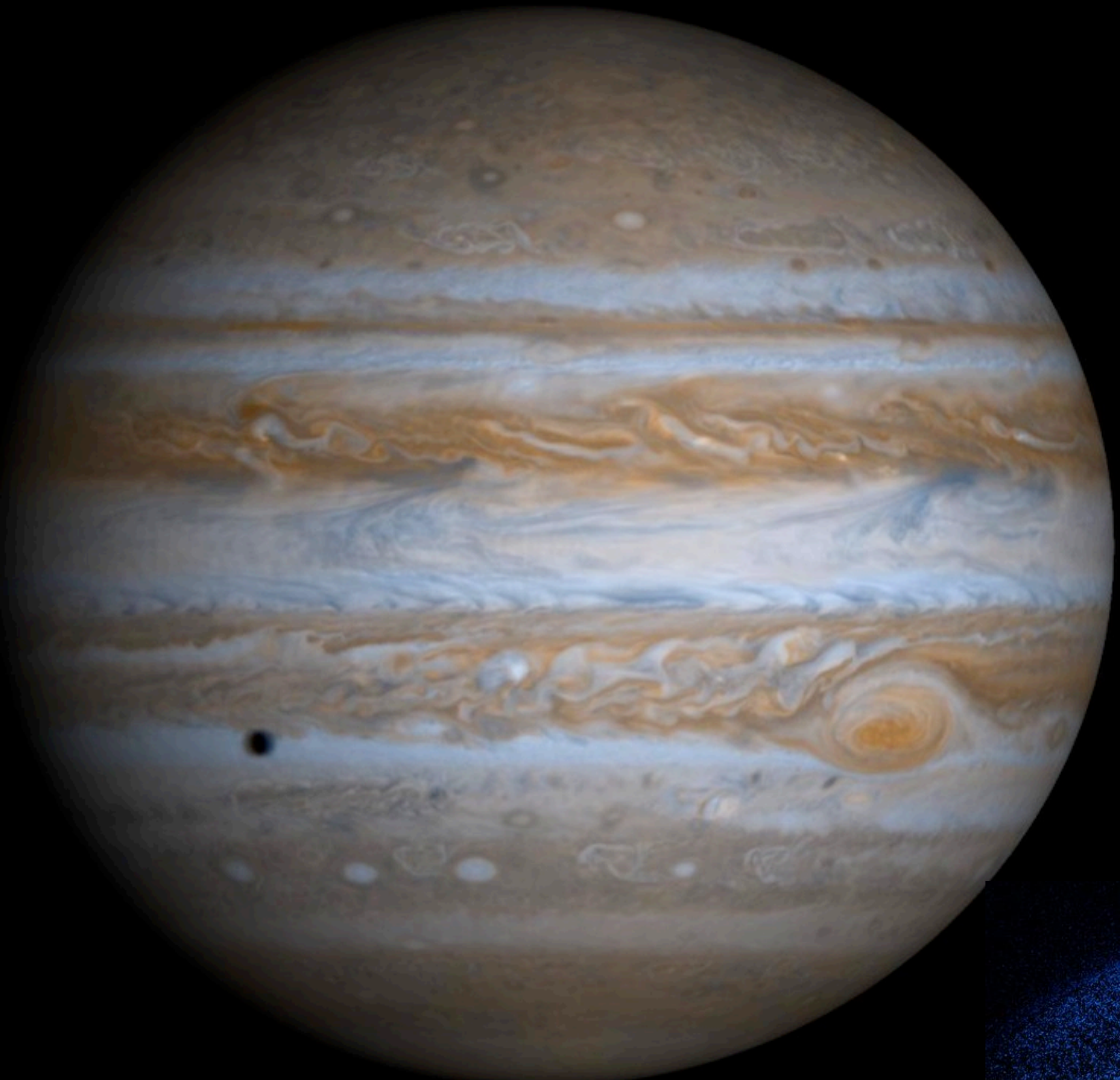
Mars



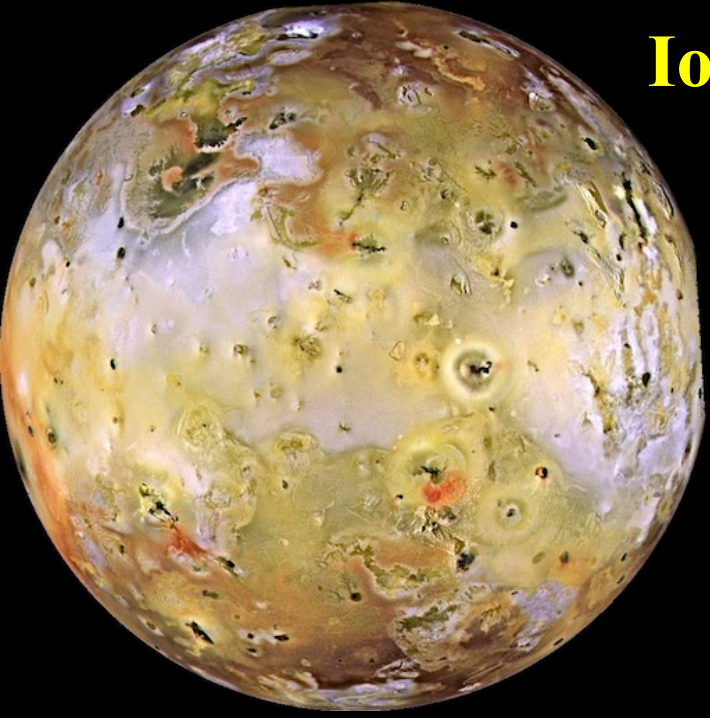

hadriacum
HELLAS
hellespontus
argyre I
noachis
ausonia
borealis
mare
serpentis
pandorae fretum
iapigya
deucalionis
crocea
deltaton
sinus
sinus sabaeus
LIBYA
syrtis
major
aram
edom
aeria
isidis
regio
meroe
phison
arabia
hiddekel
eden


Water on Mars

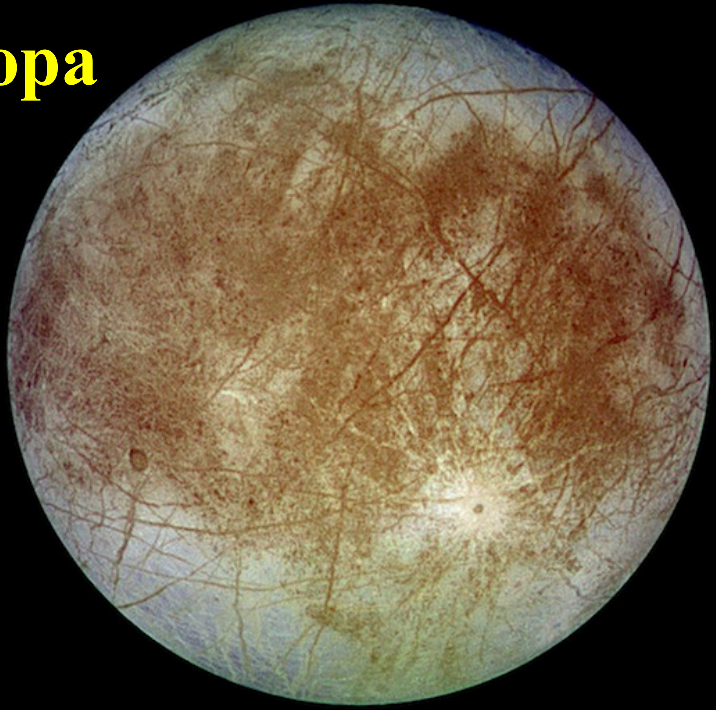
Jupiter



Jupiter’s Moons



Io

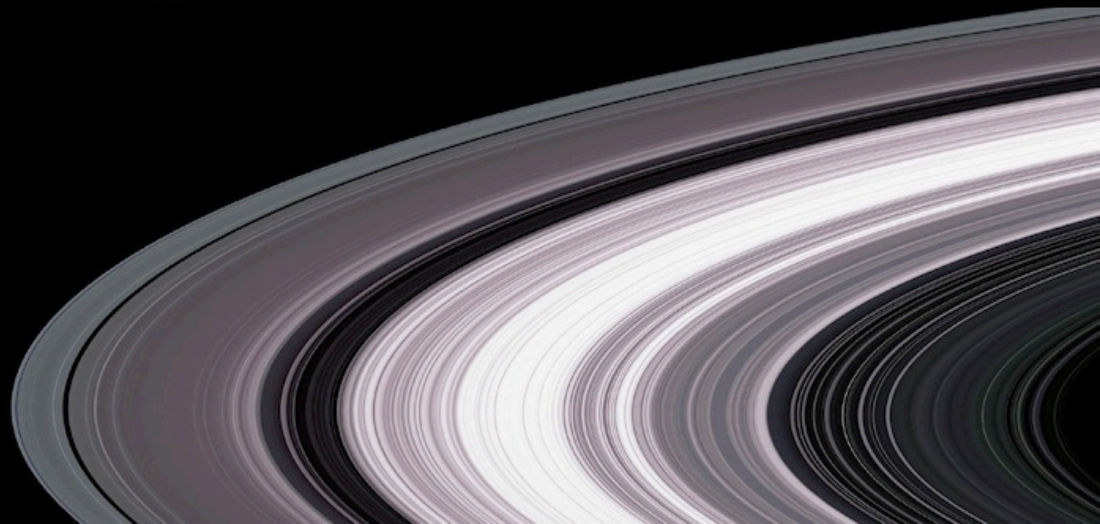


Europa

Ganymede

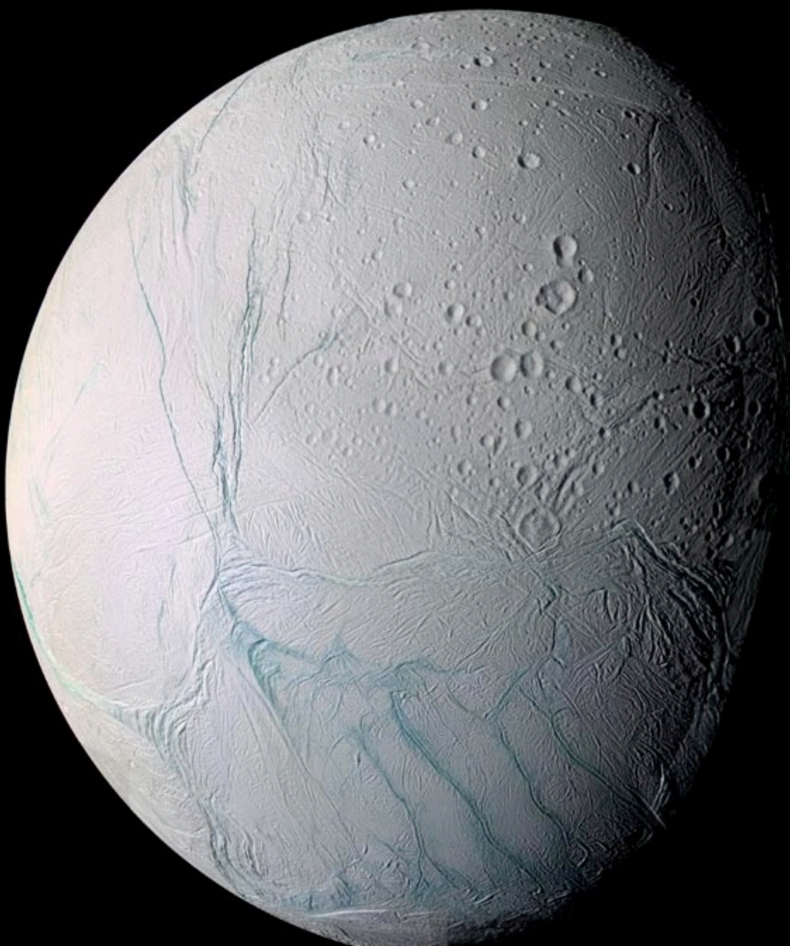
Calisto

Saturn

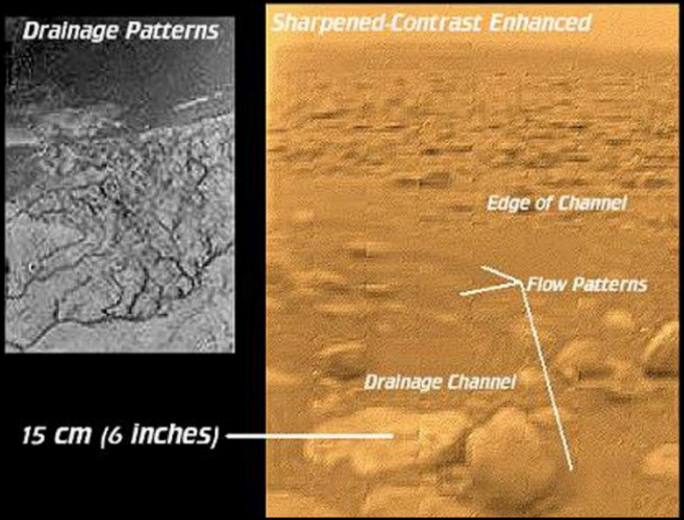


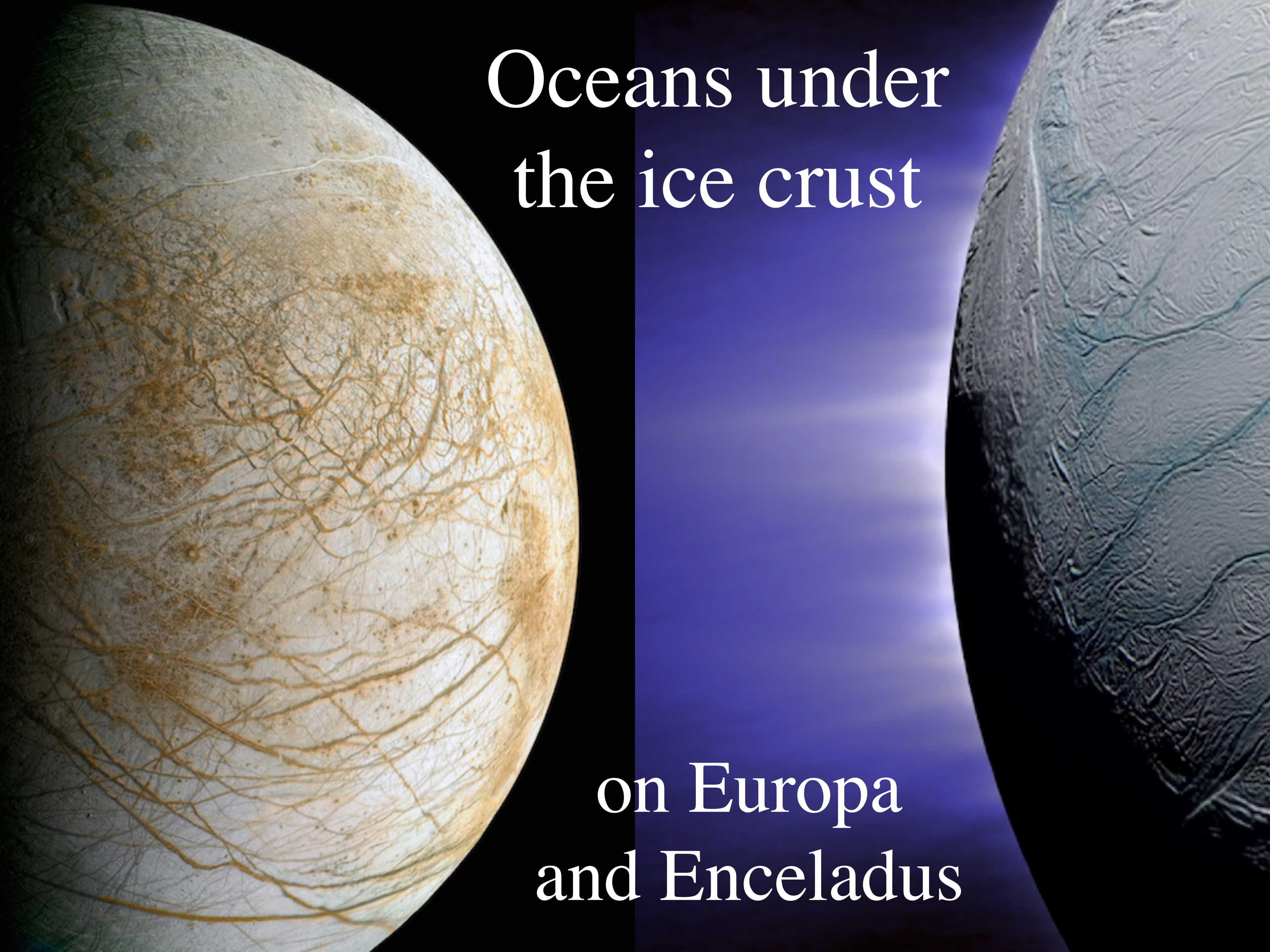
Saturn's Moons

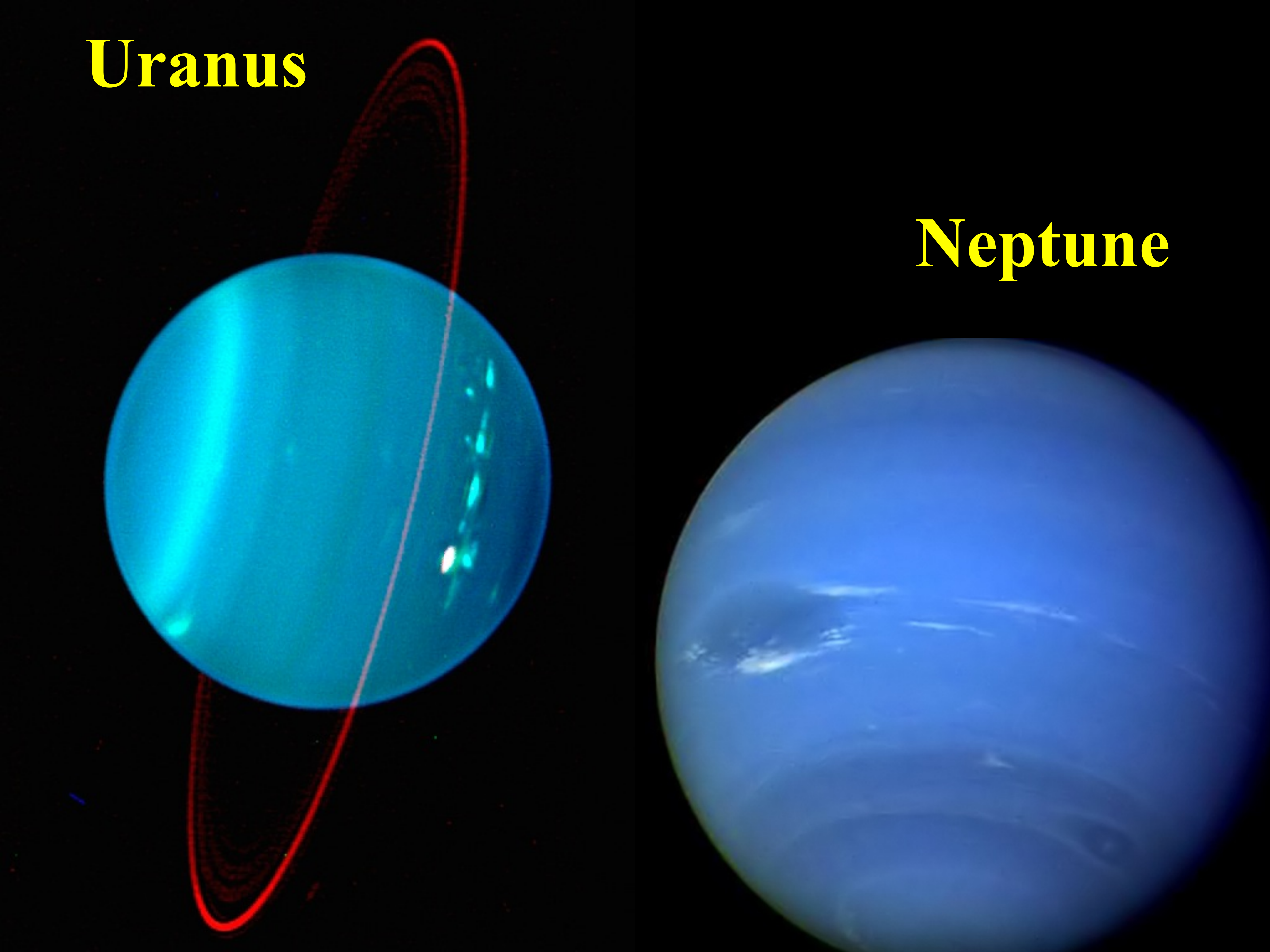
Enceladus



Titan




Oceans under
the ice crust
on Europa
and Enceladus

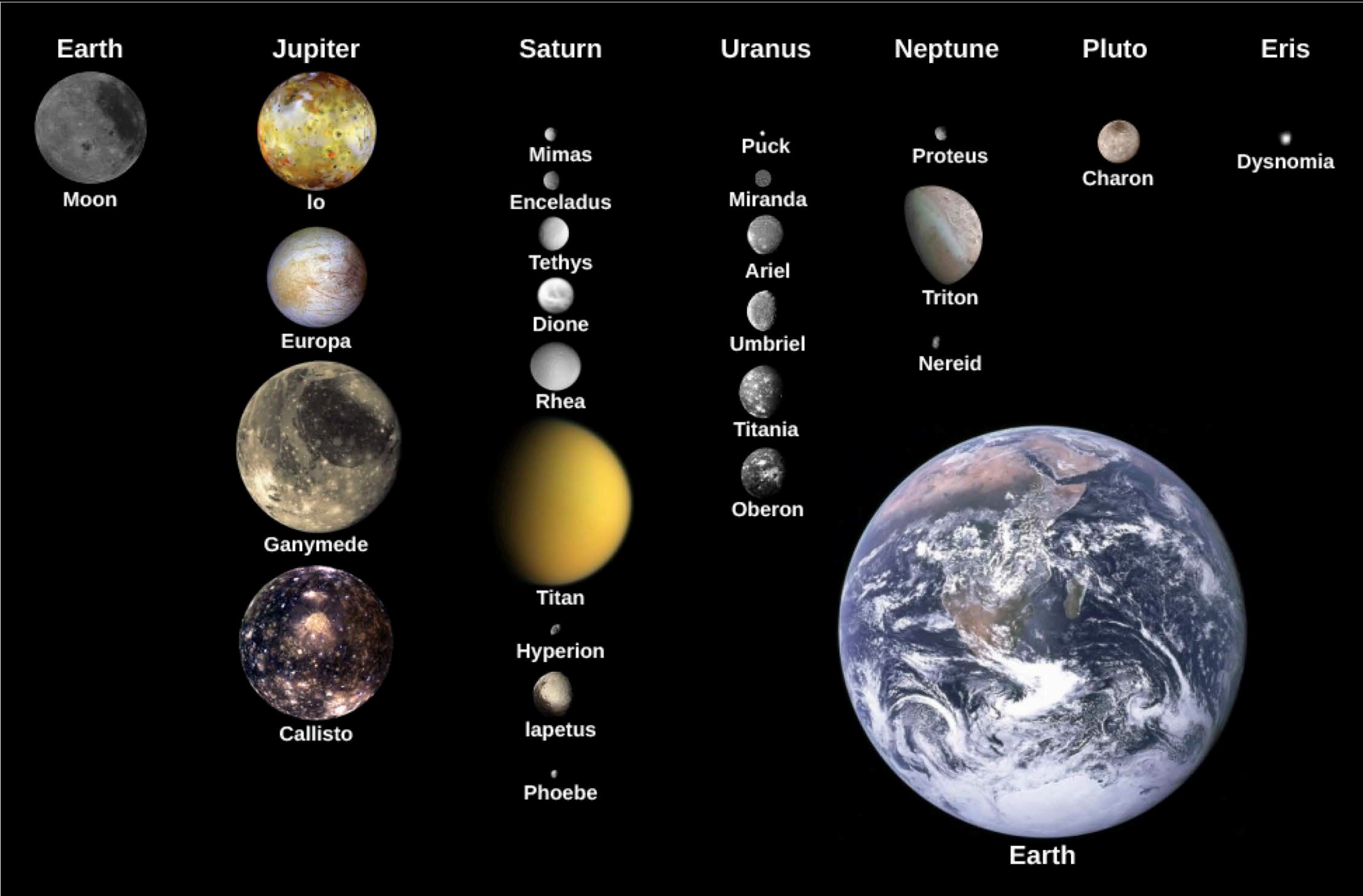

Uranus
Neptune

Pluto and Charon

Pluto Killer
(Mike Brown)

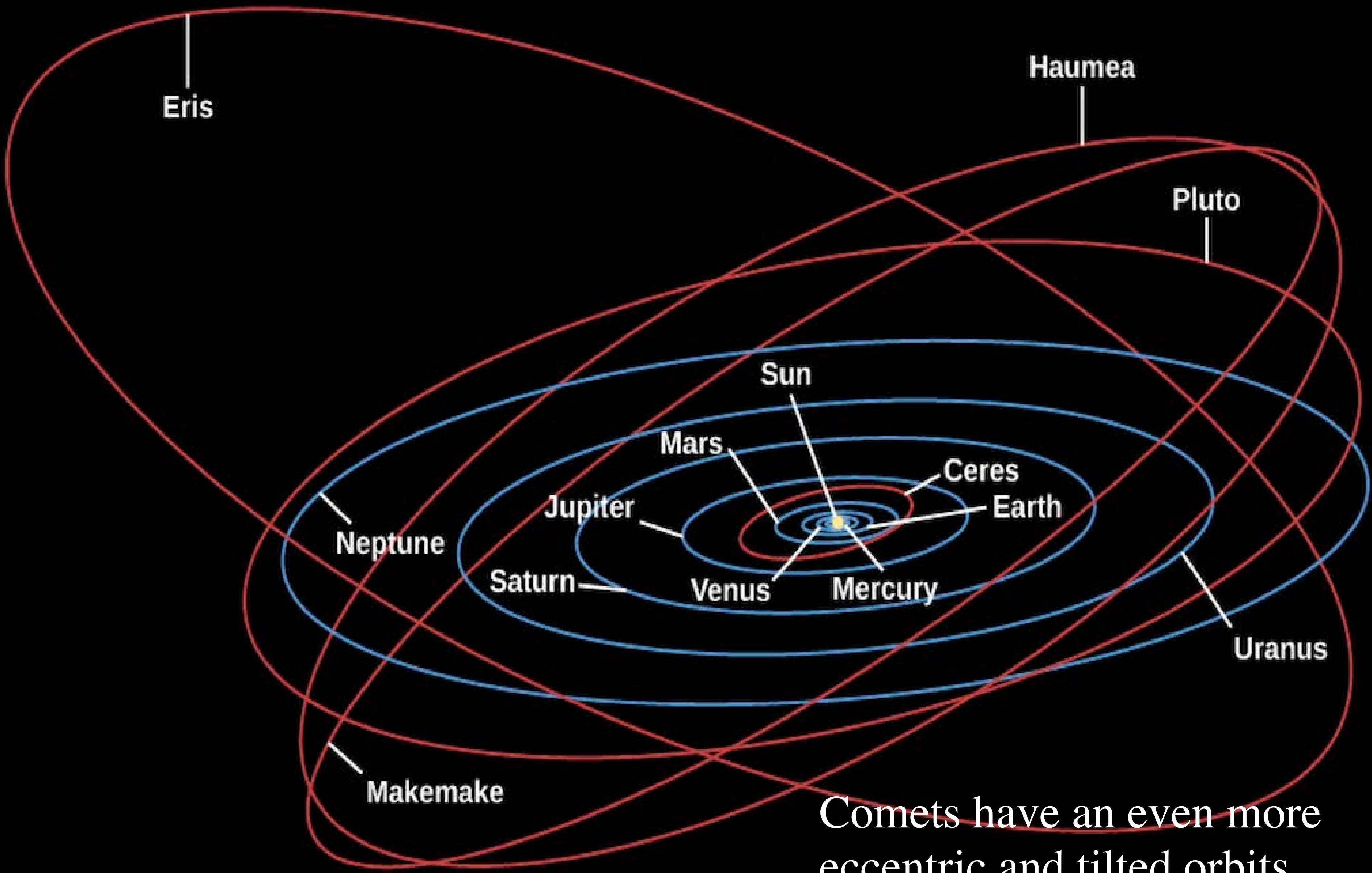

Planet Nine (?)
Predicted by Konstantin Batygin and Mike Brown (but not yet discovered)

Larger Moons in the Solar System



Largest known trans-Neptunian objects (TNOs)

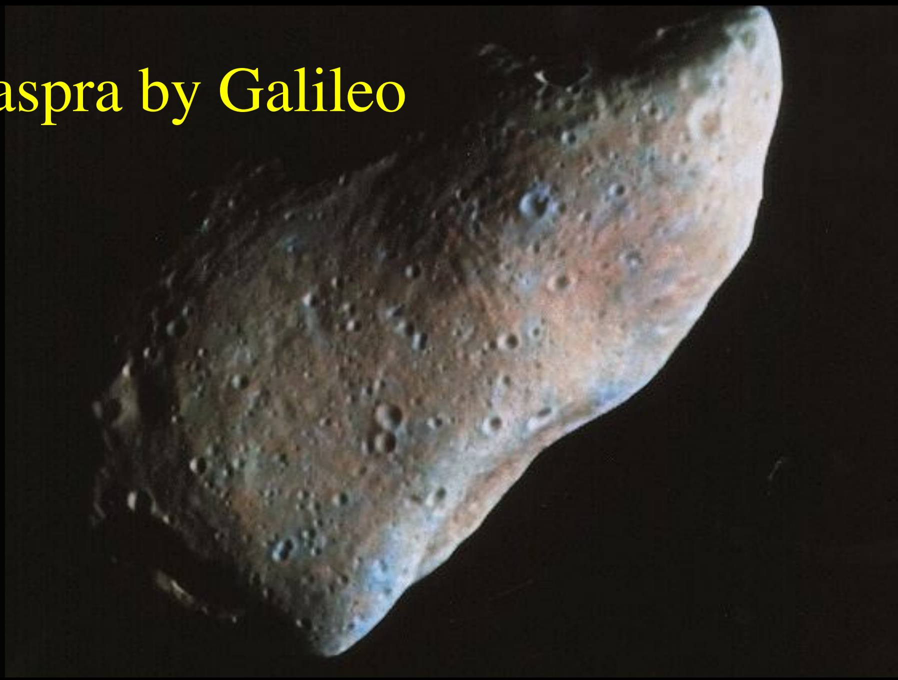
Orbits in the Solar System



Comets have an even more eccentric and tilted orbits

Asteroids: Leftover Rocky Planetesimals

Mathilda by NEAR

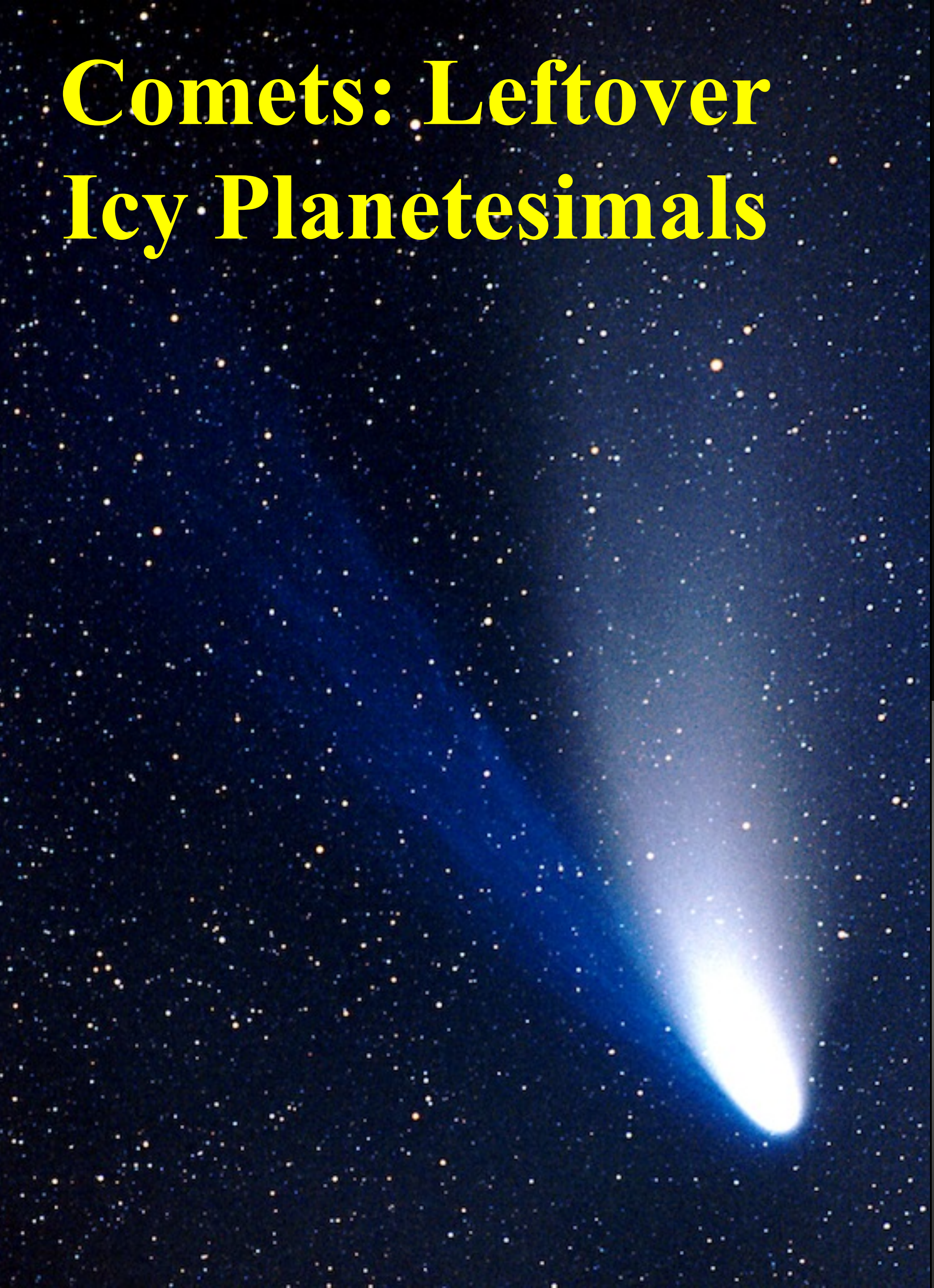


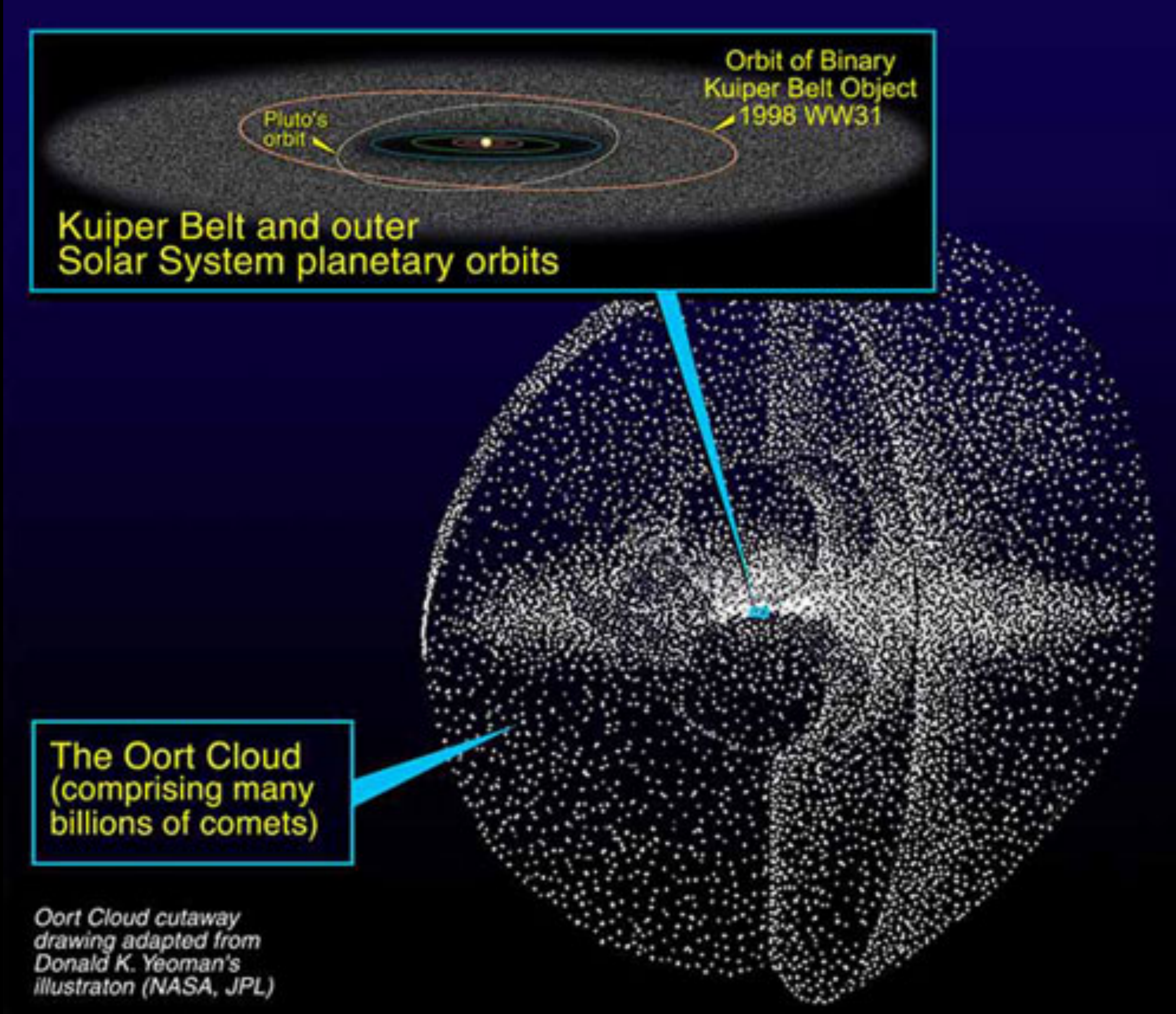
Gaspra by Galileo

Ida by Galileo

Eros by Vesta

Comets: Leftover Icy Planetesimals




Orbit of Binary
Kuiper Belt Object
1998 WW31
Pluto's
orbit
Kuiper Belt and outer
Solar System planetary orbits
The Oort Cloud
(comprising many
billions of comets)
Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
illustraton (NASA, JPL)

Zodiacal Dust:
Leftover Protoplanetary Disk Dust

?

6.2 Formation of the Solar System

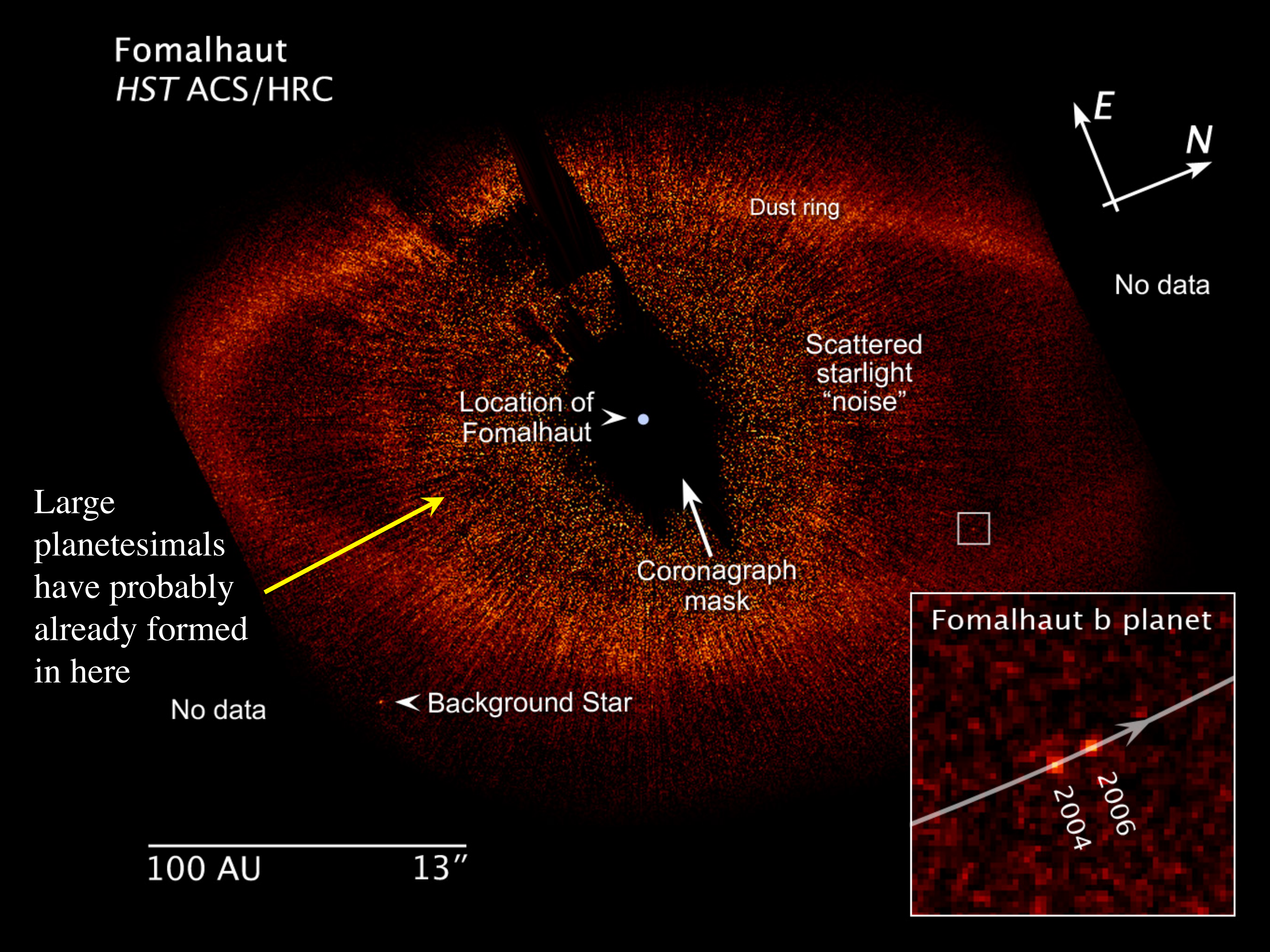
The Idea of Planetesimals and the Origin of the Solar System

Everywhere in the solar nebula, tiny pieces of matter started condensing from the gas

At different places in the solar nebula, these "little bits of grit" were different compounds

These small pieces of matter stuck to others, making larger sized blocks (the **planetesimals**)

Eventually, these planetesimals collected into objects the size of planets. Gravity got into the act when the planetesimals got big

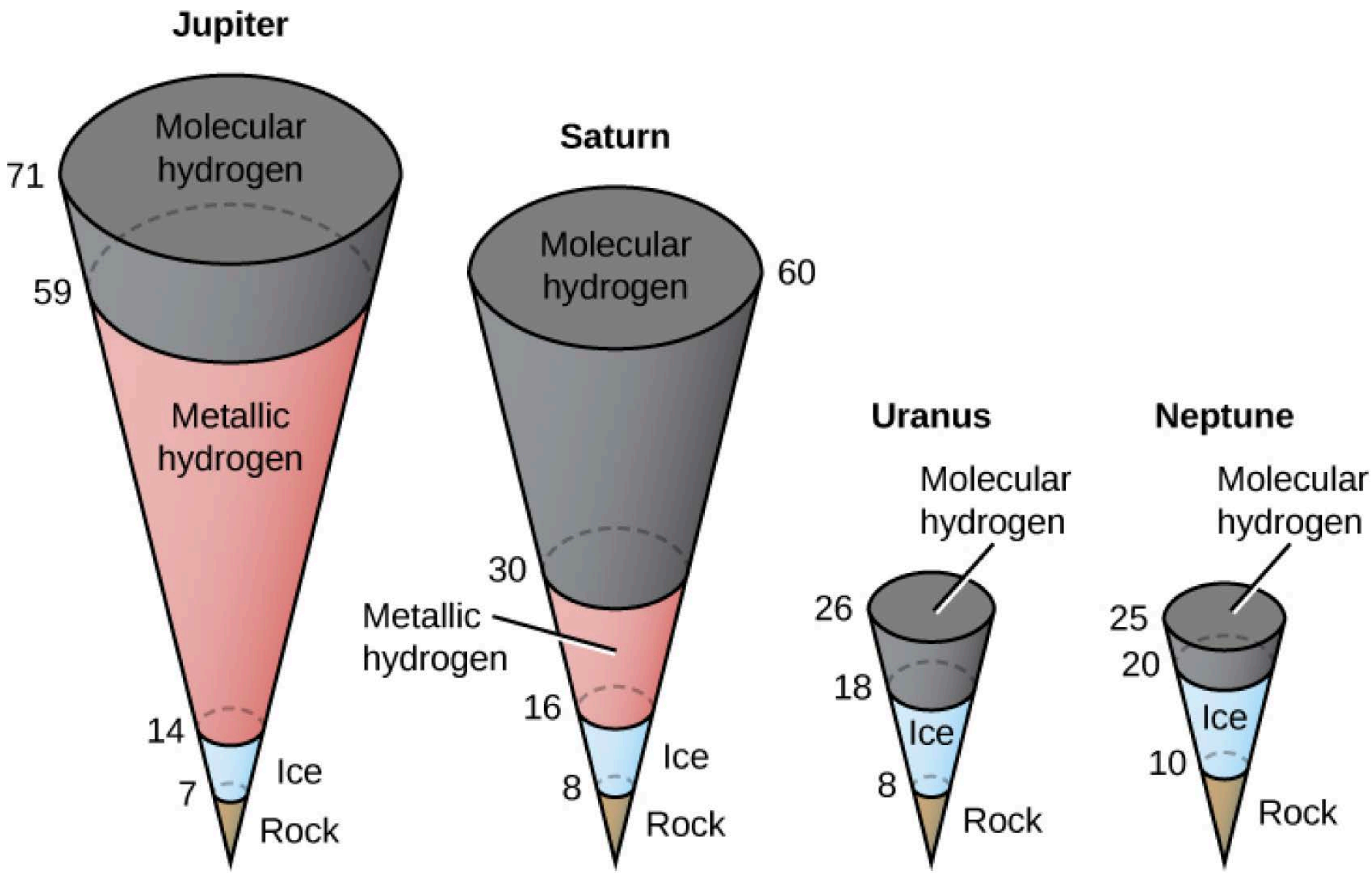


Large planetesimals have probably already formed in here

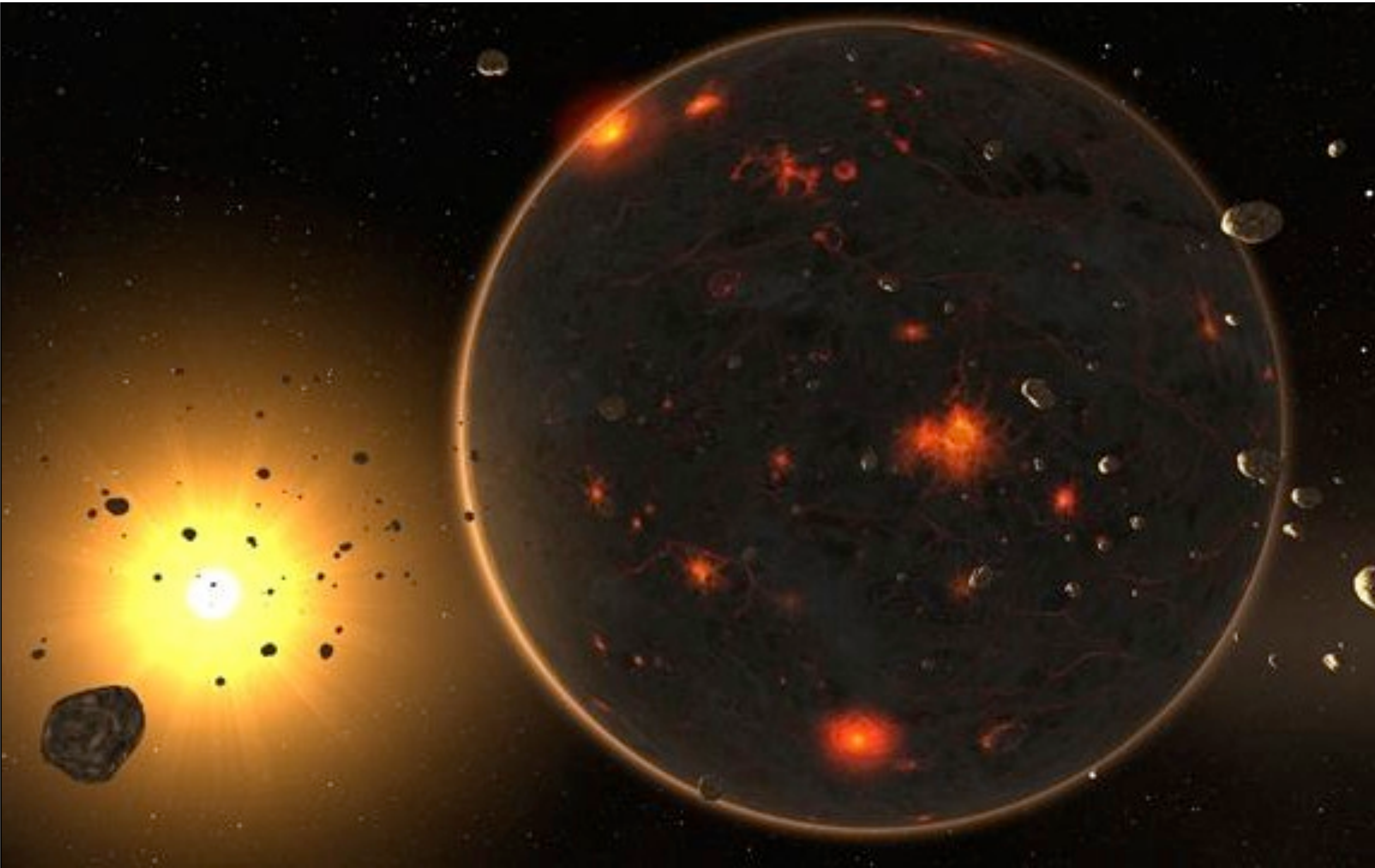
Masses and Compositions of the Major Planets

- At the location of the terrestrial planets, there was not much mass in the planetesimals, since they were formed of heavier, non-abundant elements
- In the outer solar system, there was more mass in the planetesimals, since they were formed of abundant, hydrogen-bearing compounds. Apparently, they produced more massive planetesimals that incorporated the hydrogen and helium gas that makes up most of Jupiter and Saturn
- At the position of the Earth, only silicates and other more "refractory" substances would have precipitated from the vapor state. At Jupiter and beyond, ices of water, ammonia, methane, would have condensed

Composition of the Gas Giant Planets



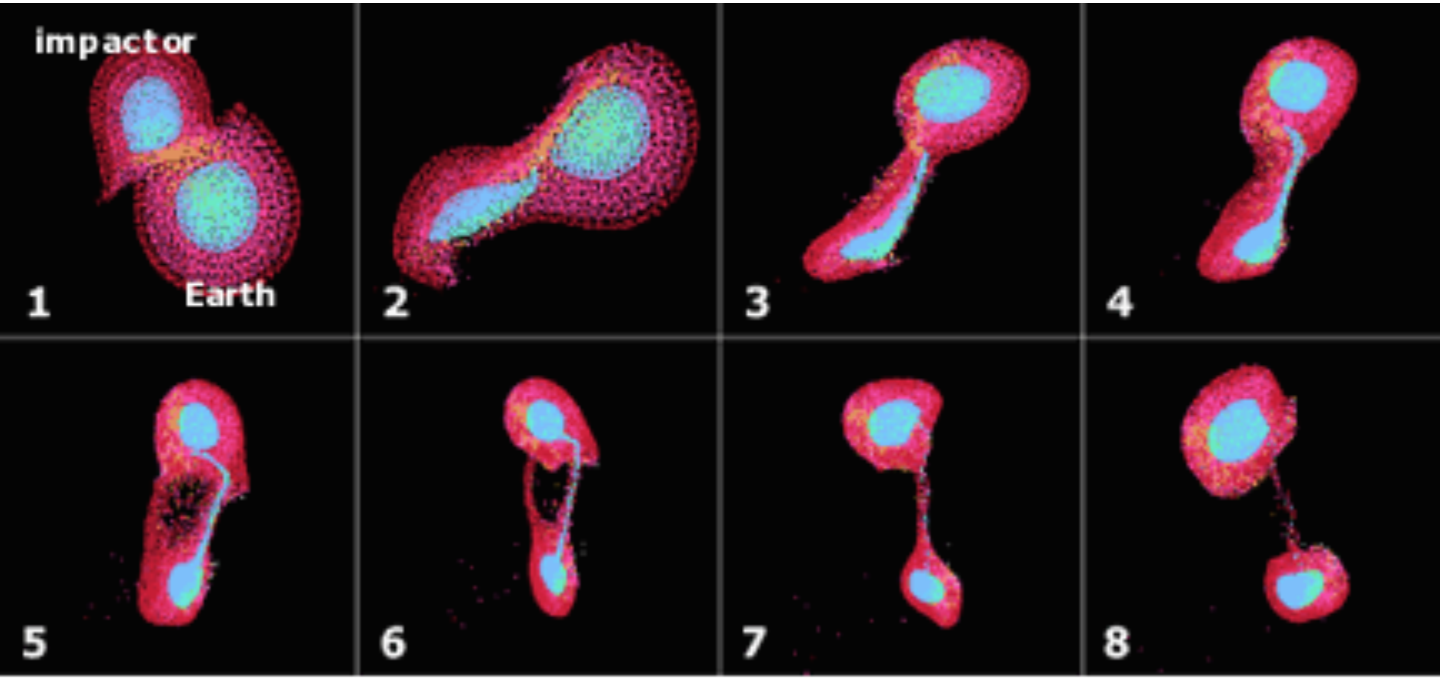
Late Heavy Bombardment



The Origin of the Moon

A Mars-sized protoplanet colliding with the proto-Earth

Moon condenses from the debris



(Courtesy of A. G. W. Cameron, Harvard College Observatory.)

Explains:

- Lunar composition
- Tilt of the Earth's axis

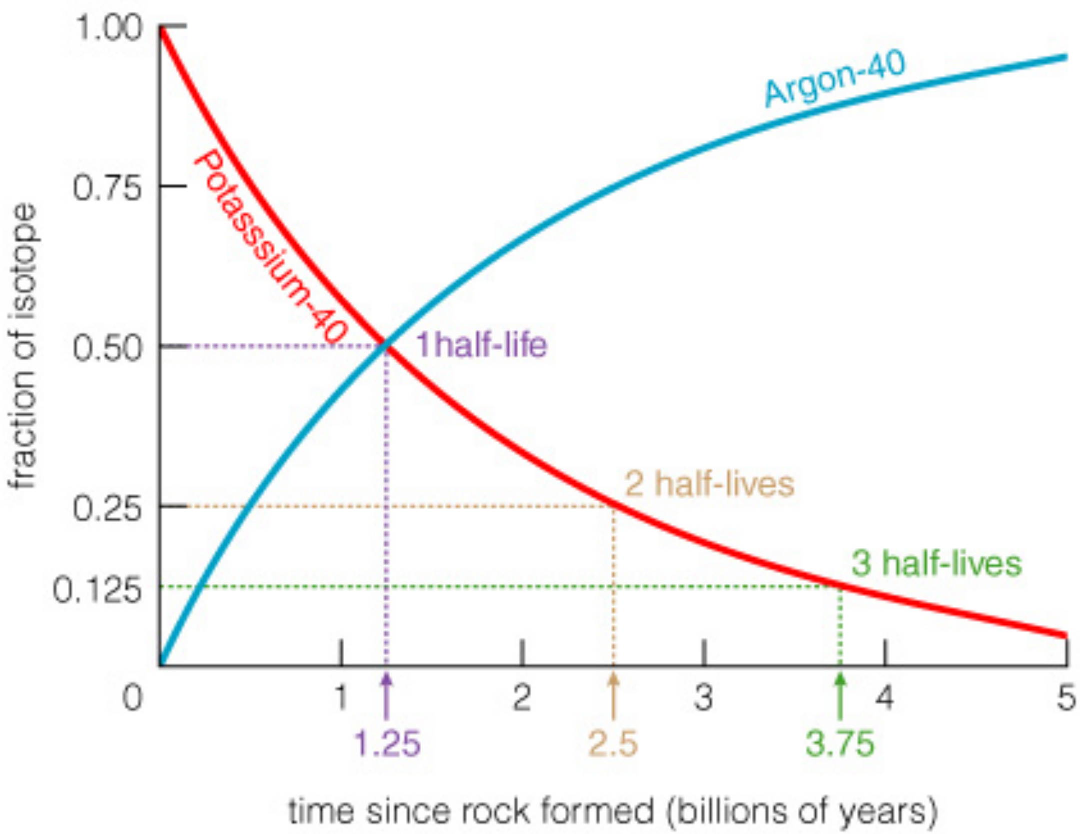
Cretaceous-Tertiary Impact Extinction

The Impacts Continue

Tunguska >

Large meteor crater, Arizona

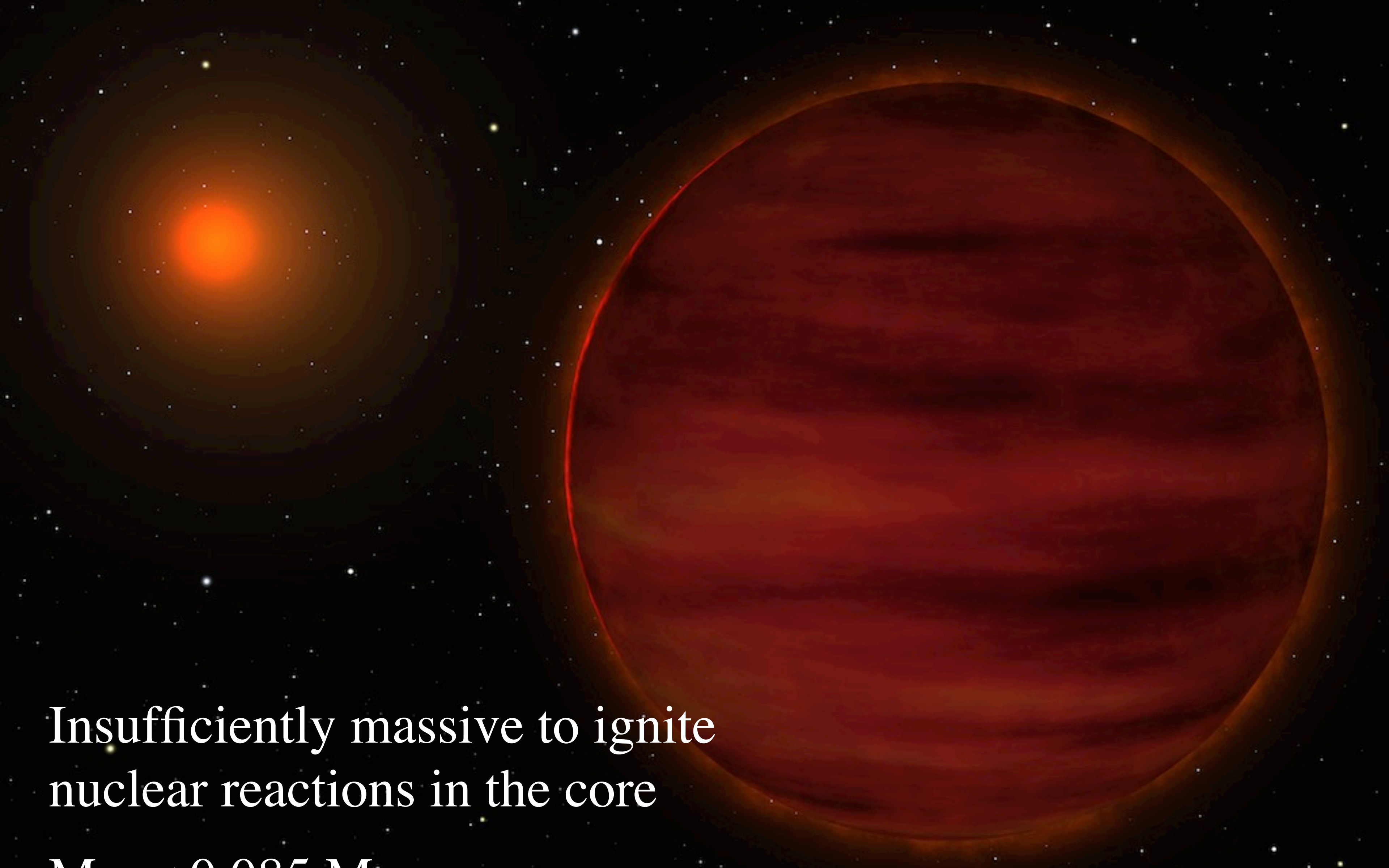
When Did the Planets Form?



- Some isotopes decay into other nuclei
- A **half-life** is the time for half the nuclei in a substance to decay
- Relative abundances of these isotopes then give us the age

- Radiometric dating tells us that oldest moon rocks are 4.4 billion years old
- Oldest meteorites are 4.55 billion years old
- Planets probably formed ~ 4.6 billion years ago

Brown Dwarfs: Between Stars and Planets



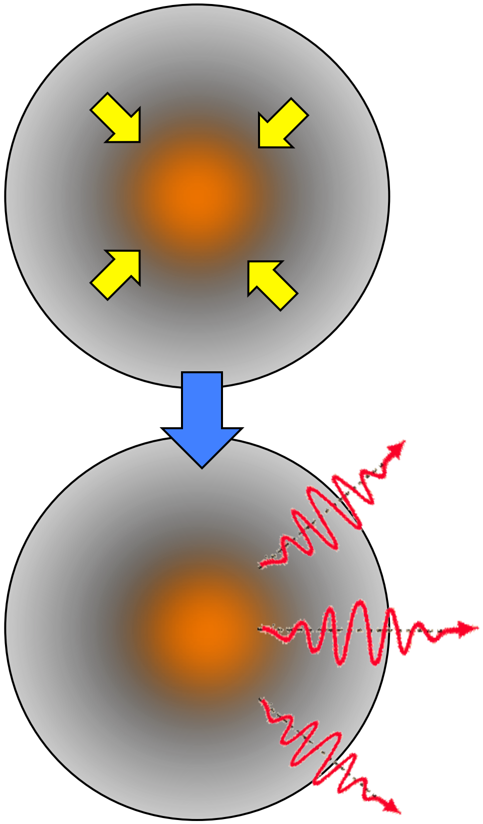
Insufficiently massive to ignite nuclear reactions in the core

$M_{bd} < 0.085\ M_{\odot}$

The Kelvin-Helmholtz Mechanism

As a planet cools, it shrinks

The release of the binding energy produces heat, that radiates away



For example, Jupiter, and all brown dwarfs

Total binding energy available divided by the luminosity gives the *Kelvin-Helmholtz time scale*

For Sun, that is ~ 18 million years

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6.3 Planetary Atmospheres

How do you obtain an atmosphere?

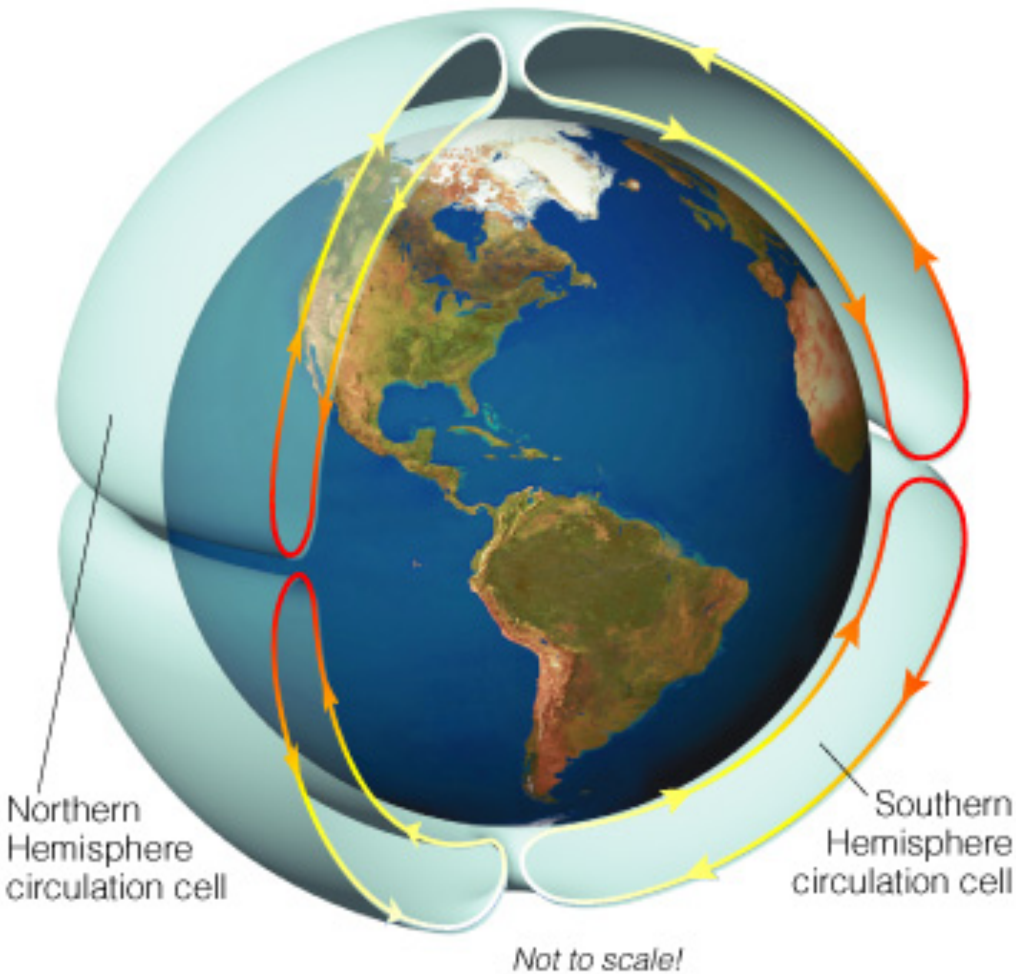
- Gain volatiles by comet impacts
- Outgassing during differentiation
- Ongoing outgassing by volcanoes

Keeping an Atmosphere

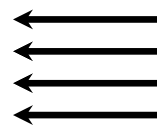
Atmosphere is *kept* by the world's gravity

- Low mass worlds = low gravity = almost no atmosphere
- High mass worlds = high gravity = thick atmosphere

Why are the winds blowing? The answer, my friends, is…



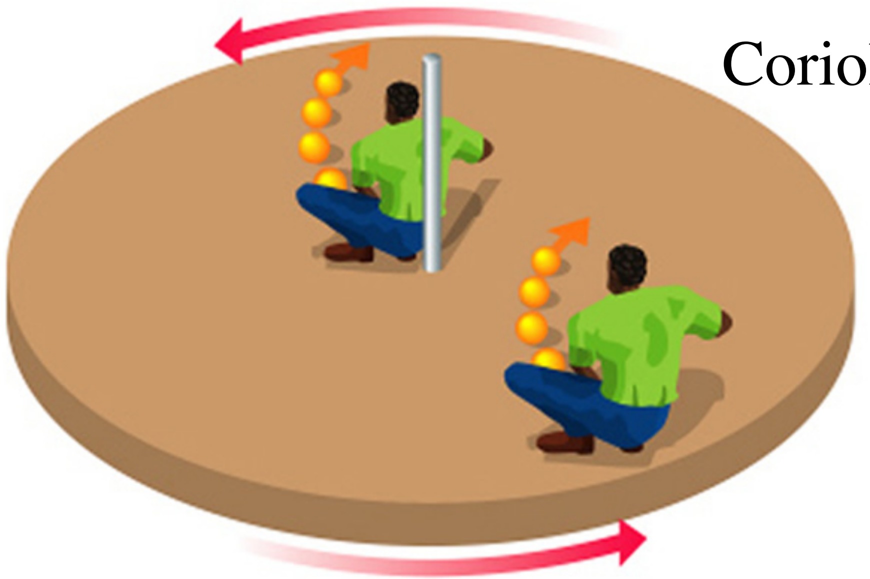
- Heated air rises at equator

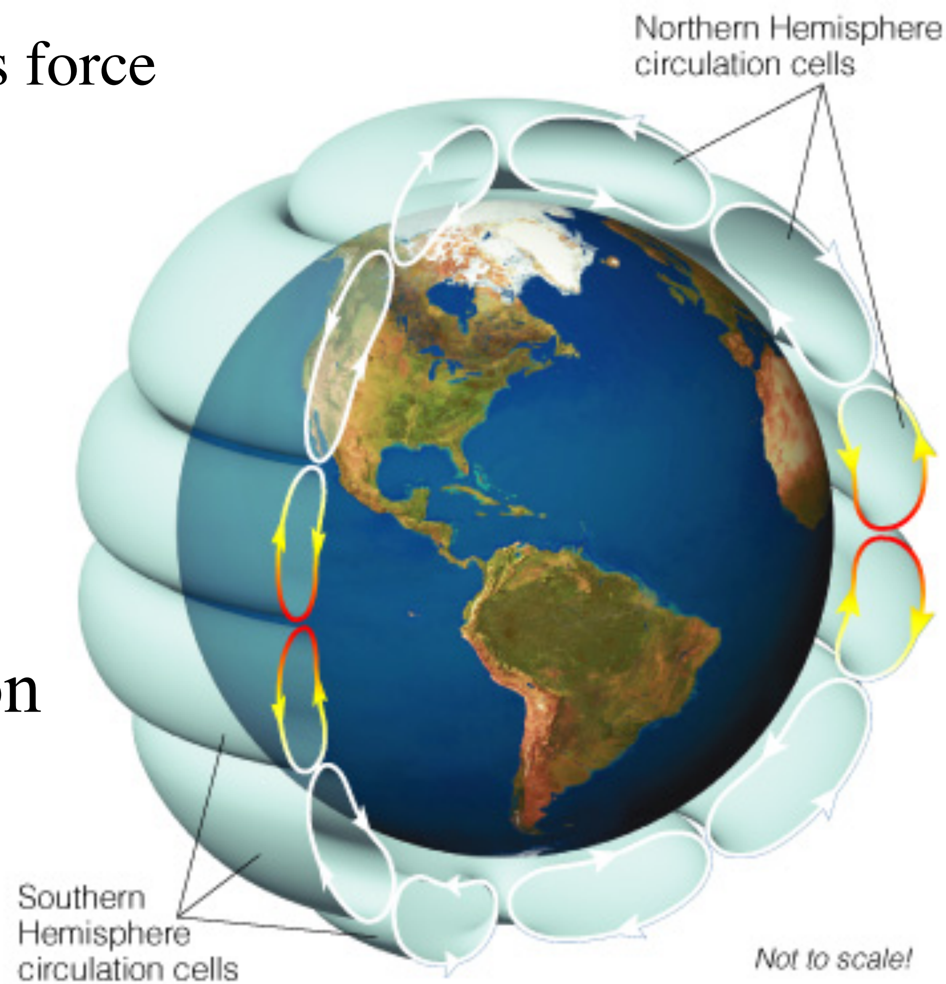


Maximum
Sun warming

- Cooler air descends at poles

The planetary rotation also plays a role:





- On Earth the large circulation cell breaks up into 3 smaller ones, moving diagonally
- Other worlds have more or fewer circulation cells depending on their rotation rate

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