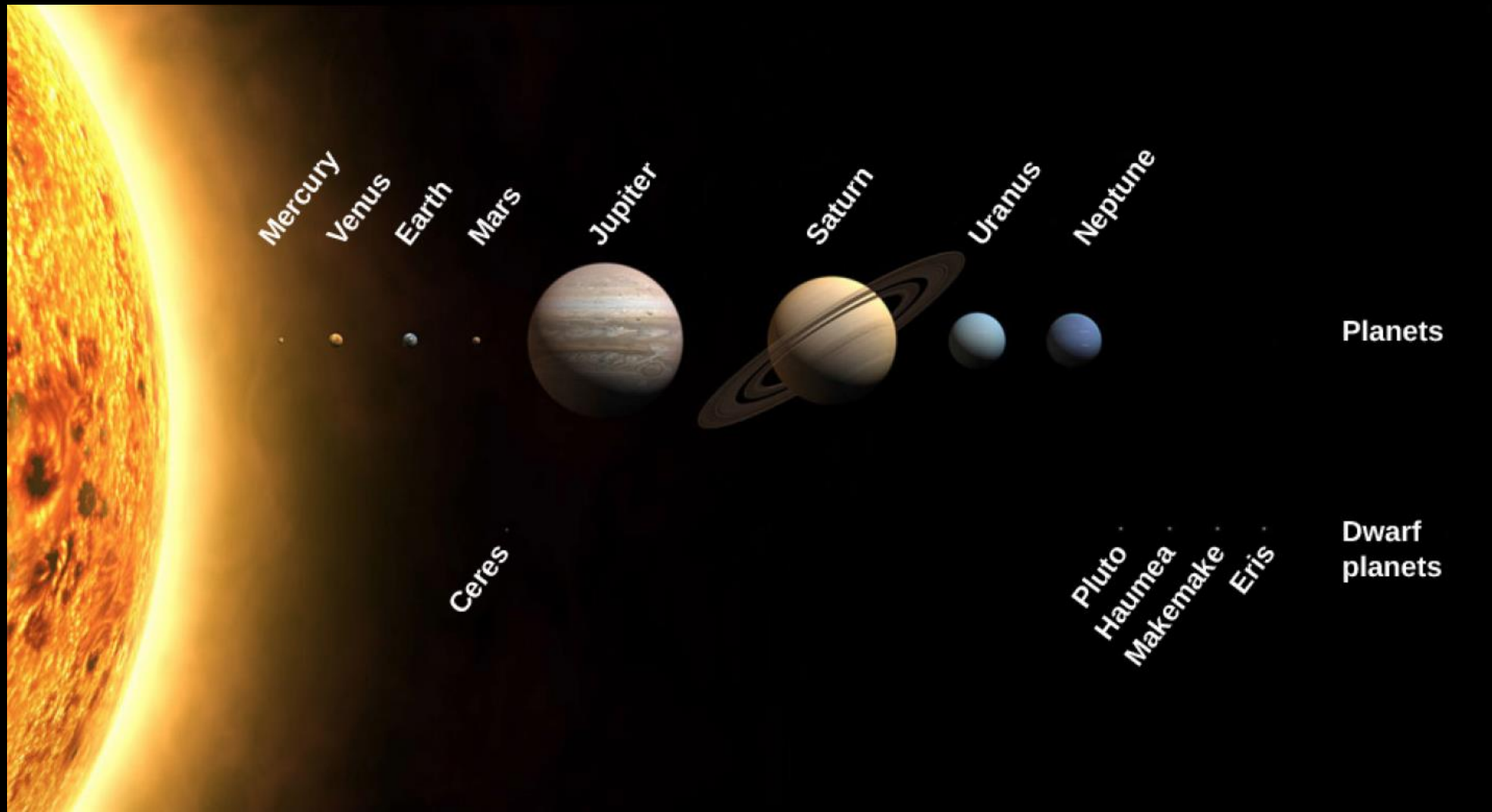
Our solar system!



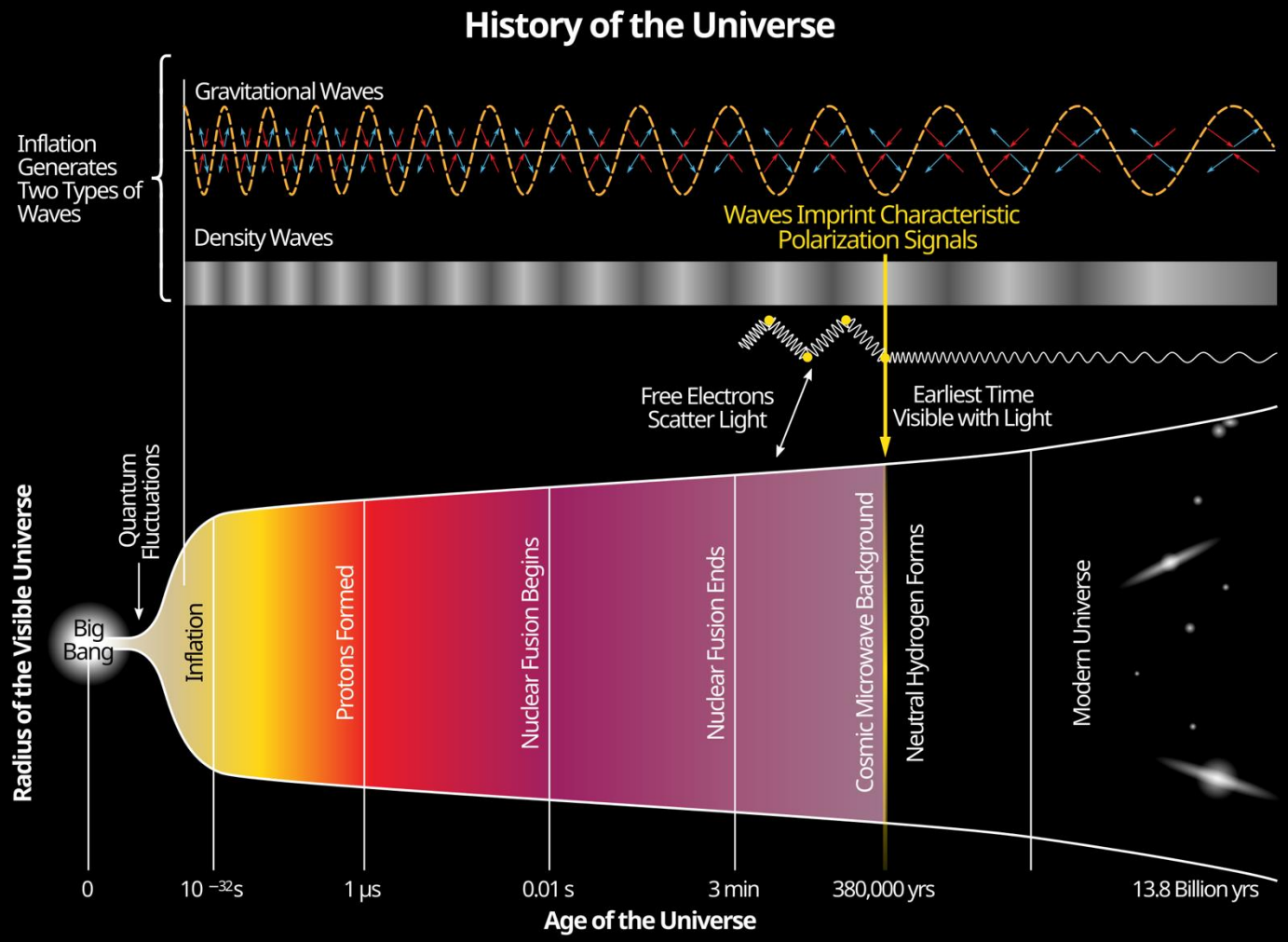
Mars or Earth?

Pluto or Earth?

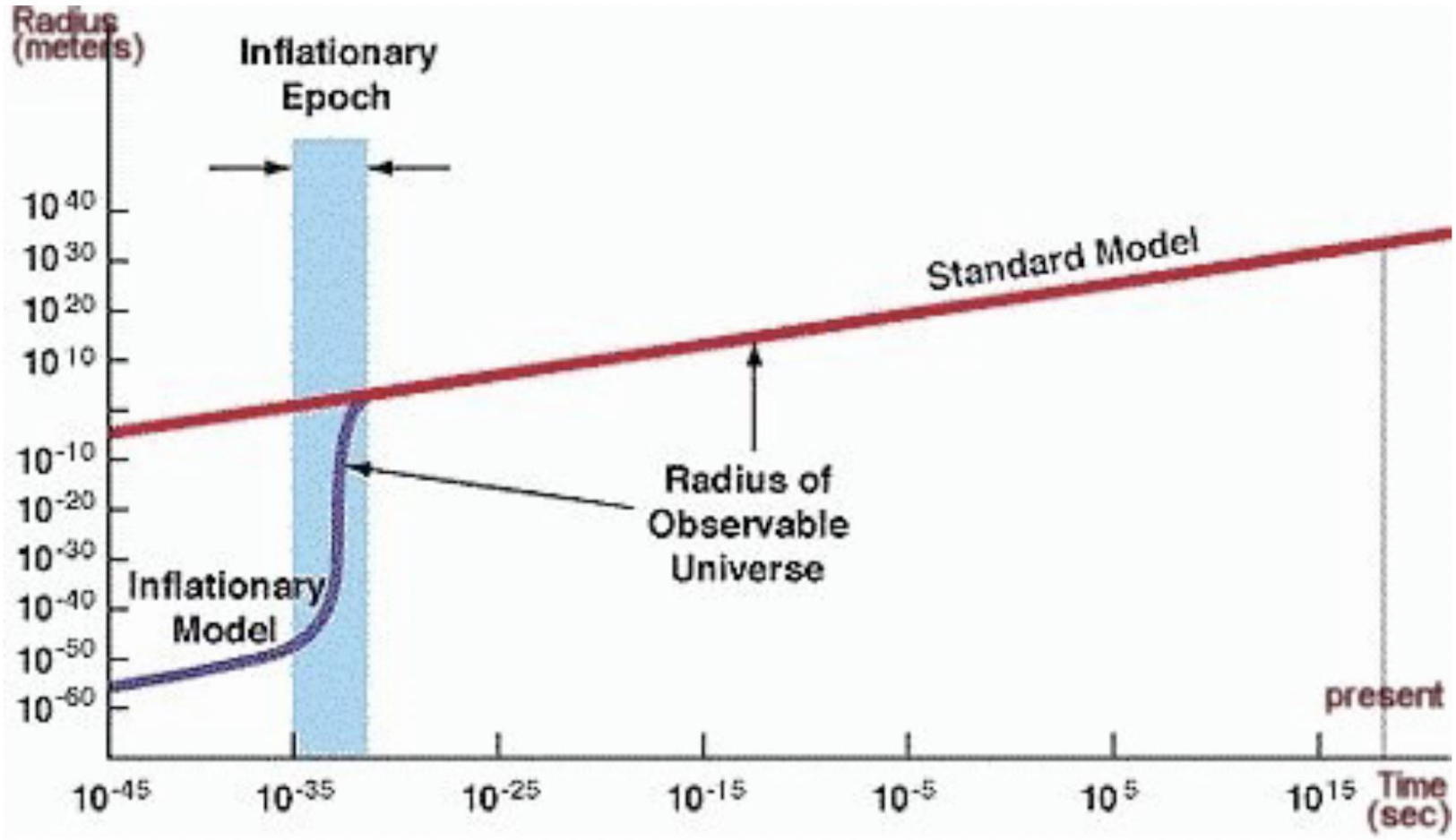
NASA/Dragonfly Titan Mission (ar
image, planned for late 2020s)

The history of the universe (in 13 slides)

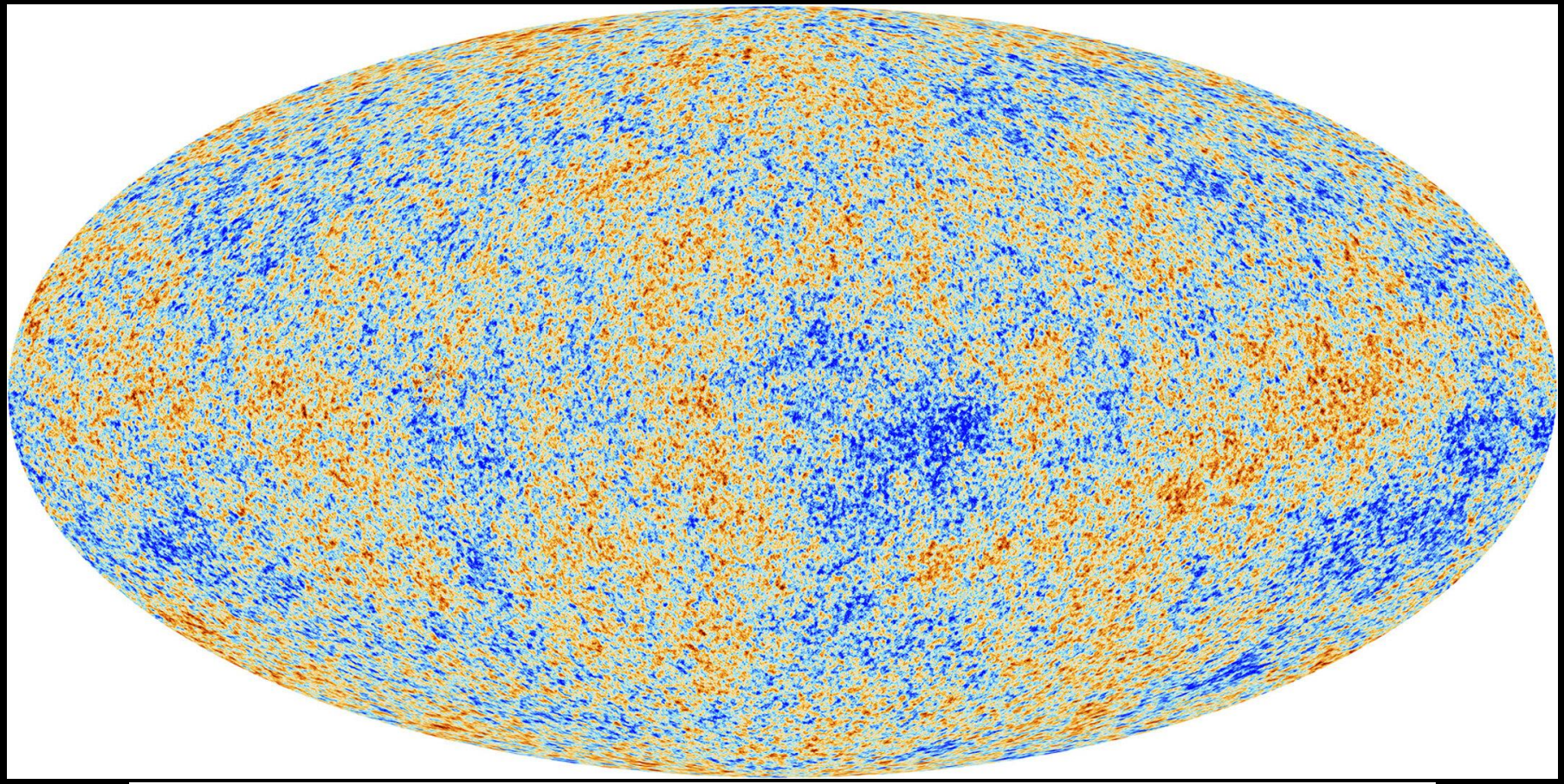
The Big Bang: an explosion of space-time!



Inflation: factor of 10^{78} from 10^{-36} to 10^{-32} s



Cosmic microwave background

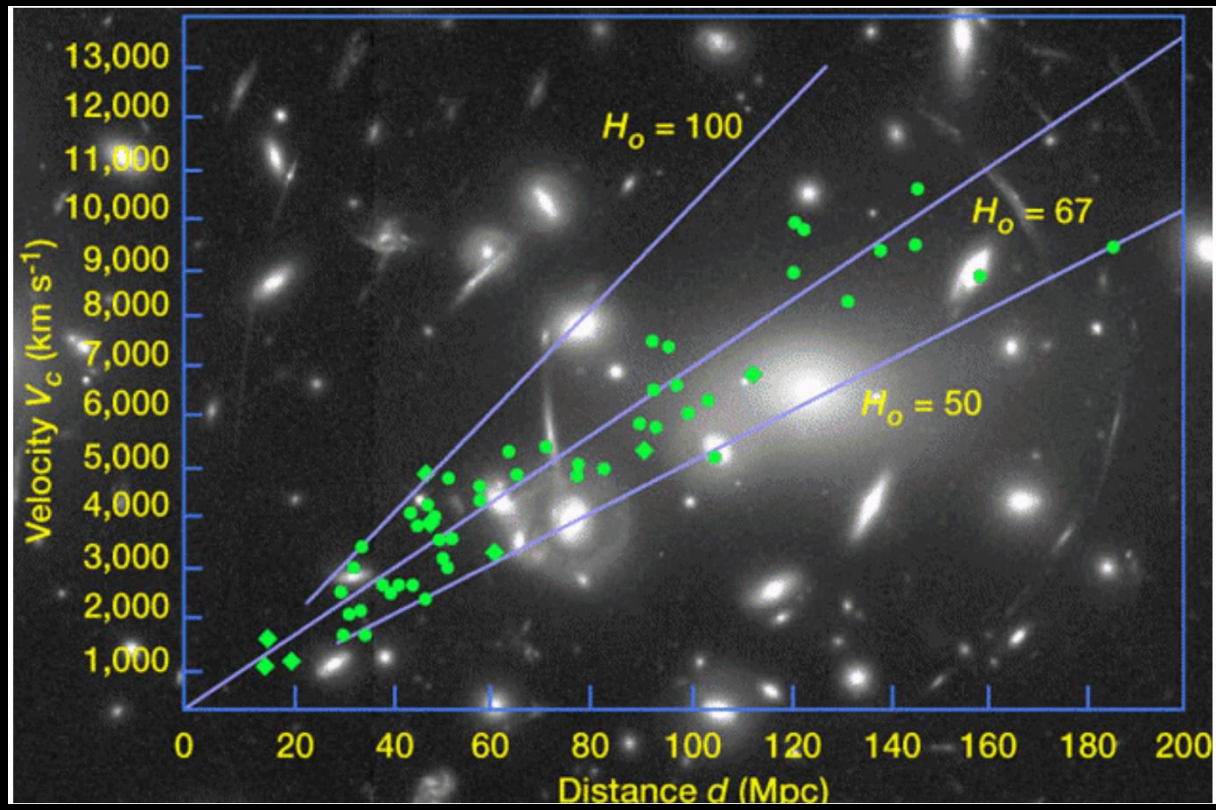


Near-uniform microwave background (smooth to 1 part in 10^4)

But not perfect: anisotropies!

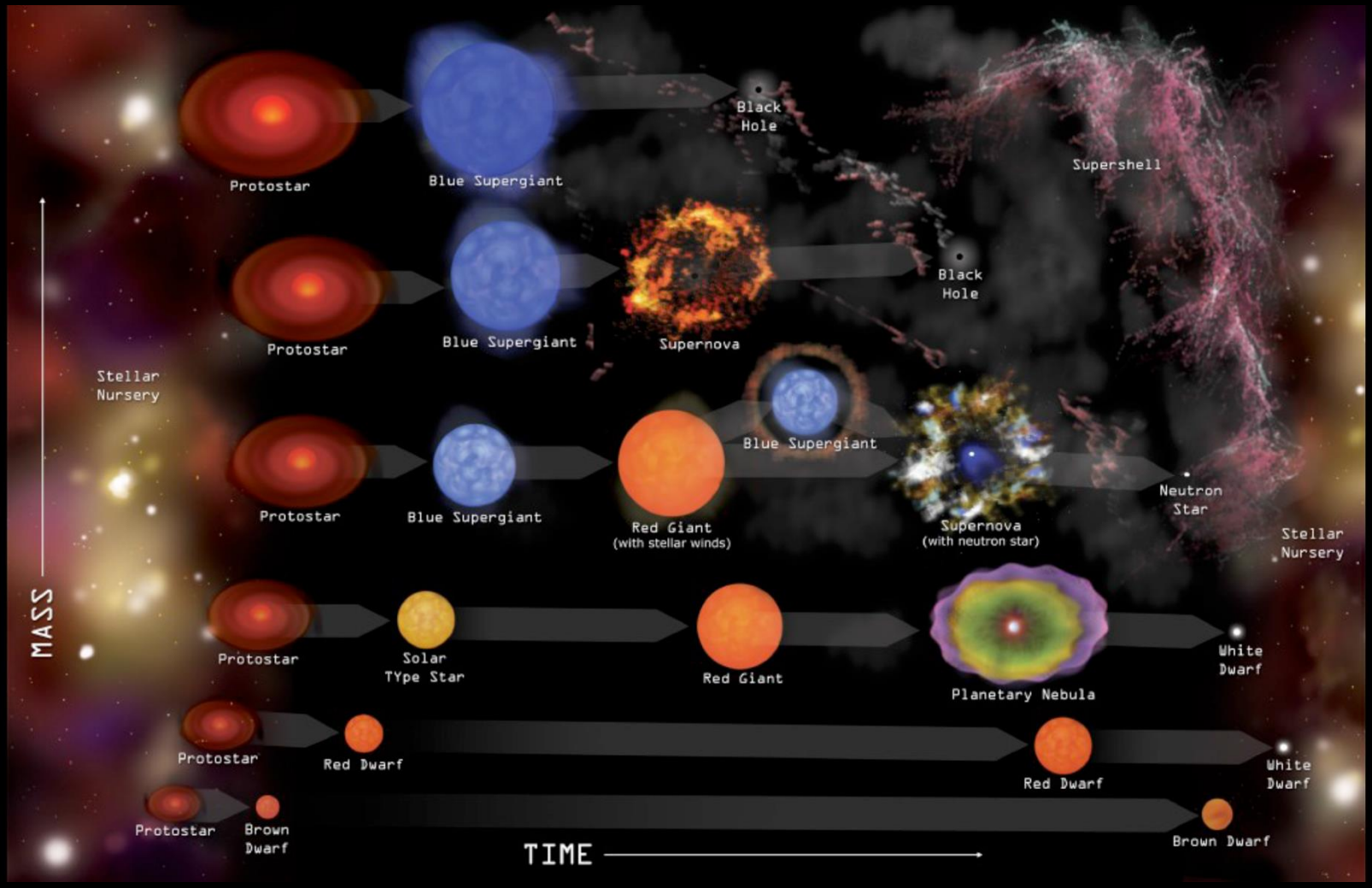
First stars and galaxies form

Cosmic expansion and Hubble's Law

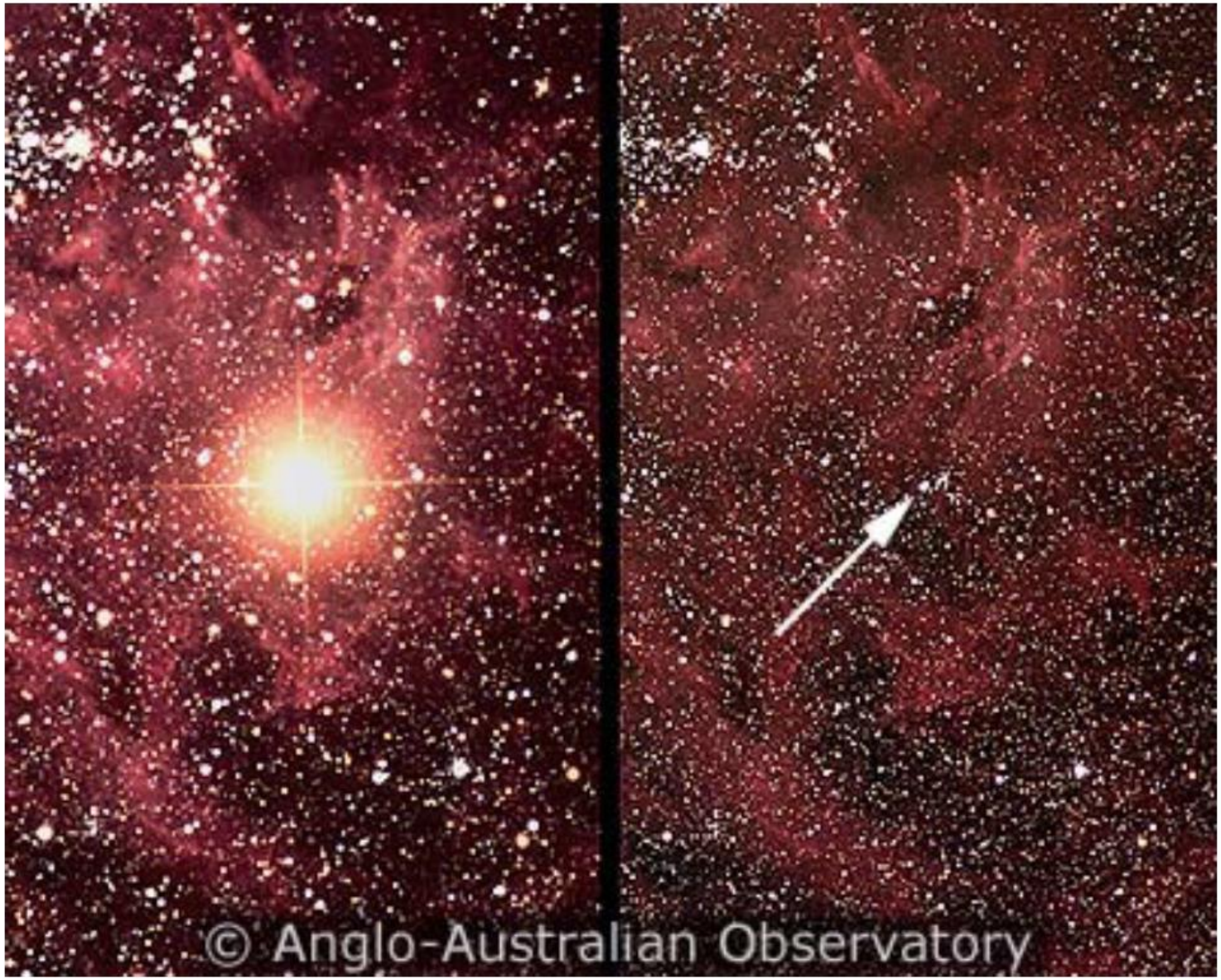


Most distant objects: redshifted (so appears red)
Distance: looks at the distance when younger (light travel time)

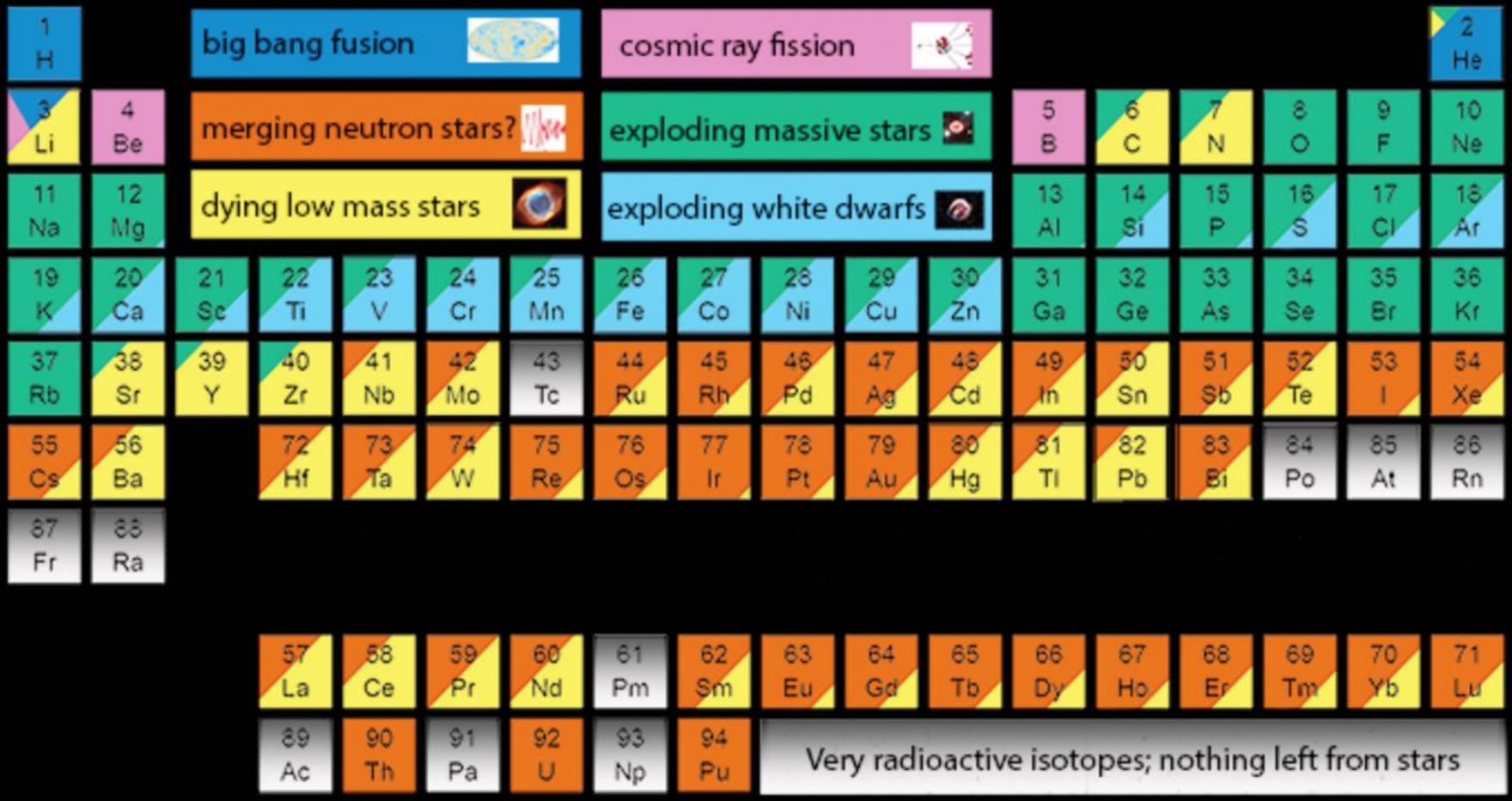
First stars are massive and explode!



Supernova 1987A (brightest in modern times)

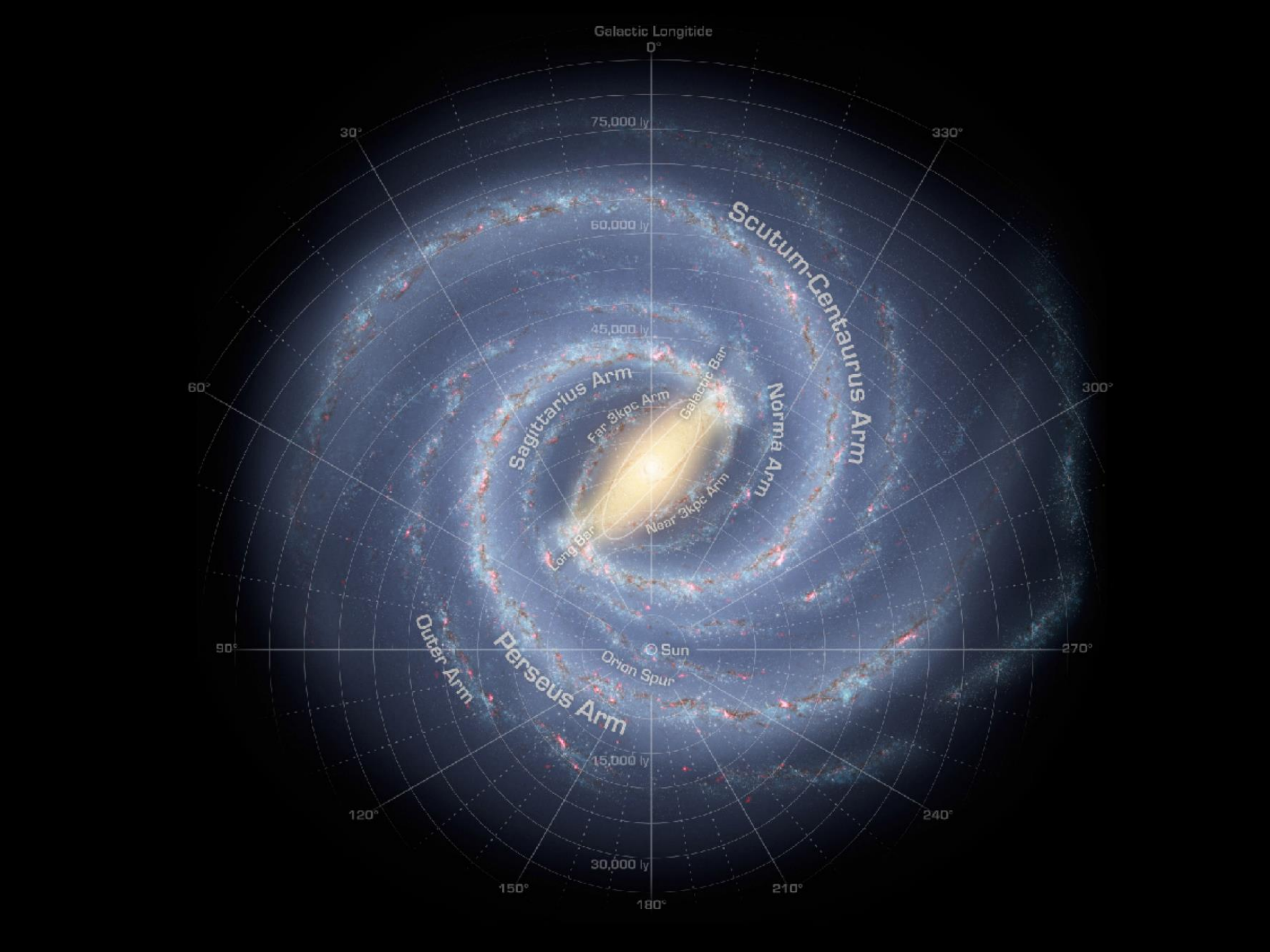


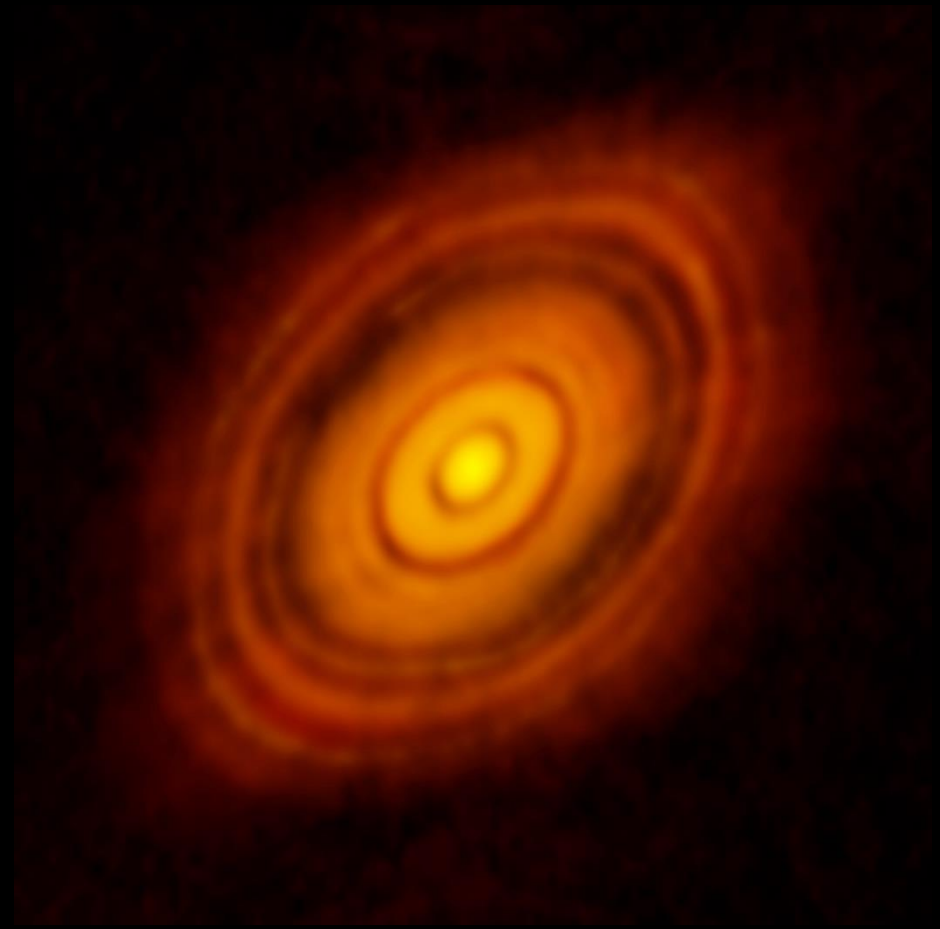
The Origin of the Solar System Elements

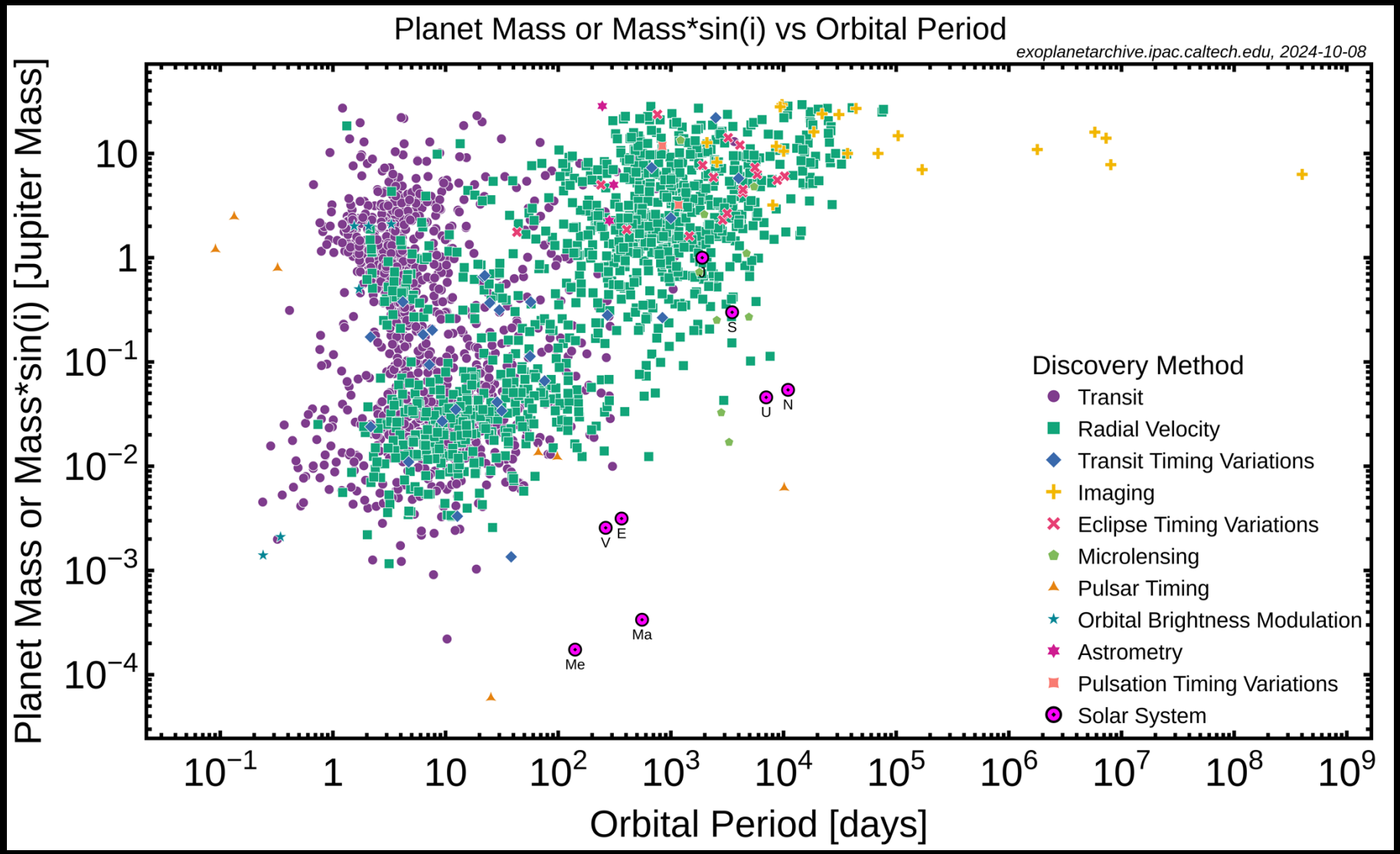


Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

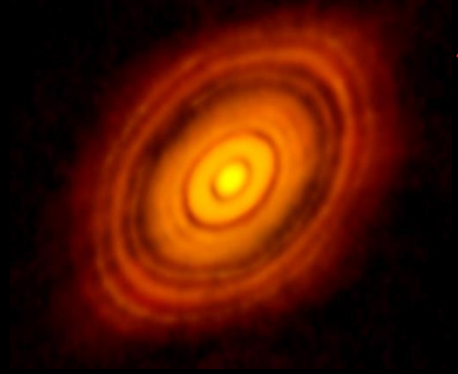
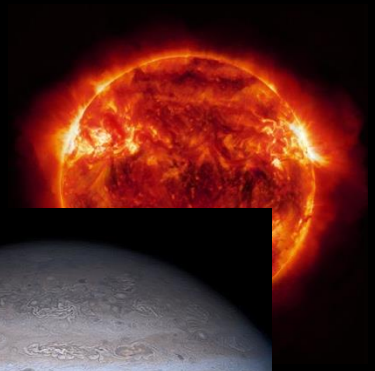
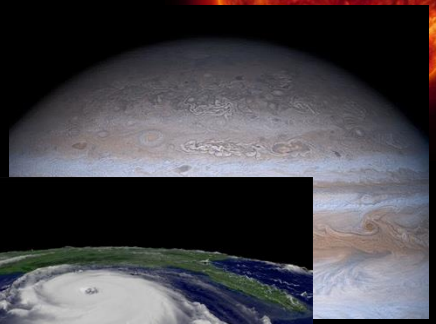
Astronomical Image Credits:
ESA/NASA/AASNova

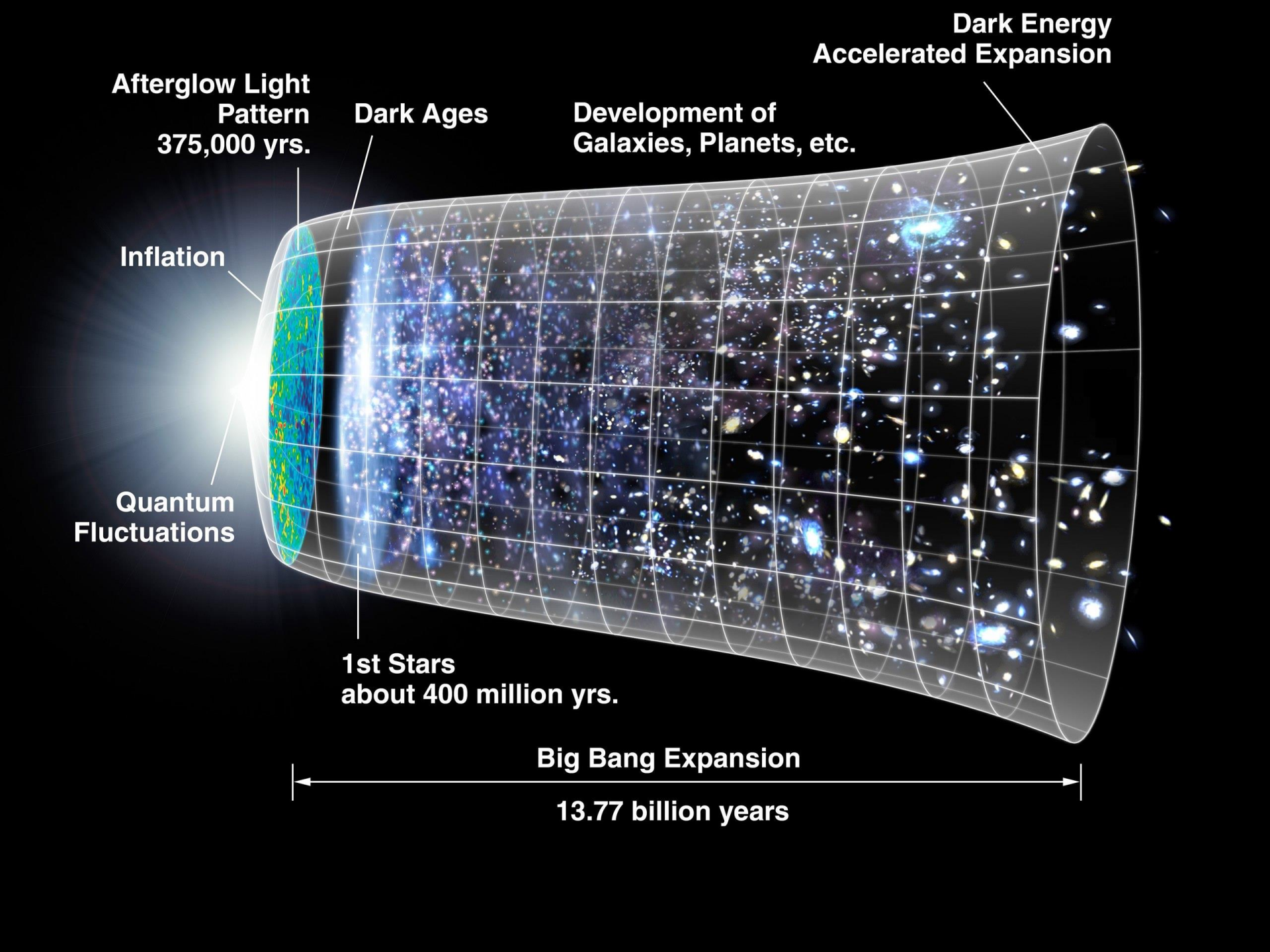

Galactic Longitide
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
Sun
Orion Spur

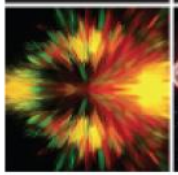
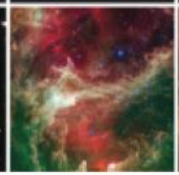
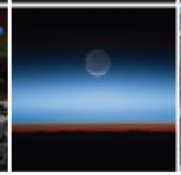



Planet Mass or Mass*sin(i) vs Orbital Period
exoplanetarchive.ipac.caltech.edu, 2024-10-08
Planet Mass or Mass*sin(i) [Jupiter Mass]
Orbital Period [days]
Discovery Method
Transit
Radial Velocity
Transit Timing Variations
Imaging
Eclipse Timing Variations
Microlensing
Pulsar Timing
Orbital Brightness Modulation
Astrometry
Pulsation Timing Variations
Solar System
J
S
U
N
V
E
Ma
Me

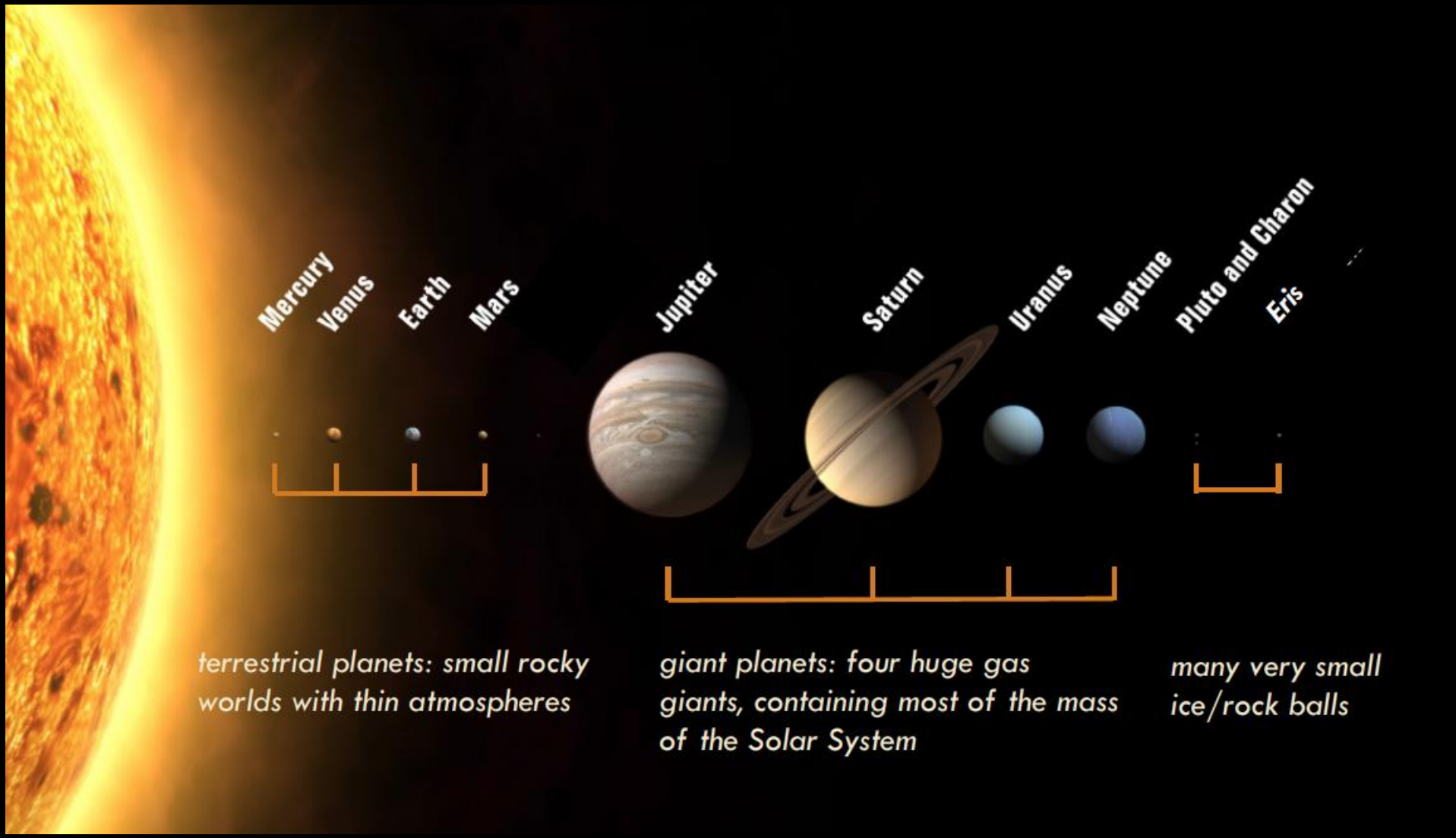


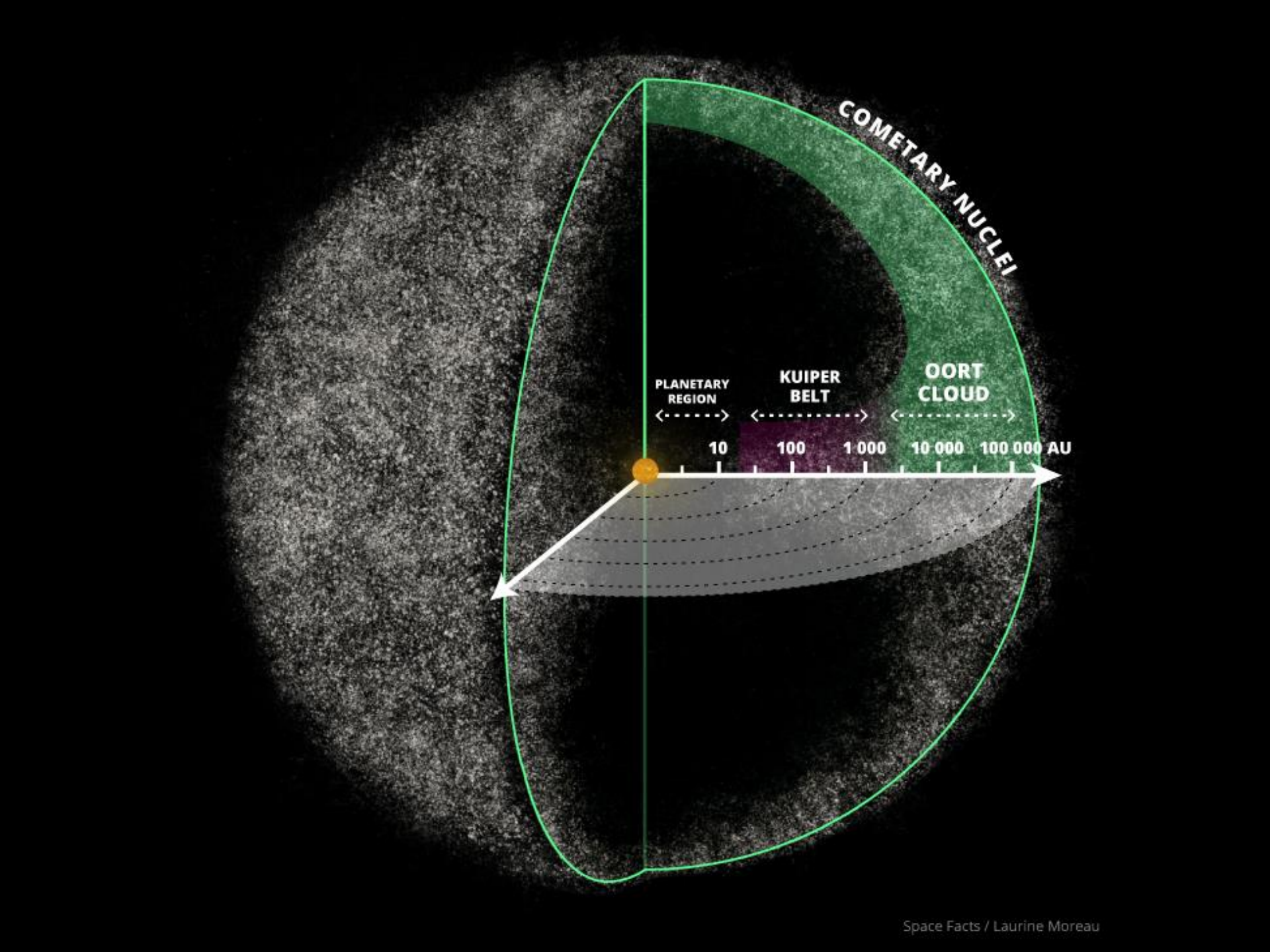





Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
375,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

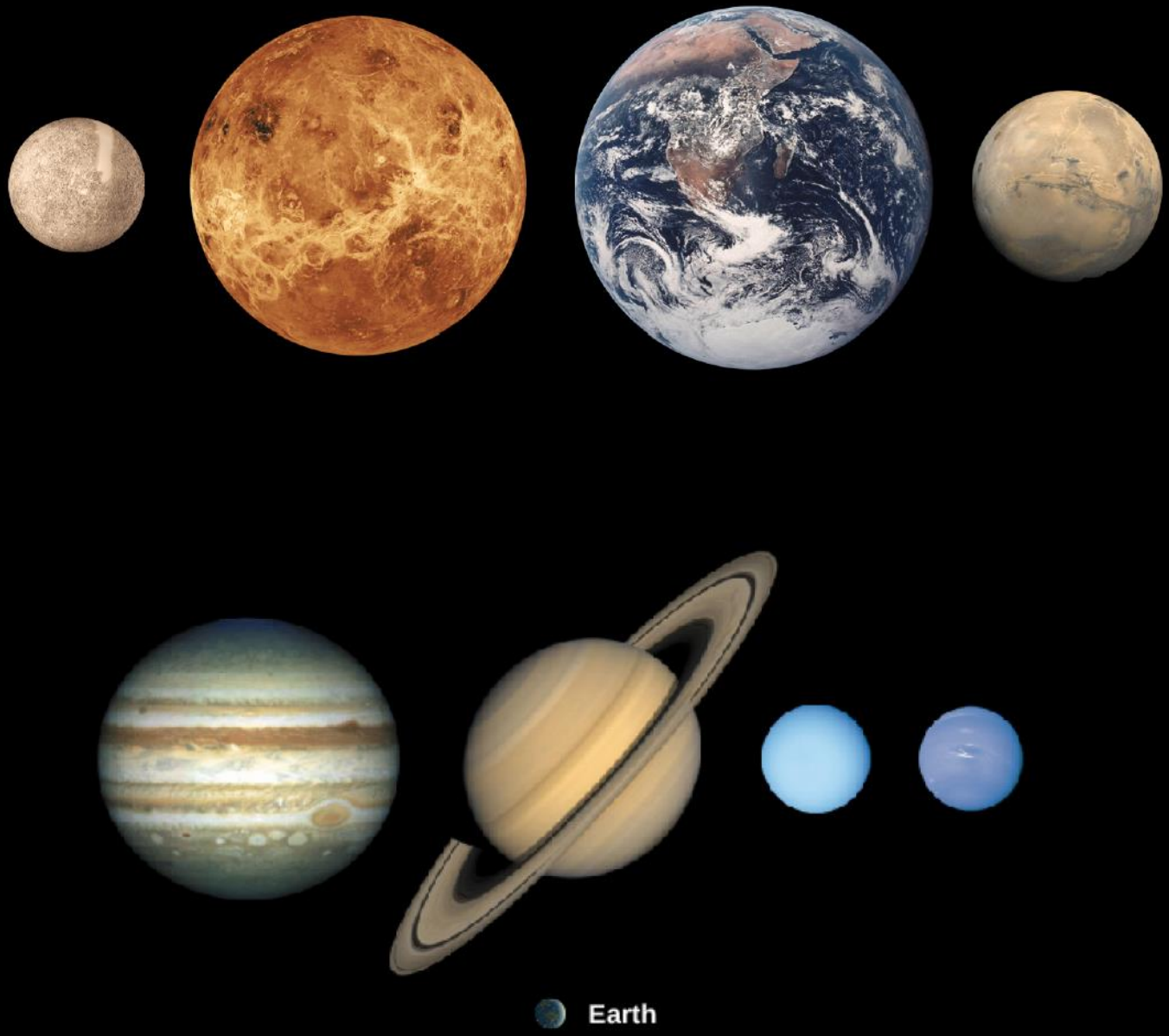
January	February	March	April	May	June	July	August	September	October	November
										
Big Bang occurs.				Milky Way Galaxy forms.				Our solar system forms. Life on Earth begins.	Earth's atmosphere becomes oxygenated.	First complex life forms appear.

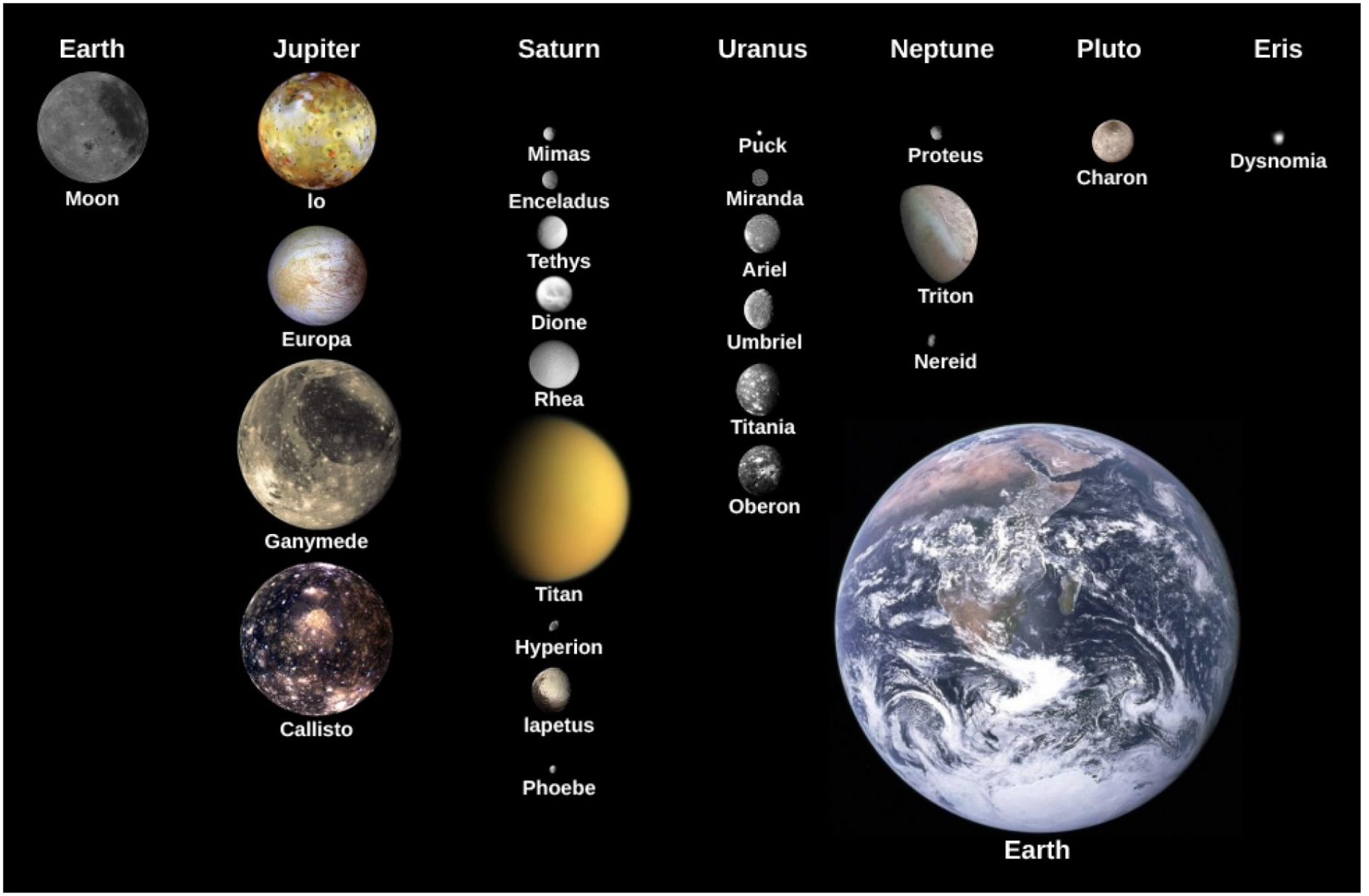
December						
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19 Vertebrates appear.	20 Land plants appear.	21
22	23	24	25 Dinosaurs appear.	26 Mammals appear.	27	28
29	30 Dinosaurs become extinct.	31 Humans appear.				

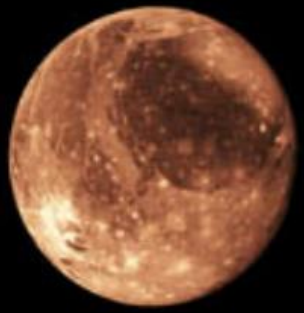

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto and Charon
Eris
terrestrial planets: small rocky worlds with thin atmospheres
giant planets: four huge gas giants, containing most of the mass of the Solar System
many very small ice/rock balls



Space Facts / Laurine Moreau

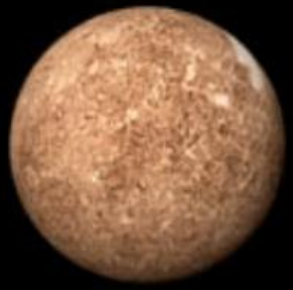

Earth


Earth
Moon
Jupiter
Io
Europa
Ganymede
Callisto
Saturn
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Uranus
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Neptune
Proteus
Triton
Nereid
Pluto
Charon
Eris
Dysnomia
Earth



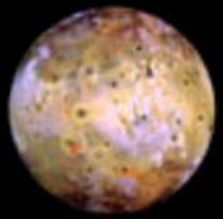
Ganymede
5262 km

Titan
5150 km



Mercury
4880 km

Callisto
4806 km

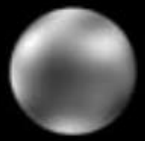


Io
3642 km

Moon
3476 km

Europa
3138 km

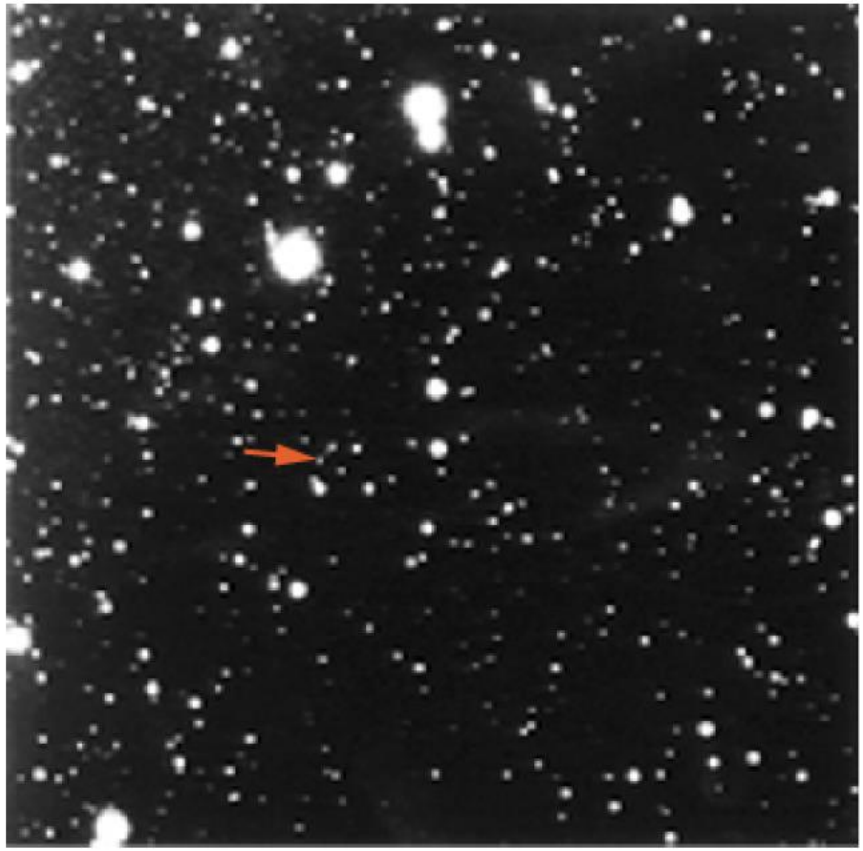
Triton
2706 km

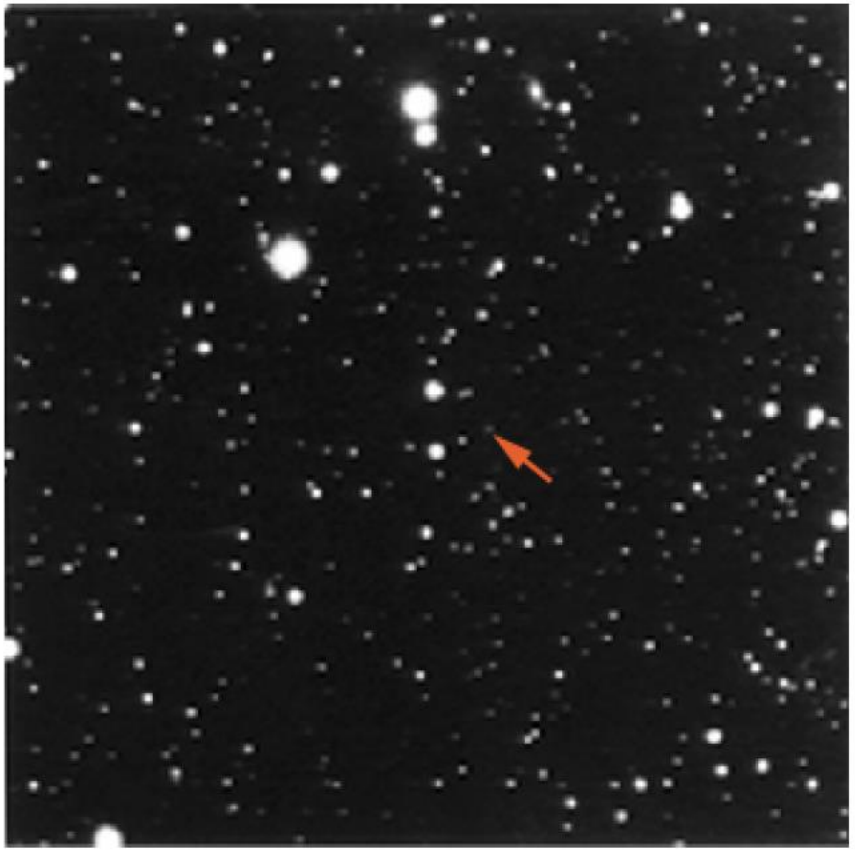


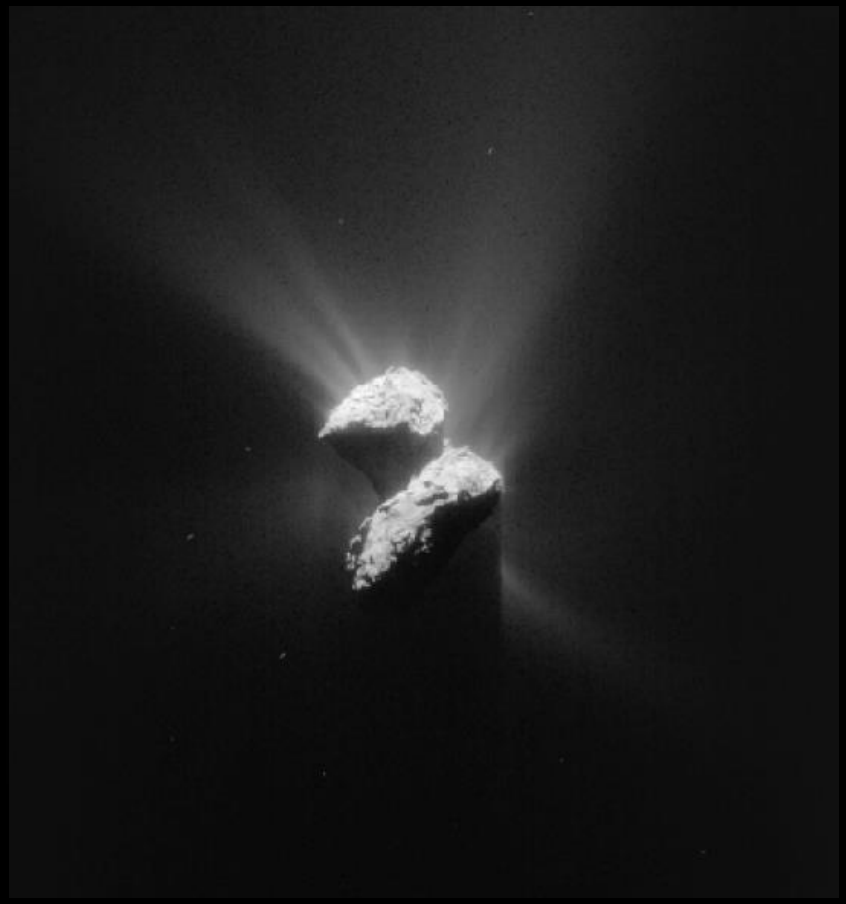
Pluto
2300 km

Titania
1580 km

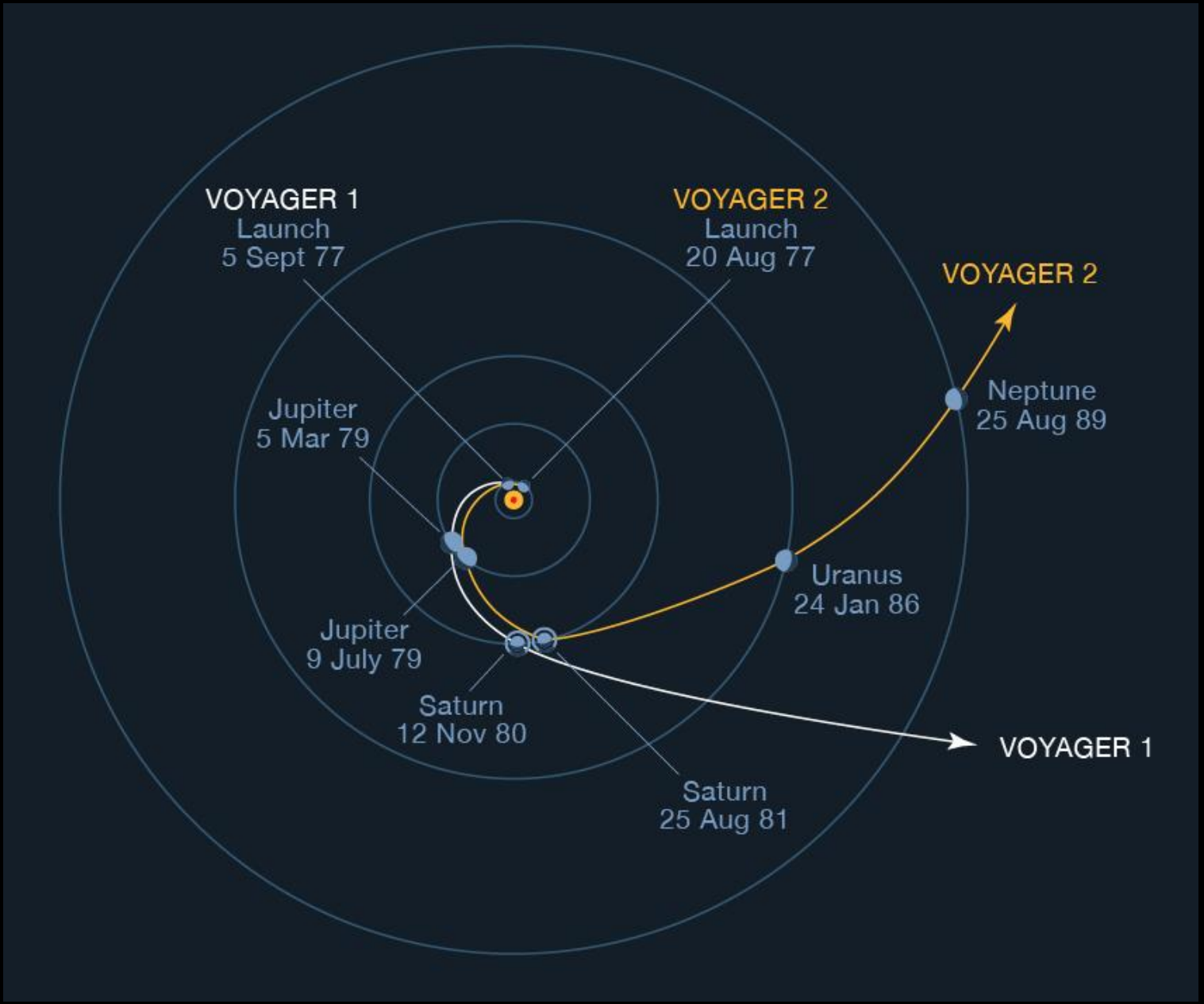
Discovery of Pluto

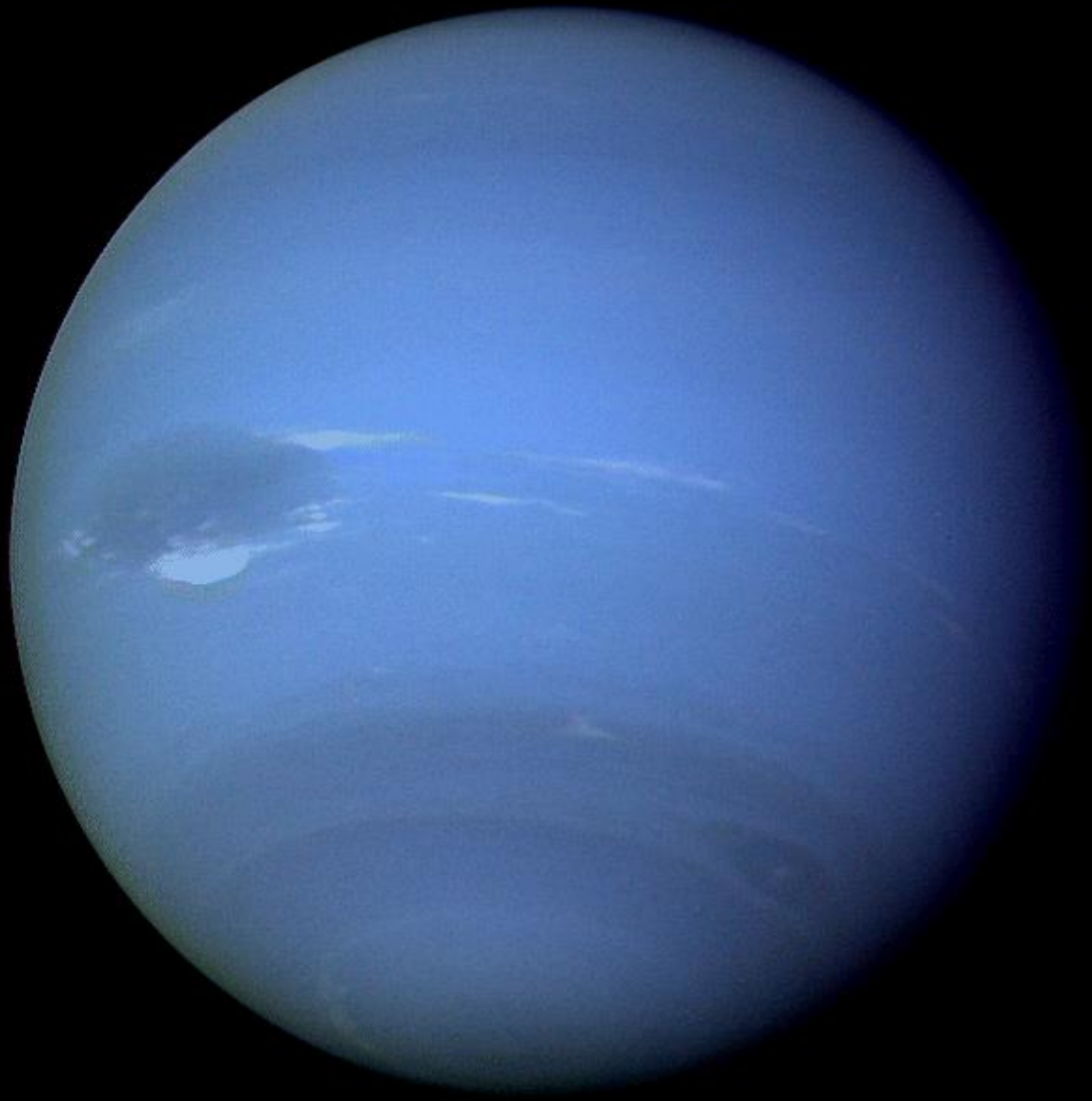






Asteroids


VOYAGER 1
Launch
5 Sept 77
VOYAGER 2
Launch
20 Aug 77
VOYAGER 2
Neptune
25 Aug 89
Jupiter
5 Mar 79
Uranus
24 Jan 86
Jupiter
9 July 79
Saturn
12 Nov 80
VOYAGER 1
Saturn
25 Aug 81

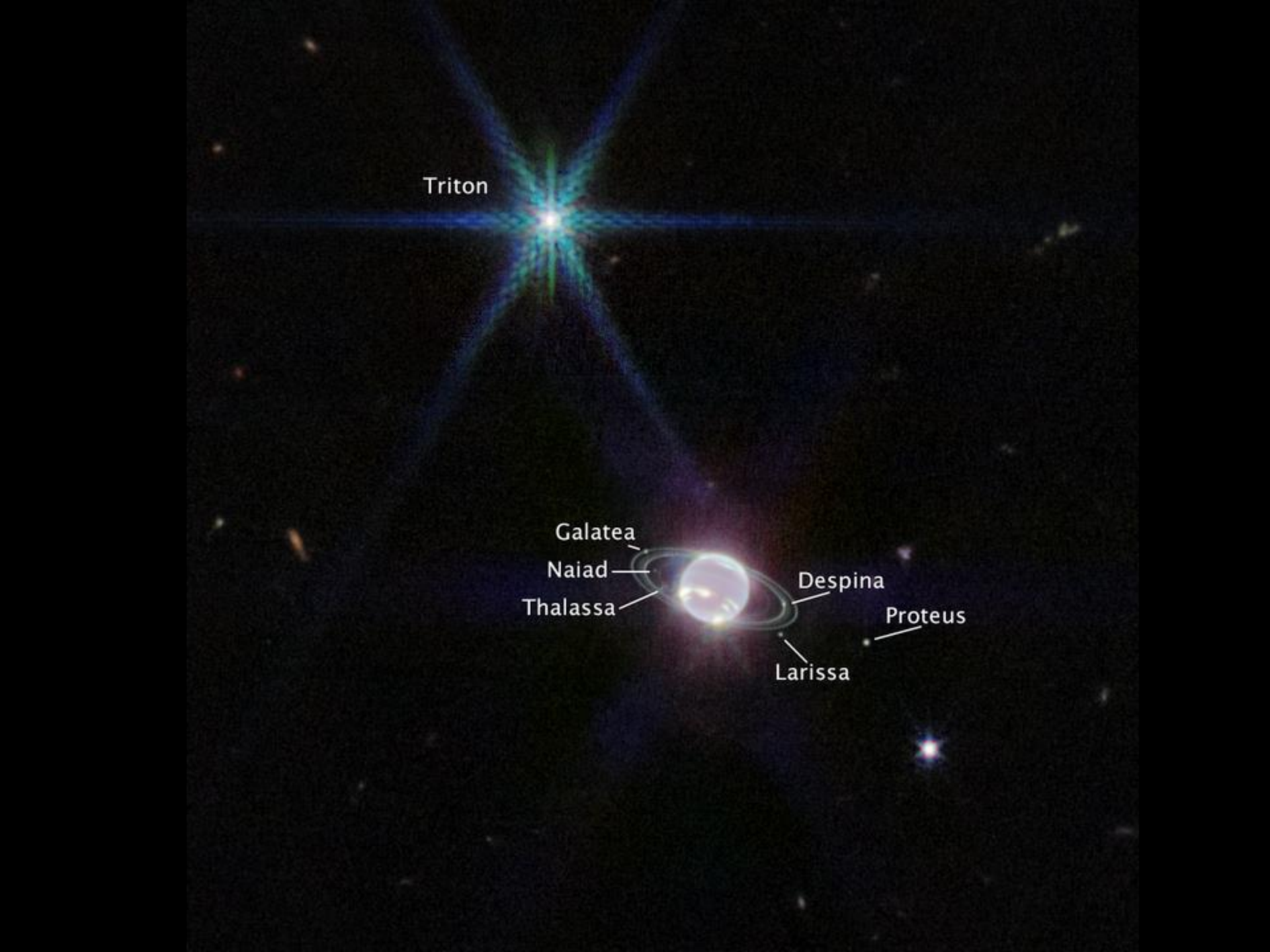


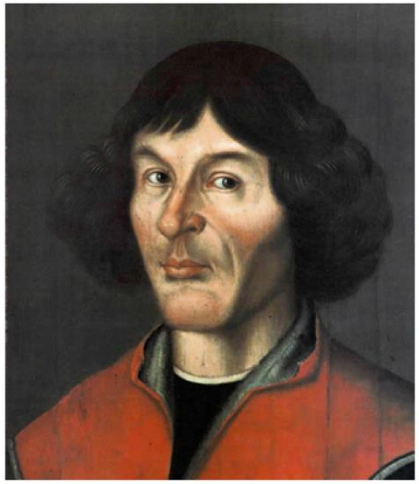
Neptune from Voyager

JAMES WEBB SPACE TELESCOPE

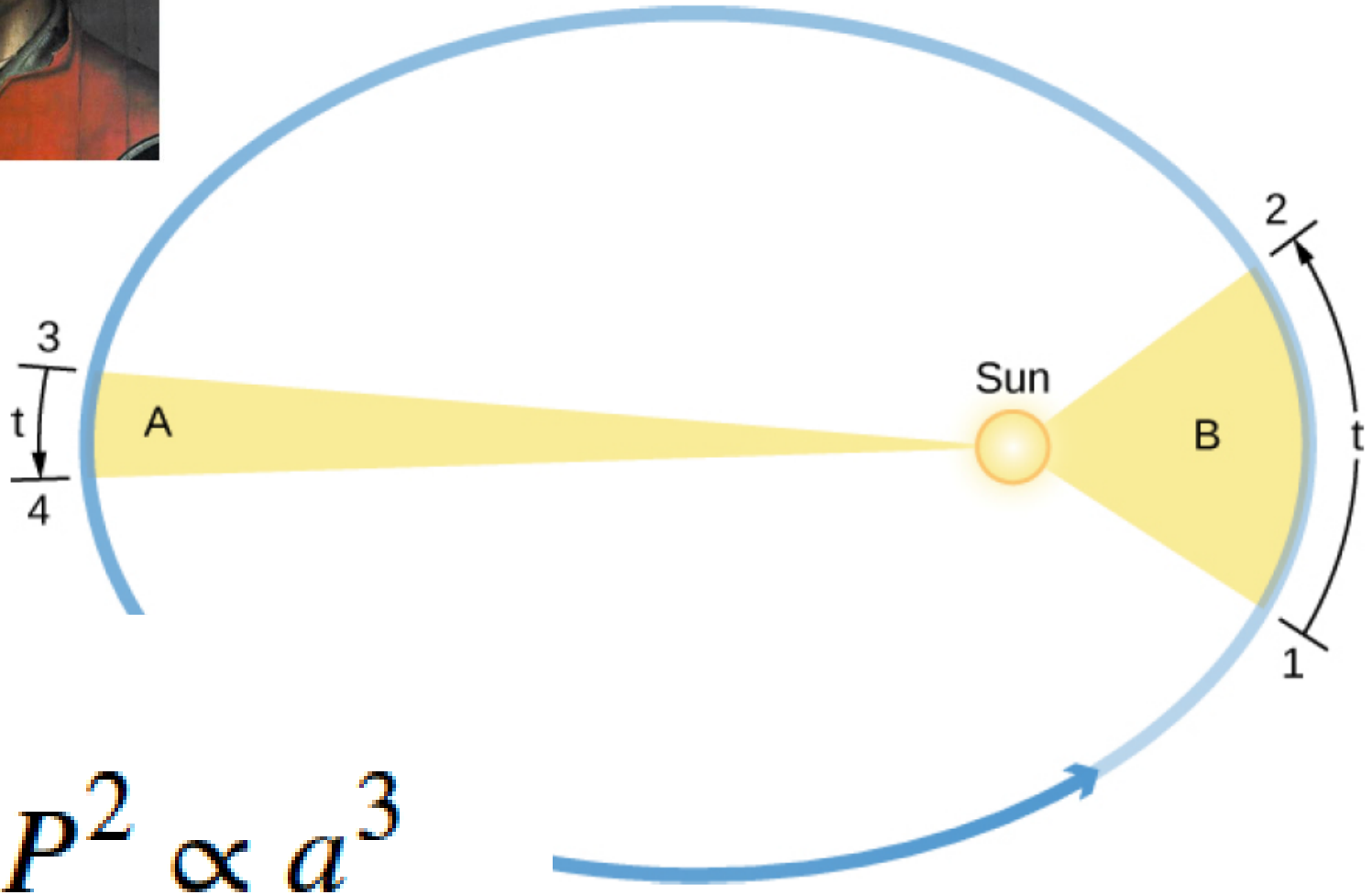
NEPTUNE

NIRCam Filters | F140M F210M F300M F460M


Triton
Galatea
Naiad
Thalassa
Despina
Proteus
Larissa



Kepler's Laws
(based on Tycho Brahe's data)

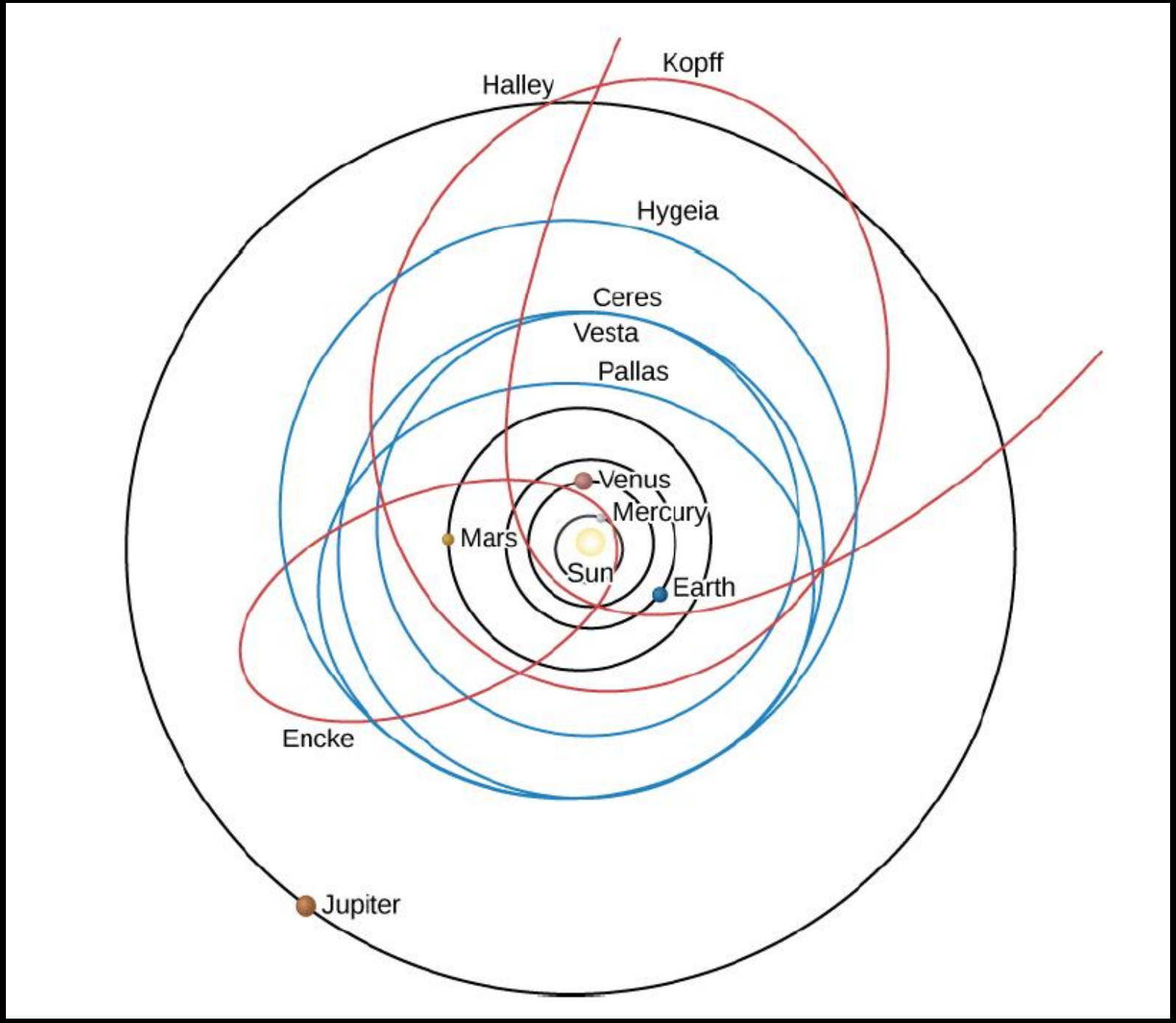


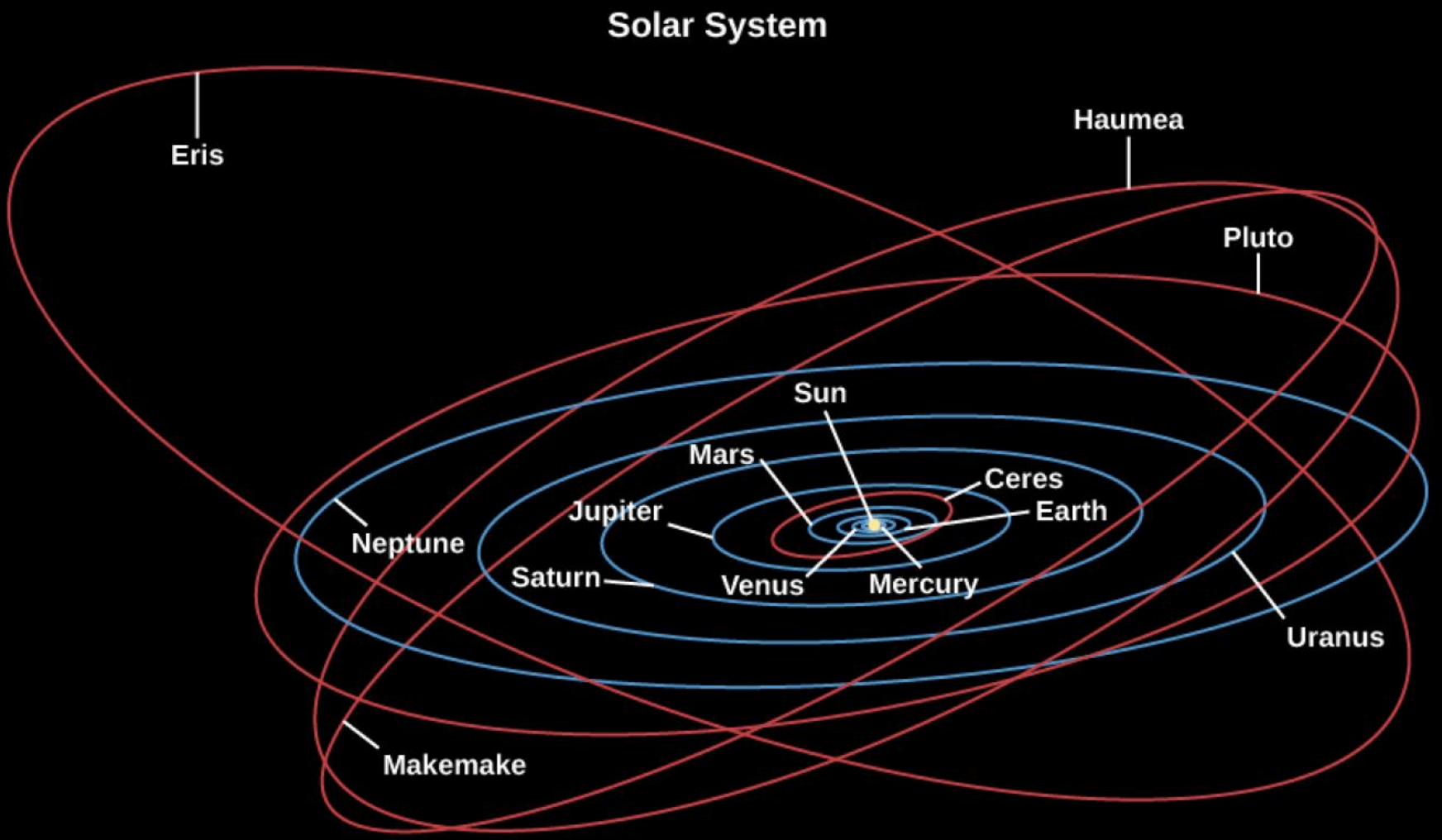
$$P^2 \propto a^3$$

Newton's Laws of Gravity

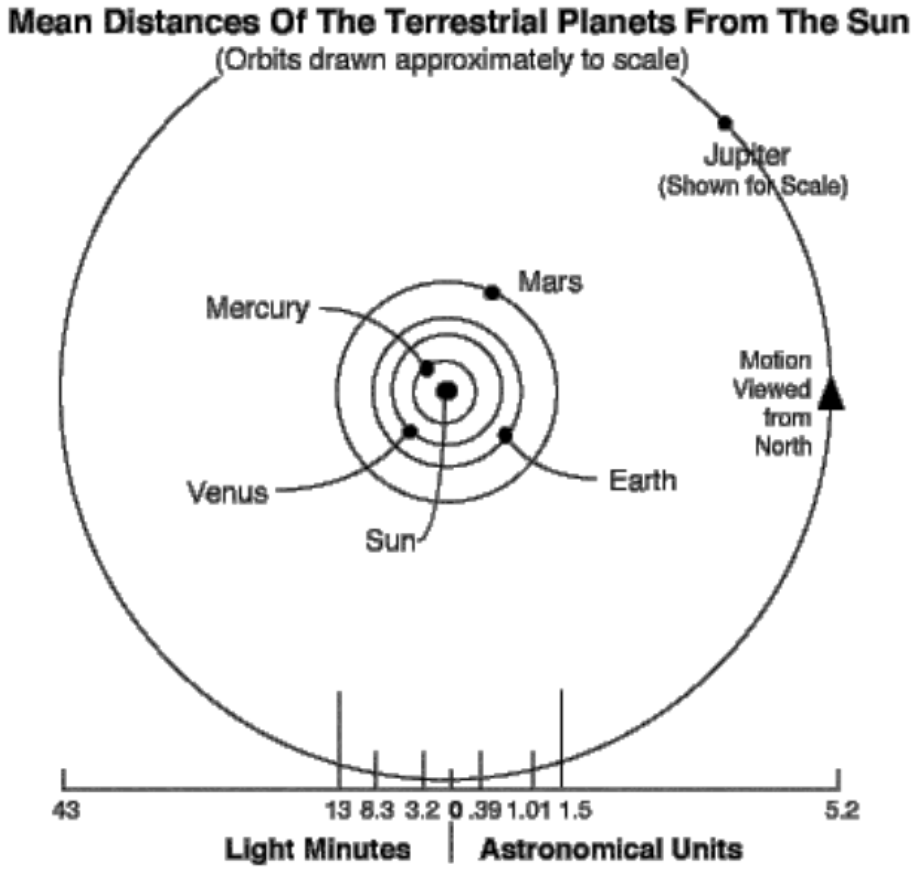
- **Newton's first law**: Every object will continue to be in a state of rest or move at a constant speed in a straight line unless it is compelled to change by an outside force.
- **Newton's second law**: The change of motion of a body is proportional to and in the direction of the force acting on it.
- **Newton's third law**: For every action there is an equal and opposite reaction (*or:* the mutual actions of two bodies upon each other are always equal and act in opposite directions).

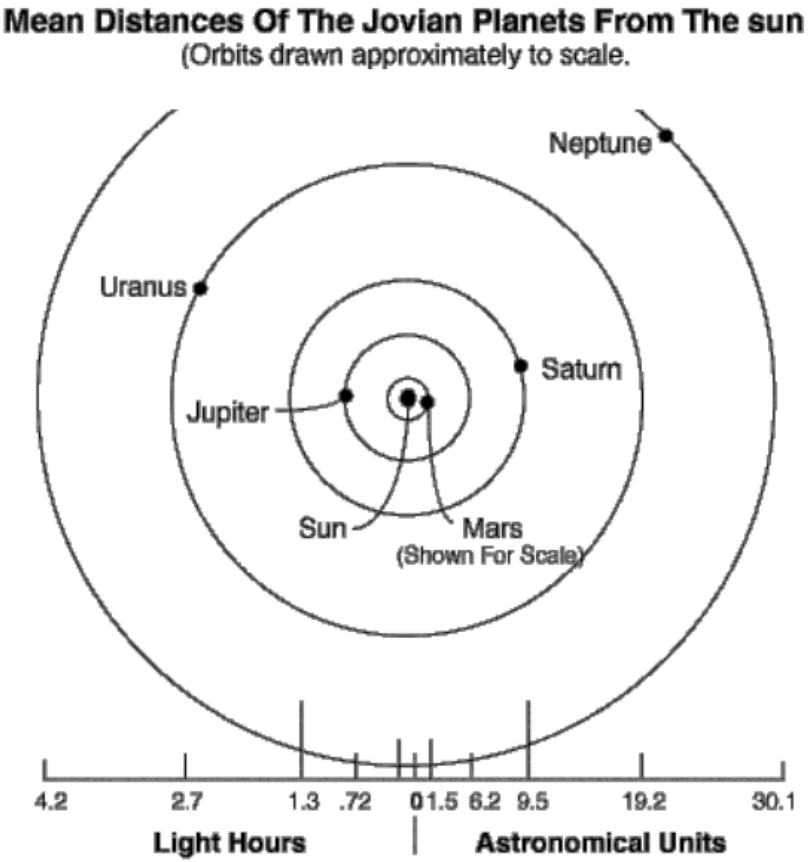
$$F_{\text{gravity}} = G\frac{M_1 M_2}{R^2}$$


Halley
Kopff
Hygeia
Ceres
Vesta
Pallas
Venus
Mercury
Mars
Sun
Earth
Encke
Jupiter

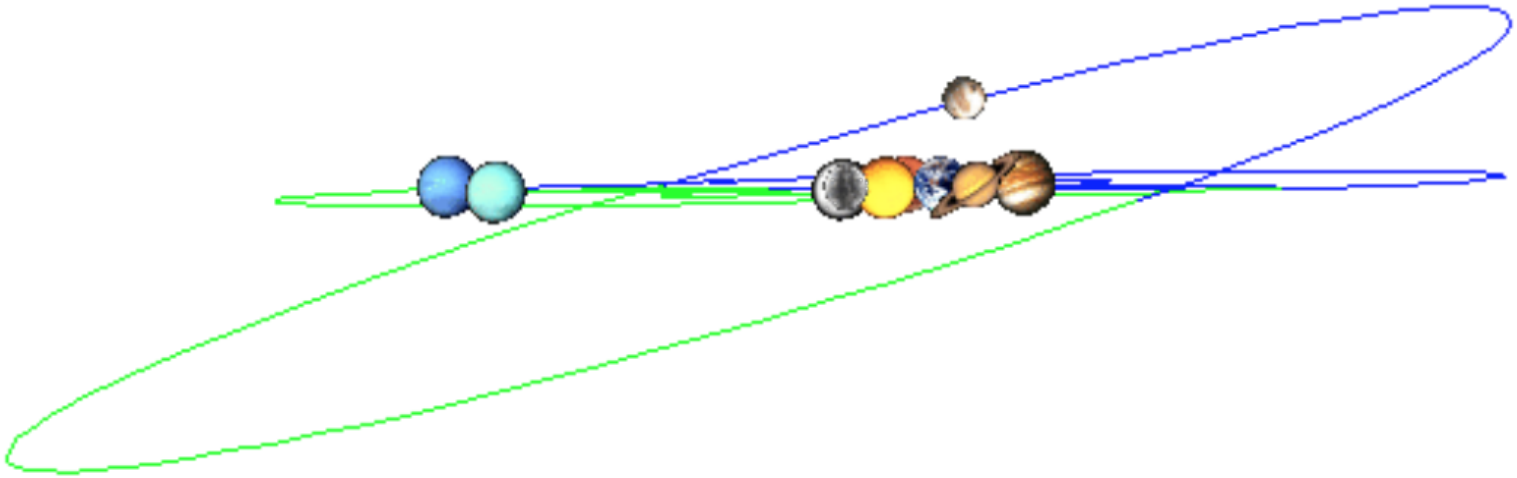

Solar System
Eris
Haumea
Pluto
Sun
Mars
Ceres
Jupiter
Earth
Neptune
Saturn
Venus
Mercury
Uranus
Makemake

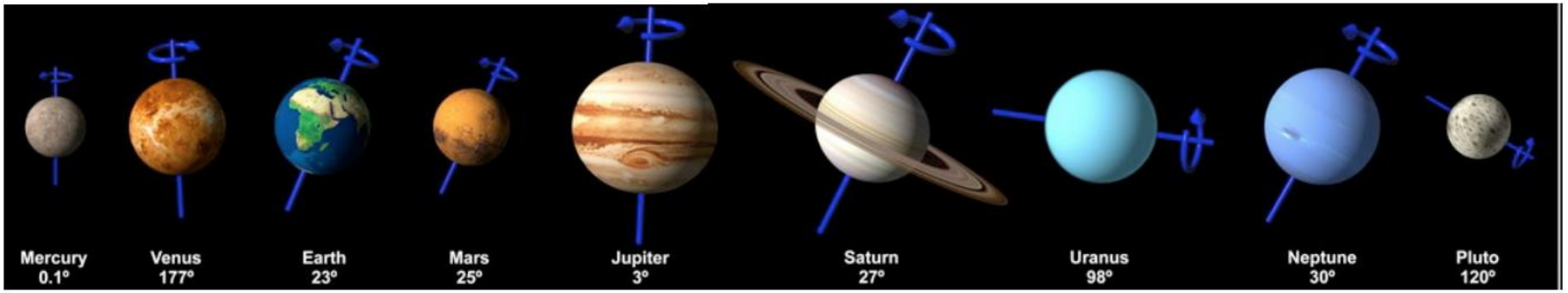
The orbits of the planets are very nearly circular and concentric.





All the planets (but not Pluto) orbit in the same direction and in the same plane: the *ecliptic* (to within 6o).

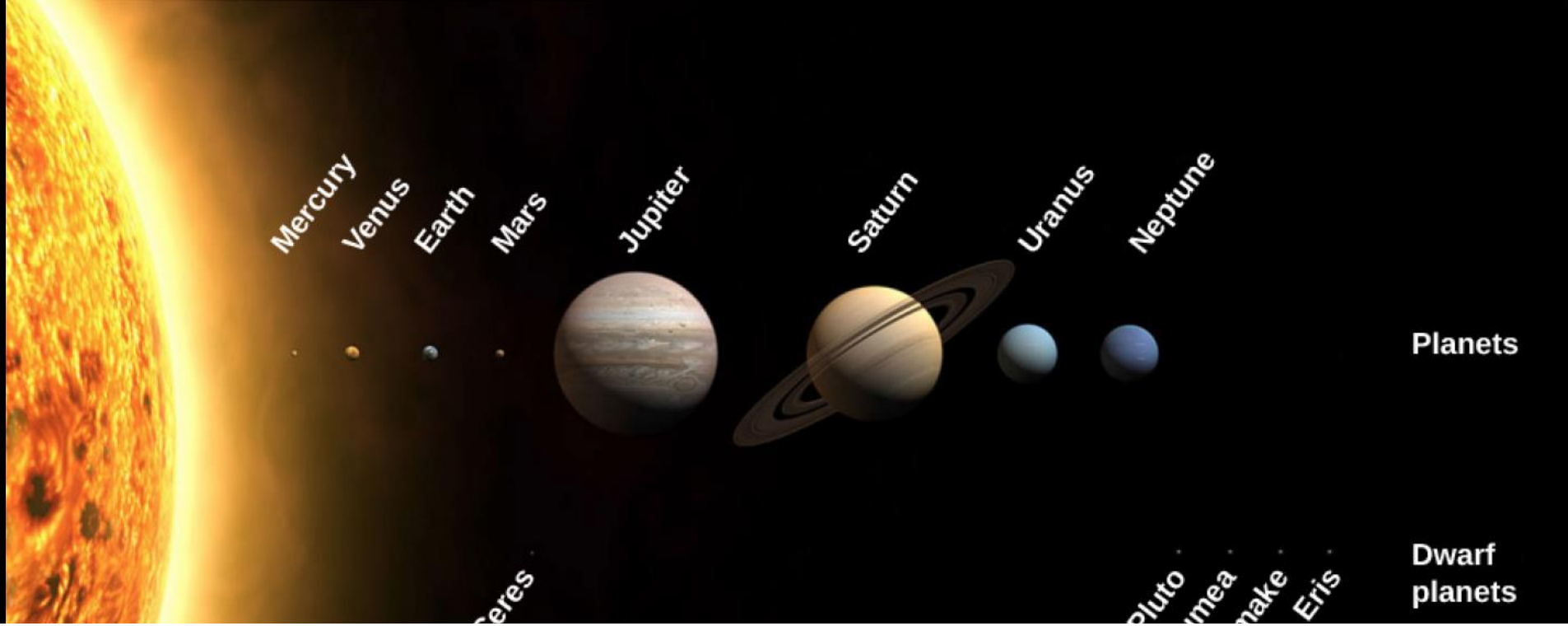



Mercury
0.1°
Venus
177°
Earth
23°
Mars
25°
Jupiter
3°
Saturn
27°
Uranus
98°
Neptune
30°
Pluto
120°

Orbital Data for the Planets

Planet	Semimajor Axis (AU)	Period (y)	Eccentricity
Mercury	0.39	0.24	0.21
Venus	0.72	0.6	0.01
Earth	1	1.00	0.02
Mars	1.52	1.88	0.09
(Ceres)	2.77	4.6	0.08
Jupiter	5.20	11.86	0.05
Saturn	9.54	29.46	0.06
Uranus	19.19	84.01	0.05

$$P^2 \propto a^3$$

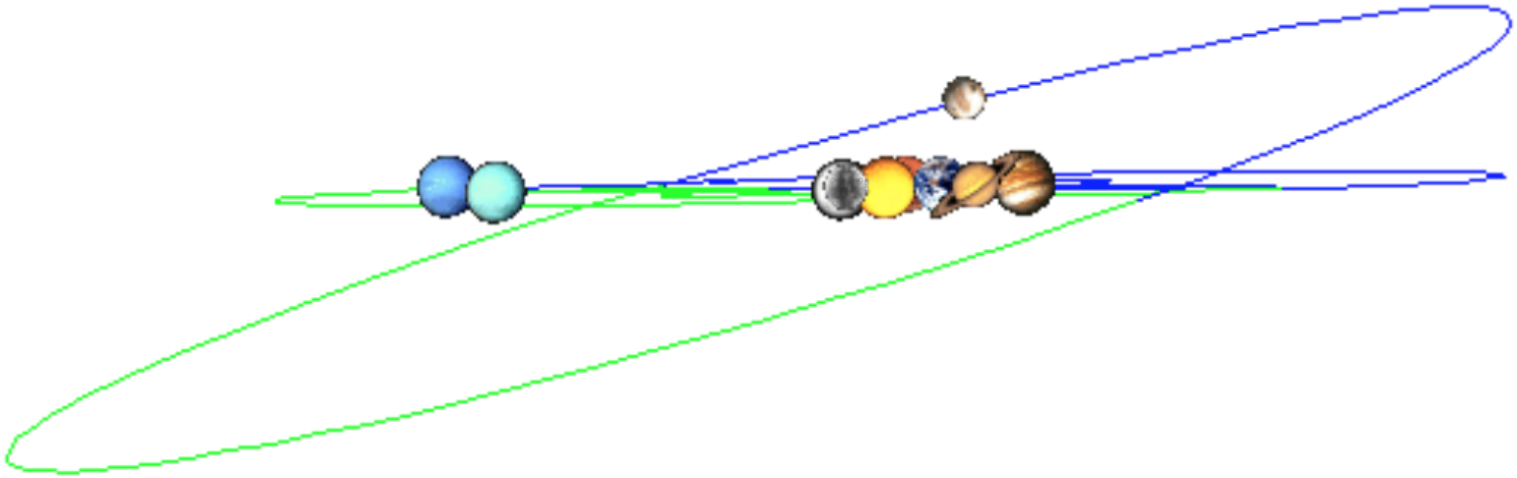


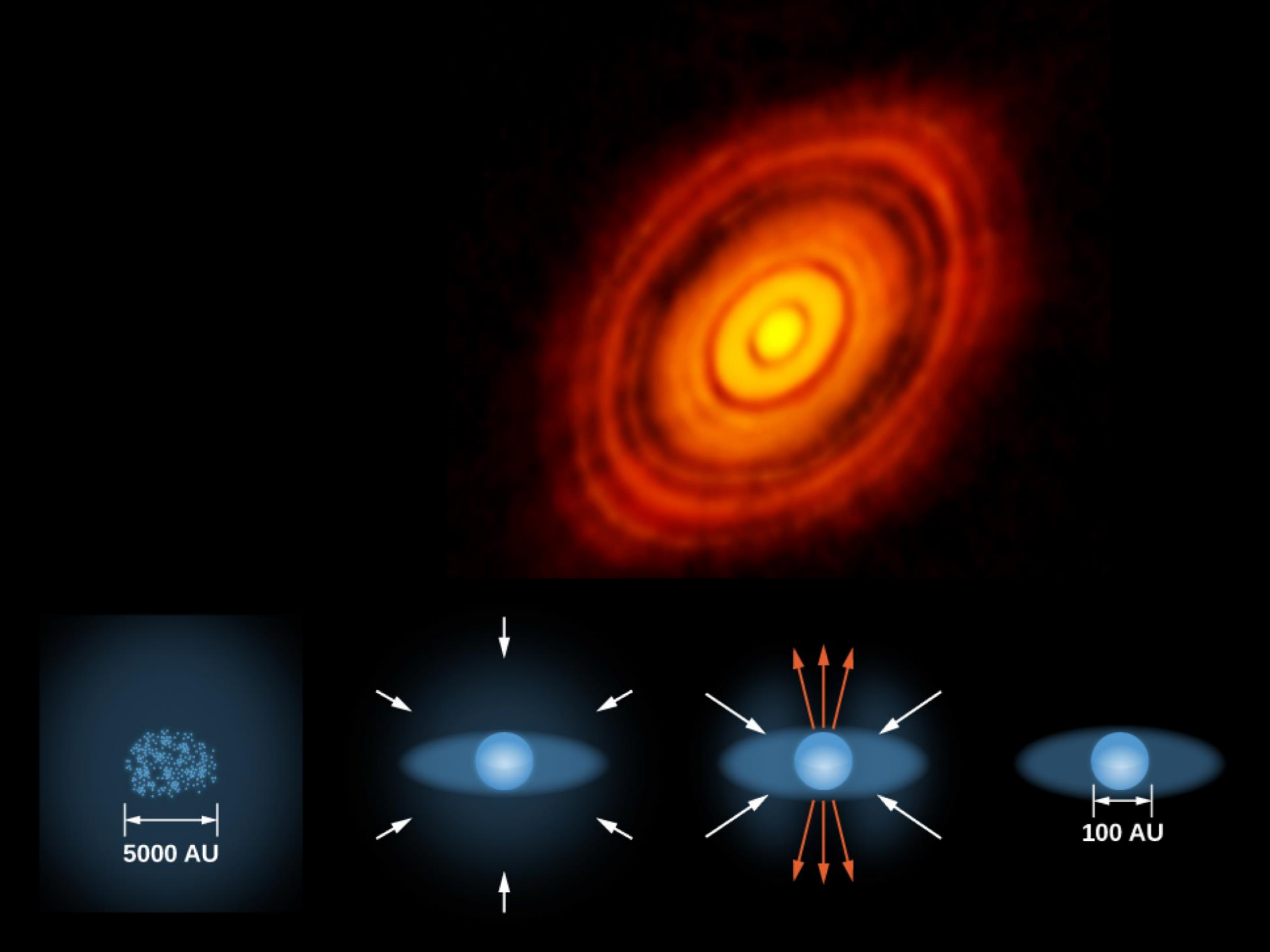
Object	Percentage of Total Mass of Solar System
Sun	99.80
Jupiter	0.10
Comets	0.0005–0.03 (estimate)
All other planets and dwarf planets	0.04
Moons and rings	0.00005

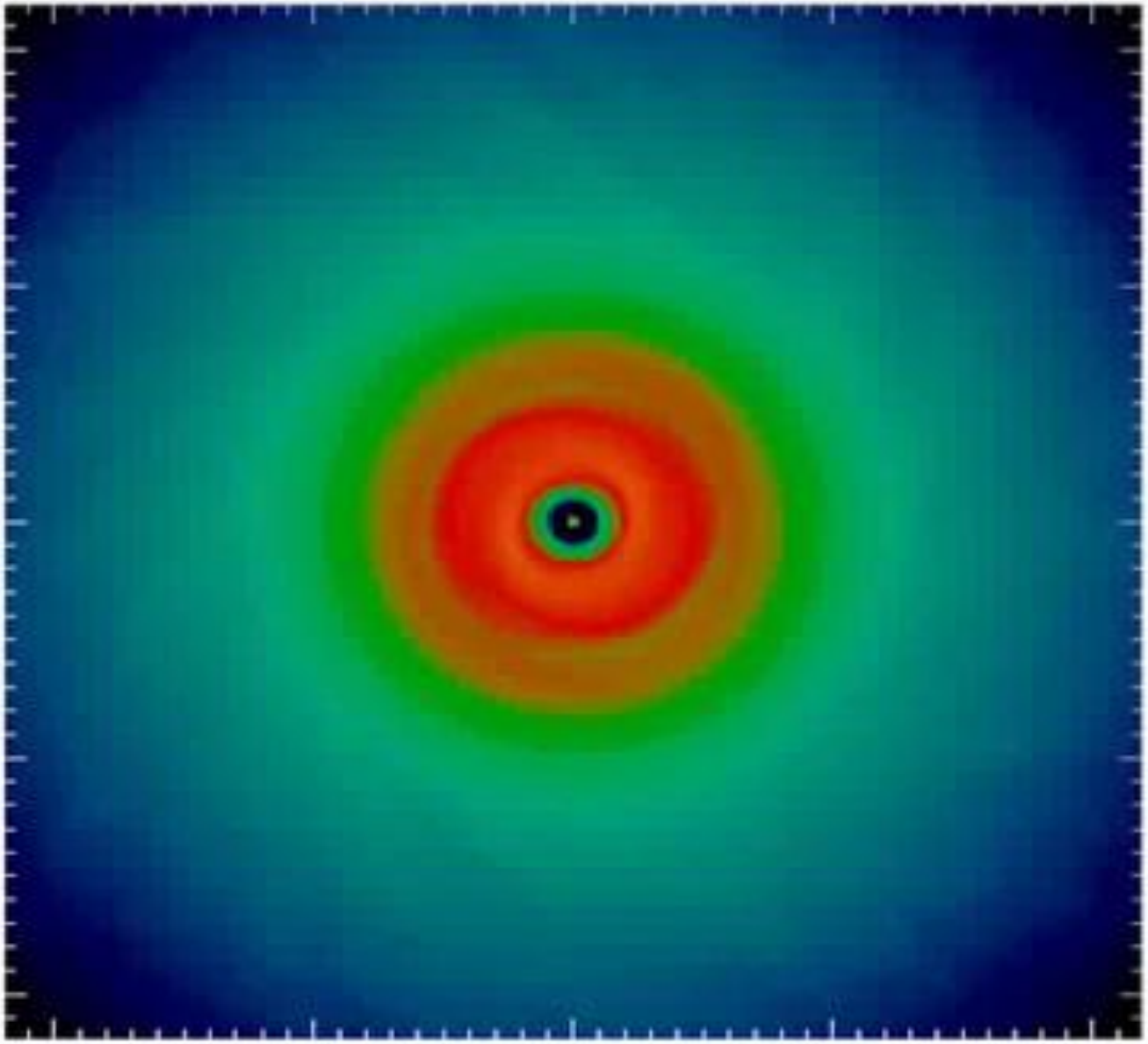
The Planets

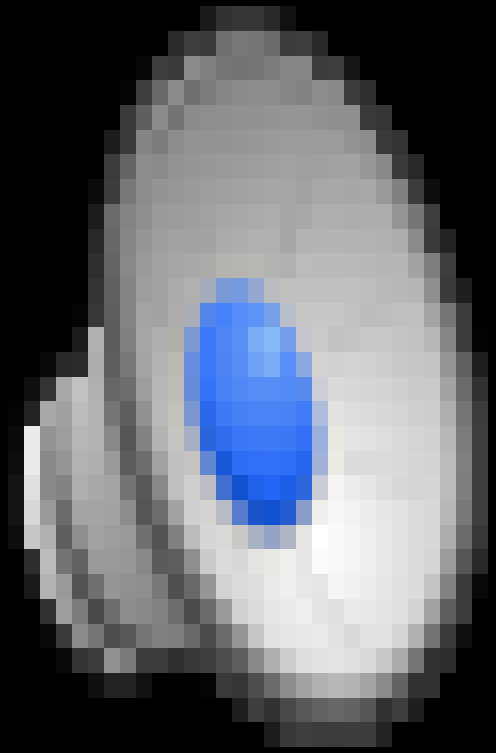
Name	Distance from Sun (AU)[2]	Revolution Period (y)	Diameter (km)	Mass (10^{23} kg)	Density (g/cm^3)[3]
Mercury	0.39	0.24	4,878	3.3	5.4
Venus	0.72	0.62	12,120	48.7	5.2
Earth	1.00	1.00	12,756	59.8	5.5
Mars	1.52	1.88	6,787	6.4	3.9
Jupiter	5.20	11.86	142,984	18,991	1.3
Saturn	9.54	29.46	120,536	5686	0.7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

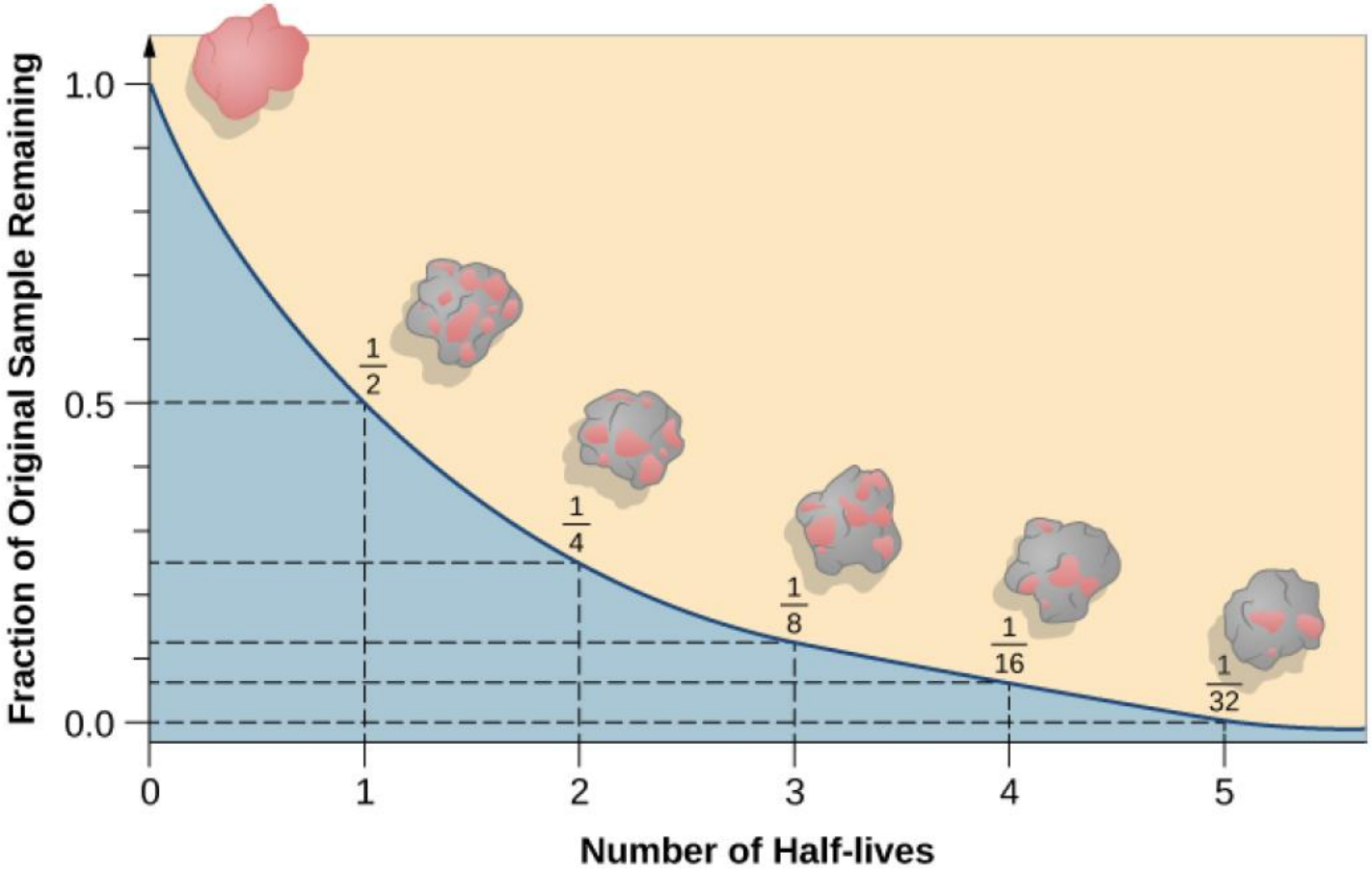
All the planets (but not Pluto) orbit in the same direction and in the same plane: the *ecliptic* (to within 6o).




5000 AU
100 AU



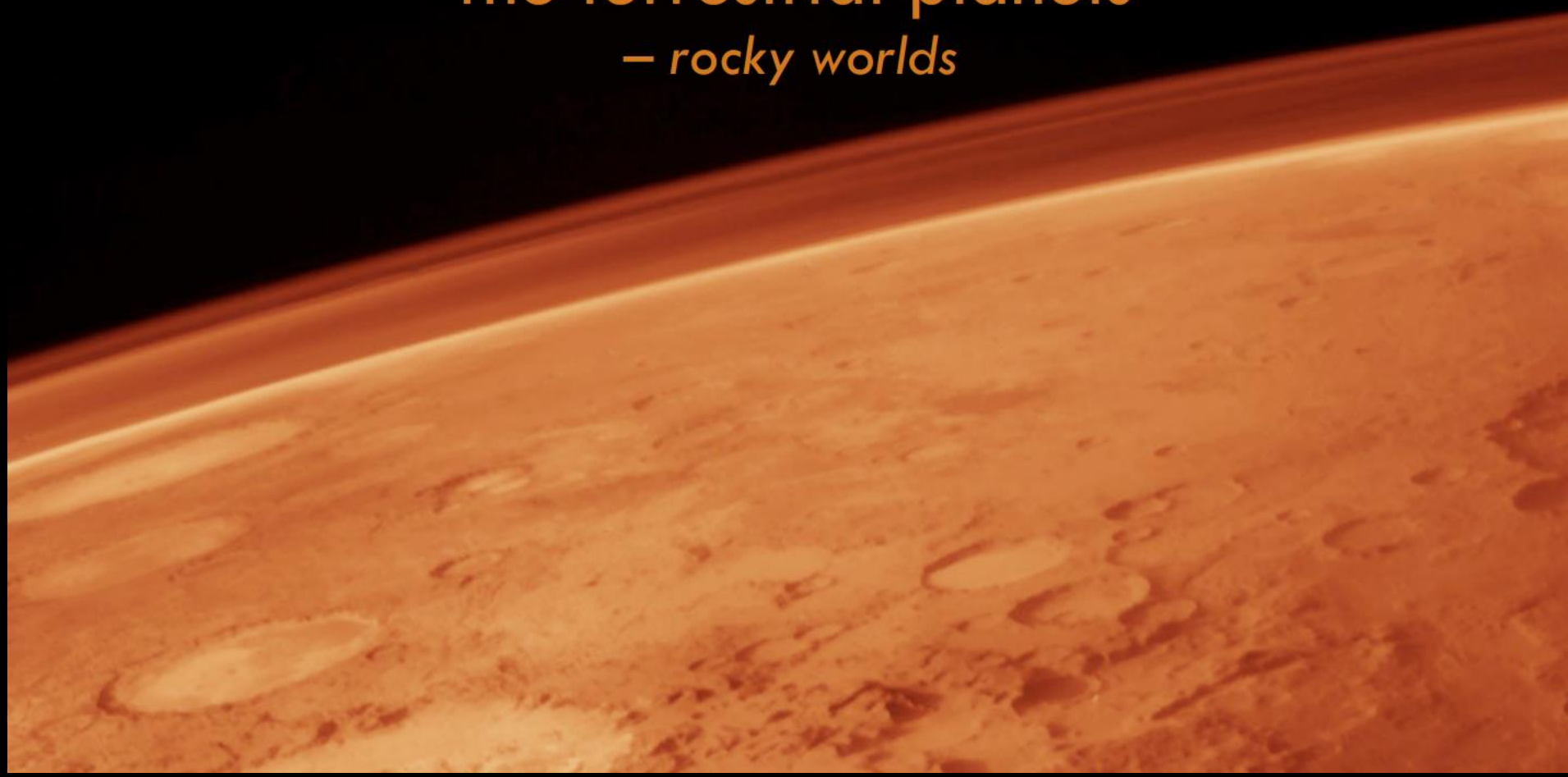




Parent	Daughter	Half-Life (billions of years)
Samarium-147	Neodymium-143	106
Rubidium-87	Strontium-87	48.8
Thorium-232	Lead-208	14.0
Uranium-238	Lead-206	4.47
Potassium-40	Argon-40	1.31

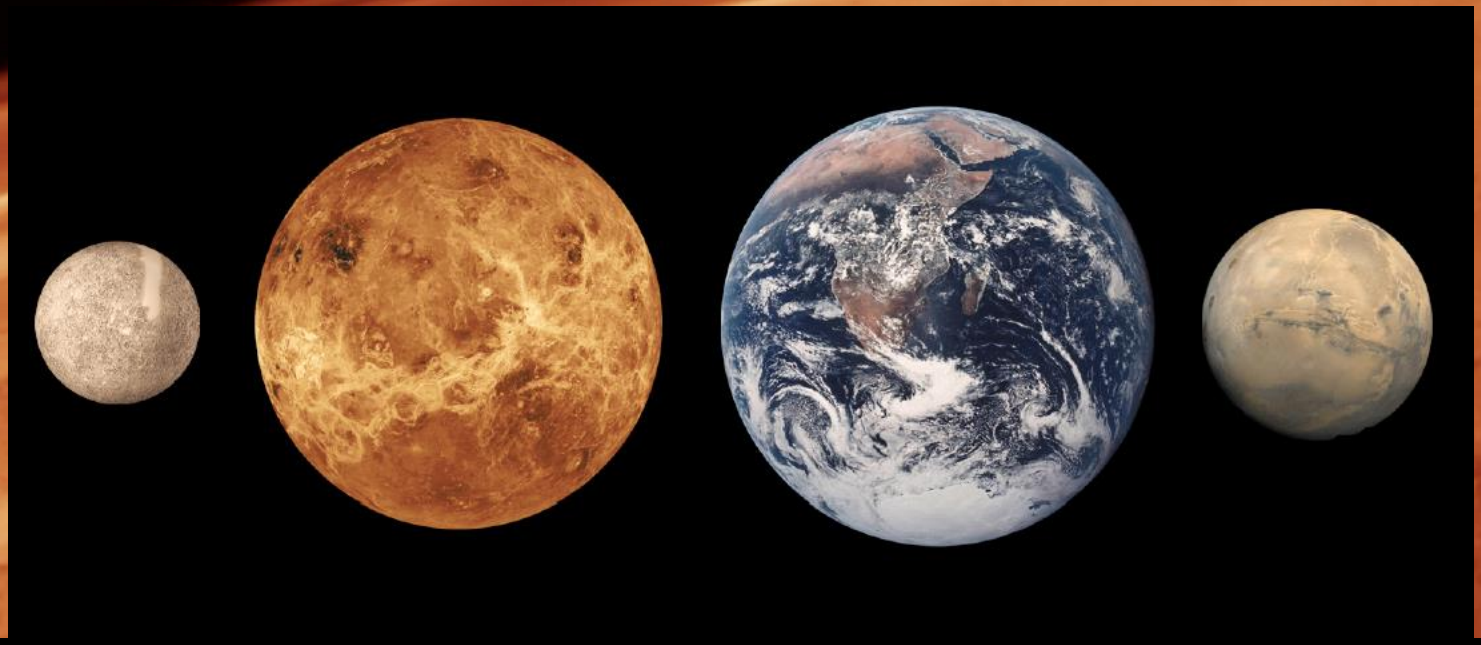
The terrestrial planets

– rocky worlds



The terrestrial planets

– rocky worlds

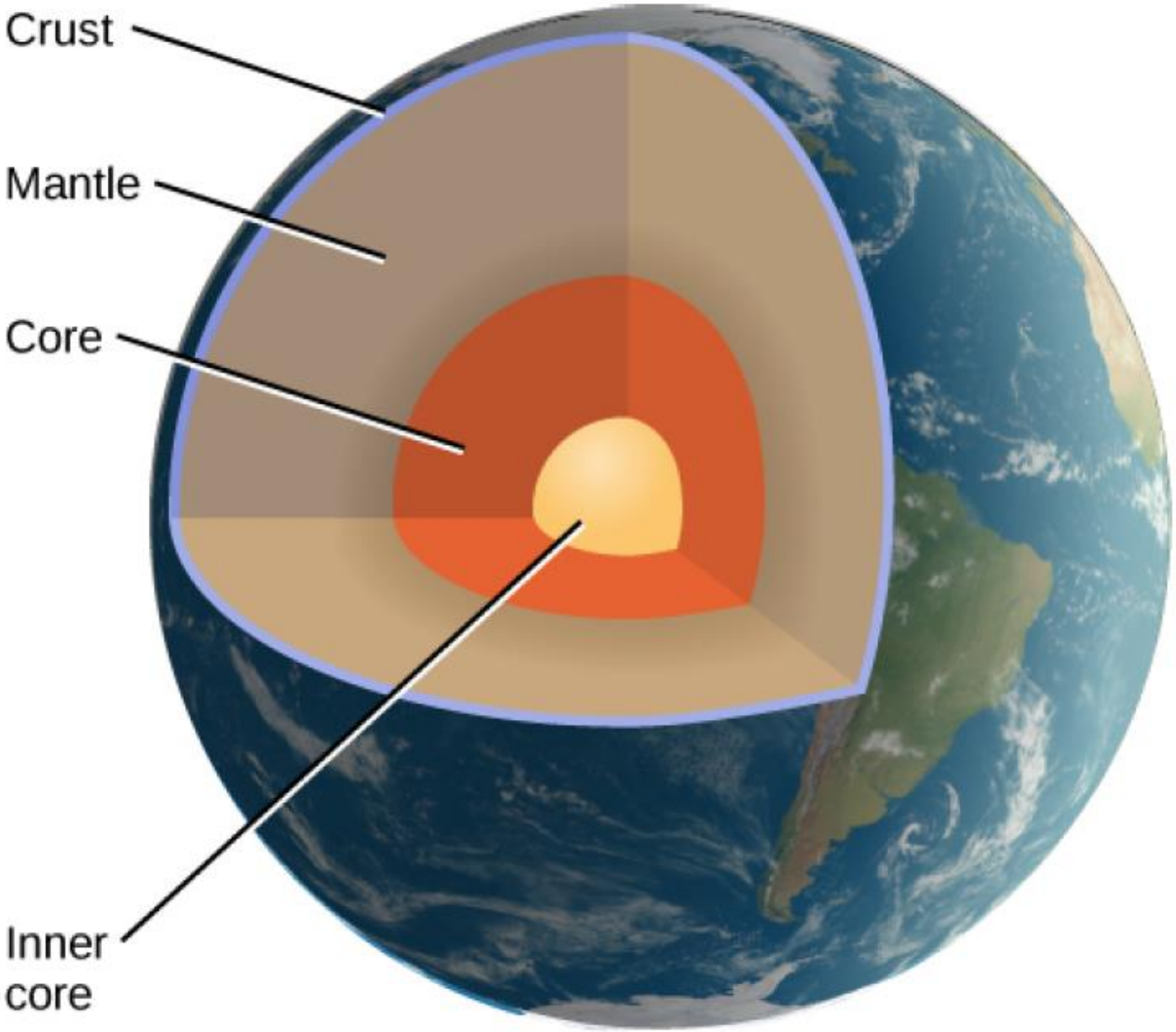


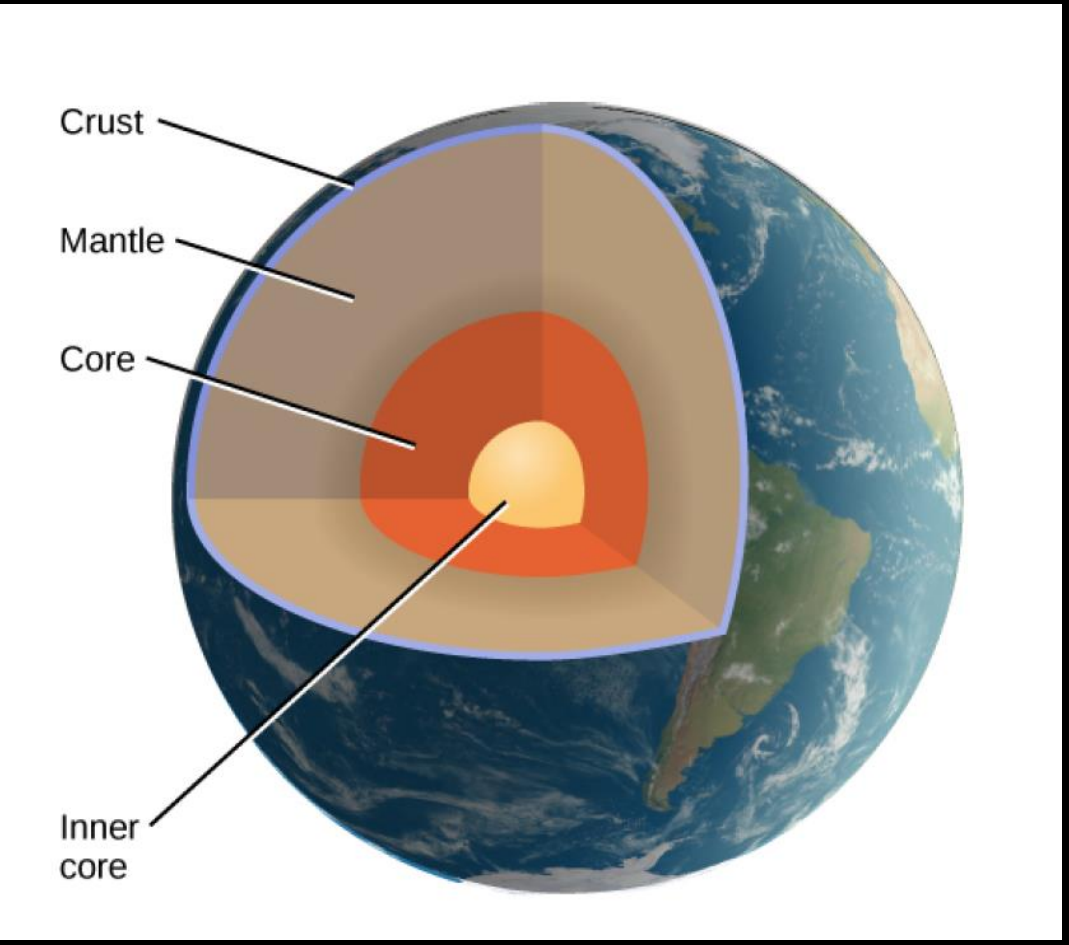
Surfaces of terrestrial planets

Bombardment (collisions with asteroids/comets)

Volcanism (includes earthquakes)
    requires molten core

Erosion (if atmosphere)

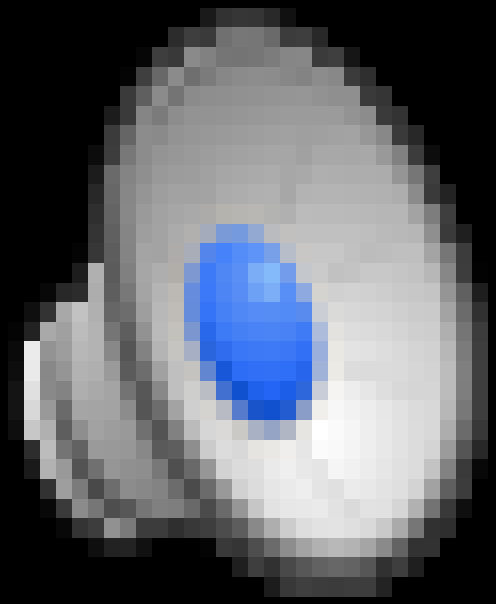

Crust
Mantle
Core
Inner
core

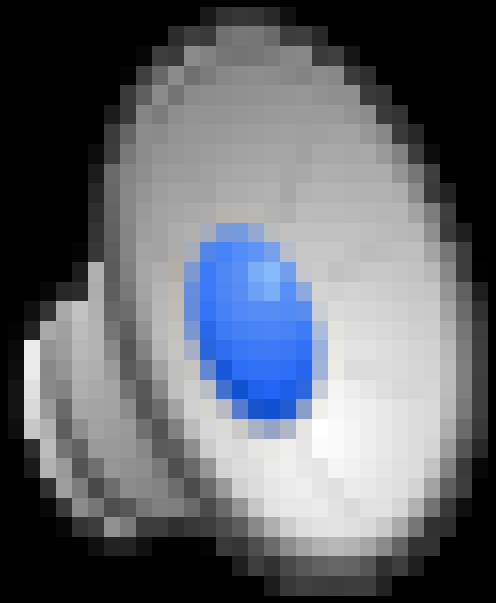


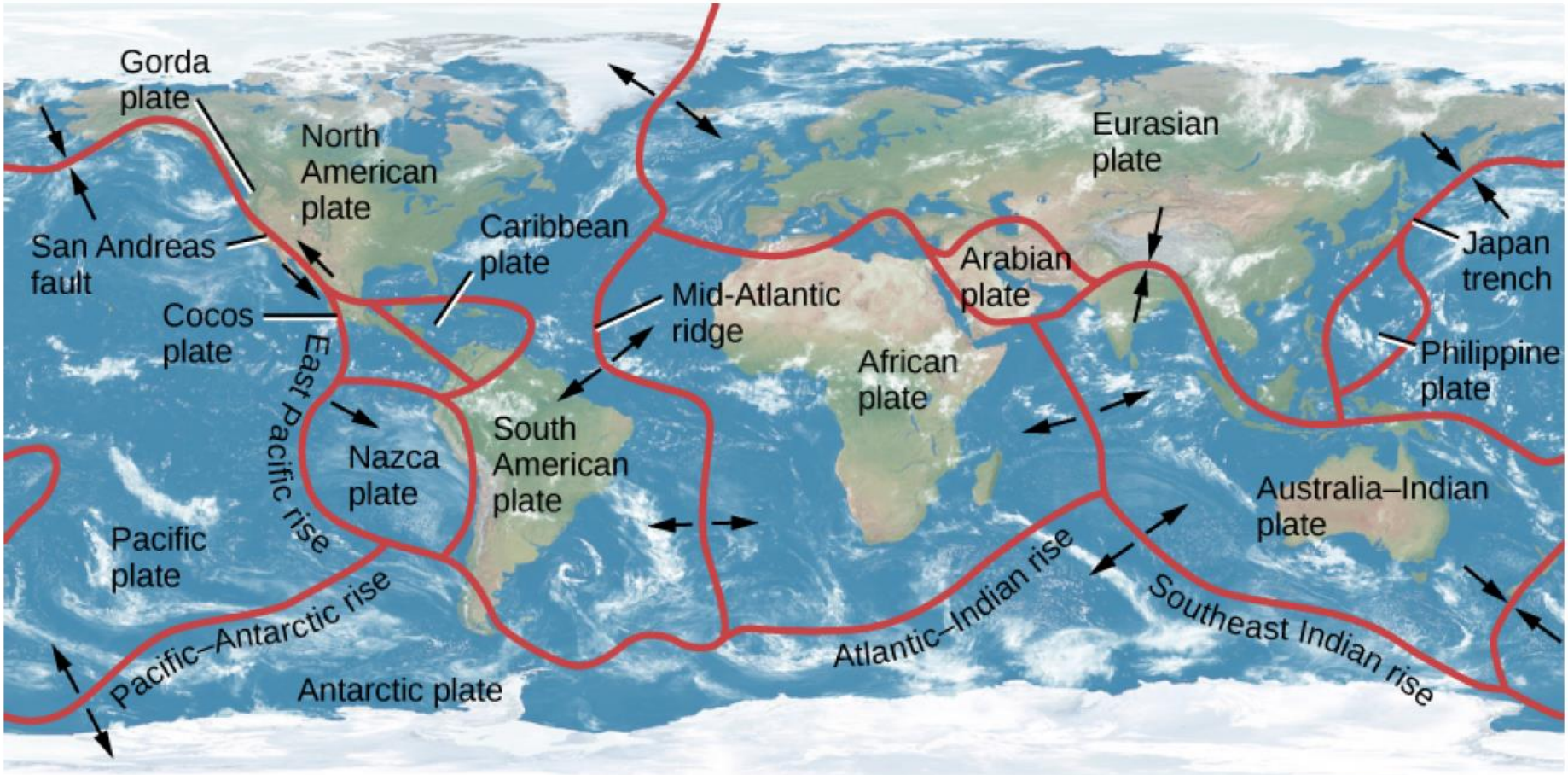
Volcanism:
need molten core

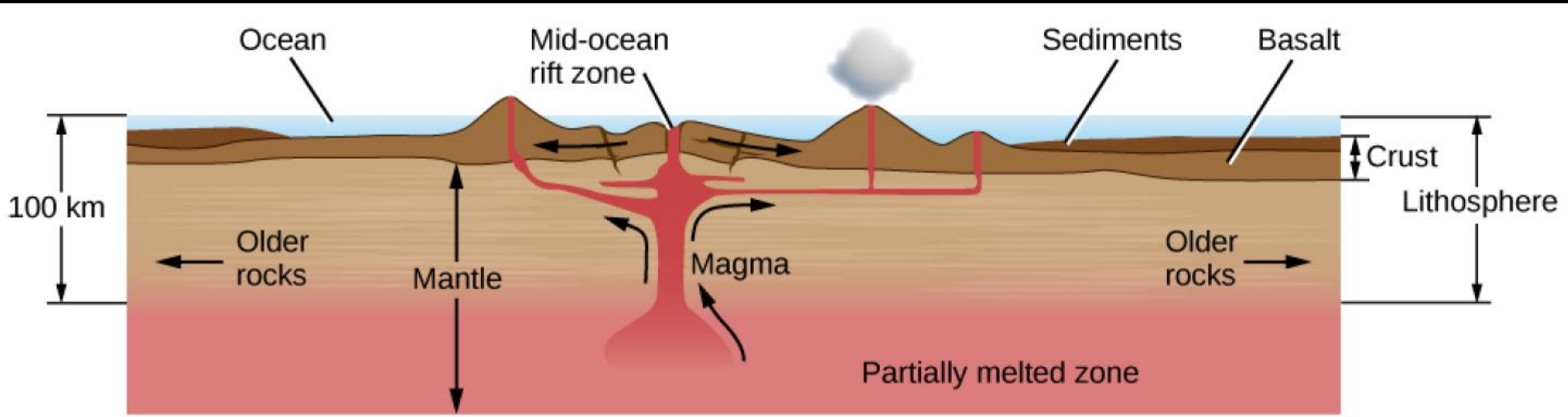
Radioactivity

Larger planets have cores that stay molten for longer

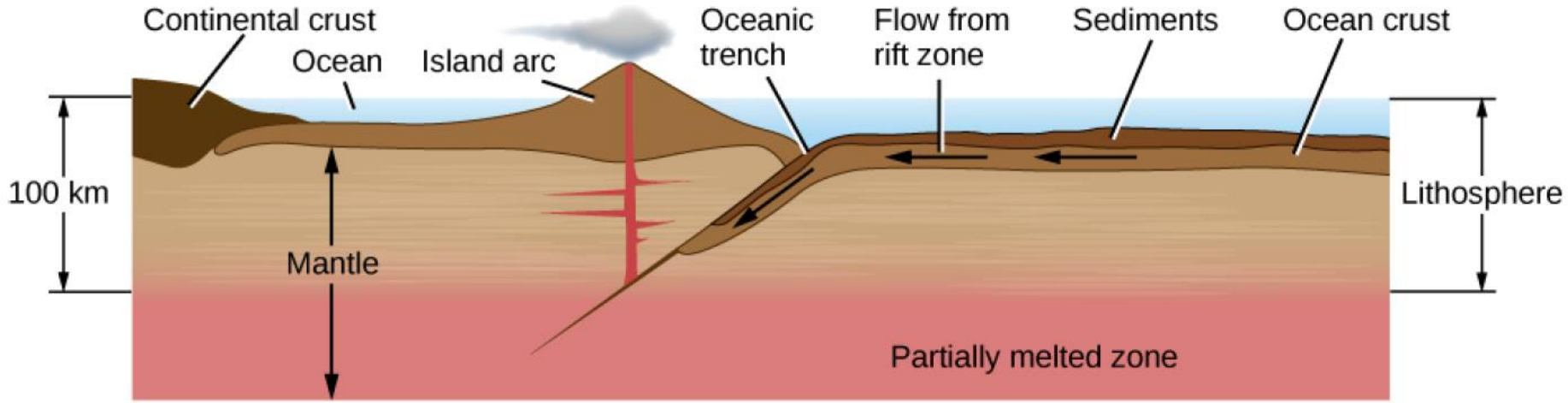





Gorda plate
North American plate
Eurasian plate
San Andreas fault
Caribbean plate
Arabian plate
Japan trench
Cocos plate
Mid-Atlantic ridge
African plate
Philippine plate
East Pacific rise
Nazca plate
South American plate
Australia–Indian plate
Pacific plate
Pacific–Antarctic rise
Atlantic–Indian rise
Southeast Indian rise
Antarctic plate



Rift zone

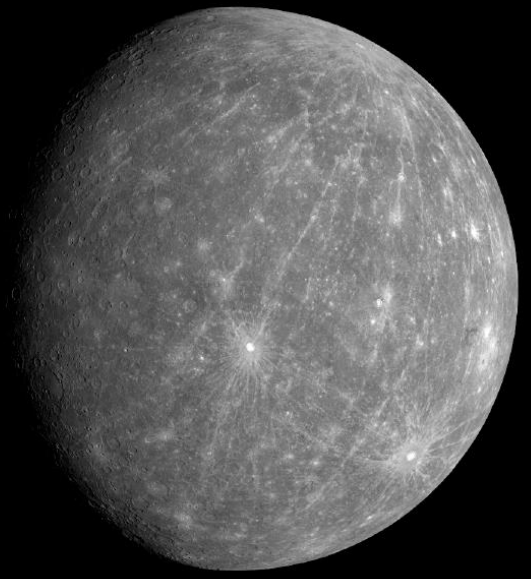


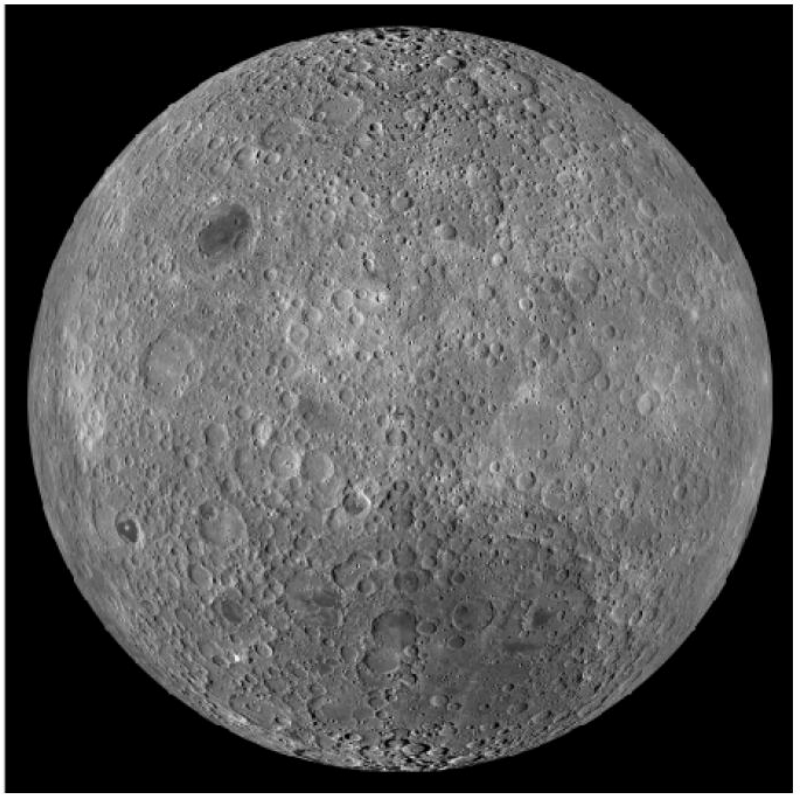
Subduction zone

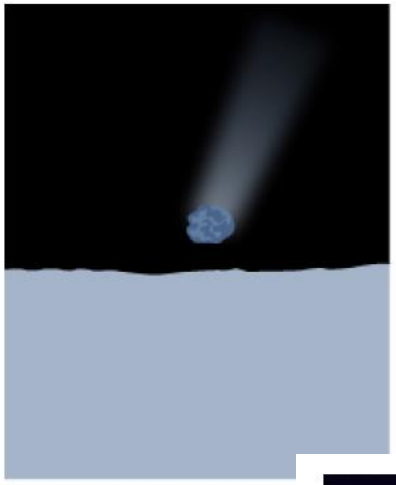
Properties of the Moon and Mercury

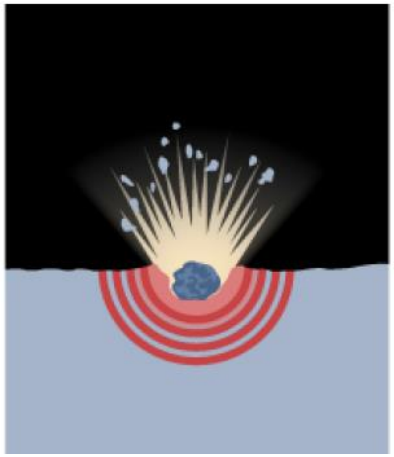
Property	Moon	Mercury
Mass (Earth = 1)	0.0123	0.055
Diameter (km)	3476	4878
Density (g/cm^3)	3.3	5.4
Surface gravity (Earth = 1)	0.17	0.38
Escape velocity (km/s)	2.4	4.3
Rotation period (days)	27.3	58.65

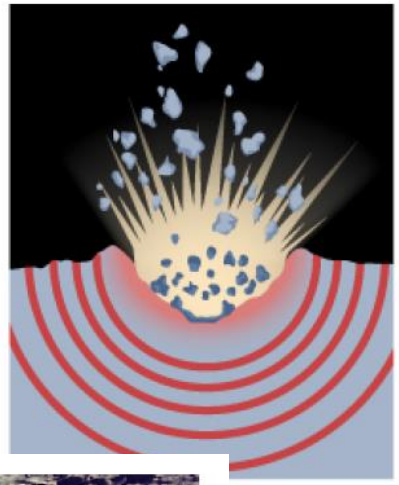
The moon and Mercury

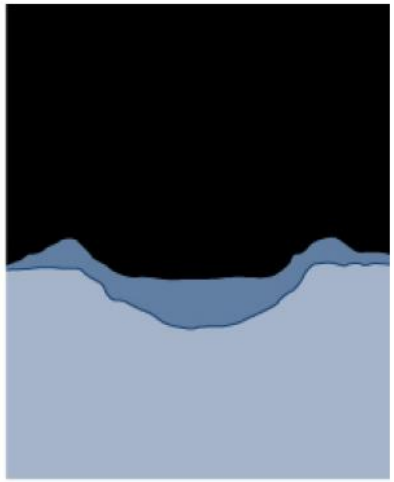


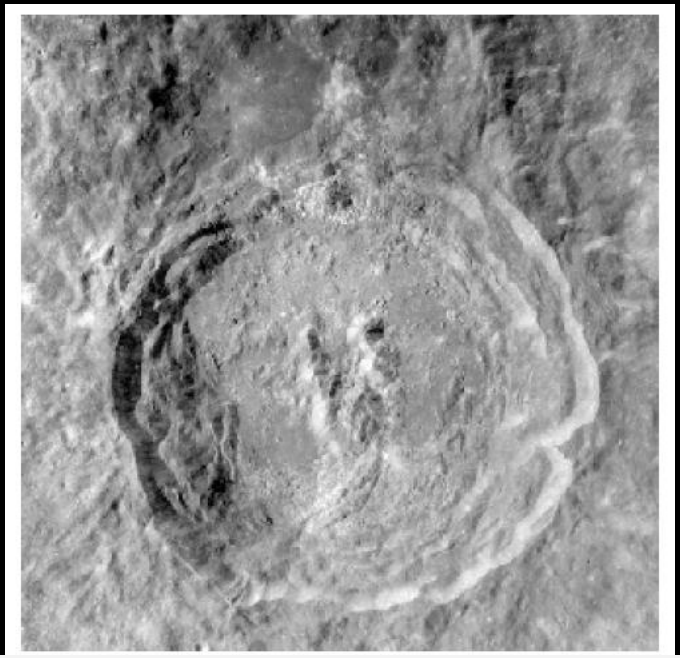






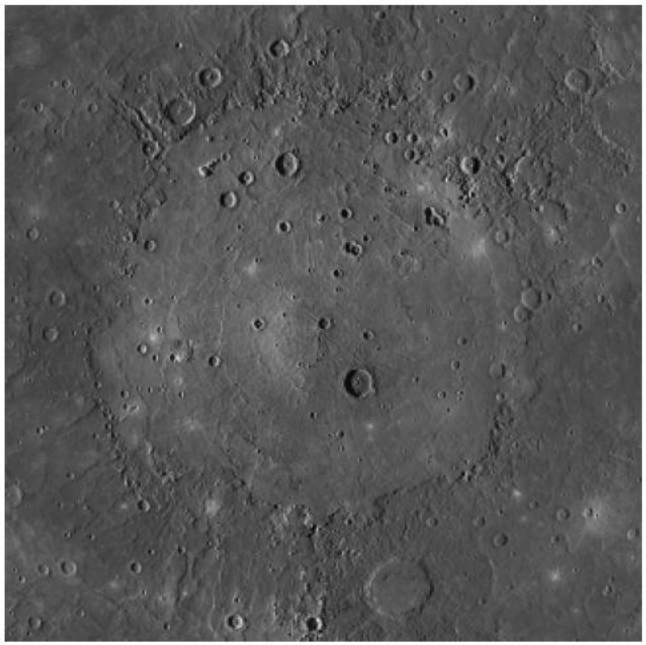






Craters: old surface
Smooth: new surface

Mare=sea



Hypothetical cratering maximum

?

Cratering of highlands

Imbrium and Orientale impacts

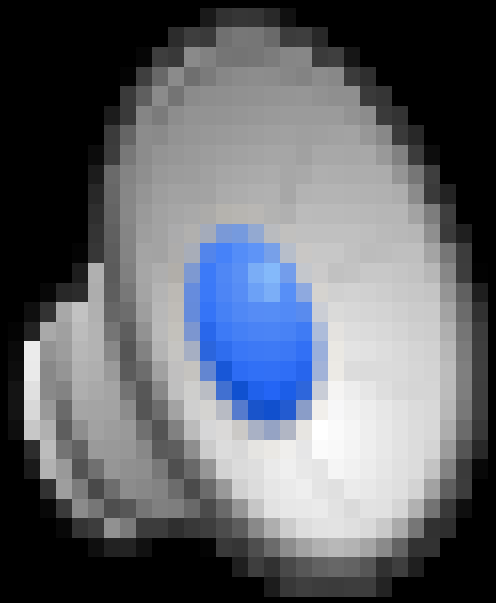
Formation of maria

Recent craters
(Tycho, Copernicus)

Rate of Formation of Impact Craters

4 3 2 1 0

Time before Present (in Billions of Years)

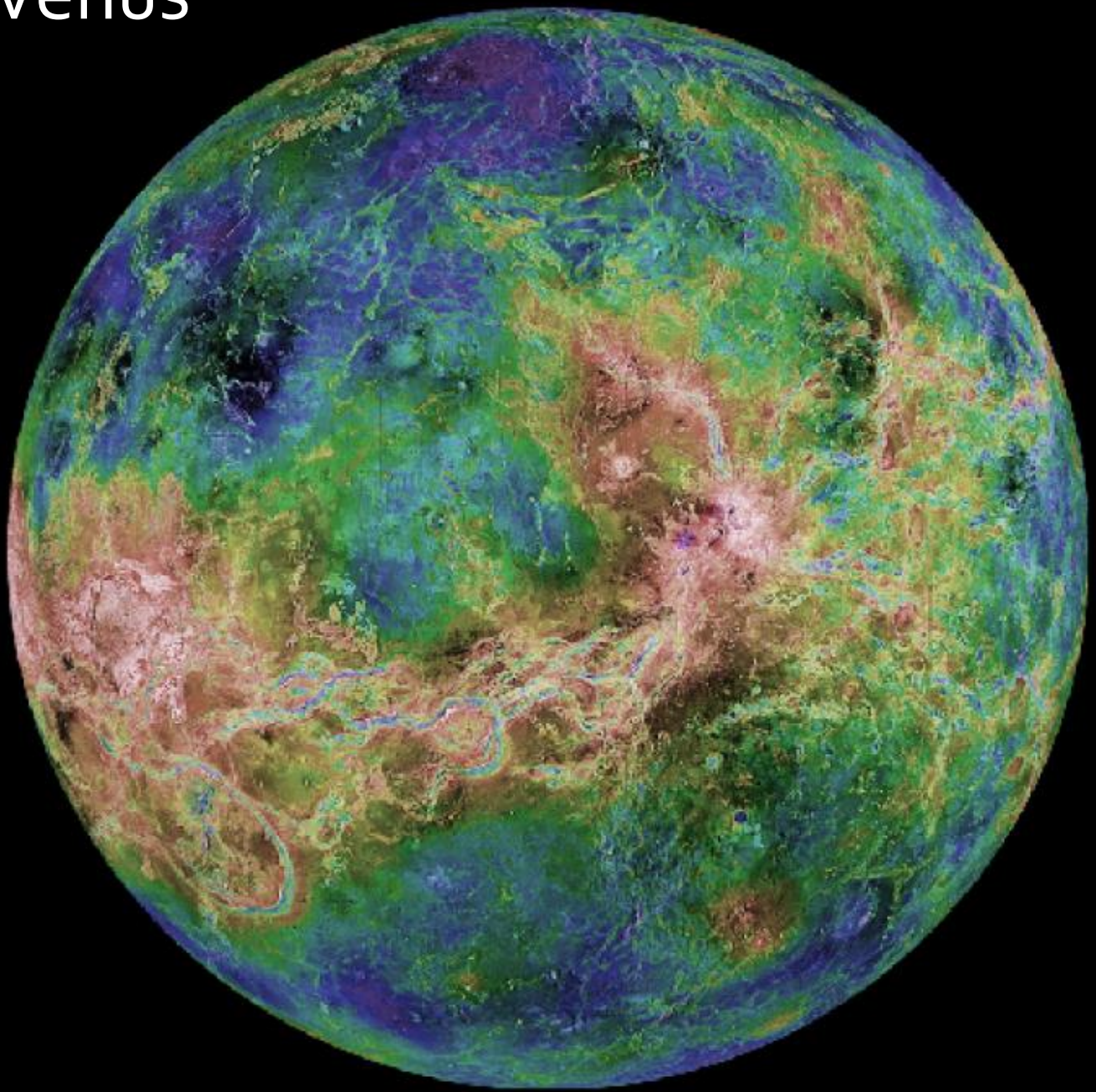


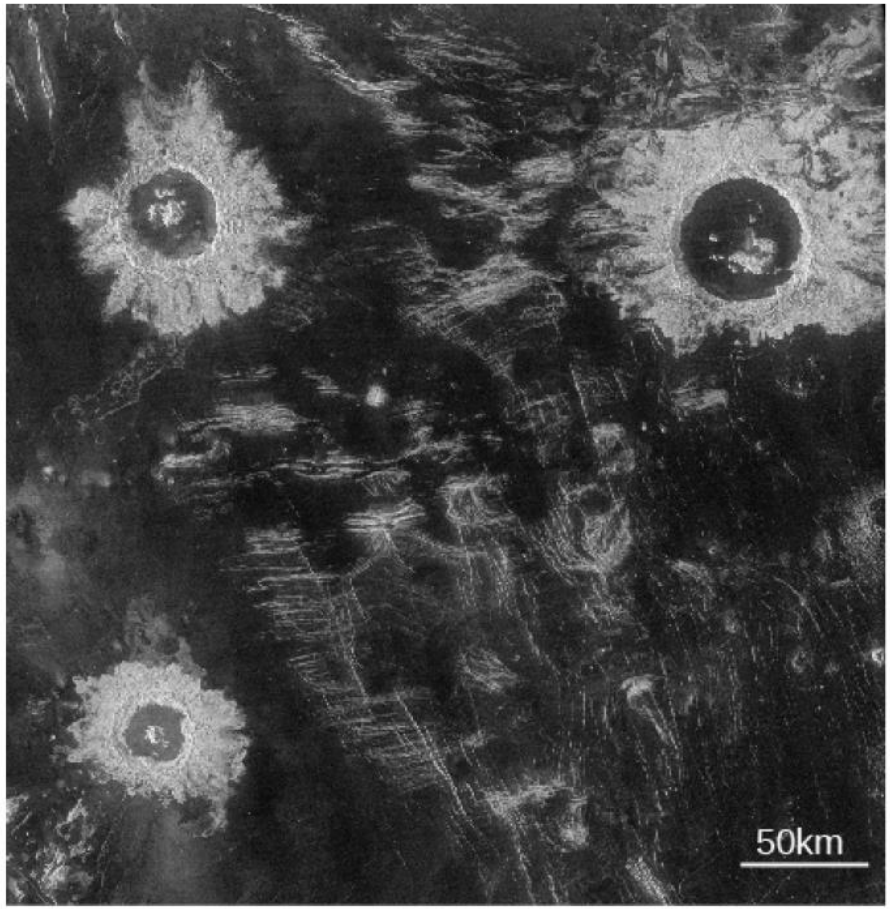
Properties of Earth, Venus, and Mars

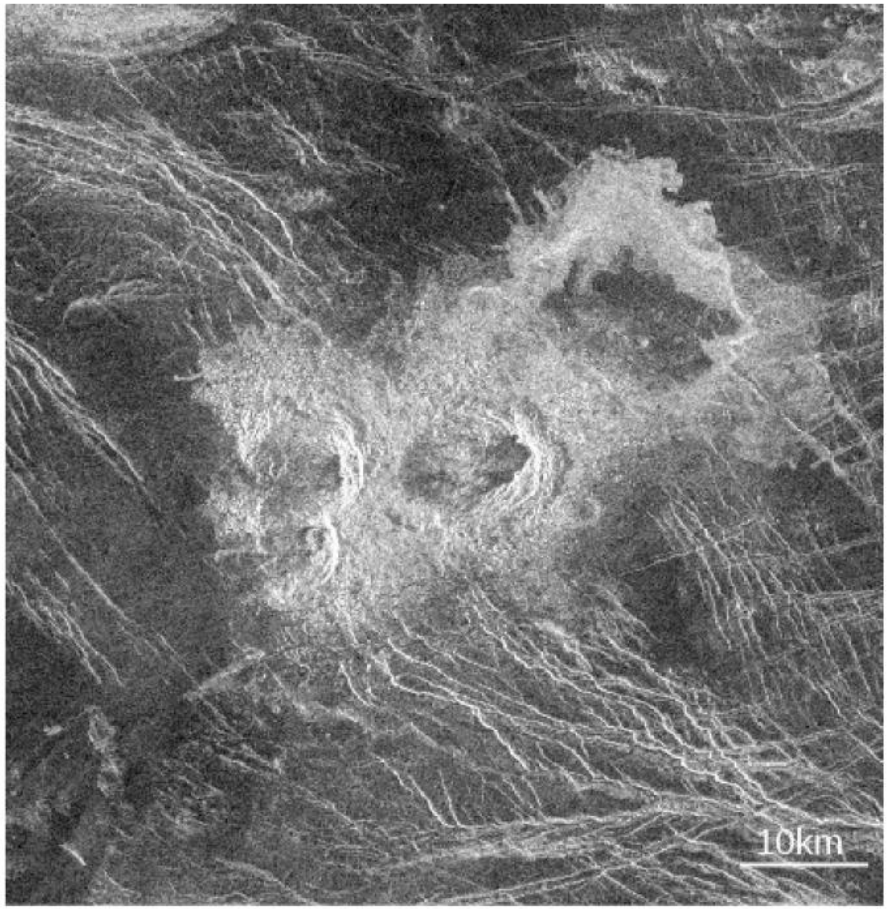
Property	Earth	Venus	Mars
Semimajor axis (AU)	1.00	0.72	1.52
Period (year)	1.00	0.61	1.88
Mass (Earth = 1)	1.00	0.82	0.11
Diameter (km)	12,756	12,102	6,790
Density (g/cm^3)	5.5	5.3	3.9
Surface gravity (Earth = 1)	1.00	0.91	0.38
Escape velocity (km/s)	11.2	10.4	5.0
Rotation period (hours or days)	23.9 h	243 d	24.6 h
Surface area (Earth = 1)	1.00	0.90	0.28
Atmospheric pressure (bar)	1.00	90	0.007

Venus
Thick atmosphere

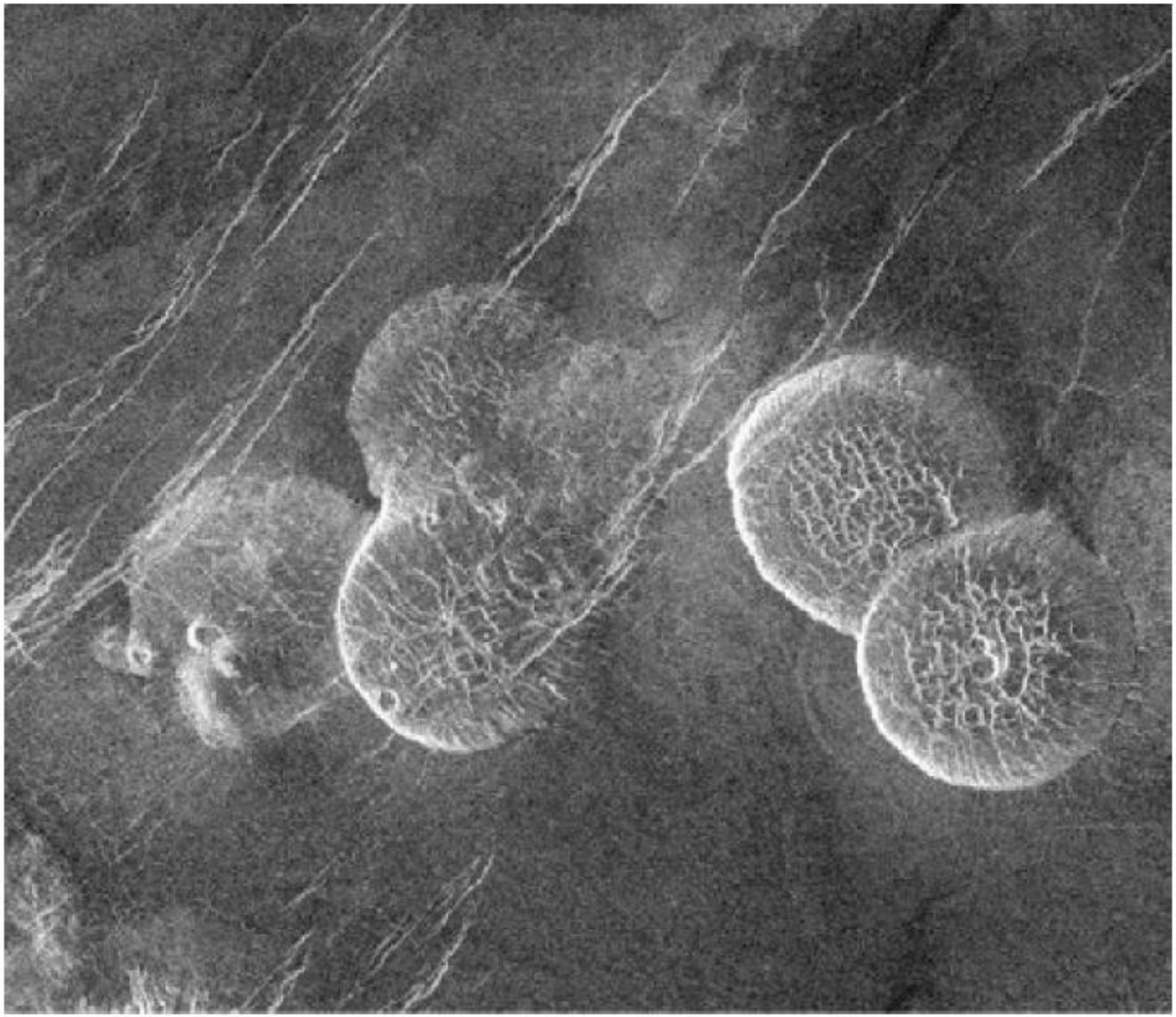
Venus

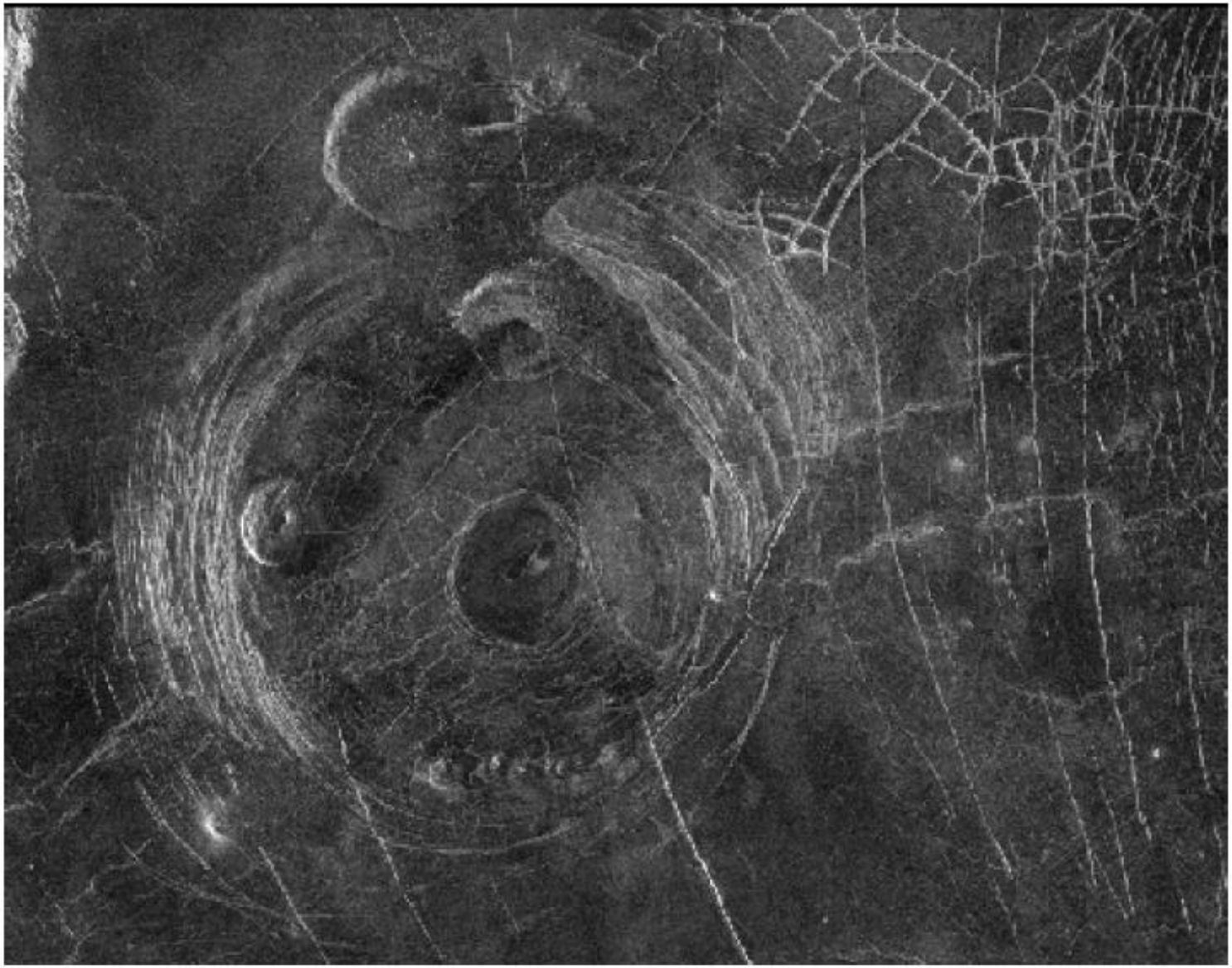


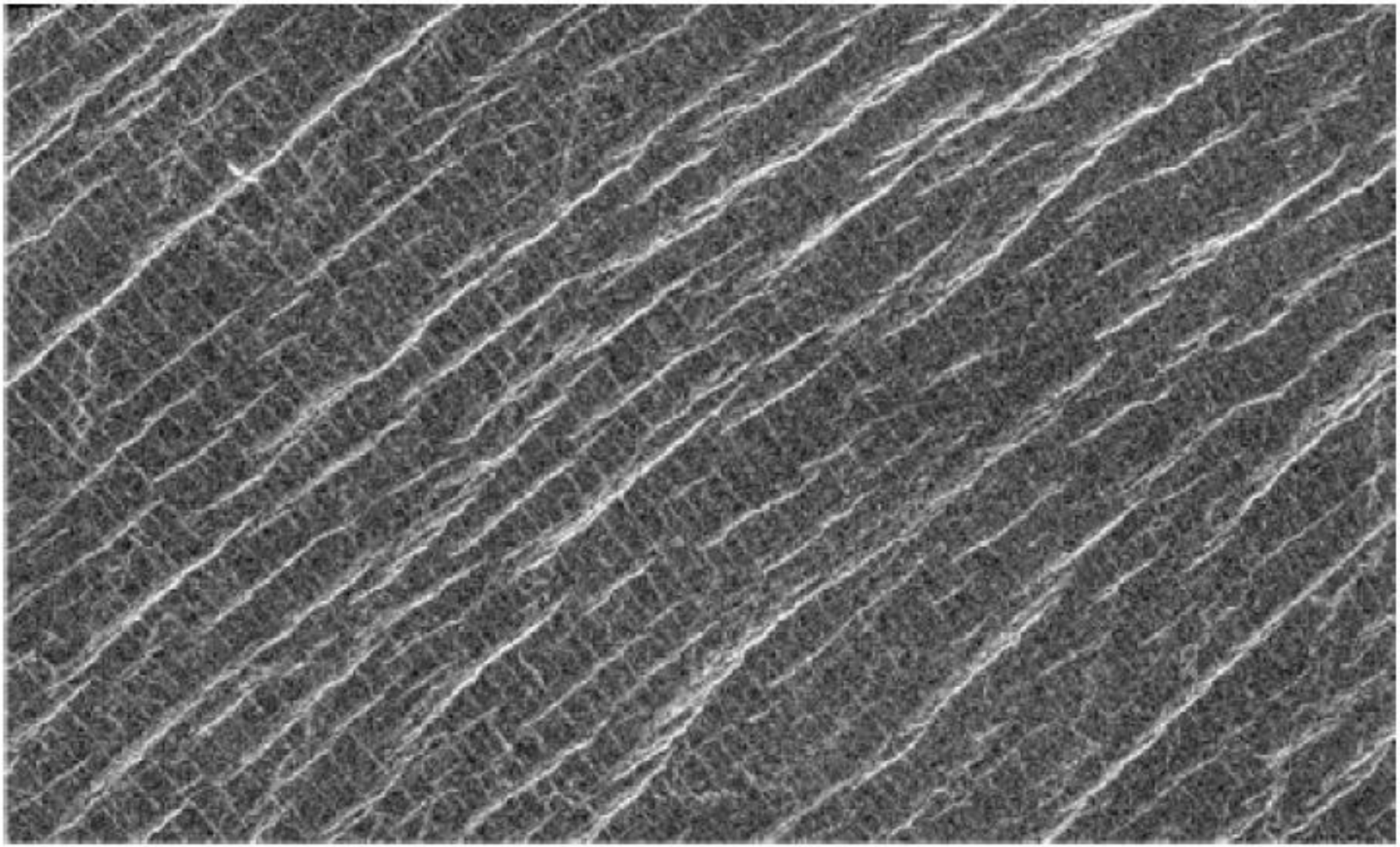


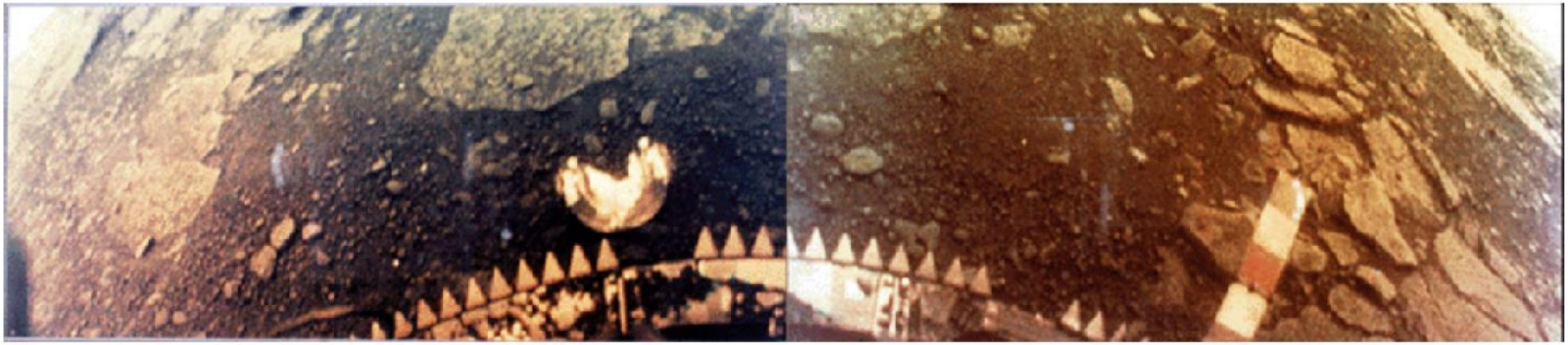


Only a few landers
(all Soviet Union)



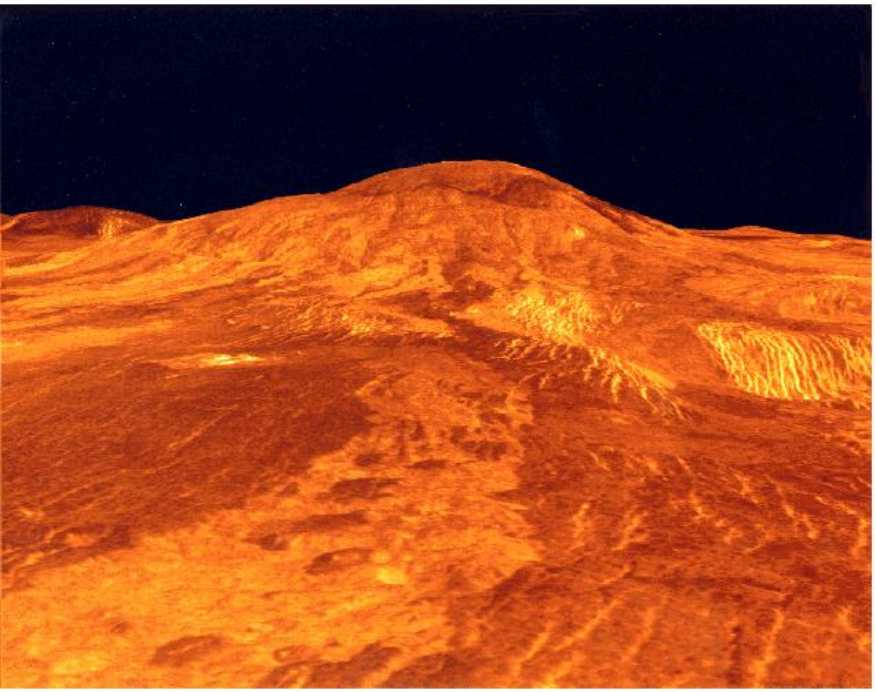






Venus has hardly any impact craters; the surface density of craters indicates most of the surface is only 600 million years old; but craters do not appear to be eroding. Where are all the older craters?

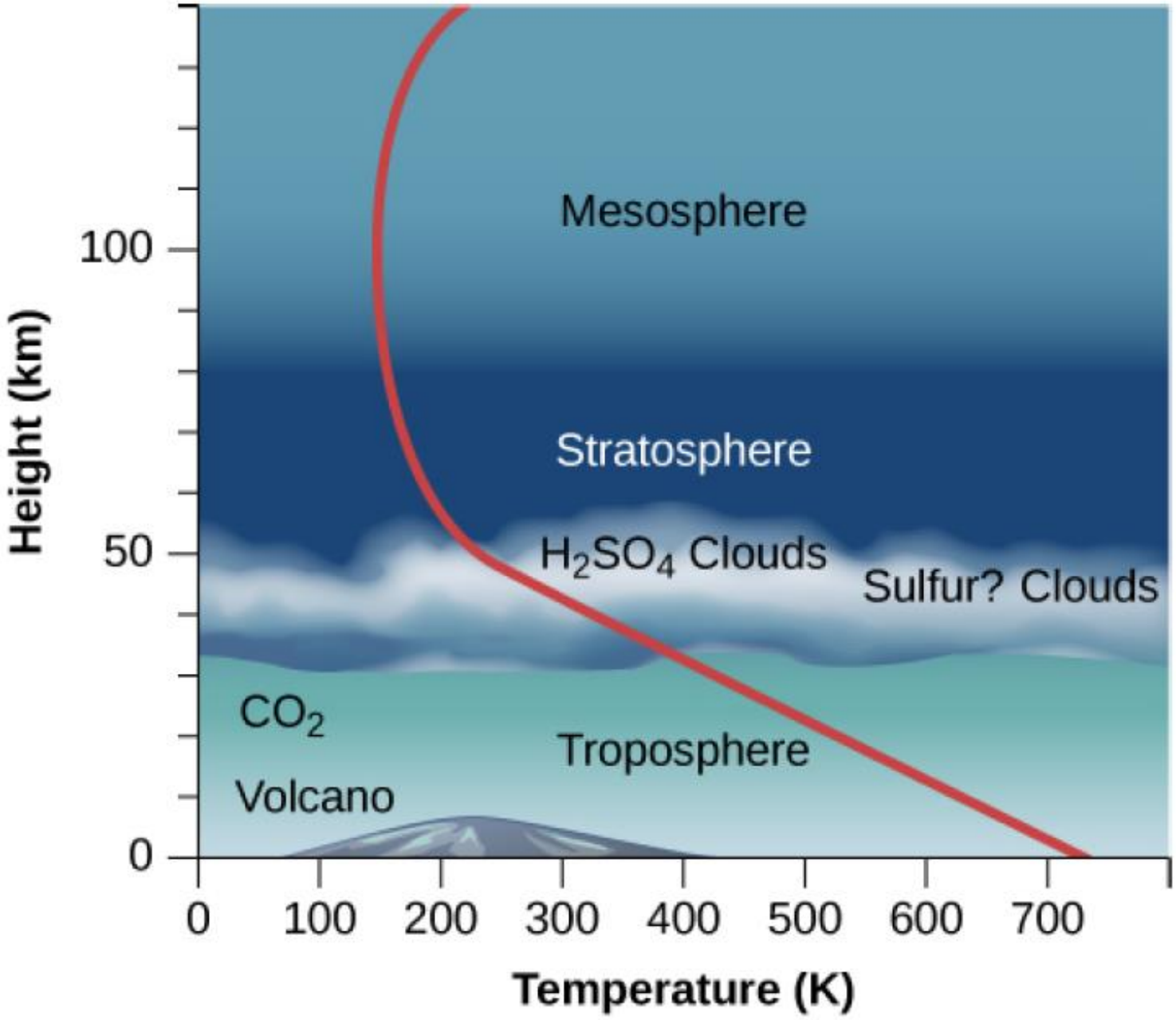
Perhaps Venus undergoes periodic *catastrophic resurfacing*. The last such event would have taken place about 600 million years ago.



The volcano Sif Mons. is about 2 km high and nearly 300 km across. There appear to be recent lava flows at the front of the image: these flows are about 120 km long, which suggests that these lavas were also very fluid.

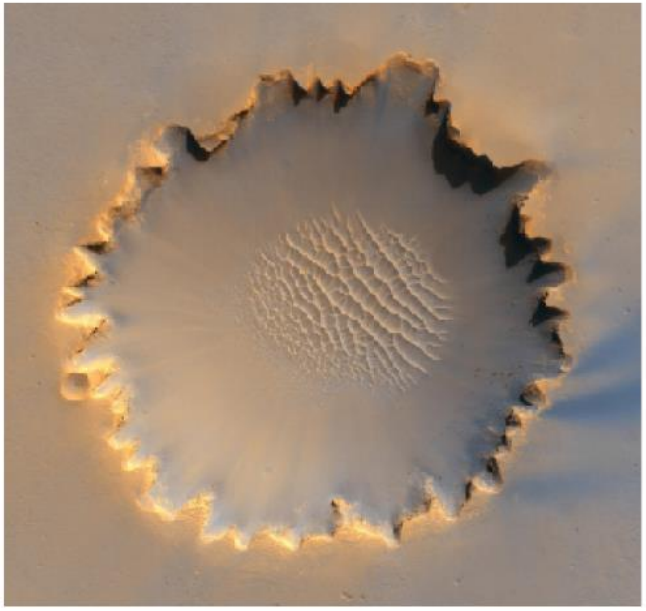
Atmospheric Composition of Earth, Venus, and Mars

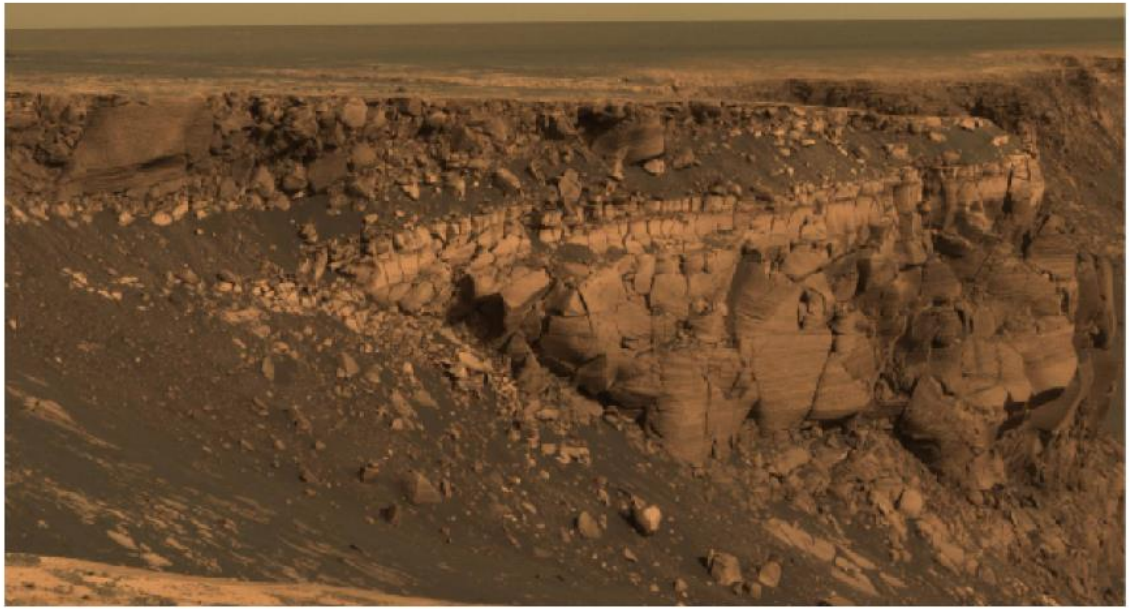
Gas	Earth	Venus	Mars
Carbon dioxide (CO_2)	0.03%	96%	95.3%
Nitrogen (N_2)	78.1%	3.5%	2.7%
Argon (Ar)	0.93%	0.006%	1.6%
Oxygen (O_2)	21.0%	0.003%	0.15%
Neon (Ne)	0.002%	0.001%	0.0003%

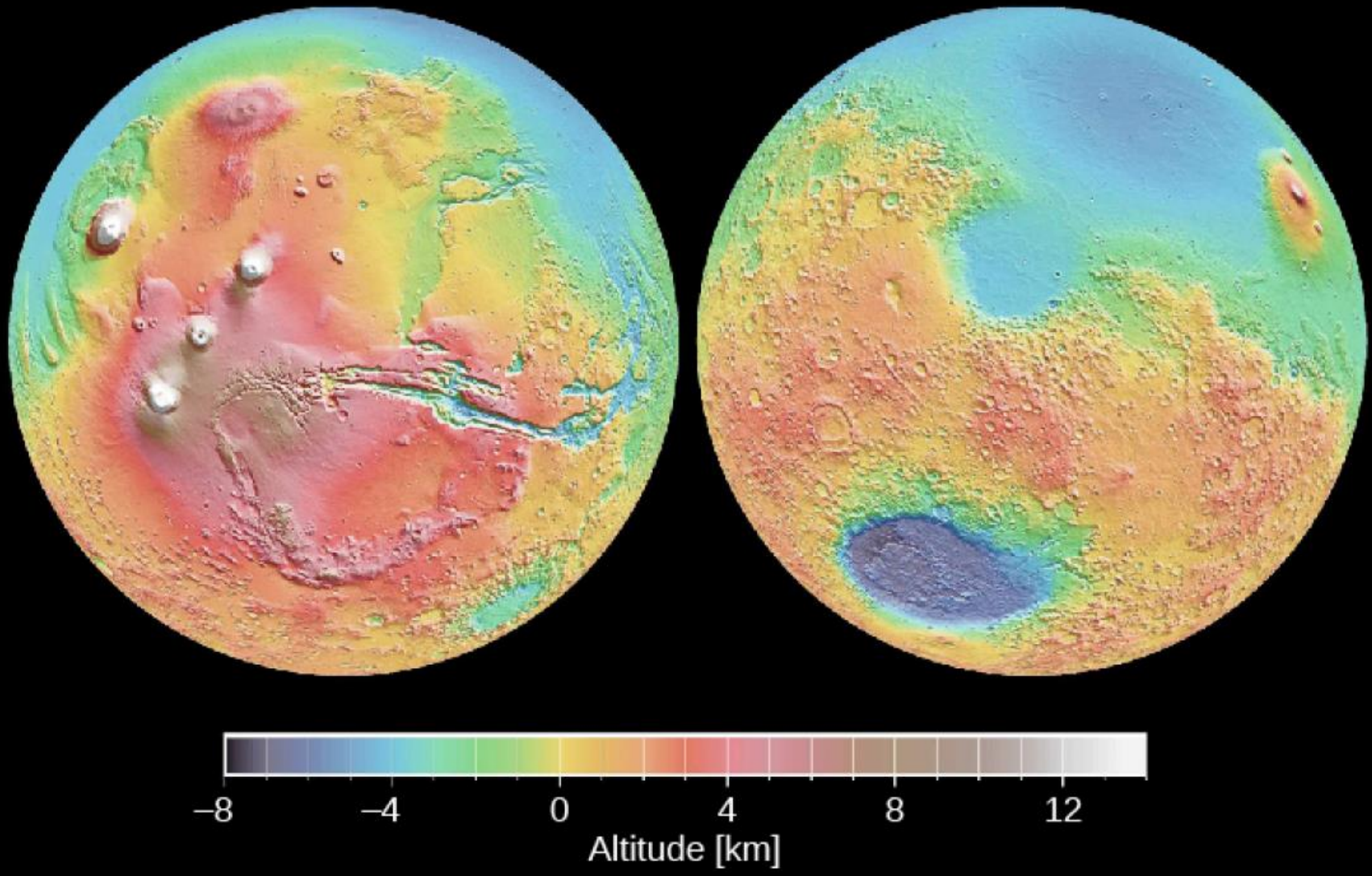

Mesosphere
Stratosphere
H_2SO_4 Clouds
Sulfur? Clouds
CO_2
Troposphere
Volcano
Height (km)
100
50
0
0
100
200
300
400
500
600
700
Temperature (K)

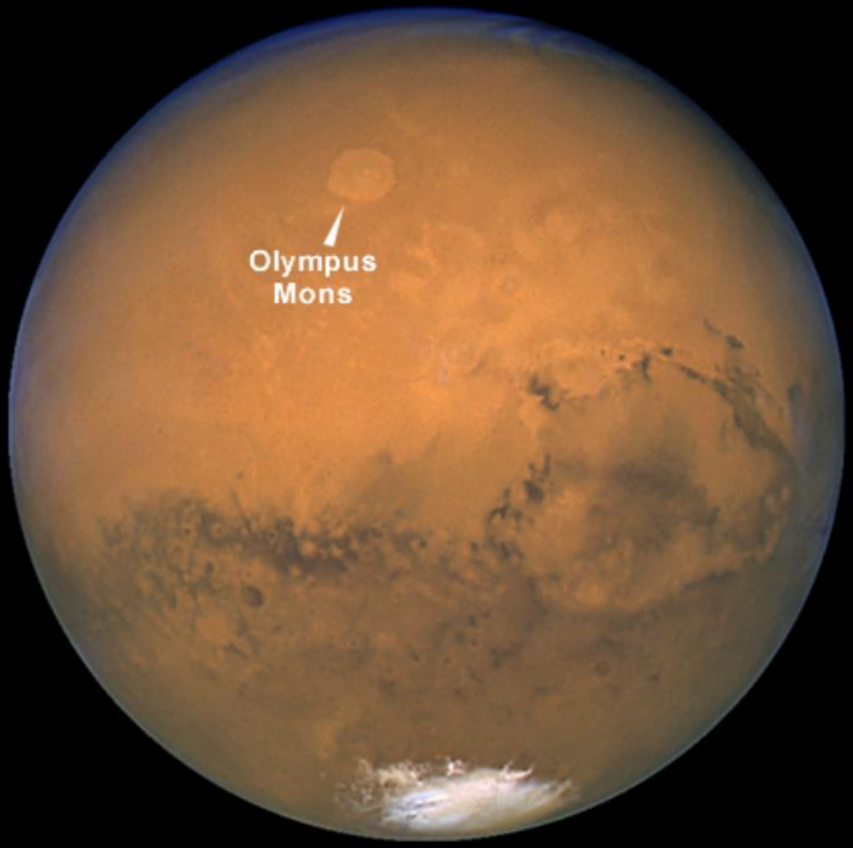
Mars

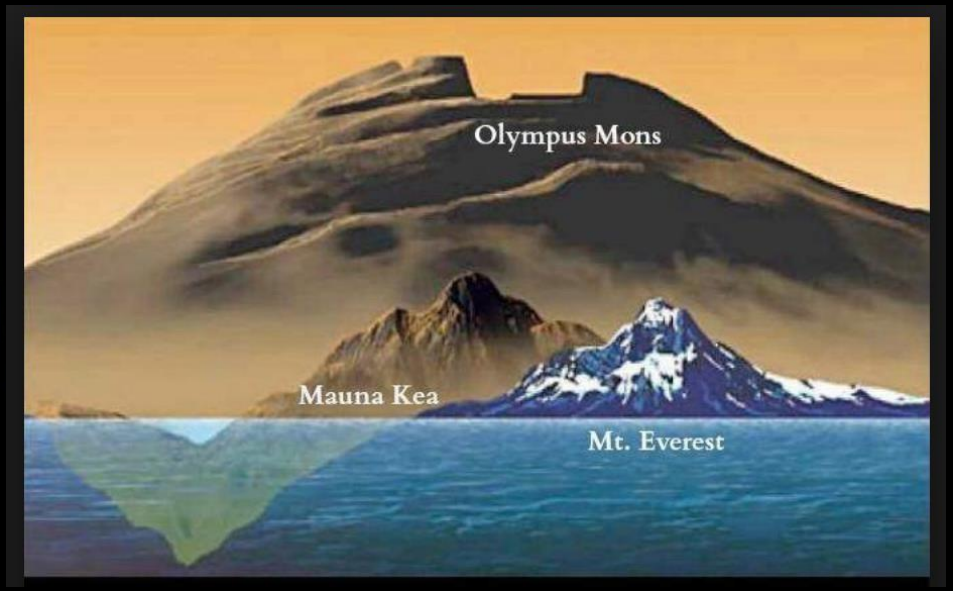
Mars rock from Antarctica!

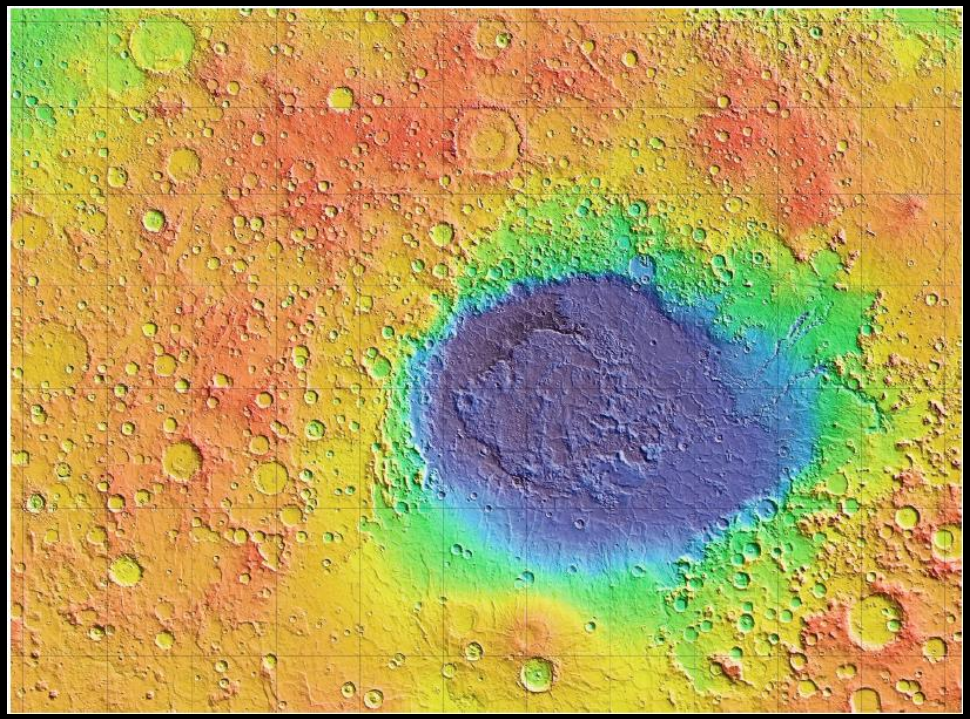


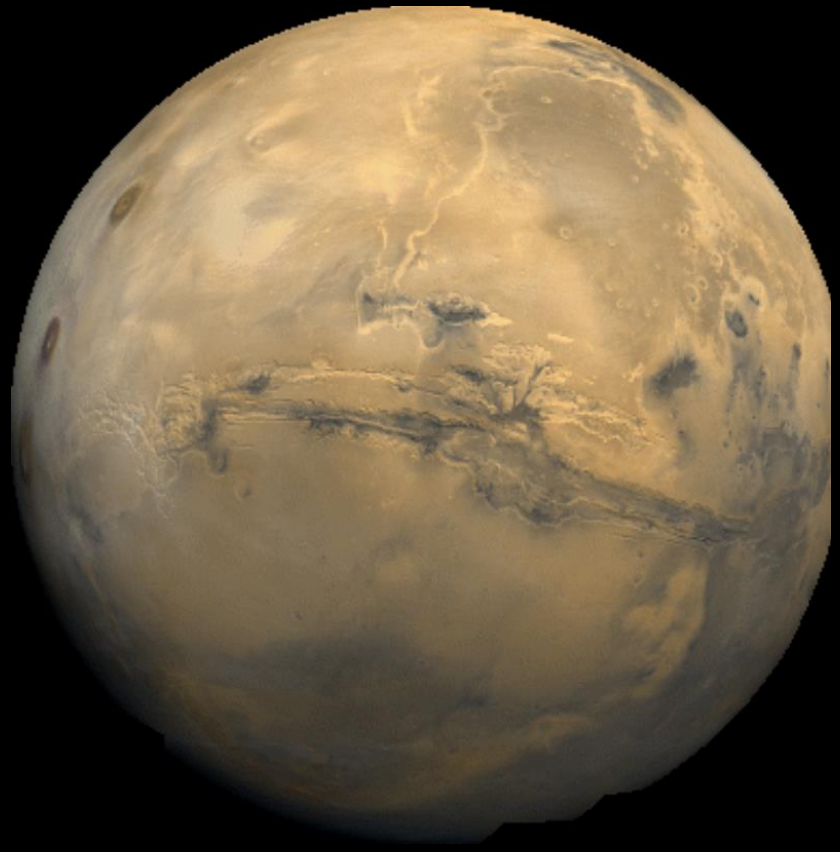


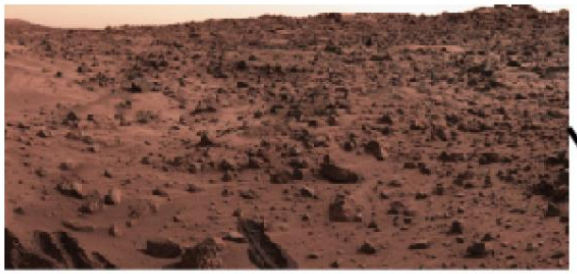

–8
–4
0
4
8
12
Altitude [km]

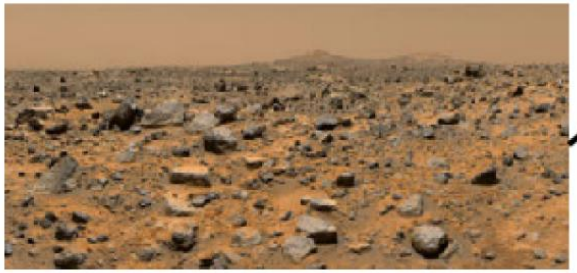

Olympus
Mons


Olympus Mons
Mauna Kea
Mt. Everest



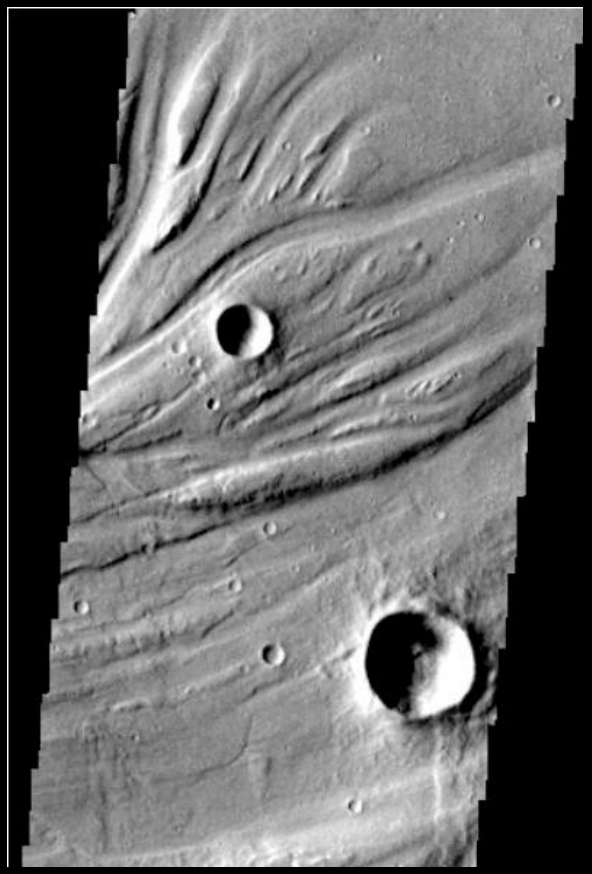


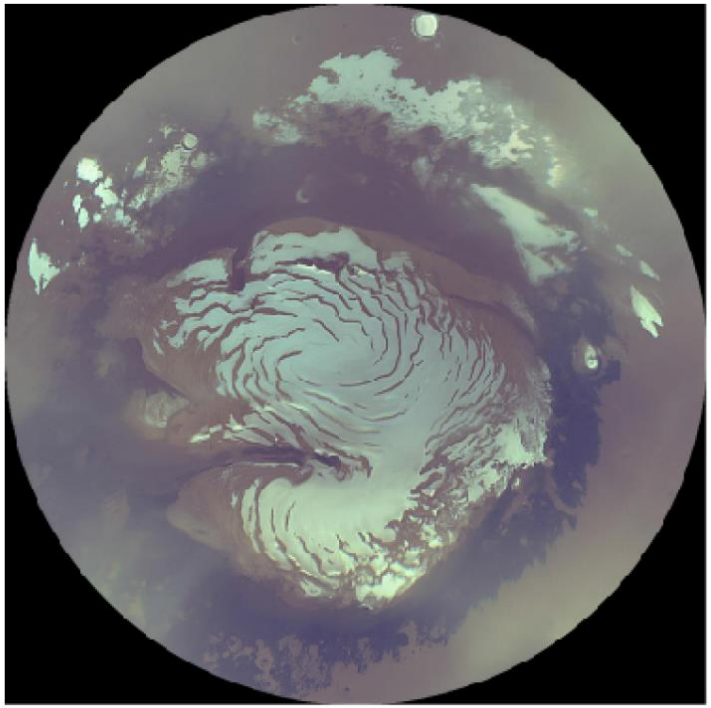


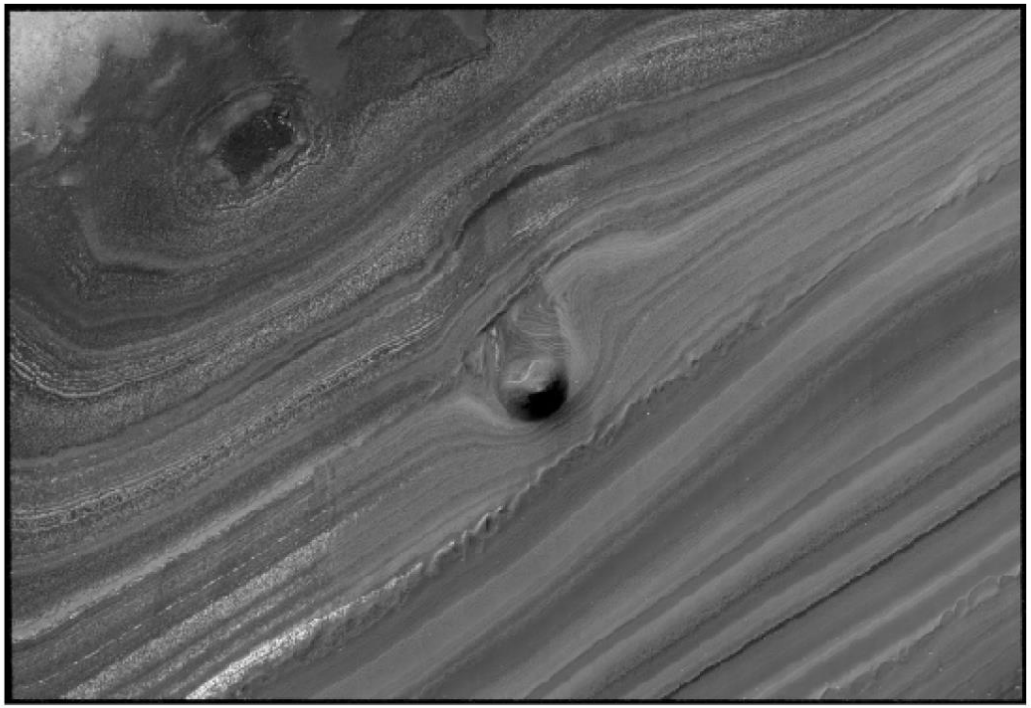


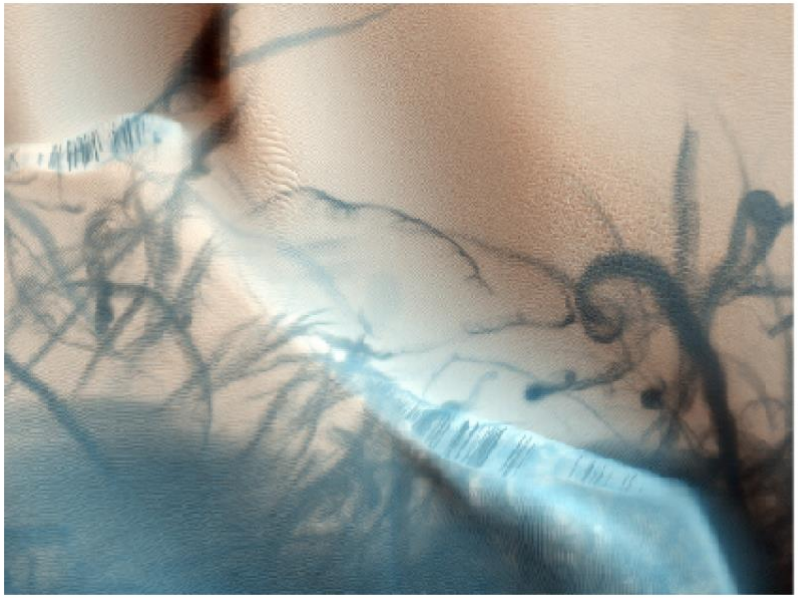

Viking 2
Viking 1
Pathfinder

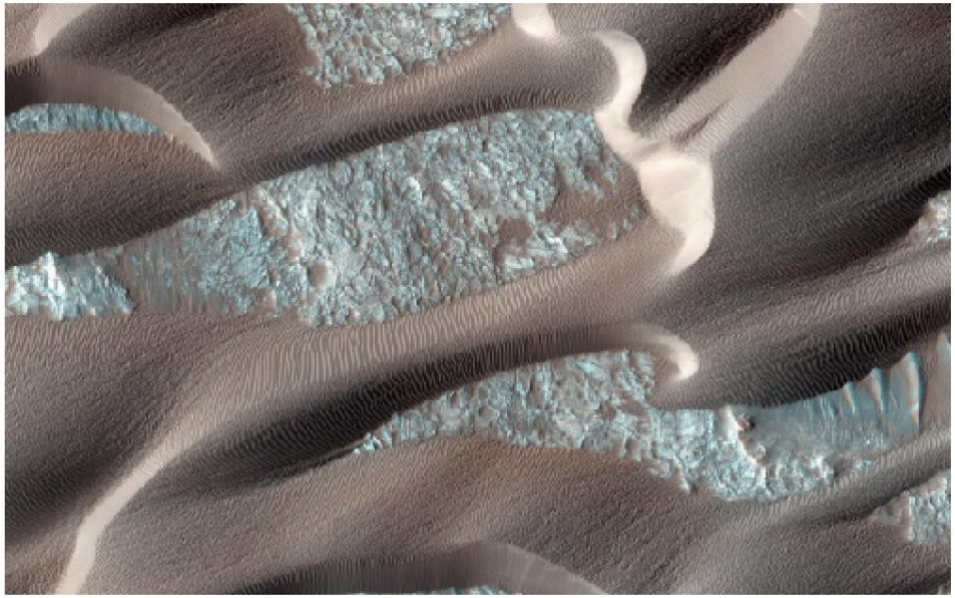
Water?

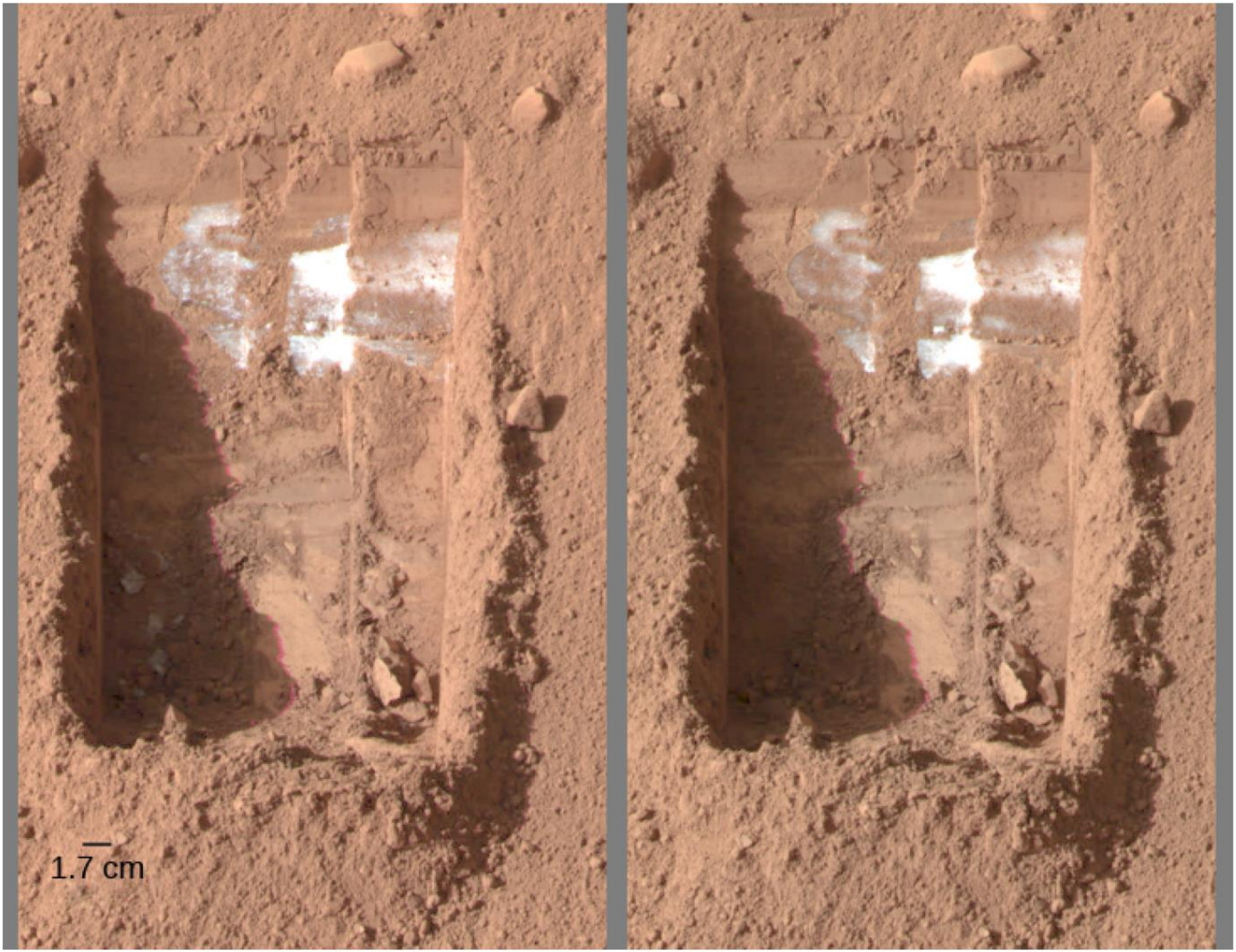


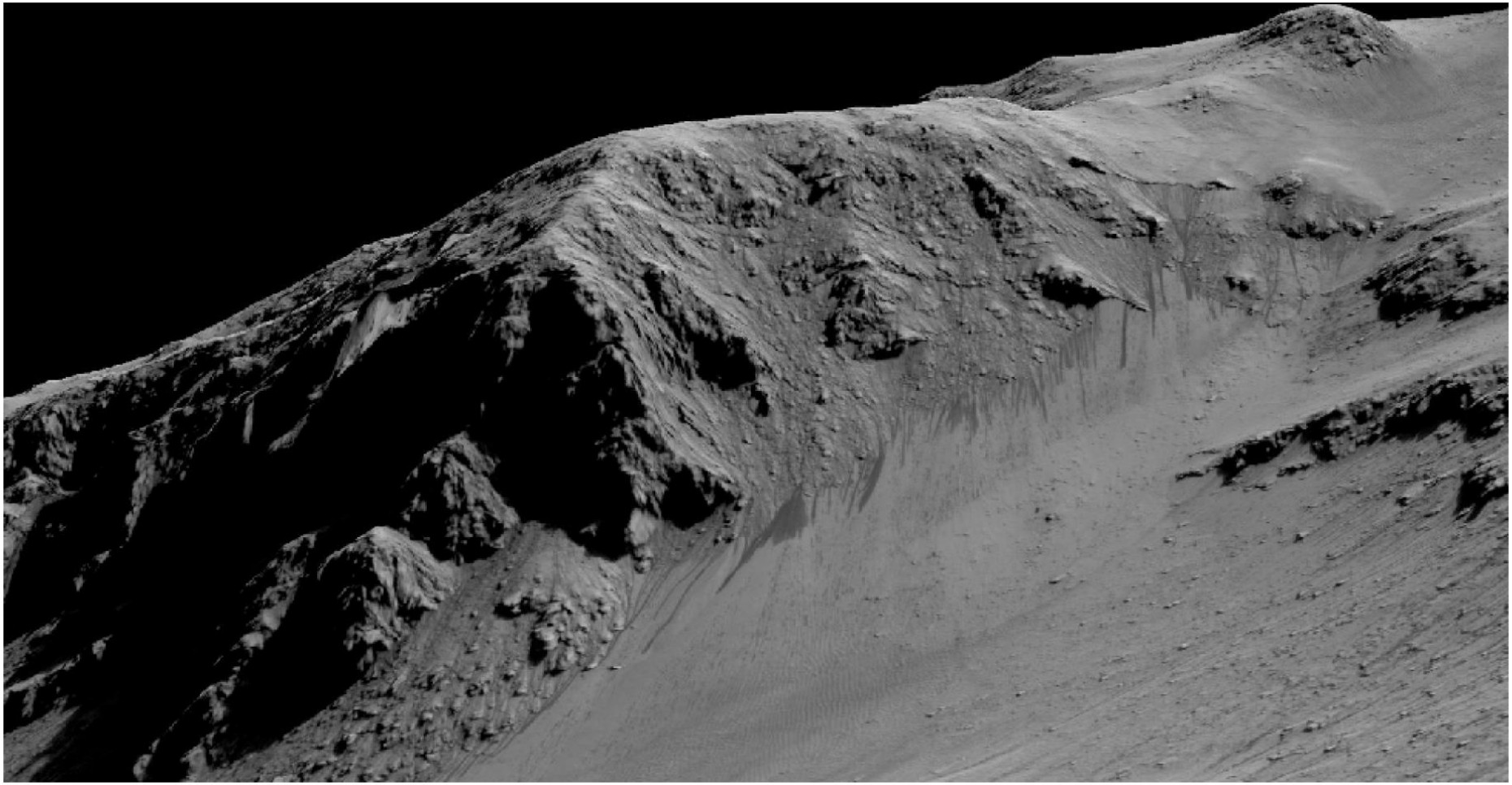




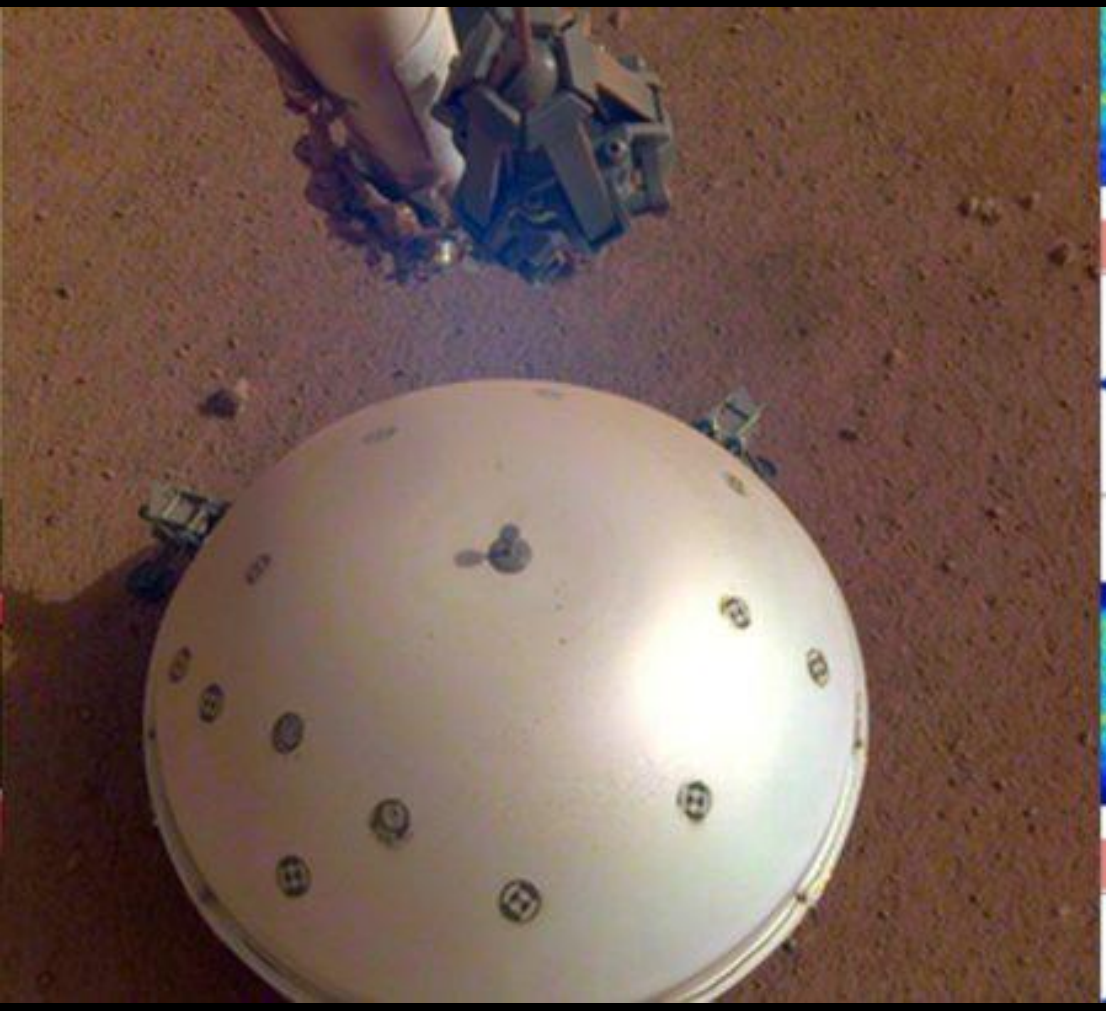


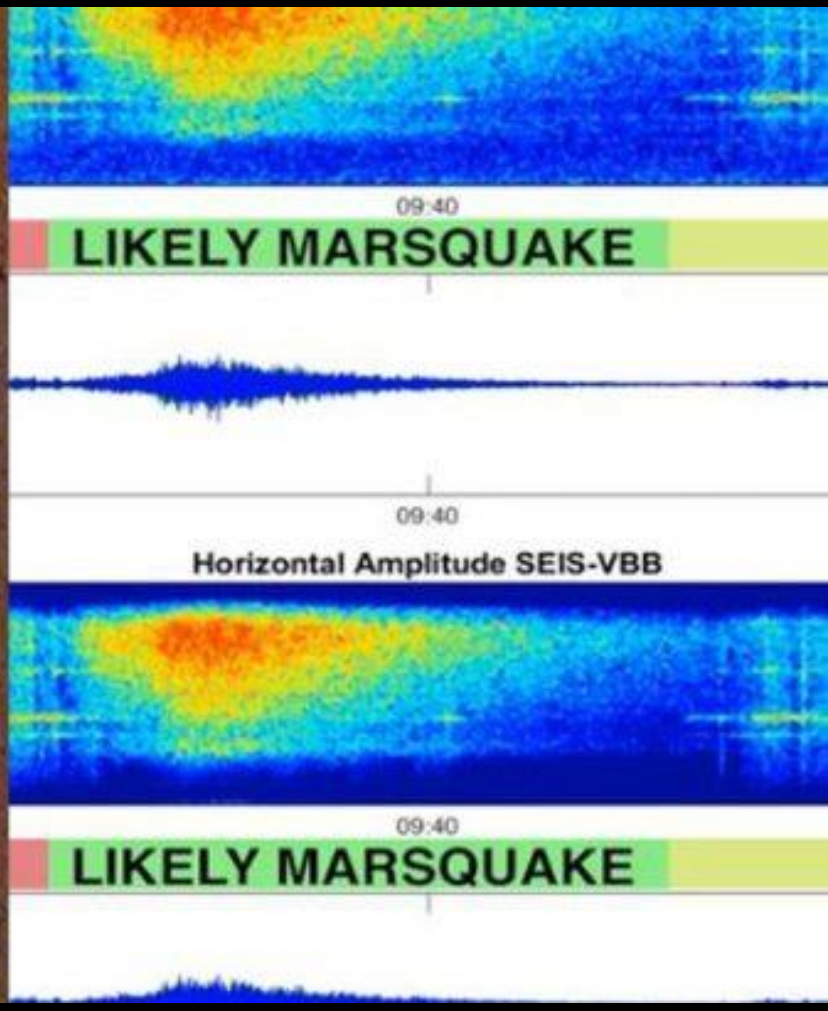


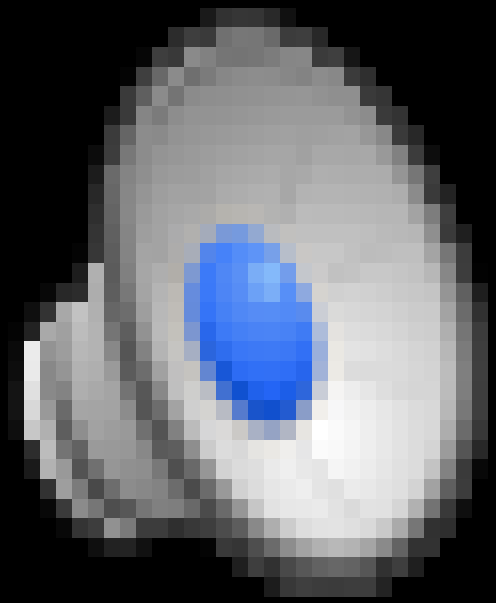

1.7 cm

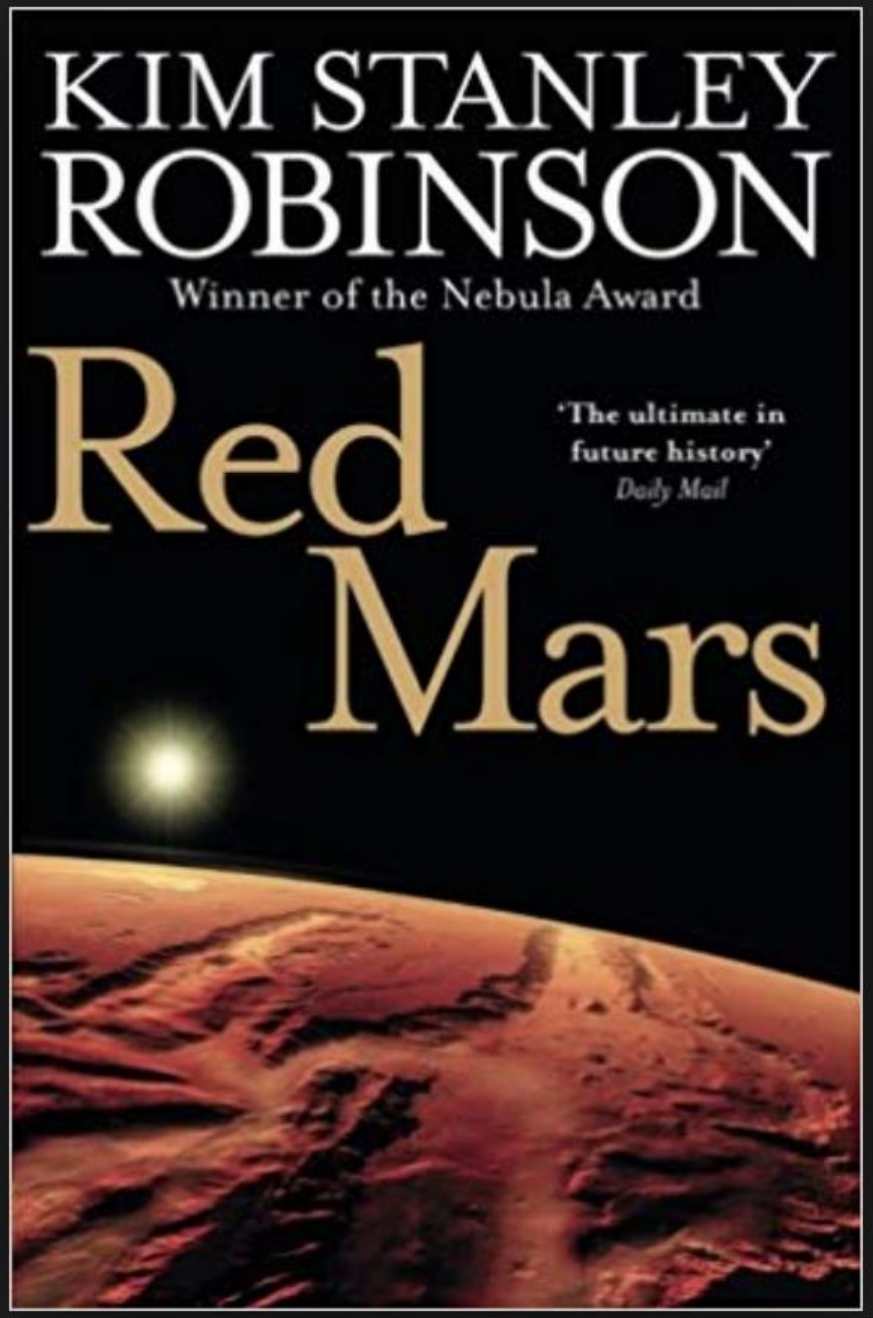


Marsquakes!




09:40
LIKELY MARSQUAKE
09:40
Horizontal Amplitude SEIS-VBB
09:40
LIKELY MARSQUAKE




KIM STANLEY
ROBINSON
Winner of the Nebula Award
Red
Mars
'The ultimate in
future history'
Daily Mail