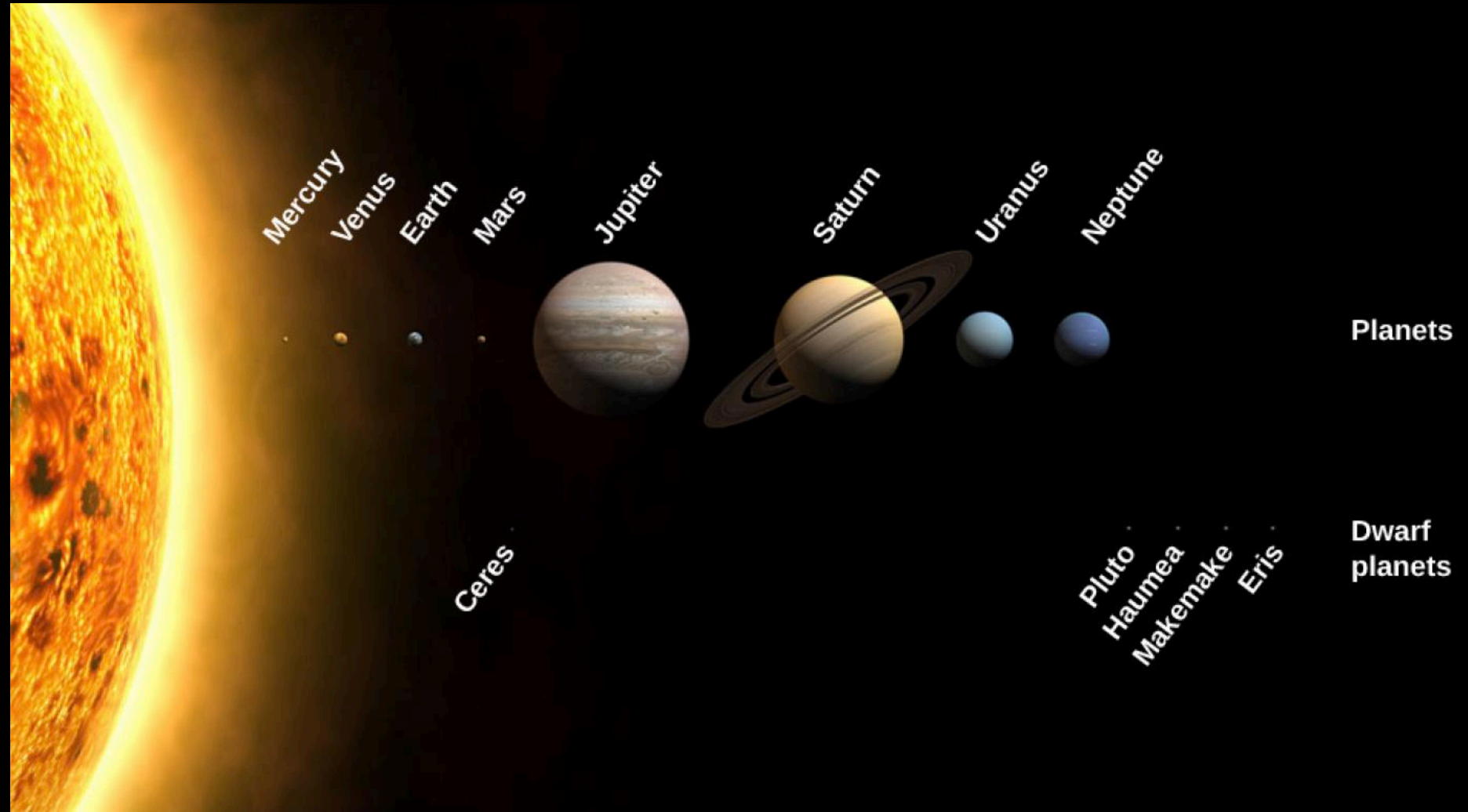


Our solar system!



Course update

- Grades for homework 3 circulated
 - Average 92 (std 7)
 - Homework: 40% (hw1 is worth 0.5 homeworks)
 - Projects: 60% (project 1 is 25%, project 2 is 75%)
- Homework 4 due on Monday, May 25
 - To be circulated by wechat by tomorrow
 - Question 3 is hard (but fun)! I do not expect everyone to answer it.
 - “I don’t know excel”: You are students! Your job is to learn!
 - I can’t put a plot in a pdf: Your job is to learn!
 - Screenshots are easy!
 - Remember sunset (or sunrise) photos
- Citizen Science projects due on May 25
 - Extensions to June 10 (no need to request)

Science in your life

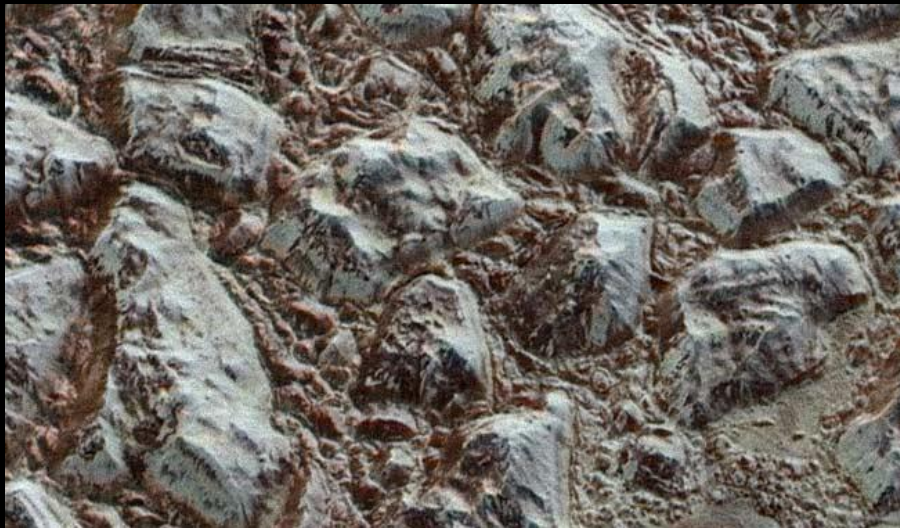
- Lemon seeds: cause lemonade to go bitter
- Jiayuan/Nongyuan, which is better
- Cooking eggs: turn fire off earlier!
- Class attendance: if attendance is monitored only sporadically, after each check, wait two weeks to attend again
- Diarrhea and lactose (milk) intolerance????

Too many gamers!!!

Mars or Earth?



Pluto or Earth?

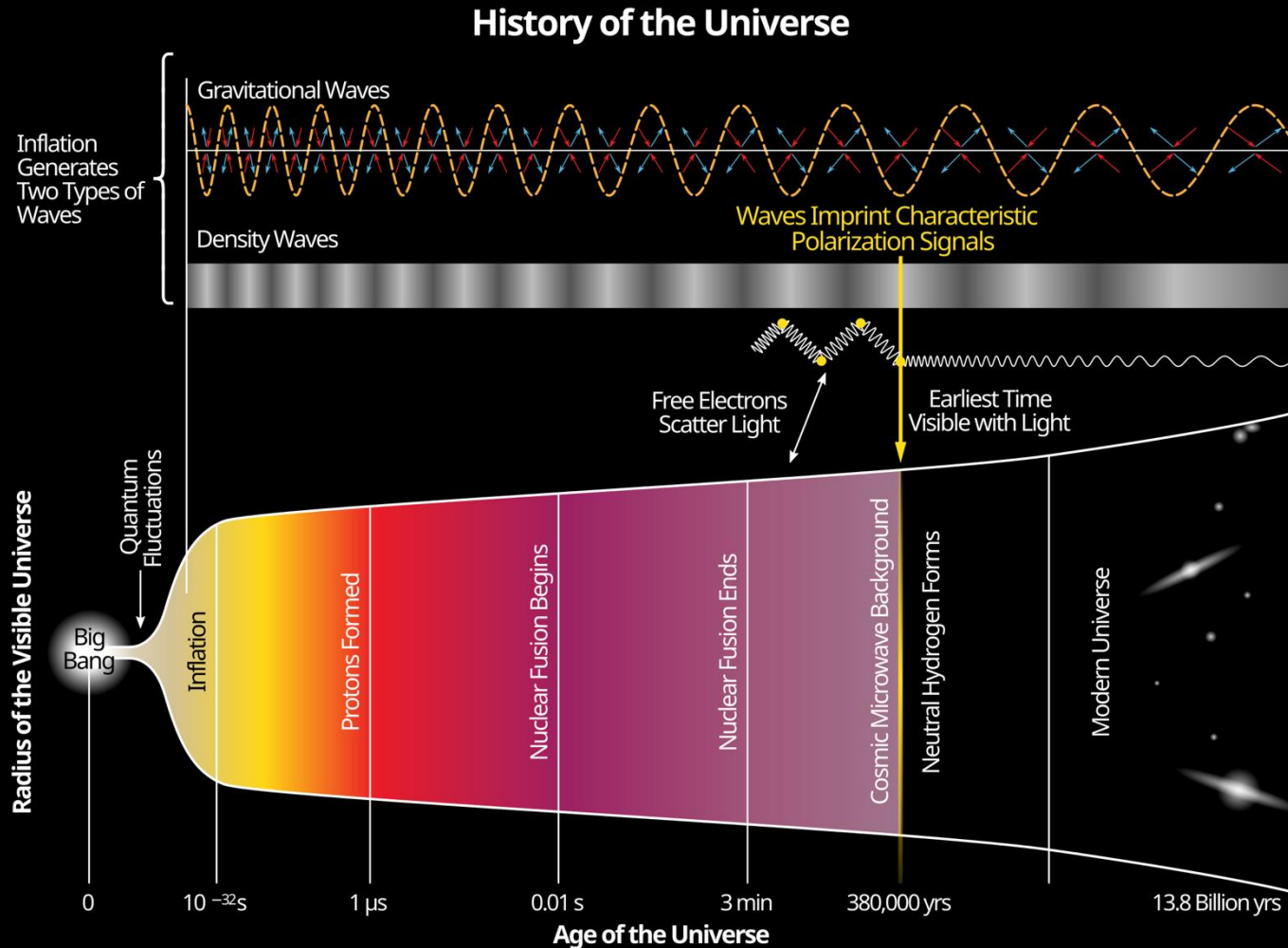




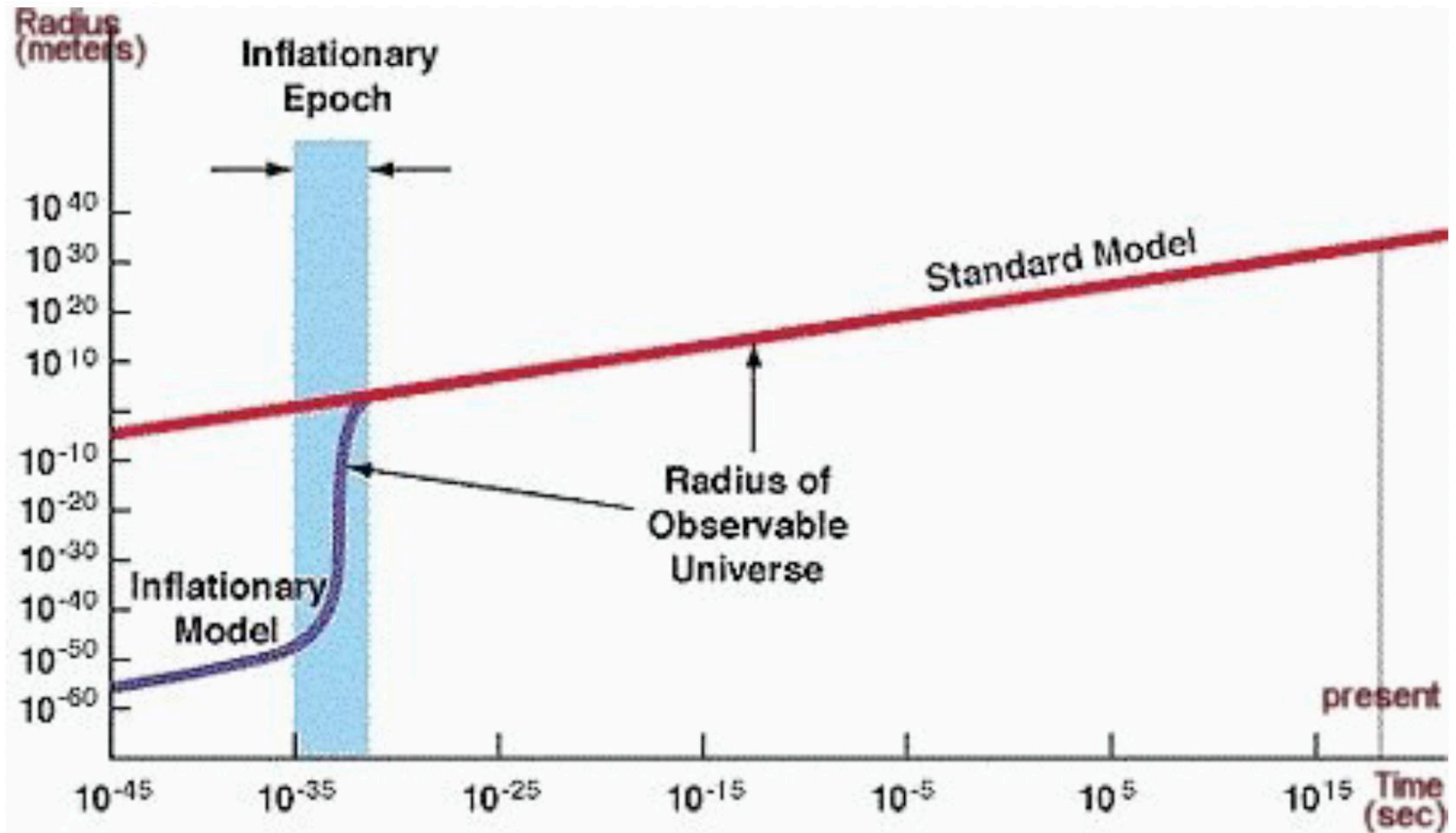
NASA/Dragonfly Titan Mission (art
image, planned for late 2020s)

The history of the universe (in 13 slides)

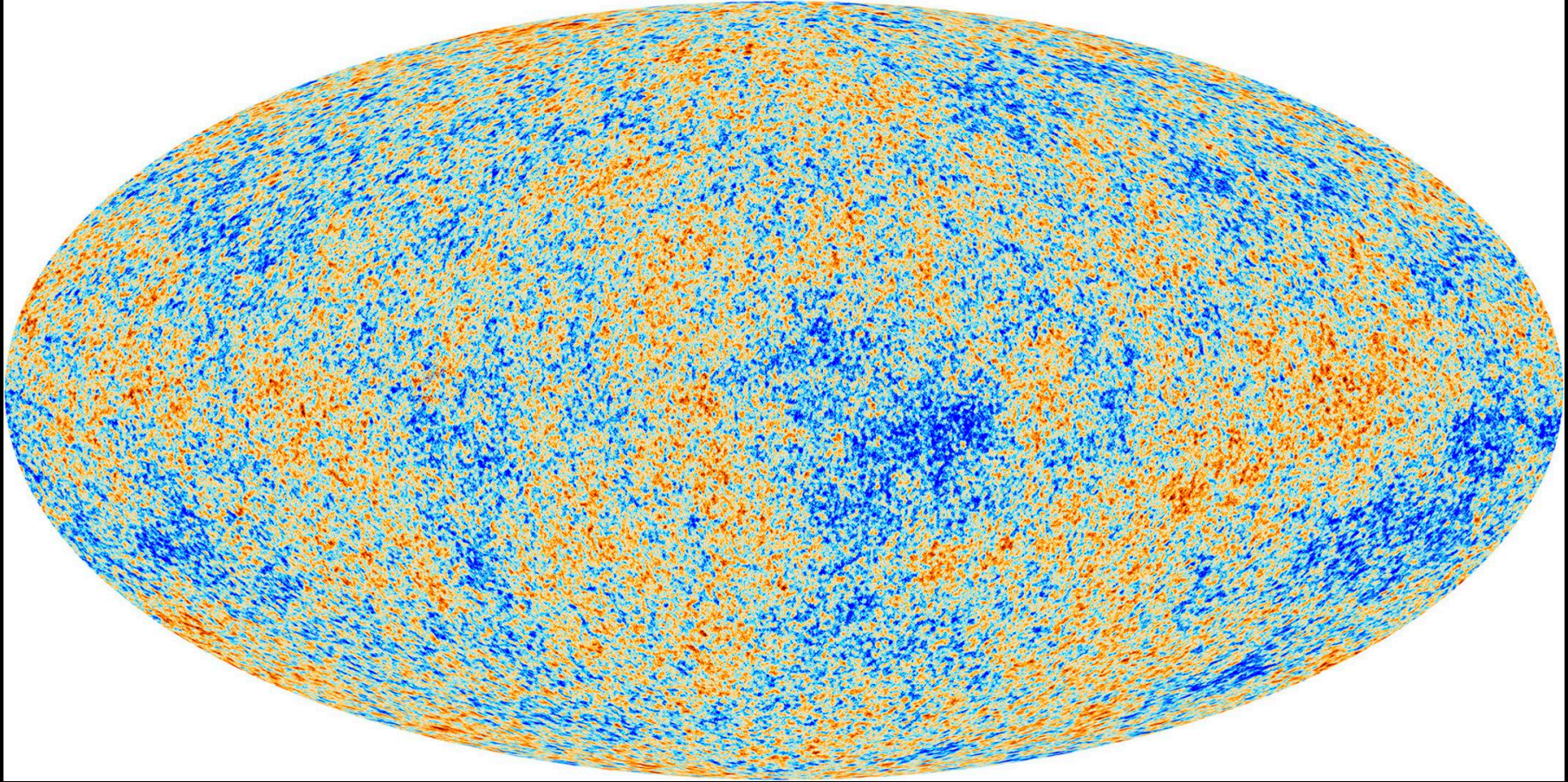
The Big Bang: an explosion of space-time!



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



Cosmic microwave background



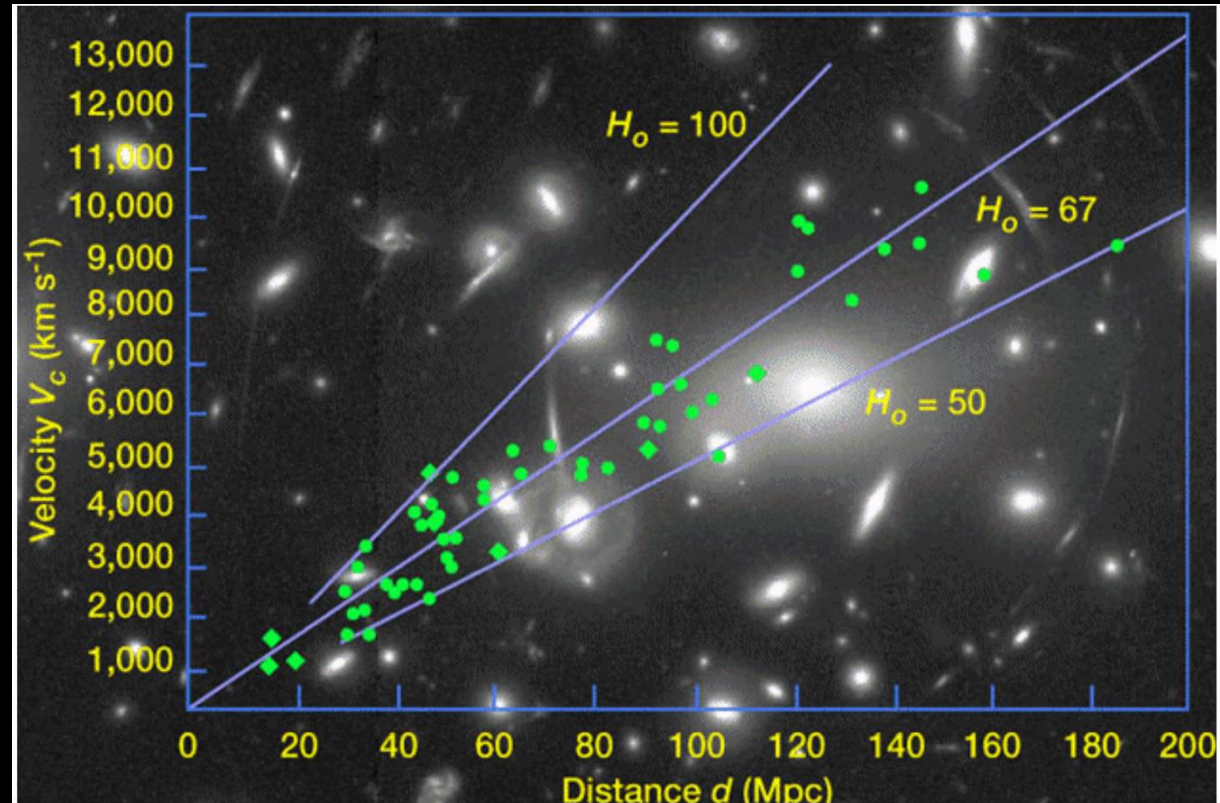
Near-uniform microwave background (smooth to 1 part in 10^4)

But not perfect: anisotropies!

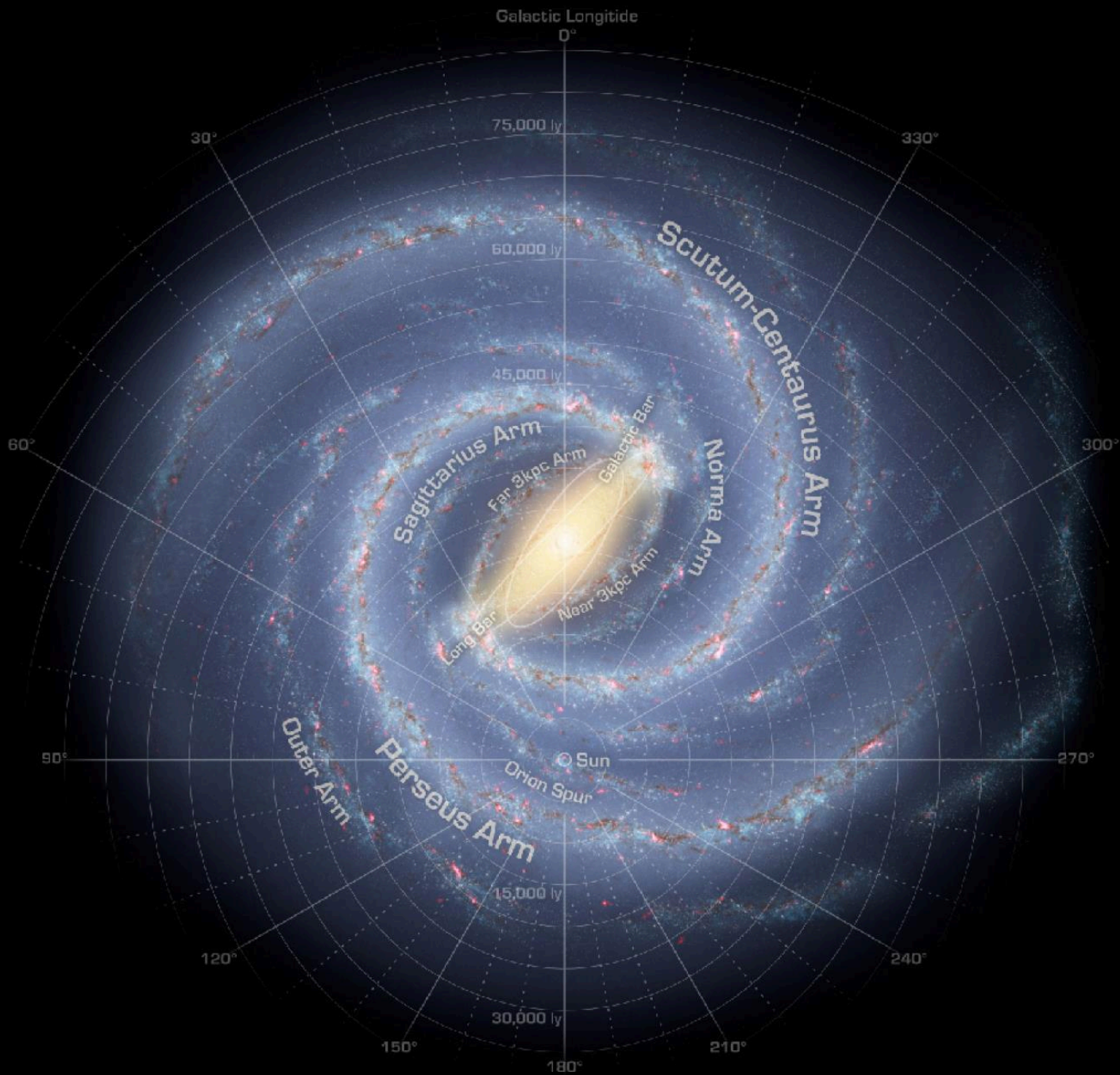
First stars and
galaxies form



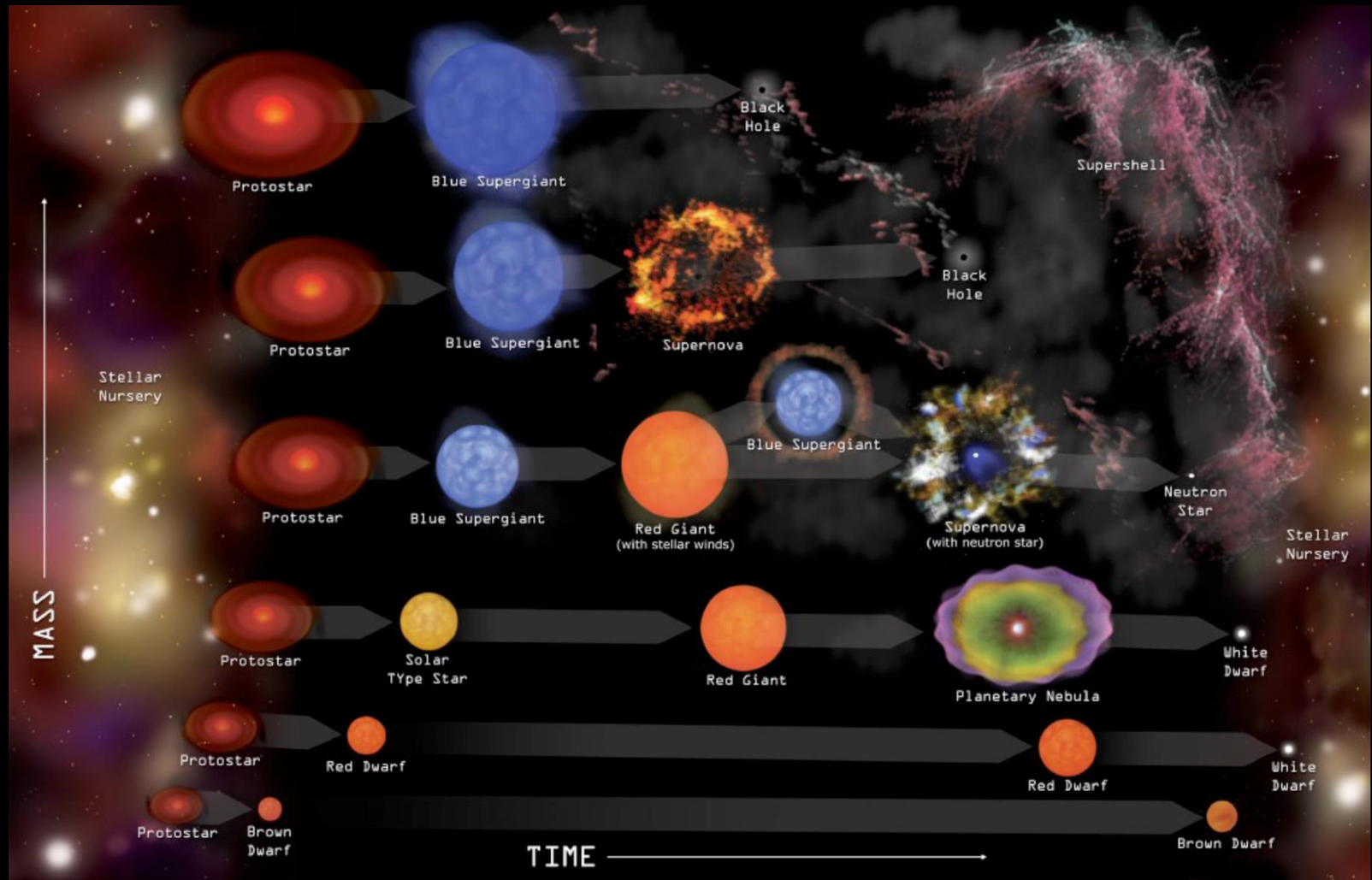
Cosmic expansion and Hubble's Law



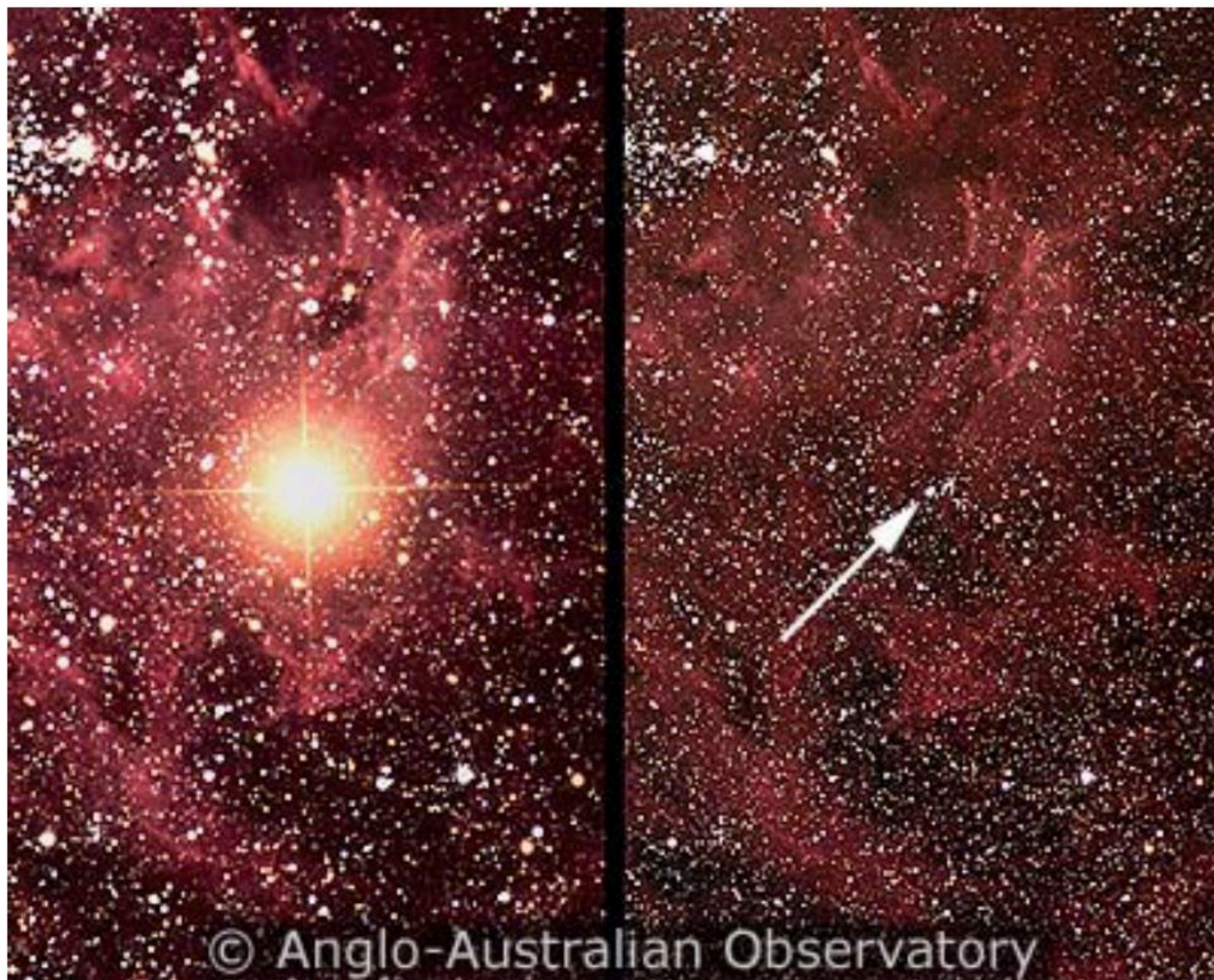
Most distant objects: redshifted (so appears red)
Distance: looks at the distance when younger (light travel time)



First stars are massive and explode!









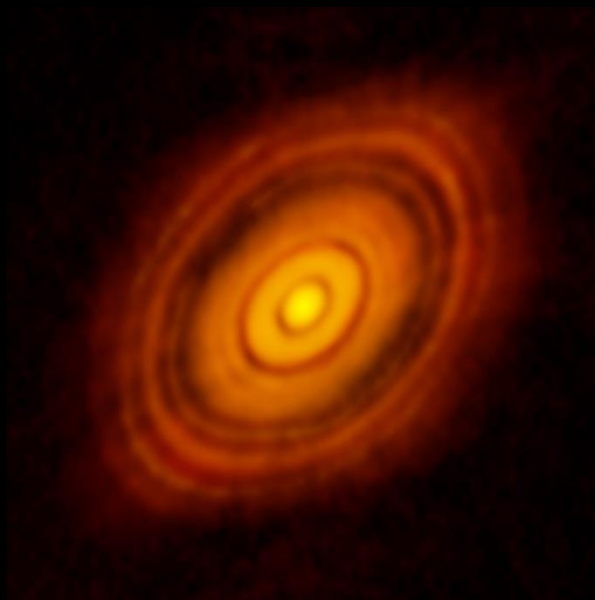
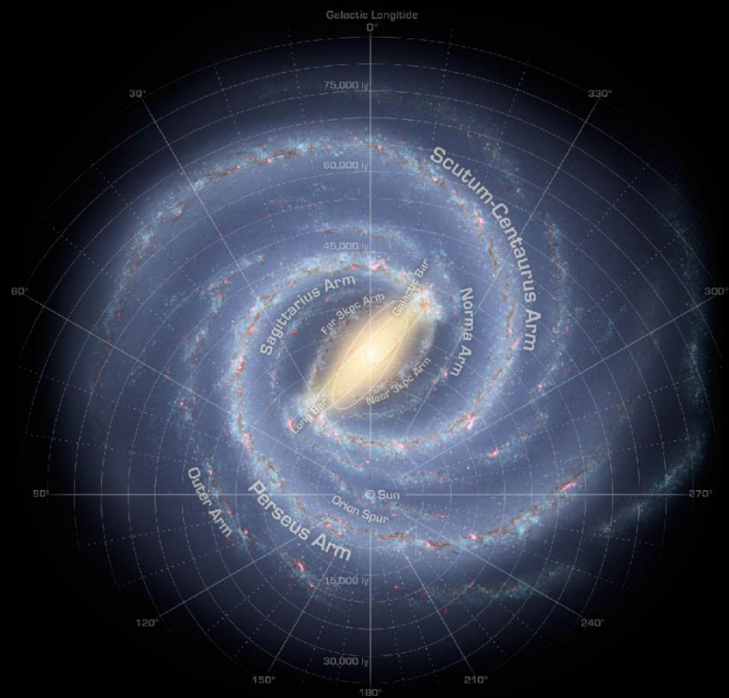
Supernova 1987A (brightest in modern times)



© Anglo-Australian Observatory

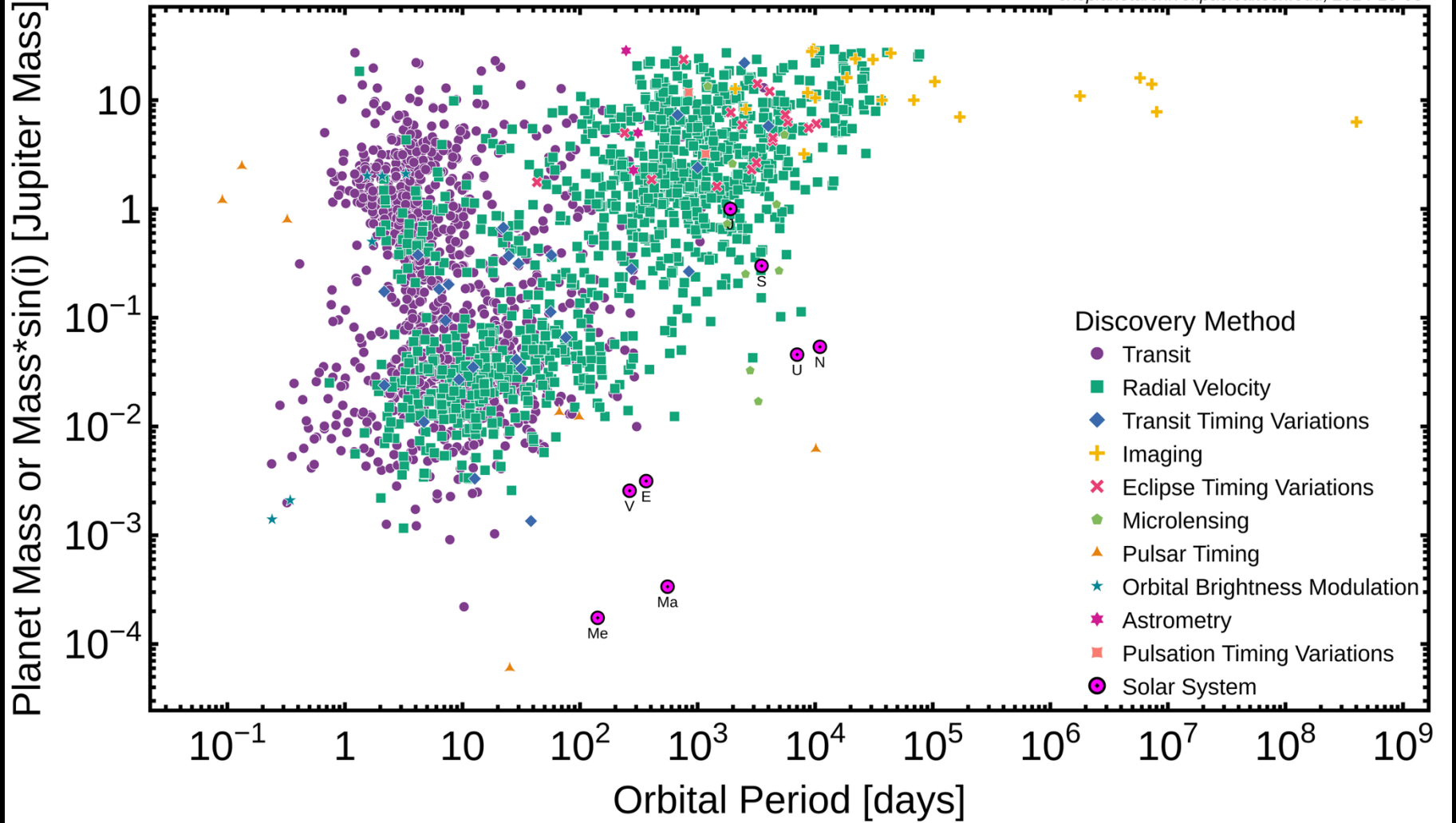
The Origin of the Solar System Elements

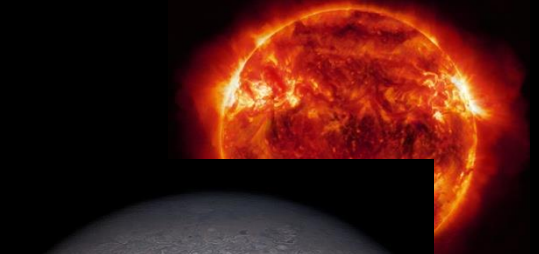
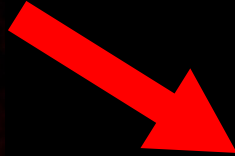
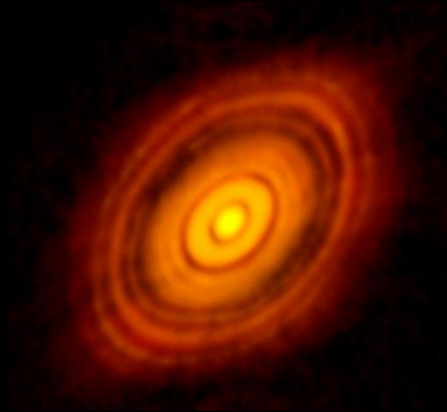
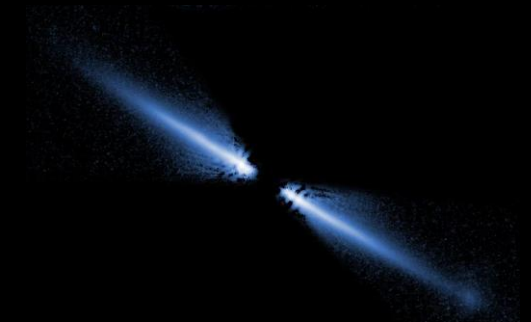
1 H	big bang fusion 						cosmic ray fission 						2 He						
3 Li	4 Be	merging neutron stars? 						exploding massive stars 						5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	dying low mass stars 						exploding white dwarfs 						13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr		
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe		
55 Cs	56 Ba	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn			
87 Fr	88 Ra																		
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu			
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	Very radioactive isotopes; nothing left from stars											

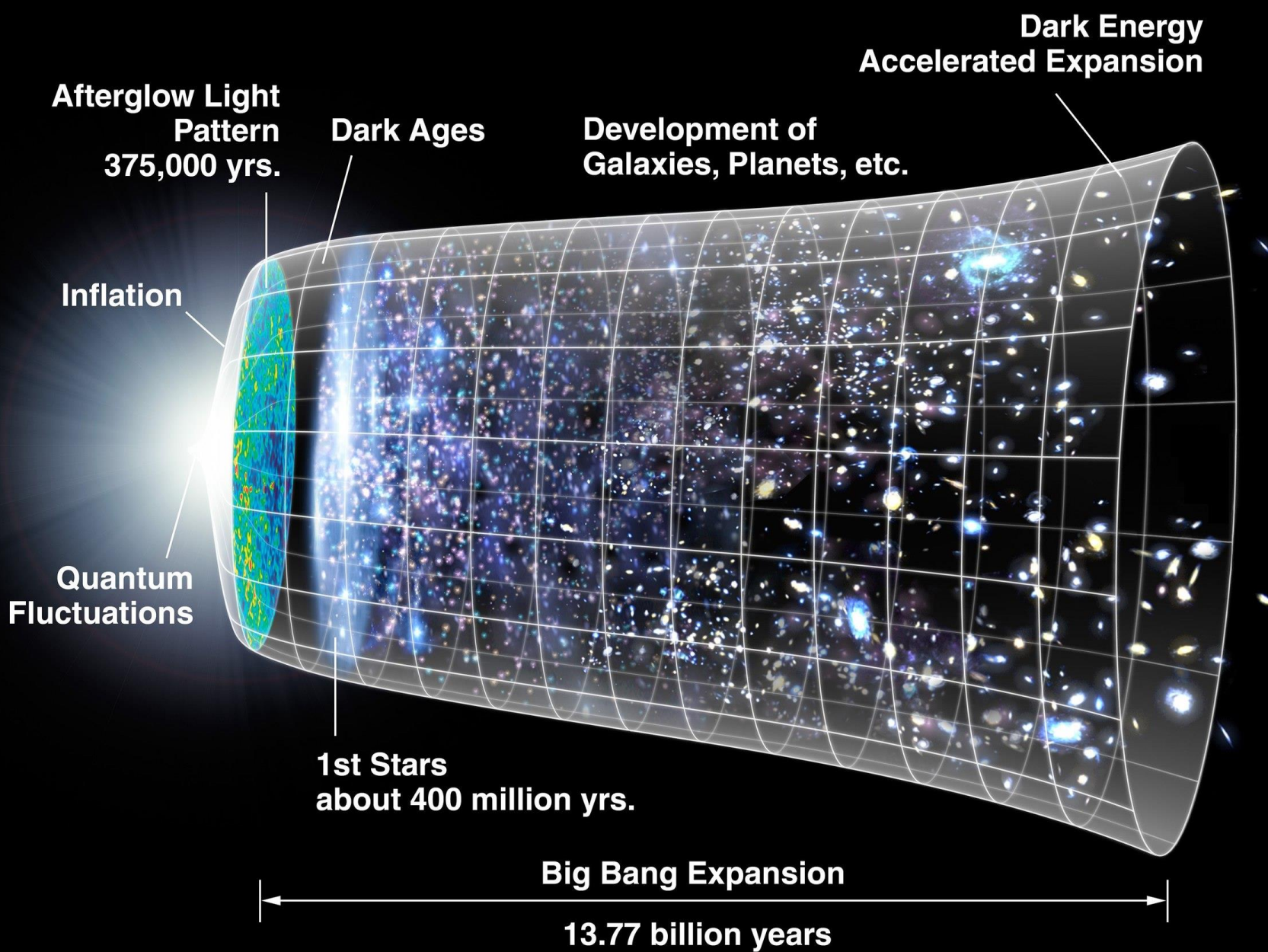


Planet Mass or Mass* $\sin(i)$ vs Orbital Period

exoplanetarchive.ipac.caltech.edu, 2024-10-08









Big Bang occurs.

Milky Way Galaxy forms.

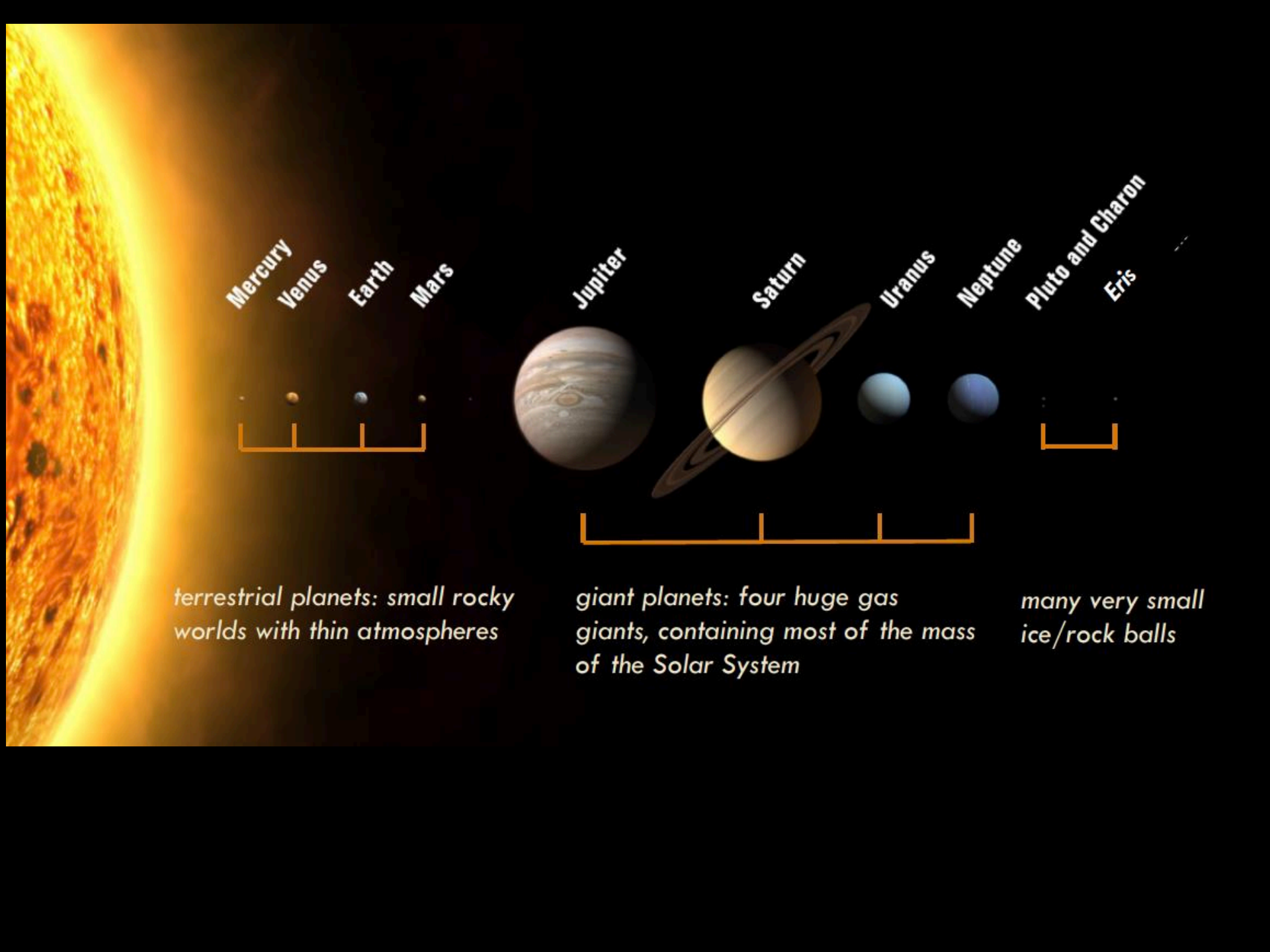
Our solar system forms. Life on Earth begins.

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



terrestrial planets: small rocky worlds with thin atmospheres

Jupiter

Saturn

Uranus

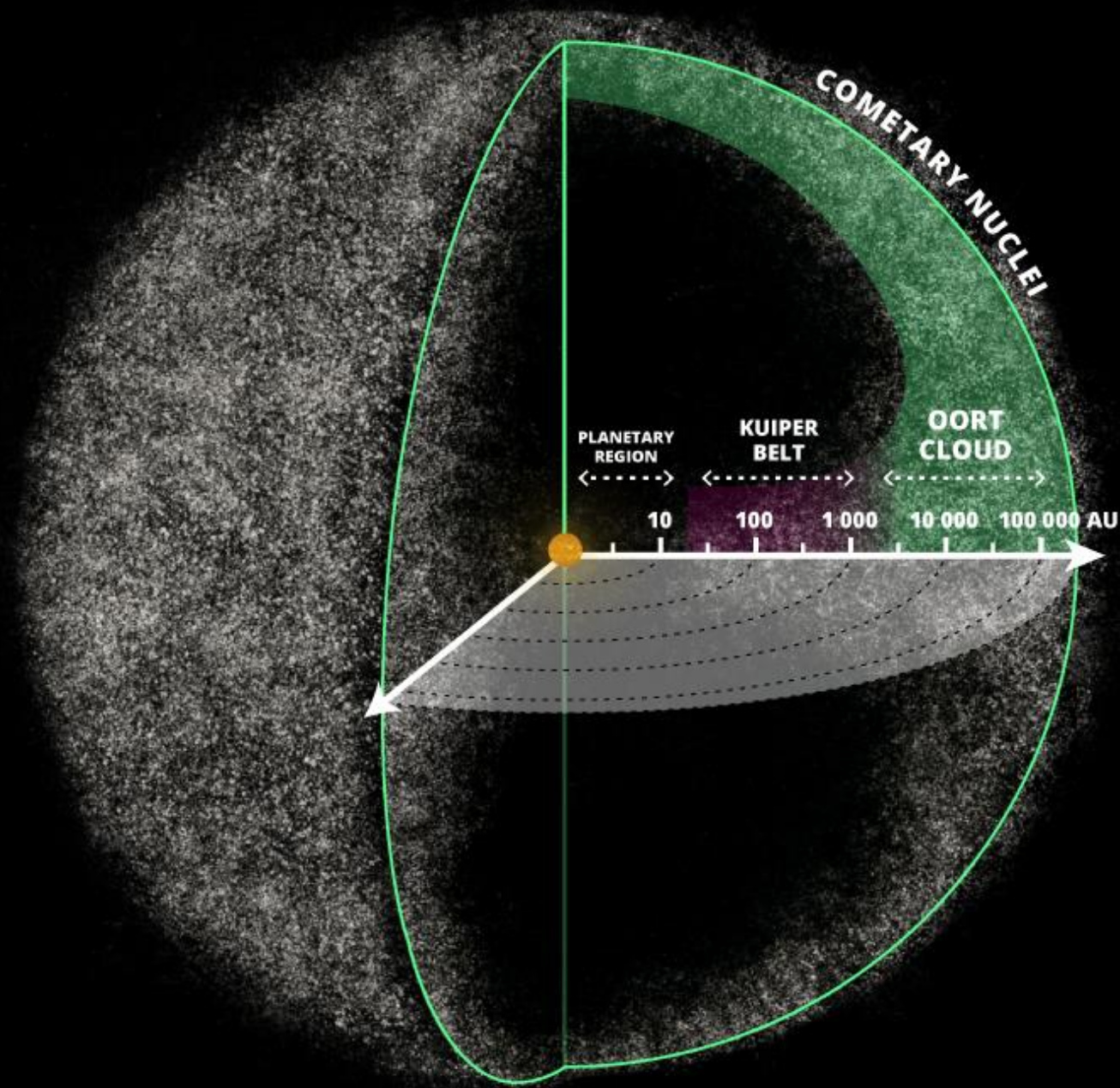
Neptune

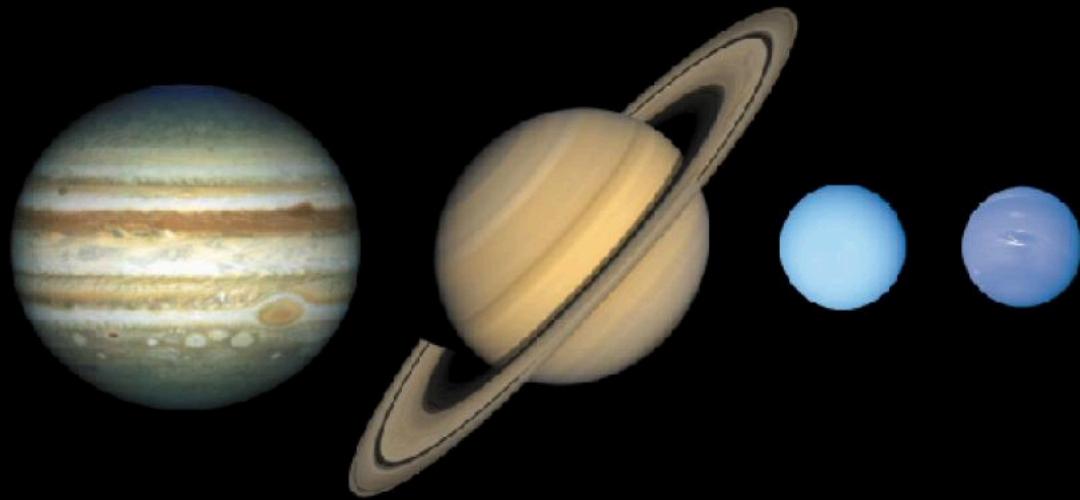
Pluto and Charon
Eris



giant planets: four huge gas giants, containing most of the mass of the Solar System

many very small ice/rock balls





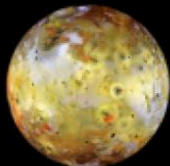
 Earth

Earth



Moon

Jupiter



Io



Europa



Ganymede



Callisto

Saturn



Mimas



Enceladus



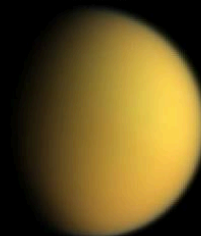
Tethys



Dione



Rhea



Titan



Hyperion



Iapetus



Phoebe

Uranus



Puck



Miranda



Ariel



Umbriel



Titania



Oberon

Neptune



Proteus



Triton



Nereid

Pluto



Charon

Eris



Dysnomia



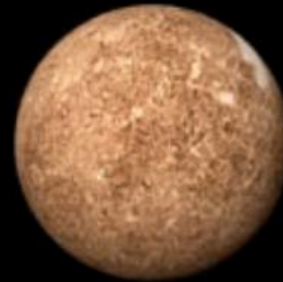
Earth



Ganymede
5262 km



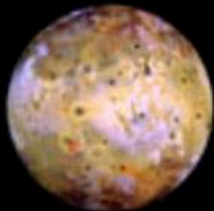
Titan
5150 km



Mercury
4880 km



Callisto
4806 km



Io
3642 km



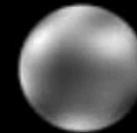
Moon
3476 km



Europa
3138 km



Triton
2706 km

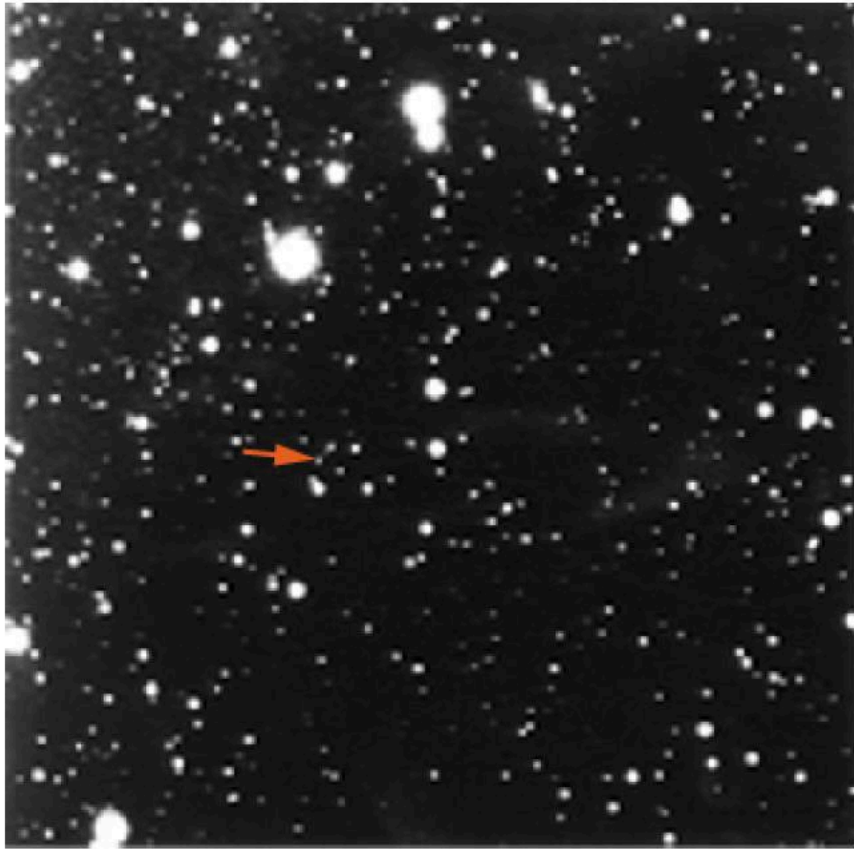


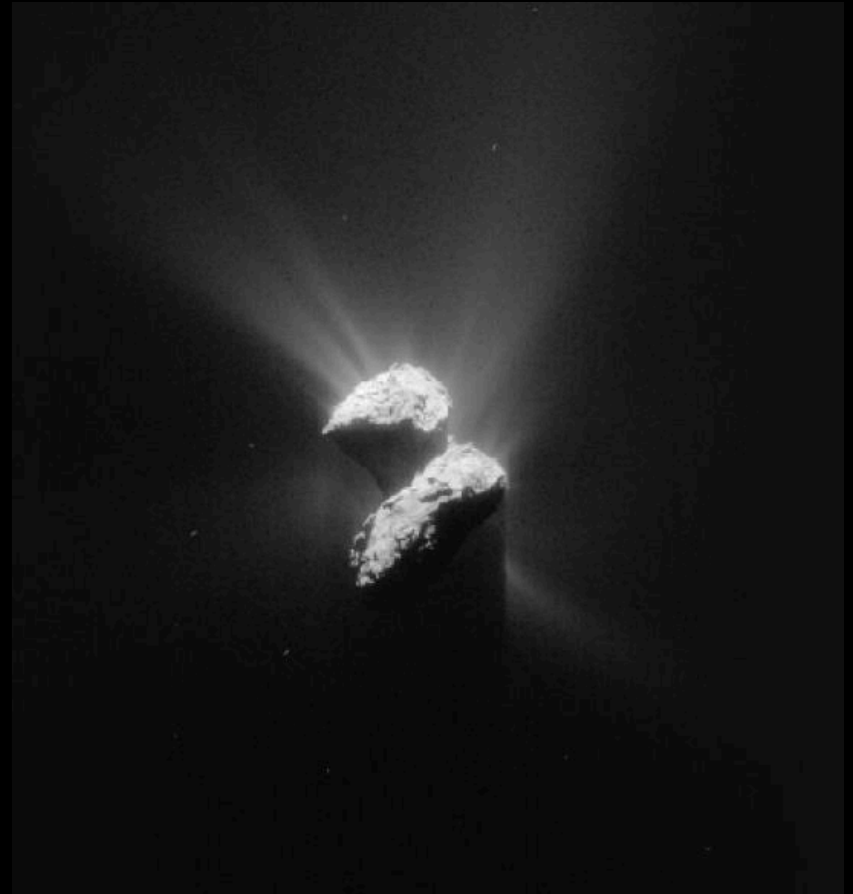
Pluto
2300 km



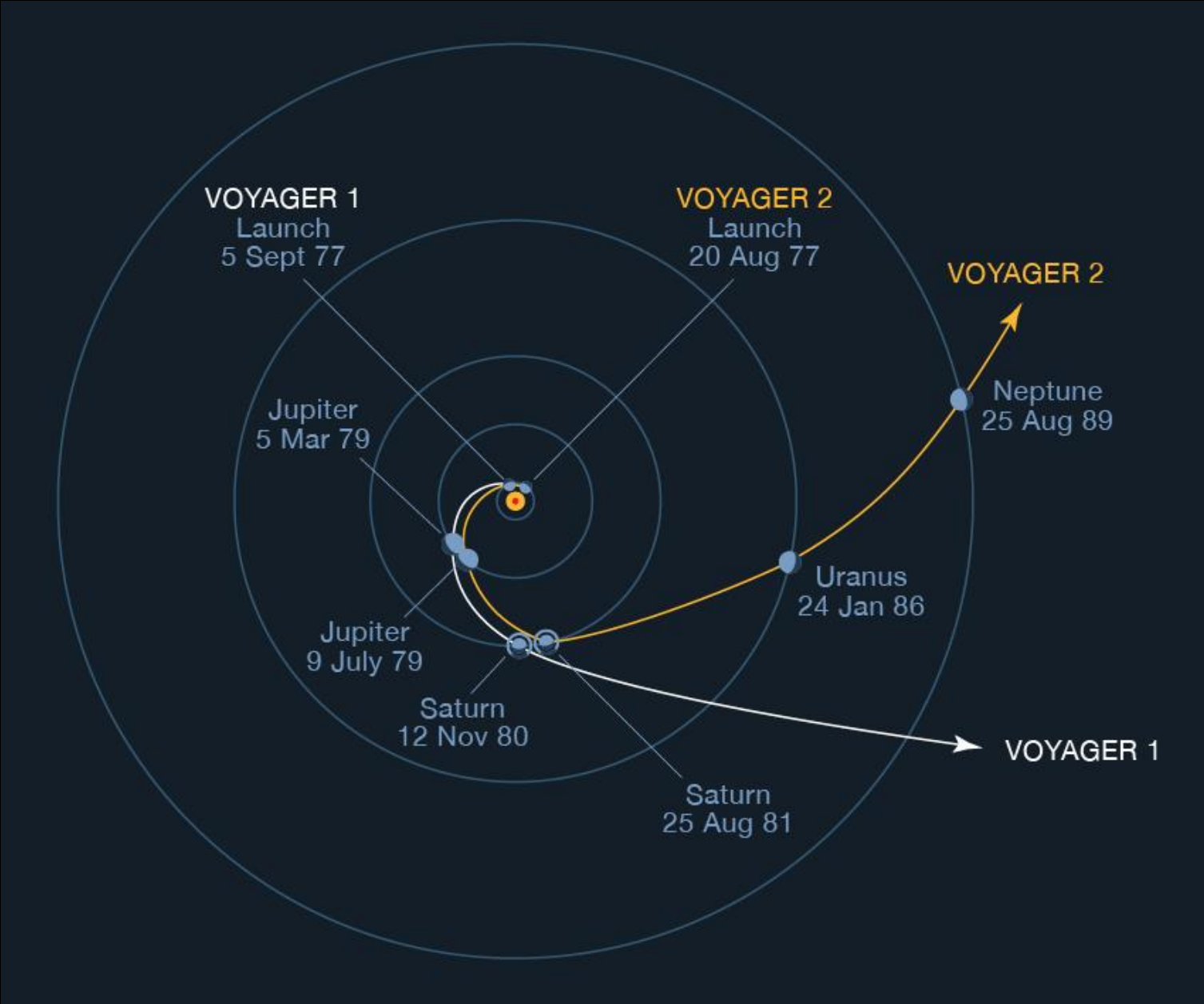
Titania
1580 km

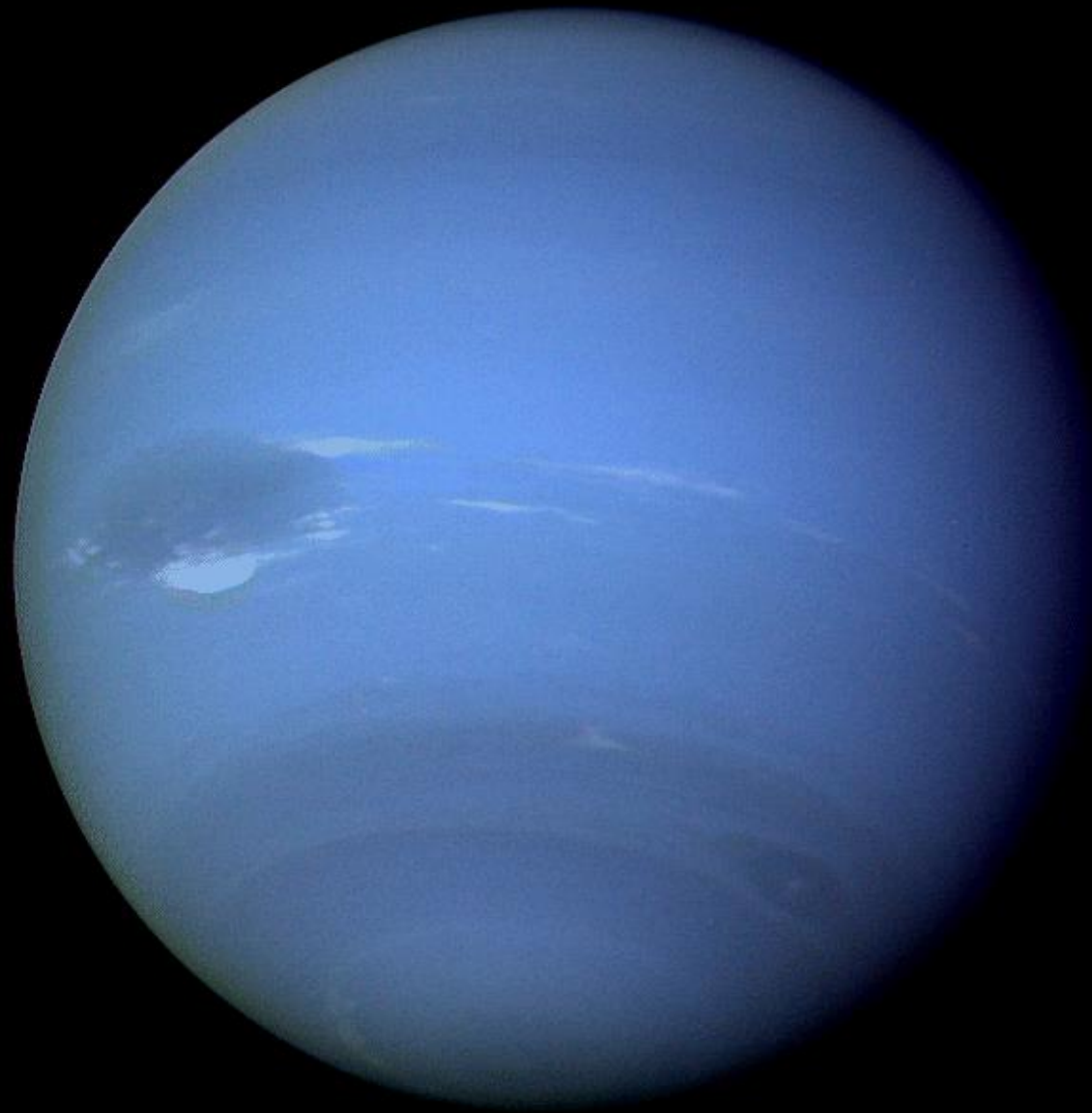
Discovery of Pluto





Asteroids





Neptune from Voyager

JAMES WEBB SPACE TELESCOPE

NEPTUNE

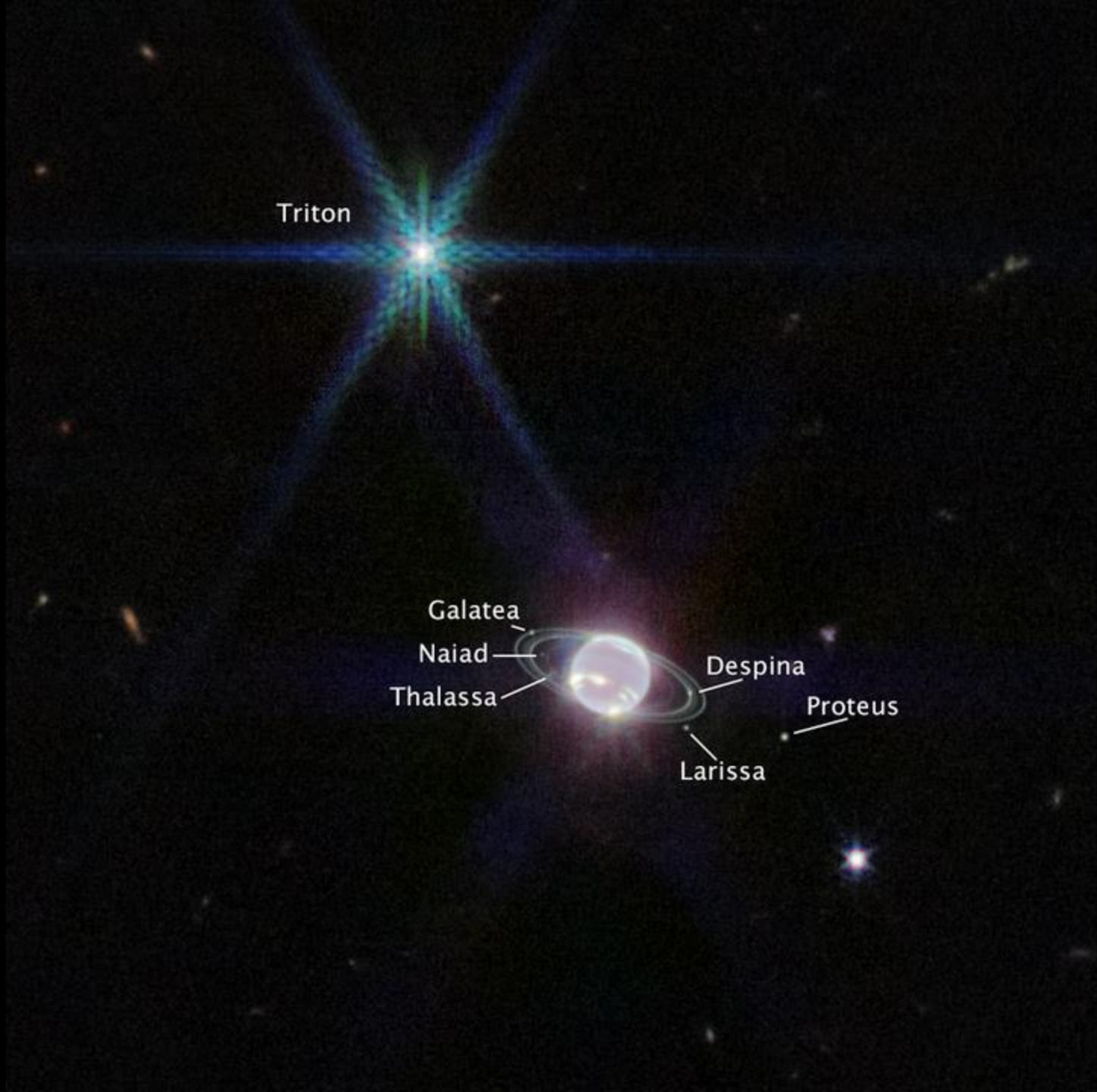


NIRCam Filters

F140M F210M F300M F460M

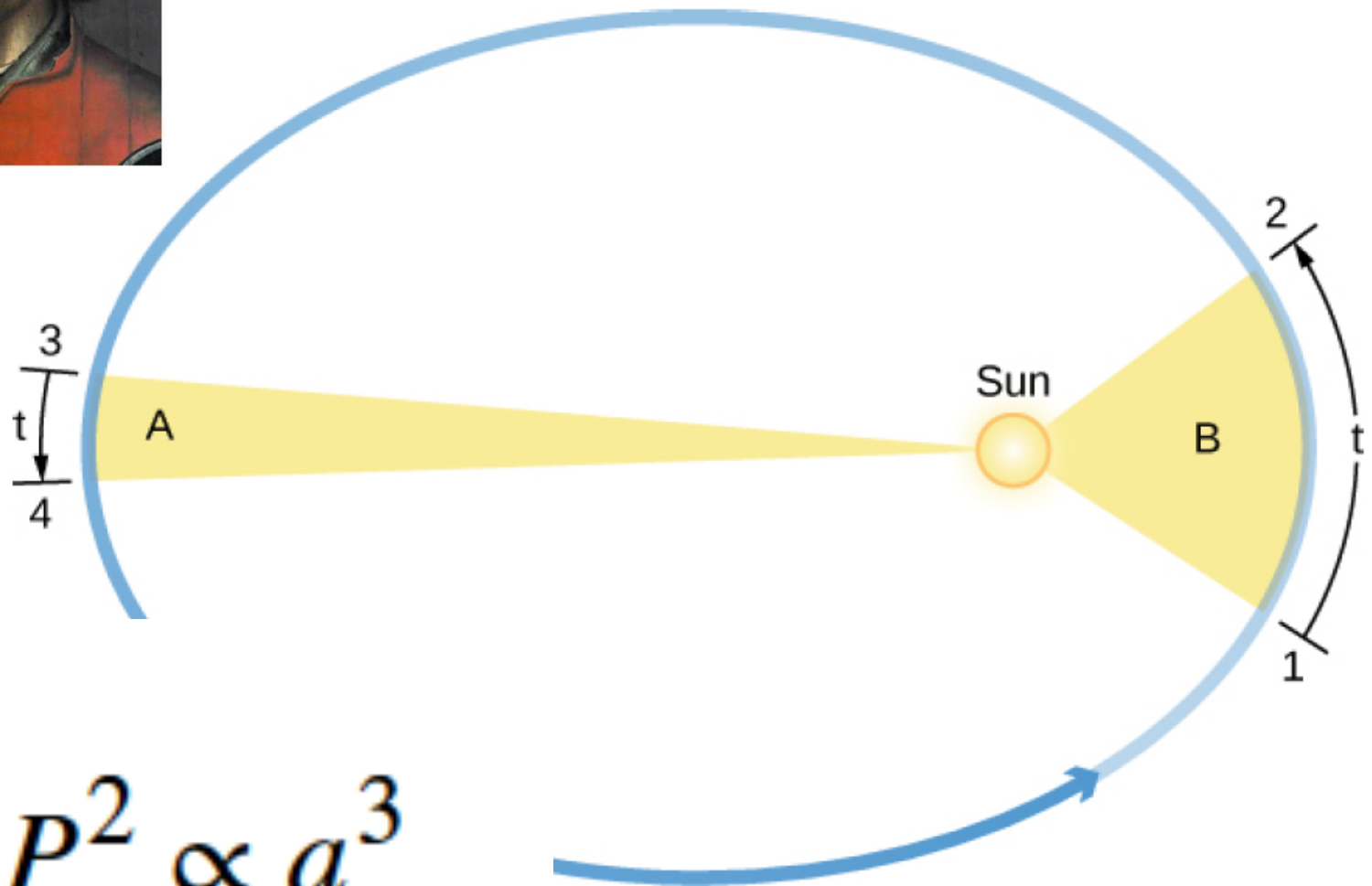
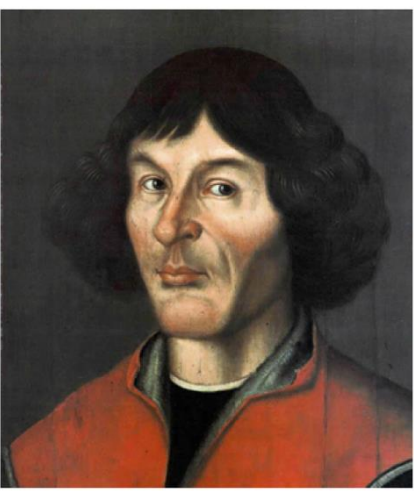
Triton

Galatea
Naiad
Thalassa
Despina
Larissa
Proteus



Kepler's Laws

(based on Tycho Brahe's data)

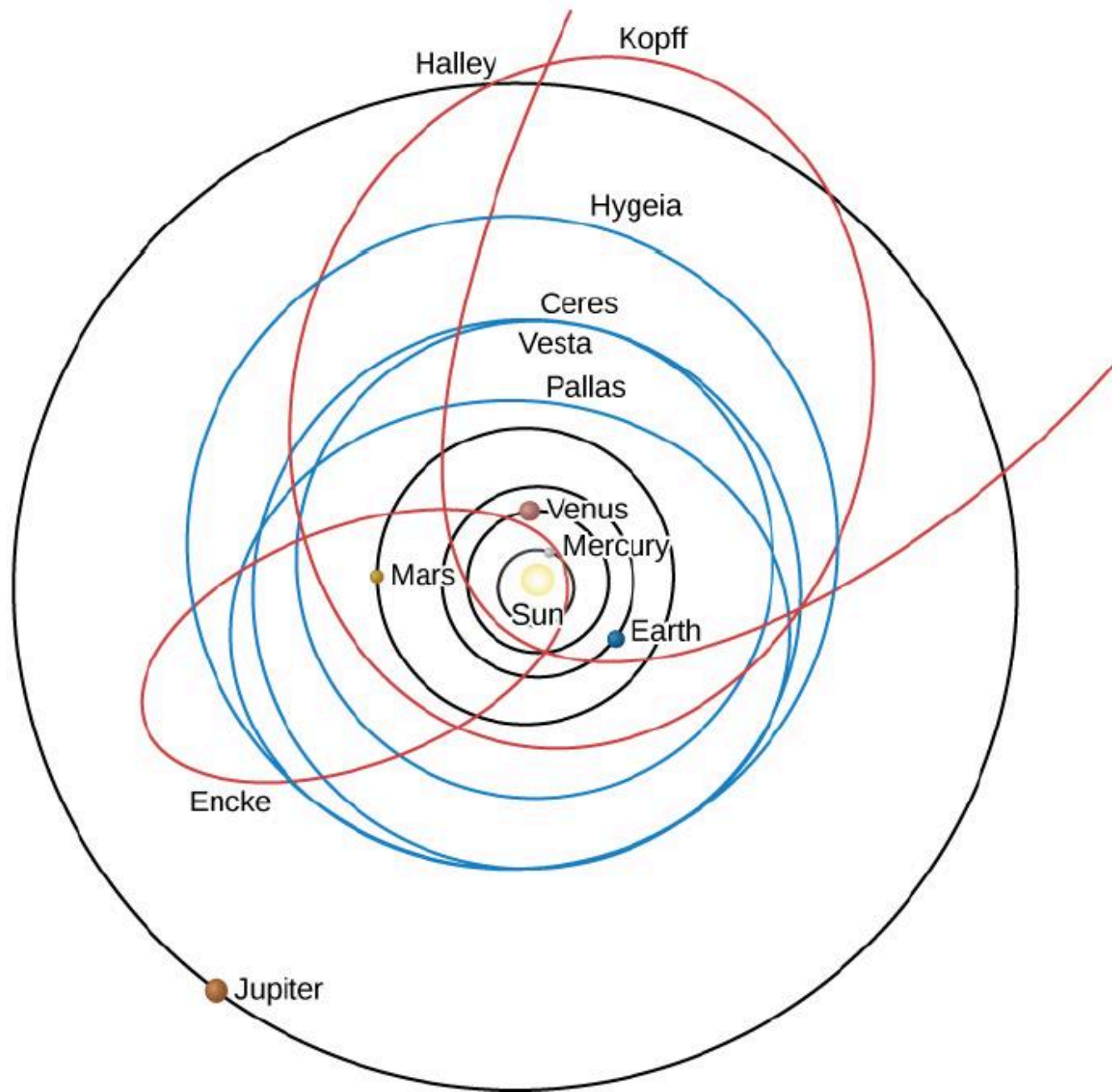


$$P^2 \propto a^3$$

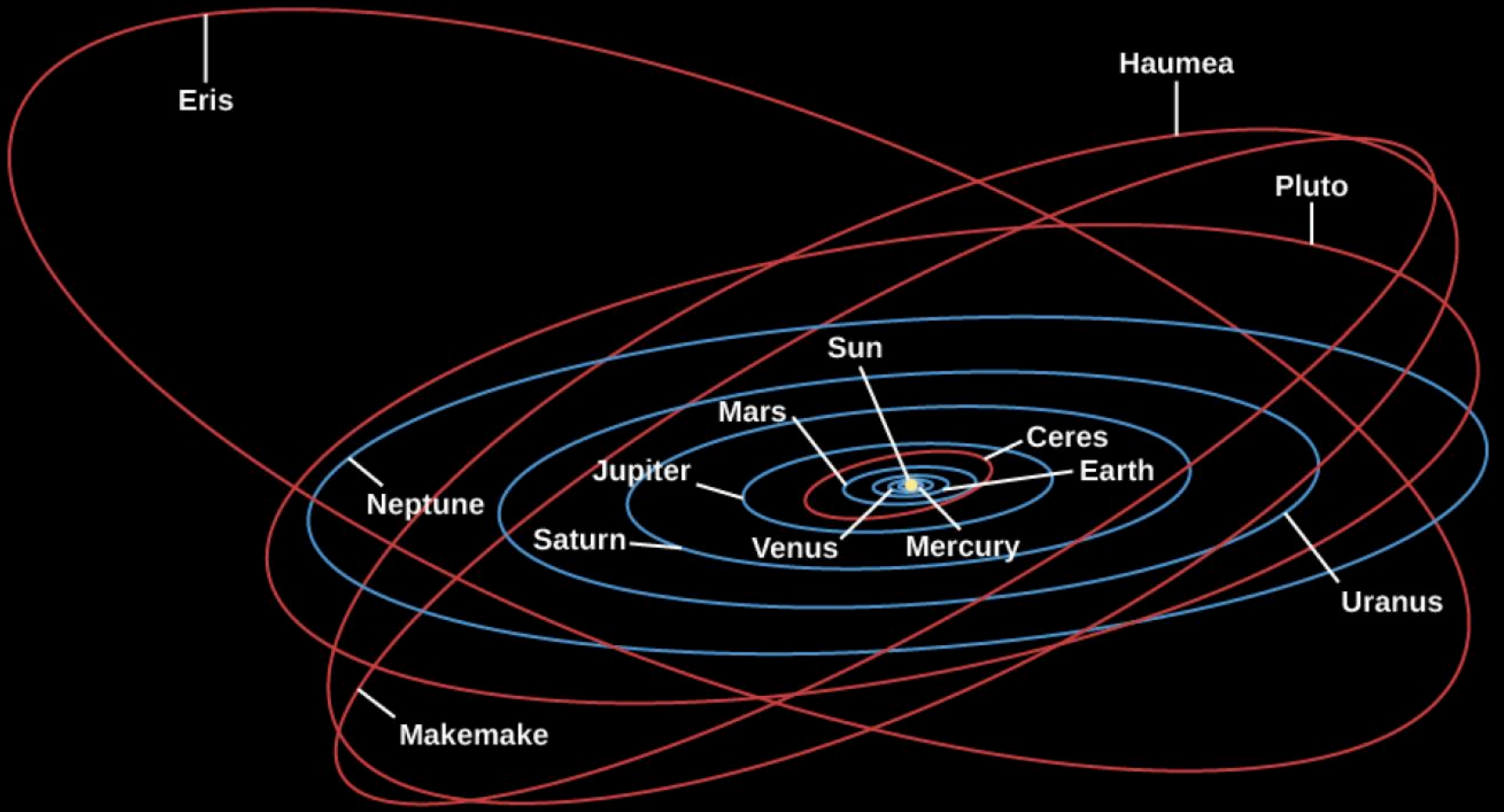
Newton's Laws of Gravity

- **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).

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

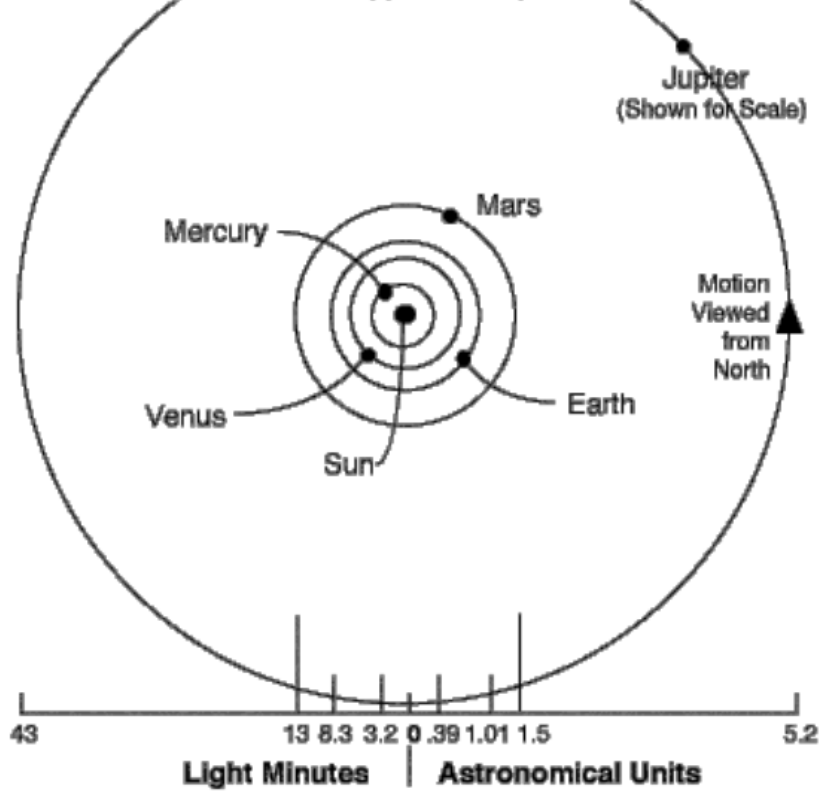


Solar System

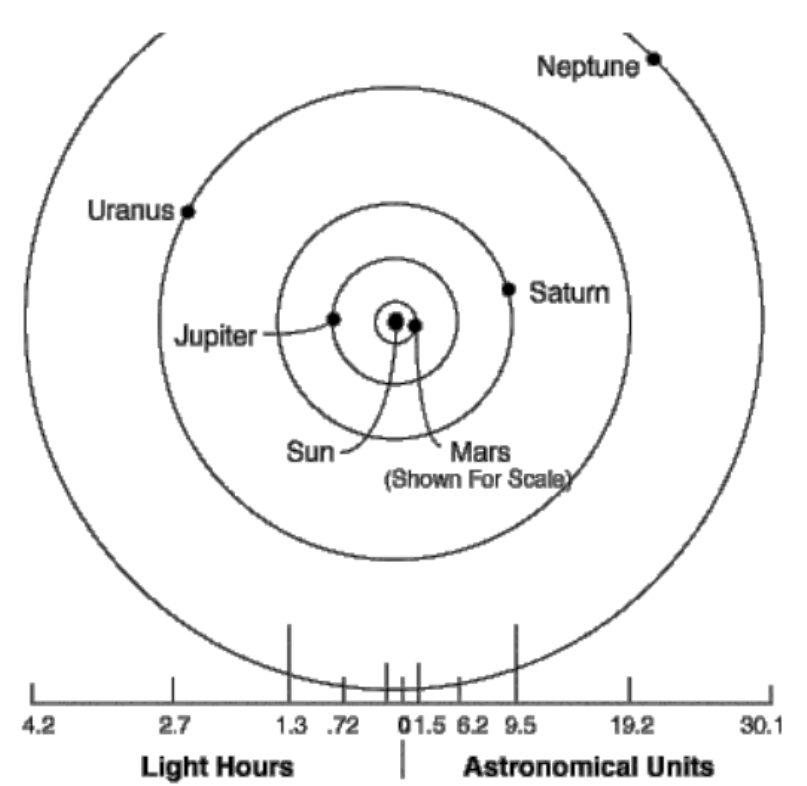


The orbits of the planets are very nearly circular and concentric.

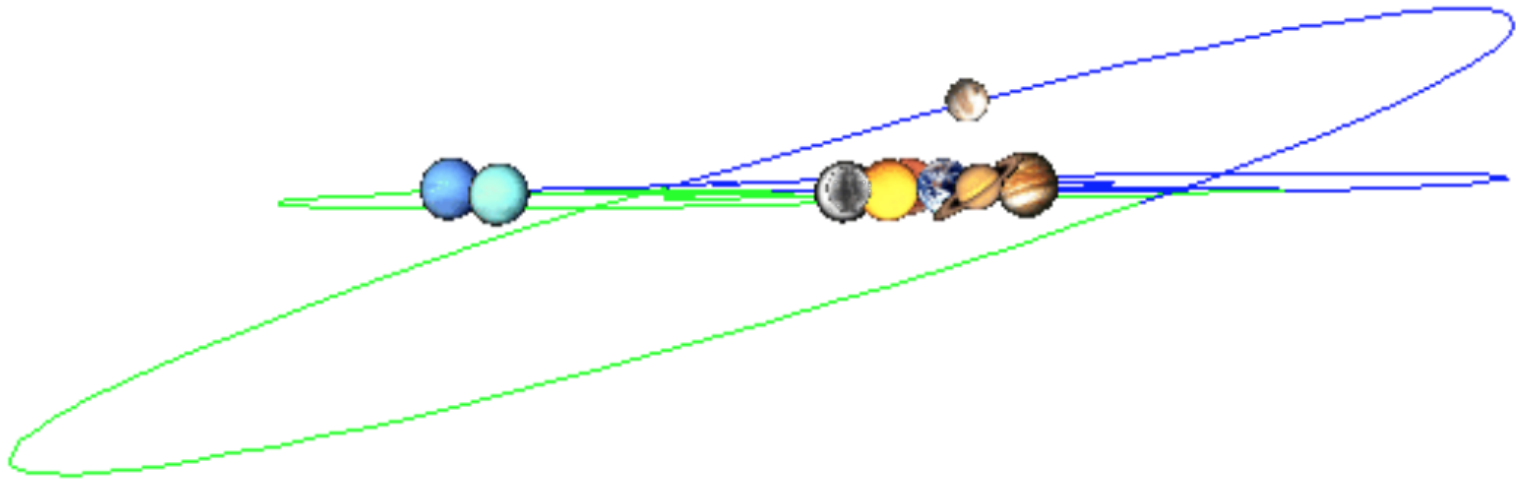
Mean Distances Of The Terrestrial Planets From The Sun
(Orbits drawn approximately to scale)

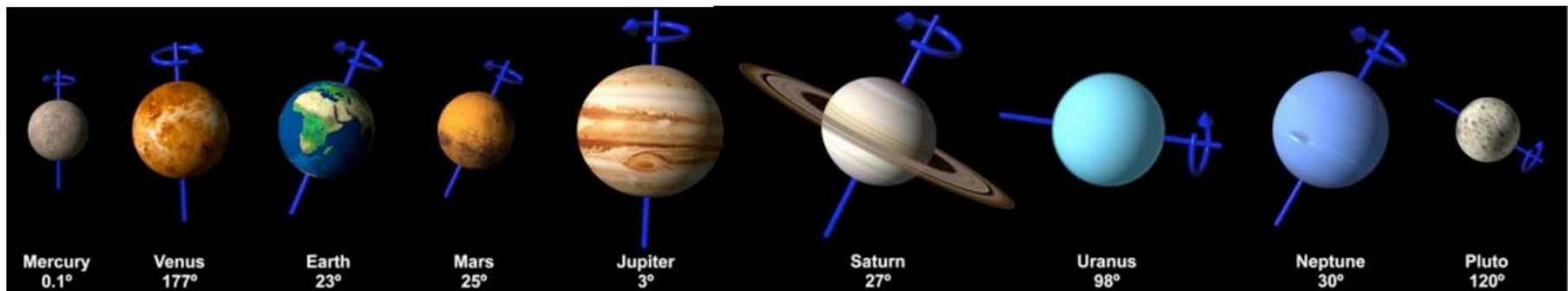


Mean Distances Of The Jovian Planets From The Sun
(Orbits drawn approximately to scale)



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

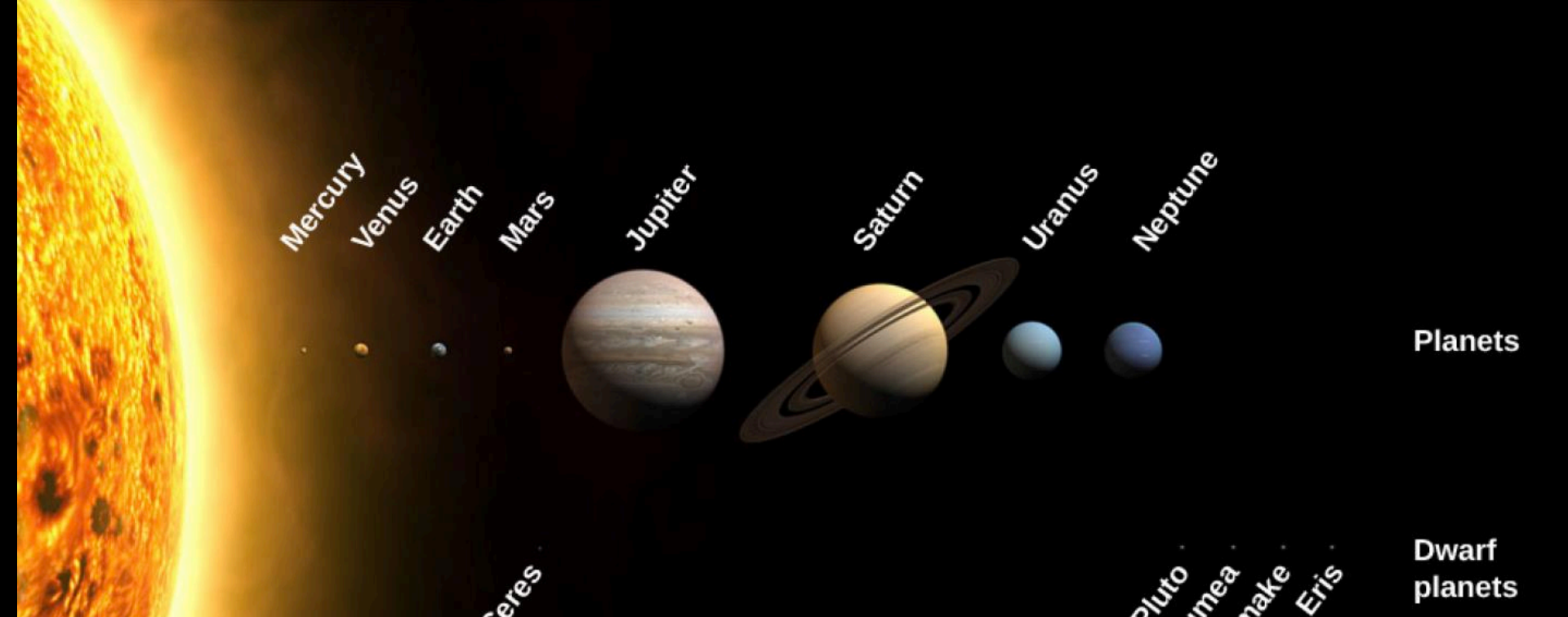




Orbital Data for the Planets

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

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



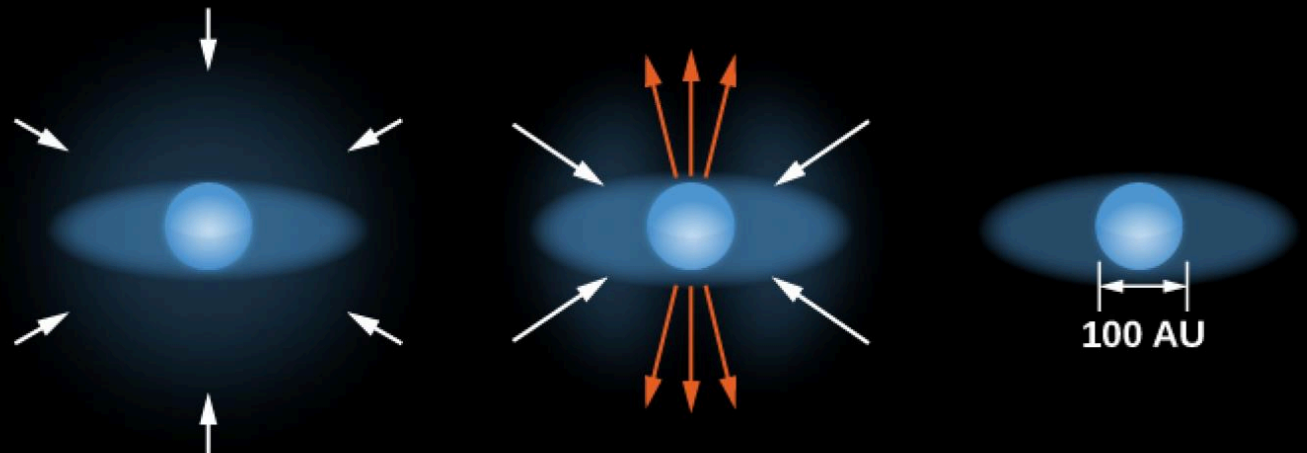
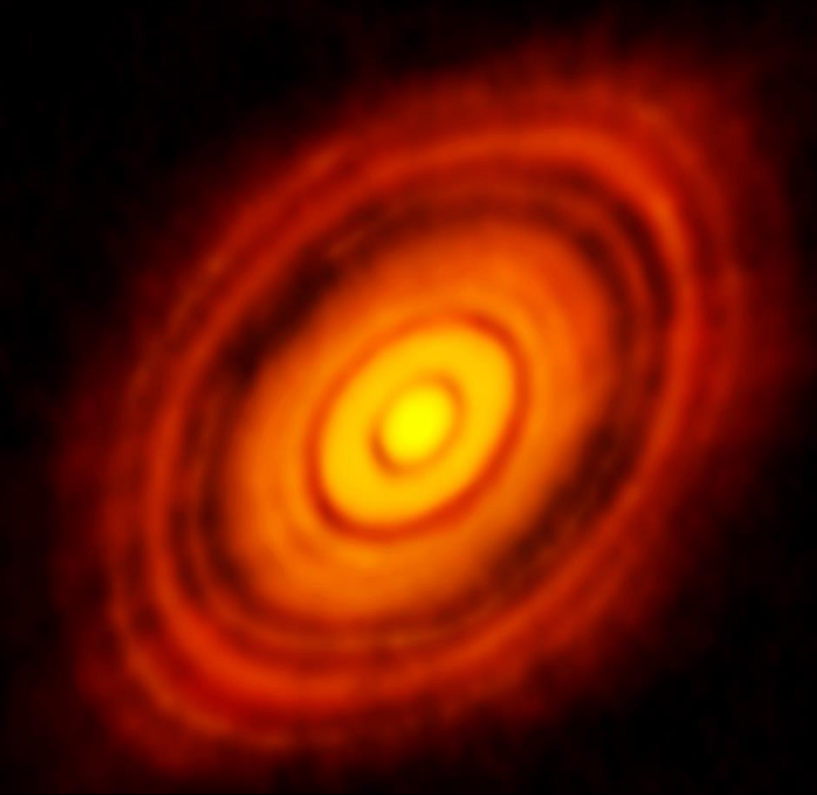
Planets

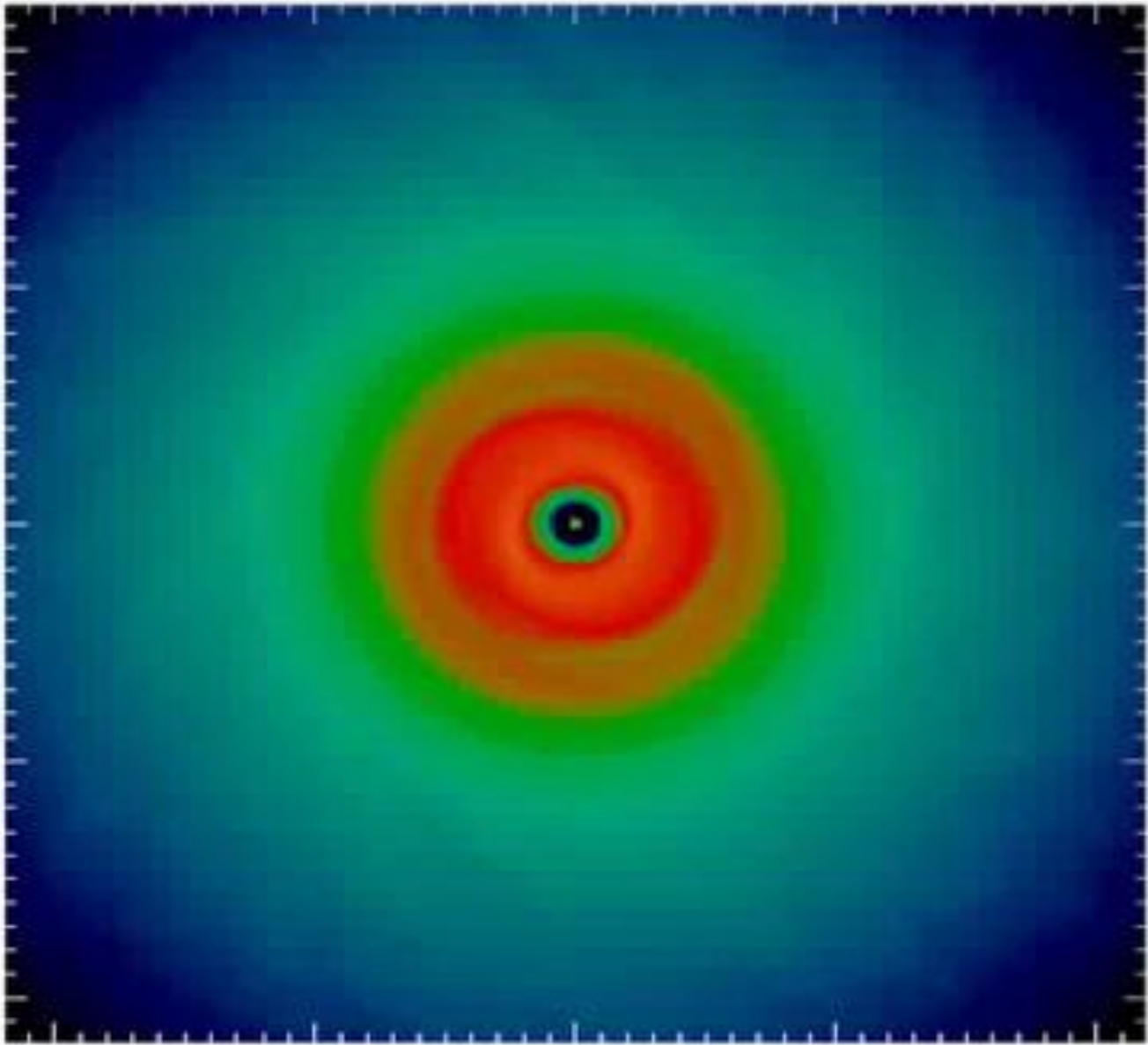
Dwarf planets

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

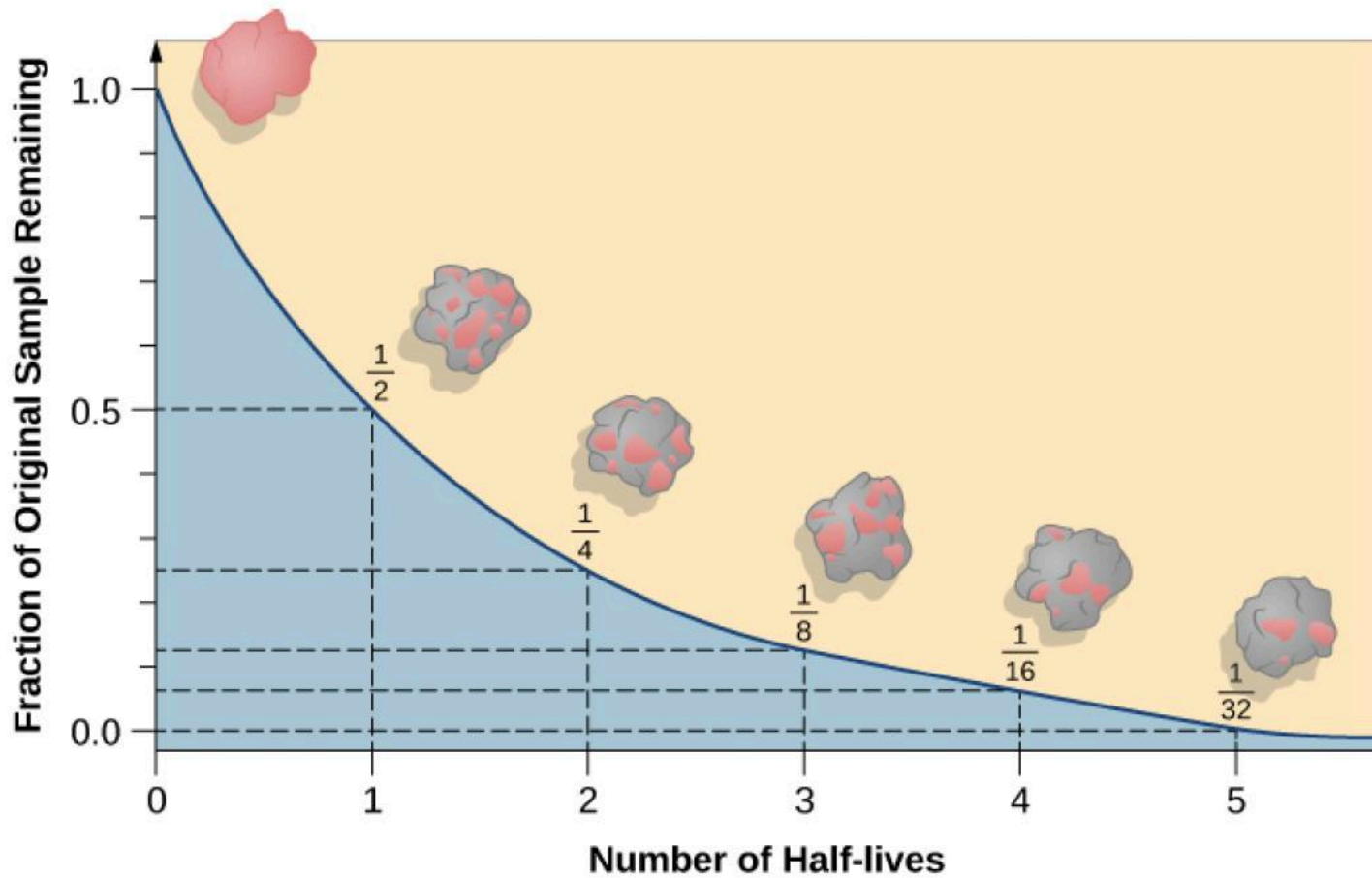
The Planets

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









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

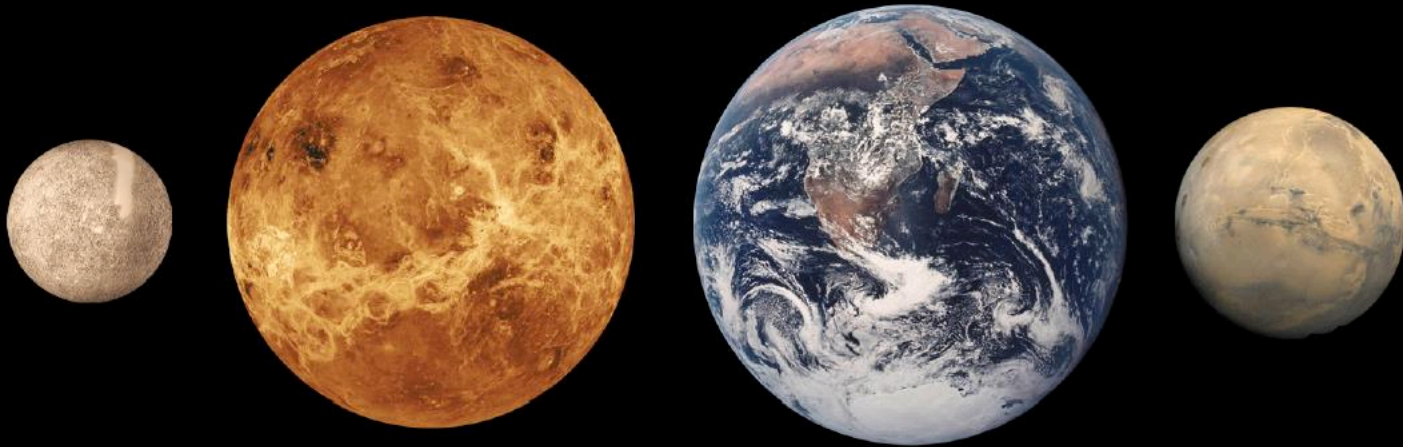
The terrestrial planets

– *rocky worlds*



The terrestrial planets

– *rocky worlds*



Surfaces of terrestrial planets

Bombardment (collisions with asteroids/comets)

Volcanism (includes earthquakes)
requires molten core

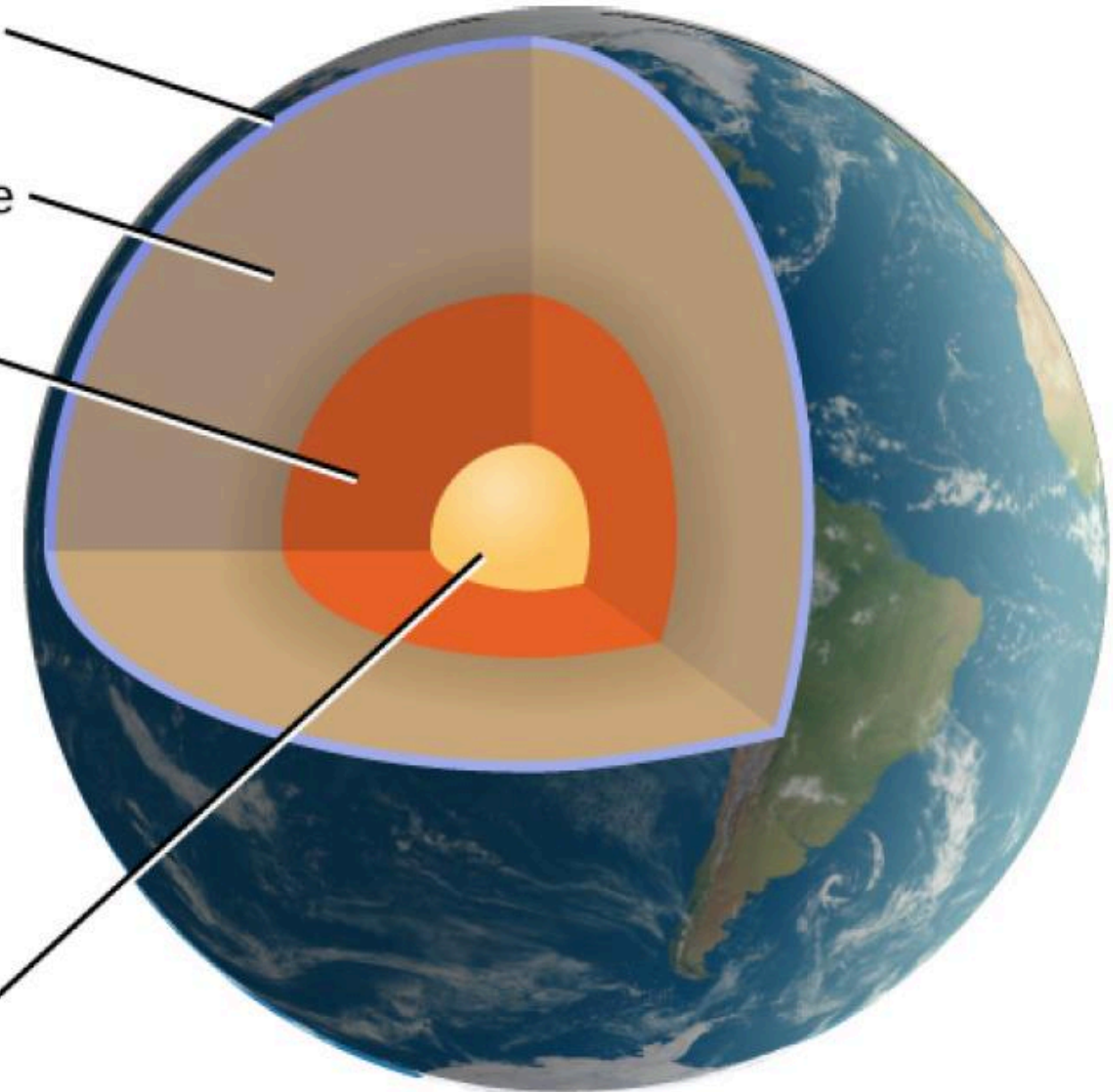
Erosion (if atmosphere)

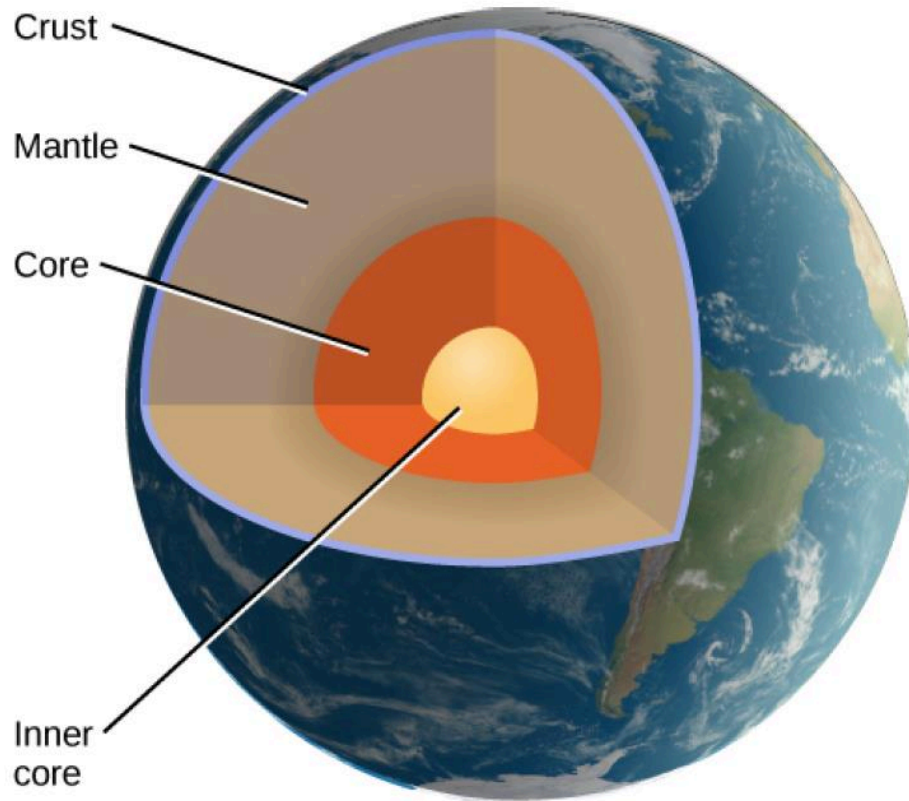
Crust

Mantle

Core

Inner
core





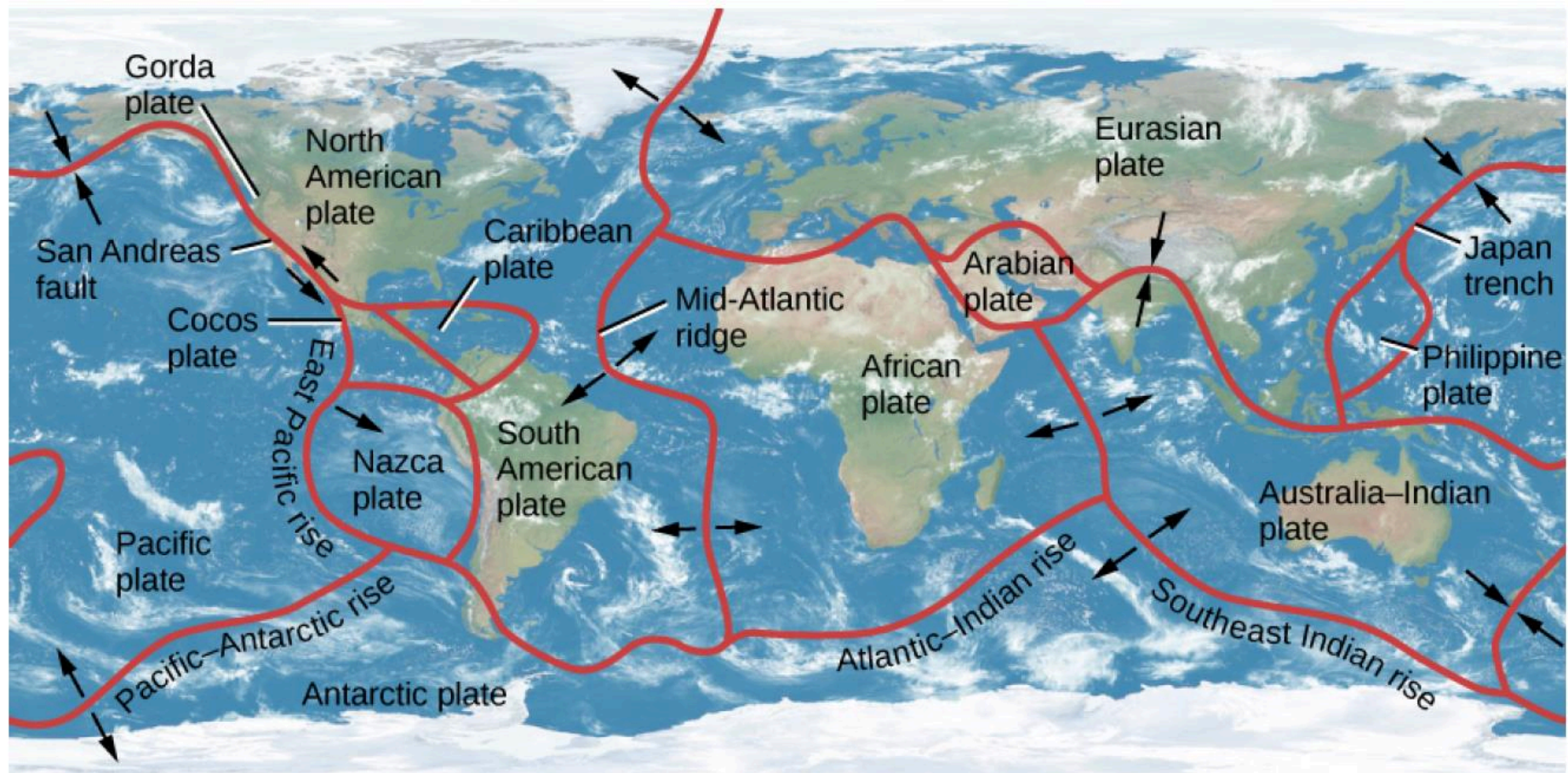
Volcanism:
need molten core

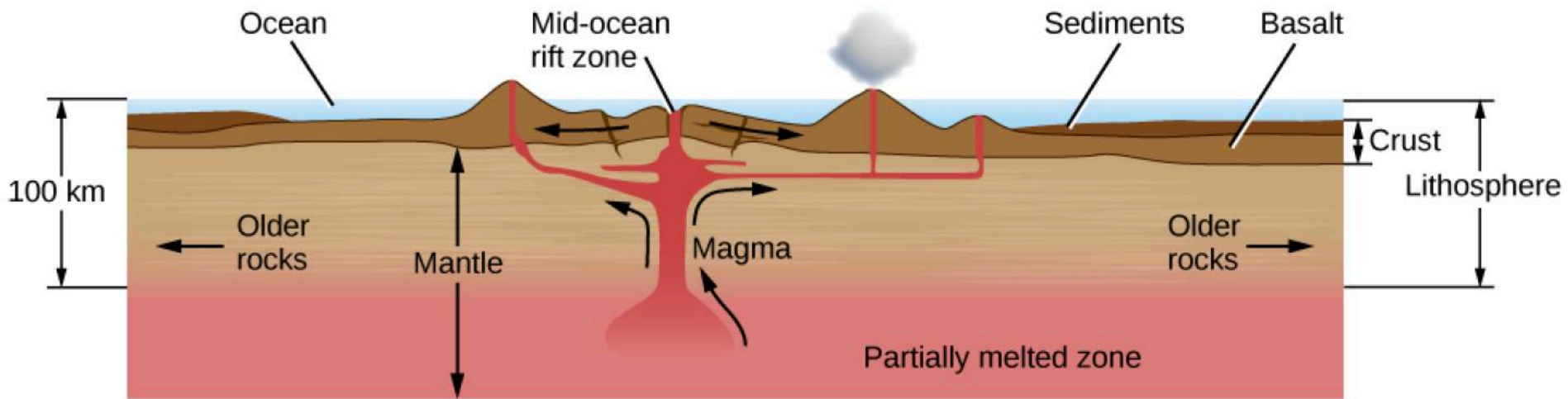
Radioactivity

Larger planets have
cores that stay
molten for longer

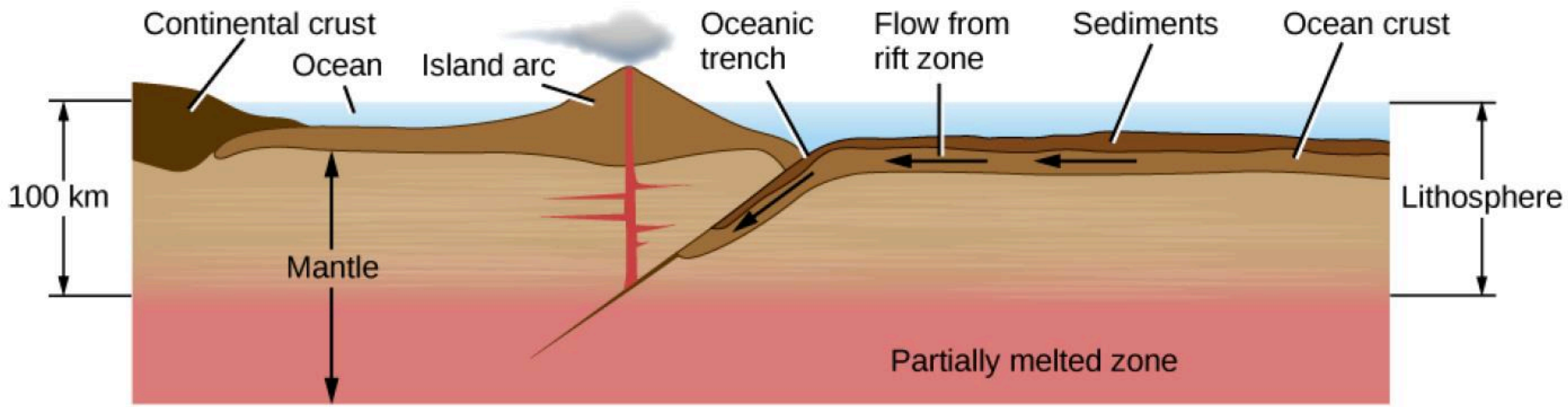








Rift zone

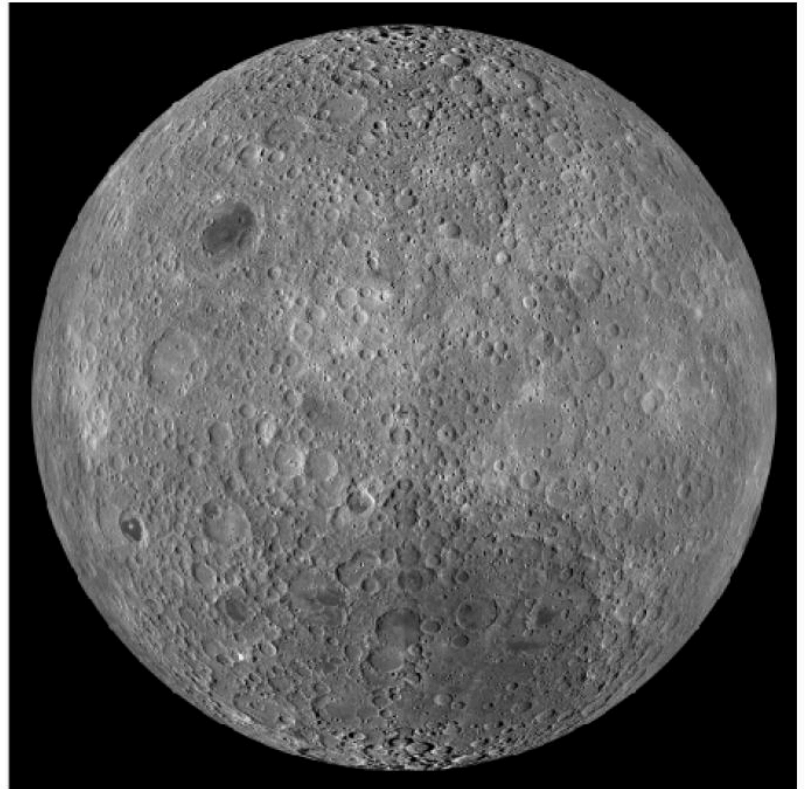
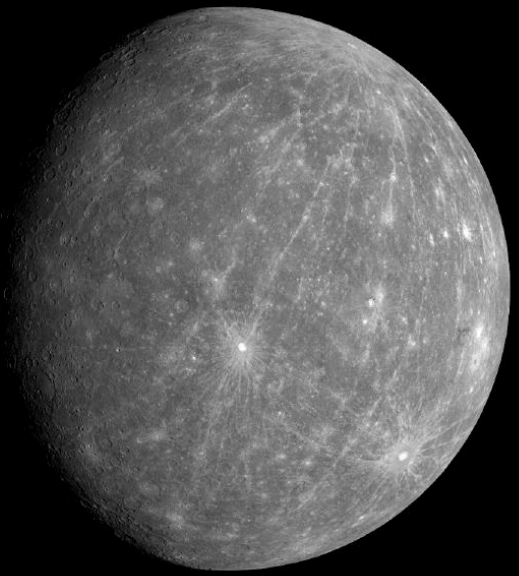


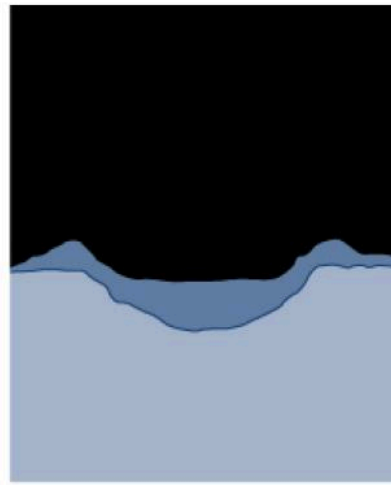
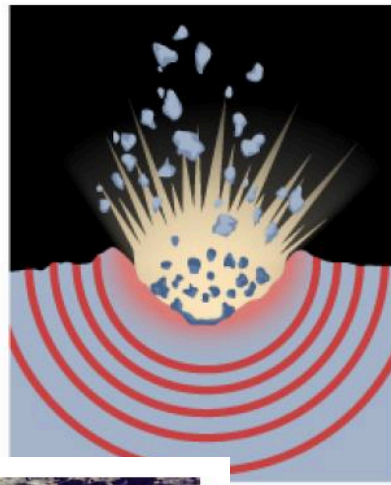
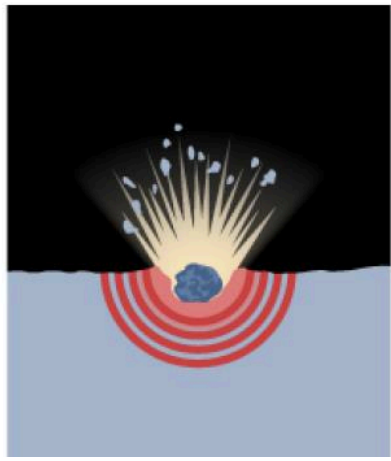
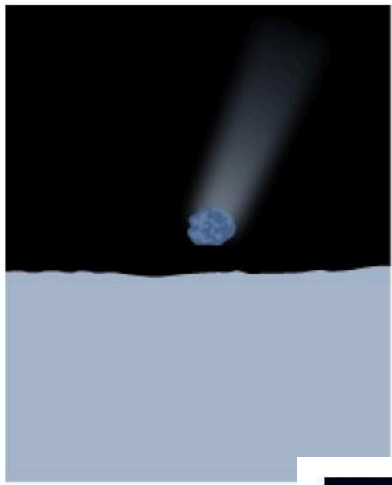
Subduction zone

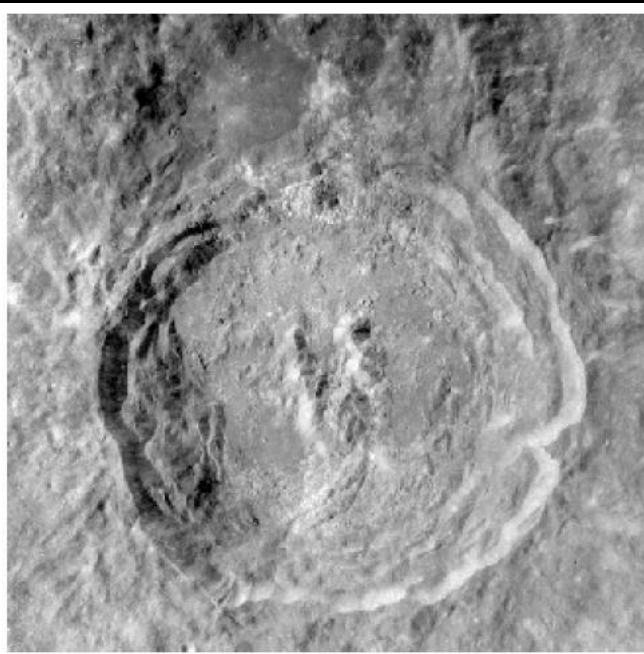
Properties of the Moon and Mercury

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



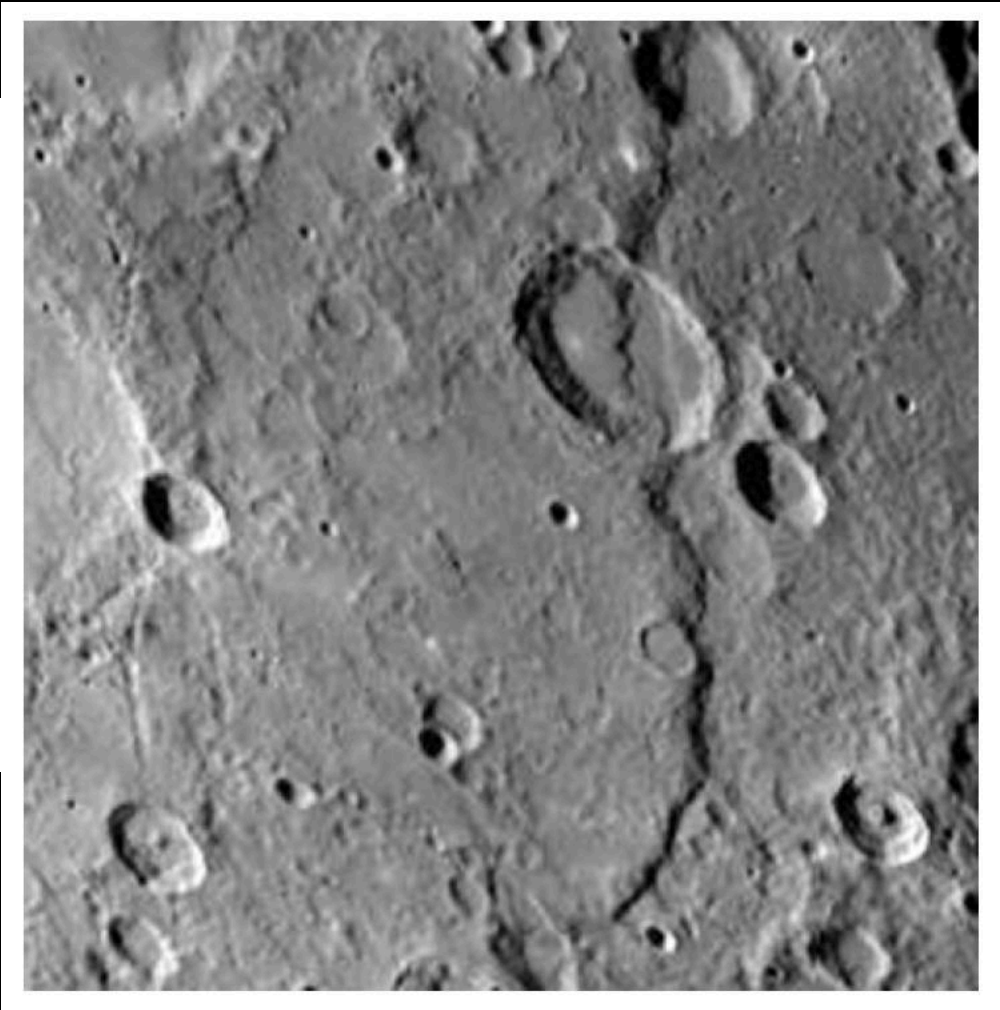
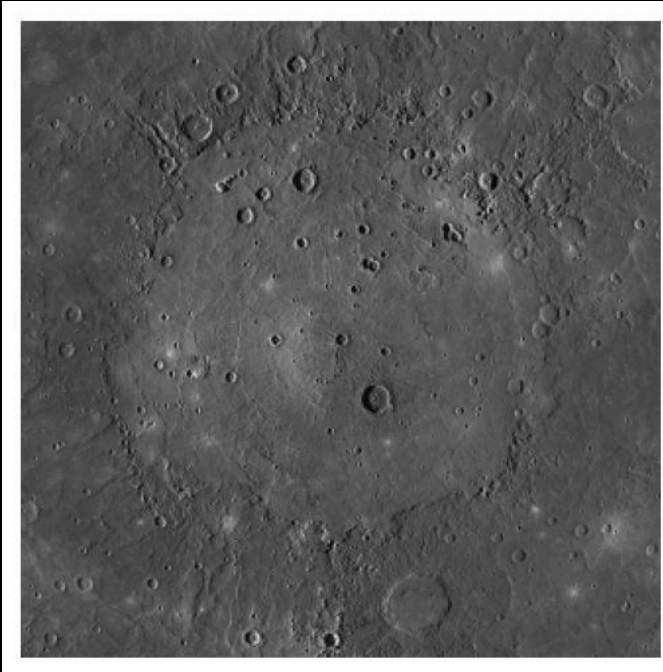


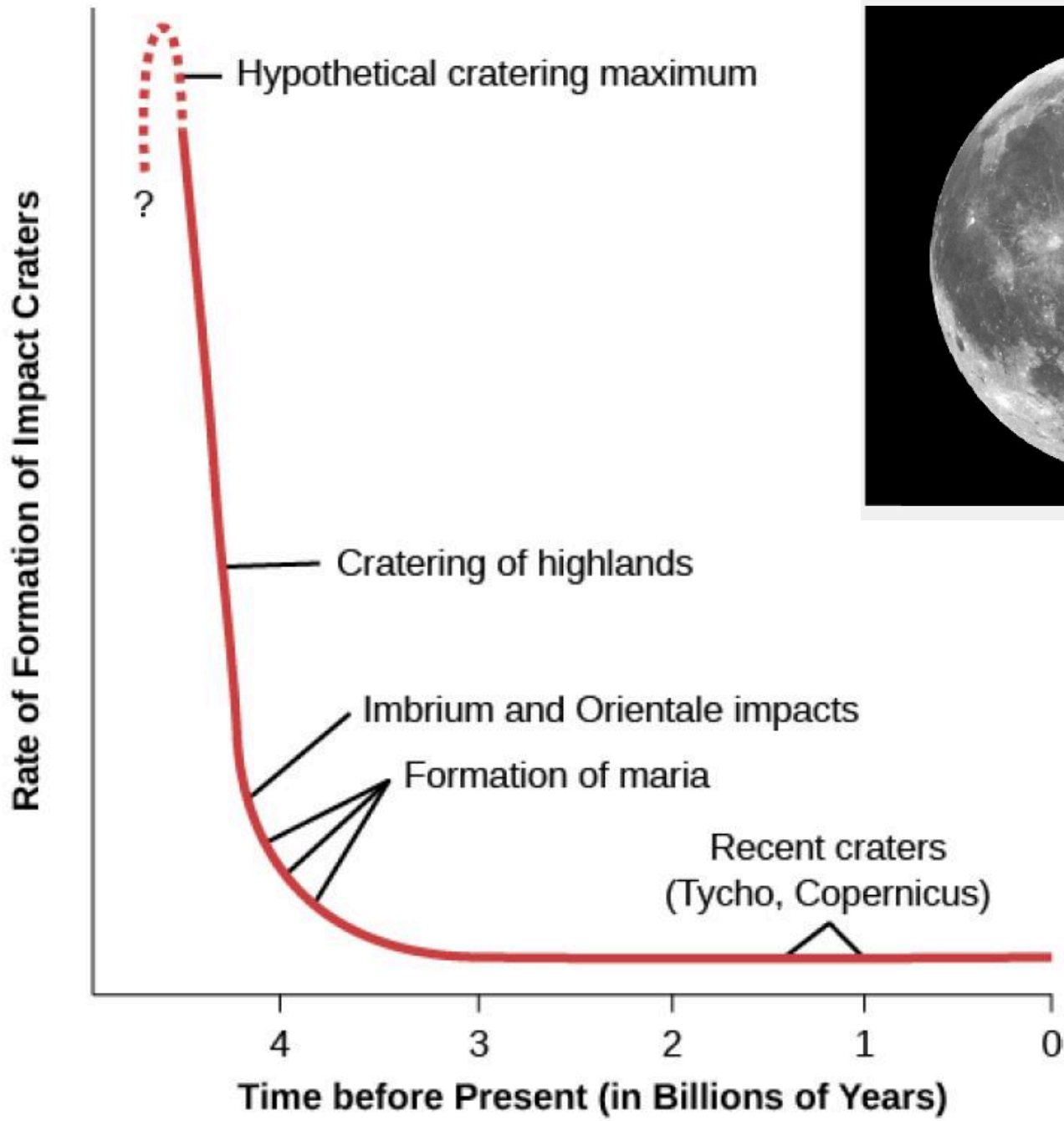
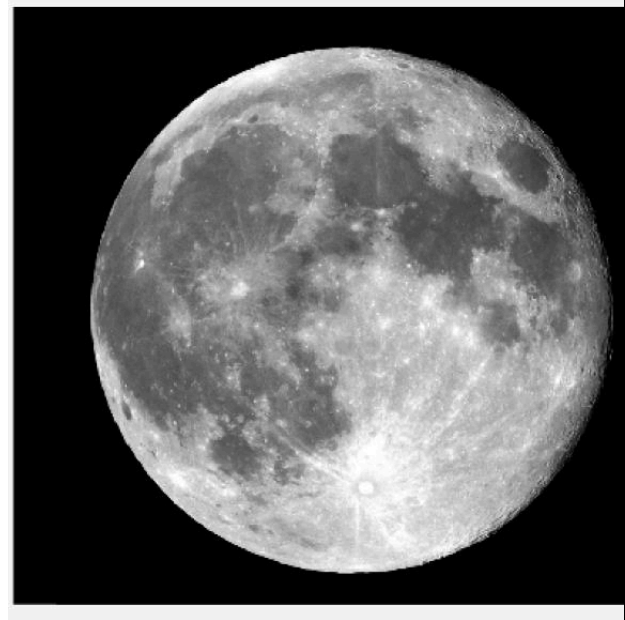


Craters: old surface
Smooth: new surface

Mare=sea







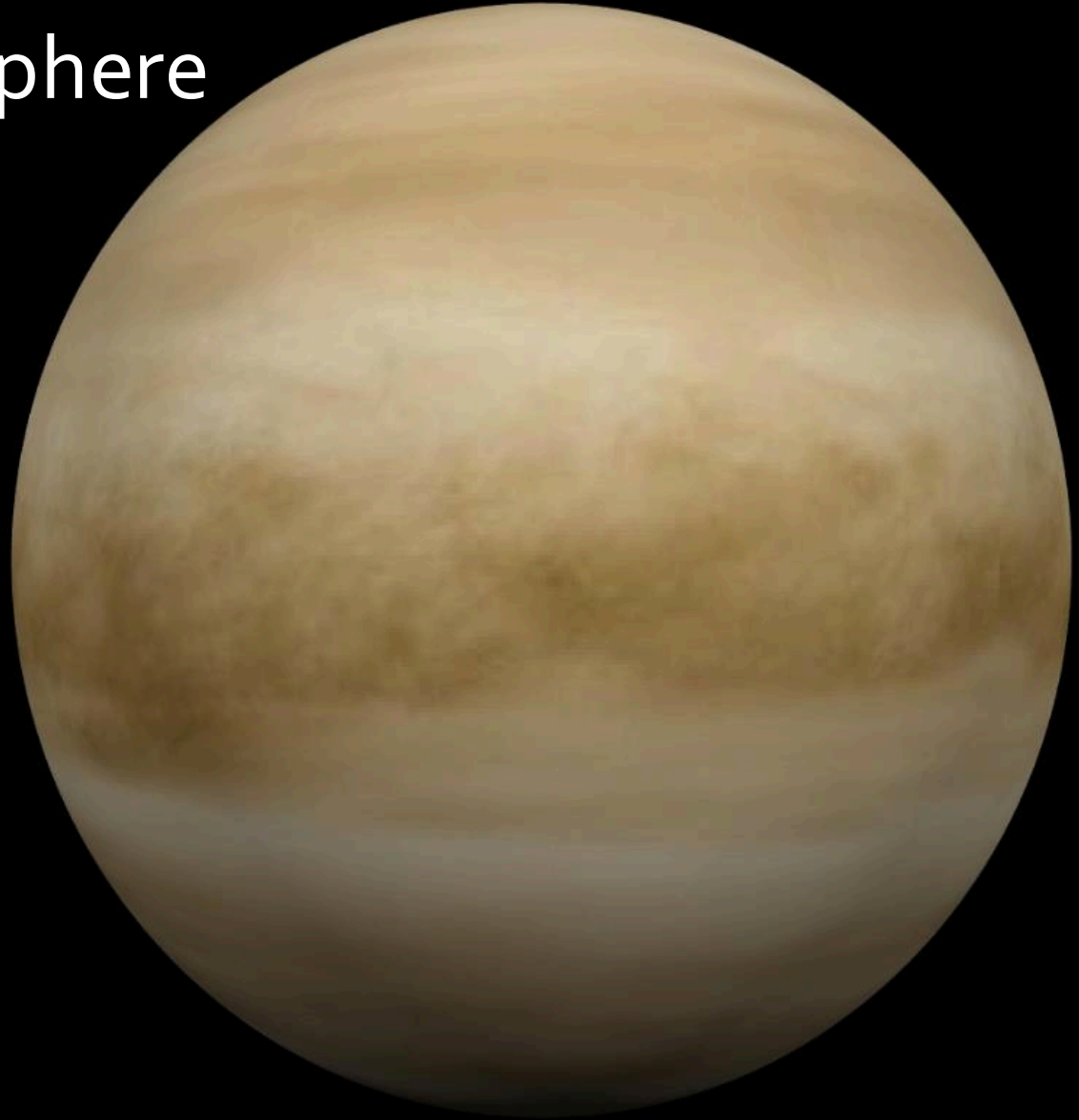


Properties of Earth, Venus, and Mars

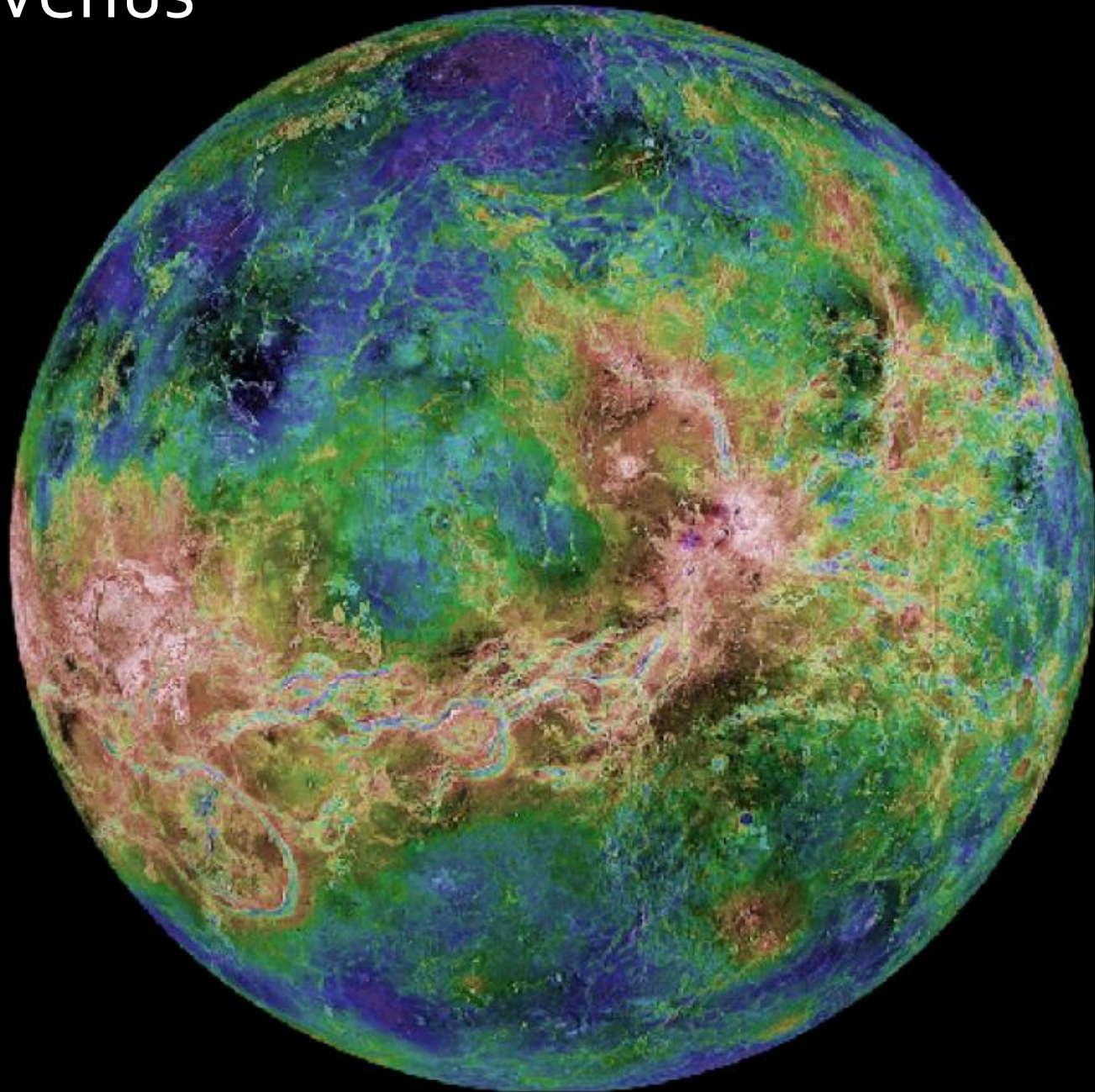
Property	Earth	Venus	Mars
Semimajor axis (AU)	1.00	0.72	1.52
Period (year)	1.00	0.61	1.88
Mass (Earth = 1)	1.00	0.82	0.11
Diameter (km)	12,756	12,102	6,790
Density (g/cm ³)	5.5	5.3	3.9
Surface gravity (Earth = 1)	1.00	0.91	0.38
Escape velocity (km/s)	11.2	10.4	5.0
Rotation period (hours or days)	23.9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

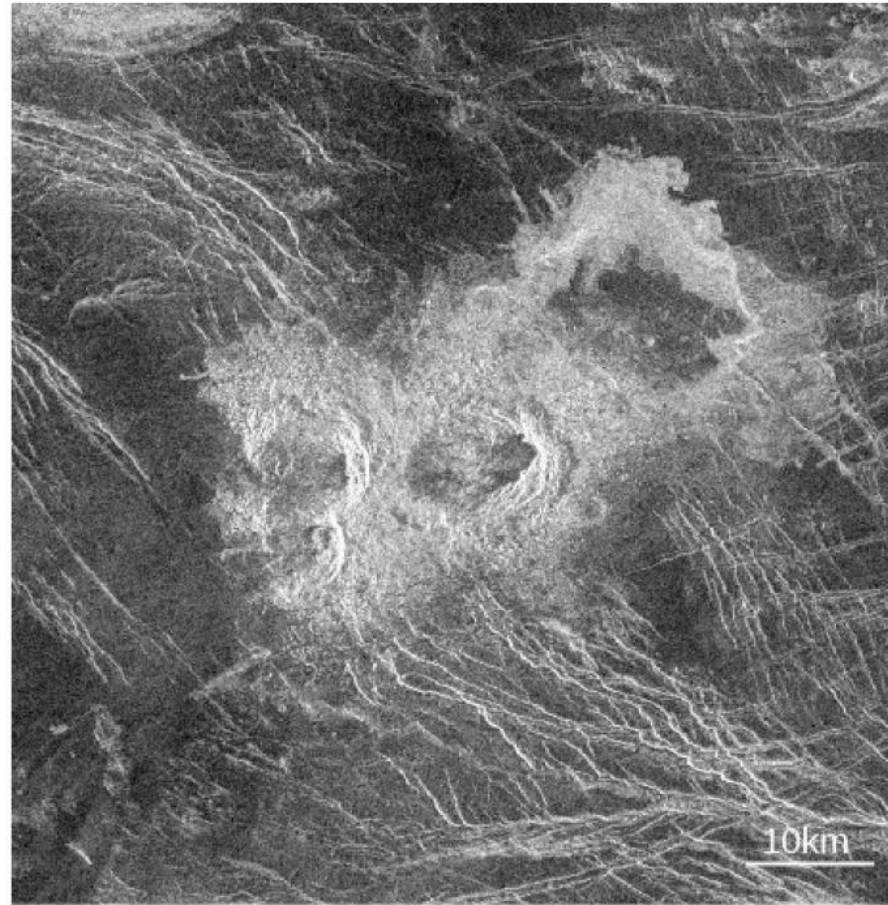
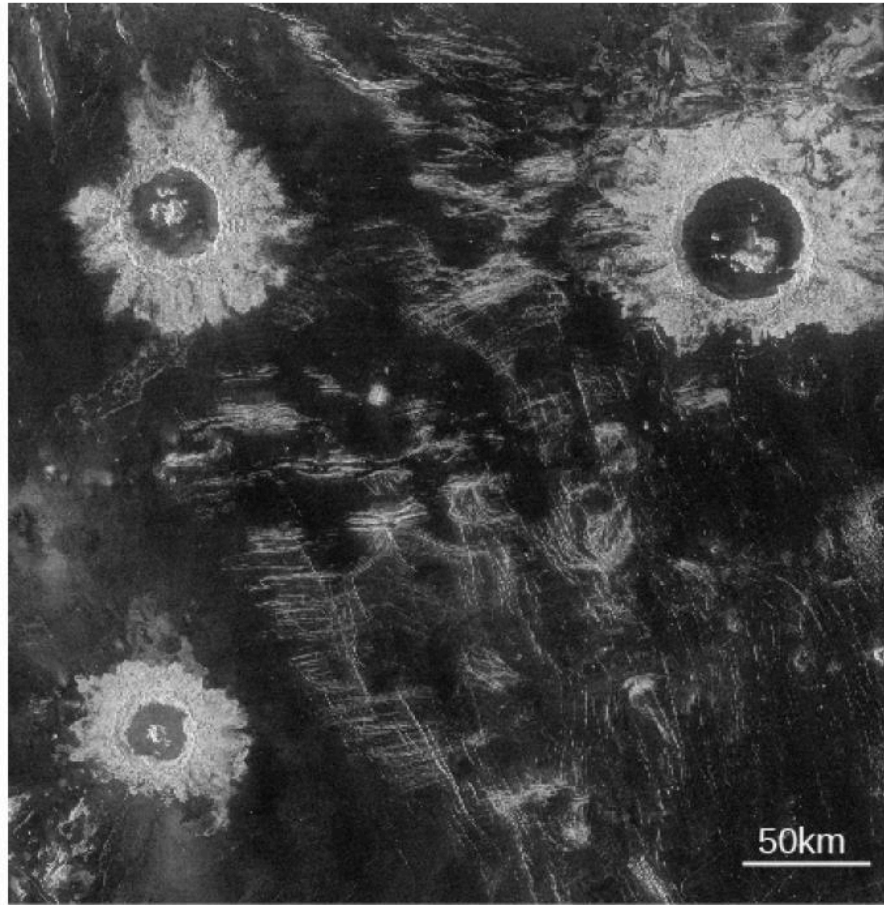
Venus

Thick atmosphere

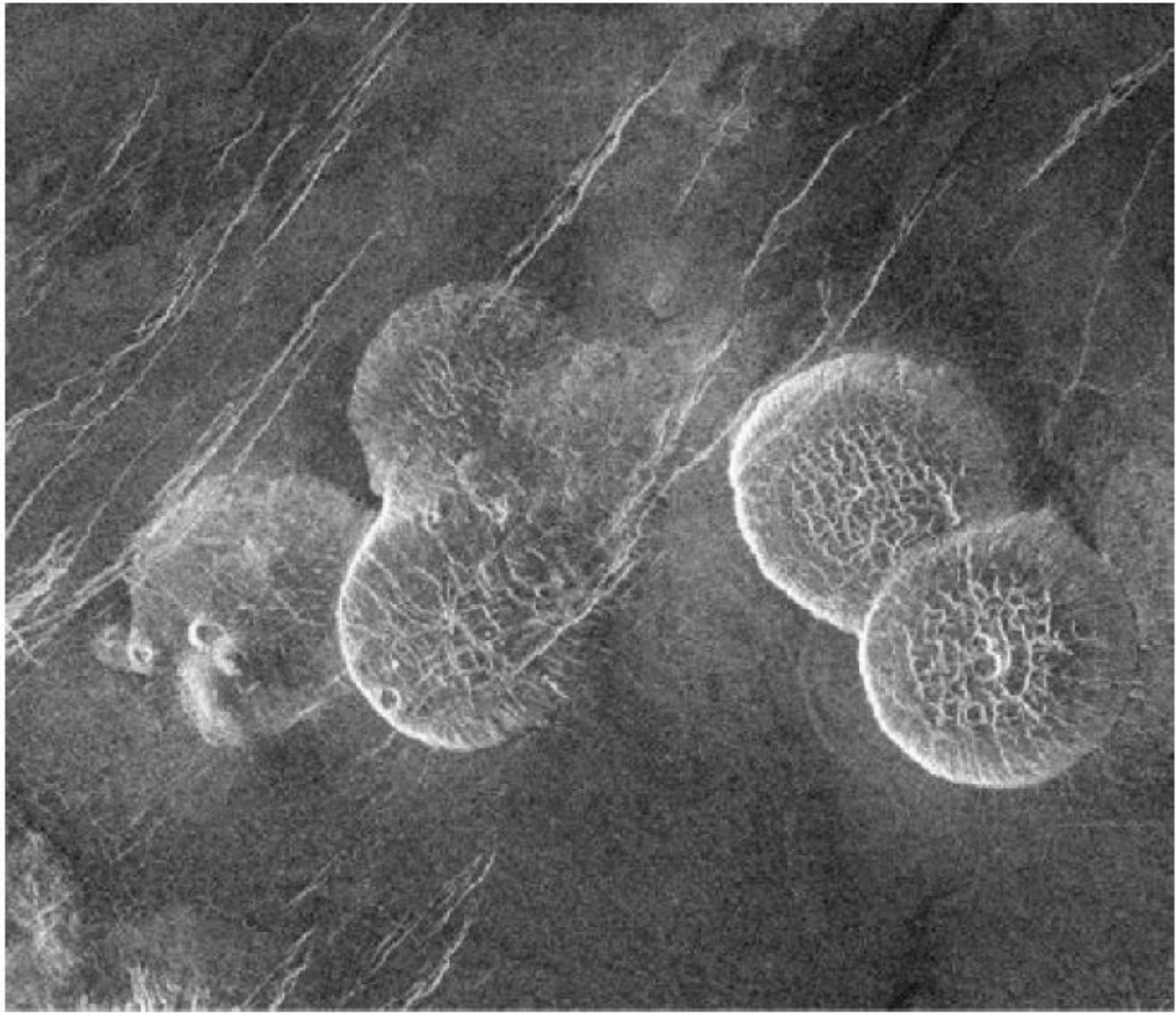


Venus

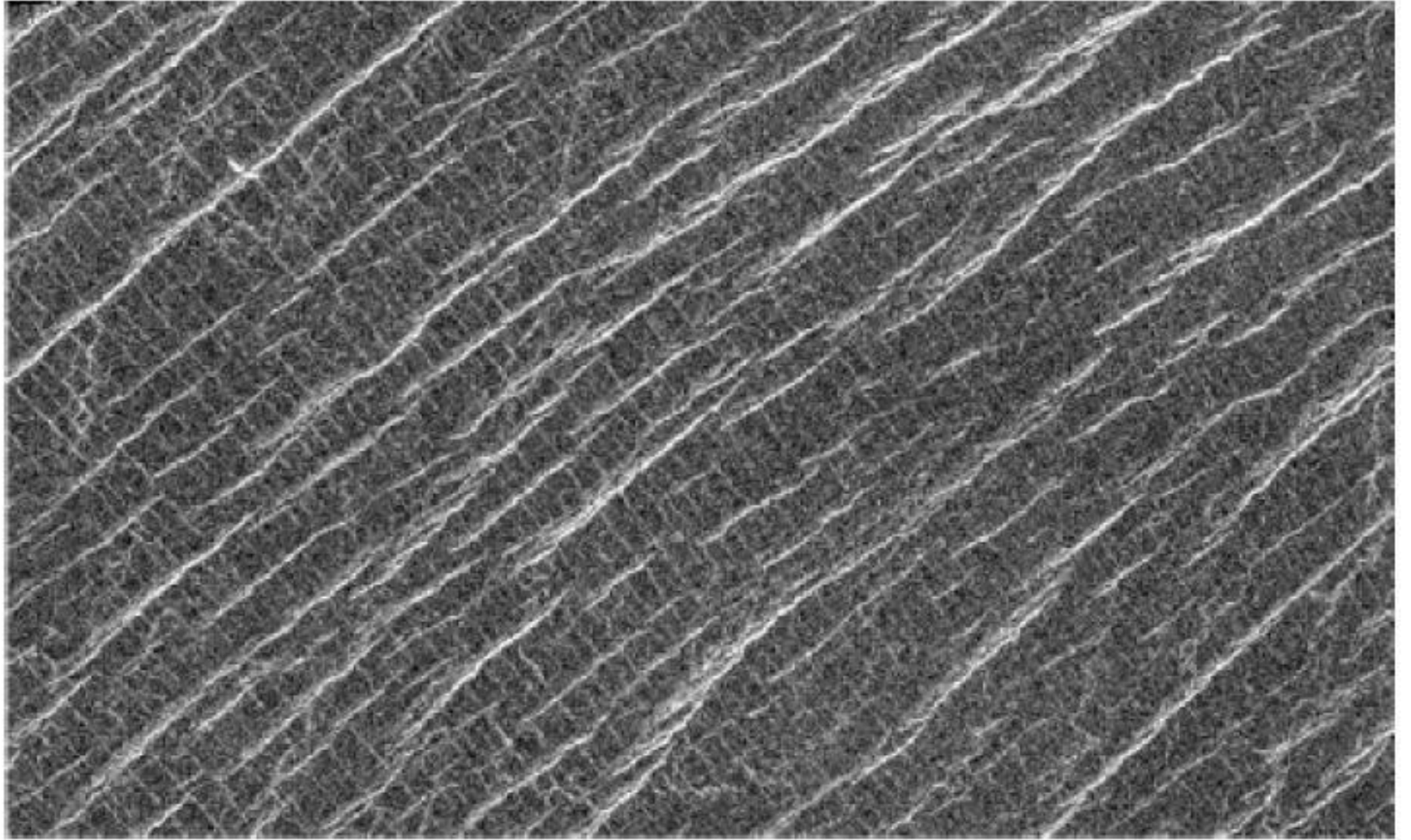


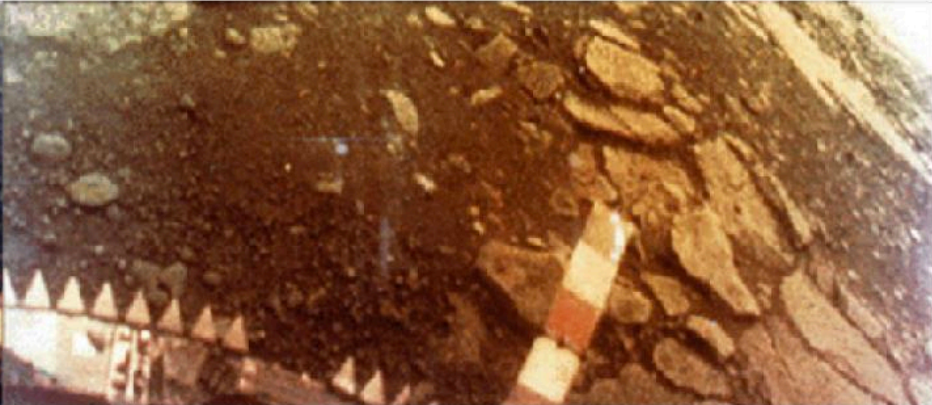


Only a few landers
(all Soviet Union)



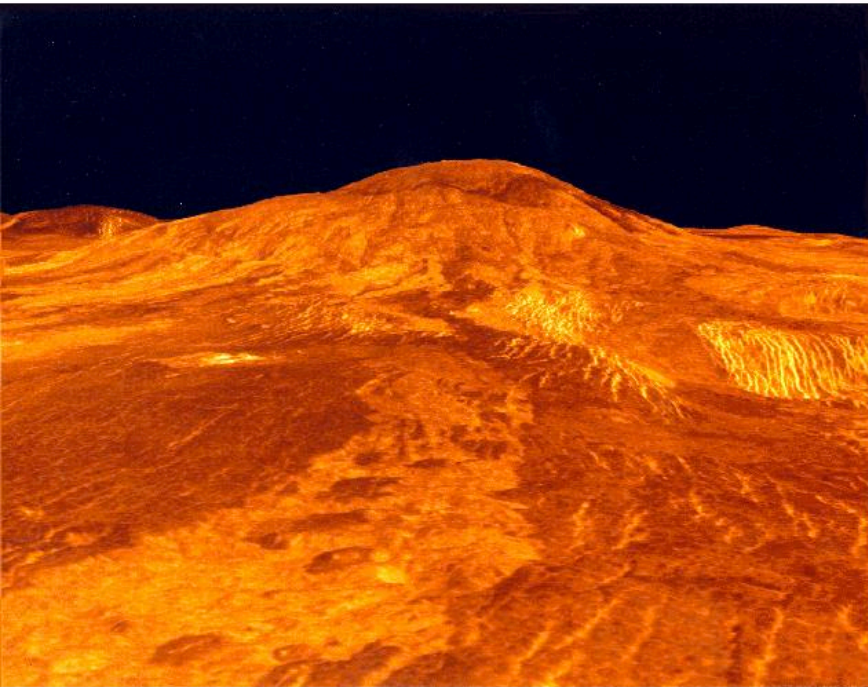






Venus has hardly any impact craters; the surface density of craters indicates most of the surface is only 600 million years old; but craters do not appear to be eroding. Where are all the older craters?

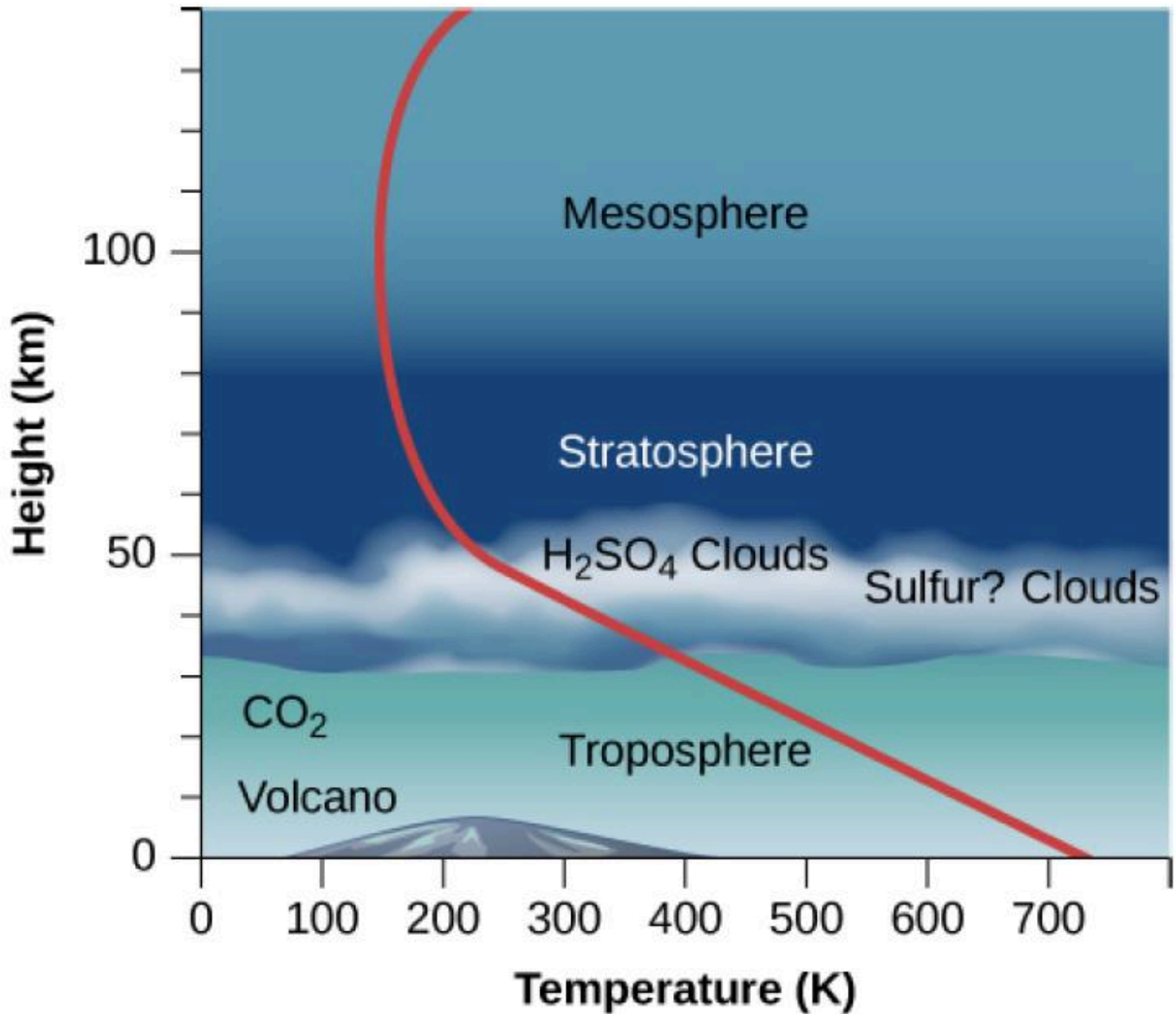
Perhaps Venus undergoes periodic *catastrophic resurfacing*. The last such event would have taken place about 600 million years ago.



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%

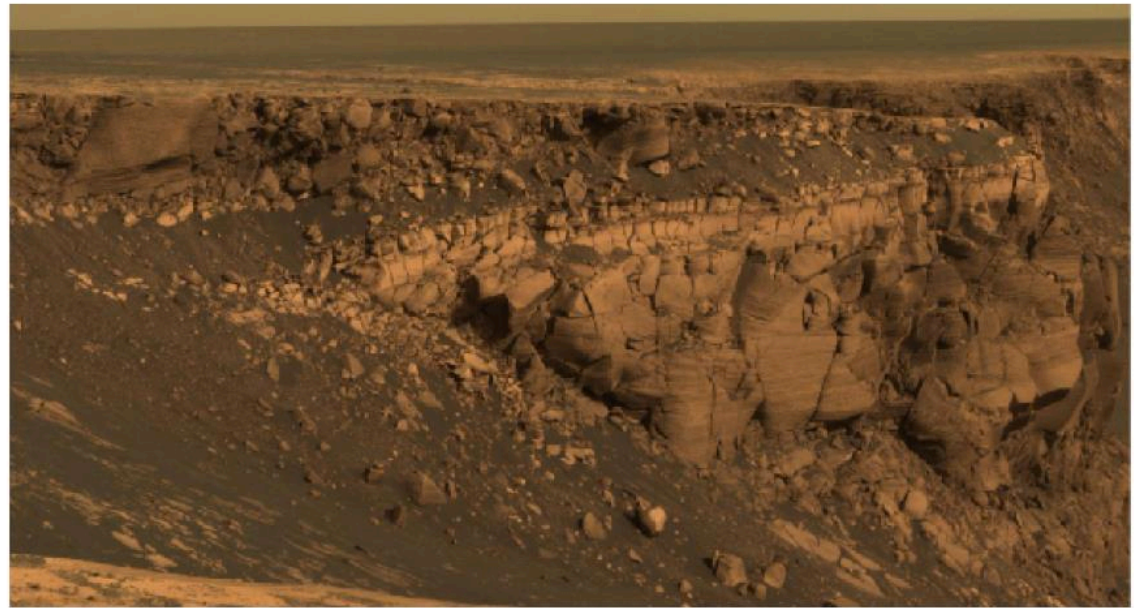
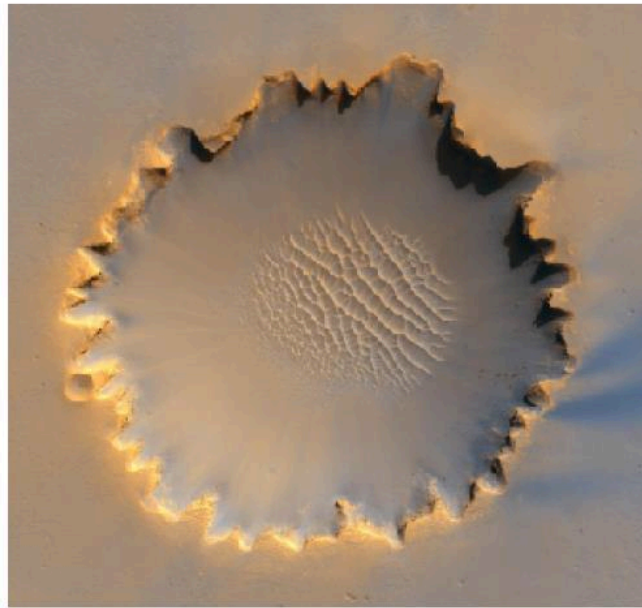


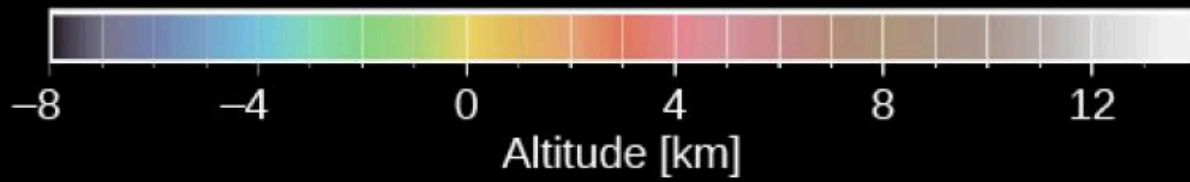
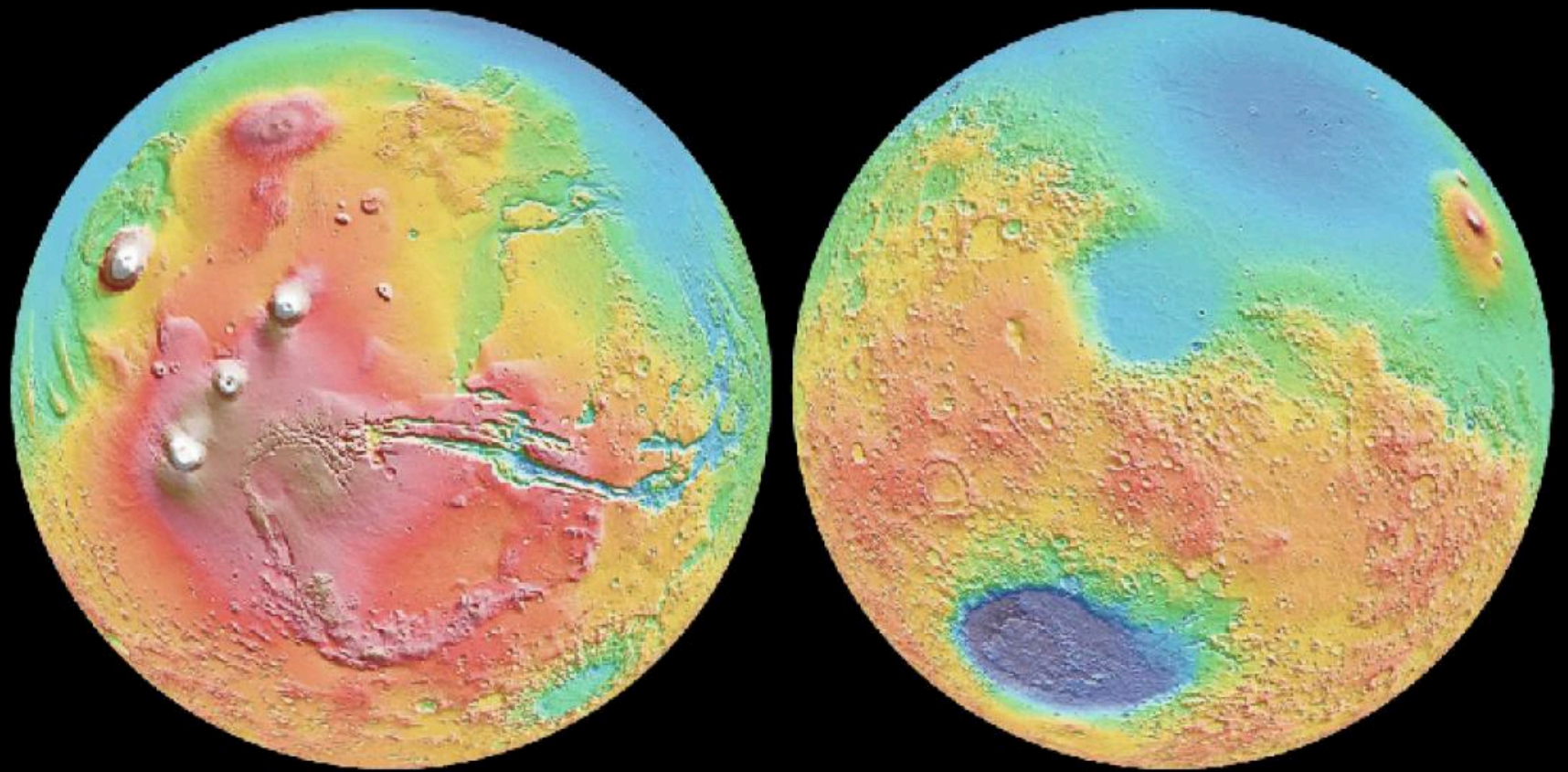
Mars

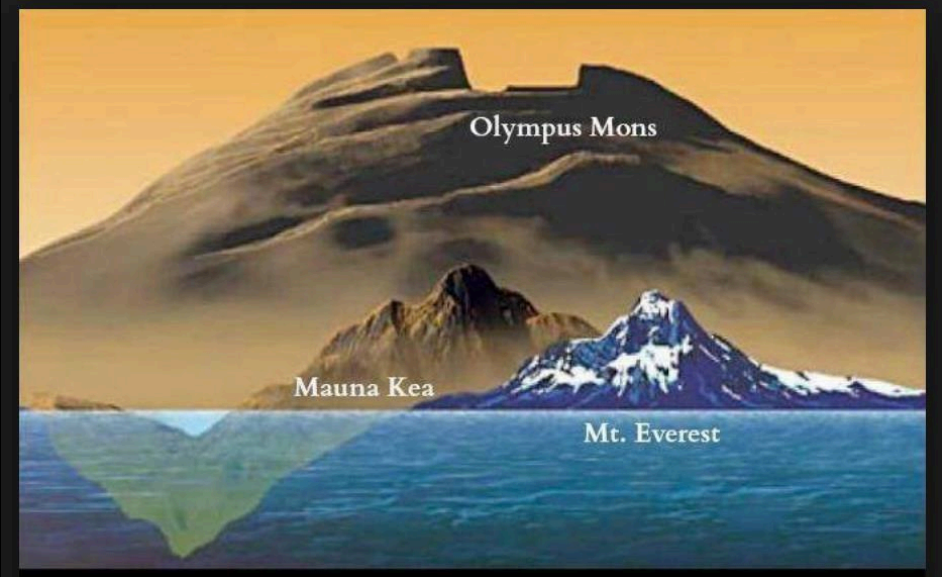
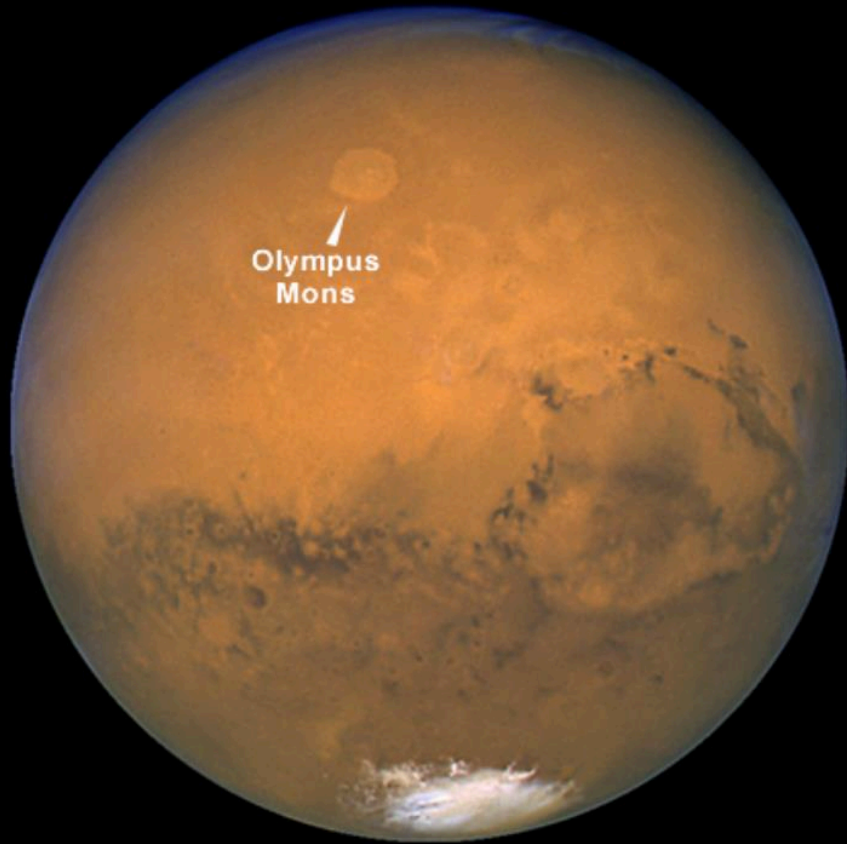


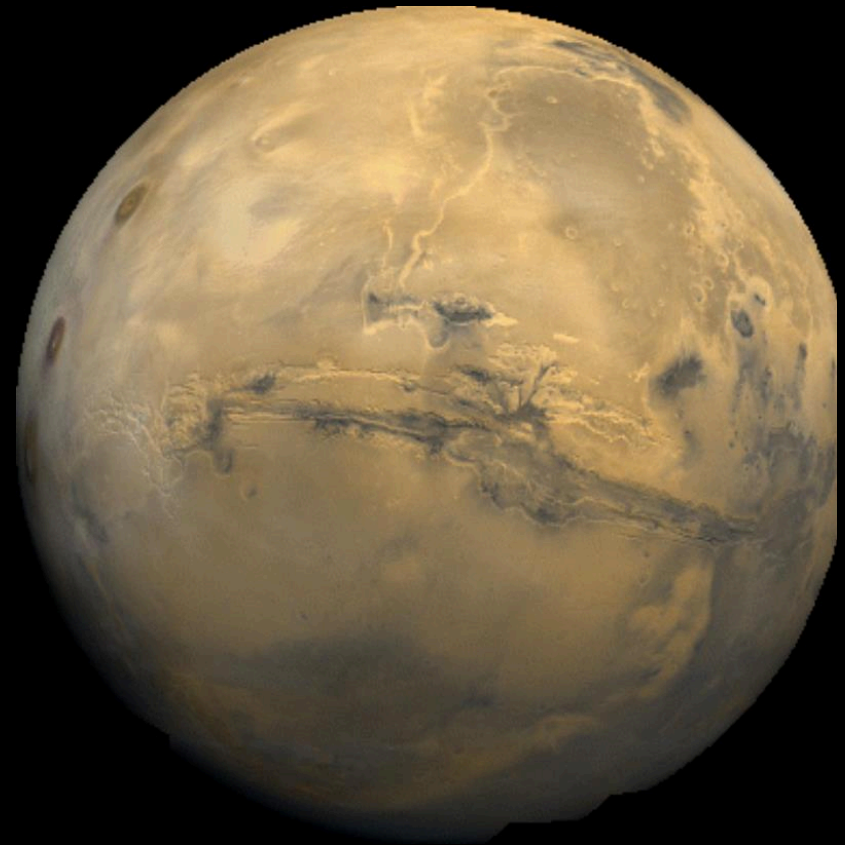
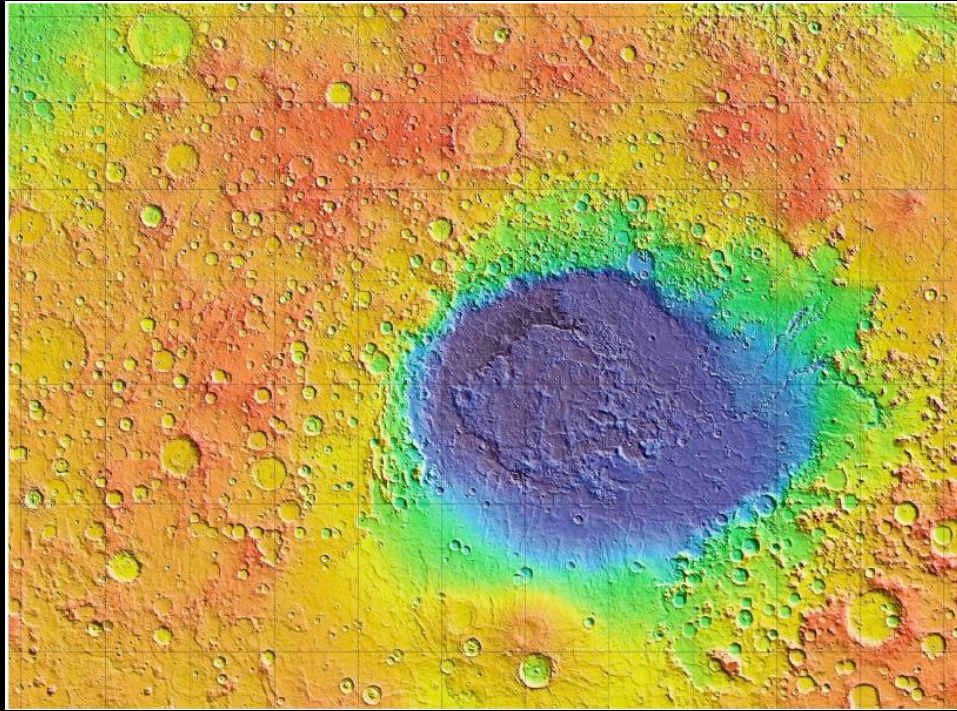
Mars rock from Antarctica!

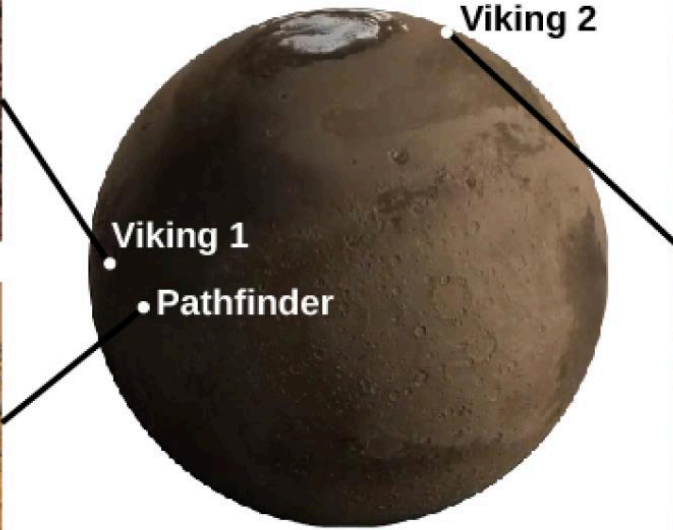
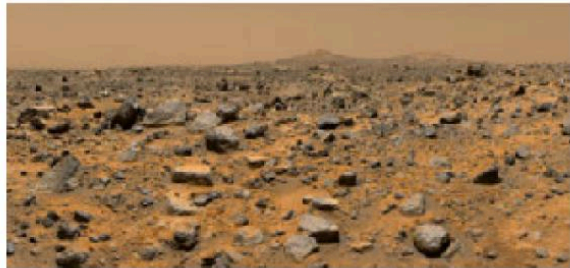
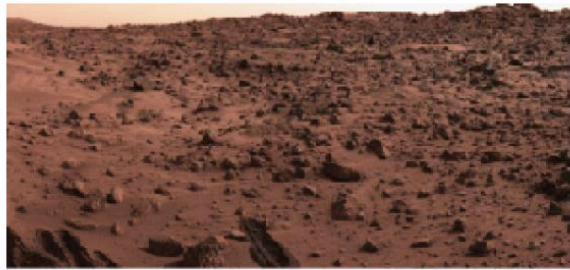




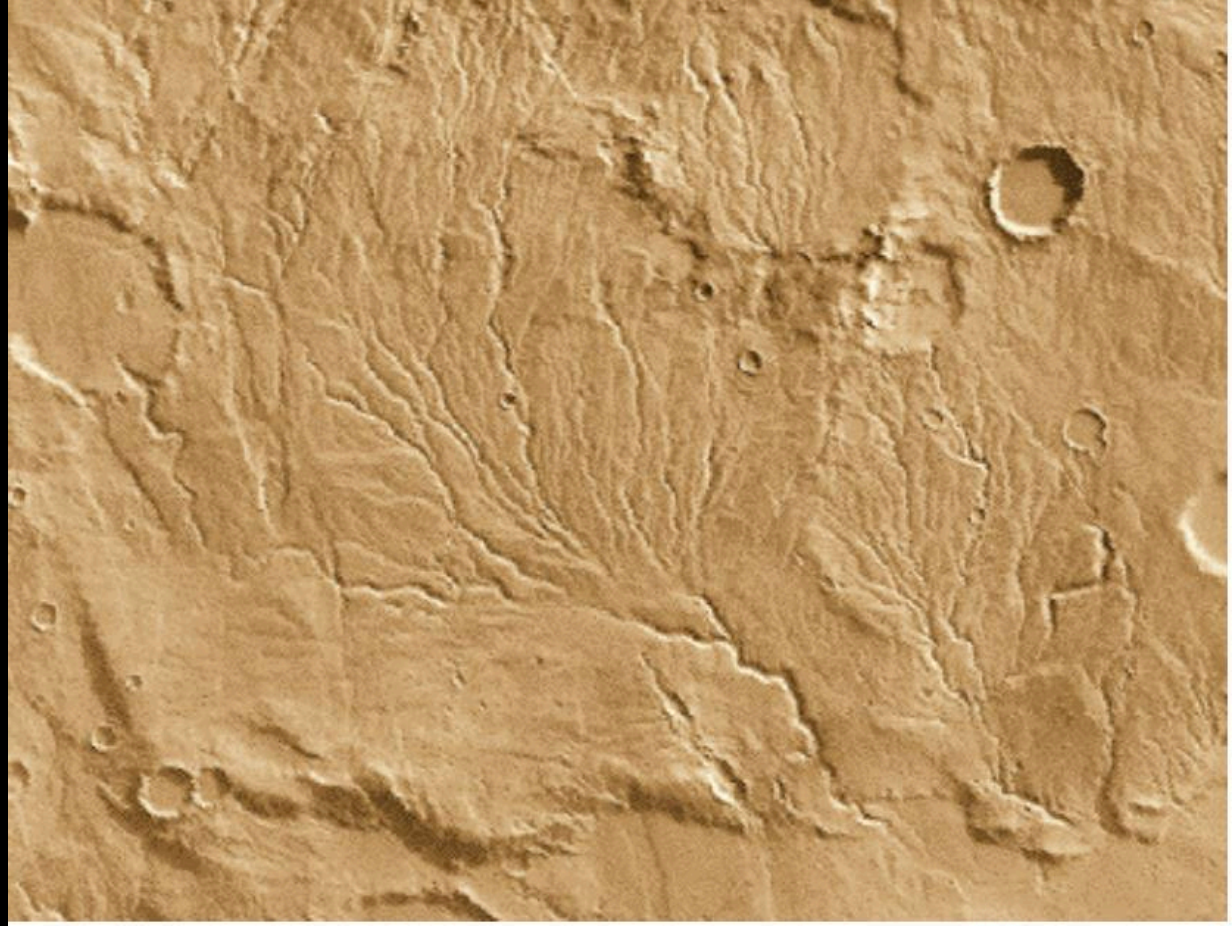
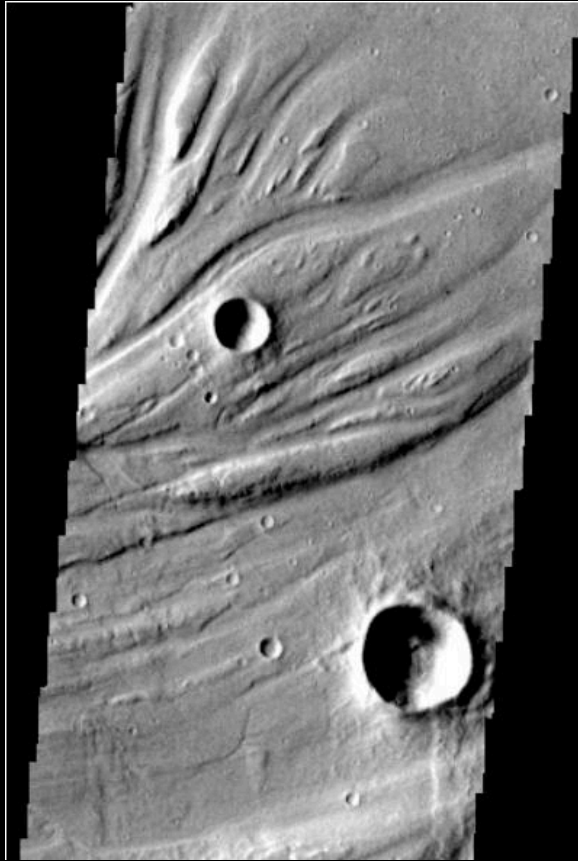


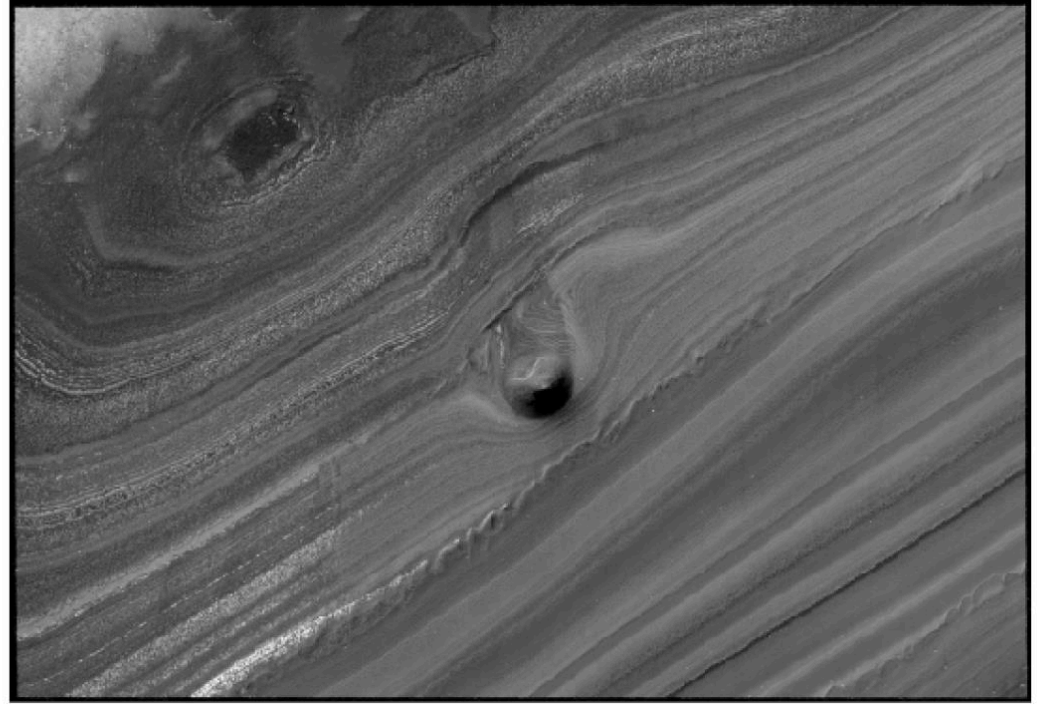
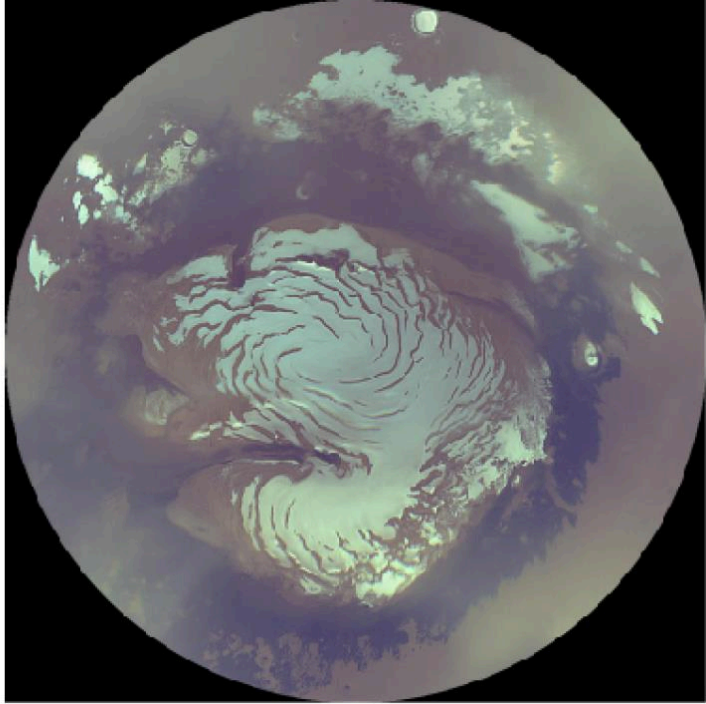


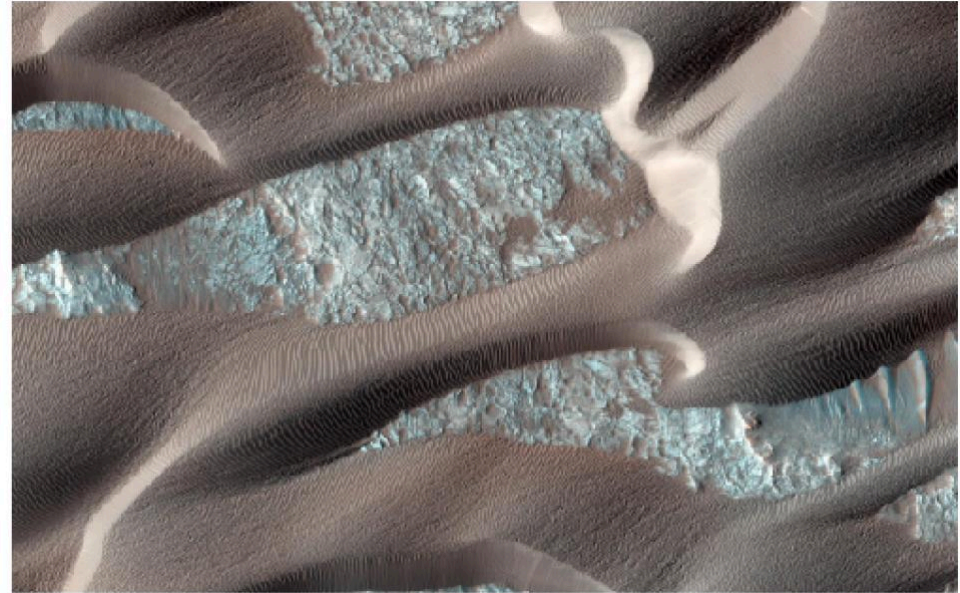
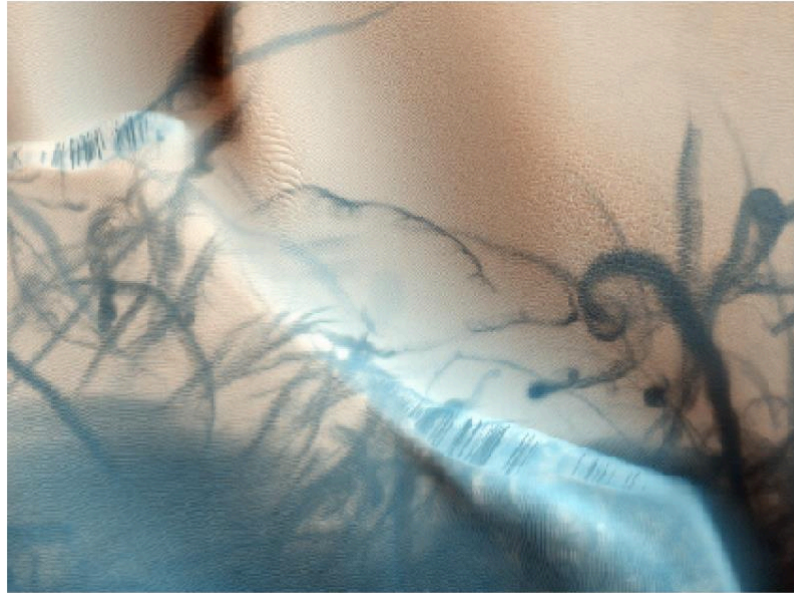


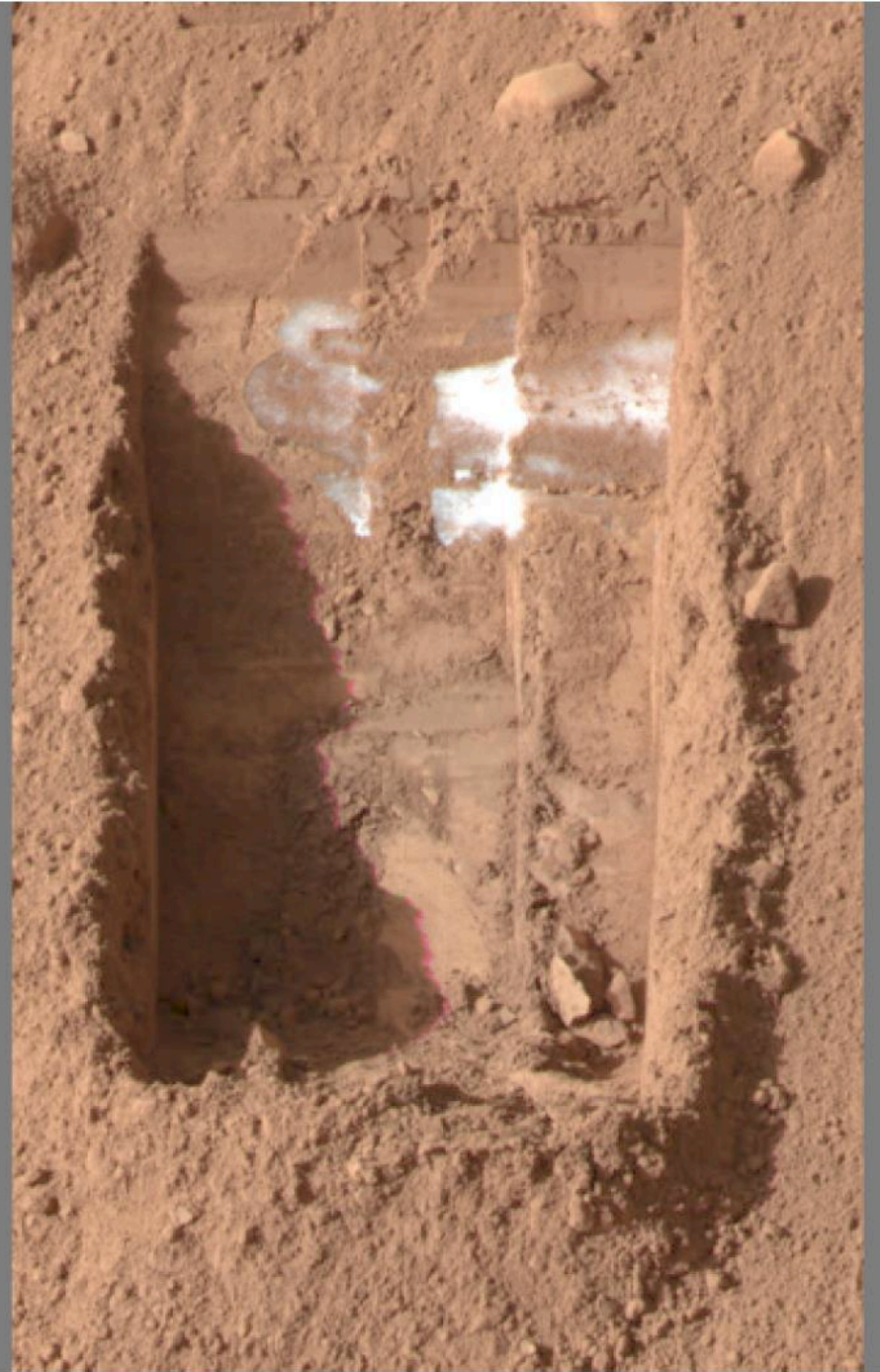


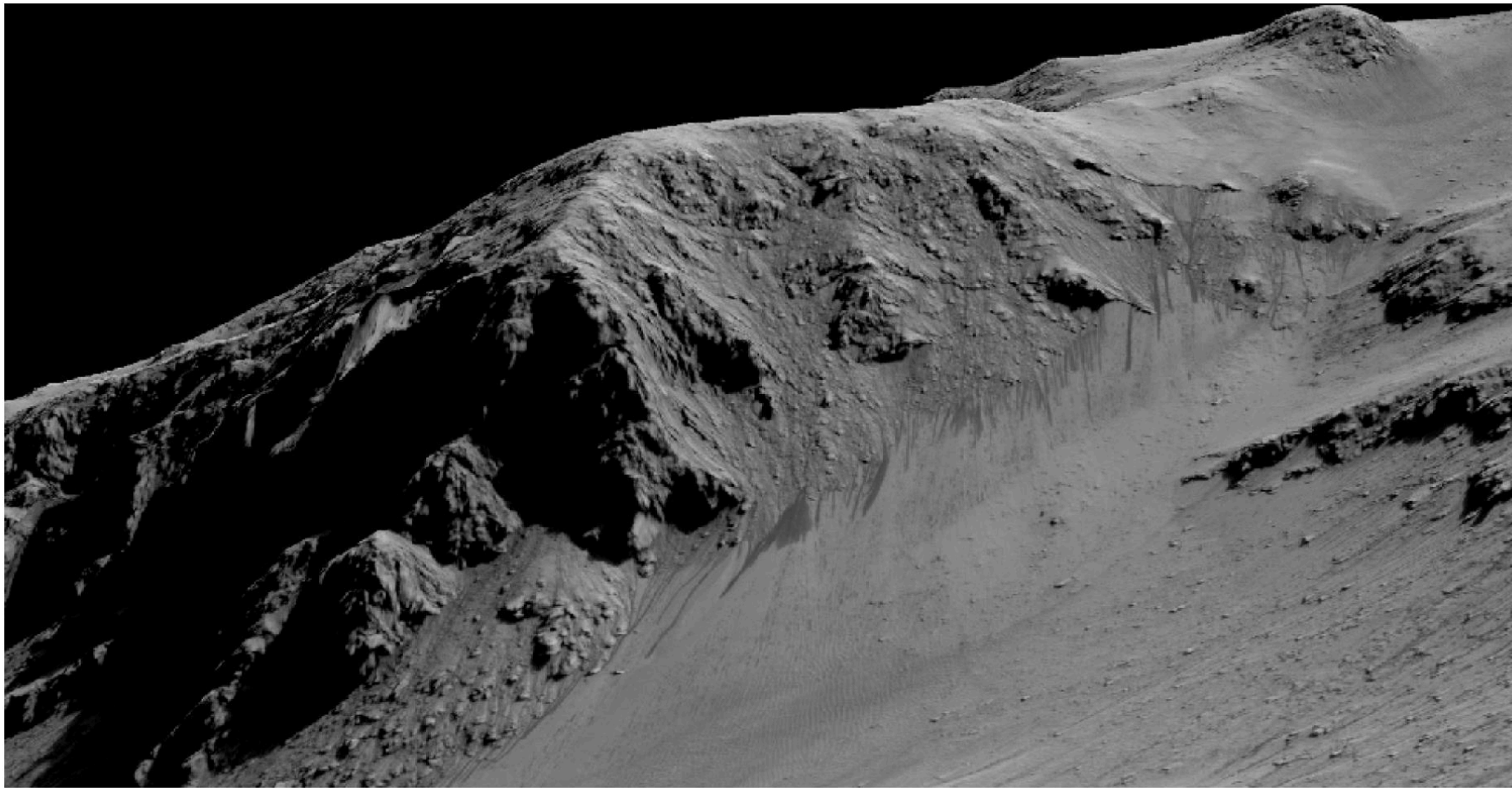
Water?





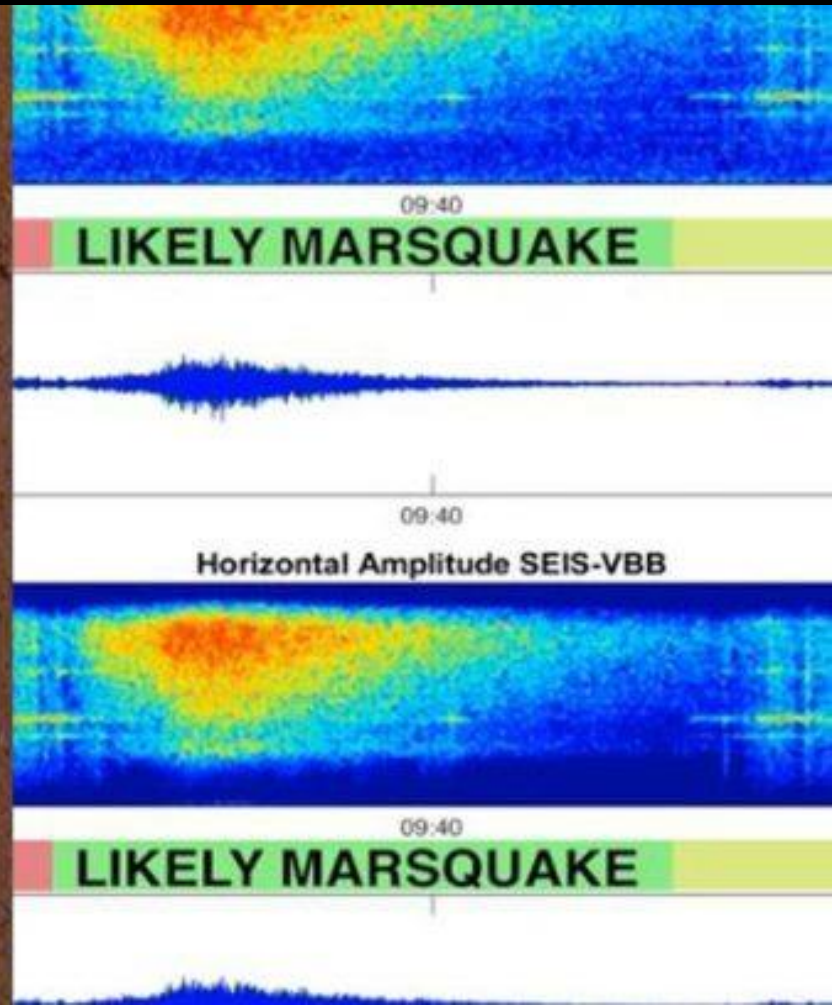








Marsquakes!





KIM STANLEY
ROBINSON

Winner of the Nebula Award

Red
Mars

'The ultimate in
future history'

Daily Mail

