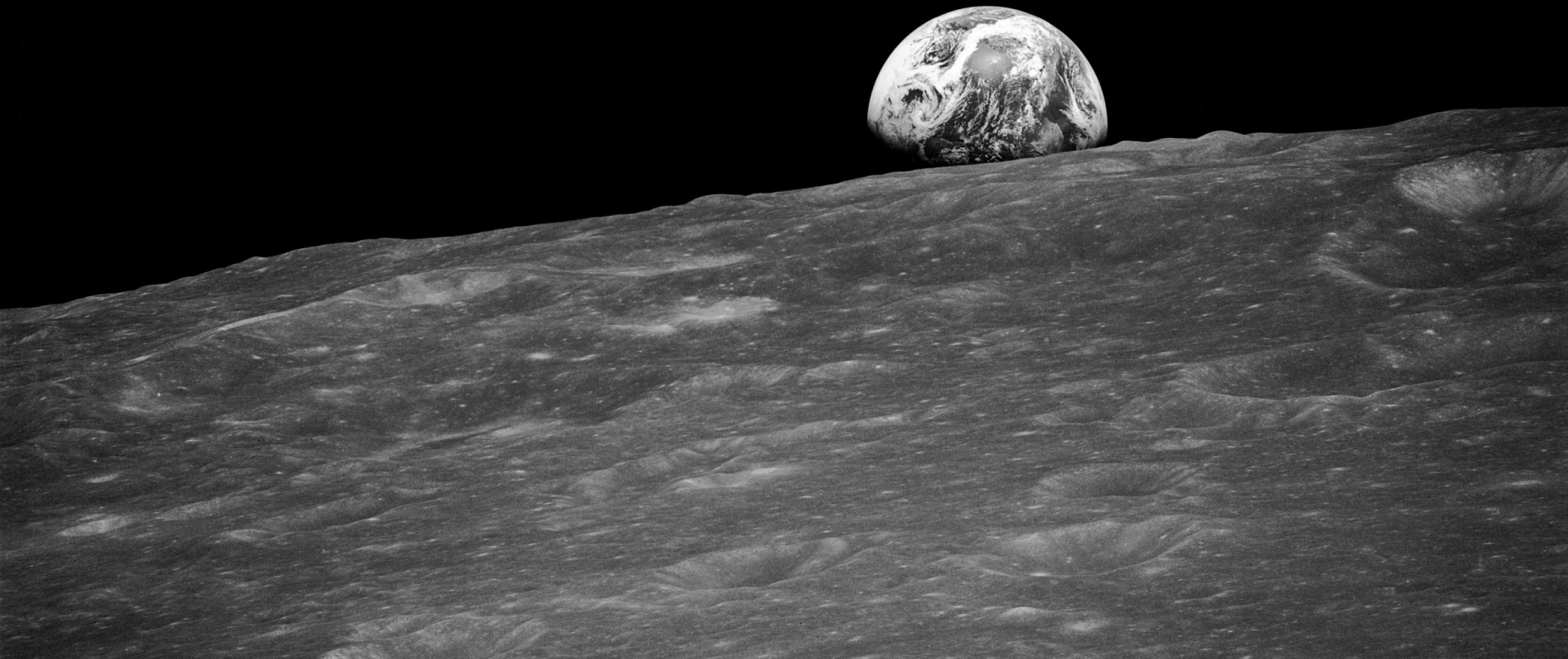
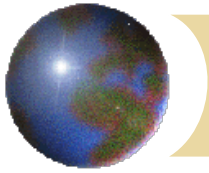


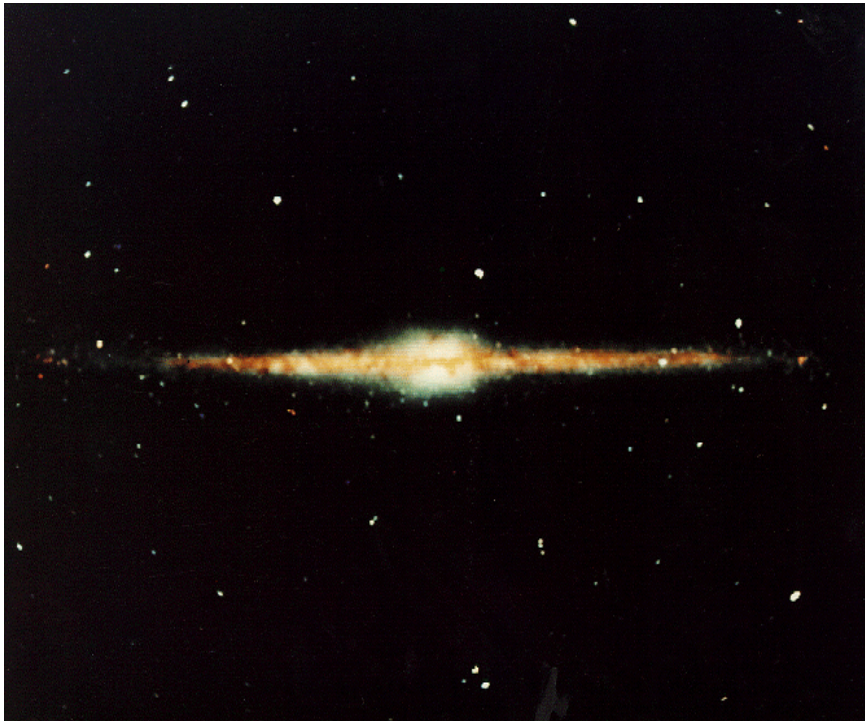
The solar system and the origin of Earth

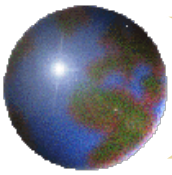




Solar System

- ✦ Consists of our star, the sun, the planets, their satellites, and asteroids
- ✦ Located on the arm of a very large spiral galaxy
- ✦ Within the Milky Way galaxy

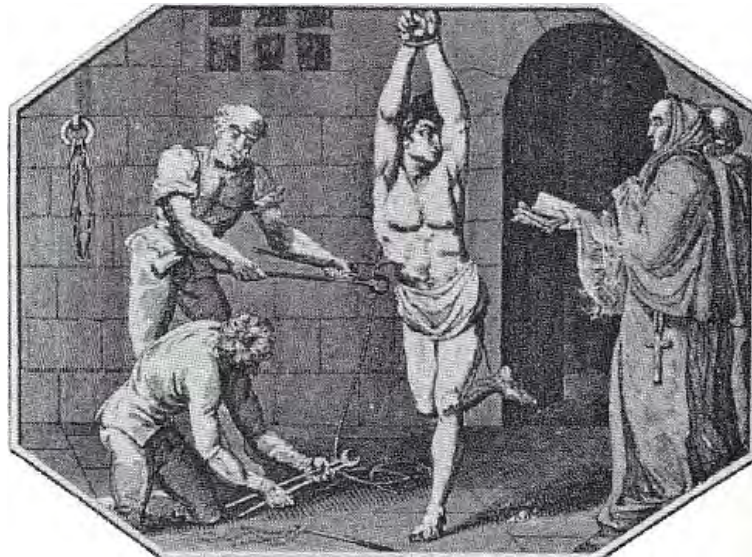


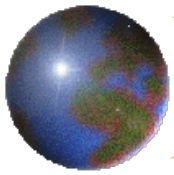


Geocentric Perspective

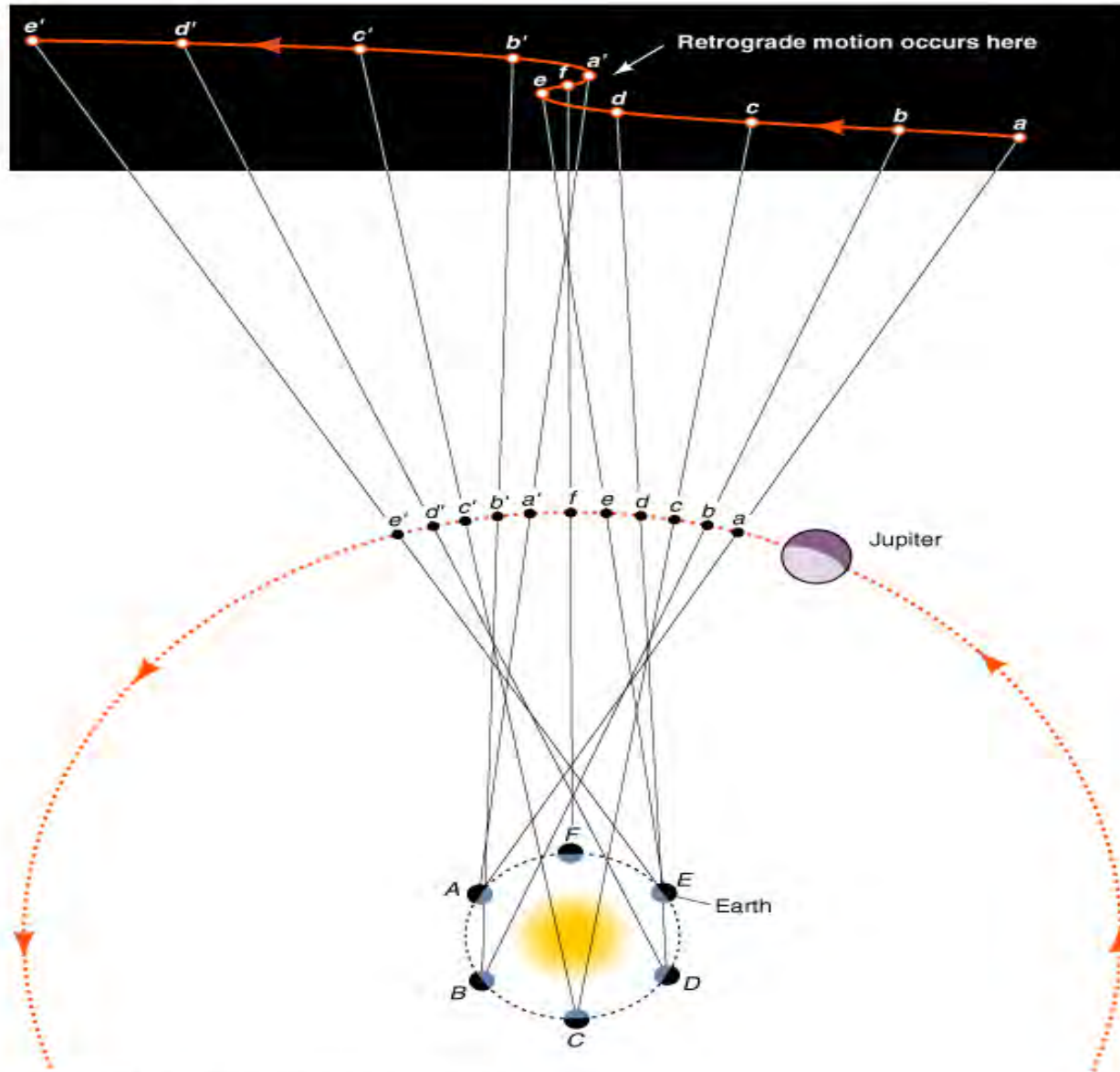
- ✦ Proposed by **Aristotle** (384-322 BCE)
- ✦ Geocentric universe deeply entrenched in church doctrine
- ✦ But, was challenged by **Aristarchus** (312-230 BCE)

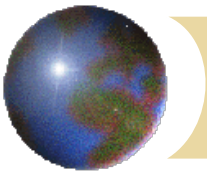
Simple spheres containing the planets and the sun revolving around Earth did not explain the retrograde motion of planets





Retrograde Motion

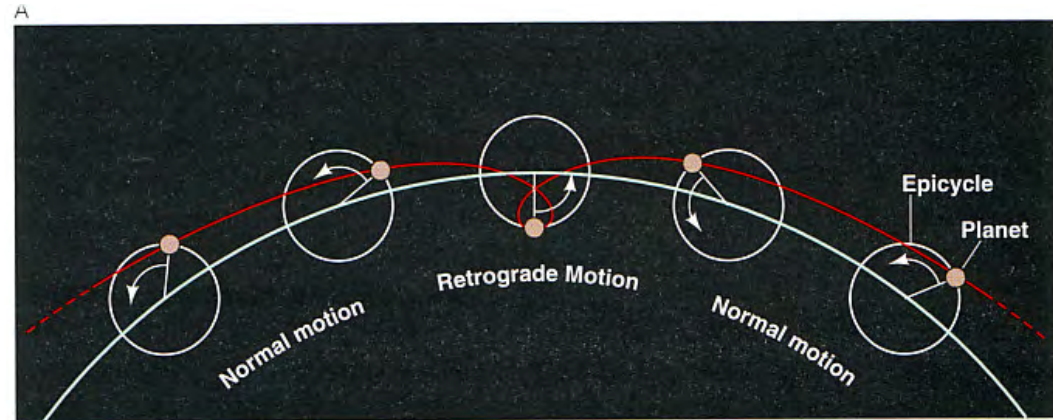


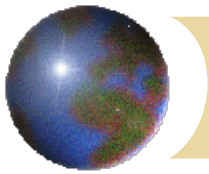


Geocentric Perspective

Ptolemy (150 CE)

- ✦ proposed that planets also follow a smaller circular orbit (epicycles)
- ✦ predictable periods of retrograde motion

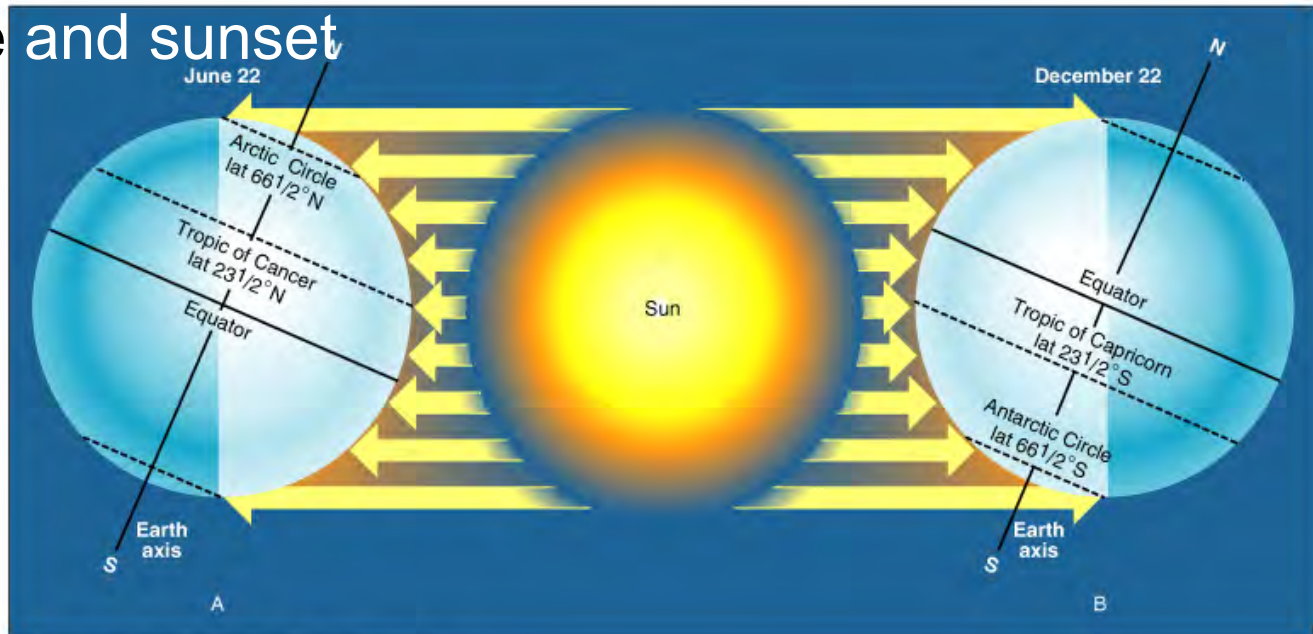


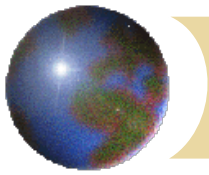


Retrograde Motion

Copernicus (1473-1543)

- ✚ suggested that because Mars has the larger retrograde motion it is the closest to Earth while Saturn, having the smallest retrograde motion is the furthest from the Earth
- ✚ proposed that the Earth spins on its axis leading to sunrise and sunset





Kepler (1571-1630)

1) law of ellipses

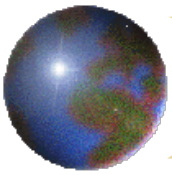
The orbit of each planet is an ellipse with sun at one focus

2) law of orbital harmony

For any planet, the square of the orbital period in years is proportional to the cube of the planet's average distance from the sun

3) law of equal areas

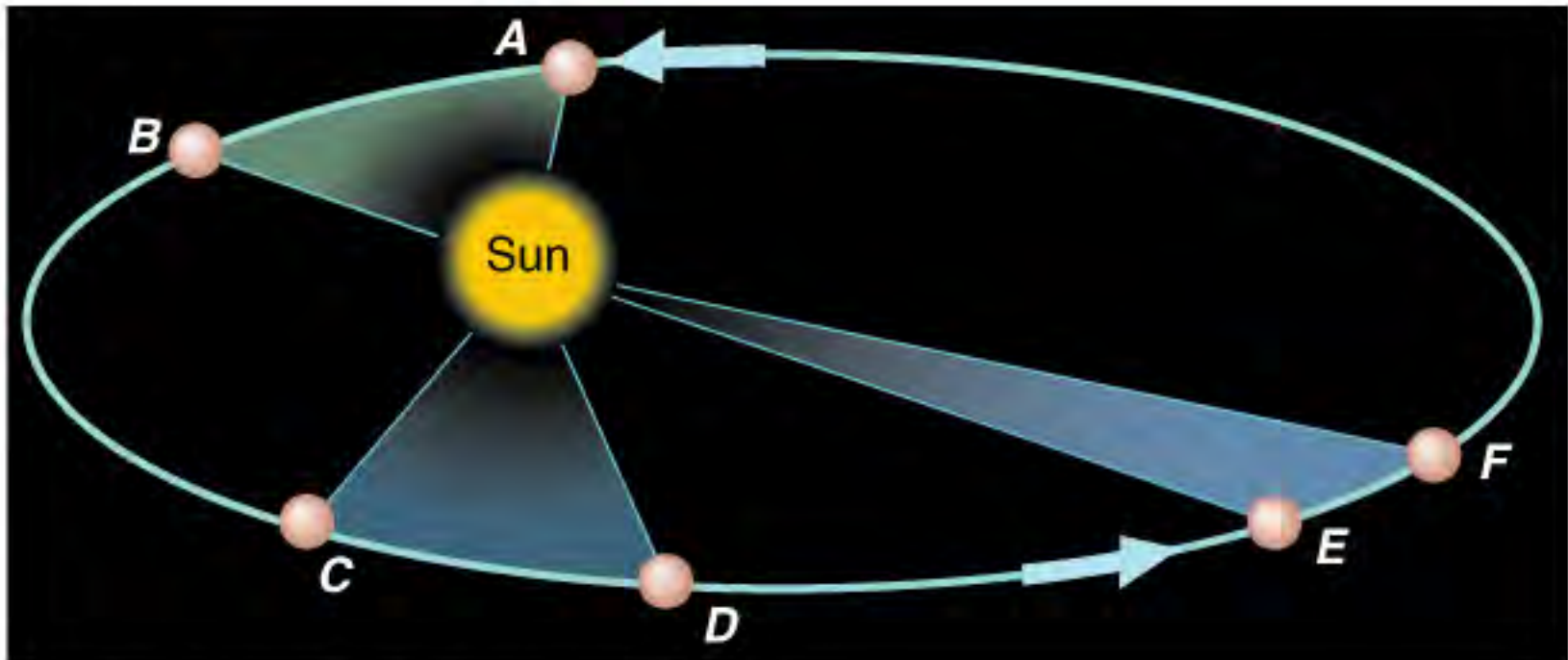


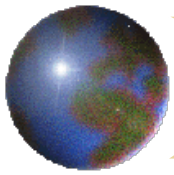


3) law of equal areas

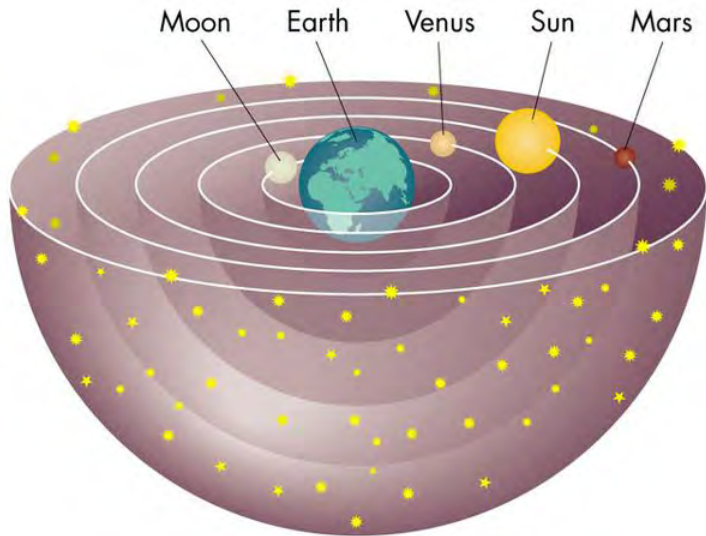
A line drawn from a planet to the sun sweeps out equal areas in equal time

The orbital velocity changes

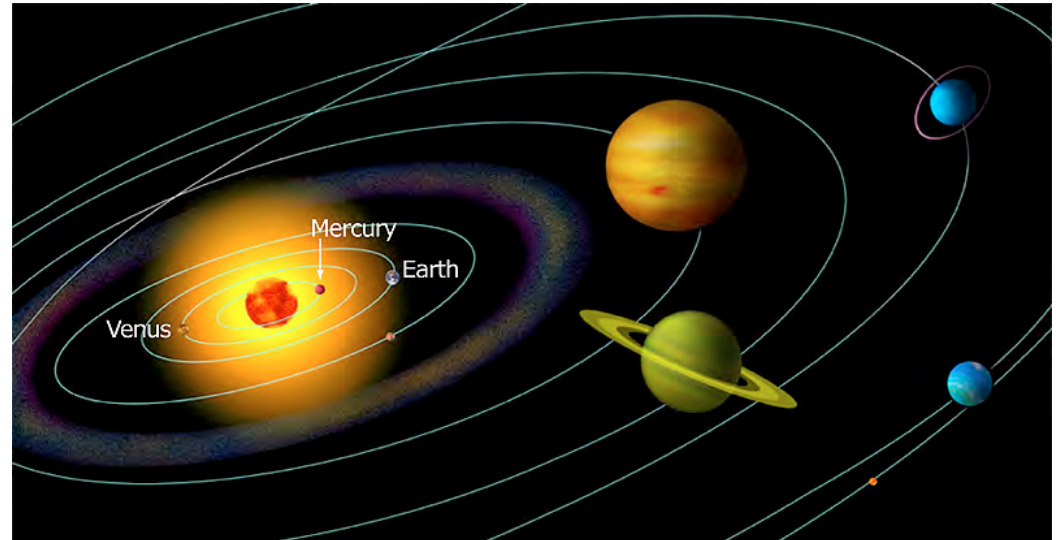




4th century BCE



17th century CE



Compared to astronomy, geology is a very 'young' science

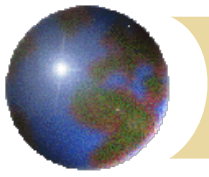
distances not to scale!



—
12,756 km diameter of Earth

—
142,800 km diameter of Jupiter

1,400,000 km diameter of the Sun

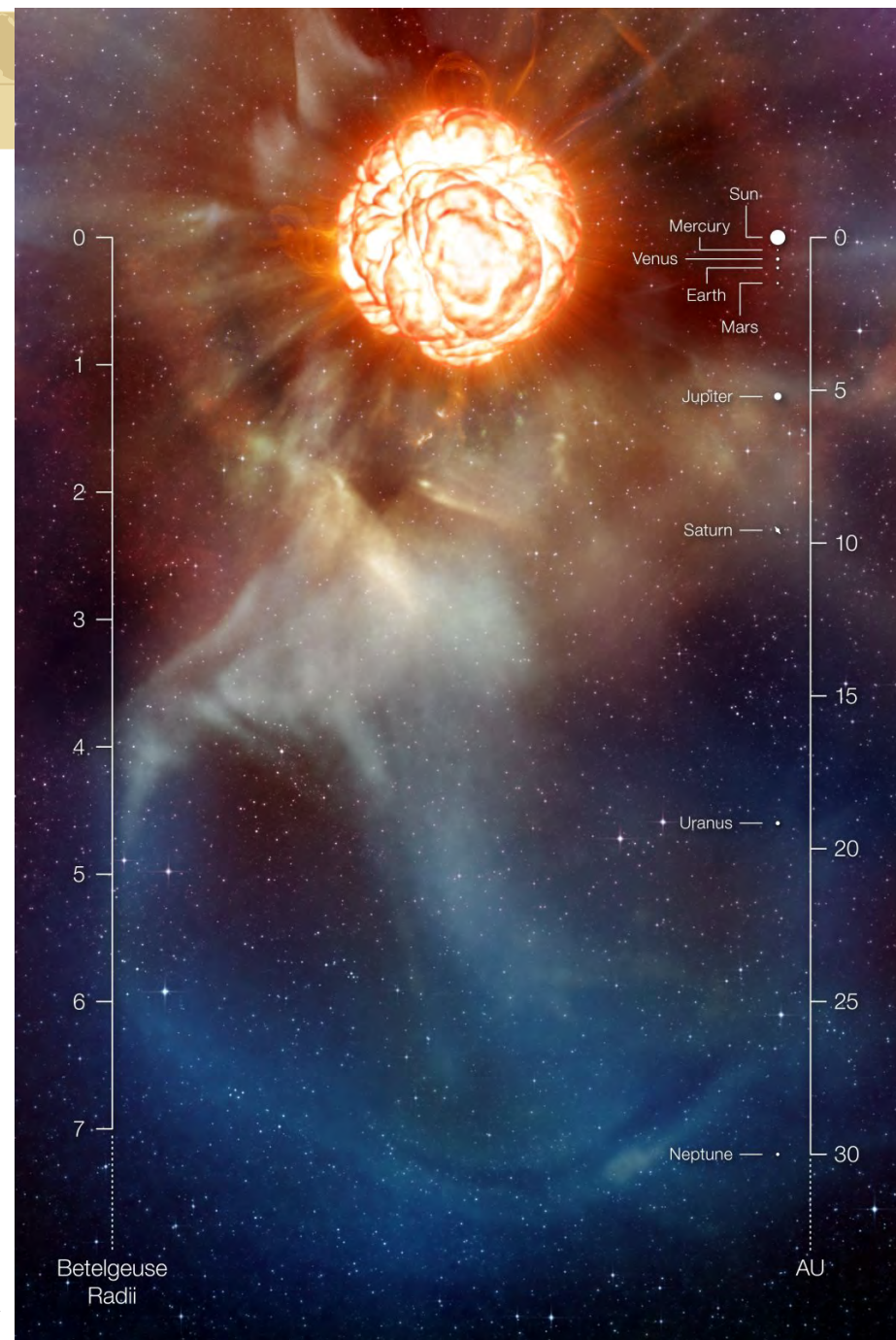


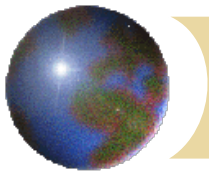
Scaled-down representation of the solar system

Let's shrink the solar system such that the distance of the Sun to Pluto (5.9×10^9 km) is 100 m

At this scale, the Sun's diameter of 1,400,000 km reduces to a 2.4 cm wooden ball

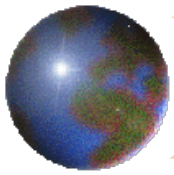
red super giant



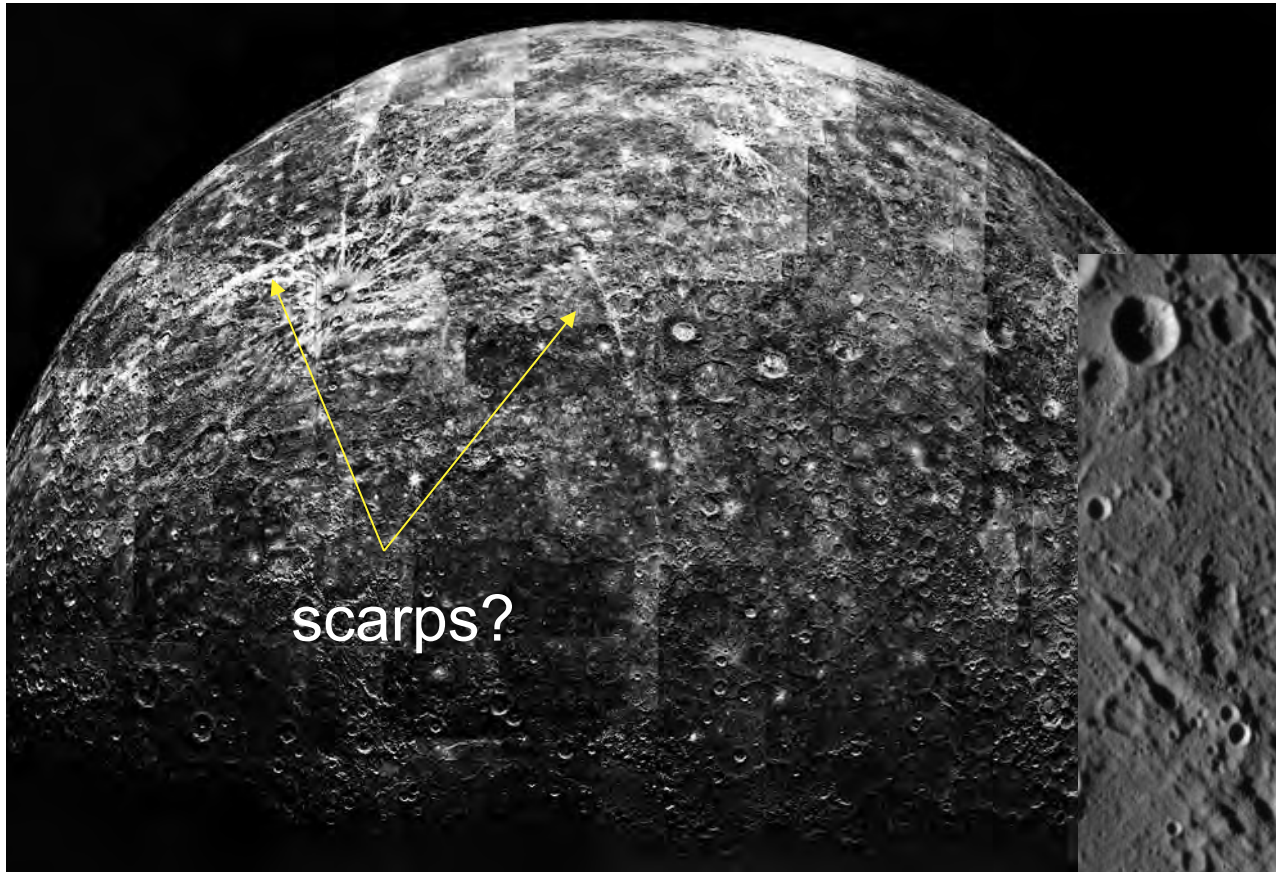


Scaled-down model of solar system

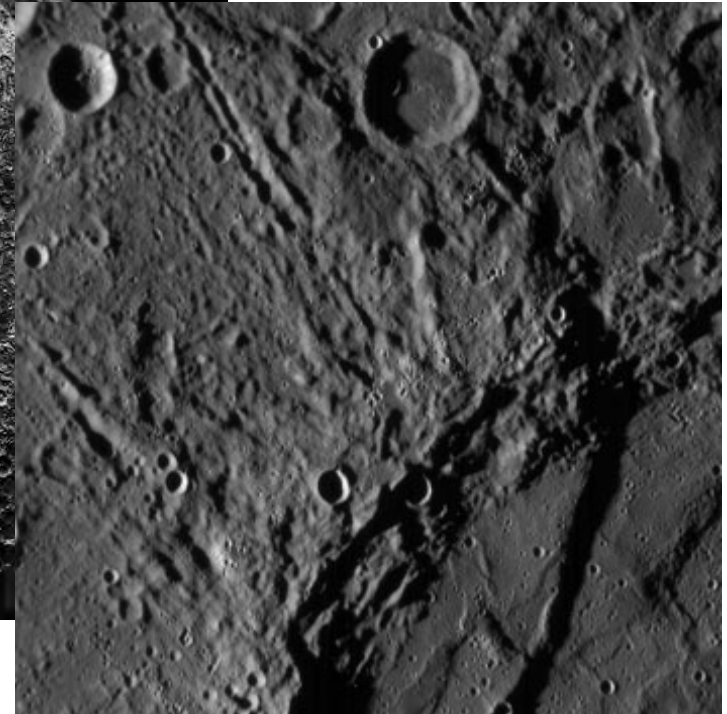
	Distance	Diameter
SUN	0 m	2.4 cm
Mercury	1.0 m	0.008 cm
Venus	1.8 m	0.02 cm
Earth	2.5 m	0.02 cm
Mars	3.9 m	0.01 cm
Jupiter	13.2 m	0.24 cm
Saturn	24.2 m	0.20 cm
Uranus	48.6 m	0.09 cm
Neptune	76 m	0.08 cm
Pluto	100 m	0.004 cm



Mercury, $d = 4,880 \text{ km}$, $\rho = 5.4 \text{ g/cm}^3$

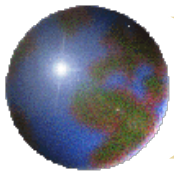


Messenger, 2011 NASA



0 satellites

- 70% metallic & 30% silicate composition; internally layered
- largest T range (-170° to 425°C)



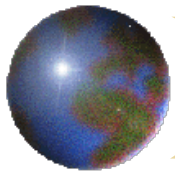
Venus, $d = 12,104 \text{ km}$, $\rho = 5.24 \text{ g/cm}^3$



Magellan radar
image, NASA

0 satellites

- Earth's twin; volcanoes, tectonics
- thick (deadly) atmosphere (inhibits telescope observation)

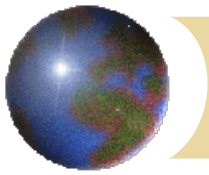


Earth, $d = 12,760 \text{ km}$, $\rho = 5.52 \text{ g/cm}^3$

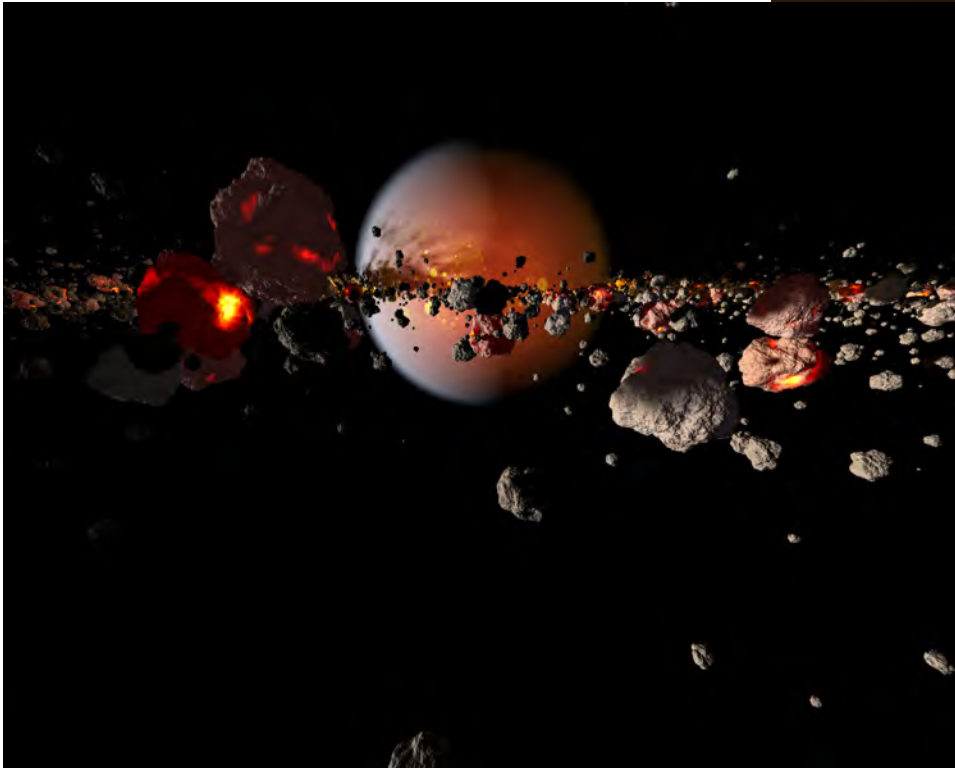


1 satellite

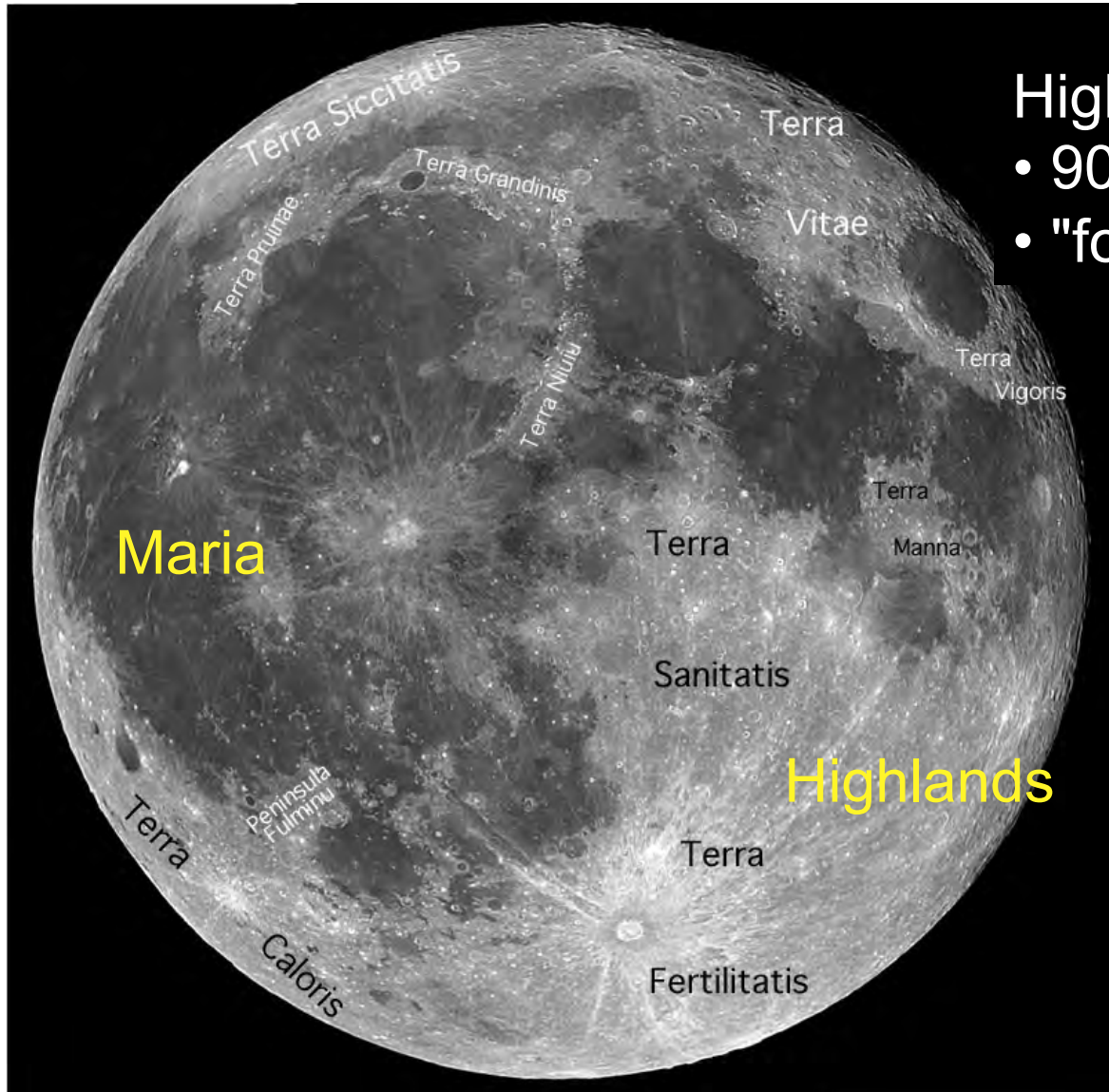
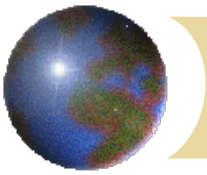
Apollo 8, 25-DEC-1968, NASA



Moon,
 $d = 3475 \text{ km}$,
 $\rho = 3.3 \text{ g/cm}^3$



Impact theory
of formation during
initial spiralling of
nebula



Highlands:

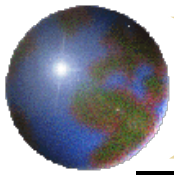
- 90% plagioclase feldspar
- "foam" on magma ocean

Maria:

- flood basalts

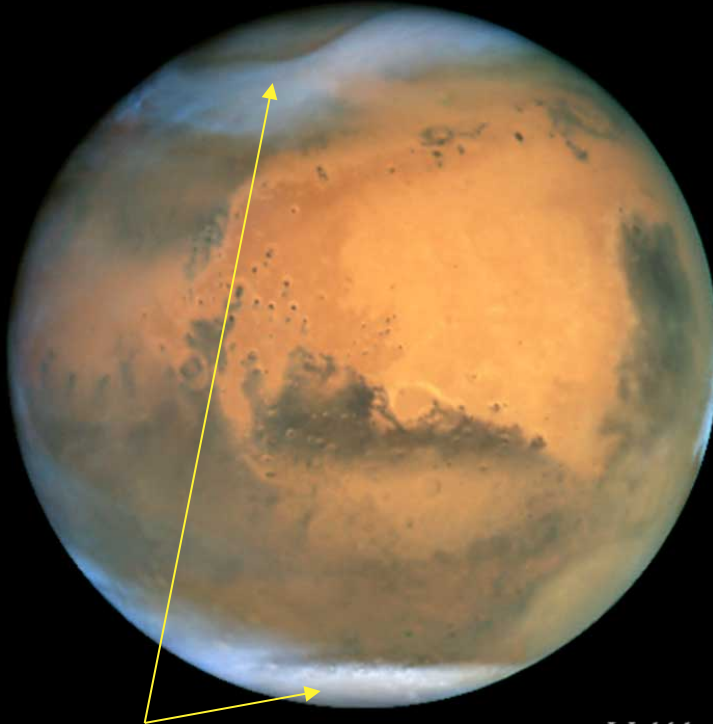
Moon evolution:

- formation of crust
- lunar highlands
- maria basins
- rayed craters



Mars, $d = 6,787 \text{ km}$, $\rho = 3.96 \text{ g/cm}^3$

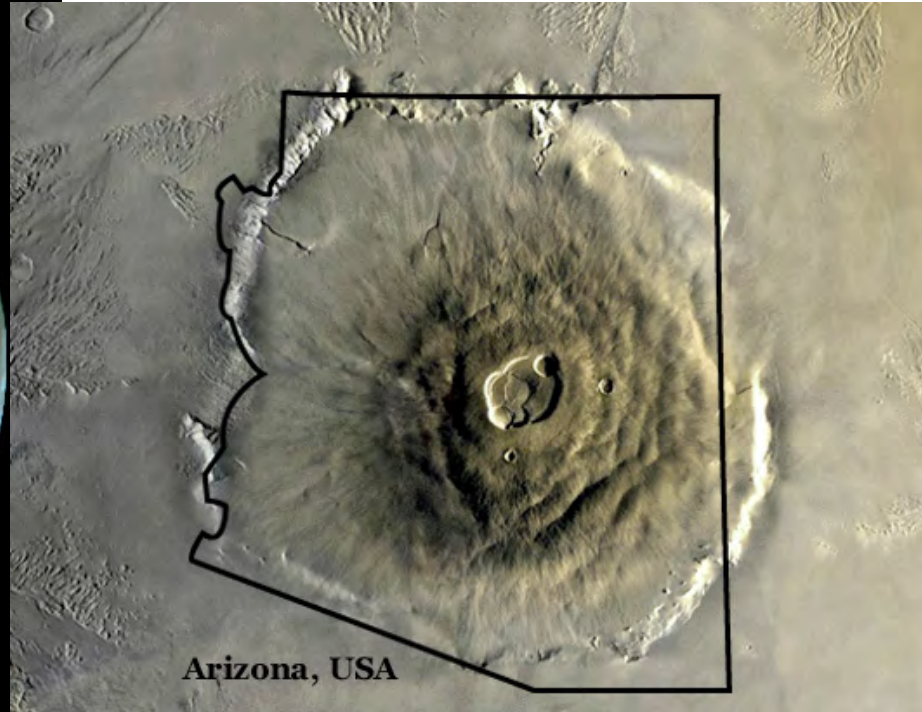
Mars • 2001 Opposition



polar ice

Hubble
Heritage

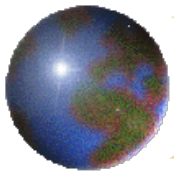
Hubble space telescope, MAR-2001, NASA



Arizona, USA

2 satellites

- ancient volcanoes & tectonics; internally layered; crust: basalt

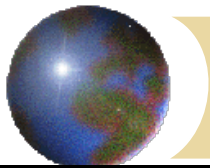


Mars, $d = 6,787 \text{ km}$, $\rho = 3.96 \text{ g/cm}^3$

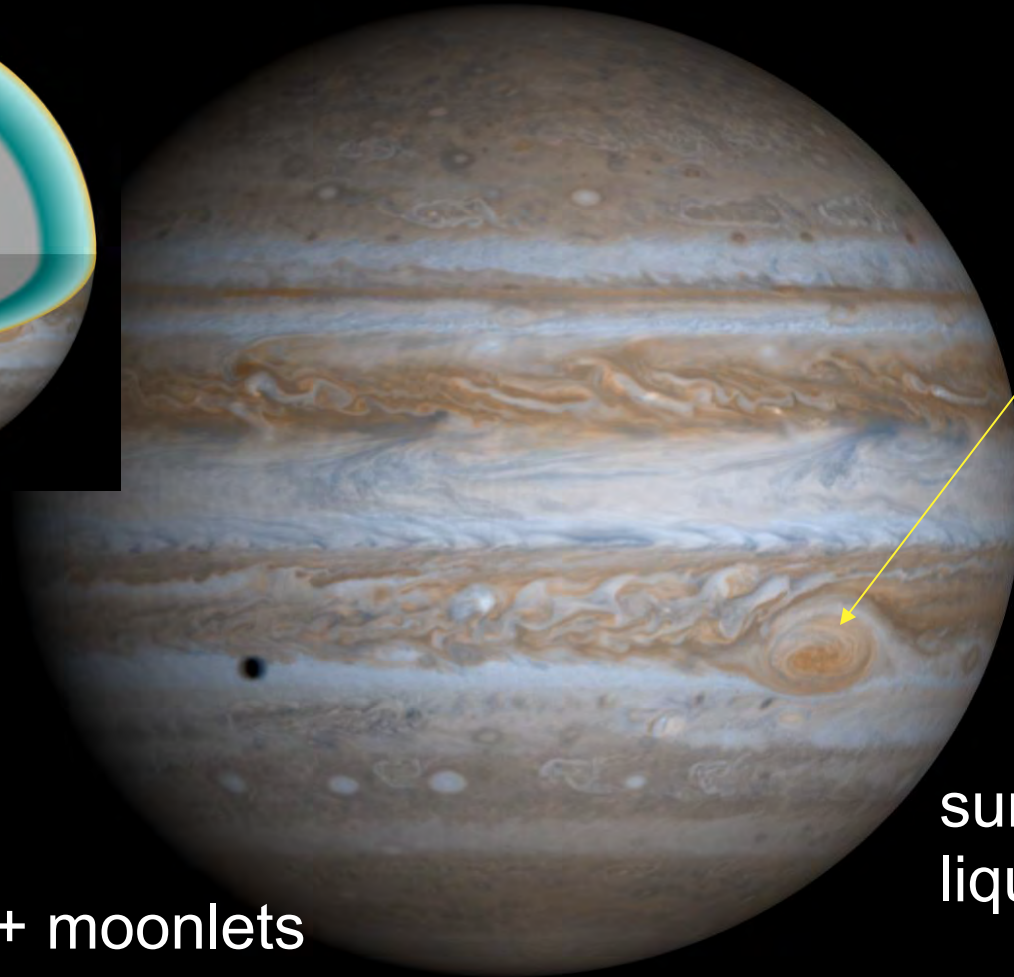
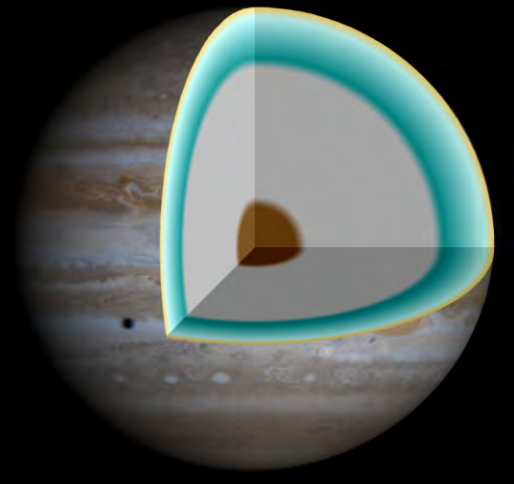


ca. 4.2 Ga

Evidence of flowing water and erosion



Jupiter, $d = 143,000$ km, $\rho = 1.33$ g/cm³



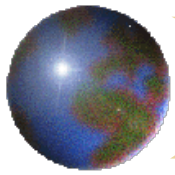
layered
atmosphere;
giant storms

surface is
liquid hydrogen

63 satellites + moonlets

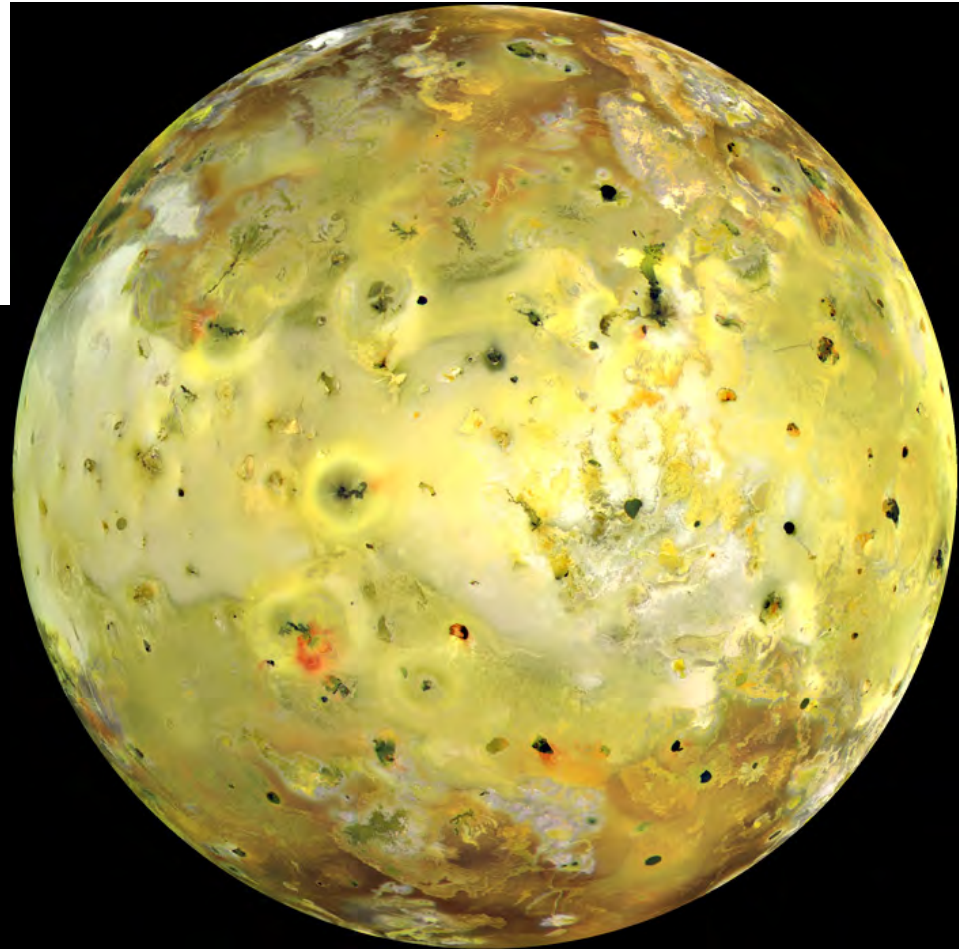
Cassini mission, 7-DEC-2000, NASA-ESA

core region is surrounded by dense metallic hydrogen,
which extends outward to about 78% of the radius of the planet

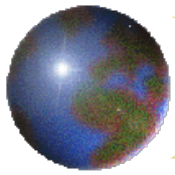


Io, one of the four Galilean satellites

- currently volcanically active
- melting is from tidal energy

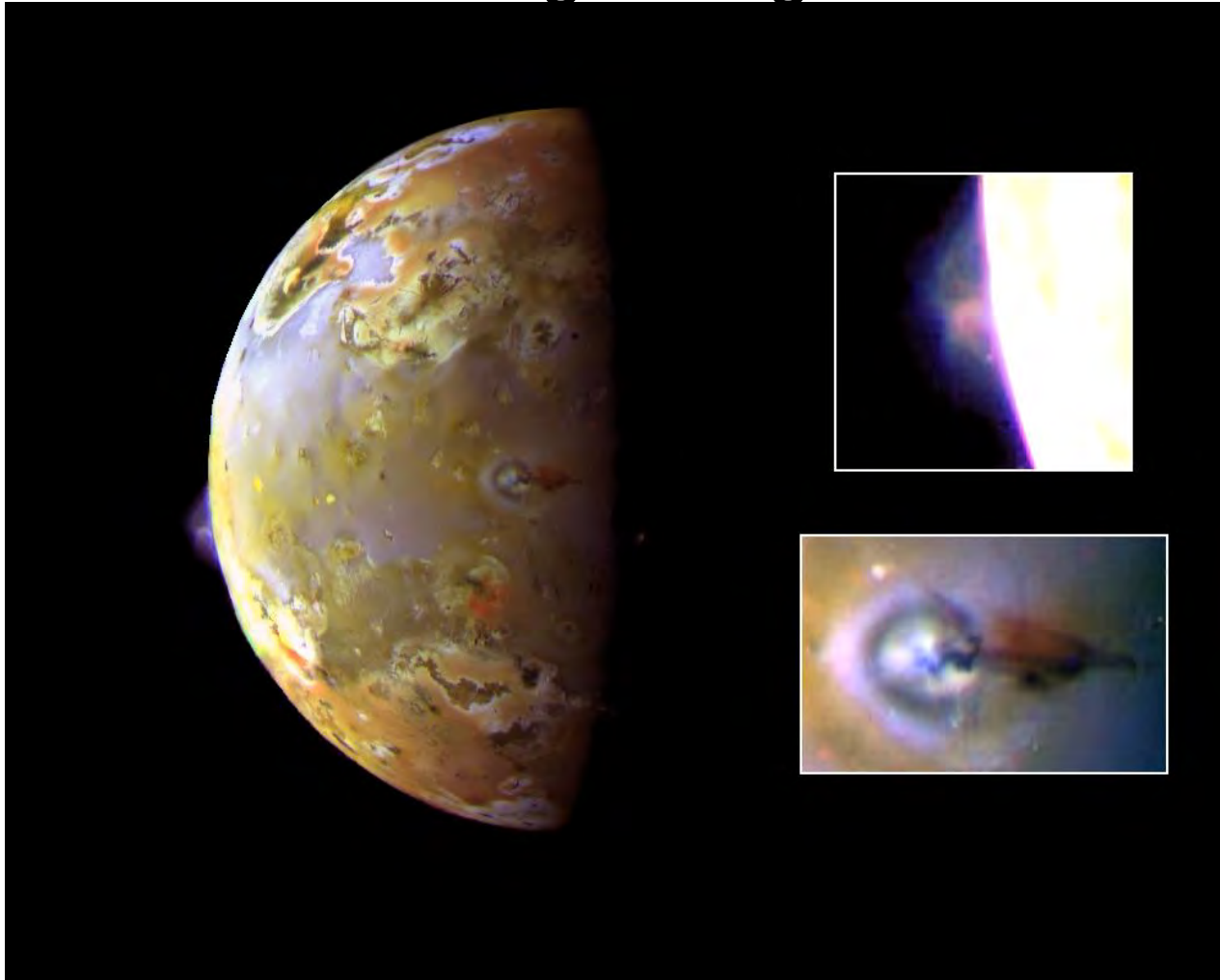


Galileo mission, 3-JUL-1999, NASA

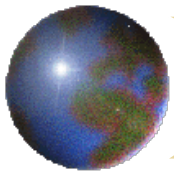


Volcanic plumes on Io

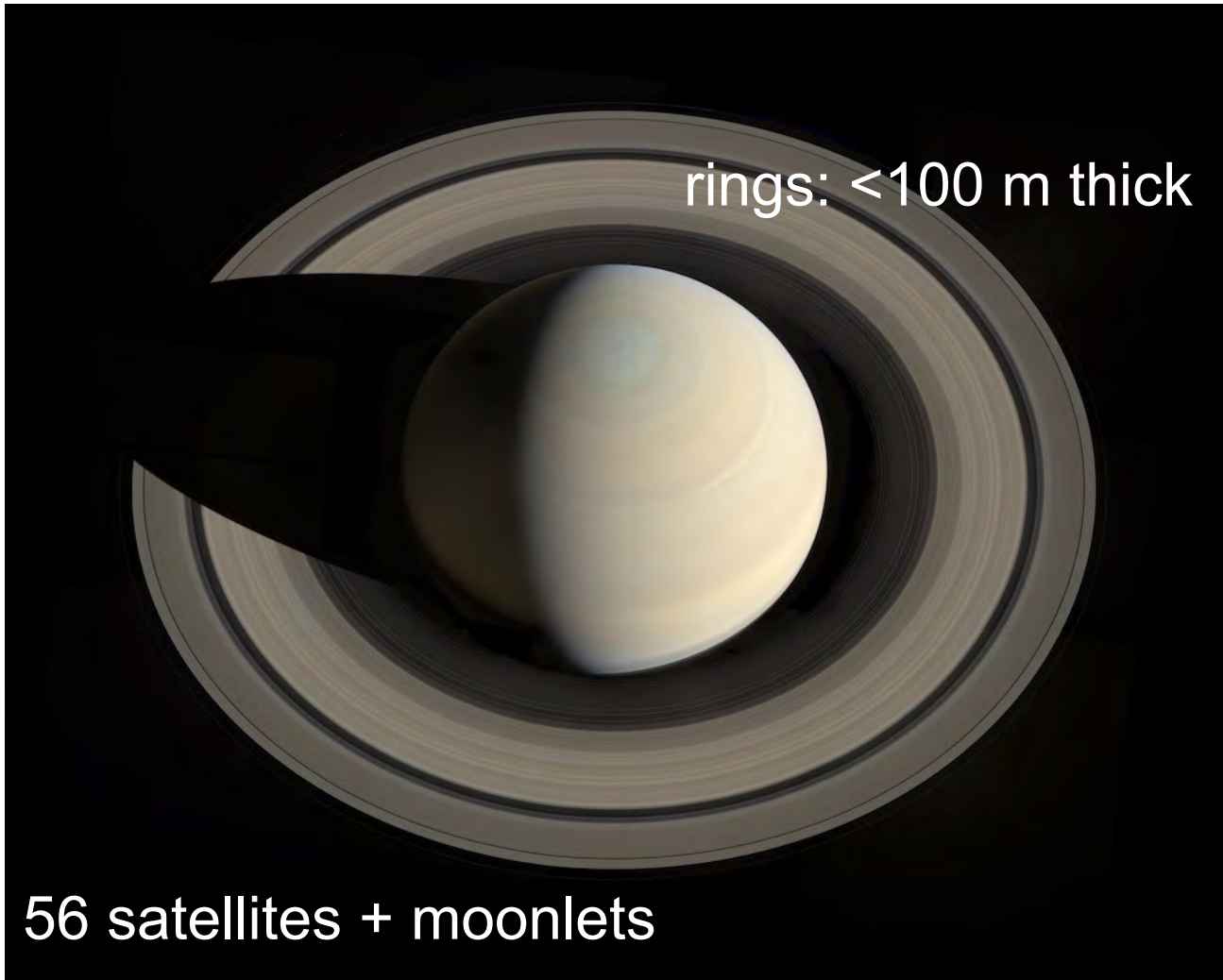
fountains of lava gushing 160 km in height



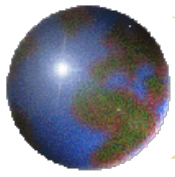
Galileo mission, 28-JUN-1997, NASA



Saturn, $d = 121,000 \text{ km}$, $\rho = 0.69 \text{ g/cm}^3$

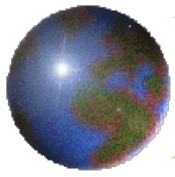


Core similar to Earth surrounded by a deep layer of metallic hydrogen an intermediate layer of liquid hydrogen and liquid helium and an outer gaseous layer; magnetic field

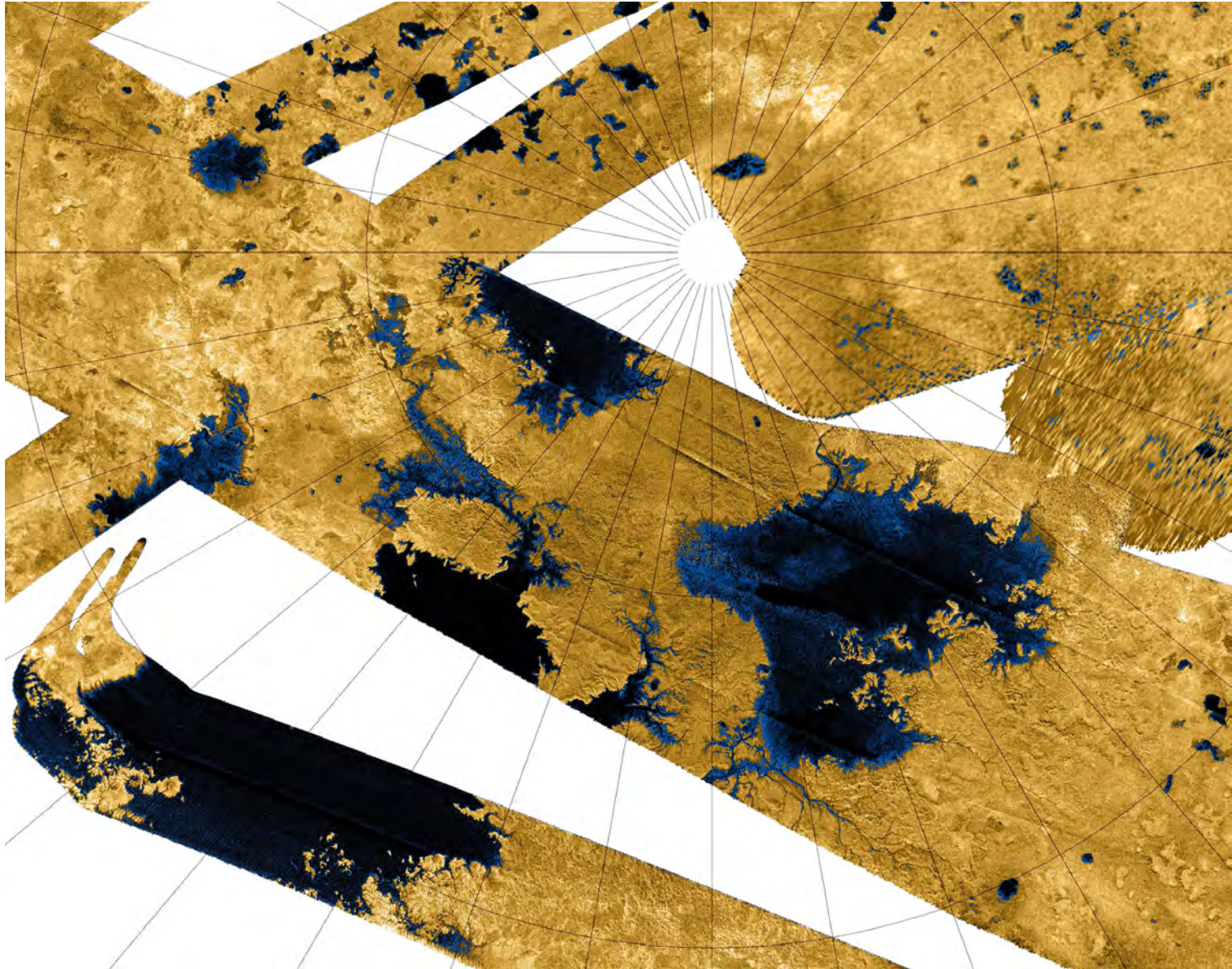


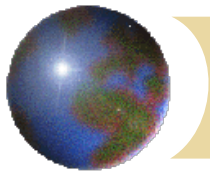
Enceladus (moon): icy planet with geysers





Titan (moon): (liquid) lakes and seas + atm!



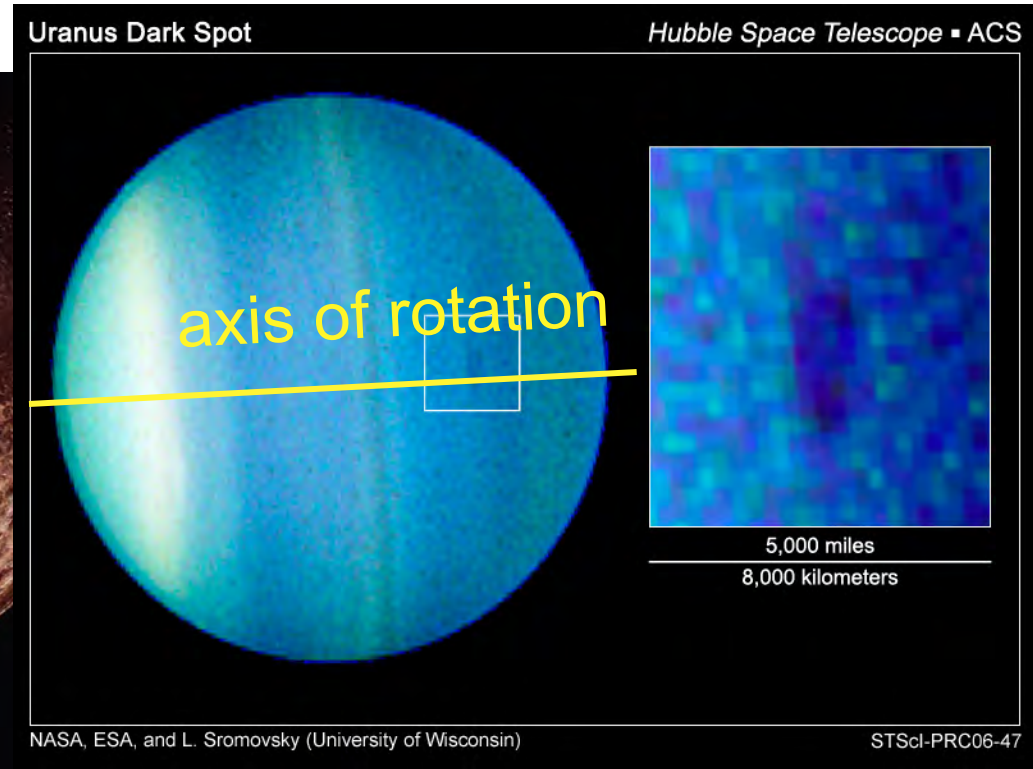
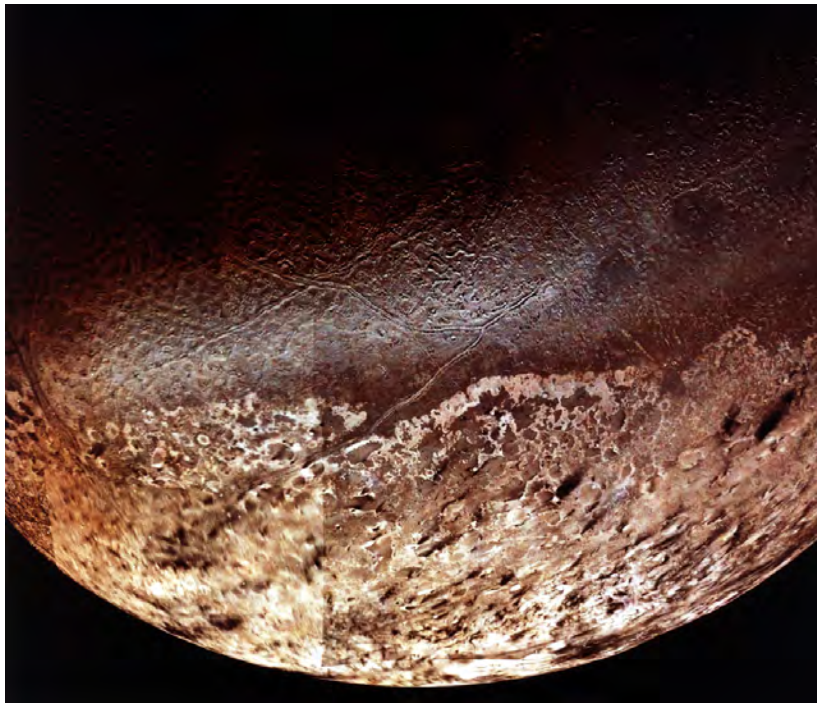


The Twins ice dominating over gases = Ice Giants

a rocky center, an icy mantle and an outer gaseous hydrogen/helium envelope; ice: water, ammonia and methane

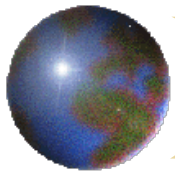
Uranus, $d = 51,000$ km, $\rho = 1.27$ g/cm³

27 satellites



Neptune, $d = 49,500$ km, $\rho = 1.76$ g/cm³

13 satellites; Triton contains cryovolcanism

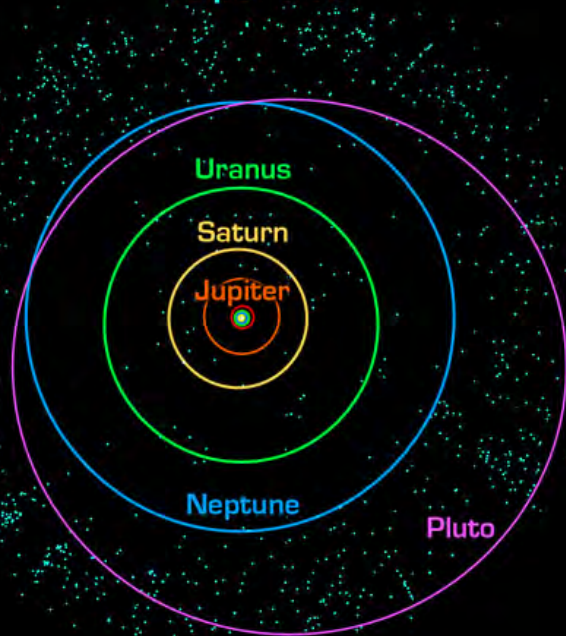


DEMOTED !

Pluto, $d = 2,300 \text{ km}$, $\rho = 2.3 \text{ g/cm}^3$

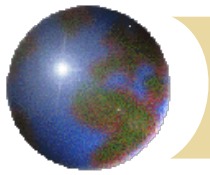
largest member of a distinct population of rock, metals, and ices called the **Kuiper belt** (dwarf planets, moons, planetesimals)

Kuiper Belt



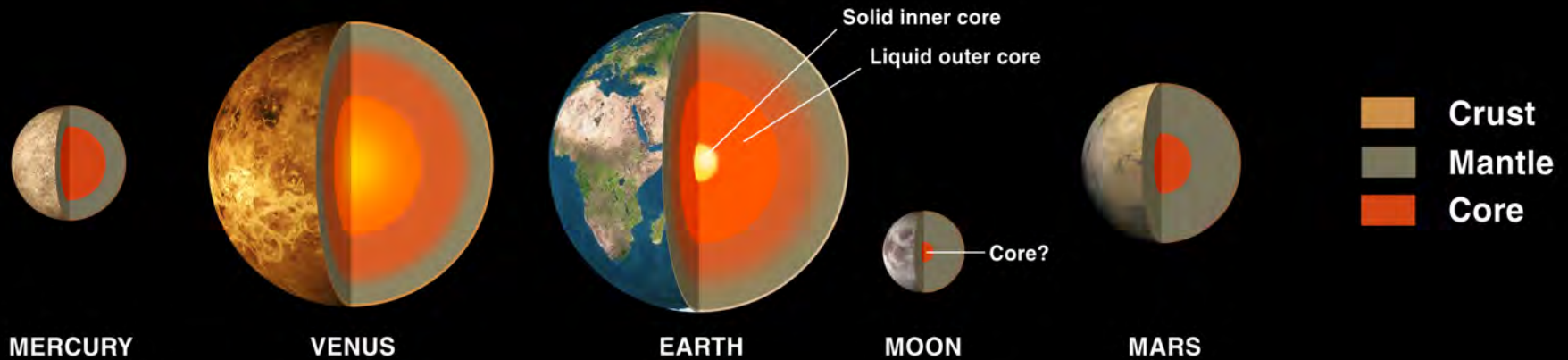
Largest known trans-Neptunian objects (TNOs)

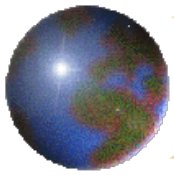




Terrestrial vs Jovian planets

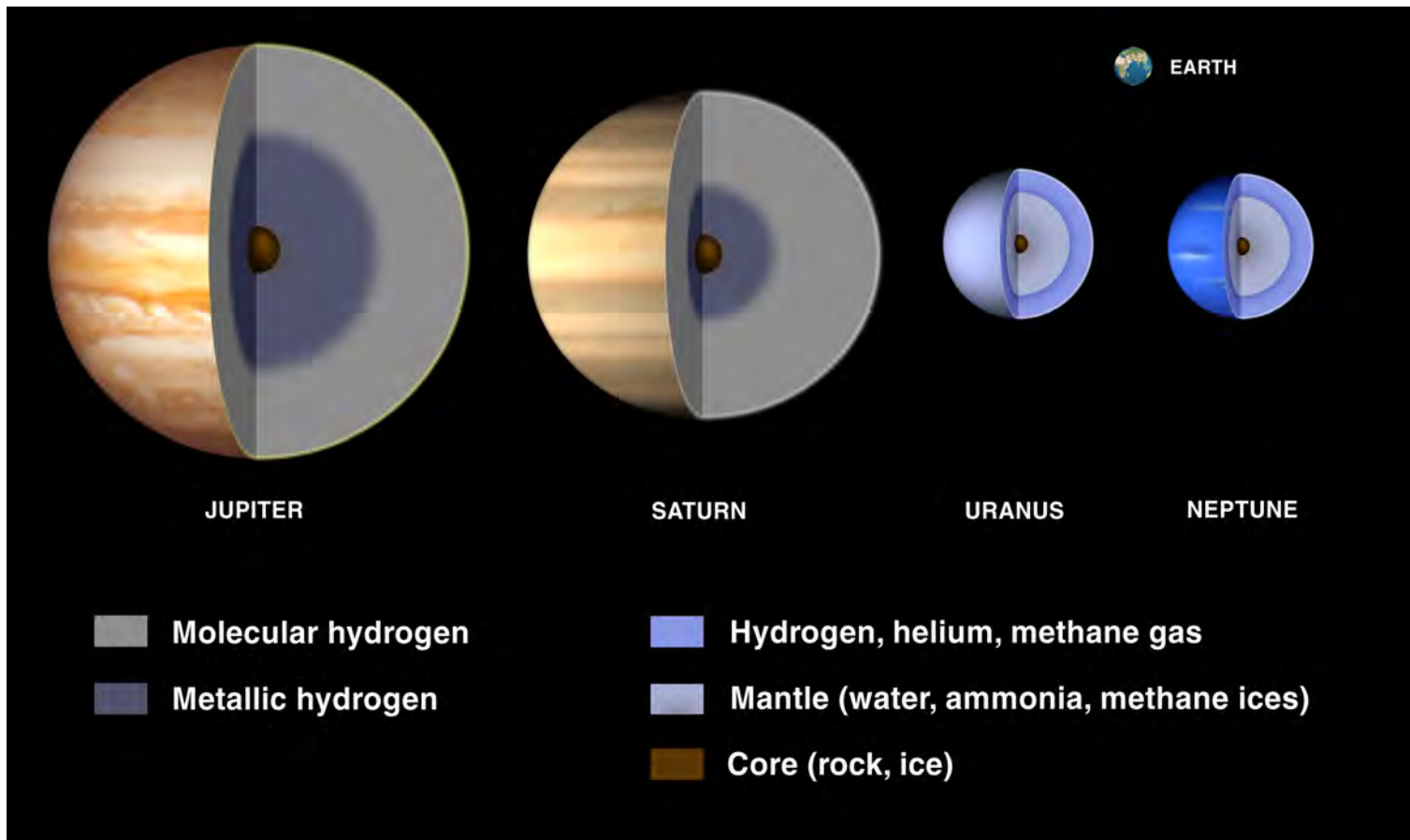
- hard silicate rocky surfaces
- close to the Sun
- larger ones have atmospheres
- dense metallic cores
- few satellites

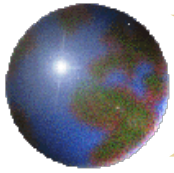




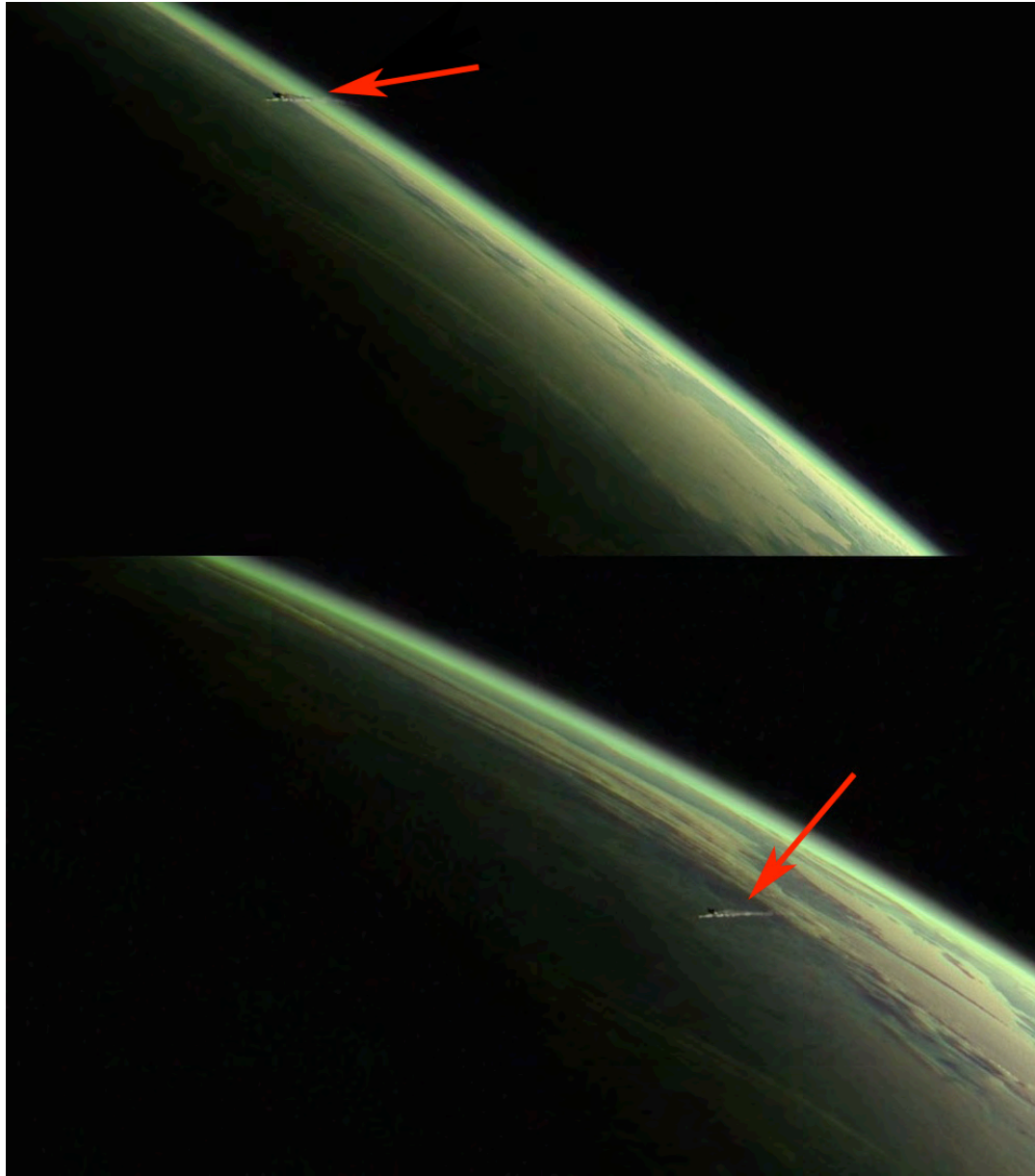
Terrestrial vs Jovian planets

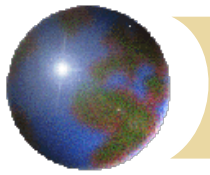
- very large outer planets
- very low density
- turbulent
- many satellites
- composed of gases, H, He, NH₃





Space flotsam





Space flotsam

asteroids: leftover planet fragments

comets: dirty snowballs

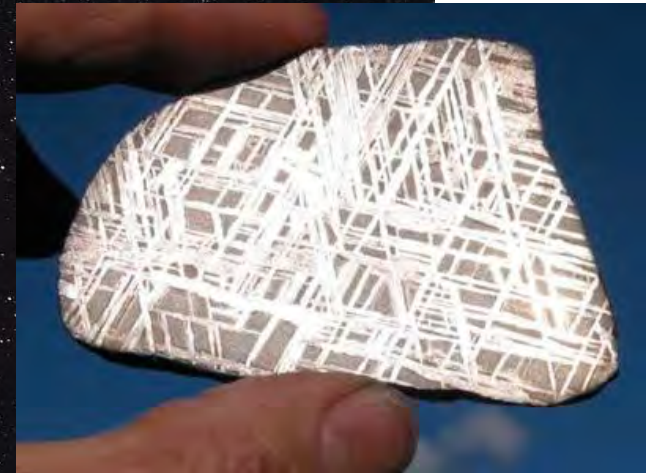
meteoroids: shooting stars
(iron & stony)

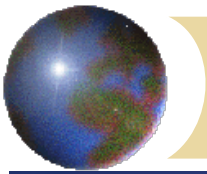
Comet Hale-Bopp

ionized
gases



dust

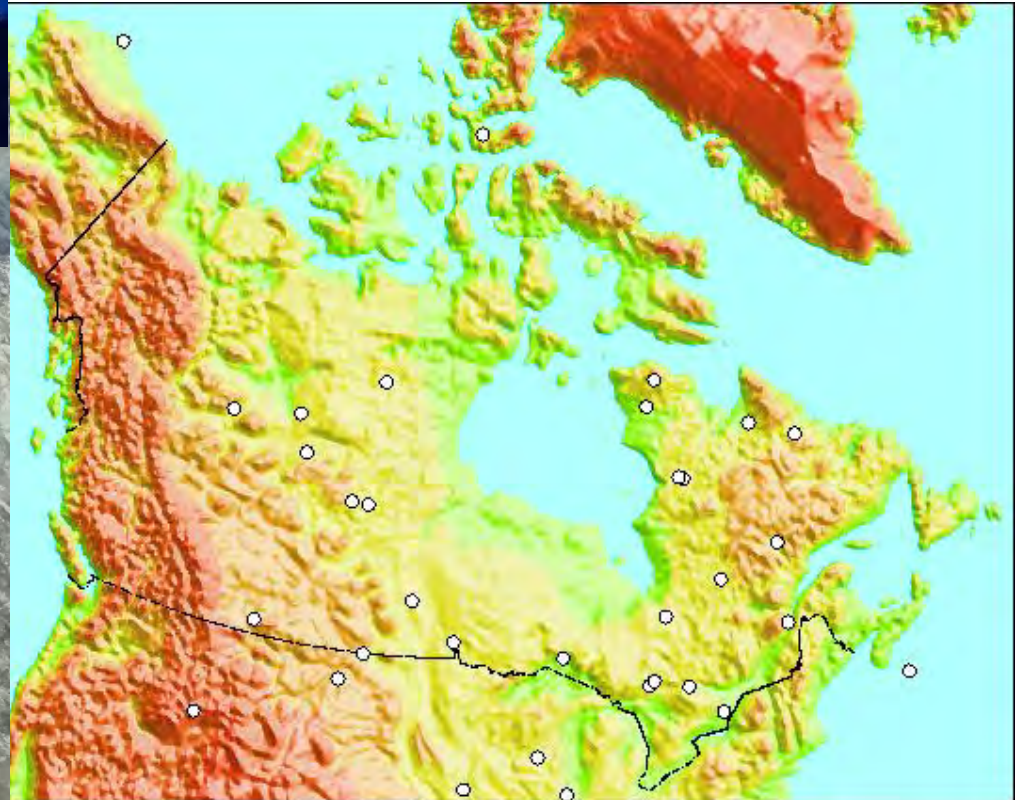


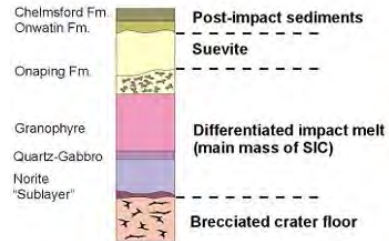
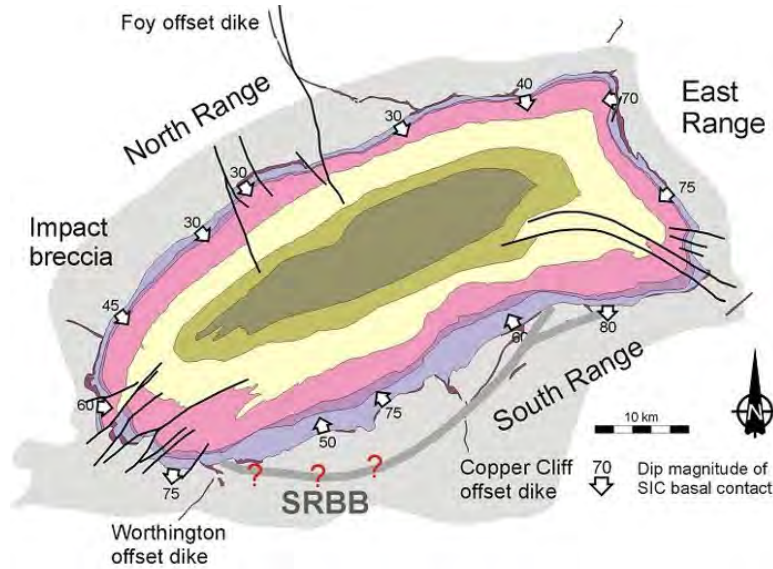
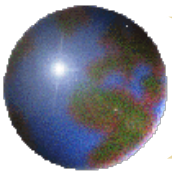


Russia, 2013



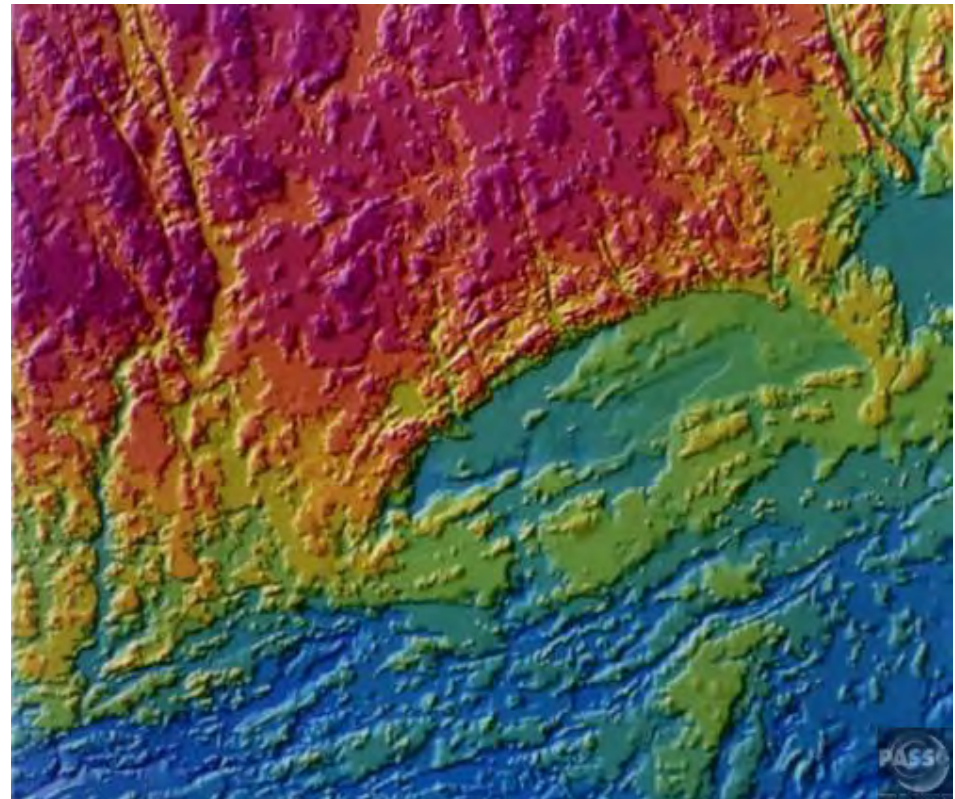
Wanapitei crater, ON, 37 Ma
Manicouagan crater, QC, 214 Ma
Charlevoix crater, QC, 342 Ma
Sudbury crater, ON, 1850 Ma





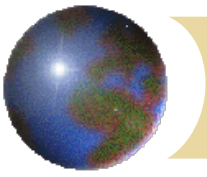
Sudbury crater, ON, 1850 Ma

nickel, copper, platinum, palladium, gold

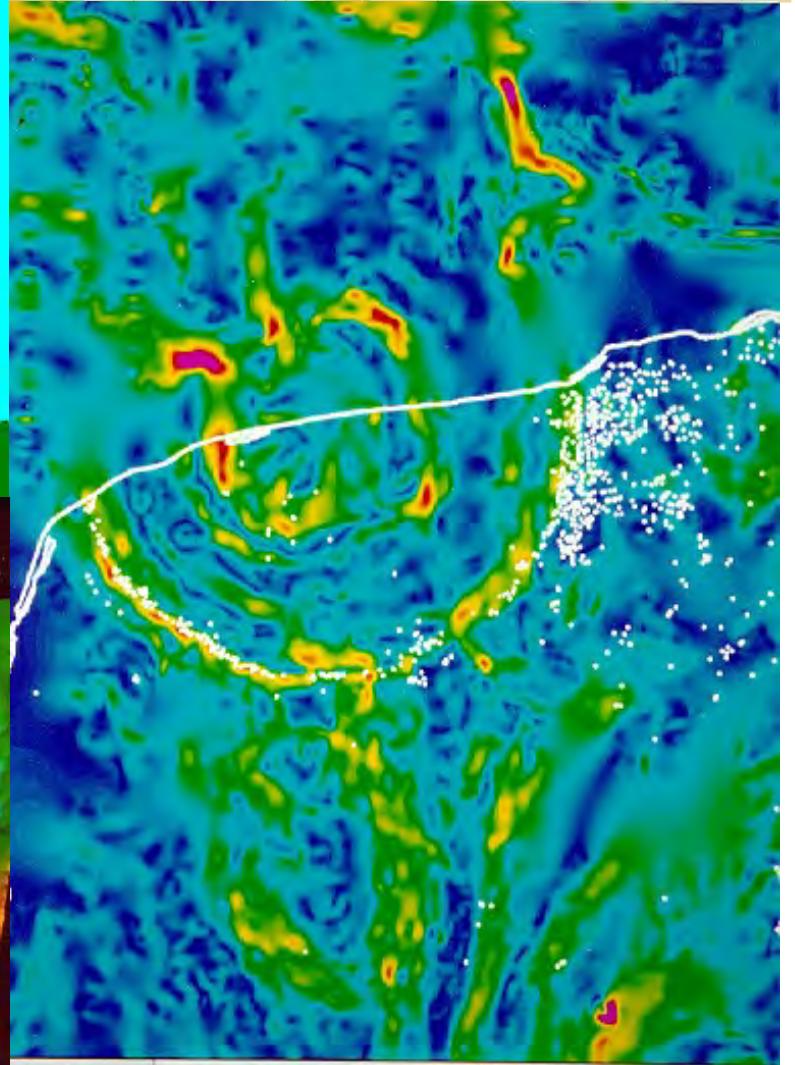
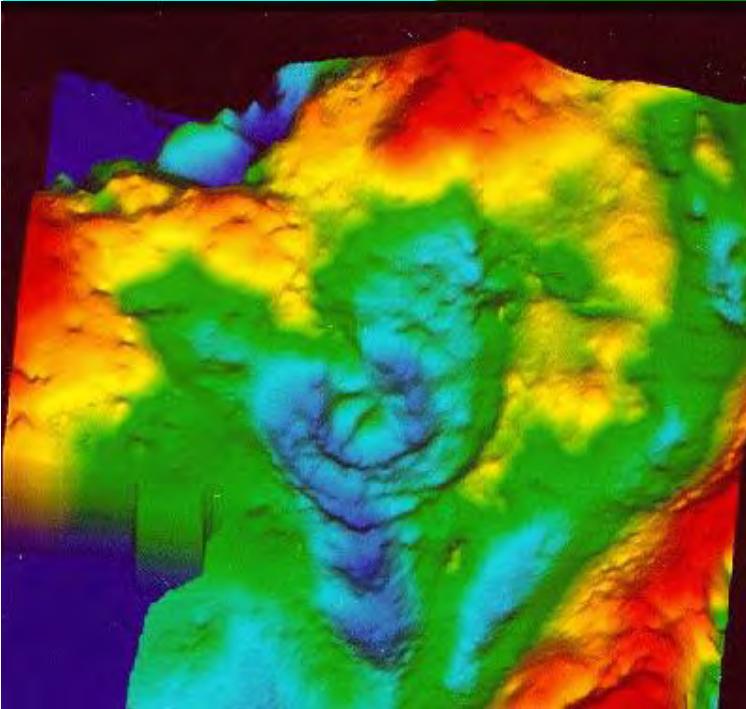


Simplified geological map of the Sudbury Impact Structure showing the main mass of the Sudbury Igneous Complex (norite, quartz-gabbro and granophyre layers) overlain by fallback deposits (Onaping Formation) and post-impact sedimentary rocks (Onwatin and Chelmsford Formations). Also shown are the dips of the basal contact of the complex as well as the distribution of quartz-diorite "offset" dikes emanating from the main mass. The complex rests on Archean and Proterozoic target rocks affected by impact brecciation.



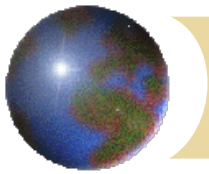


Chicxulub crater



90°

89°



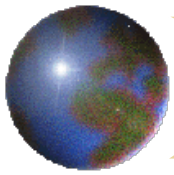
Age of solar system

- Meteorites 4.53 to 4.58 Ga
- Mars 4.2 Ga
- Moon rocks 4.4 to 4.5 Ga
- Oldest rock on Earth, Acasta gneiss in NWT is 4.1* Ga (but Earth is tectonically active, rocks keep getting recycled...)
- Oldest mineral on Earth, zircon in Australia is 4.4 Ga

*4.28 Ga in N. Quebec; highly controversial



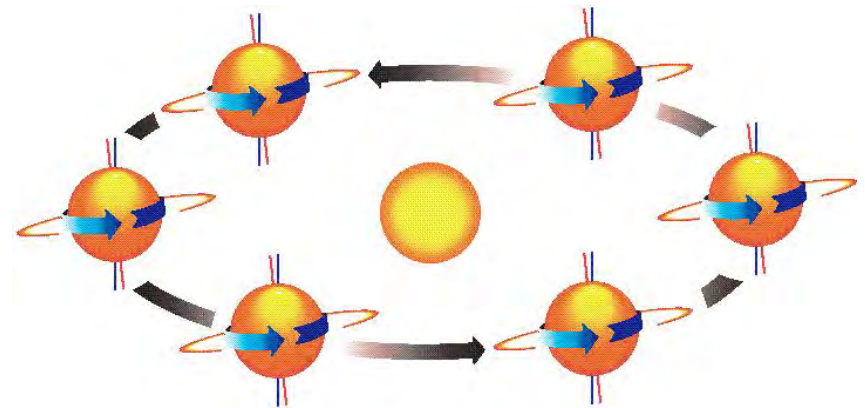
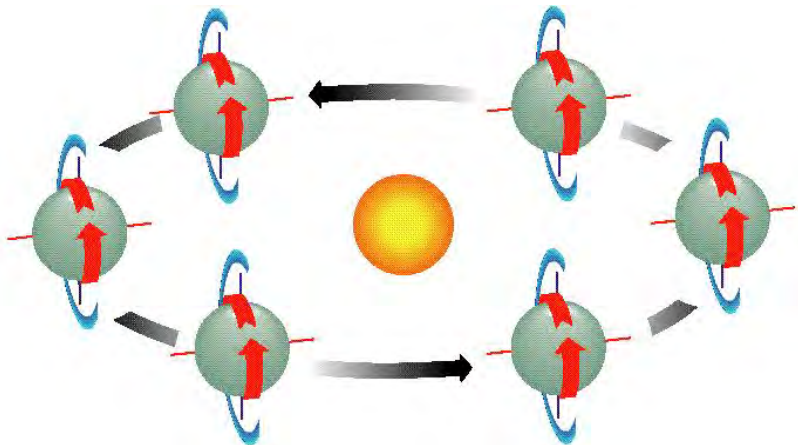
Ma = mega-annum = millions of years = 10^6 years
Ga = giga-annum = billions of years = 10^9 years

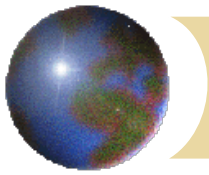


Solar nebula theory

Some observations to consider...

- ☉ All planets revolve around the Sun in the same direction (ccw when viewed from top, i.e. Earth north).
- ☉ All planets revolve within the same plane (ecliptic) except for Pluto (17° tilted from the ecliptic).
- ☉ Nearly all planets revolve ccw on their axes (Venus is cw, Uranus is severely tilted).

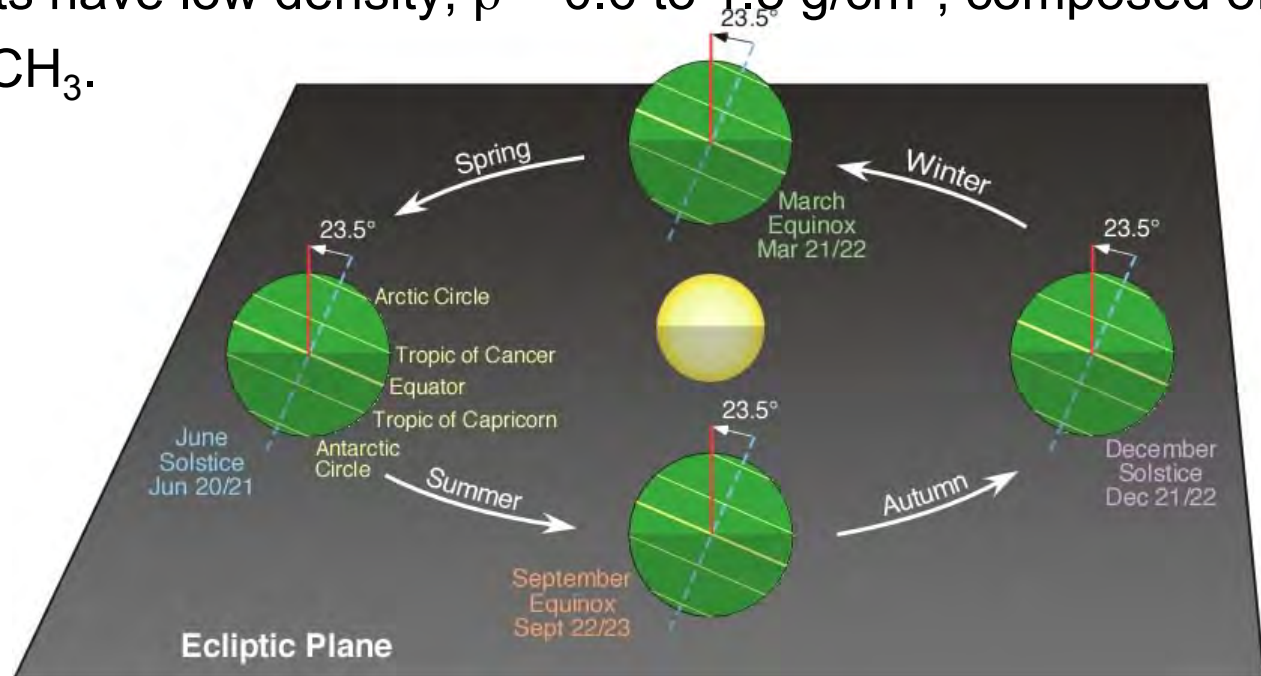


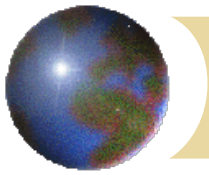


Solar nebula theory

Some observations to consider...

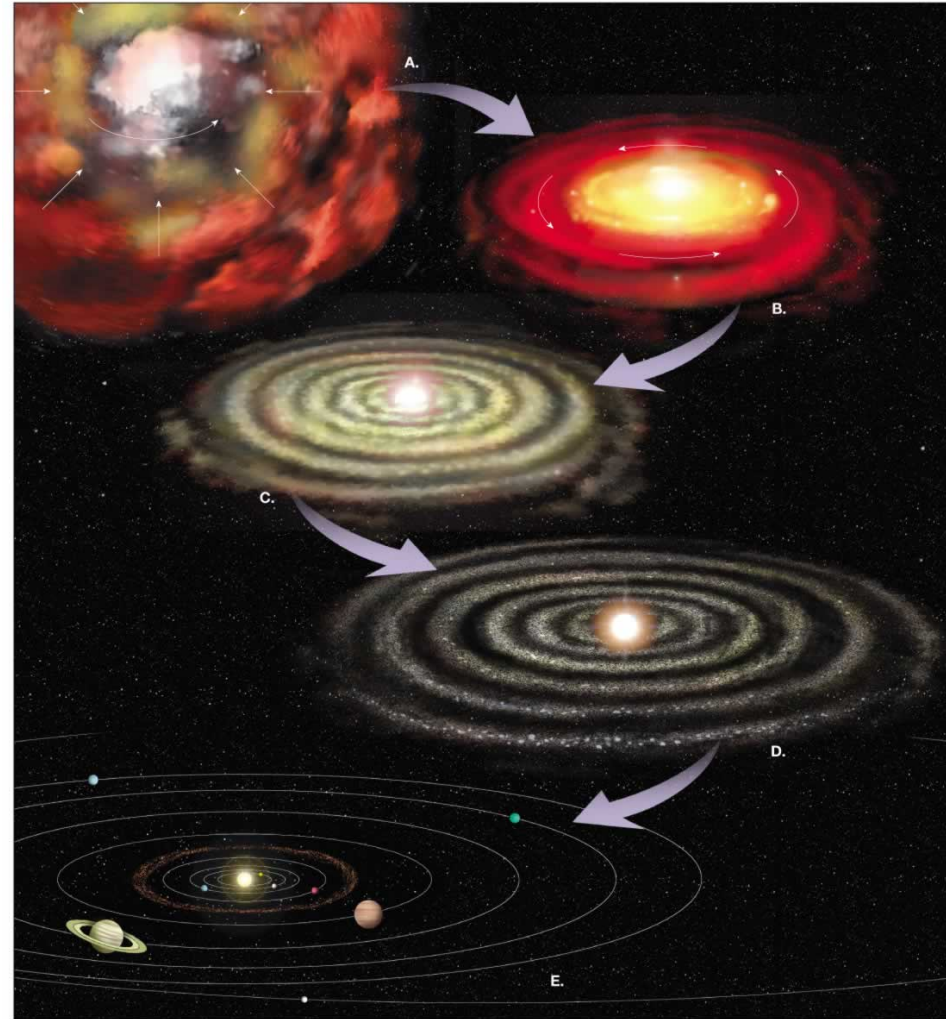
- ☉ Sun also revolves ccw on its axis ($25\frac{1}{2}$ Earth days).
- ☉ Axes of rotation of sun and planets are nearly all \perp to the ecliptic.
- ☉ Terrestrial planets have high density, $\rho = 4$ to 5.5 g/cm^3 , rocky surfaces with metallic cores.
- ☉ Jovian planets have low density, $\rho = 0.6$ to 1.8 g/cm^3 , composed of H, He, NH_3 , CH_3 .

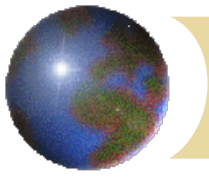




Solar nebula theory

- Solar nebula, cloud of He, H, some heavier dust
- 4.6-4.4 Ga ago, gravitational contraction, cloud initiates rotation
- Gravitational collapse, increase T, light elements driven towards outer edges of disk
- Planets result from accretion of dust, planetesimals
- Sun originates from concentration of mass at the centre

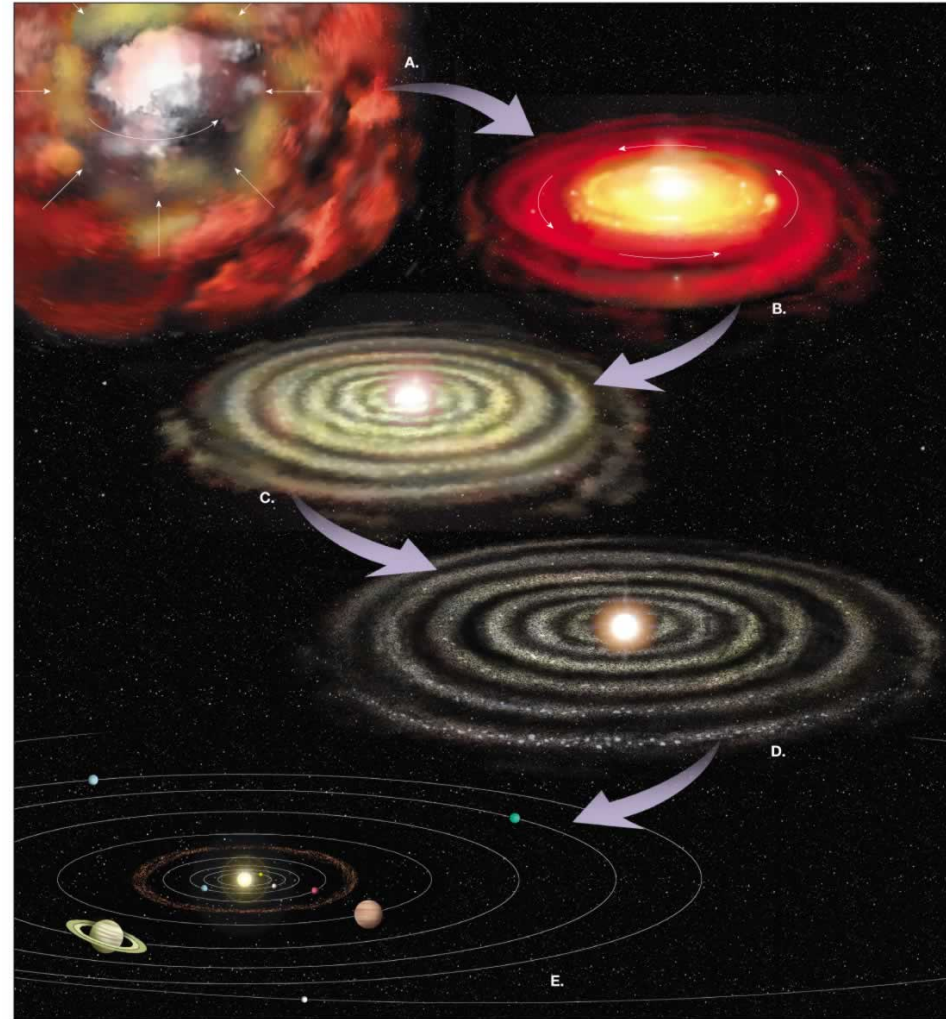


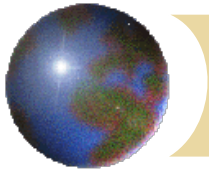


Solar nebula theory

A few problems:

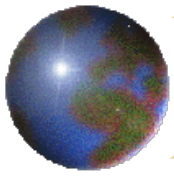
- Venus rotates cw, contrary to the majority of planets
- Origin of the asteroid belt (between Mars and Jupiter), destruction of an early planet by collision or failed accretion of planetisimals?
- Rotation speed of Sun is too slow given its position at the centre of the disk.





Earth Systems

- Sense of immense scale of solar system
- Difference between Terrestrial and Jovian planets, and what drives that is a difference
- Similar geologic processes operating on other planets
- Understanding of nebula theory



Earth Systems

