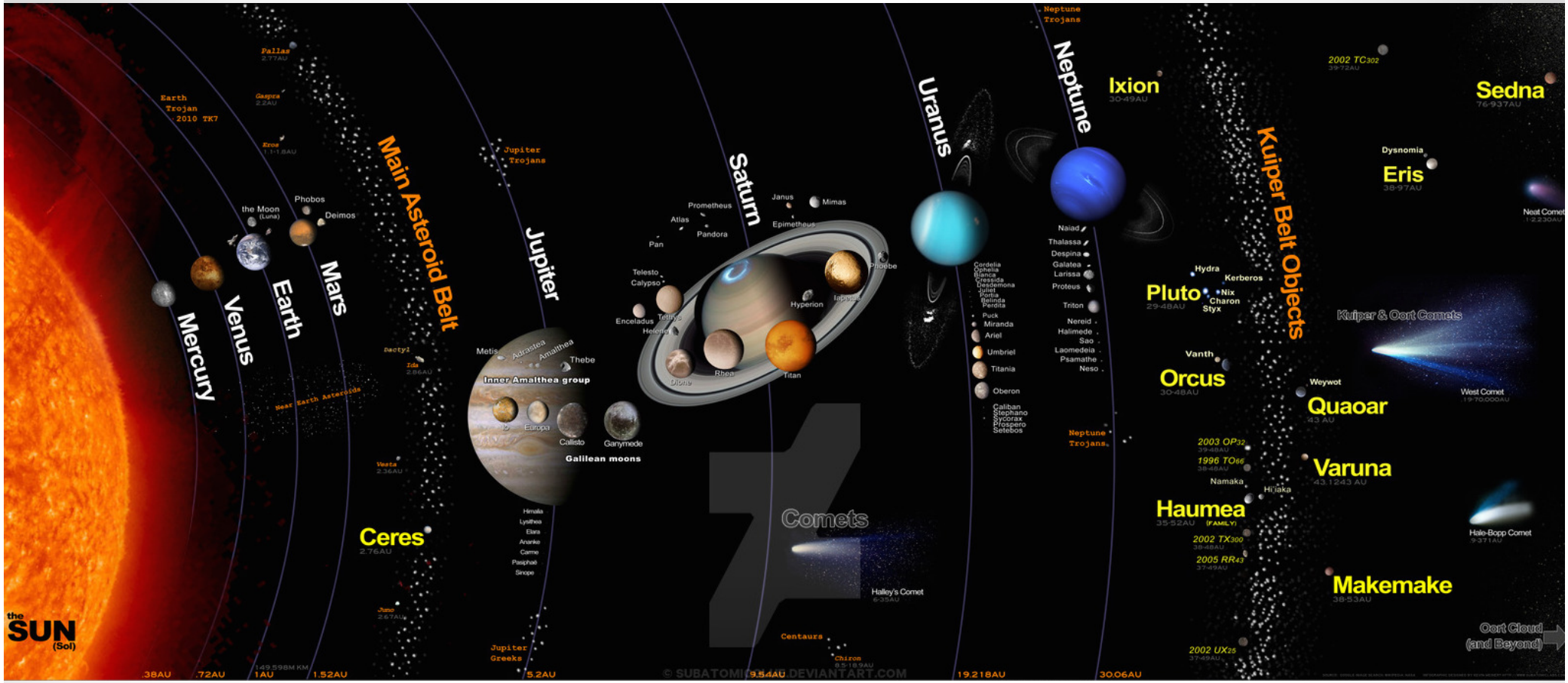
Solar System

Solar System Overview

- Sun (Sol): G2V Star, with 99.86% of the SS mass
- Rocky (terrestrial) planets: Mercury, Venus, Earth, Mars
- Gas Giants: Jupiter, Saturn
- Ice Giants: Uranus, Neptune
- Planetary moons
- Main-belt asteroids
- Kuiper-belt asteroids
- Comets
- Dwarf planets

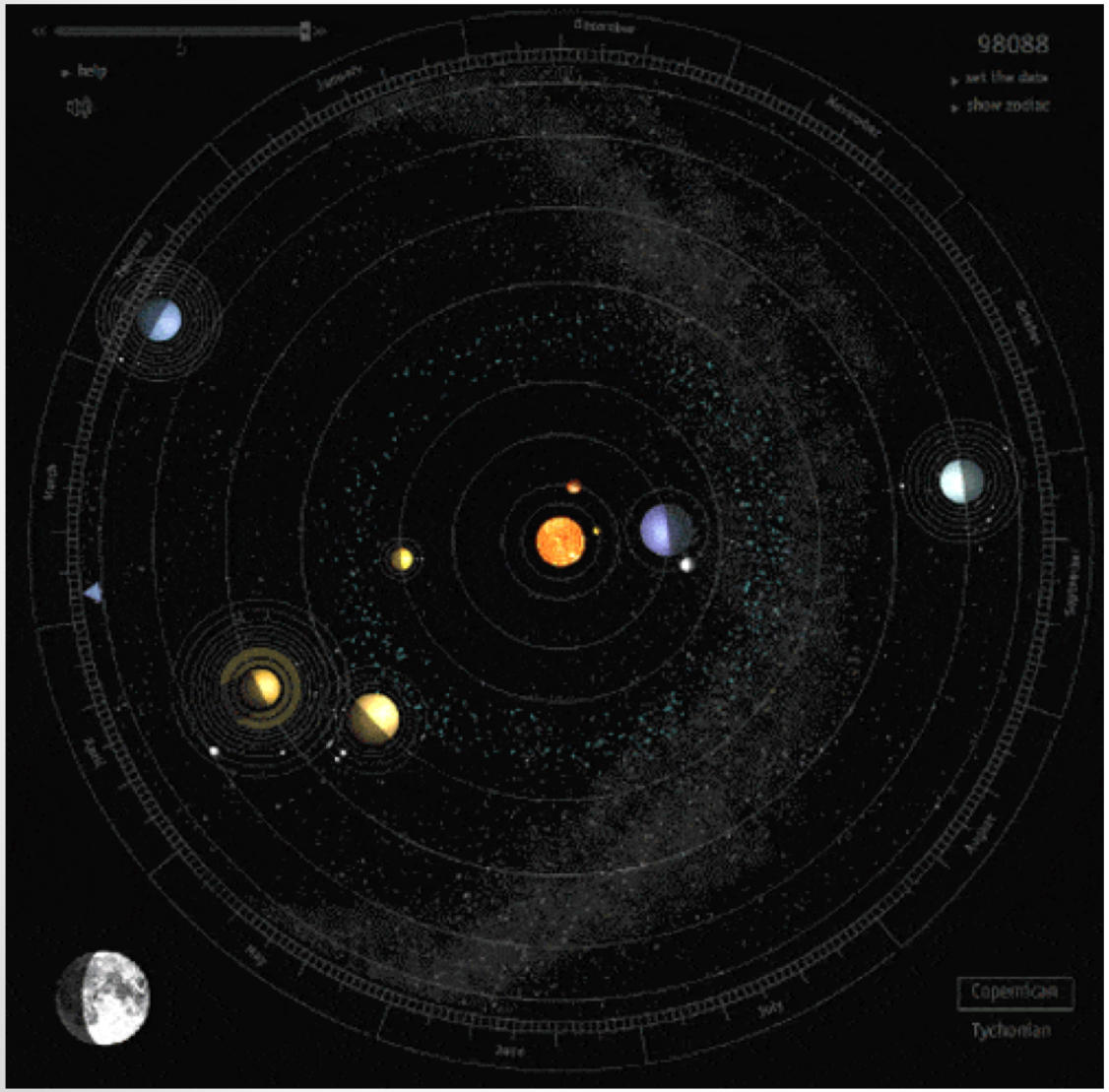
To be a member of the SS, need to be orbiting the Sun



The sizes of objects are not to scale

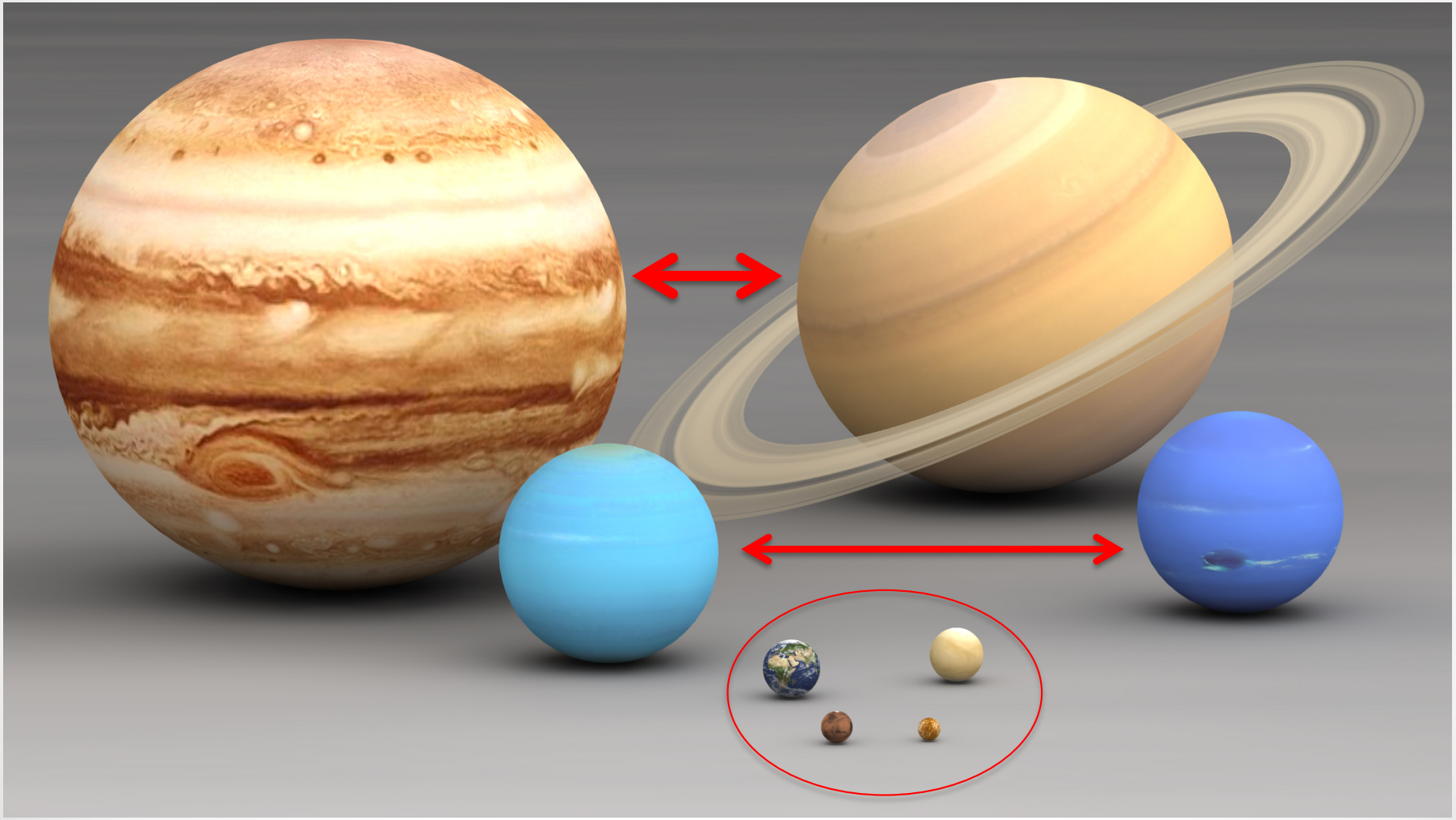
The distance scale is correct, but it is *logarithmic* rather than *linear*. Units are in Astronomical Units

Solar System: Dynamics

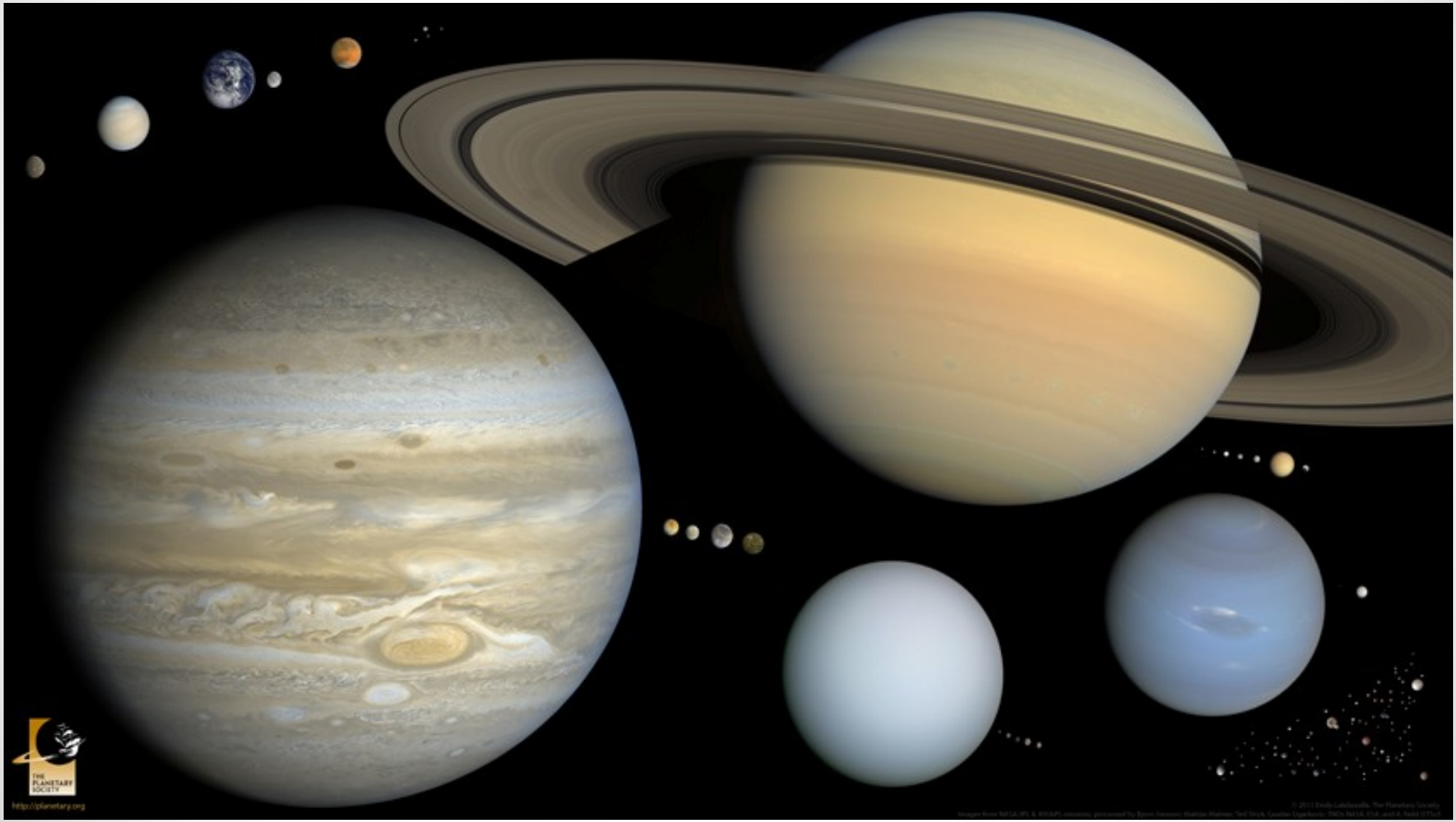


The orbital speed of a planet depends on its distance from the Sun, is set by the laws of gravity and described by **Kepler's Laws**

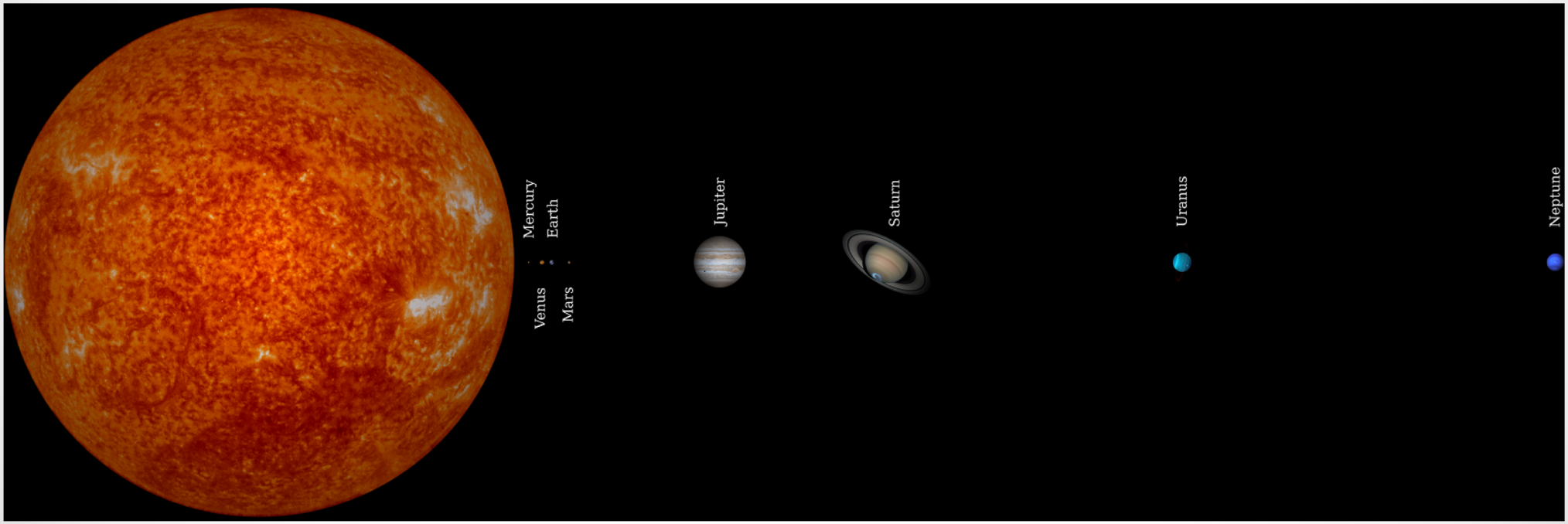
The Solar System: Planets to Scale



Solar System Objects to scale

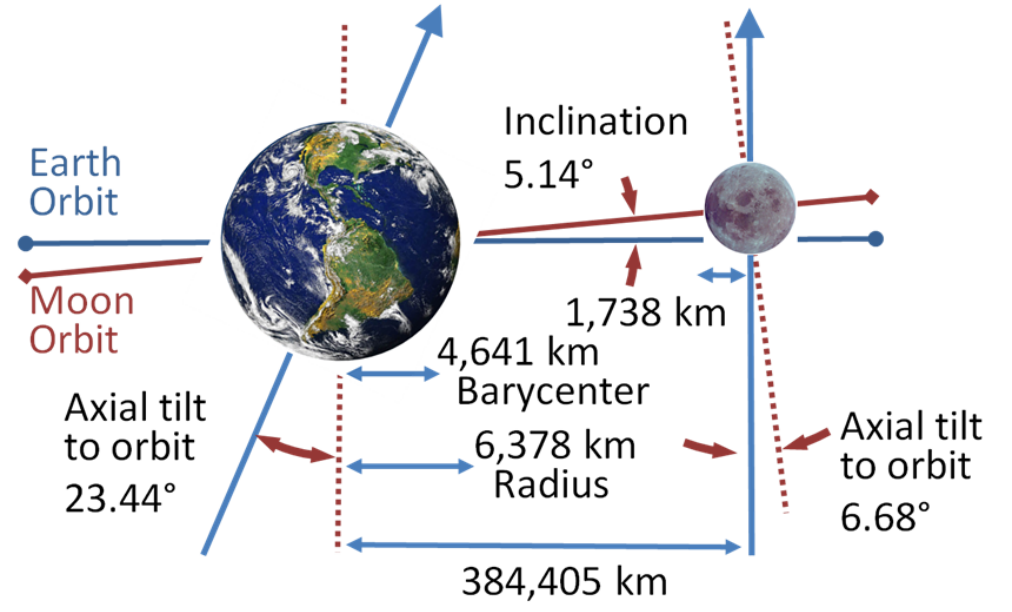


Solar System to linear scale for size and spacing

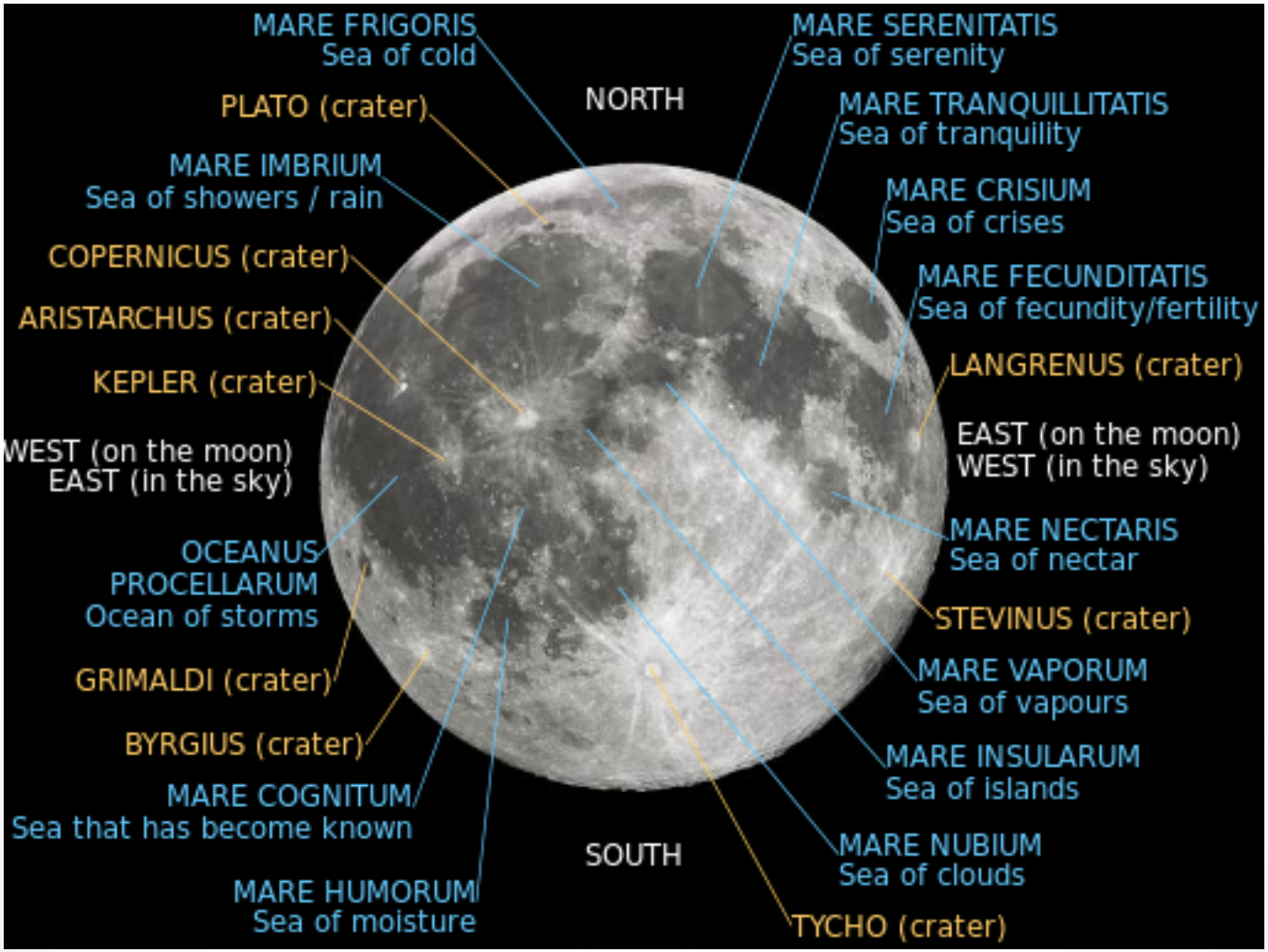


The Moon

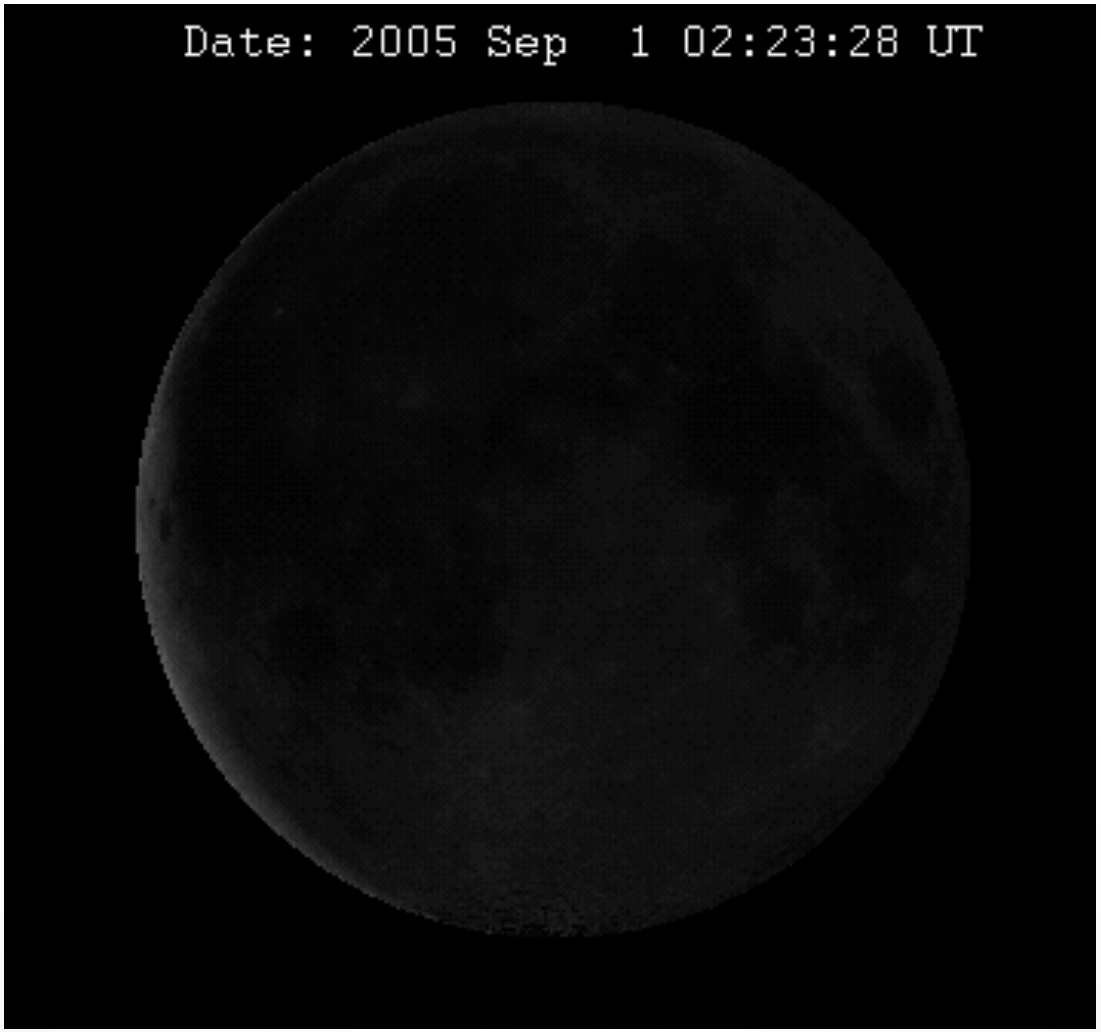
- 384,400km (238,900mi) from the earth on average
  - Tidal torques increase the distance ~3.8 cm/year
  - Same effect increases the length of an Earth day by two milliseconds/century
- Largest satellite relative to host planet in the Solar System



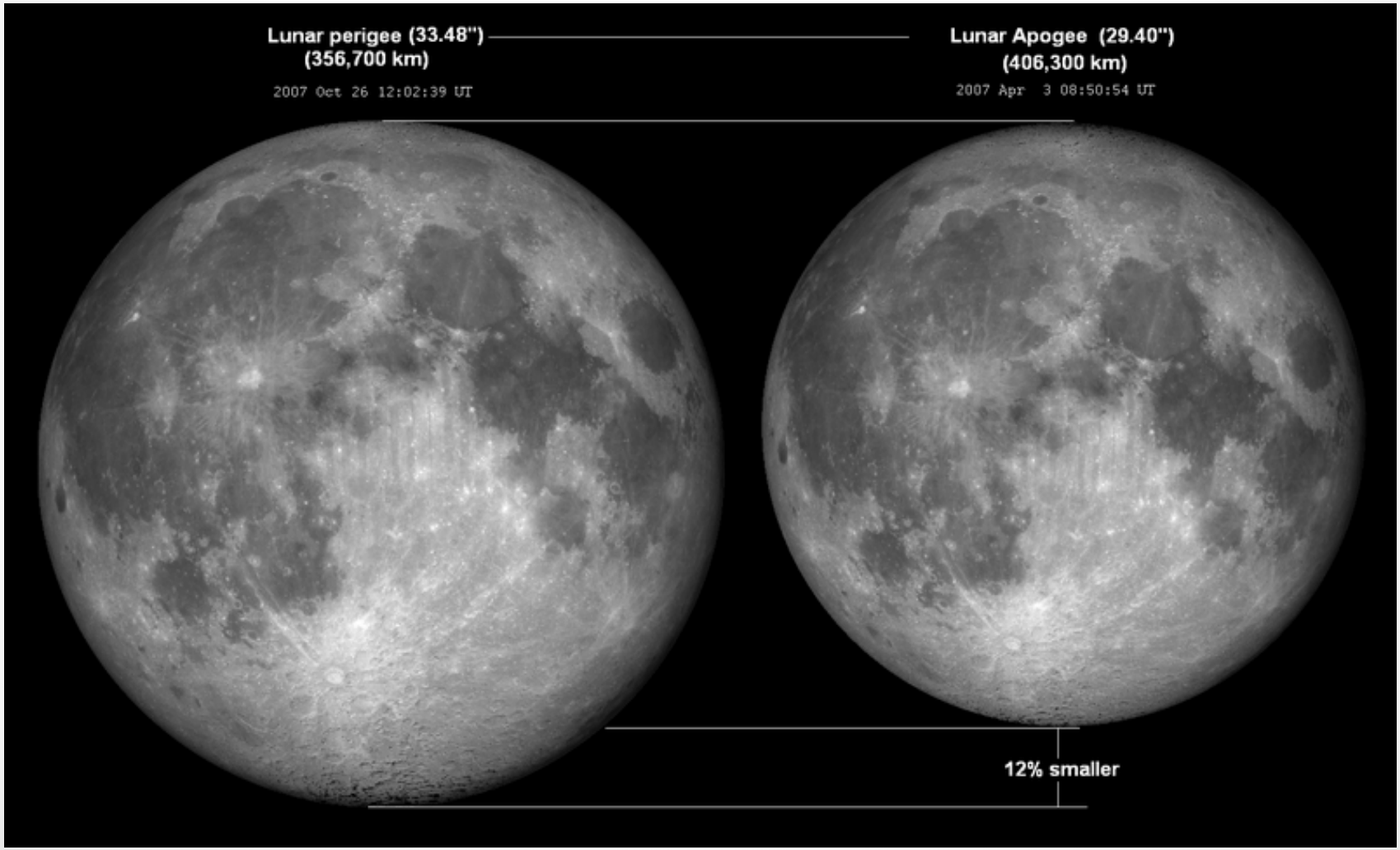
The Moon


MARE FRIGORIS
Sea of cold
MARE SERENITATIS
Sea of serenity
NORTH
PLATO (crater)
MARE TRANQUILLITATIS
Sea of tranquility
MARE IMBRIUM
Sea of showers / rain
MARE CRISIUM
Sea of crises
COPERNICUS (crater)
MARE FECUNDITATIS
Sea of fecundity/fertility
ARISTARCHUS (crater)
LANGRENUS (crater)
KEPLER (crater)
EAST (on the moon)
WEST (in the sky)
WEST (on the moon)
EAST (in the sky)
MARE NECTARIS
Sea of nectar
OCEANUS
PROCELLARUM
Ocean of storms
STEVINUS (crater)
MARE VAPORUM
Sea of vapours
GRIMALDI (crater)
MARE INSULARUM
Sea of islands
BYRGIUS (crater)
MARE COGNITUM
Sea that has become known
MARE NUBIUM
Sea of clouds
SOUTH
MARE HUMORUM
Sea of moisture
TYCHO (crater)

Lunar libration



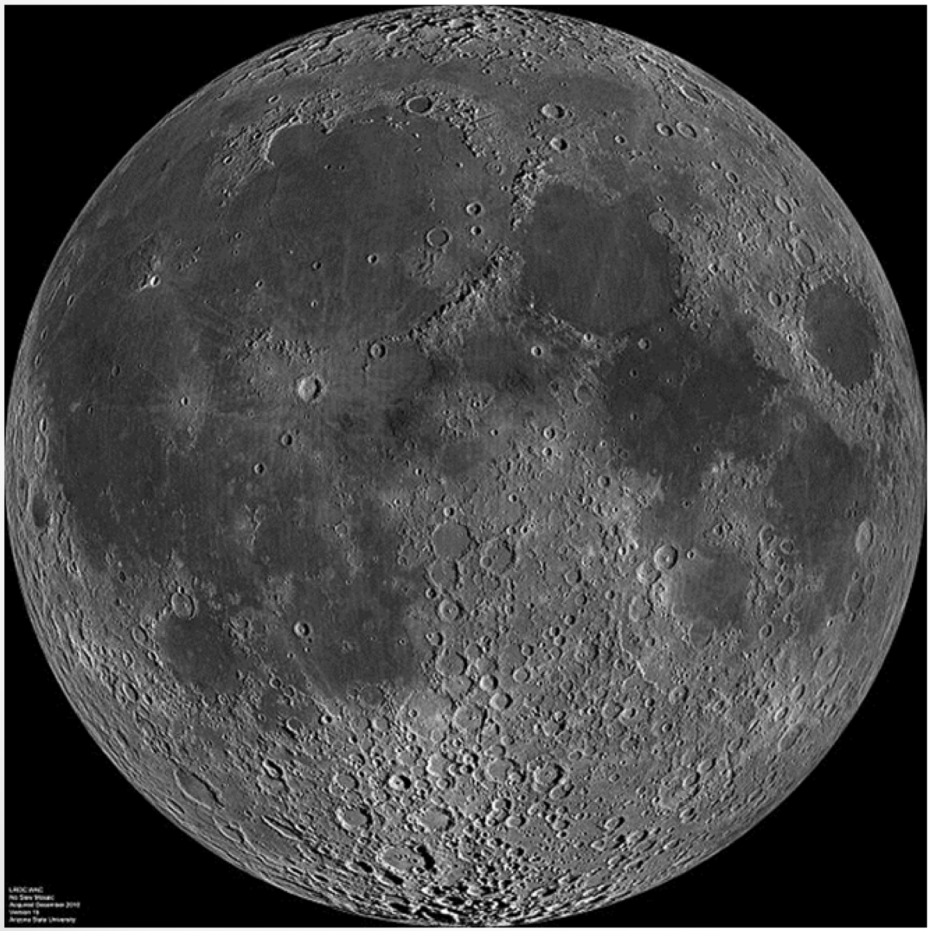
The Moon: Elliptical Orbit

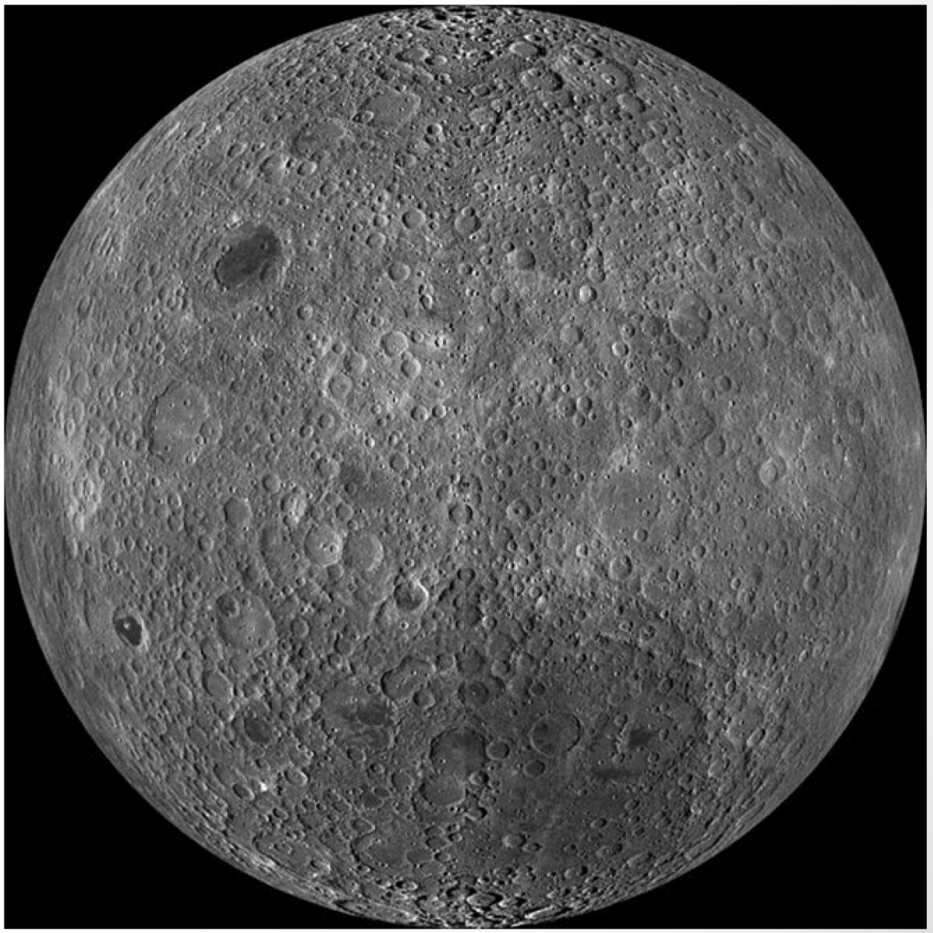


There is no dark side of the moon!

- Moon is "tidally locked" to the Earth and always shows the same face to us.

Near and Far sides of the Moon





Old surfaces in the SS

The presence of many craters on the Moon is the result of two things

- No major resurfacing via volcanism since early days of the Solar System when meteorite rates were much higher
- No atmosphere to enable surface weathering
- "Mare" (mare=sea) regions are the result of resurfacing around 3.5 billion years ago when large impacts cracked through the crust and molten materials flowed to surface. The majority of the impacts on the moon happened in the first 1 billion years of its existence (SS event at 3.85B years ago)
- Near and far side difference likely due to difference in the crust thickness although reason for this not well understood

Clicker Quiz!

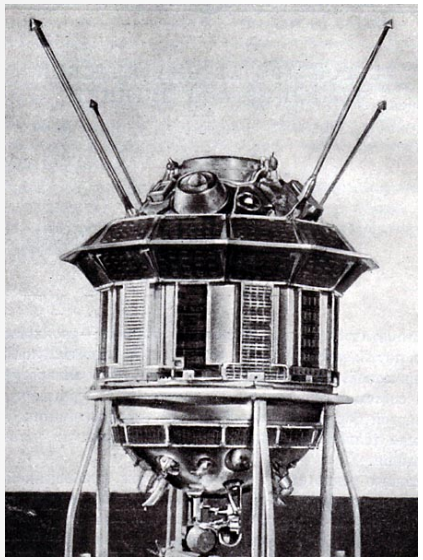
- Which body has had more large meteorite impacts over the history of the Solar System and why?

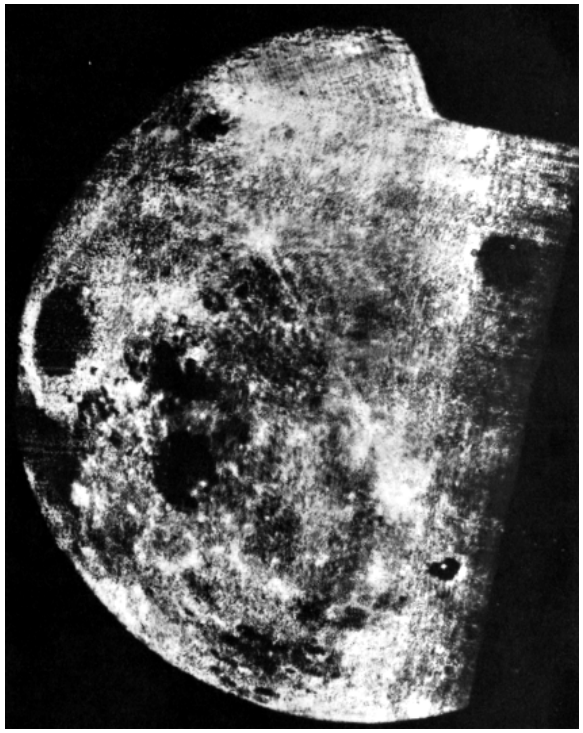
A. The Moon because it has no atmosphere
B. The Moon because is has no volcanoes or tectonic plates
C. The Earth because it has a larger surface area than the Moon
D. The Earth because it shields the Moon from impacts

The Moon: Visits

- 1958 several attempts to send spacecraft to the moon failed (typically blew up on launch)
- Finally, Soviet Luna 1 launched January 1959 successfully left Earth but missed the moon!
- Next one, Luna 2 crashed on the moon Sept 1959
- Luna 3 orbited the moon and saw the far side for the first time in October 1959. Sent photos back
- Series ran through Luna 24 (1976) and included rovers and sample/return missions
- United States dominated manned missions
  - 1968 orbit and return
  - 1969 landing and golfing (Apollo 11)

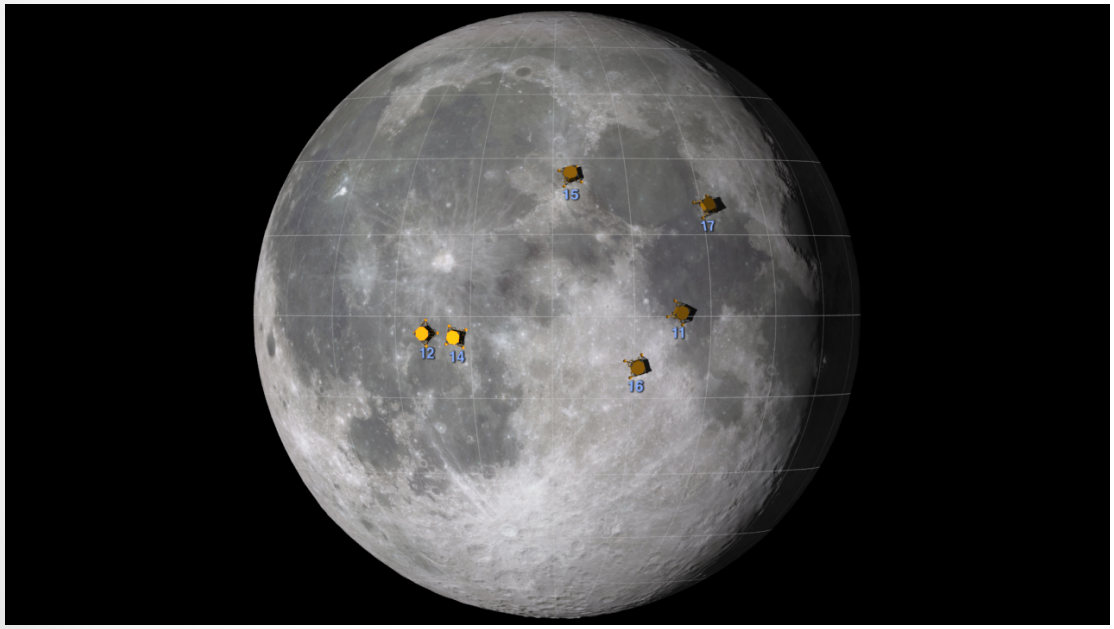
The Moon





Luna 3, first image of the far side of the moon, Neil Armstrong on the moon

Manned Program



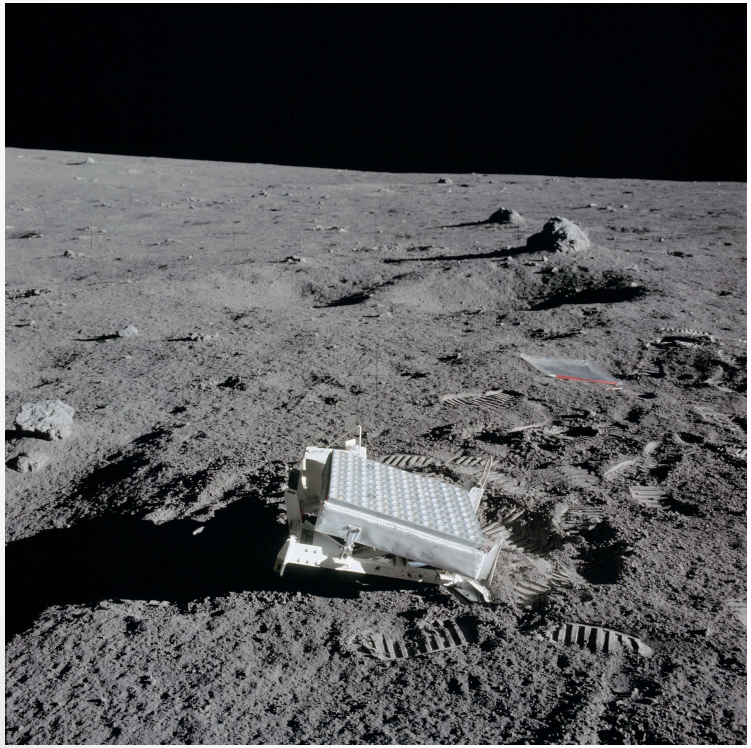
Apollo 11,12,14,15,16,17 resulted in 12 people walking on the Moon

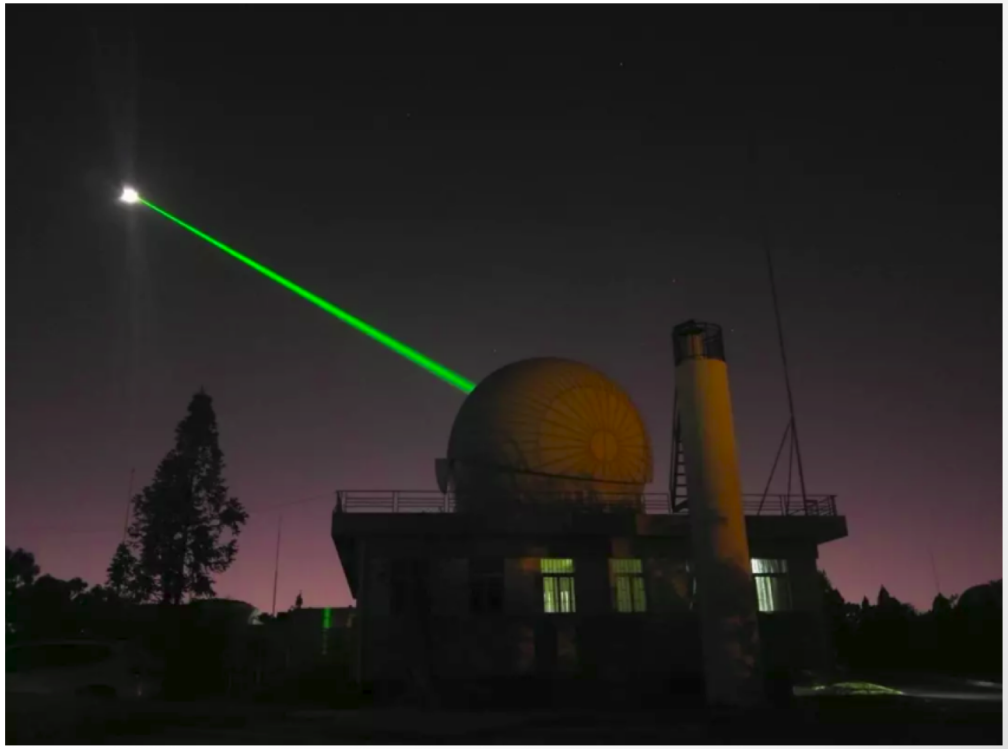
No one has been there since Dec 13, 1972

One reason we know so much about the Moon is the lunar rocks that were brought back sampling highlands, mare and transitional regions

Moon landing and Lick Observatory

- When they landed on the moon in 1969, they put out a "corner cube reflector" to be used for laser ranging experiments.





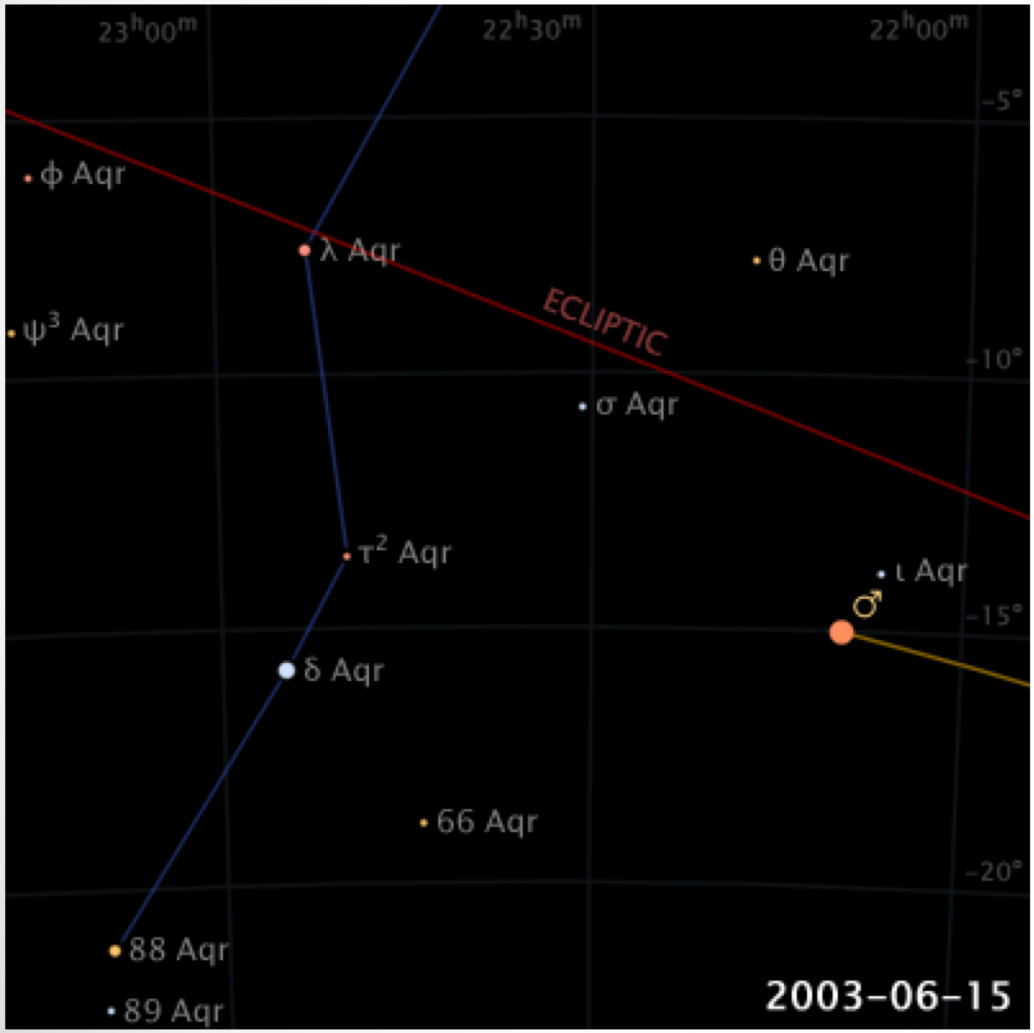
Lunar ranging experiment

The laser was built and operated by Hal Walker.

LURE

- After multiple problems, on August 1, 1969 they had the first successful return of a laser pulse from the retro-reflector on the moon to the Lick Observatory 3-meter telescope
- Measured the distance to the moon to around 25cm accuracy (with additional observations to around 3cm)
- Provided one piece of hard evidence that people really visited the moon!

The Planets

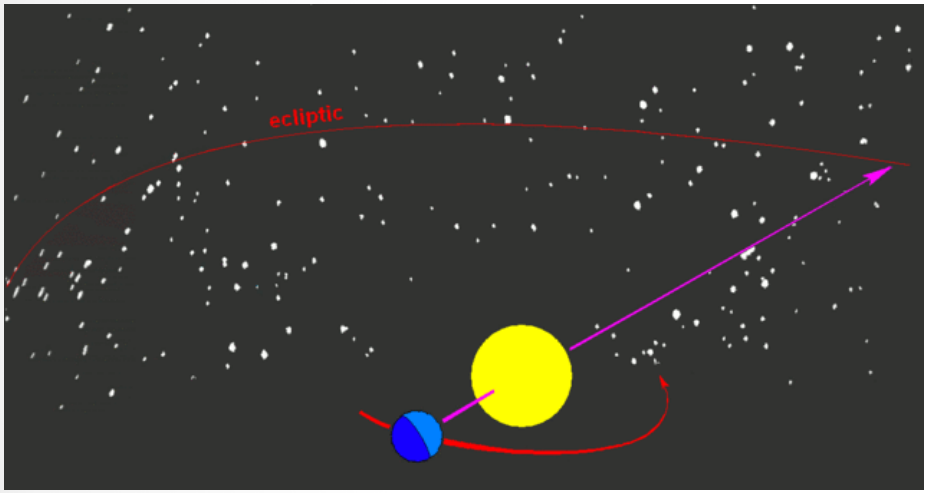


Planets first recognized as "wanderers" against field of stars

Within the context that the Earth was the center of everything in the Universe, the explanation for the planet retrograde motion was a complicated "epicycle" model

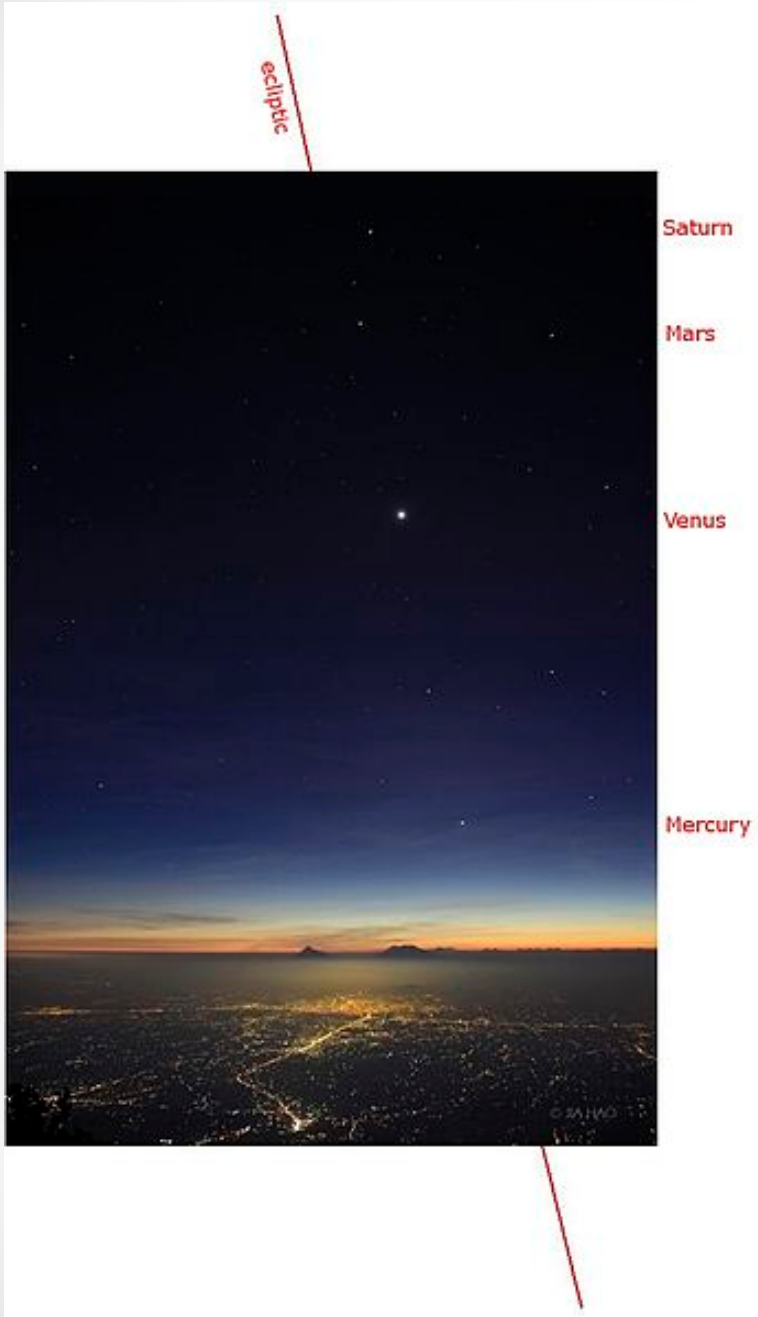
The ecliptic is the plane of the planets' orbits: projected as a line on the sky that the planets never fall far from.

Ecliptic



The line between the Earth and Sun through the year traces out a line on the sky called the ecliptic.

The stellar constellations that happen to fall near that line have special, but meaningless significance to some: the constellations of the zodiac



Because the other planets have orbits in close to the same plane as the Earth's orbit, they never are seen very far from the ecliptic

Geocentric Model

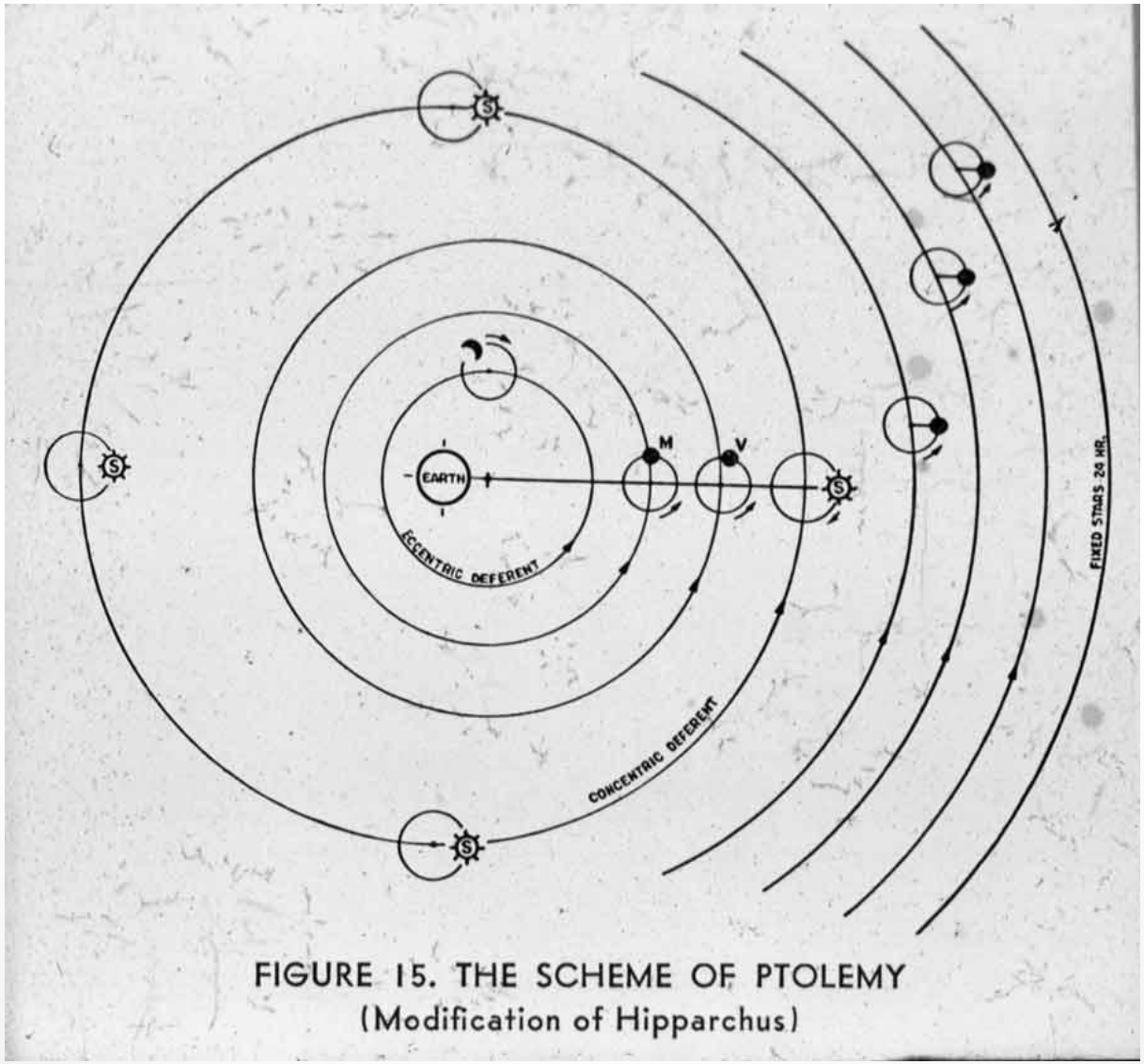
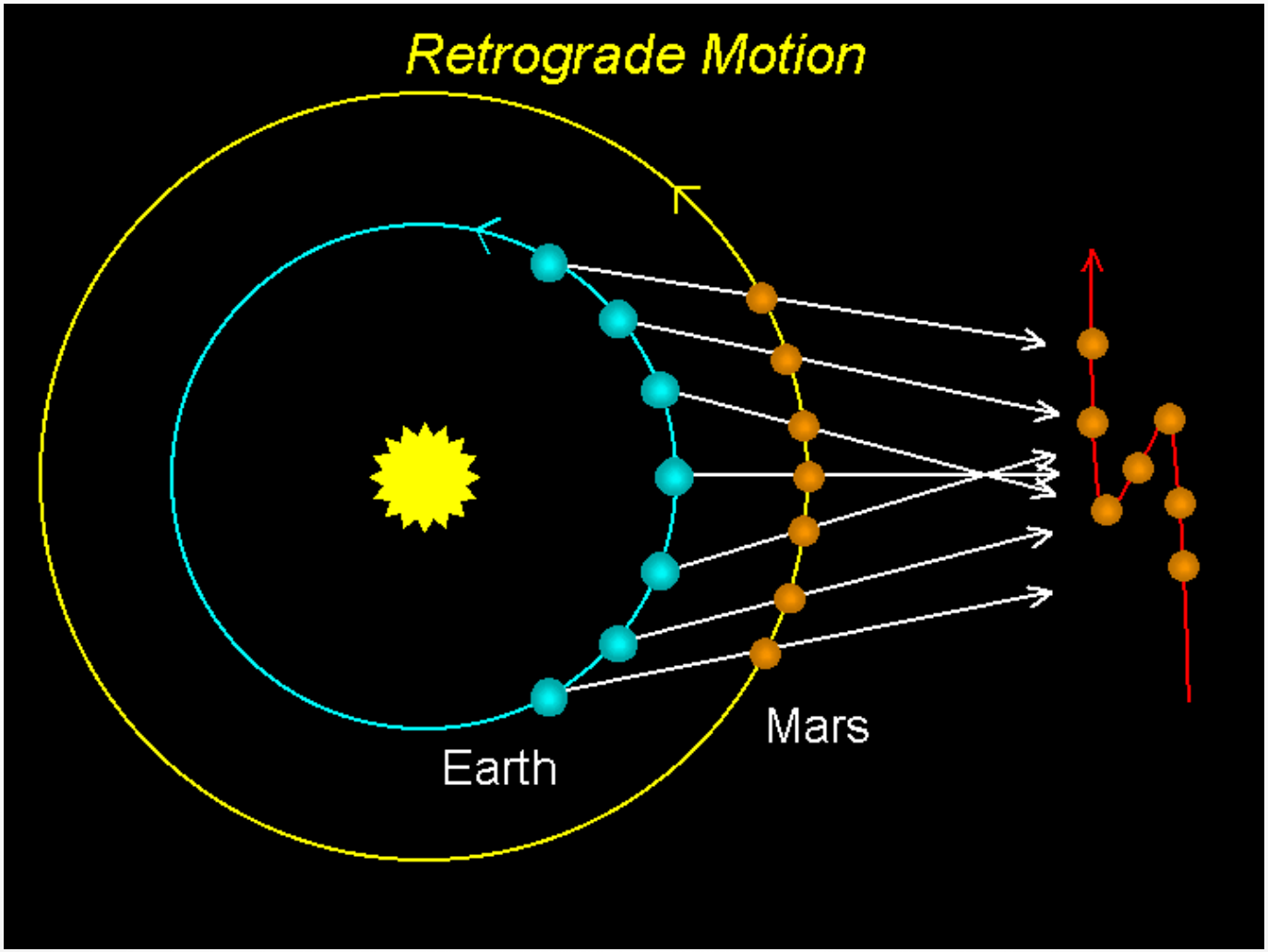
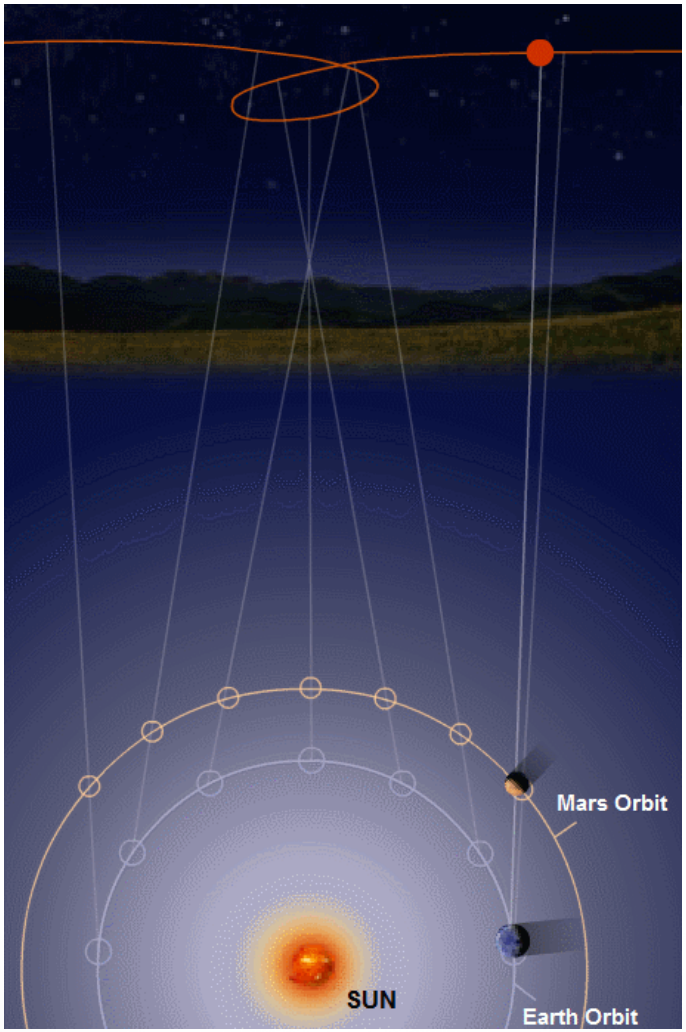


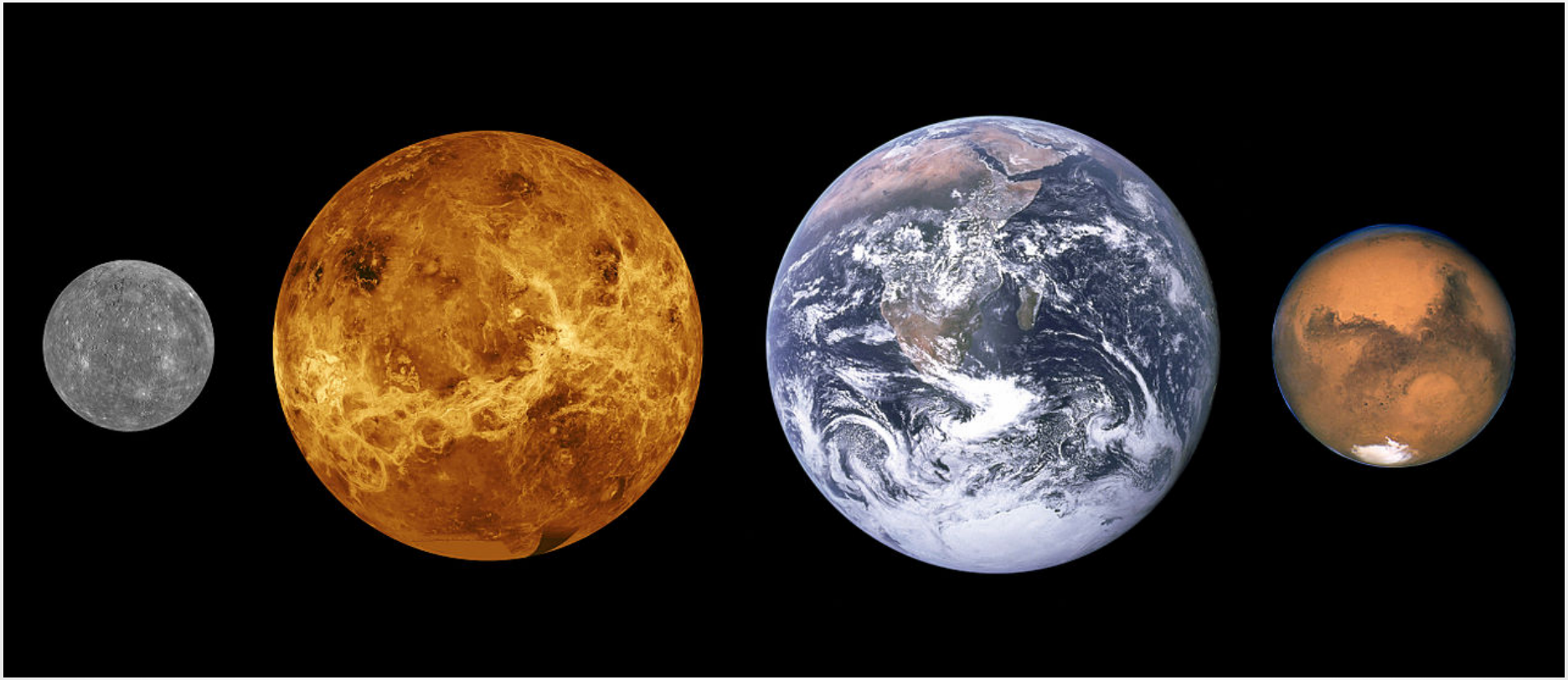
FIGURE 15. THE SCHEME OF PTOLEMY
(Modification of Hipparchus)

Planet motion in Heliocentric Model



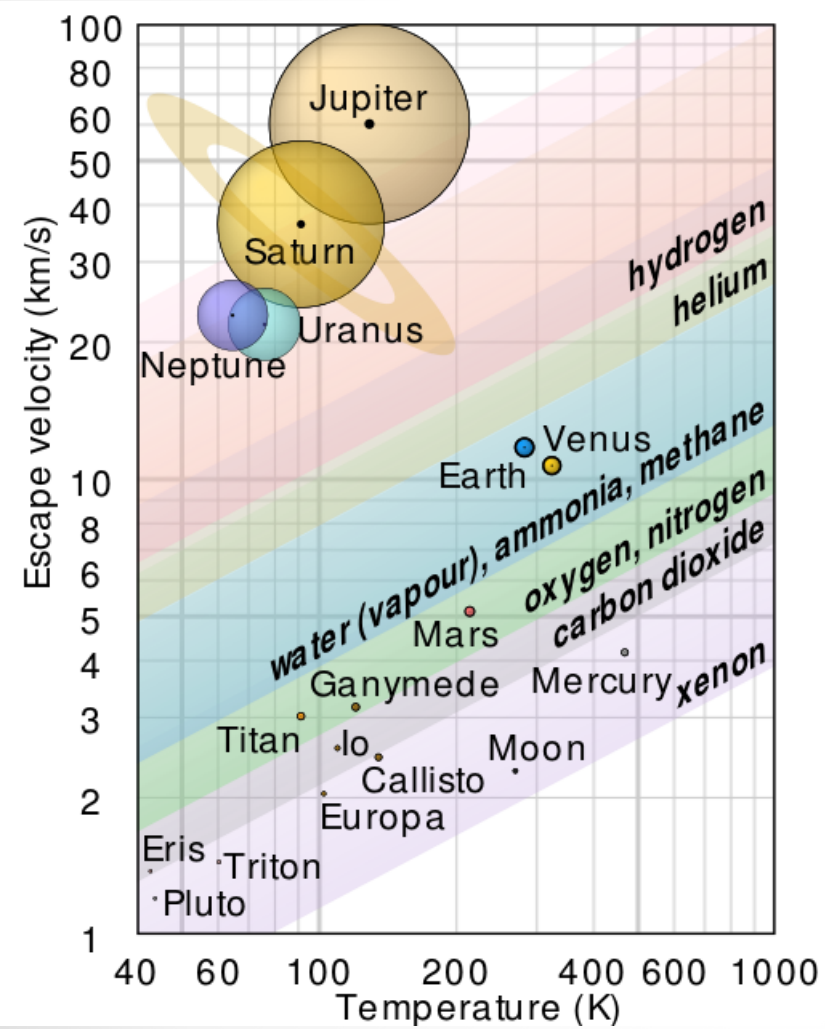

Mars Orbit
SUN
Earth Orbit

The "Rocky" Planets



Inner Planets

- The rocky (sometimes called terrestrial) planets are composed of a metallic core (mostly iron) and a silicate crust.
- Density is ~5 g/cm^3 for the four rocky planets
- Solid surfaces of different ages
- Formed in the early solar system in the inner region where temperatures were too high for water, methane and other volatiles to be stable

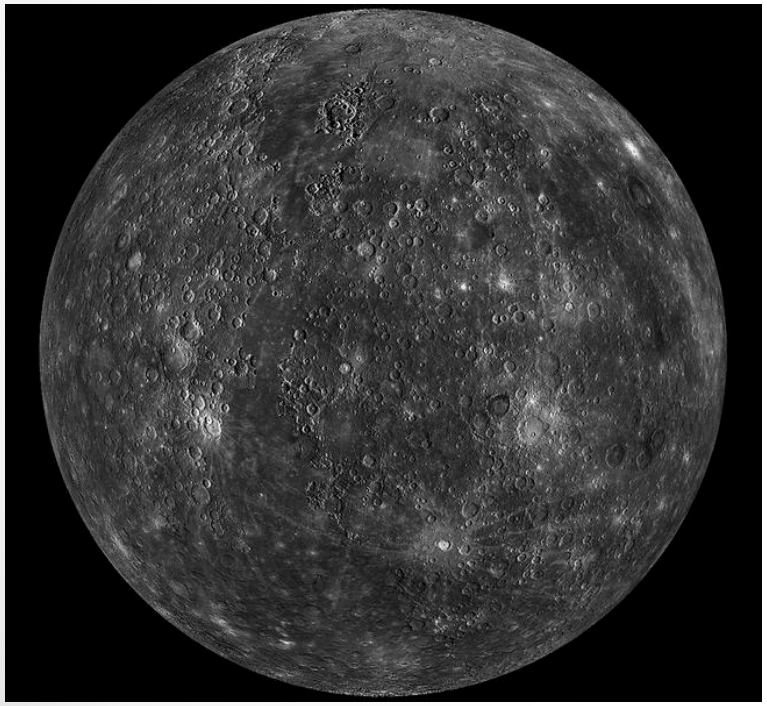


The inner planets have relatively low mass and low escape velocity

The equilibrium temperature and average velocity of light elements is such that these elements escape into space: no hydrogen and helium in the Earth's atmosphere

The gas and ice giants have a high enough mass and escape velocity to retain Hydrogen and Helium

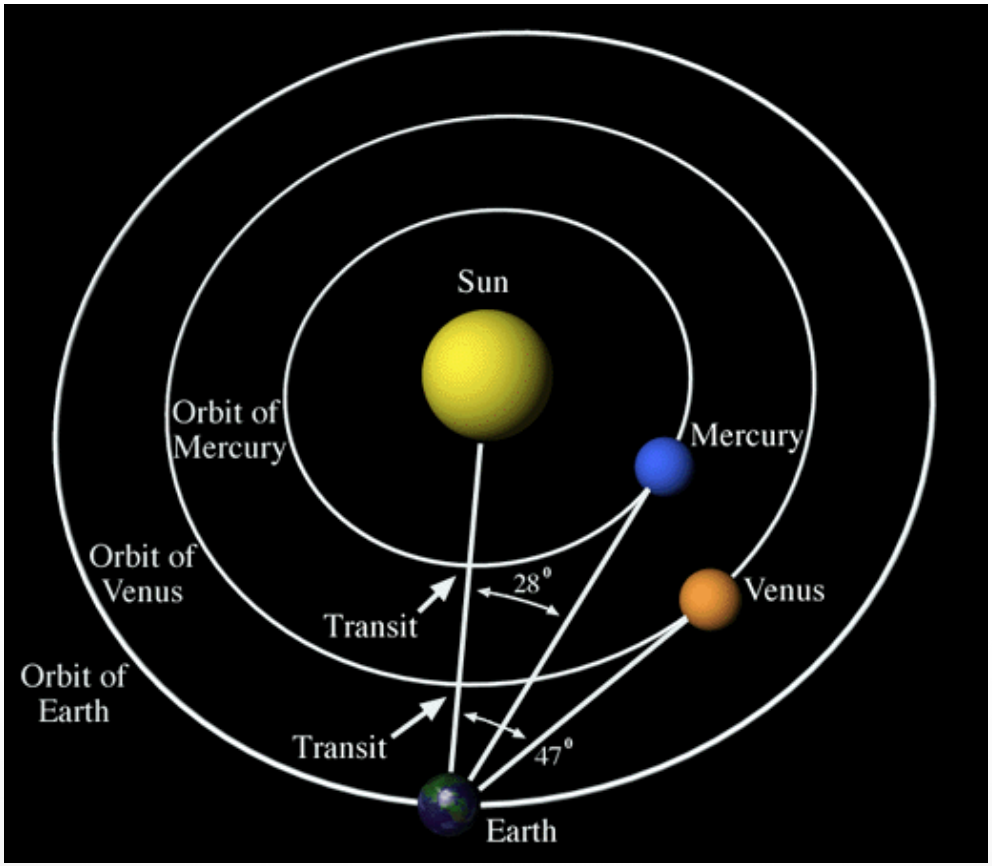
Mercury



- Orbit is 0.4 Astronomical Units in radius
- Mass is 5.5% that of Earth
- Orbital period is 88 days
- Three rotational periods per orbit
- No atmosphere but bits constantly being blasted off by solar radiation and meteors
  - Lack of atmosphere explains caters
  - No atmosphere means huge temperature extremes
- Surface temp: -173C (-279F) to 427C (801F)

Mercury II

- From Earth, Mercury is always in the twilight zone close to the Sun. With in hour of sunset or sunrise

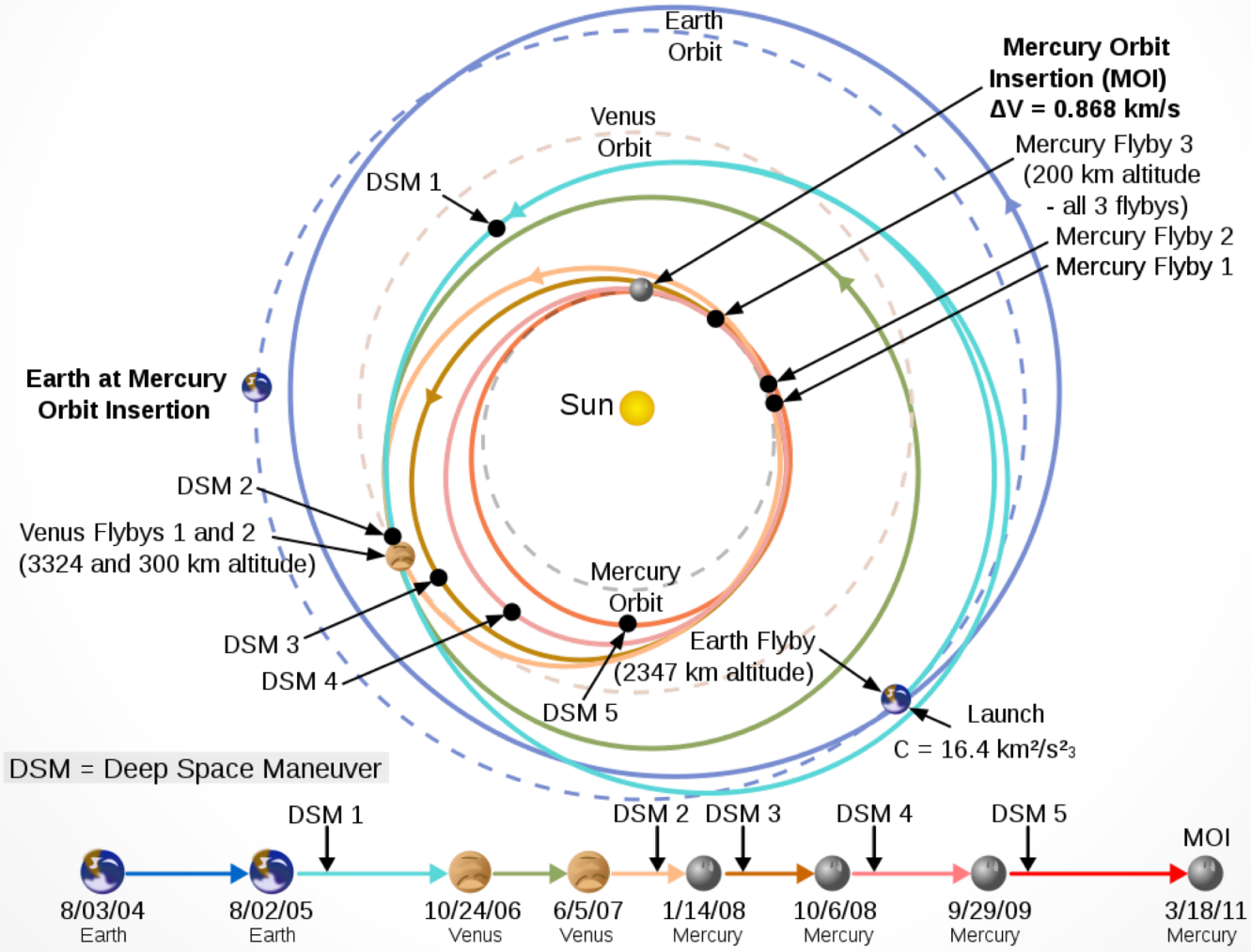


Mercury visibility

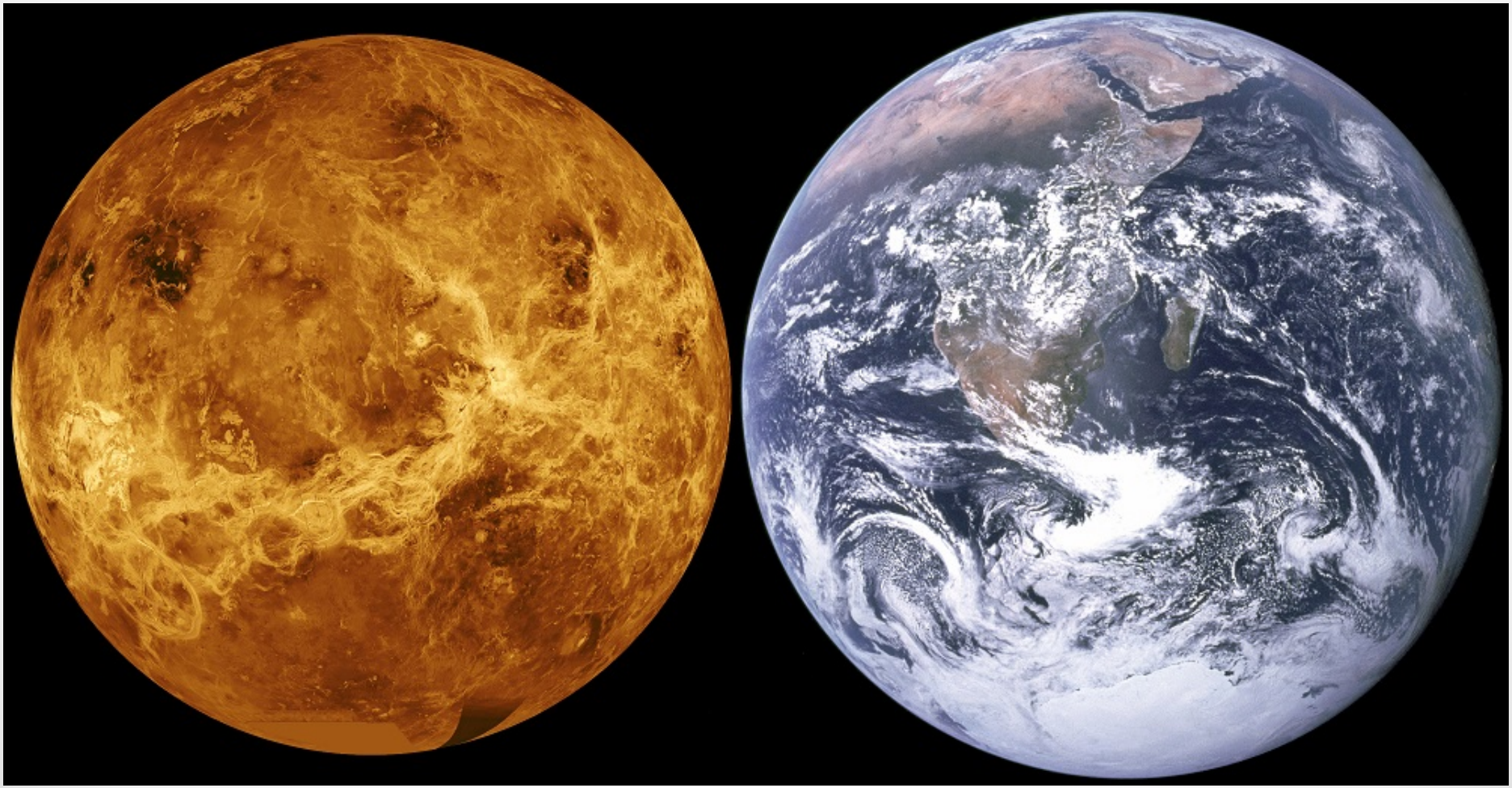
January 2016 you could see all five naked-eye planets in the sky at the same time. Right now Jupiter and Saturn high in the sky, Mercury and Venus very low at sunset, with crescent moon for the next week

What's in the sky?

Two visits: Mariner 10 (1973) and Messenger



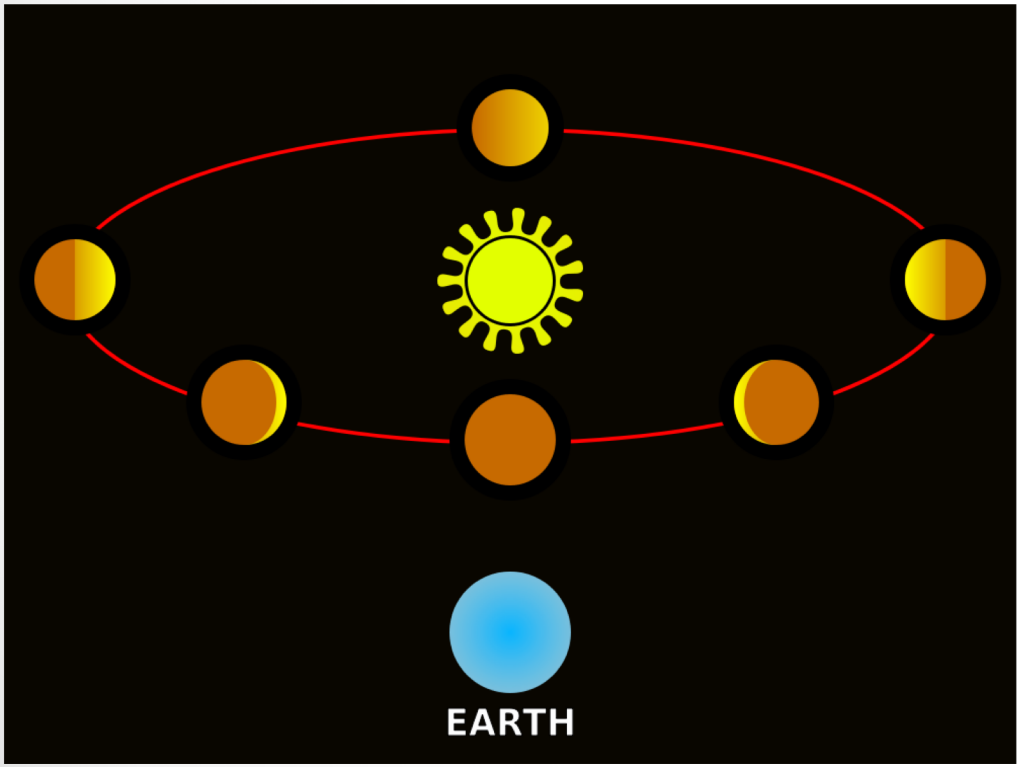
Venus



Venus

- Just a little smaller in radius than Earth
- 0.7 Astronomical Units in orbit radius
- Orbit is 225 Earth days (Venus year)
- Rotation is 243 Earth days (Venus day) and in toward the East ("backwards"): Sun rises in the west
- Very extensive atmosphere of CO_2, N_2 and sulfuric acid
- It is hot! Runaway greenhouse effect boiled oceans into atmosphere (ahem…)
- Surface temperature: 462C (870F: melts lead)
- Atmospheric Pressure: 90x Earth

Phases of Venus



Because of its position interior to the Earth's orbit:

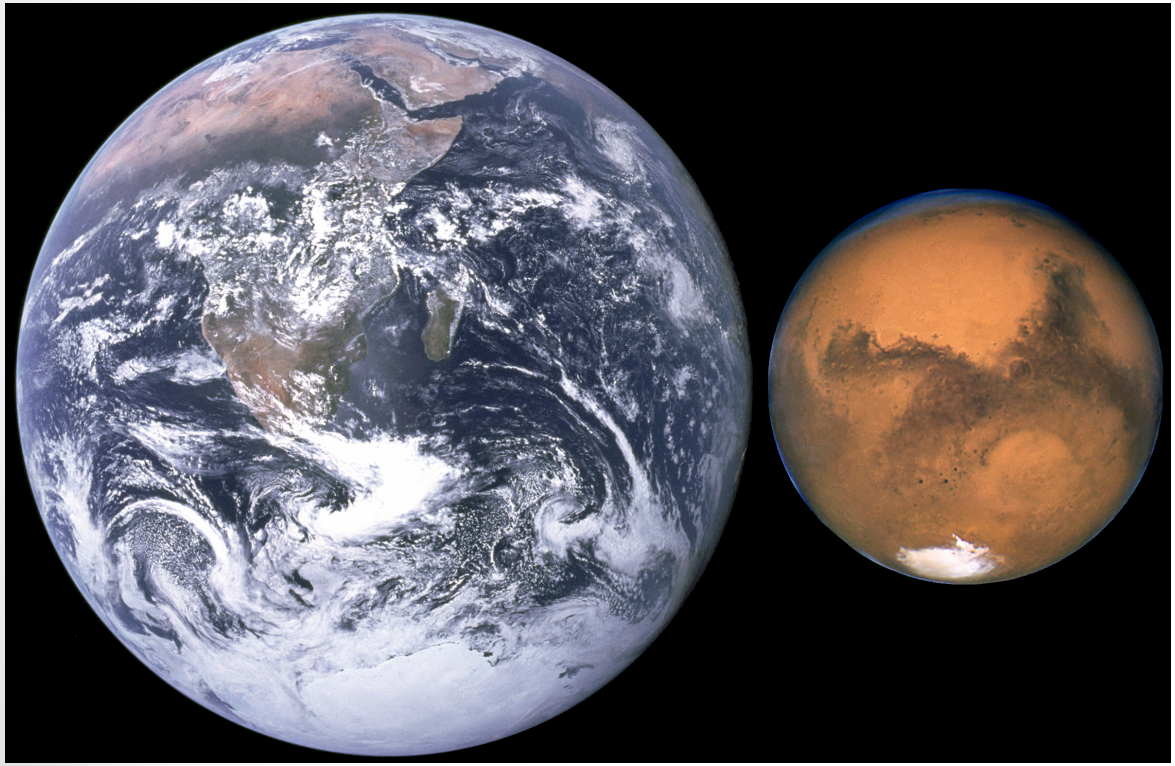
- Venus shows different phases (though never in the "full" phase)
- This was one of the most compelling evidences for the heliocentric model of the Solar System
- Venus is never more than 47° from the Sun: "morning" and "evening" star

Venus visits

- Lots of missions to Venus. The extreme cold cover makes it difficult to study the surface without sending spacecraft there
- Also possible to probe the surface topography with radar from Earth

- Venus Mission List

Mars

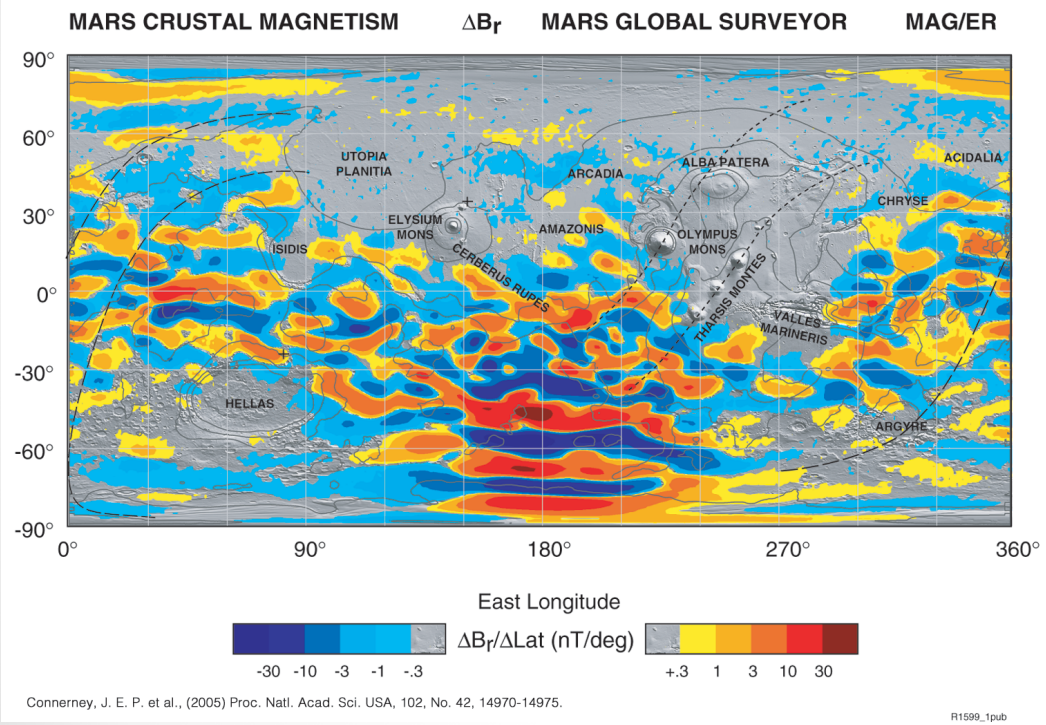


- 4th planet from the Sun
- Orbit Radius: 1.5AU
- Mars Year: 687 days
- Mars Day: 1 E-Day 40min
- Rotation tilt wrt orbit: 25˚
- Two moons

Mars: Atmosphere

- Martian atmosphere is very thin: <1% of atmospheric pressure of Earth at surface
- Composition is primarily CO_2
- The low atmospheric pressure means that liquid water can not exist on the Mars surface
- Evidence from minerals and surface features suggest that Mars once did support liquid water
- "Ice" caps at the poles in the winter are mostly water ice and some CO_2 ice. They sublime away in the summer
- Winter temps: -143C (-225F) and summer temps: 35C (95F)

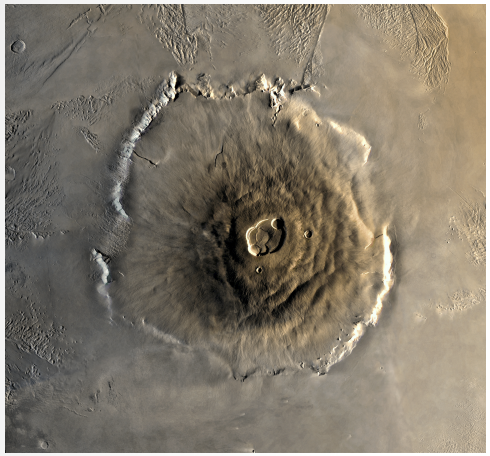
Mars: History



We know a lot about Mars because of the many sample and analyze missions, and orbiters

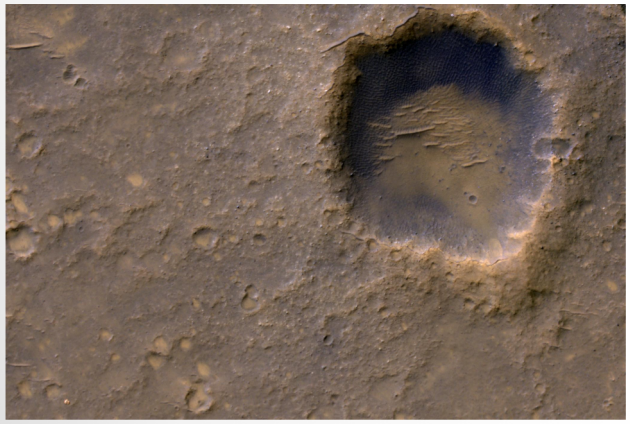
- Early magnetic field and tectonic activity ceased within the first 500 million years
- Loss of magnetic field likely led to of protection from solar wind and loss of Martian atmosphere

Mars: Topography

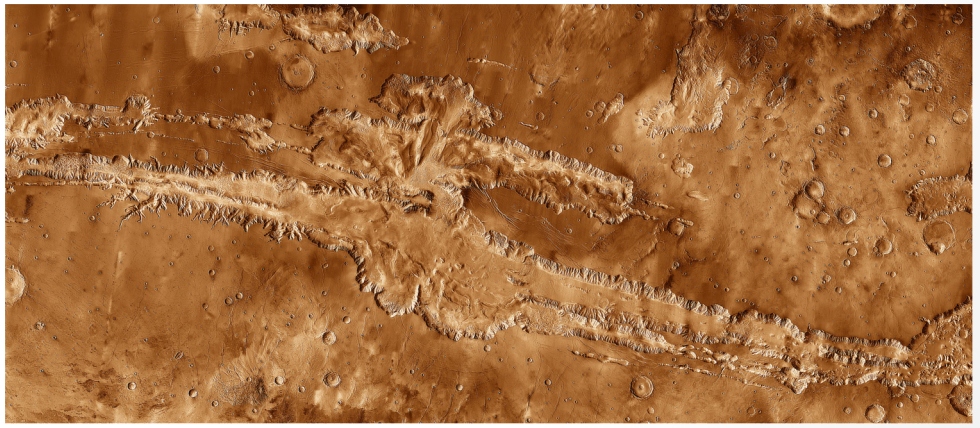


Olympus Mons: shield volcano 3x height of Mt Everest

Fresh impact craters

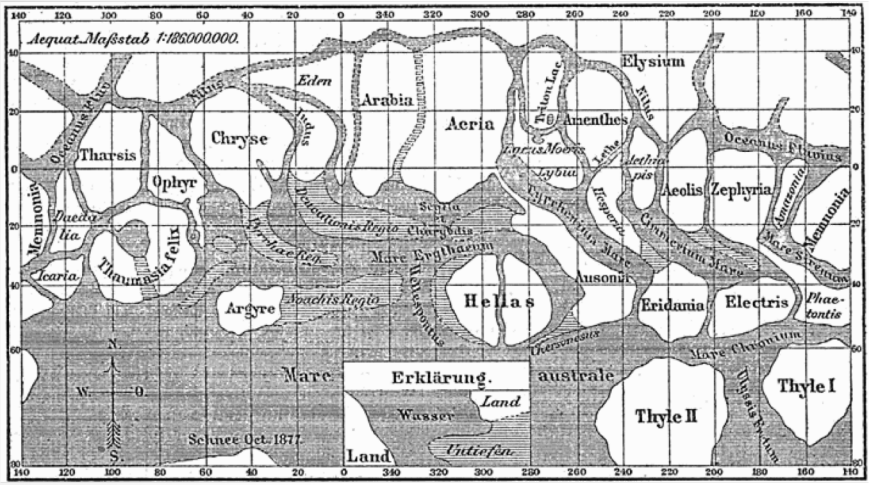


Ancient large impact craters



Mariner Valley: 2500mi collapse or tectonic boundary

Mars canals



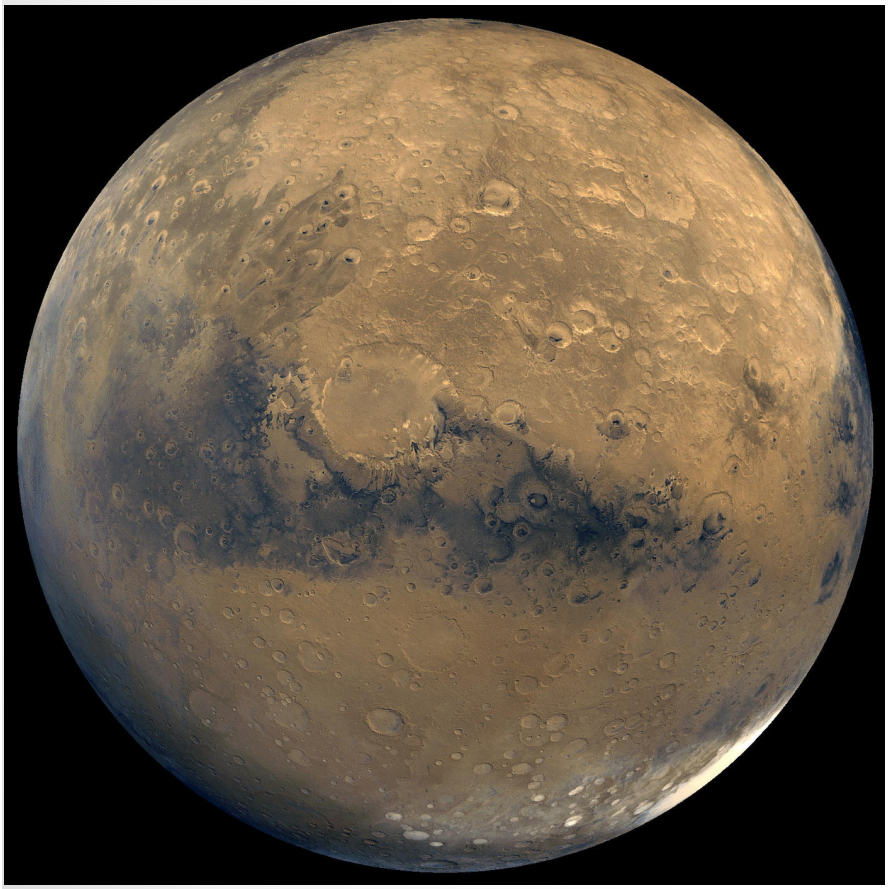
1877 Giovanni Schiaparelli sketched canals on the surface of Mars from telescopic observations

Percival Lowell took this to a whole new level and claimed canals that changed with seasons. His theory was they were built for irrigation by Martians to bring water from the icecaps

Lowell founded an observatory in Flagstaff in 1894 to further the study of Mars

Though the canals were not taken seriously by 1910 by astronomers, Lowell did inspire generations of Scifi writers including Bradberry, Heinlein and Burroughs

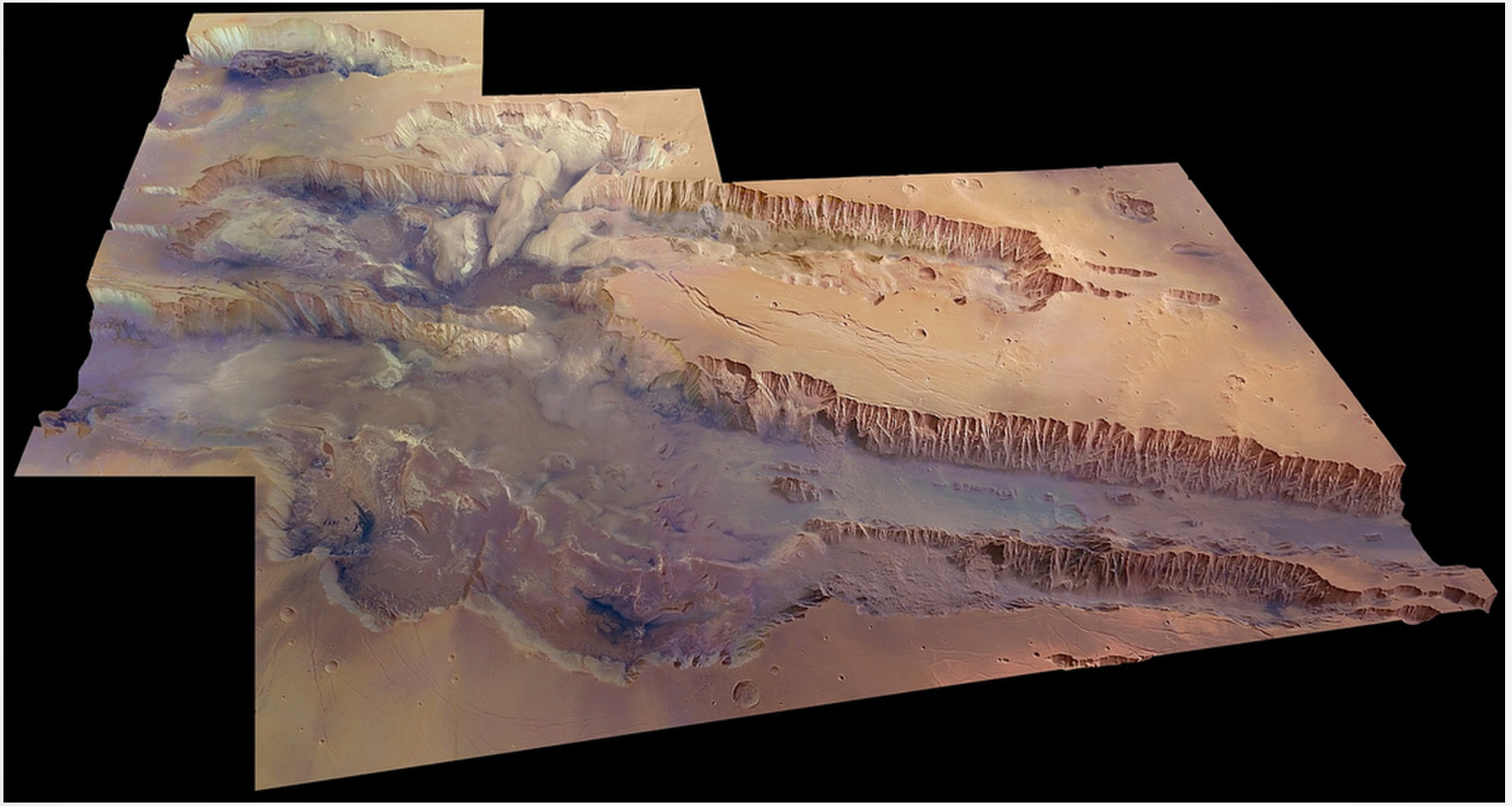
Mars Missions



There have been many Mars orbiters and landing missions

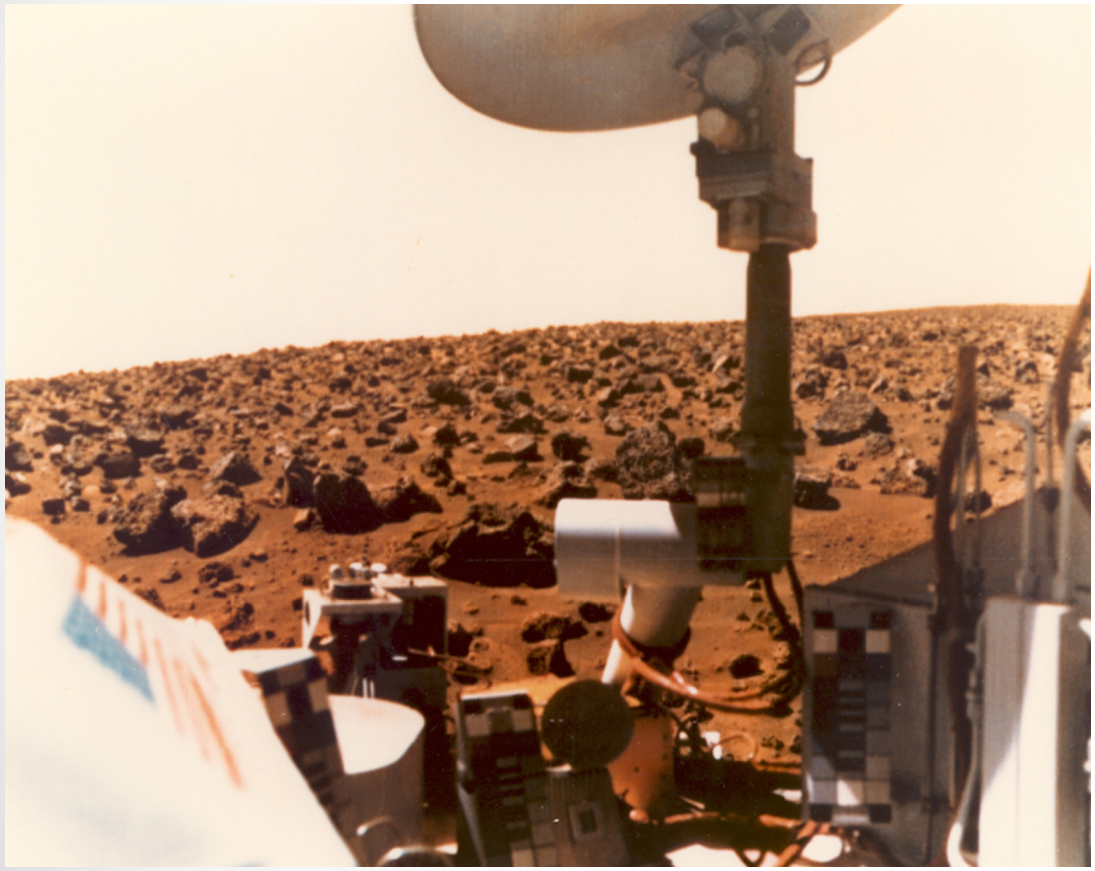
- Soviets had five failed missions in the early 1960s
- Mariner 4-6 made successful flybys and sent back ~100 photos in 1965-1968
- Mariner 9 was the first successful orbiter in 1971 and sent back more than 7000 images over a year

Mariner 9



Dust storms, young surfaces, shield volcanoes, giant deep valleys, landslides and perhaps ancient riverbeds

Viking 1 and 2



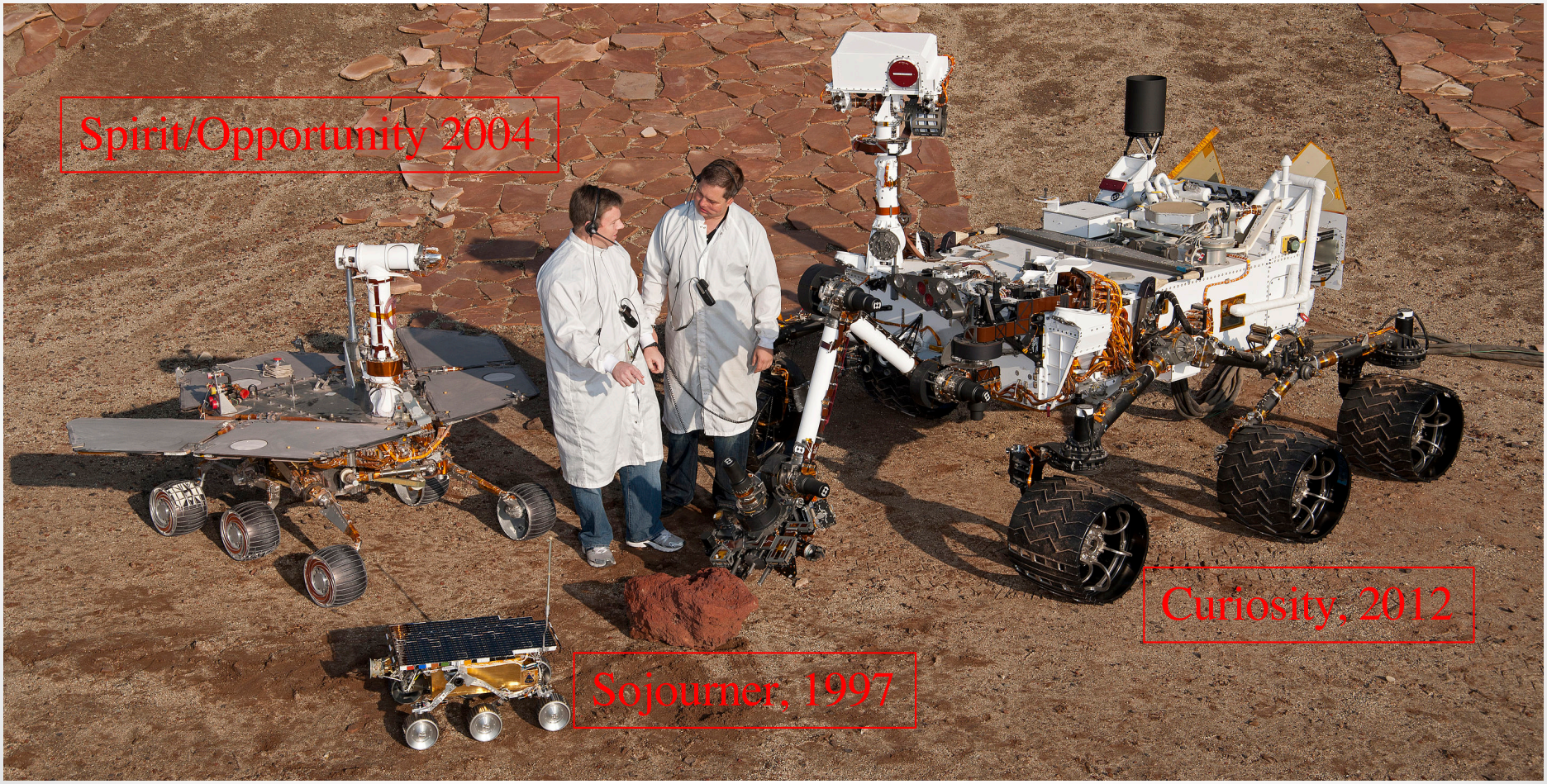
Viking 1 and 2 were combined lander/orbiter missions in 1975/1976

Carried out a number of clever sample and analyze experiments

First tests for biological activity were positive, but turned out to be explainable by other processes

Did demonstrate some unique chemical signatures that show some meteorites on Earth came from Mars

Rovers



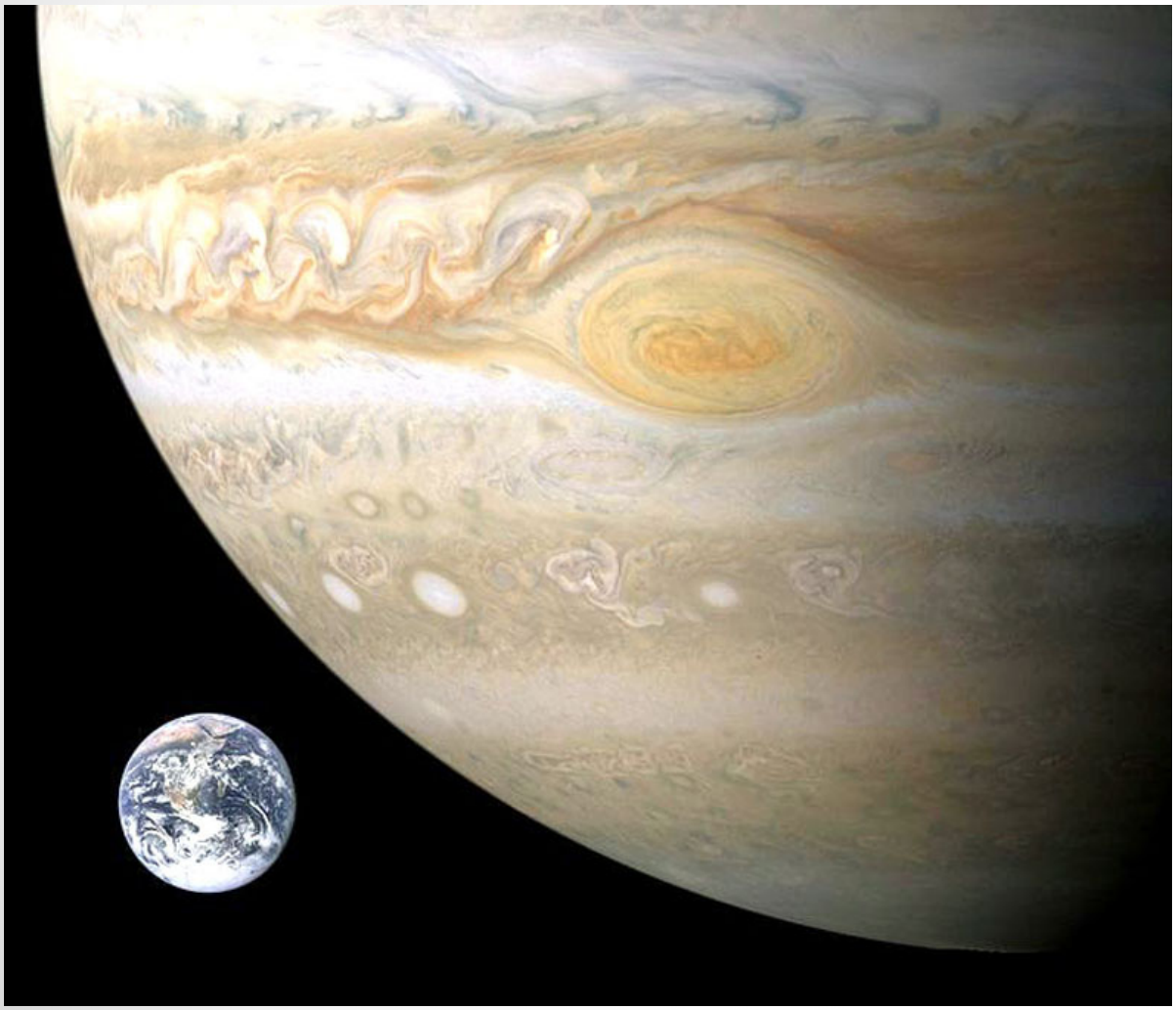
Rovers are very sophisticated: cameras, spectrometers, mass spectrometers, chemistry labs, propulsion, communications, power generation, shovels and laser beams

Mars

It is pretty clear that:

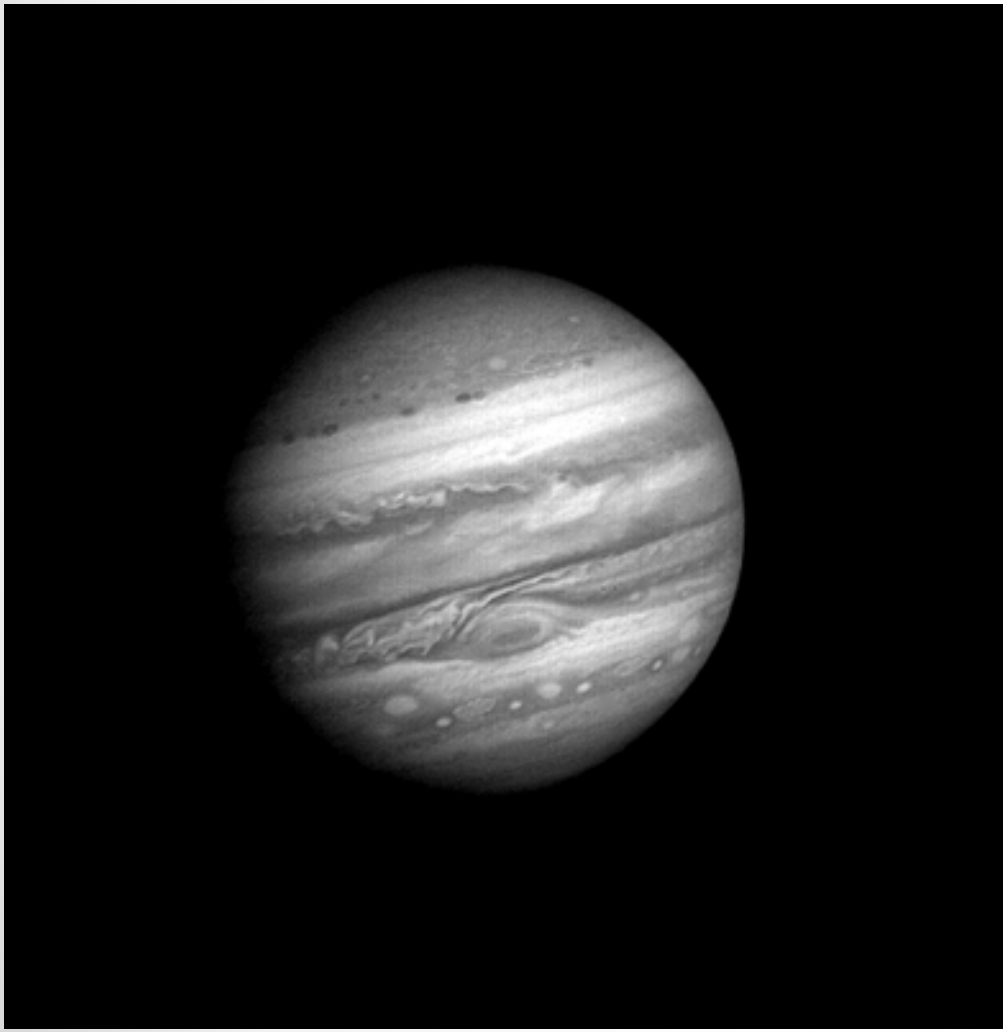
- Mars once had an atmosphere and stronger magnetic field
- Liquid something, likely water, has flowed on the surface in the past
- There is a lot of water on Mars
- No evidence to date for life existing now or in the past on Mars
- One of these centuries, people will visit the planet.
  - Hohmann Transfer Trajectory is 9 months one way

Jupiter



- Largest planet in the SS
- Orbit: 5.2 AU in radius
- Orbit tilt: 3°
- Jovian Day: 10 hours
- Jovian Year: 12 E-Years
- Composition very close to that of the Sun (large escape velocity): mostly H and He
- Powerful magnetic field
- Atmosphere extends deep into the interior to the radius where is blends into a liquid core

Winds and storms



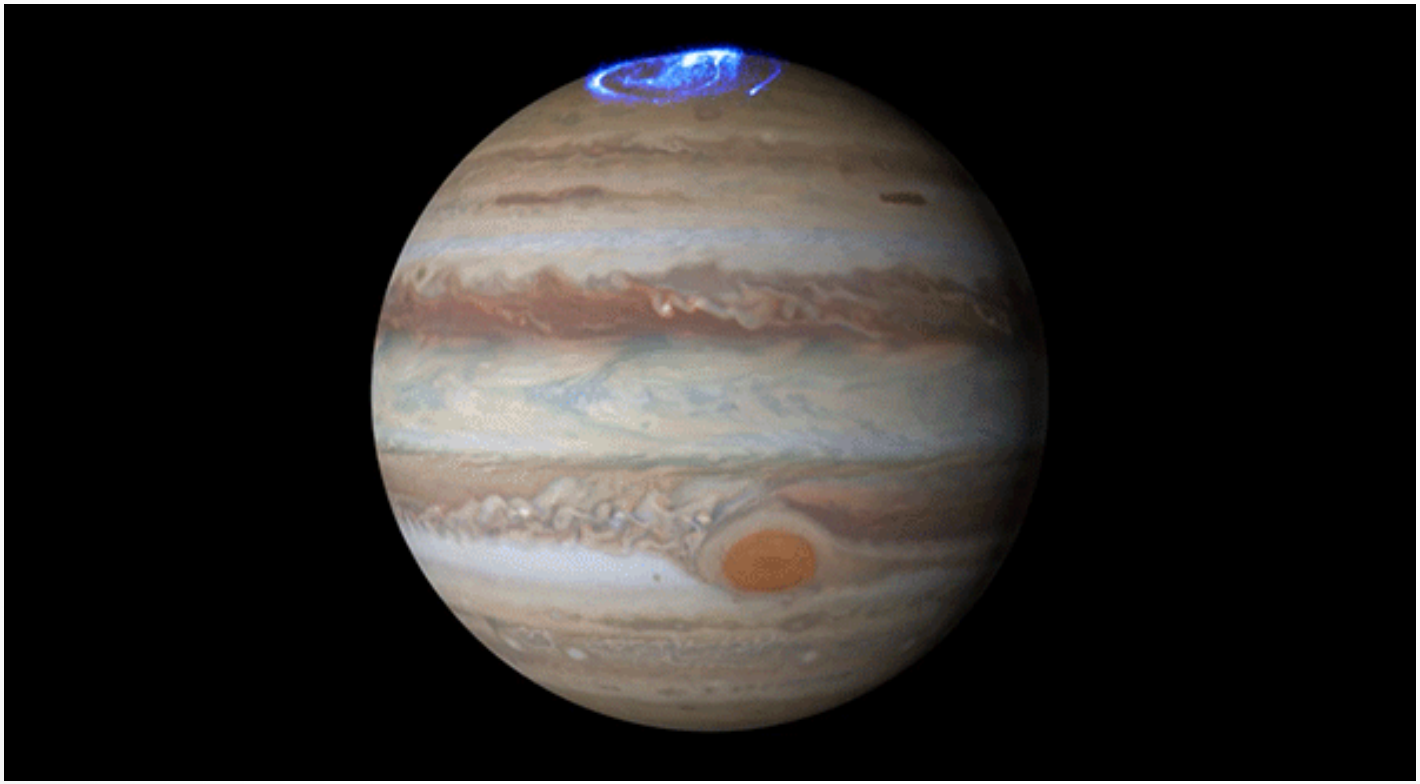
- Jupiter's 10-hour rotation and *internal energy dissipation* lead to lots of surface activity
- The Great Red Spot is a similar to a hurricane on the Earth, but has been as large as 40,000 km in size and has lasted for at least 400 years
- Jet streams have speeds of 500 km/hr
- Three main cloud "decks"
- Ammonia and hydrocarbons give the colors

Jupiter Moons

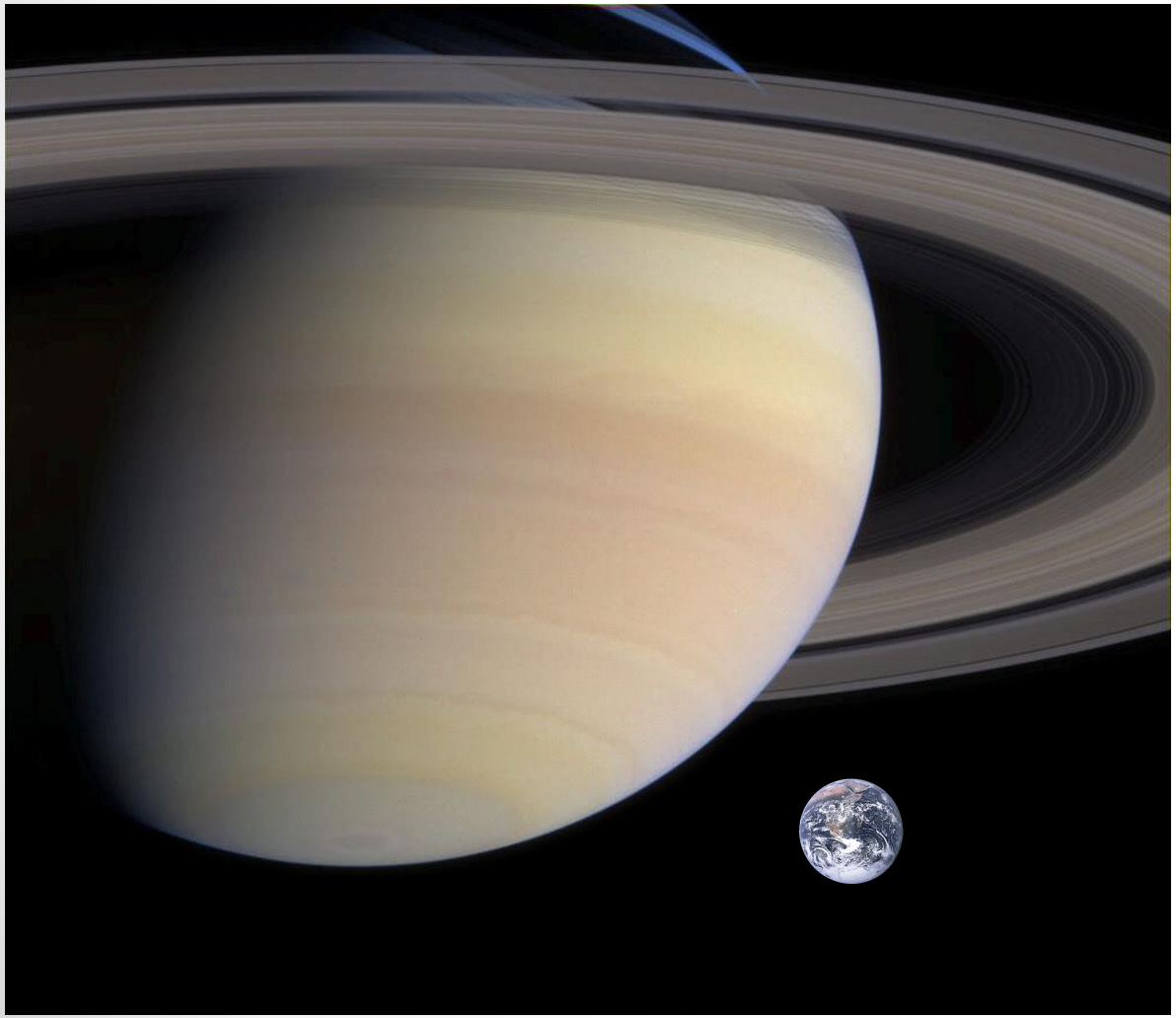
Jupiter has 67 known moons including the four Galilean Moons

Lots of interesting science and properties including Io that is tidally heated and has ~400 active volcanoes

Jupiter Aurora



Saturn

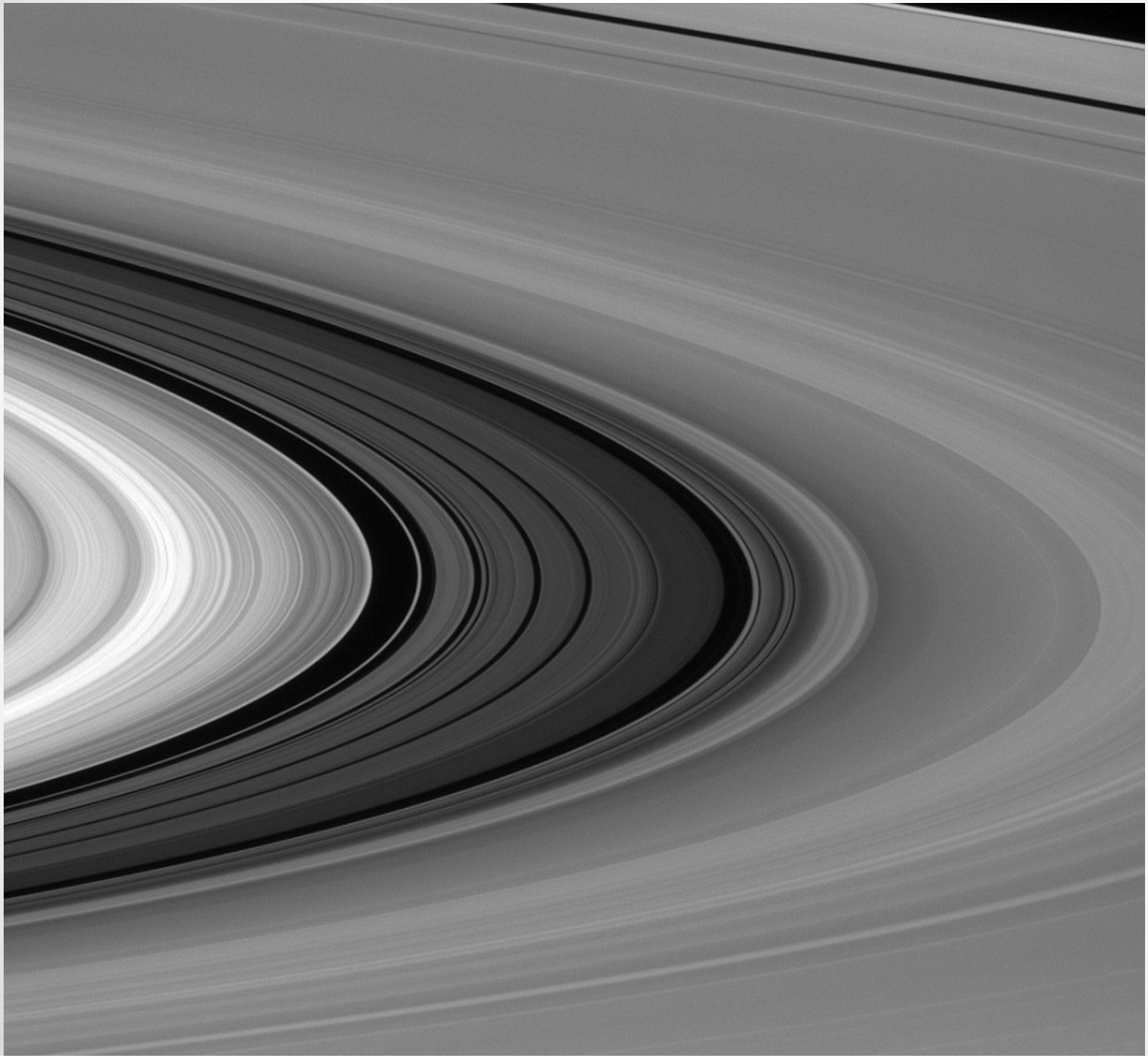


- Orbit radius: 9.5AU
- Orbit period: 29.5 E-years
- Orbital tilt: 26°
- Saturn Day: 10.5 hours
- Saturn claim to fame: fabulously beautiful rings
- Mean density: 0.7 gm/cm^3

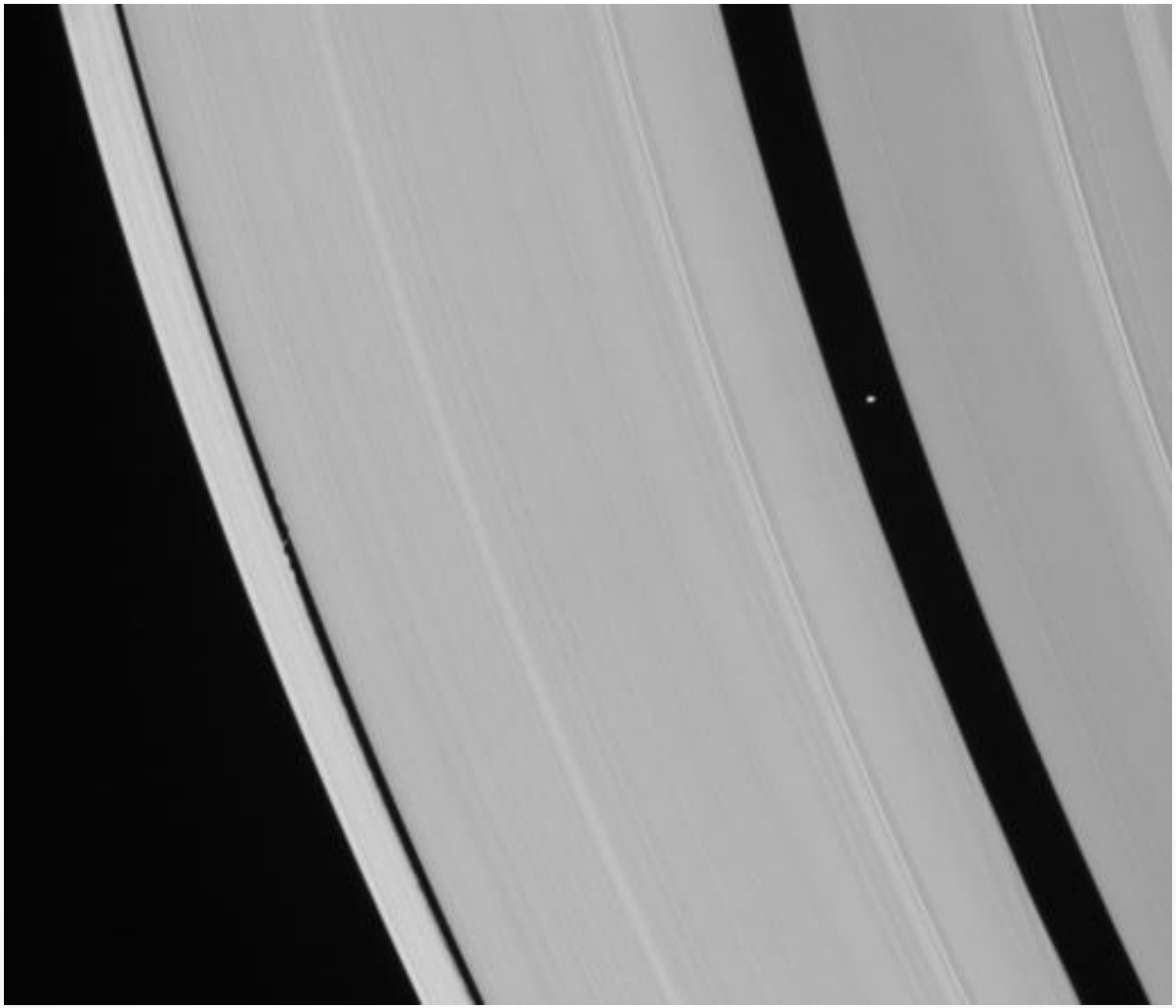
Saturn's Rings

- Saturn's rings number ~700 and span ~400,000m (240,000 miles) in radius
- The thickness ranges from 10m to 1km (!!)
- Composition is icy bodies from a few microns in size to the size of a bus
- Likely a large moon that was tidally disrupted or a large moon that did not form because of tidal forces
- The orientation of the rings change as seen from the Earth through the Saturn year
- May be temporary


Saturn Observations/ 2004 - 2009
Alan Friedman/ www.avertedimagination.com

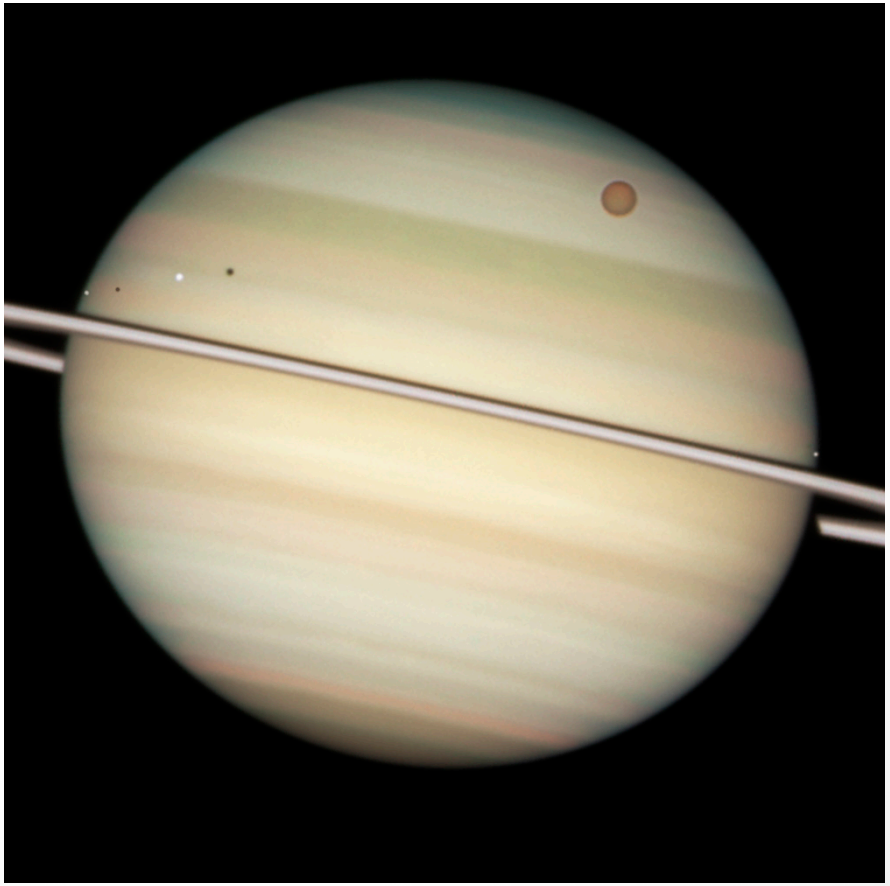


Ring gaps maintained by moonlets



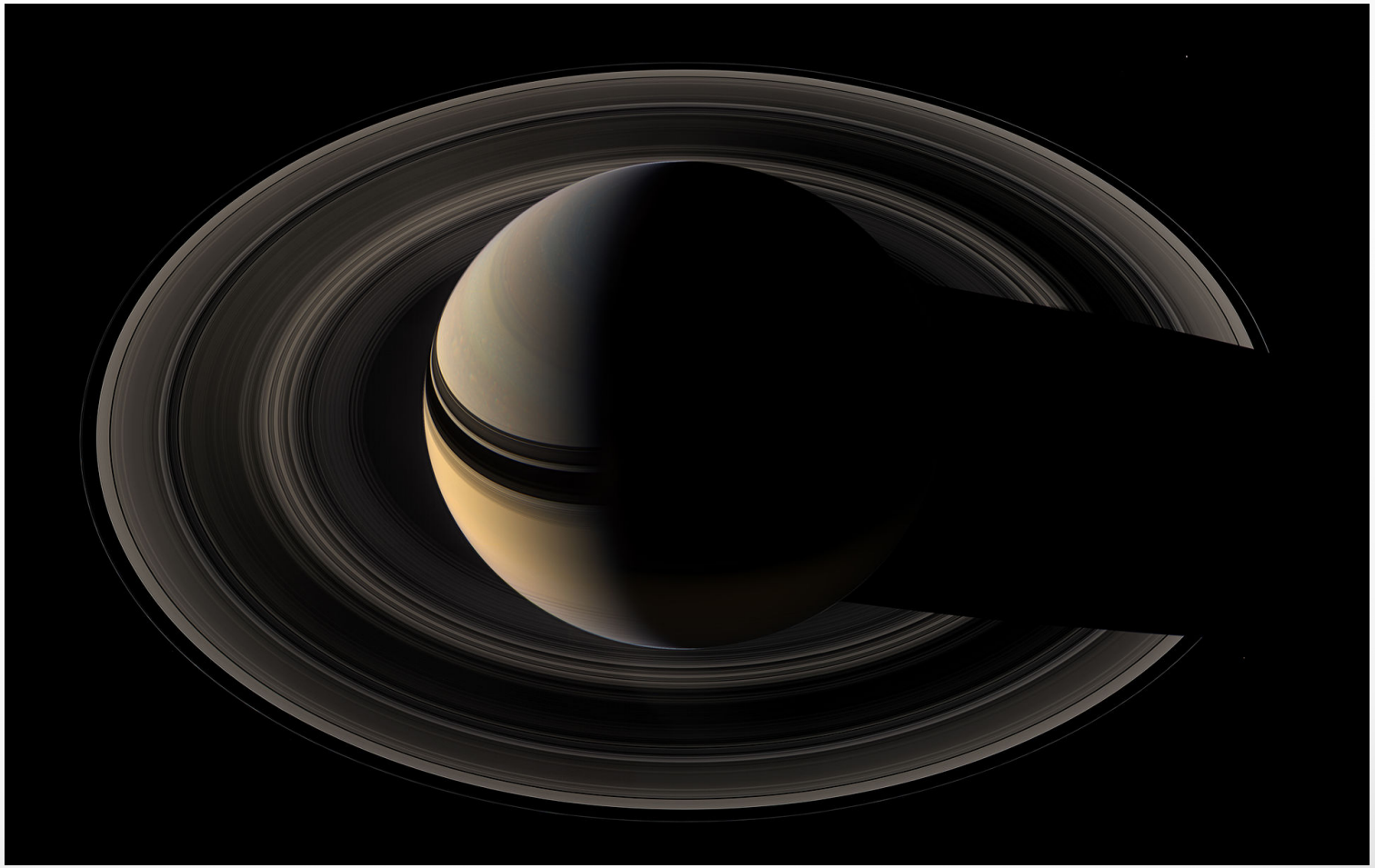
Saturn Moons

- Count as of 2017 is 62: 38 regular moons the rest captured asteroids. Titan is the second largest moon in the SS

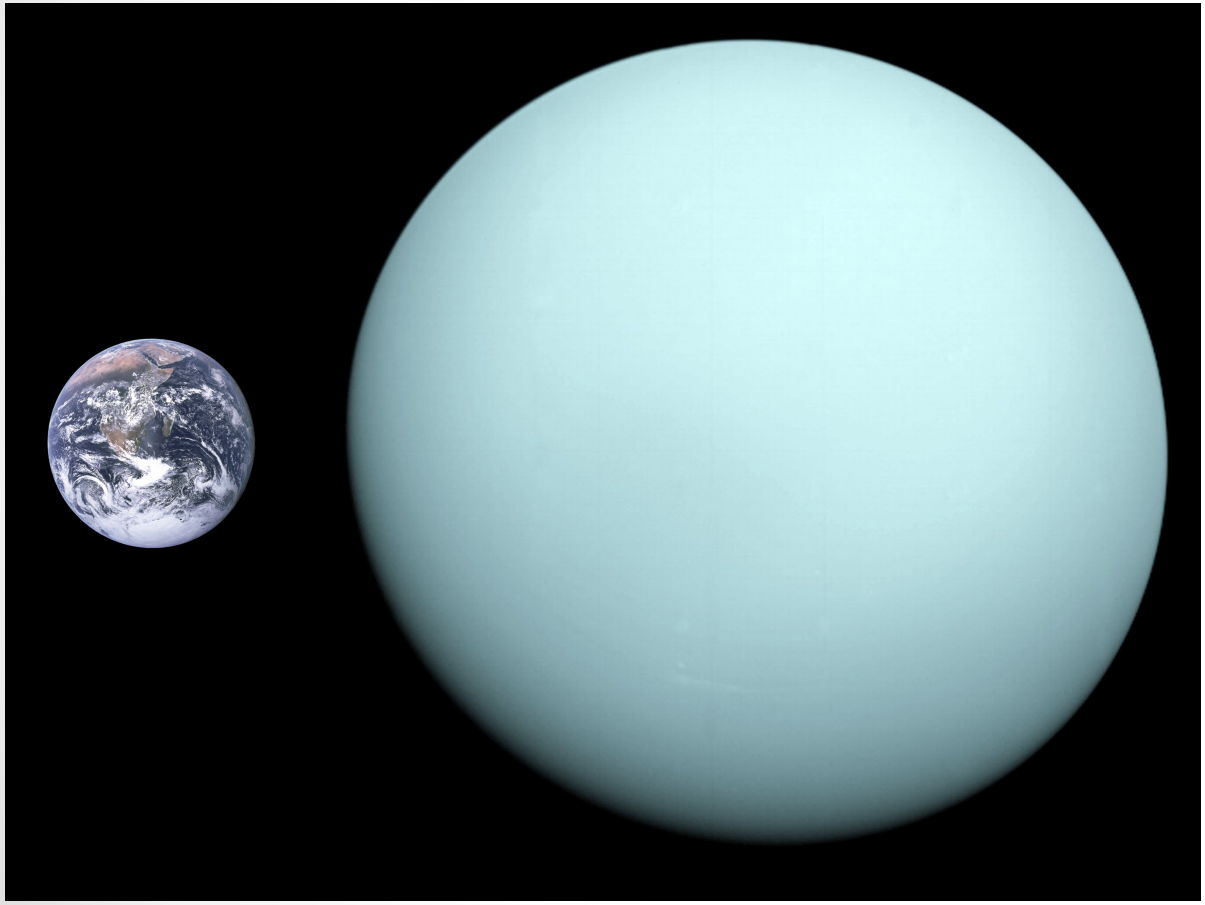


Cassini

- Pioneer 11, Voyager 1 and 2 did flybys, Cassini has been in orbit since 2004 studying Saturn and several of the moons.

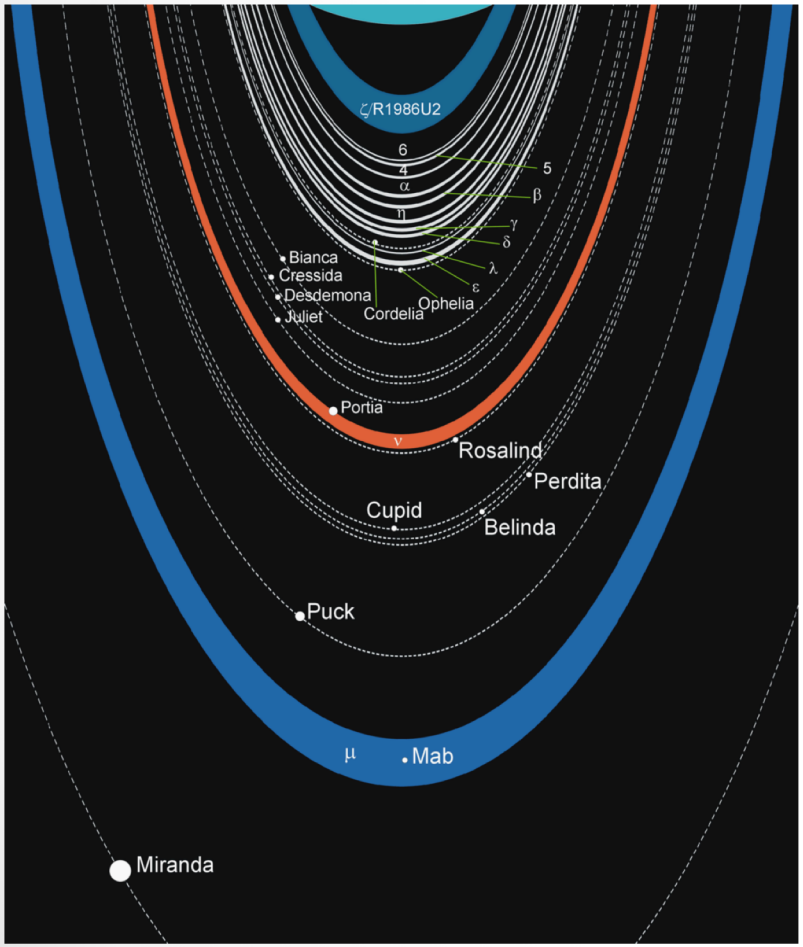


Uranus



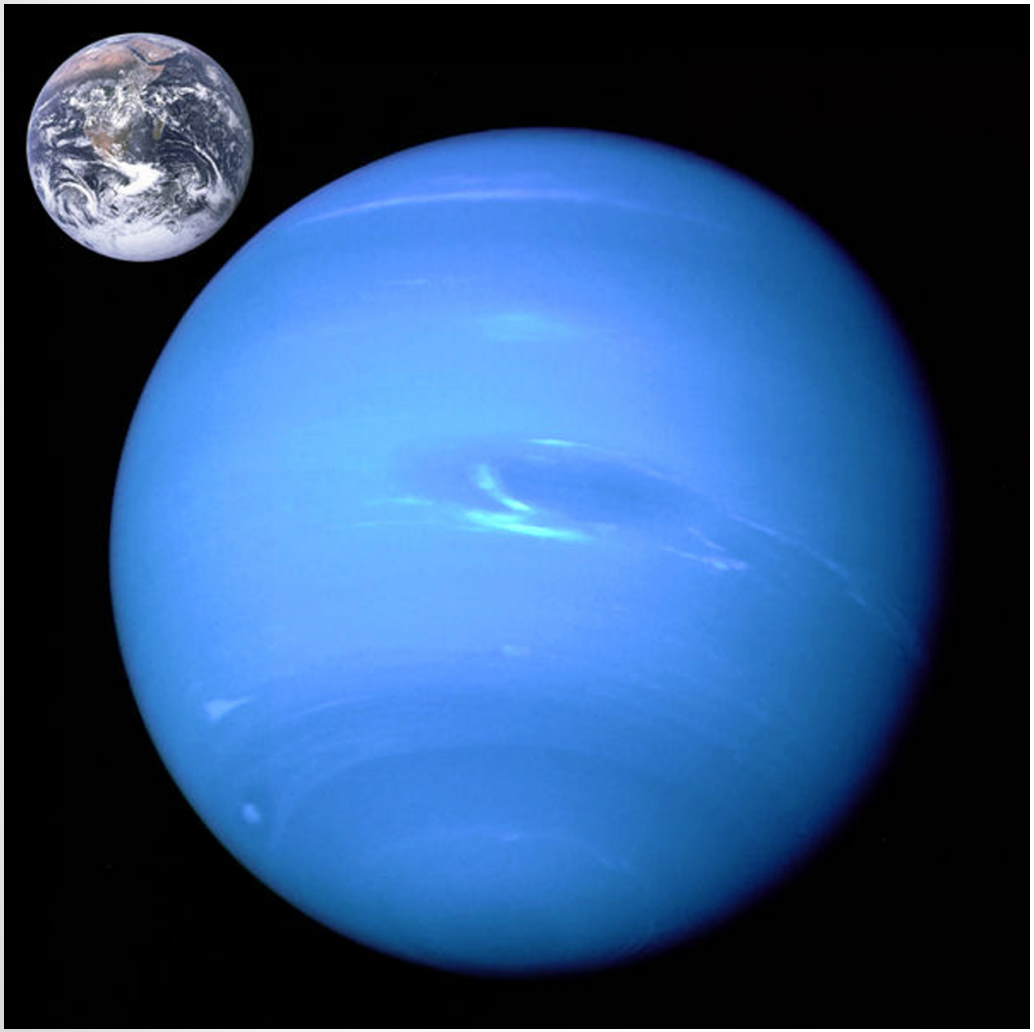
- Orbit radius 20AU
- Orbit period: 84 E-years
- Rotation period: 17 hours (retrograde)
- Orbit tilt: 98°
- Average temp: -200C
- Mass: 14.5 x $Mass_{Earth}$
- Composition: Dominated by H and He

Uranus



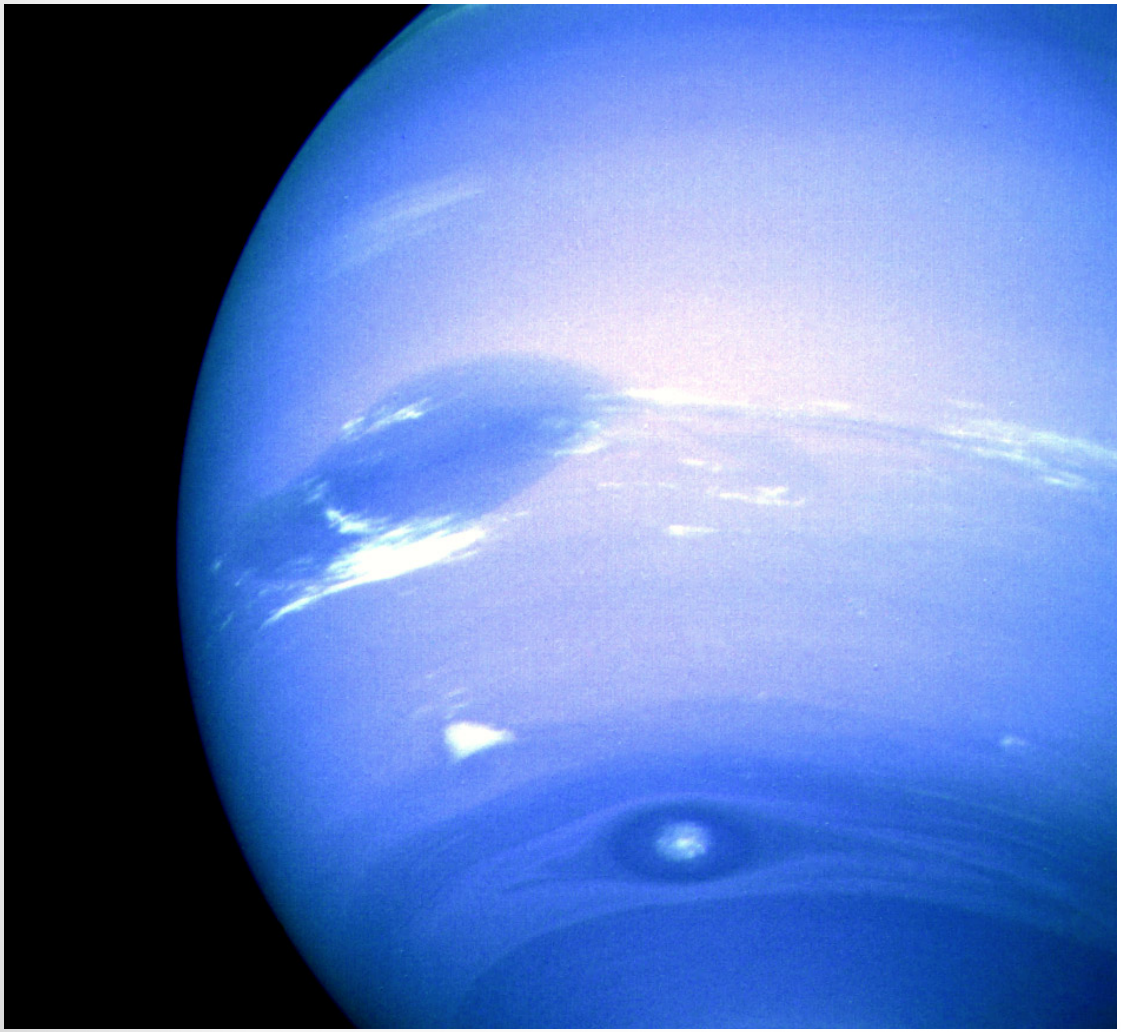
- Faintest naked-eye planet
- Rings first discovered by accident during stellar occultation observations
- Imaged by Voyager
- They are dusty and dark (low albedo)
- There are some mysteries around Uranus
  - Rotation axis tilt (early collision?)
  - Lack of internal energy source

Neptune



- Orbit radius: 30 AU
- Orbit period: 165 E-years
- Rotation period: 16 h
- Rotational tilt: 28°
- Too faint to see without a telescope. First seen by Galileo, but not recognized. Later, its position was predicted when Uranus's orbit did not quite match Kepler's Laws

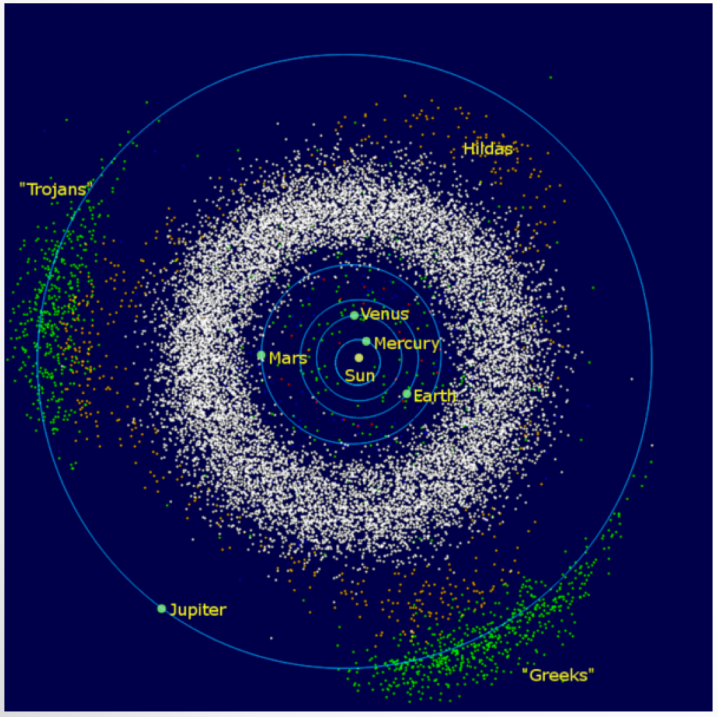
Neptune



- Unlike Uranus, Neptune has more obvious weather
- Internal heat source similar to Jupiter and Saturn
- Very cold: -218C
- 14 moons
- Voyager flyby

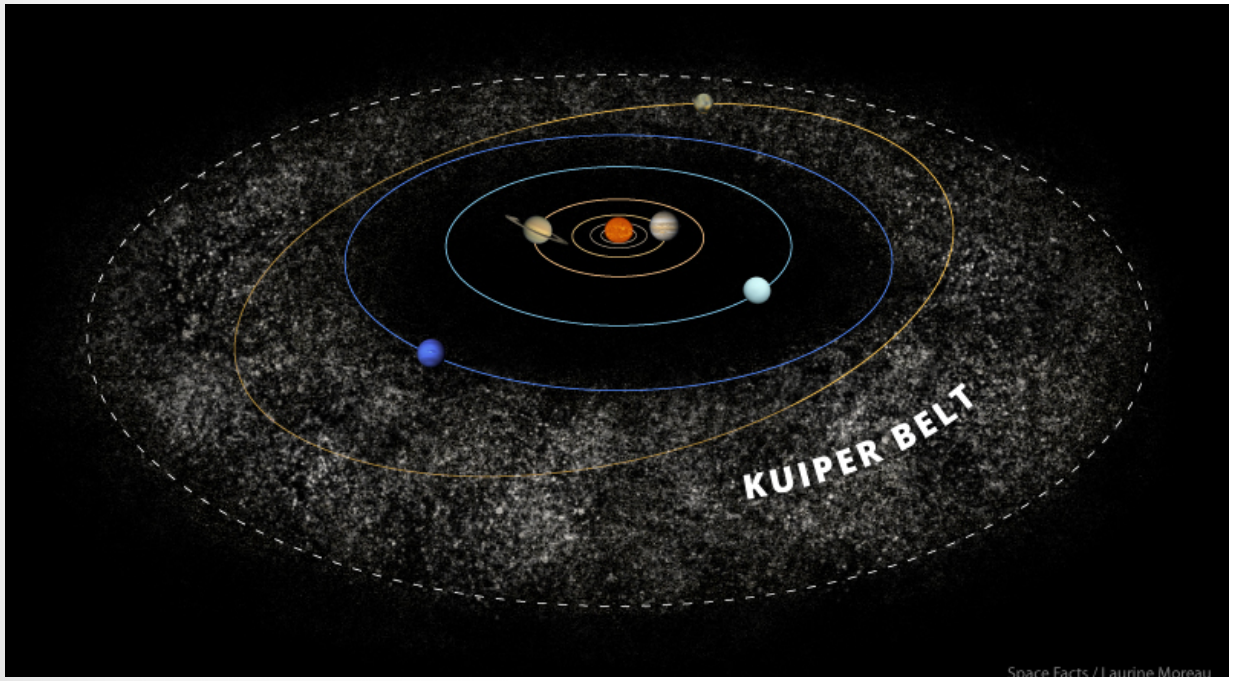
Other stuff in the SS

- There are two "asteroid" belts in the Solar System
- The Main Belt is between Mars and Jupiter is made of billions of rocky objects from pebble sizes to Ceres at ~950km in diameter



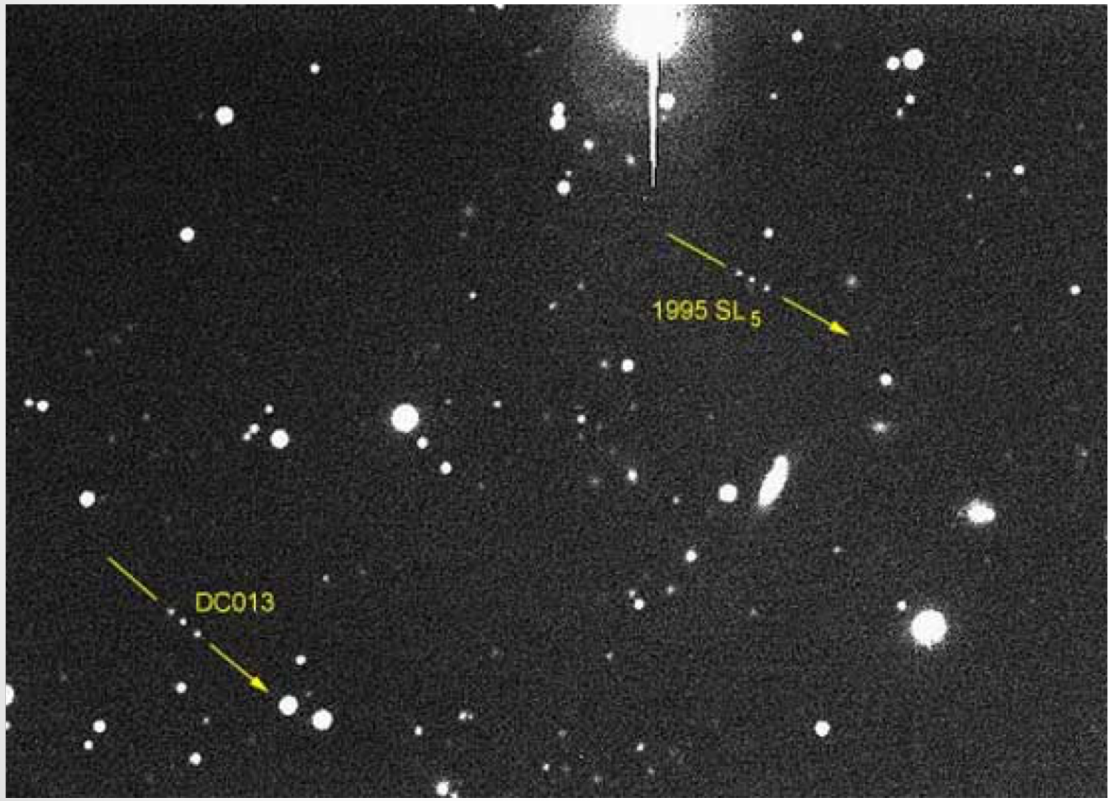
- Maybe a failed planet influenced by Jupiter
- Total mass is only ~4% that of the Moon down from ~ the mass of the Earth
- Very low density: random spacecraft path through belt has 1 chance in a billion of hitting and asteroid

Kuiper Belt



- The other major disk of objects is the Kuiper Belt beyond Neptune
- ~100 times more massive than the Main Asteroid Belt
- Composed most of icy bodies: Pluto is the second largest member (Eris)
- ~100 objects identified to date: TNOs, KBOs
- Source of short-period comets

Searching for Asteroids

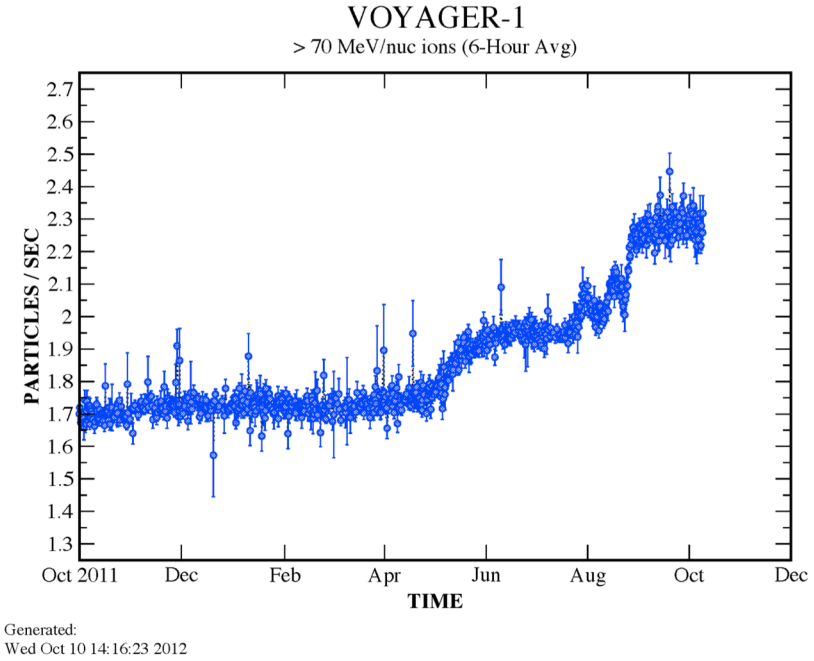


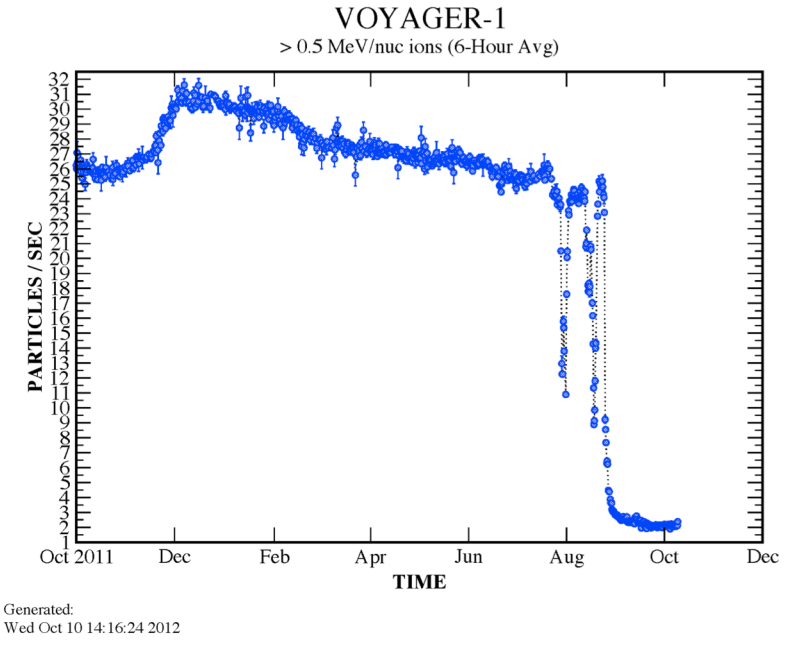
Asteroids are found by comparing images taken at different times. Register images with stars and see what is moving at a different rate and direction

Because they are seen in reflected sunlight, are far from the Sun and they have small surface areas they are hard to find!

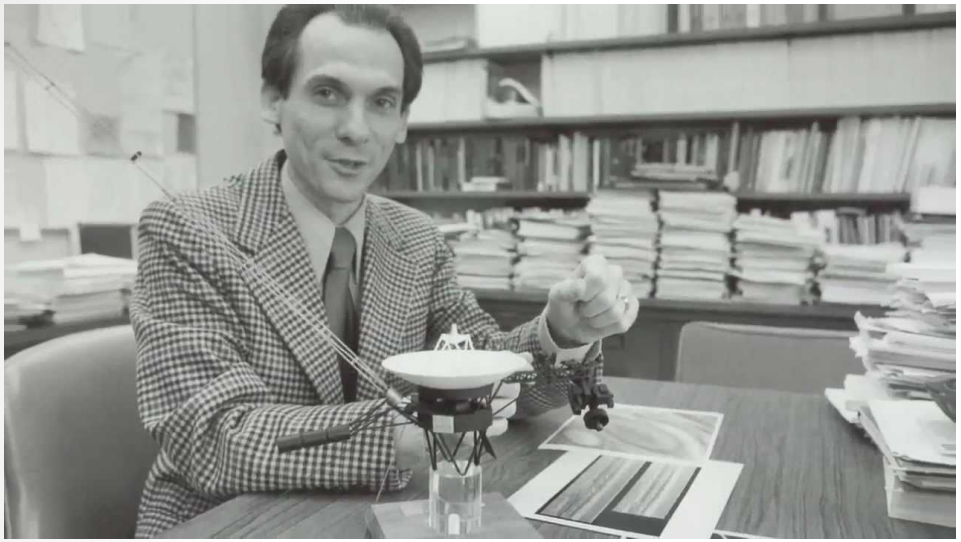
Voyager: 1st Object to leave the SS

- Voyager 1 launched in 1977 to explore the outer planets
- Currently at 138AU, in 2012 it crossed the "heliopause" and entered interstellar space

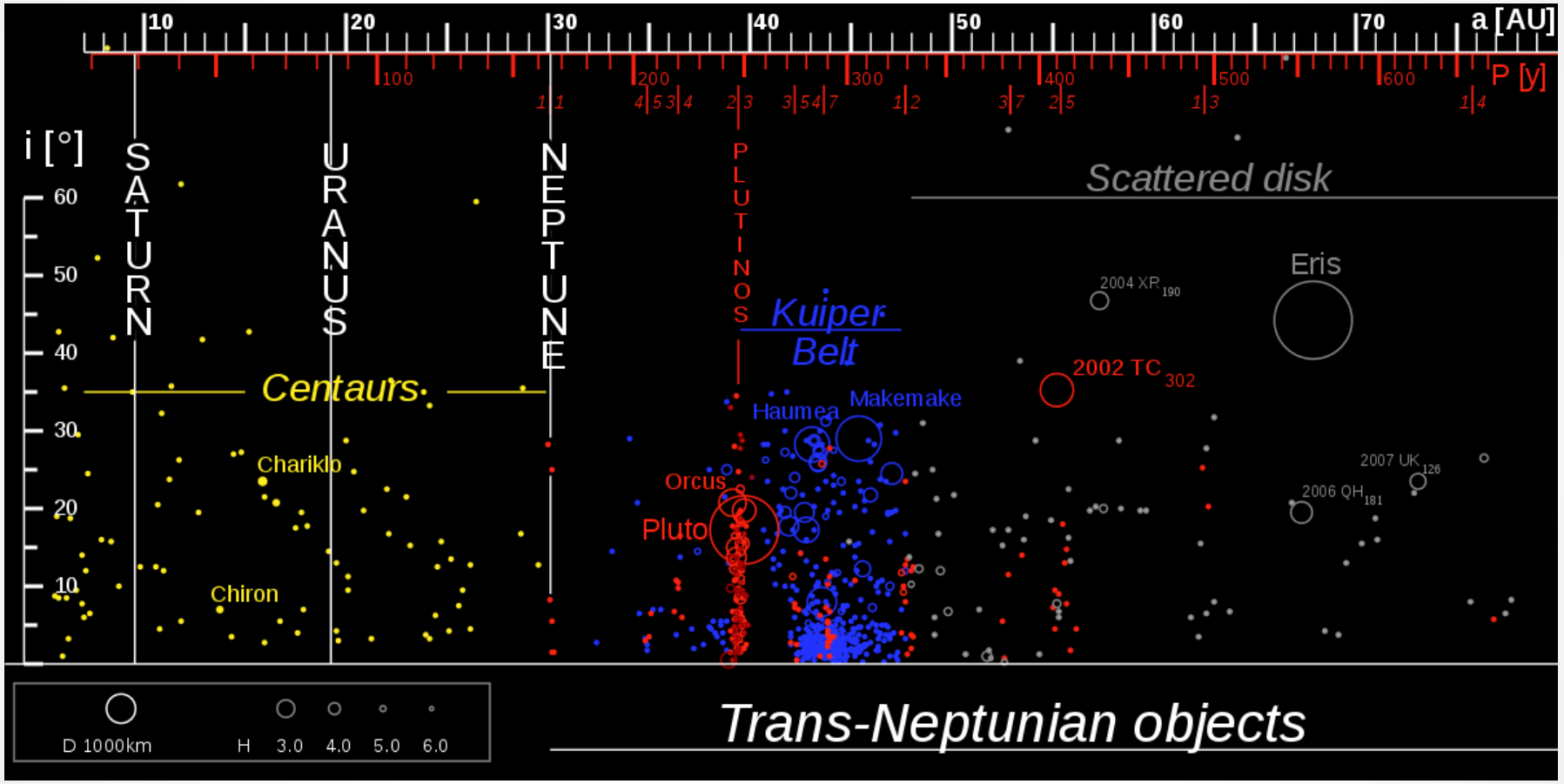




Ed Stone



Ed Stone at Caltech was the Principal Investigator of both Voyagers. Still very active in his 80's leading large projects


a [AU]
P [y]
i [°]
SATURN
URANUS
NEPTUNE
PLUTINOS
Scattered disk
Kuiper Belt
Centaurs
Eris
2004 XR190
2002 TC302
Haumea
Makemake
Orcus
Pluto
Chariklo
Chiron
2007 UK126
2006 QH181
D 1000km
H 3.0 4.0 5.0 6.0
Trans-Neptunian objects