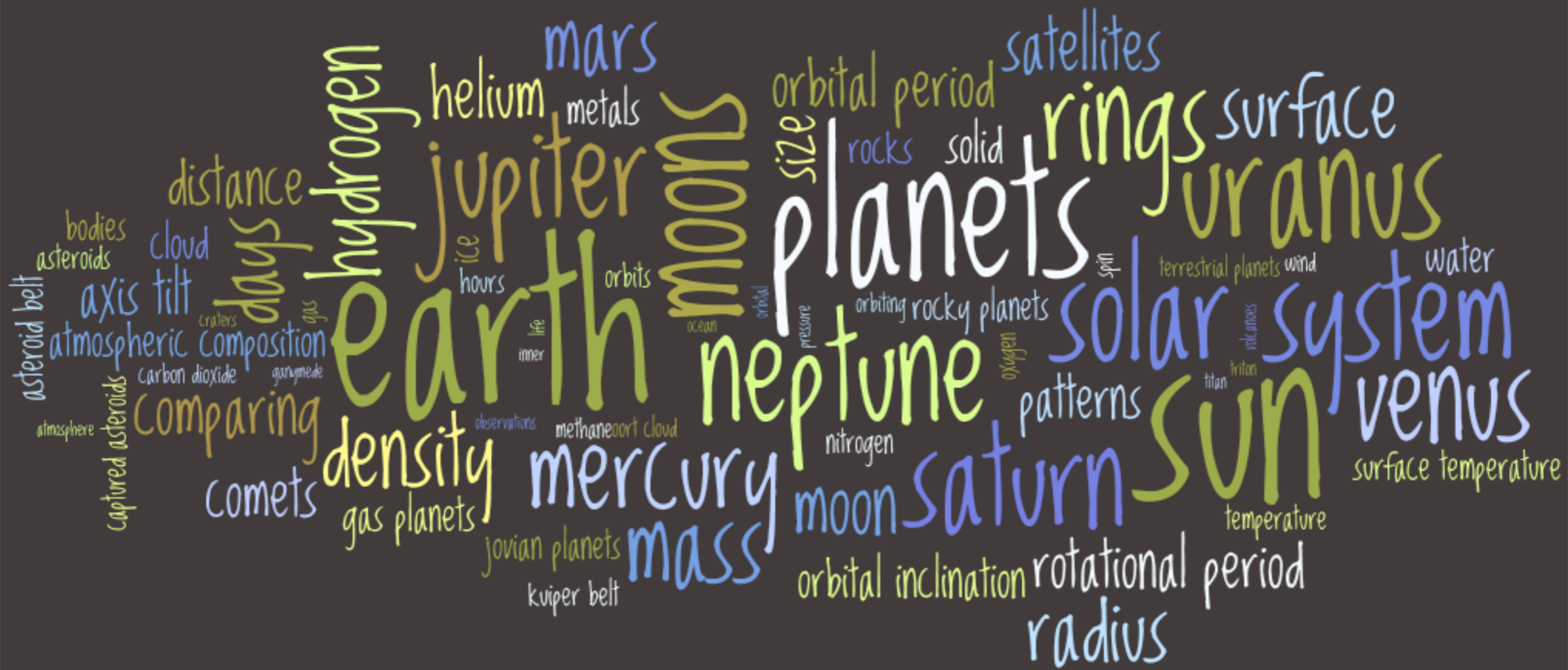


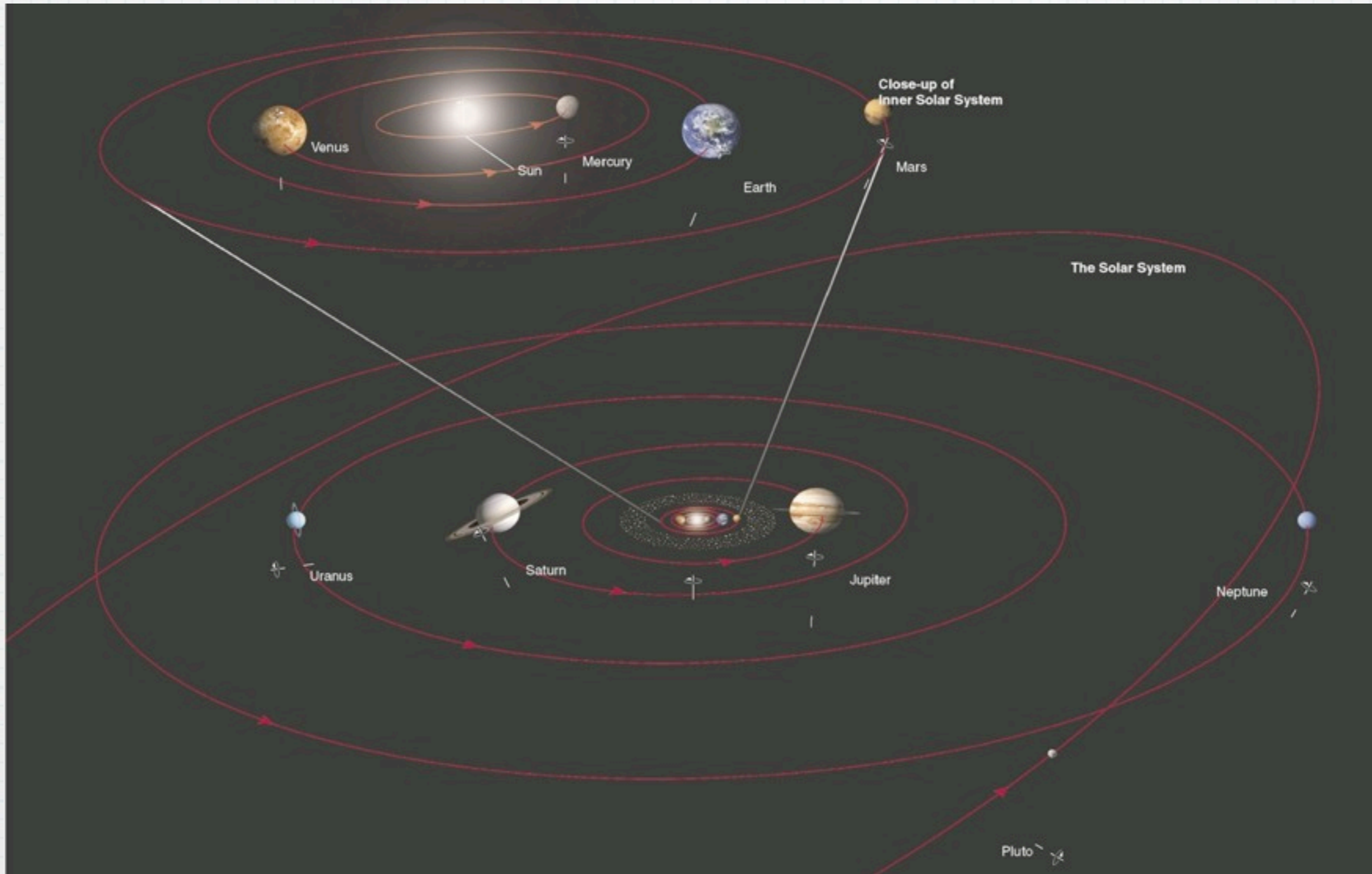
The Solar System and its Origin

Chapter 6 - part 1

**For your exclusive use.
Do not email, do not post on Internet: some material is ©**



The Solar System



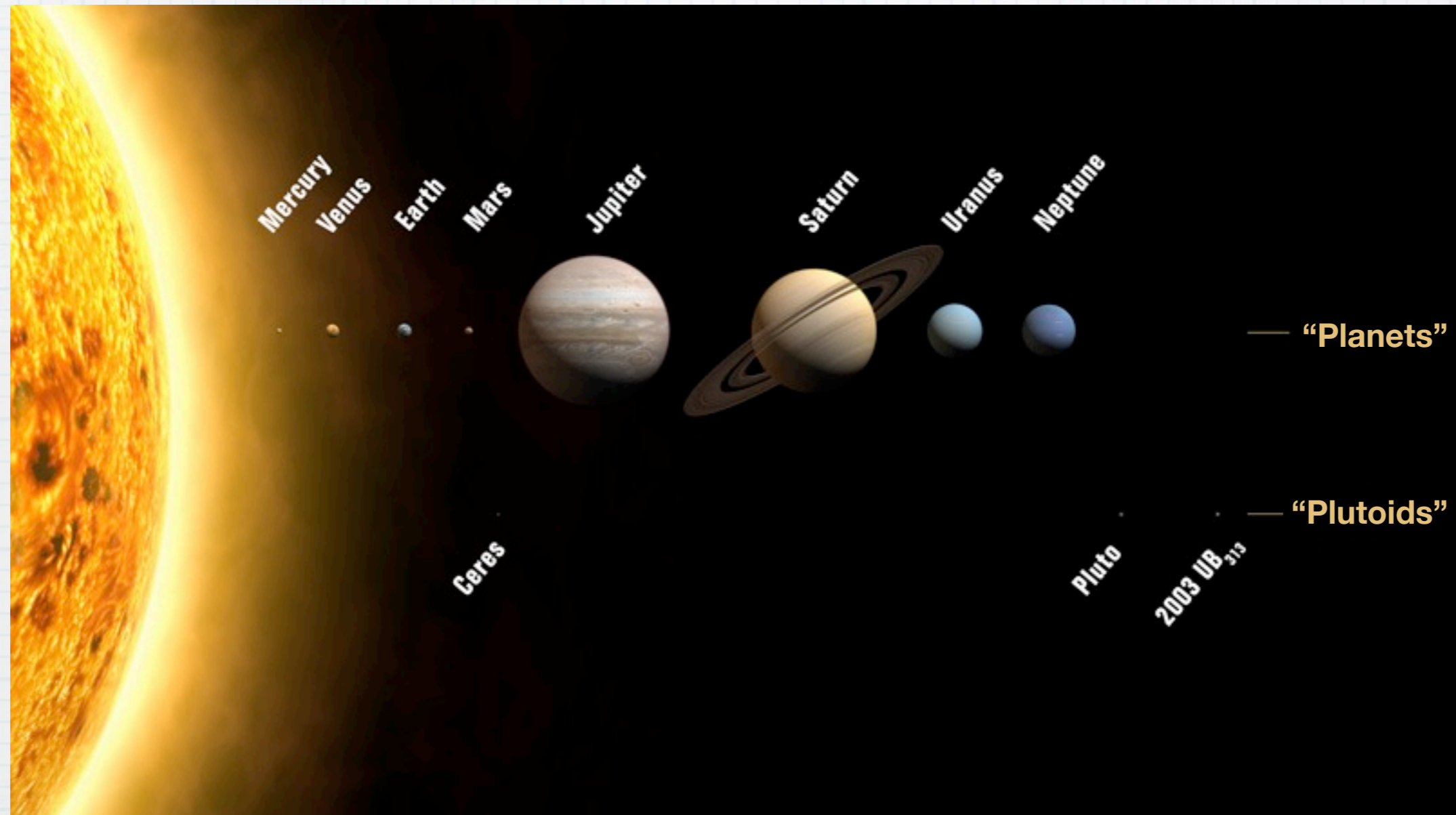
Relative Distances from the Sun

- * Location: Washington DC
- * Scale: 1 to 10 billion
- * Nearest star: in California



© The Essential Cosmic Perspective, 2005 Pearson Education

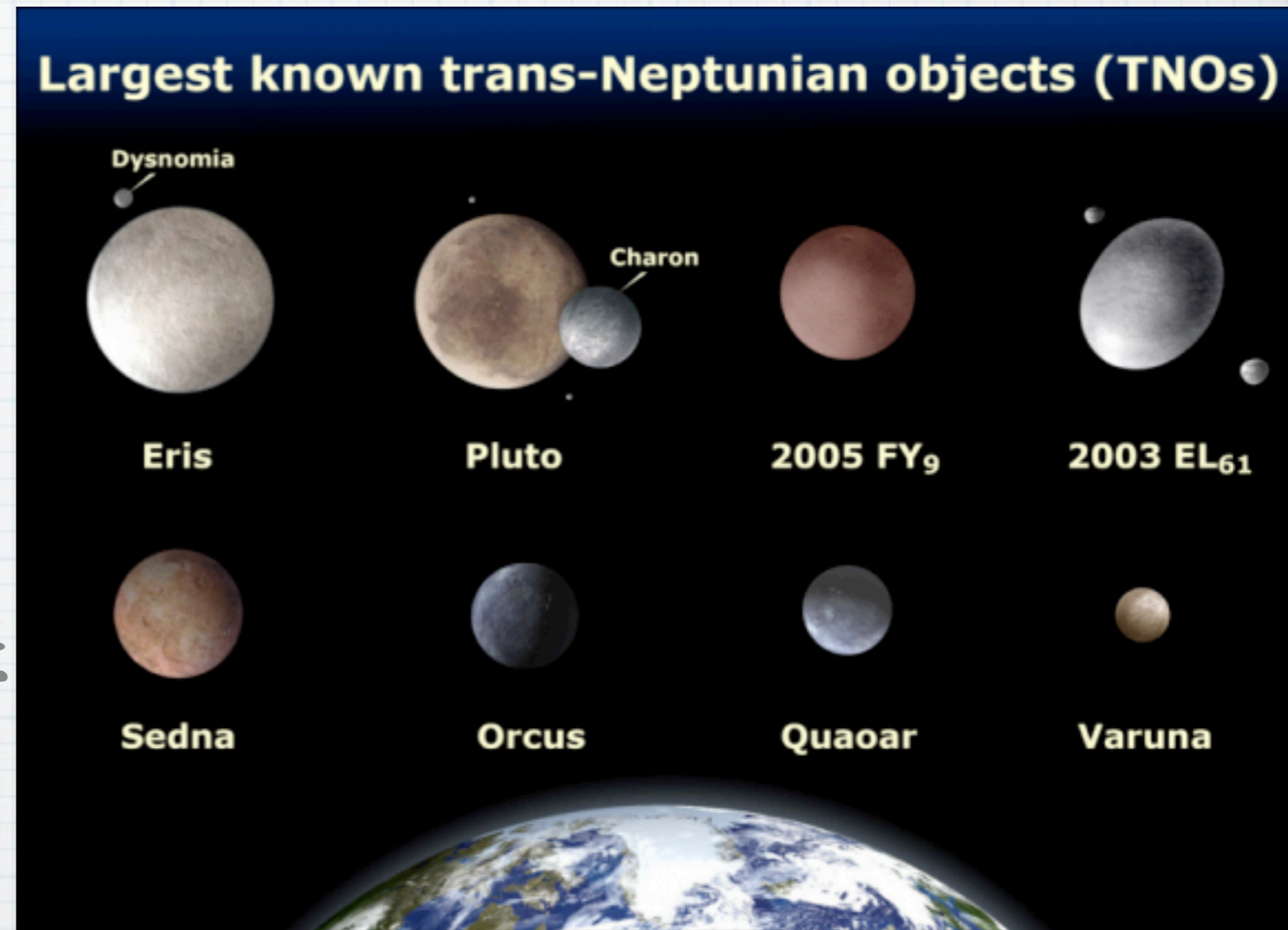
The Sun and Planets to Scale (size-wise)



Pluto's Demotion

- * More and more objects near Pluto's size have been discovered (in the asteroid and comet belts)
- * A new definition of a Planet was needed in order to keep order

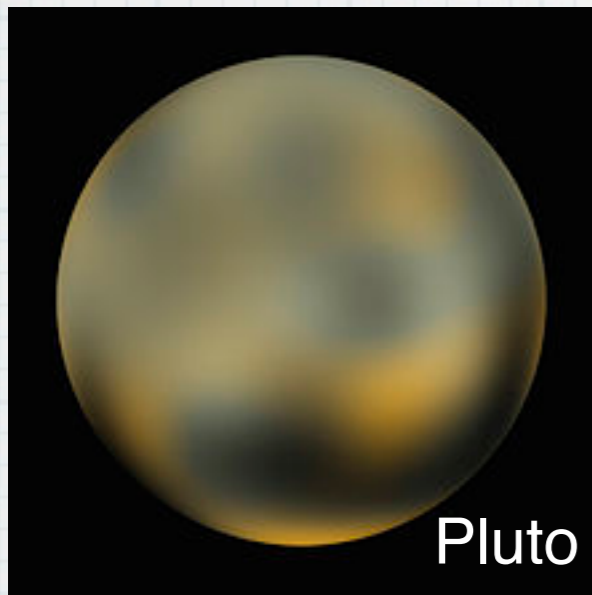
Found in the Comet belt



To Be A Planet

- * It needs to be in orbit around the Sun – Yes, so maybe Pluto is a planet
- * It needs to have enough gravity to pull itself into a spherical shape – Pluto...check
- * It needs to have “cleared the neighborhood” of its orbit – That is the rule breaker. Because of this, Pluto is not a planet

Dwarf Planets

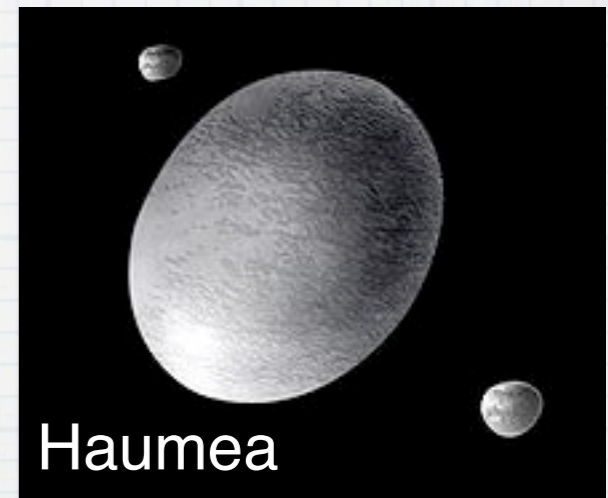


Pluto

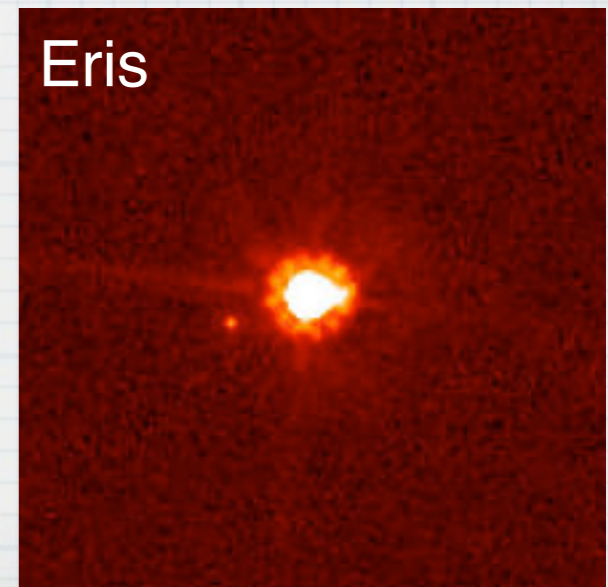


Ceres

- * A dwarf planet is a planetary-mass object that is neither a planet nor a satellite
- * Pluto shares the category with four other little worlds: Ceres, Haumea, Eris and Makemake

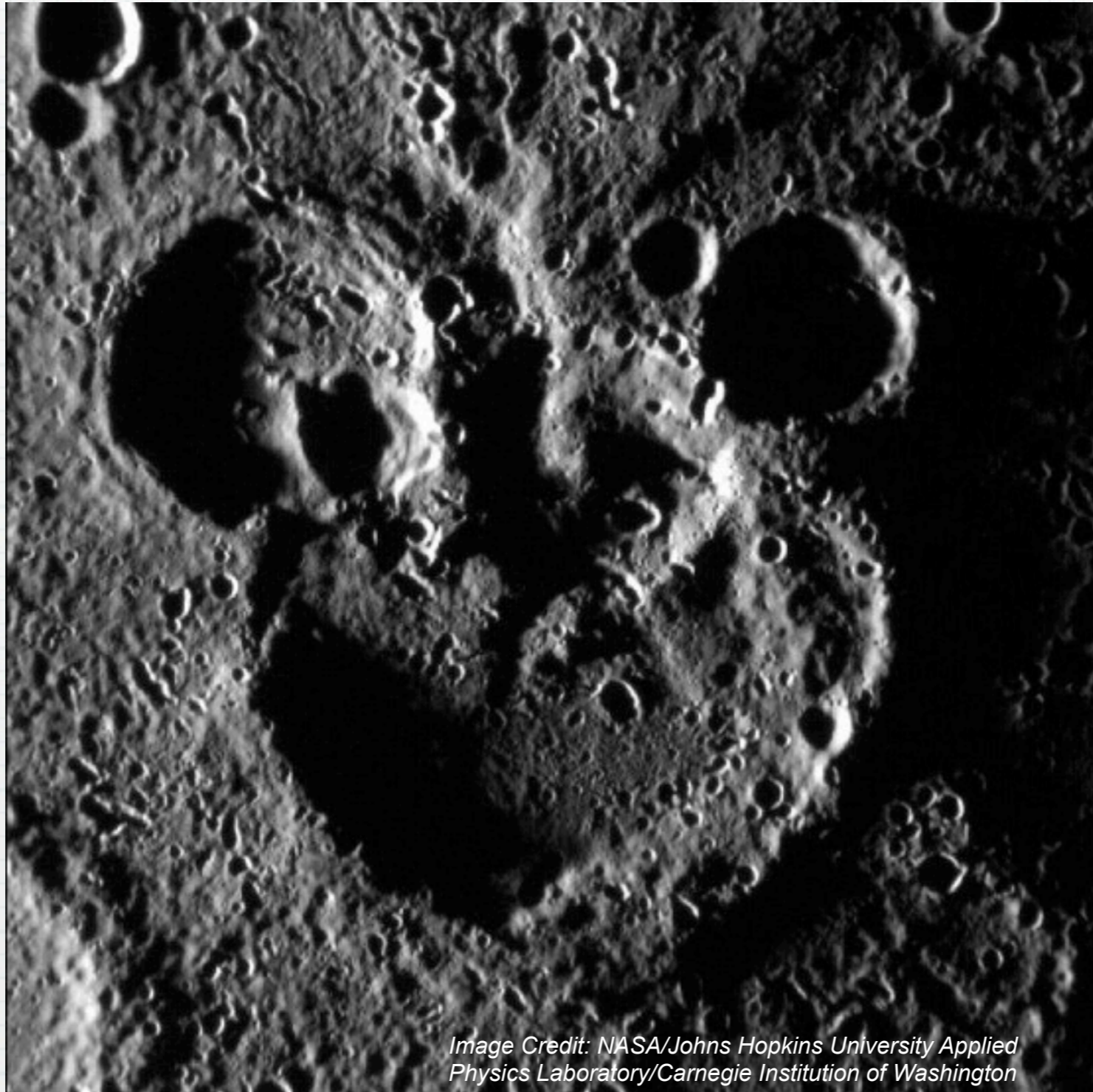


Haumea



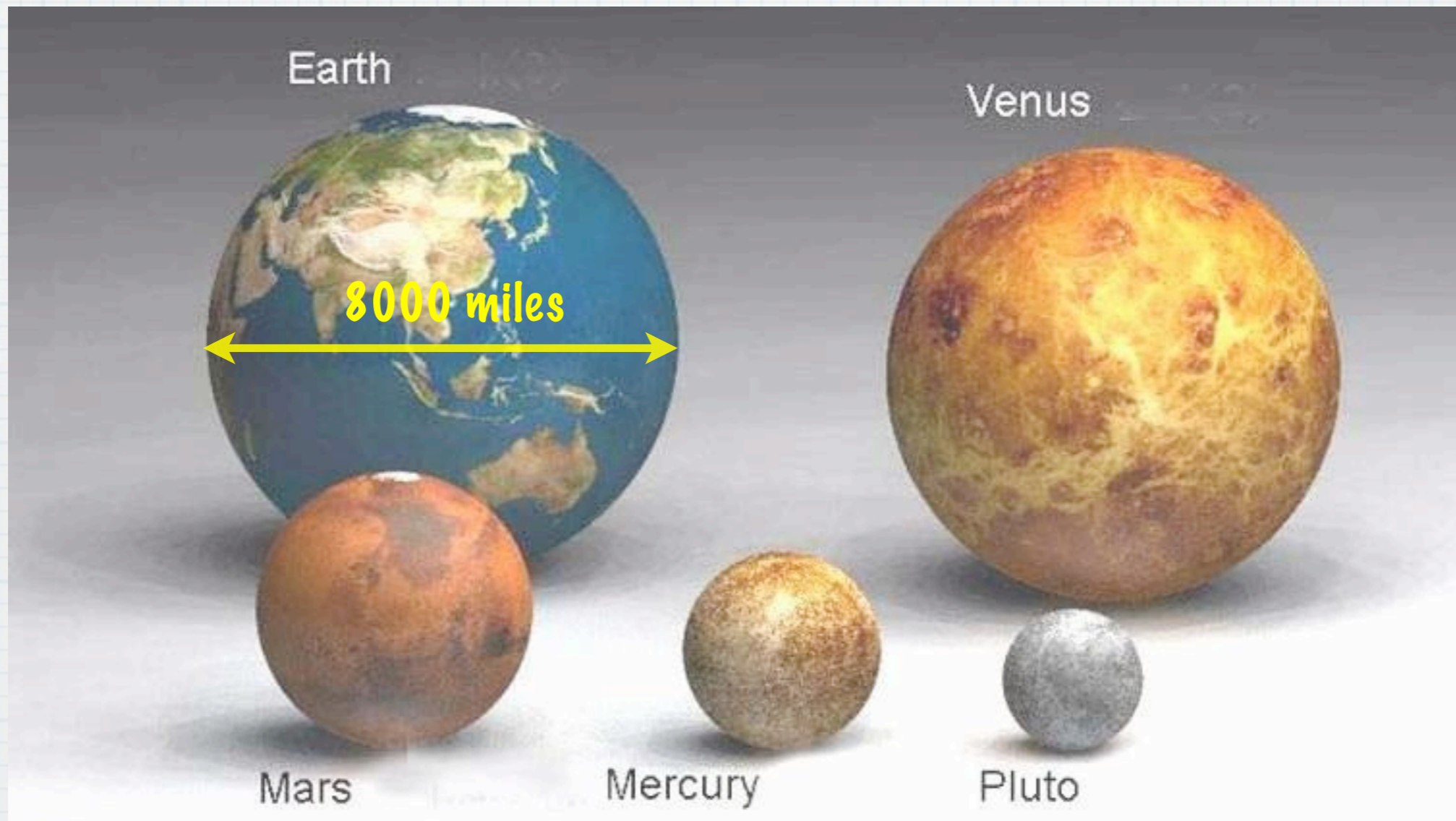
Eris

**Pluto may not be a planet any longer
however.. Mickey was found on Mercury**

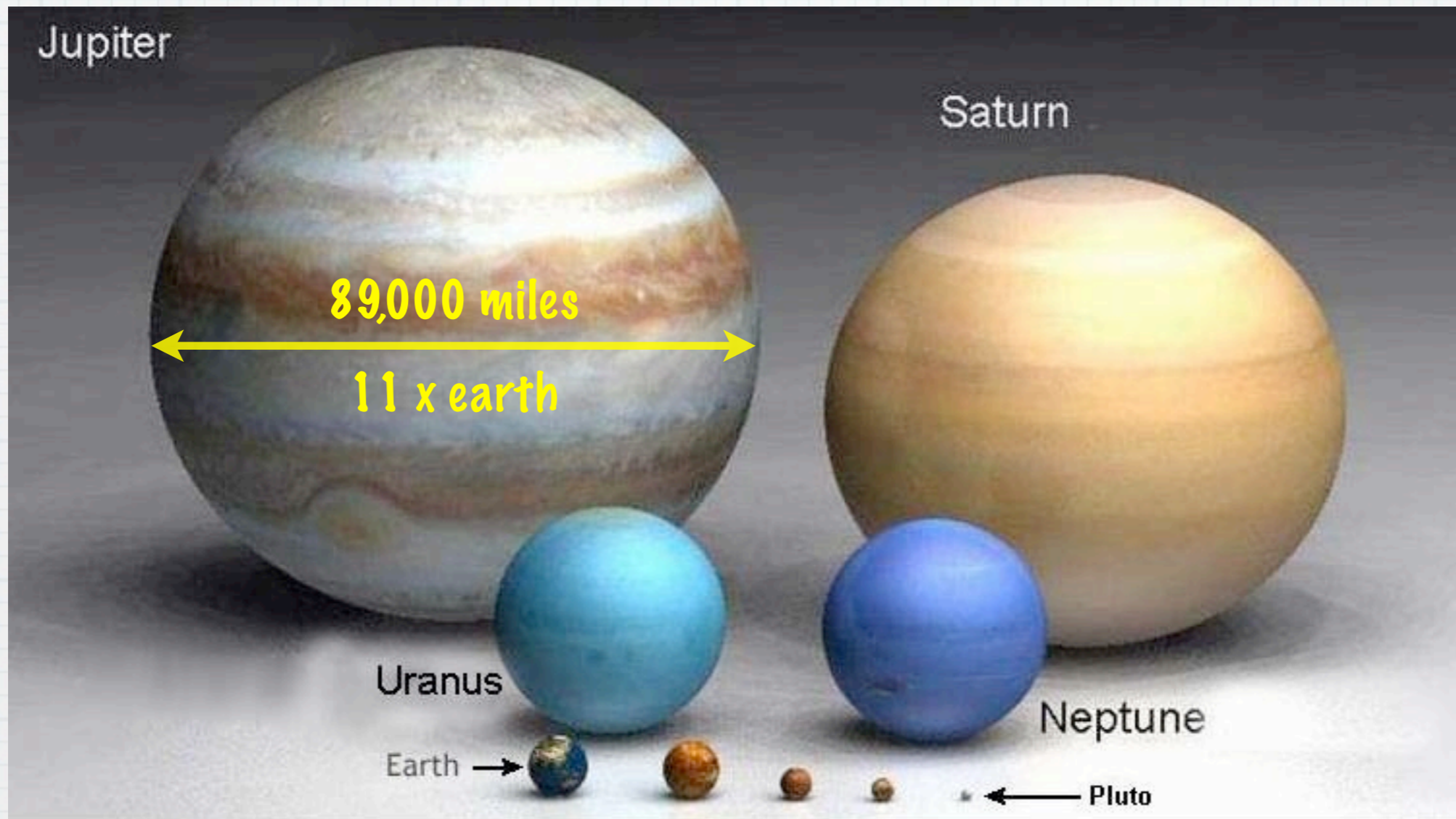


It is a small world after all ...

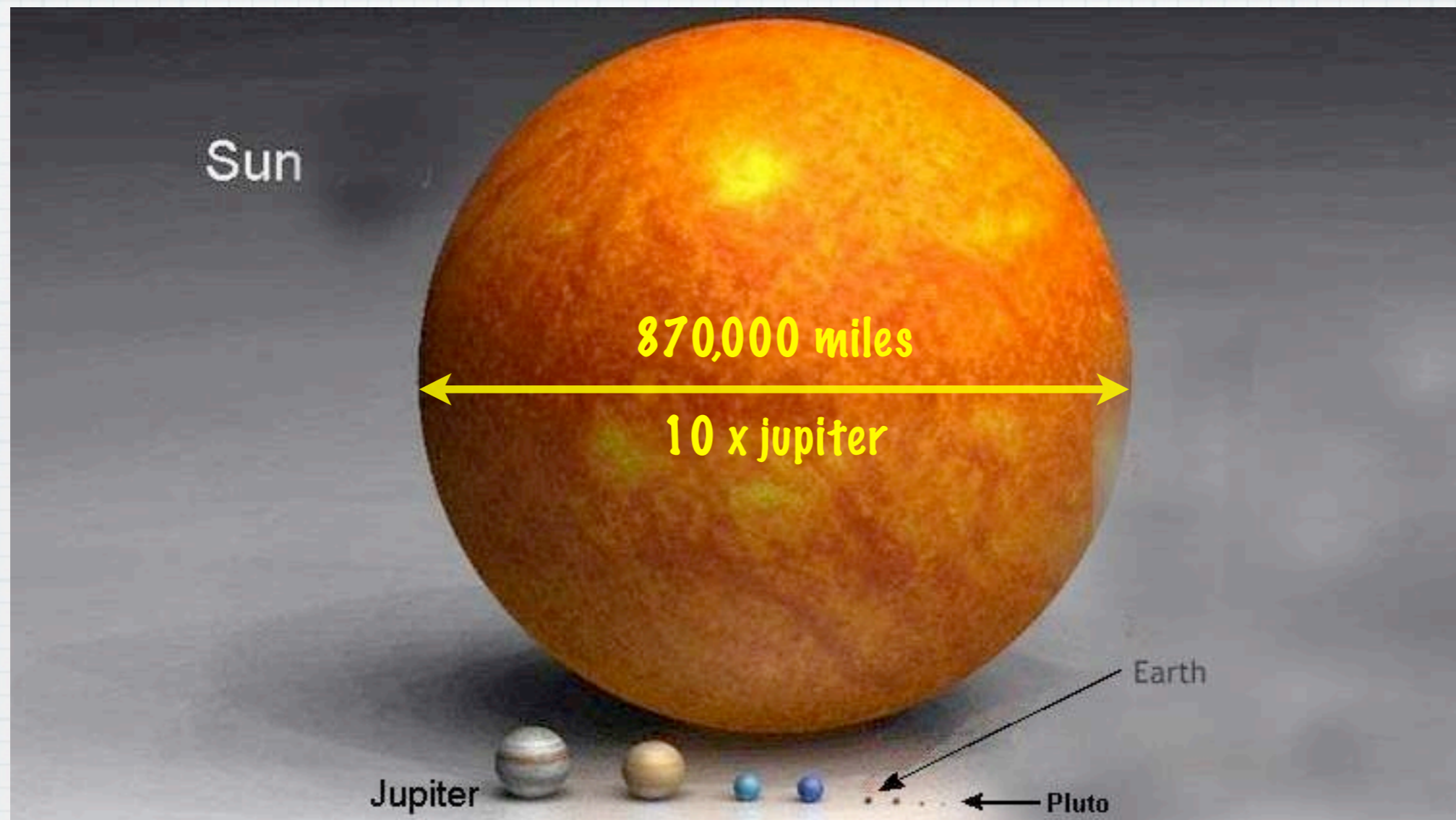
Scaling our Planets (how big is big?)



Scaling our Planets (how big is big?....)



Scaling our Planets (how big is big?....)

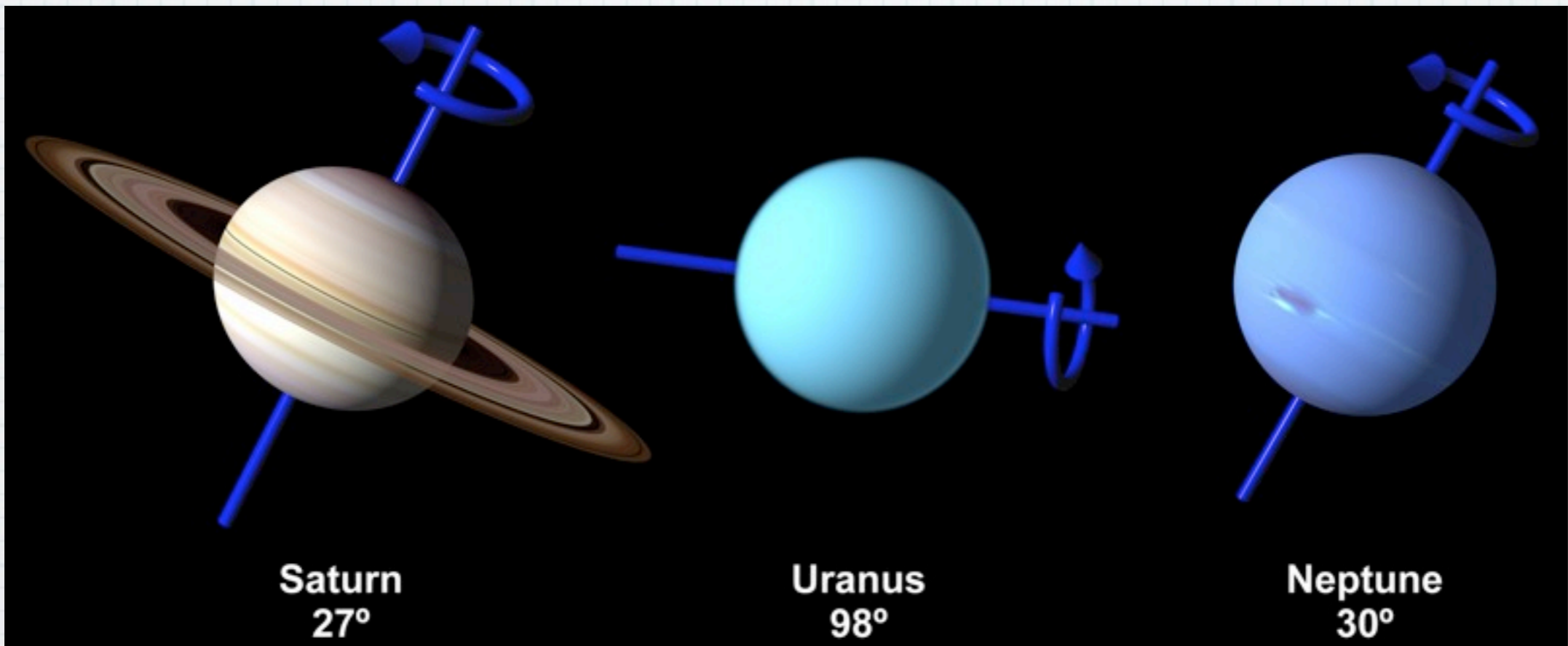
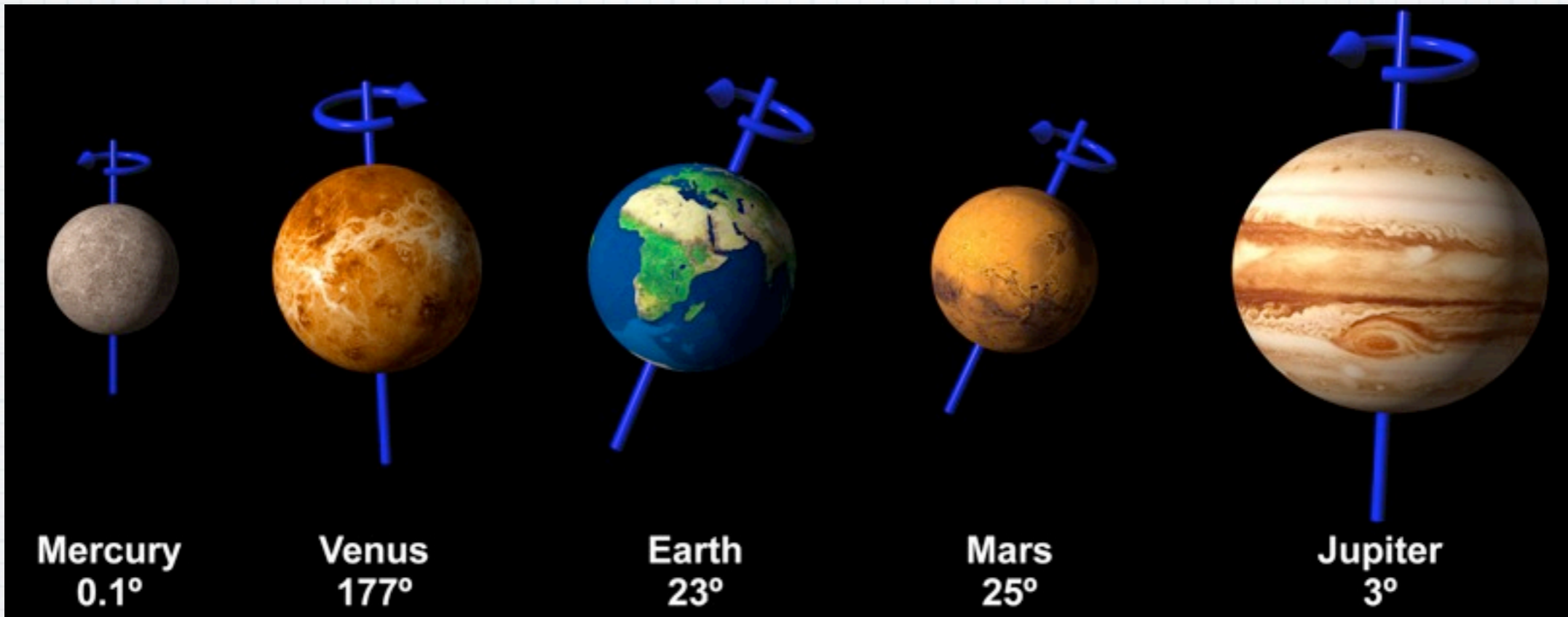


Patterns

- * In order to understand our Solar System, we need to look at its constituents and look for patterns in their:
- * orbits, inclinations, direction of rotation, direction of spins, radii, densities, compositions, surface temperatures, number of satellites, ...

Large Bodies Motion Patterns

- * The planets all orbit the Sun in the same direction
- * The Sun and all the planets spin
 - * but with different rates
 - * and different spin inclinations (their tilts are usually less than 30° with 3 exceptions)



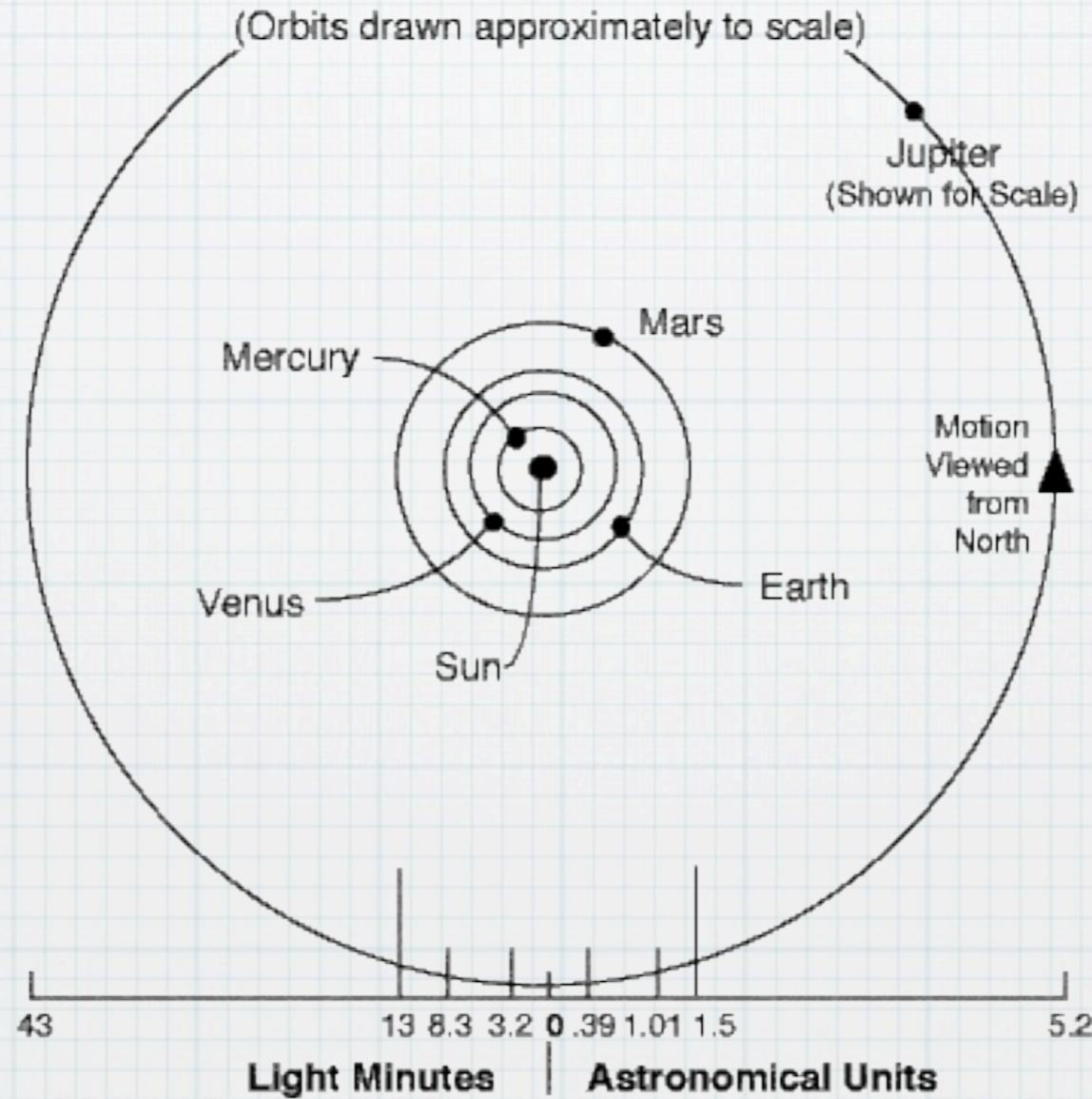
Two Major Types of Planets

- * The planets divide into **two** clear groups
- * **the small rocky planets** are close together and close to the Sun and generally have no satellites
- * **the larger gas planets** are farther apart and farther out and generally have lots of satellites

Terrestrial Planets



Mean Distances Of The Terrestrial Planets From The Sun

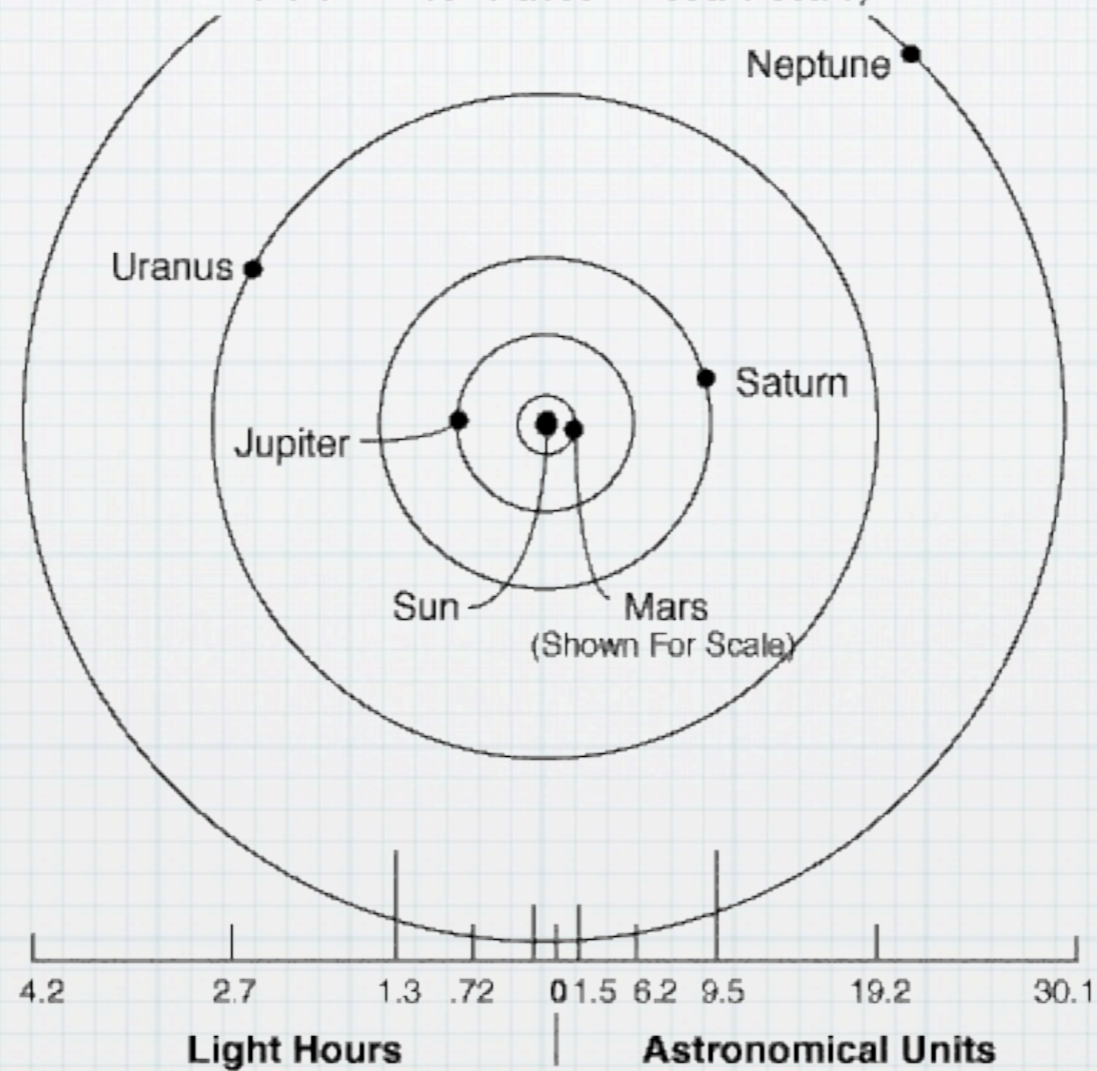


Jovian Planets



Mean Distances Of The Jovian Planets From The sun

(Orbits drawn approximately to scale.
Pluto omitted to accommodate scale)

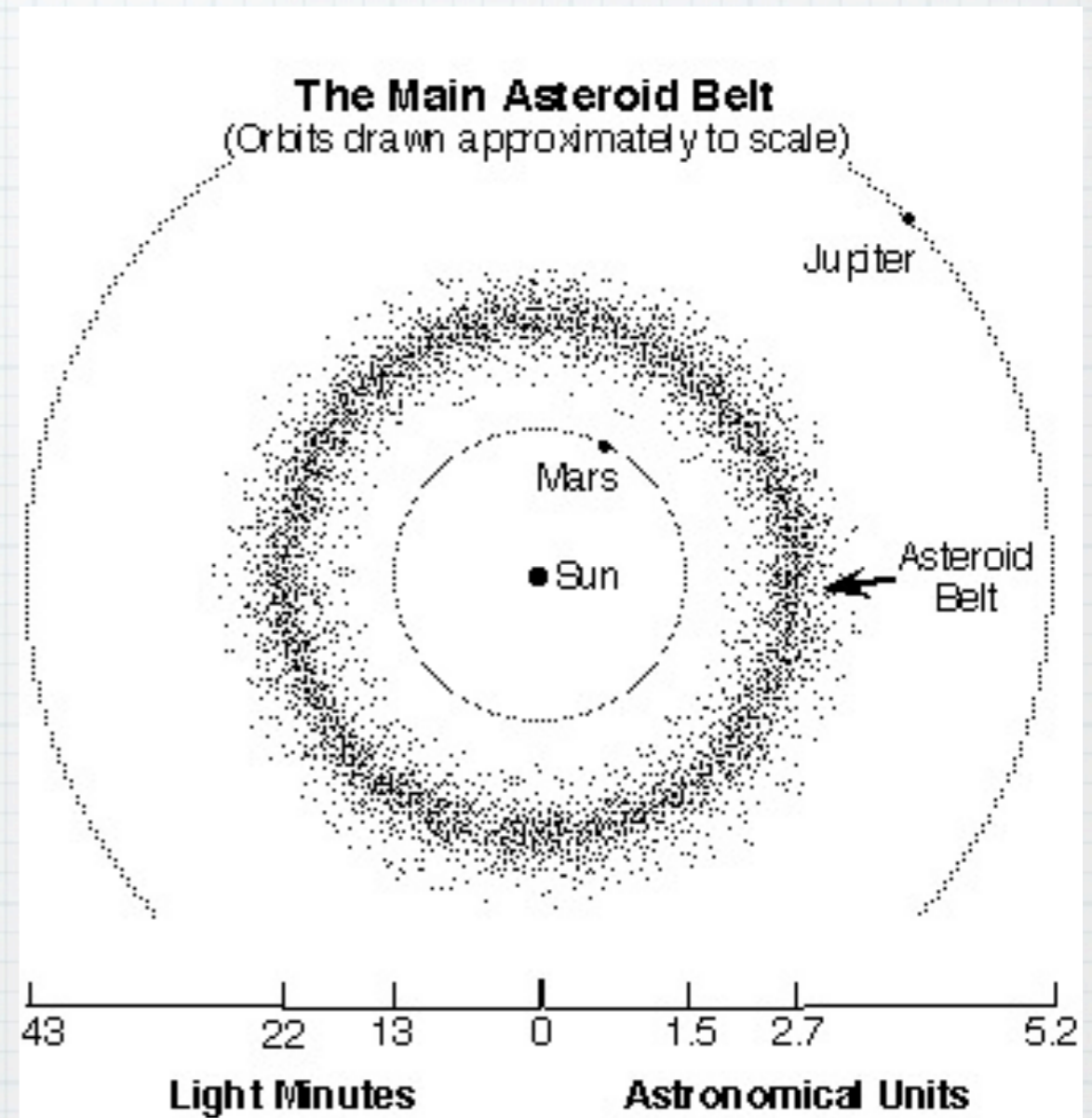


Smaller Bodies Motion Patterns

- * The satellites generally orbit their planets in the same direction
- * They all spin with different rates
- * The spin inclinations (their tilts) can vary significantly per planet

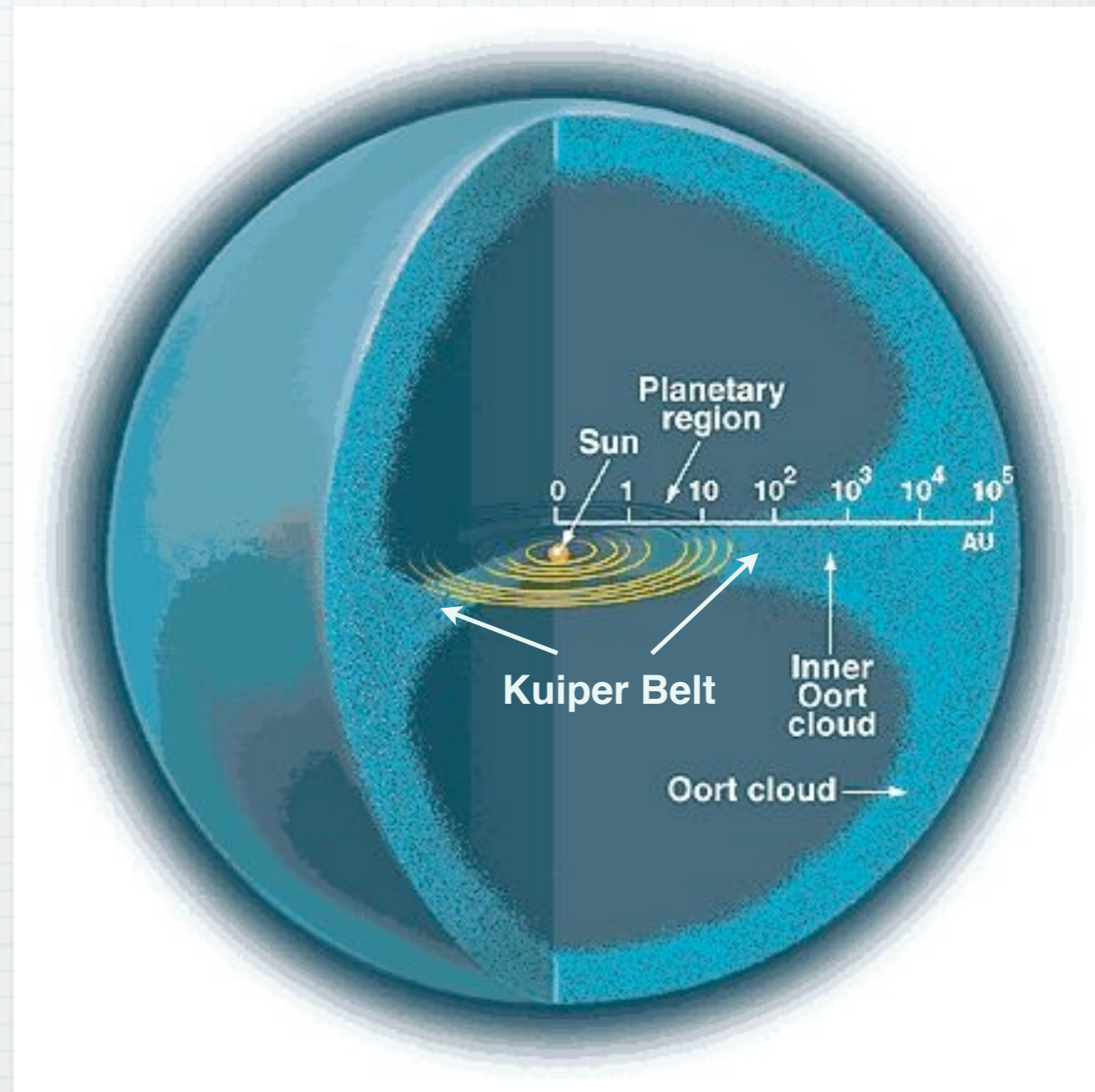
Even Smaller Bodies Motion Patterns

- * There is an **asteroid belt** hosting huge numbers of asteroids
- * That belt is between the terrestrial and gas planets



Even Smaller Bodies Motion Patterns

- * There is a **comet belt (Kuiper Belt)** beyond the farthest gas planet surrounded by an even more distant comet cloud (**Oort Cloud**)



The Rule Breakers

1. **The Earth** is unique amongst terrestrial planets:
 - a. has a satellite (the Moon)
 - b. whose radius is 27% of Earth's radius, a much larger ratio than any other moons orbiting other planets in our Solar System
2. **Uranus** has an odd, sideways tilt
3. **Venus** spins backwards

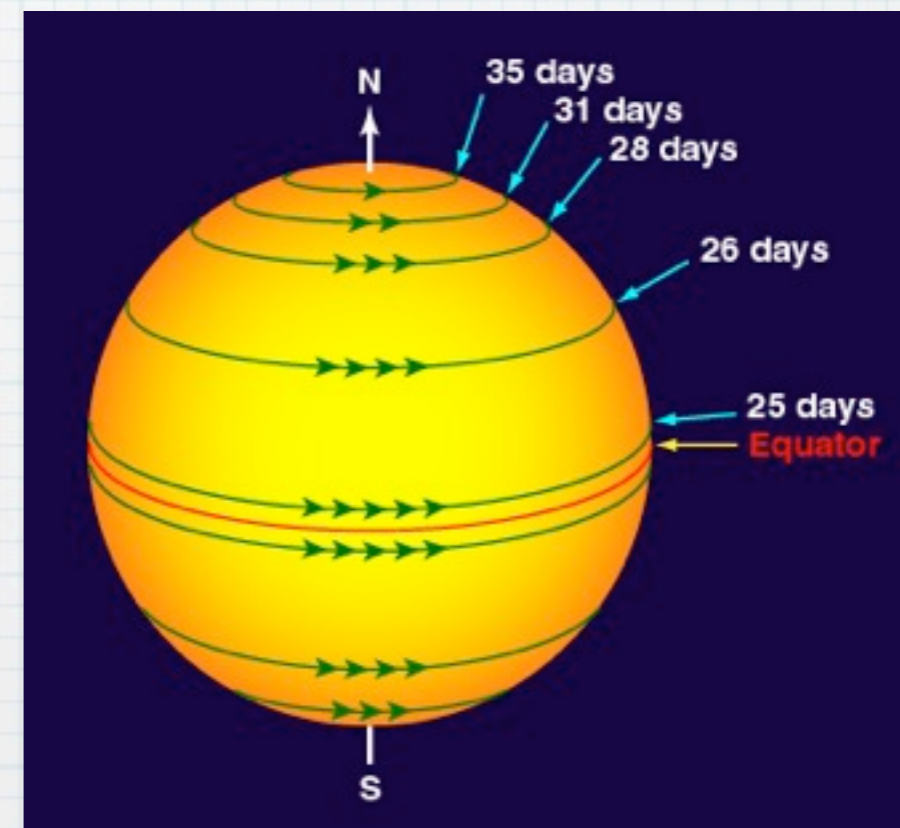
From Observations to Computations

- * In order to come up with theories that will answer how our Solar System came to be, computer models will have to simulate all our observations
- * We identified patterns in previous slides
- * Let's detail the observations

☉ The Sun ☉

Radius	<i>695,000 km</i>
Mass	<i>333,000 Earth masses</i>
<Density>	<i>1.41 g/cm³</i>
Composition (by mass)	<i>78% hydrogen, 20% helium, 2% others</i>
Rotational period	<i>25 to 36 days</i>

<Surface temperature>	<i>5,800 K (10,000°F, 5,500°C)</i>
Planets	<i>8</i>



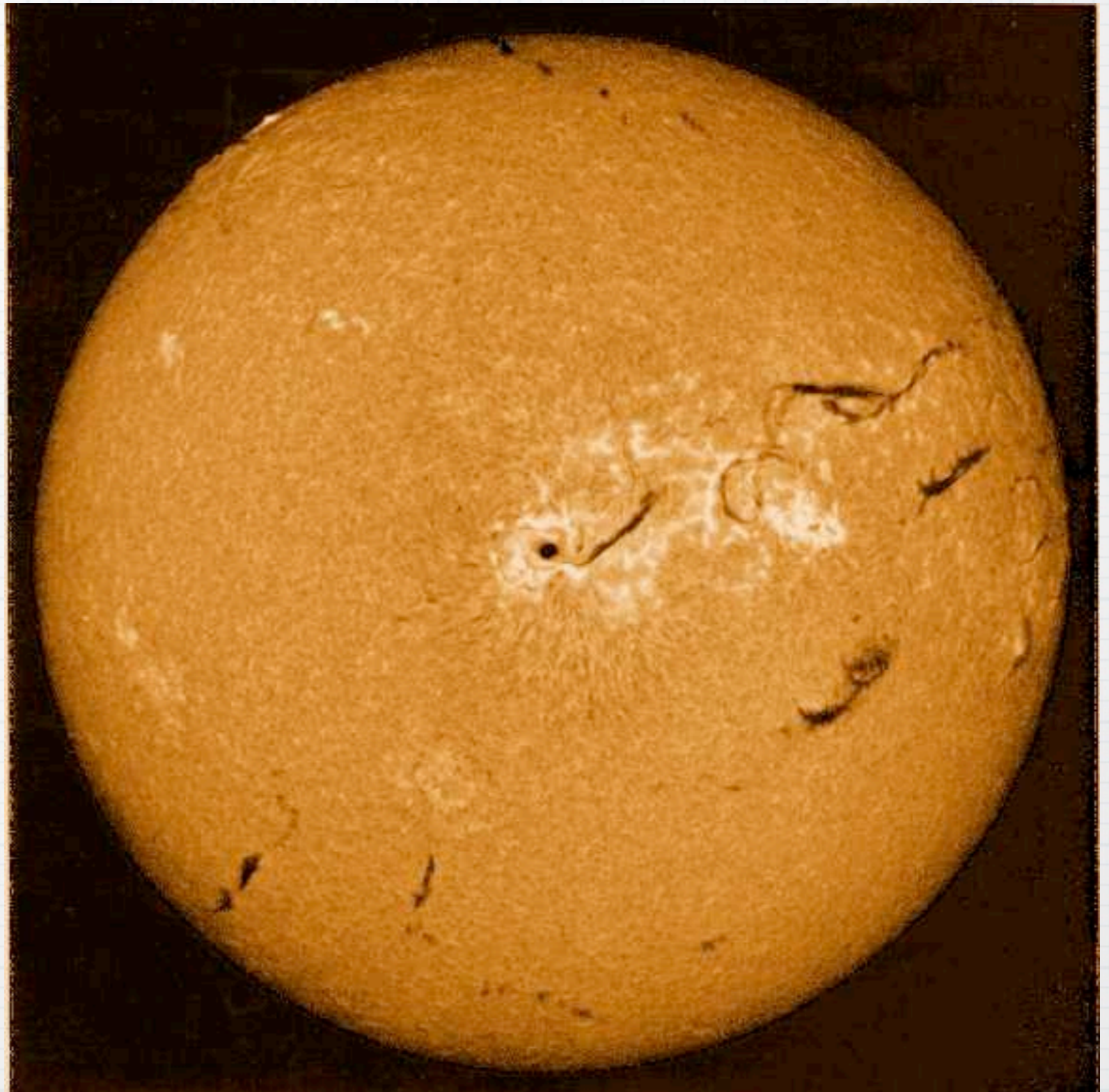
<value> = “mean value”

The Sun

- * The largest & the brightest object in the Solar System
- * Contains **99.9%** of the total mass of the Solar System
- * The surface looks solid but it is a roiling ocean of hot hydrogen and helium gas
- * The surface temperature is **5,800 K**

$$5,800 \text{ K} = 6,100^\circ\text{C} = 11,000^\circ\text{F}$$

The Sun seen with
a special filter
which only lets a
specific emission
line through



$\lambda = \text{H-alpha } (n = 3 \rightarrow 2)$

The Sun...

- * Beside photons, the Sun ejects ionized hydrogen atoms at high speed: **the solar wind**
- * The solar wind is then composed of charged particles (**protons and electrons**)
- * The solar wind affects planetary atmospheres and it eventually blows into interstellar space

♀ Mercury ♀

<Distance from Sun>	<i>0.39 AU</i>
Radius	<i>2,440 km</i>
Mass	<i>0.055 or 1/18 Earth masses</i>
<Density>	<i>5.43 g/cm³</i>
Composition	<i>rocks, metals</i>
Rotational period	<i>58.6 days</i>
solar day	<i>176 days</i>

Axis tilt	<i>0.1°</i>
Orbital inclination	<i>7°</i>
Orbital period	<i>88 days</i>
<Surface temperature>	<i>day - 700 K (800°F, 425°C) night - 100 K (-280°F, -173°C)</i>
Moons	<i>0</i>

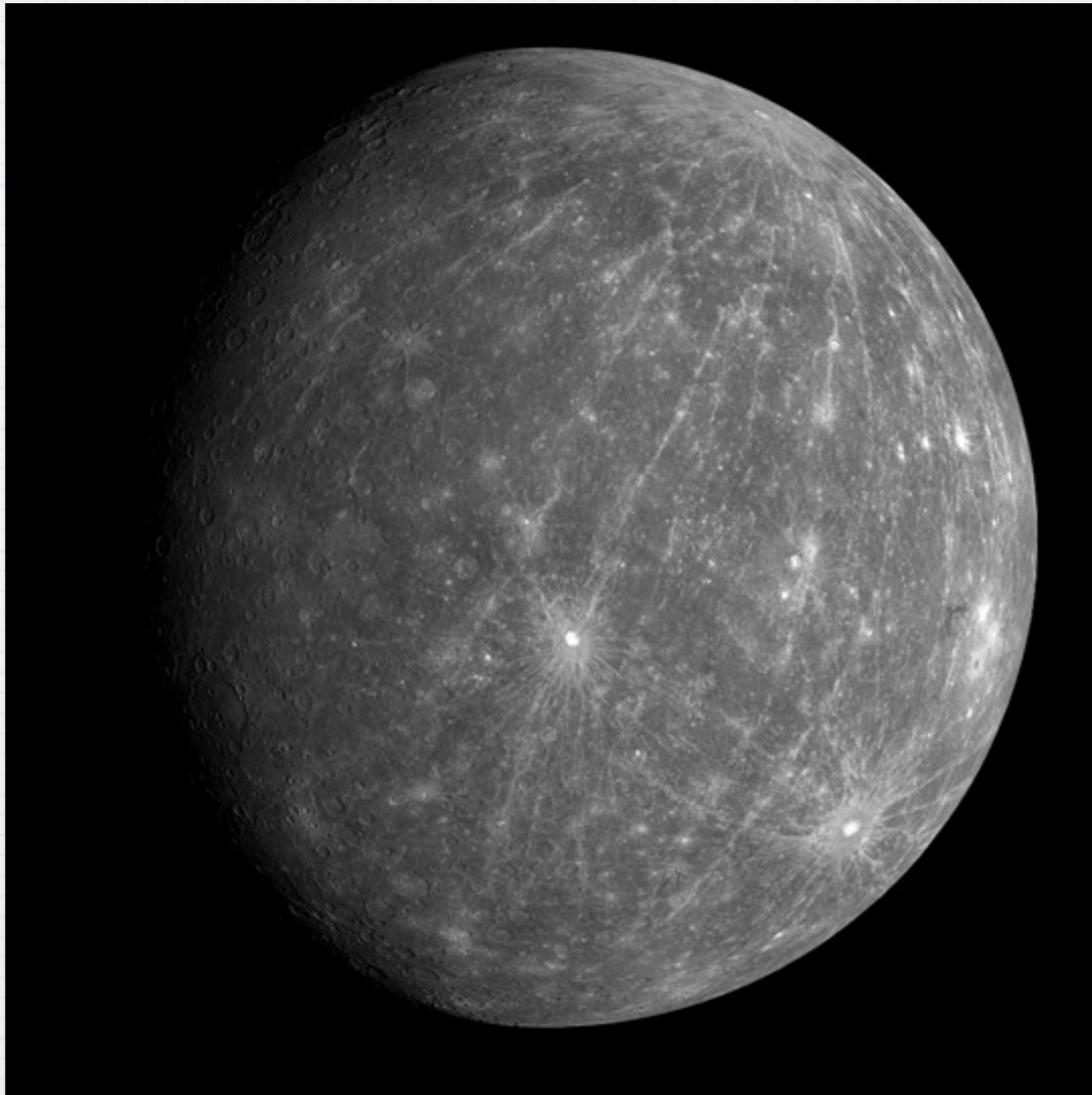
Note: $88 / 58.6 = 1.500$
 $3/2 = \text{spin-orbit resonance}$

Mercury...

- * Smallest planet (40% bigger than our Moon)
- * A dead world (no earthquakes, volcanoes, wind, rain, life)
- * Minimal atmosphere
 - * helium (42%), sodium (42%), oxygen (15%)

Mercury...

- * Craters everywhere
- * Ancient lava flows
- * Tall, steep cliffs hundreds of km in length
- * So close to the Sun that its orbit has an anomaly that Newton's laws cannot solve. But Einstein's do.
- * Water may exist buried at the North Pole



Fault lines:
hundreds of
km in length
and up to 2
km in height



♀ Venus ♀

<Distance from Sun>	<i>0.72 AU</i>
Radius	<i>6,051 km</i>
Mass	<i>0.82 Earth masses</i>
<Density>	<i>5.24 g/cm³</i>
Composition	<i>rocks, metals</i>
Rotational period	<i>243 days</i>

Axis tilt	<i>177.4°</i>
Orbital inclination	<i>3.4°</i>
Orbital period	<i>224.7 days</i>
<Surface temperature>	<i>740 K (870°F, 465°C)</i>
Moons	<i>0</i>

Note: its orbital period is shorter than its rotational one
(Its “year” is shorter than its “day”)

Venus...

- * Similar in size, mass & density as Earth
- * Very dense atmosphere
- * Create a powerful greenhouse effect
- * Surface pressure is equivalent to being 1 km beneath an ocean on Earth
- * Venus is hotter than a pizza oven day or night

Venus...

- * Atmospheric composition
 - * Carbon dioxide (96%), Nitrogen (3+%)
- * Venus' surface has mountains, valleys and craters
- * Shows signs of global volcanic activity (300 million years ago) and some local volcanic activity today

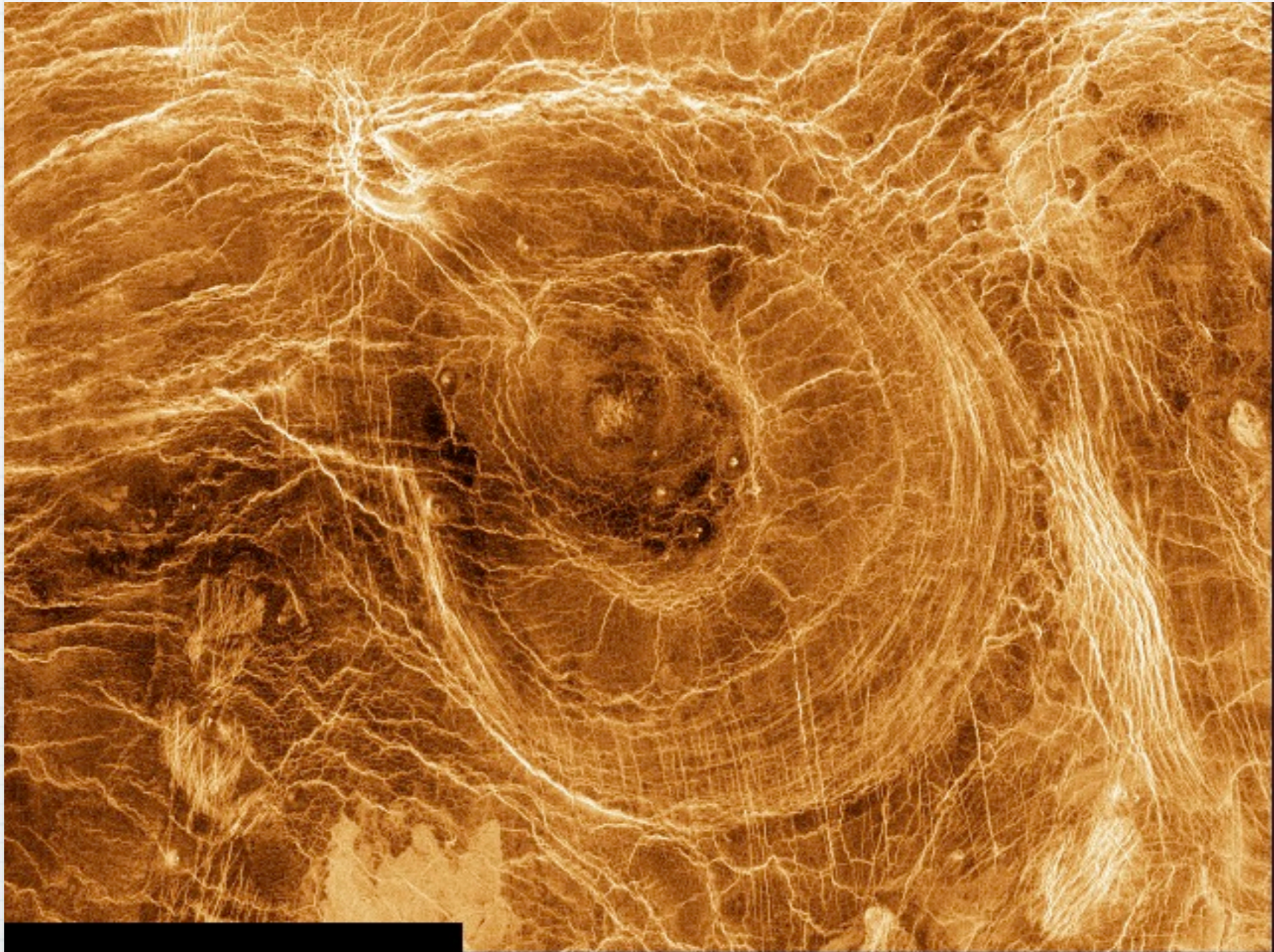


Venus with Visible and Radar Illumination

© Copyright 2000 by Calvin J. Hamilton

© The Essential Cosmic Perspective, 2005 Pearson Education

A unique Venusian geological feature: an arachnoid
Arachnoids may result from magma upwellings



Earth

<Distance from Sun>	<i>1.0 AU</i>
Radius	<i>6,378 km</i>
Mass	<i>1.0 Earth masses</i>
<Density>	<i>5.52 g/cm³</i>
Composition	<i>rocks, metals</i>
Rotational period	<i>23.9345 hours</i>

Axis tilt	<i>23.45°</i>
Orbital inclination	<i>0.0°</i>
Orbital period	<i>365.256 days</i>
<Surface temperature>	<i>290 K (62°F, 17°C)</i>
Moons	<i>1</i>

Note: Its Moon is big, relative to other planets' own moons

Earth...

- * Only known place in the Solar System able to host life (so far...)
- * Oceans cover $3/4$ of its surface
- * Continental land masses and islands
- * Polar caps covered with ice and snow
- * Evidence of advanced life can be seen from space

Earth...

- * Atmospheric composition
 - * Nitrogen (77%), oxygen (21%)
- * White clouds (water vapor) are scattered above the surface
- * Earth's surface has mountains, valleys and few craters can be seen due to an active weather-based erosion
- * Earth has an active geology

Earth and Moon at same scale and relative brightness

The Moon's radius is 27% that of the Earth: no other satellite orbiting other planets in our Solar System is anywhere that big (in comparison)



The Moon in (exaggerated) color



copyright: Noel Carboni

♂ Mars ♂

<Distance from Sun>	<i>1.52 AU</i>
Radius	<i>3,397 km</i>
Mass	<i>0.11 or 1/9 Earth masses</i>
<Density>	<i>3.93 g/cm³</i>
Composition	<i>rocks, metals</i>
Rotational period	<i>1.03 days</i>

Axis tilt	<i>25.19°</i>
Orbital inclination	<i>1.85°</i>
Orbital period	<i>687 days (1.88 years)</i>
<Surface temperature>	<i>240 K (-81°F, -63°C) to (68°F, 20°C)</i>
Moons	<i>2</i>

Note: Its 2 moons are very small (captured asteroids)

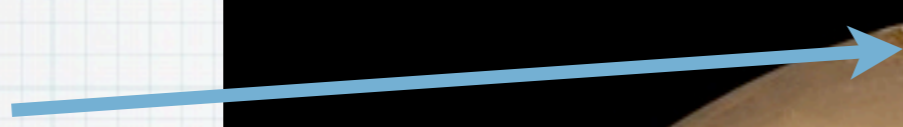
Mars...

- * Larger than Mercury and the Moon and smaller than Earth and Venus
- * Atmospheric composition
 - * Carbon Dioxide (95.32%), Nitrogen (2.7%), Argon (1.6%), Oxygen (0.13%),...
 - * Contains 1/1000 as much water as Earth's air. Yet clouds can form

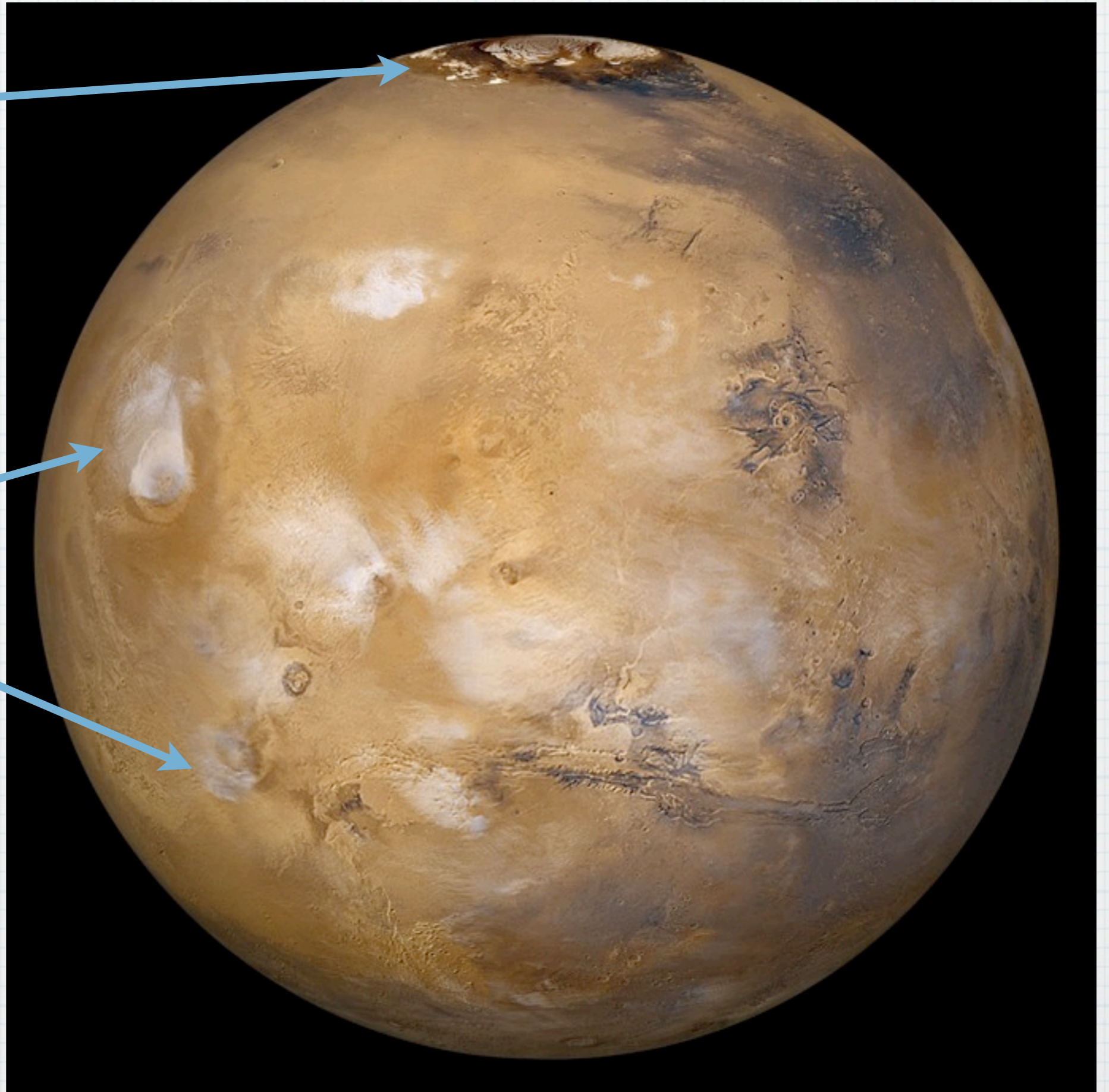
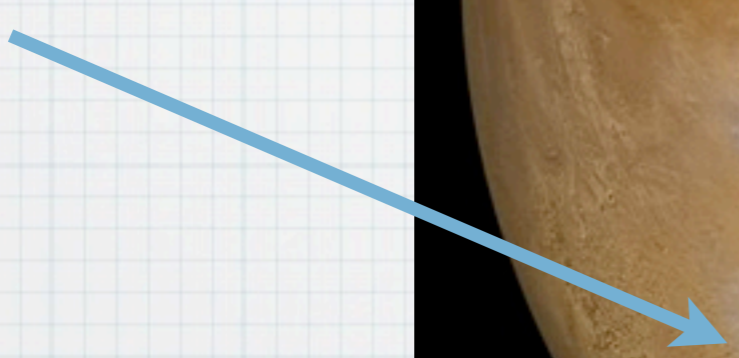
Mars...

- * Has humongous extinct volcanoes
- * Has a great canyon that runs along 1/5th the planet
- * Shows evidence of past riverbeds and floodplains
- * Mars dried up about 3 billion years ago
- * Polar caps made of frozen carbon dioxide (dry ice) and water ice

**Northern
Ice Cap**

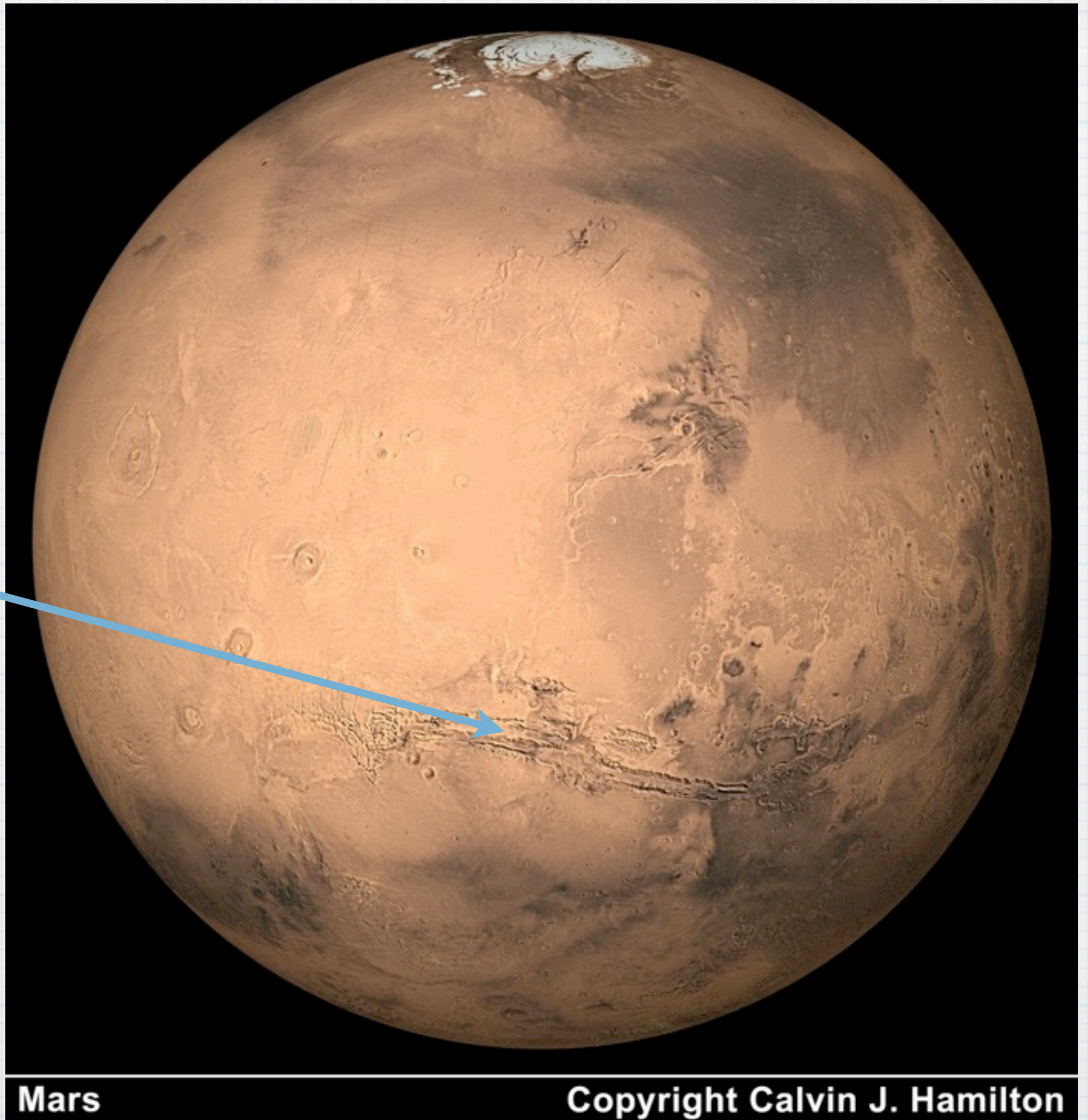


**Bluish-
white
water
ice
clouds**



© The Essential Cosmic Perspective, 2005 Pearson Education

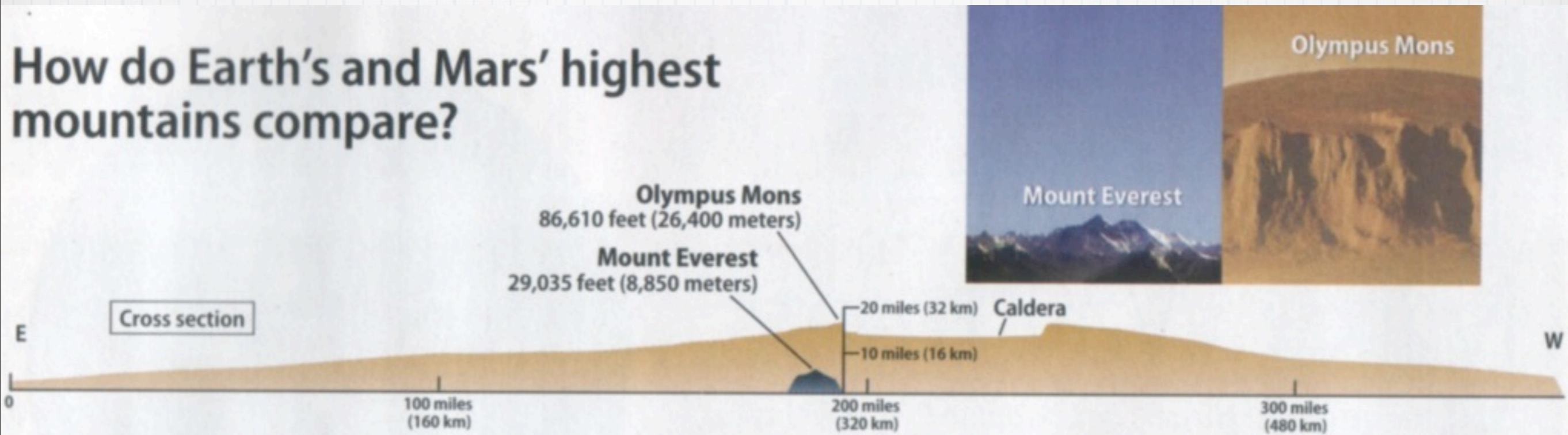
**Valles
Marineris**
(3,000 km
long & up
to 8 km
deep)



Mars

Copyright Calvin J. Hamilton

How do Earth's and Mars' highest mountains compare?



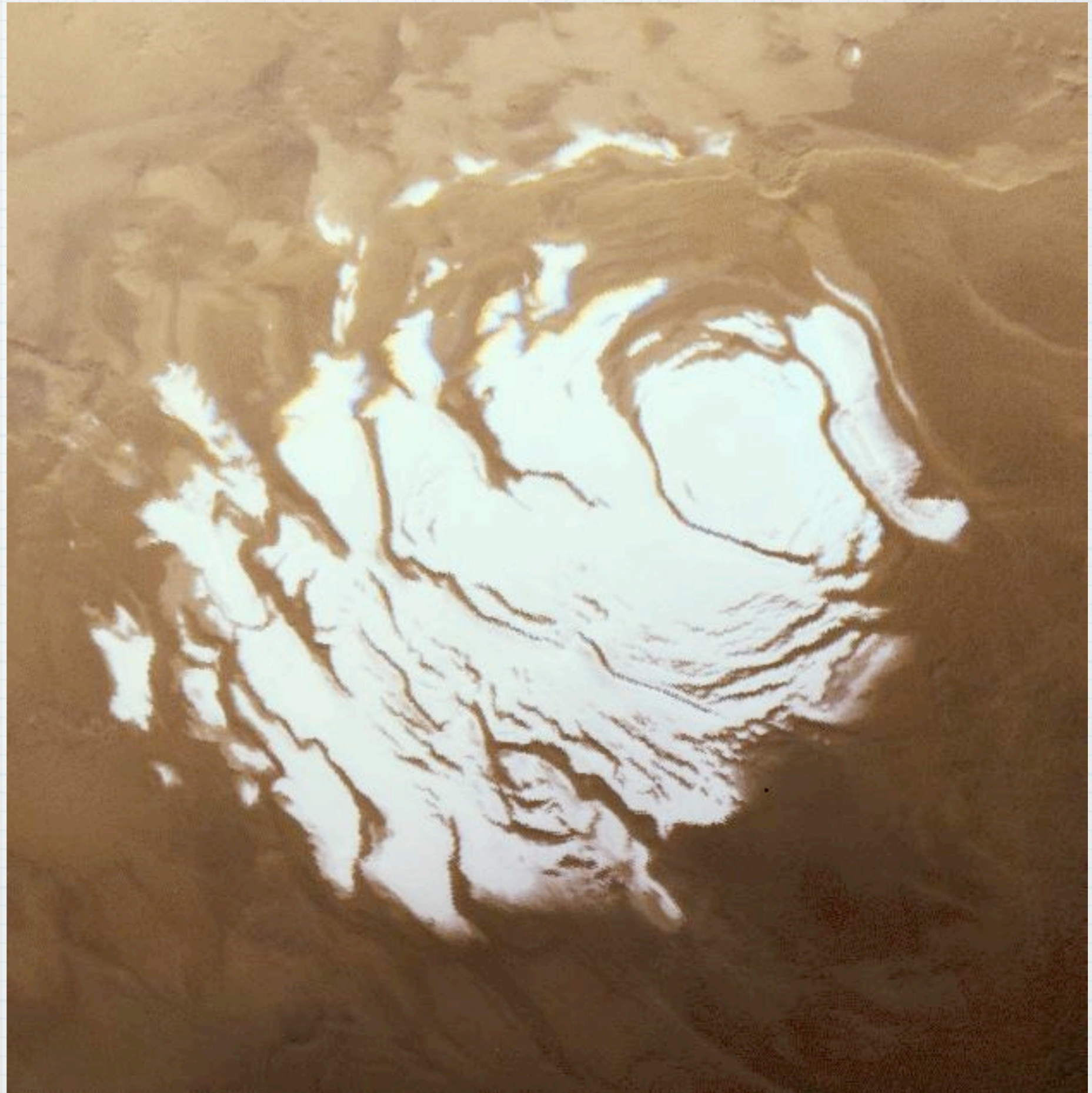
Mars' Olympus Mons, the tallest known mountain in the solar system, is 86,610 feet (26,400 meters) high. It easily dwarfs Mount Everest, Earth's highest mountain on land, both in height and in width. *Astronomy: Roen Kelly*

**Streamlined
Islands**
found
north-east
of Valles
Marineris



© The Essential Cosmic Perspective, 2005 Pearson Education

South Polar Cap
(at its minimum
size of 400 km)
**Mostly composed
of frozen carbon
dioxide**



© The Essential Cosmic Perspective, 2005 Pearson Education

24 Jupiter 24

<Distance from Sun>	<i>5.20 AU</i>
Radius	<i>71,492 km</i>
Mass	<i>318 Earth masses</i>
<Density>	<i>1.33 g/cm³</i>
Atmospheric composition	<i>90% hydrogen, 10% helium</i>
Rotational period	<i>0.414 days (9.94 hours)</i>

Axis tilt	<i>3.13°</i>
Orbital inclination	<i>1.31°</i>
Orbital period	<i>11.9 years</i>
<Top cloud temperature>	<i>125 K (-234°F, -148°C)</i>
Moons	<i>67+</i>
Rings	<i>8 thin rings</i>

Jupiter...

- * It is the biggest planet in the Solar System
- * Its volume is more than 1,000 times that of the Earth
- * Its most famous feature is a huge and long-lived storm called the Red Spot

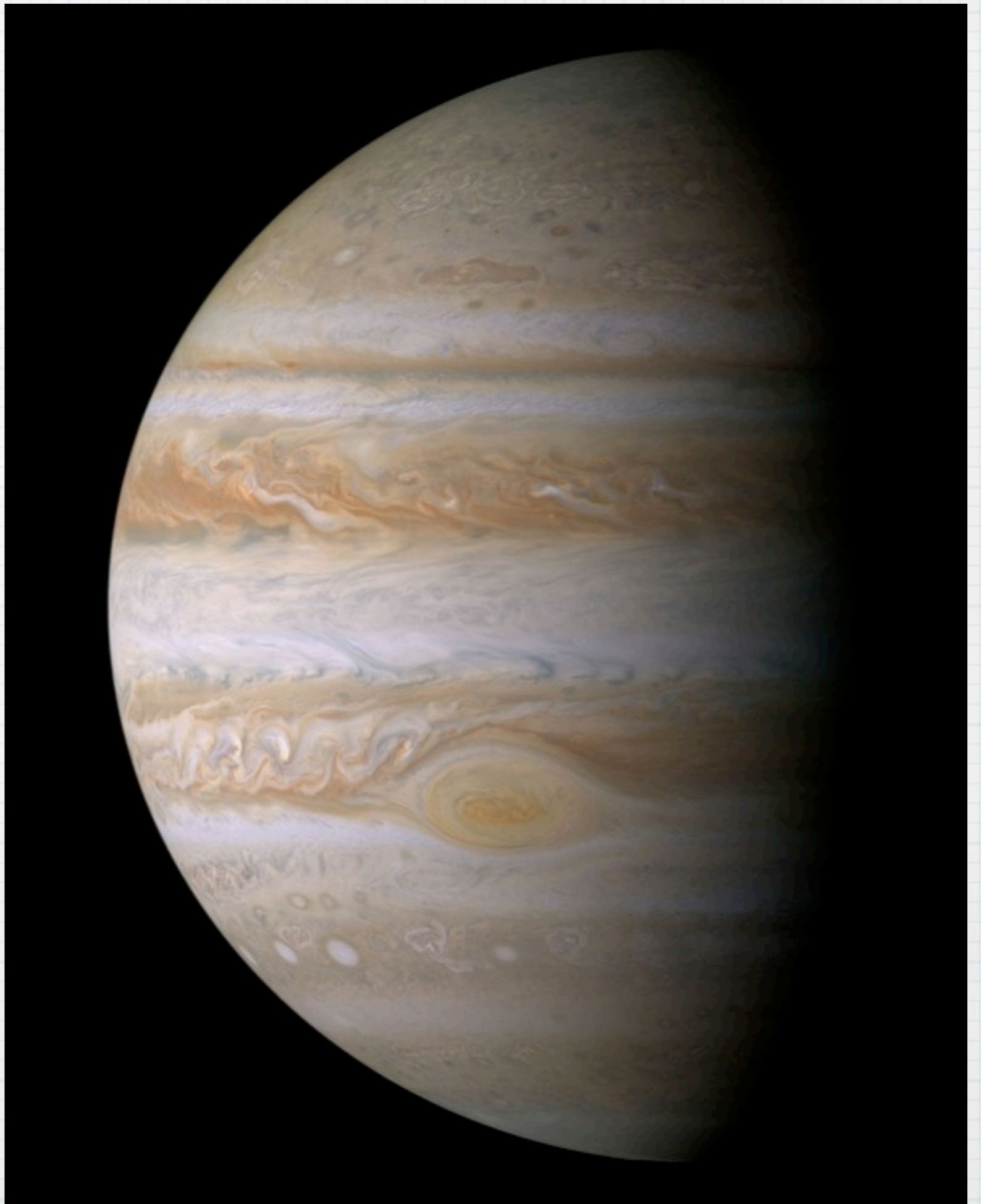
Jupiter...

- * Jupiter has no solid surface
- * If you were to plunge into it, you would eventually be crushed (and cooked) by the increasing gas pressure and temperature
- * At great depths within Jupiter, the pressure is so great that the electrons are freed from their hydrogen atoms and the hydrogen becomes “**metallic**” (being able to conduct electricity)

Jupiter...

- * Its four largest moons are similar or larger in size than our Moon
- * Ganymede is larger than Mercury and is the largest moon in the Solar System
- * Io is the most active volcanic place in the Solar System
- * Europa has an icy crust and may hide an ocean of liquid water
- * Ganymede and Callisto may, too, have subsurface oceans

True color mosaic
Taken by Cassini



Great Red Spot





Amalthea

Io

Europa

Ganymede

Callisto

♄ Saturn ♄

<Distance from Sun>	<i>9.54 AU</i>
Radius	<i>60,268 km</i>
Mass	<i>95.2 Earth masses</i>
<Density>	<i>0.70 g/cm³</i>
Atmospheric composition	<i>97% hydrogen, 3% helium</i>
Rotational period	<i>0.426 days (10.23 hours)</i>

Axis tilt	<i>25.33°</i>
Orbital inclination	<i>2.5°</i>
Orbital period	<i>29.5 years</i>
<Top cloud temperature>	<i>95 K (-288°F, -178°C)</i>
Moons	<i>62+</i>
Rings	<i>Lots of rings</i>

Note: Saturn's largest moon, Titan, is bigger than Mercury

Saturn...

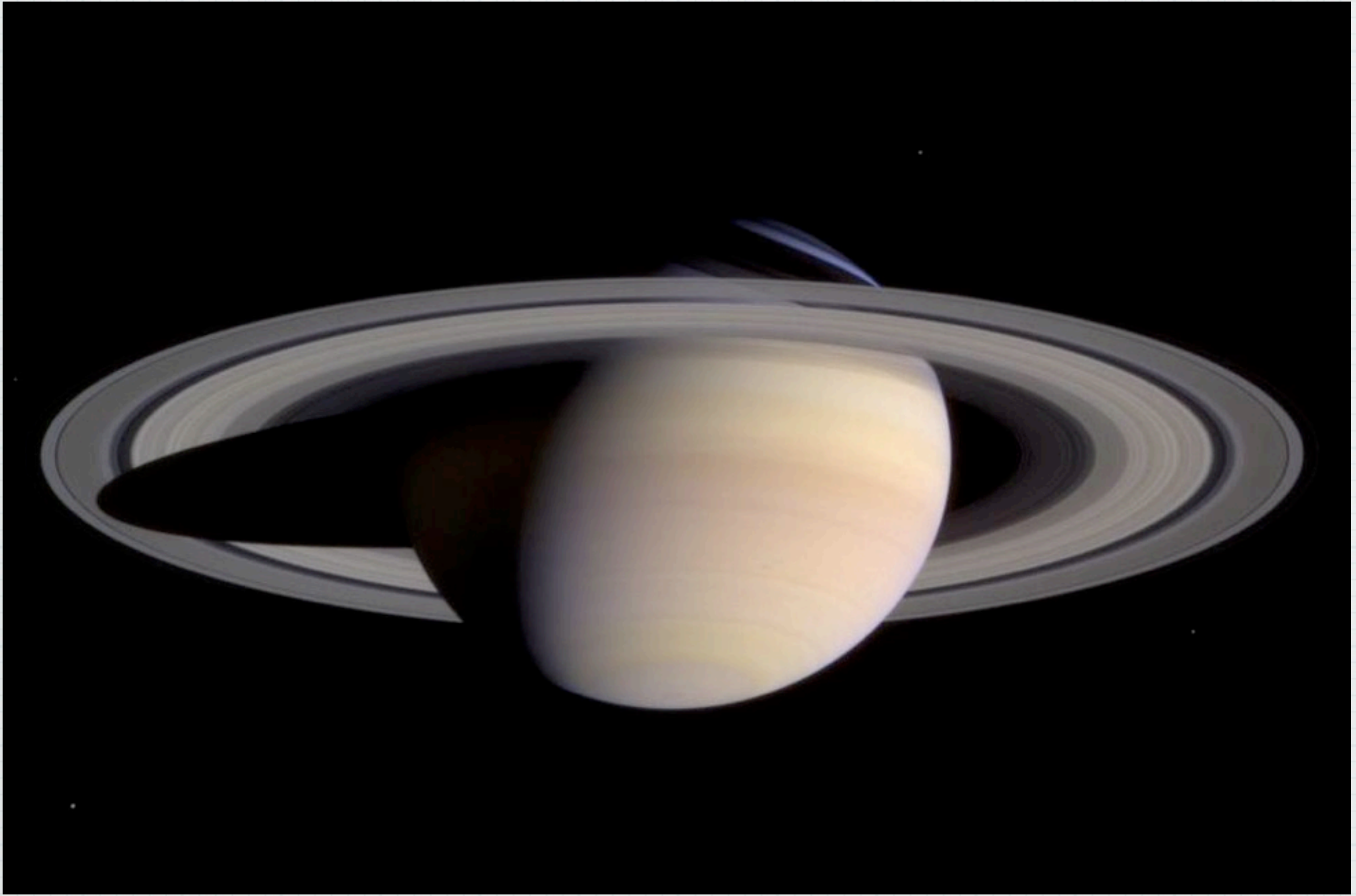
- * Second largest planet in our Solar System
- * But much less massive (1/3 Jupiter's)
- * Saturn is the only planet less dense than water
- * Like Jupiter, Saturn has no solid surface

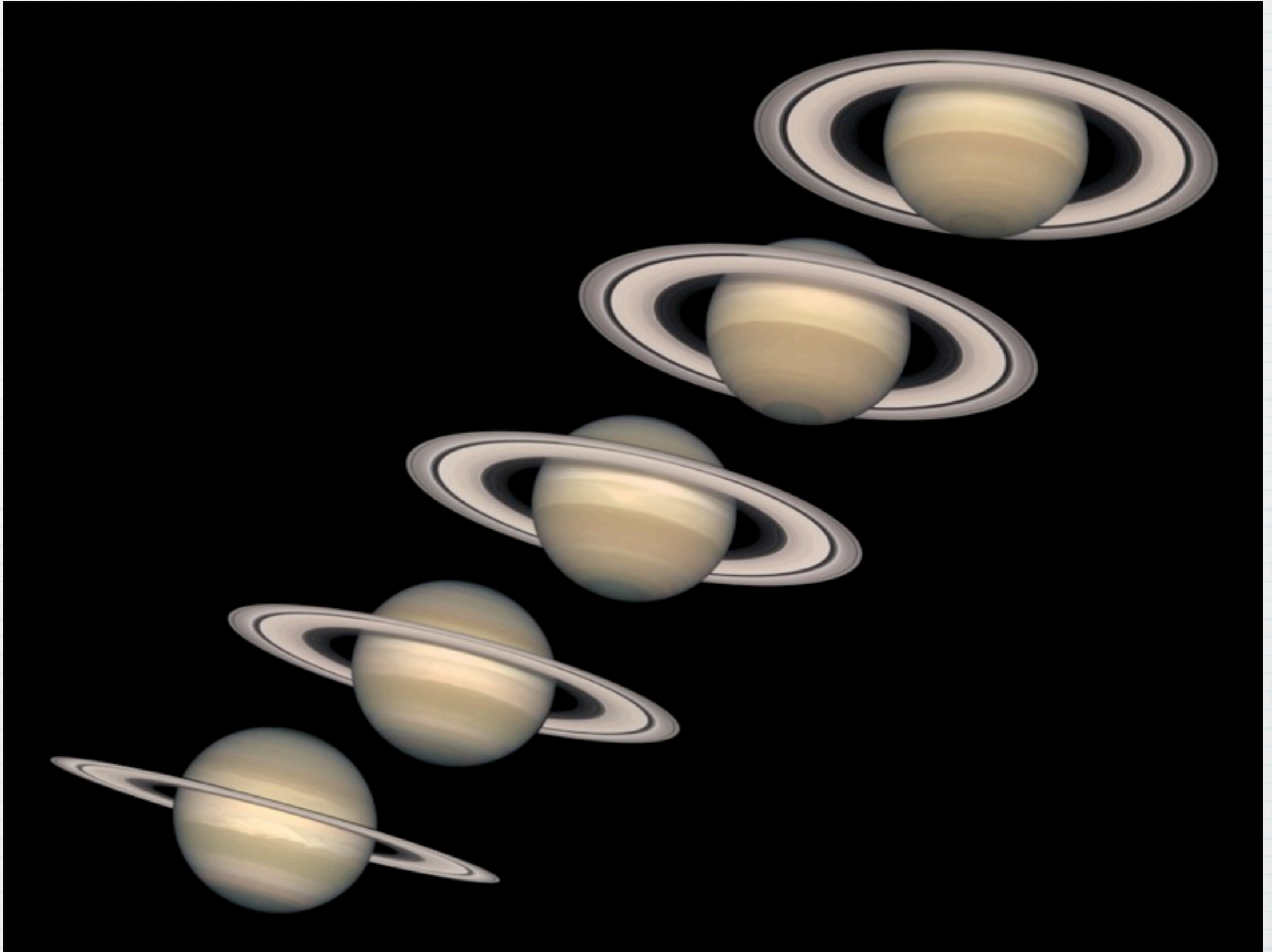
Saturn...

- * Saturn is famous for its spectacular rings which can be easily seen from Earth with a small telescope
- * The rings look solid but they are composed of countless particles of rock and ice sizing from dust to city blocks

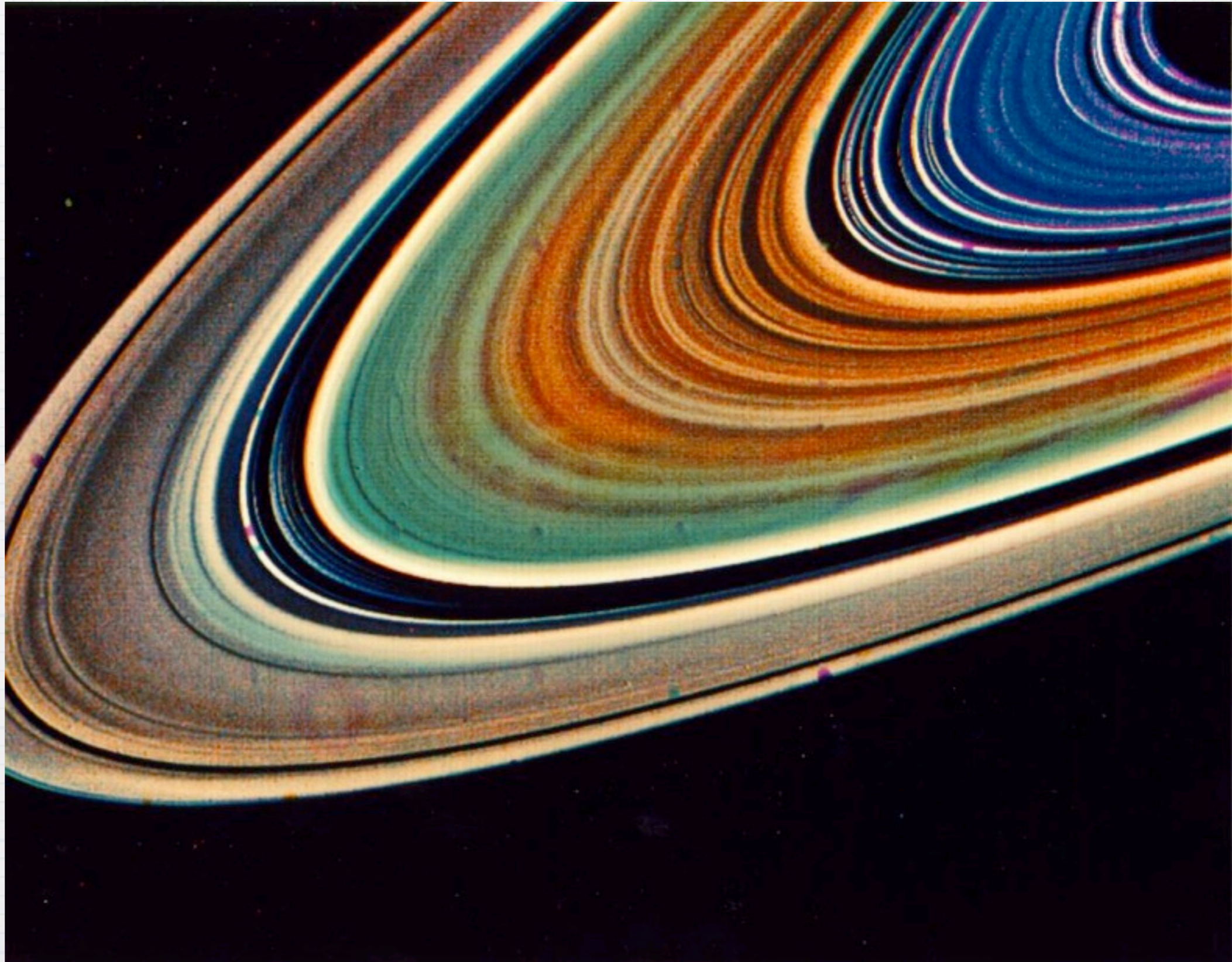
Saturn...

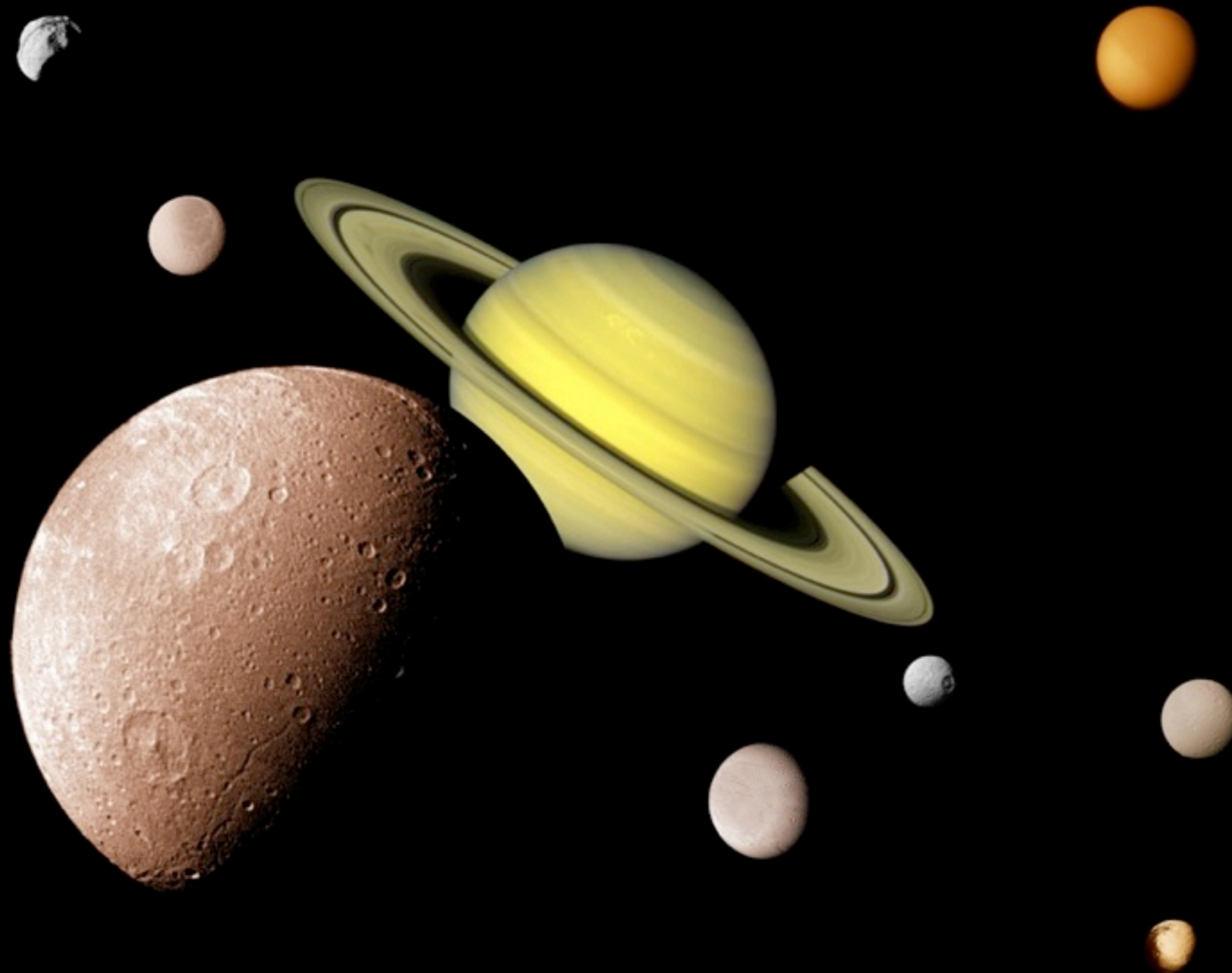
- * Many moons orbit Saturn
- * Titan is larger than Mercury and is the second largest moon in the Solar System
- * Titan has a thick but frigid atmosphere and its nitrogen contents are similar to Earth's but without oxygen





False Color Image of Saturn's Rings





The Saturn System

© Copyright 1998 by Calvin J. Hamilton

♃ Uranus ♃

<Distance from Sun>	<i>19.2 AU</i>
Radius	<i>25,559 km</i>
Mass	<i>14.5 Earth masses</i>
<Density>	<i>1.32 g/cm³</i>
Atmospheric composition	<i>83% hydrogen, 15% helium, 2% methane</i>
Rotational period	<i>-0.746 days (-17.9 hours)</i>

Axis tilt	<i>97.86°</i>
Orbital inclination	<i>0.8°</i>
Orbital period	<i>84 years</i>
<Top cloud temperature>	<i>60 K (-351°F, -213°C)</i>
Moons	<i>27+</i>
Rings	<i>11 thin rings</i>

Note: The methane gives Uranus its pale blue-green color

Uranus...

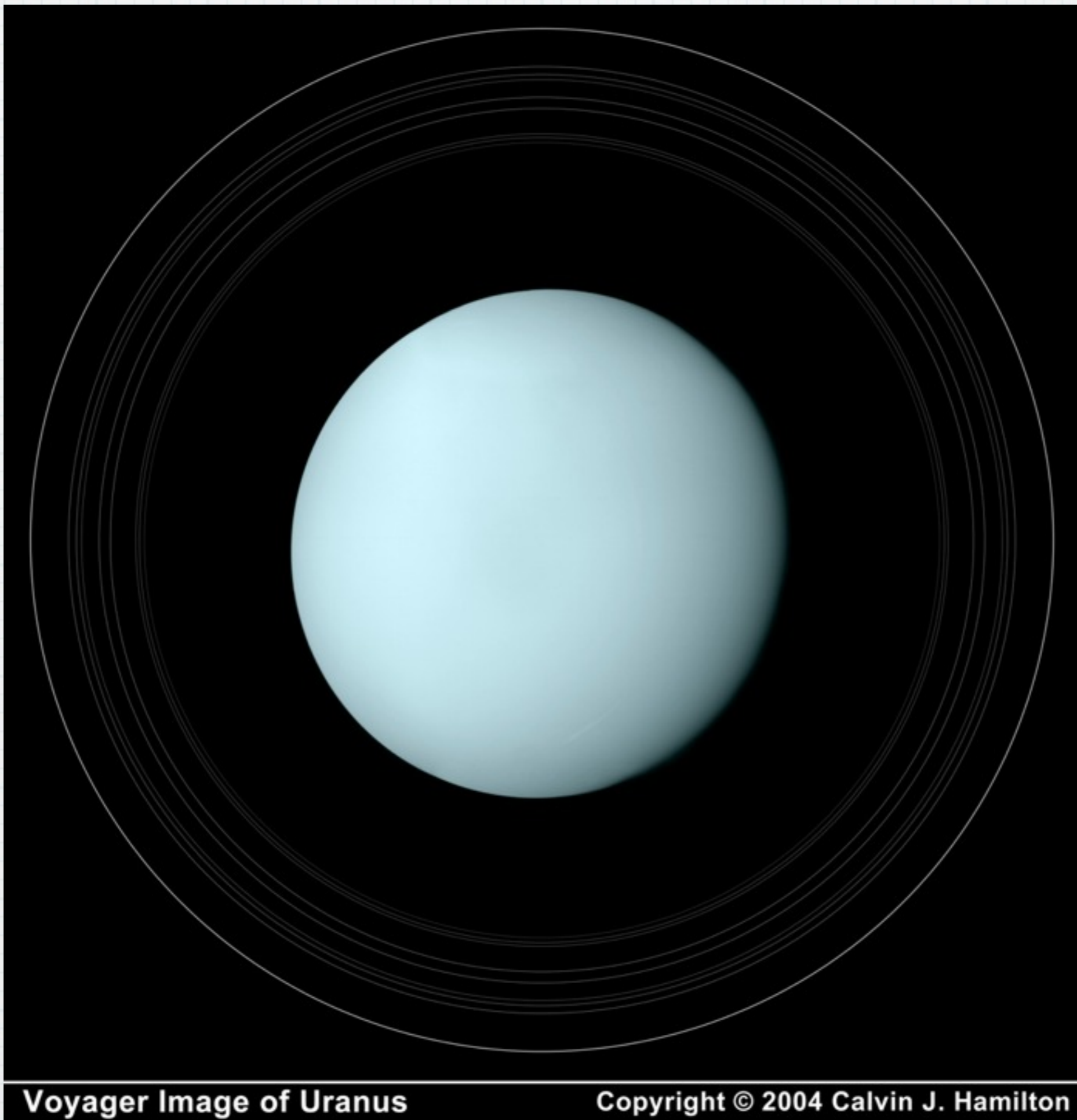
- * Third largest planet in our Solar System
- * But much smaller than Jupiter & Saturn
- * Great name to pronounce after a few drinks at a party

Uranus...

- * The planet with its rings and satellites is tipped on its side
- * Probably due to a cataclysmic collision when the planet was forming some 4.6 billion years ago
- * Its season patterns are then extreme: at a pole, daylight lasts 42 years followed by a 42-year night

Uranus...

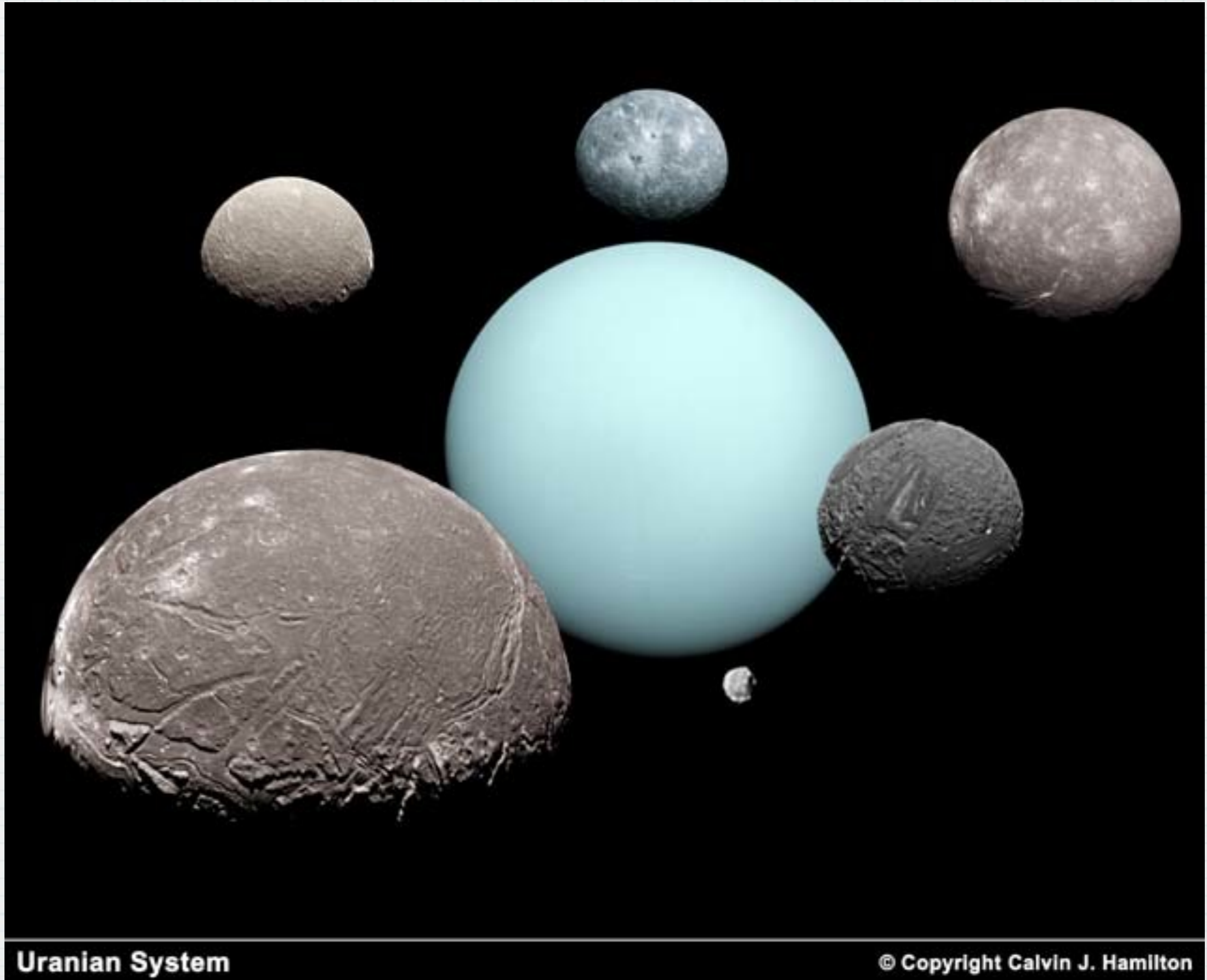
- * Uranus has 11 very thin rings ("ringlets")
- * The planet was discovered in 1781 by William Herschel
- * So were its two largest moons, Titania & Oberon



Voyager Image of Uranus

Copyright © 2004 Calvin J. Hamilton

Photo montage



Uranian System

© Copyright Calvin J. Hamilton

♃ Neptune ♃

<Distance from Sun>	<i>30.1 AU</i>
Radius	<i>24,764 km</i>
Mass	<i>17.1 Earth masses</i>
<Density>	<i>1.64 g/cm³</i>
Atmospheric composition	<i>80% hydrogen, 18% helium, 2% methane</i>
Rotational period	<i>0.671 days (16.11 hours)</i>

Axis tilt	<i>29.56°</i>
Orbital inclination	<i>1.8°</i>
Orbital period	<i>164.8 years</i>
<Top cloud temperature>	<i>60 K (-351°F, -213°C)</i>
Moons	<i>13+</i>
Rings	<i>4 thin rings</i>

Note: Neptune was discovered because Uranus' orbit was irregular

Neptune...

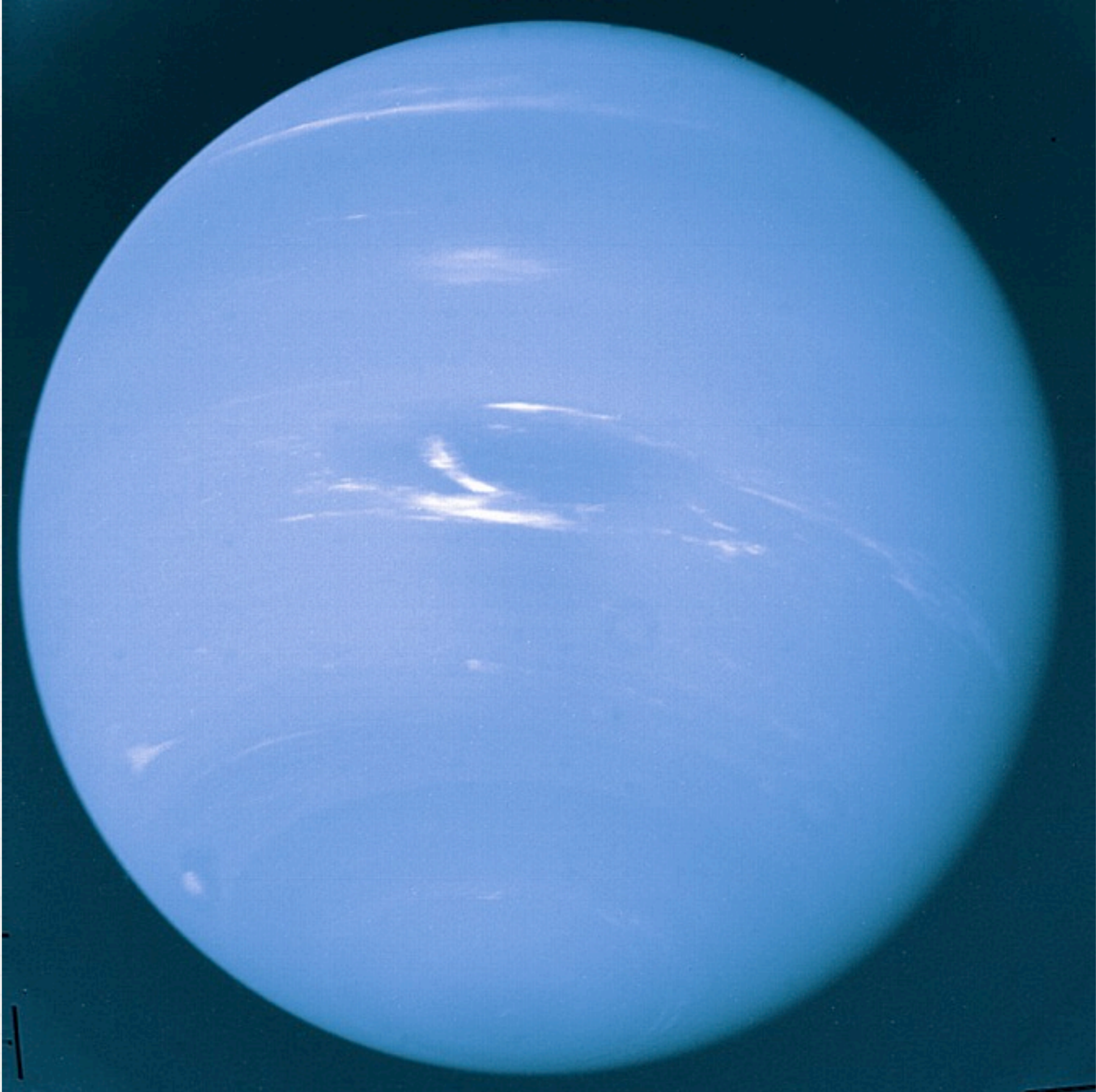
- * Fourth largest planet in our Solar System
- * Very similar in size and composition than Uranus (but weighs more)
- * It is bluer than Uranus
- * Neptune has a Great Dark Spot (long lasted storm)

Neptune...

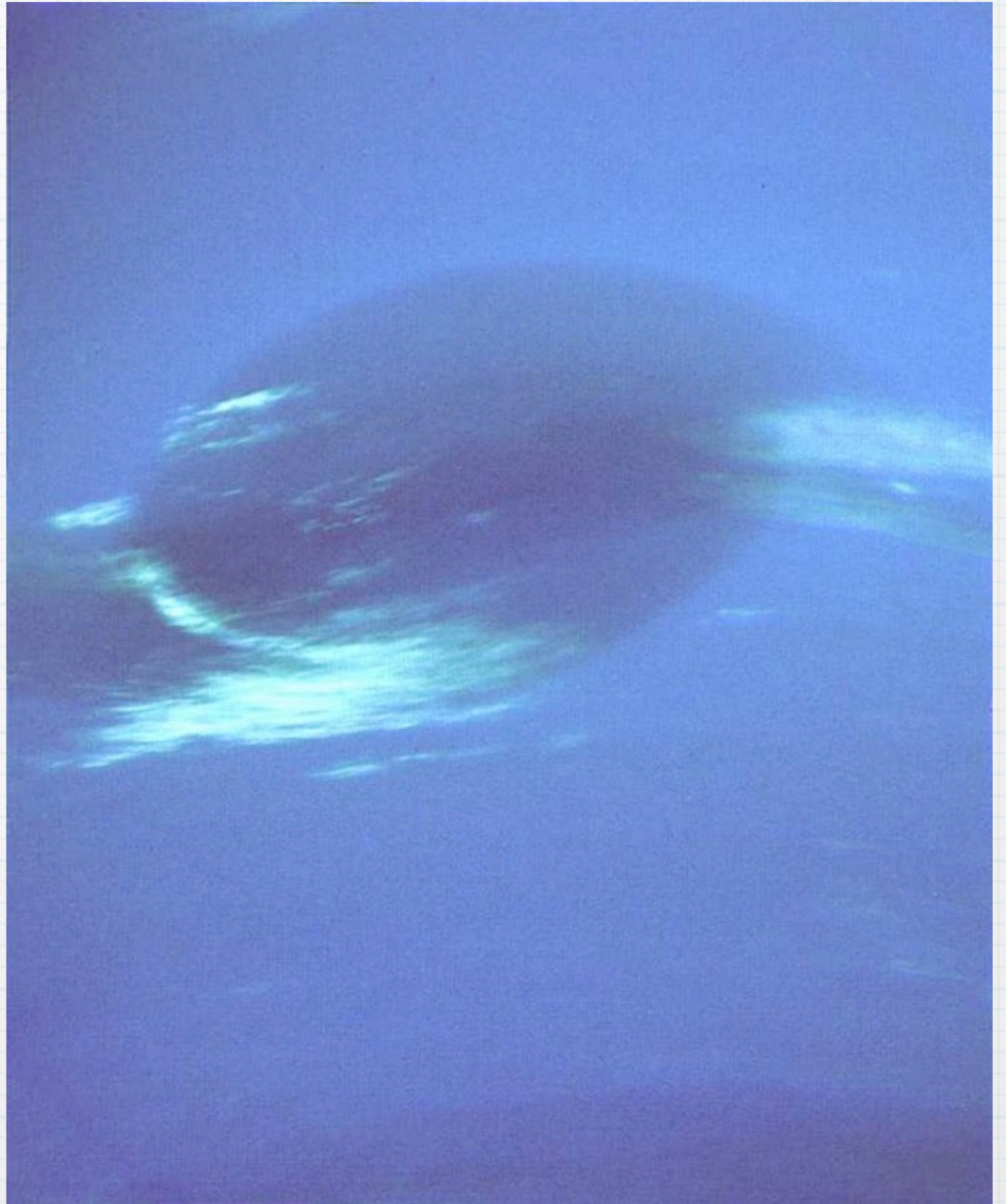
- * Neptune has 4 sets of rings
- * Its largest moon, Triton, is one of the most fascinating moons in the Solar System:
 - ➔ It orbits Neptune backwards
 - ➔ Its icy surface has features that appear like geysers but spew nitrogen gas: volcanoes spewing ice!

Neptune...

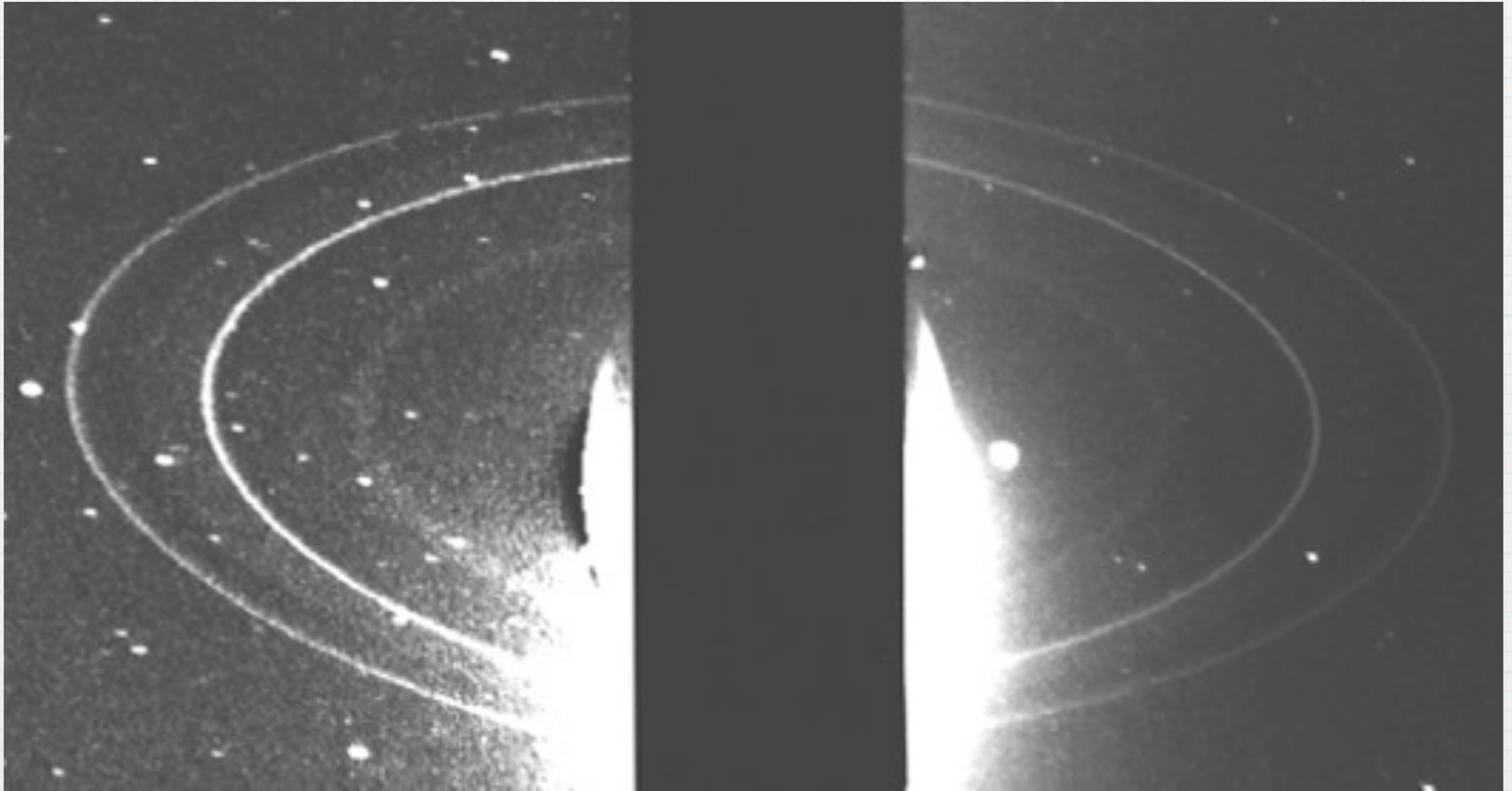
- * Neptune was the first planet to be found by mathematical prediction
- * Uranus' predicted orbital path was showing small deviations compared to its measured orbital path
- * Neptune was discovered in 1846 by Johann Gottfried Galle & Louis d'Arrest through mathematical predictions made by Urbain Jean Joseph Le Verrier



**View from 370,000
miles from the planet**



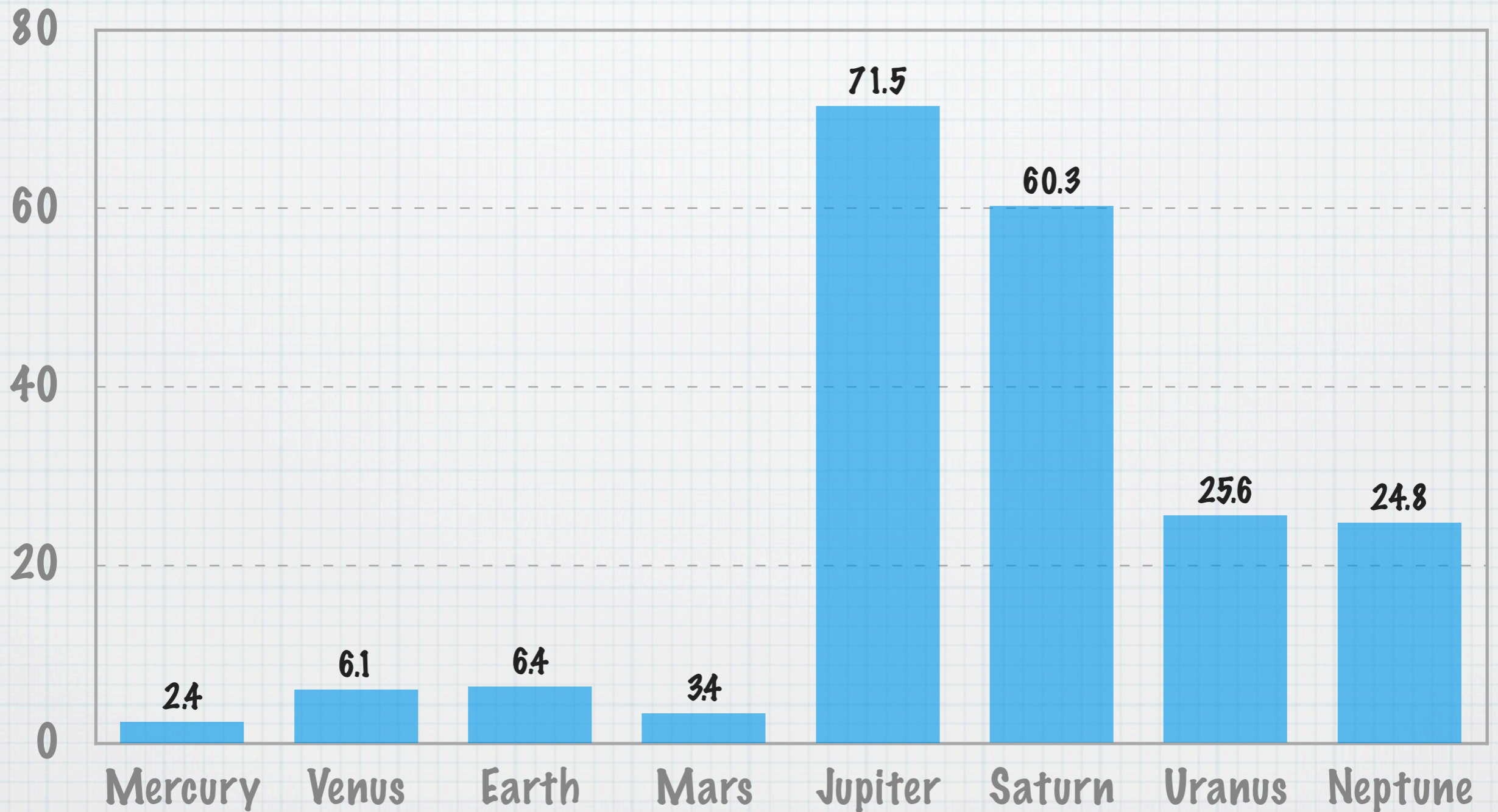
Neptune's rings



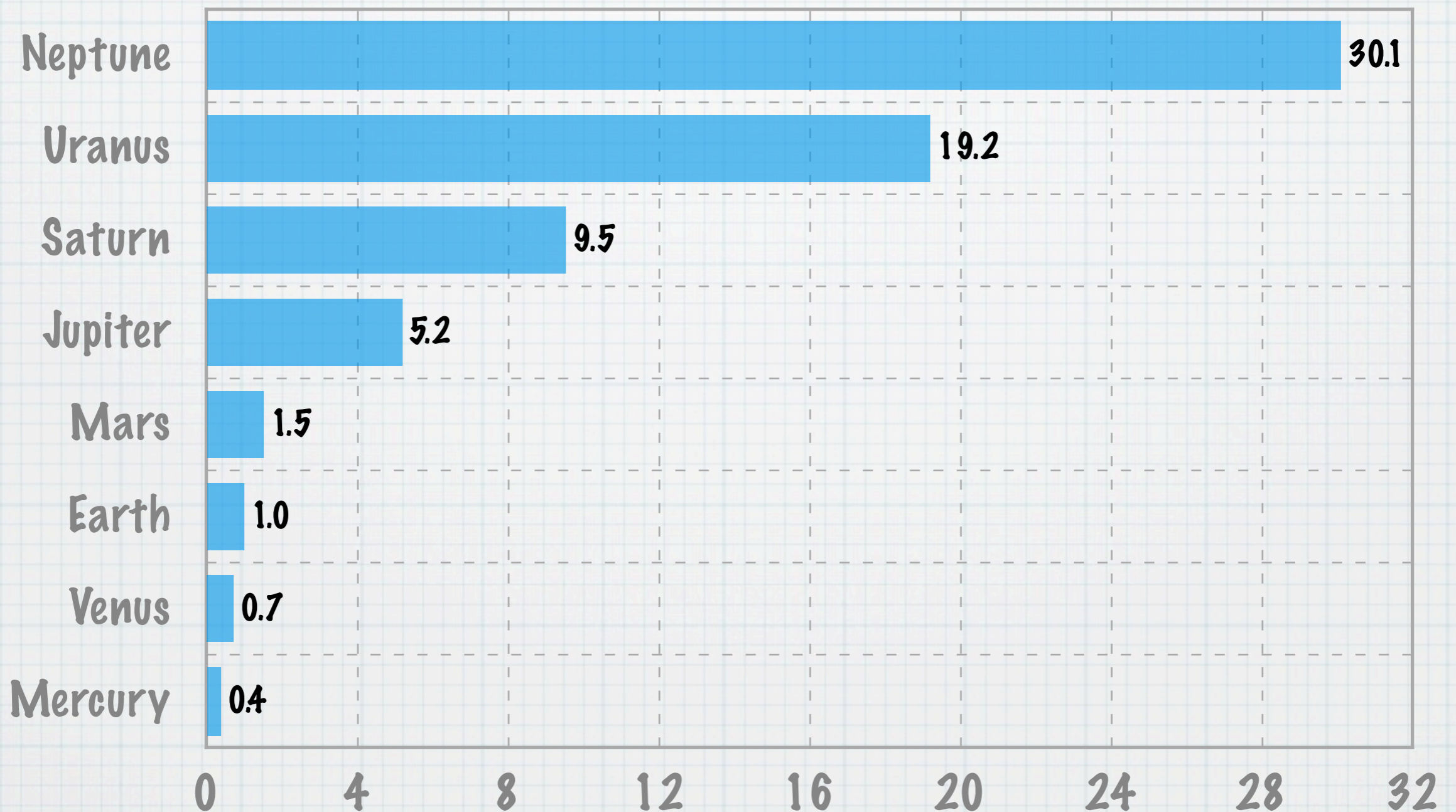
Comparing Planets

(radius in 1,000 km)

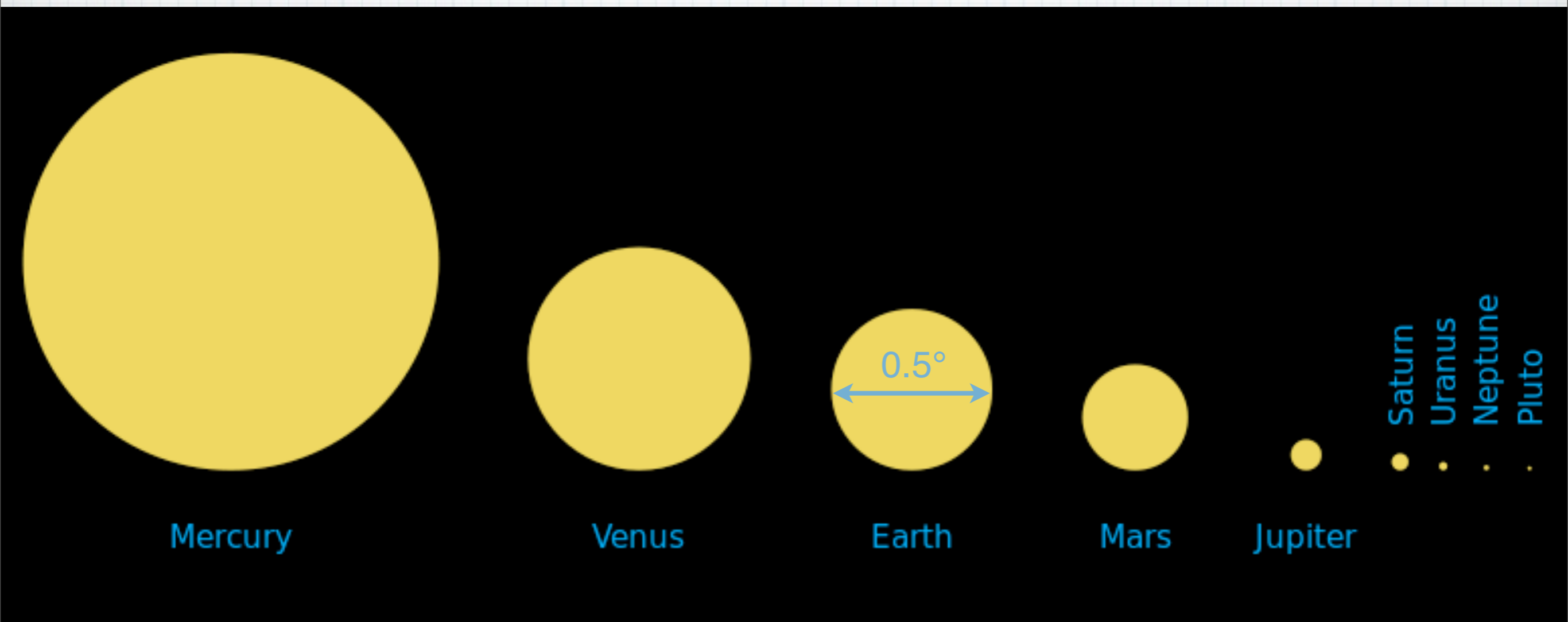
Sun: 695



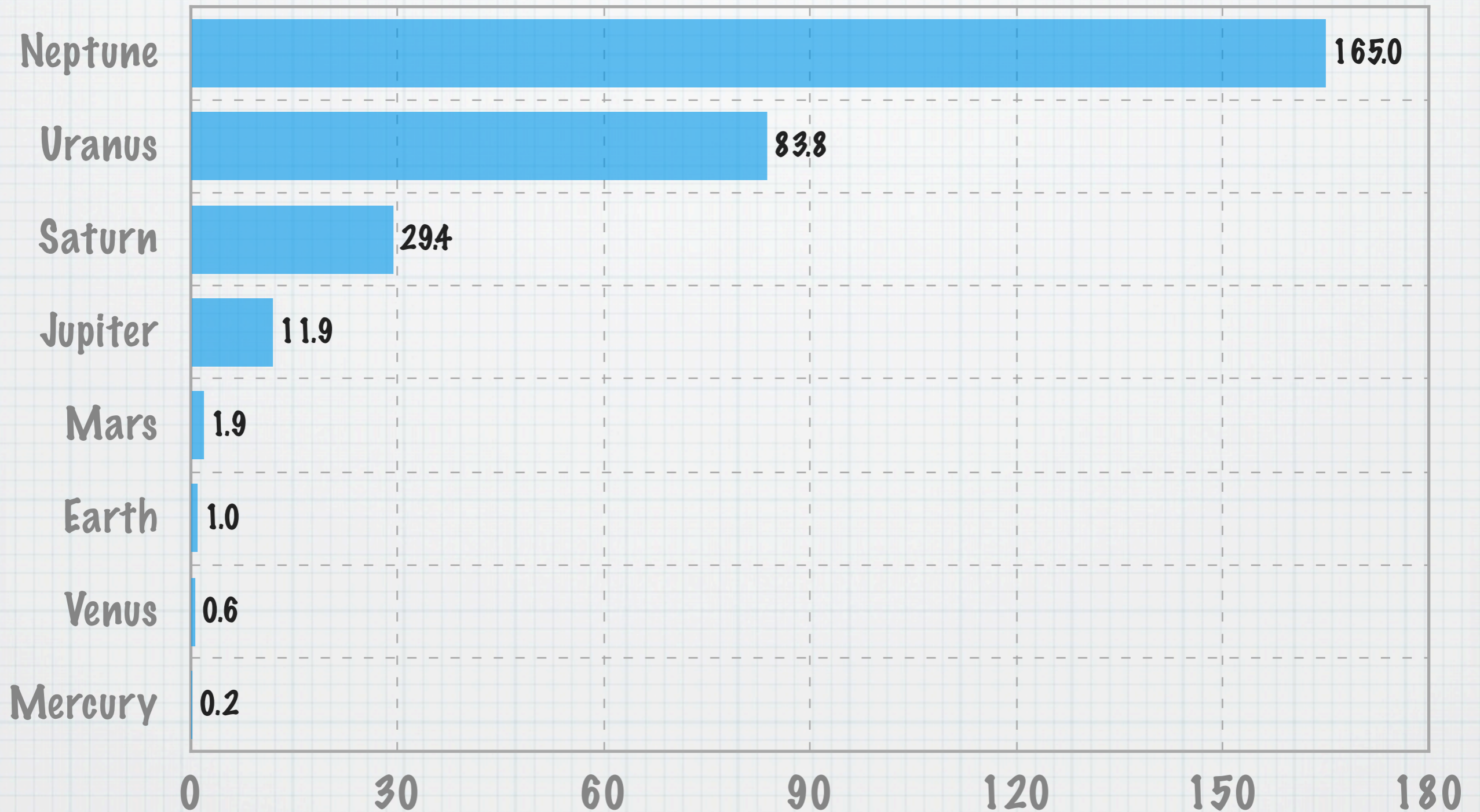
Comparing Planets (distance from Sun [AU])



How big the Sun looks in the local sky as seen from



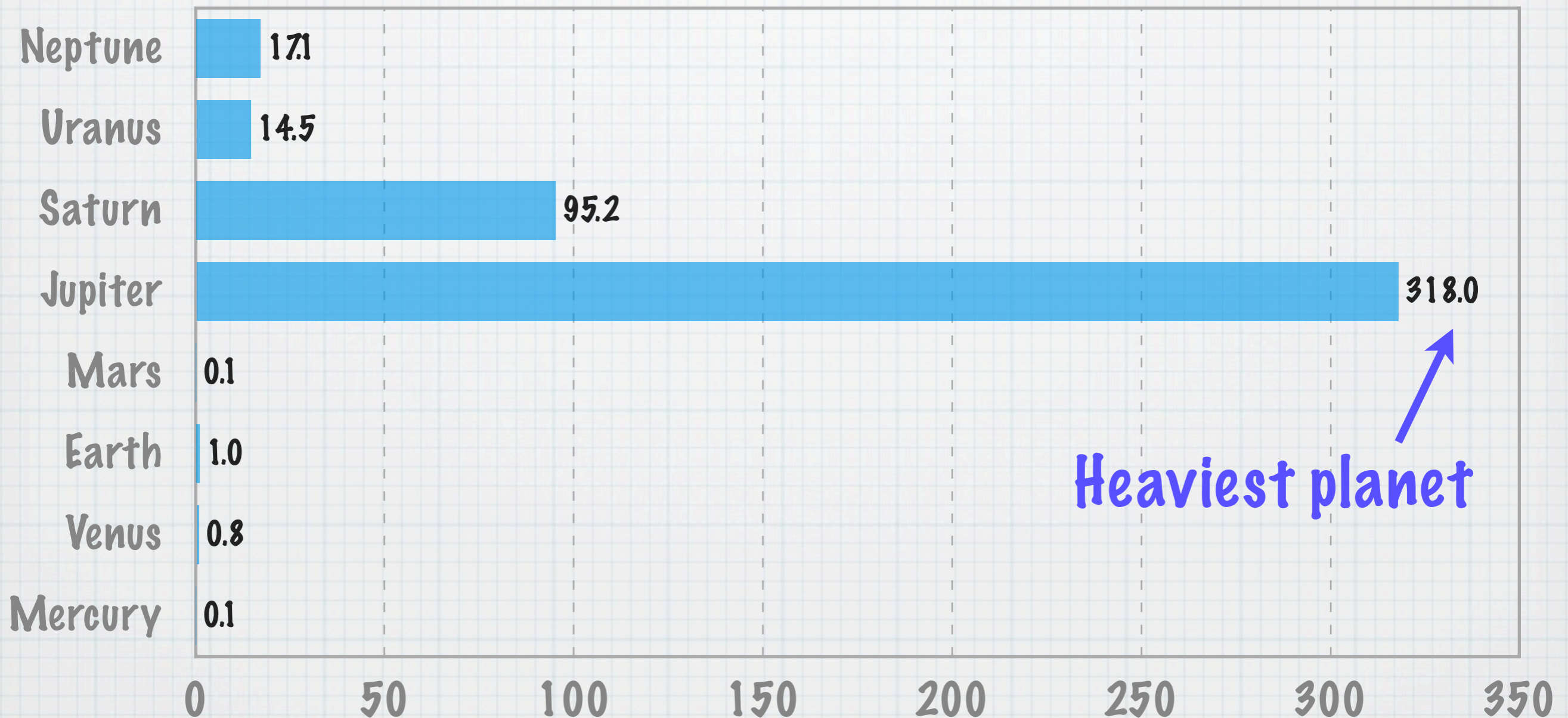
Comparing Planets (orbital period [years])



Comparing Planets

(mass in Earth unit)

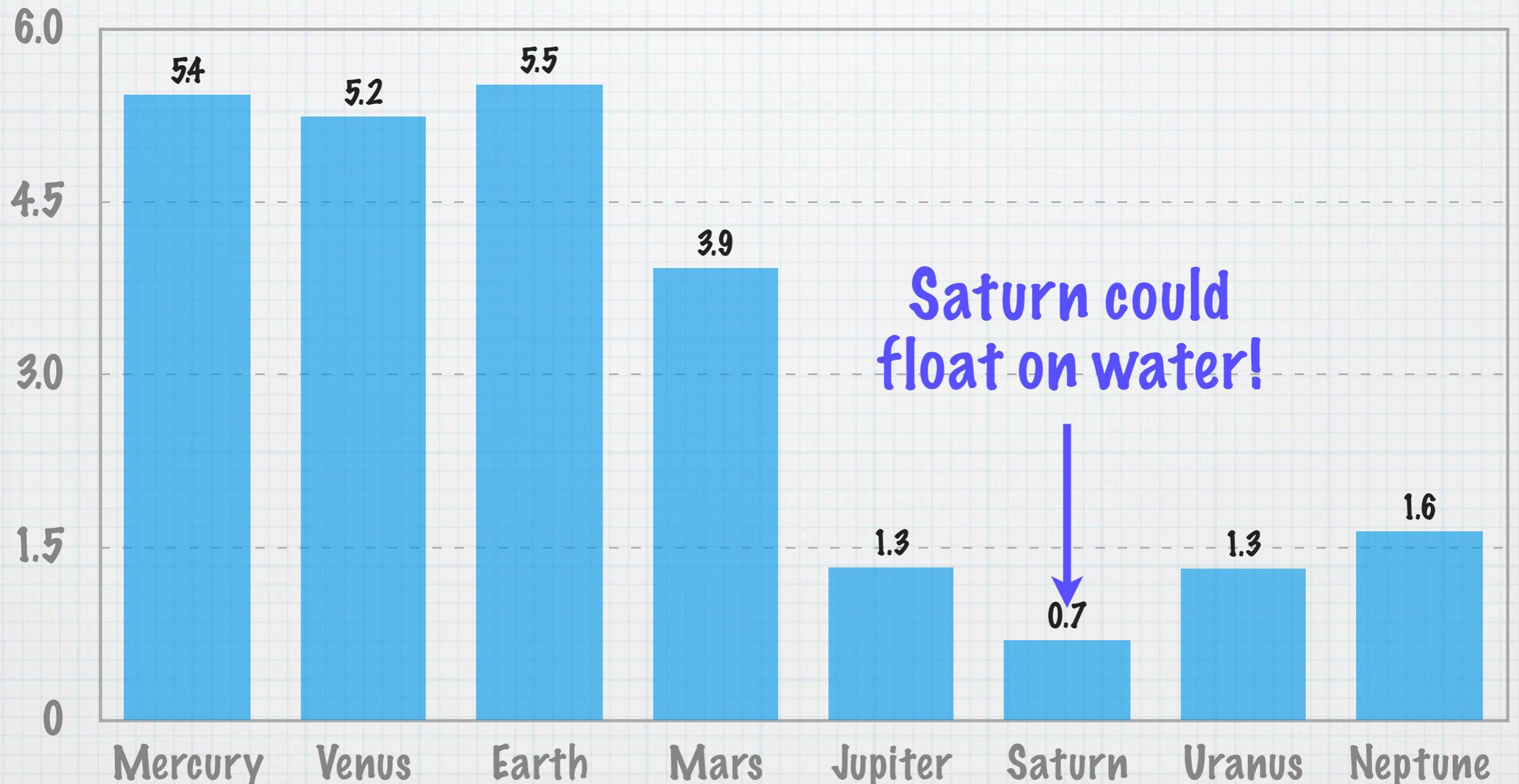
Sun: 333,000



Comparing Planets

(density [g/cm³])

Sun: 1.41

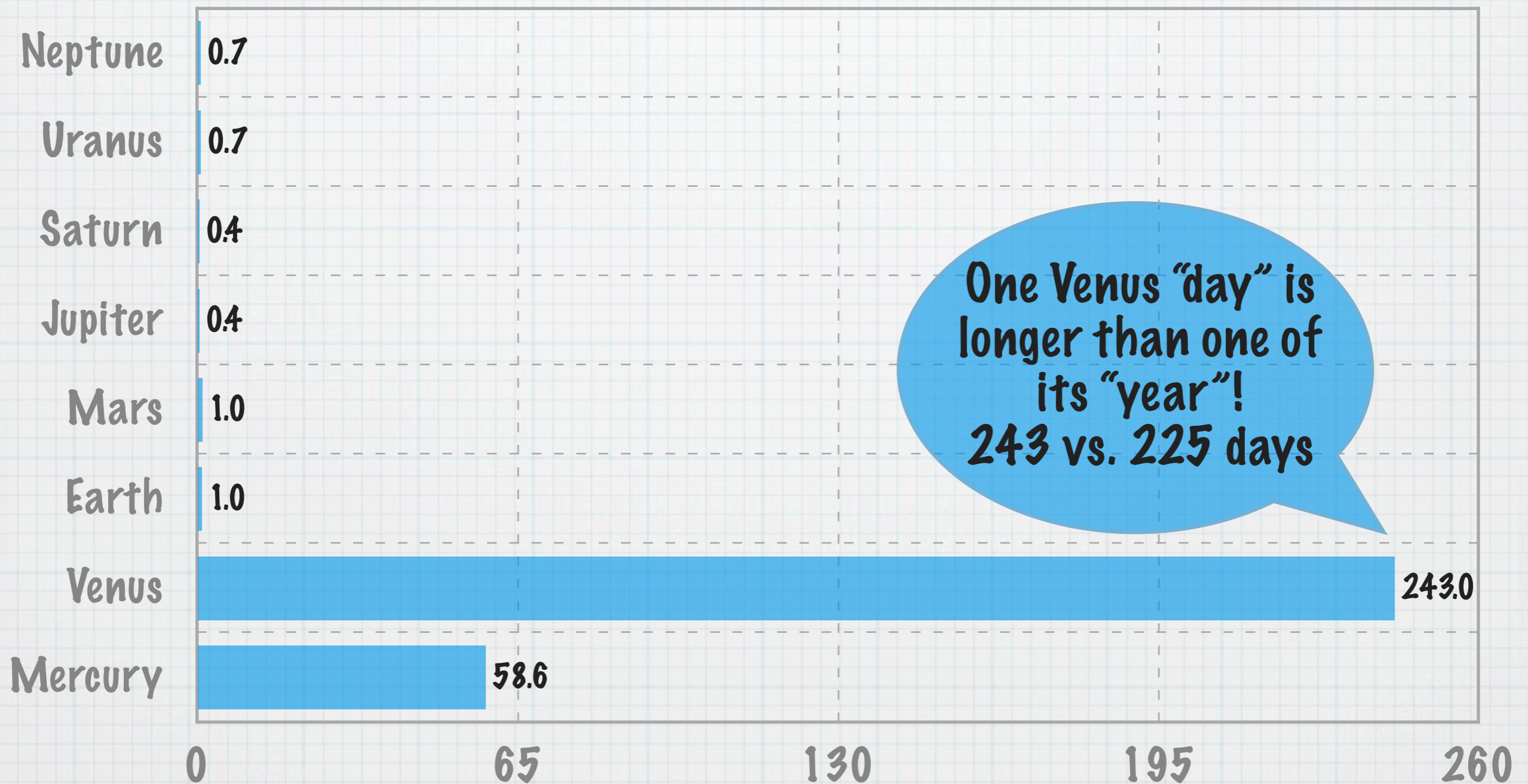


Planets' Composition

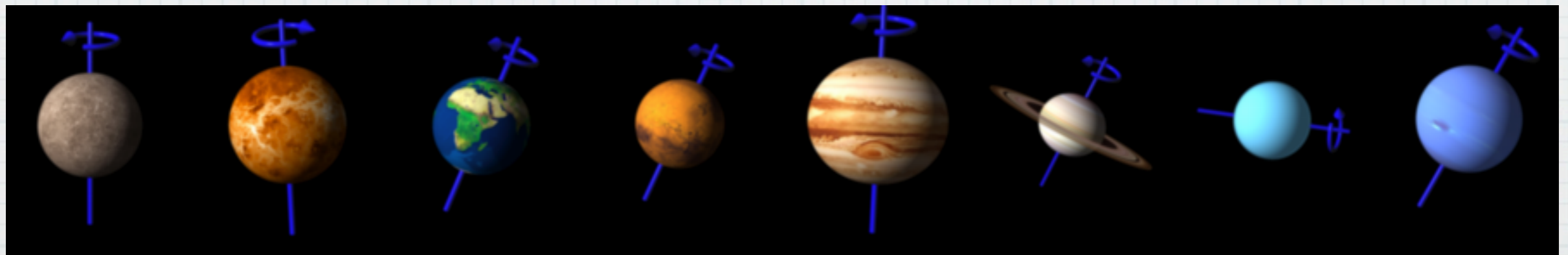
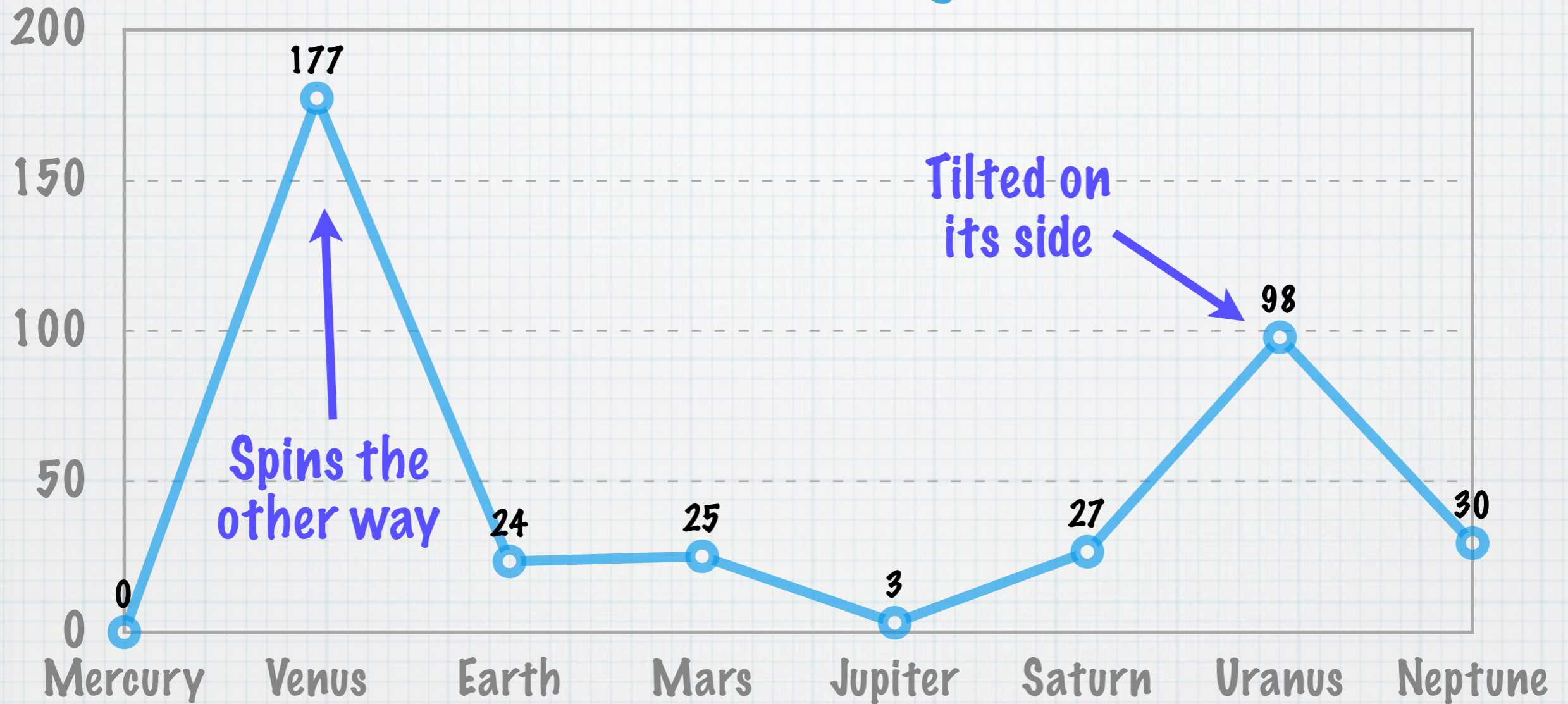
Sun: 73.46% hydrogen, 24.85% helium & 1.69% other

%	hydrogen	helium	methane	rocks	metals
Mercury				30	70
Venus				~30	~70
Earth				30	70
Mars				~35	~65
Jupiter	75	24	0.1		
Saturn	75	24	0.2		
Uranus	73	25	2-		
Neptune	70	27	2+		

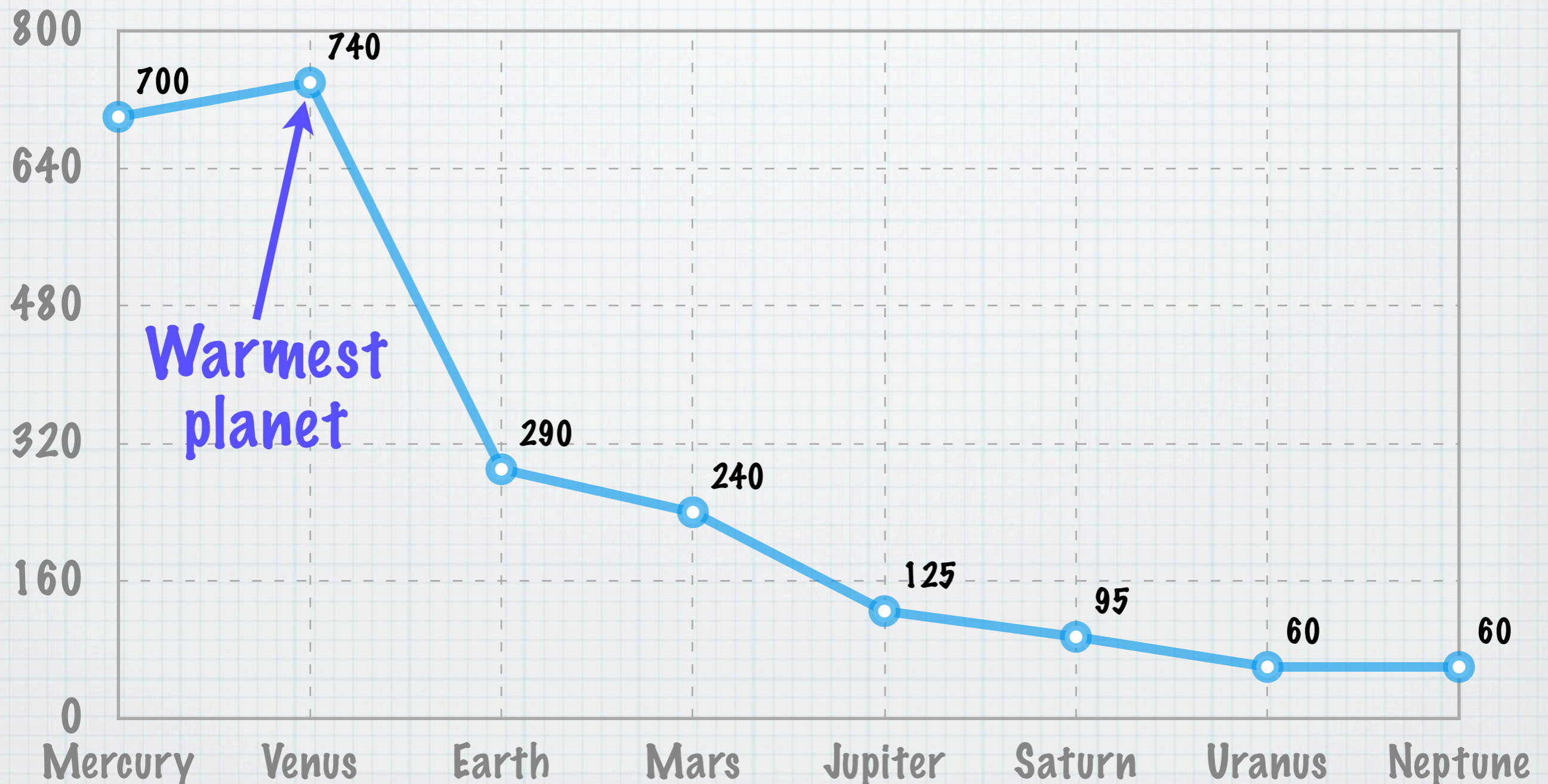
Comparing Planets (rotational period [days]) Sun: 25 - 36



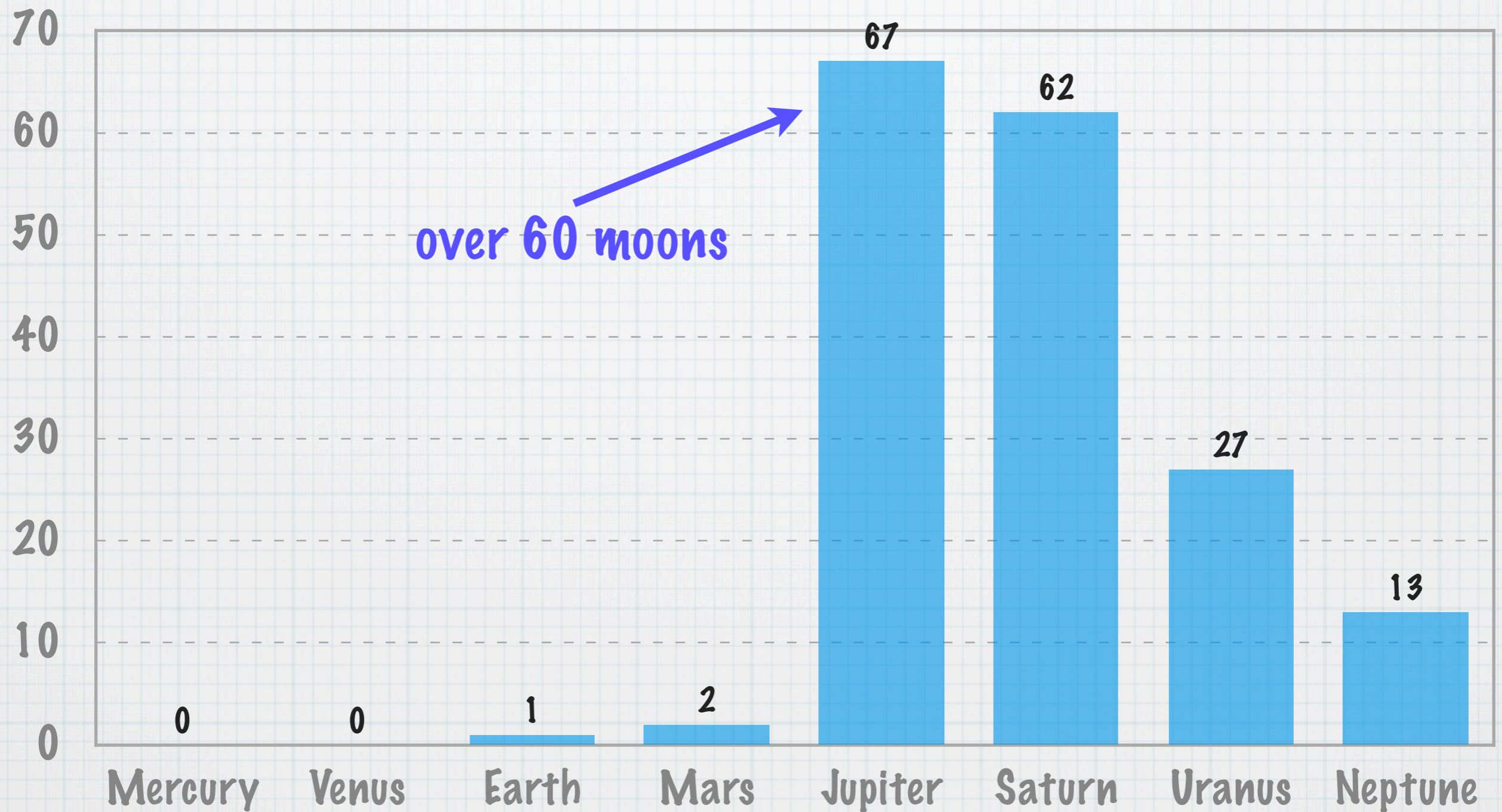
Comparing Planets (axis tilt [degrees])



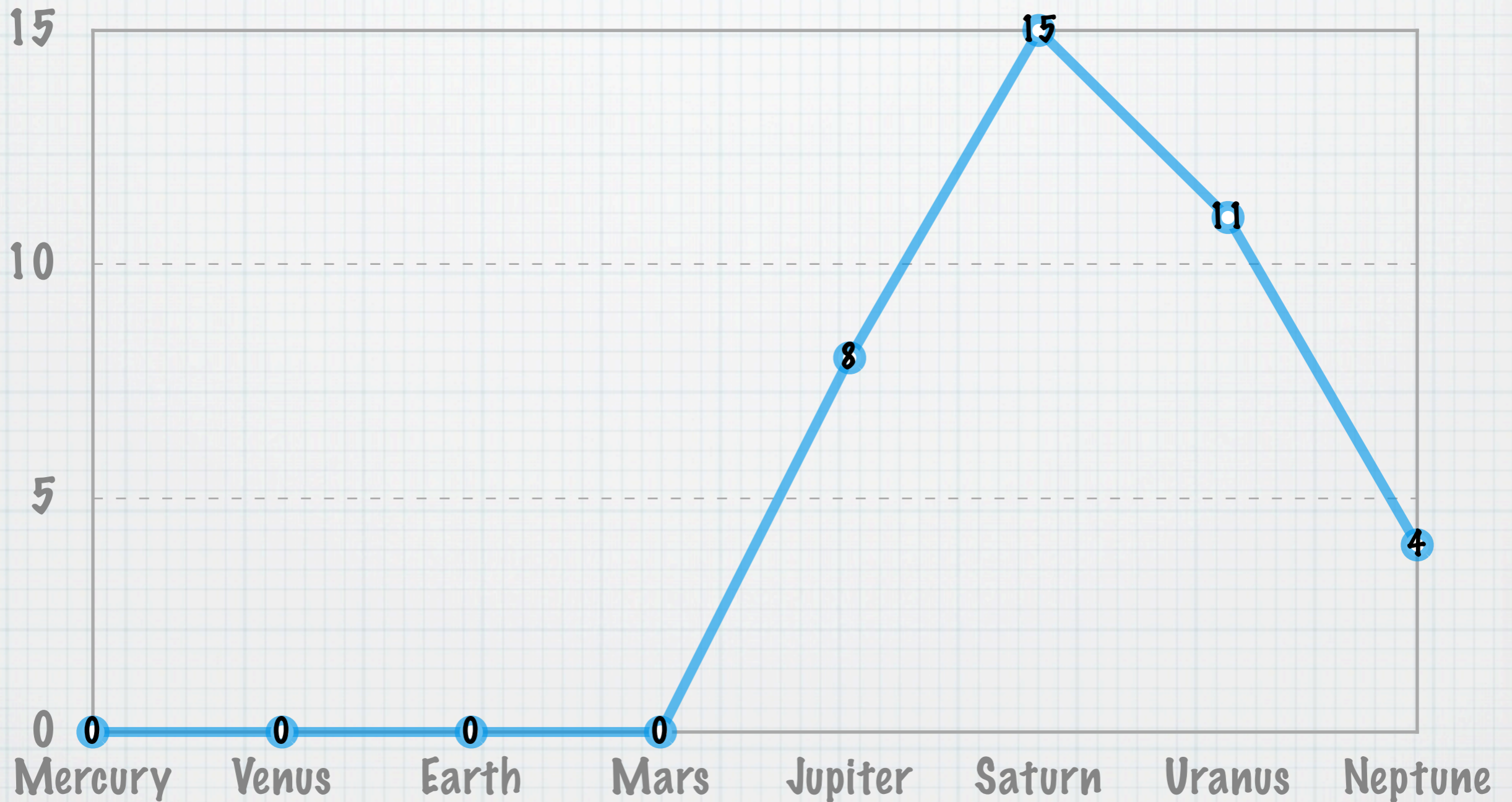
Comparing Planets (surface temp [Kelvin]) Sun: 5800



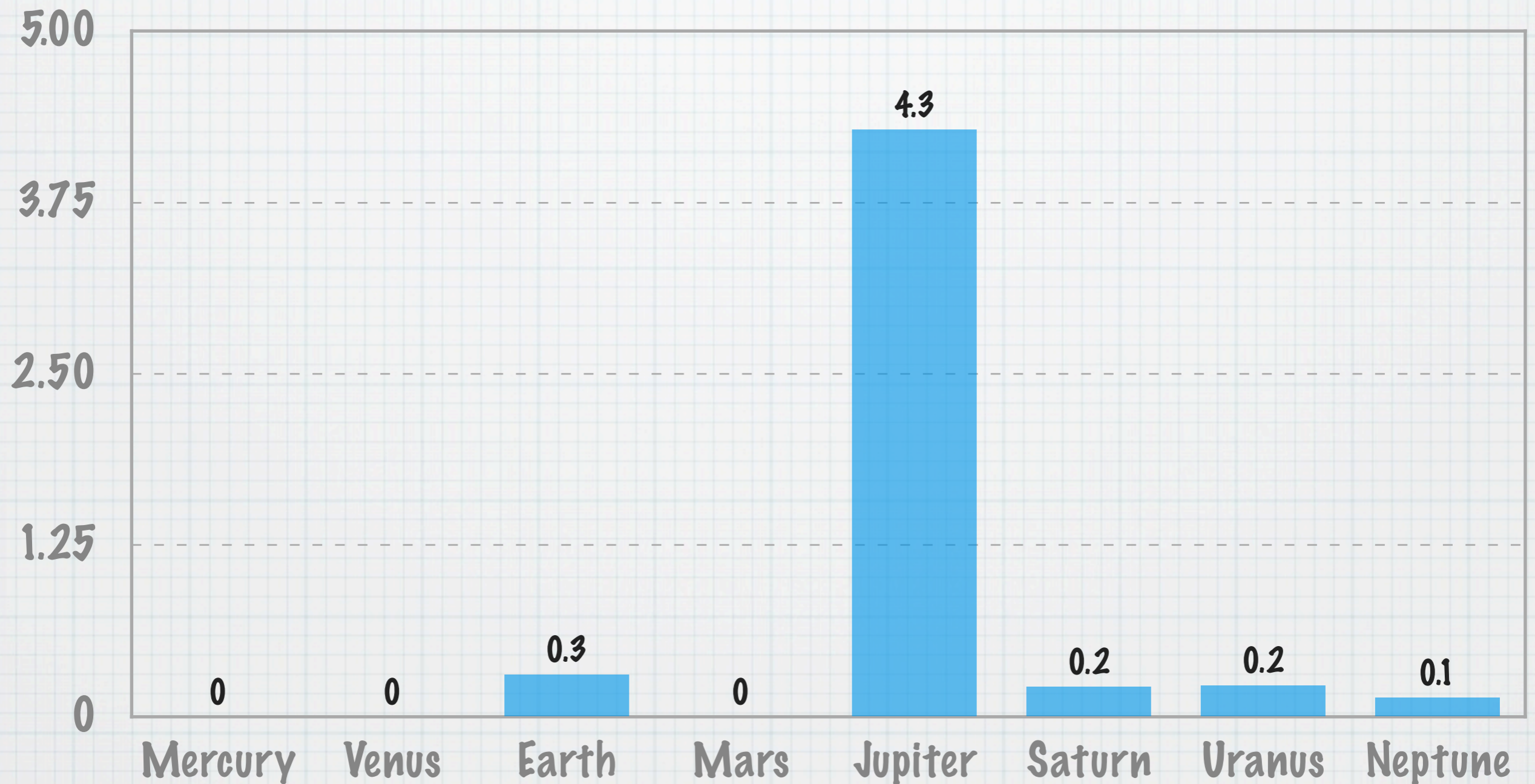
Comparing Planets (# moons)



Comparing Planets (# sets of rings)



Comparing Planets (magnetic fields [gauss])



Comparisons

Terrestrial Planets

Jovian Planets

smaller size & mass	larger size & mass
higher density	lower density
mostly rocks & metals	mostly hydrogen & helium & hydrogen compounds
solid surface	no solid surface
few (if any) moons & no rings	rings & many moons
close to the Sun -> warmer surfaces	farther from the Sun -> cool cloud tops
close grouping	farther apart

The Exceptions

Most planets follow general trends,
but there are some curiosities

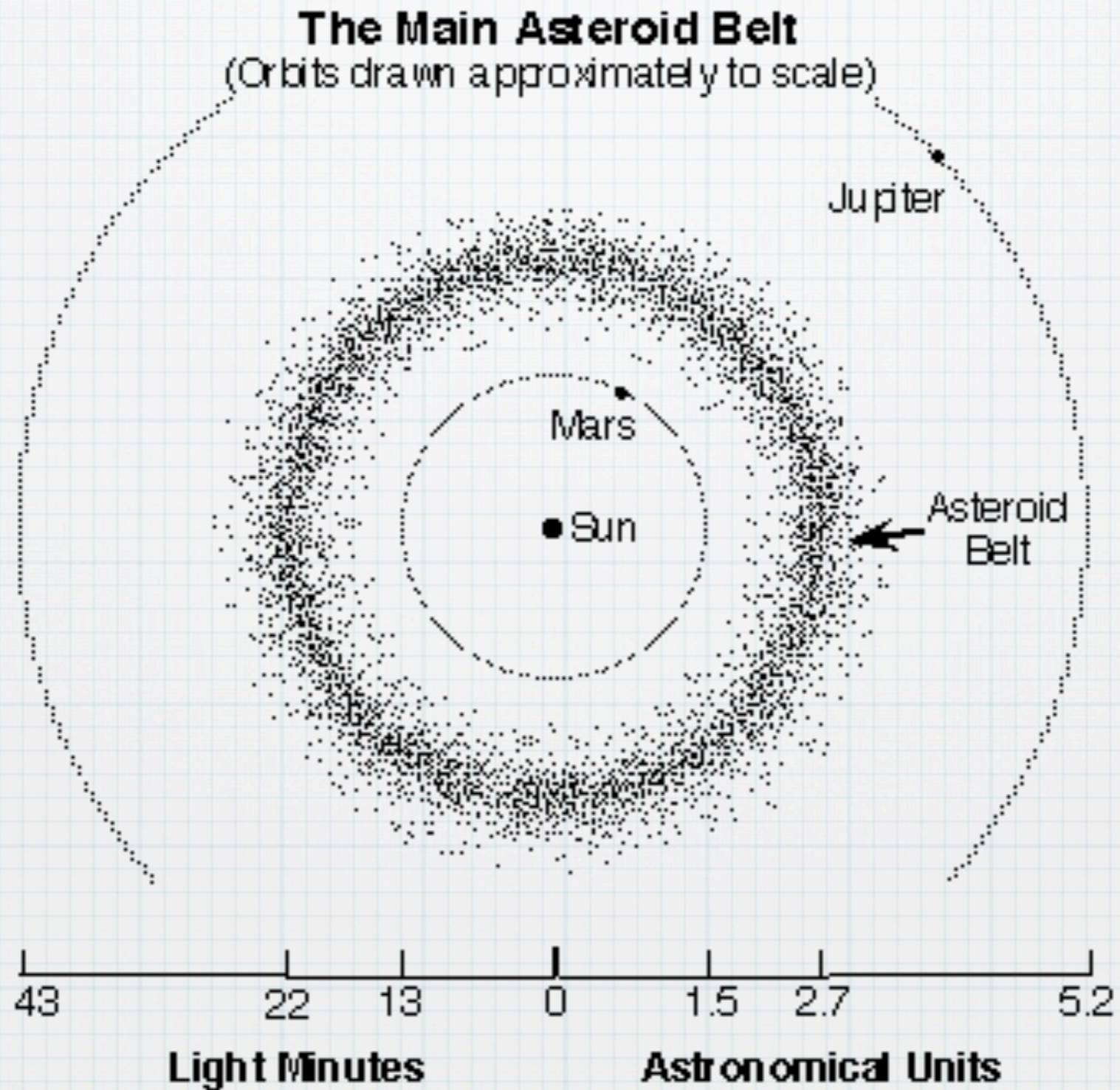
1. Venus rotates backwards
2. Uranus is on its side
3. Earth, comparatively to its size, has the largest moon by far
4. Some moons orbit in the opposite direction that their planet does

➔ Triton and some Jovian inner satellites

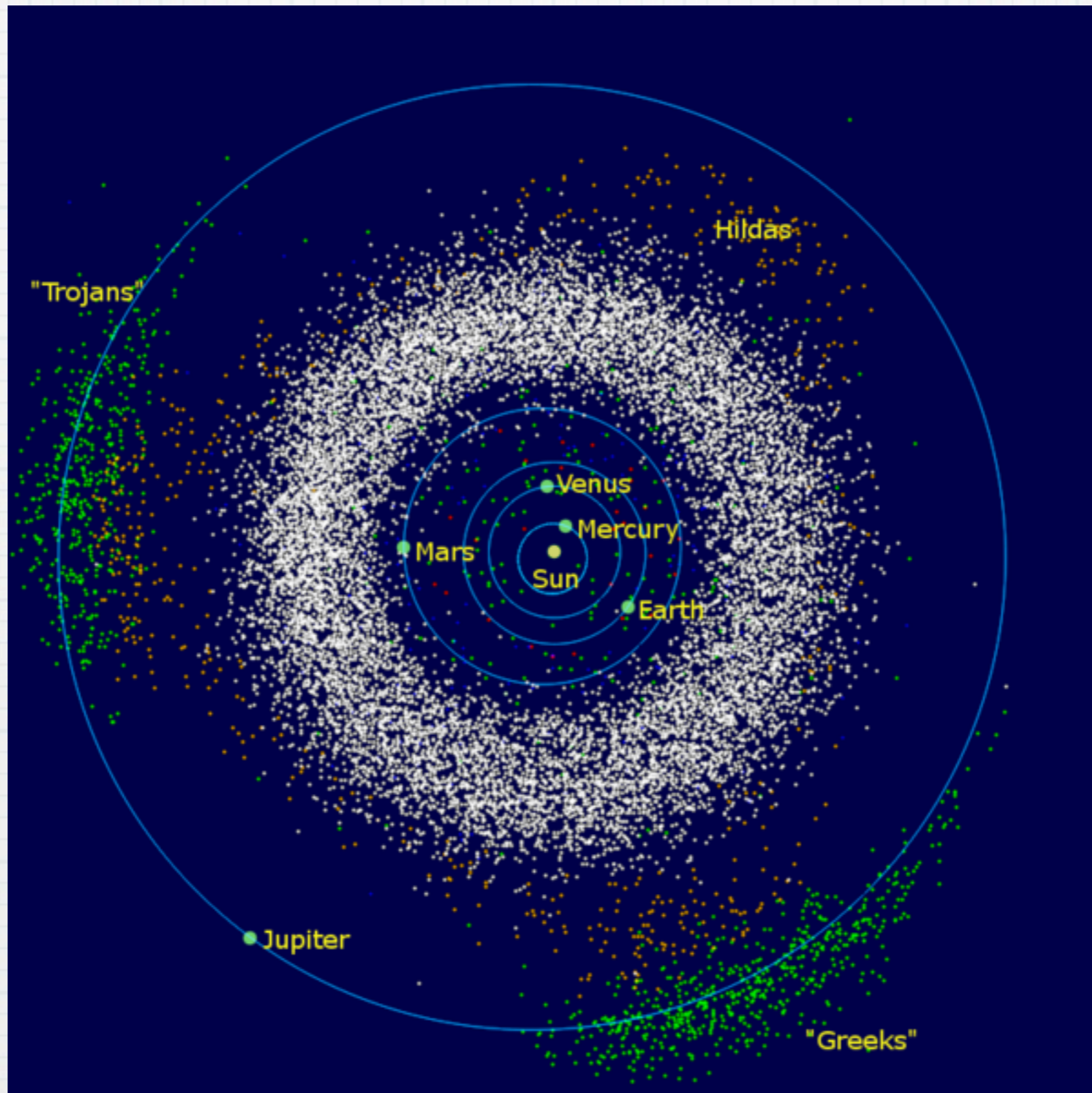
The Asteroid Belt

- * Full of small, **rocky** bodies orbiting the Sun
- * The largest radius is few hundred km
- * Most asteroids are found within the Asteroid Belt between the orbits of Mars and Jupiter

The Asteroid Belt...

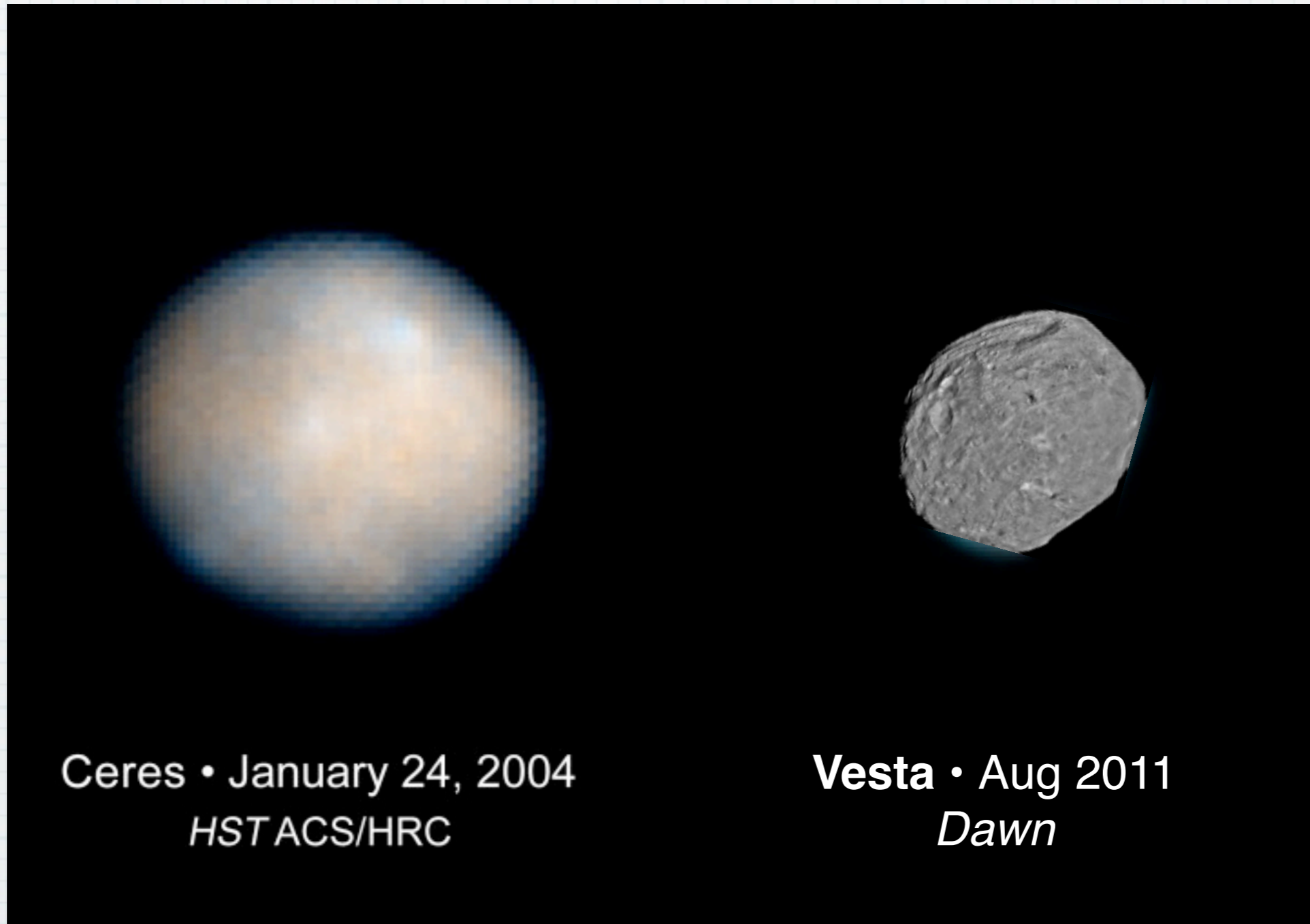


The Asteroid Belts...



The Asteroid Belt...

The biggest two asteroids

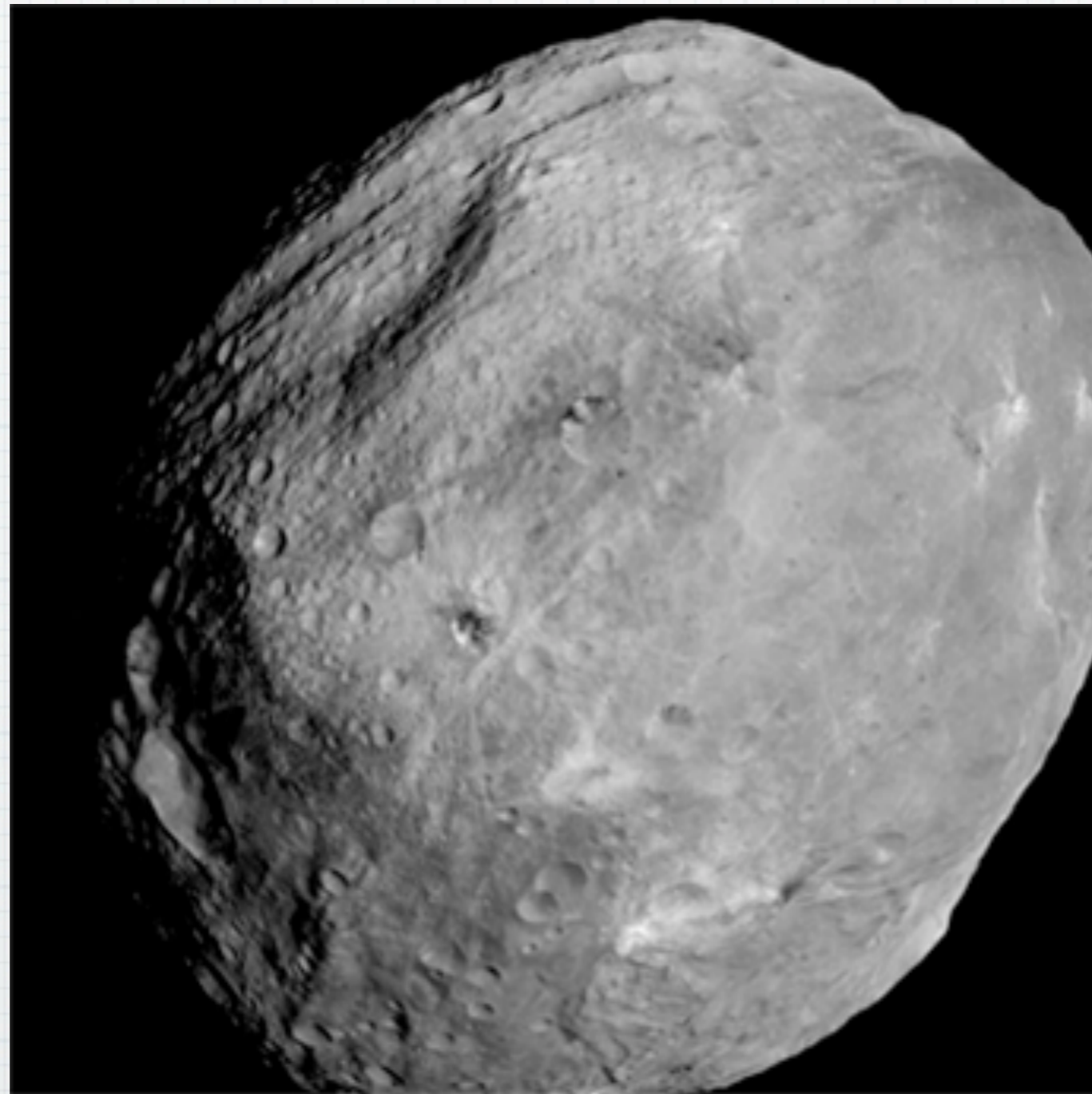


Ceres • January 24, 2004
HST ACS/HRC

Vesta • Aug 2011
Dawn

The Asteroid Belt...

Vesta, recently imaged by the Dawn spacecraft



[Vesta Rotation.gif](#) (345 × 345 pixels, file size: 5.34 MB, MIME type: image/gif, looped, 64 frames, 6.4s)

NASA/JPL-Caltech/UCLA/MPS/DLR/IDA; [Little Mountain 5](#)

The Asteroid Belt...

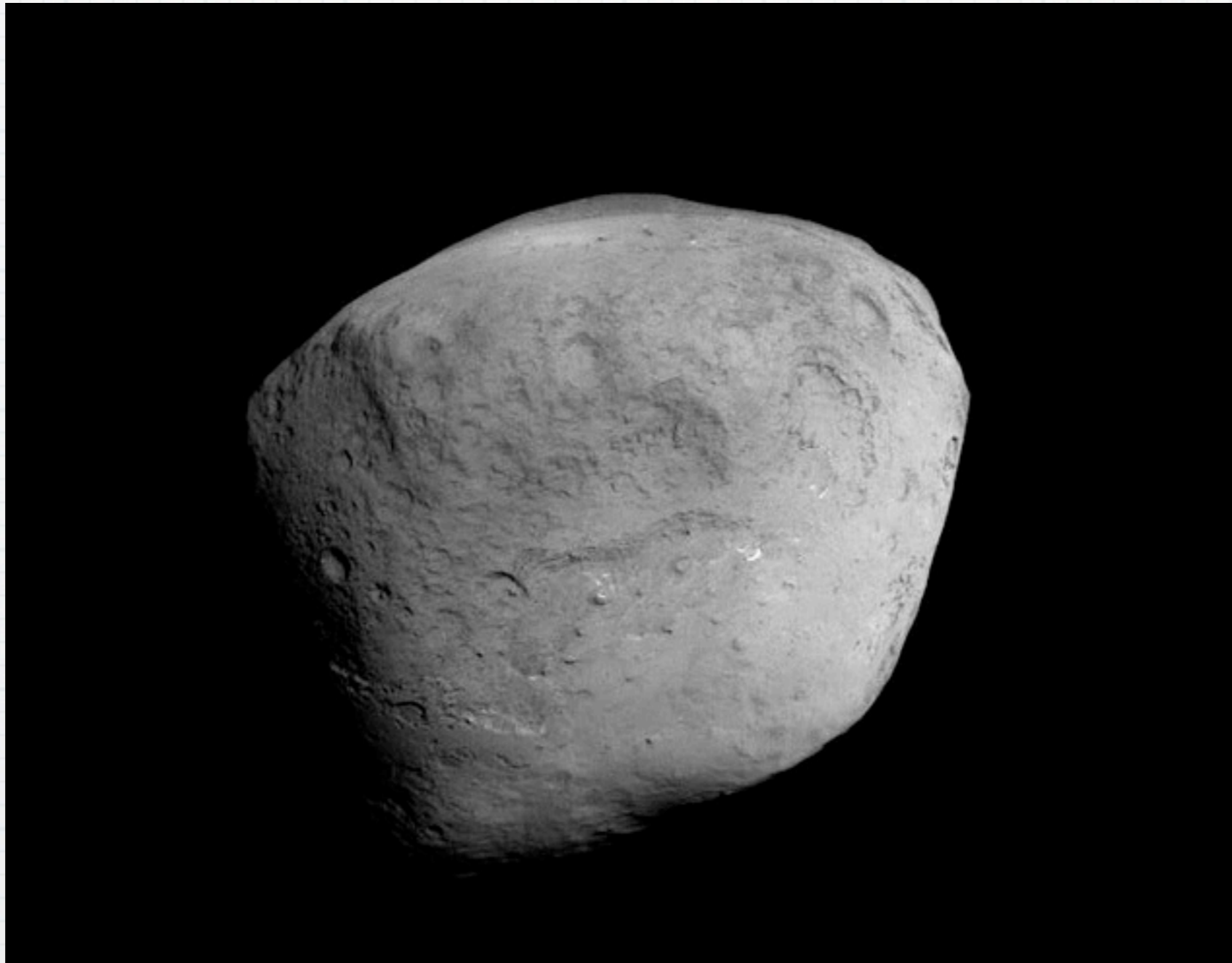


Ceres &
Vesta
sizes
compared
to Earth

Comets

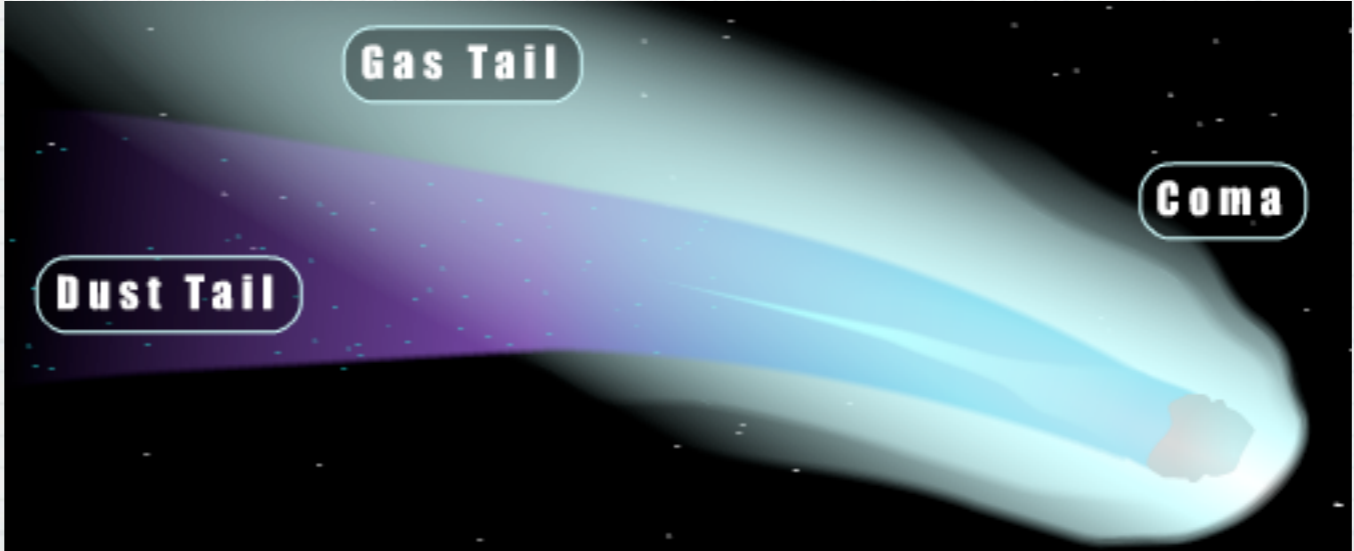
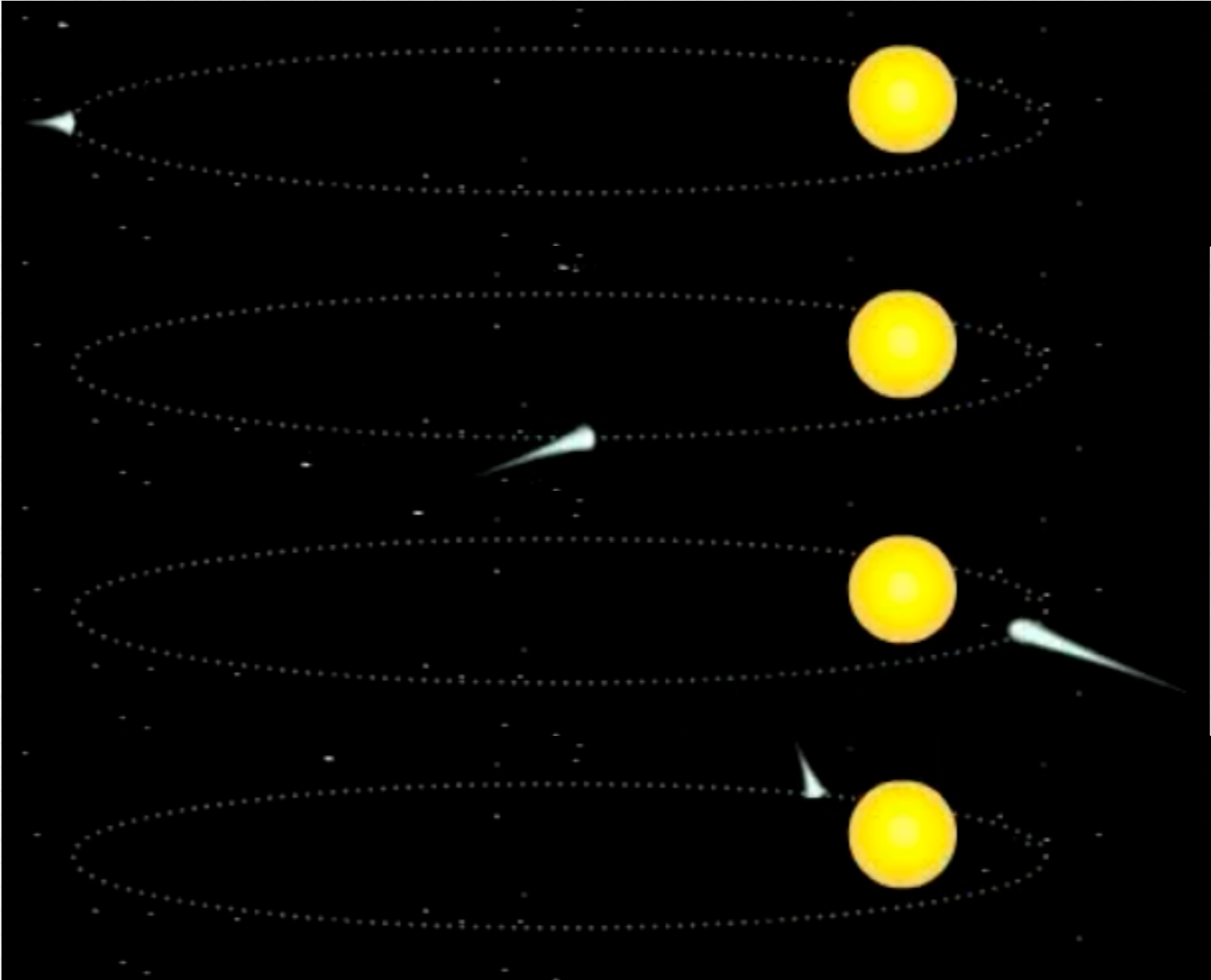
- * Small objects orbiting the Sun past Neptune and in the extreme reaches of the Solar System
- * Most will never leave their orbital regions
- * Few will make it to the inner Solar System for our delight
- * Comets are made of frozen gases (ices) and dust

Comet Tempel 1



Tempel 1 (official designation: 9P/Tempel), is a periodic comet discovered by Wilhelm Tempel in 1867. It currently completes an orbit of the Sun every 5.5 years

Comets...



Comet Garradd

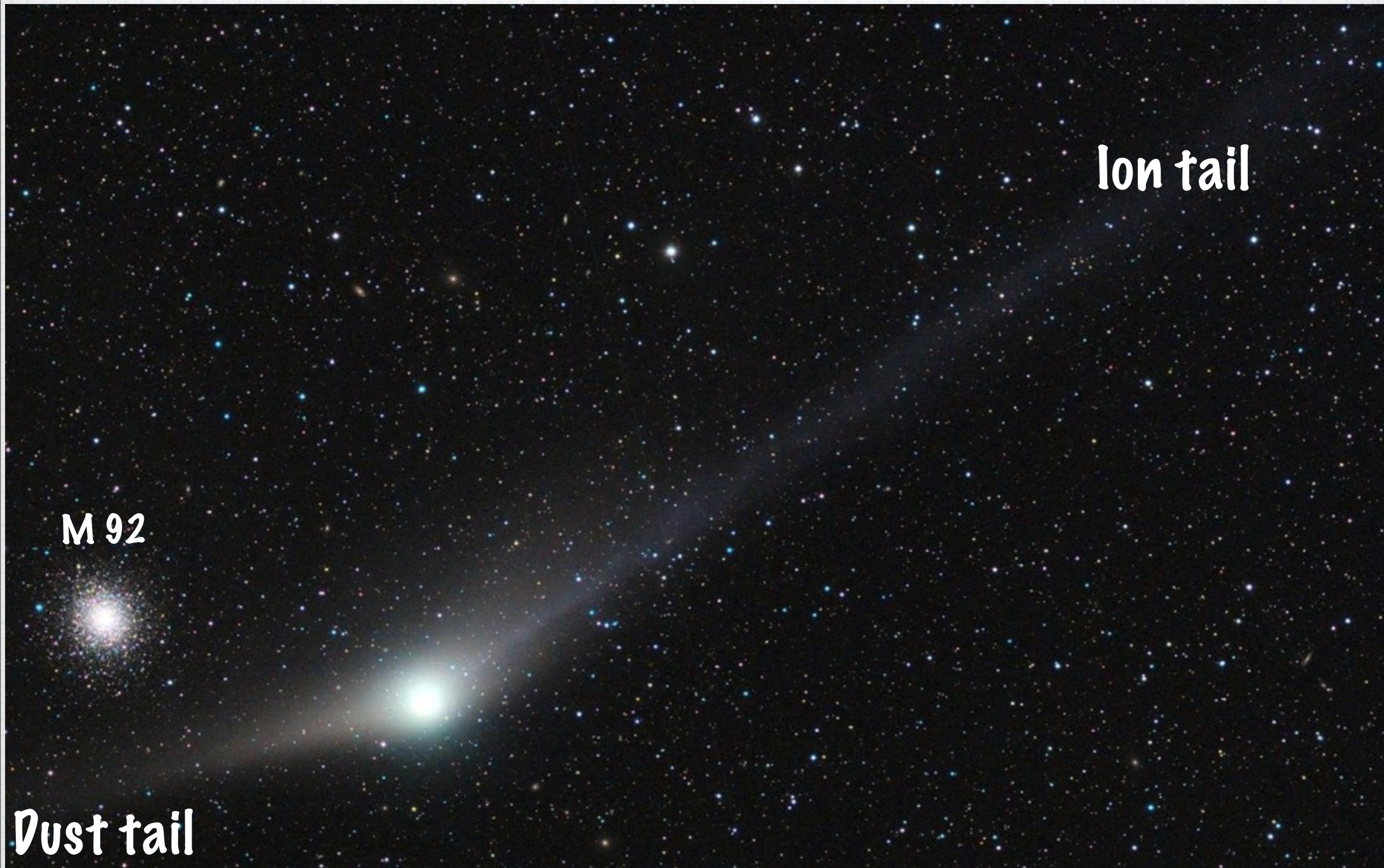


Image Credit & [Copyright](#): Rolando Ligustri ([CARA Project](#), [CAST](#))

February 3, 2012

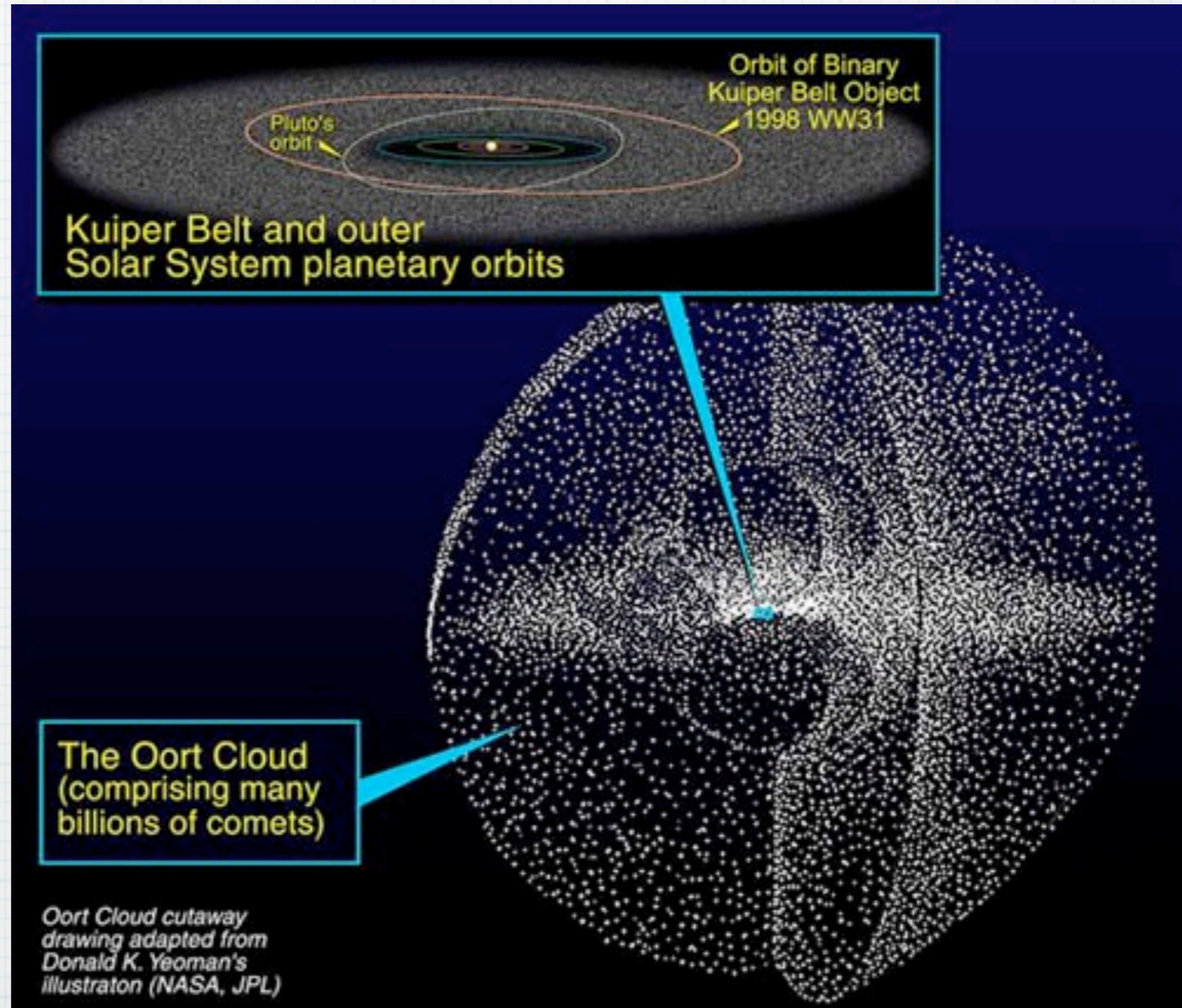
Comets...

- * There are **two** groupings of comets: **The Kuiper Belt and the Oort Cloud**
- * **Comets in the Kuiper Belt orbit the Sun beyond the orbit of Neptune**
- * **Their orbits are more or less in the ecliptic plane**

Comets...

- * The Oort Cloud contains all other comets (billions of them). It is located 50,000 to 100,000 AU away from the Sun
- * Comets have random orbits in this cloud of a more or less spherical shape

The Kuiper Belt and the Oort Cloud



Snapshot

- * What does the Solar System look like?
- * Our Solar System consists of the Sun, eight planets and their moons, and vast numbers of asteroids and comets. Each world has its own unique character, but there are many clear patterns among the worlds

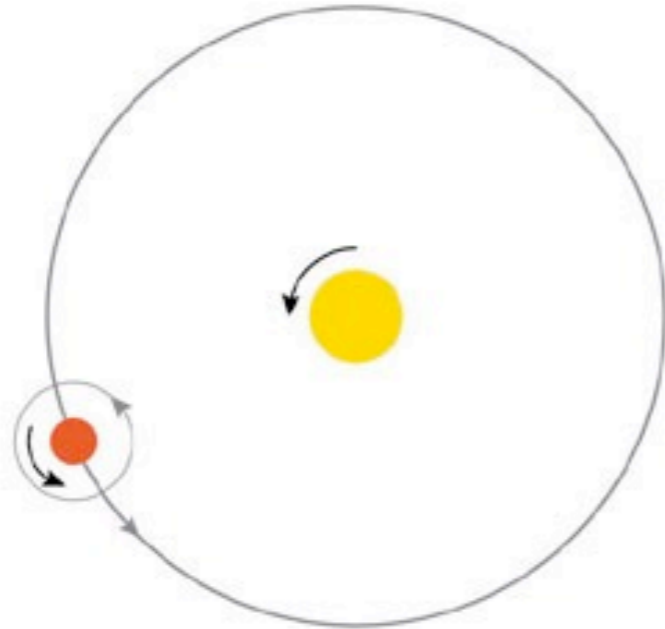
Snapshot

Terrestrial Planets

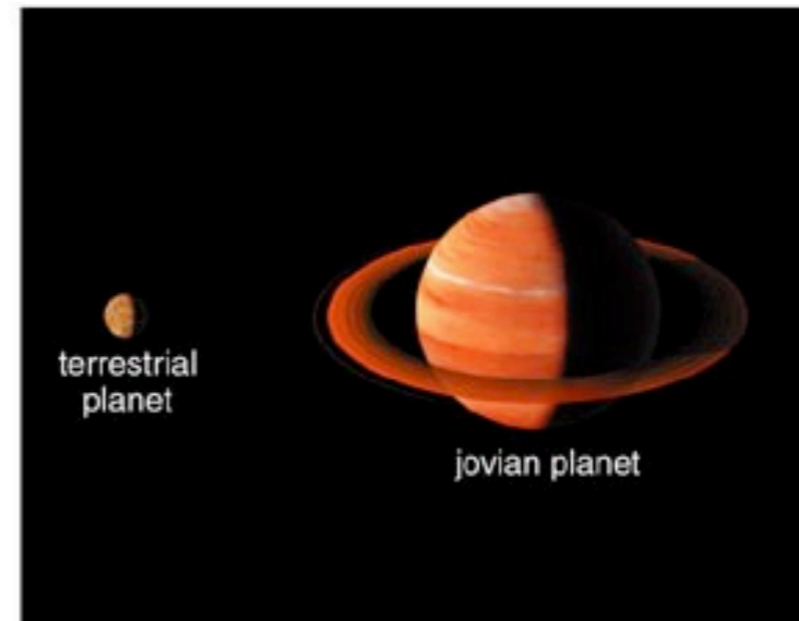
Jovian Planets

smaller size & mass	larger size & mass
higher density	lower density
mostly rocks & metals	mostly hydrogen & helium & hydrogen compounds
solid surface	no solid surface
few (if any) moons & no rings	rings & many moons
close to the Sun -> warmer surfaces	farther from the Sun -> cool cloud tops
close grouping	farther apart

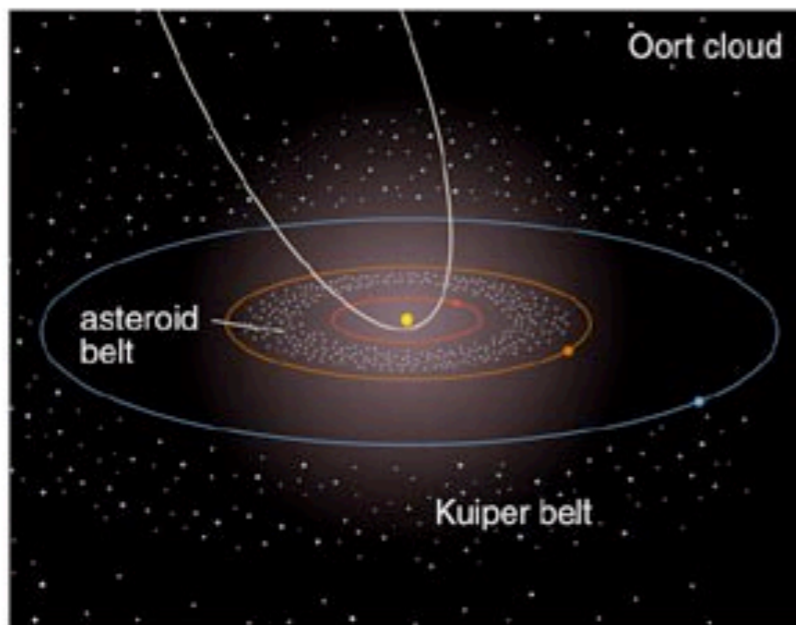
Snapshot



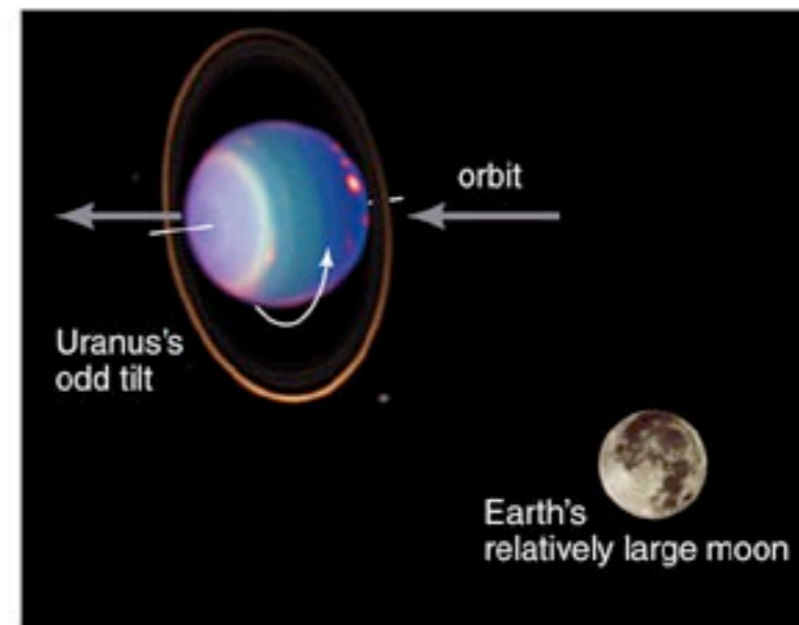
Large bodies in the Solar System have orderly motions



Planets fall into two main categories



Swarms of asteroids and comets populate the Solar System



Several notable exceptions to these general trends stand out

Snapshot

These exceptions are:

1. Venus rotates backwards
2. Uranus is on its side
3. Earth, comparatively to its size, has the largest moon by far
4. Some moons orbit in the opposite direction that their planet does

➔ Triton and some Jovian inner satellites