Announcements

Oct 6: Homework #5 is due

Oct 8: Public Star Party 6:30-10:00pm
Placitas Community Library
453 Highway 165

Oct 10: Review for Test #2, 3:25pm

Oct 11: Test #2

Oct 13: Fall break, no class

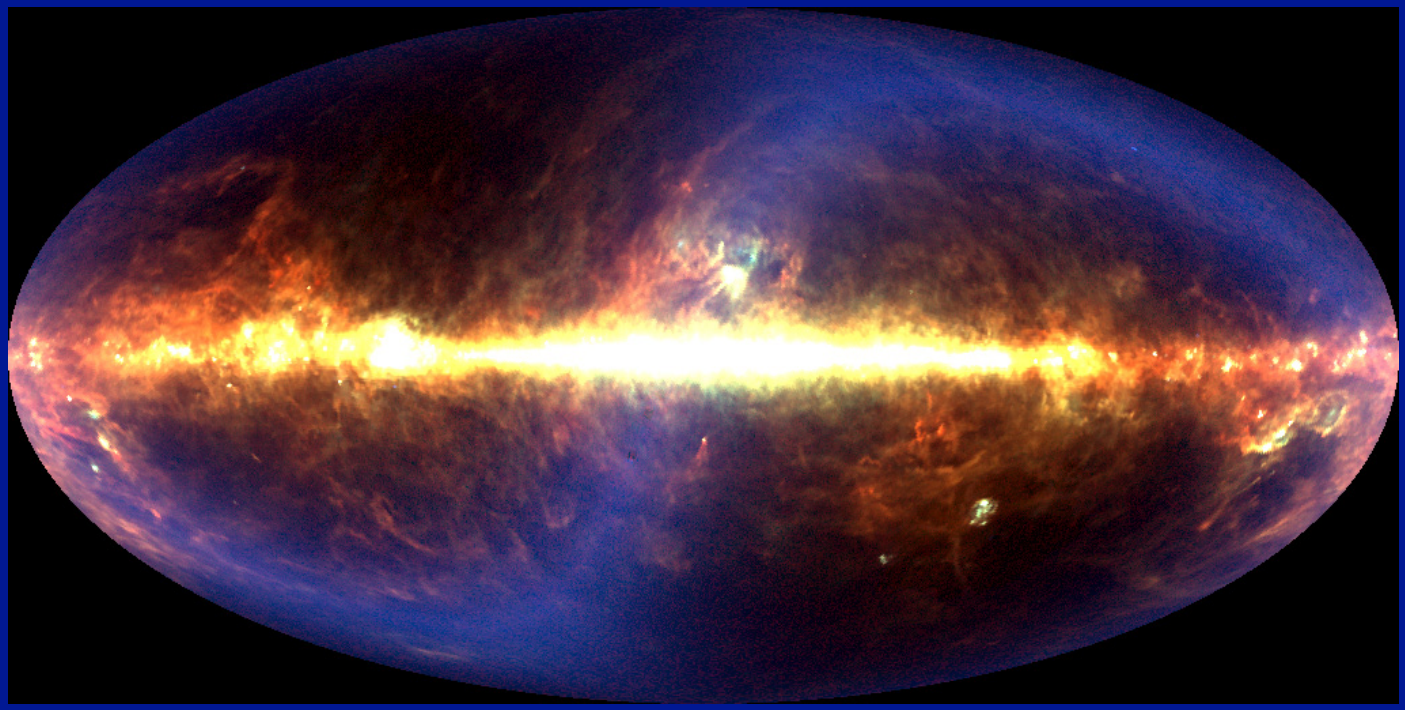
The Solar System

- Gas Giants
  - Massive: $M_J = 318\ M_{earth} \approx 0.001\ M_{Sun}$
  - Strongly influence dynamics/evolution of solar system
- Terrestrial Planets – (land/water/air interface)
- Moons and Rings
- Comets & Kuiper Belt Objects – water and other materials
- Asteroids – metals, water, other materials, $$$
- Zodiacal Dust — eroding asteroids & KBOs (comets)
  - Small in size, but large in surface area
  - Intercepts sunlight – observable scattered and thermal signatures
    - $T_{dust} \approx$ 30K - 1500K (evaporation)
    - T_{dust} (Asteroid) ~ 160K - 200K
    - T_{dust} (KBO) ~ 30 - 80K

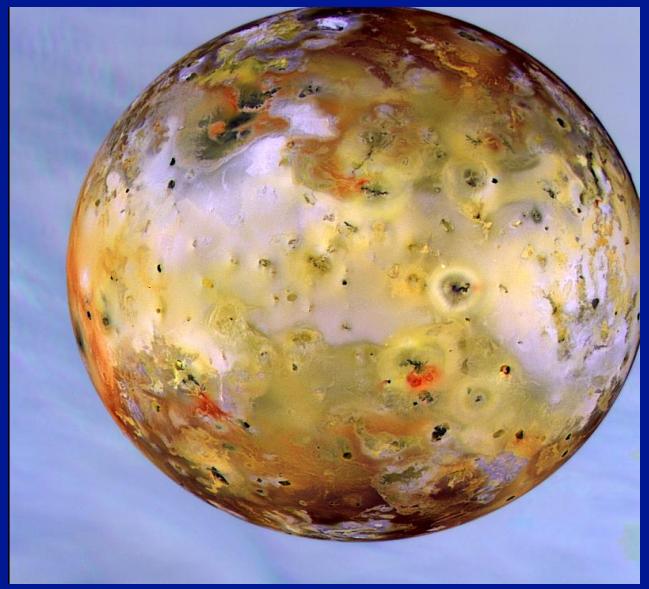
Zodiacal Dust (looking out)

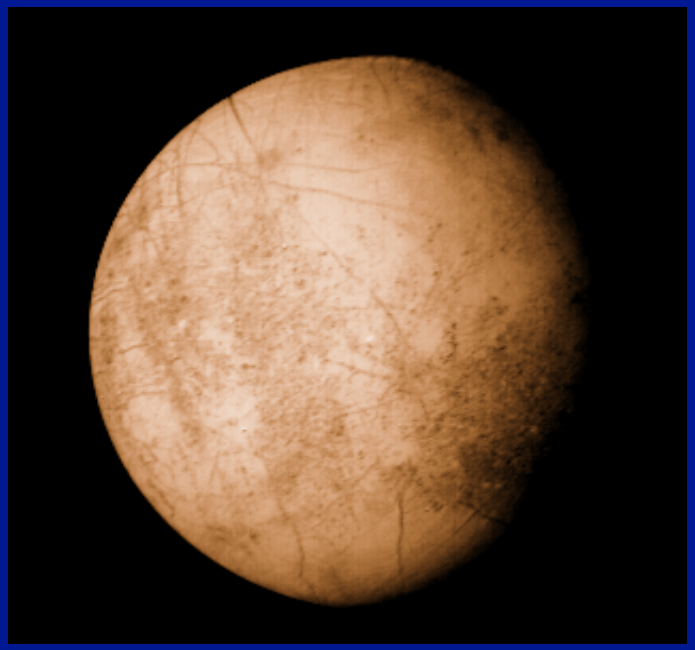
Views from the Earth

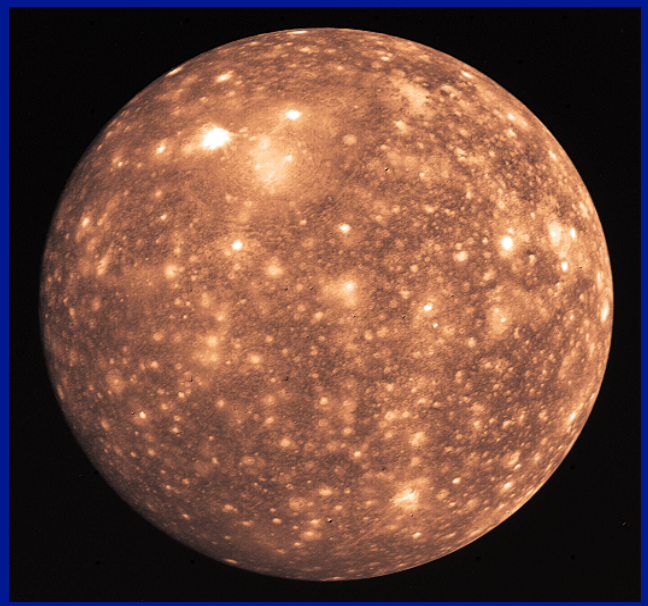
View in Galactic Coordinates



Moons of Jovian Planets







The Galilean Moons of Jupiter

(sizes to scale)

Closest to Jupiter

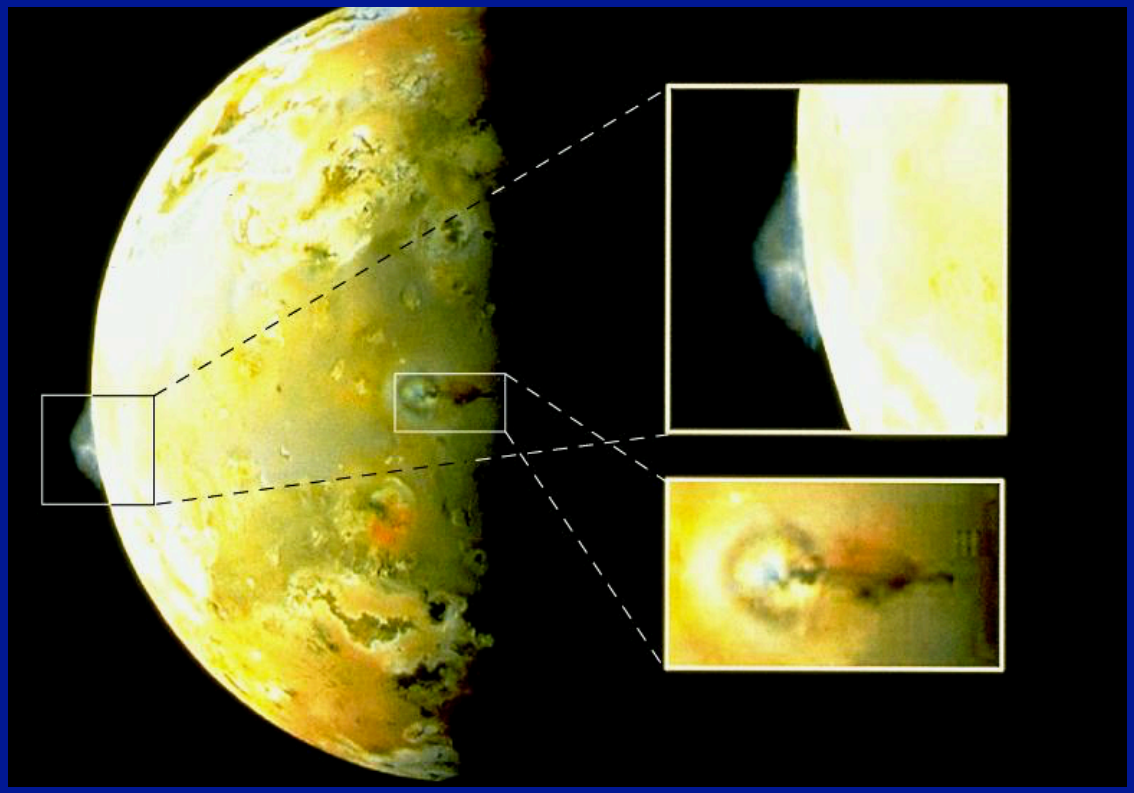
Furthest from Jupiter

Radii range from 1570 km (Europa, slightly smaller than our Moon), to 2630 km (Ganymede - largest moon in Solar System).

Orbital periods range from 1.77 days (Io) to 16.7 days (Callisto).

The closer to Jupiter, the higher the moon density: from 3.5 g/cm^3 (Io) to 1.8 g/cm^3 (Callisto). Higher density indicates higher rock/ice fraction.

Io's Volcanism

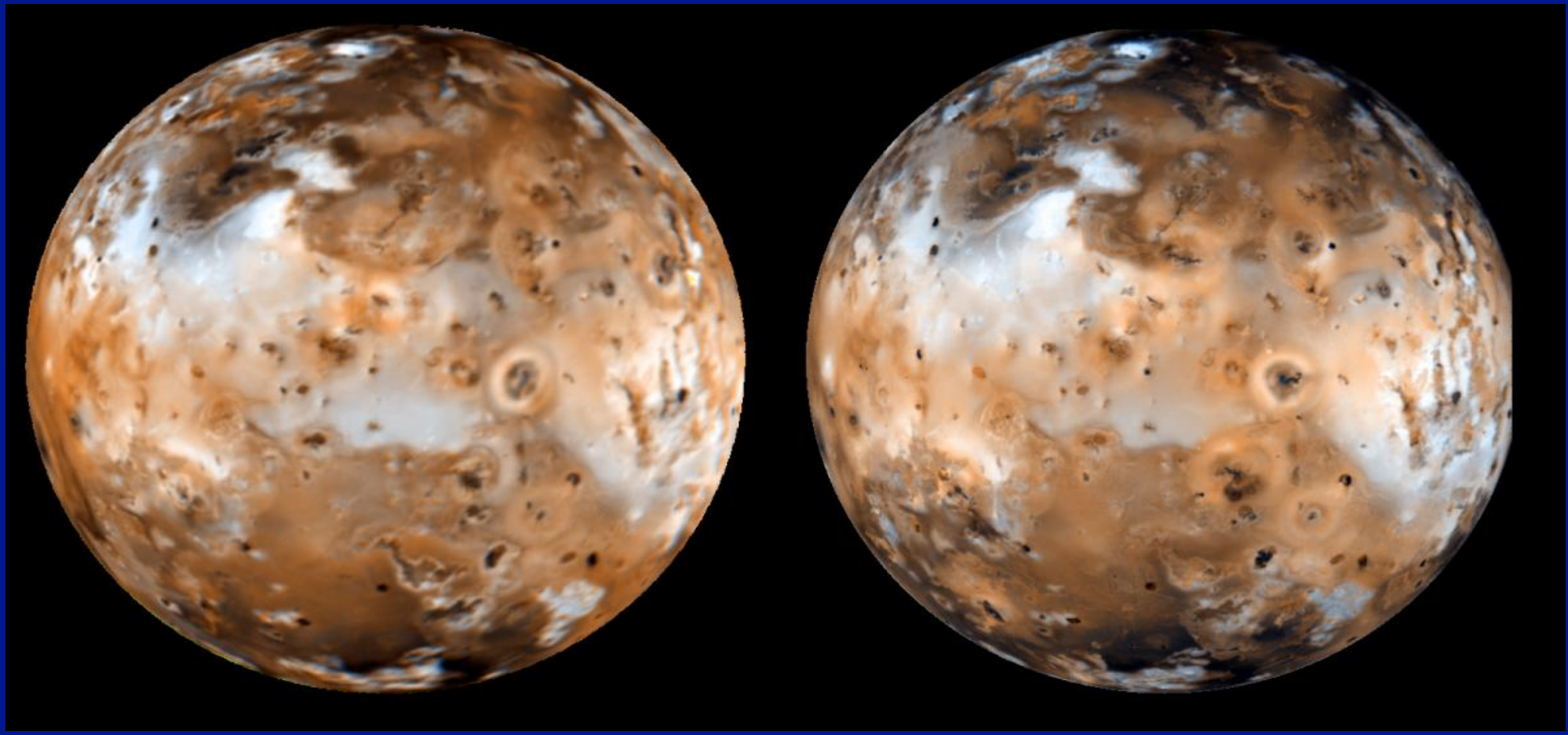


More than 80 volcanos have been observed. Can last months or years.

Ejecta speeds up to 1000 m/s. Each volcano ejects about 10,000 tons/s

Rich in S, SO_2. S can be orange, red, black depending on temperature. Frozen SO_2 snowflakes are white.

Activity causes surface to slowly change over the years:



Voyager 2 (1979)

Galileo (1996)

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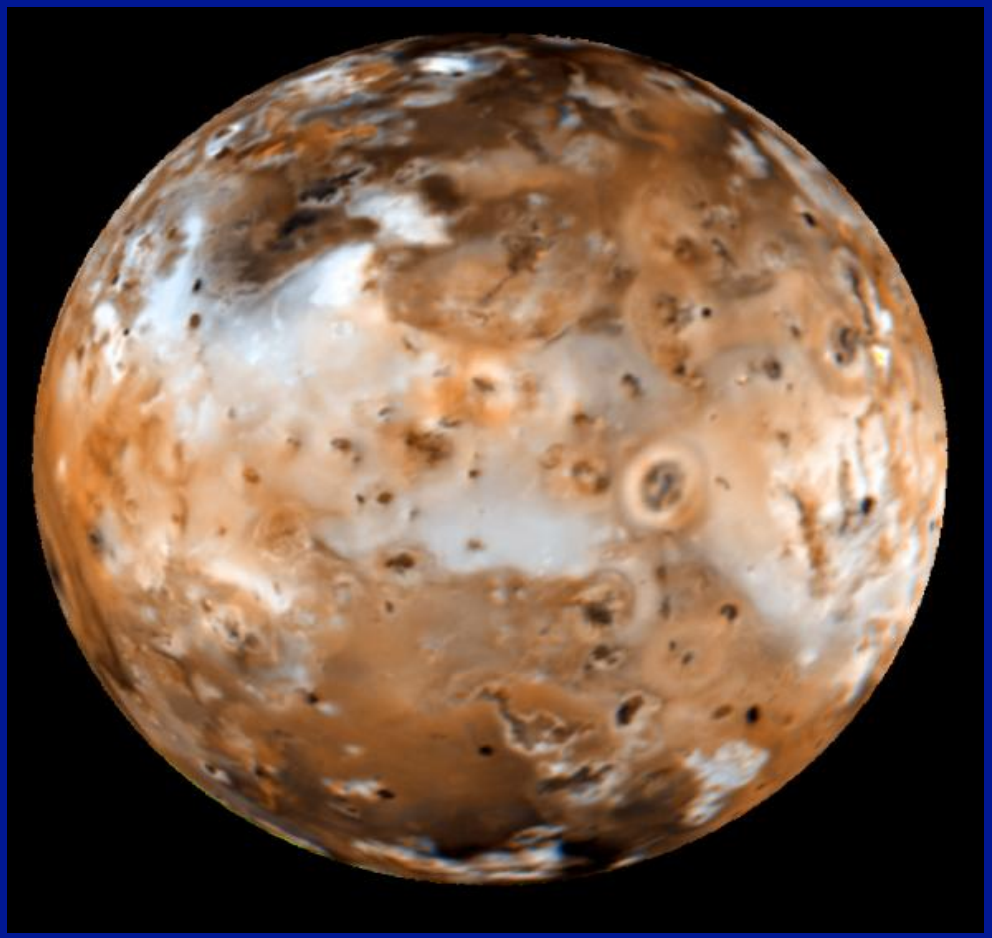

Voyager 2 (1979)

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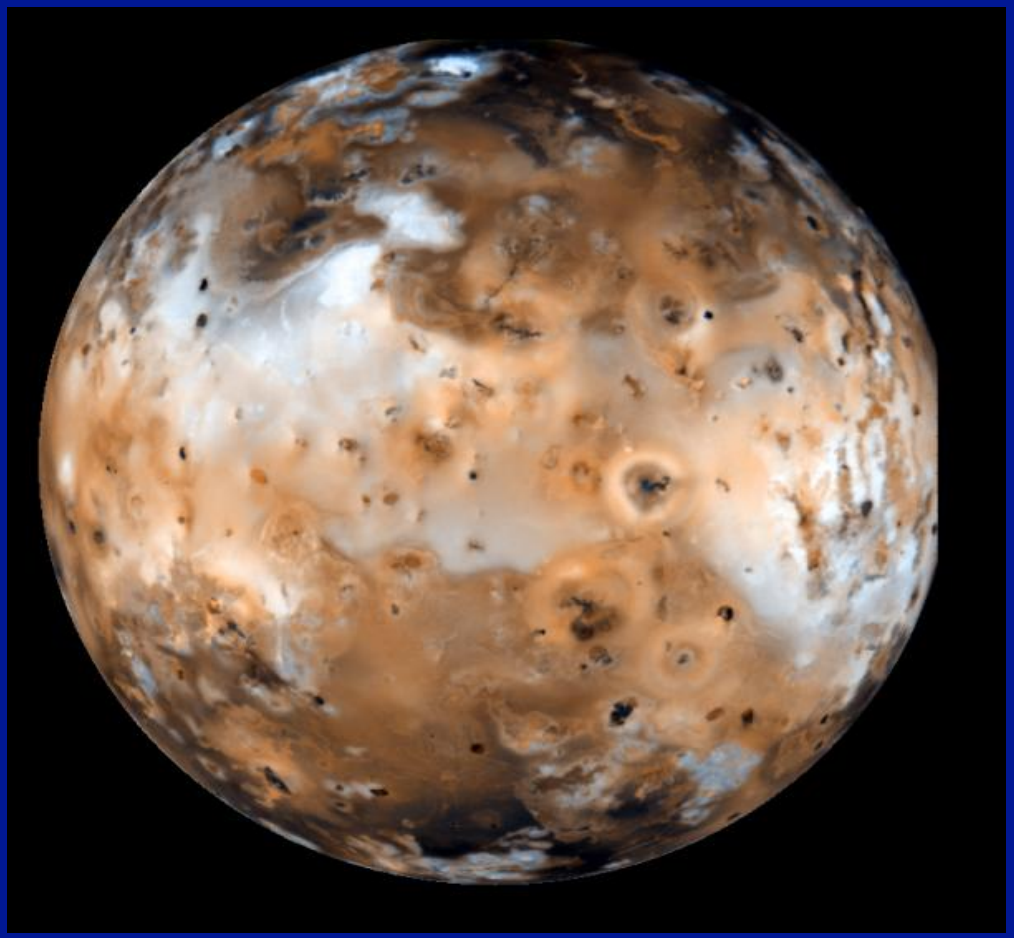
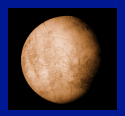


Galileo (1996)

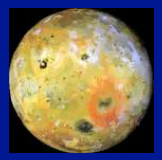
Volcanic activity requires internal heat. Io is a small body. Should be cold and geologically dead by now. What is source of heat?

First, Io and Europa are in a "resonance orbit":

Day 0

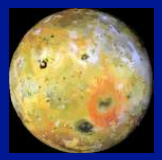


Europa

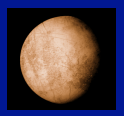


Io

Day 1.77

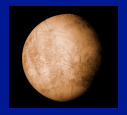


Io



Europa

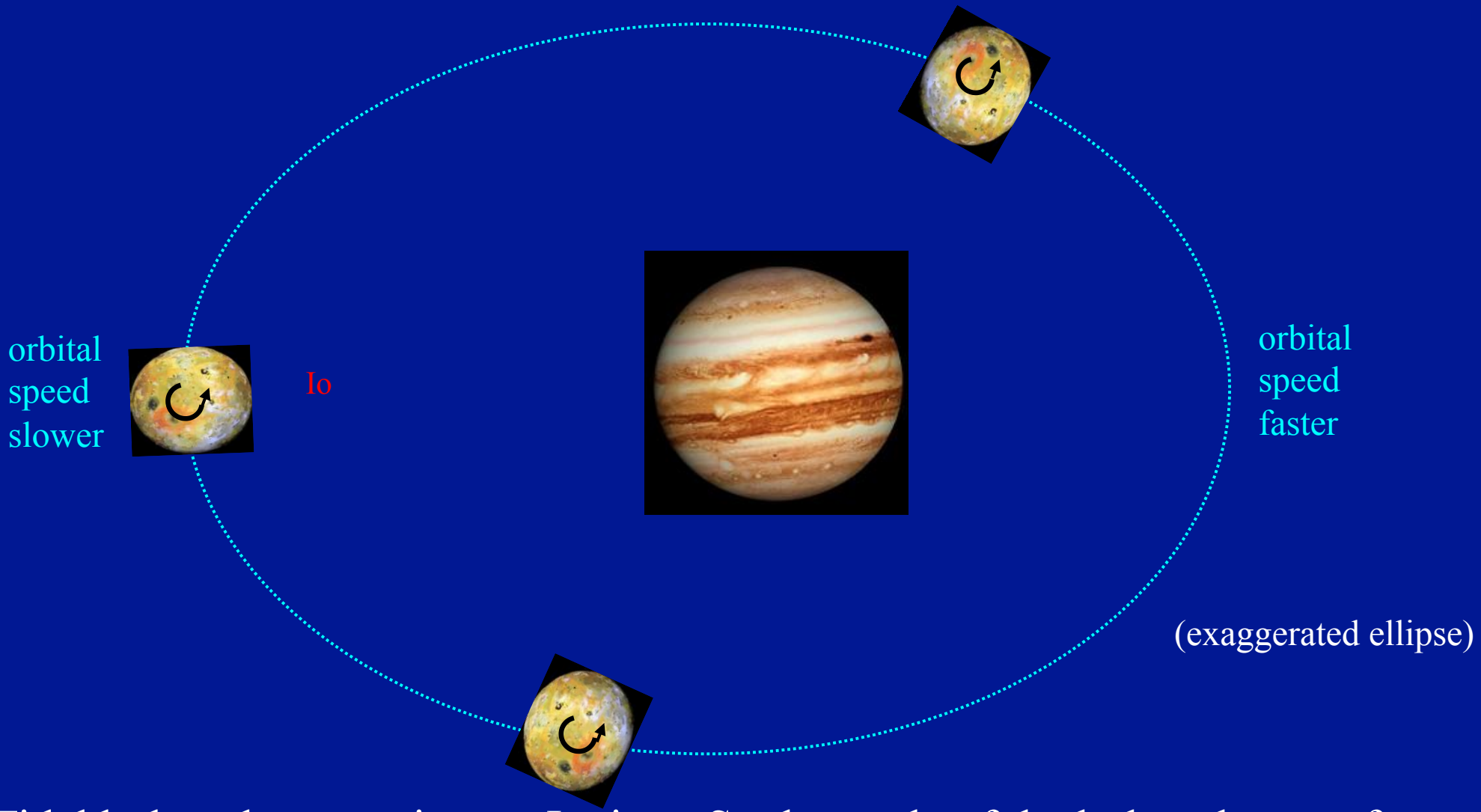
Day 3.55



Europa

Io

The periodic pull on Io by Europa makes Io's orbit elliptical.

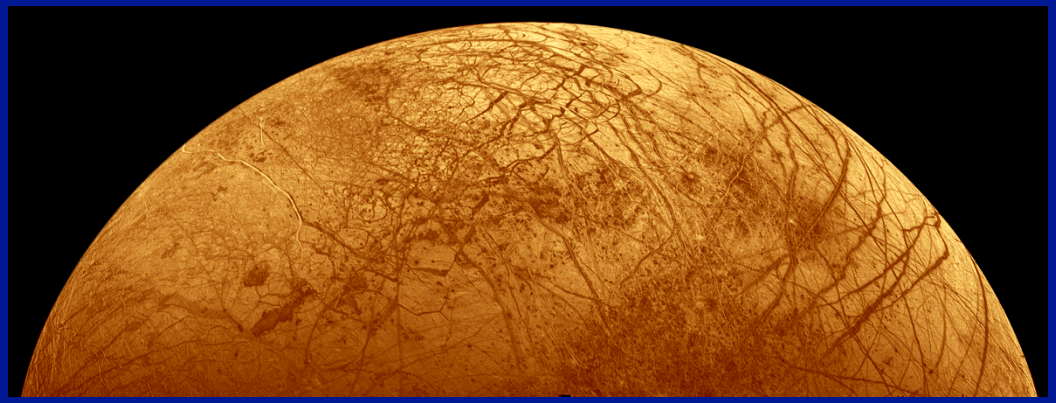


- Tidal bulge always points to Jupiter. So the angle of the bulge changes faster when Io is closer to Jupiter.

- But Io rotates on its axis at a constant rate.

- So bulge moves back and forth across surface => stresses => heat => volcanoes

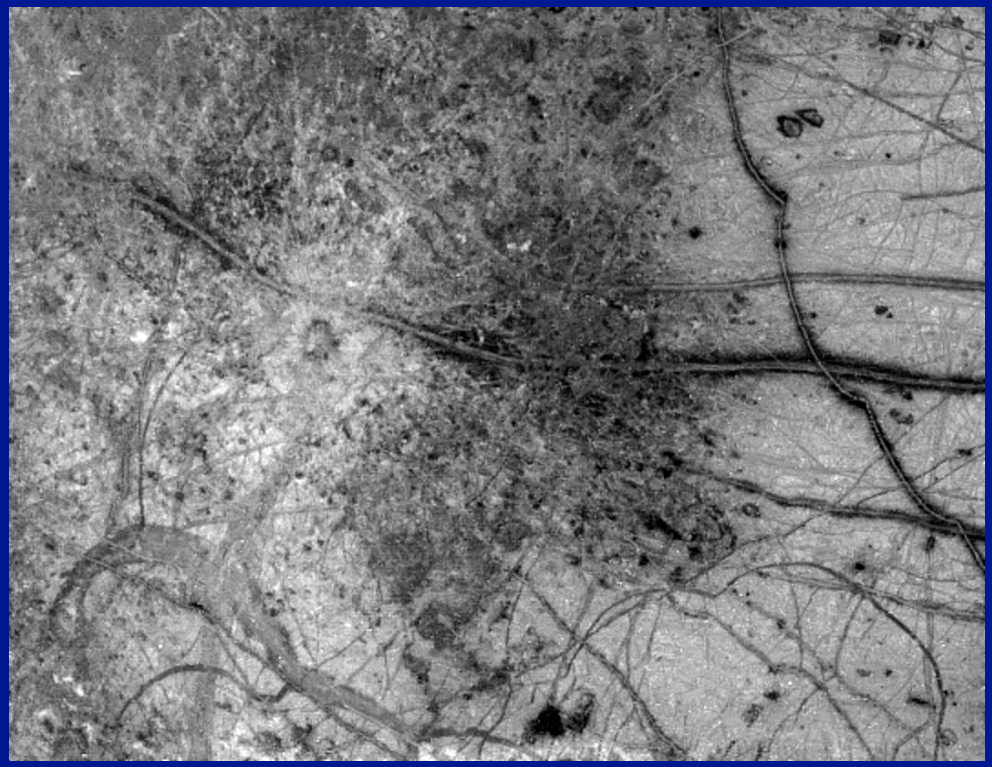
Europa may have Warm Ocean beneath Icy Surface



Fissures suggest large moving ice sheets.
Hardly any impact craters.

42 km

Icebergs or "ice rafts" suggest broken and reassembled chunks.



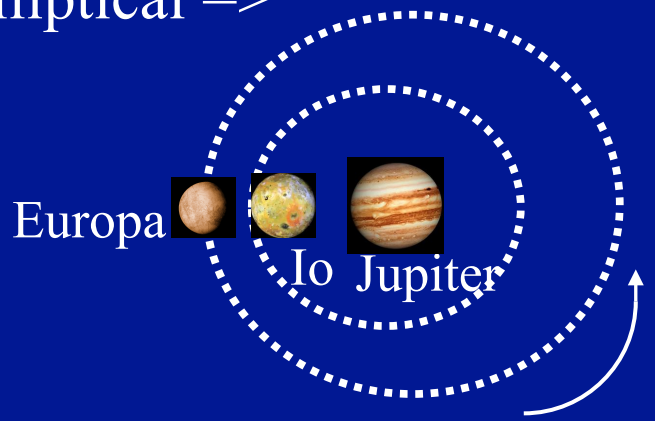
860 km

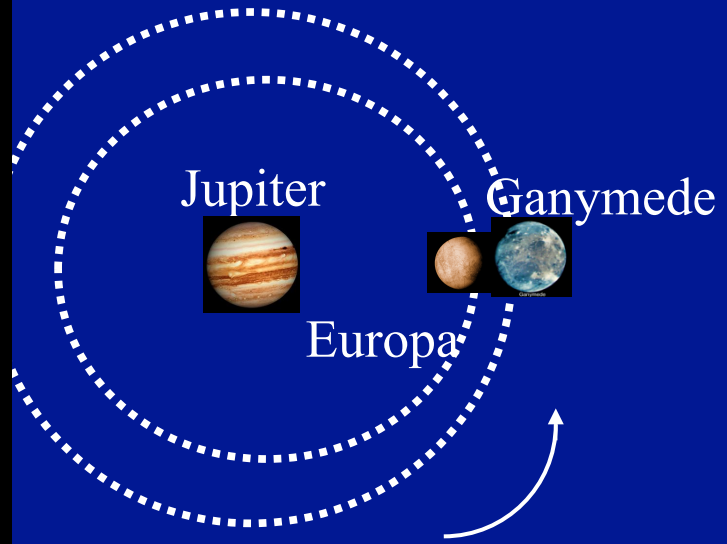
Dark deposits along cracks suggest eruptions of water with dust/rock mixed in (Europa's density => 90% rock, 10% ice).

What is source of heat? Similar to Io: resonant orbits with Ganymede and Io make Europa's orbit elliptical => varying tidal stresses from Jupiter => heat.

Warm ocean => life?

NASA mission in "formulation"

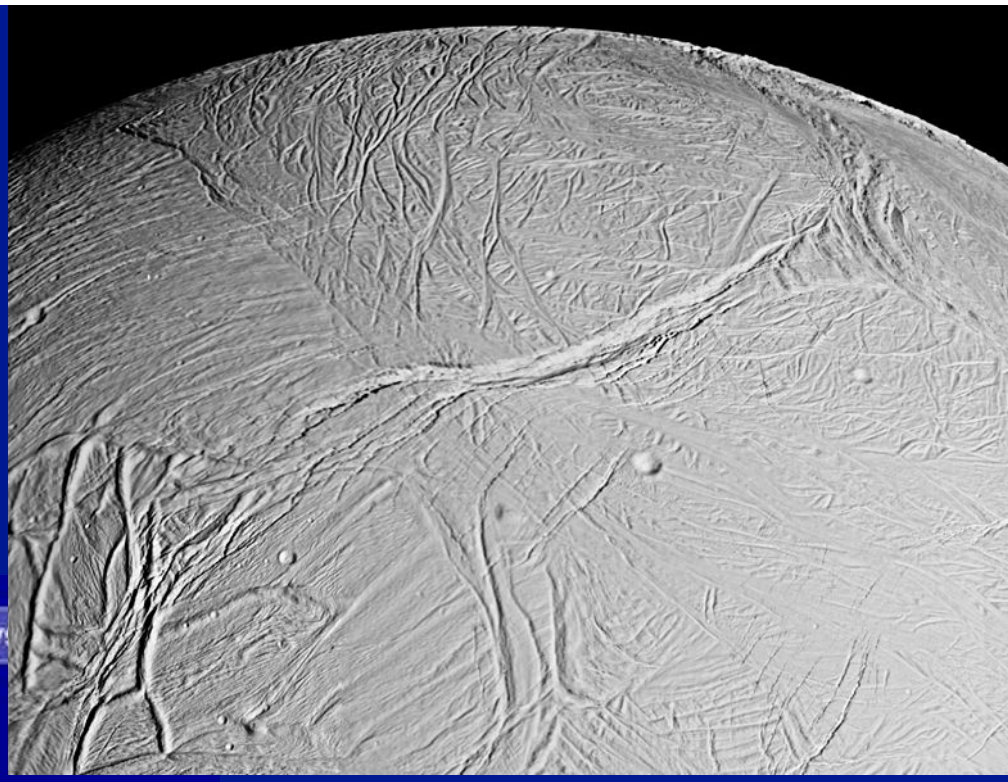


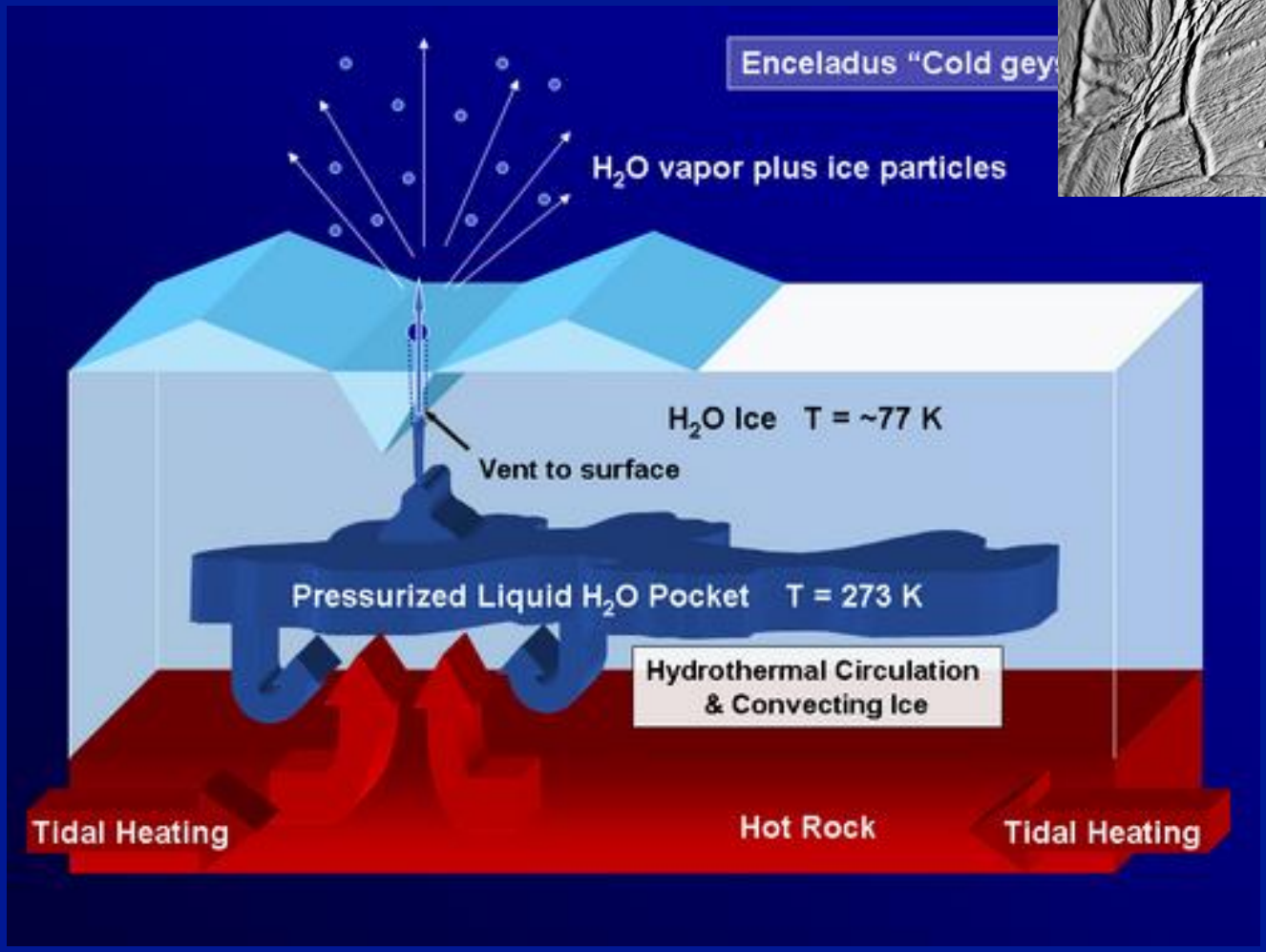


(exaggerated ellipses)

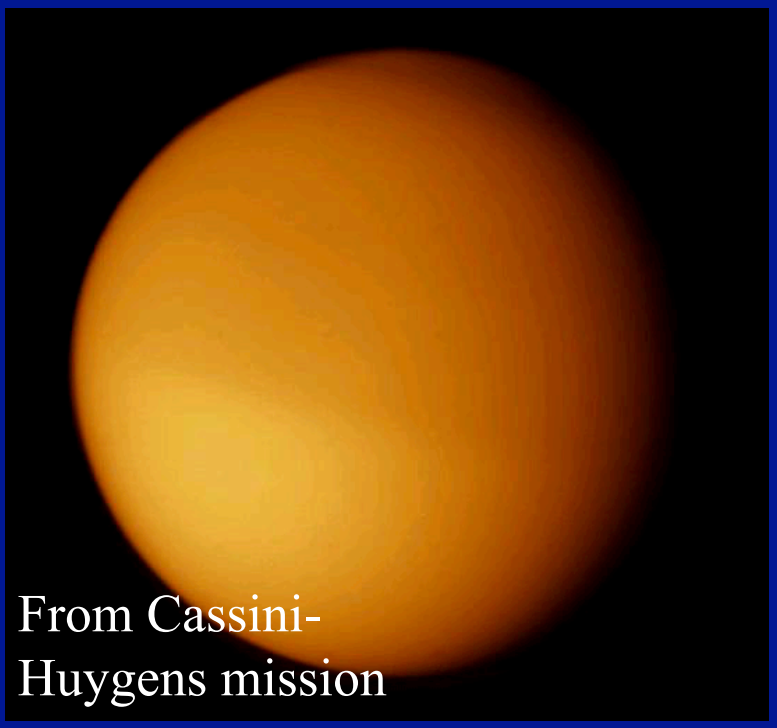
Enceladus - minor moon of Saturn
(250 km radius)
orbiting in the E-ring
Plate Tectonics!

Water Geysers!





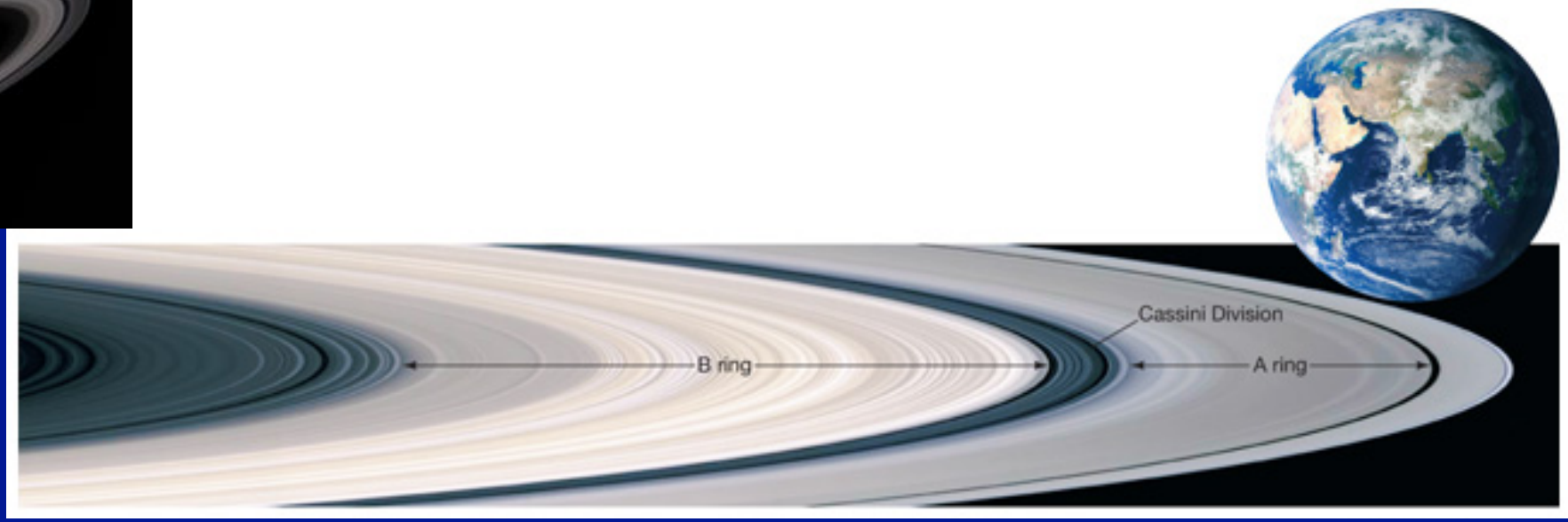
Saturn's Titan: A Moon with a Thick Atmosphere



Surface pressure is 1.6 atmospheres, T=94 K. Atmosphere 98% Nitrogen. Evidence for methane rain, a few possible slushy lakes of methane/ethane, drainage channels, liquid-eroded rocks, icy volcanoes (replenishing the methane?), complex hydrocarbons in atmosphere (e.g. benzene C_6H_6). Mostly dry now - liquid flow may be episodic. Methanogenic life?

Origin of atmosphere: probably gases trapped in water ice at formation, released by heat from natural radioactivity and volcanos into atmosphere. Trapped by Titan's cold temperature and relatively high gravity.

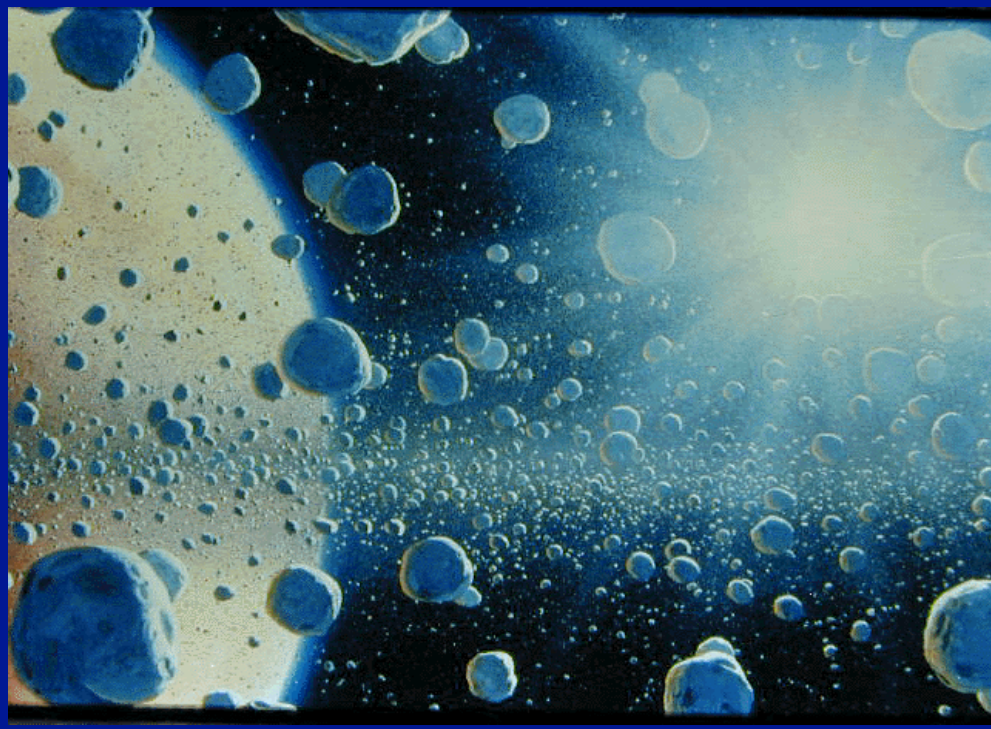
Saturn's Rings (all Jovians have ring systems)



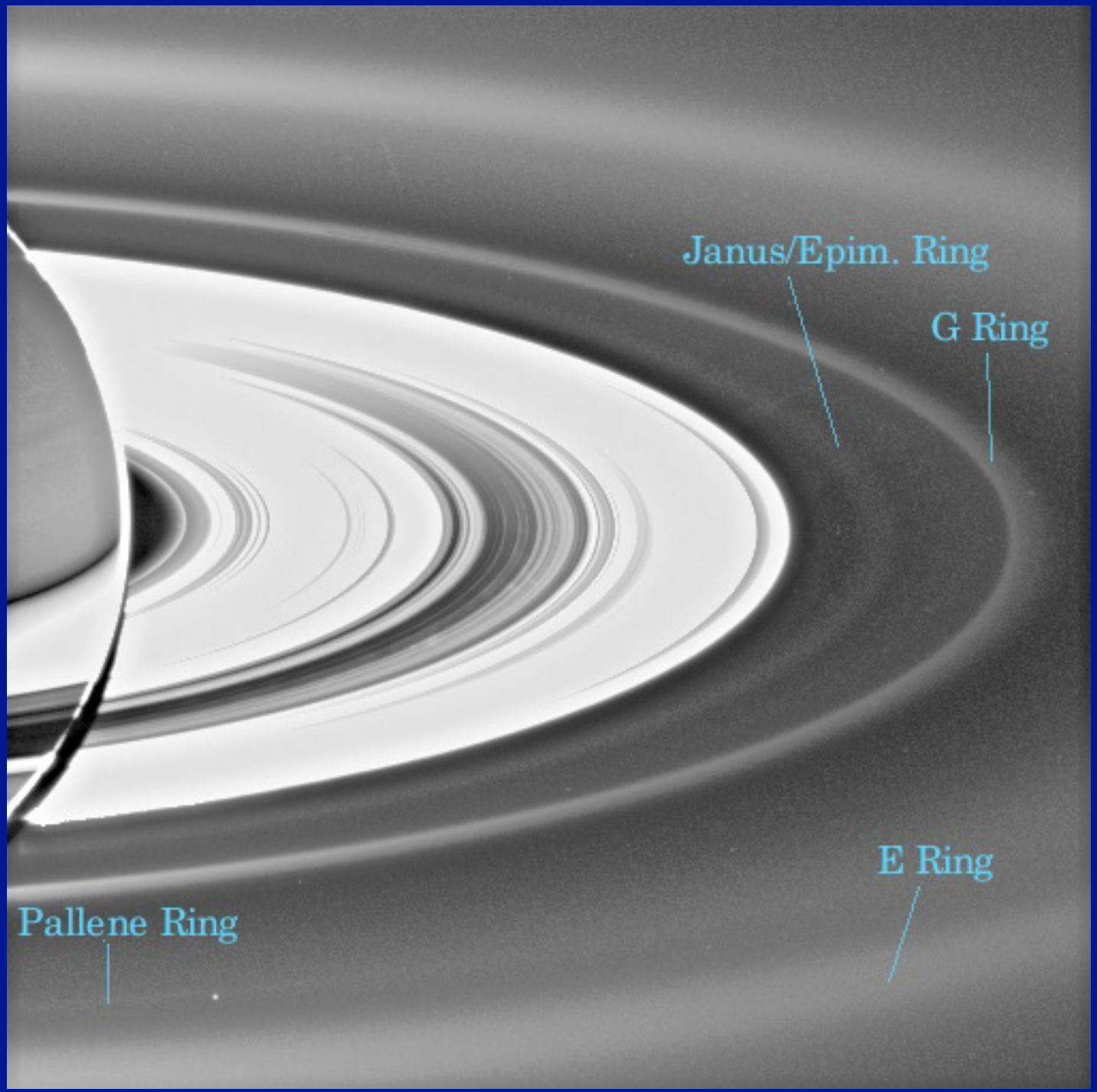
- Inner radius 60,000 km, outer radius 300,000 km. Thickness ~100 m!

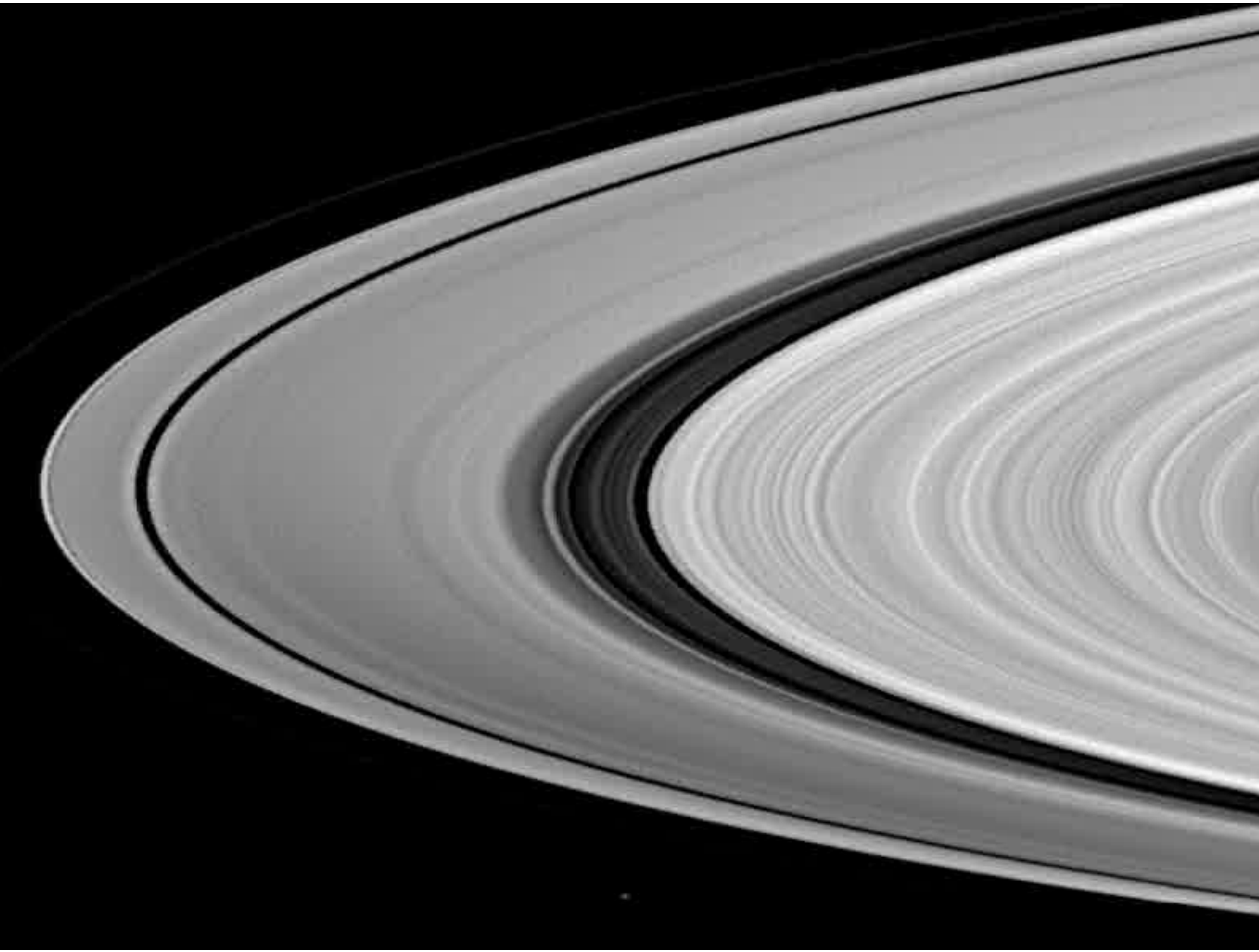
- Composition: icy particles, <1 mm to >10m in diameter. Most a few cm.

- A few rings and divisions distinguishable from Earth.

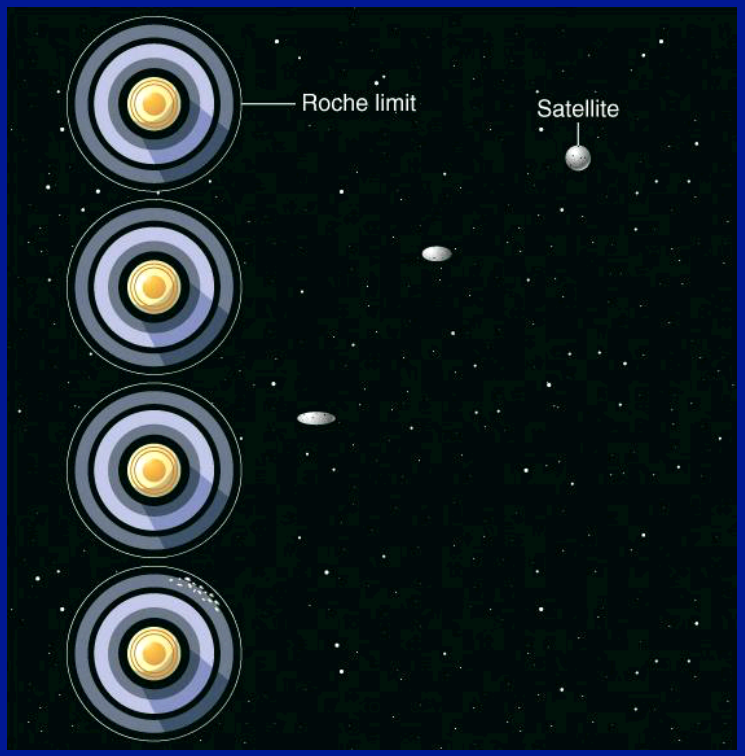


Saturn's Faint Outer Rings





Origin of Saturn's Rings:



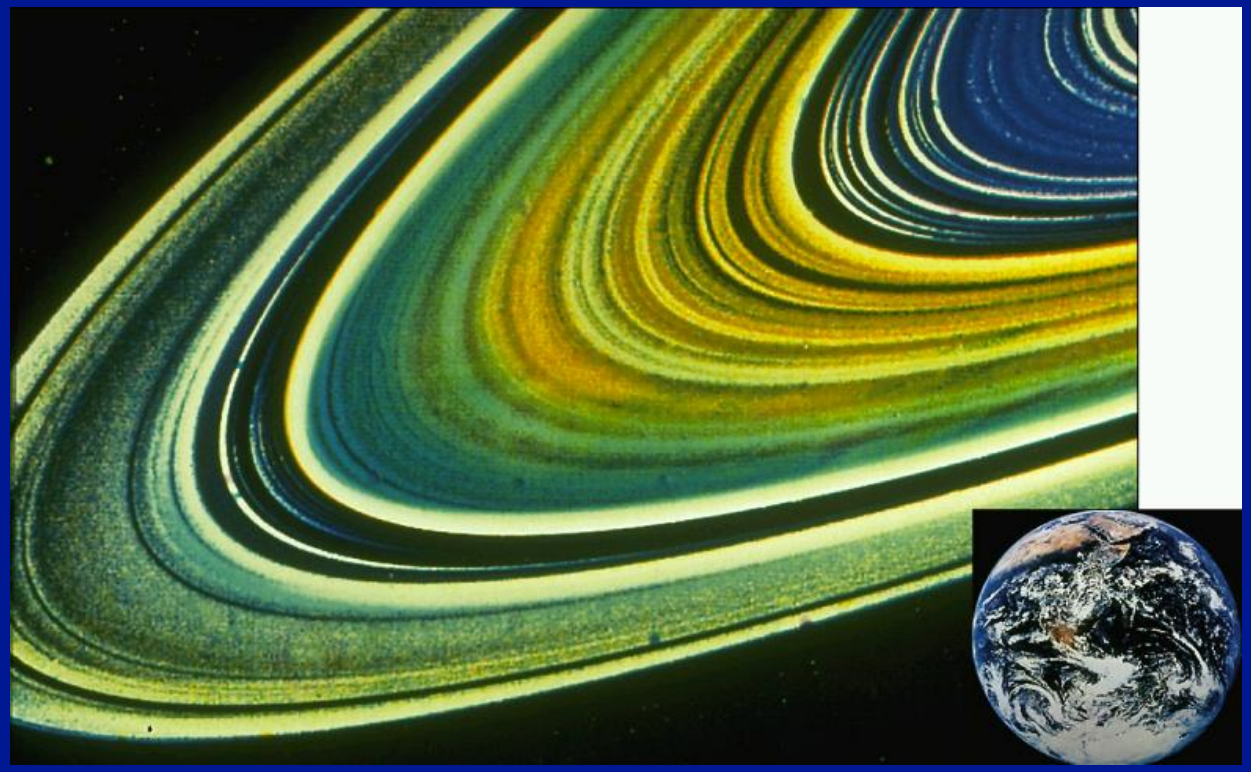
If a large moon, held together by gravity, gets too close to Saturn, the tidal force breaks it apart into small pieces. The radius where this happens is called the Roche Limit.

Total mass of ring particles equivalent to 250 km moon.

Perhaps a collision between moons sent one inwards this way, or a captured stray body.

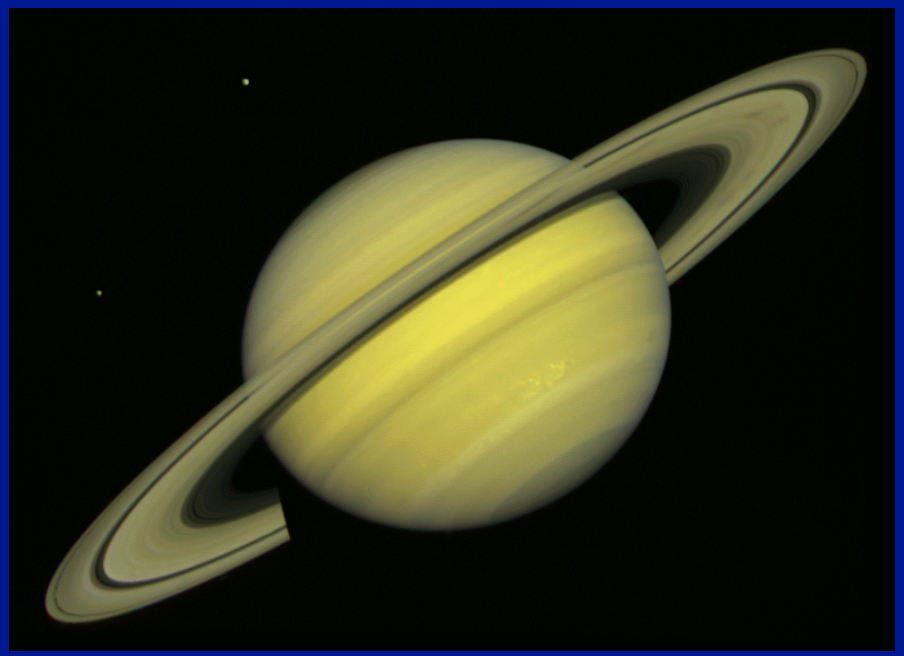
Rings expected to survive only 50-100 million years.

Voyager probes found that rings divide into 10,000's of ringlets.



Structure at this level keeps changing. Waves of matter move like ripples on a pond.

Origin of Cassini Division: another resonance orbit

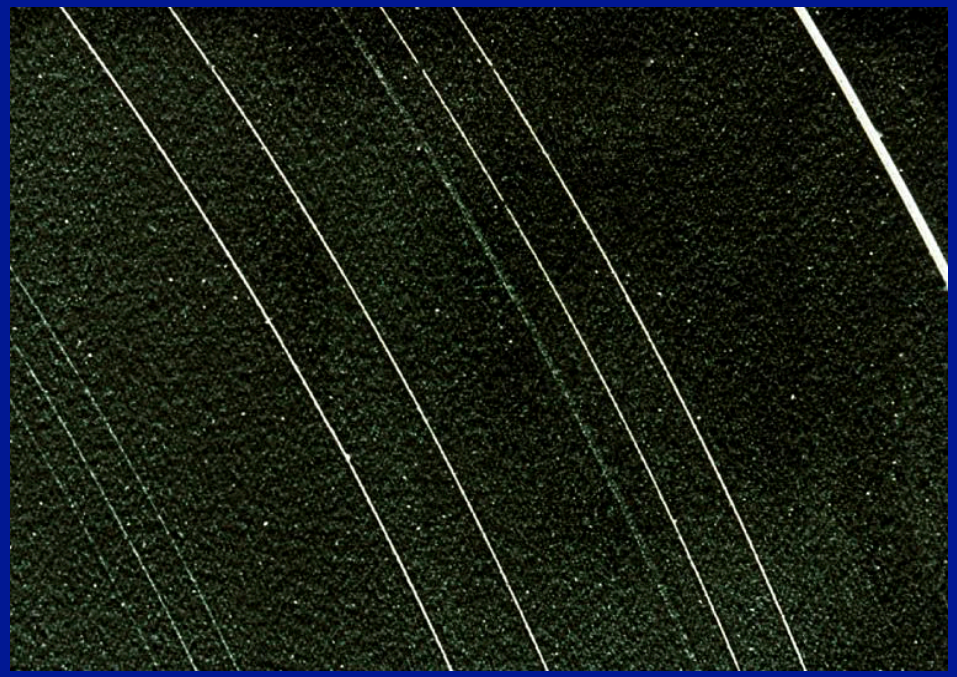


- Approximate radius of Mimas' orbit

Mimas' orbital period is twice that of particles in Cassini division. Makes their orbits elliptical. They collide with other particles and end up in new circular orbits at other radii. Cassini division nearly swept clean.

Other gaps have similar origins.

Rings of other Jovian Planets



The rings of Uranus. Discovered by "stellar occultation".

Jupiter, Uranus, Neptune rings much thinner, much less material. Formed by breakup of smaller bodies? Also maybe "sandblasting" of material off moon surfaces by impacts.

Given rings have short lifetime and all Jovian planets have them, their formation must be common.

Neptune's moon Triton is spiraling in to the planet and should produce spectacular ring system in 100 million years.

Clicker Question:

Jupiter's moon Europa is thought to have a large ocean of liquid water under a frozen surface. What is the heat source that keeps it from freezing?

A: Heat trapped inside the moon since formation.

B: A strong greenhouse effect from a dense atmosphere.

C: Tidal forces exerted by Jupiter, Io and Ganymede.

D: Radioactive decay of heavy elements in the mantle.

Clicker Question:

Saturn's rings are not perfectly uniform. What causes the observed gaps?

A: The gravitational influence of Saturn.

B: The gravitational influence of Saturn's moons.

C: Radiation pressure from Saturn.

D: The gravitational influence of the Sun and Jupiter.

Clicker Question:

The only Jovian planet without a large moon is:

A: Jupiter

B: Saturn

C: Uranus

D: Neptune

Pluto

Predicted to exist by remaining irregularities in Uranus' orbit.
Discovered in 1930 by Clyde Tombaugh (1905-1997).
Irregularities later found to be incorrect!

New Horizons mission reveals many surprises

- Ice mountains
- Scaly surface
- Glaciers
- Frozen oceans
- Dunes

Basic Properties of Pluto

Mass 0.0025 M_{Earth} or 0.2 x mass of Moon

Radius 1150 km or 0.2 R_{Earth}

Density 2.0 g/cm^3 (between Terrestrial and Jovian densities. More like a Jovian moon)

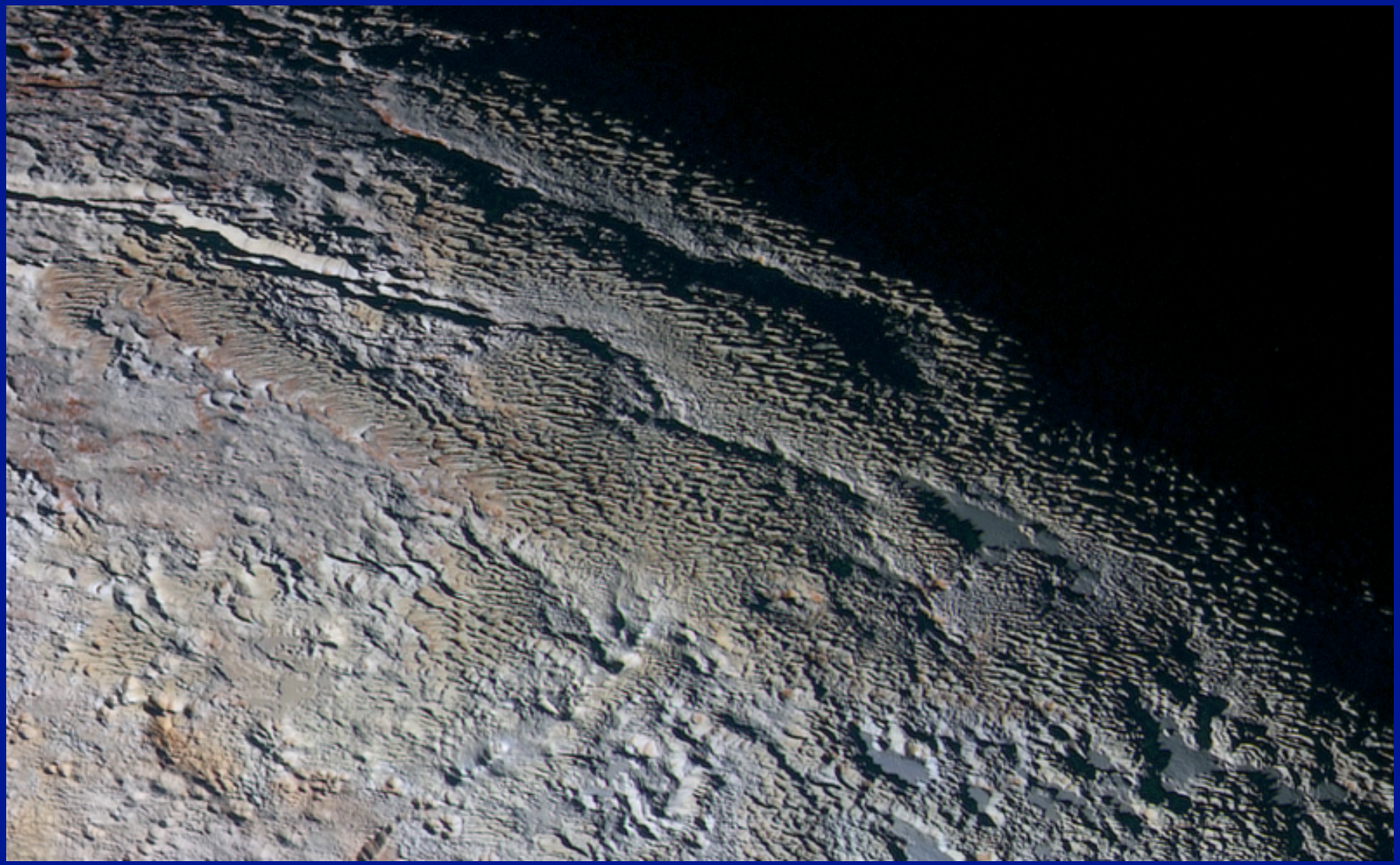
Icy/rocky composition

Eccentric, tilted orbit

Moons: Charon: radius about 590 km or 0.1 R_{Earth} . Pluto and Charon tidally locked. S/2005 P1 and S/2005 P2: about 30-100 km.

Pluto

New Horizons close-ups from July 2015 flyby



Scaly surface

Pluto

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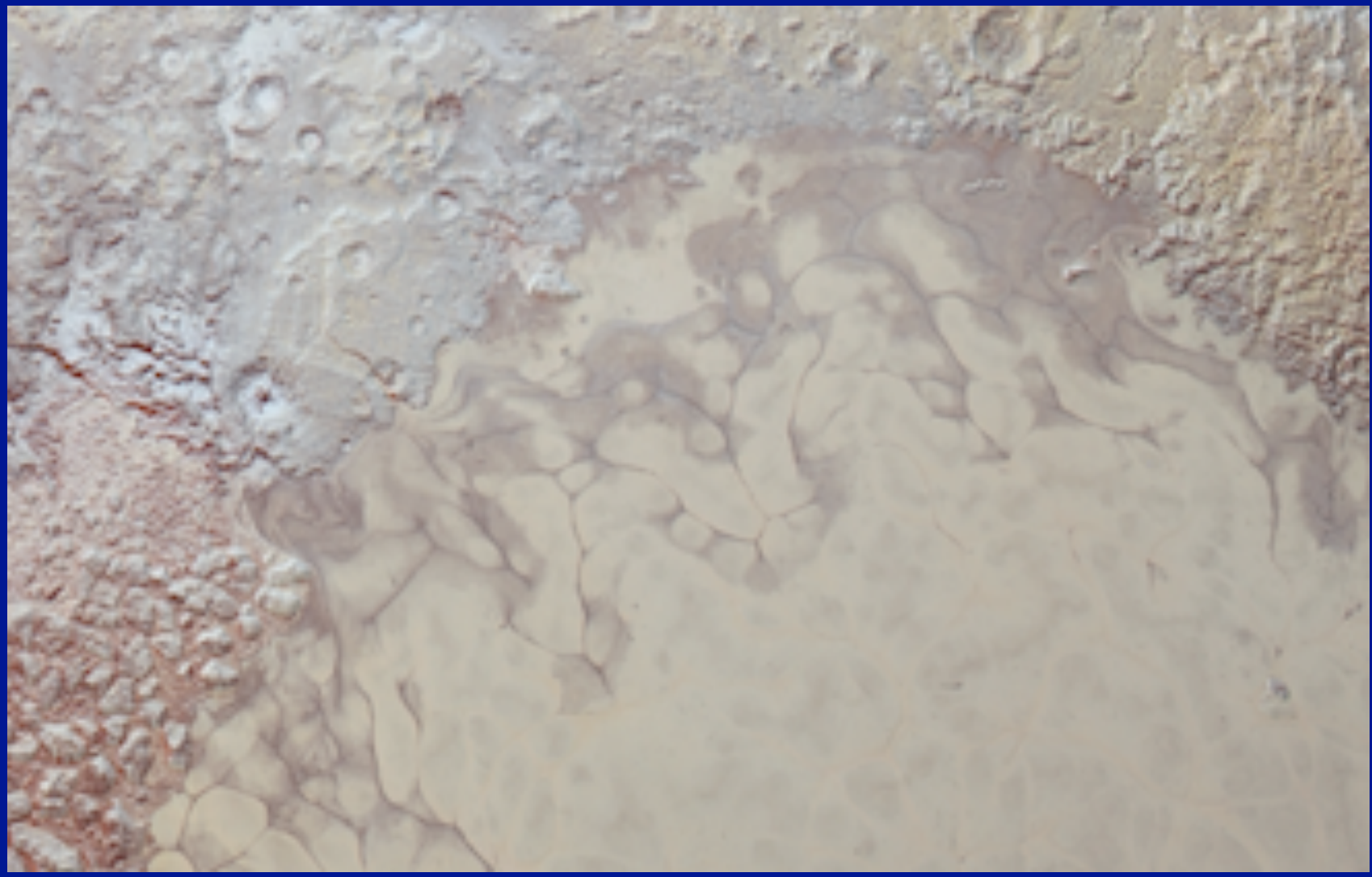
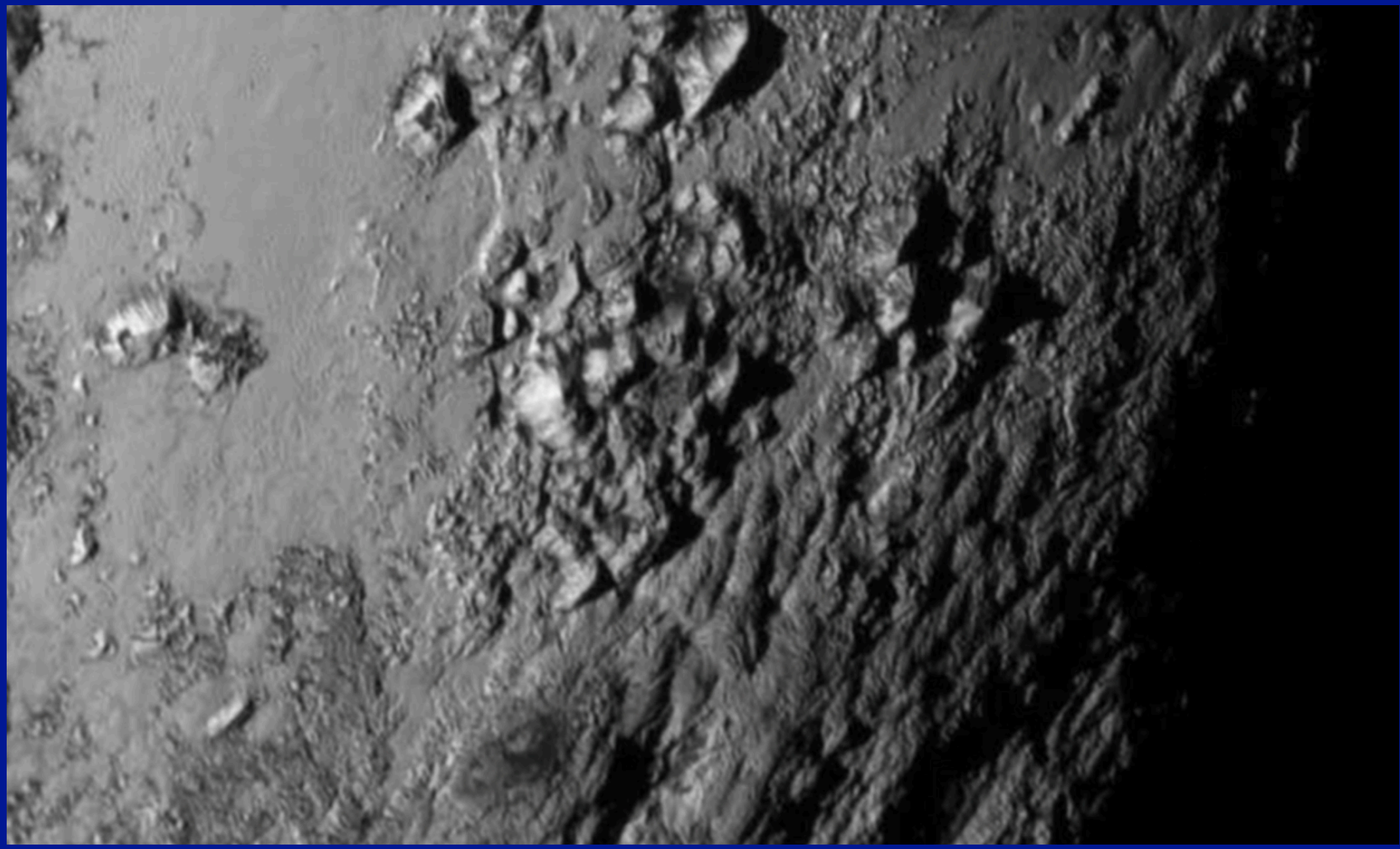


Frozen oceans reveal recent resurfacing

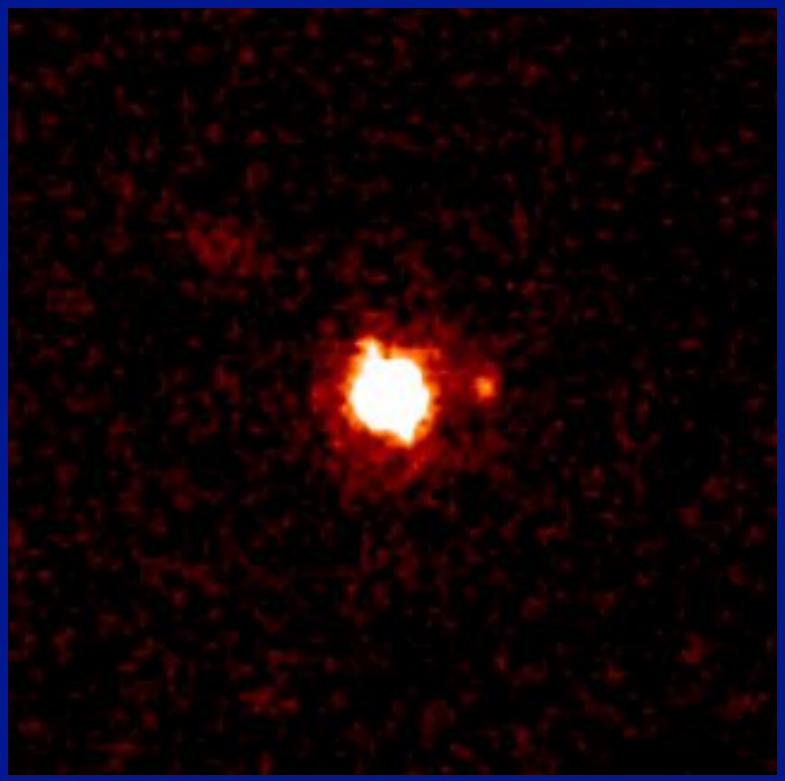
Pluto

New Horizons close-ups from July 2015 flyby

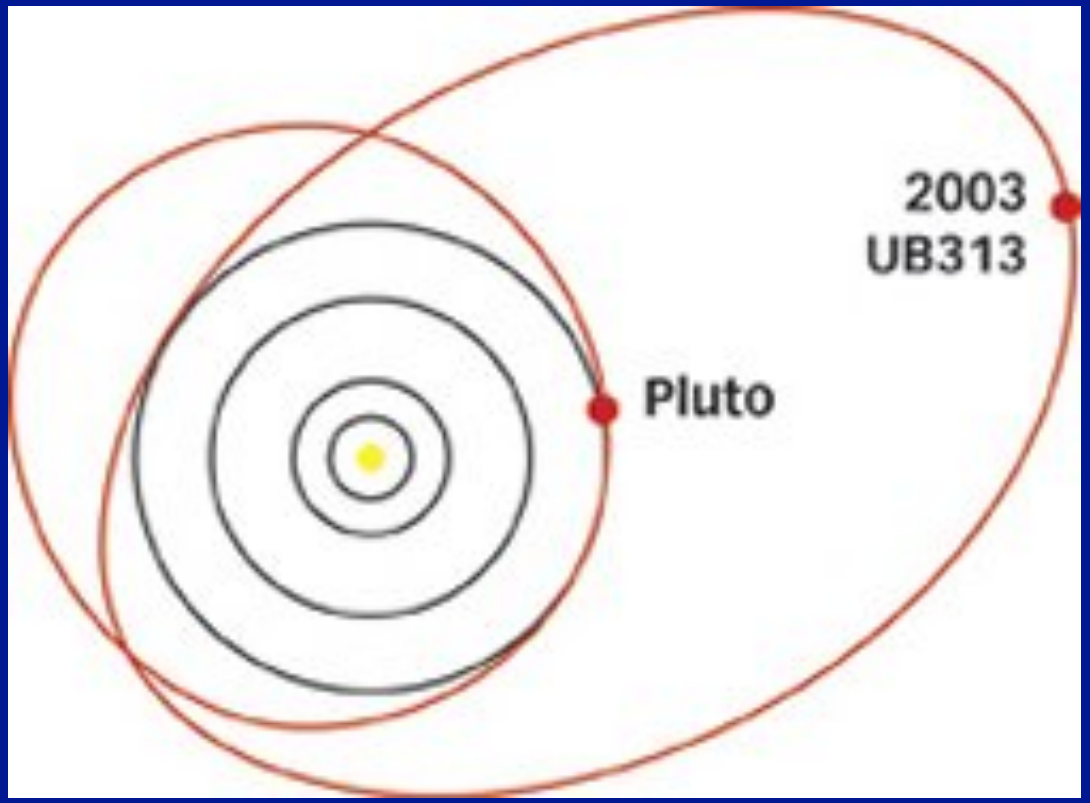


Ice Mountains up to 11,000 feet tall

The New "Dwarf Planet" (2003 UB313 = Eris)



It too has a moon (Keck telescope)



orbit

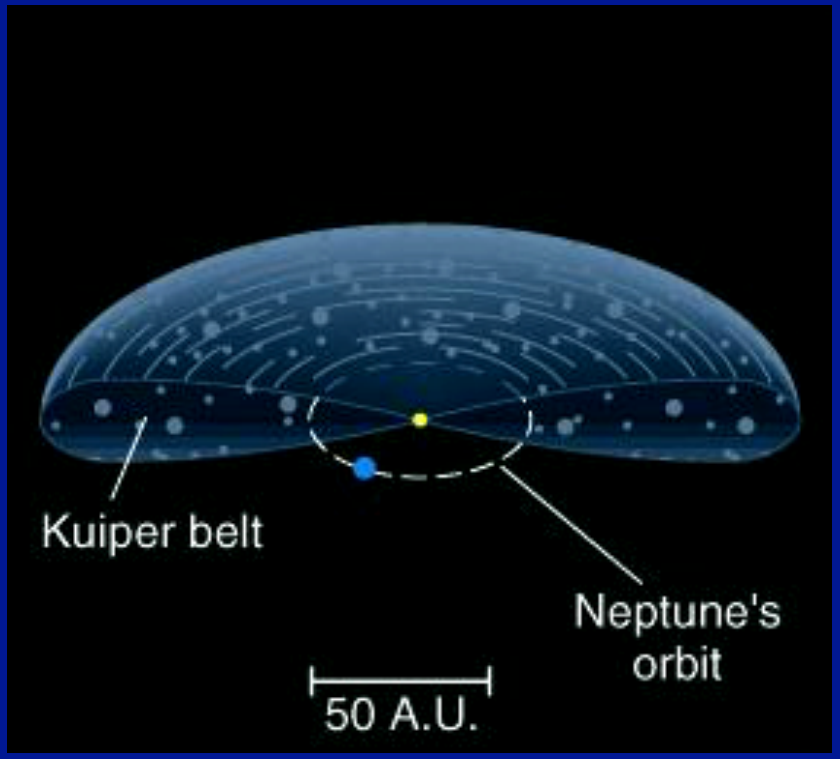
Very eccentric orbit. Aphelion 98 AU, perihelion 38 AU. Period 557 years. Orbit tilt 44°.

Radius 1200 ± 50 km so bigger than Pluto. Icy/rocky composition, like Pluto. More massive than Pluto.

Origin of Pluto and Eris

Now known to be just the largest known of a class of objects in the outer reaches of the Solar System. These objects are:

The Kuiper Belt Objects



100's found since 1992. Probably 10,000's exist.

Icy/rocky.

Orbits tend to be more tilted, like Pluto's.

Leftover planetesimals from Solar System formation?

More Solar System Debris

Comets

Comet Halley (1986)

Comet Hale-Bopp (1997)

Short Period Comets

50-200 year orbits

Orbits prograde, close to plane of Solar System

Originate in Kuiper Belt

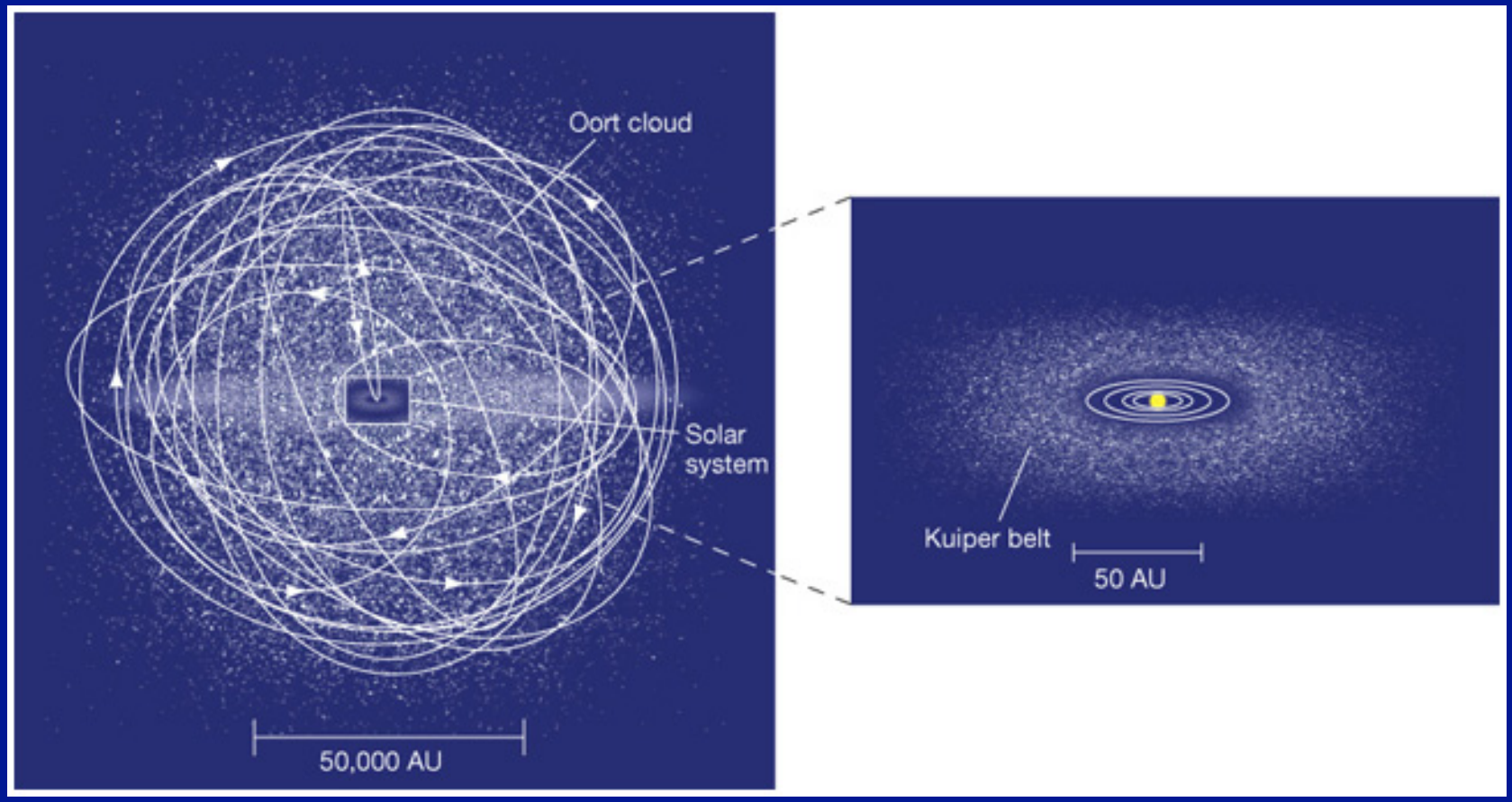
Long Period Comets

Few times 10^5 or 10^6 year orbits

Orbits have random orientations and ellipticities

Originate in Oort Cloud

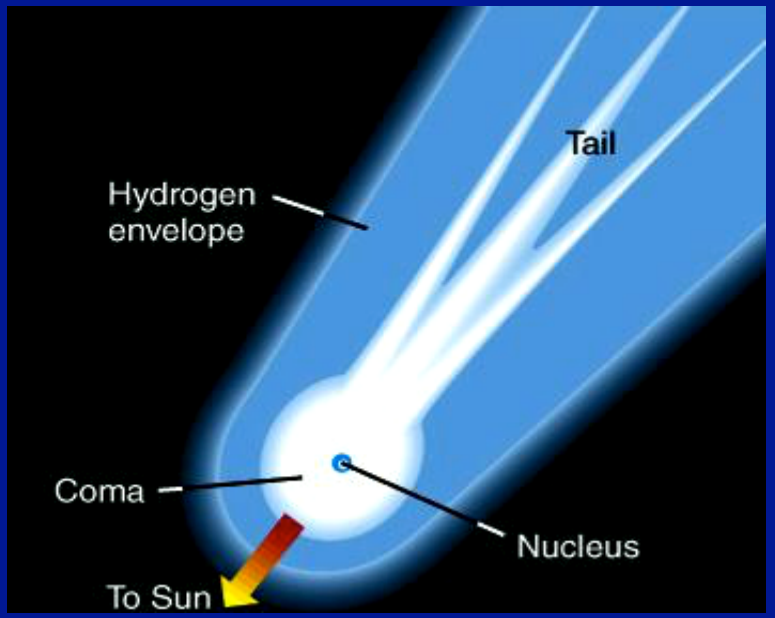
Oort Cloud is a postulated huge, roughly spherical reservoir of comets surrounding the Solar System. ~10^8 objects? Ejected planetesimals.



A passing star may dislodge Oort cloud objects, plunging them into Solar System, where they become comets.

If a Kuiper Belt object's orbit takes it close to, e.g., Neptune, its orbit may be changed and it may plunge towards the inner Solar System and become a comet.

Comet Structure



Nucleus: ~10 km ball of ice, dust

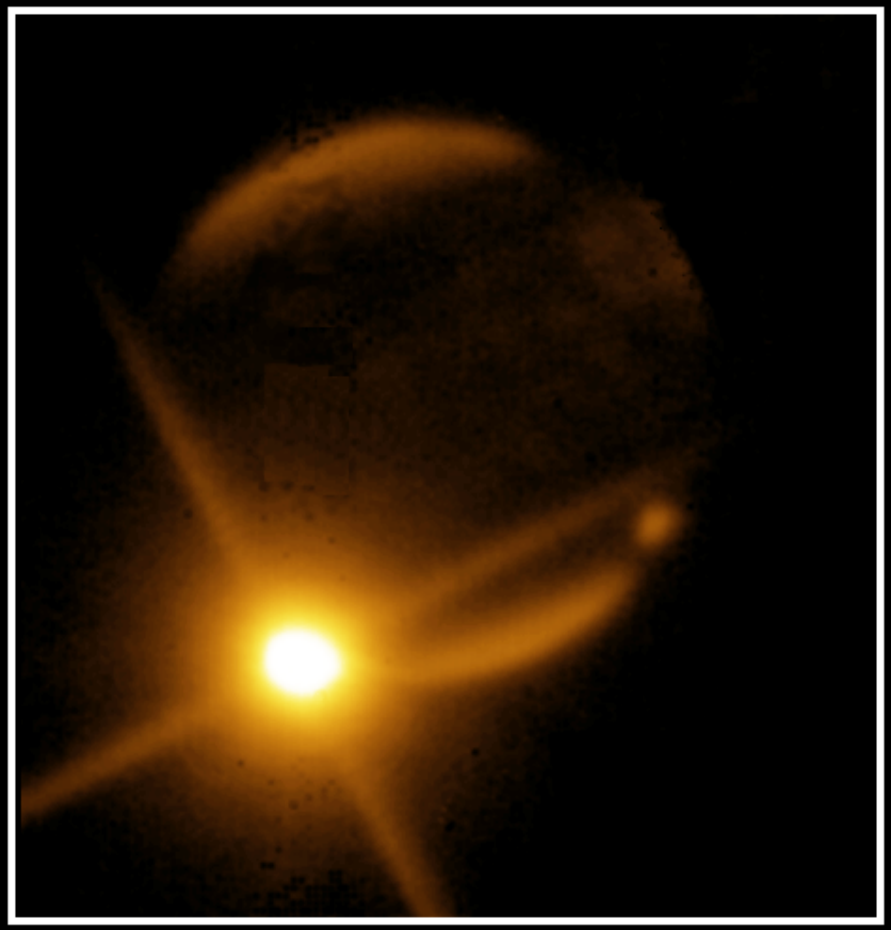
Coma: cloud of gas and dust around nucleus (~10^6 km across)

Tail: can have both gas (blue) and dust tails (~10^8 km long). Always points away from Sun.

Coma and tail due to gas and dust removed from nucleus by Solar radiation and wind.

Far from Sun, comet is a nucleus only.

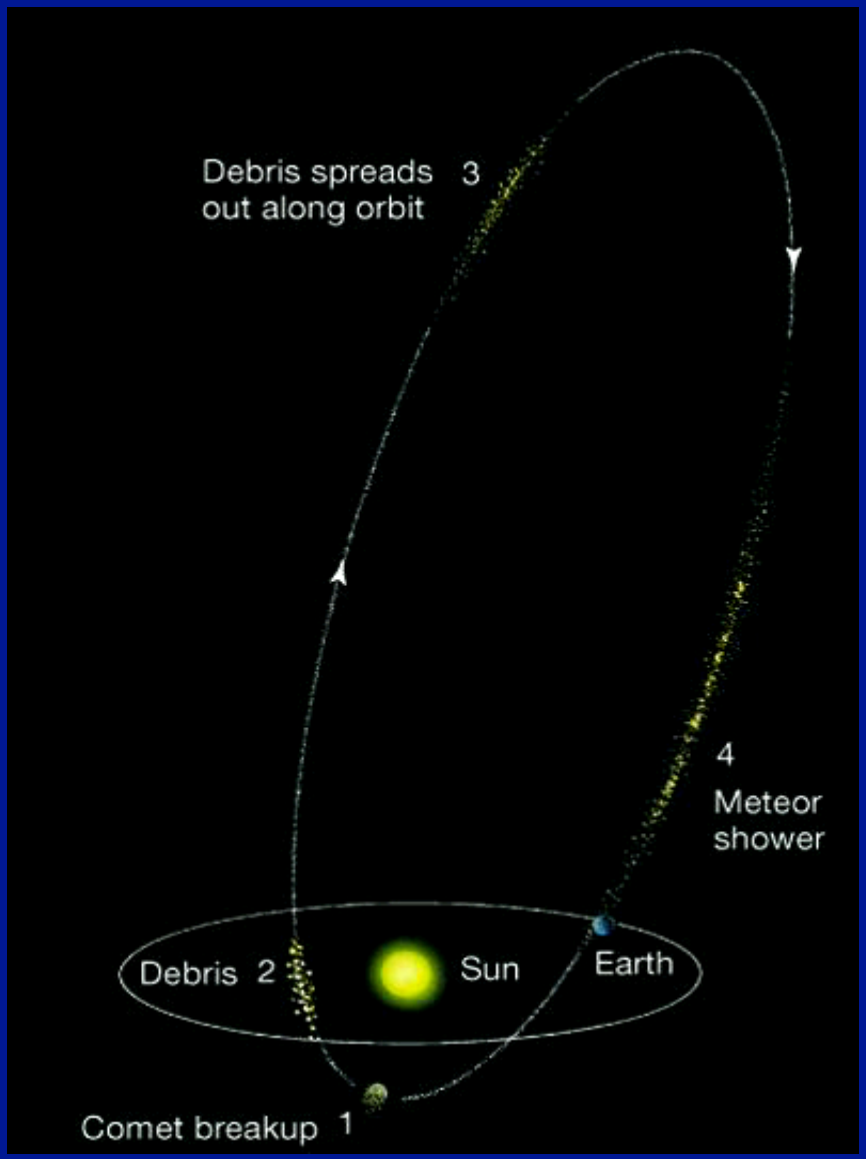
Shoemaker-Levy Impact



Impact of Fragment G of Comet Shoemaker-Levy on Jupiter
The fireball is seen 12 minutes after impact at 2.34 microns.
The impact A site is seen on the opposite limb of the planet.

Image at 2.34 microns with CASPIR by Peter McGregor
ANU 2.3m telescope at Siding Spring

Meteor Showers



Comets slowly break up when near Sun, due to Solar radiation, wind and tidal force.

e.g. Halley loses 10 tons/sec when near Sun. Will be destroyed in 40,000 years.

Debris spreads out along comet orbit.

IF Earth's orbit crosses comet orbit, get meteor shower, as fragments burn up in atmosphere.

Meteoroids

Even smaller rocky pieces left over from Solar System formation.

If one lands on Earth, called a Meteorite.

Note: Meteor is only the name of the visible streak as the rock burns in atmosphere.

Clicker Question:

The Oort Cloud is:

A: a spherical solar system halo of icy objects far beyond the orbit of Pluto.

B: a flat region just outside the orbit of Neptune in which icy and rocky objects circle the Sun.

C: the collection of rocky objects orbiting the Sun between the orbits of Mars and Jupiter.

D: a swarm of small satellites around Jupiter.

Clicker Question:

The Perseids meteor shower happens every year when:

A: the Earth passes through the constellation Perseus.

B: the Earth passes through the remnants of comet Swift-Tuttle.

C: the Oort cloud emits a burst of comets.

D: the Earth comes within closest approach to the asteroid belt.

Clicker Question:

Volcanic Eruptions have been seen on:

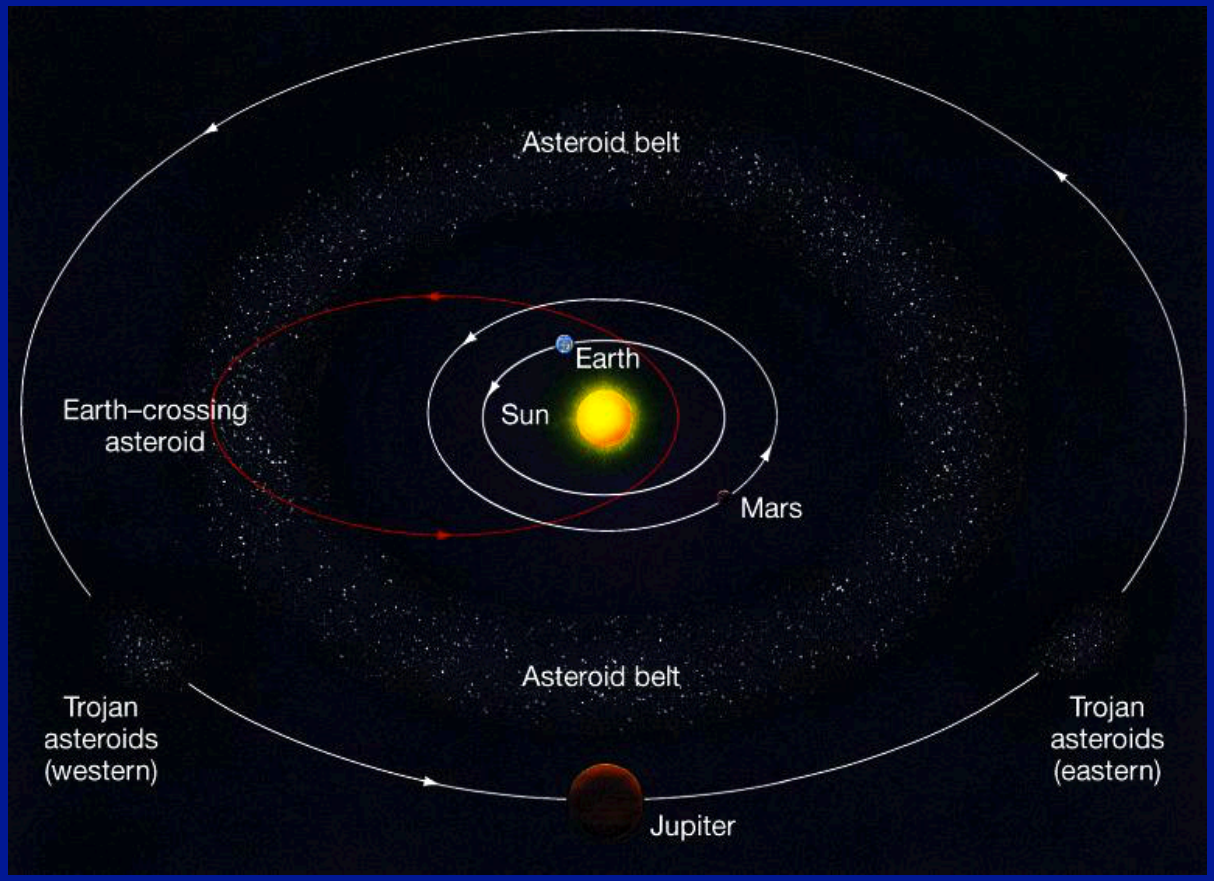
A: Earth

B: Io

C: Encaladus

D: All of the above

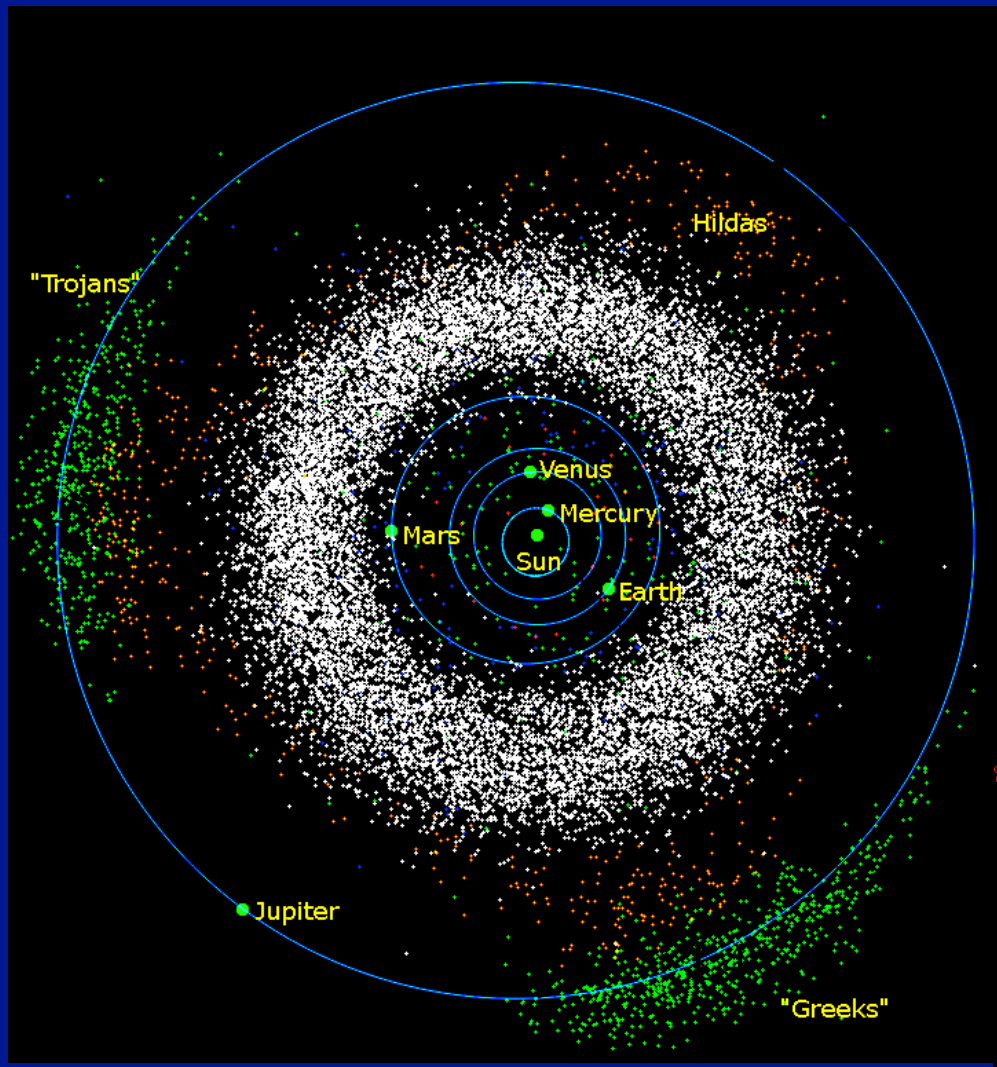
Asteroids



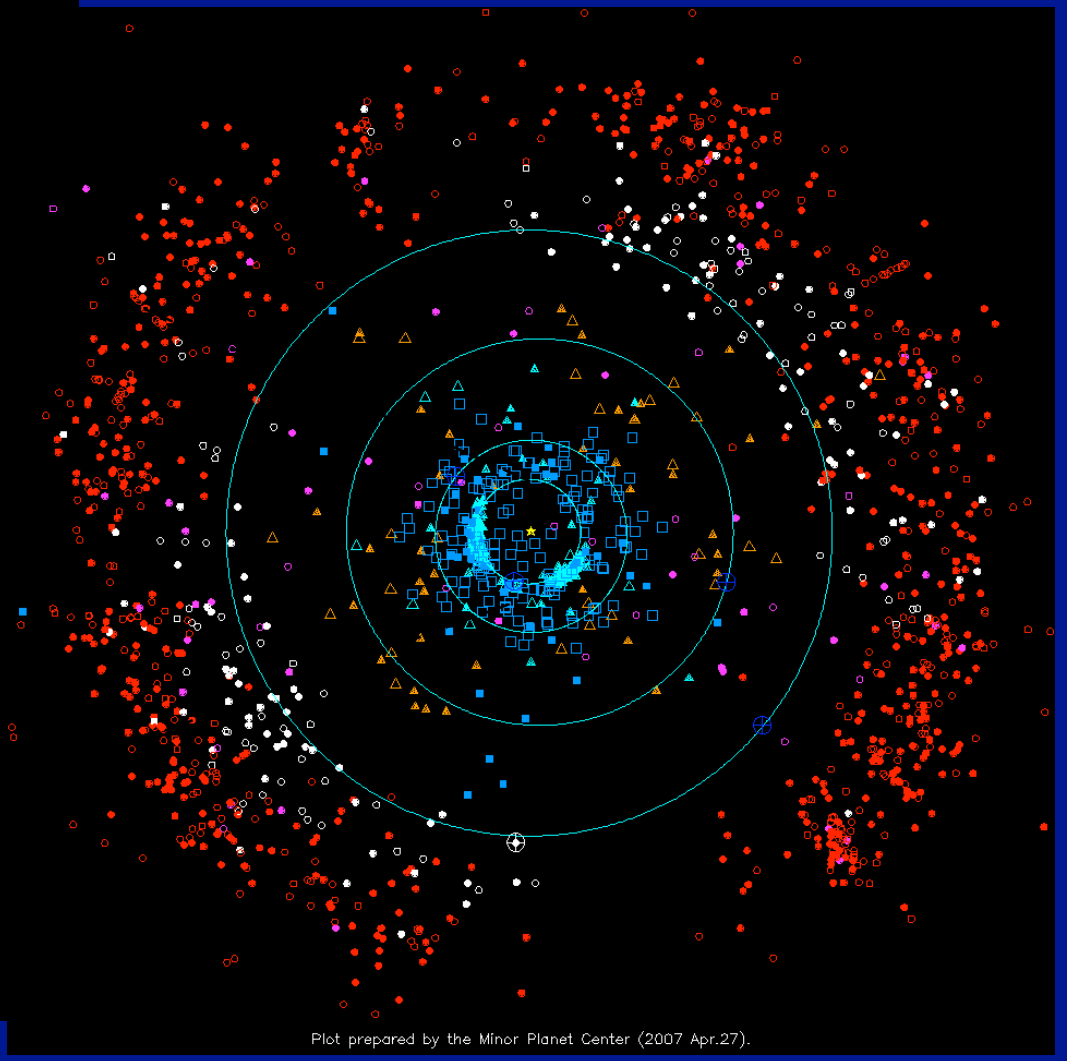
Rocky fragments ranging from 940 km across (Ceres) to < 0.1 km. 100,000 known.

Most in Asteroid Belt, at about 2-3 AU, between Mars and Jupiter. The Trojan asteroids orbit 60 º ahead of and behind Jupiter. Some asteroids cross Earth's orbit. Their orbits were probably disrupted by Jupiter's gravity.

Asteroids and Kuiper Belt Objects



~ 5 AU



~ 45 AU

Gaspra

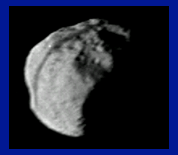
Ida and Dactyl

Total mass of Asteroid Belt only 0.0008 M_{Earth} or 0.07 M_{moon}. So it is not debris of a planet.

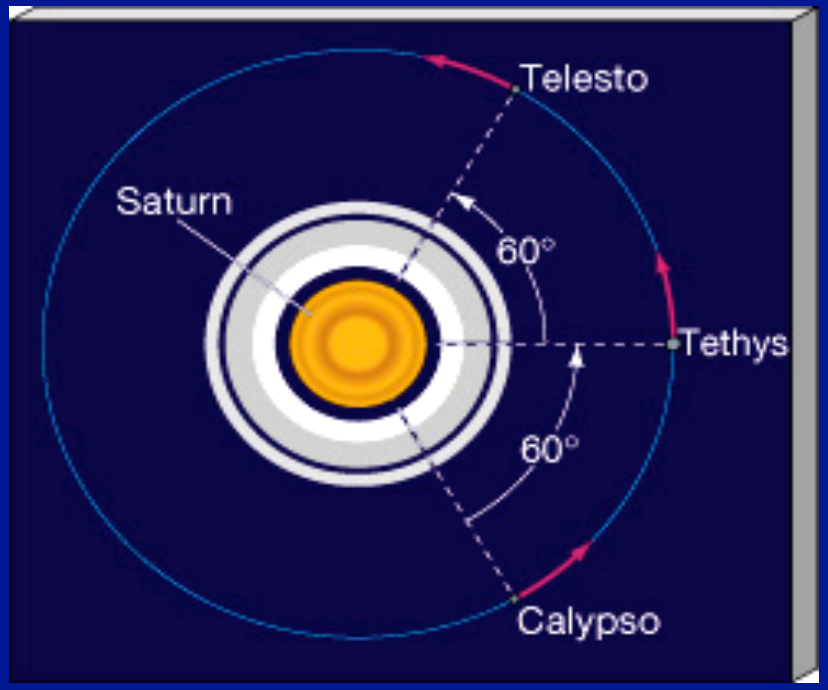
Probably a planet was trying to form there, but almost all of the planetesimals were ejected from Solar System due to encounters with Jupiter. Giant planets may be effective vacuum cleaners for Solar Systems.

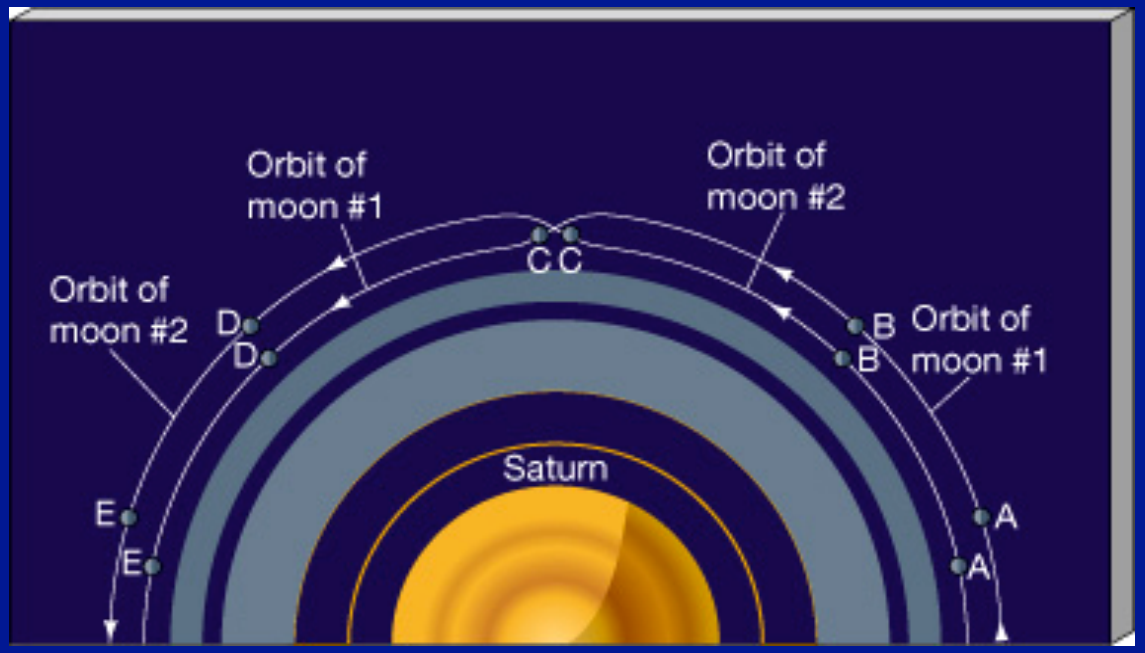
Bizarre Orbits of some of Saturn's Moons

Tethys



Janus and Epimethius





Telesto and Calypso share orbit with Tethys, and are always 60 deg. ahead and behind it! They stay there because of combined gravity of Saturn and Tethys.

Janus and Epimethius are in close orbits. When the approach each other, they switch orbits!