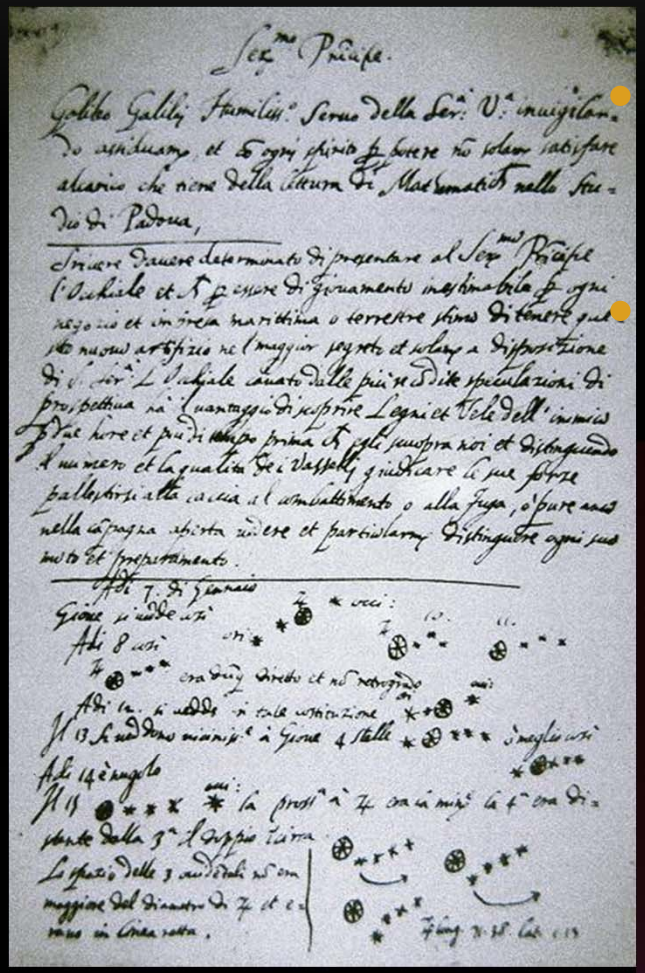
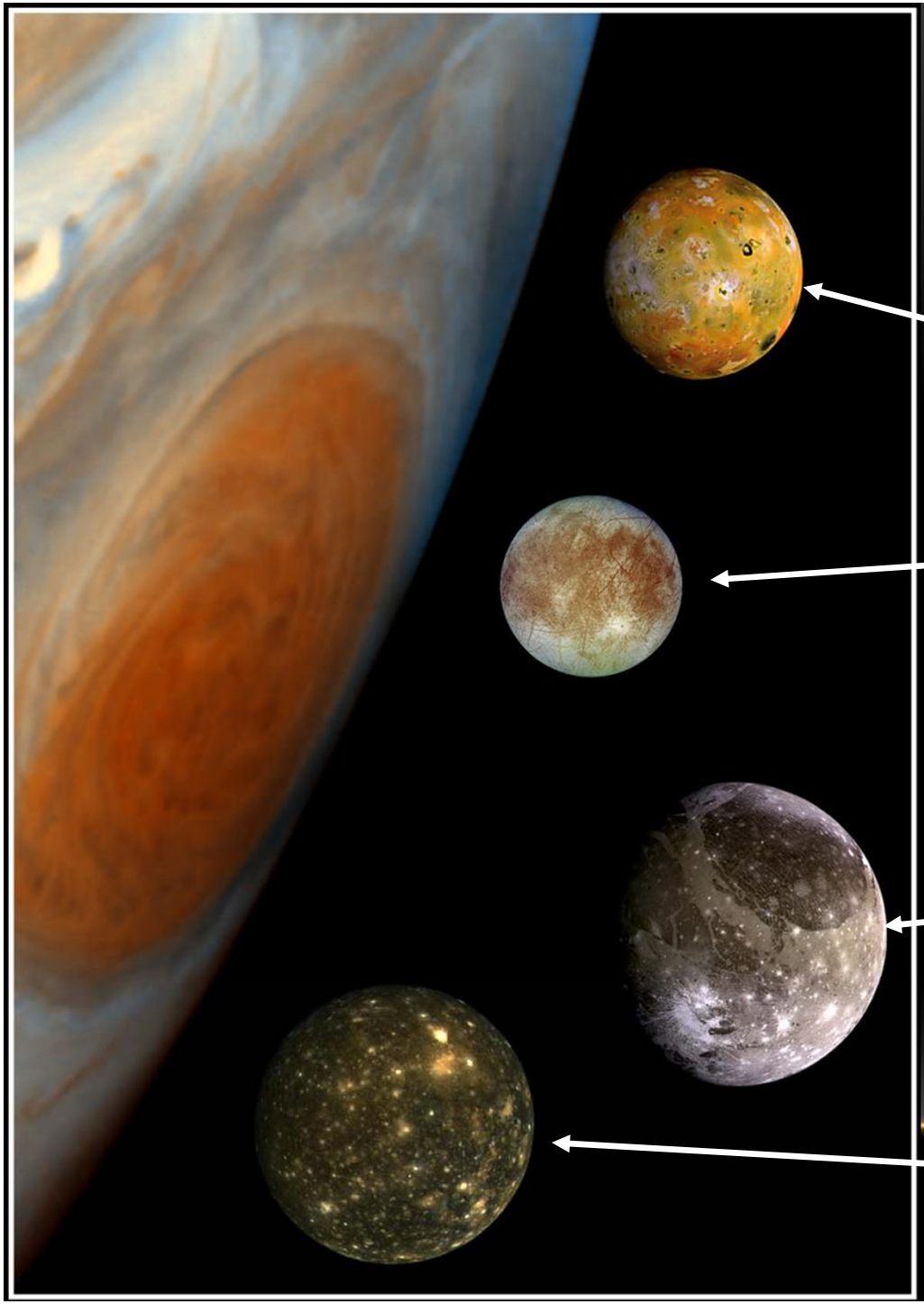
MOONS OF JUPITER



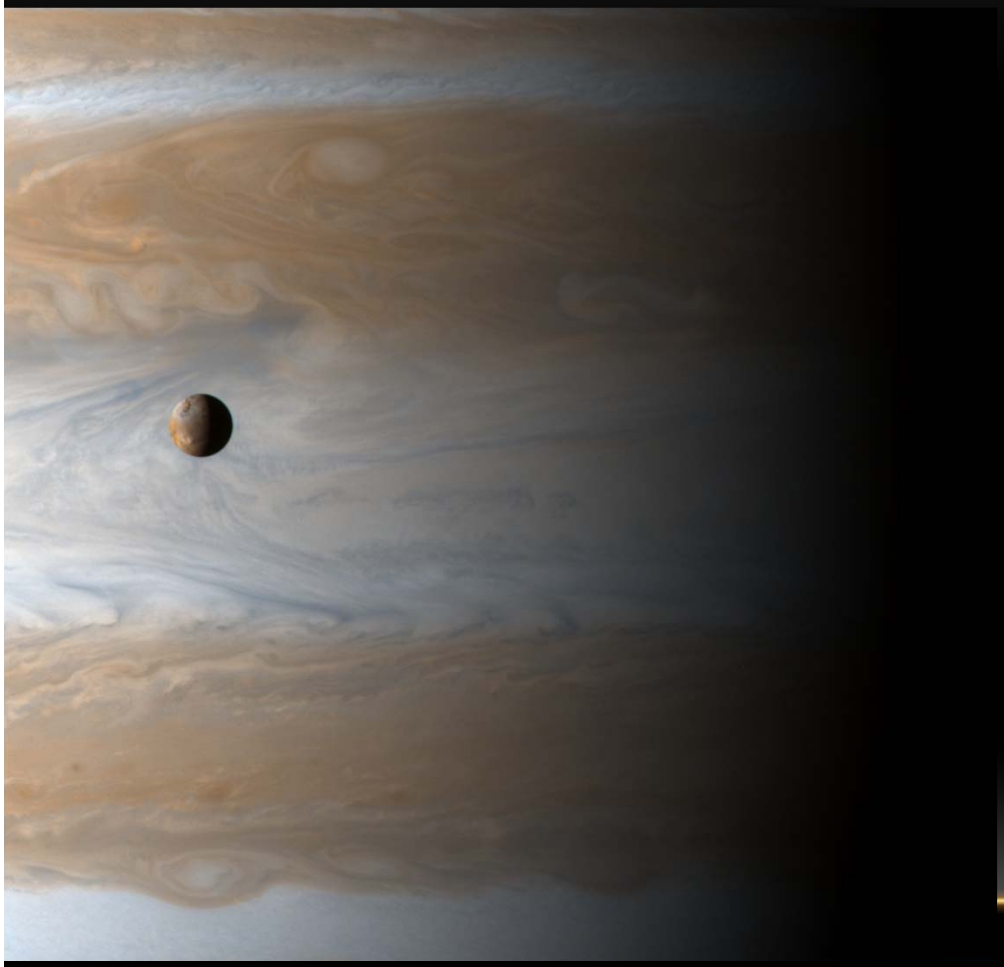
- Jupiter has 60 of them
  - Many very small, very recently discovered
- Galileo (the old Italian guy) discovered the first four

GALILEAN MOONS



- Ganymede & Callisto larger than Mercury
- Earth's moon is slightly smaller than Io

IO



Actual photo of Io and Jupiter (from Cassini)

- Nearest to Jupiter
  - 1.77 day orbit
- A bit larger in diameter than Moon
- Denser than Moon
- Extremely volcanically active

IO

- Eccentric orbit close to Jupiter
  - Large tidal forces!
  - Other moons also pull on it
- Io kneaded by Jupiter's gravity
  - Rock tides ~100m high
  - Friction heats Io
  - Volcanoes result

VOLCANOES OF IO

- Only place other than Earth where a volcano has been caught in the act
  - ~100 active volcanoes

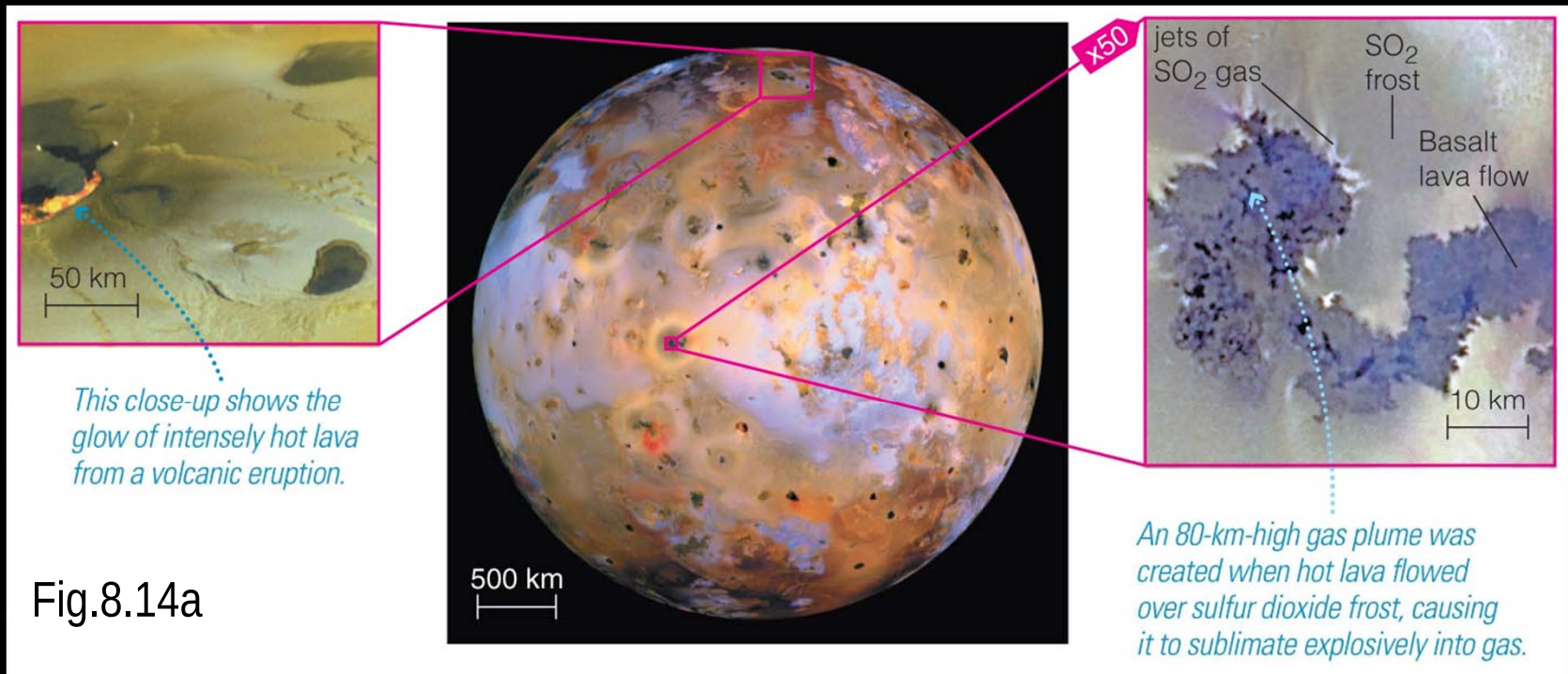
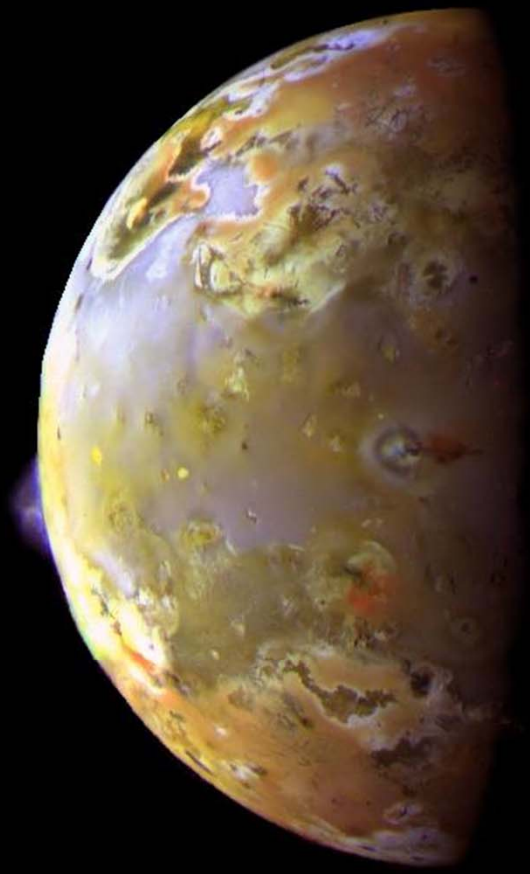


Fig.8.14a

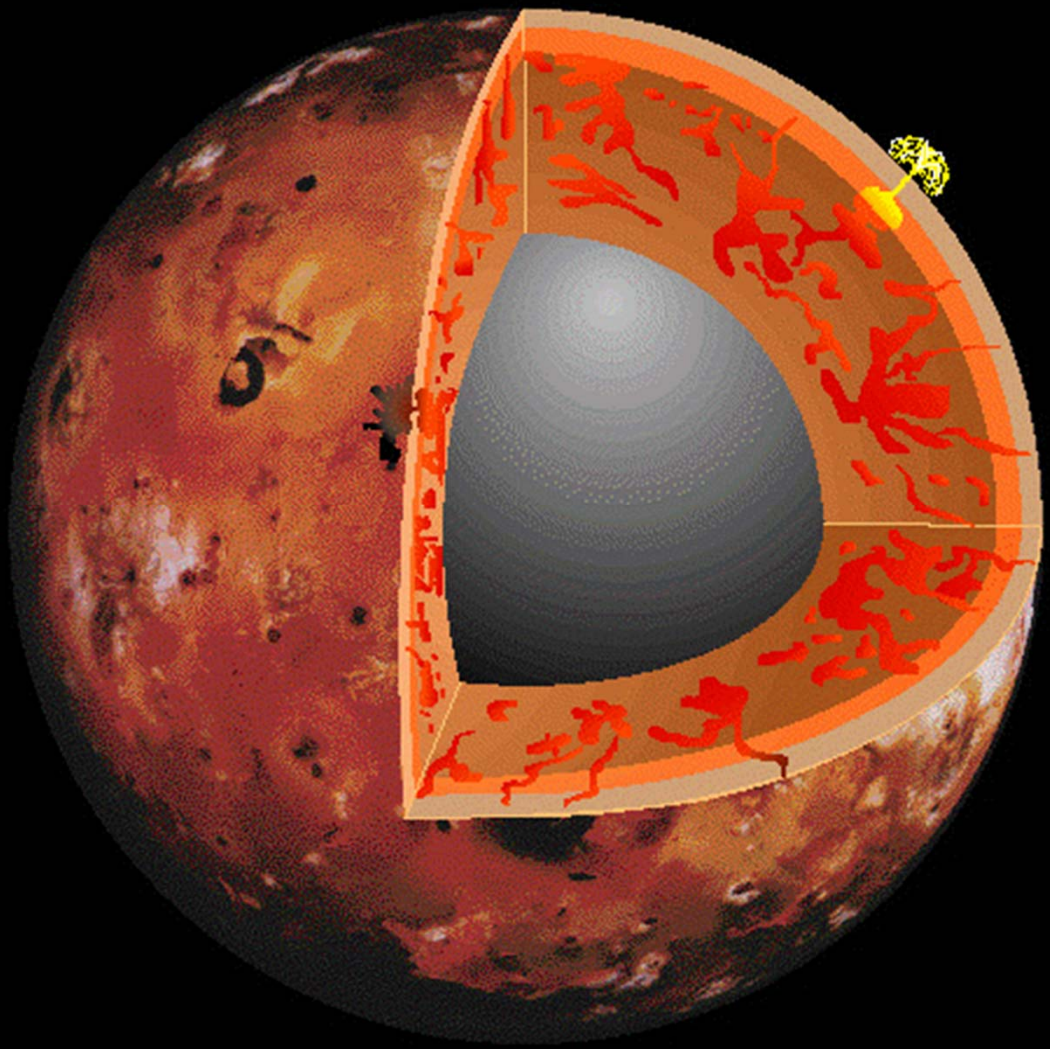
a Most of the black, brown, and red spots on Io's surface are recently active volcanic features. White and yellow areas are sulfur dioxide (SO_2) and sulfur deposits, respectively, from volcanic gases. (Photographs from the *Galileo* spacecraft; some colors slightly enhanced or altered.)

PROMETHEUS



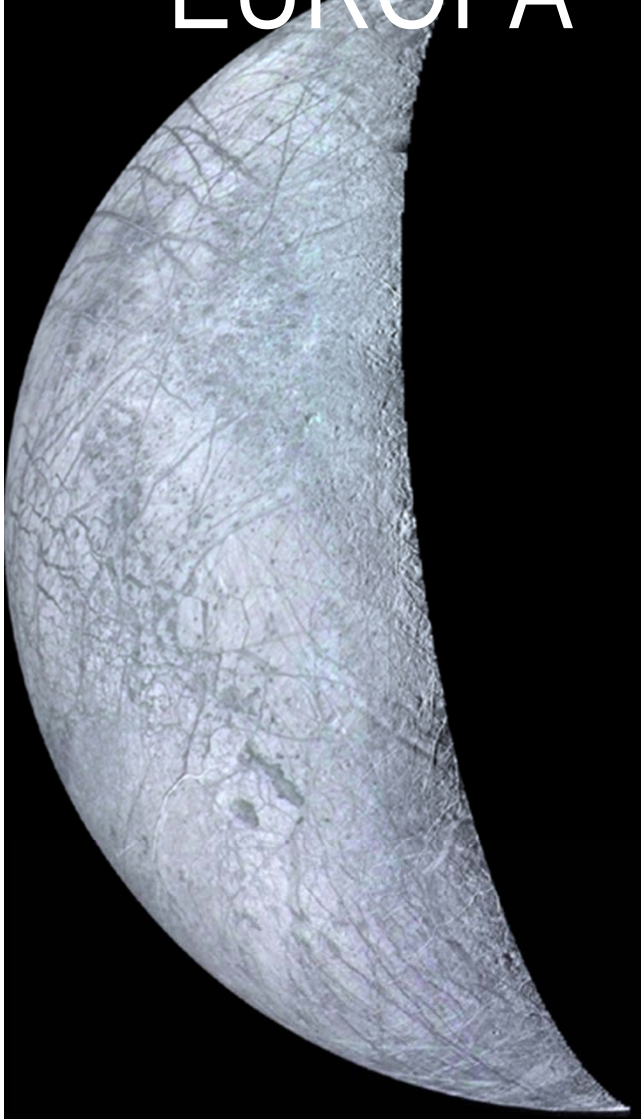
- Prometheus is a continuously active volcano
  - At least for the 18 years we have been visiting
  - Volcanic plumes huge

STRUCTURE OF IO



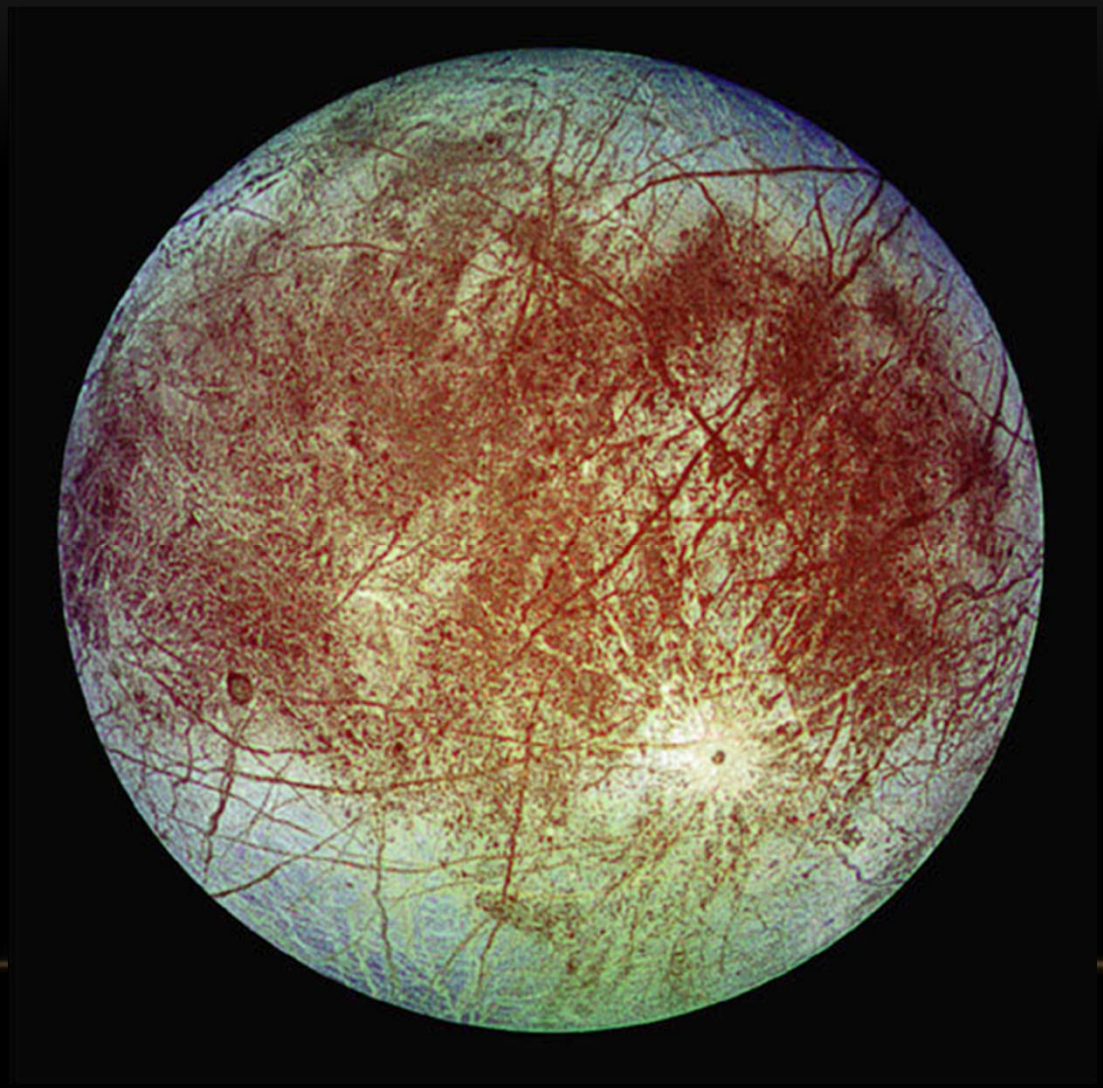
- From density and volcanic activity
  - Iron core
  - Rock mantle
  - Sulfur compounds on surface

EUROPA



- 2nd Galilean moon out
  - 1.5x as far as Io
  - 3.6 day orbit
- A little smaller than the Moon
- Less dense than Moon or Io
- Ice Surface
- Magnetic field
  - Reverses every 5.5 hours!

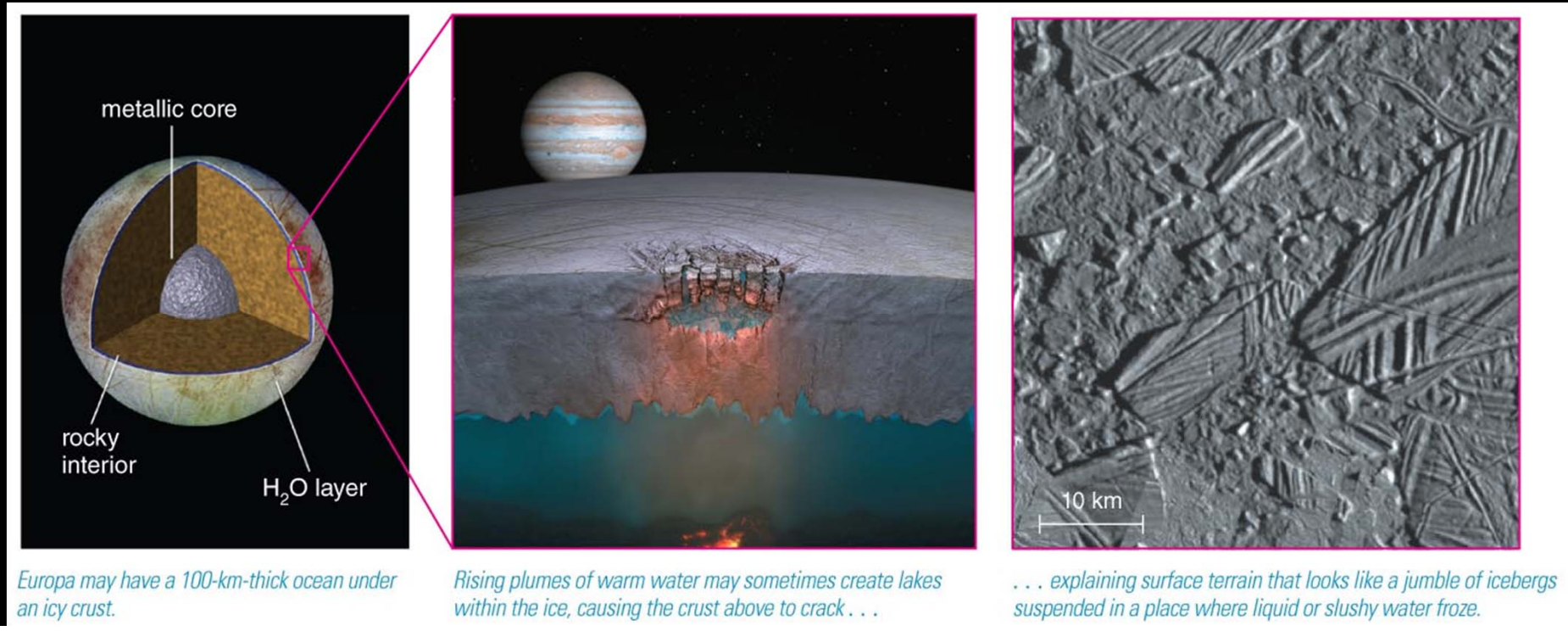
EUROPA



STRUCTURE OF EUROPA

- Density, magnetic field, icy surface suggest:
- Thick ice crust
  - Liquid water underneath
- Rocky interior
- Small iron core

Fig.8.17

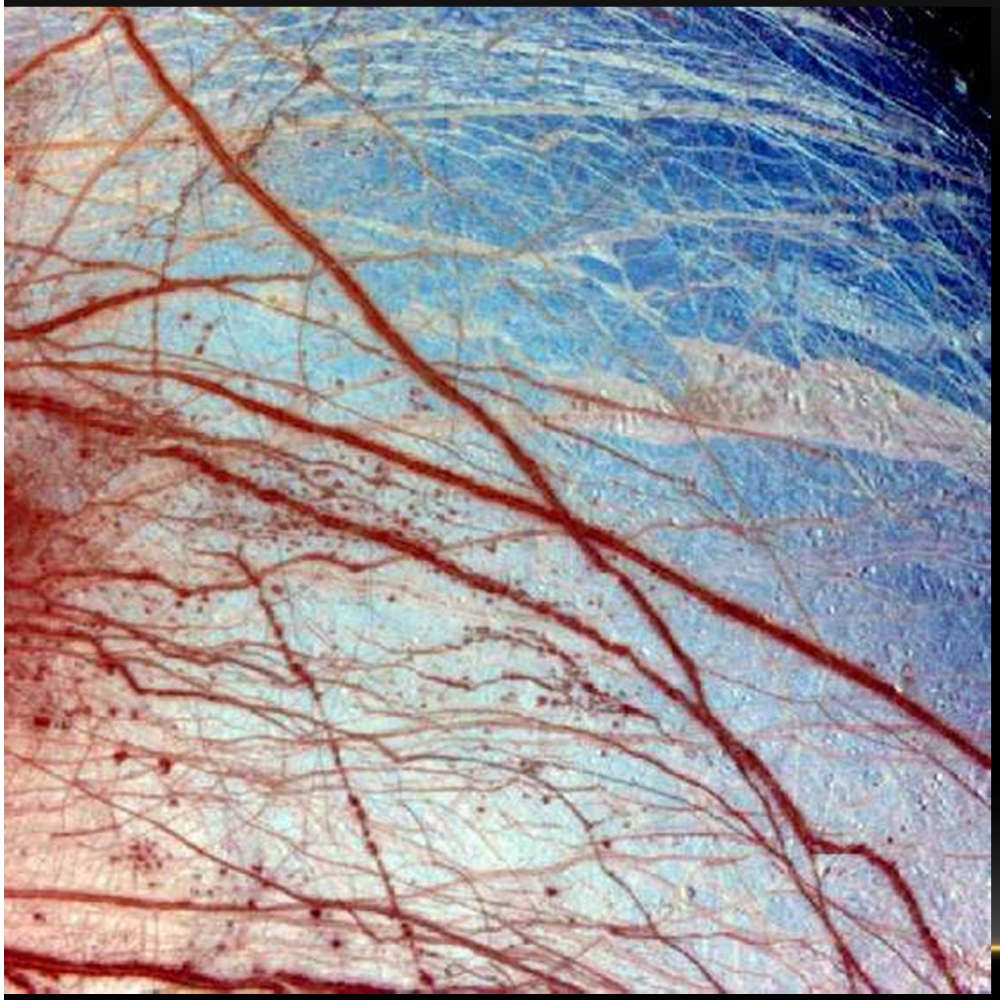


Europa may have a 100-km-thick ocean under an icy crust.

Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .

. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

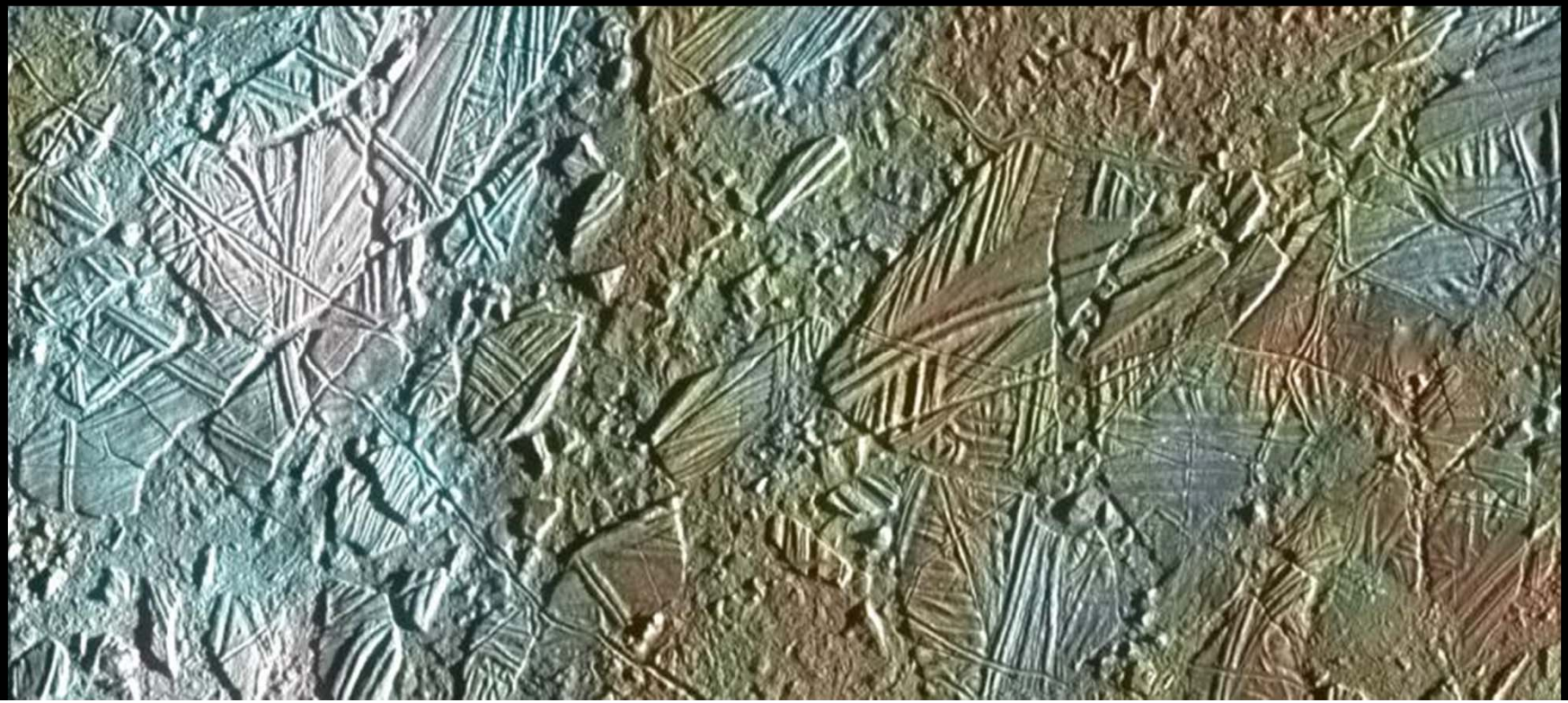
SURFACE OF EUROPA



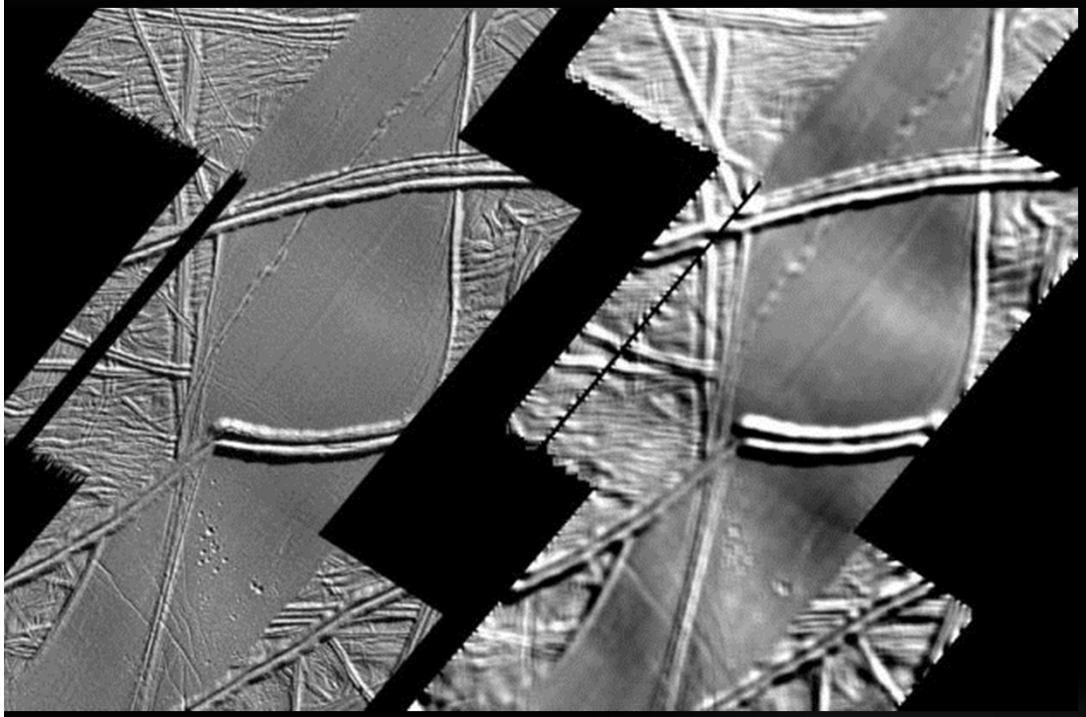
- Very young surface
  - Few craters
  - Cracks in ice surface let out water-volcanoes
- Many cracks
  - Tidal flexing of icy crust
  - Plate tectonics?

EUROPA'S SURFACE

- Close-up of surface shows ice flows all over

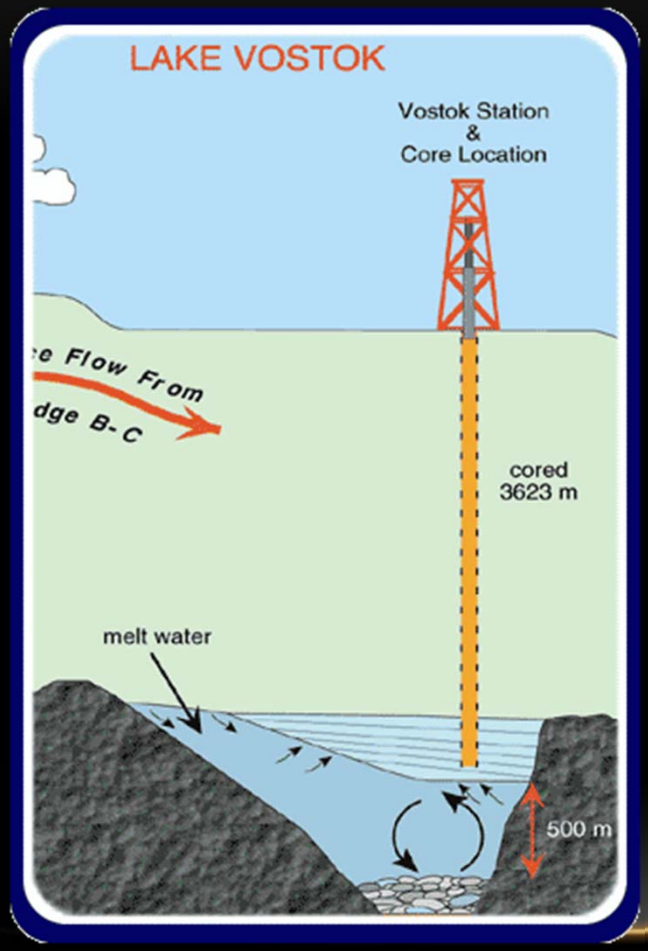


LIFE UNDER THERE?



- The degree of folding, length of cracks, etc. indicates that the water under the ice is pretty warm
- Could it be a place to look for life?
  - Liquid water!

ICY LIFE ON EARTH



- Lake Vostok under Antarctica
  - Life found in ice just over lake
  - Drilling stopped 400ft short of lake to avoid contamination
- In sea ice on the Arctic Ocean

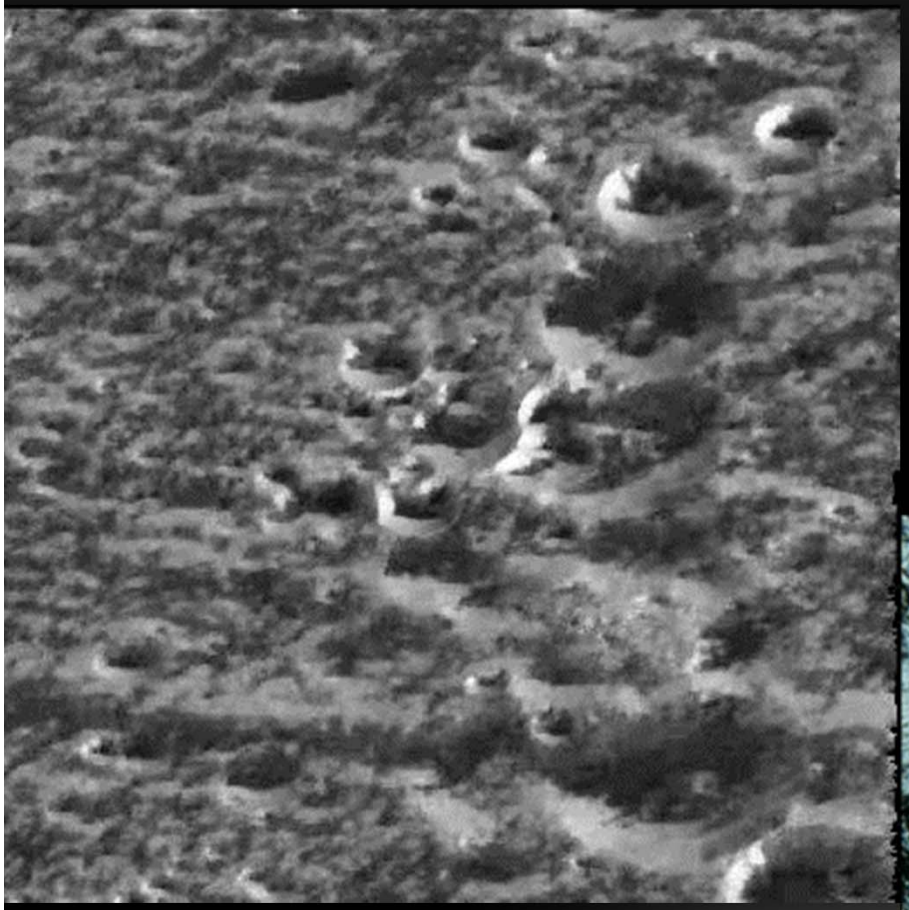
GANYMEDE

- 3rd Galilean moon out
  - 7.2 day period
- Largest moon in Solar System
  - Larger than Mercury and Pluto!
- More craters
  - Older surface, less active
- Less dense
- Very large magnetic field
- Big spot is “Galileo Regio”

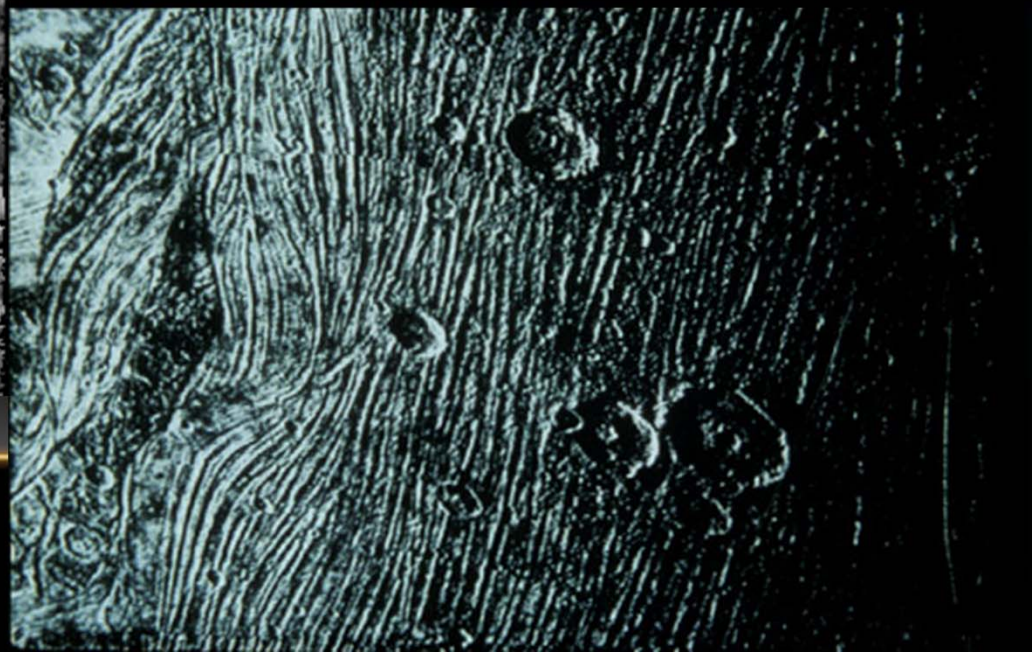
GANYMEDE'S SURFACE

- Icy surface
- Light terrain
  - At left
  - Younger
  - Less cratered

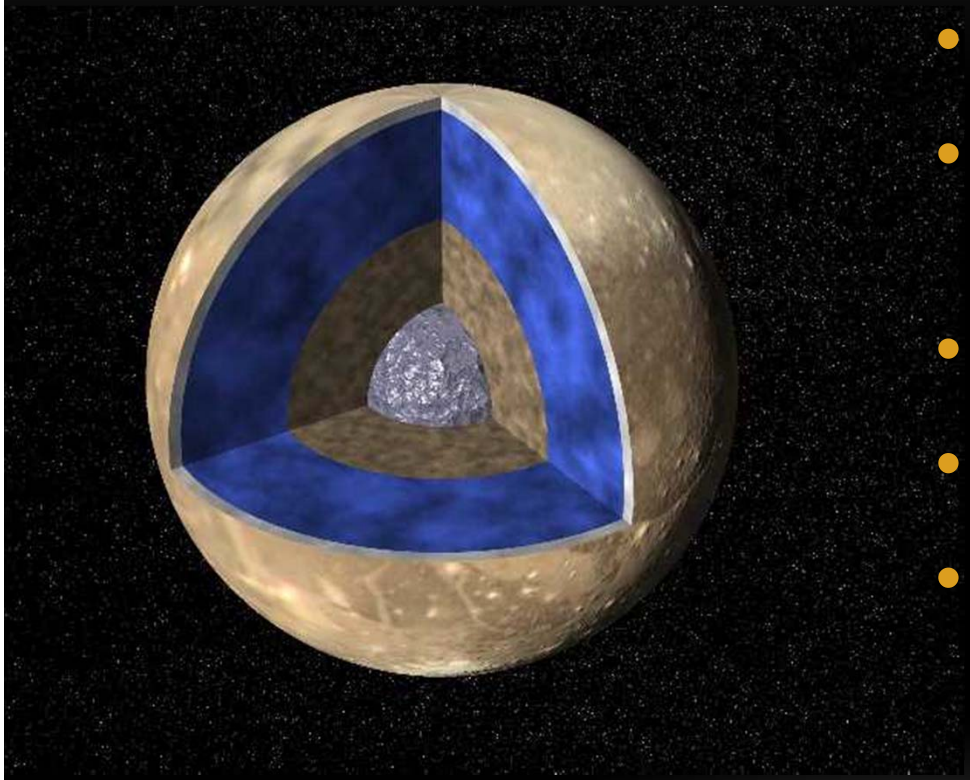
GANYMEDE'S SURFACE



- Dark terrain
  - Such as Galileo Regio
  - Older, more cratered
- Features grooved areas – stretch marks!

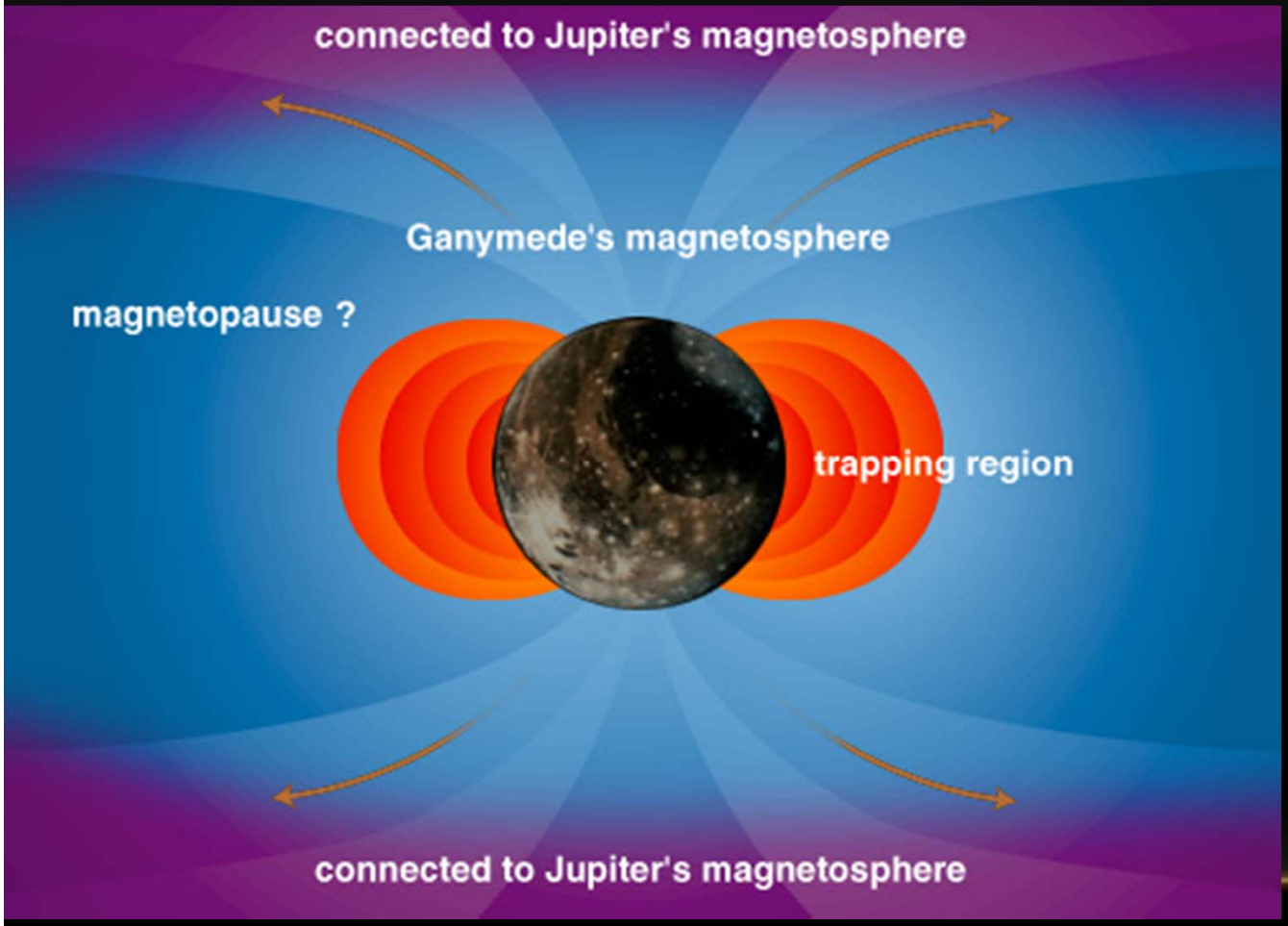


GANYMEDE'S INTERIOR



- Small average density
- Small iron or iron sulfide code
- Layer of rock
- Lots of ice and water
- Magnetic field indicates spinning conductive liquid
  - Saltwater?

GANYMEDE'S MAGNETIC FIELD



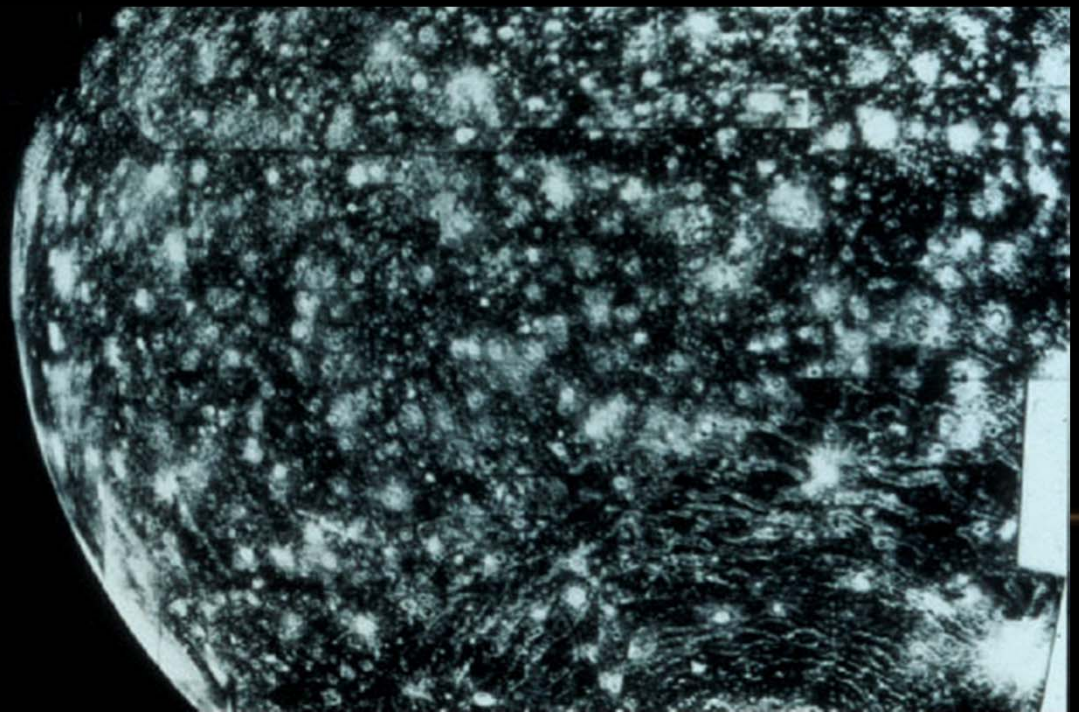
- Odd for a moon
- But sizable
- Again, liquid oceans under the ice could be a good place to look for life

CALLISTO

- 4th and last Galilean moon
  - 16.7 day period
- Slightly smaller than Ganymede
  - Still half again larger than our moon

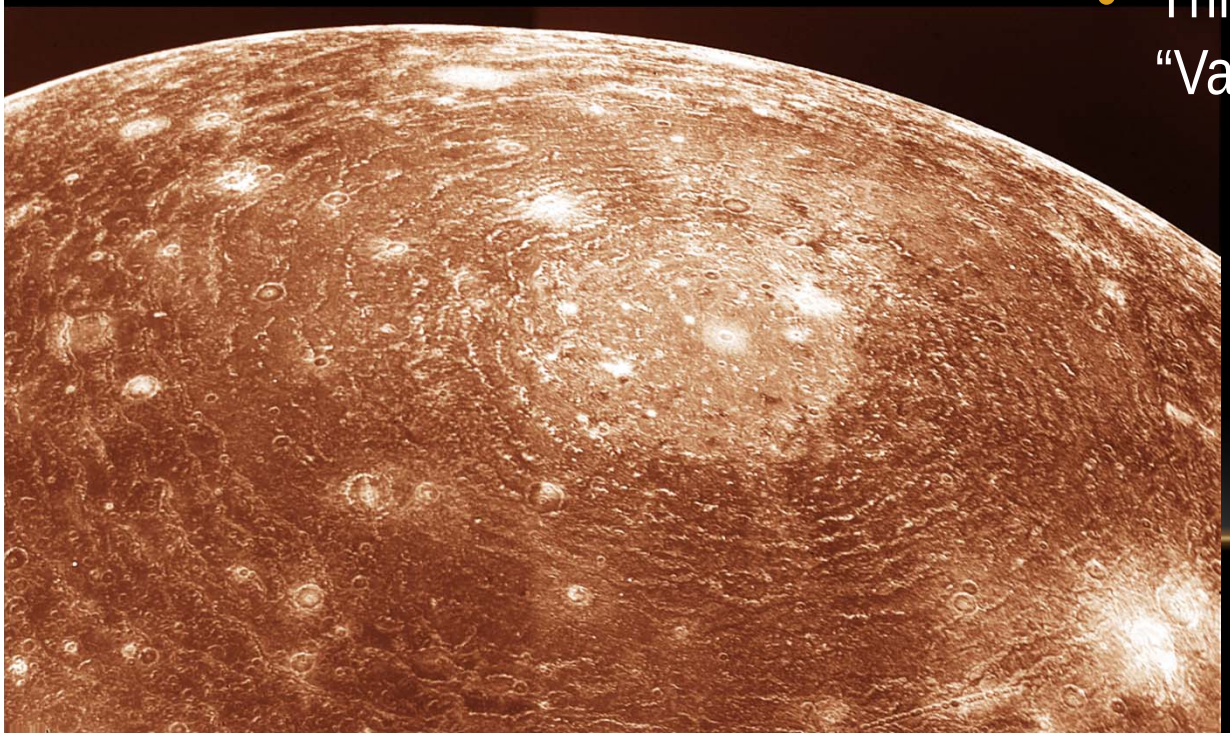
CALLISTO'S SURFACE

- Extremely cratered surface
  - Means it is very old
- No mountains, geological activity
- Made of ice



BIG WHACKS!

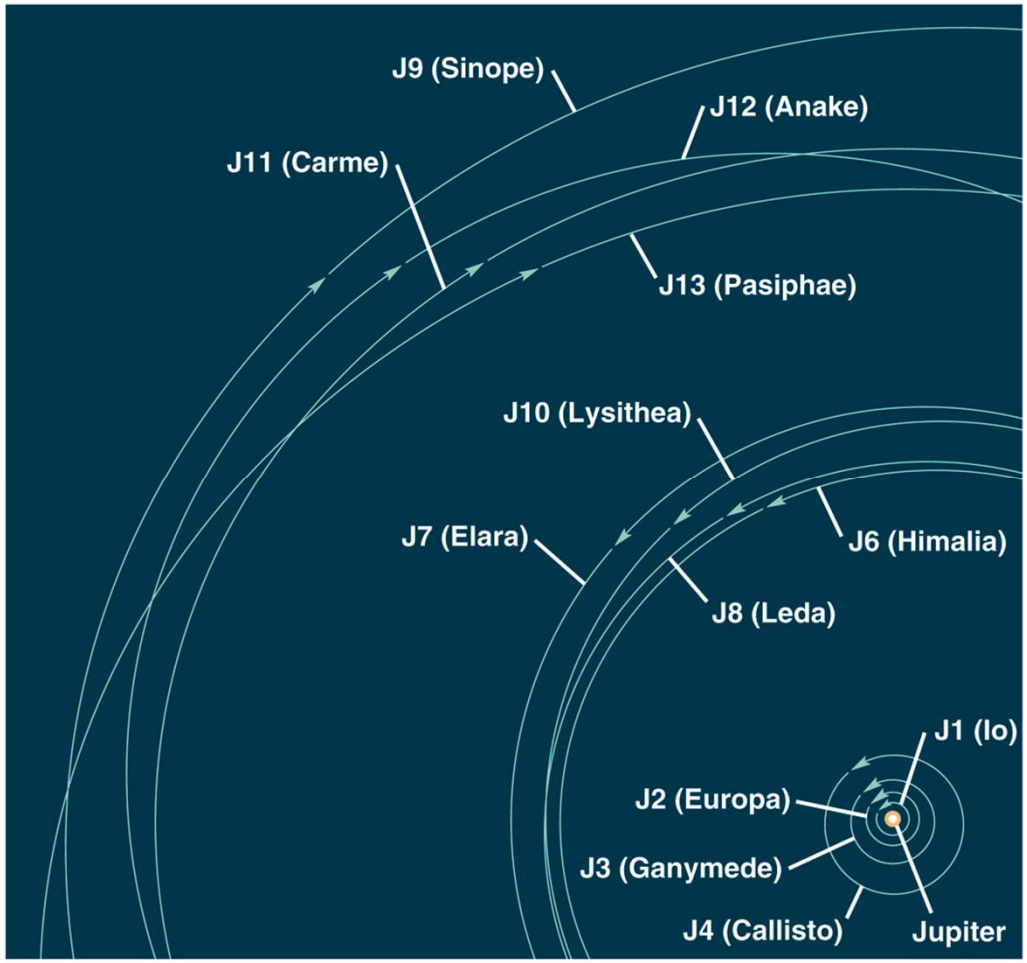
- Callisto has some enormous impacts from very early in its history
  - This is the largest, “Valhalla” crater



CALLISTO'S STRUCTURE

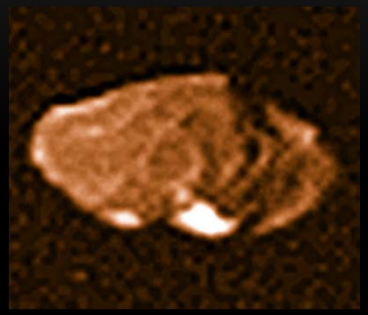
- Ganymede's magnetic field indicates a molten core
  - Was hot at some point in the past
- Callisto appears never to have melted: thus is not differentiated
  - The same icy mix of rock and ice it was when it formed
- No convincing arguments yet as to why they are so different

ORBITS



- 12 other outer moons' orbits are shown here
- Four more are even closer
- Hypothesis –
  - Perhaps the outer two groups were broken up captured asteroids?

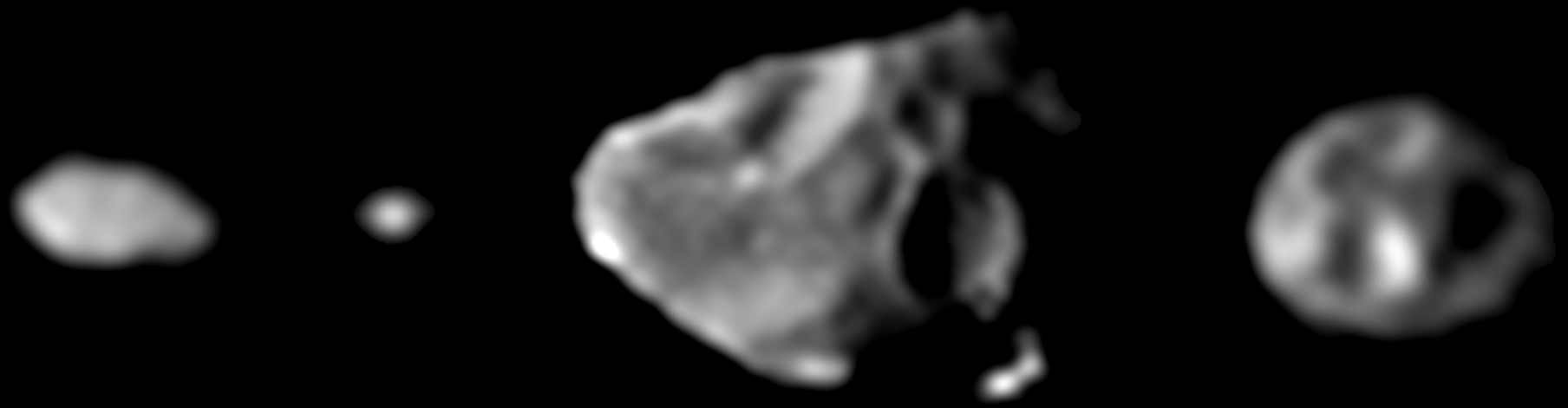
ALMATHEA



- A example small moon
  - One of the closest to Jupiter
  - Last moon discovered by direct observation (by Barnard in 1892)
  - Synchronous orbit
  - Red color from sulpher dust from Io's volcanoes
- 270x165x150 km
  - Size of a small state

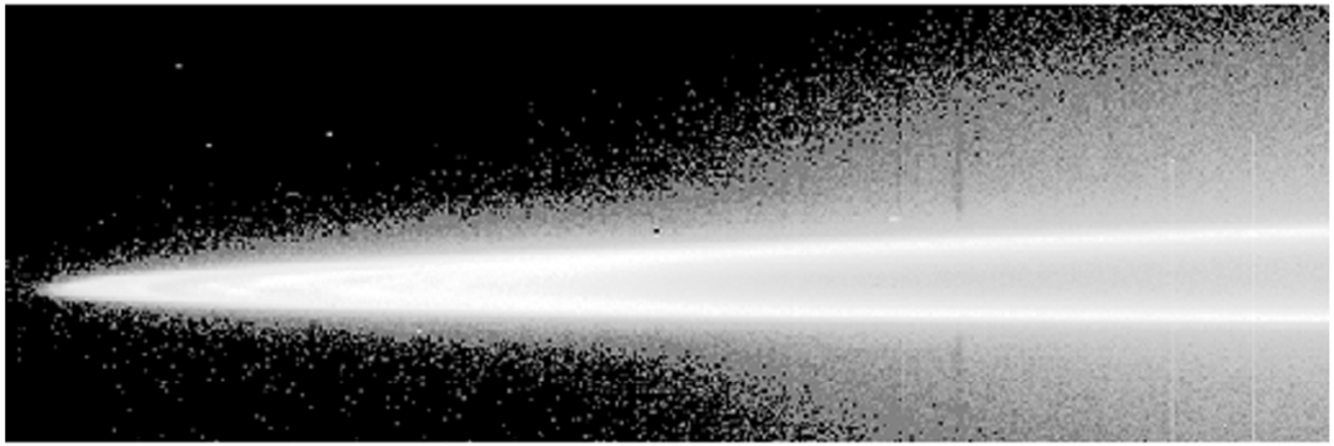
INNER SMALL MOONS

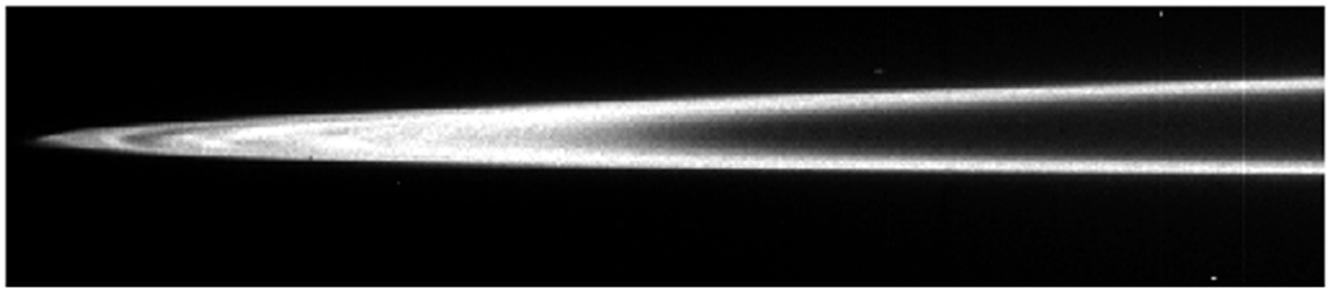
- Small irregular rocks -
  - Metis (longest dimension ~37 mi)
  - Adrastea (12 mi across)
  - Amalthea (154 miles across)
  - Thebe (72 miles across)
- Meteor impacts with these moons supply the dust for Jupiter's ring



RINGS

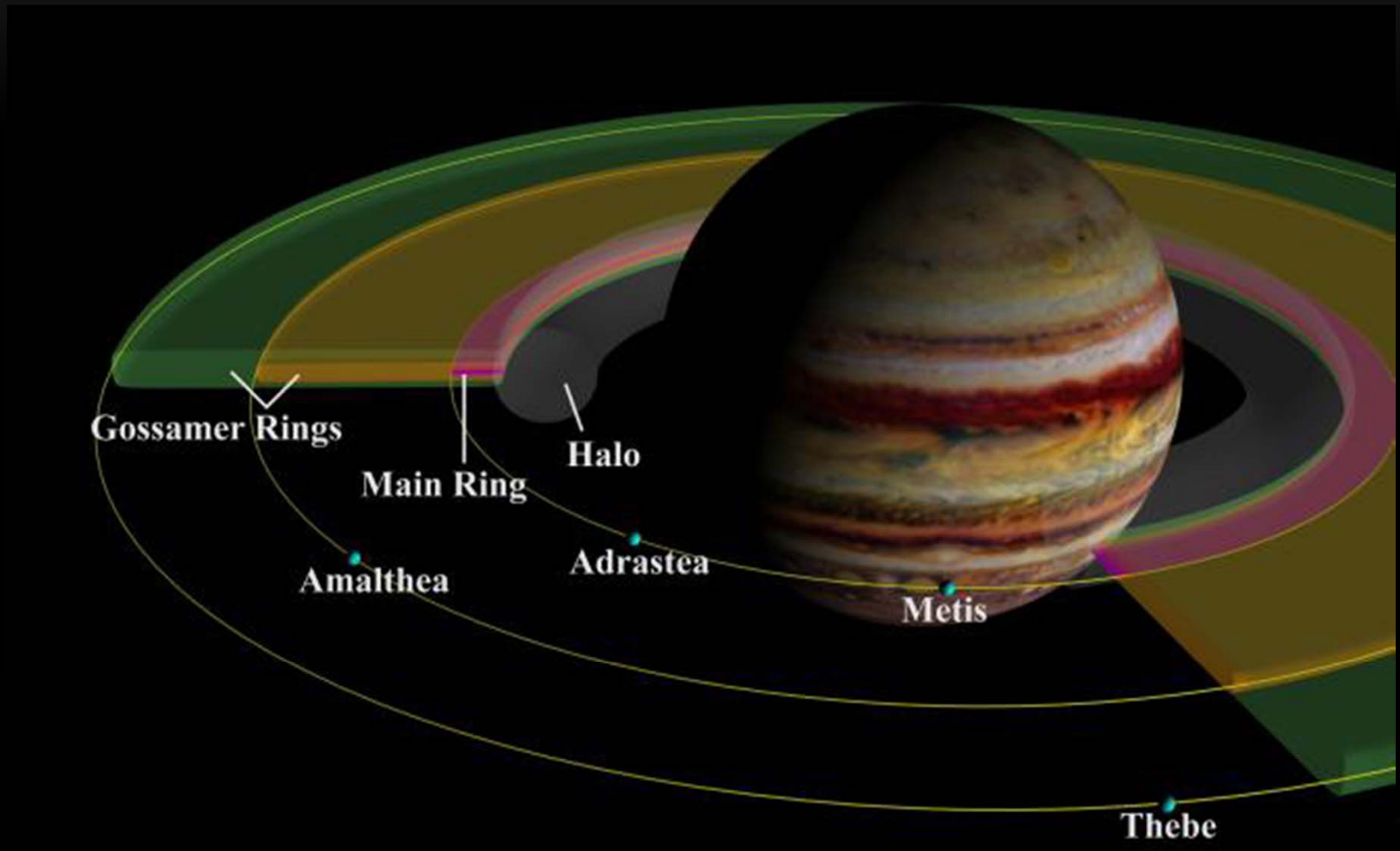
- Very thin and wispy – a 3rd, “Gossamer” ring is not seen here
- Main ring embedded in more diffuse halo ring





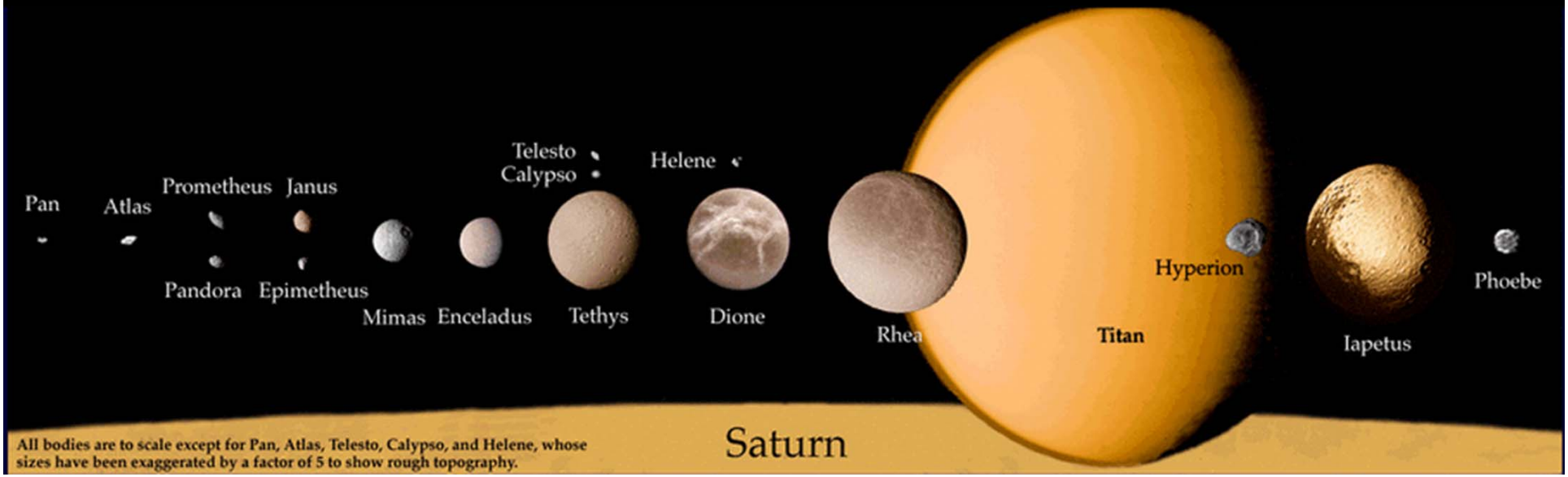
Halo caused by magnetic fields pushing main ring particles out of orbit

RING STRUCTURE

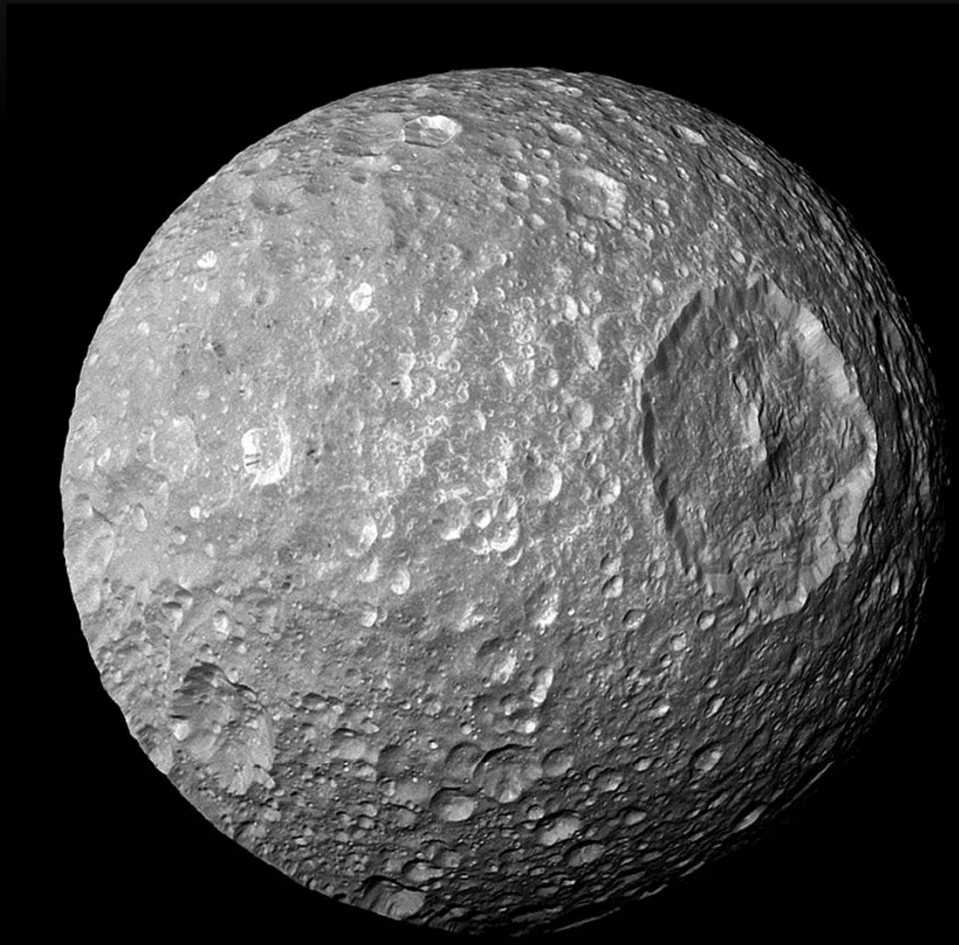


MOONS OF SATURN

- There are now 150 known moons
  - 53 actually named
- Most small
- Titan very large



MIMAS



- Medium icy moon
- Gravitational resonances cause Cassini division
- Sports the biggest crater for its size anywhere
  - Almost broke it into pieces
- No geological activity on most medium-sized moons

ENCELADUS

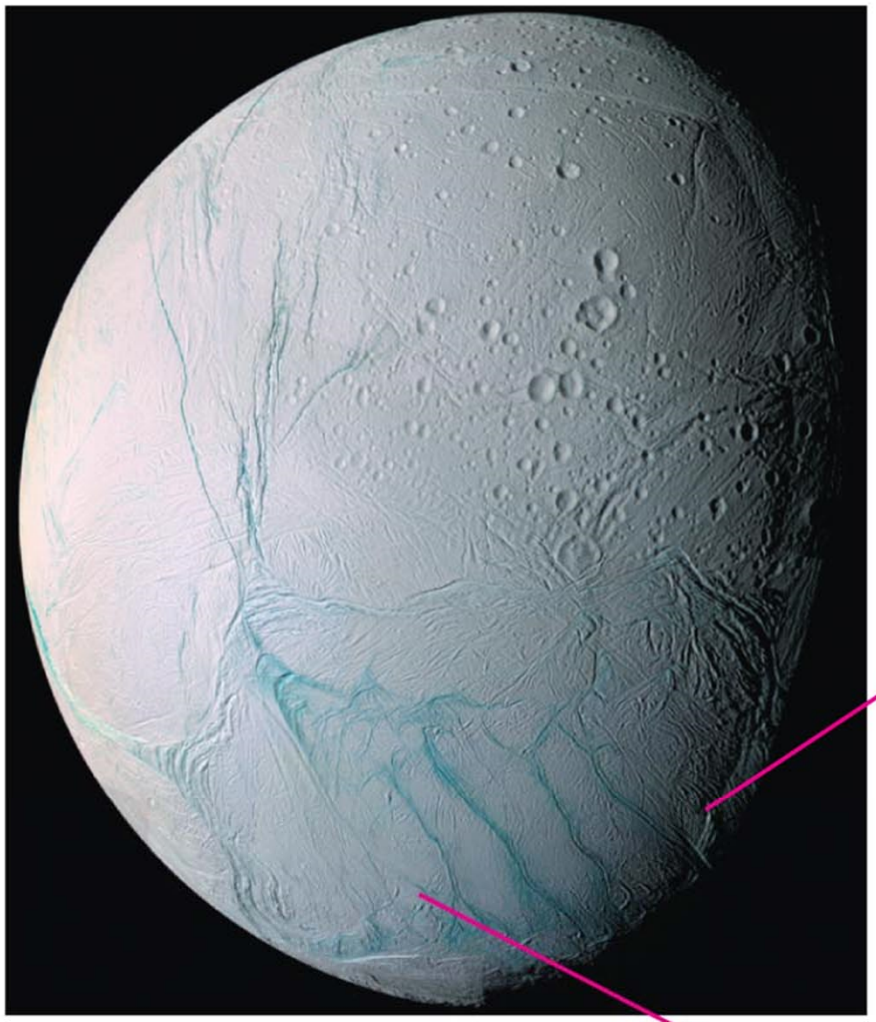
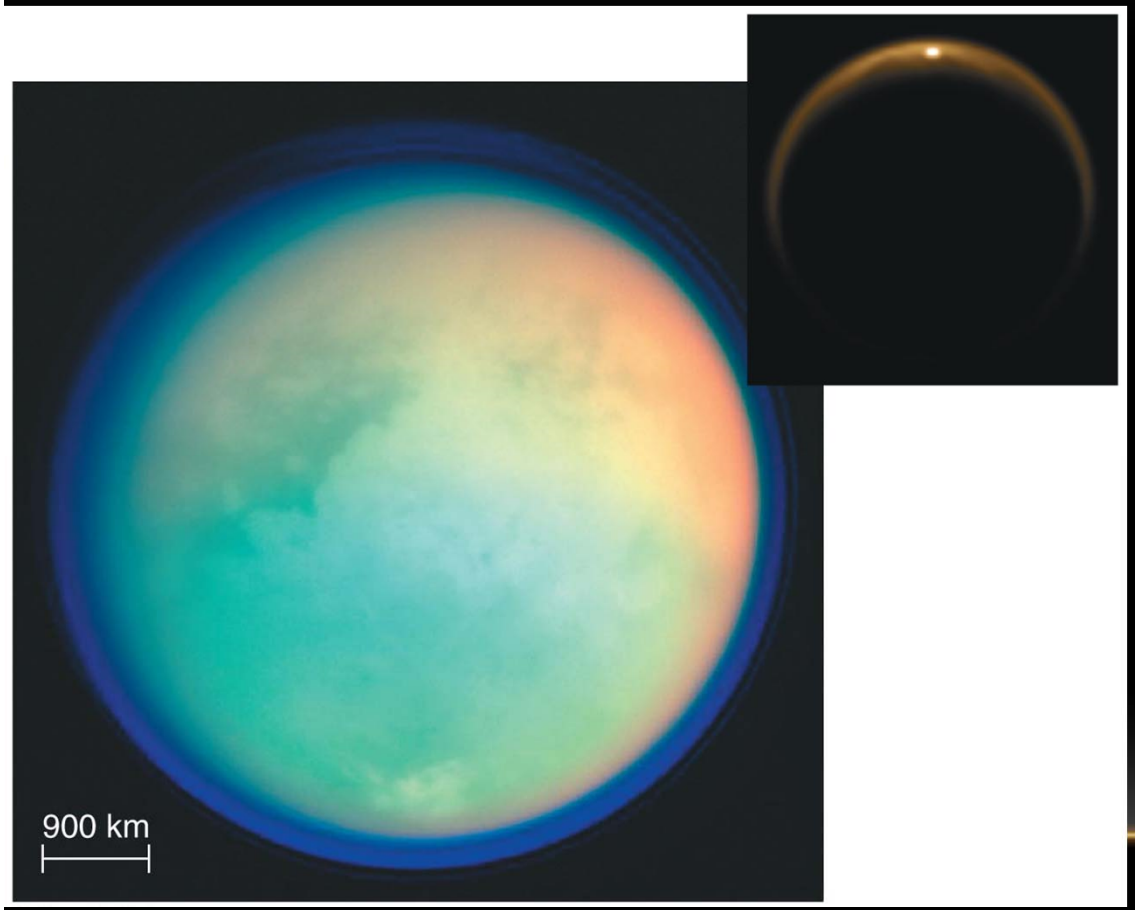


Fig.8.25

- An exception: quite active
- Fountains of ice and water vapor
  - Like cold volcanos

TITAN



- 2nd largest moon in Solar System
  - Slightly smaller than Ganymede
  - Bigger than Mercury, Pluto
- Has atmosphere!
  - 80% N2, 10% Methane
  - 0.6 atmospheres pressure
  - Only 95 K at surface
- Lakes of liquid methane
- Rocks made of ice

Fig.8.20

HUYGENS PROBE

- Cassini mission dropped it onto Titan

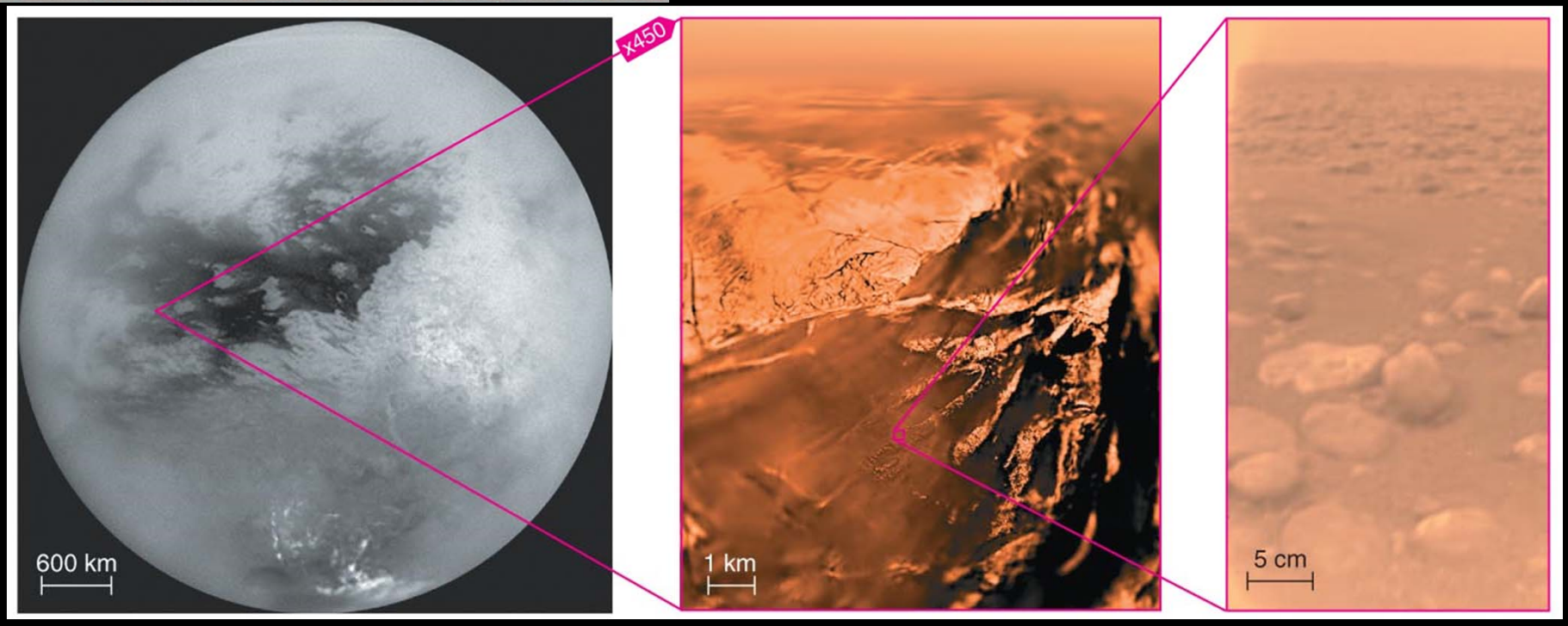
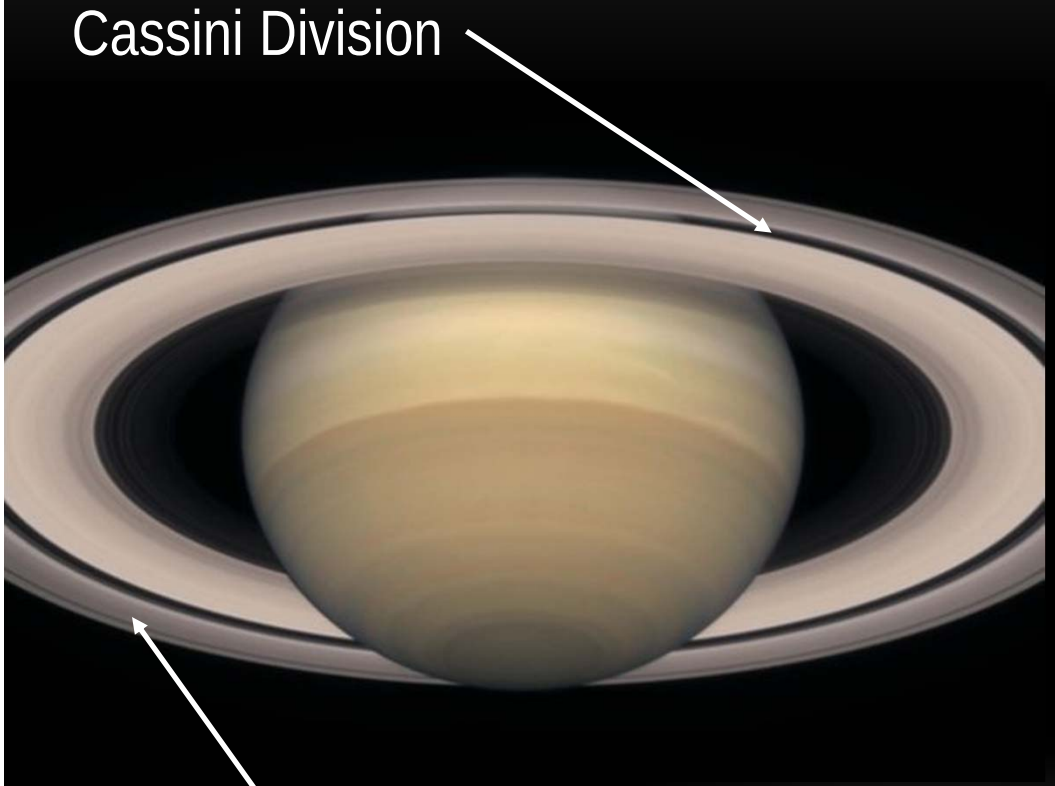


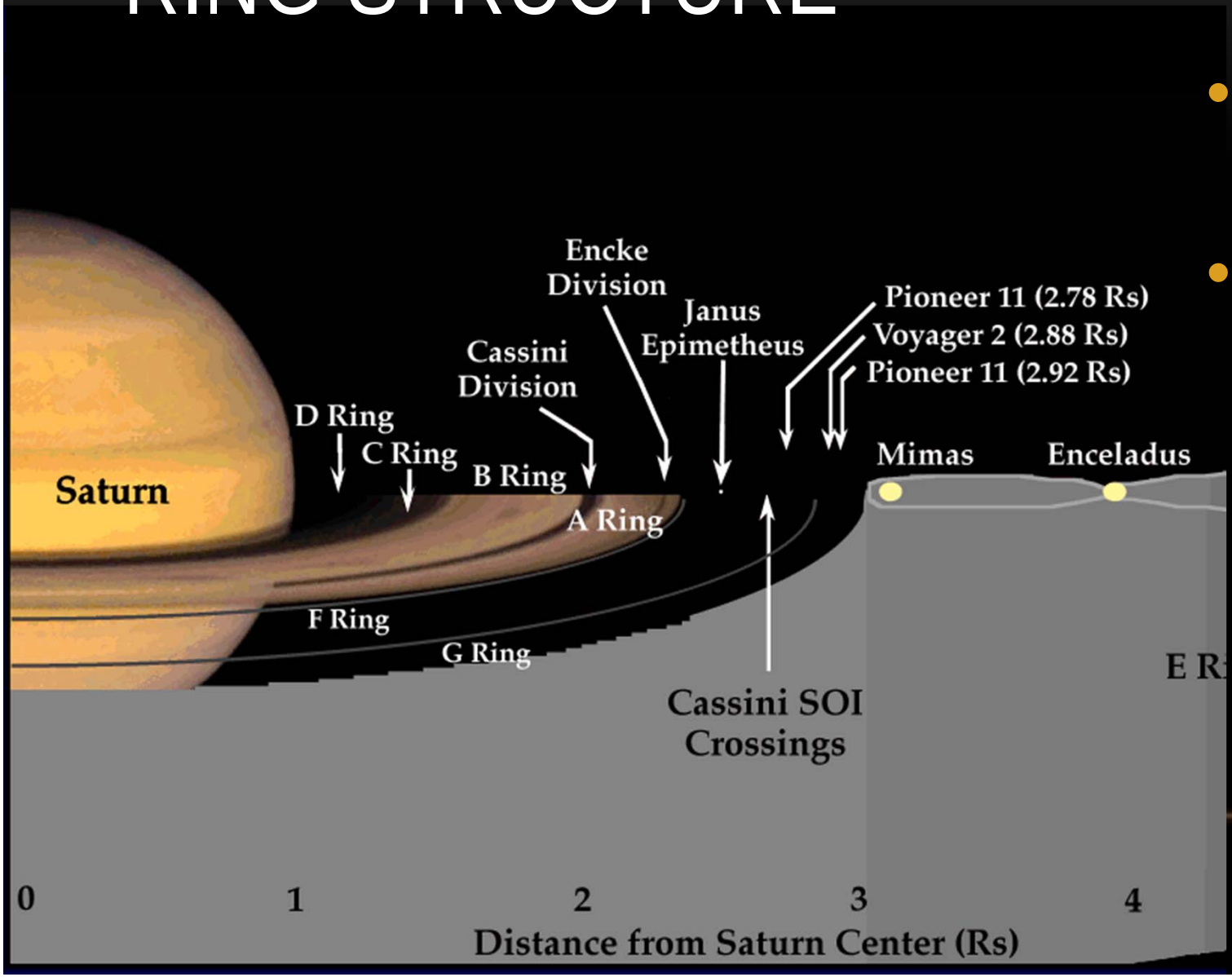
Fig.8.21

RINGS



- The Big, Obvious thing about Saturn
- Galileo noticed “ears”
- Huygens had good enough observations 50 years later to see that they are rings
- Complex structure – several rings separated by divisions

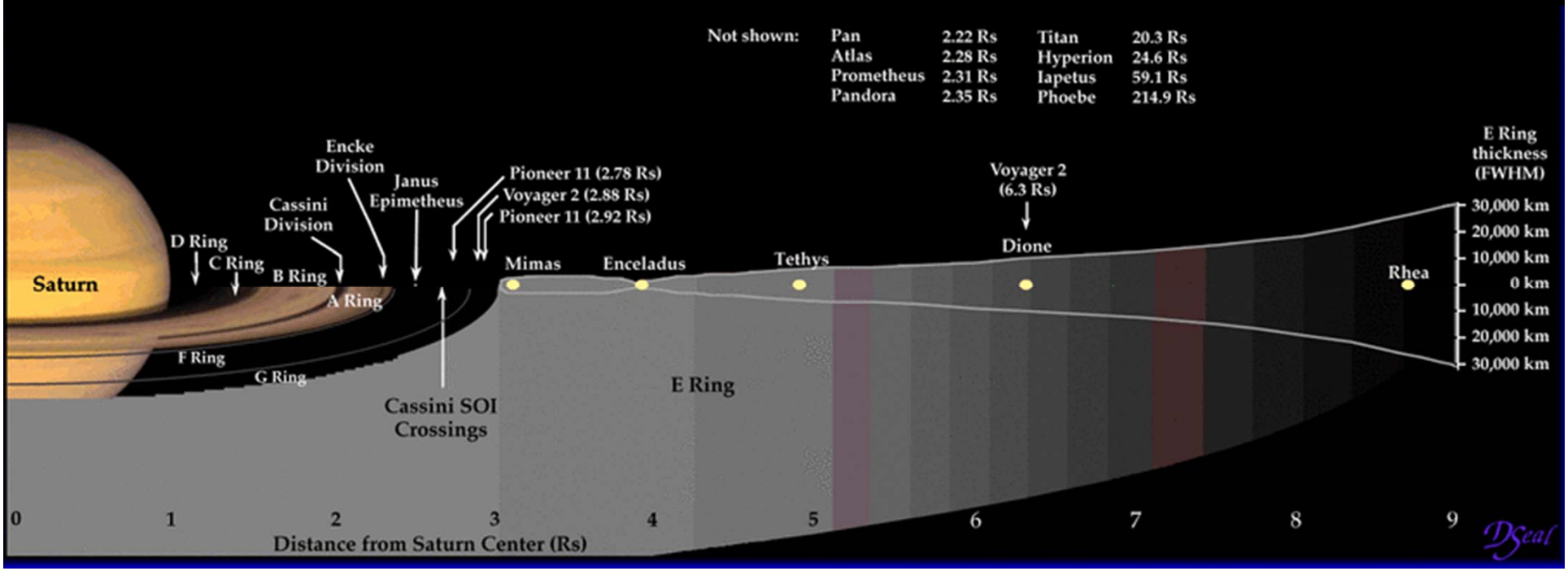
RING STRUCTURE



- Rings thin, wide
- A, B, C are the rings you usually see pictures of

RING STRUCTURE

- Most rings very thin but wide: < 100 meters thick!
- A, B, C are the rings you usually see pictures of
- Faint, large E ring gets thicker



RING COMPOSITION

- Rings made of small (marble to house-sized) icy chunks
  - Rocky dust coatings
  - *Albedo* ~ 80%
  - Clumps form and break up regularly
- Data from stellar occultations reveals structure

ALL JOVIAN PLANETS HAVE THEM

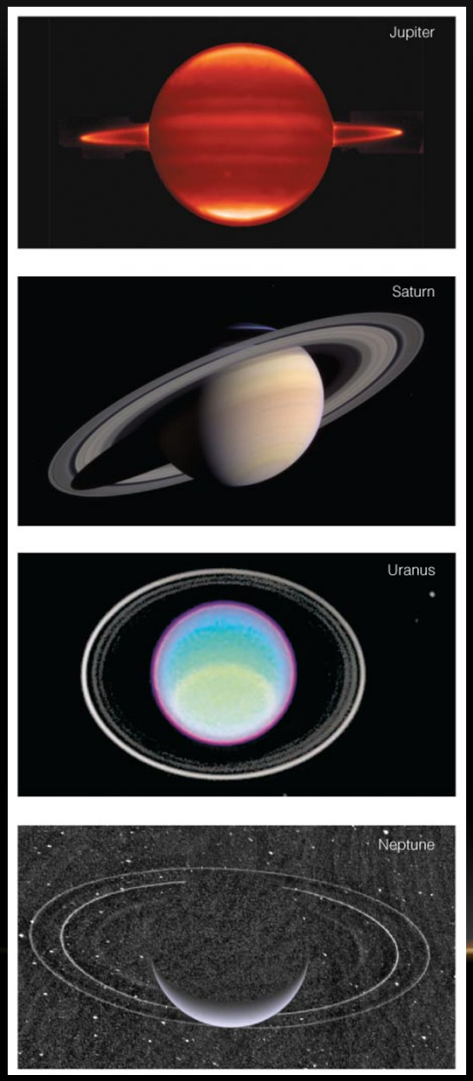


Fig.8.31

- Saturn's are just the most obvious

RING ORIGINS

- Impacts on the many moons keep spraying stuff out there that forms rings
- Ring particles small enough that their orbits aren't stable: must be continuously replaced
- Saturn's rings so obvious partly because they're made of shinier stuff, but possibly also because a more recent, large impact really kicked up a lot of dust

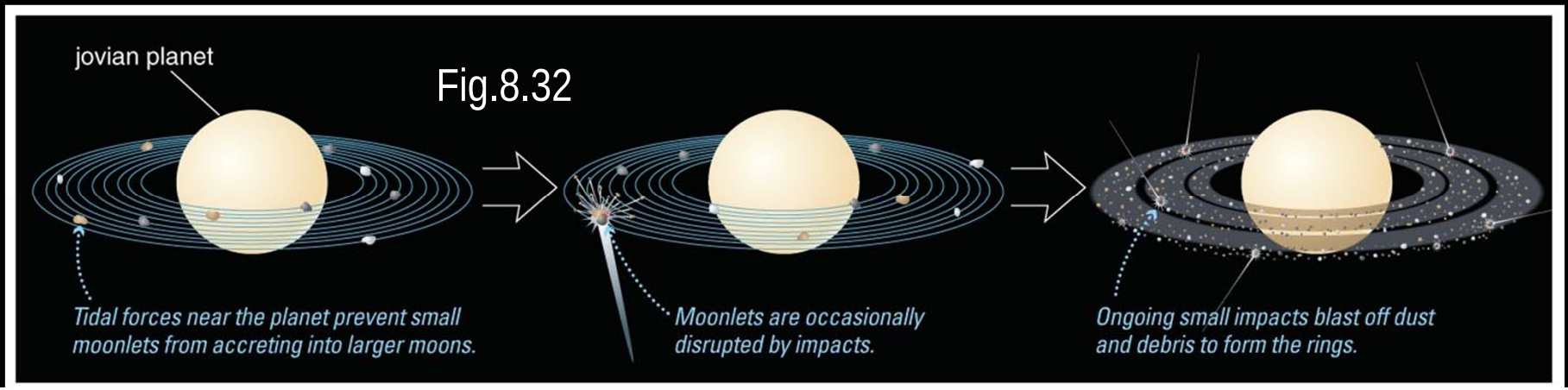
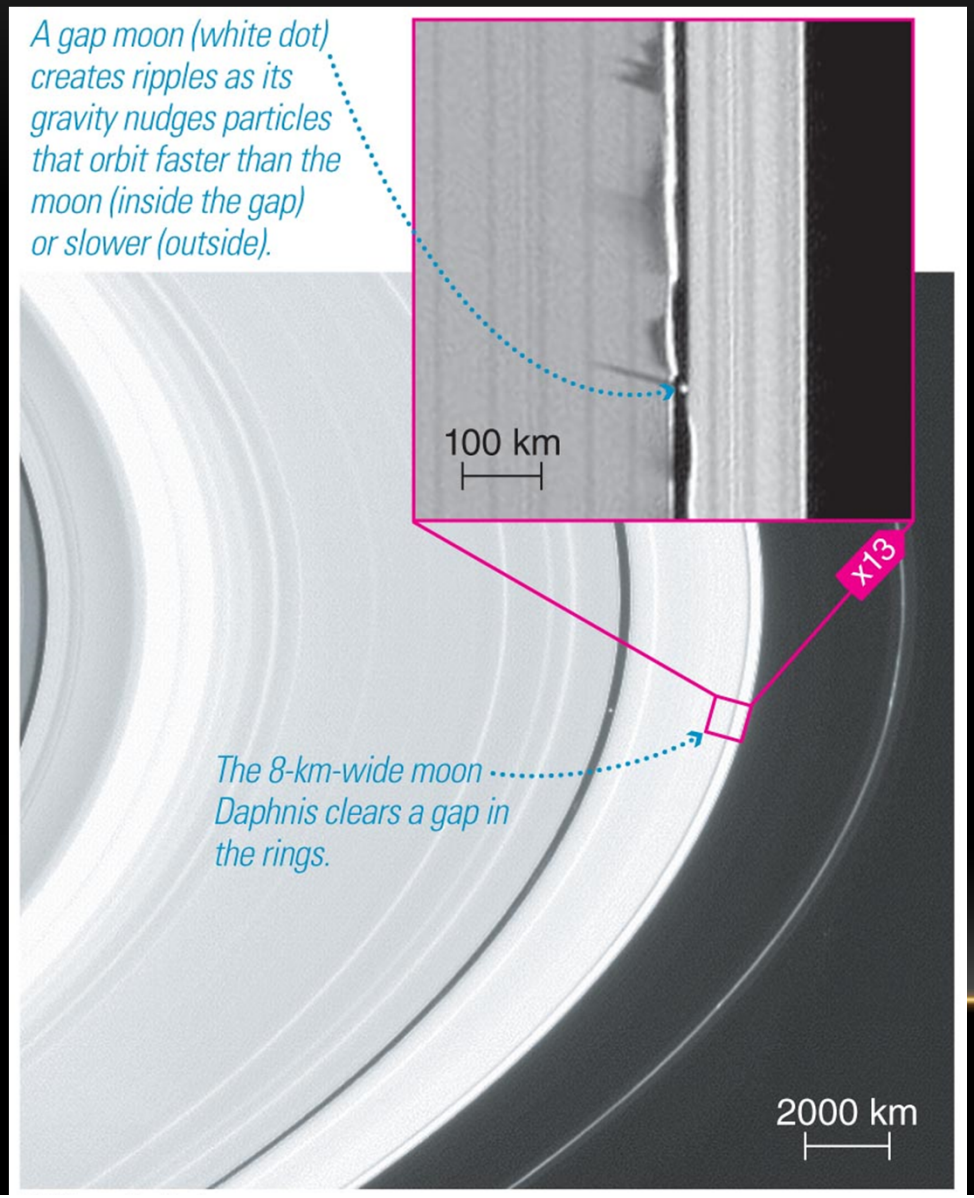


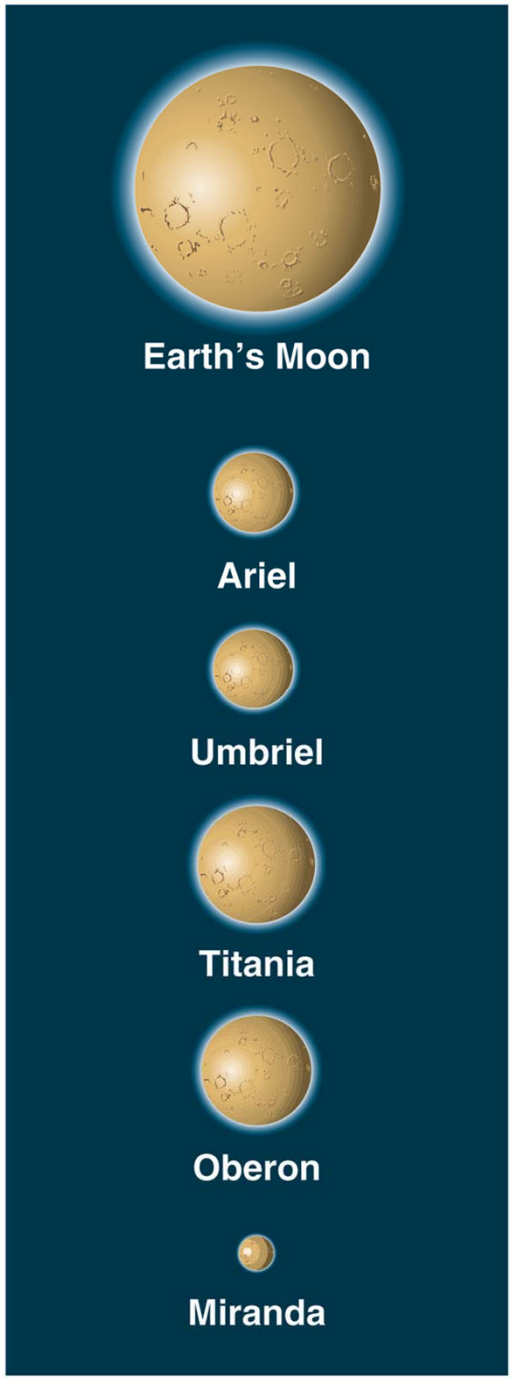
Fig.8.32

SHEPHERD MOONS



- Why gaps etc?
- Fine gaps
  - ~20km sized moonlets
  - Simply sweep a path
- Cassini division
  - Space where gravity from Medium moon Mimas balances with Saturn
- Narrow rings
  - Small “Shepherd Moons” make them
  - Gravitationally “herd” particles

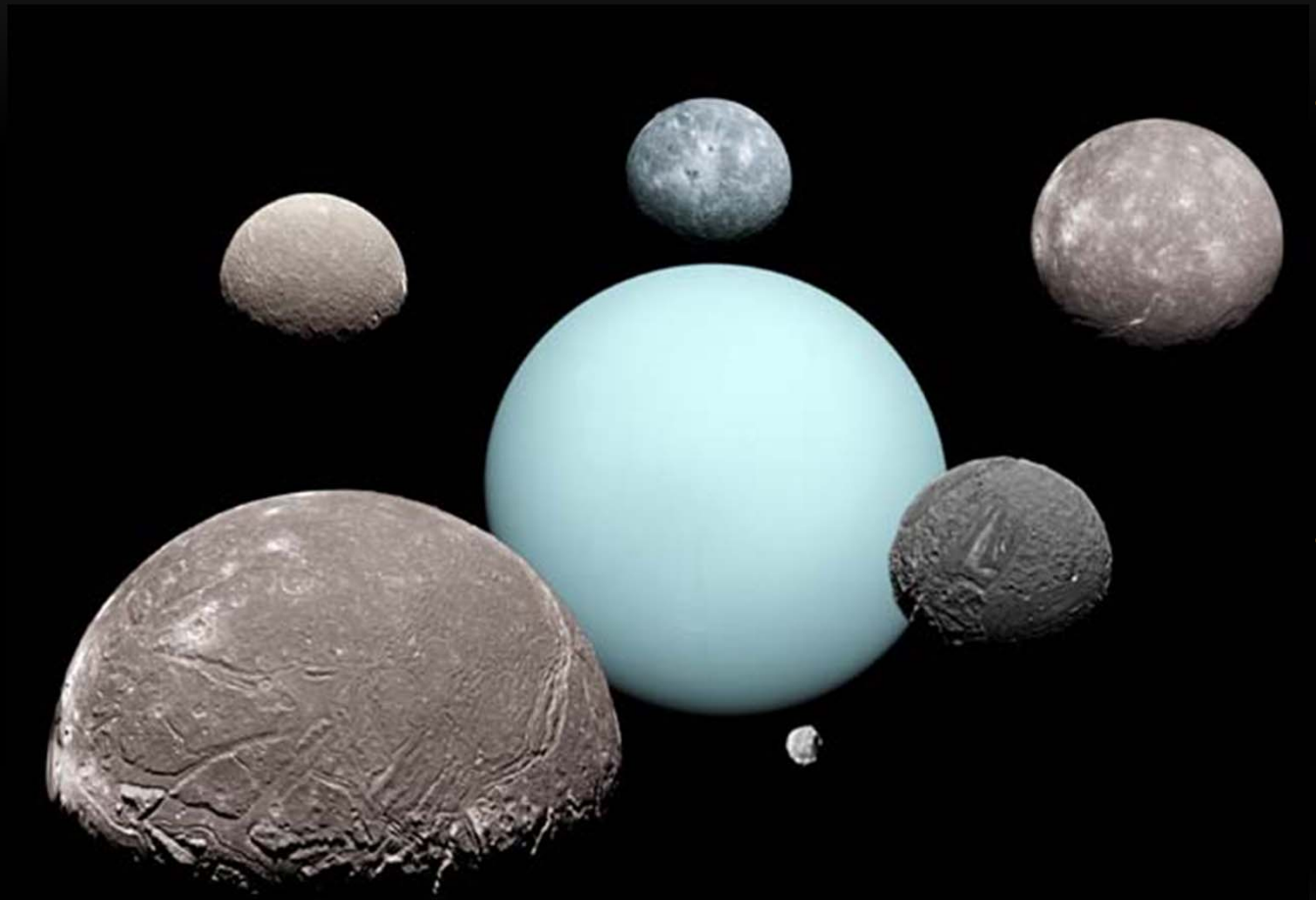
Fig.8.30



MOONS OF URANUS

- 21 moons, mostly small
- Several medium-sized icy moons
- Heavily cratered
- No geological activity in a long time

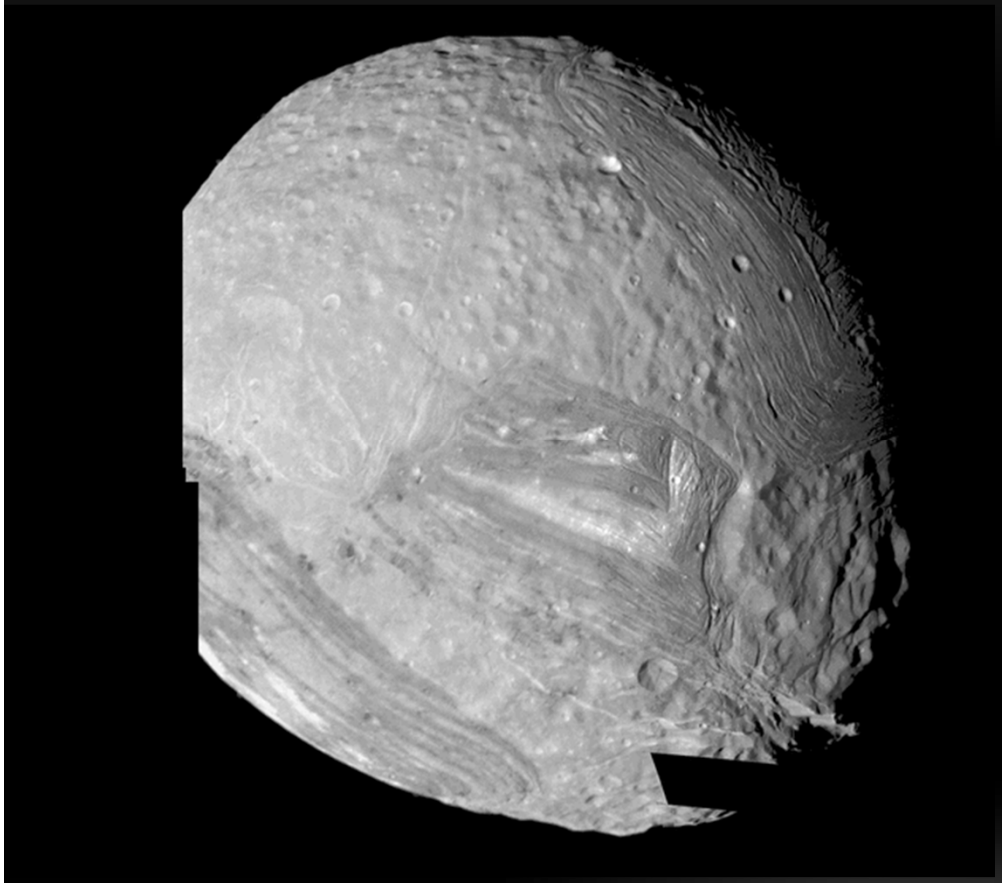
MONTAGE OF URANUS SYSTEM



Uranian System

- Voyager pictures of larger Uranian moons
- Voyager 2 is only probe to visit Uranus and Neptune

MIRANDA



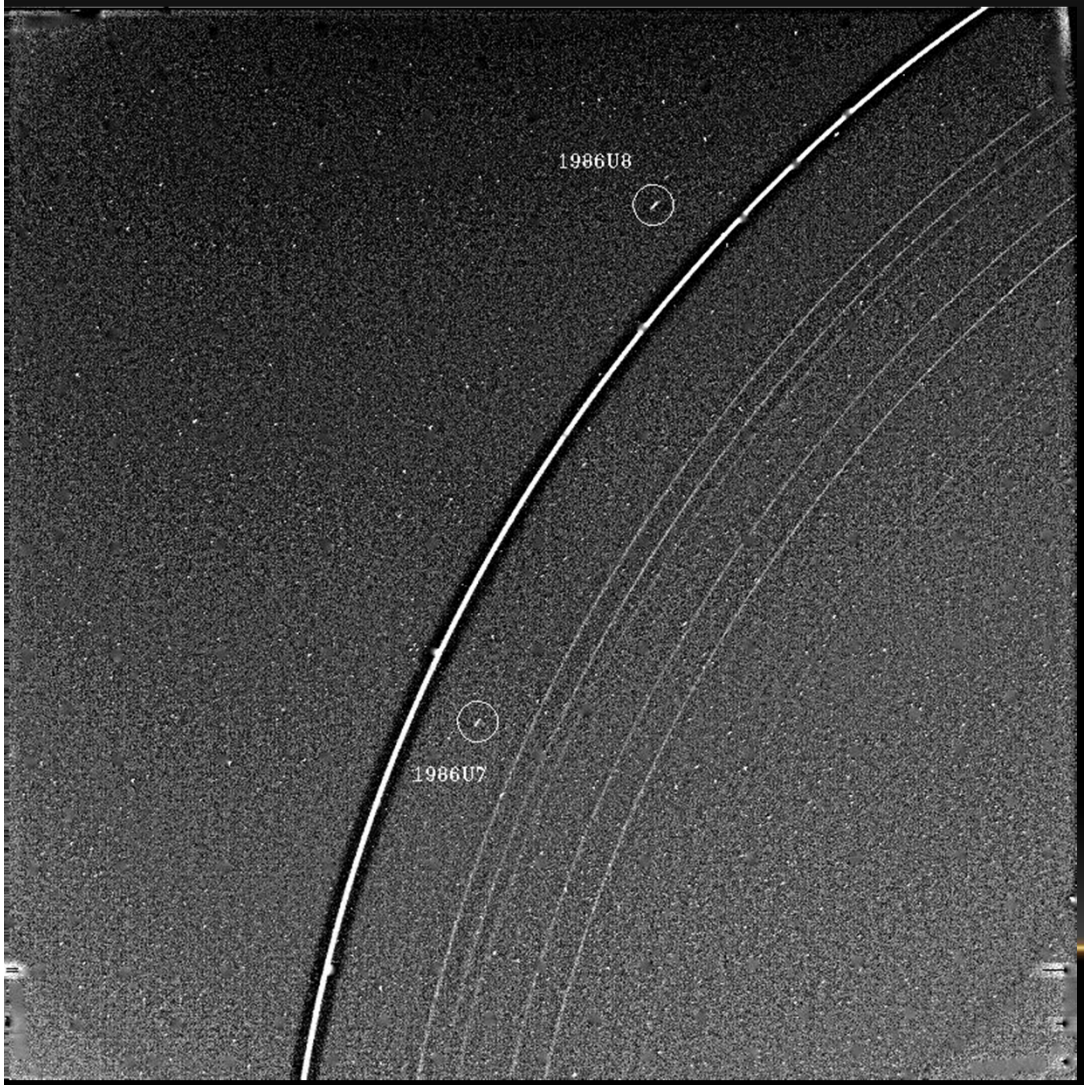
- “Chevron” startling feature
- Enormous grooves
- What happened in the history of Miranda to make these?
  - Impact almost large enough to blow it to bits

RINGS OF URANUS

- Very dark
  - Albedo only 5% (charcoal colored!)
  - Discovered from Earth during stellar occultation
  - Made star blink before the planet passed by!
- Some rings incomplete

False-color closeup to show details

URANIAN SHEPHERD MOONS



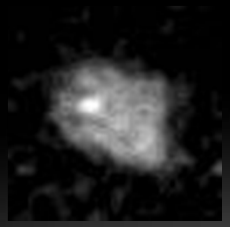
- Cordelia and Ophelia
- Two of the many small moons
- Shepherding one of Uranus' rings

RINGS OF NEPTUNE

- Voyager discovers narrow, lumpy rings
- Also very dark

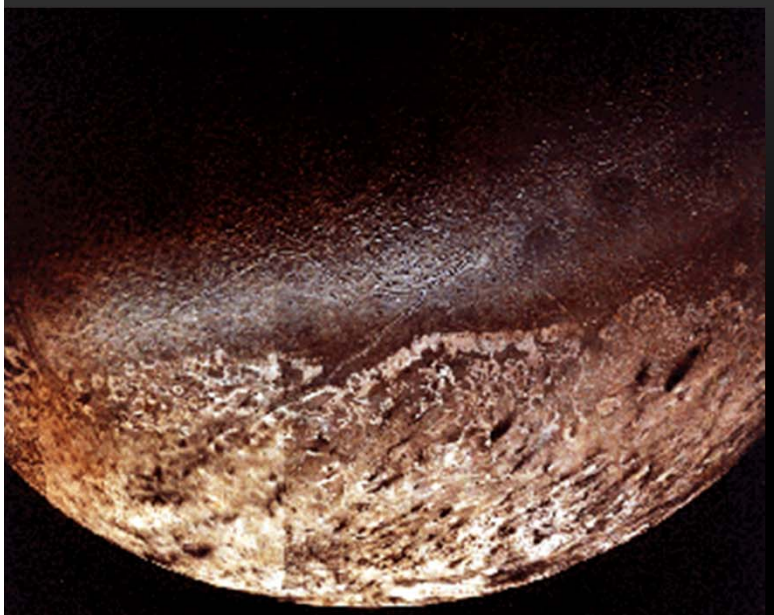
MOONS OF NEPTUNE

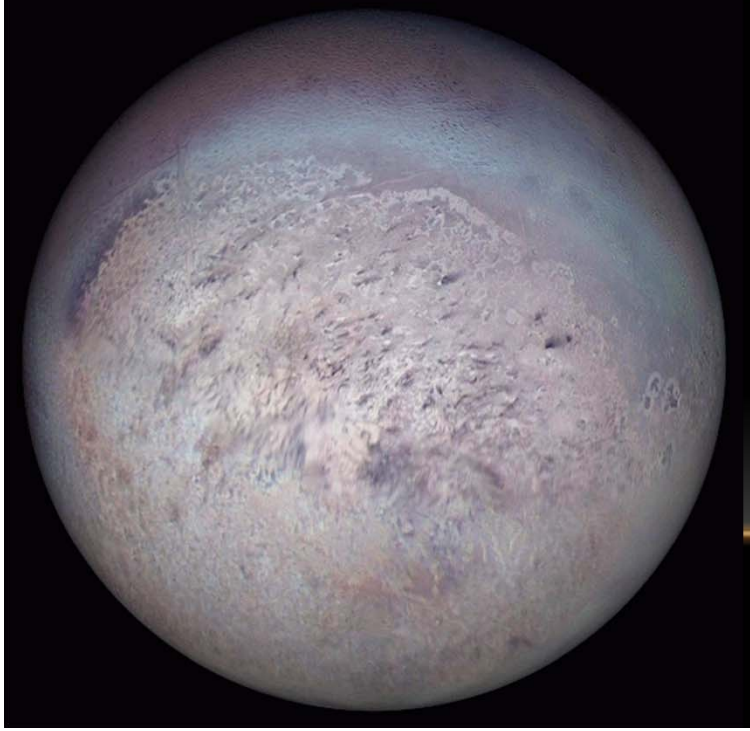
Proteus



Nereid

- Neptune has 11 moons
- Triton is a large moon
  - 2/3 out Moon's diameter
  - Similar to Europa
- Proteus medium-sized icy moon
- The rest small asteroidy moons
  - Nereid has an extremely elliptical orbit





TRITON

- Retrograde orbit!
- Cold, thin atmosphere
  - 37 K
  - Nitrogen
  - Made by liquid nitrogen geysers
- Very new, icy surface
- Smooth or Cantaloupe-like surface

A SOMEWHAT WILD POSSIBILITY

- Perhaps Neptune has experienced a near-miss in the past
- Captured Triton into a retrograde orbit
  - it is quite similar to Pluto and other Kuiper Belt Objects
- Put Nereid into extremely elliptical orbit

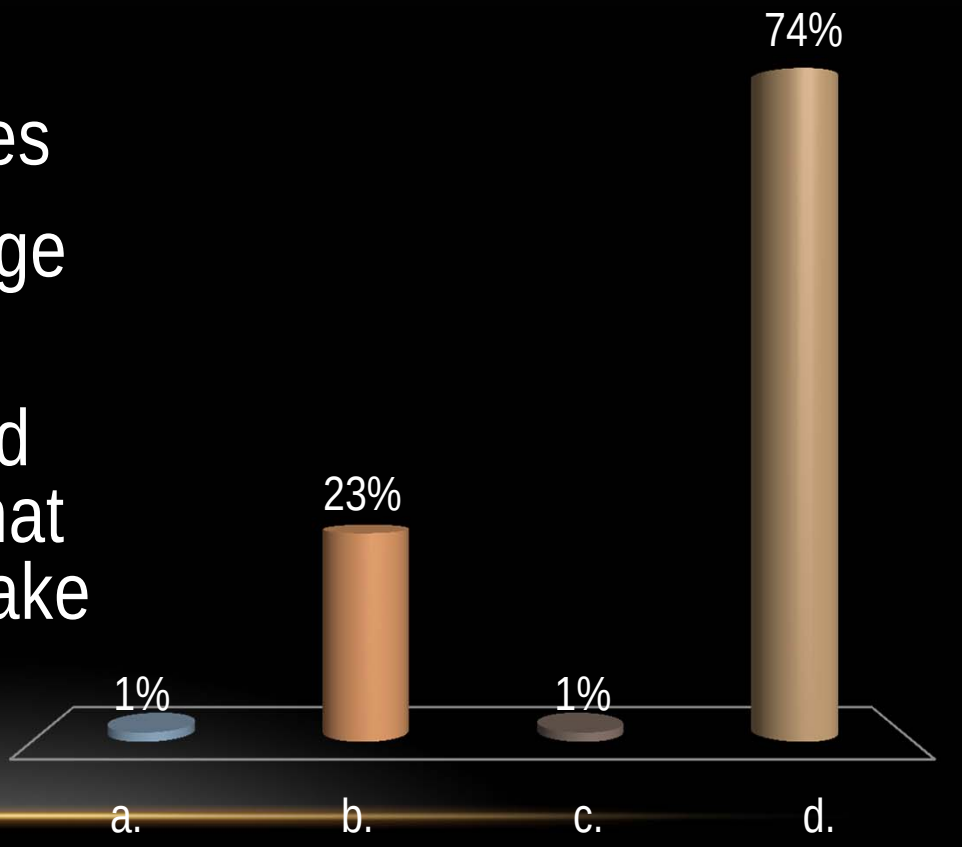
WHY DO JUPITER, SATURN, URANUS, AND NEPTUNE ALL HAVE RINGS?

a. Rings were left over from solar system formation

b. They all captured particles

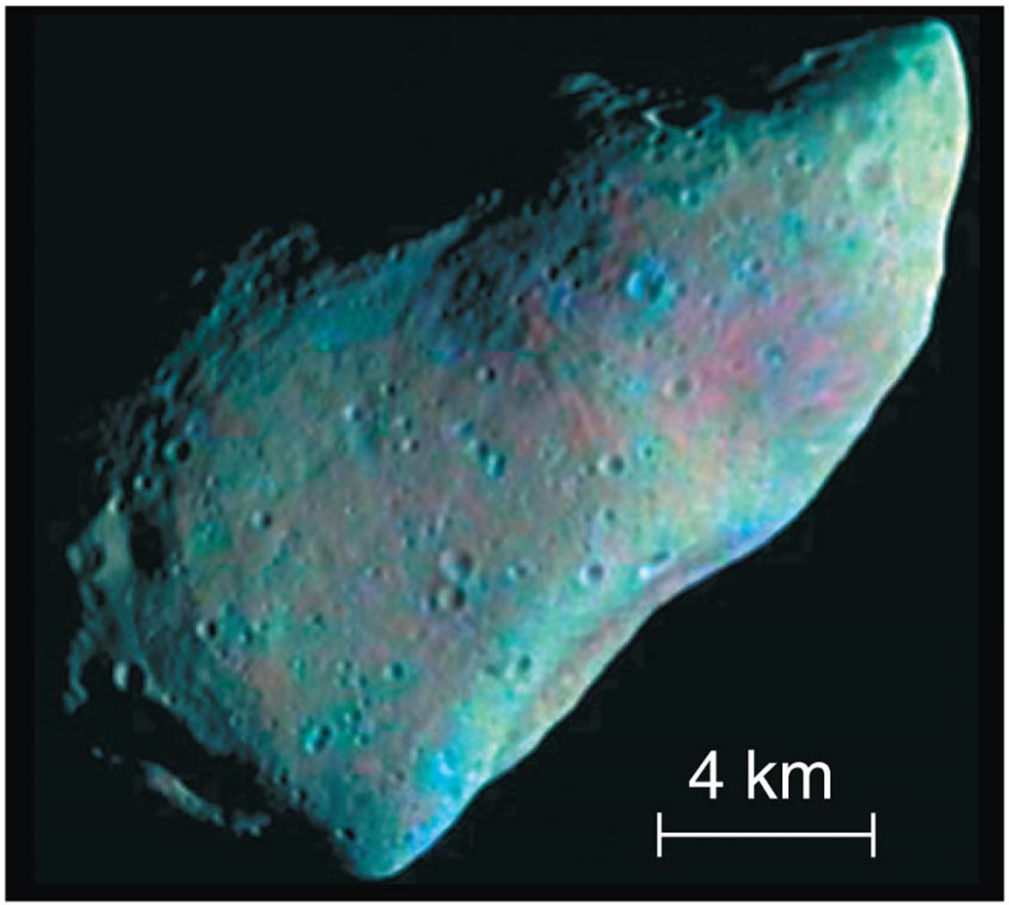
c. All four planets had a large moon that disintegrated

✓ d. All have small moons and small orbiting particles that constantly collide and make rings



ASTEROIDS

- Smallish rocky things

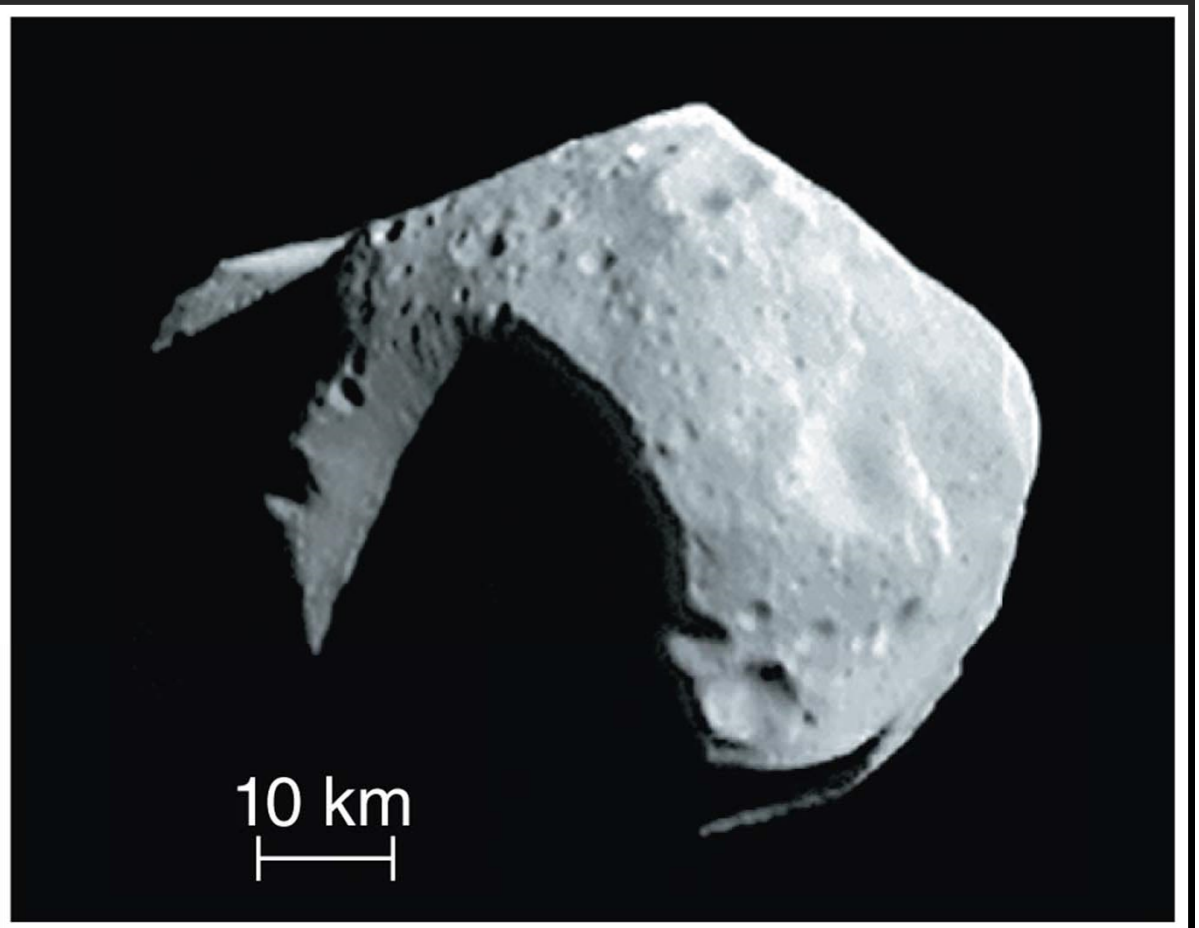


a Gaspra, photographed by the *Galileo* spacecraft. Colors are exaggerated to show detail.

Fig.9.8a

ASTEROIDS

- Mostly orbit between Mars and Jupiter

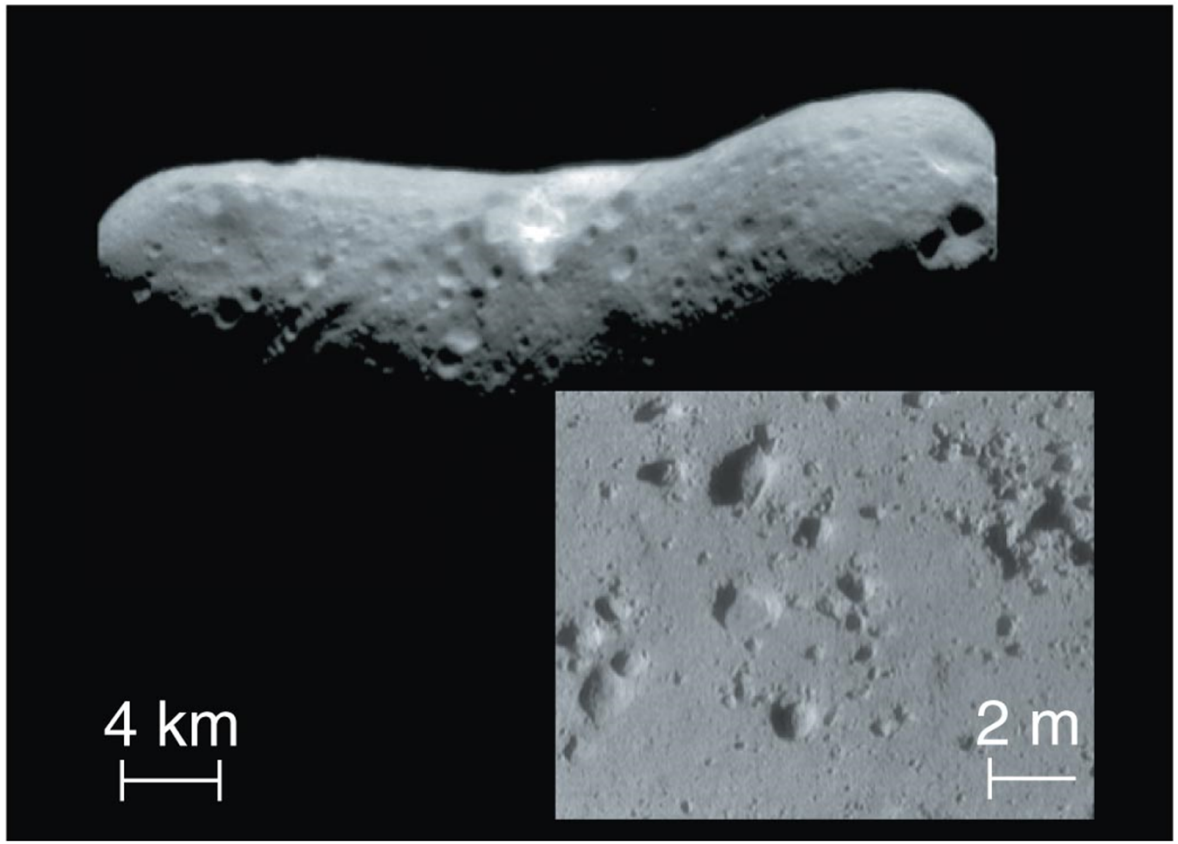


b Mathilde, photographed by the *Near-Earth Asteroid Rendezvous* (*NEAR*) spacecraft on its way to Eros.

Fig.9.8b

ASTEROIDS

- In the “Asteroid Belt”

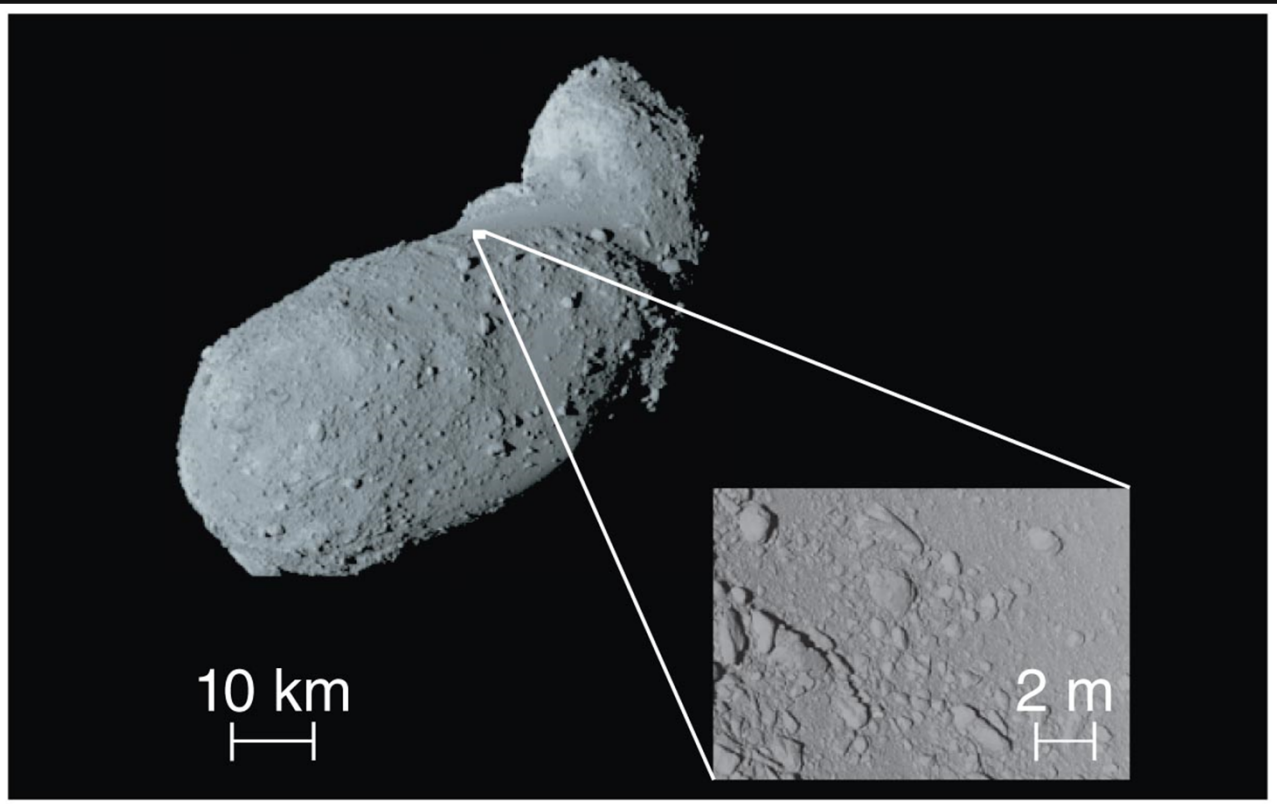


c Eros, photographed by the *NEAR* spacecraft, which orbited Eros for a year before ending its mission with a soft landing on the asteroid’s surface.

Fig.9.8c

ASTEROIDS

- Which looks nothing like the one in "The Empire Strikes Back"



d Itokawa, photographed by the Japanese *Hayabusa* mission, which landed on the surface and attempted to capture a sample for return to Earth.

Fig.9.8d

ASTEROID FACTS

- Asteroids are rocky leftovers of planet formation.
- The largest is Ceres, diameter ~1000 km.
- There are 150,000 listed in catalogs, and probably over a million with diameter >1 km.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.

Check out this claymation from Greenwich all about this chapter!

HOW TO FIND THEM

Fig.9.1

- They’re faint (small, dark colored, reflecting sunlight)
- But since they orbit the sun, they appear to move compared to the stars

WHERE ARE THEY?

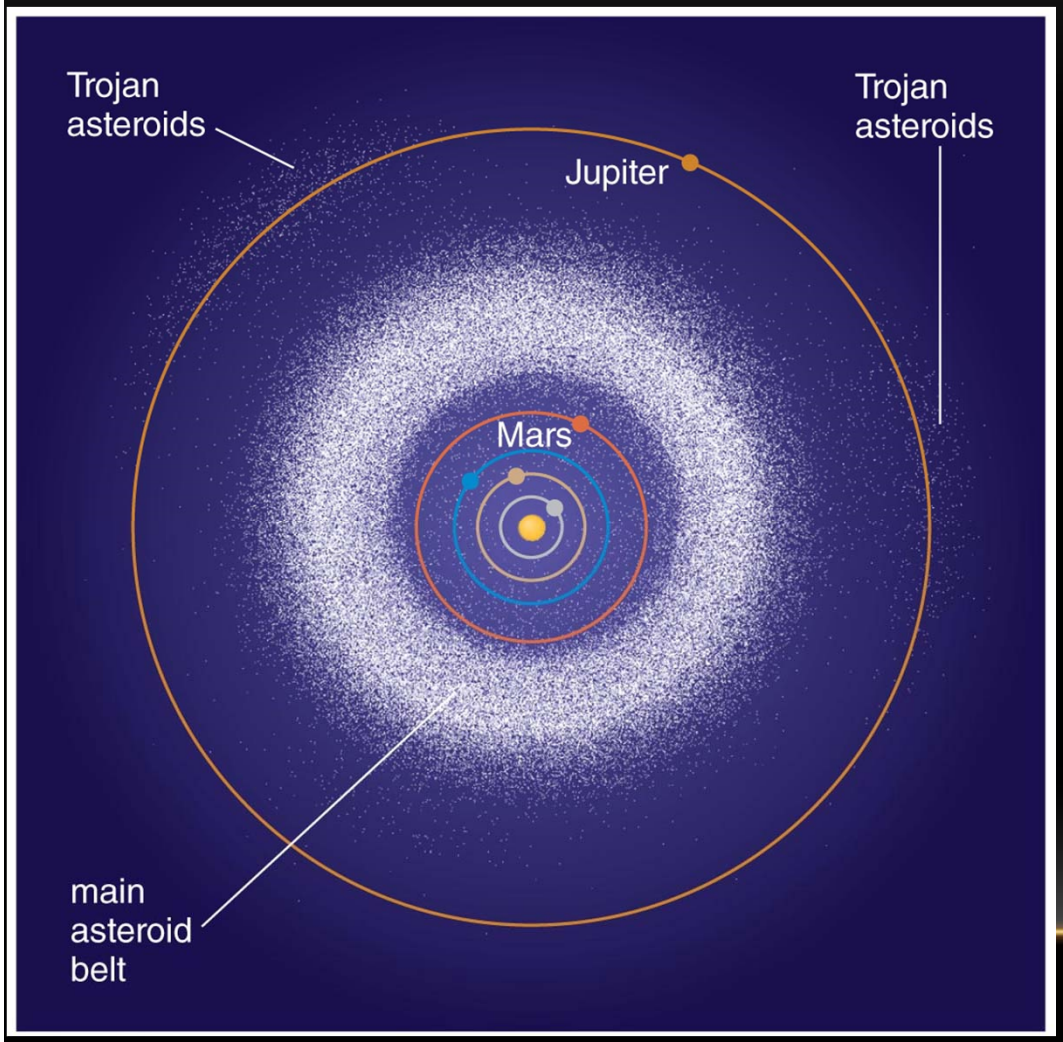


Fig.9.10

- Calculate up their orbits…
- Mostly between Mars and Jupiter
- This looks dense, but remember the scale: space is really big, asteroids are pretty small

WHY?

- Jupiter's gravity pulls on them too, kept them from forming a larger planet
- We can still see the effect of this gravity on their orbits

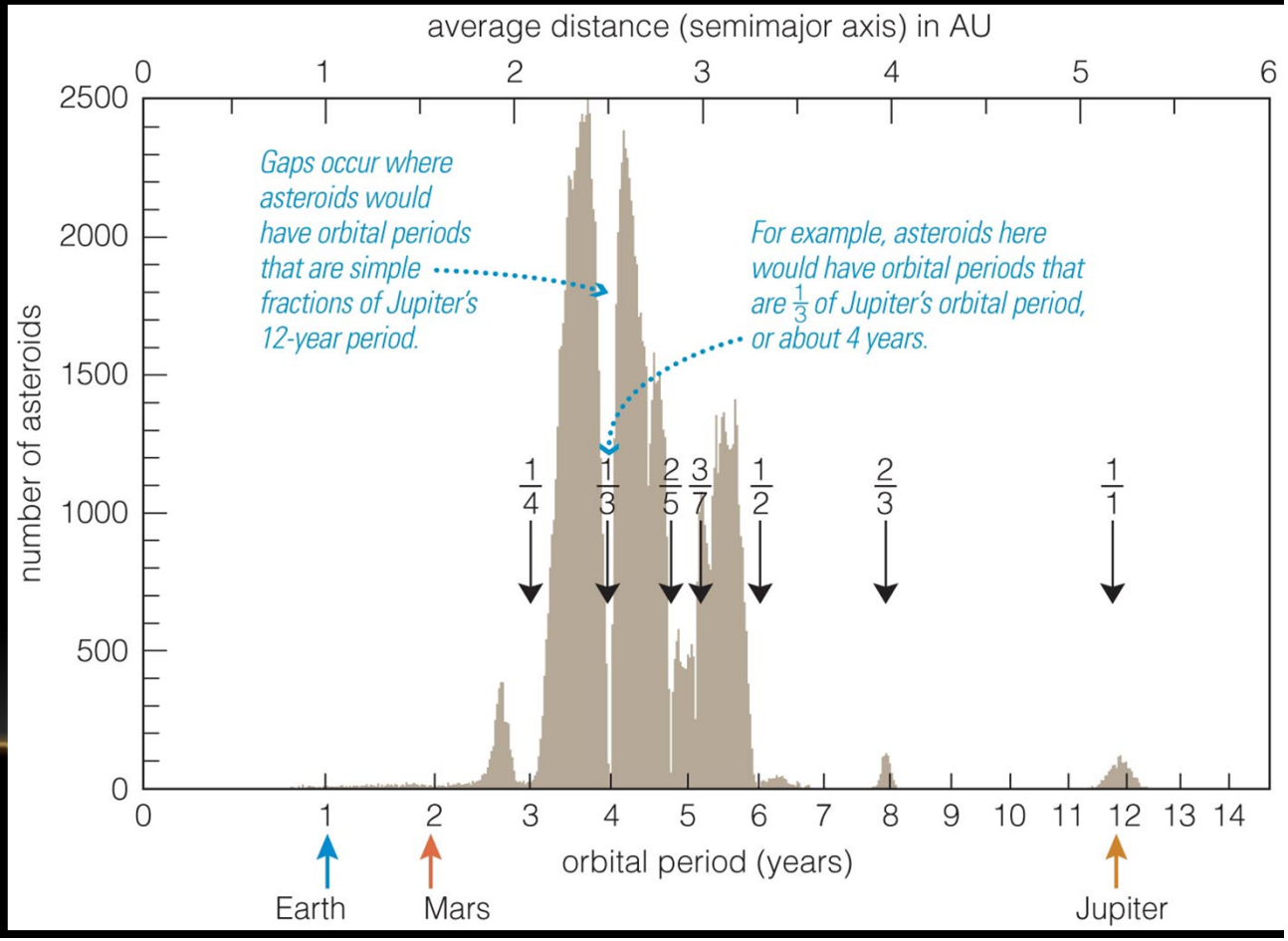


Fig.9.11

WHY ARE THERE VERY FEW ASTEROIDS BEYOND JUPITER'S ORBIT?

a. There was no rocky material beyond Jupiter's orbit.

b. The heaviest rocks sank toward the center of the solar system.

✓ c. Ice could form in the outer solar system.

d. A passing star probably stripped away all of those asteroids, even if they were there at one time.