ASTR 380
Possibilities for Life on the Moons of Giant Planets

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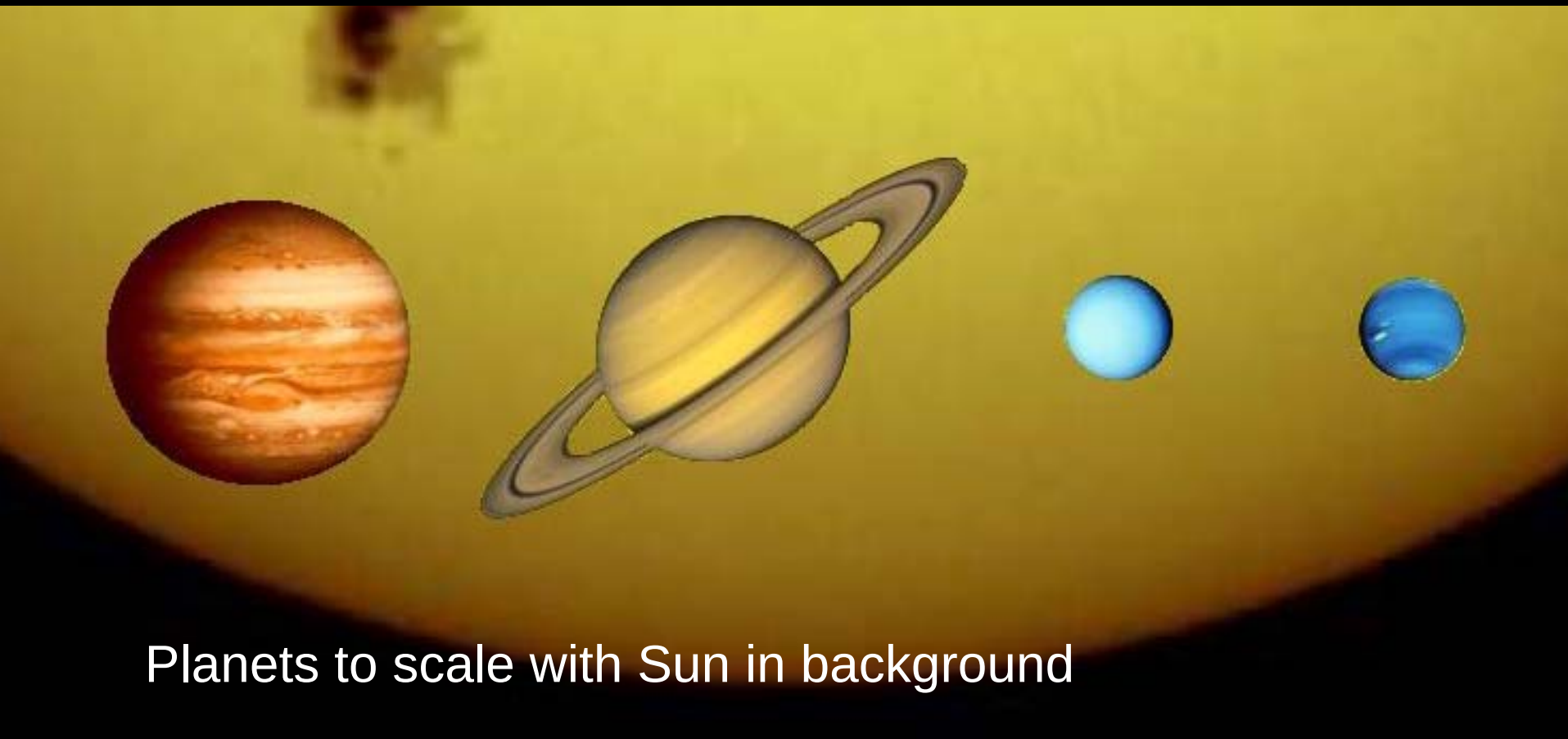
Let's first consider the large gas planets: Jupiter, Saturn, Uranus and Neptune



Planets to scale with Sun in background

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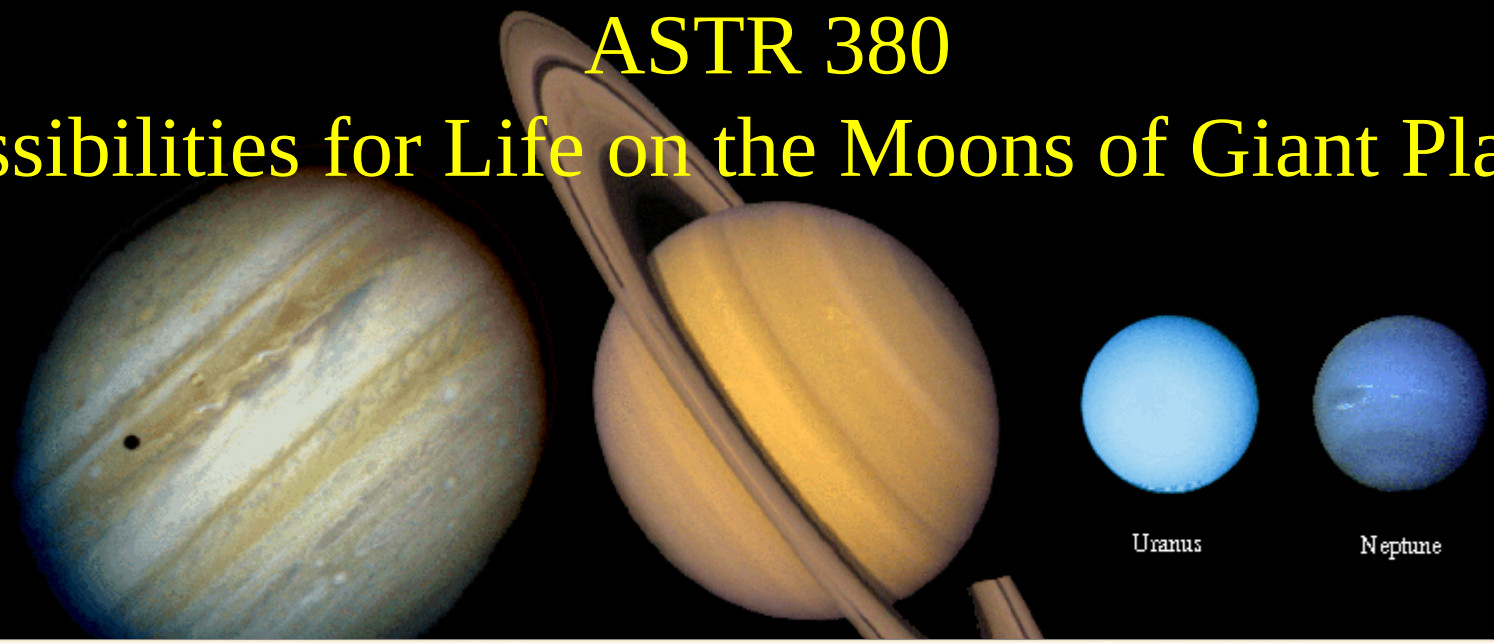

Object	Orbital Semimajor Axis (A.U.)	Orbital Period (Earth Years)	Mass (Earth Masses)	Radius (Earth Radii)	Number of Known Satellites	Rotation Period* (days)	Average Density (kg/m^3)	(g/cm^3)
Mercury	0.39	0.24	0.055	0.38	0	59	5400	5.4
Venus	0.72	0.62	0.82	0.95	0	−243	5200	5.2
Earth	1.0	1.0	1.0	1.0	1	1.0	5500	5.5
Moon	—	—	0.012	0.27	—	27.3	3300	3.3
Mars	1.52	1.9	0.11	0.53	2	1.0	3900	3.9
Ceres (asteroid)	2.8	4.7	0.00015	0.073	0	0.38	2700	2.7
Jupiter	5.2	11.9	318	11.2	61	0.41	1300	1.3
Saturn	9.5	29.4	95	9.5	31	0.44	700	0.7
Uranus	19.2	84	15	4.0	27	−0.72	1300	1.3
Neptune	30.1	164	17	3.9	12	0.67	1600	1.6

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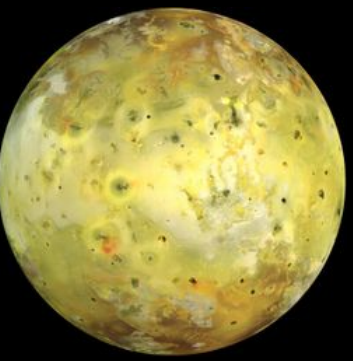
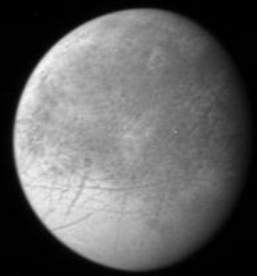
The many moons of the outer planets….. Most of the moons are very small – 1 to a few hundred km in diameter.





Planet	Number of moons
Jupiter	63
Saturn	60
Uranus	27
Neptune	13

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Why are their so many moons around the giant planets compared to the terrestrial planets?

The outer solar system is a busy place:

asteroid belt

Trojan and Greek asteroids

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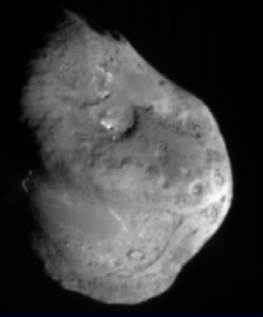
Possibilities for Life on the Moons of Giant Planets

The outer solar system is a busy place:

the Kuiper belt



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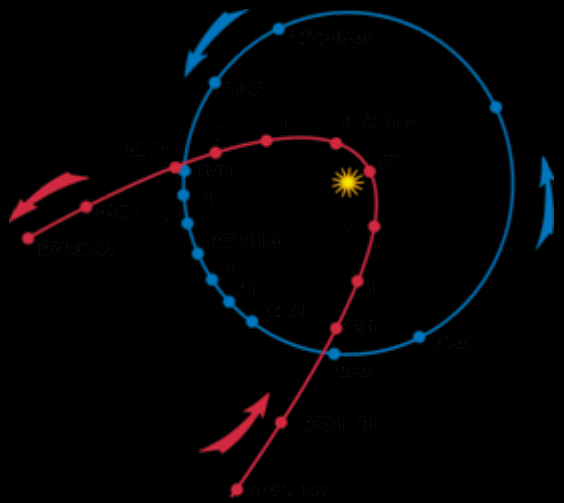
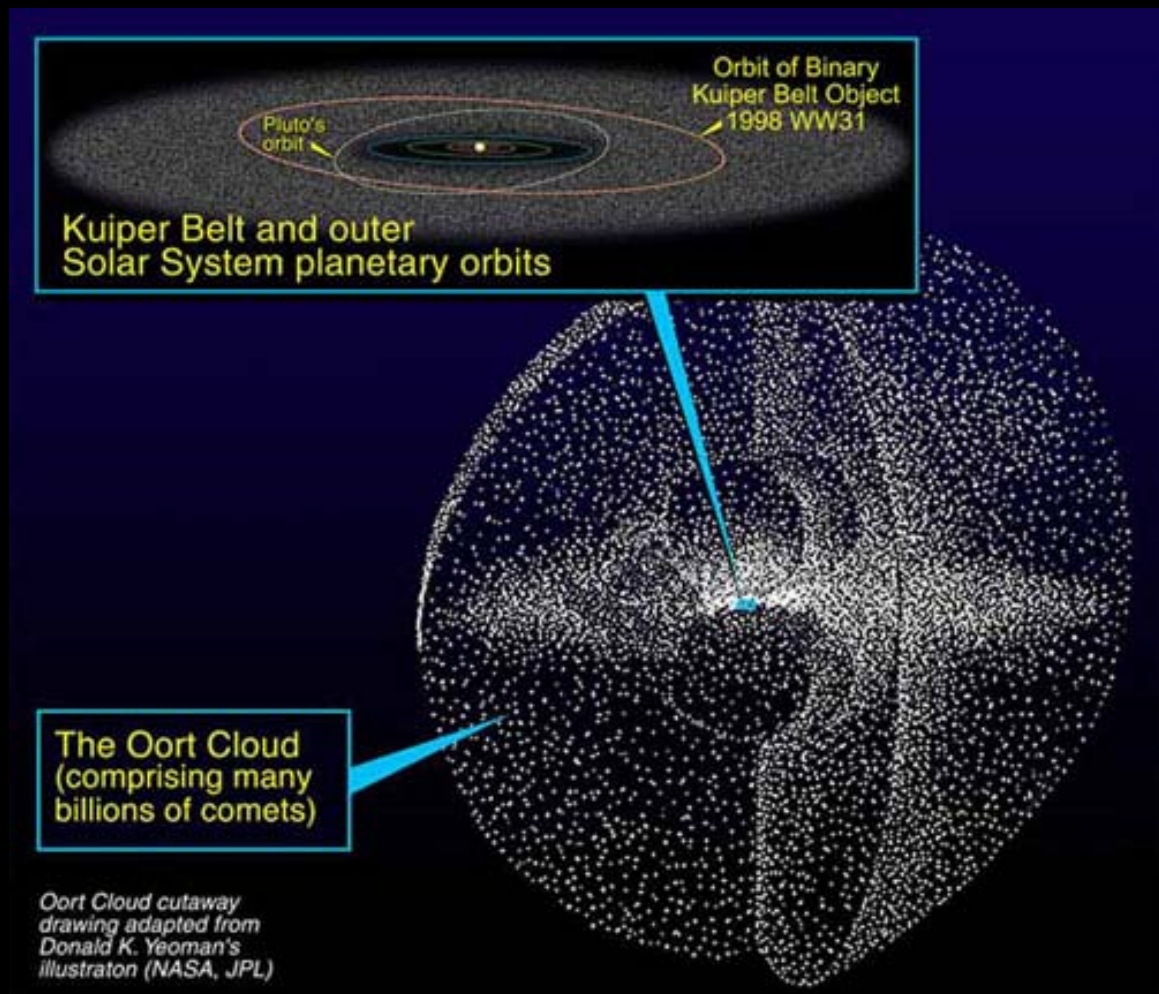
The outer solar system is a busy place:

the Oort Cloud

The Oort Cloud is the origin of long period comets





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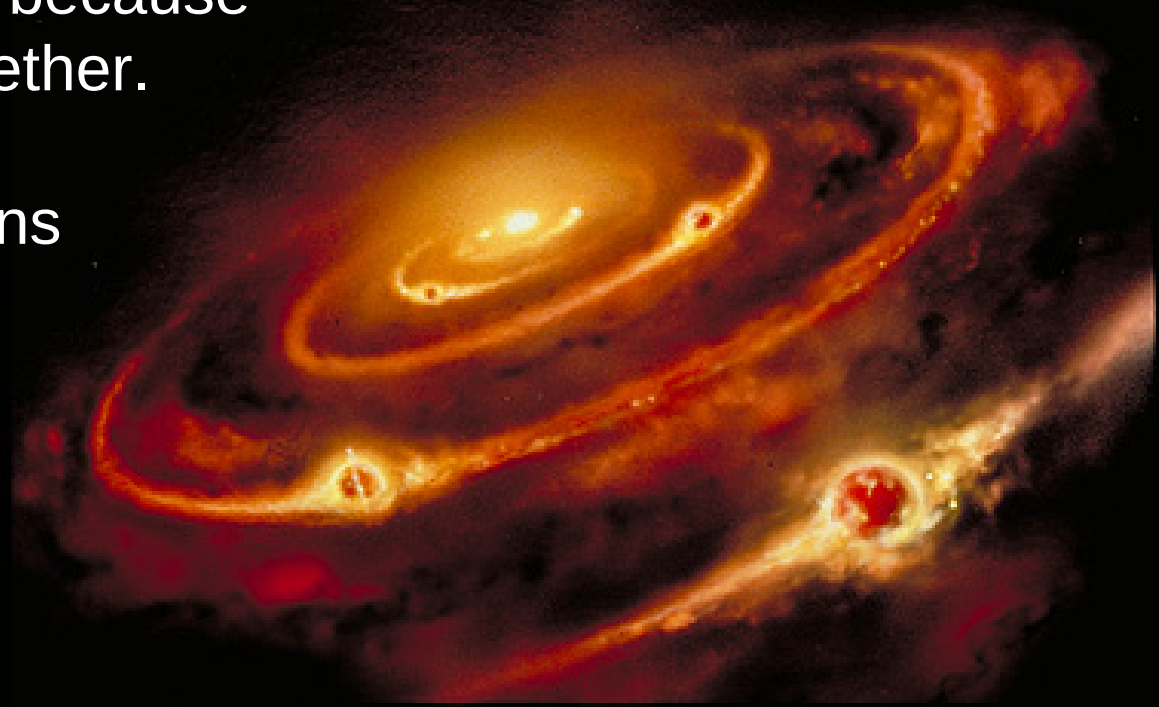
The asteroids, Kuiper Belt objects and comets are remnants of the formation of the solar system.

Such remnants were cleared out of the inner solar system because planets are so close together.

There a no stable locations for billions of years… they crash into planets.



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The bigger spacing between planets and the bigger planets in the outer solar system push the objects around but they don't necessarily collide with planets.

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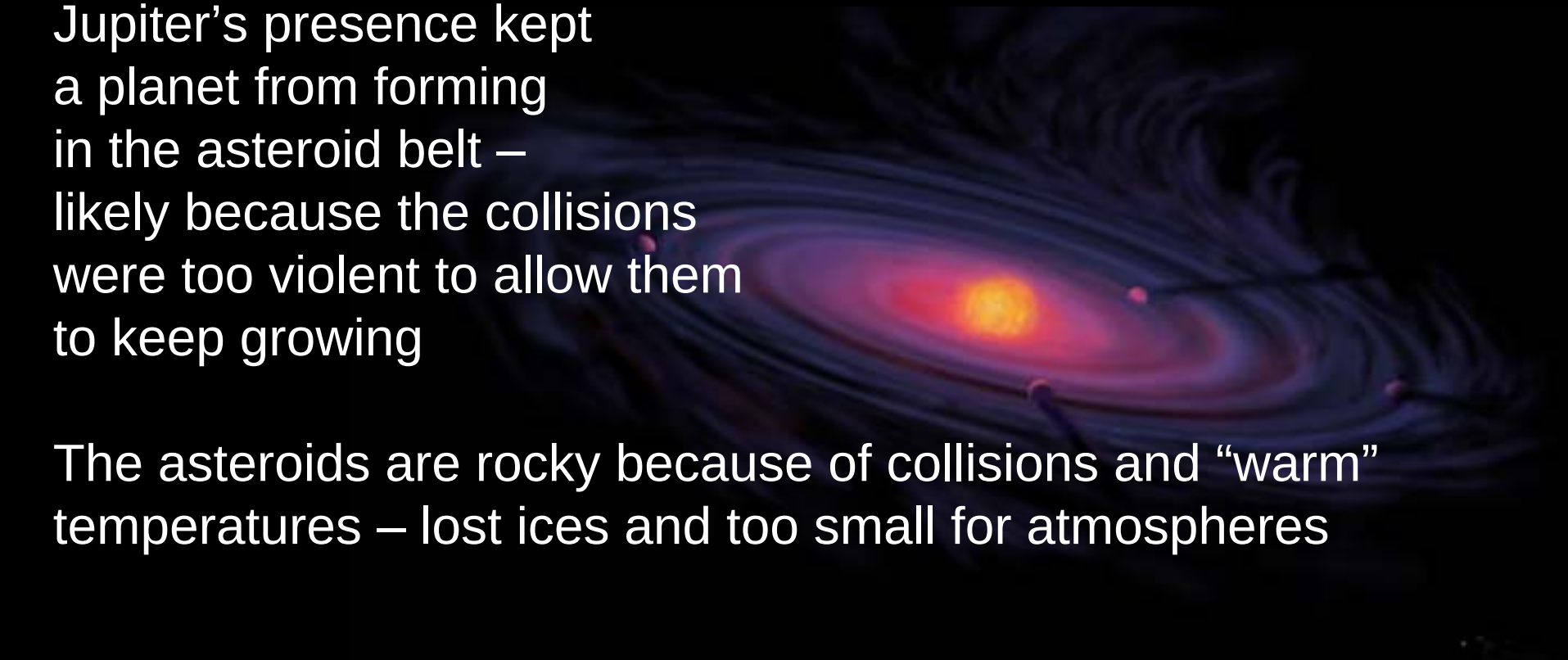
Possibilities for Life on the Moons of Giant Planets

Formation scenario:
Jovian planets grew through accreting planetessimals then gas as they became large enough.

Jupiter's presence kept a planet from forming in the asteroid belt – likely because the collisions were too violent to allow them to keep growing



The asteroids are rocky because of collisions and "warm" temperatures – lost ices and too small for atmospheres

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Formation scenario:

The Jovian planets ate or scattered into large orbits planetessimals around and between themselves.

These are rocky and icy bodies.

Ices stayed because of
cold temperatures and
Gentle collision history –
if you didn't get eaten by a planet

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Formation scenario:

Comets are examples of planetessimals that were scattered into large orbits – creating the Oort Cloud and Jupiter family comets.

Kuiper Belt Objects are survivers. Pushed to larger orbits by the Giant planets but not eaten or strongly scattered.

Some, like Sedna, Pluto, Are comparable to large moons.

Artist conception of Sedna

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Formation scenario:

So most moons, especially the small ones, were captured by the planets from the early Kuiper Belt population – ones the escaped being eaten but couldn't get away.

The exceptions are the big inner moons of Jupiter

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Formation scenario:

Io, Europa, Ganymede, and Callisto show a pattern of increasing icy composition and average density with increasing distance from Jupiter.

They orbit in a plane,
like a mini-solar system.

These characteristics argue that the moons formed like a mini-solar system from gas and dust around the young Jupiter

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For life, the small ones are least interesting because they:

- cannot hold an atmosphere
- cannot hold a liquid on their surface

The largest moons of the giant planets

Planet	Satellite	Luna masses
Jupiter	Io	1.2
	Europa	0.6
	Ganymede	2.0
	Callisto	1.6
Saturn	Titan	1.5
Uranus	Titania	0.05
	Oberon	0.04
Neptune	Triton	0.3

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Possibilities for Life on Moons of Giant Planets

History of Exploration of the Outer Solar System

Spacecraft	Closest approach	Jupiter close approach	Planets visited (dwarf planet)
Pioneer 10	December 3, 1973	130,000 km	Jupiter
Pioneer 11	December 4, 1974	34,000 km	Jupiter, Saturn
Voyager 1	March 5, 1979	349,000 km	Jupiter, Saturn
Voyager 2	July 9, 1979	570,000 km	Jupiter Saturn, Uranus, Neptune
Ulysses	February 1992	409,000 km	Jupiter
	February 2004	240,000,000 km	Jupiter
Cassini	December 30, 2000	10,000,000 km	Saturn
New Horizons	February 28, 2007	2,304,535 km	Jupiter, Pluto

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Possibilities for Life on the Moons of Giant Planets

Io: Jupiter's inner most moon

average density = 3.57 g/cm3
tidally heated by Jupiter interaction
likely no water, methane or ammonia
left due to volcanic activity
lots of heat, sulfur compounds

Life based on
sulfur ?

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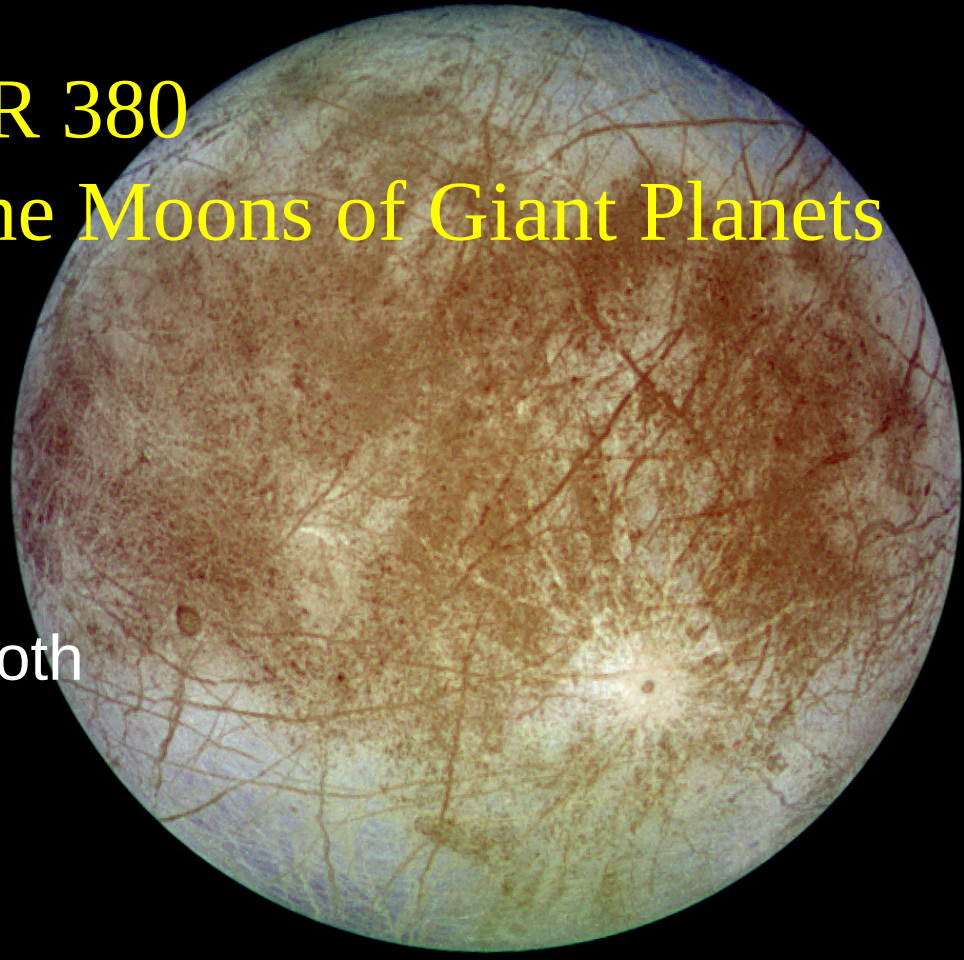
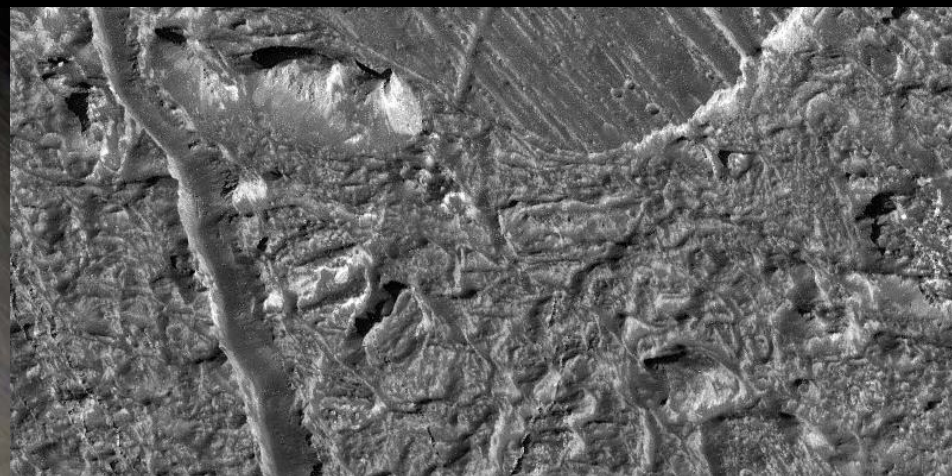


Europa: Jupiter's second moon

- Average density = 3 g/cm3
- Icy surface… but very smooth
- Constantly resurfaced!



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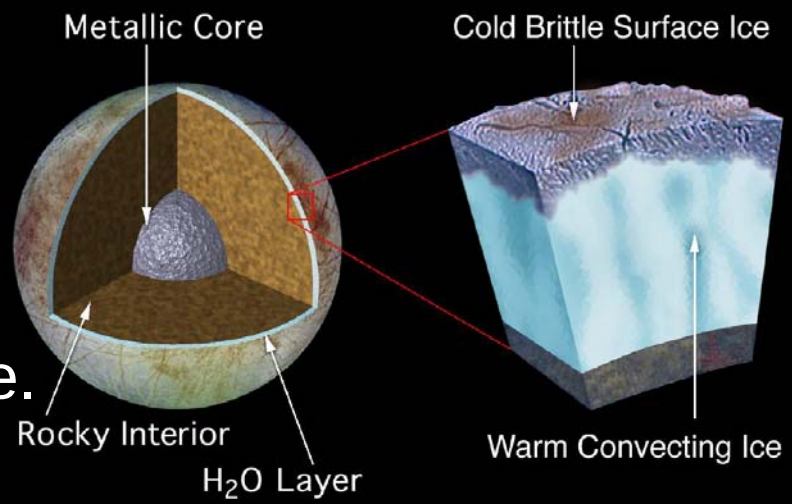
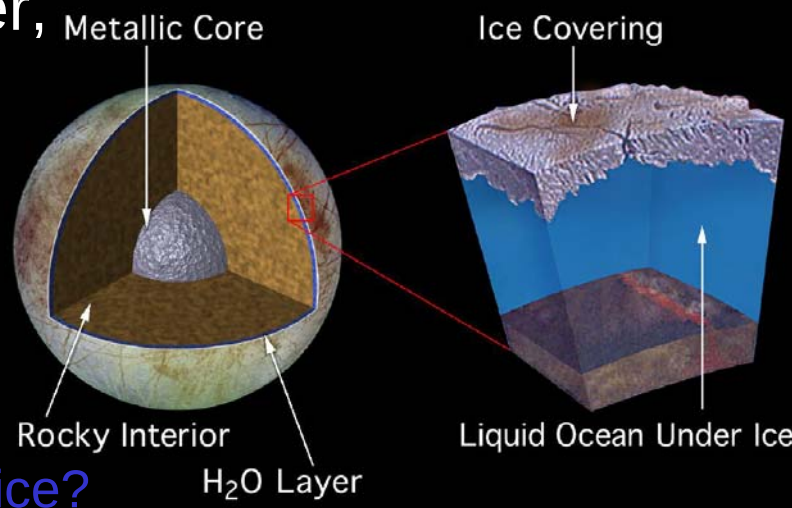
Europa: Jupiter's second moon

Rocky core, a silicate rock mantle, and 80 – 170 km thick skin of water or water ice.



Current expectation: liquid water under a thick ice layer – water, methane, ammonia !



Life in oceans under ice?

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Possibilities for Life on the Moons of Giant Planets

Ganymede: Jupiter's largest moon

Average density = 1.9 g/cm3

More icy composition than Europa

Ice surface has new and old areas

Life in oceans under ice?

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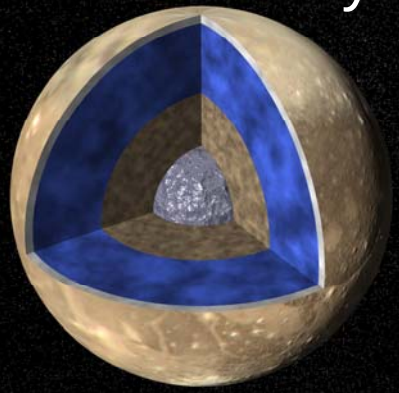
Possibilities for Life on the Moons of Giant Planets

Ganymede: Jupiter's largest moon

Likely liquid water resurfaces parts of moon.

Speculated that might have 150 km thick layer of surface ice – likely with liquid water below thick icy layer.



Life in oceans under ice?

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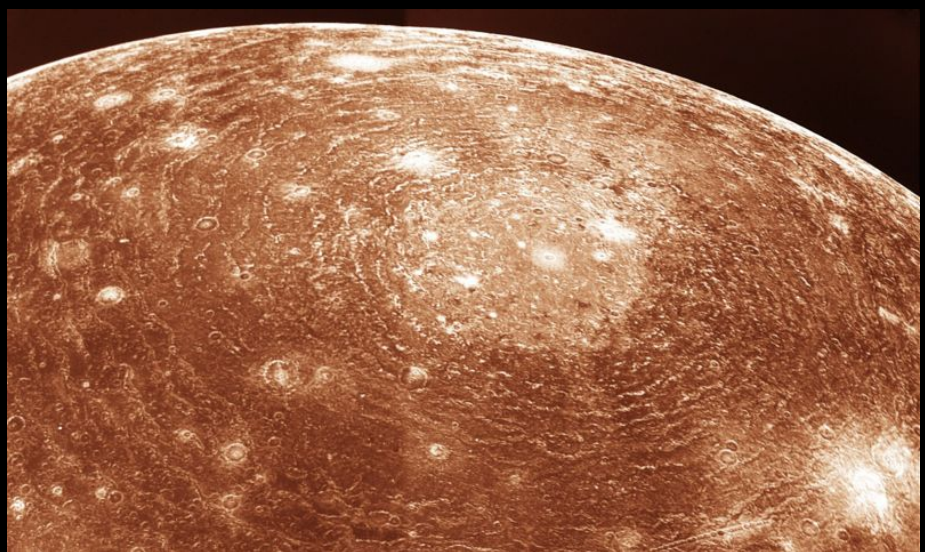
Callisto: Jupiter's outermost large moon

Average density = 1.9g cm3

Mixed ball of icy and rock

Thick surface layer of water ice



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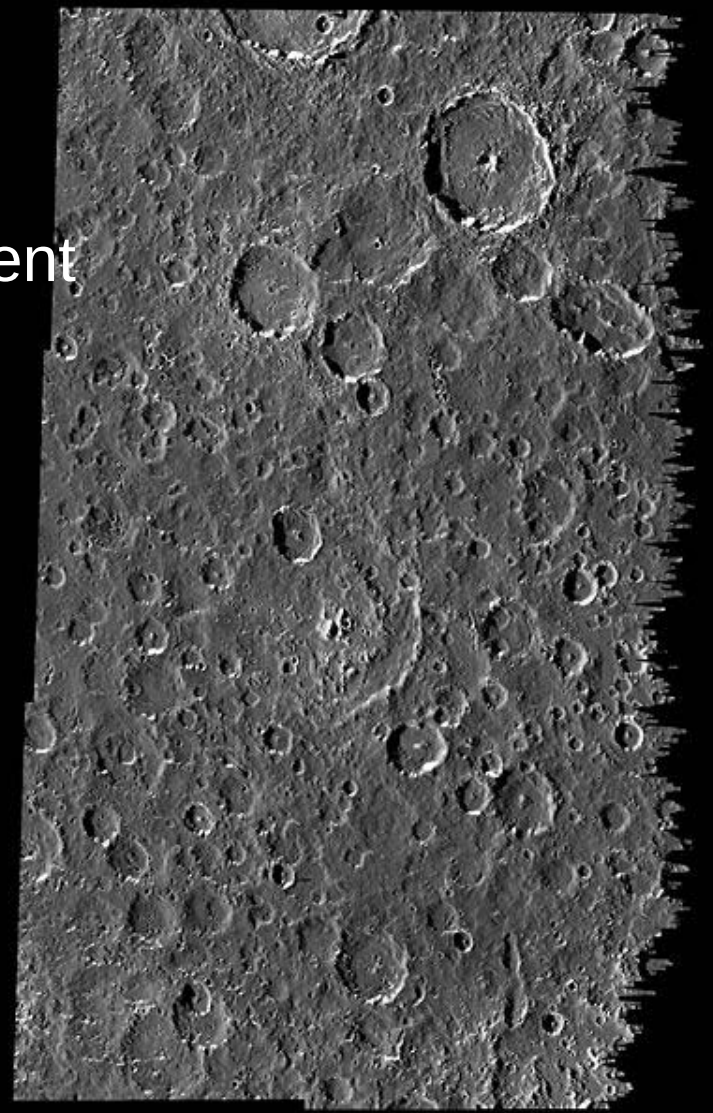
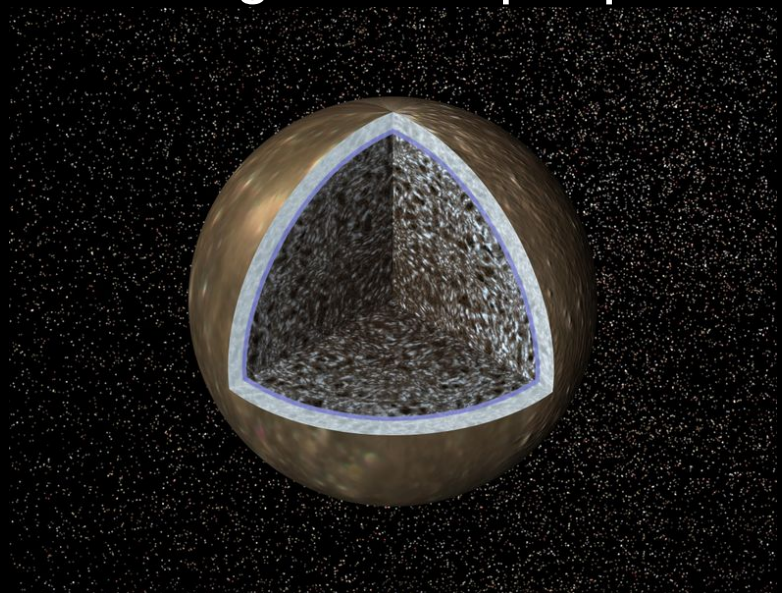
Possibilities for Life on the Moons of Giant Planets

Callisto: Jupiter's outermost large moon



Surface show old craters – thought to date back to heavy bombardment period.

Tidal heating weak – may be enough to keep liquid water.



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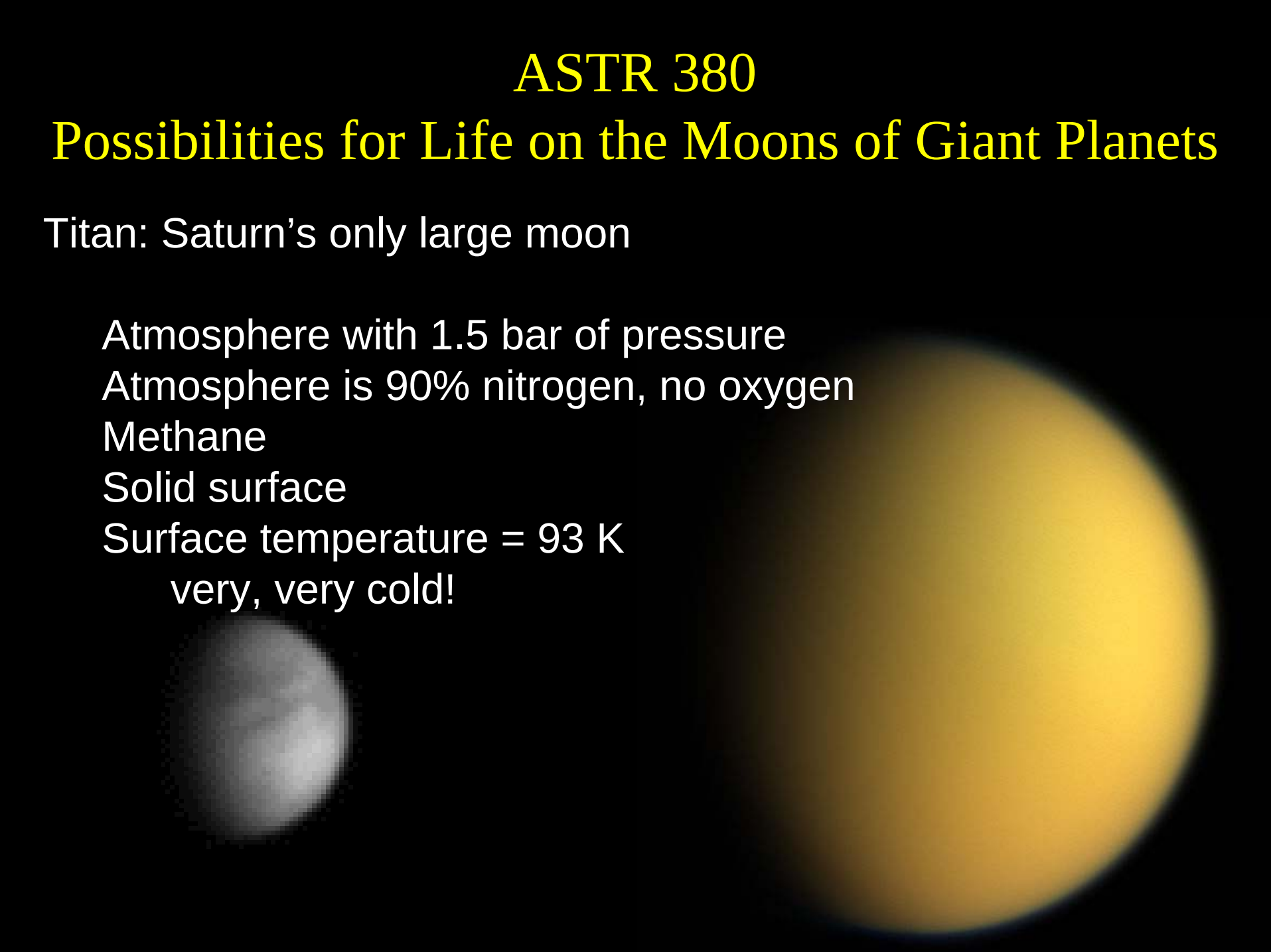
Titan: Saturn's only large moon

- Atmosphere with 1.5 bar of pressure
- Atmosphere is 90% nitrogen, no oxygen
- Methane
- Solid surface
- Surface temperature = 93 K
  - very, very cold!



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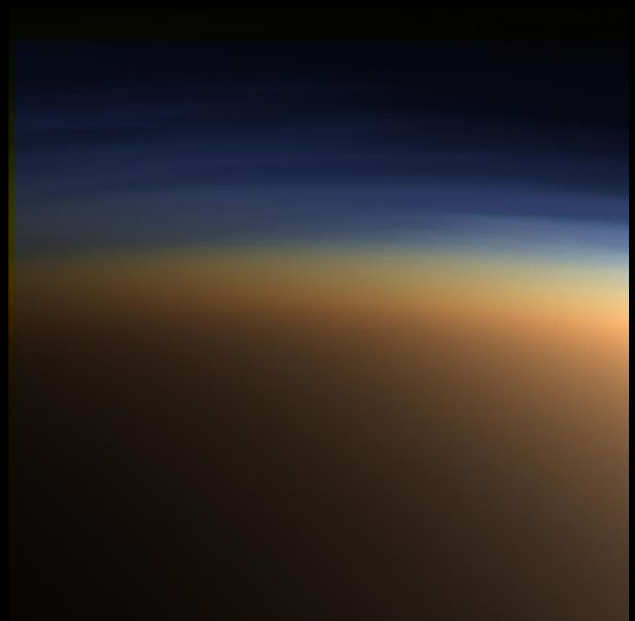
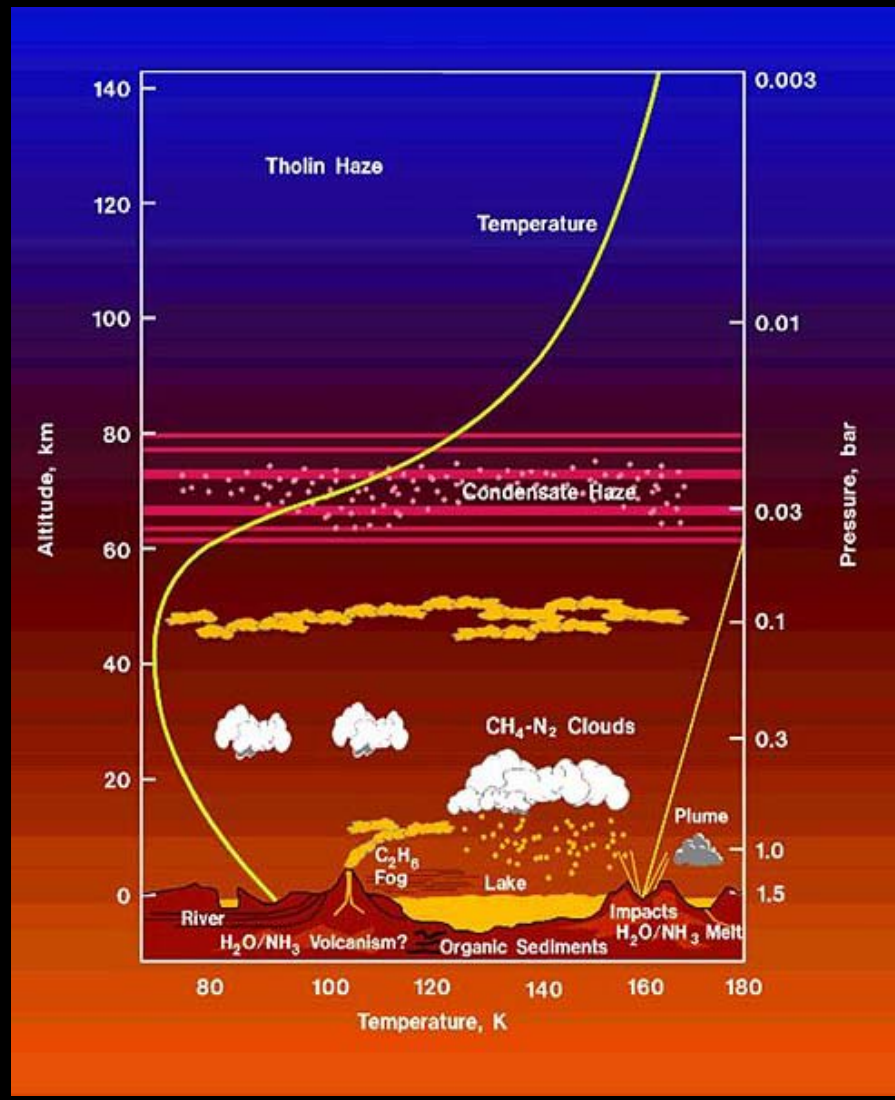
Possibilities for Life on the Moons of Giant Planets

Titan: Saturn's only large moon

Huygens probe from Cassini spacecraft landed on Titan giving information about the atmosphere and surface.





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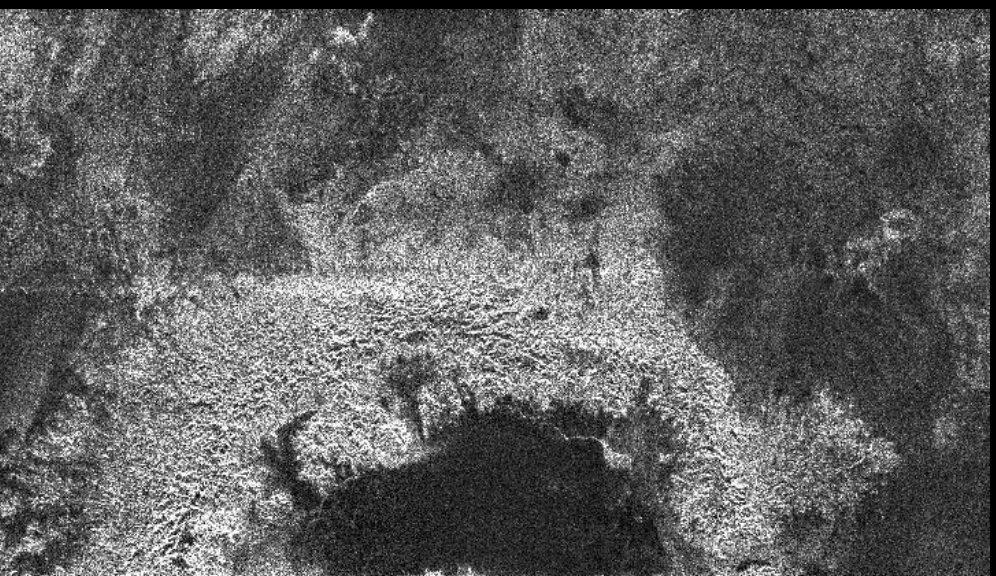
Titan: Saturn's only large moon

- Pictures show features likely carved by liquids – liquid methane probably
- But no direct pictures of streams or pools
- Solid ice on surface, "ice rocks"



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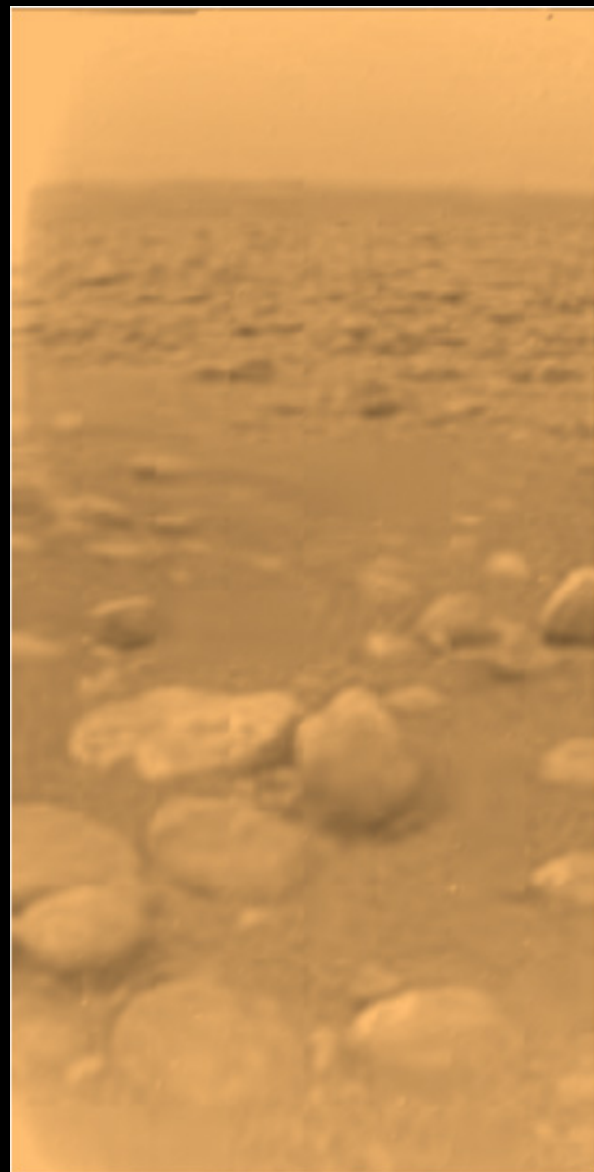

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Possibilities for Life on the Moons of Giant Planets

Titania and Oberon: the largest moons of Uranus

Small – 0.04 to 0.05 Luna masses
Very cold
Average density = 1.5 – 1.6 g cm3
Ice and rock balls with icy surface

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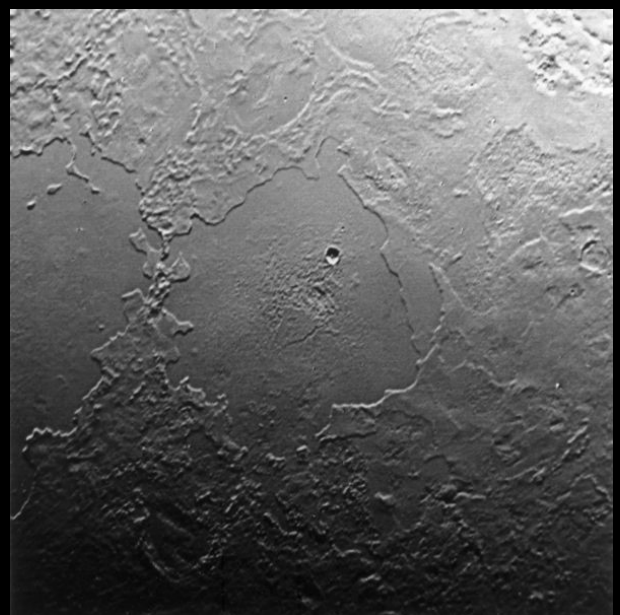
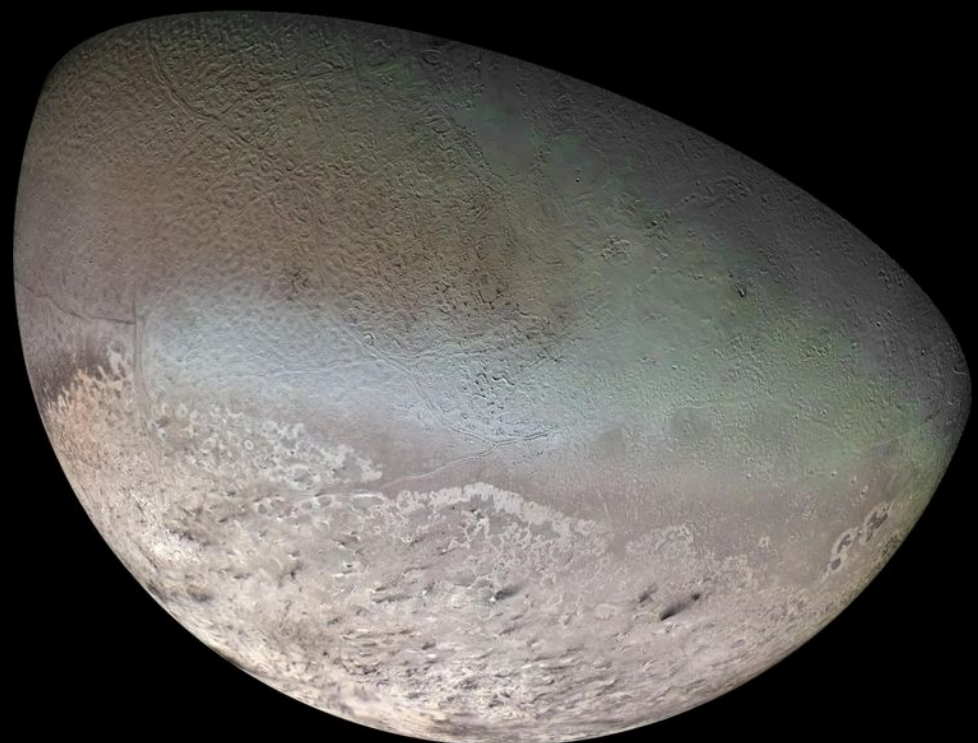
Possibilities for Life on the Moons of Giant Planets

Triton: the largest moon of Neptune

- Small – 0.04 to 0.05 Luna masses
- Very cold
- Average density = 1.5 – 1.6 g cm3
- Ice and rock balls with icy surface
- thin atmosphere





Possibility of Life on the Moons of the Giant Planets

Europa and Ganymede versus our checklist:

chemical building blocks: Lots of C, N, O and solid surface

energy: Cold surface – unknown how warm interior, no light where liquid water is….

liquid: Likely present in abundance under thick icy layer

stability: likely very stable for long period

Chance for life? Biggest problem is energy even if it is warm.
Life needs a source of extra energy compared to the average… just being generally warm isn't good enough

Possibility of Life on the Moons of the Giant Planets

Titan versus our checklist:

chemical building blocks: Lots of C, N, O and solid surface, and atmosphere!!!

energy: Very cold surface, sunlight there but weak

liquid: evidence of liquid methane, water frozen solid

stability: likely very stable for long period

Chance for life? Can you do it with liquid methane? Argument can be made that it is not a good liquid for life….

Possibility of Life in the Inner Solar System

And then there are the what-ifs….

We know that Jupiter and the other giant planets gave off more energy when they were very young

-- perhaps for the first 100 million years Jupiter would have supplied more energy to its moons than the Sun.
-- perhaps there were only very thin ice layers on Europa and Ganymede, and the water was warm.
-- perhaps there was a Titan type atmosphere on Europa or Ganymede that has now been lost.

We need to explore these moons more to know.

Possibility of Life in the Inner Solar System

And then there are the what-ifs….

What if… Jupiter were 2-5 times bigger?
-- it would still be hotter and could heat its moons.

What if Jupiter's inner moons were 10 times more massive?
-- perhaps they could have held an atmosphere
-- and retained more heat
-- and have a liquid water surface….

These are possibilities – even likely situations – around other stars where we see Jupiter–like planets.

This is why our Jovian moons are such an opportunity!!