

# ASTR 380

## Possibilities for Life on the Moons of Giant Planets



"Oh yeah?.. well back home on Planet Tharg  
I'm considered to be something of a ladies man!"

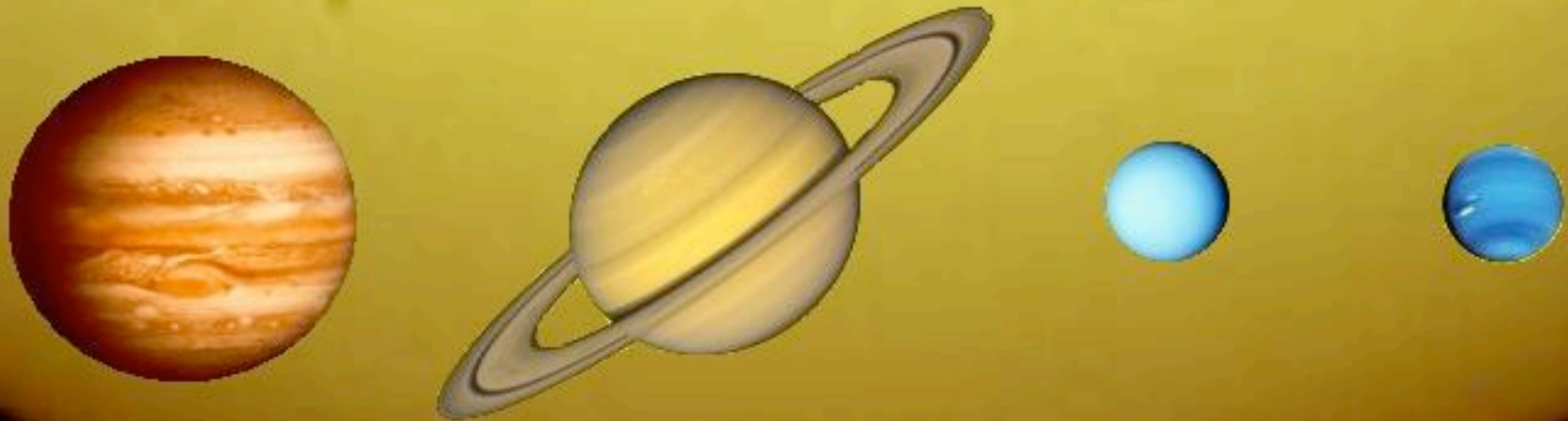
# Outline

- Moons of the giant planets
- Tidal effects; beyond the habitable zone
- Europa
- Titan

## ASTR 380

# Possibilities for Life on the Moons of Giant Planets

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



Planets to scale with Sun in background

# ASTR 380

## Possibilities for Life on the Moons of Giant Planets



Uranus

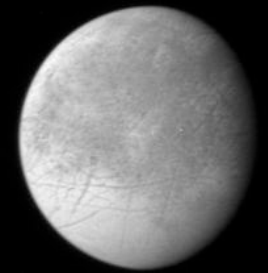
Neptune

| 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 <sup>3</sup> ) | (g/cm <sup>3</sup> ) |
|------------------|-------------------------------|------------------------------|---------------------|----------------------|----------------------------|-------------------------|--------------------------------------|----------------------|
| 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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## Possibilities for Life on the Moons of Giant Planets

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



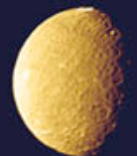
| Planet  | Number of moons |
|---------|-----------------|
| Jupiter | 63              |
| Saturn  | 60              |
| Uranus  | 27              |
| Neptune | 13              |



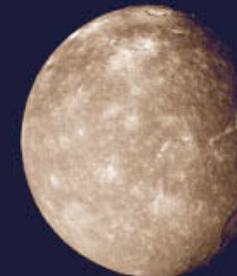
MIRANDA



ARIEL



UMBRIEL



TITANIA



OBERON

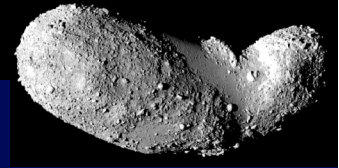
# There Could Be Even More!

- Think about difficulties at more distant planets:  
Farther from Sun, so less reflection  
Then, we get less of the reflected light!
- Therefore, “low” totals for Uranus and Neptune may not be representative

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## Possibilities for Life on the Moons of Giant Planets

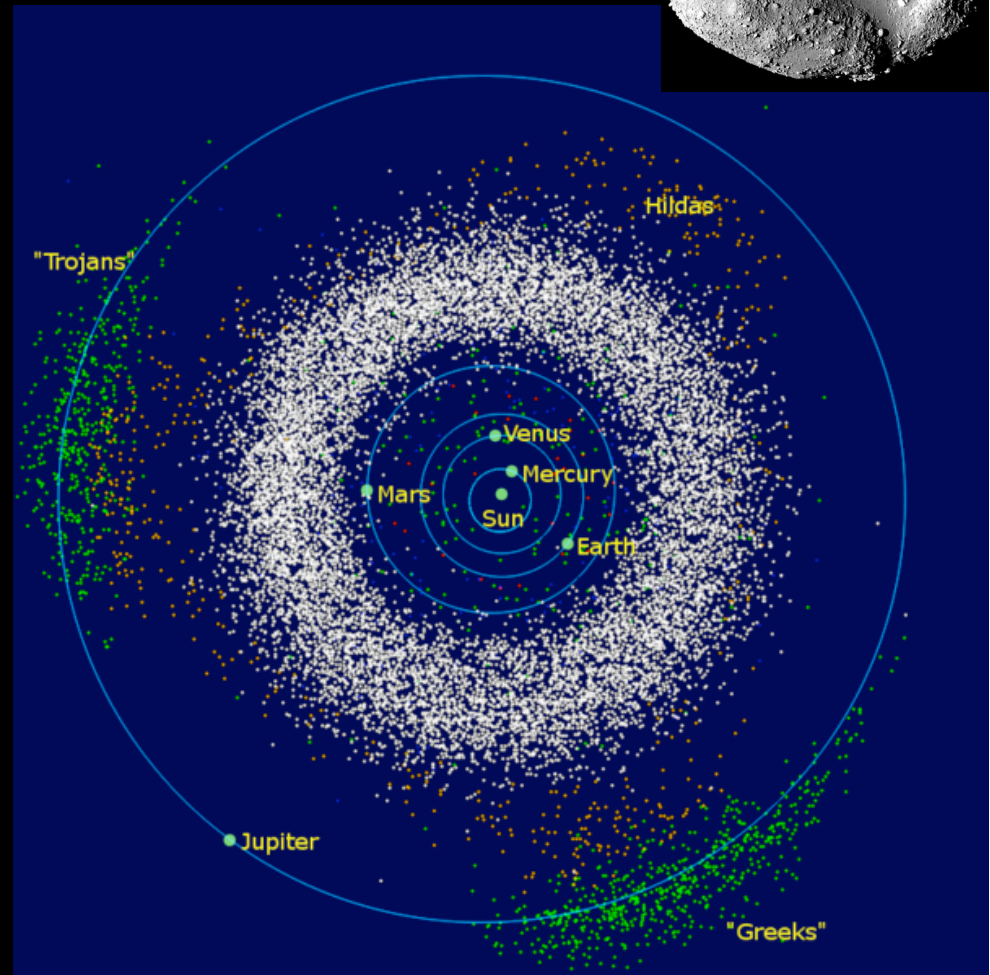
Why are there so many moons around the giant planets compared to the terrestrial planets?



The outer solar system is a busy place:

- asteroid belt

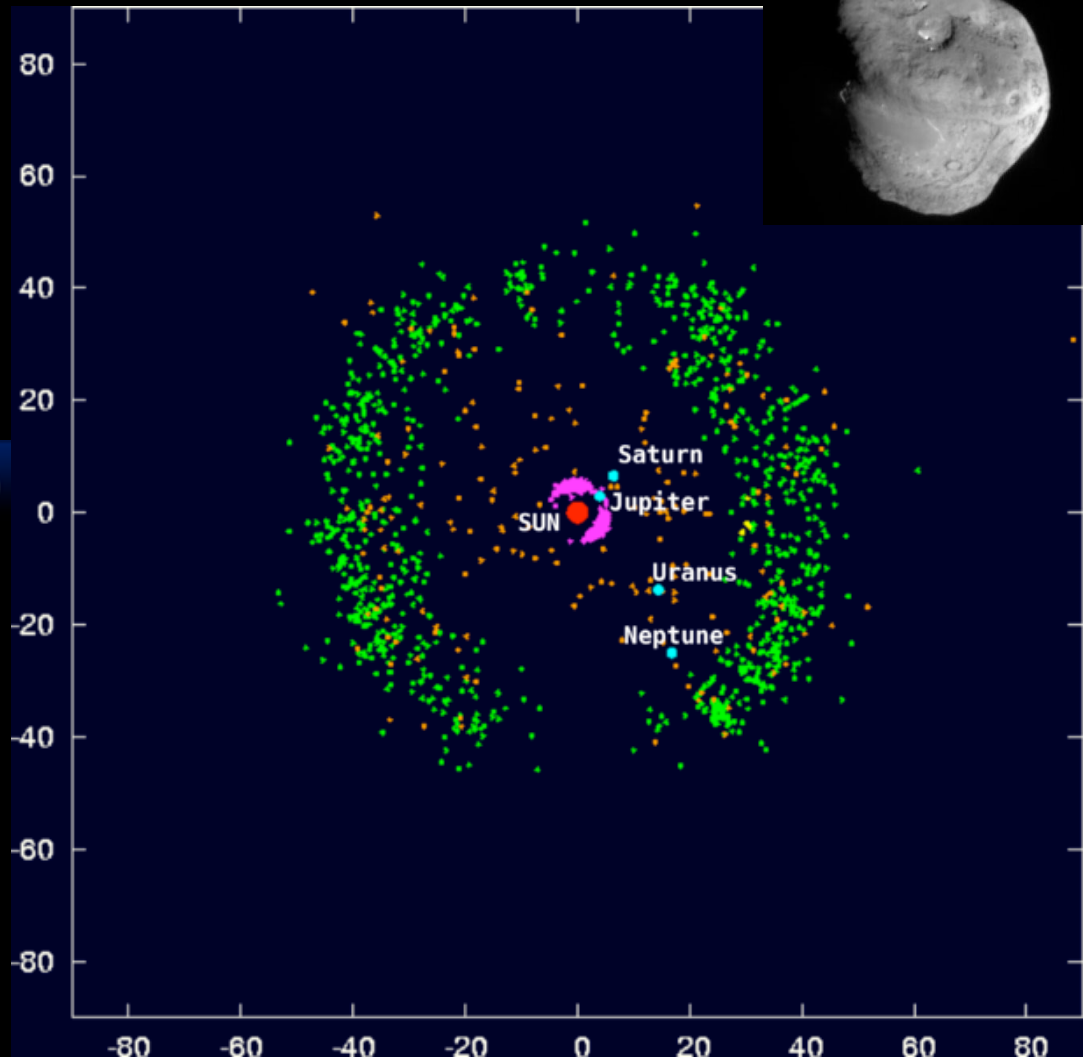
- Trojan and Greek asteroids



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## Possibilities for Life on the Moons of Giant Planets

The outer solar system is a busy place:  
the Kuiper belt



### Largest known trans-Neptunian objects (TNOs)



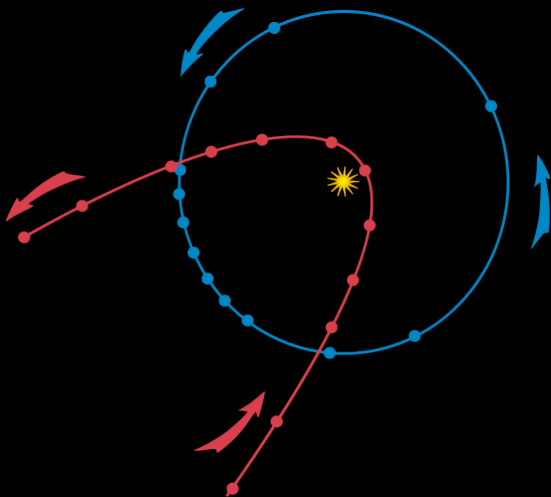


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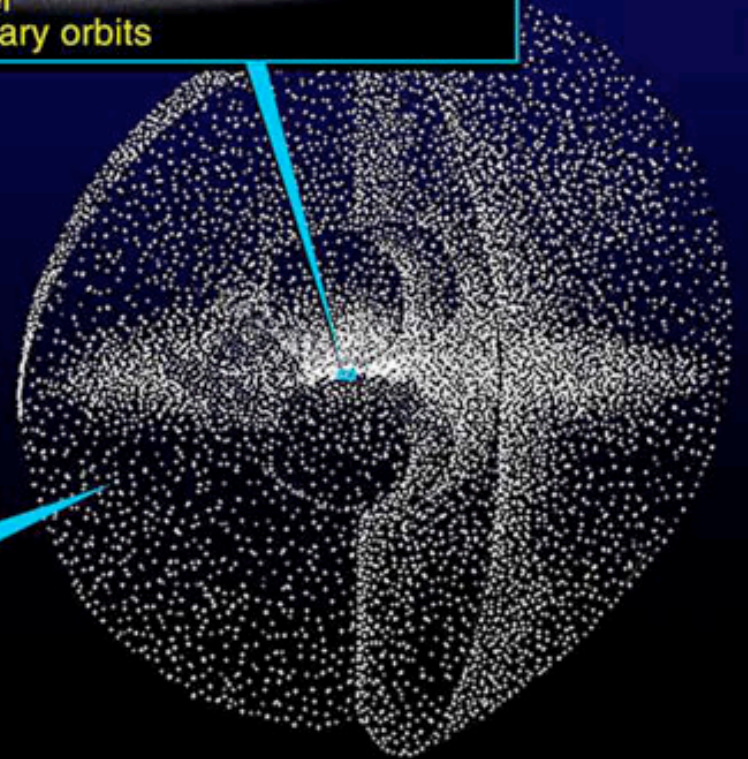
The outer solar system is a busy place:  
the Oort Cloud

The Oort Cloud is the origin of long period comets



The Oort Cloud  
(comprising many billions of comets)

Oort Cloud cutaway  
drawing adapted from  
Donald K. Yeoman's  
illustration (NASA, JPL)



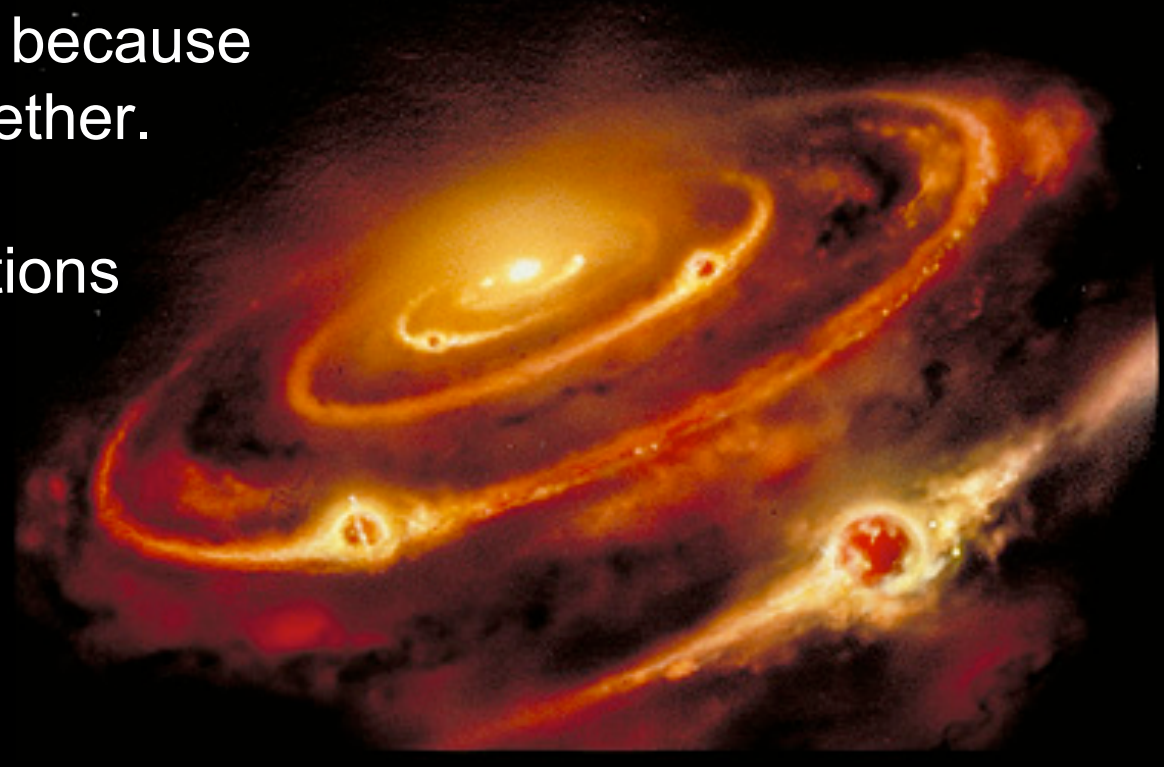
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# Possibilities for Life on the Moons of Giant Planets

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 are no stable locations for billions of years... they crash into planets.



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# Possibilities for Life on the Moons of Giant Planets

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 planetesimals 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



# Mafia Protection?

- Some people argue that our existence depends on Jupiter protecting us from asteroids
- But without Jupiter we'd have a planet there, not asteroids
- Far fewer impacts!



<http://www.beaupre.com/blog/index.cfm/2007/11/26/Social-Media-as-The-Godfather>

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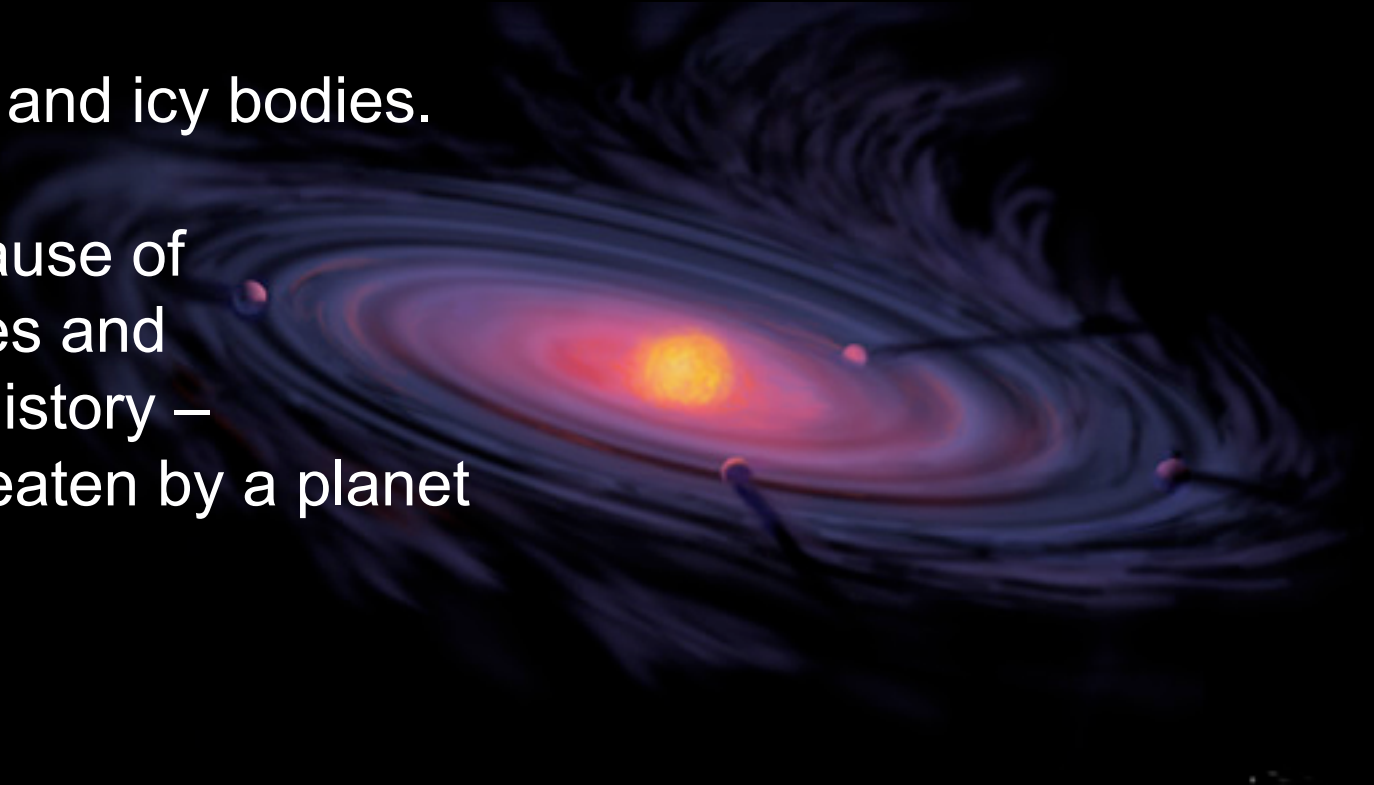
# Possibilities for Life on the Moons of Giant Planets

Formation scenario:

The Jovian planets ate or scattered into large orbits planetesimals 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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# Possibilities for Life on the Moons of Giant Planets

Formation scenario:

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

Kuiper Belt Objects are survivors. 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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# Possibilities for Life on the Moons of Giant Planets

Formation scenario:

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

Examples of exceptions are the big inner moons of Jupiter





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# Possibilities for Life on the Moons of Giant Planets

Formation scenario:

Io, Europa, Ganymede, and Callisto show a pattern of increasing icy composition and decreasing 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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## Possibilities for Life on the Moons of Giant Planets

For life, the big ones are most interesting

The largest moons of the giant planets

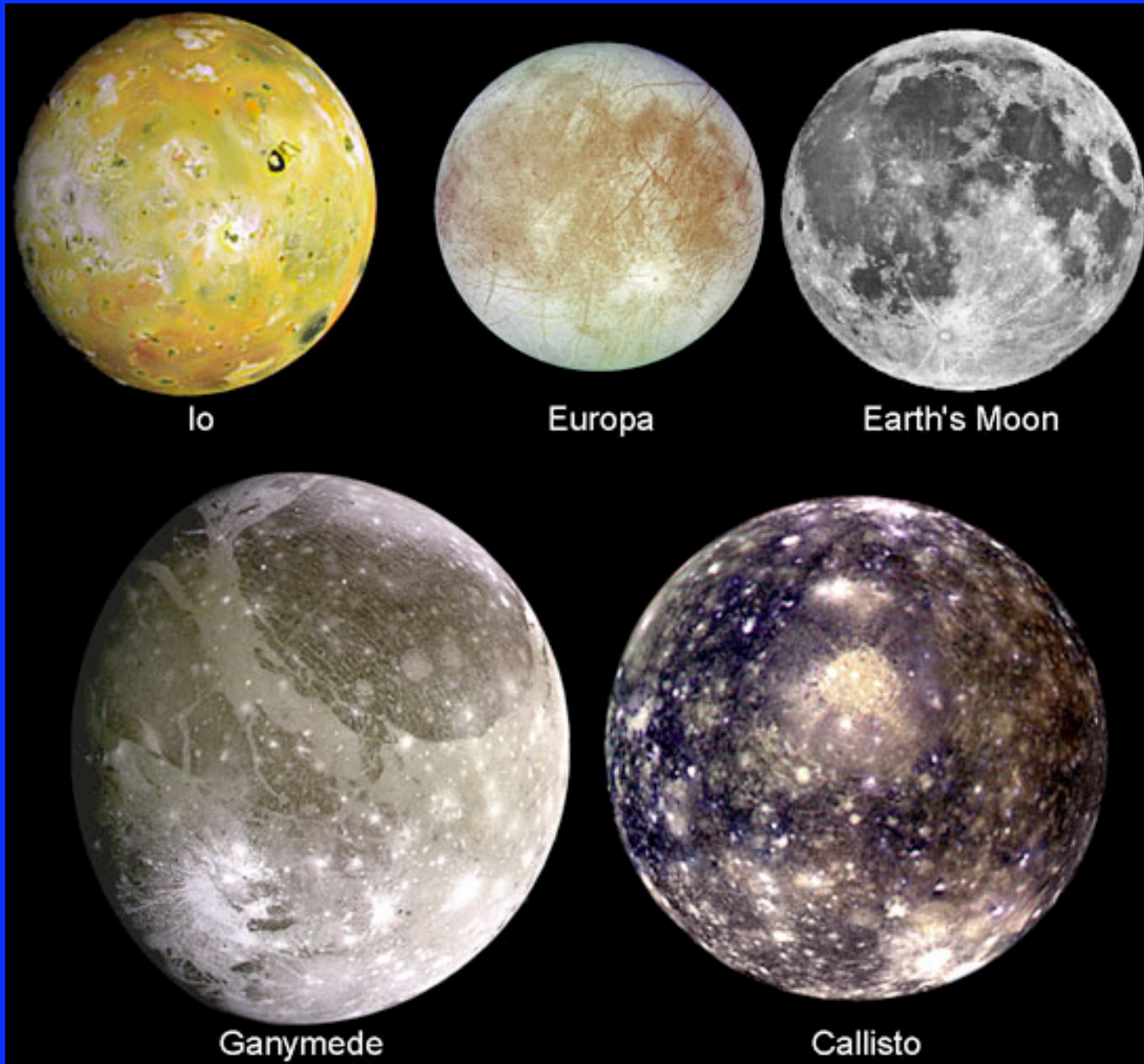
| Planet  | Satellite | Luna masses |
|---------|-----------|-------------|
| Jupiter | Io        | 1.2         |
|         | Europa    | 0.7         |
|         | Ganymede  | 2.0         |
|         | Callisto  | 1.5         |
| Saturn  | Titan     | 1.8         |
| Uranus  | Titania   | 0.05        |
|         | 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          | Launch                   | Jupiter close approach | Planets visited (dwarf planet)  |
|---------------------|--------------------------|------------------------|---------------------------------|
| <u>Pioneer 10</u>   | <u>December 3, 1973</u>  | 130,000 km             | Jupiter                         |
| <u>Pioneer 11</u>   | <u>December 4, 1974</u>  | 34,000 km              | Jupiter, Saturn                 |
| <u>Voyager 1</u>    | <u>March 5, 1979</u>     | 349,000 km             | Jupiter, Saturn                 |
| <u>Voyager 2</u>    | <u>July 9, 1979</u>      | 570,000 km             | Jupiter Saturn, Uranus, Neptune |
| <u>Ulysses</u>      | February 1992            | 409,000 km             | Jupiter                         |
|                     | February 2004            | 240,000,000 km         | Jupiter                         |
| <u>Cassini</u>      | <u>December 30, 2000</u> | 10,000,000 km          | Saturn                          |
| <u>New Horizons</u> | <u>February 28, 2007</u> | 2,304,535 km           | Jupiter, Pluto                  |



Io

Europa

Earth's Moon

Ganymede

Callisto

<http://www.astronomynotes.com/solarsys/pics/galilean-satellitesb.jpg>

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# Possibilities for Life on the Moons of Giant Planets

Io: Jupiter's innermost big moon

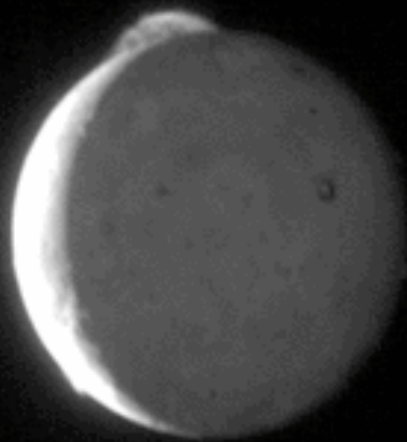
average density =  $3.57 \text{ g/cm}^3$

tidally heated by Jupiter interaction

likely no water, methane or ammonia

left due to volcanic activity

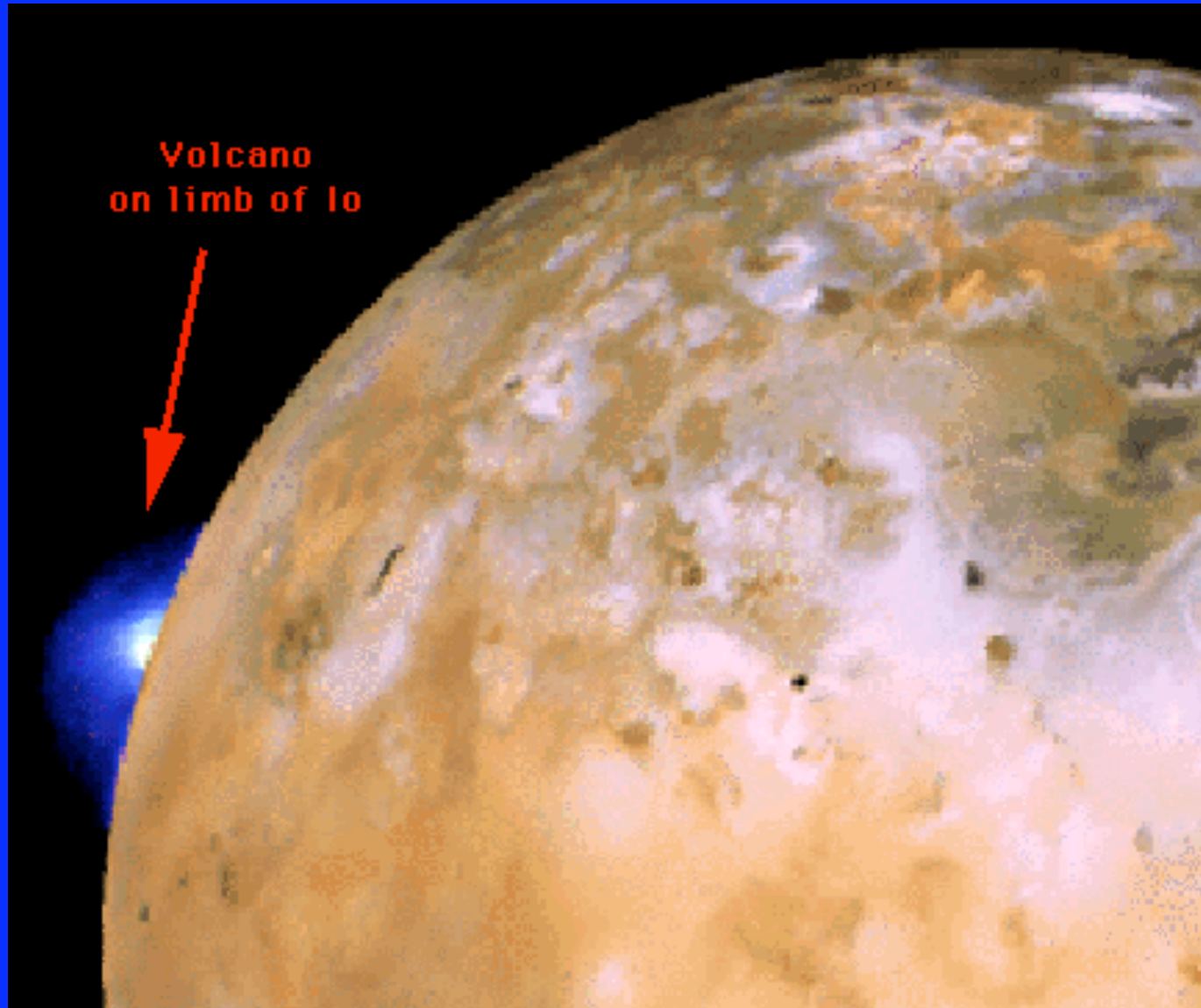
lots of heat, sulfur compounds



Life based on  
sulfur ?



# Active Volcanoes on Io



[http://shayol.bartol.udel.edu/~rhdt/diploma/lecture\\_8/io-volcano.gif](http://shayol.bartol.udel.edu/~rhdt/diploma/lecture_8/io-volcano.gif)

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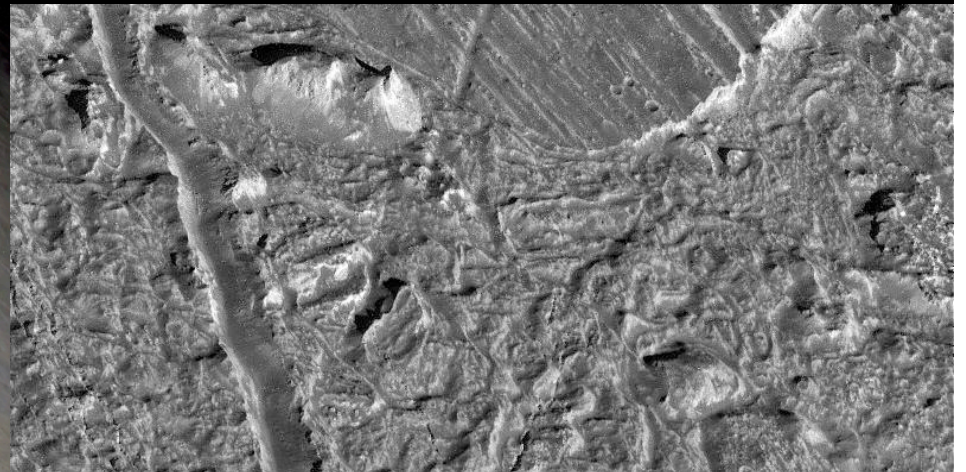
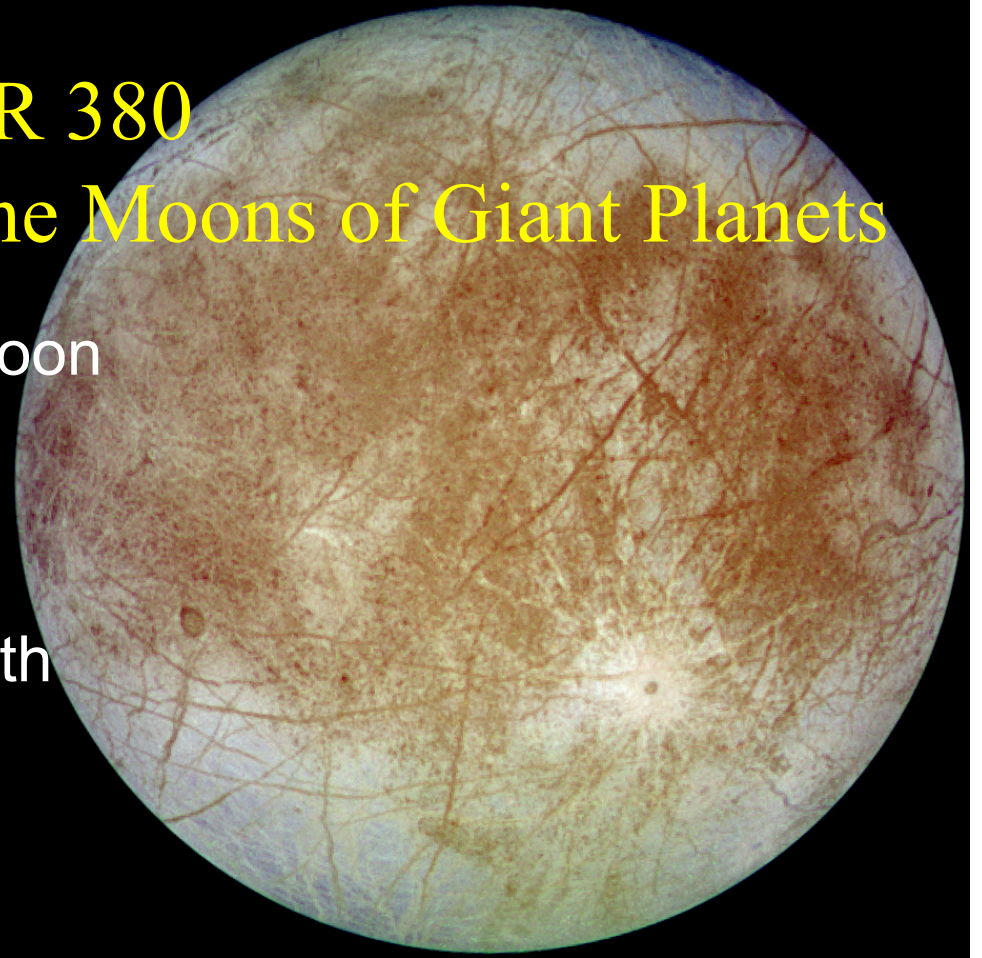
# Possibilities for Life on the Moons of Giant Planets

Europa: Jupiter's second big moon

Average density =  $3 \text{ g/cm}^3$

Icy surface... but very smooth

Constantly resurfaced!



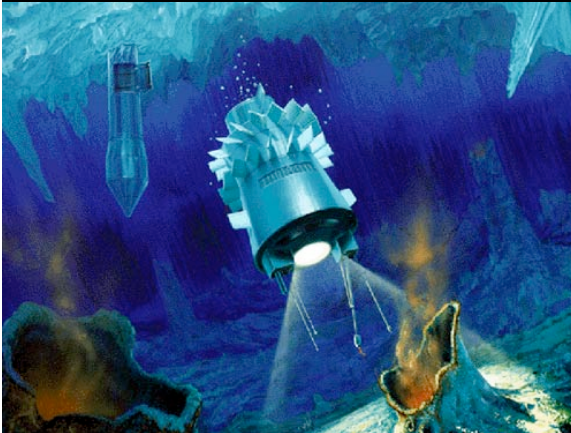
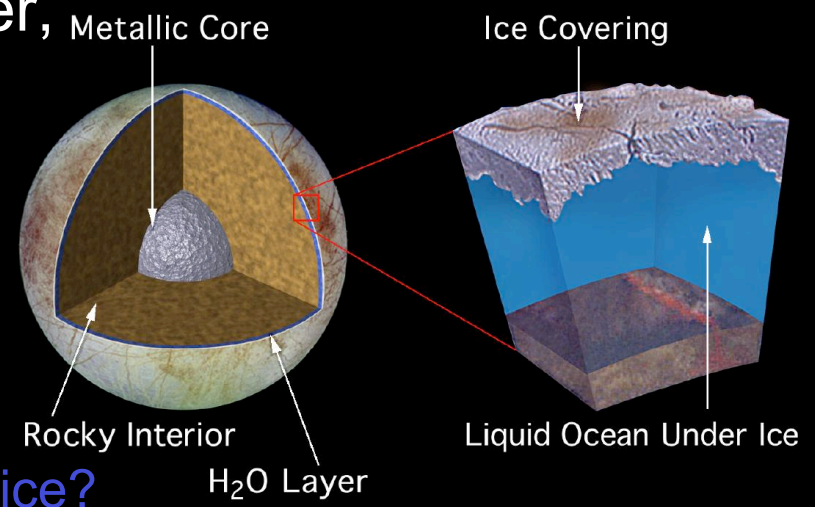
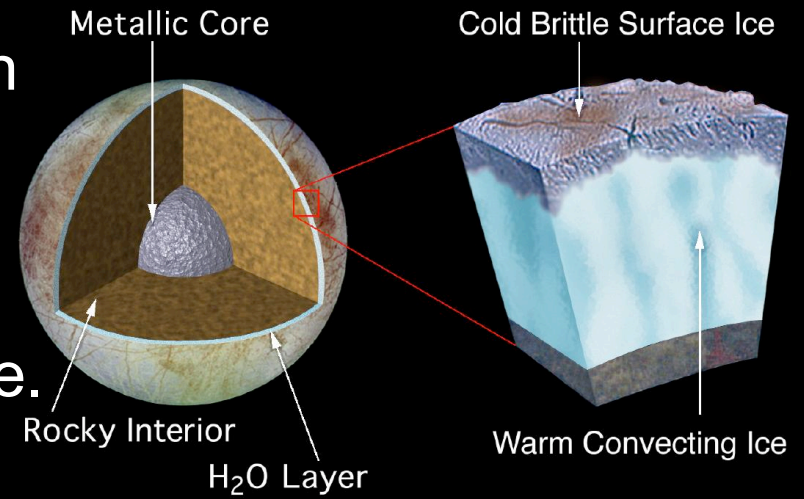
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## Possibilities for Life on the Moons of Giant Planets

Europa: Jupiter's second large 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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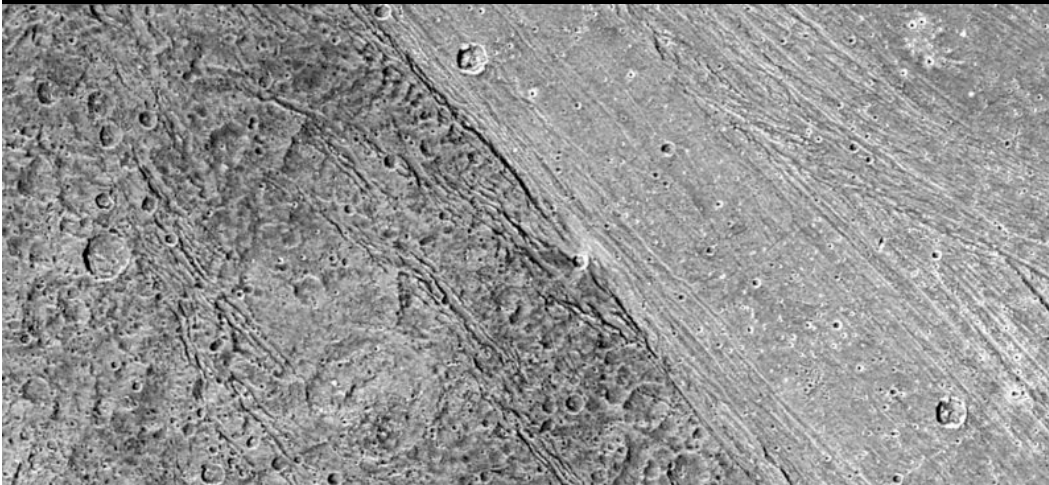
# Possibilities for Life on the Moons of Giant Planets

Ganymede: Jupiter's largest moon

Average density =  $1.9 \text{ g/cm}^3$

More icy composition than Europa

Ice surface has new and old areas



Life in oceans under ice?

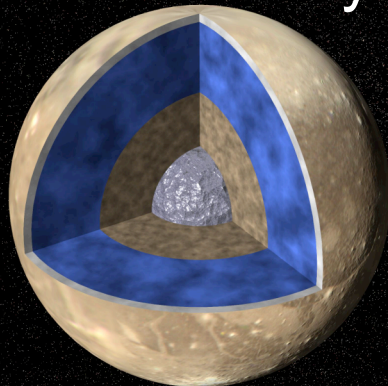
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# Possibilities for Life on the Moons of Giant Planets

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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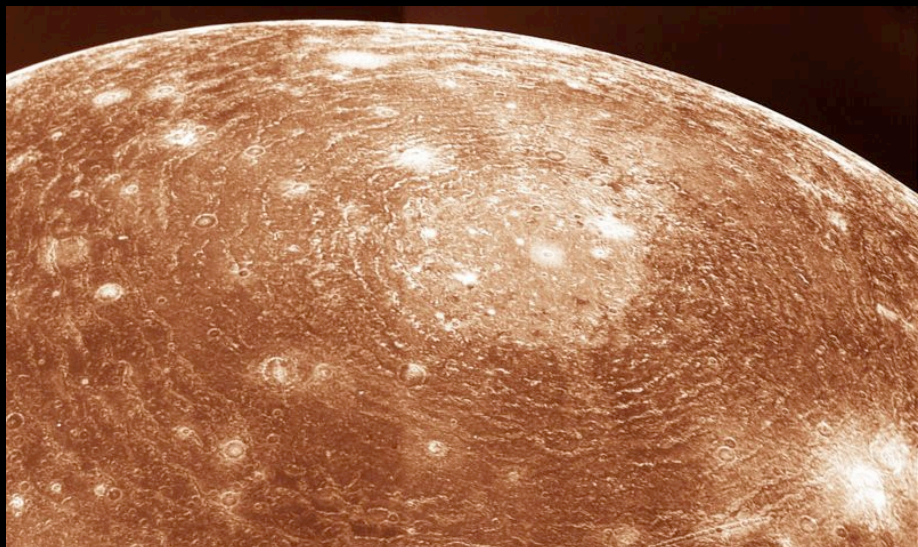
# Possibilities for Life on the Moons of Giant Planets

Callisto: Jupiter's outermost large moon

Average density =  $1.9\text{g/cm}^3$

Mixed ball of icy and rock

Thick surface layer of water ice



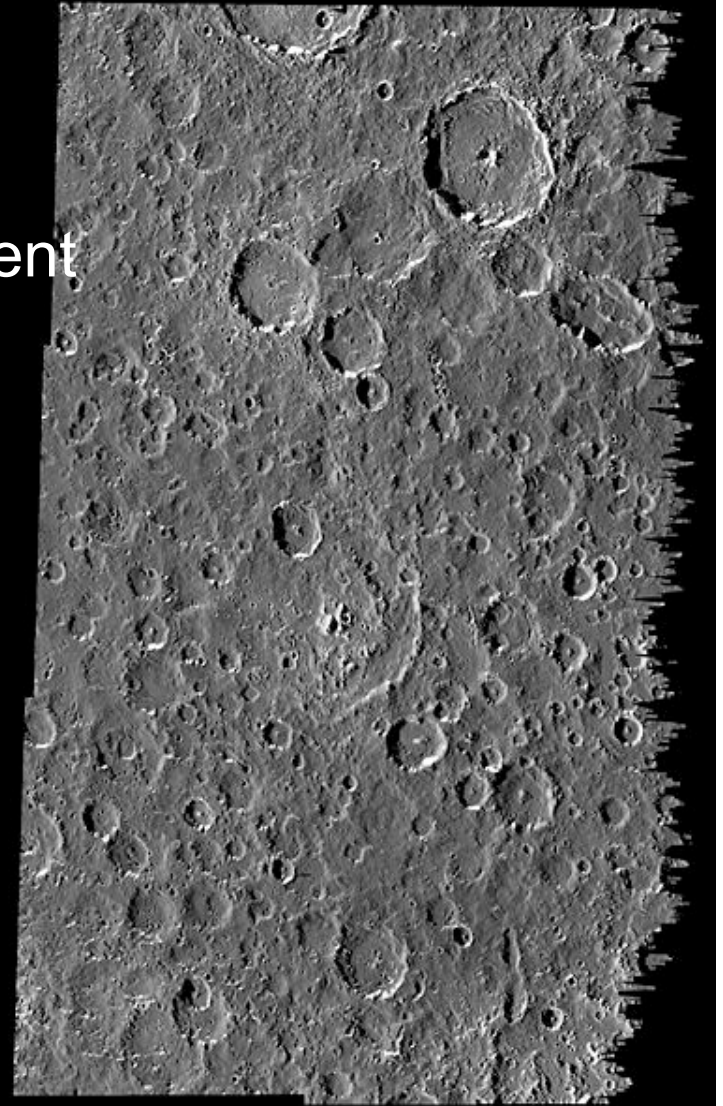
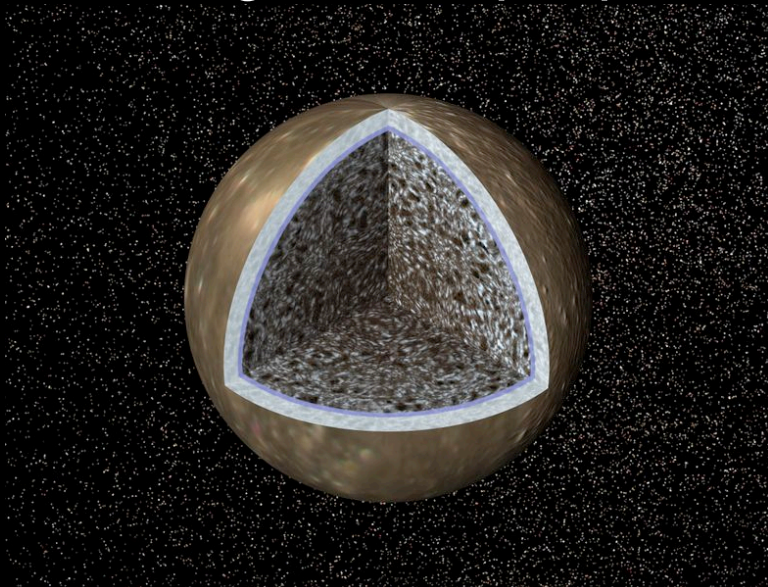
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# Possibilities for Life on the Moons of Giant Planets

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.



# Why Liquid Water on Moons?

- But wait: how could Europa and Ganymede have liquid water?
- How could Io be so hot?
- All those moons are smaller than Mars; should have cooled off and been solid by now.
- The reason gives new hope for life...

# Orbital Period Ratios

- Note a weird thing: orbital periods of Io, Europa, and Ganymede are close to 1:2:4 ratio
- Cool, but (1) who cares, and (2) that must be a coincidence, right? Not exactly...

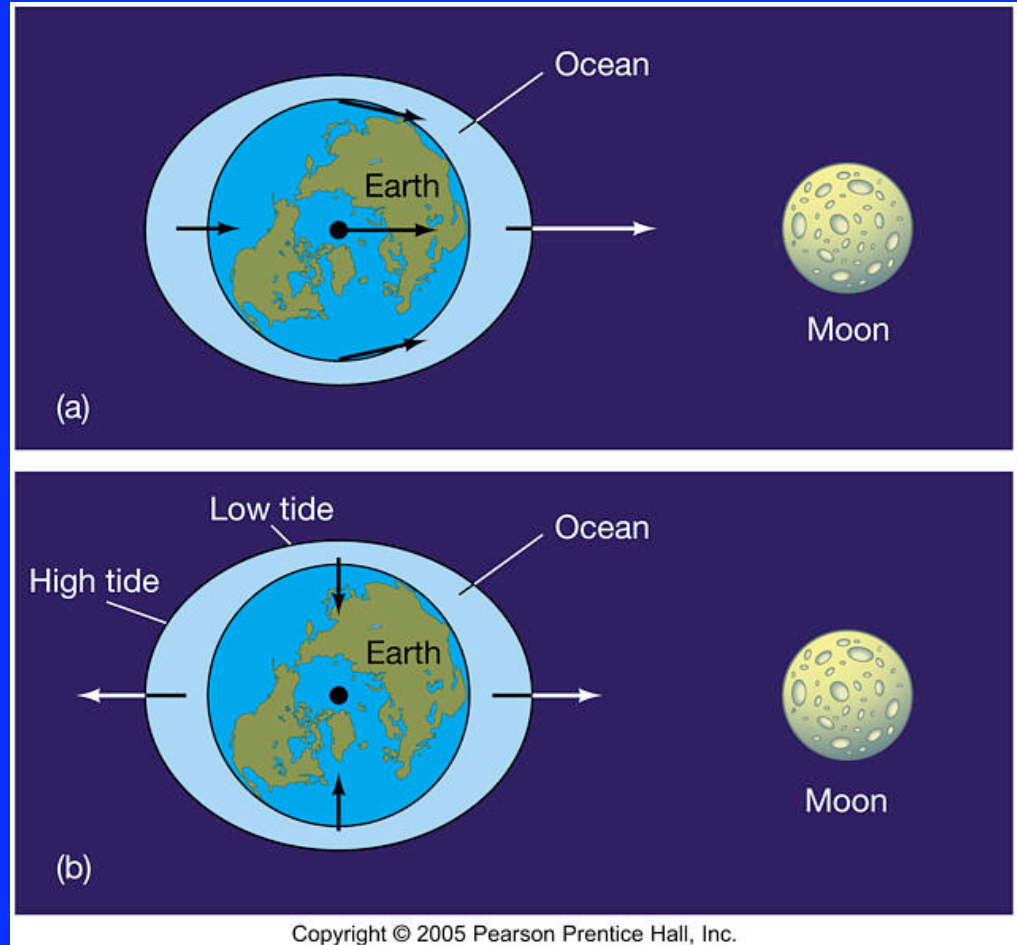
## THE GALILEAN MOONS

| <b>Moon</b>     | <b>Mass<br/>(Earth)</b> | <b>Diameter<br/>mi (km)</b> | <b>Period<br/>(days)</b> | <b><math>\alpha</math><br/>mi (km)</b> | <b>Eccentricity</b> |
|-----------------|-------------------------|-----------------------------|--------------------------|--|---------------------|
| <b>Io</b>       | 0.0150                  | 2,255<br>(3,635)            | 1.77                     | 261,450<br>(421,700)                   | 0.0041              |
| <b>Europa</b>   | 0.0080                  | 1,940<br>(3,130)            | 3.55                     | 416,070<br>(671,080)                   | 0.0101              |
| <b>Ganymede</b> | 0.0250                  | 3,265<br>(5,265)            | 7.15                     | 663,650<br>(1,070,400)                 | 0.0011              |
| <b>Callisto</b> | 0.0180                  | 2,980<br>(4,800)            | 16.69                    | 1,170,730<br>(1,888,270)               | 0.0074              |

<http://www.deepfly.org/TheNeighborhood/GalileanMoonsTable.gif>

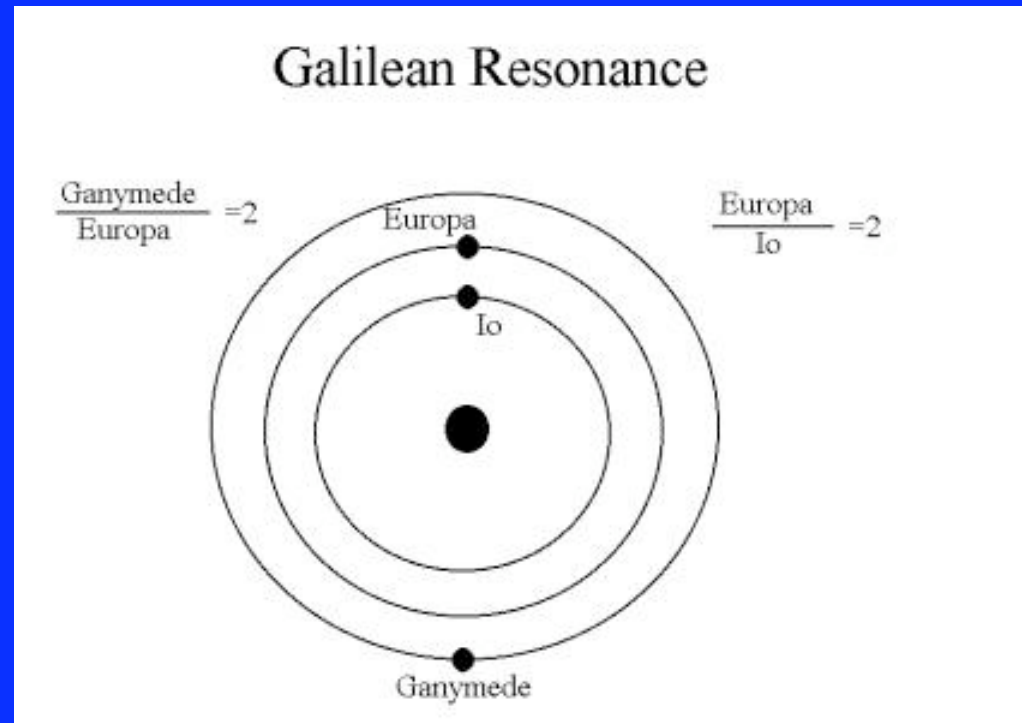
# Tidal Forces

- To understand causes, think about tides
- Near part pulled more than far. Heats body.
- However, also makes moon always face planet, and makes orbit circular
- When this happens, no more squeezing



# Tidal Forces, Part 2

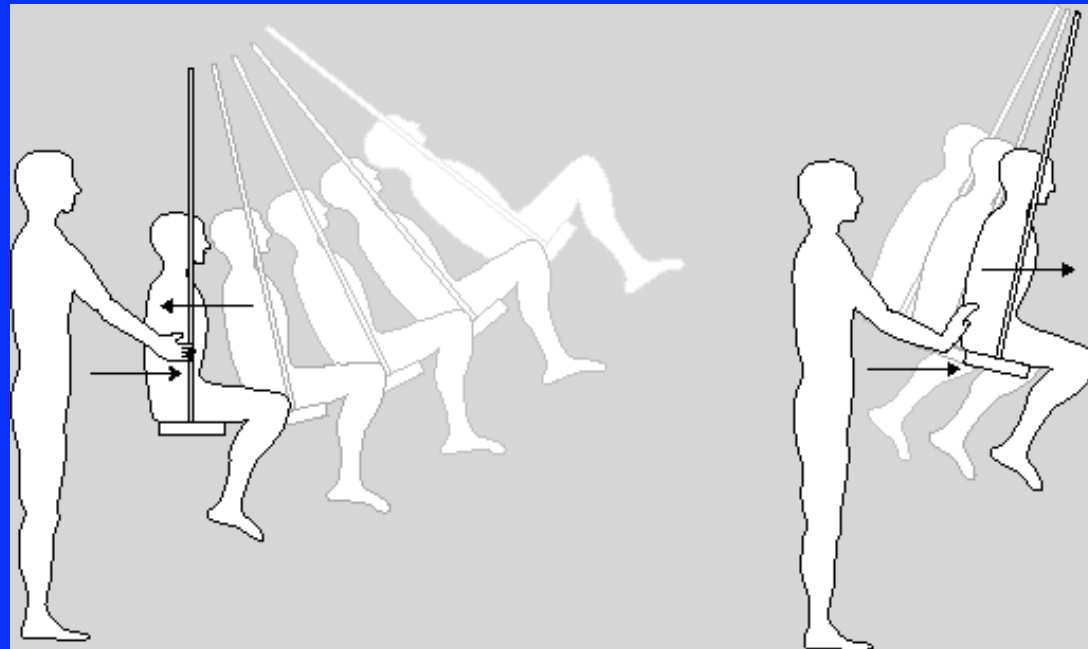
- Tidal forces are much stronger for moons that are closer in
- Therefore, Io moves out faster than Europa, which moves out faster than Ganymede
- Io can catch Europa in resonance, then Ganymede





# Resonances

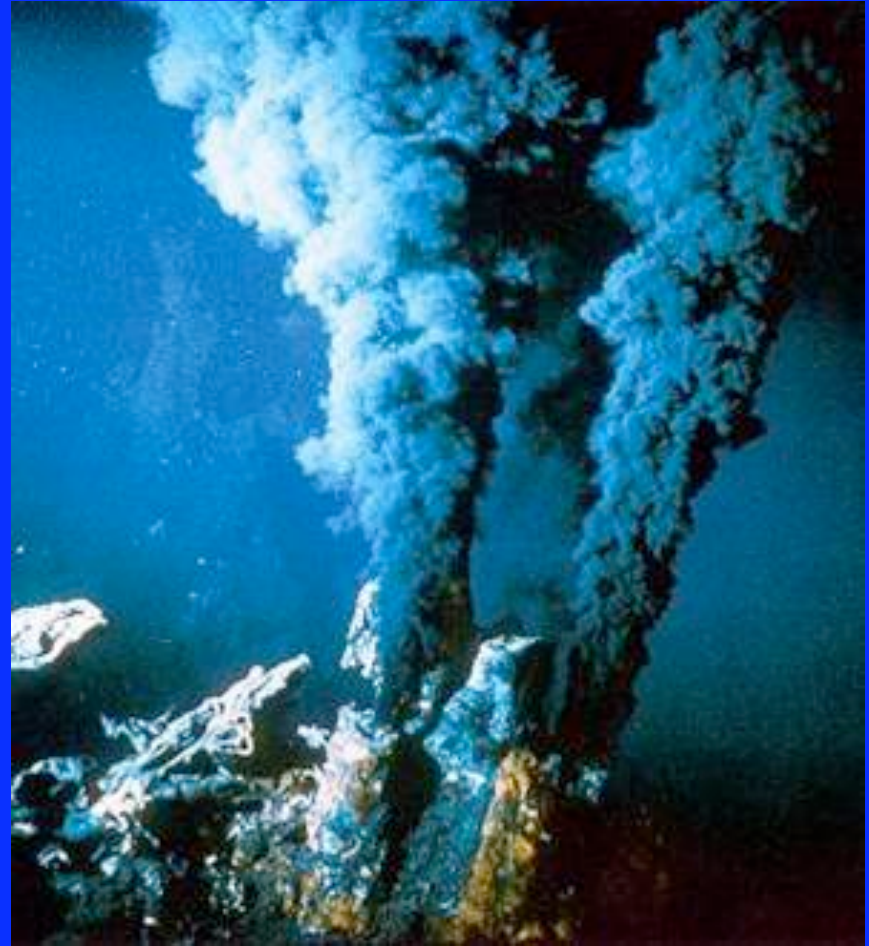
- Small integer ratios between periods
- Gravitational “kicks” add up
- Maintain non-circular orbit, so tides can continue to heat!
- Might happen with extrasolar planets



<http://www.primasounds.com/PrimaSounds/swing1.gif>

# Life on Europa or Ganymede?

- Likely hydrothermal vents near bottom of their oceans
- Supports ecosystems on Earth
- Might it do the same on these moons?



<http://www.dgukervis.nic.in/A%20black%20smoker.jpg>

## ASTR 380

# Possibilities for Life on the Moons of Giant Planets

Titan: Saturn's only large moon

Atmosphere with 1.5 bar of pressure

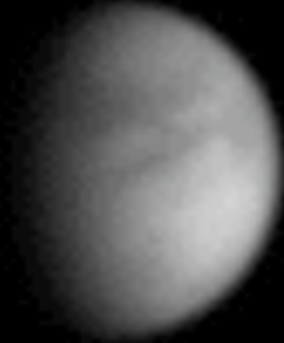
Atmosphere is 90% nitrogen, no oxygen

Methane

Solid surface

Surface temperature = 93 K

very, very cold!

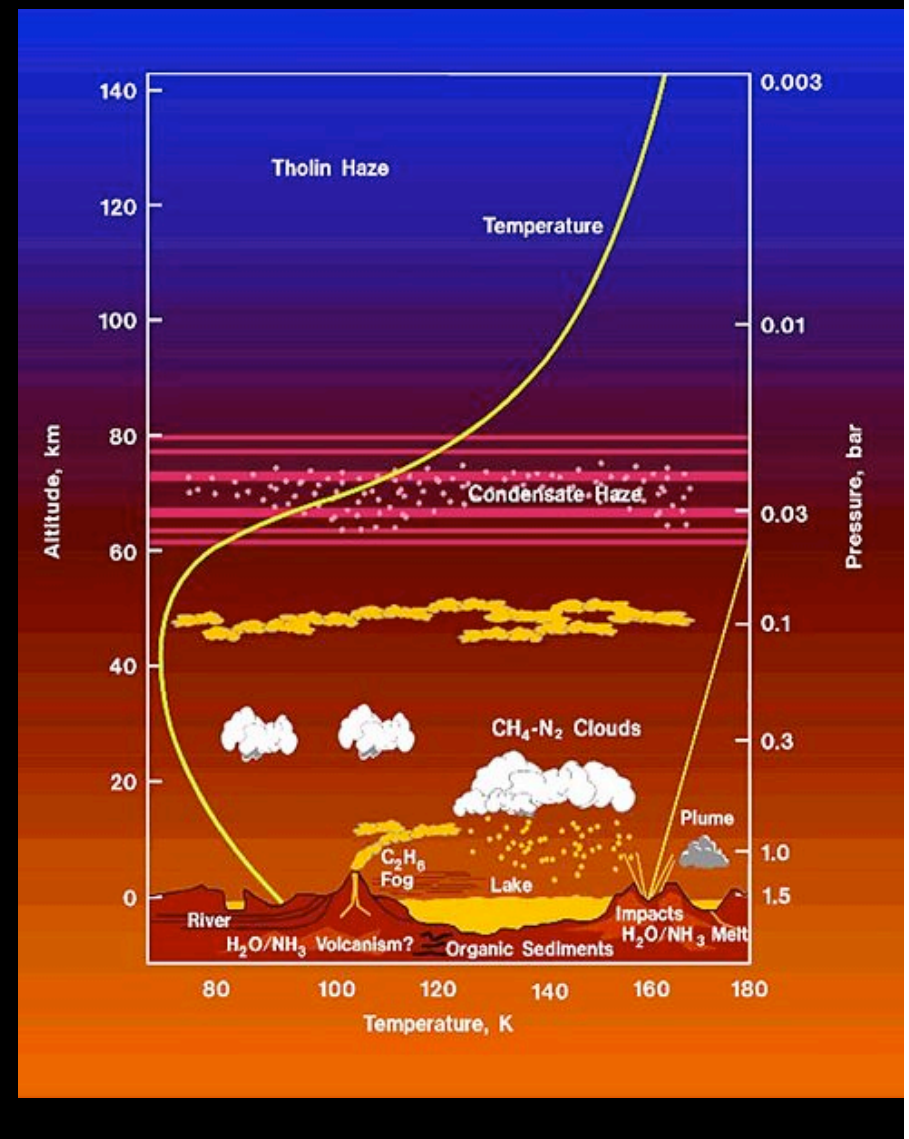
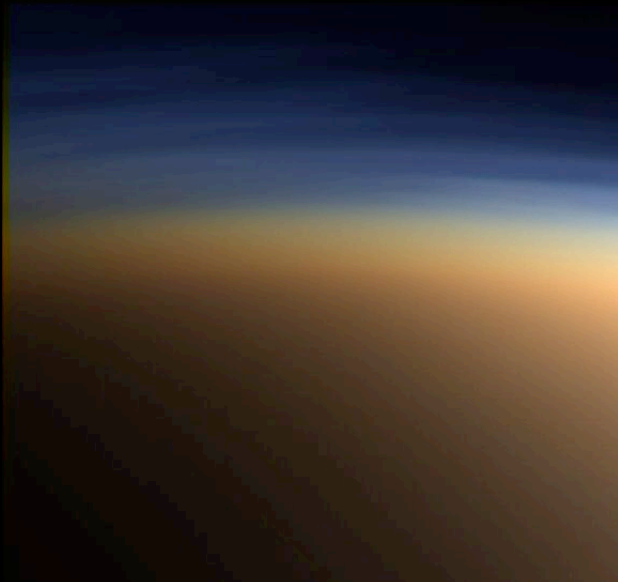


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## Possibilities for Life on the Moons of Giant Planets

Titan: Saturn's only large moon

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



## ASTR 380

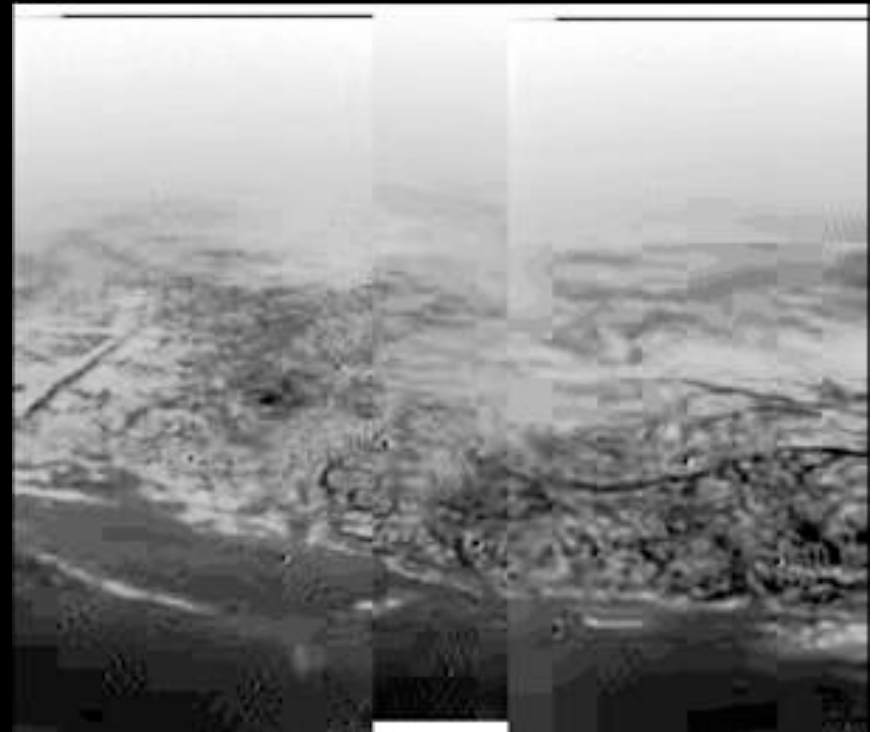
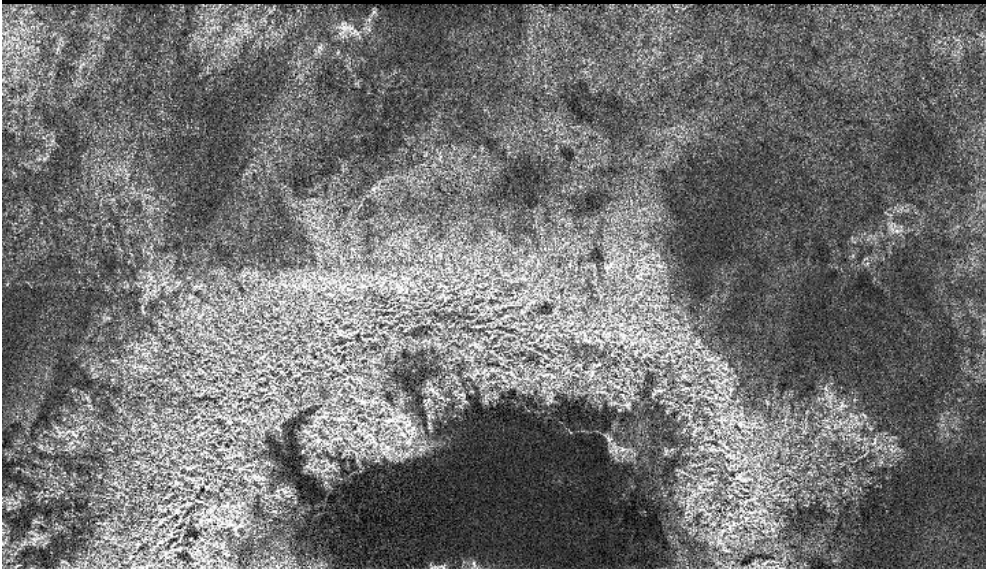
# Possibilities for Life on the Moons of Giant Planets

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”



## ASTR 380

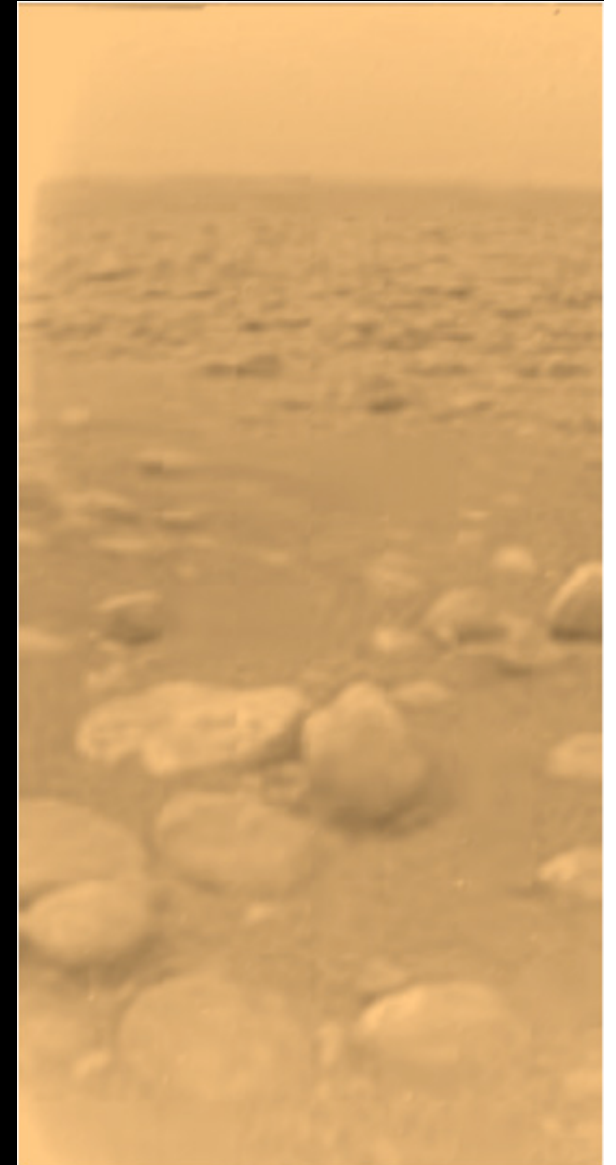
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# Possibilities for Life on the Moons of Giant Planets

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 cm<sup>3</sup>

Ice and rock balls with icy surface



TITANIA



OBERON

## ASTR 380

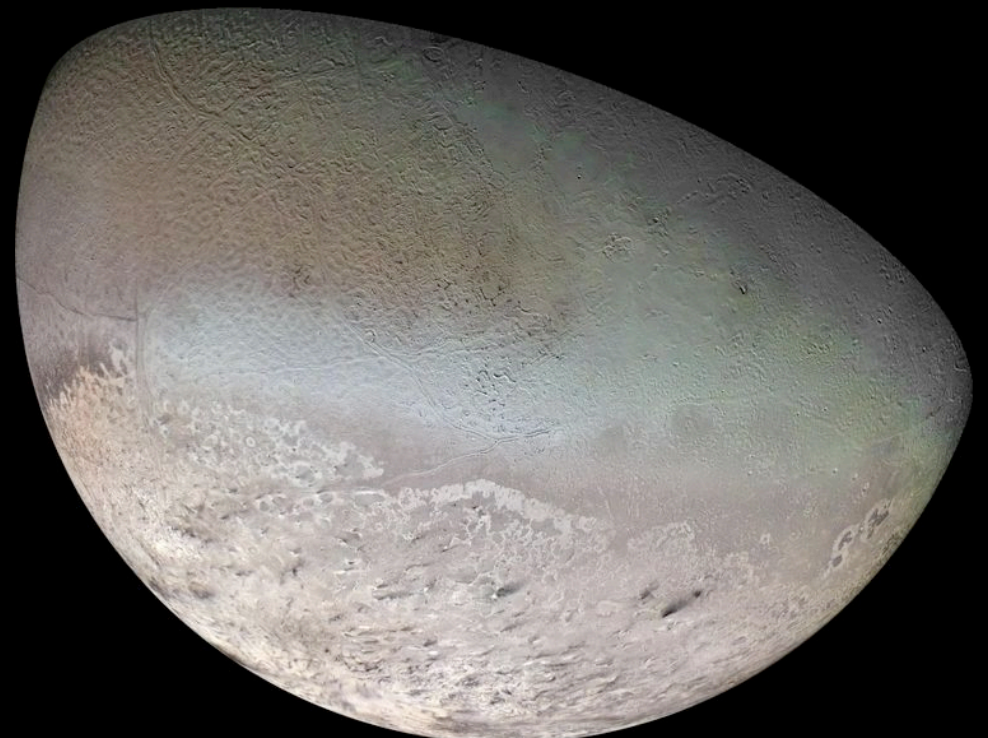
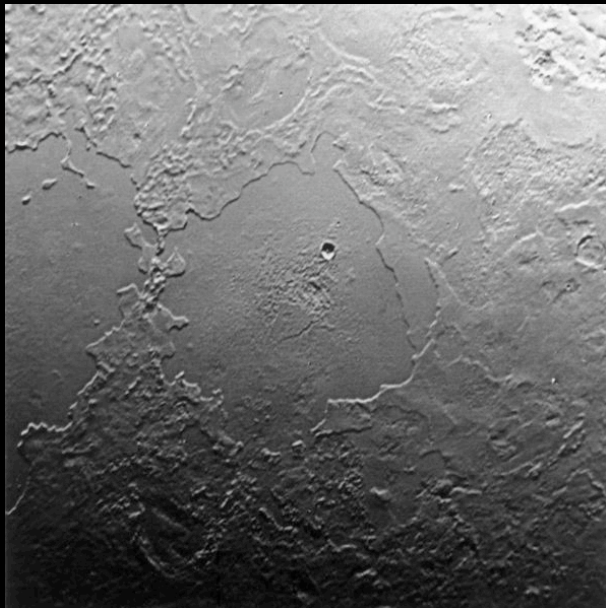
# Possibilities for Life on the Moons of Giant Planets

Triton: the largest moon of Neptune

Very cold

Average density =  $1.5 - 1.6 \text{ g/cm}^3$

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!!

# Summary

- Europa, and possibly Ganymede, are excellent prospects for life beyond Earth
- Implication: you don't need to be in the "habitable zone" for life!
- Titan is another possibility, but that about does it for the solar system