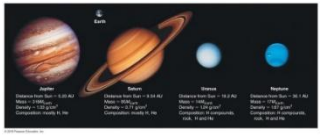
The Jovian Planets



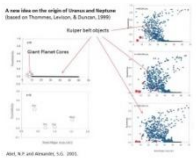
Beyond Mars and the Asteroid belt are the **Jovian or Gas Giant Planets** that are totally different than the terrestrial planets:

- They are composed almost entirely of gas
- They do not have solid surfaces like the terrestrial planets

Why do we expect planets like this in the outer reaches of the solar system?(LC)

In the Solar Nebula, beyond the frost line, planetesimals would contain a large amount of ices. Protoplanets could quickly grow to about 10 Earth masses, and then accrete and hold hydrogen and helium and grow to Jupiter or Saturn size.

One problem with this idea is that Uranus and Neptune would grow very slowly if they formed where they are presently located. In the 1990's, an alternate theory was proposed where the cores of Uranus and Neptune formed near Jupiter and Saturn. When Jupiter and Saturn quickly became gas giants, they gravitationally scattered Uranus and Neptune to their present orbits.

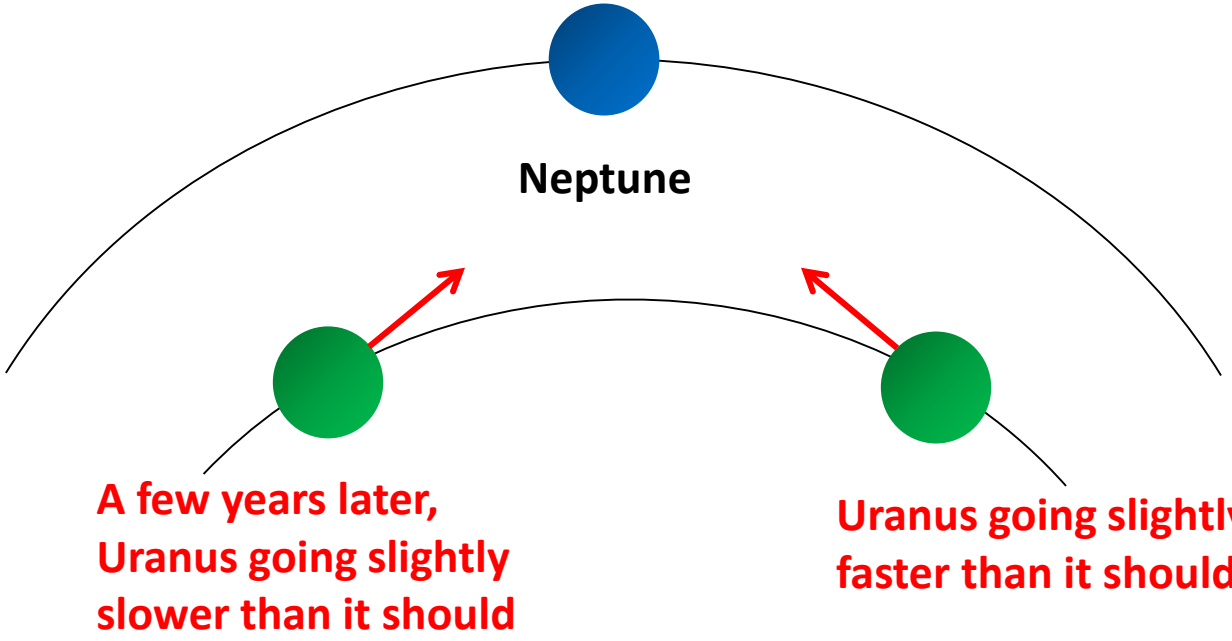


Exploration of the Jovian Planets

Jupiter and Saturn are naked eye objects and were known from antiquity; however Uranus and Neptune were discovered fairly recently.

Uranus was discovered in 1781 by the English astronomer, William Hershel, who was hunting for comets with his telescope. *(Apparently, if you have a very dark sky and know exactly where to look, you can see Uranus with the naked eye – assuming you have very good eyesight.)*

Based on the motion of Uranus, Neptune was actually predicted in 1845 (by John Adams (English) and Jean Levierrier (French)) before it was observed:



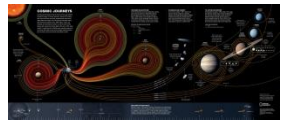
As if the gravity of something large was pulling on it.

When telescopes were pointed at the predicted location of Neptune, there it was!

This prediction was a remarkable success for Newtonian physics.

Exploration of the Jovian Planets

Since the 1970's, there have been several space missions to The Jovian planets. The most important are:



- **Voyagers 1 (Jupiter & Saturn) & 2 (Jupiter, Saturn, Uranus, & Neptune!)** (flyby missions 1977 to 1989, have left the Solar System, but are still active)
- **Galileo** (Jupiter orbiter 1995 – 2003)
- **Cassini** (Saturn orbiter 2004 to September 2017)
- **Juno** (arrived at Jupiter in July 2016 – will be shutdown 2026)
- **Europa Clipper** (launched October 2024 – will arrive April 2030)

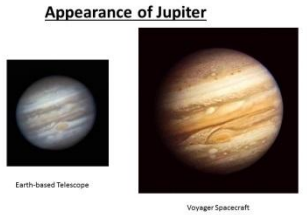
How did Voyager 2 get to all of the Jovian Planets? (LC)

Gravity Assisted Trajectories: close flybys of massive planets can speed up (or slow down) a spacecraft – some people call it the *sling-shot effect*, and we're getting pretty good at it!

Appearance of Jupiter and Saturn

Jupiter is the largest planet in the Solar System – more mass than everything else combined – **sometimes it's referred to as a "failed star"; is that true?**

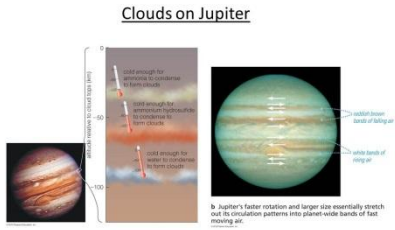
As we'll see, it has the right composition (Hydrogen and Helium), but is about 80 times too small to be a star.



Appearance of Jupiter and Saturn*:

When you look at Jupiter, you're looking at the tops of clouds that have complex motions, e.g. the Great Red Spot which is a high pressure storm that rotates about once/week.

The colored clouds are condensed chemicals at different levels in Jupiter's atmosphere. The atmosphere is continuously going through convection carrying heat from below, and Jupiter's fast rotation smears these into the banded structure.

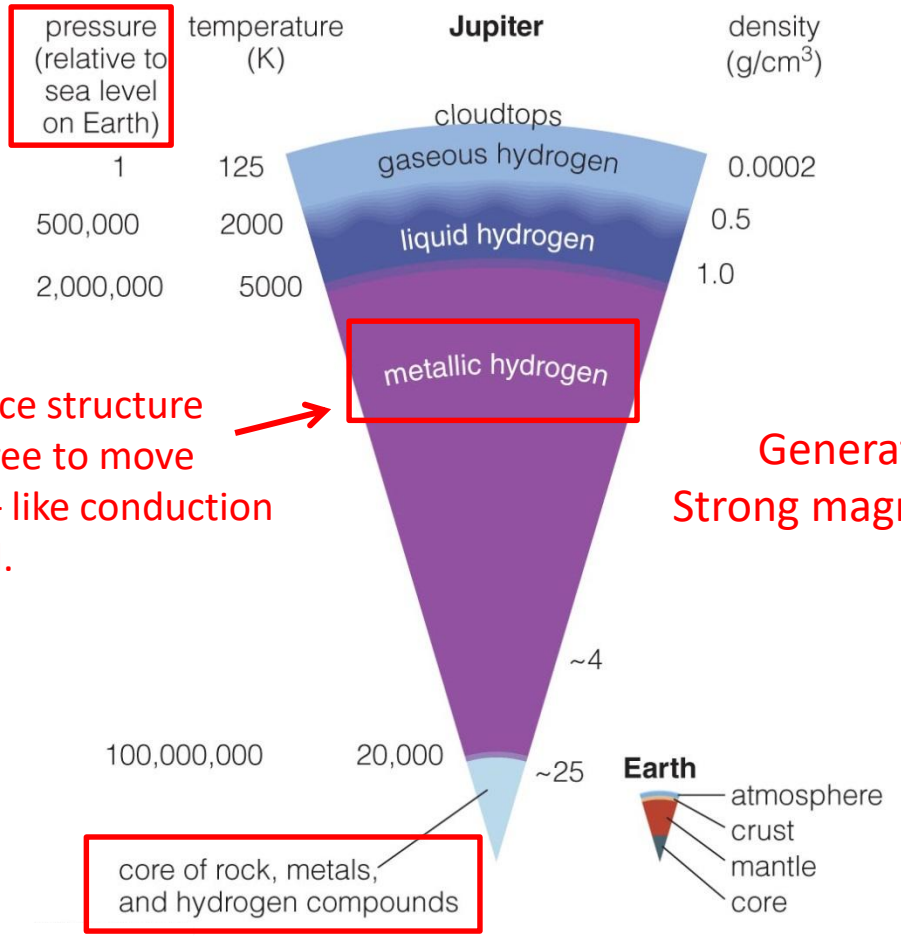


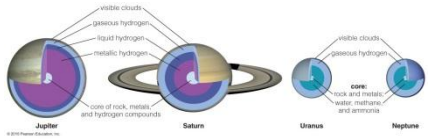
*The appearance of Saturn is similar to Jupiter – it shares many of the same features.

The Interiors of the Jovian Planets

The interiors of the Jovian Planets are vastly different than the terrestrial planets,

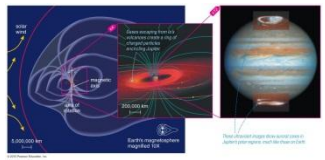
e.g. Jupiter:





protons form a lattice structure and electrons are free to move around the lattice – like conduction electrons in a metal.

Generates a Strong magnetic field

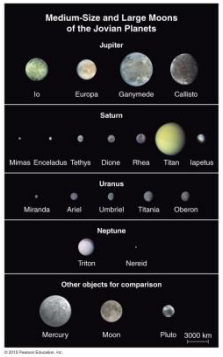


What would happen to any Carbon at the core of Jupiter?

Moons of the Jovian Planets

Prior to the space missions to the outer solar system, very little was known about the moons of the Jovian planets – the missions changed everything.

Today, we know of at least 170 moons that orbit the Jovian planets. These range in size from about 100 km to planet sized.



The four large moons of Jupiter were discovered by Galileo in 1609, and are called the Galilean Satellites. Note that several of these moons are as large or larger than the Planet Mercury!

The Galilean Satellites of Jupiter

Perhaps the biggest surprise and the most significant discoveries of the Voyager missions was our first close up look at the Galilean Satellites.

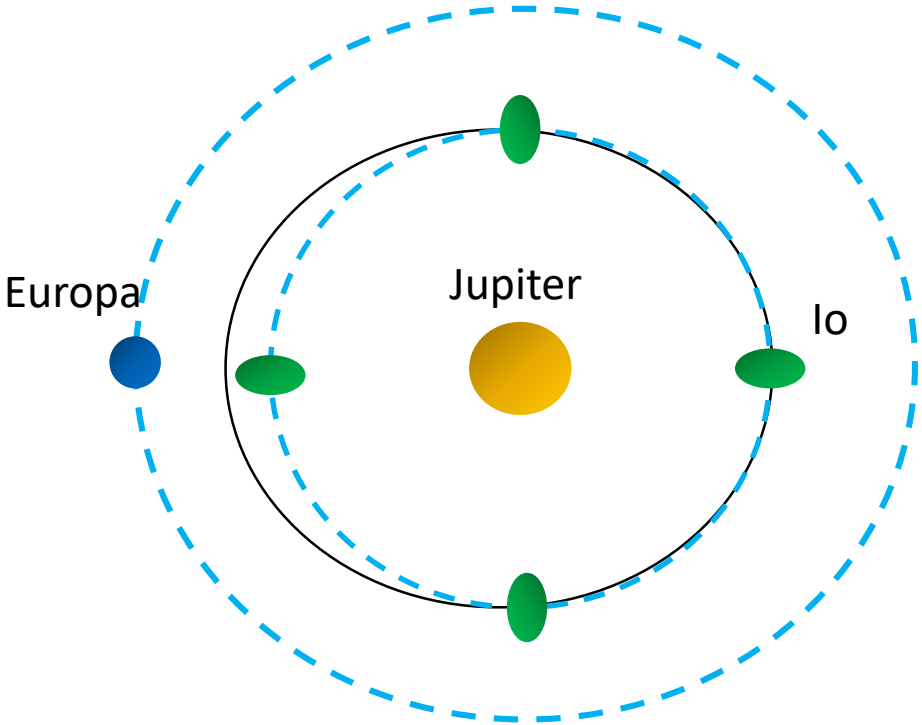
Unlike the terrestrial planets, these are mixtures of rock and ice which can lead to very different geology.

The Galilean Satellites of Jupiter

A closer look at volcanic Io and water-world Europa:

What causes the volcanic activity on Io and the (perhaps) the sub-surface ocean on Europa? (LC)

We would expect Io (and the other Galilean Satellites) to be tidally locked into a **synchronous rotation state** (orbital period = rotation period)

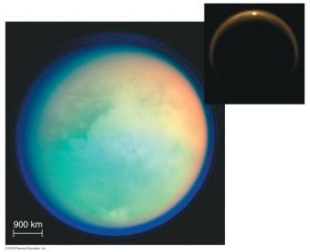


But Europa and Ganymede perturb Io's orbit to be non circular.

This sets up **tidal flexing** that heats Io's interior, and the energy is released through volcanos.

This **Tidal Heating** may have a similar effect on Europa and could create a liquid sub-surface ocean of water.

Saturn's Titan & Enceladus

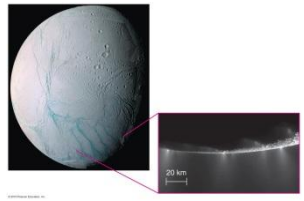


Saturn's large moon **Titan** is the only moon in the solar system that has a substantial atmosphere.

95% N_2, 5% methane, ethane
Temperature ~ 95 K (-290^{o}F)
Pressure ~ 1.5 atmospheres

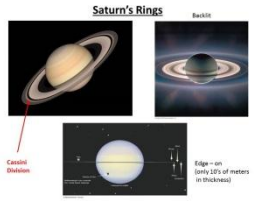
At these conditions, methane exists as a gas, liquid and solid; much like H_2O on the Earth.

The smaller moon of Saturn, **Enceladus**, (like Europa) shows signs of a sub-surface ocean produced by tidal heating.



Planetary Rings

When Galileo looked at Saturn with his telescope, the resolution was not good enough to resolve the ring. Later, Christian Huygens, using a better telescope, saw that the rings completely encircle the planet.



All of the Jovian planets have systems of rings – Saturn's are the most dramatic.

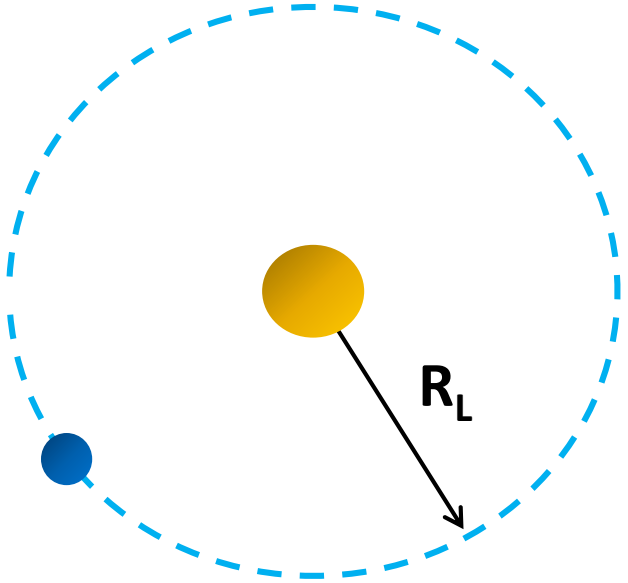
What are planetary rings?

Billions of pieces of rock and ice, each following its own orbit.

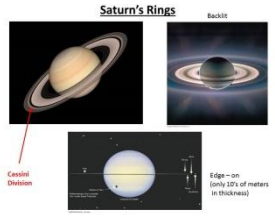
Where do planetary rings come from?

R_L , Roche Limit = closest distance that a body held together by its own gravity can approach a larger body before tides destroy it.

Tidal forces overcome self gravity and the moon is torn apart.

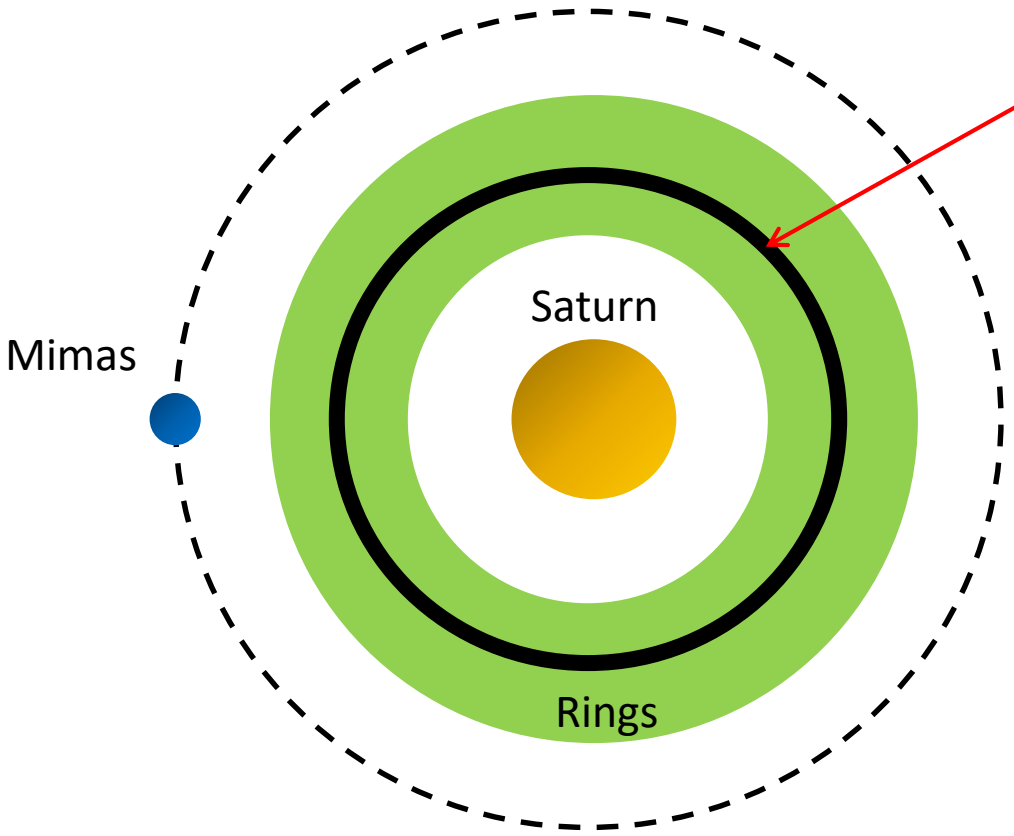


Planetary Rings



What causes the gaps in the rings – like the Cassini Division? (LC)

Orbital resonances with one of Saturn's many moons, e.g. Mimas and the Cassini Division.



A ring particle here makes 2 orbits for every 1 orbit of Mimas.

Repeated gravitational tugs will clear all ring particles from this orbital radius leaving a gap.

Cassini has also revealed that Saturn's rings are constantly changing in complicated ways.