Jovian Planet Systems

- Voyager 1 and 2 explored the outer planets in the 1970s and 1980s.
- The Galileo spacecraft circled Jupiter dozens of times in the late 1990s.
- The Cassini/Huygens orbiter and probe arrived at Saturn in 2004.
The Jovian planets have low density because they formed in the outer solar nebula where water vapor could freeze to form ice particles.

The ice accumulated into proto-planets with density lower than the rocky terrestrial planets and asteroids.

Once these planets grew massive enough, they could draw in even lower-density hydrogen and helium gas directly from the nebula by gravitational collapse.

Only near their centers do the Jovian planets have cores of dense material with the composition of rock and metal.

Jovian Planet Properties

- Jupiter, more than 11 times Earth's diameter, is the largest planet in our solar system.
- The cloud bands and zones on Saturn are less distinct than those on Jupiter.
- Uranus and Neptune are both about four times Earth's diameter.
- Uranus and Neptune are green and blue-colored because of small amounts of methane in their hydrogen-rich atmospheres.
- Earth is the largest of the terrestrial worlds, but it is small compared with the Jovian planets.
- The shadow of one of Jupiter's many moons.
Jovian Planet Properties

• Compared to the terrestrial planets, the Jovians:
  • are much larger & more massive
  • are composed mostly of hydrogen, helium, & hydrogen compounds
  • have no solid surfaces
  • have hydrogen-rich atmospheres and clouds
  • have slightly “squashed” shapes
  • have many moons
  • have ring systems

Inside the Jovian Planets

• All Jovian cores appear to be similar.
  • made of rock, metal, and Hydrogen compounds
  • 10 x the mass of Earth
• Uranus & Neptune captured less gas from the Solar nebula.
  • accretion of planetesimals took longer
  • not much time for gas capture before nebula was cleared out by Solar wind
• Only Jupiter and Saturn have high enough pressure for H & He to exist in liquid and metallic states.
Inside the Jovian Planets

- Jupiter and the other Jovian planets are all slightly flattened.
- A world with a large rocky core and mantle would not be flattened much by rotation.
- An all-liquid planet, though, would flatten significantly.

Jupiter

- Jupiter is the largest and most massive of the Jovian planets.
- It contains 71 percent of all the planetary matter in the entire solar system.
- It emits about twice as much energy as it absorbs from the sun (energy left over from the formation of the planet).
Jupiter’s Atmosphere

- In 1995, the Galileo space probe measured the atmosphere of Jupiter:
  - thermosphere {absorbs Solar X-rays}
  - stratosphere {absorbs Solar UV}
  - troposphere {greenhouse gases trap heat from both Jupiter and the Sun}
- Sound Familiar? These are the same structures found in Earth’s atmosphere.
  - Atmospheres are governed by interactions between light and gases.
  - Hydrogen compounds in Jupiter form clouds
  - Different cloud layers correspond to freezing points of different hydrogen compounds

Jupiter’s Cloud Layers

- Like Earth, Jupiter has circulation cells in its atmosphere.
- Jupiter is much larger & rotates much faster.
- circulation cells are split into many bands of rising and falling air (stripes)
- The so-called:
  - zones (rising air)
  - belts (falling air)
Jovian Atmospheres

- Other jovian planets have cloud layers similar to Jupiter’s
- The temperature profile of each planet determines the color of its appearance.
- Cloud layers form where a particular gas condenses.
- Different compounds make clouds of different colors

Why Uranus & Neptune are Blue

- They have a higher fraction of methane gas, which absorbs red sunlight.
- Blue light is reflected back into space by the clouds.
**Jovian Storms**

- All the jovian planets have strong winds and storms
- Jupiter
  - the Great Red Spot: a storm that has existed for at least 300 yrs!
  - we are not sure why it is red
- Neptune
  - the Great Dark Spot (has now disappeared)

**Jovian Magnetospheres**

- The strong magnetic field around Jupiter traps particles from the solar wind in lethal radiation belts a billion times more intense than the Van Allen belts that surround Earth
Jovian Magnetospheres

- Saturn, Uranus, & Neptune have smaller & weaker magnetospheres.
- Fraction of electrically conducting material in interiors is smaller.
- Solar wind is weaker farther out, or else their magnetospheres would be even smaller.
- We can not fully explain the magnetic field tilts of Uranus & Neptune.

Saturn

- Saturn’s cloud belts are less visible because they lie below a layer of methane.
- Most oblate of the planets: shows that its interior is mostly liquid.
- Less liquid metallic hydrogen than Jupiter due to lower internal pressure. Leads to weaker magnetic field.
- Radiates more energy than it receives from the sun.
The Rings of Saturn

- From Earth, they look solid.
  - concentric rings (A, B, C) separated by the Cassini division
- From spacecraft flybys, we see thousands of individual rings.
  - separated by narrow gaps
  - they differ in brightness & transparency
- From within the rings, we would see billions of individual particles
  - size ranges from house sized to dust
  - made of reflective H$_2$O ice (snowballs)
  - many collisions keep ring thin
Ring Formation

- Jovian planets all have rings because they possess many small moons
- Rings formed from random impacts on moons
- Gravitational force of Saturn and moons prevent the debris from becoming larger moons
- Saturn’s incredible rings may be due to a recent impact
- Rings thin out from impacts and radiation
- Ongoing impacts replenish rings

Ring Formation

- The rings orbit inside the Roche limit.
- Raw material for a moon cannot coalesce inside the Roche limit due to the gravitational forces of the planet
Rings, Ripples, and Spokes

- Gravitational interaction with moons inside the rings push particles into specific orbits.
  - clear gaps
- Interaction with larger, distant moons can clear gaps and form ripples.
- Dark patches called spokes appear and disappear.
- Perhaps they might be particles of dust drawn out by Saturn’s magnetic field.

Comparing Jovian Ring Systems

- Compared to Saturn, the other ring systems:
  - have fewer particles
  - are smaller in extent
  - have darker particles
- Why this is so, we are not sure.
- Other unsolved mysteries:
  - Uranus’ rings are eccentric and slightly tilted from its equatorial plane.
  - Neptune has partial rings.
Uranus

- Discovered in 1781 by William Herschel
- Atmosphere is over 100°C colder than Jupiter’s.
- The mantle contains rocky material and dissolved ammonia and methane.
- Circulation in this electrically conducting mantle may generate the planet’s peculiar magnetic field—which is highly inclined to its axis of rotation.
- Computer enhanced images reveal clouds and bands

Neptune

- The existence and location of Neptune was predicted from irregularities in the motion of Uranus.
- Neptune was discovered in 1846.
- Same size and interior as Uranus
- Its atmosphere contains one and a half times more methane than Uranus: bluer
Jovian Planets have Numerous Moons

- medium moons
  - 300 to 1,500 km in diameter
- large moons
  - greater than 1,500 km in diameter
- both groups formed in orbit around jovian planets.
- Enough self-gravity to be spherical
- Have substantial amounts of ice.

The Large Jovian Moons

- Jupiter
  - Io sulfur volcanoes
  - Europa world of water ice (and liquid?)
  - Ganymede active ice world
  - Callisto dead & dirty ice world
- Saturn
  - Titan has a thick atmosphere (N₂ & CH₄)
- Neptune
  - Triton nitrogen volcanoes, retrograde orbit
Rocky Planets vs. Icy Moons

- Rock melts at higher temperatures
- Only large rocky planets have enough heat for geological activity
- Ice melts at lower temperatures, so less heating is required to have molten cores. Volcanism and tectonics can occur
- Tidal heating can melt internal ice, driving activity

The Jovian Moons

- The moons of Jupiter become less dense as you get farther from Jupiter
  - “mini Solar System”
- Gravitational tidal heating due to resonances keeps the interiors of the inner moons hot.
Io

- Jupiter’s tidal forces flex Io like a ball of silly putty.
  - friction generates heat
  - interior of Io is molten
- Volcanoes erupt frequently.
  - sulfur in the lava accounts for yellow color
  - surface ice vaporizes and jets away
- Evidence of tectonics & impact cratering discovered.
- Source of ionized gas around Jupiter

Yellowstone National Park, Earth
Europa: Waterworld?

- Metallic core, rocky mantle, and a crust made of H₂O ice
- Tidal stresses crack Europa’s surface ice. Very few craters
- Evidence of a subsurface ocean.
- Europa has a magnetic field.
  - implies liquid salt water beneath the icy crust
- Where liquid water exists, there could be life!

Ganymede

- Largest moon in the Solar System
- Its surface has 2 types of terrain:
  - heavily cratered, implies old
  - long grooves, few craters, implies geological activity
- It also has a magnetic field.
- Could it have subsurface ocean?
  - tidal heating would be weaker
  - would need additional heating from radioactive decay
Callisto

- Cratered iceball.
- Has undergone differentiation like Ganymede
- No tidal heating, no orbital resonances.
- But it has magnetic field !?
- Could it have a subsurface ocean anyway?

Titan

- Titan is the only moon in the solar system to have a thick atmosphere
- It consists mostly of nitrogen with some argon, methane, and ethane
- Titan is so cold that its gas molecules do not travel fast enough to escape.
Titan’s Surface

- Huygens probe provided first look at Titan’s surface in early 2005
- Liquid methane, “rocks” made of ice

Titan’s Surface

- Drainage channels formed by liquid methane
- Radar images indicate lakes of liquid methane
- The only body other than Earth to have liquid on its surface. Could there be methane-based life?
Triton

- It orbits in the opposite direction of Neptune's rotation in a highly inclined orbit.
  - it may have disturbed at some point by another body, or it was captured by Neptune
- It has a thin nitrogen atmosphere
- Some sort of volcanic activity has occurred.

Summary

- What are the major features of the Jovian planets?
- Why are Jovian planets so different from terrestrial planets?
  - Formed in cold, outer Solar System at the centers of "miniature Solar nebulas."
- What are Jovian planets like on the inside?
  - Layered interiors with very high pressure and cores made of rock, metals, and hydrogen compounds, surrounded by H and He
  - Very high pressure in Jupiter and Saturn can produce metallic hydrogen
  - more distant planets captured less gas from the Solar nebula before it was blown away by the Solar wind.
Summary

• What is the weather like on jovian planets?
  – Multiple cloud layers determine colors of jovian planets
  – All have strong storms and winds
  – Structure of Jupiter’s atmosphere similar to Earth’s
  – Uranus and Neptune look blue because of methane

• Do jovian planets have magnetospheres like Earth’s?
  – All have substantial magnetospheres
  – Jupiter’s is largest by far

• What are the rings around jovian planets?
  – Made up of countless individual ice particles
  – Extremely thin with many gaps
  – Ring particles are probably debris from moons
  – Compared to Saturn, the other Jovian rings contain fewer particles, are smaller in extent, and darker in color.

Summary

• What are the moons of jovian planets like?
  – Moons of many sizes
  – Ices soften and melt at much lower temperatures than rock, allowing icy volcanism and tectonics at low temperatures.
  – Io: tidal heating drives activity, leading to Io’s volcanoes and ice geology on other moons
  – Europa: photos show evidence of water flows on the surface, magnetic field supports the presence of a salty ocean, and enough tidal heating to melt a layer of ice beneath the surface.
  – Ganymede: largest moon in Solar System; might have subsurface ocean.
  – Callisto: ancient cratered surface, but still could have subsurface ocean.
  – Titan: only moon with a thick atmosphere.
  – Triton: probably a captured moon, despite its large size.