Chapter 11
Jovian Planet Systems
11.1 A Different Kind of Planet

- Our goals for learning
- Are jovian planets all alike?
- What are jovian planets like on the inside?
- What is the weather like on jovian planets?
- Do jovian planets have magnetospheres like Earth’s?
Are jovian planets all alike?

- **Jupiter**: Distance from Sun = 5.20 AU, Mass = 318 \( M_{\text{Earth}} \), Density = 1.33 g/cm\(^3\), Composition: mostly H, He
- **Saturn**: Distance from Sun = 9.54 AU, Mass = 95 \( M_{\text{Earth}} \), Density = 0.71 g/cm\(^3\), Composition: mostly H, He
- **Uranus**: Distance from Sun = 19.2 AU, Mass = 14 \( M_{\text{Earth}} \), Density = 1.24 g/cm\(^3\), Composition: H compounds, rock, H and He
- **Neptune**: Distance from Sun = 30.1 AU, Mass = 17 \( M_{\text{Earth}} \), Density = 1.67 g/cm\(^3\), Composition: H compounds, rock, H and He
Jovian Planet Composition

• Jupiter and Saturn
  – Mostly H and He gas

• Uranus and Neptune
  – Mostly hydrogen compounds: water (H₂O), methane (CH₄), ammonia (NH₃)
  – Some H, He, and rock
Density Differences

- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately
Density Differences

- But that explanation doesn’t work for Jupiter…. 
Sizes of Jovian Planets

- Adding mass to a jovian planet compresses the underlying gas layers
Sizes of Jovian Planets

- Greater compression is why Jupiter is not much larger than Saturn even though it is three times more massive.

- Jovian planets with even more mass can be smaller than Jupiter.
Rotation and Shape

- Jovian planets are not quite spherical because of their rapid rotation
What are jovian planets like on the inside?
Interiors of Jovian Planets

- No solid surface.
- Layers under high pressure and temperatures.
- Cores (~10 Earth masses) made of hydrogen compounds, metals & rock
- The layers are different for the different planets. WHY?
Inside Jupiter

- High pressures inside Jupiter cause phase of hydrogen to change with depth
- Hydrogen acts like a metal at great depths because its electrons move freely
Inside Jupiter

- Core is thought to be made of rock, metals, and hydrogen compounds
- Core is about same size as Earth but 10 times as massive
Comparing Jovian Interiors

- Models suggest cores of jovian planets have similar composition
- Lower pressures inside Uranus and Neptune mean no metallic hydrogen
Jupiter’s Internal Heat

- Jupiter radiates twice as much energy it receives from Sun

- Energy probably comes from slow contraction of interior (releasing potential energy)
Internal Heat of Other Planets

- Saturn also radiates twice as much energy it receives from Sun
- Energy probably comes from differentiation (helium rain)
- Neptune emits nearly twice as much energy as it receives, but the source of that energy remains mysterious
What is the weather like on jovian planets?
Jupiter’s Atmosphere

- Hydrogen compounds in Jupiter form clouds

- Different cloud layers correspond to freezing points of different hydrogen compounds
Jovian Planet Atmospheres

- Other jovian planets have cloud layers similar to Jupiter’s
- Different compounds make clouds of different colors
• Ammonium sulfide clouds (NH$_4$SH) reflect red/brown.
• Ammonia, the highest, coldest layer, reflects white.
Saturn’s colors

- Saturn’s layers are similar, but deeper in and farther from the Sun --- more subdued.
Methane on Uranus and Neptune

- Methane gas of Neptune and Uranus absorb red light but transmit blue light

- Blue light reflects off methane clouds, making those planes look blue
Jupiter’s Bands

White ammonia clouds form where air rises.

Between white clouds we see deeper reddish clouds of NH$_4$SH.

Coriolis effect changes N-S flow to E-W winds.

Warmer red bands are brighter in IR.
Jupiter’s Great Red Spot

- A storm twice as wide as Earth
- Has existed for at least 3 centuries
Weather on Jovian Planets

- All the jovian planets have strong winds and storms
Do jovian planets have magnetospheres like Earth’s?
Jupiter’s Magnetosphere

- Jupiter’s strong magnetic field gives it an enormous magnetosphere
- Gases escaping Io feed the donut-shaped Io torus

Aurora on Jupiter
Other Magnetospheres

- All the jovian planets have substantial magnetospheres, but Jupiter’s is largest by far
What have we learned?

• Are jovian planets all alike?
  – Jupiter and Saturn are mostly H and He gas
  – Uranus and Neptune are mostly H compounds

• What are jovian planets like on the inside?
  – Layered interiors with very high pressure and cores made of rock, metals, and hydrogen compounds
  – Very high pressure in Jupiter and Saturn can produce metallic hydrogen
What have we learned?

- **What is the weather like on jovian planets?**
  - Multiple cloud layers determine colors of jovian planets
  - All have strong storms and winds

- **Do jovian planets have magnetospheres like Earth’s?**
  - All have substantial magnetospheres
  - Jupiter’s is largest by far
11.2 A Wealth of Worlds: Satellites of Ice and Rock

- Our goals for learning
- What kinds of moons orbit jovian planets?
- Why are Jupiter’s Galilean moons so geologically active?
- What is special about Titan and other major moons of the solar system?
- Why are small icy moons more geologically active than small rocky planets?
What kinds of moons orbit the jovian planets?
Sizes of Moons

• Small moons (< 300 km)
  – No geological activity

• Medium-sized moons (300-1,500 km)
  – Geological activity in past

• Large moons (> 1,500 km)
  – Ongoing geological activity
Medium & Large Moons

- Enough self-gravity to be spherical
- Have substantial amounts of ice.
- Formed in orbit around jovian planets.
- Circular orbits in same direction as planet rotation.
Small Moons

- Far more numerous than the medium and large moons.
- Not enough gravity to be spherical: “potato-shaped”
Small Moons

- Captured asteroids or comets, so orbits do not follow usual patterns.
Why are Jupiter’s Galilean moons so geologically active?
Io’s Volcanic Activity

- Io is the most volcanically active body in the solar system, but why?
• Volcanic eruptions continue to change Io’s surface
Tidal Heating

Io is squished and stretched as it orbits Jupiter.

But why is its orbit so elliptical?
Orbital Resonances

Every 7 days, these 3 moons line up.

The tugs add up over time, making all 3 orbits elliptical.
Europa’s Ocean: Waterworld?
Tidal stresses crack Europa’s surface ice.
Europa’s interior also warmed by tidal heating
Ganymede

- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radioactive decay?
Callisto

• “Classic” cratered iceball.
• No tidal heating, no orbital resonances.
• But it has magnetic field !?
What is special about Titan and other major moons of the outer solar system?
Titan’s Atmosphere

- 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’s Surface

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

- Almost all show evidence of past volcanism and/or tectonics
Medium Moons of Uranus

- Varying amounts of geological activity

- Moon Miranda has large tectonic features and few craters (episode of tidal heating in past?)
Neptune’s Moon Triton

- Similar to Pluto, but larger
- Evidence for past geological activity
Why are small icy moons more geologically active than small rocky planets?
Rocky Planets vs. Icy Moons

• Rock melts at higher temperatures
• Only large rocky planets have enough heat for activity

• Ice melts at lower temperatures
• Tidal heating can melt internal ice, driving activity
What have we learned?

• What kinds of moons orbit jovian planets?
  – Moons of many sizes
  – Level of geological activity depends on size

• Why are Jupiter’s Galilean moons so geologically active?
  – Tidal heating drives activity, leading to Io’s volcanoes and ice geology on other moons
What have we learned?

• What is special about Titan and other major moons of the solar system?
  – Titan is only moon with thick atmosphere
  – Many other major moons show signs of geological activity

• Why are small icy moons more geologically active than small rocky planets?
  – Ice melts and deforms at lower temperatures enabling tidal heating to drive activity
11.3 Jovian Planet Rings

- Our goals for learning
- What are Saturn’s rings like?
- How do other jovian ring systems compare to Saturn’s?
- Why do the jovian planets have rings?
What are Saturn’s rings like?
What are Saturn’s rings like?

• They are made up of numerous, tiny individual particles
• They orbit over Saturn’s equator
• They are very thin
Earth-based view
Spacecraft view of ring gaps
Artist’s conception of close-up
Gap Moons

- Some small moons create gaps within rings
Shepherd Moons

- Pair of small moons can force particles into a narrow ring
Resonance Gaps

- Orbital resonance with a larger moon can also produce a gap.
How do other jovian ring systems compare to Saturn’s?
Jovian Ring Systems

• All four jovian planets have ring systems
• Others have smaller, darker ring particles than Saturn
Why do the jovian planets have rings?
Why do the jovian planets have rings?

- They formed from dust created in impacts on moons orbiting those planets

How do we know that?
How do we know?

• Rings aren’t leftover from planet formation because the particles are too small to have survived this long.
• There must be a continuous replacement of tiny particles.
• The most likely source is impacts with the jovian moons.
Jovian planets all have rings because they possess many small moons close-in. Impacts on these moons are random. Saturn’s incredible rings may be an “accident” of our time.
What have we learned?

• What are Saturn’s rings like?
  – Made up of countless individual ice particles
  – Extremely thin with many gaps

• How do other jovian ring systems compare to Saturn’s?
  – Much fainter ring systems with smaller, darker, less numerous particles

• Why do the jovian planets have rings?
  – Ring particles are probably debris from moons