Chapter 8
Jovian Planet Systems
How do jovian planets differ from terrestrials?

- They are much larger than terrestrial planets
- They do not have solid surfaces
- The things they are made of are quite different
How do jovian planets differ from terrestrials?

- Terrestrial planets are made principally of rock and metal
- Jovian planets are not...
• Composition of Jupiter and Saturn
  – Mostly H and He
  – → “Gas giants”
• Composition of Uranus and Neptune
  – Mostly hydrogen compounds: water (H₂O), methane (CH₄), ammonia (NH₃)
  – Some H, He, and rock
  – → “Ice giants”
So why are the jovian planets different from terrestrials?
And why are the gas giants different from the ice giants?

Two reasons:

Location

Timing
The difference between jovian and terrestrial planets

- LOCATION is the reason for the differences between jovians and terrestrials
- Remember the frost line?
  
  ![Diagram of the frost line and planet formation]
  
- The jovian planets formed beyond it, where planetesimals could accumulate ICE (solid hydrogen compounds) as well as rock and metal
- So the jovian cores grew much larger than terrestrial cores…
- …and could therefore attract and retain H and He from the surrounding nebula
The difference between gas giants and ice giants

• Gas giants and ice giants are different mainly in how much H and He they contain
• Both LOCATION and TIMING are reasonable explanations for that

LOCATION

• planets forming in denser nebula will start forming their cores first…
• …and they will have more material to work with and thus grow faster…
• …and they will become big enough to attract H and He first

TIMING

• planets that start earlier will capture more hydrogen and helium gas before the first solar wind blows the leftover gas away
The difference between gas giants and ice giants

- The solar nebula was denser closer to the center
- Jupiter and Saturn formed closer to the center
- So they got started first and were therefore able to capture H and He longer
- Uranus and Neptune formed farther out, in a thinner part of the nebula
- So they didn’t get started as soon, and didn’t have as much material to feed on
- This limited their growth…
- …and it also made their composition different from Jupiter and Saturn, with less H and He compared to H-compounds, rock, and metal
- But there is another aspect of the differences between our jovians that can’t be explained this way…
Density Differences

- Uranus and Neptune are denser than Saturn
- This is because they have less low density H and He and more of the denser hydrogen compounds
- The more low density stuff there is, the less dense overall
- Saturn has much more H/He, so it is less dense than Uranus
- Saturn, Uranus, and Neptune follow the pattern that the more low density material, the less dense overall
Density Differences

- But Jupiter is *more* dense than Saturn
- It doesn’t follow the pattern
- It should, because Jupiter has proportionately more H/He than Saturn, so it ought to be *less* dense than Saturn
- What’s going on?
- What’s going on is gravity
- And a stack of pillows will help explain it
Sizes of Jovian Planets

- If you stack pillows, at first the height of the stack increases one pillow thickness at a time
- But eventually, the weight of the pillows above starts to flatten those below
- And the height doesn’t increase as fast
- Same thing happens with balls of gas, like jovian planets
- Adding more gas compresses the underlying gas layers to high density
Sizes of Jovian Planets

- Greater compression is why Jupiter is not much larger than Saturn even though it is three times more massive.
- And because it isn’t as much larger as it is more massive, it’s more dense.
- Jovian planets with even more mass can be smaller than Jupiter.
What are jovian planets like on the inside?

• Layers under high pressures and temperatures
• Cores (~10 Earth masses) made of hydrogen compounds, metals, and rock
• But the layers above the core are different for the different planets
• Why would this be?
• It’s because of the effect of gravity on internal pressure
High pressure inside of Jupiter causes the phase of hydrogen to change with depth.

So the layering is not from differentiation, but from pressure.

Hydrogen acts like a metal at great depths because its electrons move freely.
Inside Jupiter – Contents Under Pressure

- Denser rock, metal, and hydrogen compound material settles to the core (this is differentiation)
- But no one knows what the core is like under these extreme conditions of temperature and pressure
Comparing Jovian Interiors

- Models suggest that cores of all jovian planets have similar composition.
- But less H and He and lower pressures inside Uranus and Neptune mean no metallic hydrogen.
- There is also the possibility of diamonds!
- See [here](#) for diamonds, but see [here](#) for lowly graphite)
Jupiter’s enormous metallic hydrogen layer, created by the massive internal pressures, generates a very strong magnetic field and a gigantic magnetosphere.

- It is larger than the Sun
- Charged gases escaping Io feed the donut-shaped Io torus.
Jupiter’s Atmosphere

- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to condensation points of different hydrogen compounds.
- Other jovian planets have cloud layers for similar reasons.
• Ammonium sulfide clouds (NH$_4$SH) reflect red/brown.
• Ammonia, the highest, coldest layer, reflects white.
Saturn’s cloud layers are similar
But because it is colder, they are deeper and more subdued
The Color of Uranus and Neptune

- Methane gas on Neptune and Uranus absorbs red light better than blue light.

- Blue light reflects off methane clouds, making those planets look blue.
Jupiter’s Great Red Spot

A storm twice as wide as Earth, observed for >180 years
But unlike typical storms on Earth, it is a high-pressure storm
You can tell this by considering the “Coriolis effect”
A ball rolled on a rotating disk appears to curve. This is due to the Coriolis effect. It makes it look like a force—the “Coriolis force”—is acting on the ball.
The Coriolis effect is an illusion…
…and the “Coriolis force” is fictitious

This disk is spinning CCW

The dot doesn’t move because we are on the disk
The ball curves on the disk, but only because the disk rotates. Not because there is a force acting on it. So there is no such thing as a "Coriolis force"—it is fictitious.

If we step off of the disk, this is what we see:
The ball actually moves in a straight line.
The Coriolis effect does the same thing to wind on a planet.

Air streams in toward low pressure centers...

...causing CCW circulation in the northern hemisphere...

...and CW circulation in the southern hemisphere.
The Great Red Spot is in the southern hemisphere of Jupiter. Since its circulation is counterclockwise, it is a high-pressure storm.
Weather on Jovian Planets

- All the jovian planets have strong winds and storms.
Images taken every 10 hours over the course of 34 days by Voyager 1 as it approached Jupiter in 1979

- All the jovian planets have strong winds and storms.
- Jupiter’s atmosphere, e.g., is very active
The Moons of the Jovian Planets

These are the Galilean moons
But there are many more…
Medium and Large Moons
(diameters > 300 km)

- 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 (prograde)
Small Moons (diameters < 300 km)

- Far more numerous than the medium and large moons
- Not enough gravity to be spherical: “potato-shaped”
- Many have prograde orbits, and so probably formed along with planet
- But some have retrograde orbits, evidence of capture
Jovian moons are surprisingly active geologically

- Here are the Galilean moons and Mercury to scale
- Mercury is essentially geologically dead
- Why is this not a surprise...?
- Because Mercury is a small planet!
- So moons that are the same size or smaller than Mercury should be geologically dead, too
- But they’re not...
Io’s Volcanic Activity

- Io, for example, is the most volcanically active body in the solar system
• Ongoing volcanic eruptions change Io’s surface all the time
• The reason Io is so volcanic is “tidal heating”
Tidal Heating

Io is squished and stretched as it orbits Jupiter

far from Jupiter: small tidal bulges

close to Jupiter: large tidal bulges

But why is its orbit so elliptical?
Orbital Resonances

Every 7 days, these three moons line up.

The tugs add up over time, making all three orbits elliptical.
• The tidal flexing probably melts the mantle close to the surface
• And this is the source of the magma for Io’s 400 or so active volcanoes
Europa’s Ocean: Waterworld?
Tidal Stresses Crack Europa’s Surface Ice
Tidal stresses crack Europa’s surface ice

Tidal flexing closes crack

Tidal flexing opens crack
Europa’s Interior Also Warmed by Tidal Heating
Ganymede

- Largest moon in the solar system
- Clear evidence of geological activity
- And it too might have an internal ocean
- Internal heat from tidal heating (plus heat from radioactive decay?)
Callisto

- Heavily cratered surface
- What does that suggest?  
  → Little active geology
- No orbital resonances
  ∴ no tidal heating
- But it affects Jupiter’s magnetic field
Callisto

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- What does that suggest? → Little active geology
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- But it affects Jupiter’s magnetic field → *might* have an internal ocean
What geological activity do we see on Titan and other moons?
Titan’s Atmosphere

• Titan is the only moon in the solar system which has a thick atmosphere.

• It consists mostly of nitrogen with some argon, methane, and ethane.
• The *Huygens* probe provided a first look at Titan’s surface in early 2005.
• It had liquid methane, and “rocks” made of ice.
Titan’s “Lakes”

- Radar imaging of Titan’s surface reveals dark, smooth regions that may be lakes of liquid methane.
Medium Moons of Saturn

- Almost all show evidence of past volcanism and/or tectonics.
Ongoing Activity on Enceladus

- Fountains of ice particles and water vapor from the surface of Enceladus indicate that geological activity is ongoing.
- The Cassini probe found organic compounds in the plumes of these "cryovolcanoes".
- So Enceladus is an object of astrobiological interest.
Ongoing Activity on Enceladus

- Analysis of Enceladus’s gravity in 2014 suggested a subsurface ocean beneath surface ice (~25 km thick) under south pole
- Subsequent study by Cassini found that the ice shell is detached from the rocky core
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- This suggests that the ocean is global
Neptune’s Moon Triton

- Larger than Pluto
- Voyager saw evidence of cryovolcanism
- Has “retrograde” orbit
- Along with its composition, this suggests it’s a captured Kuiper belt object
Why are the moons of jovian planets more geologically active than small rocky planets?

- Rock melts at high temperatures
- Rocky planets only have enough heat for geological activity if they are large.
- Ice melts at lower temperatures.
- Tidal heating can melt internal ice, driving “ice geology”.
Jovian Moons and Life?

- As of today, there are 3493 confirmed exoplanets
- Of these, 291 are in the habitable zone (HZ) of their star
- Of these, more than half are Jupiter-size or bigger
- In our solar system, all of the jovian planets have moons
- Life as we know it could not exist on a jovian planet
- But it could exist on the solid surface of a HZ jovian moon
  ...think Avatar...
- So Earth-like planets in the HZ should not be the only targets of searches for extraterrestrial life
Jovian Planet Rings
Saturn’s rings

- They are made up of numerous, tiny individual particles that are constantly colliding
- Clumps of particles form larger clumps and then break up
- The particles orbit over Saturn’s equator
- Each particle or clump obeys Kepler’s laws
- The rings are very thin
Earth-Based View
Spacecraft View

- The rings are actually made of many thin rings
- Gaps separate the rings
Gap Moons

- Some small moons, like Pan shown here in the Encke Gap, create gaps within rings.
- The gravity of the moon keeps the gap clear of ring particles.
- This seems odd, but when you think about it, it makes sense.
Gap Moons

- The moon moves a little slower than the inner edge, slowing those particles down.
- They lose orbital energy and fall closer to the planet.
- The moon moves a little faster than the outer edge, speeding those particles up.
- They gain orbital energy and move farther away.
Shepherd Moons

- Some small moons “shepherd” ring particles into very thin rings in a similar way.
- The gravitational influence of the moons Pandora and Prometheus (at right) keeps the F ring sharp.
- A third moon, Janus is visible at upper left.
Jovian Ring Systems

- All four jovian planets have ring systems
- The rings of Jupiter, Uranus, and Neptune just have smaller, darker ring particles than Saturn’s rings
Why do the jovian planets have rings?

- Ring particles are too small to survive for very long periods of time
- So there must be a continuous replacement of them
- A possible source is continuing impacts between small jovian moons

Diagram:
- Tidal forces near the planet prevent small moonlets from accreting into larger moons.
- Moonlets are occasionally disrupted by impacts.
- Ongoing small impacts blast off dust and debris to form the rings.
Why do the jovian planets have rings?

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There are many small moons close-in to the jovian planets
They could be remnants of larger moons or comets
The larger moons or comets could have been ripped apart by straying into the “Roche tidal zone”
Within this zone, tidal forces exceed the gravitational forces holding large or medium moons together
Only small moons can survive there
Why do the jovian planets have rings?

- The Cassini spacecraft burned up in Saturn’s atmosphere after its “grand finale” orbits
- During the grand finale orbits, it studied Saturn’s rings in unprecedented detail
- Analysis of these results is sure to help us better understand the rings of Saturn and other jovian planets
- Stay tuned...