The Jovian planets: Jupiter, Saturn, Uranus and Neptune

- Their masses are large compared with terrestrial planets, from 15 to 320 times the Earth’s mass
- They are gaseous
- Low density
- All of them have rings
- All have many satellites
- All that we see of these planets are the top of the clouds
- No solid surface is visible
- The density increases toward the interior of the planet
- All of them located a larger distances from the Sun, beyond the orbit of Mars

Reading assignment: Chapter 7
Jupiter

• Named after the most powerful Roman god
• It is the third-brightest object in the night sky (after the Moon and Venus)
• It is the largest of the planets
• Atmospheric cloud bands - different than terrestrial planets
• The image shows the Great Red spot, a feature that has been present since it was first seen with a telescope about 350 years ago
• Many satellites, at least 79.
• The four largest are called Galilean satellites. Io, Europa, Ganymede and Callisto. Discovered by Galileo in 1610
• A faint system of rings. Too faint to see them with ground-based telescopes. Discovered by Voyager spacecrafts

Distance from the Sun: 5.2 AU
Diameter: 11 diameter of Earth
Mass: 320 mass of Earth
Density: 1300 kg/m³
Escape velocity: 60 km/s
Surface (clouds) temperature: 120 K

(Density of Earth = 5500 kg/m³
Density of water = 1000 kg/m³)
Saturn

- The second largest planet in the solar system
- Visible with the naked eye
- Named after the father of Jupiter
- Almost twice Jupiter’s distance from the Sun
- Similar banded atmosphere
- Uniform butterscotch hue
- Many satellites, at least 82. The largest is Titan, the only satellite that has a permanent atmosphere
- Spectacular ring system seen with even small telescopes
- Its density is the lowest of all planets (Water density = 1000 kg/m³)

Distance from the Sun: 9.5 AU
Diameter: 9.5 Earth diameter
Mass: 95 Earth mass
Density: 710 kg/m³
Escape velocity: 36 km/s
Surface (clouds) temperature: 97 K
Uranus

- Discovered by William Herschel in 1781
- Named after the father of Saturn
- Barely visible to naked eye, even under dark skies
- Several satellites, at least 27
- Featureless atmosphere
- Green, bluish color due to presence of methane in the atmosphere
- Methane absorb the red part of the spectrum and reflect the blue
- It showed small deviations in the expected orbit.
- Was another planet influencing its motion?
- The deviation led to the discovery of Neptune
- Faint ring system not visible with ground-based telescopes

Distance from the Sun: 19.2 AU
Diameter: 4.0 Earth diameter
Mass: 15 mass of Earth
Density: 1200 kg/m³
Escape velocity: 21 km/s
Surface (clouds) temperature: 58 K
Rotational axis tilted 98 degrees
Neptune

- This is the *other planet* whose gravitational pull is influencing the orbit of Uranus
- It’s mass and orbit were determined first, in 1845 by the English astronomer John Adams and a bit later by the French astronomer Urbain Leverrier
- It was discovered by the German astronomer Johann Galle in 1846
- Too faint, cannot be seen with naked eye
- Several satellites, at least 13
- The largest satellite Triton may be a captured object from the Kuiper belt. (Pluto is one of those objects)
- It has a bluish color due to the presence of methane in the atmosphere
- Faint ring system, not visible with ground-based telescopes

Distance from the Sun: 30 AU
Diameter: 3.9 Earth diameter
Mass: 17 Earth mass
Density: 1700 kg/m³
Escape velocity: 24 km/s
Surface (clouds) temperature: 59 K
Extreme seasons in Uranus
Tilt of rotational axis is 98 degrees
Orbital period ~ 84 years

Uranus's equatorial regions have two summers at the two equinoxes—42 years apart.

... and two winters at the solstices, with its poles plunged into darkness; also for 42 years at a time.

Northern winter solstice
Southern summer solstice

Northern summer solstice
Southern winter solstice
Spacecraft Exploration of Jovian Planets
Most of what we know about the Jovian planets comes from spacecraft data

- **Pioneer 10 and 11.** *The first to reached Jupiter, around 1973*
- **Voyager 1 and 2** left Earth in 1977
- Reached Jupiter in March and August of 1979
- Used Jupiter’s strong gravity to send them on to Saturn - *gravity assist*
- **Voyager 2** used Saturn’s gravity to propel it to Uranus and then on to Neptune
- Studied planetary magnetic fields and analyzed multi-wavelength radiation
- Both are now reaching the interstellar space!
Spacecraft Exploration of Jovian Planets

- **Galileo** - launched in 1989 and reached Jupiter in December 1995
  - Gravity assists from Venus and Earth
  - Spacecraft had two components: atmospheric probe and orbiter
  - Probe descended into Jupiter’s atmosphere
  - Orbiter went through moon system

- **Cassini** mission to Saturn arrived June 30, 2004
  - Orbiter was orbiting Saturn and its moons for several years. It mission ended in 2017.
  - **Huygens** probe launched from the Cassini orbiter in December 2004. It landed on Saturn’s moon Titan to study its atmosphere and surface.

- **Juno** mission: Arrived at Jupiter on July 4th, 2016. It will study the internal structure of Jupiter. The original plan was to fly in the inner part of the magnetosphere, within the radiation belts. Due to a failure in opening some valves to fire the rockets and change the orbit, it will remain in a longer orbit until the end of the mission. The image taken by Juno shows the region around the south pole.
Jupiter’s Atmosphere

Characterized by two main features: Colored bands (Zones and belts) and the Great Red Spot

Atmospheric content:
- Molecular hydrogen ($H_2$) – 86%
- Helium ($He_2$) – 14%
- Small amounts of methane ($CH_4$), ammonia ($NH_3$), and water vapor

- The Great Red Spot seems to be a hurricane that has lasted for 350 years
- The bands are caused by convections and high wind velocity at the top of the clouds
- Darker belts lie atop downward moving convective cells
- Lighter zones are above upward moving cells
- Belts are low-pressure, zones are high pressure
- Jupiter’s rapid rotation causes wind patterns to move East/West along equator
- The color of the bands may be due to the presence of trace elements sulfur and phosphorus and molecules of compounds of these elements
- The formation of these molecules is sensitive to temperature and that may account for the different colors of Belts and Zones
Jupiter’s Atmosphere

- Haze lies at the upper edge of the troposphere
- Below the haze, a thin layer of white ammonia (NH₃) clouds (Temp: 125 – 150 K)
- Colored clouds below that layer
  - Warmer temperatures, ~ 200 K
  - Clouds are mostly droplets or crystals of ammonium hydrosulfide (NH₄)SH
- At deeper levels, clouds of water ice or water vapor

The Galileo probe survived for about an hour before being crushed at this altitude. The electronics failed due to high temperatures. The pressure was about 22 times the sea-level pressure. The probe seems to have entered the atmosphere in a “hole” where less upper-level clouds and less water were found.
Weather on Jupiter

Main weather feature: Great Red Spot!
- Swirling hurricane winds
- Has lasted for almost 350 years!
- Diameter twice that of Earth
- Rotates with planet’s interior
- The spot appears to be confined and powered by the zonal flow

Smaller storms look like white ovals (this one is over 40 years old)

Why do the storms last so long?
On Earth, hurricanes loose power when then come upon land
No solid surface on Jupiter, just gas. Nothing to stop them once they start
Saturn’s Atmosphere

- molecular hydrogen 92.4%
- helium 7.4%
- traces of methane and ammonia

- A layer of haze at the top of the atmosphere
- Troposphere contains 3 cloud layers
  - ammonia ice
  - ammonium hydrosulfide ice
  - water ice
- Overall temperature is cooler than Jupiter
- Total cloud layer thickness is about three times that of Jupiter (caused by lower surface gravity on Saturn)
- Thicker clouds result in less varied visible colors
Weather on Saturn

• Computer enhanced image shows bands, oval storm systems, and turbulent flow patterns like those seen on Jupiter
• The colors in the image are not the natural colors of Saturn
The Atmospheres of Uranus and Neptune

The atmospheric content:
- molecular hydrogen 84%
- helium 14%
- methane 2% (Uranus) 3% (Neptune)

Abundance of methane gives these planets their blue color

Methane absorbs longer wavelength light (red) and reflects short wavelength light (blue)
Weather on Uranus and Neptune

**Uranus**
- Few clouds in the cold upper atmosphere – featureless
- Upper layer of haze blocks out the lower, warmer clouds

**Neptune**
- Upper atmosphere is slightly warmer than Uranus (despite its further distance from Sun)
- More visible features (thinner haze, less dense clouds lie higher)
- Storms – Great Dark Spot
- Seen in 1989 (In images taken by Voyager spacecraft) – gone in 1996 (Hubble telescope images)
Internal Structures of the Jovian planets

No direct experimental data – Only models based on spacecraft measurement

- **Metallic hydrogen** is a superconductor. A superconductor conduct electricity with minimum or no resistance. Its presence is important to justify the strong magnetic field of Jupiter and Saturn.
- Increasing temperature and pressure deeper in core
- Jupiter shape is distorted, about 7% larger at equator. Caused by fast rotation (Rotation period ~10 hours) and large radius (~ 71,000 km)
- Saturn less asymmetric – larger core – same basic overall structure
- Uranus/Neptune have a high density “slush” below cloud level - compressed water clouds with ammonia dissolved in the water, creating an electrically conductive layer. This may account for the planet’s magnetic field.
Jupiter Internal Heating

The left image is taken in IR. The lighter areas correspond to higher temperatures.

- Some of the Jovian planets have higher temperatures than expected from the Sun’s heating alone.
- This suggests an internal source of production of heat.
- The heat may come from stored thermal energy.
- Or it may come from heat being produced in the interior.

**Primordial Heat**

- Jupiter is slowly leaking heat that was produced during its formation by the heavy collapse of material onto the core. It was expected to have a temperature about 105 K. (due to radiation from the Sun). Instead using radio and IR observations it was determined to be about 125 K. According to Stefan’s law, the energy being radiated should be about twice as much as the energy received from the Sun, \( \Delta E = (125/105)^4 \approx 2 \).
Internal Heating

- **Generation of Heat**

  **Saturn**: generates some heat due to the gravitational heating of liquid helium droplets falling into the liquid H. This may account for the depletion of the outer layers of the atmosphere. The Helium content is about 7% in Saturn, 14% in Jupiter.

- **Uranus**: no source of internal heating. Less convention in the atmosphere, less atmospheric turbulence. That may explain the lack of features in the atmosphere.

- **Neptune**: there is internal heating. An explanation for the source is not yet clear. Possibly heat trapped from formation, which is slowly leaking due to isolation by methane?
All Jovian planets (and the Earth) have strong magnetic fields. They are caused by the rapid rotation and liquid or electrically conductive cores or mantles. In Jupiter and Saturn the conductive layer is metallic hydrogen (Superconductor).

All the Jovian planets (and the Earth) emit low frequency radio emission. The emission is caused by the interaction of electrons with the magnetic field.

The radio emission from Saturn, Uranus and Neptune is at low frequency (Less than 1.3 MHz), it cannot be received at ground level, it is not able to penetrate the terrestrial ionosphere.

The magnetic fields of some of the Jovian planets are offset from the center and have different tilt respect to the rotational axis.

Uranus and Neptune has large offset of the magnetic fields from the planet’s center.
Jupiter magnetic field and the low radio frequency emission

Jupiter has the strongest magnetic field of all the planets, about 14 times that of Earth’s magnetic field at clouds top.

- Jupiter produces strong radio emission at low frequencies. It is the only low frequency planetary emission that can be received from ground based radio telescopes. It can be detected at frequencies less than 39 MHz (short wavelength range).
- Jupiter’s radio emission is generated by electrons accelerated by the interaction of Io with the magnetic field. Electrons spiral down along magnetic field lines connecting Io and the Jupiter. Some electrons impact the upper atmosphere producing hot spots. Some are reflected and spiral outward producing radio emission.
- This radio emission can be received with simple antennas and receivers.
- The Radio JOVE is an educational/citizen science planetary radio astronomy project involved in detecting this emission. It is targeted to general public, college and high school students.
- Two types of radio emission are common: L (Long) bursts and S (Short) bursts. This radio emission can be converted to audio. Examples of audio where recorded at UF Radio Observatory.
Collision of Comet Shoemaker-Levy 9 with Jupiter

The comet was discovered by Carolyn and Eugene Shoemaker and David Levy in July 1993 in a photographic plate taken at Palomar observatory.

- Around July, 1992 the comet made a close pass near Jupiter (< 40,000 km) and broke into 23 pieces.
- This was caused by the strong tidal forces of the massive planet.
- The comet collided with Jupiter the following year, between July 16 and 22, 1994.

Another collision of a comet/asteroid with Jupiter in 2009.
A Summary of the Jovian Planet Properties

- Massive planets. Most of their mass is Hydrogen and Helium—light elements with low densities.
- High escape velocities and low atmospheric temperatures allow their atmospheres to retain these light elements.
- Dense compact core at the center.
- No SOLID surface. The gaseous atmosphere becomes denser (eventually liquid) at the core.
- Differential Rotation—outer regions rotate at a different rate than the inner regions.
- All have magnetic fields. Jupiter has the strongest magnetic field of all the planets.
- All have rings. Saturn has the most spectacular ring system.
- All have large number of satellites.
- Large diameters.
- Low average densities (Average density = Mass/volume).

**TABLE 7.1 Planetary Properties**

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass (x10^24)</th>
<th>Radius (km)</th>
<th>Average Density (kg/m^3)</th>
<th>Surface Gravity (Earth = 1)</th>
<th>Escape Speed (km/s)</th>
<th>Rotation Period (solar days)</th>
<th>Axial Tilt (degrees)</th>
<th>Surface Temperature (k)</th>
<th>Surface Magnetic Field (Earth = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.3</td>
<td>0.550</td>
<td>5400</td>
<td>0.38</td>
<td>4.3</td>
<td>59</td>
<td>0</td>
<td>100–700</td>
<td>0.01</td>
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<tr>
<td>Venus</td>
<td>4.9</td>
<td>0.82</td>
<td>5300</td>
<td>0.91</td>
<td>10</td>
<td>-243^1</td>
<td>179</td>
<td>730</td>
<td>0.0</td>
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<tr>
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<td>6.0</td>
<td>1.00</td>
<td>5500</td>
<td>1.00</td>
<td>11</td>
<td>1.00</td>
<td>23</td>
<td>290</td>
<td>1.0</td>
</tr>
<tr>
<td>Mars</td>
<td>6.4</td>
<td>0.11</td>
<td>3900</td>
<td>0.38</td>
<td>5.0</td>
<td>1.03</td>
<td>24</td>
<td>180–270</td>
<td>0.0</td>
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<tr>
<td>Jupiter</td>
<td>1.9 x10^27</td>
<td>320</td>
<td>1300</td>
<td>2.5</td>
<td>60</td>
<td>0.41</td>
<td>3</td>
<td>120</td>
<td>14</td>
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<tr>
<td>Saturn</td>
<td>5.7 x10^26</td>
<td>95</td>
<td>710</td>
<td>1.1</td>
<td>36</td>
<td>0.43</td>
<td>27</td>
<td>97</td>
<td>0.7^1</td>
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<tr>
<td>Uranus</td>
<td>8.7 x10^25</td>
<td>15</td>
<td>1200</td>
<td>0.91</td>
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<td>-0.69^1</td>
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</tr>
<tr>
<td>Neptune</td>
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<td>1700</td>
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<td>24</td>
<td>0.72</td>
<td>30</td>
<td>59</td>
<td>0.4^2</td>
</tr>
</tbody>
</table>

^1 The minus sign indicates retrograde rotation.

^2 Average values. Because of the planet's asymmetric magnetic field geometry (see Section 7.6), the field strength varies substantially from one point on the surface to another.

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