**C H A P T E R 2 3**

# Comparative Planetology of JUPITER AND SATURN

SUMMARY - GUIDEPOSTS

23-1 A Travel Guide to the Outer Planets

How do the outer planets compare with the inner planets?

* The outer planets, Jupiter, Saturn, Uranus, and Neptune are much larger than Earth and lower in density. These Jovian planets are rich in hydrogen.
* All four of the Jovian planets have rings, large satellite systems, and shallow atmospheres above liquid hydrogen mantles. Jupiter and Saturn show strong belt–zone circulation, but this is harder to see on Uranus and Neptune.
* Moons in the Jovian satellite systems interact gravitationally, and some have been heated by tides to produce geological activity. Most are old and cratered.

23-2 Jupiter

How is Jupiter different from Earth?

* Simple observations made from Earth show that Jupiter is 11 times Earth’s diameter and 318 times Earth’s mass. From that you can calculate its density, which is much lower than Earth’s. It is rich in hydrogen and helium and cannot contain more than a small core of heavy elements.
* Not far below Jupiter’s clouds, the temperature and pressure exceed the critical point, which means there is no difference between gaseous and liquid hydrogen. Consequently, the liquid hydrogen envelope has no surface; the transition from gaseous hydrogen to liquid hydrogen is gradual.
* The atmospheric composition is much like that of the sun—mostly hydrogen and helium with smaller amounts of heavier elements.
* Infrared observations show that Jupiter radiates more heat than it receives from the sun, so its interior must be five or six times hotter than the sun’s surface and is prevented from flashing into vapor by the high pressure.
* The pressure inside Jupiter converts much of its hydrogen into liquid metallic hydrogen, and the dynamo effect generates a powerful magnetic field that produces rings of auroras around the planet’s magnetic poles, interacts with the small moon Io, and traps high-energy particles to form intense radiation belts.
* The oblateness of Jupiter arises because its hydrogen envelope is highly fluid and the planet rotates rapidly.
* Ionized atoms from Jupiter’s inner moon Io are swept up by Jupiter’s rapidly spinning magnetic field to form the Io plasma torus that encloses the orbit of the moon. Powerful electrical currents flow through the Io flux tube and produce spots of aurora where it enters Jupiter’s atmosphere.
* Jupiter’s shallow atmosphere is rich in hydrogen, with three layers of clouds at the temperatures where ammonia, ammonium hydrosulfite, and water condense out. High- and low-pressure areas form belt–zone circulation. Belts are low-pressure areas where gas is sinking, and zones are high pressure areas where gas is rising.
* Spots on Jupiter, such as the Great Red Spot, are long-lasting, circulating storm systems.

How did Jupiter and its system of moons and rings form and evolve?

* Forward scattering shows that Jupiter’s ring is composed of tiny dust specks orbiting inside Jupiter’s Roche limit. The dust particles cannot have survived since the formation of the planet; rather, they are being produced by meteorite impacts on some of Jupiter’s inner moons.
* A small moon can orbit inside a planet’s Roche limit and survive if it is a solid piece of rock strong enough to endure the tidal forces trying to pull it apart.
* The dimmer gossamer rings lie near the orbits of two moons, adding evidence that the rings are sustained by particles from moons.
* Impacts on moons and planets must be common in the history of the solar system. Jupiter was hit by the fragmented head of a comet in 1992. Such impacts had not been seen before.

23-3 Jupiter’s Family of Moons

* At least some of Jupiter’s small moons are captured asteroids.
* The four Galilean moons appear to have formed with Jupiter. Callisto, the outermost, is composed of ice and rock and has an old and cratered surface. Unlike the three inner moons, Callisto is not caught in an orbital resonance and has never been active.
* Ganymede, Europa, and the innermost moon, Io, are locked in an orbital resonance, and that causes tidal heating. Ganymede’s surface is old and cratered in some areas, but bright, grooved terrain must have been produced by a past episode of geological activity.
* The inward focusing of meteorites should expose moons near massive planets to more cratering impacts, so it is surprising that Europa and Io have almost no craters.
* Europa is mostly rock with a thin icy crust that contains only a few scars of past craters. Cracks and lines show that the crust has broken repeatedly, and a subsurface ocean probably vents through the crust and deposits ice to cover craters as fast as they form. The subsurface ocean might be a place to look for life.
* Io is strongly heated by tides and has no water at all. Over 100 volcanoes erupt molten rock and throw ash high above the surface. No impact craters are visible because they are destroyed or buried as fast as they form. Sulfur compounds color the surface yellow and orange and vent into space to be caught in Jupiter’s magnetic field.

23-4 Saturn

How is Saturn different from Jupiter?

* Saturn is slightly smaller than Jupiter and less dense than water. It has a hot interior but contains less liquid metallic hydrogen, so its magnetic field is weaker than Jupiter’s and is, for some reason, closely aligned with its axis of rotation.
* Saturn is twice as far from the sun as Jupiter and is much colder. The three cloud layers seen on Jupiter form deeper in Saturn’s hazy atmosphere and are not as clearly visible.

How did Saturn and its system of moons and rings form and evolve?

* Saturn must have formed much as Jupiter did, but it is smaller and less dense.
* Saturn’s rings are composed of ice particles and cannot have lasted since the formation of the planet. The rings must receive occasional additions of ice particles when a small moon wanders inside Saturn’s Roche limit and is pulled apart by tides or when comets hit the planet’s icy moons.
* Icy particles can become trapped in stable places among the orbits of the innermost small moons, those within the Roche limit. Resonances with outer moons can produce gaps in the rings and generate waves that move like ripples through the rings. Small shepherd satellites can confine sections of the ring to produce sharp edges, ripples, or narrow ringlets.
* Without moons to confine them, the rings would have spread outward and dissipated long ago.

23-5 Saturn’s Moons

* Many of Saturn’s smaller moons, such as Phoebe, are probably captured asteroids or Kuiper belt objects. All of the moons are mixtures of rock and ice.
* Titan, the largest moon, is so cold it can retain a dense atmosphere of nitrogen with a small amount of methane. The methane condenses from the atmosphere, falls as rain, and drains over the surface, washing dark, organic material into drainage channels and on into the lowlands.
* The methane in Titan’s atmosphere can be destroyed by sunlight, so it must be continuously replenished. It probably vents from the icy crust and may form methane volcanoes. Lakes of liquid methane have been found in the moon’s polar regions.
* Some of the larger moons, such as Tethys, have old, dark, cratered surfaces with cracks and smoothed areas that suggest past activity. Enceladus, a rather small moon, is the most reflective object in the solar system and has large smooth areas, so it must have been very active.
* It orbits in a resonance with the moon Dione, and that may cause tidal heating inside Enceladus.
* Water vapor has been found above the south pole of Enceladus where water vents into space and form ice crystals, which resupply Saturn’s E ring.
* The moon Iapetus has a bright icy surface on its trailing side, but its leading side is coated with very dark material, possibly debris from Phoebe. In addition, Iapetus has a long equatorial ridge higher than Mount Everest on Earth. The ridge and the moon’s equatorial bulge may have formed when the moon was young, spun rapidly, and was molten.
* The origin and evolution of Saturn’s moons is not as clear as for Jupiter’s Galilean moons. Orbital interactions and impacts have been important to these moons.