PHY2003 ASTROPHYSICS I

Lecture 11. The Gas and Ice Giants

Jupiter

$a = 5.2$ au, $e = 0.048$, $P = 11.9$ Earth years,

1 sidereal day 0.41 Earth days

Radius $R_J = 11.2R_\oplus$, mass $318M_\oplus$,
density $\overline{\rho_J} = 1.4 \times 10^3$ kg/m^3

Three visible cloud layers: Ammonia (NH_4), ammonia hydrosulfide (NH_4HS) and water ice (H_2O).

Rapid rotation aligns clouds into zones (light) & belts (dark) - different colours depending on composition. Zones are rising regions of high pressure, belts are descending low pressure areas.

Large storms are seen, most impressive is Great Red Spot (seen since 1664). Three smaller storms formed in 1940's, merged into one in 1998–2000, which turned red at the end of 2005 (Red Spot Jr.).

Jupiter's magnetosphere largest in Solar system, easily detectable from Earth and showing large auroral ovals at the magnetic poles.

Jupiter emits ~ 1.7 times energy received from Sun (an extra 4×10^{17}W). This may be due to shrinking of Jupiter under self-gravity.

Example: The gravitational potential energy of a spherical mass is $-\frac{3}{5}\frac{GM^2}{R}$. Estimate the rate at which Jupiter is shrinking in order to generate the extra 4×10^{17}W in heat irradiated by the gas giant.

79 known satellites. Four largest moons known as the Galilean Satellites after their discoverer (Galileo).

Io - Radius 1815 km. Rocky, geologically active (volcanoes), cause by tidal stresses from Jupiter and neighbouring moons. Material from volcanoes is charged by sunlight and provides source of plasma in Jupiter's magnetic field.

Europa - Radius 1569 km. Icy, geologically active. Probably has a sub-surface ocean as evidenced by surface features and magnetic field.

Ganymede - Radius 2631 km (larger than Mercury!). Icy, geologically active in past, may also have a sub-surface ocean.

Callisto - Radius 2400 km. Icy, inert ancient surface saturated by craters

Thin ring system at $1.7R_J - 1.8R_J$.

Saturn

$a = 9.5$ au, $e = 0.056$, $P = 29.3$ Earth years,

1 sidereal day 0.43 Earth days

Radius $R_S = 9.4R_\oplus$, mass $95M_\oplus$, density $\overline{\rho_S} = 0.7 \times 10^3$ kg/m^3

Similar atmospheric belt and zone pattern to Jupiter, but less visible due to high altitude haze - can be seen in near-infrared, where haze particles do not reflect sunlight as well.

Largest ring system in the Solar system. Main rings are at $1.24R_S - 2.27R_S$ and are called A, B and C rings. Fainter D–G rings seen in high resolution images from Earth and spacecraft, and stretch out to $\simeq 15R_S$.

Rotational axis of Saturn is at 26.7° to the orbit, so see rings at various angles over 1 Saturn orbit.

Main rings have a thickness of $\simeq 1$ km, total mass is $\sim 10^{16}$ kg. Spectroscopy shows that ring system obeys Keplerian rotation $\Rightarrow$ not a solid body but composed of countless fragments.

Gravitational perturbations from moons give rise to complex ring structure. Primary gap called the Cassini division, due to 1:2 orbital period resonance with Mimas, 1:3 with Enceladus, 1:4 with Tethys. Hundreds of other resonances are visible.

Some gaps caused by small moons within the rings, other small moons create rings by shepherding particles.

62 known satellites. Largest satellite is Titan, $R = 2575$ km.

Extensive atmosphere 99% N_2, 1% CH_4. Surface pressure is $1.5P_\oplus$, surface temperature 90K. Surface invisible at optical wavelengths, but can just be seen in near-IR.

Huygens probe in 2005 imaged highly eroded surface with water-ice surface, extensive evidence of liquid methane on surface. Lakes seen near poles by Cassini spacecraft radar observations in 2006 onwards.

Icy moon Enceladus has radius of only $R = 250$ km, but Cassini spacecraft found large water-ice fountains near South pole, which are the origin of the E-ring. Currently unknown what causes this activity.

Uranus

Discovered in 1781.

$a = 19.2$ au, $e = 0.047$, $P = 84.1$ Earth years,

1 sidereal day $= 0.72$ Earth days

Radius $R_U = 4.0R_\oplus$, mass $14.5M_\oplus$, density $\overline{\rho_U} = 1.2 \times 10^3$ kg/m^3

Spectrum is dominated by Methane absorption - green/blue colour.

Rotational axis is at 98° to the orbit! In one orbital period, first one pole then the other is presented to the Sun - currently approaching equatorial aspect in 2007.

Ring system consists of ≥ 11 narrow rings, widths of 5km – 100km.

27 Known moons

Miranda most geologically complex moon. May have been shattered in a collision then reformed by self-gravity.

Neptune

Discovered in 1846.

$a = 30.1$ au, $e = 0.009$, $P = 165.1$ Earth years,

1 sidereal day 0.72 Earth days

Radius $R_N = 3.9R_\oplus$, mass $17.2M_\oplus$,
density $\overline{\rho_N} = 1.7 \times 10^3$ kg/m^3

Highly dynamic atmosphere, surprising given the large a leading to little solar energy input to drive weather systems. Strongest winds measured on any planet (500 m/sec). Large storms seen during Voyager 2 flyby in 1989.

Rings thin and highly uneven - clumped into "arcs", possibly caused by undetected moons.

14 known moons, largest moon is Triton (radius$= 0.77$ Earth's moon). Orbits at 20° to Neptune's equator and retrograde, implying it was not formed at same time as the planet. Geologically active with extensive ice geysers.