Lecture 38

The Jovian Planets; Kuiper Belt
Tides; Roche Limit; Rings
Jupiter System
Saturn, Uranus, Neptune rings
Plutinos and KBO's

Jovian System

- Solar distance: 5.2 AU
- Jupiter interior
  - H₂ 78%
  - He 19%
  - CH₄, NH₃ -1% (-10x solar)
- Rotation: 10 hrs, causing jet-stream banding of atmosphere
- Energy Balance: Out - 2x solar input; residual formation heat
- Surface Temperature 160 K (-110 C)
- Leftover material from formation formed miniature nebula heated by cooling of proto-Jupiter
  - 2 Jupiter radii: Rings: Rock fragments
  - 0.1-0.2×10⁶ km: 4 small satellites
  - 0.4-1.8×10⁶ km: 4 "Galilean" satellites: Io, Europa, Ganymede, Callisto
  - 11-23×10⁶ km: 8 small satellites
Tides

- Inner objects are dominated by "tidal forces" from Jupiter. Over an extended body, gravity from external object changes with position (due to "1/R^2" dropoff):
- **Roche Limit**: Rings are within Jupiter's "Roche limit". Tidal force larger than self-gravity, so satellite does not have a chance to accumulate from pieces.
  Roche zone: R < 2.4 R(planet) (roughly)
- **Synchronous rotation**: For inner 8 satellites, tidal force stretches object along axis pointing toward planet ("solid body tides"). Force gradually forces satellite to rotate so that one face points on that axis. Most satellites in solar system are in synchronous rotation.

The Jovian system: coformation vs capture

**Coformation**

- The Galilean satellites show a size increase and density drop-off with distance from Jupiter that looks just like that in the solar system:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Orbit (Jup radii)</th>
<th>Density (gm/cm^3)</th>
<th>Radius (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td>5.9</td>
<td>3.55</td>
<td>1816</td>
</tr>
<tr>
<td>Europa</td>
<td>9.4</td>
<td>3.04</td>
<td>1563</td>
</tr>
<tr>
<td>Ganymede</td>
<td>15.0</td>
<td>1.93</td>
<td>2638</td>
</tr>
<tr>
<td>Callisto</td>
<td>26.4</td>
<td>1.81</td>
<td>2410</td>
</tr>
</tbody>
</table>

- => they probably formed a mini-"solar system", with only rock satellites able to form near the cooling proto-Jupiter
- The inner 12 satellites all orbit in the same direction (counter-clockwise viewed from North)
Captured Satellites

Capture:
- The outer 4 satellites orbit in the opposite “retrograde” direction: this is the direction that is easiest for capture of objects in solar orbit (Jupiter catching up to an object that just happens to reach aphelion at encounter)
- Capture is very easy for Jupiter, the most massive planet: eg Shoemaker-Levy 9 comet collision resulted from capture of comet from solar orbit; probably happens every 1000 yrs or so

Outer Jovian planets.

As you go out in the solar system:
- **Planet densities**: increase apparently due to decreasing amount of captured hydrogen, helium.
- **Rings**: must be continually supplied with new particles from collisions among satellites. Sharp rings defined by moon "resonances" or by "shepherd" moons
- **Satellites**: don’t have the nice density dropoff of Galilean satellites. Many have quite unusual orbits. => Probably mostly captured from icy protoplanets during initial formation of solar system?

<table>
<thead>
<tr>
<th></th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
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<tbody>
<tr>
<td>Density gm/cm³</td>
<td>0.7</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Rings</td>
<td>1000's, ice</td>
<td>9 rocky, dark</td>
<td>2, very dark</td>
</tr>
<tr>
<td>Satellites</td>
<td>20 synch</td>
<td>15 synch, 1 capt</td>
<td>6 synch, 2 capt</td>
</tr>
</tbody>
</table>
Pluto

Pluto/ Charon
- An exception to most of the "rules"!
- Mass: < Moon-mass
- Density: 2 gm/cm³
- Orbit: size like Neptune, eccentricity 0.25, inclined 18° to ecliptic
- Rotation plane: random ("north" is 122° from ecliptic)
- System: is double planet with Charon (only discovered in 1978!). Orbit allowed mutual eclipses 1985 -1990.
  - Separation 20,000 km – 10 Pluto radii – 1/10 Moon orbit.
- Period 6d 9h. Both synchronously locked.
- Albedo: 0.4. Fairly bright: must be some kind of activity to overcome hydrocarbon darkening.

Kuiper Belt
- About 900 known (all discovered in last 10 years)
- Estimated 70,000 objects with diameter > 100 km from 30 – 50 AU
- Remnants of solar nebula – icy objects that did not accrete into planets. Many have moons: formed in collisions?
- Three classes
  - "Plutinos" in orbits that avoid Neptune with period that is exactly 3:2.
  - Classical KBO’s. ¾ of them.
  - "Scattered KBO’s". Eccentric orbits 35 – 200 AU
- Pluto classified by many as one of the larger KBOs, not a planet
Jupiter’s Rings

Jupiter’s Inner Moons

Metis    Adrastea    Amalthea    Thebe
Jupiter’s Galilean Moons

Table:

<table>
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<tr>
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<tbody>
<tr>
<td>Io</td>
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</table>

Figure 16.7, p495, Arny

Shoemaker-Levy 9 Impacts

Images:

- July 18, 1994
- July 23, 1994
- July 30, 1994
- August 24, 1994

Hubble Space Telescope • Wide Field Planetary Camera 2
Galileo Entry Probe Location

Saturn
Kuiper Belt Orbits

Red – Plutinos
Blue – CKBO’s
Black – SKBO’s

Object    D [km]    Type
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2003 UB313  2400    Scattered
Pluto      2320    Plutino
2003 EL61   1200?   Classical
2005 FY9    1250    Scattered

Largest Kuiper Belt Objects

2003 UB313 Discovery
Hubble image

2 more moons for Pluto

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