Announcements

Some generalizations for all planets (with cosmological implications):
1) orbits nearly circular
2) orbits nearly all in same (ecliptic) plane within 8°
   (the exception is Pluto's 17°)
3) all revolve in same direction (CCW viewed from NCP looking down)
4) all rotate in same direction with two exceptions: Venus
   (retrograde so as to face earth at closest approach) and
   Uranus ("sideways" with axis in ecliptic plane)
5) in most cases the moons always revolve in same sense
   (CCW from NCP looking down)

Orrery for October 20, 1992 11AM EDT = 15:00 UT (see diag.)

Seven 'planets' (=wanderers) were known to the ancients, and we recall this in the names of the days of the week:
- Sunday (sun)
- Monday (moon)
- Tuesday (Tyr, god of battle, or Mars)
- Wednesday (Mercury, Mercredi in French)
- Thursday (Tor, head god of Norsermen, or Jupiter)
- Friday (Freia, goddess of beauty, or Venus)
- Saturday (Saturn)

This is sometimes clearer in other languages (e.g. French).

Overview of solar system:

<table>
<thead>
<tr>
<th></th>
<th>Av. distance</th>
<th>Mass</th>
<th>Av. Density</th>
<th>Sidereal P.</th>
<th>Synodic P.*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in A.U.</td>
<td>in Mearth</td>
<td>in gm/cc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>inner or</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>terrestrial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bg</td>
<td>.39</td>
<td>.05</td>
<td>5.4</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Venus</td>
<td>.72</td>
<td>.82</td>
<td>5.1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.00</td>
<td>5.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mars</td>
<td>1.52</td>
<td>.12</td>
<td>4.0</td>
<td>&lt; 1</td>
<td></td>
</tr>
<tr>
<td>outer or</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jovian</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.2</td>
<td>317.8</td>
<td>1.33</td>
<td>&gt; 1</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.5</td>
<td>95.2</td>
<td>.68</td>
<td>&gt; 1</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>Uranus</td>
<td>19.1</td>
<td>14.5</td>
<td>1.60</td>
<td>&gt; 1</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>Neptune</td>
<td>30.1</td>
<td>17.2</td>
<td>2.25</td>
<td>&gt; 1</td>
<td></td>
</tr>
</tbody>
</table>

(*synodic will be discussed below)

Pluto is quite different from the other Jovians with its highly inclined orbit with high eccentricity. Pluto is inside Neptune's orbit for the rest of the century and is not generally regarded as a "Jovian" planet-- it probably is an escaped moon of Neptune.

Looking at above table there are at least 3 reasons to divide planets into "inner" vs "outer":

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1) distances from sun (inner ~1 vs outer ~ tens)
2) masses (inner ~1 vs outer ~ tens to hundreds)
3) densities (inner ~ 5 or basalt-like vs outer ~ 1-2 gm/cc)

and also fortuitously the ratio of sidereal/synodic periods.

Note we have listed distances in A.U. where
1 A.U. = mean radius of earth's orbit
       = 93 x 10^6 miles.

The Sidereal Period of a planet = once around the orbit with
respect to the stars.
The Synodic Period of a planet is the time to complete one
complete cycle of phases as seen from the moving earth, e.g.
opposition to opposition or inferior conjunction to inferior
conjunction.

For an inferior planet (Venus or Mercury)
1= inferior conjunction (new)
2=superior conjunction (phase=full)
3=gibbous
4=greatest eastern elongation (quarter)
5=crescent (large since near earth)

Inferior planet       Superior planet

For a superior planet (Mars on out)
1=conjunction (full)
2=gibbous
3=90° from sun=quadrature
4=opposition (largest, full)

For Mercury, Venus & Mars, the synodic period is larger than
the sidereal due to earth's motion (similar to the case of the
moon.
For all the rest, the synodic is basically one year plus a
small amount due the planet's motion during that year (think
of the extreme case of Pluto...) so the sidereal is greater
than the synodic for these outer planets.

Galileo observed that Venus imitates the phases of the moon.
This single observation destroyed 16 centuries of Ptolemaic
cosmology, according to which Venus always lay between earth
and sun so had to show only crescent to quarter phase (never
getting around behind the earth to be fully illumina-
ted). According to Copernican model Venus indeed should show all the phases of the moon.

One further generalization for the planets is retrograde motion, shown most prominently by Mars. Ptolemy explained this apparent "backwards" motion (westward instead of the usual eastward motion along the ecliptic) using a complicated system of planets moving on epicycles which moved on deferents (circles rolling on circles, much as a flashlight tied to a bicycle wheel moves). It is more easily explained by the Copernican model, where retrograde motion is an apparent backwards motion due to the more rapidly moving earth overtaking a slowly moving planet at opposition.

![Ptolemaic model (earth-centered)](image1) ![Copernican model (sun-centered)](image2)

There is another model briefly proposed by Tycho Brahe, which explains the phases of Venus and also retrograde motion, and has the earth at center, with the sun revolving around earth and all the rest revolving around the sun (similar to the hand-out orrery). This model explained all of the observed phenomena and could only be proved invalid when the telescope revealed the two proofs of earth's revolution: parallax and aberration of starlight.

**Tycho's model**

![Tycho's model](image3)