Jupiter and Saturn are the most massive planets in the solar system

- Jupiter and Saturn are both much larger than Earth
- Each is composed of 71% hydrogen, 24% helium, and 5% all other elements by mass
- Both planets have a higher percentage of heavy elements than does the Sun
- Jupiter and Saturn both rotate so rapidly that the planets are noticeably flattened

Guiding Questions

1. Why are there important differences between the atmospheres of Jupiter and Saturn?
2. What is going on in Jupiter’s Great Red Spot?
3. What is the nature of the multicolored clouds of Jupiter and Saturn?
4. What does the chemical composition of Jupiter’s atmosphere imply about the planet’s origin?
5. How do astronomers know about the deep interiors of Jupiter and Saturn?
6. How do Jupiter and Saturn generate their intense magnetic fields?
7. Why would it be dangerous for humans to visit certain parts of the space around Jupiter?
8. How was it discovered that Saturn has rings?
9. Are Saturn’s rings actually solid bands that encircle the planet?
10. How uniform and smooth are Saturn’s rings?
11. How do Saturn’s satellites affect the character of its rings?
Unlike the terrestrial planets, Jupiter and Saturn exhibit differential rotation. The visible "surfaces" of Jupiter and Saturn are actually the tops of their clouds. The rapid rotation of the planets twists the clouds into dark belts and light zones that run parallel to the equator. The outer layers of both planets' atmospheres show differential rotation, with the equatorial regions rotating slightly faster than the polar regions. For both Jupiter and Saturn, the polar rotation rate is nearly the same as the internal rotation rate.

Spacecraft images show remarkable activity in the clouds of Jupiter and Saturn. Storms in Saturn's atmosphere seem to be shorter-lived.

• Both Jupiter and Saturn emit more energy than they receive from the Sun, presumably both planets are still cooling.
• The colored ovals visible in the Jovian atmosphere represent gigantic storms.
• Some, such as the Great Red Spot, are quite stable and persist for many years.

Storms

• Both Jupiter and Saturn emit more energy than they receive from the Sun, presumably both planets are still cooling.
• The colored ovals visible in the Jovian atmosphere represent gigantic storms.
• Some, such as the Great Red Spot, are quite stable and persist for many years.
The internal heat of Jupiter and Saturn has a major effect on the planets’ atmospheres — where has this energy come from?

Space probes have explored Jupiter’s and Saturn’s atmosphere

- There are presumed to be three cloud layers in the atmospheres of Jupiter and Saturn
- The reasons for the distinctive colors of these different layers are not yet known
- The cloud layers in Saturn’s atmosphere are spread out over a greater range of altitude than those of Jupiter, giving Saturn a more washed-out appearance
- Saturn’s atmosphere contains less helium than Jupiter’s atmosphere
- This lower abundance may be the result of helium raining downward into the planet
- Helium “rainfall” may also account for Saturn’s surprisingly strong heat output

iClicker Question

Saturn’s density is

- A higher than Jupiter’s density.
- B highest of the gas giants.
- C lowest because of its mass.
- D is lowest because of its gravity.
- E so low you could float it in water.

iClicker Question

Voyager 1 and 2 made major discoveries about Jupiter including

- A the fact that Jupiter has a ring.
- B the fact that Jupiter's red spot has complex eddies, like a hurricane on Earth.
- C the fact that Jupiter's moons are as varied as the planets themselves.
- D All of the above.
- E None of the above

iClicker Question

Saturn gives off more heat than it absorbs

- A because of its enormous mass.
- B because its methane is a greenhouse gass.
- C because its thick clouds contribute to heat generation.
- D because of helium rain that gives off heat as it falls to center.
- E because it is radiating heat left over from its formation.
iClicker Question

Saturn has oval storm systems and turbulent flow patterns
A powered by the greenhouse effect.
B powered by convection and rapid rotation.
C powered by liquid hydrogen.
D powered by metallic hydrogen rotating at high velocity.
E powered by the rings of Saturn.

The oblateness of Jupiter and Saturn reveals their rocky cores

- Jupiter probably has a rocky core several times more massive than the Earth
- The core is surrounded by a layer of liquid "ices" (water, ammonia, methane, and associated compounds)
- On top of this is a layer of helium and liquid metallic hydrogen and an outermost layer composed primarily of ordinary hydrogen and helium
- Saturn’s internal structure is similar to that of Jupiter, but its core makes up a larger fraction of its volume and its liquid metallic hydrogen mantle is shallower than that of Jupiter

iClicker Question

Jupiter is noticeably oblate
A mainly because of its strong magnetic field.
B mainly because of its distance from the Sun.
C mainly because of rapid rotation.
D mainly because of the tidal effects of its moons.
E mainly because of its large mass.

iClicker Question

Jupiter emits more energy than it absorbs
A due to the helium rain falling in.
B due to the escape of gravitational energy released during its formation.
C due to the decay of radioactive elements.
D due to a small amount of fusion in its core.
E due to the generation of heat from tidal forces.

Metallic hydrogen inside Jupiter and Saturn endows the planets with strong magnetic fields

- Jupiter and Saturn have strong magnetic fields created by currents in the metallic hydrogen layer
- Jupiter’s huge magnetosphere contains a vast current sheet of electrically charged particles
- Saturn’s magnetic field and magnetosphere are much less extensive than Jupiter’s
Jupiter and Saturn have extensive magnetospheres

- The Jovian magnetosphere encloses a low-density plasma of charged particles
- The magnetosphere exists in a delicate balance between pressures from the plasma and from the solar wind
- When this balance is disturbed, the size of the magnetosphere fluctuates drastically

Synchrotron Radiation

Charged particles in the densest portions of Jupiter’s magnetosphere emit synchrotron radiation at radio wavelengths

iClicker Question

Jupiter emits radio waves
A caused by charged particles moving in its magnetic field.
B caused by metallic hydrogen in the mantle.
C massive gravitational forces.
D caused by the Great Red Spot.
E large Coriolis forces on the atmosphere.

Earth-based observations reveal three broad rings encircling Saturn

- Saturn is circled by a system of thin, broad rings lying in the plane of the planet’s equator
- This system is tilted away from the plane of Saturn’s orbit, which causes the rings to be seen at various angles by an Earth-based observer over the course of a Saturnian year

iClicker Question

- Saturn has a magnetic field
A caused by rapid rotation of methane clouds.
B caused by rapid rotation of nitrogen clouds.
C caused by rapid rotation of metallic hydrogen.
D caused by rapid rotation of molecular hydrogen.
E caused by rapid rotation of water ice.
Saturn’s rings are composed of numerous icy fragments, while Jupiter’s rings are made of small rocky particles.

- The principal rings of Saturn are composed of numerous particles of ice and ice-coated rock ranging in size from a few micrometers to about 10 m.
- Jupiter’s faint rings are composed of a relatively small amount of small, dark, rocky particles that reflect very little light.

- Most of its rings exist inside the Roche limit of Saturn, where disruptive tidal forces are stronger than the gravitational forces attracting the ring particles to each other.
- Each of Saturn’s major rings is composed of a great many narrow ringlets.

Saturn’s rings consist of thousands of narrow, closely spaced ringlets.
Saturn's inner satellites affect the appearance and structure of its rings.

iClicker Question

- The rings of Saturn
  A are solid rings around Saturn.
  B lie within the Roche limit of Saturn.
  C lie outside the Roche limit of Saturn.
  D lie precisely at the Roche limit of Saturn.
  E are not visible from Earth-bound telescopes.

iClicker Question

- Saturn's famous rings are
  A composed of complex carbohydrates.
  B composed of a solid thin disk of material.
  C composed mostly of rocky boulders.
  D composed of a disk of liquid helium.
  E composed mostly of icy particles moving about Saturn.

iClicker Question

- The Roche limit is an important concept
  A that defines the maximum brightness a moon can be.
  B that defines the maximum mass a moon can possess.
  C that defines the maximum density of a planet's ring system.
  D that defines the critical distance from a planet inside of which a moon can be tidally destroyed.
  E that defines the critical distance from a planet to its moon.
Jupiter’s and Saturn’s Moons

Guiding Questions
1. Are all the Galilean satellites made of rocky material, like the Earth’s moon?
2. What could account for differences between the inner and outer Galilean satellites?
3. Why does Io have active volcanoes? How does Io’s volcanic activity differ from that on Earth?
4. How does Io act like an electric generator?
5. What is the evidence that Europa has an ocean beneath its surface?
6. What is unusual about the magnetic fields of Ganymede and Callisto?
7. How is it possible for Saturn’s moon Titan to have an atmosphere?
8. Why do some of Jupiter’s moons orbit in the “wrong” direction?
9. What kinds of geologic activity are seen on Saturn’s medium-sized satellites?

Jupiter’s Galilean satellites are easily seen with Earth-based telescopes

- The four Galilean satellites orbit Jupiter in the plane of its equator
- All are in synchronous rotation

<table>
<thead>
<tr>
<th>Table 16-1</th>
<th>The Galilean Satellites Compared with the Moon, Mercury, and Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average distance from Jupiter (km)</td>
</tr>
<tr>
<td>Io</td>
<td>422,000</td>
</tr>
<tr>
<td>Europa</td>
<td>671,900</td>
</tr>
<tr>
<td>Ganymede</td>
<td>1,070,800</td>
</tr>
<tr>
<td>Callisto</td>
<td>1,881,000</td>
</tr>
<tr>
<td>Moon</td>
<td>—</td>
</tr>
<tr>
<td>Mercury</td>
<td>—</td>
</tr>
<tr>
<td>Mars</td>
<td>—</td>
</tr>
</tbody>
</table>

- The two innermost Galilean satellites, Io and Europa, have roughly the same size and density as our Moon
- They are composed principally of rocky material
- The two outermost Galilean satellites, Ganymede and Callisto, are roughly the size of Mercury
- Lower in density than either the Moon or Mercury, they are made of roughly equal parts ice and rock

The Galilean satellites formed like a solar system in miniature
The Galilean satellites probably formed in a similar fashion to our solar system but on a smaller scale. In the inner parts of both the solar and Jovian nebulae, only rocky grains survive… while in the outer reaches of these nebulae, ice and rocky grains survive.

- **Io** is covered with colorful sulfur compounds ejected from active volcanoes. Areas not observed by the Voyager spacecraft.

- **Tidal Heating**
  - The energy to heat Io’s interior and produce the satellite’s volcanic activity comes from tidal forces that flex the satellite.
  - This tidal flexing is aided by the 1:2:4 ratio of orbital periods among the inner three Galilean satellites.

---

**iClicker Question**

- The largest Jupiter moon is
  - A Io.
  - B Europa.
  - C Callisto.
  - D Ganymede.
  - E Almathea.
iClicker Question

- The most geologically active moon is
  A. Io.
  B. Ganymede.
  C. Europa.
  D. Callisto.
  E. Almathea.

iClicker Question

- Volcanic activity on the geologically active moon of Jupiter is caused by
  A. Jupiter's enormous mass.
  B. tidal stresses from Jupiter alone.
  C. tidal stresses from all other moons.
  D. tidal stresses from Jupiter and Europa.
  E. Jupiter's enormous gravity.

Jupiter's magnetic field makes electric currents flow through Io

- The Io torus is a ring of electrically charged particles circling Jupiter at the distance of Io's orbit.
- Interactions between this ring and Jupiter's magnetic field produce strong radio emissions.
- Io may also have a magnetic field of its own.
Europa is covered with a smooth layer of ice that may cover a worldwide ocean

- While composed primarily of rock, Europa is covered with a smooth layer of water ice
- The surface has hardly any craters, indicating a geologically active history
- As for Io, tidal heating is responsible for Europa's internal heat
- Minerals dissolved in this ocean may explain Europa's induced magnetic field

Other indications are a worldwide network of long cracks and ice rafts that indicate a subsurface layer of liquid water or soft ice

Liquid water may also lie beneath the cratered surfaces of Ganymede and Callisto
Ganymede

- Ganymede is highly differentiated, and probably has a metallic core.
- It has a surprisingly strong magnetic field and a magnetosphere of its own.
- While there is at present little tidal heating of Ganymede, it may have been heated in this fashion in the past.
- An induced magnetic field suggests that it, too, has a layer of liquid water beneath the surface.

- Two types of terrain are found on the icy surface of Ganymede:
  - areas of dark, ancient, heavily cratered surface
  - regions of heavily grooved, lighter-colored, younger terrain

Callisto has a heavily cratered crust of water ice

- The surface shows little sign of geologic activity, because there was never any significant tidal heating of Callisto.
- However, some unknown processes have erased the smallest craters and blanketed the surface with a dark, dusty substance.
- Magnetic field data seem to suggest that Callisto has a shallow subsurface ocean.

Titan has a thick, opaque atmosphere rich in methane, nitrogen, and hydrocarbons

- The largest Saturnian satellite, Titan, is a terrestrial world with a dense nitrogen atmosphere.
- A variety of hydrocarbons are produced there by the interaction of sunlight with methane.
- These compounds form an aerosol layer in Titan’s atmosphere and possibly cover some of its surface with lakes of ethane.

iClicker Question

- In general what can be said about Jupiter's moons?
  A That all the moons were formed with Jupiter.
  B That some formed with Jupiter and some were captured.
  C That all the moons were captured by Jupiter.
  D That some moons formed in the inner solar system.
  E That all the moons are larger that the terrestrial planets.
iClicker Question

- Saturn’s moon Titan is most interesting
  A because it possess an atmosphere like that of today's Earth.
  B because it possesses a thick atmosphere that may be like primordial Earth’s atmosphere.
  C because it has ice volcanism.
  D because it is a large moon.
  E because it demonstrates the Roche critical limit.

iClicker Question

- Titan’s atmosphere
  A consists mostly of hydrogen.
  B consists mostly of carbon dioxide.
  C consists mostly of sulfur.
  D consists mostly of methane.
  E consists mostly of nitrogen.

Jupiter has dozens of small satellites that have different origins

- As of early 2004, Jupiter has a total of 63 known satellites
- In addition to the Galilean satellites, Jupiter has four small inner satellites that lie inside Io’s orbit.
- Like the Galilean satellites, these orbit in the plane of Jupiter’s equator.
- The remaining satellites are small and move in much larger orbits that are noticeably inclined to the plane of Jupiter’s equator.
- Many of these orbit in the direction opposite to Jupiter’s rotation.

The icy surfaces of Saturn’s six moderate-sized moons provide clues to their histories

- As of early 2008, Saturn has a total of 52 moons
- In addition to Titan, six moderate-sized moons circle Saturn in regular orbits: Mimas, Enceladus, Tethys, Dione, Rhea, and Iapetus.
- They are probably composed largely of ice, but their surface features and histories vary significantly.
- The other, smaller moons include shepherd satellites that control the shapes of Saturn’s rings and captured asteroids in large retrograde orbits.

iClicker Question

- Saturn’s moon Mimas
  A has erratic orbital characteristics.
  B has a thick atmosphere similar to Earth’s primordial atmosphere.
  C apparently suffered a huge meteorite impact that nearly shattered it.
  D is the largest of Saturn’s moons.
  E is the smallest of Saturn’s moons.
iClicker Question

- Saturn has shepherd moons
  A named for the astronaut Alan Shepherd.
  B that even the Voyager spacecraft could not detect.
  C that are small moons which confine a narrow ring.
  D that are moons that are outside the Roche limit.
  E that are moons that orbit larger moons.

iClicker Question

- Most of Saturn's moons and Jupiter's moons
  A are smaller than the moons of Mars.
  B are orbiting erratically.
  C are larger than the terrestrial planets.
  D are near the critical Roche distance.
  E are tidally locked by gravity into synchronous rotation.

### Uranus, Neptune and Pluto

![Uranus, Neptune and Pluto](image)

### Table 16-1: Uranus Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from Sun</td>
<td>19.179 AU = 2,872.4 × 10⁶ km</td>
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<tr>
<td>Maximum distance from Sun</td>
<td>39.47 AU = 5.89 × 10⁷ km</td>
</tr>
<tr>
<td>Minimum distance from Sun</td>
<td>10.27 AU = 1.55 × 10⁷ km</td>
</tr>
<tr>
<td>Average orbital speed</td>
<td>6.0 km/s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>17,241 days</td>
</tr>
<tr>
<td>Revolution period</td>
<td>17,250 days</td>
</tr>
<tr>
<td>Inclination of orbit to ecliptic</td>
<td>2.4°</td>
</tr>
<tr>
<td>Inclination of orbit to equator</td>
<td>5.5°</td>
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<tr>
<td>Diameter</td>
<td>51,724 km = 0.408 Earth diameters (equatorial)</td>
</tr>
<tr>
<td>Mass</td>
<td>0.155 Earth mass</td>
</tr>
<tr>
<td>Escape speed</td>
<td>17.3 km/s</td>
</tr>
<tr>
<td>Surface gravity</td>
<td>9.12 m/s²</td>
</tr>
<tr>
<td>Average temperature at north pole</td>
<td>-185°C (−297°F)</td>
</tr>
<tr>
<td>Atmosphere composition</td>
<td>2% hydrogen, 2% helium, 7% methane, 1% carbon monoxide, 0.01% ammonia, 0.001% sulfur monoxide</td>
</tr>
<tr>
<td>Average density</td>
<td>1.2 g/cm³</td>
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</tbody>
</table>

### Table 16-2: Neptune Data

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<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Distance from Sun</td>
<td>30.36 AU = 4.57 × 10⁷ km</td>
</tr>
<tr>
<td>Maximum distance from Sun</td>
<td>51.08 AU = 7.64 × 10⁷ km</td>
</tr>
<tr>
<td>Minimum distance from Sun</td>
<td>13.60 AU = 2.07 × 10⁷ km</td>
</tr>
<tr>
<td>Average orbital speed</td>
<td>6.0 km/s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>165 years</td>
</tr>
<tr>
<td>Revolution period</td>
<td>165 years</td>
</tr>
<tr>
<td>Inclination of orbit to equator</td>
<td>0°</td>
</tr>
<tr>
<td>Inclination of orbit to equator</td>
<td>0°</td>
</tr>
<tr>
<td>Diameter</td>
<td>49,244 km = 0.389 Earth diameters (equatorial)</td>
</tr>
<tr>
<td>Mass</td>
<td>1.047 Earth masses</td>
</tr>
<tr>
<td>Escape speed</td>
<td>17.5 km/s</td>
</tr>
<tr>
<td>Surface gravity</td>
<td>9.08 m/s²</td>
</tr>
<tr>
<td>Average temperature at north pole</td>
<td>-222°C (−372°F)</td>
</tr>
<tr>
<td>Atmosphere composition</td>
<td>2.7% helium, 0.002% methane, 97% hydrogen, 0.27% helium, 0.002% methane</td>
</tr>
<tr>
<td>Average density</td>
<td>1.7 g/cm³</td>
</tr>
</tbody>
</table>

### Table 16-3: Pluto Data

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Distance from Sun</td>
<td>39.537 AU = 5.935 × 10⁷ km</td>
</tr>
<tr>
<td>Maximum distance from Sun</td>
<td>52.73 AU = 7.95 × 10⁷ km</td>
</tr>
<tr>
<td>Minimum distance from Sun</td>
<td>28.70 AU = 4.32 × 10⁷ km</td>
</tr>
<tr>
<td>Average orbital speed</td>
<td>5.0 km/s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>248.05 years</td>
</tr>
<tr>
<td>Revolution period</td>
<td>248.05 years</td>
</tr>
<tr>
<td>Inclination of orbit to equator</td>
<td>12.2°</td>
</tr>
<tr>
<td>Inclination of orbit to plane</td>
<td>17.7°</td>
</tr>
<tr>
<td>Diameter</td>
<td>2,380 km = 0.288 Earth diameters</td>
</tr>
<tr>
<td>Mass</td>
<td>0.0022 Earth mass</td>
</tr>
<tr>
<td>Escape speed</td>
<td>4.3 km/s</td>
</tr>
<tr>
<td>Surface gravity</td>
<td>1.2 m/s²</td>
</tr>
<tr>
<td>Average temperature of surface</td>
<td>-222°C (−372°F)</td>
</tr>
<tr>
<td>Atmosphere composition</td>
<td>96% nitrogen, 3% methane, 1% argon</td>
</tr>
<tr>
<td>Average density</td>
<td>1.8 g/cm³</td>
</tr>
</tbody>
</table>

### Table 16-4: Pluto Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Distance from Sun</td>
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</tr>
<tr>
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<tr>
<td>Average orbital speed</td>
<td>5.0 km/s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>248.05 years</td>
</tr>
<tr>
<td>Revolution period</td>
<td>248.05 years</td>
</tr>
<tr>
<td>Inclination of orbit to equator</td>
<td>12.2°</td>
</tr>
<tr>
<td>Inclination of orbit to plane</td>
<td>17.7°</td>
</tr>
<tr>
<td>Diameter</td>
<td>2,380 km = 0.288 Earth diameters</td>
</tr>
<tr>
<td>Mass</td>
<td>0.0022 Earth mass</td>
</tr>
<tr>
<td>Escape speed</td>
<td>4.3 km/s</td>
</tr>
<tr>
<td>Surface gravity</td>
<td>1.2 m/s²</td>
</tr>
<tr>
<td>Average temperature of surface</td>
<td>-222°C (−372°F)</td>
</tr>
<tr>
<td>Atmosphere composition</td>
<td>96% nitrogen, 3% methane, 1% argon</td>
</tr>
<tr>
<td>Average density</td>
<td>1.8 g/cm³</td>
</tr>
</tbody>
</table>
Uranus was discovered by chance, but Neptune’s existence was predicted by applying Newtonian mechanics
- Uranus recognized as a planet in 1781 by William Herschel
- Neptune’s position calculated in mid-1840’s because of slight deviations in Uranus’ orbit
- Credit shared by Le Verrier and Adams

Uranus is nearly featureless and has an unusually tilted axis of rotation
- Both Uranus and Neptune have atmospheres composed primarily of hydrogen, helium, and a few percent methane
- Methane absorbs red light, giving Uranus and Neptune their greenish-blue color

Exaggerated Seasons On Uranus
- Uranus’s axis of rotation lies nearly in the plane of its orbit, producing greatly exaggerated seasonal changes on the planet
- This unusual orientation may be the result of a collision with a planetlike object early in the history of our solar system. Such a collision could have knocked Uranus on its side

Neptune is a cold, bluish world with Jupiterlike atmospheric features
- No white ammonia clouds are seen on Uranus or Neptune
- Presumably the low temperatures have caused almost all the ammonia to precipitate into the interiors of the planets
- All of these planets’ clouds are composed of methane
- Much more cloud activity is seen on Neptune than on Uranus
- This is because Uranus lacks a substantial internal heat source

Neptune’s Clouds
- Much more cloud activity is seen on Neptune than on Uranus
- This is because Uranus lacks a substantial internal heat source
Uranus and Neptune contain a higher proportion of heavy elements than Jupiter and Saturn

- Both Uranus and Neptune may have a rocky core surrounded by a mantle of water and ammonia
- Electric currents in the mantles may generate the magnetic fields of the planets

The magnetic fields of both Uranus and Neptune are oriented at unusual angles

- The magnetic axes of both Uranus and Neptune are steeply inclined from their axes of rotation
- The magnetic and rotational axes of all the other planets are more nearly parallel
- The magnetic fields of Uranus and Neptune are also offset from the centers of the planets

Uranus and Neptune each have a system of thin, dark rings

Some of Uranus’s satellites show evidence of past tidal heating

Uranus has five satellites similar to the moderate-sized moons of Saturn, plus at least 22 more small satellites (total now of 27 moons)
Triton is a frigid, icy world with a young surface and a tenuous atmosphere
- Neptune has 13 satellites, one of which (Triton) is comparable in size to our Moon or the Galilean satellites of Jupiter
- Triton has a young, icy surface indicative of tectonic activity
- The energy for this activity may have been provided by tidal heating that occurred when Triton was captured by Neptune’s gravity into a retrograde orbit

Pluto and its moons, Charon is the largest, may be typical of a thousand icy objects that orbit far from the Sun
- Pluto was discovered after a long search
- Pluto and its moon, Charon, move together in a highly elliptical orbit steeply inclined to the plane of the ecliptic
- They are the only worlds in the solar system not yet visited by spacecraft

Pluto Surprises
- It has moons
- Original moon discovered 1978 – Charon (KAIR’ en)
- Now more – 2005 discovery of 2 additional moons – Named Nix and Hydra

Pluto's History
- Planet X predicted – from perturbations in Uranus and Neptune orbit
- Discovered February 18, 1930 – discovered by Clyde Tombaugh
  - accidental discovery (Neptune’s mass was wrong)
- First moon discovered 1978 (announced 7 July) – discovered by James Christy
- Spectroscopic studies – First attempt in ’30s, first success in ’70s

Spectral Analysis
- Compare with known samples
- First conclusions – methane ice – water ice – ammonia ice
- Develop models for surface to interior – based upon spectral analyses and density
Pluto’s Interior to Surface Model

• Model 1
  – partially hydrated rock core
  – water ice layer II
  – predominant water ice layer I
• Model 2
  – partially hydrated rock core
  – organics layer
  – predominantly water ice layer

---

iClicker Question

• Io is riddled with volcanoes because of its proximity to Jupiter’s strong magnetic field.
  – A True
  – B False

---

iClicker Question

• Europa is likely to have fishlike organisms the size of whales swimming in its ocean.
  – A True
  – B False

---

iClicker Question

• While Europa, Ganymede, and Callisto are all candidate locations for life, we expect that the most abundant and diverse life would be found in Callisto.
  – A True
  – B False

---

iClicker Question

• The fact that our Moon keeps one side always facing Earth is an astonishing coincidence.
  – A True
  – B False
iClicker Question

• Titan is simply too cold to have any life.
  – A True
  – B False

iClicker Question

• Triton might have life that uses liquid ammonia, rather than liquid water, as its transport medium.
  – A True
  – B False

iClicker Question

• Io doesn’t have a significant atmosphere because it lacks a source of outgassing.
  – A True
  – B False

iClicker Question

• Orbital resonances like that between Io, Europa and Ganymede are the results of extremely rare accidents, so we would not expect tidal heating to be important in other planetary systems.
  – A True
  – B False

iClicker Question

• If there is life on Enceladus, it probably gets its energy from sunlight.
  – A True
  – B False

iClicker Question

• If our solar system is typical, then other star systems might have an average of five to ten worlds on which liquid water (or a mixture of water and some other liquid) exists in at least some places.
  – A True
  – B False