Chapter 9: **Giant planets and magnetospheres**

- review giant planet properties
- internal structures
- atmospheres: composition, structure, weather
- magnetospheres
- sample problems

Review giant planets

Let's briefly review the high points from the material in the Planetary Overview chapter. Jupiter and Saturn are often called gas giants because hydrogen and helium constitute such a high fraction of their mass. Uranus and Neptune are often called ice or slush giants because their densities are higher than those of the gas giants and they are likely to contain relatively higher percentages of icy materials. All four giant planets are beyond the "snow line", the region in the solar system where icy volatiles are likely to have been able to condense out of the gas phase in the early proto-planetary nebula in which we think the planets were forming. Their locations should have played a role in their ability to grab volatiles, grow faster, and retain higher levels of volatiles than the terrestrial planets. All four have substantial magnetic fields, rings and large numbers of satellites. Jupiter, Saturn, and Neptune all emit approximately twice as much energy as they receive from the Sun. All four giant planets have been visited by spacecraft, although only Jupiter and Saturn have had extended visits (by Galileo and Cassini, respectively); Voyager 2 flew past Uranus in 1986 and Neptune in 1989.

Internal Structures

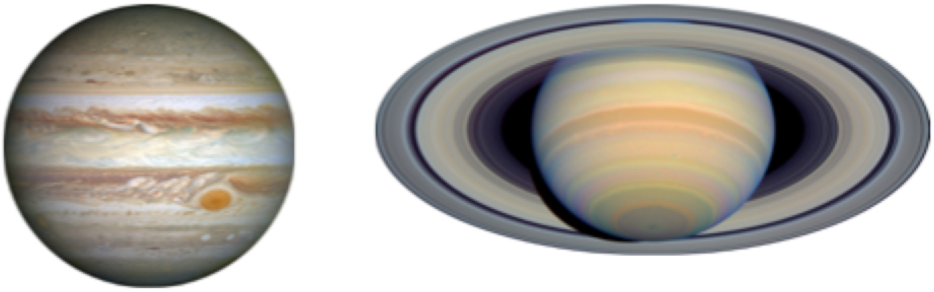


Figure 9.1: Gas giants; NASA images

Jupiter and Saturn are approximately 300 and 100 times the mass of Earth, respectively. Our best current models of their interiors suggest that they should both have rocky / metallic cores, possibly distinct from layers of icy material ("icy" meaning volatiles such as water and ammonia, not meaning that it's cold). It's not clear whether there is a distinct metallic core, differentiated from a rocky layer or whether the core is more heterogeneous. Both planets' cores are about three times more massive than Earth, and, when we include the ices, about 5 – 10 times more massive than Earth. Above their cores we expect thick layers of liquid metallic hydrogen, thicker for Jupiter than for Saturn. And above that are extensive layers of hydrogen and helium, probably varying smoothly from lower, denser, liquids to the gases, clouds, and haze we see at the visible surface. Here are sketches of their structures:

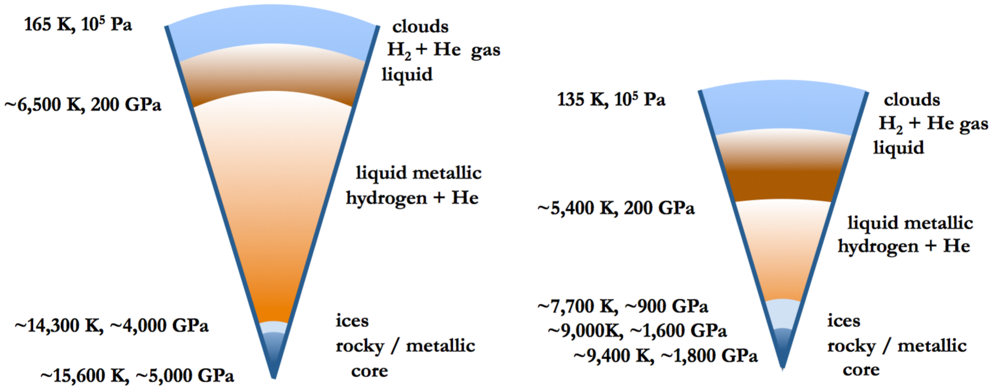


Figure 9.2: Interior models of Jupiter (left) and Saturn (right)

Metals conduct heat and electricity relatively well because some of the electrons of the atoms or molecules in a metal are delocalized, moderately free to move rather than being attracted to only one positively charged nucleus. Under the extreme pressures in the interiors of Jupiter and Saturn hydrogen molecules are forced close enough to each other that their electrons can move, leading to a layer of liquid metallic hydrogen. On Earth, the most familiar liquid metal is mercury (in which the positive ions have lost two electrons each and the electrons can move through the liquid). Models suggest that in Jupiter and Saturn the liquid metallic hydrogen layer is the location of the magnetic dynamo.

The temperatures at the visible surface layers of Jupiter and Saturn are ~124 and ~95 K, respectively; in both cases this is about 10 K warmer than if the planet were in equilibrium with incoming solar radiation. For Jupiter, the excess infrared it emits is consistent with continued slow contraction and the ongoing release of gravitational potential energy. Mathematically, the rate of gravitational energy release is given by

$$\frac{d\Phi}{dt} = \frac{d\Phi}{dr}\frac{dr}{dt} \approx \frac{GM^2}{R^2}\frac{dr}{dt}.$$

Jupiter emits about 1.7 times as much energy as it receives from the Sun, which means about ~8 $\cdot 10^{17}$ J/sec. (Given the solar luminosity, Jupiter's distance, size, and albedo, it receives ~5 $\cdot 10^{17}$ J/sec from the Sun.) That translates into a change in radius of ~5 cm / century. Saturn is similar, emitting about 1.8 times as much energy as it receives from the Sun. In the case of Saturn, the excess energy is thought to come from gravitational potential energy released by helium "rain". Helium is immiscible in liquid hydrogen at the lower temperatures present in Saturn and is expected to sink.

Uranus and Neptune are distinctly less massive than the gas giants, at 14½ and 17 Earth masses, respectively, meaning that they experience much less self-compression.

Figure 9.3: Slush giants; NASA images

The bulk properties of the giant planets are shown in the following table:

Table 9.1: bulk properties of giant planets

	Jupiter	Saturn	Uranus	Neptune
Mass (Earth masses)	318	95	14.5	17.1
Average radius (Earth radii)	11.0	9.1	4.0	3.9
Flattening ($1 - R_{polar}/R_{equator}$)	0.065	0.098	0.023	0.017
Moment of inertia factor	0.254	0.210	0.225	~0.25
Density (g/cm^3)	1.33	0.69	1.27	1.64

All the giant planets rotate, at least for the most part, as fluids, which is why they are all noticeably flattened. The moment of inertia factor = $I / (M R^2)$; recall that this ratio = 0.4 for a spherically symmetric object in which the mass is uniformly distributed. A ratio smaller than 0.4 means a more centrally condensed planet; for comparison, the ratio is 0.33 for Earth and 0.39 for the Moon. Earth is more differentiated than the Moon and all four giant planets are distinctly more centrally condensed than Earth. Uranus and Neptune must have a higher percentage of heavier elements than the gas giants, although with only the Voyager 2 fly-bys and Earth-based observations, we know even less about the possible differentiation of the cores of Uranus and Neptune than we do about Jupiter and Saturn. The following sketches of their interior models are thus less well constrained:

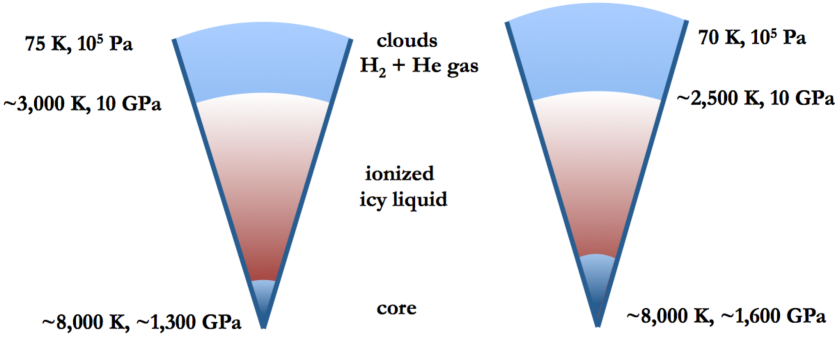


Figure 9.4: Interior models of Uranus (left) and Neptune (right)

The best current model for the composition of the ionized icy liquid is a mix of water, ammonia, and methane, in which we have ions of NH_4^+, H_3O^+, and OH^-. At high pressure, this mix should be capable of carrying the current necessary to produce the observed magnetic fields; as mentioned in chaper 5, the conditions might be right to produce superionic ice, with free hydrogens moving through an oxygen matrix.

The effective temperatures (the visible layer temperatures, equivalent to the temperature of a blackbody with the same energy output) of Uranus and Neptune are, as expected, cooler than those of Jupiter and Saturn, but they are an almost identical 59 K. The equilibrium temperatures would be 60 K for Uranus and 48 for Neptune. In other words, these two planets are very different in their energy output. Neptune emits ~2.6 times as much energy as it receives from the Sun; Uranus emits only ~1.1 times as much. Both of these numbers are problematic. One could argue that Uranus has simply cooled off inside, i.e., that it has radiated away all of the excess internal heat it might have had at formation. But it's got a magnetic field. If that magnetic field is produced by a dynamo involving interior convection then Uranus must still have internal energy or there would not be enough heat to drive convective currents. Neptune, on the other hand, would have to have retained too much of its original heat, i.e., not cooled down as much as thermal evolution models suggest that it should, if its excess heat is due to accretional energy. Some process that inhibits convection in the deep interior, i.e., less than about half the planet's radius but differing slightly for the two planets, may play a role in explaining their differing energy budgets. Some models suggest that it's possible that the lack of energy from Uranus could be related to whatever collision knocked the Uranian system on its side, but we don't yet have a totally compelling explanation for the difference between these two planets.

Atmospheres & outermost clouds of the giant planets

The atmospheres of the giant planets are defined as the layer above 10^5 Pa (i.e., above 1 bar), which is roughly the top of the visible cloud deck. The atmospheres of these planets are predominantly molecular hydrogen and helium, neither of which is particularly easy to detect spectroscopically. Hydrogen is a homonuclear diatomic molecule; recall from what you've read about molecular spectra that small linear symmetric molecules don't have a permanent electric dipole and thus don't interact readily with the infrared emission that's coming from the interior of the planet. That said, hydrogen is amazingly abundant and even unlikely transitions are detectable. The following table lists the abundances by number of the major constituents of the atmospheres of the giant planets.

Table 9.2: Atmospheric properties of giant planets

	Jupiter	Saturn	Uranus	Neptune
H_2	0.864	0.963	0.85	0.85
He	0.136	0.033	0.13	0.13
H_2O	$2.3 \cdot 10^{-3}$	$\sim 1.6 \cdot 10^{-3}$	$\sim 1.4 \cdot 10^{-3}$	$\sim 1.4 \cdot 10^{-3}$
CH_4	$1.8 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$	0.020	0.030
NH_3	$2.3 \cdot 10^{-4}$	$4.8 \cdot 10^{-4}$	$< 1.9 \cdot 10^{-4}$	$< 1.9 \cdot 10^{-4}$
H_2S	$1.9 \cdot 10^{-4}$	$3.8 \cdot 10^{-4}$	$\sim 3 \cdot 10^{-4}$	$\sim 8 \cdot 10^{-4}$
Ne	$2.0 \cdot 10^{-5}$			
Ar	$1.3 \cdot 10^{-5}$			
C_2H_6	$\sim 3 \cdot 10^{-6}$	$\sim 3 \cdot 10^{-6}$	$< 1 \cdot 10^{-8}$	$1.7 \cdot 10^{-6}$
Traces	other hydrocarbons, CO	→	→	→
	PH_3, GeH_4 →		HCN →	

In the terrestrial planet atmospheres carbon is more likely to be found in CO or CO_2 than in CH_4 and nitrogen is more likely to occur as N_2 rather than as NH_3. Chemists would call the terrestrial conditions *oxidizing* and the giant planet atmospheres *reducing*. Oxidation was originally defined as a substance gaining an oxygen atom or losing a hydrogen and reduction as the opposite. (More properly today oxidation would be defined as a loss of electrons and reduction as a gain of electrons.) For instance, the oxidation of methane could produce carbon monoxide:

$$CH_4 + 3/2\ O_2 \rightarrow CO + 2\ H_2O$$

or, if there is abundant oxygen, methane can oxidize to CO_2.

The balance of CH_4 vs. CO or NH_3 vs. N_2 depends on temperature and pressure. At the low pressures in the early solar system when ices were first condensing, CO is the more stable molecule at temperatures above ~700 K and N_2 above ~300 K. At lower temperatures CH_4 and NH_3 are favored. This assumes that the chemical reactions in the early solar nebula had a chance to reach equilibrium. You may recall that we find CO and N_2 ices on Pluto and Triton. That's not what we would expect for the outer solar system and it's evidence of disequilibrium.

The following image of Jupiter was taken in 2014 and shows the classic banded pattern of its clouds. The bright white cloud bands are traditionally called *zones* and the dark orange / brown bands are called *belts*. The oval orange storm in the southern hemisphere is the Great Red Spot. The Great Red Spot (GRS) is an anti-cyclonic storm.

Figure 9.5; Jupiter's clouds.

NASA / ESA - Hubble Space Telescope
2014 WFC3 / UVIS
http://www.nasa.gov/sites/default/files/14-135-jupiter2_0.jpg

Anti-cyclonic means that it rotates in the opposite sense relative to a hurricane or cyclone on Earth, and the central pressure is higher, rather than lower, than its surroundings. The GRS has been observed regularly since ~1830; red spots on Jupiter have been known since ~1665 and it is possible that this same storm has been in existence for 350 years. Other red spots have been observed to come and go, though, and in recent decades the GRS has been shrinking. When the Voyager spacecraft flew past in 1979 the GRS was ~23,200 km across and distinctly elongated east-west. In 2014 the spot was ~16,400 km across. In 2019 it was observed to be spinning off smaller red clouds and shrinking even more. Other Jovian cloud patterns change over time as well. Voyager 2 flew past Jupiter in July 1979 and acquired this image of the Great Red Spot and one of three white ovals, remnants of an "obscuration of the south temperate belt by a high-albedo cloud formation" in 1938 (Reta Beebe 1979). It's possible that one or two of these three white ovals predated the eruption of the 1938 white cloud. The three white ovals were relatively stable until 1998 when two of them merged. Two years later the remaining two merged, after the dissipation of a smaller oppositely rotating feature that had kept them apart. In 2006 this storm turned red; it's possible that updrafts dredged up new deeper material to heights where the Sun's ultraviolet altered the chemistry and the color. In observations of "Red Jr." in an 892-nm near IR methane absorption band the two red spots were nearly equally bright.

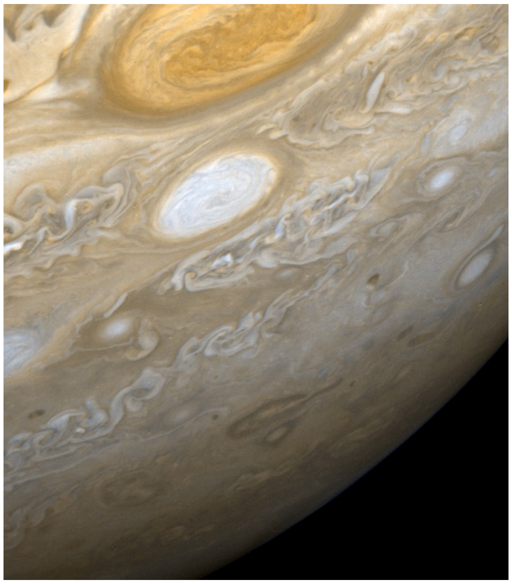
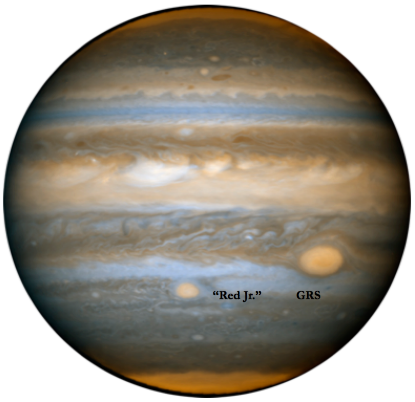


Figure 9.6: Great Red Spot and White Oval.
NASA – Voyager 2
http://nssdc.gsfc.nasa.gov/imgcat/hires/vg2_p21737.jpg

Figure 9.7: April 2006 near IR image of Jupiter's red spots.

NASA / ESA Simon-Miller, de Pater, & Wong – Hubble Space Telescope ACS / WFC
http://hubblesite.org/newscenter/archive/releases/2006/19/image/c/



Jupiter's cloud bands are not all the same altitude. White often means relatively higher layers of ammonia ice, while darker redder layers, with colorful compounds of sulfur, phosphorus, and hydrocarbons, are usually deeper and warmer. The following sketch shows roughly the thermal structure of Jupiter's atmosphere and cloud layers.

You can also tell from the three images above that Jupiter's wind speeds vary noticeably as a function of latitude. The highest winds, called jets, tend to be found at the boundaries between the belts and zones. Wind speeds at Jupiter have been measured by multiple spacecraft and they seem to be relatively stable. The sketch below and image of Jupiter are based on data taken by the Cassini mission as it passed Jupiter en route to Saturn.

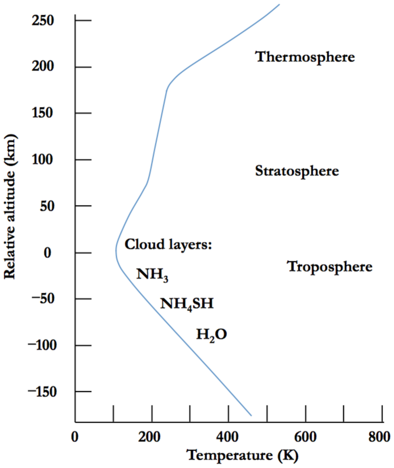


Figure 9.8: Thermal structure of Jupiter's atmosphere

Investigators have proposed several explanations for the belt / zone structure of Jupiter's clouds. One problem with establishing a persuasive model is that we don't know yet how deep seated this structure is. The Juno spacecraft, launched in 2011, arrived at Jupiter in July 2016 and is expected to orbit the planet for two years. Science objectives for the Juno mission include characterizing the Jovian atmosphere and cloud layers down to a depth of at least 10 MPa, as well as mapping Jupiter's magnetic and gravitational fields in much more detail than past observations have permitted. Juno data released in 2018 suggest that Jupiter's wind and weather layer extends to a depth of about 3,000 km; that's a deep enough layer to contain about 1% of Jupiter's mass. Juno images of Jupiter's polar storms suggest that they are long-lived. Extra-stormy convection near the poles may be related to the observation that relatively more of Jupiter's lightning occurs in polar regions, unlike on Earth where lightning is more likely at lower latitudes.

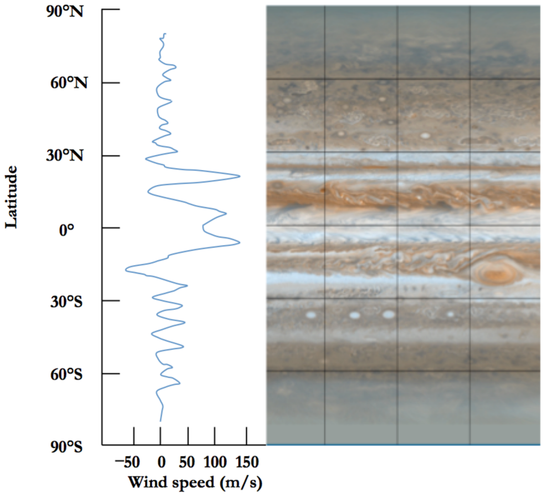


Figure 9.9: Wind speeds at Jupiter.

Image: NASA / JPL / Space Science Inst. – Cassini spacecraft, December 2000
http://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA07782

Wind speed data: Carolyn Porco et al. 2003, *Science* **299** pp. 1541 – 1547 "Cassini Imaging of Jupiter's Atmosphere, Satellites, and Rings"

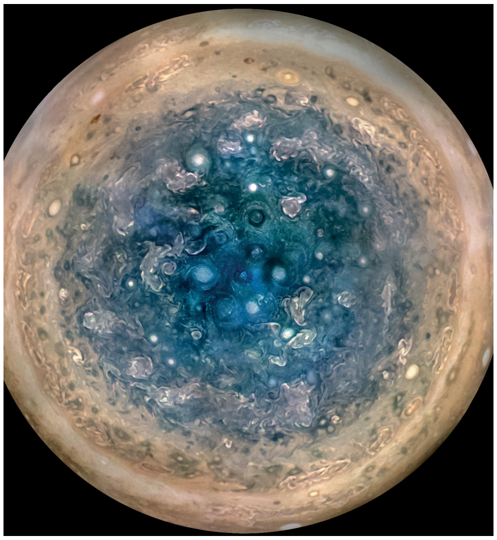


Figure 9.10: Jupiter's south polar cyclones. The cyclones are roughly 1,000 km diameter. The color has been enhanced in this image.

NASA / JPL-Caltech / SwRI / MSSS / Betsy Asher Hall / Gervasio Robles — Juno spacecraft
https://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA21641

Saturn's atmosphere also has a banded structure, although it's much more muted due to high layers of haze. Saturn also periodically has eruptions of icy storms, such as the 2011 storm shown in the following image. This image was taken ~3 months after the ice clouds first erupted, in which time the storm had circled the planet and started passing its own tail. Storms such as this seem to generate intense lightning, which produces noisy radio signals that can be observed from Earth.

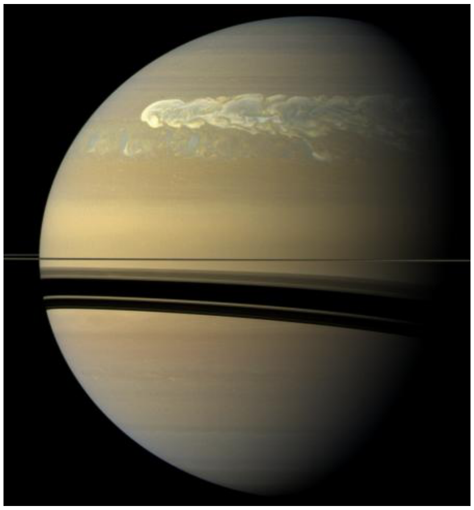


Figure 9.11: Saturn’s atmosphere and 2011 storm.

NASA / JPL / Space Science Institute – Cassini spacecraft
http://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA12826

The cloud patterns show up more clearly in near infrared; the following color-enhanced image was made by the Cassini spacecraft in three near-IR bandpasses.

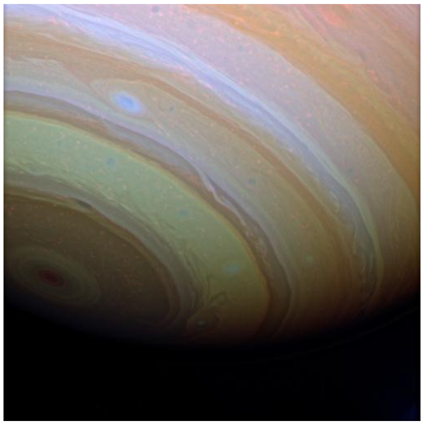


Figure 9.12: Color-enhanced image of Saturn’s clouds.

NASA /JPL / Space Science Institute – Cassini spacecraft
http://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA08952

The wind speeds on Saturn are higher than at Jupiter, particularly near the equator, but they don’t correspond quite as neatly to changes from one band of clouds to another as the jets do in Jupiter’s atmosphere. The following sketch shows approximately Saturn’s wind speed as a function of latitude as observed by the Cassini spacecraft.

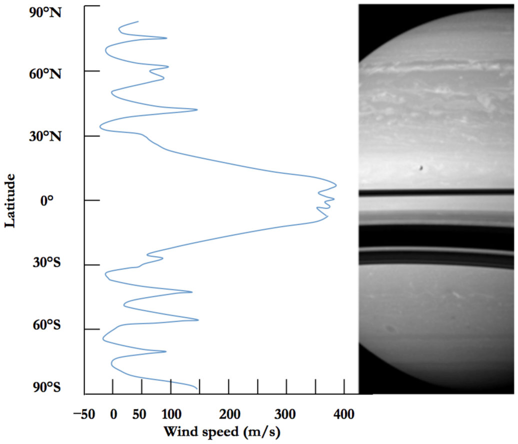


Figure 9.13: Winds on Saturn. The satellite in the image is Tethys.

Image: NASA / JPL / Space Science Inst. – Cassini spacecraft, January 2012.
http://photojournal.jpl.nasa.gov/catalog/PIA14609

Wind speed data: García-Melendo et al. 2011, *Icarus* **215**, pp. 62-74, “Saturn’s zonal wind profile in 2004-2009 from Cassini ISS images and its long-term variability.”

Saturn has intriguing polar features. Cassini observations showed that at the north pole there is a long-lived atmospheric feature that's hexagonal in shape, and that rotates with the interior rotation period. At the south pole Cassini observed a hurricane that's about the size of the entire Earth. There may be intrinsic differences between the poles or, given that Saturn's year is ~30 Earth-years long and Cassini was not able to observe Saturn's poles for an entire year, it may be that the polar winds vary with the season.

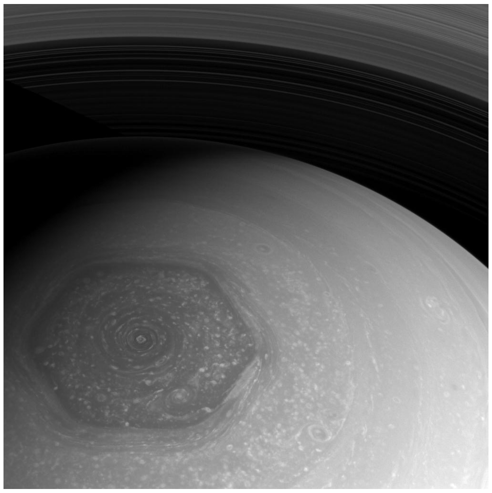


Figure 9.14: Saturn's north polar jet / hexagon.
NASA / JPL / Space Science Institute – Cassini spacecraft, July 2013.
http://photojournal.jpl.nasa.gov/catalog/PIA17141

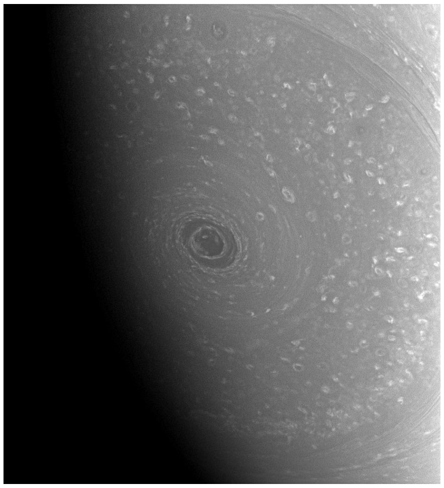


Figure 9.15: Saturn's south polar hurricane.
NASA / JPL / Space Science Institute – Cassini spacecraft, August 2008.
http://photojournal.jpl.nasa.gov/catalog/PIA10490

The thermal profile of Saturn's atmosphere is much like Jupiter's. Saturn's cloud layers are a bit thicker (with less gravity the scale heights are larger) and there's a layer of high-altitude haze and these together make it harder to see deeper warmer clouds, resulting in the bland appearance we tend to associate with Saturn.

As with their interiors, we know less about the atmospheres of Uranus and Neptune than about the gas giants. Both appear blue-ish because of methane, which has several absorption bands in the red and near IR. Uranus' appearance, in visible light, is interesting for being so amazingly boring. It, too, turns out to have a banded pattern of clouds and occasional storms. Ariel and its shadow are in the right-hand image.

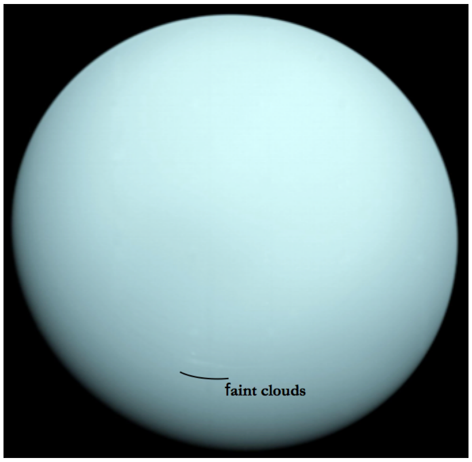


Figure 9.16: Uranus in visible light.

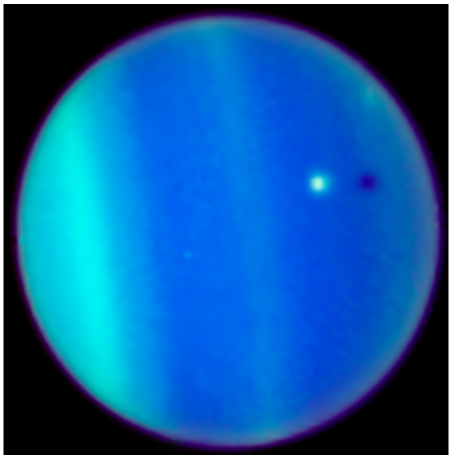


Figure 9.17: Uranus in near infrared; the

Note that these images were taken twenty years apart and from different locations, so the poles are oriented differently.

During the 1898 Voyager 2 flyby Neptune was sporting several distinctive spots. The winds blow at different speeds at different latitudes, so the spots were not always all in an image. This frame captured the three most noticeable spots.

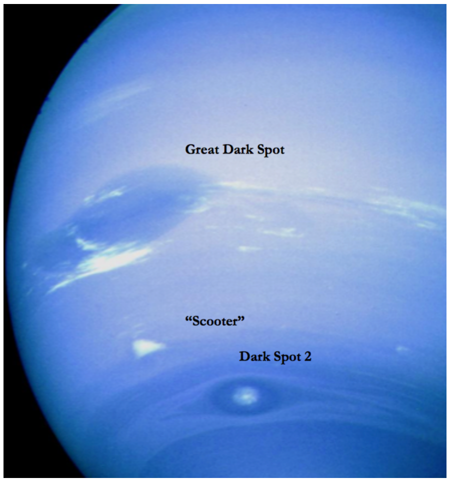


Figure 9.18: Neptune's spots

NASA / JPL – Voyager 2 spacecraft, 1989
http://photojournal.jpl.nasa.gov/catalog/PIA01142

One image, taken only two hours before closest approach, caught Neptune's high cirrus-like clouds with the sunlight at a low enough angle that the clouds cast shadows, providing evidence that they are, in fact, higher, ~50 km higher, than their surroundings.

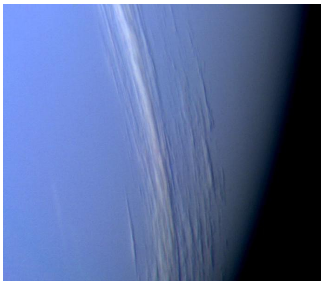


Figure 9.19: Neptune high cirrus.

NASA / JPL – Voyager 2 spacecraft, 1989
http://photojournal.jpl.nasa.gov/catalog/PIA00058

More recently, Hubble Space Telescope images have captured changes in Neptune's clouds as springtime comes to the southern hemisphere.

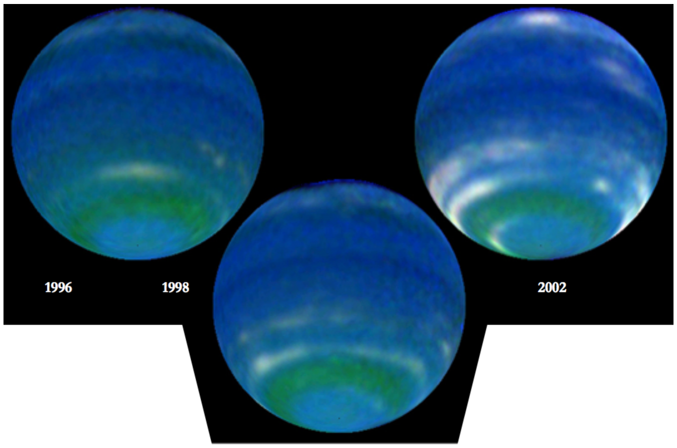


Figure 9.20: Seasonal changes in Neptune's clouds.

NASA / L. Sromovsky and P. Fry – HST WFPC2
http://hubblesite.org/newscenter/archive/releases/2003/17/image/

The following sketch shows roughly the thermal profile and cloud locations for the atmosphere of Neptune. Uranus is similar, although temperatures of ~100 K occur a bit higher in its atmosphere. Both Uranus and Neptune have strong winds. At Uranus the winds can reach ~240 m/sec and at Neptune, over 500 m/sec. In the right-hand panel, below, is a sketch of the winds of Uranus and Neptune as a function of latitude, based on data in Kaspi et al. 2013, *Nature*, **497**, pp. 344-347, "Atmospheric confinement of jet streams on Uranus and Neptune".

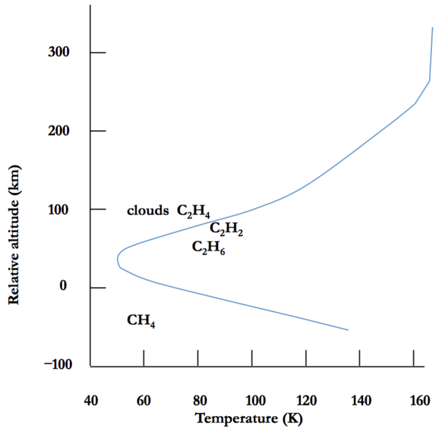


Figure 9.21: Thermal profile for the atmosphere of Neptune.

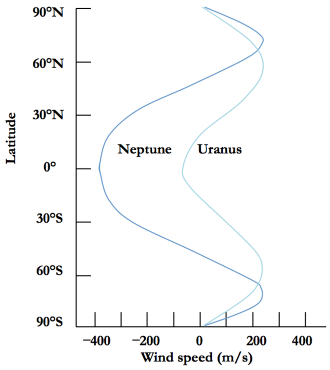


Figure 9.22: Wind speeds for Uranus and Neptune

The ice giants still have secrets. Why is Uranus tilted over on its side? Why are their magnetic fields so offset from the centers of the planets? Why do they differ in mass and in internal heat? Why are the winds so strong? We hope someday to be able to answer these questions.

Magnetospheres

A magnetic dynamo requires a rotating, convecting, conducting fluid to maintain a predominantly dipole field over the lifetime of the solar system. All four giant planets have dipole fields. For Uranus and Neptune, those dipoles are highly inclined and significantly offset from the center of the planet.

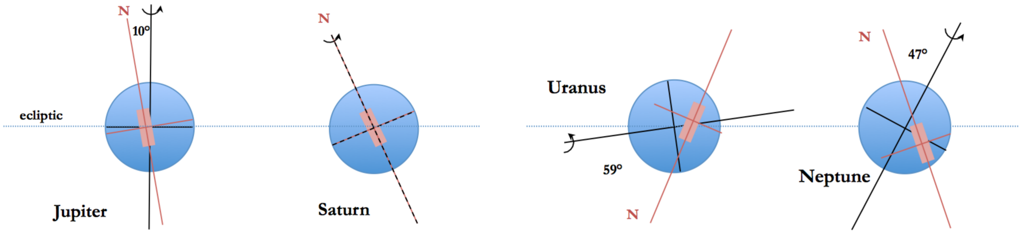


Figure 9.23: Magnetic dipole orientations

The above sketches show the orientations of the rotation axes and the magnetic field axes, relative to the ecliptic, for the giant planets. The following table gives the strengths for various magnetic fields, including the giant planets, the Earth, Ganymede, and Mercury. The surface field strength is an average value for the magnetic equator given in units of microtesla (which equal 10^2 times the field strength in gauss). For a given surface field strength a larger planet, where the surface is farther from the dynamo, must have a stronger intrinsic field; that's what the dipole magnetic moment tries to capture. It's given in units of $T{\cdot}m^3$.

Table 9.3: Magnetic field strengths of giant planets

	Surface field strength	Magnetic moment	
	µT	T·m³	relative to Earth
Jupiter	428	$1.6 \cdot 10^{20}$	20,000
Saturn	22	$4.8 \cdot 10^{18}$	600
Uranus	23	$3.8 \cdot 10^{17}$	50
Neptune	14	$2.2 \cdot 10^{17}$	25
Earth	31	$7.9 \cdot 10^{15}$	1
Ganymede	0.72	$1.3 \cdot 10^{13}$	$1.7 \cdot 10^{-3}$
Mercury	0.3	$2.8 \cdot 10^{12}$	$3.5 \cdot 10^{-4}$

An object's (star, planet, moon. . .) *magnetosphere* is the region within which the motions of charged particles are controlled by the object's magnetic field. Within the solar system, magnetospheres are crunched on the side toward the Sun, where the solar wind particles and the Sun's magnetic field push on the magnetosphere of a planet or moon. There's a *bow shock* where the solar wind particles, moving several hundred km/sec, are starting to slam into the planet's magnetosphere, and just planetward of the bow shock, a magnetosheath of shocked and slowing plasma, solar wind particles that weren't totally deflected but made it through the bow shock. The *magnetopause* is the boundary layer between this shocked solar wind region and the planet's actual magnetosphere. On the downwind side, away from the direction of the solar wind, is the *magnetotail*, which may extend for quite a ways. In the case of Jupiter, the tail extends past the orbit of Saturn! Magnetic field lines need to close, so the direction of the magnetic field lines in one half of the magnetotail is inward toward the planet and in the other half it's outward. Usually these are the north side and south side, but then most planets' magnetic axes are aligned roughly north-south. The two lobes of the magnetotail are separated by a plasma sheet, often containing trapped solar wind particles.

Nearer the planet the more tightly closed loops of the magnetic field may trap particles in radiation belts. One of the earliest discoveries of the space age was of the Van Allen belts of charged particles around Earth, named for investigator James Van Allen. Moving charged particles spiral around magnetic field lines. The field lines get pinched together near the magnetic poles, which has the effect of reflecting the particles, which proceed to bounce back and forth. Some particles hit our atmosphere, creating the aurorae, some escape, and more are added when the Sun is particularly active and its eruptions lead to geomagnetic storms. The following sketch shows the structure of the Earth's magnetosphere. Note that the field lines streaming off into the magnetotail will reconnect eventually.

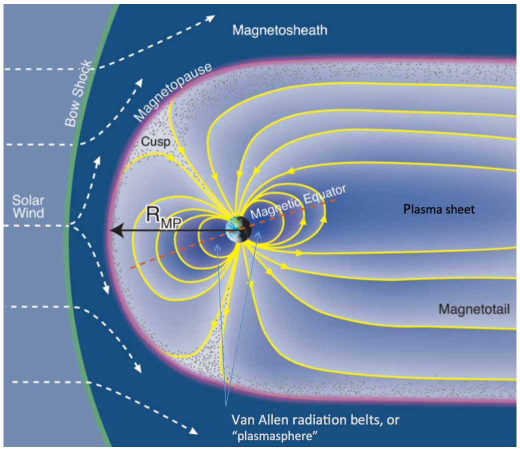


Figure 9.24: Earth's magnetosphere

Image Credit: Fran Bagenal and Steve Bartlett / University of Colorado / LASP

http://lasp.colorado.edu/home/wp-content/uploads/2010/08/MOP-1Msphere.jpg

Jupiter's inner moons orbit within its magnetosphere. Particles are ionized and lost from Io into a torus of plasma that extends all the way around Jupiter. Magnetic flux tubes carrying trapped charged particles run from Io, and to a lesser extent also from Europa and Ganymede, to Jupiter's magnetic poles. The charge carried by all the moving particles in the Io flux tube is equivalent to about 5 million amps! We see aurorae where the flux tubes connect with Jupiter's atmosphere. The following sketches show Jupiter's magnetosphere and the inner region with the flux tubes and aurorae.

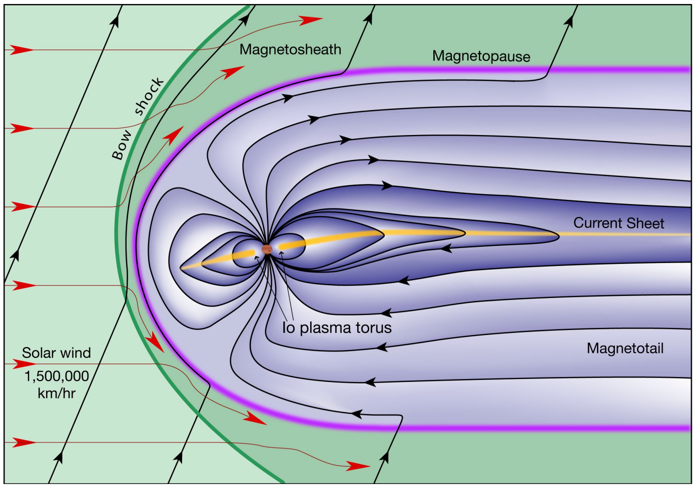


Figure 9.25: Jupiter's magnetosphere

Image Credit: Fran Bagenal and Steve Bartlett / University of Colorado / LASP

http://lasp.colorado.edu/home/wp-content/uploads/2010/08/MOP-6JupMag-8.jpg

Figure 9.26: Jupiter's inner magnetosphere: Io plasma torus, flux tubes through Galilean satellites, and UV image of aurorae.

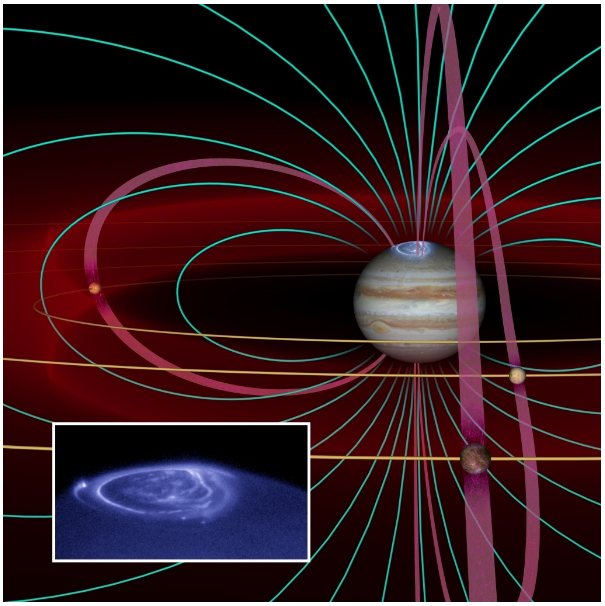


Image Credit: John Clarke and John Spencer / University of Colorado / LASP

http://lasp.colorado.edu/home/wp-content/uploads/2010/08/MOP-FluxTubes.jpg

What the above image does not show is that Ganymede carves out a small magnetosphere of its own inside Jupiter's. At Saturn we also find inner moons orbiting within the planet's magnetosphere. There's a plasma torus of particles kicked off Enceladus, for instance, and Saturn also has aurorae.

Magnetospheres vary in size with the magnetic field strength. Objects without a magnetic dynamo and hence with weak magnetic fields have very little protection from incoming solar wind particles. If we were to want to establish bases on the Moon or Mars we'd have to take measures to protect ourselves from these high-energy particles. The following sketch shows the relative sizes of the magnetospheres of Mercury, the Earth, Jupiter, and then the Sun itself, embedded in an interstellar wind of charged particles.

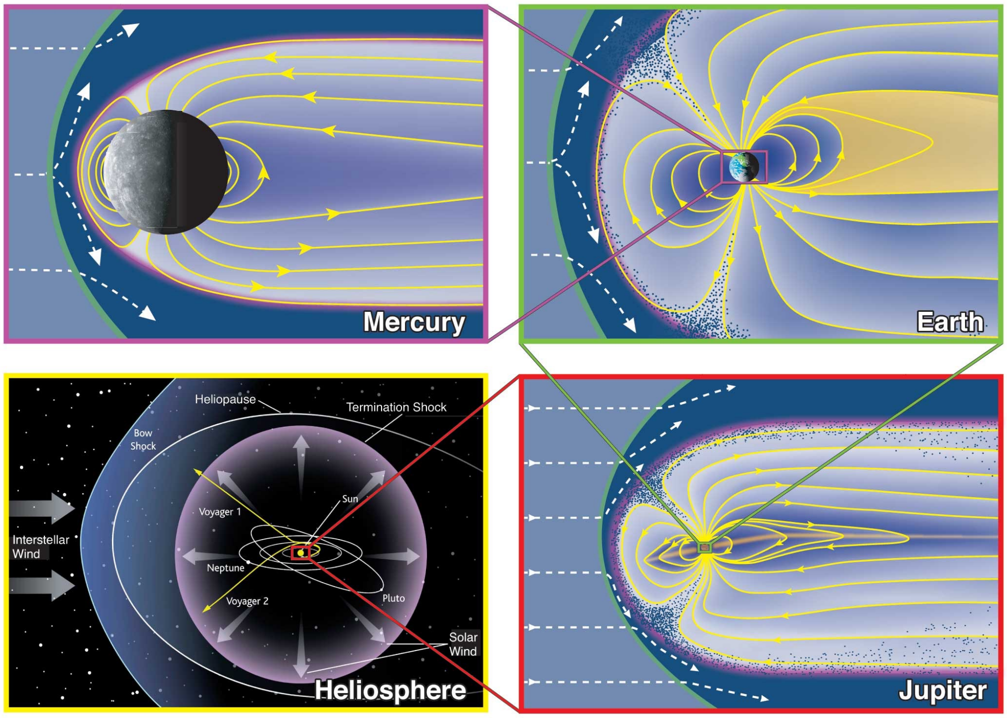


Figure 9.27: Comparative sizes of solar system magnetospheres
Image Credit: Fran Bagenal and Steve Bartlett / University of Colorado / LASP
http://lasp.colorado.edu/home/wp-content/uploads/2010/08/MOP-3MEJH.jpg

The giant planets rotate differentially, meaning that their cores don't necessarily rotate at the same rate as their outer layers and that in the visible layers the equator and higher latitudes don't necessarily rotate at the same rate. For Jupiter, for instance, latitudes near the equator rotate in ~$9^{h}50^{m}30^{s}$ while latitudes north and south of ~9° rotate more slowly, in ~$9^{h}55^{m}41^{s}$. Planetary scientists refer to these as System I and System II rotation periods, respectively. Jupiter's magnetosphere rotates in $9^{h}55^{m}30^{s}$, which shows up as a periodicity in radio emissions, and this deep-seated rotation rate, called System III, is what you'll find if you look up the planet's sidereal rotation rate. Saturn behaves similarly, rotating in ~$10^{h}15^{m}$ close to the equator, ~$10^{h}38^{m}$ at higher latitudes, and its magnetic field rotates in $10^{h}39.4^{m}$, the latter taken to represent the deep-seated rotation rate of the interior of the planet. The magnetospheres of Uranus and Neptune wobble around because the magnetic field axes are at such odd angles with respect to the rotation axes.

Sample problems

1. Check the calculation that Jupiter could supply the extra energy it emits, compared to what it receives from the Sun, by shrinking roughly 5 cm / century.

a) Jupiter's surface temperature is ~124 K. Assuming it radiates as a blackbody, what is its luminosity in J/s?

b) How much energy does Jupiter absorb from the Sun in J/s? Hints: to the Sun, Jupiter appears as a disk; don't forget to factor in the albedo.

The gravitational potential energy released as Jupiter contracts would be approximately $\frac{3}{4}\frac{GM^2}{R^2}\frac{dr}{dt}$; the factor of 3/4 accounts for the fact that Jupiter is not a homogeneous sphere of uniform density (in which case it would be a factor of 3/5).

c) Assuming *dt* is a century and the energy emitted is the difference between a) and b), estimate how much Jupiter would need to shrink for released gravitational potential energy to be sole source of the excess energy it emits relative to the energy it receives from the Sun. Hint: don't forget the virial theorem.

2. Reading carefully?

a) Where / why is liquid metallic hydrogen important?
b) What's odd about the amount of energy emitted by Uranus?
c) What are zones and belts?
d) Sketch a dipole magnetic.
e) What is a magnetosphere?
f) What is Io's plasma torus?

Answers to selected problems are on the next page:

1. a) ~ $8.23 \cdot 10^{17}$ J/s
   b) ~ $5.07 \cdot 10^{17}$ J/s
   c) ~ 5 cm per century