# Mercury

## A. Planet Profile

Orbit: 57,910,000 km (0.38 AU) from Sun  
Diameter: 4,880 km  
Mass: 3.30e23 kg

### History of Mercury

In Roman mythology Mercury is the god of commerce, travel and thievery, the Roman counterpart of the Greek god Hermes, the messenger of the Gods. The planet probably received this name because it moves so quickly across the sky. Mercury has been known since at least the time of the Sumerians (3rd millennium BC). It was sometimes given separate names for its apparitions as a morning star and as an evening star. Greek astronomers knew, however, that the two names referred to the same body. Heraclitus even believed that Mercury and Venus orbit the Sun, not the Earth. Since it is closer to the Sun than the Earth, the illumination of Mercury's disk varies when viewed with a telescope from our perspective. Galileo's telescope was too small to see Mercury's phases but he did see the phases of Venus. Mercury has been now been visited by two spacecraft, Mariner 10 and MESSENGER. Marriner 10 flew by three times in 1974 and 1975. Only 45% of the surface was mapped (and, unfortunately, it is too close to the Sun to be safely imaged by HST). MESSENGER was launched by NASA in 2004 and has been in orbit Mercury since 2011. Its first flyby in Jan 2008 provided new high quality images of some of the terrain not seen by Mariner 10. Since then Messenger has taken over 250,000 photographs coving the entire planet. Global Mosaics. The mission has provided support for the hypothesis that water ice and other volatiles do exist in the Polar Regions in permanent shadow. Mercury's orbit is highly eccentric, at perihelion it is only 46 million km from the Sun but at aphelion it is 70 million. The position of the perihelion processes around the Sun at a very slow rate. 19th century astronomers made very careful observations of Mercury's orbital parameters but could not adequately explain those using Newtonian mechanics. Until 1962 it was thought that Mercury's "day" was the same length as its "year" so as to keep that same face to the Sun much as the Moon does to the Earth. But this was shown to be false in 1965 by Doppler radar observations. It is now known that Mercury rotates three times in two of its years. Mercury is the only body in the solar system known to have an orbital/rotational resonance with a ratio other than 1:1 (though many have no resonances at all). This fact and the high eccentricity of Mercury's orbit would produce very strange effects for an observer on Mercury's surface. At some longitudes the observer would see the Sun rise and then gradually increase in apparent size as it slowly moved toward the zenith. At that point the Sun would stop, briefly reverse course, and stop again before resuming its path toward the horizon and decreasing in apparent size. All the while the stars would be moving three times faster across the sky. Observers at other points on Mercury's surface would see different but equally bizarre motions. Temperature variations on Mercury are the most extreme in the solar system ranging from 90 K to 700 K. Mercury craters Mercury is in many ways similar to the Moon: its surface is heavily cratered and very old; it has no plate tectonics. On the other hand, Mercury is much denser than the Moon (5.43 gm/cm3 vs 3.34). Mercury is the second densest major body in the solar system, after Earth. Actually Earth's density is due in part to gravitational compression; if not for this, Mercury would be denser than Earth. This indicates that Mercury's dense iron core is relatively larger than Earth's, probably comprising the majority of the planet. Mercury therefore has only a relatively thin silicate mantle and crust.

Mercury's interior is dominated by a large iron core whose radius is 1800 to 1900 km. The silicate outer shell (analogous to Earth's mantle and crust) is only 500 to 600 km thick. At least some of the core is probably molten. Measurements from the Messenger spacecraft show Mercury’s magnetic field is approximately three times stronger in the northern hemisphere than the southern hemisphere and has led to breakthrough research. Modeling by Hao Cao, a UCLA postdoctoral scholar working in the lab of Christopher Russell after considering many factors, including how fast Mercury rotates and the chemistry and complex motion of fluid inside the planet show the magnetic field of Mercury works differently than it does on Earth. Inside Earth's core, iron turns from a liquid to a solid at the inner boundary of the planet's liquid outer core and the solid inner core is growing, and this growth provides the energy that generates Earth's magnetic field. Inside Mercury’s core, iron turns from a liquid to a solid at the outer boundary and lacks a solid central core. Christopher Russell describes the mechanism: "It's like a snow storm in which the snow formed at the top of the cloud and middle of the cloud and the bottom of the cloud too". "Our study of Mercury's magnetic field indicates iron is snowing throughout this fluid that is powering Mercury's magnetic field." According to Hao the cores of both Mercury and Earth contain light elements such as sulfur, in addition to iron; the presence of these light elements keeps the cores from being completely solid and "powers the active magnetic field-generation processes. The research currently appears online in the journal Geophysical Research Letters and will be published in an upcoming print edition. Mercury actually has a very thin atmosphere consisting of atoms blasted off its surface by the solar wind. Because Mercury is so hot, these atoms quickly escape into space. Thus in contrast to the Earth and Venus whose atmospheres are stable, Mercury's atmosphere is constantly being replenished. Southwest Mercury The surface of Mercury exhibits enormous escarpments, some up to hundreds of kilometers in length and as much as three kilometers high. Some cut thru the rings of craters and other features in such a way as to indicate that they were formed by compression. It is estimated that the surface area of Mercury shrank by about 0.1% (or a decrease of about 1 km in the planet's radius). Caloris Basin One of the largest features on Mercury's surface is the Caloris Basin (right); it is about 1300 km in diameter. It is thought to be similar to the large basins (Maria) on the Moon. Like the lunar basins, it was probably caused by a very large impact early in the history of the solar system. Weird terrain opposite Caloris Basin That impact was probably also responsible for the odd terrain on the exact opposite side of the planet (left). In addition to the heavily cratered terrain, Mercury also has regions of relatively smooth plains. Some may be the result of ancient volcanic activity but some may be the result of the deposition of eject a from cratering impacts. A reanalysis of the Mariner data provides some preliminary evidence of recent volcanism on Mercury. But more data will be needed for confirmation. Amazingly, radar observations of Mercury's North Pole show evidence of water ice in the protected shadows of some craters. Mercury has a small magnetic field whose strength is about 1% of Earth's. Mercury has no known satellites. Mercury is often [visible](http://nineplanets.org/see.html) with binoculars or even the unaided eye, but it is always very near the Sun and difficult to see in the twilight sky. There are several [Web sites](http://astro.nineplanets.org/astrosoftware.html#www) that show the current position of Mercury (and the other planets) in the sky. More detailed and customized charts can be created with a planetarium program.

# Venus

## Planet Profile

Orbit: 108,200,000 km (0.72 AU) from Sun

Diameter: 12,103.6 km

Mass: 4.869e24 kg

### History of Venus

Venus (Greek: Aphrodite; Babylonian: Ishtar) is the goddess of love and beauty. The planet is so named probably because it is the brightest of the planets known to the ancients. (With a few exceptions, the surface features on Venus are named for female figures.) Venus has been known since prehistoric times. It is the brightest object in the sky except for the Sun and the Moon. Like Mercury, it was popularly thought to be two separate bodies: Eosphorus as the morning star and Hesperus as the evening star, but the Greek astronomers knew better. (Venus's apparition as the morning star is also sometimes called Lucifer.) Since Venus is an inferior planet, it shows phases when viewed with a telescope from the perspective of Earth. Galileo's observation of this phenomenon was important evidence in favor of Copernicus's heliocentric theory of the solar system. Venus surface the first spacecraft to visit Venus was Mariner 2 in 1962. It was subsequently visited by many others (more than 20 in all so far), including Pioneer Venus and the Soviet Venera 7 the first spacecraft to land on another planet, and Venera 9 which returned the first photographs of the surface. The first orbiter, the US spacecraft Magellan radar map produced detailed maps of Venus' surface using radar. ESA's Venus Express launched in November of 2005 and arrived at Venus in April 2006. The Venus Express is conducting atmospheric studies, mapping the Venusian surface temperatures and the plasma environment. Venus' rotation is somewhat unusual in that it is both very slow (243 Earth days per Venus day, slightly longer than Venus' year) and retrograde. In addition, the periods of Venus' rotation and of its orbit are synchronized such that it always presents the same face toward Earth when the two planets are at their closest approach. Whether this is a resonance effect or merely a coincidence is not known. Venus is sometimes regarded as Earth's sister planet. In some ways they are very similar:

Venus is only slightly smaller than Earth (95% of Earth's diameter, 80% of Earth's mass). Both have few craters indicating relatively young surfaces. Their densities and chemical compositions are similar. Because of these similarities, it was thought that below its dense clouds Venus might be very Earthlike and might even have life. But, unfortunately, more detailed study of Venus reveals that in many important ways it is radically different from Earth. It may be the least hospitable place for life in the solar system. Venus The pressure of Venus' atmosphere at the surface is 90 atmospheres (about the same as the pressure at a depth of 1 km in Earth's oceans). It is composed mostly of carbon dioxide. There are several layers of clouds many kilometers thick composed of sulphuric acid. These clouds completely obscure our view of the surface. This dense atmosphere produces a run-away greenhouse effect that raises Venus' surface temperature by about 400 degrees to over 740 K (hot enough to melt lead). Venus' surface is actually hotter than Mercury's despite being nearly twice as far from the Sun. Venus has a vortex at each pole. These vortices rotate vertically and recycle the atmosphere downwards. The north polar vortex has a peculliar double eye shape surrounded by a collar of cool air; it makes a complete rotation in three Earth days. Venus UV There are strong (350 kph) winds at the cloud tops but winds at the surface are very slow, no more than a few kilometers per hour. Venus probably once had large amounts of water like Earth but it all boiled away. Venus is now quite dry. Earth would have suffered the same fate had it been just a little closer to the Sun. We may learn a lot about Earth by learning why the basically similar Venus turned out so differently. Most of Venus' surface consists of gently rolling plains with little relief. There are also several broad depressions: Atlanta Planitia, Guinevere Planitia, Lavinia Planitia. There two large highland areas: Ishtar Terra in the northern hemisphere (about the size of Australia) and Aphrodite Terra along the equator (about the size of South America). The interior of Ishtar consists mainly of a high plateau, Lakshmi Planum, which is surrounded by the highest mountains on Venus including the enormous Maxwell Montes. Sir Mons Data from Magellan's imaging radar shows that much of the surface of Venus is covered by lava flows. There are several large shield volcanoes (similar to Hawaii or Olympus Mons) such as Sir Mons. Recently announced findings indicate that Venus is still volcanically active, but only in a few hot spots; for the most part it has been geologically rather quiet for the past few hundred million years. There are no small craters on Venus. It seems that small meteoroids burn up in Venus' dense atmosphere before reaching the surface. Craters on Venus seem to come in bunches indicating that large meteoroids that do reach the surface usually break up in the atmosphere. The oldest terrains on Venus seem to be about 800 million years old. Extensive volcanism at that time wiped out the earlier surface including any large craters from early in Venus' history. Venusian coronae Venusian pancakes Magellan's images show a wide variety of interesting and unique features including pancake volcanoes (left) which seem to be eruptions of very thick lava and coronae (right) which seem to be collapsed domes over large magma chambers. The interior of Venus is probably very similar to that of Earth: an iron core about 3000 km in radius, a molten rocky mantle comprising the majority of the planet. Recent results from the Magellan gravity data indicate that Venus' crust is stronger and thicker than had previously been assumed. Like Earth, convection in the mantle produces stress on the surface. However on Venus the stress is relieved in many relatively small regions instead of being concentrated at the boundaries of large plates as is the case on Earth. Venus has no magnetic field, perhaps because of its slow rotation. Venus has no satellites, and thereby hangs a tale. Venus is usually visible with the unaided eye. Sometimes (inaccurately) referred to as the "morning star" or the "evening star", it is by far the brightest "star" in the sky. There are several Web sites that show the current position of Venus (and the other planets) in the sky. More detailed and customized charts can be created with a planetarium program. On June 8 2004, Venus passed directly between the Earth and the Sun, appearing as a large black dot travelling across the Sun's disk. This event is known as a "transit of Venus" and is very rare: the last two were in 1882 and 2012, for the next you'll have to wait until 2117. While no longer of great scientific importance as it was in the past, this event was the impetus for a major journey for many amateur astronomers.

# Earth

## Planet Profile

Orbit: 149,600,000 km (1.00 AU) from Sun

Diameter: 12,756.3 km

Mass: 5.972e24 kg

### History of Earth

Earth is the only planet whose English name does not derive from Greek/Roman mythology. The name derives from Old English and Germanic. There are, of course, hundreds of other names for the planet in other languages. In Roman Mythology, the goddess of the Earth was Tellus - the fertile soil (Greek: Gaia, terra mater - Mother Earth). It was not until the time of Copernicus (the sixteenth century) that it was understood that the Earth is just another planet. Mir and Earth's limbEarth, of course, can be studied without the aid of spacecraft. Nevertheless it was not until the twentieth century that we had maps of the entire planet. Pictures of the planet taken from space are of considerable importance; for example, they are an enormous help in weather prediction and especially in tracking and predicting hurricanes. And they are extraordinarily beautiful.

The Earth is divided into several layers which have distinct chemical and seismic properties (depths in km):

-0-40 Crust

-40-400 Upper mantle

-400-650 Transition region

-650-2700 Lower mantle

-2700-2890 D'' layer

-2890-5150 Outer core

-5150-6378 Inner core

The crust varies considerably in thickness; it is thinner under the oceans, thicker under the continents. The inner core and crust are solid; the outer core and mantle layers are plastic or semi-fluid. The various layers are separated by discontinuities which are evident in seismic data; the best known of these is the Mohorovicic discontinuity between the crust and upper mantle.

Most of the mass of the Earth is in the mantle, most of the rest in the core; the part we inhabit is a tiny fraction of the whole (values below x10^24 kilograms):

Atmosphere = 0.0000051

Oceans = 0.0014

Crust = 0.026

Mantle = 4.043

Outer core = 1.835

Inner core = 0.09675

The core is probably composed mostly of iron (or nickel/iron) though it is possible that some lighter elements may be present, too. Temperatures at the center of the core may be as high as 7500 K, hotter than the surface of the Sun. The lower mantle is probably mostly silicon, magnesium and oxygen with some iron, calcium and aluminum. The upper mantle is mostly olivene and pyroxene (iron/magnesium silicates), calcium and aluminum. We know most of this only from seismic techniques; samples from the upper mantle arrive at the surface as lava from volcanoes but the majority of the Earth is inaccessible. The crust is primarily quartz (silicon dioxide) and other silicates like feldspar. Taken as a whole, the Earth's chemical composition (by mass) is: Earth-South America

34.6% Iron

29.5% Oxygen

15.2% Silicon

12.7% Magnesium

2.4% Nickel

1.9% Sulfur

0.05% Titanium

The Earth is the densest major body in the solar system.

The other terrestrial planets probably have similar structures and compositions with some differences: the Moon has at most a small core; Mercury has an extra-large core (relative to its diameter); the mantles of Mars and the Moon are much thicker; the Moon and Mercury may not have chemically distinct crusts; Earth may be the only one with distinct inner and outer cores. Note, however, that our knowledge of planetary interiors is mostly theoretical even for the Earth. Unlike the other terrestrial planets, Earth's crust is divided into several separate solid plates which float around independently on top of the hot mantle below. The theory that describes this is known as plate tectonics. It is characterized by two major processes: spreading and seductions. Spreading occurs when two plates move away from each other and new crust is created by upwelling magma from below. Seductions occurs when two plates collide and the edge of one dives beneath the other and ends up being destroyed in the mantle. There is also transverse motion at some plate boundaries (i.e. the San Andreas Fault in California) and collisions between continental plates (i.e. India/Eurasia). There are (at present) eight major plates:

North American Plate - North America, western North Atlantic and Greenland Plate boundaries

South American Plate - South America and western South Atlantic

Antarctic Plate - Antarctica and the "Southern Ocean"

Eurasian Plate - eastern North Atlantic, Europe and Asia except for India

African Plate - Africa, eastern South Atlantic and western Indian Ocean

Indian-Australian Plate - India, Australia, New Zealand and most of Indian Ocean

Nazca Plate - eastern Pacific Ocean adjacent to South America

Pacific Plate - most of the Pacific Ocean (and the southern coast of California!)

There are also twenty or more small plates such as the Arabian, Cocos, and Philippine Plates. Earthquakes are much more common at the plate boundaries. Plotting their locations makes it easy to see the plate boundaries.

The Earth's surface is very young. In the relatively short (by astronomical standards) period of 500,000,000 years or so erosion and tectonic processes destroy and recreate most of the Earth's surface and thereby eliminate almost all traces of earlier geologic surface history (such as impact craters). Thus the very early history of the Earth has mostly been erased. The Earth is 4.5 to 4.6 billion years old, but the oldest known rocks are about 4 billion years old and rocks older than 3 billion years are rare. The oldest fossils of living organisms are less than 3.9 billion years old. There is no record of the critical period when life was first getting started. Strait of Gibraltar 71 Percent of the Earth's surface is covered with water. Earth is the only planet on which water can exist in liquid form on the surface (though there may be liquid ethane or methane on Titan's surface and liquid water beneath the surface of Europa). Liquid water is, of course, essential for life as we know it. The heat capacity of the oceans is also very important in keeping the Earth's temperature relatively stable. Liquid water is also responsible for most of the erosion and weathering of the Earth's continents, a process unique in the solar system today (though it may have occurred on Mars in the past). Earth's atmosphere The Earth's atmosphere is 77% nitrogen, 21% oxygen, with traces of argon, carbon dioxide and water. There was probably a very much larger amount of carbon dioxide in the Earth's atmosphere when the Earth was first formed, but it has since been almost all incorporated into carbonate rocks and to a lesser extent dissolved into the oceans and consumed by living plants. Plate tectonics and biological processes now maintain a continual flow of carbon dioxide from the atmosphere to these various "sinks" and back again. The tiny amount of carbon dioxide resident in the atmosphere at any time is extremely important to the maintenance of the Earth's surface temperature via the greenhouse effect. The greenhouse effect raises the average surface temperature about 35 degrees C above what it would otherwise be (from a frigid -21 C to a comfortable +14 C); without it the oceans would freeze and life as we know it would be impossible. (Water vapor is also an important greenhouse gas.) Earth from Apollo 11 The presence of free oxygen is quite remarkable from a chemical point of view. Oxygen is a very reactive gas and under "normal" circumstances would quickly combine with other elements. The oxygen in Earth's atmosphere is produced and maintained by biological processes. Without life there would be no free oxygen. The interaction of the Earth and the Moon slows the Earth's rotation by about 2 milliseconds per century. Current research indicates that about 900 million years ago there were 481 18-hour days in a year. Earth has a modest magnetic field produced by electric currents in the outer core. The interaction of the solar wind, the Earth's magnetic field and the Earth's upper atmosphere causes the auroras (see the Interplanetary Medium). Irregularities in these factors cause the magnetic poles to move and even reverse relative to the surface; the geomagnetic north pole is currently located in northern Canada. (The "geomagnetic north pole" is the position on the Earth's surface directly above the south pole of the Earth's field.) The Earth's magnetic field and its interaction with the solar wind also produce the Van Allen radiation belts, a pair of doughnut shaped rings of ionized gas (or plasma) trapped in orbit around the Earth. The outer belt stretches from 19,000 km in altitude to 41,000 km; the inner belt lies between 13,000 km and 7,600 km in altitude.

# Mars

## Planet Profile

Orbit: 227,940,000 km (1.52 AU) from Sun

Diameter: 6,794 km

Mass: 6.4219e23 kg

### History of Mars

Mars (Greek: Ares) is the god of War. The planet probably got this name due to its red color; Mars is sometimes referred to as the Red Planet. (An interesting side note: the Roman god Mars was a god of agriculture before becoming associated with the Greek Ares; those in favor of colonizing and terraforming Mars may prefer this symbolism.) The name of the month March derives from Mars.

Mars has been known since prehistoric times. Of course, it has been extensively studied with ground-based observatories. But even very large telescopes find Mars a difficult target, it's just too small. It is still a favorite of science fiction writers as the most favorable place in the Solar System (other than Earth!) for human habitation. But the famous "canals" "seen" by Lowell and others were, unfortunately, just as imaginary as Barsoomian princesses. viking landing site

pathfinder landing site. The first spacecraft to visit Mars was Mariner 4 in 1965. Several others followed including Mars 2, the first spacecraft to land on Mars and the two Viking landers in 1976. Ending a long 20 year hiatus, Mars Pathfinder landed successfully on Mars on 1997 July 4. In 2004 the Mars Expedition Rovers "Spirit" and "Opportunity" landed on Mars sending back geologic data and many pictures; they are still operating after more than three years on Mars. In 2008, Phoenix landed in the northern plains to search for water. Three Mars orbiters (Mars Reconnaissance Orbiter, Mars Odyssey, and Mars Express) are also currently in operation. Mars' orbit is significantly elliptical. One result of this is a temperature variation of about 30 C at the subsolar point between aphelion and perihelion. This has a major influence on Mars' climate. While the average temperature on Mars is about 218 K (-55 C, -67 F), Martian surface temperatures range widely from as little as 140 K (-133 C, -207 F) at the winter pole to almost 300 K (27 C, 80 F) on the day side during summer. Though Mars is much smaller than Earth, its surface area is about the same as the land surface area of Earth. Olympus Moons. Mars has some of the most highly varied and interesting terrain of any of the terrestrial planets, some of it quite spectacular:

Olympus Mons: the largest mountain in the Solar System rising 24 km (78,000 ft.) above the surrounding plain. Its base is more than 500 km in diameter and is rimmed by a cliff 6 km (20,000 ft) high.

Tharsis: a huge bulge on the Martian surface that is about 4000 km across and 10 km high.

Valles Marineris: a system of canyons 4000 km long and from 2 to 7 km deep (top of page);

Hellas Planitia: an impact crater in the southern hemisphere over 6 km deep and 2000 km in diameter.

Much of the Martian surface is very old and cratered, but there are also much younger rift valleys, ridges, hills and plains. (None of this is visible in any detail with a telescope, even the Hubble Space Telescope; all this information comes from the spacecraft that we've sent to Mars.)

martian craters. The southern hemisphere of Mars is predominantly ancient cratered highlands somewhat similar to the Moon. In contrast, most of the northern hemisphere consists of plains which are much younger, lower in elevation and have a much more complex history. An abrupt elevation change of several kilometers seems to occur at the boundary. The reasons for this global dichotomy and abrupt boundary are unknown (some speculate that they are due to a very large impact shortly after Mars' accretion). Mars Global Surveyor has produced a nice 3D map of Mars that clearly shows these features.

The interior of Mars is known only by inference from data about the surface and the bulk statistics of the planet. The most likely scenario is a dense core about 1700 km in radius, a molten rocky mantle somewhat denser than the Earth's and a thin crust. Data from Mars Global Surveyor indicates that Mars' crust is about 80 km thick in the southern hemisphere but only about 35 km thick in the north. Mars' relatively low density compared to the other terrestrial planets indicates that its core probably contains a relatively large fraction of sulfur in addition to iron (iron and iron sulfide). Like Mercury and the Moon, Mars appears to lack active plate tectonics at present; there is no evidence of recent horizontal motion of the surface such as the folded mountains so common on Earth. With no lateral plate motion, hot-spots under the crust stay in a fixed position relative to the surface. This, along with the lower surface gravity, may account for the Tharis bulge and its enormous volcanoes. There is no evidence of current volcanic activity. However, data from Mars Global Surveyor indicates that Mars very likely did have tectonic activity sometime in the past. martian valley network

There is very clear evidence of erosion in many places on Mars including large floods and small river systems. At some time in the past there was clearly some sort of fluid on the surface. Liquid water is the obvious fluid but other possibilities exist. There may have been large lakes or even oceans; the evidence for which was strenghtened by some very nice images of layered terrain taken by Mars Global Surveyor and the mineralology results from MER Opportunity. Most of these point to wet episodes that occurred only briefly and very long ago; the age of the erosion channels is estimated at about nearly 4 billion years. However, images from Mars Express released in early 2005 show what appears to be a frozen sea that was liquid very recently (maybe 5 million years ago). Confirmation of this interpretation would be a very big deal indeed! (Valles Marineris was NOT created by running water. It was formed by the stretching and cracking of the crust associated with the creation of the Tharsis bulge.)

Early in its history, Mars was much more like Earth. As with Earth almost all of its carbon dioxide was used up to form carbonate rocks. But lacking the Earth's plate tectonics, Mars is unable to recycle any of this carbon dioxide back into its atmosphere and so cannot sustain a significant greenhouse effect. The surface of Mars is therefore much colder than the Earth would be at that distance from the Sun.

Mars has a very thin atmosphere composed mostly of the tiny amount of remaining carbon dioxide (95.3%) plus nitrogen (2.7%), argon (1.6%) and traces of oxygen (0.15%) and water (0.03%). The average pressure on the surface of Mars is only about 7 millibars (less than 1% of Earth's), but it varies greatly with altitude from almost 9 millibars in the deepest basins to about 1 millibar at the top of Olympus Mons. But it is thick enough to support very strong winds and vast dust storms that on occasion engulf the entire planet for months. Mars' thin atmosphere produces a greenhouse effect but it is only enough to raise the surface temperature by 5 degrees (K); much less than what we see on Venus and Earth. Mars south polar cap. Early telescopic observations revealed that Mars has permanent ice caps at both poles; they're visible even with a small telescope. We now know that they're composed of water ice and solid carbon dioxide ("dry ice"). The ice caps exhibit a layered structure with alternating layers of ice with varying concentrations of dark dust. In the northern summer the carbon dioxide completely sublimes, leaving a residual layer of water ice. ESA's Mars Express has shown that a similar layer of water ice exists below the southern cap as well. The mechanism responsible for the layering is unknown but may be due to climatic changes related to long-term changes in the inclination of Mars' equator to the plane of its orbit. There may also be water ice hidden below the surface at lower latitudes. The seasonal changes in the extent of the polar caps changes the global atmospheric pressure by about 25% (as measured at the Viking lander sites). Recent observations with the Hubble Space Telescope have revealed that the conditions during the Viking missions may not have been typical. Mars' atmosphere now seems to be both colder and dryer than measured by the Viking landers (more details from STScI).The Viking landers performed experiments to determine the existence of life on Mars. The results were somewhat ambiguous but most scientists now believe that they show no evidence for life on Mars (there is still some controversy, however). Optimists point out that only two tiny samples were measured and not from the most favorable locations. More experiments will be done by future missions to Mars.

A small number of meteorites (the SNC meteorites) are believed to have originated on Mars.

On 1996 Aug 6, David McKay et al announced what they thought might be evidence of ancient Martian microorganisms in the meteorite ALH84001. Though there is still some controversy, the majority of the scientific community has not accepted this conclusion. If there is or was life on Mars, we still haven't found it. Large, but not global, weak magnetic fields exist in various regions of Mars. This unexpected finding was made by Mars Global Surveyor just days after it entered Mars orbit. They are probably remnants of an earlier global field that has since disappeared. This may have important implications for the structure of Mars' interior and for the past history of its atmosphere and hence for the possibility of ancient life.

When it is in the night time sky, Mars is easily visible with the unaided eye. Mars is a difficult but rewarding target for an amateur telescope though only for the three or four months each martian year when it is closest to Earth. Its apparent size and brightness varies greatly according to its relative position to the Earth. There are several Web sites that show the current position of Mars (and the other planets) in the sky. More detailed and customized charts can be created with a planetarium program.

# Jupiter

## Planet Profile

Orbit: 778,330,000 km (5.20 AU) from Sun  
Diameter: 142,984 km (equatorial)  
Mass: 1.900e27 kg

### History of Jupiter

Jupiter (a.k.a. Jove; Greek Zeus) was the King of the Gods, the ruler of Olympus and the patron of the Roman state. Zeus was the son of Cronus (Saturn).

Jupiter is the fourth [brightest](http://nineplanets.org/datamax.html#brightest) object in the sky (after the [Sun](http://nineplanets.org/sol.html), the [Moon](http://nineplanets.org/luna.html) and [Venus](http://nineplanets.org/venus.html)). It has been known since prehistoric times as a bright "wandering star". But in 1610 when [Galileo](http://nineplanets.org/help.html#galileo) first pointed a telescope at the sky he discovered Jupiter's four large moons [Io](http://nineplanets.org/io.html), [Europa](http://nineplanets.org/europa.html), [Ganymede](http://nineplanets.org/ganymede.html) and [Callisto](http://nineplanets.org/callisto.html) (now known as the Galilean moons) and recorded their motions back and forth around Jupiter. This was the first [discovery](http://www.jpl.nasa.gov/galileo/ganymede/discovery.html) of a center of motion not apparently centered on the Earth. It was a major point in favor of [Copernicus](http://nineplanets.org/help.html#copernicus)'s[heliocentric](http://nineplanets.org/help.html#heliocentric) theory of the motions of the planets (along with other new evidence from his telescope: the phases of [Venus](http://nineplanets.org/venus.html) and the mountains on the [Moon](http://nineplanets.org/luna.html)). Galileo's outspoken support of the Copernican theory got him in trouble with the [Inquisition](http://nineplanets.org/help.html#inquisition). Today anyone can repeat Galileo's observations (without fear of retribution :-) using binoculars or an inexpensive telescope. Jupiter was first visited by Pioneer 10 in 1973 and later by Pioneer 11, Voyager 1, Voyager 2 and Ulysses. The spacecraft Galileo orbited Jupiter for eight years. It is still regularly observed by the Hubble Space Telescope. Jupiter was first visited by Pioneer 10 in 1973 and later by Pioneer 11, Voyager 1, Voyager 2 and Ulysses. The spacecraft Galileo orbited Jupiter for eight years. It is still regularly observed by the Hubble Space Telescope. The gas planets do not have solid surfaces, their gaseous material simply gets denser with depth (the radii and diameters quoted for the planets are for levels corresponding to a pressure of 1 atmosphere). What we see when looking at these planets is the tops of clouds high in their atmospheres (slightly above the 1 atmosphere level). Jupiter is about 90% hydrogen and 10% helium (by numbers of atoms, 75/25% by mass) with traces of methane, water, ammonia and "rock". This is very close to the composition of the primordial Solar Nebula from which the entire solar system was formed. Saturn has a similar composition, but Uranus and Neptune have much less hydrogen and helium. Our knowledge of the interior of Jupiter (and the other gas planets) is highly indirect and likely to remain so for some time. (The data from Galileo's atmospheric probe goes down only about 150 km below the cloud tops.) Jupiter probably has a core of rocky material amounting to something like 10 to 15 Earth-masses. Above the core lies the main bulk of the planet in the form of liquid metallic hydrogen. This exotic form of the most common of elements is possible only at pressures exceeding 4 million bars, as is the case in the interior of Jupiter (and Saturn). Liquid metallic hydrogen consists of ionized protons and electrons (like the interior of the Sun but at a far lower temperature). At the temperature and pressure of Jupiter's interior hydrogen is a liquid, not a gas. It is an electrical conductor and the source of Jupiter's magnetic field. This layer probably also contains some helium and traces of various "ices". The outermost layer is composed primarily of ordinary molecular hydrogen and helium which is liquid in the interior and gaseous further out. The atmosphere we see is just the very top of this deep layer. Water, carbon dioxide, methane and other simple molecules are also present in tiny amounts. Recent experiments have shown that hydrogen does not change phase suddenly. Therefore the interiors of the Jovian planets probably have indistinct boundaries between their various interior layers. Three distinct layers of clouds are believed to exist consisting of ammonia ice, ammonium hydrosulfide and a mixture of ice and water. However, the preliminary results from the Galileo probe show only faint indications of clouds (one instrument seems to have detected the topmost layer while another may have seen the second). But the probe's entry point (left) was unusual -- Earth-based telescopic observations and more recent observations by the Galileo orbiter suggest that the probe entry site may well have been one of the warmest and least cloudy areas on Jupiter at that time. Data from the Galileo atmospheric probe also indicate that there is much less water than expected. The expectation was that Jupiter's atmosphere would contain about twice the amount of oxygen (combined with the abundant hydrogen to make water) as the Sun. But it now appears that the actual concentration much less than the Sun's. Also surprising was the high temperature and density of the uppermost parts of the atmosphere. Jupiter and the other gas planets have high velocity winds which are confined in wide bands of latitude. The winds blow in opposite directions in adjacent bands. Slight chemical and temperature differences between these bands are responsible for the colored bands that dominate the planet's appearance. The light colored bands are called zones; the dark ones belts. The bands have been known for some time on Jupiter, but the complex vortices in the boundary regions between the bands were first seen by Voyager. The data from the Galileo probe indicate that the winds are even faster than expected (more than 400 mph) and extend down into as far as the probe was able to observe; they may extend down thousands of kilometers into the interior. Jupiter's atmosphere was also found to be quite turbulent. This indicates that Jupiter's winds are driven in large part by its internal heat rather than from solar input as on Earth. The vivid colors seen in Jupiter's clouds are probably the result of subtle chemical reactions of the trace elements in Jupiter's atmosphere, perhaps involving sulfur whose compounds take on a wide variety of colors, but the details are unknown. The colors correlate with the cloud's altitude: blue lowest, followed by browns and whites, with reds highest. Sometimes we see the lower layers through holes in the upper ones. The Great Red Spot (GRS) has been seen by Earthly observers for more than 300 years (its discovery is usually attributed to Cassini, or Robert Hooke in the 17th century). The GRS is an oval about 12,000 by 25,000 km, big enough to hold two Earths. Other smaller but similar spots have been known for decades. Infrared observations and the direction of its rotation indicate that the GRS is a high-pressure region whose cloud tops are significantly higher and colder than the surrounding regions. Similar structures have been seen on Saturn and Neptune. It is not known how such structures can persist for so long. Jupiter radiates more energy into space than it receives from the Sun. The interior of Jupiter is hot: the core is probably about 20,000 K. The heat is generated by the Kelvin-Helmholtz mechanism, the slow gravitational compression of the planet. (Jupiter does NOT produce energy by nuclear fusion as in the Sun; it is much too small and hence its interior is too cool to ignite nuclear reactions.) This interior heat probably causes convection deep within Jupiter's liquid layers and is probably responsible for the complex motions we see in the cloud tops. Saturn and Neptune are similar to Jupiter in this respect, but oddly, Uranus is not. Jupiter is just about as large in diameter as a gas planet can be. If more material were to be added, it would be compressed by gravity such that the overall radius would increase only slightly. A star can be larger only because of its internal (nuclear) heat source. (But Jupiter would have to be at least 80 times more massive to become a star.) Jupiter has a huge magnetic field, much stronger than Earth's. Its magnetosphere extends more than 650 million km (past the orbit of Saturn!). (Note that Jupiter's magnetosphere is far from spherical -- it extends "only" a few million kilometers in the direction toward the Sun.) Jupiter's moons therefore lie within its magnetosphere, a fact which may partially explain some of the activity on Io. Unfortunately for future space travelers and of real concern to the designers of the Voyager and Galileo spacecraft, the environment near Jupiter contains high levels of energetic particles trapped by Jupiter's magnetic field. This "radiation" is similar to, but much more intense than, that found within Earth's Van Allen belts. It would be immediately fatal to an unprotected human being. The Galileo atmospheric probe discovered a new intense radiation belt between Jupiter's ring and the uppermost atmospheric layers. This new belt is approximately 10 times as strong as Earth's Van Allen radiation belts. Surprisingly, this new belt was also found to contain high energy helium ions of unknown origin. Jupiter has rings like Saturn's, but much fainter and smaller (right). They were totally unexpected and were only discovered when two of the Voyager 1 scientists insisted that after traveling 1 billion km it was at least worth a quick look to see if any rings might be present. Everyone else thought that the chance of finding anything was nil, but there they were. It was a major coup. They have since been imaged in the infra-red from ground-based observatories and by Galileo. Unlike Saturn's, Jupiter's rings are dark (albedo about .05). They're probably composed of very small grains of rocky material. Unlike Saturn's rings, they seem to contain no ice. Particles in Jupiter's rings probably don't stay there for long (due to atmospheric and magnetic drag). The Galileo spacecraft found clear evidence that the rings are continuously resupplied by dust formed by micro meteor impacts on the four inner moons, which are very energetic because of Jupiter's large gravitational field. The inner halo ring is broadened by interactions with Jupiter's magnetic field. In July 1994, Comet Shoemaker-Levy 9 collided with Jupiter with spectacular results (left). The effects were clearly visible even with amateur telescopes. The debris from the collision was visible for nearly a year afterward with HST. When it is in the nighttime sky, Jupiter is often the brightest "star" in the sky (it is second only to Venus, which is seldom visible in a dark sky). The four Galilean moons are easily visible with binoculars; a few bands and the Great Red Spot can be seen with a small astronomical telescope. There are several Web sites that show the current position of Jupiter (and the other planets) in the sky. More detailed and customized charts can be created with a planetarium program.

# Saturn

## Planet Profile

Orbit: 1,429,400,000 km (9.54 AU) from Sun

Diameter: 120,536 km (equatorial)

Mass: 5.68e26 kg

### History of Saturn

In Roman mythology, Saturn is the god of agriculture. The associated Greek god, Cronus, was the son of Uranus and Gaia and the father of Zeus (Jupiter). Saturn is the root of the English word "Saturday" (see Appendix 5). Saturn has been known since prehistoric times. Galileo was the first to observe it with a telescope in 1610; he noted its odd appearance but was confused by it. Early observations of Saturn were complicated by the fact that the Earth passes through the plane of Saturn's rings every few years as Saturn moves in its orbit. A low resolution image of Saturn therefore changes drastically. It was not until 1659 that Christian Huygens correctly inferred the geometry of the rings. Saturn's rings remained unique in the known solar system until 1977 when very faint rings were discovered around Uranus (and shortly thereafter around Jupiter and Neptune).

Saturn was first visited by NASA's Pioneer 11 in 1979 and later by Voyager 1 and Voyager 2. Cassini (a joint NASA / ESA project) arrived on July 1, 2004 and will orbit Saturn for at least four years.

Saturn is visibly flattened (oblate) when viewed through a small telescope; its equatorial and polar diameters vary by almost 10% (120,536 km vs. 108,728 km). This is the result of its rapid rotation and fluid state. The other gas planets are also oblate, but not so much so.

Saturn is the least dense of the planets; its specific gravity (0.7) is less than that of water.

Like Jupiter, Saturn is about 75% hydrogen and 25% helium with traces of water, methane, ammonia and "rock", similar to the composition of the primordial Solar Nebula from which the solar system was formed. Saturn's interior is similar to Jupiter's consisting of a rocky core, a liquid metallic hydrogen layer and a molecular hydrogen layer. Traces of various ices are also present. Saturn's interior is hot (12000 K at the core) and Saturn radiates more energy into space than it receives from the Sun. Most of the extra energy is generated by the Kelvin-Helmholtz mechanism as in Jupiter. But this may not be sufficient to explain Saturn's luminosity; some additional mechanism may be at work, perhaps the "raining out" of helium deep in Saturn's interior. The bands so prominent on Jupiter are much fainter on Saturn. They are also much wider near the equator. Details in the cloud tops are invisible from Earth so it was not until the Voyager encounters that any detail of Saturn's atmospheric circulation could be studied. Saturn also exhibits long-lived ovals (red spot at center of image at right) and other features common on Jupiter. In 1990, HST observed an enormous white cloud near Saturn's equator which was not present during the Voyager encounters; in 1994 another, smaller storm was observed (left). Two prominent rings (A and B) and one faint ring (C) can be seen from the Earth. The gap between the A and B rings is known as the Cassini division. The much fainter gap in the outer part of the A ring is known as the Encke Division (but this is somewhat of a misnomer since it was very likely never seen by Encke). The Voyager pictures show four additional faint rings. Saturn's rings, unlike the rings of the other planets, are very bright (albedo 0.2 - 0.6). Though they look continuous from the Earth, the rings are actually composed of innumerable small particles each in an independent orbit. They range in size from a centimeter or so to several meters. A few kilometer-sized objects are also likely. Saturn's rings are extraordinarily thin: though they're 250,000 km or more in diameter they're less than one kilometer thick. Despite their impressive appearance, there's really very little material in the rings -- if the rings were compressed into a single body it would be no more than 100 km across. The ring particles seem to be composed primarily of water ice, but they may also include rocky particles with icy coatings. Voyager confirmed the existence of puzzling radial in homogeneities in the rings called "spokes" which were first reported by amateur astronomers (left). Their nature remains a mystery, but may have something to do with Saturn's magnetic field. Saturn's outermost ring, the F-ring, is a complex structure made up of several smaller rings along which "knots" are visible. Scientists speculate that the knots may be clumps of ring material, or mini moons. The strange braided appearance visible in the Voyager 1 images (right) is not seen in the Voyager 2 images perhaps because Voyager 2 imaged regions where the component rings are roughly parallel. They are prominent in the Cassini images which also show some as yet unexplained wispy spiral structures.

There are complex tidal resonances between some of Saturn's moons and the ring system: some of the moons, the so-called "shepherding satellites" (i.e. Atlas, Prometheus and Pandora) are clearly important in keeping the rings in place; Mimas seems to be responsible for the paucity of material in the Cassini division, which seems to be similar to the Kirkwood gaps in the asteroid belt; Pan is located inside the Encke Division and S/2005 S1 is in the center of the Keeler Gap. The whole system is very complex and as yet poorly understood. The origin of the rings of Saturn (and the other Jovian planets) is unknown. Though they may have had rings since their formation, the ring systems are not stable and must be regenerated by ongoing processes, perhaps the breakup of larger satellites. The current set of rings may be only a few hundred million years old. Like the other Jovian planets, Saturn has a significant magnetic field. When it is in the nighttime sky, Saturn is easily visible to the unaided eye. Though it is not nearly as bright as Jupiter, it is easy to identify as a planet because it doesn't "twinkle" like the stars do. The rings and the larger satellites are visible with a small astronomical telescope. There are several Web sites that show the current position of Saturn (and the other planets) in the sky. More detailed and customized charts can be created with a planetarium program.

# Uranus

## Planet Profile

Orbit: 2,870,990,000 km (19.218 AU) from Su

Diameter: 51,118 km (equatorial)

Mass: 8.683e25 kg

### History of Uranus

Careful pronunciation may be necessary to avoid embarrassment; say "YOOR a nus", not "your anus" or "urine us". Uranus is the ancient Greek deity of the Heavens, the earliest supreme god. Uranus was the son and mate of Gaia the father of Cronus (Saturn) and of the Cyclopes and Titans (predecessors of the Olympian gods). Uranus, the first planet discovered in modern times, was discovered by William Herschel while systematically searching the sky with his telescope on March 13, 1781. It had actually been seen many times before but ignored as simply another star (the earliest recorded sighting was in 1690 when John Flam steed cataloged it as 34 Taurus). Herschel named it "the Georgian Sides" (the Georgian Planet) in honor of his patron, the infamous (to Americans) King George III of England; others called it "Herschel". The name "Uranus" was first proposed by Bode in conformity with the other planetary names from classical mythology but didn't come into common use until 1850.

Uranus has been visited by only one spacecraft, Voyager 2 on Jan 24 1986.

Most of the planets spin on an axis nearly perpendicular to the plane of the ecliptic but Uranus' axis is almost parallel to the ecliptic. At the time of Voyager 2's passage, Uranus' south pole was pointed almost directly at the Sun. This results in the odd fact that Uranus' polar regions receive more energy input from the Sun than do its equatorial regions. Uranus is nevertheless hotter at its equator than at its poles. The mechanism underlying this is unknown.

Actually, there's an ongoing battle over which of Uranus' poles is its north pole! Either its axial inclination is a bit over 90 degrees and its rotation is direct, or it's a bit less than 90 degrees and the rotation is retrograde. The problem is that you need to draw a dividing line \*somewhere\*, because in a case like Venus there is little dispute that the rotation is indeed retrograde (not a direct rotation with an inclination of nearly 180).

Uranus is composed primarily of rock and various ices, with only about 15% hydrogen and a little helium (in contrast to Jupiter and Saturn which are mostly hydrogen). Uranus (and Neptune) are in many ways similar to the cores of Jupiter and Saturn minus the massive liquid metallic hydrogen envelope. It appears that Uranus does not have a rocky core like Jupiter and Saturn but rather that its material is more or less uniformly distributed.

Uranus' atmosphere is about 83% hydrogen, 15% helium and 2% methane.

Like the other gas planets, Uranus has bands of clouds that blow around rapidly. But they are extremely faint, visible only with radical image enhancement of the Voyager 2 pictures (right). Recent observations with HST (left) show larger and more pronounced streaks. Further HST observations show even more activity. Uranus is no longer the bland boring planet that Voyager saw! It now seems clear that the differences are due to seasonal effects since the Sun is now at a lower Uranium latitude which may cause more pronounced day/night weather effects. By 2007 the Sun will be directly over Uranus's equator.

Uranus' blue color is the result of absorption of red light by methane in the upper atmosphere. There may be colored bands like Jupiter's but they are hidden from view by the overlaying methane layer.

Like the other gas planets, Uranus has rings. Like Jupiter's, they are very dark but like Saturn's they are composed of fairly large particles ranging up to 10 meters in diameter in addition to fine dust. There are 13 known rings, all very faint; the brightest is known as the Epsilon ring. The Uranium rings were the first after Saturn's to be discovered. This was of considerable importance since we now know that rings are a common feature of planets, not a peculiarity of Saturn alone. Voyager 2 discovered 10 small moons in addition to the 5 large ones already known. It is likely that there are several more tiny satellites within the rings. Uranus' magnetic field is odd in that it is not centered on the center of the planet and is tilted almost 60 degrees with respect to the axis of rotation. It is probably generated by motion at relatively shallow depths within Uranus. Uranus is sometimes just barely visible with the unaided eye on a very clear night; it is fairly easy to spot with binoculars (if you know exactly where to look). A small astronomical telescope will show a small disk. There are several Web sites that show the current position of Uranus (and the other planets) in the sky, but much more detailed charts will be required to actually find it. Such charts can be created with a planetarium program.

# Neptune

## Planet Profile

Orbit: 4,504,000,000 km (30.06 AU) from Sun

Diameter: 49,532 km (equatorial)

Mass: 1.0247e26 kg

### History of Neptune

In Roman mythology Neptune (Greek: Poseidon) was the god of the Sea.

After the discovery of Uranus, it was noticed that its orbit was not as it should be in accordance with Newton's laws. It was therefore predicted that another more distant planet must be perturbing Uranus' orbit. Neptune was first observed by Galle and d'Arrest on 1846 Sept 23 very near to the locations independently predicted by Adams and Le Verrier from calculations based on the observed positions of Jupiter, Saturn and Uranus. An international dispute arose between the English and French (though not, apparently between Adams and Le Verrier personally) over priority and the right to name the new planet; they are now jointly credited with Neptune's discovery. Subsequent observations have shown that the orbits calculated by Adams and Le Verrier diverge from Neptune's actual orbit fairly quickly. Had the search for the planet taken place a few years earlier or later it would not have been found anywhere near the predicted location. More than two centuries earlier, in 1613, Galileo observed Neptune when it happened to be very near Jupiter, but he thought it was just a star. On two successive nights he actually noticed that it moved slightly with respect to another nearby star. But on the subsequent nights it was out of his field of view. Had he seen it on the previous few nights Neptune's motion would have been obvious to him. But, alas, cloudy skies prevented observations on those few critical days. Neptune has been visited by only one spacecraft, Voyager 2 on Aug 25 1989. Much of we know about Neptune comes from this single encounter. But fortunately, recent ground-based and HST observations have added a great deal, too. Because Pluto's orbit is so eccentric, it sometimes crosses the orbit of Neptune making Neptune the most distant planet from the Sun for a few years. Neptune's composition is probably similar to Uranus': various "ices" and rock with about 15% hydrogen and a little helium. Like Uranus, but unlike Jupiter and Saturn, it may not have a distinct internal layering but rather to be more or less uniform in composition. But there is most likely a small core (about the mass of the Earth) of rocky material. Its atmosphere is mostly hydrogen and helium with a small amount of methane. Neptune's blue color is largely the result of absorption of red light by methane in the atmosphere but there is some additional as-yet-unidentified chromosphere which gives the clouds their rich blue tint.

Like a typical gas planet, Neptune has rapid winds confined to bands of latitude and large storms or vortices. Neptune's winds are the fastest in the solar system, reaching 2000 km/hour. Like Jupiter and Saturn, Neptune has an internal heat source -- it radiates more than twice as much energy as it receives from the Sun. At the time of the Voyager encounter, Neptune's most prominent feature was the Great Dark Spot (left) in the southern hemisphere. It was about half the size as Jupiter's Great Red Spot (about the same diameter as Earth). Neptune's winds blew the Great Dark Spot westward at 300 meters/second (700 mph). Voyager 2 also saw a smaller dark spot in the southern hemisphere and a small irregular white cloud that zips around Neptune every 16 hours or so now known as "The Scooter" (right). It may be a plume rising from lower in the atmosphere but its true nature remains a mystery. However, HST observations of Neptune (left) in 1994 show that the Great Dark Spot has disappeared! It has either simply dissipated or is currently being masked by other aspects of the atmosphere. A few months later HST discovered a new dark spot in Neptune's northern hemisphere. This indicates that Neptune's atmosphere changes rapidly, perhaps due to slight changes in the temperature differences between the tops and bottoms of the clouds. Neptune also has rings. Earth-based observations showed only faint arcs instead of complete rings, but Voyager 2's images showed them to be complete rings with bright clumps. One of the rings appears to have a curious twisted structure (right). Like Uranus and Jupiter, Neptune's rings are very dark but their composition is unknown. Neptune's rings have been given names: the outermost is Adams (which contains three prominent arcs now named Liberty, Equality and Fraternity), next is an unnamed ring co-orbital with Galatea, then Leverrier (whose outer extensions are called Lassell and Arago), and finally the faint but broad Galle. Neptune's magnetic field is, like Uranus', oddly oriented and probably generated by motions of conductive material (probably water) in its middle layers. Neptune can be seen with binoculars (if you know exactly where to look) but a large telescope is needed to see anything other than a tiny disk. There are several Web sites that show the current position of Neptune (and the other planets) in the sky, but much more detailed charts will be required to actually find it. Such charts can be created with a planetarium program.