The Art of Stargazing

Month 1: Solar System

The Planet Jupiter

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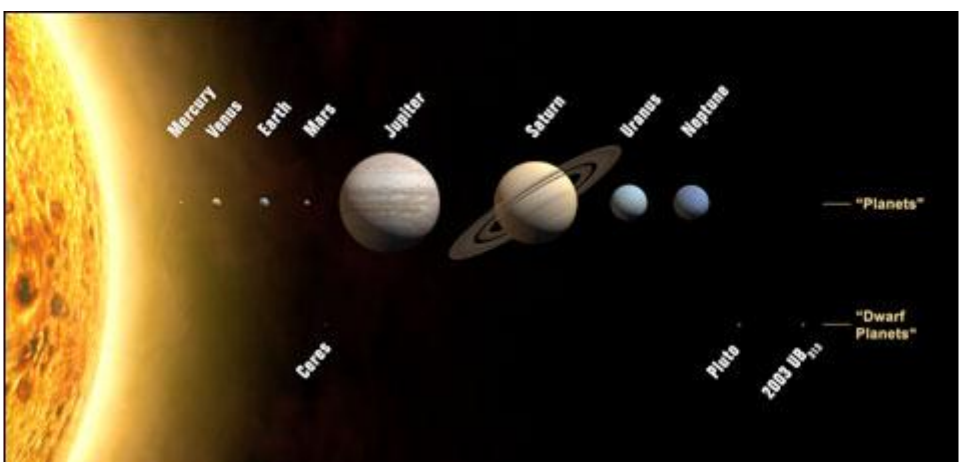
The Planet Jupiter

Jupiter is always one of the brightest objects in the night sky. It's always brighter than any star, and it's only outshone by the planet Venus and the Moon, and, very rarely, by Mars and Mercury. The planet reaches a position for optimum viewing in a telescope once every 13 months, roughly. As you are about to discover, the visible face of Jupiter displays so many interesting features visible in small scopes that the planet is a favorite target of observation for new and experienced stargazers.

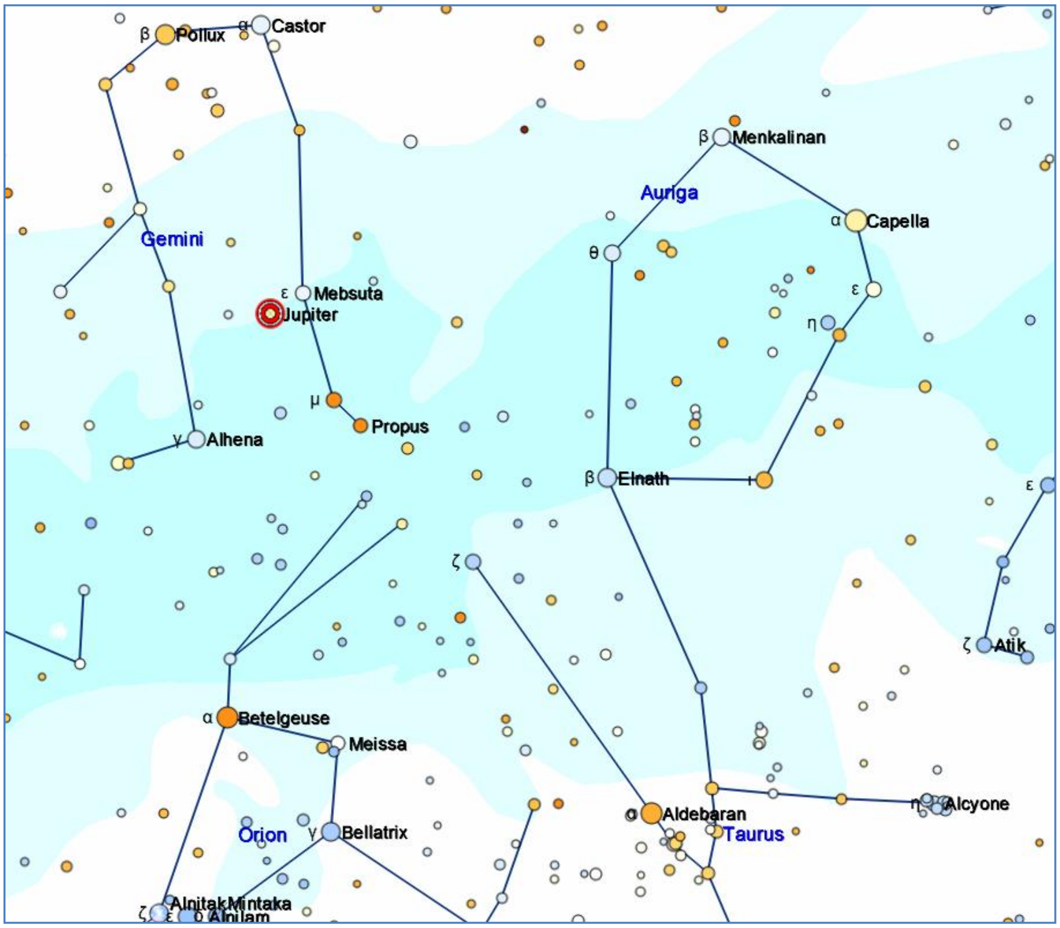
This year, in 2014, Jupiter lies in the constellation Gemini just east of Taurus, the V-shaped constellation you discovered this month during the sky tours. The sky in this area is full of bright stars, but Jupiter outshines them all. In the evening hours the planet is located high above the southwestern horizon sky for observers in the northern hemisphere and well above the north-northeastern horizon for observers in the southern hemisphere. The charts below show you where to look for Jupiter in each hemisphere at about 9 p.m. in mid-March. Again… the planet is the brightest object (save for the Moon) in the evening sky, so it's hard to miss.

Before we get into the details of Jupiter, let's do a very quick overview of our solar system. At the center, of course, is the Sun, our home star. It makes up 99.86% of the mass of the solar system. The other 0.014% is in the planets, the asteroids, comets, and so on. The solar system has eight major planets which revolve in slightly elliptical orbits around the Sun. These are, in order from increasing distance from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Little Pluto, which lies beyond the orbit of Neptune, is no longer considered a major planet, but is now one of five dwarf planets.



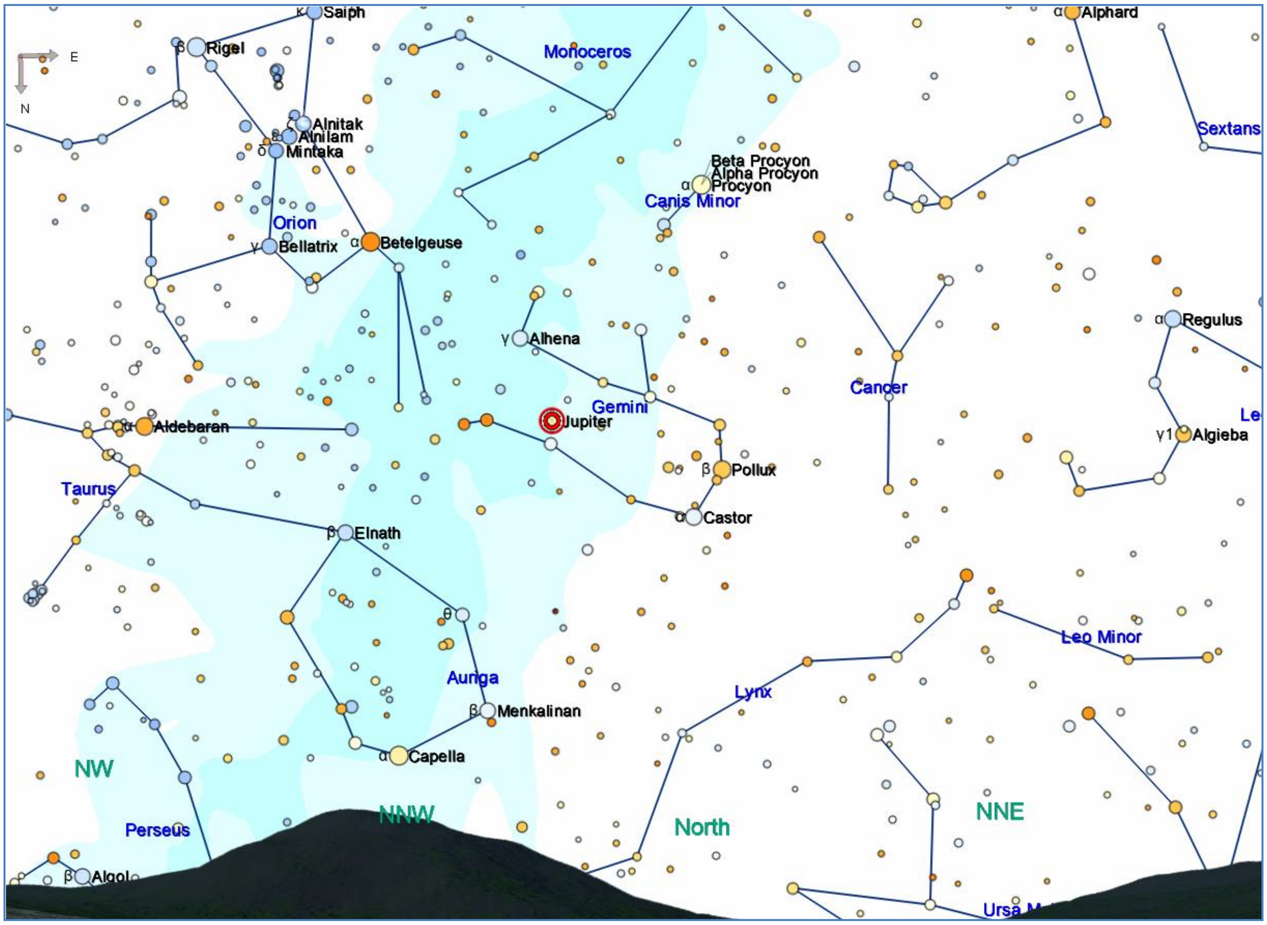
The Sun and planets of our solar system; the separation of the planets is not to scale

The image above shows the relative size of the planets, but it does not show their distance of the Sun to scale. In fact, the planets are much farther apart from each other, and their physical dimensions are much smaller than their distances from the Sun and from each other. The Earth, for example, is some 150,000,000 km from the Sun, but it is just 12,700 km in diameter. If the solar system were as large as a dinner plate, the planets would be tiny specks of sand.



Location of the planet Jupiter in mid-March 2014. Jupiter is in the constellation Gemini high above the southwestern horizon at 9 p.m. in March 2014 as seen from the northern hemisphere.

Astronomers define the scale of the solar system in terms of the “astronomical unit”, or AU, which is the mean distance of the Earth to the Sun. In these terms, Mercury is 0.38 AU from the Sun, Venus is 0.722 AU, Earth is 1.0 AU, Mars is 1.38 AU, and Jupiter is 5.20 AU from the Sun, on average. Saturn is nearly twice as far as Jupiter at a distance of 9.6 AU. Uranus is twice as far again at 19.2 AU, and Neptune lies about 30 AU from the Sun, or 30x farther than Earth. One astronomical unit is 149.6 million kilometers.



Location of the planet Jupiter in mid-March 2014. Jupiter is in the constellation Gemini above the northern horizon at 9 p.m. in March 2014 as seen from the southern hemisphere

Jupiter is the largest planet, and by far the largest object in the solar system save for the Sun. The planet is 2.5x as massive as all other planets combined. Jupiter and Saturn are both “gas giants”, which are massive planets made up almost entirely of cold hydrogen and helium gas along with traces of other gases like ammonia and methane. (Uranus and Neptune are also sometimes called gas giants, or, because they are much colder, “ice giants”). Gas and ice giants do not have well defined rocky surfaces like the Earth. Their outer layers are made entirely of clouds; further down the gas turns to compressed liquid, and at the very center may be a rocky carbon core.

Because it is so large, and because its clouds are highly reflective and intricately detailed, Jupiter is one of the finest sights in the heavens for a small telescope. To see any detail on the face of Jupiter, a telescope is required. But even a pair of simple binoculars reveals an astonishing sight: the four largest moons of Jupiter, each a small world in its own right, all lined up and moving around the planet according to Newton’s well established laws of gravity. These moons, in order from closest to farthest from Jupiter, are called Io, Europa, Ganymede, and Callisto. Because these Moons were first discovered by Galileo in 1610, they are sometimes called the Galilean Moons.

If you have the patience, you can follow the four Galilean Moons as they whiz around the big planet. Io, the closest, moves around Jupiter in just 1.78 days, while Callisto, the farthest, takes 16.7 days to make a full revolution. Even with binoculars, you can see Io and Europa change position from hour to hour during the course of an evening.

As mentioned, Jupiter is currently in the constellation Gemini. Because Jupiter has an orbital period of nearly 12 years, it appears to move eastward by approximately one full zodiacal constellation each year as it makes its way around the Sun. So next year, Jupiter will appear in Cancer, and the year after in the constellation Leo, then Virgo, and so on.

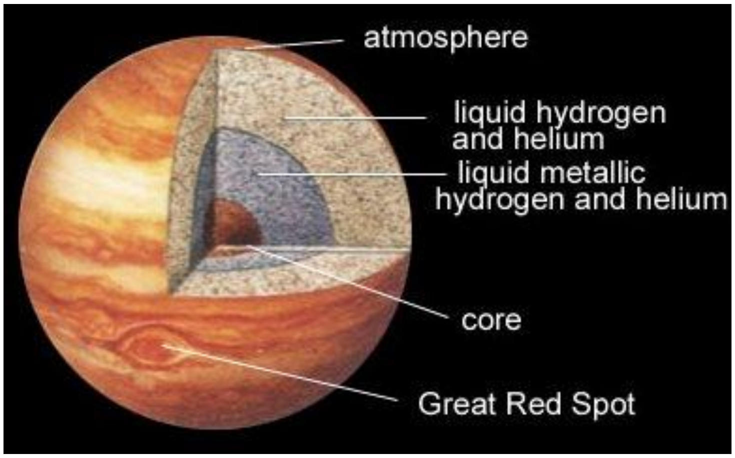
The Structure of Jupiter

As mentioned, Jupiter is the largest planet in our solar system, larger than all the other planets combined. It has a diameter of 143,000 km, about 11x that of Earth, a volume more than a thousand times Earth's, and a mass more than 300x Earth's.

Jupiter lies past Mars and beyond the asteroid belt. Its location and size allow Jupiter to act as a "protector" of the inner solar system because the planet's gravity often deflects or swallows comets and other debris from the outer solar system, preventing them from hurtling towards the inner solar system. While Earth and the other inner planets sometimes collide with comets, with catastrophic results, the collisions would be far more frequent without Jupiter. Astronomers estimate Jupiter has effortlessly swallowed thousands of comets over the past few billion years.

As you will see when you make your own observations of Jupiter, the planet rotates rapidly. At its equator, its rotational period is 9 hours 50.5 minutes. That's quick for such a large planet. The centrifugal force at the equator causes the planet to bulge: the diameter at the equator is about 6.4% greater than at the poles. You can see the resulting "oblateness"-- the flattened sphere appearance-- in a small telescope.

Towards the poles, the rotation rate of Jupiter is 9 hours and 55 minutes, slightly slower than at the equator. This slight difference is important: it means Jupiter is not a solid body like the Earth. Astronomers have understood for centuries that the visible face of Jupiter is not solid… it has features which change shape and color and position relative to each other. Astronomers now understand the face of Jupiter consists of a complex and dynamic arrangement of gaseous clouds of hydrogen, helium, and trace gases. Below these colorful layers, temperatures and pressures increase and the gases are compressed into a liquid state, then further down into a metallic state. At the center of the planet lies a rocky core made of carbon and iron. The core is about the size of Earth but ten times as massive.



The structure of Jupiter

With so much mass, Jupiter's internal gravitational energy squeezes the insides of the planet such that it generates more heat than it receives from the Sun. The heat is radiated as infrared energy. As it turns out, given its composition and structure, Jupiter is about as large as it can be. If a lot more mass were added, the planet would actually shrink and grow more dense. This contraction would cause the interior of the planet to heat up more. If the planet were some 50-75x more massive, its interior would heat up enough to cause hydrogen gas in its core to fuse into helium. Jupiter would become a star. Eventually, its radius would increase as more mass was added.

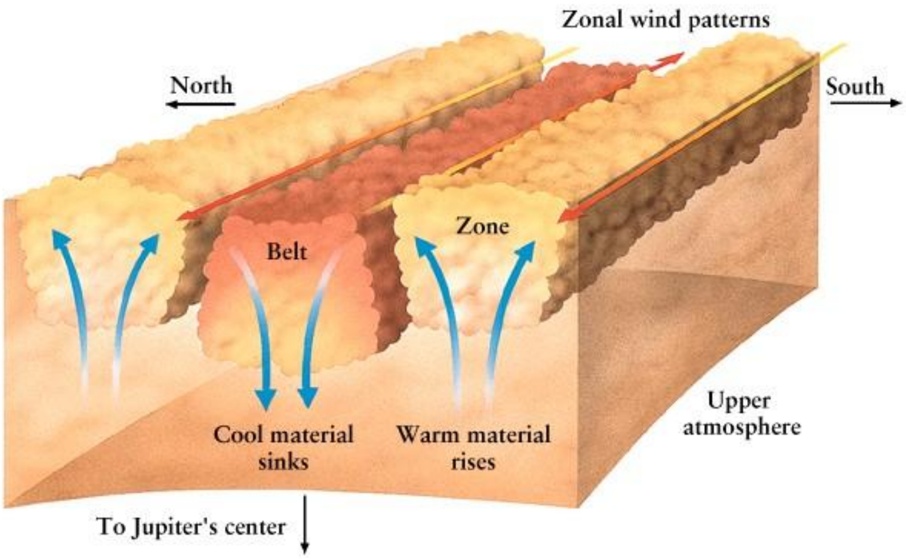
"Surface" Features of Jupiter

As backyard observational astronomers, we are most interested in the part of Jupiter we can see: the outer layers of the atmosphere. In even the smallest telescope, you can see structure in the atmosphere, usually two dark bands surrounded by lighter regions. At its closest approach to Earth, the planet's disc spans about 50", which makes it easy to observe. Only Venus, which is much closer, occasionally appears larger. But unlike featureless Venus, Jupiter reveals an enormous amount of detail to observers with a small telescope.

The dark bands on the face of Jupiter are called *belts* and the lighter bands between them are called *zones*. The two belts you see in the small image below are the *north equatorial belt* (NEB) and the *south equatorial belt* (SEB) since they each lie just north and south of the equator, respectively. These are the most prominent belts, but there are many more visible in steady sky with larger telescopes at higher magnification.

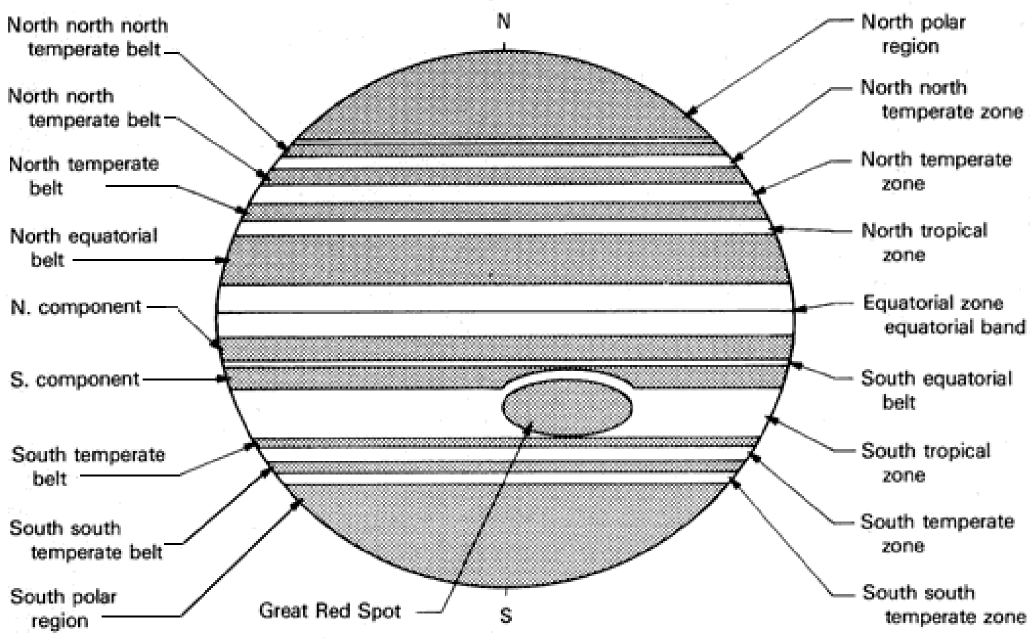
Jupiter as it might appear in a 60 mm telescope at 100x

The belts and zones are caused by churning layers of gas in the atmosphere. The rotating atmosphere has segmented itself into layers that are confined to certain latitudes on Jupiter, much like the trade winds on Earth blow in the same place and same direction throughout the year. The zones are caused by convection regions wherein warm gas rises, cools, and sinks repeatedly in the upper atmosphere. The belts are regions of cooler gas that have sunk lower in the atmosphere. The belts are dark and colorful, with tones of red, salmon, tan and brown. The color comes from phosphorus compounds that are ionized by radiation and lightening in the fast-moving winds. The zones, which are regions of warmer rising gas, are usually pale-yellow or white caused by ammonia gas crystallizing and blocking the view of the more colorful gases below.

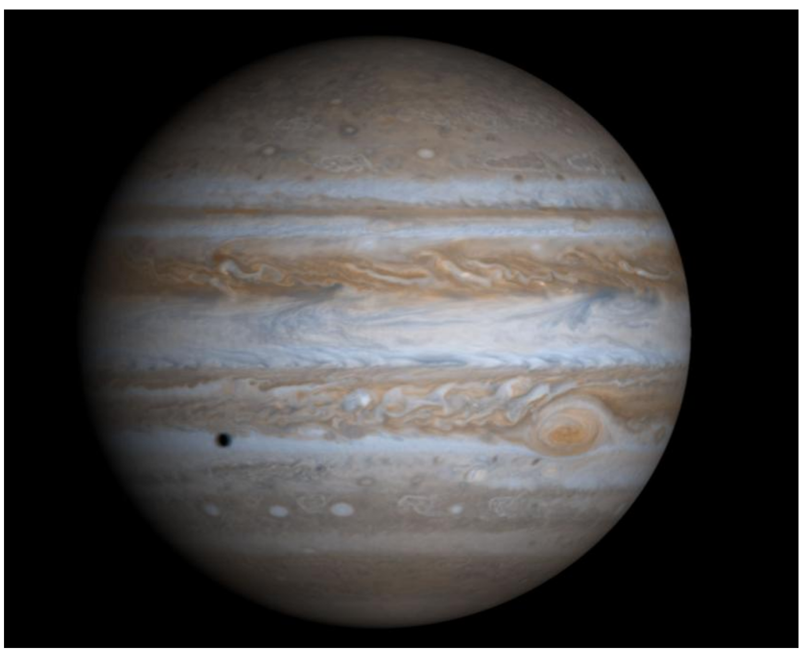


The origin of the belts and zones in Jupiter’s upper atmosphere

The interplay between the planet’s rotation, high winds, and convective rise and fall of gases have resulted in a complex structure of belts and zones, the structure of which is more or less permanent, at least over decades and perhaps centuries. The structure of the observable atmosphere of Jupiter along with the names of the major belts and zones are shown below.



The nomenclature of Jupiter's belts and zones



A spacecraft image of Jupiter. The dark spot is a shadow cast on Jupiter by one of its moons. Note the correspondence of this image to the map in the previous image.

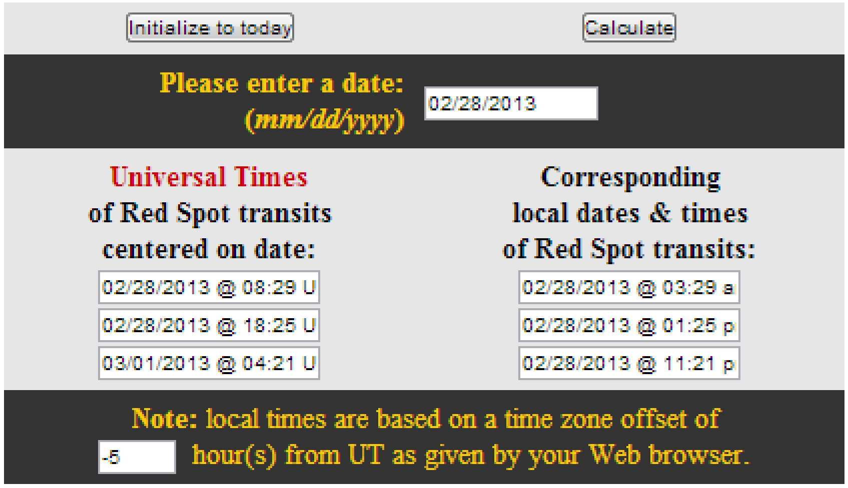
Not all the belts and zones in the images above are easily distinguished, but the most prominent regions visible in small telescopes are the equatorial belts and zones, the temperate belts and zones, and the darker polar regions.

(Note: Astronomers distinguish between a north and south region on Jupiter. "North" is simply the side of Jupiter that points north as seen in our sky).

Jet streams of opposite direction on each edge of the belts and zones confine each structure, and as the gases whirl across the face of the planet at speeds exceeding 300 km/h, turbulence occurs at the boundaries. This turbulence leads to intricate and exceedingly beautiful structures called *garlands* and *festoons* between and within each belt and zone (see image above). On nights of steady seeing, you can get glimpses of these structures in a small telescope.

As on Earth, the dynamic atmosphere of Jupiter and the so-called Coriolis force lead to circulating cells of gas that result in cyclonic storms. On Earth, these churning cells are about as high as these are tall, but Jupiter's faster rotation flattens its cells and stretches the cells longitudinally into flattened ovals. Some of these oval cells coalesce into visible and long-lasting vortices, the most famous of which is the *Great Red Spot* (GRS). This spot straddles the south equatorial belt and the lighter south equatorial zone, impinging on each. The GRS, which is larger than Earth, has been observed for centuries and may be a permanent feature in the Jovian atmosphere. Which is not to say it never changes. The GRS and the SEB both change color at unpredictable intervals. When the SEB turns lighter, the GRS darkens and vice versa. During the past several decades, the GRS was darkest in the periods 1961–66, 1968–75, 1989–90, and 1992–93. No one knows why it changes, or indeed what causes its red color.

Like other vortices, the GRS tends to stay at the same latitude but drift longitudinally across the face of the planet. And of course it rotates with the planet, so it drifts across the planet's face in the course of a few hours before swinging around to the other side of the planet not facing Earth. You'll learn shortly how to look for the GRS with a telescope. But because of Jupiter's rapid rotation, you need to know when to look for it. It's most easily seen about an hour before and after it transits (crosses) Jupiter's meridian, the line that bisects the face of the planet from north to south. This transit occurs once per rotation or about once every 9.8 hours, or about once per night on average. Printed tables and web-based tools are available to determine the times of the passing of the GRS across the meridian. Each monthly print edition of *Sky and Telescope* magazine reports these times, as does the annual Observer's Handbook of the RASC (Royal Astronomical Society of Canada). *Sky and Telescope* also has a web application that will calculate transit times of the GRS. You simply input the date and it generates a table of the next three transits. Here's an example of what it generated on 2/28/2013:



The left side of this table shows transits in Universal Time (essentially Greenwich Mean Time). It also detects from my web browser that I am in a time zone 5 hours behind GMT and applies the corrections. So on the right side of the table, I see the GRS in this example will cross the center of the face of Jupiter at 3:29 a.m., 1:25 p.m. (in daytime), and at 11:21 p.m. So if I want to see the GRS this evening, I should look from about 10 p.m. through 1 a.m., and expect the spot to cross the meridian at 11:21 p.m.

Here's the link for the *Sky and Telescope* web tool for predicting GRS transits:

http://www.skyandtelescope.com/observing/objects/planets/3304091.html

There are many other oval storms in Jupiter's atmosphere. Small storms come and go, and occasionally merge. In 2000, three white oval storms merged and turned into a red storm called the "Oval BA", or sometimes the "Little Red Spot" or "Red Spot Junior". The Oval BA lies in the south temperate belt, south of the GRS. The two storms occasionally come close but do not impinge on each other. The Oval BA is also visible in a small telescope in good conditions, though there are not yet tables to predict the appearance of this smaller spot.

Jupiter's Moons

The belts and zones and spots in Jupiter's atmosphere are great fun to watch. But the four biggest moons of the biggest planet also add drama and dynamism to the Jovian system. These four moons move around the planet over the course of hours or days. But the moons frequently pass in front and behind the planet, and also fall into the shadow of Jupiter. It all makes for great viewing on nearly every night during which Jupiter is visible. Here's a quick look at each of the four largest moons of Jupiter and what to look for in a small telescope.

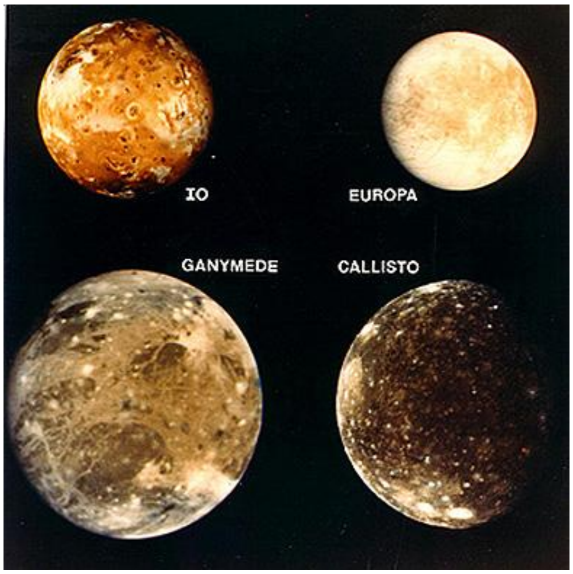
Of Jupiter's gaggle of 67 moons, the four Galilean moons are the largest. They are in fact larger than any of the dwarf planets like Pluto and Ceres and are among the largest rocky bodies in the solar system. Yet these four worlds are very different from each other.

Io ("EYE-oh") is a red-orange sulphuric hell-hole of a world, where volcanoes spray molten lava high into space. Io shouldn't have a molten core– it's too small to generate enough internal heat– but the gravitational push and pull of Jupiter kneads the core of this small world, and keeps it perpetually active.

Europa is slightly smaller than our Moon, but it's much lighter. The surface is smooth and free of craters, but long cracks criss-cross the surface. Fly-bys of NASA satellites suggest Europa has a liquid-water ocean miles under its icy surface, and some planetary scientists think the moon's hot core may furnish enough energy and minerals to stimulate the formation of simple life forms.

Ganymede ("GAN-eh-meed") also has a smooth, glassy surface with patches of older, cratered material. The moon is the largest in the solar system, outsizing even the planet Mercury. The geology of this moon is not well understood.

Callisto, the most distant of the four moons from Jupiter, is geologically dead as a doornail. Like Mercury and our own Moon, its surface is strewn with craters, which means not much has happened here since the early days of the solar system.



The Galilean moons of Jupiter

Jupiter has 63 other moons, but none are accessible in telescopes smaller than 18-20" aperture. Inside the orbit of Io lie the inner satellites or "Amalthea group": Metis, Adrastea, Amalthea, and Thebe. Well outside the orbit of the largest moons are several other groups. Most of these tiny objects are likely captured asteroids.

For backyard stargazers, aside from the clocklike motion itself of the four Galilean moons, there are four types of events related to these moons to observe in a small telescope: transits, occultations, shadow transits, and eclipses.

A *transit* is simply the apparent passage of a moon across the face of Jupiter. All four moons appear to transit the planet, but not all are easy to see when they do so. Callisto has a dark surface and contrasts well against the face of Jupiter, although Callisto often does not appear to transit Jupiter because of the axial tilt of the planet and its orientation with respect to Earth during its orbit around the Sun. Io, Europa, and Ganymede have more reflective surfaces and are harder to discern as they transit. During transits, the moons appear to move east to west across the face of the planet, as defined in the sense of our sky, not the planet itself.

A transit of Europa and its shadow across the face of Jupiter

A *shadow transit* is the passage of a moon's shadow across the face of Jupiter. Such events are governed by the position of the Sun, Jupiter, and the Earth. In the image above, for example, the Sun is off to the right of the picture, causing the shadow of Europa to fall to the left of the moon as seen from our point of view. When the Sun is on the other side of the sky from Jupiter, the shadow falls in the other direction.

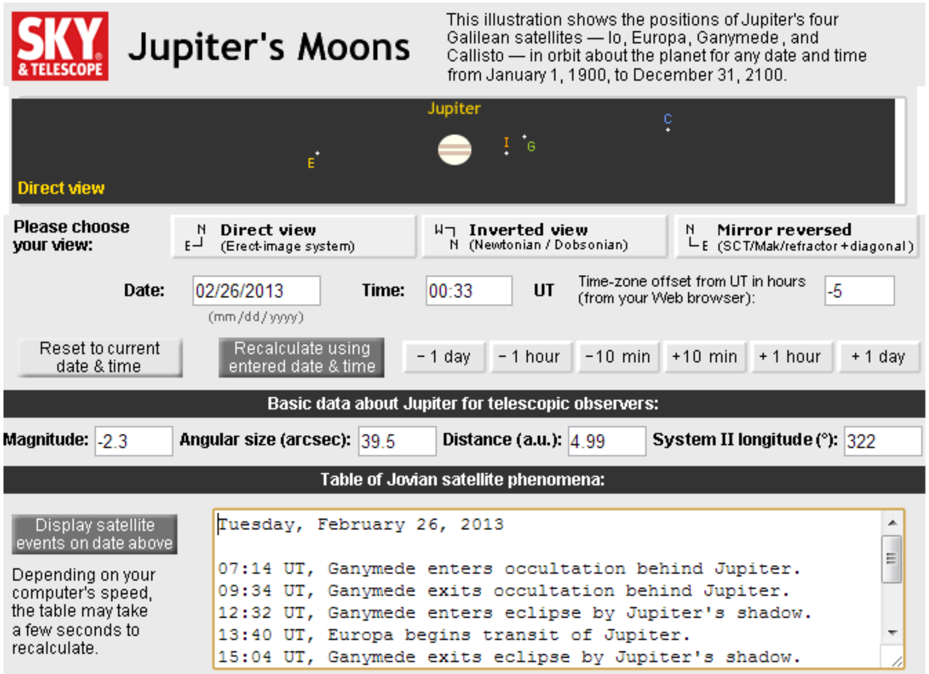
An *occultation* results when Jupiter's moons pass behind the planet. All four moons do so once during each revolution. Io, the closest moon to Jupiter and the quickest, passes through an occultation in just a couple of hours. Callisto, the slowest moon, takes much longer.

Frequently, before a moon passes behind the planet or after it emerges, it passes into Jupiter's shadow. This is an *eclipse* of the moon. When an eclipse begins and ends, it appears the moon suddenly appears out of the darkness of space as it emerges from the shadow of the big planet. These are perhaps the most dramatic events involving Jupiter's moons you can see with a small telescope.

With four moons and four phenomena—transits, shadow transits, occultations, and eclipses—one of these events can be observed, on average about once every 3.5 to 4 hours. To determine which moon undergoes which event, you must turn to a set of tables or a calculator. As with the Great Red Spot, the *Observer's Handbook* of the RASC has full tables each year for these events. And *Sky and Telescope* magazine provides a handy online calculator. Here's the link:

http://www.skyandtelescope.com/observing/objects/planets/3307071.html

Here's an example of the calculator below:



This example shows the positions of the moons on February 26, 2013 at 00:33 UT. Below, it shows a list of events on this date, starting with Ganymede entering an occultation behind Jupiter. At 13:40 UT, Europa begins a transit of Jupiter, and so on. This is a very useful planning tool for observing Jupiter.

Note also that more than one event can occur at a given time. You may see one moon passing behind the planet as another passes in front. Or you may see more than one shadow cast on the face of Jupiter at one time. There are endless variations. Rarely, you may even see one moon pass in front of another!

Observing Jupiter in a Telescope

To see any detail on Jupiter, you will need a telescope. Some telescopes are better than others for seeing Jupiter and the other planets. But the best telescope for you is the one you have right now. Here's how to get the most out of your optics and your situation when looking at Jupiter…

First, you need to pick the right time to see Jupiter, namely, when Earth is closest to the planet. That time is when Jupiter is at *opposition*, when it is opposite the Sun in the sky. At opposition, the planet rises in the east as the Sun sets in the west. The last opposition of Jupiter was January 5, 2014, so we're a couple of months past optimum and the planet is slowly starting to shrink in apparent size. But Jupiter is large enough to look good for a few months on either side of opposition, so there's still plenty to see this month.

Next, you need a night with good steady seeing. You'll learn more about this later in the course. But you can tell if the air is steady and the "seeing" is good if stars exhibit very little twinkling. If the air is turbulent, even a big telescope will show Jupiter as a boiling featureless blob.

What's the best telescope to see Jupiter? We haven't discussed telescopes yet, but here are a few tips. Generally, you want a long focal length which gives you a larger image for a given eyepiece. Refracting telescopes are often best because they have an unobstructed view and so provide the best image contrast. Larger aperture gives more resolution of fine detail, assuming your sky conditions allow it. And if you use a Newtonian reflector telescope, make sure it is well collimated.

(If you don't understand the above paragraph, don't worry. We'll get to all this in the coming months.)

With whatever telescope you presently have at your disposal, use as much magnification as it will handle when you look at the planet. This depends on the quality of your optics and on the seeing. Generally a magnification of 30-50x the aperture of your telescope (in inches) works well on nights of average seeing. So if you have a 4-inch telescope, try 120x to 200x. If you have razor sharp optics and steady sky, you can get away even more magnification. But you should experiment. Start at low magnification and work your way up until you get the best combination of image size and contrast and clarity. The best magnification may change from night to night because of changing sky conditions.

Jupiter as it might appear at 200x in a small telescope in steady seeing

With all planets in amateur telescopes, the images, even at high magnification, will be quite small. You may find this disappointing at first. But even small images can present nearly as much detail and color as you see in magazine-grade images of Jupiter (see image above). Wait for moments of steady air and you will tiny details snap into view, including the smaller belts and zones, festoons, the GRS (if visible) and possibly other smaller spots and shadows cast by the moons. Patience is critical: you might need to watch Jupiter through your telescope for half an hour to get just a few flashes of detail when the air steadies. But these fleeting moments make the effort worthwhile.

In time, as you build your astronomical toolkit, you will acquire color filters which fasten onto the back of your eyepieces. These filters help bring out more detail on the planets. A quick suggestion: try a green filter with Jupiter to bring out the contrast of the red belts and spots.