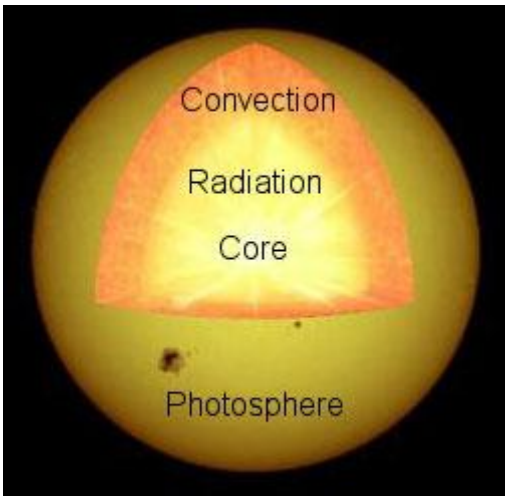
Aryabhat Astronomy Quiz

Study Material Part 1

The Sun



Our Sun (called Sol by the Romans from which we get the word solar) is a main sequence G2 dwarf star. This means that it is fusing hydrogen into helium as its main power source, and that its mass is such that it emits its most intense light at a yellow frequency at about 5800 degrees Kelvin (a G2 star).

The Sun is a micro variable star. We used to think that the Sun was a constant star, but we have learned that every star is variable to some degree.

The Sun has an absolute magnitude of 4.8 at the standard distance of 10 parsecs (2062648 AUs). This compares to an apparent magnitude -26.7 at 1 AU (8.3 light minutes). Of the hundred nearest stars only three Sirius, Alpha Centauri 1&2 are larger. Alpha Eridani is almost as large and then stars get small fast. Most are faint red dwarfs. The Sun has many features, which have no counterpart in the planets. Here are some of these features:

The Sun emits a thin **solar wind** of particles driven from the Sun's surface by light pressure, electrical charges or magnetic fluxes. This solar wind can be detected throughout the solar system. In large planets, when these solar winds interact with the magnetic field of the planet, auroras are caused.

The Sun's **corona** is its very fragile outermost atmosphere, an extremely hot gas which is in the millions of degrees. We normally do not see this gas, but during eclipses these pale outer atmosphere creates strange flame like images much larger than the Sun's disk.

The **chromosphere** is the "atmosphere" of the Sun. It is much more dense than the corona (and much cooler) but it still is relatively thin when compared to the photosphere. The chromosphere absorbs certain frequencies of the Sun's light. Each absorbed frequency is specific to a particular type of atom. The pattern of alternating bright and dark bands (the Sun's spectra) gives us a great deal of information about the Sun's composition and chemistry.

The **photosphere** is what we think of as the Sun's "surface". When you look at the Sun through filters, it is the photosphere, which displays texture. The photosphere emits the large majority of the Sun's light. This photosphere is not uniform. The Sun's surface has a mottled texture, which reminds many people of the surface of a pot of cooking oatmeal. This **granulation** is the top of "bubbles" percolating up from lower levels in the Sun.

Sunspots are blotches, which are slightly cooler than the surface as a whole. They would be brilliant if they weren't against the even more brilliant general surface. They increase and decrease in a pair of 11 years cycles (north and south hemispheres). During periods of intense sunspots, long-range communications on the Earth may be disrupted. The area surrounding a sunspot is called an **active region**, which has intense magnetic flux.

Some solar storms create huge loops of gas along lines of magnetic force forming a **prominence**. These eruptions can be hundreds of times the diameter of the Earth. Solar **flares** occur

when a granulation bubble breaks through the surface before it cools to the surface temperature. Material from the much hotter interior is exposed. Not only does visible light increase but so does the Sun's ultraviolet and x-ray radiation. Solar flares can be extremely disruptive. Sometimes the Sun's belches out a huge puff of electrically charged gas **plasma**. If this **coronal mass** (or discharge) happens to hit the Earth, power lines can be damaged, astronauts must seek shelter in the deepest parts of their spacecraft and auroras are intense.

The Sun generates its power in a central **fusion core** where the temperature is 15 million degrees Kelvin. Hydrogen gas is transmuted (changed) into helium with a great release of energy similar to the process in a hydrogen bomb. The Sun does not explode because its huge gravity holds the nuclear explosion in check. The **radiation zone** lies above the core. It is electrically conductive gas (properly called a plasma) transmits the electromagnetic radiation by direct radiation. As the radiation works its way outwards, it is progressively reduced in frequency from very short wavelength gamma radiation to x-rays and ultraviolet frequencies. The **convective zone** lies above the radiating zone and below the photosphere. This layer transmits energy by rotating vortices (bubbles). This "boiling" occurs in gas which is no longer so hot that it is a charged plasma.

Eclipses

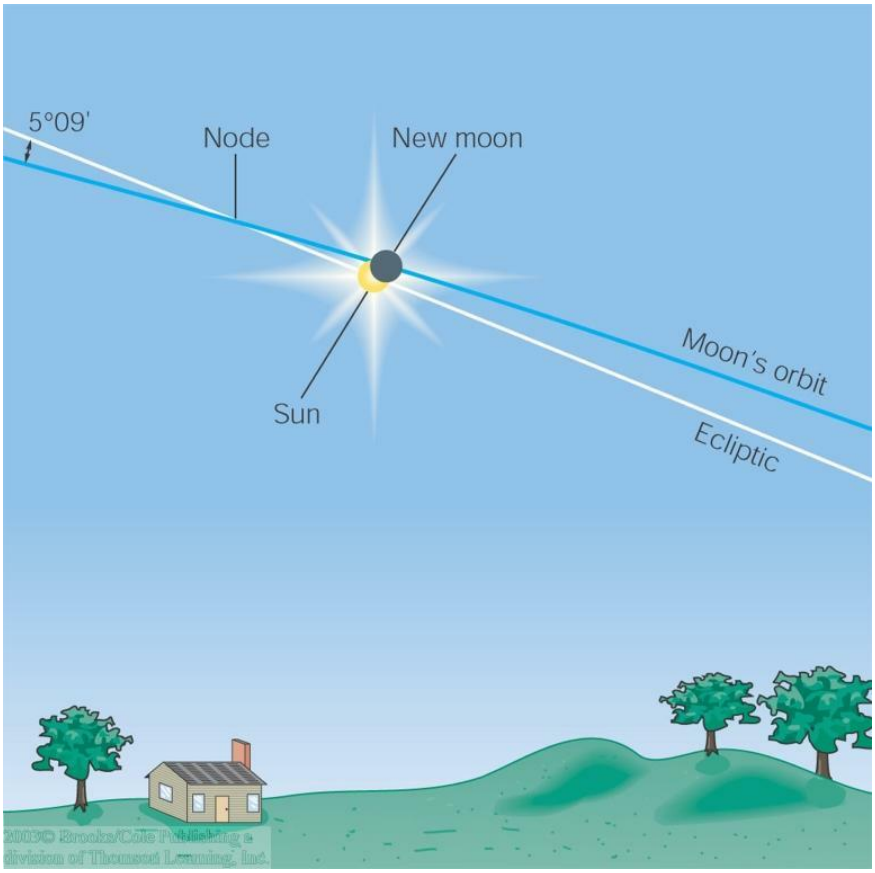
An eclipse is the concealment of a body by another. This happens if the involved bodies are aligned, in such way that one of them darkens, even if it's just in partial form, to the other body.

In the Sun-Earth-Moon system, the eclipses happen due to the rotation of the Earth around the Sun and due to the rotation of the Moon around the planet Earth. In the moment in that the Sun, the Earth and the Moon are aligned and if the Moon is going by one of its nodes an eclipse happens. Before seeing why the eclipses happen we'll revise first some basic concepts.

Apparent size: It is the size of the celestial bodies seen from the surface of the Earth. As the diameter of the Sun it is 400 times bigger than the diameter of the Moon and as the Moon is 400 times nearer, seen from the Earth, the Sun and the Moon almost has the same size (a fortunate astronomical coincidence). Because the Moon has an elliptic orbit, in some occasions it is nearer the earth than in others. Because the Earth has an elliptic orbit around the Sun in certain seasons of the year it's nearer the Sun than in another. Being more near to a body makes that this seems bigger and if this body is farther it seems smaller, it's for this reason that the apparent size of the Sun and the Moon vary during the year.

Ecliptic: It is the apparent line that describes the Sun in the sky. Imagine that the Sun goes coloring a line during its journey for the sky, this line is the ecliptic how it's seen from the earth. The old astronomers observed as the Moon should be crossing this line in order to an eclipse happen, for this reason they called it ecliptic. This line touches twelve constellations, these constellations were baptized by the old astronomers with mythological names, and when a person was born, they said that the person had been born under the constellation (or sign of the zodiac) that was behind the sun in that moment (one of the twelve zodiacs).

Plane of the ecliptic: The Earth moves around the Sun in an elliptical orbit. The plane of the ecliptic is the plane of the orbit of the Earth. The plane of the orbit of the Moon is inclined with regard to the ecliptic, approximately 5.1º. It causes that during the movement of the Moon around the Earth, the Moon only passes in two points on the plane of the ecliptic.

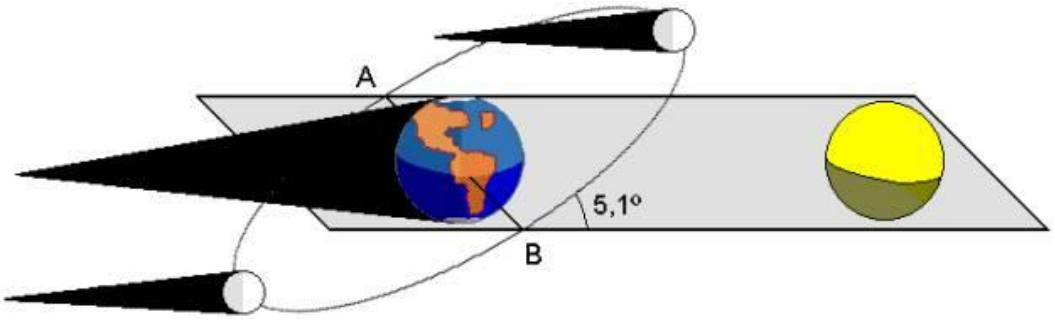


In the following illustration is shown how view from the terrestrial surface, the path of the Moon (in blue) is inclined with regard to the ecliptic (in white).

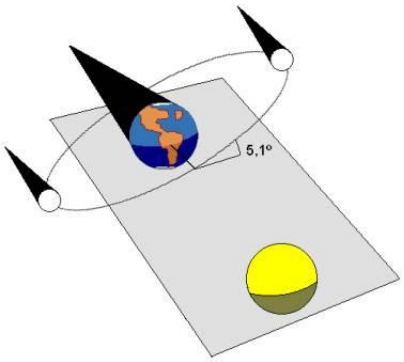
Nodes: They are the points in which the moon crosses the plane of the ecliptic. Of the above-mentioned one can deduce that during half of its orbit, the Moon is above the plane of the ecliptic and during the other half the Moon is below.

Line of nodes: It is the line that passes by the two nodes.

In the following illustration the plane of the ecliptic is observed (in gray), the plane of the orbit of the moon and its inclination of 5.1º with regard to the ecliptic. Also in this graph the points of cut of the lunar orbit with the plane of the ecliptic can be appreciated in the nodes A and B, as well as the line that unites the node A with the node B, called line of nodes.



In the previous image one can observe that if the moon passes in the front side of the Earth without be near of one of its nodes, the cone of lunar shade doesn't touch the terrestrial surface and therefore there won't be an eclipse of Sun. In the same way, if the moon passes behind of the earth, being far from one of its nodes, it doesn't go inside the cone of terrestrial shade and it doesn't cause an eclipse of Moon.



But, due to the mutual movement of the Earth and the Moon, the line of nodes changes its orientation. Being the line of nodes pointing toward the Sun, if the Moon crosses the ecliptic by the node that is in front of the Earth, it will cover in total (or partial)

form the sun, taking place a solar eclipse. If the Moon goes by the node that is behind the Earth, the planet will cover in total (or partial) form the light of the Sun that the Moon receives and a lunar eclipse will take place. All this you can appreciate in the given graphic.

It is necessary to make note that if would not exist the inclination of the plane of the lunar orbit with regard to the ecliptic, every time that the moon would pass in front of the Earth (New Moon), an eclipse of sun would take place in the regions near to the terrestrial equator (never in the area near to the poles) and every time that the Moon would pass behind the Earth (Full Moon), it would happen a total eclipse of Moon.

The Planets

New definition : In the 26th General Assembly for the International Astronomical Union, more than 2500 astronomers participated. During 17 Joint discussions, the Astronomer from world-over resolved the new definition of a planet through Resolution 5A. The IAU has resolved that "planets" and other bodies in our Solar System be defined into three distinct categories in the following way :

A **planet** is a celestial body that

- moves in a definite orbit around the Sun,
- has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
- has cleared the neighborhoods of its orbit.

A **dwarf planet** is a celestial body that

- moves in a definite orbit around the Sun,
- has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape,
- has not cleared the neighborhoods of its orbit, and
- is not a satellite.

All other objects orbiting the Sun except satellites shall be referred to collectively as “Small Solar-System Bodies”.

Objects recognized by the IAU as dwarf planets

Physical Statistics							
Name	Diameter (km)	Mass ($\times 10^{21}$ kg)	Density (g/cm³)	Surface gravity (m/s²)	Rotation period (days)	Moons	Surface temp. (K)
Ceres	946	0.94	2.17	0.29	0.38	0	167
Pluto	2380	13.05	1.87	0.58	−6.39	5	44
Haumea	1240	4.01	2.6–3.3	0.44	0.16	2	32
Makemake	1430	?	> 1.4		0.32	1	≈ 30
Eris	2326	16.7	2.5	≈ 0.8	≈ 1	1	≈ 42

Orbital Statistics						
Name	Region	Orbital Radius (AU)	Orbital Period (years)	Mean orbital speed (km/s)	Inclination to ecliptic	Orbital eccentricity
Ceres	Asteroid belt	2.77	4.60	17.882	10.59°	0.079
Pluto	Kuiper belt	39.48	248.09	4.666	17.14°	0.249
Haumea	Kuiper belt	43.13	283.28		28.22°	0.195
Makemake	Kuiper belt	45.79	309.9	4.419	28.96°	0.159
Eris	Scattered disc	67.67	557	3.436	44.19°	0.442

Dwarf Planets Quick Data		
Name	Dist from Sun (kms)	Moons
Ceres	383641330	0
Pluto	5025181045	5
Haumea	6453453400	2
Makemake	6783328745	1
Eris	10121139260	1

According to the new definition, our Solar System has EIGHT planets now, the statistics if which are given below :

Statistics of Planets						
Planet	**Diameter**	**Mass**	**Mean distance from Sun**	**Rotation period**	**Revolution period**	**Escape Velocity**
	(kms)	(kgs)	(10^6 kms)	(hours)	(earth days)	(km/s)
Mercury	4878	3.3×10^{23}	57.90	1403.73	87.97	4.25
Venus	12104	4.87×10^{24}	108.20	5816.20	224.70	10.36
Earth	12756	5.98×10^{24}	149.60	23.93	365.26	11.18
Mars	6787	6.42×10^{23}	227.90	24.62	686.98	5.02
Jupiter	142,800	1.90×10^{27}	778.30	9.84	4332.66	59.60
Saturn	120660	5.69×10^{26}	1427.00	10.23	10759.34	35.60
Uranus	51118	8.68×10^{25}	2869.60	17.24	30685.15	21.10
Neptune	49528	1.02×10^{26}	4496.60	18.40	60191.63	24.60

The innermost planets in the solar system are formed with a central core surmounted by a rocky mantle and a thin crust (and a very thin ocean on Earth). Although we do not have a great deal of direct evidence, we believe that these worlds formed while the newly ignited Sun was propelling a titanic solar wind. Although the rocky materials and heavy metallic cores could form, a dense hydrogen and helium atmosphere similar to the outer gas giants was not possible.

All these worlds bear scars from the period roughly 4.5 billion years ago when they were formed out of the collisions of countless smaller bodies. Mercury presents a visual surface that is easy to confuse with the Moon. It is heavily crated. Earth bears definite crater marks, although the forces of weather and plate tectonics have erased many of these scars. We can see traces of craters on Mars and radar images of Venus reveal similar terrain. All this confirms that the early solar system abounded with small proto-planets that cris-crossed the more circular orbits of what became the major planets.

Some of these cris-crossing worlds hit the planets and merged with them. Comet Shoemaker-Levy 9 met this process on Jupiter and we know that 65 million years ago, the dinosaurs died when a relatively small remaining proto-planetesimal struck the Yucatan Peninsula. Eventually only relatively large bodies in relatively circular orbits survived. Today, only Pluto is in a cris-crossing orbit and it survives simply because it is in a strange 2 to 3 synchronous orbit with Neptune which always keeps them at least 1/3 of Neptune's orbit apart.

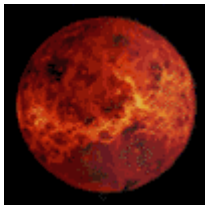
Mercury

Mercury, the innermost of the planets, shows the effects of it close proximity to the Sun in many ways. While it looks like the Moon as far as its topology goes, it differs from the Moon drastically. Its iron nickel core is a much larger percentage of its total volume. Mercury would also be the densest planet if it were as large as the Earth. Its gravity is too little to significantly compress its core.

It was once though that Mercury was tidally locked to the Sun, much the same way as the Moon is tidally locked to the Earth or the Galilean Moons are tidally locked to Jupiter. Tidally locked bodies rotate on their axis such that their "day" and their "year" are identical. Mercury revolves in synchrony with it orbit about the Sun in a ration of three Mercurian days in a Mercurian year.

The combined effects of Mercury's high eccentricity orbit and the planet's proximity to the Sun make it impossible to apply Newtonian physics to predict its position over long periods of time. The orientation of the orbit revolves slowly in accordance with Einstein's General Theory of Relativity.

Venus



The planet Venus has long been imagined as a paradise or at least an Eden. It great brilliance and its lunar like phases (suspected although not viewed since antiquity) made it a natural connection to the Moon. It is not coincidence alone that both bodies where associated with Goddesses - Venus/Aphrodite and Diana/Selene. From the middle of the 19th century until about 2/3rds of the way through the 20th century, Venus was believed to be a damp, watery world, somewhat warmer than Earth but still a very likely abode for life. Numerous stories were written about this cloud-covered world with people slogging through swamps or being besieged by rains as amphibian wildlife provided the local monsters.

The first signs that Venus might not be quite such a rainy swampland were the microwave signals from large radio telescopes. If the curves were to be believed, the temperatures weren't merely very warm but positively blast furnace like in intensity. This was confirmed when the first probes parachuted into a hellish world where the surface was hot enough to melt lead or tin, the air was as dense as water thirty feet deep, the clouds were boiling sulfuric (battery) acid, and water was no where to be found.

Venus had other surprises. It rotates backwards. Its north pole points in the same direction as the other planet's South Pole. It has an extremely long day (18 of our days longer than its year). Weirdly, three Venerean days is just about exactly two Earth years.

The air is so dense that light is refracted completely around the planet. The cloud layer is so dense that daytime is only somewhat brighter than nighttime. If we could see much of anything on the surface, everything in the distance would seem red or orange because other frequencies of light are absorbed far above the surface.

Venus is just close enough to the Sun, so that a runaway greenhouse effect took place. Electromagnetic radiation is trapped beneath the cloud deck. When volcanoes and crevasses open, any sulfurous gasses remain gas rather than cooling to a solid as they would on Earth.

Venus' apparent diameter changes radically from its farthest position to nearest point. At its most distant, it is about 1.8 AUs from the Earth. At its nearest it is about 0.2 AUs from the Earth. If we could see Venus at its very nearest, it would be 9 times as large as when it is at it is most distant. Unfortunately, both these extremes occur when it aligns with the Sun.

You might think that Venus would be brightest when it was closest, but this is incorrect. As Venus approaches, it becomes an ever-thinner crescent. As Venus approaches "full Venus" (ala full Moon), it also reaches its smallest disk. Venus is most brilliant at the point where it displays the greatest illuminated surface, a balancing act between its phases and its proximity to Earth.

Earth

When we are asked what planets are visible, we almost always forget to mention the single planet, which is always visible, day or night. It is the one underfoot, the Earth. The planet Earth (called Terra by the Romans and Gaia by the Greeks) really should probably be called planet Water. About 7/10ths of it surface is washed by oceans, seas, lakes and rivers. Earth is a very high contrast planet, with brilliant white clouds against large blue areas and smaller orange brown areas. It has two very prominent polar ice caps.

Earth is not only the only known abode of life in the solar system, but a planet, which has been radically altered, by life. Our very atmosphere was manufactured by a mutant strain of bacteria. These strange bluish green bacteria started to break down compounds and emit ferociously caustic gas oxygen. Most of the life on Earth died when in came in contact with this deadly poison. Today only in a few places where oxygen cannot reach do we find the survivors of this first and most dramatic case of air pollution. The mutant bacteria live on everywhere as blue/green algae. The scant survivors are the anaerobic bacteria found in hot springs and badly sterilized cans of food - botulism. You might think that life was basically a surface feature but you would be wrong. Our deepest wells and mines encounter bacteria many miles inside the Earth, living on whatever chemicals can sustain life.

Moon

Isn't it a bit out of place to call the Moon a rocky planet? Isn't the definition of a planet a large world, which revolves around the Sun? Aren't things, which revolve around planets called satellites? The answer to all of these questions simply points out how very odd the Moon really is.

The Moon is a large world, bigger than Pluto and not much smaller than Mercury.

While the Moon circles the Earth, it always moves forward relative to the Sun. In fact the Sun's gravity controls the Moon's orbit about 3 times as strongly as the Earth's gravity. This does not happen with any other natural satellite. It is not adequate to compute the position of the Moon simply by treating the problem as finding where the Earth is and then computing an elliptical sub orbit for the Moon. All other natural satellites can be calculated this way for almost all purposes.

Add to these two conditions the effect of tidal drag, and you get a world, which is more difficult to compute than any other object in the solar system except for comets, and asteroids, which happen to come very close to large worlds.

The Moon is composed of a rocky mantle, which is extremely similar to its co-planet Earth, but it lacks a metal core. [We can tell this through various tests such as a lack of a magnetic field and "moon quakes" which allow seismometers placed on the surface to allow examining the interior as we do on Earth. Only one theory has survived rigorous computational modeling. The Moon must have been formed when the Earth was struck a glancing blow by an early proto-planet in an elliptical orbit. This proto-planet must have been the size of Mars approximately. Some of the material from the proto-planet and a great deal of the material from the Earth's mantle collected in a dense ring quite close to the surface. Eventually this coalesced into the Moon.

Tides

Throughout most of the world, there are two high tides and two low tides every lunar day (just under 25 hours). If gravity alone were the cause of the tides, there would be just one on the side of the Earth facing the Moon. In any case, the Sun would raise a much greater tide because the gravity of the Sun on the Earth is 832 times the force of the Moon on the Earth.

Tides are caused by an imbalance between orbital speeds at the center of a body and orbital speeds at the surface. Consider our diagram. Assume the body is following the gray line. The yellow dot at the center of gravity follows this orbit with neither an excess no a deficit of speed. However, the red outer particle is actually in a slightly larger orbit but still traveling at the same speed as the yellow dot. This means that the red particle is traveling slightly too fast for the orbit it is in. Left to itself the red particle would change its orbit's shape slightly creating a larger elliptical orbit. The situation for the

blue dot is very similar, except that it is going just a bit too slow and would like to drop into a smaller orbit.

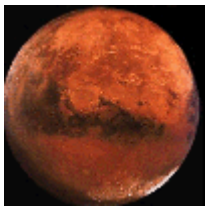
If the body were perfectly rigid, all that would happen is a tension at right angles to the orbit. However if the body is either completely fluid or covered with a fluid, a bulge is created on both the inward and outward sides of the body - a tide. On Earth, additional complications occur. First the Earth is spinning once in 24 hours (rather than just under 25 hours for the Moon). This means Earth is trying to accelerate the tidal bulge. This in turn exerts a breaking action on the Earth (the Earth's rotation is slowing a small amount every day and has been for billions of years). The loss of angular momentum must be matched by the laws of physics and the result is the Moon slowly recedes from us. A second complication is that the Sun also raises a smaller tide, which is in a 24-hour cycle. This means that throughout the lunar month the tides sometimes reinforce each other and sometimes counter each other. This causes flood and neap tides.

The tides are not only raised on the Earth, but on the Moon. The Moon's tidal bulge is cast in concrete or more precisely in granite. The face we see is raised. If the Moon drifts to one side or another (a motion called libration), the Earth exerts a torque on the bulge and returns the Moon to face us.

The closer you get to a massive body the more severe the tidal forces on an extended body. Inside a certain distance (Roche's Limit), solid bodies cannot form. The would-be satellites which venture too close to large planets become rings.

Extremely massive bodies with extremely small diameters (white dwarfs, neutron stars, pulsars and black holes) can have tides so strong that nothing can withstand them. An astronaut venturing too close to one of these monsters would feel his feet pulled into the black hole (or whatever) while his head was being wrenched off into outer space.

Mars



No planet has held a greater fascination for us than Mars. It is a place we might be able to live on if we provided ourselves with breathable air and some warmth. For those of us born before the space age, Mars was almost magical. It was the only planet with a surface that could be seen. At closest oppositions, it is quite possible to pick out polar caps, mountainous areas and plains.

However, Mars' image plays tricks on our eyes. The edges of two types of terrain seemed to be marked by long "canali". When Schaparelli used this term, it only meant "channel" in Italian but it wasn't long before the word was being called "canals". In turn, canals implied canal builders, and this in turn became ever more fanciful stories of dying races and desperate attempts to eke out meager water reserves from the polar caps for farms along the canals. Mars had other tricks to play on our eyes. Sometimes canals changed. We now know that these changes if there were seen at all were simply the result of dust storms covering and revealing the land below.

Mars is currently the target of a quixotic mission to send men to the planet. Whatever the social forces that prompt this, relatively little scientific information will be gained that could not be gained remotely.

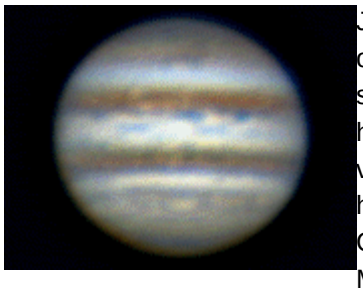
Gas Giants

During the formation of the solar system, many planetesimals formed as whirls in a disk that spun around the proto-sun. Heavy elements sank towards the center of these bodies while the outer portions were wrapped in gasses - primarily hydrogen and helium. Once the Sun reached a point where its internal temperatures allowed it to ignite nuclear fusion, everything changed. The innermost planetesimals were lashed by extremely powerful solar winds which stripped away most of the hydrogen and helium. All the while all of the large planetesimals were accumulating smaller planetesimals eventually forming the eight large planets.

By now the innermost worlds were scoured clear of most of their atmospheres. Only denser and heavier gasses remained. On Earth, much of the hydrogen combined with oxygen to form water.

However, farther out the solar wind abated and the growing planetesimals could gather huge reserves of hydrogen and helium. So much hydrogen was gathered that it began to compress into unusual forms such as metallic hydrogen.

Jupiter



Jupiter is a planet of superlatives. Only Earth rivals it for markings. It outweighs all the other planets put together by at least a factor of 2. It spins on its axis faster than any planet. A Jovian day takes less than 10 hours. Its "surface" gravity is more than twice that of the Earth. It has vast storms, larger in diameter than the Earth that swirls madly for hundreds (perhaps thousands?) of years. One such storm called the Great Red Spot has been continuously viewed since Galileo's time. Moving pictures from spacecraft dramatically show the clouds racing around the center at speeds of several hundred miles per hour.

Jupiter has a huge core of metallic hydrogen. Metallic hydrogen is hydrogen gas compressed so densely that it begins to behave like metals on Earth. In particular, it carries electrical current. This in turn creates a magnetic field, which acts as a vast buffer between Jupiter and the Sun's solar wind. If we could see magnetic lines of force the magnetosphere would be larger in our sky than either the Moon or the Sun. Jupiter has huge lightning storms with bolts so powerful that its innermost satellites, Amalthea and Io are sometimes hit by them.

Jupiter volume is just about as large as it is possible for a body to be without becoming a star. If you dumped more material into Jupiter, its diameter would begin to actually shrink as gravity increased the density faster than material could be added.

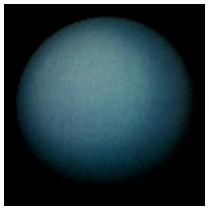
It is a mistake to think that Jupiter is nearly big enough to make a star. It is nowhere close to that mass. It would have to be between 15 times its current mass to be a brown dwarf and 80 times its current mass to be the smallest main sequence red dwarf. In spite of not being able to sustain nuclear reactions in its core, Jupiter generates more than twice as much light (in the infrared spectrum) as falls on it from the Sun.

Saturn

When you think of Saturn, the words "the ringed planet" almost certainly jumps to mind. While all the other gas giants have rings, none were discovered before the advent of spacecraft and some of them can only be detected when they blot out a background star as the planets passes in front. With Saturn there is no such problem. Saturn's Rings can be seen with the most modest tools.

The rings are swarms of tiny rock sized pieces of icy material. Long before the 20th century, astronomers and physicists knew that the rings where formed of countless particles. No rigid ring could have survived the tidal stresses on it.

Uranus



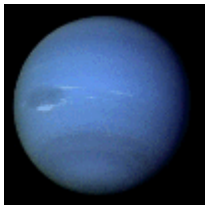
Uranus has to be the most featureless planet in the solar system. It is called green, but it is not the beautiful green of an emerald or an aquamarine but a pot of day old pea soup. You do not see the banding or cloud structures you see on Jupiter, Saturn or Neptune.

Uranus does have four substantial Moons, though none of them as large as Pluto.

Perhaps the most interesting thing about Uranus is that its axis is tilted an extraordinary 98 degrees. It keeps its north pole pointing towards the Sun. Effectively, it has a warm pole and a cold pole, but differences in temperature are minimized by surface airflow.

Uranus was the first planet found by telescopes. This is a little odd because this planet is visible to the unaided eye under favorable conditions. However, it is so dim and unremarkable, that no one ever noticed it was moving slowly.

Neptune

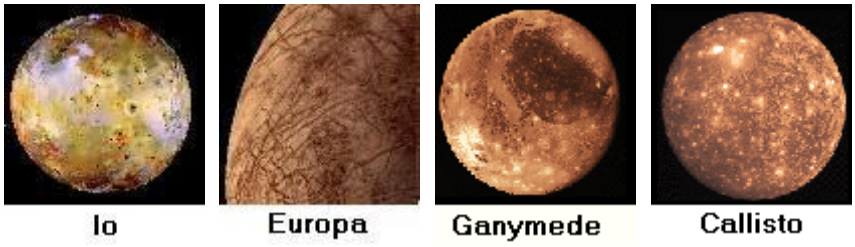


Neptune is a deep blue with white wispy clouds and a dark blue spot similar to the Great Red Spot on Jupiter. Its orbit is nearly circular, with only Venus slightly more so. Neptune is the first planet, which cannot be seen with the unaided eye. However, even the most modest binoculars can make it out as a faint bluish star, if you know where to look. At Neptune's distance, sunlight is almost a thousand times dimmer than on Earth. Sun appears as a small disk, but could be easily mistaken for an extremely bright star.

Once we past Neptune, the solar system changes radically. The hydrogen gas required to form a gas giant thinned too much to form a ninth large planet. Only icy clumps of water, methane and ammonia with chunks of rocky planetesimals and dust were left to form bodies. Just outside Neptune's orbit various small icy worldlets formed. Much farther out where the Sun's gravity feebly contends with passing stars, the final layer of the solar system the cemetery Oort cloud lies.

Satellites

Satellites in the solar system range from rocky planetesimals only a handful of miles across to great worlds larger than Pluto or Mercury. Some of these satellites had atmospheres and another seems to have a watery ocean. One satellite is white on one side and coal dark on the other. One has a huge crater that makes the satellite look like an eyeball.



Satellite Count *(as on 30 June 2018)*	
Mercury	None
Venus	None
Earth	1
Mars	2
Jupiter	69
Saturn	61
Uranus	27
Neptune	14

Some small rocky and icy planetesimals of irregular dimensions end up as captured moons of the outer planets. Capturing an asteroid requires something to slow asteroid down such as a brush with the planet's atmosphere or a close pass by a large moon. Unless the excess speed of an asteroid can be discarded by brushing the atmosphere or by slingshot orbit changes around a large Moon, any incoming asteroid will simply shoot by a large planet.

When our first robot spacecraft reach the Jovian System we could not believe what we were seeing. We expected that the four Galilean Moons would be more or less alike. Astronomers had predicted they would be a rocky center with an icy covering. We will look at some of the large satellites, but the smaller satellites are worthy of study as well.

Io is a festival world of brilliant reds, and yellows, black smudges and white streaks. You say you don't like the way it looks, well wait a few weeks and Io will change - dramatically. It is by far and away the most tectonically active world in the solar system. Io turns itself inside out ever million years or so. It has active volcanoes, which spew sulfurous compounds onto the surface at a pace, which far exceeds anything on Earth. It is as if the whole surface was like Volcano National Park on Hawaii.

If the surface wasn't wild enough, Io goes around Jupiter in a doughnut shaped cloud tube of ionized material (probably sulfur). It is as if Io has a strange atmosphere going all away around Jupiter.

Io has a really rough time being so close to Jupiter. Jupiter raises tremendous tidal forces in Io bending the rock and minerals back and forth. All this causes a great deal of heat from friction as materials rubs each other. Jupiter periodically blasts the surface of Io with great lightning bolts. The static from these flashes create the loudest radio noise in the 10-meter wavelengths.

Europa is the next major satellite out from Jupiter. It takes Europa twice as long to circle Jupiter as Io and half as long as Ganymede. Look at the surface of Europa. Those long lines are actually cracks, not in rock but ice. Mounting evidence suggests that this ice floats on a world wide watery ocean that in turn lies on a rocky core. If this sounds like our polar seas, it is hardly surprising.

While astronomers are fairly certain that Europa has some sort of an ocean, there are questions whether it is water, slush or some more exotic mixture with water and other materials acting as an antifreeze.

Ganymede is a very respectable world in its own right. While not as dense as Mercury it has a diameter, which is greater. It has a surface, which is three quarters of the Earth's land area. Ganymede is more like the Moon than any of the other Galilean Moons. It shows the type of cratering we see on both the Moon and Mercury.

Callisto is more like Pluto than any of the other Moons. Far enough from Jupiter so that tidal forces do not create frictional heat in huge amounts, it is the coldest of the Galilean Moons. Much of Callisto is icy material.


Titan

Titan, seconding size to Ganymede by a scant few miles, is another very substantial world. This moon is an orange brown color, but not because we see some tan colored soil by the only substantial atmosphere retained by any natural satellite. Its composition appears to be primarily methane with perhaps some ammonia. The molecular weight of methane is high enough that unlike hydrogen or helium, a small world can retain large quantities of it. It is through that this atmosphere is very similar to the original atmosphere of Earth before blue/green algae changed the atmosphere to a nitrogen and oxygen rich air.

Companions

Companions are bodies which orbits a third body yet are linked together in various odd ways.

Saturn has two moons Epimetheus and Janus which both orbit Saturn on opposite sides of a thin ring. Because one of the moons is an orbit, which is closer to Saturn, it travels faster and eventually overtakes the outer moon. As it gets close the outer moon decelerates the inner moon while the inner

moon accelerates the outer moon. The two moons exchange orbits with the prior outer moon now on the inside and vice versa.

Earth has a companion as well, a small asteroid called Cruithne (pronounced croo-en-ya - a Celtic hero). Although its orbit is tipped steeply to the Earth's orbit, it has a semi-major axis that AVERAGES about 0.9999 AU. The Earth is so large that it scarcely is affected by Cruithne's minuscule gravity. What happens to Cruithne is quite something else. When Cruithne is slightly inside the Earth's orbit it catches up and the Earth slingshots to a slightly outer orbit, which causes it to start to lose ground to the Earth. Eventually it loses enough ground that Cruithne is overtaken by the Earth at which time the slingshot works in reverse pulling Cruithne into an orbit closer to the Sun and speeding up the asteroid. If you counted the Earth and the Sun as a fixed line, Cruithne would trace a horseshoe pattern with respect to the Earth. It travels on the inside of the shoe when it is catching up and the outside of the shoe when it slows down. The whole cycle takes about 4 centuries.

Co-planets

When a satellite is extremely massive with respect to its planet, it really forms a binary system with both bodies revolving around a common center of gravity (the barycenter). Most satellites are very small with respect to the planet. Ganymede is the largest satellite in the solar system, but Jupiter mass is 12,817 times that of Ganymede. The pull of Ganymede is trivial compared to the pull of Jupiter on Ganymede. Two planets have satellites, which are very large relative to the primaries Earth and Pluto. The Earth is only 81 times as massive as the Moon. Pluto is about 8 times as massive as Charon.

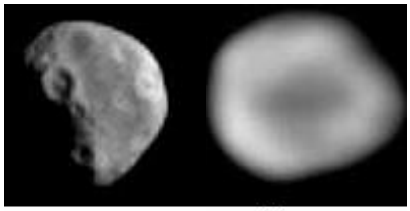
Pluto and Charon rotate about their barycenter which is 1/8 the distance from Pluto to Charon. The barycenter lies outside of Pluto.

The barycenter of the Earth and the Moon lies about 4740 kilometers from the center of the Earth in the direction of the Moon. If you didn't see the Moon from Mars, you could easily deduce it was there because the Earth moves about 1/3 of it diameter side to side every 29.5 days. This also greatly complicates calculating where the planets are because we cannot ignore our movement around the barycenter for precise calculations.

Asteroids

Asteroids are rocky heavenly bodies revolving around the Sun that are too small to be called planets. They are also known as planetoids or minor planets. There are millions of asteroids, ranging in size from hundreds of miles to several feet across. Asteroids is less than that of Earth's moon.

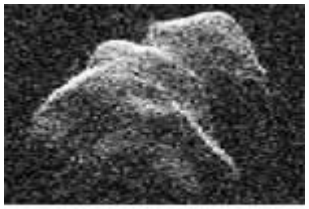
Despite their size, asteroids can be dangerous. Many have hit Earth in the past. That's one reason scientists study asteroids and are eager to learn more about their numbers, orbits and physical characteristics, keeping a close watch on their movements.



Dactyl Vesta

Vesta is one of the largest asteroids but as you can see from this photograph, it is not spherical like planets or larger satellites. Residing as it does inside the asteroid belt, even if it had original cooled as a sphere, collisions with countless smaller asteroids would have ensured that it was pockmarked and gouged.

Dactyl is a satellite of Ida. They were the first such pair discovered. Since their discovery other pairs have been discovered. At least a few of the asteroid pairs are contact pairs. They rotate very slowly because their gravitational pull on each other is very small.



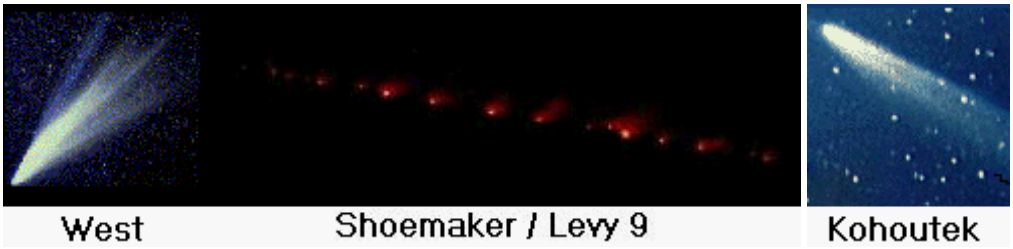
Toutatis / too close!

In the year 2004, Toutatis came within 6 Moon distances from Earth. Currently there is a lot of activity trying to establish the orbits of asteroids, which cross the orbit of Earth. Unlike long term comets which we may not see until it is too late, it is entirely possible to identify any potentially dangerous **Earth crossing asteroids** early enough to do something meaningful to pull the asteroid out of a dangerous collision.

It is rather frightening to realize how small a civilization ending asteroid can be. The asteroid, which killed the dinosaurs 65 million years ago, was not some huge near planet-sized body, but something on the order of the size of a mountain. The effects of such a collision are far ranging. There is no place on earth that would escape if a ten-mile diameter asteroid hit us. It would compress a shaft of air ten miles across until all the air became nitric oxide - the basis of nitric acid. If the asteroid hit land a huge crater would be dug and ejecta thrown up in the air blotting out the Sun for several years. During this time nothing would grow. Hitting an ocean would have even more terrible effects.

The fact we haven't been hit in 65 million years is not too much comfort to those of us who watched Shoemaker Levy 9 crash into Jupiter.

Comets



West Shoemaker / Levy 9 Kohoutek

Comets are planetesimals composed largely of volatile materials. When a comet comes close enough to the Sun it often out gasses a long and brilliant tail. Comets travel in extremely elongated elliptical orbits. At the most distant point in the orbit, the comet moves so slowly that it may stay out there thousands or even millions of years. When they move into the solar system, the relentless gravity of the Sun accelerates day after day for decade upon decade. They can be traveling at speeds up to 70,000 miles per hours when they round the Sun.

Sometimes long term comets happen to pass near a gas giant - particularly Jupiter. Either the comet will be speeded up or slowed by the encounter. If it is speeded up it will pass the Sun with excess velocity that will cause the comet to leave the solar system forever. If it slows down, the comet may become an inner comet like Halley's, which has a period less than one hundred years. There are two principle reservoirs of comets, the **Kuiper Belt** (home of the trans-Neptunian objects) just outside the orbit of Neptune and the **Oort Cloud** about 50,000 AUs (about 8/10 of a light-year) from the Sun. The Kuiper belt is a disc similar to the asteroid belt but filled with comets. The Oort cloud is spherical. The Oort belt is so far from the Sun that occasionally the Sun and another star pass close enough that the other star pulls comets of the Oort belt. Some are lost to the solar system forever but other are started on their slow way into the inner system.

Debris from comets which have melted and released their stony components, as well as broken pieces of asteroids and occasionally, pieces of planets ejected when comets crash into the planets are scattered all over the solar system. Most of then are dust particles or sand like specks. However, larger pieces exist.

Meteors

Sometimes we see a brief luminous trail in the sky, as a rock piece from space enters the upper atmosphere. This is a meteor, popularly known as *a shooting star*.

If such a rock piece hits the Earth's atmosphere it burns up in air. If the particle is large enough to hit the ground it is called a **meteorite**. Roughly 100 tons of meteors fall on the Earth each and every day.

Meteorites come in three basic forms, ones which are largely iron come from the core of some proto-planet, ones which are stony or a mixture of stone and iron which come from the collision of asteroids, and carbonaceous chondrites which are composed of carbon compounds. The meteorite ALH84001 is believed to have been chipped off Mars and eventually hit the Earth. ALH84001 caused quite a stir when scientist thought they detected fossil Martian bacteria on it. Such claims are very muted now. The bacteria fossils could have been from Earth or simply have been crystalline deposits.

Following the paths of melting comets, the density of particles can become unusually high. These create the so-called meteor storms when the Earth orbit interests the orbit of such a comet. For example, Comet Tempel-Tuttle is the source of the swarm of meteors we call the Leonids. Swarms seem to come from a single point in the sky called the **radiant**. This radiant stays located' basically in a constellation and gives the swarm its name.