Moons – script & info.

Intro
There are around 170 known moons in our Solar System – don't worry we are not going to cover them all tonight! We are going to look at some of larger moons and also some of the more interesting ones discovered to date. It is worth noting that although we have images of many moons, not a great deal is still known about the majority. Information has been gathered by fly-pasts and although we do know quite a lot about some, we are left intrigued by others as they hint at what they hold secret. Clearly there is much for us still to learn and I've no doubt some startling discoveries are still to be made here on our own doorstep.

Cruithne (pronounced KROOee-nyuh) NEO 3753
We are all familiar with Earth's satellite, our Moon but few are aware we have a second companion, a near earth asteroid "Cruithne". This object shares Earth's orbit, as opposed to orbits the Earth, but don't worry, it is stable and it will not collide with us, at least not for the next 10,000 years! Cruithne passes below Earth's position in a spiralling horseshoe, each year tracing out the horseshoe and filling it in, in a very complex motion. At its closes point it approaches to 40x Earth-Moon distance 15 million km or 0.1 AU. It was discovered on 10th October 1986 and its orbit was established by computer simulation in 1997. It has an estimated diameter of 5km (3 miles) and is inclined 20° to Earth's orbit. It is closest to Earth in the our autumn when it is below Earth's south pole. There is in fact a second NEO following the Earth in a horseshoe orbit which was discovered in September 2002. It appears to orbit the Earth once every 600 years and comes closest every 95 years.

Mars
Phobos (27 x 22 x 18 km) (discovered by Asaph Hall August 1877)
Both Martian moons are thought to be captured asteroids that possibly originated in the outer solar system. Phobos rises in the west and moves very rapidly across the Martian sky setting in the east, usually twice a day. It is so close to the surface it cannot be seen above the horizon from all points on the surface of Mars. The moon is doomed, as forces are lowering its orbit (about 1.8 meters per century) and it will either crash onto Mars or break up into a ring, in about 50 million years time. The largest feature is crater Stickney, and the lines you see on the moon were probably caused by this huge impact which nearly destroyed Phobos. Temperature varies from -4°C to -112°C; fine dust can't retain heat.

Deimos (15 x 12 x 11 km) (discovered by Asaph Hall August 1877)
Orbits at a greater distance from Mars than Phobos but it is still comparatively near the surface and would not be seen by any observer at a latitude greater than 82.7°. The moon orbits at a slightly slower speed than Mars rotation and so it appears to linger in the Martian sky for 2.7 days. Any observer on Mars would see Deimos as a star-like point, at its brightest around the same magnitude as Venus appears from Earth. You would need a small telescope to observe its phases.

Asteroids
Asteroids have natural moons too. Asteroid Ida, discovered in 1884, is a heavily cratered, irregular shaped body orbiting in the main asteroid belt between Mars and Jupiter. In 1993 Galileo flew past Ida taking photographs and in 1994, the tiny moon "Dactyl" was discovered. This is the first natural satellite of an asteroid ever discovered and photographed.

Jupiter
Io
With over 400 active volcanoes, Io is the most geologically active body in the solar system. The internal heating of Io is caused by friction due to the constant tugging by Jupiter and its other major moons, Europa, Ganymede and Callisto. The vertical difference in Io's tidal bulge due to this tugging, could be as much as 100 meters (330 ft) creating significant heating. Compare this to Earth's tidal bulge of only 60 feet and that is *water* not solid ground!
Io orbits about 420,000 km above Jupiter (similar distance as our Moon from Earth). There are no impact craters as the surface is constantly being renewed by active volcanoes erupting up to 500 km (300 miles) into space. Sulphur dioxide clouds would rapidly freeze and "snow" back to the surface.
Io also has over 100 mountains, some of which exceed the height of Everest.

Europa
Europa's surface is amongst the brightest in the Solar System as a consequence of sunlight reflecting off a relatively young ice crust. Its surface is also one of the smoothest.
The core of the moon is surrounded by a rock shell and that in turn is surrounded by a shell of water ice or even a salty ocean extending for some 60 miles to the frozen surface. As Europa's orbit is elliptical rather than circular, the constant tugging of Jupiter, Io and Ganymede creates a tidal bulge keeping the ocean liquid through tidal heating.
The fractured surface crust cracks resembling ice floes seen in Earth's polar seas. Slushy ice oozes from below onto the surface and refreezes.
Europa has become top of the list in the search for life in the Solar System. In 1977 giant tube worms, clams, crustaceans and mussels were discovered in Earth's Galapagos rift, clustered around deep undersea volcanic vents (black smokers) where no sunlight penetrated. It was always thought that life depended on sunlight as well as water but this discovery disproved that and revealed an independent life eco-system. This could be happening on Europa, or such life forms could be free floating in the ocean or hanging below the ice crust like algae.
It has also been suggested that cosmic rays impacting on Europa's surface could achieve an oxygen concentration in the ocean greater that of Earth in just a few million years. This could support larger organisms in Europa's ocean such as fish.

Ganymede
Ganymede is the largest moon in the Solar System, 2% larger than Titan and 8% larger than the planet Mercury, but only 45% of Mercury's mass. It is composed of equal amounts of silicate rock and water ice. The core is surrounded by a

rock shell, surrounded by a shell of mostly ice with rock mixed amongst it, probably around 800 km (nearly 500 miles) thick.
The moon has an ancient surface composed of dark heavily cratered regions (about 4 billion years old) and lighter slightly less ancient regions, criss-crossed by extensive grooves and ridges, the likely result of tectonic activity brought about by tidal heating. These grooves extend for thousands of kms and rise to 700 m (2,000 ft).

Callisto
With a diameter of over 4,800 km (2,985 miles), Callisto is the third largest satellite in the solar system and is almost the size of Mercury. Callisto is the outermost of the Galilean satellites, and orbits beyond Jupiter's main radiation belts. Its interior is probably similar to Ganymede except the inner rocky core is smaller, and this core is surrounded by a large icy mantle. Callisto's surface is the darkest of the Galileans, but it is twice as bright as our own Moon.
Callisto is the most heavily cratered object in the solar system. It is thought to be a long dead world, with hardly any geologic activity on its surface. In fact, Callisto is the only body greater than 1000 km in diameter in the solar system that has shown no signs of undergoing any extensive resurfacing since impacts have moulded its surface. With a surface age of about 4 billion years, Callisto has the oldest landscape in the solar system.
The moon has two enormous impact basins. Valhalla the largest with a central region 600 km in diameter and rings expanding as far as 1800 km from the centre. The second is Asgard, measuring about 1600 km in diameter.

Thebe, Amalthea, Metis and Adrastea
Thebe was discovered from Voyager 1 photographs in 1979. It's the 4th of Jupiter's moons by distance at 222,000 km and is the outermost of the inner Jovian moons. It is irregular in shape and always presents the same face to Jupiter (synchronous rotation like the Moon to Earth). Dust has escaped from the tiny moon and formed a ring on the inner side of Thebe called the Thebe Gossamer Ring. The surface of the moon appears dark and reddish in colour. The leading hemisphere is brighter than the trailing one probably due to impacts excavating brighter material from below the surface. The moon is heavily cratered the largest being Zethus, 40 km diameter, on the "away" side from Jupiter, the only feature to be named.
Amalthea has been known to us since 1892 and is the 3rd moon from Jupiter by distance. It is the largest of the inner Jovian moons and Jupiter would be an astonishing sight from its surface being appearing over 46 degrees in size! (Full Moon half a degree in size from Earth). Irregular in shape and also reddish in colour the moon also has a gossamer ring orbiting with it due to escaping dust. Its surface consists of craters and high mountains and is made from water ice and other unknown materials. Pan, the largest crater measures 100 km across and at least 8 km deep. Another crater Gaea measures 80 km across and is at least twice as deep as Pan. The leading hemisphere is also brighter than the trailing one again probably due to impacts. Two mountains have also been measured around 20 km high. Composition of the moon is thought to be mainly ice or a loose rubble pile giving it a low density.
Metis discovered in 1979 from Voyager 1 photographs, it is the innermost moon of Jupiter. In fact it orbits 1,000 km within Jupiter's main ring and orbits faster

than its parent planets day. It orbits in a gap or notch in the ring around 500 km wide and contributes a good deal of material to the main ring in the form of dust. Its mass and composition are not know but it measures 60 x 40 x 34 km. Like the others, it is highly cratered, reddish in colour and its leading hemisphere the brighter. Its orbit is decaying and one day it will impact into Jupiter.
Adrastea is the smallest of the four innermost moons and second in distance. Very little is known about the physical characteristics other than it is tidally locked to Jupiter and it measures 20 x 16 x 14 km. It orbits at the outer edge of Jupiter's main ring and again contributes to the ring by way of emitting dust. Adrastea is immune to Jupiter's tidal forces due to its small size.

Saturn
Titan
The largest satellite of Saturn and the only moon known to possess a dense atmosphere. The visit by Cassini-Huygens gave us a wealth of information that has led scientists to ponder the existence of life based on methane.
The atmosphere of Titan is largely composed of nitrogen; minor components lead to the formation of methane and ethane clouds and nitrogen-rich organic smog. The climate—including wind and rain—creates surface features similar to those of Earth, such as sand dunes, rivers, lakes and seas (probably of liquid methane or ethane) and shorelines, and is dominated by seasonal weather patterns. With its liquids (both surface and subsurface) and robust nitrogen atmosphere, Titan is viewed as similar to the early Earth, although at a much lower temperature. The satellite has thus been cited as a possible host for microbial extra-terrestrial life with an environment rich in complex organic chemistry. Researchers have suggested a possible underground liquid ocean might serve as a biotic environment. It has also been suggested that a form of life may exist on the surface, using liquid methane as a medium instead of water; and anomalies in atmospheric composition have been reported which are consistent with the presence of such a life-form, but which could also be due to an exotic non-living chemistry.

Mimas
Discovered in 1789 by William Herschel using a 40 ft telescope! It's a low density moon composed mainly of ice and some rock. Famous for its colossal impact crater (Herschel) 130 km across (81 miles) which undoubtedly nearly destroyed it, nearly one-third of the moon's diameter. Its walls are 5km high (over 3 miles) and parts of its floor 10km (over 6 miles) deep. A crater on the same scale on Earth would be 4,000 km (2,500 miles) across, wider than Canada!

Enceladus
Also discovered by Herschel in 1789 and very little was known until the 1980's when the Voyager missions flew past. But it was in 2005 when Cassini flew past that we got a surprise; a water rich plume was seen to be venting from Enceladus' South Pole. This venting is likely to be responsible for the formation of Saturn's E ring. Enceladus is a geologically active body. Analysis of this out-gassing suggests sub surface liquid water. Complex hydro-carbons have also been detected in the plumes giving rise to speculation about life existing below the surface.

Enceladus is in orbital resonance with Dione which probably accounts for its internal heating.
The South Polar Region is a young area, around 500,000 years old. Near the centre of this region are four fractures bounded by ridges, commonly referred to as the "tiger stripes". These appear to be the youngest features perhaps less than one 1,000 years old.

Tethys
Discovered by Cassini in 1684 and is about 1000 km (600 miles) across. It's composed almost entirely of water ice, the rock content only being about 6%. The moon's surface is visually very reflective due to its interaction with Saturn's E ring and constant bombardment of its surface. A sub surface ocean is thought to be unlikely.
Its surface is hilly cratered terrain dominated by a large impact crater "Odysseus" whose 450km diameter is almost $2/5^{th}$ of Tethys itself. The crater has relaxed to Tethys surface over time but the rim still stands 5km high. The central feature is a pit 2 - 4 km deep surrounded by massifs 6 – 9 kms above the crater floor which itself is 3 km above the average terrain.
The second major feature is Ithaca Chasma, a huge valley 100 km wide and 3 km deep. It stretches for about 2,000 km, about ¾ the way around Tethys and is an older feature than Odysseus. It is thought this valley formed when Tethys' internal water froze out, causing the surface to crack open to accommodate the extra volume of ice.

Dione
Largely composed of water ice, but its density suggests a dense rocky core. Dione's leading hemisphere is heavily cratered but its trailing hemisphere is uniquely marked with huge ice cliffs giving it a bright wispy or streaky appearance. These features are due to tectonic fractures in the moons past.

Rhea
Another icy moon, being the 9^{th} largest but 10^{th} in terms of mass. Rhea's composition is not certain and we need more information to determine whether or not it has a rocky core or compressed ice. There could be a water ocean under the ice, but its not certain. In appearance its similar to Dione with surface temperatures between -174C in direct sunlight and -200C. Its surface is heavily cratered with a few bright wispy-like features. There are two main impact basins around 400 and 500 km across. There is also a 48 km impact crater nicknamed "The Splat", prominent because of an extended system of bright rays, and maybe one of the youngest impact craters detected on any of Saturn's inner moons.
In 2008 NASA announced Rhea may have a tenuous ring system which would be the first discovery of a ring system around a moon. A subsequent fly past by Cassini though failed to confirm this.

Hyperion
Hyperion is interesting due to its irregular shape and honeycomb-like construction. It is also on an eccentric orbit which takes it close to Titan. It is a low density body composed mostly of water ice and some rock and has been described as a "loose rubble pile". It has low reflectivity indicating its surface

is covered with dark material and this dark material also fills the floors of its craters. Cassini confirmed that 40% of Hyperion is empty space.

Iapetus

Saturn's third largest moon and best known for its distinctive two-tone colouration. Due to its distance from Saturn and its highly inclined orbit, it is the only large moon from which the rings of Saturn would be clearly visible. The other moons would only reveal the rings as edge on and so be difficult to see. Its orbital period is 79.3 days.

Another low density moon mostly composed of ice with only around 20% rocky content. The leading hemisphere is dark whilst the trailing one contrastingly bright. Even Cassini in 1671 came to this conclusion as he could observe Iapetus on the western side of Saturn but never on the eastern side. It consists of organic compounds similar to those found in meteorites or the surface of comets. Both hemispheres are heavily cratered. The original darker material has probably been swept up by Iapetus in its orbit from material lost from other satellites. However the majority of the residue is now thought to be a result of the evaporation of Iapetus' ice, possibly darkened further by sunlight. Iapetus' slow rotation of 79 days (equal to its revolution – synchronous) would give it the highest daytime temps and lowest night temps in the Saturian system. It is estimated that over the next 1 billion years, Iapetus could lose up to 20 meters of ice from the dark areas due to this evaporation process. (Dark areas -226 to -143C at the equator: Lighter areas -173 to -280C at pole.)

A further mystery is the equatorial ridge that runs around Iaptus for 1300km, 20km wide and rising to 13km in height (20km in places). It is not clear how this ridge formed.

Phoebe

Four times more distant from Saturn than Iapetus it was the furthest known moon until several more much smaller satellites were discovered in 2000. Phoebe is roughly spherical with a diameter of 220km (140 miles), it spins on its axis once every 9 hours and takes about 18 months to orbit Saturn. The moon is quite dark in composition and heavily cratered some around 80km across with walls up to 16km high. Scientists believe Phoebe might be an object captured from the Kuiper belt (a Centaur which orbit between Jupiter and Neptune) due to its composition which is unlike those of known asteroids. If so it would the first Centaur imaged a more than a mere dot.

The Phoebe ring is a very large Saturnian ring tilted 27 degrees from Saturn's equatorial plane. It extends from at least 128 to 207 times the radius of Saturn. Since the ring's particles are presumed to have originated from micrometeoroid impacts on Phoebe, they should share its retrograde orbit, which is opposite to the orbital motion of the next inner moon, Iapetus. Inwardly migrating ring material would thus strike Iapetus's leading hemisphere, possibly causing the two-tone discoloration of that moon. Although very large, the ring is virtually invisible—it was discovered using NASA's Infrared Spitzer Telescope.

Janus

111 miles in diameter was discovered back in 1966. It shares an orbit with Epimetheus and astronomers conclude they may have been one body that broke up in the distant past. Both a little more than rubble piles.

Helene
Discovered in March 1980 only 34 miles in diameter and orbits 234,518 miles from Saturn.

Methone
Discovered from images in 2004, this tiny moon is only 2 miles in diameter and a distinctive egg shape. It orbits Saturn every 24 hours at a distance of 120,546 miles.

Uranus
Miranda
As Uranus orbits on its side and the main moons orbit in Uranus' equatorial plane, they are also subject to extreme seasonal conditions.
We only have images from the Voyager 2 probe which flew past Miranda in 1986. Diameter 472 km (293 miles), orbit and rotational period of 1.41 days and temp of -187C. Smallest and innermost of the 5 major moons.
It shows the most (ancient) geologic activity of all the moons of Uranus.
Another low density object composed largely of ice and silicate rock. Miranda's orbit was thought to be more eccentric in the distance past influenced by both Umbriel and Ariel leading to tidal heating of the interior and so geological activity.
Miranda is covered in huge faults, deep canyons up to 20km (12 miles) deep, steep cliffs and smooth plains. The Chevron is a series of dark and light grooves which dominates the surface of Miranda.

Ariel
The brightest and fourth largest of the 27 known moons of Uranus and like the planet, it orbits on its side, each pole being subjected to 42 years of daylight or darkness. We know little of this moon due to a single flyby of Voyager 2 in 1986. Orbital resonance with Miranda in the past probably led to tidal heating and geologic activity. Ariel has the youngest surface of the 5 major moons. Its terrain is of three types, cratered, ridged and plains. The surface is evenly cratered but there is a lack of large craters (the largest found being only 78km across) which adds credence to the surface being renewed at some point after its formation. Deep rift valleys criss-cross the surface forming a network similar to that seen on Mars. The smooth floors of these valleys could have been carved out by a liquid, possibly ammonia, methane or carbon monoxide.

Umbriel
The third largest Uranian moon, composed of about 50% ice and rock, similar size and density to Ariel. It has a dark surface with about half the reflectivity as Ariel and has a relatively featureless cratered surface indicating it is ancient in origin.
The only feature of note is a bright ring (Wunda crater) nicknamed the "fluorescent cheerio" which is probably an impact crater which has exposed

material from deeper within the moon's crust with a different albedo to the surface material.
There appears also to be a system of canyons but due to the poor resolution of the images, they are not officially recognised.
Only the south polar regions were facing the sunlight (as with the other moons) during Voyager's flypast so there is not information concerning the northern hemisphere.

Titania
The largest of the Uranian moons discovered by Herschel in 1787 and orbits about 436,000 km from its parent planet. Largely composed of ice and rock, the surface is quite dark and reddish in colour. Diameter 1,578km (980 miles). 8.71 days to rotate and orbit Uranus.
There are numerous impact craters up to 326 km (crater Gertrude) in diameter. The moon probably underwent a resurfacing event covering the early cratered surface and its surface appears much younger than Oberon or Umbriel. Like the other moons, Titania was probably formed out of an accretion disk around Uranus. Voyager mapped around 40% of the surface during its encounter. Some impact craters are surrounded by bright ejecta of relatively fresh ice. The surface is also intersected by a system of enormous faults or scarps. Messina Chasma is the most prominent extending 1500km from the equator almost to the South Pole. Canyons have been measured 20 to 50 km in width.

Oberon
Is the second largest and outermost of the moons (584,000 km). 13.5 days rotation and orbital period. Probably consist of 50% water ice and the rest rock. The surface is also dark and of a reddish colour.
Craters and canyons are abundant on the surface, the largest known crater Hamlet is 206 km wide. Many craters have bright rays probably revealing relatively fresh ice from deeper in the moon's crust. A peak measuring 11km in height may be the central feature of a very large crater about 375 km in width.

Neptune
Triton
To conclude we will have a look at Triton, the largest moon of Neptune by far. It is thought Triton is a captured Kuiper Belt object and its captured destroyed most of Neptune's natural moons. It has a retrograde orbit, orbiting in the opposite direction to Neptune's rotation and is the only large moon in the Solar System to do so.
A substantial rock and metal core is covered by ice and a frozen nitrogen crust. Triton is geologically active with a relatively young surface and geysers thought to erupt nitrogen. Voyager noted plumes from several geysers rising up to 8km above the surface. It is thought solar heating is enough to drive these geysers. Each eruption could last up to a year.
Due to Triton's unusual orbital inclination, its poles point in turn to the Sun rather like Uranus.
Triton's orbit, already close to Neptune is degrading and in 3.6 billion years, Triton will encounter Neptune's atmosphere and break up forming a magnificent ring system.

The moon has tenuous nitrogen atmosphere and its average temp is -237C colder than the average for Pluto at -229C. Seasonal winds move material from the geysers across the terrain. A haze permeates the atmosphere and clouds of condensed nitrogen form between 1 and 3km above the surface.
Triton's surface is geologically young varying from 50 million to just 6 million years old. It is lightly cratered and relatively flat, the topography varying by no more than a km.
Diameter 2,700km (1,677 miles). Mean distance 354,800km (220,405 miles).
Rotation and orbital period 5.87 days.

Conclusion
Clearly there is a great deal for us to explore within the Solar System and I hope tonight we've seen some rather intriguing targets for future exploration missions. I am sure there are still a great deal of surprises yet to be discovered and we are merely opening the door to what lies out there with our current incomplete but tantalising knowledge.

Lyn Smith
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Notes:
Jupiter Trojans – share the orbit of Jupiter, around the Lagrangian points, 60° ahead and behind the planet.
Trojan asteroids distributed in two elongated, curved regions around these points.
First Trojan "588 Achilles" discovered 1906 by Max Wolf.
5,253 found as at March 2012 but about 1 million thought to exist over 1 km in diameter; similar numbers to the asteroid belt.
Mars, Saturn and Neptune also have Trojan moons.
Earth's first Trojan moon was discovered in 2010 (2010TK) preceding the Earth in its orbit around the Sun; 300 m in diameter (100 feet).