Comets - Visitors from the frozen edge of the Solar System
Transcript

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Comets arrive to grace our skies every year – some are new to the inner Solar System, and some are old friends on a repeat visit, but only comparatively rarely do they reach sufficient brightness to become visible to the unaided eye. The main inspiration to give an introduction to comets for today’s lecture is that we might be in line for a sight of a ‘great comet’ later this winter, Comet ISON – but also to explain why we also might not…There’s a great quote from the famous comet-hunter David Levy: *Comets are like cats; they have tails, and they do precisely what they want.*

As you’ll see, nothing is ever certain about comets, and this unpredictability is part of their charm and interest.

**A History of Comets**

The name comet comes from the Greek aster kometes meaning ‘long haired star’, a surprisingly friendly term for an object whose appearance would bring feelings of dread and fear to people many different historical cultures around the world. Comets do not behave like any other object that we can observe in the night sky with the unaided eye. Stars remain fixed in the pattern of their constellations, and are regular in their motion through the sky from one night to the next, and from one month to the next. Even a planet (also from the Greek for ‘wandering’ stars) follows a fairly slow and predictable path. By comparison, a comet is a totally different kind of event: it will appear unexpectedly, and at any place in the sky; it will change position from one night to the next relative to the background of stars; and its path will be along a separate direction and path across the sky from the planets and stars. During the few weeks or months that it is observable it will first steadily increase in brightness from one night to the next, may change its shape – growing bigger, longer or extra tails – and then wane to invisibility, never be seen again. As a consequence, people in many cultures grew to regard comets as messages from the gods.

One of the earliest depictions of a comet portrays one as the Star of Bethlehem in Giotto’s Adoration of the Magi from 1305, a move thought to have been inspired by an apparition of Halley’s comet in 1301. This particular image is unusual in portraying the comet as a positive portent. Sudden comet apparitions were more commonly viewed as ill omens promising disasters such as war, famine, flood or the death of rulers. A selection of 17th century woodcuts portray a comet as a fiery sword blazing across the night sky, signifying war and death, and leaving chaos and disaster in their wake. Indeed, plenty of past comets have been blamed by the astrologers of their day for bringing or marking misfortune. ‘Caesar’s comet’ appeared a few months after the assassination of Julius Caesar in 44BC, and was recorded as visible even during daylight, and may be even the brightest such known. Caesar’s adopted son took advantage of the apparition and declared the comet to be the soul of his father rising up to heaven, exploiting this ‘omen’ so he could eventually seize control of the Roman Empire as Augustus Caesar. In South America the Incas observed a comet shortly before the cruel invasion of Francisco Pizarro. And the great comet of 1811, which was visible to the unaided eye for 260 days, was linked (among other events) to Napoleon’s invasion of Russia in 1812. A character in Tolstoy’s novel War and Peace describes observing an enormous and brilliant comet […] which was said to portend all kinds of woes and the end of the world.

Halley’s comet (of which more later) has by itself been blamed for several calamities. It was observed between April and June in 1066, presaging Harold II’s death at the Battle of Hastings. Chinese records of this apparition suggest it was twenty times brighter than Venus, and it is depicted on the Bayeux Tapestry. Halley’s comet also appeared three years after the fall of Constantinople to the Turks in 1453, leading (allegedly) to its excommunication as an instrument of the devil by Pope Callixtus III. Fear of the comet persisted even to its relatively recent times. There was widespread panic prompted by the prediction that its 1910 approach would be so close that the Earth would pass through the outer regions of its tail, which was known to contain traces of cyanogen. This was sensationalized in the media of the day, who stoked the fear with suggestions that mass cyanide poisoning would result. Entrepreneurs did a brisk business selling gas masks and comet pills. This is all despite astronomers reassuring people that the wispy gas in the tail would be far too diffuse to bring harm; it couldn’t penetrate Earth’s dense atmosphere, and even if it could, there wasn’t enough cyanogen to bring any real harm.

There are have been many spectacular comets throughout history; on average we are visited by what is termed a ‘great comet’ about three times a century. This appellation is saved for those comets that reach exceptional brightness (sometimes so much that they are visible during the day); there are records of them showing features such as multiple tails, haloes, red or green colours. When you read the accounts and view the paintings that record them, it does sometimes begin to feel like we’ve been shortchanged over the last few decades!

Partially because they provoked such terror, apparitions of comets have been noted through history. Some of the oldest and most extensive observations on record come from Chinese astrologers/astronomers, with comet atlases that date back to the Han Dynasty (206 BC – 220 AD) and which incorporate knowledge from much...
The nucleus is the only solid component of a comet, and the only part that is always present. It resembles a dark-coloured iceberg; it is a frozen chunk of ice ranging between 5 to 20 km in size, and with a somewhat irregular shape. The ice is not just water ice, but also contains the ices of frozen ammonia, carbon dioxide, methane and carbon monoxide. The ices are blackened as they contain small particles of dust (silicate and carbonate minerals) embedded within them, and the whole nucleus is of a low density, suggesting it to be a partially porous body. When travelling along the outer reaches of its orbit, far from the Sun, the nucleus remains frozen, dormant and inactive. As soon as its path turns the icy block into the inner Solar System, it begins to warm up and its surface becomes active. The solid ice turns directly into gas in a process known as sublimation, and is liberated from the surface. The process is particularly apparent on the sunward side of the nucleus, where the gases escape as jets, particularly through any fissures that open up in the structure. These jets also push out the particles of solid dust that had been embedded in the ice.

As it gets closer and closer to the Sun, the nucleus heats up further, and the surface activity increases, driving out yet more matter until the whole is enveloped in a luminous fuzzy cloud of gas and dust that is known as the comet's coma. This surrounds the nucleus in a halo that typically extends over a diameter of about 1 million km - ie it forms a structure that is far larger than the Earth, and which can in some very active comets, grow almost as large as the Sun! The molecules released from the nucleus are torn apart into their constituents by the energetic sunlight that falls on them. The lightweight hydrogen atoms are ejected at great speed, and can travel quite far from the nucleus before they are ionised by the sunlight and swept away to contribute to the formation of the comet's tail.

The nucleus is too small in mass to have any appreciable gravity, and so it cannot retain the material in the coma. This is swept away rapidly by both the constant stream of charged particles of the Solar wind, and the radiation
pressure of sunlight. It stretches away to form a tail, and the comet now resembles its traditional form. The coma and tail are continually replenished with fresh material only as long as the nucleus stays active, so these features only occur on the inner and warmer stretches of the orbit. Even though it develops from a comparatively tiny nucleus, a comet’s tail can extend over millions of km, temporarily becoming the largest structure within the solar system. Despite appearing so spectacular, the material in the tail is only very tenuous, with a density of matter that is really not so different from that of interplanetary space. By the 16th century it had already been well documented that a comet’s tail always points away from the Sun rather than always streaming behind the motion of the nucleus – as it leaves the inner solar system the comet will be chasing its own tail. Every comet has a different structure, and the tails can vary in shape, length, and features; some have multiple tails, and others never come close enough to the sun to develop a proper tail.

Most comets grow two types of tail: a straight plasma tail; and a more curved and yellower tail of dust grains. The ion tail is formed from the sublimating gases that have been liberated from the nucleus, and then ionised by the ultraviolet light of the Sun. The charged particles in the tail cause it to fluoresce with a blue colour. This tail is pushed behind the nucleus by the Solar wind, and always points straight and radially away from the Sun. As the material it contains is electrically charged, it responds to any changes in the intensity or direction in the magnetic field within the Solar wind, sometimes causing the tail to twist or kink, or even be completely stripped away if the Solar wind is strong. In comparison, the dust pushed out of the nucleus is affected by the radiation pressure of the sunlight. This primarily acts on the smaller and thus lighter of the solid grains, spreading them out into more of a curvy or fan-shaped tail, rendered visible by the way the grains reflect sunlight to appear with a yellowish colour. Larger dust particles (more the size of sand grains or small pebbles) that escape the nucleus are less affected by the radiation pressure, and more susceptible to the Solar gravity. Instead they are left behind in the comet’s wake to drift each in their own orbit around the Sun, no longer interacting with the other dust particles or the cometary nucleus. Not all the dust escapes – some falls back onto the surface of the nucleus, and becomes part of a dark crust that slowly develops with each successive pass of the nucleus round the Sun.

The Fate of a Comet?
The closer an orbit brings a nucleus passes to the Sun, the warmer it becomes, and the more spectacular tails are generated. Once it recedes back into the colder outer realms of the Solar System it will return to an inactive state, the coma and tail gradually fizzling out and disappearing. Many comets show a notably greenish hue if the material jetting from the nucleus contains cyanogen and diatomic carbon (C2). There are also differences in the size, and in the ice and dust content of different comets, variables which also change with time. If a nucleus is repeatedly exposed to the Sun, it will gradually become less active when it returns on subsequent visits to the inner Solar System. The periodic baking and freezing the nucleus undergoes creates a hard, dark and dusty crust that acts as an insulating layer; it is more difficult for sunlight to act on this than on a ‘fresh’ comet with a surface composed of large exposed expanses of ice, and the material can only escape through cracks in its crust that reveal the underlying water ice.

Even though much of the nature of comets was revealed from the repeat visits of Halley’s comet, many comets never even complete their first orbit; most simply fall into the Sun on the first approach through the inner Solar System. Comets are only fragile collections of material, not strongly bound by gravity. Sometimes when they are warmed or pulled by the strong gravitational tides of the Sun or Jupiter, the nucleus can completely break apart and disintegrate. Other comets follow much more open orbits that either never return them back towards the Sun, or if they do, then maybe not for hundreds of thousands of years.

Even the periodic comets that survive swooping round the Sun only have relatively short lifetimes once they become active. Material that sublimates away from the nucleus and into the coma and the tail, is lost to the comet forever. Giotto observations of the nucleus of Halley’s comet estimated that it was at that point losing 10 tons of dust and 56 tons of water every second. If a typical cometary nucleus thus loses somewhere between about 0.1-1% of its mass each time it passes by the Sun, it will survive for fewer than a 100 or a 1000 passes; depending on its orbital period, this may be only a few thousand to tens of thousands of years. Finally, what is left is so fragile that it is vulnerable to disintegration; or as the ice is preferentially removed and the crust of the object baked hard, it evolves into a dark, rocky and inactive object that more resembles an asteroid than a comet. For example, the asteroid 3200 Phaethon moves in a comet-like orbit, and follows the orbit of debris that gives rise to the annual Geminids meteor shower.

The release of solid material from an active nucleus populates the inner parts of its orbit with a loose collection of dust and rock fragments that continue to circle the Sun on their own orbits. If this swarm of debris happens to cross the Earth’s orbital path, it will generate an annual meteor shower when the Earth passes through this cloud at the same time every year. As the debris enters the atmosphere, it will decelerate and heat up through friction, producing the luminous trail known as a shooting star, until it vapourises, burning up completely in the air. (This is different from more sporadic meteors that can happen at any time of year and are not associated with any particular comet.) For example Perseids in mid-August are associate with debris from Comet Swift-Tuttle, both of the October Orionid and the May Eta Aquarid meteor showers are produced from pieces released from Halley’s comet.

Where do the Nuclei Come From?
The fact that we still observe comets today, despite the short lifetime of any individual comet (particularly in
comparision to the age of the Solar System) immediately implies that the supply of comets to the inner part of the Solar System must be continually replenished from some reservoir of cometary nuclei. We think that all the contents of the Solar system condensed out of the same thick disc-like cocoon of gas and dust that surrounded the young Sun about 4.5 billion years ago, known as the Solar nebula. This implies that the icy chunks that are the cometary nuclei formed alongside the planets, moons and asteroids, and are thus themselves very old - it’s just once they begin to enter the inner Solar System that their lives are curtailed. Thus must spend all their prior life located very far from the heating influence of the Sun.

Rocky/metal objects condense from the inner regions of original Solar nebula where conditions are warmer. The icy material found in cometary nuclei can only form out beyond the ‘snow line’ (at around 4 Sun-Earth distances) where temperatures in the nebula drop sufficiently for the volatile ices to condense and clump together. One of the reasons that comets are of particular scientific interest is that they contain material from this early Solar nebula that has been relatively unchanged. Unlike the planets, and the larger asteroids and moons, the nuclei are too small (ie less than a few hundred km) to be greatly affected by gravitational compression, so there is no heat source to promote either chemical or geological change. Their composition thus remains unaltered, and so their study can inform our knowledge of the primordial Solar System.

The period of a comet’s orbit can give you clues to its origin, and where it has been hiding all this time; the orbits seem to divide naturally into two classes of behaviour according to the length of their orbital period. Those comets which - like Halley’s comet - have an orbital period shorter than 200 years, are trapped into stable, tight orbits which have been heavily influenced by the gravity of the giant planets. The advantage of such short and predictable orbits is that we can predict their positions to enable direct observation by space missions. These comets follow orbits that generally move in same direction as the planets move around the Sun, with orbital inclinations tilted only slightly from the plane of the planetary orbits. Their orbital dynamics suggest that they originate from a more flattened cloud relatively close in to the Solar System. They are thought to come from the large ‘Kuiper belt’ that contains tens of thousands (maybe millions) of small frozen worlds distributed in a thick ring just beyond the orbit of Neptune. Named for the astronomer Gerard Kuiper (1905-1973) who predicted its existence in 1951 (and sometimes also referred to as the Edgeworth-Kuiper belt after Kenneth Edgeworth who also proposed the belt’s existence in 1943), this is like another asteroid belt, which contains many asteroids and the trans-Neptunian dwarf planets such as Pluto, Eris and the like. It could also by the home of very very many much smaller cometary nuclei, all of which are too cold, dim and distant to be observed with current technology. The comets that lie in the Kuiper belt will have formed at that location, condensing out in the very outer parts of the original Solar nebula, where the density of material remained low and there was no further coalescence of small objects to form any larger planetary bodies. Their distance from the giant planets means that they have not been significantly perturbed by their gravity, except where the gravitational tug of Neptune shapes the inner edge of the belt. The gravity of the gas giants may just occasionally pull on a nucleus, launching it on an inwards orbit, though not necessarily reaching the Sun.

The other family of comets comprises those which have periods longer than 200 years. Such ‘long-period’ comets follow orbits that have a much more random distribution than those of the planets or shorter-period comets from the Kuiper belt. They approach the Sun from all directions, orbit at all angles to the plane of the planetary orbits, and follow very elongated and unpredictable trajectories taking them well beyond the Kuiper Belt. Back-tracking the orbital paths suggests that the long-period comets arrive from a vast spherical cloud of nuclei located some 30,000 – 50,000 times further than the Earth lies from the Sun. Out here they are too far, too faint, too cold to be detected directly, but a spherical distribution can be inferred from the way that they arrive from all directions. At such distances it can take up to 10 million years to complete an orbit around the Sun. This outer reservoir of nuclei is known as the ‘Oort cloud’ after the Dutch astronomer Jan Oort (1900-1992) who first proposed its existence in 1950.

Nuclei can remain undisturbed for billions of years while out in the Oort cloud. They are so far from the Sun they are only loosely bound by its gravity, and are vulnerable to external gravitational forces – such as from nearby stars or interstellar clouds. Occasionally these forces will stir up the comets, and the cumulative effects might dislodge a nucleus from the Oort cloud and send it tumbling in towards the Sun (or, of course, even further out into space!). To have sustained the long-period comet population over the lifetime of the Solar System – and given that we are still witnessing fresh comets such as Comet ISON arriving even today - requires a vast reservoir populated by perhaps millions of inactive comets.

While the icy nuclei contained in the Kuiper belt beyond Neptune will have formed in situ, those in the Oort cloud could not have formed where they are now. Matter in the nebula so far from the young Sun would have been far too sparsely distributed to stick together at all, so we have to account for how all the nuclei were distributed so far from the Sun, and in every direction. It is thought that they were all originally part of the debris of material condensed throughout the Solar nebula, but which had not been incorporated into any planets. Icy chunks that form between the snow line and Neptune will be not be in a stable location, and will be particularly strongly affected by the gravitational influences of the (newly formed) giant planets, particularly Jupiter and Saturn. Large masses act to clear out any other bodies occupying their orbital path. Some become captured by the gravity of the giant planets to either fall into the gas giant or accreted as small satellite moons. Other chunks were hurled into the inner regions of the Solar System where they either fall directly into the Sun, crash onto the inner rocky planets, or orbit until they decay away; but many were catapulted far out to the frozen wastes of the SS to form
the proto-cometary Oort cloud.

All the ‘clearing out’ of the debris in the nebula occurred relatively early on in the history of the Solar System, and it is also responsible for a period of heavy bombardment of the inner planets that lasted until about 3.8 billion years ago. As shown by the surfaces of airless worlds such as Mercury or the Moon, impacts were ubiquitous across all the inner rocky planets; and the comets that crashed onto Earth may well have supplied the ice that formed our oceans. The freshly-formed Earth was too close to the Sun for ice to have condensed naturally out of the original Solar nebula at that location; in addition, the early Earth would have been hot and molten, and inhospitable to water. The later and huge influx of cometary bodies from more water-rich regions of the Solar System could deliver water ice to Earth. One possible snag raised with this scenario is that comets might deliver the ‘wrong’ sort of water: water is made by joining two atoms of hydrogen to one of oxygen. ‘Heavy’ water is the same chemically, only instead it uses an isotope of hydrogen that is heavier because it contains an extra neutron in its nucleus. Studies of the water content of present-day comets indicate that they are enriched in the heavy form of water compared to the ratios found in terrestrial oceans (which contain more of the lighter form of water). It is difficult to think of another source for our water, so we have to suspect that comets in the past might have had a slightly different water balance – maybe they originated from a different part of the Solar nebula that those comets that we can study most readily with our telescopes and spacecraft today. Comets also carry complex organic compounds, which could also have been delivered to Earth during the heavy bombardment period. These materials could be highly relevant for triggering various geochemical and biological cycles.

More Recent Collisions of Comets with Planetary Bodies

Even though the bulk of the bombardment finished 3.8 billion years ago, the Kuiper belt and Oort clouds still supply comets that end up on a collision course when their orbit crosses that of one of the other bodies of the Solar System.

A ‘collision’ with a gas giant is more that the comet is absorbed into its deep atmosphere, becoming compressed and heated to evaporation instantly. One spectacular example of this process happened in July 1994 with the impact of Comet Shoemaker-Levy 9 with Jupiter. The astronomers Eugene and Carolyn Shoemaker and David Levy discovered a new short-period comet in March 1993 which showed a most peculiar structure. It took the form of a string of separate small nuclei all following the same path. Follow-up observations showed they were following a somewhat elliptical orbit that partially intersected that of Jupiter. During a very close approach to Jupiter in July 1992, a single cometary nucleus passed within 25,000 km of the giant planet, close enough that the gravitational tidal forces ripped it apart to form a whole series of ‘mini-comets’ that continued on orbiting – but on a path calculated to coincide with Jupiter on their next close approach. This prediction enabled the impacts of the cometary pieces with Jupiter to be the subject of an extensive observing campaign when at least twenty large fragments of the comet collided with Jupiter during the week of July 16–22, 1994. The largest of the nuclei were estimated to be about 2km in diameter, and they all impacted at speeds of around 60km/s. Unfortunately the point of impact was just out of view from the Earth, and the damage from each was only visible once that part of Jupiter rotated into view 14 minutes later. Each of the large fragments left a large dark mark, showing where the cometary material had immediately vapourised to form a large rising bubble of hot gas high in the atmosphere. The scars were gradually dispersed by the atmospheric winds over the next few weeks. Further impact scars have been observed on Jupiter, including two in July 2010 alone, suggesting that collisions between comets and Jupiter may not be that uncommon.

Closer to home, a small comet (ie with the solid component less than 100m across) is considered to have been the responsible for the Tunguska event that occurred in central Siberia on Jun 30 1908. An enormous explosion flattened about 80 million trees over an area of around 2000 km2, and although the trees were felled radially away from a central area, no single large crater or meteoritic fragments were discovered. Instead, it seems that the impactor did not survive to hit the ground, but must have exploded in the atmosphere at an altitude of about 8km, lending credence to the idea of it being a comet rather than an asteroid. The trees were toppled by two blast waves – the first from the object’s supersonic motion through the atmosphere, and the other from the explosion itself. The energy of the blast was later estimated to be between 10 and 20 megatons of TNT. Unfortunately the point of impact was just out of view from the Earth, and the damage from each was only visible once that part of Jupiter rotated into view 14 minutes later. Each of the large fragments left a large dark mark, showing where the cometary material had immediately vapourised to form a large rising bubble of hot gas high in the atmosphere. The scars were gradually dispersed by the atmospheric winds over the next few weeks. Further impact scars have been observed on Jupiter, including two in July 2010 alone, suggesting that collisions between comets and Jupiter may not be that uncommon.

We don’t just have to wait for comets to come to us, of course. There have been a number of successful robotic missions to comets after the Giotto flypast of Halley’s comet.

Missions to Comets

The Stardust spacecraft was launched in Feb 1999 to fly past Comet Wild 2 within a distance of only 240km in January 2004. Comet Wild is a fairly freshly-arrived short-period comet, which has travelled past the Sun only a few times, and so the 5km-side nucleus has not yet been very altered by the solar heat and sublimation processes. The spaceprobe sent back images of a very rugged surface, with flat basin-like (impact?) holes about a km in diameter, each bounded by sheer cliffs. Many active gas jets were visible, expelling dust and gas out into space. Stardust flew through the comet’s tail to catch a sample of this ejected material in an exposed tray of aerogel; this was returned to Earth in a capsule two years later so that the thousands of dust particles it captured could be subject to detailed examination in the lab. Comet dust punched through a protective thin layer of aluminium foil, then breaking up on impact to explode in a pattern of tracks; how far a particle travelled into the gel depends on its mass and speed. An analysis of the composition of the dust grains shows them to contain a wide range of organic compounds – including an amino acid, glycine. Based on the isotopic composition,
surprisingly little of the dust seemed to be ‘pre-Solar’, ie created in the cool envelopes of previous generations of stars before being incorporated into the Solar nebula. However, there were silicate minerals present that are only formed at high temperature – and as Comet Wild has not made enough passages round the Sun for very much of its material to have been chemically altered by Solar heating, this material must have been formed in the inner regions of the Solar nebula. So instead of being dominated by particles formed around other stars, it seems Comet Wild comprises a curious mix of solid material formed in the inner regions of the nebula, which then has somehow have to be sprayed out so that it can be incorporated into the outer icy material. Clearly cometary formation is a lot more complicated that I have suggested earlier in this transcript!

The Deep Impact mission sent two spacecraft to visit the 14-km wide nucleus of Comet Tempel 1 on July 4th 2005. The smaller probe smashed into the nucleus, while its companion monitored the event from a few km away. The impactor craft smashed through the surface of the nucleus, excavating a large amount of dust, gas and ice that immediate formed a long plume of ejecta stretching away from the nucleus. The impact released as much material in 15 minutes as the comet usually discharges in several months, implying that the crust of the nucleus was weaker and more brittle than expected, and the underlying material within was fairly porous and fluffy. Analysis of the sunlight reflected by the cloud of debris showed it to be composed of tiny grains of silicates, and containing iron compounds and complex hydrocarbons that had not been seen before in comets. So much material was excavated on impact that it occluded sight of the impact crater generated - that had to wait for another spacecraft.

After flying past Comet Wild, the Stardust spacecraft still had some fuel left in its tanks and so it was redirected to rendezvous and re-image the nucleus of Comet Tempel 1 in Nov 2010 from a distance of within 200km; the aim was to see not just how big a crater the impactor spacecraft had made, but to also monitor how the nucleus had changed after swung twice round the Sun during the intervening 5 years. The mission-made impact crater isn’t particularly dramatic (indeed, on seeing the images one might legitimately even ask ‘What crater?’) - there is a feature about 150m across, but it doesn’t look much like a crater, suggesting that all the ejected material collapsed straight back down onto the surface to bury the impact site.

The observer craft in the Deep Impact mission was itself also recycled - renamed the Epoxi spacecraft it was redirected to fly within 700km of the nucleus of Comet Hartley 2 in Nov 2010. It reached the comet at the point where the 2km-long nucleus began nearing the Sun on its 6.5 year orbit, and starting activity as it warmed up. The images returned showed it to be quite an active comet, with large quantities of dust and gas sprayed out in jets – just not uniformly from the surface. Most seemed to emerge from the rougher terrain at either end of the nucleus, whereas the smoother saddle regions around the middle appeared to be porous, directly leaking gas into space.

A very exciting mission is going to be in the news next year, when the European Space Agency's Rosetta mission, will arrive at Comet Churyumov-Gerasimenko in 2014. The spacecraft was launched March 2004, and during a 12-year journey it has performed 3 fly-bys of Earth and one fly-by of Mars; imaged two asteroids - 2867 Steins (September 5, 2008) and 21 Lutetia (July 10, 2010) - before entering deep-space hibernation during the most remote part of its journey. The spacecraft will be revived in January 2014 once it is out near Jupiter and only a few months away from its rendezvous with the comet. After approaching close to the comet, it will undertake a systematic mapping and characterisation of the nucleus before releasing the lander Philae in November. The lander will use a harpoon and mechanical legs to grip onto the surface of the comet, and is then poised to ride the comet in from the outer reaches of the solar system, watching at first-hand how the surface activity develops as the comet approaches the Sun. Rosetta will escort the comet around the Sun until at least December 2015, and the mission will also determine the composition of surface and subsurface materials using spectroscopy and high-resolution imaging and then determine the internal structure of the comet's nucleus using radar.

Comet ISON (C/2012 S1)
Comet ISON was discovered in September 2012 by two Russian astronomers, Vitali Nevski and Artyom Novichonok. (The convention is to name a comet with the family names of its discoverers (or after the spacecraft that made the observation); but in this case the discovery came about as part of the ‘International Scientific Optical Network’, lending the object the name comet ISON.) At the time of its discovery, ISON was over 940 million km from the Sun (6 times further from the Sun than the Earth’s orbit), bound on an inwards trajectory and still very faint and inactive. It’s currently (20th Nov) well within the orbit of the Earth and falling rapidly towards the Sun. ISON is a ‘sungrazer’ comet, meaning that when it whips round the star on the 28th November it will pass within only 1.2 million km of the Solar surface – that’s less than the diameter of the Sun itself. During this close pass it will experience temperatures of over 2,500°C, although probably not for very long, given that it will be moving very fast – at speeds of about 400 km/s. We can predict its orbital trajectory in great detail; we just can’t predict in any rigorous manner exactly what will happen to the comet as it follows this path! We can only guess how bright or spectacular it will grow. The issue is exacerbated by the fact that ISON is a newcomer on its first plunge from the Oort cloud through the inner Solar System; on the one hand, this means that its surface has not been exposed to the Sun before, and is likely to become very active; it also means that we have no confidence that the object will actually survive.

It is entirely possible that the heat will open such large cracks in ISON’s nucleus that it may simply just break
apart as it nears the Sun. Certainly the comet has gone into outburst even during the last week, suggesting that it is releasing material more vigorously; the tail has also changed in appearance, developing new structures again suggesting large amounts of recent activity. This outburst has brought it to the threshold of being visible to the unaided eye, and it is certainly visible through binoculars in the pre-dawn sky. Comet ISON's tail now extends further than 8 million kilometers (over twenty times the Earth – Moon distance!). The comet's nucleus remains hidden from view by a hazy green coma, but shows no obvious sign of fragmentation yet; whether it does so in the future will depend on the size of the cometary nucleus. Computer simulations of past ‘sun-grazing’ comets suggest that an average-density snowball nucleus will break apart so close to the Sun if it is less than 200m across; reassuringly the latest estimates of the size of ISON’s nucleus place it safely in the range of 0.5 to 2km across. But the opportunity to observe a new comet like this is relatively rare, so the predicting its survival is still a relatively unexact science.

Should the comet survive its encounter and be able to resume its outbound journey, it will pass over the northern hemisphere of Earth at the end of December at a distance of only 65 million km. At this point surface activity will have peaked, and the comet should be a spectacular sight high in a relatively moonless sky. And it might – just might – be one of the brightest comets in living memory. Only time will tell…

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