Asteroids, Comets and Meteorites

There are no notes for this section in the style of the other notes. Please read chapter 10 of the textbook. However, the following are a few personal comments on asteroids and a little on comets.

On the separation of asteroids

Computer programs showing planetary orbits might draw the orbit of an asteroid at a size that would fit onto a sheet of A4. On this scale, how big is an asteroid? Take a pencil and draw a circle that just fits onto a sheet of A4. If this circle represents the orbit of an asteroid at a radius of 4 AU (= 600 million km) then 1 mm on the paper represents 6 million km. On this scale the thickness of the line represents about 1 million km. The largest asteroid would be too small a dot to see in the most powerful microscope, having a scale diameter of 0.15 microns. Any dot on the computer screen hugely exaggerates the size of an asteroid.

Let's try another scale model. Suppose a full-stop represents an asteroid 100 km in diameter. That's a pretty big asteroid. How large is its orbit? A full-stop in 12 pt Times New Roman is about 0.5 mm in diameter. The scale orbit of this full-stop will be about 6 km in diameter. The width of the asteroid belt is more than 1 km. The average distance between asteroids of about 2 million km is about 10 m in our scale model. An orbital period of 8 years will be achieved if the full-stop moves at a speed of about 0.07 mm s^{-1} (in reality 15 km s^{-1} or one diameter in 6.7 s). The Earth on this scale is about the size of a tennis ball.

Can a dot the size of a full-stop really have any impact of significance on an object the size of a tennis ball if they were to collide? Our dot at 4 AU will never get near the Earth, with its orbit at 1 AU radius, but just work out the kinetic energy of a body 100 km in diameter impacting the Earth at say 20 km s^{-1}. It is truly astronomical! The Berringer impact crater in Arizona, a mile across and 500 ft (over 150 m) deep, was created by an impacting body no bigger in volume than the building we are in. I remember doing the sum a while ago to work out how big an asteroid would need to be to have enough energy to evaporate the entire North Sea. It's only some 10 km across. A 100 km asteroid has 1000 times more mass. Our dot the size of a full-stop would create global catastrophe on the tennis ball. One reason for its devastating effect is that we live in a thin crustal skin on the Earth, in the biosphere. Taking the biosphere to have a depth of 10 km then the total volume of the biosphere is less than a thousandth of the volume of the Earth. Remember that the asteroid is ten times the depth of the biosphere and it's less surprising that a collision will initiate catastrophe.

Asteroids – summary facts

Giuseppe Piazzi, a well-known Sicilian astronomer, discovered the first asteroid on January 1st 1801, arguably the first day of the 19th century. He named it Ceres. You may wonder why he wasn't celebrating with his friends instead of peering through his telescope and I don't know the answer to that. What he was doing was searching for the 'missing planet' suggested by Bode's empirical law. In 2006, his discovery was taken away from him in that Ceres was re-classified as a dwarf planet. Strictly speaking Piazzi is now the discoverer of the first dwarf planet (one of 5 at present) and not the first asteroid. Ceres was later to be measured at 914 km in diameter. In spite of its size Ceres is normally too faint to be seen by the naked eye. Two genuine asteroids exceed 500 km in diameter (Vesta and Pallas); 100 have diameters over 100 km and there are a vast number of smaller asteroids that appear in stellar photographs as short lines, because they move across the sky at a different speed from stars. A recent estimate is that there are some 1.9 million asteroids at least 1 km in diameter in the asteroid belt. However, put them all together and you'll still not have enough to make a moon 1500 km in diameter even if you throw in Ceres, which is certainly within the asteroid belt. Many more than 10,000 asteroids have had their orbits worked out and been given designations.

Asteroids reflect light by varying amounts because they aren't all made of the same stuff. Their variety is paralleled by meteoritic material that we find on Earth.

- The majority of asteroids are dark objects of 'low albedo', described as *carboniferous chondrites*. These are called type C asteroids.
- others are comparatively bright and have stony/iron bodies. These are type S. Ceres, for example, has an average density of 2700 kg m^{-3}, about that of granite.
- others are similar to iron meteorites and are M type.
- some are called dark and primitive.

The asteroid belt is found between Mars and Jupiter. The different types of asteroids are present in changing fractions across the belt. For example S types are more common near Mars, C types in the middle and primitives nearer Jupiter. Many asteroids have orbits close to the ecliptic in the sky (i.e. the plane of the Earth's orbit around the Sun in reality) but not all. There are about 50 known Apollo asteroids larger than 1 km in diameter with orbits eccentric enough to cross the Earth's orbit. These are obviously of special interest, and not merely academic interest either!

No asteroid had been seen close-up or its detailed surface features photographed until the Galileo probe on its way to Jupiter photographed the modest sized *Gaspra* in 1990 that was passing within range of its cameras. Since then a number of asteroids have been photographed many times. A NASA probe was put in orbit around Eros and when its resources had been almost expended it was crash landed on the asteroid. The Dawn probe went into orbit around Vesta in 2011 and left in 2012 to orbit Ceres after spending a year around Vesta. It arrived at Ceres in 2015. Examples of asteroids of varying size are shown in the early slides of this section.

Asteroid collisions

I'll add another example to illustrate the amazing kinetic energy of a moderately size object travelling at say 25 km s^{-1}. Look up a picture of the Roter Kamm impact crater in Namibia. There's a nice one taken by the Copernicus Sentinel-2 mission that includes a wide area of surrounding dunes and hills. The crater was formed about 5 million years ago by an asteroid not much wider than a lorry is long. The crater is 2.5 km wide and about 130 m deep, though now filling with sand. It would take years with a fleet of the largest diggers to make a hole that big. The asteroid did it in less than 5 seconds. Don't mess with asteroids. Roughly speaking, the diameter of a crater is proportional to the diameter of the impacting asteroid.

The chance of a collision between an Earth crossing asteroid and the Earth is, fortunately, very slim. The discussion of the inclined Moon's orbit earlier in the course referred to the *nodes* of the Moon's orbit as the two points on the orbit that lay in the same plane as the Earth's orbit. Likewise, the inclined orbit of an asteroid will have two nodes. These nodes will almost always lie either inside or outside the Earth's orbit. When that is the case, at times when the asteroid is in the same plane as the Earth's orbit it will necessarily miss the Earth; it will also of course miss the Earth when it is at all other points in its orbit, since these points are all away from the plane of the Earth's orbit. Counting the number of 'near Earth objects' isn't a particularly good way of deciding the likelihood of a threat. [There are some 13,000 'near Earth objects' more than 30 m across]. Very rarely, a node of the asteroid's orbit may coincide with the Earth's orbit. Even when that does happen, it still needs the very unlikely co-incidence that both the Earth and asteroid arrive at this point in space at the same time, or nearly so. All this being so, I personally won't lose any sleep worrying about the known, Earth-crossing, Apollo asteroids.

Another reason for sleeping well is to look at Mars, which is much nearer the asteroid belt than Earth. Mars does not seem to be peppered with young asteroid craters. I've not seen any discussion of the asteroid risk to human colonies on Mars that will almost certainly be established in the future. That's more likely to be an issue in my grandchildren's time than in mine.

Of course, it doesn't need an asteroid 1 km across to cause devastation from Earth impact. If an asteroid no bigger than an office block can create the Berringer crater in about 1 second, then smaller asteroids are a genuine hazard. Spending money looking for these used to be seen as a fringe activity verging on the paranoid but the threat is now recognised as a genuine one. It is a case of an event of small probability that could create a very large catastrophe if it happened in the wrong place and hence by the definition of 'risk', the product of the two factors is seen as significant. Detection methods of visual observation or radar sensing won't provide a lot of warning so the big question is: can we do better than the dinosaurs in predicting and if necessary preventing a future catastrophe? The answer, which won't give you any comfort, is 'not yet'. However, I shall still sleep well at night for the probability that such an impact will happen in my lifetime or yours is very small and the Berringer crater may cover 2 square km but the Earth's surface is over 500 million km^2 and the probability of the impact happening in the worst of places is additionally small.

One final point while on the topic of asteroid collisions is that they are always seen as a threat. They are certainly a threat to the status quo. The dinosaurs would agree on that, for they seem to have been wiped out by the fallout effects of an asteroid collision 65 million years ago, after being the dominant animals on Earth for over 150 million years. The other side of the coin is that we owe our existence to the Chicxulub impact of an asteroid, some 10 km across. Without that impact, the Earth could still be the planet of the lizards. The conditions that led to the evolution of the hominids, including us, would likely never have taken place. Pause for reflection.

Asteroid orbits

Returning to the skies, the Trojan asteroids are in the same orbit as Jupiter, located around the two of Jupiter's Lagrangian points that are 60° in advance of Jupiter and 60° trailing (often denoted the L4 and L5 Lagrangian points). There are conjectured to be a great many Trojan asteroids in Neptune's orbit too, whose details could tell us about the early history of the solar system as Neptune drifted to its present location from its origin nearer the Sun. That, though, is another story.

Most of the other asteroids lie between the orbits of Jupiter and Mars but are not distributed uniformly in the gap. A slide shows the distribution of the orbital average distances from the

Sun within the belt. '*a*' is the parameter we used earlier to represent the average distance of an orbiting body from the Sun. Plotting the *a* values for known asteroids reveals the so-called *Kirkwood gaps*, absences due to orbital resonance with the period of Jupiter. This is the same effect that created the Cassini division in Saturn's rings.

Asteroids tumble as they orbit and hence change the amount of light they reflect to us. Some asteroids are observed to orbit around each other: asteroids with their own moons. Ida & Dactyl on the slide are an example of this.

The slides show the orbit of *Aberdonia*, the asteroid that was named in 1995 after the University of Aberdeen to mark our half millennium of existence. There is at least one other asteroid with an Aberdeen connection, namely *13551 Gadsden*. It is named after my predecessor, the late Dr Michael Gadsden, who gave his version of the astronomy and meteorology lectures in the 1990s. He was a former long-standing Secretary General of the International Aeronomy & Geophysical Association, past Council Member of the Royal Astronomical Society and a man both well-known and highly respected in international science circles.

The asteroids are considered as the residue of planetesimals that formed the original condensation of material in the solar system. They are not a planet that has disintegrated but material that never formed into a planet or aggregated with other planets, because of the stirring influence of Jupiter. They are now grinding with almost infinitesimal slowness into smaller pieces or occasionally removing themselves on collision courses with other solar system bodies. They are a permanent part of the solar system. Lots will still be around when the Sun reaches the end of its life.

Comets

These notes fade out, partly because they are intended as a supplement to the course textbook and its coverage of comets is more than enough for the time available. However, since the course in this form took shape, cometary studies and knowledge have made advances as dramatic as those in any other branch of astronomy. Comets have been described as 'dirty snowballs' but that leaves one thinking they are roughly round chunks of mainly ice with some grit in them. In fact comets seem to be oddly shaped, almost tarry black, a conglomerate of stone, dust, organic gunk, cavities and a mixture of ices of water, ammonia, nitrogen, carbon dioxide and carbon monoxide - a veritable mash up. Undoubtedly they aren't all the same either. One of the astronomical events of the decade has to be the arrival of ESA's Rosetta mission at Comet 67P/Churyumov-Gerasimenko. The Rosetta probe orbited the comet nucleus from 2014 to 2016, collecting a huge amount of data and images. It dropped a lander in 2014 that by bad luck bounced onto a dark ledge that was in solar shadow. The lander could not re-charge its batteries after the initial day or so of data collection. The comet is about 4 km long, has a very irregular shape and has been deflected during its past history into a short period orbit of 6.44 years that takes it a bit further out than Jupiter and not as near the Sun as the Earth. At the time of this update of the notes in 2017, the comet has passed round the Sun and is now heading away, too far from Earth for the Rosetta probe to send back useful information. The probe was landed on the comet's surface in September 2016 and switched off.

All comets come from either the Kuiper belt or the more distant Oort cloud. Both places are deep freezes with low temperatures beyond anything that can be sustained on Earth for long periods, say 50 K (about -220° C) for the Kuiper belt and lower for the Oort cloud. They are full of primordial material from which the planets have formed, material that has effectively been cryogenically preserved for some 4.6 billion years. To explore this stuff would tell us a lot about planet formation and would likely answer some big questions about the Earth, such as 'where did all our water come from?'. The Kuiper belt and Oort cloud are, though, a seriously long way away from Earth, further out than all the planets and hence not available for in-depth study. Comets are the gift of these regions to us. Bodies disturbed for some reason and sent hurtling in to the inner solar system. We just have to get near them to be saved the astronomical expense, time and technology of exploring outer solar system bodies.

Comet 67P/Churyumov-Gerasimenko is not the first comet nucleus to have been visited by a probe, for Halley's comet (1P/Halley) nucleus was imaged in fuzzy detail by the Giotto probe in 1986. Another elongated comet, 19P/Borrelly, was photographed in 2001 but also not in much detail. The rounder and partly cratered image of 81P/Wild 2 was seen in better detail in 2004 by the Stardust mission that also collected dust from the comet's coma and returned samples to Earth. 9P/Tempel was the subject of the Deep Impact mission that sent a probe to impact its surface so that the resulting cloud of dust could be analysed in passing. The same mission took some good pictures in a flyby of 103P/Hartley in 2010. All these comets are short-period comets (that's what the 'P' stands for) that return on schedule. The reason is one of logistics. It takes decades to plan, build and launch a comet mission and years to reach a comet (Rosetta took 10 years to reach 67P). Missions to Oort cloud comets like the spectacular Hale-Bopp of 1997 that won't come back for several thousand years are not possible with today's way of doing things.

None of the previous missions compare with the amount of information that has been delivered by Rosetta. As well as taking more detailed pictures than any yet seen of a cometary nucleus, the mission contained a raft of analysing instruments that probed the structure and material of the comet and followed the changes that took place as the comet approached the Sun. The Philae lander (named after the island in the Nile where the original Rosetta stone was found) included 13 instruments for surface analysis, with one that made detailed isotopic measurements of the carbon and other atoms on the surface that should unlock the past history of the comet. The Rosetta mission has been one of the most complex space missions ever attempted.

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