Planetary Overview

Introductory thoughts

I talked earlier in the course about the Earth-centred Universe. This wasn't only a physical description of what society believed but also a state of mind. The view has been described as geocentric and egocentric. Even when we learned that the Sun was central to the solar system, we - mankind - still took it for granted that by sitting on the Earth and viewing our surroundings telescopically we could find out enough about the Universe to understand it. I was reminded of this on reading an account of lunar astronomy written less than a century ago. Professional astronomers had been observing the Moon for centuries; good photographs had been available for more than a lifetime. Built on this knowledge the accepted theories for the basis for the Moon's appearance were that the craters were volcanic in origin and the 'maria' the result of massive flooding with surface rocks melted by impact collision. We now know this was completely the wrong way around. The craters were formed by impacts and the maria by lava eruptions. How can we be sure? Mankind has been to the Moon, collected the rocks and seen for itself. In a nutshell, we have got away from the Earth-centred view. Most of the pictures on the opening montage were not taken from the Earth.

We are living in exciting times. Knowledge of our wider surroundings is expanding at a huge rate. Much of our knowledge of the solar system is very recent. We hadn't seen in close-up any of the estimated 100,000 sizeable asteroids until the early 1990s [pictures later in the course]. How did we see this particular sight and gather a huge body of other knowledge? By getting out there with space probes. The Earth-centred Universe is finally dead and we are all the beneficiaries of that.

[In one sense, the same thing has happened in other sciences too. It is only by getting amongst the very molecules of which we and our surroundings are built that we are making astonishing progress in understanding how the world of materials and life works. Techniques such as x-ray crystallography, scanning electron microscopy, atomic force microscopy, etc. do for molecular science what space probes do for planetary science].

Overview of the Solar system

What are we living with?

In terms of material content, the solar system is 99.9% the Sun. In overview, the solar system isn't just the Sun and a few planets but is:

1 Sun; 8 planets and, so far discovered, 5 dwarf planets (Pluto, Ceres, Haumea, Make-make and Eris); 15 moons over 1000 km in diameter; over 150 known smaller moons; ~100,000 identified asteroids; comets, billions of meteorites and other debris; billions of icy bodies beyond Pluto in regions known as the Kuiper belt, the scattered disc and the Oort cloud, solar wind; magnetic field. More than 20,000 bodies in the solar system have internationally agreed names.

Bode's Law of planetary distances

The 'Law' is really an empirical relationship, not a fundamental law of nature. Bode's law is a formula that gives the distance of the planets from the Sun. It's the kind of relationship that

Kepler looked for but didn't find. It was discovered by Johann Titius and strongly publicised by Johann Bode in the second half of the eighteenth century.

12 years after Bode published 'his' law in 1772, Uranus was discovered by William Herschel at 19.6 AU, as predicted by n = 64 in Bode's formula; 19 years later in 1801, Piazzi discovered Ceres, known for the next two centuries as the largest asteroid of all, about 1000 km across at the n = 8 position of 2.8 AU. Ceres is now classified as one of the dwarf planets so Piazzi's search for a new planet was, in a way, not in vain.

Distances between nearer planets are measured accurately by radar pulses that travel at the speed of light. Other distances we get from Kepler's laws.

Bode's law seems to be saying something fundamental about our planetary system. Bode didn't know why it worked, and perhaps that's not surprising in view of the state of science in the late 18th century. What is really surprising is that to this day we can't see why it works, either. Does Bode's law tell us about the early solar system, or about conditions of stability later in the evolution of the solar system for a set of weakly interacting orbits? This raises the further question of how long the solar system has looked like it does today? Knowing as we do now the speed and position of the planets to high accuracy, how far back can you run the laws of mechanics to deduce the appearance of the solar system in the past with any confidence? The answer is not as far as you think or hope, and not nearly far enough to go back anywhere near to the formation of the solar system.

See the textbook's tables C7-1, C7-2, reproduced in essence on the slide, that show how well Bode's law fits the data.

Masses & Densities

Masses can be obtained from Newton's form of Kepler's 3rd law, for all planets with moons. Densities are found from the ratio

$$density\,(kg\;m^{-3}) = \frac{mass\,(kg)}{volume\,(m^3)}$$

Three bar-charts on the slides show the relative diameters of planets, their masses and their relative densities. It is clear that there are two groups of planets, the rocky dense ones and the gas and liquid planets.

Orbits & Satellites

Most things in the solar system are rotating the same way - anticlockwise when you look down onto the North Pole. This shows that different objects in the solar system are likely to have a common origin.

- Rotation of Sun (equator revolves faster by ~9 days than polar regions)
- Rotation of planets about their axes (except Venus, Uranus & Pluto)
- Orbits of planets about the Sun
- Orbits of moons of about planets (with exceptions)

Most orbits are nearly circular in appearance and lie close to the same plane. Mercury and Pluto's orbits are the most elliptical and the most tilted. That's what you'll find in astronomy textbooks. However, over the past few years the new generation of sensitive light detectors attached to telescopes has been exploited by several groups looking for previously unseen moons around our larger planets. The story, in brief, is that around 30 moons had been discovered and named by 1950. Another 30 moons were discovered by 1996, thanks to the Voyager space probes and other probes making quite close encounters with the planet Jupiter and beyond. In the years since then, some 100 extra moons have been added, thanks to new searches based on new technology detectors attached to ground-based telescope and new images from more recent space probes. We now know of over 170 moons.

The new moons are mainly quite far out, only a few km in diameter, and in orbits that might be quite eccentric, inclined and even retrograde. It's not only intrinsically interesting to know such 'irregular' moons exist but their presence provides important clues to the origin of the solar system. We know that such moons must have been circulating around their planets for a very long time because to capture a moon in retrograde motion, or even to create retrograde motion within the inner solar system, needs a braking mechanism and there simply isn't enough matter around planets these days to provide such braking, direct collisions excepted. Moreover, we're pretty sure there hasn't been enough for a few billion years. Hence these moons are a relic of the early solar system and tell us about conditions then, when there would have been extended gas and debris clouds around the giant planets.

Are we likely to find any more moons? Certainly, '*yes*', though not big moons. There is a useful idea, not mentioned in the textbook, called the Hill radius, named after G.W. Hill, a 19^{th} century mathematician. This is the greatest distance away from a planet orbiting a star that you can expect to find a moon in stable orbit. For the Earth it's about 1.4 million km and we've only got one moon within this distance (plus hundreds of artificial satellites). For the large planets the Hill radius is more than 50 million km and that includes a huge volume of space, not yet thoroughly explored for items only a few km across. Expect more moons to be found around all the large planets. The Hill radius is also a useful concept when it comes to considering what we expect to find when looking at planetary systems around other stars.

On quite a different timescale from the long-lived irregular moons, all the Jovian planets have ring systems of orbiting small chunks, varying in size from grains to boulders. The timescale of these is different because ring systems have a short life in comparison with the 4.6 billion years that has been the lifetime so far of the solar system.

Planetary Atmospheres

The average energy ($\frac{1}{2}mv^2$) of molecules in a gas is proportional to temperature. Hence lighter molecules travel faster.

In a gas there is a wide range of molecular speeds, called the Maxwell distribution, a law discovered in Aberdeen.

[Digression: How many have been into the Music Hall in Aberdeen? This hall was built by public subscription to be the main venue for the meeting of the British Association for the Advancement of Science held in Aberdeen in 1859. James Clerk Maxwell as local professor was one of the leading lights. There is a rare picture of the opening ceremony conducted by Queen Victoria's husband, Prince Albert. You can see a low resolution copy I have put on the web in the summary page about James Clerk Maxwell (http://homepages.abdn.ac.uk/npmuseum/Scitour/Maxwell.pdf) that is part of the Scientific Tourist in Aberdeen sequence. Maxwell was of course there on the stage. It was at this meeting that Maxwell announced the law of molecular velocities, one of the deductions he had made from his pioneering mathematical modelling of a gas as a cloud of fast moving molecules flying between one collision and the next. As far as I know, this is the only important law of Physics derived and announced at Aberdeen. The interior of the Music Hall drawn at the opening ceremony is instantly recognisable by anyone who has been in it.]

The next slide shows:

The Maxwell distribution

The graph is an Excel calculation for nitrogen molecules at room temperature. The key point to notice is that the distribution is noticeably asymmetric and has a long tail at higher speeds. These high-speed molecules play an important rôle in determining whether a planet or moon hangs on to its atmosphere. [Return to previous slide].

Three factors are relevant to a planet or moon holding onto its atmosphere. First, lighter molecules move faster than heavier molecules; secondly, a significant number of molecules travel at several times the average speed, because of the high-speed tail on the Maxwell distribution; thirdly, the outer reaches of the atmosphere are hotter than the ground level, because of heating by the Sun's UV. This last effect can be seen in the 'thermosphere' of the Earth's atmosphere that was mentioned in the meteorology lectures. The molecules in the tail of the Maxwell distribution are the most energetic molecules in an atmosphere, the ones most likely to escape. They will do so if they achieve the calculated escape velocity and avoid further collision. The escape velocity depends on the strength of gravity at the planet or moon's surface. For the Earth, for instance, it is about 11 km s^{-1}, which sounds very fast but is not fast enough to hold on to the primitive H_2 and He molecules that used to be in our atmosphere.

How molecular speeds depend on temperature

The slide (see K & K chapter 7) shows the escape velocity and temperature for all the planets and largest moons. Also shown is the variation of 10× the mean speed of different molecules with temperature. If a planet lies below the line for a certain gas, it means that the escape velocity at the temperature of the planet is too small to retain the gas over a very long time. If the planet or moon lies above the gas line, then it will hold on to gas of that type. You can see from this graph, for example, why the 4 Jupiter-like planets all have their primitive hydrogen and helium, whereas Earth doesn't. You can see why our Moon's got no atmosphere, Mars has negligible water vapour and why Titan, Saturn's largest moon, has still managed to keep an atmosphere of nitrogen. Ganymede, shown in the figure, is Jupiter's largest moon, with a diameter of over 5000 km.

Features of the solar system

We don't know all the answers but we have assembled a lot of information - facts - that any theory of formation must address. Amongst these are

- system is nearly planar

- observed rotational phenomena; putting in the numbers you find that most of the angular momentum of the solar system is in the outer regions
- observed spacing of planets
- chemical composition of planets
- larger planets have very many moons
- cratering almost everywhere
- ring systems on Jovian planets
- asteroids, comets, meteorites

Planetary systems are common around other single stars, but the ones we have discovered are not like the solar system. More on this shortly.

Formation of the solar system

Evolutionary theories are based on condensation from a very large rotating cloud of primordial matter. Conservation of angular momentum about the centre of rotation governs the fact that a contraction in the radius of the cloud must always be accompanied by a speeding up. One consequence of most of the matter ending up in a central star is that you would expect the centre to rotate very quickly. The Sun doesn't. It takes about a month to rotate around once. What has happened to its expected rotational momentum?

[A contraction parallel to the rotation axis involves no speeding up. What can happen as gravity pulls in an initially spherical rotating cloud turns out to be a tough problem. Initially the sphere gets pulled into an oblate spheroid (like the shape to the Earth) but as the contraction continues the stable configuration becomes an ellipsoid with three unequal axes. Further flattening brings on instability. One possibility is that the mass breaks into two and if it is big enough a double star system forms. This is why double star systems are very common. Another possibility is the formation of a central star with a planetary system but before a system as flattened and disk-like as our solar system is formed from the initial cloud various instabilities have necessarily occurred, making precise prediction impossible.]

The difficulty of answering the basic question of why the Sun rotates so slowly lead people to develop **catastrophe theories** in which, for example, the Solar system is considered as pulled out from Sun, or the Sun was once part of a multiple star system that became unstable. Catastrophe theories make solar systems rare. They don't seem to be. Catastrophe theories also don't stand up to detailed analysis. E.g. the deuterium content of planets is less than the deuterium content of the Sun and so the planets cannot have been ‘pulled out’ from the Sun. See the textbook for further details.

Modern evolutionary theories

are now based on von Weizäcker's analysis (in 1940s) that the instability of a rotating gas condensing around a central 'protostar' would form eddies, with larger eddies further from the centre. Slowly a sticking together of the cloud constituents occurs as particles in local elliptic orbits collide. The larger particles begin to exert enough gravitational attraction to encourage other particles to deviate towards them, giving them a bigger chance of increasing their size. These embryonic planets are called planetessimals. This stage may have taken ~ 10^5 years. Supposing a population of planetessimals have formed, objects in elliptical orbits that intersect will eventually collide. Objects in circular orbits won't. There is a tremendous heating effect as small planetessimals collide with larger ones; even rocky agglomerations would have at least their outer layers turned molten under bombardment.

Computer simulations of a contracting cloud of dust and gas around a protostar have taken over from von Weizäcker's early analysis. The number of particles in any real cloud is hugely greater than any computer simulation can handle so approximations must be made. It isn't just a matter of simulating mechanical collision and aggregation either, for processes like photo-evaporation, ionisation and the influence of the magnetic field of the protostar need to be considered. In spite of the complexity of the situation, it is already clear that the formation of planets goes through several stages and the outcome of each stage depends on individual circumstances in a particular condensation, such as how much matter there is, the ratio of gas to condensate, the distribution in sizes of aggregated particles, distance from the protostar and so on.

To form gas rich planets like Jupiter and Saturn, a substantial Earth-like core must be accreted first before most of the original gas disappears by photo-evaporation. The core then sweeps up an increasing amount of the primal gas while it is still present. The window of opportunity is around 10 million years. To form the Earth at around our distance from the proto-Sun probably took longer, around 10 – 100 million years. There's still a long way to go before a history of the solar system can be constructed that is consistent with the size, distribution and content of our 8 planets (and the rest of the stuff) but what is already clear is that a considerable variety of planetary systems can be formed in different circumstances and they don't have to be duplicates of our solar system.

Two developments of very recent years have shed more light on the evolution of our solar system. First is the observation of very different planetary systems around other stars. More on this in a few minutes. Second is the application of modern computing power to simulate a variety of possible scenarios and look at those whose outcome resembles our solar system. Both these approaches are still 'hot topics' in astronomy. It now seems clear that over hundreds of millions of years the 'gas giants' moved substantially from their initial orbits and in so doing scattered a very large amount of material that was also in orbit at the time, resulting in heavy bombardment of both the inner and outer solar system. The almost complete cratered covering of the Moon and Mercury are a testament to some of this bombardment. The process of creating the solar system we recognise today took over a billion years from the formation of the 8 planets. It also seems probable that part of a planetary evolutionary process involves ejecting material from the system, not simply forming and re-arranging the existing constituents. For example, the present position in the solar system of our 4 'gas giants' is likely the result of their being 5 gas giants in the beginning, followed by a shuffling of orbits as a result of their mutual gravitational interactions that resulted in one planet being flung out. Such a scenario pans out in multiple computer simulations. Asteroids are remaining planetessimals, or fragments of them, unable to coagulate because of the influence of massive Jupiter.

If 'evolution' as a formation mechanism for the solar system is back on the agenda, what is the answer to the missing rotational momentum of the Sun? The answer seems to be that the Sun has been slowed down by the phenomenon known as eddy-current drag. As you've seen, the Sun has a strong magnetic field associated with it. (Remember the hairy ball model). Sun also creates in its surroundings a (moving) plasma, that we call the solar wind. Now the spinning Sun moves the attached magnetic field lines through this conducting medium and the result is just the same as trying to move a magnet past a sheet of aluminium, as can be demonstrated in the class. There is a net force that tries to slow the motion. This is 'eddy-current drag'. Over 4 billion years, the Sun has been slowed from a spinning top to its present slow rate by the equivalent of eddy-current drag. That's the story. It also helps to explain why the gas giant planets rotate quickly. Jupiter, for example, goes spins around on its axis in less than 10 hours. The bigger the mass of a gas giant, the faster it rotates. The gas giants haven't slowed like the Sun for they don't have the equivalent of the solar wind (a 'planetary wind') interacting with either their own magnetic fields or the solar magnetic field.

Modern evolutionary theories are supported by extensive computer simulations. One very important consideration is how large does an interstellar gas cloud have to be before it will condense into a planetary system under its own gravity? The answer appears to be: much larger than the mass of our solar system. What, then has happened to the lost mass? The story of the formation of the solar system is not all cut and dried.

Planets around other stars

The Hipparcos distance and direction survey mentioned in an earlier chapter has given us a map of all the stars in our neighbourhood. We now know how we will appear in the sky viewed from a planet around a neighbouring star. Our near neighbours the α Centauri system was confirmed in October 2012 to have at least one planet, of Earth-like size orbiting very close to α Centauri. The slide shows how we would be seen as we passed there in our exploration ship. The Sun would be just one star in the heavens, not conspicuously different from a million others. Who would guess there was life on one of its circulating planets?

Extra solar planet search

When I was at school there were 9 known planets whose names and order we learnt. Now (2014 as I update these notes) there are approaching 2000, with several thousand other candidates waiting for firm identification. Fortunately school kids haven't got to learn all their names. My 9 orbited the Sun. Now school children have to learn only 8 names since Pluto has been demoted to one of the 5 'minor planets', as described in a later chapter of these notes. All the new planets orbit other stars and are called 'extra-solar planets'.

There have been some good programs on television describing the search for extra-solar planets and interviewing leading people in the field. The technology has got to the stage where under favourable circumstances (large planets lying far from nearby cool stars) individual planets can be crudely imaged in the infra-red. It's always satisfying to see something whose presence has been indirectly inferred. Expect significant progress in the coming years from the likes of the future James Webb Space Telescope and the European Extremely Large Telescope. Progress in discovering extra-solar planets has been faster than anyone might have guessed, notably thanks to the Kepler mission (discussed shortly). Any figures I write down will be out of date by the time you read this, for new planets are being discovered by the week. By 2010 over 500 extra-solar planets had been discovered, which seemed impressive at the time. Largely due to the Kepler mission that has been looking for planets transiting in front of their parent stars, some 2740 planetary candidates had been observed by Jan 2013.

The Kepler mission has eclipsed the previous main planetary search technique used. This has been to look for the wobble caused by the planetary motion on the central star. This wobble is caused because the centre of mass of star and planet is fixed in space and as the planet orbits, the star executes a small orbit of its own on the opposite side of the centre of mass. This motion itself can't be seen because it's too small but the Doppler shift of the spectral lines of the starlight can be detected. When the star is approaching us, the lines are blue-shifted; when the star is receding, the lines are red-shifted. As a piece of theory, this radial velocity technique sounds plausible, but how do the numbers work out. Jupiter, the solar system's largest planet, orbits the Sun in 12 years and the Doppler shift on the Sun's spectral lines is too small to be detected with the equipment now used. If the technique couldn't even detect Jupiter, is it any good at all? Surprisingly, it has detected many planets around other stars.

Extra-solar planet properties

Most planets detected are close to their parent stars and have masses comparable to Jupiter, in some cases 10 times that of Jupiter. See the two diagrams on the slide. The star υ-And (Upsilon Andromedae) has 3 planets. There is a simulation of the system on the web. The outer planet is $4.6\,M_{Jupiter}$ and has an orbit that is very obviously elliptical, with semi-diameter about 2.5 AU.

Where are they?

All around us, is the answer. The star chart of the north celestial hemisphere projected onto a plane shows the locations of about half the known planets, as of March 2008. On the web-site that originated this diagram you can see all the locations of those found in the other celestial hemisphere. The map on the web is interactive, bringing up the name of the parent star, the distance from us and the number of planets when you mouse over the star symbol. An even more impressive 3D version can be viewed from a link on the same page.

A shift in expectations

The unexpected has been found, as so often in astronomy. Many stars have large planets circulating at no more than a tenth of the distance our Earth is from the Sun. Some large planets take only a few days to orbit their star. They are very hot, over 1000°C. A good number of planets are in quite elliptical orbits, unlike most of the planets in our solar system, which are in sufficiently circular orbits that it took a long time to discover that their orbits were in fact slightly elliptical. Some planets have been found circulating binary stars, a circumstance that was considered to be unstable in the long term and therefore unexpected. The shift in expectations is that there are plenty of planetary systems out there that are very different from our solar system. The stellar wobble technique is such that we're going to see these and not, at the moment, other solar systems like ours. The eclipsing technique, mentioned next, is also biased to finding short-period planets.

Example of HD209458

HD209458 is a Sun-like star 150 LY distant in Pegasus. It has a large, $0.7\,M_{Jupiter}$, planet orbiting in 3.5 days. You can see how this fits in with other planets that have been discovered. The slide shows the radial velocity curve of HD209458. What makes HD209458 rather special is that the orbit is edge-on to us and we can detect that the planet crosses in front of the parent star.

Transit of HD209458

The loss of light as the planet moves in front of the star has been measured very accurately by the Hubble Space Telescope (see the slide). From this the size of the planet can be found, and it is larger than Jupiter. This gives it a density less than Jupiter. The change in the absorption of spectral lines can also be looked at (see slide) and from this it has been found that the planet has an atmosphere that contains sodium vapour. Slowly a picture of these strange, large, red-hot planets is emerging. An international consortium that I mentioned earlier in the course called SuperWASP has built an instrument that is finding more of these eclipsing planetary systems. See the WWW for details.

Looking for Earth-like planets

Detecting Earth-like planets will not be easy. The period of planets, as you know, is years. Planets are small and in visible light they are millions of times fainter than the parent star. To give one set of example numbers, the disc of the Earth in the sky as seen by a distant observer is only 1/13225 of the size of the Sun's disk and in addition the Sun is giving off about 28 MW per square metre of visible light but the Earth is only reflecting about 400 W m^{-2} of visible light. In other words, the Sun is 70,000 times more luminous for each square metre and more than 13,000 times the size of the Earth. Putting these two facts together, any distant observer looking this way would find the light from the Earth about 1000 million times less than the light from the Sun. In addition, on the scale of interstellar distances the Earth is virtually on top of the Sun. It's little wonder that we, looking the other way, haven't imaged any Earth-like planets in our telescopes. Interestingly enough, in the infra-red part of the spectrum, planets are not quite so much fainter than the parent star. There is hope for the future. We have entered a new era of astronomy and a raft of new and improved techniques is being developed to answer what everyone sees as a crucial question. "Are there other Earth-like planets out there?"

Gliese 581

Two Earth-like planets, or as nearly Earth-like planets as had been discovered, were detected in 2007 after a long search by Stephane Udry of Geneva using the Swiss facility at the European Southern Observatory complex in Chile. They orbit a cool, low-mass star in the Gliese catalogue of nearby stars. Gliese 581 is one of the hundred nearest stars to us and undoubtedly represents a huge population of dim stars of which we see only the very near ones. The star itself is sufficiently faint that you won't even see it through binoculars although it's only about 20 light years distant. Of course its planets have not been seen directly, only inferred from the minute wobbles in the parent star's spectroscopic lines. Gliese 581 had been known for some years to have a third planet about the size of Neptune, orbiting very close in.

In fact 6 planets have now been identified around Gliese 581, the latest, Gliese 581 g, in September 2010 seems to be right within the habitable zone if it truly exists. Because Gliese 581 is such a cool star, if 3500 K can be called 'cool', this zone is much closer to the star than is our Sun's habitable zone. Gliese 581 g orbits in 37 days The 3 possibly habitable planets Gliese c, d and g are more massive than the Earth, giving them a stronger gravity and hence necessarily a different topography. 'Earth-like' is therefore a bit of an overstatement but they are the most Earth-like planets discovered so far.

Whether the planets have any ‘life-as-we-know-it’ is going to depend intimately on their atmospheres. From a long way off, Venus might look like a contender for harbouring life in the solar system but the runaway greenhouse effect of its atmosphere has made it an uninhabitably hot, dry place. In fact the Earth would have virtually no surface liquid water on it and be too cold for most of its present life if it wasn’t for the greenhouse effect, so it’s not even obvious from afar that the Earth is a great place for life. Gliese 581 d may be too cold, like Mars, Gliese 581 c may be too hot, like Venus, or they may be just right. We shan’t know for a good while because atmospheric conditions can’t be found from the wobble technique that is the only method for inferring its existence at the moment.

Kepler Mission

NASA’s *Kepler Mission* was launched in March 2009 to monitor from space the observed light from 100,000 main sequence stars for a period of 4 – 6 years. The intention was to look for evidence of the transit of a planet in front of a star, temporally dimming the star light in a well-defined way. The technique is the same as the one used by the Hubble Space Telescope to examine the light curve of HD209458. The *Kepler* craft has on board a telescope of about 1 m diameter whose image falls on a very stable CCD image recorder. The light levels that are contributed by all the selected stars are monitored closely, and data transmitted back to mission control just for the pixels illuminated by the stars and not for the space in-between. The sensitivity of the detector on *Kepler* is such that the light curve can be measured to at least 20 parts per million (ppm). That sounds impressive (and it is!) but from the figures a few paragraphs back the Earth’s disk in relation to the Sun’s disk is only 75 parts per million so if the Earth were seen from a long way off transiting the face of the Sun it would only reduce the light from the Sun by about this amount, three-and-a-half times the random fluctuations in the detector. The result would be a very small signal in the equivalent of a *Kepler* mission looking this way from afar. Aliens would have to analyse their signals very carefully to find us.

Kepler has been in an Earth-trailing orbit around the Sun, staring with its unblinking eye 1 m in diameter at the same region of space near the plane of the Milky Way in the constellation of Cygnus. No problem about getting a stiff neck. The project had an important element of ‘guest observers’. Subject to agreement by the *Kepler* team, any astronomer can propose targets of interest to observe within the field of view, even if the reason to monitor them may not be to find extra-solar planets. This, surely, has to be an excellent example of international co-operative science at its best. The news from *Kepler* since it has been launched has been stunning. Over 2700 new planet candidates had been found as of Jan 2013, circulating around some 2000 stars. To keep looking in exactly the right direction the spacecraft had 3 stabilising reaction wheels and one spare. In May 2013 two had failed and the original mission came to a halt, though all the data returned has still to be analysed (2014). The *Kepler* mission is not yet worthy of the words ‘…with muffled drum/ Bring out the coffin, let the mourners come’ that Geoff Marcy penned. After a year of thinking what to do with a partially active probe the mission has been ‘re-purposed’ in mid 2014 as K2, undertaking a variety of high-precision photometric studies. NASA’s next related exoplanet hunting attempt will be the TESS (Transiting Exoplanet Survey Satellite) project that will be equipped with 4 wide-angle telescopes. It is due to be launched in 2017.

ESA launched the COROT polar orbiting satellite in late 2006, which included amongst its goals observing transits of Earth-like planets. It has a smaller telescope with a smaller field of view than *Kepler* and was looking at a smaller area of the sky. COROT has discovered some two dozen transiting planets but a systems failure in late 2012 terminated its science program. The task of finding transiting planets is not as easy at it might sound. If the only means we had of finding Mercury and Venus was to look for their transits across the face of the Sun over a period of a few years, the chances are that we wouldn't know of their existence.

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