GRESHAM

COLLEGE

THE GIANT PLANETS

A Lecture by

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5 February 1999

The Giant Planets

Jupiter, and to a lesser extent Saturn, dominate the solar system. As with the terrestrial planets, they can be seen with the naked eye and therefore like the comets, which we have already discussed, they were known to the ancients. Our solar system comprises at least three other planets and a profusion of satellites associated with Jupiter, Saturn, Uranus and Neptune. Everything further out than Saturn and all the moons both large and small had to wait for the invention of the telescope and then the space programme before revealing themselves to man.

It is in fact rather surprising that Uranus, the only planet in the solar system ever to be identified by accident, took so long to be discovered. Firstly its magnitude is just on the edge of what can be seen without artificial aids and therefore it could have been expected to have been spotted by some eagle-eyed early stargazer. Then after Galileo changed the perspective of astronomy forever, at least twenty catalogues of the stars, produced over a nearly two hundred year period, listed Uranus as a star without realising in fact that it was rather closer to Earth; Galileo himself may even have seen the sixth planet.

So the honour of being the first man to find a planet fell to Sir William Herschel on March 13th 1781. Herschel was undertaking a complete star survey but he and his sister Caroline were avid comet trackers so when it was realised that Uranus was in rapid motion against the starry background they thought they had discovered a candidate cometary object. Later observations by themselves and Astronomer Royal Nevil Maskelyne showed a sharp outline and no coma or tail, so the interpretation was changed in favour of a planet and the size of the solar system was doubled at a stroke. Herschel enjoyed the lifetime patronage of George III and wanted to name the new planet Georgium Sidus (George's star). The king thought it was a good idea, he said it would "compensate me for the loss of the American colonies". French astronomers preferred to name the new member of the solar system after Herschel the discoverer; Bode, whose law Uranus obeyed, insisted on the mythological name, Uranus being the father of Saturn who had been the father of Jupiter.

The planets beyond Uranus owe their entry into our cognescence due to mathematics rather than astronomy. It was realised independently by John Couch Adams and Jean-Joseph Le Verrier that yet another planet, Neptune, had to exist to explain Uranus's orbit. Adams, would have had precedence but, as he was a young man without any reputation, he communicated his ideas to the Astronomer Royal, Sir George Airy, who ignored him. Pluto, the only non-gaseous planet in the outer solar system was also predicted because of orbital problems. Neither Neptune or Pluto obey Bode's law which has turned out to be a fortuitous accident and is now confined to the history books.

The advent of the telescope of course allowed other things to be learned about the giant planets that had never been known before. Gresham's own Robert Hooke suggested that Jupiter had a period of rotation (10 hrs, the fastest of the planets) a conclusion he drew after being the first man to see the Great Red Spot in 1664. The Red Spot, is still not fully understood but is certainly a vortex in Jupiter's dynamic gas circulation; it is 26,000 x 14,000 km (big enough to fit two Earths in) and extends to an unknown but probably great depth. The spot has changed in size and colour, and wandered right around the planet over the years, but is still with us compared to some other features of Jupiter which have proved quite transient.

The atmospheres of all the giant planets are predominantly H_2 and He in approximately the proportions of the sun. Indeed had these objects got a lot bigger they could have been mini suns and our star a binary system. It needs about 12 Jupiter masses to initiate hydrogen burning and 80 Jupiter masses to start nuclear reactions involving deuterium. Given the preponderance of hydrogen the minor constituent recognised in the atmospheres of giant planets are all very reduced, e.g. CH_4, H_2O, NH_3, H_2S and even things like PH_3 and GeH_4.

Another discovery attributable to the telescope was the fact that Saturn had rings. Thanks to the Voyager spacecraft it is now known that Jupiter, Uranus and Neptune have them as well. Galileo who saw them first associated with Saturn thought they were separate objects and must have been pretty shaken when they temporarily disappeared (they go edge on to Earth every 15 years) in 1612. It was not until forty years later that Christian Huygens correctly concluded the planet was enclosed by an inclined flat disc. He thought it was solid, others argued for 200 years at to whether liquid or gas was more appropriate before James Clerk Maxwell showed that the rings could only be a suspension of minute particles. The grains do not coalesce because the force on them from the planet is greater than they exert on each other. There has been considerable discussion on the origin of the dust, the most accepted theory being that because various planetary moons have orbits coinciding with the rings so the dust is a characteristic of a particular moon. The recent Galileo mission to Jupiter has provided evidence that, at least in Jupiter's case, the dust is being thrown outward from the innermost satellites.

The knowledge that the giant planets have a multiplicity of satellites is again thanks to Galileo the chief user of the primitive telescope (it should be remembered that others had telescopes before Galileo, his contribution was primarily to put the invention to effective use). Eleven were seen around Jupiter before space missions started and the whole now stands at sixteen. The first four (galilean) moons of Jupiter named Io, Europa, Ganymede and Callisto, legendary characters associated with Jupiter, were all first observed in 1610. An example which Herschel would later copy, Galileo tried to name the moons for his sponsor (Cosmo de Medici)'s family. Having discovered the first moons other than our own, he proceeded to argue that satellites going round Jupiter were evidence for Copernican theories of the solar system. Later he wriggled out of a heresy charge, but he came dangerously close to being condemned to something for worse that house arrest for the remainder of his life after 1633. The moons of Jupiter caused worse trouble for Gresham Professor Lawrence Rooke, founder member of the Royal Society, he caught a chill hurrying home after observing them as a result there was an unanticipated vacancy in the college.

Just as Jupiter has four large moons, Saturn also has one of considerable size Titan. Gresham's Christopher Wren spotted Titan but thought it was a star and, so like those who overlooked Uranus, missed out on an astronomical claim to fame. The five major moons of Jupiter and Saturn could be considered planets on their own account. They are comparable to Earth's moon and Mercury and far bigger than Pluto; they are amongst the most exciting objects in the solar system. Three of those around Jupiter, Europa, Callisto and Ganymede have been recognised as having features which suggest that water exists in a liquid form. The most obvious of these clues is the fact that unlike just about everywhere else in the solar system their surfaces are not disfigured by intense bombardment. Something must be remaking these icy satellites and the only hypothesis worth considering is upwelling of water from below. Liquid water is prerequisite for life, and life dominates everywhere in the public's and the space agencies agenda. Europa and its compatriots are candidates for dedicated (probably landing) spacecraft in the relatively short term.

Io and Titan are also fascinating in their own right. The latter is the only satellite with a dense atmosphere, primarily nitrogen, but containing up to 10% low molecular weight hydrocarbons. A space mission named Cassini with a probe called Huygens will enter the planets atmosphere and crash land. Since Titan is a very cold place, the surface temperature is 94K, there is a reasonable possibility the probe will survive if the suggestion that a liquid paraffin ocean awaits to cushion the impact. Both Cassini and Huygens carry a strong contingent of British provided instruments to beam back data in 2005.

Io could not be more different from Titan if it tried. It consists of a world of volcanoes, nine of which were in a state of eruption when the Voyager spacecraft arrived in 1979. Nor is this just ordinary volcanism. Io's activity stems from molten sulphur and the different colours orange, red, black and white can be explained by deposits of various allotropes. Special explanations have to be put forward to understand the intense tectonic processing going on. The most likely being that Io is in an orbit where Jupiter and the other Jovian satellites inflict tremendous tidal forces on its crust to produce a unique heat source.

Astronomers are romantics at heart and so even though many of the smaller moons we now know about have been recognised by space programmes the theme of classical names continues. Jupiter has a total of sixteen, Saturn eighteen and Neptune eight. Uranus is slightly different, its first four moons, identified by Herschel were named after Shakespearean characters. The tradition has continued for the eleven others. A catalog of the moons of the solar system has even been produced in the lyrics of a pop song by Blur.

One of the more exciting discoveries in Astronomy of the last few years has been the detection of giant planets around other stars. The number of additional solar systems now stands at close to twenty, although it is not always certain whether the objects associated with the main star should be classified as a planet or a brown dwarf (a second star in a binary system which did not quite make enough mass for ignition). The common way of finding extrasolar planets makes use of Newton's Second Law "action and reaction are equal and opposite". What this means for planet searchers is that a giant planet does not simply orbit its sun. The sun to some extent is pulled off station by the gravitational forces exerted on it. The pair of objects orbit a common balance point. Seen from outside its environment the star appears to wobble and its light has a small but perceptible Doppler shift. When the sun is moving toward an observer on Earth it is blue-shifted; when it is moving away red-shifted. Looking for stars which have peculiar motions as a way of extending our knowledge about planetary systems in the universe seems to have been around since the late 1930's; the first occurrence being the case of Barnard's star. Truly successful applications of stellar wobble have only been forthcoming since 1995. The recognition of protoplanetary discs around stars seemingly have provided the impetus for the studies which were rewarded by the discovery of 51 Pegasi.

A look at the list of giant planets which have been found so far will show that other solar systems are not like our own. Many of the giant planets recognised to date have orbits very close to their parent stars; for example those around Tau Bootis, 51 Pegasi, Upsilon Andromedae, Rho Cancri and Rho Coronae Borealis have periods of 3.3, 4.2, 4.6, 14.6 and 39.6 days, all much shorter than Mercury at 88 days. Some giant planets with highly elliptical orbits (eccentricity of nearly 0.6) have been found; even though these objects spend some time at the distance of our Jupiter they also approach their stars inside the orbital equivalent of our Mercury. No star has yet been found with more than one giant planet whereas of course there are four in our solar system. The explanation to these several paradoxes above are that the sun early in its history might have had single eccentrically orbiting large bodies in close proximity as part of the accretion process. The state which exists now is one of where the chaos of former times has regulated itself like the smooth running well ordered machine that our planetary system has become.

So far we have not found anything resembling a solar system as we know it around another star. In order to extend our chances of detecting life elsewhere in the universe, people have argued that we need to discover planets in a so-called "habitable zone". In this respect a habitable zone is defined as a place where liquid water exists at virtually all times at most locations on a planet or moon. This is rather a high level requirement and may be a criteria for development of higher life forms rather than microscopic ones. Both Mars and the moons of Jupiter fall outside the Sun's habitable zone and yet both locations are still high on our list of good places to look for evidence of biological activity by past and even present micro-organisms.

Other factors not associated with the central star may also come into play. Obviously there is the geological activity of the planet in question. A careful balanced carbonate-silicate cycle can turn greenhouse effects on and off to provide a rather wider local window for life processes. Then there is the possibility of heating through tidal stresses or electromagnetic induction. On the downside, it is inevitable that the satellites of giant planets everywhere in the universe will become locked on to their hosts rotational period. Day length could be much longer or shorter. Organisms would have to adapt to different extremes of light sensitivity (to say nothing of radiation etc).

The evidence for extrasolar planets so far is circumstantial (there is just a single case where one might have been fortuitously observed) but for the future of what is now called astrobiology, things which are not just giant balls of gas will need to be scrutinised. Obviously however the best place to look for terrestrial-like Earth-sized planets (moons of the giant planets are beyond our scope for the foreseeable future) will be in systems as near as possible to our own. The search for life is going to be conducted by examining the atmospheres of anything found and recognising disequilibrium. The presence of spectroscopic bands for carbon dioxide, hydroxyl groups etc are the sorts of things which will need to be found. Methane, a metabolic product of micro-organisms, will be sought but its signal is not strong. In the infrared, one of the most easily seen absorptions will be that of ozone which could act as a tracer molecule for atmospheres which have much larger quantities of oxygen. None of these quests is likely to happen for ten or fifteen years but research into giant planets obviously did not end with the discovery of Neptune and the quest for life will not cease when our solar system has been explored.

Further Reading

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