Meteorites, Meteors and Comets

There are many areas in which professional and amateur co-operation brings benefits to both. Speakers at the RAS-BAA Pro-am discussion meeting on May 10 explored observational work on some of the debris in the solar system. The meeting concluded with a lecture given in memory of the noted amateur astronomer, George Alcock. Jonathan Shanklin reports.

Around 80 astronomers gathered together on 2003 May 10 for a discussion meeting held in the Open University Berrill Lecture Theatre in Milton Keynes. It was organised by **Jonathan Shanklin** (BAA), with help from **Margaret Penston** (RAS) and local organisation by **Barrie Jones** (Open University). Several displays were available for inspection during the day, including comet drawings by George Alcock, samples of Libyan desert glass, cuttings from old journals and information on the Journal of the International Meteor Organisation.

The morning session was devoted to meteorites and meteors, with **Monica Grady** (Natural History Museum) having the unenviable task of setting the scene. The solar system formed in a region similar to the Orion Nebula, with asteroids being remnant fragments. Pieces of asteroids fall to earth as meteorites. Spectra of asteroids match those of meteorites and also the orbits of fireballs match those of asteroids. There are three types of meteorites - irons, stones and stony-irons. Irons contain nickel and many other metals in trace amounts. Heat (from gravitational collapse and radioactive decay) allows reduction reactions similar to those in a blast furnace and metal accumulates in the centre of the asteroid. Iron meteorites tell us about core formation. Stony-irons come from the boundary of core and mantle and are the most beautiful meteorites, with intermixed peridotite (olivine) and nickel-iron. Stones form the majority of meteorites. Their main components are chondrules and calcium-aluminium inclusions. The chondrules say something about asteroid formation. The CAIs formed 3 my before the chondrules, 4.568 by ago. Interstellar grains are also present as silicon carbide and diamonds. The silicon carbide has variable isotopic composition and therefore comes from different stars undergoing different reactions. At least 35 stars contributed material. Meteorites may also come from comets, the moon and mars. Deserts such as the Sahara and Antarctica are good places to hunt for meteorites. They come in various sizes - the Arizona meteorite crater was formed by an object 40 metres across and gave a 1 km diameter crater. The object that fell 65 my ago had significant effects on life on earth. On average one meteorite falls over the UK every 11 years. Falls are not predictable and the next one could be over Milton Keynes!

Neil Bone (BAA) introduced the work of the Meteor Section, which he directs. The BAA is the largest UK organisation collecting amateur observations. Denning was an early Director and produced a catalogue of meteor shower radiants. Another Director, Prentice, was seconded to Jodrell Bank to correlate visual and radio observations. Harold Ridley and George Alcock both had long associations with the meteor section. Alcock in particular worked with Prentice on plotting tracks. Prentice was a solicitor and many of his observation reports have the wills of former clients on the reverse side! Today visual observers concentrate on rate information. A few observers using telescopes (or binoculars) still do plotting and there are also photographic surveys. Fireball reports come in at the rate of around one a week, mostly seen at 11pm whilst out walking the dog! Occasional bright events are seen widely, but the tracks often end over the sea. There may be possible fireball streams as there are some periods of enhanced activity, eg the end of June. Showers are listed in the BAA Handbook, however this year most showers are affected by moonlight. A simple formula converts the observed rate into a zenithal hourly rate and for example Perseids observed at one a minute equates to a ZHR of 80. Observations give a profile of the ZHR and the Perseids showed an unexpected spike of activity in the early 1990s, which was still present as late as 1997. Such surprises show the value of visual observations. The profile of the Geminids has changed over the last couple of decades. Leonid storms have been observed over the last few years. Photography can be very pleasing and also scientifically useful. Trail photography and video work are very important. Spectra are being obtained by amateurs and could be analysed professionally. A few amateurs carry out radio work. Results are published in the Section newsletter and the BAA Journal.

Our next speaker was **Iwan Williams** (Queen Mary College, London), talking about meteor streams, their formation, evolution and observation. For a long time each aspect had been a separate discipline, for example comet specialists weren't interested in the bits once they had left the comet. We have known since the 1860s that a lot of meteor showers are associated with comets. Small ejected particles are blown away in the solar wind but large particles share the orbit with the comet. What happens next is highly mathematical, but results in the prediction of meteor storms etc. The sun vaporises ice in a comet and the resulting gas ejection speed is around 1 km/sec. Comets orbit the Sun at around 30 km/sec, so the particles must have a similar orbit to the comet as the difference in velocity is small, and it is possible to show possible changes in the orbital parameters. It is actually a 3-D problem, so the plane of the orbit can change, and with it the position of the nodes. The nodal position of a meteor is known very accurately (it is the time when it is seen), so the shift in nodal position between meteor and comet gives a measure of the out of plane ejection velocity. For the Leonids this amounts to around 20 m/s. Computer models can show the effect of differing ejection velocities, but it is also a function of where the ejection takes place, which makes the analysis more complex. Radar studies give us problems! They see very small meteors and lots of them - perhaps fragments of asteroids rather than comets. Recent TV results show evidence for hyperbolic orbits implying an interstellar origin if real. A third problem is that the density of meteors is generally quite high compared to that expected from comets, so there is either evolution of meteoroids or some of the theory is wrong!

Andrew Elliott (BAA) concluded the morning session with a talk on video-recording meteors. This was very straightforward with the right equipment, which could record over 100 meteors per night during good showers, and several hundred during the recent Leonid “storms”. As well as creating a permanent record, video can yield scientific-quality results. He used image intensifiers, which can be expensive and not easy to obtain, but the associated equipment – video camera, time inserter and video recorder – are within amateur budgets. A wide angle lens gives a 50° field-of-view and enables video-recording of the sky down to naked eye magnitude. The system needs a video time inserter for accurate meteor timing and these are available in manually-set or radio and GPS-controlled types. Single-station work alone can yield meteor rates, magnitude distribution, radiant position, and clustering information. Two-station work allows “triangulation” for the computation of accurate meteor orbits, particularly when combined with photography. A significant number of scientific quality orbits had been obtained. Using gratings, it is also possible to carry out meteor spectroscopy by intensified video, but this has not yet been attempted in the UK. Meteor impacts on the moon have also been successfully recorded during the recent Leonid storms, mainly in the USA. Finally, fireball survey work covering the whole of the UK could be accomplished by a small number of cameras, with or without intensifiers but there were difficulties setting up such a network. Manual examination of video tapes to extract meteor details is **extremely** laborious, taking about three times the duration of the tape to do! Fortunately software developed by German amateur Sirko Molau allows real time recording and reduction of the video stream on a PC. Modern security-type CCD video cameras are coming down in price and, with quoted sensitivities down to 0.0003 lux, they are capable of recording meteors on their own. Although not quite as sensitive as image intensifiers, they have certain advantages and some amateurs are experimenting with them for meteor capture. Andrew then showed spectacular results from recent expeditions, including the 2001 Leonid storm over Arizona, the 2002 Leonid storm over Spain, and the 2003 Quadrantids and Lyrids in the UK.

Jonathan Shanklin (BAA) started proceedings after lunch, giving a brief history of the BAA Comet Section and lamenting the fact that early observations had disappeared during World War II. Although George Alcock and Albert Jones had made visual discoveries of comets, amateur visual comet discovery was probably now a thing of the past, thanks to asteroid search programmes such as LINEAR and spacecraft such as SOHO. However at the moment there was still a 'twilight zone' where amateurs stood a chance, particularly in the Southern Hemisphere. Visual observation of features in the coma and tail was also a thing of the past as CCDs now gave much more objective images. Amateurs could however make significant contributions by visual magnitude studies. Observations of 153P/Ikeya-Zhang showed variation across the course of the apparition, possibly reflecting the inhomogeneous comet nucleus loosing several metres as it rounded the Sun. Comet 2001 A2 (LINEAR) showed significant variation with a period of around a month, which might reflect precession of the nucleus. Comet 46P/Wirtanen had a relatively normal light curve, but by contrast 67P/Churyumov-Gerasimenko, the new Rosetta target, had a linear light curve, peaking some xx days after perihelion. During questions David Hughes suggested that this might be due to a single active area becoming illuminated. Jonathan concluded by posing some questions: should observations be restricted to light pollution free areas (no, as this would eliminate most observations from the UK), do visual observers hallucinate (probably yes, as the brain often lets us see what we expect) and should light curves only be compiled from observations by experts (no, all observations are valuable).

David Hughes (Sheffield University) demonstrated how he used magnitude parameters derived from amateur visual observations. Short period comets (those with period less than 20 years) are seriously affected by Jupiter. Their median period is 7.2 years, however when perihelion is at 1 AU the period is 5.46 years and when at 3 AU the period is 8.3 years. This means that the shorter period object goes round more frequently and there must be plenty of short period comets with larger q (1.5 - 3 AU) still waiting to be discovered. We can measure the size of a comet either directly with the HST or via a light curve as the log of the radius is theoretically proportional to 0.2 H_{10}. This absolute magnitude can either be derived by assuming that the comet brightens as 10 log r (=> H_{10}) or by fitting to the light curve (=> H). Different molecular emissions may have different slopes. When he first plotted values from selected periodic comets he didn't get a very good fit, however revised values did better. There is still a lot of scatter, which implies different surface activity. Around 2 metres is lost from 1P/Halley each revolution, implying that it will last for around 250,000 years. One might expect that size and perihelion distance are correlated, given that comets with shorter period will loose more material. A paper by Lamy shows no such correlation, however David's interpretation of the data is that it doesn't disagree with the hypothesis. The average Jupiter family comet starts with a radius of around 3 km and slowly shrinks. The gradient of size versus perihelion distance will give a clue on the average age. There are no bright comets passing close to the Sun. The average comet has a radius of 1.4 km and perihelion distance of 1.8 AU. Short period comets are literally disappearing in front of our eyes and after 400 orbits (2,500 years) half will have gone. If we are in a steady state Jupiter must be throwing in more objects to the inner solar system.

Alan Fitzsimmons (Queen's Belfast) told us about some of the interesting things that he is doing at the moment under the title of Recent results in the ground based imaging of distant comets. He concentrated on three aspects: why we should study nuclei, snapshot surveys and dedicated observations. Spacecraft show that 1P/Halley is quite a large nucleus about 18 km long. Sublimation is seen on the surface giving jets of dust and gas. 19P/Borrelly is 8km long, and images show that the nucleus is complex and has real geology, quite different from the theoretical construct of ground based observations. Nuclei were formed in the outer solar system, which was a wild and dangerous place at the time, and are collisional ejecta from the Kuiper belt. They are a repository of organic matter and are important for studies on the origin of life. The nucleus is also the source of the coma and tail. Alan and colleagues had previously run a snapshot survey programme to study bare nuclei, obtaining size limits on 56 objects to get a size distribution. Their most recent observing run was last summer, using the William Herschel Telescope with its prime focus camera, giving 4096x4100 pixels at a scale of 0.25" per pixel. A preliminary inspection of the data revealed that 43P/Wolf-Harrington at 4.43 AU was at a visual magnitude 21.6 but still showed a slight dust coma. 143P/Kowal-Mrkos at 4.74 AU was brighter at a red magnitude of 20.5, but showed a bare nucleus. Such objects are possibly bright enough for amateurs to image, so they could contribute to these studies. 1998 U4 (P/Spahr) was the most distant object imaged at 6.14 AU (beyond Jupiter) when it had a red magnitude of 23.3. His team is now moving on to dedicated observations, looking at size, colour and rotation. For example, Stephen Lowry (now in Belfast) and Paul Weissman (JPL) observed 22P/Kopff for a total of 3.6 hours to reveal a dust trail behind the comet. The individual frames show a light curve with a period of about 6.15 hours. 6P/d'Arrest has a period of 7.20 hours with an amplitude of around 0.1 magnitudes. New planned studies include monitoring activity all round the orbit and a search for comet ice, as no water has yet been detected on a nucleus. A search for comets near the Sun is planned to come on line in a few months with the provisionally titled SuperWASP1 instrument on La Palma, a fully robotic telescope which will have a 247 square degree field and image down to 16th magnitude in 30 seconds. The primary task is to search for planets round other stars at the opposition point, but they hope to try and search for SOHO like comets at 45° - 60° elongation from the Sun.

The session concluded with **Nick James** (BAA) describing CCD imaging by amateurs. Automated searches such as LINEAR find practically everything, however amateurs can carry out rapid follow up, observe structure near the nucleus, do photometry and monitor faint objects. CCDs also give a pretty picture. Is astrometry worth doing? Yes, once you have the images. Astrometrica (commercial software) is fast and catalogues are good. It is particularly important for objects on the NEOCP. Peter Birtwhistle is getting down to 19.8. Photography didn't have enough dynamic range to show structure in the coma, but CCD processing can be used to bring out details. For example Hale-Bopp had apparently stationary jets prior to perihelion. A rotational gradient filter enhances radial features such as seen in 153P/Ikeya-Zhang. Photometry is difficult. What aperture should be used ? What comparison stars ? Are filters needed ? Overall photometry is now seen as the most difficult area for amateurs. Specific targets for amateurs include the potential Rosetta target 67P/Churyumov-Gerasimenko, comets which have outbursts such as 29P/Schwassmann-Wachmann. Nick wasn't sure if spectroscopy was valuable, however Maurice Gavin had obtained spectra of 2002 C1 and 2002 V1. Finally the amateur could take pretty pictures and there is nothing wrong with this. In addition wide field images do contain lots of structure. New CCD chips such as Kodak KAF1600 at 14x9mm and KAF1000 at 25x25 mm are becoming comparable to film, but expensive. Alternatively it is possible to mosaic smaller fields and these show considerable tail structure. Another technique is to use an ordinary camera lens with a CCD. Some digital cameras can record comets and more expensive digital SLRs are comparable to CCDs. Nick emphasised the need to use the standard naming convention when submitting images. Brian Marsden confirmed that astrometry and imaging were important to check if objects on the NEOCP where comets and that it was very important to submit results as quickly as possible. When LINEAR reports an object they usually have no idea if it is cometary or not.

Alan Fitzsimmons and **Paul Murdin** (RAS) briefed the gathering on possible grants for scientific projects. The RAS has a small grants program open to fellows for peer reviewed proposals. There is a six month cycle, with £18,000 per year available distributed in grants ranging from £500 to £5000. They are normally awarded for purposes not funded by PPARC, for example travel, to teachers etc. Pro-am work would come within this remit, but proposals must come from fellows. Full details are posted on the RAS web pages at http://www.ras.org.uk/html/ras_grants.html. The Faulkes and Liverpool telescopes will hopefully become operational this summer and will welcome proposals from amateurs, which can either be live or via email. The BAA has Ridley grants which are open to all astronomers. There is also the Shoemaker grant in the US which has about $35,000 per year for NEO related activities.

During the tea break speakers and audience were photographed, which meant that we reassembled to hear **Graeme Waddington** (BAA) speak on Random Meanderings by Jove slightly later than planned. Nothing much happened for 13.7 billion years, then along came Kepler and Newton. He discussed the forces that must be considered when computing a comet's orbit, primarily the Sun and Jupiter. Solar heating on comets gives outgassing and hence what are called the non gravitational effects, which assume that the acceleration imparted to the nucleus follows an ideal water-ice vaporisation curve. They are only significant when the comet is closer than about 3 AU of the Sun. In the real world outgassing is assymmetric on a peanut shaped, precessing nucleus and peaks after perihelion. It is also from discrete sources, which may not be continuously active. Observations of the light curve and inner coma may help to distinguish between interpretations of the forces. Graeme illustrated the computation of cometary orbits by using comet 2002 C1 (Ikeya-Zhang) as an example. When discovered, the orbit of the comet was remarkably similar to two historical comets, C/1661 C1 and C/1532 R1. As more astrometric observations came in during 2002 the connection with 1661 was assured and the mooted connection with 1532 became problematic. He showed it was possible to link the orbit with comets seen in 1273 and 877. Was there a link to the comet of 1532? Since the descending node of 2002 C1 is very close to the descending node of Jupiter, very close approaches of the comet to Jupiter can occur - rendering the long-term orbital evolution well-and-truly chaotic. As a result it is possible to engineer a link to the 1532 comet by postulating a splitting at a relative separation of 1 ms^{-1} or less prior to the 877 return. Looking into the future, the predictions allow just about anything to be possible, but one solution gives a return date for the 1532 comet of 2013 May 1!

The concluding presentation was the George Alcock Memorial Lecture, which was given by **Brian Marsden** (Smithsonian Astrophysical Observatory). George Alcock was a noted British amateur astronomer, who had observed meteors in the 1950s to help professional radar observations at Jodrell Bank and who had discovered five comets. More details on his life are given in a wonderful biography by Kay Williams entitled 'Under an English Heaven'. Brian first visited George, with Mike Candy, on August 31 1959, the day following George's discovery of 1959f. This was the first UK comet discovery since Denning had found 1894 I. In a 1977 letter George depicted a thin pencil-like beam seen low in the sky on 1963 September 12, questioning whether it might have been the comet discovered by Pereyra in Argentina two days later, when this comet was already three weeks past perihelion.

Like many comets that closely approach the Sun this was a member of the sungrazing Kreutz group. Brian has demonstrated that sungrazing comet Ikeya-Seki and the great September comet of 1882 had rather obviously separated from each other at their previous perihelion passage. While the precise date of the 1882-1965 separation cannot be established, there was a comet in 1106 that may match. Although they were not so directly related to the 1882-1965 pair, Brian has noted that the Kreutz sungrazers of 1843 and 1880 also probably separated from each other on their previous approach to the sun. The periods of these comets are not well determined, but assumption of the hypothesis would put them at around 400 years, with the splitting around the second half of the fifteenth century. Since the period of the rather similar Pereyra comet of 1963 was clearly a century more than twice 400 years, it is tempting to speculate that it may have separated from the 1843-1880 parent at the perihelion passage <u>before</u> the 1843-1880 split. This speculation would mean that the 1843-1880 parent was at perihelion in 1463 or, more probably, in 1487, but no observational record of a comet then has been found.

Three other Kreutz sungrazers have been observed from the ground during the nineteenth and twentieth centuries, namely, in 1887, 1945 and 1970. In 1981 there came word of what appeared to be a comet on images obtained from the space-based SOLWIND coronagraph two years previously. The object dispersed within a matter of hours as it approached the sun, and although the orbit could not be "determined" in any sense of the word, it seems likely that it was also a faint Kreutz sungrazer. By the time of its demise in 1984 SOLWIND had found six likely Kreutz sungrazers. By 1989 the Solar Maximum Mission had added ten more, and since 1996 SOHO has found a startling 465 of these objects. The arrival of members separated in time by only a matter of hours suggests that splitting also occurs far from the sun, such splitting involving bodies that had already been weakened by tidal interaction with the sun at the previous perihelion passage. Sekanina has made an extensive study of such evolution, which also leads to more of a spread in the perihelion distance and angular orbital elements of the comets. This mechanism also allows a more efficient evolution of members of the different subgroups evident in the ground-based data, and Sekanina and Chodas have recently demonstrated how the 1970 member could have separated in 1749 from a possible third comet spawned with the 1882 and 1965 members in 1106.

Rather surprisingly, several other groups of near-sun comets, totally unrelated to the Kreutz comets, have been recognised in the SOHO data during the past three years or so. Groups were recognised by German amateur astronomer Maik Meyer and by Brian himself and an additional group by Rainer Kracht, another German amateur. The Meyer group now has at least 34 members. The Marsden group, with at least 13 members, also seems to be related to the Daytime Arietid meteor stream. Intriguingly, the perihelion direction of longitude 102 degrees, latitude +10 degrees, is also closely shared by comet 96P/Machholz and the Quadrantid meteor stream, although the perihelion distances are in excess of 0.1 AU and the orientation of the orbital planes are significantly different. Furthermore, the perihelion direction is also shared by a distinct group of 14 or more additional SOHO comets at perihelion distance 0.05 AU but with inclination only 14 degrees.

The enormous prevalence of groups of comets in the SOHO data (with no group member surviving perihelion passage) becomes even more evident when one considers that there are only 16 SOHO comets with perihelion distances under 0.1 AU that are not known to be members of a group. Furthermore, apart from the eight definite Kreutz members, there are just 19 other comets with perihelia less than 0.1 AU that have been observed from the ground over the whole of history, and three of these seen during the seventeenth century have been considered suspect Kreutz comets. Four of the remaining 16, including comet 1970a depicted by George and comet 1953h that Brian recalls searching for in vain, failed to survive perihelion, presumably because, like the SOHO comets, they were tiny objects that completely vaporized near the sun. Among the better known survivors are the great comet of 1680, the Seki-Lines comet of 1962 and the recent C/2002 V1 (NEAT), the most spectacular comet so far to show on SOHO images.

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