Asteroids: past, present and future

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For many years, our traditional view of asteroids has been limited to those objects orbiting between the paths of Mars and Jupiter now known as the Main Belt. But within just the last 15 years or so, our perspective has radically changed with the discovery of many bodies occupying the Edgeworth–Kuiper belt and other so-called Scattered Disk objects, the orbits of which extend well beyond the conventional confines of the solar system previously delineated by the planets Neptune and Pluto. How did this come to pass? In this paper, I shall describe the evolution of our knowledge of this system of minor planets, not only to provide you with some answers to this question but also to illustrate how our understanding of these mysterious objects has developed and how it might expand in the future. In so doing I shall also trace those activities which involved the BAA and more particularly the Asteroids and Remote Planets Section.

The early history of asteroid discovery

The tale of how asteroids were first discovered has been told many times. It harks back to the latter years of the 18th century when scientific enquiry was developing apace in many European countries. In particular, the last two decades of the century witnessed an unprecedented increase in the popularity of telescopic observation as a means of extending our knowledge of celestial phenomena. William Herschel discovered the planet Uranus in 1781, and thanks to him and several other keen observers, many new comets were found as were several new types of variable star, and companion satellites were seen to circle both Saturn and Uranus.

As the 18th century drew to a close, astronomers including Wilhelm Olbers and Johannes Bode, each of whom had already discovered a comet, postulated the existence of numerous lesser bodies within the solar system. With this idea in mind, and at the behest of Baron von Zach, a group met on 1800 September 20 in Lilienthal, Germany, and formed a society of 24 practical astronomers distributed throughout Europe. The express purpose of this group, which came to be known as the ‘Celestial Police’, was to investigate the region of space between Mars and Jupiter close to the ecliptic, searching for new planets. Coincidentally and by chance, Giuseppe Piazzi, who was working on a star catalogue at Palermo Observatory, Italy, came across a moving star on 1801 Jan 1, which he realised might be different from a comet, possibly another planet similar to Georgium Sidus (Uranus). Subsequent observations indeed showed it to be a small planet, and that it occupied the space between Mars and Jupiter close to the distance where the Titius–Bode Law predicted a planet to be. The object was named Ceres Ferdinandea, in honour of King Ferdinand IV of Sicily, and later became known more simply as Ceres. A learned account of the discovery of Ceres can be found in the book *Asteroids III* written following the international conference held in Palermo in 2001 June.[1]

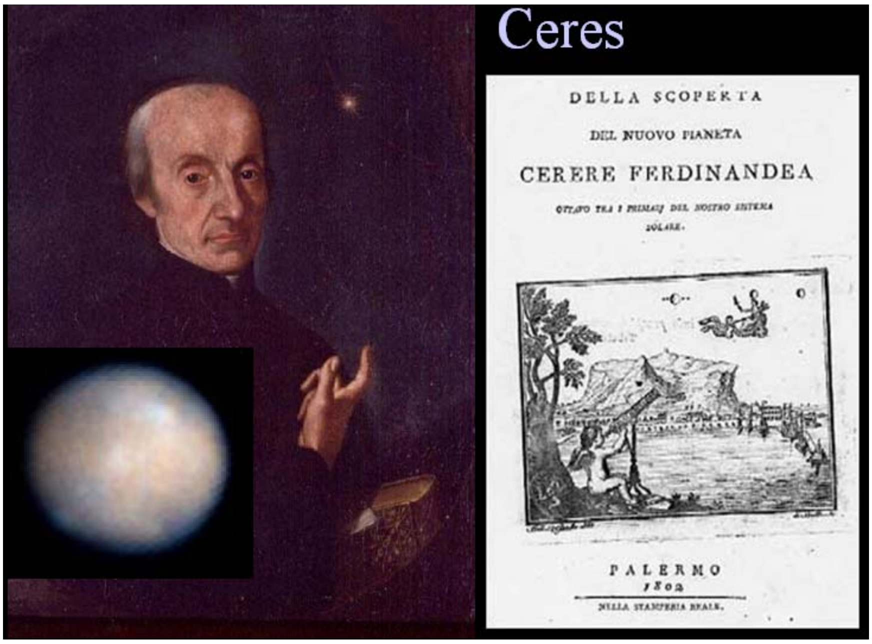


Figure 1. Giuseppe Piazzi, discoverer of the first asteroid, with the title page of his *Della scoperta del nuovo pianeta Cerere Ferdinandea... (Dibner Library of the History of Science & Technology)*. Inset: HST image of 1 Ceres. *(NASA/STScI)*

By 1807, thanks to the activities of the Celestial Police three further asteroids were found, namely Pallas and Vesta discovered by Wilhelm Olbers in 1802 and 1807, and Juno by Karl Harding in 1804. However, there the story remained and no others were found for a further four decades. Books on astronomy during those times referred to the solar system as comprising the conventional system of seven known planets together with the first four asteroids, Ceres, Pallas, Juno and Vesta, thought by some to be the remains of a disrupted

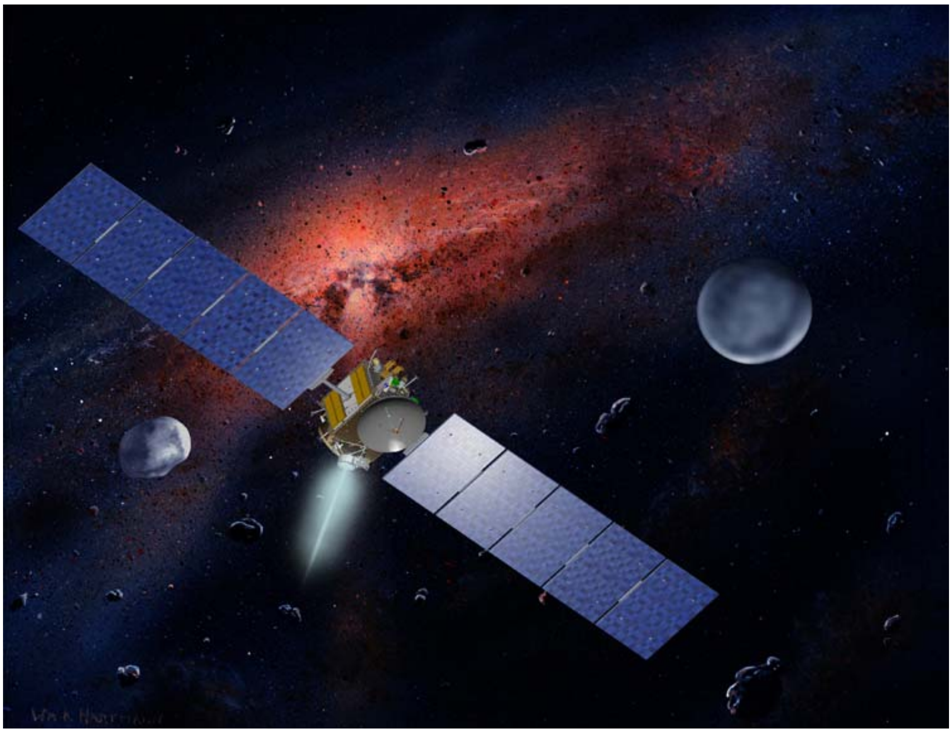


Figure 2. William K. Hartmann's artistic depiction of NASA's *Dawn* space probe and the early solar system. *(NASA)*

planet. More than two centuries on, we appear to have turned full circle as we now can anticipate the forthcoming visit to two of these bodies by the space probe *Dawn,* launched on 2007 September 27. Powered by a futuristic xenon ion drive this probe is due to reach Vesta in 2011 August where it will remain in orbit until 2012 May before going on to visit Ceres in 2015 February.

By studying these two minor planets in unprecedented detail it is hoped that new light will be shed on the nature of the early solar nebula and the formation of the solar system. These advances will be a far cry from those early years of the 19th century when, apart from their orbit (all four remained between the orbits of Mars and Jupiter), little of fact was known about them. Herschel coined the term 'asteroid' in part to distinguish them from the major planets. Attempts were made to measure their angular diameter and size but these remained highly speculative in that different observers reported widely differing values. We now know that their apparent size as seen from the Earth is smaller than the seeing disk of stars as seen with those early telescopes. Schröter and others even claimed that they were surrounded by an atmosphere which varied in extent,[2] which we now know is not the case.

Asteroid discovery during the 19th and 20th centuries

A long interval of almost 40 years accumulated without any further finds until in 1845 Karl Hencke, a postmaster and amateur astronomer in Driesen, Prussia, discovered Astraea after more than a decade of intensive searching, followed in 1847 by Hebe.[3] This advance reawakened interest in the subject. John Hind, observing from George Bishop's observatory at Regent's Park, London, discovered Iris and Flora also in 1847.[4] Although a few keen amateurs were successful in finding a handful of new objects (the first ten asteroids having been found by 1849), the real advance in the rate of discovery was made possible beginning in the 1850s and thereafter when detailed star charts became available, most notably the extensive *Bonner Durchmusterung,* comprising the positions of more than 324,000 stars.[5] Figure 3 illustrates the accelerating rise in the discovery rate which took place throughout the 19th century.

As more and more new asteroids were identified, it became clear that these were all located between Mars and Jupiter, and this region became known as the 'asteroid belt'. An illustration of the distribution of what we now term the 'main-belt' asteroids is shown in Figure 4. Many hundreds of objects were found circulating close to the plane of the ecliptic, confined there in part by the gravitationally dominant planet Jupiter. Beginning in 1891, photography proved an effective means for identifying moving objects such as asteroids and comets. Although asteroids to all intent and purposes look entirely stellar when observed visually, they can be easily differentiated by their apparent motion relative to the fixed stars, in that they appear as a short streak or trail on a photographic plate that has been exposed for several hours whilst the telescope, on which the camera is mounted, tracks the stars at sidereal rate.

As more and more were found it became clear that their orbits were increasingly varied, such that in 1898 the very first object was found which crossed the orbit of Mars and approached the Earth quite closely. 433 Eros was discovered

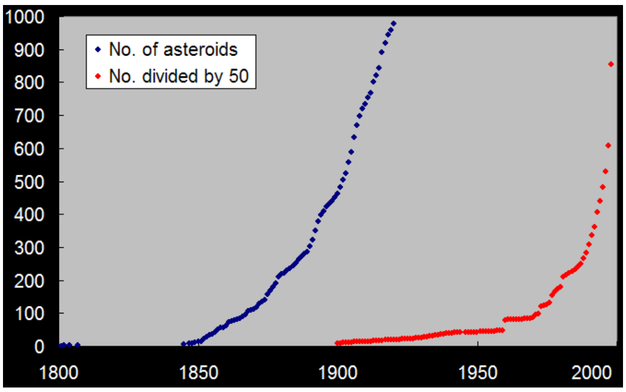


Figure 3. Discovery statistics based on data available from the Minor Planet Center (see **http://www.cfa.harvard.edu/iau/lists/NumberedPerYear.html**)

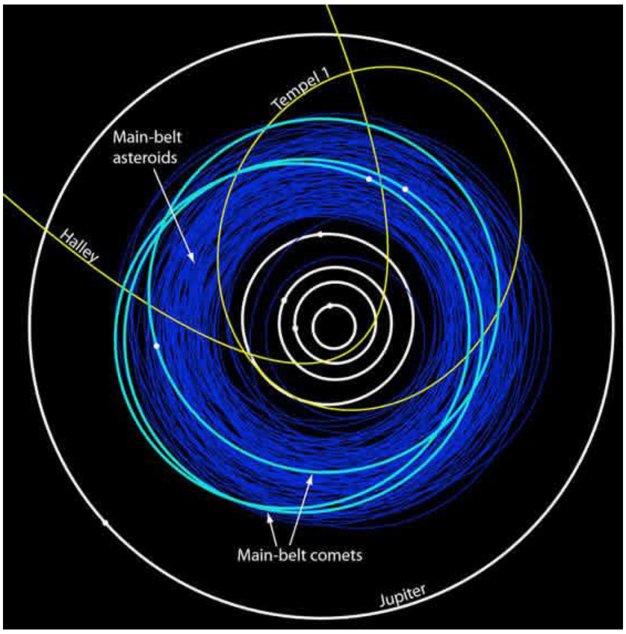


Figure 4. Illustration showing the orbits of main belt asteroids (shown in dark blue) and some comets. *Adapted from an illustration by Pedro Lacerda, Univ. of Hawaii and Univ. of Coimbra (see* **http://www.solstation.com/solsys/mb2comet.jpg**)

during photographic searches by Gustav Witt in Berlin and independently by Auguste Charlois in Nice. The unusual nature of Eros' orbit was soon recognised at the time, since it is the first example of that special class of objects which can approach the Earth to within a distance of 0.2 AU or less, and which are now appropriately termed 'near-Earth asteroids' or NEAs.

Between 1900 and 1959, the rate of discovery remained roughly constant at about 32 objects per year, to reach a total of 2,321. It was during this period when photography was the prime astronomical tool that asteroids acquired the nickname 'vermin of the skies'. The tell-tale sign of an asteroid was the streak produced on a long exposure photograph, which was regarded by some as a distraction from

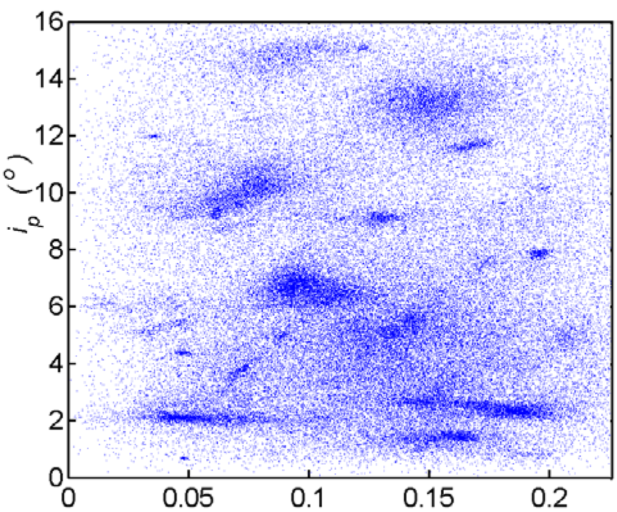


Figure 5. Plot of proper inclination vs. eccentricity for current numbered asteroids (adapted from **http://en.wikipedia.org/wiki/Image:Asteroid_proper_elements_i_vs_e.png**)

an otherwise perfect image: hence the nickname. Also at this time, sufficient numbers had been discovered that their orbital characteristics were able to be looked at from a statistical standpoint. Groupings or families were recognised, for example sharing similar orbital inclinations and eccentricities, and these have therefore been interpreted as being fragments from past asteroid collisions. Often there is one large body, such as in the case of Vesta, Pallas, Flora and Hygeia, accompanied by a swarm of much smaller asteroids with similar orbits as shown in Figure 5, which is indicative of violent collisions occurring within the asteroid belt in the distant past.

As a footnote to history, it should be mentioned that although Kiyotsugu Hirayama was the first to investigate the existence of such asteroid families in a number of papers beginning in 1918,[6] William Monck, a founder member (No.12) of the BAA, had previously referred to the existence of small groups of asteroids for which he coined the term 'family' back in 1888.[7]

Following the publication in 1960 of the Palomar–Leiden Survey, which employed the 1.2m Schmidt to study a 12°×18° area of sky and discovered more than 2,400 small asteroids down to 20th magnitude, it was recognised that asteroids grow increasingly numerous at smaller and smaller sizes. However it was impractical to scan the entire sky in search of asteroids down to sizes of a few kilometres using conventional plate photography. The revival of asteroid discovery had to wait for the application of CCD cameras and computers to the task, for which they were eminently suited. Tom Gehrels established the first such concerted search programme using the 0.9m Spacewatch telescope on Kitt Peak, with an early CCD camera operating in drift-scan mode.[8] From 1992 to 1995, Spacewatch observed and automatically detected more than 60,000 asteroids down to a limiting magnitude of about V=21 in an area of almost 4,000 sq.deg of sky near the ecliptic. In 1997, the Lincoln Near-Earth Asteroid Research (LINEAR) project began and some ten years on has discovered well in excess of 200,000 objects, of which more than 2,000 are NEAs and more than 200 are comets.

One consequence of the virtual explosion in the discovery rate during the last decade has been to make it extremely difficult for amateur astronomers to discover asteroids themselves. The automated surveys have swept the skies clear down to 18th magnitude at least. To picture how the scene has changed, consider Figure 6, which depicts the area of sky in the vicinity of Messier 44, the Beehive Cluster, as seen on 2007 October 31 (the date of this address). Included on the upper chart are all those asteroids which were known at the time when the BAA Minor Planets Section was formed in 1984. In contrast the lower chart includes all asteroids known to date and clearly illustrates the extensive change that has taken place during the intervening years. Before LINEAR began operations, BAA member Brian Manning, using photography, was able to discover or recapture some 28 asteroids, breaking UK observer John Russell Hind's record of the 19th century.[9] The most prolific UK amateur discoverer to date has been Peter Birtwhistle, observing from Great Shefford in Berkshire. Using 0.3m and more recently 0.4m telescopes and a high-performance CCD camera, he

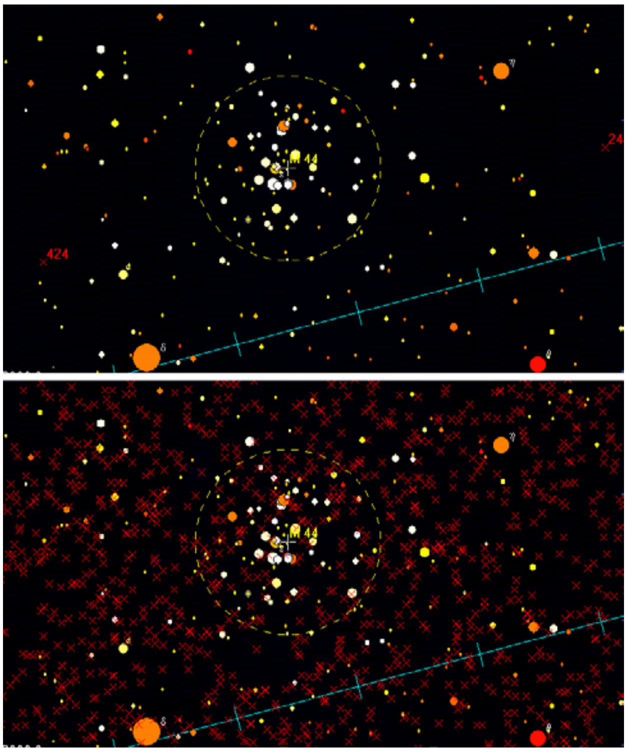


Figure 6. Charts of M44 made using the planetarium programme GUIDE 8.0, depicting the positions of all asteroids (red crosses) known by 1984 (upper chart) and 2007 (lower chart).

has found 82 new objects to date as serendipitous discoveries, largely whilst engaged in imaging newly-discovered NEAs. By 2007 October 31, a grand total of 387,205 new objects had been designated of which just 14,148 have been named. One such name of relevance to the Association is that of asteroid 4522 Britastra, named by the discoverer, professional astronomer and BAA member Ted Bowell, to commemorate the BAA centenary in 1990.

The expanding solar system

The exploration of the solar system by observation from here on Earth has been rather akin to the investigation of a near-impenetrable jungle in which more and more strange exotic creatures are discovered. The longer the search continues, the more aware and informed we become as to the multiplicity of animals which exist but which remain largely hidden from sight. Although Percival Lowell began his search in 1905 for the fabled entity Planet X, the landmark discovery took until 1930 when after a long and protracted search Clyde Tombaugh found what was believed to be the 'ninth planet', later named Pluto (Figure 7). The object appeared as a 15th magnitude point of light, which to all intents and purposes was the same as any other asteroid but its orbit was far removed from the asteroid belt, so much so that Pluto was considered to be a unique entity. We now know that Pluto is in fact one of the largest members of what is now termed the Kuiper Belt, or more correctly the Edgeworth–Kuiper Belt in recognition of the contribution made by BAA member Kenneth Edgeworth in first postulating the existence of many planetesimals well beyond the major planets, which serves as a reservoir for comets which occasionally enter the inner solar system.[10] Indeed, with some notoriety, the IAU has recently approved the reclassification of Pluto as a dwarf planet which has been assigned the number 134340, one of several almost equally large bodies beyond Neptune.[11]

Binary asteroids

We now know that many asteroids exist as binary objects orbiting their common centre of mass. Indeed, one can argue that the first such binary system was Pluto itself. In 1978 James Christy at the US Naval Observatory noticed that several images of Pluto which he had taken as part of a programme of astrometry appeared unusually elongated. Looking at other archive images it became obvious to Christy that Pluto had a close companion or satellite,[12] one which he later named Charon and which is locked in synchronous rotation with Pluto circling every 6.39 days. The first conventional asteroid to be found associated with an encircling natural satellite was 243 Ida, when in 1994 images taken in 1993 by the *Galileo* spacecraft were found to reveal the presence of a small moon 1.4 km in size, now named Dactyl.

The existence of binary systems in which the two companions are similar in size has been suggested in the past on the basis of the existence of many paired impact craters on the Moon as well as on the Earth (e.g. Clearwater Lakes in Quebec, Canada). Apart from Pluto and Charon, the first such system (1994 AW_1) was discovered from 1994 observations and reported in 1997 by Pravec & Hahn.[13] Since that time the number of binary asteroids which have been positively identified from lightcurve data and direct detection by radar from Arecibo and Goldstone has grown to number well over one hundred.

An interesting case is that of the long-lost asteroid 1937 UB (Hermes), first sighted as a bright trail on a photograph by Karl Reinmuth observing from Heidelberg on 1937 October 28. Reinmuth was able to follow it for five days before it receded and was lost. Believed to be almost 1 km in diameter,

Figure 7. Clyde Tombaugh and his discovery photographs of Pluto taken on 1930 January 23 and January 29. *(courtesy of Lowell Observatory archives, available at* ***http://en.wikipedia.org/wiki/Image:Pluto_discovery_plates.png*** *and* ***http://en.wikipedia.org/wiki/Image:ClydeTombaugh.jpg****)*

Figure 8. False-colour image of 243 Ida and companion Dactyl as imaged by the *Galileo* spacecraft. *(courtesy NASA)*

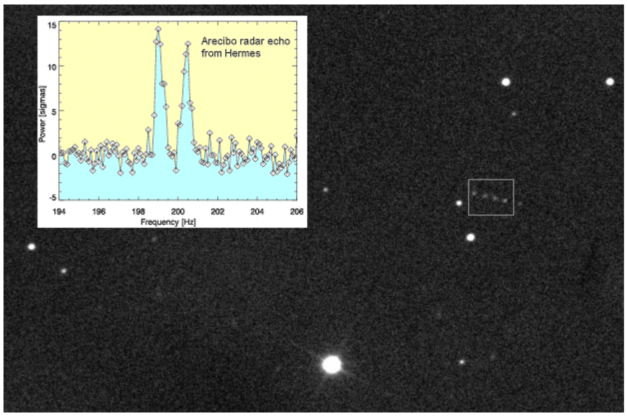


Figure 9. Four superimposed 30-sec exposures of 1937 UB (Hermes) taken on 2003 October 15 at 19:54–20:15 UT using a 0.30m Newtonian and KAF-0401E CCD, showing the object's motion *(courtesy N. D. James)*. Inset: Doppler spectrum of the radar echo from 69230 Hermes made using the Arecibo telescope on 2003 Oct 17, showing two clearly separated components. *(courtesy J.–L. Margot)*. See also **http://www2.ess.ucla.edu/~jlmargot/NEAs/Hermes/**

it is the largest object known to have passed within two lunar-distances of the Earth, which it did on 1937 October 30.7, and most surprisingly it repeated this some five years later coming even closer on 1942 April 26.8.[14] Given its size and speed (about 18 km/s relative) it packed the potential to cause massive devastation on the Earth. Then on 2003 October 15, Brian Skiff of the Lowell Observatory Near-Earth-Object Search (LONEOS) found a 14th magnitude fast-moving object, which he posted to the Minor Planet Center's Near-Earth Object Confirmation Page.[15] BAA member Nick James imaged the then unknown object (see Figure 9) before later the same day from orbit calculations, the object was linked to long-lost Hermes. Given the size of this potential Earth-impactor, radar observations were scheduled the very same day from Arecibo. These revealed it to be a binary system comprising two objects of similar size (about 400 metres across) separated by just 1200 metres and spinning around their common centre of gravity every 13.89 hours (see inset to Figure 9).

Centaurs and Trans-Neptunian Objects (TNOs)

Our knowledge of the outer solar system is really very recent. For fifty-seven years, 944 Hidalgo was the only asteroidal object known to travel beyond the orbit of Jupiter, but in 1977 Charles Kowal, who was engaged in a search for unusual solar system objects using the 1.2m Schmidt telescope at Palomar Observatory, discovered 2060 Chiron.[16] Chiron largely resides between the orbits of Saturn and Uranus and requires more than fifty years to complete a single, rather eccentric orbit around the Sun. For ten years or so Chiron remained an enigma but then in 1988 it was observed to undergo an outburst in brightness of about 0.7 magnitudes[17] – Chiron was in fact a comet, and is now known as periodic comet 95P/Chiron. In all about 50 objects have been found which orbit further from the Sun than Jupiter yet closer than Neptune and these are classed as Centaurs: a most appropriate name given what we now understand of their nature, which for several is 'half-comet, half-asteroid'.

Then during the 1990s several types of very distant asteroid were discovered (see Table 1). Most notable was the very first object, 1992 QB_1, found by Dave Jewitt and Jane Luu,[18] which was the first example of a TNO (sometimes called cubewanos, a verbal play on the QB_1 designation): a class of object which on average orbits beyond Neptune. We also now know that Pluto has orbital characteristics which it shares with a number of other objects called Plutinos, in that they are all in 3:2 mean motion resonance with Neptune, orbiting the Sun twice for every three revolutions of Neptune. Plutinos are a special class of TNO as are Scattered Disk Objects or SDOs. The latter comprise objects in eccentric orbits that take them well above and below the plane of the ecliptic, which are mooted to have once been ordinary TNOs but which came too close to a major planet and were scattered by gravitational perturbation of their orbit.

I have already touched on Edgeworth's idea that there exists beyond Pluto a 'reservoir' of comets, which through collision or close approaches occasionally become short-period comets. In 1950, a few years after Edgeworth proposed his hypothesis, Jan Oort put forward a theory to explain the existence of long-period comets by supposing that the Sun is associated with an enormous halo of cometary nuclei situated many thousands of AU beyond the outer

Table 1. Asteroids – some noteworthy milestones

1868	100th numbered asteroid (Hekate) discovered
1891	First photographic discovery of an asteroid (323 Brucia) by Max Wolf
1898	First near-Earth asteroid (433 Eros) discovered by C. G. Witt/A. Charlois
1906	First Jupiter Trojan (588 Achilles) discovered by Max Wolf
1918	Hirayama identifies the existence of asteroid families
1921	1,000th numbered asteroid (Piazzia)
1977	First Centaur (2060 Chiron) discovered by Charles Kowal
1978	Pluto's moon Charon, first binary asteroid, discovered by James Christy
1981	10,000th numbered asteroid (Myriostos, discovered in 1951)
1992	First TNO discovered (1992 QB_1)
1993	First Plutino discovered (1993 RO)
1996	First scattered disk object discovered (1996 TL_{66})
2000	100,000th numbered asteroid (Astronautica)
2003	First Inner Oort Cloud object discovered (90377 Sedna)

Figure 10. The largest known trans-Neptunian objects. *(courtesy Wikipedia at **http://en.wikipedia.org/wiki/Image: EightTNOs.png**)*

The more TNOs that are found, the more opportunities amateurs will have to observe these distant asteroids. An example of what can be done at present is the lightcurve plot of 2003 EL_{61} in Figure 11, which was obtained by BAA member John Saxton using a 0.30m Schmidt–Cassegrain telescope from Lymm, Cheshire. At the time of the observation, an 85% illuminated gibbous Moon produced a bright sky background, degrading the signal-to-noise of the 17th magnitude asteroid. In all 532 images of 30-sec duration were used and by co-adding subsets of these, a characteristic lightcurve was produced having two maxima and two minima per revolution.

regions of the then known solar system.[19] This concept has been given a name, the Oort Cloud, although it must be said that so far there is no direct evidence that it really exists. The nearest we have come is with the discovery of 2003 VB_{12} by Mike Brown. Now designated 90377 Sedna, it orbits close to the plane of the ecliptic but its very eccentric orbit takes it out as far as 976 AU from the Sun! Some astronomers consider this is far enough that it should be assigned to a new class of asteroid, an Inner Oort Cloud object.

In order to be detected at all, 90377 Sedna had to be of a significant size. Figure 10 is an artist's impression of the largest TNOs known, drawn to scale. It seems that each of the objects depicted is unusual in some respect. 136199 Eris is an SDO, discovered by Mike Brown, Chad Trujillo & Dave Rabinowitz, which has been found to be more massive than Pluto. We know this for sure since both objects have satellites, the orbital characteristics of which permit the mass of the primary to be determined with fair accuracy. Another unusual TNO depicted in Figure 10 is 2003 EL_{61}, in that not only does it possess at least two moons but it is also very significantly elongated, so much so that as it rotates it varies in brightness exhibiting an amplitude of 0.28 magnitudes and a period of 3.92 hours.[20]

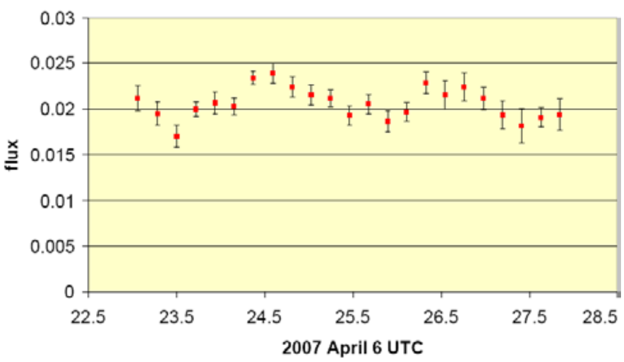


Figure 11. Lightcurve of trans-Neptunian object 2003 EL_{61} *(courtesy J. M. Saxton)*

Asteroids and the BAA

In late 1980, at the request of the BAA Council, Richard Baum was asked if he would incorporate minor planet study into the programme of the Terrestrial Planets Section.[21] The Minor Planet Group was duly set up under the guidance of Andrew Hollis as Coordinator, and the first observing project involved visual observation of 18 Melpomene, which reached magnitude 7.9 in 1981 August, a particularly bright opposition. Prior to this time there had been no attempt to organise groups of observers in the study of minor planets apart from possibly on the occasion of the two close approaches of 433 Eros in 1930/'31 and 1974/'75, and the pioneering work of Gordon Taylor in the prediction of stellar occultations. A summary of selected asteroid-related activities involving the BAA is given in Table 2. The Minor Planet Group became an independent observing Section of the Association in 1984 under the directorship of Andy Hollis, with myself as Assistant Director. Within 12 months it had grown into the Aster-

Table 2. Asteroids – milestones of BAA involvement

1958	Gordon Taylor predicts first successfully-observed occultation by an asteroid (SAO 112328 by 3 Juno)
1981	Minor Planets Group formed within the BAA Terrestrial Planets Section
1984	Minor Planets Section formed (Andy Hollis as Director, Richard Miles as Assistant Director)
1984	First photoelectric photometry project (8 Flora)
1985	Renamed Asteroids and Remote Planets Section to include observations of Uranus, Neptune and Pluto
1986	ARPS *Observers' Manual* published
1989	Occultation of star 28 Sagittarii by Titan widely observed in the UK[34]
1990	Asteroid 4522 Britastra named by the discoverer Ted Bowell to commemorate the BAA centenary
1996	First asteroidal occultation observed from UK (892 Seeligeria on Nov 9)
2001	ARPS Section Meeting in Clanfield, Hampshire (Nov 3)
2005	Roger Dymock appointed Section Director
2006	ARPS *Newsletter* began in March

Figure 12. Andy Hollis (right) and Richard Miles (left) with some of their children in 1982. The 0.35m Cassegrain telescope at Andy's Ormada Observatory can be seen in the background.

oids and Remote Planets Section (ARPS), taking on responsibility for not only asteroids but also planetary satellites and the outer planets, Uranus, Neptune and Pluto.

The advances in technology starting in the late 1970s have made an enormous difference to amateur astronomy and the potential opportunities for observing asteroids. The first phase of this rise involved the development of solid-state electronics, which enabled keen amateurs like myself and Andy Hollis to construct photometers built around photomultipliers as the light-sensitive detector.[22] These photometers were single-channel devices operated manually and required a good deal of manual dexterity and perseverance, in that the telescope had to be moved three times to afford a single magnitude determination: first to the target asteroid, then to an empty region of background sky and thence to a suitable comparison star. Despite this they were extremely accurate and had an enormous dynamic range, enabling one to use comparison stars of any brightness. Keen amateurs also ventured into the realm of astrometry by either building their own plate-measuring machines or getting access to the large and expensive Zeiss machines found at professionally-run establishments.

Computers were also evolving and during the mid-1980s it was possible to use hand-held programmable calculators to record and print out the photometric measurements directly. By 1988, portable computers had arrived and the data could be recorded to disk and displayed on a flat-screen monitor in real time. However, the one technological revolution which really made the difference was the appearance of commercially-available CCD cameras around 1990. The rest is history as they say, in that these devices could readily be employed for both brightness and position measurement with high precision – the perfect answer to an asteroid observer's dreams.

Meetings and publications

We have seen a gradual expansion of asteroid-related activities over the years thanks to technology and computers, in particular the introduction of e-mail and most strikingly in recent years the Web (the Minor Planet Center website to name but one), and search engines such as Google, all of which have enabled ready access to vast amounts of information. However, despite this high level of electronic communication, observers like to meet together from time to time to discuss topics of common interest face to face. In this respect, nothing has changed throughout the long history of the BAA, with meetings being as popular as ever. The first ARPS Section meeting was a session at the joint BAA/IAPPP symposium at Herstmonceux in 1984 September.[23] Other notable meetings of late include the workshop held at Clanfield, Hampshire on 2001 Nov 3 (see Figure 13) and the Section meeting held as part of the Winchester Weekend in 2005 with Roger Dymock as Section Director, this being in effect the 21st anniversary of the Section's formation. Links with professional astronomers are important and at the latest ARPS meeting at Newbury in 2007 June, Alan W. Harris and Mark Kidger contributed to the proceedings.[24]

Astronomy is a pursuit of people worldwide, the night sky being accessible to all, and so international cooperation is an essential feature of the subject. Section members have attended international gatherings such as those involving the European Asteroid Occultation Network (EAON), and the Meeting on Asteroids and Comets in Europe (MACE) to name but a few.

Prior to the formation of the ARPS, little by way of literature was available to guide the would-be observer of asteroids. An observers' manual covering all aspects of the subject was produced to fill this gap in 1986 but it has not been

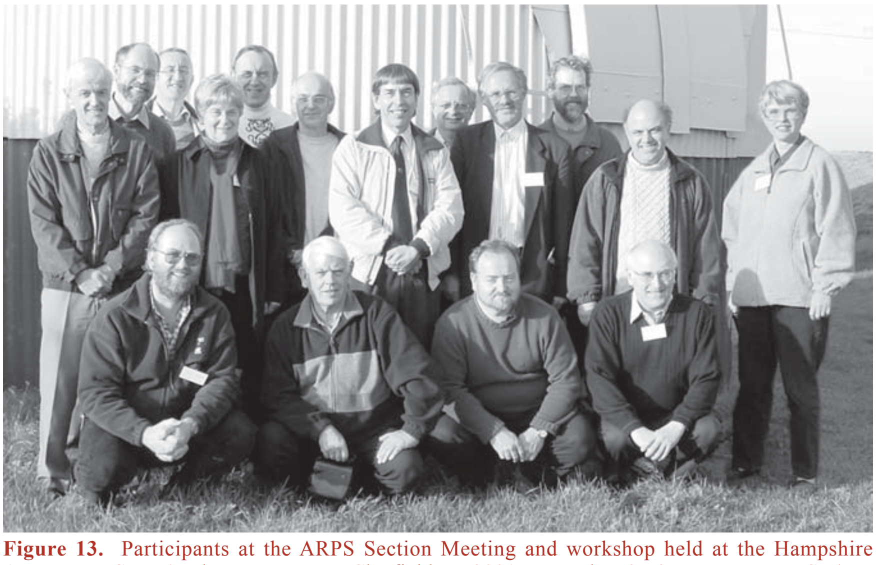
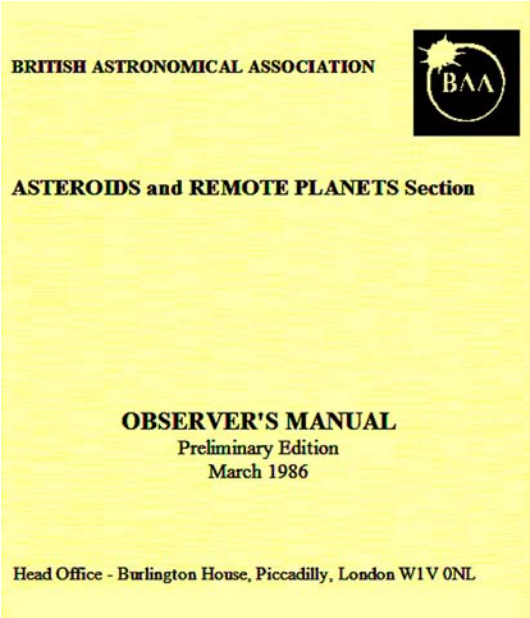


Figure 13. Participants at the ARPS Section Meeting and workshop held at the Hampshire Astronomy Group's observatory near Clanfield on 2001 November 3. *(courtesy H. McGee)*


BRITISH ASTRONOMICAL ASSOCIATION

BAA

ASTEROIDS and REMOTE PLANETS Section

OBSERVER'S MANUAL
Preliminary Edition
March 1986

Head Office - Burlington House, Piccadilly, London W1V 0NL

Figure 14. The cover of the ARPS observers' handbook published in 1986.

updated since that time. In the meantime much has changed and so a complete revision of this manual is needed. The work of Section members is reported in a number of ways; through papers published in the *Journal*, formal submission of observations to the Minor Planet Center and other organisations, publishing further afield, and last but not least in the Section Newsletter *Impact*, which Roger Dymock has compiled and published electronically since 2006 March.

Occultations

During the early 1950s, Gordon Taylor, an astronomer working at the Royal Greenwich Observatory and BAA member contributing to the work of the Computing Section, began to provide predictions of possible stellar occultations by the first four asteroids, 1 Ceres to 4 Vesta. In those early days, few asteroids had accurately known orbits and the available star catalogues were of limited value. Despite these shortcomings, the first claimed success was on 1958 February 19 when 3 Juno was seen to occult BD +6° 808 from Malmo, Sweden, although there is some doubt about this since the brightness drop was only about 0.6 magnitudes for this event.[25, 26] The first undisputed success was a photoelectric recording of the occultation of BD –5° 5863 by 2 Pallas from Naini Tal, India on 1961 October 2.[25]

Although many stellar occultations have been witnessed worldwide since this time, the first positive event seen from the UK was by the present author and involved 892 Seeligeria occulting GSC 4695 0543 on 1996 November 9, thanks to predictions generated by myself using Brian D. Warner's *Asteroid Pro* Version 2.0 software. Predictions using this software continued to be issued and this effort was rewarded on 1998 September 10, when Hazel McGee timed an occultation by 1574 Meyer, and on 1998 December 18 when Fiona Vincent observed an occultation by 70 Panopaea.[26] Occultations continue to be an important aspiration for UK-based observers, for which predictions are now distributed by Andrew Elliott. In recent years we seem to have suffered a run of bad luck with few favourable events and bouts of poor weather at critical times. If luck averages out in the long run then we may be destined for some spectacular events within the next few years.

Photometry and rotational lightcurves

During the early years of the Section, photoelectric photometers were used to measure the brighter asteroids, one example being the 1984 campaign to determine the rotation period of 8 Flora. It was a difficult objective since Flora is almost spherical in shape and exhibits a lightcurve of very low amplitude. The outcome of this joint effort by observers in the UK, France and Australia was the identification of a possible rotation period of 12.79 hr as well as an estimate of the pole position.[27] The value currently accepted for the period of 8 Flora is 12.799 hr.[20]

A fundamental restriction of the photoelectric photometer for asteroid work was that the image of the target object had to be centered in a small aperture hole typically 1–2mm in diameter, so as to exclude extraneous stars and restrict the sky background contribution. As such, the object had to be readily visible, which largely limited photometry to asteroids of 12th magnitude or brighter. When CCD cameras found their way into the hands of observers, a revolution ensued. Not only could objects down to 18th magnitude be measured but there was no need to move the telescope to find a suitable comparison star or to measure the sky background since everything the photometricist needed was usually on the one image frame. The potential for CCD photometry is virtually unlimited except that handling the large datafiles and analysing the images to extract magnitude information is a non-trivial task. Software such as *AIP4WIN* and *Canopus*

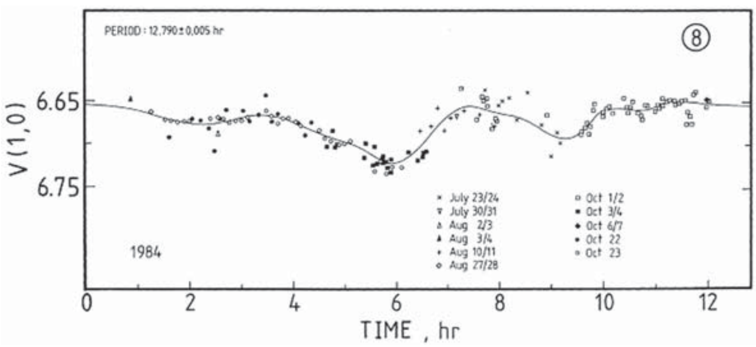


Figure 15. Composite lightcurve of 8 Flora in 1984.[27]

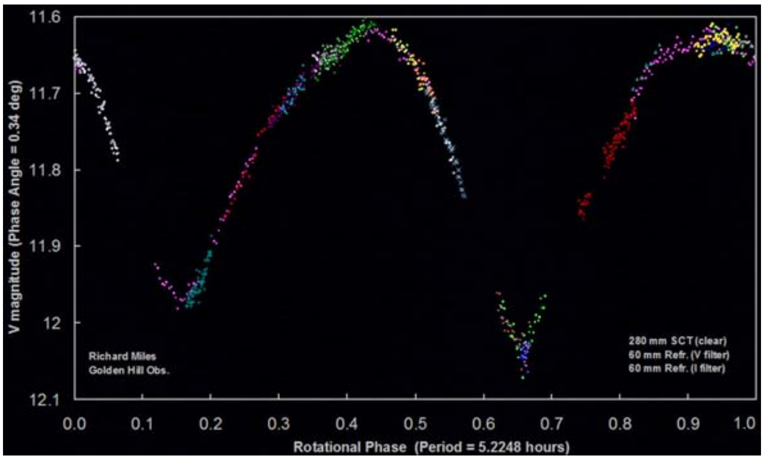


Figure 16. Composite lightcurve of 130 Elektra based on 17 nights of observation by the author during 2005 February 14–April 10.

has made differential photometry a good deal easier, but we are still some way from attaining the holy grail whereby the magnitude information is available in near real-time thus providing direct feedback to the observer on progress during an actual observing run.

Surprisingly, after all these years of space-borne observatories, we still lack an accurate catalogue of broadband magnitudes (*viz.* B,V, R and I) for stars suitable for use as comparisons down to 15th magnitude. This limitation has been a fundamental restriction preventing the determination of true magnitudes as a matter of routine. Instead, most observers have reported differential magnitudes and so objects with particularly slow rotations have tended to be overlooked. The most accurate source of all-sky V magnitude data is that provided by the *Hipparcos* mission, but on average, there are only about three stars available per square degree of sky.

To overcome this shortcoming, the author mounted short-focus telescopes with a wide field of view alongside his main instrument so that *Hipparcos* stars could be imaged through filters at the same time as a target asteroid and other nearby stars using the main scope. The advantage of this approach is that it yields an accurate measurement of the V magnitude of the asteroid and so, unlike differential methods, combining observations from different nights made over periods of many weeks becomes a straightforward exercise. One merely has to apply a correction which takes into account the varying heliocentric distance, Earth-asteroid distance, and asteroid phase angle so that every night's set of measurements can be combined. Figure 16 is an example, where 17 observing runs on 130 Elektra, some lasting just a few minutes, have been plotted colour-coded on one composite rotational lightcurve, yielding in the process an accurate and unambiguous rotation period for this object. The accepted value for the period of Elektra is 5.225 hr.[20] Clearly, CCD photometry can reach levels of precision which were unthinkable just 20 years ago, and it will continue to prove a valuable tool in the hands of the amateur for many years to come.

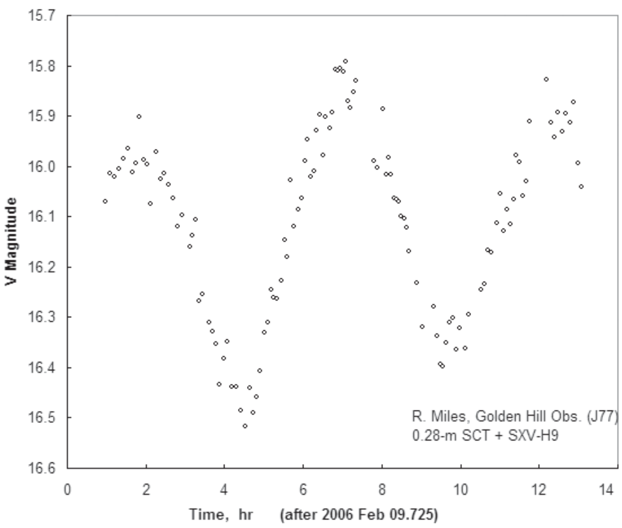


Figure 17. Lightcurve of 2000 BD_{19} obtained during a single 12-hour photometric observing run by the author on 2006 February 9/10.

The CCD's other great strength is its capacity to record and measure faint objects. Figure 17 depicts the results of one of the author's several observing runs on the unusual object 137924 (2000 BD_{19}), the orbit of which is so extreme that it is not only a Mars-crossing asteroid but is also an Earth-crosser, Venus-crosser and Mercury-crosser. Indeed, it approaches closer to the Sun than any other body in the solar system for which an accurate orbit is known. No other lightcurve of this object is known to the author. It appears to rotate every 10.6 hours or so, but by combining the results of several observing runs when the object reached almost 18th magnitude, it should be possible to derive a much more accurate rotation period and an estimate of the object's shape.

Given our normally unreliable weather, it is not always possible to obtain sufficient photometric coverage of favourably-placed asteroids and so it is often best to organise an international observing campaign so that intensive coverage of any one object can be achieved. In future, it is hoped that more observers will undertake absolute photometry of this kind. One new opportunity, where amateurs will be able to cooperate, will be in quantifying the 'opposition effect' or phase angle brightening of various different classes of minor planet. The task here will be to try to measure the brightness over a range of phase angles, and especially at very low phase angle on the night of opposition.

Astrometry

In some ways we have now reached a 'golden age' for amateur astronomers, who by taking advantage of modern technology can contribute equally to the work of the professional community. Several amateurs have come from a background in computing and have been able to contribute by providing software tools which facilitate analysis, for example of CCD images. One notable example is the Austrian amateur Herbert Raab. By writing the *Astrometrica* software, and by providing support via his user group, he has provided the amateur with a powerful tool for measuring the astrometric positions of celestial objects, more especially

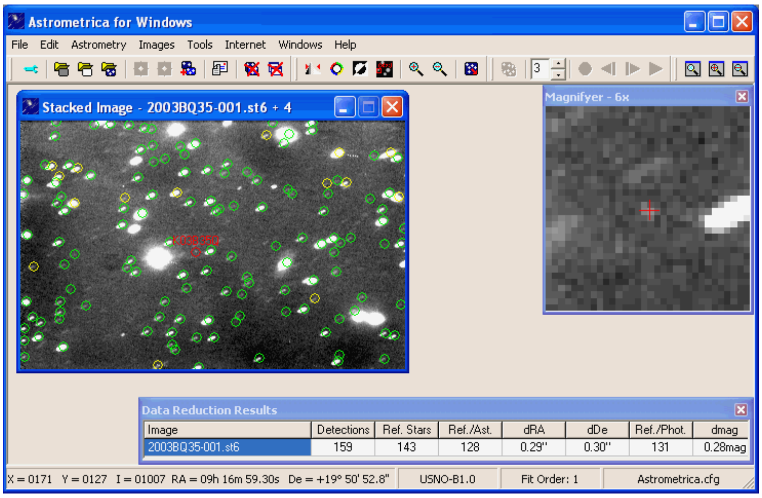


Figure 18. An example of a 'plate solution' obtained using the software *Astrometrica*. In this case, 128 star positions (circled in green) were used to achieve a positional accuracy of about ±0.3 arcseconds. *(courtesy of H. Raab)*

moving ones such as comets and asteroids.[28] *Astrometrica* is worlds apart from the technology of plate-measuring machines and is a joy to use. It is particularly useful for measuring the positions of fast-moving objects such as NEAs. One well-known exponent of this pursuit is Peter Birtwhistle, mentioned already with regard to his asteroid discoveries. Peter's particular interest is in following up newly-discovered objects which appear on the NEO Confirmation Page. At the time of writing he has reported no less than 9,248 accurate astrometric positions of NEAs, all since 2002 June 10.

Near-Earth asteroids

There is no doubt in my mind that near-Earth asteroids are the most exciting objects for observers at present and will remain so for years to come. We still know the orbits of only a small fraction of objects which are less than 300 metres in size. So any object which is detected approaching to within say 10 lunar-distances of our planet is invariably a newly-discovered one and may have originated from almost any region of our solar system, having been perturbed into its present orbit by gravitational forces following a close approach to a planet or other object, or indeed it may be a fragment left over from a collision many millions of years ago. So here is our chance to pay close attention to these strange and varied bodies: some may be derived from the interior of much larger asteroids, some may be desiccated remnants of comets, or even material ejected from a planet's surface by a particularly energetic impact. With the recent dramatic success of automated searches, more and more NEAs are being found, many before they make very close approaches to the Earth with some passing between us and the Moon.

When a new object is announced on the NEOCP, the priority is to obtain astrometry of it so that its orbit can be defined more accurately. If only a few positions are obtained over a short time interval, say less than 24 hours, then the object can easily be lost. A proportion of these objects are classed as 'potentially hazardous asteroids' or PHAs, i.e. asteroids whose orbit approaches within 0.05 AU of the Earth's orbit, and which are brighter than an absolute visual magnitude H = 22.0, corresponding to a diameter of at least 110–240 metres. At the time of writing (2008 June 11), there are 957 known PHAs.[29] Objects which approach very close to the Earth astronomically speaking, say closer than our Moon, are typically much less than 50m in size and would therefore not fall into the PHA category as currently defined. So far some 68 objects are known to have passed by closer than the Moon; the first was picked up in 1991 and the largest was 2002 MN at H=23.4 or around 60–120m diameter. One example is 2007 EH, shown imaged by Peter Birtwhistle in Figure 20 when it was moving at an angular speed of 1249 arcseconds per minute.

In addition to astrometry, NEAs passing close-by are interesting photometric targets since it is the only opportunity

Figure 19. Photograph of Peter Birtwhistle surrounded by meteorites at the Naturhistorisches Museum, Vienna, taken by the author on the occasion of the Meeting on Asteroids & Comets in Europe [MACE] on 2006 May 12–14.

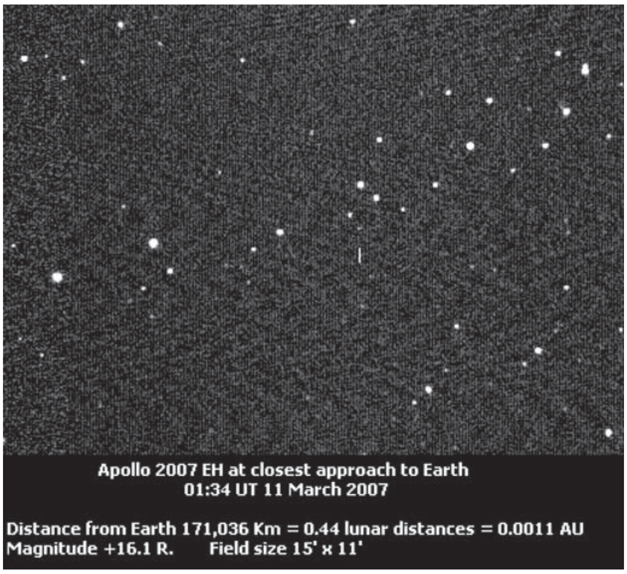


Figure 20. Stacked image showing the 12m object 2007 EH passing less than half the Moon's distance from the Earth. *(P. Birtwhistle)*

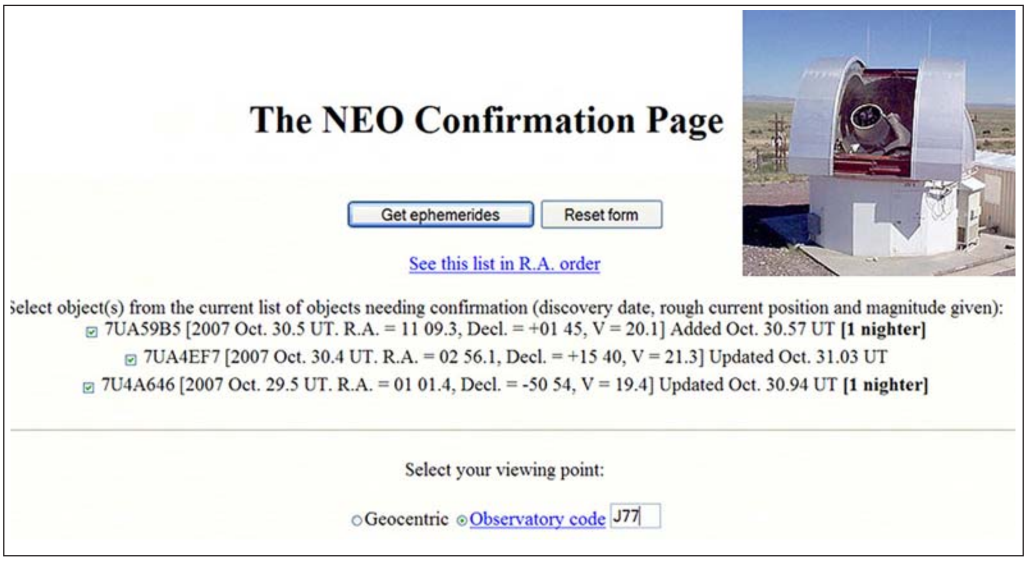


Figure 21. Part of the NEO Confirmation Page screen downloaded in 2007 *(courtesy Minor Planet Center)*. An image of one of the two LINEAR robotic survey telescopes has been added as the inset. *(courtesy Lincoln Laboratory)*

we have to study such small objects close up. However, measuring the rotational lightcurve of a very fast moving object or VFMO can be a considerable challenge, not least because of the rapid motion across the field of view causing extreme trailing and the need to continually chase the object along its trajectory. In the case of Figure 21, the image is made up of three 0.3-sec exposures tracked to follow the asteroid and stacked using *Astrometrica*. Stacking in this way increases signal to noise, permitting higher precision when the resultant stack is measured photometrically. Figure 22 illustrates the brightness changes of the PHA 2005 WC1 turning end-over-end as it traversed the sky. In this case a period analysis performed using the *Peranso* software, written by amateur astronomer Tonny Vanmunster, unambiguously shows that it rotates every 2.57 hr.[30]

When contemplating photometry of newly-discovered NEAs, it is usually imperative to start observing as soon as possible after the discovery announcement, preferably within a few hours, since the total apparition when the object is visible may only be a day or two. Consequently, the more people who participate in a photometry campaign the better. Figure 23 shows the composite rotational lightcurve of the 250m PHA 2006 XD_2, obtained from images by Nick James and Fiona Vincent, folded on a period of 3.7 hr. The smallest NEAs, those less than about 150 metres in size, tend to rotate very quickly as they often comprise monoliths of rocky material formed by fragmention during a collision between two larger bodies. To improve our understanding of the dynamics and evolution of our solar system, it is important to survey small asteroids photometrically so as to determine how their spin rate varies with size and to see whether some of these objects are tumbling through space, i.e. simultaneously rotating about two axes. Several such asteroids are known to be 'superfast rotators', turning a full 360° in just a few minutes.[20]

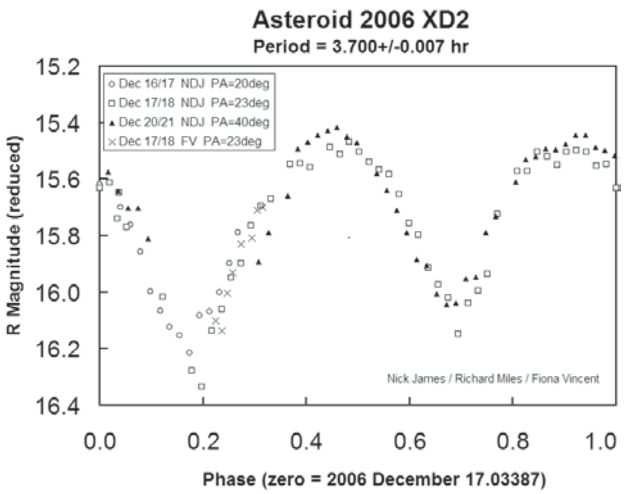


Figure 23. Composite lightcurve of 2006 XD_2 (period = 3.70 hr). From an ARPS observing campaign launched the day after the discovery announcement on MPEC 2006-X43 (2006 December 13).

The unique case of AL00667

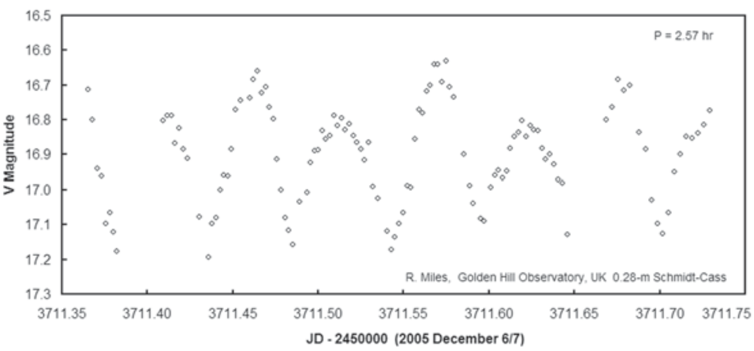


Figure 22. Asteroid 2005 WC_1 makes more than three complete revolutions during the 9-hr observing run by the author on 2005 December 6/7.

Of the 68 objects known to have passed within the Moon's orbit, many were detected *after* reaching perigee, i.e. whilst on the outward departing stage of their journey. It is not so surprising therefore that no object detected whilst still incoming has been found to be on a collision course with the Earth. One day in the near future this will undoubtedly happen. However, we have already had a practice exercise ahead of the real thing in the case of NEOCP object AL00667 on 2004 January 13. This object, now designated 2004 AS_1, was detected by LINEAR, and the initial orbit posted on the Minor Planet Center (MPC) website indicated that it was very close and moving towards the Earth. The author was one of the first people to notice its unusual nature and that the apparent trajectory placed it on a direct course towards the Earth. It was evident that the collision if it were to happen would have occurred within about 24–36 hours.

The weather across most of Europe was poor that night apart from southern England. Peter Birtwhistle was unable to observe the object as his telescope could not reach the region of sky in question, but the author spent about one hour imaging the area from Golden Hill Observatory without finding the moving object, concluding therefore that it was travelling on some other trajectory and was not in fact a threat to the Earth. By the time a message was posted to this effect on the Minor Planet Mailing List,[31] the skies had clouded over in Dorset and it had begun to rain. Some five hours passed before two US amateurs joined the search for the object, which had been reckoned to have a 1 in 4 chance of being on an Earth-impact trajectory. It was not detected by anyone that night because, instead of approaching us, it was in fact receding and therefore much further away than first thought and growing fainter. It was finally recovered by LINEAR and shown to be an ordinary Apollo-type asteroid orbiting the Sun every 1.11 years and reaching a perihelion distance of 0.88 AU.

The MPC has now changed its procedures to highlight potential Earth-impacting trajectories automatically before posting predictions on the NEOCP webpage. In the case of AL00667 the general media were not informed of the happenings at the time, the first reports only appearing some five weeks later.[32]

The future beckons...

As we have seen, our understanding of asteroids and other small solar system bodies is expanding rapidly and will continue to do so in the coming years. The boundaries separating comets from asteroids will become increasingly blurred.

Several large new survey telescopes are being constructed and are due to come on line within the next decade.[33] These include

- the 4.3m DCT or Discovery Channel Telescope, which will be sited near Lowell Observatory, Arizona and have a 2 sq.deg. field of view. It is due for completion in 2010.
- the 4×1.8m Pan-STARRS (an acronym for Panoramic Survey Telescope And Rapid Response System), equivalent to a single 3.6m mirror with a 3° field of view, which will probably be located on Mauna Kea, Hawaii.
- the 8.4m LSST or Large Synoptic Survey Telescope, which is planned to have a field of view of more than 3° and should see first light in 2015 at Cerro Pachón, northern Chile.

We have much to look forward to, as and when these futuristic instruments embark on their search and mapping of the solar system. No doubt these advances will provide new opportunities for the keen amateur to play his or her part in the exploration of the solar system 'jungle', with many strange new 'creatures' yet to be found. Let's go hunting!

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