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Asteroids and Dwarf Planets and How to Observe Them

with 152 Illustrations
Acknowledgements

While writing this book I requested the help of many amateur and professional astronomers with images, diagrams, specific projects, and those sections with which I was not familiar. I have been truly amazed with their responses – my requests were answered speedily and additional images and information were frequently offered. My only hope is that this book does justice to their efforts.

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It seemed quite an omission to me that, to the best of my knowledge, no similar book existed, since many other aspects of amateur astronomy, e.g., comets, lunar, planetary, solar and variable stars were well catered for. Our knowledge of asteroids has increased rapidly of late – even during the time it has taken to write this book. Perhaps having set the ball rolling others will be encouraged to follow in my footsteps.
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Part I

Asteroids and Dwarf Planets
The asteroid world is ever changing. In no other area of astronomy are new objects being discovered at so fast a rate. New theories as to the evolution of asteroids, particularly beyond Neptune, are continually being put forward. Automated telescopic surveys and space missions are constantly making new discoveries and providing new data as to the nature of asteroids and dwarf planets. All this will be covered in the first part of the book. There is much the amateur, even with modest equipment, can do, as will be explained in Part II.

There is a downside to this rate of change. There are sometimes competing theories which, at the time of writing, have yet to be resolved, and it may be that some well established ideas are overturned in the near future – how planets have captured asteroids and turned them into moons, for example. Nothing new in this, but be aware that something you may read here is not necessarily wrong but may just be out of date or one of several theories on the subject.

After our Sun and its retinue of planets had formed around 4.5 billion years ago, there was a fair amount of ‘builders rubble’ left over. These lumps of material, stony, iron, or a mixture of both, some solid, and some loosely bound collections of smaller pieces could be found in large numbers in what is now known as the Main Belt between Mars and Jupiter, and we refer to them as asteroids. They do, of course, turn up in many other places with names (and orbits) that are by no means constant over the years: Vulcanoids, Trojans, Centaurs, Edgeworth–Kuiper Belt Objects, Trans-Neptunian Objects, Plutinos, Plutoids, Scattered Disk Objects, the Oort Cloud. You will find more on these groups in Chap. 3, and how they got to be where they are in Chap. 5. It is not only our planetary system that has such bodies. The search for extrasolar planets has turned up disks around other stars that may well contain asteroid belts similar to our own.

To return to our own locale, here is a short story. (Beware that this is a brief, generalized description of how an asteroid might journey from the Main Belt to the inner Solar System and may not be specific to this particular object. A fuller description is given in Chap.5.)

Sunlight falling on a particular rotating asteroid exerted a force that caused it to slowly spiral outwards from its original location in the Main Belt. After several millions of years it reached an unstable area devoid of any of its companions – a Kirkwood Gap. Here it came under the gravitational influence of the gas giant planet Jupiter, which caused the eccentricity of its orbit to change significantly over a few tens of thousands of years. This change in eccentricity caused the asteroid to become a Mars-crosser and then to arrive in the vicinity of Earth – a near-Earth
object, or NEO. Further planetary perturbations circularized the orbit to ensure it remained in the vicinity of Earth. This particular asteroid, Apophis, is not only an NEO but also an NVO, a near-Venus object.

Its arrival was first noted in June 2004 by astronomers using the Steward Observatory’s telescope on Kitt Peak, Arizona, and a provisional designation, 2004 MN₄, was assigned. It was not seen again until the following December, when it was rediscovered by the Siding Spring Survey in Australia. Orbital calculations from these two sets of observations, by NASA’s Jet Propulsion Laboratory and the University of Pisa, suggested that there was a greater than 1% chance of an impact on Earth in 2029, causing damage over a large area. This merited a rating of 4 on the Torino scale (explained in Chap.6), used by astronomers to define both the chances of an impact and the resulting devastation to life on Earth.

Not since the scale was formulated in 1999 had such a high rating been assigned to an incoming asteroid. By projecting the orbit backwards in time astronomers found the object on images obtained by the Spacewatch telescope on Kitt Peak in March 2004 (a precovery). Amateur astronomers also played a part in helping to define the orbit of 2004 MN₄ more accurately. Both the Goodricke–Pigott Observatory in the United States and the Observatori Astronomic de Mallorca submitted astrometry to the Minor Planet Center. Radar observations in January 2005 using the Arecibo radio telescope enabled the orbit to be further refined and showed that there was now no chance of an impact on the original date, but there would be a very close pass in 2029 and the possibility of an impact in 2036. Figure 1.1 shows the error ellipse, or region of uncertainty, through which 2004 MN₄ was predicted to pass when close to Earth. As can be seen Earth was a possible target until more accurate data was obtained and a new orbit calculated.

Without knowing the size or composition of an asteroid the damage likely to be caused by an impact is hard to assess. Spectra obtained in January 2005 showed that this Aten class asteroid, now numbered and named (99942) Apophis, was made of material similar to an ordinary chondritic meteorite. This data enabled the reflectivity, or albedo, and thus the size of the body to be calculated – approximately 270 m in diameter.

![Error ellipse, or region of uncertainty, as 2004 MN4 approached Earth (Credit Lou Scheffer).](image)
Earth’s gravity, being much weaker than that of Jupiter, does not usually affect the orbits of asteroids to such a great extent, but the proximity of Apophis to Earth in 2029 will cause a significant change in that asteroid’s orbit. Exactly what that change will be cannot be calculated with any precision until the close approach. Amateur astronomers, with relatively modest equipment, will be able to play an important part along with professional optical and radar observers. To calculate an orbit you need accurate astrometry (measures of the asteroid’s position) – how to do this is explained in Chaps. 10 and 11. At its closest Apophis will reach third magnitude and will thus be one of the very few asteroids visible to the naked eye. Although a bonus to those without binoculars or telescopes, it is not one which we should hope will occur too often! In fact, at its closest, Apophis may be too bright for the sensitive detectors used by the automated surveys, thus giving amateurs an even more significant role.

Is there a point to the above story? Yes – more than one. It both introduces terminology that will be explored in greater depth in this book, and touches on the part that amateurs can still play in improving our understanding of these bodies once labeled the ‘vermin of the skies.’

This book is aimed at those who can find their way around the sky and have a general knowledge of matters astronomical. You will probably have been observing for a couple of years or so and have access to the required equipment – your own, your local astronomical society, or robotic telescopes. Note that, for brevity, the term ‘asteroids’ will be used to encompass both those bodies and dwarf planets. ‘Asteroids’ is certainly easier on the mind than ‘Small Solar System Bodies with the exception of Comets,’ but more on that in Chap. 2! Beginners are not ignored. Chap. 8 will describe what is necessary to start you down the road to enjoying simply finding asteroids (“star-like objects,” for that is what the word means) among the stars.

As you will find in Part II of this book, you can observe asteroids with a wide range of instruments and imagers: binoculars, refracting and reflecting telescopes, webcams, digital SLR cameras, video cameras, and CCD imagers. You can brave the elements and sit outside with your own equipment, or operate it remotely from the comfort of a warm room or your home via a wireless link, for example. If you would rather not lay out the capital to purchase your own equipment then you can use one of the commercial, remotely operated robotic telescopes. In fact you don’t actually have to directly use any such equipment to ‘observe’ asteroids. There are a number of photographic and image archives available on the Internet that can be searched for these elusive bodies. The professional automated searches have, in the past, recruited members of the public to search their images for new asteroids and given them credit for such discoveries. Although no longer available at present it can be hoped that some of the forthcoming search programs will include such a facility.

As the author did, you can get considerable enjoyment and satisfaction from tracking down and observing asteroids visually with a small telescope or binoculars (and even get an award for your efforts as described in Chap. 8). However it must be pointed out at this early stage that, if you wish to progress to making accurate, scientific observations, computer literacy and immediate access to a computer is necessary. The best approach is to have a laptop computer or other device that can be transported to your observing site and on which the necessary data can be displayed. Asteroids, especially fast-moving NEOs, by their very nature, do not stay in the same part of the sky for very long, and their orbits change over the years, so
any data you do have will soon be out of date. This is particularly true of newly
discovered asteroids whose initial orbits, calculated from a few days’ worth of
observations, may not be particularly accurate. If you wish to be aware of new
discoveries and make further observations of them, then real-time access to the
Internet is a must. You can waste an awful lot of paper by printing star charts earlier
in the day and then having to throw them away because the sky has clouded over – in
England and Maryland at least!

By the time you reach the end of this book you should have a reasonable under-
standing of the origins, whereabouts, and make-up of asteroids and dwarf planets;
the equipment required to observe and image them; the terminology used to
describe them; and the knowledge to make astrometric (positional) and photo-
metric (brightness or magnitude) measurements and construct light curves plus
monitor occultations of stars by asteroids. Do not discard an observation because
it doesn’t fit with what has gone before. It may be a fault with your equipment or
an error in your analysis, but it could just be real. If you are unsure check with a
colleague before going public. There are other books that cover some of these topics
in much greater depth, and the Internet is a truly wonderful resource. There is a
list of relevant books and websites at the end of this book.

There are numerous local and national astronomical societies, international
groups and special Interest mailing lists that welcome newcomers and experienced
amateurs alike. Some of these organizations make grants available for the purchase of
equipment for specific projects. If you can get to meetings of like-minded amateurs
then try to do so, but quite often such gatherings are broadcast live or available in
recorded form over the Internet. Sharing your findings and your problems will help
you make much faster progress and contribute to your enjoyment of this particular
aspect of amateur astronomy. In general, both amateur and professional astronomers
respond positively to questions sensibly posed. As your knowledge and experience
grow you will then be in a position to return the favor. In Part II you will find
examples of amateur activities ranging from simple-to-make visual observations
to the most advanced work using CCD and video cameras.

The demise of the amateur astronomer has been rumored for some years now.
This is particularly true as far as the subject matter of this book is concerned. The
professional automated surveys, especially those yet to become operational, such
as the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)
and the Large Synoptic Survey Telescope (LSST), will make us all redundant, won’t
they? Not so! There are many areas where amateur astronomers can make a real
contribution to our knowledge of asteroids. Follow-up observations of new discov-
eries, light curves, occultations, and measurements of absolute magnitude are as
relevant today as they have been for years. Once you have shown yourself to be a
competent observer then your results will be as readily accepted as those made by
professionals and very much welcomed by those same people. It does no harm to
one’s sense of well-being to see one’s name included in the list of authors at the
head of a paper published in a respected refereed journal!

This author’s exposure to the asteroid world came sometime in the late 1950s.
A popular comic (in the UK) was the ‘Eagle,’ and one of my favorite characters was
an intrepid astronaut (they were called ‘spacemen’ way back then) by the name of
Dan Dare. On one of his travels his spaceship appeared to be on a collision course
with an asteroid. Luckily it turned out to be a binary, and they passed safely
between the two objects. My second encounter came via a BBC radio series
‘Journey into Space,’ the lead character being one Jet Morgan. Some of you may
believe the NEAR spacecraft was the first to (crash)land on an asteroid, but you would be wrong. Jet Morgan’s ship did so, but, judging by the sound effects, his landing was somewhat harder than that of NEAR. Some years later, while working in the United States, I took my two sons to see the film *The Little Prince*, based on the book of the same name, at Radio City Music Hall in New York. The little prince lived on asteroid B-612 from which the B612 Foundation (see Chap. 6) takes its name. As this asteroid has active volcanoes it must be a large differentiated asteroid, as described in Chap. 4, with a mantle of molten rock – possibly a candidate for dwarf planet status? There is actually a real, Main Belt, asteroid B612 that has the formal designation (46610) Besixdouze (Fig. 1.2) – B612 being the hexadecimal equivalent of that number. Designations and asteroid groups are described in Chaps. 2 and 3, respectively.

Before we look at the various ways in which you can observe and image asteroids, let us take some time to examine the nature of asteroids and discover how they came to be where they are in the Solar System. In this first part of the book you will find many references to the role of amateur astronomers as described in Part II.

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Fig. 1.2. Orbital diagram of asteroid (46610) Besixdouze (Credit: NASA/JPL – Caltech).
Chapter 2

Small (and Not So Small) Solar System Bodies

This chapter will cover the somewhat confusing terminology surrounding:

- How planets, dwarf planets, and asteroids are so defined.
- The meaning of the myriad of numbers and names used to designate asteroids.
- The quantities used to describe the orbit of an asteroid around the Sun – its orbital elements.

Planets and Dwarf Planets

It used to be so simple. There were the large objects (the Sun and the planets), the small objects (the asteroids and comets) and the very small (dust, meteoroids, solar wind, cosmic rays, and the like). Pluto, with its eccentric and highly inclined orbit (relative to the other planets), was something of an oddity, but nobody really questioned whether or not it was a planet, at least not until the discovery of a large Edgeworth–Kuiper Belt Object (EKBO) in July 2005. Subsequently numbered and named (136199) Eris, 2003 UB₃₁₃ proved to be slightly larger than Pluto (now numbered 134340). Should this object, informally named ‘Xena’ at the time of discovery, be considered as the tenth planet? The astronomical world was divided. Some wanted it defined as a planet proper, while others were not so sure. There was much debate as to what such a non-planet should be called, or indeed how planets and asteroids should be categorized.

The matter was resolved at the XXVIth General Assembly of the International Astronomical Union (IAU), which was held in Prague, Czech Republic, during August 2006. Two resolutions, 5 and 6, were passed, but not without considerable discussion relating to planets, asteroids, and comets. The outcome of these resolutions is that the Solar System is now made up of planets, dwarf planets, and small solar system bodies (e.g., asteroids and comets). The formal definitions are:

Resolution 5

A planet is a celestial body that:

- Is in orbit around the Sun.
- Has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape.
- Has cleared the neighborhood around its orbit.

A dwarf planet is a celestial body that:

- Is in orbit around the Sun.
- Has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape.
- Has not cleared the neighborhood around its orbit.
- Is not a satellite.

All other objects, except (natural) satellites, orbiting the Sun shall be referred to as ‘small solar system bodies.’

Resolution 6

Pluto is a dwarf planet and is recognized as the prototype of a new category of trans-Neptunian object (TNO). An IAU process will be established to select a name for this category.

In summary a planet is a large round object and a dwarf planet is a small round object. In practice the term ‘small solar system bodies’ appears to have been still-born. These mostly irregularly shaped bodies are still known, and will probably always be known, as asteroids and comets.

At this time asteroids in orbits similar to that of Pluto were known, informally, as Plutinos. The first of these, 1993 RO, was discovered by Dave Jewitt and Jane Luu in 1993. Such objects make two orbits for every three made by Neptune and are thus said to be in a 3:2 resonance with that planet. Up to 2004 152 of these objects were discovered, and it is estimated that there could be 1,400 with a diameter greater than 100 km.

In June 2008 the IAU introduced the term plutoid – the formal announcement being:

Plutoids are celestial bodies in orbit around the Sun at a semi-major axis greater than that of Neptune’s that have sufficient mass for their self-gravity to overcome rigid body forces so that they assume a hydrostatic equilibrium (near-spherical) shape, and that have not cleared the neighborhood around their orbit. Satellites of plutoids are not plutoids themselves, even if they are massive enough that their shape is dictated by self-gravity.

The three known and named plutoids are (134340) Pluto (136199), Eris, and (136742) Makemake. There are many more large asteroids waiting in the wings to be ‘upgraded’ to dwarf planet status and, almost certainly, many more orbiting beyond Neptune waiting to be discovered.

You will note that in the IAU announcement concerning plutoids there is no mention of 3:2 resonance with Neptune, merely that the semi-major axis of a plutoid should be greater than that of Neptune. So all plutinos are plutoids, but
not all plutoids are plutinos! EKBOs, TNOs, plutinos, and plutoids are discussed in more detail in Chap. 3.

Earlier we used the term ‘resolved,’ but that is perhaps a little too definitive at the present time! In August 2008 a conference ‘The Great Planet Debate: Science as Process’ was held at the Johns Hopkins University Applied Physics Laboratory, Maryland. The post-conference press release stated ‘Different positions were advocated, ranging from reworking the IAU definition (but yielding the same outcome of eight planets), replacing it with a geophysical-based definition (that would increase the number of planets well beyond eight), and rescinding the definition for planet altogether and focusing on defining subcategories for serving different purposes. No consensus was reached.’

One of the most sensible proposals suggests that in the same way we have various classes of stars, we should have various classes of planets, but that they should all be planets, e.g., Jovian, terrestrial, and dwarf.

**Asteroids**


Asteroids are by no means all solid bodies, as will be explained in Chap. 4. Those less than 100–150 m in diameter can be considered as solid, while larger ones, between 100 and 300 m or so, are frequently rubble piles, for example (25143) Itokawa visited by the Japanese spacecraft *Hayabusa* in 2005 September and shown in Fig. 2.1. These are the result of the parent bodies being disrupted by impact and then reforming under the influence of gravity – much as planetesimals formed in the early Solar System.

Itokawa shows no outward signs of such an impact, but (2867) Steins certainly does! Figure 2.2 is a series of images obtained by the *Rosetta* spacecraft in September 2008 while on its way to comet 67P/Churyumov–Gerasimenko. The asteroid is approximately 5 km in diameter and was obviously involved in a mighty collision, the crater at the top being of the order of 2 km in diameter. The crater chain

**Fig. 2.1.** (25143) Itokawa, an example of a rubble-pile asteroid (Credit: JAXA).
Running from top to bottom in the image shows that it suffered further after the main impact. The evidence of the sequence of impacts is that the topmost small crater overlaps the rim of the large one, showing that it occurred after the major impact.

The distinction between asteroids and comets is somewhat fuzzy – pun intended. If an object shows no signs of a coma or tail, then it is usually classed as an asteroid. However some objects initially classed as asteroids have later shown evidence of cometary activity. One such example, shown here imaged in August 2005, is 2005 EX₁₂. This was reclassified as a periodic comet, 169/P. Its faint tail can be seen in Fig. 2.3.

This image is actually a number of images stacked to allow for the motion of the object – the stars therefore appearing as lines of dots. The software that makes this possible is Astrometrica, which will be discussed in more detail in Chaps. 10 and 11.

On the other hand comets, after many orbits around the Sun, eventually outgas all of their volatiles and become extinct. 2003 PG₃ may be just such an object. Just to complicate matters further, (5154) Pholus, a Centaur, is most likely a comet nucleus that has never been active.
Designations Old and New

The first asteroids, discovered in the nineteenth century, were given a name without an associated number, e.g., Ceres and Pallas. In 1852 James Ferguson developed a system of numbering asteroids in order of their discovery, namely: ① Astraæa, ② Hygiea and ③ Eunomia. There is some debate as to who introduced this system, as Wolf and Gould also claim to have done so in 1851. A few asteroids were also given rather complicated symbols, for example (7) Iris was denoted by the symbol ⅠΙ, but this method was discontinued because the symbols became hard to draw and recognize. The assignment of a number was made by the editor of the publication Astromische Nachrichten (AN). The problem with this system was that a newly discovered object could be nothing of the sort but merely a further observation of a known asteroid.

In 1892 a system of provisional designations, suggested by Kruger, was implemented with new asteroids identified by their year of discovery followed by a capital letter. The following year the designation was changed to include the year followed by two capital letters. These were to be used consecutively irrespective of any change in year.

The present day system of designations was suggested by Bower in 1924 and implemented in 1925. An example of a provisional designation is 2008 VU₂. The first four numbers are the year of discovery, the next letter indicates the half-month period during which the object was discovered, and the final letter and number the order of discovery within that period. The periods are shown in Table 2.1.

For example, the first 25 asteroids discovered during the half month period November 1–15 in 2008 will be numbered 2008 VA to 2008 VZ. The next 25 will be numbered 2008 VA₁ to 2008 VZ₁. For subsequent discoveries in that period the subscript number will be 2, 3, 4, and etc. There have been other designations, used by special surveys, for example, and during wartime when the discoverers were unable to communicate their findings to the appropriate body.

Observations reported to the Minor Planet Center (MPC) include the provisional designation in packed format. So 2008 TT₂₆ becomes K08T26T, the first two digits of the year being indicated by the letter K. Reporting will be explained in greater detail in Chap.11.

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