

Near Earth Objects—a threat and an opportunity

Jonathan R Tate

The Spaceguard Centre, Llanshay Lane, Knighton LD7 1LW, UK

Abstract

In the past decade the hazard posed to the Earth by Near Earth Objects (NEOs) has generated considerable scientific and public interest. A number of major films, television programmes and media reports have brought the issue to public attention. From an educational perspective an investigation into NEOs and the effects of impacts on the Earth forms a topical and dynamic basis for study in a huge range of subjects, not just scientific. There are clear routes to chemistry, physics, mathematics and biology, but history, psychology, geography, palaeontology and geology are just a selection of other subjects involved.

A number of projects have been established, mainly in the USA, to determine the extent of the hazard, and to develop ways of countering it, but the present situation is far from satisfactory. Current detection and follow-up programmes are underfunded and lack international coordination.

Introduction

While major impact events are mercifully rare it is inevitable that, unless we take preventative action, a large object will sooner or later strike the Earth, with devastating consequences.

The immediate effects of a major impact, including blast, firestorms, intense acid rain, the production of pyrotoxins and the destruction of the ozone layer, coupled with the possible triggering of volcanism and seismic activity, will cause a significant environmental disaster and massive loss of life and property. However, the main threat to the global ecosphere will be the vast amount of dust and debris injected into the upper atmosphere, blocking the Sun and causing phenomena similar to a 'nuclear winter'. Many smaller strikes, though not globally threatening, have caused massive damage to the area of impact, and often at considerable distance. Two thirds of the Earth's surface is covered by water, and a major impact at sea will have far-reaching and catastrophic effects due to the production of a massive tsunami by

the force of the impact. The spread of human settlement makes it much more likely that a future impact, even relatively small, will result in the massive loss of human life and property.

The threat

There are four classes of extraterrestrial object that can potentially threaten the Earth: asteroids, short-period comets, long-period comets and cometary debris. Because these objects are relatively small very subtle effects can modify their orbits, sometimes causing them to fall in towards the Sun and the inner solar system.

Asteroids are remnants of the original disk of material around the young Sun that accreted into the planets. However, because of the gravitational influence of Jupiter, the asteroids were unable to condense into a large planetary body. Most asteroids are confined to the main asteroid belt, orbiting the Sun between Mars and Jupiter, but there are significant groups that have orbits that



Figure 1. Artist's impression of a major impact. (Image courtesy David A Hardy (www.astroart.org.)

cross that of the Earth. As pieces of a 'failed planet' asteroids are rocky or metallic objects, made of the same materials as the terrestrial planets. While we are fairly confident that we know what asteroids are made of, we are far less sure of how they are put together. Are asteroids solid monoliths, do they have cracks or voids, or are they simply flying gravel piles?

All comets are believed to have similar compositions. They have been described as 'dirty snowballs,' but 'icy mud-ball' may be a more accurate description. The main constituents of comet nuclei are volatile ices, mainly water, mixed with dust and hydrocarbons. The two nuclei that have been closely studied (Comets Halley and Borelly) are blacker than coal, due to a coating of dark hydrocarbons. Once a comet has outgassed all of the available volatiles, its coma and tail will disappear, and the remaining, inert nucleus will take on the appearance of a low-albedo asteroid. There is increasing evidence that there might be a significant population of 'dead' comets occupying Halley type orbits, and finding such bodies could

present new challenges to search programmes, probably requiring the use of infrared technology.

Short-period comets come from a wide band of solar system debris called the Kuiper Belt, which starts just beyond the orbit of Neptune. The average short-period comet has an orbital period measured in years or decades (by definition, up to 200 years). The vast majority have orbits close to the plane of the solar system (the ecliptic), so once found, their orbits can be predicted with some accuracy. An increasing number of Kuiper Belt Objects (KBOs) have been discovered over the past five years, incidentally giving rise to considerable debate over the status of Pluto: is Pluto a bona fide planet or just a large KBO?

Long-period comets originate in a spherical cloud of debris that surrounds the Sun at distances between 20 000 and 100 000 AU (astronomical units), i.e. almost halfway to the nearest star. Five to ten significant cometary bodies approach the Sun each year, while an unknown number of smaller bodies pass undetected. Unlike short-period comets, whose orbits are relatively close to the ecliptic, long-period comets can come from any direction. Their orbital periods are longer than 200 years, and they will often only return after thousands or even millions of years. As a result, most long-period comets will be new to science when they reappear, and they will do so with little or no warning.

It now seems probable that the break-up of comets, like Comet Shoemaker-Levy 9 which crashed into Jupiter in 1994, is far more common than previously suspected. When a comet nucleus shatters, either because of a collision or because of internal stresses as its volatile components vaporize, it will produce a stream of fragments and debris in its wake. These will vary in size from dust to lumps a few hundreds or thousands of metres in diameter. Such a debris stream could pose a significant and recurring threat to the Earth from the impacts of the larger fragments, but also from the dusting of the upper atmosphere by fine dust particles. Atmospheric dusting will reduce the amount of sunlight and heat reaching the surface and it looks as though this could be a significant factor in climate change. There is serious research currently being done into the links between periods of atmospheric dusting and the onset of environmental change.

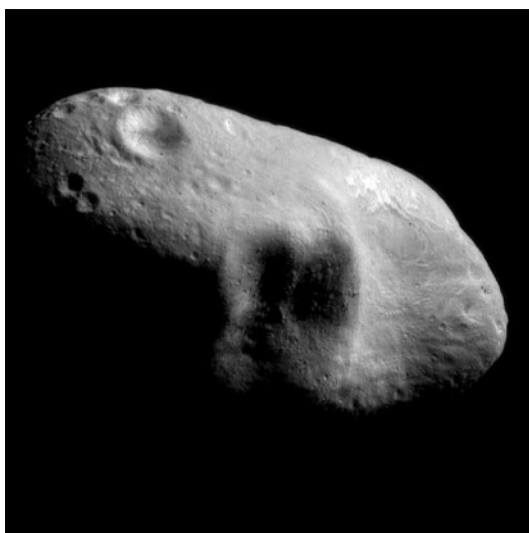


Figure 2. The asteroid 433 Eros as imaged by the NEAR–Shoemaker probe in 2000. It is about 30 km long. (Photograph: NASA.)

Dealing with the impact hazard is a three-stage process: detection (‘find’), follow-up (‘fix’) and collision avoidance (‘neutralize’).

Detection

The most important requirement for any detection program is a telescope with a large field of view (FOV); however, it is equally important to have suitable detectors mounted at the focal plane. Until the late 1980s most of the telescopes used for asteroid detection and follow-up used photography, but this has been replaced by CCD technology. CCDs (charged coupled devices) have distinct advantages over photography: they are very sensitive, so can detect small, faint objects with reasonable exposure times, and they produce an electronic image that can then be enhanced, processed and measured digitally.

There are only six detection programmes in operation around the world. Of these, five are in the United States and one is in Japan. These projects find about 15–20 new NEOs every month and their efficiency is increasing, mainly due to the development of more efficient sensors and data processing systems. However, there are a number of problems. There is no search program active in the southern hemisphere, so about 30% of the sky is unpatrolled. The programs are not well coordinated and sky coverage is

not uniform, especially at high declinations and low solar elongations. In addition, some of the NEO populations, especially those that have orbits closer to the Sun than the Earth, are definitely undersampled.

The original ‘Spaceguard’ project, proposed by Dr Gene Shoemaker, was to develop a network of six telescopes, positioned around the world to provide all-sky coverage. Although there is currently no funding for this project, an international network of large aperture telescopes (3–4 metre) is still considered the best way to tackle the problem of NEO detection. To capture asteroids that orbit the Sun inside the Earth’s orbit some form of space-based telescope will be needed, and both NASA and ESA are looking at this possibility, perhaps by ‘piggybacking’ a telescope on a spacecraft designed for some other purpose.

Follow-up

The discovery of an asteroid or comet is only the beginning of a long process. A new object will need to be observed over a period of time to determine its exact orbit, and to see whether it poses a threat to the Earth. However, current detection programmes are largely dedicated to their primary role, leaving the subsequent follow-up observations to others. While there are a few professional follow-up programmes the lion’s share of this work is done by amateur astronomers around the world. This is for one simple reason—numbers. It was once pointed out that there are more people working at your local McDonalds restaurant than there are professional astronomers searching for NEOs. In recent years interest in NEOs has grown and this situation has changed, but telescope time will always be at a premium for professionals. The amateur, on the other hand, with his or her backyard telescope can observe whatever they like, whenever the sky is clear. With CCD cameras and computers amateurs not only have the power to do astrometric reductions in seconds but can also make useful observations using dedicated equipment.

Asteroid and comet discoveries and targets for follow-up observation are collected and coordinated by the Minor Planet Centre (MPC) based in Cambridge, Massachusetts, and the Spaceguard Central Node (SCN) in Italy. Neither organization is properly staffed or funded, and



Figure 3. Comet Hale–Bopp, which was visible from Earth with the naked eye in 1997.

the exceptional service that they offer is largely based on the dedication of a few, hard-pressed individuals.

In addition to determining an object's orbit around the Sun it is also necessary to find out something about its physical properties—what is it made of, how is it constructed, how fast is it spinning? Much of this work can be done using ground-based observations, but *in situ* investigations by spacecraft are an essential part of the process. The United States (NASA) and Europe (ESA) have active space-based NEO research programmes that include space missions such as NEAR–Shoemaker, Deep Space 1, Deep Impact, the ill-fated Contour and Rosetta. These missions greatly extend our knowledge of NEOs, but also teach us that asteroids and comets are diverse and complicated objects. No two are the same, and we would be foolish to develop 'generic' models of minor planets.

Collision avoidance/mitigation

Studies have been conducted in both the United States and Russia on methods of avoiding potential NEO impacts. However, any strategy to deal with a potentially hazardous NEO must be developed in light of the object's physical properties; there can be no generic solution. There are three possible courses of action available once a threat has been identified.

Evacuate/ride the storm. Given adequate warning it might be possible to evacuate the point of impact and areas in danger, such as low-lying coastal regions. This might be reasonable for small impacts, but for larger, globally threatening events, long-term protection and supply will be necessary for any surviving population. Natural food sources will not be available for over a year, and even then, there will be no infrastructure to support society once the skies have cleared. Major climatic changes resulting from the effects of the impact may make the environment hostile to human survival for extended periods, making the re-establishment of civilization difficult.

Destruction. The possibility of destroying potential impactors, probably with high yield nuclear weapons, has been studied in some detail. With the current lack of knowledge of the exact composition of particular objects, and their structural strength, there is doubt as to the effectiveness of this course of action. The fear is that incomplete disruption of the object would subject the Earth to multiple impacts from fragments of the original body. The effects of transforming a cannon ball into a cluster bomb could be more far-reaching than the original threat.

Deflection/acceleration/deceleration. If a potential impactor can be identified early enough, its orbit could be modified sufficiently to ensure that a collision will not occur. The amount of modification required is inversely proportional to the time available before impact, so early warning of a potential threat will be crucial. Possible methods include the detonation of a nuclear weapon close to the body to change its orbit, the deployment of solar sails, the use of the Yarkovsky effect or the use of propulsion units or mass drivers (using the material of the object itself as fuel) to physically drive it from its path. Only very small adjustments would be required to ensure a miss rather than a hit.

While there is a body of literature dealing with the physical processes of asteroid and comet deflection, little or no research has been done into the sociological and psychological effects of an impending impact event. This is not strictly a question for astronomers, but the wider social and political implications of the hazard have yet to be addressed.



Figure 4. The Spaceguard Centre in mid-Wales. (Photograph: The Spaceguard Centre.)

Opportunities

Scientific

A comprehensive programme aimed at the study of the origins, orbits and compositions of asteroids and comets would have enormous impact on the scientific community. These bodies represent the primordial material from which the solar system formed some 4500 million years ago, and their analysis would be invaluable to studies of the formation and early evolution of the solar system, and to the search for similar systems around nearby stars.

Educational

It has been said that any subject that involves big explosions, spaceships and dinosaurs cannot fail as an educational tool! As the scientific community has found out over the past ten years, the study of the impact hazard is a truly multidisciplinary undertaking; in fact, there are very few subjects, from anthropology to zoology, that aren't involved in some way or other. Indeed, we can go beyond science. Amongst other things, historians are now investigating possible impact events in the historical record that have been misinterpreted as mythology or allegorical accounts of unexplained phenomena. As a gateway to more conventional

curricular subjects the cosmic impact hazard has a lot to offer, and there are a multitude of resources available on the Internet or in print. A short list of websites that provide additional information and links can be found at the end of this article.

Commercial

The mining of minerals, metals, hydrocarbons and, significantly, water from asteroids and comets for use in the exploitation of space could become viable, reducing the requirement to lift such materials from Earth's gravity well (the most expensive part of any space project). Once deflection techniques have been refined, the nudging of NEOs into convenient orbits and the subsequent mining of their resources could become the enabling technology for man's exploration of the universe.

Conclusion

It is only recently that mankind has realized that there is a real threat from collisions with cosmic debris. Until the latter half of the twentieth century there was still controversy over whether the craters on the moon were caused by impacts or by volcanic action. It was only after moon rocks collected by the Apollo astronauts were analysed that the matter was settled. While there is no doubt that there is a substantial long-term threat this hazard is qualitatively different from other natural disasters such as earthquakes, floods or volcanoes:

Rare. Major impacts are rare (on human time-scales) and therefore easy to dismiss as irrelevant to the current generation.

Devastating. The destruction wrought by a major impact will be orders of magnitude greater than any resulting from other natural phenomena.

Avoidable. It is now technically possible to avoid, or at least mitigate, the effects of impacts.

Despite all of this, the current situation regarding NEOs is far from satisfactory. Impacts have catastrophically disrupted the ecosphere in the past and will again; the only question is when. However, for the first time in the history of our planet, there is a species with the ability to prevent disaster, and to reap the rich harvest of resources provided by asteroids and comets.

Websites for further information

The Spaceguard Centre, Knighton, Powys
www.spaceguarduk.com

The leading NEO information source in the UK: visits, online resources, current news, reading suggestions. Visits here were reviewed in the September 2002 issue of this journal (2002 *Phys. Educ.* **37** 452–4).

The Faulkes Telescope Project
www.faulkes-telescope.com

Practical astronomy projects, online resources.

NASA NEO Website
<http://neo.jpl.nasa.gov>

Current news, online resources.

Cambridge Conference Network (CCNet)
<http://abob.libs.uga.edu/bobk/cccmenu.html>

Current NEO news and debate.

National Near Earth Object Information Centre
www.nearearthobjects.co.uk

A government sponsored NEO website.

Received 15 January 2003
 PII: S0031-9120(03)58326-5

Further reading

Atkinson H (chair) 2000 *Report of the Task Force on Potentially Hazardous Near Earth Objects* DTI/Pub 4990/5k/9/00/NP.URN00/1041 (London: DTI)

Baillie M 1999 *Exodus to Arthur* (London: Batsford)

Carusi A 2001 *Present and Future of the Spaceguard Survey, International Workshop on Collaboration and Coordination among NEO Observers and Orbital Computers, Okayama*

Carusi A *et al* 2000 *Spaceguard Integrated Systems for Potentially Hazardous Objects Survey* ESOC Contract 13265/98 (Paris: ESA)

Lewis J S 1996 *Mining the Sky* (Reading, MA: Addison-Wesley)

Morrison D (chair) 1992 *The Spaceguard Survey, Report of NASA International Near-Earth-Object Detection Workshop* (NASA Office of Space Science and Technology)

Rather J D G, Rahe J H and Canavan G 1992 *Summary Report of the Near Earth Object Interception Workshop, Los Alamos National Laboratory*

United Nations 1999 *Report of the Third UN Conf. on the Exploration and Peaceful Uses of Outer Space* UN Publication A/CONF.184/6 (Vienna: UN)

Jonathan Tate runs The Spaceguard Centre in mid-Wales with his wife Anne. This small, privately run centre is the national focus in the UK for studies into the threat from NEOs; they aim to provide accurate and timely information about the hazard. They welcome educational visits.