Comet and Asteroid Impacts: Does Earth Need Protection?
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Comet and Asteroid Impacts: Does Earth Need Protection?

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Introduction

Cosmic catastrophes

Some 65 million years ago on Earth, a devastating event occurred to wipe out not just the dinosaurs but many other types of organisms on the planet. Many threads of evidence supporting this event converge at the Caribbean basin as the site of a collision between Earth and an asteroid or comet some 10 kilometres across.\textsuperscript{1} Separate research groups at the Yucatan Peninsula have uncovered evidence of an ancient crater and associated deposits some two hundred kilometres across.

An asteroid even a tenth of this size may be able to disrupt world agriculture through the effects of global cooling and darkening caused by a dense cloud of post-impact debris. The resulting political and social disorder would surely rank as the greatest catastrophe in human history.\textsuperscript{2} However, there is as yet not a single recorded instance of a person being killed by a smaller meteorite impact, although near-misses have occurred.

The cratering records evident on the Earth and the Moon suggest that large impacts occur hundreds of thousands to a few million years apart. The recent cratering record on Earth show several large impacts about 10 000 years ago, and three smaller ones about 6000 years ago, all possibly from the one main object.\textsuperscript{3} It is possible that other asteroid pieces related to these events still remain in orbit in the Solar System to return to Earth at any time.

Following the recent cometary impact on Jupiter, concerns have risen about similar events re-occurring on Earth. Although the comet that struck Jupiter was moderate in size, its effects exceeded the expectations of planetary scientists. Considerable global change occurred to the Jovian atmosphere from the series of comet fragment impacts.

What then could occur on Earth in a similar situation? This paper addresses the matter by describing comets and other interstellar matter, then examining the extent of the risk. Monitoring programs are limited and may require links to future technology to seek out and


\textsuperscript{2} Pike, J., 'The Sky Is Falling: The Hazard of Near-Earth Asteroids', p. 16.

\textsuperscript{3} Pike, p.18.
divert any threatening objects away from Earth. The paper also notes that some international treaties apply to any such action in space.

Comets, Meteors, Meteorites and Asteroids

Comets and asteroids are interrelated objects that orbit around and inside the Solar System, of our Sun and its nine planets, and have long been of interest to humans. In times past, people associated these apparitions with local events such as wars, famines and death. In more recent times, we have come to laugh off this view as superstitious nonsense. Perhaps this is a little foolish as indeed, a comet might again bring to an end life as we know it on Earth. On the other hand, some scientists suggest that comets may also bring new life, water and organic material to Earth.

Comets are objects with nuclei usually about 10 kilometres across that are volatile stores of ices and dust that accrete in the distant reaches of the solar nebula. As they approach the Sun, solar radiation releases the gases and dust from the frozen body to form a tail. Comets display a tail (coma) of dust of gas when nearing the Sun, while asteroids do not. Comets appear to come from several places. Firstly, from the Oort cloud, a vast reservoir of primordial solar system material that lies far beyond the outermost planet Pluto. A second source may be closer and lie near Pluto's orbit which is forty times the distance between Earth and the Sun. A third belt of asteroids and possibly comets lies between the orbits of Mars and Jupiter. Comet Objects displaying cometary properties may be in long-period (over two hundred years) or short-period orbits about the Sun. There are about 200 known short-period comets.

The so-called 'shooting stars' often seen from Earth are actually cometary debris in the form of small dust particles known as meteors that burn up as a result of frictional heating. Trails of dust particles create the regular meteor showers such as the Geminid, Perseid and other such normal streams. Bodies larger than 10 metres in diameter, termed meteorites, can survive their atmospheric passage and fall to Earth's surface. A meteoroid is such an object in interplanetary space, smaller than 10 metres in diameter. These represent little threat to us here on Earth.

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5 Binzel, p.11.
Asteroids are larger, more solid objects, and astronomers have tracked at least 6000 of them. Yet, astronomers have only found some 200 near-Earth asteroids. Their estimates suggest that there are from five to ten thousand objects existing that are larger than 0.5 kilometres across. They are classified in three ways:

- **Amors** are asteroidal objects that cross the orbit of Mars and approach Earth.
- **Apollos** are asteroids that cross Earth's orbit.
- **Atens** mostly lie inside Earth's orbit, but may cross it.

All of these objects vary in chemical composition and origin. The population of near-Earth asteroids probably includes many dormant comets too. They have a sinister feature in that as they approach the inner Solar System, they fragment into many potentially dangerous pieces.

In one controversial theory, some scientists claim that comets of 10 metres in size constantly bombard the Earth at about twenty per minute. They vaporise into water and dust as they hit, adding matter to the atmosphere. Possibly, they were responsible for filling the world's oceans and forming the polar ice caps, thus assisting the creation of life on Earth. Whether or not the case, it does seem that between 100 to 1000 tonnes of extra-terrestrial material hits the Earth each day. Fortunately, most of this material is dust and not a threat, but our concerns lie with the less frequent, larger, solid objects.

**Near misses and collisions**

Recent history demonstrates that near misses by larger objects are common. On 11 August 1972, an object estimated at 80 metres in diameter and weighing about one million tonnes narrowly missed Earth. It burned in our atmosphere for 101 seconds on a path over the

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6 Steel, D. 1994, 'Asteroids: The vermin of the skies', The Helix, CSIRO Double Helix Science Club, Number 34, February/March, Canberra, p.28.

7 Binzel, p.9.

8 Pike, p.17.

United States before heading into deep space again. However, a more recent close call was on 19 January 1991 when asteroid 1991BA, a 10 metre diameter object, passed between Earth and the Moon's orbit. Then in December 1992, the object 4179 Toutatis passed us only about four million kilometres away. On 21 May 1993, an entirely unpredicted asteroid of 10 metres size travelled past Earth, missing by only 150 000 kilometres. On 16 April 1993, a body of about four metres across detonated some eighteen kilometres above Dubbo, New South Wales. It rocked the city with explosive vibrations, alarming the local populace. More recently, Broken Hill had a similar experience.

Direct hits are readily evident in the crater records around Earth. The object responsible for the one kilometre diameter, 25 000 year-old Meteor(ite) Crater, in Arizona, was about 50 metres across. We could expect such an object every sixty years or so. In 1908, an object that was probably an icy cometary fragment exploded over the Tunguska region of Siberia. It flattened 2000 square kilometres of uninhabited forest. We could expect an object of this size every fifty years. In Australia, there are nineteen recognised impact sites including Gosses Bluff in the Northern Territory and Wolfe Creek in Western Australia. Of these sites, four are less than 5000 years old, but many more probably await discovery. While the Wolfe Creek event was localised, the Gosses Bluff strike had global impact. Thousands of fragments from more than 300 distinct meteorite falls have been found across Australia. Cometary impact may be involved in creating tektites, small glassy fragments found in the desert.

Of course many such objects land in the oceans or in remote locations, never to be seen. However, there is always the possibility that a large enough object will cause harm. Researchers estimate that there are more than 10 000 objects of sufficient size from 0.5 to 5.0 kilometres

11 Steel, 'Asteroids: The Vermin of the Skies', p.28.
13 Steel, D. 1994, 'Do we live on a safe planet?', *Sky and Space Magazine*, April, p.44.
14 Steel, 'Asteroids: The Vermin of the Skies', p.29.
across to cause potentially serious terrestrial consequences. Yet, we have only charted 163 (about one percent) of the objects that could have global effect if they came here. A process called chaotic dynamics may be responsible for removing objects from their normal orbits and placing them on trajectories that bring them near to the Earth. Meteoroids enter the Earth's atmosphere at speeds from twelve to thirty kilometres a second for smaller objects (43 000 to 108 000 km/hour). Larger asteroids hit at from fifty to sixty kilometres a second (180 000 to 216 000 km/hour). Their size will determine whether they maintain this speed at ground zero, or be subject to atmospheric braking effects. Even where these occur, a shock wave could still devastate the region below, so the result is much the same. Thus the question is whether we can reasonably expect such an object to reach Earth.

Estimating the risk

Scientists now estimate - albeit from a data base that is still fairly scanty - that there is a one in 10 000 chance that a large two-kilometre or so asteroid or comet will collide with the Earth during the next century. This event would disrupt the ecosphere and kill a large proportion of the world's population. It would be a catastrophe to destabilise modern civilisation, but not an event to totally eliminate humanity. Such an impact is then an extreme case of a low probability but high consequence hazard, worthy of further review and action.

There are many uncertainties in the effects of an impact. These include the impact site geography and strike angle, environmental influences, ground geology and so on. The total effect on biological communities remains uncertain, but the synergisms between various ecological stresses suggests a global holocaust. In the unlikely event that an urban area were struck, millions of people would die instantly, an event unknown in recorded history. Yet even in this century, there have been at least 10 separate natural disasters each responsible for

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the deaths of well over 100 000 people.21 These include floods, earthquakes, and a cyclone, but all such events are limited in comparison to the devastation from an impact.

Already some attempts have been made to quantify the level of risk facing the Earth from these objects.22 However, data collection remains at an early stage and it will be necessary to gather much more information about comets and asteroids - particularly those in near-earth or earth-crossing orbits - before truly reliable statements about risk are possible. This suggests that search programs should receive priority.

Search programs

The search programs for near-Earth asteroids currently involve only some twenty or so astronomers. Even so, the extraordinary discovery rate is about two per month.23 The Planet-Crossing Asteroid Survey, begun in 1973, covers vast areas of the northern sky during a one week period per month at the Palomar Mountain Observatory in Southern California. After the initial manual photographic detection, a loose network of observers around the world makes follow-up position measurements to compute the object's orbit. Another search, the Spacewatch Telescope at Kitt Peak, Arizona, uses a semi-automatic electronic detection system. It has found about fifty asteroids and a previously undiscovered belt located near Earth.

In Australia, museums have meteorite research programs, while observatories watch for events. These and amateur observers search the southern skies for the emergence of new comets. The Anglo-Australian Observatory began a near-Earth Asteroid Survey in May 1990 and has discovered about ten objects a year.24 The program has direct funding from the Australian Research Council and the Department of Employment, Education and Training. It has enabled

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21 Chapman and Morrison, Impacts on the Earth by asteroids and comets: assessing the hazard, p.37.

22 Chapman and Morrison, Impacts on the Earth by asteroids and comets: assessing the hazard.


discovery of over three dozen asteroids and has determined their precise orbits about the Sun.\textsuperscript{25}

To visit any of the known Earth orbit-crossing asteroids requires far less energy than required to return to the Moon or any planet. The first-ever photograph of a moon of an asteroid was produced by the NASA Galileo spacecraft in August 1993. The asteroid Ida has a natural small satellite. The Galileo craft also provided the first-ever picture of an asteroid, Gaspra, in October 1991. Located in the asteroid belt, Gaspra is an odd-shaped chunk of rock, pocketed with craters itself. The ESA Giotto spacecraft visited Comet Halley in 1986 while the ISEE craft inspected comet Giacobini-Zinner in late 1985. In early 1994, two NASA scientists produced the first-ever detailed, three-dimensional reconstruction of an asteroid using radar data and a computer model. This allows use of other radar observations to better interpret asteroid shape and size. In late 1998, the NASA NEAR (Near Earth Asteroid Rendezvous) probe should visit asteroid Eros. In future, asteroid missions could collect specimens for origin determinations and possible mining of ores and minerals. This would help us better understand them.

\textit{Spaceguard}

A NASA committee concluded that a twenty-year international telescopic survey using a network of six new large telescopes could account for nearly all of the objects that might threaten civilisation. This Spaceguard project would be spread over all latitudes and longitudes and discover several thousand objects each month.\textsuperscript{26} However, Spaceguard would still take fifteen to twenty years to finish a complete survey, and would cost around A$400 million over twenty years. It would be likely to provide some decades of warning to enable decision about the best course of action to divert a threatening object. It is now understood that NASA and the US Defense Department have announced a joint ten-year program to monitor the skies. It would remain expensive to detect other smaller objects that could create great localised natural catastrophes. Rocks that are some ten metres or so in size pass unseen several times each day, closer to Earth than the Moon.

Even with smaller pieces significant damage can occur. Should a one hundred metre size asteroid detonate over the western Pacific Ocean, the resulting tidal wave would deluge the cities of Sydney and Brisbane.


\textsuperscript{26} Steel, D. 1994, 'Do we live on a safe planet?', \textit{Sky and Space Magazine}, April, p.45.
and the east coast. Such an event occurs on average every 5000 years. What, if anything, might be done about it?

**Diversion of dangerous objects**

Means of diversion may include the use of defensive systems or nuclear weapons adapted from military applications, discussed in the next section, or other techniques such as rockets and solar lightsails. If we could attach rockets to the object, well in advance of its Earth arrival, a slight rocket nudge would change its trajectory, and even a small change made well in advance of Earth impact would cause a clear miss of our planet. This would require very careful planning.

Solar sails (or lightsails) are large areas of thin fabric stretched out in space that move by means of the pressure received from the Sun's solar radiation and wind. The constant flux of the wind against a sail attached to an object could again be sufficient to alter its course away from us. It is important to note that the further away from Earth a 'nudge' is applied, the less powerful it need be, but the less powerful will be the energy from solar radiation. Nonetheless, solar sails still await proper demonstration in space.

**Is military technology useful?**

Given that the impact of a larger object, though far less probable than encounters with smaller material, could have devastating global consequences - in the worst case perhaps fatal to all terrestrial life - some have suggested that military technology be adapted to protect the planet. In this connection it has been suggested that some of the technology developed for the former US Strategic Defense Initiative (SDI - popularly known as 'Star Wars') might be applicable.

**Requirements for military technology**

- **Target acquisition:** it would first be necessary to identify a threatening object, ascertain its precise orbital characteristics and verify that it would hit the earth. This could be done at longer ranges by astronomical technology and closer in by earth or space-based radar systems.

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27 Steel, 'Do we live on a safe planet?', pp.44-45.
• **Target characterisation**: it would also be necessary to obtain precise information about the threatening object itself: especially its mass, composition, and dimensions.²⁸

• **Mission determination**: finally it would be necessary to decide just what sort of mission would need to be carried out: in particular, whether it would be more effective to attempt to destroy the object or merely to divert it from its course so that it missed the earth.

### Available or potential weapons technologies

Clearly a capability to lift substantial loads into earth orbit, and thence to deep space in order to intercept an object, would be needed. This section deals rather with possibly applicable weapons technologies, and assumes a capacity to deliver a weapon to target when required. As already noted, there have been suggestions that some of the technologies researched during the US SDI program might be applicable.

**Directed energy weapons**

One of the most widely publicised features of the former SDI program was the research conducted into various forms of so-called directed energy weapons. These essentially consisted of two types: various forms of high-energy lasers, using electromagnetic radiation²⁹, and so-called particle beam weapons, using subatomic particles at high energies.

The most potent relevant technology researched under SDI was probably the X-ray laser. This weapon was intended to produce a beam of X-rays at very high energies capable of vaporising (or at least melting) its target. However, it suffered from the fundamental disadvantage that it required a nuclear explosion to power the laser, so that each X-ray laser could be fired only once, as the nuclear weapon destroyed the laser on firing. Moreover, as research progressed it soon became clear that there were fundamental scientific and engineering problems. Research on this weapon has been abandoned; if it was decided that an X-ray laser was necessary for use

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²⁸ Objects of the sort under consideration are rarely neatly spherical bodies like planets; they tend to be irregularly shaped lumps of rock, iron and/or various ices (water ice, frozen gases, etc).

²⁹ Electromagnetic radiation takes numerous forms, from (in descending order of energy) gamma rays, through X-rays, ultra-violet, visible light, infra-red and radio waves.
against dangerous objects, substantial research and development would still be required, with no guarantee of success.

Similar comments apply to particle beam weapons. These devices were intended to generate beams of subatomic particles at high energies, again with the objective of heating a target to destruction or - in the case of the nuclear warheads - scrambling delicate electronics so that the warhead would not detonate. But research on these weapons did not reach a stage of demonstrating any useful capability against nuclear warheads, and in any case the applicability of particle beam weapons, if ever one were successfully developed, to dangerous space objects is doubtful. This is so because a nuclear warhead re-entering the atmosphere at (say) 19 000 km/hour is much easier to destroy or divert than (say) a kilometre-thick lump of rock travelling at ten times the speed, which is typical of the objects under consideration.

Kinetic energy weapons

Another type of weapon researched under the SDI program were so-called kinetic energy weapons (KEW). Unlike high-energy lasers and particle beam devices, kinetic energy weapons are simple in principle. Pistols and rifles are kinetic energy weapons which damage their targets by transferring the energy of flight of the bullet to the target on impact.\(^\text{30}\)

Indeed, in one sense the objects under discussion in this paper - be they asteroids, comets or anything else - are natural kinetic energy 'weapons': the threat they pose to the planet comes less from size (a 10km object is little more than a dust mote on astronomical scales) than from the immense velocities with which they might strike.

In the Star Wars program, most KEW research was directed at so-called 'railgun' weapons, where metallic projectiles were accelerated by magnetic forces along a rail. But this research was directed principally at use against very small objects (eg, satellites, nuclear warheads) and would have little if any applicability against astronomical objects.

Nuclear weapons

Given the sizes and speeds of dangerous objects, it is clear that large amounts of energy will be required in order to destroy or divert them. The only extant technology capable of producing such energies is that of large nuclear weapons. In the nuclear atmospheric testing era of the fifties and sixties, some very large nuclear devices were detonated, the largest being a huge weapon of approximately 60 megatons (MT) yield

\(^{30}\) Thus an artillery piece is not a KEW, because it relies not on the impact of the shell but on the explosive in the shell to do damage.
detonated by the then Soviet Union in October 1961. It may be necessary to build weapons with even greater yields for the purpose of dealing with dangerous astronomical objects. Given that the Soviets were capable of building a 60MT device thirty years ago, there is no obvious technology problem in constructing even larger weapons today if required. Nor, given modern computer modelling techniques, should it be necessary to test such a weapon on earth. The challenge will lie in target detection and characterisation and in safe delivery of the weapon(s).

Implications for global military affairs

Were it ever decided that it was necessary to use nuclear weapons against a dangerous astronomical object, there would be significant implications (and probably complications) for global military affairs.

Outer Space Treaty

In 1967 the 'Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies' - more usually called the 'Outer Space Treaty' - was signed. This treaty, which remains in force, forbids the placing into orbit, installation on celestial bodies or stationing in any manner in outer space of nuclear weapons or other weapons of mass destruction. Clearly any use of nuclear weapons against dangerous astronomical objects would be a violation of this treaty. If the necessity ever arose, international agreement to circumvent this difficulty would be necessary.

Military balance implications

One reason for the Outer Space Treaty was the recognition that the placement of nuclear weapons in earth orbit afforded the power possessing them significant military advantages. Weapons already in orbit could be delivered to earthly targets with little warning; the elaborate launch detection systems developed by the superpowers during the Cold War would not be effective against weapons 'stored' in earth orbit and activated at a time of crisis.

Therefore, if it were ever adjudged necessary to use nuclear devices against dangerous astronomical objects, it would be vital to put in place some form of effectively safeguarded control (probably

31 SIPRI Yearbook 1991, p.42. A megaton is the equivalent of one million tons of TNT.
international) such that no state could secure the military advantages which might otherwise accrue.

Paradoxically, however, the size of the nuclear weapons likely to be needed for planetary protection purposes might assist in the negotiation of suitable controls and guarantees. The nuclear weapons of the Cold War period - notwithstanding that there were tests of much more powerful devices - rarely exceeded 5MT yield and most were well below 1MT. This contrasts with the likely requirement for far higher explosive yields in planetary protection devices.\textsuperscript{32} But weapons of this type (50+MT yield) have little utility for terrestrial warfare, so that possession of them might not be as threatening as might at first appear.\textsuperscript{33} Nevertheless, effective and credible international safeguards and controls would doubtless be required.

Conclusions

The spectacular phenomena surrounding the impact of comet Shoemaker-Levy on Jupiter have highlighted the possibility of significant astronomical bodies - comets, comet fragments or meteors - striking the earth. These objects represent a threat not so much because of size (though that is a factor) as their very high impact velocities - typically between forty and sixty kilometres per second (144 000 to 216 000 kilometres per hour).

The earth has without doubt been struck by such bodies in the past. Recent research has almost certainly confirmed that a large (about 10km) body struck on what is now the Yucatan peninsula in Mexico some 65 million years ago, causing climate changes sufficient to cause mass extinctions, including of the then dominant life form, the dinosaurs. Even today, the devastation of large areas of eastern Siberia early this century and craters such as that in Arizona testify to the violence of impacts from astronomical objects.

Though estimates have already been made of the probability of some similar event occurring in future, these must be treated with caution.

\textsuperscript{32} High-yield bombs have an advantage because the intent is to 'nudge' oncoming object(s) off-course. Given the effort involved in delivering weapons to astronomical targets, it is likely (though not certain) that it would be more effective to use a few big weapons rather than more but smaller bombs.

\textsuperscript{33} As already noted, no operationally deployed Cold War nuclear weapon had yields much above 5 MT. Given the precision of modern guidance and delivery systems, lower-yield warheads are more than adequate to take out both large 'soft' targets (such as cities) and point 'hard' targets (eg, missile silos, hardened bunkers, etc). Hence weapons in the tens of megaton range have little military value.
because we have not as yet identified all objects potentially dangerous to earth. It will be important, therefore, to conduct an observation program of sufficient scope to identify such objects, so that a realistic assessment of the threat, and its probability over time, can be made. This is an activity to which Australia, because of its history of excellence in astronomical research, its southerly location and its modern observation facilities, could make a useful contribution.

Not until this is done will it be sensible to talk in any detail about countermeasures. There are a range of technologies which might be applicable including some essentially civilian devices such as lightsails (discussed above), as well as certain options derived from military technology - principally the US 'Star Wars' (SDI) program.

Many of the SDI-based technologies, however, appear unpromising - notably particle beam weapons, high energy lasers and kinetic energy weapons. In fact the military technology most likely to be of use is the old-fashioned large-yield nuclear weapon put into space and detonated in such a way as to divert an oncoming object away from the planet. By contrast, 'Star Wars' exotica are unlikely to be of value.

Thus, before specific technologies for use against dangerous objects are developed, it will be necessary to have identified a specific target object - the further away the better - and to address a range of international military considerations. Among the latter are the application of the 1967 Outer Space Treaty and the question of control over large space-based nuclear weapons.

Therefore, the principal immediate effort should not be directed at countermeasures development, but at gathering sufficient data on the nature and level of the threat so that in future countermeasure questions can be addressed, if they need to be, in an informed context.
References


