48. The risk of asteroid impacts

FROM TIME TO TIME, the topic of near-Earth asteroids, and their potential for impact hazards to our planet, hits the scientific and popular headlines.

I will relate an episode which played out in 2000, during the preparation of the scientific case for Gaia. This involved a number of high-profile personalities, and an important and remarkable opportunity for Gaia.

But ultimately it left me perplexed, and not a little disappointed, at the outcomes which can emerge when different people – in other words different ideas and different priorities – come together from disparate fields.

I IMAGINE THAT most who are reading this will be at least vaguely aware that some of the minor objects in the solar system, continually nudged by gravitational forces, can in principle sooner-or-later impact the Earth.

Left over in colossal numbers from the processes that shaped our solar system's formation, some of the trillions of rocky asteroids, and to a lesser extent the icy comets, could pose some sort of threat.

At the lowest masses, 'dust' and small objects rain down on us continuously. Indeed, it is estimated that 10^5 – 10^6 kg of meteoritic material falls on Earth each day. Larger bodies are rarer, and so is their chance of impact. But their potential for damage is vastly more.

Let me go further back in time to provide some context. During the first 500 Myr of the solar system's existence, some 4–4.5 Gyr ago, Earth grew by colliding with other 'planetesimals'. The energies involved were sufficient to melt much of the growing planet, allowing dense iron melts to sink to the centre to form Earth's core.

Collision of the proto-Earth with a giant impactor, less than 100 Myr after the birth of the solar system, resulted in ejected material coalescing to form our Moon.

The subsequent decline of giant impact events, and the progressive cooling of the Earth's surface, would have allowed the formation of an initial planetary crust. Later tectonic processes destroyed all remnants of this initial crust, and the meteoritic impact sites. But traces of this 'terminal bombardment' are clearly evidenced by the remarkable cratering record of the lunar surface.

IN MORE RECENT geological history, the Earth has experienced many huge impacts, catalogued in the Earth Impact Database, which records their age and size.

For example, in addition to the massive Vredefort and Sudbury craters from 2 billion years ago, impact structures include Morokweng at around 145 million, Chicxulub at 65 million, Popigai and Chesapeake Bay at 35 million, and Kara-Kul at 5 million years ago.

An area of active research today is investigating the possible relationship between the biggest impacts, and the extinction events which are evident in the geological record. Chicxulub, notably, occurred at or close to the Cretaceous–Tertiary boundary, and may have caused the mass (dinosaur) extinction around that time.

In more recent history, the Siberian Tunguska event of 1908 has been attributed to a 50-metre diameter object which probably broke up some 6–8 km above the ground, generating a destructive blast wave and high-speed wind over more than 2000 square kilometres.

The Chelyabinsk meteor, estimated at 20-metre in size, entered Earth's atmosphere over Russia in February 2013, exploding in an air burst at a height of 30 km. Its explosion led to many hundreds of injuries, and thousands of damaged buildings in six cities across the region. Dmitry Medvedev, Prime Minister of Russia, subsequently called for a 'spaceguard' system to protect the planet from similar objects in the future.

NEAR-EARTH ASTEROIDS, or NEOs, are defined as the subset of objects whose orbits come within 1.3 au of the Sun. Only a handful were known in 1980, nearly 1000 in 2000, and more than 25 000 are known today. If their orbits cross the Earth's, and are larger than 140 m in size, they are termed 'potentially hazardous objects'. Two adopted measures, the Torino and Palermo scales, rate their impact risk and predicted consequences.

Of the various searches ongoing, the US and the European Union collaborate on the Spaceguard programme. Encouragingly, an early US Congress mandate for NASA to catalogue at least 90% of NEOs more than 1 km in diameter by 2020, was actually met by 2011.

Excitement, and indeed concern, can grab the news headlines when a possible impactor approaches, but interest typically wanes as the immediate danger recedes. Nevertheless, various events elevated awareness and interest to unprecedented levels in the year 2000.

On the first working day of the new millennium, Lord David Sainsbury, he of the supermarket dynasty but more pertinently UK Minister for Science and Innovation at the time, unveiled a task force to assess the risks. *'The risk of an asteroid or comet causing substantial damage is extremely remote'*, he said, *'But we cannot ignore the risk, however remote, and a case can be made for monitoring the situation on an international basis'*.

Liberal Democrat MP Lembit Öpik (whose grandfather, Ernst Öpik, of Opik's law, was an Estonian astronomer who had worked at Armagh Observatory), had lobbied for the task force, and praised Sainsbury for what he said was a *'brave political move'* in launching it.

The panel comprised just three people: Dr Harry Atkinson (formerly Science and Engineering Research Council and past chair of ESA's Council), Professor David Williams (then RAS President, University College London), and Sir Crispin Tickell (former British ambassador to the United Nations). They were charged with assessing the hazards, and with suggesting how the UK should contribute to international efforts to deal with them.

It is difficult, today, to appreciate the widespread interest that this whole subject generated at the time. The Sainsbury panel, the warnings of scientists, the voices of those involved in experiments searching and tracking these potential impactors, and of course journalists, had brought the topic to much wider public attention. A high-profile competition was even launched to solicit ideas for detecting and deflecting them.

One voice in this drama was Russell (Rusty) Schweickart, lunar module pilot on the 1969 Apollo 9 mission. After leaving NASA in 1977, he served as California Governor's assistant for science and technology, then on California's Energy Commission. In 2002, he co-founded the B612 Foundation, aimed at 'defending Earth from asteroid impacts'. He still serves as its chair emeritus.

I met Schweickart in 2002 during one of his visits to The Netherlands, and he showed a great interest in the potential of space astrometry to assist in this task – the Hipparcos results had recently become available, and the prospects for Gaia were moving to centre stage.

The Sainsbury panel report was duly published on 18 September 2000, and it made 14 recommendations. Amongst these, their third was specific to Gaia's nascent capabilities: *We recommend that the Government draw the attention of the European Space Agency to the particular role that Gaia, one of its future missions, could play in surveying the sky for Near Earth Objects.*

Marching alongside all of this activity, Gaia was competing for its place in ESA's scientific programme. As I have described elsewhere, this involved a detailed review of its scientific case by ESA's scientific advisory committees, and led to its adoption by the high-level Science Programme Committee in October 2000.

Amongst its harvest, the combination of on-board detection, faint limiting magnitude, observations at small Sun-aspect angles, and confirmation from successive field transits, showed that as well as observing all known asteroids, Gaia would discover some $10^5 - 10^6$ new objects down to diameters of 260–590 m at 1 au.

Concerning asteroid impacts, simulations showed, rather remarkably, that the predicted orbital errors based on the Gaia observations alone *100 years after the end of the mission* would be at least 30 times better than the predicted errors corresponding to the *entire set of past and future ground-based observations*.

Let me re-phrase that in somewhat over-simplified and slightly more hyperbolic language: for any big rocks out there of a size likely to inflict substantial damage to Earth, the orbits from Gaia would allow a good prediction of whether they would hit the Earth, or not, *some 100 years in advance* – time enough for some avoidance manoeuvres to be evaluated and, perhaps, enacted.

At a high-profile meeting in Paris on 11 May 2000, representatives of ESA and its Science Programme Committee, of the European Southern Observatory, of the European Science Foundation, of the European Physical Society, and of the International Astronomical Union, all endorsed the pivotal contribution that Gaia promised.

Gaia is indeed today measuring asteroid orbits in huge numbers, and with unprecedented accuracy.

But the '100 year' impact-warning capability applied to the accuracies which were targeted when it was adopted in 2000, viz. 10 microarcsec at 15 mag. Subsequently, in three separate 'de-scopes', Gaia's target accuracy at 15 mag dropped to 15 microarcsec in 2002, to 20 microarcsec in 2004, and to 25 microarcsec in 2006.

As Project Scientist, with full overview of the scientific and technological challenges, I agreed with the first, but not the others. They were nonetheless signed off between the Project Manager (who held the purse strings) and the ESA Director of Science, against my own recommendations and those of the community I represented.

Let me spell out the disapppointment I referred to at the start. Recommendations were made by Lord Sainsbury's panel to search for ways of predicting future impacts. Gaia provided everything demanded. But the urgency of the panel's findings soon faded, and Gaia's ability to address the problem was quietly curtailed.

When the problem resurfaces, it is worth recalling that a solution through astrometry is still at hand.