Bulletin Issue 12
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Editorial

This is my last Bulletin as Editor and although I have enjoyed the role, contributions from members have been disappointing few and far between. However I am very grateful for the few who did provide reports, papers or information. By moving the issue dates I had hoped that I might have received some reviews/comments about the Cheltenham Science Festival but it was not to be. I hope whoever takes over from me has greater success.

Members

We welcome Paul and Ana Gifford Nash who have joined the Society.

News/Comments

The Society continues to provide a prize to Cirencester College for Commitment in the Scientific Field and this year it was awarded to Svetlana Kulikouskaya. Her citation was "Svetlana is a very keen student who undertook many ambassadorial roles; she could be relied on to provide honest and considered opinions to future students. Her interest in science, particularly Biology and Chemistry, always let to challenging and informative discussion and it was rewarding to watch her develop her understanding. We are sure that her determined approach is helping her succeed as she reads Medicine at Cardiff University.

On 24th and 25th June, Cirencester College held their second "STEM Big Bang" event – a celebration of STEM activity in the region and creating a festival-like environment to celebrate STEM activity and STEM careers. It attracted almost 1000 primary and secondary school children with participation from over 20 activity providers including regional STEM industry and HE establishments.

Two ongoing themes running through the event were 'Women in STEM' and 'Engineering Careers for the Future'.

Participating schools were encouraged to enter a competition on the day: either the IET 'Luxury Global Transport Challenge', or by preparing a rocket car, which would be powered by either compressed air or a mini ‘Estes’ rocket as developed by Bloodhound.

The college worked closely with STEMNET coordinators in Gloucestershire and Wiltshire, as well as contacts sourced through ‘Inspiring the Future’ in order to involve a wide variety of ambassadors and contributors.

All activities were scheduled so that pupils from each school followed an itinerary consisting of time in the college theatre for ‘Wonderstruck’ and a short key note speech on careers in Engineering, as well as the opportunity to participate in various exciting workshops of 30 minutes duration with the contributors.

The Big Bang event is the flagship event for STEM at the college, bringing together many different threads of activity and acting as a regional STEM hub. The hub enables effective communication between the key components of regional STEM, including schools and industry, and aims to embed the Big Bang as an annual event, along with associated careers awareness events held at other times of the year.

The College is launching new initiative with the aim of creating a STEM Academy which is fully affiliated with the Career Academies UK.

This year’s Cheltenham Science Festival ran from 3 – 8 June and from a personal point of view I found the programme less inspiring than last year. However the Discovery Zone seemed as popular as ever with schoolchildren.

One or two controversial issues were raised including Robert Winston reigniting the debate on sex selection with the comment “In my view, choosing the sex of your child isn’t such a bad thing” and Professor Richard Dawkins arguing that parents should consider sweeping aside childhood fantasies and fairy-tales in order to “foster a spirit of scepticism” in their children. He claimed that the stories we tell our children about fairies, unicorns and Santa Claus were second-rate when compared to the scientific world view. Two lectures I particularly enjoyed were “Music and the Brain” and “The Secret of Bones”. Olga Bobrovnikova – a Moscow Conservatoire-trained concert pianist with Multiple Sclerosis (MS) - talked with Mary Baker, the current chair of the European Brain Council about brain research and how the brain reacts to music. She provided a range of intriguing musical examples and some of the results of studying the neurology of her MS-damaged brain. BBC evolutionary biologist Ben Garrad and Alice Roberts talked about skeletons and bones and using the hands of a wide range of primates gave a very convincing demonstration of evolution at work.

The Sky is Falling! – Risks and Mitigations
by Michael McEllin

The explosion of a meteor 23 km over Chelyabinsk in the Ural Mountains on 15th February 2013 is possibly the first well-recorded case of an extraterrestrial impact causing a significant amount of human injury and structural damage. In some ways, this is rather surprising, because the predicted average annual death rate from extra-terrestrial impacts is ~90/yr. However, using annualised death rates can be very misleading when the majority of the risk is associated with rare but extremely destructive events. Nevertheless, the Chelyabinsk event – equivalent to ~500 kt of TNT – is by no means out of line with statistical expectations. (See [1] for an excellent survey.) We may, in fact, regard ourselves as lucky that we have not seen worse. Indeed, had the Chelyabinsk object approached on a steeper trajectory, giving deeper atmospheric penetration before exploding at low altitude, it could easily have been very much worse – especially as the Russian equivalent of Aldermaston is located in that region.

No-one worried about cosmic impacts until 1980, when Alvarez et al. [2] controversially invoked a 10 km asteroid as the cause of the mass extinction marking the end of the Cretaceous Period (and the *coup-de-grace* for the dinosaurs). However, in February of this year, the 50m diameter near earth object (NEO), catalogued as *2012 DA14,* also passed below some of our satellites. It is, in fact, becoming clear that the risk levels may be higher than most of us perceive, since until recently we were never aware of the many near misses. Though most of these remain unobserved, we now see some because we are actively looking, and with better instruments. (N.B. I am making the term 'NEO' do a general stand in for a number of more precise terms used by planetary scientists. For the present overview we do not need these fine distinctions. Informally, NEOs are Solar System 'minor bodies' that are steadily leaking, mostly from the asteroid belt, into orbits close to Earth's. We call them meteorites when they actually hit the Earth. A meteor is the visual phenomenon.)

In the last decade we have made spectacular progress. Fully automated telescopes can now scan the sky, identify previously unknown NEOs, calculate their orbits, predict possible future Earth encounters, and then email notice of Armageddon to nominated astronomical observatories and data-clearing houses, such as Minor Plant Centre (MPC) at Harvard, all before breakfast. However, if a prediction raises concern, protocol dictates an escalation route through NASA, involving independent verification by experts of the orbit calculations, before governments are alerted. The White House has been contacted on one occasion, in 2008, when the Catalina Sky Survey issued an impact warning, fortunately, in this case, for a meter-sized object that exploded harmlessly over the Sudan a few hours later.

However, a US Air Force (USAF) planning exercise in 2009 assumed that the US President may first hear about an impending major strike from the public news networks. The need for a rapid mobilisation of astronomical observing resources, to gather crucial additional data, means that the raw information is distributed world-wide very quickly, and rapid leaking to new channels is highly probable. The exercise considered that they might even have to start managing an unplanned evacuation already in progress by the time government woke up. The USAF concluded that they were ‘unprepared and uncomfortable’, partly because the potential scale of damage is larger than with other types of major hazard and, in some locations, it could even instantaneously change an established balance of power and ‘destabilise the World Order’.

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With the next generation of super-sensitive instruments (such as the *Large Synoptic Survey Telescope* (LSST) – see www.lsst.org) we may well spot a new NEO that, initially, appears to present a significant threat about once a decade. (The 8m diameter LSST – just starting construction – represents a major leap in technology, and is designed to scan the entire available sky for transient astronomical events every few nights with unprecedented sensitivity and automated data-handling capability.) For the vast majority of cases, subsequent observations will refine the knowledge of their orbits, decrease position uncertainties, and reduce the bounds on impact probabilities to negligible levels. The application of such refining techniques has occurred with the 300 m diameter NEO (99942) Apophis. When first identified, it was accorded an estimated 3% chance of hitting the Earth in 2029. Later radar observations provided a more accurate velocity estimate and confirmed that it would miss *that* rendezvous – but might catch up in 2036. The most recent radar observations from a close passage in January/February 2013 confirm that we will be safe in 2036 – but that we now have 1/189,000 chance of impact in 2068. These probabilities are not negligible for an event that could devastate an entire country, and a UK report [3] concluded that if similar levels of risk were associated with an industrial process, action would be required.

As a result of NASA surveys (http://impact.arc.nasa.gov, informally known as ‘Spaceguard’ after a fictitious organisation in Arthur C Clarke’s ‘*Rendezvous with Rama*’, we are now reasonably sure that all NEOs capable of causing global catastrophe (i.e. > 3 km diameter) have been catalogued, along with most of those >1 km diameter, and all of these are very unlikely to strike during the period in which NEO orbits remain reasonably predictable (a few centuries). That is fortunate, since we do not possess any means to mitigate the impact risk from these larger objects. However, for at least some objects smaller than 1 km, which now represent the bulk of the residual impact risk, it does appear to be feasible with current or near future technology to successfully deflect threatening NEOs.

Unfortunately, at any one time, about half the hazardous NEOs are between the Earth and the Sun and therefore hard to see, so if we rely only on ground-based instruments, about half of all impacts will come with little or no warning. Ideally, we need a telescope flying between Earth and the Sun to find and characterise these objects, observing in the infrared, where these small dark objects are relatively much brighter. No government is at present proposing to mount such a mission, but the 'B612' foundation in the USA has now raised funds to fly "*Sentinel*", the World's first privately funded interplanetary mission. Within five years of launch, *Sentinel* should identify all potentially hazardous NEOs capable of causing regional destruction, perhaps 90% of those larger than 140m in diameter, as well as a large fraction of smaller objects.

The plane of an NEO's orbit can be determined very accurately, intersecting the Earth's surface along a track of uncertainty perhaps only 10 km wide. Predicting the actual impact location is usually more difficult because very accurate velocity measurements are required to determine the exact impact time. For smaller objects (<100 m) mitigation by evacuation is therefore a real possibility since people may only need to move 50 km north or south of the impact locus to be relatively safe. Events similar to the 1908 airburst over Tunguska (which flattened several thousand square kilometres of Siberian forest) would indeed produce massive destruction over city-sized areas, but lives could be saved.

If, as with Apophis, advance detection gives us decades to prepare, then deflecting the object may well be feasible. The 'Deep Impact' space mission to comet Temple has demonstrated that we can accurately fire a heavy mass into a remote NEO. A two cm/s change in velocity is feasible for sub-kilometre bodies and this would accumulate over two decades to about 12,000 km – enough for a miss. We already have enough heavy-lift capability to reach many smaller NEOs with sufficient velocity and mass. Other options are being studied and look feasible with near-future technology.

If there is less warning time, or for larger bodies, nuclear explosions may have to be used because they can produce a larger, though much less precisely controllable, impulse. The bomb would need to explode a few hundred meters away from the body, causing the surface to evaporate or fracture and eject towards the explosion, and pushing the object in the opposite direction. Completely fragmenting the object (which in any case would take much more energy) is very much what you do *not* want to do. The best guess is that perhaps half of the fragments would hit you anyway, producing dozens of Tunguska-like events that might well be more destructive than a single ground strike. Developing and testing space-hardened nuclear capability in the absence of a specific threat is currently forbidden by international treaty, so we would need time to design and build novel technology. Nevertheless, with perhaps five years of grace, experts believe that such a space mission could be mounted. Given the risks and consequences of failure, most likely all space-faring nations would wish to mount independent but coordinated missions.

Because more warning time gives more options, the best way to mitigate future impact events must involve an extension of the Spaceguard survey, and the US Congress has now mandated NASA to catalogue all NEOs larger than 140 m by 2030. (This size limit would address most of the remaining risk, and is also technically feasible.) Unfortunately, it has voted no money for new instruments and space missions, so completion of the survey is, in fact, unlikely on that time scale. (The private *Sentinel* mission will hopefully make considerable progress on this task by 2030.)

That was the good news. Anyone who reviews this topic is immediately struck by the many uncertainties. Stony objects make up the majority of impactors and the smaller examples (<100m diameter) normally fragment in the atmosphere (but some certainly do not). Theory says that even 500m stony bodies *may* sometimes fragment. Over land that would probably be much more destructive than a ground strike. (The Tunguska event, according to some authorities, may have been caused by an airburst from a body as small as 40m.)

We are uncertain about what happens when a large impact occurs in the deep ocean. Some estimates suggest that a 500m impact into the North Atlantic would cause highly damaging tsunamis all round the US and European coasts. (But others claim that the effect would be no worse than a severe storm surge.) If the pessimistic estimates are correct, about half the impact risk from presently untracked NEOs would be associated with impact tsunamis, because tsunamis are an efficient mechanism of propagating impact energy large distances to populated coasts. In my view, the pessimistic estimates securely bound the worst-case scenarios, but they might overestimate the real risk by an order of magnitude.

Validation evidence for any of the tsunami predictions is almost completely lacking. Most of what we know about earthquake-generated tsunamis is not relevant to ocean impacts, particularly because the initial wave amplitude and shape produce very different wave propagation characteristics, leading to strong attenuation of wave height in proportion to distance from the source (more like $1/r$ than $1/r^{0.5}$).

There ought to be some signs of impact tsunamis in the geological record, and maybe these can inform the risk estimates. For example, there seems to be no obvious alternative explanation for 286 ton boulders deposited by water 33 m above sea level on the eastern coast of Australia. Coarse sandstone deposits in Chile contain melted quartz globules, strongly suggesting an impact tsunami, and inland surface deposits in Antarctica reveal marine micro-fossils, which can only have been carried there by a mega-tsunami. Some or all of these may be connected with a 1-2 km impact in the Belinghausen Sea (between Chile and Antartica) about 2.5 million years ago. Unfortunately the dating evidence from the disturbed ocean floor deposits is only approximate, so the connections between this event and the various tsunami deposits are all speculative. Furthermore, the expected rate of ocean impacts makes it reasonable to explain these geographically dispersed deposits by multiple, smaller impacts. Other marine-impact craters have been found, but all are difficult to relate to associated tsunami deposits – except for the enormous Chicxulub impact, a 180 km diameter, now buried, crater near the Yukatan peninsula in Mexico, which is believed to have terminated the Cretaceous Period. Even in this case, none of the deposits is diagnostic of the wave height. In no case can we relate the size of a tsunami to the size of an impact.

All the above discussions depend on computer simulations of complex physics, involving extreme conditions that are difficult to reproduce in the laboratory. It appears to me that most of the published work has few details that let one assess its dependability. Les Hatton [4] has shown in the past that many scientific codes contain more implementation errors that their authors would like to believe. More recent discussions in the IEEE journal *Computational Science and Engineering* (July/August 2012) have talked of a 'crisis of confidence' in computational science, with few published results being truly reproducible. The extent of disagreement in published work means that most of the calculations (at the very least) have to be wrong – but we cannot yet tell if any deserve to be believed.

I do not worry about asteroid impacts. The risks are low (though not as low as many think). However, the current expenditure on Spaceguard and associated activities is also low ($4M/yr), and under threat. Given that the US alone spends about $700M/yr to mitigate an expected 11 US deaths/yr from earthquakes, expenditure appears unbalanced. As with asteroid impacts, most of these deaths would be associated with large but rare events. The difference is that the US has already had a big earthquake in San Francisco in 1906 – and sufficiently regular minor tremors to remind people of the threat. It is all a matter of risk perception, and governments do not like to be in a position when they could have done something but did nothing. Perhaps Chelyabinsk will change some perceptions.

References

[1] NAS NRC, 2010. Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies: Final Report: Committee to Review Near-Earth Object Surveys and Hazard Mitigation

[2] Alvarez, Luis W. , Alvarez, Walter, Asaro, Frank and Michel, Helen V., 1980. Extraterrestrial Cause for the Cretaceous-Tertiary Extinction, Science, Vol. 280, no 4448, pp 1095-1108

[3] Atkinson, H., Tickell, C., Williams, D., 2000. Report of the task force on potentially hazardous near Earth objects. http://dx.doi.org/10.1.1.22.1904, accessed 23 May 2013

[4] Hatton, L., 1997. The T experiments: errors in scientific software. IEEE Computational Science Engineering 4, 27 –38

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Forthcoming Events

The British Science Festival celebrates all things scientific and will be hosted by the University of Birmingham in September 2014. Organised by the British Science Association, the event offers something for everyone
Venue: Birmingham City Centre and Edgbaston Campus
http://www.birmingham.ac.uk/university/british-science-festival/index.aspx

Tailpiece