# Cosmic Roulette

Travelling twenty kilometres every second the asteroid will take less than ten seconds to breach our atmosphere and impact the ground. Two billion tons of rock will come to an abrupt halt, yielding an energy equivalent of a million nuclear bombs in a maelstrom of heat, radiation and shock waves. A large fraction of the energy propagates through the earth's crust as seismic shocks, triggering secondary volcanic eruptions. Deeper seismic waves penetrate the earth's interior, refocusing at the antipodal point with devastating results.

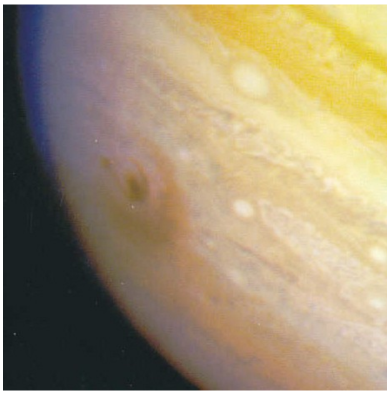
Large quantities of asteroid and earth rock are ejected back into space on low energy orbits only to rain down hours later over the entire planet in a deadly hail of fire and rock. The gossamer layer of our atmosphere is churned by ferocious hurricanes fuelled by the super-heated turbulent conditions and widespread forest fires. Huge amounts of choking dust and gases spread over the planet. An ominous dark blanket of dust slowly settles over the entire planet's surface, which, in the course of geological times, is overlaid and incorporated as yet one more layer in the geological strata of rock chronicling our planet's history.

A hundred million years later, the dark narrow layer, surprisingly rich in elements like Iridium, more usually found in asteroids, may be all that survives as evidence of a moment when life as we knew it came to a halt. Chilling clues perhaps in a future detective story for any life-form curious enough to bother investigating.

Now you can't say we weren't warned. Our own moon, the very picture of serenity, smiling down peacefully on us day after day, should more soberly remind us of a time when the cosmic shooting gallery was more active than it appears today. Even through small binoculars, the moon's weather-less surface, unchanged for millions of years, reveals countless impact craters, many over a hundred kilometres wide, with ejection debris and secondary craters strewn across the entire surface. Even the relatively smooth maria conceal a violent history of secondary molten outpourings backfilling the deepest gouges.

And then there is the 1994 impact. First detected on 24 March 1993 by a team of astronomers at Palomar observatory, initial calculations indicated an object about 5 km across moving on a direct collision course, with impact predicted for 16 months. Earlier photographs of the same region of sky were scrutinised for pre-discovery images. Intense observations followed over several weeks and the orbit recomputed using the most accurate data available. Calculations were complete by May 1993, predicting an imminent collision at 19:13 Universal Time on 16 July 1994.

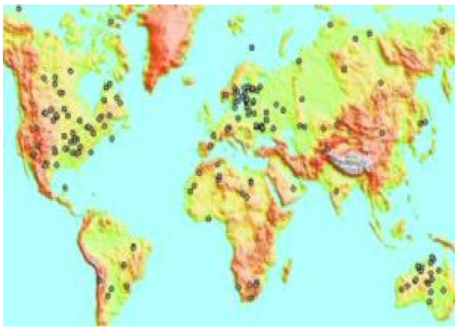
Within twenty minutes of the predicted time, the first of twenty-one fragments, the largest about 3 km across, impacted at speeds of 60 km per second. Stupendous destruction spread out across the planet's surface, devastating an area many times the size of the earth. The impact of comet Shoemaker-Levy with Jupiter was the first recorded collision between two bodies of our solar system. The event was observed by an armada of satellites, the Hubble telescope and numerous ground based observatories on earth.



In 1990 the buried remains of a crater 200 km wide and 20 km deep were found near the town of Chicxulub on the Yucatan peninsula in Mexico. Debris from an asteroid estimated at 15 km in diameter was found linking the impact to the well documented extinction event of 65 million years ago when the dinosaurs and 90% of the planet's species disappeared.

Recently, oil-company geologists discovered a 40 km crater under the Barents Sea off the Norwegian coast. Analysis of rock grains and radioactive minerals from the seabed indicate a 2 km object impacting some 150 million years ago.

In the Tunguska event of 1908, an area of Siberian forest hundreds of kilometres wide was flattened when a near-miss object grazed the upper atmosphere. In all some 150 impact craters have been identified on earth, with some of the largest linked to significant extinction periods in the world's history.



Object 1994 AN10 is an earth-crossing asteroid about 1 km across. Initial orbit calculations predicted a near-miss at 3 earth diameters for 7 August 2027. Subsequent calculations incorporating pre-discovery images now put close approach at some 30 earth diameters. The earth's gravity will perturb the asteroid's orbit during the encounter, so three subsequent passes predicted this century will also be observed.

2003 QQ47 is a similar earth-crossing asteroid with close approach predicted for 21 March 2014. Latest calculations predict a 40 earth diameters encounter.

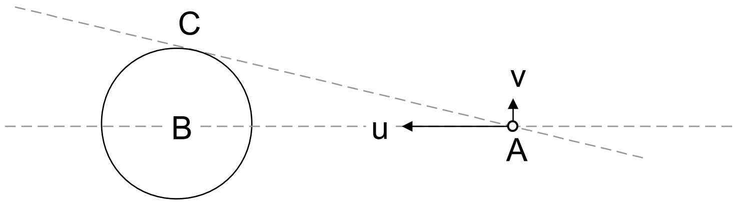
On 14 June 2002 asteroid 2002 MN, an object about a hundred meters across passed within 8 earth diameters. Eros 433 regularly buzzes the earth in the course of its orbit around the sun. Its last visit saw NASA land a car-sized probe on its surface.

In all, between 500 and 1000 potentially lethal earth-crossing asteroids are known and their orbits monitored routinely by organisations such as Spaceguard, NEAT, LINEAR and NEAR. These bodies organise the observations and computation of collision probabilities. The latest collision probability for the 2014 encounter is calculated at 1 in 909,000.

Many of us consider the odds of winning the jackpot sufficiently attractive to buy a lottery ticket on occasion. Yet the computed probability of collision in 2014, while seemingly remote at 1 in 909,000, nevertheless represents a ten times greater risk than winning the jackpot. Each lottery ticket sold is an implicit acknowledgement that extinction is a more likely outcome than becoming rich overnight.

In the film Armageddon, Bruce Willis and his crew of roughnecks save the world from an impending asteroid collision. Exciting, tear-jerking stuff and in true Hollywood style we end up grateful to our favourite role models, human altruism and technology. But what's not generally acknowledged, maybe because the prospects really are too scary for general consumption, is that present day technology could do very little about such an event. In the game of cosmic lottery played out by the largest planets of our solar system, where city sized boulders are routinely tossed down our end of the solar system, it seems we can do little more than pray our number doesn't come up just yet.

To see this requires a few order of magnitude calculations. Suppose that the object is at A, initially a distance d from earth and is approaching with speed u on an exact collision course AB. We now ask, what is the minimum transverse speed v to apply at A to cause the object to follow a near-miss course AC?



At approach speed u, the time to collision is given by t = d/u. The speed v must therefore be sufficient to develop a transverse distance of one earth radius R over the time available, that is  v = Ru/d. Clearly, the earlier we can apply this nudge, the smaller its magnitude need be in order to effect a near-miss.

How might we achieve such a nudge? The easiest way is to arrange a cosmic collision of our own. When a bomb explodes, fast moving material is ejected in all directions. For a bomb exploding "beneath" the asteroid, half the bomb's mass ejects at high speed into the asteroid in the required direction, the other half in the opposite direction without effect. For a bomb of mass [illegible] and ejection speed w, the transfer of momentum to the asteroid amounts to $\mu w/2$. Hence for an asteroid of mass M, the transverse speed developed is $v = \mu w/2M$.

How large a bomb is required to provide this impulse? Nuclear bombs convert about 1% of their core mass into kinetic energy via the well known equation $E=mc^2$. The energy imparted to one half of the bomb's mass is therefore $0.5 \times (0.01 \mu) \times c^2$, which equating to $0.5 \times (0.5 \mu) \times w^2$, yields the estimate $w \approx c/7$. Substituting this estimate into $v = \mu w/2M$ and rearranging gives the bomb size in terms of the required nudge speed $\mu = 14Mv/c$.

For a nudge speed $v = Ru/d$, we therefore require $\mu = 14MRu/cd$ .

Let's fix ideas with some realistic data for object 2003 QQ47:

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|---|---|
| $M = 5 \times 10^{12}$ Kg | $d = ut = 9 \times 10^{12}$ m |
| $R = 6000$ km $= 6 \times 10^6$ m | $t = 10$ years $= 3 \times 10^8$ s |
| $u = 30$ km/s $= 3 \times 10^4$ m/s | $c = 3 \times 10^8$ m/s |

Substituting these values gives,

$$v = Ru/d = (6 \times 10^6) \times (3 \times 10^4) / (9 \times 10^{12}) \approx 0.02 \text{ m/s}$$

$$\mu = \frac{14MRu}{cd} = \frac{14 \times (5\times10^{12}) \times (6\times10^6) \times (3\times10^4)}{(3\times10^8) \times (9\times10^{12})} \approx 5000 \text{ Kg}$$

Conventional hydrogen bombs are thought to have cores of up to 100 Kg mass. The construction and delivery of fifty such bombs therefore represents a substantial, though perhaps still feasible, demand.

However, there is another consideration. How accurately can we know the incoming orbit in the first place? Our calculations take as a starting point that the object is on an exact collision course with the earth. We have seen, in this case, we might just be able to effect a near-miss orbit if we act early enough. But what if our knowledge of the initial orbit is slightly inaccurate and the object is already following a near miss orbit?

The uncertainty in orbit prediction arises mainly from the uncertainty in the observational data, typically about 1 part in $10^6$. This results in, not one unique computed orbit, but an entire "tube" of candidate orbits all consistent with the observational data. The proportion of orbits in the tube which are computed to subsequently collide with the Earth, defines the collision probability. As further observations become available, the width of the tube narrows, so that eventually the collision probability tends to 0 (no collision) or 1 (definite collision) as the orbit becomes completely specified by observational data.

In the case of the Shoemaker-Levy collision a 20 minute uncertainty in impact time existed right up to a few months before collision. A 20 minute uncertainty may not sound very much, but at orbital speeds of 30 km/s, a target such as the earth will travel its own diameter in about 7 minutes, turning a collision into a near-miss, or perhaps more ghastly, a near-miss into a collision.

All this leaves our would-be Bruce Willis with a tricky decision. Notwithstanding our best technical and intellectual efforts, the actual outcome in a hit / near-miss scenario may well remain uncertain right up to a few months before impact, by which time the opportunity to nudge the object into a near miss will have passed. On the other hand, taking the nudge option ahead of a sufficiently accurate knowledge of the orbit could turn out completely unnecessary or, in the grisliest scenario ever scripted, convert a near miss into a direct hit.