The Tunguska Event and the Threat from Near-Earth Objects

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Let us go back one hundred and one years, to the 30th June 1908, and imagine a group of people, somewhat like ourselves, meeting to spend an hour or two together. There was no reason, on that warm and pleasant evening, for anyone to think they were about to experience something unusual. British Summer Time had yet to be introduced, so the sun set, as expected, at around 8.30 pm, heralding the onset of night-time. Everything seemed perfectly normal. However, as the light coming from the sun faded away, it was becoming increasingly evident that there was a strange reddish glow in the northern sky, which prevented darkness falling. This persisted all through the night, and for several subsequent nights. The same phenomenon was observed in all parts of Britain and, indeed, throughout Europe, from Berlin to Spain, and also in North America. British newspapers published letters from people saying that they had found it light enough after midnight to be able to read small print outdoors, and to play golf or cricket. There were reports of farmers taking advantage of the situation to work throughout the night, bringing in the hay while the weather remained fine.

On 4 July, *The Times* newspaper responded to readers' questions about a possible explanation. It noted that some experts thought it likely that the phenomenon was similar in nature to the aurora borealis, and might be linked to sun-spot activity. However, it then went on to point out that a similar reddish glow had been seen in the night sky in 1883, when it was known to have been caused by dust thrown into the upper atmosphere by the Krakatoa eruption, so it suggested that there may have been a massive volcanic eruption somewhere on this occasion too. It later emerged that sensitive instruments in laboratories at six different locations in England had all recorded unusual fluctuations in barometric pressure beginning shortly after 5 o'clock on the morning of June 30. This was taken to indicate that there had been a large atmospheric disturbance in some part of the world several hours before then. Unfortunately, there was nothing to indicate a precise time or place. With no leads to follow up, British, European and American interest in the matter quickly dissipated.

In Russia, interest was more sustained because, as well as the general observation of light nights, there were more specific reports and scientific data to consider. An earthquake-detecting station at St Petersburg recorded a tremor occurring during the morning of June 30, and corresponding seismic, magnetic and atmospheric disturbances were recorded at the Irkutsk Observatory in southeast Siberia. Subsequent analysis showed the data to be consistent with the occurrence of a large explosion on the Central Siberian Plateau, in the region of the Stony Tunguska River, at 7.14 a.m. local time (corresponding to 12.14 a.m. GMT). At about this time, passengers on the Trans-Siberian Express, 600 km to the southwest of the Tunguska region, heard loud bursts of noise and the train began to shake wildly on the tracks, forcing the driver to bring it to an emergency stop.

On 15 July, an Irkutsk newspaper reported that, on the morning of 30 June, peasants in the village of Nizhne-Karolinskoye, about 465 km southeast of the Tunguska region, watched a distant bright object fall for about 10 minutes before disappearing in a huge cloud of black smoke as it approached the ground. This was followed by a loud crash, causing all the buildings in the village to shake, and a forked tongue of flame broke through the cloud, making the superstitious villagers think that the world was coming to an end. Another newspaper report, from a correspondent in the village of Kezhma, 215 km southwest of

Tunguska, appeared on 26 July. This described a body of fiery appearance cutting across the sky from south to north. When it touched the horizon a huge flame shot up that cut the sky in two. This was followed by loud bangs and the earth began to shake, causing buildings to tremble. Animals and people alike ran around in a state of panic.

However, at the time, Russia was in political and social turmoil, and so, not surprisingly, the authorities in St Petersburg showed no interest in sponsoring an expedition to the Tunguska region to investigate what had happened – particularly since it was a remote, inaccessible area of thickly forested taiga, where the ground was frozen solid for most of the year, and boggy during the remainder. Only after the First World War and the Bolshevik Revolution did the possibility of an investigation arise, and that was largely due to the enthusiasm and determination of one man, the mineralogist Leonid Kulik, who had established a reputation for himself as an authority on meteorites. In 1921, the Soviet Academy of Sciences appointed Kulik to lead an expedition to locate and examine meteorites which had fallen in well-populated parts of Russia. It was on this expedition that Kulik first became aware of the Tunguska event of 1908, and the indications that it had been caused by the fall of a meteorite

Let me mention a few definitions at this stage, with the warning that distinctions between categories are often not clear-cut. Solar System objects consisting predominantly of rock and/or metal, which are substantial but not considered large enough to be classified as planets, are known as asteroids. Objects considered too small to be classified as asteroids – and there is no universal agreement about where the cut-off occurs: some say 50 metres in diameter, others 10 metres - are known as meteoroids. Meteoroids which enter the Earth's atmosphere, and show up as streaks of light because of the frictional heat generated, are termed meteors. Most meteoroids entering the atmosphere, which are generally towards the bottom of the size range, i.e. little more than specks of dust, burn up completely before reaching the Earth's surface. However, parts of larger ones may survive the passage through the atmosphere and, when these are found on the Earth's surface, they are termed meteorites. These were what Kulik was searching for.

On his 1921 expedition, Kulik was shown a brief note about the Tunguska event, apparently written in 1910, which claimed that, shortly after the loud crash which shook the region on the morning of June 30 1908, a large meteorite, initially too hot to touch, had been found protruding from the ground. That stimulated Kulik into an energetic search for newspaper reports and eye-witness accounts. However, his expedition had already run out of time and money, so he had to return to Petrograd (the new name for St Petersburg), without being able to carry out a search for the Tunguska meteorite, but he was convinced of its existence.

The Academy of Sciences members were far more sceptical, and rejected Kulik's application for funds to visit the region. A few years later, three articles in the magazine *Mirovedeniye* changed the situation. In 1925, A.V. Vosnesensky, who had been Director of the Irkutsk Observatory in 1908, wrote that the magnetic storms and atmospheric waves recorded on 30 June of that year were probably caused by the explosion of a meteorite about 30 km above the surface of the Earth, and the corresponding Earth tremor by the shock of the fragments hitting the ground. In the same year, the geologist S.V. Obruchev gave an account of what he had been told by the nomadic Tunguska people, the Evenki, when he was working in the region in 1924. They had described a flattened forest northeast of Vanavara, and a related sacred object (apparently a giant meteorite) whose location was a secret. In 1927, an ethnographer, I.M. Suslov, reported 60 eyewitness accounts of the event which he had collected during the previous year from the Evenki people. They spoke of the forest being flattened, reindeer herds being annihilated, and grain stores destroyed.

These accounts helped Kulik to secure further Academy funding and, in 1927, he left Leningrad (the latest name for what had been St Petersburg) on the first of his four expeditions to investigate the remote, inhospitable Tunguska region. To cut a long story short, Kulik's small party set off from the tiny trading post of Vanavara, the most northerly outpost of civilisation, following the Stony Tunguska River and, 5 days later, came across a swathe of fallen trees. To get a better perspective, the party spent two days climbing a nearby mountain and, from the summit, gazed over an oval plateau, 70 km wide, where the entire forest had been flattened, the trees burnt, stripped of foliage, and snapped off in the same direction, clearly as a result of an enormous blast. For various reasons, it took Kulik more than a month to get to an area where the fallen trees radiated out in every direction from what must have been the epicentre of the blast. To his considerable surprise, the epicentre itself was marked by a cluster of trees which, although scorched and bare of foliage, were still standing erect. Furthermore, contrary to his expectations, there was no sign of any giant meteorite or large crater formed by its impact. That caused him to make adjustments to his thinking, and propose that the blast had not been caused by the impact of a single, large meteorite, but by the arrival of a cluster of smaller meteorites. He therefore spent much of time on his subsequent expeditions searching various depressions and holes in the region of the epicentre for evidence of meteorite fragments, without finding any. Evgeny Krinov, who served on Kulik's third expedition and went on to become chairman of the academy's meteorite committee, came to the conclusion that Kulik had been wasting his time. The most likely explanation of the evidence was that the incoming object had exploded in the atmosphere in comprehensive fashion, leaving no residual fragments of any significant size to carry on and hit the ground.

Although forming his own view on that point of detail, Krinov otherwise agreed with Kulik that the fallen trees, radiating out from an epicentre, were testimony to the fact that a huge explosion had occurred in the region on June 30 1908. An estimated 80 million trees had been knocked over, in an area of over 2000 square kilometres. An aerial photograph taken at the instigation of Kulik in 1938 showed that the devastation had occurred in a butterfly-shaped pattern, with the epicentre near to the butterfly's head. Apart from one old man who died of shock, it appeared that no human being had been killed by the blast, but, as Kulik pointed out, that was simply because the region was so sparsely populated. He went on to write, "Had the meteorite fallen in central Belgium, there would have been no living creature left in the whole country; on London, none left alive south of Manchester or east of Bristol". No survivors south of Manchester? Kulik was undoubtedly guilty of exaggeration there. At the trading station of Vanavara, a farmer, Semen Semenov, was sitting on the porch outside his house when he was knocked off his chair by the force of the explosion. He said later that the heat seemed to be burning his shirt and he lost consciousness for a moment. Then his wife helped him back to his feet and into the house, which was still standing, although the windows were shattered. Like Semenov and his wife, all the other inhabitants of Vanavara survived the blast, even though they were only 70 km from the point of the explosion, i.e. about the distance from London to the Newport Pagnell service station, less than a third of the way to Manchester.

Nevertheless, regardless of Kulik's exaggeration, it is clear that, if the epicentre of the blast had been in London, or any other major city, the death toll would have been enormous. It has been pointed out that that, if the source of the Tunguska blast was indeed an extraterrestrial object, as Kulik and Krinov supposed, and if it had arrived just four hours and 45 minutes earlier, it would have devastated St Petersburg, then the capital and political centre of Russia, and the subsequent history of the world might have been very different.

Let us leave the Tunguska event for a few minutes, and look in more general terms at the threat to Earth from asteroids and large meteoroids, as well as from comets, and consider how knowledge of this threat has developed. In the western world for much of the past two thousand years, the appearance of brightly-tailed comets and shooting stars, i.e. meteors, has caused consternation, because they were generally seen as signs from God of an impending disaster. Look at the terrified expressions on the people on the left-hand side of the Bayeux Tapestry as they stared up at Halley's comet in 1066, and the implication on the right-hand side that the comet foretold doom for Harold. However, in what might seem like a contradiction, but isn't, there was at the same time a dogmatic certainty that celestial objects such as this comet could not, themselves, pose a threat to the Earth as a result of any natural process. The reason for this was the adoption by Christian philosophers of Aristotle's 'onion skin' view of the Universe, with the Earth in the centre, surrounded by a series of spheres containing the stars and planets. The heavenly spheres were regarded as perfect and unchanging, and were segregated from the corrupt Earth. Hence nothing could fall to Earth from the heavens. This geocentric model of the Universe was demolished during the 16th and 17th centuries, when it was demonstrated that the planets, including the Earth, moved around the Sun according to natural laws, but, even then, the philosophical belief that the Earth was isolated from the heavens continued to hold sway. In his *Principia Mathematica* of 1687, Isaac Newton showed conclusively that comets were objects obeying the same laws of motion as other cosmic bodies, but then went on to argue that, since God was benign, he would have taken care to make sure at the time of Creation that they were in orbits that would not cause them to crash into the Earth.

Claims that meteorites had fallen from the sky were treated with considerable scepticism, because of philosophical considerations. In 1768, a group acting on behalf of the French Academy of Sciences investigated reports that a large stone had fallen from the sky near Lucé, and concluded that the incident could not possibly have happened as described, so all the witnesses must have been mistaken or lying. In contrast, an investigation by the German physicist, Ernst Chladni, into the origin of several large masses of iron found at the Earth's surface, concluded in 1794 that they had probably come from space. His conclusions were dismissed out of hand by most other scientists, one critic writing, "He contradicts the entire order of things and does not consider what evil he is causing for the moral world". However, when several thousand stones fell out of a clear sky in Normandy in 1803, the Academy investigators had little option but to accept the claims of the witnesses. Yet, even after that, when President Thomas Jefferson was told that two Yale scientists were claiming that a meteorite had struck the Earth at Weston, Connecticut, he is reported to have replied, "It is easier to believe that two Yankee professors would lie, than that stones should fall from the sky".

Although the extraterrestrial origin of meteorites became generally accepted during the 19th century, it seemed that a meteorite fall could do no more than cause panic and a little localised damage. Some oxen were apparently killed by a meteorite in Brazil in 1836, a young horse similarly in Ohio in 1860, and a dog in Egypt in 1911, but, even by the mid-point of the 20th century, there had been no confirmed cases of any human dying in this way. At this time too, it was apparent that several centuries of detailed observations of comets had not found one in an orbit which posed any threat to the Earth. An asteroid belt was known to exist between Jupiter and Mars, but so what? It seemed a safe distance away. There was no certain knowledge of asteroids in Earth-crossing orbits until 1932, when Apollo was discovered and named by the Heidelberg astronomer, Karl Reinmuth.

A number of large craters were known which could possibly have been caused by the impact of an extraterrestrial object, but there was considerable scepticism about that. Because of its accessible location, the 1.2 km diameter crater in Arizona had been subjected to detailed study since 1886. Some small metallic meteorite fragments found in the vicinity suggested a possible impact origin, but the first main investigator, Grove Karl Gilbert, eventually concluded that the crater had been formed by an explosion linked to volcanic activity. The main problem for the impact theory was that there was no evidence within the crater of a buried meteorite of appropriate size. Also, the crater was roughly circular, whereas it was thought that an oval one would have been created by an extraterrestrial object arriving at any angle other than more-or-less vertical. Indeed, an oval depression 17 metres in length near Haviland, Kansas, was shown in 1915 to be an impact crater because it contained a meteorite weighing 39 kg. Only much later did it become apparent that a larger projectile would maintain a fast speed through the atmosphere, and so explode on impact, producing a circular crater of much greater diameter than the impacting object, and leaving few meteoritic traces. Eventually, around 1960, through the work of Gene Shoemaker and others, it became established that the Arizona crater and a number of similar ones elsewhere had an impact origin. It was concluded that the Arizona crater had been produced by the impact of an asteroid of about 50 metres in diameter, consisting predominantly of metal, because a stony asteroid of that size would not have been able to survive its passage through the atmosphere and strike the Earth’s surface.

By this time, developments in astronomy and the use of space probes were beginning to reveal a hitherto unsuspected picture of a Solar System in which violent encounters had been a significant feature throughout its history. Unlike all the other planets, Uranus orbits the Sun with its axis of rotation in approximate alignment to the orbital plane, having apparently been knocked over in a collision with a giant comet or other cosmic body. Our Moon was apparently formed by accretion of material blasted into space from the young Earth, as a result of a collision with a body that may have been larger than Mars. Planets and moons with solid surfaces are generally pock-marked with impact craters. Examples include Callisto, a heavily-cratered satellite of Jupiter, and Mimas, a satellite of Saturn, which has one particular crater of such great size that the impact which caused it must have come close to blasting Mimas apart. Much closer to the Sun, the surface of the planet Mercury is covered with impact craters.

It is generally accepted that most of the mayhem took place during the early history of the Solar System, more than 3,800 million years ago. That was before the planets had settled into their present orbits and before many of the myriad of wandering smaller bodies had been mopped up by the planets, some by accretion through direct impacts and others by capture to become irregular additions to a natural satellite system. Nevertheless, impacts by smaller bodies on larger ones have continued to occur at a steady rate ever since, as judged by the cratering record of our own Moon, which has been investigated in detail. As evidence that this process is ongoing, a series of large fragments resulting from the breakdown of Comet Shoemaker-Levy 9 were seen to plunge into Jupiter in 1994. In our Solar System today, comets, and also asteroids, are crossing the orbits of planets, with the inevitable risk of a collision.

It is believed that there are many millions of cometary nuclei, consisting primarily of ice and dust, in the outer reaches of the Solar System, in the Oort Cloud and the Kuiper Belt. Most of these are thought to have diameters of between 1 and 10 km, with a smaller proportion being above or below that size range. Some of these cometary nuclei are in highly elliptical orbits which bring them on occasions into the Inner Solar System, where evaporation caused by the heat of the Sun leads to the production of a spectacular tail – or, to be precise, tails, one consisting of dust and the other of ionised gas. Comets coming into the Inner Solar System in this way generally fall into the category of long-period comets, i.e. they have an orbital periodicity of more than 200 years. However, a close encounter with a planet can bring about a change of orbit, which sometimes results in the comet becoming a short-period one, remaining inside the orbit of Pluto. The 19th century Russian astronomer, Anders Lexell, calculated that the comet named after him moved into a short-period orbit in 1767 after passing close to Jupiter. After missing the Earth by just 6 lunar distances in 1770, it then moved back into a long-period orbit after a further brush with the giant planet. In 1992, concern was expressed that Swift-Tuttle, a short-period comet with a nucleus 10 km in diameter, which was then making a close approach to the Earth, might collide with our planet 134 years later on its next visit to the inner Solar System. In fact, although comet Swift-Tuttle will indeed cross the Earth's path in 2126, it will almost certainly pass by safely on that and several subsequent occasions, but might possibly collide in 3044.

Comets which come close to the Earth are included in the category Near-Earth Objects, NEOs. An object is regarded as an NEO if its orbit brings it within 0.3 AU of the Earth's orbit, 1 AU being the average distance of the Earth from the Sun. Many asteroids similarly qualify as Near-Earth Objects. The most recent count, in August 2009, identified 6,326 NEOs, of which 82 were comets and 6,244 were asteroids.

The main asteroid belt between Jupiter and Mars is far from stable. Individual asteroids are seen to be irregularly shaped and scarred by impact craters. Examples include Gaspra. Ida and Matthilde. It is clear that asteroids in the belt have frequently collided with others in the past, sometimes knocking bits off or even splitting them apart. Orbits have changed as a result of such collisions. Studies on the orbits and surface composition of some minor asteroids have indicated they have been blasted from the large asteroid, Vesta, by an impact. In some cases, fragments have been ejected from the main belt altogether. Certain achondrite meteorites found in Antarctica have compositions which suggest they were originally part of Vesta.

Possibly as a result of such processes, three asteroid belts currently exist between the main belt and the Sun. The Amor asteroids, which include the peanut-shaped Eros, 30 km in length, are in elliptical orbits which cause them to cross the orbit of Mars. The Apollo asteroids are in elliptical orbits which keep them for most of the time between the orbits of Mars and the Earth, and which take them inside the orbit of the Earth for the remainder. The Aten asteroids are the other way round, i.e. they are inside the orbit of the Earth for most of the time, and outside it for the rest. It seems likely that collisions between main-belt asteroids, and close encounters between main-belt asteroids and other bodies, may still be adding more members to the Amor, Apollo and Aten asteroid belts.

By definition, all Apollo and Aten asteroids cross the Earth's orbit and so are included in the category of Near-Earth Objects. Also, some Amor asteroids come close enough to the Earth's orbit to be regarded as NEOs. Of the 6,244 Near-Earth asteroids currently known, 1,075 are additionally classified as Potentially Hazardous Asteroids (PHAs). These have diameters of at least 150 metres and are in Earth-crossing orbits which have either brought them in the recent past to within two lunar distances of the Earth, i.e. to less than twice the distance from the Earth to the Moon, or will do so in the near future. Given the uncertainties involved, this is a situation that could lead to an actual collision with the Earth in the more distant future. .

Hermes, originally thought to be 1 km asteroid in the Apollo belt, but now known to be a binary of two 300 metre asteroids in close proximity, passed by the Earth at less than two lunar distances in 1937, and again in 1942. The 350 metre diameter Apollo asteroid, Asclepius, missed us by much the same margin in 1989, as did a similar object designated YB5 in 2002. Two lunar distances may seem a long way, but it is a fine margin in astronomical terms, and put into perspective by the fact that, in 1989, Asclepius passed through the same position in space that the Earth had occupied only 6 hours earlier.

Moving on, Toutatis, a 5 km asteroid which follows a path taking it from inside the Earth's orbit to the fringes of the main asteroid belt and back again, approaches the Earth every four years. Its closest recent fly-past was in 2004, when it came within four lunar distances of us, and it will come close again in 2069. A 2 km asteroid with a similar orbital range, XF11, will pass by at about 2.4 lunar distances in 2028. A 500 metre Apollo asteroid, TU24, came to within 1.4 lunar distances in January 2008. Of greater potential significance than any of the previous examples, Apophis, a 500 metre diameter Aten asteroid, will be much closer to us than the Moon in April 2029. Its orbit will be modified by this very close approach, and there is a chance, albeit a small one, that it will actually collide with us in 2036. There is also a possibility that the 1 km Apollo asteroid 1950 DA will hit the Earth in the year 2880.

More than 800 Near-Earth Asteroids with diameters of 1 km or more are now known. The largest is the Amor asteroid, Ganymed, which has a diameter of about 32 km. There are also at least 50 Near-Earth Comets with nuclei of diameter 1 km or more. Furthermore, the Earth may also be threatened by the sudden appearance of a long-period comet whose existence was previously unknown to us. Comet Hyakutake was seen for the first time on 30 January 1996 and passed by the Earth two months later. As it happened, it missed us by a comfortable margin but, for all we knew, it could have been on a collision course. Hyakutake had a nucleus 1 km in diameter, but, again, it could easily have been 10 times that value, for cometary nuclei of diameter 10 km are not uncommon. A comet's nucleus is made of lighter material than an asteroid, but a long-period comet in particular would probably be travelling faster relative to the Earth than an asteroid of comparable size, so would produce a similar effect in the event of an impact.

If a 10 km object, be it an asteroid or a cometary nucleus, struck the Earth, projectile and rock would be instantly vaporised, leaving a crater of about 180 km in diameter. An impact centred on Milton Keynes, for example, would produce a crater stretching from Nottingham to London. An intense fireball would rise from the impact site, and there would be devastating and long-lasting consequences throughout the world.

An impact of this size occurred in shallow water off the coast of Mexico 65 million years ago, a time when a great mass extinction event is known to have taken place, with two thirds of all species becoming extinct. Amongst the victims were the dinosaurs, who had been the dominant land animals for the previous 140 million years. It is far too simplistic to see everything that happened as a direct consequence of the impact – it seems, for example, that the dinosaurs had been declining in numbers and diversity for a few million years before the impact occurred, so they may have been on the road to extinction anyway, but an explosion on that scale, equivalent to about 100 million megatons of TNT, 5,000 million times more powerful than the Hiroshima bomb, must have played a significant role in the events taking place.

Moving down the scale, the impact of a 1 km extraterrestrial object would cause an explosion 50 million times more powerful than the Hiroshima bomb. A crater almost 20 km in diameter would be formed by a strike on land, and there would be widespread devastation, albeit on a regional rather than a global basis. It is possible than an impact of this size occurred in the region of North America about 13,000 years ago, when more than three-quarters of the species of large land-animals on that continent, including all the mastodons and mammoths, became extinct.

On an even smaller scale, a 500 metre object would still have an impact energy half a million times greater than the Hiroshima bomb, and would produce a crater about 10 km in diameter.

On the assumption that the present composition of the Near-Earth asteroid belts is typical one, it has been calculated that more than ten 500 metre asteroids and several of at least 1 km diameter are likely to strike the Earth every million years. If allowance is made for that fact that many impacts must have taken place in geologically active areas where traces would be quickly destroyed, or in the deep oceans, the astronomical estimates are reasonably consistent with the known record of impact craters at the Earth's surface. The cratering record also shows that there have been at least 5 impacts involving objects with diameters of 5 km or more during the past 220 million years, including the 100 km Manicouagan crater in Canada.

Governments recognise, at least in principle, the continuing threat from space. In the USA, Congress has mandated NASA to identify and characterise all Near-Earth objects with a diameter of 1 km or more, to enable plans to be drawn up should one prove to be on a collision course with the Earth. Early warning is important, because of all that would need to be done to enable a suitable mission to be launched. Also, it is desirable to be able to intercept the approaching object when it is still far enough away to allow realistic attempts to be made to adjust its motion and cause it to miss the Earth. Current estimates suggest that there are likely to be around 200 Near-Earth Objects in the specified size range still unaccounted for. As part of project Spaceguard, the USA, the EU, and some other nations are scanning the skies for NEOs, but that is mainly in the northern hemisphere and leaves about 30% of the sky uncovered. Australian involvement in the Spaceguard project ended in 1996 when government funding was withdrawn, despite worldwide protests, but there are now hopes that something can be worked out to plug the gap.

Most NEOs, of course, are much less than 1 km in diameter, and some of these smaller ones have been observed to pass very close to the Earth. In March 2004, a 30 metre object, 2004 FH, flew past at a distance of just one-tenth that to the Moon, and in March 2009, a similarly-sized body, known as DD45 2009, passed by at about one-sixth of the lunar distance. Two weeks after the brush with 2004 FH, a 2 metre meteoroid with the designation 2004 FU162 came even closer, passing within one-sixtieth of the distance to the Moon. However, had it been on a collision course, it would have simply burned up in the atmosphere without causing any harm. Many small meteoroids do that every year. The first specific prediction of such an event occurred last year, when a 4-metre asteroid, 2008 TC3, was discovered to be approaching the Earth on a trajectory that would cause it to enter the atmosphere over Sudan on 5th October 2008, as indeed it did.

Objects 10 metres wide enter the atmosphere at the rate of about one a year, disintegrating before reaching the surface of the Earth. If the residue from a 10 metre object, or even from a less-common 20-metre one, penetrates to the surface as a meteorite, it poses only a localised threat. In July 1999, a fireball exploded over North Island, New Zealand, showering the Earth with meteorite fragments. A similar event occurred in County Carlow, Ireland, several months later. Early in 2000, an explosion over Yukon, Canada, resulted in a fall of meteorites weighing in total more than 1 kg. In June 2002, there was an airburst over the Mediterranean Sea. The following September, a flash in the sky was followed by the fall of a meteorite in Siberia. In Peru in September 2007, a fireball exploded with the formation of a crater, which was found to contain meteorite fragments. In none of these, and many other, incidents, was anyone hurt.

However, what would have happened had the arriving object been somewhat bigger, yet still much less than 1 km in diameter? That brings us back to a consideration of the Tunguska event. Over a thirty-year period following the Second World War, it became accepted by most, although not all, scientists, that a fifty-metre wide stony or carbonaceous asteroid, or cometary fragment, had exploded 5-10 km above the Tunguskan forest in 1908, releasing energy equivalent to that from 10-20 megatons of TNT, i.e. it was at least 500 times more powerful than the Hiroshima atomic bomb. This airburst scenario was consistent in another way with what had happened in Japan in 1945, because the finding of small cluster of erect trees at the epicentre of the Tunguska blast was paralleled by the fact that the buildings directly under where the bomb exploded were the only ones in central Hiroshima to remain standing. A metallic asteroid could be eliminated from consideration as a cause of the Tunguska event, because it would have penetrated right through the atmosphere and exploded on contact with the Earth’s surface, generating a large crater, as had happened in the similar-scale event which produced the famous crater in Arizona tens of thousands of years ago.

The only problem was that no meteorite or other material of undoubted extraterrestrial origin had been found on the ground at Tunguska to provide positive proof for the generally-accepted scenario. That left it open for others, including some scientists of repute, to suggest alternative explanations for the destruction to the Tunguskan forest. These showed much ingenuity, but had major weaknesses. The passage of a small black hole through the Earth might explain why there was an explosion as it approached the Earth over Siberia, but not why there was no corresponding blast as it emerged from the Earth on the other side. The arrival of a clump of anti-matter from space would certainly have caused an explosion, but this would have begun as soon as it made contact with the atmosphere, not several minutes later. An explosion linked to volcanic activity could have felled the trees, but couldn’t explain the observations of a fiery object travelling through the atmosphere just prior to the blast. And these were the more plausible alternatives to the arrival of an asteroid or comet. Amongst the more fanciful arguments were claims that analysis of the various eye-witness accounts showed that the object had changed direction several times before exploding, and was therefore likely to have been an alien spaceship in trouble. That disregards the notorious unreliability of eye-witness accounts about matters of precise detail, particularly if collected almost twenty years after the event, as most of these were.

So, the mainstream debate continued to focus mainly on whether an asteroid or a comet had been involved. It seemed unlikely to some that a small comet would have been able to travel through the atmosphere for as long as the Tunguska object did without breaking up. On the other hand, the Slovak astronomer, Lubar Krésak, pointed out in 1978 that the event had occurred at the peak time of the β-Taurid meteor showers, which are associated with Comet Encke, so he argued that the object which exploded may have been a fragment derived from Comet Encke. Others have suggested that the distinction between asteroids and comets is not necessary clear-cut, because some objects classified as asteroids may actually be extinct or dormant cometary nuclei, i.e. ones that have lost all their volatile material, or have been completely sealed by an insulating coat, preventing further release of volatile material. A likely example is the Apollo asteroid, Phaethon, which is associated with the Geminid meteoroid stream, whereas other meteoroid streams are linked to active comets. Some British astronomers, including Bill Napier, Victor Clube and Mark Bailey, have taken these arguments a stage further by arguing that Comet Encke, the Taurid meteoroid stream and other objects, including a supposed asteroid, Oljato, are all derived from a giant comet which disintegrated several thousand years ago. On that theory, the Tunguska object would be another of the breakdown products of the original giant comet.

Meanwhile, following a more traditional approach, Giuseppe Longo and Luca Gasperini of Bologna, are continuing the search for meteorite fragments in the Tunguska region, and believe they may be very close to finding one. Their supposition is that, after the explosion in the air, some fragments continued in the direction they'd been travelling before falling to Earth, one of them producing a crater that now holds Lake Cheko, 8 kilometres north of the epicentre of the blast. The lake is in an oval depression that could have been produced in the first instance by the impact of a small meteorite, and subsequently enlarged by the release of gas and water following the melting of the permafrost by heat generated during the impact. Because of its remote location, Lake Cheko was only discovered around 1960, so it could have been formed in 1908, but it is also possible it was already in existence at the time of the explosion. In 1999, Longo and Gasperini surveyed Lake Cheko using acoustic echo sounders, which revealed the presence of a dense, metre-sized object buried beneath the lake. It could be a meteorite or it could just be compacted ground. Longo and Gasperini are intending to return to Tunguska sometime soon to drill down and find the answer.

In another development, supercomputer simulations carried out by in 2007 by Mark Boslough in Albuquerque, indicated that the explosion would not have been instantaneous – fragments produced by the initial explosion would have themselves exploded as they fell towards the ground. The consequence of that is that much of the explosive force would have been produced closer to the ground than previously thought, and it would have directed downwards to a greater extent than had been appreciated. Hence the energy release necessary to have produced the devastation which resulted would have been equivalent to only 3-5 megatons of TNT, rather than the 10-20 megatons of earlier estimates, and the extraterrestrial object responsible would have been smaller than supposed.

That is far from comforting. Most asteroid searches are geared to finding asteroids larger than 140 metres in diameter. The US Congress has asked American scientific bodies to implement measures to detect 90% of Near-Earth asteroids in that size-range by 2020, but a recent interim report by the chairman of the co-ordinating committee, Irwin Shapiro, said that target is unlikely to be achieved with the resources currently available. If it is still proving difficult to find 140- metre bodies, then something 50 metres across, the size of the Tunguska object according to earlier estimates, could easily escape detection. The situation looks even worse if the object which caused all the devastation in the Tunguska region had in fact been significantly less than 50 metres in diameter. There must be thousands of hitherto undetected Near-Earth objects which are of that size or larger. Clearly there are issues that still need to be addressed by Governments. A United Nations working group is currently drafting out procedures for handling the NEO threat. However, as far as you and I are concerned, there’s no need to start building air-raid shelters just yet. Current estimates suggest that impact explosions of a size comparable to the Tunguska event occur with an average frequency of somewhere between one in a hundred years and one in a thousand years. From a personal point of view, there is little point in worrying about when and where the next one will be. Sleep well tonight!