PUPIL RESEARCHER INITIATIVE

Collision Course

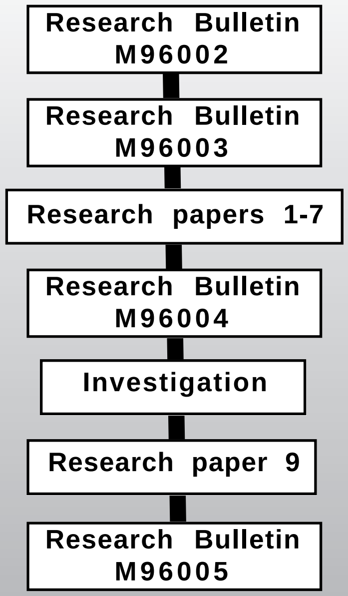
Pupil Research Brief

Teachers' Notes

Syllabus Coverage *Subject Knowledge and Understanding*

- ❏ comets have orbits which are far from circular
- ❏ comets are very much closer to the Sun at some times than at others. This is when they can be seen
- ❏ the further away an orbiting body is from the Sun the longer it takes to make a complete orbit

Route through the Brief



Introduction

In this Brief pupils learn that the Earth has been hit several times by massive objects from space in the distant past. They are presented with information that suggests an impact from a comet or an asteroid may occur in the future, and the consequences for life on the planet could be devastating. They are asked to assess the risk of such an event occurring again and they conduct experiments that allow them to estimate the physical damage a massive object would cause to the Earth. They are also required to make recommendations as to what plans, if any, should be made to detect and track Near Earth Objects to give early warning of an imminent collision.

Experimental and investigative skills

- planning an investigation
- obtaining evidence
- analysing evidence and drawing conclusions
- evaluating evidence

Prior knowledge

Before attempting the Brief, pupils should already have knowledge of the Solar System, its planets and the asteroid belt. They should also know a little about comets and about meteors.

Pupil Research Brief

Teachers' Notes continued

Running the Brief

Pupil grouping

Pupils could work in a number of groupings during this Brief. Suggestions are:

Initial briefing	-	whole class; teacher briefly introduces topic and sets the context for the Brief
Introductory STAR Centre Bulletins	-	individual or pairs
Background papers selected from papers 1-7	-	individual or pairs
Research Bulletin M96004 (Paper 8) and investigation	-	pairs, threes or fours (depends on equipment availability)
Analysis of results	-	pairs, threes, fours, or individually if work is to be assessed
Papers 9 and 10	-	individual or pairs
Communication	-	compilation of reports- individual or groups and whole class discussion of work (optional)

Timing

The Brief should take at least 3 hours of classroom time. It can be used as part of an examination course, but it could also be used in a science or astronomy club context.

Activities

The teacher should issue the pupils with the **Study Guide** which provides pupils with a summary of what they should produce as they work through the Brief. It can also act as a checklist for pupils to monitor their own progress. Pupils are then given STAR Centre **research bulletins M96002 and M96003**. These papers set the scene, outlining the topic they are to study and listing the activities contained in the Brief. The second paper (M96003) splits up the Brief into four sections.

Section 1 - Background information
Seven information sheets are presented in the form of simulated magazine articles.

Research paper 1 *The Doomsday crash*. This paper presents information about what the likely effects the impact of a massive meteorite would have on Earth.

Research paper 2 *Meteorites 4 Cars 0*. This paper is about the four known incidents of meteorites hitting cars.

Research paper 3 *Tracking the Peekskill meteorite*. This article gives an account of how astronomers calculated the orbit of a particular meteorite that crashed to Earth in 1992.

Research paper 4 *Earth's greatest hits*. This sheet explains how modern imaging techniques have revealed the sites of massive meteorite collisions that occurred in prehistoric times.

Research paper 5 *Meteorite! In the beginning....* This gives information about the nature and composition of meteorites.

Research paper 6 *Rocking around the Solar System*. This is an article about asteroids.

Research paper 7 *Where do comets come from?* The article explains the origin of comets.

Pupils do not have to read all of these, but they should read and make notes on at least papers 1, 4, 6 and 7. Some papers could be used as reading homework assignments.

Section 2 - Risk assessment
In this section pupils are given a practical investigation to carry out. **Research paper 8 (Research bulletin M96004)** gives instructions on how to simulate the effect of large meteorite impacts on Earth. This involves preparing a tray of powder and dropping marbles, ball-bearings, golf balls, etc. onto the powder at different heights. Measurements of the size of craters and the length of the ejecta rays are made. The results of the experiments, together with the information found in research paper 1 should allow pupils to describe the effect that a large impact would have on Earth. **Research paper 10** (**Research Bulletin M96005**) contains a table and a graph summarising the chances of collision with massive objects from space. These should be used by pupils when writing their reports.

Section 3 - Detection
Research paper 9 gives information about meteoroid upper atmosphere impacts detected by US Department of Defence satellites between 1975 and 1992. **Research paper 10** explains that a programme called 'Spaceguard' has been proposed. This would

Teachers' Notes continued

fund the construction of six observatories to survey the skies to look for Near Earth Objects. These two papers help pupils to prepare a brief section of their report about detecting objects that may collide with Earth.

Section 4 - Recommendations
Here pupils should decide what, if any, action should be taken to give us early warning of impacts from comets or asteroids. Are the odds against such a collision high enough to allow us to ignore the problem? Should we ensure that there is a comprehensive programme of surveillance of space in order to detect and track Near Earth Objects? If so, how do we prevent them colliding with Earth? These are questions pupils should address when writing their reports.

Investigation details

Research bulletin M96004 contains a list of possible investigations into the effects of an impact from a massive object on the surface of the Earth. The equipment they will need to make impact craters and to measure them is given, but pupils need to decide how to proceed. They could be split into different groups to investigate the effect of one of the four variables listed under the heading 'Investigation choices'. In every instance pupils (individually or in teams) should write out a plan showing how they are going to conduct the investigation to ensure that their tests are fair. When using powder as the impact surface it is important to test beforehand that it is of sufficient depth for the heights from which the different impact object masses are dropped.

When measuring crater diameter it is best to measure the outside of the rim rather than the inner diameter. Pupils might also investigate the relationship of the height of drop with the volume of the crater.

The practical work on ejecta rays is likely to use large amounts of powder that can be used only a few times before the paint discolours the powder too much, and so it may be advisable to put pupils into larger groups for these experiments. Ejecta rays are the trails of debris that fall round an impact crater in a 'star pattern'.

The heading 'Investigation interpretation' has a list of 6 questions that the results of the experimental work should answer. Questions 1 and 3 mention impactor velocity. Some pupils will need guidance on how to calculate the velocity on impact of the object they have dropped.

Pupils are asked to evaluate their results by addressing the first two points listed under the heading 'Investigation discussion'. The third point under this heading requires them to use their results to estimate the crater sizes that would be caused by impacts of meteorites of three different large diameters. Pupils have to decide how they can do this, for example, from extrapolation of their results.

Using IT. Pupils could use spreadsheets to produce graphs from their results, and to model the process of crater formation on a larger scale by extrapolation. Velocity of the object could be measured using light gates.

Technical details

(See Research bulletin M96004 in the Brief)

Safety issues

PLEASE NOTE: It is also important that you prepare your own risk assessments for the practical work in this Brief in the usual way.

Sodium hydrogen carbonate and Plaster of Paris ($CaSO_4.H_2O$): minimal hazard.

Harmful if swallowed in quantity. Seek medical advice.

Bouncing balls: danger of balls bouncing off hard surfaces (especially ball bearings and golf balls). (Small) danger of dust inhalation.

Wear eye protection.

Keep face away from impact area.

Assessment issues for *Experimental and Investigative Science* (National Curriculum for England and Wales, Northern Ireland Curriculum)

P	Planning	O	Obtaining evidence
A	Analysing evidence	E	Evaluating evidence

Crater formation investigations are introduced in Research bulletin M96004. For **Skill Area P**, highest mark levels are possible provided that scientific knowledge is used to plan strategy. The amount of guidance given to pupils will need to be taken into account.

For Skill Area O, the procedures used to obtain measurements and observations can be simple but attention to precision and reliability can allow pupils

Teachers' Notes continued

to achieve the highest mark range. For **Skill Areas A and E**, higher marks can be achieved if they relate results to predictions and to scientific knowledge, extrapolate, deal with the variability of measurements and compare their results and extrapolations to data obtained from other Solar System bodies.

Scottish syllabus coverage

Standard Grade Physics - *Space Physics*

Further pupil research opportunities

Pupils could do background research into past Earth impacts and their effects, and produce a display/exhibition. There has been a good deal written about this topic and there is a considerable interesting and useful information on the Internet.

PUPIL
RESEARCHER
INITIATIVE

Pupil Research Brief

Collision Course

Setting the Scene

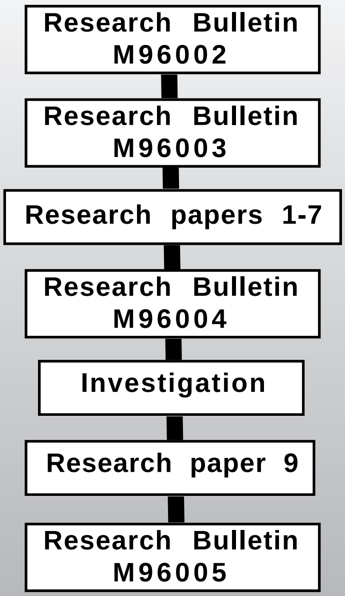
You will be learning about the massive rocks from space that have crashed into Earth a long time ago and you will be given information that will help you assess the risk of such an event happening again. You will carry out experiments to estimate the damage such as an impact will cause and make recommendations about what plans we should make to detect and track nearby massive objects in space to give us an early warning of danger.

Study Guide

Syllabus Targets *Science you will learn about in this Brief*

- ❑ comets have orbits which are far from circular
- ❑ comets are very much closer to the Sun at some times than at others. This is when they can be seen
- ❑ the further away an orbiting body is from the Sun the longer it takes to make a complete orbit

Route through the Brief



Outcome Checklist

You will produce a research report dealing with the issue of impacts of objects from space on the Earth and make recommendations for action to prevent a possible global disaster. You will be guided through the Brief by three research bulletins and a series of background papers. You should make sure you produce the following items as you work through the Brief.

Research Bulletins M96002 and M96003

- ❑ a framework for writing your report
- ❑ an outline of the research requests

Research papers 1-7

- ❑ brief notes on the information in the papers

Research Bulletin M96004

- ❑ investigation plan
- ❑ investigation results and analysis

Research paper 9

- ❑ brief notes on high altitude meteoroid explosions

Research Bulletin M96005

- ❑ brief notes on Spaceguard survey

STAR Centre

Sheffield Hallam University **Research Bulletin:** M96002

Subject: Collision Course
From: Director of Star Centre
To: PRI Schools
Date

In 1994 comet Shoemaker-Levy crashed into Jupiter with a force which would have devastated the Earth. The crash raised the inevitable question - could it happen here?

STAR Centre is asking schools, through the Pupil Researcher Initiative, to research the issue of impacts of objects from space on the Earth and make recommendations about any action which could be taken to prevent a global disaster.

We ask that your research report presents an all-round, considered view of the subject. Your report should contain:

- evidence for past and recent impacts on Earth
- which objects are likely to crash into Earth and where they come from
- effects of impacts on Earth
- findings of your own practical investigation into cratering
- a risk assessment of the chances of Earth collisions
- methods of detecting impact objects in space
- methods of destroying or diverting potential impact objects before they strike
- recommendations for action, if any, which should be taken.

To help you with your research we have attached a set of papers from Star Centre's data files. The Research schedule and Study guide will help you to tackle the research request. There is also a practical investigation which asks you to produce your own findings on impacts.

We hope that you enjoy exploring this explosive aspect of our Solar System!

Dennis Ashton

Director, STAR Centre

STAR Centre

Sheffield Hallam University **Research Bulletin:** M96003

Subject: Collision Course
From: Director of Star Centre
To: PRI Schools
Date

Research request

The aim of this research request is that you prepare a report on potential Earth impacts and use it to make a recommendation for action.

The attached papers are drawn from STAR Centre files. We have numbered them so that you can see which papers are relevant to each section.

Research schedule - Preparing your report

Section 1 - Background information:

- evidence for impacts with earth in the past (Papers 1-4)
- recent impact events (Papers 2-4)
- the nature of impact objects, what they are, where they come from (Papers 3-7)

Section 2 - Risk assessment:

- practical investigation into cratering (Paper 8)
- effects of impacts on Earth (Paper 1)
- frequency and power of impact events (Papers 9-10)

Section 3 - Detection:

- detection of possible impact objects - equipment, methods, range results (Paper 9)
- protection - possible ways of destroying impact objects before they hit Earth (Papers 9-10)

Section 4 - Recommendations:

- whether any action should be taken to give early warning of Earth impact, and if so, what action, cost estimates, sources of funding? (Paper 10)

The Doomsday Crash

by Hilary Phipps

Hilary Phipps discusses the possibility of a repeat of the mass extinction of 65 million years ago: could a comet collide with Earth?

A space rock to destroy the Earth?

It comes screaming out of the sky like a missile from Hell. It is bigger than a mountain and packed with more energy than the world's entire nuclear arsenal. It hits the atmosphere at a 100 times faster than a speeding bullet. Then a second later it crashes into the ground with an explosive force of 100 million tonnes of TNT.

According to astronomers, that's what would happen if a space rock 10 kilometres across collided with Earth. This is the size of the comet believed to have hit Earth 65 million years ago, killing off the dinosaurs and two-thirds of all life.

Vapourised

The shock wave from the crash landing would travel at 30,000 kilometres per hour, smashing down everything within 200 kilometres. The space rock is destroyed by the heat of impact and a jet of vapourised stone blasts a hole in the atmosphere. High in the air the vapourised rock cools and condenses, falling back to Earth as millions of tiny stones. As they stream to the ground in the next hour they heat up and their glow turns the sky pink.

Flame and acid

Steam hisses from green leaves as plants 'boil'. Trees and buildings burst into flame: an area of thousands of square kilometres is incinerated. But other effects are long-term and spread over the entire globe. Nitrogen and oxygen in the air react to form nitric acid to spray the Earth with a solution as acidic as a car battery. Worse still the original explosion blasts billions of tons of debris into the air. The dust is carried around the world, blacking out our planet for centuries. Plunged into darkness our planet cools and freezes in perpetual night.

Hundreds of years later, when the dust settles, what will remain of life on Earth?

Possibilities

Many astronomers believe that such a collision is not only likely, but that sooner or later it is inevitable. Thousands of small meteorites hit the Earth every year and bigger space rocks regularly pass close to Earth: it is only a matter of time before a big one hits. On March 23, 1989, an asteroid one kilometre across missed us by only one million kilometres and no-one saw it coming. If it had arrived 6 hours earlier it might have wiped out all of our civilisation. In the year 2126 Comet Swift-Tuttle will pass close by Earth and only a small change in its predicted path is needed for it to collide with us. In 1994 Comet Shoemaker-Levy actually crashed into Jupiter with a force which would have devastated Earth.

Action

The impact of a comet or asteroid could kill everyone and everything on Earth. But we now have the technology to find - and possibly destroy - any threatening space rock.

The government must act now: we have the technology. First they must commission surveys to determine the real risk posed by objects from space. Then they should set up purpose built telescopes to identify objects before they hit the Earth. Finally any big space rock should be diverted or destroyed using missiles launched from Earth or the Space Shuttle.

This action is needed now. Otherwise we, like the dinosaurs, may become extinct.

Meteorites 4, Cars 0

by Hilary Phipps

Hilary Phipps looks at the effect meteorites landing on the Earth have had on four unlucky motorists.

Unlucky? Or very lucky?

Either Earth is overpopulated with cars or meteorites have a grudge. Four times this century, and twice in just over two years a space rock has chosen a car for its target. No one was seriously injured in any of the incidents, which means the drivers and passengers were extremely lucky.

Asteroid fragment

One travelled north up the east coast of the USA, giving a firework trail seen by millions. Much of the asteroid fragment burned up on hitting the atmosphere. One piece survived and crashed down in Peekskill, New York - on Michelle Knapp's 1980 Chevrolet. The car was standing in her drive when the meteorite punched a hole through the boot of the Chevy Malibu and made a 10cm deep crater in the tarmac.

Michelle was upset at the damage to her Chevy - until a museum offered her $69,000 for the meteorite and the local TV station gave $25,000 for her unique car!

Sky marbles in Marbella

More recently, a car-conking space rock struck in Spain on June 21, 1994. José Martin and his wife Vicenta were driving from Madrid to Marbella when a 1.4kg stone smashed through the windscreen. It hit the steering wheel, broke Martin's finger and flew between the couple's heads to land on the back seat. Later over 50kg of meteorite fragments were found near the impact site.

Japanese surprise

Around midnight on February 18, 1995 many people in Japan saw a bright fireball cross the sky. Next morning school director Keiichi Sasatani had no trouble finding the meteorite responsible. It was lying on the punctured boot of his car!

Where it all started

On September 29, 1938 a 1.8kg stone fell on a Pontiac coupé in Illinois, USA. This first car-crunching meteorite was reported at the time in Sky magazine (June 1939, page 11).

What are the odds?

Meteorites are constantly hitting the Earth, although most are much smaller than the ones responsible for damaging the cars in this story. The odds on a space rock the size of a fist hitting a car are very, very small, almost too small to calculate. The odds on this many hits in so few years are less than a double win on the National Lottery. Some people are just born lucky!

Peter Brown and fellow researchers at the University of Western Ontario have calculated the orbit of the Peekskill meteorite. This is only the fourth time this has been done.

Tracking the Peekskill Meteorite

On the evening of October 9, 1992, thousands of Americans saw a fireball brighter than the full Moon fall across the sky. Several of them managed to video or photograph the meteorite trail and this record enabled us to calculate the orbit of the original asteroid.

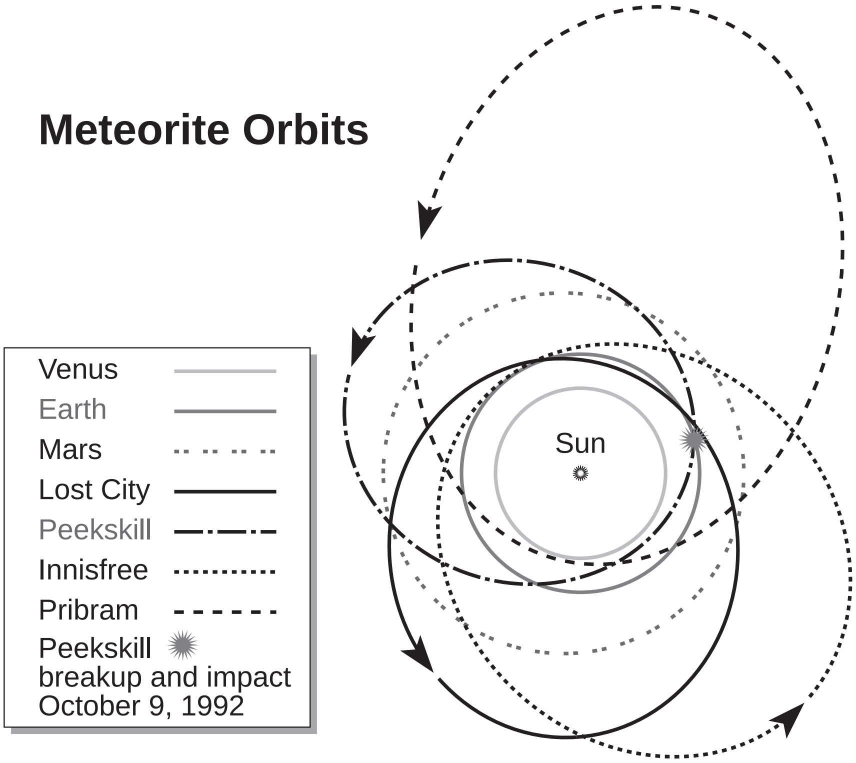
Most of the asteroid burned up in its fall through the atmosphere, but a 12kg fragment survived to crash on to a car in Peekskill, New York. From the photographs we determined the following data.

- Initial velocity: 14.7km/sec (33,000 mph)
- First video clip: 46.4km altitude
- Fragmentation begins at 41km altitude
- Final measurable velocity: 5km/sec (11,000 mph).

From photographic records of the meteorite trail we calculated the orbit of the original asteroid.

Average distance from Sun: 225 000 000km
Orbital time : 1.82 years
Inclination of orbit : 5 degrees
Eccentricity : 0.41

Figure 1.
Orbits for the four meteorites whose orbits prior to collision with Earth have been calculated



Earth's Greatest Hits

Henry Gatsby of Scott College describes how new imaging techniques reveal evidence that the Earth has had its fair share of meteorite collisions, even though its surface is not covered in craters.

With binoculars we can see craters on the Moon. Space probes have shown us craters on Mercury, Mars and the moons of other planets. Radar pictures have penetrated the clouds of Venus to show craters there. Impact craters, made by meteorites and comets, litter the surfaces of planets and their moons. But where are the craters on Earth?

Most of the craters on planets are old. The main cratering period ended 4 billion years ago, when the planets were half a billion years old. Most of the asteroids and comets which built planets had been swept up by then. We see craters on other planets because little has happened in the last four billion years to cover them up.

On Earth, however, processes of resurfacing and erosion have covered up many craters. Tectonic activity - particularly volcanoes - has deposited layers of rock on top of craters. Other impact sites have been covered by the action of wind and water.

Some impact craters are still clearly seen. Among the best are Meteor Crater in Arizona, USA and Wolf Creek in Australia. They were recognised from the air as impact craters. Now others, like Manicouagan in Canada, are being identified by satellite images.

Now new techniques are showing craters so covered up they cannot be seen by cameras. Computer image processing has been applied to satellite images. By exaggerating the height of features, impact circles show up.

Geologists can drill deep into the ground to find rocks changed by impact. Examples are recrystallised rocks which melted in the impact, and fractured rocks like shocked quartz.

The latest method involves mapping the local gravity and magnetic fields. This technique has been used to find a huge 180km diameter crater on the Yucatan coast of Mexico. This crater, called Chicxulub, may be the site of the meteorite impact some 65 million years ago which wiped out the dinosaurs.

Geologists have so far discovered 139 craters which were caused by comet or meteorite collision with Earth.

Table 1: Impact craters

Crater	Location	Age *
Manicouagan	Quebec, Canada	212
Kar-Kul	Tajikistan	10
Wolf Creek	Australia	0.3
Lonar	India	0.05
Meteor Crater	Arizona, USA	0.05

* millions of years

Rocks from space often fall to Earth.
Jim Barringer takes a look at them.

Meteorite! In the beginning....

Our Sun was born 5 000 000 000 years ago from a cloud of gas composed mainly of hydrogen, with some helium and a small amount of other elements. Around the new star a disc of gases, ice and dust began to form the planets. Space rocks, rich in iron from dead stars, crashed together to make new worlds - small rocky planets close to the Sun, large gas planets further away.

Space rocks

The planets were formed by space rocks crashing together. But some space rocks - asteroids - remained free, orbiting the Sun at a distance between the other planets' orbits. Most still orbit between Mars and Jupiter but others have orbits which bring them towards the inner Solar System and our Earth. Sometimes fragments like sand grains break away, leaving a trail of particles in space. If the Earth crashes into these particles, they burn up in our atmosphere as meteors - 'shooting stars'.

Impact

Sometimes asteroids - or fragments of asteroids - come towards Earth. Like meteors, friction with the atmosphere makes them glow as they dive towards the ground. The outer layers vapourise in a fireball, but if the space rock is large enough, fragments survive to hit the ground - another meteorite has crashed into our planet! Around 40,000 years ago a meteorite about 10 metres across crashed into Arizona. Its crater is still preserved in the desert, about 1km across and 100 metres deep.

Stone and iron

There are three main categories of meteorite: stony, iron and stony-iron. Stony meteorites are most common but the most difficult to find because they are like rocks on Earth. They are made of silicates, the commonest rock-forming minerals on Earth, and some contain large amounts of carbon compounds. Stony-irons, the rarest meteorites, contain rock crystals embedded in metal whilst the irons are almost pure iron and nickel. Some meteorites seem to be pieces of the Moon and Mars. Long ago the Moon and Mars were themselves struck by meteorites. Pieces of the Mars and the Moon were thrown into space until eventually they fell on to Earth as meteorites themselves.

Lucky escapes from killer asteroids

No-one is known to have been killed by a meteorite, although records from China suggest it may have happened in the past. However, the Earth, like all rocky planets, bears the scars of many meteorite impacts. Sometimes the craters are easy to spot, particularly from the air. However, most craters have been covered by erosion or erased in the movement of Earth's tectonic plates. Now new scientific techniques are revealing hidden craters. There is good evidence for a huge crater, perhaps 100km across, in the Yucatan Peninsula in Mexico. Many scientists believe that this is the impact which saw an end to the dinosaurs 65 million years ago. The impact was so violent that billions of tonnes of material were thrown into the sky. The climate changed under the dust clouds and the dinosaurs could not survive the change. How long will it be before another huge space rock causes a similar global catastrophe?

Rocking around the Solar System

Paul Crowder takes a look at asteroids - relics of the early Solar System

Not an exploded planet

Asteroids, sometimes called minor planets, are small rocky bodies which orbit the Sun.

The first asteroid to be discovered was Ceres, found by Italian Giuseppe Piazzi on New Year's Day, 1801. Ceres is the biggest asteroid at nearly 1000km in diameter. Only three asteroids - Ceres, Pallas and Vesta - are over 500km in diameter. Several hundred are more than 100km across and at least 100 000 asteroids are 1km or larger.

It was once thought that asteroids came from a broken planet. But if all the asteroids were collected together they would make a tiny body only 1500 km across - 5% of the mass of our Moon. Most astronomers agree that the asteroids are rocks left over from before the birth of the planets some 4.5 billion years ago. Perhaps the gravitational pull of nearby Jupiter stopped them coming together and making a planet.

Close-up view

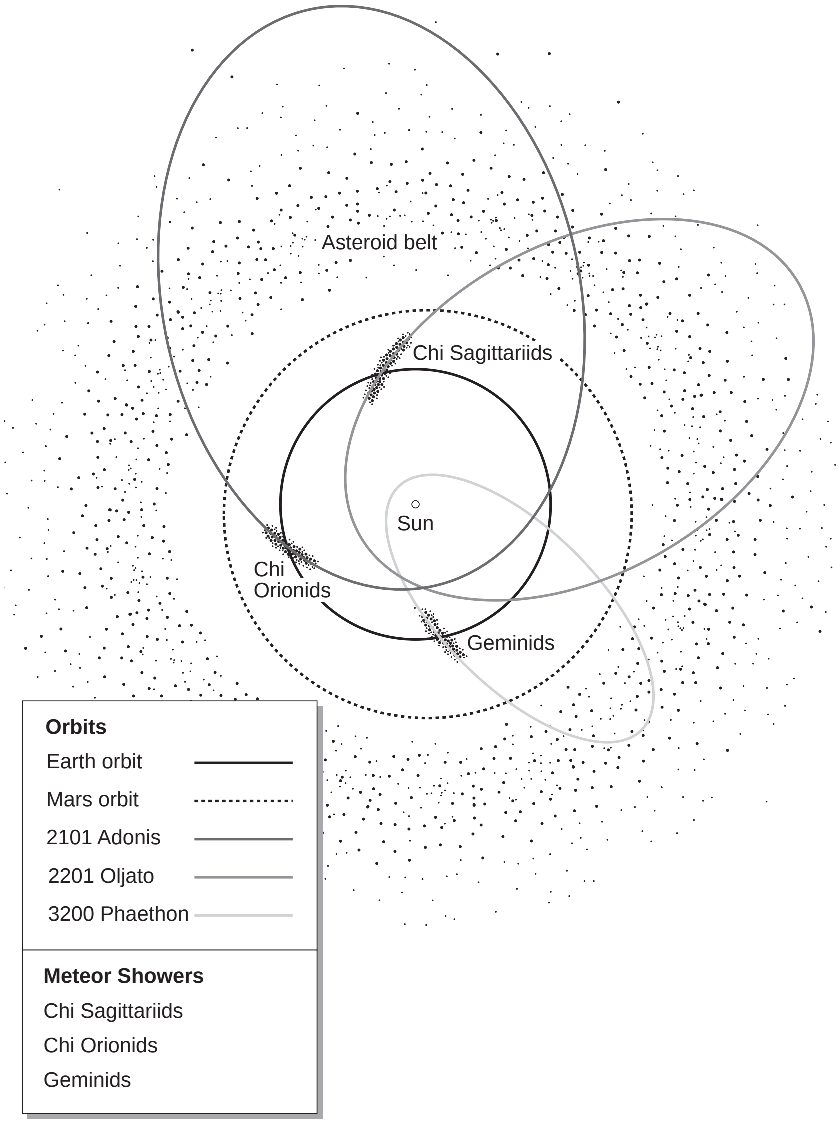
Because they are small, asteroids are only tiny points of light seen through a telescope. However in October 1991 the Galileo space probe, on its way to Jupiter, flew past asteroid Gaspra. At a distance of only 1 600 km Galileo gave us our first close-up view of a minor planet. Like most small asteroids, Gaspra is irregular in shape and measures 19x12x11km.

Asteroid orbits

Most asteroids orbit between Mars and Jupiter, about 2.8 Astronomical Units from the Sun (an Astronomical Unit, AU, is one Earth - Sun distance, 150 million km). Ceres, the largest asteroid, takes 4.6 years to orbit the Sun.

continued....

Figure 1
The inner Solar System, showing the location of the asteroids, numbering over 5000. Most are located in a distinct 'main belt' between Mars and Jupiter. Only 12 asteroids are found inside the Earth's orbit.



Some asteroids have elliptical orbits which take them towards Earth's orbit. The Amor asteroids come inside the orbit of Mars. Apollo asteroids cross Earth's orbit whilst the Aten asteroids follow paths inside the orbit of Earth. Some of these may be old comets whose ices evaporated long ago. These asteroids are potential Near Earth Objects (NEOs) - space rocks which pass close to our planet or even collide with it. In 1968 Apollo asteroid Icarus passed only six million km from Earth and nearer misses have occurred since then. A strike by a big asteroid would have devastating effects on our planet.

Naming asteroids

Hundreds of new asteroids are found each year. If the orbit can be calculated, an asteroid is given a number. There are now over 6000 numbered asteroids. Names are chosen by the discoverer. At first they were given names from Greek mythology, but now almost anything goes. So Mozart and Debussy have been joined by Clapton and McCartney and there is even a Mr. Spock out there. What would you call your asteroid?

Comets are icy bodies which sometimes make a spectacular show as they pass near to the Sun. Vladimir Melankov discusses how the origin of comets can be explained.

Where do comets come from?

Sixty-five million years ago it is thought that a comet (or possibly an asteroid) struck the Earth. It threw billions of tonnes of dirt into the atmosphere and changed the climate. When the dust settled the dinosaurs, kings of our planet then, had died out. A comet changed the course of evolution - still a controversial idea.

Comets could also be the key to life on Earth. In the first billion years of the Solar System a rain of comets, 100 000 of them, could have crashed into our young planet. Their ice could account for much of the water in the oceans. Organic molecules trapped in the ice could have been the ingredients for starting life on its evolutionary journey.

But where do comets come from? What could unleash a rain of comets?

Into deep freeze

As planets formed around the new-born Sun, blocks of ice formed in the cold outer regions beyond the planets. Some of these ice blocks were gobbled up by the gas giant planets. Others were hurled outwards by the powerful gravity of these big planets. Still held by the Sun's gravity, these mountains of ice settled into orbits far beyond the planets.

Oort's Cloud

In 1950, Dutch astronomer Jan Oort suggested that the huge ice blocks were still there. They make a sphere of objects extending from about 20 000 to 100 000 Astronomical Units (almost 2 light years) from the Sun. Each icy body is a comet nucleus, a huge block of dirty ice. As many as 2 000 000 000 000 comets may inhabit the Oort cloud.

The Kuiper Belt

Analysis of comet orbits indicated the presence of another comet region. Gerard Kuiper suggested that these comets came from a flattened area, which is now called the Kuiper Belt. The Belt begins just beyond Pluto at about 35 Astronomical Units and extends out to join the Oort Cloud. The Solar System is shrouded by a reservoir of comets.

continued.....

What makes comets move?

Comets will orbit quite happily in the Kuiper Belt and more distant Oort Cloud. Something must give them a good pull to move them in towards the Sun.

For comets in the Oort Cloud, they are probably dislodged by the gravity of a star passing close to our Solar System in its journey round the galaxy. The icy comet nucleus falls in towards the Sun and eventually becomes a visible comet with coma and tail. It then disappears into the depths of space, never to be seen again - a long-period comet.

The Kuiper Belt is nearer to the Sun and it is the gravity of the outer giant planets which dislodges them from their home. These settle into shorter orbits of less than 200 years to become short period comets like Comet Halley.

Beyond Pluto

Comets in the Oort Cloud are so distant they cannot be seen from Earth. The Kuiper Belt is closer but still beyond Pluto, so the chances of finding objects here seemed remote.

However, on 30 August 1992, David Jewitt and Jane Luu announced that they had found an object beyond Pluto. Using the 2.2 metre telescope of Mauna Kea, Hawaii, they found the object moving in front of the stars of Pisces. The object was given the code number 1992 QB1, but Jane and David called it ‘Smiley’ from the John le Carré novels. Smiley was about 200km across and the first member of the Kuiper Belt to be discovered.

Others followed, some found by the Hubble Space Telescope, and at the moment 22 Kuiper Belt objects have been seen.

A super-comet

On October 19, 1977, Charles Kowal discovered asteroid 2060. It soon became clear that 2060 was no ordinary asteroid. Its orbit lay between Saturn and Uranus, far beyond other asteroids. It was called Chiron (son of Saturn, and in Greek Mythology Chiron was the Grandson of Uranus). Chiron’s diameter was estimated at 200km.

Then in 1988 Chiron turned fuzzy. Its surface was evaporating as it came closer to the sun. Chiron is not an asteroid, but an enormous icy comet nucleus.

Chiron is similar to some of the moons of Uranus and Neptune. These icy bodies may have escaped from the Kuiper Belt or Oort Cloud, only to be captured by the giant planets. How many more Chirons are out there, perhaps on their way in towards the Sun - or our Earth?

STAR Centre

Paper 8

Sheffield Hallam University **Research Bulletin:** M96004

Subject: Collision Course
From: Director of Star Centre
To: PRI Schools
Date

Purpose: to investigate the factors which affect the size and appearance of craters. Following the investigation, using simulated impactors and planet surfaces, the effects of larger objects can be calculated or extrapolated.

Simulation: impact objects such as marbles, ball-bearings or golf balls are used to simulate impactors, eg meteorites. Powders simulate the planet surface.

Materials:

- *Impactor objects* marbles, ball-bearings, golf balls, plasticine
- *Planet surface* flour, sodium hydrogen carbonate or Plaster of Paris, powder paint as top layer for ejecta experiments
- *Container* plastic tray, aluminium pan or tray, cardboard box (at least 7.5cm deep, 30cm square)
- *Other materials* newspaper - around container to catch spilled powder
  metre stick - to measure height of drop
  ruler - to measure crater diameter and depth
  balance - to measure mass of impactor spheres
  sieve - for sprinkling powder paint if required

Preparation of 'planet surface'

1 Fill pans with powder to depth of at least 3cm (dependig on the height of drop / mass of object you may need a greater depth - so do a trial run). Smooth down surface and tap container to allow powder to settle evenly.

2 (Optional: only for ejecta ray experiments) - sprinkle powder paint over surface using a sieve.

Investigation choices

Plan and carry out experiments to investigate any of the following:

1 the effect on crater size of dropping objects from different heights

2 the effect on crater size of dropping objects of different mass

3 the effect on the length of ejecta rays of dropping objects from different heights

4 the effect on the length of ejecta rays of dropping objects of different mass

Investigation interpretation

What does your data reveal about:

1 the relationship between crater size and impactor velocity?

2 the relationship between crater size and impactor mass?

3 the relationship between ejecta ray length and impactor velocity?

4 the relationship between ejecta ray length and impactor mass?

5 the size of a crater caused by an impactor with 10 X the velocity of your highest drop?

6 the size of a crater caused by an impactor of 10 X the mass of you most massive object?

Investigation discussion

1 Which common features of real impact craters did not appear in your simulated collisions?

2 List the ways in which your simulated impacts cannot properly represent actual meteorite impacts on a planet.

3 Estimate the sizes of crater caused by impacts of meteorites of diameter:

a 100m
b 1km
c 10km

United States Department of Defence

Declassified information: release date October 1, 1993

Former classification code: AB/3 Top Secret

Subject: High altitude meteoroid explosions

Report summary

US Department of Defence (USDD) satellites have detected 136 explosions in the upper atmosphere in the period 1975 to 1992.

These impacts were caused by meteoroid impacts. The meteoroids are assumed to be fragments of comets or asteroids. The fragments self-destruct as they hit the Earth's upper atmosphere at high speeds.

Meteoroid velocity and energy

The meteoroids impact the atmosphere at velocities between 15 and 20 kilometres per second. A meteoroid 10 metres across would weigh about 1000 tonnes. The energy of impact of such a meteoroid is equal to a bomb of 20 000 tonnes of TNT - greater than the atom bomb dropped on Hiroshima in 1945.

Non-metallic objects of this size are destroyed at altitudes too high to damage anything on the Earth.

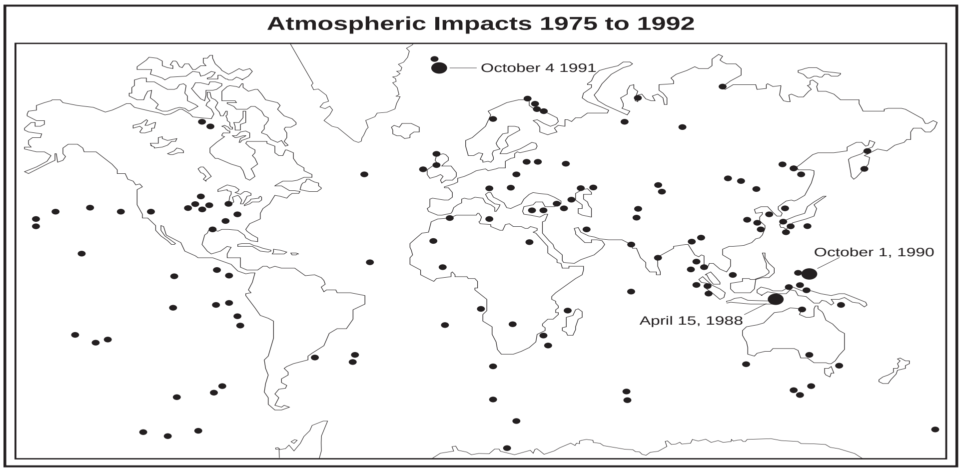


Figure 1. Worldwide distribution of 136 recorded meteoric airbursts, representing approximately 10% of impacts actually received. Three labelled impacts were particularly large (representing energy equivalent to more than 1000 tonnes of TNT)

continued....

Airburst Analysis

136 airbursts were detected between 1975 and 1992, an average of 8 impacts each year. Because of gaps in the coverage, USDD researchers estimate that 10 times more explosions actually occurred in that time (with energies greater than 1000 tonnes of TNT). It is estimated that 80 meteoroids explode in the upper atmosphere each year with energies greater than 1 kilotonne.

Highest Energy Impacts

Three particularly high energy explosions were recorded and are shown on the world map. Each impact caused a visible flash lasting only a second or two, but as bright as the Sun. Below is a brightness diagram for the airburst over Indonesia in 1988.

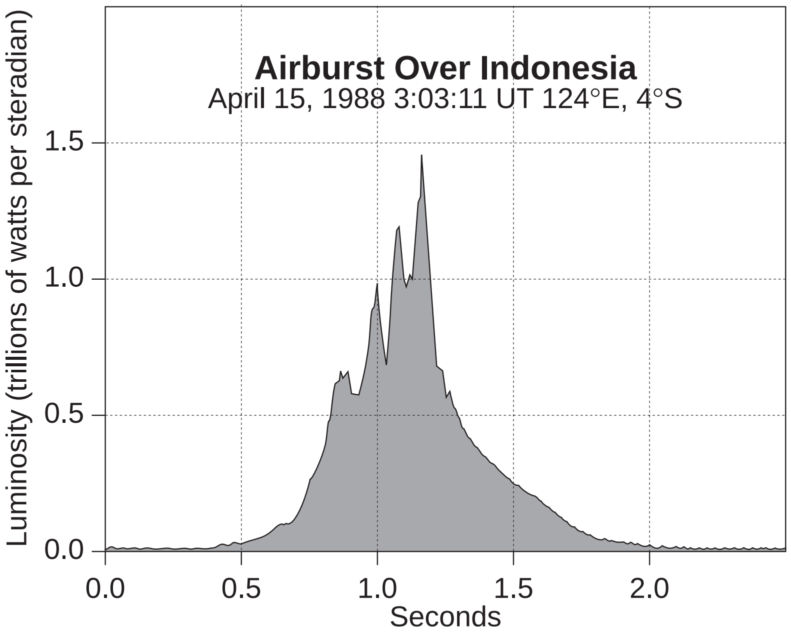


Figure 2. Luminosity measured in the seconds following a daylight fireball above Indonesia on April 15, 1988. Data recorded by a U.S. early-warning satellite. Scientists analysing the data concluded that the explosion causing the light burst was a meteoroid exploding in the atmosphere. The energy released was equivalent to 5000 tonnes of TNT.

US Dept of Defence Detectors

Airburst detectors are carried on board Sentinel satellites operating at 38 000km altitude in geosynchronous orbit. Their prime mission is to look down on Earth to detect heat from rocket engines and ballistic missiles. The main sensors detect infrared radiation but have companion visible light detectors.

The infrared sensors scan the Earth's disc every 10 seconds at a wavelength of 2.78 microns. These detectors are linked with a 3.6 metre focal length optical Schmidt telescope.

Further details remain classified.

STAR Centre

Sheffield Hallam University **Research Bulletin:** M96005

Subject: Collision Course - Spaceguard: Source - Dr Martin Beech, University of Ontario, published in *Astronomy Now,* February 1993
From: Director of Star Centre
To: PRI Schools
Date

Spaceguard

Introduction

The Earth has been pummelled by comets, asteroids and meteorites since its formation. Impacts from such objects will inevitably happen in the future - and the consequences for life on Earth could be disastrous.

Risk assessment

So what are the chances of a life-threatening impact on Earth? Studies of cratering on the Earth and Moon have given some idea of probabilities.

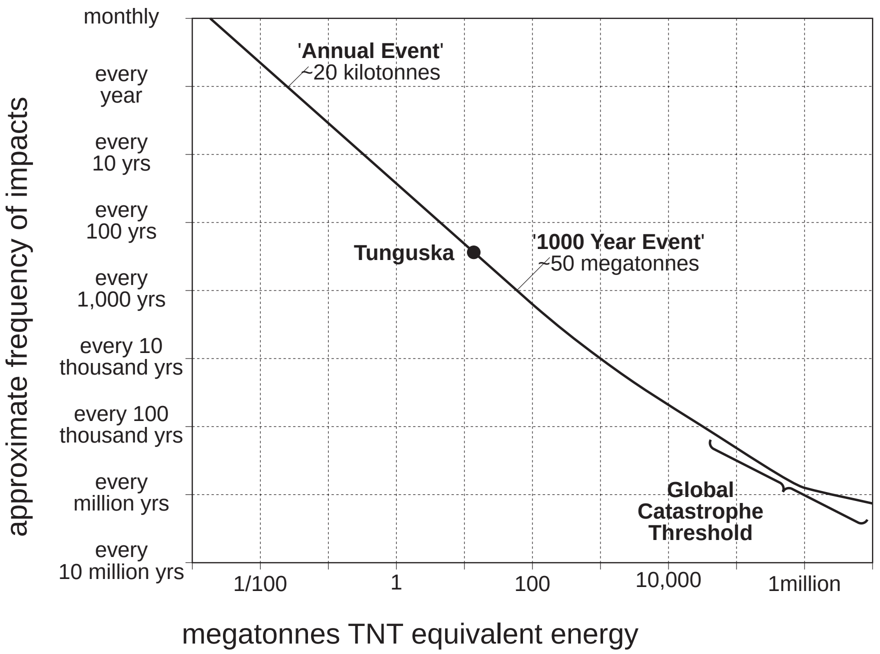
Figure 1. Risk assessment data on asteroid impacts

Asteroid Diameter (km)	Estimated Number of NEOs*	Impact Probability (once per number of years)	Impact Energy (Megatonnes of TNT#)	Crater Size (km)
0.001 (1 metre)	10 000 000	100	0.1	0.01 (10m)
0.1 (100m)	100 000	10 000	10	1
1	1 000	100 000	10 000	10
10	10	1 000 000	1 000 000	100

* NEO = Near Earth Object (asteroid or comet)
# 1 megatonne of TNT = 1 000 000 tonnes of high explosive
(the atomic bomb dropped on Hiroshima was equal to 13 000 tonnes of TNT or 0.013 megatonnes)

continued....

Figure 2. Data from Figure 1 expressed as a graph showing that the chances of a global disaster exist but fortunately are rare. The scale on each axis is logarithmic.



Spaceguard

The Spacewatch programme at Kitt Peak Observatory in Arizona has shown that Near Earth Objects (NEOs) can be detected at some distance from Earth. With larger telescopes the range of detection would be improved: after Spacewatch it is time for Spaceguard.

Spaceguard would be a system of six 2.5-metre telescopes. Preliminary calculations by David Morrison suggest that these telescopes could together monitor 6000 square degrees of sky each month. After 25 years they should have detected 90% of near Earth asteroids of 1km diameter or greater.

There is no doubt that the Spaceguard Survey would give us much more accurate data about small objects in the inner Solar System. It might also detect a meteoroid which is on collision course with our home planet and give us the opportunity to avert global disaster.

Funding

By modern standards the Spaceguard Survey would require only modest funding.

The construction of the six telescopes and a dedicated centre would cost around $50 million (£33 million) and take about five years to build. An additional $10 million (£7 million) per year would be needed to run the telescopes and process the data. Because Spaceguard has global implications, it seems a prime candidate for international cooperation and funding from, for example, Europe, America and Japan.