

The Jupiter–Comet Crash of 1994: Could it Happen to the Earth?*

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1 INTRODUCTION

It is a great honour to have been asked to give the first lecture in memory of Dr Jon Darius, whose untimely death has robbed us of a multi-talented man in the prime of his life. It is also rather appropriate that we have been chosen for this task. We both work in the area of Jon Darius' primary scientific interest, astronomy, and the subject we have chosen is one which aroused great public interest; the popularization of science was certainly one of Jon Darius' major concerns. And, finally, the collision between Comet Shoemaker Levy-9 and Jupiter was undoubtedly a very visual event. We feel that, had Jon Darius been revising his book on images of science, '*Beyond Vision*' (1), it is impossible to imagine he would not have included at least one of the spectacular pictures obtained of this event (Fig. 1).

In the July of 1994, all eyes – all astronomical eyes at least, and we are sure that many non-astronomers were similarly enthralled – were fixed on Jupiter. We were awaiting the arrival of Comet Shoemaker Levy-9 (SL9). Discovered some 15 months previously, by veteran comet watchers Carolyn Shoemaker and David Levy, SL9 was an object like no other. Carolyn Shoemaker described it as “a comet which looked like someone had stepped on it” when she first saw it in photographs taken from the Mount Palomar Observatory. As better images revealed it to consist of a chain of some twenty-plus fragments, it became known more poetically as the ‘String of Pearls’ comet.

2 IMPACT

But now it was due to die and crashing into Jupiter at a speed of 60 km/sec, each icy fragment, weighing up to one billion tonnes, would explode with an energy equivalent to hundreds of thousands megatons of TNT. Or even more. Or would it?

The mere fact that it was possible to see SL9 at a distance five times that of the Earth from the Sun was due to the enormous quantities of dust that had been generated when the powerful gravitational field of Jupiter had torn the parent body apart during closest approach in 1992 July. It was mainly that dust which was reflecting sunlight back in our direction. How much of

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Dr Jon Darius, 1948–1993



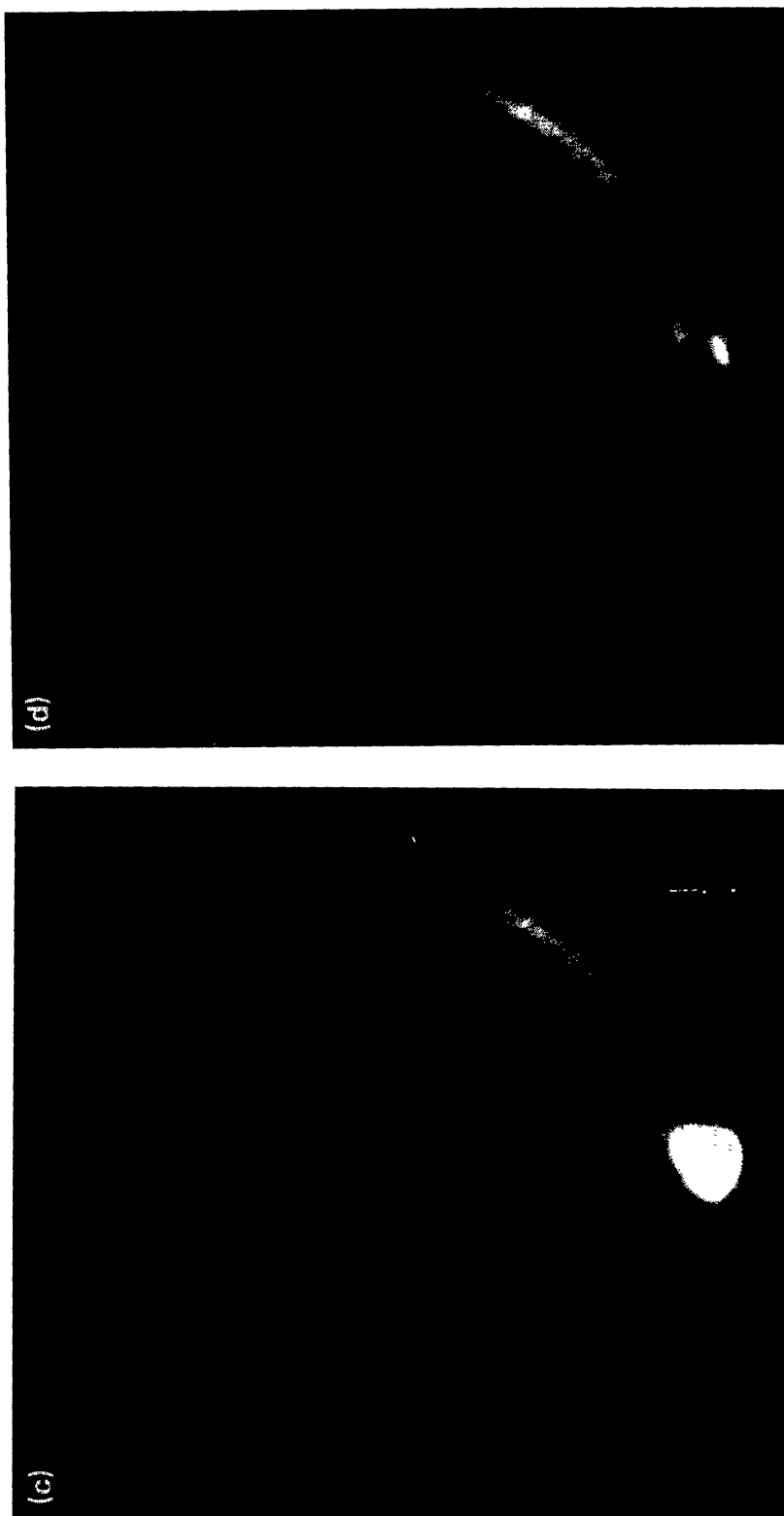
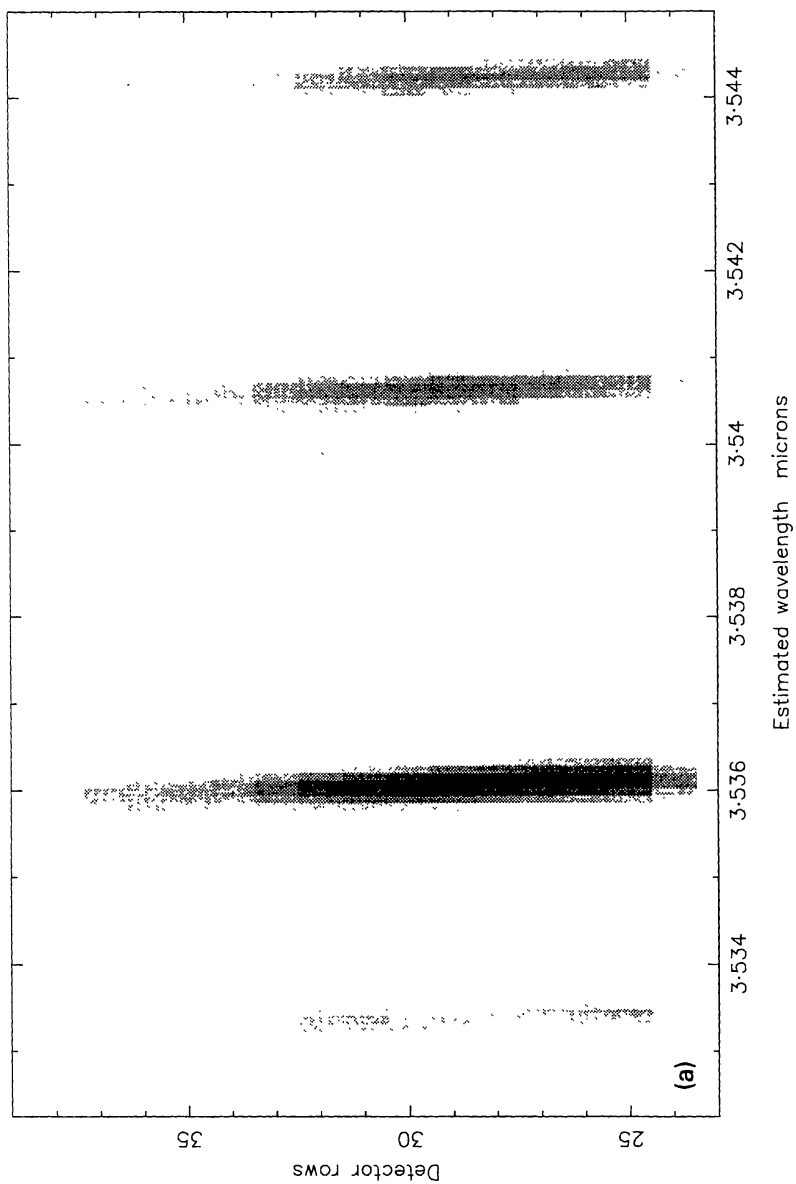


FIG. 1. The explosion of Fragment C of Comet Shoemaker Levy-9 on Jupiter imaged by NASA's Infrared Telescope Facility on Mauna Kea in Hawaii 1994 July 17. In the first image, the impact site of Fragment A – already a Jupiter day old – can be seen in the south-east (bottom left) of the planet. The commencement of the Fragment C explosion is just visible above the limb of the planet. In the following images the plume created by the explosion can be seen rising some 3000 kilometres above the planet and dying back. The sequence lasts for about 20 min.



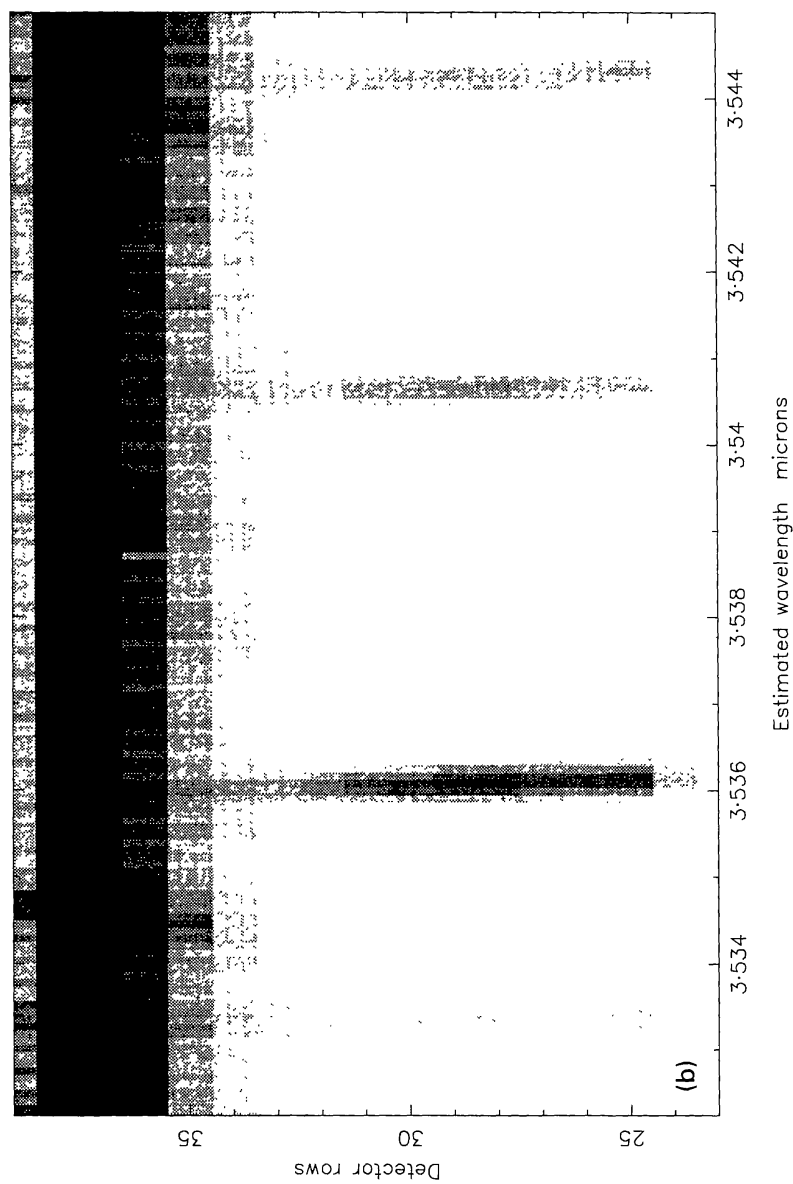


FIG. 2. The spectrum of the Fragment C explosion measured by the UK Infrared Telescope at the same time as the NASA image was obtained. The vertical axis is located from East (top) to West (bottom) along the South 44 line of latitude where the impacts were occurring. The first spectrum shows four lines due to the H_3^+ molecular ion in Jupiter's ionosphere. The explosion on the eastern edge of the planet shock heated methane in Jupiter's stratosphere to some 1500 K, producing the saturated (black) spectrum which swamps the normal ionospheric lines which can still be seen on the western side. Jupiter S44°C impact: (a) $t = -5$ min; (b) $t = +23$ min.

what could be seen in the ground-based images or those obtained by the orbiting Hubble Space Telescope – its eyesight restored to hawk-like keenness during the successful repair mission in 1993 December – was solid ice and how much was dust was open to question. Those favouring the solid ice hypothesis reckoned that the individual fragments could be anything up to 4 km in diameter. But there were other voices saying that SL9 was nothing but dust. As the week of 1994 July 16–23 approached, those astronomers who had staked their reputations and a considerable research effort into plans to observe mega-megaton explosions were therefore understandably nervous. Comets have proved unreliable in the past. Kohoutek and Halley had been public disappointments on a grand scale. Would SL9 follow? The nervousness escalated to near panic proportions as *Nature*, the world's leading scientific journal, mocked 'The Big Fizzle is coming' (2) just days before Impact Week.

Our group from UCL was watching from the infrared observatories in Hawaii, clustered on top of an extinct volcano called Mauna Kea. At 4200 metres, the UK Infrared Telescope (UKIRT) and the NASA infrared observatory (IRTF) that we were using are usually high above the clouds in an atmosphere that is clean and dry and perfect for monitoring the heat generated by the expected explosions. We were not able to observe the first fragment to arrive, Fragment A, but that was seen in Spain and South Africa; the Spanish observatories reported the resulting explosion to be "brighter than Io", Jupiter's closest moon and very bright indeed. The relief – among planetary astronomers – was palpable, to say the least.

The first visible impact from Hawaii was Fragment B, early on July 17. But that came and went, making very little disturbance except, maybe, for a change in Jupiter's outer layer, the ionosphere. Was it really "The Day of the Big Fizzle"? When Fragment C arrived some four and a half hours later, however, all the waiting and planning was rewarded. Like all the other fragments, C hit at the South 44 line of latitude, a little before the rising dawn limb of the planet. It would thus be just invisible from Earth at the exact moment of collision. But the impact site would soon emerge from behind the planet. The camera on the NASA-IRTF picked up first the impact cloud left behind by Fragment A, already a Jupiter day old, as it rotated into view. Moments later, this was followed by a flash that grew one hundred-fold in intensity (Fig. 1) over the next 10 minutes before fading away during the following 20 minutes (3).

3 RESULTS OF THE IMPACT

Data obtained on UKIRT showed a vast area of the upper atmosphere of Jupiter – the stratosphere – had been shock heated (Fig. 2). These spectra showed that stratospheric methane had been heated to around 1500 K in just a few minutes after impact and that the effects reached some 50000 km across the planet. Even 40 min after the impact, methane temperatures were still several hundred degrees above those of the normal jovian atmosphere (4).

Looking at images obtained by Hubble and the enormous Keck telescope, it was clear that SL9 impacted with a flash, a bang and a wallop (Fig. 3). The

Typical SL9 impact light curve

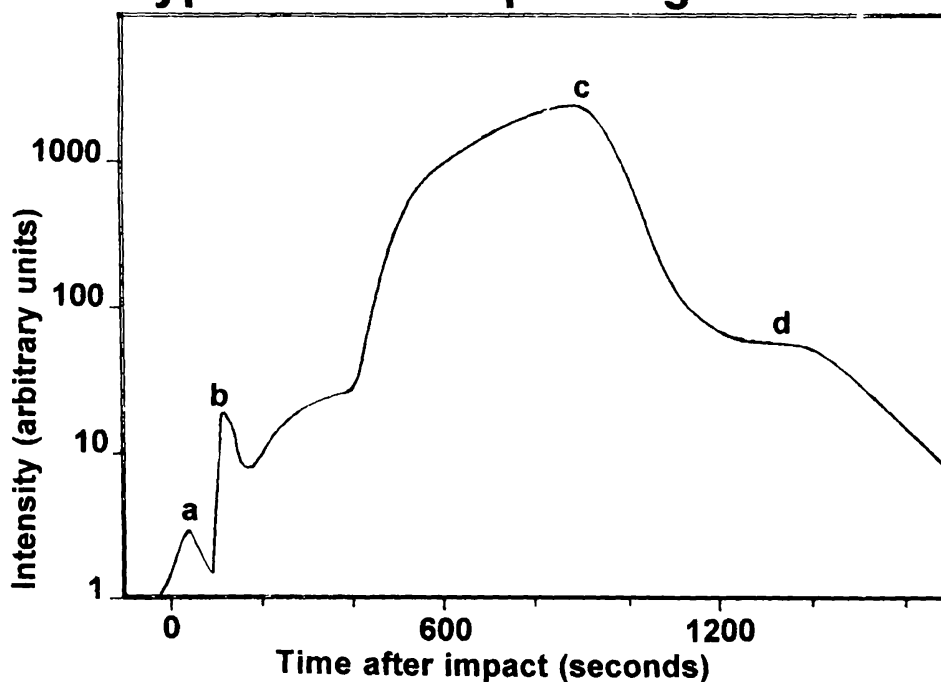


FIG. 3. A typical impact light curve: as the fragment hits the upper atmosphere, a meteor is produced, giving the first small peak (a). As the explosion takes place another, slightly larger peak (b) is produced as light is reflected off the dust left behind. The 'main event' (c) – much brighter and longer lasting – is due to the plume of hot gas rising some 3000 km above the jovian cloud tops and crashing back down onto the atmosphere once more. As the 'main event' dies away, a shoulder in the light curve is produced as the hot impact site rotates fully into view (d).

flash was caused by the fragment heating to thousands of degrees, streaking across the jovian sky like a meteor. The bang was caused by the explosion itself, deep in Jupiter's atmosphere where icy clouds of ammonia and ammonium hydrogen sulphide form. And the wallop – the brightest phase of all – was due to the 'mushroom cloud' plume rising some 3000 km above the edge of Jupiter and crashing back down onto the atmosphere. Ripples racing across the planet at 400 m a second – as across the surface of a pond – could be seen clearly in the Hubble images (5).

Days later, the debris of dust and icy particles thrown up by the impacts could be seen spreading out by the high speed winds that stir through the jovian atmosphere. East–West, they were in the process of forming a new belt. North–South, they were linking into the storm systems already present on Jupiter and interfering with the northern and southern lights which circle the magnetic poles. And, as Jupiter came out from behind the Sun at the beginning of this year, a new belt completely encircling the planet was plain to the eye.

4 COLLISIONS IN THE SOLAR SYSTEM

Could such an event happen to Earth? First let us see what other solar system bodies tell us. A well known feature of the Jovian moon, Callisto, is

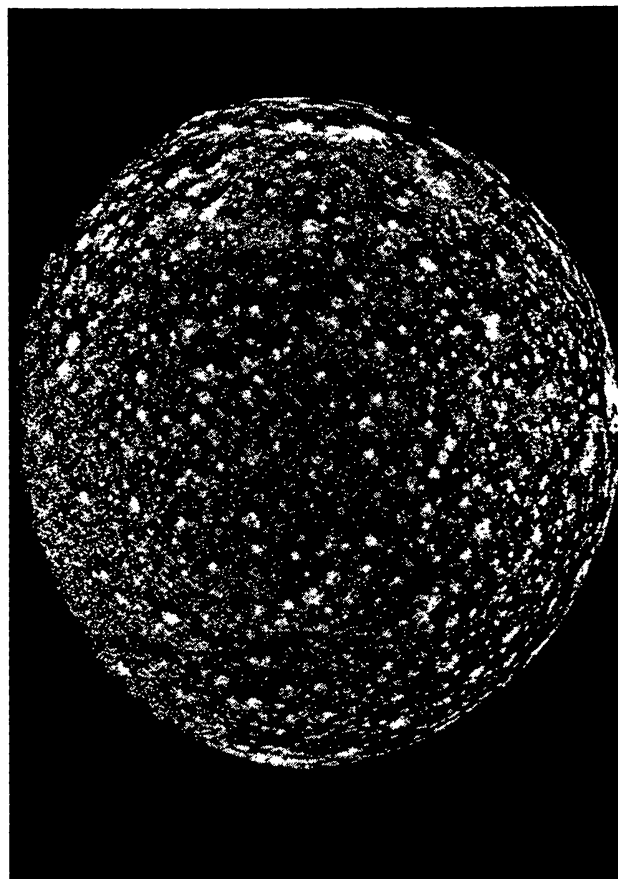


FIG. 4. Cratered Callisto from *Beyond Vision* by Jon Darius. The original photograph was taken by Voyager 2. NASA image.

a string of 11 impact craters all of a similar size and of a similar age. Prior to the detection of the fragmented SL9 it had been believed that these craters were caused by a single bouncing body – an explanation we call the ‘pogoing’ comet model. Of course it now seems likely that this was the remnant of a comet ripped apart by Jupiter which piled into Callisto.

Indeed, an inspection of Callisto (Fig. 4) shows that the satellite is completely pock-marked with craters caused by impacts. Even more spectacular is Mimas, one of Saturn’s moons and shown in Fig. 5. The massive crater shown is the remnant of a huge collision which came close to breaking Mimas apart. Moving closer to us in the solar system, both Mars (Fig. 6) and its moon Phobos (Fig. 7) show many scars due to impacts. Indeed, our own moon shows many such features.

The good news is, however, that the solar system was a much more dangerous place when it formed four and a half billion years ago than it is now. Most of the primordial objects which flew round about us have either crashed into something or escaped into outer space. The impact scars are preserved on bodies like our moon which have no atmosphere and hence no weather to gradually wash away the impact scars.

On Earth impact craters are much less long lived. However, a number of

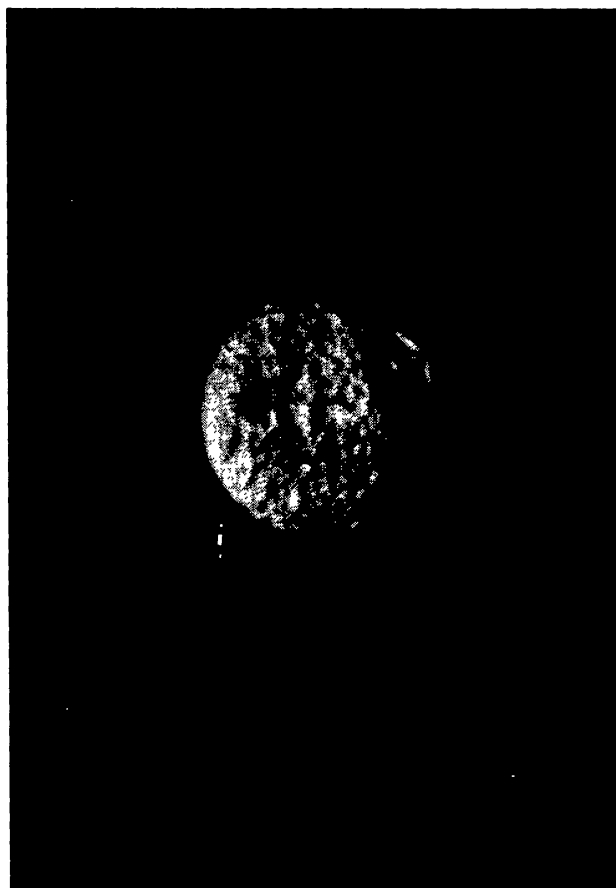


FIG. 5. The Cyclopius Eye of Mimas, from *Beyond Vision*. The original photograph was taken by Voyager 1. NASA image.

features are known. Several large craters have been discovered by remote observation of earth from space, including one spanning 70 kilometres at Manicouagan, Canada. It is estimated that a crater such as this would require an impactor several kilometres in diameter. More visible at ground level is the Barringer Crater in Arizona which is several hundred metres deep and about one kilometre in diameter. This crater was created by a comet only about 50 metres in diameter. Such an impact would be pretty bad news to anyone actually standing in the immediate vicinity, but would have very little consequence on a global scale.

A number of craters have the remains of the impactor left. The largest meteorites that have been recovered are only a few metres in diameter. They nevertheless provide a unique opportunity to study extraterrestrial matter – perhaps even from deep space – under the microscope.

The advance of unmanned space flight has given us the opportunity to inspect more massive comets and asteroids at close quarters. The Galileo space-craft, while en-route to Jupiter, passed close to the asteroid Gaspra. This irregularly shaped object some 18 km in diameter looks more like a knobbly potato than a perfect sphere and is somewhat larger than Comet



FIG. 6. Martian splotches from *Beyond Vision*. The original photograph was taken by the Viking 1 orbiter. NASA image.

Shoemaker Levy-9 prior to its break-up. Gaspra, however, is in a stable orbit about the Sun in the asteroid belt and thus provides no threat to Earth.

5 COMETS: OBSERVATION AND PUBLIC PERCEPTION

The observation of comets goes back to the earliest age of recorded astronomy. Similarly cometary observations were intimately linked with the development of photographic techniques in observational astronomy. The photograph of the great Comet of 1882 shown in Fig. 8 was originally taken to record this spectacular event for posterity. However, when the photograph was developed it was realized that not only was the image of the comet recorded but also that of many, many stars. The use of photography to give accurate stars maps, far more reliable than by eye observation and hand drawn maps, was born.

A decade later saw the first photographic detection of a comet, Comet 1892 V or Barnard's Comet (see Fig. 9). A hundred and one years later the technique for finding new comets had only changed by one subtle but important detail. When Carolyn Shoemaker sat down to an evening's comet searching in 1993 March, she used a stereoscopic technique. This involved taking not one, but two pictures of a particular region of sky as determined by the position of the stars. Detailed comparisons of this pair of pictures,



FIG. 7. The wrinkles of Phobos from *Beyond Vision*. The original photograph was taken by the Viking 2 orbiter. NASA image.

made with a special stereoscopic microscope, is a painstaking task. The signature of a new comet or asteroid is any unknown object which moves relative to the star positions. Fragmented Comet SL9 was originally seen by this method as a strange cigar shaped object.

Carolyn Shoemaker's detection of Comet SL9 was of immense importance. It gave astronomers 15 months warning of the crash, long enough to make both preliminary models of the impacts and detailed observing plans. Without the early detection none of this would have been possible and indeed it is quite plausible that the whole sequence of impacts, which occurred at a time of year unfavourable for Jupiter watching, would have passed unnoticed.

On Earth, comets have often been greeted with outbreaks of irrationality or hysteria. Predictions of gloom and doom through the ages abound (Nigel Calder's *The Comet is Coming* (6)). The arrival of Comet SL9 proved no exception. A Polish nun, Sister Marie Gabrielle, took the opportunity to bombard the British press with adverts predicting dire consequences unless mankind mended its ways. Such hysteria can even become serious. Shortly after the SL9 impact, *The Times* carried a story identifying a comet on a possible collision course with Earth (7). In Bavaria, a large explosion and



FIG. 8. Cometary stimulus for celestial cartographers from *Beyond Vision*. The original photograph was taken by Sir David Gill in South Africa in 1882. Royal Astronomical Society.

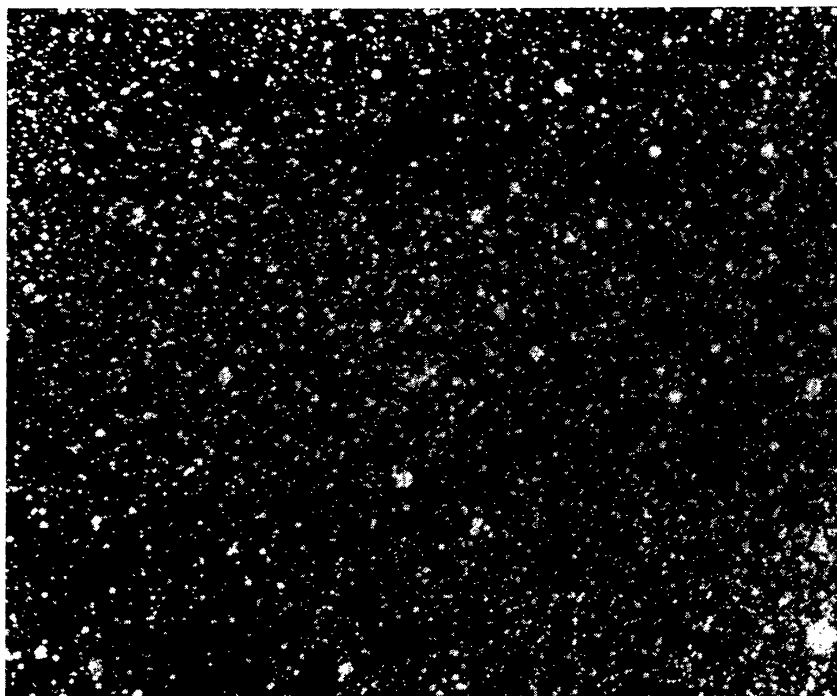


FIG. 9. Photographic capture of a comet from *Beyond Vision*. The original photograph was taken by E.E. Barnard from California in 1892. Royal Astronomical Society.

associated crater was attributed to an impact of a meteor weighing 100–200 kg. More prosaically it turned out to be a landowner illegally blasting an artificial lake (8). Such mixed reactions were typified by Bennet's Comet, clearly visible from Earth in 1970. While serious spaceborne observations monitored this comet, some Egyptians feared it was an Israeli secret weapon!

Of course comets and their impacts should not be looked at entirely in a negative light. Many believe that most of the Earth's water, a vital component for all life forms, came here in the form of comets, which are, of course, essentially dirty snowballs.

6 EARTH IMPACTS

There is a constant drizzle of space dust into the Earth's atmosphere. This drizzle provides shooting stars and also micro meteorites, which are widely being studied, but it provides little threat to life. Indeed, in the last two hundred years there is no recorded case of a human fatality caused by the impact of a heavenly body (9). However, to conclude from this that impacts present zero threat to life is to go too far.

Geological evidence from many locations around the world shows a similar band of dark material between rock from the Cretaceous and Tertiary Eras (known as the K/T Boundary). This layer has a peculiar atomic composition which was widely attributed to the dust thrown up in a cometary impact, even prior to the discovery of the actual impact site. This site has now been identified in the Yucatan peninsula in Mexico. The impactor was probably similar in size to the undisrupted Comet SL9.

This impact threw up sufficient dust to coat the entire planet with a layer thick enough to be seen 65 million years later. There can be little doubt that such an event must have had a profound effect on the climate – blocking out much of the sunlight and casting the world into many years of near darkness. This is the 'nuclear winter' much feared as a consequence of nuclear warfare. The decline in the dinosaurs also dates from this period, but whether the impact actually caused the fall of these giants, as has been vigorously argued in some quarters, is still a matter of debate (10).

Observations of SL9's collision with Jupiter allowed us to monitor the effects of a succession of large impacts. The many scars visible on the planet after the impacts are caused by dust thrown high into the atmosphere. These scars are clearly visible because of the difference in how they absorb or reflect sunlight compared to the undisturbed atmosphere. At the infrared wavelengths we observe in, several of the scars were as big as the Earth. Several months after the impacts the scars had blended into a single belt all round the planet.

The only significant impact in modern times occurred in the Tunguska region of Siberia in 1908. This explosion devastated forest over a diameter of about 50 km. Although this was rather bad news for the local reindeer population, it had little human consequences and few eye witnesses because of the remoteness of the region. Present estimates are that this event was caused by an object about 30 m in diameter which exploded some 20 km up in the atmosphere (11). This event neatly illustrates that however spectacular

such events may be, they are unlikely to be a serious cause of fatalities as only small regions of the Earth's surface are densely populated. In other words the likely scenario of a minor impact is the opposite of that which always appears to be envisaged by Hollywood. In dramas comets always appear to target city centres – life is more prosaic.

7 CHANCES OF AN IMPACT AND ITS CONSEQUENCES

Estimating the chances of a major Earth impact is fraught with difficulty. First, however, one must recognize that the circumstances which led to Comet SL9 hitting Jupiter do not apply to Earth. Jupiter is massive and of the eight hundred or so known comets and asteroids orbiting in the solar system, all except two or three orbit the Sun; the others orbit Jupiter.

A comet orbiting a single body – either Sun or Jupiter – is stable and should continue for ever. However, the gravitational forces from other smaller objects – such as Jupiter's moons – perturb these orbits. This perturbed motion is now chaotic and thus difficult to predict accurately, however estimates are that Comet SL9 had undergone some 30 revolutions round Jupiter – a sixty year dance of death as it was gradually sucked closer and closer to the planet.

For a comet to hit Earth it is simply a question of our being in the right (or perhaps wrong) place at the right time. The planets, and the asteroid belt, all inhabit a single plane, the so-called solar ecliptic. However, cometary orbits in general lie outside this plane making such an Earth impact exceedingly unlikely.

Although the consequences of a large impact might seem dire, the chances of any of us being killed by such an event are slim (9). It is estimated that the chance of being killed is somewhere between the chances of being killed in a plane crash (on the high side), and being killed by a snake (on the low side). No-one is advocating that everyone in the world routinely carries snake bite antidotes. Why is it, therefore, that some people are seriously suggesting that we spend huge sums – amounts approaching the annual gross domestic product of the UK – on developing anti-comet missile systems? Besides the obvious answer that the break-up of the USSR means that some people require a new 'evil empire' to stay in business, there is also a serious concern.

An impactor large enough to set up a global nuclear winter would have catastrophic consequences. These might include the death of half of the world populations and the complete disintegration of civilization as we know it. This scenario is so dire, even if it is also very, very unlikely, that it is at least worth contemplating whether one can combat it. In fact the major uncertainty in estimating the mortality statistics quoted above is the chance of a major, nuclear winter creating, impact.

At present Carolyn Shoemaker's husband, Eugene, is heading commissions to address this problem. This commission is building on an early report 'The Spaceguard Survey' by David Morrison (12). Its aim is a programme to detect all objects with orbits which bring them near to Earth. One encouraging conclusion of the earlier report is that such a survey would give us at least six months warning of any impending major impact – plenty of time, they claim, to organize a cometary shooting party.

8 CONCLUDING REMARKS

To conclude with we would like to remind readers of the story of Chicken Licken. Chicken Licken was a keen observer who one day was struck on the head by a falling acorn. Without waiting to analyse his data, Chicken Licken concluded that the sky was falling in. He immediately rallied all the heavy weights in the farm yard to form a delegation to the funding authorities – the King – to broadcast the news. En route to the King they met the fox who invited them to dinner to discuss their proposals. Unfortunately for Chicken Licken and his friends, they forgot to ask what, or who, was on the menu. They never made it to the King.

This parable is an important reminder to us to keep a sense of perspective. A cometary impact could lead to death and destruction on a global scale, but this is exceedingly unlikely. While humans have in their possession weapons which could destroy the world many times over, there are more serious and immediate problems to worry about.

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