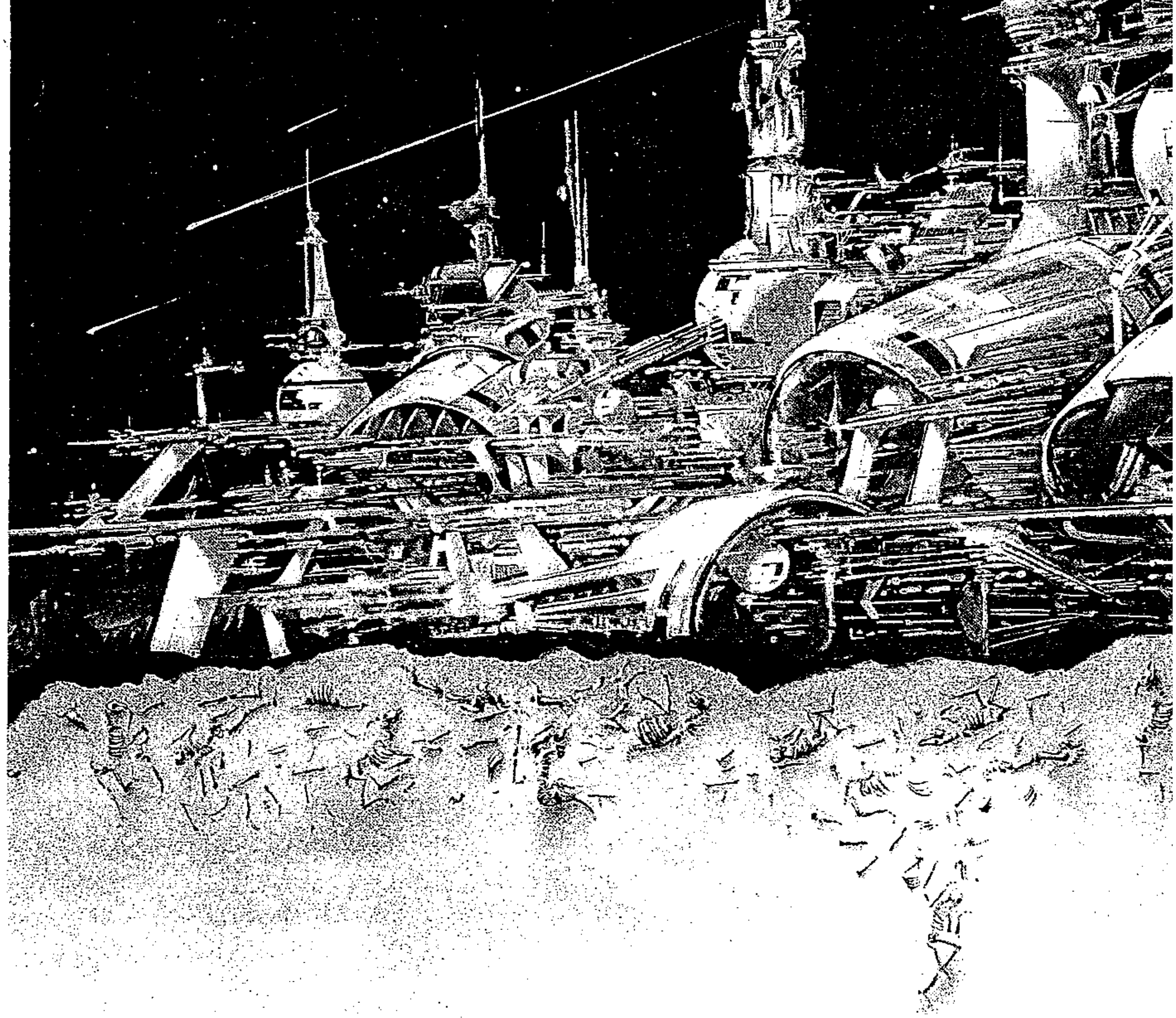
PERIODIC COMET SHOWERS: THE MAINSPRING OF EVOLUTION?

by Piet Hut

Mass extinctions of animals and plants have taken place at various times during the Earth's history. Comet showers triggered by a companion star to the Sun might be the cause.



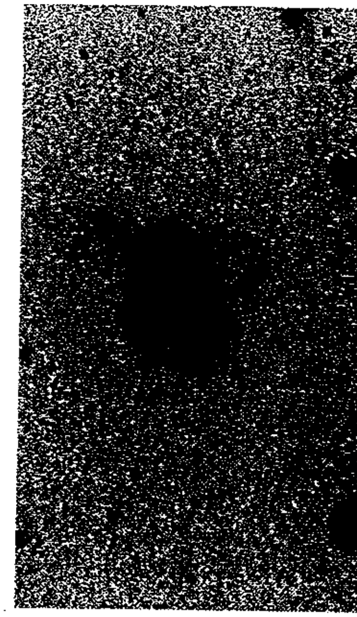
when one examines the environs of the bright infrared galaxies: about one out of four appear to be colliding or merging galaxies, a ratio far higher than is found in the general population of galaxies. This characteristic suggests that strong gravitational interactions of galaxies can trigger bursts of star formation on a grand scale.

Some infrared-bright galaxies may have active centers like Seyfert galaxies, in which a compact primary energy source—perhaps in some cases a black hole—is embedded in dust. A possible example of this, although the interpretation is not certain, is the remarkably luminous galaxy Arp 220, which IRAS found to be not only 80 times brighter in the infrared than in the visible but also about 100 times more luminous than normal galaxies overall. The large sample of isolated galaxies and of galaxies in groups and clusters measured by IRAS promises some answers to the fascinating problems of galaxy energetics and the influence of surroundings on activity within galaxies.

Continuing the adventure

The IRAS survey of the infrared universe has been completed, and its magnificent images and catalog of the skies have been carefully prepared for serious study. Astronomers have already uncovered a few of the surprises lying hidden in cool cosmic matter ranging in distance from light-minutes to billions of light-years away. But the full intellectual fruits of this pioneering venture will be gathered only after years of probing: asking the right questions, finding the right way to wrest the answers from the inscrutable numbers, pursuing the critical follow-up observations, and relating these facts to the general body of astrophysical knowledge. The space agencies of both the United States and Europe are planning orbiting infrared observatories for the 1990s that can carry forward the exploration begun by IRAS. Rarely have measurements based on a single technique so suddenly illuminated such a diverse sample of the universe. It seems likely that the biggest surprises and insights are yet to come.

G. E. Danielson, C. J. Lonsdale, and B. T. Soifer



Arp 220, one of the most remarkably luminous galaxies detected by IRAS, is shown above in a visible-light negative image obtained with the Palomar Observatory five-meter telescope. Its disturbed central region and wispy tails suggest that it is a system of colliding galaxies.

FOR ADDITIONAL READING

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Leif J. Robinson, "The Frigid World of IRAS—I," *Sky & Telescope* (January 1984, pp. 4–8).

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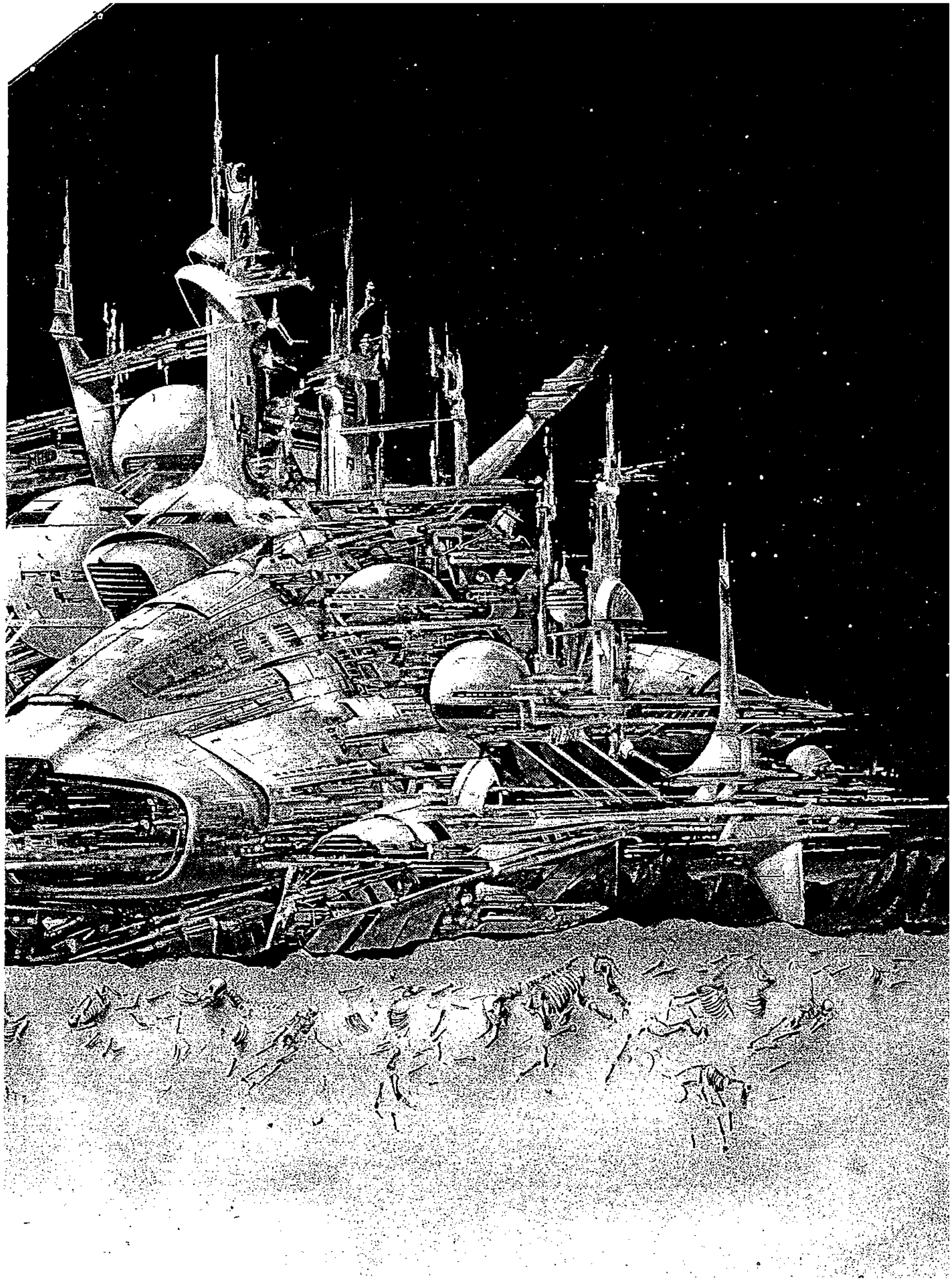

During the last ten years it has become more and more apparent that life on Earth has not evolved gradually; instead, occasional worldwide catastrophes have played a large role in the process of evolution. The previously accepted view of a gradual evolutionary process in which plant and animal species develop very slowly, only to make way after many millions of years for new species, is now seen as only one aspect of the development of life on our planet. Equally important, according to the newer theory, are relatively sudden changes that took place during periods of time of at most a few million years—very little time on a paleontological scale. During these periods of rapid development changes that took place within species were much more drastic than the accumulated gradual changes that had occurred over the previous tens of millions of years.

A look at past geologic eras supports this theory. The last 570 million years are divided into three main eras: the Paleozoic, the Mesozoic, and the Cenozoic. Each of these is further divided into a number of shorter periods of about 50 million to 100 million years. These divisions are based on the findings of various fossils in rock layers of different ages. Every boundary between two periods is matched to the disappearance of large numbers of species from the fossil record and the subsequent appearance of many new ones. This is especially marked at the boundary lines between eras; in both cases, Paleozoic-Mesozoic and Mesozoic-Cenozoic, more than half of all the plant and animal species for which there is fossil evidence died out within only a few million years. For a long time the explanation of these catastrophic boundary periods has been one of the great riddles of paleontology.

The limited scope of this article precludes any detailed discussion of the explanations that have been proposed for these extinction events. Through the years many were devised, none of which was clearly more convincing than any of the others. The question to be resolved was often phrased in reference to the largest of the recent extinction events: "What killed the dinosaurs?"

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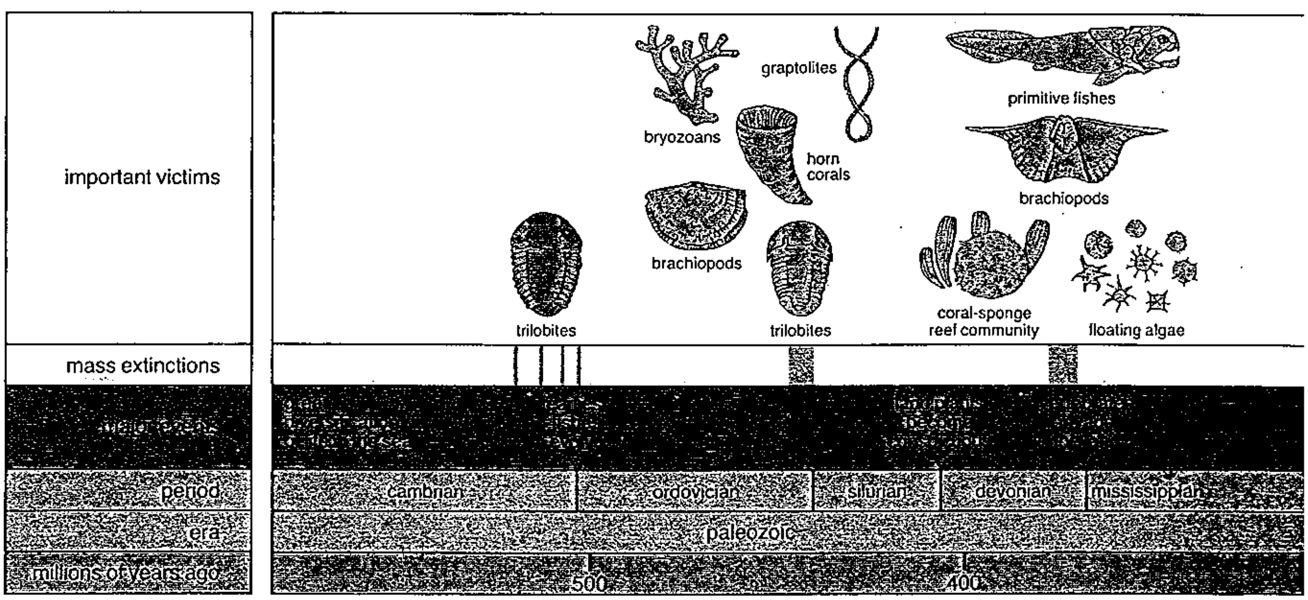
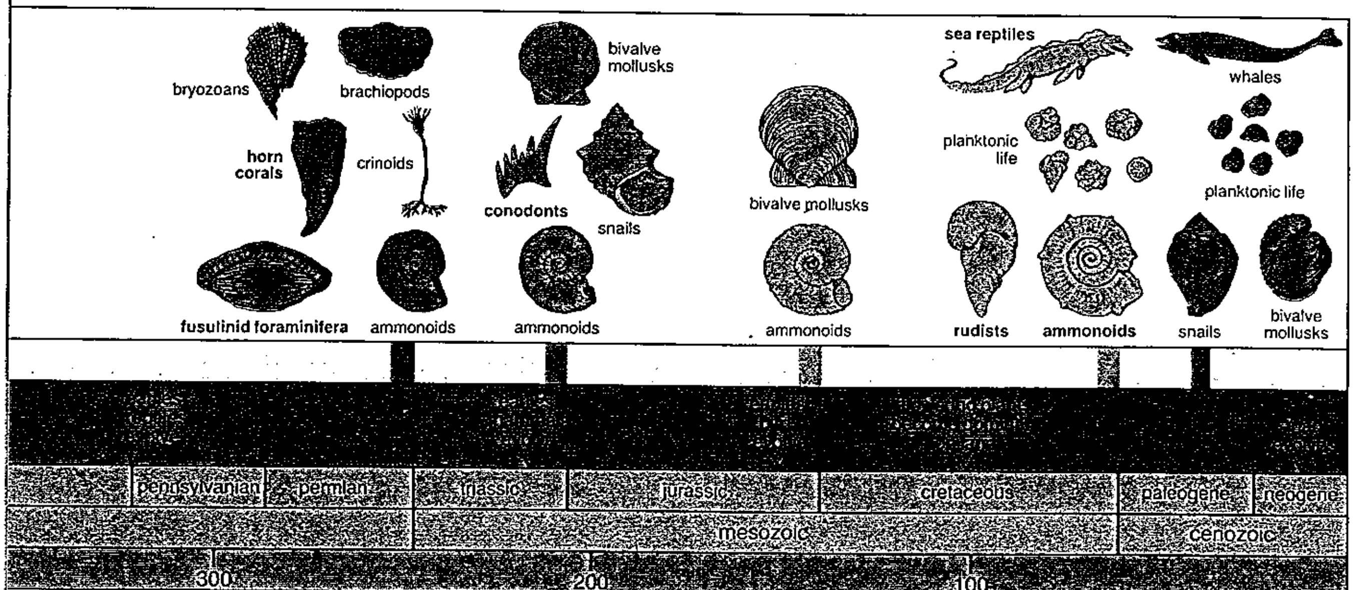
(Overleaf) Illustration by Ron Villani



An answer to that question recently came from an unexpected quarter: research in nuclear physics. At the University of California at Berkeley an interdisciplinary team devised a method to date the various geologic periods more closely than had previously been possible. This team consisted of Luis Alvarez, a Nobel laureate in physics at Lawrence Berkeley Laboratory; his son, Walter Alvarez, professor of geology at the University of California at Berkeley; and Frank Asaro and Helen Michel, nuclear chemists at Lawrence Berkeley Laboratory. Their dating method involved measuring the amount of iridium present in rock. Iridium is a very rare element on the Earth's surface, because most of it sank to the core of the planet as the Earth cooled. Iridium is also rare in meteorites but not as rare as it is on the Earth's surface, since meteorites are composed of material very similar to the original material of Earth. The Alvarezes, Asaro, and Michel planned to measure the iridium present in particular strata and to determine from those measurements the number of micrometeorites that had rained down over millions of years. From this determination they hoped to infer how long it had taken for the strata to form, under the assumption that the rain of meteorites had remained constant throughout the history of the Earth.

Contrary to their expectations, the Alvarez team discovered an abnormally large amount of iridium in a very thin clay layer that marked the boundary between the Mesozoic and the Cenozoic eras; this layer closely coincides with the geologic time during which the dinosaurs died out. This amount of iridium, although still small in absolute value, was larger than normal amounts by a factor of about 100; it constituted about one-millionth of a percent of the total matter in the clay layer. The Alvarez team concluded that the massive extinctions at that time, 65 million years ago, were caused by the impact of an object from space with a diameter of a few miles. Such an asteroid or comet would contain enough iridium to spread a layer of it all around the Earth after the impact. A tremendous amount of energy must have been released by the impact of an object traveling at a speed of about 160,000 kilometers

Mass extinctions (colored lines and bars) have affected a large variety of marine plants and animals during the past 570 million years, ranging from single-celled algae and plankton to huge sea reptiles and whales. The best-known extinction took place at the end of the Cretaceous Period, about 65 million years ago. Most marine species were eliminated as were the dinosaurs on land. In some cases plant and animal groups recovered after crises and new species evolved, but other groups (bold type) vanished completely from the world's oceans.



Lawrence Berkeley Laboratory

Walter Alvarez (second from right) holds a sample of clay from the layer that marks the boundary between the Mesozoic and Cenozoic eras, about 65 million years ago. Clay in this layer contains about 100 times more iridium than would normally be expected, leading to the conclusion that an extraterrestrial object rich in iridium struck the Earth at that time and caused the mass extinctions of dinosaurs and other animals. Alvarez is surrounded by other members of his research team (from left) Helen Michel, Frank Asaro, and Luis Alvarez.

(100,000 miles) per hour. It has been estimated that this energy must have been equal to 500 million megatons, an amount of explosive energy 10,000 times greater than that of all the nuclear weapons stockpiled by the United States and the Soviet Union combined. It is, therefore, not surprising that such an explosion could have deposited a worldwide layer of clay, nearly an inch thick, with an abnormally high iridium content. As it turned out, the predictions of the Alvarez team, made in 1979, were confirmed; within a few years in many places, on land and under the sea, similar layers also located at the Mesozoic-Cenozoic border were found to contain an unusually high percentage of iridium.

Impact of an asteroid or comet

What are the consequences for life on Earth of the impact of an interplanetary rock several miles in diameter? This question is unfortunately relevant to today's political situation, with tens of thousands of nuclear warheads in stockpiles ready to unleash a catastrophe not so different from that which might have destroyed the dinosaurs.

The consequences of the impact on Earth of a rock the size of a small mountain cannot be accurately predicted. One thing is certain, however; the Earth's atmosphere would be drastically altered, and it would require months at least for it to return to equilibrium. The circulation patterns of warm and cold currents in the air and the oceans would be disrupted; and no one can predict with any certainty how those disruptions would develop and what changes in patterns would occur before equilibrium was finally reestablished.

Calculating the effects of this impact on life on the Earth is even more complicated. At present, there is much controversy over the question of how and to what extent human activities affect the environment, involving such issues as acid rain and worldwide deforestation. It is difficult enough to make objective and comparable measurements of long-term developments in plant and animal populations; it is practically impossible to pinpoint which convoluted chains of ecological reactions have their origins in human activities.

Since it is so difficult to measure the consequences of human activity on the ecology of the planet, it is hardly surprising that scientists have no idea, not even a qualitative one, of the sudden and more dramatic effects of the impact of an extraterrestrial object. Many theories have been put forward, but their underlying assumptions vary so much that no idea can be formed of even the effect on world temperature. As an example of the uncertainties, even the direction of the change in temperature is a matter of controversy. Some theories predict a "greenhouse" effect. According to these, assuming that the comet or asteroid fell into the sea, so much steam would be added to the atmosphere that this damper atmosphere would absorb more infrared rays from the Sun and thus hinder the Earth's cooling. This would cause surface temperatures to climb, as the Earth's heat would be trapped under the air "blanket." Others predict that large amounts of dust and debris would be thrown up into the atmosphere by the impact; they maintain that even if the object landed in the sea, the force of the impact would blow part of the seafloor up into the air. This layer of dust would let in less sunlight than a clearer atmosphere, reflecting the Sun's heat away from the Earth with the result that surface temperature would drop sharply.

There can be no doubt that a collision between the Earth and a comet or asteroid would have serious consequences for life on Earth. After the discovery of a worldwide layer of iridium, deposited at roughly the same time as the extinction of the dinosaurs and therefore indicating that such a collision might have taken place, researchers naturally wondered whether there might be more such layers. The answer came in 1981, when the Alvarez team reported the discovery of a second iridium layer, in a rock stratum 34 million years old and thus in the later part of the Eocene Epoch (early Cenozoic Era)—also coinciding with a period of mass extinctions. In the spring of 1984 the discovery of yet a third iridium layer was announced. Chinese researchers found a high concentration of iridium in a rock layer at the Paleozoic-Mesozoic boundary, the time of one of the most severe mass extinctions (the trilobites, a group of marine arthropods, were one of the many types of animals that died out at that time).

These findings support the idea of a connection between impacts and extinctions. More support has come from a closer study of the first iridium layer discovered by the Alvarez team. This layer was found to contain, along with iridium, abnormally high percentages of gold and platinum, elements that also point to the impact of an asteroid or comet.

Periodic impacts?

In October 1983 two paleontologists at the University of Chicago, David Raup and John Sepkoski, announced a new discovery, one that put a different light on the question of mass extinctions. Sepkoski had worked for

Illustration by Don Davis; courtesy, Space Art International

One or more objects from space may have collided with the Earth at the end of the Cretaceous Period. Such impacts would have generated a huge dust cloud that prevented sunlight from reaching the Earth's surface, thereby suppressing photosynthesis and causing the death by starvation of the dinosaurs and many other forms of life.

years on an extremely detailed catalogue that included information about the extinctions of some 3,500 families of marine animals over geologic time. This extensive material clearly indicated several mass extinctions of those animals over the last 250 million years. The extinctions happened relatively quickly, during periods of at most a few million years and possibly much quicker.

The big surprise came when Raup and Sepkoski scrutinized this catalogue more closely, throwing out of their statistical analysis those families for which evidence was less solid. The result of this weeding-out process was that most of Sepkoski's work was put aside, leaving only 567 families for which the data were considered secure. The history of those families, now much better defined than in comparable studies, included the time of their origins, the rise and fall of the number of fossils from those families in the subsequent geologic periods, and the time at which each family died out. Raup and Sepkoski performed their statistical analysis on this select catalogue of families and found 12 different periods (each of which lasted at most a few million years) at which an abnormally high number of species died out. Most interestingly, these periods occurred at regular intervals, approximately once every 26 million years.

At first glance (and, indeed, at second glance as well), this result was puzzling. A few years earlier, in 1977, Alfred Fischer and Michael Arthur of Princeton University had made a similar suggestion of a periodicity in mass extinctions with a 32 million-year period. But without a quantitative analysis their ideas attracted few supporters. Now, however, the much stronger evidence for periodic extinctions could not be sidestepped, even though the connection between impacts and extinctions (not known to Fischer and Arthur in 1977) made such periodicity even more unlikely. If a time of mass extinctions was caused by the impact of an object from space, how could such extinctions be periodic? Both the object and the Earth circled the solar system for billions of years, and the distance between objects in the solar system is enormously greater than the diameters of the planets. Collisions may occasionally occur between comets or asteroids and planets such as the Earth, if the smaller objects cross the orbital paths of the larger ones. These collisions are the result of such complicated interactions among orbiting objects that, practically speaking, they cannot be predicted over time scales of several million years or longer. For this reason almost all scientists had considered it obvious that the impacts that had caused extinctions on Earth were random and unpredictable disasters.

A companion star?

A possible explanation of the puzzling 26 million-year periodicity of mass extinctions caused by impacts was put forward in December 1983, shortly after Raup and Sepkoski's findings were made available. Two groups of astrophysicists independently proposed that the Sun might have a companion star with such a wide orbit that it would take 26 million years to complete a full revolution around the Sun. This hypothesis is partially based on the fact that most stars in the universe are double stars; if our Sun is a single star, it is an exception. One version of the companion star theory was put forward by Daniel Whitmire of the University of Southwestern Louisiana and Albert Jackson of the Computer Sciences Corp. in Houston, Texas. The other version was proposed by Marc Davis and Richard Muller of the University of California at Berkeley along with Piet Hut of the Institute for Advanced Study in Princeton, New Jersey.

How could a double star be a sort of alarm clock for periodic mass extinctions? The central idea in this theory is that comets and not asteroids are responsible for the impacts that cause the extinctions. Most comets have very wide orbits that reach far beyond the planetary system; the farthest point in those orbits can be up to 1,000 times the distance

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Barringer (or Meteor) Crater in Arizona, 180 meters (600 feet) deep and 1.2 kilometers (0.75 mile) wide, provides evidence that objects from space have collided with the Earth. Scientists estimate that a small asteroid about 45 meters (150 feet) in diameter created the hole some 25,000 years ago.

from the Sun to the outermost planet, Pluto. A typical observed comet normally passes through the planetary system once every million years or so. Most comets, however, never come close to the planetary system and slowly traverse the outer regions of the solar system on their wide orbits. Perturbed by passing stars, the cometary orbits will drift, and every now and then an orbit will intersect with the inner planetary system, bringing a "new" observable comet on its first passage close to the Sun. In fact, based on the appearances of new comets on extremely elongated orbits, the astronomer Jan Oort at Leiden Observatory in The Netherlands in 1950 proposed the existence of a large "cloud" of comets beyond the realm of the planets but still within the sphere of the Sun's influence. The existence of the Oort comet cloud, estimated to contain over 100,000,000,000 comets (and possibly 10 or 100 times more), is now generally accepted.

If there were a lightweight "second Sun" orbiting around our Sun, so far away that it might appear too faint even to be seen with binoculars, how would its orbit develop, and how would it affect the comets? These questions can be studied in turn.

A companion star that revolves around the Sun in a wide elliptical orbit once every 26 million years has been proposed as the explanation for the 26-million-year periodicity of mass extinctions on the Earth. According to the theory the companion passing near the Sun would cause the orbits of nearby comets to be shifted so that they would come much closer to the planets. Some of these comets would collide with the Earth, generating the huge dust clouds that cause the extinctions.

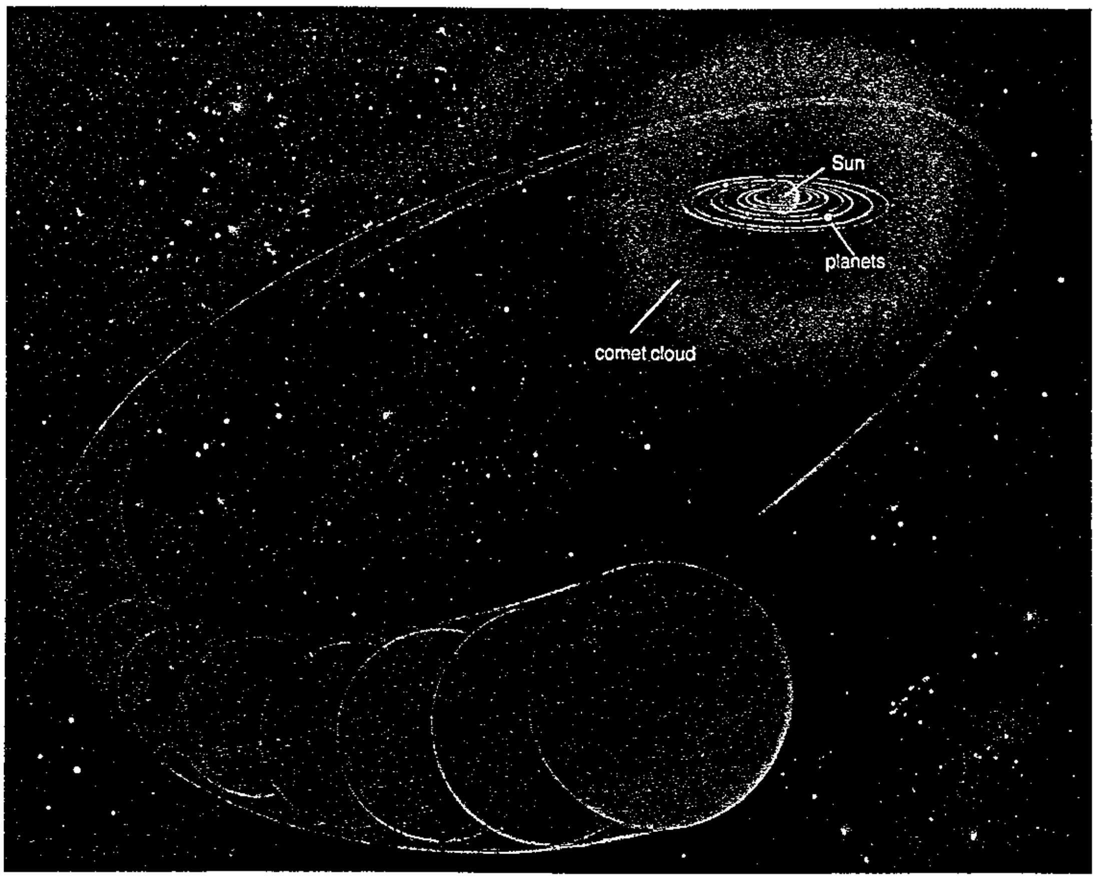


Illustration by Ron Villani

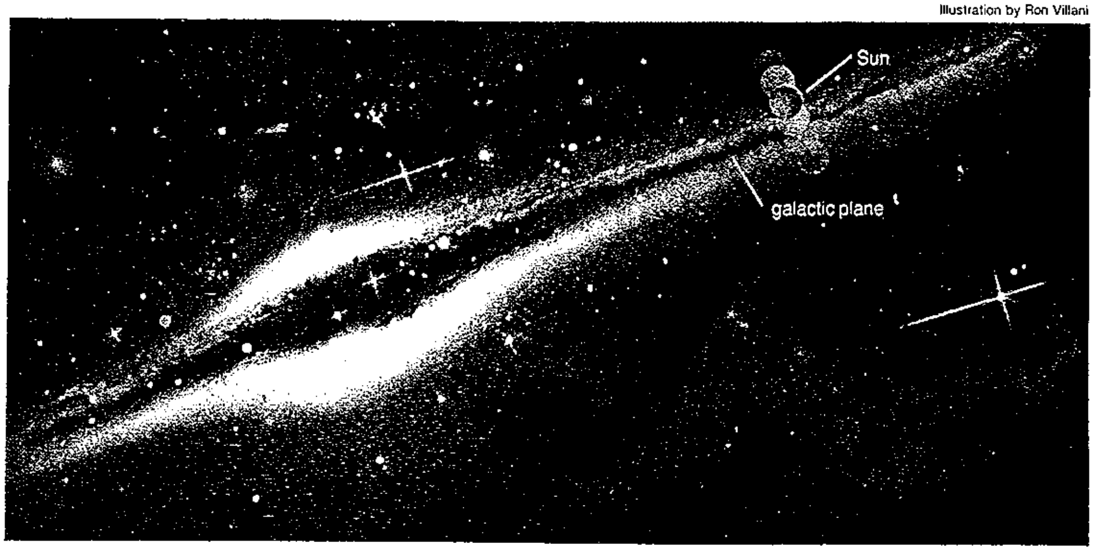
For the solar companion star to have an orbital period as long as 26 million years, its orbit would have to be very wide indeed, extending a large part of the way toward the nearest stars. (One light-year equals 9,460,500,000,000 kilometers or 5,878,000,000,000 miles). At present, the companion star is thought to be at a distance from the Sun of slightly more than two light-years, and it will approach the Sun to within less than half a light-year around 15,000,000 AD—the time at which the next extinction is expected. An orbit that takes the companion star light-years away from the Sun is not as stable as the much smaller planetary orbits. Many stars will pass close by such a companion, and once in about a million years a random passing star might even pass through its orbit around the Sun. This would cause the orbit of the companion to change slowly in an erratic fashion and, therefore, in the course of a billion years the companion would have changed its course considerably. Fortunately, though, even on such a slowly tumbling and jittering orbit a companion star has a negligible chance of entering the solar system. Such an intrusion would disturb the orbits of all the planets and would thereby induce significant temperature variations on the surfaces of the planets.

Because a companion star with a wide orbit is unlikely to penetrate the planetary system, it would not influence the orbits of the asteroids, which are located inside that system. Comets, on the other hand, orbiting well outside the planetary system, would be affected by the companion when it passed close to the Sun. It is relatively simple to estimate how many comets would be disturbed by such a passage. Such an estimate shows that the frequency of comets entering the planetary system during the companion's passage might easily be 100 times larger than normal. Presently, only a handful of new comets is detected each year, of which only one every few years is easily visible to the naked eye. During the passage of the companion near the Sun conditions would be rather different, since the perturbing influence of the companion would have increased the comet flux significantly during a period of about a million years. The above numbers would rise to a few new comets every day and a spectacular new comet about once a week. If there were observers during such a passage of the companion star, on a clear night such persons would be able to see several comets scattered across the sky without having to use a telescope.

Such a spectacle of several brilliant comet tails filling part of the sky might have poetic beauty, but it would not be harmless. Each comet that came close enough to the Sun to cross the Earth's orbit would have a tiny chance of colliding with the Earth itself. This chance would be no greater than one in a billion, but during the million years needed for the companion to pass by the Sun more than a billion comets would come close enough to the planetary system to threaten the Earth. Thus during that million years there would be a clear possibility of several collisions.

The theory that the Sun has a companion star that is responsible for a periodic shower of comets is not the only explanation proposed for periodic mass extinctions. Alternate theories have been put forward by Michael Rampino and Richard Stothers of the Goddard Institute for

Illustration by Ron Villani



Another explanation of mass extinctions involves the motion of the Sun perpendicular to the plane of the Milky Way Galaxy. Approximately once every 30 million years the Sun passes through the mid-plane of the Galaxy, a periodicity that closely matches that determined for the extinctions. At the mid-plane the Sun moves close to dense gas clouds. These clouds, some scientists believe, trigger comet showers on the Earth and other planets.

Space Studies in New York City, and also by Richard Schwartz and Philip James of the University of Missouri. Both of these theories explain the periodic impacts and mass extinctions in terms of the Sun's passage through the galactic plane. Roughly once every 60 million years the Sun completes an up-and-down movement inside the outer regions of the Milky Way Galaxy. This is a small perturbation in its main orbit of revolution around the galactic center, a revolution that takes more than 200 million years to complete. In the course of the complete oscillation perpendicular to the galactic disk, the Sun passes through the mid-plane of the Galaxy twice, once every 30 million years. This periodicity seems to match approximately that found by Raup and Sepkoski.

Rampino and Stothers explained the periodic comet showers as consequences of the solar system's passage close to the dense gas clouds that are most likely to reside close to the galactic mid-plane. The difficulty with this explanation is the fact that the Sun at present is passing through this mid-plane, but the next catastrophe is not expected for another 15 million years. The fact that the passage of the Sun through the galactic plane is thus out of phase with the periodic catastrophes was enough for Davis, Hut, and Muller to discard this explanation in favor of the theory of a companion to the Sun. Schwartz and James also realized this difficulty but proposed a different argument: each time the Sun is farthest from the galactic plane, the solar system might be more exposed to X-rays by lack of galactic shielding. They did not give quantitative estimates for this effect, however, and it is by no means clear that there exist X-rays strong enough to make a difference for life on Earth (nor did they give an explanation for the iridium anomalies).

At present the theory of a companion star has passed the tests put to it, but it does lack one major piece of evidence—the companion has not yet been found. In this sense the companion star theory is the most falsifiable of those so far proposed. If the companion is not found after several years of intensive search and if this search is complete enough to preclude the existence of a solar companion heavy enough to cause sizable comet showers, then the theory will lose credibility. On the other hand, if the companion is found, the theory will be vindicated.

Further developments

The theory of periodic comet showers was generally received with skepticism when it was proposed in December 1983. However, this is a normal reaction in science to new speculations; the first thing to do with a new idea is to try to shoot it down, and only when no serious flaws can be found can a theory be taken seriously. To date, the theory has stood up well against all attacks. And, what is more, within a month of the proposal, partial confirmation was obtained from additional geologic evidence. Walter Alvarez and Richard Muller decided to use the available literature to investigate the age distribution of impact craters on the surface of the Earth. They found indications for a periodicity of 28 million years in the ages of previously dated craters, a time span well within the range of uncertainty of the species extinction periodicity discovered by Raup and Sepkoski. The crater ages were also in phase with the mass extinctions, further evidence that a greater chance of impacts and accomanying mass extinction can be expected around 15,000,000 AD.

One month before the publication of all the relevant articles on the companion star theory in the April 19–25, 1984, issue of the British journal *Nature*, a conference was held in Berkeley on the subject of periodic comet showers. Organized by Luis Alvarez, Frank Asaro, Helen Michel, and David Raup, the meeting was a change from the usual scientific conferences, which tend to deal with highly specialized subdivisions of already specialized fields of research. Present at this conference were paleontologists, geophysicists, astronomers, nuclear physicists, chemists, and others. Afterward, several groups began the search for the companion star, and theorists began working to refine the details of how the theory works. These calculations are quite complex, involving the use of much computer time to determine the exact interactions between the Sun, the companion, comets, and planets.

The last word is not yet in on periodic extinctions and their causes. Whichever explanation proves to be correct, there can be no doubt that the consequences of these extinctions on life on Earth, and on its evolution, are far-reaching. This was underscored by Raup and Sepkoski in the closing lines of their original article, published in February 1984:

> The implications of periodicity for evolutionary biology are profound. The most obvious is that the evolutionary system is not "alone" in the sense that it is partially dependent upon external influences more profound than the local and regional environmental changes normally considered. Much has been written about the "bottlenecking" effect of mass extinction. With kill rates for species estimated to have been as high as 77% and 96% for the largest extinctions, the biosphere is forced through narrow bottlenecks and the recovery from these events is usually accompanied by fundamental changes in biotic composition. Without these perturbations, the general course of macroevolution could have been very different.