Timberlane High School Science Summer Reading Assignment:

Course: Space Science

Instructions

Please read the following selection(s) from the book A Short History of Nearly Everything by Bill Bryson.

- Please provide written answers (short essay style) to the questions at the end of the reading

  •Questions adapted from Random House Publishing Inc.
  https://www.randomhouse.com/catalog/teachers_guides/9780767908184.pdf
- The written assignment is to be turned into your teacher by **Thursday, September 5th and Friday, September 6th,** for potential full credit. Accepted until Sept 12th with 10% deduction in grade per day. Not accepted after Sept 12th.
- This is a graded assignment worth up to 3% of your quarter 1 grade. **Grading Rubric:**

The writing will be assessed on the following 0 to 3 scales

- Each answer should be in a short essay style (minimum one paragraph).
  - 1: most answers are short one word answers.
  - 3: complete thoughts and sentences that fully convey the answers.
- Each answer should demonstrate evidence of reading to comprehension.
  - 1: answers indicate that the reading was not completed o 3: answers show clear comprehension of the reading
- Each answer should be correct, relevant to the topic, should strive for detail and completeness.
  - 1: answers are not relative to question or reading o 3: Answers demonstrate clear relevancy to passage and get to the heart of the rationale for question in relation to subject area.
- Each answer should refer to a specific statement or include a quote from the reading.
  - 1: the writing is vague, incomplete and contains little detail o 3: writing is detailed, complete and references specific statements or quotes from the reading passage.
- Each answer should be original (no plagiarism)

Tips on how to read science text for comprehension:

Break the reading into more than one session (2 to 4 pages per day). This should take about 15 minutes each time. Read slowly! Understand each sentence before reading the next. Be sure to examine unfamiliar words and concepts; try to determine meaning from the reading (or look them up). Make notes on each paragraph! It is OK to reread as you go or even reread the entire text. Read to understand, think about the ideas as you read and relate to what you already know, and what you may want to find out.

2 WELCOME TO THE SOLAR SYSTEM

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ASTRONOMERS THESE DAYS can do the most amazing things. If someone struck a match on the Moon, they could spot the flare. From the tiniest throbs and wobbles of distant stars they can infer the size and character and even potential habitability of planets much too remote to be seen—planets so distant that it would take us half a million years in a spaceship to get there. With their radio telescopes they can capture wisps of radiation so preposterously faint that the total amount of energy collected from outside the solar system by all of them together since collecting began (in 1951) is "less than the energy of a single snowflake striking the ground," in the words of Carl Sagan.

In short, there isn't a great deal that goes on in the universe that astronomers can't find when they have a mind to. Which is why it is all the more remarkable to reflect that until 1978 no one had ever noticed that Pluto has a moon. In the summer of that year, a young astronomer named James Christy at the U.S. Naval Observatory in Flagstaff, Arizona, was making a routine examination of photographic images of Pluto when he saw that there was something there—something blurry and uncertain but definitely other than Pluto. Consulting a colleague named Robert Harrington, he concluded that what he was looking at was a moon. And it wasn't just any moon. Relative to the planet, it was the biggest moon in the solar system.

This was actually something of a blow to Pluto's status as a planet, which had never been terribly robust anyway. Since previously the space occupied by the moon and the space occupied by Pluto were thought to be one and the same, it meant that Pluto was much smaller than anyone had supposed—smaller even than Mercury. Indeed, seven moons in the solar system, including our own, are larger.

Now a natural question is why it took so long for anyone to find a moon in our own solar system. The answer is that it is partly a matter of where astronomers point their instruments and partly a matter of what their instruments are designed to detect, and partly it's just Pluto. Mostly it's where they point their instruments. In the words of the astronomer Clark Chapman: "Most people think that astronomers get out at night in observatories and scan the skies. That's not true. Almost all the telescopes we have in the world are designed to peer at very tiny little pieces of the sky way off in the distance to see a quasar or hunt for black holes or look at a distant galaxy. The only real network of telescopes that scans the skies has been designed and built by the military."

We have been spoiled by artists' renderings into imagining a clarity of resolution that doesn't exist in actual astronomy. Pluto in Christy's photograph is faint and fuzzy—a piece of cosmic lint—and its moon is not the romantically backlit, crisply delineated companion orb you would get in a National Geographic painting, but rather just a tiny and extremely indistinct hint of additional fuzziness. Such was the fuzziness, in fact, that it took seven years for anyone to spot the moon again and thus independently confirm its existence.

One nice touch about Christy's discovery was that it happened in Flagstaff, for it was there in 1930 that Pluto had been found in the first place. That seminal event in astronomy was largely to the credit of the astronomer Percival Lowell. Lowell, who came from one of the oldest and wealthiest Boston families (the one in the famous ditty about Boston being the home of the bean and the cod, where Lowells spoke only to Cabots, while Cabots spoke only to God), endowed the famous observatory that bears his name, but is most indelibly remembered for his belief that Mars was covered with canals built by industrious Martians for purposes of conveying water from polar regions to the dry but productive lands nearer the equator.

Lowell's other abiding conviction was that there existed, somewhere out beyond Neptune, an undiscovered ninth planet, dubbed Planet X. Lowell based this belief on irregularities he detected in the orbits of Uranus and Neptune, and devoted the last years of his life to trying to find the gassy giant he was certain was out there. Unfortunately, he died suddenly in 1916, at least partly exhausted by his quest, and the search fell into abeyance while Lowell's heirs squabbled over his estate. However, in 1929, partly as a way of deflecting attention away from the Mars canal saga (which by now had become a serious embarrassment), the Lowell Observatory directors decided to resume the search and to that end hired a young man from Kansas named Clyde Tombaugh.

Tombaugh had no formal training as an astronomer, but he was diligent and he was astute, and after a year's patient searching he somehow spotted Pluto, a faint point of light in a glittery firmament. It was a miraculous find, and what made it all the more striking was that the observations on which Lowell had predicted the existence of a planet beyond Neptune proved to be comprehensively erroneous. Tombaugh could see at once that the new planet was nothing like the massive gasball Lowell had postulated, but any reservations he or anyone else had about the character of the new planet were soon swept aside in the delirium that attended almost any big news story in that easily excited age. This was the first American-discovered planet, and no one was going to be distracted by the thought that it was really just a distant icy dot. It was named Pluto at least partly because the first two letters made a monogram from Lowell's initials. Lowell was posthumously hailed everywhere as a genius of the first order, and Tombaugh was largely forgotten, except among planetary astronomers, who tend to revere him.

A few astronomers continue to think there may be a Planet X out there—a real whopper, perhaps as much as ten times the size of Jupiter, but so far out as to be invisible to us. (It would receive so little sunlight that it would have almost none to reflect.) The idea is that it wouldn't be a conventional planet like Jupiter or Saturn—it's much too far away for that; we're talking perhaps 4.5 trillion miles—but more like a sun that never quite made it. Most star systems in the cosmos are binary (double-starred), which makes our solitary sun a slight oddity.

As for Pluto itself, nobody is quite sure how big it is, or what it is made of, what kind of atmosphere it has, or even what it really is. A lot of astronomers believe it isn't a planet at all, but merely the largest object so far found in a zone of galactic debris known as the Kuiper belt. The Kuiper belt was actually theorized by an astronomer named F. C. Leonard in 1930, but the name honors Gerard Kuiper, a Dutch native working in America, who expanded the idea. The Kuiper belt is the source of what are known as short-period comets—those that come past pretty regularly—of which the most famous is Halley's comet. The more reclusive long-period comets (among them the recent visitors Hale-Bopp and Hyakutake) come from the much more distant Oort cloud, about which more presently.

It is certainly true that Pluto doesn't act much like the other planets. Not only is it runty and obscure, but it is so variable in its motions that no one can tell you exactly where Pluto will be a century hence. Whereas the other planets orbit on more or less the same plane, Pluto's orbital path is tipped (as it were) out of alignment at an angle of seventeen degrees, like the brim of a hat tilted rakishly on someone's head. Its orbit is so irregular that for substantial periods on each of its lonely circuits around the Sun it is closer to us than Neptune is. For most of the 1980s and 1990s, Neptune was in fact the solar system's most far-flung planet. Only on February 11, 1999, did Pluto return to the outside lane, there to remain for the next 228 years.

So if Pluto really is a planet, it is certainly an odd one. It is very tiny: just one-quarter of 1 percent as massive as Earth. If you set it down on top of the United States, it would cover not quite half the lower forty-eight states. This alone makes it extremely anomalous; it means that our planetary system consists of four rocky inner planets, four gassy outer giants, and a tiny, solitary iceball. Moreover, there is every reason to suppose that we may soon begin to find other even larger icy spheres in the same portion of space. Then we will have problems. After Christy spotted Pluto's moon, astronomers began to regard that section of the cosmos more attentively and as of early December 2002 had found over six hundred additional Trans-Neptunian Objects, or Plutinos as they are alternatively called. One, dubbed Varuna, is nearly as big as Pluto's moon. Astronomers now think there may be billions of these objects. The difficulty is that many of them are awfully dark. Typically they have an albedo, or reflectiveness, of just 4 percent, about the same as a lump of charcoal—and of course these lumps of charcoal are about four billion miles away.

And how far is that exactly? It's almost beyond imagining. Space, you see, is just enormous—just enormous. Let's imagine, for purposes of edification and entertainment, that we are about to go on a journey by rocketship. We won't go terribly far—just to the edge of our own solar system—but we need to get a fix on how big a place space is and what a small part of it we occupy.

Now the bad news, I'm afraid, is that we won't be home for supper. Even at the speed of light, it would take seven hours to get to Pluto. But of course we can't travel at anything like that speed. We'll have to go at the speed of a spaceship, and these are rather more lumbering. The best speeds yet achieved by any human object are those of the Voyager 1 and2 spacecraft, which are now flying away from us at about thirty-five thousand miles an hour.

The reason the Voyager craft were launched when they were (in August and September 1977) was that Jupiter, Saturn, Uranus, and Neptune were aligned in a way that happens only once every 175 years. This enabled the two Voyagers to use a "gravity assist" technique in which the craft were successively flung from one gassy giant to the next in a kind of cosmic version of "crack the whip." Even so, it took them nine years to reach Uranus and a dozen to cross the orbit of Pluto. The good news is that if we wait until January 2006 (which is when NASA's New Horizons spacecraft is tentatively scheduled to depart for Pluto) we can take advantage of favorable Jovian positioning, plus some advances in technology, and get there in only a decade or so—though getting home again will take rather longer, I'm afraid. At all events, it's going to be a long trip.

Now the first thing you are likely to realize is that space is extremely well named and rather dismayingly uneventful. Our solar system may be the liveliest thing for trillions of miles, but all the visible stuff in it—the Sun, the planets and their moons, the billion or so tumbling rocks of the asteroid belt, comets, and other miscellaneous drifting detritus—fills less than a trillionth of the available space. You also quickly realize that none of the maps you have ever seen of the solar system were remotely drawn to scale. Most schoolroom charts show the planets coming one after the other at neighborly intervals—the outer giants actually cast shadows over each other in many illustrations—but this is a necessary deceit to get them all on the same piece of paper. Neptune in reality isn't just a little bit beyond Jupiter, it's way beyond Jupiter—five times farther from Jupiter than Jupiter is from us, so far out that it receives only 3 percent as much sunlight as Jupiter.

Such are the distances, in fact, that it isn't possible, in any practical terms, to draw the solar system to scale. Even if you added lots of fold-out pages to your textbooks or used a really long sheet of poster paper, you wouldn't come close. On a diagram of the solar system to scale, with Earth reduced to about the diameter of a pea, Jupiter would be over a thousand feet away and Pluto would be a mile and a half distant (and about the size of a bacterium, so you wouldn't be able to see it anyway). On the same scale, Proxima Centauri, our nearest star, would be almost ten thousand miles away. Even if you shrank down everything so that Jupiter was as small as the period at the end of this sentence, and Pluto was no bigger than a molecule, Pluto would still be over thirty-five feet away.

So the solar system is really quite enormous. By the time we reach Pluto, we have come so far that the Sun—our dear, warm, skin-tanning, life-giving Sun—has shrunk to the size of a pinhead. It is little more than a bright star. In such a lonely void you can begin to understand how even the most significant objects—Pluto's moon, for example—have escaped attention. In this respect, Pluto has hardly been alone. Until the Voyager expeditions, Neptune was thought to have two moons; Voyager found six more. When I was a boy, the solar system was thought to contain thirty moons. The total now is "at least ninety," about a third of which have been found in just the last ten years.

The point to remember, of course, is that when considering the universe at large we don't actually know what is in our own solar system.

Now the other thing you will notice as we speed past Pluto is that we are speeding past Pluto. If you check your itinerary, you will see that this is a trip to the edge of our solar system, and I'm afraid we're not there yet. Pluto may be the last object marked on schoolroom charts, but the system doesn't end there. In fact, it isn't even close to ending there. We won't get to the solar system's edge until we have passed through the Oort cloud, a vast celestial realm of drifting comets, and we won't reach the Oort cloud for another—I'm so sorry about this—ten thousand years. Far from marking the outer edge of the solar system, as those schoolroom maps so cavalierly imply, Pluto is barely one-fifty-thousandth of the way.

Of course we have no prospect of such a journey. A trip of 240,000 miles to the Moon still represents a very big undertaking for us. A manned mission to Mars, called for by the first President Bush in a moment of passing giddiness, was quietly dropped when someone worked out that it would cost $450 billion and probably result in the deaths of all the crew (their DNA torn to tatters by high-energy solar particles from which they could not be shielded).

Based on what we know now and can reasonably imagine, there is absolutely no prospect that any human being will ever visit the edge of our own solar system—ever. It is just too far. As it is, even with the Hubble telescope, we can't see even into the Oort cloud,* so we don't actually know that it is there. Its existence is probable but entirely hypothetical.

About all that can be said with confidence about the Oort cloud is that it starts somewhere beyond Pluto and stretches some two light-years out into the cosmos. The basic unit of measure in the solar system is the Astronomical Unit, or AU, representing the distance from

* Properly called the Opik-Oort cloud, it is named for the Estonian astronomer Ernst Opik, who hypothesized its existence in 1932, and for the Dutch astronomer Jan Oort, who refined the calculations eighteen years later.

the Sun to the Earth. Pluto is about forty AUs from us, the heart of the Oort cloud about fifty thousand. In a word, it is remote.

But let's pretend again that we have made it to the Oort cloud. The first thing you might notice is how very peaceful it is out here. We're a long way from anywhere now—so far from our own Sun that it's not even the brightest star in the sky. It is a remarkable thought that that distant tiny twinkle has enough gravity to hold all these comets in orbit. It's not a very strong bond, so the comets drift in a stately manner, moving at only about 220 miles an hour. From time to time some of these lonely comets are nudged out of their normal orbit by some slight gravitational perturbation—a passing star perhaps. Sometimes they are ejected into the emptiness of space, never to be seen again, but sometimes they fall into a long orbit around the Sun. About three or four of these a year, known as long-period comets, pass through the inner solar system. Just occasionally these stray visitors smack into something solid, like Earth. That's why we've come out here now—because the comet we have come to see has just begun a long fall toward the center of the solar system. It is headed for, of all places, Manson, Iowa. It is going to take a long time to get there—three or four million years at least—so we'll leave it for now, and return to it much later in the story.

So that's your solar system. And what else is out there, beyond the solar system? Well, nothing and a great deal, depending on how you look at it.

In the short term, it's nothing. The most perfect vacuum ever created by humans is not as empty as the emptiness of interstellar space. And there is a great deal of this nothingness until you get to the next bit of something. Our nearest neighbor in the cosmos, Proxima Centauri, which is part of the three-star cluster known as Alpha Centauri, is 4.3 light-years away, a sissy skip in galactic terms, but that is still a hundred million times farther than a trip to the Moon. To reach it by spaceship would take at least twenty-five thousand years, and even if you made the trip you still wouldn't be anywhere except at a lonely clutch of stars in the middle of a vast nowhere. To reach the next landmark of consequence, Sirius, would involve another 4.6 light-years of travel. And so it would go if you tried to star-hop your way across the cosmos. Just reaching the center of our own galaxy would take far longer than we have existed as beings.

Space, let me repeat, is enormous. The average distance between stars out there is 20 million million miles. Even at speeds approaching those of light, these are fantastically challenging distances for any traveling individual. Of course, it is possible that alien beings travel billions of miles to amuse themselves by planting crop circles in Wiltshire or frightening the daylights out of some poor guy in a pickup truck on a lonely road in Arizona (they must have teenagers, after all), but it does seem unlikely.

Still, statistically the probability that there are other thinking beings out there is good. Nobody knows how many stars there are in the Milky Way—estimates range from 100 billion or so to perhaps 400 billion—and the Milky Way is just one of 140 billion or so other galaxies, many of them even larger than ours. In the 1960s, a professor at Cornell named Frank Drake, excited by such whopping numbers, worked out a famous equation designed to calculate the chances of advanced life in the cosmos based on a series of diminishing probabilities.

Under Drake's equation you divide the number of stars in a selected portion of the universe by the number of stars that are likely to have planetary systems; divide that by the number of planetary systems that could theoretically support life; divide that by the number on which life, having arisen, advances to a state of intelligence; and so on. At each such division, the number shrinks colossally—yet even with the most conservative inputs the number of advanced civilizations just in the Milky Way always works out to be somewhere in the millions.

What an interesting and exciting thought. We may be only one of millions of advanced civilizations. Unfortunately, space being spacious, the average distance between any two of these civilizations is reckoned to be at least two hundred light-years, which is a great deal more than merely saying it makes it sound. It means for a start that even if these beings know we are here and are somehow able to see us in their telescopes, they're watching light that left Earth two hundred years ago. So they're not seeing you and me. They're watching the French Revolution and Thomas Jefferson and people in silk stockings and powdered wigs—people who don't know what an atom is, or a gene, and who make their electricity by rubbing a rod of amber with a piece of fur and think that's quite a trick. Any message we receive from them is likely to begin "Dear Sire," and congratulate us on the handsomeness of our horses and our mastery of whale oil. Two hundred light-years is a distance so far beyond us as to be, well, just beyond us.

So even if we are not really alone, in all practical terms we are. Carl Sagan calculated the number of probable planets in the universe at large at 10 billion trillion—a number vastly beyond imagining. But what is equally beyond imagining is the amount of space through which they are lightly scattered. "If we were randomly inserted into the universe," Sagan wrote, "the chances that you would be on or near a planet would be less than one in a billion trillion trillion." (That's 10^{33}, or a one followed by thirty-three zeroes.) "Worlds are precious."

Which is why perhaps it is good news that in February 1999 the International Astronomical Union ruled officially that Pluto is a planet. The universe is a big and lonely place. We can do with all the neighbors we can get

Chapter 2: Welcome to the Solar System

Discussion Questions

1. Describe Percival Lowell's contributions to astronomy. Classify each as important or unimportant to furthering the study of astronomy. Defend each classification.

2. What are some characteristics of Pluto that may have led to its reclassification as a dwarf planet?

3. If the earth were reduced to the diameter of a pea, how large and how far away would Jupiter be? How large and how far away would Pluto be? The Exploratorium website is helpful for these questions.

4. What are some problems that must be solved before people can travel to Mars?

5. Why is it unlikely that aliens have visited Earth?

6. What are some arguments for or against Pluto's status as a planet?

7. What is the current thinking about objects beyond Neptune that belong to the solar system? (How are they classified? What characteristics do they share?)

8. How long did it take for the Voyager craft to reach Neptune's orbit?

9. How much farther from the sun is Pluto compared with earth? (What unit of distance easily expresses this comparison?)

10. What is the Oort Cloud? If we can't see it, even with the best telescopes, what makes us think it is there?

11. Given current estimates of the number of stars in a typical galaxy and the number of galaxies in the universe, how many total stars are there in the universe? Express your answer in scientific notation.

13 BANG!

PEOPLE KNEW FOR a long time that there was something odd about the earth beneath Manson, Iowa. In 1912, a man drilling a well for the town water supply reported bringing up a lot of strangely deformed rock—"crystalline clast breccia with a melt matrix" and "overturned ejecta flap," as it was later described in an official report. The water was odd too. It was almost as soft as rainwater. Naturally occurring soft water had never been found in Iowa before.

Though Manson's strange rocks and silken waters were matters of curiosity, forty-one years would pass before a team from the University of Iowa got around to making a trip to the community, then as now a town of about two thousand people in the northwest part of the state. In 1953, after sinking a series of experimental bores, university geologists agreed that the site was indeed anomalous and attributed the deformed rocks to some ancient, unspecified volcanic action. This was in keeping with the wisdom of the day, but it was also about as wrong as a geological conclusion can get.

The trauma to Manson's geology had come not from within the Earth, but from at least 100 million miles beyond. Sometime in the very ancient past, when Manson stood on the edge of a shallow sea, a rock about a mile and a half across, weighing ten billion tons and traveling at perhaps two hundred times the speed of sound ripped through the atmosphere and punched into the Earth with a violence and suddenness that we can scarcely imagine. Where Manson now stands became in an instant a hole three miles deep and more than twenty miles across. The limestone that elsewhere gives Iowa its hard mineralized water was obliterated and replaced by the shocked basement rocks that so puzzled the water driller in 1912.

The Manson impact was the biggest thing that has ever occurred on the mainland United States. Of any type. Ever. The crater it left behind was so colossal that if you stood on one edge you would only just be able to see the other side on a good day. It would make the Grand Canyon look quaint and trifling. Unfortunately for lovers of spectacle, 2.5 million years of passing ice sheets filled the Manson crater right to the top with rich glacial till, then graded it smooth, so that today the landscape at Manson, and for miles around, is as flat as a tabletop. Which is of course why no one has ever heard of the Manson crater.

At the library in Manson they are delighted to show you a collection of newspaper articles and a box of core samples from a 1991–92 drilling program—indeed, they positively bustle to produce them—but you have to ask to see them. Nothing permanent is on display, and nowhere in the town is there any historical marker.

To most people in Manson the biggest thing ever to happen was a tornado that rolled up Main Street in 1979, tearing apart the business district. One of the advantages of all that surrounding flatness is that you can see danger from a long way off. Virtually the whole town turned out at one end of Main Street and watched for half an hour as the tornado came toward them, hoping it would veer off, then prudently scampered when it did not. Four of them, alas, didn't move quite fast enough and were killed. Every June now Manson has a weeklong event called Crater Days, which was dreamed up as a way of helping people forget that unhappy anniversary. It doesn't really have anything to do with the crater. Nobody's figured out a way to capitalize on an impact site that isn't visible.

"Very occasionally we get people coming in and asking where they should go to see the crater and we have to tell them that there is nothing to see," says Anna Schlapkohl, the town's friendly librarian. "Then they go away kind of disappointed." However, most people, including most Iowans, have never heard of the Manson crater. Even for geologists it barely rates a footnote. But for one brief period in the 1980s, Manson was the most geologically exciting place on Earth.

The story begins in the early 1950s when a bright young geologist named Eugene Shoemaker paid a visit to Meteor Crater in Arizona. Today Meteor Crater is the most famous impact site on Earth and a popular tourist attraction. In those days, however, it didn't receive many visitors and was still often referred to as Barringer Crater, after a wealthy mining engineer named Daniel M. Barringer who had staked a claim on it in 1903. Barringer believed that the crater had been formed by a ten-million-ton meteor, heavily freighted with iron and nickel, and it was his confident expectation that he would make a fortune digging it out. Unaware that the meteor and everything in it would have been vaporized on impact, he wasted a fortune, and the next twenty-six years, cutting tunnels that yielded nothing.

By the standards of today, crater research in the early 1900s was a trifle unsophisticated, to say the least. The leading early investigator, G. K. Gilbert of Columbia University, modeled the effects of impacts by flinging marbles into pans of oatmeal. (For reasons I cannot supply, Gilbert conducted these experiments not in a laboratory at Columbia but in a hotel room.) Somehow from this Gilbert concluded that the Moon's craters were indeed formed by impacts—in itself quite a radical notion for the time—but that the Earth's were not. Most scientists refused to go even that far. To them, the Moon's craters were evidence of ancient volcanoes and nothing more. The few craters that remained evident on Earth (most had been eroded away) were generally attributed to other causes or treated as fluky rarities.

By the time Shoemaker came along, a common view was that Meteor Crater had been formed by an underground steam explosion. Shoemaker knew nothing about underground steam explosions—he couldn't: they don't exist—but he did know all about blast zones. One of his first jobs out of college was to study explosion rings at the Yucca Flats nuclear test site in Nevada. He concluded, as Barringer had before him, that there was nothing at Meteor Crater to suggest volcanic activity, but that there were huge distributions of other stuff—anomalous fine silicas and magnetites principally—that suggested an impact from space. Intrigued, he began to study the subject in his spare time.

Working first with his colleague Eleanor Helin and later with his wife, Carolyn, and associate David Levy, Shoemaker began a systematic survey of the inner solar system. They spent one week each month at the Palomar Observatory in California looking for objects, asteroids primarily, whose trajectories carried them across Earth's orbit.

"At the time we started, only slightly more than a dozen of these things had ever been discovered in the entire course of astronomical observation," Shoemaker recalled some years later in a television interview. "Astronomers in the twentieth century essentially abandoned the solar system," he added. "Their attention was turned to the stars, the galaxies."

What Shoemaker and his colleagues found was that there was more risk out there—a great deal more—than anyone had ever imagined.

Asteroids, as most people know, are rocky objects orbiting in loose formation in a belt between Mars and Jupiter. In illustrations they are always shown as existing in a jumble, but in fact the solar system is quite a roomy place and the average asteroid actually will be about a million miles from its nearest neighbor. Nobody knows even approximately how many asteroids there are tumbling through space, but the number is thought to be probably not less than a billion. They are presumed to be planets that never quite made it, owing to the unsettling gravitational pull of Jupiter, which kept—and keeps—them from coalescing.

When asteroids were first detected in the 1800s—the very first was discovered on the first day of the century by a Sicilian named Giuseppi Piazzi—they were thought to be planets, and the first two were named Ceres and Pallas. It took some inspired deductions by the astronomer William Herschel to work out that they were nowhere near planet sized but much smaller. He called them asteroids—Latin for "starlike"—which was slightly unfortunate as they are not like stars at all. Sometimes now they are more accurately called planetoids.

Finding asteroids became a popular activity in the 1800s, and by the end of the century about a thousand were known. The problem was that no one was systematically recording them. By the early 1900s, it had often become impossible to know whether an asteroid that popped into view was new or simply one that had been noted earlier and then lost track of. By this time, too, astrophysics had moved on so much that few astronomers wanted to devote their lives to anything as mundane as rocky planetoids. Only a few astronomers, notably Gerard Kuiper, the Dutch-born astronomer for whom the Kuiper belt of comets is named, took any interest in the solar system at all. Thanks to his work at the McDonald Observatory in Texas, followed later by work done by others at the Minor Planet Center in Cincinnati and the, Spacewatch project in Arizona, a long list of lost asteroids was gradually whittled down until by the close of the twentieth century only one known asteroid was unaccounted for—an object called 719 Albert. Last seen in October 1911, it was finally tracked down in 2000 after being missing for eighty-nine years.

So from the point of view of asteroid research the twentieth century was essentially just a long exercise in bookkeeping. It is really only in the last few years that astronomers have begun to count and keep an eye on the rest of the asteroid community. As of July 2001, twenty-six thousand asteroids had been named and identified—half in just the previous two years. With up to a billion to identify, the count obviously has barely begun.

In a sense it hardly matters. Identifying an asteroid doesn't make it safe. Even if every asteroid in the solar system had a name and known orbit, no one could say what perturbations might send any of them hurtling toward us. We can't forecast rock disturbances on our own surface. Put them adrift in space and what they might do is beyond guessing. Any asteroid out there that has our name on it is very likely to have no other.

Think of the Earth's orbit as a kind of freeway on which we are the only vehicle, but which is crossed regularly by pedestrians who don't know enough to look before stepping off the curb. At least 90 percent of these pedestrians are quite unknown to us. We don't know where they live, what sort of hours they keep, how often they come our way. All we know is that at some point, at uncertain intervals, they trundle across the road down which we are cruising at sixty-six thousand miles an hour. As Steven Ostro of the Jet Propulsion Laboratory has put it, "Suppose that there was a button you could push and you could light up all the Earth-crossing asteroids larger than about ten meters, there would be over 100 million of these objects in the sky." In short, you would see not a couple of thousand distant twinkling stars, but millions upon millions upon millions of nearer, randomly moving objects—"all of which are capable of colliding with the Earth and all of which are moving on slightly different courses through the sky at different rates. It would be deeply unnerving." Well, be unnerved because it is there. We just can't see it.

Altogether it is thought—though it is really only a guess, based on extrapolating from cratering rates on the Moon—that some two thousand asteroids big enough to imperil civilized existence regularly cross our orbit. But even a small asteroid—the size of a house, say—could destroy a city. The number of these relative tiddlers in Earth-crossing orbits is almost certainly in the hundreds of thousands and possibly in the millions, and they are nearly impossible to track.

The first one wasn't spotted until 1991, and that was after it had already gone by. Named 1991 BA, it was noticed as it sailed past us at a distance of 106,000 miles—in cosmic terms the equivalent of a bullet passing through one's sleeve without touching the arm. Two years later, another, somewhat larger asteroid missed us by just 90,000 miles—the closest pass yet recorded. It, too, was not seen until it had passed and would have arrived without warning. According to Timothy Ferris, writing in the New Yorker, such near misses probably happen two or three times a week and go unnoticed.

An object a hundred yards across couldn't be picked up by any Earth-based telescope until it was within just a few days of us, and that is only if a telescope happened to be trained on it, which is unlikely because even now the number of people searching for such objects is modest. The arresting analogy that is always made is that the number of people in the world who are actively searching for asteroids is fewer than the staff of a typical McDonald's restaurant. (It is actually somewhat higher now. But not much.)

While Gene Shoemaker was trying to get people galvanized about the potential dangers of the inner solar system, another development—wholly unrelated on the face of it—was quietly unfolding in Italy with the work of a young geologist from the Lamont Doherty Laboratory at Columbia University. In the early 1970s, Walter Alvarez was doing fieldwork in a comely defile known as the Bottaccione Gorge, near the Umbrian hill town of Gubbio, when he grew curious about a thin band of reddish clay that divided two ancient layers of limestone—one from the Cretaceous period, the other from the Tertiary. This is a point known to geology as the KT boundary,[1] and it marks the time, sixty-five million years ago, when the dinosaurs and roughly half the world's other species of animals abruptly vanish from the fossil record. Alvarez wondered what it was about a thin lamina of clay, barely a quarter of an inch thick, that could account for such a dramatic moment in Earth's history.

At the time the conventional wisdom about the dinosaur extinction was the same as it had been in Charles Lyell's day a century earlier—namely that the dinosaurs had died out over millions of years. But the thinness of the clay layer clearly suggested that in Umbria, if

[1] It is KT rather than CT because C had already been appropriated for Cambrian. Depending on which source you credit, the K comes either from the Greek Kreta or German Kreide. Both conveniently mean "chalk," which is also what Cretaceous means.

nowhere else, something rather more abrupt had happened. Unfortunately in the 1970s no tests existed for determining how long such a deposit might have taken to accumulate.

In the normal course of things, Alvarez almost certainly would have had to leave the problem at that, but luckily he had an impeccable connection to someone outside his discipline who could help—his father, Luis. Luis Alvarez was an eminent nuclear physicist; he had won the Nobel Prize for physics the previous decade. He had always been mildly scornful of his son's attachment to rocks, but this problem intrigued him. It occurred to him that the answer might lie in dust from space.

Every year the Earth accumulates some thirty thousand metric tons of "cosmic spherules"—space dust in plainer language—which would be quite a lot if you swept it into one pile, but is infinitesimal when spread across the globe. Scattered through this thin dusting are exotic elements not normally much found on Earth. Among these is the element iridium, which is a thousand times more abundant in space than in the Earth's crust (because, it is thought, most of the iridium on Earth sank to the core when the planet was young).

Alvarez knew that a colleague of his at the Lawrence Berkeley Laboratory in California, Frank Asaro, had developed a technique for measuring very precisely the chemical composition of clays using a process called neutron activation analysis. This involved bombarding samples with neutrons in a small nuclear reactor and carefully counting the gamma rays that were emitted; it was extremely finicky work. Previously Asaro had used the technique to analyze pieces of pottery, but Alvarez reasoned that if they measured the amount of one of the exotic elements in his son's soil samples and compared that with its annual rate of deposition, they would know how long it had taken the samples to form. On an October afternoon in 1977, Luis and Walter Alvarez dropped in on Asaro and asked him if he would run the necessary tests for them.

It was really quite a presumptuous request. They were asking Asaro to devote months to making the most painstaking measurements of geological samples merely to confirm what seemed entirely self-evident to begin with—that the thin layer of clay had been formed as quickly as its thinness suggested. Certainly no one expected his survey to yield any dramatic breakthroughs.

"Well, they were very charming, very persuasive," Asaro recalled in an interview in 2002. "And it seemed an interesting challenge, so I agreed to try. Unfortunately, I had a lot of other work on, so it was eight months before I could get to it." He consulted his notes from the period. "On June 21, 1978, at 1:45 p.m., we put a sample in the detector. It ran for 224 minutes and we could see we were getting interesting results, so we stopped it and had a look."

The results were so unexpected, in fact, that the three scientists at first thought they had to be wrong. The amount of iridium in the Alvarez sample was more than three hundred times normal levels—far beyond anything they might have predicted. Over the following months Asaro and his colleague Helen Michel worked up to thirty hours at a stretch ("Once you started you couldn't stop," Asaro explained) analyzing samples, always with the same results. Tests on other samples—from Denmark, Spain, France, New Zealand, Antarctica—showed that the iridium deposit was worldwide and greatly elevated everywhere, sometimes by as much as five hundred times normal levels. Clearly something big and abrupt, and probably cataclysmic, had produced this arresting spike.

After much thought, the Alvarezes concluded that the most plausible explanation—plausible to them, at any rate—was that the Earth had been struck by an asteroid or comet.

The idea that the Earth might be subjected to devastating impacts from time to time was not quite as new as it is now sometimes presented. As far back as 1942, a Northwestern University astrophysicist named Ralph B. Baldwin had suggested such a possibility in an article in Popular Astronomy magazine. (He published the article there because no academic publisher was prepared to run it.) And at least two well-known scientists, the astronomer Ernst Öpik and the chemist and Nobel laureate Harold Urey, had also voiced support for the notion at various times. Even among paleontologists it was not unknown. In 1956 a professor at Oregon State University, M. W. de Laubenfels, writing in the Journal of Paleontology, had actually anticipated the Alvarez theory by suggesting that the dinosaurs may have been dealt a death blow by an impact from space, and in 1970 the president of the American Paleontological Society, Dewey J. McLaren, proposed at the group's annual conference the possibility that an extraterrestrial impact may have been the cause of an earlier event known as the Frasnian extinction.

As if to underline just how un-novel the idea had become by this time, in 1979 a Hollywood studio actually produced a movie called Meteor ("It's five miles wide . . . It's coming at 30,000 m.p.h.—and there's no place to hide!") starring Henry Fonda, Natalie Wood, Karl Malden, and a very large rock.

So when, in the first week of 1980, at a meeting of the American Association for the Advancement of Science, the Alvarezes announced their belief that the dinosaur extinction had not taken place over millions of years as part of some slow inexorable process, but suddenly in a single explosive event, it shouldn't have come as a shock.

But it did. It was received everywhere, but particularly in the paleontological community, as an outrageous heresy.

"Well, you have to remember," Asaro recalls, "that we were amateurs in this field. Walter was a geologist specializing in paleomagnetism, Luis was a physicist and I was a nuclear chemist. And now here we were telling paleontologists that we had solved a problem that had eluded them for over a century. It's not terribly surprising that they didn't embrace it immediately." As Luis Alvarez joked: "We were caught practicing geology without a license."

But there was also something much deeper and more fundamentally abhorrent in the impact theory. The belief that terrestrial processes were gradual had been elemental in natural history since the time of Lyell. By the 1980s, catastrophism had been out of fashion for so long that it had become literally unthinkable. For most geologists the idea of a devastating impact was, as Eugene Shoemaker noted, "against their scientific religion."

Nor did it help that Luis Alvarez was openly contemptuous of paleontologists and their contributions to scientific knowledge. "They're really not very good scientists. They're more like stamp collectors," he wrote in the New York Times in an article that stings yet.

Opponents of the Alvarez theory produced any number of alternative explanations for the iridium deposits—for instance, that they were generated by prolonged volcanic eruptions in India called the Deccan Traps—and above all insisted that there was no proof that the dinosaurs disappeared abruptly from the fossil record at the iridium boundary. One of the most vigorous opponents was Charles Officer of Dartmouth College. He insisted that the iridium had been deposited by volcanic action even while conceding in a newspaper interview that he had no actual evidence of it. As late as 1988 more than half of all American paleontologists contacted in a survey continued to believe that the extinction of the dinosaurs was in no way related to an asteroid or cometary impact.

The one thing that would most obviously support the Alvarezes' theory was the one thing they didn't have—an impact site. Enter Eugene Shoemaker. Shoemaker had an Iowa connection—his daughter-in-law taught at the University of Iowa—and he was familiar with the Manson crater from his own studies. Thanks to him, all eyes now turned to Iowa.

Geology is a profession that varies from place to place. In Iowa, a state that is flat and stratigraphically uneventful, it tends to be comparatively serene. There are no Alpine peaks or grinding glaciers, no great deposits of oil or precious metals, not a hint of a pyroclastic flow. If you are a geologist employed by the state of Iowa, a big part of the work you do is to evaluate Manure Management Plans, which all the state's "animal confinement operators"—hog farmers to the rest of us—are required to file periodically. There are fifteen million hogs in Iowa, so a lot of manure to manage. I'm not mocking this at all—it's vital and enlightened work; it keeps Iowa's water clean—but with the best will in the world it's not exactly dodging lava bombs on Mount Pinatubo or scrabbling over crevasses on the Greenland ice sheet in search of ancient life-bearing quartzes. So we may well imagine the flutter of excitement that swept through the Iowa Department of Natural Resources when in the mid-1980s the world's geological attention focused on Manson and its crater.

Trowbridge Hall in Iowa City is a turn-of-the-century pile of red brick that houses the University of Iowa's Earth Sciences department and—way up in a kind of garret—the geologists of the Iowa Department of Natural Resources. No one now can remember quite when, still less why, the state geologists were placed in an academic facility, but you get the impression that the space was conceded grudgingly, for the offices are cramped and low-ceilinged and not very accessible. When being shown the way, you half expect to be taken out onto a roof ledge and helped in through a window.

Ray Anderson and Brian Witzke spend their working lives up here amid disordered heaps of papers, journals, furled charts, and hefty specimen stones. (Geologists are never at a loss for paperweights.) It's the kind of space where if you want to find anything—an extra chair, a coffee cup, a ringing telephone—you have to move stacks of documents around.

"Suddenly we were at the center of things," Anderson told me, gleaming at the memory of it, when I met him and Witzke in their offices on a dismal, rainy morning in June. "It was a wonderful time."

I asked them about Gene Shoemaker, a man who seems to have been universally revered. "He was just a great guy," Witzke replied without hesitation. "If it hadn't been for him, the whole thing would never have gotten off the ground. Even with his support, it took two years to get it up and running. Drilling's an expensive business—about thirty-five dollars a foot back then, more now, and we needed to go down three thousand feet."

"Sometimes more than that," Anderson added.

“Sometimes more than that,” Witzke agreed. “And at several locations. So you’re talking a lot of money. Certainly more than our budget would allow.”

So a collaboration was formed between the Iowa Geological Survey and the U.S. Geological Survey.

“At least we thought it was a collaboration,” said Anderson, producing a small pained smile.

“It was a real learning curve for us,” Witzke went on. “There was actually quite a lot of bad science going on throughout the period—people rushing in with results that didn’t always stand up to scrutiny.” One of those moments came at the annual meeting of the American Geophysical Union in 1985, when Glenn Izett and C. L. Pillmore of the U.S. Geological Survey announced that the Manson crater was of the right age to have been involved with the dinosaurs’ extinction. The declaration attracted a good deal of press attention but was unfortunately premature. A more careful examination of the data revealed that Manson was not only too small, but also nine million years too early.

The first Anderson or Witzke learned of this setback to their careers was when they arrived at a conference in South Dakota and found people coming up to them with sympathetic looks and saying: “We hear you lost your crater.” It was the first they knew that Izett and the other USGS scientists had just announced refined figures revealing that Manson couldn’t after all have been the extinction crater.

“It was pretty stunning,” recalls Anderson. “I mean, we had this thing that was really important and then suddenly we didn’t have it anymore. But even worse was the realization that the people we thought we’d been collaborating with hadn’t bothered to share with us their new findings.”

“Why not?”

He shrugged. “Who knows? Anyway, it was a pretty good insight into how unattractive science can get when you’re playing at a certain level.”

The search moved elsewhere. By chance in 1990 one of the searchers, Alan Hildebrand of the University of Arizona, met a reporter from the Houston Chronicle who happened to know about a large, unexplained ring formation, 120 miles wide and 30 miles deep, under Mexico’s Yucatán Peninsula at Chicxulub, near the city of Progreso, about 600 miles due south of New Orleans. The formation had been found by Pemex, the Mexican oil company, in 1952—the year, coincidentally, that Gene Shoemaker first visited Meteor Crater in Arizona—but the company’s geologists had concluded that it was volcanic, in line with the thinking of the day. Hildebrand traveled to the site and decided fairly swiftly that they had their crater. By early 1991 it had been established to nearly everyone’s satisfaction that Chicxulub was the impact site.

Still, many people didn’t quite grasp what an impact could do. As Stephen Jay Gould recalled in one of his essays: “I remember harboring some strong initial doubts about the efficacy of such an event . . . [W]hy should an object only six miles across wreak such havoc upon a planet with a diameter of eight thousand miles?”

Conveniently a natural test of the theory arose when the Shoemakers and Levy discovered Comet Shoemaker-Levy 9, which they soon realized was headed for Jupiter. For the first time, humans would be able to witness a cosmic collision—and witness it very well thanks to the new Hubble space telescope. Most astronomers, according to Curtis Peebles, expected little, particularly as the comet was not a coherent sphere but a string of twenty-one fragments. "My sense," wrote one, "is that Jupiter will swallow these comets up without so much as a burp." One week before the impact, Nature ran an article, "The Big Fizzle Is Coming," predicting that the impact would constitute nothing more than a meteor shower.

The impacts began on July 16, 1994, went on for a week and were bigger by far than anyone—with the possible exception of Gene Shoemaker—expected. One fragment, known as Nucleus G, struck with the force of about six million megatons—seventy-five times more than all the nuclear weaponry in existence. Nucleus G was only about the size of a small mountain, but it created wounds in the Jovian surface the size of Earth. It was the final blow for critics of the Alvarez theory.

Luis Alvarez never knew of the discovery of the Chicxulub crater or of the Shoemaker-Levy comet, as he died in 1988. Shoemaker also died early. On the third anniversary of the Shoemaker-Levy impact, he and his wife were in the Australian outback, where they went every year to search for impact sites. On a dirt track in the Tanami Desert—normally one of the emptiest places on Earth—they came over a slight rise just as another vehicle was approaching. Shoemaker was killed instantly, his wife injured. Part of his ashes were sent to the Moon aboard the Lunar Prospector spacecraft. The rest were scattered around Meteor Crater.

Anderson and Witzke no longer had the crater that killed the dinosaurs, "but we still had the largest and most perfectly preserved impact crater in the mainland United States," Anderson said. (A little verbal dexterity is required to keep Manson's superlative status. Other craters are larger—notably, Chesapeake Bay, which was recognized as an impact site in 1994—but they are either offshore or deformed.) "Chicxulub is buried under two to three kilometers of limestone and mostly offshore, which makes it difficult to study," Anderson went on, "while Manson is really quite accessible. It's because it is buried that it is actually comparatively pristine."

I asked them how much warning we would receive if a similar hunk of rock was coming toward us today.

"Oh, probably none," said Anderson breezily. "It wouldn't be visible to the naked eye until it warmed up, and that wouldn't happen until it hit the atmosphere, which would be about one second before it hit the Earth. You're talking about something moving many tens of times faster than the fastest bullet. Unless it had been seen by someone with a telescope, and that's by no means a certainty, it would take us completely by surprise."

How hard an impactor hits depends on a lot of variables—angle of entry, velocity and trajectory, whether the collision is head-on or from the side, and the mass and density of the impacting object, among much else—none of which we can know so many millions of years after the fact. But what scientists can do—and Anderson and Witzke have done—is measure the impact site and calculate the amount of energy released. From that they can work out plausible scenarios of what it must have been like—or, more chillingly, would be like if it happened now.

An asteroid or comet traveling at cosmic velocities would enter the Earth's atmosphere at such a speed that the air beneath it couldn't get out of the way and would be compressed, as in a bicycle pump. As anyone who has used such a pump knows, compressed air grows swiftly hot, and the temperature below it would rise to some 60,000 Kelvin, or ten times the surface temperature of the Sun. In this instant of its arrival in our atmosphere, everything in the meteor's path—people, houses, factories, cars—would crinkle and vanish like cellophane in a flame.

One second after entering the atmosphere, the meteorite would slam into the Earth's surface, where the people of Manson had a moment before been going about their business. The meteorite itself would vaporize instantly, but the blast would blow out a thousand cubic kilometers of rock, earth, and superheated gases. Every living thing within 150 miles that hadn't been killed by the heat of entry would now be killed by the blast. Radiating outward at almost the speed of light would be the initial shock wave, sweeping everything before it.

For those outside the zone of immediate devastation, the first inkling of catastrophe would be a flash of blinding light—the brightest ever seen by human eyes—followed an instant to a minute or two later by an apocalyptic sight of unimaginable grandeur: a roiling wall of darkness reaching high into the heavens, filling an entire field of view and traveling at thousands of miles an hour. Its approach would be eerily silent since it would be moving far beyond the speed of sound. Anyone in a tall building in Omaha or Des Moines, say, who chanced to look in the right direction would see a bewildering veil of turmoil followed by instantaneous oblivion.

Within minutes, over an area stretching from Denver to Detroit and encompassing what had once been Chicago, St. Louis, Kansas City, the Twin Cities—the whole of the Midwest, in short—nearly every standing thing would be flattened or on fire, and nearly every living thing would be dead. People up to a thousand miles away would be knocked off their feet and sliced or clobbered by a blizzard of flying projectiles. Beyond a thousand miles the devastation from the blast would gradually diminish.

But that's just the initial shockwave. No one can do more than guess what the associated damage would be, other than that it would be brisk and global. The impact would almost certainly set off a chain of devastating earthquakes. Volcanoes across the globe would begin to rumble and spew. Tsunamis would rise up and head devastatingly for distant shores. Within an hour, a cloud of blackness would cover the planet, and burning rock and other debris would be pelting down everywhere, setting much of the planet ablaze. It has been estimated that at least a billion and a half people would be dead by the end of the first day. The massive disturbances to the ionosphere would knock out communications systems everywhere, so survivors would have no idea what was happening elsewhere or where to turn. It would hardly matter. As one commentator has put it, fleeing would mean "selecting a slow death over a quick one. The death toll would be very little affected by any plausible relocation effort, since Earth's ability to support life would be universally diminished."

The amount of soot and floating ash from the impact and following fires would blot out the sun, certainly for months, possibly for years, disrupting growing cycles. In 2001 researchers at the California Institute of Technology analyzed helium isotopes from sediments left from the later KT impact and concluded that it affected Earth's climate for about ten thousand years.

This was actually used as evidence to support the notion that the extinction of dinosaurs was swift and emphatic—and so it was in geological terms. We can only guess how well, or whether, humanity would cope with such an event.

And in all likelihood, remember, this would come without warning, out of a clear sky.

But let's assume we did see the object coming. What would we do? Everyone assumes we would send up a nuclear warhead and blast it to smithereens. The idea has some problems, however. First, as John S. Lewis notes, our missiles are not designed for space work. They haven't the oomph to escape Earth's gravity and, even if they did, there are no mechanisms to guide them across tens of millions of miles of space. Still less could we send up a shipload of space cowboys to do the job for us, as in the movie Armageddon; we no longer possess a rocket powerful enough to send humans even as far as the Moon. The last rocket that could, Saturn 5, was retired years ago and has never been replaced. Nor could we quickly build a new one because, amazingly, the plans for Saturn launchers were destroyed as part of a NASA housecleaning exercise.

Even if we did manage somehow to get a warhead to the asteroid and blasted it to pieces, the chances are that we would simply turn it into a string of rocks that would slam into us one after the other in the manner of Comet Shoemaker-Levy on Jupiter—but with the difference that now the rocks would be intensely radioactive. Tom Gehrels, an asteroid hunter at the University of Arizona, thinks that even a year's warning would probably be insufficient to take appropriate action. The greater likelihood, however, is that we wouldn't see any object—even a comet—until it was about six months away, which would be much too late. Shoemaker-Levy 9 had been orbiting Jupiter in a fairly conspicuous manner since 1929, but it took over half a century before anyone noticed.

Interestingly, because these things are so difficult to compute and must incorporate such a significant margin of error, even if we knew an object was heading our way we wouldn't know until nearly the end—the last couple of weeks anyway—whether collision was certain. For most of the time of the object's approach we would exist in a kind of cone of uncertainty. It would certainly be the most interesting few months in the history of the world. And imagine the party if it passed safely.

"So how often does something like the Manson impact happen?" I asked Anderson and Witzke before leaving.

"Oh, about once every million years on average," said Witzke.

"And remember," added Anderson, "this was a relatively minor event. Do you know how many extinctions were associated with the Manson impact?"

"No idea," I replied.

"None," he said, with a strange air of satisfaction. "Not one."

Of course, Witzke and Anderson added hastily and more or less in unison, there would have been terrible devastation across much of the Earth, as just described, and complete annihilation for hundreds of miles around ground zero. But life is hardy, and when the smoke cleared there were enough lucky survivors from every species that none permanently perished.

The good news, it appears, is that it takes an awful lot to extinguish a species. The bad news is that the good news can never be counted on. Worse still, it isn't actually necessary to look to space for petrifying danger. As we are about to see, Earth can provide plenty of danger of its own.

Chapter 13: Bang! Discussion Questions

1. Upon discovery of the Manson Crater geologists attributed it to volcanic action. Was this an irrational conclusion at the time? Why or why not?

2. Why is the Manson Crater "invisible" at the surface of Iowa today?

3. Why did Daniel M. Barringer's mining operation in Meteor Crater, AZ fail?
4.
5. Popular depictions of the asteroid belt between Mars and Jupiter show a dense accumulation of craggy rocks that are reminiscent of scenes from *Star Wars* movies (remember those TIE-Fighter chases?). In reality, what is the average distance between asteroids in the belt?

6. What is the current hypothesis that explains the existence of the asteroid belt?

7. How many asteroids large enough to "imperil civilization" regularly cross the orbit of our Earth?

8. What is the closest recorded distance that an asteroid has come to the Earth? What is unnerving about the timing of its discovery?

9. What is the K-T boundary? Why is it not called the C-T boundary?

10. How much space dust falls to Earth annually? Bryson isn't clear how this space dust gets here – what do you think?

11. Iridium is a very heavy element that is scarce in the Earth's crust. It is probably an important constituent of the Earth's core and perhaps also the lower mantle. Some geologists have argued that the iridium layer at the K-T boundary is volcanic in origin. How could volcanism create such an iridium-rich layer?

12. Who first proposed that the dinosaurs were dealt a death blow from space? When did the Alvarez father/son team propose the same idea? Despite not being the first, the Alvarez team is widely credited as being the source of this idea – why do you think this is so?

13. How was the impact of Shoemaker Levy 9 with Jupiter important to the K-T impact theory?

14. Where was Gene Shoemaker buried?

15. Why is the Chicxulub crater so difficult to study?