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The Sky is Falling, Part III: Spaceguard

By
Michael McCollum

I would like to take this opportunity to apologize to all of my readers who may not be sleeping soundly because of these articles on the hazards of asteroids and meteors. It was not my intent to frighten you when I pointed out that a football-field-size rock can fall out of the sky at any instant and land squarely on your head. However, being rational human beings, it is difficult not to be frightened when you realize that the nice, safe, comfortable world in which you have lived all your life is actually a shooting gallery in which the fates are taking aim at everyone who crosses their field of view — which is to say, everyone. It is enough to make you want to go back to bed and pull the blanket over your head as you did when you were frightened as a child. Go ahead. That particular defense strategy is about as effective as any other remedy we have available to us … at the moment.

For those who believe that "it can't happen to us," try to visualize standing on the beach at Bandar Aceh last December, wondering why the waves have just receded a mile offshore and watching a large wave building in the distance. The December tsunami killed 300,000 people who had not a care in the world ten minutes earlier. An asteroid or comet falling from the sky will make the largest tsunami seem like the most minor of all problems.

Now that we know that giant meteor impacts *can* happen, that they *have* happened, and that they *will* happen again, perhaps we should bestir ourselves long enough to consider what, if anything, we can do about the problem. Don't get me wrong. I know that we baby-boomers and Generation-Xers do not like thinking about unpleasant realities when we have so many imaginary dangers to occupy our minds. Still, perhaps we can tear ourselves away from our 200 channels of television long enough to consider the extremely unlikely possibility that our antiseptic world will disappear tomorrow in a flash of light and a mile-high tidal wave.

Which brings up the question, "Just how likely is it that a giant meteor will fall from the sky and kill us all?" If you are feeling complacent, consider this intriguing little fact: *Your chances of being killed by meteor strike are slightly greater than your chances of dying in the crash of a commercial airliner!* That is one of those odd statistics that requires more explanation, which we will provide a bit later in this article. In the meantime, having proved that Chicken Little was right and the sky really is falling, what can we mere mortals do to protect ourselves?

That will be our subject this month.

Edmund Halley's Neighborhood

Did you happen to see the return of Halley's comet in 1986? I did. I got my entire family up at four o'clock in the morning, we drove down the freeway about forty miles to get away from the lights of Phoenix, and then we parked in some farmer's front yard to see the celestial event of the century. What a disappointment! The comet for which I had waited my entire life was a dirty smudge of light in the sky, barely visible. In fact, nineteen years later, I still wonder if my wife was humoring me when she said that she could see it.

What went wrong? In 1910, Halley's comet filled the sky from horizon to horizon. The centenarians still talk about going out with their parents and being awed by the sight. The problem is that in 1910, Halley's comet and the Earth were on the same side of the sun during the comet's periodic dive into the inner solar system, and in 1986, we were on opposite sides of the sun. In fact, in that year we did not come within hundreds of millions of miles of one another. As everyone instinctively knows, and artists are explicitly trained to understand, distance diminishes objects. It sure diminished Halley's comet, to my utter disappointment. I waited all my life to see that smudge of light in the sky! It hardly seemed worth rousing my family out of bed at 4:00 AM. Oh well, there is always next time. Or is there?

Halley's comet will return in 2061 and, unfortunately, we will once again be on opposite sides of the sun. In other words, the view will be just as crappy next time. However, take hope. The next visit after that, the one in 2137, is going to be spectacular! If you are still reading *The Art of Science Fiction Series* at that time, I will be sure to give you my firsthand account of the event.

The varying views of Halley's comet illustrate an important point for worriers about the hazards caused by asteroids and comets as they careen through space. In order to crash into the Earth, the orbit of the asteroid or comet must intersect the Earth's orbit at the precise moment that Earth is passing the point of intersection. If the two lines of flight never meet, then there is no possibility of a collision and we can all go back to sleep.

This is a subtle point that is widely misunderstood by the public. They look up in the sky, see a million-kilometer-long streak of light, and assume that we are in immediate and extreme danger. This tendency to personalize everything is due to a broad parochial streak in our makeup. It is a human tendency to believe that dangers familiar to us are important and frightening, while those unknown do not exist. My wife illustrates this principle nicely. Whenever she hears about some new disease, she becomes convinced that she has contracted it. It is as though the germs come into existence at the moment she first becomes aware of them and that they make a beeline directly for her bloodstream!

A more general illustration of this tendency toward self-centeredness is that current environmental bugaboo, the hole in the ozone layer. Before we knew the ozone layer existed, there was no problem. Suddenly, when we discover the layer, we find that it is being ripped to shreds by evil, money-grubbing Freon-producing capitalists, and that we must modify our whole way of life to protect it. I find this recurring discovery-disaster theme decidedly odd. For example, why wasn't the ozone layer dissipated in the

nineteenth century, causing the human race to die out from increased skin cancer rates? Why not in the nineteenth century B.C.? Why now and why us?

Perhaps there is another explanation for the seeming oddity that our awareness of a phenomenon is followed immediately by a crisis. Perhaps ignorance truly is bliss, and the best way to protect ourselves from global hazards is not to learn of their existence in the first place.

Death by asteroid is another of these "dangers of the moment" of which we have recently become aware. The human race and its progenitor species survived quite well for more than four million years without being rendered extinct by a rock from out of the sky. Why hyperventilate just because we have become aware of the fact that it does, occasionally, happen?

Yet, because we are each the center of our personal universe, we have historically believed that every passing comet is an evil omen and have predicted dire consequences. The truth is that most comets are innocent travelers through the void. They begin their lives out in the Oort Cloud, where the detritus left over from the formation of the solar system is stored, they dive sunward every few centuries, and they give all the planets a wide berth. They bother no one and are bothered by nothing, continuing their endless elliptical journeys until their volatile substances are finally all boiled away to space, leaving a jumble of boulders and billions of grains of sand to mark the path where once a mighty comet lived.

This cometary aversion to coming close to the Earth may indeed be a result of a divine plan, or it might just be the operation of the laws of probability. The Earth is a remarkably difficult target to hit. That is because the planet moves its own length every seven minutes. Any cosmic bullet launched our way millions of years ago must pass directly into our orbital path at the exact moment we happen to be at that same point, and must arrive with a schedule tolerance of no more than ±3.5 minutes. Annie Oakley couldn't shoot that well.

Unfortunately, as the dinosaurs discovered the hard way, Mother Nature can.

The Solar System is a big place, much larger than most people realize, and the vast majority of the traffic never makes it into our small neighborhood. Halley's comet, for instance, can never hit us because (as illustrated by the poor showing of 1986), our two orbits do not come anywhere near one another. In fact, any rock that orbits beyond the orbit of Mars or inside the orbit of Venus is no threat to us and we can safely ignore its existence for the rest of eternity.

It is our "fellow travelers" that we need worry about. Those are the asteroids whose orbits lie near or pass through the plane of the Earth (the technical term is "the ecliptic"), and whose path around the sun causes it to cross our own circular orbit. These are typically called Earth-approaching asteroids, or more commonly, Near Earth Objects (NEOs).

We should be studying the Near Earth Objects, for it is they that represent whatever hazard exists from extraterrestrial bombardment. If we understand NEOs, we can better understand the risk of our own extinction.

Near Earth Objects

The technical definition of a Near Earth Object (NEO) is one where some portion of the body's orbit lies within 1.3 astronomical units (AU) from the sun. Since the Earth's orbit is 1.0 AU from the sun, this brings the orbiting asteroids into periodic conflict with us, resulting in close approaches of varying degrees of danger.

To quantify the danger, astronomers have recently formed a new classification of Near Earth Object, the Potentially Hazardous Asteroid (PHA). Potentially Hazardous Asteroids are those with an Earth Minimum Orbit Intersection Distance (MOID) of 0.05 AU or less, and an absolute visual magnitude (H) of 22.0 or less. In other words, asteroids that do not approach Earth within 0.05 AU (roughly 7,480,000 km or 4,650,000 mi), or are smaller than about 150 m (500 ft) in diameter (*i.e.* H = 22.0 with assumed albedo of 13%) are not considered PHAs.

There are currently 184 PHAs known to astronomers. This is not the last word on the subject, however. These are only the close approaching asteroids that we know about. There are a great many more that we do not know about. Yet, while our knowledge of the subject is currently in its infancy, you can get some idea of the problem by studying current list of PHAs. At the end of this article is a separate appendix file containing this data, including: 1) a list of all known PHAs, 2) a list of the closest future approaches to the Earth, and 3) a complete chronological list of close approaches for the coming century. As you peruse the data, however, keep one thing in mind. These close approach tables will be longer next year, and every year thereafter until we finally are able to map every PHA in the solar system.

The tally (as of August 25, 1999, when this article was originally written) is: 814 Near-Earth objects, 307 of which are asteroids with a diameter of approximately 1 kilometer or larger, with 184 classified as PHAs.

To further understand the nature of PHAs, we need to introduce a new concept, that of Earth's "Zone of Influence." Figure 1 shows a diagram of the Zone, which is arbitrarily defined as a sphere 0.05 astronomical units in radius (rounded up to 5 million miles for convenience). This is approximately 20 times the distance between the Earth and Luna.

When an asteroid or a comet passes close to a planet, the planet's gravity alters its trajectory. That is what happened to Comet Shoemaker-Levy 9. It passed too near Jupiter on one of its trips around the sun, and Jupiter pulled it into a new orbit. The comet looped high above the planet and then crashed into the big world on its next pass. Jupiter's gravitational pull was so strong on the penultimate pass that tidal stresses broke the comet into pieces, producing the famous "string of pearls" that first brought it to our attention.

While Jupiter is the largest of the planets, it is not the only world that attracts orbiting space junk. All the planets, including the one we happen to be standing on, do the same thing. The Earth's gravity pulls on passing asteroids and comets, deflecting their orbits in our direction such that their minimum orbit intersection distance decreases. This is illustrated in Figure 1 with the paths of the two NEOs. Deflecting an asteroid's orbit does not mean that the next trip around the sun will produce another near miss, however. The next orbit could well find us on opposite sides of the sun, just as Halley's comet was in 1986. It can take centuries before everything lines up just right again, but

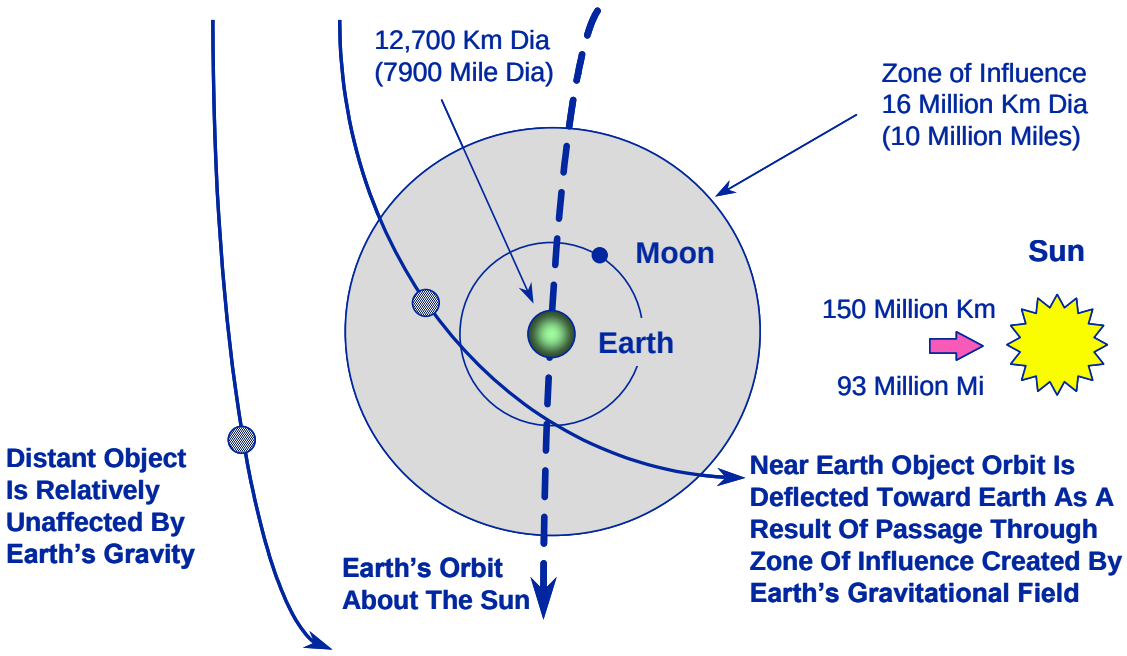

Figure 1: Near Earth Objects and the Zone of Influence

when it finally does, the approach will be closer than it was. It will be closer the next time the two orbits are synchronized, and the next, and the next. Eventually, the asteroid's MOID drops to zero and it collides with the Earth.

What is the significance, then, of the Zone of Influence? The significance is that we can safely ignore any object whose orbit does not currently penetrate our zone. The rule of thumb is that close encounters with the Earth will change an asteroid's MOID by about 0.02 AU per century. Thus, everything outside our Zone of Influence will require at least 250 years before the Earth's gravitational attraction can make it a hazard. The farther a rock's orbit lies outside the zone, the longer we can ignore it.

The only objects we need worry about, then, are those that actually penetrate our Zone from time to time. That doesn't sound so bad, does it? How many of these "close passers" can there be? An interesting question, and one we are just beginning to be able to answer.

Figure 2 shows a graph relating the theoretical number of Near Earth Objects to size. By checking the graph, we discover that there are ten million 100-meter objects that pass relatively close to the Earth, and more than 10,000 that are one kilometer in diameter or greater. Compared to those numbers, the fact that we have discovered 184 PHAs does not sound very impressive at all. It is also the reason you can expect the tables in the appendix to grow dramatically over the next few years.

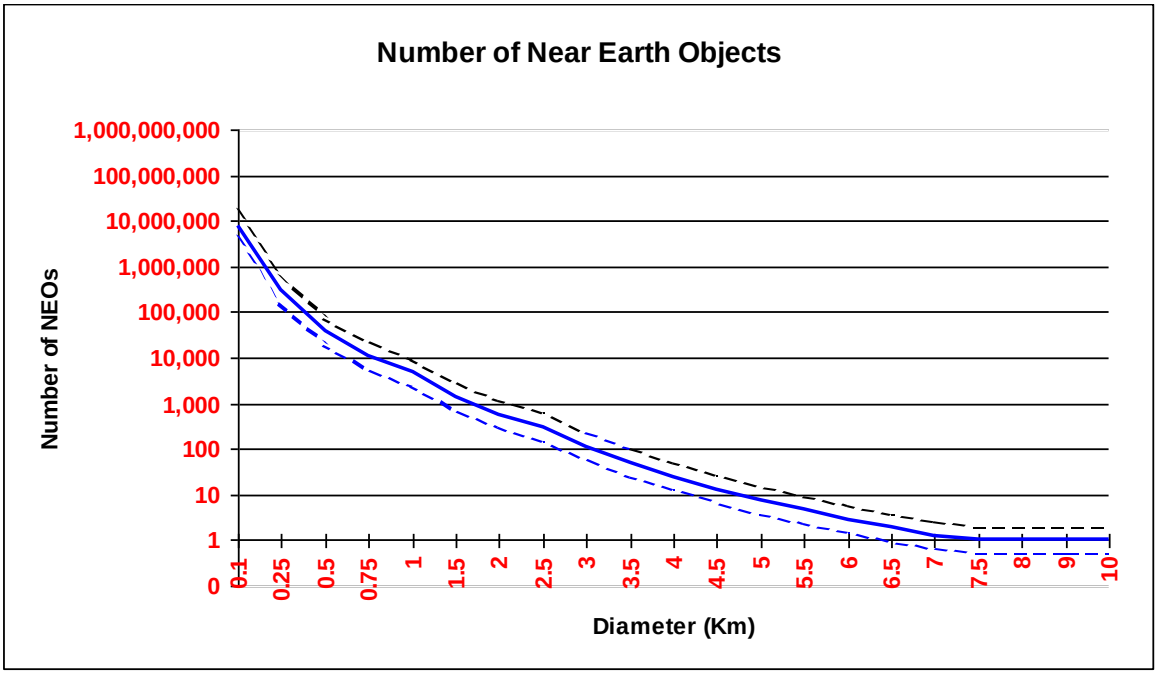

Figure 2: Theoretical Number of NEOs Related to Physical Size

Table 1:
Close Approaches To Earth, 1998-2000

Asteroid						
Number	Name	Date	Time (GMT)	Distance (AU)	Distance (Miles)	% Penetration Zone of Influence
	1998 BZ7	05-Mar-98	16:19	0.113	10,509,000	0%
8201	1994 AH2	17-Jun-98	13:26	0.193	17,949,000	0%
	1987 OA	28-Aug-98	13:12	0.109	10,137,000	0%
1865	Cerberus	24-Nov-98	18:00	0.163	15,159,000	0%
	1996 FG3	25-Nov-98	18:29	0.038	3,534,000	29%
	1989 UR	28-Nov-98	4:05	0.058	5,394,000	0%
	1994 WR12	13-Jan-99	20:10	0.094	8,742,000	0%
	1991 VE	18-Jan-99	21:50	0.157	14,601,000	0%
6047	1991 TB1	18-Mar-99	12:29	0.163	15,159,000	0%
	1992 SK	26-Mar-99	6:14	0.056	5,208,000	0%
1863	Antinous	01-Apr-99	14:38	0.189	17,577,000	0%
6489	Golevka	02-Jun-99	19:26	0.05	4,650,000	7%
	1989 VA	21-Nov-99	21:22	0.194	18,042,000	0%
	1991 DB	18-Mar-00	16:05	0.102	9,486,000	0%
	1986 JK	11-Jul-00	10:48	0.122	11,346,000	0%
	1991 BB	27-Jul-00	4:19	0.166	15,438,000	0%
4486	Mithra	18-Aug-00	8:10	0.046	4,278,000	14%
2100	Ra-Shalom	6-Sep-00	0:58	0.19	17,670,000	0%
2340	Hathor	25-Oct-00	6:00	0.197	18,321,000	0%
4179	Toutatis	31-Oct-00	4:34	0.074	6,882,000	0%
	1992 HF	18-Nov-00	13:41	0.193	17,949,000	0%
4183	Cuno	22-Dec-00	18:58	0.143	13,299,000	0%

Table 1 is a list of the close approaches during the period 1998-2000. The closest approach to Earth during this three-year period was by 1996 FG3 on 25 November 1998.

On that day, the asteroid penetrated our Zone of Influence by 29%, which was a miss of 3,534,000 miles. That doesn't seem too frightening, now does it?

Before we become complacent, however, let us consider the history of the closest observed approaches to Earth.

Table 2 puts a new light on things. On December 9, 1994, Asteroid 1994 XM1 passed within 70,000 miles of Earth, penetrating our Zone of Influence by 98.6%. On May 20, 1993, Asteroid 1993 KA2 penetrated our zone by 98.2%. In fact, there have been four rocks that passed between the Earth and the Moon in the recent past — that we know of! How many have there been that we do not know about?

Then there is the case of 1997 XF11. This asteroid was officially discovered in December, 1997 (although it had been recorded on film seven years earlier). Shortly after its discovery, the general press was filled with reports that it might collide with the Earth on October 26, 2028. The resulting flurry of overheated rhetoric is a good example of a newly discovered hazard suddenly becoming a crisis. As it turned out, the Jet Propulsion Laboratory recomputed the initial orbital information based on both the pre- and post- discovery data and concluded that it would miss by a comfortable 600,000 miles (0.0036 AU). Figure 3 is a graph of the original calculation that stirred things up. It shows the asteroid, whose orbital plane is inclined to that of the Earth, passing through the ecliptic at almost precisely the Earth's orbital distance. Figures 4 and 5 show the original close approach data, and Figure 6 shows the recalculated orbital data. Needless to say, we were all glad to learn that the world would not end in 2028. For one thing, it would mess up my plan to stick around to see a third return of Halley's comet!

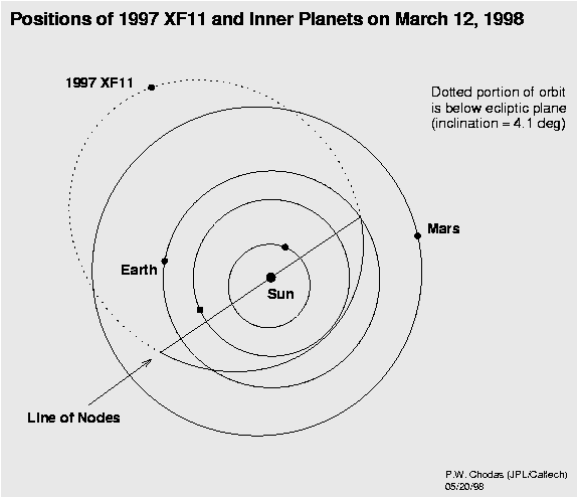

Figure 3: Orbital Diagram Showing Possible Collision at Line of Nodes

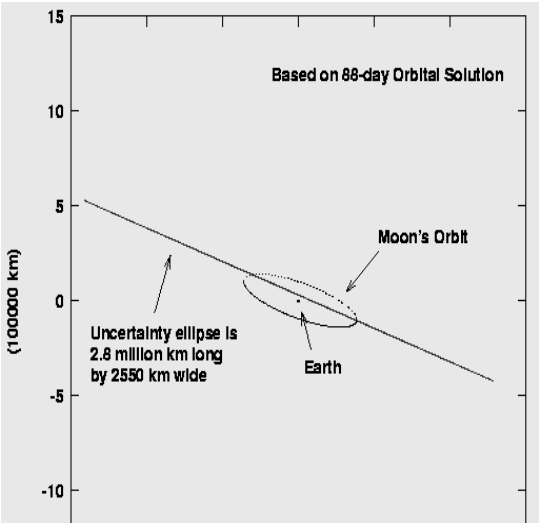

Figure 4: Plot of Close Approach Data From Initial Observations

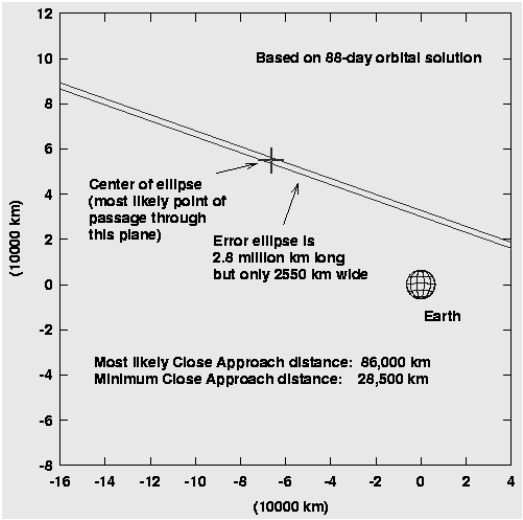

Figure 5: Expanded View of Original Data Showing Close Approach

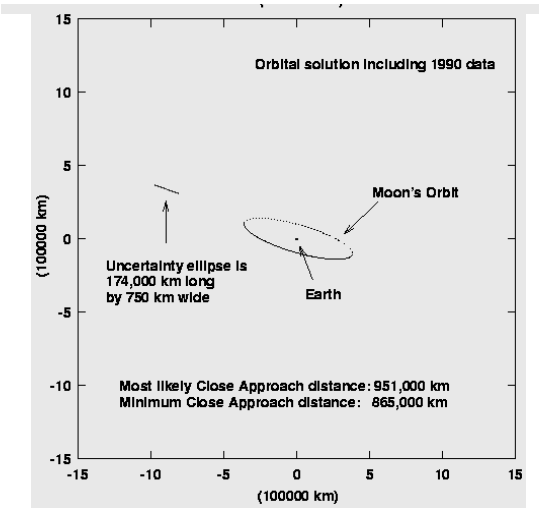

Figure 6: Expanded View of Close Approach Using Full Data

Based on what little we know about NEOs, the danger of collision with some of this orbiting space junk is much greater than we had imagined, especially if more than 95% of all NEOs have yet to be identified. The question, then, is just how likely is it that our luck will run out someday soon? How often does the Earth get hit with these whirling mountains in space and what are the consequences of such impacts?

Cosmic Actuarial Tables

Scientists who study the possibility that a comet or an asteroid will hit the Earth are able to use their relative abundance in space to predict how often we will be hit. When studying these probabilities, however, one must distinguish between asteroids and

comets. The probability of being hit by an asteroid is substantially higher than for a comet because Potentially Hazardous Asteroids orbit in the inner solar system and encounter the Earth numerous times during any given century. Comets, on the other hand, are visitors from the outer void. Many of them dive into the inner solar system once and then are never seen again. Even the periodic comets, which visit us repeatedly, tend to do so less often than the asteroids, making them less of a threat. However, since comets approach Earth from much farther out than do asteroids, they arrive with higher velocities and much greater energies than their rocky counterparts. This is an example of being between a rock and a hard place. (Pun intended.)

Table 3 lists our best current estimates of the probability that the Earth will be struck by an asteroid or comet. Remember, as we learn more, these estimates will probably be adjusted — upwards! The worst impacts, a rock big enough to cause globally catastrophic destruction, occur about every 500,000 years. Two per million years may not seem like very many, but when you shift your thinking to the geological timescale, you realize that we are being hit at a horrendous rate. At two catastrophic strikes each million years, there have been 130 such impacts since the big rock that took out the dinosaurs some 65 million years ago. That's a lot of impacts.

Table 3: The Probability of Being Struck by an Asteroid or Comet

Globally Catastrophic Impact:	Every 500,000 Years
Tunguska Class Impact On:	
Earth	Every 100-300 Years
In A Populated Area	Every 3,000 Years
In A World Urban Area	Every 100,000 Years
In A U.S. Urban Area	Every 1,000,000 Years
Number of Deaths	
Globally Catastrophic Impact:	2.5 Billion
Tunguska Class Impact/ Populated Area:	1 Million

The other number to note regarding globally catastrophic impacts is the number of deaths that result. Essentially, a single impact on this scale will kill approximately half the human race, or 2.5 billion people. That is where the odd statistic about your chances of dying by meteor strike comes from. The probability of the event is low, but the consequences are huge. Although no human being has ever been killed by a meteor (that we know of), if a large asteroid ever does impact the Earth, the number of dead will be staggering. A low probability event with a large number of dead gives a much higher probability number than a more likely event with fewer dead (such as an airliner crash).

The other possibility is that we will be hit by a smaller bit of rock that will do significant, but not globally catastrophic, damage. Such was the case with the Tunguska meteor strike of 1908. Only, Tunguska wasn't a piece of rock. It was a piece of ice split off Comet Encke. Tunguska-class impacts happen every 100 to 300 years. If they hit in an urban area, they can easily kill a million people. Let's see … Tunguska was in 1908, it is now 2005, and … hmmm, we seem to be due!

We know that these events can happen and that if they happen again any time soon, a great many people are going to be killed. The hazard, it appears, is real, if remote. The question arises: "What, if anything, can we do about it?"

Which brings us to a modest little proposal —

Spaceguard, An Insurance Policy

In 1992, NASA studied the problem of Near Earth Objects and recommended establishing a program to map all of the nearby sky junk that might be a potential hazard. They dubbed this program "Spaceguard." The purpose of the proposed Spaceguard system is to detect all Near Earth Objects capable of endangering life on Earth. The plan calls for building a network of six telescopes with apertures of 2-3 meters. These telescopes are to be equipped with charge-coupled-detector arrays (CCDs) and are monitored by computers rather than astronomers. They will scan the sky, looking for nearby asteroids with visual magnitudes down to 22, the lower size limit for PHAs.

Such a sky survey would not have been possible in the days when asteroids and planets were identified by scanning photographic plates with a blink comparator. The identification process requires too much labor to be effective over the entire sky, even when performed by legions of minimum wage undergraduates and moonlighting housewives. With the advent of solid-state electronics and computers, however, the impossible task becomes practical.

Figure 7 shows a diagram of one of the proposed Spaceguard Telescopes. The telescope has a CCD detector in which light is focused on a rectangular array of light-sensitive pixels. By monitoring the pattern of electrical charges as points of light move from one pixel to another, the computer can "see" the stars.

Unlike normal telescopes, the Spaceguard telescopes would be stationary. Rather than compensating for the Earth's rotation, astronomers use the rotation to scan the heavens. As the stars sweep majestically across the sky, their images move slowly in unison across the face of the CCD array. The monitoring computer is programmed to ignore anything moving across the detector with the characteristic speed of Earth's rotation. However, images that are out of sync with the fixed stars are immediately noticed. In this way, nearby comets and asteroids can be culled from among the background stars with only a few minutes or hours of observation time, much faster than the traditional photographic plate method.

Given this wondrous piece of technology, how long will it take us to do our sky survey and determine whether we are truly safe? Surprisingly, even with the best telescopes money can buy, it will take more than three decades before we can be sure that we have captured 95% of the PHAs. Nor can this period be reduced so long as we use ground-based telescopes for our search. Figure 8 illustrates the reason why, something that astronomers have dubbed the "picket fence" problem.

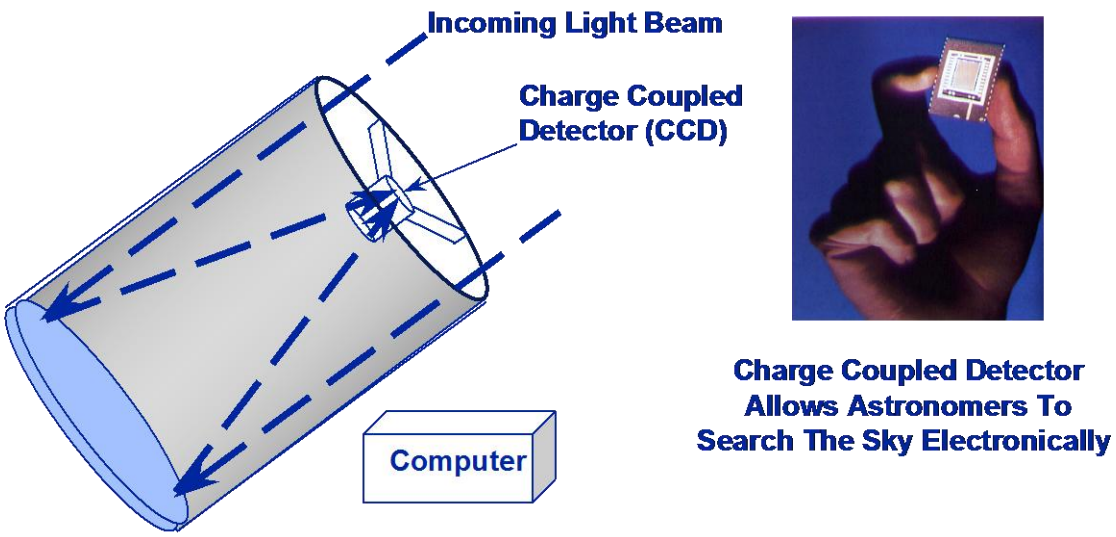

Figure 7: Spaceguard Telescope with CCD Detector

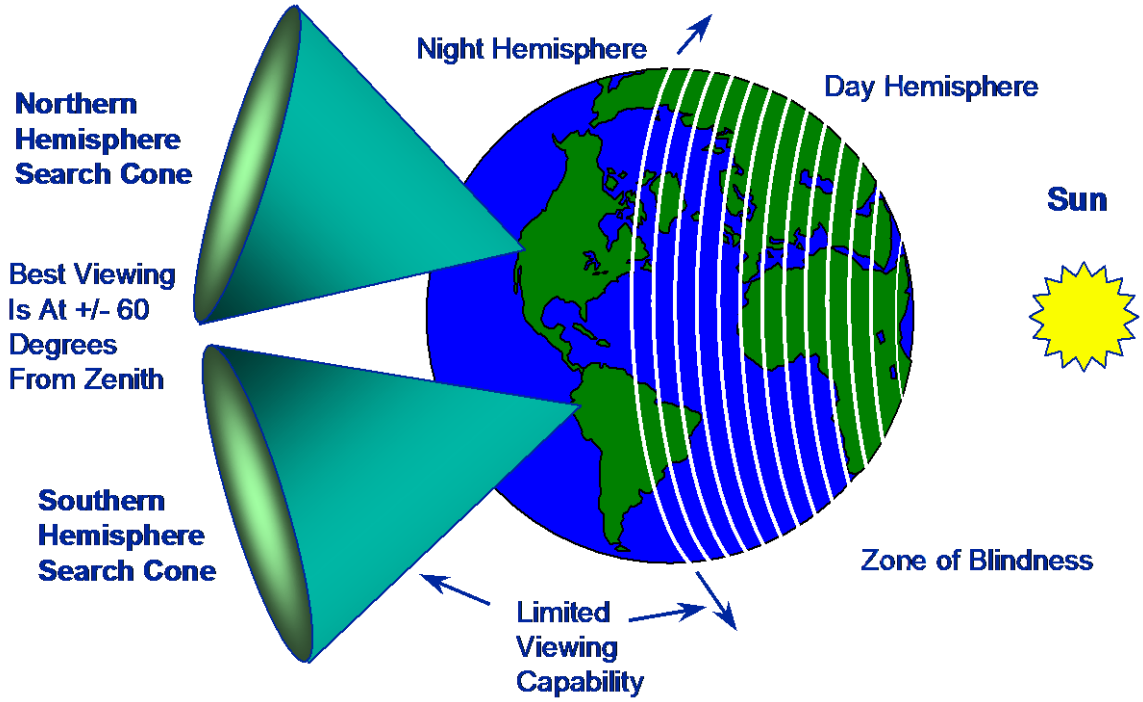

Figure 8: The "Picket Fence" Problem in Astronomy

Astronomers have always been creatures of the night, primarily because that is the only time they can do their jobs. At other times, the Great Hydrogen Bomb in the Sky is above the horizon and pretty much ruins our view of the stars. We have a special name for that portion of Earth's rotation cycle when astronomers sleep. We call it "daytime."

If we can't see asteroids and comets in daylight, and we are limited by the atmosphere to looking within approximately 60 degrees of the zenith, each night's observation will sweep out a slice of the sky defined by the eight to 14 hours of darkness at the telescope sites (depending on season). The next night, we can sweep another arc of sky. However, because the Earth has moved along its orbit for 24 hours between observations (remember, we move our own length every 7 minutes), the second night's slice of the sky does not overlap the original observation. Throughout the year, we scan 365 "pickets" worth of sky, but miss the 365 "holes" between them. The next year we pick up much of the missed area, but since asteroids and comets do not stand still, we cannot be sure that our targets aren't playing hide-and-seek with us. The problem is a complex one involving orbital mechanics, the time it takes for the Earth to circle the sun, and the number and size of targets to be found. The bottom line, however, is that before we can be sure that we've gotten everything (well, you can't ever be sure of *everything*, but almost everything), the planet will have made 35 trips around the sun and those of us reading this article will be a great deal older. That, unfortunately, is life.

How much will Spaceguard cost? The scientists who proposed the system estimate that the six telescopes will cost $48 million to build and $12 million per year to operate for the life of the survey, for a total of approximately $500 million dollars expended over 40 years. A word of caution here. Scientists' cost estimates are notoriously unreliable. The physicists who proposed the atom bomb thought it would cost less than $100 million. It actually cost $2 billion.

Still, even if the estimates are off by a factor of ten, and the bill over 40 years is $5 billion, and still less than congress wastes on some of their social engineering experiments in a single year.

What has the reaction been from the congress to the Spaceguard proposal? They have been unable to find the money to recommend it for a new program start in the last dozenbudget cycles.

Some things never change.

I always end my lecture on meteor strikes by flashing Figure 9 on the screen and asking two questions:

<u>Conclusion:</u>

When I give my lecture on asteroids and comets, I always end by pointing out that the risk is low and there is probably nothing to worry about. After all, there hasn't been a global-catastrophe size impact in the entire history of the human race. What chance that there will be one tomorrow, or the next day, or even for the next century? On the other hand, won't we all feel silly if there is one and we could have done something to stop it had we only known?

Figure 9: Visitor from the Deep Black

I always end my lecture by asking two questions:

1) "IS THERE A GIANT METEOR IMPACT IN OUR FUTURE?"

2) "CARE TO BET YOUR LIFE ON IT?"

Well, do you?

The End

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2. Procyon's Promise - ^{US}$7.50

Three hundred years after humanity made its deal with the Life Probe to search out the secret of faster-than-light travel, the descendants of the original expedition return to Earth in a starship. They find a world that has forgotten the ancient contract. No matter. The colonists have overcome far greater obstacles in their single-minded drive to redeem a promise made before any of them were born...

3. Antares Dawn - US$6.00

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$7.50

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.50

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$7.50

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

7. The Clouds of Saturn - US$7.50

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$7.50

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $7.50

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.50

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gibraltar Stars – First Time in Print — [US]$7.50

The great debate is over. The human race has rejected the idea of pulling back from the stars and hiding on Earth in the hope the Broa will overlook us for a few more generations. Instead, the World Parliament, by a vote of 60-40, has decided to throw the dice and go for a win. Parliament Hall resounds with brave words as members declare victory inevitable.

With the balance of forces a million to one against *Homo sapiens Terra*, those who must turn patriotic speeches into hard-won reality have their work cut out for them. They must expand humanity's foothold in Broan space while contending with a supply line that is 7000 light-years long.

If the sheer magnitude of the task isn't enough, Mark and Lisa Rykand discover they are in a race against two very different antagonists. The Broa are beginning to wonder at the strange two-legged interlopers in their domain; while back on Earth, those who lost the great debate are eager to try again.

Whoever wins the race will determine the future of the human species… or, indeed, whether it has one.

12. Gridlock and Other Stories - US$6.00

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

13. The Art of Writing, Volume I - US$10.00

Have you missed any of the articles in the Art of Writing Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 72,000 words. Now you can learn about character, conflict, plot, pacing, dialogue, and the business of writing, all in one document.

14. The Art of Writing, Volume II - US$10.00

This collection covers the Art of Writing articles published during 1998. The book is 62,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

15. The Art of Science Fiction, Volume I - US$10.00

Have you missed any of the articles in the Art of Science Fiction Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 70,000 words. Learn about science fiction techniques and technologies, including starships, time machines, and rocket propulsion. Tour the Solar System and learn astronomy from the science fiction writer's viewpoint. We don't care where the stars appear in the terrestrial sky. We want to know their true positions in space. If you are planning to write an interstellar romance, brushing up on your astronomy may be just what you need.

16. The Art of Science Fiction, Volume II - US$10.00

This collection covers the *Art of Science Fiction* articles published during 1998. The book is 67,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

17. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

