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COMMENTARY

The Big Wham: Thoughts on Comets, Risks, and a Strategic Defense Initiative for the Eco-System

Gregory Benford

In mid-July of 1994, Jupiter's fireworks upstaged the 25th anniversary celebrations of the Apollo moon landing. While aging astronauts exchanged toasts, fragments of Comet Shoemaker-Levy 9 slammed into the giant planet. Only two years ago we did not even know this comet existed. In July, it triggered hotspots as large as the Earth.

Those days of ferocious pounding saw the most energetic events ever witnessed by humans. They struck a clear, vibrant chord in the public. Here was disaster, drama, danger. Chunks of ice and dust up to 2.5 miles across vaporized in fiery moments. Acne larger than worlds blotched Jupiter's face.

Scientists, too, got a bonus. Up through the entry tunnels in Jupiter's ammonia cirrus flowered plumes of fried debris. Surprisingly, there was no immediate evidence for water in the upwelling. Close study may reveal the depths of Jupiter's atmosphere, telling us much we could never learn on our own.

Many drew an even deeper lesson. Worldwide fascination focused beyond the fireworks, to the future. Could that happen to us? Sure; in fact, it has happened to our home world before.

Meteoric bombardment has been well known to astronomers for well over a century. Science fiction authors, always game for a bit of catastrophe, started using the idea half a century ago.

The notion seems to have re-emerged because the striking photos from our planetary survey craft of the 60s and 70s underlined how many bodies in the inner solar system were riddled with impact craters—Mercury, Mars, of course our moon, and the moons of Jupiter as well. Meteor bombardment was once quite common, and even now bits of debris from the early solar system regularly smash into some larger target. Each day about a hundred tons of small particles, mostly ice, fall into our own atmosphere.

I became involved with the idea of meteor impact as a threat in the 1960s, spurred by J. E. Enever's factual article "Giant Meteor Impact" in the March, 1966 *Analog*. As far as I know, it was the first detailed study—one not referenced by astronomers.

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The theme surfaced for me again in roundabout fashion, through a film deal which eventually aborted. In the late 1970s there blossomed a mini-genre of what my friend Bill Rotsler termed Big Rock Hits Earth novels.

Bill and I had begun work on an idea I first used around 1970, for a short story called "Icarus Descending" (a *Magazine of Fantasy and Science Fiction* cover story, 1972), and later incorporated into my novel, *In the Ocean of Night*. But part way through the novel Bill and I planned, we learned that two of our friends were nearly finished with *Lucifer's Hammer*. Larry Niven and Jerry Pournelle were using the idea because their editor, Bob Gleason, had asked them to tone down a planned novel about alien invasion. Gleason liked the idea of demolishing civilization by dropping an asteroid on the Earth, and wanted them to separate it from the invasion plot.

Some products of that time were a TV movie somewhat based on *Lucifer's Hammer*—Sean Connery's worst film, *Meteor*—and finally the novel with Bill Rotsler, *Shiva Descending*. Because of delays after we turned in our manuscript, our novel appeared well after *Lucifer's Hammer*. Most of the writing was Bill's, with most of the science from me. Whereas most Big Rock books are disaster novels, this one, we resolved, would be about averting disaster, which seemed like more fun. It wouldn't be easy, we learned.

I used the 1968 M.I.T. Project Icarus study for technical calculations—a compact little manual born in a special topics course for the ever-inventive MIT undergraduates, many of them science fiction fans. Inspired by Enever's article, it gave design specs, costs, probabilities, the works.

But mainstream scientists knew little of such matters then. In the decade since, science has seen a paradigm shift.

Now most believe that a ten-kilometer asteroid killed the dinosaurs. The revolution came from a thin sliver of the element iridium found worldwide, buried in fossil-bearing sedimentary rocks laid down 65 million years ago. Iridium is rare on Earth's surface, but more common in asteroids. The layer plainly pointed to an asteroid strike large enough to scatter iridium-tinged dust around the globe. Such an impact is thought to have touched off a nightmare of storms, tsunamis, bitterly cold darkness, acid rains, global fires, and eventually maybe even greenhouse warming.

The iridium layer lies exactly at the point in the fossil record where the lovable lizards died. No rival theories of dinosaur extinction have nearly as much empirical evidence—including a hypothetical outburst of vulcanism, which could pump iridium-rich ore from the earth's metallic core. (See *Scientific American*, October 1990 for a typical round in the continuing battle.)

Iridium concentrations found in the USA and Latin America are thicker, strongly suggesting that the killer probably struck between Cuba and Panama, blasting a hundred-mile-wide crater in the ocean. A sea impact is worse than one on land, contrary to intuition. The jet of steam spikes up to the very edge of our atmosphere, then cloaks the planet in clouds for longer, plunging temperatures further and faster. The immediate blast effects are worse, too. Apparently the American dinosaurs died first—within hours, in fact.

What's more, a further stunning bit of data startled the world in 1984: mass extinctions seemed to be periodic, coming every 32 million years. This implies that a dim, unrecognized companion star orbiting our sun may scramble up the orbits in the comet cloud beyond Pluto, sending them crashing into the inner planets. This as-yet unfound star was quickly dubbed "Nemesis." Niven and Pournelle used a similar agency to start their plot rolling. Luckily, the next comet storm seems to lie about 15 million years in the future.

Is the periodicity real? Many dispute it now, and searches for the faint infrared dot that would mark our sun's brother have been futile. Nemesis would be on the very outer swing of its elliptical orbit, moving nearly directly away from us, and thus would show little apparent motion across the sky. This would make it indistinguishable from the plethora of dim dots in the infrared surveys.

All of this is heady stuff, but a more obvious danger lurks in the asteroids already circling the sun, in the realm of the inner planets—especially the Apollo-class asteroids, which cross our orbit. In 1978, when Rotsler and I were finishing the book, both the iridium discovery and Nemesis were a few years away—so I opted for the Apollo explanation. It seemed a less remote possibility, compared with a singular comet plunging in from beyond Pluto.

Since then, patient observers have picked out many more Apollo asteroids. Now they need not work from thin scratch-like signatures on photographic plates. New devices called charge-coupled detectors can sniff out dim dots of light and computer-compare them with images from an hour earlier, scanning for traces of motion. Since they're near us and moving at about seven miles/second, even small asteroids of a mile or so across can stand out.

We have found about 200 near-Earth asteroids, adding another two or three a month. From estimates of how much of the night sky we've scrutinized, we can judge that about 10,000 whirl around in the space near us—and thus are candidates for a fateful crossing of their paths and ours.

These are a handy scientific resource, in a way. In terms of energy needed to get there, they are the simplest and cheapest missions we could fly which would return a sample. NASA estimates that for 150 million dollars we could get a kilogram or so back, fresh from one of the big rocks now looping sedately in and out of our orbit. This would be much easier than going to the asteroid belt itself for a sample, over twice as far from the sun as Earth. Yet the sample would be of an asteroid, for the near-Earth vagrants are fugitives from the great belt of asteroids which hangs between Mars and Jupiter. The tidal interference of Jupiter stopped them from coalescing into a planet long ago. The nearest they got was Ceres, the largest asteroid, 933 kilometers across. Now any of the many millions of roughly mile-wide asteroids can smack into each other, resulting in chunky debris or even a coagulated, more massive body—bound on a fresh orbit, one that could strike an inner planet. We can calculate that the lifetime of such asteroids which wander into the inner solar system is fairly short—about one percent of the solar system's age, or 45 million years. They end up contributing to the mass of the inner worlds, including ours.

About every century a meteor delivers an impact comparable to a nuclear warhead somewhere on Earth. The most recent, June 30, 1908, fell near the Siberian Tunguska River. It apparently was mostly ice, because it vaporized with an immense bang sensed by weather equipment in London, but leaving little iron or stone as evidence.

In 1972 something came as close as you can get without hitting us. It skipped across the upper atmosphere above the USA, a bright trail picked up on radar. It had to be at least 80 feet across to make such a trail, skimming like a flat rock spun across a pond by a cosmic child—then gone. Since then, there have been two other recorded near misses.

Those two were known objects, making calculated passes, missing the Earth by a few hours of orbital time. And 99 percent of the near-Earth rocks at least half a kilometer in size we haven't even found.

In 1991, this prompted several astronomers to call for a worldwide program to defend against these intruders. Their logic was simple. Even a rock half a kilometer in diameter would hit with energy equal to a thousand megatons of TNT—far greater than any nuclear weapon. If a bigger chunk hit us square on, it would destroy civilization, perhaps end the human species.

Think of it like an insurance agent. A big hit would kill about five billion people. Say the probability of this happening is once in 50 million years—a reasonable estimate, longer than the Nemesis time. (Asteroid astronomers say a big hit occurs between 25 and 50 million years, averaging over the last billion years of Earth's bombardment.) Then the death rate averaged over that whole time is about a hundred people per year.

Here statistics collide with our emotions. After all, such colossal impacts are very rare; why bother?

Surveys show that people regard risks rarer than the proverbial one in a million as too small to bother with. Asteroid danger is at this level. Still, statisticians forget that we do not feel through numbers. Studies show that people thinking about risk shrug off dry data, heavily favoring two emotional factors. They ask: Is it dreadful? Is it unfamiliar?.

Asteroid impact is both. Dreadful means huge, uncontrollable, with high risk to future generations. The unknown nature—we haven't thought about this before, and one could be heading for us right now—heightens our sense of threat.

This explains why people around the world reacted strongly to the bright Jovian fireballs. Most know that if such hammer blows exterminated the dinosaurs, they could kill us. Billions of us massacred, all at once, rivets attention more than the slow, steady deaths from well known dangers, like heart disease and auto accidents.

How can we compare rare catastrophe with everyday danger? One way is to note that, averaged over long times and all humanity, you're as likely to die by asteroid impact as in an airplane crash.

Of course, we must be careful handling averages. I'm reminded of the doctor who told his patient that he had both good and bad news. The patient asked for the bad news first.

> "You have a disease which kills nine out of ten people who get it," the doctor said.
> "My God! What's the good news?"
> "Well, my last nine patients with this disease all died."

So we should ask ourselves, Does this rough equality with the airline death rate mean anything? Some are outraged at such statistics, as if to quantify human matters robs them of meaning. Alas, situations far beyond our experience, such as risks with low probability but immense consequences, require numbers outside our intuitive grasp. To get an idea of what risks are worth worrying about, consider our present policies. How much money does this society actually spend to prevent a hundred deaths?

That depends on both geography and culture. In health programs funded in the Third World, saving a single life costs about $200 (usually due to malnutrition). Cancer screening in advanced nations takes $75,000 to find an early cancer and stop its growth, extending a life for at least five more years. Think about the implications of these last two numbers: society's concern rises as dangers approach our personal phobias.

Thus, highway safety agencies in the USA spend about $120,000 to save a life, via better highway dividers, easier on-ramps, and the like. Air pollution control costs roughly a million dollars to avoid one case of deadly lung disease. Eliminating natural radioactivity in drinking water would cost $5 million per life saved—which is why we don't do it. For nuclear plant safety, we spend $2.5 billion per life. (Hard to believe, yes. The Soviets spent far, far less and they got Chernobyl—which has killed about 100 people directly so far, harmed thousands, and promises to kill many thousands over the next few decades, by delayed cancers. In the USA there hasn't yet been a single bystander death from nuclear power, luckily. The estimated death rate from breathing the fumes of oil and coal-fired power plants, though, is about 10,000 nationally. That's a major cost in the air pollution expense above.)

Suppose we accept the value placed on life in the industrial nations. Taking the cancer screening level of spending, times a hundred deaths per year, we get $7.5 million/year—just about enough to find all asteroids near us within a decade and assess our danger.

Like any rational calculus, outcome strongly depends on assumptions. Ours is a rather rarefied argument, spreading the kill rate from one big hit over 50 million years—mathematically interesting, perhaps, but is it convincing? Does it hit people in the guts, where they live?

Here those two elements, dreadful and strange, may well settle the issue. People care about so immense a disaster, the end of civilization. As calamities go, this one plays in Peoria.

In contrast, policy mavens such as William Pfaff have already derided Congressional funding to search for asteroid threats. They clearly see a one-in-a-million chance as beyond the pale. Pfaff gloomily noted (1994) that since "at some point the world will come to an end," why prevent "the eventually inevitable"? Far better to spend the money on, say, Bosnia.

I must admit I have a visceral objection to this line of argument. (Does Pfaff take antibiotics if he gets an infection? He's interfering with God's will!) In gut terms, I suspect he is wrong; the sheer drama of such calamity will drive public policy to take the threat seriously.

Suppose we find that we are in some danger? Then an investment of about $50 million a year (with some bigger start-up costs, mostly in recasting existing weaponry) would provide a stand-by capability of knocking out the intruder, even if the warning only gives us a matter of weeks to act. It would be much less expensive if we have several years' warning.

By historical accident, we have already spent a trillion dollars developing the instruments which can kill an asteroid—the hydrogen bomb and the liquid chemical rocket. Actually, their simultaneous appearance is no accident—the rocket was pushed strongly after the massive war which introduced nuclear explosives. They were made for each other, and their fateful wedding sealed the strategic standoff which has made our time tense but strangely peaceful, compared to the half-century before it.

Rendezvous an automatic rocket with the offending rock, place a warhead (or several) next to it—and set it off with a remote command. Reduced to chunks a few meters across, the killer becomes a mere spectacular amusement. When it hits our upper atmosphere, the cloud of debris will make a brilliant meteor shower, streamers burning in blues and yellows, flashing orange and gold for many minutes.

We have to be careful about slinging nuclear devices around, of course. Carl Sagan has forcefully objected to any standing ability to put nuclear warheads into space, arguing that they could be co-opted for Earthly wars. True enough—but the force needed would be small, certainly not enough to destroy a country.

More generally, we should recognize that dealing in astronomical matters necessarily demands harnessing energies of immense scale. Lifting off, Apollo 11 burned as much oxygen as half a billion people. Stopping big threats demands big guns to knock them down. If humanity learns that we have a foreseeable danger of extinction of our species, who would oppose developing the means to stop it?

We might have little warning of a suspect intruder. That would mean trying to hit the incoming rock in the last few hours of its approach—the worst case scenario.

A dud device could mean we fail to destroy the target. Even if we did, there could be a high cost for an explosion which did not touch our fragile atmosphere at all. We have many billion of dollars of orbiting servants—mostly, communications satellites—which a nuclear blast would kill. Not through the shock wave, but through an effect we discovered in the late 1960s. The Argus experiments of that era set off hydrogen warheads in space over the south Pacific. Within minutes, swarms of electrons lit up the auroral regions at both poles. Satellites went off the air, permanently silenced.

The reason was simple—in hindsight. A nuclear device makes a plasma cloud of ionized matter. Electrons, liberated from their peaceful atoms, streak away. They infest the metallic satellites, swamping their electronics gear. They race along the earth's magnetic field, concentrating at the poles and lighting up the high atmosphere with their energies. A nuclear explosion these days would destroy a fortune in satellites, and worse, shut down the vast net of communications we have built up.

So we cannot hit an incoming rock anywhere in the vast zone dominated by the earth's magnetic field. This region, called the magnetosphere, extends about 10 times the earth's radius into space, roughly a tenth of the way to the moon. We would have to block the intruder somewhere beyond that—the further, the better—so that the nuclear debris will be blown outward by the solar wind, away from Earth and ultimately into the realm beyond the solar system. In turn, that requires a good idea of where the candidate intruders are, how they move, their size. A solar system inventory.

Saving the world for a few billion dollars—rather a bargain, I think. NASA's present annual budget is over 14 billion. A hundred million for finding the candidate rocks isn't beyond our means. True, the odds of a thousand-megaton impact occurring right away are small—one hits about every 10,000 years. There has been none in recorded history, which coincidentally is a span of about ten thousand years. Of course, an impact in, say, the Pacific ocean might not have excited enough interest in ancient Babylon to have merited being inscribed in mud tablets—or the tablets might be lost by now. Such events are random, of course, so the odds of their happening in a given year don't get higher if you go a long spell without one—as we have. In fact, some astronomers believe that a large comet broke up in the inner solar system about 20,000 years ago. It left swarms of debris which we see in annual, regular meteor showers. But probably there are much larger chunks, still unseen, swooping by us in the dark.

Some argue that we should be making a solar system inventory anyway, taking the long view of what we may need in the next century. Uplifting the bulk of humanity from poverty, where a paltry $200 can save a starving child, will demand resources far beyond those we know. Within a century, I believe the inner solar system will begin to yield up such resources. It will have to. I cannot see how we can sustain a technological society in this thin, rather delicate biosphere, if we keep mining and smelting and burning as we have. In the long run, only a practice of doing the dirty jobs of resource extraction outside the biosphere will make sense. Metals, the crucial ingredient in modern technologies, are getting harder and harder to scrape out of the crust of our Earth.

Far better, then, to mine a tumbling mountain beyond the sky for iron, manganese or platinum, than to blow it to smithereens.

Jupiter's agony has illuminated our own predicament and opportunity. For many, NASA is a synonym for boring. A search for civilization-killing monsters a mile across is both dramatic and, in the astronomical scale of budgets, inexpensive. The public will support it, intuitively sensing its importance.

Our House of Representatives has already voted to require NASA to track asteroids whose orbits might intersect Earth's. More legislation seems on the way. Seizing this opportunity with some fanfare would be smart public relations and smart science.

Also, for once we humans would be defending the entire ecosphere, not just ourselves. Not only humans would die in a large impact.

Like it or not, we are the sole stewards of our world, in all its rich abundance. The dinosaurs were once, too—but look what happened to them.

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Gregory Benford is Professor of Physics at the University of California, Irvine. He conducts research in plasma turbulence theory and experiment, and in astrophysics, having published over a hundred scientific papers. He is a Woodrow Wilson Fellow and a visiting fellow at Cambridge University. Throughout the last decade he has worked as an advisor to the Department of Energy, NASA, and the White House Council on Space Policy. In 1989 he was host and scriptwriter for the television series *A Galactic Odyssey*, which describes modern physics and astronomy from the perspective of the evolution of the galaxy. His articles on science have appeared in *The Smithsonian Magazine*, *Natural History*, *New Scientist*, and *Omni*. He is also the author of over a dozen novels, among them *Timescape* (a Nebula award winner) and his most recent, *Beyond the Fall of Night*, written with Arthur C. Clarke. He has won the Nebula Award twice, the John W. Campbell award, and the Australian award for international novel. In 1989 he won the United Nations Medal in Literature. He is on the Editorial Board of the *Journal of Social and Evolutionary Systems*, where his essays frequently appear.