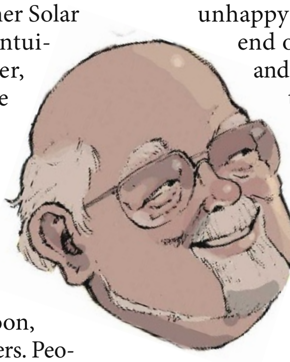
THE BURGER BAR THAT SAVED THE WORLD

Fewer people are searching for near-Earth asteroids, astronomer David Morrison said in the 1990s, than work a shift in a small McDonalds. But that group — a little larger now — has over the past two decades discovered a host of happily harmless rocks, and in doing so reduced the risk of an unknown asteroid blighting civilization (see page 1178). **David Chandler** puts together the story in the words of those who watched, and those who watched the watchers.

Clark Chapman: About 60 years ago, there were some prescient things written by Ernst Öpik, by Ralph Baldwin, and by Fletcher Watson. Only a handful of near-Earth asteroids had been discovered, but they came up with order-of-magnitude-correct understandings about how often a bad thing would happen.

David Morrison: That understanding arose almost without reference to Tunguska. Öpik and Gene Shoemaker did some kind-of-heroic calculations based on almost zero data. In the 1950s, we only knew of a few Earth-crossing asteroids and had data on a couple of comets that had come into the inner Solar System. And they, using physical intuition and consistent with each other, made the first predictions of what the impact flux might be. Before that, it was pure arm-waving. Öpik and Shoemaker quantified it, and within the right order of magnitude.

Carolyn Shoemaker: When the first Apollo mapping studies were done, trying to get better photos of the Moon, they became much more aware of craters. People like Gene were convinced that the majority were caused by impacts. They looked so much like those on the Earth. Not only Meteor Crater, but also nuclear-bomb craters. So he was convinced they were caused by impacts.



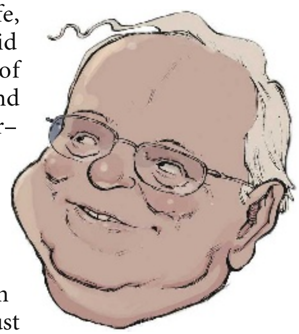
Rusty Schweickart: I tramped all around Meteor Crater with him, as did all of us who were part of the Apollo programme back then. Nobody knew whether features on the Moon were impact or volcanic. So we went all over the world to volcanic sites, to impact sites, with the top people in the world, including Gene. Frankly, very few people thought the main cause was volcanic. People did think there might be some volcanic features, which of course there are.

1978
Known near-Earth asteroids, end June
Large = 41
Total = 48

Chapman: Gene got very unhappy with NASA, there at the end of the Apollo programme, and kind of consciously wanted to get away from it all. He'd been interested in craters on the Earth, and clearly was aware that they were related to asteroids in the sky, and got interested in going off to sit in observatories on lonely mountain tops to discover them in the early 70s. He hooked up with Glo Helin to do a joint observing programme.

Steve Ostro: Observations of near-Earth objects were growing — the stuff by Helin and by Shoemaker — and we started getting some radar opportunities on newly discovered objects. In 1979, I met all the asteroid people and got very enthused, and then I was pretty sold on asteroids and wrote my own observing proposals. Within a year I was basically doing that more than anything else.

Brian Marsden: Helin and Shoemaker fell out and had their own separate programmes. It's always been a bit of a mystery — I've never fully understood it. Gene decided he could get Carolyn, his wife, involved. Carolyn did all the examining of the films, so she found all those Shoemaker–Levy comets. Gene was more the big picture: he did do a fair bit of the actual drudge work you might say, but Carolyn did a lot more of it, just as Helin and her people had done.



Shoemaker: I think there were only nine near-Earth asteroids known when Gene started the programme with Helin. They found a few, not

Who's who and what's what

Clark Chapman, of the Southwest Research Institute in Boulder, Colorado, has studied asteroids and comets throughout his career. In the early 1980s he became interested in the risks posed by **near-Earth asteroids**, which are those that come within 45 million kilometres or so of the Earth's orbit. *Cosmic Catastrophes*, by Chapman and **David Morrison**, an astronomer at NASA's Ames Research Center in Moffett Field, California, drew attention to the risk in the late 1980s. ● **Tunguska** was the Earth's most destructive twentieth-century impact (see page 1157). ● The late **Gene Shoemaker** of the US Geological Survey in Flagstaff, Arizona, went from studying craters to discovering asteroids with his wife **Carolyn**. At **Meteor Crater** in Arizona (see page 1172) he trained astronauts such as **Rusty Schweickart**, who flew on Apollo 9. ● **Eleanor 'Glo' Helin** discovered or co-discovered 872 asteroids. Before she retired, she worked at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, as does **Steven Ostro**. ● **Brian Marsden** ran the

ASTEROID NUMBERS FROM A. CHAMBERLIN, JPL

ILLUSTRATIONS BY D. PARKINS

many, and Gene's feeling was that we have to find them a lot faster — develop another programme to find more and faster. We went to using film that had a very fast emulsion, and we'd take two films, 45 minutes apart, so anything near would seem to move.

Then Tom Gehrels started Spacewatch in the 1980s, which Jim Scotti continued.

Chapman: Now Tom, he was sort of 'Mr Asteroid' in the 1960s. He'd been studying asteroids just for the sake of their scientific interest — measuring their light curves and other physical properties.

Tom Gehrels: We had a **CCD** on a telescope, the dedicated telescope that was the Spacewatch telescope, by 1983. Soviet submarines had already used CCDs in the 1970s, and our colleagues there were quite free to talk about it, which was quite remarkable, so I learned a lot about CCDs. The first asteroids were discovered by Spacewatch in 1984, and the first near-Earth asteroids were found with that system in about 1986. This was done against everybody's opposition, including Shoemaker's — he fought like a tomcat.

Shoemaker: There was some communication [with Spacewatch], and I guess competition in a sense. They were able to see much fainter magnitudes than we could. That's been their big contribution.

Killing the dinosaurs

Gehrels: Öpik and Harold Urey had warned very clearly of the impact hazard, but I had totally ignored that, and it was the **Alvarez paper** that really woke that up.

Morrison: Until the Alvarez paper on the **K/T boundary** there was no reason to think that any impact, short of some humongous thing, would have any global consequences. The truly remarkable thing was that such a small impact — that has no effect on the Earth's rotation, its axis, its magnetic field, completely negligible physically — could nevertheless wipe out most of the life on the Earth. To say that the biosphere was so fragile was a real revolution. In terms of the hazard, it was key.

1988
$N_{Large} = 81$
$N_{All} = 108$

Chapman: So **Bill Brunk** and Shoemaker put together this group of I'm going to guess 40 people that included a few people from the military, asteroid scientists like myself, people who knew about orbits such as George Wetherill of the Carnegie Institution in Washington, and some NASA mission-planning-type people. It was just a wide-ranging discussion — it included the nature of the threat, the possible damage to the environment.

Morrison: It took a while for other people to accept the idea of an impact. Especially palaeontologists, who thought this ridiculous egotistical physicist was trying to tell them what killed the dinosaurs.

The astronomers embraced the Alvarez result very quickly, and geologists such as Shoemaker started drawing conclusions from it, but the palaeontologists resisted it equally dramatically, for quite a while.

Chapman: People were aware of **Project Icarus**, and there was even discussion of the politics of it. Wetherill in particular was very concerned that the project would open up the door to the use of nuclear weapons in space. All those kinds of issues were discussed during this 3- or 4-day meeting at Snowmass in Colorado. And a report was written, a very lengthy report, but it was never published.

Morrison: That group actually made the recommendation that NASA should consider how to discover and how to defend against incoming objects. It was quite early. Now, that doesn't mean it was accepted. But the guy who really was in the intellectual leadership on this was Shoemaker.

Gehrels: I was pretty good friends with Shoemaker. He didn't believe in it. He would say 'Tom, this is not for real'. He organized the meeting, and for a day and night we were not supposed to go out and see the snow or anything like that, we just worked, worked, worked, so we could put a book together. And by the time it was put together, Shoemaker was totally convinced that it was not for real. And so we never got the book off his desk until somebody in Flagstaff actually pinched it, and then copies started floating around, but the book was never published

Congress and comets

Morrison: None of the Spaceguard stuff would have happened at NASA if Congress hadn't called for it. Congress asked NASA to organize two workshops, one on detection and one on defence against asteroids. I chaired what became known as the Spaceguard workshop on detection.

Chapman: I was asked to run the first major scientific conference on near-Earth asteroids in '91. It was a pretty large meeting, 80 people or so, and it also received some national press: it was covered by *Time* magazine, I was interviewed by National Public Radio. Morrison's Spaceguard committee held one of its meetings in conjunction with the scientific conference. And then the next year was the meeting at **Los Alamos** on deflection, also run by NASA but with **Edward Teller** and **Lowell Wood** and others playing a prominent part.

Morrison: At Los Alamos, the astronomers, led by Shoemaker, went face to face with the weapons people led by Teller and Wood, and that was a real wake-up call for us, that this whole other world existed, which didn't speak our language, which didn't operate the way we operated.

International Astronomical Union's Minor Planet Center in Cambridge, Massachusetts, a central clearing-house for information about new asteroid and comet discoveries, until his retirement in 2006. ● In 1980, **Tom Gehrels** and Robert McMillan of the University of Arizona in Tucson started the Spacewatch asteroid-search programme, which pioneered the use of **CCDs** (charge-coupled devices) as an alternative to photographic films. ● The **Alvarez paper**, published in 1980, was a study by geologist Walter Alvarez, his Nobel-prize winning father Luis, and their colleagues. The paper established that there was a layer of iridium present all around the world at the boundary between the Cretaceous and Tertiary periods (the **K/T boundary**) 65 million years ago. This was taken as evidence of a large asteroid or comet impact that spread dust around the Earth, cutting off sunlight, cooling the climate and triggering a mass extinction event that claimed the dinosaurs, and many other types of life, among its victims. ● **Bill Brunk** was head of NASA's Planetary Astronomy programme in the early 1980s. ● **Project Icarus** was a study done by students at the Massachusetts Institute of Technology (MIT) in the 1960s that looked at the possibility of deflecting an asteroid likely to hit the Earth. ● **Los**

Shoemaker: Teller, being a man of the background he had, was interested in possibly sending something out to blow up a near-Earth object. So that became an argument.

Morrison: The cultures of the two groups could not have been more different. Just seeing the confrontation between Teller and Shoemaker was absolutely one of the memorable things in my life. Because Teller was idealized and feared by all these people. All the weapons people seemed to be beholden to him, probably for their jobs, they almost worshipped him, they fawned over him, it was always "Dr Teller". If he so much as cleared his throat everybody in the room stopped to let him have his say. In contrast, here was good old Shoemaker — nobody would ever call him Dr Shoemaker — and we'd go out drinking with him and we had a much more egalitarian sense of things. And we did open peer-reviewed publications and the weapons guys didn't. It was really a clash of two cultures.

The weapons people seemed to think the problem was an order of magnitude greater than the astronomers did. They were for rockets on the pad with nuclear bombs, practically what you would use for a ballistic missile, and shoot the thing down right before it came into the atmosphere. It took a long time for them to even grasp the concept that if you carried out a survey you could make the discovery long in advance, and that completely changes the calculation.

At one point Teller actually stood up and said that the asteroid threat, which was real, was the appropriate justification for building much bigger nuclear bombs — a hundred or a thousand times bigger than we had.

Gehrels: Shoemaker changed with Shoemaker–Levy 9. After the impact with Jupiter, he was totally converted and he really threw his weight behind that.

Shoemaker: Gene came home from a conference that was right after it had happened, I think it was in Seattle, and he said "at last, my geologist friends believe that impacts occur". Before, people would say yeah, maybe that's so, but they just didn't really have a deep conviction that impacts occurred. After Shoemaker–Levy 9, when one could see what was happening on Jupiter, yes, we knew for sure. And geologists generally, I think, came to accept impacts. Not everyone yet, but most of them. It's really kind of amazing — it's something that was easier for astronomers to accept I think than for geologists.

1998
$N_{\text{Large}} = 211$
$N_{\text{All}} = 528$

Surveys and scares

Marsden: The discovery rate has steadily gone up as the CCD surveys came along: Spacewatch in the '80s; Helin's NEAT at end of '95; then LINEAR. In '98 they really boosted up, and they were the leader.

Shoemaker: The biggest and most successful sky survey is LINEAR, which started out using one of the telescopes that belongs to the Air Force, and that developed as a combination of MIT and Air Force technology. So they were way ahead to begin with on software sorts of things — they have kind of just thrust us all off our feet. They're the sort of thing that Gene knew we had to have if we were really going to find these bodies in anything like reasonable time. We just weren't doing that with our survey, with film and the old telescope.

Marsden: When we had the 1997 XF11 situation, people had been searching for some time and finding things, but nobody had really been doing anything from the point of view of whether these objects can be a danger. For XF11 there was a possibility of its coming very close in 2028, it could have come as close as 32,000 kilometres. Because we'd had it under observation for only 3 months, it would have been impossible to say that it might not hit us a few years after that approach. There were several opportunities on subsequent approaches, particularly in 2040.

Chapman: It's important that astronomers don't appear to be Chicken Little, and lose credibility. Public assertions by supposedly credible astronomers that there was a "small" chance that the Earth would be hit in the year 2028 by the 1.6-kilometre-wide asteroid, 1997 XF11, were corrected a day later.

Andrea Milani: I went to my office and opened my e-mail, and my folder was full of mail about 1997 XF11. I was immediately quite upset. None of the scientists involved in discussing the issue actually knew how the computation of whether an asteroid could strike the Earth could be done.

There was a real lack of knowledge. It would have been better if they just said "we don't know", rather than saying something wrong. The actual conclusion in doing the post-mortem is that the two groups of scientists who were fighting about it were both wrong. Neither had the correct algorithm.

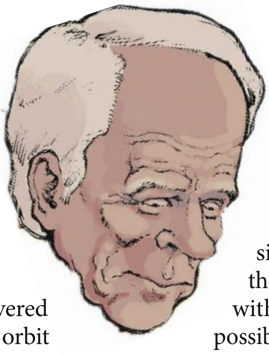
Marsden: I did in a way stir things up a little bit at that time. At the time, it was possible it really could have hit us in 2040, based on the information we had. As we got further information, that possibility went away. And that really did get people thinking.

Milani: We needed a fully nonlinear theory of impact prediction. We found a method capable of doing this and in April '99 we were ready with a paper announcing a possibility of impact for the asteroid 1999 AN10 with a probability of 10^{-9}. Our result, from our point of view, was very good precisely because we had detected a very minute possibility. From the point of view of the journals, the result was not important because the probability was minute. But of course what

Alamos National Laboratory in New Mexico is one of the three US national laboratories concerned with nuclear-weapons design. **Edward Teller**, who was partly responsible for the design of the hydrogen bomb, and his protégé **Lowell Wood**, a nuclear-weapons designer, came from one of the other weapons labs, Lawrence Livermore National Laboratory in California, where both of them worked at the time on 'Star Wars' missile defence systems. ● **Shoemaker–Levy 9** was a comet discovered by Carolyn Shoemaker, her colleague David Levy and her husband. Pulled apart into a 'string of pearls' by a close approach to Jupiter, the comet crashed into the planet in 1994. ● After working with Gene Shoemaker, Helin went on to found the Near-Earth Asteroid Tracking (**NEAT**) survey which, like Spacewatch, used CCDs and computerized its search procedures. The Lincoln Near-Earth Asteroid Research (**LINEAR**) programme, run by NASA, the US Air Force and MIT's Lincoln Laboratory, uses similar but more advanced technology on a telescope in White Sands, New Mexico, developed for tracking satellites. It was the most powerful asteroid survey system until the advent of the Catalina Sky Survey, headed by Steve Larson of the University of Arizona, which uses two telescopes in Arizona and one in Australia. ● **Andrea Milani**

mattered was the method; the specific announcement was irrelevant.

I think it was the most important paper I ever wrote, but for a long time I was unable to publish it. Someone found this paper on our website, and I was more or less simultaneously accused of hiding this, and of spreading alarm.



Chapman: In 2004, an object was discovered by LINEAR and the nominal calculated orbit had the asteroid hitting the Earth the next day. A whole lot of people went into a real frenzy trying to get more observations of this object, because — well, if it's going to hit the Earth tomorrow, it's not a very big object, but it was about half the size of what caused Tunguska.

Europeans tried to look for it, but the weather was bad there, it was cloudy over most of the United States, and so people could not follow up on it immediately, despite considerable attempts to do so. The people at JPL, who are as expert as any, actually concluded that there was something of the order of a 30% chance that this object would hit the Earth during the next three days. Now, it turns out that the thing was much farther away and much bigger and came nowhere near the Earth. But based on the observations that were available up to that time it was a very significant probability. So we were debating late into that night, at what point should we go public with this?

That was the first incident that really raised the questions of who makes the decisions and how does the information get communicated, because before that event we've always thought of these near-Earth asteroid issues as being long-term ones, where something may be discovered now but it's going to hit in 30 years time. The idea that you'd really need to talk to people within hours just really hadn't occurred to us. Because of this event, we now realize that although the chances of something hitting tomorrow are very, very low, the way the observations are collected can certainly make it seem possible that something's going to hit tomorrow.

2008
$N_{\mathrm{Large}} = 743$
$N_{\mathrm{All}} = 5{,}448$

Schweickart: The B612 Foundation has formed a committee, working with the United Nations, to work on things such as warnings and all-clears. We're working on a decision programme, similar to the mission rules we came up with for space flight — every possible eventuality is taken into account, so when something happens, you don't start arguing about it, you just do it. We will make recommendations to the UN in September, and it will begin debating it next year. We have to set in place a process. If somebody is going to deflect something, how do you determine who does it?

Ostro: Sooner or later we will want to, or we will have to, send spacecraft to near-Earth asteroids, and come very close to them, possibly land on them. But it's very difficult to navigate around these objects, because of the unusual shapes, the spin states, and the low masses. The dynamics around a near-Earth asteroid are very different from around a big massive sphere such as the Earth — the orbits are gorgeous, geometrically intricate and complex, and every asteroid has a different dynamic environment.

Schweickart: We've hired the JPL to do a full-blown analysis of the gravity tractor which will point the way to a demonstration mission, to learn what the control parameters are.

Ostro: People have workshops on what do we do, should we deflect or blow it up, but they almost never use a realistic model of a near-Earth asteroid, they always assume a sphere or that we will know what the physical properties are before we have to do something. It's almost impossible to figure out what to do unless you know something about the object. That's where radar comes in. Right now, we've gotten radar echos from 340 asteroids.

Looking ahead

Marsden: A UK government task force produced a pretty nice report suggesting we should extend the searches down to objects 300–400 metres across. Then NASA did further studies and said we've got to go down to 140 metres and find them in 20 years, 90% of them. That's tens of thousands of objects! Over 100,000, I think. That's a big survey.

Chapman: At some level, it's going to happen anyway. At least the Pan-STARRS telescope is going to become operational any month now — it saw first light some time last year. The people running it have already spent energy on what to do if they find near-Earth asteroids on their CCDs.

People are working on the LSST, which is a project that sounds like it's ultimately going to happen. If NASA does not pay for it, it will happen more slowly, but it's going to happen.

Shoemaker: I liked looking at the sky. I liked doing all those other things that some people thought were awfully time-consuming and might be tedious, but which to me were fun. I retain my interest in all the results, but I don't do the work anymore. For me, the romance of observing is gone.

One of the real pleasures of our programme was the fact that if we found something exciting, and needed confirmation or more positions, we could ask people here and there throughout the world, and they would do follow-up work for us. And by the same token we would do the same thing for them. It was both competitive and cooperative. It doesn't always happen in science, but it worked pretty well for us in those days, and that was a real joy. ■

David Chandler is a freelance science writer in Massachusetts.

See Editorial, page 1143, and Commentary, page 1178.

is an expert in orbital mechanics from the University of Pisa, Italy. ● **The B612 Foundation**, named after the asteroid in Saint Exupéry's *Le Petit Prince*, is a think-tank and lobby group set up by Schweickart to further the Earth's protection against asteroid strikes. Its short-term aim is to demonstrate a technological capacity for changing the orbit of a near-Earth asteroid. One technology under discussion is that of a **gravity tractor**, a spacecraft that uses its gravitational attraction to change a small asteroid's trajectory. Surprisingly, such a spacecraft does not need to be very massive, provided that the asteroid and deflection needed are small. ● **Pan-STARRS** is the Panoramic Survey Telescope & Rapid Response System, a telescope array paid for by the Air Force. The first of its four mirrors is in the process of being commissioned. The **LSST**, or Large Synoptic Survey Telescope, is a next-generation instrument that will observe all manner of transient phenomena, including passing asteroids, when it goes into commission in the mid 2010s. **D.C.**