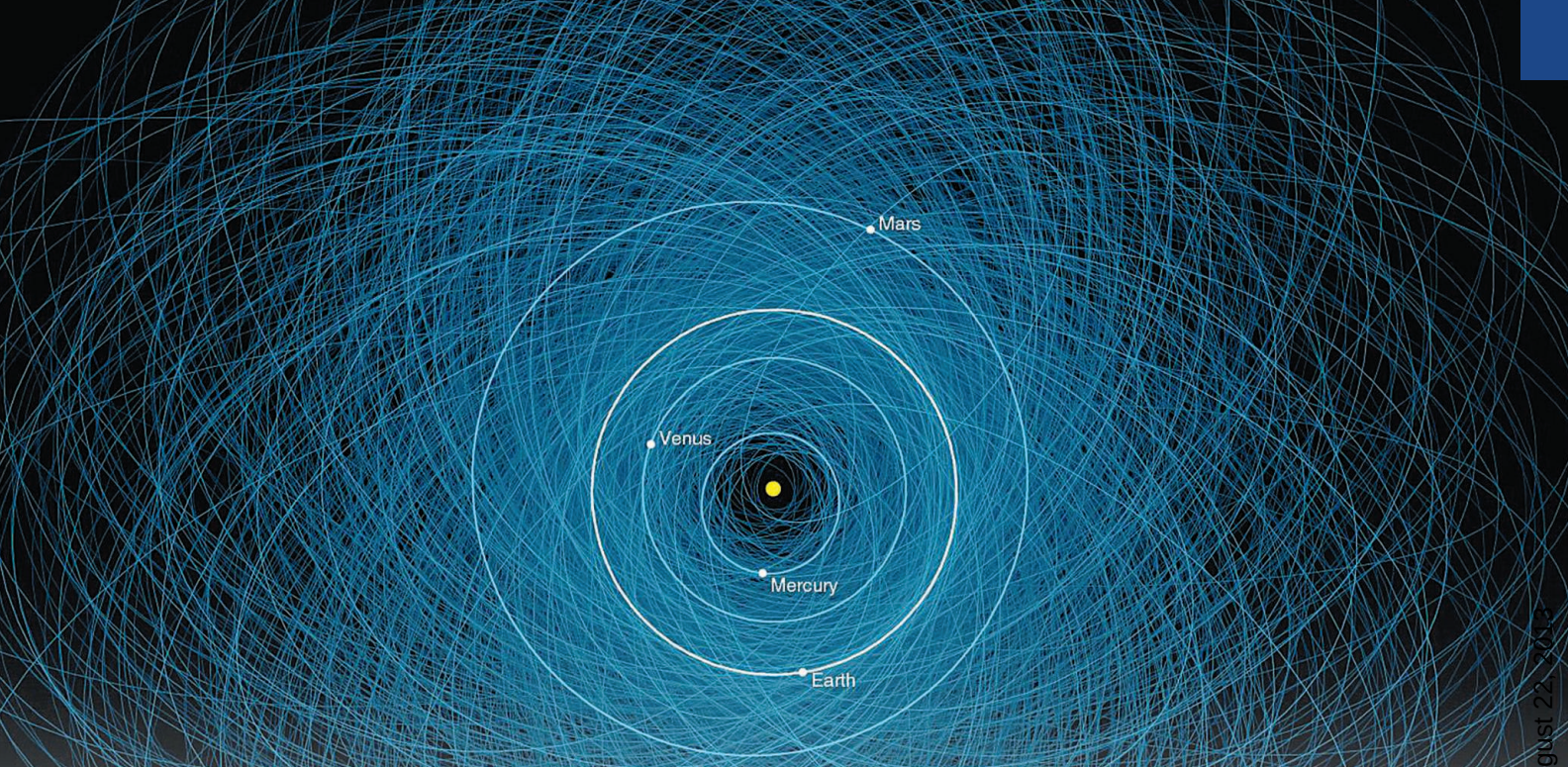

CREDIT: NASA/JPL-CALTECH

Dodge the bullets. NASA has identified just 1% of the 1 million sizable asteroids thought to swirl close to Earth's realm. This plot shows the orbits of the known Near-Earth Objects more than 140 meters across—those most dangerous should they collide with our planet.

PLANETARY SCIENCE

The Save-the-World Foundation

Convinced that NASA will not finish the job, a private foundation intends to raise $450 million for a space mission to find asteroids that may threaten Earth

MENLO PARK, CALIFORNIA—In Antoine de Saint-Exupéry's beloved novella, *The Little Prince*, a pilot stranded in the Sahara Desert encounters a being from an asteroid called B-612. "There are also hundreds of others," Saint-Exupéry wrote, "some of which are so small that one has a hard time seeing them through the telescope."

That figure was far too conservative. There may be a million asteroids with masses far greater than ocean liners in Earth-approaching orbits, nearly all of which telescopes have yet to see. Far from being benign abodes like the Little Prince's domain, some of those Near-Earth Objects (NEOs) are potential killers.

Those at least 40 meters across could wipe out a metropolis; a kilometer-wide asteroid could devastate part of a continent and shroud the planet in soot. NASA-sponsored searches, mostly from the ground, have found most of the kilometer-size, civilization-threatening asteroids, but only a fraction—perhaps 1%—of the smaller, but still menacing, objects. Two former astronauts with a soft spot for Saint-Exupéry and a drive to safeguard fellow citizens have set out to find the rest.

Planetary scientists agree that a full inventory of NEOs will require a dedicated space observatory—at least a half-billion-dollar proposition. That's a stretch for NASA, in a thin budgetary era when new planetary missions without "Mars" in the title are rare. Even the agency's current assignment, a 2005 mandate from Congress to identify 90% of NEOs at least 140 meters wide, is behind schedule. More than halfway toward the target date of 2020, NASA has found just 10% of them.

"I believe the agency has ducked its responsibility a little bit," says Lindley Johnson, NASA's program executive for NEO Observations. "I never dreamed it would take as long as it has to develop a robust capacity." Although it now seems feasible to deflect an incoming asteroid, scientists would need many years of advance warning to do so—an unlikely cushion at current rates of discovery.

Into this breach have stepped the astronauts and their B612 Foundation. The foundation has set its sights on launching a $450 million mission by July 2018. The infrared telescope, called Sentinel, would spy a half-million NEOs from a vantage point near Venus. B612 has a star-studded team of planetary science veterans and a fixed-price contract with Ball Aerospace & Technologies to build and operate the satellite.

In the new economy of commercial ventures into Earth's orbit, the B612 Foundation is aiming for much farther—into deep space—propelled by nothing but philanthropic dollars. Although the team's mission design has sparked some dissent and the fundraising goal is steep, all agree that Sentinel's dynamic cartography of the swarm of objects in Earth's milieu would transform planetary science. Says physicist Mark Boslough, an impact specialist at Sandia National Laboratories in Albuquerque, New Mexico: "If we're going to take the impact threat seriously, we have to do something like this."

Online

sciencemag.org

Podcast interview with Robert Irion (http://scim.ag/pod_6148).

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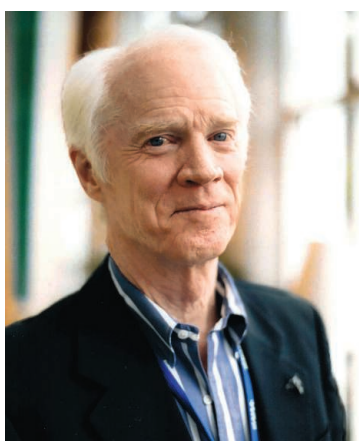
The Mercury 7 mystique

The public faces of B612 are astronauts from two generations: CEO Edward ("Ed") Lu, 50, and Russell ("Rusty") Schweickart, 77, chair emeritus of the board of directors. Their passions and cultural cachet have lifted B612's profile. "The Mercury 7 mystique of 'the best of the best' still exists," says Sentinel program architect Scott Hubbard of Stanford University in Palo Alto, California, and former Mars program director for NASA. "They have a special place in society."



Protectors. Former NASA astronauts Ed Lu (*top*) and Rusty Schweickart spearhead the B612 Foundation.

Lu, an astrophysicist and solar scientist, flew on two space shuttle missions before spending 6 months on the International Space Station in 2003, in the wake of the Columbia shuttle disaster. He and Russian cosmonaut Yuri Malenchenko maintained the station and ran experiments, but Lu also had time for photography, playing a compact electric piano (his renditions of Beethoven's *Moonlight Sonata* and *Linus and Lucy* by Vince Guaraldi are both on YouTube), and Earth-gazing. "You see shooting stars below you," he says. "You know where the impact craters are. It's a constant reminder." After leaving NASA in 2007, Lu worked as program manager for advanced projects at Google—but protecting Earth had become an irresistible pull.

That transition took longer for Schweickart, a U.S. Air Force fighter pilot chosen for NASA's third class of astronauts in 1963. He flew on Apollo 9 in March 1969, the first test of the lunar module in orbit—a critical step in the sequence leading to the moon landing. During a spacewalk, Schweickart had the rare luxury of simply watching Earth pass under him for 5 minutes as one of his crewmates fixed a jammed camera. Not until 1974, during a remarkable unscripted speech to the Lindisfarne Association—a group dedicated to issues of spirituality and consciousness—did he express how that serendipity had changed him. "You know very well at that moment … that you're the sensing element for man," he said. "You're a piece of this total life. You have to bring that back somehow. And that becomes a special responsibility."

Schweickart took a step toward fulfilling those words in 1995 by founding the Association of Space Explorers, a cadre of former astronauts devoted to public education and planetary stewardship. Then in 1998, he saw Stanford University geophysicist Norman Sleep speak about Earth's impact history. "The incredible energies blew my mind," he says.

Lu and Schweickart soon began discussing how to prevent such blasts from happening again. They founded the B612 Foundation in 2002 with astrophysicist Piet Hut of the Institute for Advanced Study in Princeton and planetary scientist Clark Chapman of the Southwest Research Institute in Boulder. For a decade, they and colleagues examined ways to nudge an NEO off a collision course given at least 10 years of warning. Lu and fellow astronaut Stanley Love devised the "gravity tractor," a spacecraft hovering near an NEO to alter its orbit a touch. Another leading concept, ramming a projectile into an asteroid, would also do the trick if done far enough in advance, studies showed.

"We were four guys and a website and tens of dollars," says Lu, who talks about planetary cataclysms with next-door-neighbor informality. "We came to the conclusion that deflection was doable. Finding the other 99% [of NEOs] is the entire problem."

All along, the team pushed NASA to ramp up the search for hazardous asteroids—often in harsh terms from the characteristically blunt Schweickart. But when Lu spoke at Google and lamented that the government seemed incapable of putting money down, an engineer approached him and said, "Why don't you just do it?" Lu called Schweickart, and B612's new purpose was clear to both of them.

"We put together a list of the 10 best people in the world, and we hired them all," Lu says. "That took about 2 weeks." In addition to Hubbard, they recruited veteran mission director Harold Reitsema, retired from Ball Aerospace; program manager John Troeltzsch, also of Ball Aerospace, who also manages the Kepler planet-hunting telescope; and mission scientist Marc Buie of the Southwest Research Institute, an asteroid authority. B612 also convened a review team that Troeltzsch calls "a *Who's Who* of every deep-space mission flown in the last 45 years."

To Venus, and beyond

Troeltzsch describes Sentinel as a "pinnacle mission" for its heritage of proven systems from other space probes—notably Kepler, the infrared Spitzer Space Telescope, and the comet-colliding Deep Impact. Ball Aerospace played a central role in each one.

The contract between Ball and B612 lays out a cost of about $250 million for Sentinel; launch, operations, and staffing will take about $200 million more. In his talks, Lu specifies a launch date of 20 July 2018, the anniversary of Neil Armstrong's famous step. Plans call for a 6.5-year mission, the time needed to find 90% of the NEOs larger than 140 meters in diameter and perhaps half of the ones down to 40 meters across. Extending the mission to 10 years would sweep up many others.

Sentinel's half-meter-wide telescope will spot NEOs with new infrared detectors sensitive to 10 microns—a long wavelength at which asteroids warmed by the sun pop out against the cold backdrop of space. But the most notable aspect of Sentinel's design is its planned orbit in a path similar to that of Venus. This perch, Buie says, will allow Sentinel a view of fully illuminated asteroids as it looks out toward Earth's orbit, away from the sun. Ball engineers first made a pitch for a Venus-like orbit in 2002, Buie recalls: "I said, 'You guys have got the answer.' I could see it in an instant."

But the choice forces compromises. For instance, Sentinel's remote position means that it will not detect as many smaller NEOs in the 40-meter range as it might from a closer vantage, says Tim Spahr, director of the Minor Planet Center at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. That's the suspected size of the object that blew up in 1908 over Tunguska, Siberia, flattening 2000 square kilometers of forest. B612's website leads off with the bold slogan "Sentinel: Prevent the Next Tunguska." But as Spahr points out, "If you want that as your goal, you must stay near the Earth."

In another tradeoff, Sentinel's distance from Earth—between roughly 40 million kilometers to 250 million kilometers—limits the amount of data it can beam back. B612

CREDITS (TOP TO BOTTOM): NASA; COURTESY OF THE B612 FOUNDATION

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signed an agreement with NASA to use its Deep Space Network of radio antennae to download data, but to limit the burden an onboard computer will allow Sentinel to transmit only image frames in which an object appears to have moved within 1 hour. "The vast majority of the sky will not have changed," Reitsema says. That step, he projects, will trim data rates by a factor of 1000.

Spahr frets about that purge, as does astronomer Amy Mainzer of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, who has proposed that NASA fund an alternative NEO-hunting satellite, called NEOCam, to be stationed closer to Earth. "Most of what you'll find that's new is at the faintest limit of detection," she says. "You have to have all of the data [to find them]. If you don't, you might as well cut the telescope aperture in half." As a case in point, Mainzer notes that a deeper analysis of the full data set from a recent extension of NASA's Wide-field Infrared Survey Explorer (WISE) mission, called NEOWISE, should yield NEOs beyond the 134 new ones her team announced in 2011.

Reitsema says that the B612 team parsed its orbital options thoroughly and knows Sentinel won't catch everything. But he says the goal driving the design—notwithstanding the Tunguska banner on the website—is finding 90% of the 140-meter-size asteroids and above, as Congress dictated. For that, Reitsema states, "We're quite confident Venus is the preferred orbit."

If the satellite spies an NEO that could make a very close pass by Earth, large radar antennae on the ground will bounce signals off the asteroid to zero in on its trajectory. A precise orbit usually rules out an impact, but Lu pegs the odds that Sentinel will find an NEO requiring deflection sometime in the next century at 3-in-10. If one looms, nations will confront the tangled geopolitics of deflection. Altering an orbit, Schweickart points out, may shift the likeliest impact spot from one country to another until the projected path misses Earth. Years of debate about asteroids in U.N. committees, he says, haven't led to a set of "mission rules" about what to do. "In some ways this will be the first global decision on survival," he says. "Will we recognize our commonality well enough to overcome our differences?"

Space surprise. A 17-meter-wide asteroid that no one saw coming exploded in February near Chelyabinsk, Russia, but even space surveys will strain to find objects that small.

Sentinel (artist's concept)

CREDITS (TOP TO BOTTOM): © JIANG KEHONG/XINHUA PRESS/CORBIS; B612 FOUNDATION/BALL AEROSPACE

Museum wings and observatories

The overall reaction to B612's plans has been positive. "I think they're doing everything right," says Donald Yeomans, manager of NASA's NEO program office at JPL. But he worries that the philanthropic goals are too ambitious.

The foundation's immediate goal is $20 million in donations by the new year, followed by at least $40 million each year for a decade. To oversee the effort, Lu hired Karen Putnam, a veteran of East Coast museum fundraising and former CEO of the Central Park Conservancy in New York. Lu compares Sentinel's costs to the wing of a major art museum—a "midsize project," he says, "with the added benefit that you can help save the world." Putnam declined to state the amount raised to date, noting only that "we have the $20 million in various stages in the pipeline."

A recent study by economist Alexander MacDonald, program executive for NASA's emerging space office, suggests that B612's financial goals are no more ambitious than those of classic astronomy ventures. MacDonald examined the costs of major observatories built before World War II, almost entirely with private money. When he scaled those expenses to 2008 dollars as comparable fractions of the U.S. gross domestic product, he found that Mount Wilson Observatory in California and Yerkes Observatory in Wisconsin would have cost $408 million and $441 million, respectively. Others were even more lavish.

If B612 falls short, might NASA carry the project? "We'd be happy to talk about a deeper public-private partnership, sure," Lu says. "Our goal isn't us building the telescope; our goal is completing the telescope." Johnson at NASA headquarters says the climate in Washington, D.C., for asteroid detection is "the best that it has been." At a House of Representatives science committee hearing in March, 1 month after the surprising airburst of a 17-meter-wide asteroid near Chelyabinsk, Russia, receptive legislators heard the B612 Foundation called out seven times by NASA Administrator Charles Bolden and Office of Science and Technology Policy Director John Holdren. Lu has testified twice on Capitol Hill as well.

Some in the field regret that it took Chelyabinsk to trigger this rush of concern. "It's unlikely any space survey would find such [small] objects, and they should not be sold that way," says planetary scientist Edward Beshore of the University of Arizona in Tucson, former director of the Catalina Sky Survey—the world leader in numbers of NEOs found to date.

Distinctions among asteroid sizes may elude the public, but B612 team members report they've never encountered such rapt reactions in classrooms, public forums, and elevators when they describe their goals. And if Sentinel flies, the new NEO catalog will yield rich insights into our solar system's flotsam and jetsam—and how best to stay out of its way. "I've always thought that asteroids were solvable," Spahr says.

That's just how two problem-solving astronauts see it. **–ROBERT IRION**

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