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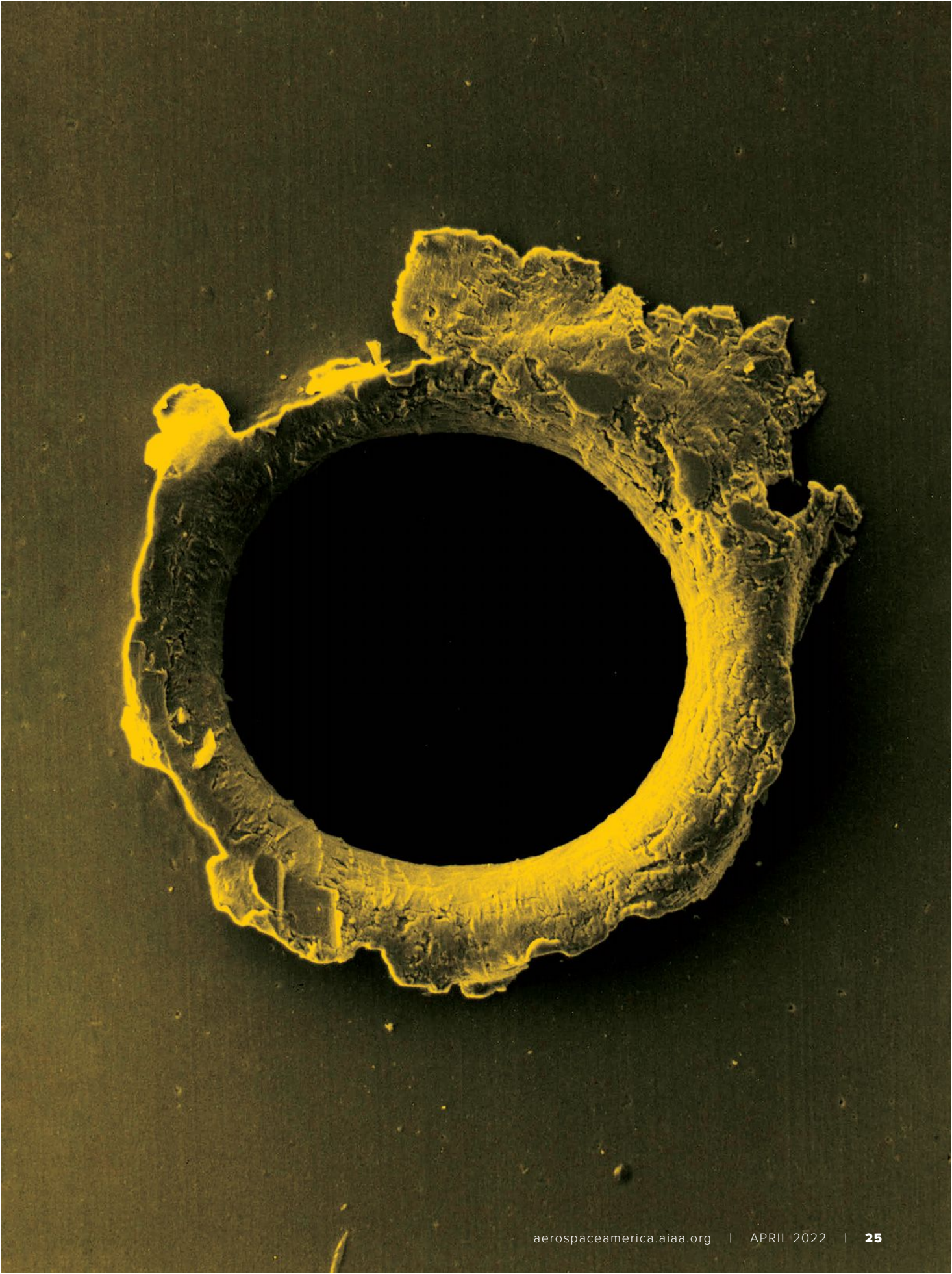
HOPE FOR SOLVING SPACE DEBRIS

After decades of spaceflight, Earth orbit resembles the Wild West mixed with a demolition derby. Traditions rather than laws govern behaviors, and every now and then a frightening crash litters the track. Our modern lives, the safety of astronauts, space adventurers and the security of the free world depend heavily on this poorly managed domain. Can a brighter future be forged? Jonathan O'Callaghan found reasons for hope.

BY JONATHAN O'CALLAGHAN | jonathan.d.ocallaghan@gmail.com



SPACE DEBRIS
SPECIAL REPORT

Celine D'Orgeville has a space laser. More specifically, her team at the Australian National University has built a laser that could nudge pieces of space junk off collision courses. As far as she can tell, the laser is the only one like it on the planet.

The project has stalled, however. D'Orgeville and her team ran out of funding before they could test the laser at Mount Stromlo Observatory in the hills of Canberra in Australia. As such, the world's only known space junk laser is currently disassembled and sitting in storage. "I wish we could demonstrate this technology," says D'Orgeville. "That's the frustration that comes with research."

Nevertheless, the laser exemplifies the industry's growing determination to solve the space junk problem, the rich tableau of ideas about how to do it and the fact that it won't be easy.

Today, some 5,000 active satellites orbit our planet, along with 2,500 dead satellites and tens of thousands of articles of debris bigger than a baseball. If one counts objects down to the size of a popcorn kernel, the total grows to millions, thousands from widely derided anti-satellite tests conducted in recent years by China and Russia. Any one of these pieces of debris could, depending on the impact location, destroy a satellite or poke a hole in a crew capsule or habitat and cause a potentially deadly depressurization.

"It's only a matter of time before human lives are lost because of a piece of garbage," says Moriba Jah, a space environmentalist at the University of Texas at Austin and an Aerospace America columnist.

If nothing is done, the amount of junk is certain to grow as satellite numbers continue to rapidly increase. In the past two years alone they have nearly doubled, and by 2030, an estimated 150,000 active satellites could be in space, due in part to the mega-constellations being launched by companies including SpaceX in the United States and OneWeb in the United Kingdom.

▲ Debris pierced a small hole in one of the segments of the robotic Canadarm2 on the International Space Station in 2021. NASA flight controllers and ground specialists in Houston discovered the damage in May while inspecting the arm with cameras mounted to the exterior of ISS.

NASA/Canadian Space Agency

In the worst-case scenario, one collision could trigger a series of cascading collisions among pieces of junk and operational satellites that would spread orbital pollution widely and dangerously. This worry was modeled in 1978 by meteoroid scientist Donald Kessler of NASA's Johnson Space Center in Houston, who retired in 1996. The Kessler Syndrome, as the scenario was eventually dubbed, could make it impossible to launch satellites or humans to certain orbits because the risks of collisions would be too high.

Some argue the syndrome has already begun.

"It's just happening on time scales of decades and centuries, like climate change," says Brian Weeden, director of program planning for the Secure World Foundation of Washington, D.C.

Can the trend be stopped or even reversed?

"We're starting to see a deeper understanding of what's required," says Hugh Lewis, a space debris expert at the University of Southampton.

For Jah, his epiphany came in 2006 when he moved to the Hawaiian island of Maui and saw the effect of tourism and the garbage it produced on the otherwise idyllic locale. Observing space with a telescope from the island's highest mountain, he saw the same thing taking place in space.

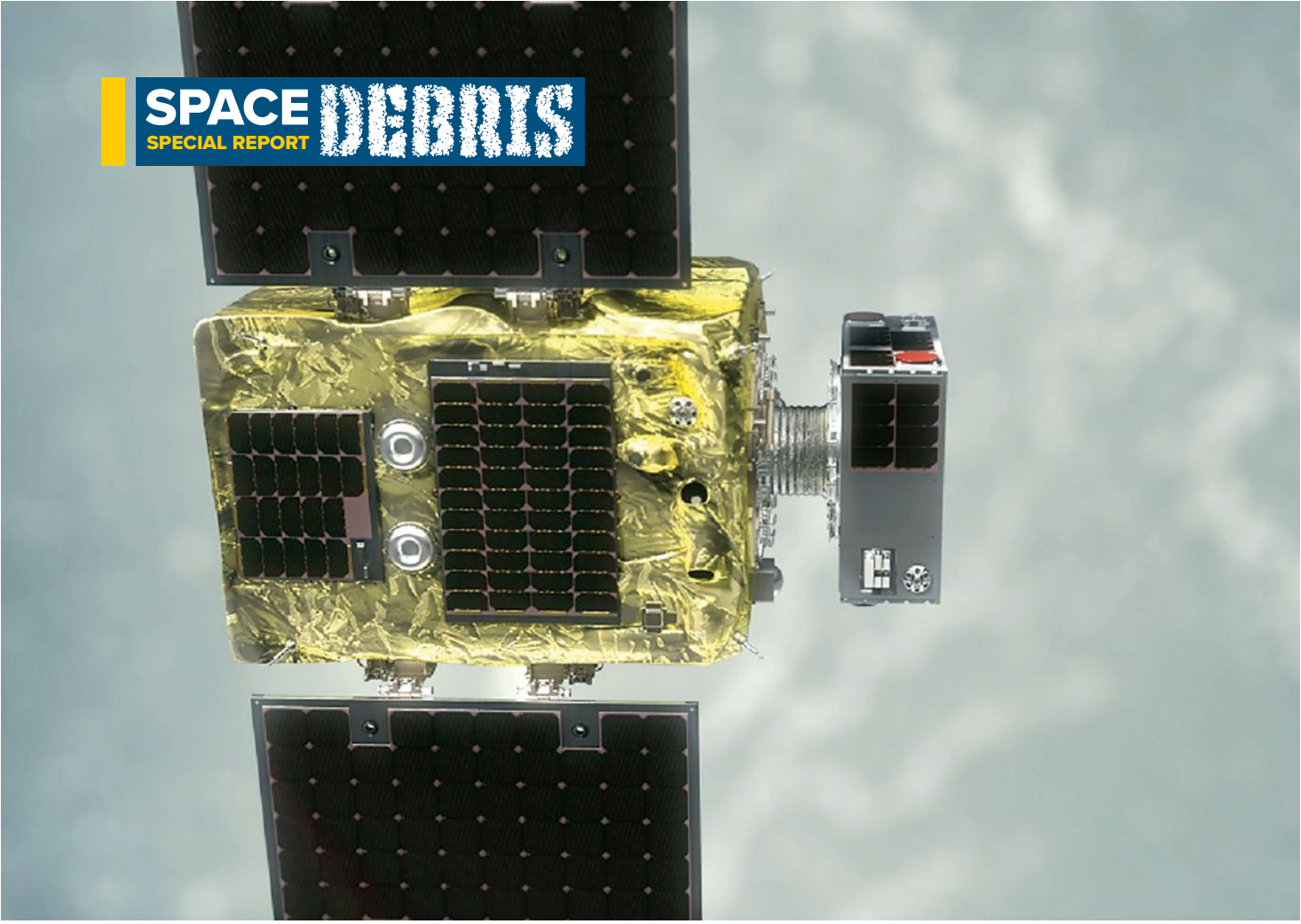
"Most of the objects up there were garbage," he says. "It really upset me."

Jah and others set about raising the profile of the issue. Today, experts in the field see three interrelated goals that together offer the best chance of solving the space junk problem:

- Objects must be prevented from colliding.
- The most dangerous debris, such as dead satellites and derelict rocket stages, must be removed.
- Rules must be established to prevent the creation of new debris, perhaps including a bar on anti-satellite weapon tests.

Preventing collisions

Preventing collisions requires careful tracking and, if necessary, a maneuver to avoid an impact. Traditionally, satellite operators in the United States



have relied on data and alerts from the U.S. Air Force and later Space Force to know when it's time to maneuver out of the way of debris or other satellites. The projections have been less than perfect though. In 2009, the risk of collision was not properly realized in advance of one of the most infamous space junk incidents. The active Iridium 33 communications satellite and the defunct Russian communications satellite, Cosmos 2251, collided over Siberia, shattering them into nearly 2,000 new pieces of debris, much of which still orbits Earth today.

To prevent this from happening again, more rapid and accurate tracking of satellites and debris in orbit is needed. One company leading this field is LeoLabs of California, which currently operates four radar sites in Alaska, Costa Rica, New Zealand and Texas, and plans to open more in the coming years.

"With the four radar sites, we cover all orbits," says Daniel Ceperley, the company's CEO and co-founder. "Now we're in the process of building up more sites so we get more timely information," he says, referring to the company's plan to ultimately operate at least 20 radar stations.

Whereas legacy databases such as the Space Force's update positional information on satellites every eight hours, LeoLabs can do so within minutes.

"Eight hours is not sufficient warning time" if a close pass of two objects, called a conjunction, might be in the cards, says Darren McKnight, the company's senior technical fellow. "Any object that crosses one of our radars, within seven minutes we reissue conjunction data messages to all of our customers."

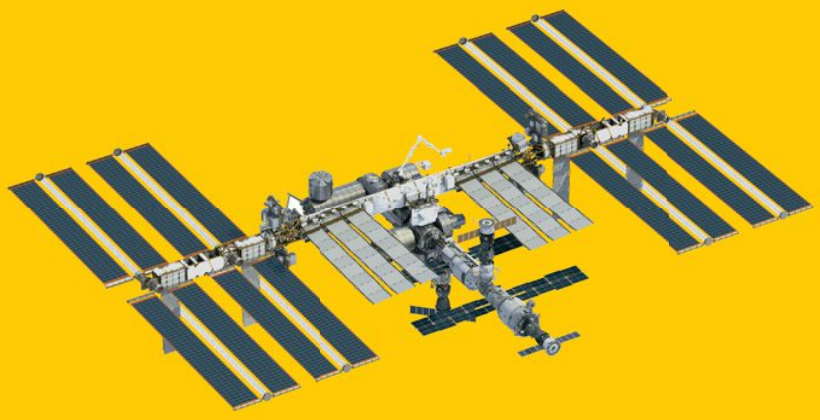
About 60% of satellite operators in low-Earth orbit — including OneWeb — currently pay for access to LeoLabs' alert system. In a typical year the company says it will identify about 800,000 possible conjunction events, and that number is only set to grow as more satellites are launched.

Other companies are looking at different approaches to the problem of space traffic management. Privateer of Hawaii emerged from stealth mode in March to say it will launch sensor technology to space that can track debris as small as a few centimeters, a similar size to LeoLabs. Apple co-founder Steve Wozniak and robotics entrepreneur Alex Fielding founded the company with Jah.

"Our life on Earth is connected to space, and even the smallest debris orbiting the Earth can damage and destroy these critical capabilities," Wozniak said in an emailed statement through a spokesperson. "My

▲ In this rendering, Astroscale' s servicer satellite (left) is magnetically joined to the client satellite by a metal plate (center). The servicer and client have made several autonomous close-range captures and releases over the past year in preparation for more difficult captures at longer distances.

Astroscale



SPACE STATION CLOSE CALL

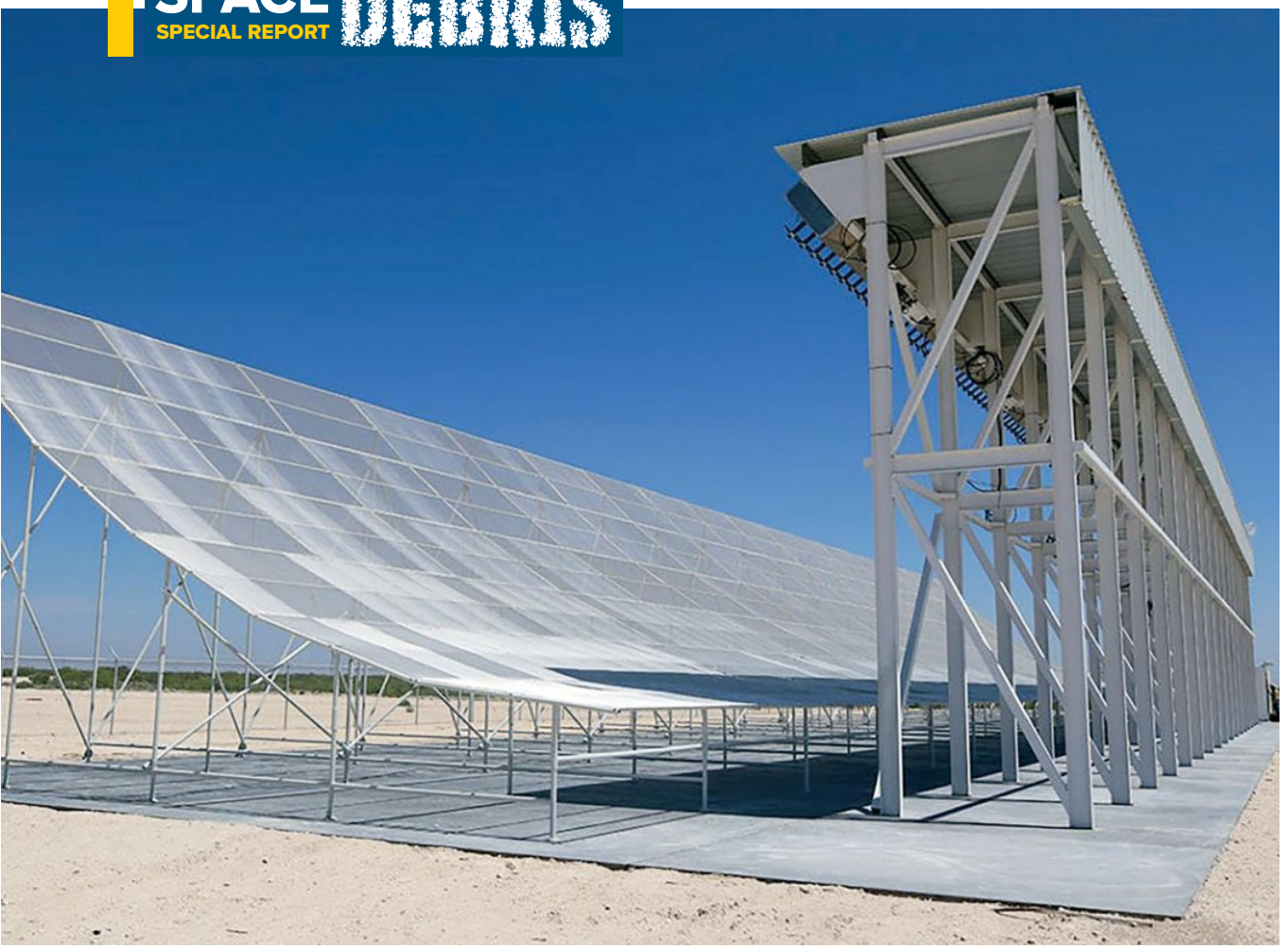
While International Space Station managers had of course thought about how to react to the possibility of a debris strike, a close call in 2009 drove home the human stakes and led to the refined procedures that were last put into action in November 2021 when debris from Russia's anti-satellite test sent astronauts and cosmonauts to shelter in their docked spacecraft. Here's an account of the 2009 close call from former NASA astronaut Sandy Magnus, in her own words.

It was mid-March, and I was nearing the end of my months of research aboard the International Space Station. A call from mission control in Houston came in over the loudspeaker on one of the communication panels, "Hey, between 11:35 and 11:45 p.m. local time we need you to go sit in the docked Soyuz capsule because we're having a red conjunction." We didn't know it at the time, but the "red" meant that there was no time to maneuver ISS out of the way of an object that was on course to enter the keep-out zone, the imaginary 25-kilometer protective box NASA maintains around ISS.

Back at NASA's Johnson Space Center in Houston a few months later, I learned that the orbital path of an old payload assist motor had been incorrectly calculated, and it was much closer to ISS than indicated by data from the catalog maintained by the U.S. Air Force.

This was the first red conjunction, so we had no set procedure. As we were nearing the time to shelter in Soyuz in case evacuation became necessary, there was still some discussion between the ground control center in Moscow and the one in Houston: Do we shut the hatches on each module to prevent a depressurization of one module from reaching the others? Do we not shut all the hatches? There's no good answer to these questions because we didn't know how big the debris was or where it might strike the station and the subsequent effect. The debate went on for a long time about the appropriate response; we ended up shutting all the hatches in the U.S. side and leaving all the hatches open on the Russian side.

Luckily, the debris did not hit the station, and we returned to the ISS from the Soyuz shortly after, but when we returned to Earth in late March our big debrief point was: "You people need to come up with a good procedure for the crew because the confusion and lack of clarity for the crew response is not acceptable." NASA's ISS operations team worked with the other ISS partners and came up with the procedure that we saw in action most recently in November after Russia's ASAT test. — *Sandy Magnus*



▲ LeoLabs currently operates four radars, including this one in Midland, Texas. The company plans to eventually operate 20 to track pieces of debris as small as 2 centimeters.

LeoLabs

focus at Privateer is on being an advocate for tackling this huge issue before it becomes too late."

At the moment, anyone can go to the Privateer website and play with an open access version of its Wayfinder software, which pools together government and industry tracking data to provide live updates about satellite and debris positions. Soon, the company hopes to start flying its own lightweight sensors in space, possibly this year, both on its own "Pono" satellites — the Hawaiian word for "do the right thing" — and those of other companies.

The sensors "can monitor 150 kilometers in any direction" via a combination of wavelengths including visible light and radar, says Fielding.

The aim is to "provide a foundational level of knowledge for the industry" so that objects are represented as more than featureless "cannonballs," explains Jah. In particular, the company plans to provide high-quality views of some of the most dangerous regions of orbit, such as where orbits come together near the poles.

Operators must also talk to each other in the event of a collision risk to decide which satellite should move. Traditionally, this has been done by phone or email, a slow and lengthy process. Slingshot Aerospace of Texas hopes to take over this burden with its Slingshot Beacon software, which carries out the conversations between subscribed operators. More than 60% of satellites in orbit are already signed up to the service since its release in August, says Melanie Stricklan, the company's CEO and co-founder.

Meanwhile, the European Space Agency is funding Neuraspace in Portugal to develop software that would automate a satellite operator's maneuver decisions, using artificial intelligence to "decrease the number of false positives and negatives," says Chiara Manfletti, Neuraspace chief operating officer. This would significantly lessen the amount of human hours spent on space traffic management.

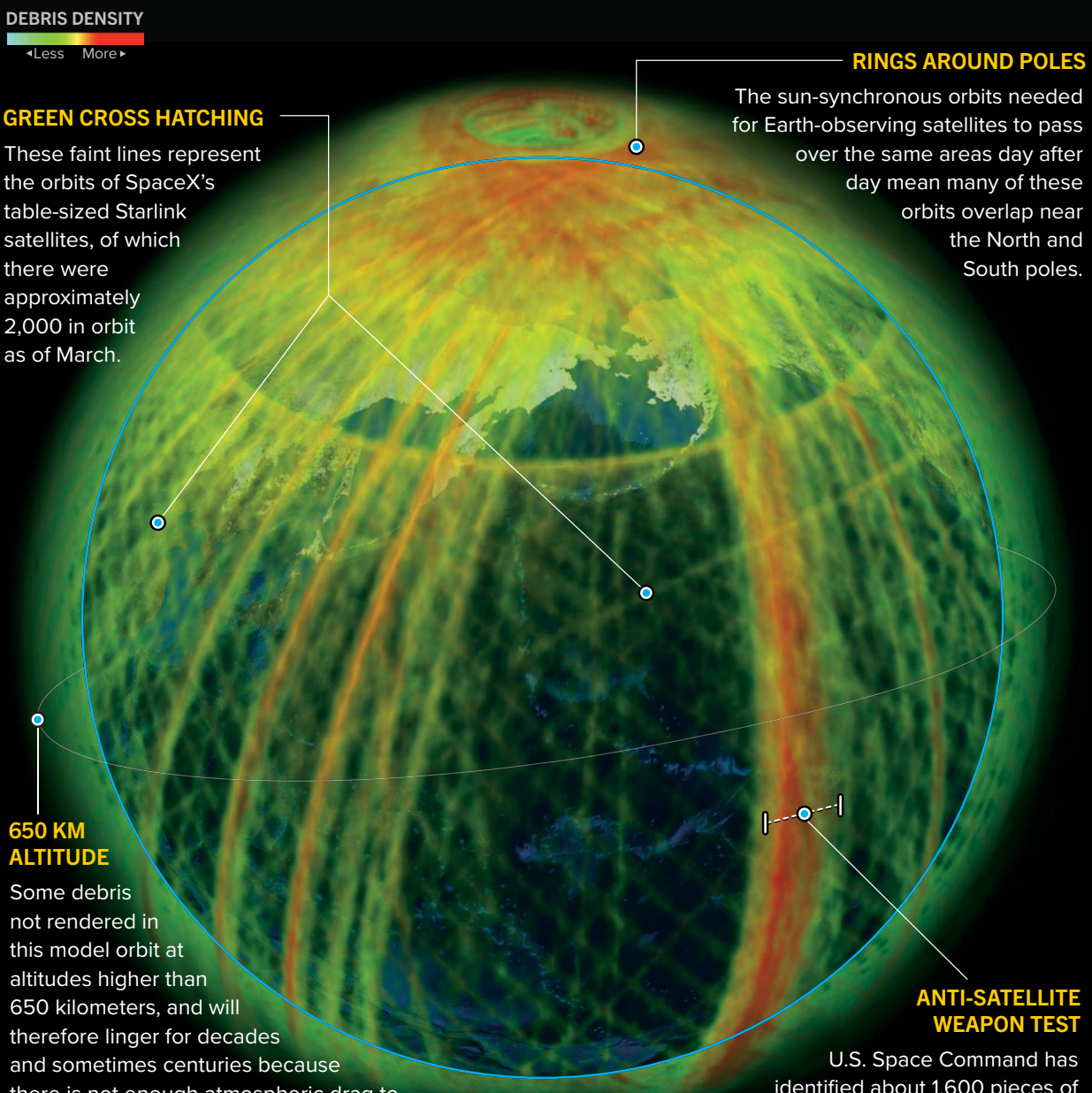
"The idea is to make space traffic a nonissue," says Manfletti.

Removing debris

Overall, it is the dead, uncontrollable objects that could present the biggest challenge and the highest stakes. A collision between them or with an

Crowded space

Planning the orbit for a satellite is getting more and more complicated. Models such as this one by the Commercial Space Operations Center (COMSPOC), a debris tracking company, help operators determine which orbits are the most heavily populated. The shading shows areas of high density.



Graphic by David Evans, reporting by Cat Hofacker
Earth model by AGI/Ansys and COMSPOC

Low-Earth orbit as of March 14

"IT'S ONLY A MATTER OF TIME BEFORE HUMAN LIVES ARE LOST BECAUSE OF A PIECE OF **GARBAGE**."

— Moriba Jah, UT Austin and Privateer Space

operational satellite would suddenly present space traffic managers with hundreds or thousands of new objects that would need to be detected so that their locations in time and space, called ephemeris, can be calculated and projected into the future to warn of possible conjunctions.

This is where D'Orgeville's laser comes in, an idea almost two decades in the making. Creon Levit, formerly of NASA's Ames Research Center in California and now at the satellite firm Planet, and his colleagues were among the first to raise the concept, and it was a product of happenstance.

The year was 2009, and the Iridium-Cosmos collision had just occurred, presenting space traffic experts with an enormous ephemeris math problem. Levit's team set out to learn whether supercomputing could be applied to improve collision warnings. They spotted something unusual in the findings: Solar activity, specifically the pressure of photons radiating from the sun during its more active periods, was shifting the paths of the satellites enough to "make the difference between a collision and no collision," says Levit. "We were like, 'Wait a minute, what if we could get a laser shining on the satellite equal to the solar radiation pressure?'"

The result was LightForce, a conceptual laser that would push objects in orbit to avoid collisions. In a paper, the authors calculated that a 10-kilowatt laser would be required, making it 10 million times more powerful than a standard laser pointer and dangerous enough to send a person to the hospital. Hitting objects with such a laser a day or two before the projected conjunction would change the courses enough to remove the potential for collision.

"It looked like it would be feasible," recalls Levit.

Proposals to build a prototype were rejected, however, and the research at NASA ceased in 2015. But in Australia, D'Orgeville and her team continued the work with Craig Smith, chief technology officer of the Australian firm EOS Space Systems, who was involved in LightForce with NASA researchers. Over the next few years, they built a working prototype in a clean room at Mount Stromlo Observatory, including a less powerful "guide laser" to point the more powerful laser toward a suitable piece of space debris, such as a solar panel drifting through space. By 2019, it was ready. Unfortunately, partly because of delays caused by the pandemic, her team ran out of funding in mid-2021 before the system could be tested.

Still, if it worked, it could be used not just to nudge debris off collision courses but remove it from space entirely. "If the technology works reliably, you could increase the laser power and start thinking about pushing [debris] back down into the atmosphere," D'Orgeville says.

Such ideas remain somewhat fanciful for the time being, but there are nearer-term solutions for removing dangerous debris from orbit. One company leading that charge is Astroscale, a Tokyo-based company that wants to capture satellites with magnets and pull them back into the atmosphere. The goal is to have spacecraft ready to launch that can remove dead

satellites, or even empty rocket stages, from orbit.

The company has been demonstrating aspects of the concept with a mission called ELSA-d, short for End-of-Life Service by Astroscale-demonstration, launched in March 2021. So far, the ELSA-d servicer spacecraft has made several close-range autonomous captures of a small companion satellite equipped with a metal plate that represents a future client for the service. In the coming months, ELSA-d will attempt an autonomous capture of the client from a greater distance, the ultimate goal being to capture the client while tumbling and adjust its orbital altitude.

"If that happens, it's basically demonstrating all the technologies we'll need to do an end-of-life service," says Mike Lindsay, Astroscale's chief technology officer.

OneWeb's satellites have such metal plates so that those that fail or wear out can be pulled back into the atmosphere by this technique once it's proven.

Beyond that, Astroscale has a contract with the Japan Aerospace Exploration Agency, JAXA, to perform the first large-scale debris removal in orbit. In 2025, Astroscale plans to launch a spacecraft that will sidle up to the upper section of a Japanese rocket orbiting about 600 kilometers above Earth and push it back into the atmosphere.

"We're designing a robotic arm interface to mate with it," says Lindsay. "This will be our first foray into active debris removal."

Such technology, if successful, could be invaluable. There are an astonishing number of empty rocket bodies orbiting Earth, more than 2,000 — mostly from China, Russia and the U.S. — some heavier than an elephant. If any two of these were to collide, they would produce thousands of new pieces of debris. Proposals like Astroscale's could eventually help clean up this mess.

"You would want to remove about five a year to start reducing the risk in a meaningful way," says Privateer's Jah. "You could put a bounty on [them], and governments could fuel business."

Other ideas include attaching small satellites to bring them back to life. "Put a small [satellite] on the side of it with thrusters and a receiver, and it can avoid collisions," says LeoLab's McKnight.

Taming the Wild West

The final piece of the space junk puzzle would be establishing adequate regulations. The United Nations in 2007 approved loose guidelines in hopes of controlling debris. One calls for satellites to burn up in the atmosphere no more than 25 years and to vent any remaining explosive fuel. Compliance is low, however. The 2021 Space Environment Report from the European Space Agency found that more than half of satellite operators were not following the guidelines.

Efforts are underway to put more rigorous requirements in place. Jared Zambrano-Stout, a space policy expert in Washington, D.C., was the chief of staff for the White House National Space Council in 2018 when former President Donald Trump signed Space Policy Directive-3. Among its edicts was the goal to "mitigate the effect of orbital debris on space activities."

That would include better tracking of debris but also stricter rules on satellite licensing to direct companies to better clean up their own mess in space.

"The next step is comprehensive legislation from Congress dealing with this issue," says Zambrano-Stout.

While progress has been slow, there are positive signs. During a handful of town-hall-style virtual meetings on space debris hosted by the Office of Science and Technology Policy in January to elicit comments, space executives were among those that urged the U.S. government to create stricter rules for operators and allocate funding for active debris removal demonstrations, among other actions.

"That's what's missing," Zambrano-Stout says. There are rumblings that such legislation could be on the horizon and perhaps set in stone some true rules for satellites and debris orbiting Earth in the U.S. "I think there probably is something coming," he says.

Creating global laws would be more difficult. Unless the United Nations elects to do so, it will be up to other countries to decide whether to follow in the footsteps of the U.S. And in any event, what should any potential rules stipulate?

"There's a lot of debate over that," says Weeden of the Secure World Foundation.

The 25-year deorbit guideline, for example, is "disputed by a lot of other technical experts," Weeden notes. Many experts want a shorter timeframe and also want to see a ban on anti-satellite tests, like the one Russia conducted in late 2021, to prevent large buildups of debris.

In lieu of legislation, some companies have taken it upon themselves to set their own guidelines, joining together in the Space Safety Coalition, with best practices that include removing some satellites as quickly as five years after the end of their mission — something other operators, including SpaceX with its Starlink megaconstellation, are already doing.

Weeden is among those who caution that sooner or later, however, solving the junk problem will require more stringent rules, or at the bare minimum better compliance with the existing guidelines.

Even then, regulation alone will not solve the space junk problem. Rather, it will be a multifaceted approach of tracking and removing debris, alongside holding space actors accountable when necessary. While there is a long way to go, many of the experts spoken to for this story expressed cautious optimism that all three can be achieved.

"I have every hope we can do it," says Lewis at the University of Southampton.★