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On a New Moon Far, Far Away

GLIMPSES OF AN EXOMOON ORBITING A PLANET 8,000 LIGHT-YEARS FROM EARTH

Also:

THE FIRST FEMALE PHYSICS LAUREATE IN 55 YEARS

FIXING OUR SPACE JUNK PROBLEM

A NEW WAY OF SEEING QUANTUM MECHANICS

WITH COVERAGE FROM
nature

An illustration of the space debris surrounding Earth, with each piece greatly enlarged for emphasis.

The Quest to Conquer Earth's Space Junk Problem

Zombie satellites, rocket shards and collision debris are creating major traffic risks in orbits around the planet. Researchers are working to reduce the threats posed by more than 20,000 objects in space

By Alexandra Witze

MACIEJ FROLOW GETTY IMAGES

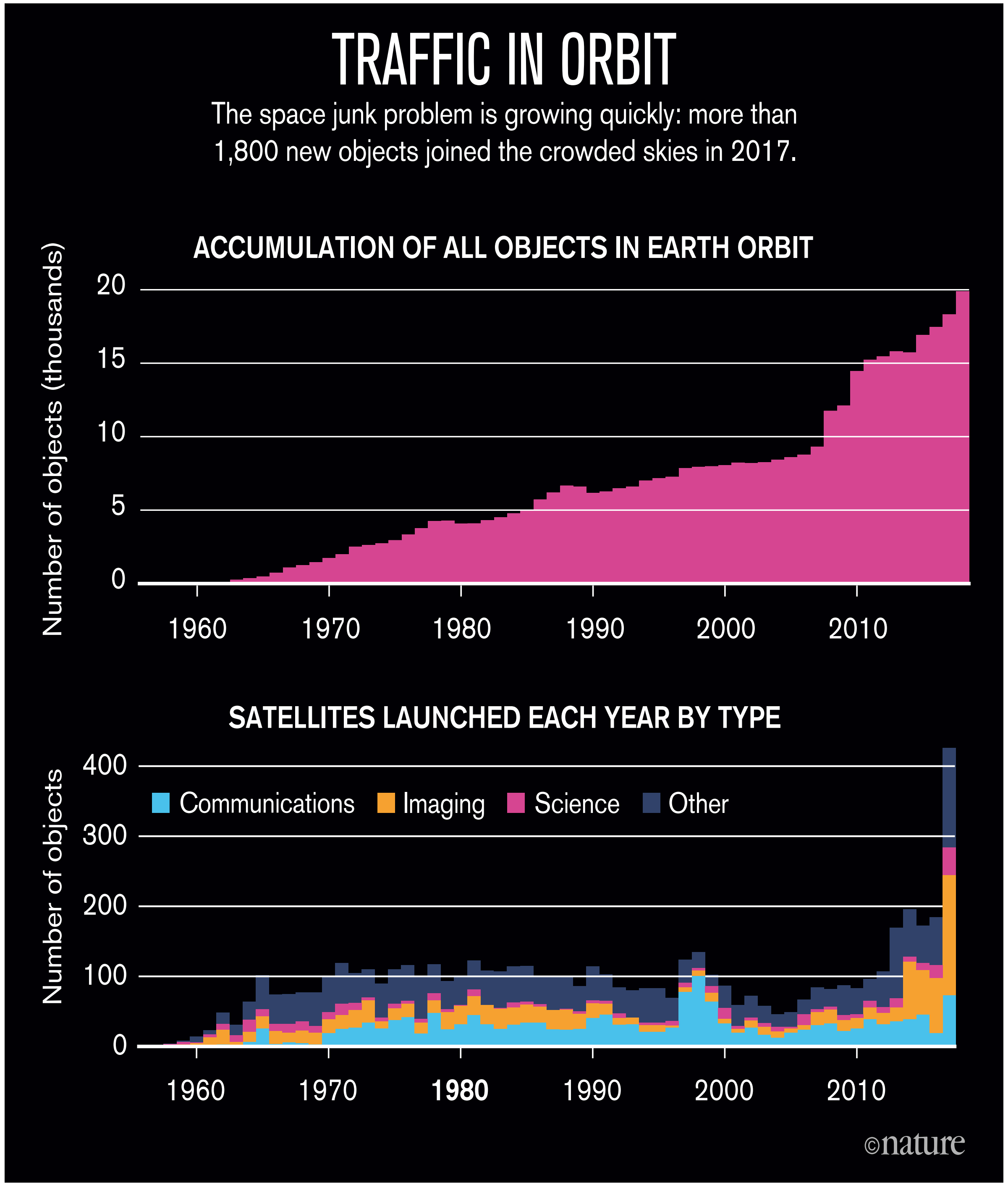
Alexandra Witze works for *Nature* magazine.

ON MONDAY JULY 2, THE CRYOSAT-2 spacecraft was orbiting as usual, just over 700 kilometers above Earth's surface. But that day, mission controllers at the European Space Agency (ESA) realized they had a problem: a piece of space debris was hurtling uncontrollably toward the €140-million (U.S. $162-million) satellite, which monitors ice on the planet.

As engineers tracked the paths of both objects, the chances of a collision slowly increased—forcing mission controllers to take action. On 9 July, ESA fired the thrusters on CryoSat-2 to boost it into a higher orbit. Just 50 minutes later, the debris rocketed past at 4.1 kilometers a second.

This kind of maneuver is becoming much more common each year, as space around Earth grows increasingly congested. In 2017, commercial companies, military and civil departments and amateurs lofted more than 400 satellites into orbit, over four times the yearly average for 2000–2010. Numbers could rise even more sharply if companies such as Boeing, OneWeb and SpaceX follow through on plans to deploy hundreds to thousands of communications satellites into space in the next few years. If all these proposed mega-constellations go up, they will roughly equal the number of satellites that humanity has launched in the history of spaceflight.

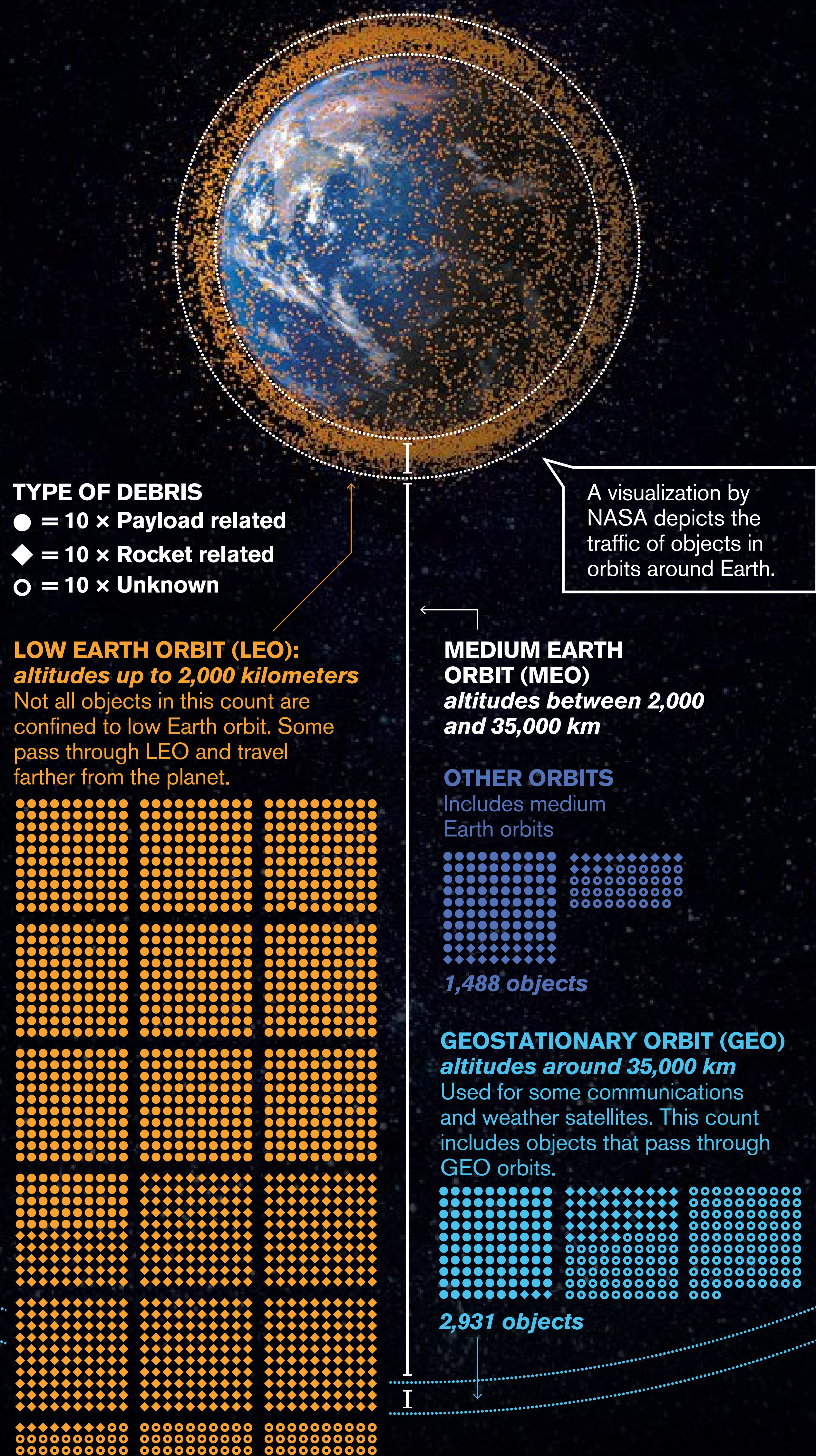
All that traffic can lead to disaster. In 2009, a U.S. commercial Iridium satellite smashed



NATURE, SEPTEMBER 5 2018, DOI: 10.1038/D41586-018-06170-1; SOURCE: ESA ANNUAL SPACE ENVIRONMENT REPORT

BUSY SKIES

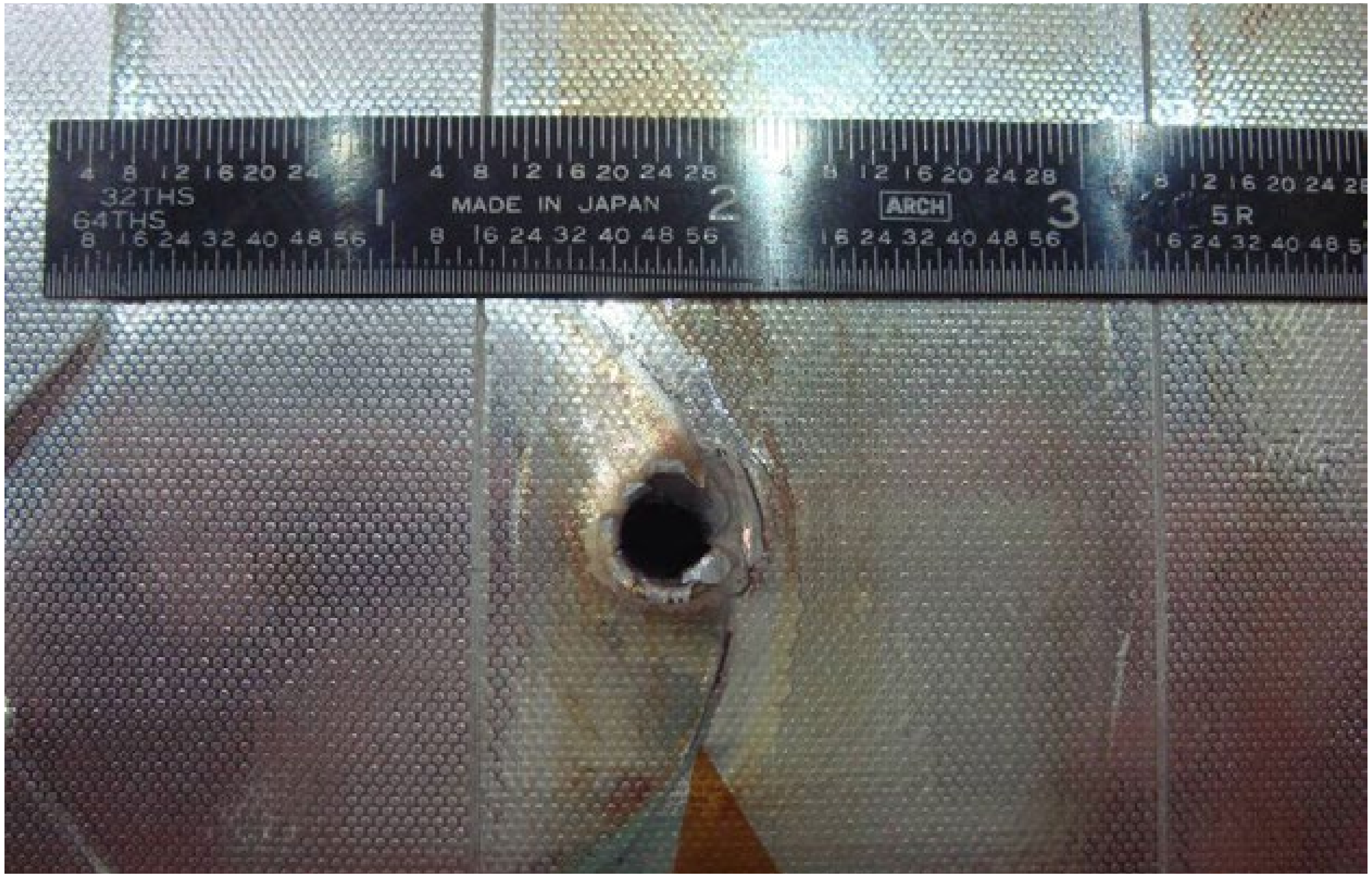
There are currently more than 20,000 objects in orbit around Earth, according to catalogues that track operational satellites, dead ones and other human-made debris, such as pieces from rockets.



NATURE, SEPTEMBER 5 2018, DOI: 10.1038/D41586-018-06170-1; SOURCE: ESA ANNUAL SPACE ENVIRONMENT REPORT. EARTH DEBRIS IMAGE: NASA GODDARD SPACE FLIGHT CENTER AND JSC

into an inactive Russian communications satellite called Cosmos-2251, creating thousands of new pieces of space shrapnel that now threaten other satellites in low Earth orbit—the zone stretching up to 2,000 kilometers in altitude. Altogether, there are roughly 20,000 human-made objects in orbit, from working satellites to small shards of solar panels and rocket pieces. And satellite operators can't steer away from all potential collisions, because each move consumes time and fuel that could otherwise be used for the spacecraft's main job.

Concern about space junk goes back to the beginning of the satellite era, but the number of objects in orbit is rising so rapidly that researchers are investigating new ways of attacking the problem. Several teams are trying to improve methods for assessing what is in orbit, so that satellite operators can work more efficiently in ever-more-crowded space. Some researchers are now starting to compile a massive data set that includes the best possible information on where everything is in orbit. Others are developing taxonomies of space junk—working out how to measure properties such as the shape and size of an object, so that satellite operators know how much to worry about what's coming their way. And several investigators are identifying special orbits that satellites could be moved into after they finish their missions so they burn up in the atmosphere quickly, helping to clean up space.



Damage to the Space Shuttle Endeavour from a collision with piece of space debris or a micrometeorite.

The alternative, many say, is unthinkable. Just a few uncontrolled space crashes could generate enough debris to set off a runaway cascade of fragments, rendering near-Earth space unusable. "If we go on like this, we will reach a point of no return," says Carolin Frueh, an astrodynamical researcher at Purdue University in West Lafayette, Ind.

DIRTYING ORBITS

Astronomers and others have worried about space junk since the 1960s, when they argued against a U.S. military project that would send millions of small copper needles into orbit. The needles were meant to enable radio communications if high-altitude nuclear testing were to wipe out the ionosphere, the atmospheric layer that reflects radio waves over long distances. The Air Force sent the needles into orbit in 1963, where they successfully formed a reflective belt. Most of the needles fell naturally out of orbit over the next three years, but concern over dirtying space nevertheless helped to end the project.

It was one of the first examples of the public viewing space as a landscape that should be kept clean, says Lisa Rand, a historian of science in Philadelphia and a fellow with the American Historical Association and NASA.

Since the Soviet Union launched the first satellite, Sputnik, in 1957, the number of objects in space has surged, reaching roughly 2,000 in 1970, about 7,500 in 2000 and about 20,000 known items today. The two biggest spikes in orbital debris came in 2007, when the Chinese government blew up one of its satellites in a missile test, and in the 2009 Iridium-Cosmos collision. Both events generated thousands of fresh fragments, and they account for about half of the 20-plus satellite maneuvers that ESA conducts each year, says Holger Krag, head of ESA's space-debris office in Darmstadt, Germany.

NASA

Each day, the U.S. military issues an average of 21 warnings of potential space collisions. Those numbers are likely to rise dramatically next year, when the Air Force switches on a powerful new radar facility on Kwajalein in the Pacific Ocean. That facility will allow the U.S. military to detect objects smaller than today's 10-centimeters limit for low Earth orbit, and this could increase the number of tracked objects by a factor of five.

Even as our ability to monitor space objects increases, so too does the total number of items in orbit. That means companies, governments and other players in space are having to collaborate in new ways to avoid a shared threat. Since the 2000s, international groups such as the Inter-Agency Space Debris Coordination Committee have developed guidelines for achieving space sustainability. Those include inactivating satellites at the end of their useful lifetimes by venting leftover fuel or other pressurized materials that could lead to explosions. The intergovernmental groups also recommend lowering satellites deep enough into the atmosphere that they will burn up or disintegrate within 25 years.

But so far, only about half of all missions have abided by this 25-year guideline, says Krag. Operators of the planned megaconstellations say they will be responsible stewards of space, but Krag worries that the problem could increase, despite their best intentions. "What happens to those that fail or go bankrupt?" he asks. "They are probably not going to spend money to remove their satellites from space."

Tiny CubeSats are released from the International Space Station in 2012.

NASA

TRAFFIC COPS FOR SPACE

In theory, satellite operators should have plenty of room for all these missions to fly safely without ever nearing another object. So some scientists are tackling the problem of space junk by trying to understand where all the debris is to a high degree of precision. That would alleviate the need for many unnecessary maneuvers that today are used to avoid potential collisions. "If you knew exactly where everything was, you would almost never have a problem," says Marlon Sorge, a space-debris specialist at the Aerospace Corporation in El Segundo, Calif.

The field is called space-traffic management, because it's analogous to managing traffic on the roads or in the air. Think about a busy day at an airport, says Moriba Jah, an astrodynamicist at the University of Texas at Austin: planes line up in the sky like a string of pearls, landing and taking off close to one another in a carefully choreographed routine. Air-traffic controllers know the location of the planes down to one meter in accuracy.

The same can't be said for space debris. Not all objects in orbit are known, and even those included in databases are tracked to varying levels of precision. On top of that, there is no authoritative catalogue that accurately lists the orbits of all known space debris.

Jah illustrates this with a Web-based database that he developed, called ASTRIAGraph. It draws on several sources, such as catalogues maintained by the U.S. and Russian governments, to visualize the locations of objects in space. When he types in an identifier for a particular space object, ASTRIAGraph draws a purple line to designate its orbit.

Only this doesn't quite work for a number of objects, such as a Russian rocket body launched in 2007 and designated in the database as object number 32280. When Jah enters that number, ASTRIAGraph draws two purple lines: the U.S. and Russian sources contain two completely different orbits for the same object. Jah says that it is almost impossible to tell which is correct, unless a third source of information could help to cross-correlate the correct location.

ASTRIAGraph currently contains some, but not all, of the major sources of information about tracking space objects. The U.S. military catalogue—the largest such database publicly available—almost certainly omits information on classified satellites. The Russian government similarly holds many of its data close. Several commercial space-tracking databases have sprung up in the past few years, and most of those do not share openly.

Jah describes himself as a space environmentalist: "I want to make space a place that is safe to operate, that is free and useful for future generations." Until that happens, he argues, the space community will continue devolving into a tragedy of the commons, in which all spaceflight operators are polluting a common resource.

He and other space environmentalists are starting to make headway, at least when it comes to U.S. space policy. Jah testified on space-traffic management in front of Congress last year, at the invitation of Ted Cruz, a Republican senator from Texas who co-introduced a space-regulations bill this July. In June, President Donald Trump also signed a directive on space policy that, among other things, would shift responsibility for the U.S. public space-debris catalogue from the military to a civilian agency—probably the Department of Commerce, which regulates business.

The space-policy directive is a rare opportunity to dis-

A piece of space debris that is thought to be from a space shuttle mission in 1998.

NASA

cuss space junk at the highest levels of the U.S. government. “This is the first time we’re really having this conversation in a serious fashion,” says Mike Gold, vice president for regulatory, policy and government contracts at Maxar Technologies in Westminster, Colo., which owns and operates a number of satellites.

THE ORBITING DEAD

The space around Earth is filled with zombies: some 95 percent of all objects in orbit are dead satellites or pieces of inactive ones. When someone operating an active satellite gets an alert about an object on a collision course, it would be helpful to know how dangerous that incoming debris is. “With more and more objects, and the uncertainties we currently have, you just get collision warnings no end,” says Frueh. (Micrometeorites represent a separate threat and can’t be tracked at all.)

To assess the risk of an impending collision, satellite operators need to know what the object is, but tracking catalogues have little information about many items. In those cases, the military and other space trackers use telescopes to gather clues in the short period before a potential collision.

Working with the Air Force, Frueh and her colleagues are developing methods to rapidly decipher details of orbiting objects even when very little is known about them. By studying how an object reflects sunlight as it passes overhead, for instance, she can deduce whether it is tumbling or stable—a clue to whether or not it is operational. Her team is also experimenting with a machine-learning algorithm that could speed up the process of characterizing items.

Once researchers know what an orbiting object is made of, they have a number of potential ways to reduce its threat. Some sci-fi–tinged proposals involve using magnets to sweep up space junk, or lasers to obliterate or deflect debris in orbit. In the coming weeks, researchers at the University of Surrey in Guildford, U.K., will experiment with a net to ensnare a test satellite. The project, called RemoveDEBRIS, will then redirect the satellite into an orbit that will re-enter the atmosphere.

But such active approaches to cleaning up space junk aren’t likely to be practical over the long term, given the huge number of objects in orbit. So some other experts consider the best way of mitigating space junk to be a passive approach. This takes advantage of the gravitational pulls of the sun and the moon, known as resonances, that can put the satellites on a path to destruction. At the University of Arizona in Tucson, astrodynamicist Aaron Rosengren is developing ways to do so.

Rosengren first came across the idea when studying the fates of satellites in medium Earth orbit (MEO). These travel at altitudes anywhere between about 2,000 kilometers up, where low Earth orbit ends, and 35,000 kilometers up, where geostationary orbits begin.

Satellites in low Earth orbit can be disposed of by forcing them to re-enter the atmosphere, and most satellites in the less heavily trafficked geostationary region can be safely placed in “graveyard” orbits that never interact with other objects. But in MEO, satellite trajectories can be unstable over the long term because of gravitational resonances.

An early hint that spacecraft operators could harness this phenomenon came from ESA’s INTEGRAL γ-ray space telescope, which launched in 2002. INTEGRAL travels in a stretched-out orbit that spans all the way from low Earth orbit, through MEO, and into geostationary orbit. It would normally have remained in space for more than a century, but in 2015, ESA decided to tweak its orbit. With a few small thruster burns, mission controllers placed it on a path to interact with gravitational resonances. It will now re-enter the atmosphere in 2029, rather than decades later.

In 2016, Rosengren and his colleagues in France and Italy showed that there is a dense web of orbital resonances that dictates how objects behave in MEO (J. Daquin *et al. Celest. Mech. Dyn. Astr.* 124, 335–366; 2016). Rosengren thinks this might offer a potential solution. There are paths in this web of resonances that lead not to MEO, but directly into the atmosphere, and operators could take advantage of them to send satellites straight to their doom. “We call it passive disposal through resonances and instabilities,” says Rosengren. “Yeah, we need a new name.”

Other researchers have explored the concept before, but Rosengren is trying to push it into the mainstream. “It’s one of the newer things in space debris,” he says.

These disposal highways in the sky could be easy to access. At a space conference in July in Pasadena, Calif., Rosengren and his colleagues reported on their analysis of U.S. Orbiting Geophysical Observatory satellites from the 1960s. The scientists found that changing the launch date or time by as little as 15 minutes could lead to huge differences in how long a satellite remains in orbit. Such information could be used to help calculate the best times to depart the launch pad.

Being proactive now could head off a lot of trouble down the road, as operators of satellites such as CryoSat-2 have found. When ESA decided to take evasive action in early July, its engineers had to scramble and work through the weekend to get ready for the maneuver. Once the space junk had safely flown by, CryoSat-2 took a few days to get back into its normal orbit, says Vitali Braun, a space-debris engineer with ESA.

But the alerts didn’t stop coming. In the weeks that followed, mission controllers had to shift various satellites at least six times to dodge debris. And in August, they nudged the Sentinel-3B satellite out of the way of space junk for the first time. It had been in orbit for only four months.