SPACE

ORBITAL AGGRESSION

How do we prevent war in space?

By Ann Finkbeiner

Illustration by John Anthony Di Giovanni

Ann Finkbeiner is a science writer based in Baltimore. She specializes in writing about astronomy, cosmology, and the intersection of science and national security. Finkbeiner is co-founder and proud co-proprietor of a group science blog, The Last Word on Nothing.

ON JANUARY 30, 2020, AN AMATEUR SATELLITE WATCHER TWEETED, "Something to potentially watch." Cosmos 2542, a Russian inspection satellite, was "loitering around" USA 245, an American spy satellite, and, he wrote, "as I'm typing this, that offset distance shifts between 150 and 300 kilometers." USA 245 then adjusted its orbit to get away from Cosmos 2542, which in turn tweaked its own orbit to get closer again. "This is all circumstantial evidence," the watcher wrote, but "a hell of a lot of circumstances make it look like a known Russian inspection satellite is currently inspecting a known U.S. spy satellite."

Laura Grego, an astrophysicist who studies space technology, saw the tweets; she catalogues satellites, so she has been reading amateur watchers' communications, she says, "since before Twitter was invented." One country's satellite stalking another's is exactly what people like Grego, who worry about space war, worry about. Space war is not warfighters shooting one another in space. Nor is it war from the highest of all military high grounds: "Satellites don't 'drop' bombs," Grego says, "and aren't faster, better or less expensive than other ways of bombing." Space war is war on satellites. Cosmos 2542 could have been equipped to interfere with or damage USA 245 or to blow it to pieces. And if it had done so, the U.S. might have retaliated, perhaps by destroying a Russian spacecraft, and we might have had a space war. And then which satellites, and which services civilization depends on, would be destroyed?

For the U.S. more than anyone else, space war could be ruinous. The country relies heavily on its satellites to transmit signals for GPS, credit-card transactions, hospital systems, television stations, weather reports; the list goes on and on. But it depends more than any other country on its military satellites for communication and surveillance. And all satellites—bright and moving in predictable, public orbits—are essentially sitting ducks, nearly impossible to defend; space war is what the military calls "offense-dominant."

The U.S. military's solution to vulnerability is, of course, military. Last December the Department of Defense created the Space Force, saying that Russia and China had "weaponized space" and that space is now a "warfighting domain." Space Force's job is to protect U.S. satellites and to respond to bad behavior by adversaries.

Cosmos 2542, as the then head of Space Force, General John Raymond, sternly told *Time* magazine, "has the potential to create a dangerous situation in space." But Cosmos 2542's stalking turned out not to start a space war. Neither Grego nor the amateur watchers know what Cosmos was doing, but their best guess is that it was something like what Russian trawlers do when they hang around U.S. Navy ships: annoy, or intimidate if possible, and see what they can see. In any case, in mid-March the amateur watcher tweeted that USA 245 had made a small maneuver "that will put it at a distance of thousands of kilometers for weeks to come if not months," and after that Cosmos 2542 took itself elsewhere. Before it did, Grego added her own tweet: "A good time to establish some shared understandings about how close is too close."

Grego is at the Union of Concerned Scientists, a nonprofit that is part of the three worlds—nongovernmental organization (NGO), military and diplomatic—focused on space war. To her, the best way to stop a space war is to enter an international agreement to prevent or limit one. So far negotiations are stalled in international politics. Diplomats never work fast, Grego says, but right now they are "splashing around in the puddle of diplomacy" without getting much done.

So here we are, with the possibility of an escalating space war that would bring certain and incalculable civilian consequences. Yet attempts at diplomacy have been lackluster, and the military's response sounds as aggressive as it does protective. "I don't know if space war is imminent," says John Lauder, a 30-year veteran of the intelligence community's arms-control monitoring efforts, "but there are trends that make space more dangerous. It's not sitting on top of us, but it's moving in our direction at a rapid speed."

SPACE PEARL HARBOR

FOR ALMOST AS LONG as there have been satellites, there have been weapons to use against them and networks to track them. Satellite number one, of course, was Sputnik 1, put into orbit by the former U.S.S.R. on October 4, 1957. Sputnik and its successors were tracked immediately by amateurs with cameras; by February 1959 the Defense Advanced Research Projects Agency had set up the first satellite-surveillance network. The first antisatellite weapon was a missile called High Virgo, launched by the U.S. on September 22, 1959. In 1963 the former U.S.S.R. tested the first "satellite fighter"; in a 1968 test, another satellite fighter entered the same orbit as a U.S.S.R. target satellite, maneuvered next to it and exploded.

After this energized beginning, the U.S. and the former Soviet Union turned their attention from space war to the nuclear balances of the cold war. The U.S. spent the subsequent decades building satellites that were "exquisitely capable and costing billions of dollars and functioning very, very well," says Brian Weeden of the Secure World Foundation. "But they were not built with the idea of having an adversary do something to them." Once the U.S.S.R. collapsed, he says, "America thought it would be dominant in space forever."

Space war appeared briefly on the U.S. agenda in 2001, when a security commission report, headed by Donald Rumsfeld before he left to become secretary of defense, warned of U.S. vulnerability and included the notable phrase "a Space Pearl Harbor." Douglas Loverro, then an air force program director, began advocating for a kind of space force, but "9/11 happened, and everybody forgot about space," he says.

Meanwhile, Grego says, France, Japan, the U.K. and India had launched their own satellites, and more nations had built, bought or operated satellites launched by others. Loverro and other officials, helped by Representatives Mike Rogers of Alabama and Jim Cooper of Tennessee, both on the House Armed Services Committee, kept pushing for a space branch of the military and got nowhere until December 2019, when Space Force was created by presidential fiat. "Magically, we were revived," Loverro says.

This suddenness meant that for a while, Space Force was long on rhetoric but short on specifics and subject to snide remarks from people on the Internet. Its public image was not helped when its first official act was to design uniforms (camouflage, even for soldiers whose field of battle is in front of a computer) and a logo (the delta-shaped wing shared by patches of the U.S. Air Force and the National Reconnaissance Office—and *Star Trek*). By June, however, Space Force and its Combatant Command, U.S. Space Command, were recruiting tech-smart people; coordinating with international allies; deciding which technologies to buy; and running war-game simulations in which teams attack, counterattack and outthink one another. Space war "doesn't have to be inevitable," says Brigadier General Thomas James, commander at Joint Task Force–Space Defense, a component of Space Command, but "it's very serious business, and we take it seriously."

OFFENSE AND DEFENSE

ANYONE ATTACKING SATELLITES can choose from a long, varied menu of weapons. The splashiest option, called a direct-ascent antisatellite weapon, or DA-ASAT, is a missile shot from Earth that blows up a spacecraft. The U.S. and Russia have had DA-ASAT missiles since the cold war. China and India have both tested DA-ASATs on their own satellites. Russia's latest test was this past April.

Another option for attacking satellites is a maneuverable satellite, like Cosmos 2542, which can approach another country's vehicle. Satellites have often used small engines to move for safety reasons, such as to avoid space debris, and maneuverable satellites could be used for refueling or repair. But maneuverable satellites can be dual use, equally capable of colliding with other satellites or of spying on or shooting them. In the past few years the U.S. and Russia have used satellites to deploy smaller subsatellites that roam around: Cosmos 2542 emitted Cosmos 2543, which also stalked USA 245. The U.S. has the X-37B, a smaller, robotic version of the Space Shuttle that does generally secret things, including emitting subsatellites. What these subsatellites can do that parent satellites cannot is also secret and therefore unclear: Weeden says that all we know about them is what we see.

A space war technology that we cannot see, in contrast, is electromagnetic radiation. Satellites can carry equipment to jam others' communications from or to ground stations, or they can mount spoofing attacks to trick other satellites into communicating the wrong things. The U.S., China and Russia routinely jam other countries' links with navigation satellites. Lasers on satellites or on the ground can dazzle or blind spy satellites' imaging sensors, although exactly who has what laser technology with which capabilities is, again, classified or unknown.

In all these hostilities, the U.S. has much to lose. Of the 3,200 or so functioning satellites, the U.S. owns 1,327. Of those, 935 are commercial satellites that provide broadcasting and secure, global communications. Around 200 U.S. satellites are government and scientific satellites that collect data for predicting hurricanes, monitoring droughts, watching the creep of continents and, like the Hubble Space Telescope, understanding the universe. The remaining handful are military and intelligence satellites, most of which are used for communications—command and control of forces, for example, or directing of drones—and for spying. Together the satellites enable modern civilization. They provide the Internet access and GPS navigation and timing signals on which everyone in the world depends and support industries from banking to food supply, the power grid, transportation, the news media and health care.

The few military and intelligence satellites are fundamental to U.S. security and are the source of its vulnerability. The early-missile-warning system uses only 10 satellites, the intelligence community's high-resolution imagery is provided by maybe a dozen, and military command and control communications depend on just six. "The central military problem has been," Grego says, "that we extended ourselves into space, and now we're vulnerable."

This vulnerability matters because no one is sure how satellites can be defended. Perhaps imaging satellites could be fitted with a shutter that reacts fast to too much light, or bodyguard satellites could protect other satellites. Whether such defenses have been put into practice is unknown. "You won't find a lot of official details on the technologies for defense," Weeden says, "due to classification." "Cloaking" a satellite is technically possible, he says, but also expensive and difficult. You can make a spacecraft dark to radar or to telescopes but not to both, and the process can hamper the satellite's performance.

Most efforts at defense tend to focus on deterrence. "The natural place for the military to go is deterrence by punishment," Grego says. "You use ASAT on me; I'll use it on you." The first prob-

Satellites in Space

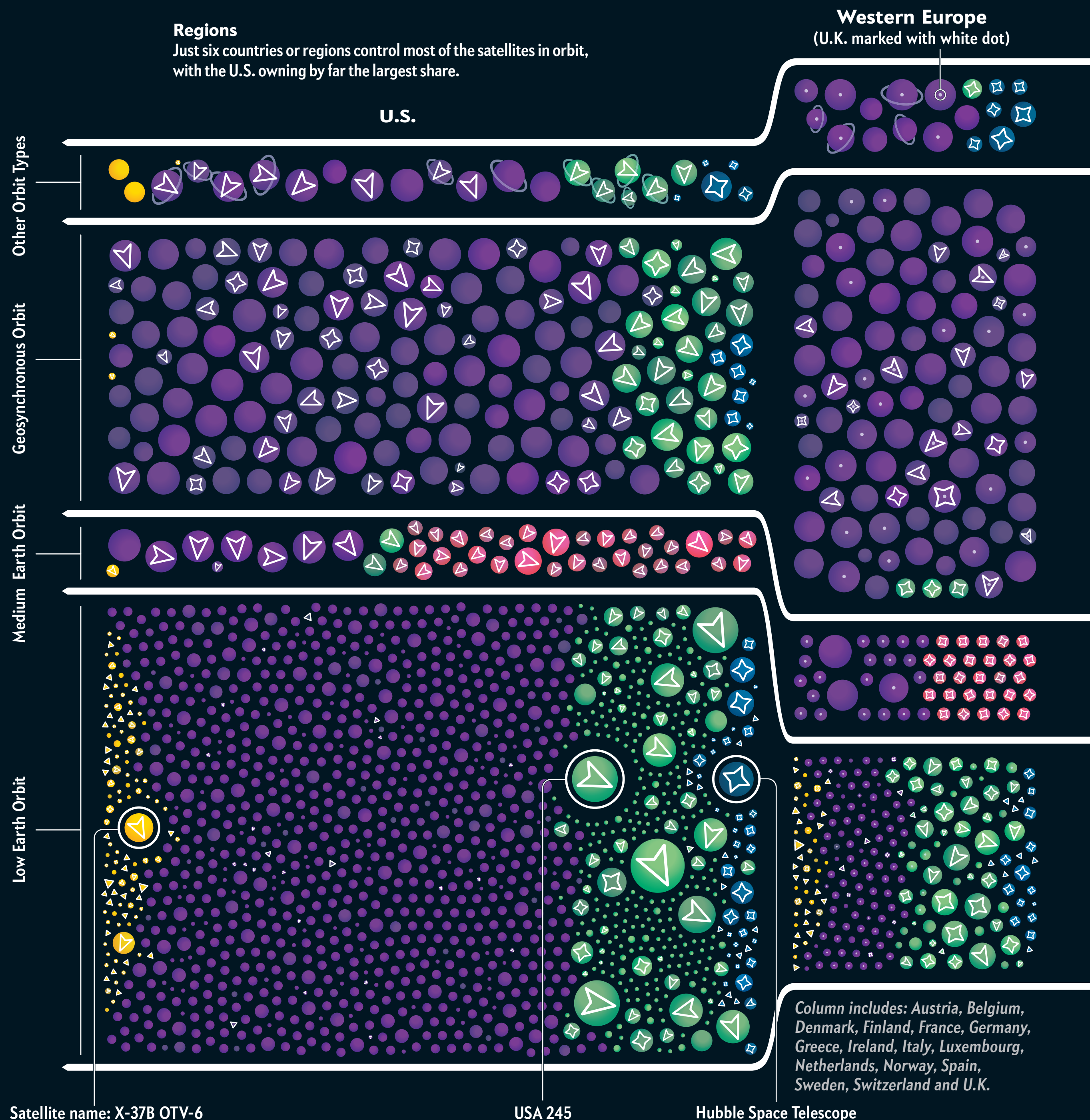
Much of space is vast and empty, but the portion near Earth is not. The orbital corridors around our planet are clogged with satellites large and small. These spacecraft transmit communications; image the ground; conduct research; and provide broadcasting, GPS, weather forecasts and many other aspects of modern life. One even carries humans. This chart shows each of the thousands of active satellites, as well as their owners, where they are and what they do.

HOW TO READ THE CHART

Each of the 2,956 dots below represents an active satellite, as recorded in Jonathan C. McDowell's *General Catalog of Artificial Space Objects* as of September 1, 2020. The dots are organized by controlling region (*columns*) and orbital type (*rows*).

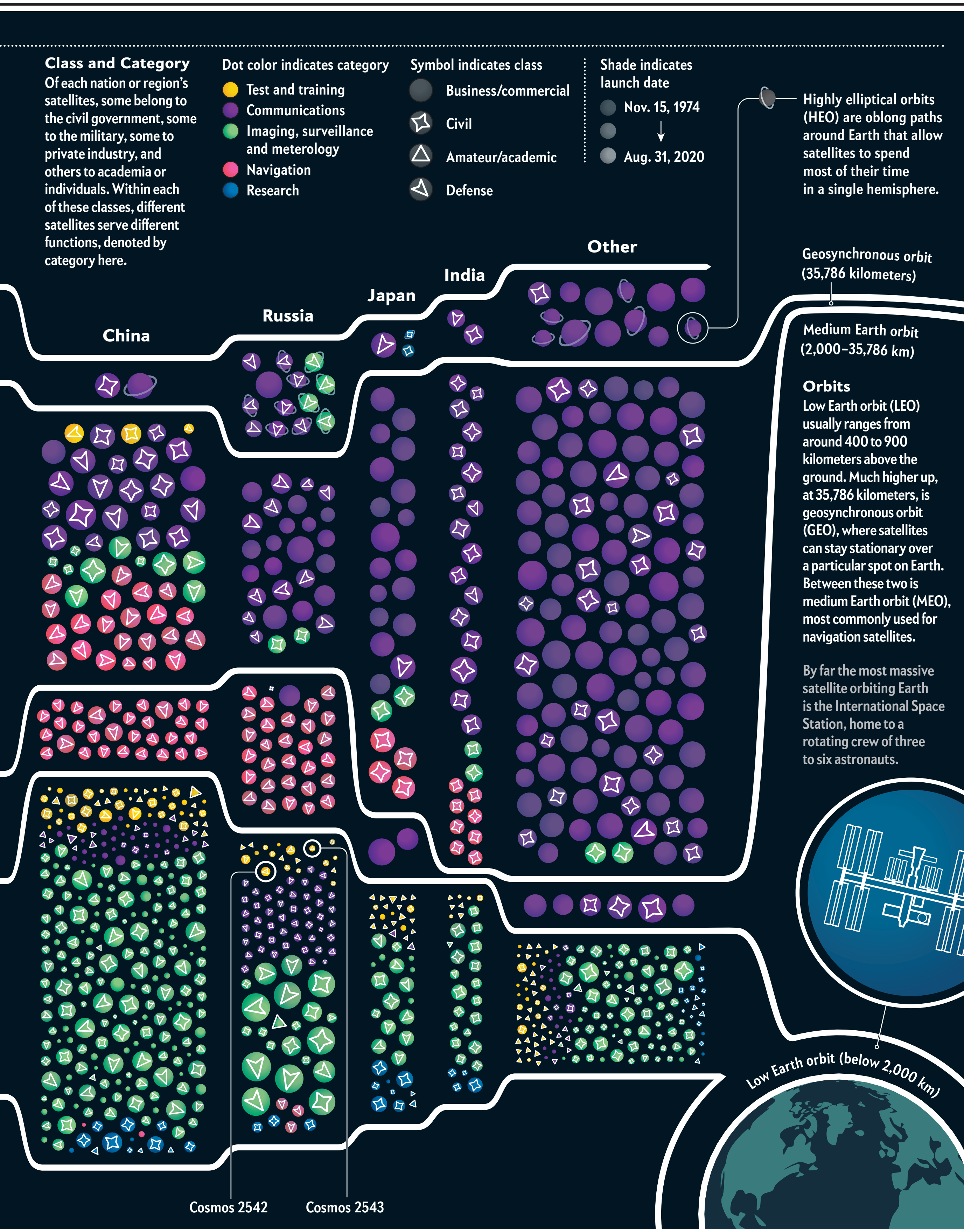
Dot size represents mass of satellite

- 100 kilograms
- 1,000 kg
- 5,000 kg



SOURCE: JONATHAN C. McDOWELL. *GENERAL CATALOG OF ARTIFICIAL SPACE OBJECTS*, RELEASE 1.1.5; SEPTEMBER 2020 *https://planet4589.org/space/gcat*

Graphic by Nadieh Bremer


Class and Category
Of each nation or region's satellites, some belong to the civil government, some to the military, some to private industry, and others to academia or individuals. Within each of these classes, different satellites serve different functions, denoted by category here.
Dot color indicates category
Test and training
Communications
Imaging, surveillance and meterology
Navigation
Research
Symbol indicates class
Business/commercial
Civil
Amateur/academic
Defense
Shade indicates launch date
Nov. 15, 1974
Aug. 31, 2020
Highly elliptical orbits (HEO) are oblong paths around Earth that allow satellites to spend most of their time in a single hemisphere.
China
Russia
Japan
India
Other
Geosynchronous orbit (35,786 kilometers)
Medium Earth orbit (2,000–35,786 km)
Orbits
Low Earth orbit (LEO) usually ranges from around 400 to 900 kilometers above the ground. Much higher up, at 35,786 kilometers, is geosynchronous orbit (GEO), where satellites can stay stationary over a particular spot on Earth. Between these two is medium Earth orbit (MEO), most commonly used for navigation satellites.
By far the most massive satellite orbiting Earth is the International Space Station, home to a rotating crew of three to six astronauts.
Low Earth orbit (below 2,000 km)
Cosmos 2542
Cosmos 2543

lem with punishment, though, is unpredictable escalation. The second is the flip side of U.S. vulnerability—that Russia and China do not need their military satellites as much as the U.S. does. "It's only really the U.S. that needs to conduct military operations anywhere in the world all the time against anyone," Weeden says, whereas most of Russia's and China's need for defense communications is local or regional and "can generally be solved with [other] means."

Alternatively the U.S. could deter attacks by denying their benefits. In other words, a redundant, resilient system that could take losses without losing effectiveness would not be as attractive a target. This is standard deterrence theory; whether the Pentagon is practicing it is not clear. The official Defense Space Strategy, published this past June, avoided this level of detail in the unclassified version of the report.

Deterrence by denial of benefits is effectively being supplied, however, by the commercial space industry. Traditionally the Pentagon has contracted with defense-industry giants such as Lockheed Martin, Raytheon and Northrop Grumman to build its satellites. These spacecraft tend to be the size of large pickup trucks, and one reason for that is economic efficiency, says Colonel Eric Felt of the Air Force Research Laboratory's Space Vehicles Directorate. Whatever new function you need, he says, "just glue it on to whatever you're building." The so-called New Space companies, however—SpaceX, Blue Origin, Virgin Galactic, Planet—have reusable launchers and satellites the size of watermelons at a quarter to a tenth the cost. The savings allow the military to launch more satellites more often, Felt says, spreading out different functions to different vehicles and making replacement easier.

Getting spacefaring countries to agree to behave themselves is not simple. International law governing space is a work in progress.

New Space companies are linking hundreds or thousands of small satellites into large constellations that ensure Internet access and continuous imaging coverage of every spot on the globe and serve as textbook denial of benefits. The Space-Based Infrared System (SBIRS), in contrast, is a constellation of 10 large early-warning satellites and is "a fat, juicy target," says Joshua Huminski of George Mason University's National Security Institute. "I hit three SBIRS satellites, and you don't have early warning." But if SBIRS were a megaconstellation of small satellites, he says, "I take out three, and it's annoying, but the constellation will heal itself."

Felt says that Space Force is developing close relationships with New Space companies, is adopting New Space's rule for ordering new technology not by specification but by function ("I need a five-inch coffee mug" versus "I need a caffeine-delivery system") and is buying good-enough commercial imagery with a credit card.

SPACE DIPLOMACY

BY MID-JULY, months after Cosmos 2542 emitted Cosmos 2543 and drifted away from USA 245, amateur trackers noticed that Cosmos 2543 was suddenly accompanied by a projectile, Object 45915, which then zoomed off, apparently using its own motor, at more than 700 kilometers per hour. Raymond called it an "on-orbit weapons test." The U.K.'s Ministry of Defense tweeted that it hoped Russia would work with international partners toward responsible behavior in space.

Getting spacefaring countries to agree to behave themselves is not simple. International law governing space is a work in progress: NGOs are working on space-law manuals, Weeden says, but "law about conflict in space is so far undefined." International binding treaties are nonspecific or old or on indefinite hold. The United Nations Charter prohibits threats to territorial integrity that extend to outer space. The Outer Space Treaty bans nuclear weapons in space but was signed in 1967, before the great advances in space technologies. In 2014 Russia and China proposed the Prevention of the Placement of Weapons in Outer Space treaty, which prohibits stationing weapons in space; the U.S. does not agree to the proposal's terms but has made no counterproposal. Most recently, the U.N. Committee on the Peaceful Uses of Outer Space agreed on 21 nonbinding guidelines for behavior—for example, "adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities"—which, Grego says, took "a considerable amount of work but do seem a little vague and underwhelming when you read them. You would be disappointed if you hoped they would address space war, but they are not meant to."

The issues on which countries would have to agree are complex and prickly. How do you include everyone—not just the elephantine U.S.-China-Russia triad but all 10 or so countries that can reach space? What is the definition of "weapons" when, say, a robot arm could be used either to replace a defunct sensor or to grab another country's satellite? How to set up lines of communication so that a message of "Sorry, I didn't mean to hit your satellite" can go out before miscalculation and escalation occur? What counts as aggression—hitting another country's satellite with a DA-ASAT missile? Sidling up to another country's satellite? How close is too close? How do you verify that no one cheats on an agreement? And which targets for attacks would cross the line into war, asks John Klein, a fellow at Falcon Research and an instructor at George Washington University's Space Policy Institute? "If you blow up all the GPS satellites—that's critical infrastructure; that's probably war. Take out a small satellite, probably not war."

Meanwhile, Grego points out, countries more or less abide by unofficial norms of behavior: registering new satellites sent into orbit, deorbiting their dying ones to avoid creating debris, not testing DA-ASATs on their own satellites and not destroying another country's satellites. So if a binding treaty is too hard, how about a nonbinding international agreement based on current norms? "The U.S. and Russia are talking about this," Lauder says. "Not that we know in detail what they're talking about, but that they're talking is a good thing. Because nobody can be confident of winning a space war."

Grego agrees with the consensus that it is best to use current norms as a starting point in talks, but she is a little fed up with the pace of diplomacy's progress. The situation "should have been managed years ago by some kind of agreed limits," she says. Shouldn't the State Department get going on this? "We are," says Eric Desautels, director of the Office of Emerging Security Challenges at the State Department. In July 2020 U.S. and Russian officials discussed opening lines of communication to prevent miscalculation and escalation—the first such discussion since 2013—and expressed interest in continuing the discussion. Meanwhile the U.S. supports a new U.N. agreement that would "break the impasse" on space and also reduce risk of escalation.

ALWAYS WATCHING

THE FUNDAMENTAL NECESSITY of space security is knowing where every satellite is and how it is behaving. Space Force's June 2020 doctrine calls this "space domain awareness." Officially that awareness comes via a global network of sensors on satellites and telescopes on the ground that covers all orbits all the time and tracks everything bigger than 10 centimeters: 3,200 live satellites, as well as 24,000 nonfunctioning "zombies" and pieces of space debris that, in a collision with a satellite at 35,400 kilometers an hour, would cause a catastrophic breakup.

The information is sent to Space Force's 18th Space Control Squadron at the Combined Space Operations Center at Vandenberg Air Force Base in California. Data on the secret satellites are set aside, and the rest go into a public, free, online catalog called Space-Track, from which "conjunction notifications" are issued when two satellites look like they might get too close.

The 18th Space Control Squadron works in a secretive operations center that, judging by press release photographs, values functionality over hominess—a maze of connected computer desks, banks of wall monitors and shiny metal letters spelling out "Where Space Superiority Begins" on a beige wall. In this barn of a room, five to seven members of the 18th Squadron sit next to one another and, to ensure complete and accurate analyses, also next to their colleagues from the U.K., Australia, Canada, NASA and the Department of Commerce, as well as a representative from a collective of New Space companies (all with security clearances). Not on the same floor but available nearby for consultation are representatives from France, Germany and the U.S. intelligence community, including the National Reconnaissance Office. Most people in the 18th Squadron are younger than 25 years, although some experienced "graybeards" bring the average age up to 27. All are tech whizzes. "They've blown my socks off," says Lieutenant Colonel Justin Sorice, the 18th's commander.

The 18th Squadron can say only so much about the details of its job. To find out how to track a satellite, ask the amateurs. They prefer to be called hobbyists; 20 to 100 of them are active, lots are retirees and all are tech-minded. They use binoculars and stopwatches or radio receivers—although sometimes they get fancier—and provide global coverage by being international. They sometimes communicate on Twitter but mostly use a public mailing list called SeeSat, which is how Grego followed them pre-Twitter. "I stopped calling them amateurs a long time ago," she says. "They're quite skilled."

Their low-tech approach means they track mainly the brightest, biggest satellites. They pick spacecraft from Space-Track, from Web sites listing which satellites will be over which cities on a given night, or from rocket-launch notices telling navigators to avoid particular areas. They watch the satellite pass a star, and they hit a timer. As they watch it pass a second star, they check the time to a fraction of a second. By knowing the stars' positions and the time, they can derive an orbit. The last time the secret X-37B, a maneuverable satellite/spy plane, flew, the hobbyists had its orbit in 24 hours.

"The orbit gives a surprising amount of information," says Jonathan C. McDowell, a hobbyist and an astronomer at the Center for Astrophysics | Harvard & Smithsonian. Many satellites, for instance, are in low Earth orbit (LEO), which is up to 2,000 kilometers high. These see the least area but take the crispest pictures, so satellites in LEO are often imagers either doing science, such as monitoring weather, or spying. Others in geosynchronous orbit (GEO), at 35,786 kilometers, hover over and move exactly with one spot on Earth. "You've effectively built a 35,000-kilometer tower," McDowell says, "and taken away the tower," so the satellites in GEO are mostly for communications or broadcasting. Satellites in highly elliptical orbits usually spend most of their time over the Northern Hemisphere and tend to be early-warning or spy satellites. And in sun-synchronous orbits, satellites keep in lockstep with the sun so that the shadows on Earth are unchanging—perfect for spying.

Information also comes from a satellite's behavior. If it is adjusting its orbit, it could be countering Earth's drag or watching one spot on Earth: "During the 1973 war," McDowell says, referring to the Yom Kippur War between Israel and a coalition of Arab states, "satellites moved to give more frequent passes over Egypt." Satellites can "flare" when the sun glints off their flat surfaces; if the flaring is random, the satellite is tumbling out of orbit.

McDowell thinks maybe 10 percent of the satellites they track are classified— spacecraft for military command and control, early-warning equipment, and radio and optical spy satellites—some of which are high-resolution instruments that resemble the Hubble Space Telescope but look down instead of up. These do not show up on Space-Track. The hobbyists are the only open source of information on all countries' classified satellites and, Weeden says, a "primary source of data on American military objects." These space watchers are aware that they bear a responsibility to be careful of speculating about how a spy satellite is being used, McDowell says, but on the whole they are not worried about revealing national secrets: rival countries can buy binoculars and stopwatches, too.

In any case, McDowell thinks the hobbyists are generally apolitical. The enemy, as they see it, is not as another country but the failures of function to which machines are prone, such as RUD (rapid unplanned disassembly), and IOBM (in oceans by mistake). They see themselves, as the 18th Squadron surely must, "as an international community of engineers in space battling Murphy's Law and nature," McDowell says. And they like solving puzzles, finding the gaps in Space-Track left for classified satellites and filling them in: "It's the Sudoku thing," McDowell says.

Ultimately the hobbyists matter in the way that oversight and transparency always matter. Everything about satellites and space war is beset with secrecy—some necessary, some perhaps not. If the hobbyists had not published the Cosmos stalking, Grego says, the U.S. would have been free not to acknowledge a vulnerability, and Russia would have been free to deny that anything had happened. These hobbyists, she says, "can be powerful in their own way." The military and the diplomats work secretly in their own spheres, but if the rest of us want to track the probability of space war, the hobbyists are out there making sure it is as open source as possible. SA

FROM OUR ARCHIVES

Space Wars—Coming to the Sky Near You? Theresa Hitchens; March 2008.

scientificamerican.com/magazine/sa