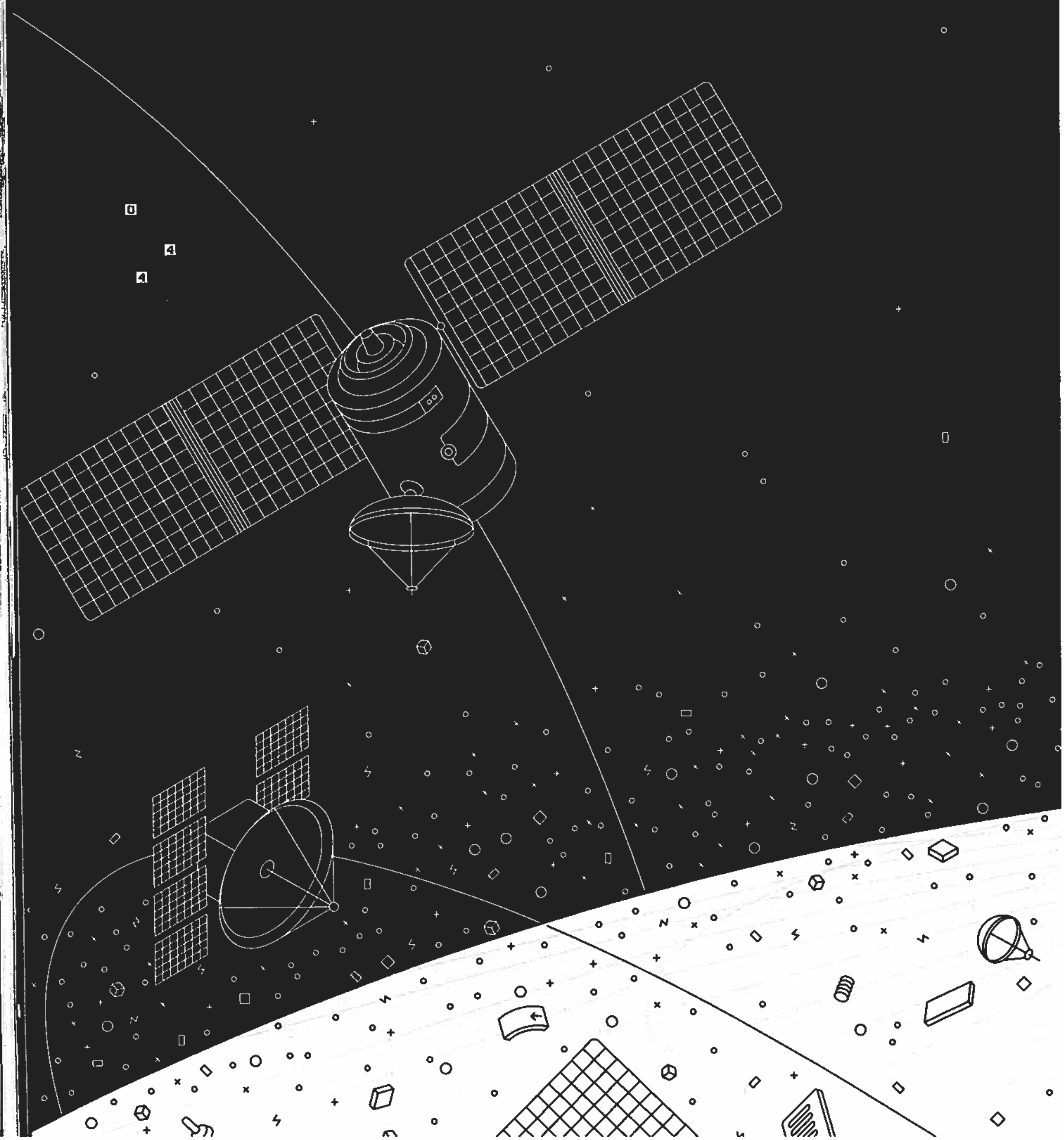
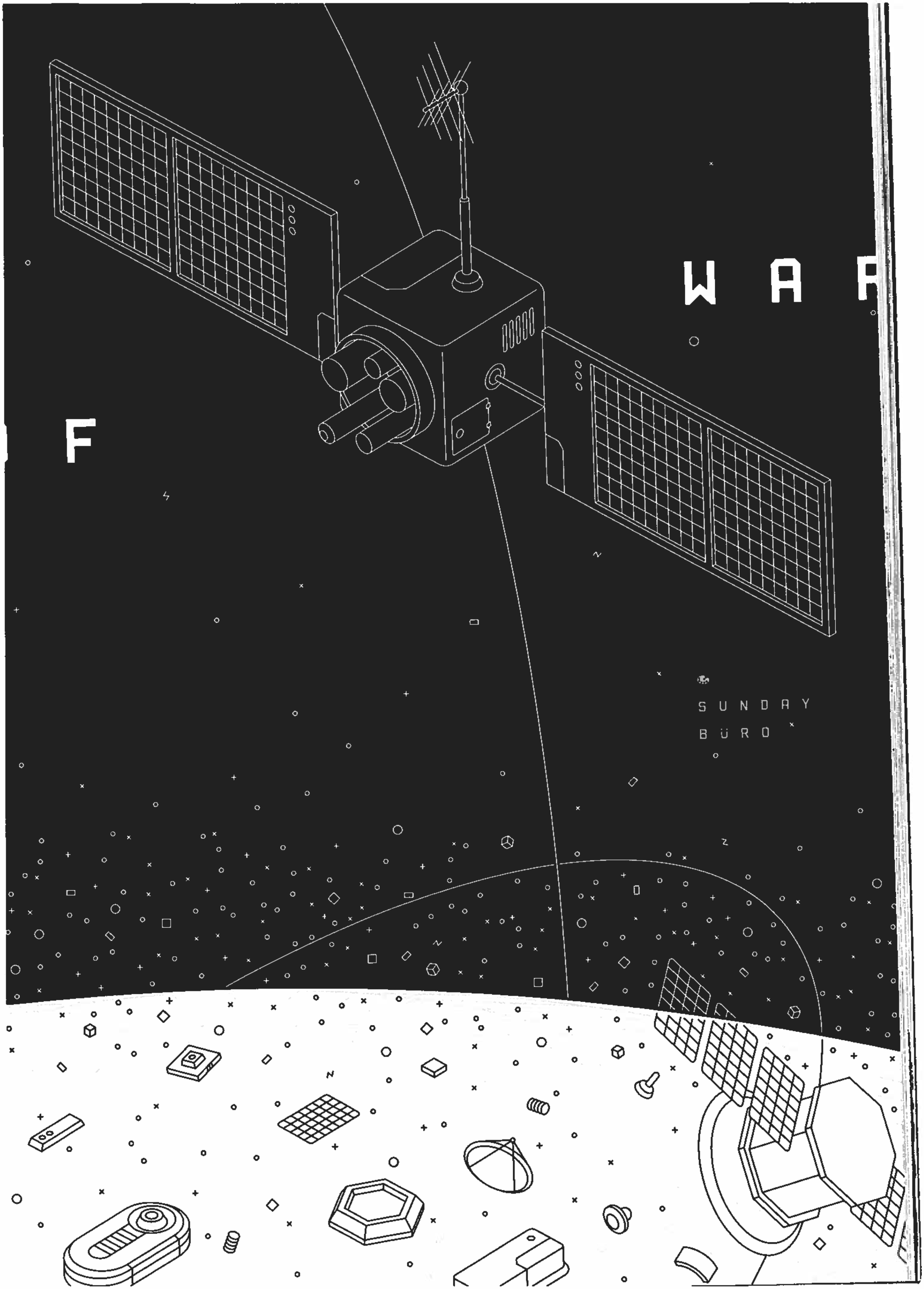
THE OUTER LIMITS

GARRETT
GRA




WAR
F
SUNDAY
BÜRO

A NEW ARMS RACE IS THREATENING TO EXPLODE—500 MILES ABOVE OUR HEADS.

In the midafternoon of January 11, 2007, US Air Force major general William Shelton sat at the head of a table in a command center at California's Vandenberg Air Force Base, holding a telephone to each ear. Shelton was the commander in charge of maintaining the US military's "situational awareness" in space—and the situation, at the moment, seemed to be deteriorating fast. One phone connected Shelton to his boss, the head of US Strategic Command, in Nebraska; the other connected to Shelton's operations center, a windowless room full of analysts just next door. In front of Shelton was a can of Diet Dr Pepper, and arrayed around the table were the members of his increasingly nervous senior staff.

For days, US intelligence had been picking up indications that China was about to conduct a missile test aimed at outer space. The analysts next door—and their counterparts around the world—were tracking ground-based radar signals, monitoring infrared sensors, and poring over images from telescopes in space. All of them were briefing Shelton on what they were observing in real time. At 2:28 pm (PST) their readouts showed a ballistic missile taking off from China's Xichang Satellite Launch Center, located in the wooded mountains of Sichuan province. The missile rose into low Earth orbit, about 500 miles above Earth's surface, and appeared to close in on an aging Chinese weather satellite.

Then the telescopes showed a bright flash.

Minutes later, the radar screens began to track a growing cloud of debris—at least 3,000 pieces of shrapnel that would each, Shelton knew, spend

GARRETT M. GRAFF

the next several years slingshotting around Earth at speeds that could far exceed that of a bullet. Shelton was stunned. The Chinese had just shot a satellite out of the sky.

Not only was this a stupendous technological achievement—to launch a missile from the ground and hit a celestial target moving as fast as 17,000 mph—it also showed a level of audacity not seen in space for decades. "We couldn't imagine they would go against an actual satellite," Shelton recalls. "Because of the debris something like that creates, it's almost unthinkable." It felt like a wake-up call.

In the conference room, Shelton exhaled, set down his two telephones, and pushed himself back from the table. "This changes everything," he said to his staff.

For decades, America's satellites had circled Earth at a largely safe remove from the vicissitudes of geopolitics. An informal global moratorium on the testing of anti-satellite weapons had held since 1985; the intervening decades had been a period of post-Cold War peace—and unquestioned American supremacy—high overhead. During those decades, satellites had become linchpins of the American military apparatus and the global economy. By 2007, ships at sea and warplanes in the air had grown reliant on instant satellite communications with ground stations thousands of miles away. Government forecasters relied on weather satellites; intelligence analysts relied on high-resolution imagery to anticipate and track adversaries the world over. GPS had become perhaps the single most indispensable global system ever designed by humans—the infrastructure upon which the rest of the world's infrastructure is based. (Fourteen of the 16 infrastructure sectors designated as critical by the Department of Homeland Security, like energy and financial services, rely on GPS for their operation.)

Now, Shelton feared, all those satellites overhead had become so many huge, unarmored, billion-dollar sitting ducks.

In the decade since China's first successful anti-satellite missile test, Shelton's premonition has largely come true: Everything *has* changed in space. A secretive, pitched arms race has opened up between the US, China, Russia, and, to a lesser extent, North Korea. The object of the race: to devise more and better ways to quickly cripple your adversary's satellites. After decades of uncontested US supremacy, multinational cooperation, and a diplomatic consensus on reserving space for peaceful uses, military officials have begun referring to Earth's orbit as a new "warfighting domain."

On the ground, the military is starting to retrain pilots, ship captains, and ground troops in fail-safe forms of navigation that don't rely on GPS—like celestial navigation. The US military must relearn how to fight "unwired" and defend itself in space. "We knew how to do that, and somehow we forgot," General John E. Hyten, the head of US Strategic Command, said in 2015.

When former director of national intelligence James Clapper left office at the end of the Obama administration, he told me that the increasing sophistication of America's adversaries in space was one of the top three strategic threats he worried about. Clapper's successor, Dan Coats, warned last spring that "Russia and China remain committed to developing capabilities to challenge perceived adversaries in space, especially the United States."

Since he took office, President Trump has dropped numerous hints of the warnings he's evidently getting from military and intelligence leaders. During a spring livestream with astronauts aboard the International Space Station, he alluded, obliquely and without context, to the "tremendous military applications in space." And he has repeatedly floated the idea of creating a new branch of the armed forces specifically for celestial combat.

But if space is indeed becoming a war-fighting domain, it's important to understand the stakes, not just for America's strategic standing but for the species. A Russo-Sino-American space war could very well end with a crippled global economy, inoperable infrastructure, and a planet shrouded by the orbiting fragments of pulverized satellites—which, by the way, could hinder us all on Earth until we figured out a way of cleaning them up. In the aftermath of such a conflict, it might be years before we could restore new constellations of satellites to orbit. Preparing for orbital war has fast become a priority of the US military, but the more urgent priority is figuring out how to prevent it.

GROWING UP IN OKLAHOMA CITY,

William Shelton dreamed of becoming a pilot. He got as far as the Air Force Academy before he discovered his eyes weren't good enough. So instead he became an astronomical engineer. In 1976 he began serving as a launch facility manager at Vandenberg Air Force Base, the military's oldest space and missile launch base, perched on the California coast north of Santa Barbara. He arrived just as the Air Force was beginning to understand how crucial space would be to its future: The nation's first early-warning satellites had been put in orbit with the intention of tracking Soviet missile launches, and satellite imagery was becoming increasingly critical to intelligence gathering. Shelton's poor eyesight, it turned out, had led him to the center of the Air Force's new frontier.

In August 1990, Shelton, then a young lieutenant colonel, took command of the 2nd Space Operations Squadron in Colorado. When he arrived at his post, the Air Force was busy building a new constellation of satellites—launching new ones from Cape Canaveral in Florida every few months to help fill out what he was told would ultimately be a global system aimed at helping the US improve its navigation and increase the precision of its bombs and missiles. This was the new Global Positioning System, and one of Shelton's first duties at "2Sops" was to build support and enthusiasm for the new effort. To impress visitors (including the brass), he carried around a demo GPS unit that weighed 10 pounds, cost $3,000, and could tell America's soldiers, sailors, airmen, and Marines exactly where they were on the surface of the planet.

The power of the new system that 2Sops ran was proven faster than anyone imagined. The Gulf War caused a rush of final preparations to get GPS ready for battle. Around 2:30 am on January 17, 1991, GPS-equipped helicopters snuck into Iraq, using the technology to guide themselves through the darkened desert and knock out air defense radars. The first bombing campaign of the war had begun. Reporters marveled at precision-guided bombs zeroing in on their targets and cruise missiles appearing to turn street corners to hit the right buildings. Shelton had a front-row seat to this transformation.

As the technology has improved, so has the precision of GPS. The system originally provided accuracy to within 17 yards; with it, you could pinpoint a specific copse of pine trees. Today, if you're using a smartphone, it can generally locate an object to within five yards—a resolution fine enough to locate a pair of pine trees within that copse. Soon it could be able to zero in on a pine cone: Research from UC Riverside has demonstrated that the latest tech is reliable to within an inch. And research has shown that 1-millimeter accuracy might be eventually possible—which means that the system could locate an individual seed inside that pine cone.

Today, troops on the ground use GPS to navigate foreign streets; drone pilots can program a flight plan from thousands of miles away. And because GPS satellites also house America's detection system for nuclear detonations, we rely on them to tell us if North Korea launches a nuclear weapon, and to tell our missiles and

(@vermontgmg) is a WIRED *contributing editor. He wrote about US special counsel Robert Mueller's combat experience during the Vietnam War for issue 26.06.*

bombs where to find their targets. "When you look at our American way of war, the strategy is largely underpinned by space assets—navigation, early warning, timing," Shelton says.

And that's just the military. The creators of GPS probably never intended for the system to become the backbone of daily life, but it has. I visited Colorado while reporting this story and tried to keep tabs on everything I did that relied on GPS. There were the obvious navigational moments—my Uber ride to the airport, my American Airlines flight to Denver, my own Google Maps-guided drive in a rental car to Schriever Air Force Base, outside Colorado Springs. But there were also less obvious instances, like the phone calls I made along the way (cellular networks rely on GPS data to keep their stations synchronized), my stop at the ATM (banks use GPS to track deposits and withdrawals), and the fill-up at the gas station (the credit card system also relies on GPS). Moreover, GPS is no longer the world's sole geolocating mechanism. Russia, China, and the European Union have now all either deployed or begun working on their own full constellations of navigation satellites, ensuring that they won't have to rely on the US system. It also means that, in the early moments of a war, it's a fair bet that satellites—the other guy's satellites—could be among the first targets.

DURING THE COLD WAR, A US ARMY

mountain outpost in the Fulda Gap, the shortest route between East and West Germany, served as an early warning trip wire for a Soviet invasion of Europe. If Russian tanks ever made a surprise attack, NATO planners knew that the soldiers there would likely be the first to find out.

Today, the members of 2Sops play a similar role. Deep inside the squat, beige, windowless Building 400 at Schriever Air Force Base—the destination I had plugged into Google Maps during my trip to Colorado—10 people at a time remotely operate the heavenly constellation of GPS satellites that guide Tomahawk cruise missiles to their targets, deliver Lyft passengers to their destinations, and help farmers cultivate their crops. They also watch out for any shocks or attacks on the system.

The average GPS operators are in their mid-twenties. During one recent shift, the entire Global Positioning System was being operated by two 19-year-old airmen (who, the Air Force emphasizes, are rigorously trained). Their commander, US Air Force lieutenant colonel Peter Norsky, is in his mid-thirties. Together, they watch over the roughly three dozen GPS satellites, troubleshooting the geolocation system and minding the quirks of each orbiting craft—this one's damaged solar panels, that one's balky communications links—as if they were remotely tending a stable full of temperamental horses.

As integral as GPS is to daily life, the way it actually works is little understood by most people outside of Schriever Air Force Base. Fundamentally, the function of GPS is to provide the globe with a shared clock. GPS satellites allow phone companies to keep their systems in sync, battleships to chart open waters, and ATMs to time-stamp their transactions by triangulating signals from overhead and measuring how long it takes those signals from different satellites to reach a GPS receiver.

The system works by making daily calculations, employing Newtonian physics and Einsteinian relativity, to minutely tweak the time broadcast from each GPS satellite as it moves through space—the high-tech version of tuning your grandfather clock to within 100-billionths of a second. Time is, after all, relative; as of January, the time in space was 18 seconds ahead of Earth's "Coordinated Universal Time," since space doesn't recognize the leap seconds that scientists add to terrestrial time to account for the planet's slowing rotation. Additionally, the time-keeping device on each satellite gives a subtly different reading, the result of variations in their atomic clocks, which tell time by measuring the precise oscillations of an atom. (Some GPS satellites use rubidium atoms, which are highly accurate day to day; some use cesium, which is more accurate over long stretches.)

Any malfunction in the GPS system threatens to plunge the global economy into chaos. Fortunately those glitches are rare, but they're not unheard of. On January 25, 2016, one of 2Sops' flight commanders, Captain Aaron Blain, was awoken by a call from work in the middle of the night. User reports from around the country suggested that the system's precision had "wobbled," making measurements increasingly inaccurate. Blain raced to Schriever in his Ford pickup and found that the constellation's timing was off by about 13 microseconds. It was an infinitesimal number—over 25,000 times shorter than the blink of an eye—but for the finely tuned GPS it was a yawning crevice. Left uncorrected, the glitch could have ricocheted through the global economy, corrupting not just driving directions but stock trades too.

Alongside the rest of his team, Blain worked through the night, chugging Mountain Dew. It took about six hours to locate the problem—a single corrupted measurement—and then individually reset the affected satellites. (Russia's GPS equivalent, known as Glonass, has suffered even more serious issues. In 2014 it went dow for 10 hours, but many Glonass receivers ca also use GPS as a backup, so the systemic cha was limited.)

2Sops averted a benign catastrophe th night, but it seems increasingly worried abo what China and Russia are doing up in the hea ens, out of sight. It recently doubled the nu ber of airmen who oversee the satellites, one team can run the GPS constellation wh another trains to face worst-case scenarios what the Pentagon refers to as "a contest degraded, and operationally limited envir ment." That is, a space war.

IN ONE RESPECT, SPAC IS ALREADY

like a war zone: It's increasingly shot thr with flying shrapnel. By some estimates, t are more than 100 million pieces of debris zip around in Earth's orbit. China's 2007 anti-s lite test is estimated to have created some 15C new ones, many too small to be tracked. In some of those fragments hit a Russian satell threatening to add still more debris to the o mix. And as commercial ventures like Space Blue Origin ramp up their space tourism p Earth's orbit is about to get even more cro with both junk and spacecraft. Scientist there could be a point at which the dens objects spinning around the planet reac threshold—called the Kessler effect—tha gers a runaway cascade of collisions: an orbit, in other words, set to Blend.

Another tricky thing about space de that sometimes it isn't just debris. A US tary program called the Space Surveillanc work carefully tracks and monitors every of space junk that's larger than a softbal currently amounts to some 20,000 obj everything from old satellite parts to dis rocket boosters to a pair of pliers lost du astronaut's spacewalk. In 2014, a piece sumptive space junk known to the US mili Object 2014-28E began to behave strange object, known to be of Russian origin, sta perform complicated maneuvers. "Tha cerning—when you see something that a to be debris come to life," Shelton says. 2014-28E was, in fact, an autonomous craft capable of veering off course and up to other objects, including Americ mercial communications satellites.

In the years since, Object 2014-28E has been joined by similar space objects of Russian provenance. Analysts fear that they might mark the revival of a Russian program known as Satellite Killer, which was shut down after the Cold War. But it's difficult, even for US government analysts, to know for certain whether that fear is warranted. The secrecy that surrounds nearly everything space-related makes it hard to assess any adversary's capabilities. Discerning *intentions* is especially difficult. "If I wanted to build a satellite that looked very different from its actual mission, that's not hard to do," Shelton says.

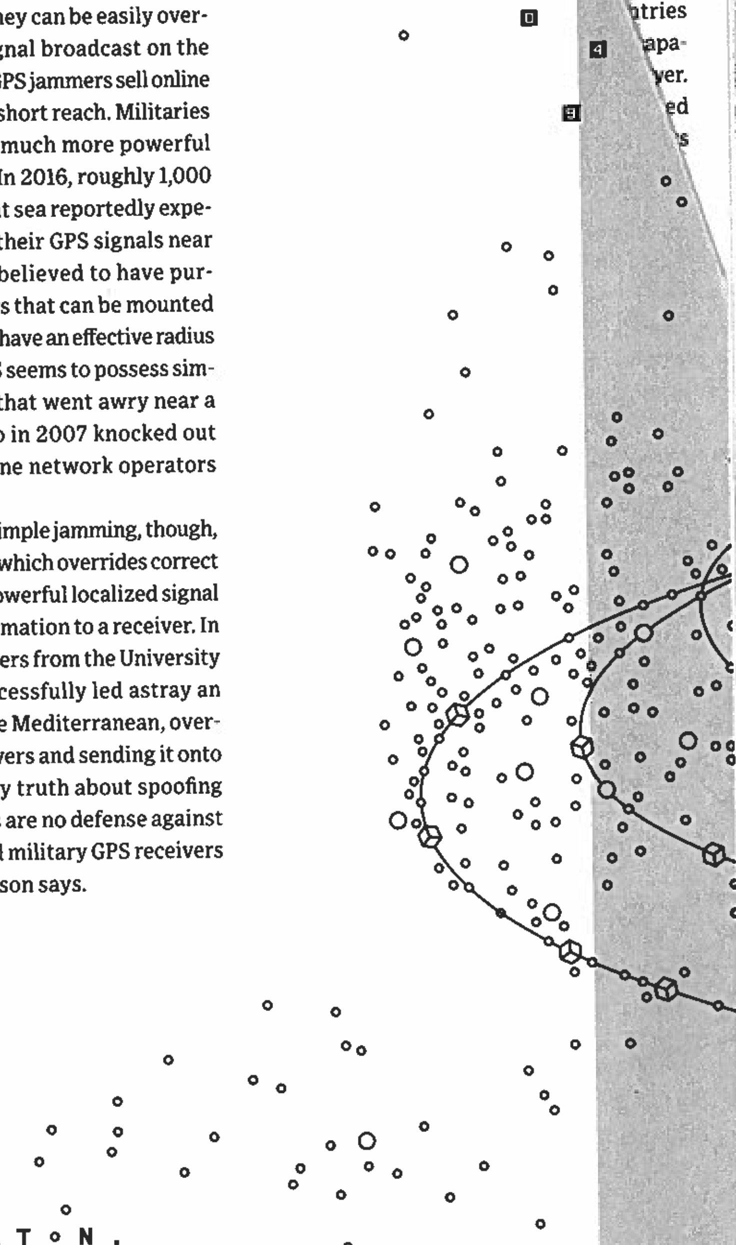
A satellite that maneuvers close to another could be doing a repair job or squaring up for an attack—and it might use the same tools for both. "Small satellites with small grappling arms—they have both military and nonmilitary uses," says Dean Cheng, who studies China's military capabilities at the Heritage Foundation. "If I manipulate a satellite's bits and pieces, I can also rip something out." The US has also been secretive in developing what may or may not be weapons in space. Last May, the Air Force announced that an unmanned space-shuttle-like vehicle that appears to be classified had completed 718 days orbiting Earth, doing who knows what. As of this May, another OTV was circling the globe, more than 200 days into its mostly classified mission.

Todd Harrison, director of the Aerospace Security Project at the Center for Strategic and International Studies in Washington, explains that there are effectively four categories of space weapons: kinetic (aimed at destroying a satellite), nonkinetic (aimed at disabling a satellite without touching it), electromagnetic (aimed at interfering with a satellite's signals), and cyber (aimed at corrupting the data sent to a satellite).

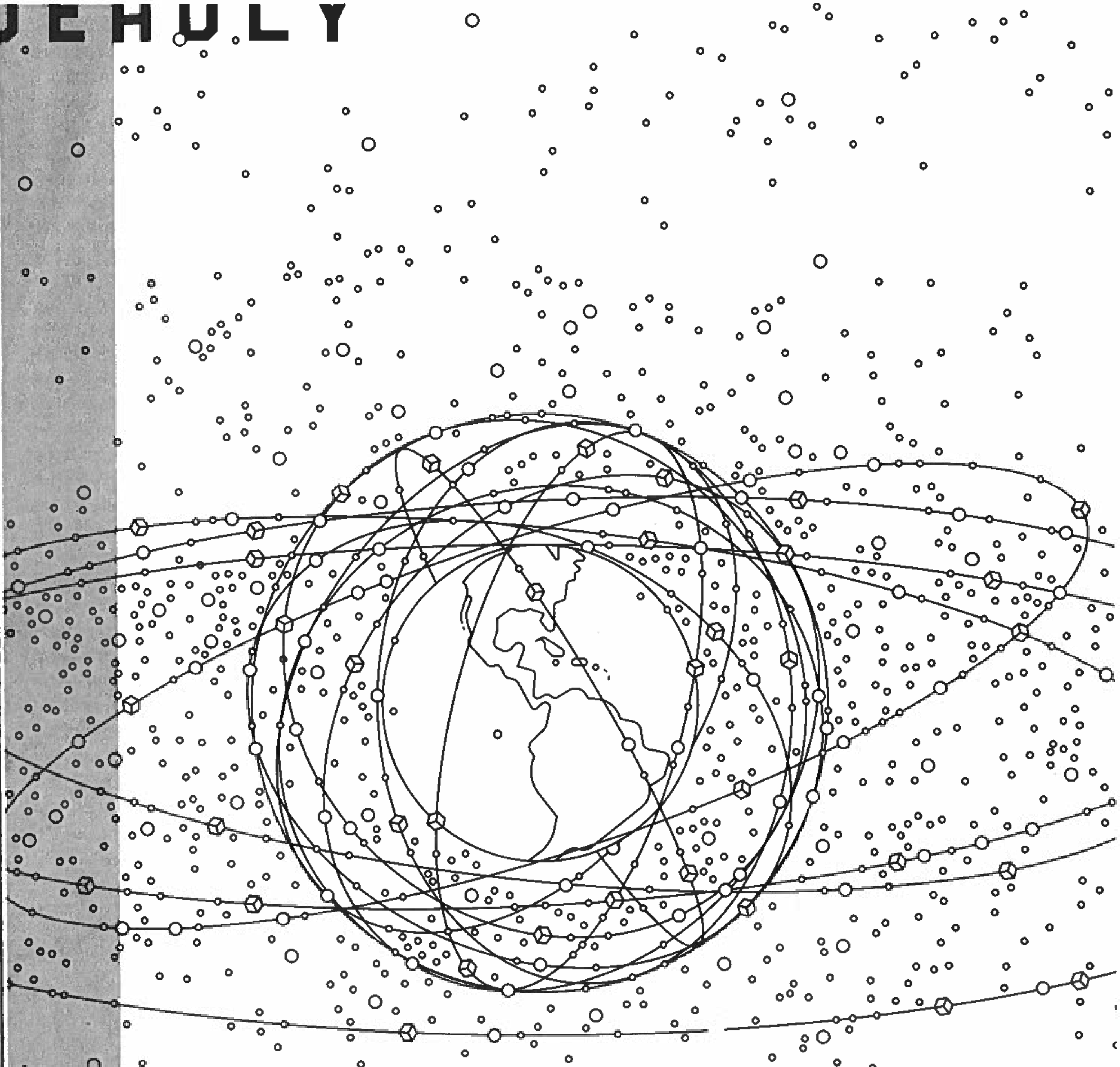
The US tested its own anti-satellite missile in 2008, shooting down an errant spy satellite as it was falling out of orbit. Russia has repeatedly flight-tested a so-called direct ascent weapon, the PL-19 Nudol ballistic missile, which could strike objects in orbit, although it hasn't conducted a live attack on an orbiting satellite. And in the decade since China shot down its weather satellite in 2007, Beijing has launched multiple ballistic missile tests that extended into orbit. In addition, a trio of Chinese satellites have practiced "close-proximity operations," similar to those performed by the Russian Object 2014-28E. Anti-satellite weapons form just one part of what China calls *shashoujian*, or "assassin's mace" systems, which can be used at the start of an attack to achieve a surprise, decisive advantage over a technologically superior foe. There's also the growing challenge of cyberattacks on satellites: Chinese hackers have reportedly infiltrated the US weather satellite system, and a Romanian hacker announced that he had accessed the server of one of NASA's space flight centers. In the past decade, at least two nonmilitary US satellite systems have experienced brief, unattributed glitches tied to hacking attacks.

Some actors have begun to exploit the fragility not of satellites themselves, but of the signals they broadcast. By the time the radio signals from a GPS satellite reach Earth from thousands of miles up, they can be easily overridden by a stronger signal broadcast on the same frequency. Simple GPS jammers sell online for $119, but they have a short reach. Militaries appear to be acquiring much more powerful jamming technologies. In 2016, roughly 1,000 planes and 700 vessels at sea reportedly experienced problems with their GPS signals near North Korea, which is believed to have purchased Russian jammers that can be mounted on trucks. Those devices have an effective radius of 30 to 60 miles. The US seems to possess similar technology; a test that went awry near a Navy base in San Diego in 2007 knocked out GPS signals to cell phone network operators for at least two hours.

More troubling than simple jamming, though, is the rise of "spoofing," which overrides correct GPS data with a more powerful localized signal that delivers false information to a receiver. In 2013 a team of researchers from the University of Texas at Austin successfully led astray an $80 million yacht in the Mediterranean, overpowering its GPS receivers and sending it onto a new course. The dirty truth about spoofing is that secure channels are no defense against it. "Even our encrypted military GPS receivers can be spoofed," Harrison says.



SHELTON, WHO RETIRED IN 2014 after 38 years in the Air Force, lives not far from 2Sops in Colorado; these days he chairs an educational and advocacy nonprofit called the Space Foundation. He still expends a lot of energy worrying about what is happening in the heavens. "We as a nation have been too slow to respond to this threat," he says. He's particularly troubled by the failure of the US to procure new space systems. Some GPS satellites are older than the people running them. "Our systems are archaic," Shelton says. "Because space assets are so expensive, we deploy 'just enough'; there's no backup or excess capability." (The Air Force noted that the GPS constellation consists of more than 30 satellites, which provides some redundancy.)



IN ORBIT, TRASH BECOMES SHRAPNEL

DEBRIS

When objects in space collide—whether by accident or because, say, someone down on Earth has decided to launch a missile at a satellite—it sometimes creates a hail of smaller fragments that fan out across Earth's orbit. Those pieces of extraterrestrial shrapnel can keep flying around for years, at up to 17,000 mph, more than five times faster than a bullet. Even dust-sized specks and stray paint flecks can do damage because of their sheer momentum. If countries were to open fire on one another's satellites, it could shroud Earth's orbit in what is essentially a perpetual hail of bullets.

It's already getting difficult to operate satellites and conduct launches amid all the junk zipping around up there. That's why, around the world, scientists and engineers are devising ways to pull space junk out of orbit. In April, a SpaceX rocket carried a collection of experimental debris-removal technologies to the International Space Station. During its time in orbit, the satellite will test out nets, harpoons, and drag sails designed to reduce detritus.
—SARASWATI RATHOD

20,000
Pieces of space debris larger than a softball

500,000
Pieces of debris the size of a marble or larger

4,300
Number of satellite in space

72
Percent of satellites that are non-functioning

$1.4 billion
Cost of degradatic commercial satelli caused by debris

China, by contrast, is investing heavily in its space program, seeing it as a symbol of its growing prominence. As soon as this year, it could land a craft on the never-before-touched far side of the moon. And China's global navigation satellite system, known as BeiDou, has some capabilities that outmatch even the United States' GPS. In 2015, China created a new space-focused military service, known as the People's Liberation Army Strategic Support Force. Meanwhile, the US relies entirely on Russian rockets to get its astronauts to the Space Station (although NASA has awarded contracts to Boeing and SpaceX to fix that). As Cheng says, "Today China is one of two countries that can put a person into space—and the other country isn't the United States."

Many of America's space warriors, as they call themselves, share Shelton's sense that the US isn't responding nearly quickly enough to the threat of orbital war. "We needed to be marching faster," says Deborah Lee James, who served as President Obama's secretary of the Air Force. "Why aren't there more space and cyber officers at the top of the Air Force?"

Addressing these issues, as James' question suggests, is not just about throwing money at the space-industrial complex. It involves organizational changes too. The Air Force is building what it calls the nation's first Space Mission Force, made up of airmen trained to respond to the demands of an orbital war. On the same base as the 2Sops command center, the military has established the National Space Defense Center, which puts representatives from various military and intelligence offices focused on space under a single roof. And the defense authorization bill is full of upgrades to the Air Force's space-fighting capabilities, including the creation of an additional Air Force unit responsible for space warfighting operations.

Not content to tinker with the Air Force, a growing number of people in Washington are talking about creating an entire *new* military branch dedicated to space operations. In May, during a ceremony honoring West Point's football team, President Trump told his audience, "You will be part of the five proud branches of the United States Armed Forces—Army, Navy, Marines, Air Force, and the Coast Guard. And we're actually thinking of a sixth, and that would be the Space Force." He went on: "We're getting very big in space, both militarily and for other reasons, and we are seriously thinking of the Space Force."

While these "Space Force" comments sounded to many listeners like yet another oddball Trumpian tangent, they actually do reflect a solid policy proposal. Last year, a bill that included the creation of just such a new branch of the military passed the US House of Representatives, but that provision was taken out of the Senate version.

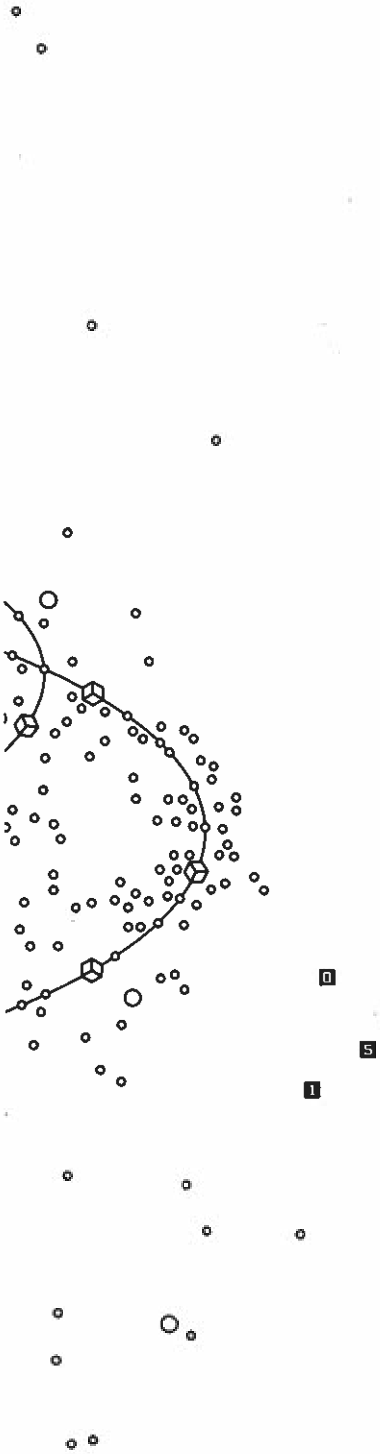
Part of the challenge in figuring out how to think about space conflict is the sheer complexity of the environment—an arena that has long belonged to nation-states will increasingly become a domain of commerce and tourism. How do countries protect their interests up above—and down here? Right now, countries appear to be racing to build their military capabilities—but an arms race isn't the only answer.

The last time an arms race appeared poised to overtake space, the world's superpowers banded together to sign the 1967 Outer Space Treaty, which banned weapons of mass destruction in space and held that "the moon and other celestial bodies" should be reserved for peaceful purposes. The Outer Space Treaty is still in force, but it is by now full of holes. Legal scholars had a hard time proving that China's 2007 anti-satellite test, for instance, violated the agreement. That's because the missile that China fired was not technically addressed in the 50-year-old treaty.

Part of what makes space such volatile terrain right now is that it's hard even to apply the existing laws of war to it. No country can claim sovereignty in orbit, and it's impossible to occupy territory there. So what counts as an act of territorial aggression? What qualifies as a proportional response? It's even difficult to say, with certainty, what the physics of war in space will look like. We don't well understand, for instance, how a kinetic attack on a satellite constellation might spill over into a spiraling Kessler effect.

Humans have "millennia of experience in blowing up things on land," says Laurie Blank, a law professor at Emory University and a specialist in the laws of armed conflict. "We're still learning the consequences of all these things in space."

Blank recently joined together with an international team of legal experts to create what they're calling the Woomera Manual on the International Law of Military Space Operations—a kind of rule book for celestial international conflict, one that will endeavor to translate the laws of terrestrial war for space. It's a daunting task, and the resulting document will be nonbinding. But, Blank says, it's a necessary first step for anyone who would seek to contain a conflict that has, in some senses, already begun.



2,000
Number of trackable fragments created by the last major satellite collision in 2009

160 million
Estimated number of pieces of space junk too small to be tracked