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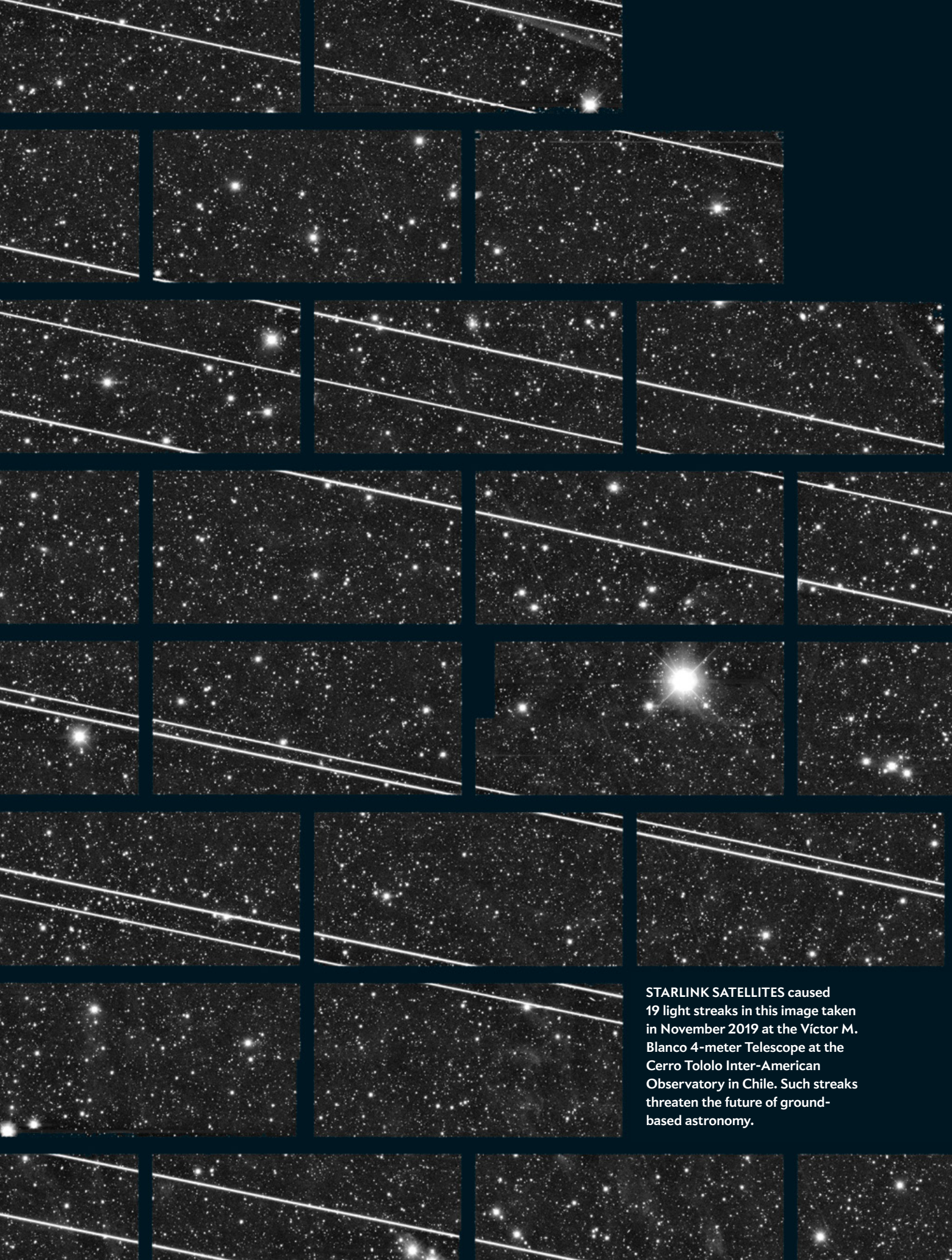
ASTRONOMY

The Threat of Satellite Constellations

Growing swarms of spacecraft in orbit are outshining the stars, and scientists fear no one will do anything to stop it

By Rebecca Boyle



STARLINK SATELLITES caused 19 light streaks in this image taken in November 2019 at the Víctor M. Blanco 4-meter Telescope at the Cerro Tololo Inter-American Observatory in Chile. Such streaks threaten the future of ground-based astronomy.

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RACHEL STREET FELT FRIGHTENED AFTER A RECENT PLANNING MEETING FOR THE VERA C. RUBIN Observatory. The new telescope, under construction in Chile, will photograph the entire sky every three nights with enough observing power to see a golf ball at the distance of the moon. Its primary project, the Legacy Survey of Space and Time, will map the galaxy, inventory objects in the solar system, and explore mysterious flashes, bangs and blips throughout the universe. But the telescope may never achieve its goals if the sky fills with bogus stars. New swarms of satellite constellations, such as SpaceX's Starlink, threaten to outshine the real celestial objects that capture astronomers' interest—and that humans have admired and pondered for all of history. "The more meetings I attend about this, where we explain the impact it is going to have, the more I get frightened about how astronomy is going to go forward," says Street, an astronomer at Las Cumbres Observatory in California. As one astronomer mentioned moving up observations in the telescope's schedule, a sense of foreboding fell over her. Her colleagues were talking about making basic observations early because at some point, it might be too late to do them at all. "That sent a chill down my spine," Street recalls.

As low-Earth orbit fills with constellations of telecommunications satellites, astronomers are trying to figure out how to do their jobs when many cosmic objects will be all but obscured by the satellites' glinting solar panels and radio bleeps. Recent reports from the Rubin Observatory team and from the U.S. Government Accountability Office (GAO) describe a dire situation in which astronomy—the first science—comes under direct threat. Astronomers say that if unchecked, satellite constellations will jeopardize not just the Rubin Observatory's future but almost any campaign to observe the universe in visible light. "It is somewhere in the range of very bad to terrible," says Jonathan McDowell, an astronomer at the Center for Astrophysics | Harvard & Smithsonian who tracks satellites. How bad depends on how many satellites launch in coming years and how bright they are. "A few thousand satellites are a nuisance, but hundreds of thousands is an existential threat to ground-based astronomy."

Telescope project managers are rewriting scheduling programs to avoid the new satellite swarms, but that already impractical task will grow impossible as the number of spacecraft in low-Earth orbit keeps rising. Astronomers are trying to write software to eliminate bright satellite streaks from their all-sky images. But this, too, will be futile if the newest planned satellites make it to orbit; they are so bright that they threaten the electronics of telescope cameras. People who study phenomena as diverse as colliding black holes and near-Earth asteroids worry their work will become impossible. Astronomers talk about the satellite swarms in increasingly ominous terms. "As Chicken Little said, the sky is falling. But instead of one acorn, I think it really is falling," says Anthony Tyson, an astronomer at the University of California, Davis, and chief scientist for the Rubin Observatory. When it comes to sounding the alarm, "it is probably very high time. I might even say almost too late."

CTIO (*preceding pages*)

THE FIRST ARTIFICIAL SATELLITE was Sputnik 1, launched by the Soviet Union in October 1957, and now more than 5,400 satellites orbit Earth at any given time. More than half are owned by U.S. companies or agencies, according to a database maintained by the Union of Concerned Scientists. Most satellites are in low-Earth orbit, less than 1,200 miles above the ground. These satellites, including the International Space Station, make a full orbit every hour and a half or so.

Beginning in May 2019, SpaceX started populating those orbital planes with hundreds of its Starlink satellites, designed for broadcasting Internet and cell phone service around the globe. As of December 2022, 3,268 of all satellites orbiting Earth—more than half—were Starlink, according to McDowell's tracking efforts. The spacecraft are launched in groups and orbit Earth in patterns, called constellations, that enable them to work together. Both the number of satellites and their brightness pose problems for astronomy. They are most visible soon after they launch, glinting across the twilight sky like a tiny dazzling train. To the digital cameras on telescopes, they appear as bright streaks of light, blocking stars and astronomical objects while overexposing the entire field of view. "It's like you're driving down the road and you're looking out through your windshield, and there's this oncoming car with its brights on," Tyson says. "You lose a lot of information—not just at the position of those headlights but all over, and your eyes are overexposed, too."

The $700-million Rubin Observatory is uniquely threatened among ground-based astronomy projects. The telescope is scheduled for first light in 2024, and by then tens of thousands of satellites, including the Starlink constellation and others, could be orbiting Earth. The observatory's planned Legacy Survey of Space and Time will use an 8.4-meter telescope combined with a 3.2-gigapixel digital camera—the largest ever built—to capture 1,000 images of the sky every night for a decade. Each image will cover 9.6 square degrees of sky, which is about 40 times the area of the full moon. The telescope is meant to find new and potentially threatening near-Earth objects, as well as transient events such as supernovae—and things no one has thought of yet, as Tyson puts it. But these observations could be "significantly degraded by the alarming pace" of new satellite deployments, according to an analysis written primarily by Tyson and posted last August by the Rubin Observatory team.

Another report, prepared by the GAO and sent to Congress on September 29, found that the satellite constellations could harm astronomy and cause environmental impacts as they fall back through Earth's atmosphere. "As more satellites are deployed into [low-Earth orbit], nearly all facets of optical astronomy may be negatively affected," the GAO wrote. In a subsequent report released November 2, the watchdog agency urged the FCC (which regulates satellite communications in the U.S.) to more thoroughly investigate the environmental effects of large satellite constellations and reconsider the standards required for their licensing. But many astronomers worry such rules won't come soon enough, or be stringent enough, to save ground-based astronomy.

The first and most prominent provider of these satellite swarms is SpaceX, which is also the only company, so far, to publicly work with astronomers to try to dim its satellites. The company has created DarkSat, a light-absorbing darker satellite, as well as antireflective coatings for solar panels. (SpaceX did not respond to a request for comment.) Between SpaceX and other companies, such as British satellite provider OneWeb and a Chinese company called Galaxy Space, more than 4,000 satellites designed for constellationlike networked coverage are now in orbit. According to permits filed with the world's two leading telecommunications agencies—the U.S. Federal Communications Commission and the International Telecommunication Union (ITU)—a combined 431,713 satellites in 16 constellations are planned to launch in the coming years.

The satellite companies point out that more than one third of the world's population—some 2.9 billion people, according to a 2021 ITU report—has still never used the Internet. Constellations of communications satellites could change that. But light from the Starlink constellation alone will add streaks to at least 30 percent of images made from the Rubin Observatory. If 400,000 satellites make it to orbit, every image taken in the early evening will have a streak. The OneWeb constellation will orbit at a higher elevation than other constellations, so it will be visible all night long during certain times of year. (OneWeb also did not respond to a request for comment.) And even if software programs can erase the satellites to salvage pixels that surround the bright streaks, data errors on the light-detecting chips will still pose a problem. "Operators of satellites in [low-Earth orbit] will present a significant threat to the main mission of LSST [Large Synoptic Survey Telescope]: discovery of the unexpected," the Rubin Observatory report concludes.

Astronomers and at least one private company are working on software that can eliminate some of the satellite streaks or change where the telescope is looking in order to avoid them. But it's hard to do because the satellites are moving and appear differently in various color filters, among other problems. Meredith Rawls of the University of Washington works on a team that will send out alerts for new phenomena Rubin Observatory catches in the night sky, which could reach 10 million alerts a night. Software is supposed to filter those and to automatically contact the global astronomy community only for meaningful events, such as asteroids or supernovae, she says.

"With the streaks, you can get these little weird blip-blip patterns, which our software will think is a potential object or a supernova, and it will flag it. And it's just a satellite," Rawls says. "This is going to [cause] more false positives than we would hope to have, and then you start trying to guess, how many? Is

it going to be five a night or 500 a night? We don't know."

Rawls worked on a project that fed known satellite locations to the observatory's scheduler algorithm and found that if the telescope operators know where the satellites are, the algorithm can point the telescope elsewhere to avoid them. But this took so much effort that it risked choking the entire pipeline of observations, Rawls and her colleagues found. They're planning to submit their findings to the *Astrophysical Journal Letters*.

Meg Schwamb, an astrophysicist at Queen's University Belfast, was the astronomer who proposed doing the Rubin Observatory's twilight studies early in its 10-year lifetime, before satellite constellations made these observations impossible. Twilight is when near-Earth asteroids may be easily found and when the Rubin Observatory could detect many new ones. The Chelyabinsk meteor, for instance, which shocked everyone when it exploded over Russia in 2013, arrived from a similar direction as the sun and is just the kind of object the Rubin Observatory was designed to catch. But partially sunlit observations will be more difficult because the satellite constellations' solar panels will be illuminated at that time.

"I never thought, as an astronomer, I would be advocating for doing things early because we don't know what the satellite field is going to be like," Schwamb says. More often astronomers anticipate extending their observatories' life spans and coming up with new campaigns in later years. Reversing this order, by instead making sure some basic science gets done before the observatory is blinded by light, is contrary to how many scientists plan their work and even their entire careers. Schwamb compares the satellite constellations to orbital advertisements and argues that humanity needs to figure out how to control them and what we want them to do. "If it wasn't Starlink but Coca-Cola, would we be okay with that?" she asks. "This is a deeper cultural question, too. Should Elon Musk control what people see in the night sky?"

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> —Meg Schwamb *Queen's University Belfast*

Astronomers acknowledge that SpaceX has tried a variety of methods to darken its satellites, but the spacecraft are still visible, and other providers are not adopting any such mitigation strategies. What's more, newer Starlink satellites and those made by other companies are much larger and brighter. A company called AST SpaceMobile launched a prototype last September—BlueWalker 3. Two months later, when BlueWalker 3 deployed its 693-square-foot (64.4- square-meter) phased array of antennas to allow communication with cell phones on Earth, it became one of the brightest objects in the night sky, outshining more than 99 percent of the stars visible to the naked eye.

AST SpaceMobile aims to launch 168 even larger satellites, called BlueBirds, in the next few years. A company spokesperson said testing of BlueWalker 3 will help engineers evaluate the satellite's materials and judge its brightness, adding that the company is actively working with industry experts and NASA to mitigate brightness concerns. AST SpaceMobile is considering antireflective materials and changes to operations to make the satellites dimmer. There will be many fewer BlueBird satellites than other constellations, but they may pose a different type of problem. Some telescopes may be able to avoid very bright BlueBirds, the way some telescope cameras are designed to avoid bright objects such as the planets or the moon. But hundreds of them will be harder to escape. And a bright satellite passing through a digital camera's long exposure could fry the camera's sensitive electronics.

"It is clear that the technology is here. If you wanted to destroy the night sky, you can," McDowell says. "It's going to depend on the details of the business cases for these companies and the details of the regulatory environment whether or not that happens. Therefore, we should talk about whether that's acceptable."

But the pace of satellite construction and launches is much faster than the pace of astronomical research, let alone regulation. "Everyone is increasingly alarmed. We are not really sure where to put our shoulder to the wheel, because there are so many wheels," says Aparna Venkatesan, a cosmologist at the University of San Francisco who also studies cultural astronomy. "The power and the momentum are very one-sided. Astronomers tend to do things very slowly and carefully and convene conferences and meetings—and by then, another few thousand satellites have launched."

Several astronomers say new rules from the FCC would not be enough. Astronomers have been working with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), which held a meeting on satellite swarms last spring, but the process is slow going. McDowell says if COPUOS considers protecting the night sky part of its mission, then member states may be encouraged to use their own national regulatory frameworks to make rules about how many bright satellites can be launched and where they can be.

Many astronomers hope their field may be saved if the satellite constellation operators eventually pull back because not enough people sign up for their Internet services. Or the companies may end up working together to slow their launches to prevent space debris, which would limit everyone's access to space. But the hard truth is that there isn't much anyone can do at this point to stop the steady launch of satellite

SPACECRAFT in a satellite constellation, as shown in this illustration, orbit in a collective pattern to work together.

Jacques Dayan/Alamy Stock Photo

constellations and their sun-reflecting solar panels.

Astronomers have even resorted to a sort of gallows humor about the coming years. Several people pointed out a satellite loss from last February, when some Starlink satellites were in a low orbit in preparation to move to their permanent altitudes. A solar flare traveled to Earth and sparked a plasma storm in the uppermost layers of the atmosphere, causing excess atmospheric drag and radio interference; 40 satellites tumbled back down and burned up. Asked what astronomers can do to prepare for the growing flotilla of satellites, more than one joked, "Wait for solar maximum," when the sun's activity is expected to increase and cause more such storms.

Short of software patches or a geomagnetic storm that knocks out the satellites, physical changes to the spacecraft are one way to prevent total viewfinder contamination. Dimmer objects are easier for software to edit out, and lower orbital altitudes would require faster speeds so the satellites don't fall to Earth, which means they would zip out of the way more quickly. Rubin Observatory team members are hoping private companies will build less reflective satellites and park them in lower orbits, but these decisions would be up to the companies; there are no laws requiring them to do so. The companies should reach out to astronomers and explain their projects' goals and potential impacts on astronomy, Rawls says. "Kind of like in a city, when they want to build a new bike lane, it takes three years because they have to have 700 meetings with stakeholders. I would like to have that for space," she adds. "But in some ways, everyone who ever looks up is a stakeholder in this. And that makes it a real challenge."

Astronomers are not monolithic in their opinions about the issue, and members of the community have expressed varying levels of awareness and alarm about satellite constellations. The amount of fear depends in part on one's knowledge of the satellites and on one's specific interest, including which observatories are affected, McDowell says. "If your science is like the Rubin Observatory, then yes, the sky is probably falling. If your science is narrow-field spectroscopy [studying starlight], it's not as obvious that the sky is falling—but it yet may be," he says.

The alarm is focused on the near future, and although many people are worried, no one knows how bad it will be—or how long the problem will last. It may simply represent a preview of what's to come for the cosmos in general. Cosmologists such as Tyson debate the eventual fate of the universe. One likely scenario is a "big freeze," in which all matter is pushed so far apart that stars will burn out and go extinct. As the universe continually expands, accelerated by the mysterious force called dark energy, the broader cosmos will eventually become invisible from Earth. If any humans remain by that time, they will have to dispense with the starry heavens as a means of understanding the universe—and themselves.

"This is a version of that," Tyson says of the satellite constellations. "Very soon the sky will be visually dominated by these satellites rather than the stars themselves, and that will be true independent of whether you live in a city or out in the country. The future is one in which the sky is twinkling constantly, everywhere, from all of these satellites." SA

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Orbital Aggression. Ann Finkbeiner; November 2020.

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