Somebody's watching over you

We sit at home on our couches, waving to family members and classmates through our computer cameras. Satellites transport our likenesses across long distances. We watch TV, which tells us that more than a million U.S. citizens have contracted COVID-19.

We learn about the measures taken by other countries to defeat this virus as scientists work on vaccines. Satellites make it possible for them to exchange data and discoveries and communicate potential cures at nearly the speed of light.

While we are all immersed in this global pandemic, our satellites watch over us undistracted by events on Earth.

You may not see them, but they are there. Orbiting the equator and orbiting the poles. Enabling us to communicate on social media and Zoom in the social-distancing age of COVID-19. They provide our TV news, allow us to phone a friend, check on our relatives and warn us about hurricanes, monitor Antarctic ice sheets, ozone holes, fires and volcanoes. They take care of us and our environment.

But they weren't always there. Before Oct. 4, 1957, our moon and rocks and space dust from 4.6 billion years ago were all that orbited our planet. And then came Sputnik, the Soviet Union's tiny, basketball-sized beeping satellite. The U.S. followed, with the launch of Explorer-1 on Feb. 1, 1958.

These two satellites were followed by weather, communications, commercial and spy satellites, the shells of manned spacecraft rocket engines, and some very weird stuff.

During the last six decades space has become crowded, and some of our orbiting caretakers are in danger.

By the end of 2019, there were more than 2,200 active satellites in orbit, with more than 1,400 in LEO.

LEO, low Earth orbit, is an orbit with an altitude between 160 km to 2,000 km (99 mi to 1200 mi) where objects make at least 11.25 orbits around Earth each day. Most human-made objects in outer space are in LEO.

Technical Deputy for Space Science Mission Operations, NASA/Goddard Space Flight Center Russell Carpenter said "if we start to clog up LEO, we can't put up science missions. We want to be able to continue to study the environment. [We will] have to put satellites in higher orbit, which can make doing science more difficult."

Designing, building and launching active satellites to avoid space debris creates additional complications, because inactive satellites can't be moved to prevent impacts.

John Crassidis, Mechanical and Aerospace Engineering Professor, University at Buffalo, explained that increasing the number of satellites significantly raises the probability of collisions. "[i]f the probability [of a collision] is greater than 1-in-10,000 then people start to get worried,"

he said.

And it's about to get even more crowded.

University of Texas Associate Professor of Engineering Moribah Jah said LEO "is a finite resource. Most of what we put there never comes back. We risk saturating these orbital highways. We just wouldn't be able to put satellites into those orbits."

We need to protect our satellites, most of which are in low Earth orbit, or LEO. The International Space Station orbits in LEO. So does NASA's Earth Observing System fleet, which gathers data on Earth's environment, including its surface, biosphere, atmosphere and oceans.

The International Space Station in LEO. NASA. July 7, 2010. https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-orbit-58.html public domain

Carpenter explained the importance of protecting LEO. In order to continue studying the environment satellites would need to be put into higher orbits to avoid collisions, making science more difficult and expensive.

In 2018, the European Space Agency moved its CryoSat 2 satellite from its usual orbit to avoid a potential space junk collision, just a week after issuing a report that there was about 3,600 kg (about 8,000 lbs) of space junk in LEO. An impact with even a small piece of debris, orbiting at nearly 7.5 km/s (about 17,000 mph) could have destroyed this important satellite.

The $162 million CryoSat 2 studies ice and glaciers, enabling earth scientists to create 3-D models of the Antarctic ice sheet, melting patterns and sea level changes.

SpaceX, the brainchild of Elon Musk, has already launched 420 Starlink satellites that appear as bright pearls in the night sky.

SpaceX plans to launch 12,000 more satellites within the next seven years, creating a global high-speed broadband internet network accessible from any location on Earth.

To learn more about Starlink visit:
https://metro.co.uk/2020/04/24/starlink-satellites-work-12604227/?ito=cbshare
Twitter:
https://twitter.com/MetroUK
Facebook:
https://www.facebook.com/MetroUK/

SpaceX Starlink satellites have collision detection software, but in 2019, one of its satellites nearly collided with a European Space Agency (ESA) satellite. ESA was forced to move its satellite to avoid the collision. SpaceX later reported that its failure to cooperate with ESA was due to a communications issue that the company intends to fix.

OneWeb, another global communications company with communications plans similar to those of SpaceX, filed for Chapter 11 in March 2020. The company already launched 74 satellites. It was in the process of securing additional funding when the COVID-19 epidemic created financial problems that stopped additional launches. It's possible that those 74 satellites will become space junk if OneWeb abandons them.

What is space junk?

Some of the strangest stuff in Earth orbit includes a tool bag lost by an astronaut Heidi Piper, a spatula from the space shuttle Discovery, one of astronaut Ed White's gloves from his June 3, 1965 Gemini 4 spacewalk. During a 2017 spacewalk, astronaut Peggy Whitson lost a thermal blanket that provides protection on the International Space Station.

Space junk is "[a]nything that's not useful anymore. Anything flown off a satellite," Crassidis said. This includes more than 1,100 inactive satellites.

Jah described a U.S. Air Force project that deployed millions of copper needles into LEO. These needles were supposed to provide radio communication capabilities if a nuclear test destroyed the ionosphere, the layer of Earth's atmosphere that reflects radio waves. Some of the needles are still in orbit.

In 2018, a California walnut farmer called the police when he found a strange metal object in his field. A bit of detective work and a call to Vandenberg Air Force Base, helped identify the object as a spent fuel tank of the Iridium 70 communications satellite, which fell out of orbit three days before it was found.

But not everything stays up there. In 1992, the Space Shuttle Columbia carried some of Star Trek creator Gene Roddenberry's cremated remains into space in a small capsule, returning it to Earth, rather than increasing the amount of space junk already in orbit.

How much is out there?

To be cataloged, space researchers are required to identify an object's launch location, which can prove extremely difficult, since a lot of space debris has been in orbit for more than 50 years. They also use radar and large telescopes to find space debris.

Lee Jasper, Chief System Engineer at Space Dynamics Laboratory, Kirtland AFB, said that the U.S. Air Force Space Surveillance Network has been cataloging space debris since 1967.

According to Carpenter, they can only track objects larger than a baseball. But smaller items include paint flecks, nuts and bolts.

There is "also a lot of guestimation involved in space debris identification," Crassidis said. Sometimes identification is impossible.

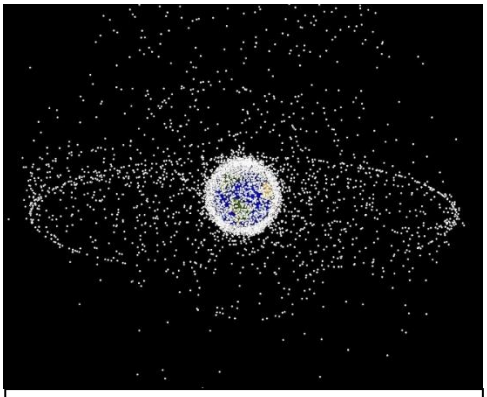
Whose satellite is this?

The United Nations Office of Outer Space Affairs (UNOOSA) maintains a list of all objects launched in space, but sometimes satellites fall through international cracks.

The 1974 Convention on Registration of Objects Launched into Outer Space requires that the launching nation report its activities to UNOOSA. About 90% of the objects in Earth's orbit are registered, but at least 700 are not.

The NNS-6 and NNS-7 satellites were built by Lockheed Martin Commercial Space Systems for the Dutch International NV Corporation, launched by the French Arianspace SA in France. Once in orbit the satellites became the property of the Dutch company. None of the three nations involved took responsibility for registration.

This may seem trivial, but if one of these satellites crash, under the 1972 Convention on International Liability Caused by Space Objects, one of these countries, most likely the Dutch, would be responsible for paying to remove the junk.



Computer-generated image representing space debris as seen from high Earth orbit. The two main debris fields are the ring of objects in geosynchronous Earth orbit (GEO) and the cloud of objects in low Earth orbit (LEO). NASA Orbital Debris Program Office, February 1, 2005, public domain https://en.wikipedia.org/wiki/Space_debris

Who left that trash there?

There is no international space traffic control system. Active satellites can usually be controlled, but inactive satellites and debris cannot.

Some of these objects are moving at nearly 36,000 km/hr (22,300 mph), and when they collide, they make a celestial mess. Others simply explode.

Carpenter said "The part that is the most interesting is that these are very rare events, like this pandemic. How much effort do we put into dealing with rare events? How do we make decisions under uncertainty? [This is a] great domain for statisticians."

Aaron Rosengren, Assistant Professor in the College of Engineering, University of Arizona, said there are "five explosions per year of things that blow up." These explosions, usually the result of non-collisional mishaps,

Find out how NASA protects astronauts and the International Space Station from space debris impacts. Check out NASA's A Research Guide to International Space Station: Environmental Effects, https://www.nasa.gov/sites/default/files/files/NP-2015-03-015-JSC_Space_Environment-ISS-Mini-Book-2015-508.pdf and Space Debris and Human Spacecraft, https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

create even more pieces of junk moving at incredible speeds.

Rosengren said that the number of explosions could be reduced by sending commands to satellites before they are inactivated to instruct them to dump their fuel and disconnect their batteries.

The U.S., Japan, Europe and India are big producers of space junk, but Crassidis said that the worst offenders are Russia and China.

In 2007, the Chinese destroyed their own FY-1C satellite during a test, producing about 3,000 additional objects large enough to be individually tracked.

On Feb. 10, 2009, in the first accidental space collision, Russia's nonoperational Cosmos 2251 satellite crashed into an active, polar-orbiting Iridium 33 satellite. This impact created more than 500 pieces of debris.

Aerospace Corporation's Marlon Sorge, Principal Engineer, Space Innovation Directorate, Center for Orbital and Reentry Debris Studies, explained that had this been a weather satellite, its destruction would have had an impact on weather forecasting ability.

Space agencies, mission planners and astrodynamicists use models that usually predict collisions and near misses. But as Carpenter said, this collision "sent a huge message that the models aren't good enough."

Jah and his colleagues at the Advanced Sciences and Technology Research in Astronautics (ASTRIA) program developed software to create "awareness of the trackable population and consistency and inconsistency in opinions of where stuff is."

The team is trying to assess compliance and non-compliance with space laws, policies, and guidelines. "[You] can't enforce what you don't know," Jah said.

"Who is going to get the insurance or pay for it if the insurance rates skyrocket?" Crassidis said. The answer to his rhetorical question impacts all of us.

Sorge said that additional costs will likely be passed on to satellite service users, meaning nearly everyone on planet Earth.

But increased costs are not the only issue. Collisions will significantly curtail our ability to watch our planet from space.

Jasper explained that "We will have to shield our spacecraft. That increases cost and reduces capability, trading mass for functionality." This means that funding will pay for satellite self-protection, rather than satellite Earth science.

The 25-year plan

Sorge said that international cooperation is required to control space junk.

The Inter-Agency Space Debris Coordination (IADC) Committee, which includes NASA and 12 other space agencies, has adopted a rule that requires satellite operators to move their satellites out of LEO within 25 years of the end of a satellite's life. The satellite would need to be brought back to Earth or kicked into a higher orbit.

Sorge is a member of the NASA delegation of the IADC. He explained that countries have their own space debris simulation models, which yield different results, so committee members meet to understand why their model results differ and to better understand how to remove space junk.

Taking out the trash

Each year, about 300 tracked objects enter Earth's atmosphere on their own. About 100 reach Earth's surface. Most other objects take hundreds or thousands of years to deorbit, far too long given the number of satellites now being launched into LEO.

The Kessler syndrome is a theoretical scenario proposed by NASA scientist Donald J. Kessler in 1978. The density of objects in LEO could become so great that collisions among objects could create a cascading effect, where the collision debris could create a chain of collisions, like falling dominoes, destroying satellites on which we all depend.

Carpenter said that a Kessler syndrome would affect human activity by potentially destroying environmental monitoring satellites observing the oceans, soil, and clouds.

In 2017, Jah testified before the United States Senate Committee on Commerce, Science, and Transportation Subcommittee on Space, Science, and Competitiveness. He said that the Resident Space Objects (RSO) catalog operated by U.S. Strategic Command (USSTRATCOM) was inadequate.

Jah said that the RSO has over 24,000 records. More than 18,400 of the catalog objects have been sufficiently tracked, about 1,300 are operational satellites, and the rest are space junk.

Jah tried to impress on the Senate that some of those launching satellites into LEO were behaving based on their own self-interests, rather than considering their impacts on the whole environment. He suggested that the Department of Commerce provide space traffic services, but he was unsure if the Senate had taken any action.

The best laid plans

To be successful, any debris removal method will need to eliminate large pieces of space debris which are likely to do the most damage to other satellites and human space activities. Magnets, harpoons, nets, cubesats and tethers have been proposed for capturing space debris to return it safely to Earth.

"We are looking at a revolution in space, and with that comes a certain set of responsibilities," Sorge said. One of those is removing inactive satellites as well as any debris they leave in LEO.

"If we only remove five large bodies every year, then we can actually significantly reduce the number of collisions in the long run," Jasper said.

But Carpenter said there is currently no practical way to remove space debris.

Active debris removal is "really fun, but super hard," Japser said, and it requires physical contact with the space junk, changing its motion.

Jasper explained that an object that moves another country's active satellite, even to protect it from a collision, could be viewed as a defensive weapon.

On April 15, Russia launched an anti-satellite missile to test technology designed to remove satellites in LEO. The U.S. Space Force considers it a threat to American satellites.

A cubesat is a tiny satellite made of 10 cm x 10 cm x 10 cm units, with a mass of no more than 1.33 kg (about 3 lbs) per unit. These little satellites often use low-cost off-the-shelf components and are primarily used for scientific research. Source: Wikipedia https://en.wikipedia.org/wiki/CubeSat#/media/File:Cubesatkit_1u-skeleton.jpg, CC BY-SA 3.0

Universities, private companies and international consortiums are designing and testing creative and clever solutions to removing space debris.

Rensselaer Polytechnic Institute is designing a tiny cubesat called OSCaR that uses a tether system. Each OSCaR should be able to remove four pieces of space junk.

In 2018 a European and South African consortium deployed the RemoveDebris satellite which successfully captured a little cubesat. Crassidis said that the capture method used by the RemoveDebris satellite uses complicated dynamics, and trying to capture a satellite can destabilize it, making its motion more unpredictable.

Some astrodynamicists and satellite engineers think there are better ways to deal with the space junk that doesn't require actual contact.

In 2016, Rosengren and his colleagues calculated that the gravitational pull of the moon and sun could be used to move satellites. The team determined that changing a satellite's launch time by as little as 15 minutes could significantly affect whether that satellite could be safely deorbited at the end of its life.

Another possible solution is the Ion Beam Shepherd, proposed by ESA in 2011. The idea behind

this technology is simple. Accelerated plasma aimed at a satellite would be used to push it into a safe orbit, without needing to dock with it. This would eliminate inducing even more motion in a difficult-to-capture object.

Developed by a Swiss startup company, ESA's ClearSpace-1 is scheduled for launch in 2025. That spacecraft will capture the Vega Secondary Payload Adapter (VESPA) upper stage that was left in LEO orbit after the 2013 second flight of ESA's Vega spacecraft. VESPA is similar in size to a small satellite. This mission will provide ESA an opportunity to test this new technology, and, if successful, ClearSpace-1 might be utilized to remove larger space debris.

Space policy

Many of the technological aspects of space traffic management (STM) have been identified and solved. Nations under the auspices of the IADC cooperate and share space debris data.

In the U.S., however, there is a tangled web of governmental agencies involved in satellite licensing and deployment. NASA and the Department of Defense have differing space goals, which creates disputes. Resolution has been left in the hands of the Vice President and the National Space Council.

To learn more about space objects, visit:
Stuff in Space http://stuffin.space/ Space Track, https://www.space-track.org/auth/login
Celestrak, https://celestrak.com/
LeoLabs, https://www.leolabs.space/

The U.S. Department of Transportation licenses commercial launches via the Federal Aviation Administration (FAA), the Federal Communications Commission (FCC) is responsible for licensing commercial satellite communications operators. The U.S. Commerce Department licenses commercial remote sensing satellites via the National Oceanic and Atmospheric Administration (NOAA). The Office of the Director of National Intelligence and the State Department are also involved.

The Space Safety Coalition (SSC) was formed in September 2019. The SSC consists of nearly 40 space operators, manufacturers, launch providers and insurers. Rather than waiting for governmental agencies to sort out their disputes, the SSC issued its own set of space best practices, incorporating IADC policies, but endorsing a 5-year satellite disposition rule, rather than the 25-year rule.

In 2018, the current administration designated the Department of Commerce as the agency responsible for future STM rules, and for providing space operators with space situational awareness (SSA) data.

On April 6, the White House issued an Executive Order on Encouraging International Support for the Recovery and Use of Space Resources. This directive stated that "Americans should have the right to engage in commercial exploration, recovery, and use of resources in outer space, consistent with applicable law."

The directive continues: “Outer space is a legally and physically unique domain of human activity, and the United States does not view it as a global commons. Accordingly, it shall be the policy of the United States to encourage international support for the public and private recovery and use of resources in outer space, consistent with applicable law.”

But space is a global commons now, more than ever before, and no pronouncement by any government will change that.

So look up. And when you see a tiny, bright pearl-like dot moving steadily across the sky, remember that it’s a satellite, watching over you.

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Sources

Interview: Thursday, April 24, 5:55 am-6:35 am, via NASA WebEx Conferencing System
Dr. (James) Russell Carpenter
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Carpenter attended The University of Texas at Austin, receiving a Ph.D. in Aerospace Engineering in 1996. He received the NASA Exceptional Service and Exceptional Achievement medals. He was the AIAA National Capital Section’s Young Scientist/Engineer of the Year in 2000. He has more than 60 publications, receiving the Best Paper award at the 2011 Astrodynamics Specialists Conference. He is an associate fellow of the AIAA, and an associate editor for the Journal of the Astronautical Sciences. He began working at NASA in 1987 and was at Johnson Space Center until 1998. He then moved to Goddard Space Flight Center. Until 2016, he was a navigator focused on the development of onboard navigation systems.

Interview: Friday, April 17, 3:30-4:07, 716-997-4568
Dr. John L. Crassidis
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Crassidis received his B.S., M.S., and Ph.D. in Mechanical Engineering from the State University of New York at Buffalo. He was NASA postdoctoral research fellow at Goddard

Space Flight Center (1996-1998), director of UB's Center for Multisource Information Fusion (CMIF), and founder and director of UB's Nanosatellite Laboratory.

Interview: Monday, April 20, 12:30-12:47, 808-269-4237
Dr. Moriba Jah
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Jah's academic credentials include degrees from Embry-Riddle Aeronautical University Aerospace Engineering B.S. 1999, University of Colorado (Boulder) Aerospace Engineering Sci M.S. 2001, and University of Colorado (Boulder) Aerospace Engineering Sci. Ph.D. 2005.

Interview: Tuesday, April 21, 3:30 pm - 4:15 pm, 303-204-1156
Lee Jasper
Chief System Engineer at Space Dynamics Laboratory
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Jasper graduated from the University of Colorado Boulder with a B.S. and an M.S. in 2010 in Aerospace Engineering and a Ph.D. in 2014, in Aerospace Engineering with an emphasis in Astrodynamics.

Interview: Friday, April 24, 2:30 pm – 3:05 pm, 347-583-0038
Aaron Rosengren
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Rosengren is an assistant professor in the College of Engineering at the University of Arizona and affiliate member of the Interdisciplinary Program in Applied Mathematics, specializing in astrodynamics-based space situational awareness. Prior to joining UA and the SSA-Arizona Initiative in 2017, he spent one year at the Aristotle University of Thessaloniki in Greece

working in the Department of Physics, as part of the European Union H2020 Project ReDSHIFT. He has also served as a member of the EU Asteroid and Space Debris Network, Stardust, working for two years at the Institute of Applied Physics Nello Carrara of the Italian National Research Council. He has authored or co-authored around 20 peer-reviewed journal publications and 60 conference papers and abstracts, reporting research in space situational awareness, orbital debris, celestial mechanics, and planetary science.

Interview: Monday, April 20, 4:00 pm – 4:45 pm, via Skype

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Sorge received his bachelor's degree in physics and a master's degree in aeronautical and astronautical engineering from Purdue University.

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