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Polish Space Agency (POLSA) Optical Network telescopes, Deep Sky Chile

DANGEROUS

When we gaze at the clear blue sky, we do not realize the staggering amount of trash that is out there, orbiting the Earth.

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The space in near-Earth orbit is used for scientific purposes – such as research at the International Space Station and deep-space astronomical observations using the Hubble Space Telescope – but above all, it is home to the numerous satellites that support our modern-day lives. These satellites keep us supplied with the various kinds of data we use every day: when we travel, work out, plan our journeys using public transport, research recommended tourist attractions, and check the weather forecast. Information

obtained from Earth observation satellites also helps in climate research, and is widely used in agriculture and aviation. Satellite data has also become an essential tool in the fight against natural disasters, such as forest fires. It is difficult for us to imagine our lives without access to such services as satellite navigation and telecommunications, especially during rescue operations in remote areas with no urban infrastructure – in the mountains or at sea. But the benefits from the use of satellite data also come at a certain price, which is seldom considered:

Space trash

The second half of the twentieth century ushered in the period of human space exploration. Since the launch of the first Sputnik satellite in 1957, we have



SPACE DEBRIS



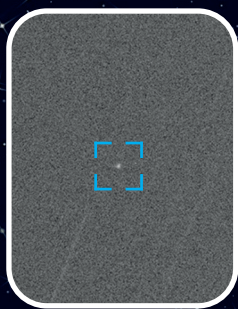
The Canadarm2 robotic arm punctured by space junk, NASA

placed nearly 60,000 objects into Earth orbit. Half of them are still up there, but only 9,000 are active satellites – ones that provide data for services and applications. Everything else can be described as “space junk”: defunct satellites, fragments of rocket bodies, bolts, tools lost by astronauts, and even flakes of chipped off paint or remnants of fuel. These fragments of debris pose a direct threat to active satellites, as they move in similar orbits and at similar speeds (about 8 km/s). A collision with a piece of space trash can not only damage an active satellite, shortening its operational lifespan. In extreme cases, it can break the satellite apart and by so doing create more pieces of dangerous debris.

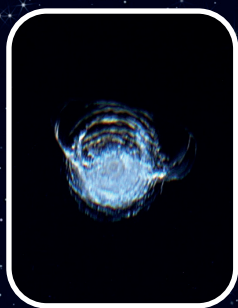
The problem is especially acute in the region of Low Earth Orbit (LEO), stretching from approx. 100 km to 2,000 km above the planet’s surface. Most of the observation satellites that provide the data we regularly use are located there. But this is also a region of space where astronauts aboard the International Space Station have been working for over two decades, conducting scientific research in such fields as medicine and materials science. The risk of colliding with space debris is already so high that astronauts receive such warnings as often as several times a year, typically prompting preparations for a potential evacuation.

The International Space Station is indeed constantly hit by the smallest pieces of debris, which is why it has been designed to mitigate their impacts and protect the living area. But the station’s solar panels and exposed components are not protected: the windows of the Cupola module, allowing observation of the Earth’s surface, have not been immune to collisions, and a piece of debris actually punctured the Canadarm2 robotic arm in 2021.

Over the past decade, Low Earth Orbit has also become an area of intensive expansion of satellite internet constellations, including Starlink, as well as research projects that involve launching miniature objects about 10 cm in size (called CubeSats). In 2022 alone, more than 180 rockets were launched, most of them into the LEO region, to deliver satellites, space station infrastructure, and people. The number of active satellites is projected to exceed 100,000 objects by 2030. Consequently, the amount of various types of space debris will also continue to rise. Collisions with satellites and fragmentation events, or the detachment of some components from space stations or satellites, will become an increasingly common problem. To avoid the former, space agencies are already executing multiple maneuvers a year, shortening the lifetime of satellites. Currently, we observe one or two fragmen-



Cubesat-1 space debris measuring $12.5 \times 5 \times 5$ cm, observed with POLSA Optical Network telescopes



Cupola module window hit by space junk, ESA

tation events each year, but this figure may increase even tenfold, resulting in a rapid surge in the amount of space junk.

In-orbit collisions

Collisions with space debris are not uncommon. In 2016, one of the solar panels of the European Earth-observing Sentinel-1A satellite was hit by a piece of debris that was only one millimeter in size. However, the energy of the impact was enough to cause damage over 40 centimeters in diameter. Such tiny specks of debris have also posed a significant hazard for shuttle missions and are often responsible for abrupt shut-downs of satellites in orbit. The ESA estimates that there could be over 130 million fragments of debris of similar dimensions, making collisions with them an inevitable concern.

With larger pieces of space debris, the impact of such a collision is greater, but so is the chance of finding and tracking such objects. With an early warning, a maneuver can be performed to alter the orbit of the satellite at risk so that it can avoid a collision. Such information gets incorporated as early as at the planning phase of new missions. We can't track debris less than 1 cm in size using existing observational techniques, but objects larger than 5 cm are cataloged and regularly monitored by networks of astronomical observatories or radars. These observations are conducted by such organizations as the US Space Surveillance Network, and in Europe by the EU Space Surveillance and Tracking Consortium (EUSST). Its members include Poland, which boasts one of the world's most extensive networks of astronomical observatories. Collectively, ground-based observatories provide satellite operators and space agencies orbital data for around 26,000 pieces of debris.

However, an orbital maneuver to modify the orbit of a satellite is not always successful or feasible.

In 2009, two telecommunications satellites – Iridium 33 and the defunct Kosmos 2251 – ran together in an accidental in-orbit collision about 800 km above the Earth's surface, creating over 2,000 pieces of debris. In December 2020, the Polish satellite named Brite-PL almost collided with a fragment of the Pegasus rocket. The distance between the objects was a mere 4.5 meters. The former collision could have been prevented if the maneuvering engines had been started early enough. In the second situation, however, the scientific satellite, which has no such engines, would not have had a chance.

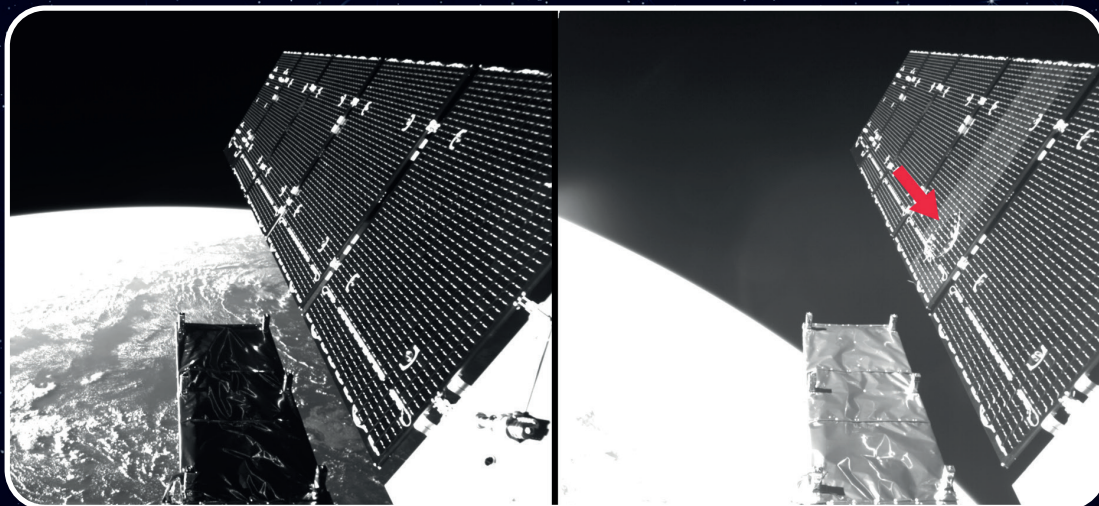
In-orbit collisions may also be caused deliberately, as part of anti-satellite weapon testing. It is estimated that such events account for one-fourth of space debris. Most of the world's superpowers have gained notoriety in this field, with the debris of Fengyun-1C (2007), Microsat-R (2019), and Kosmos 1408 (2021) posing a threat to all satellites in the LEO region.

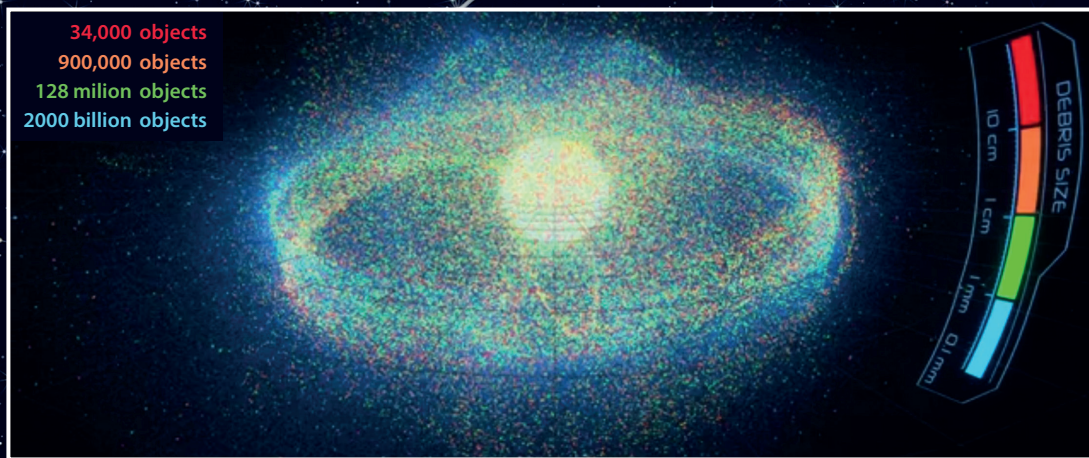
Cleaning up space

The lifetime of space debris and satellites varies depending on their orbit. The closer they are to the Earth's surface, the greater the friction with the Earth's atmosphere becomes, leading to their gradual descent until they burn up. For objects with no propulsion that are placed at an altitude of up to 500 km, the typical time to naturally drop out of orbit (to "deorbit") is 25 years. It increases to 100–150 years for an altitude of 800 km and exceeds two millennia for an altitude of over 1,200 km. Satellites placed into geostationary orbit, or over 36,000 km above the Earth's surface, are likely to stay there forever. At the end of their mission, such satellites are moved to what is called a graveyard orbit, located about 300 km higher.

The persistent orbital hazard posed by space debris has prompted national and international organizations such as the National Aeronautics and Space

Sentinel-1A satellite damaged after being hit by space junk, ESA





The scale of the space junk problem, as illustrated by an ESA simulation

Administration (NASA), the ESA, the EU, the United Nations (UN), and the Organisation for Economic Co-operation and Development (OECD) to take steps aimed at reducing the amount of such debris. Even if no new satellites are placed into orbit, the amount of space junk will not significantly decrease any time soon, with existing satellites remaining susceptible to collisions or even spontaneous fragmentation. For this reason, recommendations are being introduced that are aimed not so much at resolving the problem of debris in orbit, as at helping bring it under control in the coming decades.

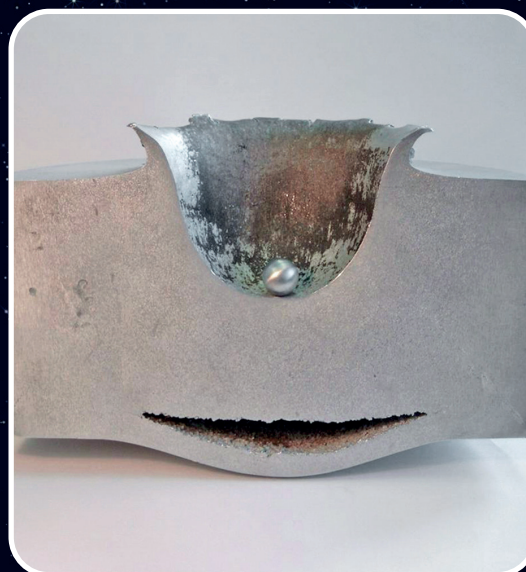
One of these recommendations pertains to designing satellites in a way that will make it possible to deorbit them safely and in a controlled manner at the end of their missions (maximum 25 years). Recent examples include the deorbiting of the Aeolus meteorological satellite. Also, there is a gradual increase in the number of rocket fragments burned after launch, which also reduces the amount of the most dangerous fragments of debris. But such reductions come at a price: the deorbiting process is directed toward a specific area in the Pacific Ocean known as Point Nemo. It is intended for the heaviest space objects, including the Mir station and in the future perhaps also the International Space Station. This practice pollutes the Earth's environment, which is why new satellites should be constructed in a way that allows them to burn up entirely in the atmosphere. With respect to small pieces of debris in low orbit, there are also plans to use laser beams to gradually lower their orbit, and the ClearSpace-1 (Adrios) mission, slated for 2025, is expected to demonstrate the viability of deorbiting of a fragment of space junk using a special satellite.

Protecting natural resources

When we plan our journey from one place to another down here on Earth using satellite navigation, we are not directly affected by the pollution of space around planet. However, if we continue to use such technology without adhering at least to the minimum

recommendations for deorbiting satellites, avoiding collisions, or refraining from anti-satellite weapon testing, we will lead to a scenario in which it will no longer be possible to use Earth orbit. Referred to as the "Kessler syndrome" (after NASA scientist David Kessler), this scenario was first described in the late 1970s and assumes an uncontrollable increase in the amount of space debris that resembles a chain reaction. If this disastrous prospect materializes, we essentially will no longer be able to send anything up into space, and services based on satellite data will simply stop working. Moreover, such a situation could even persist for hundreds of years.

Regrettably, Kessler's scenario is not just some far-off prospect; it could be triggered, for example, by a collision of the largest fragments of debris remaining in orbit (e.g. the eight-metric-ton Envisat-1 satellite) or involving a constellation of satellites. Therefore, the international community is beginning to realize that we should be concerned for maintaining the clean space of Earth orbit as one of the natural resources, comparable to clean air and climate. The time to act is now – not in fifty or a hundred years. ■



The result of a test simulating an impact between a small piece of space debris and a spacecraft, ESA

Further reading:
https://www.esa.int/Space_Safety/Space_Debris