Bringing down the trash

The density of junk orbiting the Earth is at or near a critical value beyond which this man-made debris will self-perpetuate, forming many smaller pieces that are even more of a problem. **Stephen Ornes** reports on the latest ideas about how to bring down the trash

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Space is usually thought of as an empty and serene place. But stay in orbit for too long and you might get shot. That is because the Earth is wrapped in a cloud of projectiles that race around the planet faster than speeding bullets. The number of these lethal flying objects, known collectively as "space junk", is on the rise, and experts warn that the situation is getting out of hand.

Consisting of man-made space debris as well as natural meteoroids, space junk is no abstract concern. Though the chance of a collision between a piece of debris and a working spacecraft is slim, the consequences of such a crash could be severe. In April 2011, for example, the International Space Station (ISS) was forced to change course to avoid a known piece of space junk – a 10–15 cm bit of metal left over from a disastrous collision in February 2009 between a defunct Russian communications satellite and a functioning US satellite. The ISS manoeuvre was not dramatic – a 3 min 18 s burn that shifted the station's velocity by about half a metre per second – but it was the fifth time in three years and the 12th since October 1999 that the station was forced to move because the risk of collision was too high. If a satellite collides with a piece of space junk, it may merely "go dark". But if the ISS is in danger, then so are human lives.

The good news is that, over time, objects gradually lose height because of drag, and most burn up as they descend through the atmosphere. The bad news is that, overall, the number of space-junk fragments continues to escalate because existing large objects collide or fall apart, spewing a sea of smaller – but still dangerous – fragments. Experts worry that in regions of space near the Earth, the density of space junk is either at or near a critical point beyond which debris will self-perpetuate, even without humans sending up any further material. Space would then be a dangerous place for satellites and manned missions alike, threatening the satellite communications on which we rely and limiting our exploration of space.

Despite this known problem we are still creating junk. In 2007, for example, China used a missile to blow up an old weather satellite as a test of an anti-satellite system. This event alone created thousands of pieces of new debris and increased the chance of low-Earth-orbiting satellites colliding with junk by about 25–30%. Last November Russia's Phobos-Grunt spacecraft, designed to travel to Mars's moon Phobos to collect soil, failed because of an engine mishap shortly after lift-off and became marooned in a near-Earth orbit. The crippled vessel carried several tonnes of fuel and a collision could have been disastrous, but

Space Junk3D, Melrae Pictures, LLC

thankfully it fell safely into the Pacific Ocean.

To avoid reaching the point of no return and turning space travel into a risky gamble, action must be taken. Spacefaring countries worldwide need to stop fuelling the junk problem and also co-operate in actively *removing* debris. Several inventions to remove junk have been proposed, from ground-based lasers to suicidal "space janitors", but action is tough in a sensitive political climate where the EU and US must collaborate with India, China and Russia – with Vladimir Popovkin, chief of Russia's Federal Space Agency, speculating only this year that foreign sabotage could not be ruled out as the reason for Phobos-Grunt's demise.

Looming liability

One big danger on the horizon is Envisat, launched by the European Space Agency (ESA) in 2002. Then the largest non-military environmental satellite ever put into orbit, the celebrated spacecraft produced data for thousands of projects and studies, ranging from tracking giant squid in Chile to measuring the

What's out there

The documentary film *Space Junk 3D* tells the story of how we have reached the tipping point in terms of debris in low Earth orbit, potentially jeopardizing working satellites and future manned missions to space.

ESA

Break-up This visualization of a rocket-stage separation illustrates how much space junk is created by every successful launch.

ESA

Out of control ESA lost contact with its Envisat satellite in April and French space agency CNES has confirmed that it is not in "safe mode" as was hoped.

loss of Arctic sea ice caused by climate change. However, this record-setting eye on the Earth may have just become a big liability. Scientists had estimated that the behemoth would run out of fuel some time in 2013, but in April this year Envisat met a similar fate – ahead of schedule – when ESA lost contact with the satellite. If the craft has broken down, it will have lost the ability to guide itself through space and the same satellite that for more than a decade had beamed data back to Earth about our changing planet will join the largest junkyard in the known universe – a swath of space called low Earth orbit (LEO), which extends up to about 2000 km. The satellite may linger in LEO for 150 years before it re-enters Earth's atmosphere, with a 15–30% chance of smashing or being smashed by another object before then.

In theory, Envisat could collide with one of the thousand or so functioning satellites, but it is more likely to encounter refuse – leftover scraps from defunct satellites, disused rockets or empty fuel tanks. According to NASA's Orbital Debris Program Office, space trash includes nearly 20 000 pieces sized 10 cm or larger. There are roughly half a million pieces sized between 1 and 10 cm, and tens of millions of smaller pieces; and most of it inhabits LEO – the closest and therefore cheapest orbit for artificial satellites, and also where broken fragments remain. Many communications satellites orbit farther out in geostationary orbit (GEO), at about 36 000 km above the Earth. Studies indicate GEO's debris population is less dense than LEO's, but because many satellites are sent to a "graveyard orbit" just above GEO after their missions are complete, the problem in GEO could become severe in the future.

All kinds of space debris can cause damage. "[But] the most probable impact is in the small-size domain," says Heiner Klinkrad, ESA's senior space-debris expert. He points out that 1 mm objects could jeopardize a satellite's systems, and a collision with a 1 cm object will most likely end a mission. As for objects measuring more than 10 cm, they will cause "catastrophic disintegration", he says. "It's particularly bad if you have two objects of similar sizes and a large impact." Before contact with it was lost, the eight-tonne Envisat, which is 26 m long, 10 m wide and 5 m deep, even had to fire its thrusters to avoid colliding with the upper stage of a Chinese rocket.

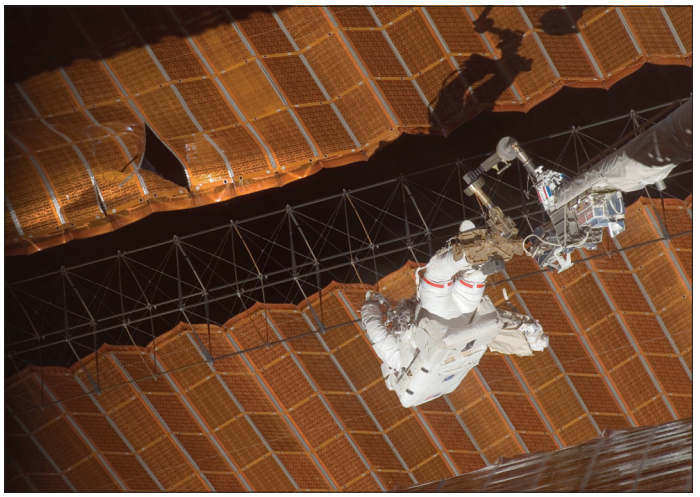
Taking it seriously

Policymakers have started to take notice of the space-junk problem. The EU is working with various nations to develop a space code of conduct, although those efforts have largely stalled, with countries such as China and India annoyed that they were not consulted earlier in the drafting process. Last August a new report from the US National Resources Council (NRC) warned that the junkyard had already reached a threshold where, because of collisions, the number of objects will continue to increase. Even if satellites stopped going into space, junk would remain a threat for decades, if not centuries to come.

But after more than 50 years of sending objects into space – the first accidental orbital break-up occurred in mid-1961 – the problem has advanced beyond the point of being solvable by implementing guidelines in future missions. Donald Kessler, who led the committee behind the recent NRC report, has been thinking about orbital debris and removal since the 1970s. In a 1978 paper, he argued that debris accumulation over time could lead to a runaway event – an unstoppable cascade of collisions that could result in a "debris belt" of dangerous fragments. (In a press interview from the same time, his colleague John Gabbard referred to this event as "Kessler syndrome", a name that has stuck ever since.) Kessler says that if nations do not start thinking seriously about how to reverse the trend in LEO, "we're definitely going to go past that point of instability". The problem extends to higher orbits, too, but LEO presents a more immediate concern. "The only way to reverse the trend of debris accumulating, and reduce the amount, is to retrieve objects," Kessler says.

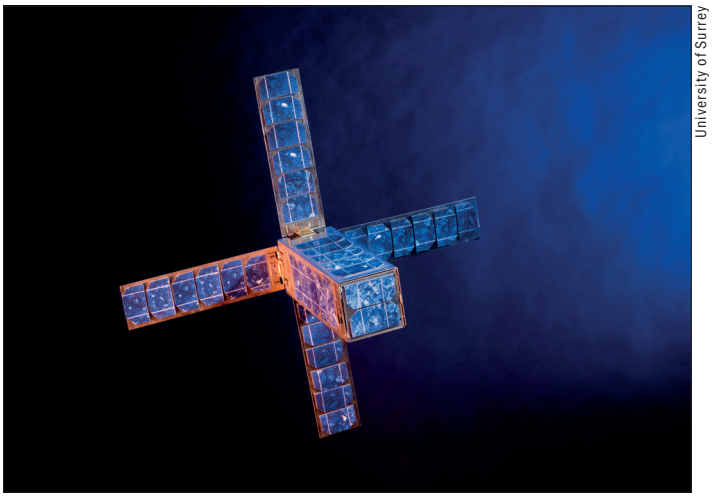
In 2010 US President Barack Obama, in the latest national space policy, directed NASA and DARPA – the research and development agency of the Department of Defense – to start thinking about how to clean up space. Though NASA has not yet been given responsibility to bring down space junk, both agen-

NASA



In the line of fire In 2007 astronaut Scott Parazynski repaired damage to the International Space Station's solar sails caused by space debris.

University of Surrey



Under consideration The CubeSail attachment, being developed at the University of Surrey, would open to bring down expired satellites via drag.

cies are listening to ideas about how it could be done.

But taking down space junk is more than just an engineering challenge. "We can go remove a rocket body if we have to," says Nicholas Johnson, chief scientist at the NASA Orbital Debris Program Office. What is even tougher is dealing with the tricky political and legal ramifications, and the exorbitant potential cost of the clean-up job. The estimated cost of bringing down Envisat could run into hundreds of millions of dollars. The challenge, says Johnson, is to "marry the technical part with something cost-effective" – which is easier said than done, considering that the cost of sending mass into space is thousands of dollars per kilogram.

Spacefaring nations have already taken some steps to reduce the debris risk of new satellites. In 2002 the Inter-Agency Space Debris Coordination Committee (IADC), which facilitates international work on space debris, adopted guidelines asking member nations to build satellites that would leave LEO no more than 25 years after the end of the mission. Computer models predict that defunct satellites staying any longer could significantly add to the small-debris population through break-ups and collisions. New satellites should be designed to not contribute to the long-term problem. They should either be sent to a much higher graveyard orbit once they have reached the end of their working life, or brought down low enough that atmospheric drag takes over and pulls them down so that they burn up.

Down to Earth

As for space junk that is already stuck in orbit, scientists have proposed a wide variety of solutions for how to bring it down. In 2009, for example, NASA and DARPA hosted the first International Conference on Orbital Debris Removal. There, among other ideas, Jerome Pearson from Star Technology and Research – a research company based in South Carolina – together with his colleagues introduced a tether system called the ElectroDynamic Debris Eliminator (EDDE) vehicle. The lightweight EDDE vehicles have small nets at either end of a long conducting cable, with solar arrays attached along the middle. The vehicle collects debris in the nets and releases it at a lower altitude, reducing the orbital lifetime. Each vehicle can remove 36 tonnes per year; in six or seven years, the researchers say, the vehicles could remove all large objects from LEO.

Other ideas teeter toward science fiction. Jim Hollopeter from Texas-based firm GIT Satellite Communications has proposed spraying orbital debris with water mist that would add enough mass to de-orbit the trash. "The worst that could happen is more snow," he says.

Amateur scientist Sean Shepherd, a librarian at Eastern New Mexico University, has even suggested that sticky adhesives with large cross-sectional areas could be used to de-litter space. Meanwhile, at the University of Surrey, space engineer Vaios Lappas and his team are developing a device, called a CubeSail, that could be sent up with new satellites. At the end of the mission, the sail deploys – dragging down the spacecraft.

Claude Phipps, a physicist who worked at the Los Alamos and Lawrence Livermore national laboratories and now runs a company called Photonics Associates, thinks ground-based lasers may be the answer. Phipps and colleagues, including laser experts at the Sandia and Lawrence Livermore national laboratories, recently gave new life to an idea he invented in 1996, known as a laser broom, in which lasers are used to clean up LEO. The idea is that high-intensity, 10 ns pulses from a ground-based laser could vapourize a bit of the debris, creating a tiny plasma jet. The jet propels the debris low enough to re-enter the Earth's atmosphere.

Although the idea is not new, Phipps says it makes

1 mm objects could jeopardize a satellite's systems, and a collision with a 1 cm object will most likely end a mission

Hands off, it's mine

If scientists do find and fund an efficient way to clean up the Earth's orbiting junkyard, they cannot just run out and launch. Before the trash collectors can be dispatched – be they lasers, tethers or sails – a host of thorny issues need to be resolved. They run the gamut of legal topics, including intellectual property rights, national-security interests and the moving of an object of one country by another.

In the US, for example, "turf battles and interagency interests are very severe", says attorney Joanne Gabrynowicz, director of the National Center for Remote Sensing, Air and Space Law at the University of Mississippi School of Law and a frequent adviser to UN officials on space law. A tricky example would be if a US intelligence organization wanted to remove a defunct satellite while keeping its existence a secret from the Department of Defense. "You can't assume that the CIA wants NASA or the NOAA or the DOD touching its satellites," Gabrynowicz says. "They're all very jealously guarding their satellites for a lot of good reasons."

Different issues emerge on the global scale. According to the 1967 Outer Space Treaty, which has been ratified by most spacefaring nations, an object in space is the sole property of the country that launched it. Ownership does not change if the craft explodes or collides with another, which means individual pieces of debris are not up for grabs. "When an object is placed in space, the nation that put it there is the only one that has the right to retrieve it," says Gabrynowicz. The problem with the removal of debris, she adds, is that one country will be destroying objects in a place populated by the belongings of many different countries. "Anything that has the potential to retrieve or destroy an object in space can be seen as a weapon," she says. "Let's say you have a laser in space, and you say you're using it to get rid of non-functioning objects. There's going to be a great deal of skepticism as to whether that's true or not."

A country does not need permission to remove its own trash, Gabrynowicz points out, but any effort to remove debris should be as transparent and diplomatic as possible. One nation's efforts to remove another's space trash may be misconstrued as an attempt to poach space technology.

NASA

Eyes on the sky NASA uses radar systems such as this one at the Goldstone Observatory in California, as well as optical telescopes, to monitor orbital debris.

more sense now because there is more infrastructure – including the telescopes and lasers – to make it a reality. "Back then, you could dream about it", he says, "but now you can build it." A few stations would suffice to cover LEO, and larger objects could be brought down with repeated pulses. Although Johnson and his NASA colleague J-C Liou reported in *Science* in 2006 (**311** 340) that lasers were not practical, Phipps says times have changed, and we should now revisit the idea. "You could be working on 800 objects in parallel, and at the end of those two or three years re-entered them all," Phipps says. "You wouldn't have to fly up there. The sensible way to do it is to have a laser do the job."

Some even believe the way to clean up space is to send up a "janitor". In February scientists at the Swiss Space Center at the École Polytechnique Fédérale de Lausanne introduced CleanSpace One, a project aimed at building grappling satellites that can go into space and, with the aid of a giant metal claw, manually grab the trash. Once it has secured the debris, the clean-up satellite heads down – and the janitor and its cargo both burn up in the descent.

Climate-change help

In early 2011 Liou published the results of a computer simulation, which showed that removing five large pieces of debris annually would halt the runaway growth of the LEO population. But in August 2011 researchers in the UK said five was not enough. Writing in the *Journal of Geophysical Research* (**116** A00H08), a team led by Hugh Lewis at the University of Southampton pointed out that the increasing amount of carbon dioxide in the atmosphere – the same force driving climate change on Earth – causes the temperature of the thermosphere, the largest swath of the Earth's atmosphere, to drop. That means it is becoming less dense – in fact, it has been suggested that within 100 years the thermospheric density at some heights could drop to half its present value. Lewis's team reported that as a result of the thermosphere's density decreasing, the drag force on pieces of orbital debris lessens and the trash stays put. Taking into account the fewer pieces of debris exiting LEO and burning up in the Earth's atmosphere, the researchers concluded that to stabilize LEO, not five but 10 large debris objects must be removed per year.

If a solution to bringing down space junk can be found, then perhaps in the near future one of those 10 objects can be Envisat. The giant satellite is simply too large to ignore. Unfortunately, while space junk is not a problem that is going away, it is a problem that is easy to put off for now. Policymakers and scientists need to find solutions to remove debris soon – but they cannot afford to rush into anything.

"In the long term, the sooner you do it, the cheaper it's going to be," Kessler says. However, he adds that rushing into such an enormous and costly project is not the right way to go about things. "We need to study the alternatives in terms of how we reverse the trend. In LEO, we can only reverse it by bringing things back." ■