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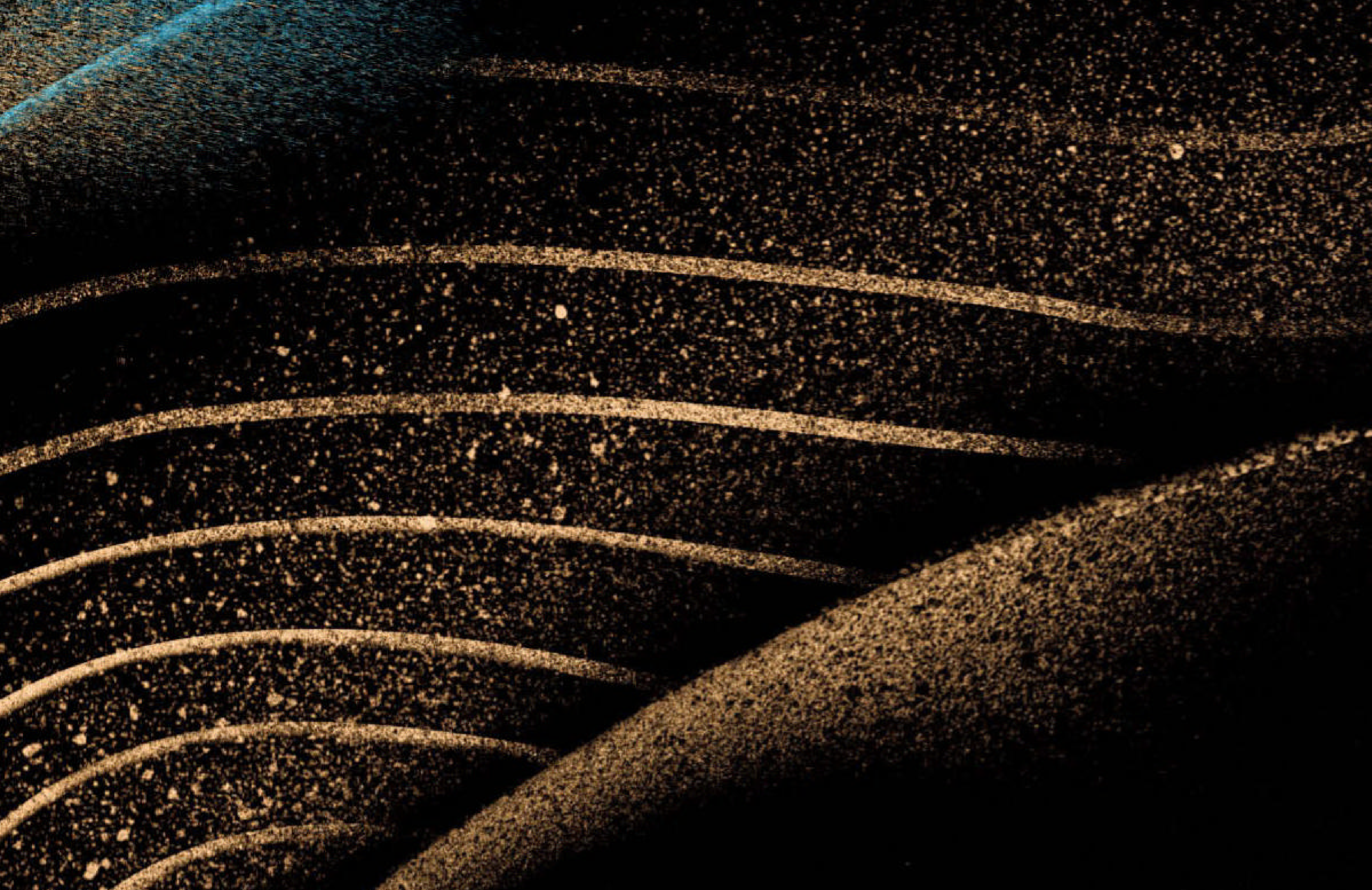


The new age of sail

We are on the cusp of a new type of space travel that can take us to places no rocket could ever visit, says **David Hambling**

JOHANNES KEPLER is remembered for writing down the laws of planetary motion. But the 17th-century astronomer also liked to observe comets and, one day, he noticed that their tails always pointed away from the sun, no matter which direction they were travelling in. To Kepler, it could mean only one thing: the comet tails were being blown by a wind from the sun.

The idea must have seemed exotic in Kepler's day, but he floated it in a 1610 letter to his friend Galileo Galilei. "Provide ships or sails adapted to the heavenly breezes, and there will be some who will brave even that void," he wrote. You would be forgiven for smiling at the thought. But Kepler was right. The sun produces a wind in space and, in principle, it can be harnessed.

ADA ZIELINSKA

There is no shortage of reasons to try. Rockets may be great for blasting us into orbit, but their limitations are serious. Their finite supply of propellant puts a cap on the manoeuvres they can make. Build a solar sailing ship for space, though, and you can tap into the effectively limitless source of power that Kepler noticed all those years ago.

There is a craft demonstrating this in Earth orbit right now. With no need for fuel, this technology could also enable long-term observation posts in space. Meanwhile, NASA has advanced plans to sail to asteroids in regions of usually inaccessible space – and who knows what we might find when we begin to explore such places. We may be on the cusp of an exciting new age of sail.

When the wind touches our cheek we are feeling molecules of the atmosphere brushing against it. The wind in space is made of different stuff. First, there are particles of light streaming from the sun constantly, each carrying a tiny bit of momentum. Second, there is a flow of charged particles, mostly protons and electrons, also moving outwards from the sun. We call the charged particles the solar wind, but both streams are blowing a gale.

In 1924, Friedrich Zander, a scientist working in the Soviet Union, developed the first serious solar sail concept. He imagined harnessing light, not charged particles, because all that would be required is a huge mirror for photons to nudge along. Decades before space travel became possible, Zander understood that sailing would provide a unique way of getting around up there.

Today, rockets are the workhorses we rely on, whether for a short hop to the

"With its steady acceleration and enough time, a solar sail can catch up with anything"

International Space Station or a mission to Pluto. A rocket operates on the principle of action-reaction: as it fires out propellant in one direction, a force moves the craft the other way. Beyond our atmosphere, there is no friction, so a rocket will stay on the same trajectory unless affected by another force, such as the gravitational pull of a large object. This means that if a rocket wants to slow down or change direction it must expend propellant. The size of the fuel tank limits how much of this it can do.

This is why spacecraft routinely exploit the gravity of planets, orbiting a few times then briefly firing their thrusters to slingshot themselves in a new direction. But this tactic has limits. For one, it means that craft can only launch during a time window when the alignment of the planets is right. Plus, it only works within the narrow plane that our solar system's planets orbit in, known as the ecliptic.

There are other intriguing bodies that orbit in different planes. Take Eris, a dwarf planet that is more massive than Pluto. Or Pallas, the third largest asteroid we know of, which orbits at a wild angle of 34 degrees to the ecliptic. The off-kilter tracks of these bodies show that they have a different history to the rest of the solar system. Visiting them to learn about it would require a prohibitive amount of rocket fuel – but sails have no such limitation. "Solar sails can get you to places that you can't get to with conventional propulsion," says Les Johnson at NASA's Marshall Space Flight Center in Huntsville, Alabama.

The sail of NASA's Near Earth Asteroid Scout probe is small and tidy when packed up

NASA

Sailing in space

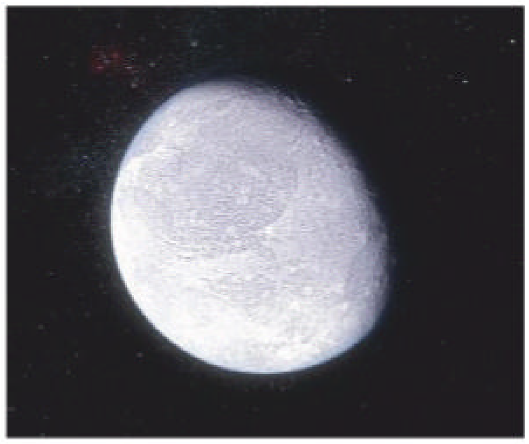
Catching the solar breeze demands a sail that is wide but paper-thin, to net as many particles of light, or photons, as possible without being too heavy. But you can't have a delicate sail flapping around during a launch into space. This means sails must be packed up and unfurled beyond the atmosphere – a devilish challenge. We only showed this could be done in 2010, when JAXA, the Japanese space agency, launched its IKAROS probe. It reeled out a tape that was then stretched into a 0.007-millimetre-thick square sail measuring 20 metres diagonally.

A sail that size wasn't large enough to noticeably move the probe it was attached to. Then along came CubeSats, tiny, cheap satellites that could be controlled from the ground. "CubeSats made it financially viable for an organisation like us to demonstrate the technology," says Bruce Betts at the Planetary Society, which is dedicated to space advocacy. After a failed attempt in 2015, the society's LightSail 2 mission was launched last year. At first, operators struggled with the sail, which is about the size of a boxing ring, and the craft tumbled. But after some adjustments, they established control and showed that a craft could manoeuvre using light pressure alone.

LightSail 2 was expected to last a year, but it has experienced less wear than anticipated and is still going. "We didn't know how it would work out," says Jennifer Vaughn, also at the Planetary Society. The craft has successfully shown that the sail can be used to change its orbital height, by up to 2 kilometres so far. The biggest surprise has been how hard it is to steer. To sail steadily, the craft's centre of mass must line up exactly behind the centre of thrust provided by the sail. The lack of friction in space means this can easily slip and, if left uncorrected, the craft gets out of control. LightSail 2 has been in so-called "de-tumble mode", correcting the alignment, for a third of its time in orbit.

NASA

Johnson has plans for much more ambitious voyages. First on his destination wish list are asteroids on oval-shaped orbits that pass close to Earth before zipping off into the outer reaches of the solar system. We have never visited such objects because they speed past us so quickly that a rocket can't catch up. But Johnson is planning a mission called Near Earth Asteroid (NEA) Scout, due for launch in 2021, which might do it. "With its slow, steady acceleration, and given enough time, a solar sail can catch anything," he says.



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An artist's impression of Eris (above) where solar sails might take us. A 20-metre wide sail tested at a NASA facility (centre)

The exact target isn't yet decided, but it could be an object measuring about 12 metres across called 1991 VG, which veered close to Earth in 1991 and 2017. Such objects could hit our planet, so finding out more about them – for instance, whether they are sturdy boulders or piles of loose rubble – could help us protect ourselves. The NEA Scout team is learning lessons from LightSail 2; the NASA craft will have a special mechanism to keep its sail and centre of mass aligned.

The next step for space sails could well involve staying perfectly still. That is more useful than it might sound. A spacecraft perched in interplanetary space could make long-term observations, for instance of solar storms surging towards Earth. Johnson is planning to test this idea with a proposed mission called NASA Solar Cruiser. On its first leg, the probe would slip into a spot called the L_1 Lagrange point. Here, the gravitational pulls of the sun and Earth balance out. The trouble is that staying there is like trying to balance on a needle; whatever you put there would need to apply small forces to stay in position. A rocket would eventually exhaust itself, but a craft with a light sail can, in theory, remain there indefinitely.

After attempting to hover at the L_1 point, Solar Cruiser would tack towards the sun. Most rockets we send this way approach using gravity assists to slow down and so must stay in the ecliptic. This wouldn't be a problem for Solar Cruiser, which would drift upwards and try to hover over the solar poles. These are thought to be critical to the sun's weather, but they are hard to study, being out of sight from Earth. The only effort that aims to do something similar is the European Space Agency's Solar Orbiter, which launched in February. Its goal is to get the first pictures of the poles by slipping into an inclined orbit around the sun, but this will take a huge amount of fuel.

Johnson's sails would be pushed by light – which is fine if you are exploring around the sun. But as light spreads out it gets more diffuse; a solar sail in the depths of the solar system just won't have as much light to fill it. This is why Pekka Janhunen at the Finnish Meteorological Institute thinks we need to sail not just with photons, but with the solar wind, the flow of charged particles.

It is true that the solar wind also gets more diffuse as it streams away from the sun. But in 2006, Janhunen came up with an idea for how to harness its power even quite far out. The electric sail, or e-sail, would consist of dozens of wires many kilometres long radiating from a hub. The whole thing would spin slowly to keep the wires straight. Each wire would carry a positive electric charge so that when positively charged protons in the solar wind bump against them, they repel the sail and give it a push. But here is the nifty part: closer to the sun, the powerful solar wind would mostly rifle through the gaps between the wires. Further away, the solar wind is gentler and would catch the sail nicely. This counter-intuitive bit of physics could provide a way to sail in the outskirts of the solar system.

The first Finnish e-sail mission in 2013 failed, but Jaan Praks at Aalto University, also in Finland, says the team is working on successors called Foresail-1 and 2. The aim of these missions is to use a single wire design to apply a slowing force and de-orbit a satellite at the end of its life. It is a finger in the wind that could help get us to bigger and better e-sails. NASA is also interested in this technology and is developing the concept into the Heliopause Electrostatic Rapid Transport System. Ground experiments suggest this could reduce the transit time to the edge of the solar system by 60 per cent compared with a conventional rocket.

As any sailor knows, the wind isn't a perfect source of propulsion because you can only sail so close to it before you have to start tacking and gybing. This means any cosmic sailing ship would clip along nicely when going away from a star, but would struggle to turn back.

Still, this won't impede the dream of people like Johnson, who want to use these new techniques to set a course for worlds currently far beyond our reach – namely the planets orbiting our nearest star, Alpha Centauri. To do that we would need to accelerate a solar sail to about a fifth of light speed, which, if not easy, isn't impossible. "My career goal is for my work on the solar sail to be a footnote when they write the history of the exploration of Alpha Centauri," says Johnson. "I want to see a future where we are exploring other stars." ■

David Hambling is a technology journalist based in London