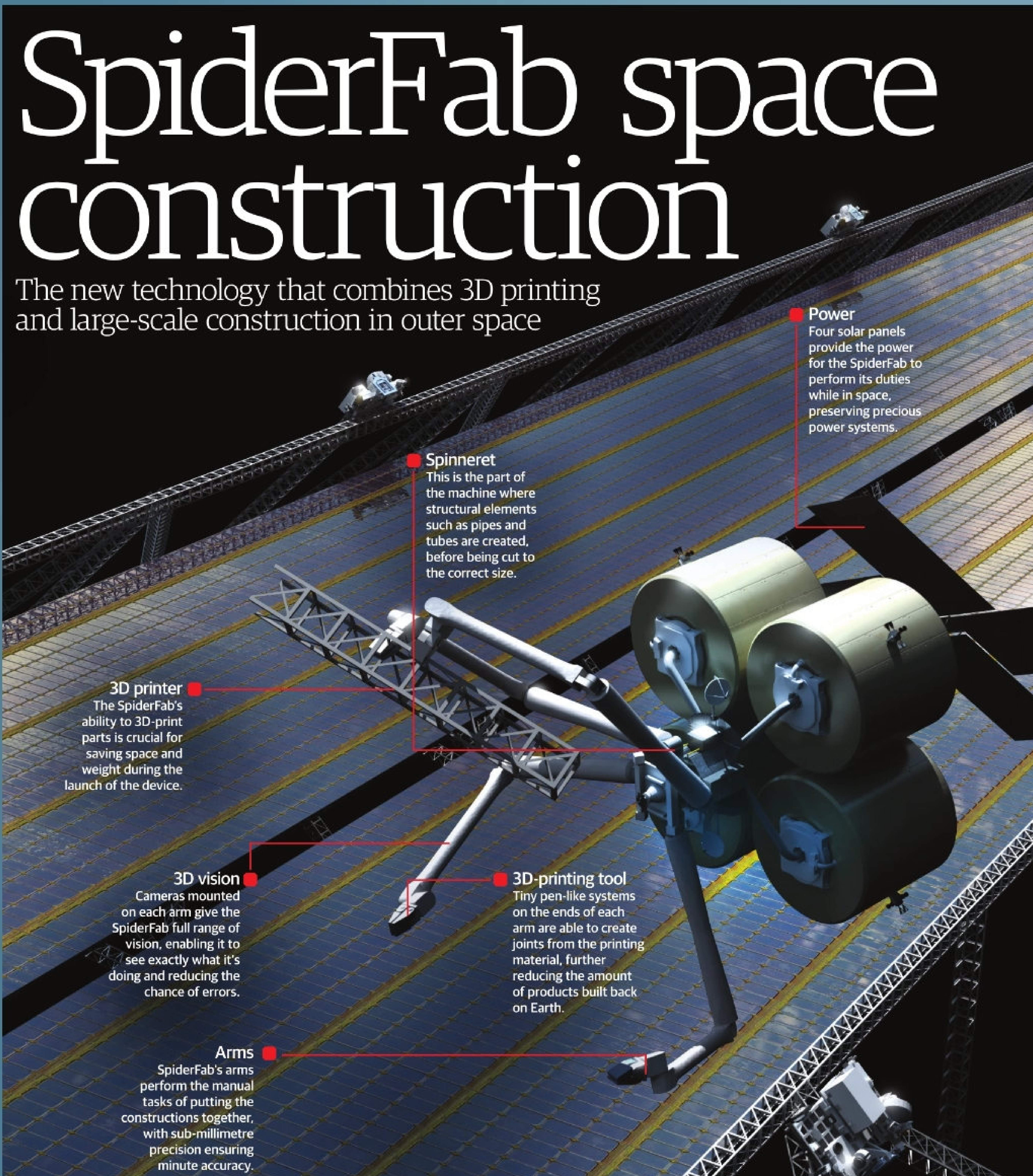
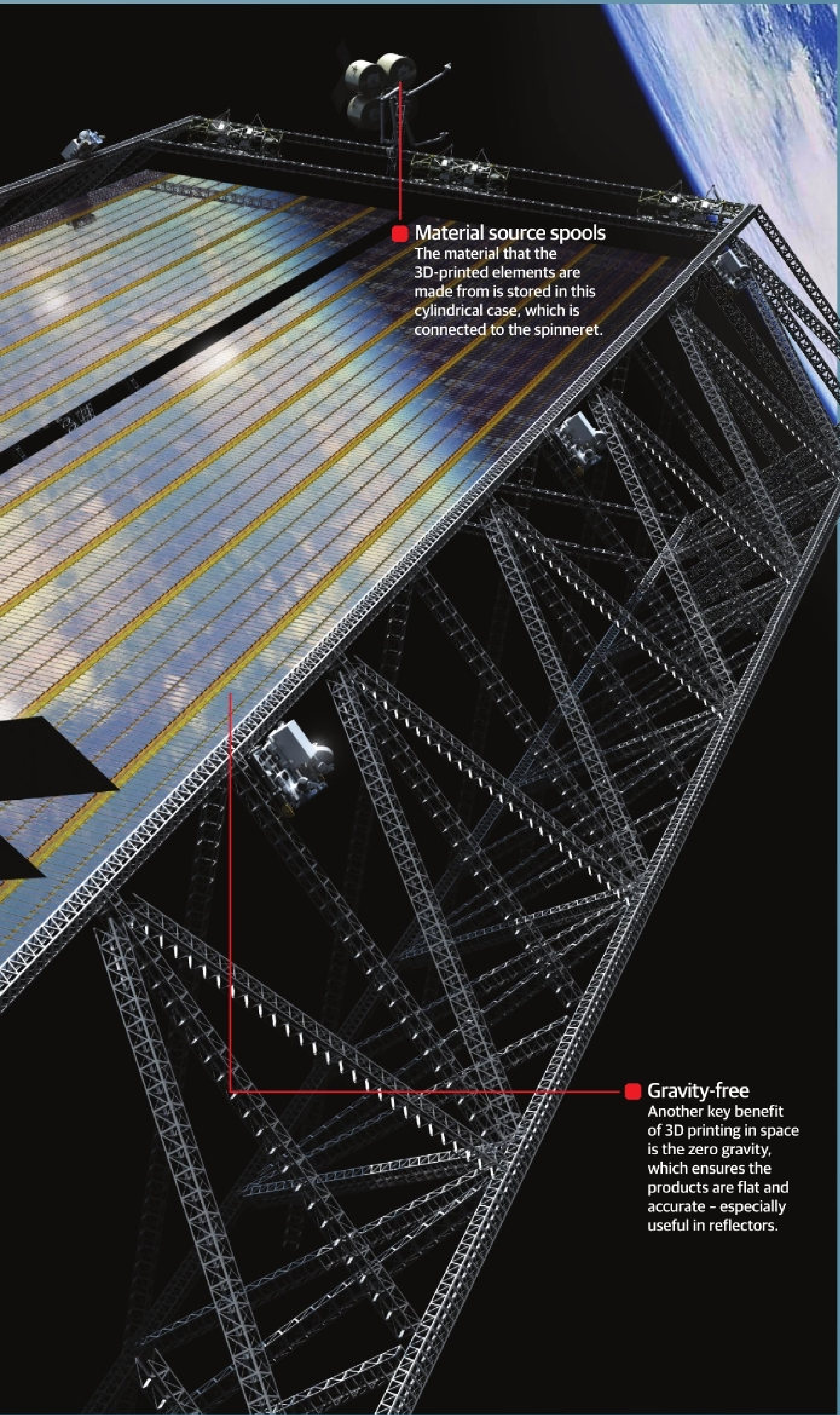
THE BOOK OF AMAZING SPACE INVENTIONS

FUTURE

SpiderFab space construction

The new technology that combines 3D printing and large-scale construction in outer space





If you think putting together an IKEA wardrobe is tough, you should see one of the latest technologies to get the green light from NASA's Institute of Advanced Concepts (NIAC).

SpiderFab is a creation from Tethers Unlimited that will build structures in space, slashing the cost and difficulty of launching mission devices. At the moment structures like the Starshade, for the New Worlds Observer mission, have to be put together on Earth before being launched into space. This requires a large and powerful rocket, increasing both the cost and difficulty of the mission.

The idea behind the SpiderFab is to have all the individual components stored in the payload and, once the smaller, more-efficient rocket has delivered them safely into space, it will get to work constructing the device. The Starshade is essentially a large screen placed in front of a space telescope that enables it to photograph the exoplanets of far-away stars, so the benefits for constructing this using the SpiderFab are plain to see.

By sending the Starshade up in pieces to be put together in space, efficient packing would enable the construction to be twice the size, with exactly the same mass and an incredible 1/30th of the volume - halving the mission cost.

The 3D-printing element is a key aspect of the SpiderFab's appeal. It can construct elements such as carbon-fibre tubes, seemingly from nowhere, once again saving hugely on the space used and the cost of sending pre-built tubes into space.

It can also 3D-print joints, meaning that it only needs to be sent up with the bare-minimum of pre-built objects and the material to 3D-print the rest. It's accurate to sub-millimetre levels so scientists should have few concerns about accuracy.

The SpiderFab is aptly named, as its appearance is much like a spider, with a number of limbs that it uses to assemble the structure, along with a 3D vision system to enable it to detect what it's doing.

Another amazing thing about the device is its sheer range of abilities. Not only does it have the handyman skills to construct a device in outer space, but SpiderFab can create many useful space products such as parabolic reflectors, optical mirrors, solar arrays and phased array antennas. Far from being a one-trick pony, the SpiderFab could be the solution to sending products into space far more easily and cheaply.

With this new-found flexibility, scientists could learn more about the universe, sending up more missions due to reduced cost. They could also push the boundaries of what we previously thought was possible, once the SpiderFab has made bigger, better and more-accurate astral constructions a real possibility. We could gaze further, in greater detail, and perhaps even travel vaster distances, all thanks to one small, multi-limbed, 3D-printing robot.

"SpiderFab could be the solution to sending products into space"

Nautilus-X

The artificial gravity spacecraft that could take humans to the Moon and beyond

When it comes to manned missions into deep space there are no shortage of proposals on the drawing board. People have dreamed up spacecraft with various fantastical elements, from futuristic propulsion engines to somewhat ambitious aesthetic designs, but one proposal that warrants a serious glance is Nautilus-X. It's a spacecraft that builds largely on existing technology to make human exploration of the Solar System a realistic possibility, and at a reasonable price, too.

Drawn up by NASA engineers Mark Holderman and Edward Henderson, this deep space vehicle might not be as exciting to look at as some of the other futuristic proposals being touted but it's certainly one of the most promising. The full name of the vehicle is the Nautilus-X, which stands for Non-Atmospheric Universal Transport Intended for Lengthy United States Exploration, while this type of spacecraft is known as a Multi-Mission Space Exploration Vehicle (MMSEV).

Nautilus-X would be capable of supporting a crew of six for missions lasting from one month to two years. Although it might look like a mini space station, the whole thing is designed to be able to travel throughout the Solar System, be it near the Moon or Mars. Although not capable of descending to the surface of another world itself, it has docking ports to which landing craft can be attached.

The intention of the vehicle is that, once built, it could remain in space for many years with several different crews utilising it. For example, one crew could travel to Nautilus-X in an Orion spacecraft and then take the entire spacecraft to Mars for a mission lasting up to a year. They would then return in Nautilus-X at the conclusion of the mission and leave the spacecraft near Earth orbit, ready and waiting for another crew, while they travel back to the surface of Earth in their Orion capsule.

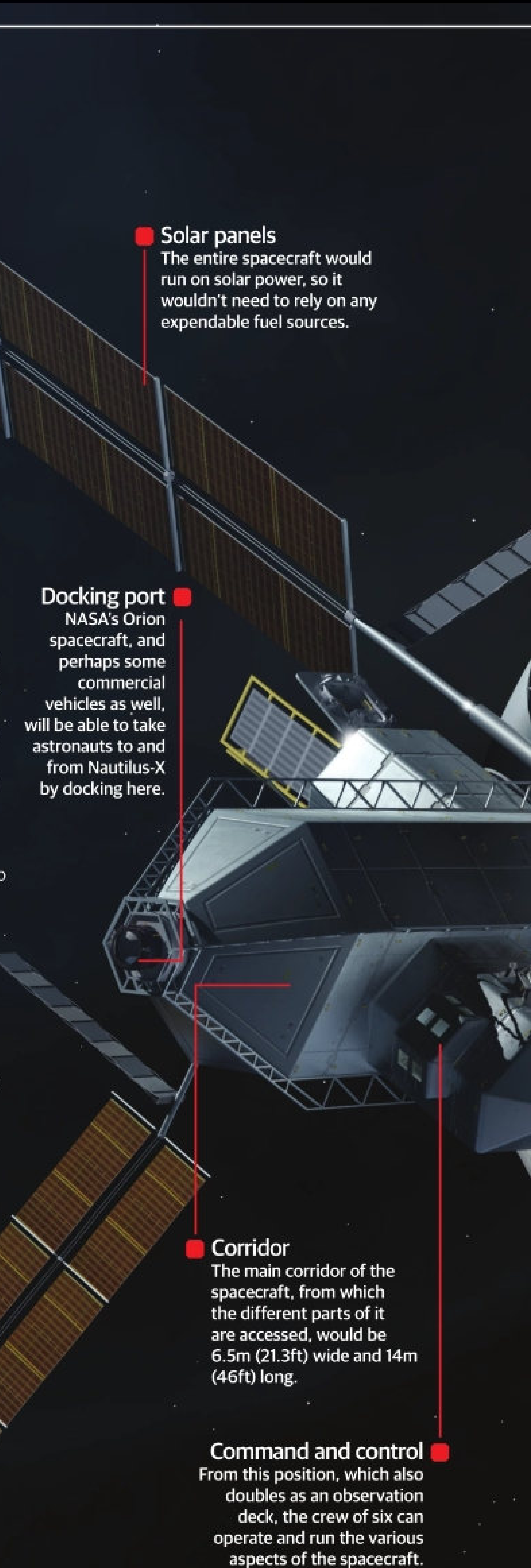
Such an implementation would allow multiple rotating crews to make use of the spacecraft on a variety of missions. Solar panels would make the station almost entirely self-sustainable, while on-board farms could provide astronauts with food. At the outset of a mission, though, it's likely astronauts would need to bring some supplies with them, perhaps on a separate spacecraft such as SpaceX's Dragon.

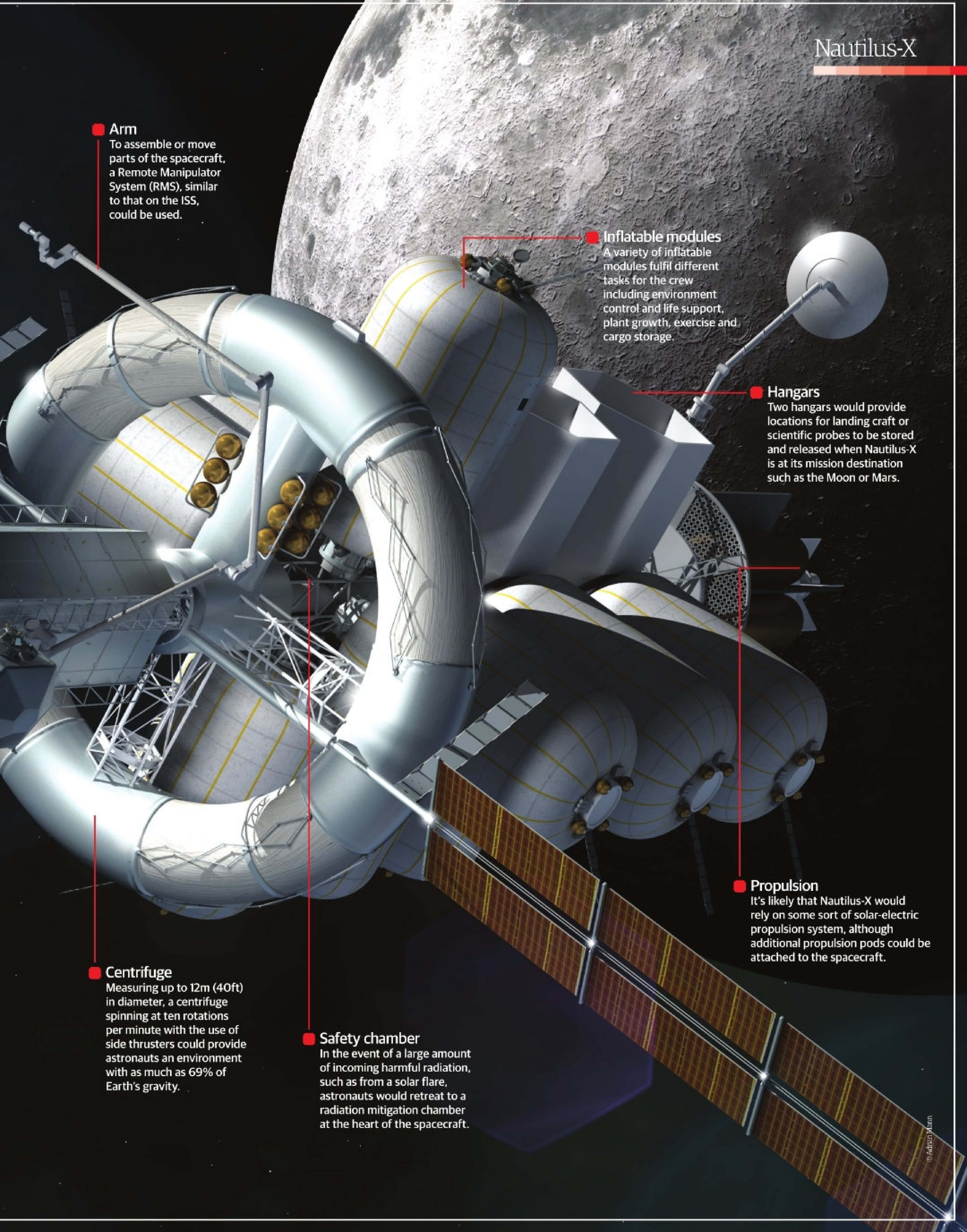
Another key feature of Nautilus-X is, as you may have noticed in our accompanying illustration, the centrifuge. It is well documented that prolonged exposure to space can have a debilitating effect on an astronaut's health, in particular their muscle and bone strength. It is estimated that as much as two per cent of bone mass is lost for every month an astronaut is weightless in space, so providing an artificial gravity environment could be essential for long-term exploration missions. The centrifuge on Nautilus-X would provide between 0.51 and 0.69 of Earth's gravity, allowing astronauts to recuperate bone mass they may have lost while on other parts of the spacecraft or outside on a mission. Such a centrifuge had been suggested as an additional module for the International Space Station to test the technology, but unfortunately that now seems to be on hold due to budgetary reasons.

On the subject of money, Nautilus-X carries with it a rather alluring price tag. The brains behind the project estimate it would cost around $3.7 billion (£2.3 billion), not even twice the price of NASA's Curiosity rover, while development could be completed in just over five years. Such figures are attractive, especially for the money-conscious top dogs at NASA, so there is a chance that after further research this spacecraft may come to fruition.

But on that note, when could we expect to see any work on Nautilus-X begin? At the moment, NASA's manned exploration funding is tied up in a number of projects, namely Orion, Commercial Crew Development (which includes funding for SpaceX, Boeing and Sierra Nevada Corporation's upcoming manned vehicles), the ISS and the Space Launch System heavy-lift rocket. The latter would be essential for launching and assembling the various components of this spacecraft in Earth orbit. Whether we will ever see Nautilus-X fly is up for debate, but it's good to know that NASA has a sound proposal for a deep space exploration vehicle if it ever does decide to go down that route.

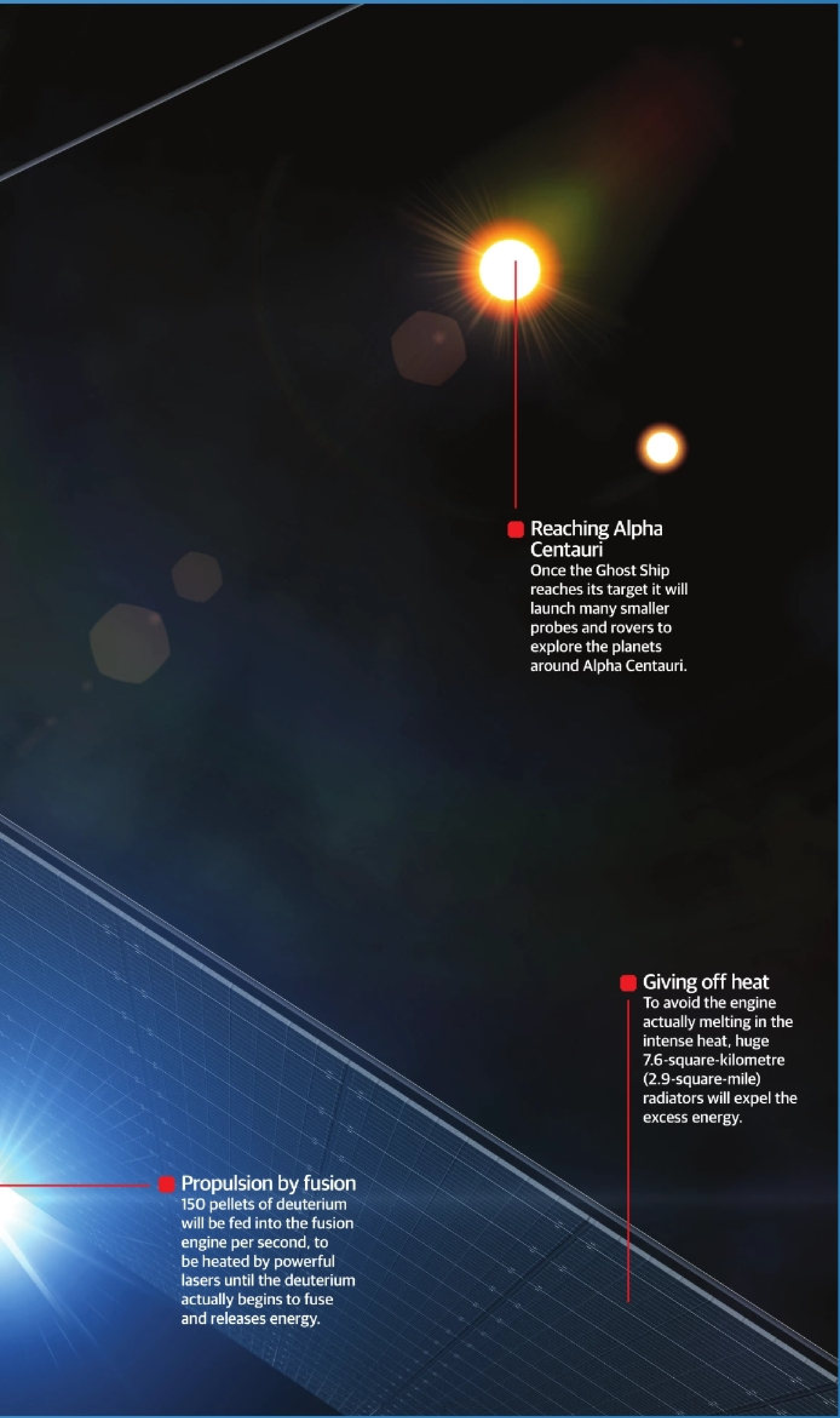
> "Nautilus-X would be capable of supporting a crew of six for missions lasting from one month to two years"




Arm
To assemble or move parts of the spacecraft, a Remote Manipulator System (RMS), similar to that on the ISS, could be used.
Inflatable modules
A variety of inflatable modules fulfil different tasks for the crew including environment control and life support, plant growth, exercise and cargo storage.
Hangars
Two hangars would provide locations for landing craft or scientific probes to be stored and released when Nautilus-X is at its mission destination such as the Moon or Mars.
Propulsion
It's likely that Nautilus-X would rely on some sort of solar-electric propulsion system, although additional propulsion pods could be attached to the spacecraft.
Centrifuge
Measuring up to 12m (40ft) in diameter, a centrifuge spinning at ten rotations per minute with the use of side thrusters could provide astronauts an environment with as much as 69% of Earth's gravity.
Safety chamber
In the event of a large amount of incoming harmful radiation, such as from a solar flare, astronauts would retreat to a radiation mitigation chamber at the heart of the spacecraft.
© Adrian Mann

Ghost ship to Alpha Centauri

It's all hands on deck to Alpha Centauri aboard the interstellar Ghost Ship



The destination is Alpha Centauri, a triple system of stars located some 4.37 light years away from the Sun. The system could have at least one Earth-sized world called Alpha Centauri Bb and perhaps more. To learn about and explore other stars and exoplanets closer, Alpha Centauri is our best bet but, even though it might be relatively close, getting there will be a feat in itself.

That's what Project Icarus is all about. A joint project between the British Interplanetary Society and Icarus Interstellar, its goal is to design a craft using current or near-future technology. As part of its development, Project Icarus members were encouraged to form teams to design possible propulsion schemes using nuclear fusion that could feature in the final Icarus design. The winning design was the Ghost Ship, led by Andreas Hein of the Technical University of Munich. While Ghost Ship is still only a concept, its new ignition system could be the way forward when it comes to interstellar travel.

Nuclear fusion is a popular means of generating energy when scientists consider how to reach the stars. Fusion involves two atoms, such as deuterium, tritium or helium-3, fusing into one. This releases energy in the process and is far more-efficient than nuclear fission, which splits atoms and is what runs our nuclear power stations today. In the 1970s Icarus' ancestor, a British Interplanetary Society project called Daedalus, showed that a fusion-powered starship could reach about ten per cent of the speed of light, meaning it would take 43.7 years to reach Alpha Centauri.

Ghost Ship would be a little slower, accelerating for 15.5 years up to six per cent of the speed of light, after which the 153,800-ton craft will cruise through interstellar space for 54 years. It does this using a method known as inertial confinement fusion fast ignition. Here 150 tiny pellets of deuterium are heated by powerful lasers every second, until they grow so hot and dense that the atoms inside the pellets begin to fuse, expelling large amounts of energy and lots of high-energy neutrons. This neutron radiation can be extremely dangerous, so the engine is separated from the rest of the craft on a long boom. However, the neutrons can also be gathered and recycled to provide the additional energy to power the lasers that ignite the fusion and create more of these neutral subatomic particles.

Once the ship gets close to Alpha Centauri, it will deploy a magnetic sail to drag on the hydrogen gas that lurks in deep space, slowing Ghost Ship down to one per cent of the speed of light before firing its fusion engine in reverse to complete the deceleration. Probes carrying rovers, ready to uncover the secrets of our nearest star system, will then be launched to explore.

> "While Ghost Ship is only a concept, its new ignition system could be the way forward"

Venusian plane

An American aerospace giant aims to send an inflatable flying wing to Earth's evil twin

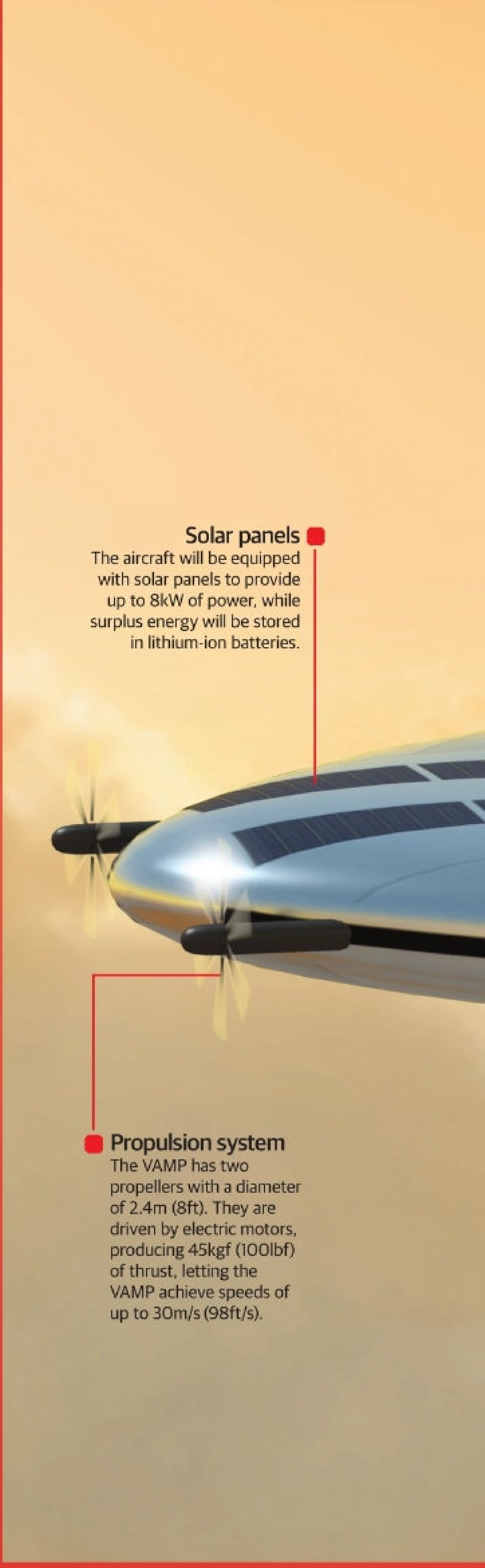
Distinguished aerospace firm Northrop Grumman has a thing about flying wings. If you've ever seen pictures of an amazing 1940s silver flying wing bristling with propellers, that was them, as too is the current B2 Stealth Bomber. Now in a move that would surely thrill company founder and flying wing enthusiast Jack Northrop, the firm may be sending one to the second planet from the Sun.

Venus' atmosphere makes the planet the most difficult place to explore in the Solar System - dominated by carbon dioxide, it has a runaway greenhouse effect that gives it an average surface temperature of over 400 degrees Celsius (752 degrees Fahrenheit). Carbon dioxide is also much denser than air, making the surface pressure 90 times that of Earth's; added to which sulphuric acid rains out of a dense, planet-wide cloud cover. However, there is increasing interest in exploring and even colonising Venus' upper atmosphere because the same mechanisms that make the surface so inhospitable produce a one bar, 15 degrees Celsius (59 degrees Fahrenheit) environment at 50 kilometres (31 miles) altitude. The Venus Atmospheric Manoeuvrable Platform (VAMP) is a 900-kilogram (1,984-pound) inflatable flying wing, with a 55-metre (180-foot) wingspan, which Northrop hope to enter into NASA's New Frontiers Solar System exploration competition. It will take advantage of this sweet spot on Venus, flying between 52 and 68 kilometres (32 and 42 miles) high, whilst sampling the atmosphere and scanning the surface far below. But the first remarkable thing it does will be in space.

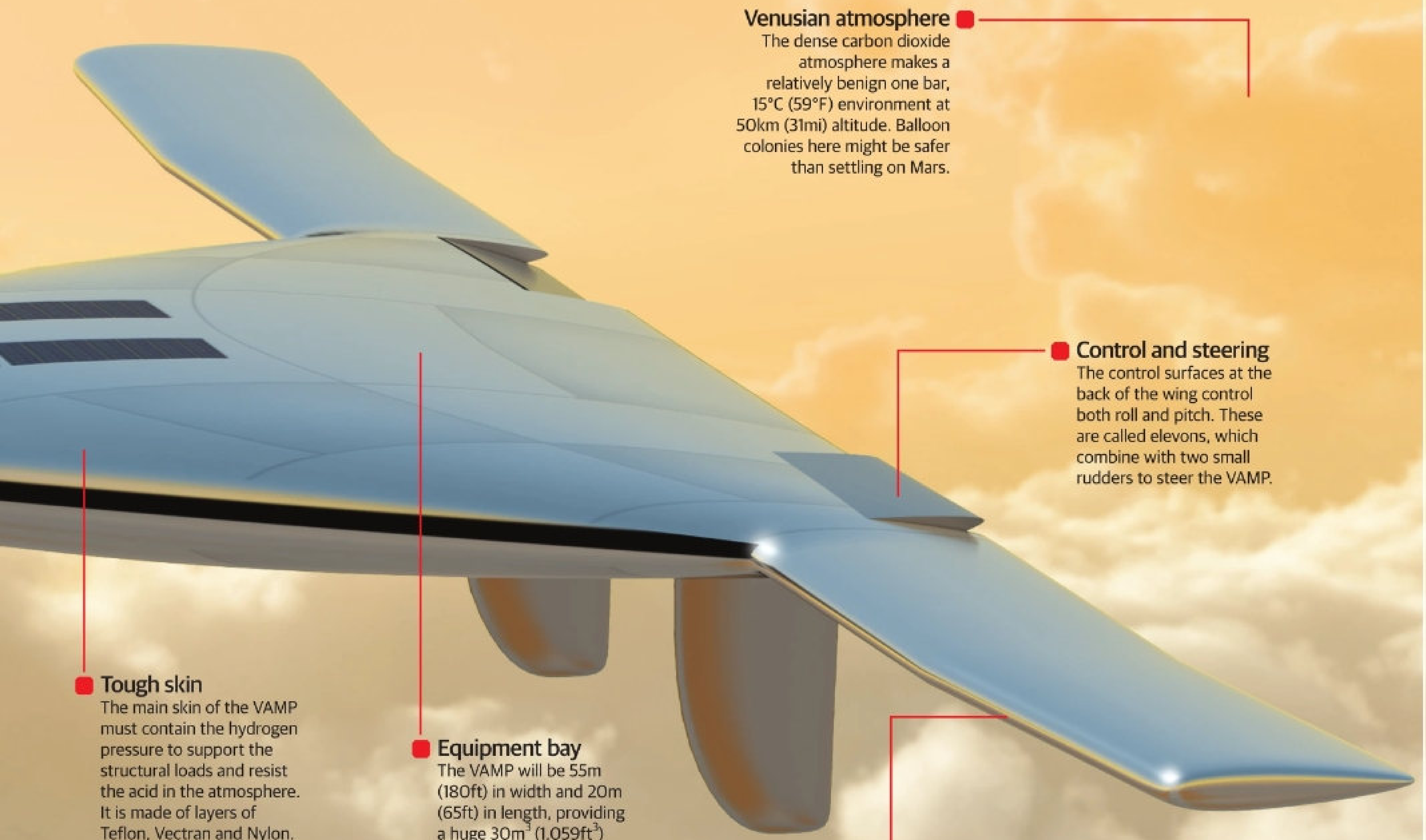
VAMP's designers hope to be able to save considerable payload mass for experiments by entering Venus' atmosphere in a novel way. Atmospheric entry, generally known as "re-entry" on Earth, is difficult because spacecraft in orbit are travelling at around 7.8 kilometres (4.8 miles) per second, and when heavy, blunt spacecraft enter the atmosphere, they plunge straight down into denser air. As they collide with the air molecules, their speed is converted into tremendous heat, which can interrupt communications with the spacecraft as it creates a shield of plasma around the vehicle - such heating even led to the tragic loss of the Space Shuttle Columbia in 2003 after its shielding was damaged. But VAMP will be inflated in space when it first arrives in Venus' orbit. Because VAMP will be a large, diffuse wing-shaped balloon, it will be affected by the atmosphere much higher up, and will therefore be able to slow down gradually, so it won't need a heavy heat shield. It will still experience 1,200 degrees Celsius (2,192 degrees Fahrenheit) on the leading edge of the wing, but the wing will be protected by a woven ceramic fabric called Nextel.

Since VAMP will be filled with hydrogen gas before it even enters the atmosphere, it will never have to land. Indeed even with no power at all, it will be 100 per cent buoyant at 51 kilometres (31.6 miles) altitude. But VAMP will also have electrically driven propellers, powered by eight kilowatts of solar panels and a battery storage system. These, and the VAMP's wing shape, will enable it to fly up to 68 kilometres (42 miles) altitude, where 91 per cent of its lift will be aerodynamic rather than from balloon lift. Then at night, when there is insufficient power to sustain level flight, it will sink back down to 52 kilometres (32 miles) to wait for sunrise. VAMP will be able to continue doing this as long as there is enough gas remaining in the balloon envelope, possibly as long as a year. Flying along at a very speedy 30 metres (98 feet) per second while Venus' winds carry it around the planet every six to seven days, VAMP will be able to extensively explore our nearest neighbour's upper atmosphere, while providing an unrivalled vantage point for scanning the surface far below.

"VAMP will be filled with hydrogen gas before it enters Venus' atmosphere. It will never land and, even with no power, will be 100 per cent buoyant"



Aerodynamic shape
VAMP is a flying wing, which means that the entire aircraft is part of the wing - this will allow it to "take off" from 51km (31.6mi) where it floats as a balloon, and then fly up to 68km (42mi) as an aeroplane.



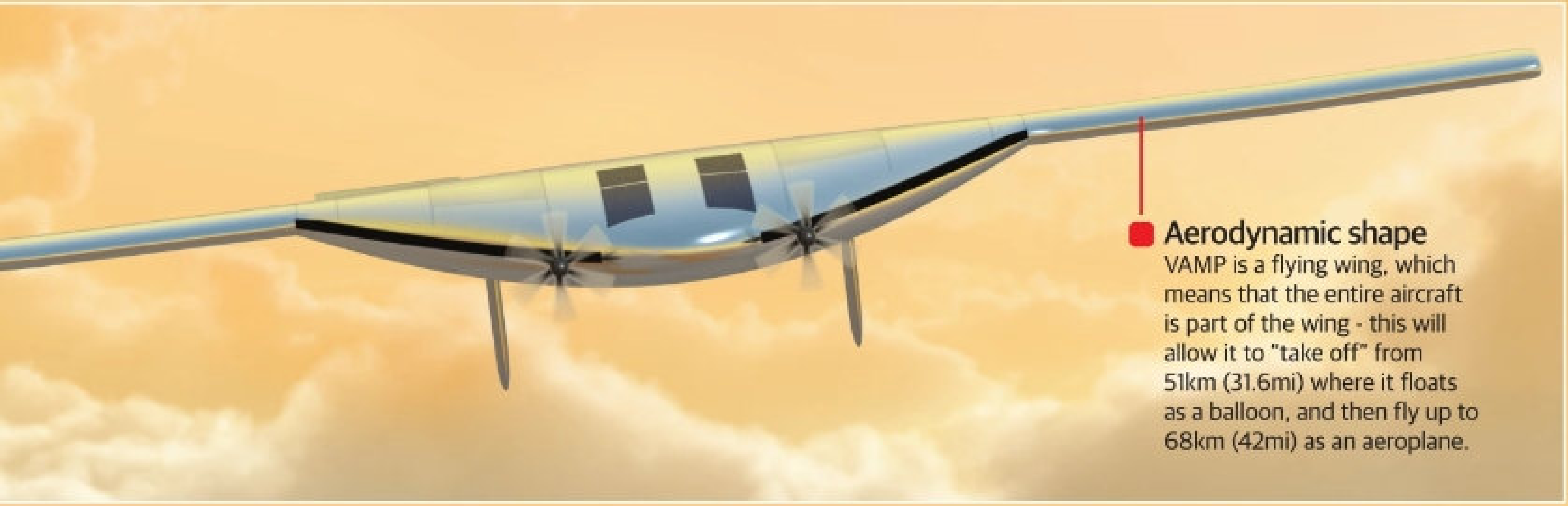
Venusian atmosphere
The dense carbon dioxide atmosphere makes a relatively benign one bar, 15°C (59°F) environment at 50km (31mi) altitude. Balloon colonies here might be safer than settling on Mars.

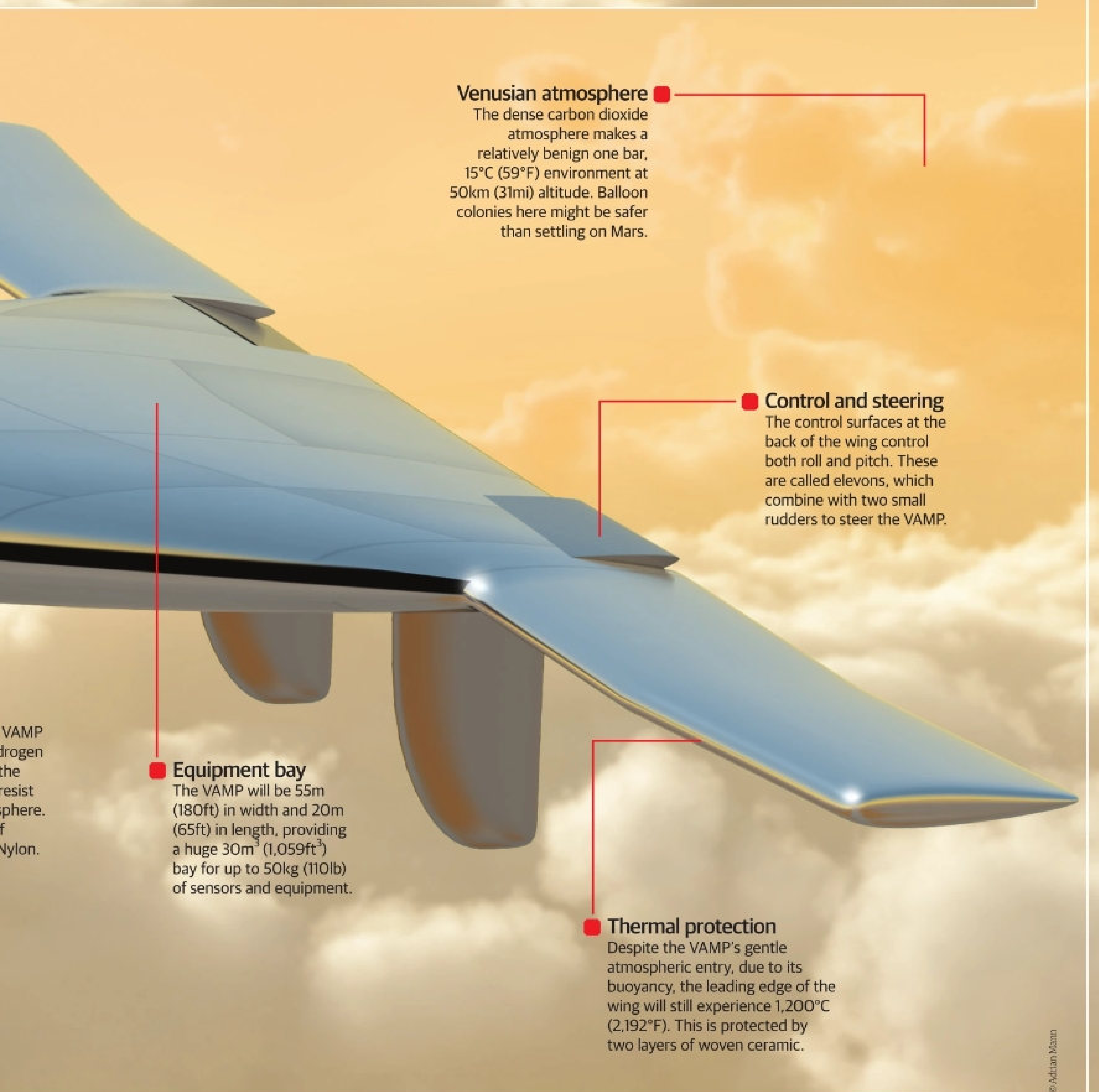
Control and steering
The control surfaces at the back of the wing control both roll and pitch. These are called elevons, which combine with two small rudders to steer the VAMP.

Tough skin
The main skin of the VAMP must contain the hydrogen pressure to support the structural loads and resist the acid in the atmosphere. It is made of layers of Teflon, Vectran and Nylon.

Equipment bay
The VAMP will be 55m (180ft) in width and 20m (65ft) in length, providing a huge 30m^3 (1,059ft^3) bay for up to 50kg (110lb) of sensors and equipment.

Thermal protection
Despite the VAMP's gentle atmospheric entry, due to its buoyancy, the leading edge of the wing will still experience 1,200°C (2,192°F). This is protected by two layers of woven ceramic.





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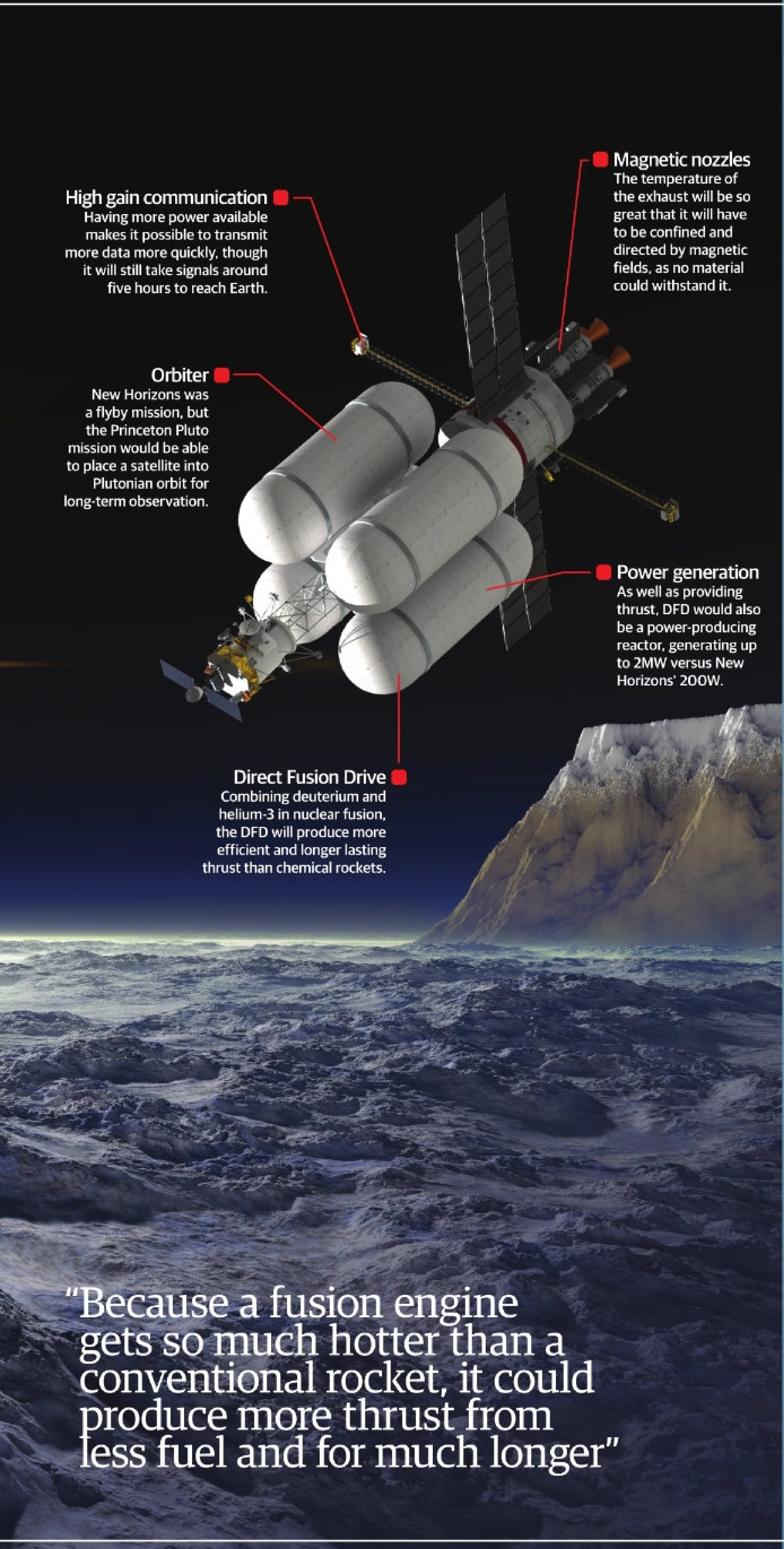
Pluto orbiter and lander

US aerospace consultancy, Princeton Satellite Systems, is working with NASA on an engine that could open up the Solar System

Pluto orbiter and lander



"Because a fusion engine gets so much hotter than a conventional rocket, it could produce more thrust from less fuel and for much longer"

We are used to the idea of hopping between planets or even star systems in fiction, but the real distances, even within our own Solar System, are difficult to comprehend. If we are to truly explore and settle in space we need a new form of propulsion, and a New Jersey-based company, Princeton Satellite Systems, has just received a NASA contract to work on the design of one: the Direct Fusion Drive (DFD). New Horizons was one of the fastest spacecraft ever launched, yet it took over nine years to reach Pluto. It pushed the limits of our capability and delivered its extraordinary data from a 400-kilogram (880-pound) craft with just 200 watts of power – that's lighter than a grand piano and using less energy than a couple of light bulbs. This is because there is only so much energy available in chemical fuels, so space missions typically have a short sharp rocket burn at the start and then months or years of coasting as they have to go the slowest and most efficient route.

But the DFD would work on a nuclear reaction called fusion. This is not like nuclear fission, which is used in current power stations and occurs where energy is released by splitting heavy atoms like uranium. In fusion, energy is released by combining light atoms, and in DFD's case those light atoms would be deuterium and helium-3; this method is how stars shine and produces much more energy without creating any nuclear waste, but it is difficult. Fusion is being extensively studied for producing clean energy on Earth, but progress has been slow.

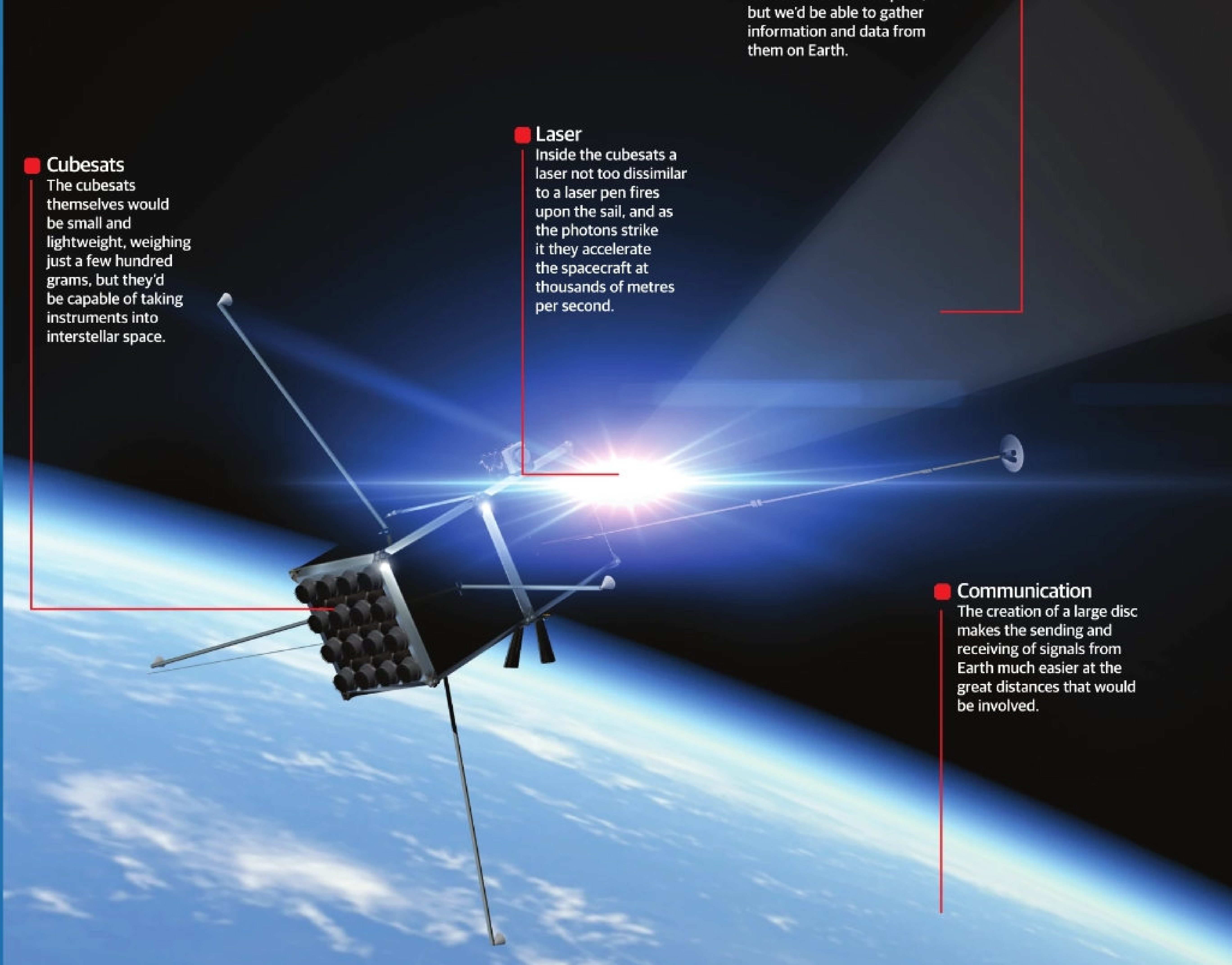
Princeton's engine is based on an innovative concept from the Princeton Plasma Physics Laboratory called the Field Reversed Configuration (FRC). In this reactor the fusion fuel is trapped in a cylinder of magnets and heated up to millions of degrees Celsius by radio waves beamed into the chamber, similar to a microwave oven. The challenge for all fusion projects is in containing plasma at these tremendous temperatures, so the FRC reactor uses a special arrangement of rotating magnetic fields to create a self-contained rolling 'smoke ring' of plasma in the chamber. It is in this region that fusion would occur, and the FRC's developers believe it could at last give us practical fusion power.

Used in space as the basis for the DFD, the gases undergoing fusion would heat up extra gas passed through the reactor. Then the whole lot would be allowed to escape out of a nozzle formed of magnetic fields to produce thrust. Rocket thrust strongly depends on how hot the working fluid gets and how fast it escapes the nozzle. As fusion engines get much hotter than conventional rockets, it could produce more thrust from less fuel and for much longer.

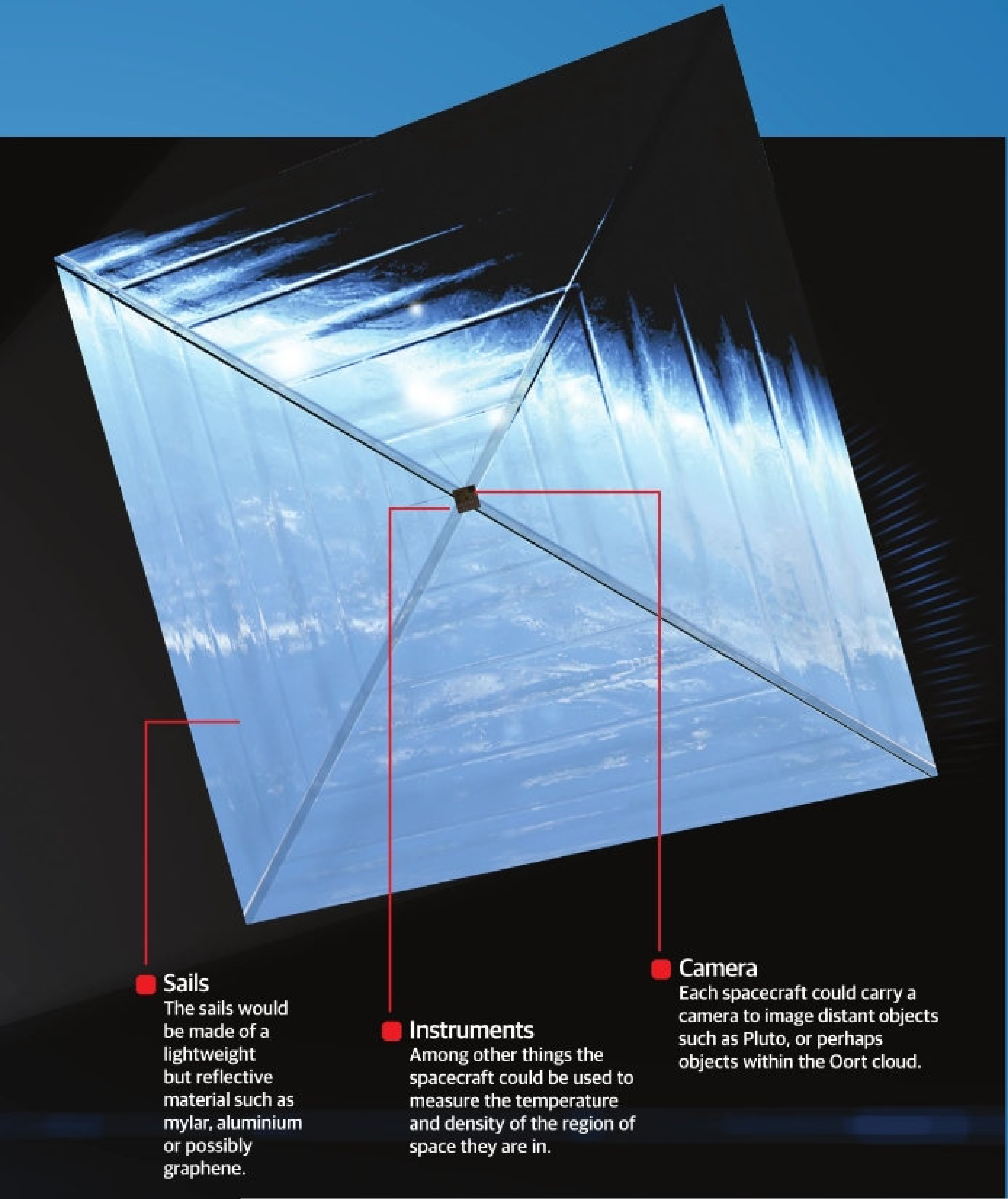
Princeton's NASA project will develop enhanced models of how DFD would work, and apply this data to the design of a fusion-enabled Pluto mission. Initial studies suggest a 1,000-kilogram (2,204-pound) craft, featuring an orbiting satellite and a surface lander, could be delivered to Pluto in just four years. Another benefit of the DFD is that it could function as a power-generating reactor even when it is not producing thrust; the prospective Princeton Pluto mission could have 2 million watts of power at its disposal. It will be quite some time before a fusion drive is powering our exploration of the Solar System, but with this project, NASA is laying the foundations of a transformation in propulsion.

Project Dragonfly

The innovative laser sail technology that could propel us to interstellar space



Project Dragonfly



The prospect of sending probes on an interstellar mission is often accompanied by thoughts of high costs, decades of planning and large spacecraft. That's not necessarily the case, though, according to the Institute for Interstellar Studies (I4IS), whose goal is to ultimately take humanity out beyond the Solar System.

"We believe it's possible to actually launch probes into deep space, whether it's outside the Kuiper belt, into the Oort cloud or beyond, within the next 10 to 20 years," Kelvin Long, the executive director of I4IS, tells **All About Space**.

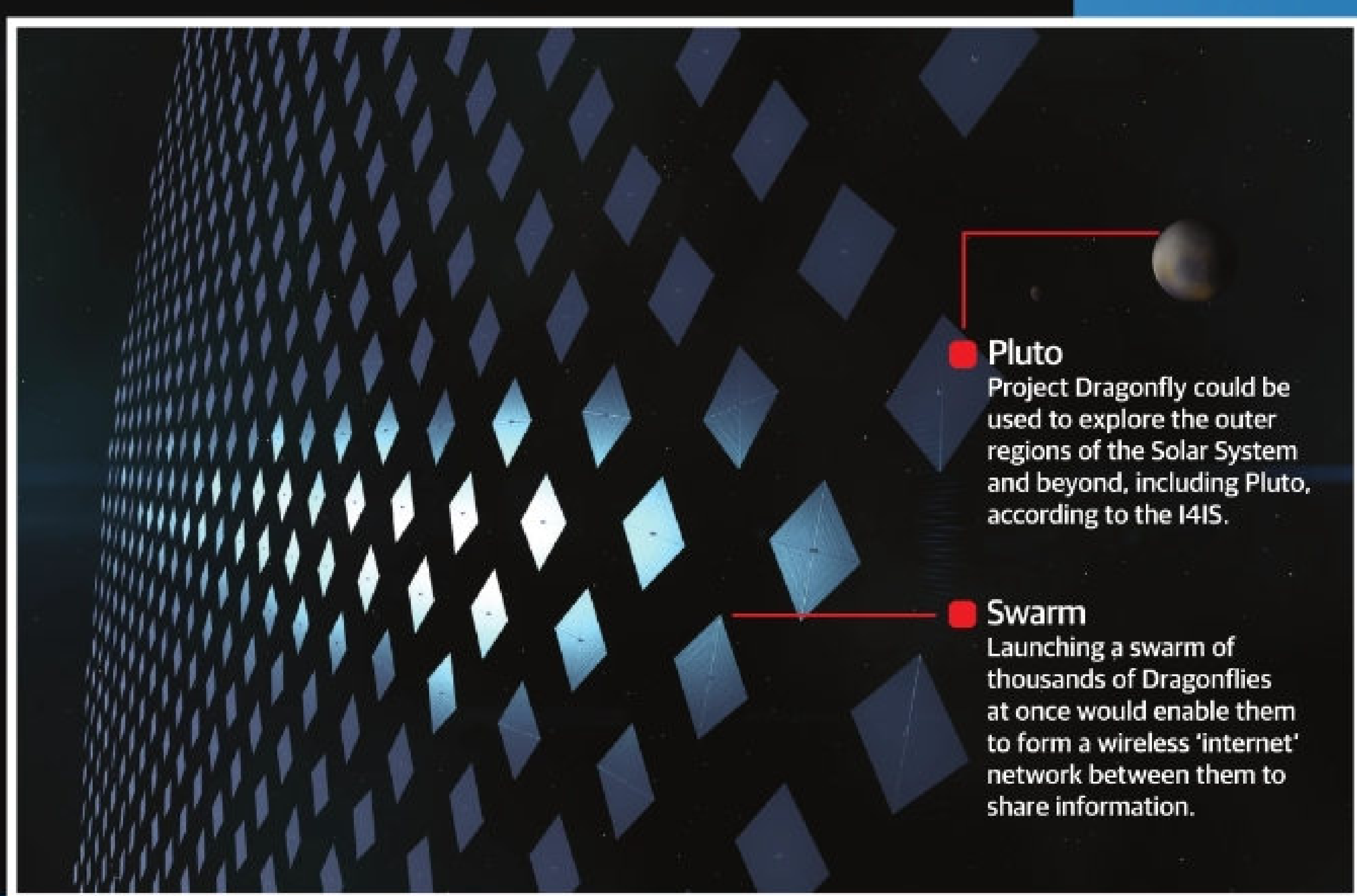
To do so the I4IS has proposed a spacecraft called Project Dragonfly. This innovative vessel would consist of a central hub that contains all the instrumentation, and in front of it would unfurl a large thin sail made of material such as mylar, aluminium or graphene. Inside the central hub would be a laser, which would fire upon the sail. The impact of photons on the sail would propel the spacecraft to great speeds, possibly up to ten per cent the speed of light, to make unmanned interstellar travel a more realistic proposition.

Dragonfly is the flagship project for the young I4IS, which was formed only in 2012. "We launched Dragonfly at a symposium in May for the British Interplanetary Society (BIS), who are massive supporters for us," says Long. "Laser sail propulsion is an area no one is really working on."

At the upper end of the I4IS proposal, they say a spacecraft weighing 100 kilograms (220 pounds) with a sail one kilometre (0.62 miles) in diameter, using a lens 200 kilometres (125 miles) in diameter to collect a 25 gigawatt power beam, could reach speeds of 30,000 kilometres (18,640 miles) per second. That's around ten per cent the speed of light, meaning it could travel four light years in just four decades.

Aside from this larger spacecraft, however, Long also says the I4IS is considering the launch of much smaller probes, weighing just a few hundred grams. At their core would be a cubesat containing instrumentation. The idea for this mission is that thousands of these miniature spacecraft, which would unfold their sails in space like an umbrella, would be launched together. As they venture out of the Solar System the combination of their sails would form a large dish, making communication with the spacecraft from Earth at great distances much easier.

With funding, Long says they could launch a demo mission of laser sail propulsion in Earth orbit within three to five years. Within ten years he says they could send a spacecraft towards the Oort cloud and the edges of the Solar System, to a distance of up to 10,000 AU, for about $1 million (£600,000).

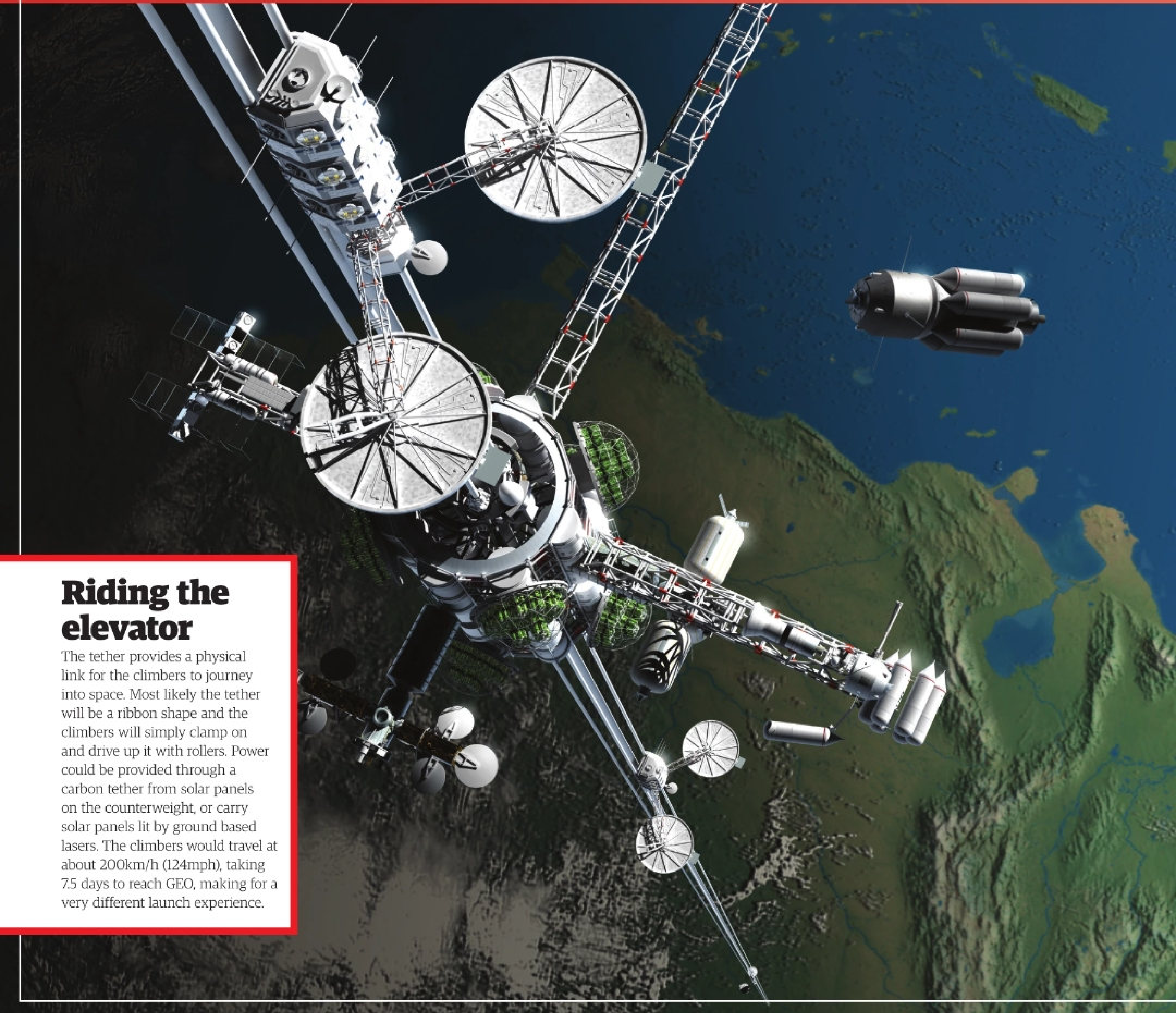


Space elevator

Launching into space is a hazardous process. Wouldn't it be simpler if we could take a lift?

A space elevator is the idea of building a lift connecting the ground to Earth orbit. The first person to consider it was Konstantin Tsiolkovsky (who was the first to set out the equations that govern orbital rocket launches), in 1895 he was inspired by the new Eiffel Tower to point out that if such a tower could be built 35,800 kilometres (22,245 miles) tall, you could go to space just by taking the lift up the tower. To appreciate why (and why 35,800 kilometres or 22,245 miles) we must consider how orbits work.

When spacecraft launch into space they don't just pass out of the atmosphere and start floating. Getting past the atmosphere is fairly easy; the boundary of space is only 100 kilometres (62 miles) up. To be in orbit, a craft has to be travelling fast enough horizontally (eight kilometres/five miles per second) that the tendency to be flung away from Earth is



Riding the elevator

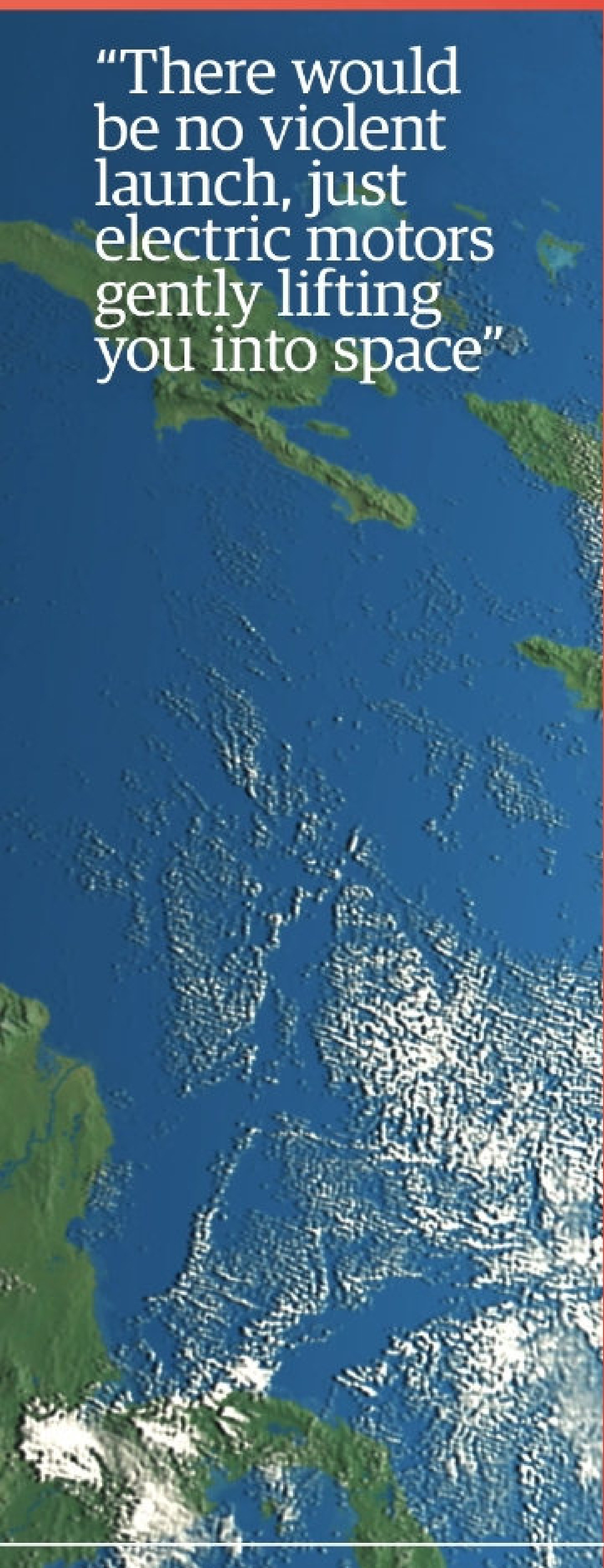
The tether provides a physical link for the climbers to journey into space. Most likely the tether will be a ribbon shape and the climbers will simply clamp on and drive up it with rollers. Power could be provided through a carbon tether from solar panels on the counterweight, or carry solar panels lit by ground based lasers. The climbers would travel at about 200km/h (124mph), taking 7.5 days to reach GEO, making for a very different launch experience.

balanced by the gravity trying to pull it back down, so that it continuously circles Earth. The higher the orbit, the faster the spacecraft must travel, and the longer it takes to orbit; 35,800 kilometres (22,245 miles) high is an orbit called "geostationary" (GEO). In GEO it takes 24 hours to make one orbit, so spacecraft appear to hover over the same spot on Earth - this is used for satellite TV so you get continuous signal.

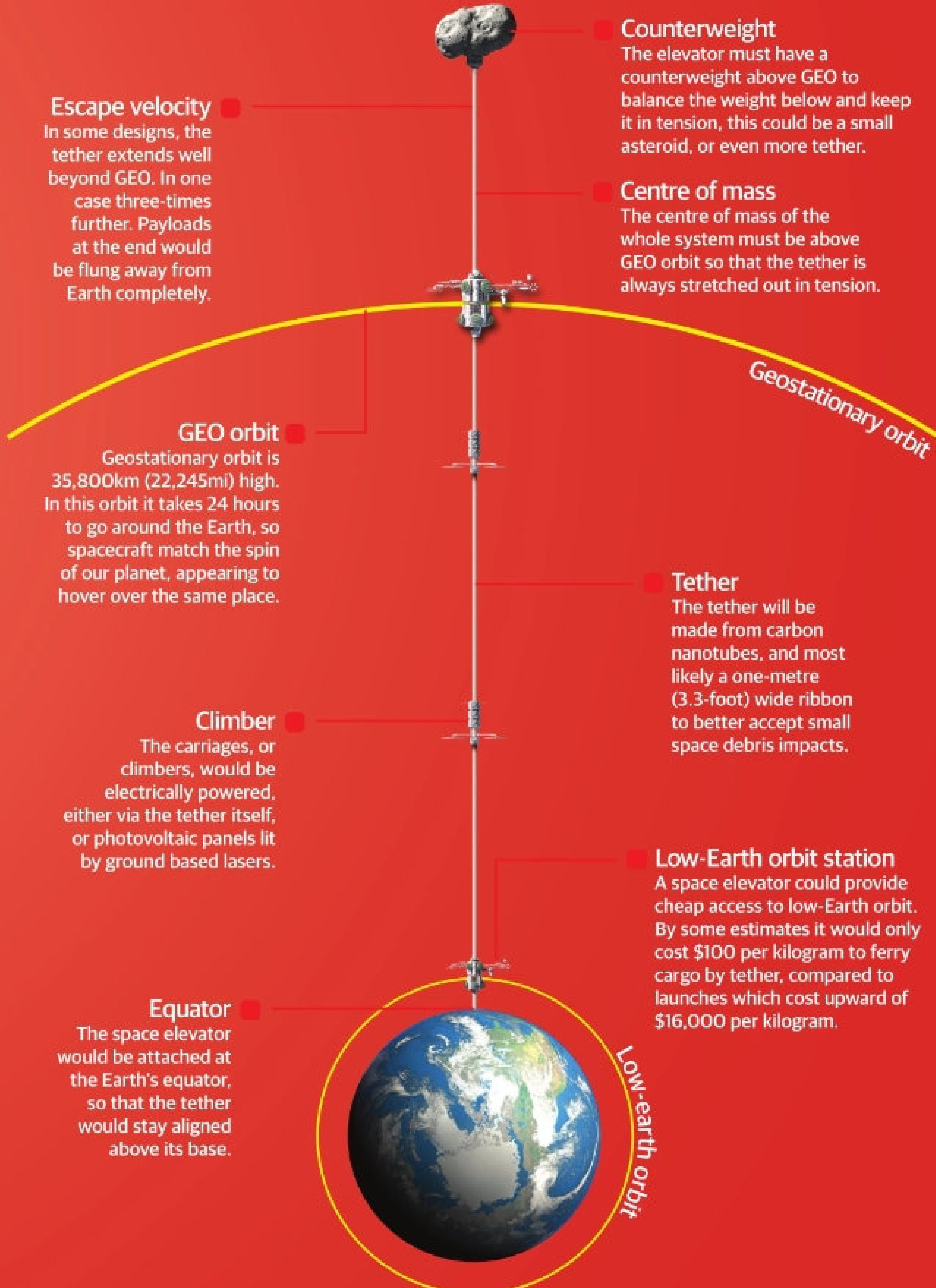
Travelling on a space elevator, you would slowly gain both the height and speed required to be in GEO at the top. There would be no violent launch, or highly stressed rocket engines, just electric motors gently lifting you into space over the course of a few days (it is the same as taking a train 90 per cent of the distance around the world). But we can't build a tower that tall; no material comes close to supporting its own weight at such a height, but in 1959 another Russian scientist, Yuri Artsutanov, suggested that it might be possible to build such a structure if it was a cable in tension, rather than a tower in compression.

In this case, a satellite is deployed in GEO and begins to wind a tether downwards, while another tether winds outwards with a counterweight on the end. Ultimately, the first tether touches down on Earth where it can be anchored while the counterweight, being flung outwards by the rotation of the system, balances the weight of the tether, plus some spare capacity for the weight of the elevator cars (climbers) moving on it. The concept was considered science fiction for many years, though, as no materials came close to the strength needed. That changed in the 1990s with the discovery of carbon nanotubes; cylindrical molecules of carbon that would be strong enough, if we can make them long enough. A NASA study from 2000 proposed that a small 20-ton nanotube tether could be launched and installed from GEO. It would be anchored to a floating platform and then small robotic climbers would run up adding more material. This would build a one-metre (3.3-foot) wide tether, thinner than a sheet of paper but still extremely capable of lifting 20-ton climbers.

Unfortunately, no one has made nanotubes longer than 50 centimetres (19.7 inches). But, a number of organisations are working towards Space Elevators. LiftPort Group in the US are developing a commercial carbon nanotube business in support of their plans, and intend to build a space elevator headed for the Moon with existing materials by 2020. So, we may even see a railway to the sky before the second half of this century.

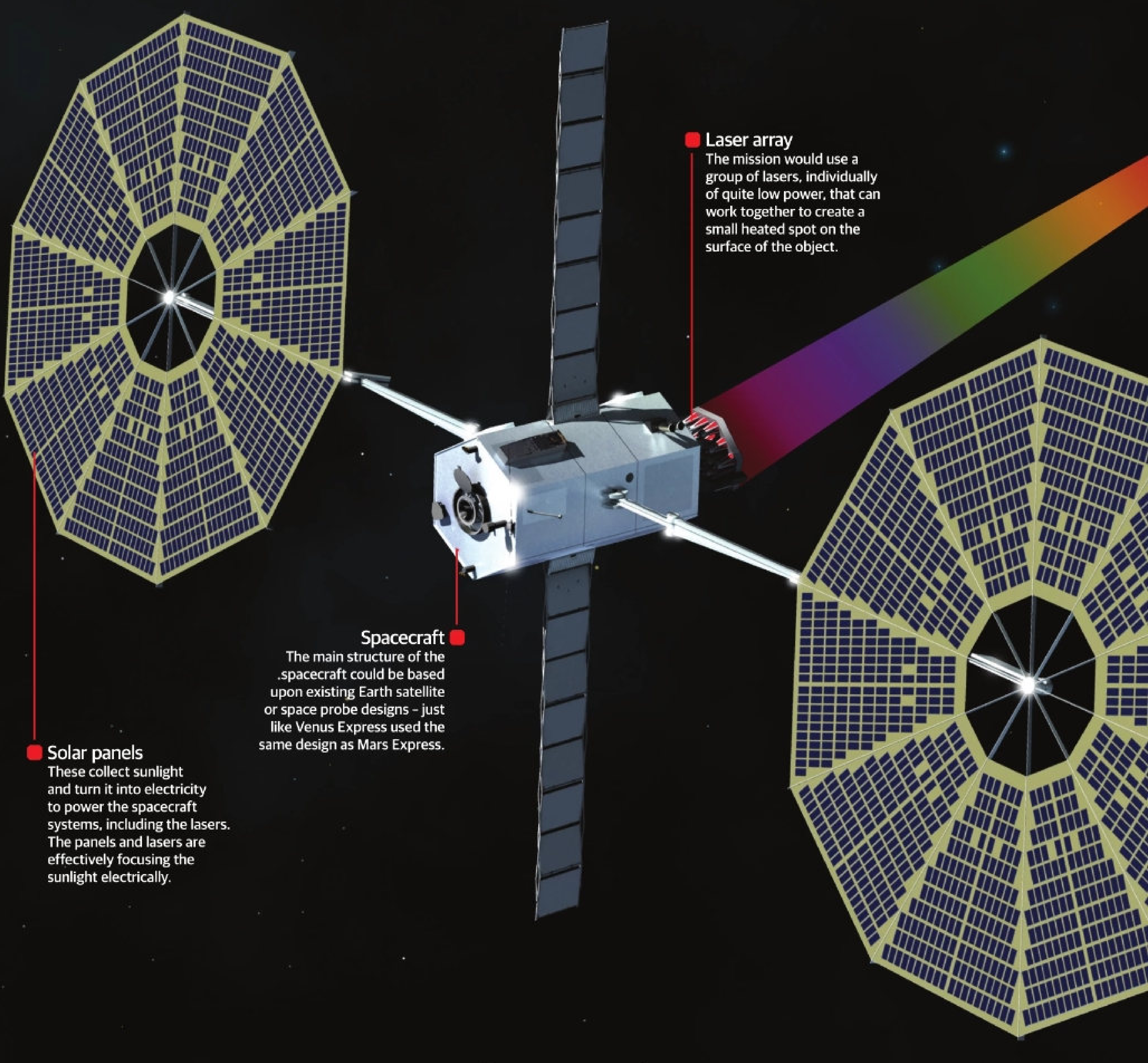


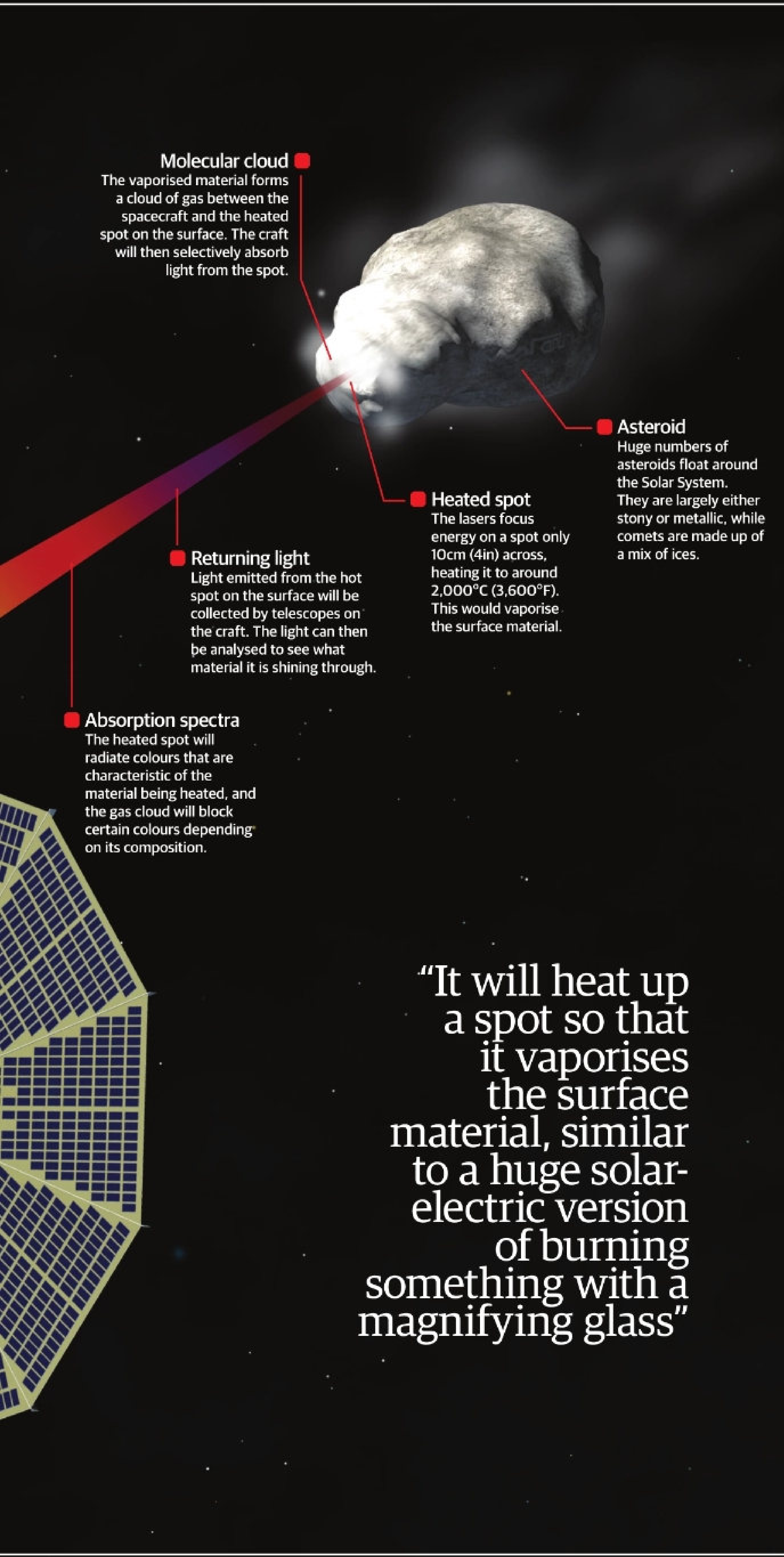
"There would be no violent launch, just electric motors gently lifting you into space"



Distant target analysis

When it comes to protecting Earth from impacts, it is crucial to know what asteroids are made of. NASA is working on a device to find out





"It will heat up a spot so that it vaporises the surface material, similar to a huge solar-electric version of burning something with a magnifying glass"

Distant target analysis

The Solar System is filled with small cold asteroids and comets, all whizzing around in varying orbits. They represent both a threat to us, as demonstrated by the Chelyabinsk meteor in 2013, and an opportunity for in-space mining. But if we are to deflect or exploit these bodies, we need to know what they are made of and, ideally, without having to go to the trouble of landing on them all. Fortunately, Dr Gary Hughes of California Polytechnic State University has a solution to this problem, and he has just received funding from NASA to work on it.

We can actually tell the composition of stars over tremendous distances because they are hot bodies emitting light, and we can analyse this light with a technique called spectroscopy. If you let sunlight fall on a prism you'll see a rainbow split out of the white light, but more careful study will reveal dark lines cutting through the colours at various points. This is because the matter the light is shining through absorbs characteristic wavelengths of light, leading to the gaps; helium was actually found in the Sun this way before it was identified on Earth. But the small objects NASA are interested in interrogating are cold and only reflect light rather than emit it, so to counter this they are going to zap them with a laser!

Lasers are not the blasters we think we know from science fiction though; a laser is a specialised light source that produces something called coherent light. Different colours are actually different wavelengths of the electromagnetic waves we see as light; conventional white lighting produces a mix of colours all spreading out in different directions. Coherent laser light is composed of just one pure colour/wavelength, and all the peaks and troughs of the electromagnetic waves are lined up and travelling in a parallel and directed beam. This is how laser light can be shone at great distances (it is regularly bounced off the Moon to measure its orbit), how it can transmit data, or can be brought to a sharp focal point to cut through material.

In the new mission, solar panels will produce electricity to power an array of lasers, which can be focused together to heat a small spot on the asteroid or comet's surface. This will heat up the spot so that it vaporises the surface material and glows white hot, similar to a huge solar-electric version of burning something with a magnifying glass. This will result in a sample of the asteroid material forming a cloud of gas in front of the bright light emitting from the heated spot on the surface. As a result, telescopes on the craft will be able to collect the light from the spot and see what elements in the cloud are blocking out light. This process could be repeated on the same spot to gradually measure how the composition changes with depth, or on multiple spots to create a surface composition map of the whole asteroid.

The initial project is to carry out more research into the distant laser technique, produce a design concept, and to create a hypothetical mission plan for sampling a near-Earth asteroid. It may be some time before such a mission takes flight, but it builds on proven technologies and would be invaluable in assessing the threat and value of comets and asteroids. Indeed, larger versions could be used to protect Earth, not by destroying an asteroid on a collision course, but by producing thrust from the heated spots, which would gently push it away.

New Worlds mission

By putting a huge umbrella into space, we could come closer to finding extraterrestrial life

The question of whether life exists on other planets is one that scientists frequently ponder, but have so far failed to answer. Hoping to change this is the New Worlds mission that, while still in the early phases of development following years of research, is likely to bear fruit in the near future.

One of the problems with observing extrasolar planets is the amount of light emitted by the parent star they orbit. When scientists use a telescope to look deep into space, they find the brightness of these stars drowns out the light from the orbiting planets. They still see the more-intense glow of larger planets, but the smaller ones are virtually impossible to spot. Since those tinier planets are, like Earth, more likely to contain signs of life, it means experts risk missing potential life-supporting worlds.

Dr Webster Cash, of the University of Colorado at Boulder, has devised a method to combat this problem. He proposes using a starshade, effectively a large blocker spacecraft that would be placed between the telescope and the target star. It would prevent light from the star reaching the telescope that would, in effect, be cast within a shadow. Just as a ball heading your way from up high on a bright day is better seen if you hold your hand to block the sunlight, so the planets orbiting their parent star are brought into view when the brighter light is blocked.

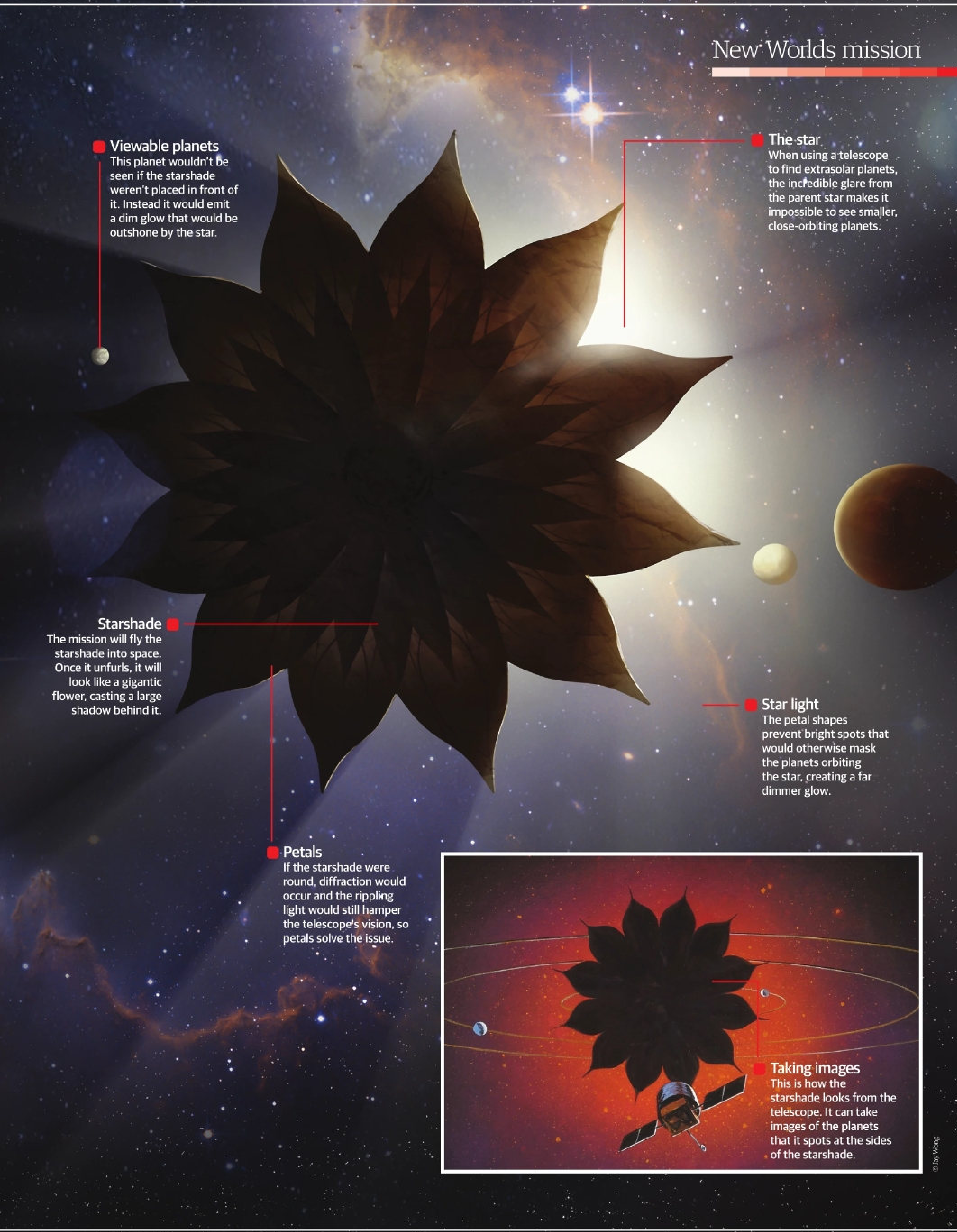
In 2013 NASA created a mockup of the starshade. The initial plan had been to produce a round disc, but this caused a problem with diffraction. When light from the parent star hits a round circle, it will diffract around the edge. Not only does this give a halo-like glow but it also drowns out the dimmer light of the smaller extrasolar terrestrial planets being sought, because it remains so bright.

The idea is to make the starshade look like a series of slit petals, each one sitting around the inner disk. Since the perimeter shape of the object the light is hitting governs diffraction, this design controls the way the light waves of the star behave, drastically cutting diffraction. Because the starshade will be tilted when put into space, the light from our own Sun will not disrupt the telescope's view of the extrasolar planetary system either.

Although the proposal is to fly the starshade and the telescope into space in formation, it's more likely that the telescope will be sent up first and the starshade will follow at a later date. Though a launch date is far from being confirmed, the mission concept is being put together and should be complete by 2015. The team behind it is conscious of cost – with a budget of around £1.8 billion ($3 billion) – so it'll either work with an existing collector, such as the James Webb Space Telescope, or a four-metre (13-foot) telescope likely to be built in the future.

This won't be an easy mission, as the starshade will be sent to space in a folded state before unfurling. It also needs to be aligned with a telescope around 200,000 kilometres (124,000 miles) away. With little room for error and the need to maintain alignment, so much could go wrong. If the mission enables scientists to see planets they'd otherwise miss, enabling them be to analysed for water vapour, carbon dioxide and oxygen, the big question of the universe could be answered soon.

> "It needs to be aligned with a telescope around 200,000 kilometres away"


Viewable planets
This planet wouldn't be seen if the starshade weren't placed in front of it. Instead it would emit a dim glow that would be outshone by the star.
The star
When using a telescope to find extrasolar planets, the incredible glare from the parent star makes it impossible to see smaller, close-orbiting planets.
Starshade
The mission will fly the starshade into space. Once it unfurls, it will look like a gigantic flower, casting a large shadow behind it.
Star light
The petal shapes prevent bright spots that would otherwise mask the planets orbiting the star, creating a far dimmer glow.
Petals
If the starshade were round, diffraction would occur and the rippling light would still hamper the telescope's vision, so petals solve the issue.
Taking images
This is how the starshade looks from the telescope. It can take images of the planets that it spots at the sides of the starshade.
© Jay Wong

Remote-control missions

How astronauts will one day remotely operate vehicles on other worlds

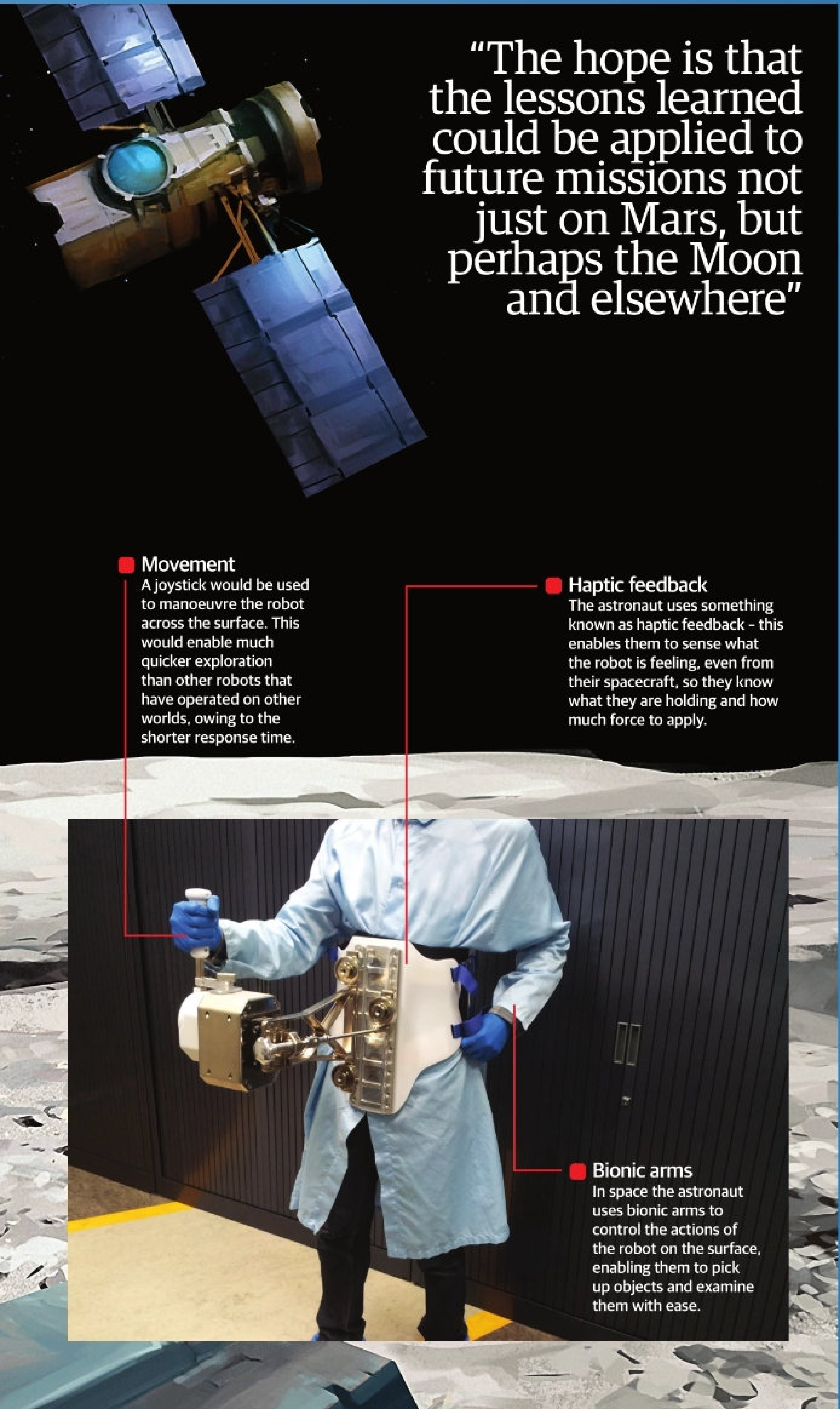
Response time
The goal of ESA and other agencies is to have a robot on another world that would be controlled by an astronaut in orbit. With a reaction time of just 20 milliseconds, it would be quick enough to enable accurate exploration from afar.

Surface
This telerobotics system would enable faster and more-accurate exploration of the surface of the Moon, for instance, than has been possible. It wouldn't require humans to be sent to the surface, although they'll need to be in orbit.

Robot explorer
A robot such as this could be a future explorer on Mars. The main core of the machine is a rover with wheels, but at its front is a human-like torso with arms that can manipulate the environment.

Maintenance
Here we see a robot being used by an astronaut in orbit to perform work on another lander that has been sent to the surface of the Moon.

> "The hope is that the lessons learned could be applied to future missions not just on Mars, but perhaps the Moon and elsewhere"



Arguably one of mankind's greatest achievements in space exploration has been landing the Curiosity rover on Mars. Here, a high-tech suite of instruments is being taken around the surface of the Red Planet by the advanced rover, providing unprecedented information about this world.

The mission has one noticeable limitation: because the rover is controlled from Earth, progress is fairly slow. While it has an average speed of 30 metres (98 feet) per hour, it must wait for a signal from Earth before driving in a direction or carrying out a task. The return time is about 30 minutes for any communications to and from Mars, which means a seemingly easy task such as observing a rock, takes a lot longer than it would take a human.

While the ultimate goal is to have humans walk and work on the surface of worlds like Mars, a short-term solution could be the use of astronauts in the vicinity to control vehicles on the surface. This is known as telerobotics. Think of how you might operate a remote-controlled toy car on Earth – because you are within a short distance, your actions on the controller are instantly replicated by the car.

The same could be the case for astronauts in orbit around a planet or moon. They would be close enough that their actions on a space-based remote control would be emulated near-instantly by a rover on the surface below. By sending robots to various locations on an object's surface, scientists could explore vast regions without leaving their spacecraft.

With this in mind, ESA has designed systems that can be used by astronauts to remotely operate vehicles. In the first tests, astronauts will be controlling robots on Earth, but the hope is that the lessons learned could be applied to future missions not just on Mars, but perhaps the Moon and elsewhere as well.

On 12 August 2014 a European-built cargo ship, known as ATV-5 (Automated Transfer Vehicle), docked with the ISS. On board it carried an important piece of cargo related to telerobotics – a body-mounted joystick that will be used by astronauts to control a robot on Earth.

The joystick uses touch-based feedback, enabling the user to finely and accurately move a robot, as well as react to any obstacles in an environment. It's mounted to the body of an astronaut, who is in turn attached to a stationary object on the ISS.

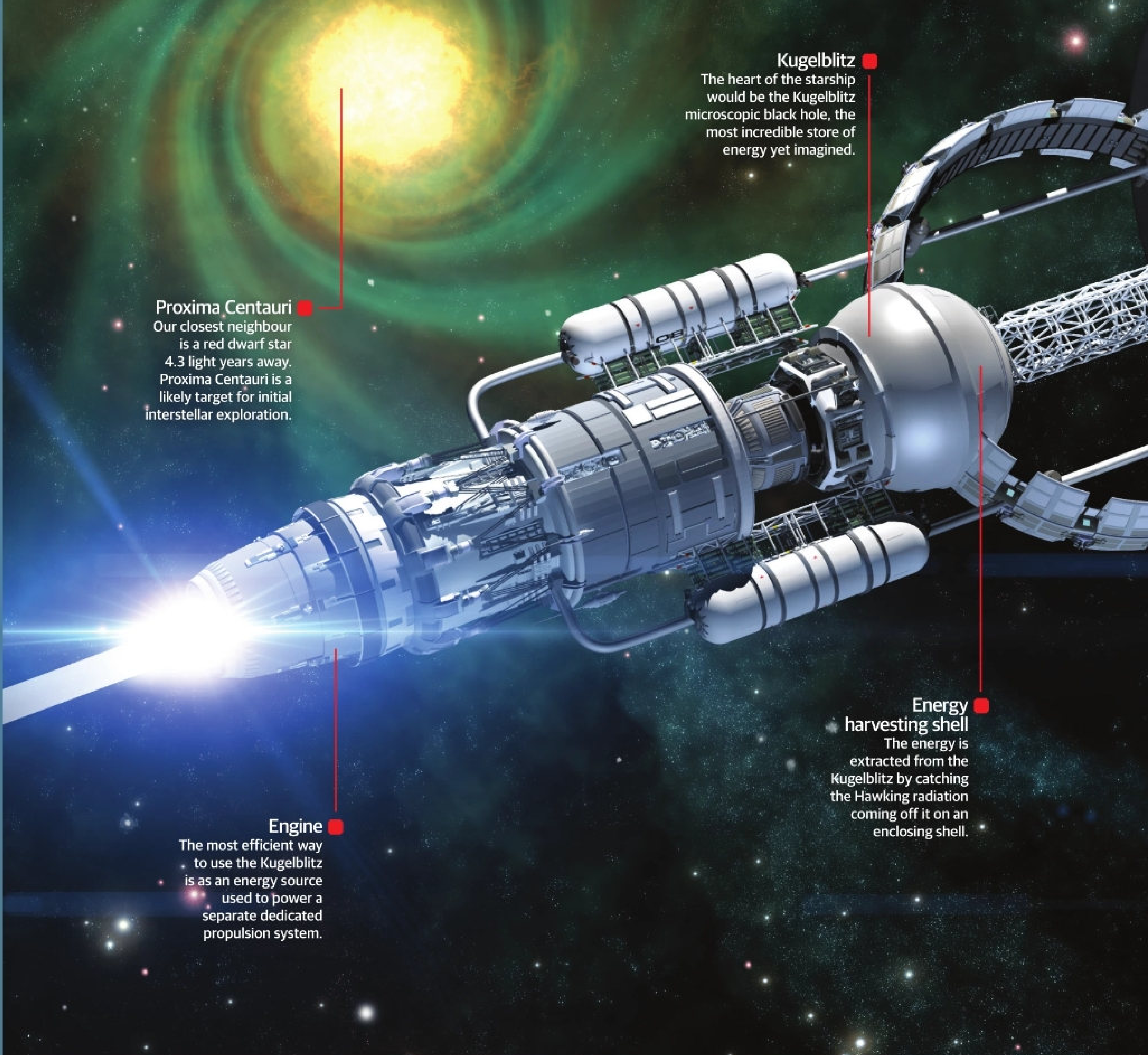
The aim of the joystick is to provide astronauts with a remote sense of touch, to give them the greatest degree of control possible over the robot. While the joystick is used mostly for movement, eventually astronauts will have access to a bionic arm of sorts that emulates an actual arm on a robot.

By reaching their own arm out and moving it, the robot will do the same. A small hand on the end of the arm will enable them to use the robot to pick up objects such as rocks. Force feedback on the arm – known as haptic technology – will let the user know what sort of object they are holding and how much force they can apply without it breaking.

These technologies are part of the Multi-Purpose End-to-End Robotic Operation Network (METERON) initiative, which is investigating telerobotics for space. It may be innovative systems like this that enable future astronauts to explore other worlds like never before.

Black hole power

Interstellar flight will need a tremendous amount of energy; we may be able to store it in a miniature black hole



"A Kugelblitz would be smaller than a proton, yet have a mass of 606,000 tons, and produce 160 Petawatts – 10,000 times the power consumption of humanity – for 3.5 years"

Interstellar distances are difficult to conceive. Our nearest star is Proxima Centauri, a red dwarf 4.3 light years away. That's more than 266,000 times the distance from Earth to the Sun and if our fastest spacecraft, Voyager 1, which is flying at 18 kilometres (11 miles) per second, were headed that way it would still take 80,000 years to get there. For humans to be able to explore the galaxy we are going to need another way to travel, but while the focus has been on the propulsion side of the puzzle, equally challenging is how we power such journeys. But there's a strange concept that might solve both problems: the Schwarzschild Kugelblitz, a craft powered by a black hole.

To make interstellar journeys in a reasonable time we will have to achieve a good per cent of the speed of light (300,000,000 metres or 984,252,000 feet per second). For every kilogram (2.2 pounds) of mass that makes up the composition of a spacecraft and its payload, when travelling at 99.9 per cent the speed of light it will have a kinetic energy more than six times that contained in the 1961 Tsar Bomba, the largest nuclear weapon ever detonated. All this energy must be safely stored in a form that can be built into a spacecraft, and supplied to the prospective starship without destroying it.

Writing in 1955, American physicist John Wheeler (believed to have coined the terms 'black hole', 'wormhole' and 'quantum foam') proposed that if enough energy could be concentrated into a small space, the energy would form a microscopic black hole. He nicknamed this concept the Kugelblitz – meaning 'ball lightning' in German – and as a black hole is defined by being mass-energy squashed so that its gravity won't let light escape, compressed within the Schwarzschild radius, it has become known as the Schwarzschild Kugelblitz.

Counterintuitively, black holes actually produce radiation; it was first proposed by Stephen Hawking in 1974 that when quantum fluctuations happen next to the horizon of a black hole, it leads to the creation of two particles, but instead of the particles annihilating each other, one gets sucked into the black hole letting the other escape. Because of the conservation of energy, this process uses up energy from the black hole, and unless it sucks in more stuff, this Hawking radiation will eventually cause it to evaporate. This effect would be even more pronounced with a Kugelblitz micro-black hole, enabling us to extract energy from it. A practical Kugelblitz will be a balancing act – it must be small enough that it makes enough Hawking radiation, light enough that a spacecraft carrying it can accelerate it, but big enough to last long enough to be useful. Such a Kugelblitz would be smaller than a proton, yet have a mass of 606,000 tons, and would produce 160 petawatts (over 10,000 times the power consumption of humanity) for 3.5 years.

The simplest option for using this power source would be to place it at the focus of a vast parabolic reflector and use this to make a beam of Hawking radiation to push the craft along. While this approach is simple, it wouldn't make good use of the Kugelblitz's power; it would only be able to reach four per cent of light speed before the Kugelblitz evaporated. A more challenging but efficient option would be to enclose the Kugelblitz in a spherical shell, capturing all of its energy and using this to drive a heat engine of some sort. Assuming 100 per cent energy efficiency, this could accelerate a craft to ten per cent of light speed in 20 days. The engineering challenges are huge, but the Kugelblitz is the most compact energy source ever conceived, even over anti-matter. Perhaps one day it will be powering humanity across the stars.

Droids on another world

From C-3PO to Robby and K-9, science fiction is full of helpful robots. Now NASA is making it a reality

The word robot comes from the Czech word robota, meaning slave; and it was created for *Rossum's Universal Robots*, a play first performed in Prague in 1921. It featured humanoid robots produced to do humanity's drudgery and their eventual rebellion; it proved a worldwide success and gave us the word and the classic science fiction robot. Robots are now an integral part of most futuristic space fiction, yet reality has both far exceeded expectations and somewhat underwhelmed.

Robotic spacecraft have touched down on six different bodies, driven around on the Moon and Mars and reached interstellar space. But classic science fiction humanoid robots have been in short supply. Fortunately, NASA is actually working on making them our new helpers in space.

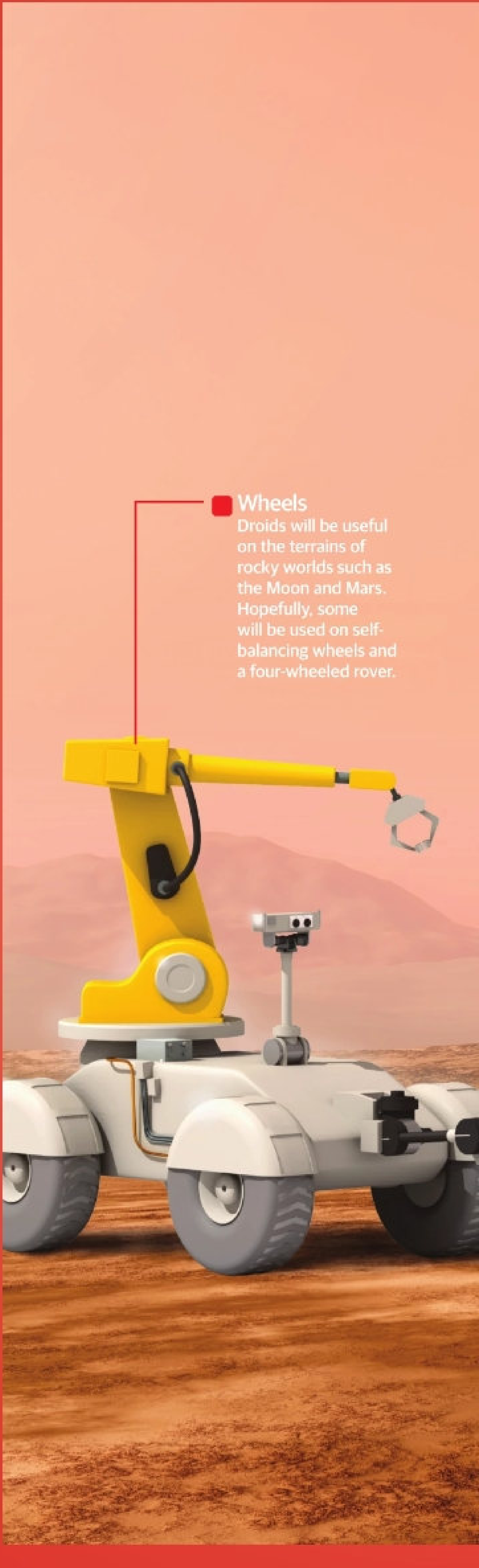
When the International Space Station (ISS) was still in development in the 1990s, the idea of having a humanoid robot to help the astronauts on board was suggested. It may sound fanciful, but if you can build a robot in a human shape it would be a huge advantage in them working with humans, especially in an environment as challenging as space. The working areas of the ISS are designed around, and for, humans, so a robot helper would only be a hindrance if it gets in the way of the astronauts. A successful humanoid robot could work in the station in concert with the astronauts rather than around them; using the same facilities and tools without the need for separate "robot" equipment.

This idea has become Robonaut, developed by NASA in conjunction with robotics firm Oceaneering and General Motors. The Robonaut programme is working to build up the capability of these assistants in stages, starting with Robonaut Type 1 in 2000. The Type 1 focused on creating a multi-purpose humanoid torso, arms, and head that could be mounted in different ways. Within the space station it would have a single grappling leg, as in zero gravity it wouldn't need two; outside it might be attached to the end of the station's robot arm, enabling an astronaut to perform an Extra-Vehicular Activity (EVA) via telepresence, without having to risk going outside themselves.

Taking this further, NASA integrated a Type 1 with self-balancing, Segway-like wheels, as well as a more substantial four-wheeled rover, to evaluate the practicality of these robots assisting astronauts on planetary surfaces, particularly the telepresence exploration of remote or dangerous terrain. This resulted in a really menacing looking "Centaur"; a chunky looking torso and arms with a Boba Fett helmet mounted on an elongated neck!

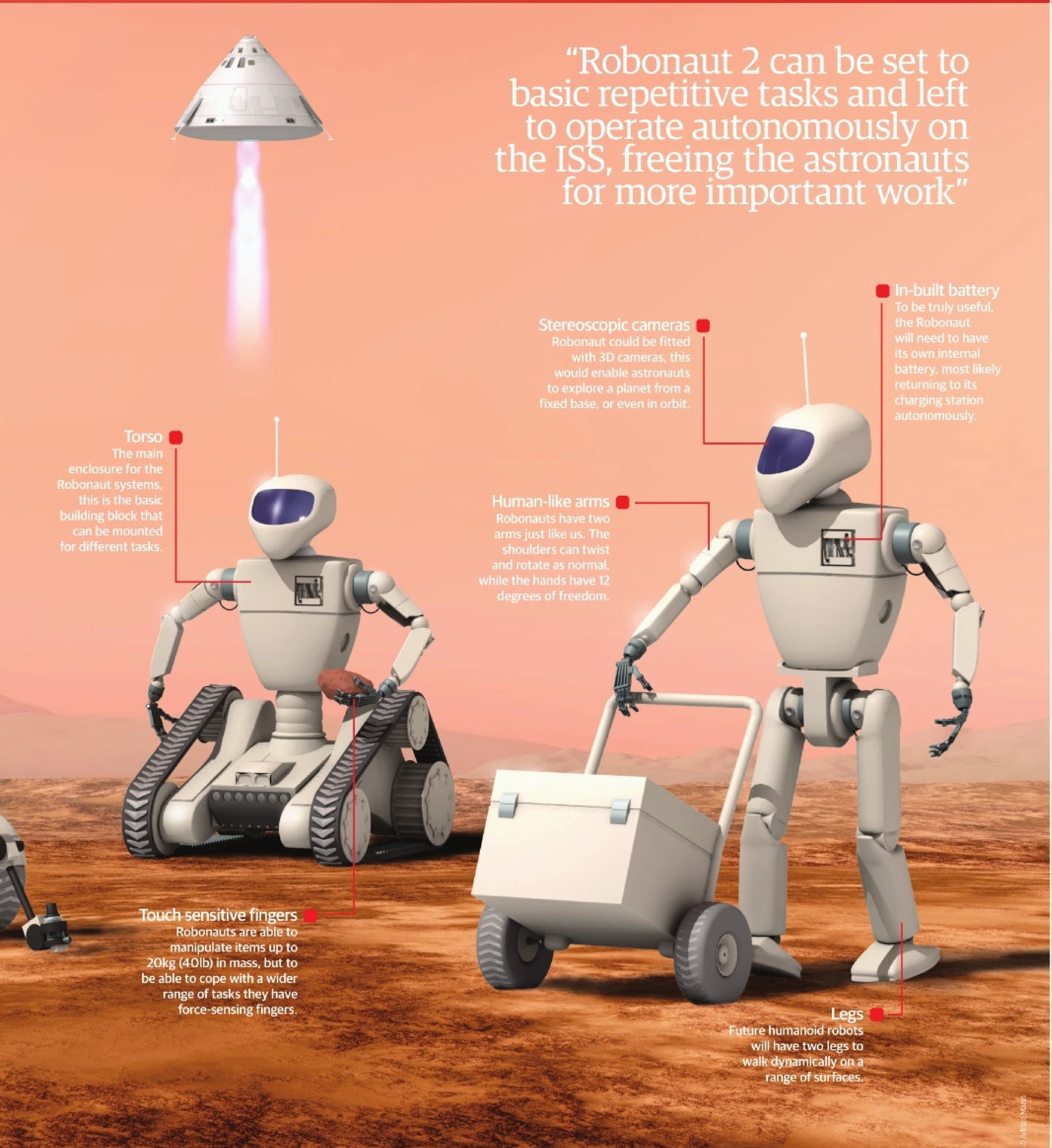
Finally, in 2011 a Robonaut made it to the ISS, in this case the rather more friendly looking Type 2. The Type 2 is able to operate faster and more dexterously than its predecessor and can manipulate items up to 20 kilograms (40 pounds). It can be controlled either by astronauts on the space station, or by operators on the ground via telepresence. It features touch sensors in its finger tips among a total of 350 different sensor inputs, and 38 different computer processors around its distributed control system. A major aim for the Robonaut programme is that it can be set to basic repetitive tasks and left to operate autonomously, freeing the astronauts for more important work. This is another area where the humanoid form is an advantage, just as we can turn our hands to many different tasks without specialisation, so can the Robonaut.

Robonaut was first powered up on the ISS in August 2011 and has been undergoing gradual development ever since. Exploring initially how the fixed torso could help inside the station, it has now received some legs in anticipation of its own battery pack (enabling free movement) in the near future. We're still a long way off C-3PO, but at least there is now a real humanoid robot helping us in space.



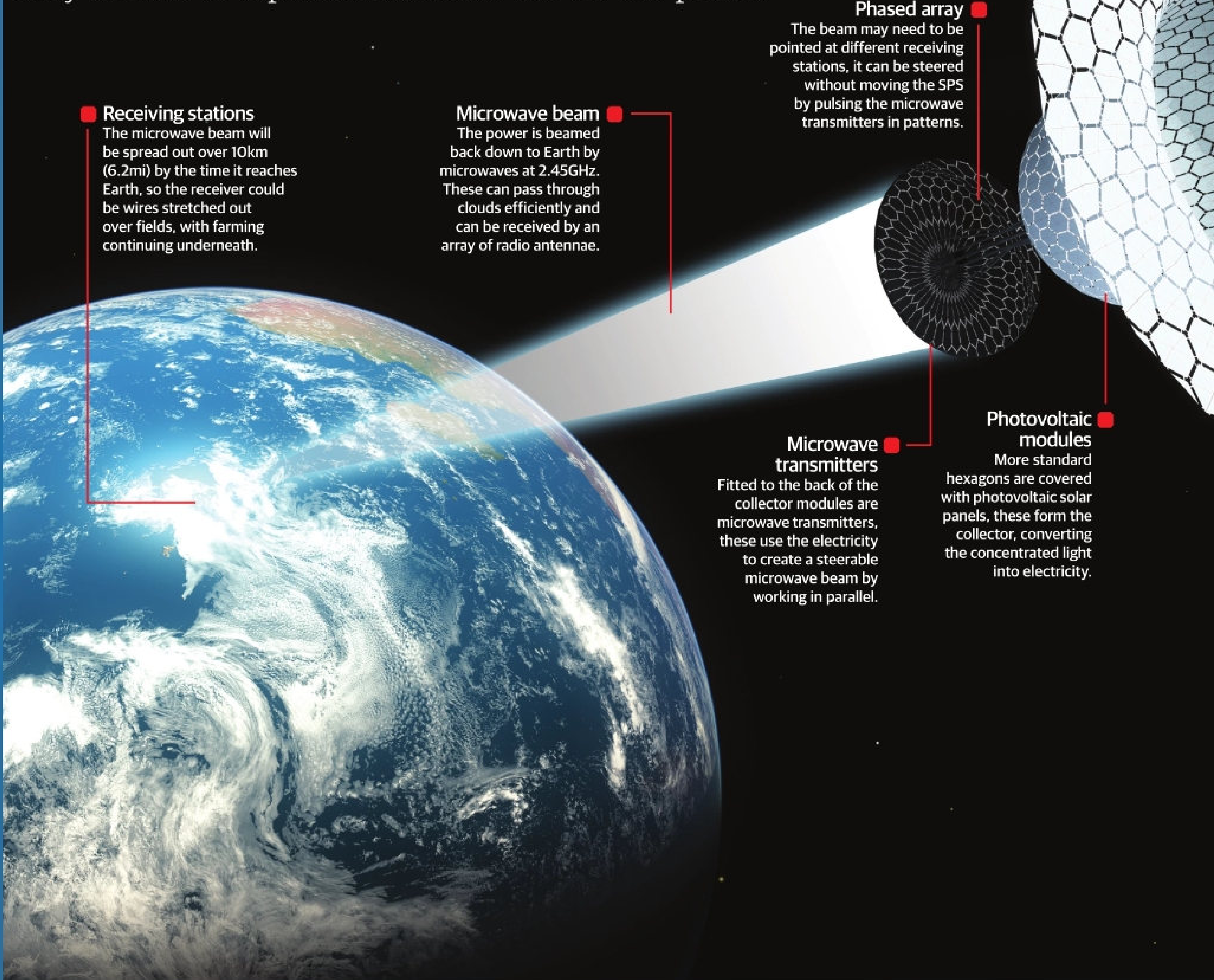
Wheels
Droids will be useful on the terrains of rocky worlds such as the Moon and Mars. Hopefully, some will be used on self-balancing wheels and a four-wheeled rover.

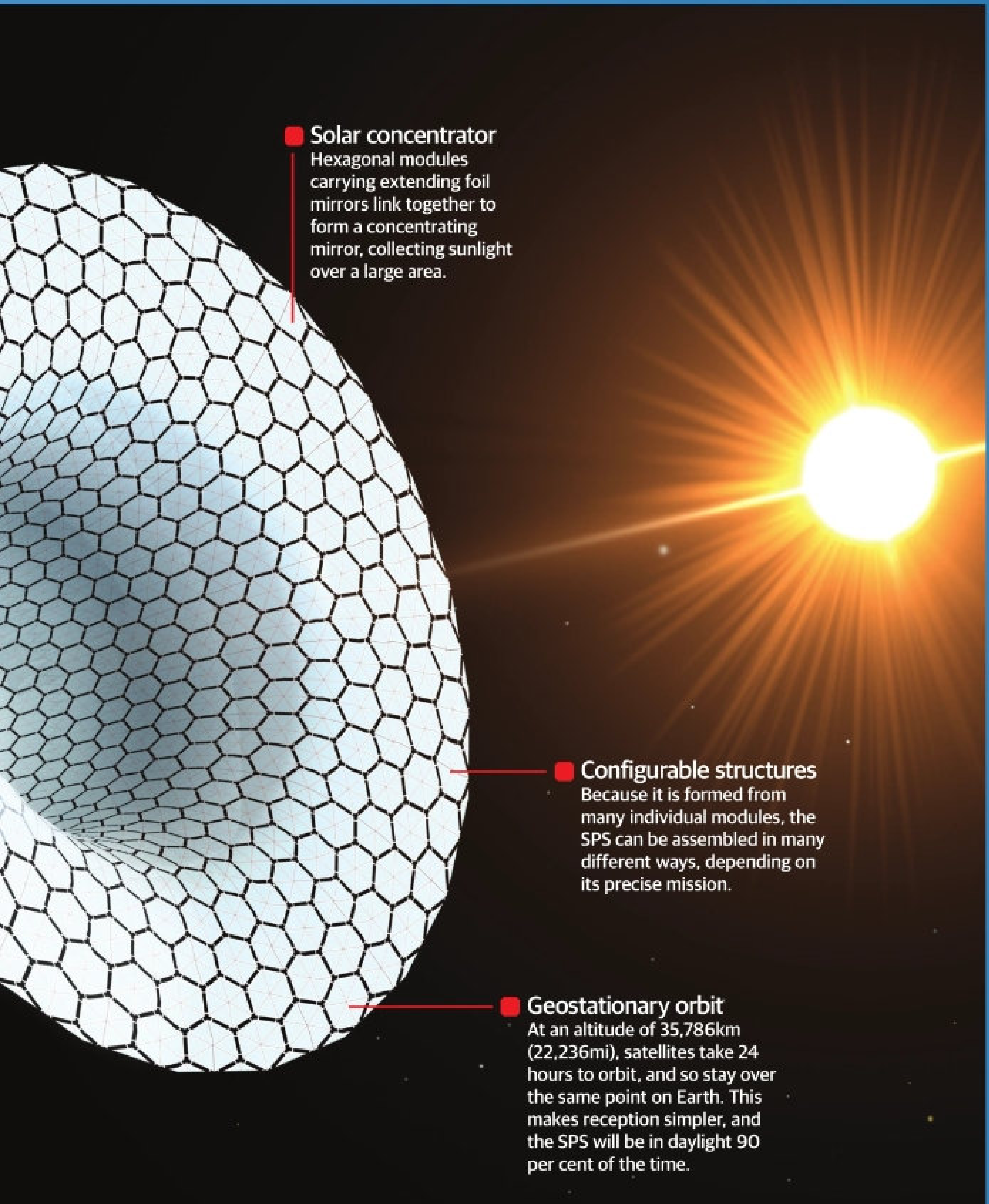
> "Robonaut 2 can be set to basic repetitive tasks and left to operate autonomously on the ISS, freeing the astronauts for more important work"



Space-based solar power

Sunlight is abundant just outside Earth, and soon we may be able to capture it there for use on our planet





> "The Earth receives more solar energy in one hour than humanity uses in one year, and in space it is undiminished by the atmosphere"

Space-based solar power (SBSP), the idea of collecting solar power in space for use on Earth, is potentially one of the most important applications that cheaper launches could make possible. SBSP was first studied in the 1970s by NASA and the US Department of Energy (DoE), and established designs have always called for rigid structures much larger than the International Space Station (ISS). These would be assembled in orbit by astronauts, but researcher John C Mankins has an alternative plan.

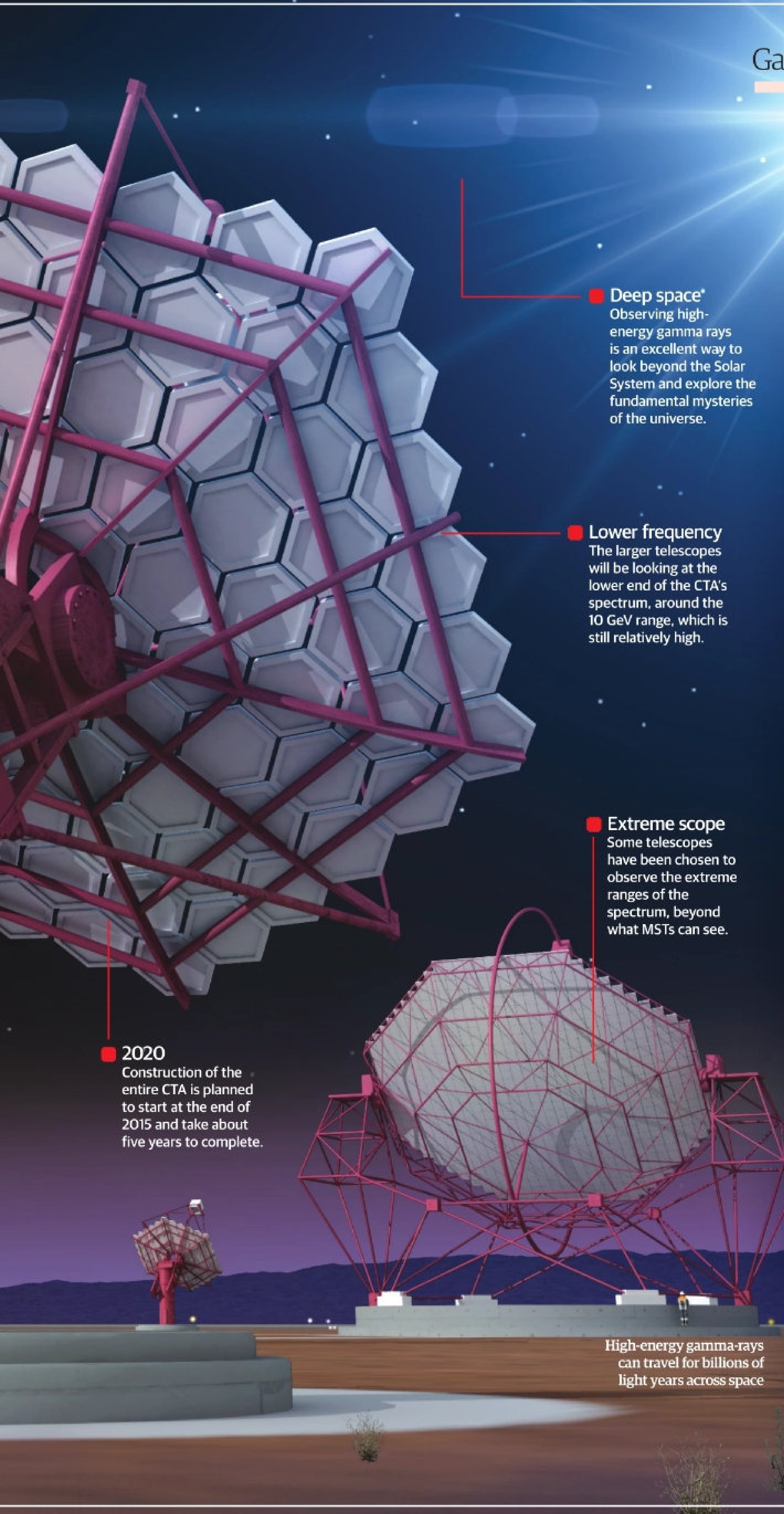
We are used to solar panels on satellites and the ISS, but how can panels in space be used on Earth? The Earth receives more solar energy in one hour than humanity uses in one year, and in space it is undiminished by the atmosphere; a solar panel in geostationary orbit (GEO, which takes 24 hours and hovers over the same point) is in sunlight 90 per cent of the time. But GEO is 35,786 kilometres (22,236 miles) high, so how can we get the power down? Most studies settle on beaming it down to a receiver with microwaves, which would reach the ground whatever the weather and be converted directly to electricity by a large area of radio antennae. It may sound hazardous, but the beam would spread out over a ten-square-kilometre (6.2-square-mile) area - birds could safely fly through it and the area underneath the aerials could be used for farming.

So far so good - clean, reliable solar power, beaming down 90 per cent of the time - so why don't we have this already? The NASA/DoE study estimates the panels would need to be over one kilometre (0.62 miles) across and would take over 100 heavy-lift launch vehicles to put up. We'd require a lot of very expensive hardware to be assembled in orbit, after many expensive launches. However, Mankins - a space consultant and NASA alumni - has proposed a new and more practical approach to SBSP. His concept, Solar Power Satellite via Arbitrarily Large Phased Array (SPS-ALPHA) would use three types of mass-produced components, hexagonal frames four metres (13 feet) across, deployable metal beams and connecting links. All the parts of the SPS-ALPHA would be built on the hexagonal frames; reflecting panels from one frame with an extending beam at each corner that would spread out foil to make a mirror. The generating panels would use the same frame but would be covered with solar cells on one-side and microwave generators on the other.

All of these modular panels could be stacked and launched inside a normal rocket fairing, and could be assembled with double-ended robot arms that walk about the hexagonal frames. The frames would be joined to make a concentrating mirror that focuses sunlight onto the generating panels; these produce electricity, convert it into microwaves and beam it back to Earth. The microwave beam could then be steered, without having to move the SPS-ALPHA, by pulsing the generating panels in pattern - the "phased array" in the title. Because it is made from modular panels, the SPS-ALPHA could be built in different configurations and expanded over time as needed. It would be a big project to launch an SPS-ALPHA, but by creating it from mass-produced, self-assembling modules, Mankins' concept cuts the cost of manufacture, launch, assembly and operation, and offers consistent solar power on a large scale - something the world is in great need of.

Gamma-ray observatory

This far-sighted, next generation telescope array may help answer some of the universe's biggest mysteries



High-energy gamma-rays can travel for billions of light years across space

It can be easy to forget that one of the best ways to view the greater universe is to peer far beyond visible light, into the gamma-ray end of the electromagnetic spectrum. With the ability to more-efficiently see beyond our Solar System, gamma-ray astronomy is an important field for helping us understand the cosmos.

The Cherenkov Telescope Array (CTA) plans to take the gamma-ray approach one step further than traditional arrays. By looking into much higher energy ranges than ever before, astronomers will be able to observe non-thermal processes that enable them to research some mysteries of the universe.

Non-thermal radiation is considered to be different from normal radiation occurring on the electromagnetic spectrum. It's thought to be created when elementary particles decay, which are the fundamental building blocks for all matter. However, the process isn't completely understood. Cosmic rays are included in this definition, and their source is one of the mysteries that the CTA aims to discover.

Observations will be made of different nebulas, including those formed after supernovas and where stars are forming anew. The galactic centre will also be observed, along with extragalactic gamma-ray sources such as galaxy clusters. It's thought these extragalactic gamma rays are altered by the tiny fluctuations in space-time, known as quantum gravity. If they exist, this would go against basic principles of special relativity.

The plan is that the CTA will be split up over two sites, one in the Northern Hemisphere, which uses 19 dishes, along with a larger sister site in the Southern Hemisphere that will contain 99 dishes. The location of the array in the Southern Hemisphere has been narrowed down to two sites: Aar in Namibia and the existing European Southern Observatory Paranal-Armazones site in Chile.

The telescopes used in each array are made up of three different dish types, although only two of these will be used in the northern site. The Large-Size Telescopes (LST) will be 24 metres (79 feet) in diameter and will measure the lower end of the CTA's target spectrum, around the 10 GeV range and higher. This is usually the higher range monitored by current gamma-ray telescopes.

Medium-Size Telescopes (MST) of a ten- to 12-metre (33- to 39-foot) class will join the LSTs to look into the range of 100 GeV to about 10 TeV. This is being labelled as the core energy range of the CTA, where a lot of the research into non-thermal processes will occur. These MSTs, along with the LSTs, will make up the majority of telescopes in the Northern Hemisphere.

The southern site will also feature Small-Size Telescopes (SST), which will be looking at the highest energy range in the CTA, anything around and above a few TeV. This can be achieved by using a number of larger telescopes, however the CTA Consortium has settled on using a greater number of smaller four- to six-metre (13- to 20-foot) telescopes for a better price-performance ratio.

The Automaton of Venus

A new NASA project is looking to send a walking, clockwork robot with mechanical programming to the second planet from the Sun

Despite being our closest neighbour, Venus has such a harsh environment that it is still relatively unexplored compared to Mars. Because its atmosphere is mostly carbon dioxide, the surface pressure is 92 times that of Earth's, and it has an average temperature of 462 degrees Celsius (864 degrees Fahrenheit), which is hot enough to melt lead. The Soviet Union managed to put eight stationary landers on Venus between 1970 and 1985, but the longest survivor only lasted 127 minutes. No missions have landed since.

The heat is the biggest challenge; systems and electronics could be embedded into solids or left open to accommodate the pressure (like deep sea submersibles), but with no way to dump heat, they will slowly cook. In an effort to get more long-term data from Venus, NASA JPL engineers Jonathan Sauder and Evan Hilgemann are working on an alternative approach, based on an ancient technology. Before electronics there was a long history of mechanical automata; the Greeks built the Antikythera automata, a mechanical astronomical computer around 2,300 years ago. By the 19th century mechanical programming was in use in settings from life-like, animated sculptures to industrial textile machinery. Now, such mechanisms may be the answer to surviving on Venus.

Sauder's project is the Autonomous Rover for Extreme Environments, or AREE. "Rather than try and get a lot of data for only minutes, we're looking to use purely mechanical systems to collect simple environmental data over weeks or months," says Sauder. Rather than batteries, AREE will use a wind turbine to keep a spring wound up, which will provide power for a 'Strandbeest' walking mechanism - an ingeniously simple system developed by Dutch artist, Theo Jansen, that produces a smooth walking motion with six crank driven legs. AREE will be controlled by mechanical sequencers - potentially pin barrels or punched strips - as it progresses across the landscape, and will be guided by reactive mechanisms that respond to difficult terrain intrinsically without the need for computer control.

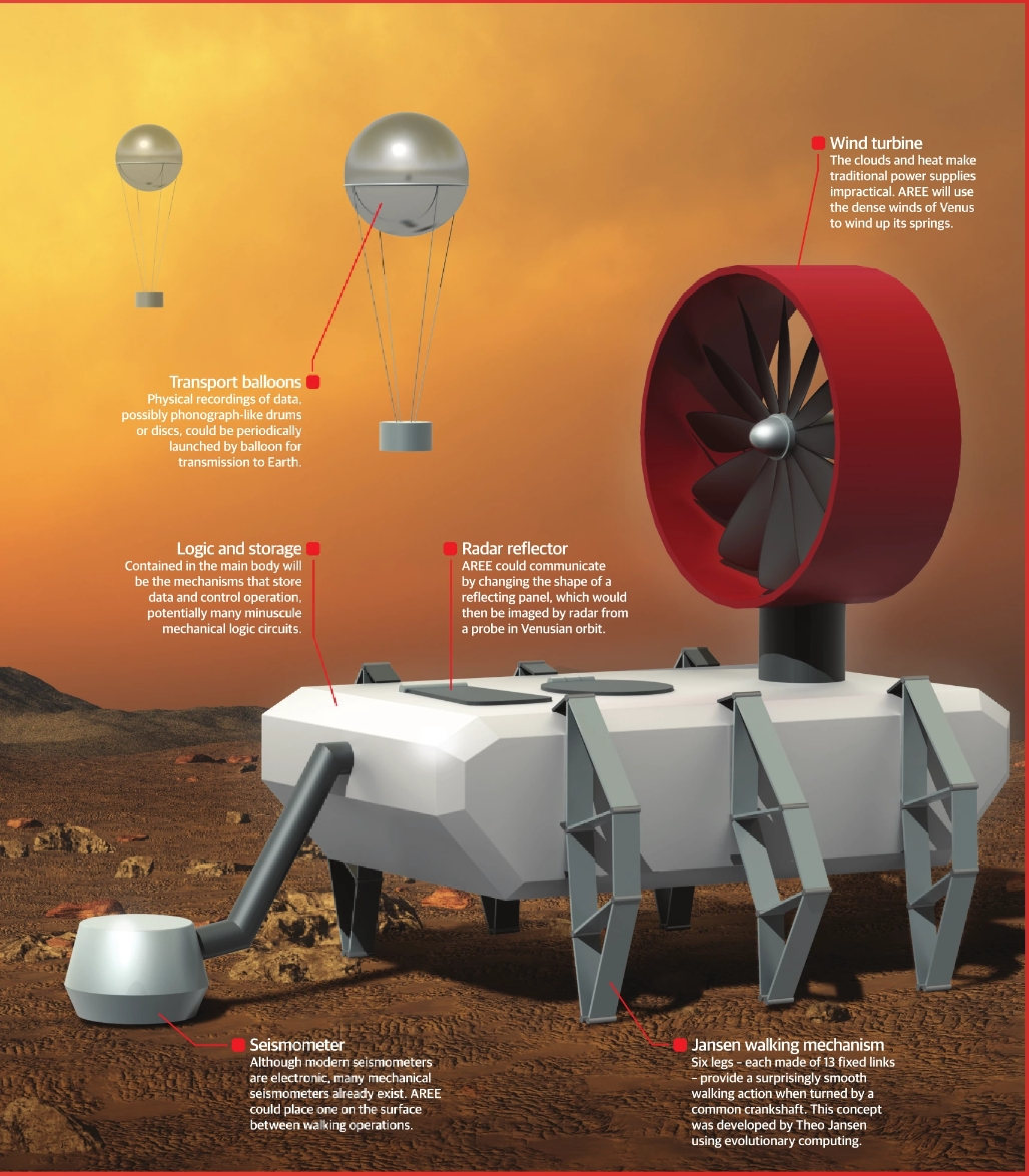
AREE's instruments would also have to be mechanical; wind speed and direction could be collected from the turbine, temperature by bi-metallic strips that bend to a particular angle for a given temperature, and between steps it would place a seismometer down to listen for Venus-quakes. But how do you record data without computer memory, or transmit it off the planet? AREE might record LPs! It would capture sensor data by cutting it into grooves on a disc or cylinder like a phonograph, which then could be sent by balloon up to the benign upper atmosphere.

At 50 kilometres (31 miles) altitude, Venus' atmosphere is around 20 degrees Celsius (68 degrees Fahrenheit) and has a pressure similar to Earth's. This means that a variety of flying probes are envisaged to reside there in the future, and one of them could collect the records and transmit the data to Earth. Another possibility could be radar semaphore, with AREE adjusting the shape of a reflector so that a satellite could detect the changes by sending a radar pulse from orbit. JPL is also looking at the potential of mechanical logic circuits for storing data and maybe controlling AREE.

Computers are made up of huge numbers of tiny switches and circuits that use binary numbers to perform logical operations - things such as, "If this input *and* that input are both on, turn on that output." Complex computing is built out of such simple steps, but done incredibly quickly by tiny components. Sandia National Laboratories has demonstrated that mechanisms 50 micrometres across, with 8MB of mechanical storage, would fit on a flat, 40-centimetre (15.7-inch) square.

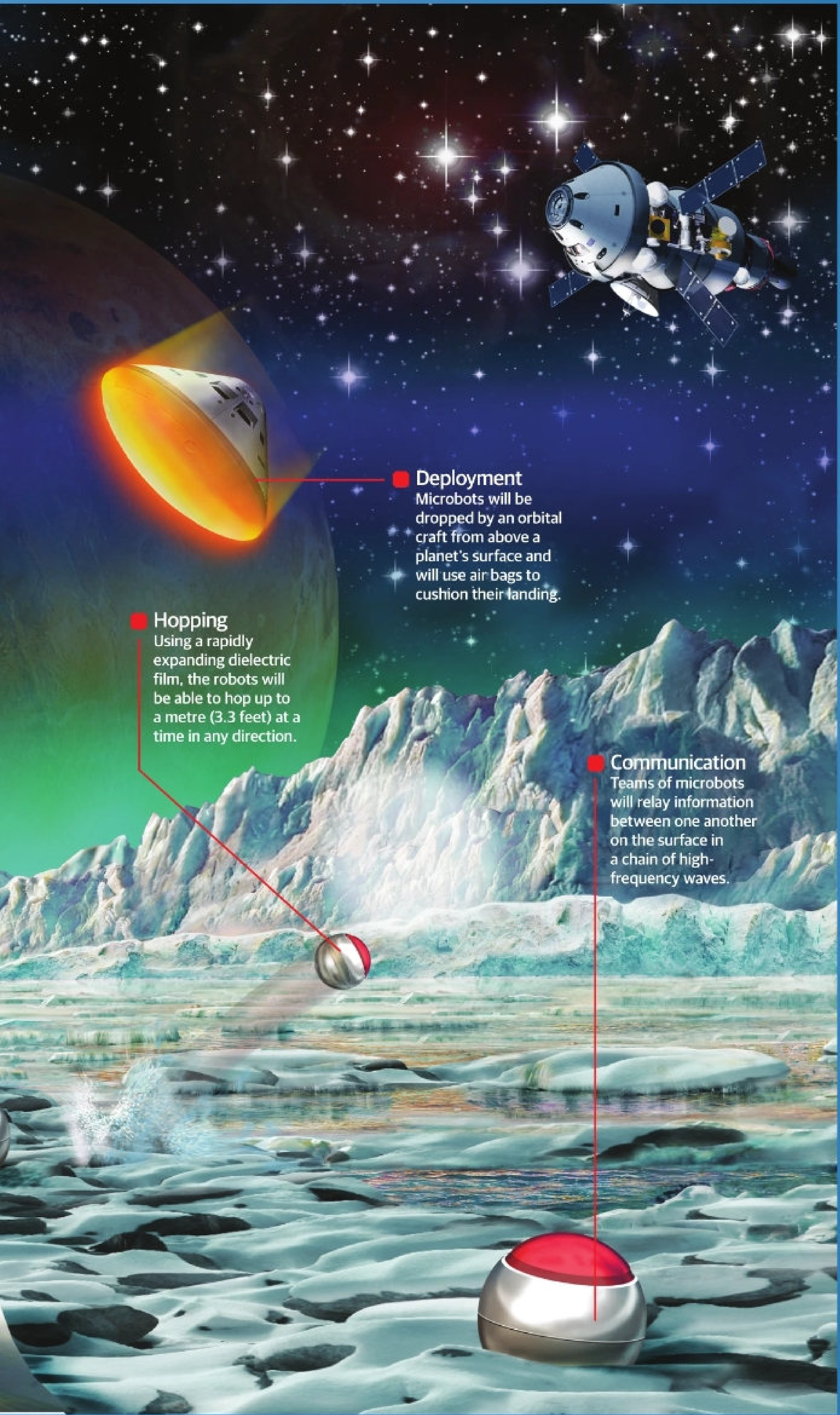
It is still in the early stages, but AREE is an ingenious solution to challenging environments - as well as Venus, it could be used on the searing surface of Mercury, or in the lethal radiation environment of Io. As seen in *Dr Who*, clockwork robots really might have a place in our future!

> "AREE will be controlled by mechanical sequencers - potentially pin barrels or punched strips - as it progresses across the Venusian landscape"


Wind turbine
The clouds and heat make traditional power supplies impractical. AREE will use the dense winds of Venus to wind up its springs.
Transport balloons
Physical recordings of data, possibly phonograph-like drums or discs, could be periodically launched by balloon for transmission to Earth.
Logic and storage
Contained in the main body will be the mechanisms that store data and control operation, potentially many minuscule mechanical logic circuits.
Radar reflector
AREE could communicate by changing the shape of a reflecting panel, which would then be imaged by radar from a probe in Venusian orbit.
Seismometer
Although modern seismometers are electronic, many mechanical seismometers already exist. AREE could place one on the surface between walking operations.
Jansen walking mechanism
Six legs – each made of 13 fixed links – provide a surprisingly smooth walking action when turned by a common crankshaft. This concept was developed by Theo Jansen using evolutionary computing.
© Adrian Mann

Microbot explorers

This new generation of all-access planetary probes will delve further than ever before



From the moment the Soviet Union landed the Lunokhod 1 lunar rover on the Moon in November 1970, scientists and astronomers have been working tirelessly to create more-efficient and effective methods for searching a planet's surface. We have seen rovers, landers and probes, but a team from the Department of Mechanical Engineering at MIT are working on microbots, the next generation of planetary investigators.

These tiny spherical robots - often no larger than a baseball - are able to hop, bounce and roll around the surface of a planet, get into crevices and negotiate obstacles in ways that traditional rovers are unable to.

Within the next ten to 40 years, engineers are hoping to reduce microbots to just ten centimetres (four inches) in diameter and have them weighing no more than 100 grams (3.5 ounces), so they are able to get themselves into hard-to-reach places. They would be constructed of lightweight polymers and carry miniaturised scientific equipment for research. Many of the key components encased in the machines will be around the size of a coin, with the mass spectrometer measuring just 0.6 cubic centimetres (0.04 cubic inches) and the 4GB hard drive only just larger than a two-pence piece or a dollar coin.

The idea is to deploy hundreds of microbots on the surface of a planet, using an orbital craft to carry them and an airbag system to ensure they're intact when they hit the planet's surface. From there, the microbots will spread out in teams, scouring the planet's surface and finding their way into lava tube caves. This will enable in-situ examinations of the planet's composition, history and chemical structure. They will then send this information back to the surface, where it can be stored and communicated to teams back on Earth. The microbots would sometimes have to work in a relay to get the information back to the surface as electromagnetic waves struggle to get through rocky structures. This means that the information would be transmitted using high-frequency waves, jumping from bot to bot until the signal is eventually able to be picked up on the surface.

A Dielectric Elastomer Actuator - an elastic dielectric film placed between stretchy electrodes - creates the hopping movement of the microbots. When current is passed through this, the electrodes are stimulated and laterally expand the film. This rapid expansion enables a microbot to hop on its bistable leg and travel across the planet's surface, easily traversing obstacles such as rocks. Each hop could take a microbot as far as a metre (3.3 feet), which would enable it to travel across dozens of metres every day, collecting important scientific information as it goes.

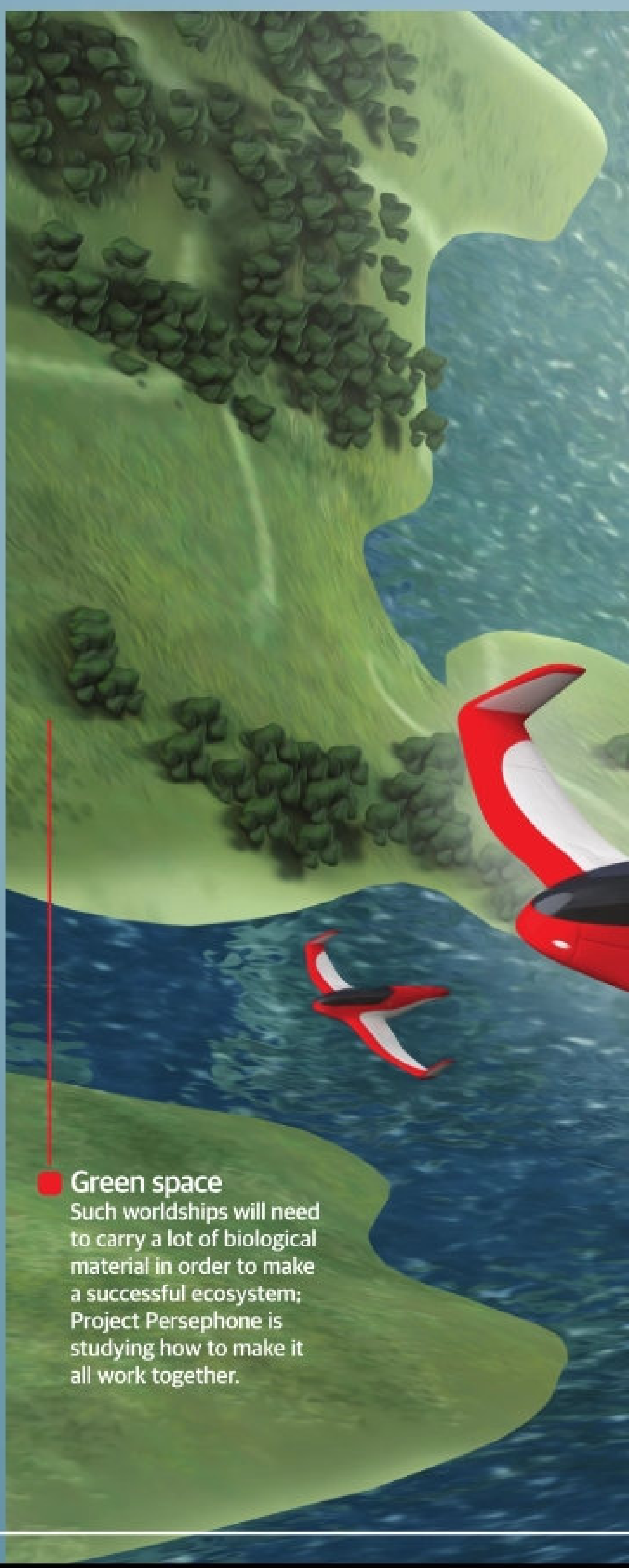
Mars would be one of the first obvious ports of call for this generation of planetary explorers. There has been an awful lot of analysis of the Red Planet recently, but the opportunity to go deeper than ever before is one the team at MIT will find hard to pass up. The Moon, with its pock-marked surface, will be another key area for the microbots to be deployed, but any planet or satellite with an inhospitable, rocky surface will be on the radar for these access-all-areas robots.

Interstellar space ark

An international team of researchers are figuring out how to make a living interior for a starship

When you picture a starship what comes to mind? *Star Trek*'s Enterprise warping between star systems, or the Millennium Falcon zipping through hyperspace? While the starships of fiction are small machines that are faster than light and built like earthly vehicles, the first real starships are likely to have more in common with tropical islands, teeming with life, whilst supporting a community for generations. These will be 'worldships', a place to live on the move rather than a vehicle, and University of Greenwich researcher Dr Rachel Armstrong is leading an international project to investigate how we could create this "living architecture" - Project Persephone.

The first attempts at creating self-contained biospheres (living environments) have demonstrated how much more complicated it is than first thought. The BIOS-3 tests in the former Soviet Union succeeded in producing oxygen with algae and recycling the majority of its water, but food was



> "All parts of the worldship will contribute towards keeping its ecology and its colonists alive, as even the buildings will include living material"

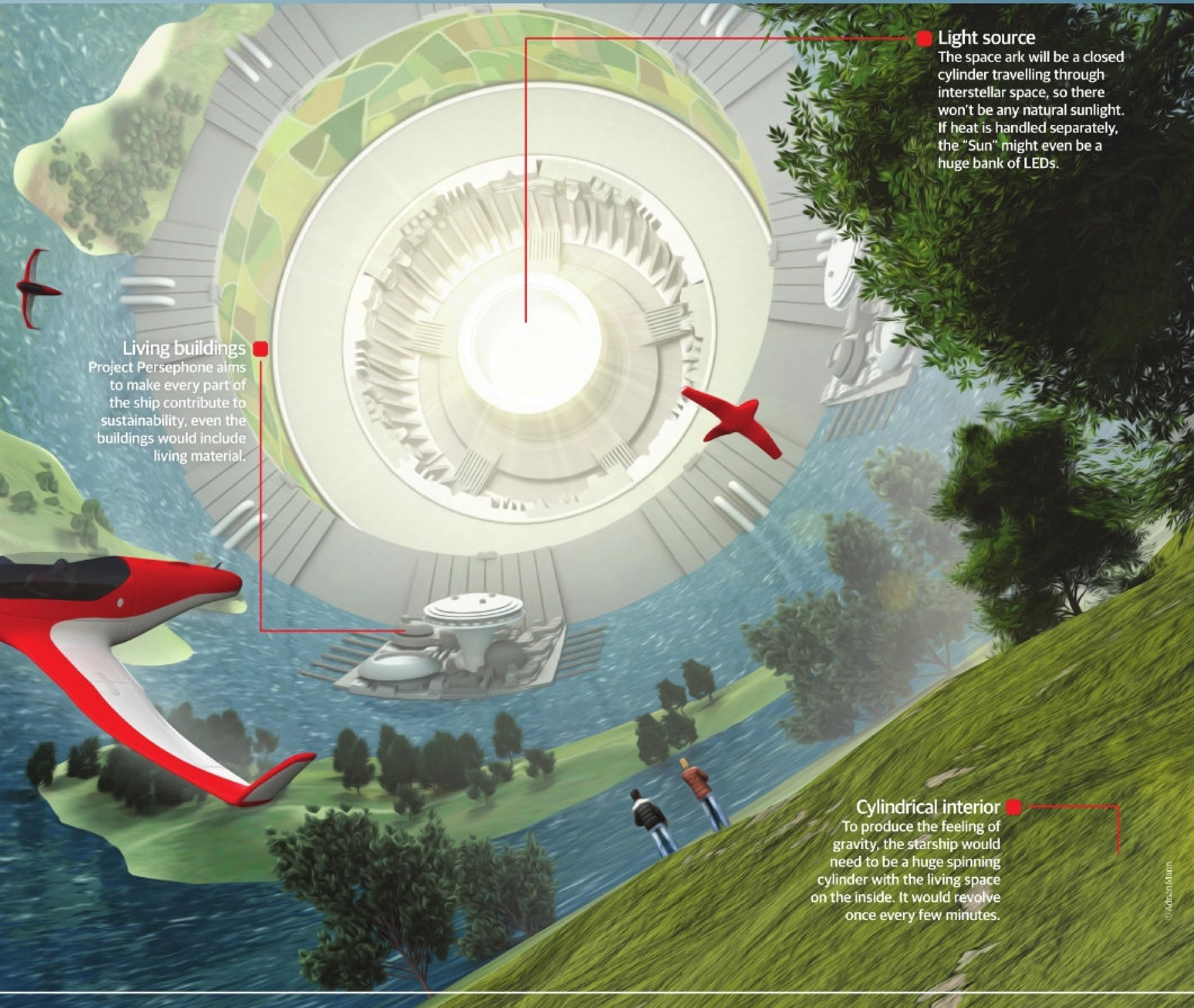
separately provided from outside; this study would be useful for Mars missions, but not a worldship. Biosphere 2 (Biosphere 1 being the Earth) built in the 1990s in Arizona was a much bigger project, with different climatic regions in a large sealed greenhouse. Oxygen creation wasn't fast enough and carbon dioxide fluctuated, while the ocean section acidified and the pollinating insects died; true to form though, the ants and cockroaches thrived!

With Project Persephone, Armstrong's team believe the key to a sustainable ecological system is: the soil, building life, and the environment from the bottom up. Soil may look inert but it is actually teeming with bacteria and microbes, recycling resources and building up biomass. Whereas when we normally build with natural materials we remove the life - baking soil into bricks, cutting trees up into timber - Armstrong hopes to preserve the "liveliness" of everything; so that all parts of the worldship can contribute towards keeping its ecology, and its colonists, alive and thriving.

So, far from being hard metallic vehicles like aeroplanes or submarines in space, these starships could well feature houses made of living trees or soil walls, in lush green spaces. Use of in-situ resources will be critical, as these ships will be so big it would be pointless-to-impossible to try and launch everything needed from Earth. One possibility could be to robotically hollow out an asteroid, or use asteroid material to feed a system that could 3D print a huge cylindrical skeleton, into which the interior could be built-up. It would need to be cylindrical so that it could spin to create gravity, as we are finding more and more that gravity is a crucial component to all sorts of living processes.

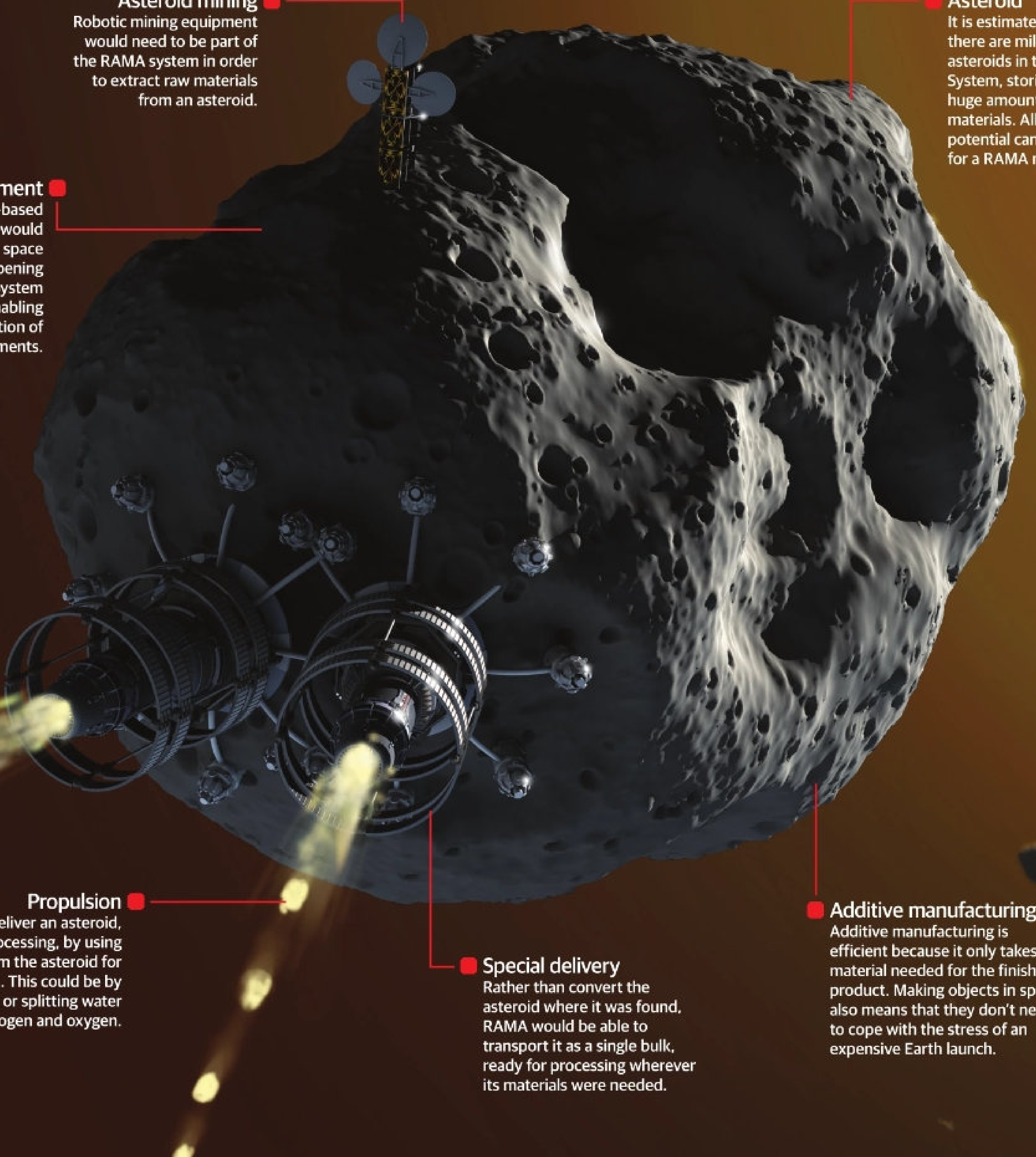
The worldships would still, of course, need technological systems working in concert with the living interior; and its own source of energy, which would most likely be a fusion reactor also powering the engines. Though Persephone is working towards a sustainable system, it is not expected to be a closed system, as the Earth has received matter from the outside and continues to receive energy from the Sun, so the Persephone worldships would be able to collect and utilise more resources as and when they found them.

Persephone is part of the Icarus Interstellar organisation, a group of researchers and projects dedicated to developing interstellar technology by the early 2100s. But their findings are likely to be of use elsewhere too; they could, of course, help efforts to colonise the Solar System, but here on Earth imagine if our buildings and infrastructure were not just dead objects, but living systems all helping to contribute to our environmental wellbeing. So Project Persephone may well help us to keep the Earth habitable, as well as helping us reach for the stars.



Project RAMA

A Californian company wants to turn asteroids into autonomous spacecraft - to mine them and to relocate them in space



"A RAMA mission could be sent to a potentially Earth-crossing asteroid to push it off course and collect it for its resources – the ultimate Earth revenge!"

Every year NASA selects a range of speculative projects through its Innovative Advanced Concepts (NIAC) programme, and this year space 3D printing specialist, Made In Space (MIS), has received an award for Project RAMA. The project is partly named after an Arthur C Clarke story where an empty, automated colony ship built in an asteroid arrives in the Solar System; the initials in this case stand for Reconstituting Asteroids into Mechanical Automata.

Based in Mountain View, California, MIS was founded in 2010 with the aim of using additive manufacturing (3D printing) to dramatically reduce the costs of operations in space. In additive manufacturing a supply material, often a plastic filament or metal dust, is fused together into objects rather than cut out of a bigger piece. For launch from Earth this would save volume and mass and space missions would be able to print spare parts as needed. MIS recently supplied a printer to the ISS in order to test the process in microgravity.

But MIS's ultimate goal, which would enable mass settlement in space, is to employ additive manufacturing with materials sourced in space; and this is where RAMA comes in. Not only would it save the cost and difficulty of launching stuff from Earth (we'd only need to send people and their luggage), but there are far more resources available up there.

The RAMA concept will likely consist of a whole range of technologies that could be deposited on an asteroid, where they could extract raw materials, process them into usable forms and pass them on. These materials could then be used for additive manufacturing to build things, possibly even bigger versions of the extraction and manufacturing systems, so a small initial lander could build up an asteroid-scale installation out of the asteroid itself.

RAMA's other main system will be propulsion, which will use material from the asteroid as a reactive mass. In its most basic form, this could mean firing rubble off the surface with an electromagnetic catapult. Better performance could be gained if the asteroid could provide water or hydrocarbons that could be used in a conventional rocket engine. Once a RAMA installation was in place on the asteroid then it could be moved en-masse to wherever in the Solar System its resources were needed: a self-contained and propelled mine and factory in one.

It only takes a small change in speed to gradually change the orbit of an asteroid so, as well as delivering resources, RAMA may be useful for Earth defence. Astronomers are making increasing efforts to track and record the orbits of potentially Earth-crossing asteroids. When a candidate is found, its orbit is analysed so that the uncertainty of its future path is reduced until we can be sure if it will miss the Earth or not. Because of the consistency of orbits we should know several years, even decades, in advance. In which case, a RAMA mission could be sent to the offending asteroid to push it off course and collect it for its resources – the ultimate Earth revenge!

Although NIAC projects are not expected to deliver immediate results, RAMA does build on technologies that are already maturing; now it's just a question of scale. If they are able to do it, MIS could become one of humanity's most significant companies; making huge profits, while enabling space settlement and protecting Earth from asteroid impacts.

Solar flapper

To explore another planet faster than a rover and in more detail than a satellite, we need to fly, and the best way to do it may be to copy birds

When we first started to build flying machines, we understandably began by copying natural flyers: birds. In the initial stages of human flight, numerous people tried jumping from high places with poorly designed wings, leading them to fall to their deaths - the earliest account of this is of a man named Armen Firman trying this out during the 9th century. Despite this, attempts at flapping wing flight continued into the machine age, typifying the early films of hopelessly eccentric airplanes flapping themselves to pieces on the ground.

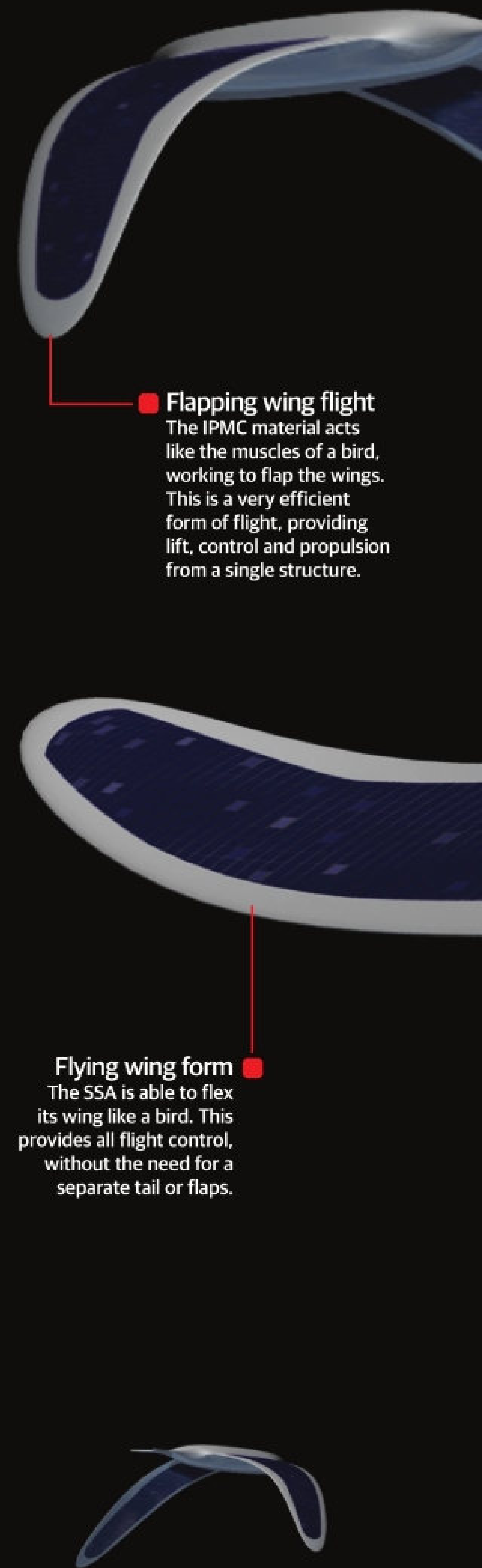
It wasn't until 2010 that a team from the University of Toronto, Canada, made the first successful flight of a piloted, engine-powered ornithopter, a craft that 'flaps' its wings. While fixed wings combined with a separate source of propulsion finally took us into the air, flapping wing flight has a lot of potential benefits - it's just really hard to do. But now, if a study presented to the NASA Institute of Advanced Studies comes to fruition, then these remarkable, solid state, solar-powered ornithopters could be flying on other planets sooner than we think.

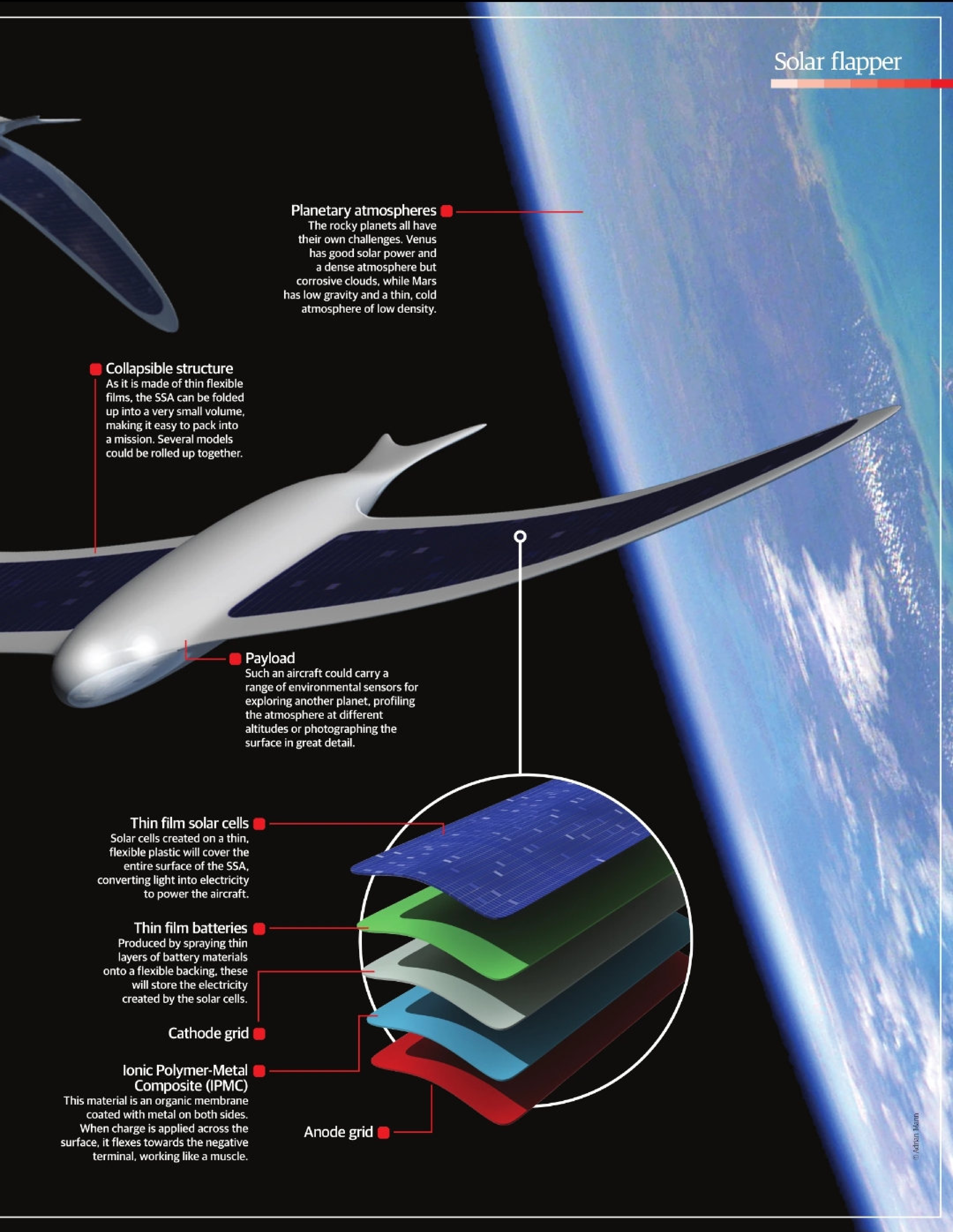
The Solid State Aircraft (SSA) study has been led by Anthony Colozza of the Ohio Aerospace Institute, with contributors from universities across the United States. With their unique aircraft concept, they are looking to combine thin film solar cells and thin film batteries with an electrically responsive synthetic muscle material to create an airplane with no moving parts. Designed as a rectangular flying wing with no tail, solar energy would be collected by flexible photovoltaic cells at just a thousandth of a millimetre thick. Despite their thinness, they can convert 10 per cent of the light falling on them into electricity, while still being able to flex with the wing. This energy would then be stored in thin film lithium-ion batteries, which are of a similar chemistry to the batteries used in smartphones and computers. However, they are produced by spraying the layers that make up the battery, such as the electrical contacts and the electrolyte - the substance that allows the charge to flow - in thin layers onto a flexible backing. This backing could then be used as the back of the solar cells.

The power supply could then be used to drive the Ionic Polymer-Metal Composite (IPMC) - this is material that acts like a muscle, flexing when electricity is applied. It is made of a substance called ion exchange membrane, which is coated with metal layers. When electricity is applied to the metal layers it causes molecules of water and sodium in the membrane to cluster at the negative terminal. This makes the negative side expand and the positive side contract, bending the membrane and flexing the wing. The IPMC could be incorporated as skeleton-like strips into the wing, or indeed spread out over the whole wing, with the pattern of the electrodes determining how it flexes. Given the combination of power supply, storage and propulsion into these thin films and the availability of miniaturised computing and sensors, the SSA could be an intelligent flying plastic sheet.

The SSA's incredible simplicity and low mass would be great advantages for missions exploring other planets, where every kilogram (or pound) costs millions of pounds to send and there is no chance of making repairs. Flapping is the most efficient form of flight, with the SSA making it possible to cruise around Venus indefinitely or grasp a hold in Mars' tenuous atmosphere - we can finally fly like the birds and soar to other planets, too.

"The SSA's low mass would be a great advantage for missions exploring other planets, where every kilogram costs millions of pounds to send"




Planetary atmospheres
The rocky planets all have their own challenges. Venus has good solar power and a dense atmosphere but corrosive clouds, while Mars has low gravity and a thin, cold atmosphere of low density.
Collapsible structure
As it is made of thin flexible films, the SSA can be folded up into a very small volume, making it easy to pack into a mission. Several models could be rolled up together.
Payload
Such an aircraft could carry a range of environmental sensors for exploring another planet, profiling the atmosphere at different altitudes or photographing the surface in great detail.
Thin film solar cells
Solar cells created on a thin, flexible plastic will cover the entire surface of the SSA, converting light into electricity to power the aircraft.
Thin film batteries
Produced by spraying thin layers of battery materials onto a flexible backing, these will store the electricity created by the solar cells.
Cathode grid
Ionic Polymer-Metal Composite (IPMC)
This material is an organic membrane coated with metal on both sides. When charge is applied across the surface, it flexes towards the negative terminal, working like a muscle.
Anode grid
© Adrian Mann

Dyson sphere

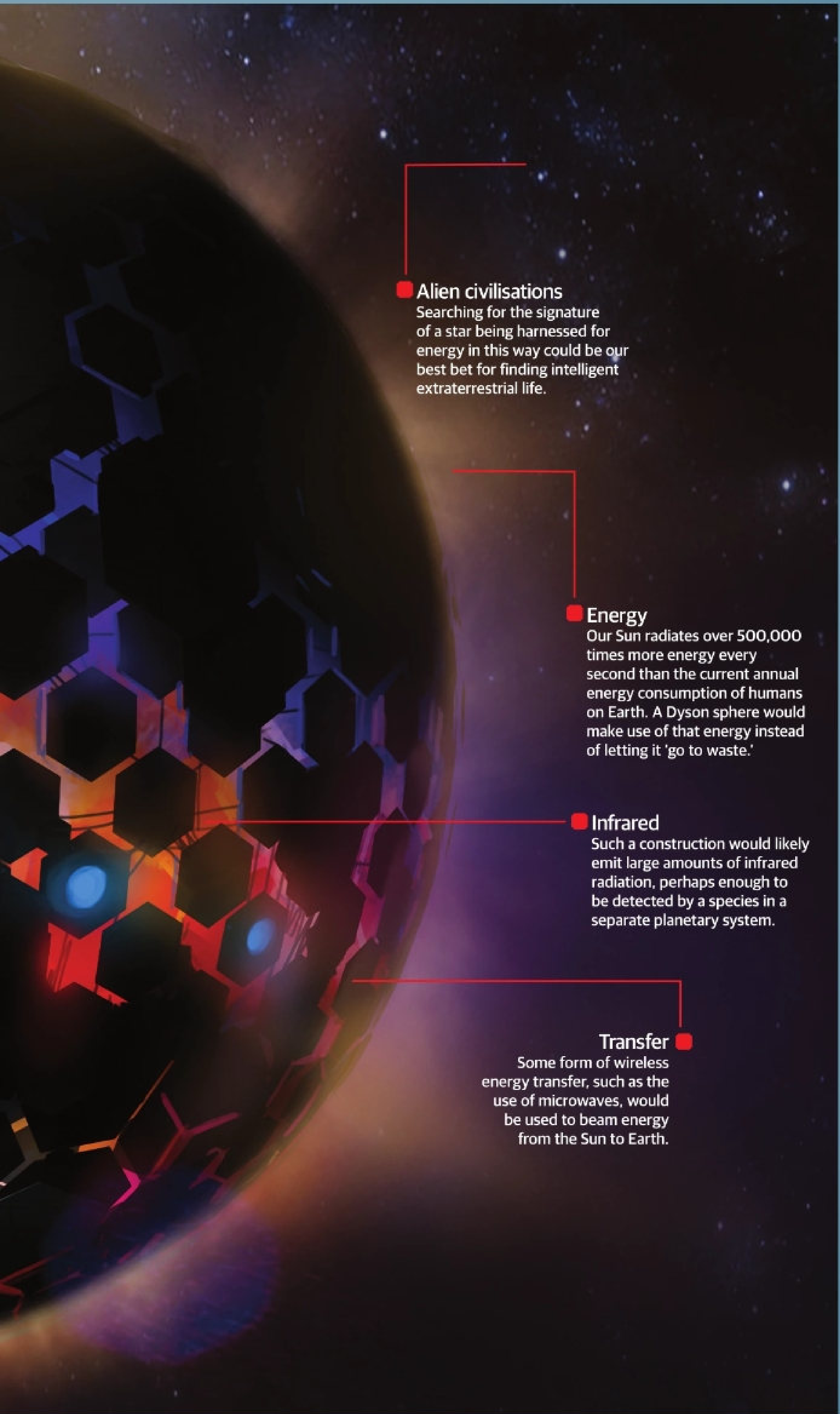
Could an advanced civilisation harness the power of stars to sustain their energy needs?

Satellites
The diameter of the Sun is 100 times greater than Earth, so we'd need to evenly spread out solar power satellites to gather energy for transfer to Earth.

Mass
If the satellites were fairly small, the amount of material needed to build them would reduce drastically, therefore making the proposal more feasible.

Sails
The satellites would be kept in position around the star by virtue of large light sails, which would use the radiation pressure of the star to counteract the force of gravity.

Poles
A 'swarm' of orbiting satellites is preferred to a solid sphere, as the latter would likely lose structural integrity at the poles where there was no rotation.



First proposed by physicist Freeman Dyson in 1960, a Dyson sphere is a hypothetical swarm of satellites that would surround a star in order to harness its energy. Although more commonly known as a Dyson swarm, some people have discussed the possibility that, rather than a swarm of satellites, a star could be encased in a solid sphere by a future civilisation. But this is an idea that Dyson himself is keen to stray away from. Indeed, for a planetary system like our own, such a structure would likely require every object in the Solar System other than the Sun to be dismantled and rebuilt into a giant sphere owing to the huge size of the Sun.

Dyson's initial proposal was suggested as a way that a future civilisation could sate their vast energy needs. As the energy requirements of a civilisation increases they may require an ever-growing amount of energy, a crisis perhaps solved only by harnessing the power of stars. With it this carries further connotations, that there may be advanced races elsewhere in the Solar System that have built such structures. Dyson postulated that these would radiate a large amount of infrared radiation noticeable even to us here on Earth.

The idea has gained enough ground that the SETI Institute in California, USA, has been on the lookout for Dyson spheres, while Fermilab near Chicago has carried out its own analysis of observations from outside the Solar System to ascertain the likelihood of the existence of Dyson spheres. Aside from finding four candidates that were "amusing but still ambiguous and questionable," though, nothing too promising has been found.

While fun to imagine, the logistics of a Dyson sphere are also quite far-fetched. Taking the solid shell idea, this structure would be thin at perhaps just a few tens or hundreds of metres thick with its membrane covered in solar panels, but it would still be many times more massive than Earth. Placed around a star, though, it would have little chance of keeping its structural integrity; if made to rotate so as to keep it in 'orbit' around the star, the areas around its artificial equator would be stable but at the poles, where there was no rotation, the structure would succumb to the forces of gravity and collapse.

This is why Dyson favours the swarm idea. With this, many thousands of solar energy-gathering satellites would be placed around the star. They would then beam their energy to a central hub to be utilised by a civilisation. Using separate satellites, all in orbit around the star, the structure would remain intact and huge amounts of energy could be transferred from the star.

While this particular structure might seem impractical, something on a smaller scale could feasibly do a similar job. For example, some theories suggest that a large solar-gathering spacecraft placed between Earth and the Moon would be able to absorb huge amounts of power that could be beamed to our planet. Known as space-based solar power (SBSP), this is something that sci-fi writers have favoured and is a much more promising technology than an entire Dyson sphere. However, perhaps many thousands of years in the future when we become interstellar explorers, it may be necessary to find huge resources of energy and, as far as we know, there's nothing better than an entire star.

Sun-skimming spacecraft

Things are heating up at NASA as Solar Probe Plus prepares to take a plunge into the Sun

The Sun has always held a great fascination for humankind due to its incredible life-giving, yet destructive heat, and we might soon know much more about it thanks to NASA's Solar Probe Plus. This intrepid spacecraft follows in the footsteps of Helios 1 and Helios 2, which launched in 1974 and 1976 respectively and continued returning data about the Sun until the 1980s. This pair of solar probes are still in heliocentric orbit, travelling at record-breaking velocities of 252,792 kilometres (157,078 miles) per hour.

NASA's Solar Probe Plus is due to set off from Earth on 30 July 2018, getting closer to the Sun than any man-made object ever has before. Back in March, the probe underwent advanced design and testing, meaning that building work was finally given the green light. This exciting development brought the project – which was originally announced back in in 2008 – a step closer to its ultimate goal of getting to within 8.5 solar radii (6 million kilometres/3.7 million miles) of the Sun.

It will do this by swinging around the Sun then using Venus as a flyby anchor, flinging it back towards the Sun at speeds of up to 200 kilometres (125 miles) per second. It will perform the Venus flyby seven times and orbit the Sun 24 times in total. The last three orbits will be the probe's closest, beating the previous record by seven times.

The mission is being orchestrated by the Johns Hopkins University Applied Physics Laboratory, which was responsible for the MESSENGER craft orbiting Mercury. The lab is using some of the technology from that mission to protect the probe in its most vulnerable stage.

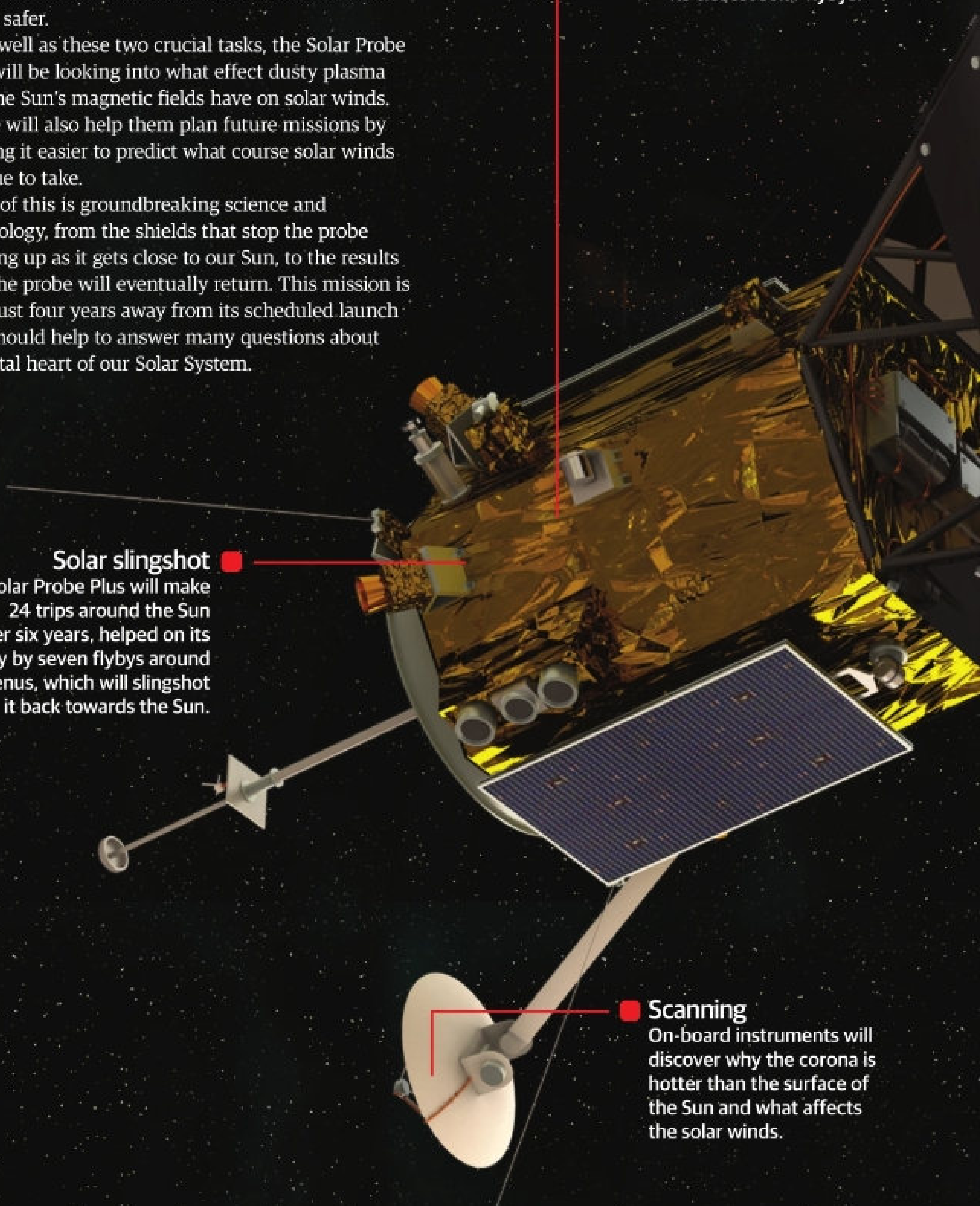
It will be protected from the intense heat of the Sun by using a heat-resistant carbon-composite shield. It must be capable of dealing with temperatures of 1,371 degrees Celsius (2,500 degrees Fahrenheit) heat as well as the radiation that will be blasting out from the star's surface.

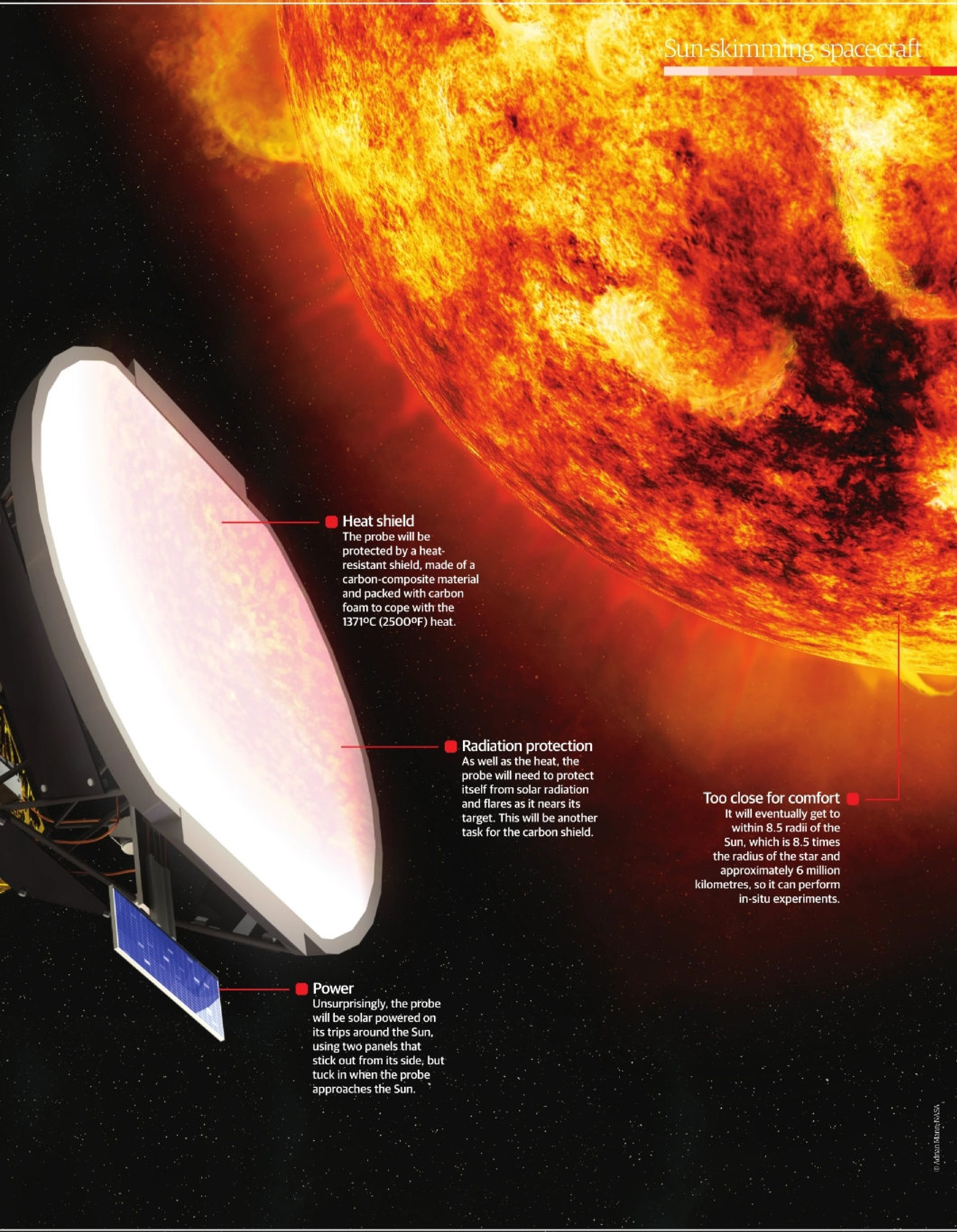
The first of Solar Probe Plus' two key objectives is to study the outer atmosphere of the Sun, known as the corona, and find out how it is heated. The fact that the corona is so much hotter than the Sun's visible surface is something that has mystified scientists for years, so an in-situ investigation should help to provide some much needed answers.

The probe will also aim to learn more about solar winds and why they get accelerated. Both of these investigations will help scientists plan missions in the future in order to make the lives of astronauts much safer.

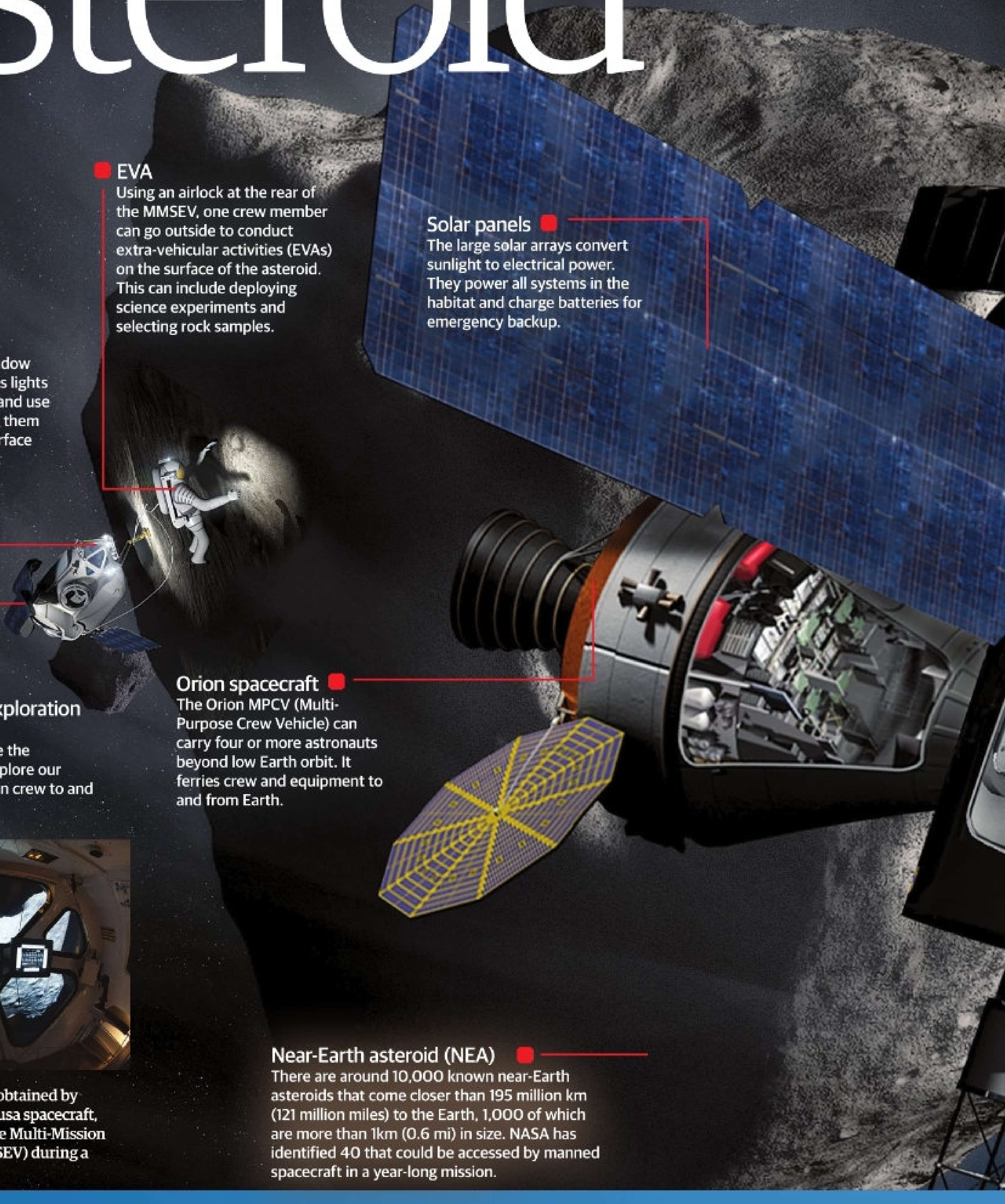
As well as these two crucial tasks, the Solar Probe Plus will be looking into what effect dusty plasma and the Sun's magnetic fields have on solar winds. These will also help them plan future missions by making it easier to predict what course solar winds are due to take.

All of this is groundbreaking science and technology, from the shields that stop the probe burning up as it gets close to our Sun, to the results that the probe will eventually return. This mission is now just four years away from its scheduled launch and should help to answer many questions about the vital heart of our Solar System.




Heat shield
The probe will be protected by a heat-resistant shield, made of a carbon-composite material and packed with carbon foam to cope with the 1371ºC (2500ºF) heat.
Radiation protection
As well as the heat, the probe will need to protect itself from solar radiation and flares as it nears its target. This will be another task for the carbon shield.
Too close for comfort
It will eventually get to within 8.5 radii of the Sun, which is 8.5 times the radius of the star and approximately 6 million kilometres, so it can perform in-situ experiments.
Power
Unsurprisingly, the probe will be solar powered on its trips around the Sun, using two panels that stick out from its side, but tuck in when the probe approaches the Sun.

Manned mission to an Asteroid



EVA
Using an airlock at the rear of the MMSEV, one crew member can go outside to conduct extra-vehicular activities (EVAs) on the surface of the asteroid. This can include deploying science experiments and selecting rock samples.

Solar panels
The large solar arrays convert sunlight to electrical power. They power all systems in the habitat and charge batteries for emergency backup.

Grappling arm
The MMSEV has a large window array at the front and carries lights so that crew can easily see and use the grabbling arm, enabling them to explore the asteroid's surface and to obtain rock samples.

Multi-Mission Space Exploration Vehicle (MMSEV)
The MMSEV, which looks like the submersible craft used to explore our oceans, transports a two-man crew to and from the space habitat.

Orion spacecraft
The Orion MPCV (Multi-Purpose Crew Vehicle) can carry four or more astronauts beyond low Earth orbit. It ferries crew and equipment to and from Earth.

Images of the Itokawa asteroid, obtained by the Japanese unmanned Hayabusa spacecraft, seen through the windows of the Multi-Mission Space Exploration Vehicle (MMSEV) during a simulation exercise

Near-Earth asteroid (NEA)
There are around 10,000 known near-Earth asteroids that come closer than 195 million km (121 million miles) to the Earth, 1,000 of which are more than 1km (0.6 mi) in size. NASA has identified 40 that could be accessed by manned spacecraft in a year-long mission.

To simulate a mission to an asteroid, video screens show images of asteroid 25143 Itokawa through the windows of the Multi-Mission Space Exploration Vehicle (MMSEV) at the Johnson Space Center

NASA plans to send manned expeditions to near-Earth asteroids in order to discover more about their formation and structure

Asteroids can tell us a great deal about the formation of our Solar System and could be the stepping stones to the long-term colonisation of the Moon and interplanetary trips to Mars and beyond.

They might well contain water and air that could be used to support deep space manned missions, and there is the possibility of mining them for their precious metals. They certainly have the potential to enhance human existence, yet there are at least 1,000 dangerous asteroids that pose a risk to Earth.

In April 2010, President Barack Obama announced that NASA should send a manned mission to an asteroid by 2025. One of NASA's plans is to use an unmanned spacecraft to capture a 500-ton, seven-metre (23-foot) diameter asteroid and send it into a high lunar orbit. Here, unmanned spacecraft and manned crews using Orion spacecraft could easily visit and study it in detail. The Asteroid Capture and Return (ACR) spacecraft would take about four years to reach a suitable asteroid, 90 days to deploy a large capture bag, and a further two to six years to take it to the Moon. One NASA proposal is to launch an ACR craft in time for an Orion lunar orbital mission scheduled for 2021.

A more advanced plan is to use a combination of Orion spacecraft and a Deep Space Habitat (DSH) to go beyond Earth orbit (BEO). The habitat would consist of a four-man habitation (HAB) module and would be suitable for 60-day missions. With an additional Multi-Purpose Logistics Module (MPLM) linked via a utility tunnel and docking module to the HAB, it could operate for 500 days. These modules would be based on existing, already proved, International Space Station designs and technology. Either option would be propelled by a Cryogenic Propulsion Stage (CPS) using liquid hydrogen/liquid oxygen engines, and in future by more advanced ion engines.

The DSH would also carry a small two-man Multi-Mission Space Exploration Vehicle (MMSEV). This would take the astronauts from the DSH to a nearby asteroid where they can obtain geological samples and carry out science experiments. Testing of a prototype Generation 2A MMSEV has already been conducted at the Johnson Space Center, which involved two astronauts spending three days and two nights living inside it. Using virtual reality headsets and a rig to suspend the astronauts to reproduce weightlessness, they evaluated simulated extra-vehicular activities (EVAs) on the surface of an asteroid. Other training projects are dealing with living in deep space for long periods of time.

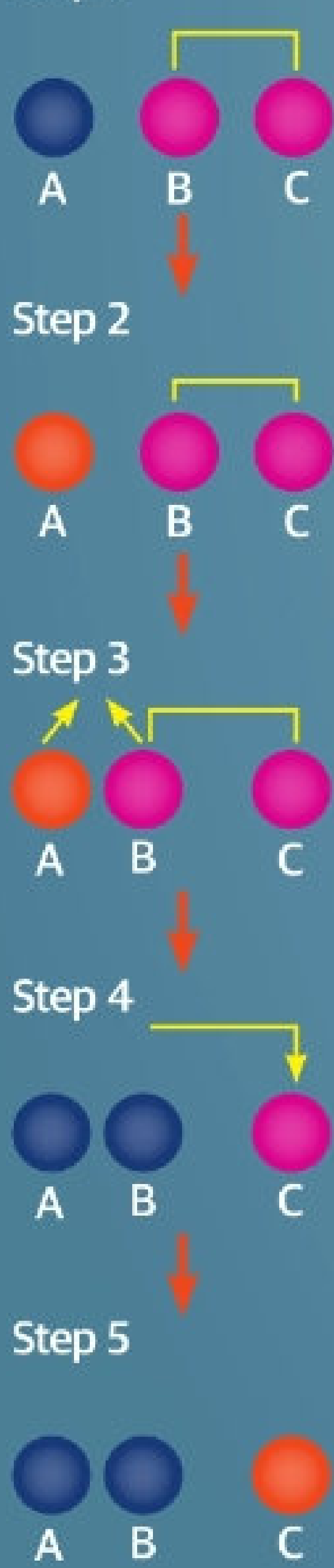
These plans all depend on funding but, in the long-term, visiting, exploring and mining asteroids could give a tremendous boost to new industries and the further exploration of our Solar System.

Teleportation

It sounds impossible but scientists are working on devices to teleport energy and matter that could eventually revolutionise communication, data transfer and transportation over vast distances

American writer Charles Fort coined the word teleportation in 1931, to describe the sudden disappearance and appearance of objects due to some form of paranormal activity. The idea was taken up by science-fiction writers and was popularised in the Sixties when the *Star Trek* television series featured matter-energy transporters that could instantly send people between planets and spacecraft.

Quantum teleportation



Step 1 — **Entanglement generation**
Two atoms (B and C) are entangled to create a pairing connected by an invisible wave.

Step 2 — **Preparation**
The state of the atom's energy, motion or magnetic field is created in a third atom (A).

Step 3 — **Joint measurement**
One of the paired atoms, in this case B, is entangled with atom A, and both are measured.

Step 4 — **Conditional transformation**
Atom C receives the result of the measurement, over any distance.

Step 5 — **Teleportation**
In milliseconds, atom C changes into the same state as A, and simultaneously destroys the quantum state of A.

Only four years after Fort's christening of teleportation, the foundation of its creation in reality came about when the EPR paradox was studied by Albert Einstein, Boris Podolsky and Nathan Rosen. They were critical of Niels Bohr's quantum theories, and showed that according to the rules of special relativity the paradox is either impossible or that Bohr's concepts were incomplete.

The EPR paradox concerns the fact that two particles when formed in the same place and time are linked by an invisible force, and share the same existence. When the state of one particle is changed the other particle will also instantly change, even if they are separated by a great distance. What Einstein dismissed as "spooky action at a distance" is now known as quantum entanglement.

CERN physicist John Bell resolved the paradox in 1964; he labelled it as a 'nonlocal' aspect of quantum physics, which is different from conventional physics known as local realism.

Entanglement of paired photons has been used in experiments that have huge implications for future communication systems and networks. Thomas Jennewein at the University of Waterloo in Ontario, for example, suggests using Earth-orbiting satellites that could create and beam down millions of entangled photons to two ground reception stations. The ground stations would compare the communication signals and if they are not identical they will know that they have been intercepted. This system enables the signals to travel further in the vacuum of space, than via fibre optic cables, and they provide ultra secure encryption for sensitive data and transactions.

Jian-Wei Pan of the University of Science and Technology of China (USTC) has also experimented with paired photons. He has sent teleported photons along a laser beam to a detector 97 kilometres (60 miles) away. There are now plans to launch a satellite in 2016 to carry out quantum experiments, and to pave the way for a global communications network that will use entangled multiple quantum bits (qubits) to transmit at high speed to powerful quantum computers.

Entangled photons are easy to transmit, but they are not easy to store. In contrast, larger ions and atoms are harder to transmit but preserve entanglement for longer. Work is progressing rapidly throughout the world to perfect the methods of creating and transmitting data and energy using quantum entanglement, but we are still a long way from beaming up solid objects and people.

Quantum entanglement equipment is used at Vienna University, Austria, to prove that when a particle is changed its entangled particle will also change, irrespective of how far away it is

Creating a permanent Moon base

Robert Bigelow explains Bigelow Aerospace's plans for a modular lunar base

Bigelow Aerospace's BEAM is an expandable space station module set for use on the ISS between 2015 and 2017

Technology and innovation continue apace and the idea of manned lunar base is far from dead

On average, the Moon is 384,400 kilometres (239,000 miles) away from us, and is a mere hop away compared to the rest of the major objects in our Solar System. Yet, even after landing on its surface in 1969 the dream of establishing a permanent base there has so far eluded us.

The idea of a permanent base was proposed during the Cold War, when the US Army Ballistic Missile Agency envisaged creating a 12-man military outpost that would be protected by missiles and used for Earth surveillance. Peaceful options include using a base to exploit lunar resources, as a springboard for launching expeditions to the rest of the Solar System, and for fostering international scientific research and collaboration.

There was a distinct possibility of creating a lunar base when NASA revealed its Vision for Space Exploration in 2004. This proposed building a base near one of the lunar poles, between 2019 and 2024. It was intended to study lunar geology and consider the feasibility of using lunar resources for construction. Another major goal was to use this as a base for assembling and launching spacecraft to Mars. This project was cancelled in 2010.

Nonetheless, other countries have come up with new schemes. The Japanese Aerospace Exploration Agency, in 2010, announced that it was investing $2.2 billion (£1.4 billion) to send robotic rovers and androids to the Moon. These would collect detailed information about the lunar environment with a view to creating a robot colony on the Moon by 2020. Manned missions and the establishment of an International Lunar Base would then follow.

The Chinese space agency is running a long-term Chinese Lunar Exploration Program (CLEP), which intends to launch lunar manned missions by 2030. One objective would be to create a base where the rare helium-3 isotope could be mined. Russia also has plans for a Moon base to be created by 2032.

Most Moon base concepts consist of modules supplied from Earth that could be connected together and improved over time. Lunar materials could then be mined and used for construction purposes. This would enable bases to be built underground or inside craters, which would provide a constant temperature and better protection against cosmic radiation and meteorite strikes. Power would be supplied by solar panels and fuel cells, or by nuclear fission reactors. Ice deposits discovered at the lunar north pole might also be extracted and used by future colonists.

Recently the European Space Agency and the Foster + Partners architectural firm have put forward the idea of using 3D printing to create a lunar base. A large tubular frame would be sent to the location from Earth, and then robots would pulp and spray raw lunar material over it to create an igloo-like structure that can house four people.