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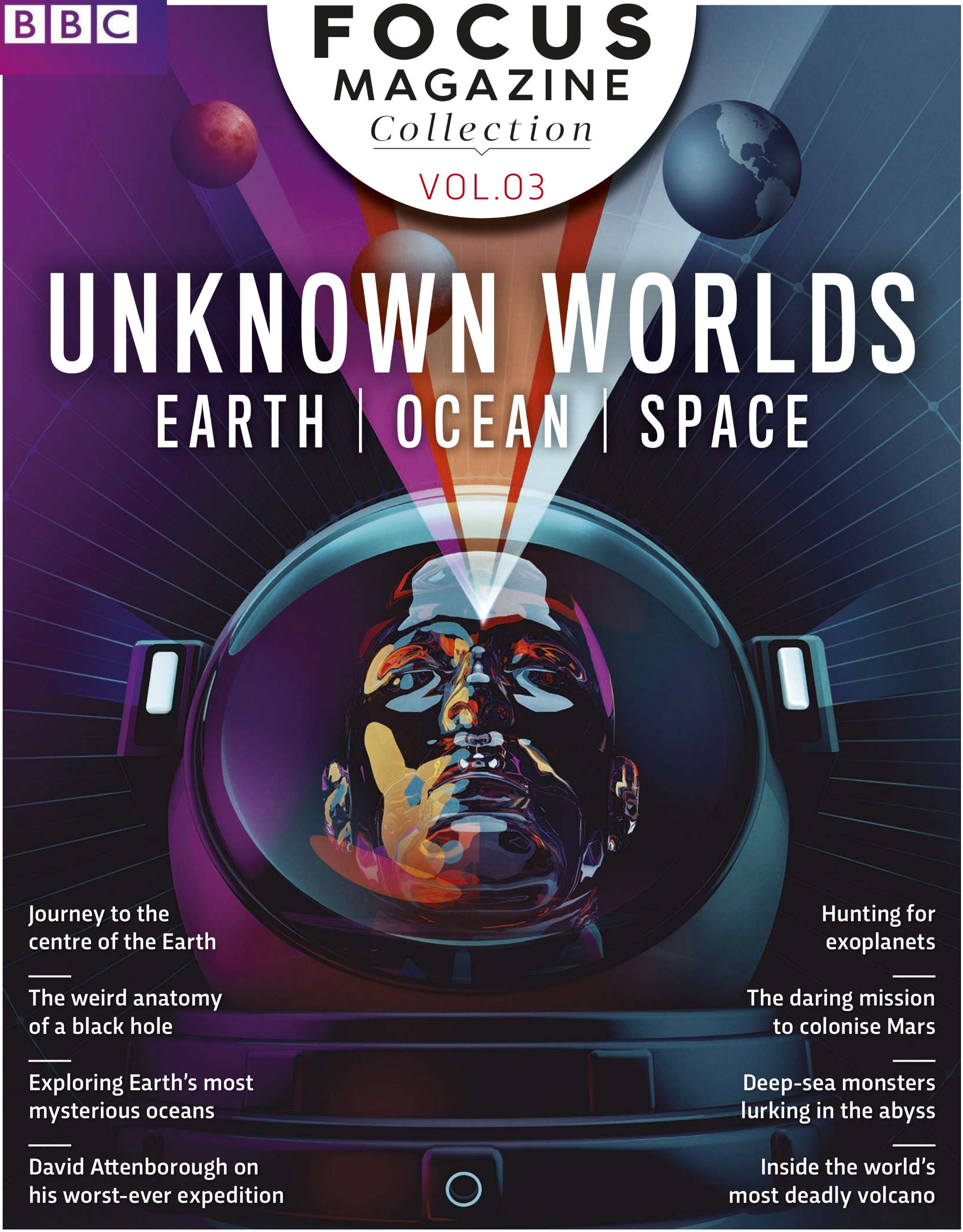
FOCUS MAGAZINE Collection

VOL.03



UNKNOWN WORLDS

EARTH | OCEAN | SPACE

Journey to the centre of the Earth

The weird anatomy of a black hole

Exploring Earth's most mysterious oceans

David Attenborough on his worst-ever expedition

Hunting for exoplanets

The daring mission to colonise Mars

Deep-sea monsters lurking in the abyss

Inside the world's most deadly volcano

MISSION INTO THE SUN

We've visited Pluto and the outer reaches of the Solar System, and our rovers are trundling over the surface of Mars. Yet the Sun has remained stubbornly out of reach… until now

WORDS: **STUART CLARK**

This summer, NASA will launch one of its most ambitious space missions to date: the Parker Solar Probe. Travelling at a blistering 720,000km/h (450,000mph), the spacecraft will repeatedly dive closer to the Sun than any previous spacecraft in history. It will venture so close that the probe team refers to it as 'touching' the Sun. In fact, it will dive in and out of the

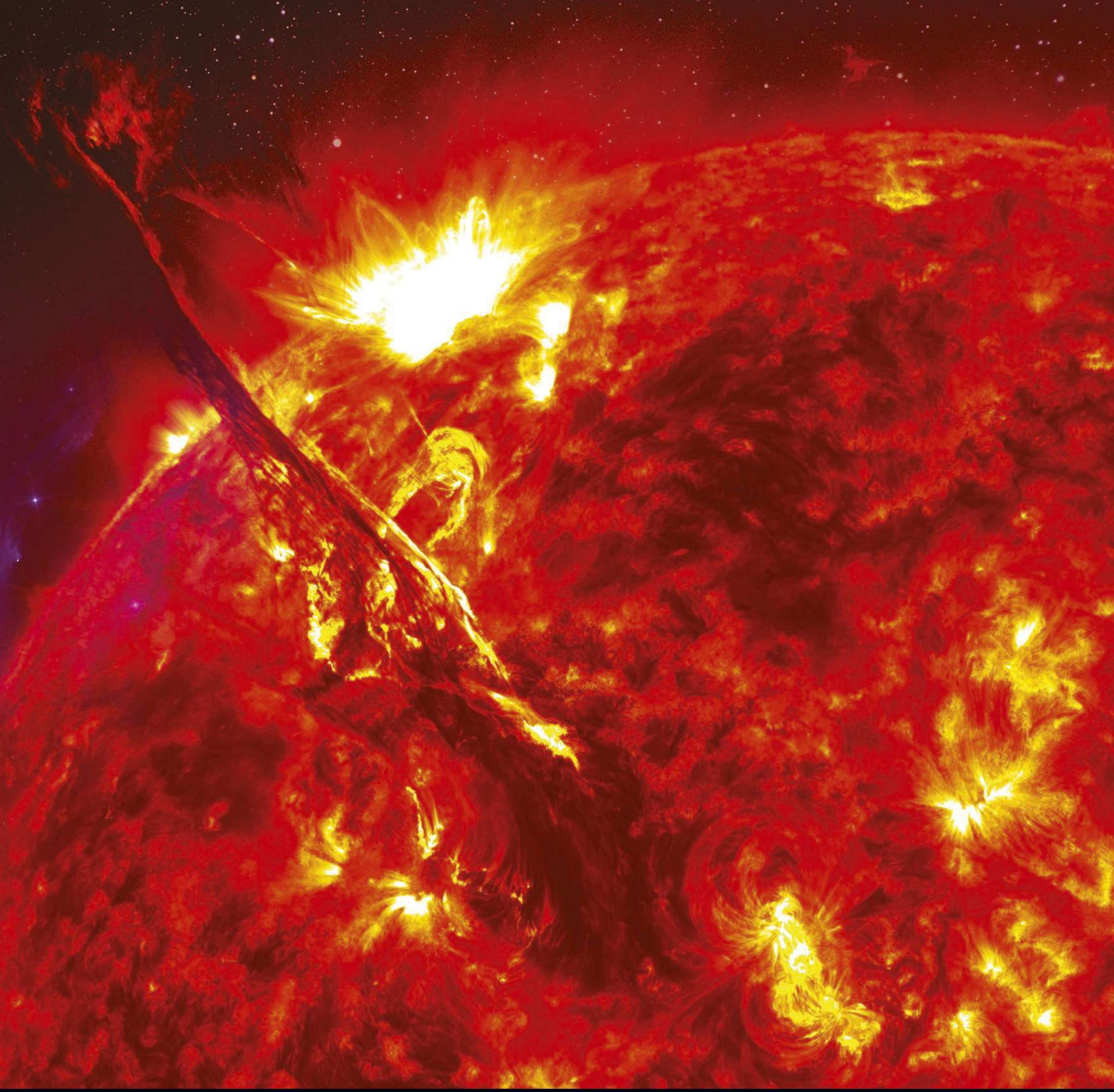


ILLUSTRATION: ANDY POTTS

Sun's atmosphere, known as its corona. And it's not going to be alone up there.

In February 2019, the European Space Agency (ESA) will launch a solar mission of its own, called Solar Orbiter. This craft will not go as close to the Sun as its NASA counterpart but it will still be bathed in intense sunlight, almost 500 times that experienced by a spacecraft in Earth's orbit. Unlike Parker Solar

Travelling at a blistering 720,000km/h, the spacecraft will repeatedly dive closer to the Sun

Probe, which spends only a short amount of time in the fierce heat as it dives in and out, Solar Orbiter will stay put for years, watching and measuring the Sun.

Both of these missions have a key goal: to find out more about the way electrified gas, known as plasma, is launched from the Sun's atmosphere out into space. This continuous stream is known as the solar wind. It carries energy and the Sun's magnetic field through space, and understanding it could solve a problem that's been mystifying scientists for decades and could be the key to safeguarding our technological society.

WHAT A WIND

When the solar wind collides with Earth, it can disrupt or even destroy electrical technology in orbit and on the ground.

The Carrington Event, which took place in 1859, is the greatest of these so-called solar storms on record. Back then, society was more low-tech, but the global telegraph network went down and compasses spun uselessly.

Yet while solar storms of this magnitude would only happen once every couple of hundred years, smaller storms happen more frequently. Most of these cause little disruption, but all have an effect. In March 1989, for example, a small solar storm severely damaged a power transformer on the Hydro-Québec power system. It took down their power grid for more than nine hours as emergency repairs were carried out. And more recently, in 2003, a series of solar storms that took place around the Halloween period caused more than half of NASA's satellites to malfunction in some way, while aeroplanes had to be re-routed away from polar latitudes because of the large amounts of radiation associated with the intense aurora.

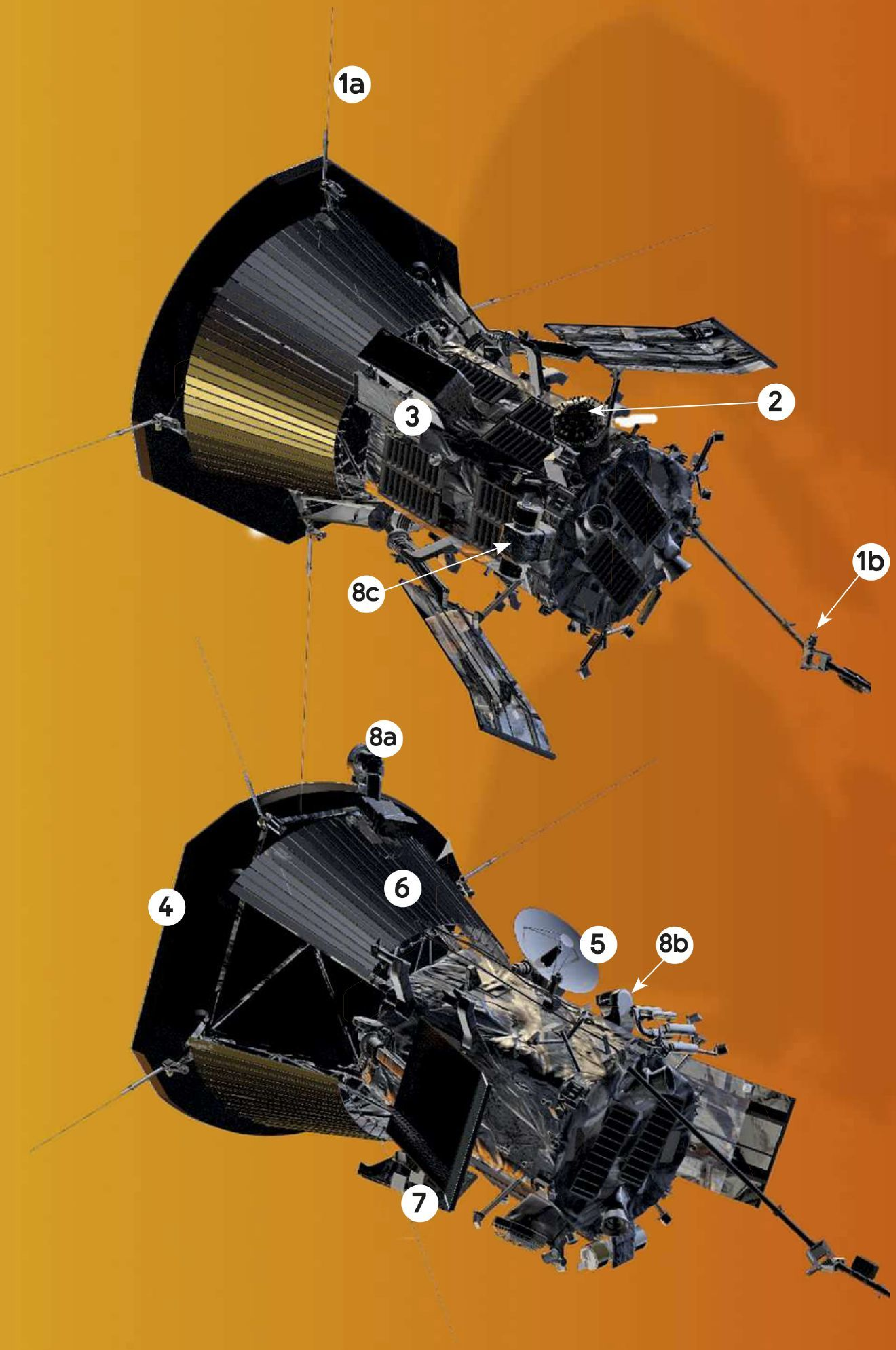
The solar array of the Parker Solar Probe undergoing thermal tests

One recent study by the US National Academy of Sciences found that without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone, and it would not be quick to fix. The report found that such an enormous solar flare could cause so much damage to power stations that the US eastern seaboard could be left without power for a year. Europe is similarly vulnerable.

Without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone

While studying the Sun has never been more timely, the desire to do so stretches back before the space age to the 19th Century, when a solar mystery was uncovered. On 7 August 1869, astronomers gathered across Russia and North America to observe a total solar eclipse. In those fleeting minutes of darkness, the scientists got to see something not visible at any other time: the ghostly veils of the solar corona, the Sun's outer atmosphere. It was an object of fascination for the astronomers of the day. Two of the astronomers, Charles Augustus Young and William Harkness, were using spectroscopes to split the coronal light into its constituent wavelengths. They knew that the various chemical elements gave out light at

NASA ILLUSTRATION: ACUTE GRAPHICS



PARKER SOLAR PROBE

1 FIELDS EXPERIMENT
Makes direct measurements of electric and magnetic fields and waves in the solar wind, and of density fluctuations and radio emissions.

2 INTEGRATED SCIENCE INVESTIGATION OF THE SUN (ISIS)
Observes highly accelerated electrons, protons and heavier particles, and correlates them with solar wind and coronal structures.

3 WIDE-FIELD IMAGER FOR SOLAR PROBE (WISPR)
Provides images of the solar wind, shocks and other plasma structures as they approach and pass the spacecraft.

4 THERMAL PROTECTION SYSTEM (TPS)
An 11.43cm-thick carbon-composite shield that will withstand temperatures outside the spacecraft that reach nearly 1,377 °C.

5 HIGH GAIN ANTENNA
Used to communicate with Earth. The downlink data rate when close to the Sun will be around 167kb/s. Not much compared to modern broadband speeds.

6 SOLAR ARRAY COOLING SYSTEM
Operating in 475 times the solar intensity experience in Earth orbit, the solar arrays are cooled by a $4m^2$ radiator that sheds waste heat into space.

7 SOLAR ARRAYS
Although just $1.55m^2$ in area, the solar arrays generate 388W of electrical power at closest approach to the Sun.

8 SOLAR WIND ELECTRONS ALPHAS AND PROTONS (SWEAP) INVESTIGATION
Counts the most abundant particles in the solar wind and measures their properties such as velocity, density and temperature.

specific wavelengths, and by measuring these 'spectral lines' they would be able to establish the chemical components of the corona. Working independently, they both discovered a green spectral line with a wavelength of 530.3nm. It caused great excitement at the time because there was no known chemical related to this wavelength, so the astronomers thought they had discovered a new element. They named it coronium.

It turned out that Young and Harkness were wrong, yet it wasn't until the 1930s that scientists understood why. Astrophysicists Walter Grotrian and Bengt Edlén conducted laboratory experiments and found that iron could give out that green light, but only if it were heated to an extraordinarily hot 3,000,000°C, turning it into plasma. With this realisation the real mystery was born. What exactly is heating the Sun's corona to 3,000,000°C? The magnitude of the problem is enormous because the surface of the Sun is a mere (astronomically speaking) 6,000°C. "It defies the laws of physics and nature. It's like water flowing uphill. You move away from a heat source and it should get cooler not hotter," says Nicola Fox, mission project scientist at the Johns Hopkins University Applied Physics Laboratory. "What happens in this region that suddenly accelerates all of this coronal material to temperatures

The Sun at the moment of an eruption

NASA/SOHO

The solar wind bathes the planets, and when it collides with the Earth, it sparks stunning auroras

exceeding 3,000,000°C? It is mystery number one," says Fox.

And if that wasn't a big enough conundrum, there is a second, related mystery. The gas breaks away from the Sun just where the temperature peaks. "If you think of the Sun as a giant gravitating star, it is going to hang onto its material. And yet the plasma is able to break away and move out and bathe all of the planets," says Fox.

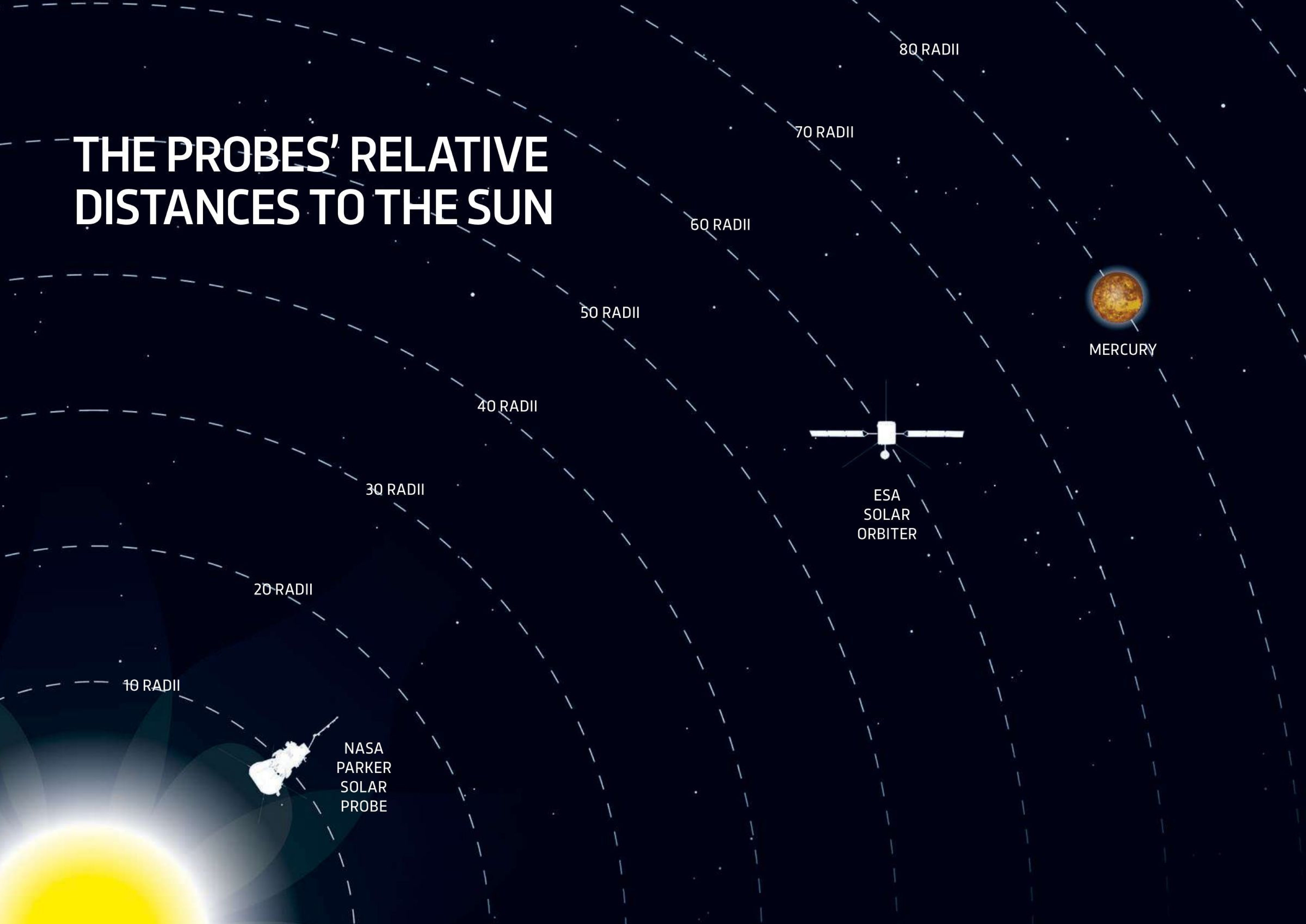
This solar wind that Fox refers to is made mostly of hydrogen and helium. The iron that betrayed the corona's great temperature actually makes up just a tiny fraction of its composition. The solar wind carries with it the Sun's magnetic field and streams out into space at about 1,600,000km/h (1,000,000mph). It bathes the planets, and when it collides with the Earth, it sparks the stunning auroras that shine in the polar skies.

STAY COOL

Astronomers say that the acceleration of the solar wind occurs at about 10 solar radii (one solar radius is equal to the radius of the Sun). "That's where Parker Solar Probe is going, it's a scientifically important region of space," says Imperial College London's Prof Tim Horbury, who is a co-investigator on Parker Solar Probe's FIELDS instrument.

Through its series of extraordinarily close encounters with the Sun, Parker Solar Probe will repeatedly explore this key region. It will survive its plunge thanks to an innovative thermal protection system (TPS). This heat shield is made of two plates separated by a layer of carbon foam. The layer that faces the Sun is white and reflective. The foam itself

THE PROBES' RELATIVE DISTANCES TO THE SUN



Parker Solar Probe will 'dive' as close as 10 solar radii to the Sun, whereas Solar Orbiter will remain a constant 60 radii away

is diffuse and light, and is composed of 97 per cent air. It was developed and manufactured especially for the spacecraft and is one of the key technologies that has enabled the mission to take place. It is just over 11cm thick, and will be heated to around 1,377°C during its close solar passes. On the other side of the TPS, where the spacecraft is located, the design will almost completely dissipate the heat, reducing it to a comfortable room temperature of around 21°C.

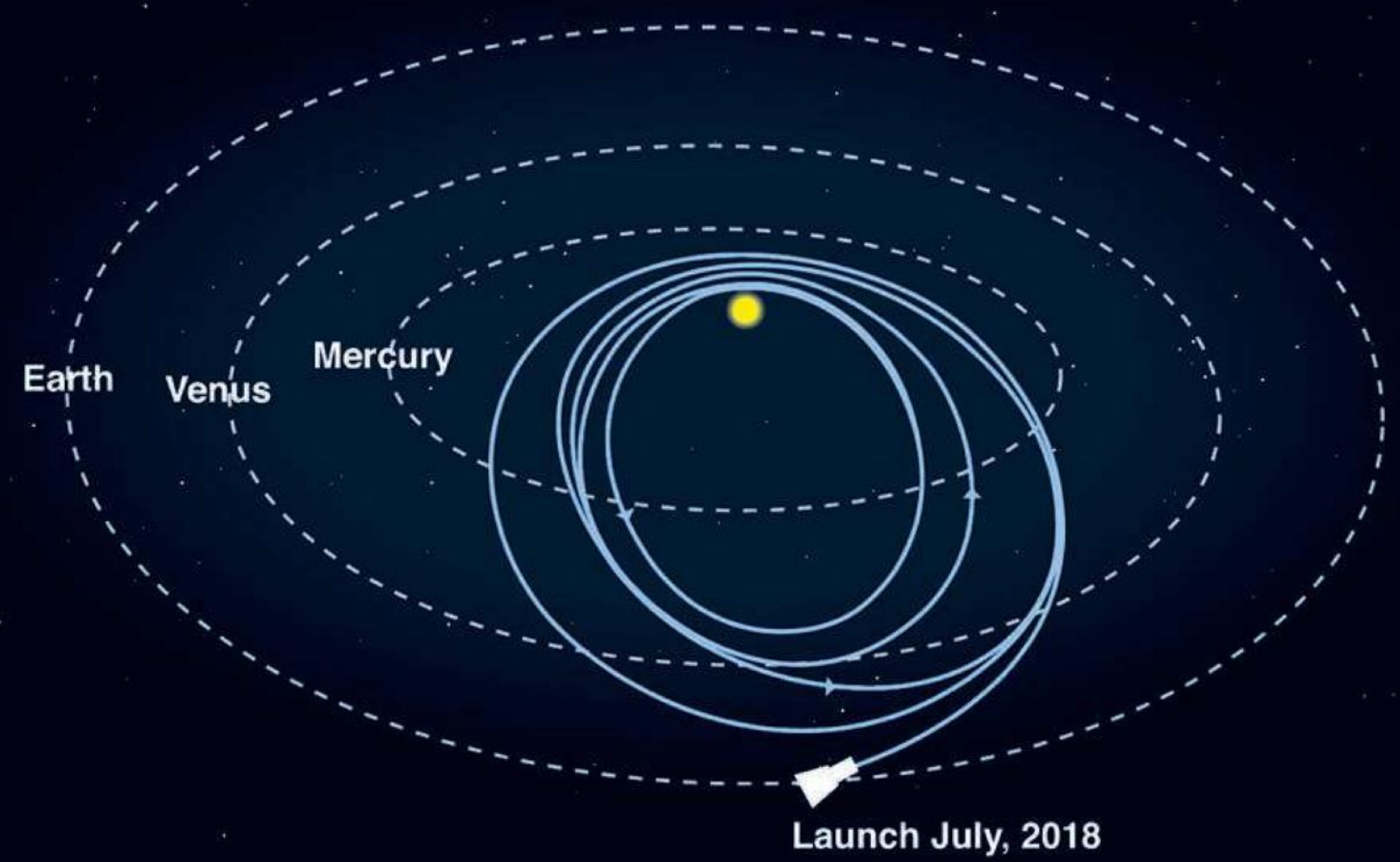
Solar Orbiter's heat shield takes a different approach because it has to withstand lower but constant heating. Its maximum temperature is likely to be around 520°C, but it is not going to head out to the orbit of Venus to cool down, like the Parker Solar Probe. Solar Orbiter's heatshield is pitch black rather than white and reflective, as this means it will absorb heat and radiate it back out into space. It is made from titanium covered with a protective skin called SolarBlack, which is derived from a charcoal-based pigment made of burnt animal bones. This pigment is a type of black calcium phosphate and is widely used for fertiliser and metal alloy production, and for filtering heavy metals out of water. This skin keeps the European space probe safe so that it can operate continuously at a distance of 60 solar radii. Although this is six times further away than Parker Solar Probe's closest approach, there is a particular reason for choosing this distance. "It goes as close as you can go and still use telescopes to look at the Sun," explains Horbury. Parker Solar Probe's only telescope looks to the side to take images of the solar wind rushing by.

Solar Orbiter's telescopes will study the Sun's surface with a variety of instruments over a wide range of different wavelengths so that astronomers can determine the surface gas's densities, temperatures and the magnetic field. It then contains a second suite of instruments that measure the same properties for the solar wind as it passes the spacecraft. Parker Solar Probe is designed to fly through the exact region of the Sun's atmosphere where it breaks its connection

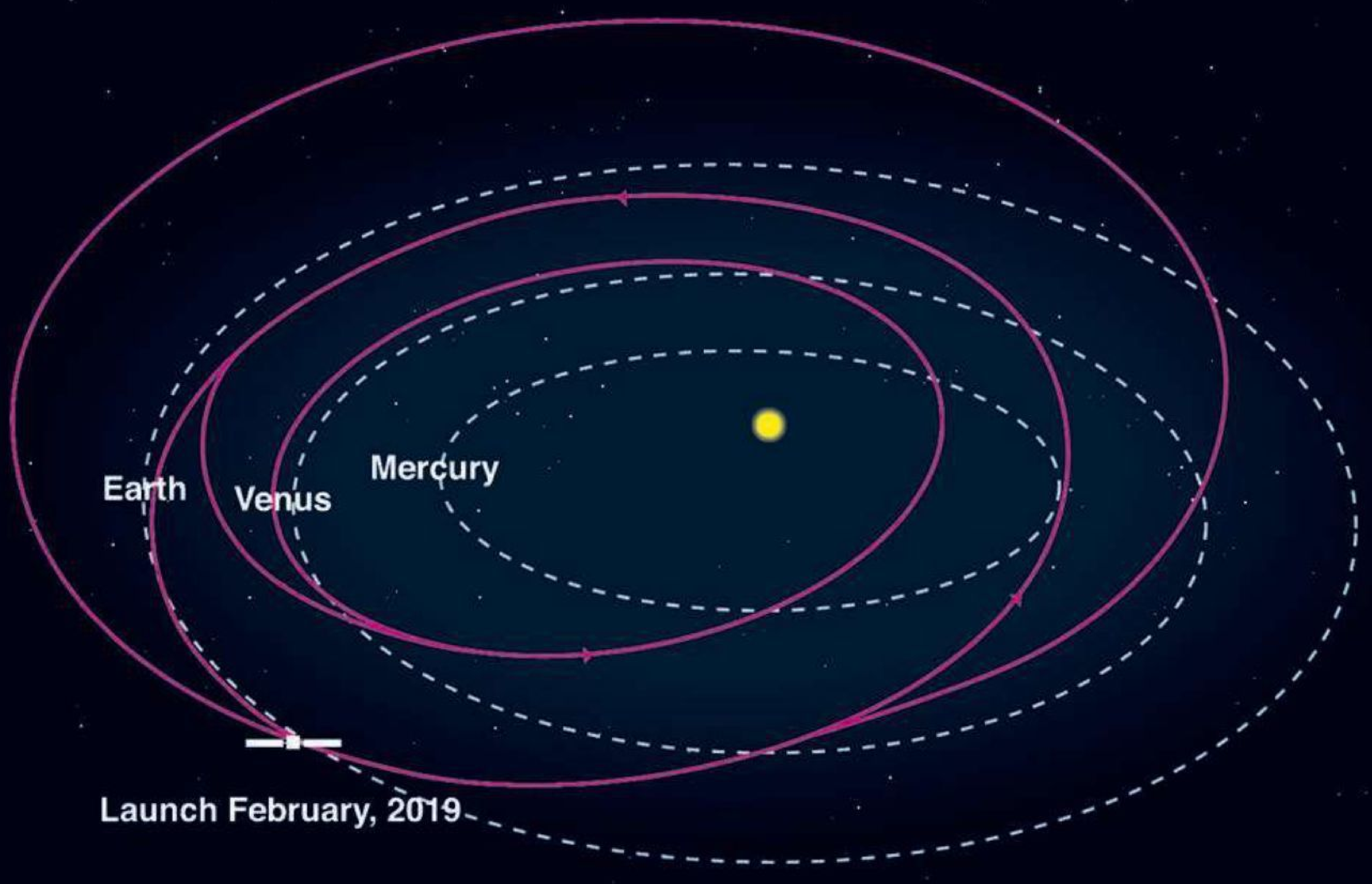
ILLUSTRATION: ACUTE GRAPHICS

They should help us to safeguard the tech we rely on every day – from sat-navs to telecommunications to power stations

PARKER SOLAR PROBE'S LAUNCH PATH



SOLAR ORBITER'S LAUNCH PATH



to the solar surface and becomes the solar wind. So by sharing their data the mission scientists can make the connection between events on the solar surface, the launching of the solar wind, and the downstream conditions. This is the stuff of dreams for the people involved in understanding space weather.

"Solar Orbiter is about making the connection between what happens on the Sun and what happens in the solar wind," says Horbury.

EARLY WARNING

Solar storms throughout history have shown how the interaction of the solar wind with Earth's magnetic field can severely damage important technology. So, while these missions to the Sun are likely to reveal all sorts of interesting data and maybe even new theories about our star, more crucially, they should help us to safeguard the tech we rely on every day – from sat-navs to telecommunications to power stations.

Currently, we get only 30 to 60 minutes warning from a NASA spacecraft called ACE (Advanced Composition Explorer). Once these two missions have performed their work, the hope is that this warning time will rise to a day or two. That's because solar storms are sparked by flares on the Sun that trigger a sudden ejection of material from the corona into the solar wind. It takes a day or two for this eruption to cross space, so knowing the way in which the solar wind is launched is critical if we are going to calculate the severity of any incoming solar storms. It could also give us more time to prepare and protect any important electrics.

"The data we are supplying will be used to make transformational improvements to the models. A few years from now when we see a big event, the model is going to accurately tell us what is coming to the Earth," says Fox. "It is extremely fortuitous that we have the two missions going up in a similar time frame. They are so synergetic, that I couldn't be more excited that they will be up together. It's perfect."

Dr Stuart Clark is an astronomy writer with a PhD in astrophysics. His latest book is *The Unknown Universe*