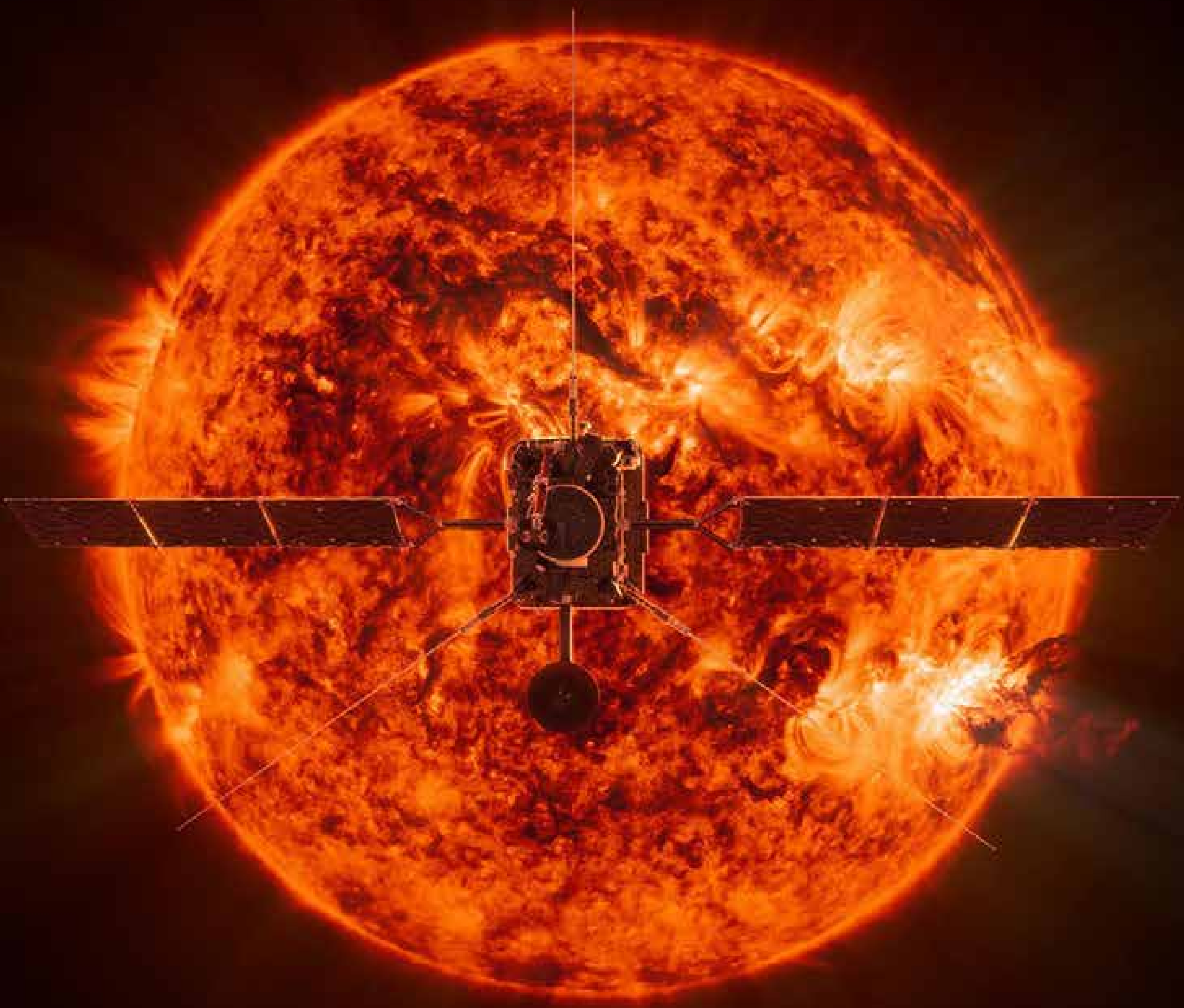

# solar orbiter

## → FACING THE SUN

# ESA'S SPACE SCIENCE MISSIONS

## solar system

**bepicolombo**
Europe's first mission to Mercury will study this mysterious planet's interior, surface, atmosphere and magnetosphere to understand its origins.

**cassini-huygens**
Studying the Saturn system from orbit, having sent ESA's Huygens probe to the planet's giant moon, Titan.

**cluster**
A four-satellite mission investigating in unparalleled detail the interaction between the Sun and Earth's magnetosphere.

**juice**
Jupiter icy moons explorer, performing detailed investigations of the gas giant and assessing the habitability potential of its large icy satellites.

**mars express**
Europe's first mission to Mars, providing an unprecedented global picture of the Red Planet's atmosphere, surface and subsurface.

**rosetta**
The first mission to fly alongside and land a probe on a comet, investigating the building blocks of the Solar System.

**soho**
Providing new views of the Sun's atmosphere and interior, and investigating the cause of the solar wind.

**solar orbiter**
A mission to study the Sun up close, collecting high-resolution images and data from our star and its heliosphere.

**venus express**
The first spacecraft to perform a global investigation of Venus's dynamic atmosphere.

## astronomy

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Characterising exoplanets known to be orbiting around nearby bright stars.

**euclid**
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**plato**
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Solving the mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

## exploration

**exomars**
Two missions comprising an orbiter to study the martian atmosphere, a surface science platform and a rover to search for life below the surface.

Cover image: Spacecraft: ESA/ATG medialab; Sun: NASA/SDO/P. Testa (CfA)

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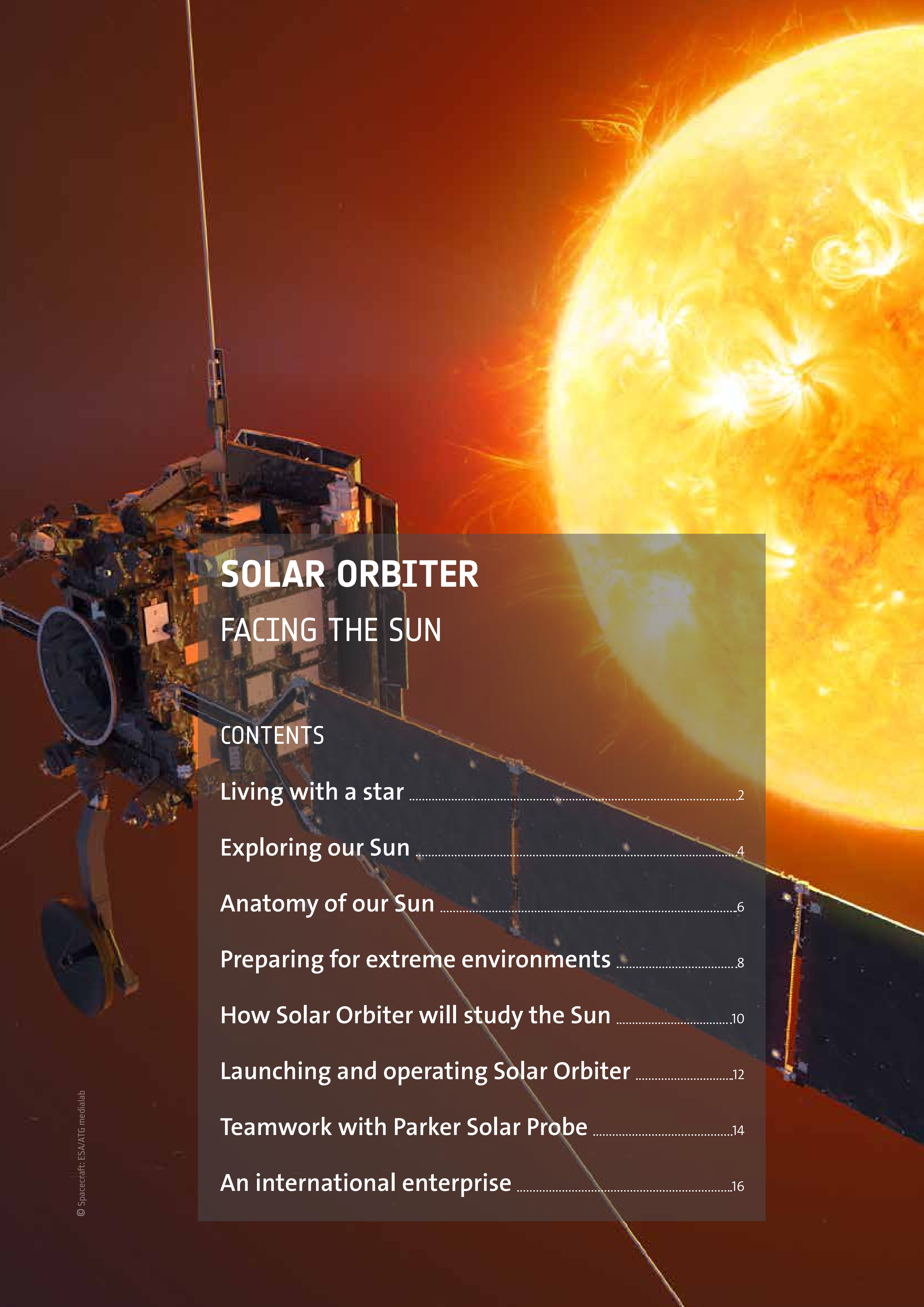

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# SOLAR ORBITER

## FACING THE SUN

## CONTENTS

# → LIVING WITH A STAR

SOHO watches a solar storm unfold (composite image)

SOHO (ESA & NASA), SDO (NASA), JHelioviewer (ESA)

Humans have always known the importance of the Sun to life on Earth. We have sent various missions to learn about it. From 2020, Solar Orbiter will build on earlier missions to give Europe its most advanced look at the Sun.

From the stone-age humans who built aligned monuments to watch the Sun rising at various important times of the year, to the astronomers in the 19th century who first started to unlock its scientific secrets, the Sun has long held a fascination. We now know that beyond providing the obvious heat and light necessary to keep our world a living planet, the Sun interacts with us in electrical and magnetic ways too. Although these effects are imperceptible to most living things, they are important to us now because they can affect the way our technology works.

Understanding in detail how the Sun works is the key to understanding both how it generates its life-giving energy and also how to protect our technology and way of life.

Dark blemishes on the solar surface, known as sunspots, have been known since ancient times. In the early 17th century, both Italian astronomer Galileo Galilei and German astronomer Christoph Scheiner used early telescopes to study sunspots in more detail, and found that the Sun rotates in 27 days.

It wasn't until 1843, however, that the sunspot cycle was discovered by another German astronomer, Samuel Heinrich Schwabe. After observing the Sun for 17 years, he realised that the number of sunspots fluctuates in a cycle that lasts approximately 11 years. At the beginning of the cycle, there are few sunspots and they appear at higher latitudes on the solar surface. This period is known as solar minimum. Over the next five or six years the number of sunspots gradually builds, and the latitudes at which they appear move towards the Sun's equator. When the maximum number appear, nearest the equator, this is called solar maximum. From there, the number dwindles back to another solar minimum, and the cycle begins again but with magnetic polarity reversed, making a 22-year full cycle.

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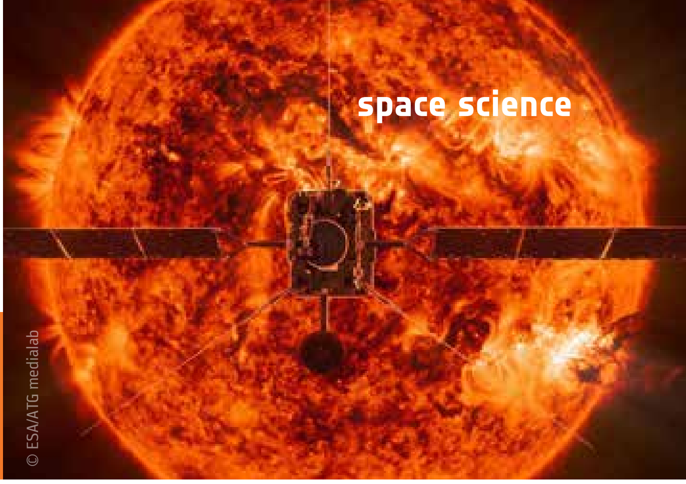


Solar Orbiter will face the Sun from inside the orbit of planet Mercury

© ESA/ATG medialab

The 19th century was a particularly fertile time for solar research. The recognition of the solar cycle brought with it the realisation that the Sun is a magnetic body that affects the behaviour of technology on Earth. For example, it was noticed that magnetic compasses are affected by sunspots – and the more sunspots, the greater the effect. We now know that this is because of the way solar activity affects the Earth's ionosphere.

In 1859, English astronomer Richard Carrington observed a giant solar flare. It was accompanied by a record-breaking magnetic storm on Earth, during which time compasses spun uselessly and the electrical telegraph system of communication was severely disrupted. These observations showed that somehow the Sun's magnetism was reaching Earth.

Several astronomers had already noted that the tails of comets always point away from the Sun, and this had led to the suggestion that there was some kind of 'wind' flowing away from the Sun. However, only in 1958 did American astrophysicist Eugene Parker put this on a scientific footing by realising that this was related to the solar atmosphere, known as the corona. The high temperature of the corona at large distances from the Sun meant that its constituent particles had enough energy to escape the Sun's gravity and flow through space. He called this outflow the solar wind.

Confirmation that the solar wind was real came just one year later from the Russian spacecraft Luna 1. Luna 1 made the first direct measurements of the solar wind and found that it was composed of plasma, an electrically conductive gas that represents the fourth state of matter after solid, liquid, gas. It found there were hundreds of particles in every cubic centimetre of space.

The solar wind creates a bubble around the entire Solar System. Known as the heliosphere and bounded by the 'heliopause', it is inflated by plasma originating from the Sun and is the realm of 'space weather'. This is the term for disturbances in the solar wind, which communicate the Sun's magnetic influence to Earth. Space weather is driven by activity on the Sun, such as solar flares and coronal mass ejections. The aurorae in Earth's skies are produced by a complex series of magnetic interactions that eventually result in the collision of solar-wind plasma particles with molecules in our planet's atmosphere.

As we become more reliant on sensitive electrical systems in our technology, so we must protect ourselves from intense space weather, known as 'solar storms'. In trying to unlock the mechanism behind the acceleration of the solar wind, Solar Orbiter is contributing essential science that could one day lead to a space-weather forecasting service that will allow us better to protect our essential technology on Earth.

In the pursuit of these goals, ESA's Solar Orbiter mission is a world-class scientific collaboration with the strong participation of NASA. It is pushing the limits of space technology and preparing for the future of space exploration in extreme environments. As well as requiring hardware development, it is also enlarging ESA's experience in space operations under harsh conditions. In short, Solar Orbiter will allow us to investigate the Sun's control over the heliosphere – and Earth's place within it – as never before.

An aurora is a visible display of electrically charged atomic particles from the Sun interacting with Earth's magnetic field.

# → EXPLORING OUR SUN

Solar Orbiter will address big questions in Solar System science to help us understand how our star creates and controls the giant bubble of plasma that surrounds the whole Solar System and influences the planets within it. It will concentrate on four main areas of investigation.

## The solar wind and the corona's magnetic field

The solar wind is a constant stream of electrically charged particles that the Sun emits in all directions of space. The particles reach speeds of between 300 to 800 kilometres per second, but the acceleration mechanism is unknown. It is clearly linked to the magnetic field that exists in the corona, although here too is a mystery: no one knows in detail how that magnetic field is generated. Solar Orbiter will investigate what drives the solar wind, and the origin of the corona's magnetic field.

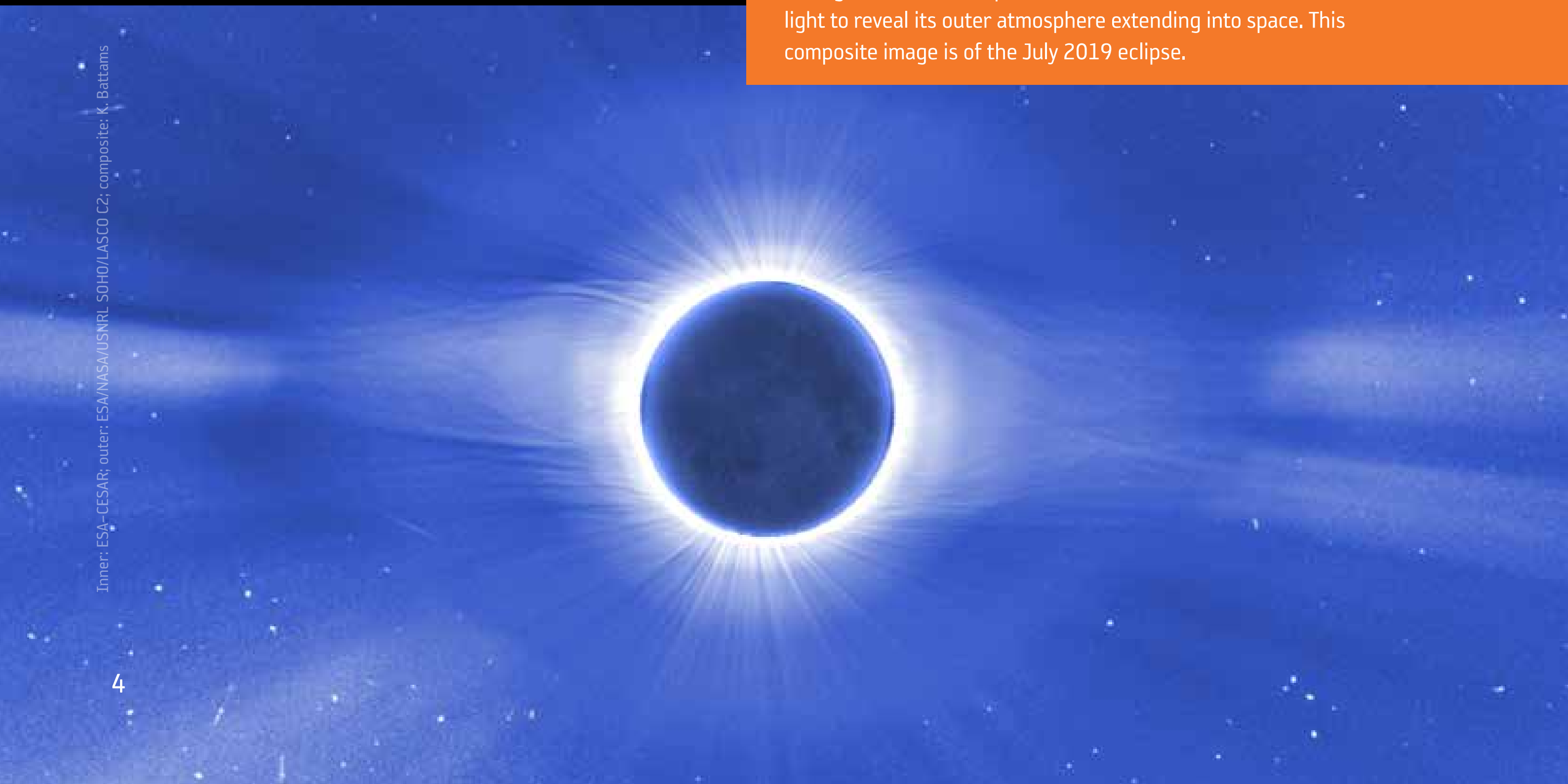
Solar Orbiter will investigate the physics that connects the plasma at the solar surface to the heating and acceleration of the solar wind in the corona. It will do this by moving in front of the solar surface quite slowly during its close passes. This will enable it to measure the changing properties of the solar wind, and correlate those with the changing properties of the source region below it.

Solar Orbiter will also make very detailed measurements of the composition of the solar wind at distances closer than the Earth's orbit. This will give us an understanding of the wind at its origin point before any changes take place in it as it journeys outwards through the Solar System. This data will be used to distinguish between competing theories of how the solar wind is generated.

## Sudden solar events and their effects

Sudden events on the Sun's visible surface are known as transients. They propagate into the corona and sometimes outwards into the solar wind. They include explosive phenomena such as flares, coronal mass ejections, eruptive prominences, and shock waves. These events all create space weather by affecting the behaviour of the solar wind.

Being so close to the Sun, Solar Orbiter will get a closeup view of solar transients and how they affect the plasma that flows outwards to fill the heliosphere. By watching these events unfold, and being able to measure the properties of the magnetic fields and plasma that flow past the spacecraft as a result, Solar Orbiter will be able to gauge the properties of the solar wind heading out to the heliosphere, and measure the heliospheric consequences of these often titanic transient events.



The Sun's corona can only be seen by Earth-based observers during a total solar eclipse, when the Moon blocks out the Sun's light to reveal its outer atmosphere extending into space. This composite image is of the July 2019 eclipse.

Inner: ESA–CESAR; outer: ESA/NASA/USNRL SOHO/LASCO C2; composite: K. Battams

## Solar eruptions and the energetic particles they produce

The Sun is the most powerful particle accelerator in the Solar System. It regularly emits ‘storms’ of particles at close to the speed of light. These can penetrate the protective layers of Earth’s magnetic field and atmosphere and can even be detected at the surface of our planet. Solar energetic particle events are an extreme form of space weather and can severely affect space hardware. They can disrupt radio communications and cause commercial air traffic to be routed away from polar regions, where the energetic particles find it easy to penetrate our atmosphere.

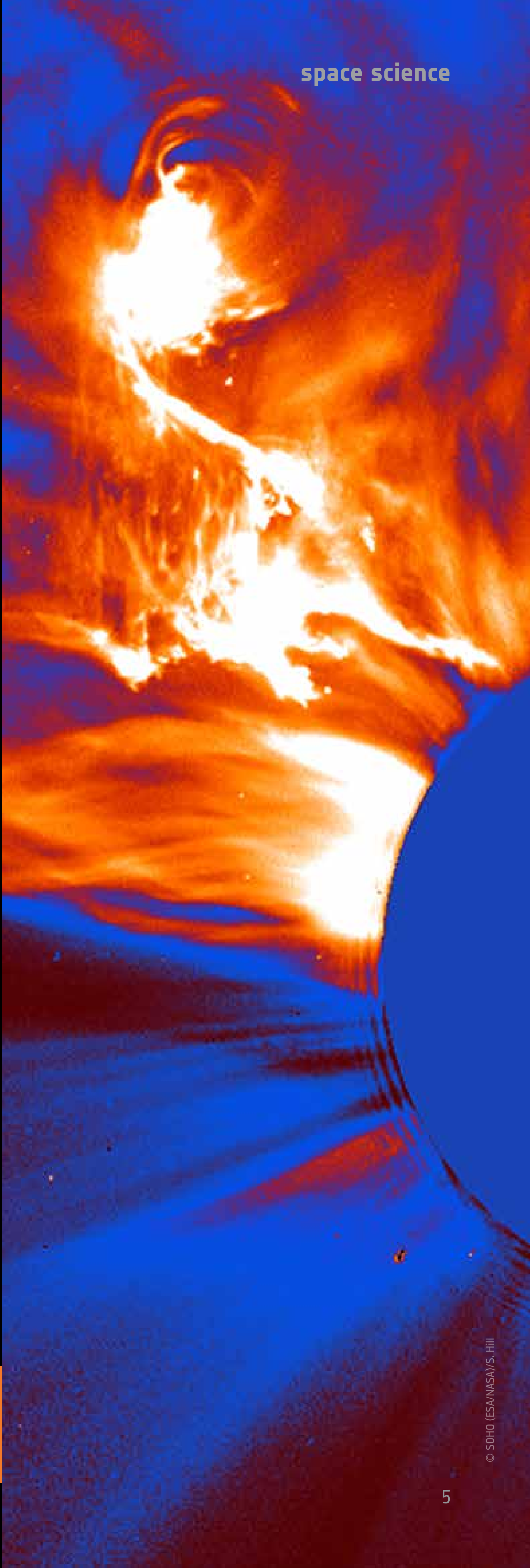
All of Solar Orbiter’s instruments will contribute in the attempt to track down the cause of solar energetic particle events. By examining the particles themselves and by taking measurements and images at different wavelengths of the environment they come from, Solar Orbiter will provide ‘ground truth’ that can then be compared to theories.

## Generation of the Sun’s magnetic field

The Sun’s magnetic field is responsible for all the solar activity we see; it drives the 11-year sunspot cycle, and dominates the behaviour of the solar atmosphere. Extensive studies have revealed a lot about the large-scale nature of the Sun’s magnetic field once it is free from the Sun’s interior. Yet the details of its generation inside the Sun – the so-called ‘solar dynamo’ – are not yet understood.

Theorists believe that the Sun’s magnetic field is generated in a region of the Sun called the tachocline. This is the layer between the radiative zone and the base of the convection zone, where the properties of the Sun’s rotation change dramatically, and this leads to great shearing forces in the plasma. Computer models suggest that a flow of solar plasma from the equatorial regions of the solar surface to the poles sweeps away the decaying magnetic fields from the sunspots and other active regions. Once at the poles, these magnetic fields are swallowed back down into the Sun and rejuvenated by the motion of the plasma at the tachocline. From there, they rise back to the surface and create the sunspots and active regions of a subsequent solar cycle.

Solar Orbiter will measure the various flows that transport magnetic fields around the solar surface, providing invaluable data to constrain the models.



A coronal mass ejection, coloured to indicate the intensity of matter being ejected by the Sun: white is the greatest intensity and blue the least. The blue disc is a mask that blots out direct sunlight to allow study of the corona.

© SOHO (ESA/NASA)/S. Hill

# → ANATOMY OF OUR SUN

## Granulation

This is caused by convective patterns that occur in the photosphere. Each granule is about 1000 km wide and consists of hot plasma rising in its centre. As it releases its energy into space, the plasma cools and this makes it flow to the sides of the granule and sink back down into the photosphere. Individual granules persist for about 20 minutes; after this, new ones develop in slightly different places.

## Prominence

This is a large structure, often many thousands of kilometres in extent. Prominences are made of tangled magnetic field lines that keep dense concentrations of solar plasma suspended above the Sun's surface, and often take the form of loops that arch up from the chromosphere. They can persist for several weeks or even months.

## Photosphere

This is the visible 'surface' of the Sun. Almost all radiation from the Sun is emitted from this thin layer of several hundred kilometres' thickness, which lies at the upper boundary of the convective zone. It is where the energy generated in the core can finally move freely through space. The temperature of the photosphere varies from place to place, but lies between 4500–6000 degrees Celsius.

## Chromosphere

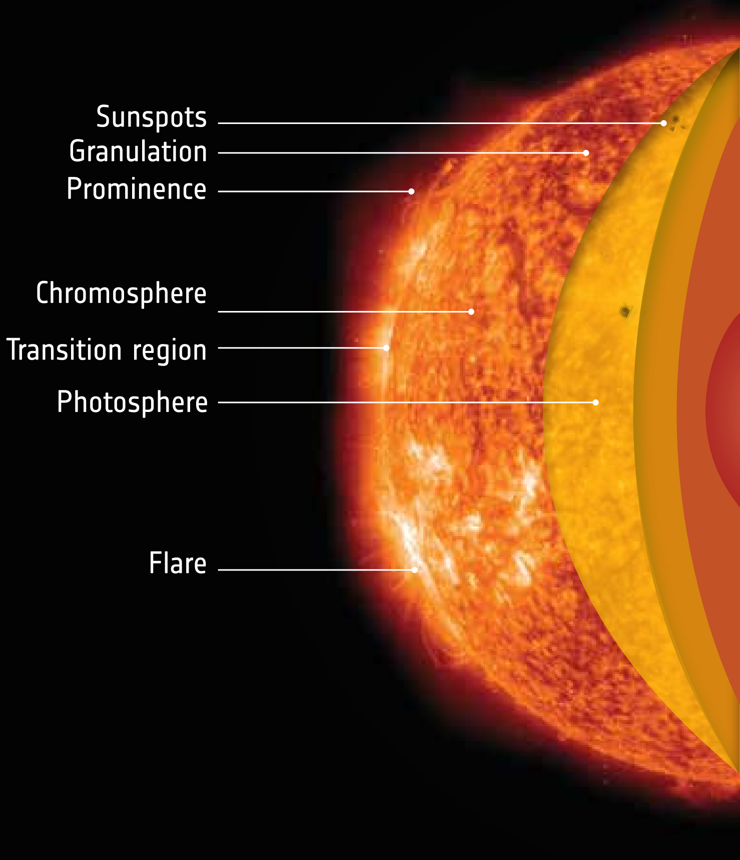
This is the layer above the photosphere, where the density of plasma drops dramatically. In general, the chromosphere is roughly 1000–2000 kilometres thick, with a temperature that rises from around 4000 to about 25 000 degrees Celsius. Spires of chromospheric gas, known as spicules, can reach up to a height of 10 000 km.

## Transition region

This is a thin, irregular layer that separates the relatively cool chromosphere from the much hotter corona. Across the transition zone, the temperature of the solar plasma soars to nearly a million degrees Celsius. While the convection zone and (partly) the solar photosphere are dominated by flows that are capable of moving regions of strong magnetic flux around, the transition region and corona are dominated by the magnetic field, which forces the plasma to move predominantly along field lines.

## Sunspots

These are temporary features on the photosphere. They look like dark patches against the brighter region of the photosphere because they are about 1000 degrees cooler and so do not emit as much light. They are caused by magnetic fields breaking through the photosphere of the Sun and cooling the gas there. Sunspots can be anything from a few tens of kilometres across to larger than 150 000 km.

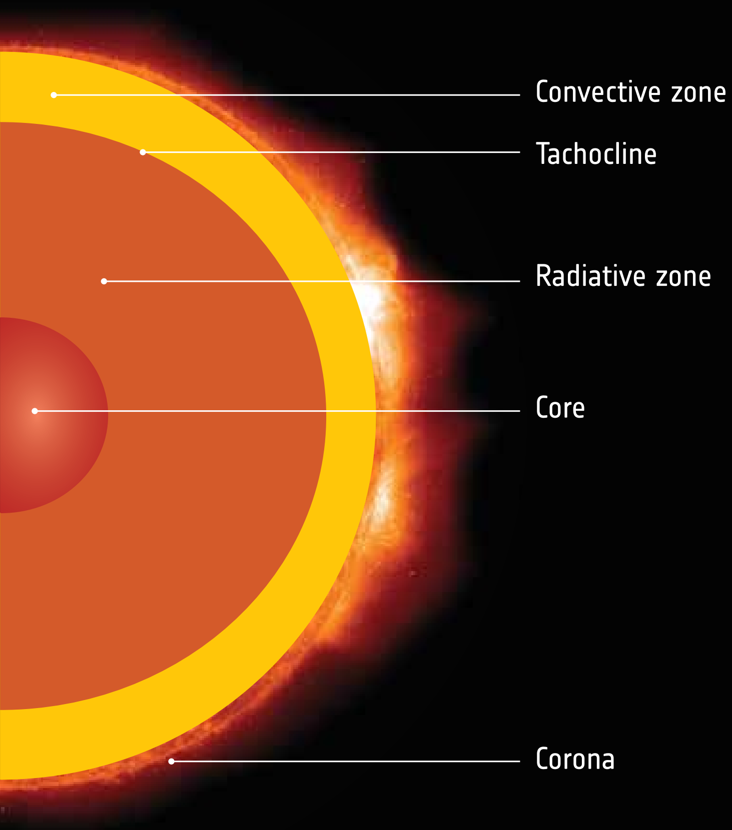


## Flare

This is a sudden release of energy. A flare is usually created when the magnetic field lines that make sunspots transform themselves rapidly into more stable configurations. This is a bit like a stretched elastic band breaking and releasing all of its stored energy as it snaps back into position. The energy released by solar flares strongly influences the behaviour of the solar wind.

## Convective zone

This lies between the radiative zone and the photosphere. The convective zone is 200 000 km deep. While the top layer is the same temperature as the photosphere (between 4500–6000 degrees Celsius), the base of the convective zone reaches two million degrees Celsius. Plasma at the base of the zone is heated rapidly. This makes it buoyant and so it rises rapidly, creating a turbulent convection pattern, rather like a boiling pan of water – only this is 200 000 km deep and surrounds the entire Sun.



## Coronal mass ejections

These are vast eruptions of billions of tonnes of plasma and accompanying magnetic fields from the Sun's corona. They travel out from the Sun at speeds of hundreds to thousands of kilometres per second, and if sent into the pathway of Earth, can create geomagnetic storms (see image on previous page).

## Tachocline

This is the boundary between the convective zone and the radiative zone. Below the tachocline, the Sun rotates like a solid body. Above it, the Sun rotates at different speeds according to its latitude. The change of rotation speed across the tachocline is very abrupt, resulting in shearing forces that are thought to be important in the creation of the magnetic fields that lead to sunspots.

## Radiative zone

This is the layer above the core. Although not as dense as the core, the plasma is still packed so tightly in the radiative zone that convection cannot take place. Instead, the energy created in the core diffuses slowly through the plasma. It takes photons around 170 000 years to pass through the radiative zone: a photon travels at the speed of light, but can travel only a few millimetres at a time before it is absorbed by an atom and then re-emitted in a random direction. At the top of the zone, the temperature is around two million degrees Celsius. At the base, next to the Sun's core, the temperature is around seven million degrees Celsius.

## Core

This is where the Sun generates its energy. The temperature in the core is around 15.7 million degrees Celsius. This, combined with the huge pressure and density of the plasma, forces hydrogen nuclei to fuse together, creating helium and releasing vast quantities of energy in the process. Every second, the Sun converts four million tonnes of matter into energy, which begins a slow journey towards the surface.

## Corona

This is the Sun's outer atmosphere and extends millions of kilometres into outer space. It is most easily seen during a total solar eclipse. The plasma in the corona is extremely hot at more than one million degrees Celsius, yet is very rarefied. Its density is typically just one trillionth of the density of the photosphere. The solar wind originates in the corona.

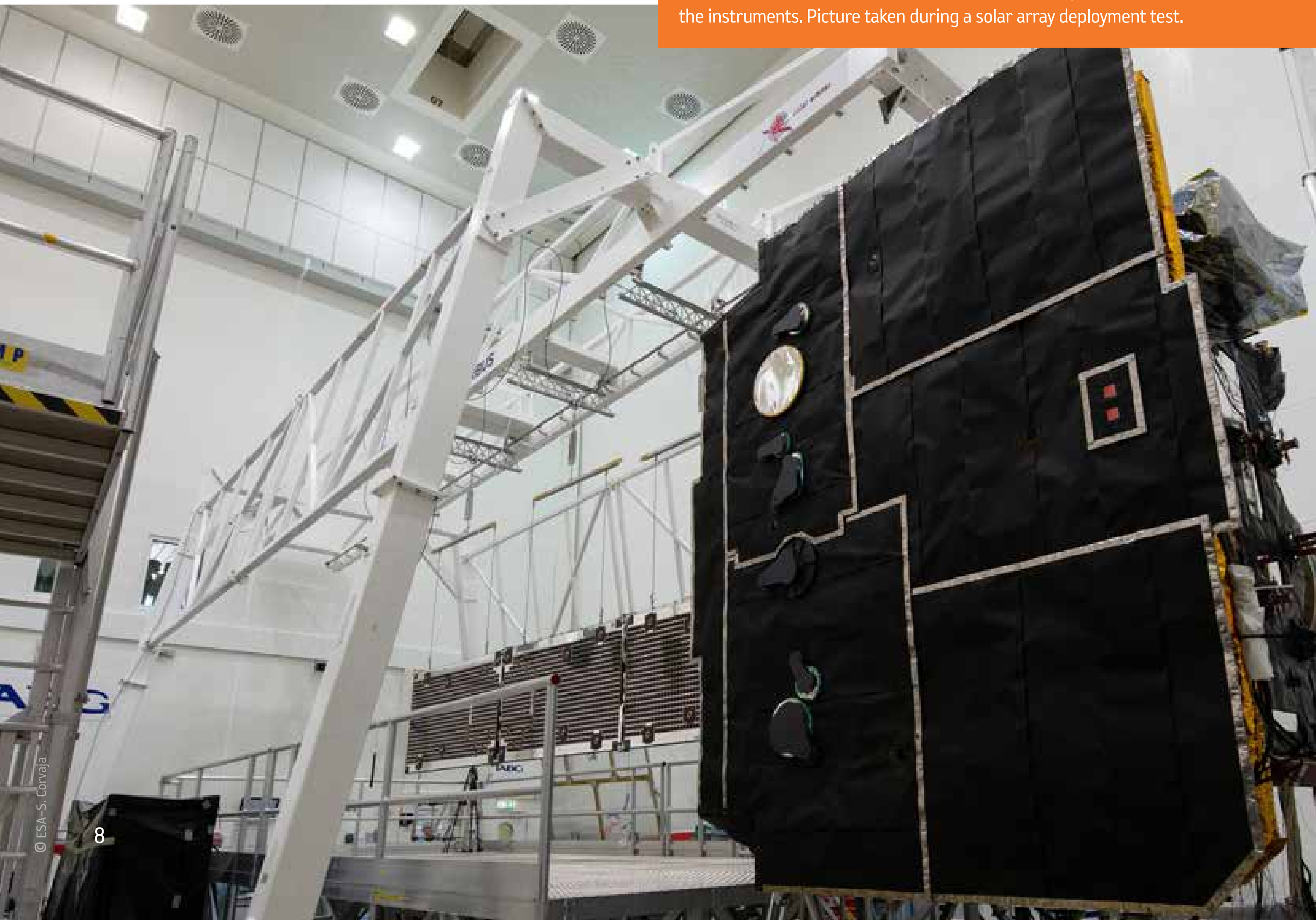
# → PREPARING FOR EXTREME ENVIRONMENTS

Solar Orbiter must operate for years in one of the most hostile regions of the Solar System. At closest approach, approximately 42 million kilometres from the Sun, it will be at just over a quarter of the distance between the star and our planet. Not even the scorched inner planet Mercury gets this close to the Sun. The closest Mercury ever approaches is around 58 million kilometres, but that's still enough to heat its surface to around 430°C – more than hot enough to melt lead.

To protect the 1.8 tonne spacecraft from such extremely high temperatures, ESA and the spacecraft's prime contractor, Airbus Defence and Space, have developed unique heatshield technologies with other industrial partners. In particular, the Irish company Enbio has developed a novel product called SolarBlack.

SolarBlack is a calcium phosphate preparation that has been applied to the outermost layer of Solar Orbiter's heatshield. It is excellent at absorbing heat and will not decay by shedding layers, or gradually turn into gas, no matter how much infrared and ultraviolet radiation it soaks up. Behind this thin layer of SolarBlack, the outer portion of the heatshield is made up of twenty wafer-thin layers of titanium, which can withstand temperatures of up to 500°C. Behind this is a gap, which guides the heat out to the sides and away from the spacecraft. The only bits of hardware that cross this gap are ten star-shaped brackets that attach the top layer of the heatshield to the base.

Solar Orbiter's 'SolarBlack' heatshield, with covers to protect some of the instruments. Picture taken during a solar array deployment test.



© ESA–S. Corvaja

© Airbus Defence and Space/IABG

Infrared view of the spacecraft during thermal testing

The base itself is a 5 cm-thick aluminium honeycomb that is covered by 30 layers of lower-temperature insulation. This can handle temperatures of up to 300°C. The entire heatshield is then fixed to the spacecraft by ten 1.5 mm-thin titanium 'blades' to minimise the transfer of heat through the spacecraft's superstructure.

The heatshield is the key to making this mission possible, as Solar Orbiter will be subjected to thirteen times the amount of solar heating that satellites in Earth's orbit experience.

Solar Orbiter relies on solar power to generate its electricity. It consists of solar panels that can be rotated, so that when the spacecraft is close to the Sun the panels can be angled away to protect them from getting too hot. When Solar Orbiter is in the outer parts of its orbit, however, the arrays can be rotated face-on to provide enough power.

## The instruments

Solar Orbiter carries a full complement of ten science instruments (see next page). While they are behind the heatshield, the instruments are safe, but to do their job they must also be able to see the Sun, or at least be able to see the areas of space near the Sun that they are designed to study.

To accomplish this, the instruments are split into two types, identified as *in situ* and 'remote sensing'. The *in situ* instruments measure the conditions around the spacecraft itself. Some can remain in the shadow of the heatshield; others must look towards the Sun and so are equipped with their own mini heatshields or protection. The remote-sensing instruments measure what is happening at large distances away, in the Sun. Small sliding doors in the heatshield let sunlight into the internally-mounted remote-sensing instruments. On most of these, special windows block out most of the heat to protect the instrument, though two have other arrangements: the SPICE instrument allows all the light in and internally filters out what it doesn't want, and the wide-field camera, SoloHI, peeks around the side of the sunshield but doesn't look at the Sun directly.

Together, both sets of data can be used to piece together a more complete picture of what is happening in the Sun's corona and the solar wind.

# → HOW SOLAR ORBITER WILL STUDY THE SUN

## THE *IN SITU* INSTRUMENTS

### EPD: Energetic Particle Detector

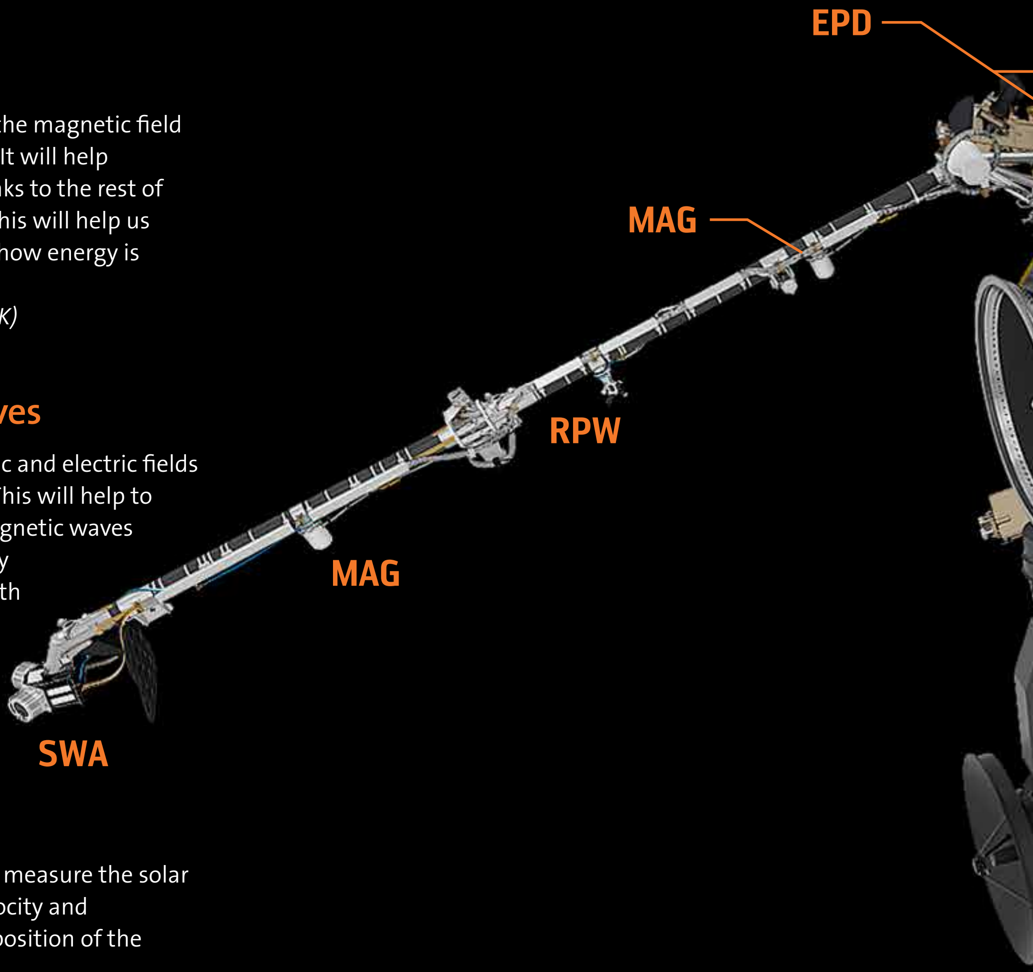
EPD will measure the energetic particles that flow past the spacecraft. It will look at their composition and variation over time. The data will help scientists investigate the sources, acceleration mechanisms, and transport processes of these particles.
*Principal Investigator (PI): Javier Rodríguez-Pacheco, University of Alcalá (ES)*

### MAG: Magnetometer

MAG has two elements that will measure the magnetic field around the spacecraft with high precision. It will help determine how the Sun's magnetic field links to the rest of the Solar System and changes with time. This will help us understand how the corona is heated and how energy is transported in the solar wind.
*PI: Tim Horbury, Imperial College London (UK)*

### RPW: Radio and Plasma Waves

RPW will measure the variation in magnetic and electric fields using a number of sensors and antennas. This will help to determine the characteristics of electromagnetic waves and fields in the solar wind. RPW is the only instrument on Solar Orbiter that makes both *in situ* and remote sensing measurements.
*PI: Milan Maksimovic, LESIA, Observatoire de Paris (FR)*



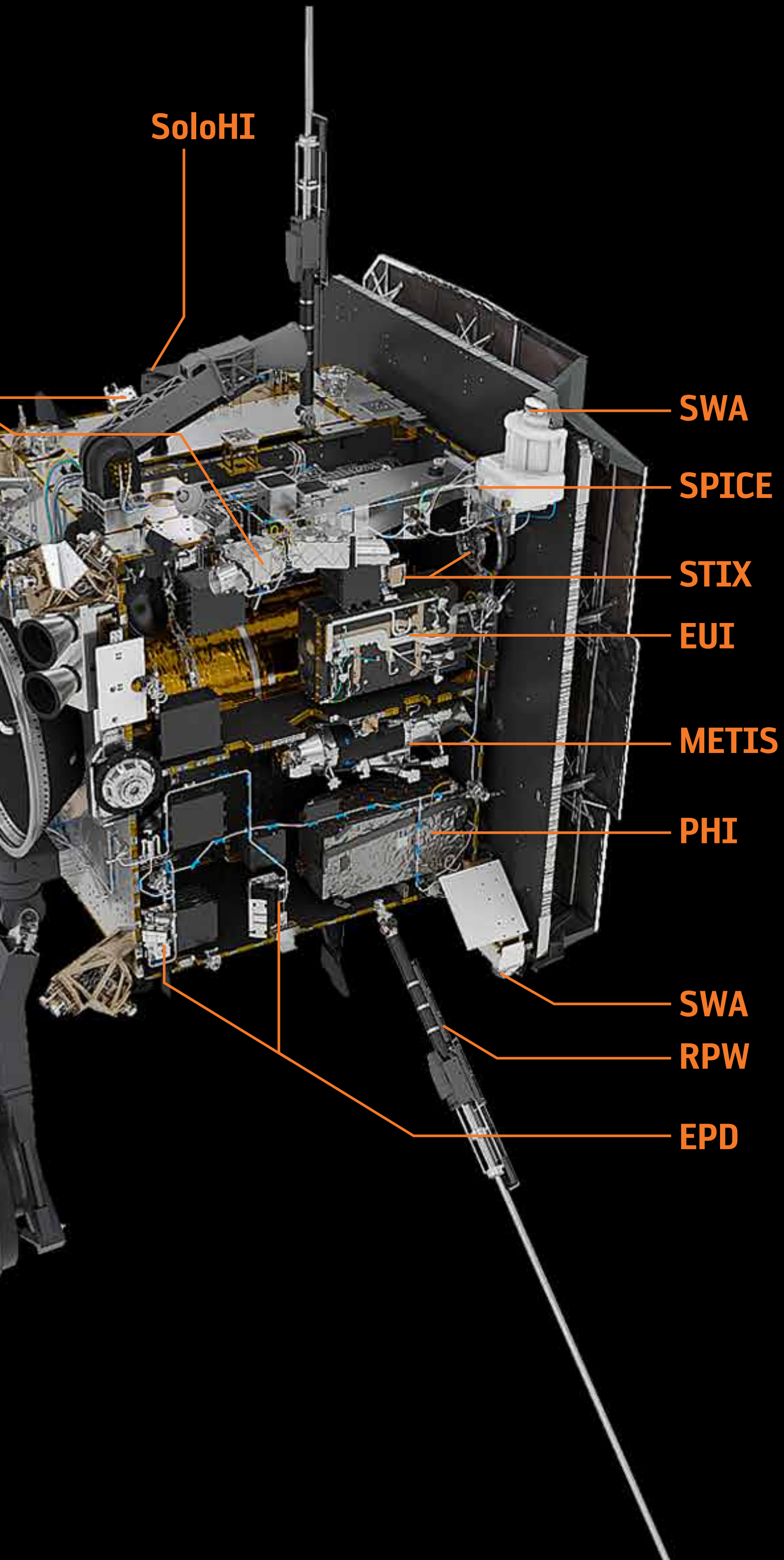
### SWA: Solar Wind Plasma Analyser

SWA consists of a suite of sensors that will measure the solar wind's bulk properties, such as density, velocity and temperature. It will also measure the composition of the solar wind.
*PI: Christopher Owen, Mullard Space Science Laboratory (UK)*

# THE ‘REMOTE-SENSING’ INSTRUMENTS

## EUI: Extreme Ultraviolet Imager

EUI will take images of the solar chromosphere, transition region and corona. This will allow scientists to investigate the mysterious heating processes that take effect in this region and will allow *in situ* measurements of the solar wind to be related back to their source regions on the Sun.
*PI: Pierre Rochus, Centre Spatial de Liège (BE)*



## Metis: Coronagraph

Metis will take simultaneous images of the corona in visible and ultraviolet wavelengths. This will show the structure and dynamics of the solar atmosphere in unprecedented detail, stretching out from 1.7 to 4.1 solar radii. This will allow scientists to look for the link between the behaviour of these regions and space weather in the inner Solar System.
*PI: Marco Romoli, INAF – University of Florence (IT)*

## PHI: Polarimetric and Helioseismic Imager

PHI will provide high-resolution measurements of the magnetic field across the photosphere, and maps of its brightness at visible wavelengths. It will also produce velocity maps of the movement of the photosphere that will allow helioseismic investigations of the solar interior, in particular the convective zone.
*PI: Sami Solanki, Max-Planck-Institut für Sonnensystemforschung (DE)*

## SoloHI: Heliospheric Imager

SoloHI will take images of the solar wind by capturing the light scattered by electron particles in the wind. This will allow the identification of transient disturbances in the solar wind, such as the type that can trigger a coronal mass ejection, in which a billion tons of coronal gas can be ejected outwards into space.
*PI: Russell A. Howard, US Naval Research Laboratory, Washington, DC (US)*

## SPICE: Spectral Imaging of the Coronal Environment

SPICE will reveal the properties of the solar transition region and corona by measuring the extreme ultraviolet wavelengths given off by the plasma.
This data will be matched to the solar wind properties that are subsequently detected by the spacecraft’s *in situ* instruments.
*European-led facility instrument; PI for Operations Phase: Frédéric Auchère, IAS, Orsay (FR)*

## STIX: X-ray Spectrometer/Telescope

STIX will detect X-ray emission coming from the Sun. This could be from hot plasma, often related to explosive magnetic activity such as solar flares. STIX will provide the timing, location, intensity, and energy data for these events so that their effects on the solar wind can be better understood.
*PI: Säm Krucker, FHNW, Windisch (CH)*

# → LAUNCHING AND OPERATING SOLAR ORBITER

Solar Orbiter will follow a complex series of orbits, altered by gravitational assist manoeuvres.

Solar Orbiter is due to launch from Cape Canaveral, Florida, on an Atlas V 411 rocket supplied by NASA in February 2020. Following the initial commissioning round of its systems and instruments, its first pass by the Sun will take place in June when the spacecraft will be at around half the distance of Earth's orbit from the Sun.

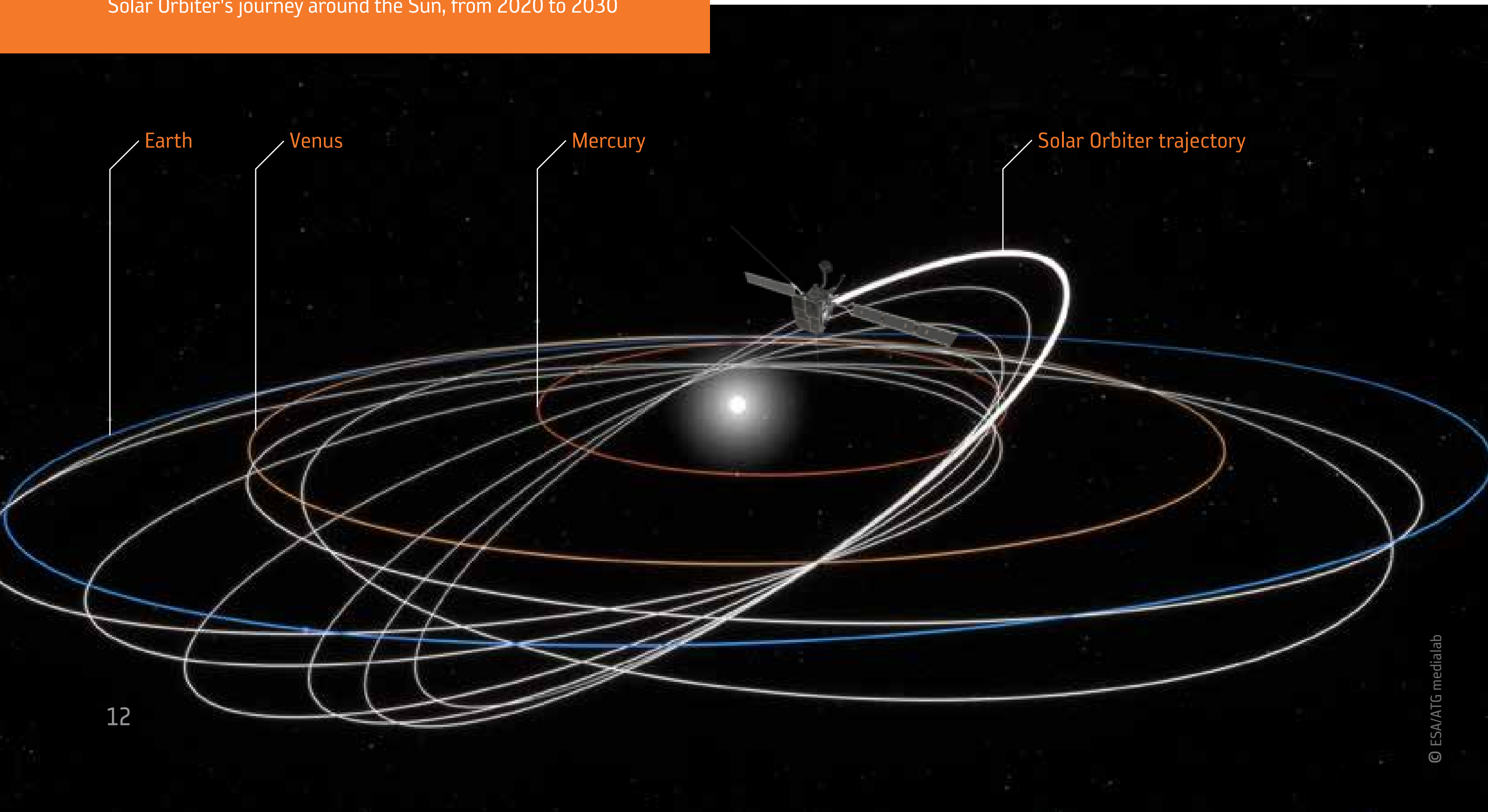
During the remainder of the cruise phase, which lasts until November 2021, Solar Orbiter will perform two gravity-assist manoeuvres around Venus and one around Earth to alter the spacecraft's trajectory, guiding it towards the innermost regions of the Solar System. At the same time, Solar Orbiter will acquire *in situ* data and characterise and calibrate its remote-sensing instruments. The first close solar pass will take place at the end of March 2022 at around a third of Earth's distance from the Sun.

Having arrived in the near-vicinity of the Sun, the spacecraft will be in an elliptical orbit that initially takes 180 days to complete. This means it will make a close approach of the Sun every six months. During these close approaches Solar Orbiter will pass within 42 million kilometres of the Sun's surface, or about 60 solar radii.

The spacecraft's orbit has been chosen to be 'in resonance' with Venus, which means that it will return to the planet's vicinity every few orbits and can again use the planet's gravity to alter or tilt its orbit. Initially Solar Orbiter will be confined to the same plane as the planets, but each encounter of Venus will increase its orbital inclination. This means that each time Solar Orbiter encounters the Sun, it will be looking at it from a different perspective.

Solar Orbiter's nominal science mission is set to last for four years. During this time, the inclination of the orbit is set to reach 17°. This will allow the spacecraft to image regions closer to the poles of the Sun for the first time (the Sun's polar regions are not visible from Earth). During its proposed extended mission phase, Solar Orbiter would lift its inclination even more, to 33°, bringing the polar regions into even more direct view.

Solar Orbiter's journey around the Sun, from 2020 to 2030



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ESA's 35 m radio antenna at the Malargüe ground station, Argentina

## Ground support

Solar Orbiter will communicate with Earth via ESA's deep space tracking network, ESTRACK.

The spacecraft will not communicate with Earth in real time during its flybys. Instead, payload operations requests will be transmitted to the spacecraft by the Mission Operations Centre located at ESOC, Darmstadt, Germany. The resulting science data will be collected and stored on the spacecraft, and then downlinked during designated eight-hour communications windows with ESA's 35-metre ground station in Malargüe, Argentina. Other ESTRACK stations such as New Norcia in Australia and Cebreros in Spain will act as backups.

The Science Operations Centre (SOC) located at ESAC, Villanueva de la Cañada, Spain, will be responsible for all mission planning. Since the orbital characteristics of the mission change significantly from one orbit to the next, the Science Working Team and the SOC must perform detailed planning at all times. The SOC will also be responsible for archiving all of the Solar Orbiter data in a way that it can be easily accessed by anyone. This will secure the legacy of the mission by ensuring it becomes a resource for any scientist who wishes to use the data, even long after the operational phase of the mission is complete.

# → TEAMWORK WITH PARKER SOLAR PROBE

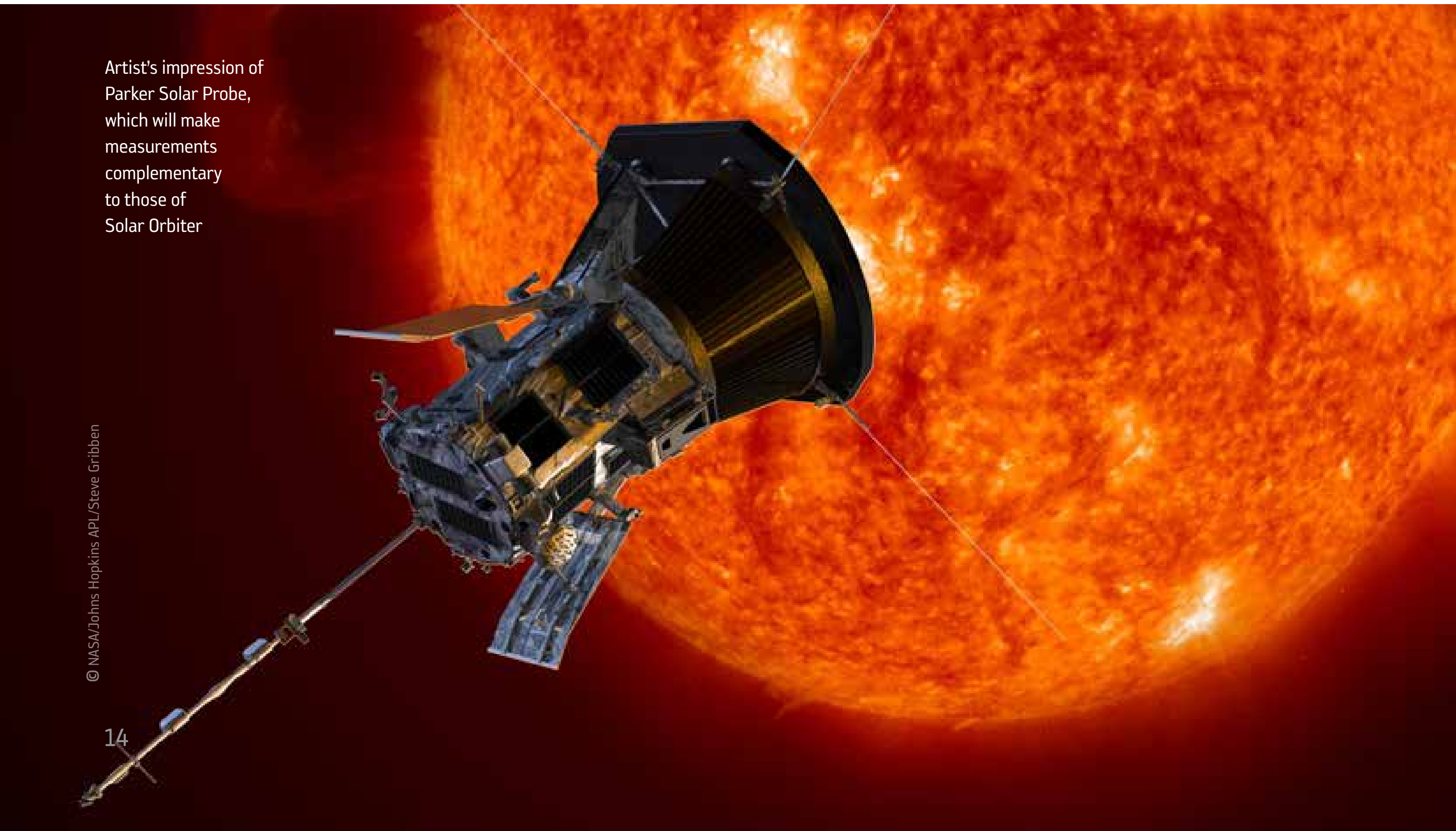
ESA’s Solar Orbiter will be one of two complementary spacecraft studying the Sun at close proximity: it will join NASA’s Parker Solar Probe, which is already engaged in its mission. Launched from Cape Canaveral on a Delta IV Heavy rocket on 12 August 2018, Parker Solar Probe was named after Eugene Parker, who developed the theory of the solar wind in 1958.

Parker Solar Probe carries a smaller payload than Solar Orbiter but it goes closer to the Sun. Like Solar Orbiter, it too uses gravitational assist manoeuvres to plunge it closer and closer to the Sun. It already holds the record for the closest pass of the Sun. On 4 April 2019, it passed the solar surface at a distance of around 24 million kilometres, and this will only get closer during the 24 close encounters it is expected to have with the Sun. On the final three orbits of its nominal mission, Parker Solar Probe will pass within 6.2 million kilometres of the Sun’s surface, facing heat and radiation like no spacecraft before it.

Parker Solar Probe carries instruments to sample the Sun’s corona, and is targeting the region of space where the coronal plasma detaches to become the solar wind. This will give the scientists ‘ground truth’ about the conditions of the plasma in that region, and help pinpoint how it is accelerated outwards towards the planets. However, Parker Solar Probe has no cameras that view the Sun directly. No current technology could look at the Sun from that close a distance and survive. This is where Solar Orbiter comes in.

Beyond accomplishing its own science goals, Solar Orbiter will provide contextual information to improve the understanding of Parker Solar Probe’s *in situ* measurements. By working together in this way, the two spacecraft will collect complementary data sets that will allow more science to be distilled from the two missions than either could manage on its own.

The Sun is obviously essential to life on Earth. It is both the central engine of the Solar System, and its central enigma. By the end of the ESA's Solar Orbiter mission we will know more about the Sun, and how to reduce the risks of its disruption of our technology on Earth, than ever before.



Artist’s impression of Parker Solar Probe, which will make measurements complementary to those of Solar Orbiter

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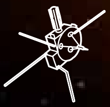
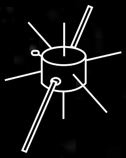
# Missions to the Sun

1990–2009 **Ulysses**



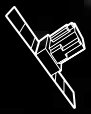
Investigating the solar wind coming from the Sun's polar regions



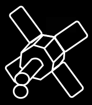
Studying the radio waves and plasma in the solar wind

**Wind** 1994–present

1995–present **Solar and Heliospheric Observatory (SOHO)**



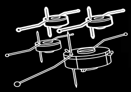
Studying the Sun's behaviour from its interior to its outer atmosphere



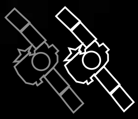
Studying the way magnetic fields reach out from the Sun and into the solar atmosphere

**Transition Region and Coronal Explorer (TRACE)** 1998–2010

2000–present **Cluster**

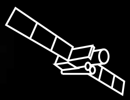


Four identical spacecraft studying what happens to Earth's magnetic environment when the solar wind strikes it



Two spacecraft recording the way disturbances in the solar wind propagate from the Sun to our planet

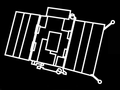
**Solar Terrestrial Relations Observatory (STEREO)** 2006–present



Studying the way in which the Sun's magnetic field interacts with its atmosphere

**Hinode**

2009–present **Project for Onboard Autonomy-2 (Proba-2)**

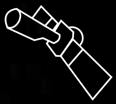


Imaging the Sun and studying the plasma passing through Earth's magnetic field

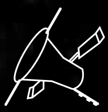
Returning real-time images of the Sun and tracing solar activity

**Solar Dynamics Observatory (SDO)** 2010–present

2013–present **Interface Region Imaging Spectrograph (IRIS)**



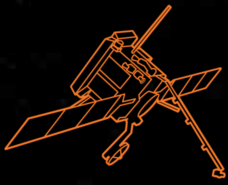
Observing the lower solar atmosphere to provide complimentary data for SDO



Diving close to the Sun to study how its atmosphere becomes the solar wind

**Parker Solar Probe** 2018–present

2020– **Solar Orbiter**

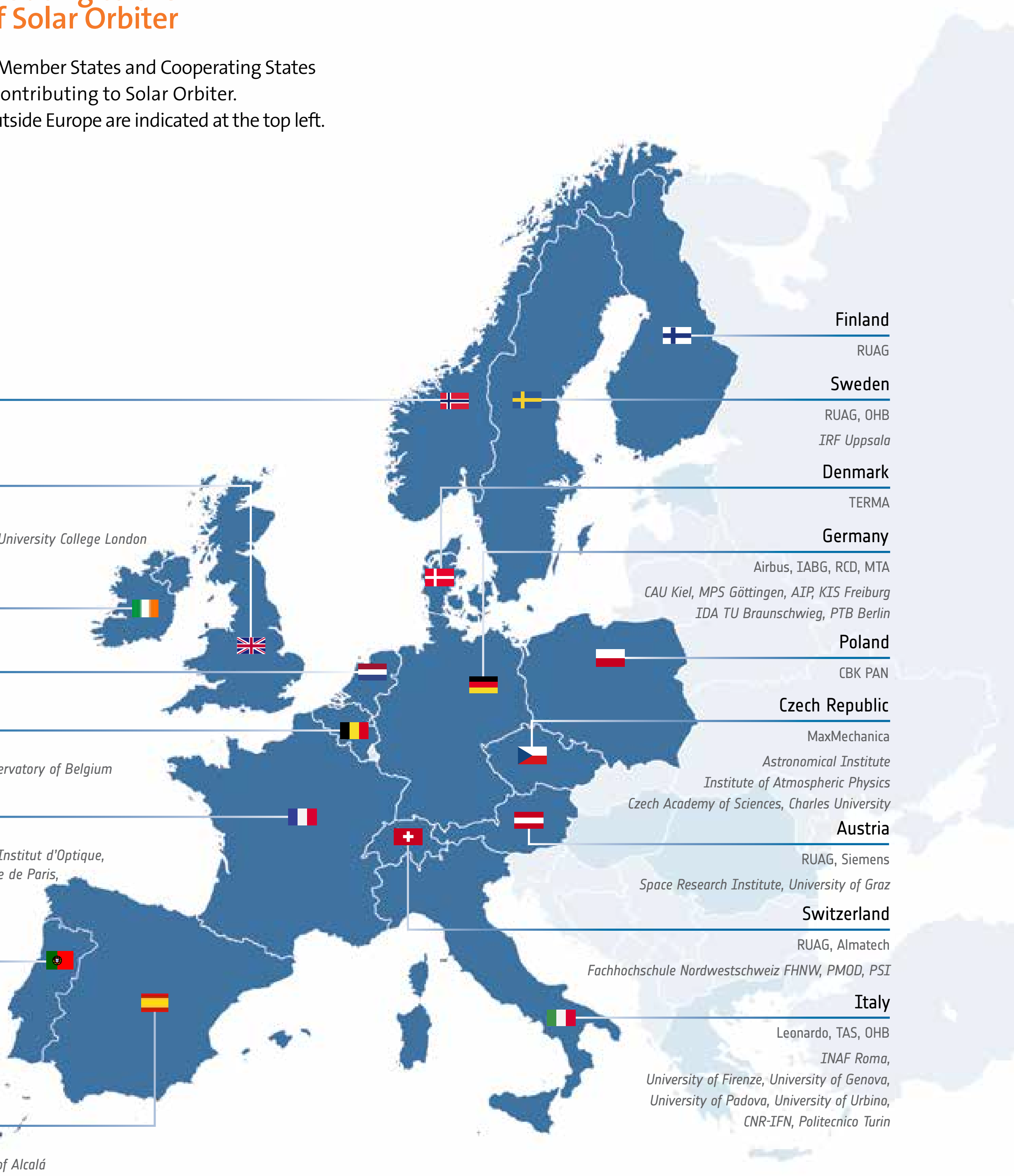


Studying the Sun up close, collecting high-resolution images and data from our star and its heliosphere

# → AN INTERNATIONAL ENTERPRISE

## Countries contributing to the development of Solar Orbiter

The map highlights ESA Member States and Cooperating States within Europe that are contributing to Solar Orbiter. Participating countries outside Europe are indicated at the top left.



**USA**

*Naval Research Laboratory*
*Southwest Research Institute*
*University of Michigan*
*University of New Hampshire*
*GSFC, JPL, APL*

**Norway**

KDA

*ITA, University of Oslo*

**United Kingdom**

ABSL, Airbus, ESTL, Tessella
*Imperial College London*
*Mullard Space Science Laboratory, University College London*
*Rutherford Appleton Laboratory*

**Ireland**

CAPTEC, ENBIO

**The Netherlands**

Airbus, Tessella, TNO

**Belgium**

TAS, RHEA

*Centre Spatial de Liège, Royal Observatory of Belgium*

**France**

Airbus, CNES

*Institut d'Astrophysique Spatiale, Institut d'Optique,*
*IRAP Toulouse LESIA, Observatoire de Paris,*
*LPP, LPC2E, CEA*

**Portugal**

Active Space, Critical Software

**Spain**

Airbus, Sener, TAS, INTA

*Space Research Group, University of Alcalá*
*Instituto de Astrofísica de Andalucía*
*University of Valencia, University of Barcelona*
*UPM, IAC*

**Finland**

RUAG

**Sweden**

RUAG, OHB

*IRF Uppsala*

**Denmark**

TERMA

**Germany**

Airbus, IABG, RCD, MTA

*CAU Kiel, MPS Göttingen, AIP, KIS Freiburg*
*IDA TU Braunschweig, PTB Berlin*

**Poland**

CBK PAN

**Czech Republic**

MaxMechanica

*Astronomical Institute*
*Institute of Atmospheric Physics*
*Czech Academy of Sciences, Charles University*

**Austria**

RUAG, Siemens

*Space Research Institute, University of Graz*

**Switzerland**

RUAG, Almatech

*Fachhochschule Nordwestschweiz FHNW, PMOD, PSI*

**Italy**

Leonardo, TAS, OHB

*INAF Roma,*
*University of Firenze, University of Genova,*
*University of Padova, University of Urbino,*
*CNR-IFN, Politecnico Turin*

Industry partners

*Lead scientific institutes or universities contributing to the science payload*

**Find out more about Solar Orbiter:**
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