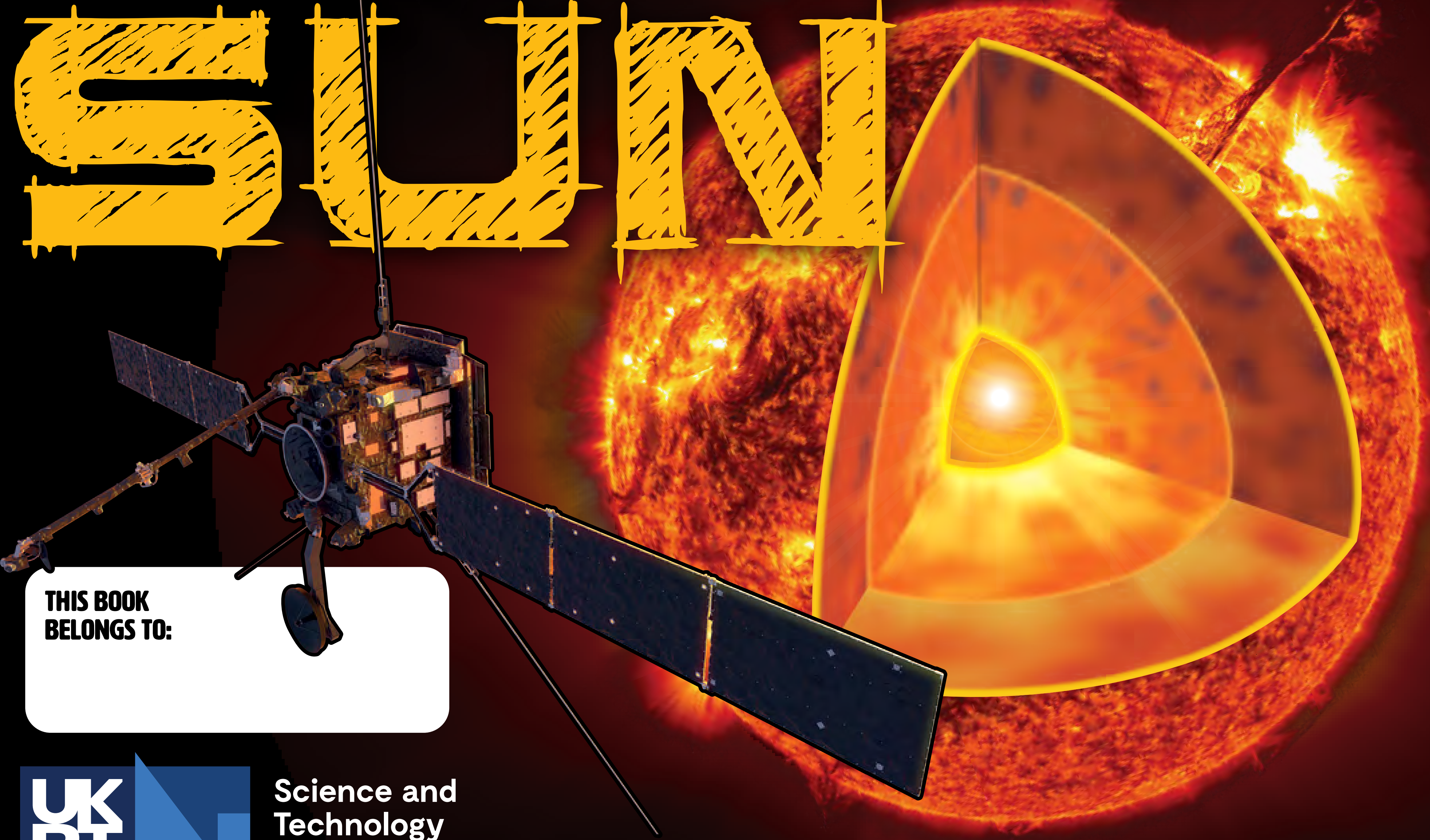
THE LITTLE BOOK OF THE SUN



THIS BOOK BELONGS TO:

UKRI Science and Technology Facilities Council

What is the Sun made of and what makes it so hot?

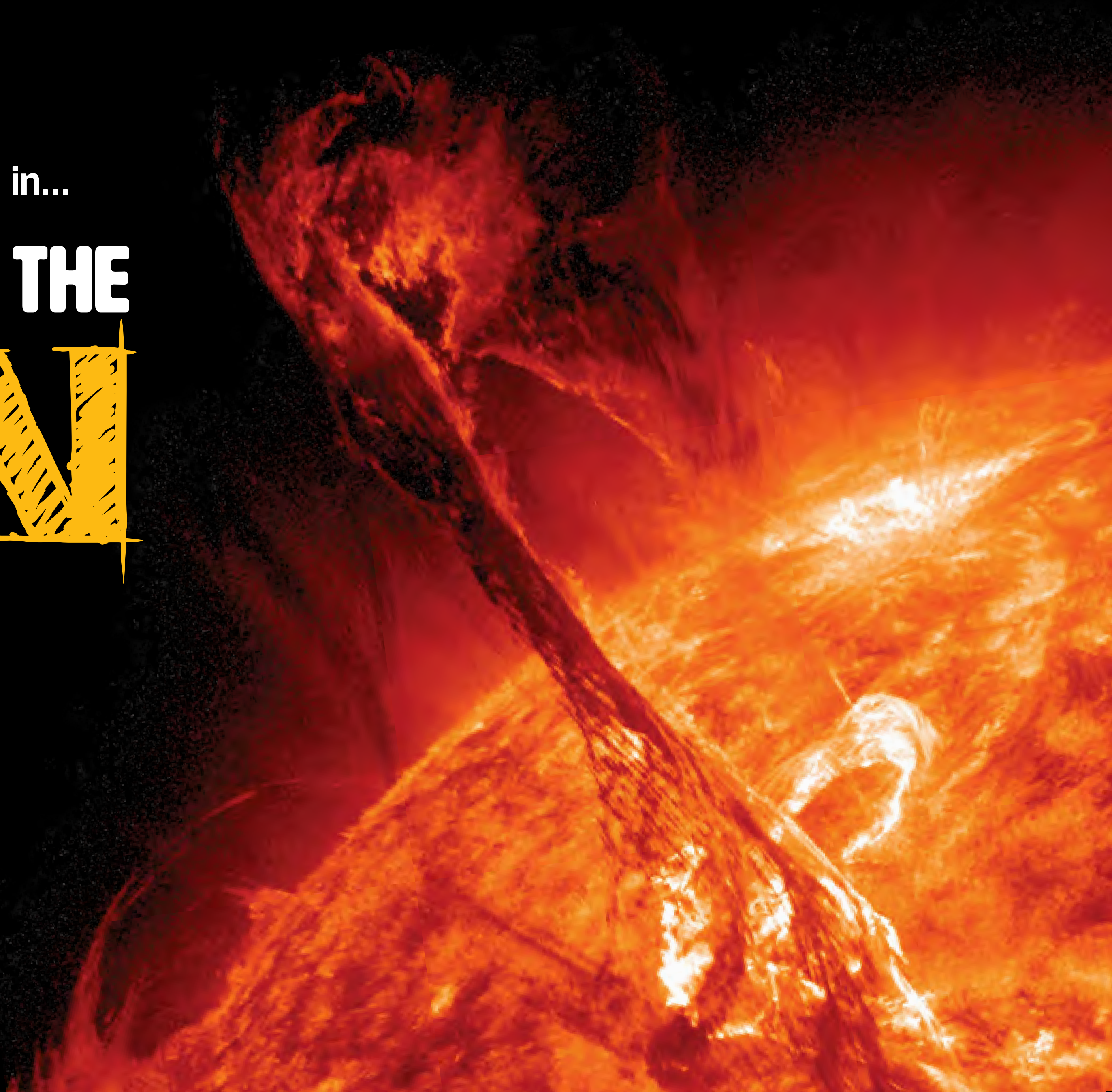
What causes solar eclipses to happen?

How do scientists study the Sun and what can looking at it in different ways tell us?

What are solar flares and why do they happen?

You'll find all this out (and lots more) in...

THE LITTLE BOOK OF THE SUN



CONTENT DEVELOPED AND WRITTEN BY

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OTHER IMAGES: NASA, ESA, ESO

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1 HOW THE SUN WORKS

The Sun is our nearest star. It provides the Earth, which orbits at a distance of 150 million kilometres, the right amount of light and heat to support life.

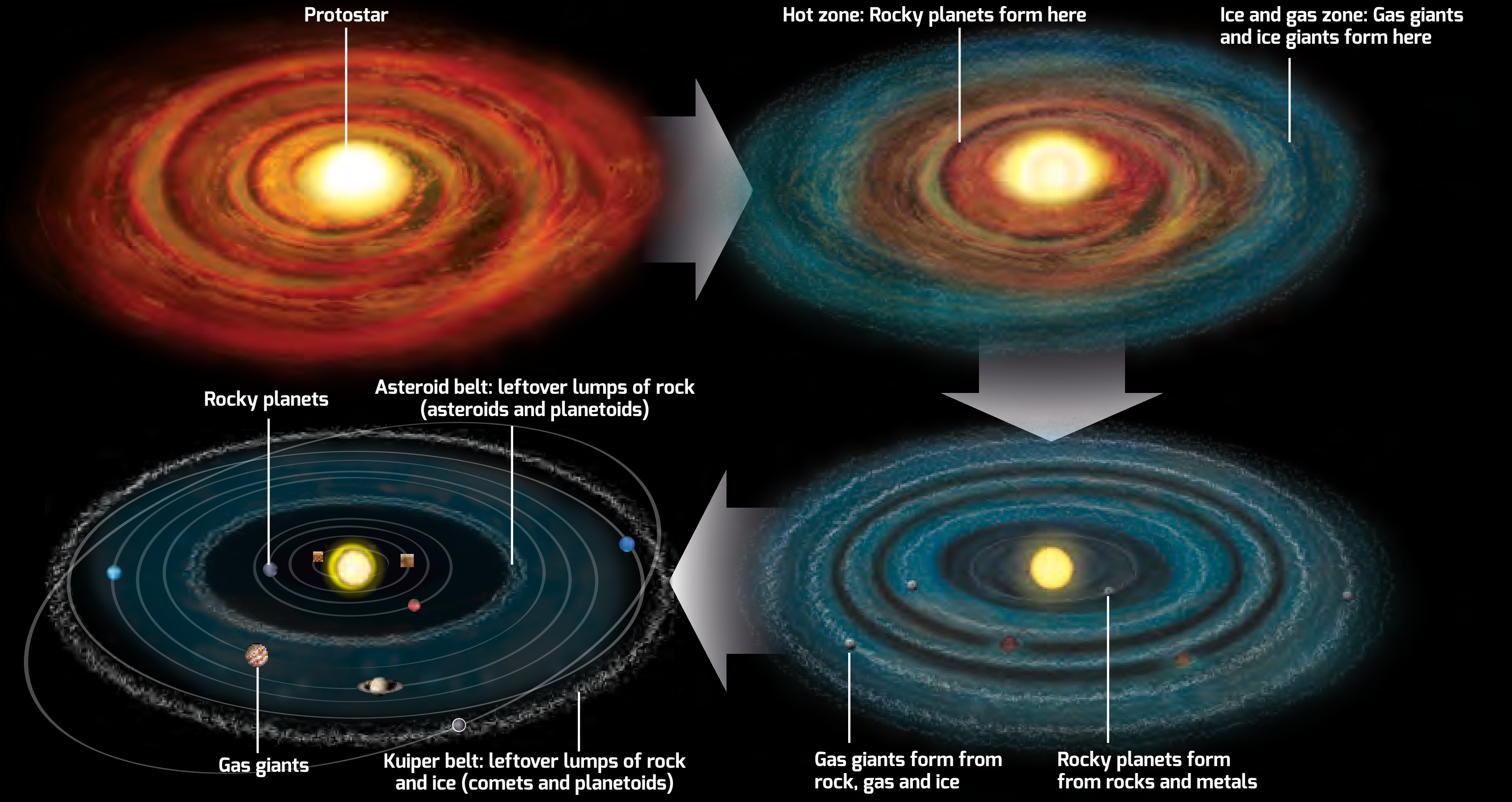
Believe it or not, but the Sun, all the planets, and the entire Solar System itself was formed from a giant cloud of dust and gas!

HOW THE SUN WAS BORN

The cloud of dust and gas that would become our solar system started to collapse about 4.6 billion years ago.

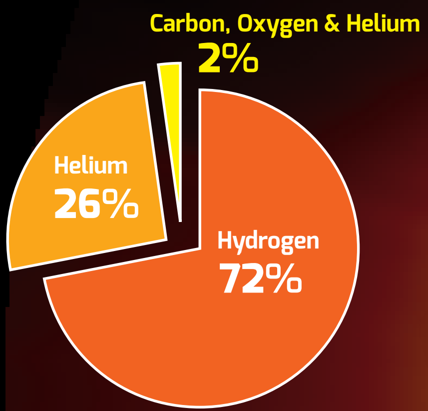
It took about 100,000 years for the protostar to become hot and dense enough for nuclear fusion to begin.

It took another 10 million years for the gas giants, like Jupiter, to form and 100 million years for the inner rocky planets to form.



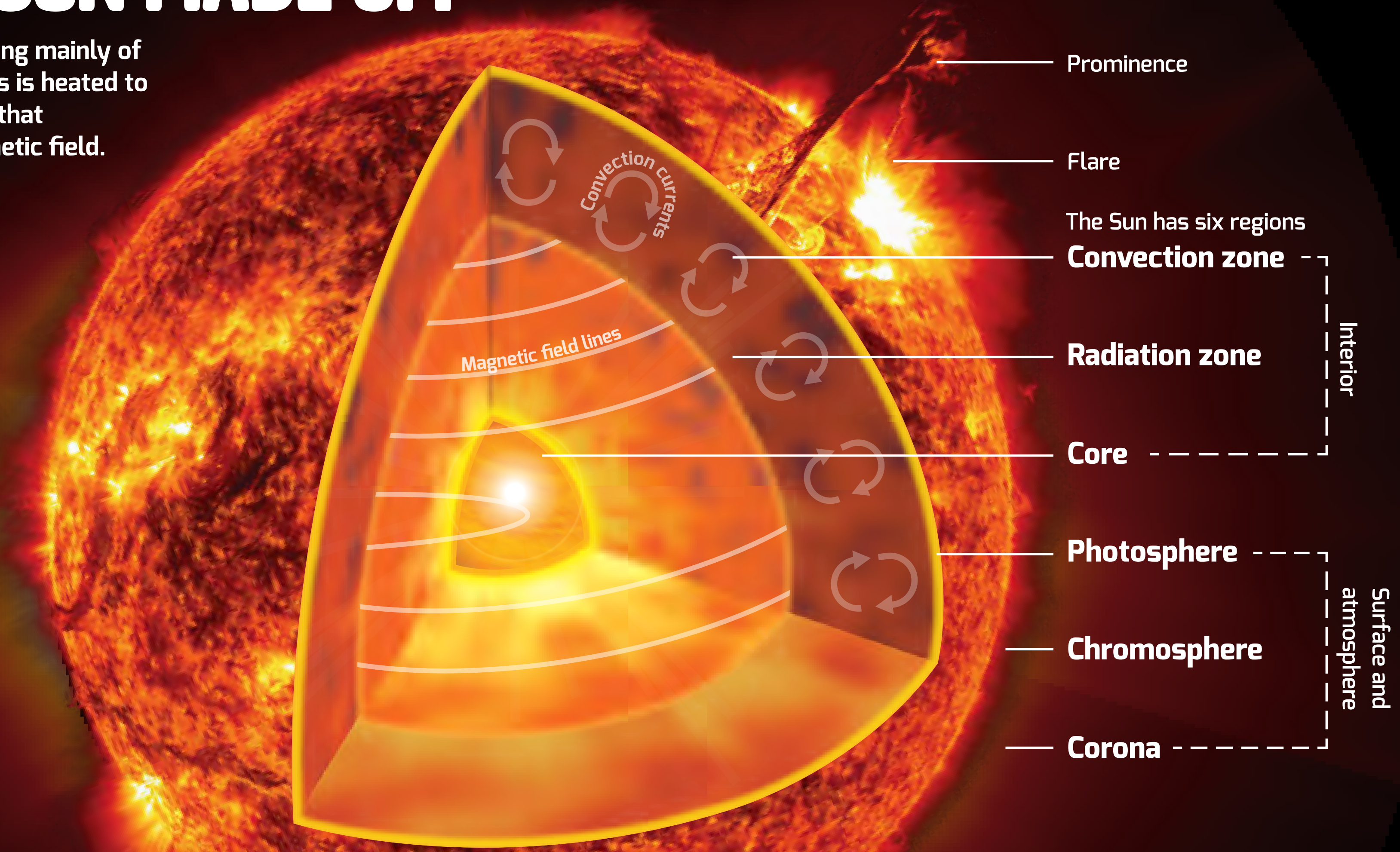
WHAT IS THE SUN MADE OF?

The Sun is a giant ball of gas, consisting mainly of hydrogen and helium. Most of this gas is heated to form an electrically-charged plasma that circulates, generating the Sun's magnetic field.

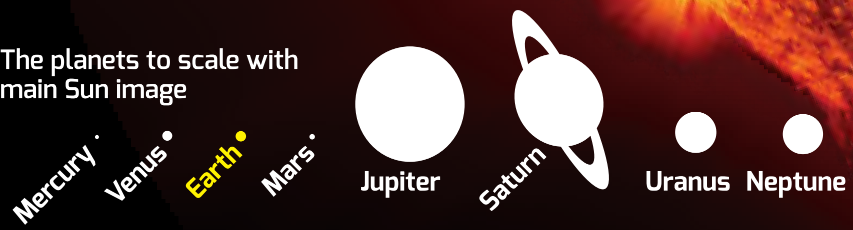


The mass of the Sun is about **330,000** times greater than the mass of the Earth

The Sun contains about **99.86%** of the mass of the Solar System

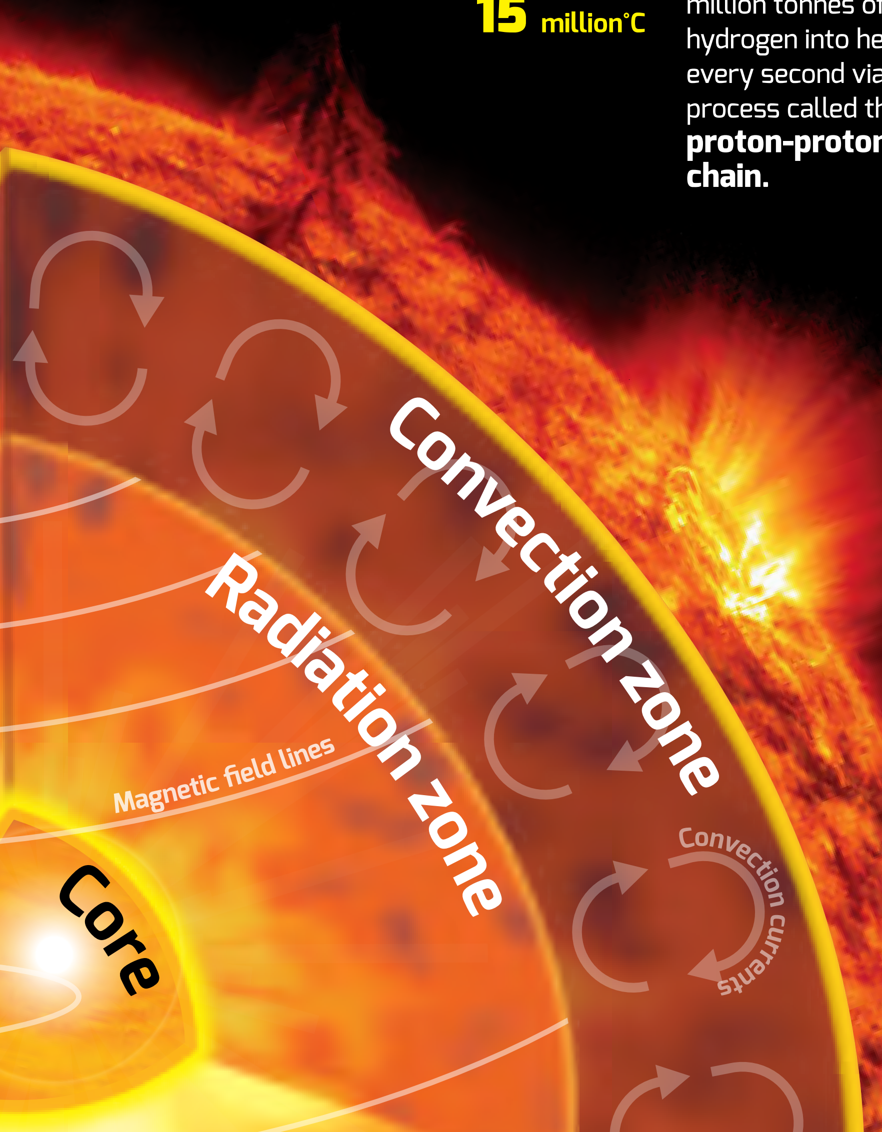


The planets to scale with main Sun image



Every second, the Sun converts **600** million tonnes of hydrogen into helium

THE SUN'S INTERIOR

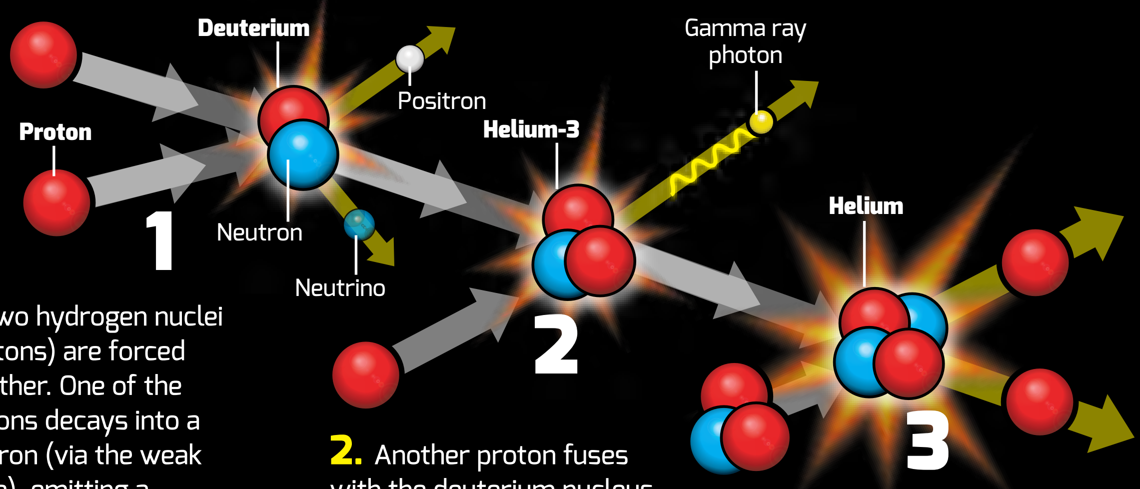


Core

15 million°C

The core is the engine room of the Sun. Here, the extreme temperature and pressure is sufficient to sustain nuclear fusion.

The Sun converts 600 million tonnes of hydrogen into helium every second via a process called the **proton-proton chain.**



1. Two hydrogen nuclei (protons) are forced together. One of the protons decays into a neutron (via the weak force), emitting a positron and a high-energy neutrino – creating a deuterium, or heavy hydrogen, nucleus.

2. Another proton fuses with the deuterium nucleus, emitting a high-energy gamma ray photon – creating a helium-3 (light helium) nucleus.

3. Finally, two helium-3 nuclei fuse to create a helium (helium-4) nucleus. Two protons are ejected along with lots of energy.

Radiation zone

2 to 7 million°C

Energy from the core travels through the radiation zone in the form of electromagnetic radiation (photons). The region is so dense that photons are continually absorbed and re-emitted by atoms – it takes an average 170,000 years for energy to leave it.

Convection zone

2 million°C

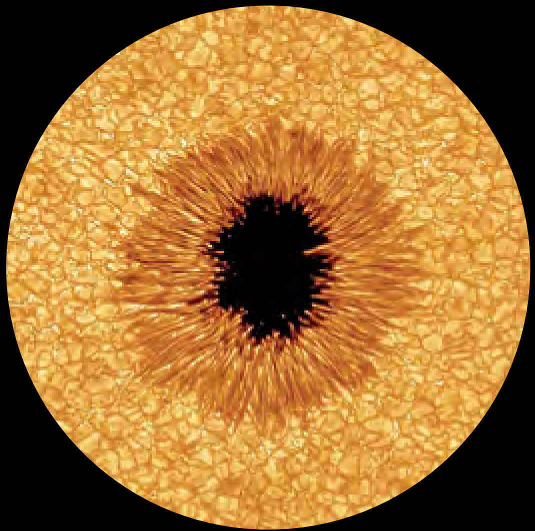
This turbulent region carries energy to the Sun's surface in thermal columns. The material cools at the surface and plunges back to the bottom of the convection zone. It is reheated by the radiation zone where it travels back to the surface once more.

THE SURFACE AND ATMOSPHERE

Photosphere

5,700°C

The photosphere is the visible surface of the Sun. It is just 100 kilometres thick and has a granulated appearance caused by the upwelling hot material, which is brighter, surrounded by sinking cool material, which appears darker.



Sunspots are dark, planet-sized regions on the photosphere. They are dark because they are cooler than their surroundings. Sunspots are caused by strong magnetic disturbances. They evolve over several days and may last for months. They are active regions and are associated with solar flares and Coronal Mass Ejections.

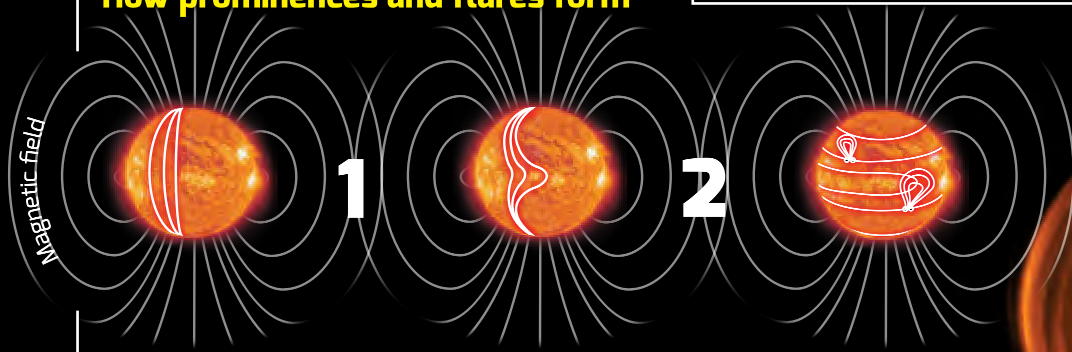
Chromosphere

6,000 to 20,000°C

The chromosphere is the layer of the Sun's atmosphere that extends about 400 to 2,100 kilometres above the photoshere. Here, hydrogen atoms absorb energy from the photosphere and re-emit it as reddish light (chromo means colour).

It is here that spectacular and violent events, such as prominences and solar flares occur.

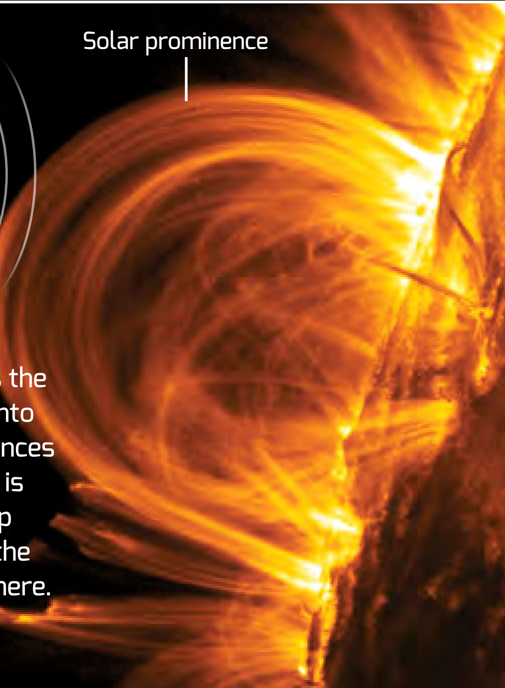
How prominences and flares form



1. The Sun rotates faster at its equator than it does near its poles. This difference causes the magnetic field to become distorted.

2. It becomes twisted into loops that break through the surface. In some regions, the loops merge into complex 'active regions', which can generate explosive solar flares or expel plasma into space as coronal mass ejections.

In some cases the loops evolve into solar prominences where matter is trapped in loop structures in the solar atmosphere.



Corona

More than 1 million°C

The Corona is the Sun's extended atmosphere – larger in volume than the entire Sun.

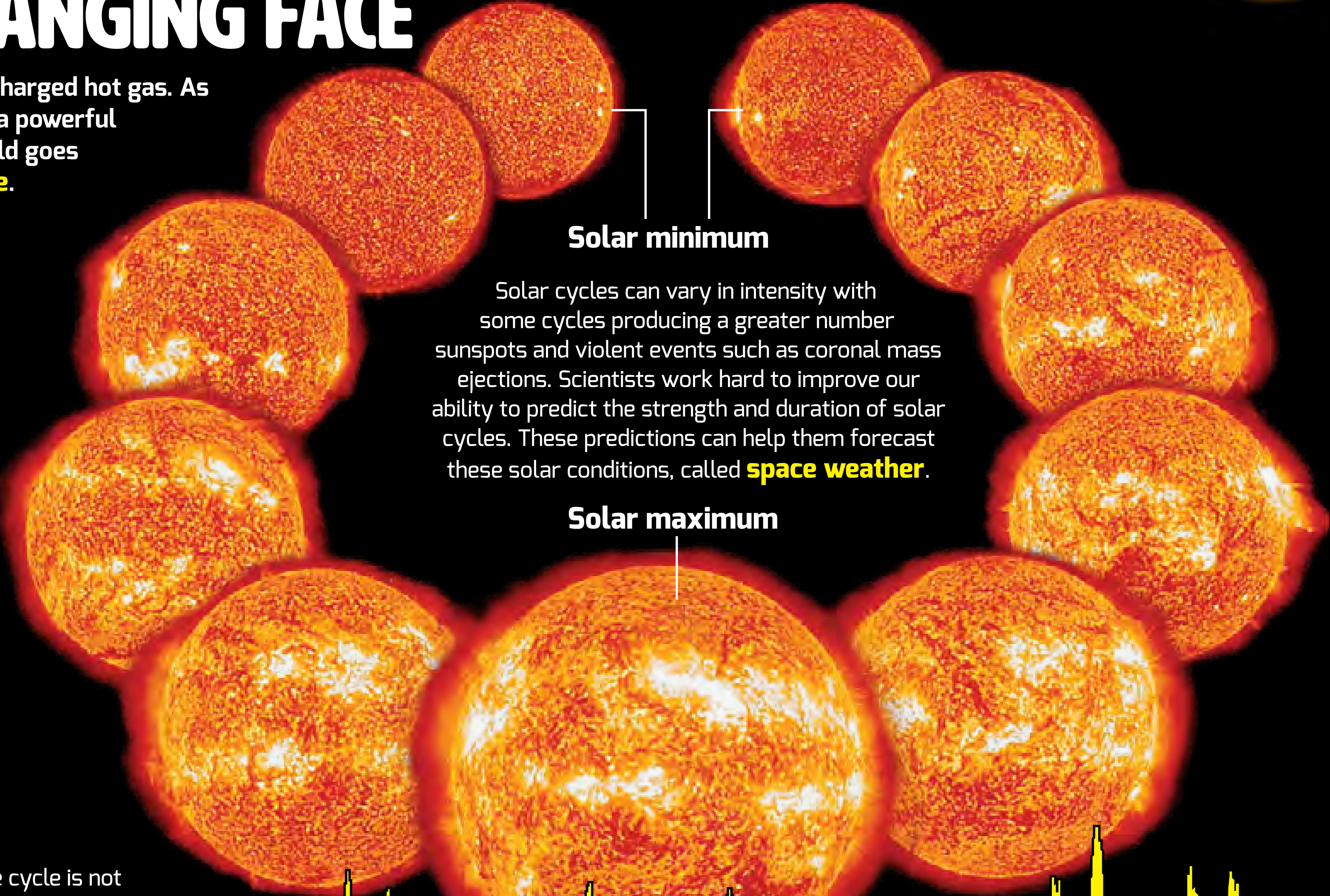
Why the corona is so much hotter than the Sun's surface is one of science's biggest mysteries.

THE SUN'S CHANGING FACE

Our Sun is a huge ball of electrically-charged hot gas. As this charged gas moves, it generates a powerful magnetic field. The Sun's magnetic field goes through a cycle, called the solar cycle.

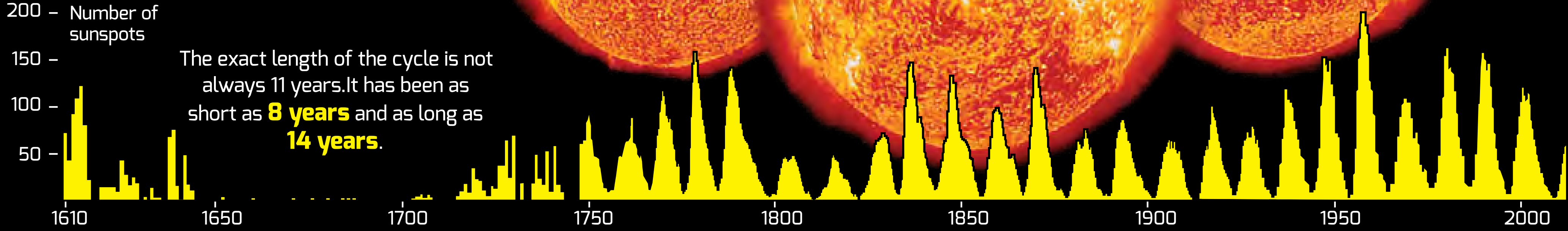
Every **11 years** or so, the Sun's magnetic field completely flips and the north and south poles switch places. Then it takes about another 11 years for the Sun's north and south poles to flip back again.

The solar cycle affects activity on the surface of the Sun, such as sunspots and solar flares. As the magnetic fields change, so does the amount of activity on the Sun's surface – peaking every 11 years before calming down again.



Solar cycles can vary in intensity with some cycles producing a greater number sunspots and violent events such as coronal mass ejections. Scientists work hard to improve our ability to predict the strength and duration of solar cycles. These predictions can help them forecast these solar conditions, called **space weather**.

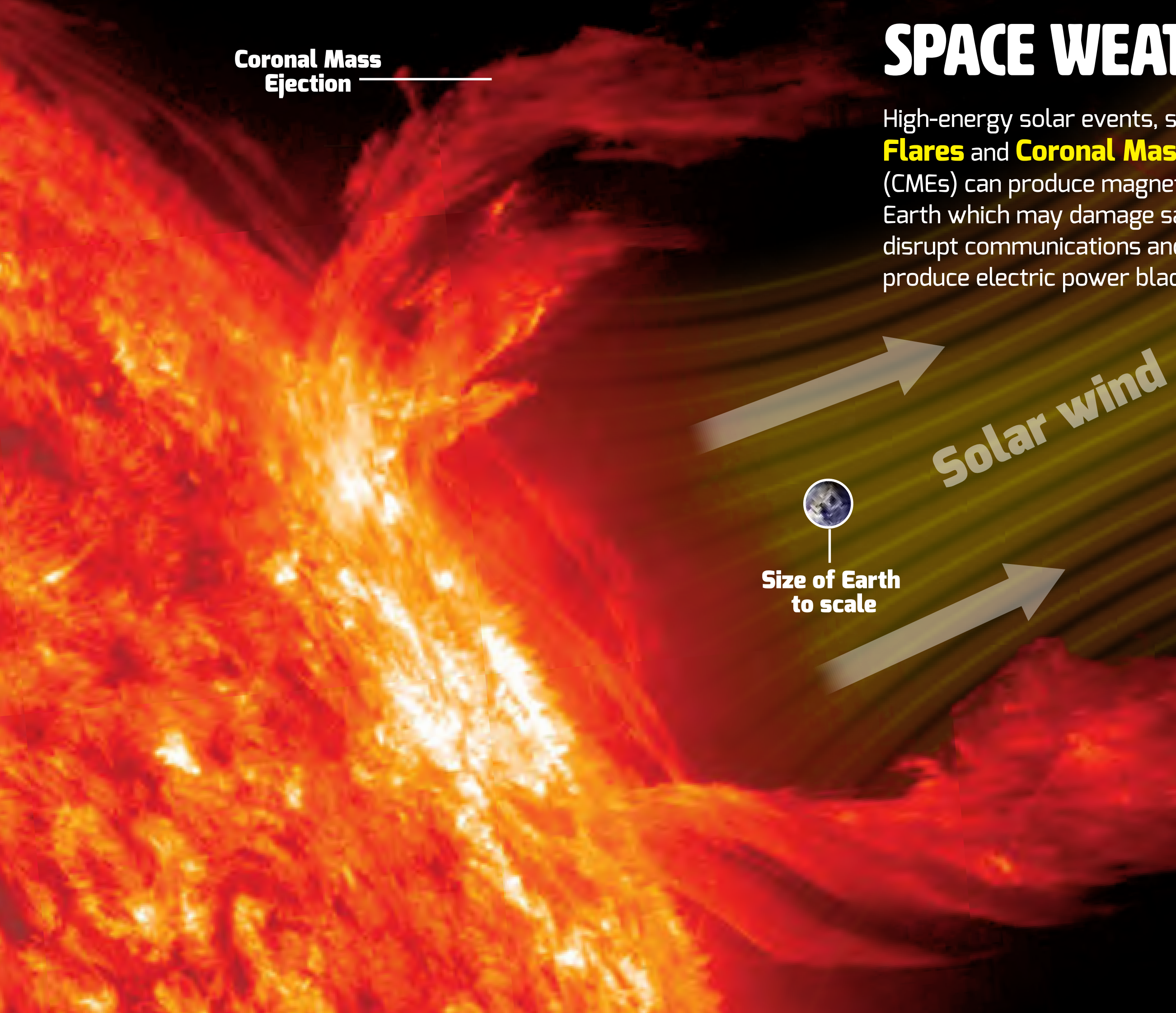
Solar cycles since 1610



The exact length of the cycle is not always 11 years.It has been as short as **8 years** and as long as **14 years**.

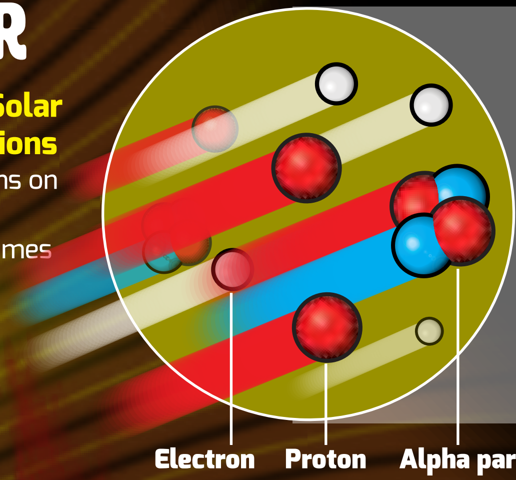
2 THE SUN-EARTH CONNECTION

You can think of the Sun and the Earth as being part of a single interconnected system. One way the Earth is influenced by the Sun is by its gravity, which holds the planet in orbit. Visible light warms the Earth and provides the energy needs of life on Earth, while more violent solar events can have a more dramatic influence.



SPACE WEATHER

High-energy solar events, such as **Solar Flares** and **Coronal Mass Ejections** (CMEs) can produce magnetic storms on Earth which may damage satellites, disrupt communications and sometimes produce electric power blackouts.



The **solar wind** is a stream of plasma – electrons, protons and alpha particles (helium nuclei) – released from the upper atmosphere of the Sun.

Coronal Mass Ejections (CMEs) are the most powerful events in the solar system. A single CME event can throw more than ten billion tonnes of charged particles into space – covering an area as wide as 30 million miles.

Although the main CME might take several days to reach Earth, shockwaves can accelerate some of its particles to close to the speed of light – at this speed they can cover the 150 million miles to Earth in as little as 90 minutes.

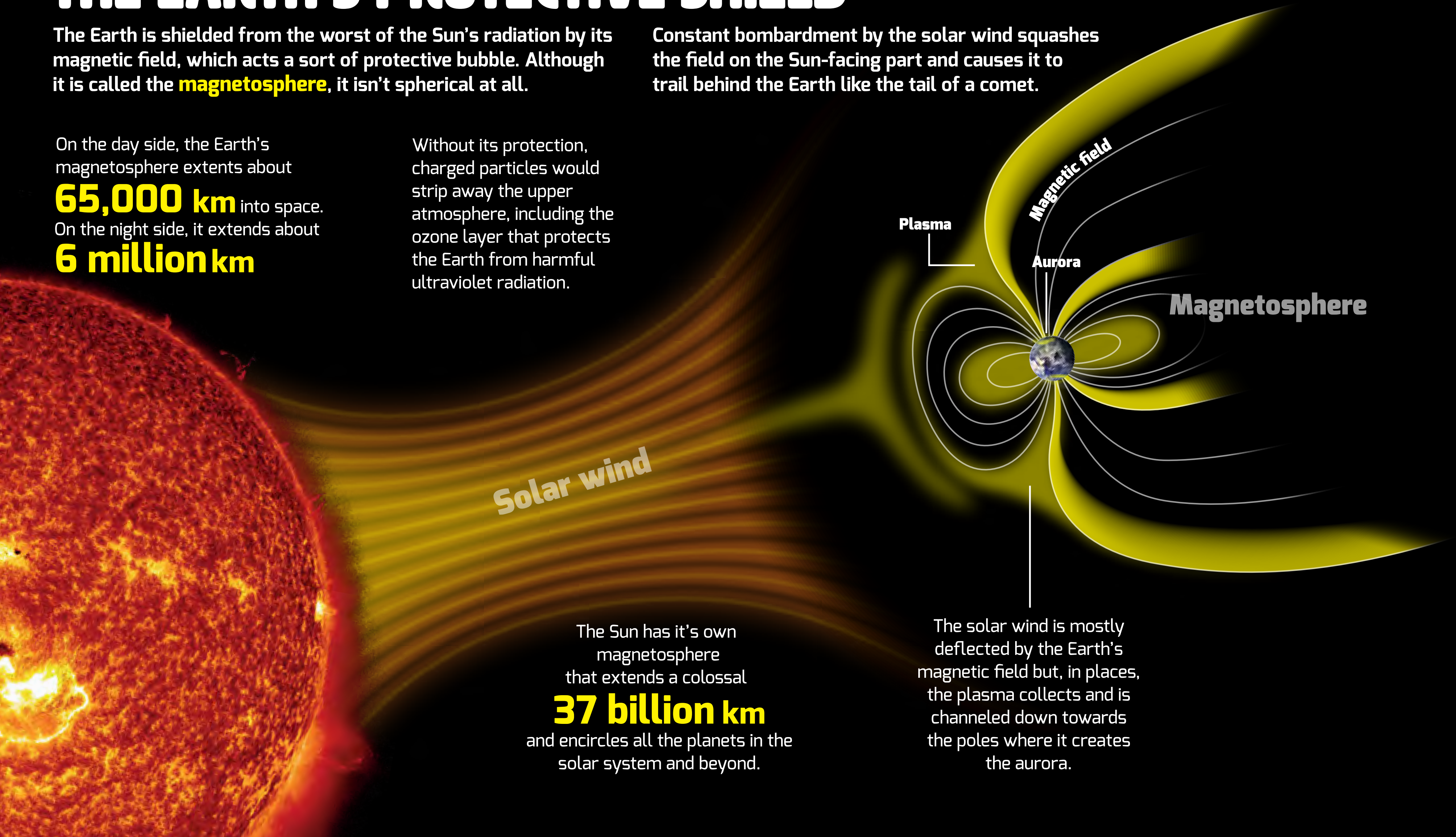
THE EARTH'S PROTECTIVE SHIELD

The Earth is shielded from the worst of the Sun's radiation by its magnetic field, which acts a sort of protective bubble. Although it is called the magnetosphere, it isn't spherical at all.

Constant bombardment by the solar wind squashes the field on the Sun-facing part and causes it to trail behind the Earth like the tail of a comet.

On the day side, the Earth's magnetosphere extents about **65,000 km** into space. On the night side, it extends about **6 million km**

Without its protection, charged particles would strip away the upper atmosphere, including the ozone layer that protects the Earth from harmful ultraviolet radiation.



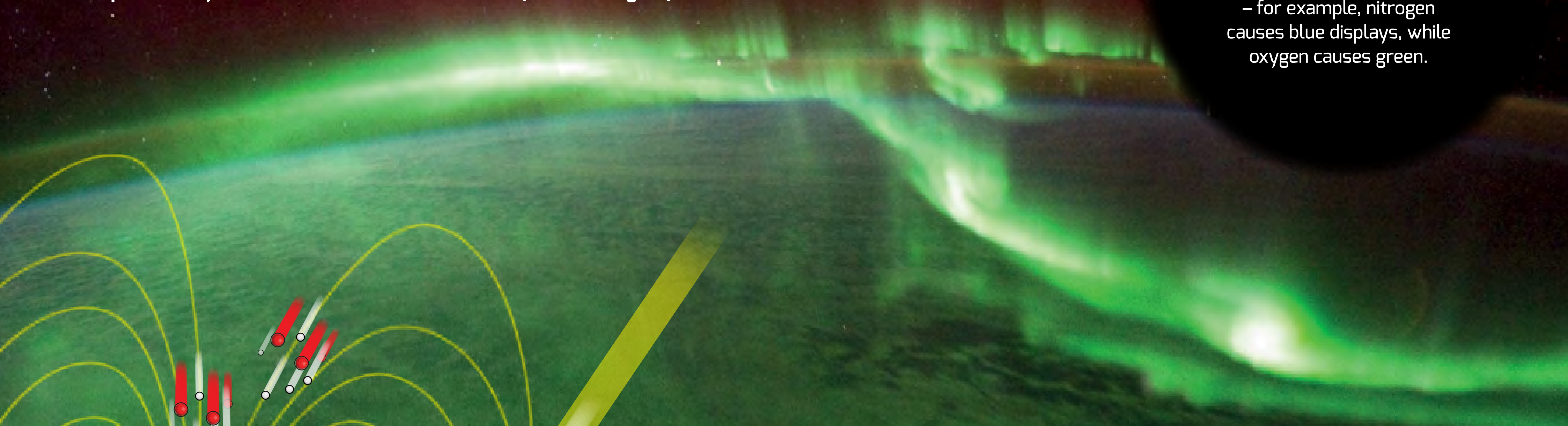
The Sun has it's own magnetosphere that extends a colossal **37 billion km** and encircles all the planets in the solar system and beyond.

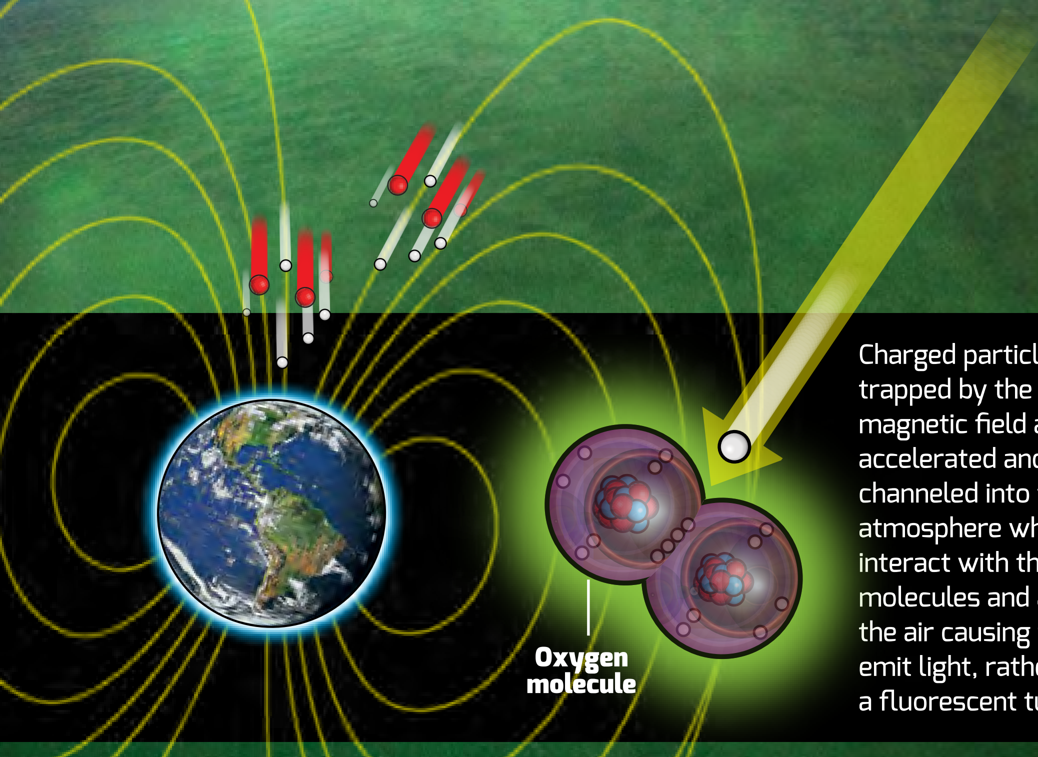
The solar wind is mostly deflected by the Earth's magnetic field but, in places, the plasma collects and is channeled down towards the poles where it creates the aurora.

HOW THE SUN CAUSES THE AURORA

The most beautiful (and most easily observable) effect of the interaction between the Earth's magnetic field and solar wind are the **aurora**. In the northern hemisphere, they are called the **aurora Borealis** (northern lights), whereas in the southern hemisphere, they are called the **aurora Australis** (southern lights).

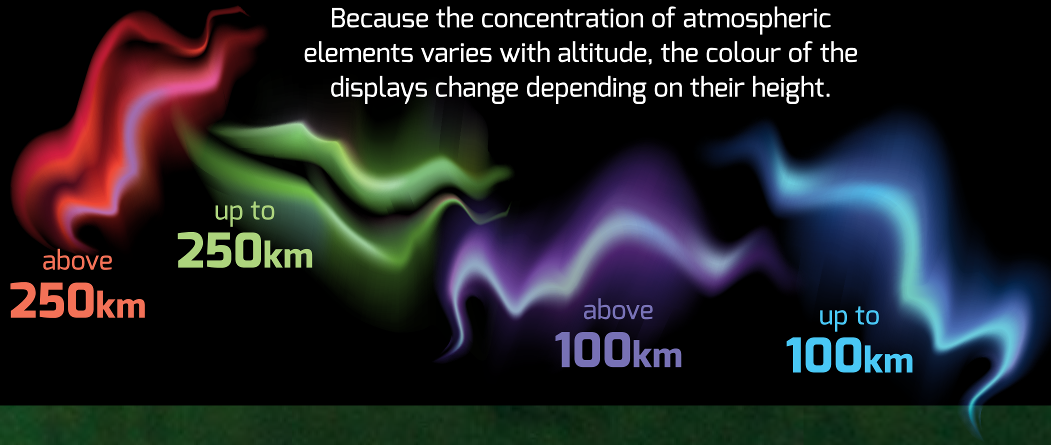
The colour of the aurora display depends on the atmospheric element the charged particles collide with – for example, nitrogen causes blue displays, while oxygen causes green.





Charged particles trapped by the Earth's magnetic field are accelerated and channeled into the polar atmosphere where they interact with the molecules and atoms in the air causing them to emit light, rather like in a fluorescent tube.

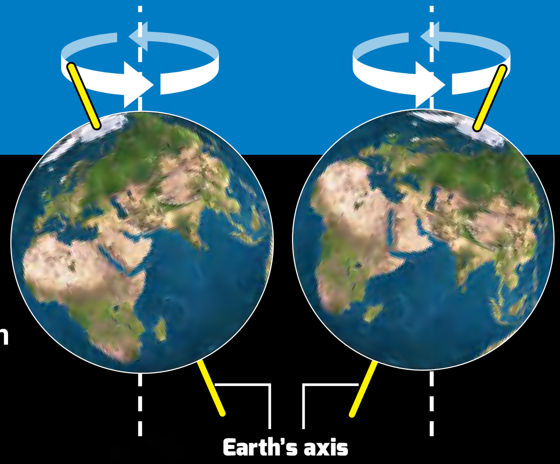
Because the concentration of atmospheric elements varies with altitude, the colour of the displays change depending on their height.



THE SUN-EARTH CONNECTION

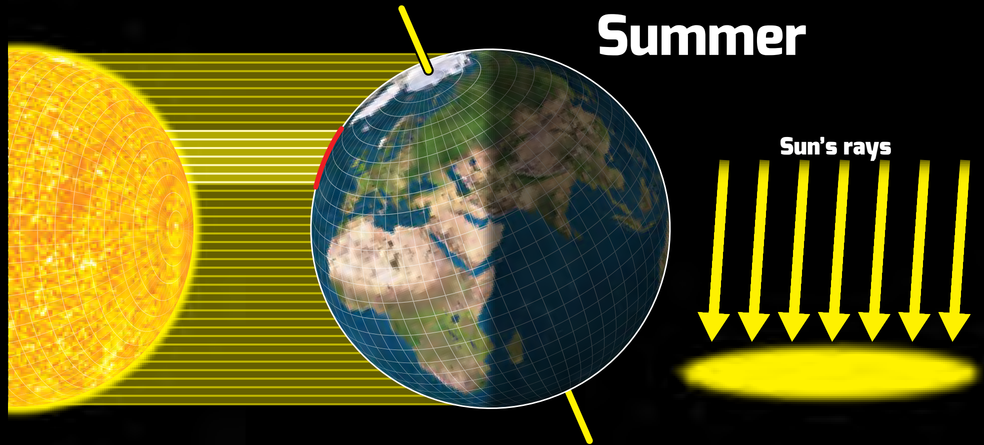
THE SEASONS

Although the distance between the Earth and Sun does vary throughout the year, this is not the cause of the seasons. The real reason is that the Earth's axis is actually tilted at an angle of 23.45 degrees. This causes the Earth to wobble from side to side as it orbits the Sun.

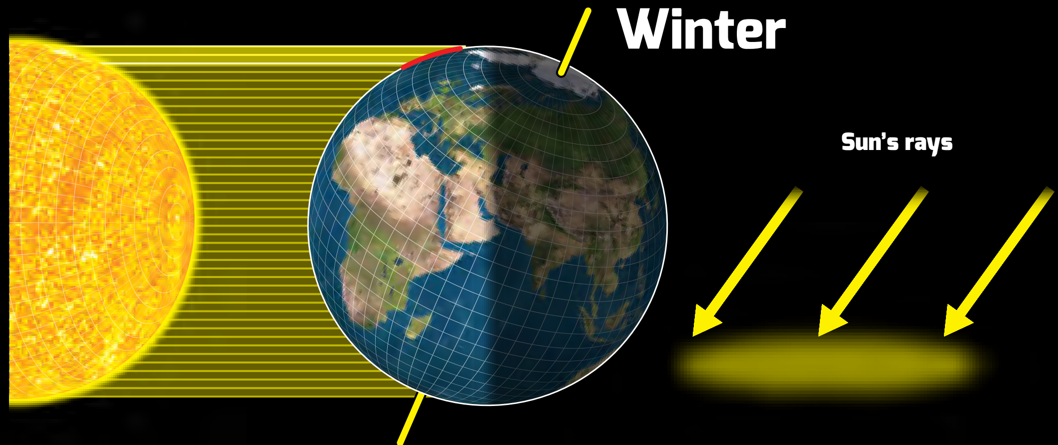


In the summer, the northern hemisphere tilts towards the Sun. The Sun's rays hit the Earth at a more direct angle – meaning more sunlight can fall on a smaller area than it does during winter.

Summer

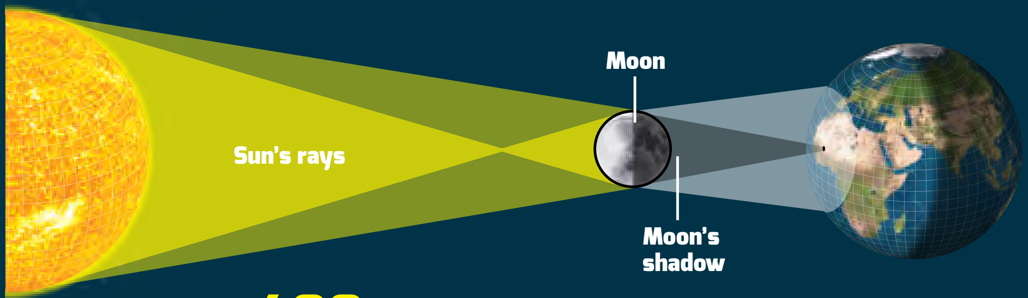


Winter



ECLIPSES

A **solar eclipse** occurs when the Moon passes directly between the Sun and the Earth.



A **lunar eclipse** occurs when the Moon passes directly behind the Earth into its shadow.

The Sun is **400 times** wider than the Moon but, by a cosmic coincidence, the Moon is **400 times** closer to the Earth.
This means the Moon and the Sun appear to be same size in sky – making total eclipses possible.

3 LOOKING AT THE SUN

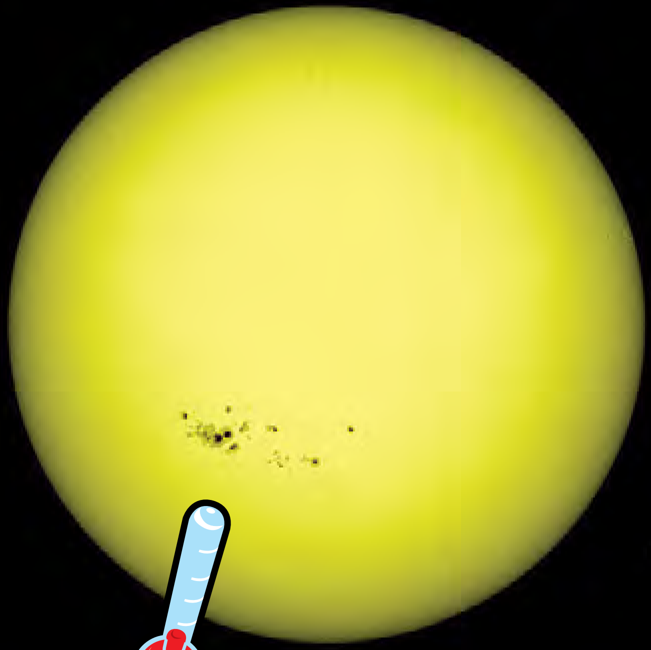
If you take a photo of the Sun with a standard camera, you will be rewarded with the bright, yellow, featureless disk that we are all familar with. Although it appears yellow to us, the Sun actually emits light across the electromagnetic spectrum.

Specialised instruments in ground-based or space-based telescopes can observe the Sun in a wide variety of wavelengths – each of which can reveal information about different parts of the Sun's surface and atmopshere.

THE SUN IN DIFFERENT WAVELENGTHS

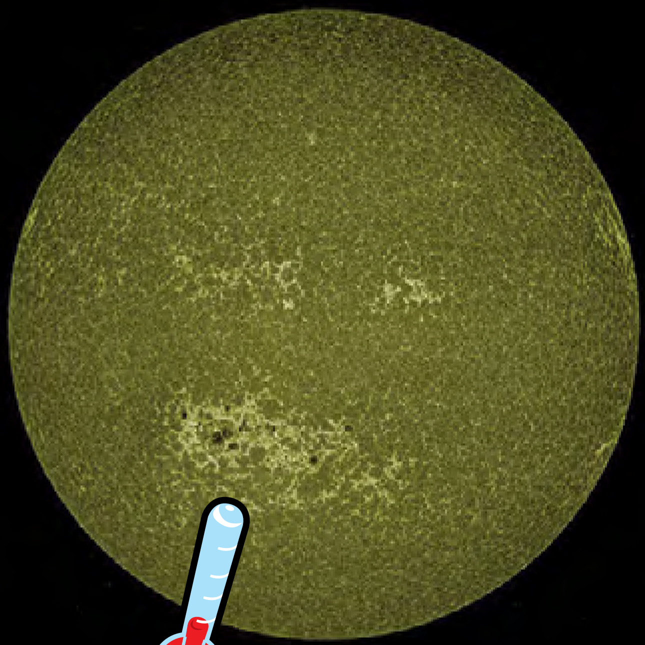
These images, taken by NASA's Solar Dynamics Observatory range from the visible spectrum to the extreme ultraviolet.

Each wavelength shows features of the Sun's surface and atmosphere shining at different temperatures.



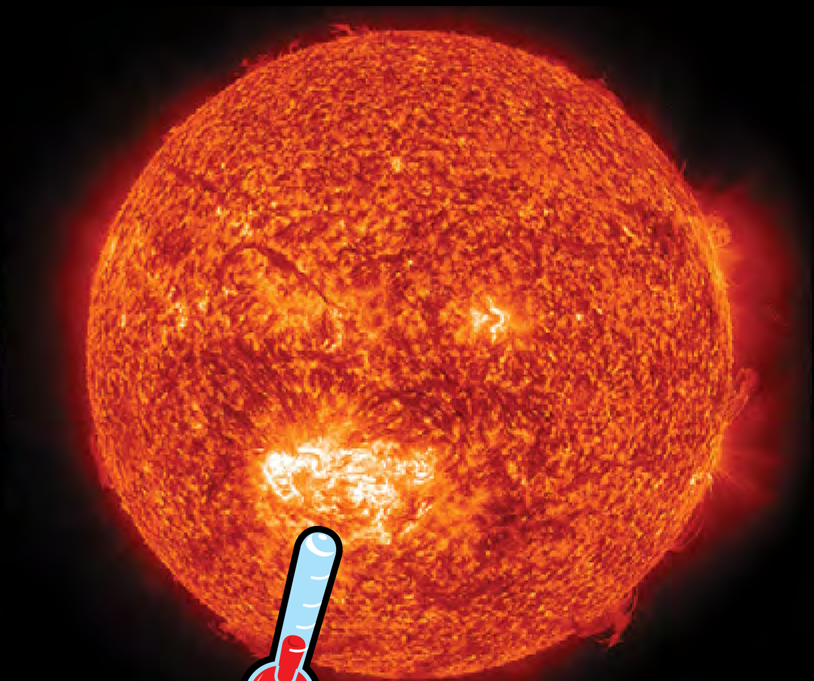
5,700°C

The photosphere (revealing sunspots)



9,700°C

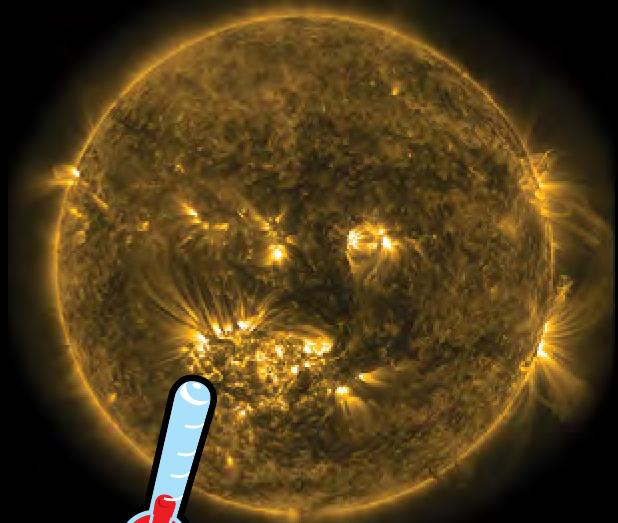
The upper photosphere



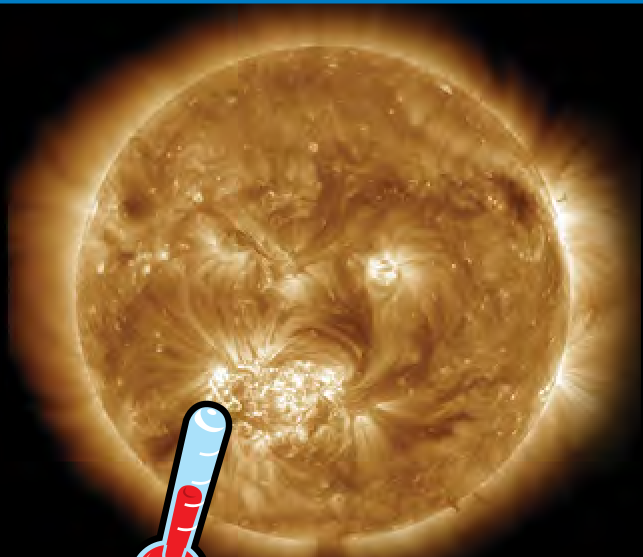
49,700°C

The lower chromosphere

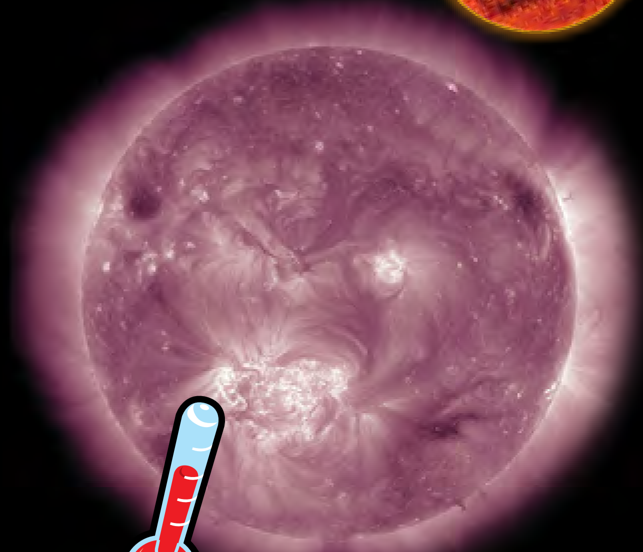
LOOKING AT THE SUN



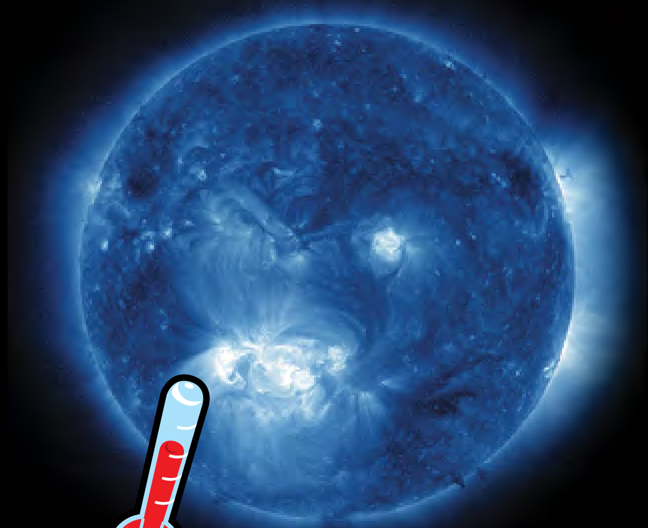
600,000°C
The corona



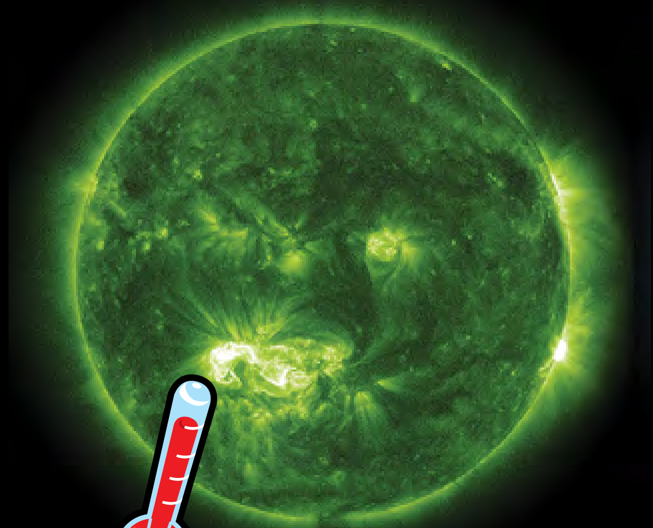
1 million°C
Hotter region of the corona and solar flares



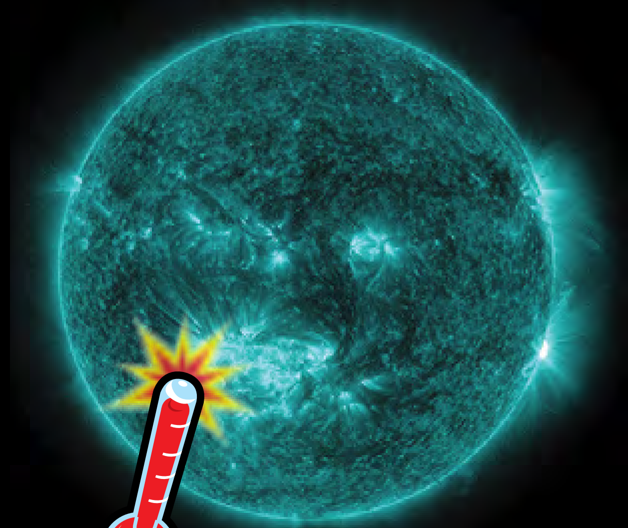
2 million°C
Hotter, magnetically active regions in the corona.



2.5 million°C
Hotter, magnetically active regions in the corona.



6 million°C
Regions of the corona during a solar flare



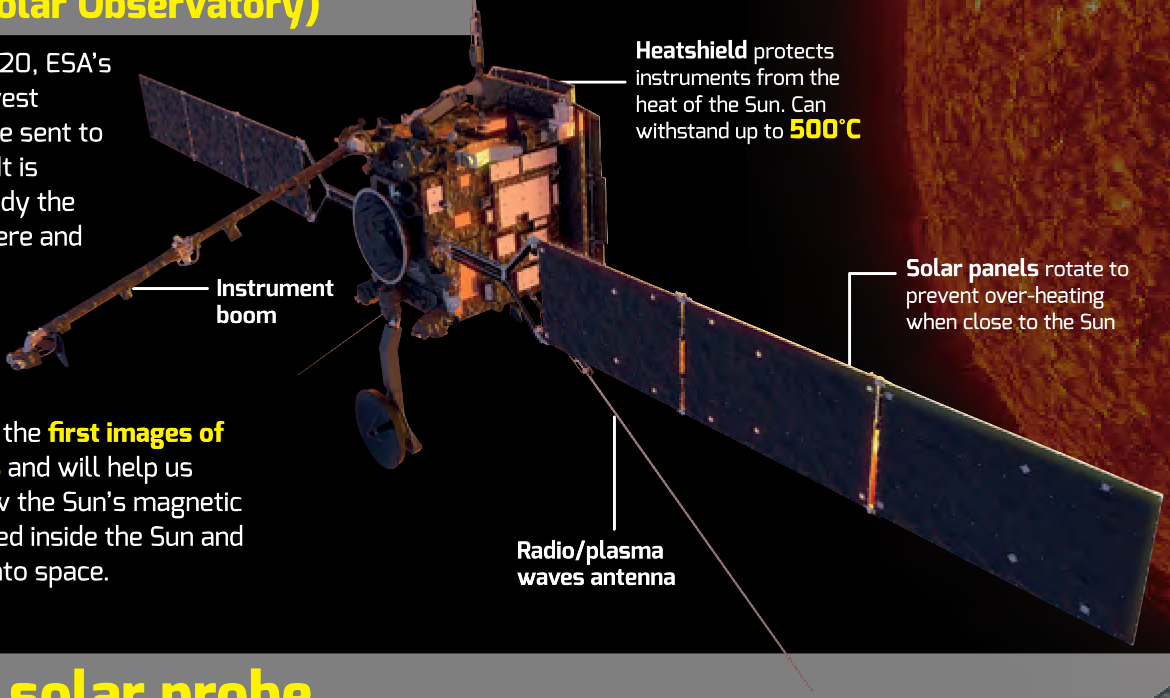
10 million°C
The hottest material in a solar flare

SPACECRAFT STUDYING THE SUN

The Sun is the only star we can study up close. By studying the Sun we live with, we learn more about stars throughout the universe. There is a veritable fleet of solar observation spacecraft currently studying the Sun. Some are brand new while others such as SOHO have been in operation since 1995 (despite its originally mission being designed to last just 2 years)

SolO (Solar Observatory)

Launched in 2020, ESA's SolO is the newest spacecraft to be sent to study the Sun. It is designed to study the Sun's atmosphere and the solar wind.

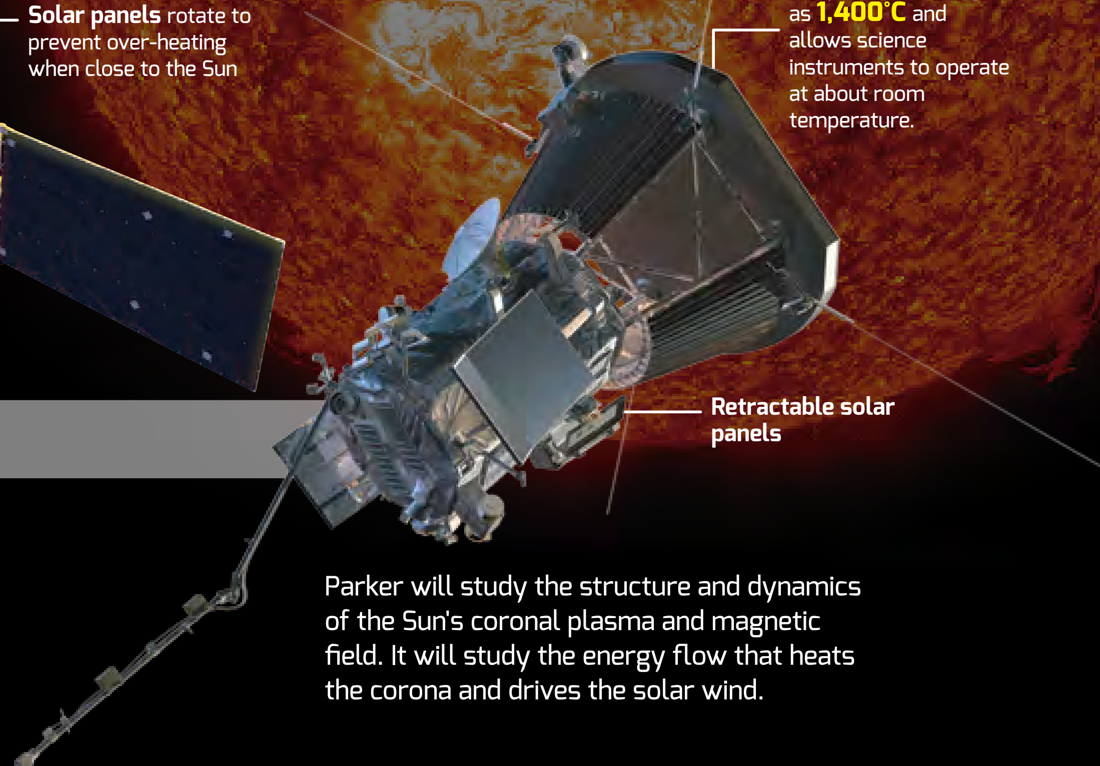


SolO will make the **first images of the Sun's poles** and will help us understand how the Sun's magnetic field is generated inside the Sun and it propagates into space.

Parker solar probe

NASA's Parker Solar Probe launched in 2018 with the mission of making observations of the outer corona of the Sun.

The spacecraft will fly through the Sun's atmosphere as close as **3.8 million miles** to our star's surface, well within the orbit of Mercury and more than seven times closer than any other spacecraft. (Earth's average distance to the Sun is 93 million miles.)



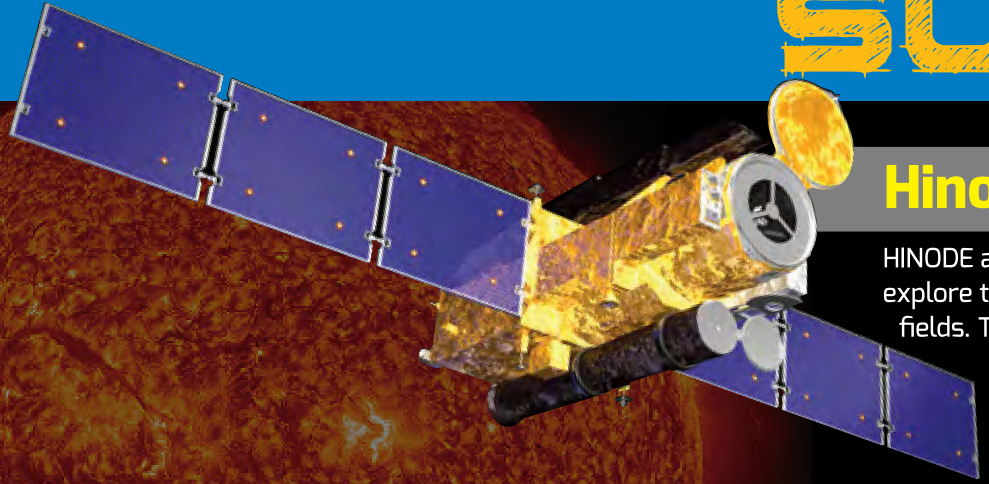
Parker will study the structure and dynamics of the Sun's coronal plasma and magnetic field. It will study the energy flow that heats the corona and drives the solar wind.

LOOKING AT THE SUN

SOHO (SOlar and Heliospheric Observatory)

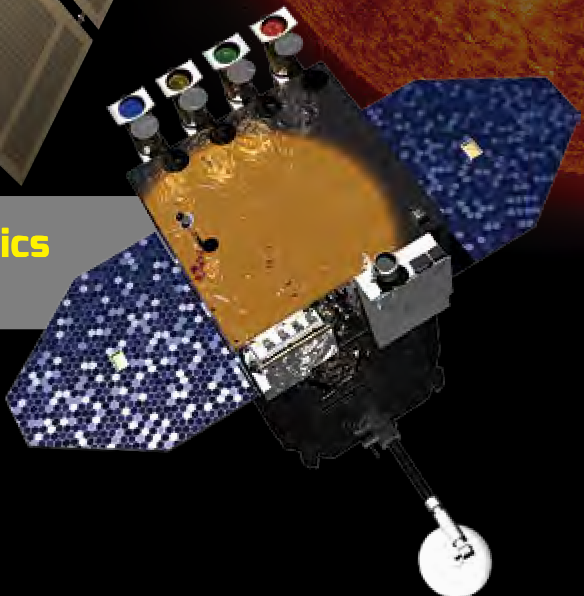
This joint ESA/NASA mission has revolutionised our understanding of solar physics. Launched in 1995, its twelve instruments monitor the Sun's internal structure, its outer atmosphere and the solar wind.

Hinode (Sunrise)



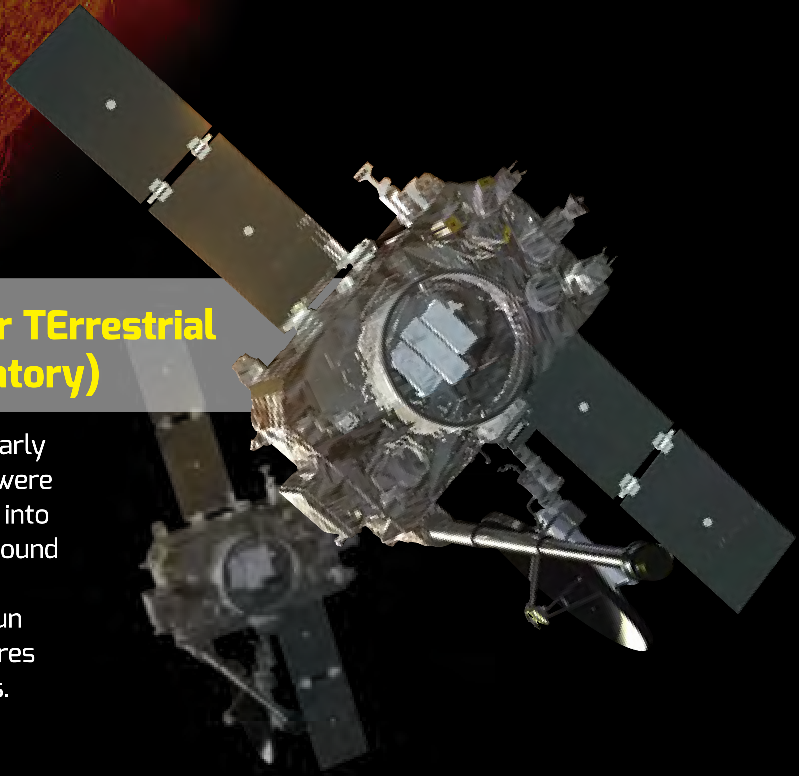
HINODE aunched in 2006 to explore the Sun's magnetic fields. This joint Japanese/US/UK mission uses optical, extreme ultraviolet (EUV), and x-ray instruments to investigate the interaction between the Sun's magnetic field and corona.

SDO (Solar Dynamics Observatory)



NASA's SDO has been observing the Sun since 2010. It is studying how the Sun's magnetic field is generated and how stored magnetic energy is converted and released as solar wind and energetic particles.

STEREO (Solar TErrestrial RElations Observatory)



STEREO consists of two nearly identical spacecraft. They were launched by NASA in 2006 into slowly separating orbits around the Sun. This gives them a stereoscopic view of the Sun and of events like solar flares and coronal mass ejections.

Science and Technology Facilities Council

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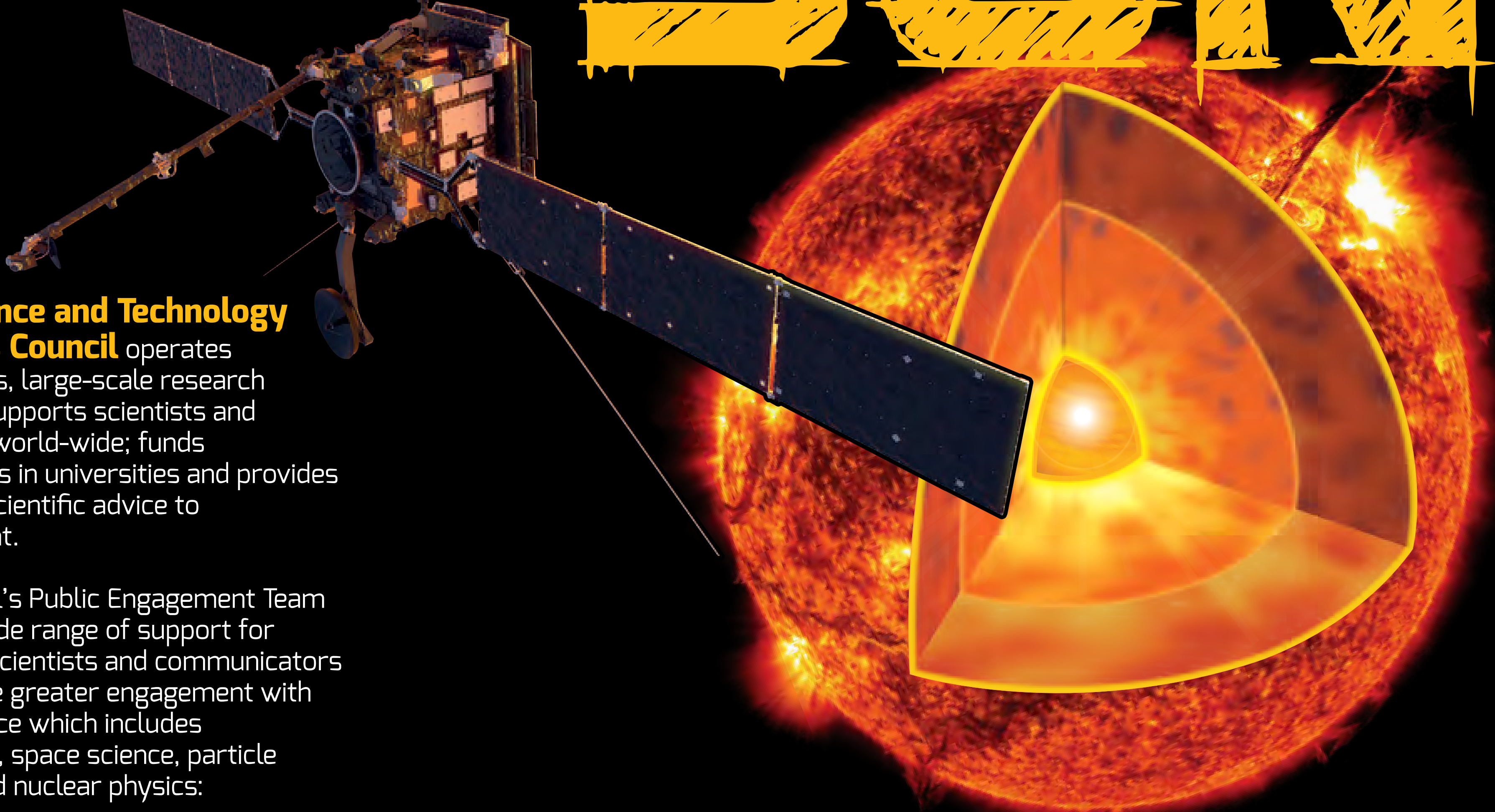

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