OUR SUN IS GETTI HOTT

As our nearest star enters its next solar cycle, physicists have revealed what the future holds – and it's not what they expected

Reported by James Romero

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As a life-giver that warms and lights up our world, it is easy to forget the true, violent nature of the Sun. As the Sun enters a new cycle of surface activity, we are only now beginning to fully appreciate the wide-ranging ways our star's changeable nature can impact our planet and modern lives.

Solar weather describes the influence of the Sun on the Earth-space environment. Back in 2011 it was added to the UK government's National Risk Register and placed on a similar level to the emergence of a new disease due to the number of people it could potentially impact on Earth.

"The Sun is very dynamic," says Helen O'Brien, lead engineer on the European Space Agency's Solar Orbiter mission. "It has different moods, it is very explosive and it has the potential to damage our modern infrastructure." As well as providing heat and light, our star is constantly throwing out more deadly material. The solar wind is the name given to this constant stream of energised, charged particles, primarily electrons and protons.

On Earth we are shielded by our planet's magnetic field while high-energy X-rays and ultraviolet light are absorbed high up in the atmosphere. They electrify their surroundings to create the Earth's ionosphere and simultaneously excite constituents of our own atmosphere so they glow and create the famous aurorae.

While the aurorae are harmlessly enjoyed by polar communities and tourists, the Sun's own

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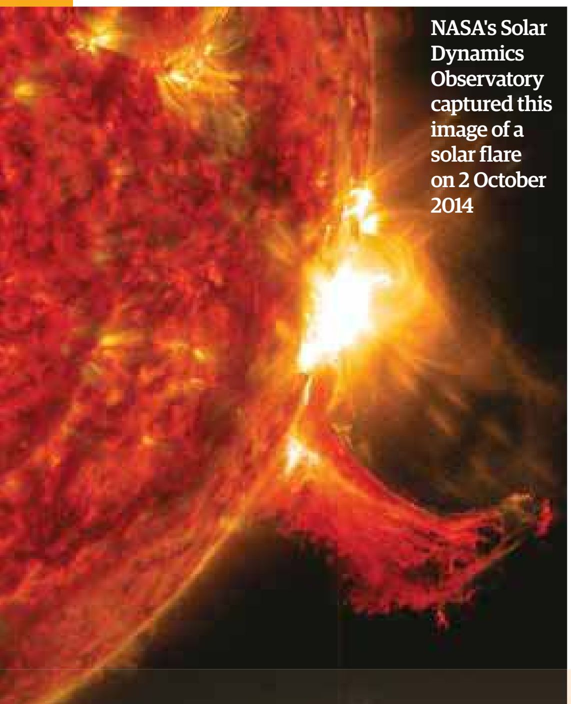
magnetic field can throw far more violent eruptions our way. Its much larger field is composed of a series of magnetic lines that connect distant points on the surface. Over time these lines can become twisted as the Sun's compositional fluidity sees material at its equator rotate faster than at its poles, and the magnetic field gets wrapped around the star. "When you distort a magnetic field it is like stretching an elastic band," says Chris Scott, professor of Space and Atmospheric Physics at the University of Reading. "You are storing up energy."

Those magnetic distortions cause complex knots to form, which burst to the surface as sunspots. When the Sun is very active you have lots of energy stored up in these knots, and occasionally the system will reconfigure itself through solar flares that throw out vast quantities of high-energy plasma like a cloud from the Sun's atmosphere.

These eruptions can be incredibly violent. The largest, known as coronal mass ejections, can contain billions of tonnes of material, which travels out at speeds of several million miles per hour.



NASA's Solar Dynamics Observatory captured this image of a solar flare on 2 October 2014

If Earth is in the crosshair of these large storms the consequences can be both spectacular and costly. This was evident even back in September 1859 on the night of the most famous direct hit, known as the Carrington event, which bathed almost the entire surface of the Earth in beautiful aurorae. Though Carrington was spectacular in its scale and spectacle, it was also the first example of solar weather impacting our technology - recently rolled out telegraph systems in America and Europe were hit by fires and gave people electric shocks.

In today's information age of integrated power networks and satellite communications, a similar strike today could bring down radio communications and upset electronics on the ground, causing long-distance power grids to fail. In 1989 a coronal mass ejection blacked out the entire Canadian province of Quebec, while last year an economic risk assessment by researchers from the University of Oxford found that a Carrington-style event could leave the UK with £15.9 billion (approximately $20.5 billion) worth of damage.

In general, a direct threat to human life on the Earth's surface is low. However, a small proportion of our population are spending more and more time higher up, and that does create risks. Storms increase the radiation impacting spacecraft to levels that could threaten astronaut health, while more transatlantic flights are crossing the poles where solar wind material is constantly funnelled by Earth's magnetic field.

Exposure from a single flight during normal solar conditions will be tiny, but there is concern for flight staff working up there year round. Also, recent research from Clive Dyer of the University of Surrey Space Centre suggests flying in modern aircraft

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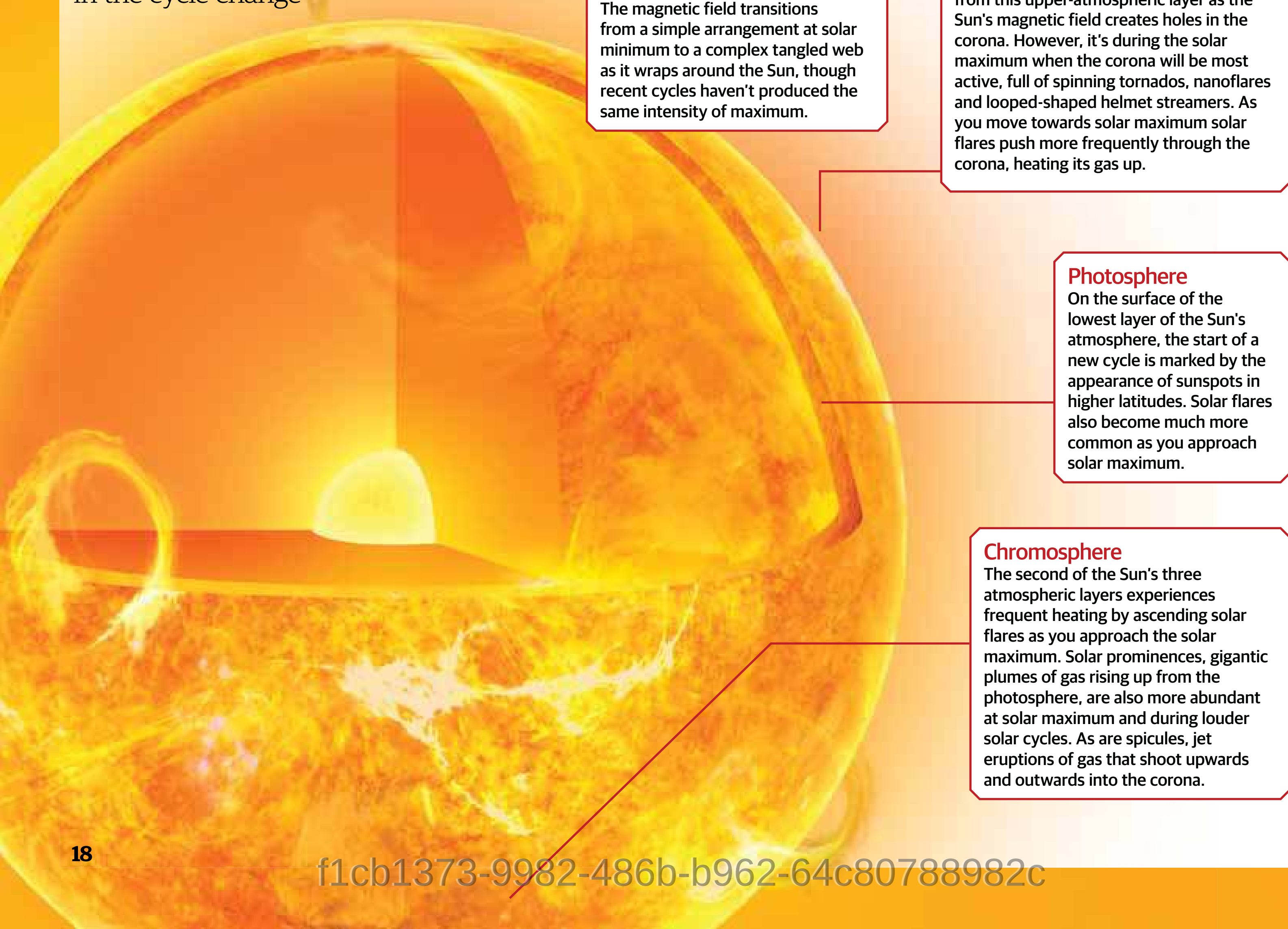
What's going to happen to the Sun?

Each layer of our home star is affected in the cycle change



Sun's effect on the planets

Whether stripping them away or lighting them up, the atmospheres of the Solar System's worlds are continually shaped by the output of our star

Neptune

Aurorae were spotted on Neptune by the Voyager 2 flyby in the 1990s. However, the distinct offset between the planet's magnetic field and its rotational axis means these weak light displays can be found across the surface.

Uranus

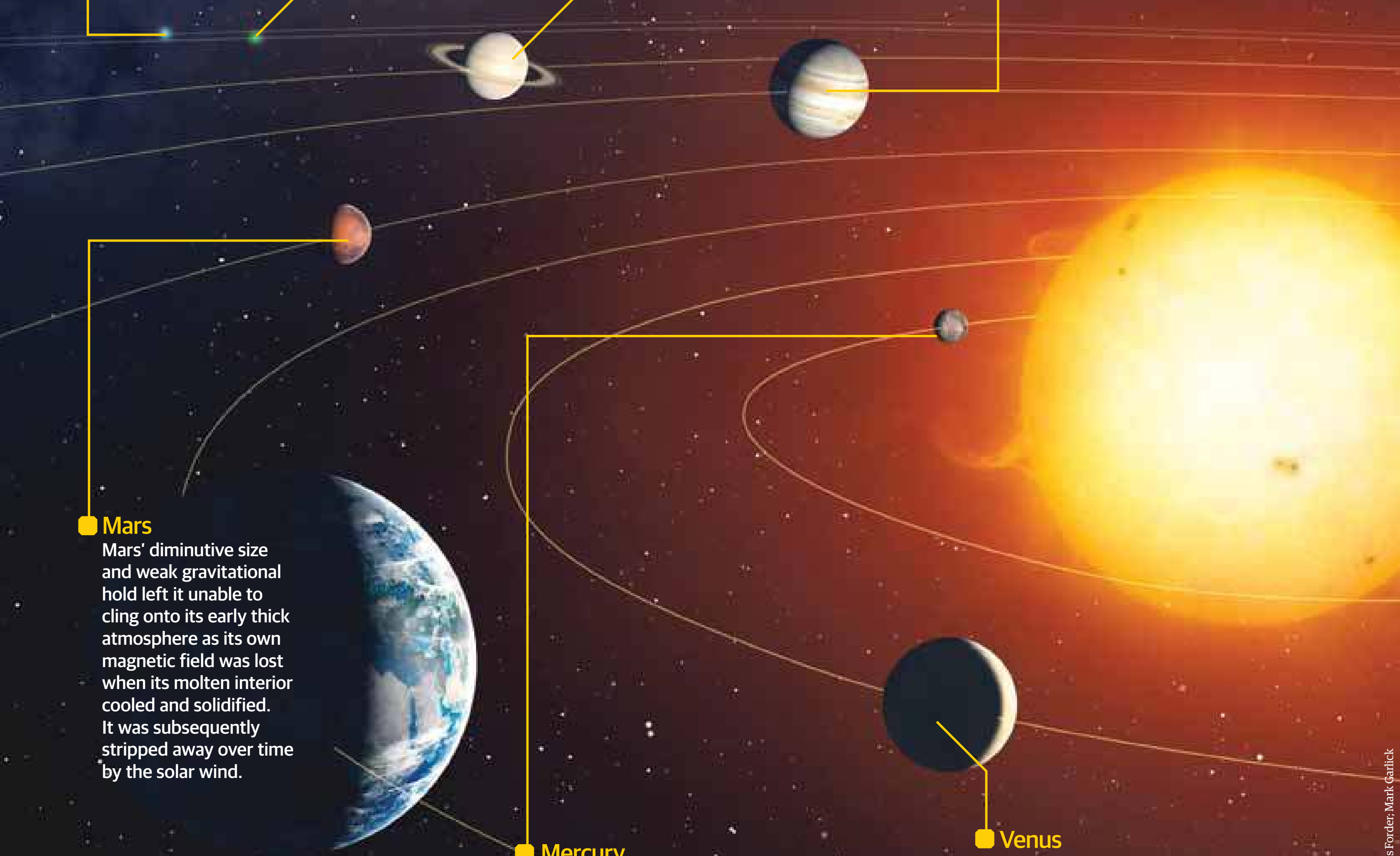
On Uranus the solar wind excites atmospheric hydrogen to create its aurorae, which can be found close to its geographical – though not geomagnetic – equator, as the planet orbits on its side.

Saturn

Above and below its ringed equator, Saturn's poles are regularly lit up by strong aurorae, though as they are in the UV and infrared part of the spectrum they would be invisible to us. However, weaker aurorae of pinky-purple visible light have been observed.

Jupiter

Recent data from NASA's Juno spacecraft suggests Jupiter's powerful blue aurorae are not entirely powered by the same solar wind mechanism behind aurorae on the other planets. Can the largest planet in our Solar System generate its own?



Mars

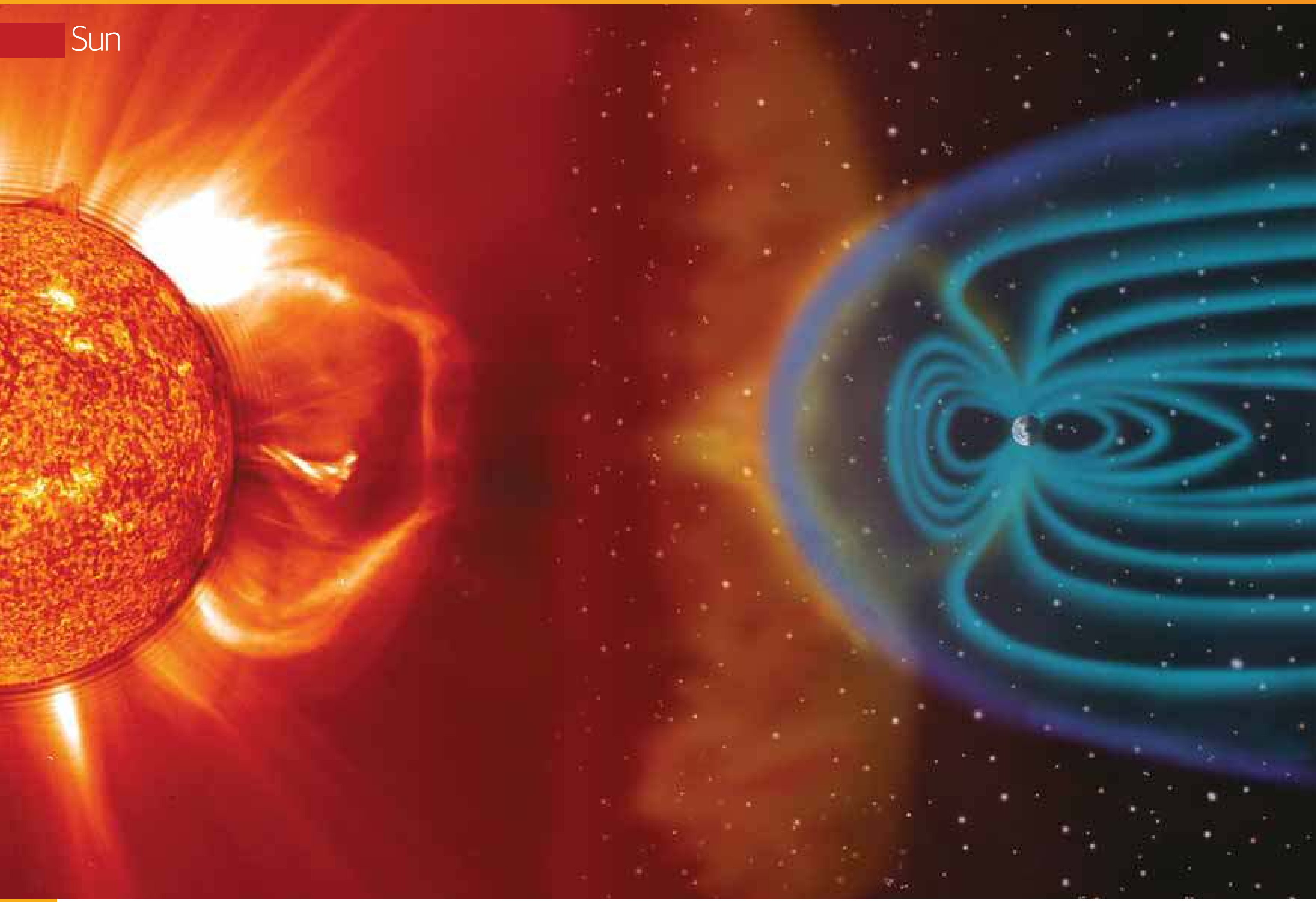
Mars' diminutive size and weak gravitational hold left it unable to cling onto its early thick atmosphere as its own magnetic field was lost when its molten interior cooled and solidified. It was subsequently stripped away over time by the solar wind.

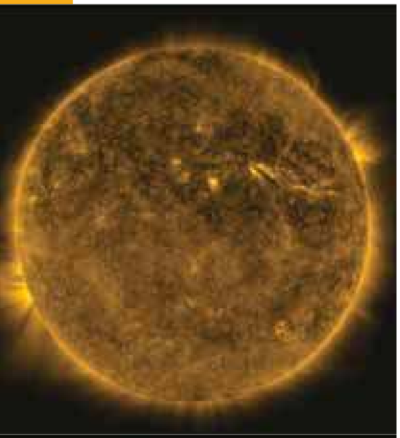
Mercury

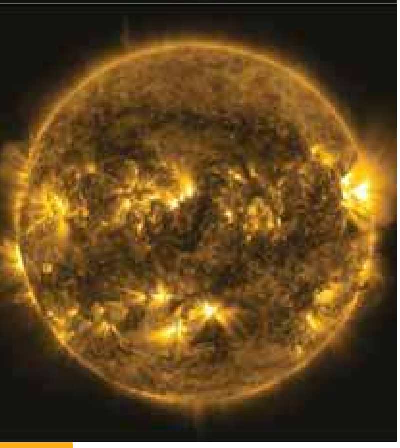
Mercury's close proximity to the Sun and lack of atmosphere leaves its relativity weak magnetic field swamped by solar eruptions and its surface bathed in the radiation of the solar wind.

Venus

Without its own magnetic field lighter gases from Venus' thick atmosphere, including water vapour, are continuously blown away by the solar wind, creating an ionosphere that resembles a comet's tail emanating from its night side.







during a solar storm could expose passengers to radiation levels equivalent to the annual working limit for air crews. This threat has left satellite companies, aircraft operators and power companies monitoring the solar cycle for clues as to when the threat level will be at its highest.

By counting sunspots on the Sun's surface scientists have for some time known of 11-year cycles of increasing and decreasing solar activity and surface eruptions, driven by the tangling and untangling of the magnetic field lines. These plots indicate we are approaching the latest solar minimum, and therefore entering a new cycle.

Recent magnetic field evolution models developed by the Center of Excellence in Space Sciences in India concluded that the solar maximum of the next cycle, solar cycle 25, will occur around 2024. They also suggested the cycle could buck a wider trend of decreasing solar maximum intensities since the early 1990s, though perhaps not in a way that would greatly threaten ground- or space-based infrastructure.

"It is unlikely that this will affect big solar storms, as these can happen at any stage of the solar cycle," says Scott. However, anticipating the timing and severity of the coming solar cycle could help us prepare for the more local effects such solar variability that effect our lives and which have only come to light in the last decade or two.

Researcher Pablo Mauas has published a series of papers analysing river flows of the Paraná River, as well as measuring snow accumulation and counting tree rings to establish a remarkable agreement between local precipitation rates and the number of sunspots, tracked back over many decades. "I can quite believe there is an 11-year cycle in the flow rates of the river," says Scott, who points to evidence of similar solar-influenced systems closer to home.

During recent low periods of solar activity it seems the jet streams become more meandering, and you get more 'blocking events' where air-pressure systems get stuck over a certain location. These phenomena are thought to account for some of the very cold recent winters in northwest Europe, but perhaps this trend may reverse slightly if the next solar cycle is more active, as the Indian research team suggests.

In his own research Scott has shown that fast jets of solar wind passing the Earth, associated with more active solar periods, can result in a substantial increase in lightning strikes across Europe for up to 40 days as a result of disturbances to the electrical properties of the atmosphere. While communities and populations may need to adapt to changes in these localised weather systems, a better way of predicting larger scale solar weather on a more detailed day-to-day basis is an urgent priority.

This becomes more pressing if Carrington events prove to be more common than that 'once-in-a-century' tag. Reanalysis of magnetic behaviour measurements in the Earth's atmosphere by Scott's colleague Mike Lockwood has found storms in

Solar surveyors

In order to better understand and anticipate solar weather, space agencies have sent up a family of orbiters and satellites

Parker Solar Probe

The mission to 'touch' the Sun, this probe is the first man-made object to get within 6 million kilometres (4 million miles) of the Sun's surface. At that distance it measures the pristine solar wind up close before the 'outburst' gets jumbled up in the journey towards Earth.

RESULTS: Pending

Solar Orbiter

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Wind

A NASA science spacecraft launched in 1994 to study radio waves and plasma that occur in the solar wind and in the Earth's magnetosphere.

RESULTS: Researchers have found evidence for a type of plasma wave moving faster than theory predicted within the solar wind using Wind data. The research suggests that a different process than expected may be driving the waves.

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RESULTS: In 2013, IBEX results revealed the Sun's heliosphere has a tail.

IRIS

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Hinode

A Japan Aerospace Exploration Agency-led satellite whose Sun-synchronous orbit over the day/night terminator allows near-continuous observation to explore the magnetic fields of the Sun.

RESULTS: In 2018 astronomers using the Hinode spacecraft observed the strongest magnetic field ever directly measured on the surface of the Sun.

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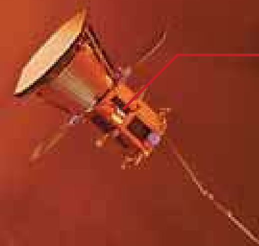

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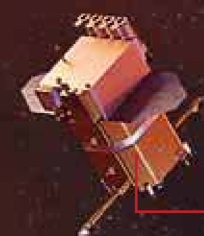

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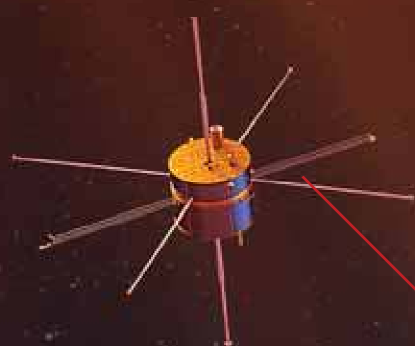

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STEREO

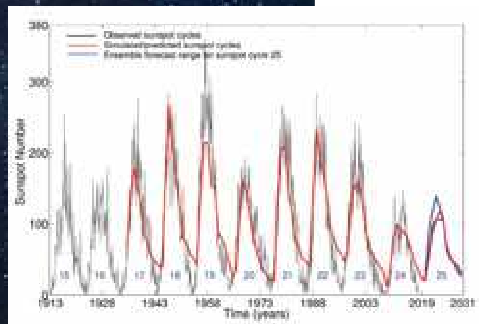
Two near-identical spacecraft launched in 2006 into orbits around the Sun ahead of and behind the orbit of the Earth. This enables stereoscopic imaging to provide in-depth information when observing solar phenomena, such as coronal mass ejections.
RESULTS: One of the STEREO craft – STEREO A – was in the path of the solar storm of 2012 which was similar in strength to the Carrington Event. Its instrumentation was able to collect and relay a significant amount of data about the event.

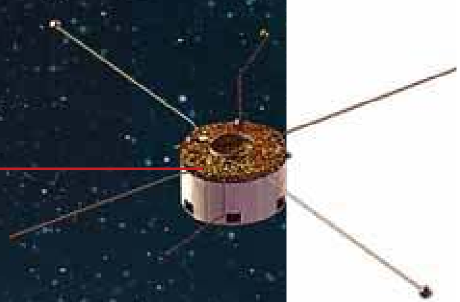
SOHO

One of the original craft still in operation, SOHO was launched in 1995 and combines imagers and spectrometry instruments to probe the layered structure of the Sun with in-situ measurements of the solar wind as it goes past.
RESULTS: SOHO has also discovered over 3,400 comets as they orbit around the Sun, as well as providing the main source of near-real-time solar data for space weather prediction.

Solar Dynamics Observatory

Launched in 2010 to investigate how the Sun's magnetic field is generated and structured and how this stored magnetic energy is converted and released into the heliosphere in the form of solar wind, energetic particles and variations in the solar irradiance.
RESULTS: Has identified possible precursors to space weather in the behaviour of plasma within the regions encircling sunspots.





Cluster II

Launched in 2000, the Cluster II mission is an in-situ investigation of the interaction between the solar wind and the magnetosphere by using four satellites.
RESULTS: Has developed the first models of the Earth's magnetic field and its interaction with the solar wind based on actual measurements rather than theory.

DSCOVR

Originally proposed by then-Vice President Al Gore, DSCOVR monitors variable solar wind conditions and their impact on the Earth, including changes in ozone, aerosols, dust and volcanic ash, cloud height, vegetation cover and climate.
RESULTS: Took the second picture of the entire Earth, following on from the final Apollo mission's famous Blue Marble picture.

Above: Researchers have modelled the number of sunspots between 1913 and 2031

Below: The coronal mass ejection, viewed in four extreme ultraviolet wavelengths, in 2012 that sent a massive solar storm that just missed Earth

vulnerable parts of their grids, safe modes for their satellites, back-up routes for transatlantic airlines and safe houses for orbiting astronauts. However, today's rudimentary early warning systems make preparedness a significant economic risk.

"A lot of satellite operators choose not to worry about space weather forecasts because they do not have sufficient accuracy to make it worth their while," says Scott, who calls for a new observation-focused mission to put a spacecraft out far enough to see the Sun and the Earth in the same field of view. It would be stationed near enough to us to provide continuous real-time observations.

Further notice could be provided by looking for signature surface behaviour that proceeds major eruptions. This is where two of the latest additions to the Sun's community of human-made companions could prove useful. O'Brien's ESA-funded Solar Orbiter mission is due to launch in 2020. It combines solar wind particle and magnetic field measurements with direct surface observation, all from inside the orbit of Mercury.

Key to the Solar Orbiter's ability to spot impending eruptions will be its highly elliptical orbit, which will allow it to spend 10 to 15 days co-rotating with the Sun, providing uninterrupted coverage of sunspot, flare and storm development.

While the Solar Orbiter will take direct solar observation closer than ever before, NASA's Parker Solar Probe is pushing the boundary yet further. On its journey to 'touch' the Sun the probe will eventually fly as close as 6.1 million kilometres (3.8 million miles), meaning it will pass through the Sun's outer atmosphere.

At that distance it hopes to measure the pristine solar wind – what it looks like when it leaves the Sun before it gets jumbled up in the 150-million-kilometre (93-million-mile) journey to Earth. "We will be able to couple together unprecedented details on what is happening on the dynamic, bubbling, boiling surface of the Sun with what is going in interstellar space," says O'Brien, who believes these new data sets and monitoring stations provide hope for our ability to give fair warning of future eruptions during the next solar cycle.