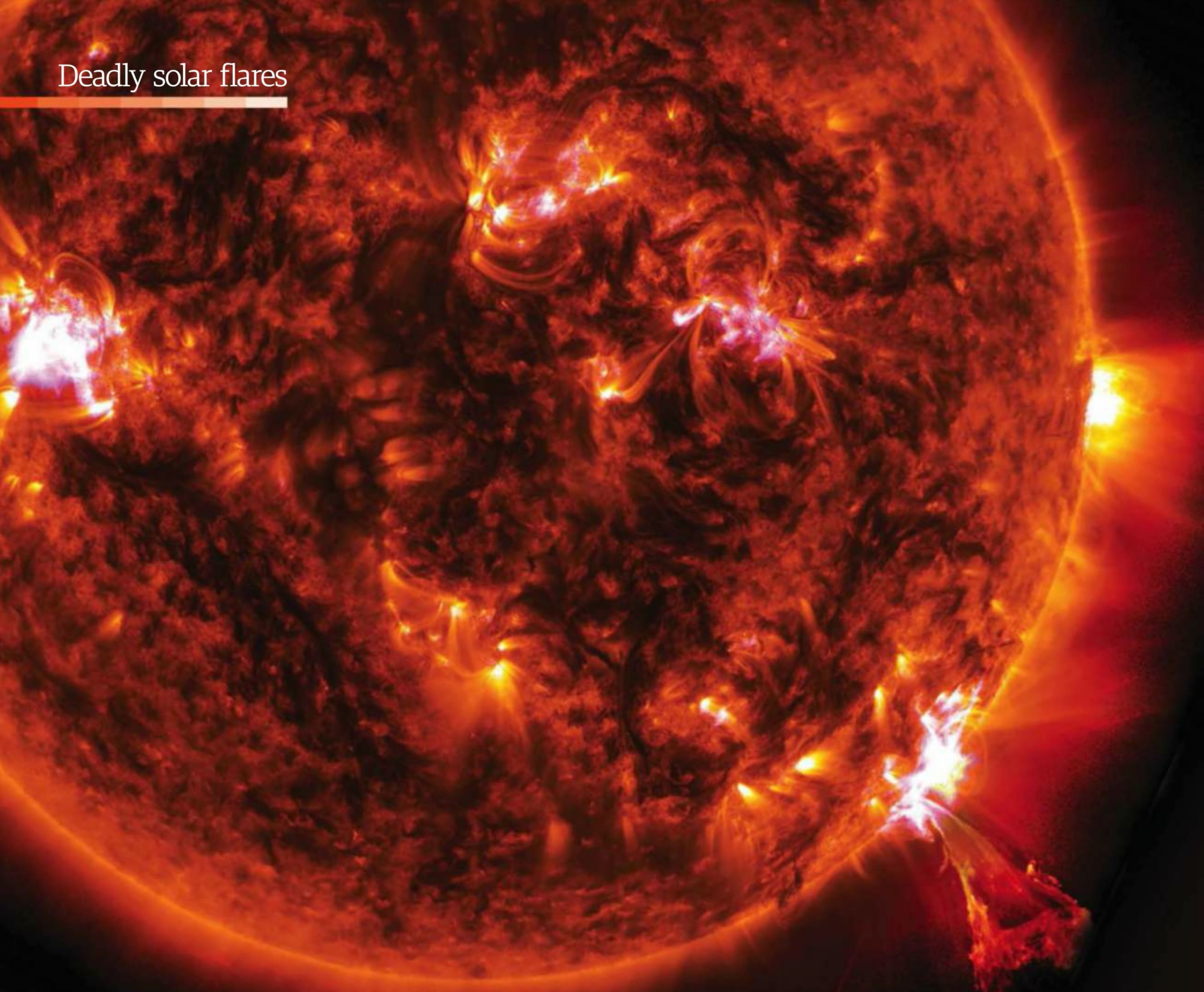
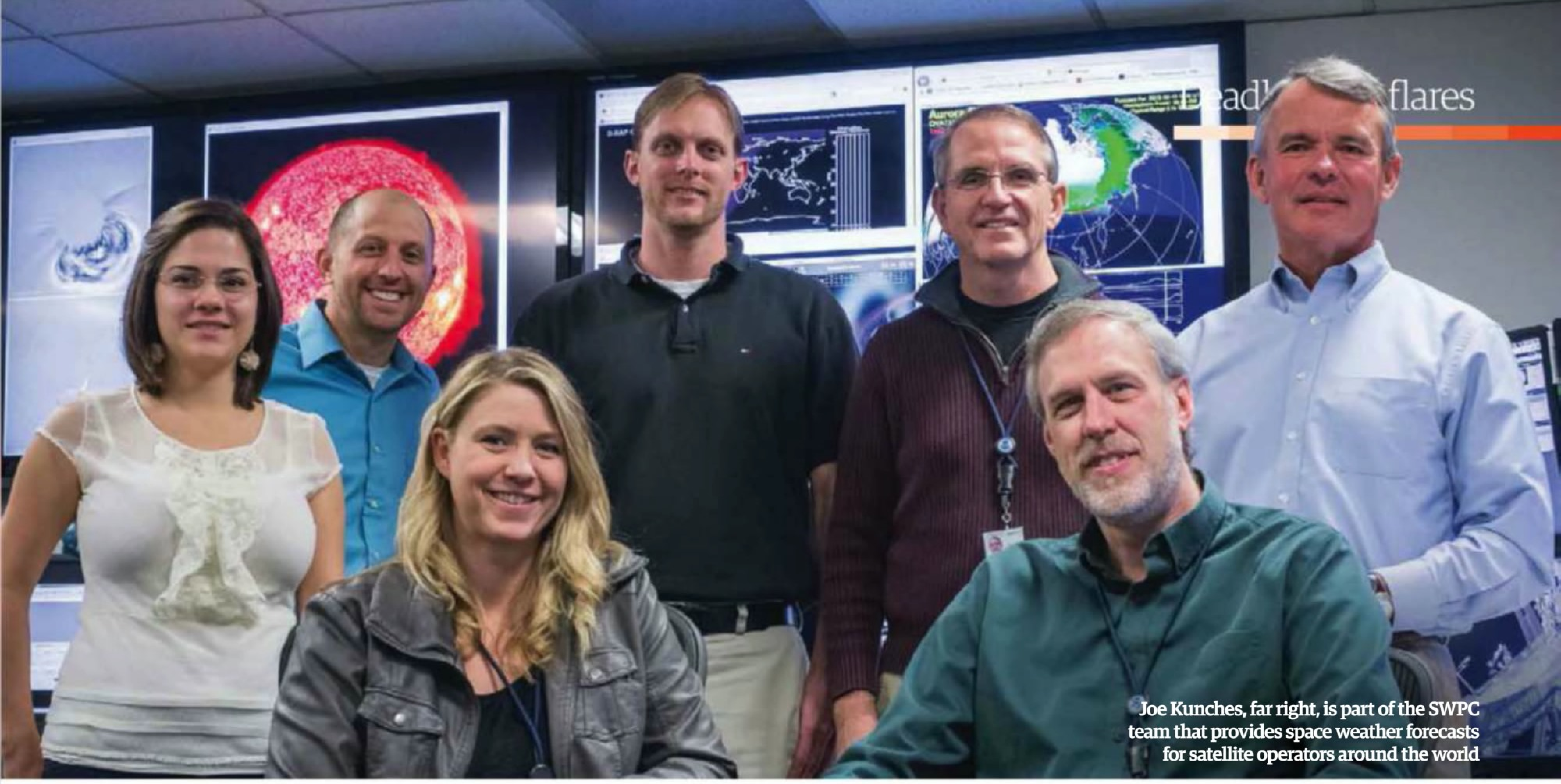


DEADLY SOLAR FLARES

What would become of the Earth if a large solar storm was directed our way, and would we be able to survive such an event? We take a look at how the Sun's activity has threatened life on Earth before, and how it might again

Written by Jonathan O'Callaghan



Joe Kunches, far right, is part of the SWPC team that provides space weather forecasts for satellite operators around the world

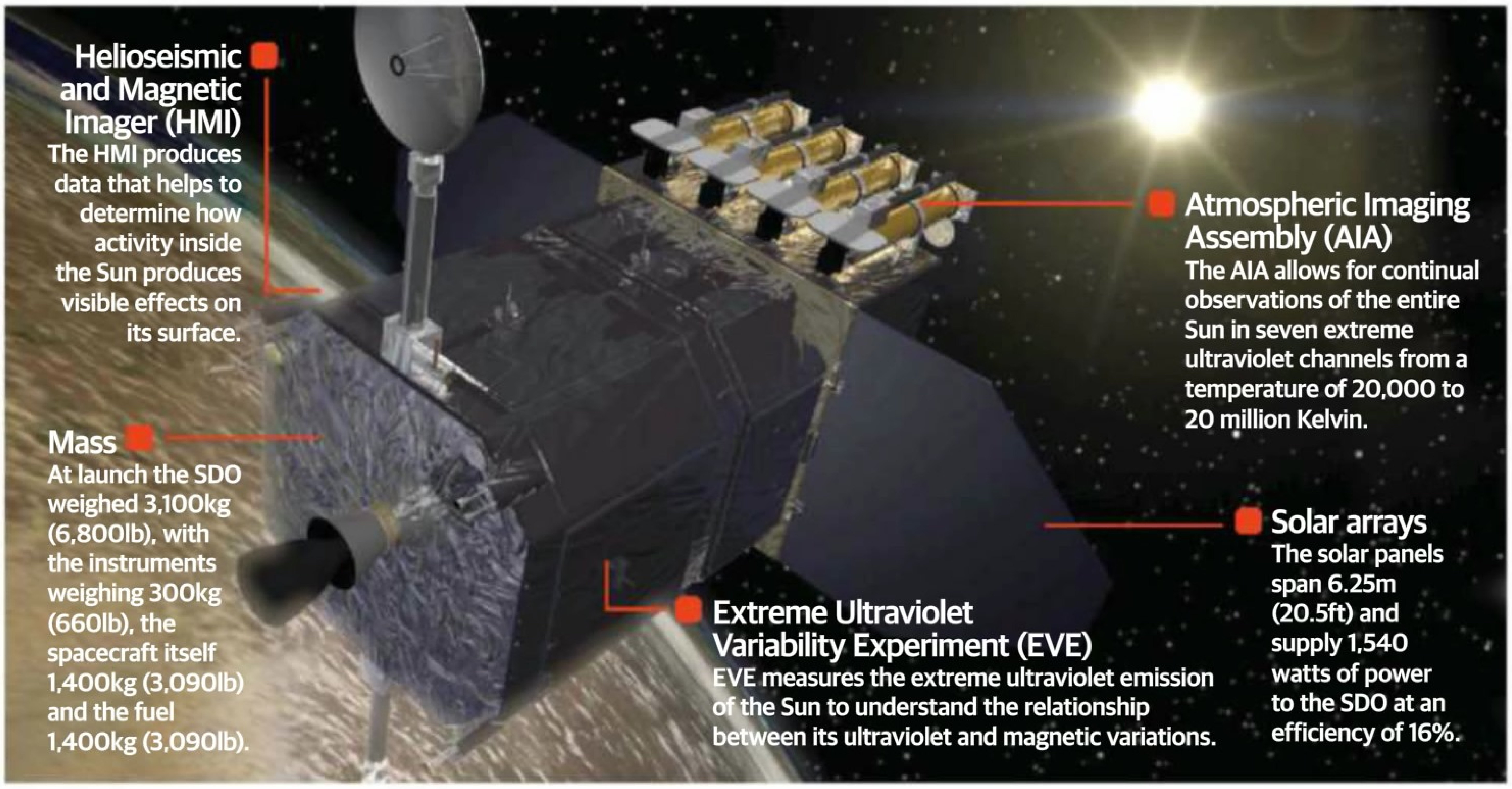
The Earth is under constant threat from a whole host of things in space, from asteroids to comets. However, the one thing that is essential to life on our planet, the Sun, may also be the most dangerous threat of all to life as we know it. "[A large solar flare] would certainly have a widespread ubiquitous footprint all the way around the world," said Joe Kunches from the National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC), which provides solar weather forecasts to satellite operators and agencies across the globe. "The question is, how deep would the effects be, and how long would it take to recover from that?"

The Sun is a volatile and dangerous ball of gas that, while it is the heart of our Solar System, also has the potential to wreak havoc on not only our world but the other planets and moons as well. It is a constantly churning furnace of energy that releases radiation into its surroundings. As our closest star it is the perfect laboratory to observe how such stars behave, and indeed we have been studying the Sun for centuries to try to further our understanding of it.

"We rely on infrastructure that is known to have sensitivities to space weather"

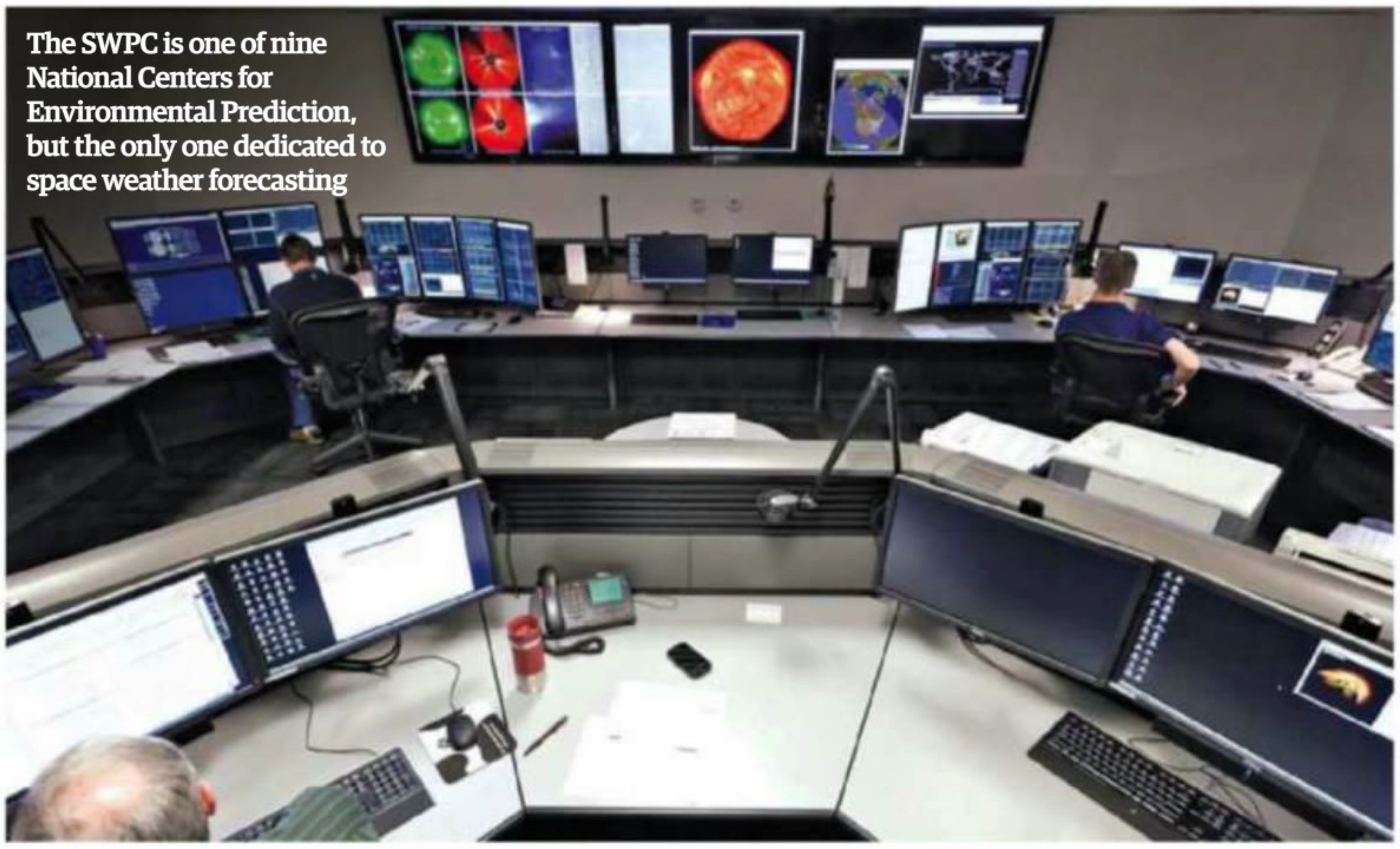
While the Sun is constantly emitting energy and radiation, it goes through a period of cycles that tend to govern how active it is at any given time. The solar magnetic activity cycle has a period of 11 years, and at its peak it significantly increases detectable changes and emissions from the Sun including sunspots and solar flares. It is at these times, during a solar maximum, that the Earth's infrastructure is under greatest threat. In the last few decades organisations like the SWPC have used a multitude of observatories both in space and on Earth to monitor these cycles and to predict when a large solar event could endanger our planet.

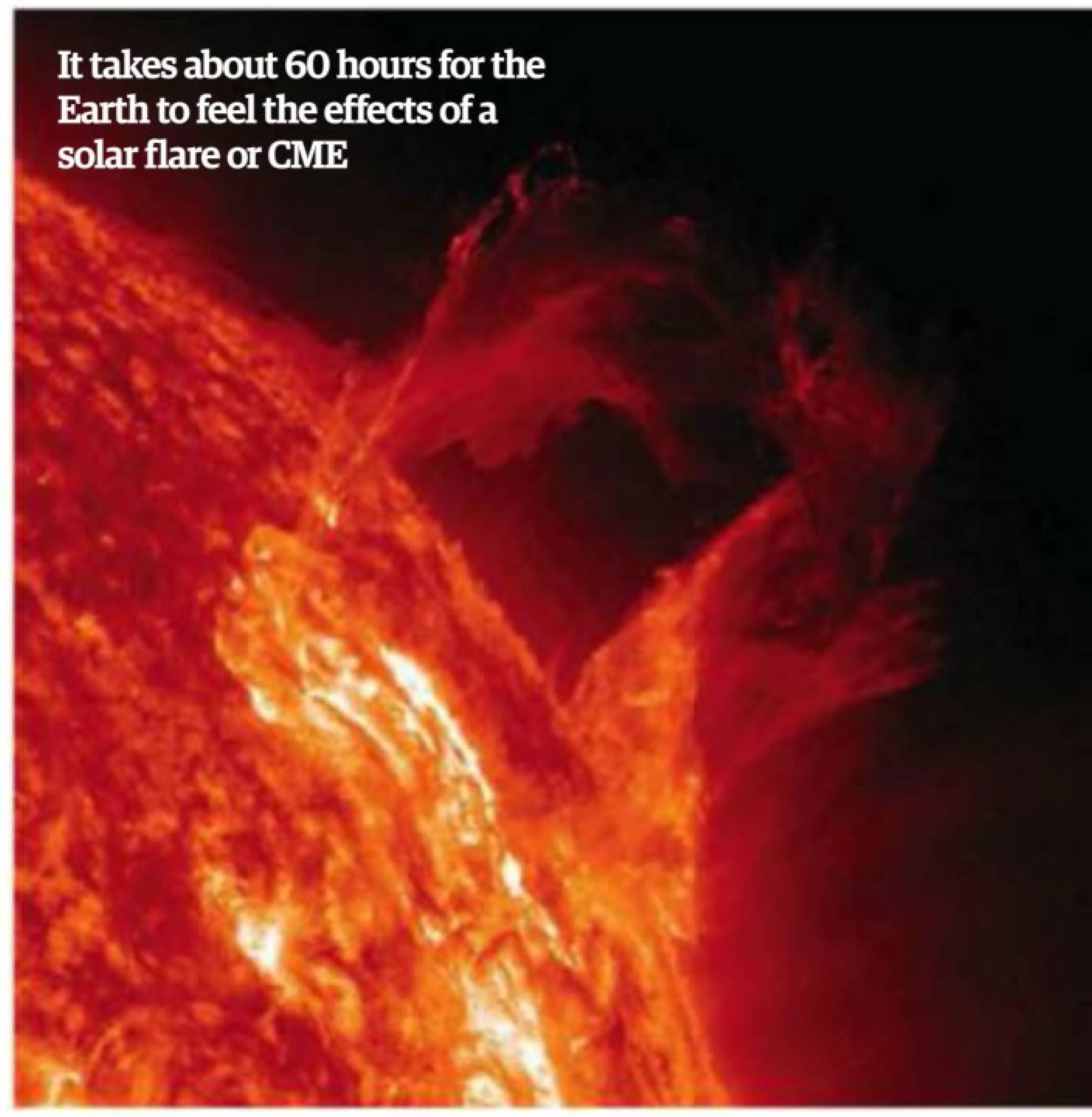
"There have been plenty of cases of serious damage to satellites," said Kunches. "It happens mostly when the Sun is active and very eruptive at the peak of the solar cycle, and right now we're at the peak of the current solar cycle, although this one has been pretty uneventful." However, based on previous experiences, Kunches knows that the SWPC cannot take anything for granted. "During the last solar maximum era, around Halloween in 2003, there was a two-week episode of very turbulent space weather conditions," he said. "There were documented cases of satellite failures, and some total failures."



Inside SDO

There are a multitude of telescopes and observatories constantly observing the Sun, but NASA's Solar Dynamics Observatory (SDO) is currently able to get some of the highest-resolution images of our Solar System's central star from its orbit around the Earth. Launched on 11 February 2010, the SDO's main goal is to understand the influence of the Sun on Earth and surrounding space by measuring in several wavelengths simultaneously.


The SWPC is one of nine National Centers for Environmental Prediction, but the only one dedicated to space weather forecasting


It takes about 60 hours for the Earth to feel the effects of a solar flare or CME

A solar flare is a sudden increase in brightness on the surface of the Sun. It occurs when built-up magnetic energy in the solar atmosphere is released, resulting in a huge emission of energy equivalent to millions of 100-megaton nuclear bombs exploding simultaneously. This energy is usually the result of closely occurring loops of magnetic force extending out from the Sun's surface and, if they 'snap', a burst of solar wind combined with magnetic fields known as coronal mass ejections (CME) will be emitted. A solar flare itself is an ejection of clouds of electrons, ions and atoms, with a CME usually following the flare. Solar flares and CMEs both usually result from the collapse of magnetic field loops, but the relationship between the two is not fully understood. The breaking of a magnetic field loop is usually indicated by the appearance of sunspots, visibly dark areas on the Sun occurring in pairs. The reason for 11-year solar cycles, when these emission events increase, is still under debate.

The study and detection of these solar phenomena has been carried out for decades by various observatories and telescopes. These include the space-based Solar Dynamics Observatory (SDO) and the Solar and Heliospheric Observatory (SOHO), the former run by NASA and the latter run jointly by ESA and NASA. "In the satellite world there are at least ten spacecraft that provide real-time information to the SWPC," said Kunches. "Then in addition to that there are ground-based observatories, and also ground-based sensors like magnetometers. If you put a round number on it there would be about 50 to 100 sensors contributing to the real-time information stream that we tap into here."

The work of the SWPC, and other similar organisations, is hugely important in protecting ourselves from the Sun. Although predicting the occurrence of world-changing solar events is important, it is largely everyday satellite operators that rely most on the solar weather prediction organisations in ensuring that their spacecraft remain operational and continue to provide the service they are intended to. They use regular bulletins from places like the SWPC to know when to prepare for

What happens when a solar flare hits Earth?

Observers
A variety of observational spacecraft including the SDO, STEREO and SOHO are used to predict when the Sun will erupt and how powerful the eruption will be.

International Space Station
Radiation risks for astronauts on the ISS are minimal, but for future astronauts travelling to deep space locations like Mars they could be more severe.

GPS failure
Increased solar activity can prevent GPS navigation satellites operating functionally and, as most are in a similar orbit, one is not able to provide backup for another.

Spacecraft electronics
Hard X-rays from an incoming solar flare can damage the internal electronics of spacecraft and prevent instruments from working.

Atmosphere
Soft X-rays from X-class flares can increase the ionisation of the atmosphere so that, while it might produce fantastic auroras, it also interferes with radio communication.

Power grid
Increased solar activity can cause geomagnetic storms, which have been known to knock out power grids to entire cities in the past.

Orbital decay
Increased ionisation of the atmosphere caused by solar storms can increase the drag on satellites, decaying their orbit, as was the case with NASA's Skylab space station in 1979.

Aircraft
In the event of increased solar activity aircraft must avoid flying near the poles and at high latitudes to ensure that communications aren't affected.

Pipelines
Telluric currents, those found in long pipelines, can be affected by solar flares when systems designed to protect pipelines from corrosion are overloaded.

Telephone mast
Even cell phones are not adverse to the effects of solar flares, as the increased activity can prevent devices communicating with telephone masts.

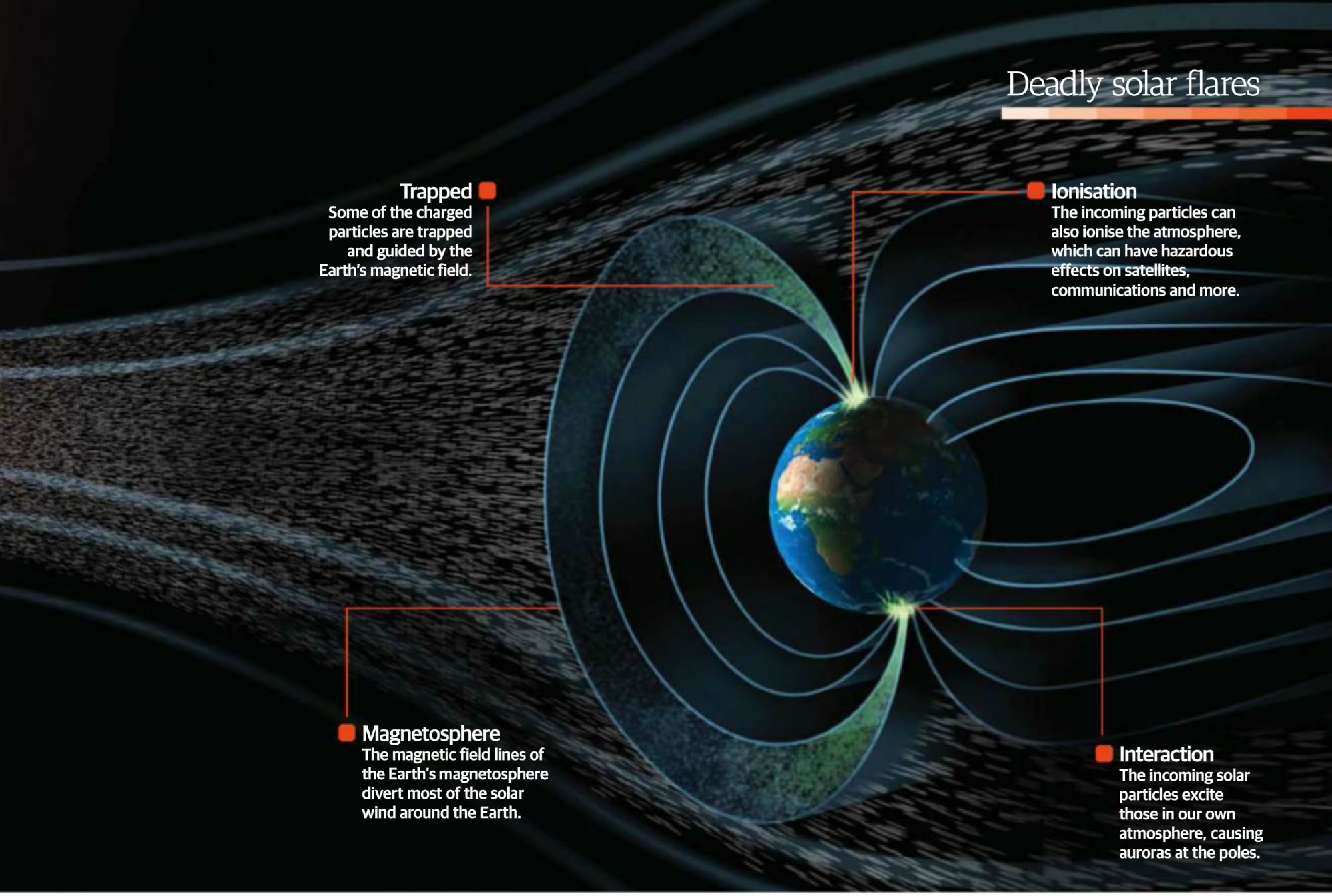
How a solar flare interacts with Earth


Project Manager Lt. Jeff Shoup at work in the Space Weather Prediction Center

a solar event. However, contrary to popular belief, satellites are not shut down if a solar storm is incoming because the danger of a satellite failing if it is turned off and on is fairly high. Some instruments can be turned off and ground teams can prepare for the worst but, as Kunches put it, "you can't run and you can't hide."

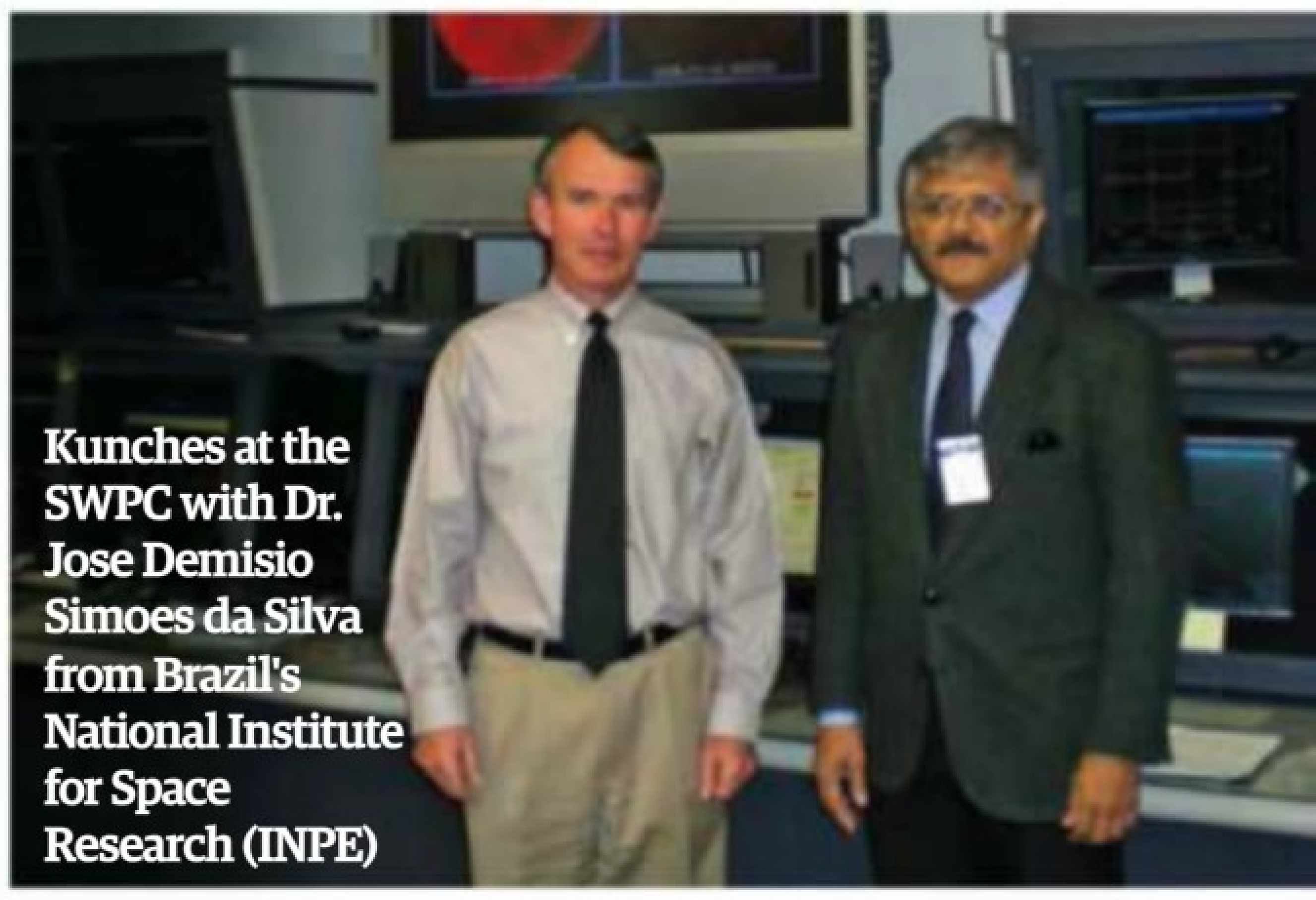
The SWPC is able to produce accurate forecasts for up to the next 27 days detailing what sort of activity the Sun is expected to go through. If a solar flare or CME is seen by one of the many active telescopes, it takes about 60 hours for the Earth to feel the effects of such an event. However, as Kunches explained, just detecting the event is not enough. The SWPC must track the emission as it makes its way towards Earth to discern when it will arrive and how powerful it will be, with the latter known as the magnitude. "Ten years ago we could get the timing down to plus or minus 12 hours," said Kunches. "Now we've cut that in half, but it's not easy being accurate. It's 150 million kilometres (93 million miles) from the Sun to the Earth and a lot can happen in-between."

While working out the timing of an incoming solar flare is becoming more accurate, it is the size of such an event that proves the most troublesome. "The hardest thing for us to predict is the magnitude," said Kunches. "There's a key element that plays into the magnitude, how disturbed the Earth's magnetic field is going to get, and that's the strength of the embedded magnetic field that's contained within the CME. Think of a hurricane; if the weather forecasters knew the direction of it, and they had some sense of how fast it was moving, but they had no idea of the



"Right now we're at the peak of the current solar cycle, although this one has been pretty uneventful"

Joe Kunches, Space Weather Prediction Center


Kunches at the SWPC with Dr. Jose Demisio Simoes da Silva from Brazil's National Institute for Space Research (INPE)

strength of the eye of the storm, it'd be very difficult to know how much of an impact it was going to have as it made landfall, and that's kind of analogous to what we have in space weather forecasting."

Solar flares are classified in magnitude according to the number of watts per square metre they carry, and their frequency. A-class flares are the most frequent and the least powerful, increasing in power through B, C, M and finally X. The latter are the ones that are the most dangerous to Earth. The magnitude of a solar storm will determine how much of an impact it will have on Earth.

The largest recorded geomagnetic solar storm caused by a solar flare was the Carrington Event in 1859. Observed by British astronomer Richard Carrington, the storm was noticeable around the world. Auroras reached as far south as the Caribbean, while it was reported that residents of the northeastern US could read a book by the light of the aurora. Of most concern, however, was that telegraph offices all over Europe and North America failed, with some throwing sparks or catching fire. This led to much speculation about the effects a similar storm would have in the modern world, where electronics are a much more integral part of our lives.

In March 1989 that question was answered when a large CME coupled with a solar flare caused a severe geomagnetic storm on Earth. Although it temporarily knocked out some satellites and spacecraft, the worst effects of the storm were felt in Québec, Canada. The variations in the Earth's magnetic field, coupled with Québec's location on a large rock shield that prevented the flow of current through the Earth, tripped the circuit breakers in the power grid of the Hydro-Québec power station and knocked the station offline, sending 6 million people into a blackout lasting nine hours.

The geomagnetic storm of 1989 served as a reminder that solar flares can cause widespread damage, and since then numerous power stations have taken measures to ensure such an event does not occur again. "In the past few decades, the grid has undergone major changes to make it more robust and better able to neutralise the geomagnetic effects of solar storms," a spokeswoman for the Hydro-Québec power station told us. "Since 1989, solar


NASA's SDO captured this image of a powerful solar flare on 11 April 2013

How the NOAA classifies solar radiation storms

Minor

50 per 11-year solar cycle
A minor solar radiation storm causes minimal impact on high-frequency (HF) radio in the polar regions, but otherwise causes no damaging effects.

Moderate

25 per cycle
A moderate storm affects navigation at the polar caps and may, in rare instances, cause problems in satellites, but poses no threat to humans.

Strong

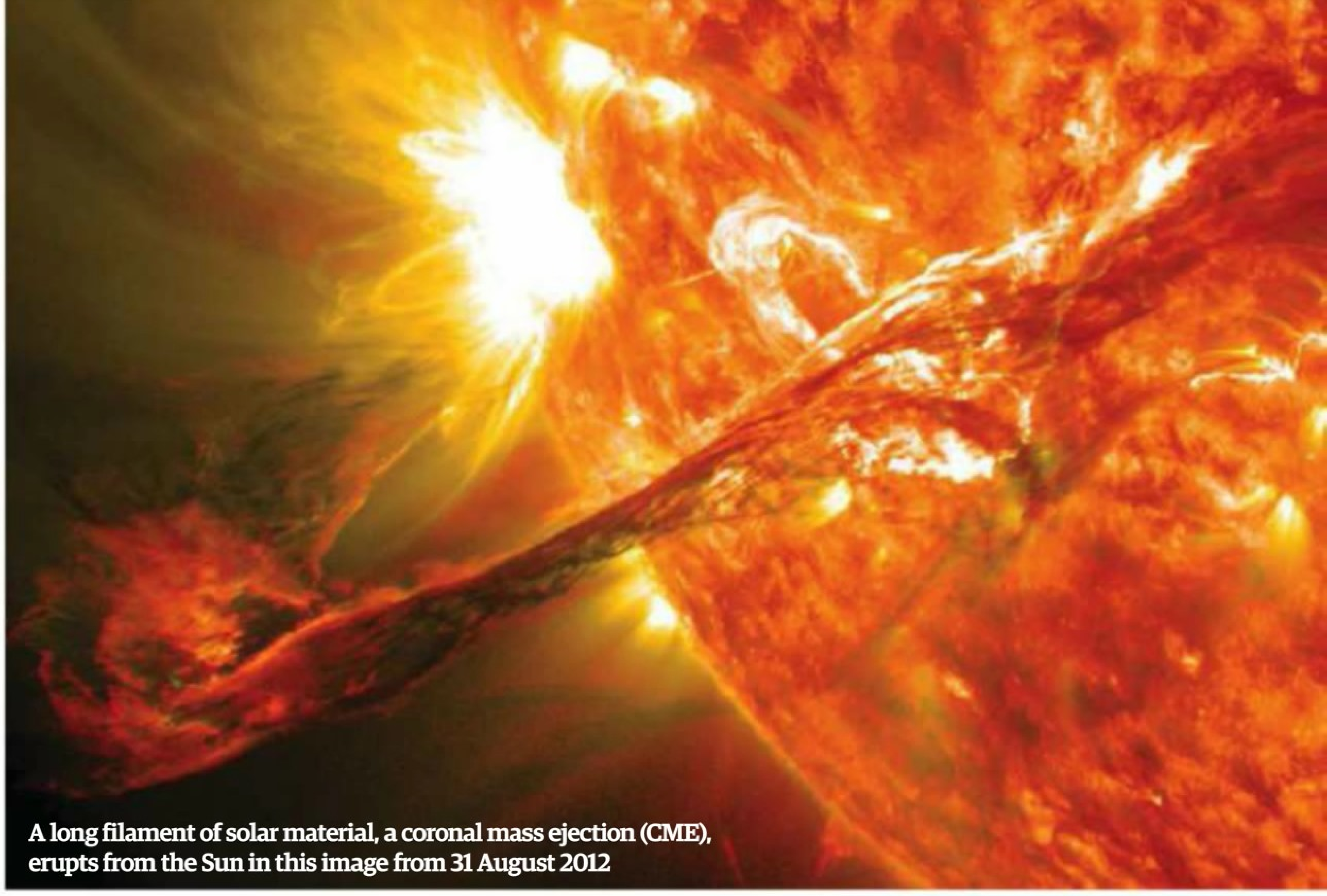
10 per cycle
During a strong storm astronauts are advised to seek shelter, while satellites could lose power and instrument usage. HF radio will degrade at the poles.

Severe

3 per cycle
Astronauts and passengers on planes may be exposed to radiation, while satellites could experience orientation problems. HF radio blackout at the poles.

Extreme

Less than 1 per cycle
Astronauts and aeroplane passengers exposed to high radiation. Satellites may be rendered useless. HF communications blackout in polar regions.



A long filament of solar material, a coronal mass ejection (CME), erupts from the Sun in this image from 31 August 2012

activity has not disrupted the performance of Hydro-Québec's transmission system."

That, however, does not mean we are safe from a future huge outburst from the Sun. "We are so reliant on satellite-based technology, like GPS-based applications, and you look at them and they're all very similar," Kunches said. "One really couldn't be a backup for another because they all fly at about the same orbits. And then you get to the electrical power grids and how interconnected they are, and if you get induced currents that cause transformers to be damaged and the ripple effects from those could be quite strong. We rely on infrastructure that is known to have sensitivities to space weather."

And while the general public may not have much of an interest in space weather, a large solar storm would certainly be noticeable to the layman on Earth. "I think everyone would agree that if you had a Carrington-like event there's no doubt that normal citizens, who have no awareness of space weather and really don't care about it, would wake up in the morning and they would see that something is different," said Kunches. "They would find that something, be it their electricity or their television or their cell phone, is not available as they wish it to be."

With space weather prediction agencies like the SWPC we are able to prepare for the worst when it comes to solar storms but, ultimately, if a huge emission event were to occur we don't have much of a defence. In extreme cases we can power down equipment, and prepare our electronic infrastructure to deal with an increase in energy, but there is no way to deflect solar flares and not much we can do if a particularly powerful one interacts with the Earth.

While we can estimate when a storm will arrive, determining its power as it travels from the Sun to the Earth will be of most importance for the future of predicting solar storms in order to try to minimise the effects of a large solar flare. "The next big step to be taken is in the science to better understand the information that's available to us right now," said Kunches. "I think that's the challenge of the next generation of space scientists, to try and understand better than we do now which of all the remarkable features we see back at the Sun are going to be the ones that really impact the systems we depend on."

Solar space observatories

SOHO
The Solar and Heliospheric Observatory (SOHO) launched on 2 December 1995 to observe the Sun from a position between the Earth and the Sun, the L1 Lagrange point, and it continues to operate today. A joint project between ESA and NASA, it is currently the main source of data for space weather predictors.

ACE
NASA's Advanced Composition Explorer (ACE) has been in space since 25 August 1997, with its main goal being to study the composition of solar wind. Like SOHO it is located at L1, and it is expected to continue operations until around 2024 when its fuel will be depleted.

STEREO
These twin spacecraft, known as the Solar Terrestrial Relations Observatory (STEREO), launched on 26 October 2006 and, through their respective solar orbits, they are able to get stereoscopic images of the entire Sun. This has proven useful for detecting solar flares.