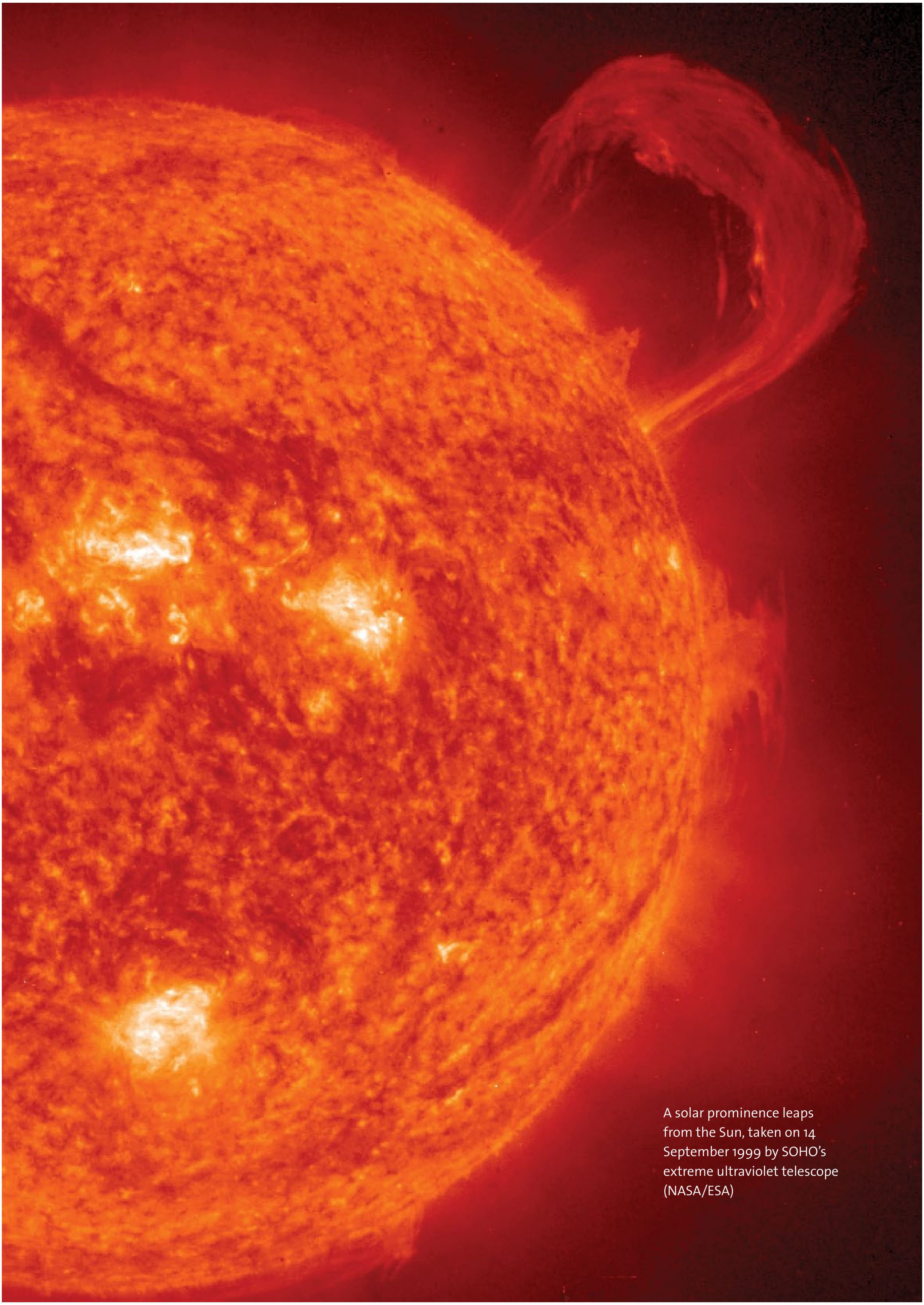

A solar prominence leaps from the Sun, taken on 14 September 1999 by SOHO's extreme ultraviolet telescope (NASA/ESA)

→ SOHO

Two decades of observing the Sun

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Originally planned as a two-year mission, the ESA/NASA space-based observatory SOHO has been studying the Sun for 20 years, each day sending thrilling images from which research scientists learn about the nature and behaviour of our star.

SOHO, standing for 'Solar and Heliospheric Observatory', is stationed 1.5 million km out, on the sunward side of the Earth, where it enjoys an uninterrupted view of the Sun. Experts around the world use SOHO images and data to help them understand the workings of the Sun's core, its hot and dynamic outer atmosphere, the solar wind and its energetic particles.

Crucially, we also rely on the mission to monitor the impact of space weather on our planet, with a vital role in forecasting potentially dangerous solar storms. In addition to investigating how the Sun works, SOHO is the most prolific discoverer of comets in astronomical history, with the destinies of more than 3000 comets tracked as these icy worlds endure fiery encounters with the Sun.

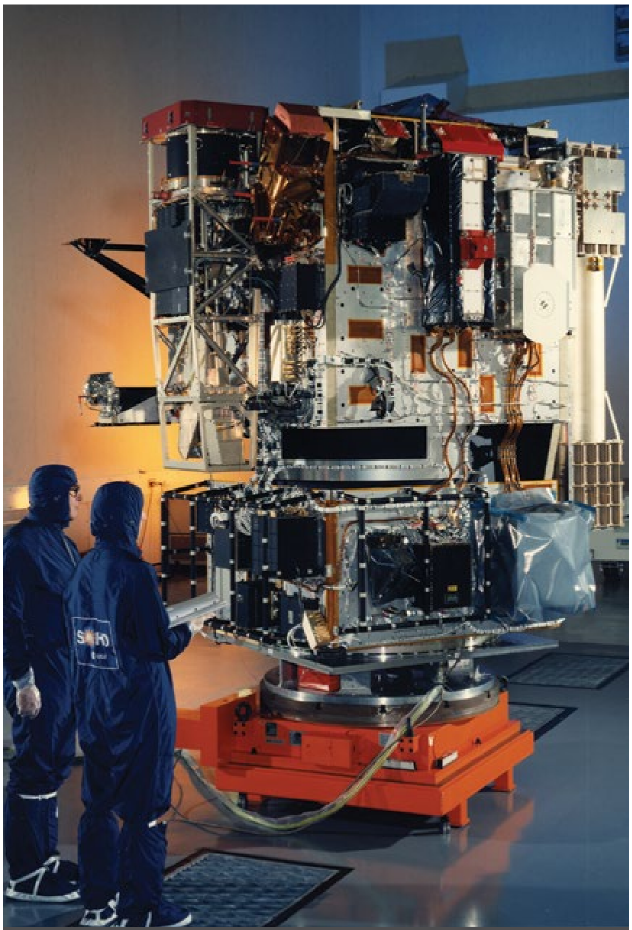
SOHO is a joint project of international cooperation between ESA and NASA. The spacecraft was built for ESA by Europe's aerospace industry, in a consortium led by Matra Marconi Space (now Airbus Defence & Space), and was launched on a US Atlas launch vehicle on 2 December 1995. It began operations in May 1996.

The longest Sun-watching mission

Originally planned for a two-year mission, its numerous extensions have allowed it to cover nearly two 11-year solar cycles – the complete cycle 23 and already a large fraction of cycle 24. SOHO is thus the longest-lived Sun-watching mission.

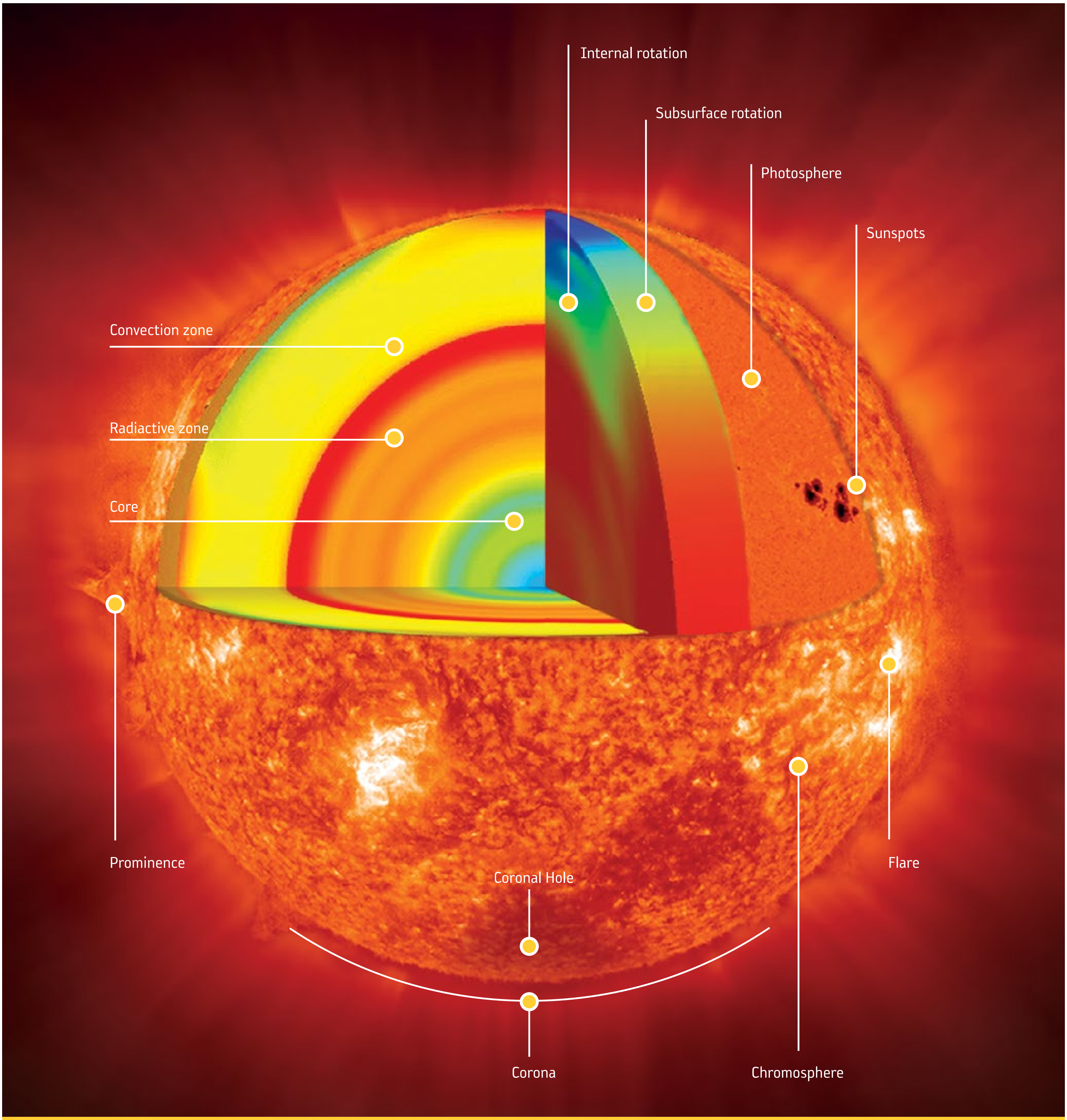
Of the satellite's 12 science instruments, nine come from multinational teams led by European scientists, and three from US-led teams. More than 1500 scientists in 20 countries are directly involved in SOHO's instruments and research programmes. NASA launched SOHO and is responsible for communications and daily operations.

Although four of the original 12 science instruments are no longer used – they were superseded by the next generation of sensors on newer missions – SOHO continues to provide unique and important measurements of our star.



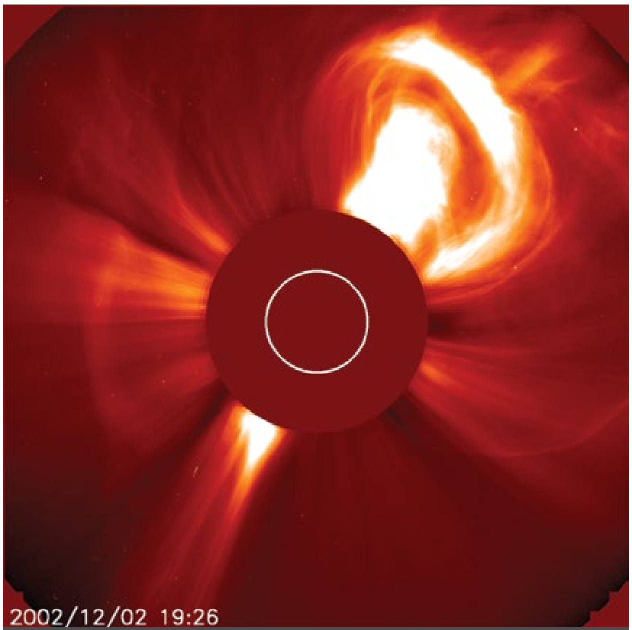
↑ ESA engineers inspect SOHO during assembly at the Matra Marconi Space facility (ESA/NASA)

↑ Launch of SOHO on an Atlas II-AS (AC-121), from Cape Canaveral Air Station on 2 December 1995 (NASA)

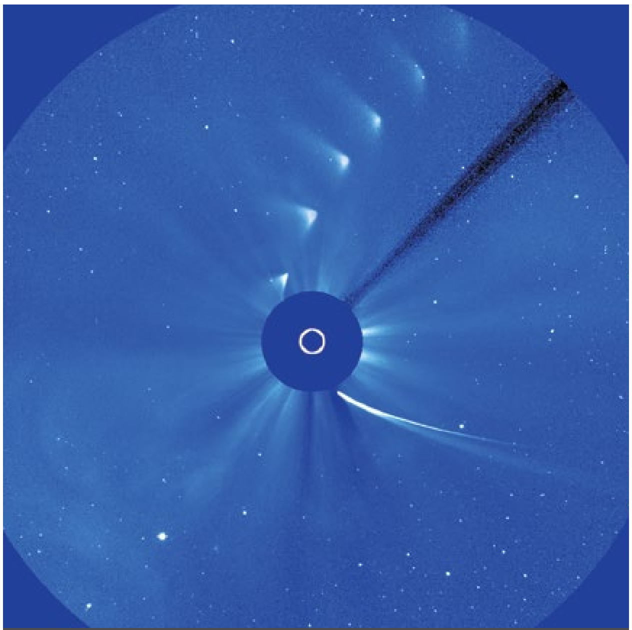


→ The anatomy of our Sun

Left cutaway: The Sun's interior explored with sound waves. Red depicts layers where sound travels faster than predicted by theory, implying that the temperature is higher than expected, while blue indicates slower speeds and lower temperatures. The prominent red layer marks the transition between the turbulent outer convection zone and the more stable inner radiative zone. Right cutaway: The Sun's internal rotation, where red depicts fast rotation and blue slower rotation. Outer layers: Visible light images show sunspots, cool dark features in the photosphere, which lies below the chromosphere. Flares, resulting from the release of a buildup of magnetic energy, and coronal mass ejections (CMEs, giant clouds of electrically charged atomic particles launched into space) often occur in magnetically active regions around sunspot groups.



↑ This LASCO C2 image shows a very large coronal mass ejection (CME) blasting into space on 2 December 2002. It has the classic shape of a CME: a large bulbous front with a more compact, inner core of hot plasma. This material erupts away from the Sun at speeds of over a million km/h (ESA/NASA)



↑ The demise of Comet ISON as it came within 1.2 million km of the Sun on 28 November 2013, fading from view in the following days. The small white circle in the middle indicates the position and size of the Sun behind the occulting disc of the LASCO coronagraph (ESA/NASA)

Seeing inside the Sun

Just as seismology reveals Earth's interior by studying seismic waves from earthquakes, solar physicists use 'helioseismology' to probe the solar interior by studying the frequency and oscillations of sound waves reverberating through it.

SOHO opened and pioneered the new field of 'local area helioseismology', providing the first images of structures and gas flows below the Sun's surface and even images of activity on the far side.

It discovered 'sunquakes' and a slow subsurface current of gas flowing from the equator towards the poles. Deeper inside the Sun, about a third of the way towards the centre at the transition between its turbulent outer shell – the convection zone – and the more orderly radiative zone, SOHO found that the speed of the rotating gas changes abruptly.

The measurements indicated that, near the equator, the outer layers rotate faster than the inner layers, while at mid-latitudes and near the poles the situation is reversed. This boundary region is of particular interest because it is where the solar dynamo that creates the Sun's everchanging magnetic field is believed to operate. SOHO also shed light on the 'solar neutrino problem' – a major discrepancy between the rate at which neutrinos were predicted to be created by nuclear fusion in the deep solar interior and the rate measured at Earth.

SOHO confirmed that the standard model of the Sun is correct, ruling out that possible explanation. Instead, the discrepancy had to be explained by the physics of the neutrino, as confirmed by better neutrino measurements a few years later.

The solar heating mystery

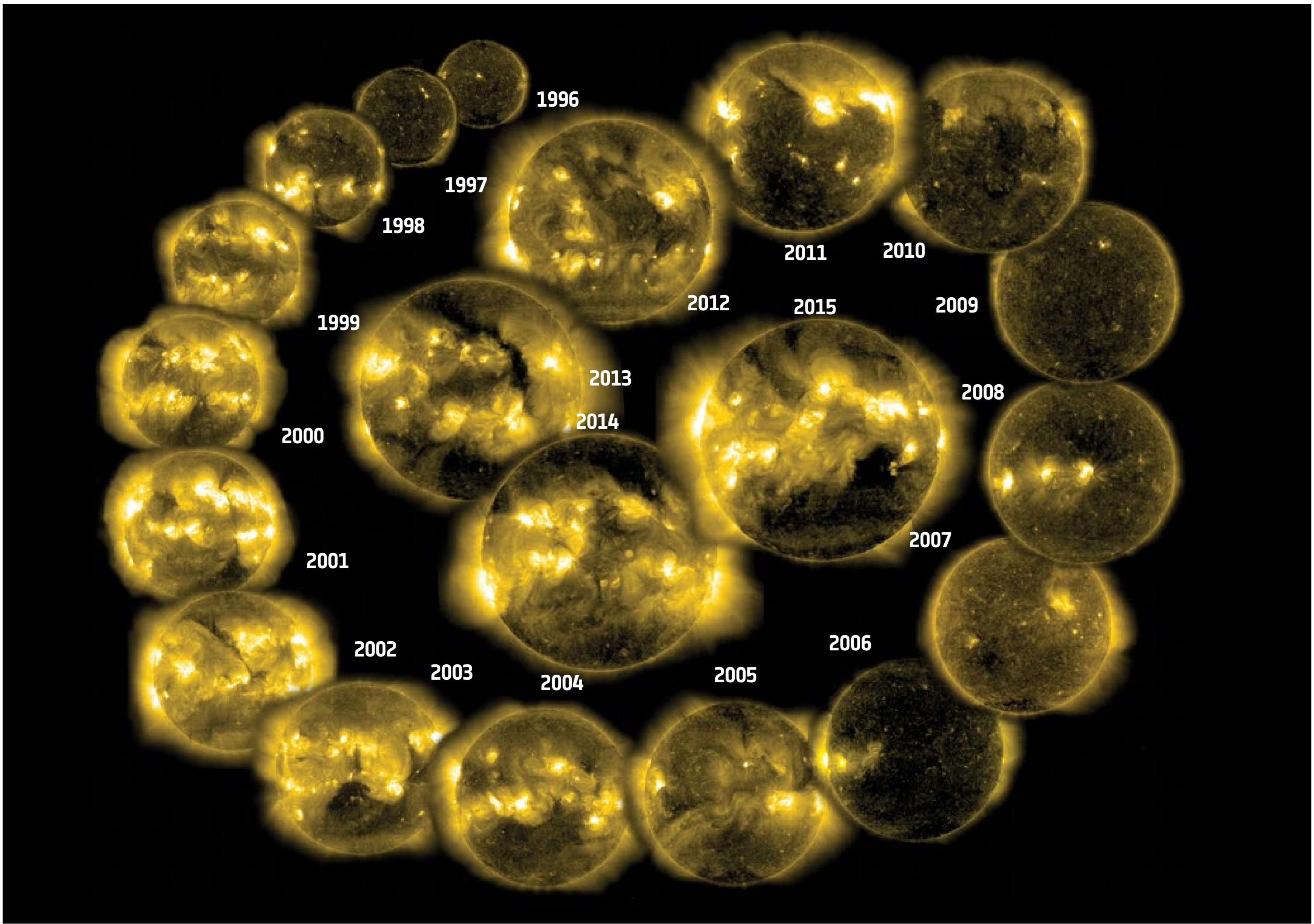
The question of why the Sun's outer atmosphere is heated to the extremely high 1–2 million degrees when the visible surface is 'only' about 5500°C has long been a mystery of solar physics.

SOHO has revealed an extremely dynamic atmosphere where plasma flows and small-scale transient events play

↑ Aurora borealis over an Icelandic lake (C. Gauna)

→ Members of the SOHO recovery team at NASA Goddard Space Flight Center in September 1998, including staff from ESA, NASA, Matra Marconi Space, Allied Signal Technical Services Co., Computer Sciences Corp. and Space Applications Corp. (NASA/ESA)

an important role. They also discovered new dynamic phenomena such as solar tornadoes and global coronal waves – disturbances associated with coronal mass ejections that can travel around the entire solar globe – and provided evidence for the upwards transfer of magnetic energy from the surface to the corona through a magnetic carpet, a weave of magnetic loops extending above the Sun's surface.



↑ The changing face of the Sun seen through SOHO's Extreme ultraviolet Imaging Telescope from 1996 (small, most distant disc) to 2015 (largest, central disc). The images were taken each northern spring and show the waxing and waning of activity during the 11-year solar cycle (ESA/NASA)

Gone with the solar wind

A prime goal was to observe where the solar wind – electrically charged atomic particles streaming from the Sun – is produced and how it is accelerated to beyond 3 million km/h. Scientists have made great strides in answering this fundamental question. They measured the acceleration profiles of both the 'slow' and 'fast' solar wind and found that the fast solar wind streams into interplanetary space by 'surfing' on waves produced by vibrating magnetic field lines.

Mapping the outflow of the plasma from coronal holes – darker, cooler and less dense areas of the Sun's corona where the Sun's magnetic field reaches into space, allowing hot gas to escape – revealed a clear connection between the flow speed and the structure of the chromosphere.

SOHO also revealed that heavy solar wind ions in coronal holes flow faster and are heated hundreds of times more strongly than protons and electrons.

The Sun–Earth connection

With its near-continuous monitoring of the Sun, SOHO has revolutionised our understanding of the Sun–Earth connection and dramatically boosted space weather forecasting.

The major driver of space weather are CMEs, the most powerful eruptions in the Solar System, which propel billions of tonnes of electrified gas into space at millions of kilometres per hour. If CMEs hit Earth, in addition to causing intense auroral displays in polar regions by electrically charging atoms in our upper atmosphere, they can cause major geomagnetic storms, which can damage satellites, disrupt telecommunications, endanger astronauts, lead to corroded oil pipelines and cause current surges in power lines.

SOHO is a pioneer in detecting when such a solar storm is incoming. It has studied more than 20 000 CMEs to date, pinpointing their sources on the Earth-facing hemisphere of the Sun, and determining their speed and direction to provide up to three days' warning – sufficient to take mitigating action on Earth. From its vantage point matching Earth's orbit, the observatory can also make *in situ* measurements when a CME and its energetic particles arrive.

Star bright

The Sun's surface brightness is an important part of SOHO's long-term studies, because changes could influence Earth's climate. SOHO monitors the total brightness as well as variations in the extreme ultraviolet flux, both of which are which are important for understanding the effect of solar variability on climate. The measurements show that the Sun's total brightness changes by only 0.1% between the minimum and maximum of a cycle.

A prolific comet-hunter

Besides watching the Sun, SOHO is also a prolific comet discoverer: more than 3000 comets have been found, the majority by amateurs accessing realtime data via the Internet. While many of these sungrazing comets perish in the Sun's heat, some survive, albeit in various states of degradation: SOHO has watched many comets lose their heads and tails during their solar encounter.

Near-loss and dramatic recovery

The mission almost ended on 25 June 1998 when control was lost during a routine spacecraft manoeuvre. It took three months to restore operations in one of the most dramatic recovery operations in space history, including just over two weeks to thaw frozen hydrazine propellant in the tank and pipes. Unexpectedly, all 12 instruments survived despite the extreme temperatures they suffered during the time that contact was lost.

But the drama was not over yet: all three gyroscopes later failed, the last in December 1998. New control software that no longer relied on gyros was developed and installed in February 1999, allowing the spacecraft to return to full scientific operations. This made SOHO the first spacecraft to be stabilised in three axes without gyros. Despite these problems, engineers have kept SOHO functioning with all its instruments performing well.

After it went into space in 1995, SOHO was meant to operate until 1998, but the mission is so successful that it has already seen several extensions. It currently has approval until end 2018 (subject to a mid-term review in 2016). These extensions enable SOHO's scientists to compare the Sun's behaviour (for example, sunspot activity) not only at different times in one solar cycle, but also during different solar cycles.

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