cluster

→ CLUSTER 2000–10: A DECADE REVEALING THE SUN–EARTH CONNECTION IN 3D

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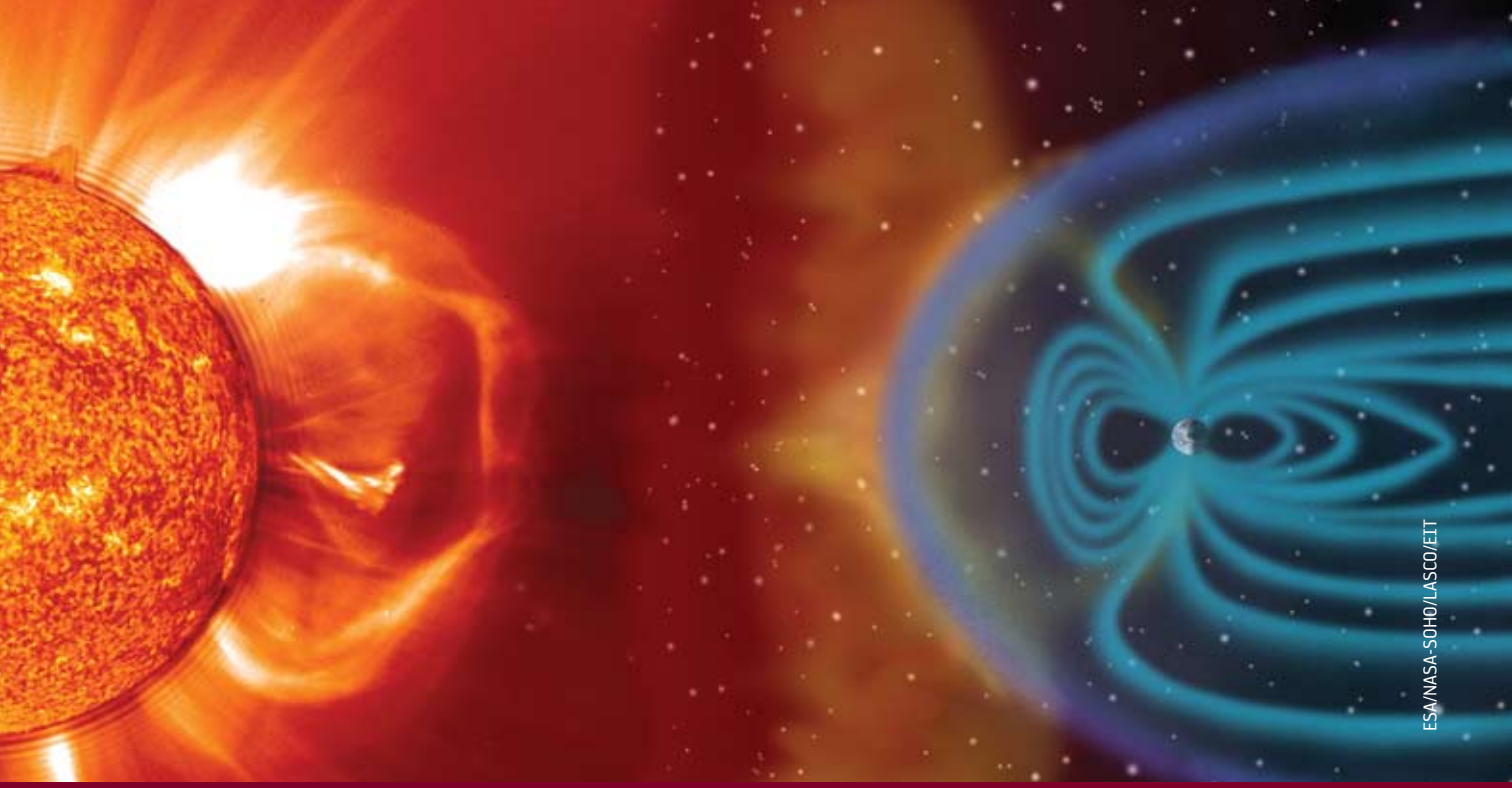
European Space Agency



→ CLUSTER CONSTELLATION

Cluster is a constellation of four satellites flying in formation around Earth. Their separations can be varied from just a few tens of kilometres to 10 000 km. They have spent a decade studying our planet's magnetic interaction with the Sun. The satellites each carry an identical set of 11 scientific instruments, working together to provide a 3D perspective on the invisible medium.

The Sun constantly emits a thin, hot, electrified gas that carries particles and magnetism into space, known as the solar wind. Earth is shielded from this solar wind by its magnetic field.

Cluster is making the most detailed investigation ever of the interaction between the solar wind and Earth's magnetic field. This is more than pure science, as many of the phenomena being studied can also pose a danger to spaceborne electronics and major electrical systems on the ground.

The Cluster mission was proposed in November 1982. After the unfortunate loss of the original satellites during launch in 1996, the first pair of replacements was launched in July 2000, the second pair a month later.

→ EARTH'S MAGNETIC SHIELD

Earth's magnetic field is generated deep inside our planet but extends far into space, forming a protective bubble in the solar wind, known as the magnetosphere. It has a comet-like tail – the magnetotail – extending hundreds of thousands of kilometres behind the Earth.

Unfortunately, the magnetic field is only partially protective. Gusts and storms in the solar wind are known as 'space weather', which can penetrate the shield and cause a variety of disruptive effects. Cluster has spent a decade revealing these interactions in unprecedented detail.

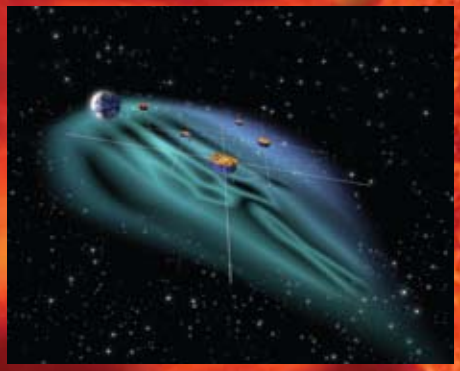
Christophe Carreau

→ JOINING FORCES

'Magnetic reconnection' can take place when magnetic fields collide. The field lines connect differently, changing the shape of the magnetic 'landscape' and allowing previously separated plasmas to mix. It efficiently accelerates particles and heats the plasma.

However, certain fundamental properties of this phenomenon remain unknown. One key issue is what happens right in the middle of the process – the magnetic 'null' point. Cluster data have led to the first 3D picture of a null, the magnetic heart of reconnection. Vital new insights include showing that the magnetic field can be twisted into 500 km-wide tubes.

Understanding magnetic reconnection is a major quest in physics. It is responsible for tremendous solar explosions – solar flares – that can be a billion times more powerful than an atomic bomb. In the magnetotail, magnetic reconnection can funnel particles towards Earth, leading to increased auroral activity. In Earth's laboratories, unwanted reconnection frustrates efforts to produce electricity in fusion reactors.



→ WAGGING EARTH'S MAGNETOTAIL

In mid-2004, Cluster's four satellites and one from the Chinese/ESA Double Star mission were coasting through the nightside magnetosphere at a time when Earth's magnetotail was quivering, and took detailed measurements.

Though it is still unknown exactly what triggers these fluctuations in the magnetotail, the satellites revealed that they take place across scales larger than 30 000 km. A wave motion begins in the centre of the magnetotail and moves outward like the waves created by a boat travelling across a lake. This suggests that the oscillations are generated in the tail itself, rather than imposed on it from outside by a gusty solar wind.

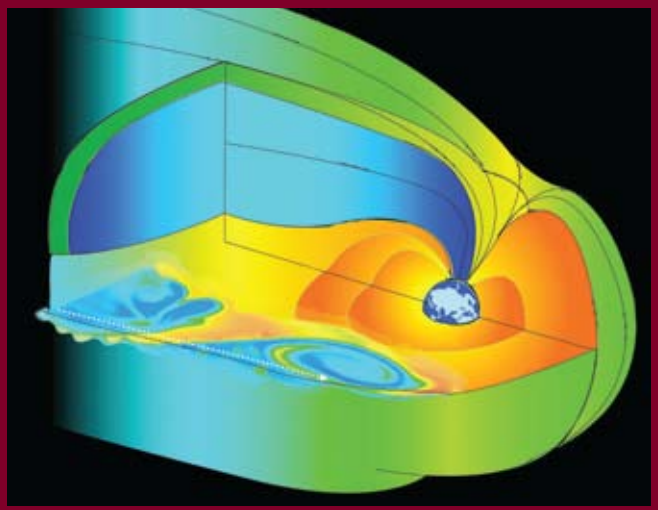
Because of the geometrical arrangement of the satellites at the time, the oscillation was detected closer to Earth than ever before – only 70 000 km. At such proximity, oscillations like these probably direct particles into Earth's atmosphere, sparking colourful auroras.

→ WHIRLPOOLS AT THE EDGE OF SPACE

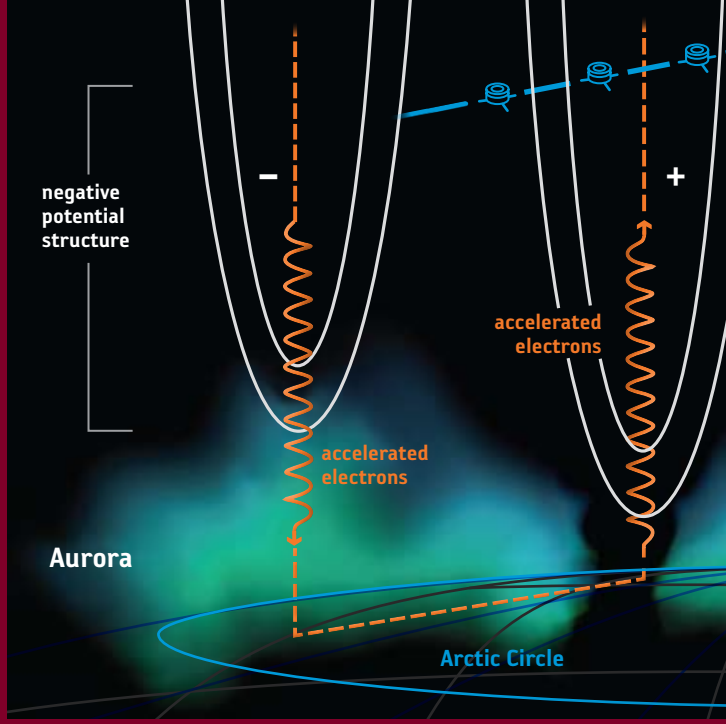
Earth's magnetosphere protects the planet from the electrically charged particles pouring from the Sun. However, it is only partially effective. Giant whirlpools of plasma can form along the flanks of our magnetic shield, boring into it. These whirlpools are generated by the solar wind sliding past Earth's magnetic field in roughly the same way as wind blows across the surface of an ocean.

Thanks to multi-point measurements by Cluster, the size of these vortices has been found to be huge: around 40 000 km across, nearly six times Earth's radius.
Computer reconstructions show that these whirlpools inject electrified gas into Earth's magnetic environment by forcing magnetic reconnection to take place. This opens passageways that allow the plasma to cross the usually impenetrable boundary.

This discovery has solved a long-known mystery: how the outer layer of Earth's magnetosphere can be constantly topped up with electrified gas, when it had been thought that it should rather act as a shield.



Adapted by ESA from Hasegawa et al., 2004

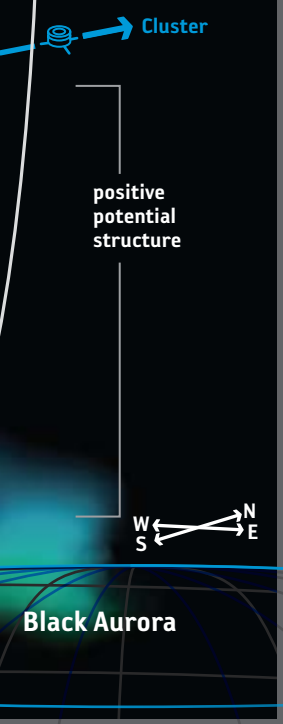


→ BLACK AURORAS

Anyone living near the Arctic or Antarctic Circle will be familiar with the aurora, the red and green curtains of light in the upper atmosphere or 'ionosphere' that illuminate the long winter nights. Much less familiar is the mysterious 'black aurora', which produces dark, empty regions within the visible northern and southern lights.

The black aurora takes on various guises: dark rings, curls or blobs that punctuate the glowing colours. Cluster has shown that these peculiar patches occur where there are 'holes' in the ionosphere. In these holes, negatively charged ionospheric particles are shooting upwards into space. This is the opposite of what happens in the bright, coloured aurora, where electrons spiral down from space into the atmosphere, collide with ionospheric particles, and make them fluoresce. Thus, the black aurora is in fact an anti-aurora, a hole in the visible one.

Indeed, Cluster has shown that after a few tens of minutes, all available electrons are 'sucked' out of the ionosphere, and the black anti-aurora is filled in by the normal coloured one.



Plasma	Electrically charged gas
Magnetosphere	The region of space controlled by Earth's magnetic field
Magnetotail	The extended nightside tail of Earth's magnetic field
Solar cycle	The rise and fall of solar activity usually lasting 11 years
Solar activity	The sudden magnetic expulsion of plasma and energy

→ RISE OF THE KILLER ELECTRONS

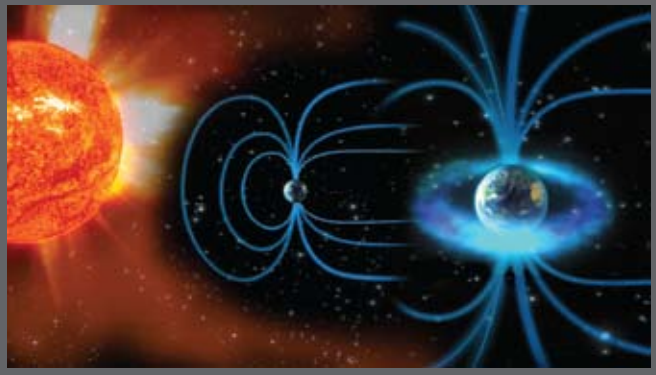
Earth is surrounded by two belts of trapped high-energy particles held in place by Earth's magnetic field: the Van Allen radiation belts. Killer electrons in the outermost belt move close to the speed of light and carry a lot of energy. These can penetrate satellite shielding and cause microscopic lightning strikes that damage and sometimes destroy vital components.

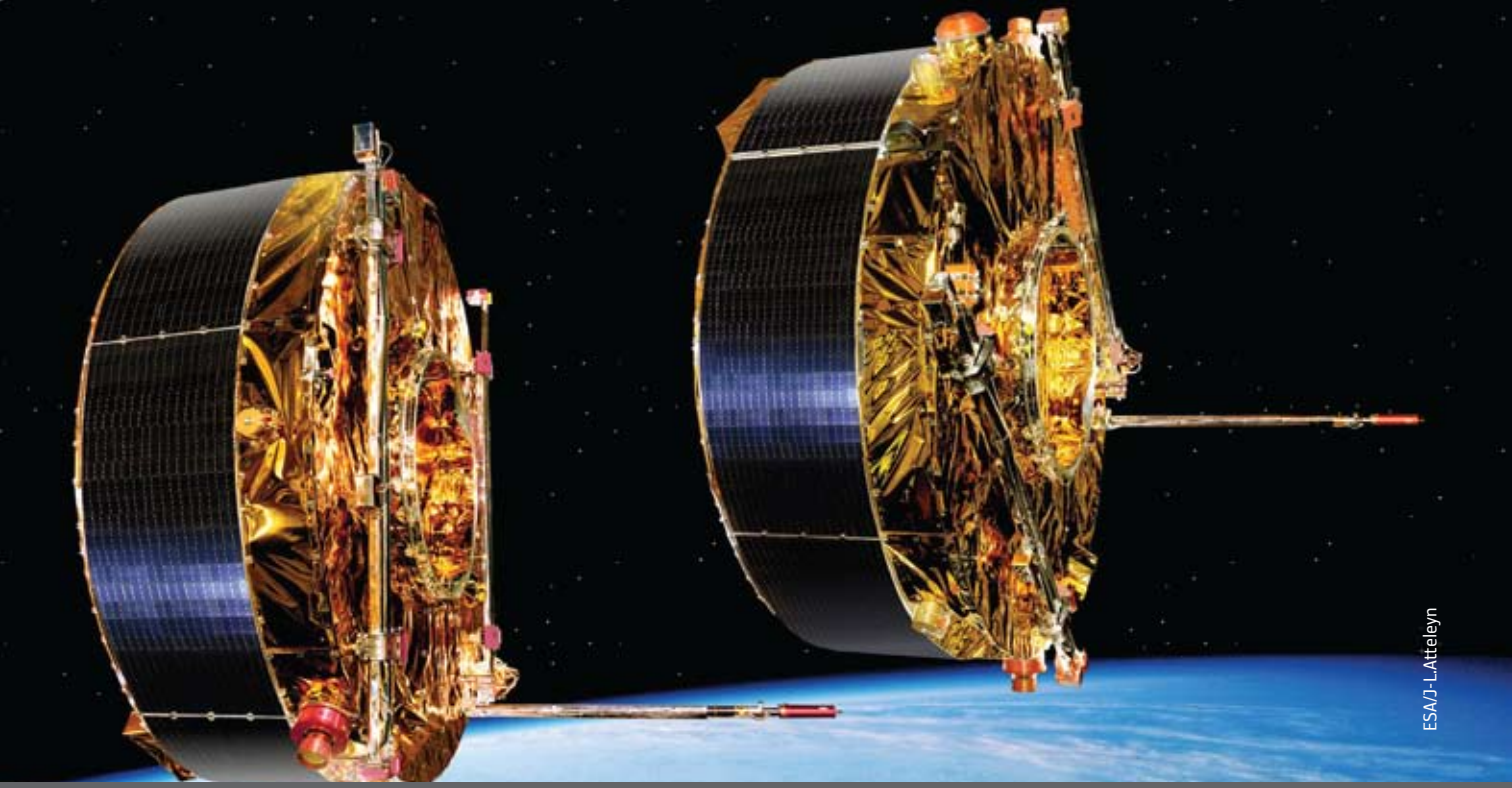
Even before the Space Age, the behaviour of Earth's magnetic field during solar storms suggested that Earth is surrounded by a variable ring current generated by electrically charged particles from the Sun. Such particles were indeed found in the Van Allen belts, but it was only some 40 years after their discovery that Cluster was able to make an accurate determination of the permanent ring current around Earth through its detailed measurement of the magnetic field in this region.

Intense solar activity can disrupt the Van Allen belts, and Cluster made another vital discovery when it was on hand to observe directly the effects of a particularly strong solar shock wave hitting the magnetosphere in 2004.

It saw the creation of killer electrons through what turns out to be a two-step process. The electrons are initially accelerated by the shock wave compressing Earth's magnetic field. Then Earth's magnetic lines wobble, making something like a very large-scale, low-frequency laser, which accelerates the electrons even more, to 'killer' energies.

And Cluster showed that this transition, from normal to killer intensities, can happen in just 15 minutes.





→ CLUSTER'S FUTURE

Cluster's operational lifetime, which started in February 2001, has been extended twice: first to 2009 and then to 2012. A further extension until 2014 is under consideration.

If this extension is granted, Cluster scientists and engineers will be able to study the rise and peak of the Sun's current 11-year cycle of activity, solar cycle 24, which should peak in 2014. Cycle 23 was unusually long, presenting the deepest and longest minimum of solar activity since the start of the Space Age, its unusual nature giving the potential for a cornucopia of new insights in the analyses under way. Cluster will continue to observe the magnetosphere as cycle 24 builds, providing us with full coverage of the unusual transition and, hopefully, its implications.

Cluster has revealed the need for measurements at multiple points and different scales. It was coordinated for part of its time with a Chinese spacecraft pair, Double Star, and it has paved the way for future space plasma missions. New mission concepts involve collections of spacecraft at varying scale sizes – clusters within clusters – which will bring us even closer to understanding not only how the Sun and the terrestrial magnetosphere interact, but how the plasma universe behaves.

→ CLUSTER ARCHIVE

The entire duration of the mission will provide scientists with a wealth of data, all of which are made available at the Cluster Active Archive, the first depository of high-resolution space plasma physics data (caa.estec.esa.int).

An ESA Communications Production
BR-290 | ISBN 978-92-9221-035-9 | ISSN 0250-1589