Cluster's 20 years of studying Earth's magnetosphere

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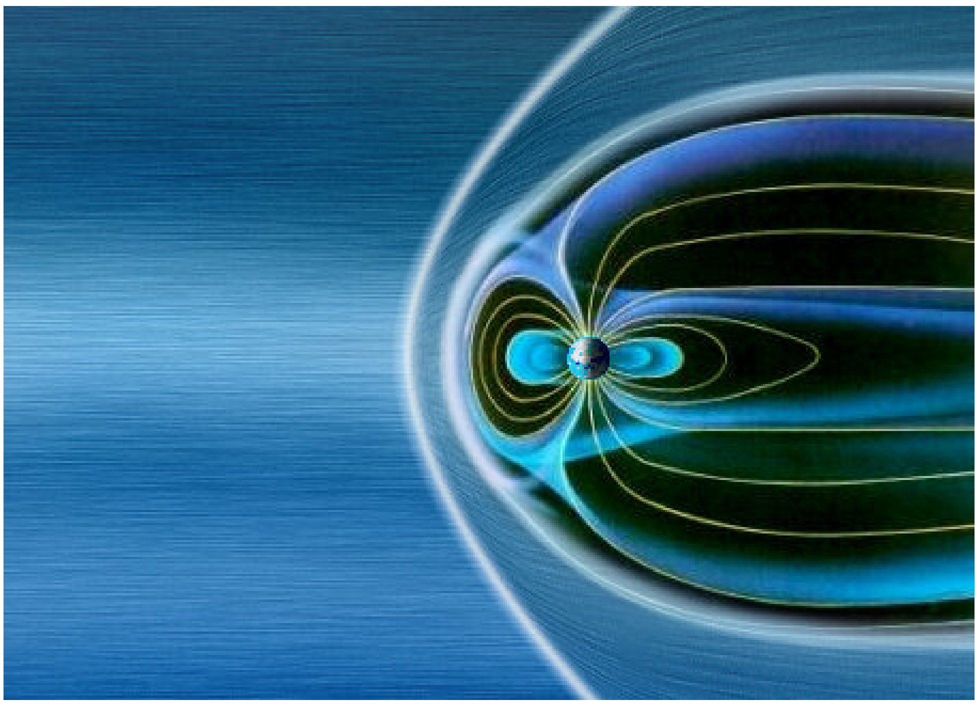


This artist's impression shows Earth's bow shock, a standing shockwave that forms when the solar wind meets our planet's magnetosphere. Credit: ESA/AOES Medialab

Despite a nominal lifetime of two years, ESA's Cluster is now entering its third decade in space. This unique four-spacecraft mission has been revealing the secrets of Earth's magnetic environment since 2000 and, with 20 years of observations under its belt, is still enabling new discoveries as it explores our planet's relationship with the Sun.

As the only planet known to host life, Earth occupies a truly unique place in the Solar System. The Cluster mission, launched in the summer of 2000, was designed and built to study perhaps the one main thing that makes Earth a unique habitable world where life can thrive. This one life-enabling thing is Earth's powerful magnetosphere, which protects the planet from the bombardment by cosmic particles but also interacts with them, creating spectacular phenomena, such as polar lights.

Earth's magnetosphere, a tear drop-shaped region that begins some 65,000 kilometers away from the planet on the day side and extends up to 6,300,000 kilometers on the night side, is a result of the interaction between the planet's magnetic field, generated by the motions of its molten metal core, and the solar wind. Cluster is the first mission to have studied, modeled and three-dimensionally mapped this region and the processes within it in detail. By doing so, it helped to advance our understanding of space weather phenomena, which arise from the interplay between the magnetosphere and the energetic particles forming the solar wind. These phenomena can damage not only living organisms, but also electronic equipment, whether on the ground or in orbit.

Rumba, Salsa, Samba and Tango

The Cluster mission comprises four spacecraft flying in a pyramid-like formation on an elliptical polar orbit. The four spacecraft, called Rumba, Salsa, Samba and Tango, each carrying the same payload of 11 advanced instruments, were dispatched to orbit with two rocket launches on 16 July and 9 August 2000.

Although the mission has become an enormous success, having enabled numerous scientific breakthroughs, it's early days didn't go off without a hitch. An under-performance of the first stage of the Soyuz launcher left Rumba and Tango in an incorrect orbit, forcing them to rely on their own propulsion, as well as the Fregat upper stage of Soyuz, to get to the right position to join Salsa and Samba. The mishap followed the failed launch of the original Cluster I quartet in 1996.

"ESA was a bit worried 20 years ago, during the launch of the second pair of spacecraft," admits Philippe Escoubet, Cluster Project Scientist at ESA "Ever since then, the mission has made huge progress, and it is far from finished."

Over the past two decades, Cluster observations have uncovered details about the processes in the magnetosphere, revealed how the atmosphere supports life, and provided essential insights into space weather needed to enable safe satellite communications and space or air travel.

A unique architecture

The key to the mission's power is not just its four-spacecraft configuration but also the fact that operators can adjust the distance between the four satellites from 3 up to 60,000 kilometers depending on the scientific objective.

"This multi-spacecraft design is key to Cluster's success," explains Philippe. "By using four spacecraft instead of one, Cluster is able to uniquely measure multiple areas of space—and gain multiple perspectives on a particular event or activity, such as a solar storm—simultaneously."

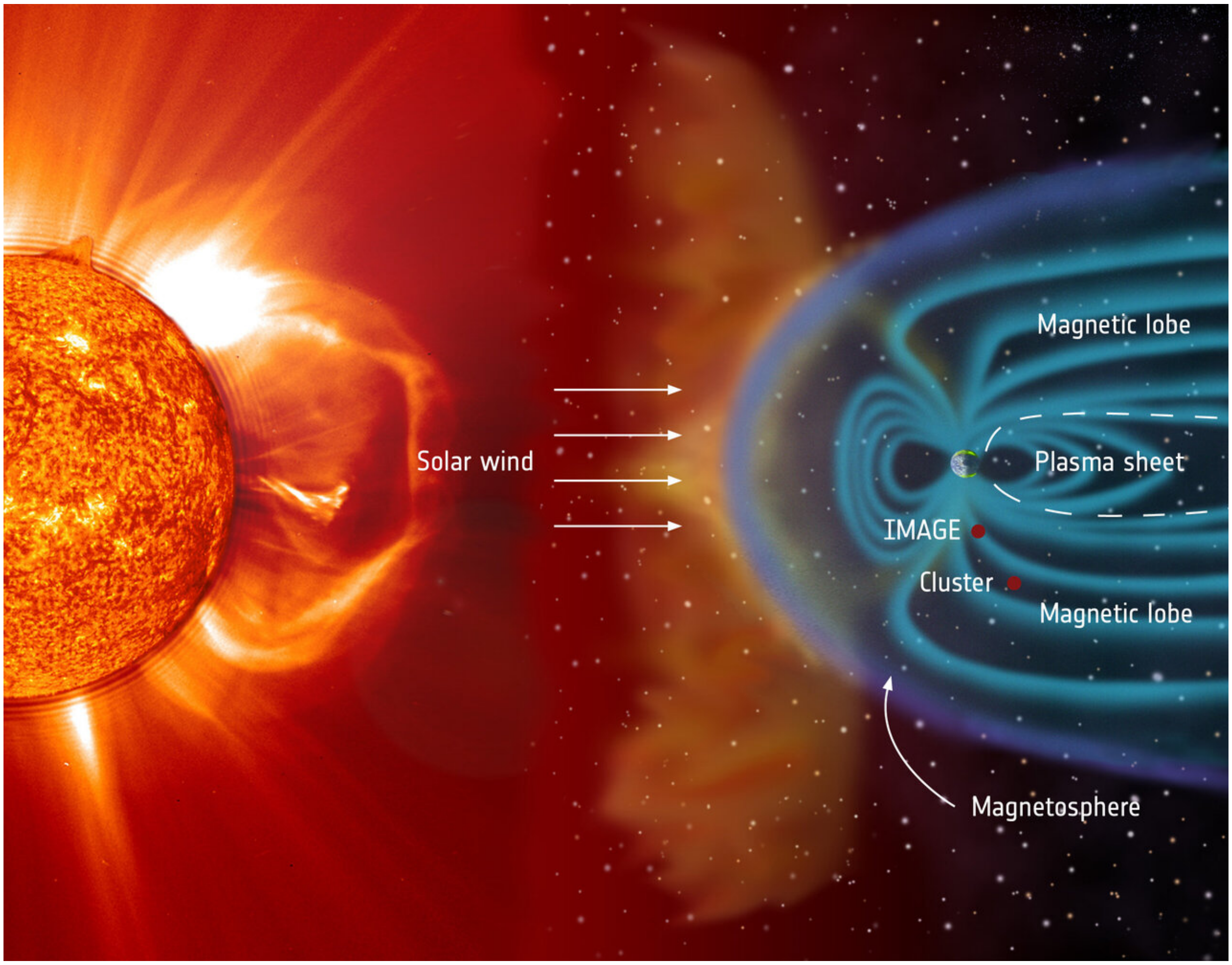
When closer together, the Cluster spacecraft can dig into the finer magnetic structures in near-Earth space; when more separated, they can obtain a broader view of wider-scale activity. Across its orbit, Cluster flies both within and outside of Earth's magnetosphere, allowing it to investigate the phenomena on both sides of our planet's magnetic shield.

Polar power

While most missions exploring Earth's magnetic phenomena focus on the equator where many electric currents flow, the Cluster quartet circles the Earth in a polar orbit, which allows it to pass periodically above both Earth's poles. The polar regions are magnetically extremely dynamic. Solar wind in this area can penetrate deeper into Earth's upper atmosphere through the polar cusps, funnel-like openings in the magnetosphere above the poles, giving rise to the spectacular auroras.

Cluster's ability to observe higher latitudes than other missions made the mission a key player in forming a global magnetospheric map.

One element of this was accurately mapping the position and extent of so-called cold plasma (slow-moving charged particles) around Earth in three dimensions. Such plasma—which Cluster found to, surprisingly, dominate the magnetosphere's volume up to 70% of the time—is thought to play a key role in how stormy space weather affects our planet. Cluster has also studied how the inner parts of Earth's magnetosphere work to replenish other parts with fresh plasma, observing not only sporadic plumes that push plasma outwards, but also a steady atmospheric leak of almost 90 thousand kilograms of material per day



The night side of the terrestrial magnetosphere forms a structured magnetotail, consisting of a plasma sheet at low latitudes that is sandwiched between two regions called the magnetotail lobes. The lobes consist of the regions in which Earth's magnetic field lines are directly connected to the magnetic field carried by the solar wind. Different plasma populations are observed in these regions – plasma in the lobes is very cool, whereas the plasma sheet is more energetic. The diagram labels by two red dots the location of an ESA Cluster satellite and NASA's Image satellite on 15 September 2005, when particular conditions of the magnetic field configuration gave rise to a phenomenon known as 'theta aurora'. Credit: ESA/NASA/SOHO/LASCO/EIT

20 years of discovery

Through its mapping of Earth's magnetic field, and comparison of this to Mars' lackluster present-day magnetism, Cluster has reaffirmed the importance of our magnetosphere in shielding us from the solar wind.

Cluster has revealed more about the dynamics within the magnetotail, the part of the magnetosphere extending 'behind' our planet away from the Sun. The mission identified that the magnetic field in this region oscillates in amplitude due to internal 'kink-like' waves, and solved a long-standing mystery by determining that the phenomenon of 'equatorial noise' (noisy plasma waves found near the equatorial plane of Earth's magnetic field) is generated by protons.

By investigating the spatial characteristics of the outer region of the magnetosphere, Cluster has brought a deeper understanding of how solar wind particles can penetrate our magnetic 'shield'. The solar wind is a stream of charged particles flooding out into space from the Sun, moving at speeds of up to 2000 kilometers per hour. Cluster identified tiny swirls of turbulence that affect how energy (heat) is distributed throughout this wind, and discovered that, while it protects us from incoming particles, our magnetosphere is quite porous and sieve-like, allowing super-heated solar wind particles to drill through.

By collaborating with other missions, Cluster has helped reveal the workings of high-latitude 'theta' auroras and less familiar 'black auroras', enabling a detailed understanding of how different regions of space exchange particles. The mission also discovered the origin of so-called 'killer electrons', energetic particles in Earth's outer belt of radiation that can cause havoc for satellites, by observing this process first-hand. Cluster found these electrons to arise as solar storm-related shock waves compress Earth's magnetic field lines, resulting in these lines vibrating and accelerating electrons to high, and dangerous, speeds.

Cluster has investigated the dynamics of a process known as magnetic reconnection, providing the first in situ observations of magnetic field lines breaking and reforming—a finding that required multiple simultaneous observations, as only Cluster could provide at the time. Cluster data also showed that energy is released in unexpected ways during reconnection events, helping scientists to build a fuller understanding of plasma dynamics.

Space weather and geomagnetic storms, phenomena driven by Earth's relationship with the Sun, have been a topic of focus for Cluster. The mission has modeled Earth's magnetic field at both low and high altitudes, and identified the complex dynamics at play in the solar wind itself, with the goal of enabling more informed and accurate 'space weather forecasting'. Late last year, by analyzing Cluster's comprehensive Science Archive, scientists were also able to release the eerie 'song' emitted by Earth when it is hit by a solar storm, created by magnetic field waves.

A treasure trove of data

Across its many years of operation, Cluster has amassed an unprecedented repository of data about Earth's environment. In fact, by drawing on 18 years of this data, scientists recently found that iron is widely, and surprisingly, distributed throughout our planet's vicinity, demonstrating the enduring power of Cluster in facilitating novel scientific discovery.

"Having such a long baseline of data has enabled a number of truly ground-breaking findings," adds Arnaud Masson, Deputy Project Scientist for the Cluster mission at ESA. "By continually monitoring and recording the dynamics and properties of Earth's magnetosphere over two decades, Cluster has created brand new opportunities for scientists to spot new or longer-term trends on differing spatial and temporal scales."

Cluster, along with other ESA spacecraft, is also paving the way for forthcoming missions such as the European-Chinese Solar wind-Magnetosphere-Ionosphere Link Explorer (SMILE), which is scheduled for launch in 2023. SMILE will dig deeper into the Sun-Earth connection, and will build upon the remarkable work of Cluster to reveal even more about the complex and intriguing magnetic environment surrounding our planet.

"For two decades now, Cluster has been an exciting and truly cutting-edge mission, sending back all manner of new information about the Universe around us," says Philippe. "Thanks to its unique design, long lifetime, and advanced capabilities, Cluster has unlocked a wealth of secrets about the environment around Earth. Cluster is still going strong, and will continue to help us characterize the phenomena we see around us for—hopefully! – years to come."

Provided by European Space Agency

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