Alfvén Waves: When Earth's Shield Comes under Attack

Dr Andreas Keiling

CREDIT: NASA/Space Weather

Scientia

ALFVÉN WAVES: WHEN EARTH'S SHIELD COMES UNDER ATTACK

The Earth's magnetic field has long protected us from surges of harmful charged particles originating from the Sun, yet physicists still don't entirely understand what happens during this interaction. To explore the issue, **Dr Andreas Keiling** of the University of California at Berkeley studies the complex processes that take place during these so-called solar storms. His work has now begun to unravel the mysteries of the electromagnetic battleground far above Earth's surface.

Solar Storms

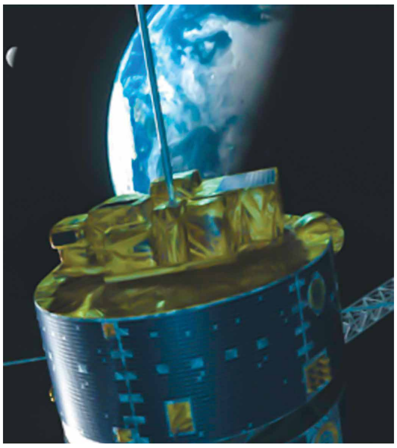
The surface of the Sun is a vibrant, ever-changing landscape. As complex reactions and collisions take place endlessly throughout our host star, it sends a continual stream of hot, charged particles (plasma) hurtling into space in every direction – a phenomenon astrophysicists have dubbed the 'solar wind'. Occasionally, highly energetic events on the solar surface send brief yet powerful bursts of these particles, collectively known as 'coronal mass ejections', in specific directions, in episodes known as 'solar storms'.

Inevitably, some of these plasma surges will stream continually towards Earth – a threat that could have prevented life from ever forming on our planet. However, the Earth has put a safeguard in place that significantly reduces this risk. When plasma interacts with the Earth's magnetic field, electromagnetic forces cause its particles to be deflected, largely preventing them from reaching our atmosphere.

Yet despite this robust shield, Earth's magnetic field is not always invincible against the strongest surges of charged particles. During solar storms, when the energy of the plasma hitting the field is particularly strong, it can have a strong influence on the field – potentially allowing significant amounts of energy to transfer down to Earth's atmosphere. Therefore, it is vital that we understand exactly what is happening when our planet feels the effects of solar storms.

'When a hurricane is forming over the ocean, we want to know where it is heading and what kind of damages it might cause on land. Similarly, when a solar storm in outer space is launched from the Sun, we want to understand how it affects our planet and our near-Earth space environment – or "geospace",' explains Dr Andreas Keiling of the University of California at Berkeley.

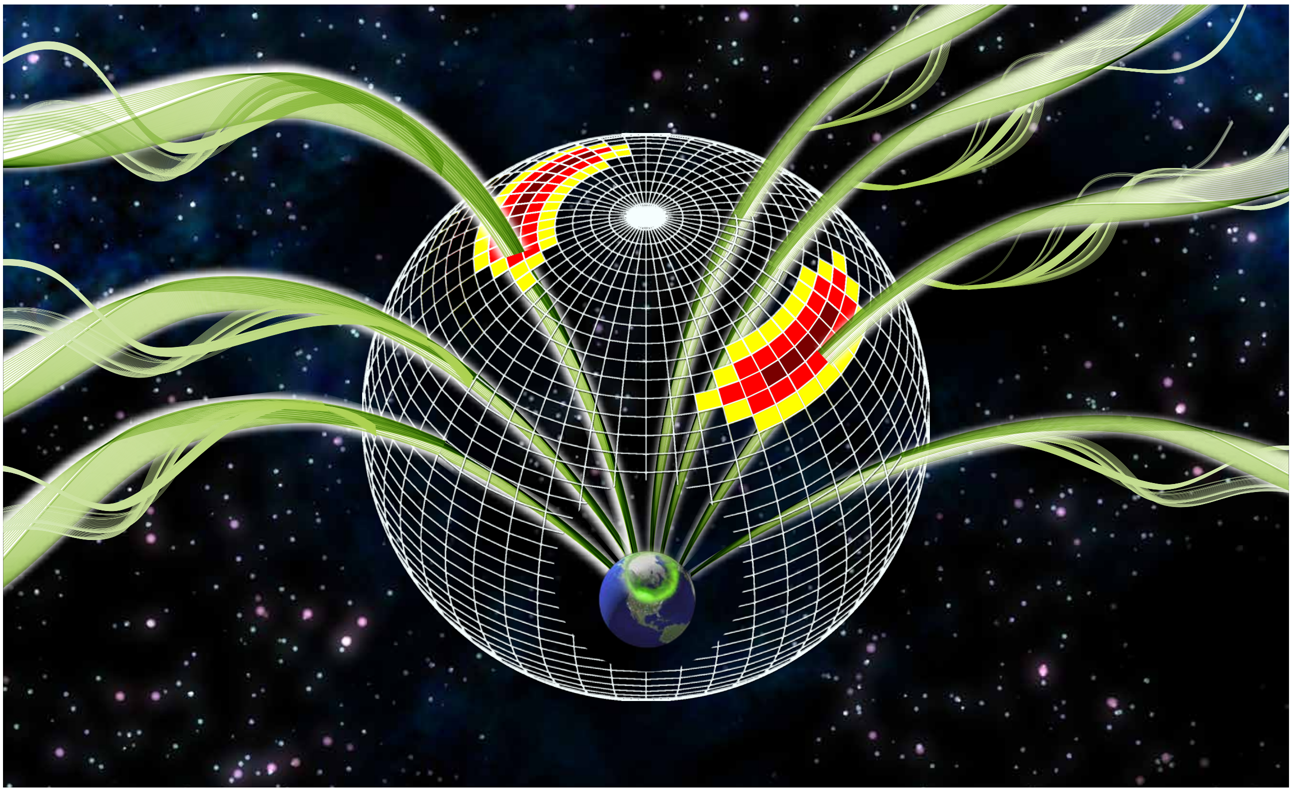
'Solar storms dump increased amounts of energy into geospace, which trickles down to Earth through a sequence of energy transfer processes,' he adds. 'Space physicists study how energy travels through geospace, and how much of this energy reaches Earth's atmosphere.' By gaining a more in-depth knowledge of these processes, Dr Keiling hopes that we will be able to prepare for and mitigate the damage that solar storms create, such as widespread power outages and disruptions to communications.



CREDIT: NASA/Polar satellite

Making Waves

For some time, space physicists have roughly understood how Earth's magnetic field influences incoming solar winds. Through satellite observations,



we now know that after hitting the field, plasma tends to slow down in front of Earth, after which it is diverted around it. Nevertheless, through various mechanisms, energy can cross the magnetic barrier. 'Some of the energy shows up in a special kind of wave, called an Alfvén wave – named after Swedish physicist Hannes Alfvén,' says Dr Keiling. 'In the 1940s, Alfvén first predicted the waves theoretically by describing how magnetic field lines "wiggle" when disturbed by solar energy.'

Another important discovery was that in geospace, some of the energy travels along Earth's magnetic field, which acts like a giant "magnetic funnel" above the polar regions. Alfvén waves preferentially travel along this magnetic funnel toward Earth.

'Waves play a central role in nature. They pick up energy and then carry it to other regions, sometimes very far away from the source region,' says Dr Keiling 'This is their most important role, and that's why it is important to study Alfvén waves in geospace.'

Nature's Most Impressive Light Display

Dr Keiling has now spent years studying the influence of Alfvén waves on the Earth, paying particular attention to how they vary over time and space. In a 2003 study, he and his colleagues focused on where the waves occur above Earth's polar regions. Their research took account of the shape of Earth's magnetic field in high latitudes, where field lines protrude from the north pole – wrapping around the entire planet before disappearing again around the south pole and creating a 'funnel' shape above both poles.

Perhaps most notably, Dr Keiling's team found that Alfvén waves are partly responsible for a remarkable feat of nature we are all familiar with. Because the waves travel along magnetic field lines, they can travel close enough to Earth to reach its polar regions (north and south) when inside the magnetic funnel. When this happens, Alfvén waves cause vibrant swirls and flashes of colour which can be seen with the naked eye. 'In this case, Alfvén waves in outer space do not directly cause the aurora, but instead dump their energy onto electrons, making them go faster,' Dr Keiling explains. 'At some later point, the electrons collide with molecules in the ionosphere, causing them to give off light – the aurora.'

In their study, Dr Keiling's team used the NASA satellite Polar – launched specially to observe the aurora – to investigate Alfvén waves above Earth's poles. 'We discovered that the energy carried by Alfvén waves from far away along the "magnetic funnel" is partially but significantly used to generate the aurora over the entire polar region,' he explains.

This research offered some fascinating insights into the origins of these spectacular events, and the extent to which Alfvén waves are involved in their formation. Using the insights gathered in this early research, the physicists could shed new light on the influence of Alfvén waves on Earth's entire magnetosphere, particularly at times when the solar wind is dangerously energetic.

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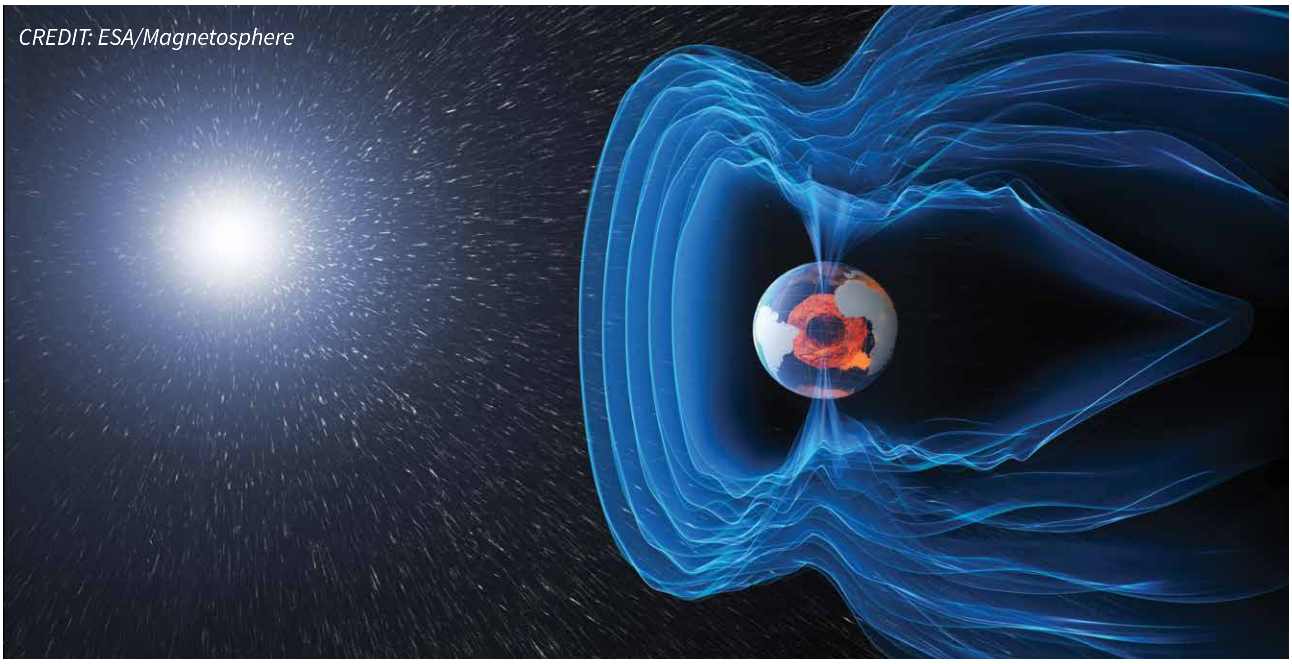

CREDIT: ESA/Magnetosphere

Defending Against Solar Storms

Ambient solar winds may interact with Earth's magnetic field continuously, but in the case of solar storms, Dr Keiling notes that far more energy can be transferred from incoming plasma to our atmosphere – a process for which Alfvén waves can at least partly be held responsible. 'In the case of a solar storm, the solar wind "shakes" the entire magnetosphere strongly, generating much more wave activity,' he explains.

As this shaking becomes more pronounced, the energy of the resulting Alfvén waves will increase, potentially having a strong impact on the total energy dissipated into the atmosphere. However, physicists have previously had little idea of the extent of the waves' influence during intense solar winds. To answer this question, 'we decided to look at the most dynamic space event – the solar storm – and asked: how different is the impact of Alfvén waves during solar storms compared to less disturbed times?' Dr Keiling describes.

In their latest work, Dr Keiling and his colleagues again used the Polar satellite to measure Alfvén waves from above Earth's poles. 'The satellite traversed the "magnetic funnel" relatively close to Earth – at 20,000–30,000 km – while enabling measurements over the entire polar region,' he says.

In this case, the magnetic funnel was particularly useful, because Alfvén waves – which travel along magnetic field lines – could reach the satellite from multiple directions. This gave the researchers a global picture of the total energy due to Alfvén waves flowing toward Earth's atmosphere during solar storms. 'Because of the "funnelling effect", we could capture a significant portion of these waves, even those that might have been generated 200,000 kilometres and more away,' explains Dr Keiling.

Dr Keiling and his colleagues analysed Polar's measurements collected over six years, which is half a solar cycle, when many bursts of plasma originating from the Sun reached Earth's magnetosphere. For the first time, the measurements allowed the team to quantify precisely how much more energy is carried toward the atmosphere in the form of Alfvén waves during solar storms.

'We found that the energy input is about four times higher during storms, meaning there is even more energy available from Alfvén waves to power parts of the aurora,' says Dr Keiling. The experiment confirmed that Alfvén waves do indeed play an increased role in carrying energy to Earth's atmosphere during solar storms.

Continuing Research

The results uncovered by Dr Keiling and his colleagues provide much-awaited answers for space physicists and other researchers interested in the processes that play out in Earth's magnetosphere, particularly during strong surges of solar activity. However, mysteries still remain about the physical processes that form Alfvén waves, giving the researchers a wide scope for future research.

In the future, Dr Keiling hopes to study these processes in yet more detail. 'Our work continues,' he says. 'We want to understand more aspects of these waves, such as how the solar wind affects the turning on and off of these waves.' Through this work, researchers could soon gain a more in-depth knowledge of the systems that protect us from some of the most harmful effects of outer space.

Meet the researcher

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Born in Berlin, Germany, Dr Andreas Keiling was an undergraduate student at Imperial College, London, before moving to the University of Minnesota, where he completed his PhD in 2001. Following a two-year postdoctoral position at Paul Sabatier University in Toulouse, France, he moved to the Space Sciences Laboratory at the University of California, Berkeley in 2004, where he currently works as a Research Physicist. Dr Keiling has also taught at the University of Wisconsin-River Falls and the University of Maryland-University College, and is a visiting researcher at institutions in Japan and Korea. His research covers a broad range of topics within space science, and he has been the editor of four scientific books, and the organiser of numerous conferences on this subject.

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