

# Ultrafast substorm auroras explained (w/ video)

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(PhysOrg.com) -- From time to time, sudden releases of energy in Earth's magnetosphere lead to major disturbances that result in bright auroral displays over the planet's polar regions. These auroras are caused by a phenomenon known as a geomagnetic substorm. The precise cause of these substorms has been debated for decades, but new computer simulations, allied to analysis of data from ESA's Cluster spacecraft, are now filling in many of the missing pieces in the puzzle.

Earth's magnetic field is continuously buffeted by [clouds](#) of energetic, electrically charged, [particles](#) – mainly electrons and protons - which are carried in the solar wind or released during huge explosions on the Sun, known as coronal mass ejections.

The magnetic bubble that surrounds [Earth](#) – the magnetosphere – generally protects the planet from these particles, but the shield is sometimes breached, enabling particles and energy to accumulate in the magnetotail.

This stored energy is subsequently released as the result of a sudden rearrangement of the magnetic field lines. Electrified particles then race along the field lines and enter the atmosphere above the magnetic poles, creating bright rings of light in the form of colourful auroras.

Although this basic process has been recognised for many years, there has been no scientific consensus about where the geomagnetic substorms are initiated.

One question concerned whether they are caused by a sudden disruption of electric current about 64 000 km from the planet, or by a process called magnetic reconnection which occurs much further down the magnetotail, at a distance of around 125 000 – 200 000 km.

Although recent research appears to favour the magnetic reconnection mechanism, a major problem with this theory involves the rapid onset of auroras after the sudden realignment of the [magnetic field](#) lines.

According to established theory, the energy from the reconnection event is carried by Alfvén waves - a type of magnetic wave that propels the charged particles in the plasma towards and away from Earth.

However, these Alfvén waves travel quite slowly, reaching Earth after a travel time of about 250 seconds. They cannot account for some observations of substorm events which indicate that auroras intensify less than one minute after the onset of reconnection – much earlier than expected. This discrepancy led to the suggestion that another, faster, type of wave – known as a kinetic Alfvén wave (KAW) – might also be generated during a substorm.

Unlike ordinary Alfvén waves, which move both ions and electrons towards Earth at 500 - 1000 km/s, kinetic Alfvén waves influence only electrons. This enables them to travel much faster through the plasma, at speeds of several thousand kilometres per second.

In an effort to investigate these questions, Michael Shay, a professor at the Bartold Research Institute in the Department of Physics and Astronomy at the University of Delaware, began a series of simulations on a Cray XE6, one of the most powerful computers in the world. Located at the National Energy Research Scientific Computing Center, the HOPPER supercomputer crunched away at solving fluid equations that simulated the behaviour of individual particles energised by

reconnection.

"We ran a very simple system, and simulated how the reconnection event released energy in the plasma sheet of charged particles," said Shay. "We were looking for a faster mechanism for propagating the signal from the explosion than the Alfvén waves that were already widely recognised."

The simulations confirmed that KAWs could be generated by reconnection and then propagate rapidly away from the site of the explosion, reaching Earth in less than one minute. They also confirmed that KAWs carry enough energy to intensify auroras.

Further verification of this result came from Jonathan Eastwood, a Research Fellow at The Blackett Laboratory, Imperial College London, who began to trawl through data sent back by the four [Cluster spacecraft](#) during their decade-long exploration of near-Earth space.

Eastwood was sifting through the data returned by the Fluxgate Magnetometer (FGM) and the Electric Fields and Waves (EFW) instrument on each spacecraft, in a search for measurements which coincided with magnetic reconnection events in the magnetotail.

"I found 18 events which occurred at the time the four spacecraft were flying through the tail region," said Dr. Eastwood. "The fast signal predicted by Michael Shay showed up in the Cluster data, supporting the theory that kinetic Alfvén waves generated by reconnection were rapidly energising the auroras."

"It's rather like what happens in a thunderstorm," he added. "The fast-moving lightning flash arrives first, followed some time later by the slower sound waves of the thunderclap."

"The Cluster data also supported the theory that reconnection occurs far

from Earth, some 125 000 - 200 000 km down the tail."

"We have shown that kinetic Alfvén waves are no longer simply a theoretical conjecture, but an entirely plausible source for generating [auroras](#)," said Shay.

"This research is a striking example of how Cluster data are now being used by theoreticians around the world to back up their simulations and transform scientists' understanding of the complex processes that take place in near-Earth space", said Arnaud Masson, ESA Deputy Project Scientist for the Cluster mission.

**More information:** Shay, M.A., J.F. Drake, J.P. Eastwood, T.D. Phan, Super-Alfvénic Propagation of Substorm Reconnection Signatures and Poynting Flux, *Phys. Rev. Lett.*, 107, 065001, 2011

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