Heart of the black auroras revealed by Cluster

April 9 2015

This dramatic panorama shows a colourful, shimmering auroral curtain reflected in a placid Icelandic lake. The image was taken on 18 March 2015 by Carlos Gauna, near Jökulsárlón Glacier Lagoon in southern Iceland.

Most people have heard of auroras - more commonly known as the Northern and Southern Lights - but, except on rare occasions, such as the recent widespread apparition on 17 March, they are not usually visible outside the polar regions. Less familiar are phenomena known as black auroras, dark patches which often subdivide the glowing curtains of red and green light.

For almost 15 years, ESA's four Cluster satellites have been orbiting Earth, sending back data on electrical fields, magnetic fields and particle populations as they sweep above the region of space where these colourful curtains of light are created.

By flying in close formation through Earth's magnetosphere – the invisible magnetic bubble that surrounds our planet - the quartet has gathered a treasure trove of multi-point observations which help to cast light on the physical processes taking place in auroral nurseries and the secrets of how the dark "cavities" in the shimmering auroras are created.

Auroras are known to be generated by beams of electrons which are accelerated along Earth's magnetic field lines. The fast-moving electrons collide with atoms in the ionosphere at altitudes of between 100 to 600 km. This interaction with oxygen atoms results in a green or, more rarely, red glow in the night sky, while nitrogen atoms yield blue and purple colours.

Whereas bright auroras are created by electrons plunging downward into the ionosphere, neighbouring black auroras are caused by electrons escaping from the ionosphere - like a kind of anti-aurora. However, until now, scientists have been struggling to explain the relationship between the two auroral types.

The first observations of the dynamical behaviour of black auroras were made by the four Cluster spacecraft and reported back in 2001. This study revealed that the electron population of the ionosphere becomes more and more depleted in these dark regions.

Now scientists from the UK and Sweden have used the huge archive of Cluster data to develop the first accurate model of electric fields and currents at the heart of the black auroras. Their new paper, published in the *Journal of Geophysical Research - Space Physics*, accounts for the observed evacuation of electrons from the ionosphere to the magnetosphere and explains the dynamic behaviour of the black aurora.

The scientific collaboration came about as a result of a series of three week-long workshops hosted by the International Space Science Institute (ISSI), which were led by Andrew Wright, a researcher at the School of Mathematics and Statistics in University of St Andrews and a co-author of the paper.

"The ISSI, which is partly funded by ESA, provides a unique facility for scientists to meet and discuss a common research interest, and it was instrumental in bringing us together. Our research resulted directly from our team participating in these workshops," said Wright.

The first step in the diagnosis of the black auroras' creation was made by Tomas Karlsson, a researcher in the Department of Space and Plasma Physics at the Royal Institute of Technology in Stockholm, Sweden, and a co-author of the paper.

"I have been studying the Cluster data archive over many years because the four spacecraft provide multipoint measurements when they fly through a region of near-Earth space," said Karlsson. "This makes it possible to analyse how physical properties evolve over time.

"On a few occasions, particularly on 18 February 2004, I noticed a weird combination of electrical and magnetic field measurements that were different from normal, and I wanted to understand the physics behind the data. On each occasion, the Cluster spacecraft were flying over the night-time auroral region.

"I presented the data at a workshop held by the International Space

Science Institute in Bern, Switzerland, in 2012. This led to a collaboration with team leader Andrew Wright and with Alex Russell, who agreed to try to model the Cluster measurements."

By concentrating on data collected by the Electric Field and Wave (EFW) and Fluxgate Magnetometer (FGM) instruments on the four Cluster spacecraft, the two UK scientists were able to generate a computer model that explained the unusual readings.

"We found strong evidence of a two-way interaction between the ionosphere and the magnetosphere," said Alexander Russell, a post-doctoral Research Fellow in the Department of Mathematics, University of Dundee, UK, and lead author of the paper in JGR – Space Physics.

"Auroral arcs are created by electric currents. The beam of electrons shooting down towards Earth along magnetic field lines is actually an electric current aligned with Earth's magnetic field. It is called an upward, field-aligned current because the negatively charged electrons are moving downward.

"On the other hand, when a downward magnetospheric current meets the ionosphere, electrons are driven upwards and 'sucked' from the ionosphere, creating a black aurora. However, when the electron density in the ionosphere drops markedly the black aurora becomes less intense.

"This evacuation of the ionosphere is essential in shaping the black auroras. The process is much more important on Earth's nightside than on the dayside because sunlight creates new electrons which fill the 'hole'.

"Our model demonstrates how this two-way electrodynamic coupling between the magnetosphere and ionosphere works. This is made possible by a horizontal drift of ions in the ionosphere, known as the Pedersen current, which closes the current system."

The main feature of the model is a field-aligned current system comprising a narrow region of downward current sandwiched between two much broader - and much weaker - upward currents. If the downward current intensifies, it can cause a large number of electrons to move upward into the magnetosphere, thus depleting the ionosphere and creating a density cavity.

"In our paper we think of the currents flowing into the ionosphere as being carried by waves which propagate along magnetic field lines," said Andrew Wright. "This a key feature of our theory. The depleted density and electrical conductivity in a black aurora substantially modify the wave reflected from the ionosphere, producing signatures in the magnetosphere like the unusual Cluster observations.

"For the first time we are able to reproduce the phenomenon of the black aurora and in particular what happens at its heart, where strong electric fields are present. We hope that this will lead to a better understanding of the interaction between the upper atmosphere and the space environment."

"This is a very nice example of how theorists and experimenters can make much greater progress when they work together instead of separately," said Tomas Karlssson.

"The paper presents a major improvement of the existing magnetosphere-ionosphere coupling model," said Philippe Escoubet, ESA's Cluster project scientist.

"The modelling of the ionosphere's physical state is of prime importance in our modern technological society. For example, GPS signals can be modified by changes in electron content in the ionosphere, so that their navigational and timing accuracy are significantly reduced. Improved modelling of the ionosphere is necessary to make the necessary corrections.

"Aircraft flying over the North Pole rely on radar and radio signals which can also be affected by changes in the ionosphere, so this is not just an academic exercise."

More information: "Magnetospheric signatures of ionospheric density cavities observed by Cluster." *Journal of Geophysical Research*.
DOI: 10.1002/2014JA020937

Provided by European Space Agency