

Space physics

Rhythms of the auroral dance

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Earlier this year, the four satellites of the Cluster mission passed through part of the electric circuit that causes aurorae. Their observations support the view that intense aurorae form in regions largely devoid of electrons.

Early in the space age, measurements from rocket flights established that bright auroral displays (Fig. 1) are associated with beams of accelerated electrons from space¹. Dynamic displays that are visible with the unaided eye are known as discrete aurorae. Ground-based research on auroral forms and motions, using all-sky cameras, suggested that the electrons are accelerated by electric fields aligned along the direction of the Earth's magnetic field lines². Later, more sophisticated satellite measurements established the existence of

such electric fields³. But it has always been difficult to reconcile these quasi-steady electric fields with standard plasma theory, which predicts that cold background electrons in the ionosphere should quickly move in the direction opposite to the electric field and cancel it out.

So we have a long-running mystery. Understanding when and how these magnetic-field-aligned electric circuits are created is key to explaining how aurorae form, and one important question is the timescale over which the fields evolve. On page 724 of

this issue⁴, Marklund and colleagues report on the first multi-satellite encounter with the auroral circuit, and the resulting observations that bear on this question.

There are severe limitations on the measurements possible from a single satellite. In particular, when the satellite records a change, it is usually unclear whether the structure of the auroral electric circuit is really changing, or whether the satellite is simply moving to a different part of it. This spatial-temporal ambiguity can be addressed by using several coordinated satellites, preferably with identical instruments. The first such mission to be flown is the European Space Agency's Cluster, which consists of four tightly grouped satellites, whimsically named after Latin dances: Rumba, Salsa, Samba and Tango. The Cluster satellites had a perigee (point of orbit closest to Earth) well above the expected electron acceleration region, the site of the important physics. So the satellites' encounter with the region was not predicted, and is all the more exciting for that.

Figure 1 of Marklund and colleagues' paper (page 724) shows the overall auroral circuit, in which current flows towards Earth from space, through the magnetosphere and the ionosphere, and then out into space again. Figure 2 here depicts the two acceleration regions (downward and return) in more detail. These regions include currents, driven by magnetospheric processes, and the mysterious electric fields that accelerate electrons to the high energies needed to create aurorae. Surveys from single-satellite missions have shown⁵ that auroral electric fields rarely occur above an altitude of 15,000 km. Yet on 14 January 2001 Cluster encountered just such a rarity: Rumba, Salsa, Samba and Tango traversed a portion of the auroral acceleration structure at an altitude of 22,000 km, passing through it like beads on a string.

This chance encounter was actually with the return current region, shown in Fig. 2b. The satellites' most notable finding was that the electric fields evolved over a characteristic timescale of 200 seconds. Given the observed strength of the auroral return current, this would be about the time needed to completely evacuate the geomagnetic field line of electrons. Electric currents must form a closed loop (in the absence of a build-up of charge in space), meaning that the return current should exhibit the same behaviour as the downward current above the aurora itself. These findings support the interpretation that intense aurorae are associated with a reduction of the background electrons in the ionosphere to near-zero densities.

The results from Cluster's fortuitous encounter with auroral acceleration structures agree well with other findings, such as the tendency for discrete aurorae to form in darkness, rather than sunlight⁶ (the reason is that ultraviolet light from the Sun creates free

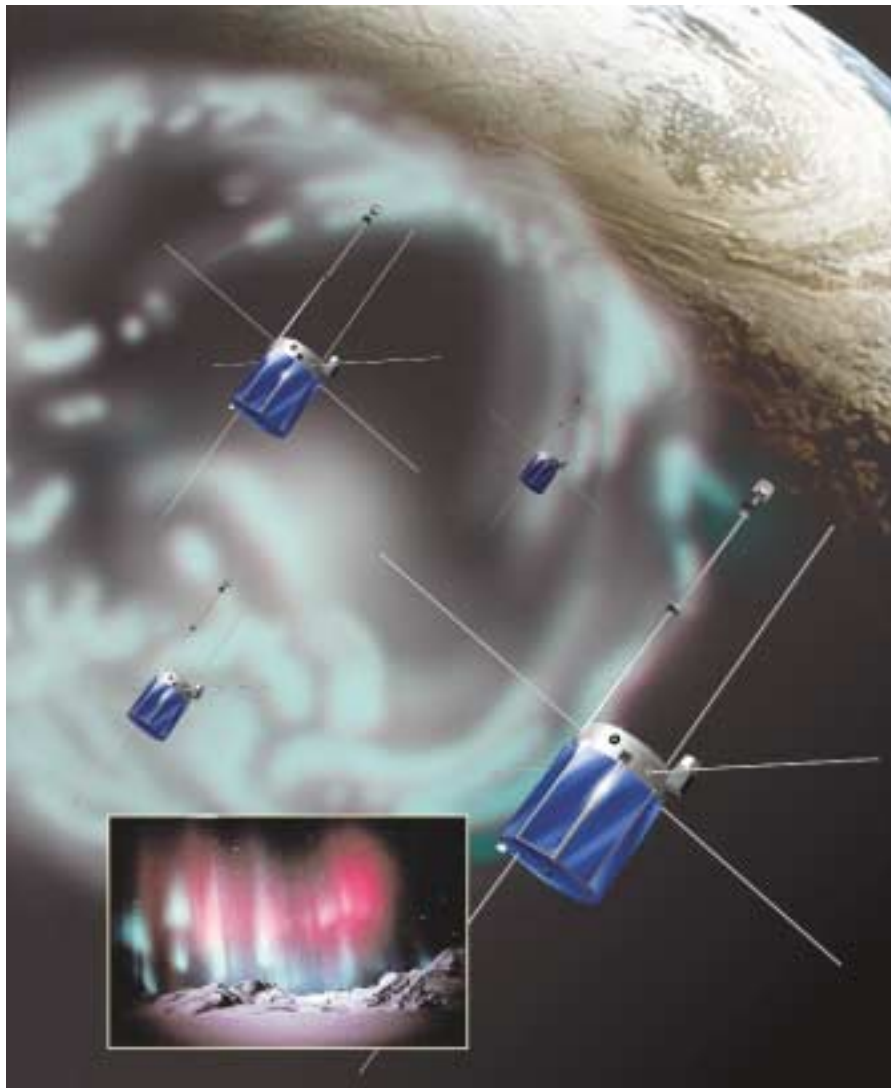


Figure 1 Auroral displays seen from space and (inset) from Earth. The main image is an artist's impression of what we can hope is the future: a mission along the lines of Cluster except at altitudes more suitable for auroral observation. Several satellites with identical instruments should traverse the aurora simultaneously. (Main image courtesy of B. Mauk, JHU/APL.)

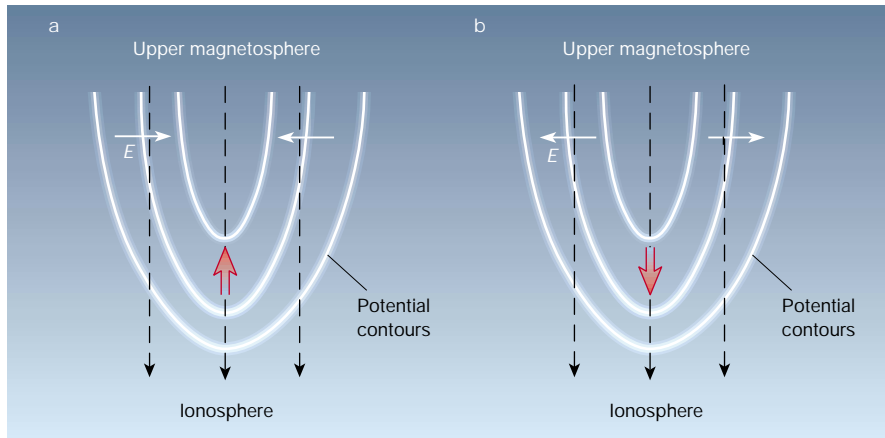


Figure 2 The auroral circuit. (See also Marklund *et al.*'s⁴ Fig. 1 on page 724.) a, Converging electric fields occur in regions of currents leaving the ionosphere and create intense aurorae. Here the electrons are being accelerated downwards, so current flow is upwards (because electrons are negatively charged, current flows in the opposite direction to electrons). b, These currents are 'closed' by the region of auroral return current, which has been observed by satellites of the Cluster mission and is described by Marklund *et al.*⁴. Here electrons are being accelerated upwards, so current flows downwards. Lines in black show Earth's magnetic field; red arrows indicate the auroral currents; E , the accelerating electric fields. Acceleration occurs because charged particles such as electrons gain or lose energy when crossing potential contours (lines of constant electric potential).

electrons in the ionosphere, by separating them from neutral atmospheric atoms). The definitiveness of Marklund and colleagues' conclusions is limited by the fact that the observation was necessarily of an auroral oddity (the auroral structure was unusually high in altitude, or it would not have been detected), and because only the auroral return current and associated electric field were observed. Whether flights through a typical aurora, preferably through the downward acceleration region, would show the same behaviour cannot be known for sure. A dedicated multi-satellite auroral mission, such as shown in Fig. 1, is needed for a final verdict.

It is clear, though, that Marklund and colleagues' paper represents a first look at the future of auroral research. The spatial and temporal ambiguities of single-satellite

measurements have hampered progress for years, and nearly all auroral scientists are eager to see a Cluster-like configuration flown at altitudes typical of the aurorae. In the meantime, the rich data set provided by Marklund *et al.* will be scrutinized thoroughly to see whether inferences made from single-satellite measurements hold up. ■

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