Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 61 (2018) 2050–2056

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Electric potential structures of auroral acceleration region border from multi-spacecraft Cluster data

S. Sadeghi [a], M.R. Emami [a,b,*]

[a] Department of Computer Science, Electrical, and Space Engineering, Luleå University of Technology, Box 812, Rymdcampus, S-981 28 Kiruna, Sweden
[b] Institute for Aerospace Studies, University of Toronto, Toronto M3H 5T6, Canada

Received 7 June 2017; received in revised form 1 January 2018; accepted 16 January 2018
Available online 31 January 2018

Abstract

This paper studies an auroral event using data from three spacecraft of the Cluster mission, one inside and two at the poleward edge of the bottom of the Auroral Acceleration Region (AAR). The study reveals the three-dimensional profile of the region's poleward boundary, showing spatial segmentation of the electric potential structures and their decay in time. It also depicts localized magnetic field variations and field-aligned currents that appear to have remained stable for at least 80 s. Such observations became possible due to the fortuitous motion of the three spacecraft nearly parallel to each other and tangential to the AAR edge, so that the differences and variations can be seen when the spacecraft enter and exit the segmentations, hence revealing their position with respect to the AAR.

Keywords: Auroral acceleration region; Auroral electric potential structures; Multi-spacecraft Cluster data; Multi-spacecraft observations

1. Introduction

Auroral emissions are one of the end products of the interaction between the solar wind, planetary magnetic field, and the ionosphere. In the analysis of in-situ data, the term *auroral arc* typically refers to regions of electron precipitation with signatures of acceleration by electric fields parallel to the geomagnetic field (Paschmann et al., 2002). Such electric fields were predicted by Alfvén (1958), and confirmed experimentally by in-situ measurements revealing downward monoenergetic electrons observed by sounding rockets (McIlwain, 1960), upward ion beams by S3-3 satellite (Shelley et al., 1976), and direct observations (Mozer et al., 1977). The most dominant acceleration process for producing stable auroral forms is acceleration by quasi-static parallel potential differences (Hultqvist, 2008). They are called quasi-static since they are stable on a time scale longer than the time needed for a charged particle to pass through them. The potential drop corresponding to the parallel electric field has its contours along the magnetic field lines, resulting in U-shaped potential structures at the bottom of which resides the parallel electric field/potential drop. On the two sides of such a potential structure, the electric field is converging, hence the name *converging* potential structures (Gurnett, 1972). Because of the negative divergence of the electric field, these are also called *negative* potential structures. As such, auroral arcs are associated with regions of upward field-aligned currents, upward ions, downward electrons, and negative potential structures with bipolar converging electric fields. The electric field can also be monopolar, in which case it is represented with S-shaped potential structures (Mizera et al., 1982), indicating incomplete decoupling of the magnetospheric and ionospheric electric fields. When a U-shaped potential structure affects the electrons, those at the center of the structure gain more energy

* Corresponding author at: Luleå University of Technology, Box 812, Rymdcampus, S-981 28 Kiruna, Sweden.
E-mail address: reza.emami@ltu.se (M.R. Emami).

https://doi.org/10.1016/j.asr.2018.01.024
0273-1177/

than those at the edges. This results in the *inverted-V* signature, expressing their relatively narrow-energy (*monoenergetic*) distribution.

The peak energy of the downgoing electrons provides a measure of the potential drop on the magnetic field line above the satellite. Complementarily, upgoing beams of accelerated ions are also usually observed with the arcs, and provide a measure of the potential drop on the field line below the satellite. The downgoing electrons, i.e., above the satellite, provide information on the acceleration source above the satellite, and the upgoing ions, i.e. below the satellite, yield information about the source below. For a negative U-shaped potential structure, the acceleration potential inferred from the upgoing ions roughly matches the potential calculated from integrating the electric field along the satellite trajectory, as they both represent the acceleration potential below the satellite (Chiu et al., 1983; Block, 1990; Marklund, 1993). In the altitude range where the downward/upward acceleration of electrons/ions takes place, a density cavity is formed along the geomagnetic field lines (Persoon et al., 1988). The region in space where such quasi-static acceleration of the charged particles takes place is called the Auroral Acceleration Region (AAR), which is mainly concentrated between 4000 and 12,000 km altitude (Paschmann et al., 2002), but a percentage of the acceleration potential can be located even beyond 14,000 km altitude (Mozer and Hull, 2001; Marklund et al., 2012; Johansson et al., 2004; Li et al., 2014).

There are also downward parallel electric field regions, between 1000 and 4000 km altitude, creating diverging (positive) potential structures, accelerating electrons upward and corresponding to the return current (Marklund and Karlsson, 1997; Hultqvist, 2002). These are thought to be the reason behind the black aurora, i.e., the dark filaments between auroral arcs. Fig. 1 illustrates the converging and diverging electric potential structures with the parallel electric field at the bottom (Marklund et al., 2011a).

In addition to the quasi-static process/component, Alfvén waves are also known to be capable of accelerating electrons, especially close to the Polar Cap Boundary

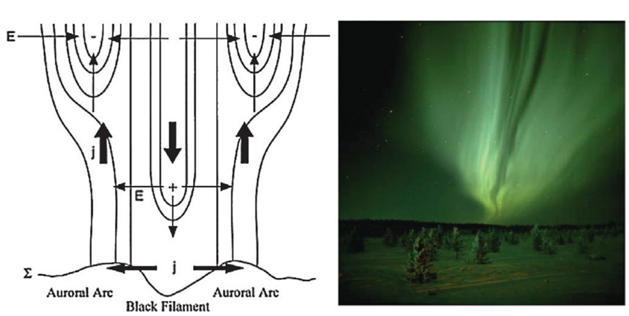

Fig. 1. Schematic of two converging electric potential structures separated by a diverging potential structure (left) representing two parallel arcs separated by dark filaments (right) (From Marklund et al., 2011a).

(PCB) and at arc boundaries (Paschmann et al., 2002). The parallel electric field can form at the wave front and contribute to particle acceleration (Fedorov et al., 2004; Keiling, 2009). Kinetic Alfven Waves (KAW) had been suggested to explain the perpendicular electric fields since the first observations (Goertz, 1984).

To reveal the spatiotemporal features of the AAR, multi-spacecraft observations are needed. The satellite pair in the Dynamics Explorer mission made observations far below and above the bottom of the AAR, revealing important features of the coupling between the two regions (e.g., Weimer et al., 1985). With the multi-spacecraft opportunity provided by the four satellites of the Cluster mission, Marklund et al. (2011a) obtained the two-dimensional synthesis of an electric potential structure, using two of the satellites passing inside the AAR, revealing the altitude distribution of the electric potentials and its stability within a period of 5 min. In another event study, Marklund et al. (2011b) use Cluster and DMSP radial passages of the oval to reveal overlapping quasi-static and broad-energy acceleration processes at the polar cap boundary at the top of the AAR. Sadeghi and Emami (2017) study mission concepts with a cluster of 6–12 cubesats with specific onboard payloads for studies of auroral acceleration region through measuring field-aligned currents and quasi-static features. So far, there has been no direct observation significantly close to the bottom of the AAR with one satellite inside, i.e., above the bottom, and one at the edge, moving tangential to the AAR poleward border to reveal the shape of the AAR as a three-dimensional volume. Here, we present such an observation, made by three of Cluster satellites. Fig. 2 shows the trajectories of all four Cluster spacecraft, of which Cluster 1, 3, and 4 are used, as they pass inside or at the poleward border of the northern hemisphere auroral oval.

The spacecraft trajectories are mainly in the direction from the dusk towards the noon, with Cluster 3 (C3) and Cluster 4 (C4) about 0.3–0.8° of latitude poleward of the path of Cluster 1 (C1) in the RoI (The region of interest, i.e. the part of the trajectories inside the yellow box). In this event, the spacecraft are passing through regions generally known to be the poleward borders of the upward current region (e.g., Iijima and Poterma, 1978). The distance between the trajectory of C1 and that of C3/C4 enables us to reveal the total acceleration potential variations, and hence the spatial features of the AAR, while the time differences between the passages allow for addressing the ongoing temporal variations/stabilities. The event takes place in a period of low geomagnetic activity, with both AU and AL indices below 100 nT, and K_p index below 2.

The region on the trajectories marked by a blue rectangle in Fig. 2 delimits the main RoI. The elongation direction of the rectangle has been derived from the East-West deviation angle of a current sheet observed there by Cluster 1.

Cluster 3 is on the same path of Cluster 4, lagging behind (e.g. in reaching any constant-MLT meridian) by