EPSC Abstracts
Vol. 5, EPSC2010-667, 2010
European Planetary Science Congress 2010

Auroral Acceleration Processes: Comparisons Between Earth and the Gas Giants

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Abstract

Field-aligned currents provide momentum transfer between different plasma regimes. At the Earth, where magnetospheric convection is driven by the solar wind, field-aligned currents provide the closure current in the ionosphere to move the ionosphere through the neutral atmosphere that is a source of frictional drag. At the gas giants, plasma from the moons is brought up to corotation speed by the closure of field-aligned currents driven by the ionosphere. Furthermore, Alfvén waves propagate between the ionosphere and magnetosphere to communicate changes. The ubiquity of field-aligned currents leads to a commonality in auroral acceleration processes. In particular, we expect to see energetic electrons accelerated by large-scale parallel electric fields, low energy electrons carrying current into the ionosphere, and Alfvén-wave accelerated electrons.

1. Introduction

The magnetospheres of the Earth and the gas giants appear to be significantly different, both in terms of size and the relative importance of the solar wind in driving magnetospheric plasma convection. Furthermore, unlike the Earth, the moons of the gas giants are the major source of plasma. Nevertheless, there are common physical processes operating. Most importantly, the ionosphere and magnetosphere for each of the planets need to be coupled. Magnetospheric plasma convection is controlled by the solar wind, or the mass addition, while the ionosphere tends to corotate because of collisions with the neutral atmosphere. This difference in convection requires transfer of momentum between the ionosphere and magnetosphere, which is mediated by field-aligned currents.

Field-aligned currents are also associated with field-aligned acceleration of electrons, and hence aurora. In the next section we review the physical processes responsible for field-aligned currents, and the corresponding acceleration processes, based on terrestrial phenomena. In section 3 we extend this discussion to the gas giants, again emphasizing the role of field-aligned currents. We summarize the discussion in the last section.

2. Field-Aligned Currents

Strangeway [4] discusses the role of field-aligned currents in providing the connection between the terrestrial magnetosphere and ionosphere. In particular he emphasizes that within the magnetosphere the **jxB** force is balanced by plasma pressure gradients and plasma inertia forces. For the ionosphere, on the other hand, the **jxB** force balances frictional drag through collisions with the neutrals. Field-aligned currents provide the linkage between the transverse magnetospheric and ionospheric currents.

Strangeway [4] also emphasizes that field-aligned currents can be quasi-static, or wave-like. In particular, the shear-mode carries field-aligned currents, and it is this mode that transmits information concerning changes in the magnetosphere to the ionosphere. Thus we now know that the aurora can be considered to be of three types [1]: Energetic electron aurora, carrying large-scale upward field-aligned currents, often referred to as inverted-V electrons; the downward current region, which often contains low energy electrons; and the Alfvén aurora, where bi-directional electrons are observed. The Alfvén aurora appear to be transient in nature. Also, because the Alfvén waves have short transverse scales, they can maintain parallel electric fields through the electron inertia term [2]. Thus the Alfvén aurora are associated with high fluxes of low energy electrons.

3. The Gas Giants

The dynamics of the Earth's magnetosphere is dominated by reconnection of the Earth's magnetic field with the Interplanetary Magnetic Field (IMF). Furthermore, while the ionosphere does contribute to the plasma within the magnetosphere, the solar wind is a major source of plasma. At the gas giants reconnection with the IMF is much less important, since the magnetospheres are rotating rapidly and the IMF is substantially weaker. Furthermore, the moons are a significant source of plasma. The prime example is the Jovian moon, Io.

Because the plasma from Io is locally ionized, and the parent neutral population is moving at the orbital velocity, rather than the corotation velocity, there is a difference in flow between the iogenic plasma and the neutral atmosphere of Jupiter. Thus field-aligned currents must flow to provide the momentum transfer between the two plasma regimes [3].

We can take the lessons learned from the Earth and apply them to the gas giant magnetospheres. In particular, we expect the three different types of aurora as discussed briefly in section 2. This also reinforces the connection between auroral acceleration processes and Jovian decametric radiation (DAM) and Saturn Kilometric Radiation (SKR). At the Earth it has been demonstrated that Auroral Kilometric Radiation (AKR), which is the terrestrial analog to DAM and SKR, is associated with electron acceleration by parallel electric fields above the aurora [5].

4. Summary and Conclusions

The terrestrial magnetosphere is dominated by solar wind driven reconnection, while the magnetospheres of the gas giants are dominated by rotation. Furthermore, the moons are the primary source of plasma for these magnetospheres. Nevertheless, despite these differences, momentum transfer between the magnetosphere and the ionosphere requires field-aligned currents and Alfvén waves to flow between the ionosphere and the magnetosphere. Thus there are similar acceleration processes acting at the Earth, Jupiter, and Saturn.

As a consequence of these similarities we expect to see signatures of acceleration by large-scale parallel electric fields, upward flowing electrons carrying current into the ionosphere, and Alfvén-wave accelerated electrons.

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