Cluster, Equator-S and the magnetosphere

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The article provides a quick tour through auroral and magnetospheric plasma physics. New insights to be gained by a successful Cluster mission concern the dynamic role of three-dimensional and small-scale structures in the interaction with the solar wind and the coverage of the coldest plasma constituents. This will be measurable by controlling the spacecraft potential.

**Keywords:** aurora borealis; reconnection; meso-scale structures; potential control

1. Introduction

The magnetosphere has perhaps been the favourite subject of research of Professor Willi Riedler but by far not the only one. The breadth of his interests and achievements will be illustrated by the ensemble of articles collected in this volume. In this article we ask ourselves why this man got so fascinated by the magnetosphere, what the Cluster mission might promise to him and us, and what he gained from the Equator-S mission. Certainly much of his affection for the magnetosphere is accidentally related to his first experiences as a young scientist in Northern Scandinavia, where the magnetosphere manifests itself so brilliantly by the aurora borealis. The author had similar experiences and shares the fascination.

In 1969, Willi Riedler was invited to fly an instrument on a Norwegian sounding rocket, manufactured in the newly founded Institut für Nachrichtentechnik und Wellenausbreitung of the Technische Hochschule Graz, of which he has been the director ever since. This was the first space experiment of Austria. The first task in those days was to just register what kind of particles came down from the magnetosphere into the upper atmosphere and created the evasive northern lights. But soon the questions started to be more ambitious:

Where are these particles accelerated, by which processes, from where is the energy derived, what is the origin of the fascinating auroral forms and their motions? Furthermore, the payloads became more complex. Whole laboratories were flown, like the Porcupine payloads to which Willi Riedler contributed an ion detector. Satellites explored the inaccessible heights by sounding rockets. However, Willi Riedler’s most original contribution to this research was his choice of a low cost approach which made use of the fact that from balloon altitudes (up to 36 km) one can measure the X-ray bremsstrahlung of the high energy component of the auroral particle spectrum and the electric fields. So he flew some 50 relatively small and simple payloads from ESRANGE in Kiruna and became one of the leading figures in magnetospheric ballooning worldwide. One result of this has been his long-lasting chairmanship of the COSPAR Panel of Scientific Ballooning.

What are we after when we register the auroral light from infrared to X-rays, when we measure the electric and magnetic fields from ground to far above the ionosphere and the distribution of ions and electrons in energy and direction with the best possible resolution and the widest possible range? Do we just want to find a better explanation of the northern lights or aurora borealis than the often heard simple statement “energetic particles come from the sun, enter the earth’s magnetic field and run down the field line until they hit the denser upper atmosphere where they...”
are stopped and excite the atmospheric atoms and molecules to emit the visible light. This is actually our first goal, but we want to go further, we want to understand the whole combination of processes of which only one result is the aurora borealis; others are the radiation belts, the magnetic storms and a host of striking or rather subtle phenomena not noticeable from the earth. The reward will be the ability to generalize the obtained insights so that they may be applied to the understanding of much of the high energy radiation that the astronomers observe from the most dynamic and exotic sources in the universe.

2. Geotail, Cluster and Equator-S

What is the magnetosphere? It can be defined as a magnetic obstacle in the solar wind plasma flow. It has two peculiar characteristics, more or less common to the magnetic fields of other planets, but very different from the magnetic environment of hot stars. The magnetic field is filled with an extremely tenuous plasma, mostly not even one ion-electron pair per cubic centimeter, and this highly conducting plasma is shielded from the planetary surface by a neutral, i.e. non-conducting atmosphere. Stellar atmospheres, however, like the solar corona have much higher densities and are electrically conducting all the way to the stellar interior. The consequence of this is that the magnetic field of a hot star, at least its upper layers, is firmly attached to the stellar interior. It may be transported with slow convection in these layers, but the magnetic field firmly couples the plasma within a flux tube. Not so in the earth's magnetosphere. There, the dilute and hot plasma can flow relative to the surface of the planet only subject to some friction with the atmospheric neutral particles at the lower ends of the magnetic field lines. What makes it flow? Forces applied at high altitudes, many earth's radii away from the surface (Fig. 1). And these forces, whatever their origin, are transmitted by electric currents which close in the still well conducting ionosphere. The magnetic perturbations observed on the ground and the electric fields, already measurable at balloon altitudes, bear witness of the plasma convection.

The currents transmitting the force from high altitudes towards the ionosphere may, in certain regions and occasions, become so intense that the dilute electron population in the magnetosphere is unable to carry them without being accelerated to speeds much higher than their original thermal speed. This acceleration produces the streams of primary auroral particles. Thus, when we observe a beautiful auroral arc, we know there are intense currents flowing above the atmosphere driven by strong forces in the outer realms of the magnetosphere. And the distribution, the forms and the motions of the aurora borealis give us hints about these forces and the places where they act.

Previous research has brought us a wealth of information on these places of action in the outer magnetosphere and its long magnetic tail. The most important process by which the solar wind can transfer energy and mass to the magnetosphere is the magnetic reconnection. Once the solar wind magnetic field gets connected to that of the earth, a process whose efficiency depends strongly on the existence of anti-parallel components where the two fields get into contact, the solar wind can drag the internal field, can pull and stretch it into the tail and thus store energy in the magnetospheric system (Fig. 2). This energy is of elastic nature being contained in the distortions of the magnetic field. Some of it is used up immediately by driving the aforementioned convection from the dayside to the nightside and back towards day along the auroral oval. Another part is temporarily stored in the stretched and compressed tail and released in dramatic events, the magnetospheric substorms. They are the result of a reversal of the front-side reconnection. Magnetic field-lines connected to the solar wind field separate again at a downstream distance of 20 to 30 earth’s radii. Part of the magnetic flux shoots with high speed earthward, while the outer part is ejected as so-called plasmoids in the downstream direction.

The earthward jetting plasma and field carries a substantial amount of energy which assembles in the midnight sector of the outer magnetosphere and constitutes the energy reservoir from which the night-time aurora is being driven. In other words, here is the location of the generator of the auroral current system. Gradually more and more information has been gained, but many facets are still obscure, some of which can only be clarified by multi-satellite observations. For instance, it is still discussed by which process a magnetospheric substorm is initiated. Does it commence at the reconnection site, at 20 to 30 Re, or much closer to the earth? Simultaneous measurements at various critical positions are needed to finally clarify this question.

However, also on smaller scales there are many unsolved problems. For instance, the reconnection pro-

![Fig. 1. Forces applied to the plasma in the outer magnetosphere are transmitted to the ionosphere via field aligned electric currents](image-url)