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The dynamics of the plasmasphere: Recent results

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ABSTRACT

The purpose of this paper is to review recent advances in the study of the Earth's plasmasphere. Most of these have been obtained with data from two missions launched in 2000, Cluster and IMAGE. Indeed, those missions have deeply modified our understanding of this region due to their specificity: Cluster is a 4-spacecraft mission and IMAGE a global imaging mission, both types studying the plasmasphere for the first time. We review here some results of recent studies of the global evolution of the plasmasphere under the increase of the geomagnetic activity: plasmaspheric erosion, evolution of the plasmapause, plasmaspheric plumes, modification in the plasmaspheric corotation, refilling of the plasmasphere and evolution towards a smooth plasmasphere during prolonged quiet period. We also review results on plasmaspheric waves, which are formed and propagate at all stages of plasmaspheric evolution.

1. Introduction

The Earth's plasmasphere has been discovered during the 1950s (Storey, 1953; Gringauz et al., 1960; Carpenter, 1963). It consists of a dense and cold plasma that originates in the ionosphere (see reviews by Lemaire and Gringauz, 1998; Darrouzet et al., 2009a). The density varies between 10 and 10^4 cm^{-3} and decreases with L. The temperature is a few eV and increases with L (e.g., Farrugia et al., 1989). This region extends out to several Earth radii (R_E) to a boundary known as the plasmapause or the plasmasphere boundary layer, or PBL (Carpenter and Lemaire, 2004). Its position depends on magnetic local time (MLT) and geomagnetic activity (e.g., Chappell et al., 1970). During extended quiet periods, the plasmasphere can expand to beyond geosynchronous orbit (e.g., Moldwin et al., 1994), whereas the plasmapause moves earthward, down to $L < 2R_E$ during periods of high geomagnetic activity (e.g., Spasojević et al., 2003). The plasmasphere's configuration and dynamics are highly sensitive to disturbance activity in the solar-terrestrial environment.

Since 2000, two missions have added substantially to our knowledge of the plasmasphere and its coupling with the inner magnetosphere: Cluster and IMAGE (Imager for Magnetopause-to-Aurora Global Exploration). The Cluster mission consists of four identical spacecraft (C1, C2, C3 and C4) launched during summer 2000. They are positioned in a tetrahedral configuration with a separation distance that varies with time, from 100 km to a few R_E. The spacecraft fly along similar polar orbits, with a period of approximately 57 h, an apogee of about 19.6 R_E and an initial perigee of about 4 R_E (Escoubet et al., 1997). This allows Cluster to cross the plasmasphere as the spacecraft fly from the Southern to the Northern Hemisphere around perigee. Since 2007, the perigee of the Cluster orbit has moved closer to the Earth, down to about 1.3 R_E in the year 2010. The orbit has also changed from originally being polar to a much lower inclination. Those orbit modifications bring the spacecraft deeper inside the plasmasphere but also inside the radiation belts. The IMAGE spacecraft was launched in March 2000 into a polar orbit with a perigee of 7400 km and an apogee of 8.2 R_E (Burch, 2000). Several instruments onboard IMAGE provide global images of the plasmasphere. Data from other satellites, as well as ground-based data, have also been used in recent studies of the inner magnetosphere.

The plasmasphere is very dynamic and its structure and composition can evolve drastically under the influence of its environment and geomagnetic activity. We review in Section 2 some recent studies that further our understanding of this global evolution of the plasmasphere. Section 3 discusses some results related to plasmaspheric waves. We summarize and conclude in Section 4.

2. Global evolution of the plasmasphere

When a solar wind disturbance arrives at Earth, the magnetospheric convection electric field becomes stronger. The outer layer of the plasmasphere is stripped away, and the plasmasphere shrinks (Grebowsky, 1970; Chen and Wolf, 1972). This process is known as

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plasmaspheric erosion (see Section 2.1). The plasmasphere develops then a sharp outer boundary, the plasmapause (see Section 2.2). At the same time, if the disturbance is strong enough, it can produce a plasmaspheric plume at the dayside, which first extends sunward and then rotates around the Earth into the nightside (see Section 2.3). In such situations the plasmasphere is not rigidly corotating (see Section 2.4). While the magnetospheric electric field becomes smaller, the plasmasphere is refilled from the ionosphere during several hours or even days (see Section 2.5). Thus the plasmasphere becomes denser and larger, without a clear and sharp boundary (see Section 2.6). During this global evolution of the plasmasphere, various types of waves can be generated and propagate through this medium (see Section 3).

2.1. Erosion of the plasmasphere

Plasmaspheric erosion occurs regularly with increased geomagnetic activity. It is therefore important to quantify the amount of material removed from the plasmasphere during disturbance intervals. Spasojevíc and Sandel (2010) have used EUV (Extreme Ultra-Violet) data taken onboard IMAGE to calculate the global loss of plasmaspheric ions. The EUV instrument measures the He^+ fraction in the plasmasphere, which is a tracer of the total plasmaspheric ion content. For a set of moderate disturbance events, the authors found that between ~ 0.6 and 2.2×10^{30} He^+ ions are removed from a region of the plasmasphere between $L = 1.5$ and $5.5\,R_E$ (see Fig. 1). This loss constitutes 20–42% of the initial plasmaspheric He^+ content. By using several values of the He^+ to H^+ number density ratio, the total mass lost due to erosion is found to be between 20 and 80 metric tons.

2.2. Plasmapause

Recent Cluster and IMAGE observations in the plasmasphere have shown that the plasmapause structure is more complex than previously thought (Goldstein et al., 2004; Darrouzet et al., 2009b). Vertical total electron content (VTEC) measured by GPS satellites can be used to determine the ionospheric projection of the plasmapause and then to derive its position. Fig. 2 presents some results obtained from a study by Pedatella and Larson (2010) of the variations of the plasmapause position with local time and geomagnetic activity. The plasmapause is on average roughly symmetric in local time but there is significant variability: at any given time it exhibits significant structure in local time. Globally, during 2008, the plasmapause position has a periodic variation of 9, 13.5 and 27 days, in connection with recurrent geomagnetic activity during solar minimum activity.

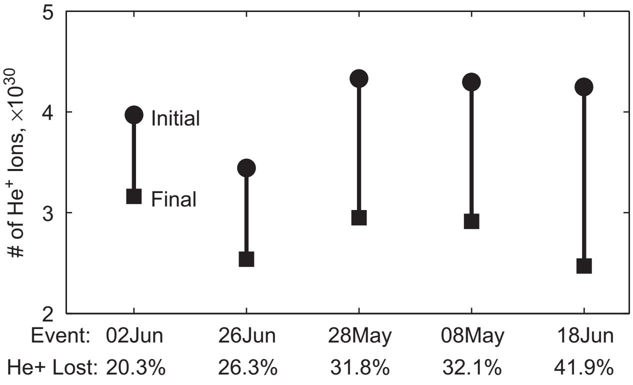

Fig. 1. The initial and final He^+ abundance in the plasmasphere, as well as the loss percentage for each of five moderate disturbance events, determined from EUV data taken onboard IMAGE (adapted from Spasojevíc and Sandel, 2010).

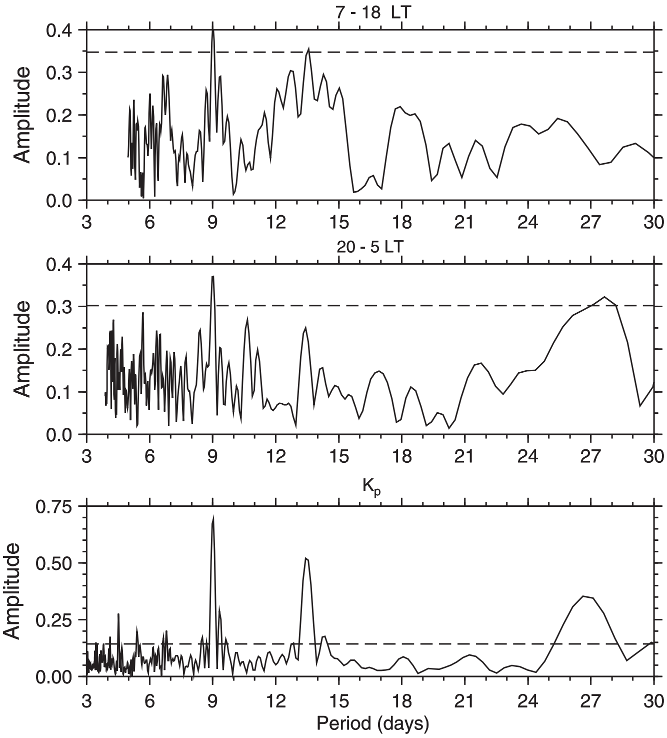

Fig. 2. Lomb–Scargle periodograms of the COSMIC plasmapause location during 2008 for the (top) daytime and (middle) nighttime as well as (bottom) *Kp*. The 95% significance level is indicated by the horizontal dashed lines (adapted from Pedatella and Larson, 2010).

2.3. Plasmaspheric plumes

Large-scale density structures are regularly observed close to the plasmapause or PBL. Some of those structures are regions of plasmaspheric plasma connected to the main body of the plasmasphere and extending outward into the surrounding more tenuous magnetosphere. They have been called “plasmaspheric tails” (Taylor et al., 1971) or “detached plasma elements” (Chappell, 1974) in the past. They are now commonly known as “plasmaspheric plumes” (e.g., Elphic et al., 1996; Sandel et al., 2001; Foster et al., 2002; Goldstein et al., 2003; Yizengaw et al., 2006; Darrouzet et al., 2006, 2008).

Concerning density trough structure, Fu et al. (2010) have built 2D electron density images from images taken onboard IMAGE. In one event, a density trough is observed inside the plasmasphere extending from $L \sim 2.3\,R_E$ to $L \sim 3.0\,R_E$. It extends along the magnetic field lines from the IMAGE orbit to about 41°*MLAT* and possibly down to the ionosphere.

Small-scale density fluctuations have also been observed in the plasmasphere and, more specifically, in plumes. Chappell et al. (1970) observed large electron density fluctuations with OGO 5 data. More recently, small-scale plasmaspheric density irregularities seen by Cluster have been analyzed by Darrouzet et al. (2004) and by Décréau et al. (2005). McFadden et al. (2008) reported density fluctuations inside plumes measured by the THEMIS (Time History of Events and Macroscale Interactions during Substorms) satellites. Borovsky and Denton (2008) examined density fluctuations and their relation to turbulence using data from the geosynchronous LANL (Los Alamos National Laboratory) satellites. Data from CRRES (Combined Release and Radiation Effects Satellite) have been used to study density irregularities at the plasmapause. Kelley et al. (2012)