PLASMASPHERE RESPONSE: TUTORIAL AND REVIEW OF RECENT IMAGING RESULTS

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Received: . . . ; Accepted in final form: . . .

Abstract.
The plasmasphere is the cold, dense innermost region of the magnetosphere that is populated by upflow of ionospheric plasma along geomagnetic field lines. Driven directly by dayside magnetopause reconnection, enhanced sunward convection erodes the outer layers of the plasmasphere. Erosion causes the plasmasphere outer boundary, the plasmapause, to move inward on the nightside and outward on the dayside to form plumes of dense plasma extending sunward into the outer magnetosphere. Coupling between the inner magnetosphere and ionosphere can significantly modify the convection field, either enhancing sunward flows near dusk or shielding them on the night side. The plasmaspheric configuration plays a crucial role in the inner magnetosphere; wave-particle interactions inside the plasmasphere can cause scattering and loss of warmer space plasmas such as the ring current and radiation belts.

1. Introduction

This tutorial paper reviews some recent space-based imaging observations that have confirmed or improved our understanding of the dynamic global response of the plasmasphere and inner magnetosphere to the effects of the solar wind and interplanetary magnetic field (IMF). The level of discussion is intended to be accessible (with some help from the cited references) to non-specialists and students.

1.1. Plasmasphere Origin

The plasmasphere is a cold (1 eV), dense (10–10,000 cm^{-3}) torus of H^+ (nominally about 80%), He^+ (10–20%), and O^+ (a few to several percent, depending upon geomagnetic activity) (Lemaire and Gringauz, 1998). Figure 1a shows a schematic illustration of the plasmasphere, with a nominal equatorial size of 4 Earth radii (R_E). The plasmasphere is populated by filling from the dayside ionosphere; the sunlit ionosphere leaks up into space along magnetic field lines, slowly filling dayside flux tubes with cold ionospheric plasma (see inset of Figure 1a). Combined with the eastward rotation of the Earth's magnetic field, dayside filling produces a torus of cold plasma of ionospheric origin. During prolonged periods of very quiet geomagnetic conditions when ionospheric filling is the dominant effect, the

Space Science Reviews **00:** 1–15, 2005.

plasmasphere can become quite large, reaching beyond geosynchronous orbit ($L = 6.62$, where L is equatorial geocentric distance in units of R_E) and having no distinct outer boundary (Goldstein et al., 2003b).

1.2. Plasmasphere Observations

Observations of the plasmasphere span decades, from first discovery (Carpenter, 1963) to the present (Lemaire and Gringauz, 1998). The earliest measurements of the plasmasphere, obtained by analyzing whistler mode waves from the ground, showed a well-defined outer density gradient (often with a 1–2 order of magnitude density drop) called the plasmapause. Geomagnetic disturbances move the plasmapause inward to smaller L values (Carpenter, 1970; Chappell et al., 1970), and the average plasmapause is larger for duskside magnetic local time (MLT) than for dawnside MLT (Carpenter, 1967). Early models (Grebowsky, 1970) of the plasmasphere offered an explanation for these observations: sunward convection (see Section 2) erodes the outer layers of the plasmasphere, removing plasma and creating a steep plasmapause boundary whose L value is inversely dependent upon geomagnetic activity level and whose MLT shape is influenced by a duskside stagnation region where sunward convection and eastward corotation are oppositely directed. The plasmapause density profile was observed to possess extensive meso-scale (0.1–1 R_E) and fine-scale ($< 0.1\ R_E$) structure (LeDocq et al., 1994), including regions of dense plasma that appeared to be completely detached from the main plasmasphere (Chappell, 1974). The convection paradigm explained detached plasma as the single-point observational signature of a two-dimensional plume of sunward-convecting eroded plasma; a spacecraft moving obliquely across L values would see a cross section of this plume that would appear detached from the main plasmasphere. However, the plume interpretation (of the detached plasma observations) was not universally accepted (Chappell, 1974), and it was not until recently that the existence of plumes has been unambiguously confirmed (see Figure 1b, Figures 2a–d, and Section 2).

In the past several years, new techniques have been developed for observing the plasmasphere. From the ground, interpretation of magnetometer data (Dent et al., 2003) and signals from GPS satellites (Foster et al., 2002) provide proto-tomographic capabilities. From space, magnetospheric imaging achieves a global perspective previously only provided by models. The Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite (Burch et al., 2001a) was launched in 2000 with two plasmasphere instruments onboard. The radio plasma instrument (RPI) (Reinisch et al., 2001) uses active radio wave sounding to determine remote electron density, and has yielded some needed information about the density dependence along magnetic field lines (Reinisch et al., 2004). The extreme ultraviolet (EUV) imager (Sandel et al., 2001) routinely obtains full global images of the Earth's plasmasphere by remote-sensing solar 30.4-nm light that has been resonantly scattered by plasmaspheric He^+ ions. Figure 1b shows an EUV plasma-

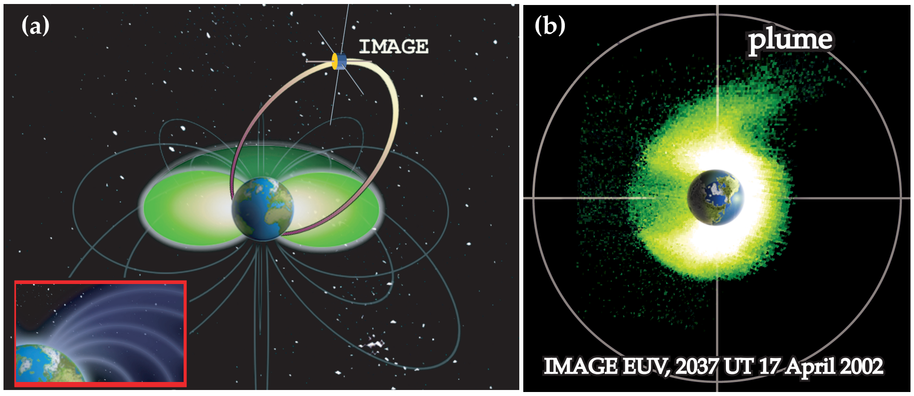

Figure 1. (a) Illustration of idealized plasmasphere torus and schematic IMAGE orbit. The view is from an oblique polar angle. The Earth is drawn in the center, with magnetic field lines drawn in perspective at $L = 4$ and $L = 6$, every 3 hours of magnetic local time (MLT). The plasmasphere is the green torus surrounding the Earth. A cross-section is taken along the noon-midnight MLT meridian. Inset: schematic/conceptual illustration of ionospheric outflow, in which dense ionospheric plasma leaks up into space to populate the magnetic field lines in the plasmasphere. (b) Global He^+ plasmasphere image obtained in 30.4-nm wavelength ultraviolet light by the IMAGE EUV imager, 2037 UT on 17 April 2002. The view is from above the magnetic north pole, looking down on the SM-coordinate magnetic equator. The Sun is to the right; the Earth is illustrated in the center. Geosynchronous orbit (6.6 R_E) and the X- and Y- axes are drawn in. The plasmasphere is shown in false color as the green/white region extending to an average distance of 3.3 Earth radii (R_E). The Earth's shadow extends antisunward, dimming the 30.4-nm emissions. A plasmaspheric plume can be seen extending sunward (to the upper right) from the duskside plasmasphere. EUV images such as this one have provided unambiguous proof of the existence of plumes, confirming predictions that sunward convection erodes the plasmasphere during geomagnetic disturbances (Grebowsky, 1970). (EUV image courtesy of B. R. Sandel.)

sphere image from 2037 UT on 17 April 2002. The brightness of the green-white part of the image is proportional to the line-of-sight integrated He^+ column abundance. The visible portion of the plasmasphere in EUV images corresponds to total (electron) number density above about 40 cm^{-3} (Goldstein et al., 2003c; Moldwin et al., 2003). Plasmasphere images are obtained by EUV every 10 min with a nominal spatial resolution (pixel size) of 0.1 R_E or better. One of the first ideas validated by images such as that in Figure 1b is that plasmaspheric plumes form (as a result of erosion) during geomagnetic disturbance times (Grebowsky, 1970). The plasmasphere depicted in Figure 1b is mostly circular except near dusk (i.e., top of the figure), where a plume is evident. Plumes such as that of Figure 1b have been seen following every erosion event witnessed by EUV, and simultaneous (or near-simultaneous) in situ observations have verified that the plumes in EUV images are identical to detached plasma regions (Spasojević et al., 2003; Garcia et al., 2003; Goldstein et al., 2004b). Plasmaspheric imaging has indeed confirmed the existence of plumes (though it is still probable that much lower density blobs of completely detached plasma do exist in the magnetosphere).

2. Inner Magnetospheric Convection

2.1. Dayside Magnetopause Reconnection (DMR)

During times of geomagnetic disturbance, sunward plasma convection (or advection), plays a crucial role in plasmaspheric dynamics. Perhaps the most fundamental cause of inner magnetospheric convection is dayside magnetopause reconnection (DMR). The magnetopause is the boundary between the geomagnetic field and the interplanetary magnetic field (IMF), nominally found at subsolar distance 10 R_E. When the IMF at the magnetopause is oriented opposite (southward) to the geomagnetic field, these oppositely-directed fields can undergo reconnection, a process that causes dayside geomagnetic field lines to become joined to the IMF lines, which then are dragged antisunward (along with the prevailing solar wind flow) into the stretched out magnetospheric tail (magnetotail). This magnetic flux transfer drives sunward convective flows in the inner magnetosphere (Dungey, 1961). Associated with this sunward convection is a solar-wind electric (E) field that points from dawn to dusk, with magnitude given by the product of the solar wind speed (V_{SW}) and the Z-component of the IMF ($B_{z,IMF}$). The zero-order influence seems to be the polarity of $B_{z,IMF}$, which acts as a switch, turning convection on for southward IMF ($B_{z,IMF} < 0$) and off for northward IMF ($B_{z,IMF} > 0$).

2.2. Plasmasphere Erosion

Plasmasphere images indicate there is an excellent correlation between $B_{z,IMF}$ polarity and the behavior of the plasmasphere (Goldstein et al., 2003a; Spasojević et al., 2003; Goldstein et al., 2002; Goldstein et al., 2003d). The plasmaspheric effect of an enhancement in DMR-driven convection depends upon the magnitude of the convection increase as well as the state of the plasmasphere at the onset of enhanced convection. The most dramatic plasmasphere erosion events are precipitated by exceptionally large convection enhancements that follow prolonged intervals of quiet geomagnetic conditions. If the convection increase is mild, and/or the plasmasphere has very recently been eroded, little or no erosion may occur.

2.2.1. *Erosion: Phases of Plume Evolution*

In plasmasphere images (and consistent with other observations), erosion follows a repeatable 4-phase pattern that was predicted by convection-based models (Grebowsky, 1970; Spiro et al., 1981). Figures 2a through 2d depict a typical erosion event, witnessed by IMAGE EUV on 18 June 2001 (Goldstein and Sandel, 2005). The top row shows EUV plasmasphere images; the bottom row shows plasmapause locations extracted from the images. The general result of the erosion was the sunward displacement of the plasmapause. The initial nightside plasmapause moved inward ($+X$-direction, or sunward) by about 1 R_E, and the dayside bulge of the initial plasmasphere (Figure 2a) surged sunward to form a broad dayside plume

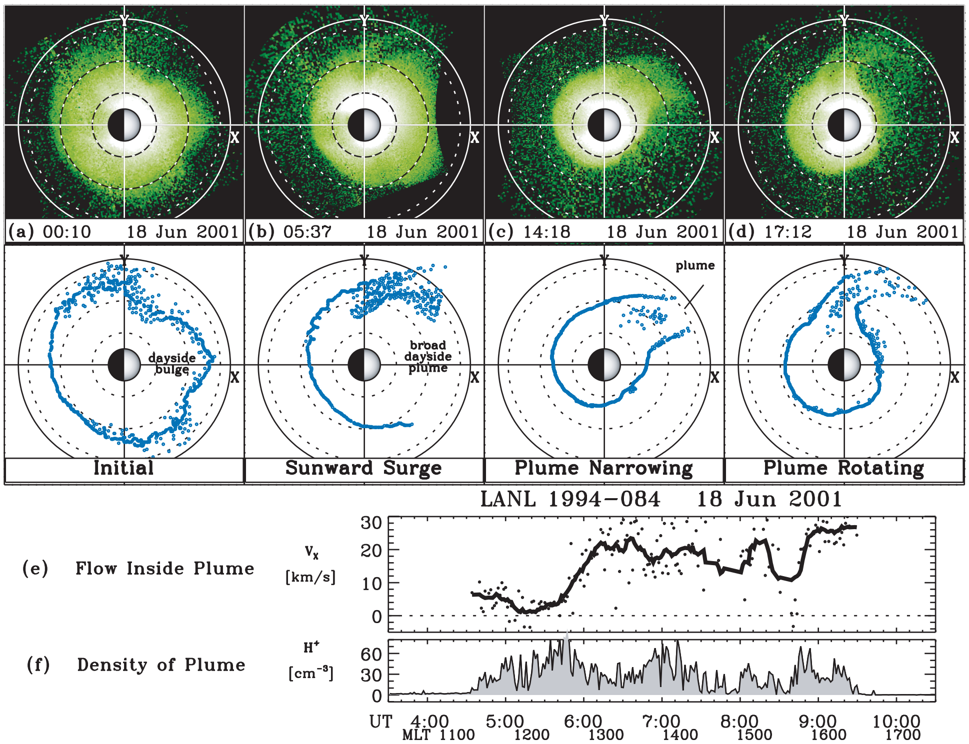

Figure 2. (a–d) Top row: EUV plasmasphere images from a typical erosion event on 18 June 2001 (Goldstein and Sandel, 2005). The format is similar to that of Figure 1b; the Sun is to the right and Earth is the half-shaded circle in the center. Dotted circles are drawn at $L = 2$, 4, and 6; the solid circle indicates geosynchronous orbit. Bottom row: Extracted plasmapause points from the images directly above. During the erosion of 18 June, plasmaspheric plasma moved sunward. The nightside moved inward (Earthward) by about 1 R_E, and the dayside bulge (see panel a) surged sunward to form a broad dayside plume (panel b). Over time, the plume narrowed in MLT (panel c) and then rotated eastward (see panel d) when the convection strength weakened. (e and f) Data from the Magnetospheric Plasma Analyzer (MPA) onboard Los Alamos National Laboratory (LANL) geosynchronouse satellite 1994–084, obtained during the erosion event of 18 June 2001. Consistent with a convective interpretation of the 18 June EUV images, the LANL in situ measurements show the presence of dayside (1120–1630 MLT) plasmaspheric (10–80 cm^{-3}) plasma that is flowing sunward (i.e., positive V_X) due to enhanced convection. The bold line in (e) is a 14-minute running average of the dots. (EUV images courtesy of B. R. Sandel; LANL data courtesy of M. F. Thomsen.)

which subsequently narrowed in MLT (Figure 2c) and then rotated eastward (Figure 2d) when the convection strength decreased This 4-phase pattern of evolution (initial, sunward surge, plume narrowing, plume rotating) represents the canonical development of plasmaspheric plumes during erosion events (Goldstein and Sandel, 2005). Figures 2e and 2f show in situ measurements from the Los Alamos National Laboratory (LANL) Magnetospheric Plasma Analyzer (MPA), obtained on 18 June 2001, taken on the dayside. These data clearly support a convective model interpretation of EUV images, for they confirm that cold dense plasma does indeed flow sunward inside plasmaspheric plumes.

2.2.2. *Energy Transfer from Solar Wind to Inner Magnetosphere*

Plasmaspheric imaging allows separation of spatial and temporal effects, which has been important in studies of the timing of erosion events. The first erosion event witnessed by IMAGE EUV occurred during 0450–0830 UT on 10 July 2000 (Goldstein et al., 2003a). During the erosion, the nightside plasmapause moved about 2 R_E inward of its starting position, and the plasmapause motion was driven by southward IMF; during northward IMF the plasmapause speed was zero. For this event there was a time delay of 30 minutes between the arrival of southward IMF at the magnetopause and the subsequent inward motion of the nightside plasmapause. Similar time delays (10–30 minutes) have consistently been observed during EUV-witnessed erosion events (Goldstein et al., 2003b; Spasojević et al., 2003; Goldstein et al., 2004b; Goldstein and Sandel, 2005). Time-delayed convection is also experienced by the ring current (Goldstein et al., 2003a), and by implication, the entire inner magnetosphere. (See Section 3 for more about the ring current and other plasma regions.) What causes this delay? Although it is reasonable to assume some delay is required for the global convection field to reconfigure itself (Coroniti and Kennel, 1973), this explanation has not been verified. This question needs an answer if we are to fully understand the way solar wind energy is imparted to the inner magnetosphere.

Tracking the speed of the plasmapause boundary during erosion can provide an estimate for the electric field associated with the erosion, assuming $E \times B$ motion of the cold plasma (Carpenter et al., 1972). Careful analysis of EUV images during erosion events has yielded 1D and 2D maps of equatorial plasmapause electric fields (Goldstein et al., 2004c; Goldstein et al., 2004a; Goldstein and Sandel, 2005; Goldstein et al., 2005b). From EUV E-field estimates, approximately 10–12% of the solar wind electric (E) field E_{SW} is felt at the plasmapause. This result is consistent with model predictions (Volland, 1973; Maynard and Chen, 1975) that only a fraction of E_{SW} is transmitted inside geosynchronous orbit, possibly owing to less-than-perfect reconnection efficiency (i.e., not all southward IMF lines reconnect). There have been few missions to measure the innermost magnetospheric E-field (Wygant et al., 1998); in this regard plasmasphere imaging has provided a much-needed additional data source.

2.3. SUBSTORMS

The substorm is a critical magnetospheric process that is only partially understood even after decades of research (Akasofu, 1964; Goldstein et al., 2005b). Substorms are believed to occur when excess magnetic flux in the magnetotail is suddenly released (Baker et al., 1996). In this scenario the global nightside magnetic field reconfigures from a tail-like geometry (indicative of stored magnetic flux and high magnetic tension) to a more dipolar geometry (indicative of the release of magnetic tension). This magnetic dipolarization causes rapid sunward motion of geomagnetic field lines, which induces a global electric field (Aggson et al., 1983) that transports plasma earthward. Early studies of the plasmaspheric effects of substorms suggested that the substorm induction E-field reduces the nightside plasmapause L (Carpenter and Stone, 1967; Carpenter and Akasofu, 1972). These predictions were recently confirmed by plasmaspheric imaging (Goldstein et al., 2004a; Goldstein et al., 2005b); a substorm that occurred at 1900 UT on 17 April 2002 caused ripples to propagate along the plasmapause, eastward and westward from pre-midnight MLT. The motion of the ripples was consistent with the interpretation that a sunward-propagating impulse swept past the plasmasphere, distorting the plasmapause shape during its passage. In contrast with DMR-driven convection events which produce a net reduction of the plasmapause L, the substorm-triggered plasmapause motion was only temporary; after the passage of the disturbance, the plasmapause returned to its starting location/shape. The plasmapause distortion was found to be strongly correlated both with auroral signatures of the substorm and with intensification and distortion of the ring current (Goldstein et al., 2005b). This correlation implies that the substorm was the cause of the plasmapause (and ring current) distortion and also indicates strong coupling among different plasma populations. Imaging of plasmasphere and ring current (see Section 3.1), allows determination of causal relationships and global spatial/temporal properties of the propagating impulse.

3. Intra-Magnetospheric Plasma Coupling

The inner magnetosphere is a complex, electrodynamically coupled, self-modifying system; individual plasmas such as the plasmasphere, ring current, ionosphere, and radiation belts evolve interdependently and in many cases physically overlap. Interested readers are directed to the references cited in this section for a more complete survey of how imaging has improved our understanding of global intra-magnetospheric coupling (Burch et al., 2001a; Burch et al., 2001b; Goldstein et al., 2005b).

3.1. Ring Current Imaging

The ring current (Daglis et al., 1999) is a magnetically-confined plasma composed of warm (1–100 keV) ions (H^+, O^+) and electrons in the inner magnetosphere. In this energy range ions and electrons are subject to oppositely-directed magnetic drifts (see Figure 3a), producing a net westward current. A major loss term for ring current ions is charge exchange, in which a warm ion accepts an electron from a nearby cold neutral particle in the Earth's exosphere, thereby producing an energetic neutral atom (ENA) which is not magnetically confined. The IMAGE

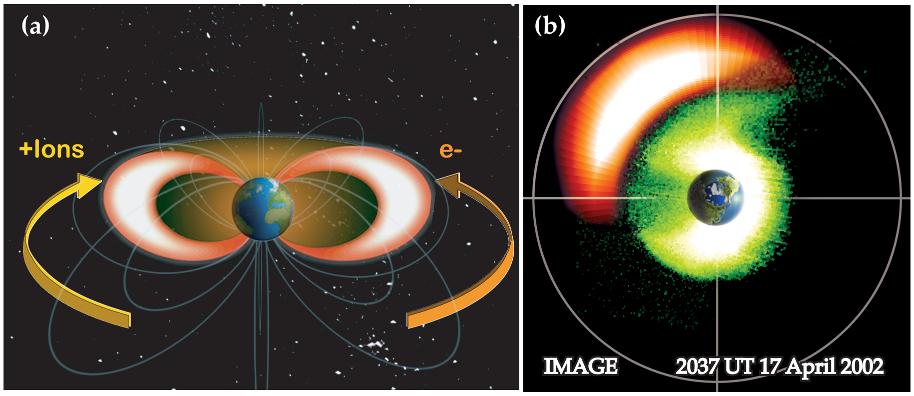

Figure 3. (a) Illustration of idealized ring current, format identical to that of Figure 1a. The ring current is the orange torus surrounding the Earth. Westward (eastward) magnetic drift of ions (electrons) indicated by the yellow (orange) curved arrow. (b) Global composite image of the inner magnetosphere (Pulkkinen et al., 2005). IMAGE HENA proton pressure (10–60 keV, 0.5–0.8 nPa) image has been overlaid onto Figure 1b. The HENA image shows the partial ring current that has been injected by a substorm. The plasmasphere and ring current are roughly spatially complementary, although there is some overlap near dusk, at the eastern edge of the plasmaspheric plume. (HENA image courtesy of P. C. Brandt; EUV image courtesy of B. R. Sandel.)

high-energy neutral atom (HENA) imager (Brandt et al., 2002) remotely detects escaping ENAs in the energy range 10–60 keV. Mathematical inversion of ENA images yields H^+ ring current pressure distributions (DeMajistre et al., 2004).

During quiet times the ring current is roughly symmetric (as depicted schematically in Figure 3a), but geomagnetic disturbances produce strong partial (asymmetric) ring currents with pressure localized in MLT (Daglis et al., 1999). Figure 3b shows a HENA proton pressure distribution obtained at 2037 UT on 17 April 2002, overlaid onto the EUV plasmasphere image of Figure 1b. This image was obtained near the end of a substorm that affected both ring current and plasmasphere (Section 2.3). As a result of the substorm, a strong partial ring current formed (Figure 3b) in the pre-midnight MLT sector where the plasmapause was similarly distorted by magnetic dipolarization.

3.2. Electrodynamics of Ring Current and Ionosphere Coupling

Currents flow continuously in closed loops. Owing to its finite azimuthal extent, the westward-directed partial ring current cannot close at low latitudes, and so is instead diverted along field lines to close in the ionosphere (Vasyliūnas, 1970). The field-aligned currents (FACs) that couple the dynamics of the ring current and the ionosphere, called region 2 (R2), are depicted in Figure 4. On the duskside, R2 FACs flow from the western edge of the ring current (RC) down into the ionosphere. On the dawnside, R2 FACs flow up from the ionosphere to connect with the eastern edge of the partial RC. Ring-current-ionosphere coupling is of fundamental

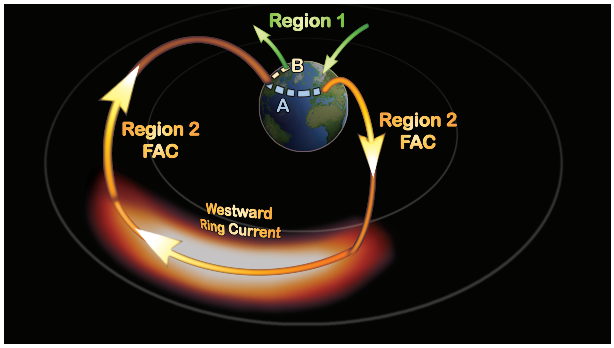

Figure 4. Cartoon of global current system linking the ring current to the ionosphere. Current must flow in closed loops, so the partial westward ring current gets diverted along field lines to form the region 2 field aligned current (FAC) system. Current closure is achieved in the ionosphere, either via an eastward current (path A) linking the two branches of the region 2 FACs, or via a northward current (path B) that connects the region 2 FAC to the more poleward region 1 auroral zone currents.

importance because it modifies the inner magnetospheric electric field. The nature of that modification depends on how the R2 FACs are closed in the ionosphere.

3.2.1. *Shielding, Undershielding, and Overshielding*

If the duskside (into the ionosphere) R2 FAC is connected to the dawnside (out of the ionosphere) R2 FAC by an eastward-flowing ionospheric current (path A in Figure 4), this generates an eastward (dusk-to-dawn) electric field. This eastward E-field opposes the dawn-to-dusk convection electric field, thus shielding the inner magnetosphere from convection (Jaggi and Wolf, 1973). Effective shielding requires the establishment (via Alfvén waves) of this system of R2 and ionospheric currents, which happens on a time scale $\leq$ 1 hour (Kelley et al., 1979; Senior and Blanc, 1984). Changes in convection strength which occur slower than this time scale may be effectively shielded, but sudden changes produce a residual "penetration" E-field in the inner magnetosphere (Goldstein et al., 2003d). A sudden southward IMF transition causes undershielding, in which shielding is temporarily unable to counter the newly enhanced convection. During undershielding, the plasmasphere can be eroded, but within an hour the erosion tapers off if effective shielding is established (Goldstein and Sandel, 2005). Following a rapid northward IMF turning, overshielding occurs: convection suddenly decreases, leaving a residual eastward (dusk-to-dawn) E-field that drives antisunward convection. Because the ionospheric conductivity is lowest in the midnight-to-dawn MLT sector, it is there that antisunward convection (from overshielding) can often be strongest (Senior and Blanc, 1984; Fejer and Scherliess, 1995), which has been demonstrated to create shoulder-like bulges of the plasmapause (Sandel et al., 2003; Goldstein and Sandel, 2005). Because the solar wind and IMF conditions typically fluctuate on much faster time scales than that required to establish the shielding current system, evidence of perfect shielding (exactly canceling out the convection E-field) is rare in global images (Spasojević et al., 2005).

3.2.2. *Sub-Auroral Polarization Stream (SAPS)*

If the duskside region 2 (R2) FAC is connected to the auroral current system (called region 1) via a poleward-flowing ionospheric current (path B in Figure 4), this generates a northward E-field and associated westward flow known as the subauroral polarization stream (SAPS) (Foster and Burke, 2002). Because of the low ionospheric conductivity at subauroral latitudes, the northward SAPS E-field can be quite large, and when mapped (along magnetic field lines) to the magnetic equator, produces an intense radial E-field located at the inner edge of the ring current, i.e., just outside or overlapping the plasmapause (Goldstein et al., 2003b). The SAPS E-field produces strong westward flows that move the duskside plasmapause inward and can create narrow duskside plumes (Foster et al., 2002; Goldstein et al., 2003b; Goldstein et al., 2004a; Goldstein and Sandel, 2005; Goldstein et al., 2005a). Westward SAPS flows are a major influence near dusk, where models that ignore SAPS incorrectly predict a flow stagnation region.

3.3. Hot-Cold Plasma Interactions

This section considers the role of cold plasmaspheric plasma in the dynamics of the warmer particle populations, the ring current and radiation belts.

3.3.1. *Ring Current and Plasmasphere*

The ring current was introduced in Sections 3.1 and 3.2. As depicted in Figure 3b, the plasmasphere (green) and ring current (orange) are roughly spatially complementary, but the two plasmas do overlap in the range 1600–1800 MLT. This overlap can lead to the loss of the ring current, as follows (Spasojević et al., 2004). The intermingling of warm ring current ions and cold, dense plasmaspheric plasma favors the growth of electromagnetic ion cyclotron (EMIC) waves (Gary et al., 1995), which can scatter the ring current ions into the ionosphere. Thus, where the ring current encounters the plasmasphere, it can suffer EMIC-wave scattering and dump its particles into the ionosphere, producing distinctive auroral signatures (Spasojević et al., 2004). Overlap between the plasmasphere and ring current is an unstable situation, so that on long enough time scales the plasmasphere and ring current should be spatially complementary.

3.3.2. *Radiation Belts and Plasmasphere*

The radiation belts (or "Van Allen" belts) are magnetospheric regions of magnetically trapped high-energy ions and relativistic electrons (Van Allen and Frank, 1959). The relativistic electrons are separated into two belts, an inner belt below $L \approx 2$ and an outer belt above $L \approx 3$ (see Figure 5a). Whereas the inner belt is quite stable, unaffected by all but the most severe geomagnetic storms, the outer

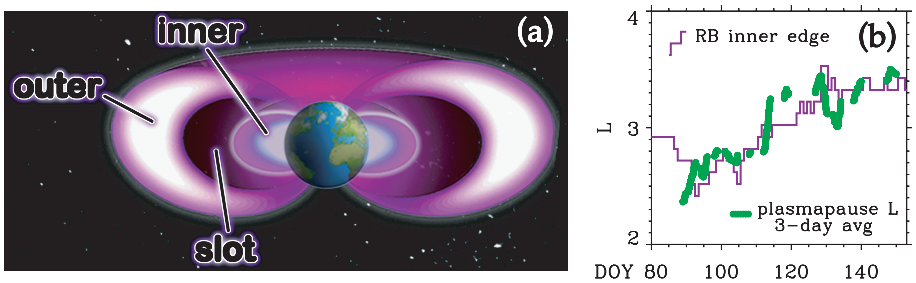

Figure 5. (a) Cartoon of the radiation belts, showing the inner and outer belts and the slot region. (b) Plot illustrating the close relationship between the inner edge of the outer radiation belt (purple), and the 3-day-averaged plasmapause (green), for two months in 2001 (Goldstein et al., 2005c).

belt is highly sensitive to geomagnetic conditions. The two belts are normally separated by a "slot" region devoid of relativistic electrons, but during intense storms, the outer electron belt can move inward to penetrate (and rarely, completely fill) the slot region (Baker et al., 1994). A crucial role in the creation of the slot region is played by the plasmasphere, which is typically filled with broad-band whistler mode wave emissions known as plasmaspheric hiss (Thorne et al., 1973). Radiation belt electrons outside of $L \approx 2$ are susceptible to scattering by the hiss wave emissions; thus, for decades it has been believed that pervasive wave-particle interactions (between hiss waves and radiation belt particles) inside the plasmasphere are the cause of the electron losses that maintain the slot region. If this is true, the outer extent of the plasmasphere should on average coincide with the inner extent of the outer electron belts (Russell and Thorne, 1970). Recent studies comparing global plasmasphere images with in situ relativistic electron data have confirmed this prediction (Baker et al., 2004; Goldstein et al., 2005c), as illustrated in Figure 5b, and have shed light on the conditions under which the outer belt can penetrate the slot region. Intense storms produce severe erosions, so that the plasmapause moves inside the nominal slot region; without the usually-present hiss to remove the electrons, the slot region may have the opportunity to be filled in by newly-energized relativistic electrons.

4. Concluding Remarks

The advent of space-based imaging has provided a unique perspective to study the response of the inner magnetosphere to the ever-changing solar wind conditions. Decades-old hypotheses about how the plasmasphere is eroded by enhanced convection have been confirmed, and important sub-global effects (such as SAPS and shielding) have proven to be a critical part of the behavior of the inner magnetosphere. Imaging has allowed us to see that plasmasphere erosion is just one aspect of the coupled response of the entire inner magnetosphere and ionosphere.

Acknowledgements

I am grateful indeed to have been invited to such an exciting and fruitful workshop. I wish to thank all the 2005 ISSI workshop participants, the members of the organizing committee, and our gracious and generous host institution ISSI. I was delighted to interact with solar and heliospheric physicists, and to make new friends. Scientific discussions with G. Haerendel, J. Linker, D. Baker, I. Daglis, R. Lin, and B. Fleck were particularly rewarding. Special thanks are given to M. Desai and M. Guhathakurta for animated conversation at the lunch table, to S. Gibson for the introduction to Dr. B. T. Klöun, and to T. Zurbuchen for making physicists look good at the Einstein house. Data were most kindly provided by B. R. Sandel (IMAGE EUV), M. F. Thomsen (LANL MPA), P. C. Brandt (IMAGE HENA), and I thank J. Burch for the continuing success of the IMAGE mission. Research support from the NASA Sun-Earth Connections Guest Investigator program under NAG5-12787, and from the NASA IMAGE mission under NAS5-96020, is most gratefully acknowledged.

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