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POSSIBLE PLASMA DYNAMICS IN NIGHTTIME MAGNETOSPHERE ASSOCIATED WITH Pi 2 ONSET AS OBSERVED FROM DIP-EQUATOR (EXTENDED ABSTRACT)

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A brief summary of this work

Fluxgate magnetometer observations with higher accuracy of timing (0.1 s) and amplitude resolution (0.01 nT) were carried out at the dip-equator (Huancayo, Peru; 1.44° N, 355.9° in geomagnetic coordinates; 12.1° S, 75.2° W in geographic coordinates; $L=1.00$) during PROMIS (Polar Region and Outer Magnetosphere International Study) periods (March 1–June 20, 1986). Based on these ground data, SAKA *et al.* (1998) studied the onset of ground Pi 2 pulsation, and examined statistically a concurrent onset signature of magnetic field changes as observed by the geosynchronous satellites GOES 5 (75° W in geographic coordinates), and GOES 6 (107° W in geographic coordinates), which were at a meridian close to Huancayo. According to the above work the initial perturbations associated with the ground Pi 2 onset were characterized predominantly by an increase of the radial component (V) being accompanied by a decrease of the field magnitudes and by nearly equal occurrence probabilities for positive and negative changes of the H component (along the dipole axis). In this report, we summarize the statistical results obtained by SAKA *et al.* (1998), and discuss how the Pi 2 onset at the geosynchronous altitudes can be modeled in the substorm expansion onset.

Why we did this work

Pi 2 magnetic pulsations (damped oscillations with periods of 40–150 s) are widely accepted as a transient oscillation of the field-aligned currents in the midnight magnetosphere that are associated with substorm onset. Basic morphological pictures were established in 1960s and 1970s (see SAITO, 1969; JACOBS, 1970; ORR, 1973; LANZEROTTI and FUKUNISHI, 1974; SOUTHWOOD and STUART, 1980; MCPHERRON, 1980). The field-aligned currents divert into the ionosphere in the midnight sector from the cross-tail currents in the plasma sheet to form a substorm current wedge system, which is established in the midnight sector at the substorm onset (MCPHERRON *et al.*, 1973). Such field-aligned currents have been believed to respond in a transient manner to Pi 2 oscillations (SAKURAI and MCPHERRON, 1983) (current wedge model). Another model for the Pi 2 excitation is based on an unbalance of the plasma pressures created at the geosynchronous altitudes in association with plasma injection excites locally field-aligned currents, which then oscillates transiently (particle driven model). Indeed, low energy particle flux enhancements at geosynchronous altitudes have been found to be correlated significantly with the occurrence of Pi 2 events (YEOMAN *et al.*, 1994; SAKA *et al.*, 1994, 1996a). The observed wave characteristics associated with field line oscillations and particle modulations are in accord with this model (SAKA *et al.*, 1996b, c, 1997). A major difference between these two models is in the number of field-aligned currents involved, namely single line current for the current wedge model whereas twin currents with opposite polarity for the particle driven model at each meridian.

The waveforms detected by magnetometers on board geosynchronous satellites are often irregular, which make it difficult to perform waveform comparisons with the ground Pi 2 events in the statistical manner. Nevertheless, the initial responses of the magnetic field lines at satellite altitudes often show a simple structure with respect to the Pi 2 onset at the ground station (dip-equator), and indicate a systematic change (SAKA *et al.*, 1998). In this report, we review the work of SAKA *et al.* (1998), and discuss such initial changes in conjunction with a possible plasma dynamics occurring in the inner magnetosphere.

Summary of our previous work

The observations described by SAKA *et al.* (1998) can be summarized in terms of the initial perturbations both in H, V, D components and in B, Theta, Phi of spherical representations in dipole coordinates (H is along the dipole axis, V is outward, and D is azimuthally eastward: B is the field magnitude, Theta is the field inclination measured from the equatorial plane, and Phi is the azimuthal angle measured from the V axis). In many cases, the initial perturbations at geosynchronous altitude started slightly prior to the onset of the ground Pi 2 oscillation (of the order of 10–20 s). Changes toward positive V are accompanied by a decrease of B and by nearly equal occurrence probabilities for the positive and negative changes of the H component.

The initial perturbations as described above were best interpreted as indicating a set up of eastward currents at the Pi 2 onset, in the region south of the satellite latitudes (9°–11°) at an L often earthward of the geosynchronous altitudes.

What we found

It has been widely accepted that the substorm onset is characterized by the formation of a current system in the midnight sector referred to as the substorm "current wedge". In this model, the eastward cross-tail current is short-circuited by the field-aligned current through the ionosphere (MCPHERRON *et al.*, 1973). Because the field-aligned current flows into the ionosphere in the dawn sector and flows out of the ionosphere in the dusk sector (being closed via the eastward current in the midnight magnetosphere), the magnetic flux inside the wedge increases when the current system is set up. Since the Pi 2 oscillations are often superimposed on this field increase (positive bay) as observed at the middle latitude stations, it is natural to interpret the Pi 2 oscillations as resulting from the transient response of the field-aligned currents in the substorm current wedge system (*e.g.*, SAKURAI and MCPHERRON, 1983). If such a current system is invoked to account for the geosynchronous data, the cross-tail part of the current system would appear at geosynchronous altitudes.

It has been suggested that local instabilities such as the ballooning-mode instability is a possible candidate to excite MHD oscillations in the pulsation band during the substorm onset (ROUX *et al.*, 1991). For this case, the ring current particles are considered to be an available energy source, which are supplied from the inner magnetosphere during the dipolarization (SAUVAUD and WINCKLER, 1980). For such a local instability, the wave number along the field lines is much less than the perpendicular one, which then results in the field perturbations localized in azimuth direction (ROUX *et al.*, 1991). In contrast, the field oscillations associated with Pi 2's are reported to be global with comparable scale size between the azimuth and zenith directions (*e.g.*, SAKA *et al.*, 1997). Accordingly, it is likely that such instability is not a suitable source of the present Pi 2 oscillations (*e.g.*, SAKA *et al.*, 1997).

It is worthy of note that the field lines threading the satellite latitudes (11–9°) would often stretch tailward reaching the plasma sheet (*e.g.*, KAUFMANN, 1987; BAKER *et al.*, 1993), as is illustrated in Fig. 1 (The original figure is adopted from BAKER and PULKKINEN, 1991). If we assume that hot plasmas diffused quickly along these field lines at the substorm expansion onset, plasmas may fill the flux tube that is emanating from the chaotic domain in the plasma sheet, in a time characterized by the bounce periods of plasma sheet particles (order of seconds). The longitudinal extent of such a flux tube would be in the range of 4–5 hours of local time in the midnight sector (*e.g.*, SAKA *et al.*, 1997). Then, the magnetic stress balances the plasmas therein by exciting diamagnetic currents. The diamagnetic currents increase the curvature of the surrounding field lines. These are propagated with the Alfven velocity along the field lines until being reflected back again from the ionosphere forming standing oscillations. A characteristic time for growing the diamagnetic current might be determined by the wave periods, namely the Pi 2 period. If this scenario can be adapted to the formation of the current sheets at Pi 2 onset, the observed current sheet may correspond to the

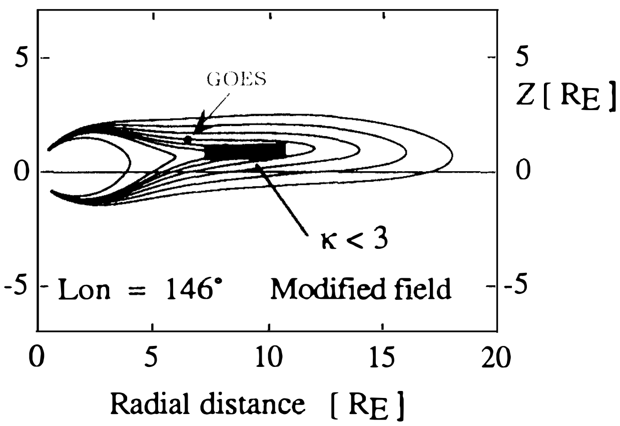

Fig. 1. A diagram adopted from BAKER and PULKKINEN (1991) illustrating a meridional cross section of the field lines. GOES position is plotted in the figure by the circle. Blocked area marked by κ < 3 indicates a domain where chaotic electron motion takes place. Hot plasmas supplied from chaotic domain are assumed to diffuse along the stretched field lines and fill the flux tube threading GOES position (see text).

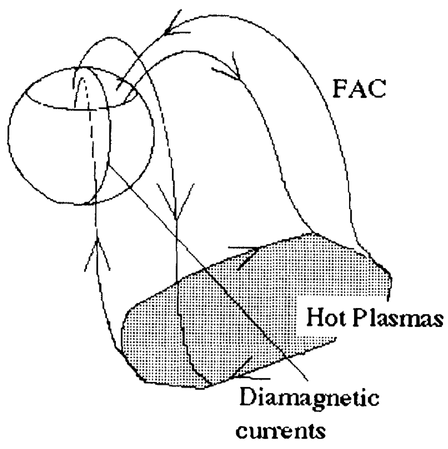

Fig. 2. A schematic illustration of the current system associated with the formation of the hot plasmas in the midnight sector. The field-aligned currents (FAC) divert from the diamagnetic currents.

diamagnetic current flowing in the inner boundary. The diamagnetic current generates the field-aligned current at the eastern and western edge of the flux tube, according to the following equation.

$$\nabla \cdot J_{\parallel} = \rho \frac{\partial^2}{\partial t^2}\left(\frac{B}{B^2} \cdot \nabla \times \xi\right) + J_{\perp} \cdot \nabla \ln B^2 - J_{in} \cdot \nabla \ln \rho ,$$

where $J_{\parallel}$, $J_{\perp}$, and J_{in} represent field-aligned current, diamagnetic current, and inertial current, respectively. B and ρ are background magnetic field and plasma density, respectively. ξ denotes plasma displacement. The first term of the right-hand side of the equation, together with the left-hand side of the equation, makes a set of the wave equation that describes the Alfven wave propagation along the field lines. Therefore, the first term does not contribute to the source of the field-aligned current. In the eastern and western edges, the inertial current, J_{in}, flows radially and perpendicular to $\nabla \ln \rho$. Then, the last term vanishes and the field-aligned current would stem only from the second term. If the gradient of the magnetic field lines is primarily radial, the polarity of the field-aligned current is "out of" ("into") the ionosphere at the post-midnight (pre-midnight) edge of the inner boundary (region-2 type), whereas the current polarity reverses at the outer boundary (region-1 type) (see Fig. 2). Accordingly, the field-aligned current in the inner edge amplifies the decrease of the field magnitude at the geosynchronous altitudes, together with the effect from the inner part of the diamagnetic current. Because the field-aligned current forms a current pair with opposite polarity in both the eastern and western edge, the pair current oscillates as a field line resonance (SAKA *et al.*, 1996b).

Such a current system was proposed recently to account for a large-scale region-1 and -2 current system in the dawn sector by IIJIMA *et al.* (1997). We believe that this mechanism may suggest one possible scenario at least for the initial perturbations at the substorm expansion onset.

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