P2 pulsations observed from the Polar satellite outside the plasmapause


Received 21 June 2005; revised 10 August 2005; accepted 18 August 2005; published 16 September 2005.

[1] Recently, Lee and Lyuks (1999) suggested that P2 pulsations in the inner magnetosphere originate from plasmaspheric virtual resonances (PVR). The PVR model predicts that P2 pulsations are not strictly localized to the plasmapause. Until now there have been no spacecraft observations of the PVR mode outside the plasmapause. Motivated by the theoretical work, we examine P2 pulsations simultaneously observed by the Polar satellite outside the plasmapause and at the low-latitude Kakioka (L = 1.3) station. We identify 14 events to have high coherence (> 0.7) between the compression component (bₜ) in space and the horizontal component (bₓ) at Kakioka during 2 months in 1997. The bₓ cross phase is ~180° regardless of the satellite’s distance from the plasmapause. The amplitude of the P2 pulsations tends to decrease with the distance. On the basis of these observations, we conclude that the PVR mode is an appropriate model for our P2 events observed outside the plasmapause. Citation: Kim, K.-H., D.-H. Lee, K. Takahashi, C. T. Russell, Y.-J. Moon, and K. Yumoto (2005), P2 pulsations observed from the Polar satellite outside the plasmapause, Geophys. Res. Lett., 32, L18102, doi:10.1029/2005GL023872.

1. Introduction

[2] P2 pulsations are well-known nightside HHD waves associated with the onset of magnetospheric substorms. They are damped and transient oscillations with periods of 40 to 150 s. Identification of the excitation mechanisms of P2 pulsations is one of the critical topics in P2 studies (see review by Olson [1999]).

[3] Ground-based observations at mid/low latitudes revealed that P2 pulsations occur over a wide range of latitude and longitude without significant time delay. Thus, cavity mode resonance of the plasmasphere has been proposed as the mechanism for mid/low-latitude P2 pulsations (e.g., Satellite and Yamamoto, 1989; Yoon and Orr, 1989). Recently, observational evidence for the cavity mode has been provided from ground-satellite statistical studies in the inner magnetosphere (L < 5) by Takahashi et al. [1995, 2003].

[4] The authors showed that the radial variation of the amplitude and phase of P2 pulsations can be explained by a simple cavity mode model.

[5] The plasmaspheric cavity mode has been obtained from many numerical studies (e.g., Fujita and Glassmeier, 1995; Lee, 1996; Goldstein et al., 1999; Denton et al., 2002). These studies showed that a well-defined cavity mode can be established in the plasmasphere when there is a sharp inward density gradient at the plasmapause. The cavity mode does not exist outside the plasmasphere.

[6] Lee (1998) presented an analytical study for the frequency and phase of the plasmaspheric mode. The author suggested that the plasmaspheric virtual resonances (PVR) play a significant role in determining the spectral properties of compressional (bₜ) pulsations in the plasmasphere. Using a dipole simulation Lee and Lyuks (1999) confirmed that compressional oscillations in the P2 band are strongly associated with the PVR in the plasmasphere and that they appear beyond the plasmapause unlike the plasmaspheric cavity mode. The radial amplitude and phase variations of the fundamental bₜ PVR obtained from the simulation code of Lee and Lyuks (1999) have been shown by Takahashi et al. [2003, Figure 12]. Although the bₜ power is mostly confined inside the plasmasphere, finite power exists outside the plasmapause and bₜ outside the plasmapause oscillates with a phase lag of ~180° relative to bₜ inside a nodal point. That is, P2 pulsations are not localized to the plasmapause.

[7] Until now, there has been no observational evidence of the PVR outside the plasmasphere to the best of the authors’ knowledge. In this study we examine the compressional oscillations at the Polar satellite outside the plasmasphere associated with low-latitude P2 pulsations observed on the ground. Unlike a previous study [Takahashi et al., 2001], many ground-satellite high-coherence events were observed. We discuss whether our events can be explained by the PVR mode.

2. Data and Event Selection

[8] The data used in this study include spin averaged (~6 s) magnetic field [Russell et al., 1995] and spacecraft potential [Harvey et al., 1995] measured from the Polar satellite. The spacecraft potential data are used to identify plasmapause crossings. To separate the field perturbations into the transverse and compressional components, for Polar magnetic field data have been rotated into mean-field-aligned coordinates. In this system the mean field is defined as the 300-s running vector average (B) of the 6-s magnetic field data B and the compressional component is defined as bₜ = [B - B]. This is the high-pass-filtered compressional component. The ground magnetometer data L18102

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0094-8276/05/2005GL023872$25.00

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at Kakioka (KAK, L ~ 1.3, local time (LT) UT + 9.3 hours) are used to identify equatorial-pulse P2 pulsations
To examine a phase variation of P2 pulsations inside the plasmasphere, we also use Maugade (MGD, L ~ 2.8, LT ~
+ 10.1 hours) and/or Zytymka (ZYK, L ~ 3.9, LT ~
+ 10.1 hours) ground data. The ground data have been filtered by removing 30-s running averages from the horizontal component.

The events presented in this study were selected by the following procedure. First, we examined 6-s averages of
KAK data during a 2-month (March—April) period in 1997.
Applying the automated procedure developed by Takahashi et al. (1995), we selected the P2 events in the horizontal component H in time periods when KAK was within 4 hours of midnight. Each event was identified as a P2 pulsation by visual inspection. Second, we examined the componental component (h) at Polar outside the plasmasphere during the low-latitude P2 events. Polar data were also limited on the nighttime from 2000 to 0400 magnetic local time (MLT).

Third, we applied the autoregressive time series technique [Takahashi et al., 2003] to the h-H time series to calculate the coherence and cross phase. We found 14 high-coherence events (coherence > 0.7).

3. Observations

Figure 1 shows the electron number density inferred from the Polar spacecraft potential [Scudder et al., 2000] during an inbound pass from the tail lobe into the plasmasphere on 1 April 1997. Polar encountered two sudden density increases near midnight: one is from ~0.1 cm$^{-3}$ to
~2 cm$^{-3}$ at 1618 UT and the other is from ~2 cm$^{-3}$ to

Figure 2 shows the magnetic field data from Polar and ground stations to the 20-min interval indicated in Figure 1 with a horizontal bar. The spacecraft was in the tail lobe.

Figure 3 shows the power spectra of H and $h$, and the coherence and cross phase between H and $h$, for the time interval 1556 to 1608 UT. The cross phase (solid curve) is calculated only for the frequencies at which the coherence is higher than 0.7. We find a spectral peak in $h$ and H at ~13 mHz. As expected from the time series plots of Figure 2, the H-$h$ coherence is high (0.95), and cross phase is 165° at the spectral peak.

100 cm$^{-3}$ at 1645 UT. The first increase is due to a spacecraft crossing of the lobe to plasma sheet boundary layer interface and the second increase is due to a plasmaphase crossing. The plasma regime identifications can also be confirmed from the Kappa data provided at http://www-st.physics.uow.edu.au

Figure 2 shows the time series plots of $h$, at Polar and H at KAK, MGD, and ZYK for 1550 to 1610 UT. During this interval, Polar was in the tail lobe as marked by a heavy horizontal bar in Figure 1 and the ground stations were inside the plasmasphere ($L_g$ = 5.3) and near midnight (~1.3 to 2.8 hours MLT). The ground magnetic field data at KAK, MGD, and ZYK exhibit P2 pulsations starting at ~1557:30 UT. Although the ground stations had $L$ values ranging from 1.3 to 3.9, they all recorded pulsations with nearly identical waveform and period without phase delay.

Polar observed a clear compressional ($h$) oscillation. The $h$ amplitude in space is smaller than the H amplitude on the ground. There is a high degree of similarity between $h$ and H with an out of phase signature. This implies that the $h$ oscillation outside the plasmasphere and the ground P2 oscillations inside the plasmasphere are excited by a common source. That is, the source of low-latitude P2 pulsations is not confined within the plasmasphere.

Figure 3 shows, from top to bottom, the power spectra for H at KAK and $h$ at Polar, and the coherence and cross phase between H and $h$, for the time interval 1556 to 1608 UT. The cross phase (solid curve) is calculated only for the frequencies at which the coherence is higher than 0.7. We find a spectral peak in $h$ and H at ~13 mHz. As expected from the time series plots of Figure 2, the H-$h$ coherence is high (0.95), and cross phase is 165° at the spectral peak.
Figure 4. Plasma density estimated from the Polar spacecraft potential data on 15 March 1997.

[1] The observed cross phase could arise from simple radial propagation. Assuming that the average fast mode speed between Polar ($L = 8.0$) and KAK ($L = 1.3$) is $\approx 1500$ km/s and that the average speed inside the plasmasphere is $\approx 500$ km/s, we can estimate the radial propagation phase delay for the $13$-mHz oscillation. The gray, solid, and open circles in Figure 3c indicate the $b_2$-KAK, $H$ (137°), ZYK, H-KAK, $H$ (162°), and MGD KAK, $H$ (100°) phase delays, respectively. The phase difference between the observation and estimation of $b_2$-KAK, $H$ is $\approx 30\%$. One may consider a possibility of propagation mode with this value because the average fast mode speed has uncertainties. However, the ground P2O pulsations inside the plasmasphere oscillate without phase lags, as shown in Figure 2. Therefore, the observed P2O oscillations inside and outside the plasmasphere can be explained by a standing mode signature rather than a propagating mode.

[4] Figure 4 shows another inbound plasmapause crossing by Polar near midnight on 15 March 1997. Polar was initially in the plasma sheet from 1900 to 1950 UT and then entered the plasmasphere. The plasmapause crossing at $\approx 1950$ UT is clearly identified by a sudden increase in the plasma density. Polar observed a density enhancement at $\approx 1910$ UT in the plasma sheet. This is due to an increase in particle energy flux rather than the plasma density increase. Note that the spacecraft potential can be affected by particle flux in the plasma sheet. This can be confirmed from the Hydra measurement (data not shown).

[5] Polar observed a well-defined $b_2$ oscillation in the plasma sheet during the ground P2O pulsations as shown in Figure 5. The ground stations (ZYL, MGD, and KAK) were inside the plasmasphere and observed oscillations, which were all in phase. We found a peak spectrum at $13$ mHz in both KAK $H$ and Polar $b_2$ and at this frequency the $H-b_2$ coherence and cross phase are 0.93 and 182°, respectively.

[6] Figures 6a, 6b, and 6c show the amplitude ratio, which is the square root of the Polar $b_2$ to KAK $H$ power, the cross phase between KAK $H$ and Polar $b_2$, and the Polar magnetic latitude (MLAT) as a function of $\Delta L$, for the 14 high-coherence events including the two events discussed above. Here $\Delta L$ is defined to be $L_{KAK} - L_{Polar}$ if the spacecraft is in the magnetic latitudes lower than 35°. Since the magnetic $L$ values are very large in higher magnetic latitudes and magnetic field line is open in the tail lobe, $\Delta L$ is defined to be $R_{KAK} - R_{Polar}$ where $R$ is a radial distance, if magnetic latitudes are higher than 35°. The open (solid) circles indicate the previous observed in the plasma sheet (tail lobe).

We note that the characteristics of the remaining 12 events are the same as the two events discussed above.

[7] If a P2 wave is driven in the magnetotail and radially propagating earthward from the source, the wave amplitude will increase with distance from earth. However, we find that the $b_2$ power is in a decreasing function of $\Delta L$. This indicates that the P2 pulsations at KAK do not result from waves propagating from a distant source. The cross phase exhibits no systematic radial variation with Polar position outside the plasmasphere relative to the plasma-pause, but it stays near 180°. Such amplitude and phase variations outside the plasmasphere can be explained by the PVR mode. Figure 6c shows that the high coherence events are observed off the magnetic equator ($\approx 15°$ to $60°$) outside the plasmasphere. The events' bias toward high magnetic latitude is due to Polar's high orbital inclination.

4. Discussion

[8] In a previous statistical study using magnetic field data simultaneously acquired at the AMPTE/CCE space-

Figure 5. Magnetic field data from Polar and ground stations for the 20-min interval indicated in Figure 4 with a horizontal bar. The spacecraft was in the plasma sheet.

Figure 6. (a) $b_2$ (Polar) to $H$ (Kakioka) amplitude ratio, (b) $b_2$-$H$ cross phase, and (c) magnetic latitude as a function of the distance from the plasmapause for the high-coherence P2 events. Five (nine) events were observed in the plasma sheet (tail lobe).
References


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