Association between quiet-time Pi2 pulsations, poleward boundary intensifications, and plasma sheet particle fluxes

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Abstract. Pi2 pulsations have been observed to occur at low latitudes during extremely quiet conditions. We have found an excellent correlation between an occurrence of such a Pi2 train and high-latitude Pi2 pulsations and bay-like disturbances in ground magnetic field of the type associated with poleward boundary intensifications (PBIs). The Pi2s and the PBIs that are inferred to occur simultaneously, show a ~30 min repetition rate. They also exhibit an excellent correlation with energetic particle enhancements in the near Earth tail plasma sheet. These associations demonstrate the large-scale nature of the magnetosphere-ionosphere disturbance that gives rise to PBIs and shows that the disturbance may have important effects on energetic plasma sheet particles. They show for the first time that PBIs are associated with clearly observable Pi2 pulsations at low latitudes. Our observations are consistent with the possibility that PBIs are part of a large-scale magnetospheric oscillation with ~30 min period.

1. Introduction
While substorms are generally the most dramatic auroral-zone disturbance, auroral poleward boundary intensifications (PBIs) occur frequently in the nightside auroral zone and are generally the most intense auroral disturbance at times other than during the expansion phase of substorms [Lyons et al., 1999]. They occur repetitively so that many individual disturbances can occur during time intervals of ~1 hr and occur during all overall levels of geomagnetic activity, including very quiet periods [e.g. Lyons, 2000]. They are observed near the poleward boundary of the auroral oval, but sometimes extend equatorward from the poleward boundary. PBIs are typically associated with ground magnetic perturbations of a few tens of nT at the latitudes of auroral intensification. Since the latitude of peak PBI auroral intensification is often the near poleward boundary of the auroral oval, their magnetic signature often remains at high geomagnetic latitudes (≥ 70°) and thus is distinct from the magnetic signature of substorms, which initiates at latitudes well equatorward of the poleward boundary of the auroral oval. PBIs are also associated with enhancements of equatorward flow in the ionosphere [de la Beaujardière et al., 1994] and with localized regions of enhanced reconnection and earthward flow bursts in the tail [Lyons et al., 1999; Zesta et al., 2000].

Geomagnetic Pi2 pulsations are best known for their occurrence at the time of magnetospheric substorm onsets and intensifications. However, observations of Pi2 pulsations in association with other types of disturbances have also been reported in the literature. The most common of these is their occurrence in association with pseudo-breakups, which also have other signatures similar to substorm expansion phases, such as auroral arc brightening and enhancement of the westward electrojet [Rostoker, 1998]. Sergeev et al. [1998] reported on current sheet measurements within a flapping plasma sheet; they found that plasma sheet flapping tends to occur in conjunction with ground Pi2 bursts. In addition, Lyons et al. [1999] found that series of PBIs are associated with series of ground Pi2 pulsations. A common characteristic of these various phenomena associated with Pi2 pulsations is that they all represent reconfigurations of magnetic flux and plasma flow in the magnetotail.
**Sutcliffe [1998]** demonstrated that Pi2 pulsations sometimes occur under conditions with which they had not previously been associated, namely, extremely quiet solar wind and magnetospheric conditions. It was shown that Pi2s could occur when the magnetosphere is in a near ground state and substorm activity would be expected to have ceased. The question thus arises as to the origin of these Pi2 pulsations and whether they are associated with any of the above-mentioned phenomena. Since PBIs are the most common geomagnetic disturbance that has been reported during quiet times, it is reasonable to hypothesize that extremely quiet-time Pi2 pulsations may be associated with PBIs. Here, we present an example of a quiet-time Pi2 event and show evidence that it indeed is associated with PBIs. We also find that this quiet-time PBI event exhibits clear characteristics of a large-scale ULF oscillation (~30 min period) of the type recently observed by *Lyons et al.* [2001] in association with PBI events during conditions of steady magnetospheric convection. We furthermore take advantage of a fortuitous conjunction with Geotail within the tail plasma sheet at \(X_{\text{GSM}} \sim -12R_e\) to \(-17R_e\) and find evidence that quiet-time PBIs are associated with significant energetic particle injections in the plasma sheet.

### 2. Observations on 27 December 1997

The event selected for study occurred from 18-22 UT on 27 December 1997. This was one of the ten quietest intervals in the years 1994 to 1998, based on selecting intervals where three or more consecutive 3-hour \(a_i\) indices were equal to zero, followed by further stringent selection based on solar wind data [*Sutcliffe*, 1998]. Despite such quiet conditions, significant Pi2 activity was observed during this event at Hermanus (HER; 34.45°S, 19.25°E geographic, L=1.83), which was located at 1813 to 2213 MLT. Although *Sutcliffe* [1998] observed Pi2s during a number of the other very quiet intervals, the event selected for study was that for which Geotail was best placed to observe the near-Earth plasma sheet. The event occurred when the interplanetary magnetic field (IMF) and solar wind conditions from 1130 UT onwards were significantly quieter than those required by *Gussenhoven* [1988] for a baseline magnetosphere. The \(z\)-component of the IMF remained between \(-1.0\) and \(0.5\) nT, indicating that a substorm growth phase was not possible. Nevertheless, a sequence of Pi2s occurred after 1800 UT. The polarization filtered H and D component induction magnetometer data from Hermanus and the band-pass filtered X-component magnetometer data from the IMAGE station BJN (71.2° geomagnetic latitude, magnetic midnight at 2058 UT) for the period 1800 to 2200 UT are plotted in Figure 1. Six bursts of pulsations were observed at Hermanus starting at \(\sim 1827\) UT, and all but the first burst were also observed at BJN. A noticeable feature of the Pi2 bursts, which had amplitudes similar to those typically expected during substorms, are that they occurred repetitively with a periodicity of about 30 minutes. Also noticeable, is that each Pi2 burst tended to grow then decay, rather than have impulsive onsets as often exhibited by Pi2s associated with substorms.

The unfiltered X-component magnetometer data recorded at 8 of the IMAGE stations during the same time interval are plotted in Figure 2. Magnetic perturbations occurred between 71° and 75° magnetic latitude, peaking at about 73°. Z-component perturbations (not shown) were positive poleward of 73° and negative equatorward of 73°, indicating that magnetic perturbations were associated with a westward current centered at 73°. Very little activity is seen at latitudes \(\leq 66.5°\). The latitude range of magnetic activity is characteristic of PBIs and inconsistent with substorms. Furthermore, the magnitude of the perturbations is significantly less than for typical substorms and the gradual decrease of the magnetic field during the negative bays is characteristic of PBIs and not substorms [*de la Beaujardière et al.*, 1994]. Consequently, we can infer that the quiet-time Pi2s seen during this interval are associated with PBIs.

PBIs have been found to be associated with flux enhancements of energetic particles at synchronous orbit at times when the PBIs extended to unusually low magnetic latitudes (\(\leq 67°\)) [*Henderson et al.*,...](

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Inspection of the Los Alamos National Laboratory (LANL) energetic particle data at synchronous orbit for our quiet-time event did not reveal any injections of energetic particles close to local midnight. This is expected, since very little ground magnetic activity was seen at latitudes below 70°, indicating the PBIs during this period did not extend equatorward enough to affect synchronous field lines. During this time, however, the Geotail satellite crossed the $Z_{GSM}=0$ plane in the magnetotail well toward dusk while travelling tailward. The fluxes of energetic electrons (dashed curve) and ions (solid curves) observed by Geotail at $X_{GSM} \sim -12R_e$ to $-17R_e$, $Y_{GSM} \sim 12R_e$ to $10R_e$, and $Z_{GSM} \sim 0R_e$ during the interval 1800-2200 UT on 27 December 1997 are plotted in Figure 3. Repetitive enhancements of energetic ion fluxes are clearly seen at approximately the same times as the Pi2s in Figure 1. There does not seem to be any dispersion and corresponding clear flux enhancements are not seen in the electrons.

The repetitive nature of and excellent correlation between the independent data sets in Figures 1 to 3 are clearly shown using selected data in Figure 4. In order to emphasize the periodicity of the sequence of Pi2s, the envelope of the horizontal plane amplitude of the Pi2 pulsations at HER is plotted in the top panel of Figure 4. Vertical dashed lines are drawn at the times of the low latitude Pi2 onsets. The flux of 73.7 – 89.3 keV ions at Geotail and the magnetic field X-component at BJN respectively are plotted in the following two panels. In addition, the x-component of the bulk flow velocity as measured by Geotail is plotted in the bottom panel. Figure 4 shows a clear one-to-one association between the Pi2 amplitude at HER, the energetic particle enhancements in the plasma sheet observed by Geotail, and (except for the first pulsation burst) the magnetic perturbations in the auroral ionosphere. We would expect to also see an association with $V_X$ and the total magnetic field in the plasma sheet if Geotail were located near the same MLTs as the PBIs. Despite Geotail being well toward dusk, we do see some evidence for $V_X$ oscillations in association with each Pi2 burst and a tendency for $V_X$ to reach a minimum near the times of the energetic particle flux peaks.

To further illustrate the associations between the four data sets in Figure 4 and to investigate the possibility that the disturbance may be associated with an ULF oscillation, as suggested by Lyons et al. [2001], the amplitude spectra of the four time series in Figure 4 are plotted in Figure 5 in the same order from top to bottom. The solid lines are for spectra computed from unfiltered data and the dashed lines for data that have been high-pass filtered with a cut-off frequency of 0.15 mHz. All the spectra exhibit a clear dominant peak at 0.5 mHz, as indicated by the vertical dashed line. There also appear to be higher harmonics; however, these do not match each other as well as do the fundamental peaks.

3. Conclusions and Discussion

Pi2 pulsations have been reported to occur at both low and high latitudes during prolonged periods of extremely quiet magnetospheric and solar wind conditions [Sutcliffe, 1998]. In this paper, we have found an excellent correlation between an occurrence of trains of low latitude and high latitude Pi2 pulsations during such extremely quiet conditions and bay-like disturbances in the magnetic field at high latitude ground stations that results from current systems centered near 73° magnetic latitude. The characteristics of these disturbances identify them as being due to PBIs. This demonstrates for the first time that quiet-time Pi2s are associated with PBIs. The results also show for the first time that PBIs are associated with low latitude Pi2 pulsations that have amplitudes of similar magnitude to low latitude Pi2 pulsations associated with substorm onsets.

We have shown that the quiet-time PBIs exhibited an excellent correlation with energetic particle enhancements in the near-Earth tail plasma sheet. While it has been previously shown that strong PBIs during disturbed periods are associated with energetic particle flux enhancements at synchronous orbit
when the PBIs extend to unusually low latitudes, the present results suggest that PBIs may in general be associated with enhancements of energetic particle fluxes within the plasma sheet. The PBIs examined here are also correlated with the x-component of bulk plasma velocity in the tail plasma sheet. These various phenomena all occurred repetitively with a period of ~30 min for a duration of about 4 hours.

Several researchers have recently presented observations that point to the occurrence of large-scale ULF oscillation modes having large perturbations in the plasma sheet and the auroral ionosphere. For example, Sánchez et al. [1997] found the same ULF pulsation frequencies simultaneously in the ground magnetic field, at synchronous orbit, and in the tail plasma sheet. Later, Lyons et al. [2001] found significant power at 0.5-0.7 mHz in the intensity of PBIs and ground magnetometer data in the auroral zone. They observed significant power at a likely second harmonic (~1.1-1.3 mHz) and evidence for power at possible higher harmonics. They showed that similar frequencies were present simultaneously in the fluxes of energetic protons at synchronous orbit and in magnetic field and plasma moment data in the inner plasma sheet. These events occurred during prolonged periods of strongly southward and relatively steady IMF. Lyons et al. [2001] stated that although higher harmonic oscillations similar to those that they had observed had been reported previously, the fundamental frequency that they had identified had not generally been seen previously. Walker et al. [2001] reported on strong activity observed by the SHARE and SuperDARN radars during extremely quiet solar wind conditions. This activity took the form of quasi-periodic ionospheric flow bursts with periods of about 12 minutes, that is, approximately equivalent to the second harmonic observed by Lyons et al. [2001]. Our observations demonstrate the 0.5 mHz spectral peak extremely clearly and show that the effect of these large-scale oscillations propagates to the inner magnetosphere (L-value ~1.8).

A more detailed study of additional similar quiet-time events is in progress. It is hoped that this study will address the generality of the results presented here and shed more light on the characteristics and generation of these quiet-time events in particular and PBIs in general.

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References


**Figure Captions**

**Figure 1.** Polarization filtered Pi2 pulsations observed at the low latitude station HER and band-pass filtered (0.005-0.025 Hz) Pi2 pulsations observed at the IMAGE station BJN during the interval 1800-2200 UT on 27 December 1997.

**Figure 2.** X-component data at IMAGE magnetometer network stations during the interval 1800-2200 UT on 27 December 1997.

**Figure 3.** The fluxes of electrons (dashed curve) and ions (solid curves) observed in the magnetotail by Geotail during the interval 1800-2200 UT on 27 December 1997.

**Figure 4.** A comparison of data sets, from top to bottom: the envelope of the horizontal plane amplitude of the Pi2 pulsations at HER; the flux of 73.7 – 89.3 keV ions at Geotail; the magnetic field X-component at BJN; and Vx at Geotail.

**Figure 5.** A comparison of the amplitude spectra of the time series in Figure 4.