The June 8, 2000 ULF wave activity: a case study.

by
M. Piersanti[1], U. Villante[1], C. Waters[2], I. Coco[3]

(1) Dipartimento di Fisica, Università and Area di Astrogeofisica. L'Aquila (Italy).
(2) School of Mathematical and Physical Sciences, the University of Newcastle, NSW (Australia).
(3) Istituto di Fisica dello Spazio Interplanetario-INAF, Roma (Italy).

Introduction.

Sudden impulses (SI) are sudden variations of the geomagnetic field generated by steep increases in the solar wind dynamic pressure (PSW). They are occasionally followed by ultra low frequency (ULF) waves, typically in the Pc5 range (T~150 ÷ 600 s). Their study has two vantage points: the specific source for the waves is clear and the response of the system to an impulsive or step-like function yields eigenmodes of the system. Then, these events can be used as a diagnostic tool for the magnetosphere. Here, we present simultaneous observations of Pc5 pulsations following the June 8, 2000 SI [09:10 ÷ 09:40 UT] at geosynchronous orbit (GOES8) and on the ground.

Experimental observations.

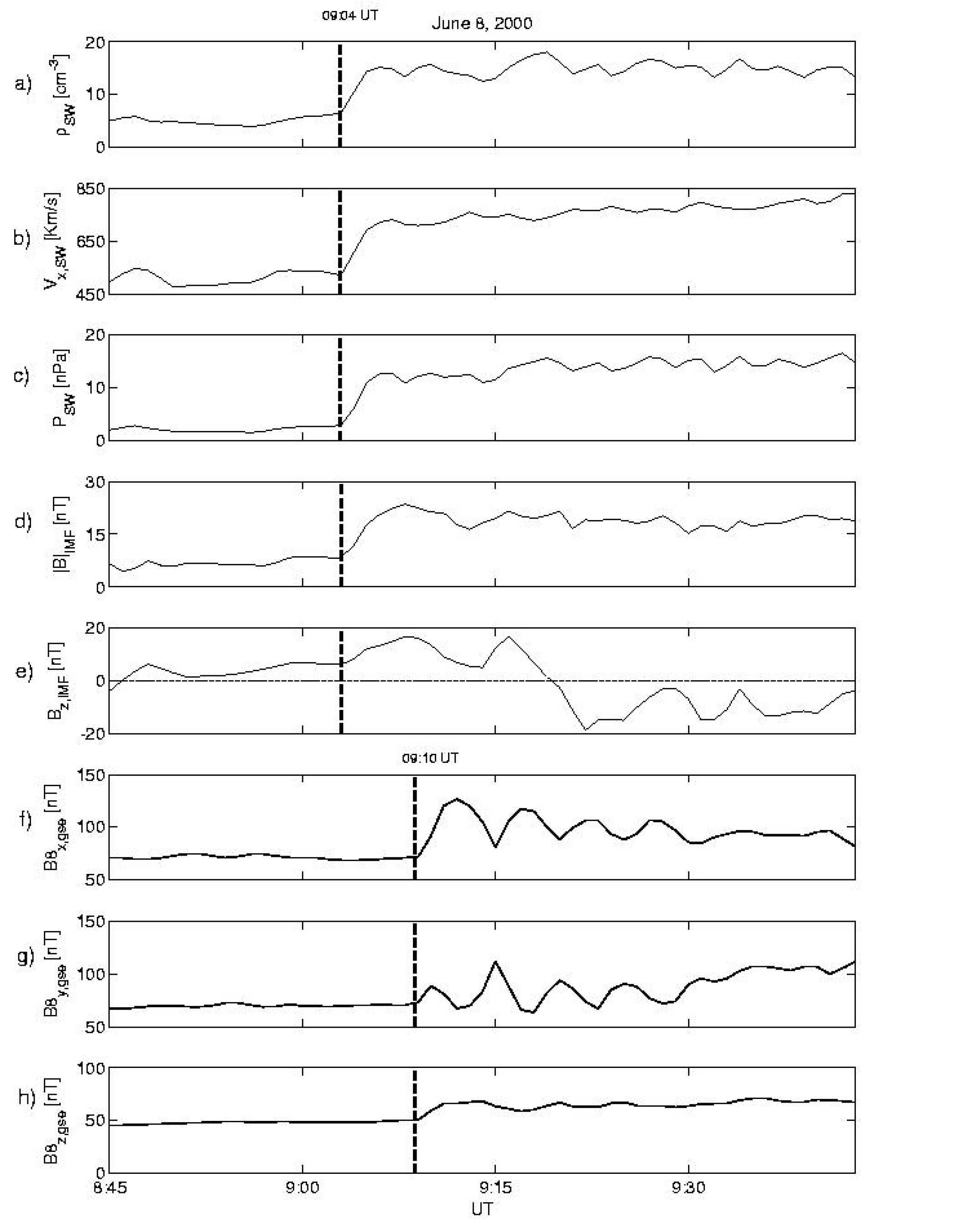

Figure 1: The solar wind (WIND) and the magnetospheric observations (GOES spacecraft) for the SC event occurred on June 8, 2000: a) the SW density; b) the SW Velocity; c) the SW dynamic pressure; d) the IMF magnitude |B|; c) the IMF B_z component; f) the $B_{X,GSE}$ component of the magnetospheric field measured by GOES8; g) the $B_{Y,GSE}$ component of the magnetospheric field measured by GOES8; h) the $B_{Z,GSE}$ component of the magnetospheric field measured by GOES8. The vertical dashed lines represent our estimation of the shock arrival.

Figure 1 shows the solar wind density (panel a), velocity (b), dynamic pressure (c), the magnitude B (d) and B_Z component (e) of the interplanetary magnetic field (IMF) observed by WIND (X_{GSE} = 40,8 R_E; Y_{GSE} = -26.4 R_E) on June 8, 2000 from 8:45 UT to 9:45 UT. A sharp pressure jump can be easily seen at ~ 09:04 UT (dotted lines): the SW velocity, in less than 3 min, varied from 490 km/s to 742 km/s, the density increased from 4 cm^{-3} to 14.5 cm^{-3} and the dynamic pressure from 1.5 nPa to 14 nPa. The IMF magnitude increased from 6.5 nT to 20 nT and its orientation was northward ($B_{Z,IMF}$ ≈ 10 nT) up to ~30 minutes after the shock front passage.

The magnetospheric field components from GOES8 (LT≈04:15, LT being the local time) are plotted in panels f, g, h. Basically, GEOS8 observed at ~09:10 UT a large increase of the B_X component, while the B_Z and the B_Y components experienced smaller amplitude changes. The most important feature observed during the event is the occurrence of sharp quasi-monochromatic wavelike oscillations in the Pc5 range (3.3 mHz).

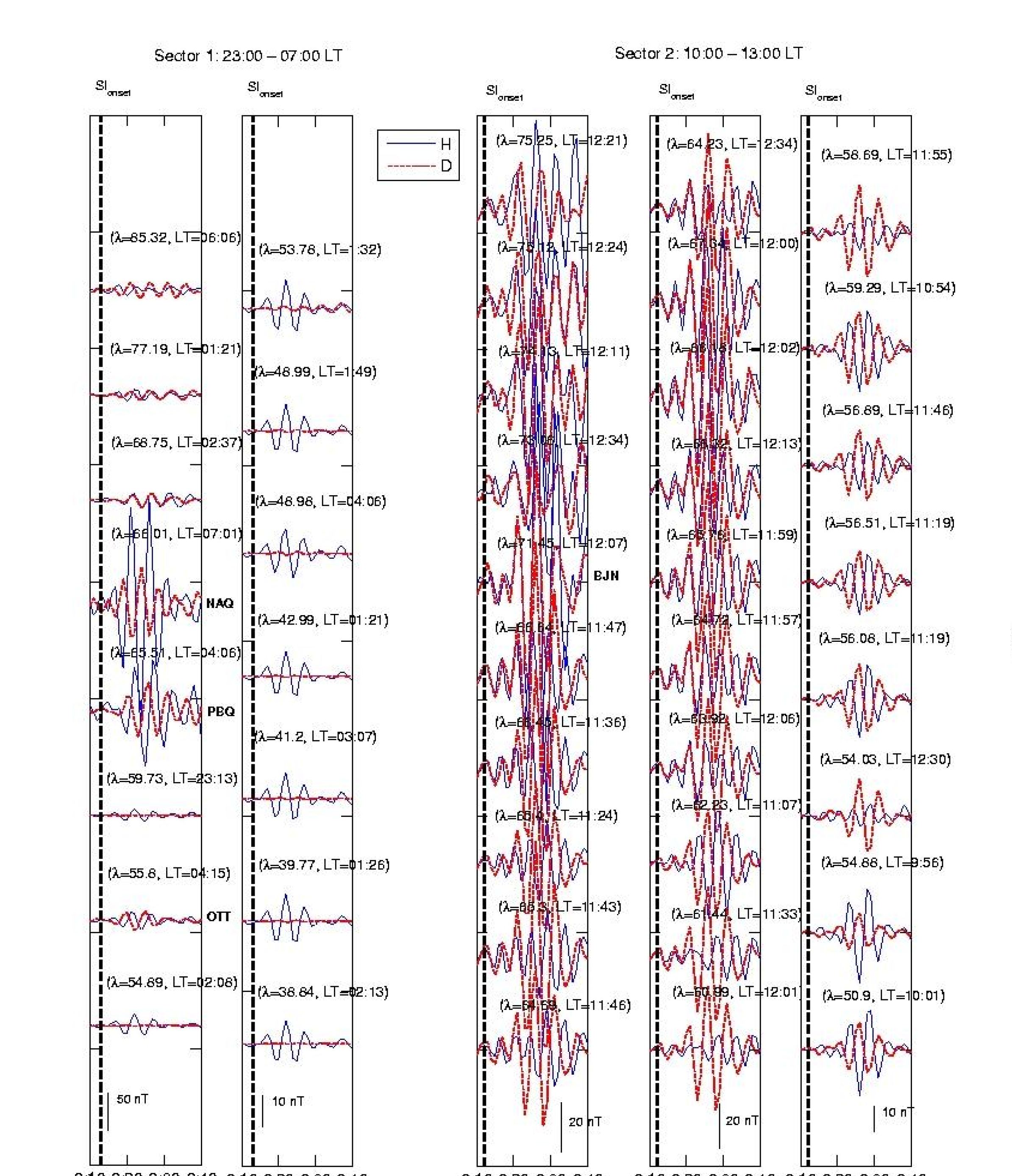

Figure 2: The H (solid) and D (dotted) components of geomagnetic field measured at ground stations during 0910÷0940 UT on June 8, 2000: left panels show the midnight/morning sector (23:00 < LT < 07:00); right panels shows the morning-noon sector (10:00 < LT <13:00); the vertical dashed line indicates the SI time occurrence (UT=09:12) at PBQ (λ= 65.51°, LT = 04:06).

To evaluate the ground response, we used 48 magnetometers of the CARISMA, INTERMAGNET, IMAGE and SAMNET arrays. We organized station observations in two sectors: the midnight/morning sector (23:00 ÷ 07:00 LT, sector 1) and the morning-noon sector (10:00 ÷ 13:00 LT, sector 2). Power spectra computed at all the ground stations (not shown) reveal a common peak centered at f≈3.3 mHz. This latitude-independent frequency has been used for coherence, amplitude and cross-phase analysis.

Figure 2 shows the filtered ground response data at f=3.3 mHz for the H (solid line) and D (red dotted line) components in the interval 09:10 ÷ 09:40 UT with magnetic latitude decreasing from top: left panels display the midnight/morning sector; right panels display the morning-noon sector. Interestingly, the PBQ station (Poste-de-la Baleine, λ=65.51°, LT= 4:06) was located close to the GOES8 footprint.

Sector 1: For λ>68°, the D component shows oscillations with amplitude comparable with the H component. For λ<65° the D component has in general negligible amplitude. Exceptions to this behavior occur at stations located around local dawn (OTT, LT=4:13; PBQ, LT=4:06; NAQ, LT=7:01) where H and D components show comparable amplitudes. Both H and D component attained their maximum amplitude at NAQ (λ= 66.1; LT = 07:01).

Sector 2: The amplitude of both H and D oscillations reached maximum values at BJN (λ=71.45°, LT=12:07). H and D components show comparable amplitude at all latitudes.

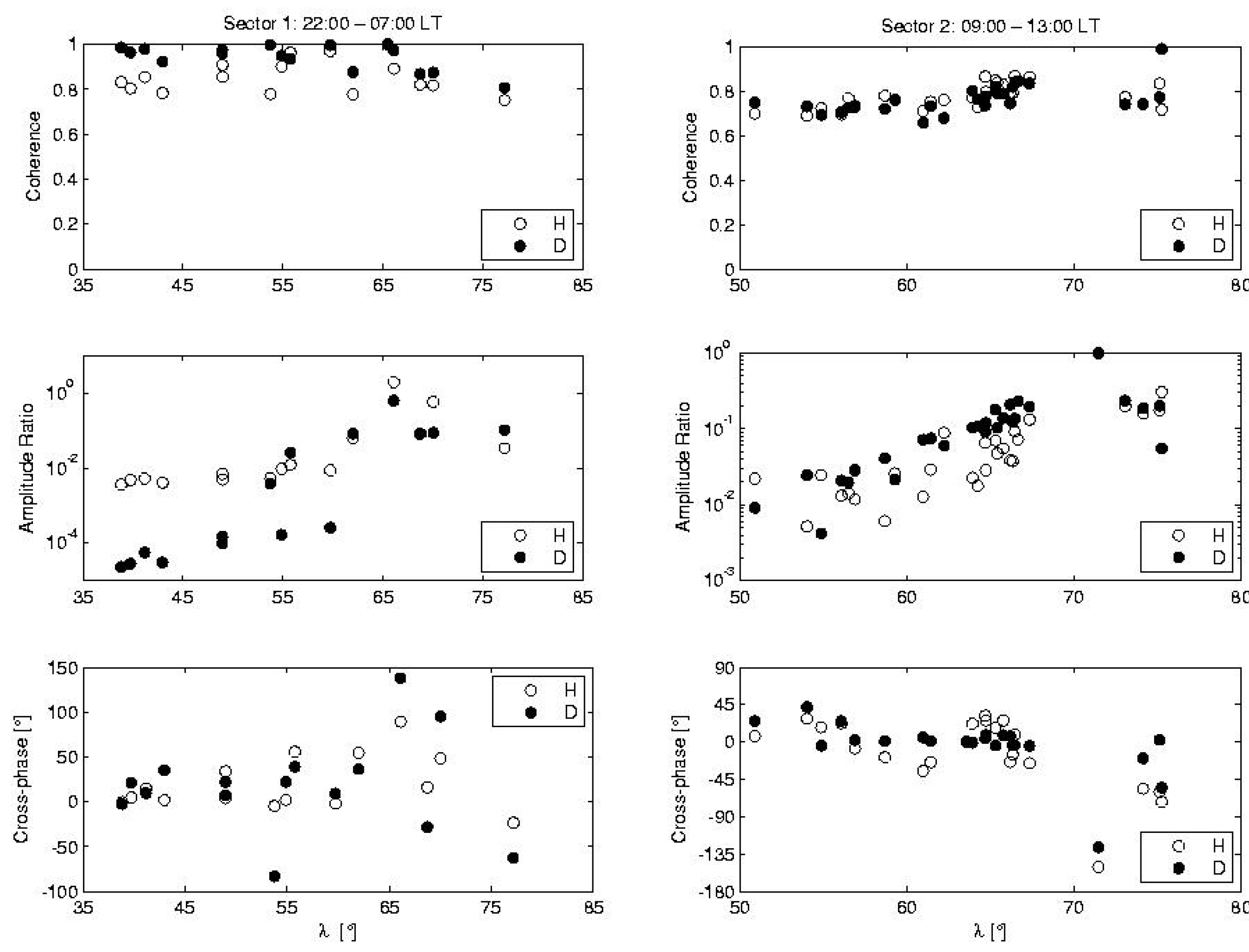

Figure 3: Left panels, from the top: the coherence coefficients (a), amplitude ratio (b) and cross-phase (c) variations between PBQ and the other sector 1 stations at 3.3 mHz as a function of geomagnetic latitude. Right panels, from the top: the coherence coefficients (a), amplitude ratio (b) and cross-phase (c) variations between BJN and the other sector 2 stations at 3.3 mHz as a function of geomagnetic latitude. The solid (open) circles represent the H (D) component.

Figure 3 shows the coherence, amplitude and cross-phase for sector 1 (left panels) and sector 2 (right panels) ground stations.

Sector 1: given its close position to the GOES8 footprint, we used PBQ as reference station. A coherence greater than 0.7 occurred in general from high (λ≈83°) to low (λ≈38°) latitudes for H (open circles) and D (solid circles); the normalized amplitudes (with respect to PBQ), increased with latitude in both components reaching maximum value at λ=66.1° (NAQ); a phase reversal (~ 145°) attained around the maximum amplitude location, at λ≈66°. Below λ≈66°, the cross-phase was scattered between -20° ÷ 50°; above λ≈66°, it decreased with increasing latitude.

Sector 2: in this case, we used BJN as reference station. A coherence greater than 0.7 occurred in general from high (λ≈75°) to low (λ≈51°) latitudes for the H (open circles) and D (solid circles). The normalized amplitudes in both H and D increased with latitude up to λ≈71.5° (BJN). A phase reversal(~ 151°) occurred around the maximum amplitude location. Below λ≈71.5°, the cross-phase was distributed throughout the range [-45° ÷ 45°]. Above λ≈71.5°, it increased with latitude. Such phase reversal at the maximum amplitude location has been reported in previous studies (Mathie et al. 1999; S.-K. Sung et al., 2006) and it was interpreted as evidence for a FLR signature.

The aspects of the polarization pattern have been evaluated using the technique for partially polarized waves (Fowler et al., 1967). In particular, the ellipticity (*ε*, i.e. the ratio between the minor and the major axis of the polarization ellipse in the horizontal plane) has been calculated over 10 minutes interval. The sense of polarization is given by the sign of *ε*: a positive (negative) *ε* corresponds to clockwise (counterclockwise) sense. The sense of polarization was defined by looking downward on the Earth, with clockwise and counterclockwise sense corresponding to right-hand and left-hand polarization, respectively.

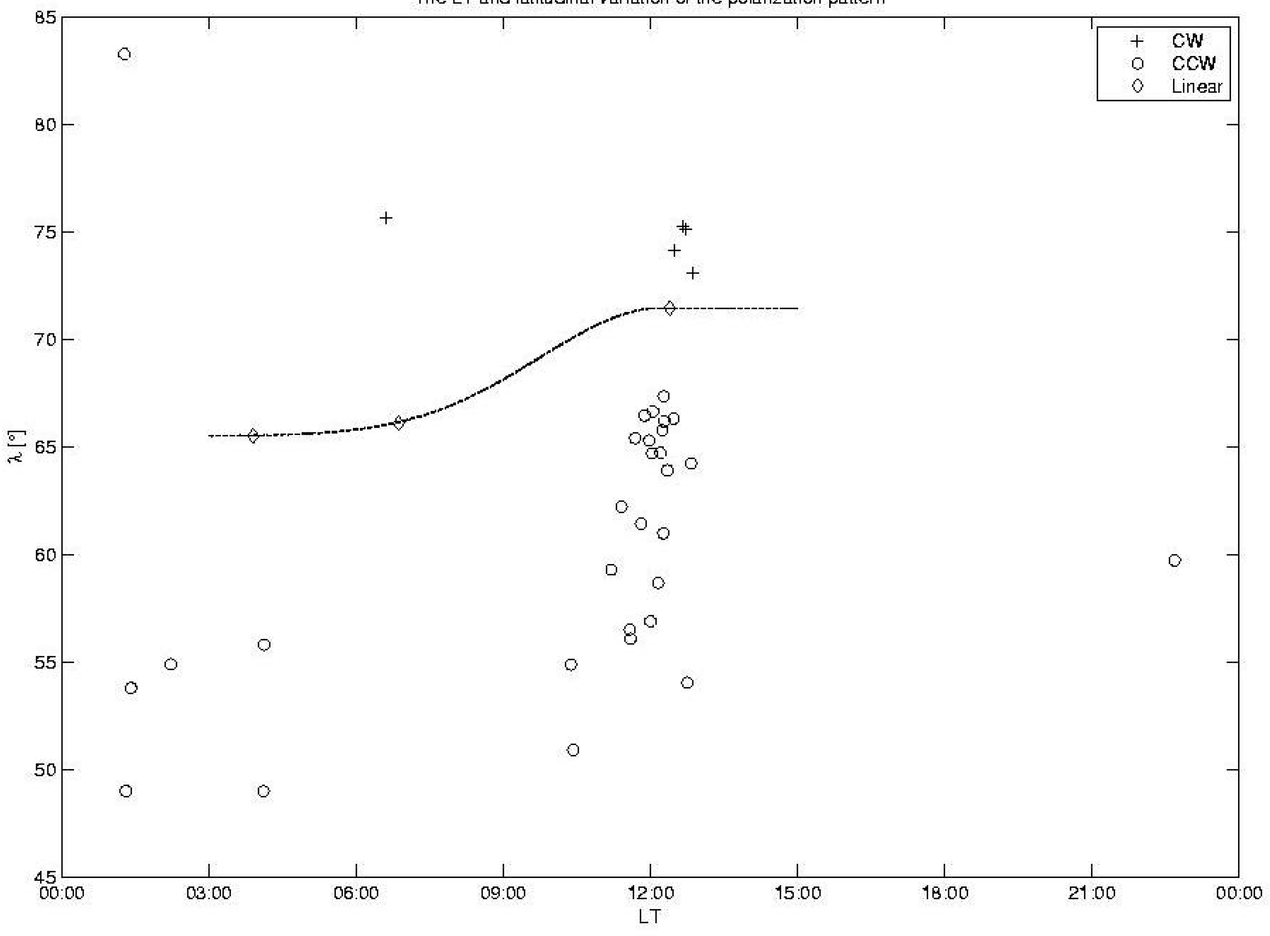

Figure 4: The latitudinal polarization pattern for all the ground stations at 00:00< LT <24:00. Open circles identify counterclockwise (CCW) polarization, solid circles identify clockwise (CW) polarization and diamond signs identify linear polarization, evaluated at 3.3 mHz.

Figure 4 presents the LT and latitudinal dependence of the polarization pattern. It clearly shows a polarization reversal at λ≈72° in the morning/noon sector and some evidence for a similar feature at λ≈66° in the midnight/morning sector. The dotted curve tentatively identifies the line of the maximum wave amplitude and corresponds to the linear polarization region. Such "wave geometry" is consistent with the one proposed by Samson et al. (1972) at high latitudes as well as the one proposed by Villante et al. (2009) at Antarctic latitudes. They interpreted the signal polarization reversing from counterclockwise to clockwise passing through a linear polarization area as a FLR signature in which the resonance region (dotted line) progressively shifts to lower latitude moving towards local midnight.

Discussion.

We showed that the SI event was followed by a 3.3 mHz wave activity. The combination of the long period of these pulsations (5 min), their extended duration (~40 min) and their ubiquitous occurrence can be interpreted as evidence for a global magnetospheric cavity oscillation (Kivelson et Southwood 1985, 1986) driven by the solar wind dynamic pressure enhancement (Lee and Lysak, 1986). The characteristics of the wave amplitude and phase evaluated at ground and the behavior of the global polarization pattern suggest that the wave leaked energy to the field line resonance at NAQ latitude (λ= 66.1; LT = 07:01) in the midnight/morning sector and at BJN latitude (λ=71.45°, LT=12:07) in the morning/noon sector. Model studies (Rankin et al. 2005) and experimental observations (Menk et al., 2000) highlighted that the FLR frequency expected at those latitudes is higher than 3.3 mHz (~5 mHz and ~6 mHz, respectively).

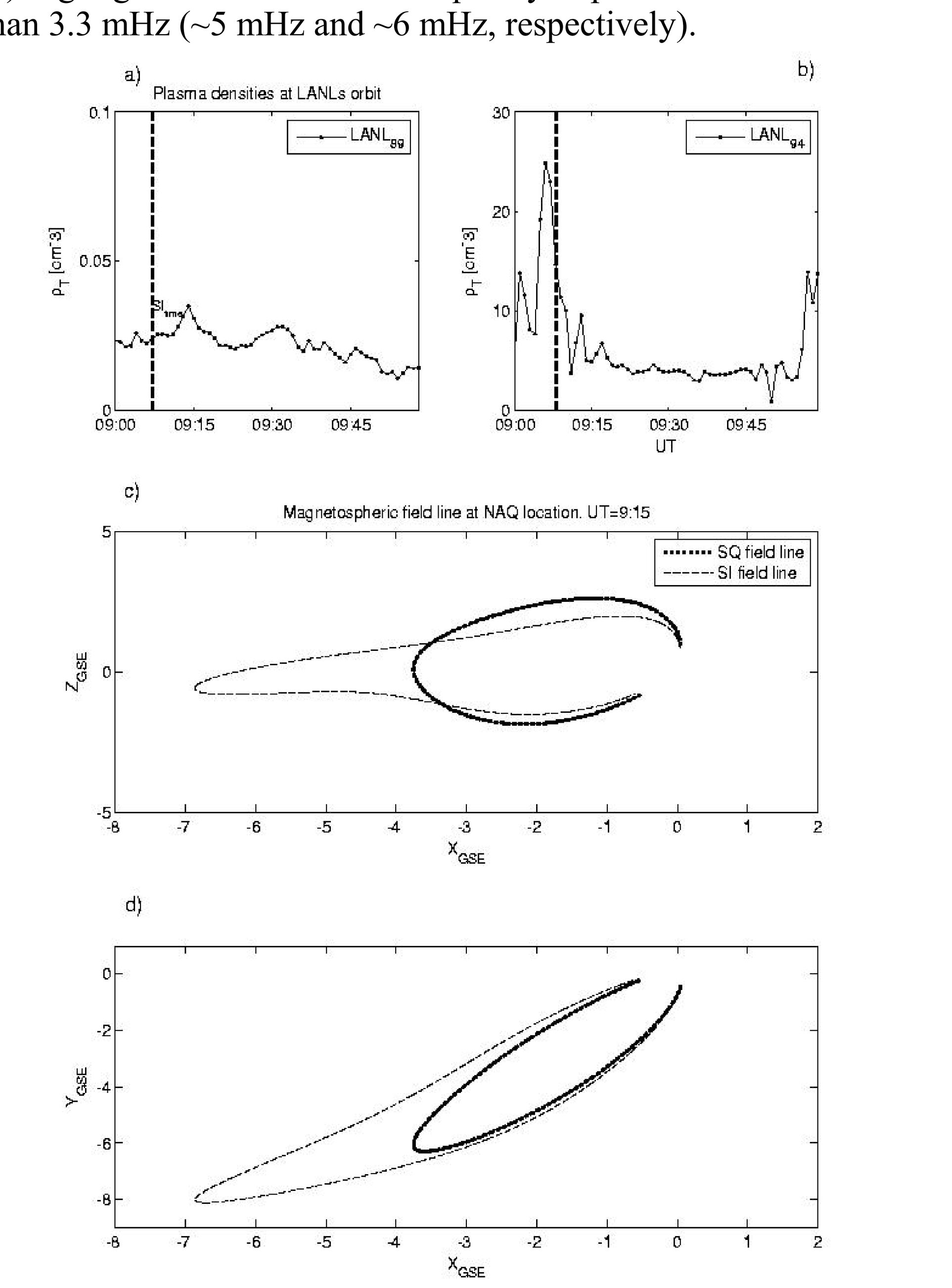

Figure 5: Panel a): the magnetospheric plasma density measured by $LANL_{89}$ spacecraft during 09:00÷09:50 UT. Panel b): the magnetospheric plasma density measured by $LANL_{94}$ spacecraft during 09:00÷09:50 UT. The vertical dashed lines represent the SI onset evaluated at GOES orbit. Panel c): the magnetospheric field line trace at NAQ location at 09:15 UT in the X-Z GSE plane evaluated using T01 model (Tsyganenko 2002) for a quiet day (dotted line) and for June 8, 2000 (dashed line). Panel d): the magnetospheric field line trace at NAQ location at 09:15 UT in the Y-Z GSE plane evaluated using T01 model (Tsyganenko 2002) for a quiet day (dotted line) and for June 8, 2000 (dashed line).

In order to better investigate this discrepancy, we evaluated the field line eigenfrequency for different field-line configurations using the T01 Tsyganenko model (Tsyganenko 2002). For this purpose, we used the TOF approximation (time of flight; Waters, 1996).

Figure 5a and 5b show the $LANL_{89}$ and the $LANL_{94}$ total plasma density measurements, respectively. $LANL_{89}$ was in the afternoon magnetosphere (X_{GSE} = 4.94 R_E; Y_{GSE} = 4.04 R_E; Z_{GSE} = -1.7 R_E) outside the plasmasphere, observing a total plasma density mean value ρ≈0.02 cm^{-3}. $LANL_{94}$ (in the nightside magnetosphere; X_{GSE} = -2.95 R_E; Y_{GSE} = -5.647 R_E; Z_{GSE} = -1.708 R_E) shows a total plasma density mean value ρ≈15 cm^{-3}. The $LANL_{94}$ and $LANL_{89}$ spacecraft data were used because of their footprint position close to NAQ and BJN, respectively. It seems that no particular plasma increment was detected after the SI event. Figures 5c and 5d show the representation of the field line anchored at NAQ in the X_{GSE} − Z_{GSE} plane (panel c) and Y_{GSE} − X_{GSE} plane (panel d) for the June 8, 2000 SI event (dashed line) and for a reference quiet day at LT=7:01 (June 4, 2000, dotted line), modeled by T01. For quiet time conditions, the field line eigenfrequency at NAQ is ~5 mHz. The same calculus for the June 8, 2000 conditions, using the modification proposed by Villante and Piersanti (2008) to interpret the aspects of the SI variations (10% smaller magnetotail hinging distance than its default value and 30% thinner current sheet thickness than its default value) in T01, provided a more stretched field line (dashed line). The eigenfrequency associated with this field line geometry resulted in ≈ 3.35 mHz, in a close agreement with the observed value. Interestingly, we repeated this procedure at noon using plasma measurements from $LANL_{89}$, obtaining a FLR latitude λ=72.5°, very close to BJN (λ=71.45°, LT=12:07).

Conclusion

The principal conclusions of our investigation can be summarized as follows:

- We showed that the June 8, 2000 SI event was followed by a 3.3 mHz wave activity. The combination of the long period of these pulsations (5 min), their extended duration (~40 min) and their ubiquitous occurrence suggests a global magnetospheric cavity oscillation (Kivelson et Southwood, 1986) driven by the solar wind dynamic pressure enhancement (Lee and Lysak, 1986).
- The characteristics of the wave amplitude and the behavior of the polarization pattern suggest that the wave leaked energy to field line resonance at NAQ latitude (λ= 66.1; LT = 07:01) in the midnight/morning sector and at BJN latitude (λ=71.45°, LT=12:07) in the morning/noon sector.
- Model studies (Waters et al., 2000; Rankin et al., 2005) showed that a change in the FLR frequency can occur as a consequence of a reconfiguration of the magnetospheric field and/or an increase in the magnetospheric plasma density *ρ(r)*. We speculated that the FLR at 3.3 mHz (Pc5) observed at the ground was caused by the particular magnetospheric field configuration characterized in particular by a field line more stretched into tail than its usual condition

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