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CORRELATIONS BETWEEN X-RAYS, VLF EMISSIONS AND MAGNETIC PULSATIONS OBSERVED AT SYOWA–TJÖRNES CONJUGATE-PAIR STATIONS NEAR $L\sim6$ (EXTENDED ABSTRACT)

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Bremsstrahlung X-rays were observed by the Polar Patrol Balloon No. 6 (PPB #6) launched from Antarctic Syowa Station in January 1993 (YAMAGAMI *et al.*, 1994; KODAMA *et al.*, 1995). X-ray data of 1 s time resolution was available in the period of 0855 UT (0914 MLT) to 1630 UT (1614 MLT) on January 5, when the balloon was located within the real-time telemetry range of Syowa Station. Temporal variations of X-rays in the energy range of 30–120 keV were compared with ground-based data of magnetic pulsations, VLF emissions and CNA at 30 MHz observed at Syowa Station and at Tjörnes in Iceland, the geomagnetic conjugate point of Syowa in the Antarctic.

Figure 1 shows the time profiles of balloon X-rays, VLF intensity at 2 kHz observed at Tjörnes, *D*-components of magnetic pulsations at Tjörnes and Syowa in the period of 0930 to 1630 UT on January 5, 1993. The VLF intensity at Syowa was very weak in this period, possibly due to an enhanced ionospheric absorption caused by energetic electron precipitations.

It is shown in the third and fourth panels of this figure that persistent magnetic pulsations continued from 0930 to 1315 UT at the both stations, and the pulsation amplitude suddenly decreased after 1315 UT. A similar feature was found in the VLF intensity at Tjörnes shown in the second panel. After the launch at 0855 UT, the balloon reached a ceiling altitude of $\sim$30 km at around 1040 UT, and the X-ray observation was available afterwards. The X-ray count rate shown in the top panel indicates pulsating features similar to the VLF intensity pulsation, especially in the period of 1100 to 1300 UT when the balloon was located within $\sim$100 km from Syowa Station. After 13 UT, the balloon drifted toward lower latitude and the X-ray count rates showed slower and larger amplitude variations. In this report, we concentrate our analysis for the period of 1208–1233 UT as marked by two arrows in the top panel, when X-ray, VLF and magnetic pulsations showed common oscillating features.

The upper panel of Fig. 2 shows temporal variations of the balloon X-rays

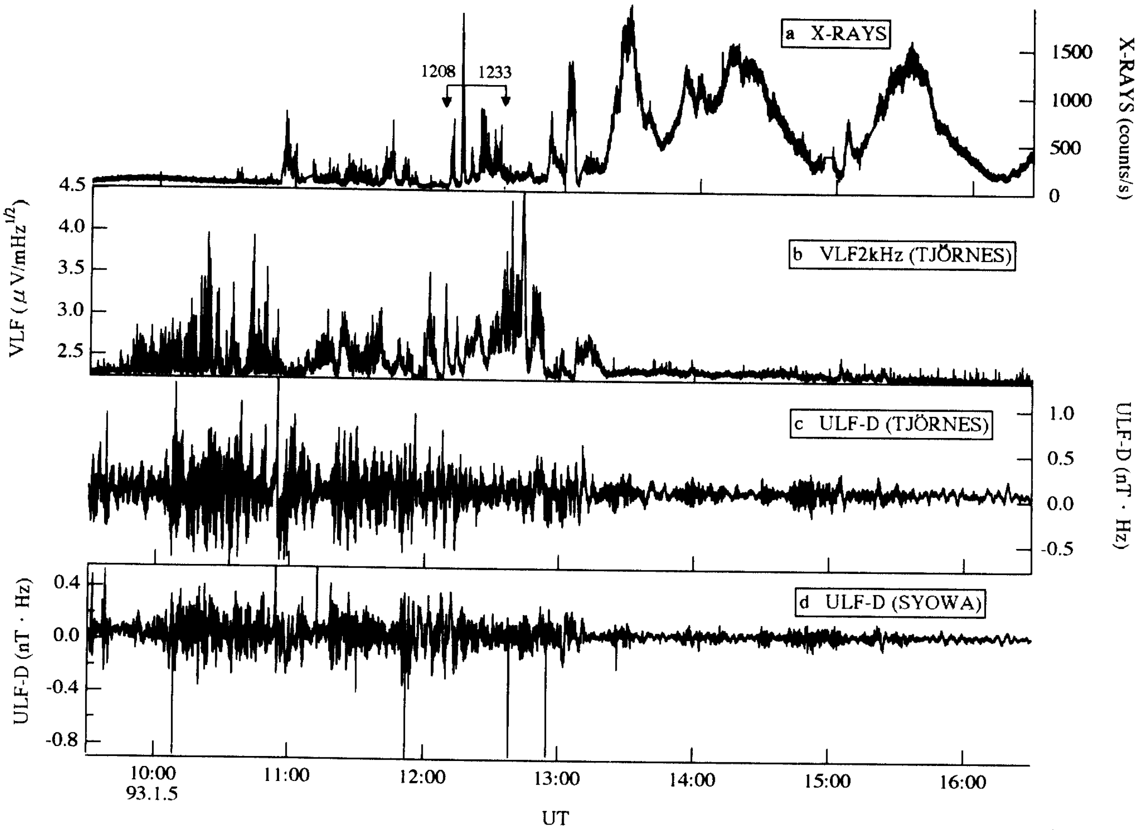

Fig. 1. Time profiles of (a) bremsstrahlung X-ray counting rates near Syowa Station (the balloon attained a ceiling altitude at 1040 UT), (b) 2 kHz VLF emissions at Tjörnes, Iceland, (c) 0.001–3 Hz ULF-D pulsations at Tjörnes, and (d) 0.001–3Hz ULF-D pulsations at Syowa Station during 0930–1630 UT on January 5, 1993. The time interval when interesting typical quasi-periodic pulsations were observed is indicated by double arrows in the top panel.

(solid line) and VLF intensity at Tjörnes (broken line) in an extended time scale. Considering counter-streaming interaction between energetic electrons and whistler mode waves in the magnetosphere, bremsstrahlung X-rays (caused by energetic electron precipitations) in the southern hemisphere should correlate with VLF emissions observed in the northern hemisphere. Observational result shows, however, that the X-ray variation lags hehind the VLF intensity variation by $\sim$1 min. This time lag is much longer than the time-of-flight difference of particles and waves from the interaction region in the magnetic equatorial region to the polar ionosphere, which is estimated to be 1–2 s (particle leads the wave).

There was notable CNA observed at Tjörnes at this time, and the temporal variation of CNA had a striking similarity to the X-ray variations. Generally, VLF waves are quite greatly absorbed by excess ionization in D-region at the time of CNA events. Therefore, it is likely that the VLF waves were weakened by D-region ionization when the X-rays showed maxima, and this caused apparent time lag between peaks of X-rays and VLF intensities. In order to confirm this assumption, the VLF intensity was corrected with CNA in the manner that the VLF intensity is

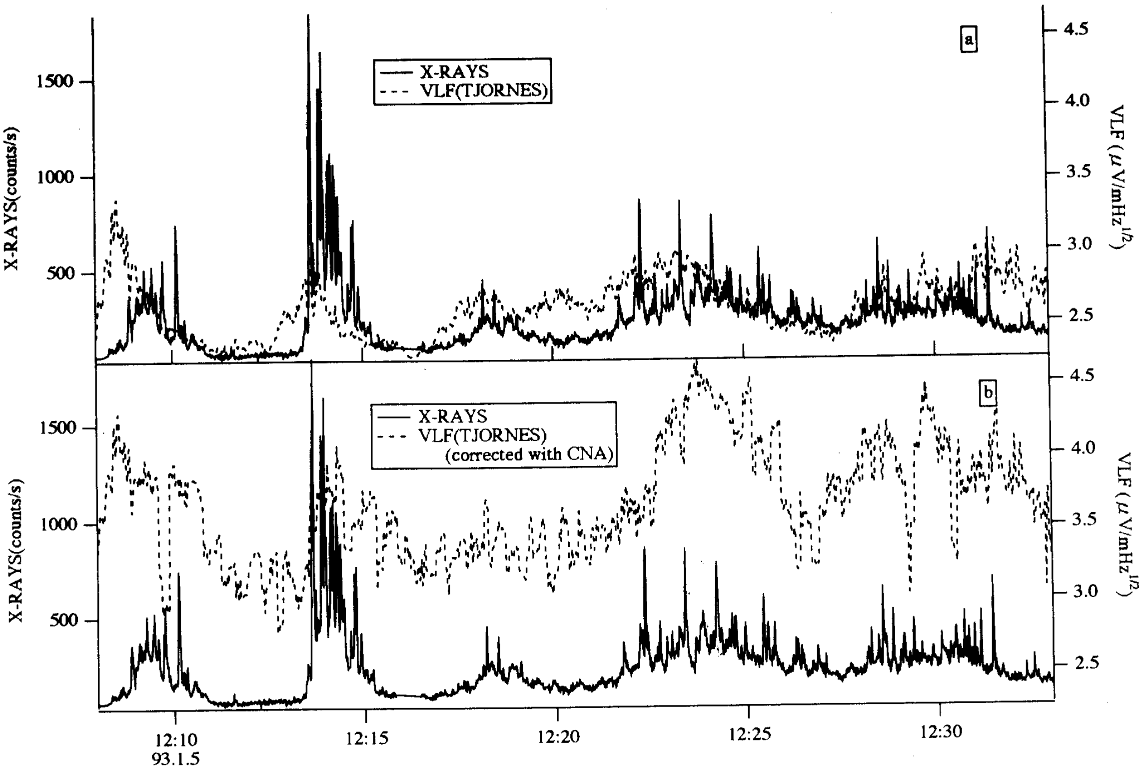

Fig. 2. Time profiles of bremsstrahlung X-ray counting rates near Syowa Station and VLF emissions at Tjörnes during the short time interval of 1208–1233 UT indicated by double arrows in the Fig. 1a are shown in Fig. 2a. Figure 2b is the same as in Fig. 2a, where VLF emissions are corrected by using CNA data from Tjörnes in which large spiky noises are neglected.

decreased proportionally to the CNA magnitude. The results are shown in the lower panel of Fig. 2. The time lag between X-rays and VLF becomes much shorter (several seconds), and the both time profiles show good agreement. The corrected time profile would represent VLF intensites above the ionosphere where absorption of VLF waves occurred. Therefore, the energetic electron precipitations were closely related to VLF emissions, and were considered to be caused by pitch angle scattering with these VLF emissions.

To make clear the close relationship between X-rays, VLF and magnetic pulsations, power spectra were calculated with FFT method for the time window of 1208:00–1225:04 UT. The results are shown in Fig. 3. The upper panel shows spectra for X-rays (solid line) and VLF (broken line), while the lower panel shows spectra for magnetic pulsation at Syowa (chain line) and Tjörnes (dotted line). There is a common spectral peak at 3.9 mHz for all of these four phenomena. This fact suggests that, in Pc 5 range, the energetic electron precipitations which cause bremsstrahlung X-rays, VLF pulsations and magnetic pulsations are closely related one another in the magnetosphere through wave-particle interaction.

There are several previous works on the simultaneous occurrence of VLF emissions, magnetic pulsation and/or precipitation pulsations. SATO and KOKUBUN

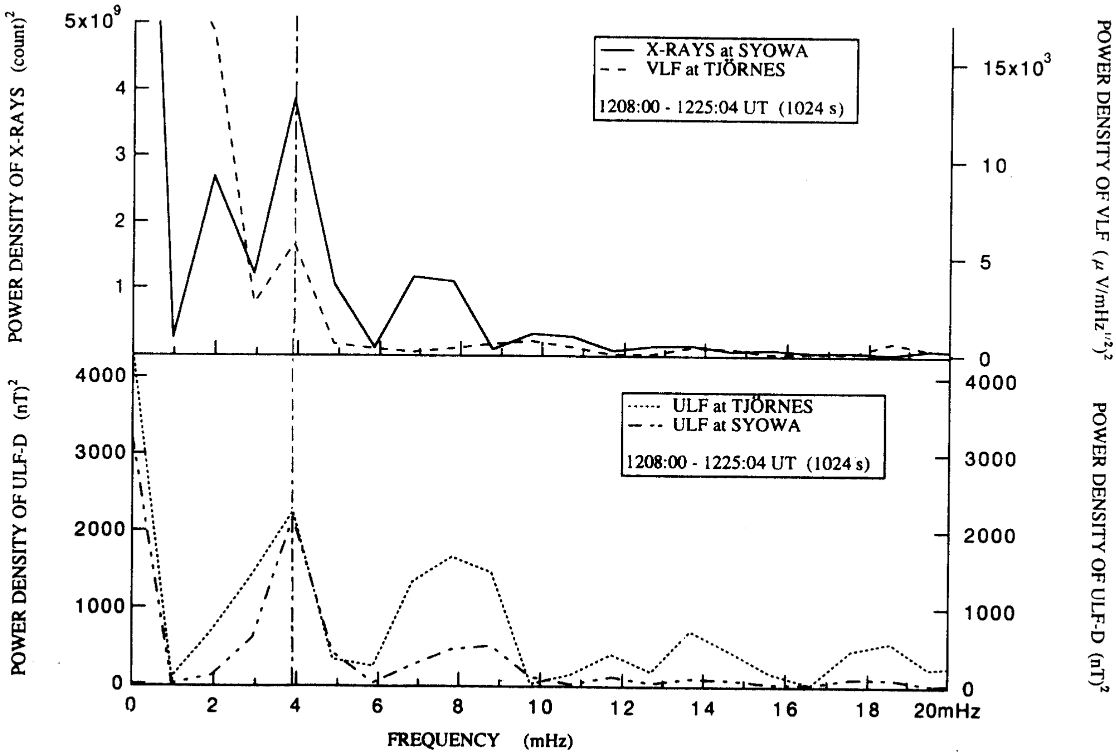

Fig. 3. Power spectra of X-rays, and Syowa ULF-D pulsations, Tjörnes ULF-D pulsations, and Tjörnes corrected VLF emissions. Time interval analyzed is 1208:00–1225:04 UT. At the conjugate locations of the southern and northern polar regions, the peak in the X-ray power spectrum is synchronous with the peaks in the power spectra of ULF-D pulsations and VLF emissions at 3.9 mHz (260 s period, corresponding to Pc 5).

(1980) analyzed the relationship between Quasi-Periodic (QP) ELF-VLF emissions and magnetic pulsations at the geomagnetic conjugate pair stations in the auroral zone. They classified QP ELF-VLF emissions into two categories, type 1 and 2. The former has a close relationship between the both phenomena, while in the latter type, only the ELF-VLF emissions show pulsation features. They interpreted type 1 QP emission as compressionnal MHD waves penetrating into the dayside magnetosphere, where the growth rate of whistler mode ELF-VLF waves is modulated. In addition to ELF-VLF emissions and magnetic pulsation, YAMAGISHI *et al.* (1985) reported a simultaneous occurrence of precipitation pulsation observed by the balloon X-ray detector. They interpreted the simultaneous occurrence of precipitation pulsation with ELF-VLF and magnetic pulsations as a result of an enhanced pitch angle scattering of the energetic electrons trapped in the magnetosphere, which is synchronized with the whistler-mode wave growth. In these papers, a good correlation was found in Pc 3 range oscillations.

In Pc 4–5 range, magnetic pulsations are often recorded in the morning to prenoon hours in the auroral zone, and when they are observed at the geomagnetic conjugate point, they show characteristic phase relationship of standing Alfvén waves in the magnetosphere, *i.e.* for the fundamental mode in-phase in *H*-

component and out-of-phase in *D*-component (TONEGAWA and FUKUNISHI, 1984). Precipitation pulsations are often associated with magnetic pulsations. As a mechanism causing precipitation pulsations, a pitch angle scattering by whistler-mode waves is an important candidate. However, there are two difficulties to explain the phenomena with this mechanism. The one difficulty is insufficient observational evidence of VLF pulsations at the time of precipitation pulsation in Pc 4–5 range (*e.g.*, SATO *et al.*, 1985). ELF-VLF waves are usually difficult to be observed on the ground at the time of CNA event due to an enhanced ionospheric absorption. So, there may be VLF emission above the ionospheric level, and a satellite observation of VLF waves will prove this. The second difficulty is that the standing Alfvén waves in Pc 4–5 range are mostly incompressional toroidal mode, and do not contribute to the modification of whistler-mode wave growth rate.

There is, however, a possibility of compressional mode MHD waves working in this phenomena. That is known as storm time Pc 5, or ballooning-mirror mode instability (*e.g.*, MIURA *et al.*, 1989; CHENG *et al.*, 1994). Azimuthal m-number of these MHD waves is very large (~100), and the spatial scale size of these waves mapped onto the polar ionosphere is several tens of km. Therefore even if these waves are present in the magnetosphere and modify the whistler-mode wave growth, the electromagnetic component of this MHD wave is easily screened by the ionosphere and cannot be observed on the ground. However, if the precipitation pulsations are associated with this phenomena (caused by an enhanced pitch angle scattering by the whistler-mode wave growth), the ionospheric conductivity will be enhanced periodically, and the geomagnetic field induced by the ionospheric current will show periodic change, especially in *H*-component. Simultaneous occurrence of the pulsations in ELF-VLF emissions, magnetic pulsations and X-rays observed in this event may suggest this process working in the magnetosphere and in the polar ionosphere.

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References

CHENG, C. Z., QIAN, Q., TAKAHASI, K. and LUI, A. T. Y. (1994): Ballooning-mirror instability and internally driven Pc 4–5 wave events. J. Geomagn. Geoelectr., **46**, 997–1009.

KODAMA, M., SUZUKI, H., HIRASIMA, Y., YAMAGAMI, T., MURAKAMI, H. and NISHIMURA, J.

(1995): Circumpolar observation of bremsstrahlung X-rays by a Polar Patrol Balloon over Antarctica. J. Geomagn. Geoelectr., **47**, 253–266.

MIURA, A., OHTANI, S. and TAMAO, T. (1989): Ballooning instability and structure of diamagnetic hydrodynamic waves in a model magnetosphere. J. Geophys. Res., **94**, 15231–15242.

SATO, N. and KOKUBUN, S. (1980): Interaction between ELF-VLF emissions and magnetic pulsations: Quasi-periodic ELF-VLF emissions associated with Pc 3–4 magnetic pulsations and their geomagnetic conjugacy. J. Geophys. Res., **85**, 101–113.

SATO, N., SHIBUYA, S., MAEZAWA, K., HIGUCHI, Y. and TONEGAWA, Y. (1985): CNA pulsations associated with quasi-periodic VLF emissions. J. Geophys. Res., **90**, 10968–10974.

TONEGAWA, Y. and FUKUNISHI, H. (1984): Harmonic structure of Pc 3–5 magnetic pulsations observed at the Syowa-Husafell conjugate pair. J. Geophys. Res., **89**, 6737–6748.

YAMAGAMI, T., NAMIKI, M., OHTA. S., YAJIMA, N., SUZUKI, H., HIRASIMA, Y., MURAKAMI, H., MORIMOTO, K., YAMAGIWA, I., NAKAGAWA, M., TAKAHASHI, T., MURAKAMI, S., NISHIMURA, J., TONEGAWA, Y., EJIRI, M., SATO, N., KOHNO, T. and KODAMA, M. (1994): A Polar Patrol Balloon observation of cosmic-ray protons and auroral X-rays in Antarctica. J. Geomagn. Geoelectr., **46**, 903–908.

YAMAGISHI, H., ONO, T., FUKUNISHI, H., YAMAGAMI, T., NISHIMURA, J., KODAMA, M., HIRASIMA, Y., MURAKAMI, H., HOLTET, J. A., ULLALAND, S. and PELLINEN, R. J. (1985): Pulsating phenomena of auroral-zone X-rays associated with quasi-periodic VLF emissions and Pc 3 magnetic pulsations. J. Geomagn. Geoelectr., **37**, 927–943.

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