Adv. Polar Upper Atmos. Res., **20**, 1–16, 2006

Similarity and dissimilarity of conjugate relationships of Pi magnetic pulsations observed during excellent similar auroras

Tohru Sakurai[1]*, Akira Kadokura[2], Natsuo Sato[2] and Yutaka Tonegawa[1]

[1] *Department of Aeronautics and Astronautics, School of Engineering, Tokai University, 1117 Kitakaname, Hiratsuka 259-1292*
[2] *National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
**Corresponding author. E-mail: tohru_sakurai2000@yahoo.co.jp*

(Received January 16, 2006; Accepted May 23, 2006)

Abstract: Similarity and dissimilarity of conjugate relationships of Pi magnetic pulsations observed during excellent similar auroras at the conjugate stations, Tjornes in Iceland and Syowa Station in Antarctica are examined. The study revealed that characteristic Pi pulsations, Pi 2 pulsations and impulsive Pi 1 pulsations were prominently observed with a close relationship to aurora activities. During the substorm growth phase they showed a good similarity between the conjugate stations. However, at the onset of substorm expansion, the appearance of Pi pulsations showed prominent dissimilarity between the conjugate stations, suggesting that there might be some asymmetry of the ionosphere and magnetosphere conditions in between the northern and the southern hemispheres.

key words: Pi magnetic pulsations, conjugate relationships, auroras, magnetosphere physics

1. Introduction

Correlation studies of short period aurora activities to geomagnetic micropulsations have been demonstrated so far by several researchers (Campbell and Rees, 1961; Yanagihara, 1963; Victor, 1965; Heacock, 1967, 1980; Chao and Heacock, 1980). Campbell and Rees (1961) reported the relationship of aurora coruscations of N_2^+ aurora emission to geomagnetic micropulsations. They found that the correlation was positive maximized in the predawn hours. Yanagihara (1963) studied short period micropulsations in the period from 0.3 to 10 s using the data obtained at the aurora zone stations, Great Whale, Churchill and the conjugate point, Bird Station. He classified aurora-zone micropulsations into two main groups: noise bursts and continuous-type oscillations. Noise bursts covered a wide range of frequency and their wave forms were irregular. They occurred suddenly and died out after a short time. The continuous-type micropulsations were divided into three subclasses: pearl type pulsations, and the other two kinds defined by their period, either shorter or longer than 3 s. He found that noise bursts occurred with an intimate relation to the central area of aurora activity. They decreased abruptly away from the central area of the activity. By comparing the occurrence of noise bursts observed at the conjugate stations, Great Whale and Churchill in the northern hemisphere and Bird Station in the southern hemisphere. He found the conjugacy was loose; *i.e.*, sometimes a burst at Bird corresponded to one at Great Whale, and sometimes to one at Churchill. Victor (1965) found sudden impulsive events (named SIE events) of the pre-midnight auroras, although the discussion in the paper was mainly related to the correlation of aurora activity to geomagnetic micropulsations of type Pc 3 oscillations. Heacock (1967) studied irregular-type micropulsations during substorm activities in the night time and found that two subtypes, Pi burst and Pi (C), which occurred at a substorm onset and in a following negative bay, respectively. Heacock (1980) extended his study of the correlation of Pi pulsations to aurora activities with the data obtained at College and Fort Yukon in Alaska, and found that they showed a good correspondence of the occurrence.

However, any clear conjugate relationship of *type Pi pulsations to aurora activities with a high time resolution* has never been demonstrated so far. Recently Sato *et al.* (2005) reported an excellent similar aurora event observed at the conjugate stations, Syowa Staion (Geomag. Lat. $\Lambda = -66.24$ deg, Geomag. Long. $\Phi = 71.62$ deg) in Antarctica and Tjornes ($\Lambda = 66.53$ deg, $\Phi = 72.30$ deg) in Iceland using the aurora data recorded with a high-time resolution by TV-camera at each 10 s. These high-time resolution data enable us to study more accurate correlation study between activities of Pi pulsations and auroras.

In this paper our study will be focused on the conjugate relationships of Pi pulsations to aurora activities.

2. Aurora activities observed at the conjugate stations

Figure 1 shows a typical similar aurora activity observed at the conjugate stations, Syowa Station in Antarctica and Tjornes in Iceland for an interval from 2243 UT to 2248 UT on 26 September 2003. This period corresponded to the growth phase of the substorm activity. The main onset of the substorm was at 2318 UT. The magnetic condition during the substorm activity was moderate with $K_p = 3$ under a slightly southward interplanetary magnetic field (IMF).

The upper and lower panels show all-sky TV images obtained at each 10 s at Syowa Station and Tjornes, respectively. In each image the poleward and equatorward directions are shown upward and downward, and the west and east are respectively to the directions of the left and right.

The first sudden brightening was observed at 2244:50 UT at the western edge of the all-sky TV images at both stations. The brightening spot began to develop from 2245:10 UT and progressed eastward to the overhead of the station within a minute, and then became a band-type aurora with extending in the east-west direction, which continued until 2248:00 UT. Then the aurora gradually disappeared from the all-sky image. These aurora activities looked almost similar at both stations. However, the shape and the location of the aurora were not similar in details.

Figures 2 and 3 show the aurora activities observed at Syowa Station and Tjornes, respectively during a period from 2248:50 UT to 2301:30 UT. The aurora activity was relatively stable. A band-type aurora at Syowa Station was observed at the poleward

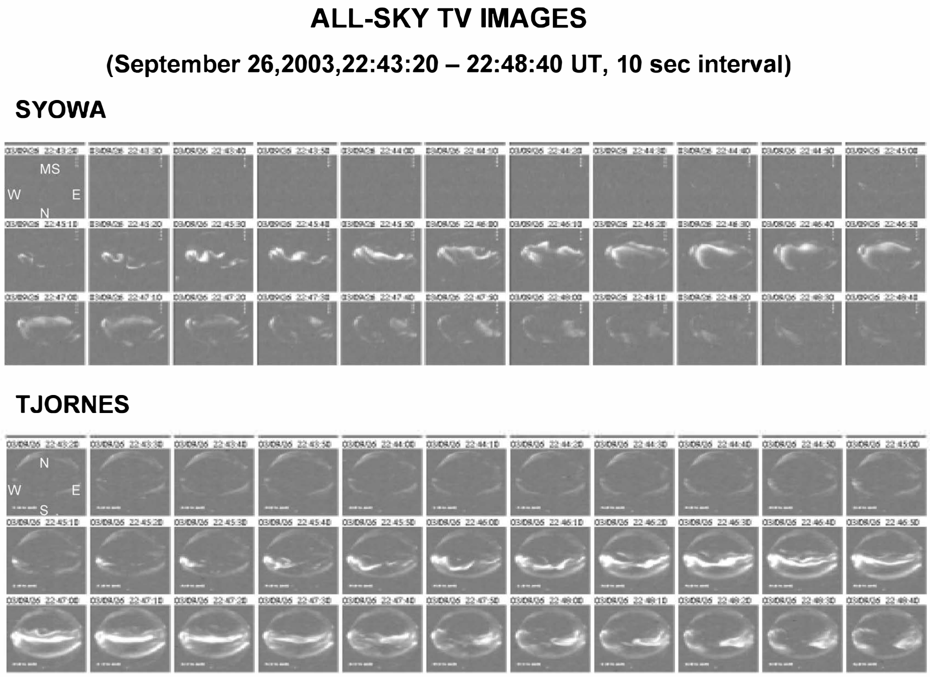

Fig. 1. Aurora observations with all-sky TV cameras at each 10 s at Syowa Station (upper panel) and at Tjornes (lower panel), respectively during an initial phase of substorm activity from 2243:20 UT to 2248:40 UT on September 26, 2003.

edge in the field of view, whereas it was observed at the central part in the field of view at Tjornes. Therefore, the conjugacy of the relative location of the band-type aurora to the station was not similar. A slight brightening was observed at the poleward eastern-edge at 2254 UT at Syowa Station, while at Tjornes it was simultaneously observed at the eastern edge, and then developed to a multiple arc over the station.

Figures 4 and 5 show the aurora activities observed at Syowa Station and Tjornes, respectively during a period from 2314:30 UT to 2327:10 UT, when the most active aurora developed in this study. The aurora began to active at 2320 UT when the substorm expansion began. Before this activation there was no activity of aurora over both stations, except for a faint east-west extending band-type aurora seen over Tjornes. Therefore, any indication of substorm onset was not identified from the all-sky images. The substorm onset was identified from a clear onset of Pi 2 magnetic pulsations at 2318 UT in the magnetograms at both stations.

The aurora brightening was observed at 2320:10 UT at the western edge of the band-type aurora, simultaneously at both stations, and the aurora developed eastward and progressed to the overhead of both stations at 2320:50 UT.

From 2321 UT the aurora increased the luminosity abruptly and covered the field of view over both stations. Then it developed rapidly eastward with a folding structure, which appeared, however, with a different shape at each station. At Tjornes it expanded to a large vortex covering over the field of view. On the other hand, at Syowa

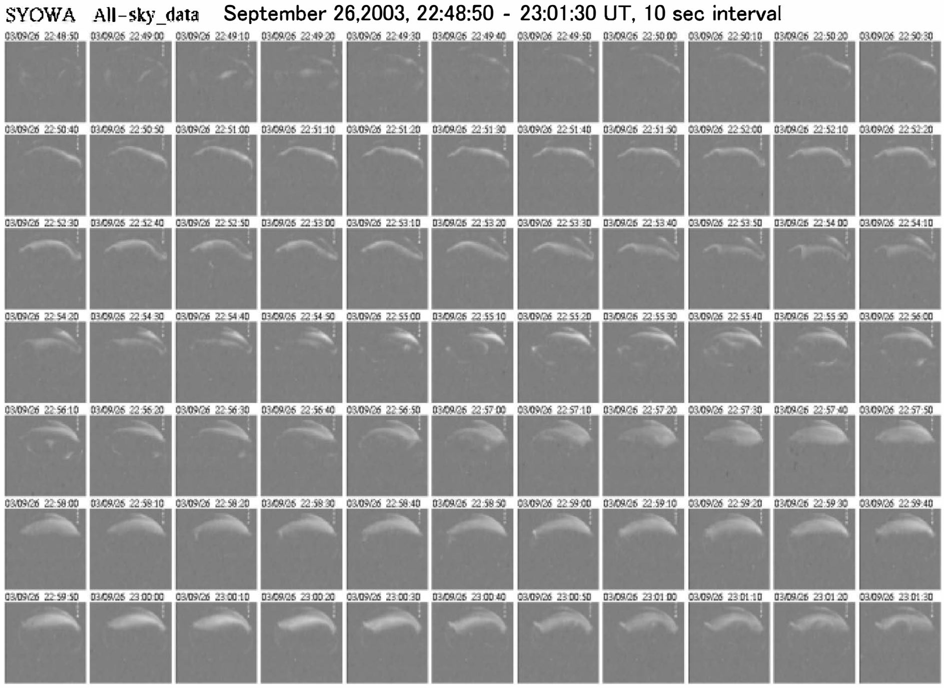

Fig. 2. Aurora observations at Syowa Station from 2248:50 UT to 2301:30 UT on September 26, 2003.

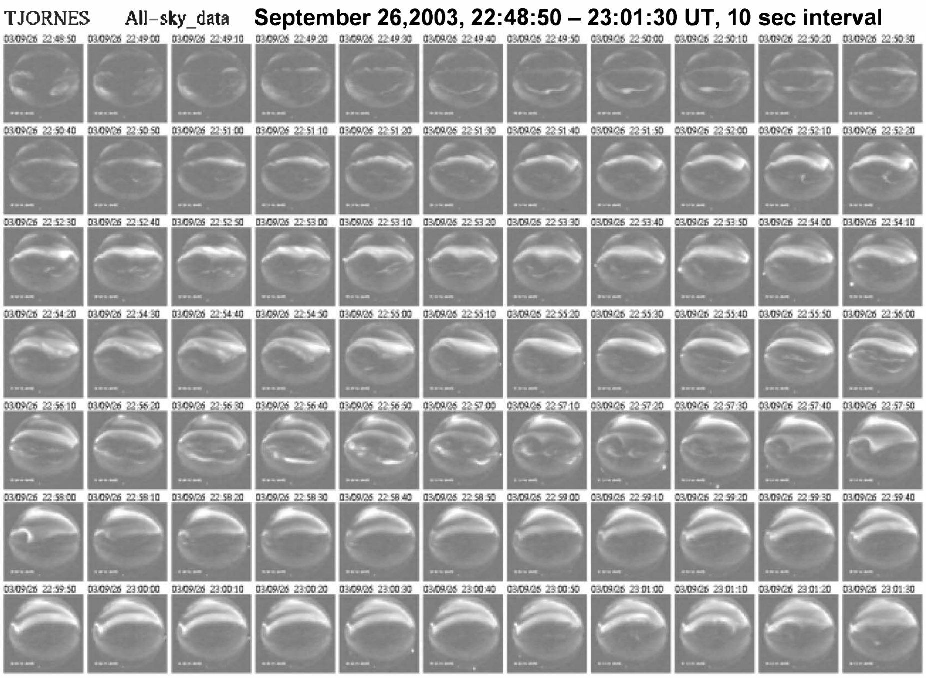

Fig. 3. Aurora observations at Tjornes for the same interval as shown in Fig. 2.

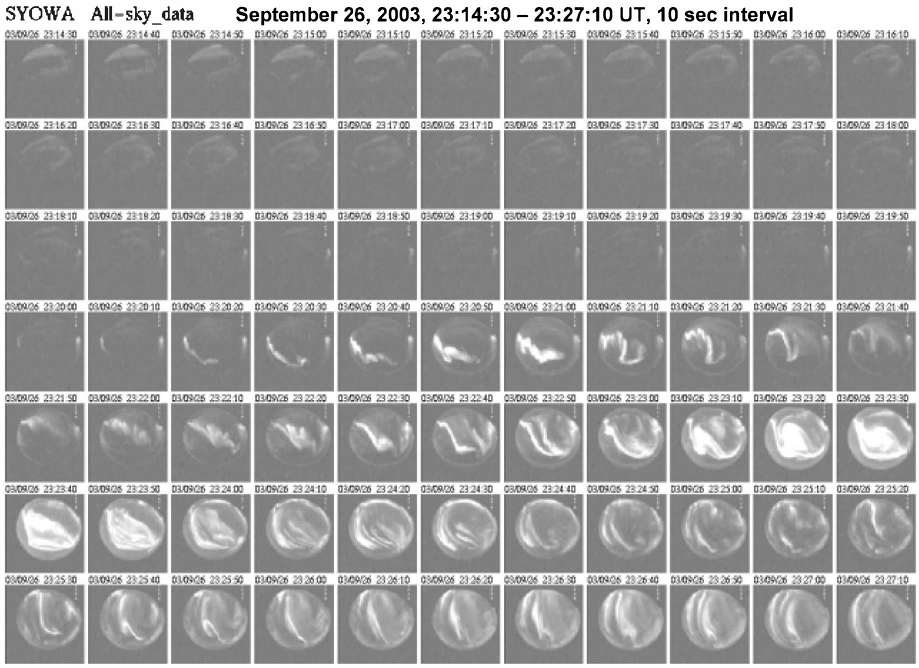

Fig. 4. Aurora observations at Syowa Station from 2314:30 UT to 2327:10 UT on September 26, 2003.

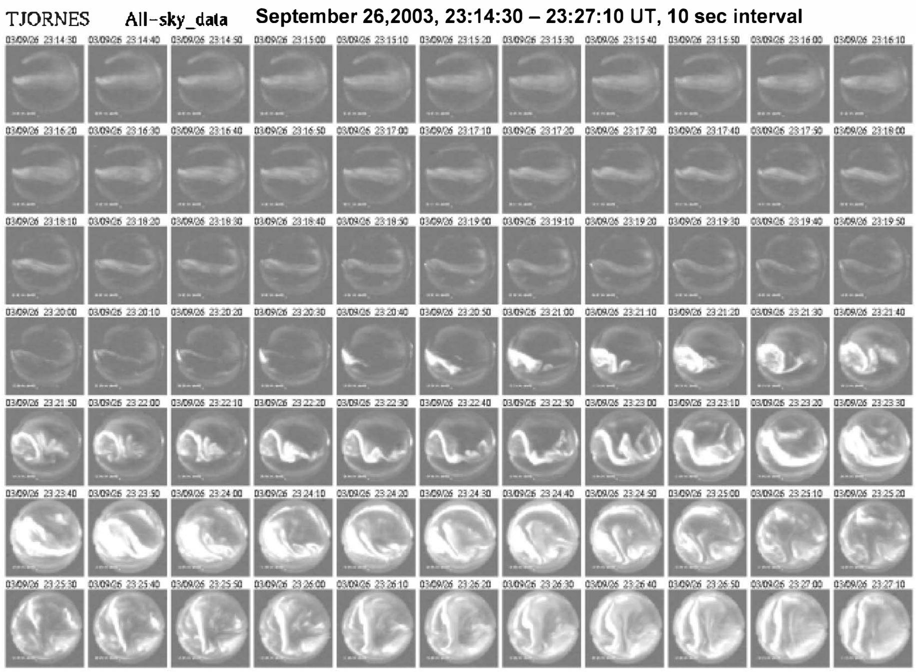

Fig. 5. Aurora observations at Tjornes for the same interval as shown in Fig. 4.

Station the folding developed equatorward until 2321:30 UT. Afterward the aurora luminosity became weak at Syowa Station. However, at 2322:40 UT the aurora appeared again clearly with a bending arc, which was similar at both stations.

From 2323:20 UT the aurora luminosity again increased and the aurora changed its shape drastically to a large bright lump expanding over the field of view until 2324:00 UT. The luminosity became weak again at 2325:00 UT and the aurora changed to the complicated shape with a multiple stripe.

At 2325:30 UT a new arc appeared extending to the north-south direction at the center of the image. This arc was quite clear looked similar at the conjugate stations, and it continued its appearance for a minute until 2326:30 UT. Then the arc spread into two or three stripes. However, they looked also similar at both stations.

The descriptions above are the aurora activities seen over the conjugate stations for the interval from 2244 UT to 2327 UT. During this interval the aurora activities were almost similar, although there were different fine structures between the conjugate stations.

By using the high resolution all-sky TV images we can examine the conjugate relationships between Pi pulsations and aurora activities in the following sections. Our study will be focused on what kinds of type Pi pulsations appeared corresponding to what kinds of aurora activity and how they appeared at the conjugate stations, Syowa Station in Antarctica and Tjornes in Iceland.

3. Background geomagnetic field variations

Before beginning detail descriptions of Pi pulsations it will be useful to introduce the background geomagnetic field variations observed during this substorm. Figure 6 shows from the top to the bottom panels, three components of geomagnetic field variations, H, D, and Z, cosmic noise absorption (CNA), and three components of the induction magnetograms, dH/dt, dD/dt and dZ/dt, observed at Syowa Station, respectively. Those observed at the conjugate station, Tjornes, are shown in Fig. 7, in which CNA observation is given in the bottom panel. From these figures it is easily understood that all of the field variations looked almost similar between the conjugate stations. Pi magnetic pulsations were distinctly observed at 2245 and 2255 UT. These were clear. The main substorm activity began from 2320 UT, which was also clearly understood from the beginning of a negative bay in the H component magnetogram. The minimal value of the H component field was observed around 2340 UT. The substorm activity ended around 0030 UT of the next day (September 27, 2003). Typical impulsive CNA absorptions were observed at 2245 UT, 2320 UT and 2350 UT. Corresponding to these CNA events the large amplitude Pi pulsation activities were observed. The strong activity of Pi pulsations began from 2320 UT and continued to the end of the substorm activity. Details of the conjugate relationships between Pi magnetic pulsations, and aurora activities are examined in the following sections.

4. Magnetic Pi pulsations observed at Syowa Station in Antarctica

Figure 8 shows three components, dH/dt, dD/dt and dZ/dt, of the induction mag-

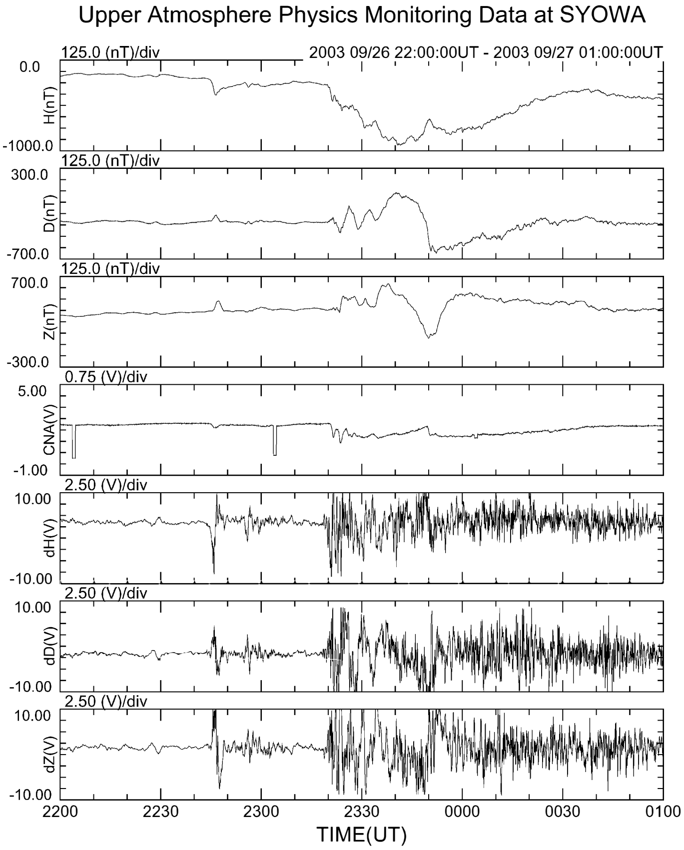

Fig. 6. Three components of magnetic field variations, H, D and Z, cosmic noise absorption (CNA), and three components of induction magnetograms, dH/dt, dD/dt and dZ/dt from the top to the bottom panels, obtained at Syowa Station from 2200 UT on September 26 to 0100 UT on September 27, 2003.

netogram from 2230 UT to 2310 UT. This period corresponds to the growth phase of the substorm. It is clear that Pi 2 pulsations were observed at 2245 UT and successively at 2255 UT. However, they appeared differently in their oscillations.

The Pi 2 pulsations observed at 2245 UT appeared with the superposition of short period Pi 1 pulsations with the period less than 10 s. The appearance of the Pi 1 pulsations was impulsive, and the oscillations died out soon from 2247 UT. This appearance corresponded to the time when the aurora brightened at the western edge in the all-sky image at Syowa Station and continued until the time when the aurora developed to the band-type aurora over the station. Around 2247 UT the band-type aurora moved poleward and disappeared from the all-sky image, which was coincident to the disappearance of the Pi 1 pulsations. Thus, the Pi 1 pulsations were observed only during the initial phase of the aurora development. The lifetime was very short, only two minutes, while Pi 2 pulsations were observed until 2250 UT.

Another Pi 2 pulsation appeared at 2255 UT. This happened with the appearance

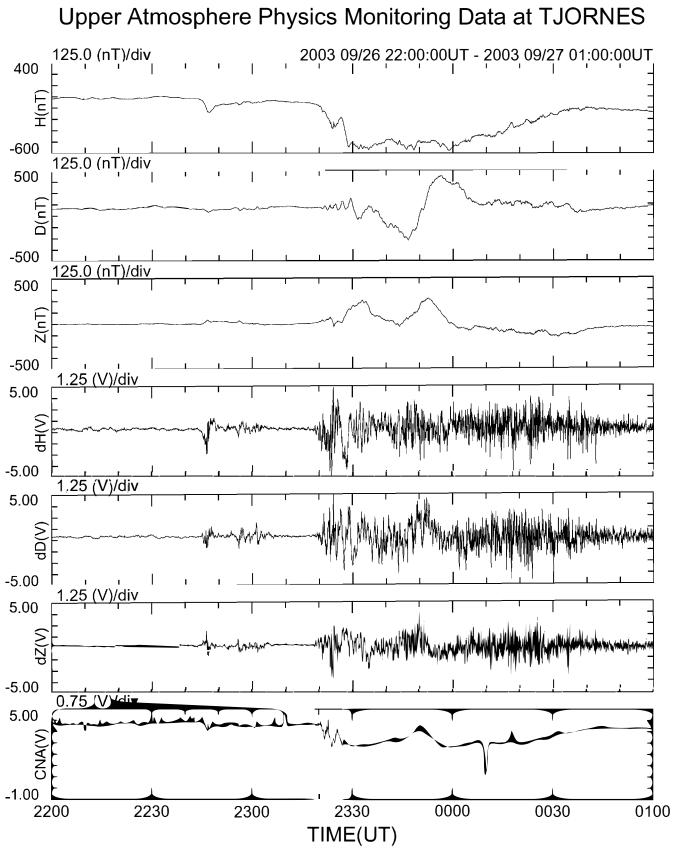

Fig. 7. Same format as shown in Fig. 6 obtained at Tjornes. CNA is given in the bottom panel.

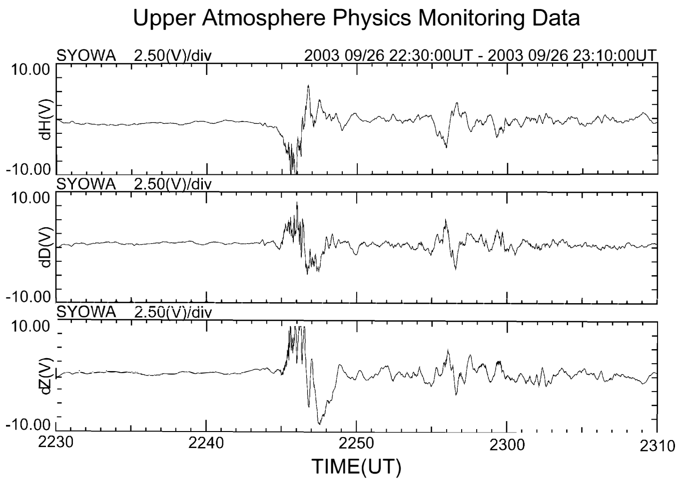

Fig. 8. Three components of induction magnetograms, dH/dt, dD/dt and dZ/dt from the top to the bottom panels obtained at Syowa Station from 2230 UT to 2310 UT on September 26, 2003.

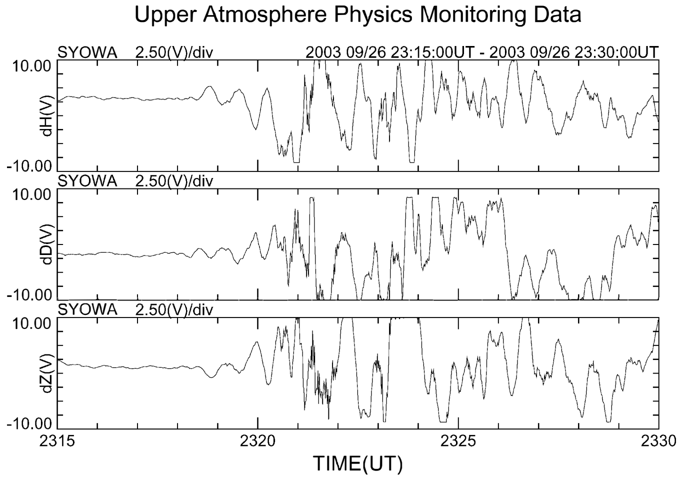

Fig. 9. Same format as shown in Fig. 8 except for the interval from 2315 UT to 2330 UT on September 26, 2003 obtained at Syowa Station.

of a new aurora arc at the poleward edge of the all-sky image at Syowa Station. In this case Pi 1 pulsations were not observed.

The main substorm onset occurred at 2318 UT, which was identified with a sudden appearance of Pi 2 oscillation as shown in Fig. 9. It is widely accepted that the ground Pi 2 pulsation onset is a useful indictor of aurora brightening (Sakurai and Saito, 1976). At this moment, however, any sudden aurora brightening was not observed in the all-sky image at Syowa Station. The oscillations of the Pi 2 pulsation continued for about two minutes until 2320:30 UT. Then another Pi 2 pulsation appeared in association with the appearance of the aurora brightening at the western edge in the all-sky image. Successively, the bright aurora developed to the arc-type aurora, and moved rapidly to the center of the field of view with a folding shape, which was observed until 2323:00 UT.

Then, at 2323:30 UT another large amplitude Pi 2 pulsation appeared associated with the expansive appearance of aurora over the station. However, in this case the impulsive Pi 1 pulsations were not observed.

From 2326 UT another clear Pi 2 pulsation appeared. This happened to occur in accordance with the appearance of striped aurora extending in the north-south direction. In this case Pi 1 pulsations were not observed, while the Pi 2 pulsations continued their activity until 2330 UT.

The pulsation activities described above are based on the *H* component of the induction magnetogram observed at Syowa Station. They were characterized with the Pi 2 and impulsive Pi 1 pulsations. The appearance of the other two components of the induction magnetograms, *D* and *Z* components were almost similar to those observed in the *H* component magnetogram.

Important results are summarized as follows: Characteristic Pi pulsations, Pi 2 pulsations and Pi 1 pulsations were observed. The Pi 2 pulsations were observed corresponding to the aurora brightening and/or the intensification irrespective of the location. However, the Pi 1 pulsations were observed impulsively, during a very short period from the appearance of the aurora brightening at the western edge of the all-sky image to the arrival of the aurora to the overhead of the station. When the aurora activated overhead and/or moved poleward, the impulsive Pi 1 pulsations disappeared.

5. Magnetic Pi pulsations observed at Tjornes in Iceland

Magnetic Pi pulsations observed at Tjornes in Iceland are shown in Fig. 10. Pi 2 pulsations were observed from 2245 UT superposed with impulsive Pi 1 pulsations. The oscillations of both the Pi 2 pulsations and the impulsive Pi 1 pulsations looked very similar to those observed at Syowa Station, except for the phase reversal in the ***D*** component oscillations of the Pi 2 pulsations. However, this out-of-phase relationship in the ***D*** component of Pi 2 pulsations between the conjugate stations is a well known observed relation indicating that Pi 2 pulsations are due to a standing oscillation of magnetic field-line connecting both hemispheres (Fukunishi, 1975; Kuwashima, 1978).

At 2255 UT another Pi 2 pulsations were observed with a similar phase reversal of the D component oscillations observed at Syowa Station. The Pi 2 pulsations appeared without the appearance of Pi 1 pulsations. This may be due to the fact that the aurora intensification occurred at the eastern edge of the all-sky image at Tjornes. The location was separate from the center of the all-sky image at Tjornes. The appearance of the Pi 2 pulsation was very similar to that observed at Syowa Station.

Another Pi 2 pulsation was observed at 2318 UT as shown in Fig. 11. However, any remarkable aurora brightening was not observed over Tjornes, although a band-type aurora had already been observed from 2314 UT as shown in Fig. 5.

From 2320 UT the oscillations of the Pi 1 pulsations were intensified. This intensification occurred simultaneously with the aurora brightening at the western edge of the

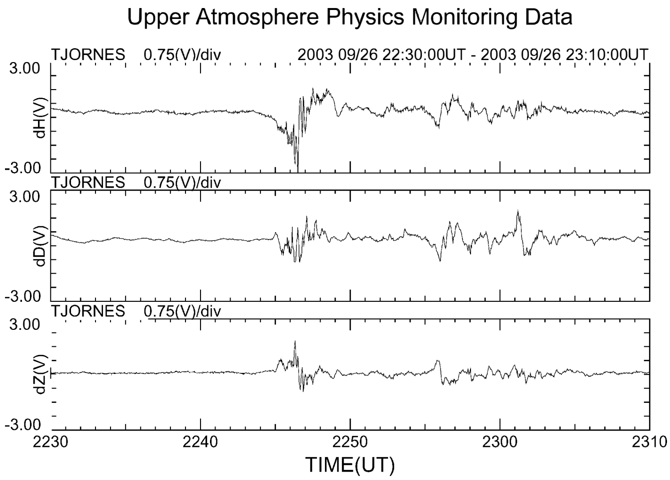

Fig. 10. Same format and same interval as shown in Fig. 8 at Tjornes.

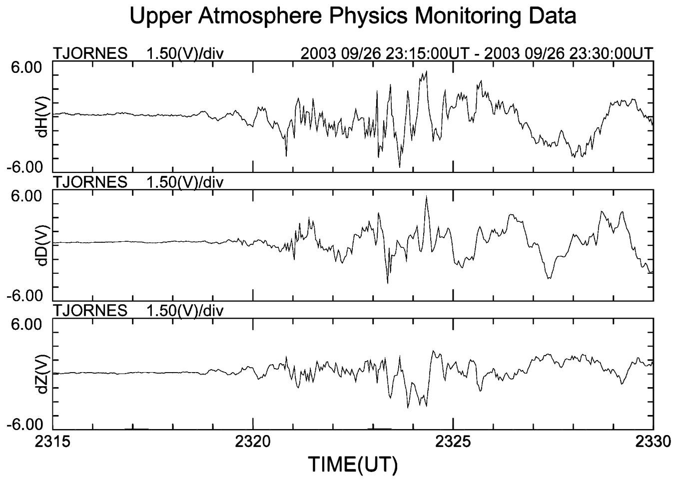

Fig. 11. Same format and same interval as shown in Fig. 9 at Tjornes.

all-sky image. The bright spot of the aurora developed to the straining shape discrete aurora and rapidly progressed to the center of the all-sky image at 2323 UT. The oscillations of the Pi 1 pulsations were dominant, except for a slight indication of Pi 2 oscillations at the beginning part. The oscillations of the Pi pulsations in the *H* component were different between the conjugate stations.

From 2323 UT another Pi 2 pulsation appeared. This happened simultaneously with the intensification of the aurora activity over the station. However, impulsive Pi 1 pulsations were not observed in this case. Instead, only the Pi 2 pulsations were observed and the oscillations continued for about three minutes until 2326 UT. After that any characteristic Pi pulsations, Pi 2 and/or impulsive Pi 1 pulsations were not observed until 2330 UT at Tjornes.

In summary, similar characteristic Pi pulsations, Pi 2 pulsations and impulsive Pi 1 pulsations, as observed at Syowa Station were also observed at Tjornes. However, it should be notified that only the impulsive Pi 1 pulsations were observed during two minutes from 2321 UT to 2323 UT, while in this period Pi 2 oscillations were not observed, although during this interval the aurora activity was almost similar between the conjugate stations, beginning of the appearance of the bright spot at the western edge of the all-sky image and then progressing to the overhead of the station. However, the fine structures were not similar. When the aurora activity intensified overhead, the Pi 1 pulsations died out and only the Pi 2 pulsations appeared.

6. Discussion and conclusions

6.1. General discussion

In this study we were able to study the conjugate relationship of Pi pulsations by comparing with the high-time-resolution all-sky images obtained during the exceptionally excellent similar auroras observed at the conjugate stations, Syowa Station in Antarctica

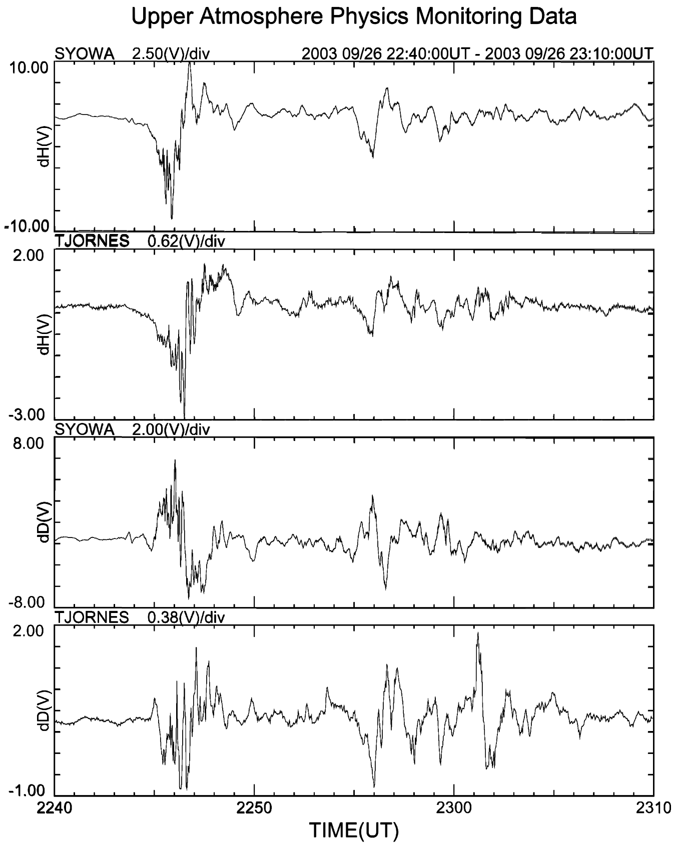

Fig. 12. Comparisons of H (upper panels) and D (lower panels) components of Pi pulsations of the induction magnetograms observed at Syowa Station and Tjornes from 2240 UT to 2310 UT on September 26, 2003.

and Tjornes in Iceland. The aurora images were examined with the snapshot at each 10 s. Owing to these high-resolution aurora data we could find interesting conjugate relationships between Pi pulsations and aurora activities seen over the conjugate stations.

In order to proceed the discussion on the Pi pulsations observed at the conjugate stations the simultaneous traces of the two stations in the *H* and *D* components of the induction magnetograms from 2240 UT to 2310 UT were shown in Fig. 12, in which those observed at Syowa Station and Tjornes are given in the upper and lower panels, respectively.

6.2. *Similarity in appearance of Pi pulsations between the conjugate stations*

The Pi pulsations observed from 2245 UT was the most typical one, which showed a good similarity in appearance between the conjugate stations except the phase relation of oscillations of the Pi 2 pulsations, *i.e.*, out-of-phase in the *D* component. These Pi pulsations appeared in a close association with a sudden appearance of aurora brightening at the *western edge* of the all-sky image at the conjugate stations. In this case the Pi 1 pulsations were observed impulsively superposed on the Pi 2 oscillations at the beginning of the Pi 2 oscillations. The appearance was very short only two or three minutes from 2245 UT to 2248 UT at both stations. The interval was the period when the aurora bright spot appeared at the western edge and then propagated to the center of the all-sky image at each station. The impulsive CNA event was also observed.

When the aurora activity decreased from 2247 UT, the impulsive Pi 1 pulsations disappeared similarly at both the conjugate stations. Therefore, we can suppose that the impulsive Pi 1 pulsations were very sensitive to the aurora activity, in particular to the aurora developing from the appearance of the bright spot at the western edge and successive progressing to the band-type aurora in the western part of the all-sky image.

This result is consistent to the previous study by Yanagihara (1963), in which short period pulsations were observed when the aurora activity was placed overhead at the station. However, the present result seems to be more accurate in relation to the aurora development, although fine structures of the band-type aurora were not similar between the conjugate stations. Thus, the important point for the occurrence of the impulsive Pi 1 pulsations seems to be the time sequence of aurora development, not its fine structure, which was different between the conjugate stations.

6.3. Similar situation, but without impulsive Pi 1 pulsations

Pi 2 pulsations observed at 2255 UT at both stations showed also similar Pi 2 oscillations between the conjugate stations as shown in Fig. 12. However, in this case Pi 1 pulsations were not observed. Any clear aurora brightening was not observed near both stations, while it was observed poleward in the all-sky image at Syowa Station and at the eastern edge at Tjornes, respectively. Therefore, we can conclude from this observation that when the aurora brightening occurred separate far from the station, any impulsive Pi 1 pulsations were not observed. This is another reason why the impulsive Pi 1 pulsations were not observed at the station.

6.4. Dissimilarity of Pi pulsations between the conjugate stations

Dissimilarity of Pi pulsations was observed at the onset of the aurora expansion at 2320 UT. The aurora activity was shown in Figs. 4 and 5, and the Pi pulsations were given in Fig. 13. This case was also important since the appearance of the Pi pulsations, Pi 2 pulsations and impulsive Pi 1 pulsations, were different between the conjugate stations. At Tjornes the Pi 1 pulsations were dominant observed in the *H* component in particular during two minutes from 2321 UT to 2323 UT, while at Syowa Station the Pi 2 pulsations were dominant, although the Pi 1 pulsations were superimposed on the Pi 2 oscillations. However, the amplitude of the Pi 1 pulsations was not large, although the signature of the aurora development looked similar. In this case the aurora brightening began at 2320 UT at the western edge of the all-sky image at both stations and then successively developed and approached to the center of the image with discrete type aurora. *The development was concentrated to the western part of the image*. During this period CNA event was also observed, which implies that the high energy particles precipitated into the ionosphere over the stations. These observed facts suggest that the

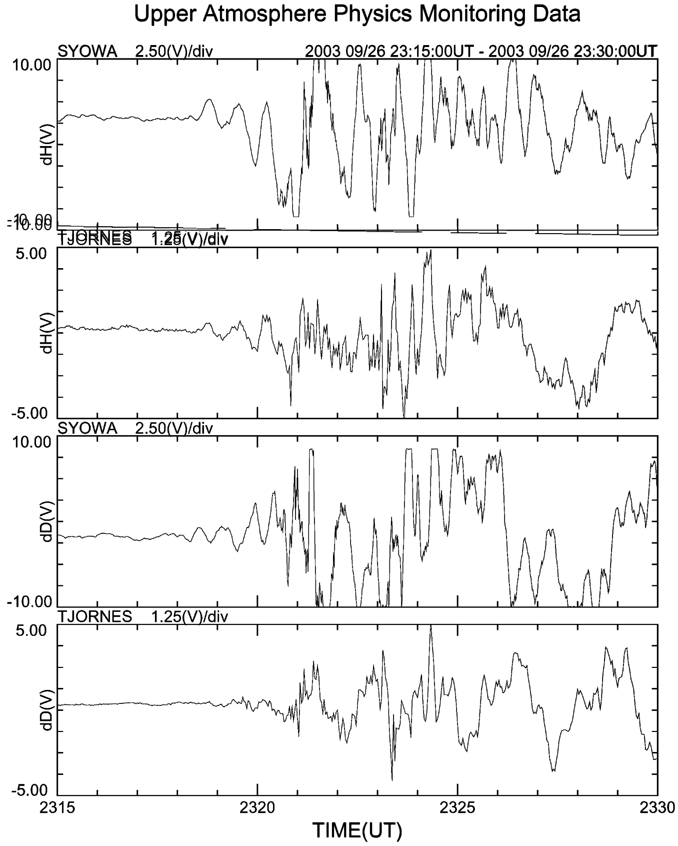

Fig. 13. Format is same as shown in Fig. 12 except for the interval from 2315 UT to 2330 UT on September 26, 2003.

aurora development in the western part of the all-sky image seems to be important for the generation of impulsive Pi 1 pulsations.

The reason of the difference in appearance of the Pi 1 pulsations between the conjugate stations is not clear since the general activity of the discrete aurora was almost similar between the conjugate stations. If there was a difference, it was the aurora development, since the development at Syowa Station was with the discrete aurora having the folding structure, while at Tjornes the aurora developed in association with the vortex structure in the western part. However, inspection of the general development of the discrete aurora, the aurora particle acceleration seems to be almost similar in the northern and southern hemispheres.

According to the paper by Sato *et al.* (2005), *it is widely understood that a discrete aurora occurs via field-aligned earthward acceleration at an altitude of 6000–12000 km through the magnetosphere-ionosphere coupling processes (Borovsky, 1993). In general, ionosphere conditions (e.g., plasma density and conductivity) will be different in opposite hemispheres, so there is no guarantee that such acceleration processes are symmetric in both* *hemispheres (Newell et al., 1996; Sato et al., 1998)*. Based on their assertions we can suppose that there might be some asymmetry in the ionosphere and magnetosphere in each hemisphere. However, the reason is not clear and needs a further study in the future.

6.5. Onset of Pi 2 pulsation as an indicator of substorm onset

It is widely accepted that one of important aspects of Pi 2 pulsations is to use an onset of Pi 2 pulsation as an indicator of substorm onset (Sakurai and Saito, 1976). A clear onset of Pi 2 pulsations was observed at 2318 UT. The oscillations of the Pi 2 pulsations were quite similar at the conjugate stations. This was also clearly understood from Figs. 12 and 13. From this onset of the Pi 2 pulsations we know the substorm onset, since there was no indication of aurora brightening in the all-sky images at both stations corresponding to this onset. The source region of this Pi 2 pulsation might be separate from both stations, probably westward from the stations since the aurora activity progressed from the west to both stations. The observed period of the Pi 2 pulsation was about 40 s, which was the shortest period (40–150 s) of Pi 2 pulsation (Jacobs *et al*., 1964). However, in the present paper this oscillation was dealt as a Pi 2 pulsation since it showed a typical phase relationship of Pi 2 pulsations observed at the conjugate stations as mentioned above.

6.6. The relation between "impulsive Pi 1 pulsations" and "impulsive Pi bursts"

In this paper we used the term "impulsive Pi 1 pulsations", which may be probably the same phenomenon named "impulsive Pi bursts" by Heacock (1967). The intimate relationship of Pi bursts to aurora breakup and CNA has been discussed by Heacock (1967, 1980) using the all-sky photograph taken by the all-sky camera at every one minute. He pointed out that Pi bursts were often observed in the preceding period of and just at the onset of negative bay. Those characteristics are almost similar to those described in the present paper. The reason why "impulsive Pi 1 pulsations" is used throughout the present paper is due to the difference of the life time between the "impulsive Pi 1 pulsations" and Pi 2 pulsations. The reason why Heacock (1967, 1980) used the term "impulsive Pi bursts" or "Pi bursts" was probably that he wanted to mean "impulsive Pi bursts" = "impulsive Pi 1 pulsations" + "Pi 2 pulsations". However, from our present study we found that the life time of each pulsation ("impulsive Pi 1 pulsations" and Pi 2 pulsations) was different, *i.e*., very short life time, two or three minutes for "impulsive Pi 1 pulsations", on the other hand, the oscillations of Pi 2 pulsations continued for about 5–10 min. Therefore, we distinguished the term "impulsive Pi 1 pulsations" from the term of "Pi 2 pulsations".

In conclusion, we found very interesting results concerning to the appearance of Pi pulsations observed at the conjugate stations during the excellent similar auroras. Two distinct type Pi pulsations, *i.e*., Pi 2 pulsations and impulsive Pi 1 pulsations, were observed. In a relatively magnetic quite condition during the substorm growth phase both Pi pulsations were observed similarly between the conjugate stations. However, at the aurora expansion onset the Pi pulsations were dissimilar between the conjugate stations, even though the aurora looked similar in its development. This implies that there might be some asymmetry of the ionosphere and magnetosphere conditions for the generation of Pi pulsations in the northern and southern hemispheres. However, the reason is not clear. In order to obtain a definite answer a more extensive study should be done in the future.

Acknowledgments

The 44th Japanese Antarctica Research Expedition carried out the optical and magnetic operations at Syowa Station. S. Johannesson, A. Egilsson, J. Helgasson, and E. Inui supported the auroral and magnetic observations in Iceland. The authors would like to acknowledge both referees for their critical reading of our original manuscript and giving us very valuable comments for constructing the paper.

The editor thanks Drs. T. Uozumi and M. Nose for their help in evaluating this paper.

References

Borovsky, J.E. (1993): Auroral arc thickness as predicted by various theories. J. Geophys. Res., **98**, 6101–6138.

Campbell, W.H. and Rees, M.H. (1961): A study of auroral coruscations. J. Geophys. Res., **66**, 41–55.

Chao, J.K. and Heacock, R.R. (1980): Modulation of type Pi waves by temporal variations in ionospheric conductivity in a three-dimensional magnetosphere-ionosphere current system. Planet. Space Sci., **28**, 475–486.

Fukunishi, H. (1975): Polarization changes of geomagnetic Pi 2 pulsations associated with the plasmapause. J. Geophys. Res., **80**, 98–110.

Heacock, R.R. (1967): Two sub-types of type Pi micropulsations. J. Geophys. Res., **72**, 3905–3917.

Heacock, R.R. (1980): Simple Pi burst micropulsation events and associated aurora at two sites in Alaska. Planet. Space Sci., **28**, 907–917.

Jacobs, J.J., Kato, Y., Matsushita, S. and Troitskaya, V.A. (1964): Classification of geomagnetic micropulsations. J. Geophys. Res., **69**, 180–181.

Kuwashima, M. (1978): Wave characteristics of magnetic Pi 2 pulsations in the auroral region—Spectral and polarization studies. Mem. Natl Inst. Polar Res., Ser. A., Aeronomy, **15**, 79 p.

Newell, P.T., Meng, C.-I. and Lyon, K.M. (1996): Suppression of discrete aurorae by sunlight. Nature, **381**, 766–767.

Sakurai, T. and Saito, T. (1976): Magnetic pulsation Pi 2 and substorm onset. Planet. Space Sci., **24**, 573–575.

Sato, N., Nagaoka, T., Hashimoto, K. and Saemundsson, T. (1998): Conjugacy of isolated auroral arcs and nonconjugate auroral breakups. J. Geophys. Res., **103**, 11641–11652.

Sato, N., Kadokura, A., Ebihara,Y., Deguchi, H. and Saemundsson, T. (2005): Tracing geomagnetic conjugate points using exceptionally similar synchronous auroras. Geophys. Res. Lett., **32**, L17109, doi: 10,1029/2005GL023710.

Victor, L.J. (1965): Correlated auroral and geomagnetic micropulsations in the period range 5 to 40 seconds. J. Geophys. Res., **70**, 3123–3130.

Yanagihara, K. (1963): Geomagnetic micropulsations with periods from 0.03 to 10 seconds in the auroral zones with special reference to conjugate-point studies. J. Geophys. Res., **68**, 3383–3397.