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EXTREMELY PERIODIC PULSATING AURORA OBSERVED NEAR $L=6$: A NEW TYPE PULSATING AURORA

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Abstract: Extremely periodic pulsating aurora, a new type pulsating aurora, was detected by three photometers (directing towards the zenith and 45° N and S in the meridian plane, for 427.8 nm emission) at Husafell in Iceland on 18–19 December 1985. We examined the characteristics of the pulsating auroras and their relationship to magnetic pulsations using the data obtained in Iceland and Syowa Station, the geomagnetically conjugate pair station in Antarctica. The characteristics of this event are as follows; 1) extremely regular periodic pulsating auroras with the frequency of ~50 mHz were observed simultaneously on the 3 photometers, 2) the periodicity of the pulsation was extremely high, and the Q-value showed more than 20, 3) the intensity variation among the 3 photometers occurred with excellent coherency and simultaneously without time lag, suggesting that these pulsating auroras were not of a propagating type but a standing type, 4) there are no correlation between the optical pulsating auroras and magnetic pulsations on the ground. These characteristics suggest that the extremely periodic pulsating aurora on this event is not a common (popular) pulsating aurora but an exceptional type pulsating aurora which would occur under a certain condition in the magnetosphere.

1. Introduction

It has been well known that pulsating auroras occurred in the morning sector during the recovery phase of magnetic substorms (*e.g.* HARANG, 1951; OGUTI, 1978; YAMAMOTO, 1988). It is also known that continuos irregular magnetic pulsations are associated with the pulsating auroras. The characteristics of the relationship between the two phenomena have been examined by a number of workers (*e.g.*, ARNOLDY *et al.*, 1982; OGUTI and HAYASHI, 1984; BURNS and CRAVEN, 1988). From the correlation studies among pulsating auroras, magnetic field variations, CNA, X-rays and VLF waves, it is suggested that the magnetic fluctuations associated with auroral pulsations observed on the ground are mostly caused by fluctuations of the ionospheric conductivity which are produced by the pulsating precipitation of electrons (HEACOCK and HUNSUCKER, 1977; ARNORDY *et al.*, 1982; OGUTI *et al.*, 1984; OGUTI and HAYASHI, 1984; GRANT and BURNS, 1995). However, the conjugacy of pulsating auroras and their relationship with magnetic pulsations is still an open question (FUJII *et al.*, 1987; MINATOYA *et al.*, 1995; SATO *et al.*, 1998).

Table 1. Location of conjugate-pair stations in Iceland and Antarctica. Geomagnetic coordinates are calculated with IGRF model. MLT is the magnetic local time at 00 UT.

Station	Geographic latitude	longitude	Geomagnetic latitude	longitude	MLT
Husafell	64.7	339.0	66.0	68.9	2357
Tjornes	66.2	342.9	66.9	73.3	0015
Syowa	−69.0	39.6	−66.5	71.8	0009

In order to observe pulsating aurora occurring in the late morning, a visible auroral campaign has been carried out at Husafell in Iceland during the midwinter season of 15–25 December 1985. High sensitive TV cameras, scanning photometers and fixed-direction photometers have been operated during the campaign period. Details of the observation system have been reported by SATO and SAEMUNDSSON (1987).

In this paper we will show a case study of pulsating auroras and demonstrate their relationship with magnetic pulsations which occurred during the midnight of 18–19 December 1985. The most interesting feature of this event is the occurrence of extremely regular periodic pulsating auroras without any relationship between pulsating aurora and magnetic pulsation. In our knowledge, this is a new type pulsating aurora. We show here the characteristics of the regular periodic pulsating auroras detected by the photometers at Husafell and their relationship to magnetic pulsations observed at conjugate stations in Iceland and Syowa Station in Antarctica. There were no optical data at Syowa because of the midnight sun. The geographic and geomagnetic coordinates for the 2 stations in Iceland and Syowa Station are listed in Table 1.

2. Observations

The regular periodic pulsating auroras were observed by the fixed-direction photometers at Husafell in Iceland from ~ 21 UT, after sunset, till 02 UT. Figure 1 shows an example of the intensity record of the extremely regular periodic pulsating auroras observed with three photometers, where PH(S), PH(Z), and PH(N) are the fixed-direction photometers directing to 45° south, zenith and 45° north in the geomagnetic meridian with the field of views of 3° at 427.8 nm. It is clearly found that extremely regular periodic pulsating auroras were observed with similar wave forms with the three photometers. It is also found that the timing of turn-on and turn-off of the auroral luminosity is almost the same at the three photometers. These spatial and temporal features suggest that this regular periodic pulsating aurora occurred simultaneously in the areas of more than 200 km along the geomagnetic meridian plane if we assume the height of auroral altitude as 100 km. In other words, this pulsating aurora is not propagating but standing (or patchy). Unfortunately we could not confirm the shape and movement of the pulsations using an all-sky TV camera, because the intensity level of the pulsating phenomena was lower than the detection level of this came ra.

In this paper the photometer data are shown in a relative scale without the absolute value. If we assume the intensity of the common type pulsating aurora is a few thousand Rayleighs, which was observed during ~0455–0515 UT as shown in Fig. 7, the

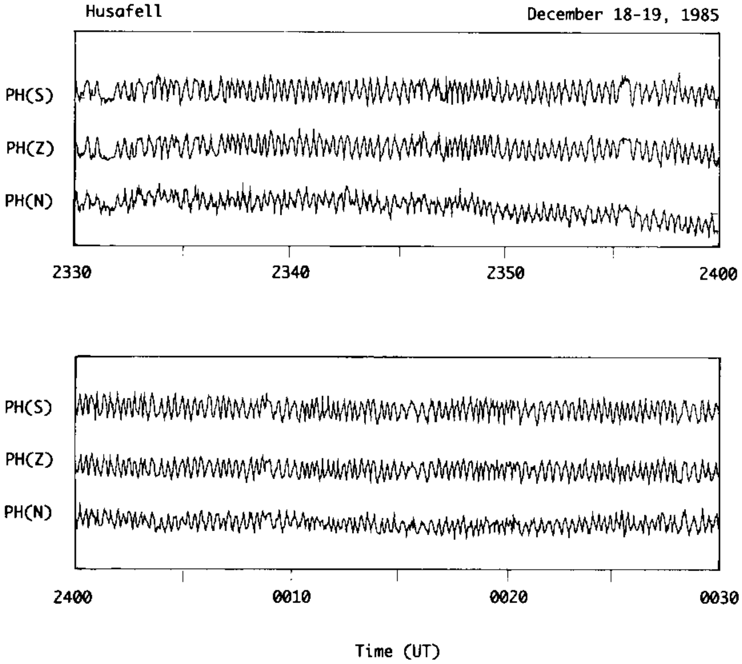

Fig. 1. Examples of the intensity record of extremely regular periodic pulsating auroras observed by 3 different direction photometers at Husafell in Iceland. PH(S), PH(Z), and PH(N) are the fixed direction photometers directed to 45° southward, zenith and 45° northward, respectively along the geomagnetic meridian with the field of views of 3° at 427.8 nm.

intensity level of this periodic pulsating aurora would be estimated as a few tens of Rayleighs.

Figure 2 shows the power spectrum of the intensity variations of PH(S) around 0100 UT. The pulsating aurora has a sharp power peak at ~50 mHz, that is, a period of ~20 s. The Q value for the degree of periodicity is more than 20 at the peak power of ~50 mHz. Figure 3 shows the frequency-time spectrum of the intensity variations of PH(S) during 22–04 UT. The peak power frequency changed with time like as a wave packet, namely it changed not continuously with time but sporadically between each group of pulsating auroras with fixed, falling-tone or rising-tone frequency. The duration of each wave packet was from 10 to 20 min. Such sporadic frequency change can be expected from the intensity record of Fig. 1, for example, between ~0015 UT to 0020 UT.

It is worth studying the relationship between regular periodic pulsating auroras and magnetic pulsations, since, most of common (popular) type pulsating aurora has a clear correlation with magnetic pulsations (*e.g.*, Oguti and Hayashi, 1984). Figure 4 shows the intensity variations of the 3 direction photometers and the H and D components of magnetic pulsations ($\mathrm{d}H/\mathrm{d}t$ and $\mathrm{d}D/\mathrm{d}t$) detected by induction magnetometers during 2330–2400 UT, where the magnetic pulsations look rather quiet. Hence it is difficult to

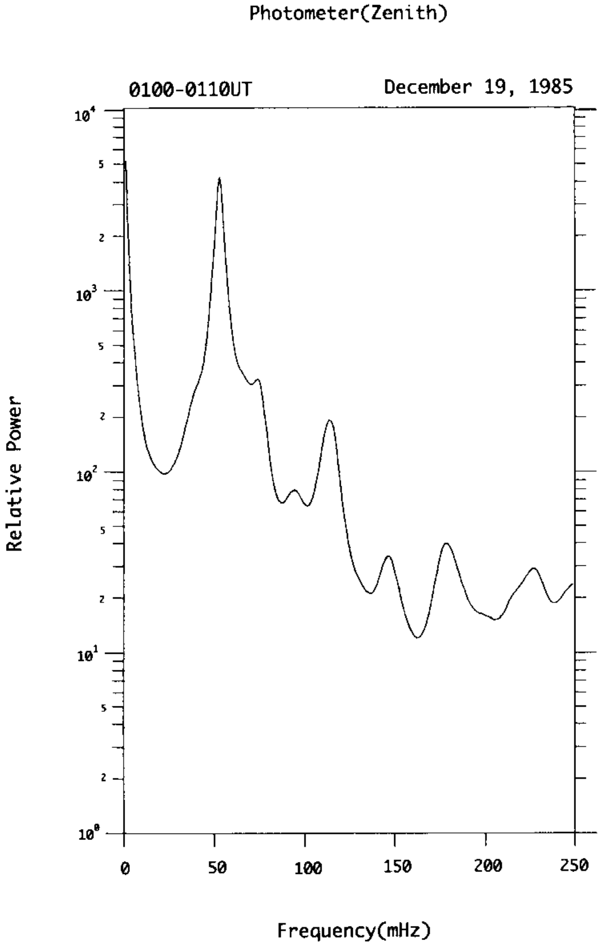

Fig. 2. Power spectra of the intensity variations of the 45° southward photometer, PH(S) during 0100–0110 UT on December 19, 1985. The pulsating aurora has a sharp power peak at ~50 mHz, the period of ~20 s. The Q value showing the degree of periodicity is more than 20 at the peak power.

identify the close relationship between the intensity variation of photometers and magnetic pulsations. In order to confirm the relationship more quantitatively between the optical variations and magnetic variations, we carried out the analysis of power spectra and cross correlation. The upper panel of Fig. 5 shows the intensity record of the PH(Z) and the *H* component of the magnetic pulsations observed at Husafell. The lower panel of Fig. 5 shows the power spectra of PH(Z), the *H* and *D* components of magnetic pulsations observed at Husafell(HL) and Syowa(SY) during the same time interval shown in the upper panel. It is noteworthy that there are no power peak for magnetic pulsation at the peak power frequency of PH(Z) at ~50 mHz, suggesting that there is no correlation between pulsating aurora and magnetic pulsation in this time interval.

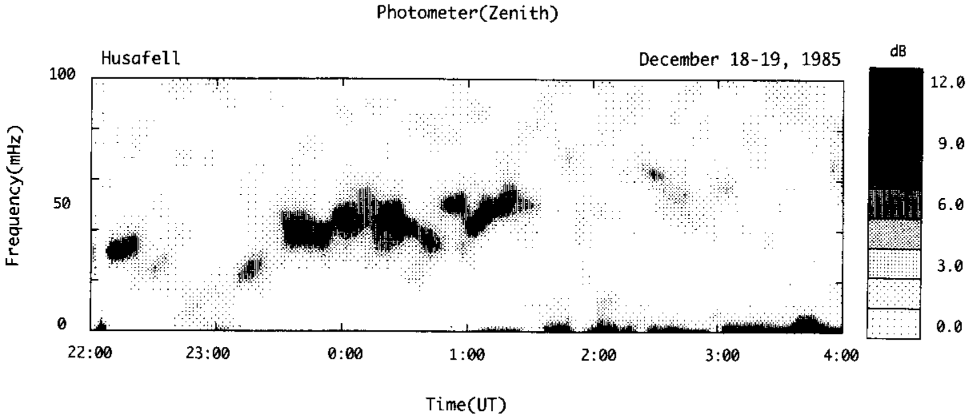

Fig. 3. Frequency-time spectra of the intensity variations of the PH(S) in the time interval of 22–04 UT on December 18, 1985.

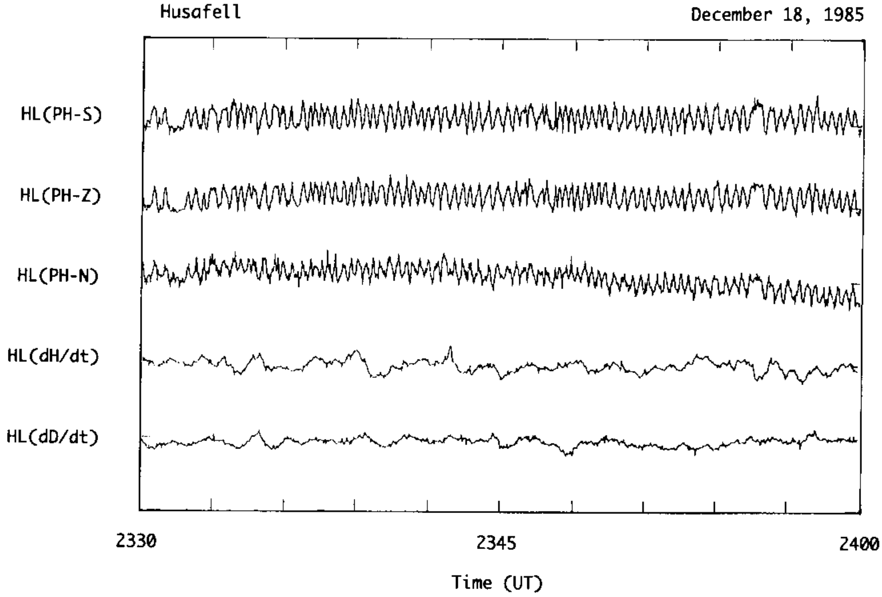

Fig. 4. Intensity variations of the 3 direction photometers and the H and D components of magnetic pulsations (dH/dt and dD/dt) detected by induction magnetometers during 2330–2400 UT on December 18, 1985.

The top panel of Fig. 6 shows the power spectrum of the zenith photometer data during 0020–0030 UT. There are two power peak frequencies at ~40 mHz and ~60 mHz. The lower panels show the coherency between the photometer records for at different directions and magnetic pulsations (the *H* and *D* components) observed at Husafell. An excellent coherency, approaching even to ~1.0, is found among the zenith photometer and southward and northward directed photometers around the peak power

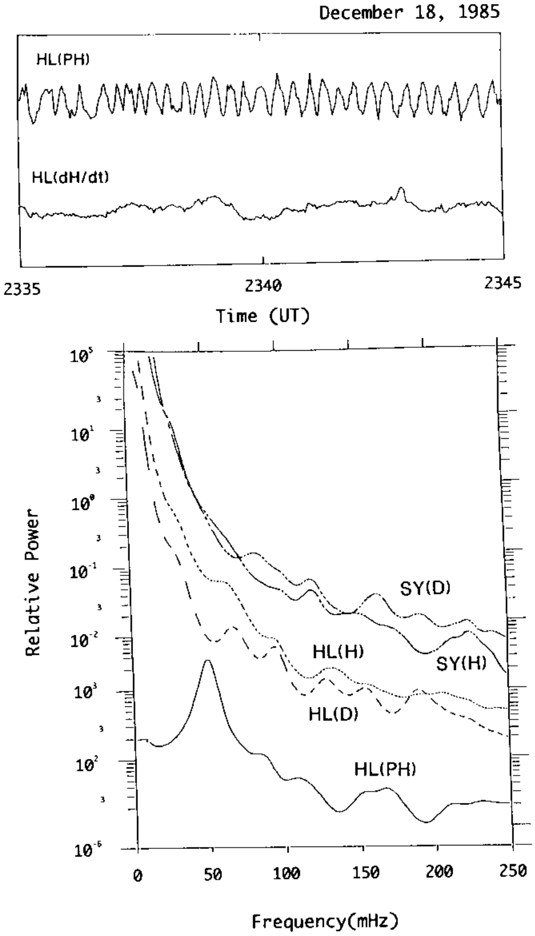

Fig. 5. *(Upper panel) Intensity record of PH(Z) and the H component of the magnetic pulsations observed at Husafell during 2335–2345 on December 18, 1985. (Lower panel) Power spectra of PH(Z), the H and D components of magnetic pulsations observed at Husafell (HL) and Syowa (SY) during the time interval shown in the upper panel. It is clear that there are no correlating power peak for magnetic pulsations at the frequency of peak power of PH(Z) at ~50 mHz.*

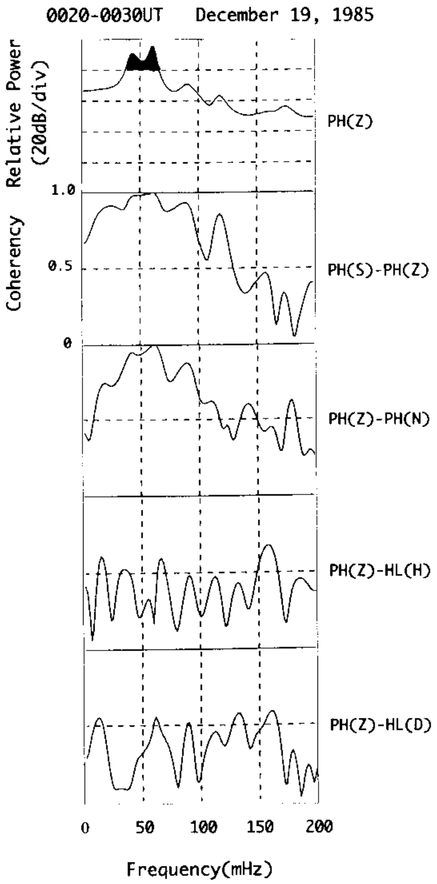

Fig. 6. *Top panel shows the power spectrum of the zenith direction photometer, PH(Z), observed 0020–0030 UT at Husafell on December 19, 1985. The lower 4 panels show the coherence between the photometers at different directions, photometer PH(Z) and magnetic pulsations HL(H) and HL(D) observed at Husafell, respectively. It is clearly found that there are no correlation between regular periodic optical pulsating aurora and magnetic pulsation though there are excellent coherence between photometer and photometer at different directions.*

frequency of 40–60 mHz. On the other hand, the coherency between optical pulsations and magnetic pulsations is less than 0.5 at the power peak frequency of the photometer records. Therefore we can conclude that there is no correlation between regular periodic optical pulsating aurora and magnetic pulsation. The results demonstrated here, such as, the existing phenomena of extremely regular pulsating auroras and no relationship between pulsating aurora and magnetic pulsation could be the first report in our knowledge; that is, a new type pulsating aurora.

3. Summary and Discussion

We summarize the characteristics of the extremely periodic pulsating aurora, a new type pulsating aurora, detected by 3 different direction photometers and their relationship to magnetic pulsations observed at Husafell and geomagnetically conjugate stations;

1) Extremely regular periodic pulsating auroras with the frequency of ~ 50 mHz are observed simultaneously on three 427.8 nm photometers directed towards 45° south, zenith and 45° north in the geomagnetic meridian.
2) The Q-value, which show the degree of periodicity, is more than 20.
3) The intensity variation among the 3 direction photometers showed excellent good coherency without time lag. Hence, these pulsating auroras are not of a propagating type but a standing type at least within the area of 200 km along the geomagnetic meridian plane.
4) Sporadic frequency change of peak power with wave packets of 10–20 min duration.
5) No correlation is found between the appearances of optical pulsating auroras and magnetic pulsations.

These characteristics summarized above suggest that the regular periodic pulsating aurora on this event is not an ordinary pulsating aurora but an exceptional type pulsating aurora. Because ordinary pulsating auroras are always accompanied by magnetic pulsations observed on the ground (*e.g.*, ENGEBRETSON, 1983). Furthermore, the periodicity of ordinary pulsating auroras is quasi-periodic or rather irregular (*e.g.*, OGUTI *et al.*, 1984).

It must be discussed, concerning this special event, why such extremely regular periodic pulsating aurora occurs without any correlation to magnetic pulsation. Such characteristics of regular periodicity and no correlation between pulsating aurora and magnetic pulsation are very similar to the regular VLF pulsations(or Type-2 QP VLF emissions) reported by SATO and KOKUBUN (1981) and SATO and MATSUDO (1986). We briefly discuss here after noteworthy event with an analogy to Type-2 QP VLF emissions. The typical characteristics of Type-2 QP are as follows; 1) the periodicity is extremely good, and the Q value of a spectral peak usually amounts to more than 10, 2) in most cases, magnetic variations during the Type-2 QP events, which occur under magnetically quiet condition, have no spectral peak corresponding to the peak in QP's spectrum, 3) however, a small but significant peak in pulsation spectrum is occasionally noted, when the Type 2 QP event occurs in moderately disturbed condition, 4) peak period is around 20 s and the average period increases with time from morning to evening.

SATO and KOKUBUN (1981) and SATO and MATSUDO (1986) suggested that the weak

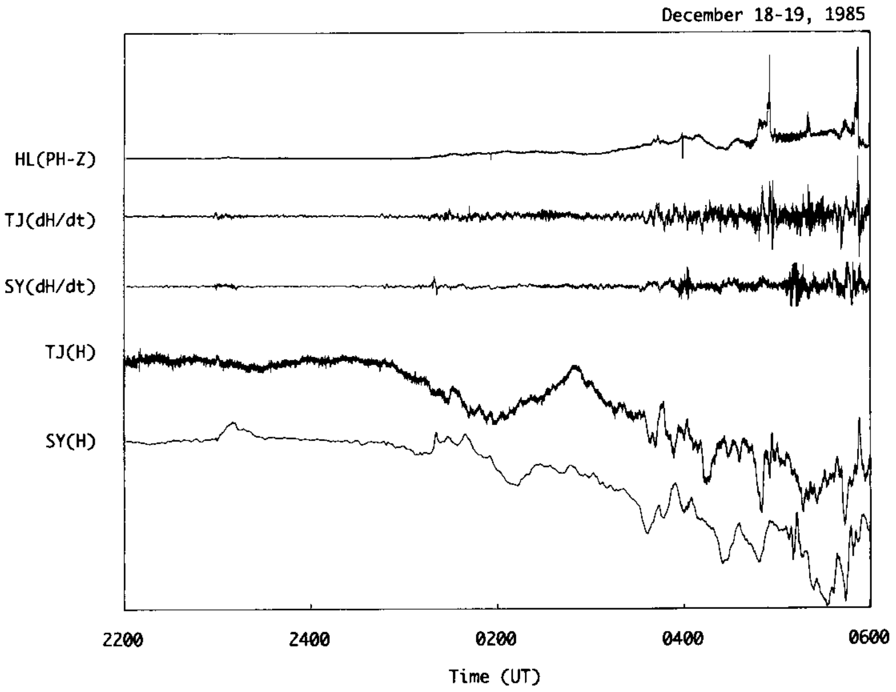

Fig. 7. Intensity record of fixed direction photometer PH(Z) at Husafell and the H component of induction (dH/dt) and fluxgate magnetometers (H) at Tjornes and Syowa. The extremely regular periodic pulsating aurora, we are interested in here, are observed during ~22–02 UT on December 18–19, 1985.

magnetic pulsations correlated with the Type 2 QP are produced by ionospheric conductivity changes associated with particle precipitation. Their interpretation is the same analogy for the good correlation between ordinary pulsating auroras and magnetic pulsations (*e.g.*, OGUTI *et al.*, 1984). When we apply this interpretation to the regular periodic pulsating auroral event in this study, it would be expected that some magnetic pulsation activity occurs associated with the optical pulsating aurora. However there were no correlation between the two phenomena as shown in Fig. 5. In order to derive a possible mechanism we need to know the relative intensity of pulsating aurora and magnetic activity during the event we deal with, because magnetic activity would be relating to ambient electric field. *Kp* index during the interval for 21–24 and 00–03 UT on 18–19 December 1985 was 2 and 3+, respectively. Figure 7 shows intensity record of fixed direction photometer at Husafell and the *H* component of induction and fluxgate magnetometers at Tjornes and Syowa. As mentioned above, the extremely regular pulsating aurora was observed during of ~2200–0130 UT. The negative spikes on the photometer at ~0156 UT and ~0358 UT show the dark current level of the photometer. The regular periodic phenomena was at enough higher level than the noise level in comparison with the dark condition level and the emission intensity level. On the other hand, ordinary pulsating aurora was observed during the period of ~0430–0450 UT and

0455–0515 UT. The intensity of ordinary pulsating aurora was quite higher than the regular period pulsating aurora (more than ~60–80 times). The ordinary common pulsating aurora observed during disturbed magnetic condition accompanying with magnetic pulsations. On the other hand, the regular periodic pulsating aurora observed during quiet condition. Therefore we propose the following two possible interpretations for the relationship between the optical pulsation and magnetic pulsation; 1) the ionospheric conductivity changes induced by the particle precipitation are negligibly small to produce any detectable magnetic pulsation, or 2) the ambient electric field is extremely weak, and magnetic variations would be undetectable, even though there is a sufficient electron flux precipitation to induce some ionospheric conductivity changes.

One of the most puzzling feature of this type of pulsating aurora is their regularity in repetition of particle precipitation. The problem is to find a reason for this regular recurrence. Though the generation mechanism for the regular periodicity is very difficult to clarify at present stage, similarly to the mechanism of Type 2 QP emission, there is a possibility that periodic modulation originates from a certain ULF wave, which may be electrostatic and accelerate electrons to produce pulsating auroras. It is also possible that the modulation agent is a localized hydromagnetic wave, that is not observable on the ground. HUGES and SOUTHWOOD (1976) have theoretically shown that a localized hydromagnetic wave of scale size less of ~ 120 km at the ionospheric level is almost screened by the ionosphere and thus is undetectable on the ground. Since ground based observations cannot give direct evidence for the existence of an electrostatic wave or localized hydromagnetic wave, coordinated observations on the ground and from satellites are needed to clarify these possibilities.

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