"Physics of Auroral Phenomena", Proc. XXXII Annual Seminar, Apatity, pp. 97 - 100, 2009

Polar Geophysical Institute

IONOSPHERIC IMAGE OF THE SOURCE REGION OF THE IPDP TYPE MAGNETIC PULSATIONS

A.G. Yahnin[1], T.A. Yahnina[1], H.U. Frey[2], T. Bösinger[3]

[1] *Polar Geophysical Institute, Kola Science Centre, Russian Academy of Science, Apatity, Russia*
[2] *Space Sciences Laboratory, University of California, Berkeley, California, USA*
[3] *Department of Physical Sciences, University of Oulu, Oulu, Finland*

Abstract. On the basis of two-year observations of geomagnetic pulsations at the Finnish meridional network of the search coil magnetometers and proton aurora from the IMAGE spacecraft we found that during intervals of pulsations of diminishing periods (IPDP) the proton arcs appear equatorward of proton oval at meridian of the ground magnetometers. The maximal intensity of the pulsations is observed at the ground station which is closest to the proton arc. The proton arcs tend to appear at lower latitudes in later MLTs. This agrees with the facts that the IPDP occurrence exhibits similar tendency and the IPDP end frequency tends to increase when MLT increases. The spatial-temporal correlation of IPDP with proton aurora arcs confirms the suggestion that the proton arcs are the ionospheric image of the region of the ion-cyclotron instability developing in the equatorial magnetosphere.

Introduction

Intervals of Pulsations of Diminishing Periods (IPDP) are a type of geomagnetic pulsations in the Pc1-2 range. Comprehensive description of the IPDP morphology and hypotheses of the IPDP generation can be found in a review by Kangas et al. (1998). Since the early stage of the IPDP investigation, it is generally accepted that the ground IPDP are the signature of the electromagnetic ion-cyclotron (EMIC) waves generated in the vicinity of the equatorial plane of magnetosphere as result of ion-cyclotron instability of ring current ions (e.g., Troitskaya et al., 1968; Fukunishi, 1969). This, in particular, suggests that IPDP may play a role in dynamics of the ring current via pitch-angle scattering of the hot ions and, as consequence, their precipitation and losses in the atmosphere. Proton precipitations related to IPDP were first observed by Soraas et al. (1980) on the basis of data from low-orbiting ESRO satellite. Yahnina et al. (2003) using the data from low-orbiting NOAA satellites statistically established a relationship between IPDP and localized precipitation of energetic protons (LPEP) equatorward of proton isotropy boundary (their LPEP of Type 2). One may expect that this precipitation produces so called proton aurora, which is the Doppler-shifted emission of neutral hydrogen atoms originated from precipitating protons due to charge exchange. Observations with FUV instrument onboard IMAGE spacecraft provided an excellent view of proton auroras from space (Frey, 2007). Different kinds of proton aurora were revealed. Towards the equator from the main proton oval associated with isotropy boundary several kinds of detached proton auroras were, indeed, observed. Some of these auroras have been already correlated with geomagnetic pulsations of the Pc1 range and EMIC waves in space. Yahnin et al. (2007) showed that the subauroral proton spots, first described by Frey et al. (2004), exhibit very nice correlation with long-lasting quasi-monochromatic Pc1 ("pearls"). As demonstrated by Yahnina et al. (2008), proton aurora flashes on the dayside, associated with magnetosphere compressions due to solar wind dynamic pressure pulses (e.g., Hubert et al, 2003), exhibit close connection with Pc1 bursts as well as with EMIC waves of similar characteristics (see, also, Zhang et al., 2008). Thus, these proton auroras "visualize" the ionospheric projection of magnetospheric domains where wave-particle interaction develops. Such visualization of the source makes clear some properties of the geomagnetic pulsations (localization, duration, and frequency variations) (Yahnin et al., 2007; Yahnina et al., 2008).

It would be also important to find the proton aurora pattern visualizing on the ionospheric "screen" the IPDP source configuration and dynamics. This is the aim of the present study in which the attempt to correlate IPDP and proton auroras is done on the basis of comparison of IPDP observed at Finnish meridional chain of induction coil magnetometers and proton aurora observations from the IMAGE spacecraft.

Data and event selection

The ground observations of geomagnetic pulsations were performed by the Finnish network of search coil magnetometers The description of the network and instrumentation is given in the companion paper by Yahnina and Manninen (this issue).

The proton aurora data were provided by the Spectrographic Imager (SI) of the Far Ultraviolet (FUV) instrument on board the IMAGE spacecraft (see Mende et al. (2000) for details), which was designed to select the Doppler shifted Lyman H-alpha line at 121.82 nm in the ultraviolet part of the optical spectrum and to reject the non-Doppler shifted Lyman H-alpha from the geocorona at 121.567 nm.

For the study the data for years 2004 and 2005 were used. First, the data from three stations IVA, OUL and NUR (representing, respectively, poleward, middle, and equatorward parts of the magnetometer chain) were searched to reveal IPDP events observed at least at one station. Then, those events were selected when observations of proton aurora from the IMAGE spacecraft were available (in all 35 events: 9 in 2004 and 26 in 2005).

Relationship of IPDP and proton aurora (Event of 9 March 2004)

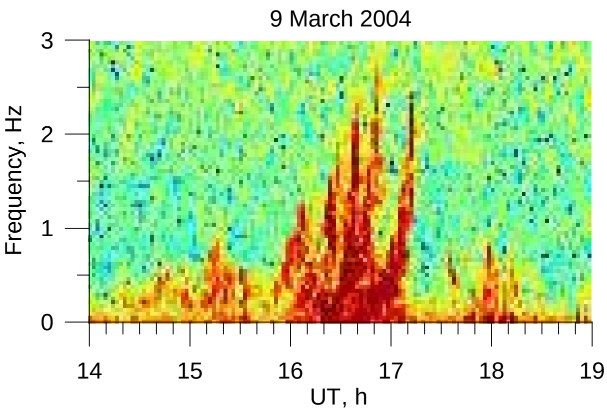
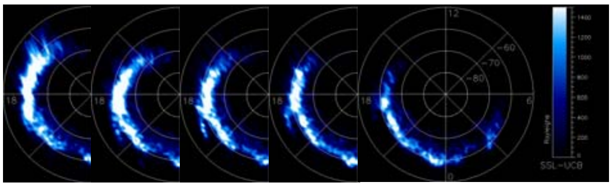


Fig. 1



16:56 17:00 17:04 17:08 17:12 UT

Fig. 2

On 9 March 2004 a series of IPDP was observed at 1550-1715 UT (Fig. 1). The end frequencies in this series reached more than 2 Hz. Let us consider phenomena related to the last IPDP event in this series at 1650-1715 UT. During this IPDP the IMAGE spacecraft observed a distinct proton arc appearing in the evening sector. The development of this arc is shown in a sequence of proton aurora images in Fig. 2. The arc became distinguishable from the proton oval at 1656 UT, and it is seen until 1712 UT. During the arc life time it slightly shifted equatorward (for about 2-3 degrees). The arc crossed the meridian of the ground network close to the latitude of the ground station NUR. The most intense IPDP signal was observed right at this station. The intensity sharply decreased with latitude; the pulsations were hardly seen in ROV and not seen poleward.

The proton arc in Fig. 2 is clearly seen in the late evening sector, but toward earlier MLT it is juxtaposed with the proton oval and, consequently, it is hardly resolved in the images. The existence of the arc at 18 MLT is confirmed by the particle data from the NOAA satellite (not shown) that crosses this region at ~1705 UT. These data demonstrate a localized precipitation of energetic protons (LPEP) equatorward of the precipitation related to the proton oval. Such precipitation pattern has been found by Yahnina et al. (2003) as closely related to EMIC waves.

Data from two geosynchronous spacecraft LANL 01A and LANL 02A (not shown), which longitudes are astride the magnetometer chain, show multiple injections of the energetic protons on the night side and consequent westward drift of the proton clouds. The drift is evidenced by the systematic delay of the flux enhancements at LANL 01A in comparison with LANL 02A and by the energy dispersion, which is more pronounced at LANL 01A. The spacecraft LANL 01A was situated about 1.5 hours MLT westward of the ground magnetometer network observing IPDP, while the spacecraft LANL 02A was 2.5 hours eastward from the network. There is a remarkable correlation between energy dispersed increases of the energetic proton flux registered onboard spacecraft LANL 01A (closest to the meridian of magnetometers) with IPDP observed on the ground.

Relationship of IPDP and proton aurora (Statistics)

The event considered above shows that IPDP relates to the appearance of sub-oval proton arc. Consideration of all 35 events, when proton aurora observations were available during IPDP events, confirmed this relationship. Indeed, in 30 cases the IPDP observations were associated with clear signatures of the proton arc appearance in the vicinity of the ground stations. The proton arcs became visible and disappeared within few minutes of the IPDP start and end, respectively. The proton arcs were observed in the latitudinal range of 54-66 CGLat and exhibited a clear tendency to appear at lower latitudes at later MLTs (this is, evidently, a consequence of the configuration in the evening sector of the proton oval, which equatorial boundary, representing the proton isotropy boundary, shifts equatorward from day to late evening). The locations of the proton arcs in coordinates MLT-CGLat is shown in Fig. 3. The vertical bars indicate the latitudinal shift occurred during the arc life time at longitude of the ground magnetometer network. In 15 cases the observations of proton aurora arcs were available when IPDP were observed at only one of three selected station (this means closeness of the pulsation source to the station). Three such IPDP were observed in IVA, six in OUL, and six in NUR. The latitudinal locations of the arcs associated with IPDP observed only in IVA, OUL, and NUR were, respectively, within 64-65; 60-62, and 54-57 CGLat, that is, close to the station observing IPDP. These arcs were observed, respectively, at 1230-1430 MLT, 1530-2200 MLT, and 1900-2230 MLT.

Most arcs exhibited a drift towards low latitudes like in the example presented in Section 3. Typically, the equatorward shift was not large and amounted to 1-3 degrees. The largest shift of the proton arc was observed during an IPDP event at 18-19 UT of 12 June 2005 (data not shown); it was as large as ~6 degrees. Some proton arcs were, in contrast, immovable.

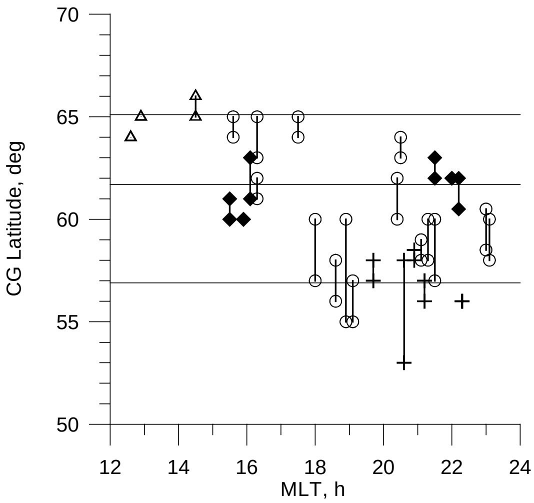


Fig. 3. The latitudinal locations of the sub-oval proton arcs related to the IPDP events in 2004-2005. Triangles, squares, and crosses mark those arcs that occurred during IPDP events registered only at IVA, OUL, and NUR, respectively. Circles mark other events.

For 28 of 30 proton arc observations, there exist NOAA POES passes which crossed the proton arcs. The data from all these NOAA passes show the presence of LPEP in conjunction with the arc. During 4 of 5 events, when the arc was not seen on proton aurora images, there were fortunate passes of NOAA POES close to locations of the ground station observing IPDP. The particle data from these passes also showed the presence of LPEP adjoining (from the equatorial side) the region of isotropic proton fluxes and conjugated with the equatorward part of the proton aurora oval. Evidently, in these cases the arcs were simply not resolved from the oval on the images.

In 34 of 35 cases of proton aurora observations the data from geosynchronous LANL spacecraft situated in the evening sector were available. In all these cases the data showed injections of hot protons during the IPDP events. In particular, the data from the spacecraft LANL-01A were available in 33 cases. In all 33 cases the injections observed onboard LANL-01A exhibited good temporal correlation with IPDP.

Summary

Observations of the proton aurora from the IMAGE spacecraft during IPDP events showed that:

a) during IPDP the sub-oval proton arcs appear at meridian of the ground magnetometer network;
b) the maximal intensity of the pulsations is observed at the ground station, which is the closest to the proton arc;
c) the arcs appearance and fading is within several minutes, respectively, with start and end of the IPDP events;
d) the proton arcs tend to appear at lower latitudes at later MLTs.

Discussion

The results listed above demonstrate the close spatial-temporal relationship between IPDP and proton arcs. This relationship confirms the suggestions about ion cyclotron instability as a mechanism producing the proton precipitation responsible for the sub-oval proton arc in the evening sector (Immel et al., 2002; Spasojevic et al., 2004; Jordanova et al., 2007). Thus, the sub-oval proton arc represents the projection of the magnetospheric source region of the IPDP onto the ionosphere.

In the evening sector the proton arcs tend to map onto the eastern edge of the plasmaspheric plume (Jordanova et al., 2007). A spatial-temporal association of IPDP and drifting proton clouds strongly suggests that wave-particle interaction responsible for both proton precipitation and IPDP develops when drift trajectories of hot protons intersect the boundary of the cold plasma represented by the plasmaspheric plume. This agrees with a current scenario suggesting ring current particle losses in the evening sector due to ion-cyclotron interaction (e.g., Bespalov et al., 1994; Kozyra et al., 1997). Recently, Jordanova et al. (2007) performed a numerical modeling of two particular events of proton arc observations on the basis of their global ring current-atmosphere interactions model including the cyclotron wave interaction with hot protons. Their modeling reasonably well reproduced the proton precipitation resembling the observed proton arc being extended along the eastern boundary of the plasmaspheric plume. Typically, the proton arc extends from higher latitudes at earlier MLT to lower latitudes at later MLT. This agrees with the plasmaspheric plume extension to larger distance from the Earth on the dayside in comparison with that in the evening sector.

The morphology of the proton arcs explains the MLT-dependence of the IPDP occurrence at these stations on MLT as shown by Yahnina and Manninen (this issue). Keeping in mind the range of latitudinal locations of proton arcs, it is clear that the IPDP signal arriving from the high-latitudinal part of the dayside source region is more distinguishable at the higher latitude ground station (say IVA). The most equatorward station (NUR) is to better discern the signal from the low-latitudinal part of the source region, which is located in the evening side. (The signal from a remote source suffers attenuation when propagating in the ionospheric waveguide. Previous studies of the relationship between sub-oval proton aurora and pulsations in the Pc1 range (Yahnin et al., 2007; 2008; Yahnina et al., 2008) have undoubtedly demonstrated the significance of wave attenuation off the proton aurora location. The decrease of the latitude of the IPDP source region towards later MLTs also agrees with the general trend of the end frequency of IPDP to increase from day to late evening local times (Yahnina and Manninen, this issue). Different dependences for given stations are due to the fact that the main contribution to the average end frequency comes from those sources, whose footprints (proton arcs) are located closer to the observation site.

Conclusion

Previous studies have established the connection between quasi-monochromatic Pc1 pulsations and Pc1 bursts with different forms of sub-oval proton aurora. In this paper such connection is proved to exist also for IPDP, which are another type of pulsations in the Pc1 range. All these pulsations represent different regimes of the ion-cyclotron interaction in the near-Earth equatorial magnetosphere. Thus, the proton aurora observations represent the two-dimensional image of the interaction region at the ionosphere level and provide a powerful tool for monitoring and diagnosis of the cyclotron interaction regimes.

Acknowledgements. The study of A.G.Y. and T.A.Y. is performed in frames of the basic research program 16/3 ‘‘Solar activity and space weather’’ of the Presidium of the Russian Academy of Sciences (RAS) and program VI.15 ‘‘Plasma processes in the solar system’’ of the Division of Physical Sciences of RAS. A.G.Y. and T.A.Y. thank the Academy of Finland for support of the exchange visit to the University of Oulu in 2007 when this study was started. The work of H.U.F. was supported by NASA under the award NNG05GF24G.

References

Bespalov, P. A., A. G. Demekhov, A. Grafe, V. Yu. Trakhtengerts (1994), On the role of collective interaction in asymmetric ring current formation, *Ann. Geophys., 12*(5), 422–430.

Frey, H. U. (2007), Localized aurora beyond the auroral oval, *Rev. Geophys., 45*, RG1003, doi:10.1029/2005RG000174.

Frey, H. U., G. Haerendel, S. B. Mende, W. T. Forrester, T. J. Immel, and N. Ostgaard (2004), Subauroral morning proton spots (SAMPS) as a result of plasmapause-ring-current interaction, *J. Geophys. Res., 109*, A10305, doi:10.1029/2004JA010516.

Fukunishi, H. (1969), Occurrences of sweepers in the evening sector following the onset of magnetospheric substorms, *Rep. Ionos. Space Res. Jap., 23*, 21.

Hubert, B., J.-C. Gerard, S. A. Fuselier, and S. B. Mende (2003), Observation of dayside subauroral proton flashes with the IMAGE-FUV imagers, *Geophys. Res. Lett., 30*(3), 1145, doi:10.1029/2002GL016464.

Immel, T. J., S. B. Mende, H. U. Frey, L. M. Peticolas, C. W. Carlson, J.-C. Gérard, B. Hubert, S. A. Fuselier, and J. L. Burch (2002), Precipitation of auroral protons in detached arc, *Geophys. Res. Lett., 29*(11), 1519, doi:10.1029/2001GL013847.

Jordanova, V. K., M. Spasojevic, and M. F. Thomsen (2007), Modeling the electromagnetic ion cyclotron wave-induced formation of detached subauroral proton arcs, *J. Geophys. Res., 112*, A08209, doi:10.1029/2006JA012215.

Kangas, J., A. Guglielmi, and O. Pokhotelov (1998), Morphology and physics of short-period magnetic pulsations (a review), *Space Sci. Rev., 83*, 435–512.

Kozyra, J. U., V. K. Jordanova, R. B. Horne, and R. M. Thorne (1997), Modeling of the contribution of electromagnetic ion cyclotron (EMIC) waves to stormtime ring current erosion, in: *Magnetic Storms*, *Geophys. Monogr. Ser.,* vol. 98, edited by B. T. Tsurutani et al., pp. 187–202, AGU, Washington, D. C.

Mende, S. B., et al. (2000), Far ultraviolet imaging from the IMAGE spacecraft: 1. System design, *Space Sci. Rev., 91*, 243 – 270, doi:10.1023/A:1005271728567.

Soraas, F., J. A. Lundblad, N. F. Maltseva, V.A., Troitskaya, V. Selivanov (1980), A comparison between simultaneous IPDP groundbased observations of energetic protons obtained by satellites, *Planet. Space Sci.* 28, 387–405.

Spasojević, M., H. U. Frey, M. F. Thomsen, S. A. Fuselier, S. P. Gary, B. R. Sandel, and U. S. Inan (2004), The link between a detached subauroral proton arc and a plasmaspheric plume, *Geophys. Res. Lett., 31*, L04803, doi:10.1029/2003GL018389.

Troitskaya, V. A., R. V. Schepetnov and A. V. Gulyel'mi (1968), Estimates of electric fields in the magnetosphere from the frequency drift of micropulsations, *Geomagn. Aeron.* (Engl. Transl.), *8*(4), 794-795.

Yahnin, A. G., T. A. Yahnina, and H. U. Frey (2007), Subauroral proton spots visualize the Pc1 source, *J. Geophys. Res., 112*, A10223, doi:10.1029/2007JA012501.

Yahnina T.A. and J. Manninen (2009), Some properties of the IPDP type geomagnetic pulsations, this issue.

Yahnina, T. A., A. G. Yahnin, J. Kangas, J. Manninen, D. S. Evans, A. G. Demekhov, V. Yu. Trakhtengerts, M. F. Thomsen, G. D. Reeves, and B. B. Gvozdevsky (2003), Energetic particle counterparts for geomagnetic pulsations of Pc1 and IPDP types, *Ann. Geophys., 21*(12), 2281– 2292.

Yahnina, T. A., H. U. Frey, T. Bösinger, and A. G. Yahnin (2008), Evidence for subauroral proton flashes on the dayside as the result of the ion cyclotron interaction, *J. Geophys. Res., 113*, A07209, doi:10.1029/2008JA013099.

Zhang, Y., L. J. Paxton, and Y. Zheng (2008), Interplanetary shock induced ring current auroras, *J. Geophys. Res., 113*, A01212, doi:10.1029/2007JA012554.