"*Physics of Auroral Phenomena*", *Proc. XXV Annual Seminar, Apatity, pp.43-46, 2002*

Polar Geophysical Institute

FORMATION OF POLARIZATION JET DURING INJECTION OF IONS INTO THE INNER MAGNETOSPHERE

V.L. Khalipov[1], Yu.I. Galperin, A.E. Stepanov[2], E.D. Bondar' [2]

[1] *Space Research Institute of RAS, Profsoyuznaya ul., 84/32, Moscow, 117810, e-mail: khalipov@iki.rssi.ru*
[2] *Institute of Cosmophysical Research and Aeronomy, Yakutsk*

Abstract

Long-lasting ground based measurements of a polarization jet (PJ) by the latitudinal chain of ionospheric stations in Yakutia ($3 < L < 5$; MLT = UT + 9 h) and by 5 subauroral Russian stations were analyzed. A number of cases were found when PJ was recorded simultaneously with energetic ion observations by AMPTE/CCE and INTERBALL 2. The data comparison shows that at least in the considered cases of strong magnetic substorms, PJ was accompanied by strong injection of ions with the energy of ~ 20 - 50 keV and intensity of ~ 10^6 $cm^{-2}c^{-1}sr^{-1}keV^{-1}$. Close to the injection region in the near midnight sector no ion dispersion was observed, but in the evening sector nose events were detected. In accordance with the mechanism suggested by Southwood and Wolf (JGR, 1978, 83, 5227) PJ was observed near the equatorial boundary of energetic ion penetration into the magnetosphere. Measurements by ionosondes at different longitudes show that the westward velocity of the front of PJ development is close to the gradient drift velocity of 20 keV ions (forming nose events). Thus, the physical mechanism of PJ formation due to energetic ion injection during a strong substorm burst is experimentally confirmed. Satellite measurements show that in the near midnight sector energetic ions reach the shell L = 3.0 in 20 – 30 minutes after a substorm commencement with AE > 500 nT.

Introduction

Polarization Jet (PJ) is a spectacular substorm phenomenon at subauroral latitudes – a supersonic narrow stream of plasma at, or near, the equatorward convection boundary (Galperin et al., 1973, 1974; Smiddy et al., 1977). Generally it was considered as occurring during substorm recovery phase (Spiro et al., 1979; Anderson et al., 1991, 1993; Karlsson et al., 1998).

However, recent analysis by Khalipov et al., 2001 of extensive ground-based observation at L = 3.0 during more than 20 years, led to the conclusion that in the near-midnight MLT sector, PJ can appear within not more than ~ 10 minutes after a significant AE – index burst (> 500 nT). These observations were made at the Yakutsk station (geographic latitude 62° N, longitude 129°; MLT = UT + 9^h, L = 3.05) using both the specific PJ signature on vertical and oblique subauroral ionograms (see, Sivtseva et al., 1984; Galperin et al.,1986; Fillipov et. al., 1989) and, when observable, the accompanying weak SAR arc from optical auroral measurements (see Ievenko, 1993, Alexeev et. al., 1984). At the same time average PJ delay from the substorm onset for all the ground-based data set is close to ~ 30 min. in the near-midnight sector and increases toward evening MLT hours reaching ~ 1.0 – 1.5 hours. These average delays are in rough accord with the statistics accumulated from the satellite crossing of PJ by Spiro et al., 1979; and Karlsson et al., 1998.

The basic idea of the physical explanation of PJ was put forward by Southwood and Wolf, 1978. It deals with injection of energetic ions into the inner magnetosphere during a substorm in the near-night sector, and with their deeper penetration to the Earth in the pre-midnight and evening sectors due to a betatron acceleration of ions at their drift motion in the presence of an electric field component directed to the west. According to this model, PJ is created by electric field directed to the pole and generated by the charges of energetic ions at an equatorial boundary of their penetration. In this case, it is natural to expect the quickest appearance of this effect in the near-midnight sector or, more precisely, near the injection meridian. Later, as the population of the injected hot ions drift in longitude to the west, its delayed development should be observed in the evening sector. Recently modification of this mechanism was conceded by Galperin, 2001.

The present paper considers polarization jet dynamics in space and time as observed by ground-based ionosonde measurements. Synchronous energetic ion measurements by AMPTE/CCE (http://sd-www.jhuapl.edu/AMPTE/) and INTERBALL are used for comparison. Referred magnetic activity indices were taken from http://swdcd.kugi.kyoto-u.ac.jp.

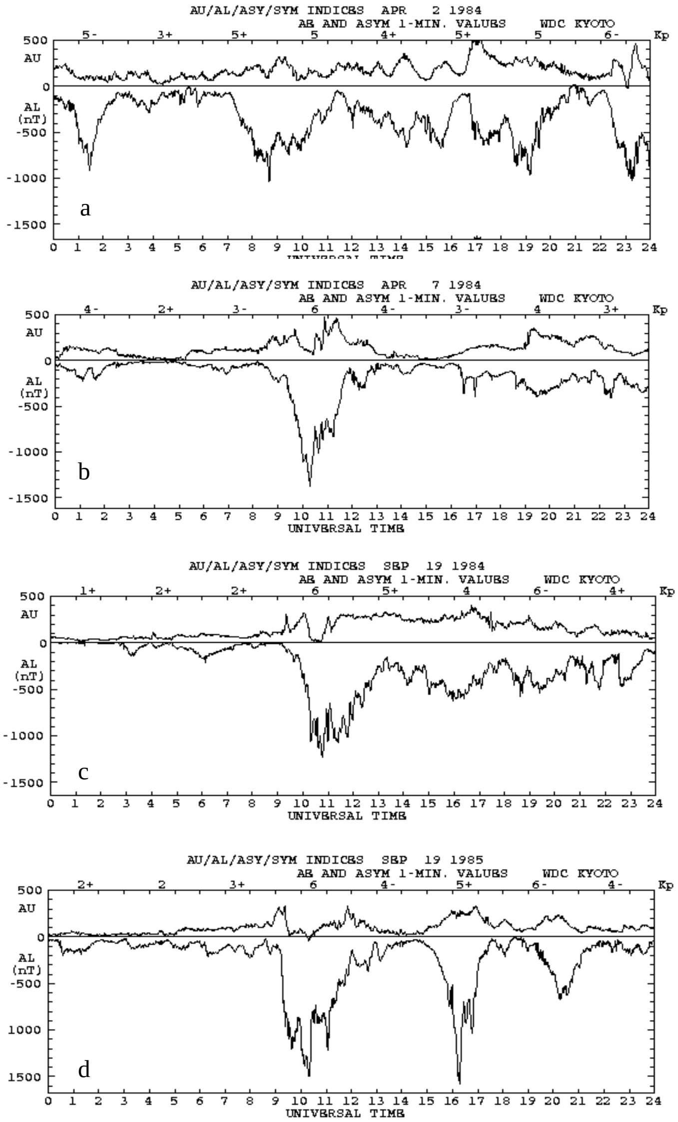

Fig.1 Indices of geomagnetic activity AU and AL for some analyzed events.

Experimental data analysis

Ionospheric measurements were provided by the Yakutian ionosonde chain (λ = 130^0?, L = 3.0 – 5.5) and ionospheric stations in Magadan (λ = 150^0?, L = 2.9), Podkamennaya Tunguska (λ = 90^0?, L = 3.0), Salekhard (λ = 67^0?, L = 4.3), Arkhangelsk (λ = 40.5^0?, L = 4.0), Murmansk (λ =33^0?, L = 5.7). (The data of World Data Center in Moscow were used.)

The PJ appearance is accompanied by the following changes of the F2 layer parameters. f_0F2 abruptly (15 – 30 min.) and significantly (1 – 4 MHz) falls down, h′F grows up by 50 – 150 km, new additional reflections with lower frequencies arise above the F2 layer. Ionospheric data also show that, with the PJ onset, sporadic-E ionization and well-defined period of partial-blackout conditions appears. These signatures permit to determine reliably the availability of PJ using the standard ionospheric processing.

Figure 1 presents variations of auroral activity indices AU and AL referred to the events, which are analyzed in details.

Figure 2 shows an example of nose-event observation by AMPTE/CCE at 13.00 UT, 19 September 1984, LT = 17.3, L = 3.3. The intensity of particle flux is $\geq 10^6$ ion·$cm^{-2}sr^{-1}s^{-1}keV^{1}$. From Figure 1c it follows that the measurements were performed 3 hours after the commencement of a strong storm with AE ~ 1200 nT. During this time energetic ions drifted from the region of their injection in the near-midnight sector toward at least 17.3 LT.

Podkamennaya Tunguzka (LT =UT + 6^h, L = 3.0) is an ionospheric station located most closely to the foot of magnetic field line crossed by the spacecraft at 13.00 UT. Registration of polarization jet began at 12.15 UT by the station (seances of ionosphere sounding are conducted every 15 minutes). While there is a difference of ~ 0.3 L between the equatorial boundaries of the two examined phenomena, it should be taken into account that the antennas of ionospheric station have a wide field of view and are capable of recording reflections from ionospheric structures located northward of the station zenith. That is why on the basis of simultaneous data of the spacecraft and ground-based ionosonde we associate PJ appearance with the energetic ion injection into the inner magnetosphere.

Close to the injection region energy dispersion is not observed and one common boundary is recorded for ions of all energies. We call it the 'injection boundary'. On September, 25 1987 AMPTE/CCE observed injection boundary at 15.00 UT, 23.2 LT, L = 2.9, 30 minutes after the beginning of a burst with AE ~ 1200 nT. Hence, this time is enough for injected ions to reach the L-shell deep inside the magnetosphere. Observations by Podkamennaya Tunguzka located 2^h LT westward of the meridian of satellite measurements show that PJ developed at 15.30 UT. 30 minutes difference in registration time is naturally connected to the delay of energetic ion arrival into the sector of ionospheric measurements.

On 3 October 1987 the injection boundary was observed at 11.15 UT, 23.30 LT, L = 3.2 AE achieved 700 nT at 10.45 UT. The ionospheric station in Yakutsk is located 3 hours westward of the meridian of satellite measurements. PJ was recorded by Yakutsk station at 12.15 UT (21.15 LT). The time delay of the PJ formation approximately corresponds to the time necessary for 20 keV ions observed by AMPTE/CCE to drift from the near-midnight toward

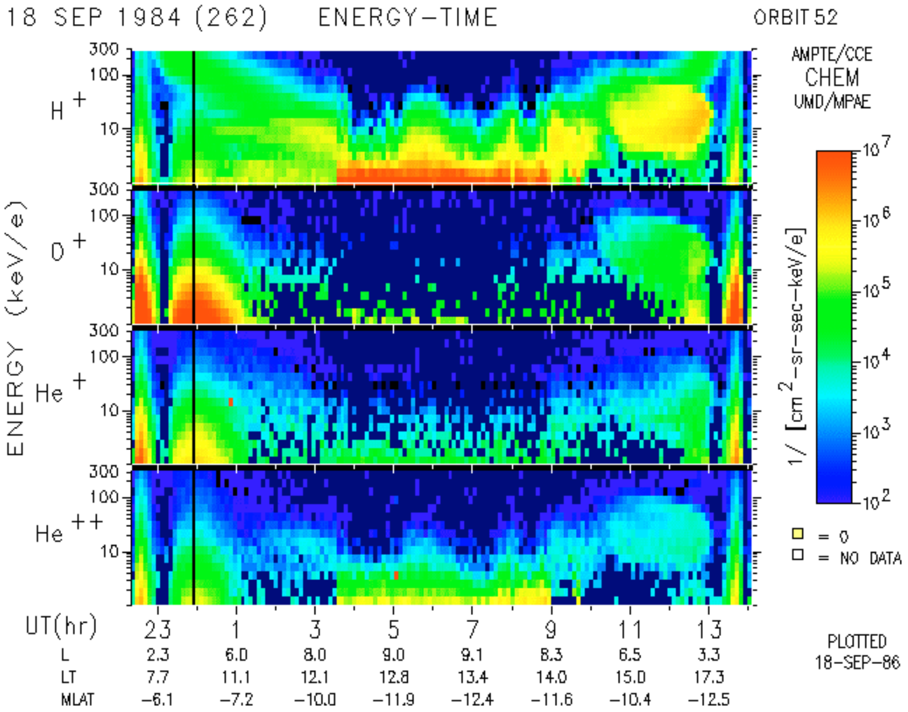

Fig.2 Nose event observed by AMPTE/CCE on 19 September 1984 at 13.00 UT in the early evening sector during polarization jet development recorded by Podkamennaya Tunguzka.

21.15 LT after the substorm commencement.

More than 20 examples of simultaneous ground-based and satellite measurements have been found already. Most of them used the AMPTE satellite data but in 3 cases the INTERBALL 2/ION data were analyzed.. In all cases of energetic ion injections into the inner magnetosphere are accompanied by PJ formation and this formation occurs close to the equatorward boundary of the injection region.

Longitudinal chain of ground-based ionospheric stations permits also to determine the velocity of the westward displacement of PJ front. Events were chosen that referred to a single burst of auroral disturbance with AE ≥ 1000 nT in the sector 09 – 12 UT. Figure 1 shows examples of such events. For the illustration: on September,19 1985 (AE index is shown in Figure 1d) PJ was recorded by the Magadan station at 10.45 UT, then by Podkamennaya Tunguska station at 11.45 UT and finally by the Arkhangelsk station at 12.30 UT (Table 1). Taking into account the longitudinal difference between the positions of the stations, the time of PJ front displacement is 4 MLT hours per hour. Such cases of registrations of PJ motion along the longitudinal chain of stations are described on Sept.19 and 23 1984 and in Table 1 and the determined velocity is shown in Figure 3. Azimuthal drift velocity of 30 keV ions is estimated to be 4 hours of MLT per hour at L = 4 and 3 hours of MLT per hour at L = 3. This velocity agrees with the velocity of the source responsible for PJ formation shown in Figure 3

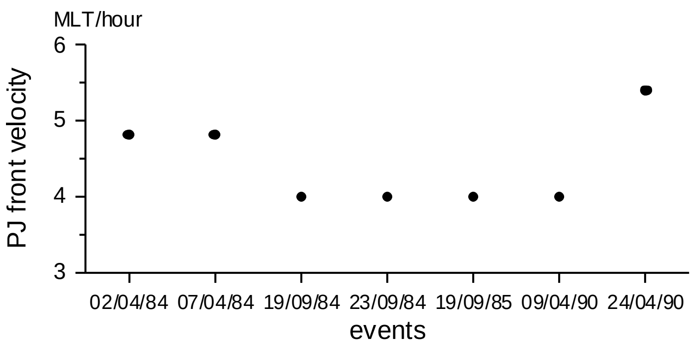

Fig.3. Westward velocity of the source of polarization jet formation for 7 analyzed events (hours of MLT per hour)

Conclusions

- Simultaneous ground-based and satellite measurements (more than 20 events) evidence that polarization jet formation is accompanied by the injection of energetic 1 – 50 keV ions with the intensity of ~ 10^6 ions/cm^2·s·sr·keV. In the dusk sector, as a rule, the ion population is observed as energy dispersed structures (nose-events). In the near-midnight sector close to the injection region a common abrupt boundary is observed for ions of all energies.
- Polarization jet appears close to the equatorward boundary of the region of energetic ion penetration into the inner magnetosphere.
- Seven cases of successive development of polarization jet are analyzed using the data of the chain of ionospheric stations in longitudinal range of 120°. It turns out that after the beginning of substorm disturbance a source responsible for the PJ formation moves from east to west with the average velocity of 4 hours of MLT per hour.

- It is shown that for the injected ions observed by AMPTE-CCE the azimuthal drift velocity is close to the velocity of the source responsible for the PJ formation along the longitudinal chain of ionospheric stations.
- In 20 – 30 minutes after a substorm commencement (AE > 500 nT) energetic ions reach L ~ 3.0 in near-midnight sector.

Acknowledgments. This work was partially supported by the NASA JURISS grant NAG5-8638, PIGS 00-02-22001.

References

Anderson, P.C., R.A. Heelis, W.B. Hanson, The ionospheric signatures of rapid subauroral ion drifts, *J. Geophys. Res*., 96, 5785, 1991.

Anderson P.C., W.B. Hanson, R.A. Heelis, J.D. Craven, D.N. Baker, L.A. Frank, A proposed production model of rapid subauroral ion drifts and their relationship to substorm evolution, *J. Geophys. Res*., 98, 6069, 1993.

Alexeyev, V.N., I.B. Ievenko, V.A. Yugov, V.M. Ignatyev, and V.L. Khalipov, Complex photometric, interphotometric and ionospheric measurements in the SAR-arc observation region, *Geomag. Aeron*., 34, 63-68, 1994.

Fillipov, V.M., D.D. Reshetnikov, V.L. Khalipov et al., Complex measurements of narrow ionization troughs in the F-region by ground-based and satellite methods, *Space Research,* 27, 568, 1989.

Galperin, Yu. I., V.N. Ponomarev, and A.G. Zosimova, Direct measurements of ion drift velocity in the upper atmosphere during a magnetic storm, *Space Res*., 11, 273-296, 1973 (in Russian).

Galperin, Yu.I., V.N. Ponomarev, A.G. Zosimova, Plasma convection in the polar ionosphere, *Ann. Geophys.*, 30**,** 1, 1974.

Galperin, Yu.I., V.L. Khalipov, V.M. Fillippov, Signature of rapid subauroral ion drifts in the high-latitude ionosphere structure, *Ann. Geophys***.,** 4, 145, 1986.

Galperin, Yu.I., Polarization Jet – Characteristics and Model, accepted in *Annales Geophys*., 2001

Ievenko, I.B., Dynamics of the diffuse auroral emission and SAR-arc during substorm, *Geomagn. and Aeron*., 33, 42-57, 1993.

Karlsson, T., G.T. Marklund, L.G. Blomberg, A. Malkki Subauroral electric fields observed by the Freja satellite: A statistical study, *J. Geophys. Res*., 103**,** 4327, 1998.

Khalipov, V.L., Yu.I. Galperin, A.E. Stepanov, and L.V. Shestakova, Formation of a polarization jet during the expansion phase of a substorm: results of ground-based measurements, *Space Res*., 39, 226, 2001.

Sivtseva, L.D., V.M. Fillipov, V.L. Khalipov et al., Coordinated investigations of processes in the subauroral upper ionosphere and the light-ion concentration trough,*Space Res.*, 22, 720, 1984.

Smiddy, M., M.C. Kelley, W.J. Burke et. al., Intense poleward directed electric fields near the ionospheric projection of plasmapause, *Geophys. Res. Lett*., 4, 543, 1977.

Southwood, D.J. and R.A. Wolf, An assessment of the role of precipitation in magnetospheric convection, *J. Geophys. Res*., 83, 5227-5232, 1978.

Spiro R.W., R.A. Heelis, W.B. Hanson, Rapid subauroral ions drifts observed by Atmosperic Explorer C., *Geophys. Res. Lett*.. 6, 657, 1979.

Table 1 Ground-based observations of polarization jet

DATE	STATION	UT	LT	L
02.04.1984	Magadan	11.00	21.00	2.9
	Yakutsk	11.15	20.15	3.0
	Arkhangelsk	12.30	12.30	15.30
07.04.1984	Magadan	11.00	21.00	2.9
	Yakutsk	11.15	20.15	3.0
	Arkhangelsk	12.30	12.30	15.30
19.09.1985	Magadan	10.45	20.45	2.9
	Podk. Tunguska	11.45	17.45	3.0
	Arkhangelsk	12.30	15.30	4.0
09.04.1990	Magadan	11.15	21.15	2.9
	Podk. Tunguska	12.15	18.15	3.0
24.04.1990	Magadan	10.45	20.45	2.9
	Podk. Tunguska	11.30	17.30	3.0