Energy Spectra of Protons and Electrons in Two Longitudinally Separate Parts of a Substorm Injection Region

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Abstract—During a substorm on March 28, 1983, two Los Alamos geostationary satellites with different longitudes turned out to be in one substorm injection region. Satellite *1981-025* was located near the western flank of the injection region, and satellite *1982-019*, in the center of it. In the central part of the injection region, the proton spectrum was measured as softer than in the western part of it, where protons accelerated up to 0.5 MeV were observed. The properties of the electron spectra were more complicated. The electron spectra in the vicinity of geosynchronous orbit are known to consist of two components, a hard and a soft one. The hard component varies negligibly during substorms on a time scale of several hours, while the soft component intensity depends on substorm activity. In our case, the hard component spectra were identical at both satellites. This can be interpreted as an indication that both satellites were at the same drift shell. The intensity of the soft component was higher at the satellite that was in the center of the injection region. We estimated the increase of typical particle energies between the satellites at 200 keV for protons and about 40 keV for electrons.

INTRODUCTION

Particle injections at geostationary orbit were considered in many papers, but still, the dependence of particle energy spectra on longitude has not been studied well. This is due to the fact that events in which two or more satellites are in one and the same substorm injection region are extremely rare. In one such case, researchers [1] succeeded in measuring particles at different edges of the injection region. It was found that at the western edge of an active region, the proton injection is dominant over electron one, and at the eastern edge, the situation is opposite. Observations of this kind are very important for better understanding of particle acceleration mechanisms during injection.

To consider injection characteristics at different points, we tried to use the data of measurements made with the satellites of the Los Alamos National Laboratory. Though the set of three such satellites have been permanently in orbit since 1976, several conditions should be satisfied to find an event suitable for studies. First, the injection region should have dimensions exceeding the longitudinal separation of satellites. Second, the magnetosphere is very unstable during substorms and geostationary satellites have little chance of being at one and the same drift shell. Besides, the time resolution of craft-borne instruments is very important, as substorm injections have typical duration of the order of several tens of seconds [2]. Detailed analysis of both global and local data of ground-based and spacecraft observations is necessary to account for the space–time structure of a perturbation. It is obvious that all these conditions can be satisfied only on rare happy occasions. We consider one such rare event in the present paper. As opposed to [1], mainly the energy spectra of particles rather than the temporal particle flux behavior are analyzed.

OBSERVATIONS

An isolated substorm occurred on March 28, 1983, and has already been studied in [3] with the data of auroral observations by the *DE-1* satellite. Both the data of [3] and the ground-level magnetic measurements analyzed by us both showed the substorm developing as a sequence of four intensifications; one of them was missed in [3] due to the poor time resolution (12 min) of the spacecraft instruments. Figure 1 shows these four intensifications as they were observed by satellite *1982-019* in the midnight sector. Four flux enhancements for protons with energies from 95 to 110 keV are in a good time correlation with pulsations Pi2 recorded by the US Air Force Geophysical Laboratory (Fig. 2). The injection that we consider here took place during the last *D* intensification. Data of the global network of magnetometers (see Table 1) allow us to determine the location and width of these intensifications. Intensification *D* covered more than eight hours of local time, in full agreement with the *DE-1* satellite data [3].

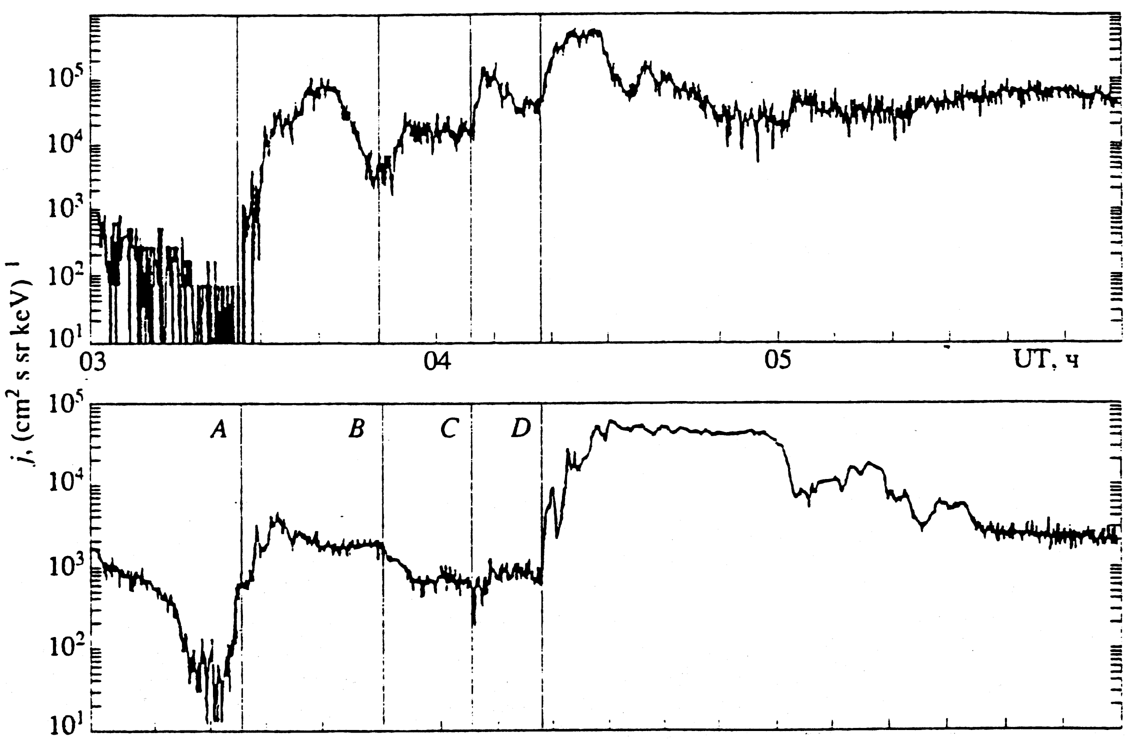

Fig. 1. Variations of proton fluxes in the energy range of 95–110 keV (upper panel), and fluxes of electrons with energies 30–45 keV (lower panel), as measured aboard the *1982-019* satellite in the night sector during the period 03–06 UT on March 28, 1983. Vertical lines *A*, *B*, *C*, and *D* mark the time of onset of substorm intensifications deduced from the data of ground-based observations.

The intensification *D* started at 04:19 UT and developed as a series of impulsive events. The Pi2 pulsations reflect this temporal structure in sudden changes of their wave form, as, for instance, at 04:27 UT (Fig. 2).

In Fig. 3, the particle flux intensities are displayed as measured at the satellites *1981-025* and *1982-019* which were at 14:27 UT in the MLT sectors 19:20 and 23:40, respectively. In the following, we will refer to them as the "evening" and "nightside" satellites. At the nightside satellite, a proton flux spike is distinguishable around 04:27 UT in most energy channels. The evening satellite detected the proton injection during the *D* intensification with a certain delay that probably was caused by the spacecraft location outside (to the west) of the active region in the beginning of the intensification. This injection with energy dispersion signatures was recorded only at 04:23. But the proton flux peak recorded at 04:27 did not show energy dispersion (at least within the limits of the data time resolution of 10 s). This means that the injection region broadened at this moment to the west. Protons of very high energies (>400 keV) were detected in this spike (Fig. 3, bottom panel). As already noted above, at 04:27 UT, the Pi2 pulsations show a sudden waveform change that marks the onset of an elementary event [4–6]. Simultaneous dispersionless injection of protons observed at the two separa... satellites do confirm this.

Around 04:27 UT, an electron flux enhancement is also seen at both satellites. The electron enhancement measured by the nightside satellite is larger in the low energy channels, while the evening satellite observes an electron spike more pronounced at higher energies. Moreover, the flux peak of the evening satellite exhibited some signatures of energy dispersion of electrons.

Figure 4 presents the proton and electron spectra of the evening and nightside satellites for the time 04:27 UT. A comparison of the proton spectra shows the spectrum in the evening sector to be considerably harder than that in the nightside sector. As for the electron spectra, the situation is more complicated. The electron spectra are composed of two components. This is a well known feature of the electron population in the near-Earth magnetosphere [7]. The electron spectra in Fig. 4 differ at the low energy part, but they are nearly identical for energies above 170 keV. The low energy component has larger intensity in the nightside sector.

DISCUSSION

The main problem in comparing particle characteristics at different longitudes in a geostationary orbit is that the particles do not drift along the orbit and the detected particles usually represent populations from different drift shells. However, we believe that, in our case, we can demonstrate that for the time under consideration, the

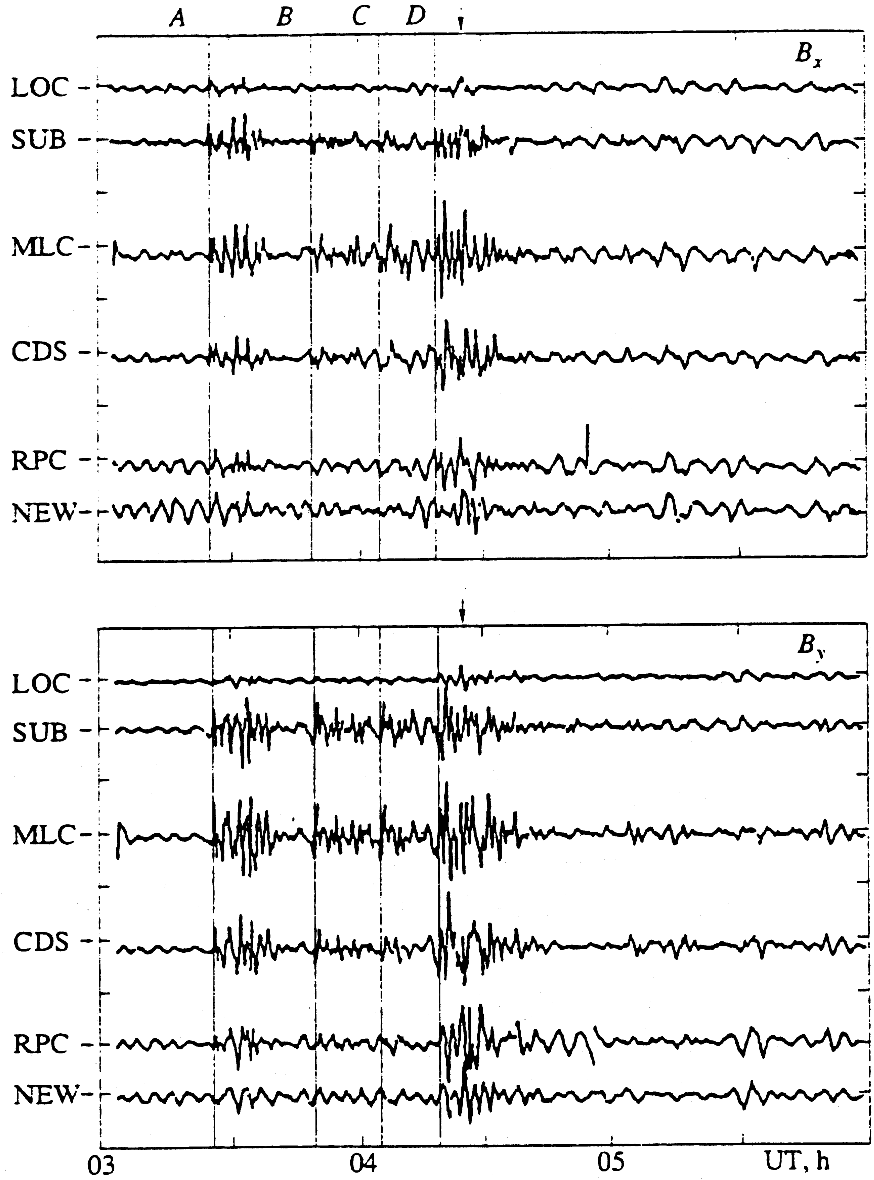

Fig. 2. Pulsations of magnetic field components B_x and B_y, recorded by a network of stations of US AF Geophysical Laboratory (see the Table for notations). Vertical lines A, B, C, and D mark the time of onsets of burst pulsations Pi2, corresponding to intensifications of a substorm explosive phase. The moment 04:27 UT is shown by an arrow.

evening and nightside satellites were on one and the same drift shell. As was shown in [7], the intensity of the high energy component ($E > 200$ keV) of electron spectra is not affected by substorm activity on a time scale of some hours, and it decreases with increase of the radial distance from the Earth. From the identity of the hard component of electron spectra, as is seen in Fig. 4, one can conclude that the satellites were indeed at the same drift shell. It is important to note, however, that this conclusion is not valid for the other time periods. In general, high energy parts of the two satellite spectra are different in the substorm intensification period D, and even immediately before 04:27 UT. This means that the satellites spent most time at different drift shells. The reason why the satellites were located on the same drift shell at the time 04:27 UT was, obviously, dipolization of magnetic field, typical for a substorm explosive phase. Let us note that the elementary injection process and the related dipolization both have a time scale on the order of one minute [2, 8]. The spike of hard electrons at the evening satellite also has the same duration, and this spike shows signatures of energy dispersion that indicate the presence of electron drift from west to east.

In the process of dipolization with corresponding injection, the evening satellite turned out to be at the lower L-shell near the western edge of the active region. As a result, the satellite detected electrons drifting eastward from the unperturbed region. The weak energy dispersion in this electron spike indicates that the satellite was indeed very close to the edge of the injection region.

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REFERENCES

1. Reeves, G.D., Belian, R.D., and Fritz, T.A., Numerical Tracing of Energetic Particle Drifts in the Model Magnetosphere, *J. Geophys. Res.*, 1991, vol. 96, pp. 13997–14008.
2. Yahnin, A.G., Bosinger, T., Belian, R.D., and Kangas, J., Some Implications on Substorm Dynamics Inferred from Correlations between Multiple Flux Peaks of Drifting High Energy Proton Clouds and Ground Observations, *Ann. Geophysicae*, 1990, vol. 8, pp. 327–336.
3. Hones, E.W., Association of Plasma Sheet Variations with Auroral Changes during Substorms, *Adv. Space Res.*, 1988, vol. 8, pp. 129–134.
4. Sergeev, V.A., Yahnin, A.G., and Raspopov, O.M., On the Space–Time Structure of a Microsubstorm Explosive Phase, in *Dinamicheskie protsessy i struktura avroral'noi magnitosfery (eksperiment SAMBO)* [Dynamic Processes and the Structure of the Auroral Magnetosphere (the SAMBO Experiment)], Apatity: Kol'skii Filial Akad. Nauk, 1978, pp. 42–54.
5. Yahnin, A.G., Sergeev, V.A., Pellinen, R.J., *et al.*, Substorm Time Sequence and Microstructure on 11 November 1976, *J. Geophys.*, 1983, vol. 53, pp. 182–197.
6. Sergeev, V.A., Bosinger, T., and Lui, A.T.Y., Impulsive Processes in the Magnetotail during Substorm Expansion, *J. Geophys. Res.*, 1986, vol. 60, pp. 175–185.
7. Cayton, T.E., Belian, R.D., Gary, S.P., and Fritz, T.A., Energetic Electron Components at Geosynchronous Orbit, *Geophys. Res. Lett.*, 1989, vol. 16, pp. 147–150.
8. Sergeev, V.A., Bosinger, T., Belian, R.D., *et al.*, Drifting Holes in the Energetic Electron Flux at Geosynchronous Orbit Following Substorm Onset, *J. Geophys. Res.*, 1993, vol. 97, pp. 6541–6548.
9. Scholer, M., Energetic Ions and Electrons and Their Acceleration Processes in the Magnetotail, in *Magnetic Reconnection in Space and Laboratory Plasma*, Hones, E.W., Jr., Ed., *AGU Geophys. Monograph*, 1984, vol. 30, pp. 216–227.