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Development of auroral streamers in association with localized impulsive injections to the inner magnetotail

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Abstract. During continuous magnetospheric activity it is not uncommon to observe narrow (in MLT) transient particle injections (duration about 1-2 minute at E=100 keV and local time extent ≤ 1 hour MLT) in the nightside part of geosynchronous orbit. Using global UV images from POLAR spacecraft we analyze the development of auroral activity on December 22, 1996 during a sequence of such injections observed by two LANL spacecraft. We found that narrow transient injections are associated with specific localized auroral form, the auroral streamer, which develops in this local time sector. The streamer first appear as a bright spot in the poleward part of the double oval ≈ 2–5 minutes before the geosynchronous plasma injection, and then develops equatorward, reaching in many cases the equatorward boundary of the UV aurora. We interprete the observations as evidence that some high speed flow bursts (BBFs) of small cross-tail extent (less than 1 h MLT), formed in the distant tail or midtail, can intrude as close to the Earth as the geosynchronous distance before being stopped.

Introduction

Recently there has been a growing interest in understanding the origin of transient flows (bursty bulk flows, BBFs) which play an important role in the mass, energy and magnetic flux transfer in the tail (*Angelopoulos et al.* [1992]). Analysis of BBFs showed that at $r < 18 - 20$ R_e the flow direction of most BBFs is Earthward and that their occurrence frequency decreases at smaller distances (*Baumjohann* [1993]). Still some BBFs have been found as close to the Earth as ≈ 10 R_e (*Shiokawa et al.* [1997]). What is a typical stopping distance for the BBFs and how closely they approach the Earth, these are still open questions. Although geostationary particle injections have been sometimes observed in association with the BBF registered in the midtail (e.g.*Angelopoulos et al.* [1995]), no firm evidence of BBF penetration to the geostationary distance has been yet reported.

An intriguing property, the small (∼ 3 R_e) cross-tail extent of the BBFs, has been recently revealed in a few event studies (*Sergeev et al.* [1996], *Angelopoulos et al.* [1997]). If this is typical, the narrow transient plasma flow channels rather than large-scale (although turbulent) convection may close the global circulation pattern and form the properties of the plasma sheet. Opportunities to observe such medium-scale structure in situ are yet very rare.

Surprizingly, very little is known about the optical counterparts of the BBFs, although the auroral observations offer the best possible way to study the transient and localized structures. There are two candidates to be the optical equivalent of the BBFs. The auroral arcs are transient structures whose equatorward motion may reflect the Earthward flow of the plasma. However, their orientation (along the auroral zone rather than along the meridian as expected from simple mapping of the tail-aligned narrow channel) and considerable length (often exceeding 1 h MLT) along the auroral zone make it difficult to connect these two phenomena.

Another candidate is the north-south (NS) aligned forms which appear at the nightside during disturbed conditions. Based on TV observations *Nakamura et al.* [1993] showed that at the early stage of the bulge growth the NS structures typically develop in the equatorward direction eastward of the westward surge. Also the NS structures are sometimes seen on the large-scale displays (e.g. a review by *Elphinstone et al.* [1997]) connecting the active poleward part of the double oval with the equatorward diffuse auroras. However no direct evidence of their relationship with the localized Earthward convection or particle injections has yet been reported besides one example recently published by *Henderson et al.* [1998].

One more candidate phenomenon linked with the BBFs may be the short-duration (∼1 min) localized (∼1 h MLT) energetic particle injections at geostationary orbit (later referred to as the narrow injections) which have been previously reported in association with pseudobreakups (e.g. *Nakamura et al.* [1994]). However, such phenomena could also be observed during continuous high activity (*Sergeev et al.* [1998]) and their origin is not clear.

In this paper we show an example of multiple narrow injections at geostationary orbit during disturbed time and focus on the associated optical (UV) manifestation, namely, localised auroral streamers. The streamers which develop from north to south a few minutes before the narrow injections should be causally linked with the same process (presumably, Bursty Bulk Flows) which eventually results in the narrow particle injection to the geosynchronous orbit.

Observations

The observations were made during active period on December 22, 1996 selected for a careful study by the team of Interball experimenters. According to WIND spacecraft data, the IMF turned to the southward direction after 12 UT and continued to stay with this orientation for about a day.

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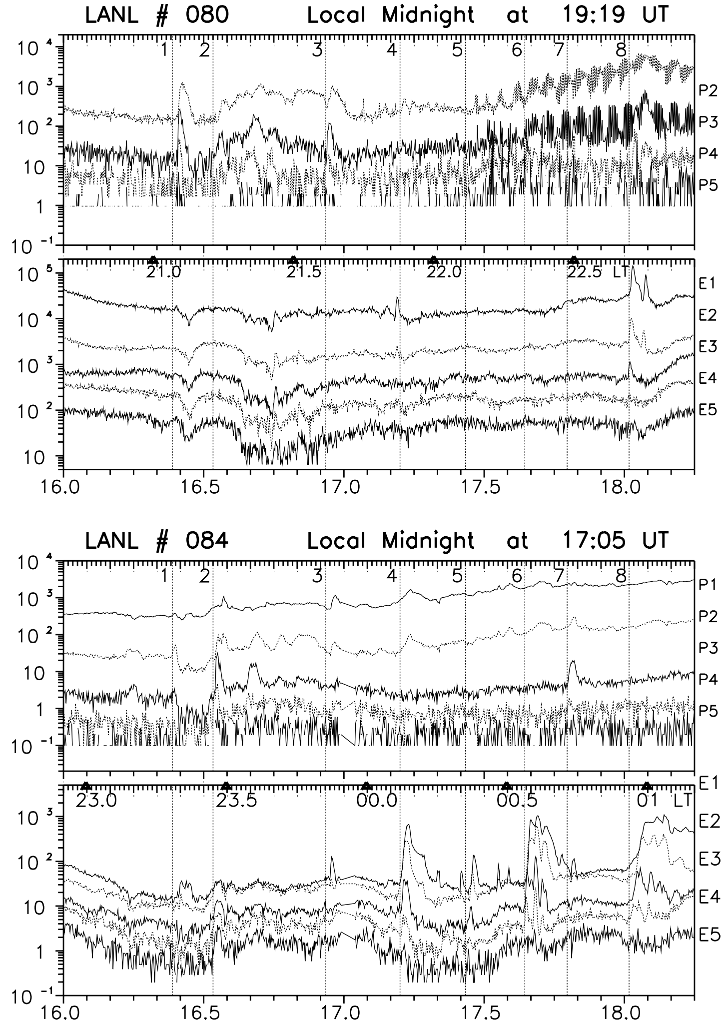

Figure 1. Variations of energetic particle flux (in $(cm^2$ s st $keV)^{-1}$) at two LANL spacecraft on December 22, 1996. Onset times of isolated injections NN 1...8 are marked by vertical lines.

The 2.5 hour long time period in study was selected because of fortunate location of a pair of LANL spacecraft and availability of the POLAR UV images. The energetic particles observations came from two LANL spacecraft (1994–084 and 1991–080, thereafter referred to as 084 and 080) equipped with identical SOPA instruments (Reeves et al., [1996]). We use the differential fluxes in the energy ranges between 50/75/105/150/225/315 keV for the electrons (channels e1–e5 in Figure 1) and 50/75/113/170/250/400 keV for the protons (p1–p5). Between 1600 and 1830 UT two spacecraft with small separation in MLT (2.2 h), made measurements near midnight and recorded more than a dozen energetic particle bursts. The burst was defined if the flux increased by at least a factor 2 in 1 minute. (Noisy proton flux variations after 17 UT at spacecraft 080 were ignored except for event 8). Eight of them had relatively isolated onsets, these injection events (marked in Figure 1 by the vertical lines) form the data base for our study.

To obtain an estimate for the azimuthal position and size of the injection we used a simple method based on the magnetic drift of particles locally injected to the drift shell at 6.6 R_e (e. g. *Reeves et al.* [1991]). For the energy dispersed particle flux increase one may find the injection time, multiplying the observed delay by the drift speed (V_D) one obtains the distance to the injection source. For the non-dispersed injection one gets the onset time immediately, and if both protons and electrons are injected with no dispersion we are supposed to be in the injection region. We also determined the energy-dependent half-width of the spike (dt) which gives an upper estimate of the width of the injection region $W = dt/V_D$ (other effects which increase the dura-

Table 1. Inferred Characteristics of Isolated Narrow Injections and UV Streamers

Event	Injection at 6.6 R_e		UV streamer		
	UT_i	MLT_i	MLT_s	UT_s	UT_s-UT_i
1	1624	21.5-23.2	23.5	1622	2 min
2	1632	21.8-00.4	00.3	1629	3 min
3	1655	22.8-23.9	23.3	gap	
4	1712	23.0-00.1	23.6	1708?	4 min?
5	1726	23.6-00.0	24.0	1720?	6 min?
6	1738(*)	23.7-00.6	23.8	1736	2 min
7	1748	00.7-01.7	01.0	1745	3 min
8	1800(*)	21.8-23.5	22.8/24	1756	4 min

(*) first of 3 superimposed injection pulses

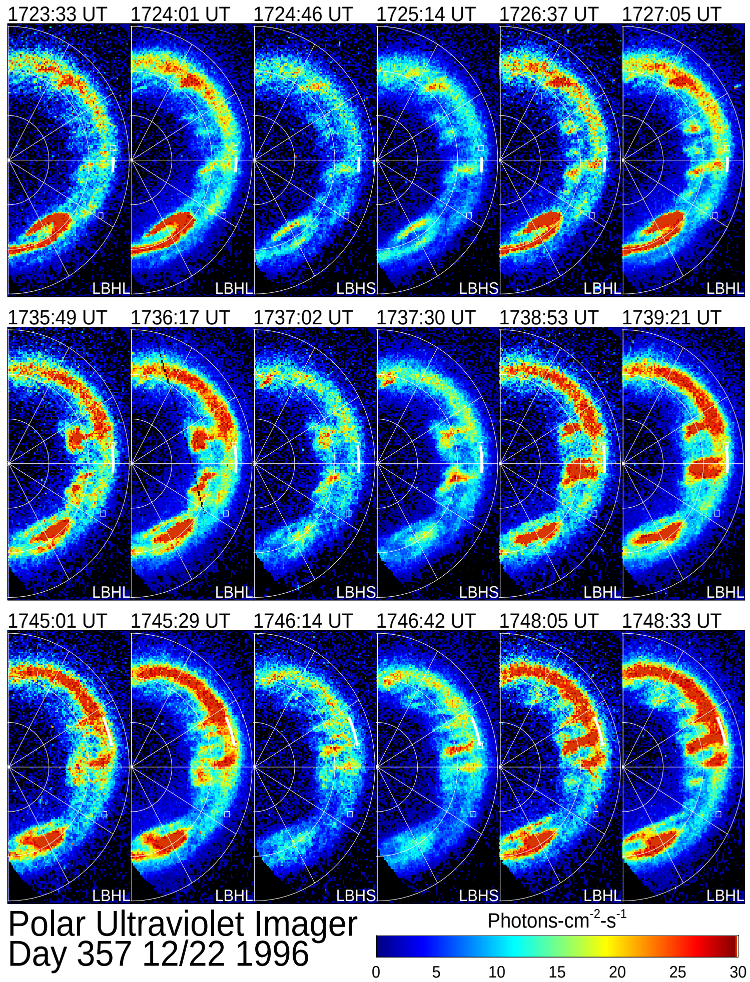

Figure 2. Time history of the auroral activity preceeding the narrow injections to geostationary orbit as seen by the POLAR UVI imager during injections NN 5,6,7. Right column corresponds to the injection times, the local time sector of injection is shown by the white segment placed at 64°Latitude, midnight is on the right side. Positions of two LANL spacecraft are also shown by the rectangles. Note the difference between LBH-L and LBH-S images when interpreting the image sequence.

tion of particle burst are the finite duration of injection, finite width of energy channel, etc). A critical parameter is the drift speed V_D value. We fixed it to be 1 hour MLT in 1.8 minutes as follows from computations for T89 $K_p = 3$ model for 100 keV particle at 80° pitch-angle near midnight.

Applying this formal procedure to all 8 bursts identified in Figure 1 and taking as MLT range of injection the maximal range of injection positions determined from both spacecraft and for both protons and electrons we end with the source positions given in the Table 1. They all are less than 2 hours MLT wide. (Recall that these were the upper estimates of the actual injection width.) A small width which justifies a term "narrow injection" follows from the short duration (< 2 minutes at $E = 100$ keV) of these bursts. Note that more long duration electron events NN 6 and 8 are also composed of ∼1 min duration individual bursts, we considered only the first burst in each series.

The auroral dynamics was monitored by the UVI imager on board the Polar spacecraft. We used the observations at two wavelength, LBH-long (L) and LBH-short (S), combined in the sequence of two L frames followed by two S frames to get the maximal temporal resolution 36 sec (e. g. *Liou et al.* [1997] for the description). Data are recomputed and plotted in the AACGM magnetic coordinate system which is an extension of well-known PACE coordinates.

After finding the injection time (UT_i) and MLT position, the next step was to look which auroral structure appeared at this place and time. To illustrate the variety of observed behaviour we show in Figure 2 examples of the UVI data for three events. In all eight cases at the time of injection we observed a bright structure near the equatorward boundary of the UVI oval looking like a spot or like elongated structure oriented at large angle to the latitude. Their approximate MLT positions at lowest latitude (MLT_s) are given in Table 1. Following this structure back in time, in all events (except for N3 which had a time gap) one could confirm that localized auroral activation appeared earlier near the poleward boundary (at the time UT_s given in Table 1) and then developed equatorward. This is a streamer according to the definition given by *Elphinstone et al.* [1997]. The uncontrolled wobbling of the spacecraft which deforms the image by spreading bright spots to bright bands (in that event mostly in meridional direction) makes it difficult to study quantitatively the meridional scale and propagation of the localized structures. (Because of these uncertainties we can not grant for sure that bright precipitation structures in question are really the North-South aligned forms. However their localization in East-West direction as well as the fact that they start to develop from the poleward oval a few minutes prior to the geosynchronous injections seem to be well established by this data set.) Therefore, in this paper we emphasize only the general behaviour of the streamers leaving the quantitative details (exact orientations, velocities etc.) for the future efforts. The rough estimates which still can be done include the MLT scale (usually a fraction of 1 hour MLT at some latituide circle) and high propagation velocities of the order of 1 km/s (roughly 3–5° Latitude in 2–5 minutes). The time interval between the initial activation and subsequent injection to 6.6 R_e is 2–5 min (Table 1).

Discussion and Conclusions

In all 8 subsequent isolated narrow plasma injections into the inner tail we systematically observed the narrow precipitation channels which developed from the poleward part of the UVI oval toward its equatorward boundary (auroral streamers). At this later epoch and in the same MLT sector narrow plasma injections were detected by two geostationary spacecraft confirming a causal link between these two phenomena. A similar behaviour of the UV auroras was noticed for the streamers by *Elphinstone et al.* [1997] based on VIKING optical observations and recently *Henderson et al.* [1998] showed a one example of the injection to 6.6 Re in association with the the North-South structure developing from north to south. The association of auroral intensifications near the polar cap boundary with localized bursts of equatorward flow was also found by *de la Beaujardiere et al.* [1994]. Also *Sergeev et al.* [1990] reported high-speed flow bursts (reaching ∼1 km/s velocity in equatorward direction) which started at the poleward oval boundary and propagated equatorward at the speed ∼1 km/s.

The observation of closely coupled development of auroral streamers and narrow injections implies that there exists some structure/process of small cross-tail size which: (1) is born in the distant or middle tail (to be mapped to the poleward oval), (2) propagates Earthward at a high speed, and, (3) eventually injects plasma into the inner magnetosphere. The analogy with the BBFs is quite transparent, in addition, the BBF cross-tail size of ∼3 R_e (*Sergeev at al.* [1996], *Angelopoulos et al.* [1997]) matches well the <∼1 h MLT size of both streamers and narrow injections. Further discussion of the streamer formation in relation to the BBFs is beyond the scope of our paper.

If the streamers are formed due to the individual BBF structures, our results imply:

- taking a ∼2–5 min lifetime of the streamer as a lower estimate for the lifetime of individual BBF, with 400 km/s threshold velocity of BBF this gives a lower estimate of their traveling distance about 10–20 R_e;

- some BBFs can intrude as close to the Earth as 6.6 R_e, much closer than it was thought before (e. g. *Baumjohann* [1993], *Shiokawa et al.* [1997]).

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