Observation of dayside subauroral proton flashes with the IMAGE-FUV imagers

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Abstract. A detailed description of an intense flash of auroral emissions that occurs equatorward of the dayside auroral oval observed with the IMAGE-FUV imagers is presented. The comparison of simultaneous snapshots of this subauroral flash obtained with the three FUV cameras indicates that proton precipitation is dominant. This transient proton aurora is triggered by the sudden increase of a solar wind dynamic pressure pulse. It occurs on closed field lines mapping to the equatorial plane at distances as small as ~4 R_E. A second similar event is presented, and several other cases are mentioned. These shock induced transcient emissions develop with a time scale of a few minutes (typically ~5 min), and have a relaxation time on the order of ~10 minutes.

1. Introduction.

Several authors have recently reported observations of long-lived subauroral emissions mainly due to precipitating protons, mostly in the afternoon sector [Fuselier et al., 2002; Immel et al., Burch et al., 2002]. We present observations of a new type of subauroral proton feature consisting of a very short-lived (less than ~5 minutes) injection extending to magnetic latitudes as low as 60° MLAT, and centered on the magnetic noon sector. The feature was observed with the IMAGE-FUV imagers [Mende et al., 2000a] WIC, SI13, and with the SI12 Spectrographic Imager at 121.8 nm, which takes 5 s snapshots of the northern polar region every two minutes. The SI12 imager isolates the auroral Doppler-shifted Lyman-α photons that are emitted by precipitation of charge-exchanged auroral protons. The main lobe of the SI12 bandwidth is centered at 121.8 nm with a width of ~0.2 nm [Mende et al., 2000b]. Both the geocoronal Lyman-α and the nearby NI 120 nm photons are rejected by the instrument. We describe the main characteristics of the observed proton flash and the solar wind conditions prevailing during this event. We speculate on the origin of this transient precipitation event. Other cases of proton flashes observed with IMAGE-FUV are briefly discussed.

2. Observations.

A subauroral dayside proton flash was observed on November 8, 2000 at 0614 and 0616 UT with the IMAGE-FUV SI12 spectrographic imager. The feature can be seen in Figure 1, which shows the sequential SI12 images at 0612, 0614, 0616 and 0618 UT, remapped in geomagnetic coordinates (corrected magnetic local time, Apex latitude [Richmond, 1995]), after removal of the background counts. This sequence shows the explosive nature of the event in the 09-15 MLT sector, especially prominent at 0614

UT. The feature of interest extents down to latitudes as low as 60° MLAT. No emission above background can be detected at this location at 0612 but the main oval intensified at that time, compared to 0610 (not shown). No significant variation of the diameter of the main oval is observed during the sequence. The proton flash has already weakened at 0616 UT, it is nearly undetected at 0618 UT, and has disappeared at 0626 UT (not shown). The duration of the explosive phase is thus between 2 and 6 minutes, with a relaxation time for complete extinction on the order of ~10 minutes. The cusp signature previously reported by Frey et al. [2002] and Fuselier et al. [2002] is seen on the oval at noon, and it strongly brightens as the flash develops. This case was explicitly discussed in details by Frey et al. [2002] who established that the cusp aurora signature on the dayside is confined to a “spot” during periods of positive IMF Bz. The spot brightness is directly dependent on the solar wind dynamic pressure, and it is mainly due to proton precipitation. The base of a transpolar arc can be seen as well in the midnight sector.

An assumption is made on the proton average energy and the proton energy flux is deduced for every SI12 pixel. It is found to be ~0.65 mW/m^2 (average over the subauroral feature at 0614 UT). The WIC and SI13 images are used to determine the characteristics of the electron precipitation. Images taken by these cameras before and after the flash were used to remove the dayglow contribution in the WIC and SI13 images at 0614 and 0616 UT. The proton contribution to the WIC and SI13 signals is removed consistently with the proton flux determined from the SI12 pixels [Hubert et al., 2002]. Finally, the remaining WIC and SI13 signals are summed up over the feature in order to obtain an average count rate representing the electron contribution. These two numbers are used to retrieve the electron average energy and energy flux from the WIC/SI13 ratio and the WIC electron-induced remaining count rate. For the brightest image at 0614 and an assumed proton average energy ~3.5 keV, both the WIC and SI13 summed up residual signals are ~0, suggesting a pure proton precipitation. Assuming larger proton energies such as ~30 keV, typical of ring current particles, the proton contribution to the WIC and SI13 signals is larger than the signal of the feature. The uncertainties of the method are discussed in Hubert et al. [2002]. In addition, the removal of the dayglow component in the SI13 and WIC images at lower latitudes is a large source of error. In any case, the electron energy flux is found to be quite weak, much smaller than the proton flux for proton energies in the vicinity of the ring current energy.

3. Solar wind and magnetic field.

Figure 2 presents the morphology of the magnetic field lines originating from the subauroral flash at 0614 UT, using a mapping code [Fuselier et al., 2002] based on the Tsyganenko model [Tsyganenko, 1995]. It shows the raw data format of the SI12 image taken at 0614 UT, and a magnetic field line mapping of the central region of the subauroral proton flash, projected on the X-Z GSM plane. It clearly appears that some parts of the subauroral feature map to dayside stably closed field lines. These field lines map to the equatorial plane to distances as small as 4-7 R_E, i.e. close to or less than the geosynchronous altitude and near the nominal position of the plasmapause.

Measurements from the Advanced Composition Explorer (ACE) satellite located at the L1 Lagrange point at ~1.4x10^6 km from Earth are used to characterize the solar wind for November 8, 2000 (Figure 3). The solar wind velocity was consistent with a delay of ~51 minutes between the ACE measurement and the arrival of the plasma on Earth. Accounting for the delay to travel through the magnetosheath and down to the ionosphere gives ~56 minutes, so that a simple propagation of the solar wind characteristics relates the proton flash to ACE measurements made at ~0518 UT. As already outlined before, a solar wind density pulse from ~5 to ~56 ions/cm^3 was detected at that time, causing a dramatic increase of the dynamic pressure from ~2 to ~19 nPa. The analysis of the delay between the ACE measurement of the density pulse and its auroral signature suggests a time delay between the compression of the field lines and the flash. However, the measurements of the GEOTAIL satellite (not shown), which was closer to the Earth at 30 R_E on the morning side of the magnetosphere (+13 R_E in the X_{GSE} direction), directly relate the dynamic pressure ramp to the time of the flash appearance, giving credibility to a direct causal relation with the compression of the magnetosphere. Thus, the flash may be viewed as a consequence of the event detected with ACE between 0500 and 0512 UT. At that time, By was negative, Bx and Bz were positive and decreasing. Additionally, this event occurred during a theta aurora, which implies that the magnetosphere configuration was already unusual when the event took place. It is also clear that sudden variations of the IMF components are often observed, whereas subauroral proton flashes are rarer events. It must be noted that the approximate timescales of the explosive phase of the flash (between 2 and 6 minutes) and of the main ramp of the pressure pulse (on the order of 6 minutes) compare well.

5. Discussion.

The subauroral proton features reported here have some similarities and some differences from those observed by Immel et al. [2002] and Burch et al. [2002]. These authors reported long-lived subauroral proton events (1 hour and more) occurring mainly in the afternoon sector, and formed of preexisting auroral features that progressively detach from the main oval, especially in the afternoon sector when the oval contracts under the effect of a change of sign of the IMF B_z or B_y components. The event described here has a very short characteristic time (a few minutes) and is centered on the noon sector. It does not progressively detach from the main oval and is related to a solar wind pressure pulse. It also reaches lower latitudes: Immel et al. [2002] report a magnetic latitude ~62°, compared to the limit of the structure lower than 61° observed here. This small difference in magnetic latitude leads to large differences in the estimated L value reached by the corresponding field line mapped to the equatorial plane. The proton flash has both similarities and differences with the June 8, 2000 event described by Fuselier et al. [2002]. Their Figure 2 shows a short-lived subauroral injection when an interplanetary shock buffeted the magnetosphere following a CME and triggered a major substorm. On November 8 2000, a quiet period was interrupted by a short density pulse (~20 minutes) that did not trigger a substorm, but a transpolar feature was present. The cusp signature was located poleward of the dayside main oval on June 8 2000, and on the dayside main oval at 1200 MLT on November 8. The IMF Bz component was positive both on June 8 and November 8. The lifetime of the June 8 event was shorter than that of November 8. Moreover, the feature we report is centered on the noon sector, and is linked to the main oval exactly at 1200 MLT at 0614 UT, whereas cases reported by other authors are centered in the afternoon sector.

The main similarity between all subauroral features reported by the previous studies and this work is the dominance of the proton injection, the electron contribution being very small. This common aspect suggests that the mechanisms responsible of the observed feature could present some similarity and that this similarity, if it does exist, may be "time scale resistant", that is, a feature of the magnetospheric dynamics that is valid at short and long time scales.

It is clear from the GEOTAIL and ACE satellites measurements of the solar wind characteristics that the proton flash is intimately linked to the increase of the solar wind density and/or dynamic pressure. The proton flash is reminiscent of the event reported by Liou et al. [2002] which is a subauroral intensification that they associate with electron precipitation induced by an interplanetary shock. The authors did not exclude that a proton flash such as the one presented here could exist in the presence of an IP shock, although they did not observe any. Additional studies are needed to determine under what circumstances a pressure pulse can produce a proton flash.

Several mechanisms may possibly account for the observation. First, Burch et al. [2002] explained that the generation of detached proton arcs likely involves the interaction of hot ring current or plasma sheet ions with cold plasmaspheric material, favored by magnetospheric compression perhaps through an enhancement of electromagnetic ion cyclotron wave activity [Anderson and Hamilton, 1993]. Second, the compression of the dayside magnetosphere can produce pitch angle diffusion of the particles trapped in the radiation belts, i.e. the plasma compression can lead to the loss cone instability, wave-particle interactions, allowing some of them to reach the ionosphere [Zhou and Tsurutani, 1999]. In this mechanism, the spatial distribution of the injection responsible of the flash would be determined by the availability of particles encountering pitch angle diffusion in the ring current, and the detailed geometry of the compression process and/or of the waves disturbing the plasma population. Another possibility is the excitation of field line resonances [Southwood, 1974; Kivelson and Southwood, 1986] by solar wind variations disturbing the trapped particle population. The spatial distribution of the flash would then be constrained by the availability of particles, and by the region of the magnetosphere entering a resonance, as the resonance frequency of a field line depends on its length. Why mainly protons precipitate in the subauroral flash remains unclear at this point. Another important observation is that these subauroral flashes are detached from the main auroral oval. The field line tracing in Figure 2 shows the implications of this detachment. The subauroral flashes are the result of proton precipitation on closed field lines that do not extend to the magnetopause. Thus, there is a region of space between the equatorial mapping of the poleward edge of the flash and the magnetopause (which maps to the auroral oval) where there is no proton precipitation. Any potential explanation for the proton flash must account for this gap.

6. Other similar cases.

We examined ~150 days of IMAGE-FUV data and found several other sudden subauroral proton flashes in the SI12 imager data. One occurred on November 8 2000, at 0343 UT (Figure 4). It appears on eight consecutive SI12 images between 0341 and 0355 UT. Simultaneously, the dayside cusp intensity increases between 0339 and 0345 UT as well as the main oval activity, especially on the nightside. At 0341 UT, a first spot appears in the noon sector around ~60° MLAT (not shown). At 0343 UT, two spots can be seen developing outside the main oval, a first one around 61.5° magnetic latitude (MLAT) at 1220 magnetic local time (MLT), and a second one at 59° MLAT at 0740 MLT. In addition, an intensification develops equatorward of the oval around 0900 MLT. Then, at 0345 UT, the whole subauroral feature reaches its maximal brightness between 0745 and 1310 MLT at ~61° MLAT, with an equatorward extreme boundary reaching ~59° MLAT at ~12h20 MLT. Then, the feature reduces to a fainter spot near noon (displaced towards the afternoon) and it has fully disappeared at 0357 UT (not shown). Here again, the relaxation time is on the order of ~10 minutes.

This event can be related to the ramp of a solar wind dynamic pressure pulse driven by a density pulse detected by the ACE satellite near 0245 UT (not shown). The calculated propagation time, as well as timing using observations of the GEOTAIL satellite (not shown) unambiguously establish the relation between the flash and the dynamic pressure pulse. Of the three IMF components (not shown), only Bz presents a similarity with the 0614 UT case. It decreases from ~16 to ~4 nT as the pulse develops, whereas Bx remains stable while By encounters a positive to negative sign reversal between 0220 and 0222 UT. In both cases observed on November 8 2000, the relaxation time of the subauroral flash was ~10 minutes whereas the density pulses detected by the ACE satellite were more than 20 minutes long. Moreover, both pulses had a bulk velocity of ~440 km/s, so that it takes ~2 minutes for the pulse to travel the ~8 R_E separating the magnetopause and the planet (up to ~4 minutes if we consider the solar wind slows down by a factor of 2 when hitting the magnetosphere). Consequently, we anticipate that the relaxation time is a property of the magnetosphere itself rather than a parameter controlled by the solar wind velocity or the length of the dynamic pressure pulse.

Several other impulsive dayside subauroral features were identified presenting similarities and differences with the two cases presented above: September 15 2000 (0450 UT), October 28 2000 (0955 UT), and between December 24 2310 and December 25 0100 UT. In this latter case, several impulsive subauroral features were observed, although a dynamic pressure pulse could not be identified for each intensification, suggesting this event could be of a different nature. However, these events did not extend to latitudes as low as the two events described before.

7. Conclusions.

Two events of dayside subauroral proton flashes extending down to ~60° of magnetic latitude have been observed with the IMAGE-FUV SI12 imager. They are related to the ramp of solar wind density and/or dynamic pressure pulses. They present a relaxation time of ~10 minutes that is probably inherent to the property of the magnetosphere rather than to the particularities of the solar wind pulses that generate them. A few other dynamic subauroral proton features were identified, most of them related to a solar wind density/dynamic pressure rapid increase. A potential counter example on December 24 and 25 2000 reveals that the mechanism governing these phenomena could hide a complexity requiring further investigation. The mechanism leading to the dominance of the protons in these subauroral injections is still unclear. A more exhaustive study of the SI12 database will be undertaken to help clarifying these questions and establish whether a one to one relationship between interplanetary shocks and proton flashes exist.. Observations obtained simultaneously by SI12 and spaceborne in situ particle detectors would be of particular interest, if available.

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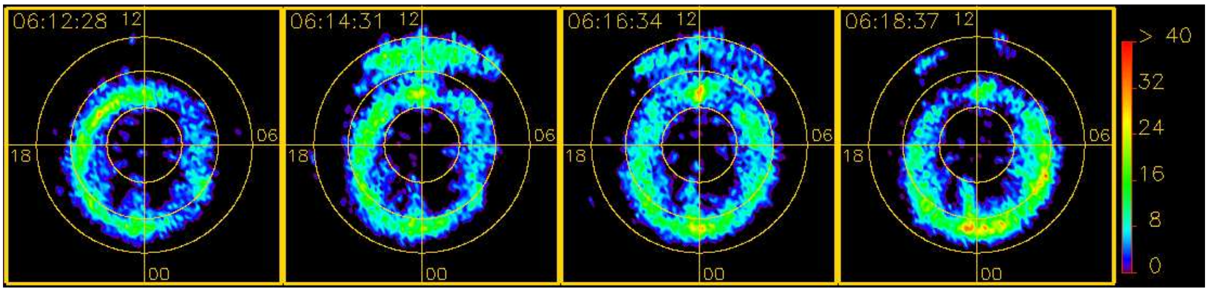

Figure 1. SI12 counts remapped in geomagnetic coordinates showing the subauroral proton flash of November 8 2000 at 0614 UT. The background has been removed. Concentric yellow circles are 10° MLAT apart, noon is at the top of each picture (MLT=12).

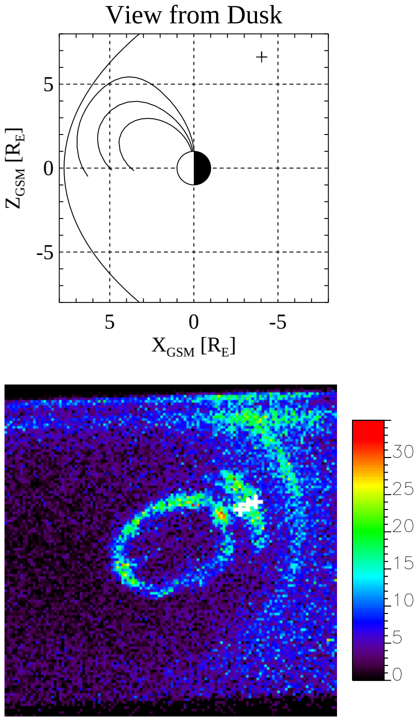

Figure 2. Mapping of three magnetic field lines originating from the proton flash of November 8 at 0614 UT. The three white crosses in the SI12 image (scale in counts) indicate the footprint of the field lines, that are shown in the upper pannel, projected in the X-Z plane.

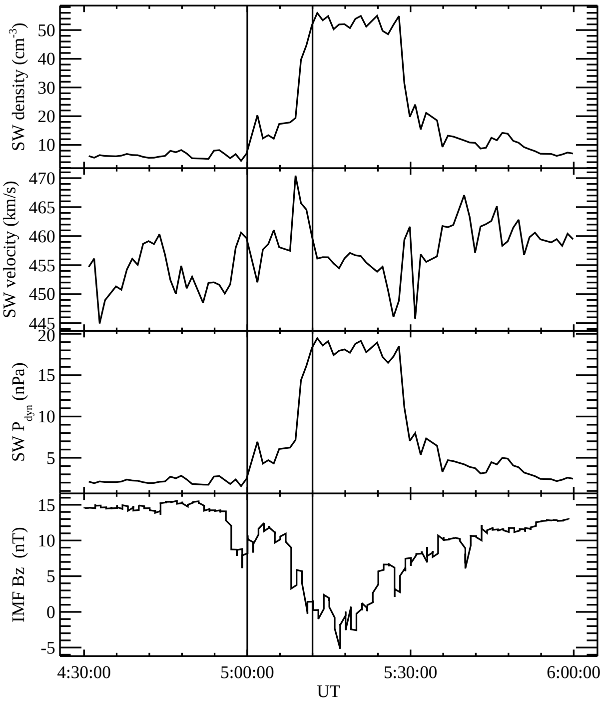

Figure 3. Solar wind properies measured by the ACE satellite on November 8, with the solar wind dynamic pressure (first pannel) defined by $P_{dyn} = \rho\ v^2$ where ρ is the density, and v the bulk velocity (all in MKS units). The time range between the two vertical lines is associated with the developpment of the proton flash (after applying an appropriate transit time shift).

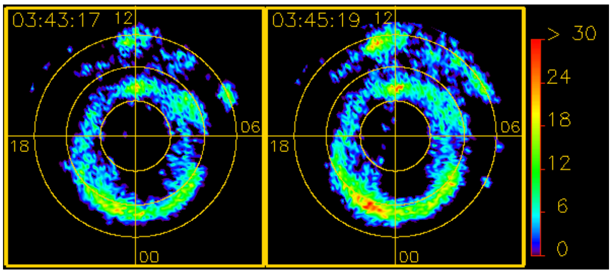

Figure 4. SI12 images remapped in geomagnetic coordinates of the proton flash that developped on November 8 2000 around 0343 UT.