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Global observations of proton and electron auroras in a substorm

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Abstract. This is the first report of a substorm observed by the IMAGE FUV instruments permitting global observations of electron and proton produced auroras. On the 28th of June 2000 at 1956 UT in the pre-substorm phase at early evening local time the proton aurora was equatorward of the electron precipitation and near midnight they were collocated. There was bright electron and proton aurora in the post midday afternoon side. The sudden brightening of the aurora at substorm onset near midnight is seen in the electrons only although there are protons present at this location. During the expansive phase both the electrons and protons expand poleward. The electron aurora forms a bright surge at the poleward boundary while the protons just show diffuse spreading. The peak intensity of the protons did not change substantially during the entire event. The proton aurora is brighter on the dusk while the electron aurora on the dawn side. As the electron surge expands poleward it leaves the protons behind. The electrons form a discrete auroral feature near the aurora-polar cap boundary, which is devoid of substantial energetic (>1 keV) proton precipitation. The presence of precipitating protons at the point where the initial brightening is seen shows that substorms are initiated on closed field lines.

Introduction

Proton induced auroras and their global morphology during magnetospheric substorms are not well understood. Ground based instruments observe the proton aurora only at night and the weak hydrogen Balmer emissions are the only features that can be clearly associated with proton precipitation. It is difficult to make observations of these weak emissions especially in the presence of strong rapidly varying electron auroras [*Mende and Eather,* 1976]. Spacecraft based global observations of proton aurora were restricted to statistical interpretations of in situ particle measurements [e.g *Hardy et al.,* 1987, 1991] until the launch of IMAGE.

Montbriand [1971] and *Eather et al.* [1976] found that diffuse electron precipitation is collocated usually with the proton aurora. During the substorm growth phase, the proton aurora moves equatorward accompanying the development of the ring current and it is absent in the leading edge of the expanding substorm auroral bulge in the premidnight region [*Fukunishi,* 1975]. In the substorm growth phase the diffuse proton aurora lies equatorward of the discrete aurora in the pre midnight region [*Vallance Jones et al.,* 1982] and at substorm onset the poleward boundary of the proton aurora can reach near that of the electron aurora. From monochromatic all sky camera observations *Mende and Eather* [1976] found that the bright part of the westward surge does not contain proton precipitation and the proton aurora expands poleward to occupy a large diffuse region located poleward of the pre-substorm position. *Samson et al.* [1992] observed that the electron arc that brightens at substorm onset is located within a region of intense proton precipitation with energy that monotonically increases with decreasing latitude.

The auroral arc that intensifies at substorm onset often forms on magnetic field lines that map to within the geosynchronous region [*Lyons and Samson,* 1992]. *Deehr* [1994] showed that in 33 substorms the electron arc is always poleward of the proton arc at onset and that this conclusion is less pronounced toward midnight (MLT). Proton precipitation is evidence for closed magnetic field region [*Samson et al.,*1992] and the development of protons might shed light on the location of the boundary of the closed field line region during substorms.

On IMAGE, the Wideband Imaging Camera (WIC) observes the aurora in broad (140-170 nm) ultraviolet band sensitive mainly to LBH N_2 and some NI lines. The SI12, one of the two channels of the Spectrographic Imager (SI), images Doppler shifted Lyman alpha to monitor the global scale proton precipitation [*Mende et al.,* 2000] and removes the intense (>10 kR) geocoronal Lyman alpha background which would otherwise appear as an impenetrable diffuse glow. The responsivity of these instruments was validated by laboratory and by various in flight calibrations using stars. The most relevant form of calibration included the observation of aurora with simultaneous FAST spacecraft based electron and ion flux measurements [*Frey et al.,* 2000]. From this data set WIC and SI12 channel counts (C_{wic} and C_{SI12} respectively) were related to FAST electron (E_e) and proton energy fluxes (E_i) normalized to 100 km altitude. The WIC and SI counts were assumed to be $C_{wic} = E_e a_{wic} + E_i b_{wic}$ and $C_{SI12} = E_e a_{SI12} + E_i b_{SI12}$ respectively and a linear regression analysis gave $a_{wic}= 1060$, $b_{wic} = 1500$, $a_{SI12} = 2.1$ and $b_{SI12} = 142$ with a correlation coefficient of >0.90. Although this approach is a gross simplification of what is known about the auroral intensity response to particle fluxes it corroborates our belief that SI12 is only minimally sensitive to electron precipitation. WIC is actually more sensitive to ion than to electron energy flux but a typical ion flux of say 0.2 ergs cm^{-2} s^{-1} produces only 300 WIC counts which is barely more than the dark counts, while typical electron auroral counts in WIC are in the sev-

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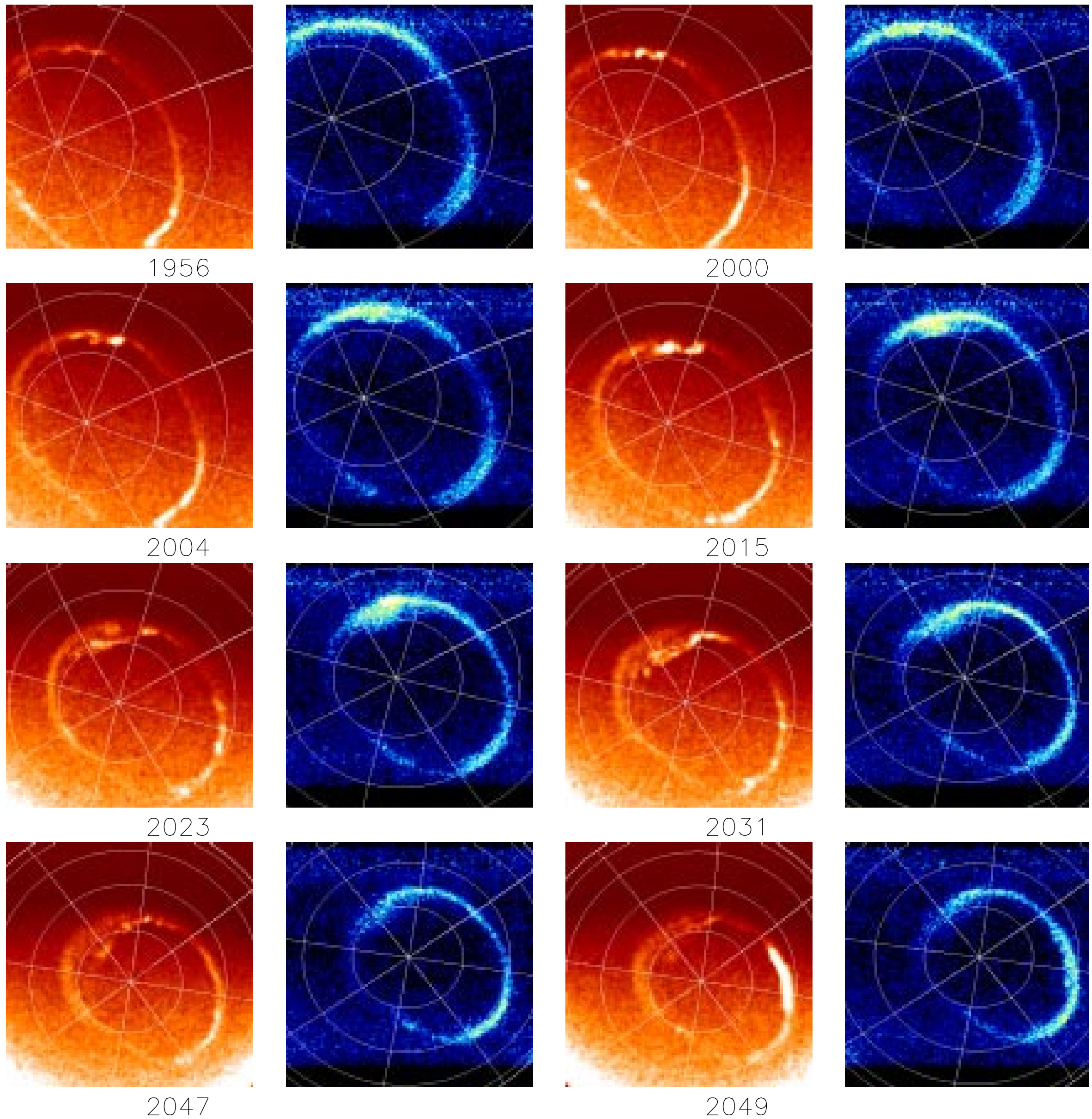

Figure 1. The WIC image (left) and the SI12 image (right). The geographic latitude/local-time grid for locating auroral features in one image relative to the other.

eral thousands range. This is in agreement with the finding that WIC and SI12 images are often completely different in appearance [*Burch et al.*, 2001].

In this paper we will describe the data when a small substorm was viewed by IMAGE FUV at 1956-2049 UT June 28^{th}, 2000 (day 180). The substorm was chosen because it occurred during a relatively quiet period and was suitable for the interpretation of various substorm features.

Observation of a small substorm

The IMAGE spacecraft was climbing towards apogee when the sequence of images shown on Figure 1 was taken. The WIND satellite was in the solar wind (GSM position of x=-3, y=-40 and z= 0). The solar wind dynamic pressure was 2 nPa and the solar wind velocity was -450 km/s. The WIND magnetic field data during the period of interest 1900 to 2200 showed that B_z was generally negative between -2 and -4 nT. B_y is negative (-4 to -6 nT) until about 2035 at which point it becomes -2. Perhaps the biggest change occurs in B_x, which goes from -2 to +4 between 2020 and 2035 UT.

In Figure 1 we present a sequence of WIC (left) and SI12 (right) images. Noon-midnight is very closely aligned with the vertical of the page (midnight is approximately at the top). The grid is geographic with 75, 60 and 45^o latitude circles. The WIC images were flat fielded and scaled with a single set of scaling parameters to optimize the brightness and contrast of the presentation and to preserve the relative brightness of the images in the sequence. The WIC images are displayed on a red-to-yellow-to-white color palette. The SI12 images were scaled to a blue-to-lightblue-to-green color palette. In the left to right direction both imagers are produced by scanning due to the spacecraft rotation and all images are intrinsically flat fielded. In the WIC images the dayglow is significant and a smoothed image was subtracted to remove the large intensity variation across the WIC images due to the dayglow.

At 1956 the aurora was quiet with very little activity in broad band LBH (WIC) except the early afternoon where we see evidence of some structuring in the form of possible Kelvin-Helmholtz waves or perhaps large spacing spatially periodic auroral distortions [*Vo and Murphree,* 1995]. The proton aurora was fairly uniform, diffuse with a peak intensity of ~35 background subtracted counts. It is located slightly equatorward of the electrons on the dusk/evening side but seems to be collocated with the electrons at midnight. At 2000 UT we see the first sign of a breakup in the electrons, beginning near midnight.

The first response of the proton aurora to the substorm is a poleward expansion occurring near midnight (2004) when the WIC signature is also relatively weak. The 2004 bright spot in the WIC does not have a proportional counterpart in the SI12 image. The poleward boundary of the protons perhaps leads the poleward boundary of the electron surge (2015) and the SI12 aurora touches the 75^o latitude circle while the electron aurora is still at 72^o or 73^o. At 2023 UT there is a faint region of proton precipitation which is at as high or higher latitude than the bright electron surge, however the bulk of the proton intensification takes place at the original location of the proton aurora. The proton count rate by this time increased from 36 counts (from 0.26) to 45 counts per exposure per pixel (to 0.31 ergs cm^{-2} s^{-1}).

At 2031 the poleward surging WIC aurora is brightest at the poleward edge of the surge while the SI aurora is brightest equatorward and duskward. At 2047 the electron aurora reaches its highest latitude and the SI12 aurora is distinctly left behind. It is also clear that the proton aurora is absent in the leading edge of the expanding electron auroral bulge [*Fukunishi,* 1975; *Mende and Eather,* 1976].

The first image which shows the entire auroral oval (2015) displays a bright region in both SI12 (mainly protons) and WIC in the early afternoon, this is the location of the afternoon arc [*Lundin,* 1988]. On the night side the protons fill the evening dusk of the oval and the electrons mainly fill the dawn side in agreement with the azimuthal drift of eletrons and protons injected at midnight.

At 2049 a sudden brightening occurs in the dusk sector. This brightening is very intense in the WIC image and it has only a fainter counterpart in the SI12 channel.

Discussion

During the afternoon evening hours the bulk of the proton precipitation was equatorwards of the quiescent aurora produced mostly by the electrons [*Eather,* 1967; *Montbriand,* 1971; *Fukunishi,* 1975; *Eather et al.,* 1976; *Vallance-Jones et al.,* 1982; *Samson et al.,* 1992].

The substorm onset is signified in the electron data as a sudden brightening at 2000. The IMAGE spacecraft rotation (2 minutes period) defines the sampling rate of the FUV system and limits the accuracy of the substorm onset timing [*Liou et al.,* 2000]. The first substorm intensification at 2000 UT followed by a fairly immediate response in the proton morphology but relatively minor change in proton peak intensity which increased only slightly.

The images at 2000 and 2004 UT show that the proton aurora was slightly equatorward of the bright patch development at the onset of the substorm in agreement with *Deehr* [1994].

The initial brightening of the substorm at 2000 UT was embedded in the proton precipitation [*Samson et al.,* 1992]. Particle measurements show that these protons are energized by the magnetospheric eletric fields and are generally located well inside the magnetosphere in the region of geosynchronous altitude satellites. The fact that the substorm initiation occurs in or near the zone of precipitating protons seriously constrains substorm theories [*Lyons and Samson,* 1992].

Initially protons and electrons both participate in the poleward expansion of the aurora but the protons slow down and only electrons populate the poleward edge of the surge. Although the proton aurora expands poleward with the electron auroral surge it appears faint and diffuse.

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