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Comment on "Low-energy particle layer outside the plasma sheet boundary" by G. K. Parks et al.

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Abstract. We consider the mapping schemes where the plasma sheet boundary layer (PSBL) in the tail is projected to the auroral oval as inconsistent with the available data. We conclude that the low-energy layer (LEL) structure discovered by Parks et al.(1992) at the outer edge of the PSBL is consistent with the mapping scheme by Feldstein and Galperin (1985) where the boundary plasma sheet (BPS) (which includes the PSBL proper and presumably can also include the newly discovered LEL) is mapped to the polar diffuse aurora (PDA). Note that this definition of BPS plasma domain in the tail (which includes only the PSBL and LEL, as distinct from the central plasma sheet (CPS)), which projects to the bulk of the region of the discrete aurora, or the auroral oval), differs substantially from the BPS as defined by Winningham et al.(1975). In Winningham's definition the BPS refers to the structured accelerated electrons precipitation region at ionospheric altitudes, and it sometimes was improperly interpreted as indicating the mapping of the nightside auroral oval to the plasma sheet outer boundary.

In the analyzed ISEE data by *Parks et al.* [1992] a new particle structure in the tail was found:the low energy layer (LEL) composed of an outward electron beam with energies ~ 100 eV and an earthward beam of low-energy ions. The structure, according to *Parks et al.*[1992] (referred to hereafter as P92), is usually present at the outeredge of the plasma sheet boundary layer (PSBL) and has a width of about (0.1-1.4) R_E at distances (15-22) R_E. The LEL complements the overall description of the tail structure, which was established from the comprehensive in situ measurements by *Eastman et al.* [1984, 1985]. It contains the central plasma sheet (CPS), the main body of hot nearly isotropic plasma in the tail, and the PSBL with field-aligned velocity-dispersed particle beams, as observed at energies > 1 keV at the outer (high latitude) edges of the CPS. The lower energies of the LEL, located at the outer edge of the PSBL, may signify some specific physical process in the distant tail, or possibly just an extension of the PSBL generation processes to lower energies and other locations. Anyway, the discovery of LEL certainly will play an important role in the theoretical and modeling studies of the distant tail.

Questions arise about the LEL mapping to the auroral ionosphere,comparisons with the corresponding measurements at lower altitudes, and the relation of this new feature to previous models. P92 propose a scheme in which the LEL is mapped to the region of subvisual auroral luminosity excited by low-energy electrons and located poleward of the discrete precipitation structures, such as inverted-V events. P92 claim that this scheme is an alternative to those proposed by *Eastman et al.*[1984, 1985] and by *Feldstein and Galperin* [1985], because the LEL was not known at that time. These two schemes, like the P92 model, relate the plasma domains observed within the tail to the distinct regions of auroral particle precipitation and luminosity.

The main differences between the models of *Eastman et al.* [1984,1985] and of *Feldstein and Galperin* [1985] were discussed at length in the latter paper and by *Galperin and Feldstein* [1989, 1991] (hereafter FG85, GF89, and GF91, respectively). In short, the former model maps the PSBL to the auroral oval, and the central plasma sheet (CPS) is mapped to the diffuse aurora equatorward from the oval. The model FG85 (see Figure 1a taken from FG85) maps the boundary plasma sheet (BPS) to the polar diffuse aurora (PDA), which is usually observed poleward from bright discrete forms of the nightside auroral oval, while the tail CPS is mapped to the oval. A schematic global distribution of auroral features is shown in Figure 1a for a disturbed period% (Kp=5). In the caption the magnetospheric plasma domains are identified, which are conjugate to respective auroral regions according to FG85.

The equatorial boundary of the oval, which was defined from bright discrete auroral forms, lies close to the boundary of stable trapping for high-energy particles (or the isotropic boundary). This boundary plays a fundamental role in our mapping scheme because it can be used as it a natural tracer observable at all altitudes. On the nightside it defines a narrow transition shell region between the quasi-dipolar magnetic field of the inner magnetosphere and the taillike, stretched field region farther in the tail. Evidently, this transition shell region is due to the inner edge, or a strong outward gradient, of

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the integrated cross-tail current of the plasma sheet (including the neutral sheet). Thus it divides the two magnetospheric regions with grossly different energetic particle motions and currents. It is the main physical basis of our scheme and notations.

The region of the inner magnetosphere extending inward from the trapping boundary (the outer radiation belt) to the soft electron precipitation boundary (SEB), a convection boundary, or the plasmapause, is thus mapped to the diffuse auroral precipitation equatorward from the nightside oval. This outer part of the trapped zone where the large-scale convection particles from the plasma sheet that are continuously convected still exists, was named the remnant layer in FG85. Low-energy and/or injected here during substorms, form the diffuse precipitation zone, with dispersed "plasma clouds" [*de Forest and McIlwain*,1971] that gradually decay. Therefore they can be considered as remnants of the plasma sheet hot plasma within the region of energetic particle trapping.

The definition of the BPS in FG85, GF89, and GF91 was some what broader than that of PSBL by *Eastman et al.* [1984, 1985] because it included lower particle energies. Electrons of < 1 keV were considered to extend further outward then those of > 1 keV. This is consistent with the generally larger observed PDA width at lower precipitating electron energies than the PSBL projection. This led us to introduce the term BPS. Now, we believe that the BPS may incorporate both the PSBL and LEL. It is interesting to note that in many recent papers the term PSBL is used in the same broad sense as we used the term BPS. It remains to be seen whether the LEL is due to a different physical process from that of the PSBL proper, and until this time we would prefer to use the term BPS as including both the PSBL and LEL. We were unable to find contradictions between the new data described by P92 and the model in FG85 and thus cannot agree with the alternative mapping proposed in the former paper.

In Figure 1a and 1b we compare the schemes of auroral luminosity structure and their mappings to the magnetospheric plasma domains during disturbed times according to FG85 and P92. In these paper bright discrete auroral forms are located between the polar and equatorial zones of diffuse precipitation. The borders of the zones in Figure 1a are given approximately in the invariant latitude -- magnetic local time coordinate frame for disturbed time (Kp ~ 5) according to various experimental data. Under disturbed conditions the polar diffuse zone width often shrinks to ~ 50 - 100 km at the oval poleward border. In Figure 1b (taken from P92) only a qualitative pattern without a coordinate frame is presented for a substorm recovery phase.

Let us evaluate and compare these two schemes. The LEL width at high altitude, as estimated by P92, is from ~ 41 to 8900 km. This LEL width, when mapped to the ionosphere using the Tsyganenko-87 model for Kp = 3 (*Tsyganenko*, 1987), gives the width of 0.55 to 121 km. Using a typical LEL width of 450 km, one calculates a projection of about 5 km. This is clearly too small to comprise the region of discrete aurora, and it is probably also too small for, or sometimes comparable to, the typical width of the PDA, even for disturbed conditions. In FG85, GF89, and GF91 it was noted that the PDA expands during quiet times, which further increases the inconsistency with the P92 mapping for the recovery phase. At the same time, the supposition that the PDA includes precipitation regions both from the PSBL and LEL, is not inconsistent with the data.

As to the precipitating particles of the PDA, in FG85 and GF89 it was also noted from the results of low-energy particle data on the COSMOS 261 and AUREOL 1, 2, and 3 satellites, that low-energy electrons with energies 30--150 eV are the main

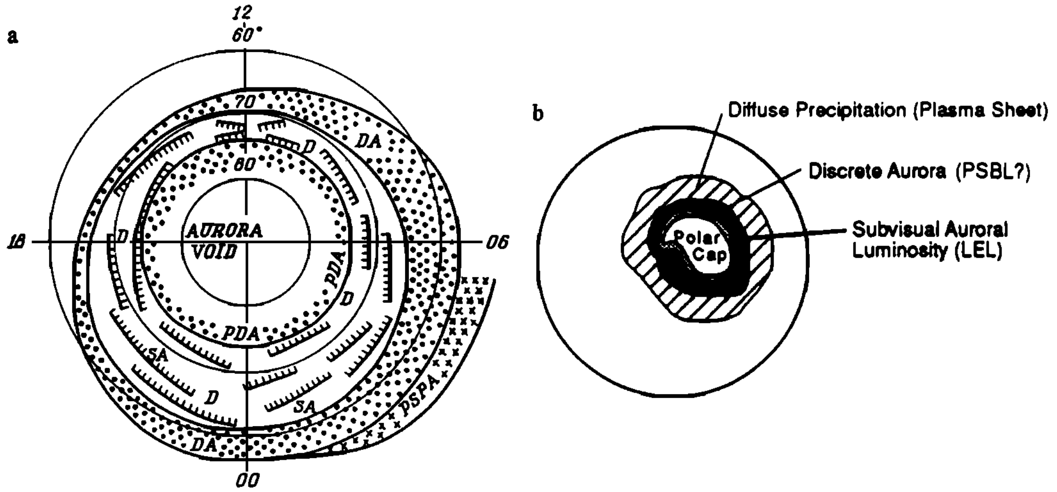

Figure 1.Schematic pictures summarizing spatial distribution of different auroral luminosity types according to the two schemes: (a) From *Feldstein and Galperin*[1985] in the Λ -- MLT frame (from their Figure 24b for Kp=5). Aurora void -- polar cap area free from bright auroral luminosity, projected to the tail lobes; polar diffuse aurora (PDA) projected to the boundary plasma sheet (BPS) in the tail; SA, structured (discrete) auroras of the auroral oval, projected to the central plasma sheet (CPS); D, diffuse auroras within the auroral oval of discrete forms; DA, diffuse aurora equatorward from the auroral oval, projected to the outer radiation belt region till the convection boundary (plasmapause); PSPA, postsubstorm plasmaspheric diffuse auroras (within the trapped radiation region);
(b) From *Parks et al.* [1992].

contributors to the excitation of the auroral emission (mostly 630-nm oxygen lines) in this region. Numerous citations to previous ground-based and airborne measurements supporting this inference were also given in the above papers. These particles are believed to be the low-energy part of the BPS population and could also include the LEL particles.

Velocity-dispersed ion precipitation structures of the second type (VDIS-II), which appear sporadically within the PDA, were reported by *Kovrazhkin* [1987], *Bosqued* [1987],and *Zelenyi et al* [1990]. As stated in the latter paper (p.12,121), the VDIS-II structures observed at ionospheric altitudes were identified, using the mapping proposed earlier in FG85 and GF89, with the ionospheric precipitation signatures of the dispersed earthward ion beams of the BPS, or the PSBL, as observed in situ by *Takahashi and Hones*[1988]. The VDIS-II structures were used in GF89 and GF91 as the natural tracers for the mapping of the PSBL to the PDA.

VDIS--II structures that consist of ion energies much greater than reported in the LEL have been observed at low altitudes from the AUREOL 3 in only about 11% of passes. At higher altitudes and at lower ion energies this percentage is much higher, up to ~ 40% as was recently shown by *Saito et al.*[1992] from AKEBONO data. These high-altitude measurements also show that the typical difference in electric potentials along the field lines which contain VDIS--II ion structures, is negligible. It cannot significantly limit the latitudinal width of VDIS--II structures and extend them above the inverted-V structures of the auroral oval, as was recently suggested by *Lyons[*1992].

As to the low-energy tailward streaming electrons of the LEL, their location on the PDA field lines is apparently accepted in P92. However, in FG85 the whole structure of the BPS is mapped to the PDA, whereas in the scheme of P92 only the LEL, that is, a narrow plasma layer at the outer part of the BPS, is mapped to the whole PDA region.

In the P92 scheme the PSBL proper is mapped, as in the work by *Eastman et al.*[1984, 1985], to the oval (but with a question mark in Figure 1b). Many arguments against such a mapping are described in detail in FG85, GF89 and GF91. In particular, the magnetic flux argument was used to show the impossibility of mapping the BPS (or PSBL) of 1--2 R_E thick to the whole width of the oval (including inverted-V events) which is usually several hundred km wide, and thus subtends much higher magnetic flux. This difficulty is also noted in P92, but did not lead to a modification of Figure 1b.

Other arguments for mapping the BPS, including the PSBL, to the PDA are described in FG85, GF89 and GF91. One of the most convincing of them is based on the direct measurements of the PSBL observed from ISEE, and its projections, using the *Tsyganenko* [1987] model, to the bright arc at the polar border of the extended oval using simultaneous auroral images from the DE 1 [*Frank and Craven*, 1988]. As the field-aligned currents were not included in the tracing model, it is difficult to decide whether the PSBL was projected exactly to the bright auroral arc or some tens of kilometers poleward from it. In this particular example the 1.5-keV electrons extended further outward within the PSBL than the electrons of 5 keV. Thus it was natural to suppose that the lower-energy electrons that constitute the main part of the precipitating electrons within the PDA extend even further outward in the BPS. In this way a wider PDA region (and the observed average poleward softening of electron energies within it), could be accounted for as a contribution from the LEL soft electrons at the outward part of the BPS.

Thus it seems that the mapping of the BPS (including PSBL), with the general softening of electrons towards its outward edge, to the region of "subvisual auroral luminosity" poleward from the oval (PDA), is well documented and supported by various measurements. It is, however, at odds with the mapping in Figure 1b, where the PSBL (with a question mark) is mapped to the discrete aurora region, despite the statement in P92 (p.2952) that "The streaming low-energy ion beams are the velocity dispersed ion streams that Zelenyi *et al.*[1990] observed in the ionosphere."

According to the mapping scheme in Figure 1a, the band of the LEL projection to the ionosphere must be located at the outer part of the PDA (i.e., in the outer part of the BPS projection) or on its outer border. We believe that this new structure in the tail now can be incorporated into the scheme of Figure 1a as part of the BPS without any changes in its other parts. Theoretical arguments for the physical distinction between the PSBL and LEL are still not very clear.

The VDIS-II structures within the PSBL are well described by the model calculations of *Ashour--Abdalla et al.* [1991, 1992] as due to nonadiabatic ion motions in the magnetic field reversal within the distant neutral sheet. The nonadiabatic effects for ions crossing the neutral sheet give rise to field-aligned acceleration for a part of the ion distribution function. The resulting ion beams are velocity dispersed by the E × B drift in the dawn--dusk electric field. The model results of *Ashour-Abdalla et al.*[1992] are very similar to the observed VDIS--II, including their fine structures. We note that the location of the LEL at the outer border of the PSBL could be a result of the same nonadiabatic acceleration process which takes place during the first encounter of the plasma mantle tailward streaming ions with the distant neutral sheet. In this first encounter a significant angular deflection of streaming ions can occur with only minor acceleration according to *Ashour-Abdalla et al.*[1991, 1992].

Onsager et al.[1991] constructed a simple kinematic model of the PSBL formation from the velocity filter effect with a particle source distributed along the distant tail. This model reproduces very well the particle distribution functions observed within the PSBL, if the plasma temperature within the CPS is supposed to be higher than in the lobe (which may be consistent with the nonadiabatic heating found by *Ashour-Abdalla et al.* [1992] for the plasma sheet ions). This kinematic model is complementary to the more rigorous ion trajectory calculations by *Ashour-Abdalla et al.* [1991, 1992]. In both of these models the PSBL is located on closed field lines of the CPS at large distances.

Another possibility for the LEL generation is a distinct ion acceleration region and/or a specific process in the far tail (e.g.,at the distant neutral line or turbulent plasma sheet). Both possibilities are consistent with the mapping of the BPS (which includes the PSBL) to the PDA.

Summarizing, we conclude that the discovery of the LEL by *Parks et al.[*1992] is fully consistent with the mapping scheme proposed by *Feldstein and Galperin* [1985], and with the low-altitude data available on the PDA. From our scheme the LEL, located at the outer boundary of the PSBL, that is within the BPS, must be mapped to the outer part, or to the boundary, of the PDA, thus complementing this scheme. We conclude that the previously known plasma domains, the

BPS (including the PSBL and, now also the LEL), the CPS, and the region of stable trapping (outer radiation belt) are mapped according to *Feldstein and Galperin* [1985] (in particular, for disturbed times in accord with Figure 1a).

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