Aurorae and the Large-Scale Structure of the Magnetosphere

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An attempt is made to construct a road map for translating various plasma domains in the magnetosphere to their counterparts in the auroral ionosphere. Results of previous work have allowed much to be inferred about where in the magnetosphere auroral processes are taking place. The main auroral oval appears to be associated with magnetospheric processes well separated from boundary layer processes with the exception of the dayside sector between about 8 and 16 MLT. This sector is apparently dominated by sources in the dayside boundary layer and by the region where the nightside cross-tail current intersects the boundary layer regions. The division between the stably trapped particles and isotropic distributions probably coincides with the most equatorward discrete arc system involved with the substorm onset. Thus the diffuse aurora equatorward of the discrete aurora would be a ring current related phenomena and the nightside discrete aurora would originate dominantly from the central plasma sheet. During magnetically active conditions the outer edge of the central plasma sheet plays a more important role in the production of the discrete aurora. Diffuse aurora poleward of the discrete system is probably linked to velocity dispersed ion signatures seen in the low altitude ionosphere.

1. Magnetospheric Structure

The Earth’s magnetosphere is formed as a result of an interaction between the solar wind and the geomagnetic field. Figure 1 shows a cartoon representing the various magnetospheric regions and their corresponding ionospheric mappings (modified from Galperin and Feldstein, 1991). The magnetospheric boundary on the dayside is located at geocentric distances of about 10 Re, and on the nightside a magnetotail extends in the antisunward direction. The above geometry of the geomagnetic field suggests the existence of large-scale currents at the surface of the magnetosphere (MC), in the tail of the magnetosphere (TC) and near the Earth (ring current (RC)). Field-aligned currents (FAC) link these systems to the Earth’s ionosphere. All of the currents together determine the large-scale structure of an external magnetospheric field, and, consequently, its division into a number of plasma regions. These include the central plasma sheet (located both north and south of the tail current), the boundary plasma sheet, the mantle, the cusp, the region of the radiation belt with stably trapped particles, and finally the plasmasphere. The main part of the ring current and the soft auroral particles arriving from the tail plasma sheet (as a result of large-scale magnetospheric convection) are located in the region called the remnant layer which extends up to the plasmapause.

In order to understand high latitude ionospheric phenomena one must first have some
knowledge of where the regions of Fig. 1 map to in the ionosphere. Making use of the Tsyganenko (1987) long magnetospheric model, Elphinstone et al. (1991a) related various regions in the equatorial plane to corresponding regions in the ionosphere and determined some fundamental relationships to the auroral distribution. On the basis of that paper and a subsequent paper (Elphinstone et al., 1991b) it appears likely that:

1) The structured auroral region in the dayside ionosphere between about 8 and 16 MLT is probably related to dayside boundary layer processes. This region is highly dynamic being alternatively on open or closed field lines and has been termed the "cleft." It is the ionospheric meeting point of magnetospheric areas greatly separated in space. Poleward of it and strongly related to the noon sector connection points of polar arcs is the magnetic cusp.

2) The locus of field lines attached to the Earth creates a region extending to about 17 RE in the dawn-dusk meridian plane and about 10 RE in the sunward direction. Increasing magnetic activity moves this subsolar point earthward and its ionospheric projection equatorward.

3) The maximum of the volume current density in the nightside equatorial plane is generally located within $x_{\text{GSM}} = -10 \, \text{R}_E$. It moves earthward and intensifies with increasing magnetic activity. An association can be made with this "nightside cusp" region and the main auroral oval. Changes to the volume current density maximum can directly result in the motions of the structured oval. This interpretation does not require directly relating open flux
changes (in the nightside magnetosphere) with the changes to the structured aurora in the midnight sector.

4) During high levels of activity particularly during substorm recovery, a second region near the outer edge of the central plasma sheet is activated and may be associated with the "double oval" which occurs during these times.

5) The plasma sheet thickness decreases in the antisunward direction while the area of the tail cross-section increases. The plasma sheet and boundary layers are thicker for low levels of magnetic activity than for high.

2. The Auroral Oval and Its Relationship to the Plasma Sheet in the Magnetotail

There is a region in the nightside magnetotail known as the nightside cusp. Earthward of this region, the magnetic field is approximately dipolar while tailward of it small ionospheric distances translate to large magnetospheric distances. This nightside cusp occurs in the vicinity of the magnetotail where the volume current density associated with the cross-tail current maximizes. Using the Tsyganenko (1987) long external field model combined with the IGRF (1985) internal field, Elphinstone et al. (1991a) evaluated the location of the maximum of the volume current density at each ionospheric local time and compared it with the latitudinal peak in the UV aurora (Lyman-Birge-Hopfield bands, 1400–1800 Å) observed by the Viking spacecraft. A summary of the results are shown here in Fig. 2. One can see, that for a wide range of Kp indices and tilt angles of the dipole axis there is a close relation between the position of the current density maximum in the magnetospheric tail and the location of the peak emissions of the UV auroral oval. The projection of the current density maximum to ionospheric heights coincides at nearly all magnetic local times with the latitude of the peak UV auroral emissions. This peak probably represents the transition region from a mainly diffuse auroral precipitation to a more discrete region in its poleward portion (Elphinstone et al., 1991b). Vasyliunas (1970) showed that the inner edge of the plasma sheet is mapped to the equatorward oval boundary. Thus, the current density maximum in the tail of the magnetosphere is located close (in the sense of its ionospheric projection) to the inner edge of the plasma sheet and to the nightside "cusp".

These boundaries near midnight usually lie in the vicinity of the so-called "sharp" trapping boundary, Aₛ, defined as a sharp decrease of the trapped (anisotropic) high-energy particle intensity in the outer belt. However, intense isotropic high-energy electrons can be seen poleward of Aₛ. Such electron fluxes increase drastically during magnetospheric disturbances. The poleward boundary of such flare-like precipitations is usually indicated as Aₛ (A background).

The fundamental importance of the Aₛ boundary arises from its proximity in the near-midnight region to where the equatorwardmost auroral arc activates (i.e., the onset region of a classic auroral substorm). Such a coincidence can be explained physically by the isotropization of high-energy particle fluxes resulting from a non-conservation of the magnetic moment close to the current sheet. In this region of the nightside "cusp" the radius of curvature of field lines becomes comparable to the Larmor radius. This decrease in the radius of curvature is related directly to the existence of the large-scale cross-tail current in the neutral sheet. Thus, a simple explanation exists for the observation that the equatorward boundary of the discrete auroral oval is related to the earthward edge of the tail current sheet.

That this inner tail region is one source for the optical substorm onset has been described
Fig. 2. The Tsyganenko (1987) model magnetospheric tail current density maximum versus the observed oval locations for low Xp, high Xp, low tilt and high tilt cases (from Elphinstone et al., 1991a, copyright American Geophysical Union).
by various authors (Lui and Burrows, 1978; Murphree et al., 1991). One reason that the substorm onset might begin from this region is that the high volume current density region leads to a magnetic field oppositely directed to that of the dipole. The development of a “break-up” phenomenon could be expected in this region of weak magnetic field and high beta plasma.

A region of diffuse auroral luminosity equatorward of the discrete auroral forms is associated with the precipitation of soft auroral electrons. The poleward boundary of this region corresponds to a sharp dropoff of the stably trapped population of \( \geq 30 \) keV electrons and coincides with the separation between the diffuse precipitation and the discrete auroral region. The equatorward boundary is termed quite naturally the Soft Electron Boundary (SEB) and the latitude of this boundary is dependent on the electron energy used to define it (lower latitudes for lower energies). Galperin et al. (1977) and Sauvaud et al. (1983) assumed that this inner boundary is directly related to the existence of a large-scale convection boundary in the near-midnight sector, i.e. of an instantaneous plasmapause. This identification has been tested via model computations by Soloviev et al. (1989). Using data on the SEB locations found before the satellite-crossing of the plasmapause, radial changes of the plasma density were computed. A simplified model of plasma convection was used assuming a given rate at which the magnetospheric plasma was replenished from the solar wind. There was a fairly good correspondence between the computations from this simple model and the experimental data for the plasma density jump. This argues for a correspondence at high altitudes on the nightside of the Earth between the SEB and the plasmapause. At low altitudes the mapping would be to the ionospheric trough wall.

To which plasma domain in the magnetosphere is the auroral oval related to—the boundary plasma sheet or the central plasma sheet? Arguments in favour of the relation to the central plasma sheet can be found in Feldstein and Galperin (1985), and Galperin and Feldstein (1991). As shown above, the equatorial oval region is mapped to the earthward portion of the current sheet. Elphinstone et al. (1991b) showed that on some occasions the “oval” could be divided into two regions of intense luminosity. The equatorward region mapped to the near Earth region and was linked to the volume current density peak. A second more poleward region of intense luminosity also exists during substorm recovery. This has a narrow latitudinal extent and is found at the poleward edge of a broad auroral “oval”. This region was associated by those authors with the “activation” of the outer central plasma sheet/inner edge of the plasma sheet boundary layer during substorm recovery phase (see Fig. 1). These results are consistent with the observations of Frank and Craven (1988) who for a single case study showed a poleward arc system on a broad oval as mapping to the outer boundary regions. Their results are shown in Fig. 3. At the top of the figure the poleward and equatorward boundaries of the oval in the near-midnight sector are determined from the DE1 auroral images. Also shown is the ISEE 2 trajectory mapped from the magnetospheric tail via Tsyganenko and Usmanov (1982) model for two levels of magnetic activity. The central panel illustrates observations of the energetic electrons from the ISEE 2 spacecraft. One can see that in their view the plasma sheet boundary layer corresponds to the polewardmost arc system on this expanded auroral distribution. Therefore, the broad auroral region equatorward cannot all be mapped to the boundary layers, and should be mapped to a more vast region in the tail of magnetosphere, namely to the central plasma sheet. The plasma sheet boundary layer, in which high-velocity plasma flows were observed, is mapped to a limited latitudinal extent corresponding to an active discrete auroral form at the poleward edge of the auroral distribution.
One of the objections to the above viewpoint has been, for a long time, the absence of structures and fast flows in the central plasma sheet. If the proposed mapping of the discrete oval to the central plasma sheet is to be accepted, some manifestation of the processes taking place in arcs should be observed there. Until recently the central plasma sheet was usually considered as a region of generally isotropic particle distribution with no significant activity in the form of flows or beams. This viewpoint has been challenged as a result of high resolution measurements from the IRM satellite at high altitudes (BAUMJOHANN et al., 1990a, b). Intense particle flows mostly of short duration were frequently observed by IRM inside the central plasma sheet and even close to, or inside the neutral sheet. These flows were seen in the central plasma sheet with occurrence rate comparable to that found in the plasma sheet boundary layer.

Poleward of the discrete auroral distribution there is a very weak diffuse luminosity.
registered both by optical means and by satellite measurements of auroral particles. Recently velocity-dispersed ion structures have been discovered inside this zone from Aureol 3 satellite observations (ZELENYI et al., 1990). From the viewpoint of this paper, this is a separate structural region that in the ionosphere lies between the polewardmost discrete aurora and the polar cap low-energy precipitation. In the magnetosphere it coincides with the region between the central plasma sheet and the tail lobes (the boundary plasma sheet in Fig. 1).

This viewpoint has recently been given further support from observations by the Akebono satellite. YAMAMOTO et al. (1991) found that the poleward arc system in a substorm recovery phase broad oval (i.e., the double oval reported by ELPHINSTONE et al., 1991b) lies just equatorward of the velocity dispersed ion signature. This is consistent with the view that this poleward arc system lies at the interface region between the central plasma sheet and the plasma sheet boundary layer (labelled the boundary plasma sheet in Fig. 1).

3. Magnetospheric Structure and Its Relationship to Different Types of Auroral Precipitations during Magnetically Quiet and Disturbed Intervals

Ground-based and satellite observations of the aurorae have been summarized by FELDSTEIN and GALPERIN (1985). Their schematics are shown in Fig. 4 and represent the spatial distributions of different types of auroral luminescence during quiet and disturbed magnetic periods. During quiet times (left panel of Fig. 4) the discrete auroral oval looks like a narrow ring. The diffuse luminosity, poleward of this ring has embedded in it sun-aligned arcs.

Fig. 4. Schematics of the different types of auroral distributions during magnetically quiet ($Kp = 0$, left) and magnetically disturbed ($Kp = 5$, right) periods. The coordinate system is corrected geomagnetic latitude and local time. The auroral oval for $Kp = 0$ is hatched, and for $Kp = 5$ is depicted by structured aurorae. The auroral forms included are: PA, high latitude polar arcs; PDA, polar diffuse aurorae; SA, structured aurorae in the main auroral oval; D, diffuse aurorae in the auroral oval; DA, diffuse aurorae equatorward of the auroral oval; PSPA, postsubstorm plasmaspheric aurorae (from FELDSTEIN and GALPERIN, 1985, copyright American Geophysical Union).
or high latitude polar arcs. Analysis of Viking image data shows that these polar arcs are related to a broad and/or twisted plasma sheet (Makita et al., 1991; Jankowska et al., 1990; Austin, 1991).

During disturbed intervals (right panel of Fig. 4) there is a broad oval region in which discrete auroral forms can be found. The phase of the auroral substorm strongly determines which region within this broad ring is particularly active. The diffuse luminosity region polewards from the oval is confined to a narrow band although polar arcs can also be found during disturbed times. The diffuse auroral luminescence equatorward of the discrete oval in the dusk sector is produced by the precipitation of soft electrons. This is primarily associated with the 630 nm emission prevailing in the F region ionosphere. In the dawn sector the latitude range of this diffuse luminescence (produced by previous injections of hot plasma) is considerably widened and is more intense due to an enhanced precipitation of hard electrons originating from the outer radiation belt. Therefore the more equatorward diffuse aurora in the dawn sector primarily originates from precipitation at E region altitudes (i.e., the 557.7 nm and 391.4 nm emission) but is also partly due to F region precipitation, especially at higher latitudes.

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Fig. 5. Mapping of auroral luminosity regions (upper left) into the magnetosphere for a model calculation of $Kp = 0$ on April 18, 1986, at 06:00 UT. Upper right panel: View of the magnetotail minimum $B$ surface (equivalent to the equatorial plane when the tilt angle is zero). The sun is towards the top and dusk is to the left. The upper left corner is at $(x = +25, y = +45)$ GSM. Bottom panels: Cross-sections of the model magnetotail in the $y$-$z$ GSM plane at $x = -15$ RE (left) and $x = -45$ RE (right). Positive $z_{GSM}$ is to the top, positive $y_{GSM}$ to the left. Each large square represents a 10 RE by 10 RE area. The small square represents the coordinate $y_{GSM} = 0, z_{GSM} = 0$. 
where the soft electron fluxes increase. In the day-time sector during a magnetically quiet interval, there occurs a latitude jump in the location of the equatorward boundary of the diffuse aurora (see Fig. 4). This is probably due to a significant intensity decrease of precipitating high-energy outer zone electrons during their longitudinal drift towards the noon sector. During disturbances the diffuse luminosity in the morning sector can be located within the ionospheric region to which the plasmasphere projects to.

The distributions of the different auroral forms shown in Fig. 4 were mapped into the magnetosphere using the TSYGANENKO (1987) external model in combination with the IGRF (1985) internal field model. The mappings were performed for April 18 at 6:00 UT, which corresponds to a dipole tilt angle of about zero degrees. A particular date and time were chosen so that the Corrected Geomagnetic coordinates could be converted to geographic and then mapped (HEARN et al., 1991). Kp = 0 and Kp = 5 were chosen to represent the quiet and disturbed conditions for the TSYGANENKO (1987) model. The results of the mappings are presented in Fig. 5 (Kp = 0) and Fig. 6 (Kp = 5).

The top left panels show the auroral distributions in the northern ionosphere; the upper right panels show the projections to the equatorial plane and the bottom panels show projections at $x_{GSM} = -15 \text{ RE}$ (left) and $x_{GSM} = -45 \text{ RE}$ (right). During quiet times, the region where the current density maximizes coincides relatively well with the narrow ring of discrete auroras. The ring, however, projects to a considerable region in the Earth’s equatorial plane.

Fig. 6. Same as Fig. 5 except that the mapping was performed for magnetically active conditions ($Kp = 5$).
This narrow ring is likely to be the projection of the equatorial region immediately tailward from the peak in the volume current density. At ionospheric local times closer to noon the projection of this oval moves to the flanks of the magnetosphere until as one approaches ionospheric local noon the nightside low latitude boundary layer and the magnetopause are reached.

The daytime sector of the oval is mapped both close to the dayside magnetopause in the equatorial plane (i.e., the entry layer), and to the low latitude boundary layer regions along the nightside flanks. Thus, the boundary regions of magnetosphere are mapped to the daytime sector of the ionosphere. The diffuse luminosity region polewards of the discrete oval during quiet times (Fig. 5), upon mapping to the equatorial plane, embraces the remote magnetospheric regions, and in the y-zGSM plane includes practically all the area at high zGSM values. The region to which the discrete oval maps to still exists (in cross-section) at xGSM = -15 RE and to a lesser extent at xGSM = -45 RE. The diffuse luminosity embraces both the region of closed field lines and that of the “open” field lines which exit the model boundaries (60 RE). So, during quiet magnetic intervals, all the internal magnetosphere, from the plasmapause to about xGSM = -10 RE on the nightside, and to the magnetopause on the dayside is mapped to the region of diffuse luminosity. The line corresponding to the region of enhanced cross tail current upon mapping to ionospheric heights, coincides approximately with the narrow band of the discrete oval (or at least its equatorward boundary). The auroral oval is mapped in the y-zGSM cross-section of the magnetospheric tail at xGSM = -15 RE to a thin layer (≈2 RE) near yGSM = 0 and thickens on the sides up to about 4–6 RE. Most of the remaining part of the tail cross-section corresponds to the region of polar diffuse luminosity. The counterpart at xGSM = -15 RE to the ionospheric region devoid of the diffuse luminosity occurs at high values of zGSM. At xGSM = -45 RE the

Fig. 7. Northern ionosphere on September 23, 1986 in eccentric dipole (1985) coordinates. Local time meridians are shown with noon at the top and 18 MLT to the middle left. 80°, 70° and 60° magnetic latitudes are also shown. Left panel: Ionospheric projection of the volume current density from the minimum B surface in the magnetosphere (Kp = 5). The black oval curve is the location of the peak current density at each ionospheric local time. The thick white line represents a 60 RE model boundary between “open” and “closed” field lines. The peak current density occurs about 10° magnetic latitude equatorward of the open boundary near midnight. Right panel: Viking UV auroral image in the same coordinates as the left panel. The main oval is 5 to 10° equatorward of the high latitude arc system and coincides quite well with the peak in the volume current density.
corresponding region forms a sickle-like area. Soft auroral particles are found in the plasma mantle between the above sickle-like region and the magnetopause.

During magnetically disturbed intervals (Fig. 6) an apparent restructing of the plasma domains in the magnetosphere takes place. The region where structured aurorae occurs (white) fills the minimum $B$ surface of the magnetotail sunward of about $x_{GSM} = -45 \, R_E$. In the $y$-$z_{GSM}$ planes, this translates to a half thickness of the plasma sheet of about 6 to 8 $R_E$ at $x_{GSM} = -15 \, R_E$ and 4–6 $R_E$ at $x_{GSM} = -45 \, R_E$. In the model, a change from $Kp = 0$ to $Kp = 5$ results in a movement of the peak in the volume current density from $x_{GSM}$ near $-10 \, R_E$ to $x_{GSM}$ near $-5 \, R_E$. In the ionosphere this translates to an equatorward displacement of several degrees consistent with the equatorward displacement of the oval during these times. In the midnight sector this maximum is near the inner edge of the plasma sheet and near the equatorward portion of the structured oval. In the daytime ionospheric sector, however, the maximum in current density and the structured aurorae are associated with the low latitude boundary layer. The region in the equatorial plane between the plasma sheet inner boundary and the

Fig. 8. Model calculation (TSYGANENKO, 1987, $Kp = 5$) for the event shown in Fig. 7. This illustrates more accurately where the magnetospheric regions map to in the ionosphere (adapted from ELPHINSTONE et al., 1991c, copyright American Geophysical Union). Left top panel: The northern ionosphere in the same coordinates as Fig. 7. The black and white regions correspond to equivalent regions in the other panels. Top right panel: Minimum $B$ surface. $x_{GSM}$ is positive towards the top and positive $y_{GSM}$ to the left. Each large square is $10 \, R_E$ by $10 \, R_E$ and the Earth is the small square $20 \, R_E$ in from the top and $40 \, R_E$ from the left. Bottom left panel: The $y$-$z_{GSM}$ plane at $x = -15 \, R_E$. Bottom right panel: The $y$-$z_{GSM}$ plane at $x_{GSM} = -45 \, R_E$. 
plasmapause is again mapped to diffuse luminosity equatorwards from the structured oval. The boundary plasma sheet in the tail, related to the poleward diffuse luminosity, surrounds the central plasma sheet in the form of a thin ($\approx 2 \text{ R}_E$) band extending to the flanks of magnetosphere. Some of the diffuse luminosity appears to map to the plasma mantle region.

Figure 7 shows an example of a specific mapping for a Viking auroral event on September 23, 1986 at about 21 UT. The panel on the left represents the model calculations ($K_p = 5$) and the panel on the right a Viking auroral image during this disturbed interval. Noon is at the top of each panel, 18 MLT to the left and 60, 70, and 80° eccentric dipole latitudes are shown. The black line in the left panel corresponds the maximum in the volume current density while the black region in the center corresponds to field lines which do not close before exiting the model boundaries. The contours of grey to white in the left panel represent low to high levels of the volume current density. The black line corresponds well to the equatorward oval region in the UV image while the “boundary” near 70° MLAT near midnight corresponds well with the poleward arc system on the broad structured oval. The asymmetry about the noon-midnight meridian is a result of internal field asymmetries (HEARN et al., 1991). This figure supports the results discussed above and illustrates the two separate auroral regimes near midnight which occur during active magnetic intervals.

The model calculations shown in Fig. 7 are represented somewhat differently in Fig. 8 so that the reader can interpret where the currents and aurora occur in the magnetosphere (adapted from ELPHINSTONE et al., 1991c). Similar model results have been reported by STASIEWICZ (1991). Comparisons with the auroral data in Fig. 7 shows that the fan systems occurring between 6 and 12 MLT are a manifestation of irregularities in the magnetopause regions. The high latitude polar arc appears as a deep tail low latitude boundary layer process and maps to

Fig. 9. Schematic illustrating the two main region 1 current paths: the dayside current circuit and the tail current sheet system with a nightside current wedge developing during substorms (from LUNDIN et al. (1991) Copyright American Geophysical Union).
high $z_{GSM}$ values at $x_{GSM} = -15$ R$_E$. It is also apparent that the relative thicknesses of the actual poleward and equatorward arc systems near midnight are reflected in magnetic flux conservation effects seen in the model results (i.e., the two separate regions mapping at midnight to 65° and 70° MLAT).

Figure 9 depicts according to LUNDIN et al. (1991) the large scale field-aligned region 1 current structure, which was schematically presented in Fig. 1. Two ionospheric current systems powered by the LLBL dynamo appear to exist. The dayside current system is connected to the dayside cusp/cleft region and the nightside tail current is connected to the nightside high-latitude ionosphere. The nightside local tail current disruption, associated with a dipolarization, an inward plasma injection and the formation of a plasmoid is typical for the active substorm phase. The cross-tail current presumably disrupts and flows along magnetic field lines into the nightside ionosphere in the poleward region of the preexisting auroral oval.

4. Plasma Region Boundaries Dynamics in the Nightside Sector on the Basis of Auroral Precipitation during Substorms

The previous sections dealt with the large-scale structure of the average magnetosphere during quiet and active times. What is the large-scale magnetospheric structure and its dynamics during magnetospheric substorms? At present, two different ideas exist concerning the location of the substorm onset region: It is initiated in the remote magnetotail region (i.e., a substorm begins in the boundary layers) or in the inner magnetosphere (i.e., a substorm begins near the inner boundary of the central plasma sheet). Figure 10 presents two separate schemes as to where the various plasma domains occur in the night-time $x$-$z$ plane of the magnetosphere during the pre-storm quiet period (top) and during the peak of the substorm development (bottom).

According to the scheme by LYONS and NISHIDA (1988) (the left panels in Fig. 10) the substorm begins along the magnetic field lines threading the boundary located in the peripheral regions of the plasma sheet. The substorm onset is due to the formation of a new near-Earth neutral line (NNL) within the magnetotail current sheet. An alternative description of the dynamical processes during a substorm is shown schematically in the right panels taken from FELDSTEIN and GALPERIN (1991). During quiet intervals the most equatorward auroral arc occurs at the boundary of stable trapped particles near the inner boundary of the current sheet. The central plasma sheet, located on both sides of the current sheet, is filled with low-energy auroral plasma up to the magnetic field line which maps to the distant neutral line (DNL). The auroral electrons responsible for soft precipitation at very high latitudes precipitate from throughout this region into the ionosphere.

The onset of the auroral substorm expansive phase is marked by the brightening or splitting of the pre-existing most equatorward arc, i.e., the one deep inside the magnetosphere, near the inner boundary of the plasma sheet. Evidence for this can be found in the Viking data shown in Fig. 7 and discussed in more detail in ELPHINSTONE et al. (1991c). The arc system associated with the substorm onset (which occurs about 10 minutes after the image shown in Fig. 7) is the equatorward system at about 62 MLAT, near midnight. After substorm onset the discrete auroral forms fill the region between the inner edge of the plasmasheet and the near-Earth neutral line. Thus, the active aurora at the poleward edge of the auroral bulge is associated with the processes originating near the newly formed neutral line. The auroral precipitation associated with the DNL would then be associated with the soft precipitation region poleward.
Fig. 10. Schematics showing the magnetospheric tail during quiet times prior to the onset of a substorm expansion phase (upper diagram) and during a substorm expansion phase (bottom diagram). From Lyons and Nishida (1988), left panel, copyright American Geophysical Union, and Feldstein and Galperin (1991) right panel. The view on the right puts auroral arc systems and the substorm onset much closer to the earth than the left hand scheme.
of the structured aurora. Although it could exist during both quiet and disturbed intervals it seems possible that the soft precipitation could disappear near the end of the expansion phase when the NNL retreats down the tail and interacts with the DNL.

This proposed model is a modification of the pattern introduced by Lyons and Nishida (1988). In contrast to the Lyons and Nishida model, an NNL occurs deep in the central zone of the plasma sheet, rather than in the periphery of the latter. Further it may not be a direct cause of the substorm onset (which may instead be directly linked to the maximum in the cross-tail current) but rather an indirect result of enhancements to the near Earth current sheet. The soft auroral electron fluxes and the faint luminosity poleward from the last discrete arc are due to precipitations from the tail boundary layer whose external surface maps onto the DNL. Thus, the magnetotail region where the most active processes occur, is located deep in the plasma sheet, rather than at its edges.

5. Conclusions

The following summarizes a probable mapping between the ionosphere and the primary plasma domains in the magnetosphere.

1) The central plasma sheet in the nightside magnetotail corresponds in a broad sense with the auroral oval. The peak in the current near the plasma sheet’s inner edge is probably related to the peak in the auroral oval’s intensity. The central plasma sheets’ outer edge during substorm recovery phase is mapped onto an active, intense discrete auroral form. During the expansion phase the poleward edge of the bulge may represent the ionospheric projection of a new neutral line.

2) The plasma sheet boundary layer (or alternatively the high altitude boundary plasma sheet) corresponds in the ionosphere to the soft auroral luminosity region poleward of the discrete auroral distribution. During a substorm involving a near Earth neutral line this region may be found between the new neutral line and the more distant one.

3) The region between the inner plasmasheet boundary and the plasmapause (remnant layer) probably is mapped onto the range of latitudes equatorward of the discrete oval and poleward of the trough wall (i.e., the equatorward region of diffuse luminosity).

4) The entry layer, comprised of closed field lines in the dayside portion of the magnetosphere is related to the active auroral distribution near magnetic local noon. Poleward of this discrete distribution can be found the low latitude boundary layer, the cusp and the mantle.

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