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Dynamics of double-theta aurora: Polar UVI study of January 10–11, 1997

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Abstract. During the much studied magnetic cloud encounter with Earth on January 10–11, 1997, pairs of polar cap arcs twice became widely separated from the auroral oval, that is, an extremely rare double θ aurora configuration arose. These events exhibit many dynamic features hitherto rarely if ever reported in the literature of θ aurora. The two independent bars proved capable of merging into a single bar, crossing the polar cap, then splitting again. Moreover, in both events, after completely crossing the polar cap, the transpolar arcs reversed direction, and crossed again. The dynamics of these double θ-aurora events appear to constrain any models of their origin. Interestingly, in the January 10 event, a double θ-aurora which had twice crossed the polar cap ended up in a configuration previously termed a double oval. Particle data from the DMSP F13 satellite demonstrates that an isolated plasma sheet fragment formed also in the southern hemisphere, at least for the January 11 event for which correlative data is available.

1. Introduction

Polar cap arcs have been recognized as a distinct auroral phenomenon for well over a century. These transpolar arcs connect to the nightside oval on one end and reach close to the midday oval on the other. Although often described as "Sun-aligned," satellite photographs reveal significant curvature away from noon can exist locally along the length of an arc [*Ismail et al.*, 1977]. Most polar cap arcs have been shown to be embedded in the expansion of the auroral oval along the dawn and dusk flanks into the polar cap [*Meng*, 1981; *Newell et al.*, 1997] and therefore are on closed (plasma sheet) field lines, continuously connected to the oval. Relatively weak intensifications can exist within the polar rain without accompanying ion precipitation, but significant precipitating electron energy fluxes are consistently associated with plasma sheet ions and closed field lines [*Shinohara and Kokubun*, 1996].

Frank et al. [1986] noted that some of these polar cap arcs can reach the middle of the polar cap and termed such instances "θ aurora." Several pieces of evidence were advanced indicating that the θ aurora differed from the more common Sun-aligned arcs which tend to lie along the flanks of the oval (and indeed are continuously connected to the oval). For example, the convection pattern over a θ aurora was shown in several instances to be antisunward convecting on each side of the θ aurora, but sunward convecting inside, suggesting an open-closed-open configuration. Later it was shown that the plasma inside the arc strongly resembles that of the plasma sheet (or the plasma sheet boundary layer), even including precipitating O^+ [*Peterson and Shelley*, 1984]. Unfortunately, many researchers simply began to refer to any instances of relatively high latitude Sun-aligned arcs as "θ auroras," either not understanding or not accepting the distinction between the common cases of expanded polar sheet plasma and the rarer cases of an open-closed-open configuration.

Newell and Meng [1995] offered strong evidence for the uniqueness of θ aurora and a theory for their formation. It has long been established that polar cap arcs occur predominately during quiet times when $B_z > 0$ [*Davis*, 1963; *Hardy et al.*, 1986]. Therefore it was naturally assumed the same would be true for θ aurora. However, Newell and Meng showed that θ aurora, if defined strictly as arcs separated by many degrees from the auroral oval, occur during the reconfiguration of the magnetosphere from northward IMF to southward IMF. Thus θ aurora originate as ordinary polar cap arcs under northward IMF conditions, but detachment from the oval occurs only when B_z turns southward. *Newell et al.* [1997] generalized this statement to include transitions from relatively slow merging conditions to more rapid merging (for example, from large $|B_z|$ to $|B_z| < |B_y|$). θ aurora seem most common during complete reconfigurations of the polar cap, including a sign change in B_y, a point further emphasized by *Chang et al.* [1998].

On January 10–11, 1997 a magnetic cloud encountered the Earth. On January 10, from ~0145 to 0430 UT a very unusual case of double θ aurora occurred (although a well-defined θ aurora of any kind is comparatively unusual). Fortunately, for this event, Geotail was in the frontside magnetosheath, and hence the magnetic field encountering the magnetopause could be monitored without ambiguity. The January 10 instance nicely followed the scenario just described, with both transpolar arcs separating from the oval during the transition from northward IMF to southward IMF conditions, and with appropriate behavior of B_y. The January 11 event, which lasted from 0420 through 0930 UT, was also a double θ, although there is no reliable IMF data available (i.e., only Wind observations 60 R_E off the Earth-Sun line). Both events were spectacular, exhibiting many novel features. Besides the intrinsic interest these new phenomena represent, they collectively provide strong constraints on any theory of θ aurora. Indeed, we

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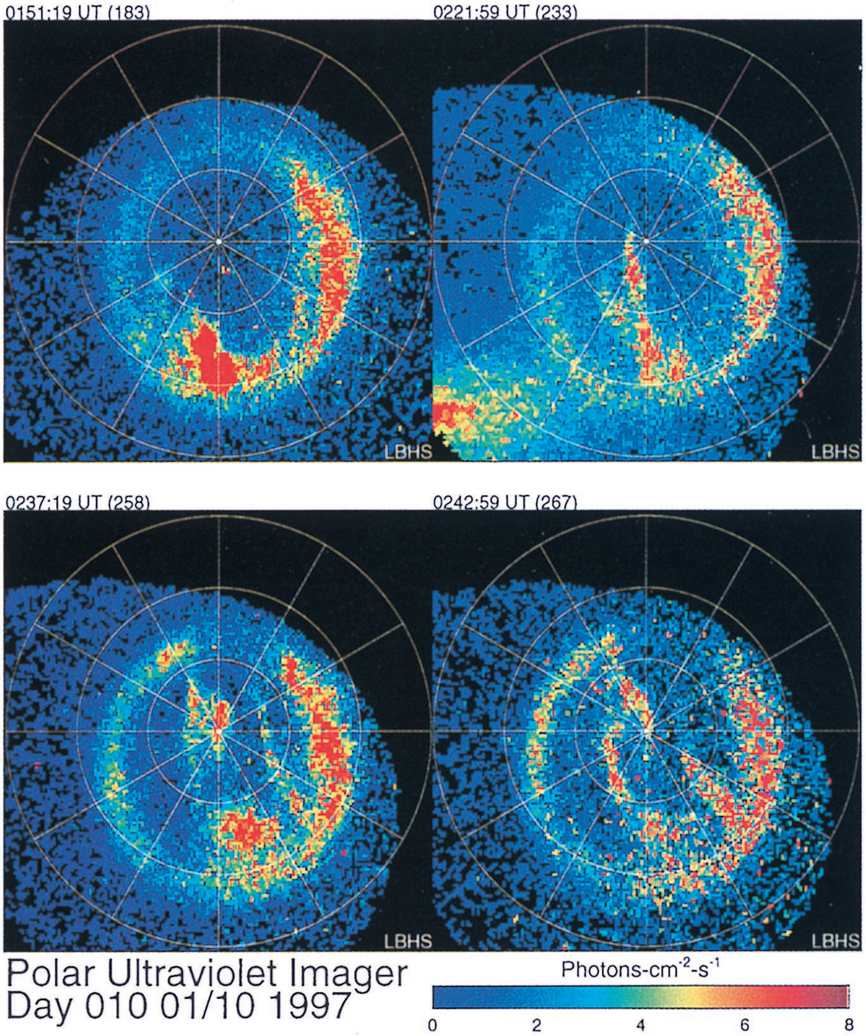

Plate 1. Polar UVI data with the LBHS filter for the January 10 double-θ aurora event. The three concentric circles of latitude represent 60°, 70°, and 80° MLAT. (top left) in a horse-collar configuration, during the initial interplanetary magnetic field northward interval. (top right) The duskside arc has detached and moved into the center. (bottom left) The dawnside arc detaches and moves toward the center. (bottom right) The two θ aurora begin fusing.

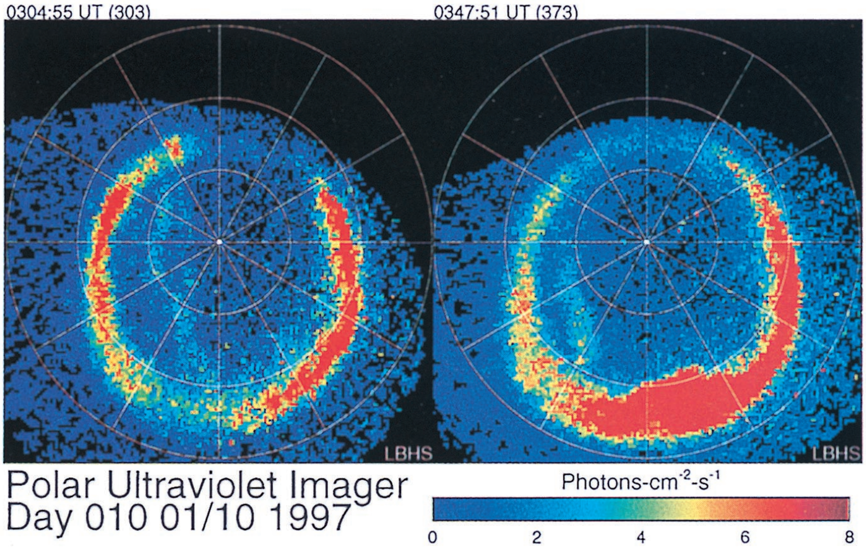

Plate 2. Continuation of Plate 1. (left) The two arcs have fused into one, and move toward dusk. (right) the combined θ aurora are now indistinguishable from a double-oval configuration. A well-developed substorm is underway.

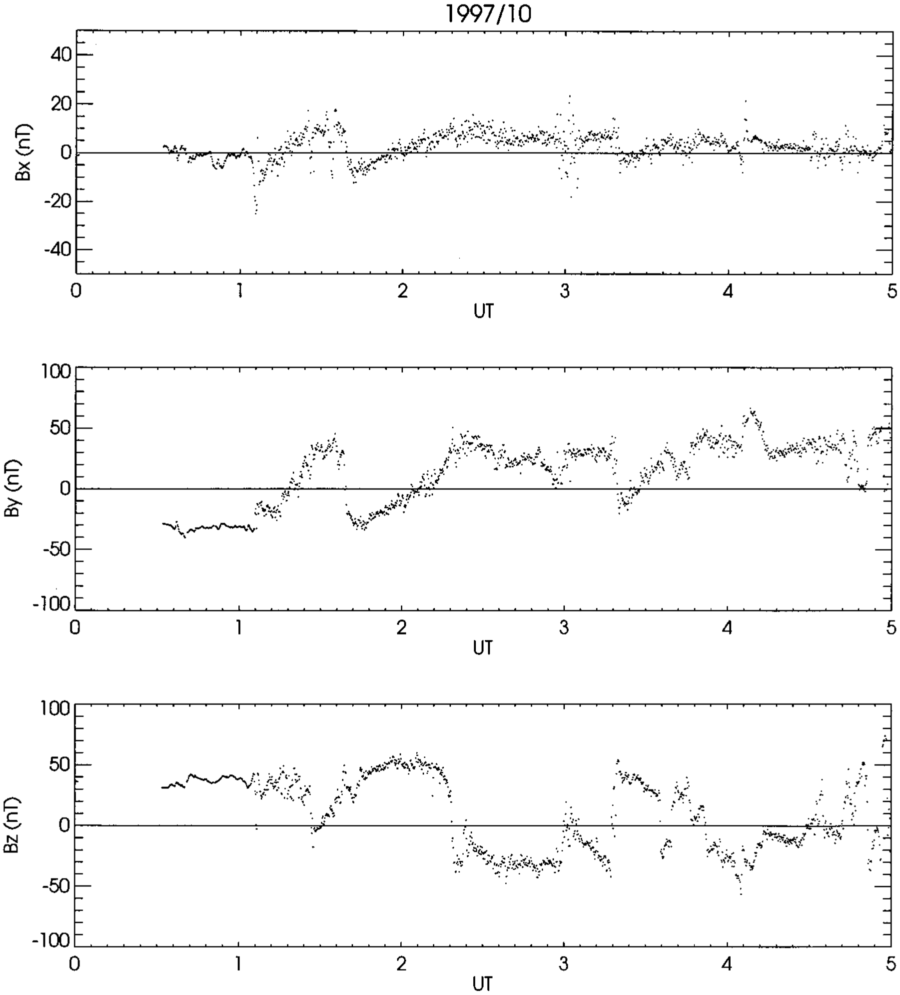

Figure 1. Geotail magnetic field data in GSM coordinates on January 10, 1997. Geotail was located in the frontside magnetosheath during this interval.

will argue these new results strongly support the model of *Newell and Meng* [1995]. For completeness, we note that *Spann et al*. [1998] examined Polar UVI images for January 10, 1998, including the polar cap structures, in less detail.

The Polar UVI instrument [*Torr et al*., 1995] and data set [*Brittnacher et al*., 1996; *Liou et al*., 1997] has been adequately described elsewhere, as has the DMSP particle detectors [*Hardy et al*., 1984]. The images shown herein are all using the Lyman-Birge-Hopfield "short" (LBHS) filter since it provides better resolution of the transpolar arcs (which are generally less energetic than nightside oval arcs). The imagers on Polar are mounted on an imperfectly despun platform, which causes a worst-case smearing of 12 pixels in the UVI images. At apogee (9 R_E), the resolution of a pixel is ~36 km, so the maximum uncertainty is ~12 × 36 km = 430 km. The images presented herein are blurred in approximately the noon-midnight direction.

2. January 10, 1997

Although the entire January 10–11 interval is subject to intense study by magnetospheric physicists, we will consider the January 10 interval from 0145 to 0430 UT, in which a θ aurora developed, moved, and disappeared. Fortunately, Geotail was in the magnetosheath during this event, so the magnetic field which encounters the magnetopause, shown in Figure 1, can be reliably determined. One mistake often made in the literature is to use IMF from satellites such as Wind which are usually far off the Earth-Sun line, and hence do not reliably represent the IMF which will encounter the Earth [e.g., *Collier et al*., 1998; *Sotirelis et al*., 1997; *Lyons et al*., 1997]. Although appropriate for statistical studies, such an approach is quite dangerous for case studies.

The relevant magnetosheath behavior can be summarized as follows: except for a brief southward excursion at ~0125 UT, B_z was positive until 0219 UT and negative thereafter for the remainder of the event. B_y was negative from about 0136 UT through 0215 UT and was positive thereafter.

Plate 1 illustrates the development of the θ aurora on January 10. In the quiet northward IMF interval prior to 0219 UT the polar cap developed a well-defined "horse-collar" auroral configuration in which the flanks of the auroral oval expand poleward (i.e., the polar cap contracts, especially at dawn and dusk). This auroral configuration is common [*Hones et al*., 1989], and is frequently characterized, as in the present case, with bars (i.e., transpolar arcs) along both oval flanks. Previous work has shown that under such conditions the bars are contiguous to the oval; that is, there is no significant gap in the plasma sheet type precipitation between the main oval and the polar cap arcs [*Meng*, 1981; *Newell et al*., 1997]. In the first frame of Plate 1 (0151 UT), the horse collar configuration can be distinguished reasonably well, although the duskside polar cap arc is bright near midnight and weak further toward the dayside. However, considering the series of images before and afterward, one can conclude that a bar extends on both flanks from nightside to dayside.

Starting around 0219 UT, the duskside bar separated from the oval and moved rapidly into the center of the polar cap, thus becoming a θ aurora. During this time the dawnside bar faded in intensity, but could be distinguished in the original data set throughout, still contiguous to the oval. Within a few minutes the new θ aurora reached the center of the oval, as shown in the second frame (top right) of Plate 1 (0222 UT). The dawnside oval remained in the undisturbed horse-collar configuration.

Little change can be observed over the next few minutes except that the intensity of the arc that originated from the dusk but is now centrally located fades, while the morphology is unchanged. Then beginning somewhere around 0232 UT the dawnside oval begins to separate. The dawnside polar cap arc, now θ aurora, moves in toward the center while the centered arc moves slowly back toward its origin, the duskside. In Plate 1, the image at 0237 UT (bottom, left) shows the situation after the dawnside arc has clearly separated from the oval. The configuration is now that of a double θ aurora.

The former dawnside arc, now also a θ aurora, continued to move into the polar cap. By 0242 UT (Plate 1, bottom, right) the formerly dawnside polar cap arc nears the center of the oval. The two arcs begin to merge, starting along the dayside. As the motion from dawn toward dusk continues, with the originally dawnside arc moving faster, the assimilation continues. By 0304 UT (Plate 2, left) an apparent single bar exists, along the duskside, slightly separated from the main oval. The intensity also has faded considerably by this time. The resolution of the UVI imager in the dawn/dusk direction (perpendicular to the blurring caused by platform wobble at this time) is ~36 km. Therefore the apparent uniting of these bars in the UVI image means that they are joined to within this resolution. Traditional single-bar θ aurora also appear as multiples when viewed from all-sky cameras on the ground [e.g., *Feldstein et al*., 1995].

After merging together, the remnants of the two arcs take over an hour to completely merge into the dusk oval. A substorm onset at 0334 UT starts at 0000 MLT, slightly removed from the nightside insertion point of the polar cap arc remnant, which is 2300 MLT. The only effect of the onset of the polar cap remnant is that it brightens slightly. For example, at 0347 (Plate 2, right) the transpolar arc is still there. An observer might well classify this configuration as the "double oval" reported by *Elphinstone et al*. [1995], and indeed, there may well ultimately prove to be an intimate connection. However, the history of how this "double oval" arose is much more complex than suggested from previous work.

The polar cap bar (or perhaps now poleward portion of the double-oval) continues to slowly merge into the duskside oval, and can no longer be distinguished sometime around 0410 UT. UVI data continue to be available for several more hours, but the event of interest has ended.

3. January 11, 1997

3.1. Polar UVI Observations

The first useful Polar UVI images for January 11, 1997, are from about 0438 UT, by which time a well-defined double-θ aurora already existed. Plate 3 (top, left) shows the situation at 0440 UT, with two very high latitude transpolar arcs apparently separated from the auroral oval dawn and dusk flanks. The two widely separated bars could almost be taken for a horse-collar configuration, except perhaps for their unusually high latitude, particularly on the dawnside. The real distinction is proven by the subsequent dynamics of the two transpolar arcs, although a late DMSP F13 pass does demonstrate an isolated plasma sheet fragment in the southern hemisphere.

The duskside transpolar arc is moving toward the center of the polar cap (and hence towards dawn) throughout the early minutes of the event. The dawnside arc is relatively stationary, hence the gap between the two shortens rapidly. By 0452 UT, as shown in the second frame of Plate 3 (top right), the originally duskside bar is nearing the center of the polar cap, and is nearing collision at one coordinate (70° MLAT, 00 MLT) with the dawnside transpolar arc. The subsequent development is fascinating. The arcs do not immediately encounter at the apparent looming collision point; instead, the duskside arc continues to close with the dawnside arc all along their lengths without touching anywhere. The result is shown in Plate 3 (bottom, left), which shows the state of affairs as of 0511 UT. The two arcs are now nearly parallel across the polar cap, except that the insertion points into the nightside oval are still spaced apart (~2315 and 0030 MLT respectively). For the next 10 min little changes except a very slow drift of both arcs toward dawn along their entire lengths.

The arcs fuse together very slowly, making it difficult to pick an onset of fusion. Our best guess is that fusion began ~0526 UT as shown in Plate 3 (bottom, right). From ~78° to 80° MLAT and at ~0030 MLT, the arcs appear to overlap. The region of overlap expands sunward, but at a glacial pace. Images over the next 5–10 min vary little from the final frame of Plate 3. Plate 4 (top, left), showing an image from 0538 UT, demonstrates however that the overlap is gradually becoming more substantial, although distinct nightside oval insertion points can still be distinguished. By 0557 UT (not shown) the fusion is complete (within the resolution of UVI, ~36 km in the dawn-dusk direction at this time), and one would never have supposed that an apparently classic single θ aurora configuration had arisen from the fusion of two separate transpolar arcs. Thereafter the combined arc system becomes almost motionless.

Indeed, little further change is exhibited for some time, although there seems to be a slight dawnward drift. Plate 4 (top, right) shows the situation at 0609 UT, with the transpolar arc at its furthest dawnward extent, which is not much different than its location 20 min earlier. The now dawnside transpolar arc remains motionless until 0621 UT. Thereafter it reverses course, moving back toward the center.

Plate 4 (bottom, left) shows the combined θ aurora shifted back to the center of the polar cap by 0633 UT. As this reverse motion back across the polar cap continues, the arcs appear to become slightly separated again. Plate 4 (bottom, right) shows that by 0704 UT the θ aurora has shifted back well toward the duskside. Notice that the nightside insertion point, although participating in the shift, moves more slowly than does the dayside portion of the arc. However, the nightside insertion

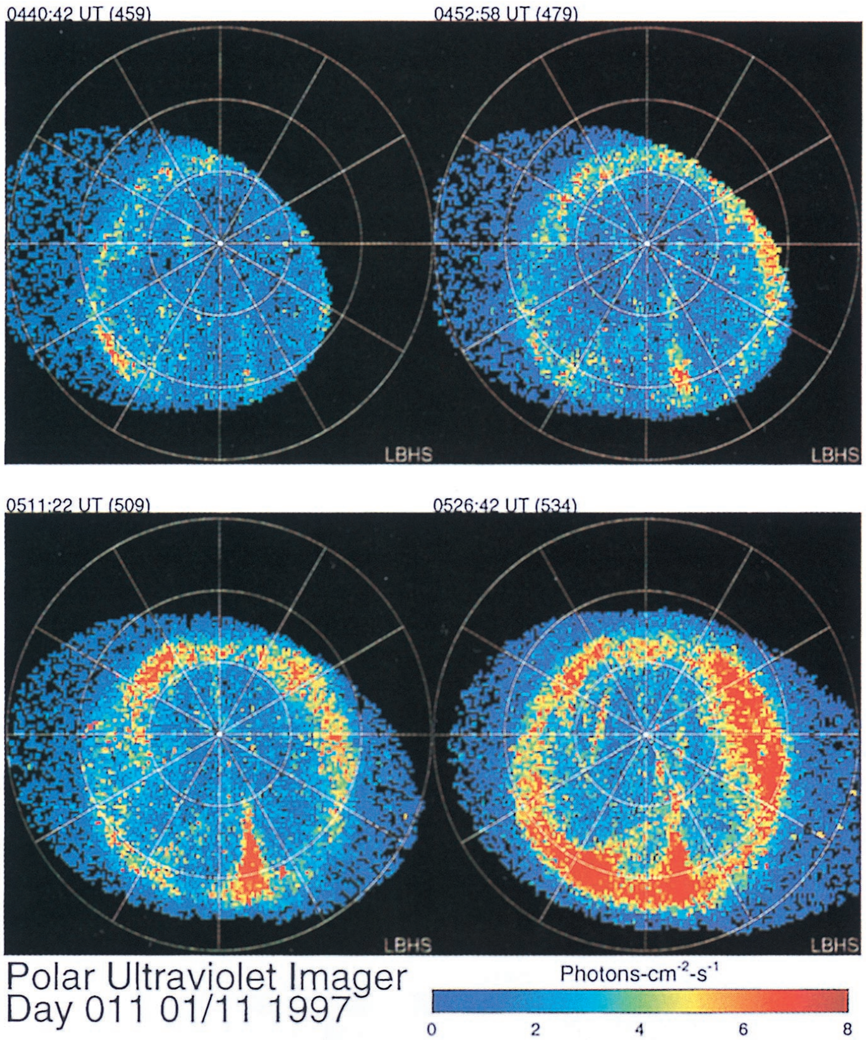

Plate 3. Polar UVI data with the LBHS filter for the January 11 double θ-aurora event (top left) Earliest available images for this event show an already well defined double θ aurora. (top right) The duskside arc moves toward the relatively stationary dawnside transpolar arc. (bottom left) the two transpolar arcs now parallel each other along their length without touching. Only the nightside insertion points are well separated. (bottom right) The arcs begin to fuse around 0100 MLT and 70° MLAT.

does indeed slowly reach the same local times as the rest of the arc. The first frame of Plate 5 demonstrates that by 0735 UT the entire bar (which again looks like a single entity) is located on the duskside. Notice how once again in Plate 5 (top, left) it is the nightside insertion point which is the most active spot on the nightside oval. Notice also that the entire oval as well as the transpolar arc has gradually brightened between 0704 and 0725 UT.

Although various portions of the oval and transpolar arc exhibit transient brightening, there is no change in the global morphology until ~0753 UT (Plate 5, top, right), when the transpolar arc suddenly fragments into two pieces, perhaps reflecting its origin as two transpolar arcs combined. Thereafter little happens for the next 25 min except variations in brightness. There appears to be a pseudo breakup in the nightside oval at ~0808 UT (not shown).

At 0830 UT a substorm onset occurs (not shown), with the initial brightening location coinciding with the nightside insertion point of the transpolar arc. The substorm onset, however, does not signal the onset of new dynamics for the θ aurora. Plate 5 (bottom, left) illustrates that 15 min later (0845 UT) the auroral bulge has spread, as expected, but the transpolar arc is largely unchanged. Our final image, Plate 5 (bottom, right), shows that at 0916 UT, >45 min after onset, the transpolar arc had undergone very little change. The arc finally faded from visibility starting around 0929 UT, dropping below reliable visibility after 0941 UT, more than an hour after onset. UVI data continue to be available for several more hours after the event ends with the fading of the arc.

3.2. DMSP Observations

There were three DMSP spacecraft operational on January 10–11, 1997, specifically F10, F12, and F13. Unfortunately, a combination of data gaps and unfortuitous orbits greatly restrict the usefulness of the DMSP data set in interpreting these events. However, some limited relevant information does exist for the January 11 event. Plate 6 shows (DMSP) F13 data from 1010 to 1024 UT, in the southern hemisphere. A well isolated plasma sheet fragment, indicated by an arrow, can be identified separated by many degrees latitude from either side of the auroral oval. Note the presence of ions in this fragment, a phenomenon usually associated with intense polar cap arcs

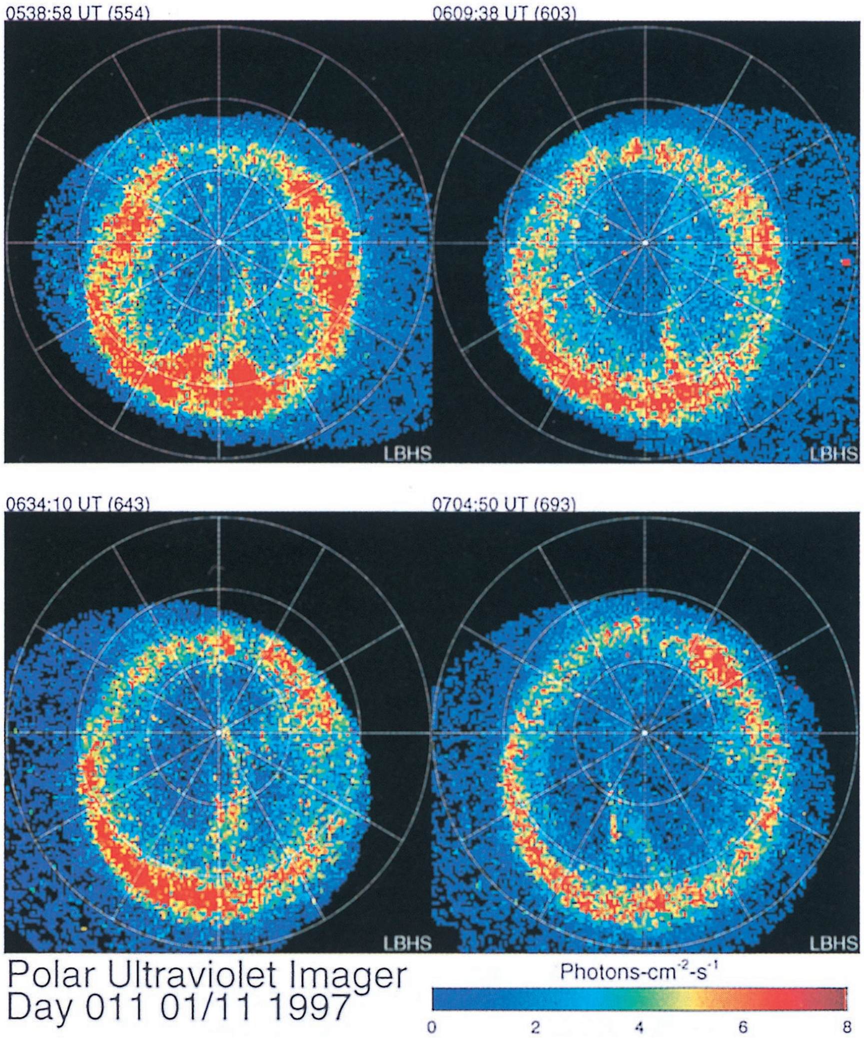

Plate 4. Continuation of Plate 3. (top left) The two θ aurora are now largely fused together, except for the nightside insertion points. (top right) the fully fused combined arc reaches its furthest dawnward limit. (bottom left) the combined arc is shifting back toward dusk, partly splitting again in the process. (bottom right) the temporarily separated θ aurora have reached the dusk flank.

typical of northward IMF [*Shinohara and Kokubun*, 1996], although we believe that θ aurora are the exception to this rule. Notice also the close resemblance between the plasma in the isolated fragment and the plasma in the poleward portions of the nightside auroral oval. The isolated plasma sheet fragment does not at this time have an electron energy flux high enough to be visible to an imager such as Polar UVI (the peak energy flux in the arc is only 0.06 ergs/cm^{2}s). Thus apparently isolated plasma sheet fragments occurred in both hemispheres and persisted even after becoming invisible to the imager and for at least 2 hours after a substorm onset.

4. Summary of Observations and Discussion

We have presented a number of new phenomena concerning the dynamics of θ aurora, that is, transpolar arcs that become widely separated from the auroral oval. Both of the events we studied exhibited much more complex development than was true in previous reports of θ aurora [*Frank et al*., 1986; *Newell and Meng*, 1995], which included only a single bar across the polar cap. Although double θ are not completely new (*Newell et al*. [1997] showed a spectrogram with a double-θ aurora), we believe this to be the first report of the dynamics of such events. (Note however that the existence of two θ-aurora for the January 10, 1997, event in Polar UVI images was shown by *Spann et al*. [1998].) Here are some of the unique features which we documented in the previous two sections:

1. The two θ aurora move in the same direction (or else one is relatively stationary).
2. If they are moving dawnward, the more duskward arc will move more quickly, and vice versa.
3. It is possible for the transpolar arcs to cross the polar cap from dusk to dawn and reverse direction, moving all the way back to dusk again (the ability of θ aurora to reverse direction was reported in a case presented by *Craven et al*. [1991]).
4. The pair of θ aurora, even though originating from opposite flanks of the polar cap, can merge into an apparent single bar (within the resolution of the imager, ~36 km). However, this merged bar is subject to subsequently splitting back into two, particularly during a dynamic period.
5. They persist at least an hour after substorm onset, presumably close to two hours after a southward IMF turning.

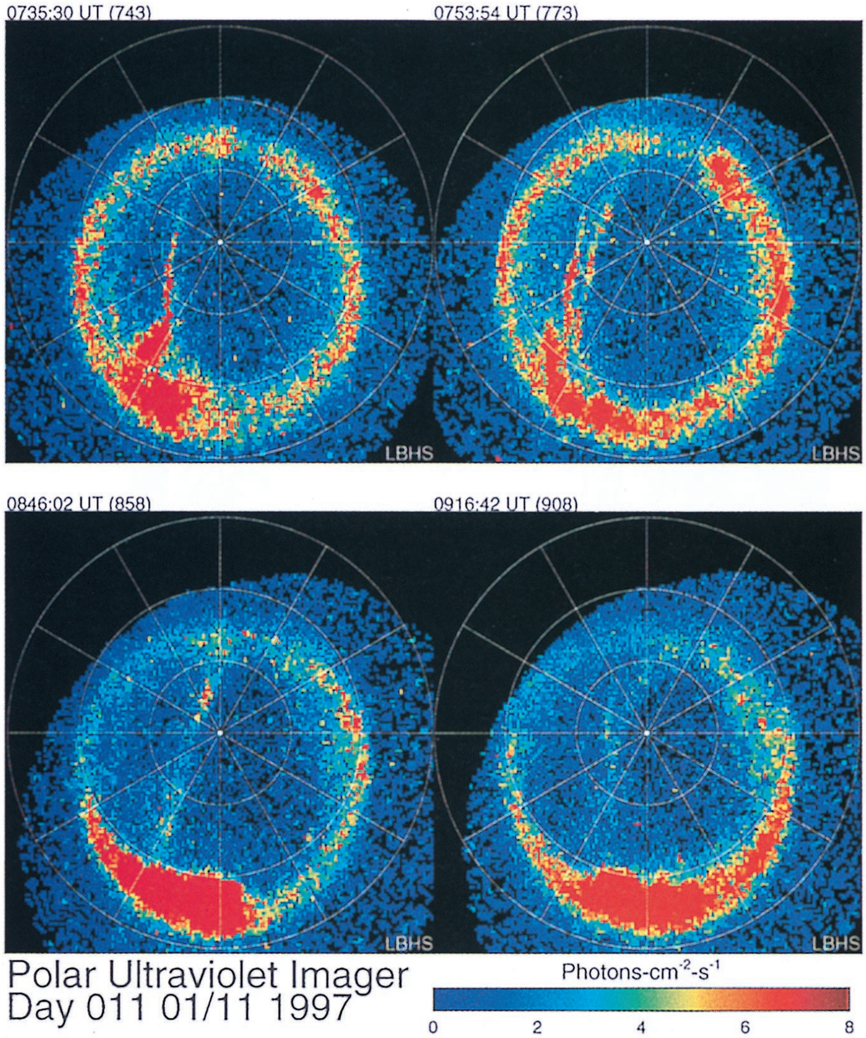

Plate 5. Continuation of Plate 4. (top left) The θ aurora have recombined, forming a single motionless transpolar arc on the dusk side. (top right) the combined arcs temporarily split apart again. (bottom left) with a well-defined substorm in progress the only response of the θ aurora is to shift slightly back toward the center. (bottom right) 45 min after substorm onset, the combined θ aurora remains visible.

This is distinct from more ordinary polar cap aurora [*Valladares et al.*, 1994], which disappear quickly after a southward IMF turning.

6. Occasional brightenings and fadings occur. The point of insertion into the nightwide auroral oval is frequently an auroral hot spot, although the apparent dayside insertion point is not.

7. A θ aurora which reach crosses the polar cap, abutting the opposite flank, can eventually be indistinguishable from a double oval configuration [*Elphinstone et al.*, 1995].

To put these observations into context, consider Figure 2, illustrating our conception of the development of θ aurora. The polar cap arcs originate in the usual way, that is under northward IMF conditions, with the plasma sheet expanding into the auroral oval, leading to a horse-collar type configuration. However, such arcs do not quite attach to the dayside oval [*Rodriguez et al.*, 1995; *Newell et al.*, 1995], leaving a gap between the transpolar arc and the cusp (with the non-midnight blurring of up to 12 pixels in these UVI images, it is not possible to verify whether the arcs attach to the dayside oval). When merging increases, new open flux convects primarily longitudinally along the open/closed boundary, and thus passes tailward of the transpolar arc without passing through it. Because the ionosphere is an incompressible fluid, the additional open flux pushes the transpolar arc away from the oval, hence creating the true θ-aurora configuration.

This model clearly explains points 1 to 2, since the addition of open flux to one flank will move the transpolar arc which is closest to the flank fastest. If the further transpolar arc moves at all, it will be moving more slowly, according to an overall reconfiguration of the polar cap. Item 3 simply requires a change in the predominant flank to which new merging is added, which normally would imply a change in IMF B_y. Item 4 seems neither to be a prediction of our model nor in contradiction to it. Item 5, the persistence of the θ aurora as opposed to ordinary high-latitude polar cap arcs, is readily understandable. Ordinary transpolar cap arcs simply represent a contracted polar cap (expanded oval) and thus the addition of new merging re-inflates the polar cap, causing prompt disappearance of such arcs after a southward IMF turning [*Valladares et al.*, 1994]. However, although the peculiar open-closed-open configuration is a relatively unusual occurrence, once it happens it appears to be relatively stable; that is, it may be almost as difficult for the magnetosphere to escape from

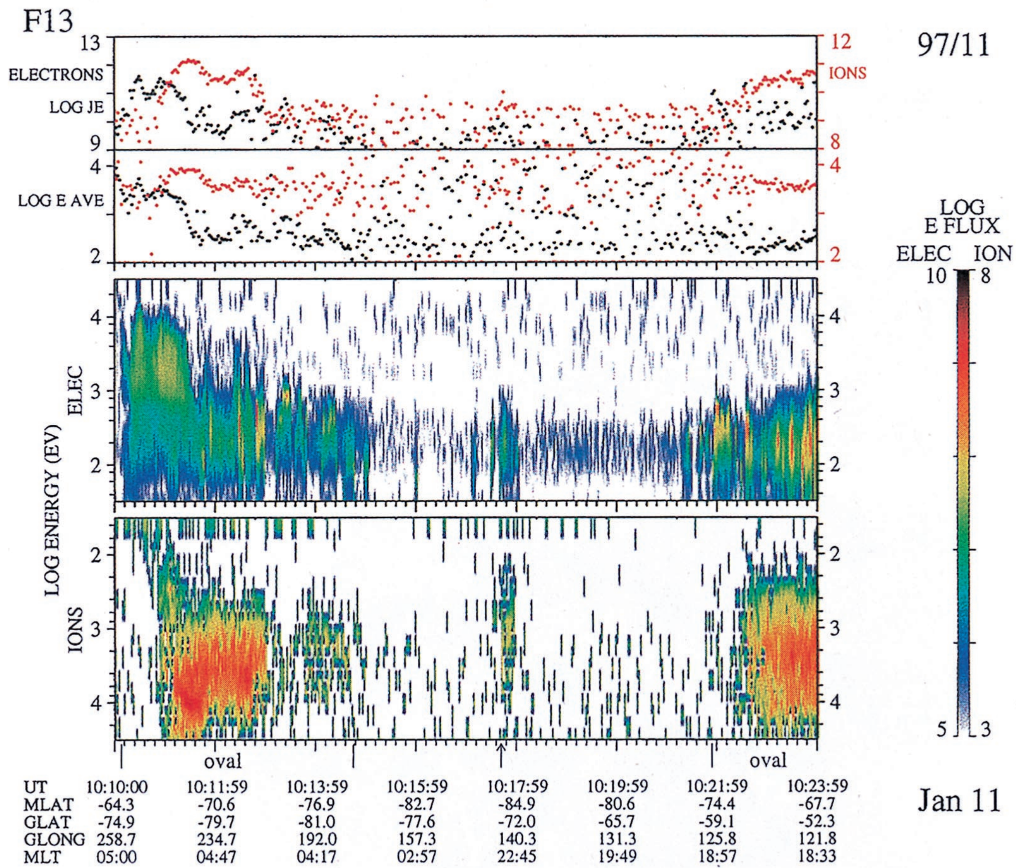

Plate 6. A spectrogram of DMSP F13 observations of precipitating electrons and ions on January 11, 1997, from 1010 to 1024 UT. An isolated plasma sheet fragment (arrow) can be observed in the southern hemisphere well detached from either oval. The precipitating electron energy flux in the polar cap arc is well below the threshold of visibility for a global imager.

this situation as it is for it to arise. A similar persistence was noted for single θ aurora by *Newell et al.* [1997], and indeed, the event shown by *Craven et al.* [1991] also persisted hours after a southward IMF turning. Finally, the model explains point 6, since we argue that transpolar arcs are connected to the nightside oval but do not quite reach the midday oval.

The January 10 event, for which Geotail was in the magnetosheath, offers additional support in that the change from

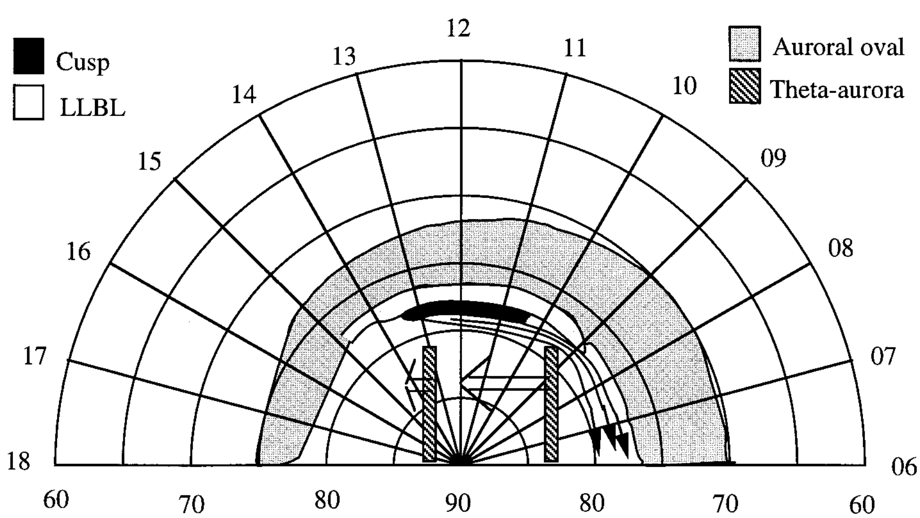

Figure 2. A mechanism for creating θ aurora, and explaining the relative motion of double θ aurora. Newly merged flux is added preferentially to one flank of the polar cap depending on the sign of IMF By. The θ aurora closer to that flank moves toward the more distant θ aurora, which is relatively slow moving, or even motionless.

dawnward motion to duskward motion corresponded to a change in the sign of B_y. There is a slight puzzle, however, in that dawnward motion apparently continued for ~7 min after B_y changed sign to positive around 0215 UT. Conceivably draping in the magnetosheath, or propagation delays in the ionosphere, could account for this slight anomaly.

There is one other model in the literature equally capable of accounting for these observations, namely that of *Chang et al.* [1998]. The *Chang et al.* [1998] model is in fact largely an extension of the work of *Newell and Meng* [1995] and *Newell et al.* [1997]. The great similarities can be seen by comparing the middle and bottom rows of *Chang et al.*'s Figure 1, especially if it is considered that the lack of an sign flip in B_y for the *Newell and Meng* [1995] model was never specified by these authors themselves. Since the model supposes a transition from a low-merging condition to a higher merging condition, the initial sign of B_y was considered ambiguous. However, it is true that observations have indicated that most theta aurora involve changes in the sign of B_y as well as B_z.

That the model of *Chang et al.* [1998] extends the earlier work and is more complete is made clear by realizing that Newell and co-workers never attempted to specify the three-dimensional configuration of the magnetosphere as *Chang et al.* [1998] do. However, one deficiency of the *Newell and Meng* [1995] model which is not corrected by *Chang et al.* [1998] is that these models predict only necessary conditions for theta aurora to occur. No one yet has been able to produce a list of conditions sufficient to insure that theta aurora definitely will occur.

Finally, we note that although occasional claims are still made that θ aurora can separate from the oval and move into the center of the polar cap for northward IMF conditions [*Cumnock et al.*, 1997; *Chang et al.*, 1998], only IMF monitors far off the Earth-Sun line have been used to find examples supporting this idea. Because of the poor correlation between such monitors and the IMF which actually encounters the magnetopause, and because of the fact that in all cases where appropriate IMF monitors were used, θ aurora formed only for $B_z < 0$ (or at least $|B_y| \gg |B_z|$), the evidence appears overwhelming that rapid dayside merging is a precondition for the formation of θ aurora. Once formed, their longevity can result in a persistence through a variety of IMF conditions. It is worth pointing out that the worst of all cases to examine based on a distant monitor is when the IMF is nearly radial ($B_y \sim B_z \sim 0$; B_x significant). In this notorious condition, the field which exists in the magnetosheath cannot be predicted from an IMF monitor even if located at the bow shock, except that the sheath field will have small B_x (a physical necessity in the magnetosheath) and much larger components of either B_y or B_z or both but with unpredictable sign. Unfortunately, *Chang et al.* [1998] argue that just such a case, observed by Wind, argues against the model of *Newell and Meng* [1995].

The poor reliability of Wind and ISEE 3 as monitors of the field which strikes the bow shock has been thoroughly documented elsewhere [*Russell et al.*, 1980; *Crooker et al.*, 1982; *Sotirelis et al.*, 1997; *Lyons et al.*, 1997; *Collier et al.*, 1998] and will not be further labored here. We wish only to emphasize that in all cases where reliable IMF monitors have been used, θ aurora separate from the oval during a reconfiguration of the polar cap from a low merging rate condition to a higher merging rate condition (and as emphasized by *Chang et al.* [1998], usually in conjunction with a change in the sign of B_y also).

5. Conclusions

The magnetic cloud event of January 10–11, 1997 resulted in two distinct intervals of θ aurora, i.e., transpolar arcs topologically separated from the auroral oval. Although the θ aurora itself is much rarer than the more common transpolar arcs which are attached to the auroral oval, these two events were even more unusual in exhibiting two simultaneous detached arcs. The dynamical behavior of these paired θ aurora includes fascinating geophysical phenomena which provide significant constraints on any model of θ aurora. The observations that both arcs consistently move in the same direction, with the forward arc moving more slowly (e.g., the dawnward arc in the case of dawnward motion) agrees well with the idea proposed by *Newell and Meng* [1995], that θ aurora arise during reconfiguration of the magnetosphere when bursts of new merging are added to one or another flank of a previously quiescent polar cap. Another observation, mentioned in one previous case in literature [*Craven et al.*, 1991], namely, the ability of the arcs to reverse direction after crossing the polar cap, similarly fits well with this model. Additional evidence is presented confirming earlier work that θ aurora, unlike the more typical high-latitude arcs, last long into the onset of higher auroral activity; persisting more than an hour after substorm onset (which itself generally happens ~40–60 min after a southward IMF turning). This resilience of θ aurora further distinguishes them from other transpolar arcs.

We found additionally several new θ aurora behavior that neither supports nor contradicts our model. These new behaviors include the ability of the paired arc systems to merge, although they can subsequently separate again, and the possibility of a θ aurora that is convected tightly against an auroral flank eventually becoming indistinguishable from the "double-auroral oval" configuration.

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