CONJUGATE BREAKUP

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Abstract: Observation of auroral breakup sequences with all-sky cameras carried on conjugately flying aircraft indicates that the breakup occurs simultaneously or near-simultaneously in the two hemispheres. Observed differences in the auroral behavior during breakup are compatible with the general finding that auroras on the 256° meridian tend to be brighter and more numerous in the northern hemisphere.

A total of 18 flights of all-sky camera-equipped aircraft have been made to investigate conjugacy of auroras along the 256° meridian through Alaska and south of New Zealand. Series of flights were conducted in March 1967, March 1968, Fall 1970 and Fall 1971 with the aircraft being deployed along conjugate paths according to the GSFC 12/66 or 10/68 field models. Here we rely primarily on results of these flights published in three papers by BELON *et al.*, 1969; STENBAEK-NIELSEN *et al.*, 1972; STENBAEK-NIELSEN *et al.*, 1973 and on results of analyses currently underway. Also the scanner images obtained by C. D. ANGER from the ISIS-II satellite and those from the U. S. Air Force DAPP satellites are quite useful in interpreting the observations of conjugate auroral breakups (SNYDER *et al.*, 1973).

A reasonable definition of the auroral breakup is that given by AKASOFU (1964) to define the onset of the auroral substorm. In his definition the onset of the substorm is the breakup; if one chooses to define the substorm as consisting of growth, expansion and recovery phases, then the beginning of the breakup defines the onset of the expansive phase. The breakup is defined as the brightening, contorting and poleward expansion in the usually weak and perhaps diffuse arcs aligned east-west along the auroral oval; such arcs apparently always exist even in extremely quiet times. Onset of the breakup statistically occurs near midnight but may be at locations several hours to either side of the midnight meridian. The breakup tends to expand east and west from the point of initiation, and a pronounced poleward expansion of discrete, violently moving, bright auroras occurs, often leaving patchy, irregular auroral forms in the wake (equatorward side) of the poleward expansion. An example of this behavior is illustrated by the four DAPP scanner images shown in Fig. 1. During Pass 1098, the aurora is in a quiet phase. The AE index indicates that a breakup initiation occurred some minutes prior to Pass 1099 which shows discrete brightening in the pre- and post-midnight sectors. Although a second breakup may actually have occurred prior

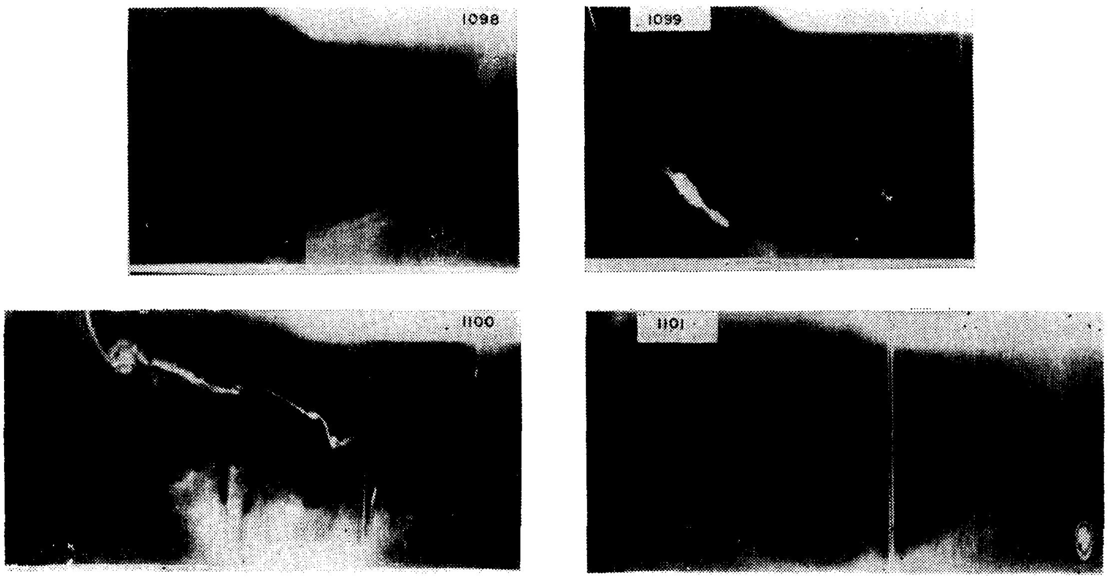

Fig. 1. Successive scanner images of the auroral oval obtained by a DAPP satellite on January 25, 1973. In each image the direction toward the sun is at top and the midnight position of the auroral oval is at bottom center. The image is approximately 3000 km wide. Bright points outside the aurora are caused by cities; the large circular spot in the lower right of Pass 1101 is an oil field.

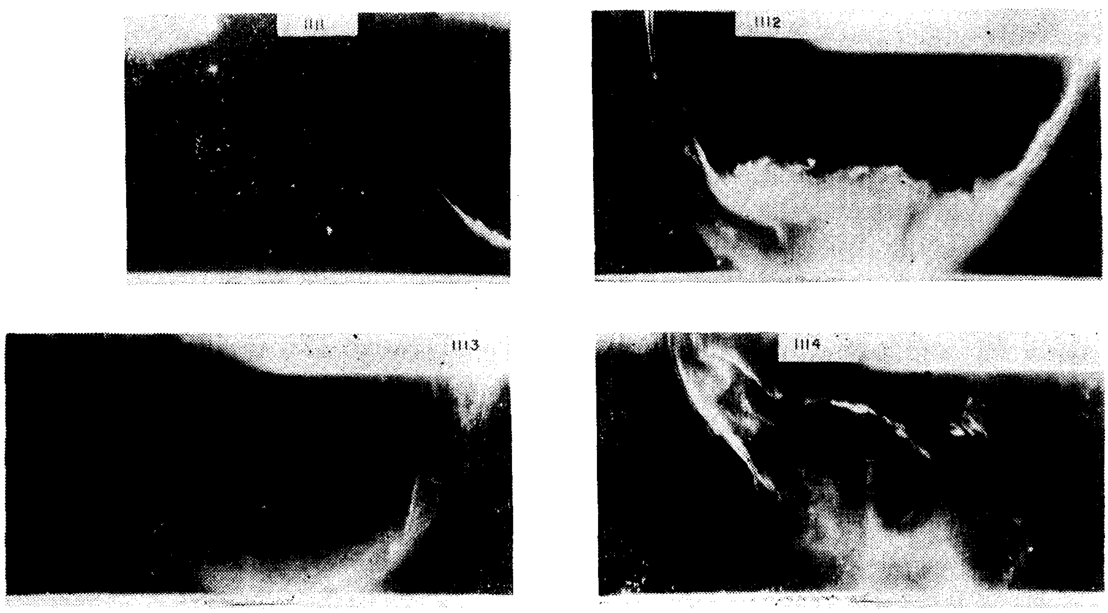

Fig. 2. Successive scanner images obtained January 26, 1973; see title to Fig. 1.

to Pass 1100, this pass shows the poleward expansion of the discrete aurora and the more diffuse and irregular auroras remaining along the previous position of the oval near midnight. By Pass 1101, 100 min later, the aurora has returned to essentially a quiet phase. In Fig. 2, the image from Pass 1112 shows the aurora near the peak of the breakup phase (expansion phase). The next pass, Pass 1113, is in the recovery phase of this large substorm. Prior to Pass 1114 a new breakup has occurred. The image obtained on Pass 1114 is not unlike the image of Pass 1100, Fig. 1. Essentially the images in Figs. 1 and 2 hint at some of the differences that occur between breakups developing under quiet and active conditions: the developments are similar in many ways, but differences are obvious.

Before focusing attention on the observations of the degree of conjugacy of the breakup itself, it is instructive to summarize the general results on conjugacy obtained by the aircraft flights in terms of the configurations observed in the ISIS-II and DAPP satellite images. BELON *et al.* (1969) reported a remarkable degree of conjugacy of auroras observed during quiet conditions, those auroras being general diffuse arcs and more-discrete arcs and bands of weak to moderate intensity. For the most part, these auroras are those lying at or near the equatorward boundary of the auroral oval such as are seen in the image from Passes 1098 and 1099 (Fig. 1) and along the equatorward boundary of the aurora shown in Pass 1113 of Fig. 2. That is to say, the diffuse and discrete auroras along the quiet time auroral oval are found to be almost exactly conjugate relative to the GSFC 10/68 field model. This region has been referred to as the 'equatorward arc system' in the descriptions of the conjugate observations (STENBAEK-NIELSEN *et al.*, 1972).

Those discrete and relatively bright auroras seen to lie poleward of the equatorward boundary, as in Passes 1100, 1112, 1113 and 1114 of Figs. 1 and 2, obviously correspond to the 'poleward arc system' as defined in the paper by STENBAEK-NIELSEN *et al.* (1972). Such auroras have been found to have corresponding but displaced counterparts in both hemispheres or, in some cases, to have no conjugacy at all. Where displacements are observed, the southern hemisphere auroras are typically equatorward by up to 150 km of their northern hemisphere counterparts, usually displaced westward by up to 200 km before breakup (or in the sector to the west of breakup initiation) and are invariably displaced eastward by 100 km to 200 km after breakup (or in the sector east of breakup initiation). Examples of displaced but conjugate active auroras are shown in Figs. 3 and 4.

At this particular longitude, dp 256°, the auroras identified as being in the equatorward arc system are invariably brightest in the northern hemisphere by a factor of approximately 1.3. The relative intensity of the discrete auroras lying poleward of the equatorward boundary of the oval is variable, but, on the average, those in the northern hemisphere also are the brightest (STENBAEK-NIELSEN *et al.*, 1973).

On several occasions during the 18 pairs of aircraft flights, the two aircraft were located advantageously to observe auroral breakups. On other occasions apparent poleward expansions could be observed but the aircraft were not appropriately located to observe the breakup initiation. In a study currently underway, we are examining the onset times of brightening and poleward expansion. We have identified 24 such events occurring on 14 nights; some of the events involve only brightening in the aurora without clear-cut poleward expansion. In

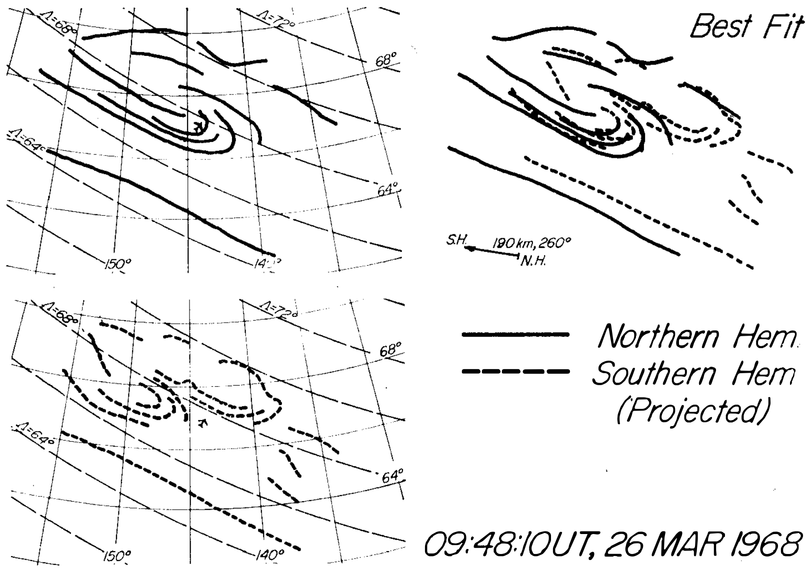

Fig. 3. *Relative westward displacement of southern hemisphere auroras observed at $\Lambda = 68°$ on 26 March 1968. The two aircraft were on conjugate positions relative to the earth's internal magnetic field as calculated by the GSFC 12/68 field model. The surge has a westward velocity of 3–4 km/sec and the southern hemisphere surge is moving 190 km ahead of the northern (from* STENBAEK-NIELSEN *et al., 1972).*

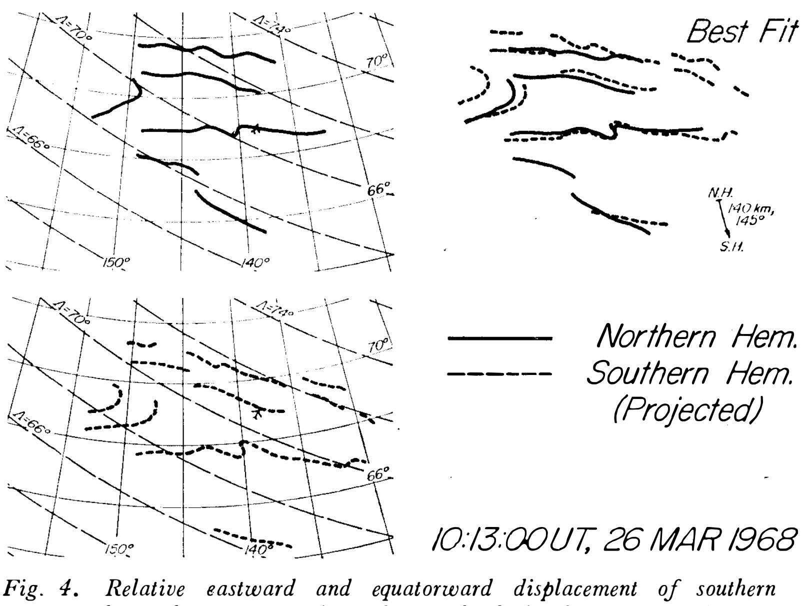

Fig. 4. *Relative eastward and equatorward displacement of southern hemisphere auroras observed in multiple bands near $\Lambda = 69°$ on 26 March 1968. The auroral bands are drifting slowly eastward. The positions of the two aircraft are conjugate with respect to the internal field model, and the southern hemisphere forms are displaced 140 km eastward and equatorward of the similar northern hemisphere auroras (from* STENBAEK-NIELSEN *et al., 1972).*

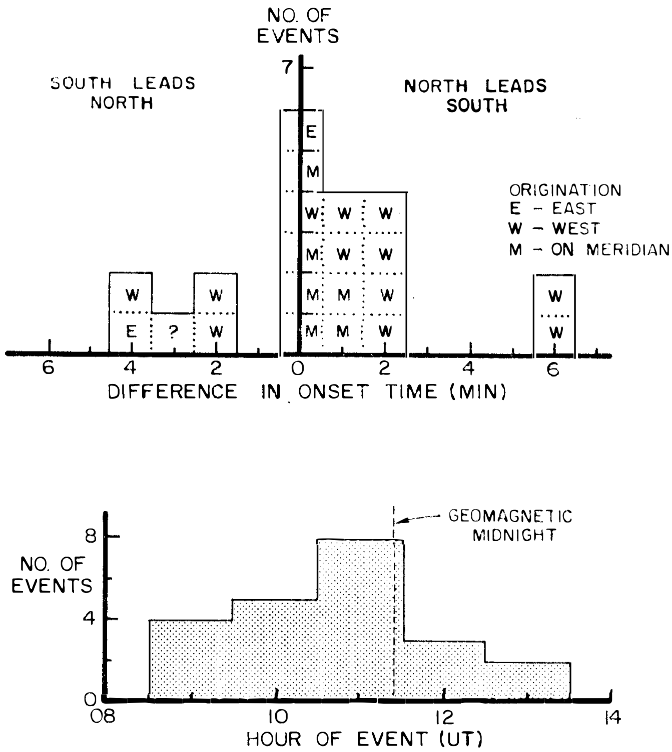

Fig. 5. Summary of 21 events with brightening and poleward expansion of auroral forms observed over conjugate areas along the College, Alaska magnetic meridian. The top part of the diagram gives the distribution of events as a function of time difference in the onset of the auroral breakup over conjugate areas. For each event letters W, E or M indicate whether the activity appears to originate west of, east of or on the meridian. The bottom part of the diagram gives the UT distribution of the 21 events.

some cases brightening or poleward expansion is detected in only one hemisphere. Some of the results are summarized in Fig. 5. There it is seen that the brightenings or poleward expansions occurred simultaneously in the two hemispheres to within 7 min and, in most cases, to within 2 min. Note in particular that events originating on the meridian appear simultaneously within 1 min. The top diagram of Fig. 5 indicates a slight tendency for events to be observed first in the northern hemisphere. However, this tendency is probably due to the tendency for auroras to be brighter in the northern hemisphere (STENBAEK-NIELSEN *et al.*, 1973) which could contribute to brightening being seen there first.

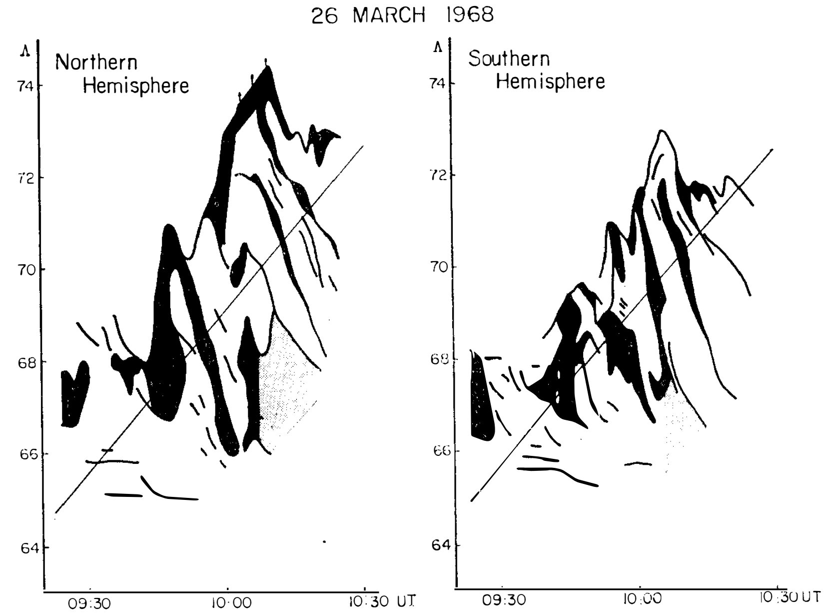

Fig. 6. Distribution of aurora along the College, Alaska magnetic meridian observed during the time interval 0930–1030 UT, 26 March 1968. The dark shaded areas indicate very bright aurora with no details visible on the all-sky film (film saturated). The lighter shaded areas are patchy aurora and glow. The auroras in the northern hemisphere are seen to be displaced 1° poleward relative to the auroras in the south. The gross features of the plots are similar in the two hemispheres, with the differences in the details mainly due to the longitudinal displacements as seen in Figs. 3 and 4. The straight lines show the aircraft position.

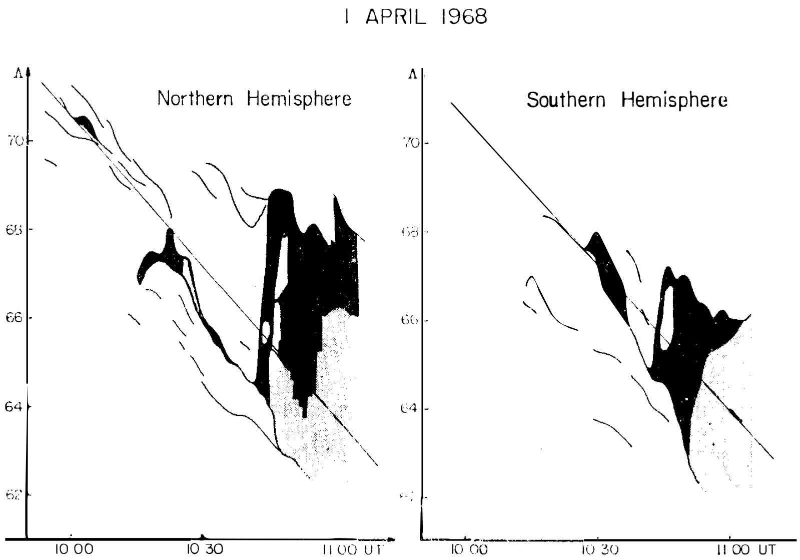

Fig. 7. Distribution of aurora along the College, Alaska magnetic meridian observed 1000–1100 UT, 1 April 1968. (See also title to Fig. 6).

It is somewhat curious that more events are observed to come from the west than the east since most of the events are observed prior to geomagnetic midnight (see bottom panel of Fig. 5). The explanation may be that the breakup sequence probably is more complex than the simplest view of it and that the initiation is not always exactly on the midnight meridian. Further, the breakup may be manifesting itself differently to the east and west of the meridian on which it originates.

In order to illustrate the similarities and differences between breakup observed in conjugate regions, we have prepared plots showing the latitude extent of aurora as a function of time. One of these, Fig. 6, shows a high degree of similarity in the distribution of auroras with time. In both hemispheres, the poleward expansion starting near 0940 UT is clearly seen. A detailed investigation of the conjugacy of the visual auroras observed during this substorm was given by STENBAEK-NIELSEN *et al.* (1972). Although the plots for the two hemispheres show difference in detail due to longitudinal displacements of the conjugate forms, the gross features and the latitudinal extent at any one time are generally similar. Figure 7 provides an example wherein the onset of the breakup and the poleward expansion are more clearly shown. However, definite differences between the auroras in the two hemispheres appear. Prior to ~1015 arc-like forms are seen in the northern hemisphere only. At that time auroras begin to appear in the southern hemisphere and the auroras in the north become more widespread in latitude. The breakup

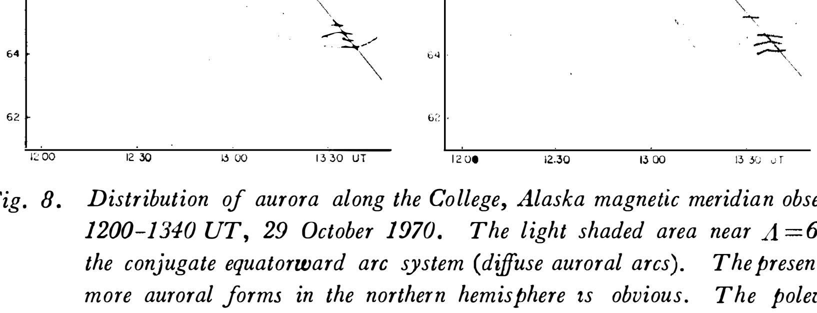

Fig. 8. Distribution of aurora along the College, Alaska magnetic meridian observed 1200-1340 UT, 29 October 1970. The light shaded area near $\Lambda=65$ *is the conjugate equatorward arc system (diffuse auroral arcs). The presence of more auroral forms in the northern hemisphere is obvious. The poleward expansion observed between 1210 and 1220 UT is only seen in the north and the breakup observed over Alaska near 1235 UT is only indicated in the southern hemisphere by the brief appearance of a few faint rayed arcs 6 minutes later.*

originates in both hemispheres near the equatorward boundary at 1042 and a rapid poleward expansion ensues. Yet the poleward expansion in the north extends much farther poleward than in the south. In general, throughout the interval shown in Fig. 7, the northern hemisphere auroras are more numerous and more widespread in latitude.

Somewhat similar behavior is shown by the example in Fig. 8. A relatively minor breakup and poleward expansion is detected essentially only in the northern hemisphere (conjugate all-sky data for this event is given in Fig. 3 of the paper by STENBAEK-NIELSEN *et al.*, 1973). However, similar activity was observed in the equatorward arc-system at 65° invariant latitude both near the beginning and towards the end of this aircraft flight.

Discussion and Summary

Analyses of the aircraft data acquired along the 256° meridian indicate that the auroral breakup occurs simultaneously or near-simultaneously in the two hemispheres. Observed differences in the auroral behavior in the conjugate regions are compatible with the general finding that the auroras on this meridian tend to be brighter and more numerous in the northern hemisphere in both spring and fall. Minor breakups (or perhaps intensifications not properly called breakups) are usually better defined in the north. Well-defined breakup sequences are either similar in the two hemispheres or show generally a more pronounced poleward expansion in the northern hemisphere. During the breakup, the aurora is so complex that it is difficult to determine the degree of conjugacy; however, it appears that the auroras on the equatorward boundary are conjugate relative to the GSFC 10/68 field model during the breakup, as they are known to be before and after. Discrete auroras poleward of these auroras usually exhibit relative displacement; the southern auroras are equatorward and eastward of the northern counterparts after the breakup and are equatorward and usually westward before. The reason why such displacements are occurring is as yet unknown. The differences in intensity along the 256° meridian are probably due to the difference in magnetic field strength at the two ionospheres. If this is the proper explanation, then observations at other longitudes should yield different intensity ratios. For example, the Syowa-Reyjavik conjugate station pair should show brighter auroras over Syowa.

Acknowledgements

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