

## DOUBLE LAYERS ABOVE THE AURORA

M. Temerin and F. S. Mozer  
 Space Sciences Laboratory and Physics Department  
 University of California, Berkeley, California 94720, U.S.A.

## ABSTRACT

Two different kinds of double layers have been found in association with auroral precipitation. One of these is the so-called "electrostatic shock," which is oriented at an oblique angle to the magnetic field in such a way that the perpendicular electric field is much larger than the parallel electric field. This type of double layer is often found at the edges of regions of upflowing ion beams and the direction of the electric field in the shock points toward the ion beam. The potential drop through the shock can be several kV and is comparable to the total potential needed to produce auroral acceleration. Instabilities associated with the shock may generate obliquely propagating Alfvén waves, which may accelerate electrons to produce flickering aurora. The flickering aurora provides evidence that the electrostatic shock may have large temporal fluctuations.

The other kind of double layer is the small-amplitude double layer found in regions of upward flowing ion beams, often in association with electrostatic ion cyclotron waves. The parallel and perpendicular electric fields in these structures are comparable in magnitude. The associated potentials are a few eV, which is substantially less than the energy of the measured particles. However, since many such double layers are found in regions of upward flowing ion beams, the combined potential drop through a set of these double layers can be substantial.

Some important questions concerning double layers and their relation to parallel electric fields in the aurora are:

1. What is the relation between small-amplitude double layers and electrostatic shocks?
2. What is the relation between electrostatic shocks and discrete arcs?
3. Are there strong double layers in the aurora?
4. What is the relation between ion conics and electrostatic shocks?
5. What are the parallel electric field magnitudes on auroral field lines?
6. Are there large parallel electric fields in the return current region?
7. How important are the dynamic properties of the parallel electric field on auroral field lines?

Here are some answers:

1. What is the relation between small-amplitude double layers and electrostatic shocks?

Small-amplitude double layers and electrostatic shocks are distinctly different phenomena. Electrostatic shocks are large, greater than about 100 mV/m, mostly perpendicular electric fields that vary discontinuously when measured at the 0.125 s resolution of the dc electric field detector on the S3-3 satellite below 8000 km altitude (Mozer et al., 1977, 1980) (see Fig. 1 for examples). Small-amplitude double layers are several mV/m, mostly

parallel electric fields lasting for a few milliseconds as measured by the S3-3 satellite (Temerin et al., 1982; Mozer and Temerin, 1983; Temerin and Mozer, 1984a,b) (Fig. 2). Electrostatic shocks occur in both upward and downward current regions (Cattell et al., 1979) in association with both upflowing ion beams and ion conics (Redsun et al., 1985) (Figs. 3 and 4). The electrostatic shocks associated with upflowing ion beams typically occur at the edges of energetic ( $>1$  keV) upflowing ion beams (Temerin et al., 1981; Bennett et al., 1983; Temerin and Mozer, 1984a; Redsun et al., 1985), and the potential drop through the electrostatic shock corresponds fairly well to the energy of the upflowing ion beam. Small-amplitude double layers, on the other hand, occur within regions of less energetic upflowing ion beams, and the potential drop through many small double layers may correspond to the total potential drop along the field line. It is often difficult to determine on the basis of the S3-3 wave data whether small-amplitude double layers occur in more energetic ion beams because of detector saturation problems associated with the large-amplitude wave turbulence that occurs in the more energetic events.

## 2. What is the relation between electrostatic shocks and discrete arcs?

It has previously been argued that electrostatic shocks are associated with discrete arcs (Torbert and Mozer, 1978; Kletzing et al., 1983). It is clear from the data that, as described in 1 above, some electrostatic shocks are associated with upflowing ion beams and inverted-V events. Other electrostatic shocks are associated with conics and counterstreaming and field-aligned electron events (Temerin and Mozer, 1984a). These latter electrostatic shocks would then not be associated with discrete arcs. It should be noted that upflowing ion beams and inverted-V electron events associated with electrostatic shocks have the  $\sim 10$  km to over 200 km latitudinal width normally associated with inverted-V electron events (Lin and Hoffman, 1979a; Redsun et al., 1985). This is typically larger than the latitudinal width of the electrostatic shock and implies that the electrostatic shock makes an oblique angle with respect to the magnetic field over part of its altitudinal extent.

## 3. Are there strong double layers in the aurora?

Whether there are strong double layers in the aurora depends to some extent on one's definition of a strong double layer. If by a strong double layer one means a potential drop the order of a significant fraction of the total auroral zone potential drop over a few Debye lengths, then the parallel electric field should be in excess of 1 V/m. Boehm and Mozer (1981) searched the S3-3 electric field data and found no convincing parallel electric fields greater than 250 mV/m in association with inverted-V events. They concluded that strong double layers are not associated with inverted-V events but could be associated with narrow discrete auroral arcs since the statistics were not good enough to rule out strong double layers if they were confined to narrow regions. This begs the question of whether there is any qualitative difference between narrow discrete arcs and inverted-V electron events with respect to the auroral potential structure. The problem of narrow discrete arc scales was raised by Maggs and Davis (1968) who reported that discrete arcs had scales down to 70 m. It has become popular to contrast such scales with inverted-V scales which are known to be much larger. However, the observation of 70 m scales was made by image orthicon television cameras that tend to emphasize small contrasts (Davis, 1978). Rocket observations indicate that typically the smallest gradients in the downward auroral electron energy flux are an order of magnitude larger (D. Evans, private communication). One should also keep in mind that inverted-V scales can be quite small. Lin and Hoffman (1979a), using AE-D data, reported that the largest number of inverted-V events had scales close to the minimum resolution of  $0.2^\circ$  or about 20 km in the ionosphere. The smallest paired electrostatic shock structure, which includes the region of smaller electric field between the large electric fields of the paired shock, and the smallest resolvable inverted-V structure on S3-3 map to about 5 km in the ionosphere (e.g., the first paired shock structure in orbit 209 in Fig. 1). In addition, one should keep in mind that smaller scale structures, such as field-aligned electron fluxes at the edges of inverted-V events (Arnoldy et al., 1985; McFadden et al., 1986) and field-aligned electron structures within inverted-V events, do not seem to correspond to larger overall potential as measured by the monoenergetic peak in the electron distribution function (Lin and Hoffman, 1979b). Thus, it seems consistent to regard narrow discrete arcs as narrow inverted-V events with the smallest scale structure within the arc as either due to relatively small changes in the field-aligned potential or enhanced field-aligned electron fluxes not directly related to changes in the potential. If this is the case, it could be that there are no strong double layers associated with the aurora. More data are needed to answer the question definitively.

#### 4. What is the relation between ion conic and electrostatic shocks?

It has been proposed that electrostatic shocks produce ion conics (Yang and Kan, 1983; Greenspan, 1984; Borovsky, 1984). Figures 3 and 4 show that many electrostatic shocks are indeed associated with ion conics. However, the idea that electrostatic shocks produce conics does not explain the clear distinction between electrostatic shocks associated with ion beams and electrostatic shocks associated with ion conics, nor does it explain the production of conics in regions where there are no electrostatic shocks. Even in regions where there are electrostatic shocks, the conic occurs in a much broader region than the electrostatic shock. Models for the generation of ion conics by electrostatic shocks show that the thickness of the electrostatic shock and the angle it makes with the magnetic field determine the relative perpendicular and parallel acceleration. One would then expect a continuous transition between conics and ion beams. In fact there is almost always at S3-3 altitudes ( $<8000$  km) a clear distinction between ion beams and ion conics, and, except for some general heating of the ion distribution, ion beams are consistent with acceleration purely parallel to the magnetic field while ion conics are consistent with acceleration purely perpendicular to the magnetic field. As mentioned previously, energetic ion beams are clearly associated with electrostatic shock. This implies that electrostatic shocks associated with ion beams are quasi-static on the ion transit time scale but that electrostatic shocks associated with ion conics are not. A more correct model of ion conic acceleration in regions of electrostatic shocks would need to take account of the fluctuations in the electric field and the general electric field turbulence in the region surrounding the electrostatic shocks. In regions of ion conics "electrostatic shocks" are not necessarily electrostatic (Temerin and Mozer, 1984a).

#### 5. What are the parallel electric field magnitudes on auroral field lines?

The parallel electric field can be measured directly or inferred from particle measurements. Measurements of ion beams and electron loss cones indicate that potential drops of 10 kV or larger can sometimes occur below the S3-3 satellite at altitudes of 6000 to 8000 km. Since the upward pointing electric field region has never been observed on S3-3 to extend below 3000 km and is usually limited to above 5000 km, the average parallel electric field in an inverted-V acceleration region must at least sometimes be the order of 5 to 10 mV/m and the maximum parallel electric field should be substantially larger since it is not likely that the electric field is uniform throughout the region. Direct measurements in electrostatic shocks indicate parallel electric fields up to about 100 mV/m (Mozer et al., 1980; Mozer, 1980). However, in most cases, the parallel electric field is less than 25 mV/m even in electrostatic shocks associated with upward flowing ion beams (Temerin and Mozer, 1984a).

#### 6. Are there large parallel electric fields in the return current region?

There are also large potential drops in the return current region. The electric field points down, which is in the direction to accelerate ions into the ionosphere and electrons into the magnetosphere. Some of the best evidence for downward pointing electric fields is shown in Figure 5, which displays some recent rocket data, courtesy of C. Carlson, J. McFadden, and M. Boehm. At 760 s into the flight, there was an almost complete dropout in the energetic electrons correlated with an enhancement in the precipitating ions flux over a narrow energy range at energies between 5 and 10 keV. At the same time, the eastward component of the magnetometer was consistent with a downward field-aligned current. These data imply a potential drop in the return current region in excess of 5 kV. Large downward electric fields can also be inferred from the observations of black aurora (Davis, 1978). Black aurora appear as narrow streaks of dark sky in regions of otherwise diffuse illumination. Broader regions of weaker parallel electric fields can be inferred from the S3-3 and DE 1 observations of upward flowing field-aligned electrons. One would expect that the narrow regions of downward pointing electric fields would correspond to paired electrostatic shocks with the electric fields in the paired shock pointing away from the region of parallel acceleration. Examples of such events are, however, comparatively rare in the S3-3 data.

## 7. How important are the dynamic properties of the parallel electric field on auroral field lines?

On the ion transit time scale the fluctuating portion of the parallel electric field must be several times larger than the dc portion. This is clear from the parallel velocity distribution of the upflowing ion beam. Typically, there is observable flux in an ion beam at energies four times larger than the energy of the maximum flux. This implies that in the frame of reference moving with the energetic ion the electric field is four times larger than the average field. These fields may be provided by the small-amplitude double layers and the parallel electric field components of the electrostatic ion cyclotron waves that are associated with the upflowing ion beams.

Another interesting dynamic property of auroral acceleration is flickering aurora. Recent data and theoretical models (Temerin et al., 1986) show that an obliquely propagating ion cyclotron wave, which may be produced by an oscillating double layer or oscillating parallel electric field, can produce the oscillating field-aligned electron flux in the flickering aurora.

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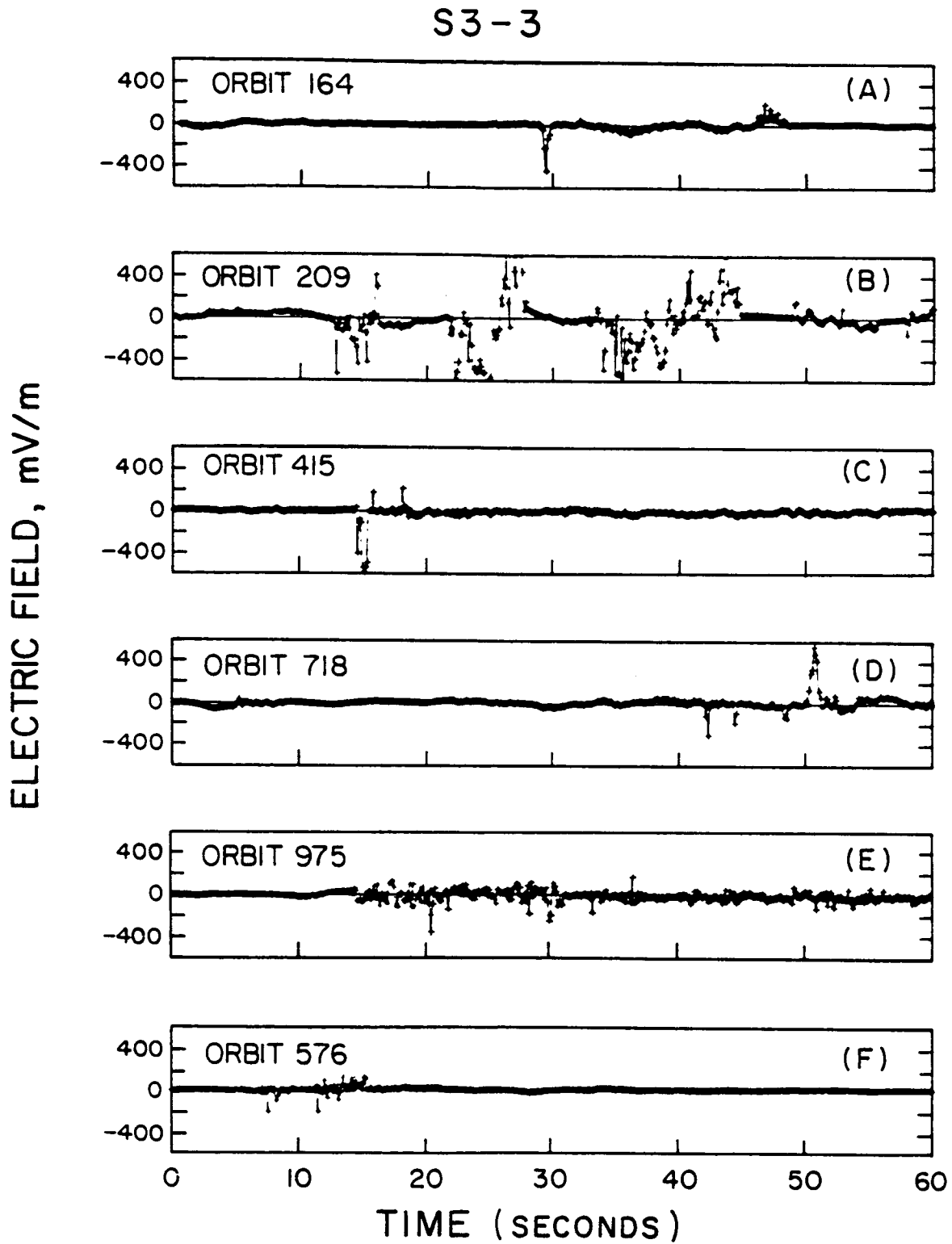


Figure 1. Examples of electrostatic shocks measured by the S3-3 satellite at altitudes below 8000 km.

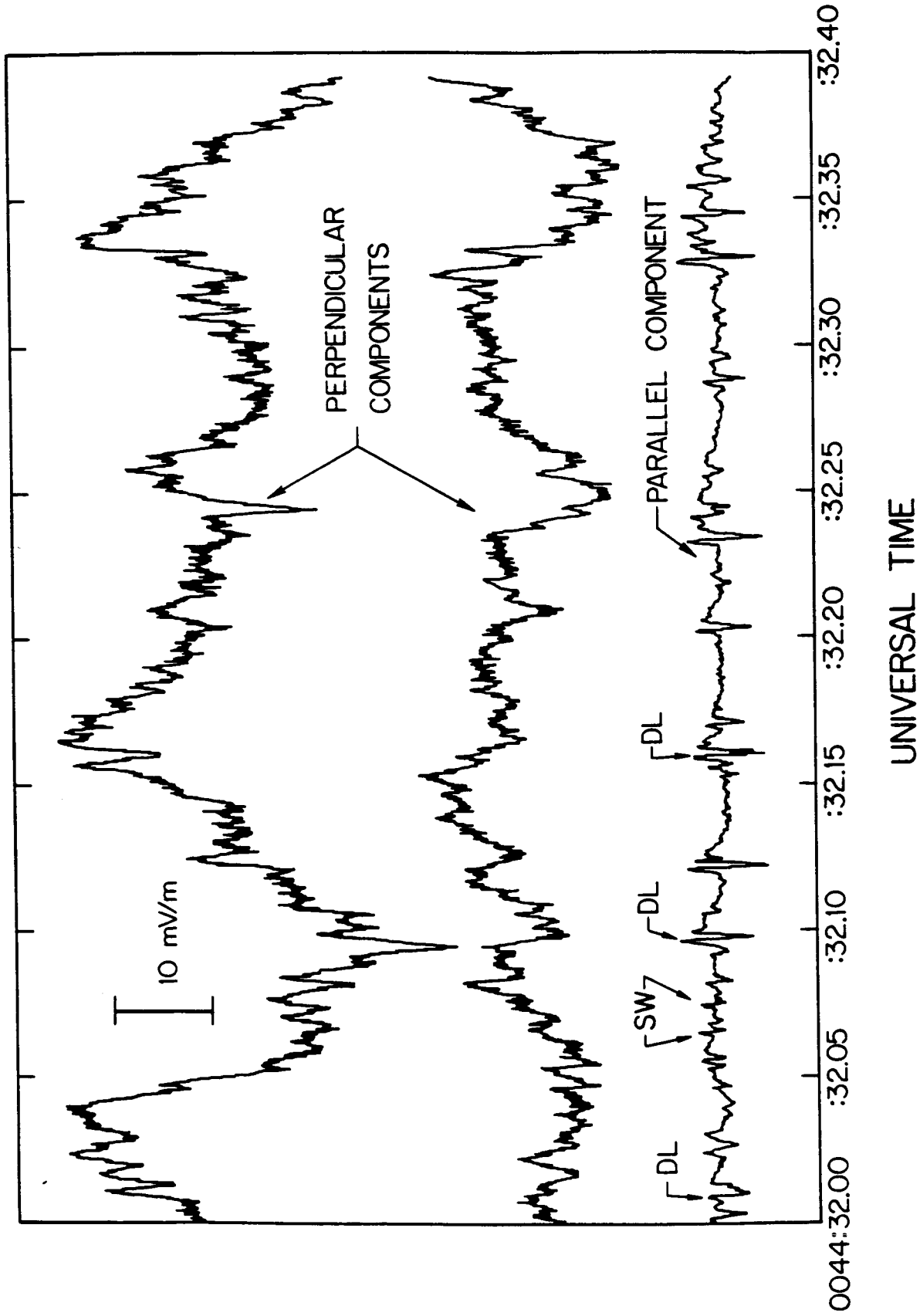


Figure 2. Examples of small-amplitude double layers measured by the S3-3 satellite. The noteworthy aspect of small-amplitude double layers is the significant parallel electric field (from Temerin et al., 1982).

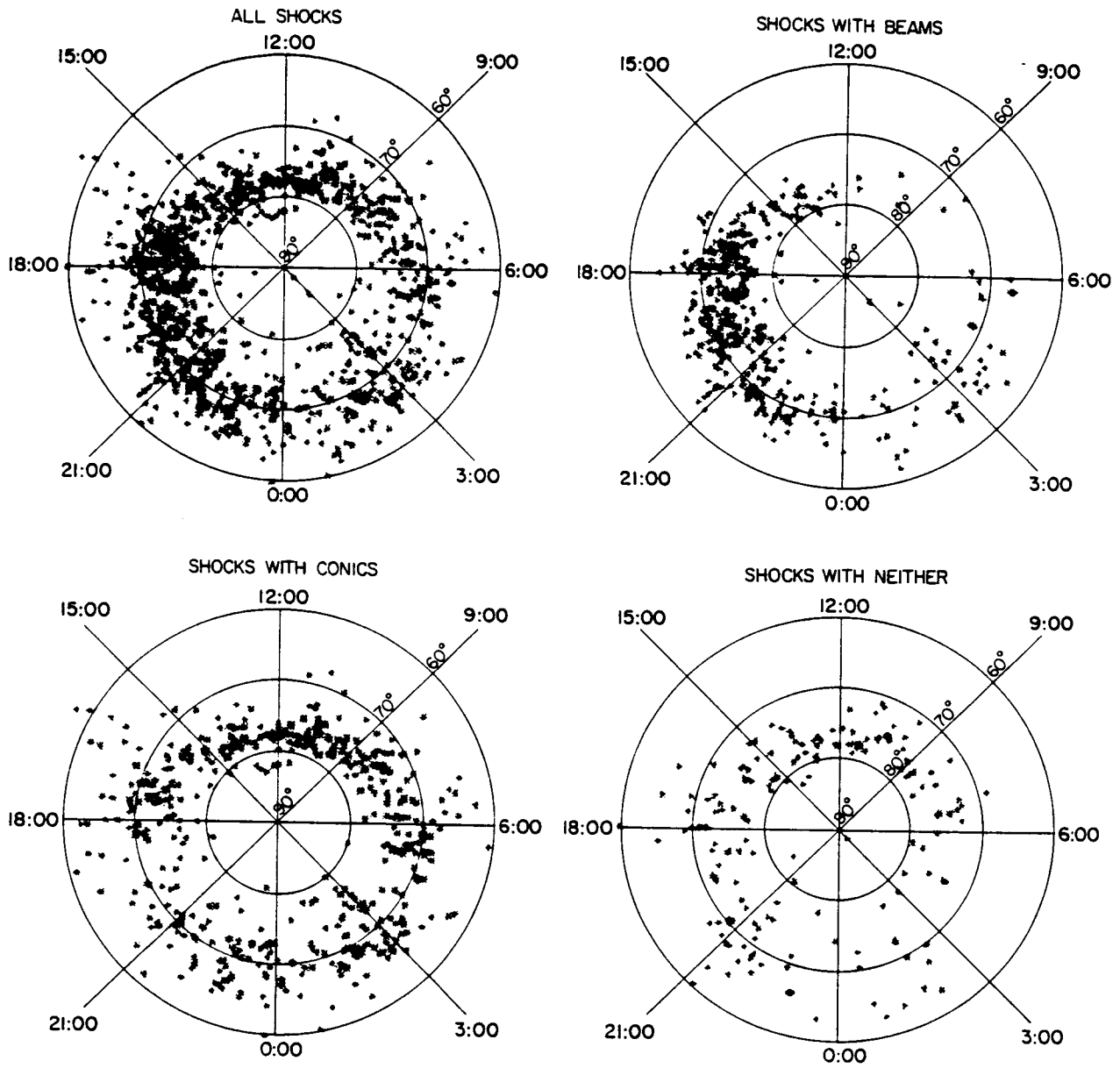


Figure 3. The distribution of electrostatic shocks as a function of invariant latitude and magnetic local time (from Redsun et al., 1985).

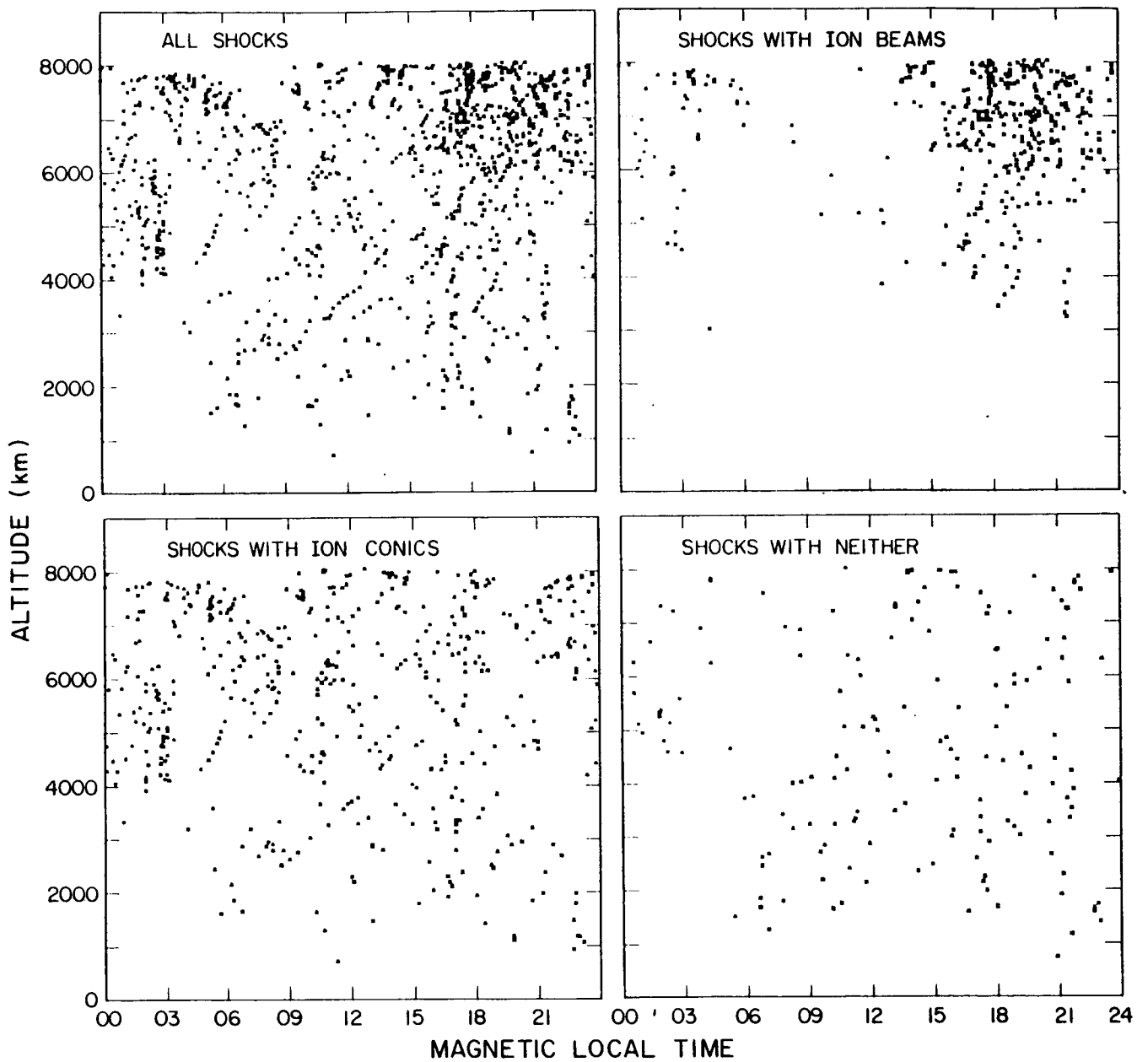


Figure 4. The distribution of electrostatic shocks as a function of altitude and magnetic local time (from Redsun et al., 1985).



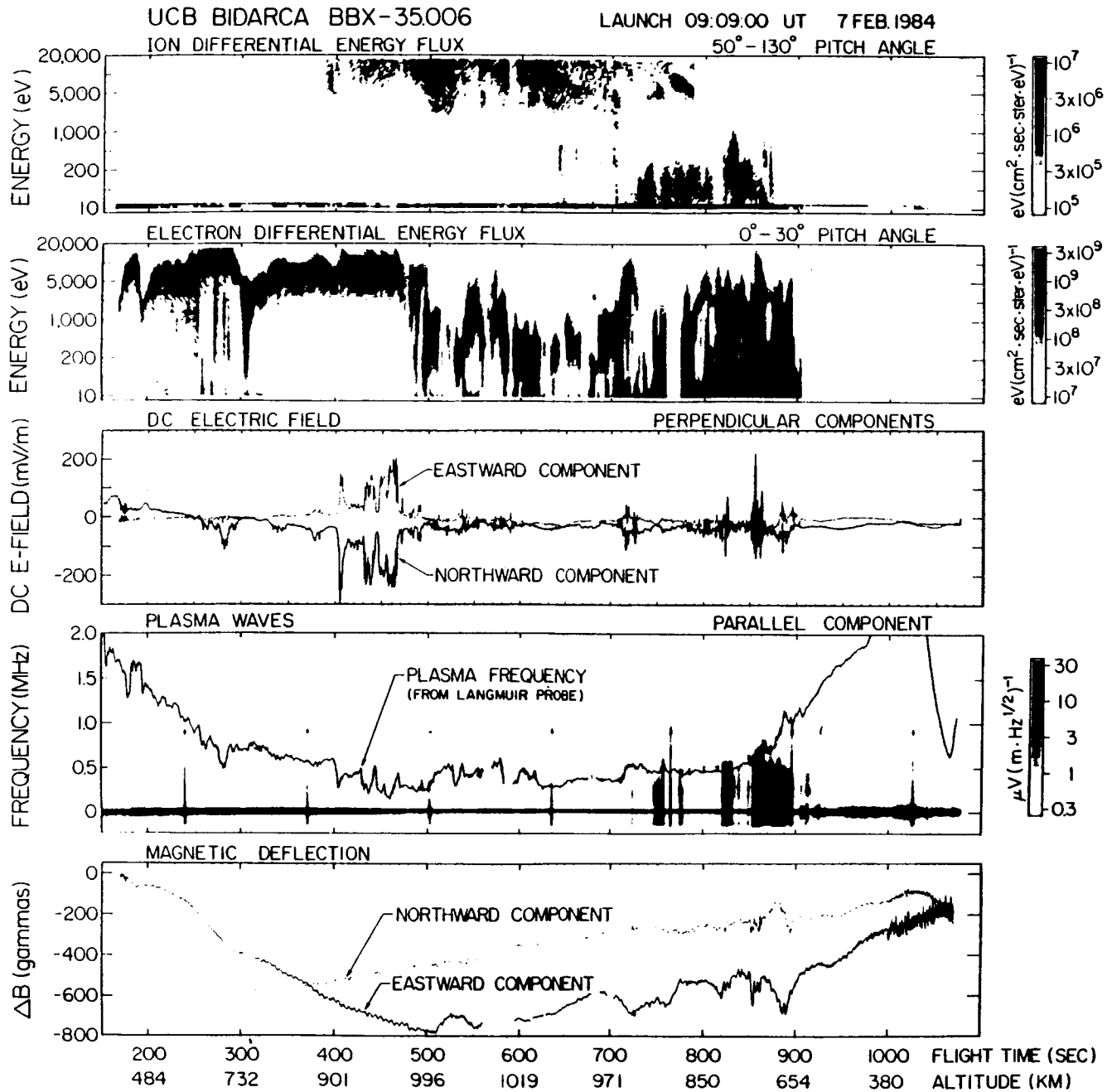


Figure 5. Recent rocket data. Example of anticorrelation of electron and ion fluxes can be seen at 760 s flight time. (Data courtesy of C. Carlson, J. McFadden and M. Boehm.)