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ELF Noise Bands Associated with Auroral Arcs

by

D. A. Gurnett and L. A. Frank

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Department of Physics and Astronomy
THE UNIVERSITY OF IOWA
Iowa City, Iowa

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D. A. Gurnett and L. A. Frank

Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52240

July 1971

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ABSTRACT

This paper reports on observations of a new type of ELF noise band which is closely associated with low-energy electron precipitation events and auroral arcs. These observations have been made at relatively low altitudes (<3000 km) with the polar orbiting satellite Injun 5. These noise bands typically have a center frequency of from 100 to 300 Hz and often appear to consist of many nearly monochromatic bursts, typically of a few seconds duration, superimposed to give the observed spectrum of the emission. These ELF noise bands are only observed in a relatively narrow (few degree) latitudinal region in the auroral zone. The local time distribution of these ELF noise bands has not been investigated in detail, however ELF noise bands of this type have been observed throughout the local time range from 12:00 to 22:00.

In considering the possible explanations of these ELF noise bands, it is noted that the spectral characteristics of this noise are very similar to a type of narrow-band magnetic noise called 'lion's roar' which has been observed at much higher altitudes in the magnetosheath with the satellite OGO-5. It is suggested that the ELF noise bands observed at low altitudes with Injun 5 are produced by lion's roar emissions which have propagated down 'open' magnetic field lines from the magnetosheath region to the Injun 5 altitude.

I. OBSERVATIONS

Intense bands of extremely-low-frequency (ELF) electromagnetic noise are frequently observed with the low-altitude polar orbiting satellite Injun 5 in association with low-energy electron precipitation events and auroral arcs. A frequency-time spectrogram illustrating the spectral characteristics of this type of ELF noise is shown in Figure 1 [see Gurnett _et al._, 1969, for a discussion of the Injun 5 spacecraft and VLF instrumentation]. These ELF emissions usually have a bandwidth of 100 Hz or less and a center frequency which is remarkably similar from event to event, seldom greater than 300 Hz or less than 100 Hz. Typical broad-band magnetic field strengths for these events are about 10 to 30 milligammas. The duration of these ELF noise bands varies considerably from event to event, from a few seconds to several tens of seconds. The frequency-time spectra of these emissions often appear to consist of many nearly monochromatic bursts, typically of a few seconds duration, superimposed to give the observed bandwidth for the emission. These individual quasi-monochromatic bursts are evident as 'fine structure' in the ELF noise band shown in Figure 1.

ELF noise bands of the type shown in Figure 1 are only observed in a narrow latitudinal region a few degrees wide in the auroral zone, typically at about 70° to 80° invariant latitude. Although a complete study of the local time distribution of these ELF noise bands has not yet been performed, most of the cases investigated in this study occurred from about 12:00 to 22:00 local time. To our knowledge the ELF noise bands do not correspond to any of the well-known categories of magnetospheric VLF emissions [Helliwell, 1965] and are clearly distinguishable from chorus and ELF hiss because of their distinctly different frequency spectra and region of occurrence.

ELF noise bands of the type shown in Figure 1 are found to be closely associated with inverted 'V' electron precipitation events of the type described by Frank and Ackerson [1971]. This association is illustrated by Figure 2 which shows the electron energy-time spectrogram for the same pass as the ELF noise band shown in Figure 1. (See Frank and Ackerson [1971] for a description of the charged particle instrumentation on Injun 5.) The inverted 'V' energy-time structure occurring from 01:49:30 to 01:50:10 UT in Figure 2 corresponds almost exactly with the location of the ELF noise band shown in Figure 1. Similar, but less distinct, ELF noise bands are also observed in association with the multiple inverted 'V' events from

01:48:00 to 01:49:00 UT. The trapping boundary for electrons E > 45 keV is located at 01:50:10 UT on this pass and, as discussed by Frank and Gurnett [1971] and Gurnett and Frank [1971], the inverted 'V' electron precipitation events are believed to occur on 'open' field lines which connect into the magnetosheath. ELF noise bands of the type illustrated in Figure 1 are frequently, but not always, observed in association with inverted 'V' electron precipitation events. Of a total of nine inverted 'V' events investigated, six were found to be associated with ELF noise bands qualitatively similar to the example shown in Figure 1. However, in every case investigated having an ELF noise band, a corresponding inverted 'V' electron precipitation event could be found.

The ELF noise band and associated inverted 'V' event in Figures 1 and 2 also occur simultaneously with a region of VLF hiss which extends from about 01:47:30 to 01:51:00 UT. This VLF hiss emission consists of a series of V-shaped VLF hiss events of the type described by Gurnett [1966]. VLF hiss events of this type are commonly observed in the same region as the ELF noise bands. This association between VLF hiss and the ELF noise bands is not unexpected since Gurnett and Frank [1971] have shown that VLF hiss emissions are also closely correlated with inverted 'V' electron precipitation events.

II. DISCUSSION

In comparing these observations with data from other satellites, it is evident that the ELF noise bands observed at low altitudes with Injun 5 have certain spectral characteristics similar to the narrow-band magnetic emissions observed by Smith _et al_. [1969] in the magnetosheath with the eccentric orbiting OGO satellites. These magnetosheath emissions consist of tone-like bursts with frequencies typically between 50 and 200 Hz, lasting from 1 to 10 seconds, and are referred to as 'lion's roar'. A frequency-time spectrogram of lion's roar observed in the magnetosheath with OGO-5 is shown in Figure 3 [from Smith _et al_., 1969]. Note the difference in time scale between Figures 1 and 3. In comparing the spectral characteristics of lion's roar with the ELF noise bands observed with Injun 5, the following relationships are noted (1) the typical center frequencies and relative bandwidth for the two phenomena are very similar, (2) both phenomena are made up of nearly monochromatic bursts with durations of a few seconds, (3) the period between the individual bursts is usually shorter for the ELF noise bands observed by Injun 5 than for the lion's roar, sometimes so short as to make the burst fine structure in the ELF noise band essentially unresolvable.

Because of the similarity in the spectral characteristics of these two phenomena, the question naturally arises as to whether the ELF noise bands observed with Injun 5 are in fact lion's roar emissions which have propagated downward from the magnetosheath region to the Injun 5 altitude. This possibility is even more suggestive in view of the recent evidence by Frank and Gurnett [1971] that the inverted 'V' electron precipitation events, which occur in the same region as the ELF noise bands, occur on 'open' magnetic field lines which extend into the magnetosheath region. This geometry is illustrated in Figure 4, from Frank and Gurnett [1971], which shows open magnetic field lines, B-B for example, extending from the magnetosheath, through the magnetopause, and down to low altitudes in the auroral zone. Since the ELF noise bands are only observed over a narrow range of latitudes, it appears that the lion's roar emissions must be guided very nearly along the magnetic field from the magnetosheath to low altitudes. As discussed by Smith _et_ _al_. [1969], the lion's roar emissions are believed to be propagating in the right hand polarized whistler mode. Although whistler mode waves do not necessarily follow the magnetic field lines due to magnetoionic guiding alone, it is well known from terrestrial whistler observations that when suitable field-aligned density gradients are present whistler mode waves are guided (ducted) almost exactly along the static magnetic field [Helliwell, 1965]. Therefore, if the ELF noise bands observed by Injun 5 are due to lion's roar emissions from the magnetosheath, then field-aligned density gradients must play an essential role in guiding these waves down to the Injun 5 altitudes. Since density variations of only a few percent are required to produce whistler mode ducting, it is virtually certain that the required density variations are present on these auroral zone field lines [Lund et al., 1967]. Even if whistler mode ducting is ineffective over part of the path, the magneto-ionic guiding effect for whistler mode propagation will assure that if the wave is initially propagating along the static magnetic field toward the earth it must continue to do so until the lower hybrid resonance frequency exceeds the wave frequency, which can only occur at relatively low altitudes (<2 earth radii). Since the wave frequency is less than the electron gyrofrequency at all points along the path, there is no propagation cutoff or resonance which could prevent whistler mode propagation over this path. A possible exception is the L=0 cutoff at low altitudes (<3000 km) discussed by Gurnett and Burns [1968]. However, if the waves are being ducted along the static magnetic field the wave normal directions will be aligned nearly parallel to the static magnetic field and mode coupling will prevent this cutoff from being effective, much as for proton whistlers at high latitudes (see Rodriguez and Gurnett [1971] and Wang [1971]). The shorter period between individual bursts, and the tendency in some cases for the individual bursts to merge into a nearly continuous noise band at the Injun 5 altitude, mentioned earlier, can be accounted for by the 'funneling' of lion's roar emission from a relatively large region of the magnetosheath into a small latitudinal region at the Injun 5 altitude. The direction of propagation of the individual bursts in the ELF noise bands observed by Injun 5 has been determined using the Poynting flux sensing techniques described by Gurnett _et_ _al_. [1971]. Both downgoing _and_ _upgoing_ bursts are observed. The upgoing bursts are believed to be caused by the reflection of downgoing bursts below the satellite.

Since lion's roar emissions are believed to be nearly always present in the magnetosheath region, the question arises as to why the corresponding ELF noise bands are not always observed when an inverted 'V' electron precipitation event occurs. At this time, the answer to this question is not clearly understood although several possibilities occur. (1) Since the ducting of the lion's roar emissions down to low altitudes depends critically on the presence of field-aligned density gradients, it is possible that in some cases the necessary gradients have not been established from the magnetosheath down to low altitudes. (2) The occurrence of lion's roar has not yet been thoroughly studied, particularly at high latitudes; it may be that there are periods or regions within the magnetosheath for which few, or no, lion's roar emissions occur.

These considerations make it entirely plausible that the ELF noise bands observed at low altitudes with Injun 5 in fact originate from the high altitude magnetosheath region. Despite this considerable body of supporting evidence it must be pointed out that without observations at intermediate altitudes in the polar magnetosphere this explanation cannot yet be regarded as totally conclusive since it is always possible that some instability mechanism associated with the inverted 'V' electron precipitation events may also be able to account for all of the observed characteristics. However, at the present time the interpretation of these ELF noise bands as having originated from the magnetosheath is considered the simplest and most likely explanation of this new phenomenon.

ACKNOWLEDGMENTS

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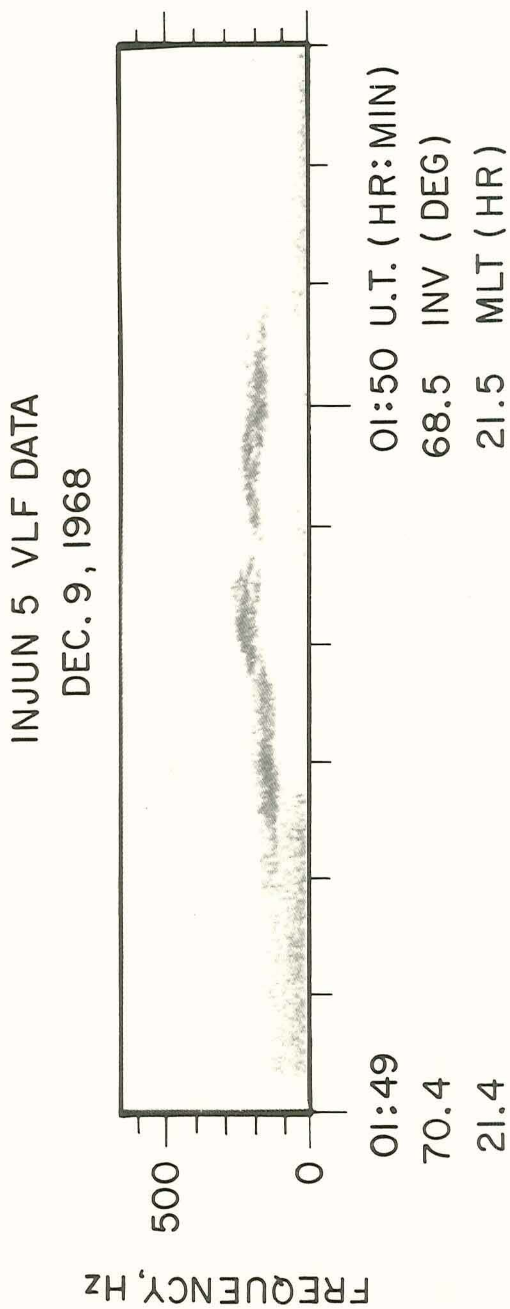
FIGURE CAPTIONS

Figure 1 Frequency-time spectrogram of a typical auroral zone ELF noise band observed at an altitude of 2471 km with Injun 5.

Figure 2 Energy-time spectrogram of precipitated electrons observed simultaneously with the radio noise data shown in Figure 1. Note the inverted 'V' precipitation event from 01:49:30 to 01:50:10 UT which corresponds to the ELF noise band in Figure 1.

Figure 3 Frequency-time spectrogram and waveform signature of 'lion's roar' observed in the magnetosheath with OGO-5. From Smith et al. [1969].

Figure 4 Illustrative model showing the magnetic field topology in the polar cusp/plasma sheet regions. The ELF noise bands observed at low altitudes by Injun 5 are believed to be lion's roar which has propagated from the magnetosheath down to low altitudes along magnetic field lines B-B, for example.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68.5 INV (DEG)
21.5 MLT (HR)

Figure 1

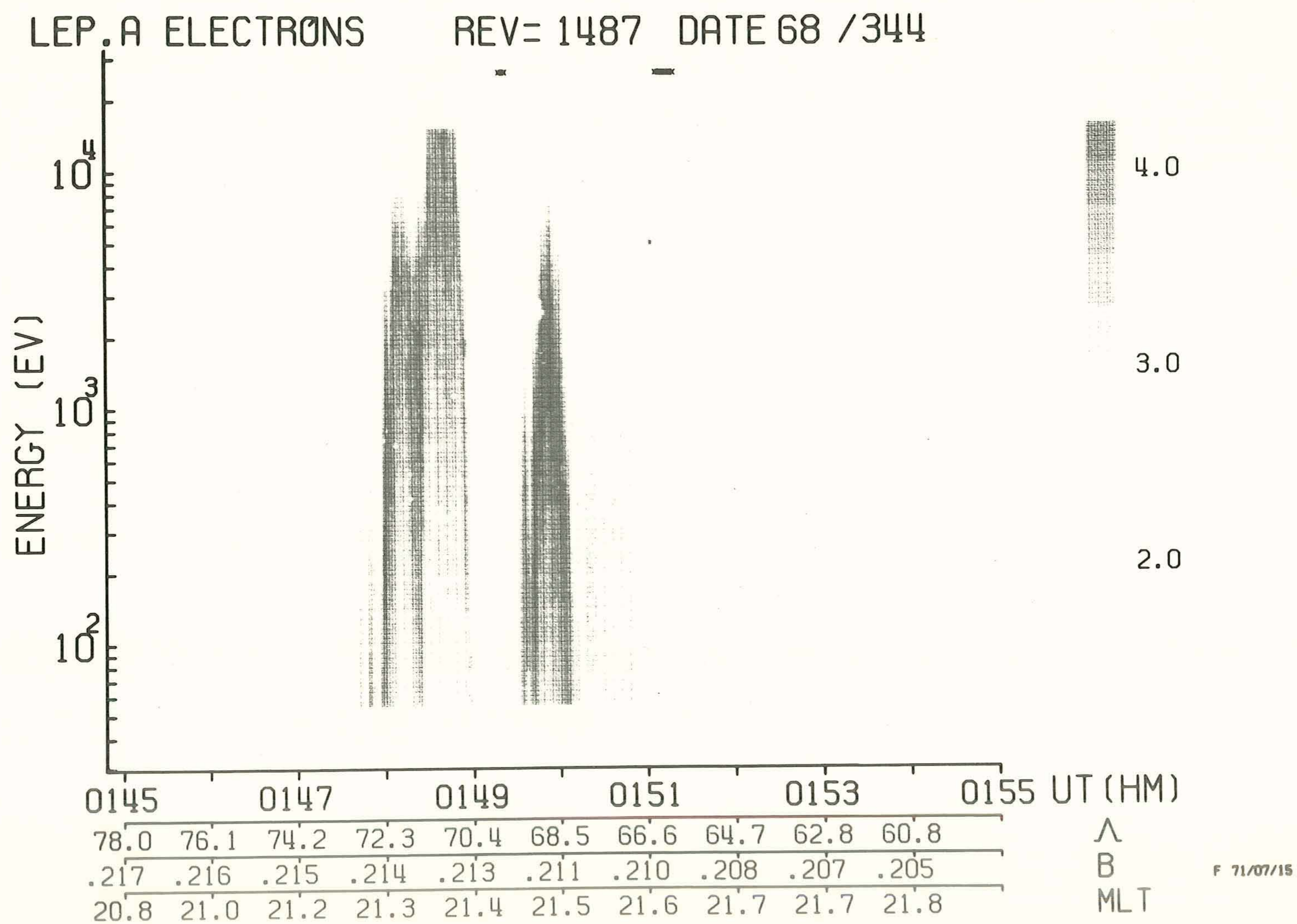
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Figure 2

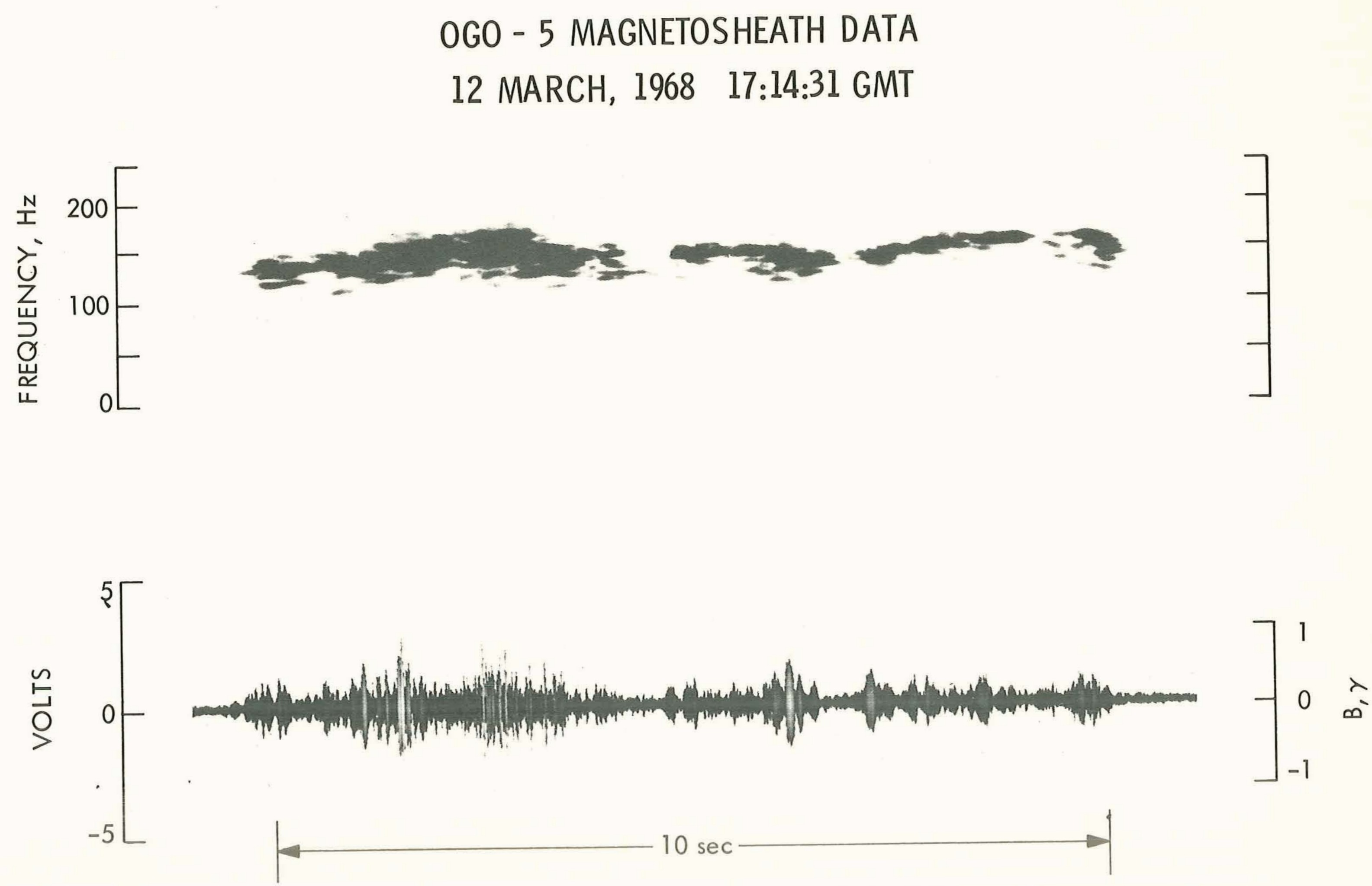
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Figure 3

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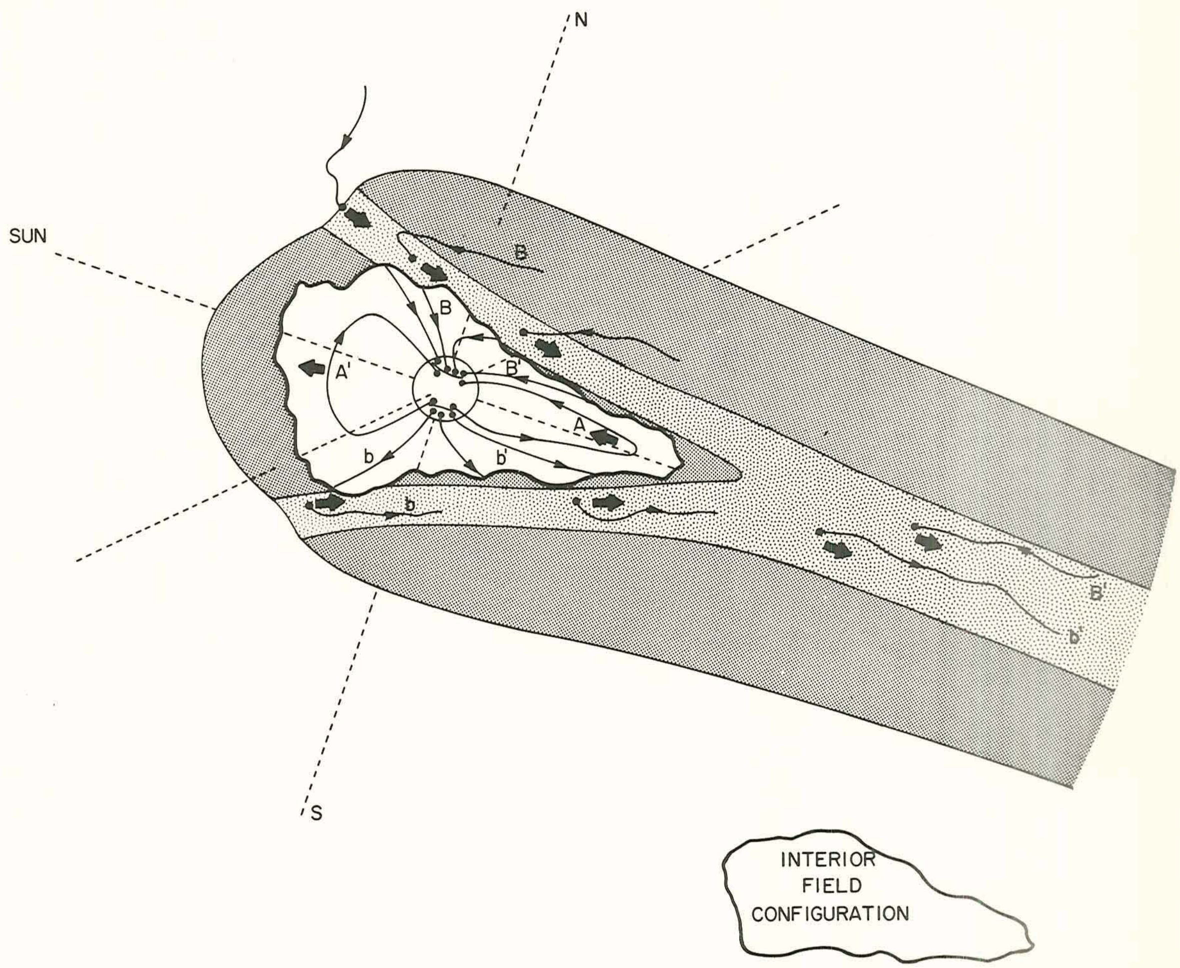

SCHEMATIC DIAGRAM FOR
MAGNETOSPHERIC AND LOW-ALTITUDE CONVECTION
(LOCAL EVENING, LOCAL MORNING)

Figure 4