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Microburst Phenomena

3. An Association between Microbursts and VLF Chorus

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Observations made with the Injun 3 satellite of bursts of precipitating $E_e \geq 40$-kev electrons and of VLF chorus emission have revealed their simultaneous occurrence. Observed microbursts are always accompanied by a group of VLF chorus emissions; chorus is not necessarily accompanied by microbursts. The maximum region of microburst occurrence from $0400 \leq$ magnetic local time ≤ 1300 and $65° \leq$ invariant latitude $\leq 70°$ lies well within the maximum region of chorus emissions from $0300 \leq$ magnetic local time ≤ 1500 and $55° \leq$ invariant latitude $\leq 75°$. It is not generally possible to find a one-to-one (burst to burst) correspondence between individual microbursts and VLF chorus bursts.

INTRODUCTION

Much theoretical and experimental effort has recently been concentrated on the investigation of wave-particle interactions in the magnetosphere [*Kennel and Petschek*, 1966; and others]. Experiments aboard the low-altitude, magnetically oriented Injun 3 satellite for the period from January to October 1963 provided the opportunity to simultaneously investigate VLF radio noises and energetic charged-particle fluxes. In this paper, we discuss an association found in the Injun 3 data between electron microbursts and VLF emissions called chorus.

A detailed description of the detectors and VLF equipment used in this study is given by *O'Brien et al.* [1964], *Gurnett and O'Brien* [1964], and a companion paper by *Oliven et al.* [1968]. The two particle detectors used in this study were sensitive to electrons of energies $E_e \geq 40$ kev and were collimated to detect particles moving approximately perpendicular (90° detector) and parallel (180° detector) to the geomagnetic field in the northern hemisphere. The VLF experiment used a loop antenna, oriented so that the geomagnetic field was in the plane of the loop, and detected the VLF magnetic field. The wideband VLF signal (200 Hz to 7 kHz) was transmitted to the ground via the satellite telemetry transmitter.

This study was limited to the investigation of VLF phenomena that are associated with impulsive precipitation of large fluxes of electrons into the auroral zone and called microbursts [*Oliven et al.*, 1968]. These microbursts are characterized by their short time scale (<1 sec in duration), energies $E_e \geq 40$ kev (as observed by Injun 3), peak precipitated electron fluxes (above background) of $\geq 10^4$ electrons cm^{-2} sec^{-1} $ster^{-1}$ for $E_e \geq 40$ kev, and a maximum occurrence during local morning at about 65°–70° invariant latitude. These electron bursts are responsible for X-ray bremsstrahlung microbursts observed at altitudes $\lesssim 100$ km by *Anderson* [1965], *Venkatesan et al.* [1968], and others.

STATISTICAL STUDY OF VLF CHORUS OCCURRENCE

A study of Injun 3 VLF records during periods of microburst activity revealed the simultaneous occurrence of VLF chorus. Chorus consists of closely spaced, often overlapping, randomly occurring, discrete bursts, usually rising in frequency in the range of ~0.5–6 kHz, with the individual bursts typically having a duration of a few tenths of a second [*Allcock*, 1957; *Helliwell*, 1965]. Frequency-time spectrograms of satellite-observed chorus are shown in Figures 1 and 2. The broadband intensity of chorus bursts detected by Injun 3 varied from approximately 1.0 mgamma (the receiver noise level) to a maximum of about 30 mgammas. Positive identification of chorus observed by Injun 3 was made by visual observation of high time resolution frequency-time spectrograms.

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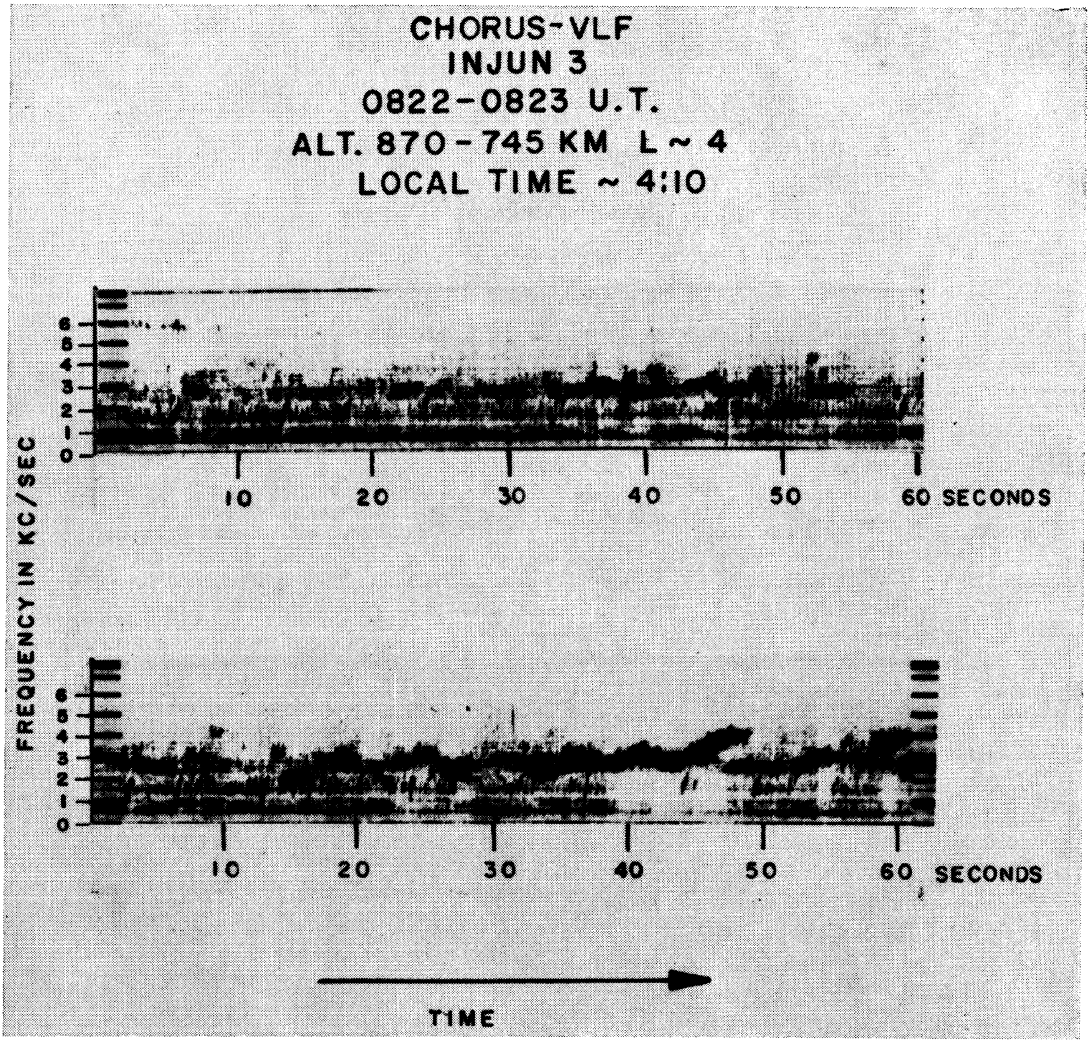

Fig. 1. Examples of spectrograms of VLF chorus. Some of these chorus bursts are so closely spaced that their individual identity is lost. Auroral identification, however, verifies their individual rising tones.

To determine the regions of occurrence of chorus, data from the entire lifetime of Injun 3 were investigated, covering 24 hours in local time and invariant latitudes from 35° to 80°. This region was divided into blocks 5° in invariant latitude and one hour in magnetic local time. In the region between 65° and 74° invariant latitude, where ground-based observations of VLF emissions have established a maximum of chorus activity, the blocks were made smaller to provide greater detail. In these regions, the blocks were 3° in invariant latitude by one hour of magnetic local time.

Data samples were chosen to be 8 seconds in length. At least ten such data samples were investigated per block. Whenever possible (in most cases) ten different passes were used per block; thus each satellite pass was permitted to contribute only one sample per block. Approximately 2400 individual samples were studied to determine the presence of chorus. Percentages of occurrence were computed by taking the ratio of the number of samples per block containing chorus to the total number of samples studied per block. Figure 3 gives the results of this investigation.

Chorus is seen to occur primarily in the region from 55° to 75° invariant latitude and from 0300 to 1500 magnetic local time. The most intense region of occurrence, between 0600 and 1200 magnetic local time, contains many blocks where the percentage of occurrence exceeds 50%. In no block, however, does the frequency of occurrence exceed 80%. This is seen in Table 1.

These statistical results appear to be in reasonably good agreement with the statistics accumulated from ground-based observations [*Laaspere,* 1964].

An investigation of about 400 microburst episodes (segments of data in which one or more clearly identifiable microbursts were found) was undertaken. These episodes varied in length from about 8 sec to several minutes, depending upon the duration of microburst activity. Samples were chosen from all regions of invariant latitude and magnetic local time in which microbursts existed. VLF spectrograms of these periods of time were produced and visually inspected for VLF emissions activity in the frequency of ~200 Hz to 7 kHz.

In all these microburst episodes it was found that whenever electron bursts were present they were always accompanied by VLF chorus emissions; no exceptions were found in any of the cases investigated. Of particular interest are

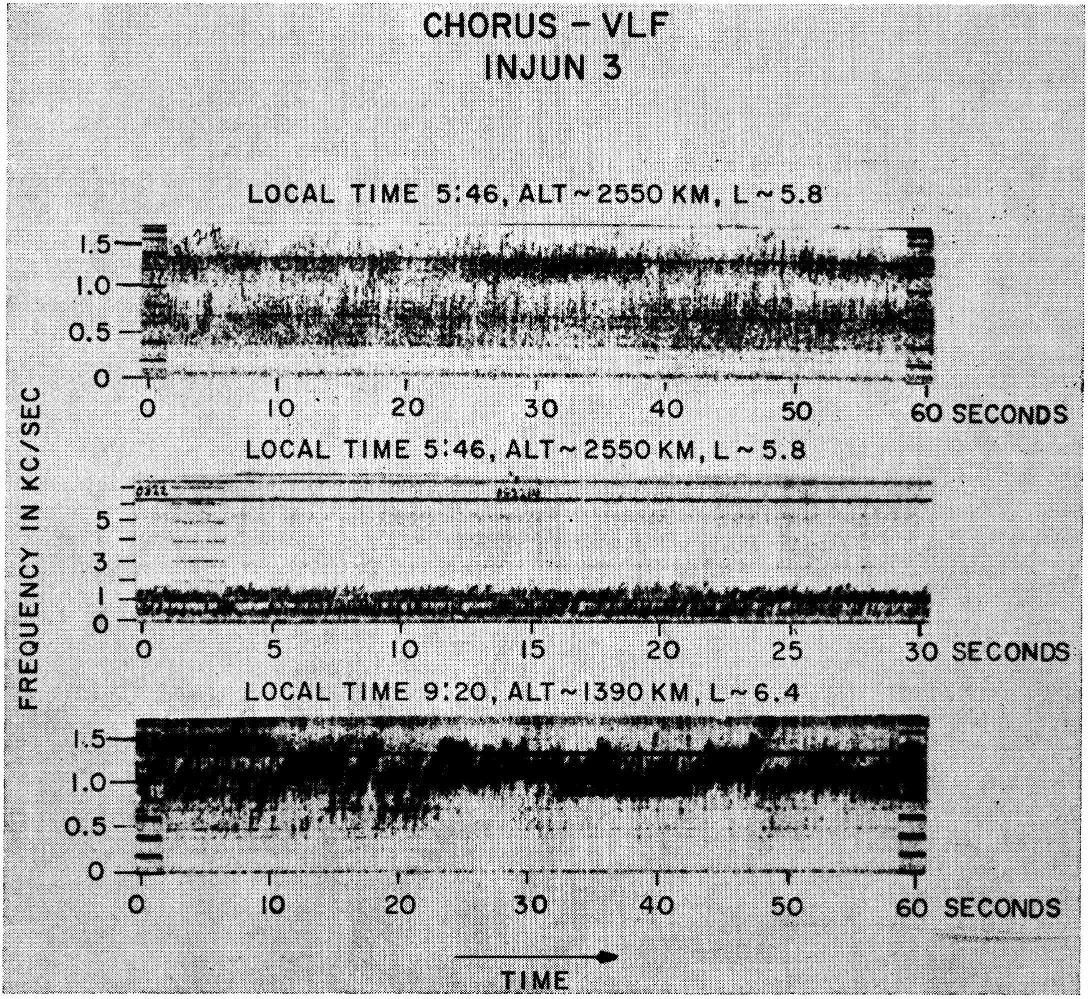

Fig. 2. Additional samples of VLF chorus. The middle strip shows the first 30 seconds of the top strip seen on a compressed vertical scale.

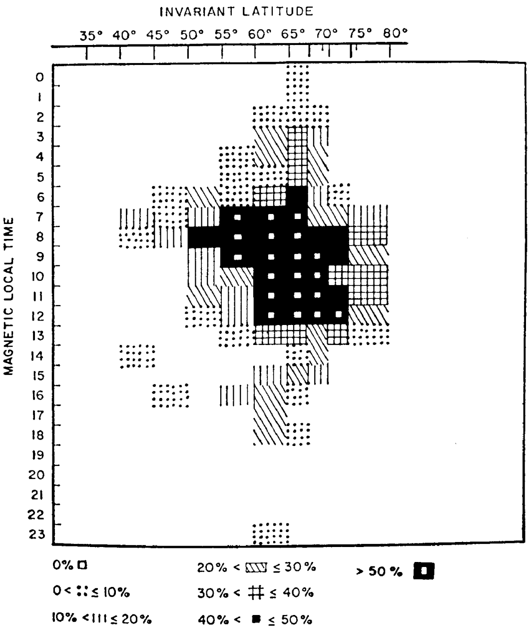

Fig. 3. The occurrence frequency in invariant latitude and magnetic local time of VLF chorus emissions detected by Injun 3. Each sample block contains at least 10 samples.

the blocks in the regions from 2000 to 0200 hours magnetic local time where the probability of finding microbursts or chorus is very small. Even in these regions the rule is inviolate; the bursts of electrons are always accompanied by chorus. A typical example of a microburst episode accompanied by VLF chorus is seen in Figure 4. The converse relation was not found to hold; namely, the occurrence of chorus is not always accompanied by microbursts.

The probability of microbursts always occurring accompanied by chorus can be found by studying the occurrence frequency probabilities of each phenomenon. Figure 6 in the companion paper [*Oliven et al.*, 1968] represents the occurrence frequency of electron microbursts. Each block covered 5° invariant latitude (3° between 65° and 74°) by one hour magnetic local time. Where possible, different samples of data were used in this study from those used to compile Figure 3.

The dependence of chorus on the occurrence of microbursts can be established by comparing the conditional probability of chorus occurring when microbursts are occurring, $P(C/M)$, with the probability of chorus occurrence, $P(C)$. Our results show that $P(C/M) = 100\%$. Comparing Figure 3 of this paper, Figure 6 [*Oliven et al.*, 1968], and Table 1, it can be seen that $P(C)$ in the region where microbursts occur is typically about 60% but never greater than 80%. Since $P(C/M)$ is substantially greater than $P(C)$, we can conclude that there is a definite association between the occurrence of chorus and the occurrence of electron bursts.

The region of maximum occurrence of microbursts, which are always accompanied by chorus, is seen in Figure 5. In the blackened regions, the probability of observing microbursts with chorus is greater than 10%. Within these blackened areas, the probability of chorus occurrence is always greater than that of microburst occurrence. Outside this region where microbursts are less common (less than 10%), the regions of maximum VLF chorus occurrence (greater than 20%), are indicated by dotted areas. From Figure 5, the region of maximum microburst occurrence is seen to lie within the region of maximum chorus occurrence.

It should be noted that the absolute frequencies of occurrence in Figures 3, 5, and 6 [*Oliven et al.*, 1968] may depend on the noise level of the detectors, the antenna noise in the case of the VLF receiver, and the background counting rate in the case of the 40-kev electron detectors. Additionally, the occurrence frequencies in the case of the electron bursts are affected by the criteria used for the identification of microburst events, as discussed in the companion paper [*Oliven et al.*, 1968]. However, the general shape and locations of the two regions of maximum occurrence would be expected

TABLE 1. Percentage Occurrence of Chorus Detected by Injun 3 within the Heart of the Chorus Region of Occurrence

Magnetic Local Time	Invariant Latitude, deg				
	55–59	60–64	65–67	68–70	71–74
0700	60	70	70	30	30
0800	60	60	60	50	50
0900	60	70	70	60	50
1000	30	60	70	60	40
1100	20	70	70	60	50
1200	20	70	70	80	70

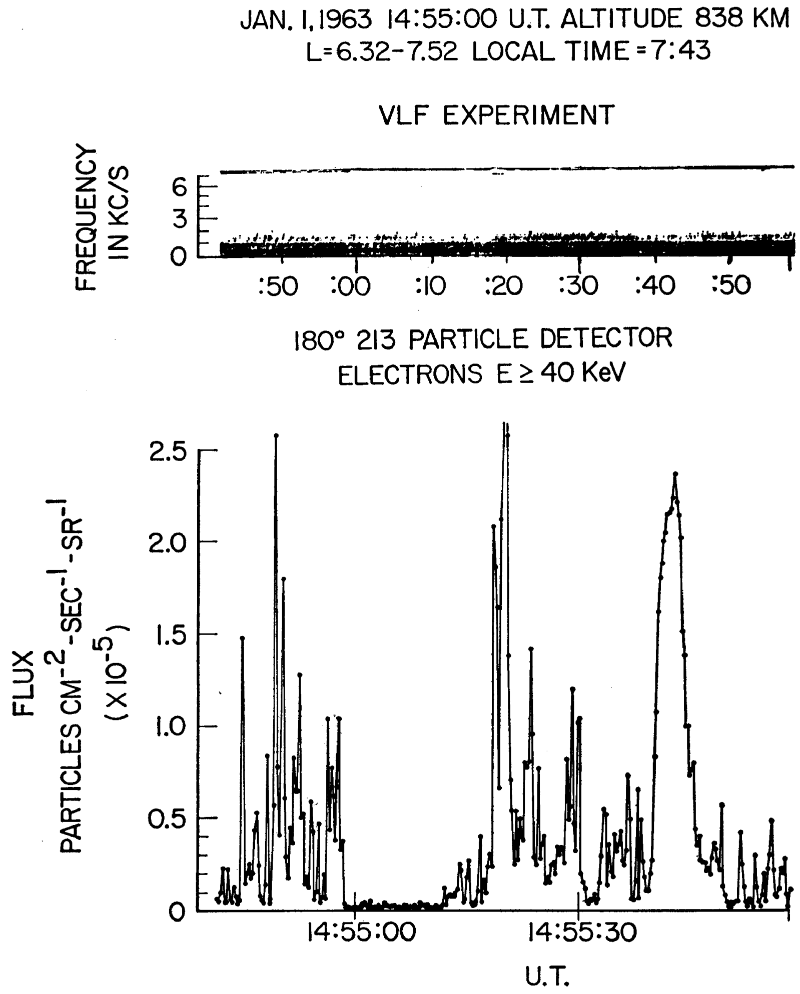

Fig. 4. Simultaneous measurements of microburst electron fluxes and VLF chorus made by Injun 3 detectors. The large fluctuations of electrons of time scale <1 sec are microbursts.

to be relatively insensitive to changes in the detection threshold.

It is usually not possible to ascribe a given burst in the electron data with a specific chorus burst in the VLF data; Figure 6 illustrates this point. It can be seen in Figure 6 that the duration of bursts in both records is similar but that it is not possible to uniquely associate a given microburst with a given chorus burst.

Greater time resolution of electron bursts can be achieved by viewing the daughter bremsstrahlung X-ray microbursts with high time resolution equipment in balloon-borne detectors. During one pass, the Injun 3 subsatellite position passed within approximately 400 km of a University of California balloon-borne X-ray experiment [*Milton and Oliven,* 1967]. Figure 7 presents the Injun 3 precipitated and trapped electron flux, $E_e \geq 40$ kev, and the balloon X-ray flux measurements, 30 kev $\leq E_{\mathrm{x\ ray}} \leq$ 60 kev, when the subsatellite point was approximately 400 km from the balloon. Both the electron data and the X-ray data indicate the presence of microbursts. No burst-to-burst correspondence of electron microbursts to X-ray microbursts is to be expected because of the limited spatial extent (about 100 km) for such events. Chorus bursts are also seen to be pres-

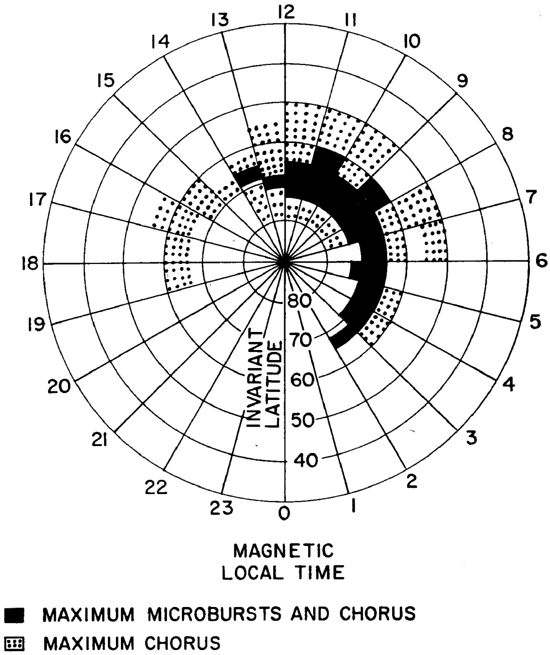

Fig. 5. Region of maximum joint occurrence of electron microbursts and VLF chorus. The black area indicates a region in which the occurrence probability of electron microbursts (accompanied by VLF chorus) exceeds 10%. Dotted areas represent regions of maximum VLF chorus occurrence (>20% occurrence probability), which is, in general, not accompanied by electron microbursts.

ent during this interval, but, again, a one-to-one matching of chorus bursts with the microbursts (electron or X-ray) is not possible. In general, there are usually several chorus bursts for each electron burst.

DISCUSSION

It has been found that microbursts observed by Injun 3 electron detectors are always accompanied by VLF chorus bursts and that the region of maximum occurrence for microbursts lies within the region of maximum occurrence for VLF chorus. Chorus bursts are not, however, always accompanied by microbursts. Also, it is not generally possible to find a one-to-one, burst-to-burst, association between microbursts and VLF chorus. The general time scale for both chorus bursts and electron bursts is very similar, generally a few tenths of a second.

These associations between chorus and microbursts suggest a common origin for both phenomena. Since incoherent radiation from energetic charged particles (cyclotron radiation from individual particles) cannot explain the intensities of VLF emissions such as chorus [*Ellis*, 1957; *Santirocco*, 1960; *Liemohn*, 1965], it is generally believed that VLF emissions are generated by plasma instabilities within the magnetosphere. A plasma instability acts to coherently bunch or organize the charged particles, so that large intensities can be obtained. On very general grounds *Brice* [1964*a*] and *Kennel and Petschek* [1966] show that the generation of whistler mode wave energy by interaction with electrons gives rise to a decrease in the pitch angle of the resonant electrons and to precipitation if the mirror altitude is sufficiently decreased. Thus, the plasma instability that produces VLF chorus may also cause precipitation of the 40-kev electrons that are observed as microbursts.

The detailed plasma instability mechanism that produces chorus emissions is not known, although several possible mechanisms have been considered [*Brice,* 1964*a, b*; *Kennel and Petschek,* 1966].

In considering the region of occurrence of chorus and microbursts, it is important to note that, whereas the guiding center of the electrons is constrained to follow a geomagnetic field line, the VLF chorus energy is guided only approximately along the geomagnetic field line to within ±19°. Thus, if chorus and the electron bursts are produced together at high latitudes in the magnetosphere, then at lower altitudes the region illuminated by the chorus should be generally larger and roughly symmetric in latitude with respect to the region where microbursts are observed. This relationship is in agreement with the observed regions of occurrence for chorus and microbursts shown in Figure 5. Also, since chorus and microbursts do not follow the same path from the region of generation, one would not necessarily expect a burst-by-burst correspondence between chorus bursts and microbursts.

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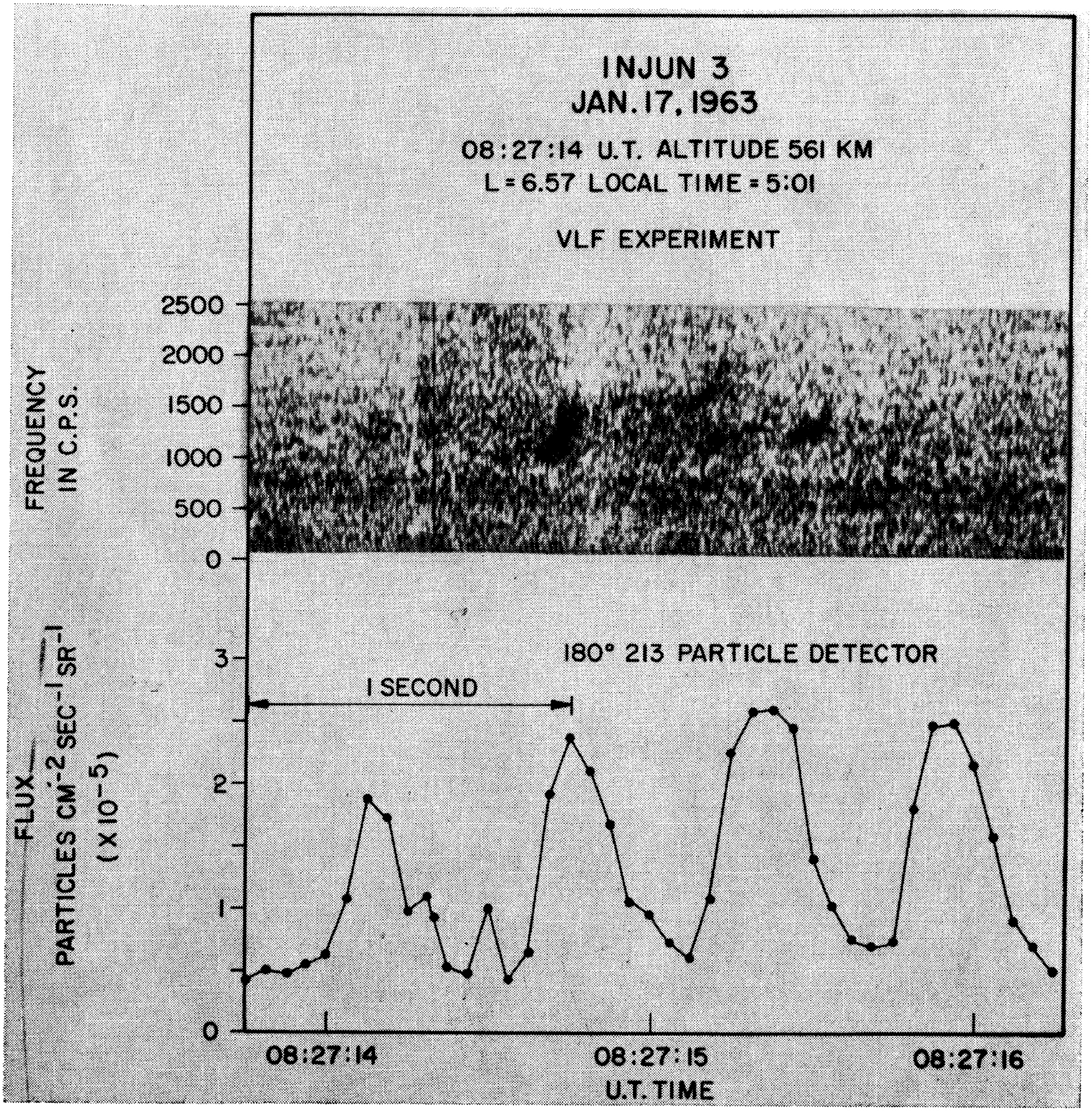

Fig. 6. High time resolution appearance of simultaneous periods of electron (microburst) and VLF chorus records. No one-to-one correspondence between bursts can be established.

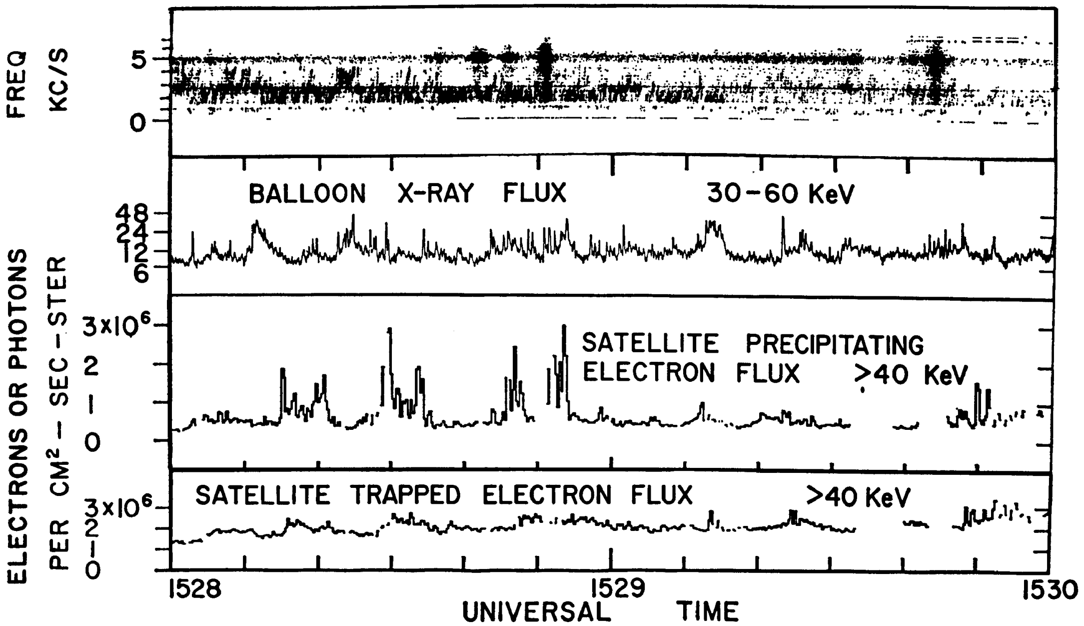

Fig. 7. Injun-3-observed electron bursts and VLF records and X-ray bremsstrahlung records of balloon-observed pulsation and microburst events seen at a longitudinal separation from the subsatellite point of ~400 km. Observations made on September 20, 1963, at 1530 UT [*Milton and Oliven*, 1967].

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