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KILOMETRIC TYPE III BURST ENHANCEMENTS ASSOCIATED WITH INTERPLANETARY SHOCKS

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Abstract. Type III bursts have been observed in the 30–100 kHz range which show localized enhancements in their spectra. The enhancements exhibited by a series of type III bursts extending over a period of several hours show a consistent decrease in frequency. The rate of this decrease is consistent with the movement of an interplanetary shock. The passage of such a shock by the Earth is suggested by the occurrence of sudden commencements at approximately the expected time.

Examination of solar type III bursts at kilometric wavelengths shows that the intensity of emissions generally decreases with decreasing frequency. In contrast, occasional bursts are observed which display band-limited enhancements of their spectra. Two such bursts are discussed below.

The observations reported here were made by the Stanford University vlf experiment on the OGO-3 spacecraft. This experiment measured the characteristics of radio waves in the 0.2–100 kHz range; only the data from a receiver sweeping the range 10–100 kHz each 2.3 min are shown here. Further details concerning this experiment are given by Dunckel *et al.* (1972) and Dunckel (1974). The digital output from this receiver has been converted into the 'ampligram' shown in Figure 1. The height of an individual trace is proportional to the logarithm of the receiver output; the overlap produced by strong emissions causes the large white areas. The narrow spectral lines of invariant frequency, as at 1415 UT at 93 kHz, are due to spacecraft interference.

Figure 1 shows a sequence of three type III bursts that exhibit large enhancements in their spectra near 70 kHz. These enhancements have power spectral densities about ten times greater than that at 100 kHz. The frequency of these enhancements decreases from 72 kHz in the first event at 12 UT to 64 kHz in the third event at 19 UT. The enhancements do not appear to be related to the plasma immediately surrounding the Earth, since the low-energy electron detector on board the OGO-3 spacecraft indicates that it was outside the bow shock during the period shown in Figure 1 except for 1203–1243 UT and 1250–1311 UT (personal communication, V. Vasyliunas). Neither do the enhancements appear to result from the effects of the local interplanetary medium, since Vela 3 measurements at 18–21 UT on this day indicate a plasma frequency of 28 kHz (Bame *et al.*, 1970). The second event is associated with a flare at W51 commencing at 1414 UT and reaching maximum at 1418 UT. The third event is associated with a flare in the same sunspot region commencing at 1753 and reaching maximum at 1806 UT. No known flares are associated with the first

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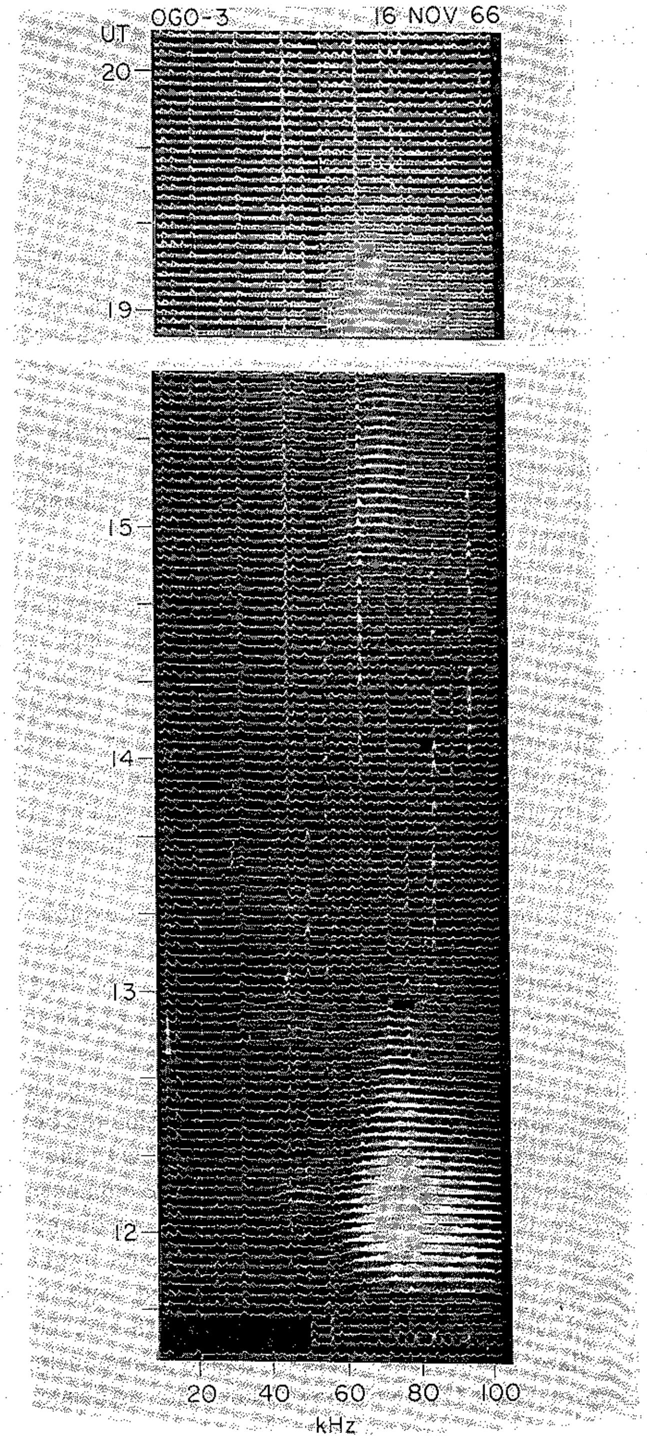

Fig. 1. Three type III bursts showing enhanced spectra in a band that decreases from 72 kHz in the first event to 63 kHz in the last event. Data is interrupted from 1535 to 1850 UT.

event. (This lack of association with known flares is not rare: it occurs for about 20% of the type III bursts observed in this frequency range.)

Pioneer 7 spacecraft data (Lazarus *et al.*, 1973) indicates that a very dense region was in a good position to be illuminated by the flares listed above. It measured an electron density of 32 cm^{-3} and a solar wind velocity of 395 km/s on day 17.65 of November from a location 5° east of the Earth at 1.06 AU. Under the assumption that this density enhancement is time-invariant, these parameters indicate that at the time of the second event of Figure 1 a dense streamer emanated from roughly 45° west solar longitude. This would place it in an excellent location to be illuminated by flare particles from the flare at 51°W. This region is considered to be the predominant generation region because of its high density, its favorable location with respect to the flare site, and because it lies close to Earth.

The times and frequencies of the enhancements in Figure 1 can be interpreted in terms of the parameters of a causative interplanetary shock once a generation model is selected. We assume that generation occurs at the plasma frequency rather than at its second harmonic because a similar class of emissions upstream of the Earth's bow shock was much stronger at the plasma frequency than at its harmonic (Dunckel, 1974). In support of this choice we note two drawbacks of the alternative hypothesis: the strong electrostatic wave expected at half the wave frequency has not been clearly observed; and the occurrence of type III emissions at frequencies down to the local plasma frequency (Dunckel, 1974) would require generation considerably beyond the orbit of the Earth, yet no observations have indicated anti-solar directions of arrival.

If densities in the interplanetary medium are assumed to vary as the inverse square of the distance from the Sun, then the change of emission frequency from 72 to 62 kHz in 7 hours corresponds to a radial shock motion of about 600 km/s. This constitutes a reasonable velocity for an interplanetary shock (Hundhausen, 1970). If it continued at the same radial velocity, it would arrive at the Earth roughly 13 hours after the last event in Figure 1, or at about 8 UT on Nov. 17. Sudden commencements (ssc's) were observed on the 17th at 0017 UT (reported by 38 stations) and at 1720 UT (35 stations). The large number of reporting stations suggest that these events were likely to have been caused by interplanetary shocks (Taylor, 1969).

A less dramatic but better documented event was the 8 July, 1966 event shown by Dunckel *et al.* (1972) and by Dunckel (1974). A curious feature of this example was the considerable enhancement of emissions near 80 kHz. We believe this to be due to the shock wave from the flare on 7 July that reached the Earth at 2106 UT on the 8th (Ness and Taylor, 1969; Lazarus and Binsack, 1969). Associated with this shock was a type II radioburst observed down to about 20 MHz by Stewart (1969). As above, generation is expected to occur in a dense region whose plasma frequency, calculated from direct measurements by Explorer 33 at 1 AU (Lazarus and Binsack, 1969), was 53 kHz. At the time of the type III burst shown by Dunckel *et al.*, the shock would be expected to lie at approximately 0.81 AU. Under the conditions indicated above, an enhancement would be expected at $53/0.81 = 65$ kHz, in reasonable agreement with the observations.

The two examples discussed here indicate that outward-propagating interplanetary shock waves are capable of modulating the spectra of Type III bursts at large fractions of an AU. Similar downward drifts in the frequencies of type III enhancements were observed in the 0.5 to 3 MHz range by Fainberg and Stone (1970).

The use of shock wave position information derived from other sources may prove of value in locating the source region of the type III bursts they modulate as well as in defining the type III generation mechanism.

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Discussion

Steinberg: What is the size of the emitting region?

Dunckel: The scale size is set by the solar wind velocity $\times 7$ second duration ≈ 3000 km.

Melrose: How was the value of the refractive index given in your thesis derived and is the value still OK?

Dunckel: The ratio of electric to magnetic field ~ 10 to 1 sets $n \sim 0.1$.

Melrose: This presupposes the waves are transverse.

Dunckel: Yes.