VARIANTS OF TILTED-V EVENTS IN JUPITER'S DECAMETRIC RADIO SPECTRA

(*Letter to the Editor*)

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Abstract. Spectra of complex Jovian S-storms can be interpreted as groups of tilted-V variants. In such an approach the basic components (wide-range S-bursts, narrow-range S-trains, emissions of type N, and shadow events) are arranged in a predictable sequence. It seems that the application of tilted-V variants offers some order for the chaos evident in many S-storm spectra.

Jupiter's S-storms can produce outstanding spectral records in the decametric range. The individual S-bursts are narrow-band emissions which may drift rapidly in the frequency domain and appear as tilted lines in the (dynamic) spectrum, i.e., in the orthogonal time-frequency plane. Drift rates may vary from -5 to $-45\,\mathrm{MHz\,s^{-1}}$, while the instantaneous bandwidths are usually less than 200 kHz (Carr *et al.*, 1983).

Many S-bursts are affiliated with other spectral features (Krausche *et al.*, 1986; Ellis, 1979). Probably the simplest of these is a combination of two S-bursts starting from a common origin but having different drift rates (Groth and Dowden, 1975; Leblanc *et al.*, 1980). If an L-burst is simultaneously present, the two S-bursts cut a tilted V-shaped opening in it, void of emission. This is known as a 'tilted-V' event (Riihimaa and Carr, 1981). It is shown here that the tilted-V event has variants, which are very common in the 20-25 MHz range and seem to be involved in many high-resolution S-spectra that exhibit complex structures.

A systematic study of tilted-V events was made from the records covering the periods August–December 1987 and September–November 1988 obtained with an acousto-optical radio spectrograph (Riihimaa, 1987) and a steerable twin crossed log-periodic antenna. Two parallel real-time records were made from the right-circular component of the emission: one of the image on the transform plane, and the other of an intensity-modulated display driven by a charge-coupled device (RL 256EC/17). The latter was operated in the manner of a TV monitor but with line and frame frequencies of 2000 and 16 Hz, respectively. Since the recording is made with a continuous-motion shutterless camera, every other frame is blanked out to avoid overlapping, resulting in 40% effective sampling time.

A total of 12 S-storms were observed, 9 in the Io-B region and 3 in the Io-C region. The outstandingly interference-free location of the Kiiminki site (30 km east of Oulu) and the almost total absence of long-range radio station interference at night (especially in 1987) made it possible to use a wide-open RF amplifier. This has no frequency conversion and is therefore absolutely free of image-frequency

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responses. A spectrum of 20 to 30 MHz could be recorded without problems. Most of the Jovian S-storms occurred at 20-25 MHz, however.

The most common variant of the tilted-V event is one in which the right side has disappeared. When both sides are missing, a 'shadow'-like feature is present but can be seen only if superimposed on an L-burst with sufficient bandwidth. Such a case is referred to as a 'fast-drift shadow (FDS) event' (Riihimaa *et al.*, 1981). In the case of an N-burst, which is actually a narrow-band version of an L-burst (Riihimaa, 1985), the tilted-V event can still be recognized if it exhibits its left side (referred to here as the "main S-burst"), plus an N-emission gap of typical duration.

Idealized sketches of the tilted-V variants are given in Fig. 1. These do not necessarily indicate the observational sequence of burst evolution, and not all stages are even observed during the same S-storm. A tilted-V event in its basic form is shown in (a). It is formed by a narrow-band emission of type N and two S-bursts that start from a common origin but have different drift rates. They cut off a section of the N-emission (the emission gap) of duration of 20–100 ms. The most common variant appears in (b), in which only the left S-burst (the main S-burst) is visible. This is usually intense, with frequency ranges varying from 1 to

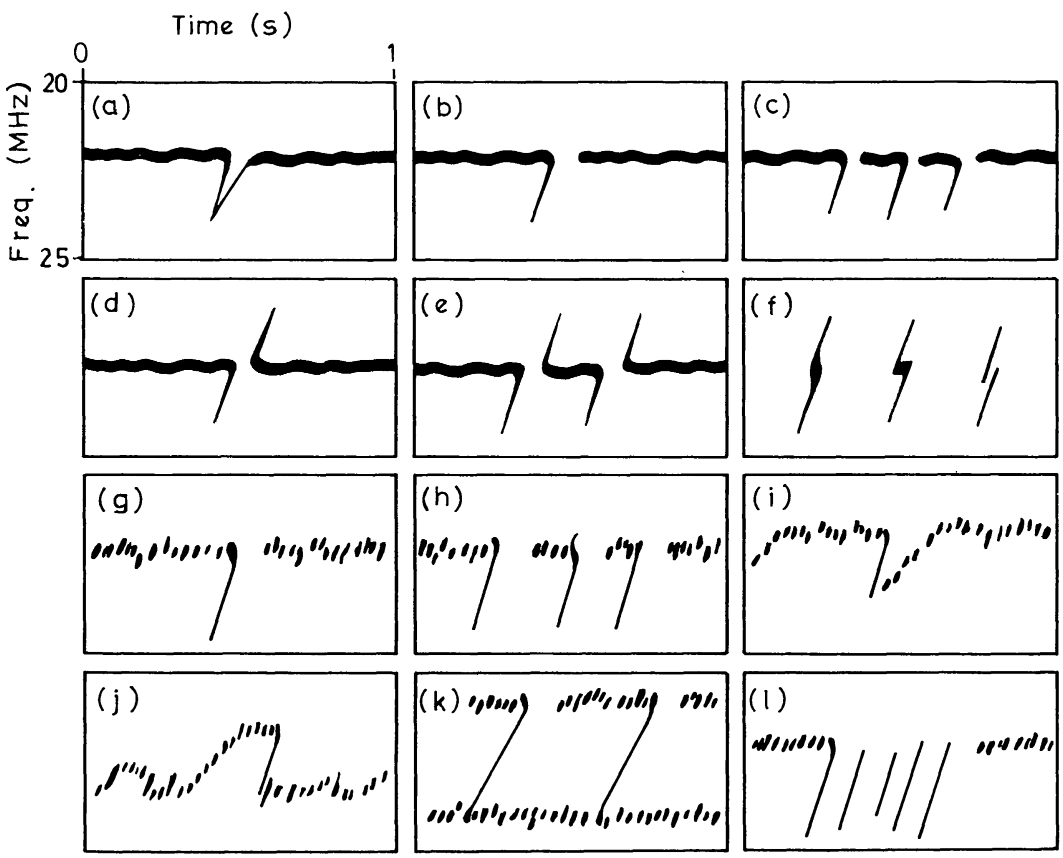

Fig. 1. Idealized sketches of the tilted-V pattern, its most frequent variants and related phenomena (refer to text).

3 MHz, sometimes up to 6 MHz. If more than one event occurs in succession, a series of '7-shaped' spectral patterns appear, as shown in (c).

S-bursts with a frequency range of at least 1 MHz have not been observed to cross N-emissions, but always seem to merge with them and disappear. Even if the situation may occasionally seem to be otherwise, records at a high enough resolution indicate that it is not the same burst that proceeds to the lower-frequency side (d). If events of this kind occur in succession, Z-shaped patterns are formed (e), which can also be recorded as discrete events with short horizontal sections (f), not necessarily evolving from (e). In an expanded time scale they are apparently the Z-patterns first described by Ellis (1973, see also Fig. 11 of Riihimaa, 1977).

The tilted-V concept also applies when the N-emission is dispersed into a train of narrow-range S-bursts (elements) with frequency ranges of 200–500 kHz occurring at a quasi-periodic rate of 20–80 Hz. Accordingly, the main S-burst now merges with one element of the S-train (g). These can also form '7-shaped' patterns (h).

At the next stage (i) the right side of the tilted-V appears in the form of a sloping S-train. The drift rates of the S-train elements are of the same order as that of the main S-burst, and the characteristic gap in emission can also be seen. An event is sketched in (j) which is the inverse of that in (i). A combination of these two may be present when two S-trains appear simultaneously, a few MHz apart (k). Here wide-range S-bursts (up to 5 MHz) may join together elements of the two S-trains, whereupon tilted-V events are formed at the upper S-train (i.e. the lower-frequency one).

The sketch in (l) shows an S-train and a few wide-range S-bursts, of which the first one serves as the main S-burst of a tilted-V event, while the rest of the wide-range S-bursts that follow seem to be capable of holding off S-train emission for as long as they recur, giving a visual impression of them all being accompanied by FDS events.

A typical slit-camera record is reproduced in Figure 2(a). This shows tilted-V variants consisting of narrow-range S-trains, wide-range S-bursts (the main S-bursts) and emission gaps in an overall irregular saw-tooth pattern. The S-train elements have frequency ranges 100-200 kHz, rate of occurrence 30–70 Hz and frequency spacing 0–300 kHz. It appears that the emission gaps occupy a considerable part of the spectrum. Three sections shown by arrows in (a) are reproduced in (b–d) as frames recorded from the CCD-driven display unit. The large S-bursts in frames (b, c) are the main S-bursts of tilted-V events. Some emissions are as short as 1–2 ms (d). The S-train elements drift in frequency, but the N-emissions do not.

Many of the isolated, short-lived, narrow-band bursts seem to be more or less degenerated remnants of tilted-V events, as shown in Figure 3. A tilted-V corner is seen in (a) in which the end section of the main S-burst joins the N-emission. Two superimposed tilted-V corners appear in (b) and a 'twisted pair' emission in

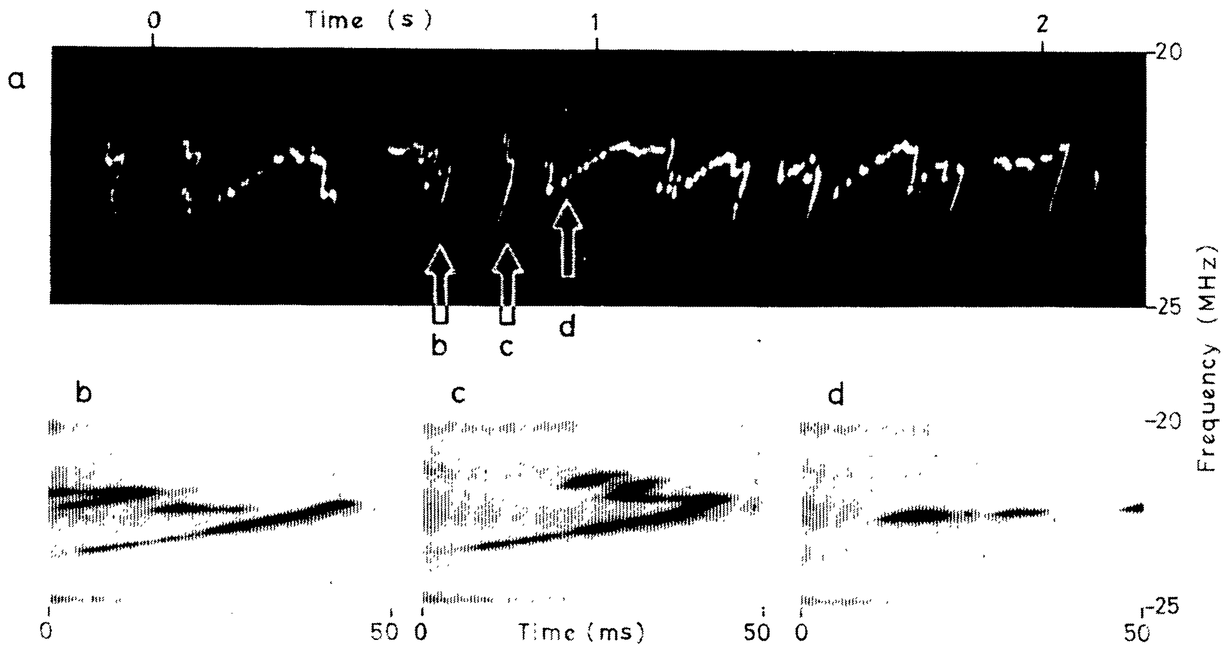

Fig. 2. Sample records of Jovian decametric spectra obtained during an Io-B storm on Dec 01, 2117 UT, 1987. The record in (a) is composed of S-trains, wide-range S-bursts and emission gaps of tilted-V events. Events marked with arrows in (a) are shown in (b-d) as CCD frames in which the time axis is expanded by a factor of 14.

(c) which has obviously degenerated further from that in (b). A short section of the main S-burst just as it merges with type N emission can be seen in (d), and a short section of the main S-burst, a few ms in duration, in (e).

It seems that the tilted-V event and its variants make an important contribution to the high-resolution morphology of the Jovian emission in the 20–25 MHz range. Many of the complicated spectral events can be derived from a relatively few basic patterns, allowing intermediate stages plus some modification and mixing. If we assume that the emission gaps are shadow events, observed not only in the S-L interaction (Riihimaa and Carr, 1981) but also in the S-N interaction (present report), then a significant proportion of Jovian high-resolution spectra must be diluted by such shadow events.

The interpretation of complex S-events goes beyond those suggested for the emission mechanism of simple S-bursts. Simple tilted-V events have been studied previously by Staelin and Rosenkranz (1982) and shadow events by Gopalswamy (1986). An interpretation of the causes of tilted-V variants is probably what is needed to understand S-storms as a whole.

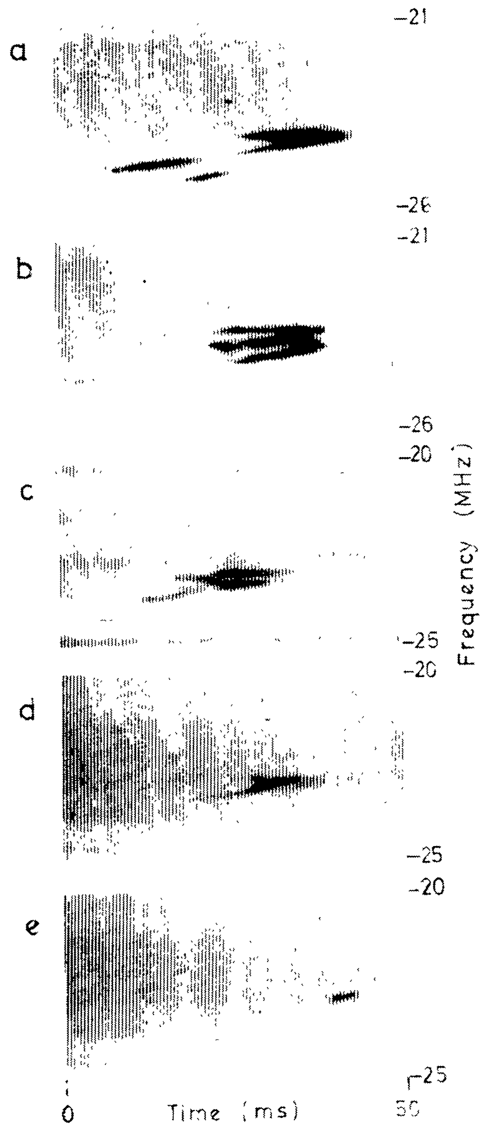

Fig. 3. Variants of tilted-V remnants recorded during three S-storms in 1987: (a, b) Oct 16, 2300 UT, Io-B; (c) Dec 01, 2109 UT, Io-B; (d, e) Oct 22, 2321 UT, (Io-C). A corner of tilted-V event is shown in (a). Two superimposed corners of tilted-V events appear in (b), and a "twisted pair" emission in (c). A short-duration corner remnant of a tilted-V is shown in (d), and a small section of the main S-burst in (e).

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