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BURSTS OF TYPE N IN JUPITER'S DECAMETRIC RADIO SPECTRA

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Abstract. Dynamic spectra of Jupiter's decametric emission often display narrow-band features, referred to as events of type N (Carr *et al.*, 1983). The average bandwidth of these emissions is in the vicinity of 200 kHz, their durations are typically in the decasecond range, and their *f*–*t* slopes are small and random. Although the N-bursts can be described as narrow-band L-bursts, it seems that they are realted to S-bursts in their area of occurrence in the Io-B region, the durations of the emission envelopes, and their bandwidths. Possible implications are discussed.

1. Introduction

The narrow-band properties of Jovian radio bursts were discovered by Gallet in observations made in 1956–1957. It was shown that bursts recorded at frequencies spaced by 2 MHz exhibited poor correlation (Gallet, 1961). Warwick (1963) described dynamic spectra of Jovian emissions with bandwidths of the order of 600 kHz (the frequency resolution limit of the Boulder spectrograph) and with durations of tens of minutes.

Further observations of narrow-band emissions have been made by Riihimaa (1964), Dulk (1965), Block (1965), Warwick and Gordon (1965), Gordon (1966), and Gordon and Warwick (1967). Spaced-spectrograph observations of narrow-band emissions were described by Riihimaa (1968a). A similarity between the spectra of narrow-band L-emissions and the envelopes of narrow-band trains of S-bursts was pointed out by Riihimaa (1968b); also the first records of band-splitting phenomena were shown.

Narrow-band emissions have been studied more recently by Krausche *et al.* (1976), Flagg *et al.* (1976), Leblanc *et al.* (1980, I), and Leblanc and Rubio (1982). Carr and Desch (1983) designated the narrow-band L-emissions as events of type N. This designation will be used in the present report. There will thus be three basic types of bursts: L, S, and N. For the properties of L and S-bursts, see Riihimaa (1978, 1977).

2. Occurence

The occurrence of N-bursts is studied in the following in the Io-B region. This is the region which is shared by the main spectral types L, S, and N, plus a multitude of unclassified complex spectral phenomena. For region designation, refer to Carr and Desch (1976).

If the occurrence diagram is plotted for L-bursts only, there appears to be a 'hole' in the CML-Io plane close to the center of Io-B. This is a relatively sharp landmark. It was

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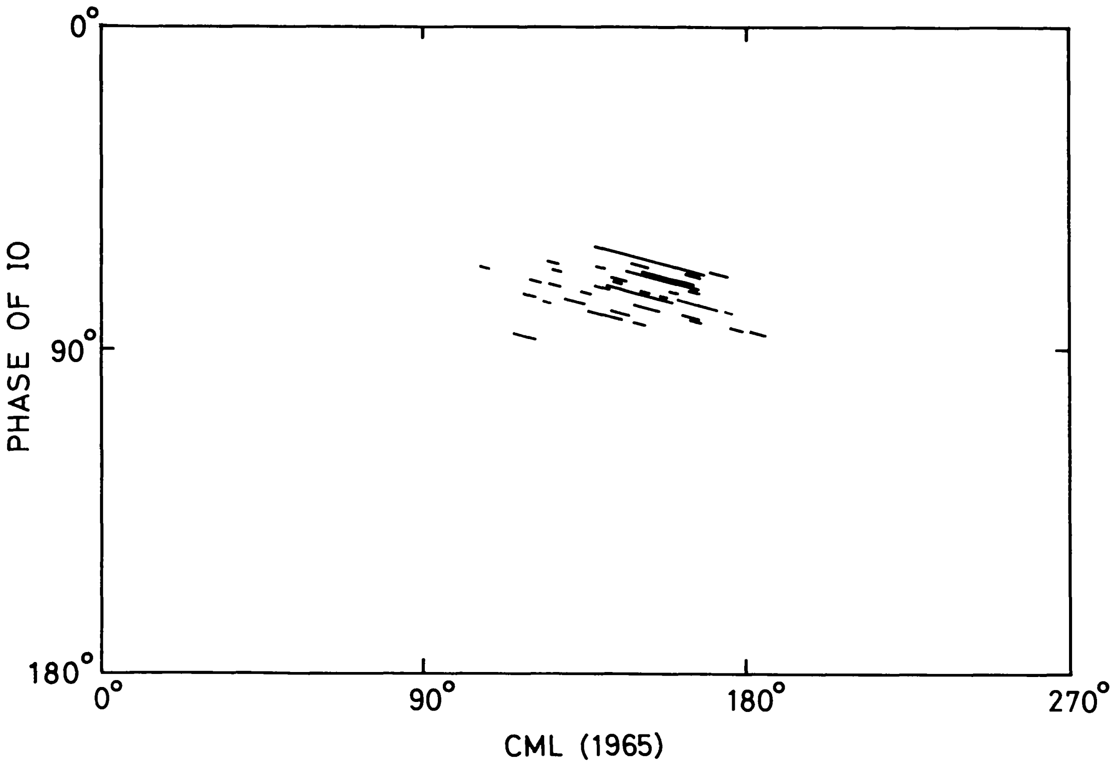

Fig. 1. Storms of type N observed in the Io-B region (refer to Figure 8 of Riihimaa, 1977, and Figure 1 of Riihimaa, (1978).

detected for the first time from the 1963–1968 high-resolution spectral observations at 19–23 MHz and was described as a 'dearth of events' (see Figure 15 of Riihimaa *et al.*, 1970). The same dearth is well visible in Figure 1 of Riihimaa (1978), centered upon CML-Io longitudes of 80 and 130°, respectively.

If the observed S-bursts from Figure 8 of Riihimaa (1977) are now plotted on top of the L-emissions, it can be seen that the L-dearth is covered by the S-bursts, while bursts of both types may occur outside the dearth. The L-dearth and its relation to S-bursts is also shown in Figure 6 of Leblanc *et al.* (1980, I), derived from observations made over a wider frequency range.

The N-strorms observed during 1974–1978 are plotted in the CML-Io plane in Figure 1. The data originate from the 2-color polarized records of a 48-channel radio spectrograph (Riihimaa, 1976) operated at the frequency range of 20.85–23.20 MHz.

It can be seen that N-bursts occur inside the S-burst zone but mostly outside the L-burst zone and do not cover the L-burst dearth. When compared with Figure 10 of Riihimaa and Carr (1981) it appears that S–L interactions and N-bursts partly share the same zone of occurrence. The best correspondence shown by the N-zone, however, is with the S-zone.

3. Spectral Characteristics of N-bursts

A 30-min section of an N-storm, reproduced from a 2-color record, is shown in Figures 2 and 3. The total duration of the storm was 50 min, during which time the emission

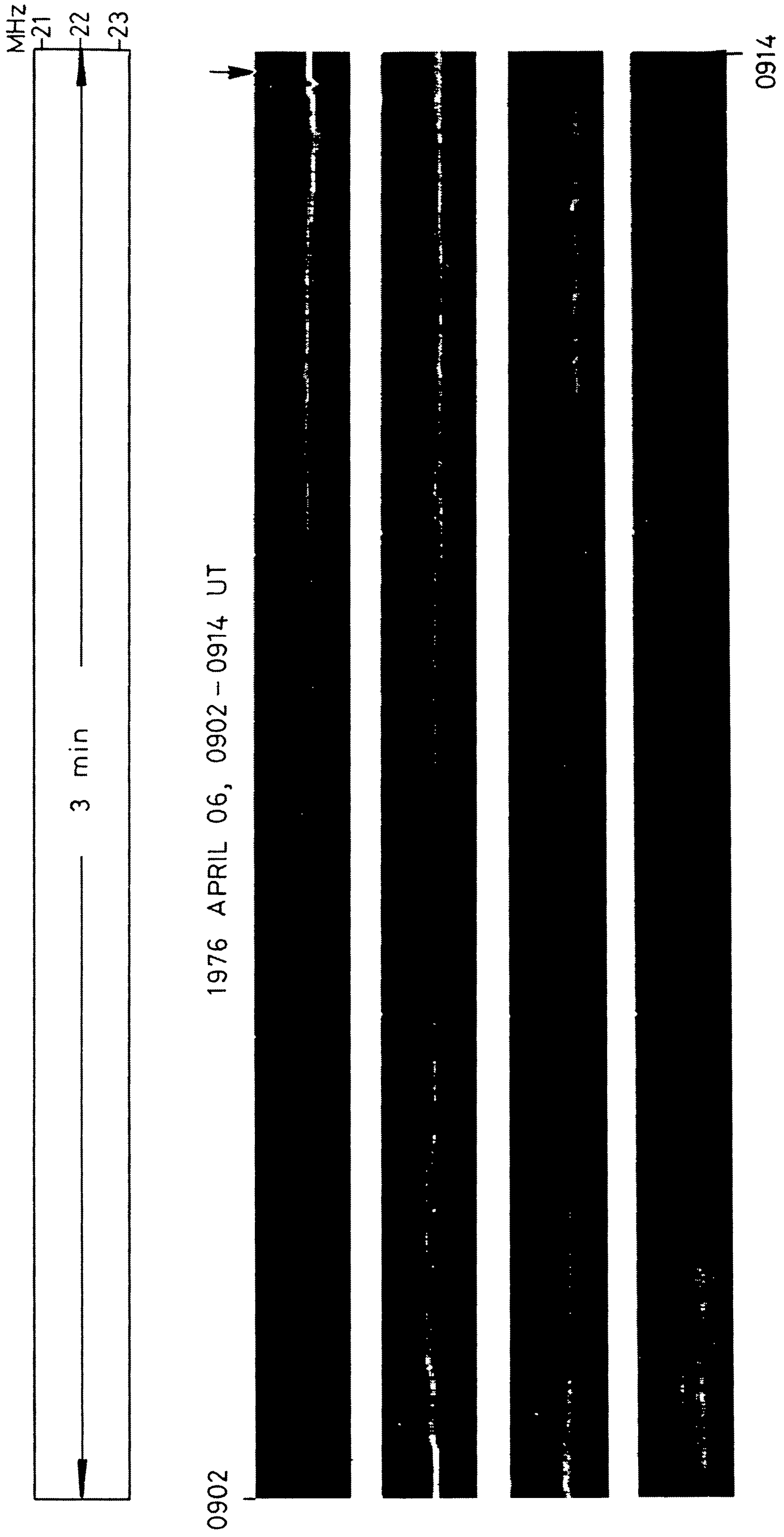

Fig. 2. Sample record of an N-storm. The record starts at the upper left-hand corner and progresses in 3-min sections from left to right and from top to bottom. A section, indicated by an arrow, is enlarged in Figure 4.

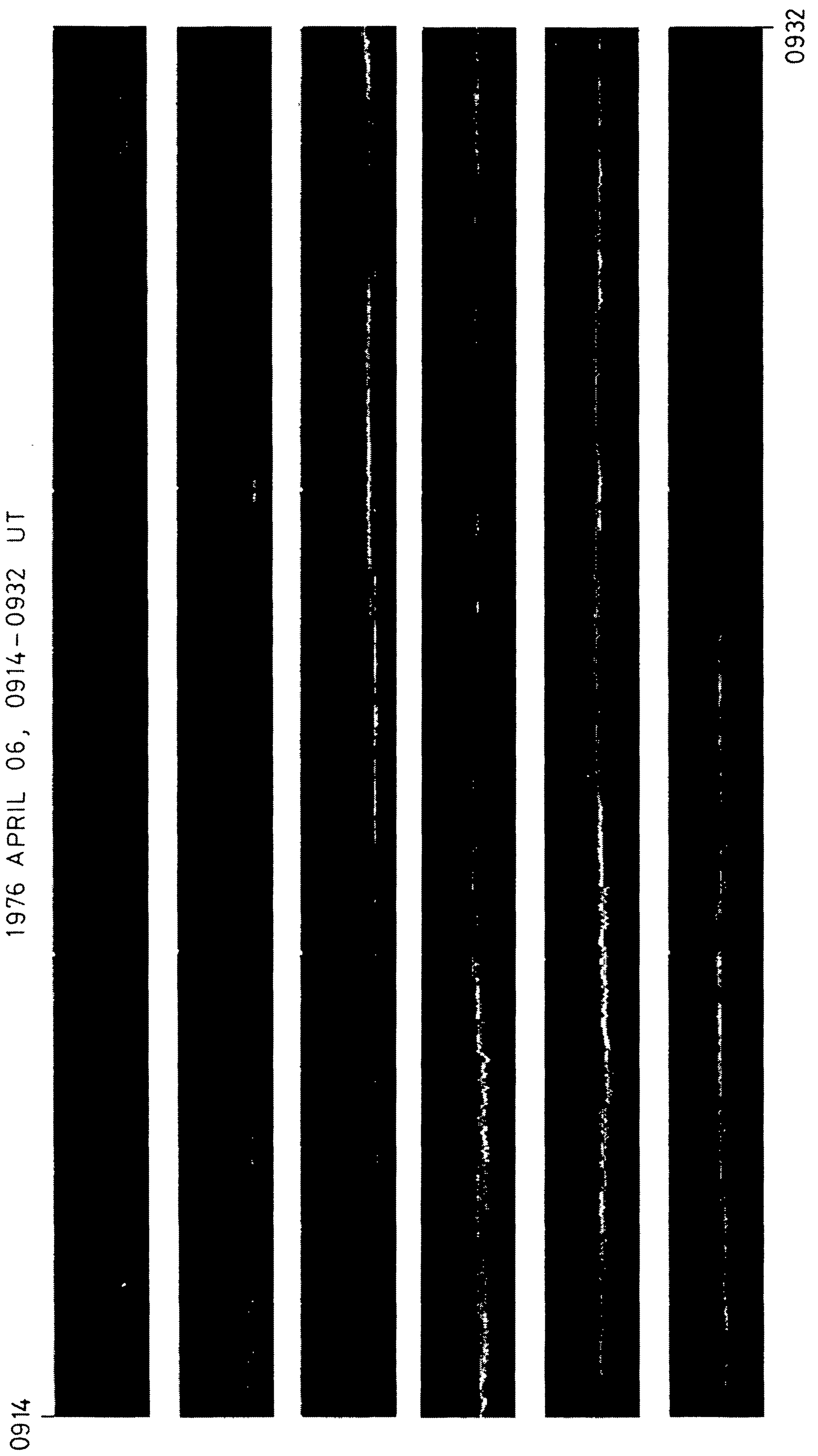

Fig. 3. As Figure 2, but for the subsequent period of 18 min.

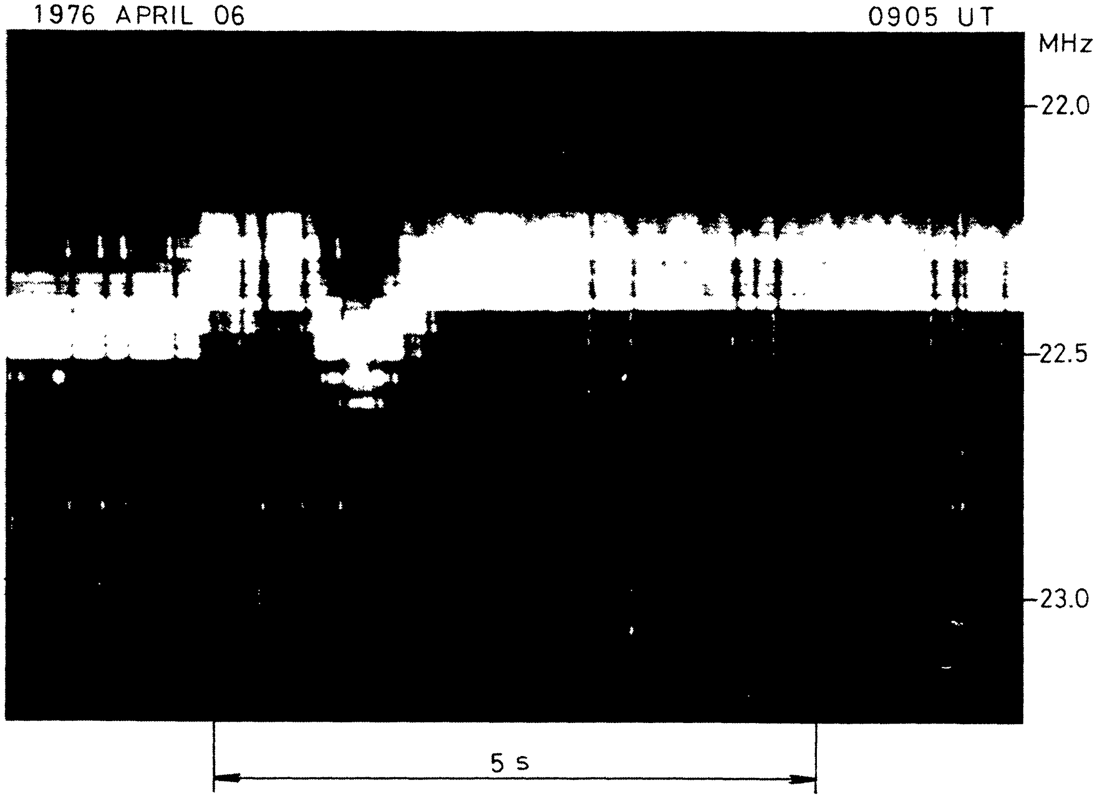

Fig. 4. Enlargement of a section of Figure 2. An N-emission of 200 kHz bandwidth is intersected by S-bursts.

remained within the 2-MHz frequency range of the equipment. For 40 min it was observed to stay within ± 0.5 MHz. The storm was polarized in the right-handed sense.

As can be seen, there are periods of uninterrupted emission up to 3 min in duration. This storm was recorded in the daytime, when Jupiter was approximately 17° east of the Sun, and when the level of interference was unusually low (all the other N-events of the present report were recorded at night, when the planet was close to opposition). The storm offers an excellent illustration of the stability of the frequency of N-emissions. However, the envelope durations displayed may not be typical, since the storm was recorded when Jupiter was behind the outer regions of the solar corona, resulting, perhaps, in an increase in the apparent angular size of the source. The storm is plotted in Figure 1, but not in the duration histograms.

Several S–N interactions occur in the sample. An enlargement of a section, indicated by an arrow in Figure 2, is shown in Figure 4. It appears that the S-bursts cut off the N-emission for short periods of time. Samples of similar records, but expanded in time scale by a factor of 10, are shown, e.g., in Figures 3 and 4 of Riihimaa and Carr (1981). This type of interaction was designated as 'tilted-V patterns' by the authors.

There are other ways in which the N and S-bursts can relate to each other. For example, an N-emission may suddenly disperse into a wide-range group of S-bursts which expand into the lower-frequency region. A record of such an event is shown in Figure 5b of Riihimaa (1977). At other times an N-burst may be accompanied by a train of S-bursts at a few MHz lower frequency. A sample of a 20–30 MHz record is shown in Figure 4b of Riihimaa (1977). A similar phenomenon is described in Figure 5a of Leblanc and Rubio (1982), and designated as type 3 splitting (note the reversed direction of the frequency axis).

The bandwidth of a typical N-burst is in the vicinity of 200 kHz, but there are observations of N-bursts with bandwidths as narrow as 50 kHz (Riihimaa, 1968b). The latter value is close to the instantaneous bandwidth of a typical S-burst (Krausche *et al.*, 1976). The bandwidth of the emission envelope of a typical narrow-band S-train is of the order of 200 kHz. The most normal appearance of S-bursts is in trains with a frequency range of 1 to 2 MHz.

4. Duration Histograms

The fixed-frequency observations of Smith and Douglas (1962), Douglas and Smith (1967), and Slee and Higgins (1968) indicated the interplanetary origin of L-bursts. The dynamic spectra of L-bursts appear as emission envelopes (Riihimaa, 1970), while part of the 1-s component is due to modulation lanes (Riihimaa, 1974). The envelope durations increase markedly towards the opposition of Jupiter. Diagrams describing this effect for L-bursts are shown in Figure 5 of Riihimaa (1970) and in Figures 3 and 4 of Riihimaa (1978).

Interplanetary scintillation undoubtedly produces envelope patterns also for the S-bursts. In order to evaluate the durations of S-envelopes it is required that the individual S-bursts should recur rapidly enough. Only such events can be used for duration measurements. For the sake of illustration, two samples of S-burst spectra are shown in Figure 5. The spectrum in (a) shows emission envelopes ranging in duration from 2 to 8 s, while the one in (b) shows one envelope which has a duration of 50 s. Neither of the samples illustrates a typical narrow-band S-burst train. For samples of such records, see Figure 1d of Riihimaa (1968b) and Figure 11 of Riihimaa *et al.* (1970).

Duration histograms for the L, S, and N-burst envelopes are shown in Figures 6 and 7 of the present report. The data for the L-profiles are derived from observations made in 1974–1976 and those for the S and N-profiles from observations made in 1974–1978 (for details, see Riihimaa (1977, 1978). The L-burst data originate from all the regions (Io-related and Io-unrelated), the S-burst data from the Io-B and Io-C regions, and the N-burst data from the Io-B region. The data are grouped in 20-day intervals before and after the opposition of Jupiter.

As can be seen from Figure 6, the envelope durations of all three types of bursts increase towards opposition. The N-envelopes seem to be consistently longer than the L-envelopes. On the other hand, the duration profiles of N and S-envelopes are remarkably similar in observations during the same intervals.

The lengthening effect of the L-envelopes is very clear from 40 d before to 20 d after opposition, while the durations of the S-envelopes remain essentially unchanged.

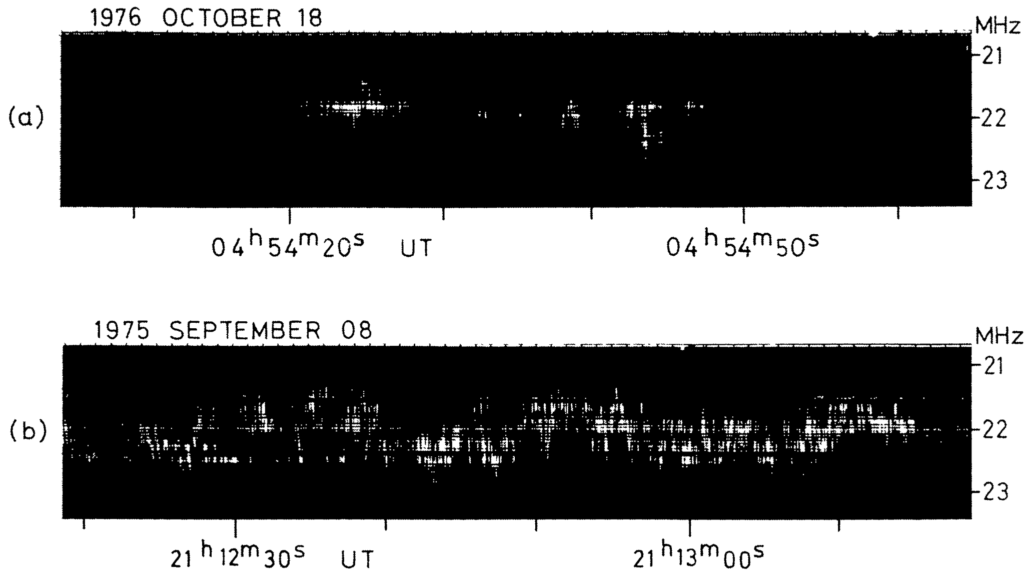

Fig. 5. Sample records of S-burst emission envelopes. Short-duration envelopes appear in (a), and one long-duration envelope in (b). Both events were recorded approximately one month before opposition.

Unfortunately, there are only a few observations of N-bursts in Figure 7. The durations of the L and S-envelopes start to decrease approximately 20 d after opposition.

It thus seems that the N and S-envelopes are longer in their average duration than the L-envelopes. Although the N and S-bursts are often more intense than the L-bursts, it is not believed that the duration effects, at least not all of them, can be artefacts created by saturation of the spectrograph. There are observations of many weaker N and S-events which do not saturate the equipment and yet display emission envelopes of remarkably long duration. Similarly, there are many records of extremely intense L-events which display short-duration envelopes. A sample of such a record is shown in Figure 2 of Riihimaa (1978). This kind of interplanetary scintillation, which is quite common in L-spectra, is never observed in N-spectra.

5. Discussion

There is no conclusive theory to explain the origin of the decametric emission of Jupiter, nor have we any definite knowledge of the locations, distributions or motions of its sources. Attempts to describe the origin of N-bursts may have to comply with observations indicating that the N-burst are related to S-bursts. This is somewhat surprising since the N-bursts can be, and have been, categorized as L-bursts in observations at fixed frequencies, and as 'narrow-band L-bursts' in spectral observations.

The first possible explanation is linked to an instrumental effect. Suppose the individual S-bursts within a narrow-band train recur in such a rapid succession that they remain unresolved by the radio spectrograph. The result would have the appearance of a continuum-like narrow-band emission. N-bursts, however, appear diffused and remain

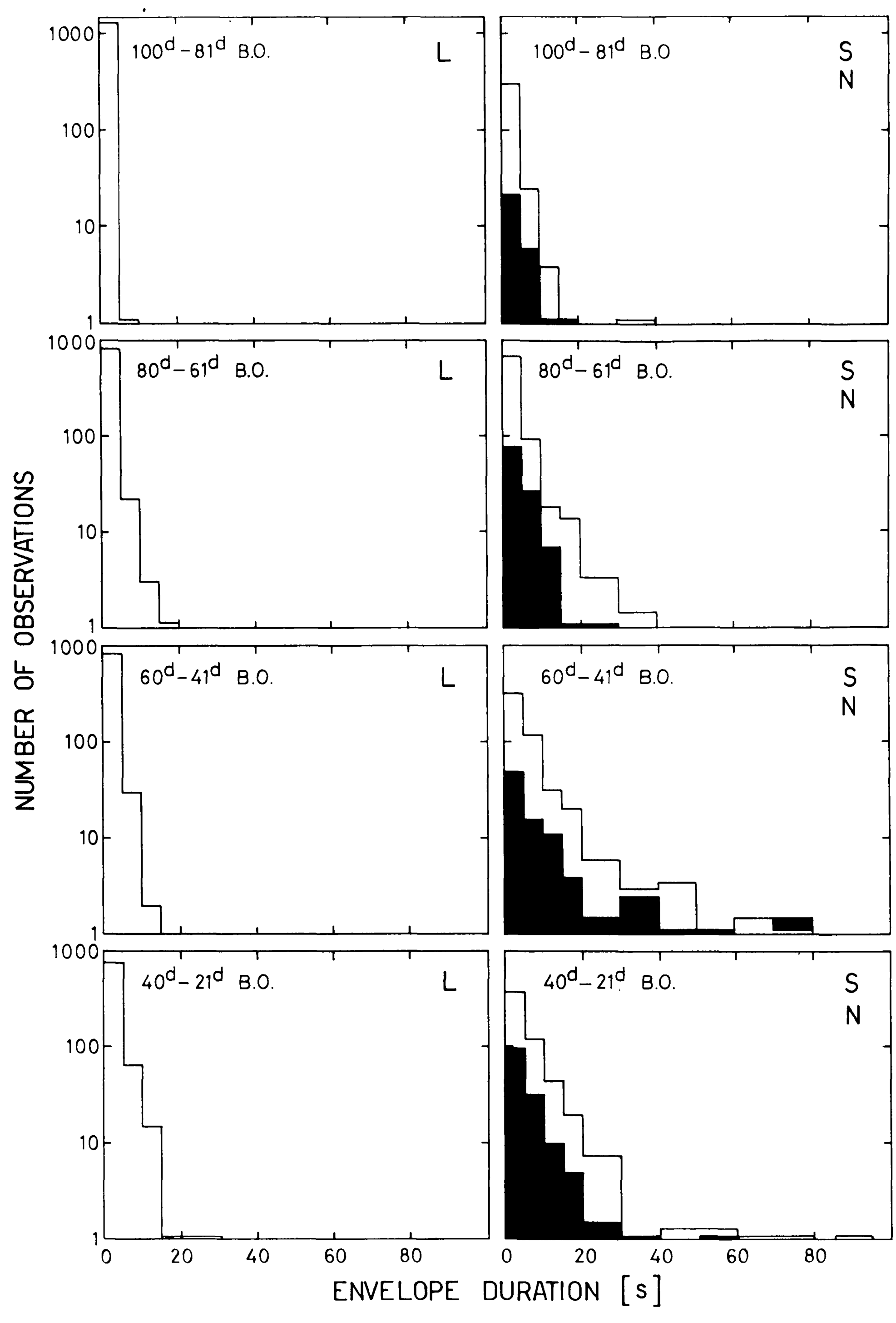

Fig. 6. Duration histograms of emission envelopes of bursts of types L, S, and N, plotted for 20-day intervals starting 100 days before opposition (b.o.). The L-bursts appear on the left, and the S and N-bursts on the right. The N-bursts are indicated as black.

unresolved at a time resolution of 4 ms (Figure 14b of Riihimaa, 1977), and even with a resolution as high as 0.3 ms (Figure 1b of Krausche *et al.*, 1976).

In another possible interpretation, the individual S-bursts do not recur rapidly, but

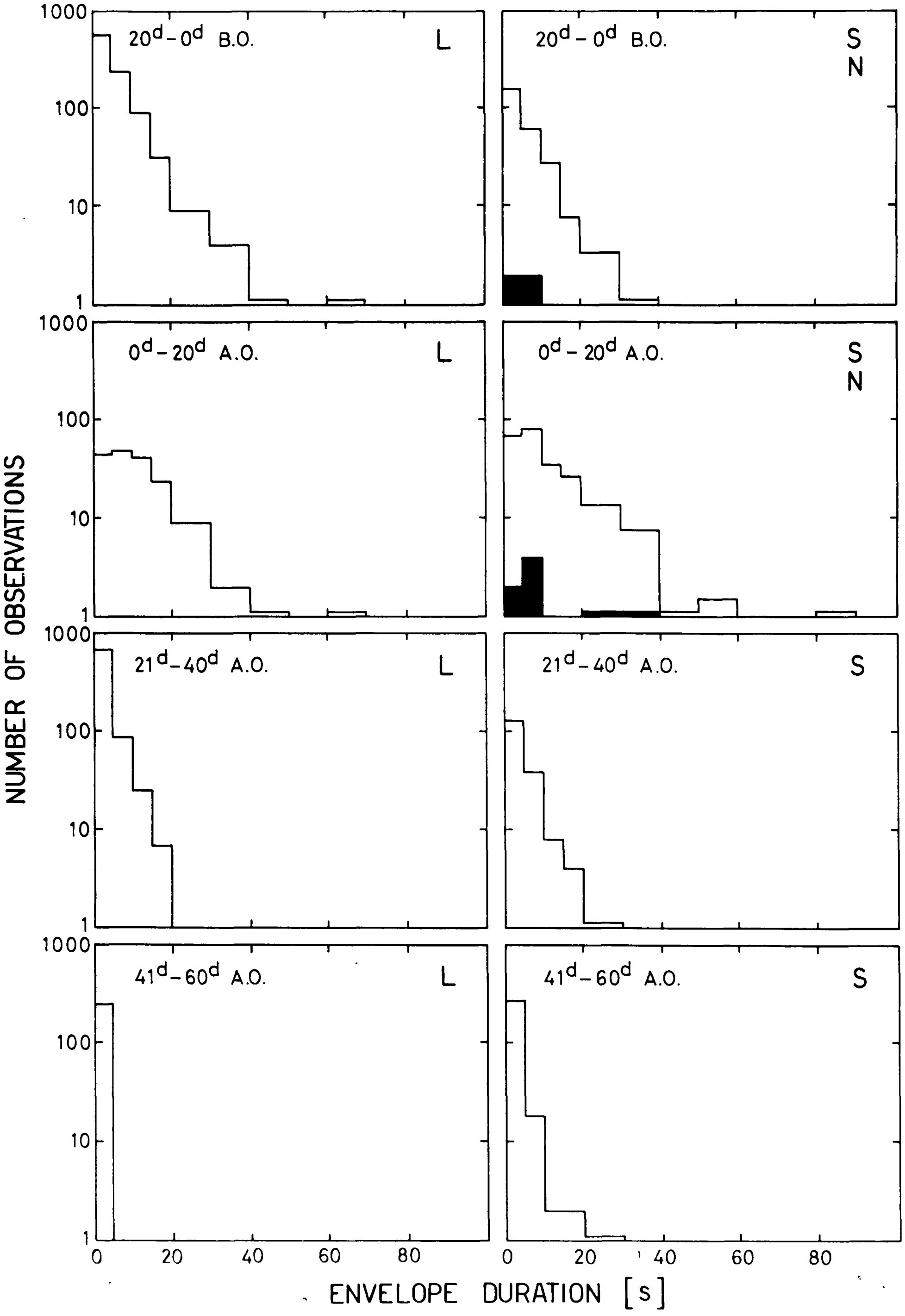

Fig. 7. As Figure 6, but for intervals of up to 60 days after opposition (a.o.).

have wide instantaneous bandwidths instead. Broad-band ('fat') S-bursts have been observed previously (Riihimaa and Carr, 1981), but occur only at the late-longitude edges of the S-zone in the Io-B region (Riihimaa, 1979). In any case, the phenomenology predicts the presence of several variants of 'fat' S-burst trains, including some that are resolved in addition to those that apparently remain unresolved. However, the former are not observed.

It seems that N-bursts are true continuum emissions, and not special cases of narrow-band S-trains. The relation between N and S-bursts may thus represent circumstances at the source itself, perhaps just two implications of the same basic mechanism.

According to the model of Ellis (1974, 1975) the S-bursts are produced by coherently-emitting bunches of electrons ascending the Io flux tube. The emission occurs at the Doppler-shifted cyclotron frequency. Flagg *et al.* (1976) presented a qualitative model for narrow-band (type N) emissions and S-trains. According to the authors there is an active region along the Io flux tube in which the emission is generated by an upward-flowing stream of electrons, at times continuous and at times bunched. The extent of the sources along the flux tube would be in the vicinity of 200 km for an emission bandwidth of 200 kHz. This value is in agreement with the very long baseline (VLBI) measurements of Lynch *et al.* (1976).

A contradiction exists, however, between the two main properties of N-bursts: they have a narrow bandwidth, implying small sources (Flagg *et al.*, 1976), but are of long duration, implying extended sources (present paper). It may be that propagation effects of some kind could extend the apparent angular size of the source at Jupiter and thereby reduce the effect of interplanetary scintillation.

In this context it is interesting to note that many important features in the spectra of Jupiter's decametric emission can be identified as propagation effects in various parts of the ray path from the source to the observer (see Genova *et al.*, 1981; Meyer-Vernet *et al.*, 1981; Genova and Boischot, 1981; Boischot and Aubier, 1981). Lecacheux *et al.* (1981) computed a dynamic spectrum based on diffraction effects in a plasma structure, such as Io torus, which was assumed to have a corotating density hole. The spectrum displayed a striking similarity to 'nested arcs' (Leblanc, 1981). The authors also suggested that the Io torus should produce strong focusing and diffration effects over the whole decametric range.

The second diffraction pattern derived by Lecacheux *et al.* (1981) was used by Leblanc and Rubio (1982) for interpreting split-band emissions. It is probable that the events of type 3 splitting described by the authors, are the same as the type N events of the present report, except that here the other component is missing due to the relatively narrow frequency of the present spectrograph. Interestingly enough, both the type N bursts and type 3 split-band events described by Leblanc and Rubio occupy the same zone in the Io-B region.

If it is assumed that a diffracting structure is the source of N-bursts, it follows that the N–S interactions and the fast-drift shadow (FDS) events (Riihimaa and Carr, 1981; Riihimaa *et al.*, 1981), and perhaps even the S-bursts themselves, should be interpreted as by-products of large-scale transients in the same diffracting structure. The N-bursts could now be designated as 'stationary S-bursts', an approach which, in fact, gains support from the whole morphology of the N–S relation.

Perhaps the simplest way to interpret the observations is to assume the existence of a multiple sub-source system in the Io-B region for emissions of type N and S. If the sub-sources were separated by distances great enough for their interplanetary scintillation to appear independent, the combined effect would cause the scintillation minima to weaken or disappear, resulting in a visual lengthening of the emission envelopes. It is worth noting that no comparison is made here between the L-burst envelope durations in the Io-B region and those in other regions. The majority of the L-bursts occurs in the regions Io-A and non-Io-A.

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