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# A New High-Gain, Broadband, Steerable Array to Study Jovian Decametric Emission

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A large array of antennae has been built at the Radioastronomy Observatory, Nançay, France, to study solar and planetary decametric emissions. This array has a high gain (25 db) in a broad range of frequencies and is steerable through a large part of the sky. We present the main characteristics of this array, and the receivers which are used to show the importance of the equipment for Jovian studies. We summarize the results already obtained and describe some topics which are presently being studied.

## I. INTRODUCTION

Although the emission of Jupiter in the decametric range (DAM) can be very intense, sophisticated instruments are required to study it. Observations have so far been made with arrays which do not possess the four qualities presented by the array described here: (a) wide bandwidth, (b) high time and frequency resolution, (c) high sensitivity, and (d) long tracking time. With low-gain antennae, the occurrence probability of a Jovian emission is only a few percent of observing time. An extremely short observing period (5 min) is obviously a severe limitation, as with the arrays in Tasmania (Ellis, 1980), although these instruments rate high in categories (a), (b), and (c). The large Florida array (Desch *et al.*, 1975) excels in categories (b) and (c) but is limited in (a). The array at Oulu (Riihimaa, 1974) has a short bandwidth (2 MHz) and medium qualities in other categories. The one at Boulder (Warwick *et al.*, 1975) has very good possibilities but has always been used as a routine instrument, particularly with low performance in (b).

The importance of high-resolution spectral studies, however, is evident. We already know that some emission features last less than a few milliseconds and that the intensity varies sometimes considerably within a few tens of kilohertz. Therefore, concerns about occurrence probability and time and frequency resolution were the main reasons why we built a high-gain instrument for Jovian studies at the Nançay Radioastronomy Observatory.

It is well known that Jupiter is a sporadic source of emission as seen from the Earth, with occurrence probability lower than a few percent in the frequency range above 20 MHz. It was important, then, for the instrument to observe daily for as long a time as possible, and particularly to track Jupiter at a time as close as possible to the 10-hr period of its rotation.

On the other hand, the few high-resolution studies of DAM emission which have been made so far were made in a limited range of frequencies and did not show clearly the variations in the different features with frequency. A terrestrial instrument covering the whole observable decametric range was needed. The high-frequency limit of Jovian emission is known to be 40 MHz, and the low-frequency limit depends on the Earth's levels of ionospheric and man-made interference.

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In Nançay this limit is around 25 MHz when Jupiter is observed in the daytime, but decreases to 10 MHz at night.

Finally, it is known that Jovian DAM emissions are highly polarized. Up to now, only the circular component has been extensively studied, although it is known from the observation of the Faraday effect in the Earth's ionosphere that the linear component is far from negligible. We designed our instrument to permit the study of the total polarization of the emission, using the arrays of antennae of opposite circular polarizations.

In this paper, we describe, first, the antennae and the different receivers used for Jovian observations, and second, the current studies at Meudon using these instruments.

## II. THE INSTRUMENTS IN NANÇAY

### *II.1. The Array*

The array is made of 144 conical helices of the type used at Clark-Lake Radio Observatory (Erickson and Fisher, 1974) (Fig. 1). The total area covered is close to 8000 m². Actually, the array is composed of two parts, each with 72 helices (6 EW × 12 NS) wound in opposite directions, giving two arrays with the same characteristics but opposite senses of circular polarization.

The conical helices (or T.P. antennae) are very broad-band (10 to 120 MHz), low-gain antennae. Their directivity pattern has a half power width of 90°, centered on the cone axis.

An interesting characteristic of this kind of antenna is its easy phasing. Actually, the helix is made of eight copper-coated steel wires wound on the surface of a cone and connected to the output coaxial cable through diode switches. Only six wires are used at a time to form the antenna; the other two, diametrically opposite, are left disconnected. By changing the connections through the diode switches, the helix can be rotated around the cone axis; this rotation corresponding to a change of the phase of the antenna by steps of $\pi/4$.

This "electrical phasing," while very simple, has the drawback of being chromatic. A delay in air travel time between the waves reaching the two antennae (due to the inclination of the direction of the source) is compensated for by a change in the phase of one of the signals; this compensation can be done accurately only at one frequency (and its harmonics). The result is that, except for the direction normal to the array (all phases being equal), the lobe axis will depend upon the frequency. This has the effect of decreasing the operational frequency range in which the array can be used at one time.

One characteristic we required for the Nançay array was that different receivers could be used simultaneously in a large frequency range (one or two octaves). This could be done by using both the above-mentioned electrical phasing (inside groups of eight antennae) and delay lines (between the nine groups for each polarization). The number of antennae in a group, and their grouping (2 EW × 4 NS), have been optimized by computer determination of the directivity, bandwidth, and tracking time of a group.

The phase of the helices is set in the manner described by Erickson *et al.* (1974) using a minicomputer which also computes the delay lines, commutable filters, mean frequency of observation, etc. Any change in the direction of observation can be made in less than 1 msec.

Table I summarizes the main characteristics of the array. We note that:

—The maximum gain (in the direction of the cone axis which is inclined 20° South in the meridian plane) is 25 db, independent of the frequency except for the lowest frequencies ($\leq$30 MHz), where the distance between two consecutive antennae is smaller than half a wavelength. In that case, the gain decreases because the effective area cannot be much larger than the physical area covered by the array.

—The array is fully steerable within the main lobe of the helices. The tracking time

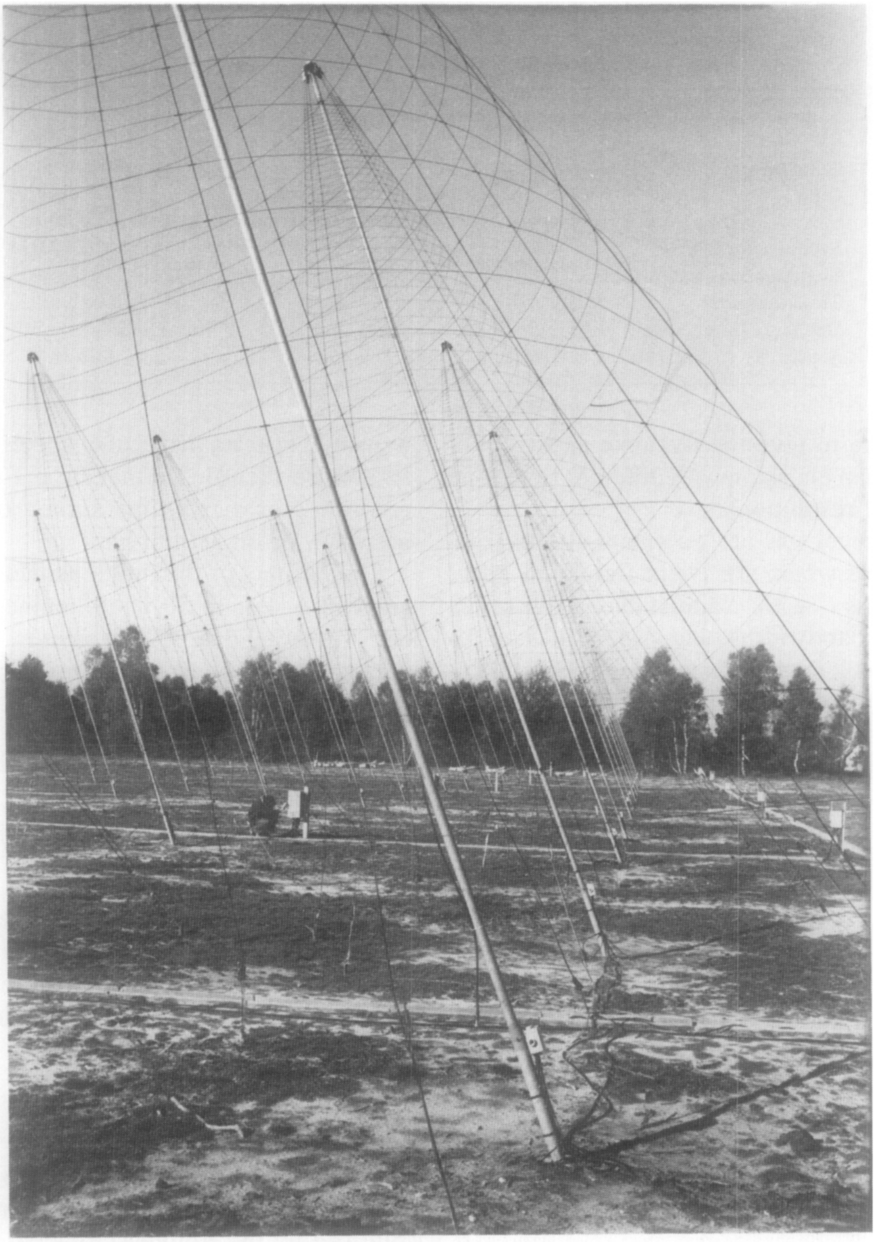

FIG. 1. The array of Nançay: 144 antennae to study decametric radio emission.

is larger than $\pm 3^h$ around the meridian transit of a source, with very little change in gain. This is illustrated in Fig. 2, which shows the occurrence probability of Jovian emission as a function of the hour angle of the planet.

—The effective bandwidth is of the order of two octaves for declinations near the ecliptic plane, decreasing for larger declinations, positive or negative. The frequency range can be chosen anywhere between 10 and 120 MHz.

*II.2. The Receivers*

As already mentioned, the large array can be connected simultaneously to several

TABLE I

CHARACTERISTICS OF THE ARRAY

| | | |
|---|---|---|
| Number of Antennae | Left-Hand circular | 72 |
| | Right-Hand circular | 72 |
| Total covered area | | 8000 m$^2$ |
| Gain | Left-Hand array | 25 db |
| | Right-Hand array | 25 db |
| Frequency range | | 10 to 120 MHz |
| Instantaneous bandwidth | | 2 octaves |
| Tracking time | | 6 to 8 hr |
| Declination coverage | | $-20°$ to $+50°$ |
| Sensitivity ($b = 1$ MHz, $\tau = 1$ sec) | | 100 Jy |

receivers to give the dynamic spectrum of the Jovian emission with different times and spectral resolutions.

The receivers are commercial spectrum analyzers which are swept-frequency spectrographs with adjustable frequency ranges, bandwidths, and sweep rates, and a home-built multichannel spectrograph (Lecacheux and Rosolen, 1975) with 50 channels of 20-kHz bandwidth, the total 1-MHz band of which can be tuned anywhere between 15 and 40 MHz.

### *II.3. Outputs and Data Acquisition*

Outputs of the receivers can be sent on different recorder and display devices. The dynamic spectra from the spectrum analyzers are recorded either on a Fac-simile recorder (for a real-time survey of Jovian activity), or on 35-mm film.

The outputs of the multichannel spectrograph are sent to 50 photoluminescent diodes recorded by a 35-mm camera. Some of the channels may be digitalized directly, or recorded on an analog magnetic tape for further analysis.

Some examples of the different displays can be seen in Figs. 3, 4, and 5.

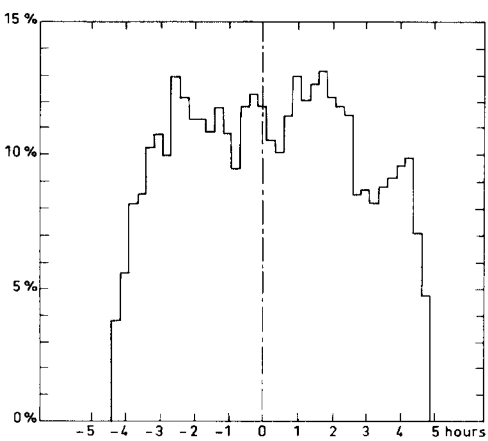


FIG. 2. Occurrence probability of Jovian decameter emission in 1978 versus hour angle of the planet showing the percentage of emission recorded over the period of observation. It confirms the long tracking time of the array and its nearly constant gain over 8 hr.

## III. OBSERVATION OF JOVIAN DAM EMISSION

The instruments described above are particularly suitable for studying the different characteristics of Jovian DAM emission. Since January 1978, the planet has been observed 8 hr daily, and several hundred storms have been recorded.

### *III.1. Jupiter Survey*

One of the uses of the array is to monitor Jovian emission in a way similar to that followed by the Boulder Observatory from 1960 to 1976 (Warwick *et al.*, 1975), but with better sensitivity and frequency resolution. These observations are made with only the right-hand array connected to a swept-frequency spectrum analyzer (30-KHz bandwidth) in the range 20 to 40 MHz when Jupiter transits in the daytime, down to 10 MHz at night. They are recorded on a Facsimile or on 35-mm film.

Figure 3 gives an example of storms

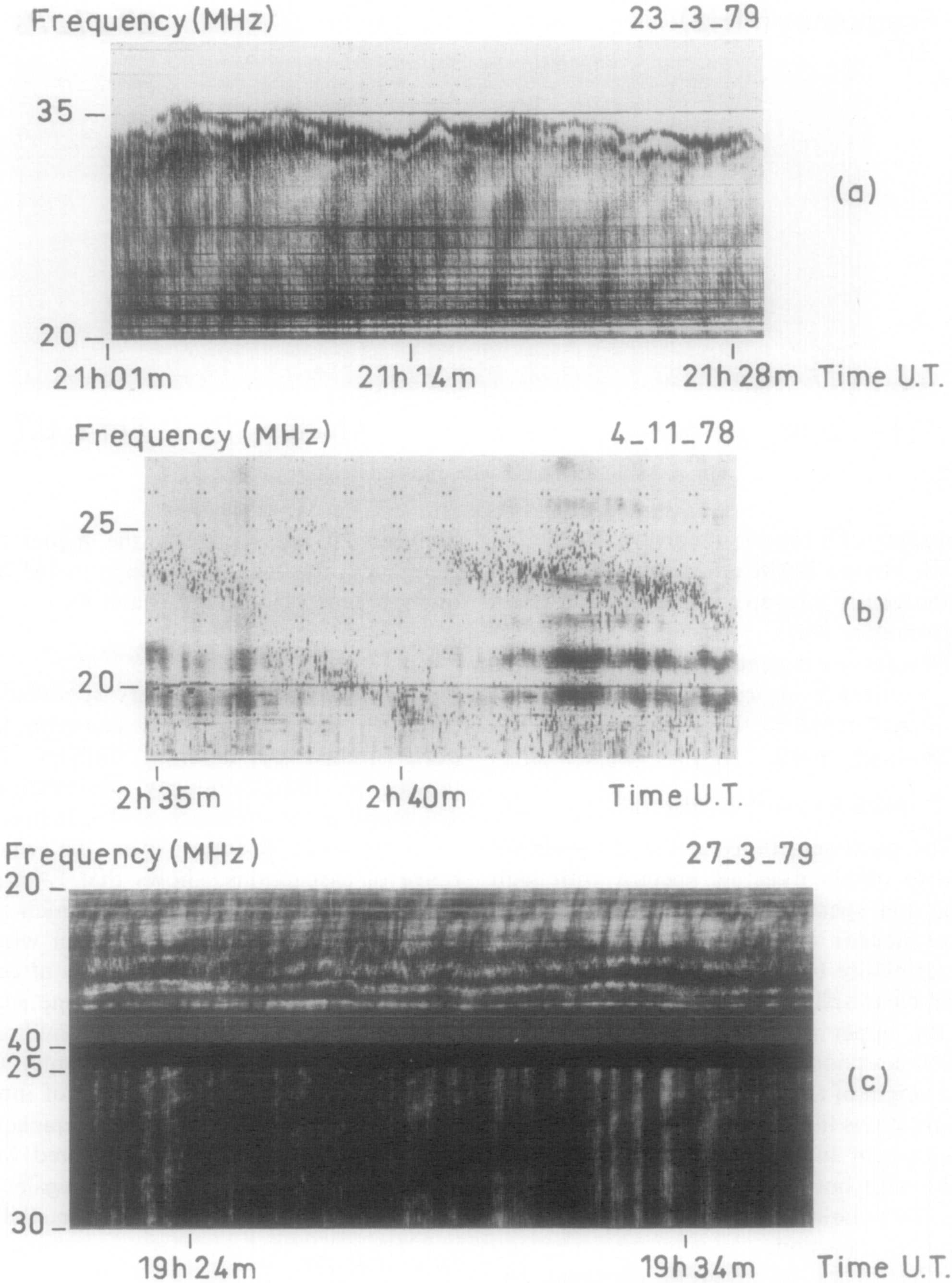


FIG. 3. A storm recorded with the routine receivers: (a) Fac-simile record showing a Jovian DAM emission structured by interplanetary scintillations; the splitting appears at the high limit frequency. (b) Fac-simile record of S-bursts. (b) Fac-simile record of S-bursts. (c) 35-mm film record showing a 20- to 40-MHz spectrum of Jovian emission without interplanetary scintillation. The splitting at the limit frequency can be seen. An enlarged part of this spectrum recorded in a narrower bandwidth (5 MHz) shows the modulation lanes.

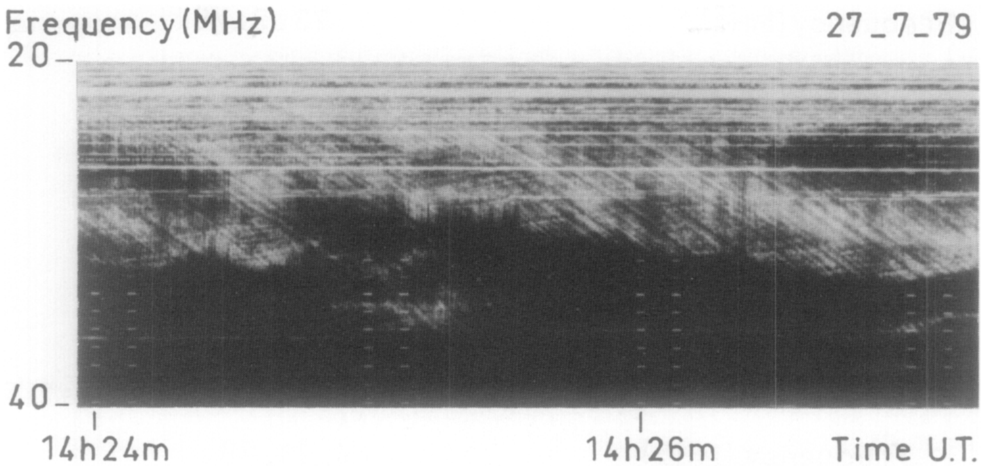


FIG. 4. Modulation lanes with opposite frequency drift.

recorded with routine receivers. A catalog of the Jovian DAM emission will be published yearly (Group for Decametric Radio Astronomy, 1981).

This survey is used for the usual studies on occurrence probability, position, and frequency range of the sources in the Io–LCM diagram, etc.

### *III.2. High-Resolution Spectra*

The great sensitivity of the array allows one to obtain dynamic spectra with high time and spectral resolution. Some structures appear on the spectra which have never before been studied. In particular, a very clear splitting is sometimes observed at the upper frequency limit of the controled emission, as shown in Figs. 3a and c. The origin of this splitting is not yet understood, but is likely due to some propagation effects near Jupiter. Note that the observations with both RH and LH arrays show that the polarization is the same for the two bands of emission.

Other work in progress concerns the modulation lanes discovered by Riihimaa (1970, 1974). These features have been observed up to now in only a small range of frequencies (a few megahertz). Our spectra show that they extend over the whole frequency range of the DAM emission and that the slope of the lanes varies slowly between 20 and 40 MHz: the higher the frequency, the higher the slope in the frequency–time plane (Figs. 3 and 4).

### *III.3. Interplanetary Scintillations*

The effect of interplanetary scintillation (IPS) on the Jovian DAM emission has been studied by different authors, but mostly on fixed-frequency observations. The study of the influence of IPS on broadband dynamic spectra, over the whole range of elongations, shows that L-bursts are broadband bursts (Fig. 3a) which implies that IPS are correlated on our whole frequency range. The observations at conjunction show that the intrinsic time scale of Jovian emission is either some milliseconds (S-bursts) or some minutes (arcs). On the other hand, important results of interplanetary scintillations at low frequencies are obtained and could be compared with those obtained on galactic and extragalactic radio sources (Genova and Leblanc, 1981).

### *III.4. S-Bursts*

These well-known, very fast bursts, frequent in the Jovian emission, can be studied easily with our instrument on dynamic spectra from the multichannel spectrograph (Fig. 5a), on the broadband routine spectra (Fig. 3b), or at several fixed frequencies (Fig. 5b). We recently studied their occur-

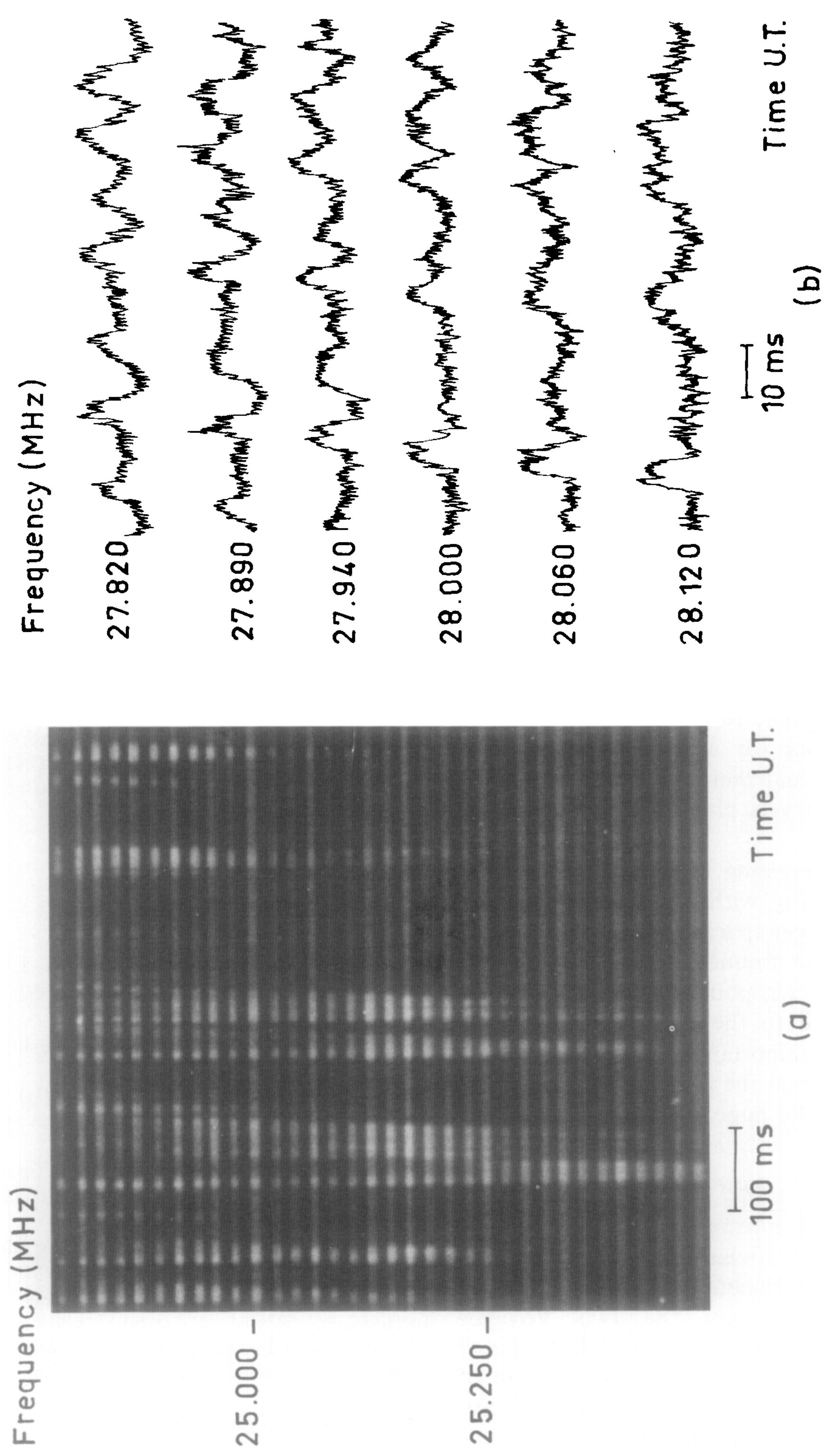


FIG. 5. S-Bursts recorded (a) with the multichannel spectrograph (b) at fixed frequencies.

rence probability and their high-frequency limit in the Io/CML plane, in the range 15–40 MHz. The S-bursts are observed only in well-defined regions of Io-B, Io-A, and Io-C sources, and their frequency limits depend upon this Io-CML configuration (Leblanc *et al.*, 1980a). The study of the frequency drift of the S-bursts observed simultaneously over a large frequency range shows that those bursts are not due to high-energy electrons trapped in the Jovian magnetosphere, but, more likely, are due to electrons accelerated in the planet's ionosphere at the foot of the Io flux tube (Leblanc *et al.*, 1980 b).

### *III.5. Polarization*

So far, the RH and LH arrays have been used separately to give two dynamic spectra, generally recorded on 35-mm film. This does not allow accurate quantitative measurement of the polarization and, moreover, gives only the circular component.

A digital spectropolarimeter which will give the four (or at least three) Stokes parameters and their variations with time and frequency is planned for the near future.

Some interesting results have been obtained recently with the PRA experiment on the Voyager spacecraft near Jupiter, but the time and frequency resolution of the instruments was poor and the observations were limited to the two circular components. It is important to resume these observations from the ground with better instruments. We hope to do that soon.

## CONCLUSION

Much new information was obtained recently on the Jovian low-frequency emission by the Planetary Radio Astronomy experiment onboard the two Voyager spacecraft when they passed by Jupiter. The Decameter Radioastronomy group of Meudon participates actively in the study of space data. This experiment extends our knowledge in the hectometer and kilometer range, and gives new information in the decameter range.

However, the space experiment, which provided only 2 months of useful observations for each spacecraft in the DAM range and only low-resolution spectra, was not able to solve all the problems of the decameter Jovian emission; ground observations are, therefore, still necessary.

We are still far from a good comprehension of the physics of the Jovian emission, which is very important in understanding the dynamics of the electrons in the planet's magnetosphere. We hope that the new facility specially built in Nançay for Jupiter studies will allow, in the next few years, a great advance in this field.

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