BEAMING OF JUPITER'S DECAMETRIC EMISSION

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Abstract. Dynamic spectra of a Jovian non-Io-A storm recorded simultaneously by the Voyager 1 spacecraft and by the Kiiminki radio spectrograph are compared. It seems that the emission beam of the storm co-rotates with the planet and has a sloped leading edge, in accordance with the result of Maeda and Carr (1984).

1. Introduction

In the early phase of the study of Jupiter's decametric radio phenomena several authors suggested that the 'sources' in the occurrence profile indicate directional characteristics of emission (Carr *et al.*, 1961; Gallet, 1961; Burke, 1961; Douglas and Smith, 1963). The discovery of the Io-effect (Bigg, 1964) promoted the development of more precise emission cone models (Dulk, 1965, 1967). Further studies on the characteristics of emission beams have been carried out by Gulkis and Carr (1966), Carr *et al.* (1970), Alexander (1975) and others.

The first experimental measurement of the beaming effect of Jovian decametric emission was described by Poquérusse and Lecacheux (1978). Simultaneous observations of Jupiter were made from the Soviet spacecraft Mars 7 and from the Nançay Radio Observatory at a fixed frequency of 30 MHz. The authors compared the storms occurring in the Io-B region (for region designation, refer to Table 7.4 of Carr *et al.*, 1983). The storms did not correlate, indicating a beaming effect in which a deviation of 15° in the Jovicentric direction resulted in a power level different of at least 10 db.

Reyes and May (1981) compared the result of Poquérusse and Lecacheux with simultaneous observations in Colorado, Florida and Chile at various frequencies and suggested that the result of Poquérusse and Lecacheux holds only for a relatively narrow frequency range.

Maeda and Carr (1984) studied the beaming of Jupiter's decametric emission from records of five storms obtained by receivers on board Voyager 1 and 2 spacecraft and a receiver at the Mizuho-cho Radio Observatory in Japan. The authors found a 'searchlight' effect in certain storms, in which the beams of emission rotated with the System III (1965) angular velocity, so that the same storm was received successively at the spacecraft and on the Earth. The observed time delay was a combination of travel time, rotational delay and a third component determined by the shape of the beam and the Jovicentric declinations of the receiving stations. The 'searchlight' effect was observed only in non-Io-A storms. As could be expected from the previous work of Poquérusse and Lecacheux, it was not observed in Io-B storms.

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2. Observations

Several Jovian radio storms were recorded at the Aarne Karjalainen Observatory from January to March, 1979. The equipment consists of a polarized 48-channel radio spectrograph and a sweep-frequency receiver, covering the ranges 20.85–23.20 and 23–28 MHz, respectively, together with two crossed log-periodic antennas in parallel (Riihimaa, 1975, 1976). The equipment is located at Kiiminki, 30 km east of Oulu (65° 05′N, 25° 54′E).

One particular non-Io-A storm is studied in the present report. This occurred on March 4, 1979, starting 14 h before the closest approach of Voyager 1 to Jupiter. At that time the spacecraft was at a distance of approximately 10^6 km from the planet. The power gain evident at the spacecraft relative to the Kiiminki spectrograph was in the vicinity of 50 db, resulting mostly from the proximity of the spacecraft to the planet. The storm recorded by Voyager 1 is therefore very strong in appearance, while the corresponding Kiiminki record is weak, like many other storms.

A 10-30 MHz section of the Voyager record is shown in Figure 1(a) and the corresponding Kiiminki record in 1(b). The latter is composed of scintillation-impressed bursts with durations of one to a few seconds, often with interference from radio stations. The Jovian origin of the bursts is confirmed by their right-handed polarization and their spectral fine structure, including modulation lines (Riihimaa, 1970). Since only the circular components are recorded, no Faraday fringes are present.

Since the intensity of the bursts is just 3 to 6 db above the detection threshold in the Kiiminki record, relatively little error is made in presenting it as an 'on-off' pattern in the time-frequency plane. It was originally recorded on a high-velocity strip film with frequency and time resolutions of 50 kHz and 0.02 s respectively, (Riihimaa, 1977). On the other hand, the decametric data from Voyager were obtained at relatively low time and frequency resolutions of 307 kHz and 6 s (Warwick *et al.,* 1979), with the result that the Voyager spectrum shows no fine structure (such as modulation lanes). For comparison purposes the time axis of the Kiiminki record is compressed so that both of the records in Figure 1 display exactly the same *f-t* aspect ratio.

3. Results

The observed starting time of the storm in the Kiiminki record is $22^{\mathrm{h}} 04.1^{\mathrm{m}}$ U.T. Since the terrestrial observations are hampered by scintillations, it is possible that the true beginning was not recorded and may have been slightly earlier. This argument is not supported when the Kiiminki and Voyager records are matched, however.

The leading edge of the beam left Jupiter towards the Earth 37.6 min earlier, the Jupiter-Earth travel time. Since the travel time from Jupiter to the spacecraft is just a few seconds, it follows that the only significant source of delay at the spacecraft is the rotational delay. This amounts to 28.6 min, based on the difference in Jovicentric right ascensions of the Earth and Voyager 1, which is 17.3° (NASA), and on the System III (1965) rotational rate 870.536° per day (Riddle and Warwick, 1976). The starting time

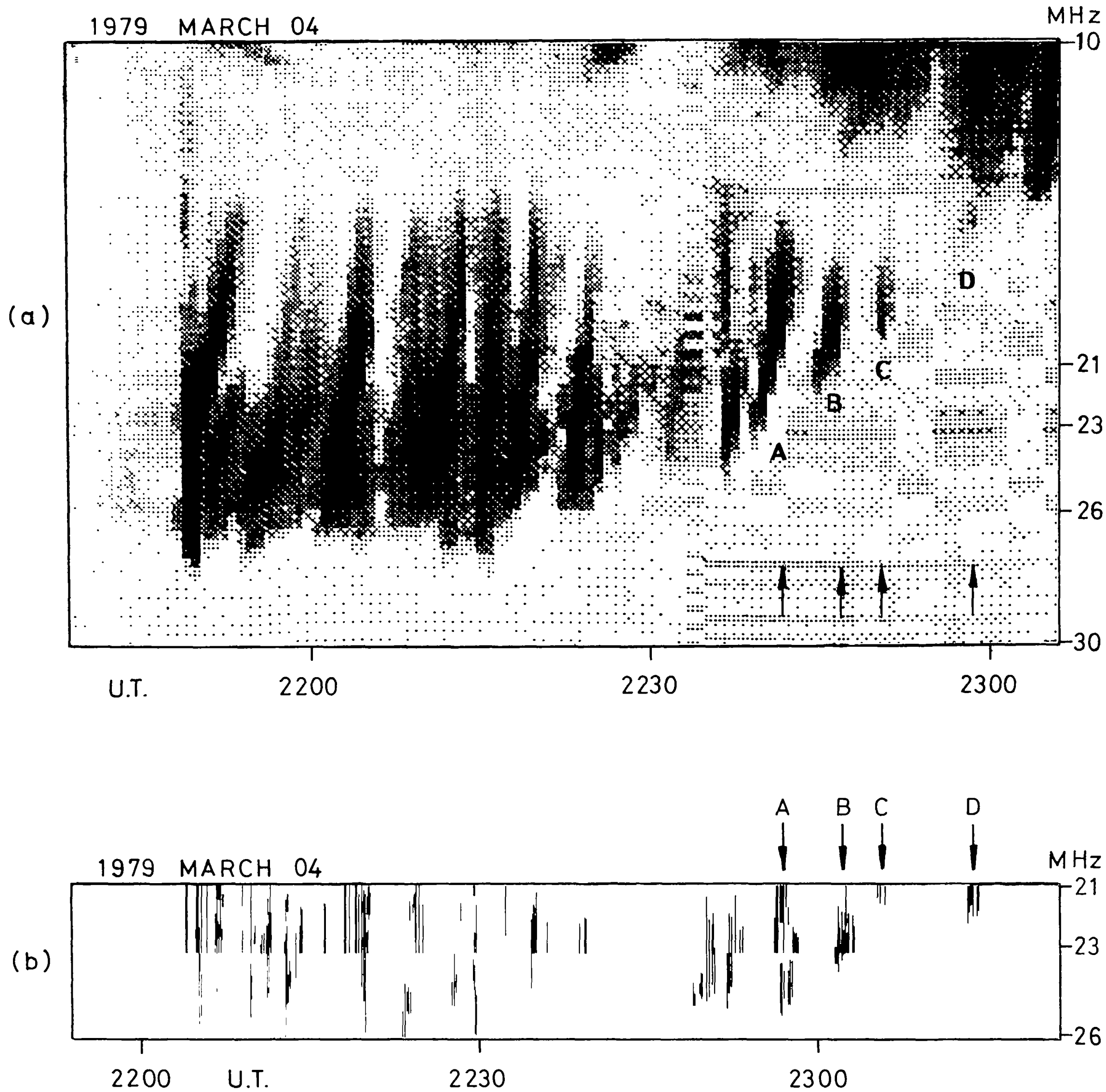

Fig. 1. A decametric radio storm recorded by the Voyager 1 spacecraft (NASA) is shown in (a) and the simultaneous Kiiminki record in (b). The upper section of (b) is obtained with a 48-channel received (20.85-23.20 MHz), and the lower section with a sweep-frequency receiver (23.2-26.0 MHz). The burst groups A, B, C, and D in (a) and (b) correspond, although their frequency ranges are not the same.

of the storm at Voyager 1 should therefore be $21^h 55.1^m$. The observed time on Voyager record, however, is $21^h 48.6^m$ which is 6.5 min earlier than expected.

This result can be interpreted in two ways: either the emission beam rotates at a higher angular velocity than that of System III, or, as postulated by Maeda and Carr (1984), the leading edge of the emission beam is inclined. The latter situation is sketched in Figure 2 in which the Jovicentric positions of the Earth (E) and Voyager 1 (V1) are shown as they appear at the start of the storm.

The magnitude of the slope can be estimated from the observed 6.5 min time advance and from the declination difference between the Earth and Voyager 1. This is illustrated in Figure 3, in which the time advance is given as System III interval and plotted as a

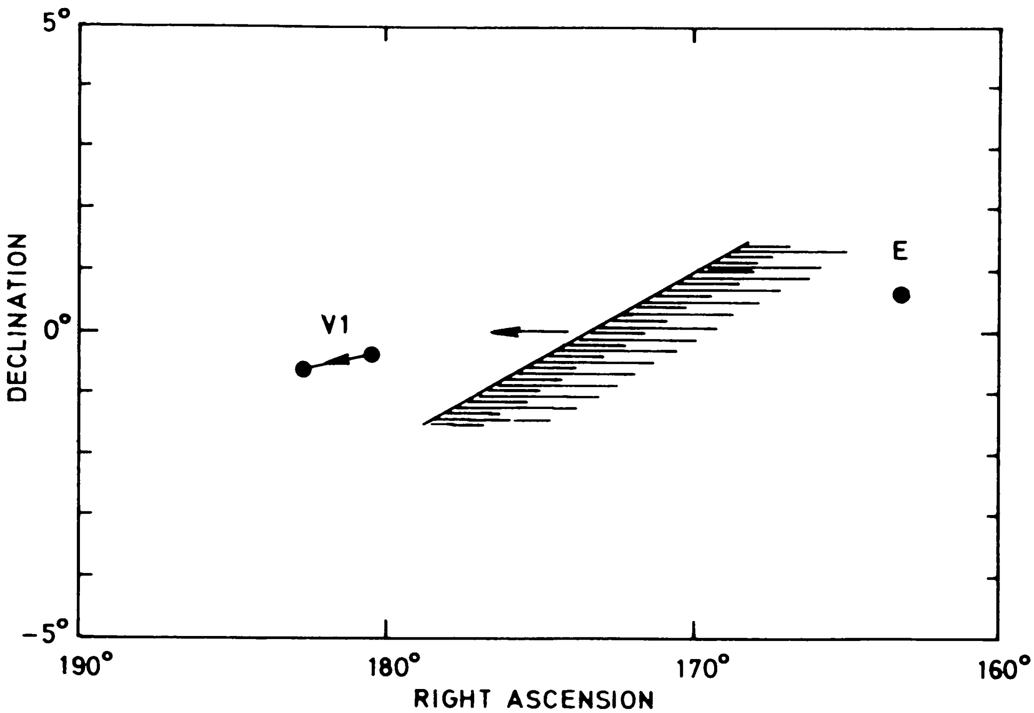

Fig. 2. Positions of the Earth (E) and Voyager 1 (VI) plotted on Jovicentric coordinates. The motion of V1 during the time when it was receiving the storm is indicated. The sloped leading edge of the beam is drawn in an arbitrary position as the beam rotates from E to V1.

function of the Jovicentric declination and the System III (1965) longitude. The declinations of E and V1 are + 0.63° and − 0.44°, respectively.

The data points given by Maeda and Carr (1984) are also shown. As can be seen, the slopes of the lines E-V1 are nearly the same. Since the data points of Maeda and Carr are calculated for the storm centers, they appear at higher values of longitude than the present data points.

The motion of the spacecraft while the storm was in progress (Figure 2) should, in fact, lengthen the storm duration observed on the spacecraft by approximately 3 min as compared with the Kiiminki record. This should be detectable, but is not evident in Figure 1. The reason could be that the track of V1 as seen from Jupiter is almost parallel to the leading edge of the beam.

On the other hand, the burst groups indicated by A, B, and C match only if the frequencies of the Kiiminki record are lowered by 2 MHz, while the frequencies of the last group D should be lowered by 5 MHz. This indicates that the shape of the beam of a storm depends on frequency, with a high-frequency cut-ott occurring with decreasing Jovicentric declination. This effect seems to be so radical that a change of 1.07° results in a drop of at least 50 db in the intensity of emission (the amount by which the Voyager receiver is more sensitive than that at Kiiminki).

There is another explanation: that the emission beam may change its shape with time, as seems to be the case with the emission beams of Io-B storms (Maeda and Carr, 1984).

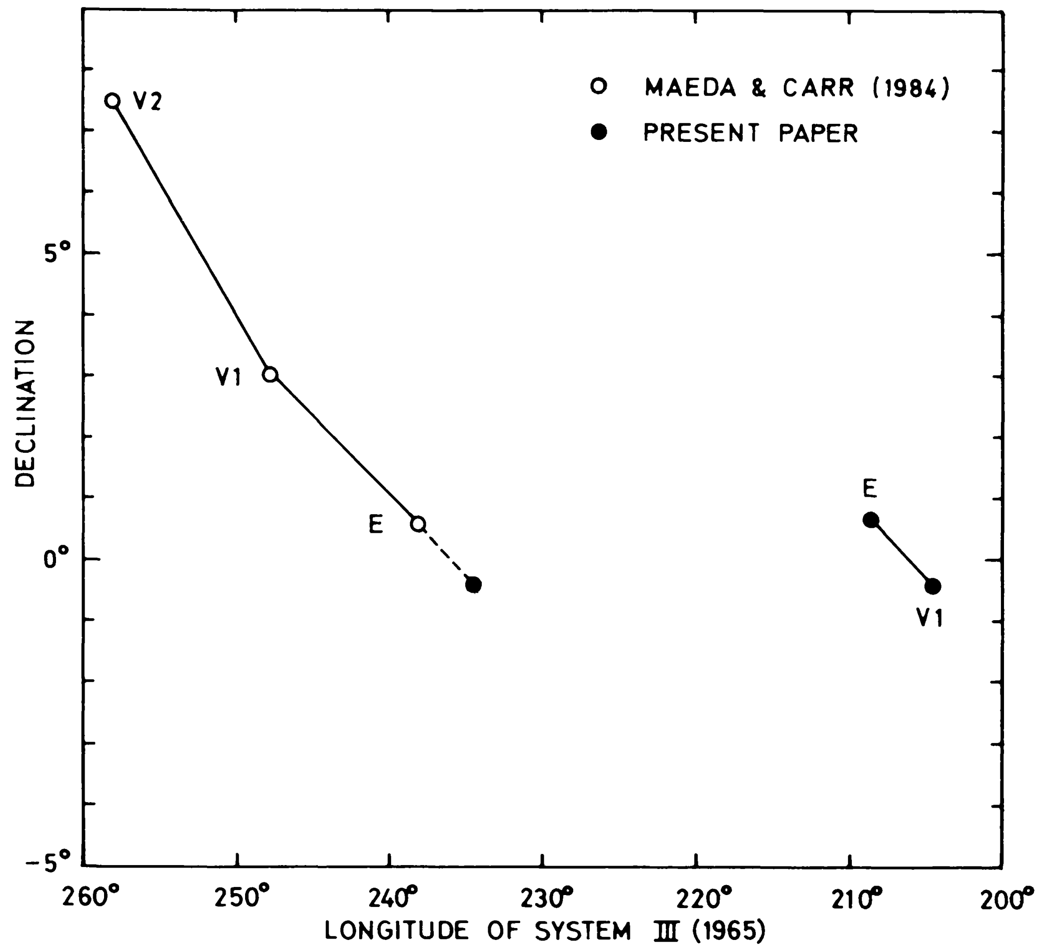

Fig. 3. Positions of E and V1 at the start of the storm plotted as a function of the System III (1965) longitude and the Jovicentric declination. Positions of E, V1 and V2 from Maeda and Carr (1984) are also shown. Line E-V1 is shifted parallel to itself to extend the curve of Maeda and Carr (dashed line).

As a matter of fact, the present storm occurred close to the border area between the non-Io-A and Io-A regions (Carr *et al.*, 1983). It is therefore possible that the end part of the present storm may show characteristics similar to those of an Io-B storm.

The Jovicentric coordinates of the Earth and Voyager 1 refer to the center of the planet, and though the location of the actual source at Jupiter is not known, it is unlikely to be at the center of the planet's disk. It follows that the Jovicentric and the true 'source-centric' coordinates of V1 show a parallax error. In the work of Maeda and Carr (1984) this error is insignificant because of the great distance of V1 from Jupiter. In the present study, however, V1 is relatively close to the planet and the error is no longer small. The agreement between the sloped-beam result of Maeda and Carr (1984) and that of the present report is nevertheless good, as can be seen in Figure 3. This indicates that if the source of the present non-Io-A storm is located west of the planet's center, it is displaced south of the equator, or, if it lies to the east, it is displaced north of the equator.

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