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IV. EXPERIMENTAL RESULTS

IV.9 JOVIAN DECAMETRIC RADIO WAVE RADIATION OBSERVATIONS (1985–1986) USING THE K-3 VLBI SYSTEM

By
Tetsuro KONDO

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ABSTRACT

The K-3 VLBI system was utilized for observations of Jovian decametric radio wave radiations. Fringes were successfully detected on both 570 m and 200-km baselines. Moreover, polarization analysis was also successfully carried out with the 570-m baseline data by Fourier analysis of the cross correlation function.

1. Introduction

Jupiter radiates very intense burst-like radio waves in a decametric range of wavelength (3–30 MHz). The flux density of these burst observed on earth often exceeds 1.0×10^{-19} Wm^{-2} Hz^{-1}, and these radio waves are the most intense received on earth except for bursts of radiation from the sun. Since the first discovery of Jovian decametric wave radiation (JDR) (Burke and Franklin, 1955)(1), many investigators have observed JDR and have studied its various characteristics.

JDR is well-characterized by its probability of occurrence. It is highly modulated not only by the central meridian longitude (CML) of System III (Carr *et al.*, 1961)(2), but also by the phase angle of the satellite Io's position (Bigg, 1964)(3),. When the occurrences of JDR are plotted on a CML-Io phase diagram, they concentrate in certain areas called "sources". Thus, sources depending on the Io phase angle are called "Io-related" sources and all others are called "non Io-related" sources.

The first JDR observation using very long baseline interferometry (VLBI) was made by Slee and Higgins (1965)(4) to measure the size of the emitting region. Afterward Dulk (1970)(5), Stannard *et al.* (1970)(6) and Lynch *et al.* (1976)(7) carried out VLBI measurements using longer baselines than those used by Slee and Higgins. They concluded that source size was on an order of 0.1" (400 km on Jupiter) for an incoherent emission source or 1.0" (4000 km) for a coherent source.

In the 1970's the Mark-III VLBI system dedicated to precise geodetic measurement was developed in the United States(8). The Radio Research Laboratory (now Communications Research Laboratory) also developed a VLBI system called K-3 designed to be compatible with the Mark-III system. This new system can perform VLBI observations of JDR more precisely than other previous forms of measurements.

The purpose of this paper is to describe our VLBI observations of JDR using the K-3 (and Mark-

III) VLBI system.

2. Observation System

Two antenna systems, consisting of crossed 4-element Yagi antennas (AX and AY) (Fig. 1) and crossed 3-element Yagi antennas (BX and BY) (Fig. 2), respectively, were established as a short baseline interferometer (570 m in distance) at Kashima Space Research Center (Fig. 3). These

Fig. 1 A crossed 4-element Yagi antenna system at Kashima (Kashima-A).

Fig. 2 A crossed 3-element Yagi antenna system at Kashima (Kashima-B).

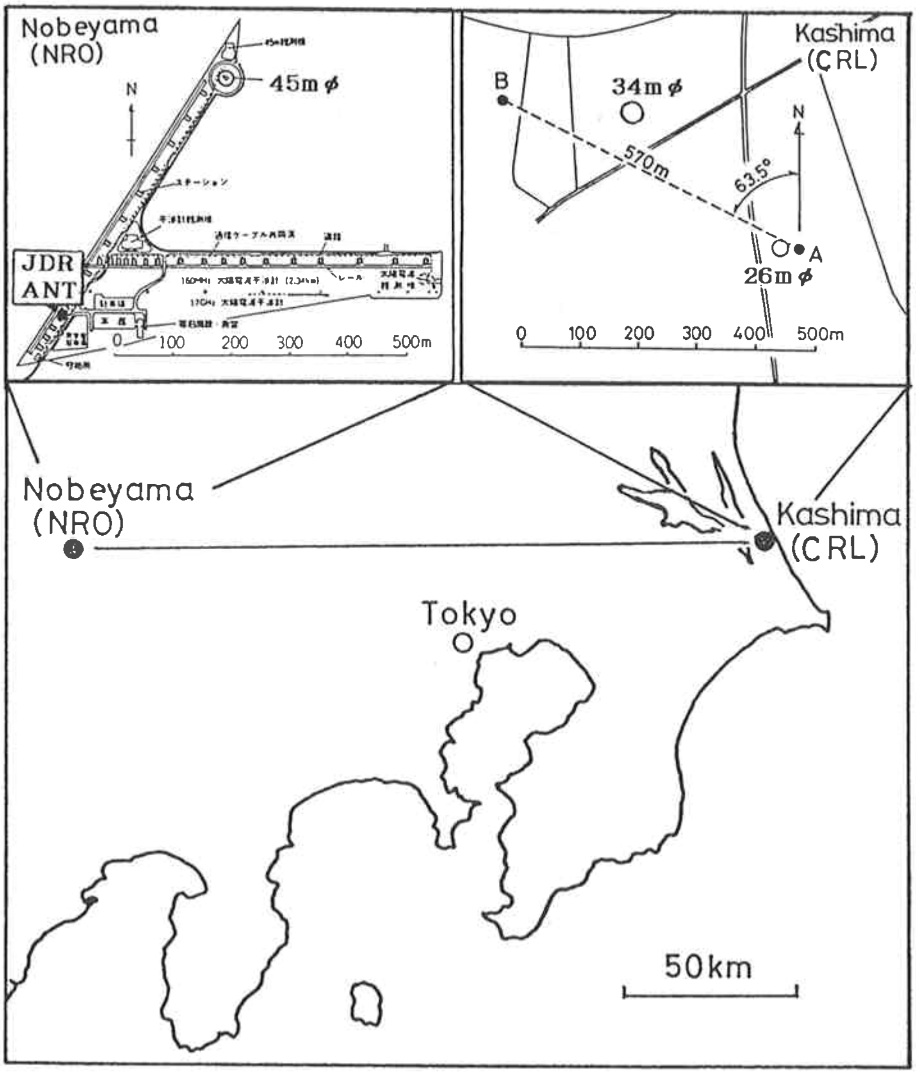

Fig. 3 Location of antenna systems.

antennas are mounted on azimuth angle rotators with fixed elevation angles of 45 degrees on towers 12 m high. By rotating the azimuth angle, rough tracking of Jupiter is possible. In addition to these antennas, a fixed 3-element Yagi antenna (Fig. 4) was temporarily established at Nobeyama Radio Observatory (NRO, about 200 km west from Kashima) as a long baseline interferometer (Fig. 3). The beam of the antenna was directed toward zenith and elements were aligned in the vertical plane in the east-west direction.

Figure 5 shows a schematic diagram of the receiving system. Received signals in a frequency range from 28 MHz to 30 MHz are fed to a pre-amplifier. The signals are then mixed with local

Fig. 4 A 3-element Yagi antenna established at Nobeyama Radio Observatory.

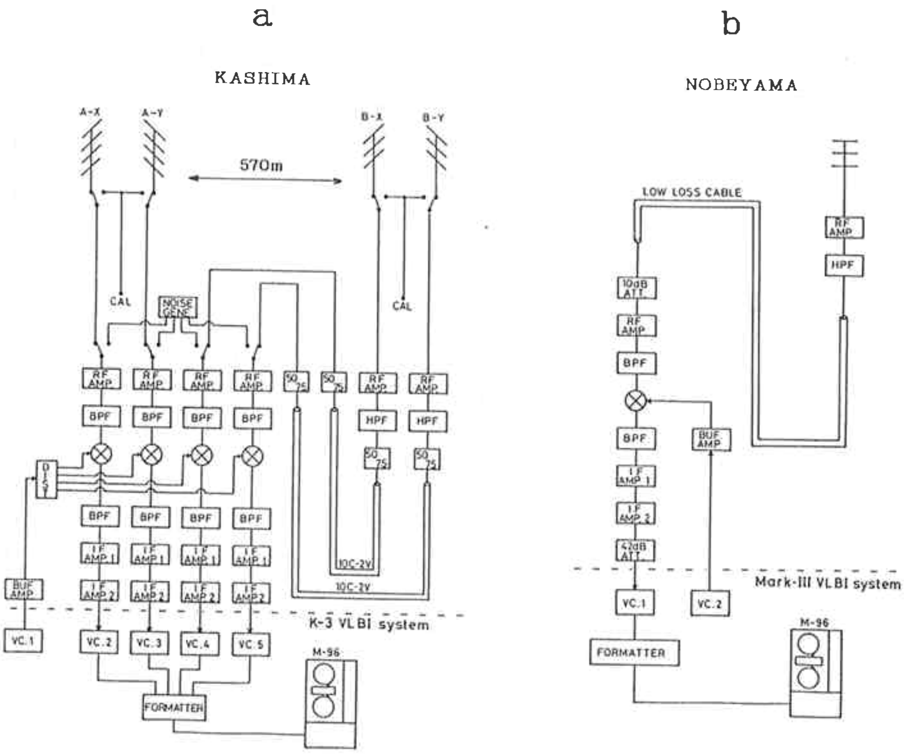

Fig. 5 Schematic diagram of receiving system. (a) Kashima. (b) Nobeyama.

frequency signals of 100 MHz supplied from the local oscillator monitor output of a video converter, and converted up to the first IF stage from 128 MHz to 130 MHz. These signals from the first IF stage are fed to the K-3 (Mark-III at NRO) video converters. Next, the signals are processed as usual geodetic VLBI observation, i.e., the signals are converted into video frequency 0–2 MHz and are sampled at a Nyquist frequency (4 MHz) by means of a 1-bit digitizing method, and finally recorded on magnetic tape. At Kashima, four outputs from two crossed Yagi antennas, AX, AY, BX, and BY, are processed independently so as to measure polarizations. Hydrogen maser oscillators were employed as frequency standards of both systems at Kashima and at NRO.

3. Observation and Data Processing

The JDR observations using the K-3 VLBI system were carried out from 1985 to 1986. The observations were limited to the late night from local midnight to dawn because of strong interferences from broadcast and/or artificial radio noise in the daytime. Furthermore, only lo-related sources were scheduled to be observed, since Io-related emissions are strongly expected for the receiving frequency range(3). From the ephemeris of Jupiter, we can calculate when the Io phase angle and CML coincide with Io-related source conditions, which turned out to be about every seven days. Each observation lasted for 96 minutes centered about the expected emission time. Data acquisition was automatically carried out by computer control. At the beginning of each observation, common noise signals were fed to the receiver to calibrate the instrumental phase delay in the system for precise measurements of wave polarization. In addition to data acquisition by a VLBI terminal, a spectrum analyzer was employed for checking the emissions from Jupiter. One channel of receivers at Kashima was always monitored by the spectrum analyzer during observation. The outputs from the spectrum analyzer were transferred to a computer to produce a dynamic spectrum. The dynamic spectrum display is very useful for checking the occurrence of an event. Only the events detected on the dynamic spectrum were cross correlated.

Correlation processing of data was performed by the K-3 correlator(9). The so-called "Pulsar mode"(9) was applied to the 570-m baseline data correlation to avoid unwanted correlation between headers embedded in the sampling data stream every 5 msec. Moreover, no fringe rotation at correlation was applied for the 570-m baselines. A unit of the K-3 correlator can produce correlated data (8-bit-lag correlation function) every parameter period (PP) defined by an operator (in this study PP is set to 3 sec for the 570-m baseline and 2 sec for the 200-km baseline). Correlation lag can be continued between correlator units, so that eight units, which form one crate, can produce a 64-bit-lag correlation function. Hence, the data output from each unit are combined and used for further analysis, that is, cross spectrum analysis and polarization analysis.

Fringe phases are calculated from cross spectra that are obtained by a Fourier transform on the correlated data. Phase difference between AX and AY (or BX and BY) produce a sense of rotation in the case of circular polarization. Looking from the rear of the antenna, elements X and Y are mounted

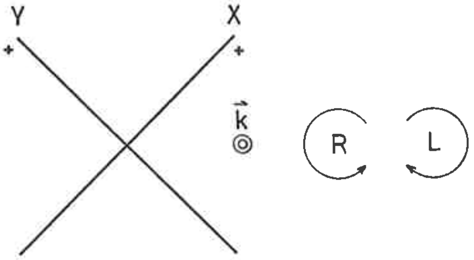

Fig. 6 Definition of antenna polarization.

as shown in Fig. 6. Consequently, radio waves polarized in the right-hand sense (RHCP) result in X phases in advance of Y phases. The relation is converse for LHCP waves. Thus, by comparing phases between AX and AY (or BX and BY), we can obtain information about the rotation of wave polarization.

4. Results

4.1 Short (570 m) Baseline in Kashima

We made 13 observations in 1985 and 14 observations in 1986 on the short baseline. Among the observations, fringes were detected for six observations.

Raw correlated data for the short baseline were usually contaminated by interference signals commonly received at both antennas because no fringe stopping was attempted at data correlation. However, when both amplitude and position of the interference source are stable, the interference can be removed from correlated data by subtracting stable components with respect to time. Figure 7 demonstrates this process for actual correlated data. Figure 7(a) shows the raw correlated data. Unwanted correlations due to the common interference signals form stable ridge-like structures parallel to the time axis. Let the raw correlation data at t be $R(\tau,t)$, then a correlation function $C(\tau,t)$ corrected for the interference signals is calculated as

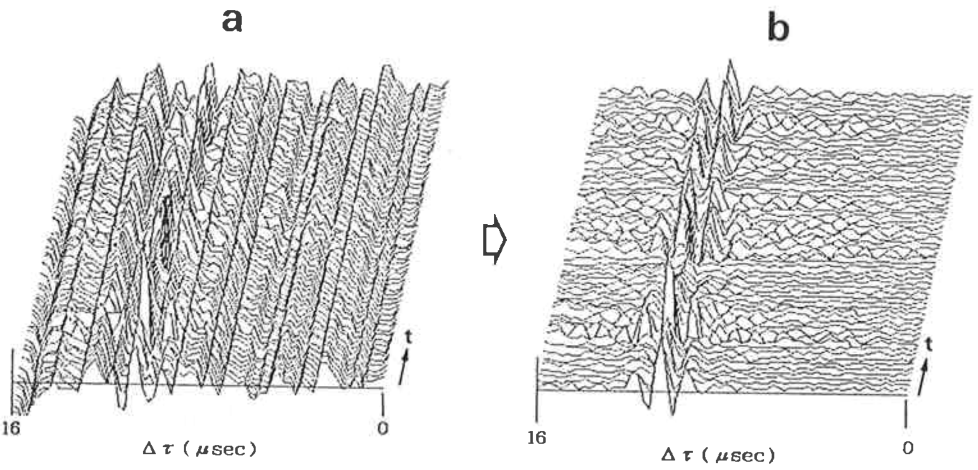

Fig. 7 An example of dynamic correlated data on the 570 m baseline. (a) Raw correlated data for three minutes. (b) After subtracting interference signals. Note that unwanted correlations due to the stable interference signals in (a) disappear significantly in (b).

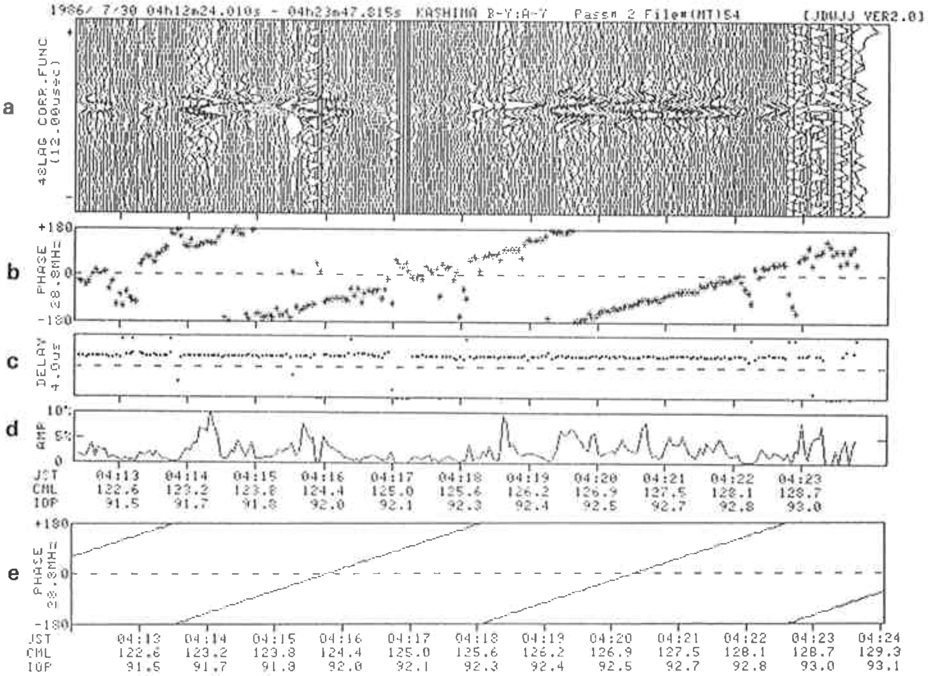

Fig. 8 Typical Jovian decametric radio wave emission observed on the 570 m baseline on July 30, 1986. (a) Dynamic cross correlation function after subtracting interference. (b) Observed fringe phase at 28.8 MHz (c) Observed delay. (d) Correlation amplitude. (e) Expected fringe phase calculated at 28.8 MHz, where JST, CML, and IOP indicate Japan Standard Time (UT + 9h), the central meridian System III longitude of Jupiter, and the phase angle of IO, respectively. Note that good coincidence can be seen between observed and expected fringe rate (rate of change in fringe phase).

$$C(\tau,t)=R(\tau,t)-\frac{1}{T}\int_0^T R(\tau,t)dt \qquad \text{(1)}$$

where τ denotes lag in the correlation function and T is an averaging period. We use 12 minutes for T in actual calculation, which is, of course, longer than the fringe period calculated for Jupiter. Figure 7(b) shows the corrected correlation function by Eq. (1). It is clearly demonstrated that this method is quite effective for removing the interference. Further analysis is demonstrated in Fig. 8. Observed fringe phases (Fig. 8(b)), which are calculated from the correlated data by Fourier transform, coincide very well with those calculated from a baseline and Jupiter geometry (Fig. 8(e)) except for constant offset phase; this strongly supports the premise that the emissions are radiated from Jupiter.

An analysis of wave polarization is shown in Fig. 9. In the figure, positive phase difference corresponds to RHCP. The analysis shows that the RHCP emission was the dominant component for this event. To avoid errors caused by interference signals that produce a constant phase shift between

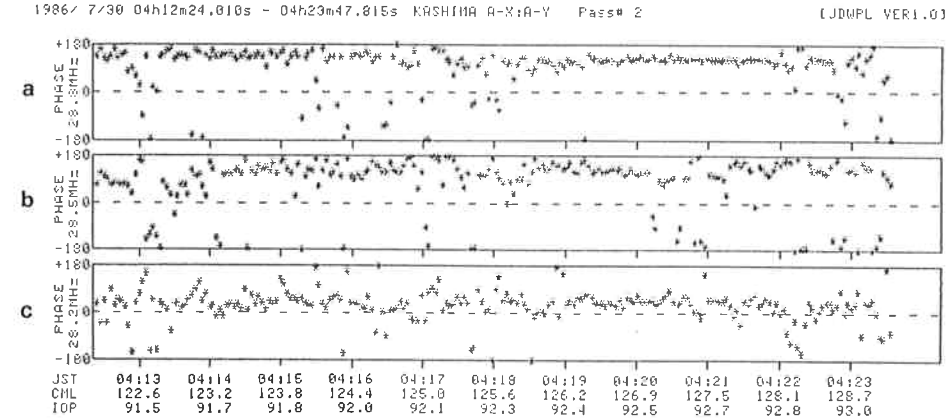

Fig. 9 **Polarization analysis of Jovian decametric radio emissions observed on July 30, 1986. Positive phase corresponds to right-handed polarization waves. (a) 28.8 MHz. (b) 28.5 MHz. (c) 28.2 MHz.**

AX and AY and masks JDR signals, the phase differences between AX and AY antennas are calculated indirectly in the polarization analysis, i.e., they are derived as differences between fringe phases observed for the AX–BY baseline and the AY–BY baseline. These calculations remove the interference effect as demonstrated in Fig. 7.

4.2 Kashima-Nobeyama baseline

On the Kashima-Nobeyama baseline, unwanted correlation due to interference signals disappears through fringe stopping. A total of ten observations were made in 1985 on the Kashima-Nobeyama baseline for the Io-related emissions. Among these observation only one event was successfully recorded, which occurred on August 16, 1985. The processing results of this event are shown in Fig. 10: a complex correlation function results from the fringe stopping performed in the correlator. Three

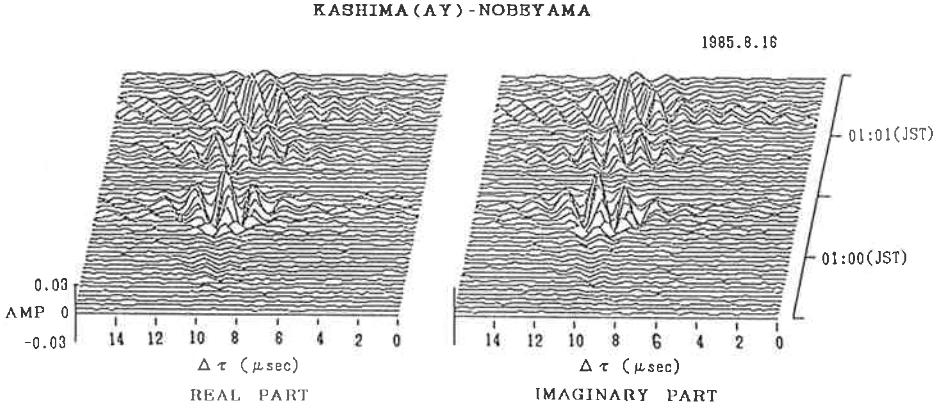

Fig. 10 **Fringes detected on the Kashima-Nobeyama baseline (200 km in length).**

bursts appeared from 01:00:00 to 01:01:30 JST, and each burst lasted for about 10 sec. Correlation amplitude reached up to 3%.

5. Conclusion

This study has demonstrated that the K-3 VLBI system developed for precise geodetic measurements is applicable to observing Jovian decametric radio wave emissions. Fringes were detected on both the 570 m baseline at Kashima and on the 200 km baseline between Kashima and Nobeyama. The one-bit digitizing method employed in the K-3 system sometimes became a weak point in the system considering the very intense interference that often appeared in the decametric range of wavelengths (3–30 MHz). However, polarization analysis could be applied to the precise phase information included in the digitized data stream. Polarization information in terms of its sense of rotation was successfully extracted from the data observed by crossed linear polarization antennas. It was difficult to obtain full polarization parameters, i.e., Stokes parameters, from one bit digitized data because of the lack of amplitude information.

The number of events observed in 1985 and 1986 is not sufficient for statistical study of Jovian decametric radio emissions. In 1988, observations was were attempted again on the 570 m baseline. However, no emissions from Jupiter were detected due to the constant presence of strong interference signals. It is thus felt that multi-bit digitizing will be required to overcome these strong interference signals (due no doubt to advances in modern society) and to obtain precise polarization information.

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