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NARROW-BAND JOVIAN KILOMETRIC RADIATION: A NEW RADIO COMPONENT

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Abstract

We describe a new component of Jupiter's radio spectrum. This component emits in a very narrow bandwidth ($\lesssim$ 40 kHz) near 100 kHz. Its waveform is a very smooth and gradual rise and subsequent fall in intensity over typically two hours. The emission is polarized with left-hand polarization associated with the Jovian northern magnetic hemisphere and right-hand with the south. The most interesting feature of the emission is its deviation from a strict system III rotation period repetition rate. The emission source of this narrow-band component clearly rotates slower by 3-5% than all other forms of Jovian radio emission. Propagation considerations coupled with this observed lack of corotation point to a source region near the equatorial plane at the outer "edge" (8-9 R_J) of the Io plasma torus.

The Planetary Radio Astronomy (PRA) and Plasma Wave instruments on the two Voyager spacecraft have extended our knowledge of the Jovian radio spectrum to long wavelengths with the recently announced discovery of a distinct kilometric wavelength (KOM) component (Warwick et al., 1979a, Scarf et al., 1979). This radiation often appears on frequency-time dynamic spectra in a tapered form with sporadic emission persisting longer at lower frequencies. Warwick et al. (1979b) have also noted an additional form of KOM, namely a narrow bandwidth emission generally confined to the 60 to 150 kHz frequency range. This KOM form has a bandwidth of typically 40 to 80 kHz and is characterized by long-duration bursts having slow build-up and decay, with relatively little fine structure apparent at the 48-sec level.

In this paper we examine this narrow-band KOM (nKOM) form in detail using observations from the PRA instrument described by Warwick et al. (1977). We describe the spectrum and occurrence statistics and contrast them with the tapered or broadband KOM (bKOM) characteristics. We will show that this nKOM emission is a distinct and separate radio component very likely originating at several Jovian radii from the surface in a source region that does not co-rotate with the planet.

Observations

Figure 1 shows a 24-hr dynamic spectrum over the PRA low band (1 kHz to 1.3 MHz) when Voyager-1 was some 160 R_J from encounter. In the lower panel total power is shown with increasing power represented by increasing darkness. In the top panel the sense of polarization is shown with black indicating left-hand polarization and white corresponding to right-hand polarization. The nKOM features can be seen near 100 kHz at approximately 02 hr, 09 hr, 14 hr, 20 hr and 23 hr. From the total power panel, the relatively smooth temporal behavior and stable center frequency can be seen.

The nKOM events shown in Figure 1 are among the most intense ever observed. Figure 2 shows a corresponding flux density spectrum taken at 0921 SCET. This event was also observed by Voyager-2 even though it was the equivalent of 18 dB farther from Jupiter than Voyager-1. The flux density in the Feb. 23 event is comparable to the flux density for the most powerful bKOM events. However, due to the extremely narrow bandwidth the isotropic power is only 10^9 W, which is just above the most probable power for bKOM events (Desch and Kaiser, 1980). A more typical isotropic power is a factor of ten less that this maximum as depicted by the Feb. 16, 1979 event, also shown in Figure 2.

The abrupt low-frequency drop in intensity levels shown in Figure 2 is similar to the low-frequency drop observed on many bKOM events (Desch and Kaiser, 1980). However, the precise frequency at which the intensity drop is observed is not in general the same on both nKOM and bKOM events. There are many instances when the nKOM events and bKOM events are both observed but the low frequency extent is different.

The high-frequency behavior of the nKOM events clearly separates them from bKOM events. Desch and Kaiser (1980) in their Figure 6 show that the bKOM spectrum typically decreases in intensity with increasing frequency until it merges with receiver background. This gradual fall-off in intensity is approximately 15 dB per frequency decade for strong bKOM events, whereas for the events shown in Figure 2 the intensity drop is greater than 100 dB per decade.

The frequency of maximum flux for the events shown in Figure 2 is 116 kHz. The majority of nKOM events have peaks at this frequency ± one PRA channel (19 kHz) although there are some occasions when the center frequency is as high as 175 kHz or as low as 56 kHz. The slow frequency drifts evident particularly on the events at 14 and 20 hr in Figure 1 is a characteristic which is observed only occasionally.

The polarization of nKOM events follows the general trend suggested by Figure 1. When the subspacecraft track is in the Jovian northern magnetic hemisphere, left-hand polarized events are observed, and right-hand polarized events are observed for the southern hemisphere. In direct contrast with bKOM events, the nKOM events do not show a polarization reversal when viewed from the post-encounter outbound trajectories. There are some nKOM events which show abrupt reversals of polarization during the event. These reversals occur near, but not exactly, at times when the spacecraft crosses the magnetic equator. A few of these events with abrupt reversals occur near the encounter periods when the spacecraft were within the Jovian magnetosphere. For those events, the polarization reversals occur almost precisely at times of current sheet crossings as identified by the Voyager magnetometer team (K. Behannon, private communication). However, there are also a large number of current sheet crossings which occur during nKOM events which show no polarization reversal.

In our view the most surprising characteristic of these nKOM events is illustrated in Figures 3 and 4. We have plotted the occurrence of nKOM events as a function of System III longitude for the periods surrounding Voyager-1 encounter (Figure 3) and Voyager-2 encounter (Figure 4). The persistent drift towards higher longitudes is striking. Clearly the source of the nKOM events does not rotate at the System III rate, but at a slower rate. For the Voyager-1 data set, the implied rotation period is 10 h 15 m, while for Voyager-2, the period is 10h 28m. These values correspond to 3.3% and 5.5% slower than corotation, respectively. Additionally, the same source region must be active for long periods of time. Figure 4 shows repeatable (with a 10h 28m period) nKOM events extending over three weeks. During the three week interval, there are times when nKOM events are not observed for several consecutive rotations. However, when the events reappear, they are at the same phase as they would have been if the emission had been observed on every rotation. There are also instances when apparently two source regions are active. In the top half of Figure 3, which corresponds to the same time period as Figure 1, there are two repeatable nKOM events on every rotation. One of the sources, however, seems to disappear after a few rotations.

Discussion

We have shown that the narrow-band kilometric wavelength emission from Jupiter which was first described by Warwick et al. (1979b) is a new and quite distinct radio component. Its spectrum and polarization characteristics clearly separate it from the bKOM emissions which are observed in the same frequency band. The fact that nKOM is not synchronous with Jupiter's System III rotation period distinguishes it from all other forms of Jovian radio emission. Kurth et al. (1980) have shown some features of bKOM at 59 kHz which they claim are not synchronous with System III. We have examined the PRA data for the period shown by them and we believe the non-synchronous features they have identified correspond to times when bKOM and unusually low-frequency (< 60 kHz) nKOM happen to coincide.

Rather strict limitations can be placed on the source location of the nKOM emission. From Figure 3, we can see that two of these events were observed just before and just after Voyager-1 closest approach each from a Jovicentric distance of ~12 R_J near the equatorial plane. In Figure 4, we show a tentative nKOM event at closest approach, 10 R_J. This is the same controversial event identified as upper hybrid resonance emissions from the Io plasma torus by Warwick et al. (1979b), so our alternate interpretation as an nKOM event must remain tentative. From the 12 R_J and, particularly, the 10 R_J locations, refraction of $\sim$100 kHz emission by the Io plasma torus severely limits the possible source locations to essentially the nearby outside "edge" of the torus itself, or positions generally more distant from Jupiter than 10 or 12 R_J. There is no evidence in our data to suggest that when the Voyagers were near closest approach (4.9 R_J for Voyager-1, 10.0 R_J for Voyager-2), the nKOM was originating at radial distances farther from Jupiter than 10-12 R_J. Additionally, beyond 10-12 R_J characteristic frequencies such as the electron gyrofrequency and the electron plasma frequency are generally well below the $\sim$100 kHz characteristic of nKOM events. However, at radial distances of 8-9 R_J, the electron plasma frequency and the upper hybrid resonance frequency are typically 100 kHz (Warwick et al., 1979a). Therefore, the one general source location which can indeed be viewed at all times and has a magnetoplasma capable of generating $\sim$100 kHz emission is the Io torus at 8-9 R_J.

Hill (1979a) discussed the general problem of corotation in planetary magnetospheres and concluded that rigid corotation would not be observed in the case of Jupiter as a consequence of rapid plasma production and weak atmosphere-magnetosphere coupling. McNutt et al. (1979) have shown that departures from strict corotation are commonplace as inferred from the Voyager plasma instrument data. Hill (1979b) shows that the Voyager plasma observations are accounted for by his theory if the mass-loading rate is $\sim 10^{30}$ amu/sec. In fact, both observation and theory show departures from corotation of $\sim$15-20% at 12 R_J. Our observations indicate departures from corotation of only 3-5% for an implied source radial location of 8-9 R_J. Additionally, our observations suggest that the source rotation period is not constant, but was somewhat longer during the Voyager-2 encounter. This would also be in agreement with Hill's (1979a) work if the mass-loading rate were somewhat higher during the Voyager-2 encounter compared to the Voyager-1 encounter. Indeed, there are indications (Sandel et al., 1979) that the Io torus was more dense during the Voyager-2 encounter period.

Summary

There now exists evidence for a new Jovian radio source rotating at 3-5% slower than System III. A plausible source location is the outer portion of the Io plasma torus. The observations indicate that for long periods of time only one segment of the torus emits. The conditions within this emitting segment of the torus must be reasonably constant because of the repeatability of the observed radio spectrum.

A large number of questions are raised by these observations. Why is emission only observed over the very narrow band centered at ~100 kHz when the torus can support radiation up to 500 kHz? What triggers the polarization reversals? What is the nature of the source location and what is the emission mechanism? These questions and many more like them will form the basis for future studies of this new radio component.

Acknowledgment

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FIGURE CAPTIONS

Figure 1. Dynamic spectra from the Voyager-1 PRA instrument covering the frequency band from 0.0 to 1.3 MHz. In the lower panel increasing darkness is proportional to increasing intensity. In the upper panel, left-hand polarized signals are shown as black, right-hand as white, and unpolarized as gray. The nKOM events are the intense features near 0.1 MHz.

Figure 2. A flux density spectrum for one of the nKOM events in Figure 1 normalized to 4 AU. Also shown is a more typical nKOM spectrum from Feb. 16, 1979.

Figure 3. The occurrence as a function of System III longitude of nKOM events observed by the Voyager 1 PRA instrument near closest approach to Jupiter.

Figure 4. Voyager-2 nKOM observations in an identical format to Figure 3.

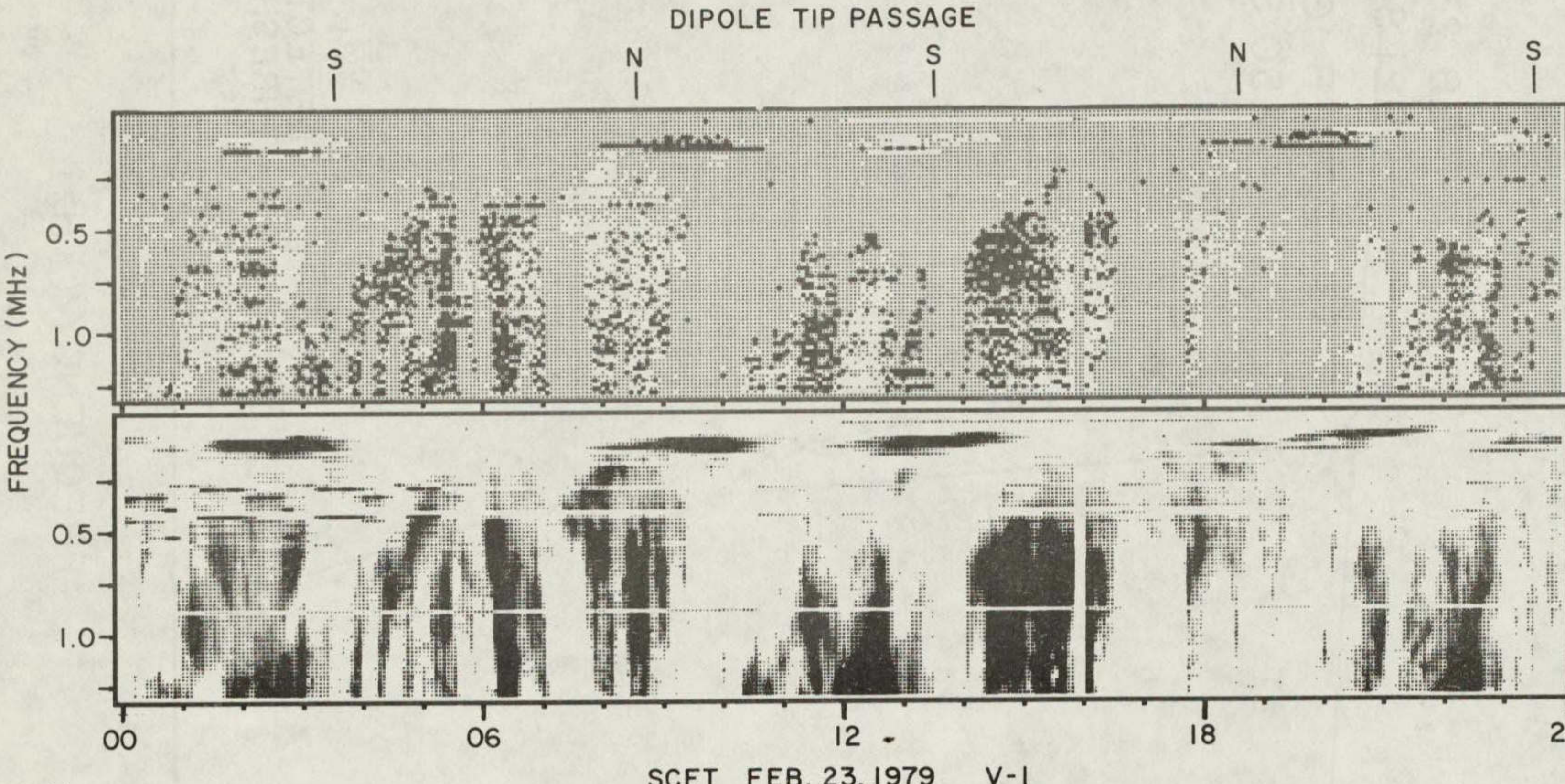
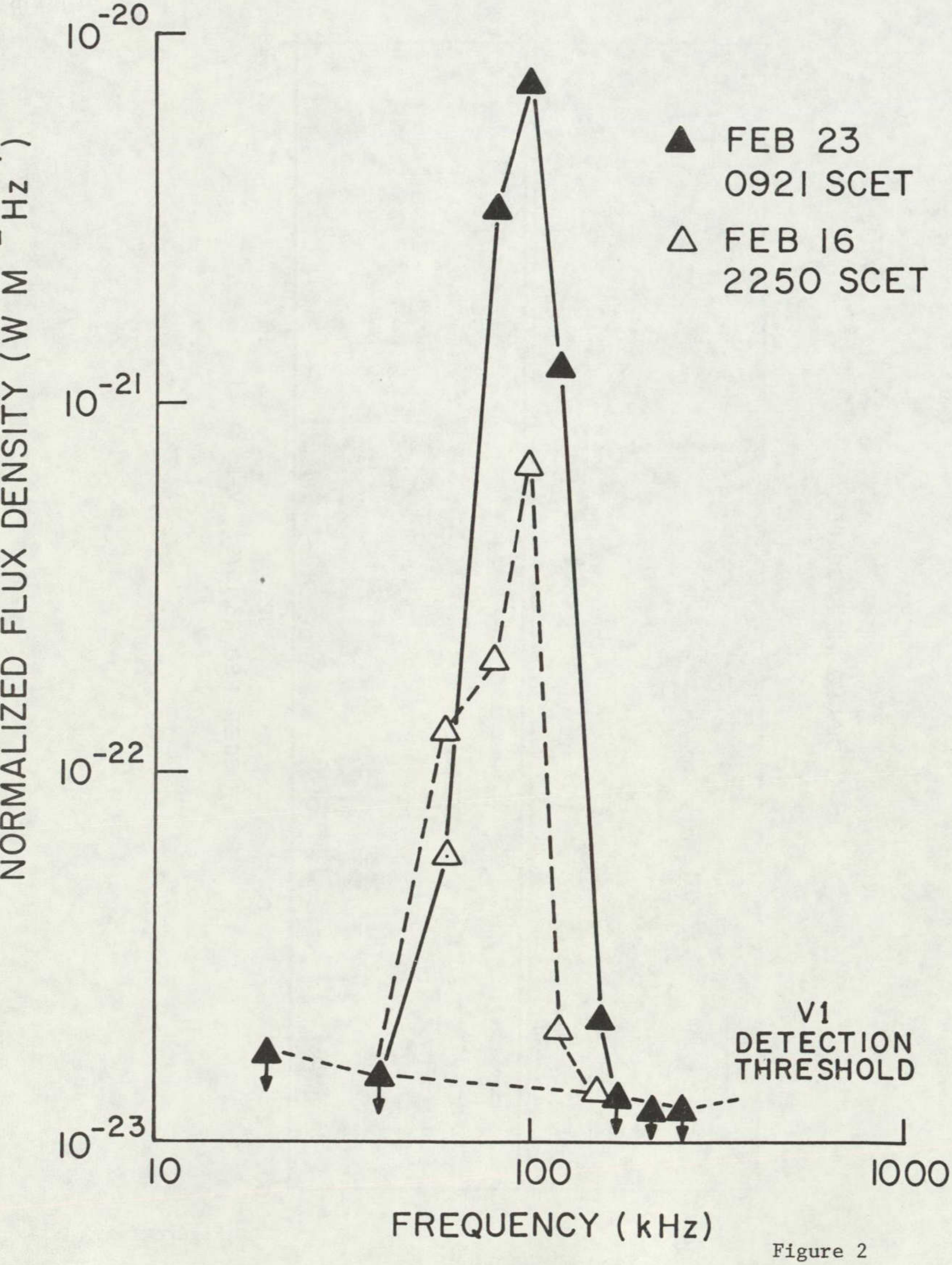

DIPOLE TIP PASSAGE
S
N
S
N
S
FREQUENCY (MHz)
0.5
1.0
0.5
1.0
00
06
12
18
24
SCET FEB. 23, 1979 V-I

Figure 1



NORMALIZED FLUX DENSITY (W M^{-2} Hz^{-1})
10^{-20}
10^{-21}
10^{-22}
10^{-23}
FEB 23
0921 SCET
FEB 16
2250 SCET
V1
DETECTION
THRESHOLD
10
100
1000
FREQUENCY (kHz)

Figure 2

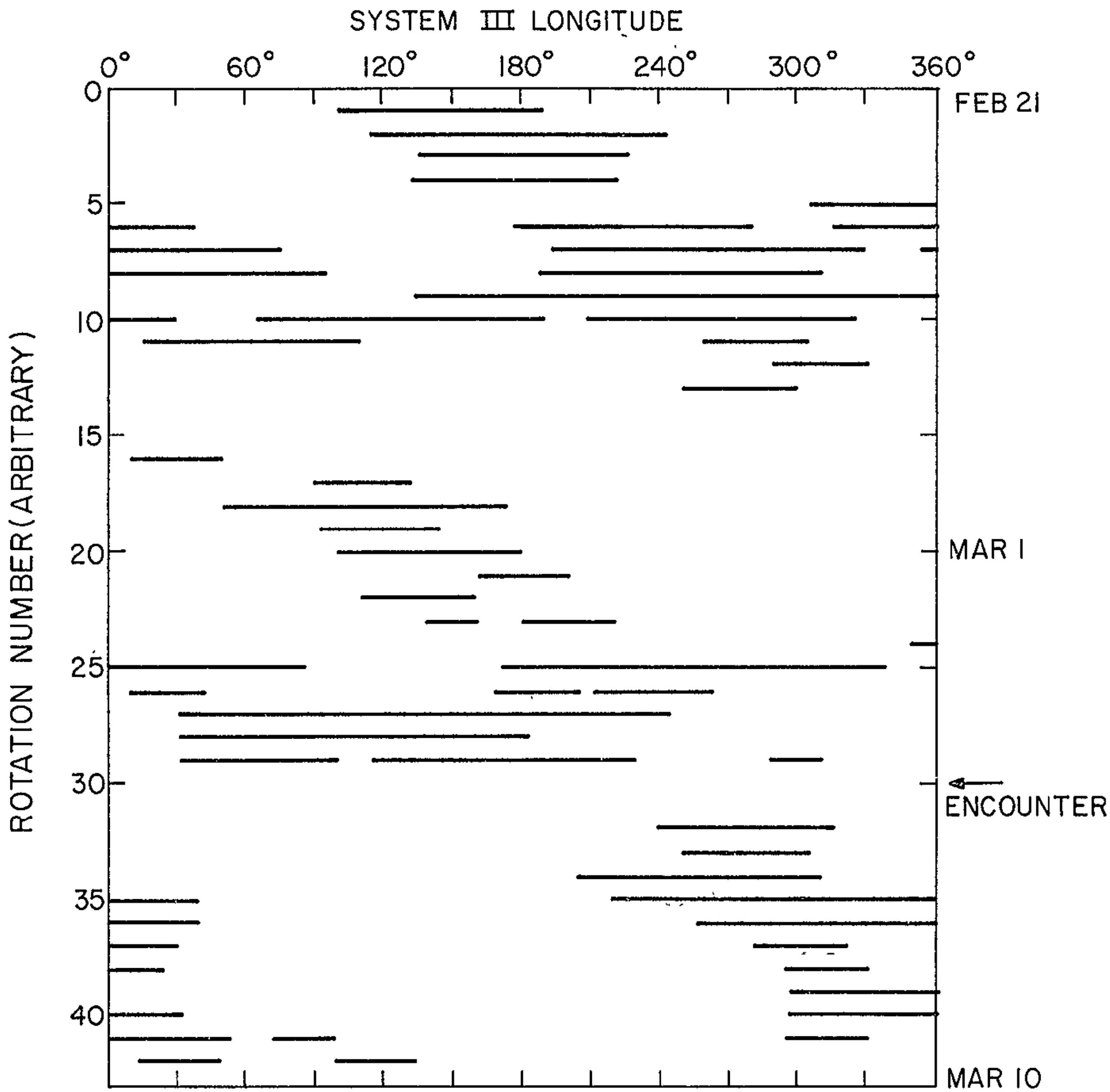
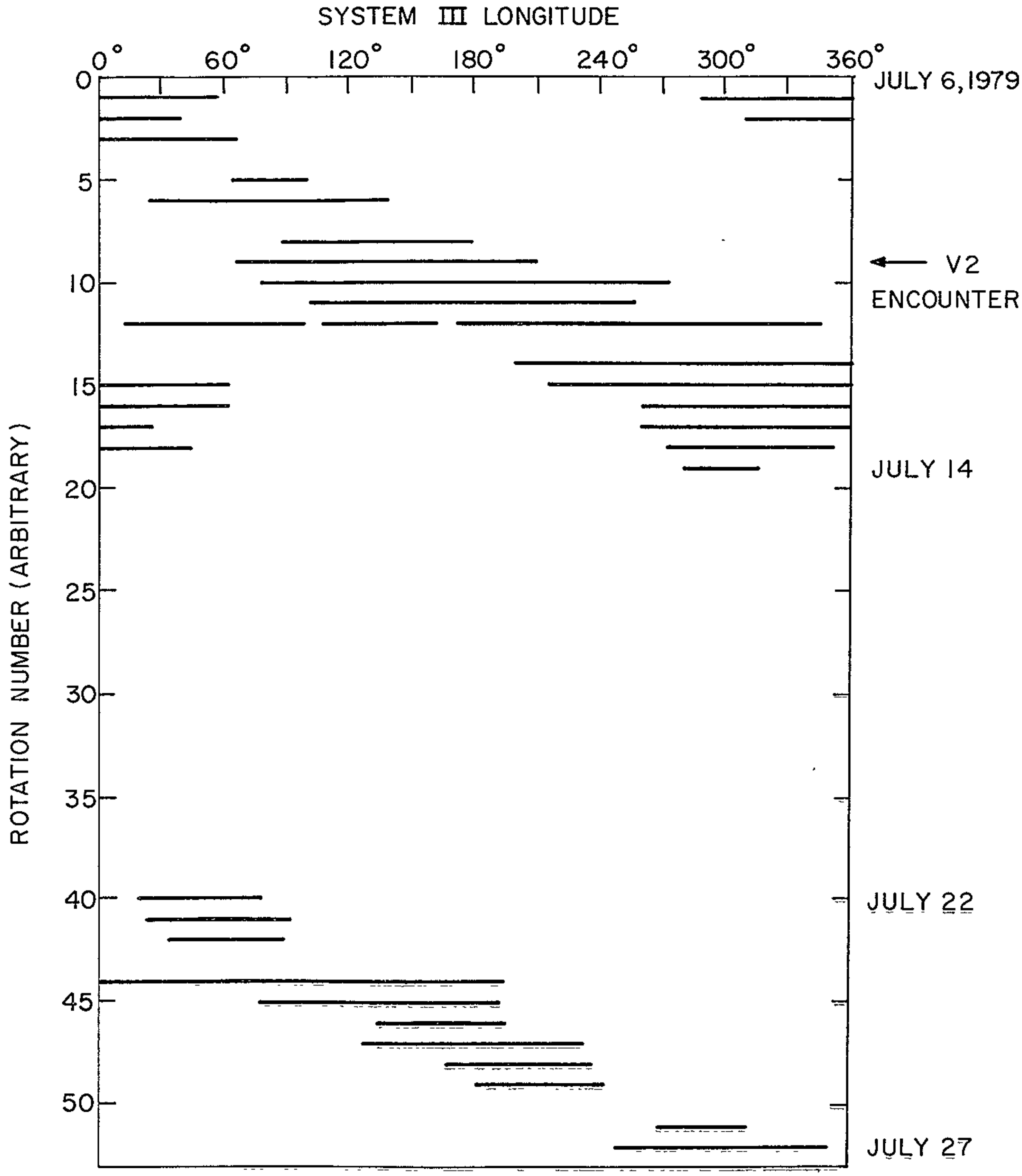

SYSTEM III LONGITUDE
0°
60°
120°
180°
240°
300°
360°
0
5
10
15
20
25
30
35
40
ROTATION NUMBER (ARBITRARY)
FEB 21
MAR 1
ENCOUNTER
MAR 10

Figure 3.



SYSTEM III LONGITUDE
0°
60°
120°
180°
240°
300°
360°
JULY 6, 1979
V2 ENCOUNTER
JULY 14
JULY 22
JULY 27
ROTATION NUMBER (ARBITRARY)
0
5
10
15
20
25
30
35
40
45
50

Figure 4

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15. Supplementary Notes

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