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ABSTRACT

The GSFC Jupiter Monitor Network has provided synoptic observations of Jupiter's emission at 16.7 and 22.2 MHz for the past 9-1/2 yr., and this report presents the results of analysis of the large, homogeneous set of measurements for the apparitions of 1966-1974. We present an update of the radio rotation period determination which includes provision for beaming effects due to variations in D_E (the Jovicentric declination of Earth). Some estimates of the magnitudes of possible long-term variations in rotation period are also discussed. The data clearly show the Io-independent emission features associated with the System III central meridian longitudes of all three major Io-related source regions as recently reported by other workers. In addition, there is some evidence for heretofore unrecognized Io-related emission features which are apparently independent of central meridian longitude. We suggest the possibility of three kinds of emission - namely (1) Io-stimulated, sharply beamed emission, (2) Io-independent, sharply beamed emission, and (3) Io-stimulated, broadly beamed emission.

Since late 1965, the Goddard Space Flight Center has conducted a program of synoptic observations of the decameter-wave emissions from Jupiter by means of a world-wide network of simple monitoring stations. The objective of this investigation has been to provide a continuous, homogeneous set of measurements which could be used for detailed studies of the morphological properties of Jupiter's sporadic radio radiation. In this report, we briefly describe the basic 9.1 year data catalog that is now available for analysis and summarize some of the results of this program. A more extensive technical description of the observing program and a detailed listing of the observations has been given in an earlier report (Alexander et al., 1975).

I. The NASA Monitoring Program

The monitoring network has been comprised of five stations* located at Greenbelt, Md; Clark Lake, Calif; Kauai, Haw.; Carnarvon, Australia; and Grand Canary Is., Spain. At each site observations are made at 16.7 and 22.2 MHz using 5-element Yagi antennas in a two-element, East-West interferometer. The antennas are mounted with equatorial motor drives which permit them to track from horizon to horizon. However, frequent problems with radio frequency interference from nearby communications channels and

*At the time of this report the Carnarvon station has been replaced with a station near Canberra, Australia, and the Clark Lake and Canary Is. stations are not in operation.

occasional equipment malfunctions have resulted in average daily observing periods of ~ 5.5 hr. at 22.2 MHz and ~ 4 hr. at 16.7 MHz. In spite of these difficulties, the global coverage provided by the network has resulted in approximately twice the monitoring capability than would be possible for a single observing site.

A summary of the observations of Jupiter from the network is given in Table 1. The basic catalog* is comprised of a total of 15,399 hr. of measurements at 16.7 MHz and 24,954 hr. of total listening time at 22.2 MHz. The system threshold flux level for detection of Jupiter is ~ 5 x 10^{-22} Jy, but as can be inferred from the tabulated apparition average occurrence probabilities for each station there have been station-to-station and year-to-year variations in that sensitivity level of the order of a factor of two.

The gross apparition average occurrence probabilities for each frequency are plotted as a function of date in Figure 1. For comparison, the values derived from the University of Colorado dynamic spectrograph during the same period (Warwick et al., 1975) are also shown. In all three plots, we can see that the level of decametric activity reached a minimum during the 1970 apparition and then increased in each subsequent year. (The slight drop in

* A magnetic tape of the complete data catalog which gives the times of each observation and activity period can be made available to interested parties.

TABLE 1. Summary of Jupiter Monitor Network Observations

STATION	Location: W. LONG	Location: LAT.	16.7 MHz: OBSERVING PERIOD	16.7 MHz: TOTAL HOURS	16.7 MHz: OCCURRENCE PROBABILITY	22.2 MHz: OBSERVING PERIOD	22.2 MHz: TOTAL HOURS	22.2 MHz: OCCURRENCE PROBABILITY
Goddard Space Flight Center	76° 50'	39° 01'N	11/65-4/66	591	0.24	11/65-4/66	265	0.0[illegible]5
			10/66-3/67	604	.22	10/66-3/67	446	.0[illegible]1
			9/67-4/68	823	.17	9/67-4/68	1089	.060
			11/68-5/69	695	.08	11/68-6/69	1167	.037
			11/69-5/70	686	.05	11/69-5/70	868	.013
			12/70-8/71	756	.06	12/70-8/71	1287	.017
			1/72-9/72	405	.14	1/72-11/72	984	.038
			2/73-12/73	840	.13	2/73-12/73	1236	.044
			4/74-12/74	429	.26	4/74-12/74	914	.038
Clark Lake Radio Observa.	116° 17'	33° 20'N	12/66-3/67	279	.19	2/69-5/69	431	.015
			1/70-8/70	669	.03	11/69-8/70	1448	.011
			12/70-7/71	966	.05	12/70-7/71	1307	.009
			1/72-11/72	607	.06	1/72-12/72	1236	.020
			3/73-12/73	610	.09	3/73-12/73	1062	.027
			4/74-7/74	309	.14	4/74-7/74	425	.047
Kauai, Hawaii	159° 40'	22° 07'N	11/67-3/68	382	.16	11/67-5/68	833	.042
			1/70-3/70	100	.10	1/72-7/72	695	.015
			1/72-6/72	186	.10	3/73-6/73	278	.049
			1/73-6/73	296	.14	5/74-11/74	1209	.026
			5/74-11/74	442	.30			
Carnarvon, Australia	246° 17'	24° 53'S	9/66-1/67	129	.14	9/66-1/67	428	.043
			8/67-5/68	162	.14	9/67-5/68	855	.022
			11/69-4/70	187	.09	11/69-4/70	716	.005
			1/71-8/71	551	.07	1/71-8/71	919	.011
			1/72-8/72	698	.04	1/72-9/72	1007	.008
Grand Canary Is. Spain	15° 36'	27° 44'N	10/68-4/69	377	.07	1/70-4/70	716	.009
			1/70-6/70	546	.03	12/70-8/71	938	.006
			12/70-4/71	302	.01	1/72-8/72	895	.014
			1/[illegible]-5/72	257	.01	5/74-12/74	1300	0.019
			[illegible]-12/73	846	.04			
			[illegible]-12/74	669	0.13			

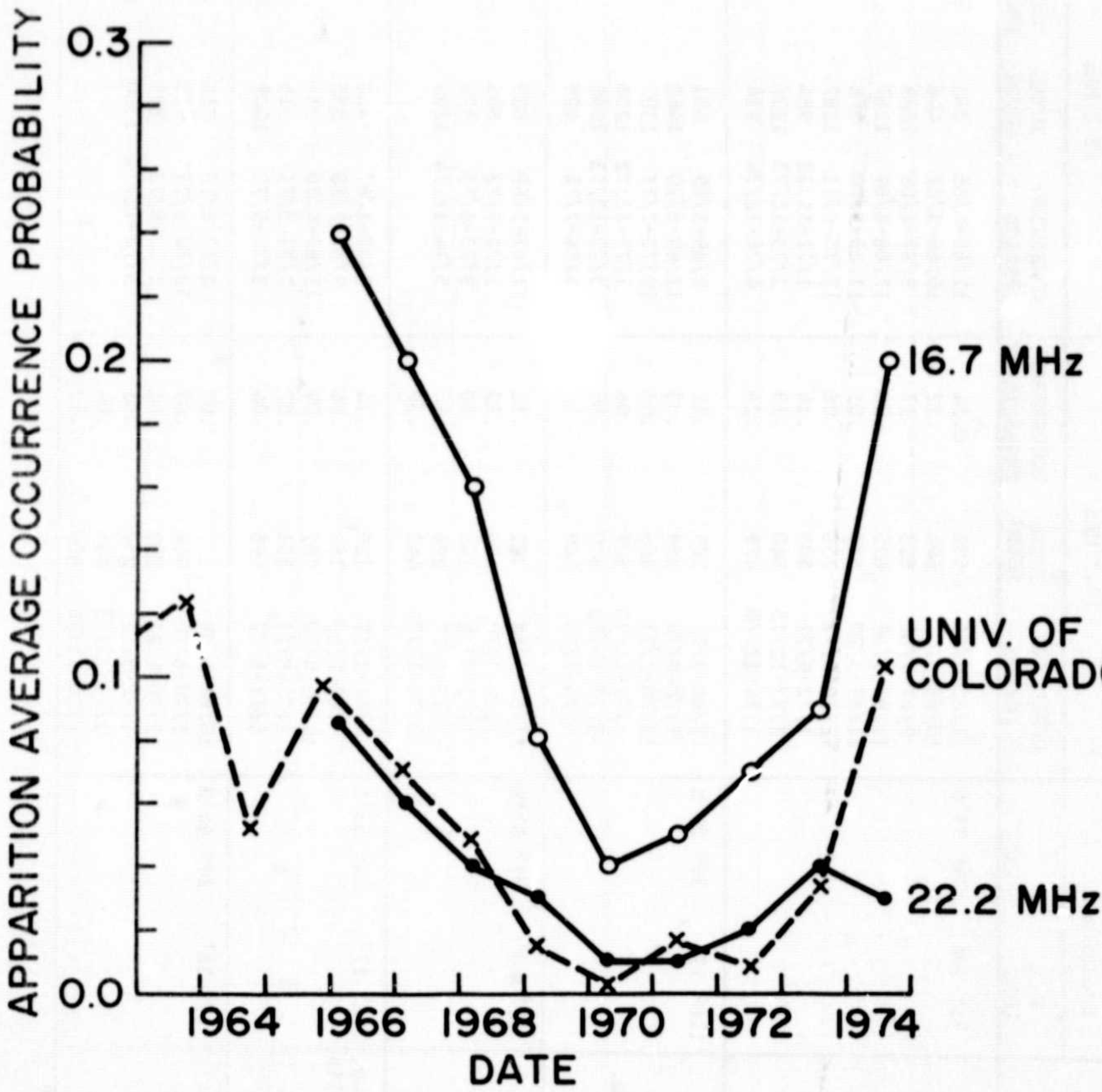

FIGURE 1. Plot of the apparition average occurrence probability for the Jupiter Monitor Network data and for the University of Colorado 7.6 to 41 MHz observations as a function of date.

average occurrence probability at 22.2 MHz for the 1974 apparition is most likely due to some equipment degradation at Goddard and Hawaii during that period). The occurrence probability minimum observed in 1970 coincides with the time of minimum D_E (the declination of Earth as observed from Jupiter) and is a manifestation of the now well-known 11.86-yr. beaming effect (e.g., see the recent review by Carr and Desch, 1975). We would expect the next maximum in integrated decametric activity to occur during the 1976 apparition.

II. System III Rotation Studies

We have subjected the 9.1-year span of observations to the power spectral analysis technique used in our previous work (Kaiser and Alexander, 1972). Briefly, this technique involves fitting a sinusoidal function of the form $[a_n \cos(n\omega t) + b_n \sin(n\omega t)]$ to the observations and adjusting ω for maximum correlation. This method has high precision because it uses the entire span of data rather than only 10-20% as in the standard autocorrelation - Fourier transform analysis. We find no reason to revise our previous sidereal rotation period of $9^h55^m29^s.70$. This is not surprising since much of the data used in our earlier analysis is a subset of the current data set.

We have also attempted to examine the second order effects on rotation period determinations discussed by Lecacheux (1974). He suggested that the power spectral method (as well as most other methods) is affected by the periodic component at 11.86 yr. - the Jovian year - which affects the overall occurrence statistics and the apparent source longitudes. Although it is not clear precisely how an 11.86-yr. periodicity could influence our technique, we have attempted to follow Lecacheux's suggestion by solving for both the rotation period and the Jovian year simultaneously. The resulting rotation period is identical to the single solution result and is not $9^h55^m29^s.66$ as Lecacheux (private communication) suggests. The results of our various period determinations are summarized in Table 2.

TABLE 2. Results of power spectral analysis period fits

		10 hr. solution	Simultaneous 10 hr. and 11.9 yr.solution
22.2 MHz	1955-72	$9^h55^m20^s.70 \pm 0^s.02$	$9^h55^m29^s.70 \pm 0^s.02$
	1965-74	$9^h55^m29^s.73 \pm 0^s.04$	$9^h55^m29^s.73 \pm 0^s.04$
16.7 MHz	1965-74	$9^h55^m29^s.69 \pm 0^s.04$	$9^h55^m29^s.69 \pm 0^s.04$

We might point out that Lecacheux's own method of analysis depends heavily on the apparent position of the early (B) and main (A) sources during the 1970-71 apparitions. Figure 1 shows that the overall occurrence probability was very low during this period causing the central meridian longitudes of the sources to be less well defined. For example, with our data we can determine the center of the main source to no better than $\pm$ 5° in central merid: . longitude for these apparitions, yet Lecacheux's Figure 1 indicates $\pm$ $1^{\circ}\!.5$ accuracy for all apparitions, including 1970-71. We suggest that a least squares fit weighted by the accuracy with which source longitudes can be determined might well give the same rotation period as the power spectral method - $9^h55^m29^s\!.70$.

It has been obvious for several years that the IAU System III (1957.0) rotation period is too low by 0.3-0.4 sec., and the need to adopt a revised rotation convention has become even more compelling in order to make precise comparisons between radio observations and the recent Pioneer 10 and 11 measurements (Mead, 1974). Based on the consensus of a large number of radio observers, Riddle (1975) has proposed a new System III (1965) rotation period of $9^h55^m29^s\!.71$, and we have adopted that system for all analyses of the NASA network data. The dispersion in a number of recent radio rotation period measurements is illustrated in Table 3.

TABLE 3. Some recent rotation period estimates

PERIOD	ACCURACY	REFERENCE
$9^h55^m29^s\!.70$	$\pm$ $0^s\!.05$	Duncan (1971)
$9^h55^m29^s\!.75$	$\pm$ $0^s\!.04$	Carr (1972)
$9^h55^m29^s\!.70$	$\pm$ $0^s\!.02$	Kaiser & Alexander (1972)
$9^h55^m29^s\!.72$	$\pm$ $0^s\!.07$	Berge (1974)
$9^h55^m29^s\!.67$	$\pm$ $0^s\!.01$	Lecacheux (1974)
$9^h55^m29^s\!.73$	$\pm$ $0^s\!.03$	Klein (1975)
$9^h55^m29^s\!.73$	$\pm$ $0^s\!.02$	Hide and Stannard (1975)

It may be possible that some of the discrepancies in Table 3 reflect real variations in the measured rotation period. The radio rotation period may not be constant at the few parts in 10^7 level quoted in Table 3 due to such effects as magnetic field drift, polar wandering and other secular and long term rotation period changes. It may be possible to assess the magnitude of these effects by analogy with the Earth especially in view of the recent comments by Kaiser and Stone (1975) regarding the similarity between the radio emissions of the Earth and Jupiter.

Measurement of the radio rotation periods of planets is presumably equivalent to measuring the rotation period of their magnetic fields. However, in the case of the Earth, the magnetic field changes with time. Sugiura and Heppner (1965) indicate that currently (1) the dipole magnetic moment of the Earth is decreasing, (2) the general field pattern is drifting westward at 0.2-0.3 degrees/year, and (3) the dipole field is shifting northward. These small changes in the field would also cause similar changes in the detailed structure of the radio noise. This change in detailed structure would, at some level of precision, result in apparent rotation period variations. Also, the various methods of rotation period determination might be sensitive to these changes in different ways. The westward drift would amount to a radio rotation period some 0.2 sec longer than the solid Earth rotation. Variations of only $\pm$ 10% in this drift would place the error bounds on the Earth's radio rotation period at the current levels of precision quoted in Table 3. In addition to these likely magnetic field changes, small but measurable changes in the rotation of the solid Earth could further reduce the accuracy to which the Earth's radio rotation period could be measured.

Jupiter's magnetic field would be expected to show fluctuations similar to those of Earth and possibly more extreme. Thus, the small discrepancies of Table 3 might be real differences in the apparent rotation period of Jupiter at different epochs. There is even reason to believe the decimetric rotation period should differ slightly from the decametric period because the relevant magnetic field lines are rooted at different depths in the interior of the planet (Hide, 1965). In view of these considerations, radio rotation period determinations should merit further careful attention.

III. Morphology of Occurrence Statistics

Two-dimensional occurrence probability contour diagrams which display the variation in decametric activity with departure of Io from superior geocentric conjunction (Io phase) and System III (1965) central merdian longitude (CML) during the 9-yr observing period are shown in Figure 2. The three major Io-controlled "sources" at Io phase $\simeq 90^{\circ}$ and $\simeq 240^{\circ}$ are obvious at both frequencies, and the low frequency "fourth source" at Io phase $\sim 105^{\circ}$ and CML $< 110^{\circ}$

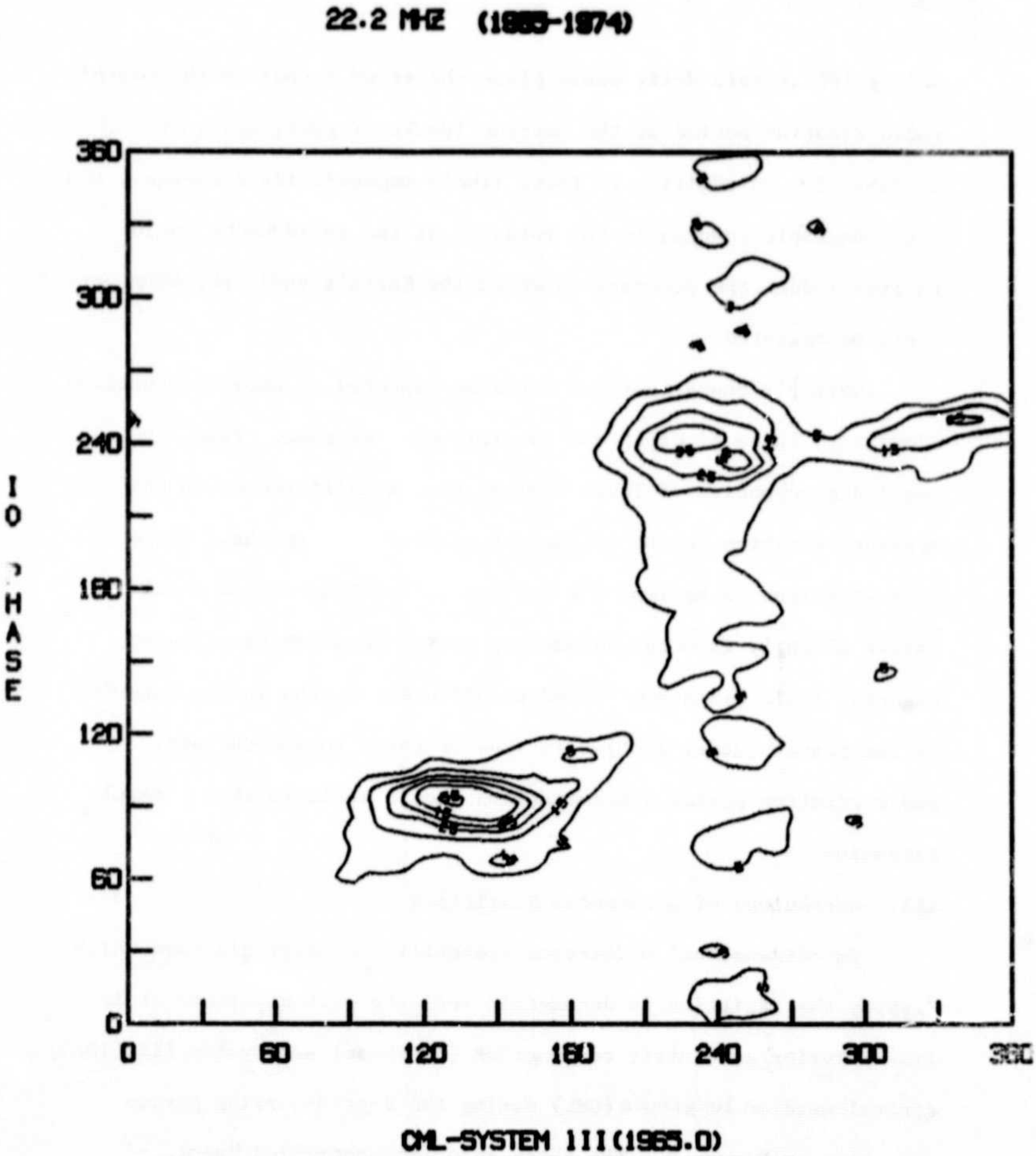

FIGURE 2a. Plot of occurrence probability as a function of System III (1965) central meridian longitude and phase of Io for NASA observations at 22.2 MHz from 1965 to 1974. Contours are in increments of 10% starting at 5%.

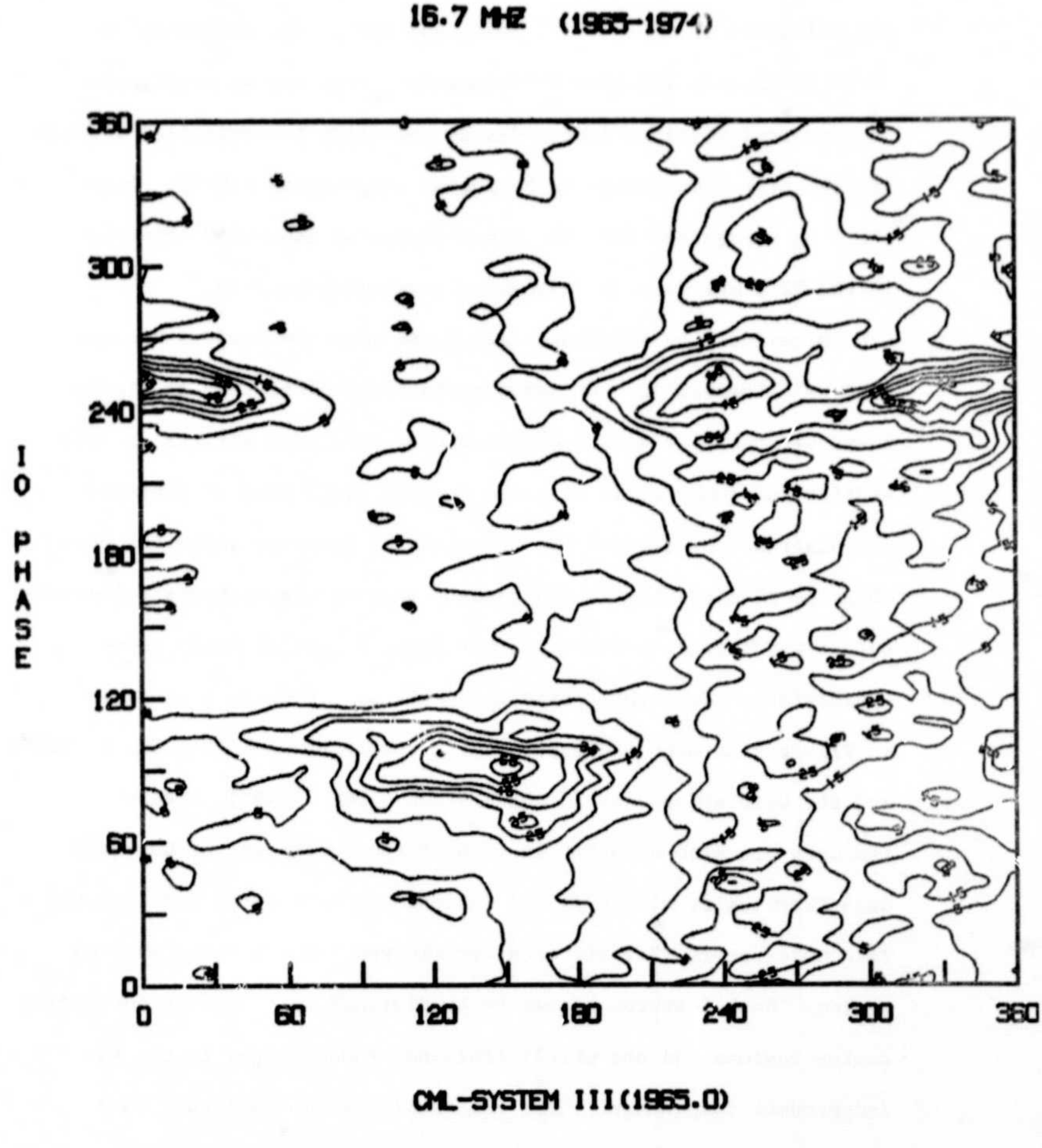

FIGURE 2b. Same as 2a but for 16.7 MHz.

can be seen in the 16.7 MHz diagram. Also discernible in the 16.7 MHz data are the three Io-independent features centered approximately at CML = 160^o, 260^o, and 320^o. The existence of three apparently distinct Io-independent features at nearly the same central meridian longitudes as the major Io-controlled sources has recently been discussed by Bozyan and Douglas (1975). Only the long recognized Io-independent source at CML $\sim 260^o$ appears in the 22.2 MHz data at occurrence probabilities > 5%.

Detailed fine structure associated with the various "source regions" observed in occurrence probability plots such as Figure 2 are often simply due to observational selection effects or other statistical imperfections in the data catalogs used to generate the diagrams. There is one such feature, however, which has been observed consistently in independent sets of measurements collected over a wide range of dates so that further careful study seems appropriate. Note that there is an extension towards the origin in Figure 2 in both the early source (at Io phase $\leq 80^o$, CML $< 120^o$) and the main source (at Io phase $< 220^o$, CML $< 240^o$). These features are also apparent in much of the University of Colorado data (Warwick et al. 1975) and in contours plots prepared from the Yale Observatory 22.2 MHz catalogs (Bozyan, 1969) for the 1962-64 period. Both features appear to be distensions of the Io-controlled source regions and not merely isolated, random highs in the Io-independent components. More remarkable is the fact that they both lie along a line of constant sub-Io longitude (200-210^o).

This is approximately the longitude towards which the magnetic dipole is tilted in the northern hemisphere. On the other hand, these features do not appear to lie along an observing lane (the line traced on the Io phase - CML plane in the course of one continuous observing session) which has a slope of approximately 4:1 rather than the constant sub-Io longitude slope of 1:1. The significance of these features is, admittedly, marginal at the present time. However, they may provide evidence that in addition to the rather sharply beamed Io-controlled and Io-independent components of Jupiter's decametric emission there exists a more broadly beamed component of emission whenever Io is situated near the longitude of the planetary dipole in the northern hemisphere. Alternatively, we may be observing an enhancement in the "radiation pattern" of the Io-controlled emission as protrayed by the occurrence probability data when Io is over this particular region of the planet. Further investigation into the nature of such weak features in the occurrence diagrams is important since they may provide a key to beginning to understand the Io-stimulation mechanism.

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