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LATITUDINAL BEAMING OF JUPITER'S LOW FREQUENCY RADIO EMISSIONS

by

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ABSTRACT

By comparing RAE-1 and IMP-6 satellite measurements of Jupiter's radio emissions near 1 MHz with recent Voyager-1 and 2 observations in the same frequency range it is now possible to study the properties of the low frequency radiation pattern over a 10° range of latitudes with respect to the Jovian rotation equator. These observations, which cover a wider latitudinal range than is possible from the earth, are consistent with many aspects of earlier ground-based measurements that have been used to infer a sharp beaming pattern for the decameter wavelength emissions. We find marked, systematic changes in the statistical occurrence probability distributions with System III central meridian longitude as the jovigraphic latitude of the observer changes over this range. Moreover, simultaneous observations by the two Voyager spacecraft which are separated by up to 3° in jovigraphic latitude suggest that the instantaneous beam width may be no more than a few degrees at times. The new hectometer-wave results can be interpreted in terms of a narrow, curved sheet at a fixed magnetic latitude into which the emission is beamed to escape the planet.

I. INTRODUCTION

The sporadic, decameter-wavelength radio emission from Jupiter (DAM for short) is sharply beamed into a radiation pattern whose geometric properties are quite stable and repeatable with time. As a consequence of this beaming, ground-based studies of DAM performed over the past two decades reveal distinct variations in the morphology of DAM as a function of the declination of the earth with respect to the jovigraphic equatorial plane (D_E). Although D_E only ranges between -3.3° and $+3.3^{\circ}$ over Jupiter's 11.9-yr solar revolution period, both the preferred System III central meridian longitudes and the relative occurrence probability for DAM activity are observed to vary significantly as D_E changes over this interval (see Carr and Desch (1976) and references therein). This so-called "D_E effect" has generally been interpreted in terms of a latitudinal dependence of the DAM radiation pattern--both in angular width and location and in intensity--that is sharp enough to modulate the characteristics of DAM even when the observer's jovigraphic latitude can change by as little as 6°.

One of the most prominent manifestations of the latitudinal beaming of DAM is the long-term variation in the level of activity which Carr et al. (1970) demonstrated to be a strong function of D_E. Both the overall average occurrence probability and the peak occurrence probability at the center of the central meridian longitude "source" regions have been found to vary by more than a factor of four when observations from apparitions near the extremes in D_E are compared. Bozyan and Douglas (1976) pointed out that the pattern of the D_E dependence of occurrence probability appeared to be different for the Io-controlled and the Io-independent components of DAM with the latter showing a stronger variation and a peak near the high end of the D_E range. Gulkis and Carr (1966) and Donivan and Carr (1969) analyzed long-term drifts in the central meridian longitude of the "main source" (or "source A") occurrence probability feature and showed that apparent motions in the longitude of the peak over a total range of about 34° were directly correlated with D_E. Register and Smith (1969) pointed out that the source A longitude drift was also due primarily to a D_E dependence of the non-Io-controlled contribution to this feature. Similar, but smaller amplitude longitude drifts have been reported for the "early" or "B source" (Donivan and Carr, 1969) and for the "late" or "C source" (Bozyan and Douglas, 1976). Several investigators have analyzed the Io-phase control of DAM activity (Lecacheux, 1974; Thieman et al., 1975; Bozyan and Douglas, 1976) and have found clear evidence for D_E control of the Io-phase co-ordinate for all three of the major Io-controlled components of DAM.

Thus, when we examine a standard two-dimensional contour plot of the probability of occurrence of DAM as a function of the phase of Io and of System III central meridian longitude, we must recognize that the statistical behavior in all three dimensions--occurrence probability, Io phase, and longitude-- depend on the value of D_E at the time that the original observations were obtained. This latitudinal beaming effect appears to be strongest for the Io-independent DAM emissions and to work in the sense that results in higher levels of activity when the observer's jovigraphic latitude is positive.

In this report, we present the first observations of Jupiter's radio emissions from jovigraphic latitudes greater than 3.3^{o}. The new measurements were obtained from the Voyager-2 spacecraft at declinations up to 6.5^{o}, and when these results are compared with simultaneous observations from Voyager-1 near the ecliptic plane (jovigraphic latitude $\sim 3^{o}$) they indicate that the latitudinal beaming effects persist and may even become stronger with higher latitudes. Since the Voyager data pertain to hectometric wavelengths (frequencies near 1 MHz), we have also combined the new results with earlier low frequency measurements from periods with D_E as low as -3^{o} in order to show how the beaming affects the occurrence of the emission over a full 10^{o} range of latitudes. Thus, this report also presents the first study of the nature of the declination effect at hectometric (HOM) wavelengths.

In the next section, we present the results of spacecraft observations of Jupiter at frequencies near 1 MHz which were obtained from Voyager-1 and 2 in 1978 and from the Radio-Astronomy-Explorer-1 (RAE-1) in 1969 and the Interplanetary-Monitoring-Platform-6 (IMP-6) in 1971-1972. As we have noted above, the combined data set provides the first opportunity to examine the statistical variations in HOM for jovigraphic latitudes ranging from below -3^{o} to above $+6^{o}$, and the Voyager-1 and 2 observations provide additional insight into the instantaneous beaming of HOM over a 3^{o} range of latitudes. In Section III, we will discuss the implications of the new results for models of Jupiter's radio emission beam pattern.

II. HECTOMETER WAVELENGTH OBSERVATIONS

The observations of Jovian HOM activity which comprise the basis for our study are summarized in Table 1. All data have been derived from space-borne radio astronomy experiments which employed low gain, simple, electric dipole antennas. The Voyager measurements cover a period of approximately seven months from mid-November, 1977 to mid-June, 1978, and were obtained by the Planetary Radio Astronomy investigation at frequencies betwen 0.5 and 1.3 MHz. Details of the Voyager instrumentation have been discussed by Warwick et al. (1977) and other aspects of the initial Jupiter radio results are presented by Kaiser et al. (1979). During this early cruise portion of the Voyager flights, Voyager-1 moved from a jovigraphic latitude of 2.6° in November, 1977, to 3.2° in June, 1978. Over the same interval of time Voyager-2 covered a wider declination range, beginning at 3.9° when Jupiter was first detected and moving northward to 6.5° in June 1978.

Table 1. Space-borne observations of Jovian HOM activity

S/C	Period (YYMMDD)	Frequency Range (MHz)	Total Activity (hr.)	Latitude Interval (deg.)
V-2	771108-780618	0.6 - 1.3	277	3.9, 6.5
V-1	771115-780630	0.6 - 1.3	282	2.6, 3.2
RAE-1	690113-690520	0.9 - 1.3	27	-2.1, -2.5
IMP-6	710420-720921	0.8 - 1.3	155	-2.0, -3.2

The RAE-1 observations used in the present study are taken from the 1969 survey conducted by Desch and Carr (1974). During that period, RAE-1 was in earth orbit at a D_E of about -2.3°. In order to make the best comparison with the Voyager data at positive jovigraphic latitudes, we have used the low frequency RAE-1 measurements at 0.9

and 1.3 MHz.

The IMP-6 measurements of HOM are taken from a survey conducted by Desch (1979) who extended the earlier analysis of Brown (1974). These data spanned a D_E range of -2.0° to -3.2° during the April 1971 to September 1972 observing period. Although Jupiter was detected down to about 0.3 MHz with IMP-6, we have used results from 0.7 to 1.3 MHz in order to match the sensitive range of spectral coverage available with the Voyager data with which we intend to make detailed comparisons.

The radio astronomy instrumentation is identical on the two Voyager spacecraft, and we estimate that the equivalent flux density cutoff (adjusted to compare with observations from the earth) was approximately 4×10^{-20} W/m^2/Hz in December 1977 and 10^{-20} W/m^2/Hz in June 1978 when the Jupiter-spacecraft range had decreased to about 1.7 A.U. On the other hand, the IMP-6 experiment operated with the advantages of a longer, more efficient antenna and a more sensitive receiving system. Consequently the threshold detection level on IMP-6 corresponded to a power flux density of about 10^{-21} W/m^2/Hz. The minimum detectable flux density in the RAE-1 survey was estimated by Desch and Carr (1974) to be 5×10^{-21} W/m^2/Hz. Consequently, the RAE-1 survey is intermediate in sensitivity between the IMP-6 and Voyager observations. The total observing time for RAE-1 was considerably lower, however, and so the statistical reliability of that survey is poorer than for the other spacecraft results. Our ability to detect and identify Jupiter in dynamic spectral records from the Voyagers is enhanced by the superior frequency resolution of the Voyager receivers (32 channels between 0.7 and 1.3 MHz compared with 6 for IMP-6 and 2 for RAE-1 over the same frequency range).

Kaiser et al. (1979) and Desch (1979) have noted that at HOM frequencies near 1 MHz there is clear evidence for ordered variations in Jovian activity as a function of System III central meridian longitude (CML) but essentially no evidence for Io-control. In Figure 1 we show CML histograms of the relative occurrence of HOM for all four spacecraft. The data have been sub-divided according to the jovigraphic latitude of the observer. The changes in the CML profiles as a function of observer's latitude are striking. The early IMP-6 data collected from low latitudes show only a single occurrence maximum centered at a System III (1965) CML = 150°-160°. That peak continues to appear for the late IMP-6, RAE-1 and Voyager-1 measurements from higher latitudes, where it moves systematically to lower longitudes. In the high latitude Voyager-2 data the centroid of the early occurrence maximum has shifted to $\sim 100^{\circ}$. In addition, we find a second activity peak in all but the very low latitude IMP-6 data which moves to progressively higher longitudes as observer's latitude increases. This feature is first seen in the late IMP-6 data at CML $\sim 280^{\circ}$, and in the late Voyager-2 data it has shifted to $\sim 330^{\circ}$. The longitude range for minimum activity also changes dramatically with observer's latitude. At low latitudes we find a broad minimum between CML $\approx 30^{\circ}$ and 70°. At higher latitudes this null disappears, and a new zone of null occurrence probability appears near CML $\approx 190^{\circ}$. As latitude increases further with the Voyager data, this null region broadens until it spans the CML range 140° to 260° in the late Voyager-2 data.

As Kaiser et al. (1979) have pointed out, the CML profiles of HOM activity for observer's latitudes at or below 3.3° are qualitatively similar to DAM longitude distributions derived from ground-based observations. The DAM data generally show occurrence probability maxima near CML = 120°-160°, 210°-260°, and 310°-340°, and these "source regions" drift in longitude as D_E changes. The sense of the longitude drift with latitude appears to be the same for both HOM and DAM although the absolute longitude of the maxima and the amplitude of the drift for a given range of observer's latitude may not be the same for both frequency ranges. We also note that both the HOM emissions described here and the component of DAM that shows the greatest D_E dependence appear to be independent of Io-control.

The variations in the morphology of Jovian low frequency radio emissions as a function of observer's latitude which we have illustrated in Figure 1 and have discussed above depend primarily on the average statistical properties of the emissions as they are observed over a period of time that is long compared to individual noise storm durations. We will now show how the instantaneous latitudinal beam size can apparently affect simultaneous measurements from Voyager-1 and 2 at two different latitudes with respect to the jovigraphic equatorial plane.

In Figure 2, we reproduce Voyager-1 and Voyager-2 dynamic spectra of HOM activity observed at different times corresponding to different latitudinal separations between the two spacecraft. Each plot displays the total power measured for polarized emissions from Jupiter detected up to 1.3 MHZ by the Planetary Radio Astronomy low frequency receiver. For the event of 2130-2230 hr. on February 5, 1978 when the two spacecraft were separated by 2.2° in jovigraphic latitude, we see that there is a reasonably close overlap between the emissions observed by the two spacecraft although the activity is not observed to be identical in all respects for the two simultaneous sets of measurements. (The corrections due to differences in System III (1965) central meridian longitude and light travel time are very small for all events illustrated in Figure 2 (1° and 1 min., respectively) and are not considered to be significant in the comparisons we are making.) By the time we get to the event of 2200-2300 hr on May 25, 1978 where the latitude difference between Voyager-1 and 2 has reached 3.2°, we see that there is essentially no correlation beween the dynamic spectra obtained from the two different spacecraft.

The events illustrated in Figure 2 are typical of the trend that developed as the latitude separation between the two Voyagers increased with time. As Voyager-2 moved farther northward compared to Voyager-1 between January and June 1978, the correlation between HOM activity observed by the two instruments steadily dropped. This pattern is illustrated dramatically in Figure 3 where we plot the fraction of HOM activity that was detected exclusively by one spacecraft when both should have been capable of detecting Jupiter as a function of the angular separation between the two in jovigraphic latitude. The separation angle in latitude ranges from 1.6° (in December 1977) to 3.3° (in June 1978 when the present study stops), and the total angular separation varies from 1.9° to 4.0° over the same period. As this separation increases, we find that the percentage of events detected by only one spacecraft rises monotonically from ~ 30% to > 70%. A least squares linear regression fit to the data points in Figure 3 predicts 100% decorrelation between the two spacecraft for a latitude separation of only 4.7° or for a total angular separation of 6.2°. As should be expected, extrapolation of the linear regression to smaller angular separations yields 0% decorrelation at 0° separation.

III. DISCUSSION

Two aspects of the new observations which we have presented in the previous section clearly show that there must be a very strong latitudinal control of the beaming of Jupiter's HOM emissions. First, there is a dependence of the CML distribution of occurrence probability which causes an abrupt change in the CML profile for observations obtained from latitudes greater than about 6.0°. Second, we find that simultaneous observations from two points separated by less than 4° in latitude can show almost no evidence of correlation or coincident detection of HOM activity. These results suggest that the beaming of Jupiter's radio emissions may be every bit as strong at hectometric wavelengths as we had deduced for decametric wavelengths on the basis of ground-based measurements of DAM from latitudes between -3.3° and +3.3°.

One relatively simple and straightforward way to interpret these results is the approach introduced by Gulkis and Carr (1966) to account for the D_E dependence of the CML of the decametric main (A) and third (C) sources. They suggested that the emission at frequencies near 18 MHz appeared to be beamed into a thin curved sheet which is inclined 6° north of the Jovian magnetic equator. Since the dipole axis is tipped by about 10° with respect to the planetary rotation axis, the System III longitudes at which this emission beam crosses an observer will depend on the observer's jovigraphic latitude. The latitudinal thickness of the beam was estimated to be about 10^{o}. Gulkis and Carr also suggested that the location of the early (B) source, which their model could not readily explain, might be influenced by significant distortions or departures from a dipole magnetic field, and further, that the preferred magnetic latitude of the center of the beam should be a function of frequency. We find the results of the hectometric wavelength measurements to be consistent with all of the above suggestions.

To determine whether a similar model will account for the low frequency observations, we have reanalyzed the data shown in Figure 1 as a function of observer's jovimagnetic latitude rather than as a function of CML. In order to calculate magnetic latitude we have utilized three different magnetic field models--namely (1) a centered, tilted dipole (9.6^{o} tilt towards 202^{o} System III (1965) longitude), (2) the 15-term O_4 octupole field model from the Pioneer-11 measurements of Acuna and Ness (1976), and (3) the 15-co-efficient octupole model from the Pioneer-10 and 11 measurements of Davis and Smith (1976). In comparing the low frequency radio data with the two Pioneer magnetic field models, we have used the B_{min} equator at a jovicentric radial distance of 2 R_J rather than at the cloud tops. The higher altitude seems more appropriate for application to the radio emission at frequencies near 1 MHz if, as a number of theories predict, the radiation is generated near the source electron gyrofrequency. The magnetic equator geometry does not change substantially over the range 1.5 to 2.5 R_J, and so our choice of 2 R_J is adequate for the present investigation even though it may be somewhat arbitrary.

The relative occurrence of the hectometric emissions is plotted as a function of the magnetic latitude of the spacecraft with respect to the centered, tilted, dipole equator in Figure 4. Note that the data are all peaked at magnetic latitudes between $+0^{o}$ and $+4^{o}$. The magnetic latitude of the histogram peaks in Figure 4 has a mean value of $+2.0^{o}$ and a standard deviation of 1.3^{o}. Similar plots in terms of the O_4 magnetic equator and the field model of Davis and Smith give similar results. The histograms for the O_4 model show peaks at a mean latitude of 2.9^o with a standard deviation of 2.1^o, and with the magnetic equator of Davis and Smith at 2 R_J the average latitude and its standard deviation are $+0.2^o$ and 3.9^o, respectively. The locations of the histogram peaks for all three magnetic latitude systems are shown as a function of spacecraft jovigraphic latitude in Figure 5. The verical 'error' bars in each plot denote the $\pm 1\sigma$ width of each of the individual magnetic latitude histograms such as those illustrated in Figure 4. The scatter about the mean latitude of the histogram peaks is slighty larger for the Davis and Smith model, but there is no other substartial difference between the models evident in Figure 5.

If the Gulkis and Carr model of an emission pattern at a fixed magnetic latitude is really workable for the hectometric radiation, then we should be able to predict the marked changes in the occurrence histograms as a function of observer's latitude which appear in Figure 1. The results of such a test are shown in Figure 6. In the left-hand panel we have plotted the jovimagnetic latitude of an observer at different jovigraphic latitudes versus System III (1965) longitude. We have used the O_4 magnetic field model in order to illustrate the asymmetries inherent in the Pioneer models even at 2 R_J. Also shown on the same plot is an assumed emission beam centered at a magnetic latitude of $+3^o$. The latitudinal width of the beam is taken to be 10^o to be consistent with the 1σ latitudinal width of the observed magnetic latitude histograms (vertical bars in Figure 5). The System III longitude at which this beam is cut by an observer clearly changes with the observer's latitude.

In the right-hand panels, we have plotted the kind of qualitative CML occurrence pattern that one would expect if hectometric emission would be detectable only when the observer were within the 10^o-wide beam centered at $+3^o$ magnetic latitude. The trends which we found in Figure 1 are well reproduced. Note that the regions of minimum activity at low longitudes for negative observer's latitudes and the increasingly broad minimum near 190° CML for positive observer's latitude are clear in Figure 6. The longitude drift of the early activity peak from $\sim$ 150° for -3° latitude to below 130° for +3° latitude is also predicted by the simple beaming model. The lack of an emission peak at high longitudes observed for the early IMP-6 data (bottom histogram in Figure 1) is not predicted by the model, however. The Voyager-2 data at jovigraphic latitudes above +4.5° show a growing amount of activity at longitudes below about 80°, and this feature is reproduced by the magnetic latitude models based on the Pioneer data as a consequence of an asymmetry in the magnetic equator location at early longitudes. The centered, tilted dipole equator would produce a family of purely sinusoidal curves instead of the more distorted traces we see in the left-hand panel of Figure 6, and so it can not account as well for the late Voyager-2 results.

Although the plots of Figure 6 show how well the O_4 model magnetic equator serves as a point of reference for a beaming model of the low frequency emission, the Davis and Smith model reproduces the general features of the longitude occurrence diagrams with essentially the same degree of precision. We find that the more complex models based on the Pioneer data both do a somewhat better job than the simple dipole model in spite of the fact that the magnetic latitude histograms do not peak quite as sharply for the IMP and RAE data as do the dipole latitude plots in Figure 4. The best fit beam for the hectometric observations is a warped sheet of $\sim$ 10° width which is centered at a constant magnetic latitude of 2°-4° north of the magnetic equator at $\sim$ 2 R_J. We should emphasize that the radio source is not necessarily located at this point in the Jovian magnetosphere, but rather that this beam model describes the angular region into which the hectometric emission appears to escape in order to propagate away from the planet towards an observer located within 10° of the ecliptic plane.

It is interesting to compare the examples of Jovian emission shown in Figure 2 with the degree of correlation between the two spacecraft we might expect based on the beam model shown in Figure 6.

The event seen by both spacecraft at 2130-2230 hr on February 5, 1978 (Figure 2a) occurs near CML = 260°. With Voyager-1 at $\sim$ +3° Jovigraphic latitude and Voyager-2 at $\sim$ +5°, Figure 6 predicts that both spacecraft should be in the beam and thus should observe the event. In Figure 2b, the event seen by both spacecraft between 0330 hr and 0420 hr occurs at a longitude of $\sim$ 130° placing both spacecraft in the beam and again Figure 6 predicts concurrence between Voyager-1 and Voyager-2. Note on this same event that Voyager-1 observes emission extending some 20-25 minutes beyond the end of the Voyager-2 event. This occurs near CML = 150° and corresponds in Figure 6 to a case where Voyager-2 is out of the beam (at higher Jovimagnetic latitudes) while Voyager-1 is still in the beam. The event seen primarily by Voyager-2 at 0700 hr (CML $\sim$ 240°), however, is not predicted correctly by Figure 6. At this longitude, both spacecraft are at slightly higher latitudes than the beam, with Voyager-2 more northerly than Voyager-1. Thus we would expect either no emission observed by either spacecraft, or weak emission observed by Voyager-1 and no emission observed by Voyager-2. The complex event observed between 2000 and 2300 hr corresponds to a longitude region (0°-75°) where Figure 6 would predict little or no emission to be observed. However, the emission observed during this three hour period is right-hand polarized (whereas all other events in Figure 2, and indeed most HOM events observed by the Voyagers, are left-hand polarized) suggesting the possibility of a beam associated with more southerly Jovimagnetic latitudes. In Figure 2c, the very intense event seen exclusively by Voyager-1 between 2200 and 2300 hr occurs at CML $\sim$ 140°. By this date, Voyager-2 had reached a Jovigraphic latitude of nearly +6.5°, and was thus well north of the beam at 140° CML. Voyager-1 remained at $\sim$ +3° Jovigraphic latitude and was therefore inside the beam.

In order to statistically examine the ability of this beam model to predict decorrelations between the two spacecraft, we show in Figure 7 the results of measuring the percent decorrelation (computed as for Figure 3) as a function of CML for each spacecraft separately. The predicted percent decorrelation (dashed line) is derived as follows: If both spacecraft are within the beam at a particular CML (see Figure 6), the percent decorrelation is predicted to be small. If one or both spacecraft are outside the beam, the percent decorrelation for a given spacecraft should be large or small depending on whether the other spacecraft is farther from or closer to the beam, respectively. Thus, considering Voyager-2 for example, we predict little decorrelation (that is, strong correlation) near 200° CML because Voyager-1 is closer to the beam and thus should tend to detect the same events that Voyager 2 detects. In agreement with prediction, the percent decorrelation is observed to be only about 0.15 in this longitude range. Overall, agreement with the beam model prediction is good at nearly all CML, particularly in the case of the Voyager-2 observations.

IV. CONCLUDING REMARKS

As we noted at the outset, there is abundant evidence to indicate that the Jovian radio radiation pattern is sharply beamed. From an analysis of the repeatability of dynamic spectral "landmark" features as a function of CML, Warwick (1963) suggested that DAM appeared to be beamed into an emission cone with a half-angle as narrow as 9°, and Lecacheux et al. (1979) have shown that this effect may also persist at HOM wavelengths. Poquerusse and Lecacheux (1978) have used simultaneous spacecraft and ground-based observations over a total angular separation of $\sim$ 15° to deduce that the beaming of the Io-controlled DAM is sharper than 9° and may be as narrow as a few degrees. The present observations, which we interpret in terms of strong beaming effects in magnetic latitude, are fully consistent with those earlier results. All of these studies seem to make one point very clear--the escape of Jupiter's radio emission into interplanetary space is often strongly dependent on the propagation conditions near the source and/or in the inner Jovian magnetosphere. Theoretical treatments which seek to explain the radio radiation must take it into account.

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FIGURE CAPTIONS

Fig. 1. Relative occurrence of Jovian hectometer wavelength radio emission versus System III (1965) central meridian longitude as observed from Voyager-1 and 2, RAE-1 and IMP-6. The data are sorted according to the range of jovigraphic latitude of the observer for each data set.

Fig. 2. Examples of simultaneous HOM dynamic spectral measurements by Voyager-1 and Voyager-2. In these displays, total power is proportional to darkness and is shown as a function of observing frequency and time. In panel (a), the Jovian HOM event between 2130 and 2230 hr is seen comparably by both spacecraft. In panel (b), the event between 0400 and 0500 hr is detected by both spacecraft while the event near 0700 hr is seen much more readily in the Voyager-2 data. The weak emission between 2000 and 2300 hr is seen by both spacecraft but the dynamic spectra are quite different in character. In panel (c), the strong event seen by Voyager-1 between 2200 and 2300 is not seen at all by Voyager-2.

Fig. 3. A plot of the variation in the percentage of Jovian radio storms that were detected at only one Voyager spacecraft during periods of simultaneous observations by both spacecraft as a function of the angular distance between the two spacecraft with respect to Jupiter. The horizontal bars denoted the span in latitude which was used to derive each data point.

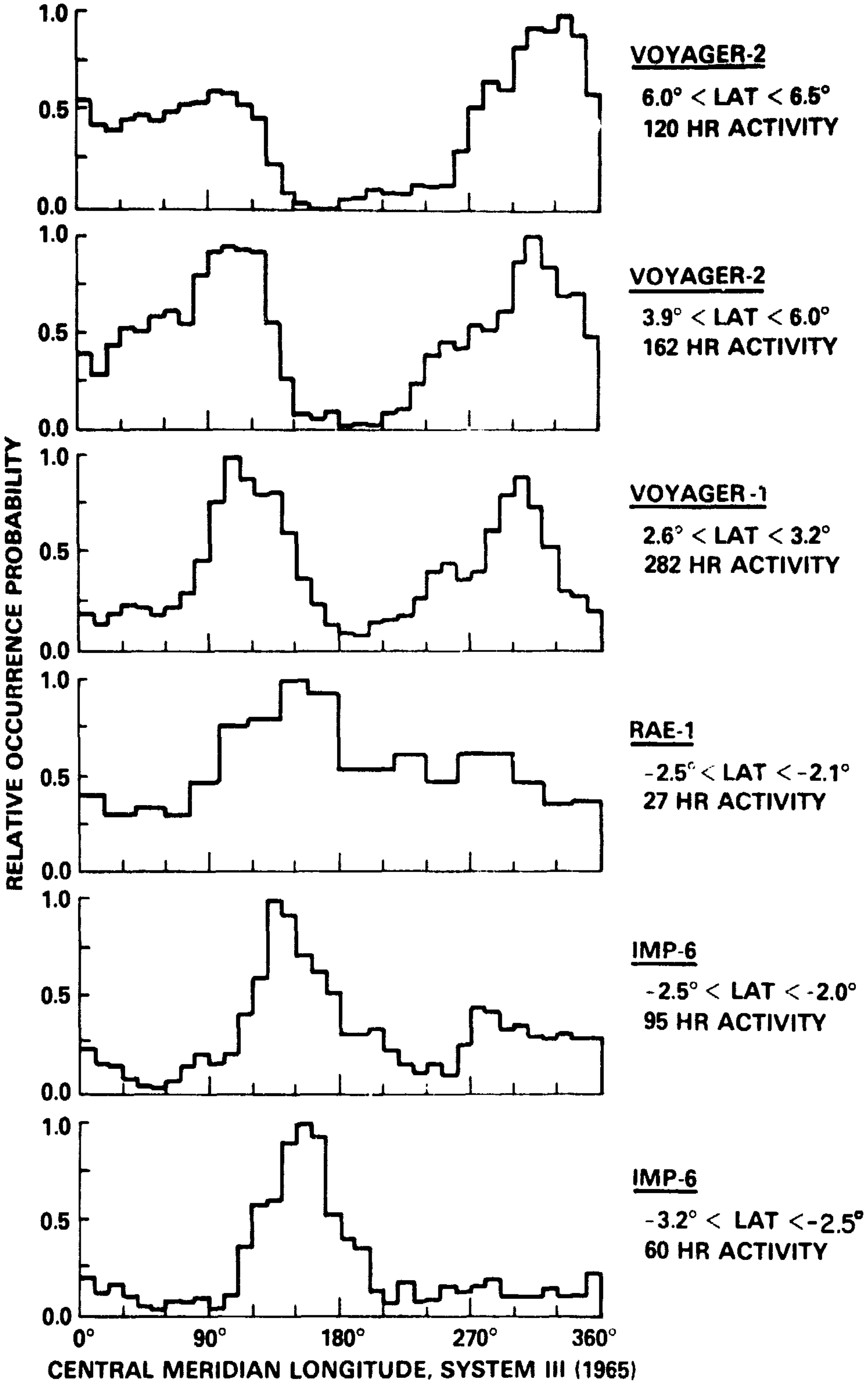
Fig. 4. Relative occurrence of Jovian hectometric emissions versus spacecraft jovimagnetic latitude for a dipole magnetic field whose North pole is tilted 9.6° towards a System III (1965) longitude of 202°. The data are subdivided in the same way as in Figure 1.

Fig. 5. Plots of the centroids (solid dots) and standard deviations (vertical bars) of the jovimagnetic lattitude distributions of HOM activity as a function of the jovigraphic latitude of each

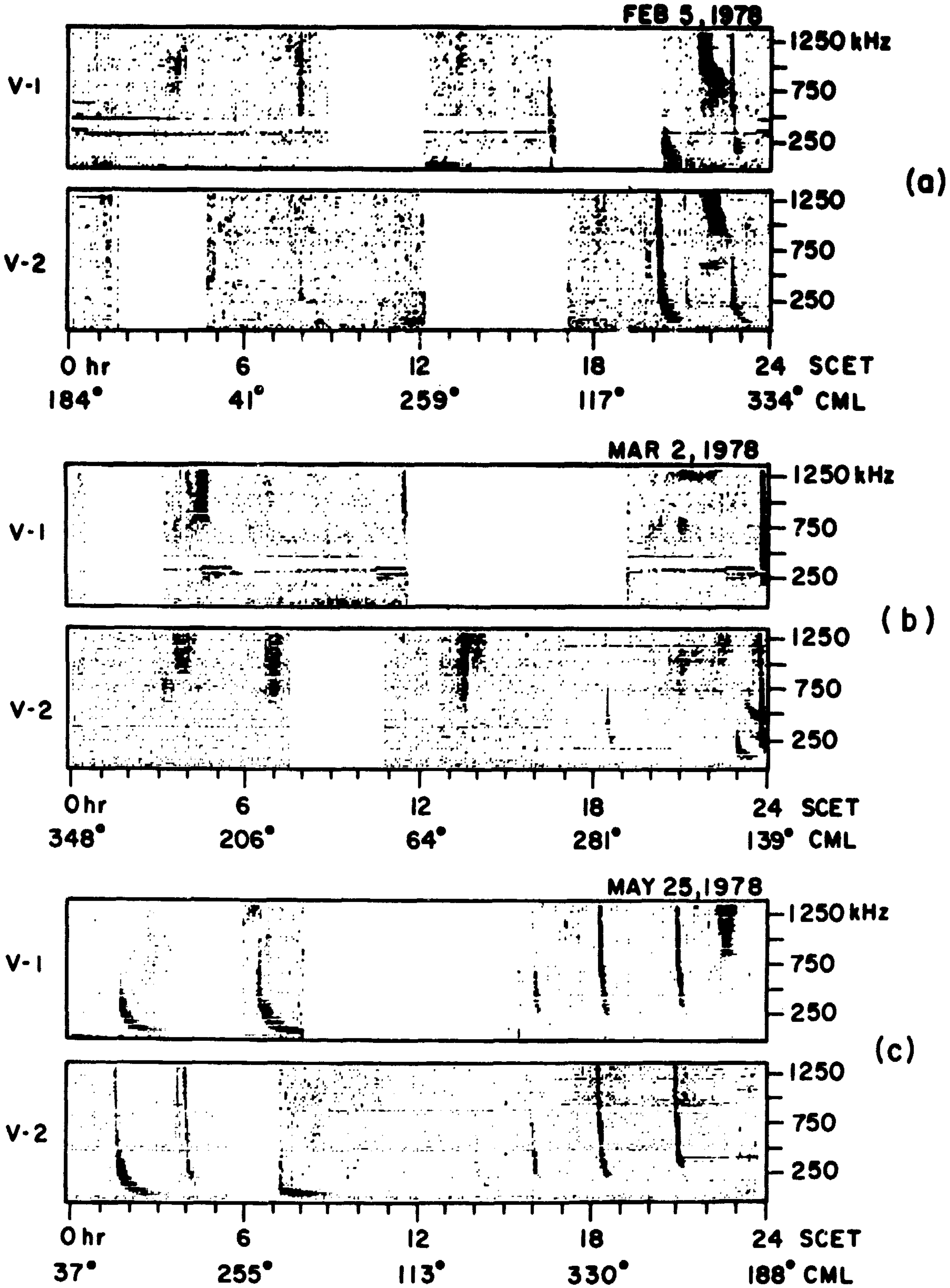
observing spacecraft. The magnetic latitudes are shown with respect to magnetic equators defined for (a) a centered, tilted dipole, (b) the Acuna and Ness (1976) O_4 model at 2 R_J, and (c) the Davis and Smith (1976) model at 2 R_J. The mean value of the magnetic latitude centroid (open circle) and its standard deviation is also indicated in each plot.

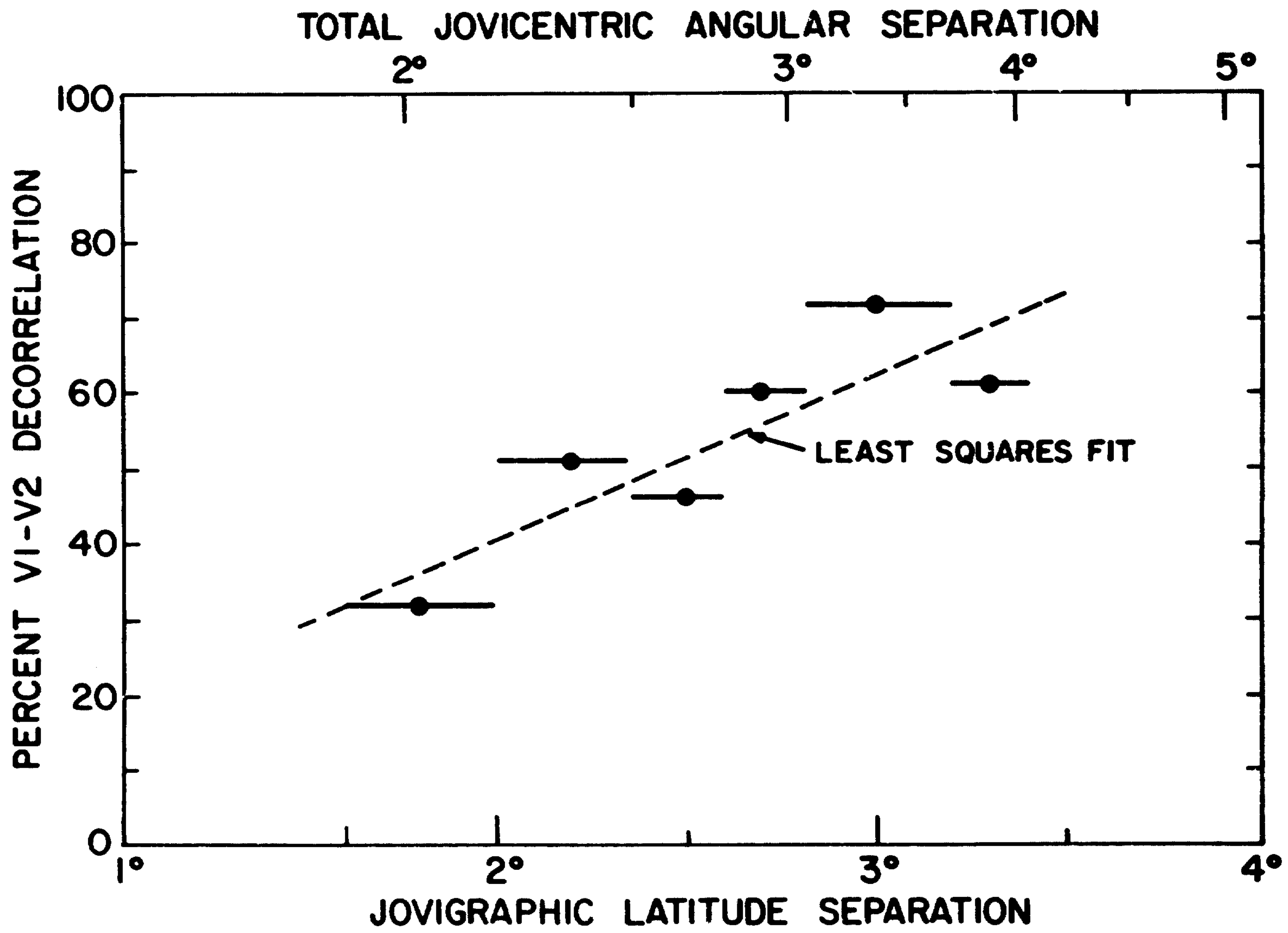
Fig. 6. (Left-hand panel) - Plots of the magnetic latitude and System III longitude of an observer for different jovigraphic latitudes. The magnetic latitude is defined with respect to the B_{min} equator at 2 R_J for the O_4 magnetic field model of Acuna and Ness (1976). The shaded band shows the angular location of a 10^o wide radiation pattern centered at a magnetic latitude of $+3^o$. (Right-hand panel) - Qualitative CML occurrence probability distributions for observers at different jovigraphic latitudes predicted for the beaming model illustrated in the left-hand panel. The solid dots denote the longitude of the center of the beam at $+3^o$ magnetic latitude. Note that these CML profiles qualitatively reproduce most of the main features of the HOM observations shown in the same format in Figure 1.

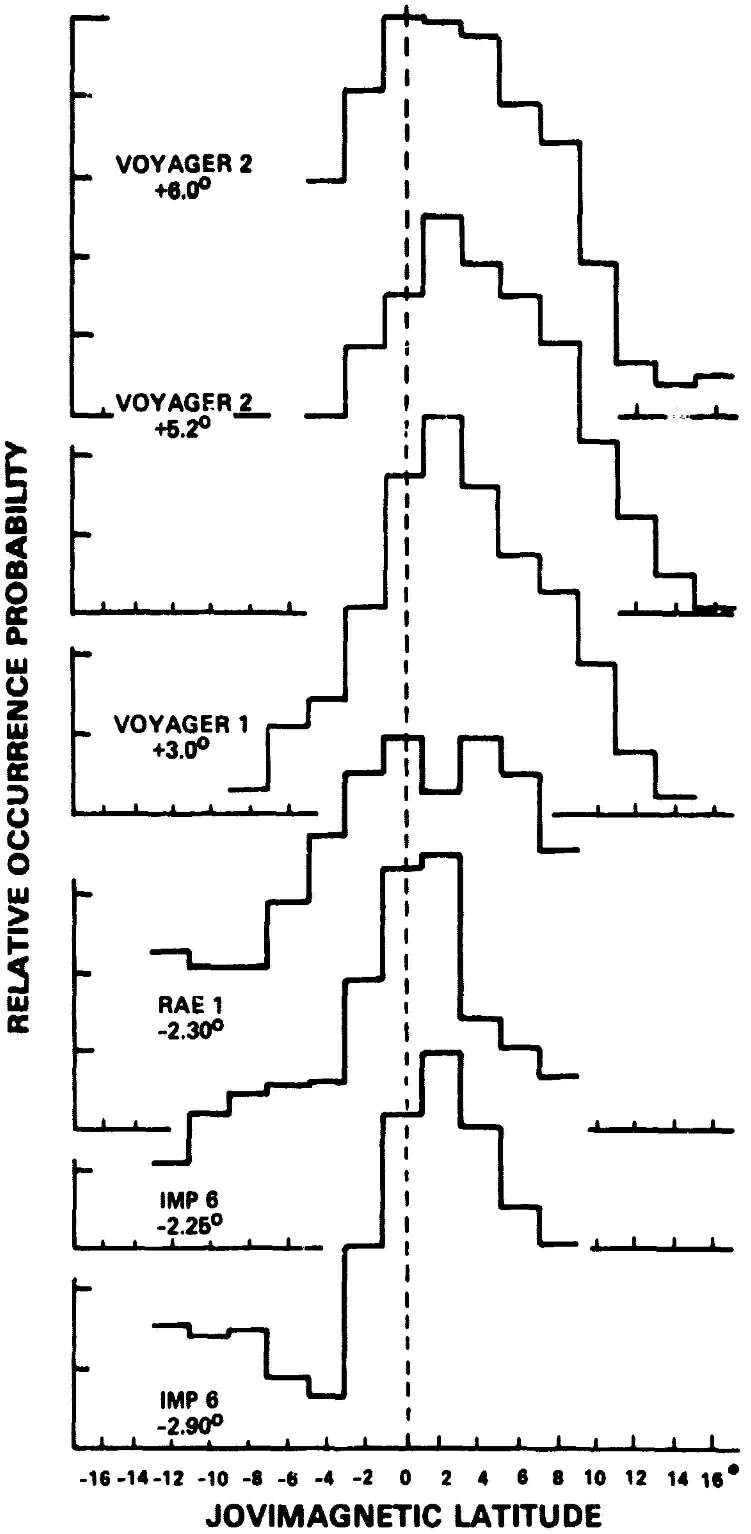
Fig. 7. Plots of the observed (histogram) and predicted (dashed line) percent V1-V2 decorrelations as a function of CML. The percent decorrelation is computed as for Figure 3. All data for which simultaneous V1-V2 measurements exist are included, with the exception of those events which were misaligned in frequency only, and those very low intensity events which were not observed by Voyager-2 for reasons related to Voyager-1's closer proximity to Jupiter. The maximum (75%) and minimum (25%) predicted percents were derived, somewhat arbitrarily, from the maximum and minimum levels observed in Figure 3.



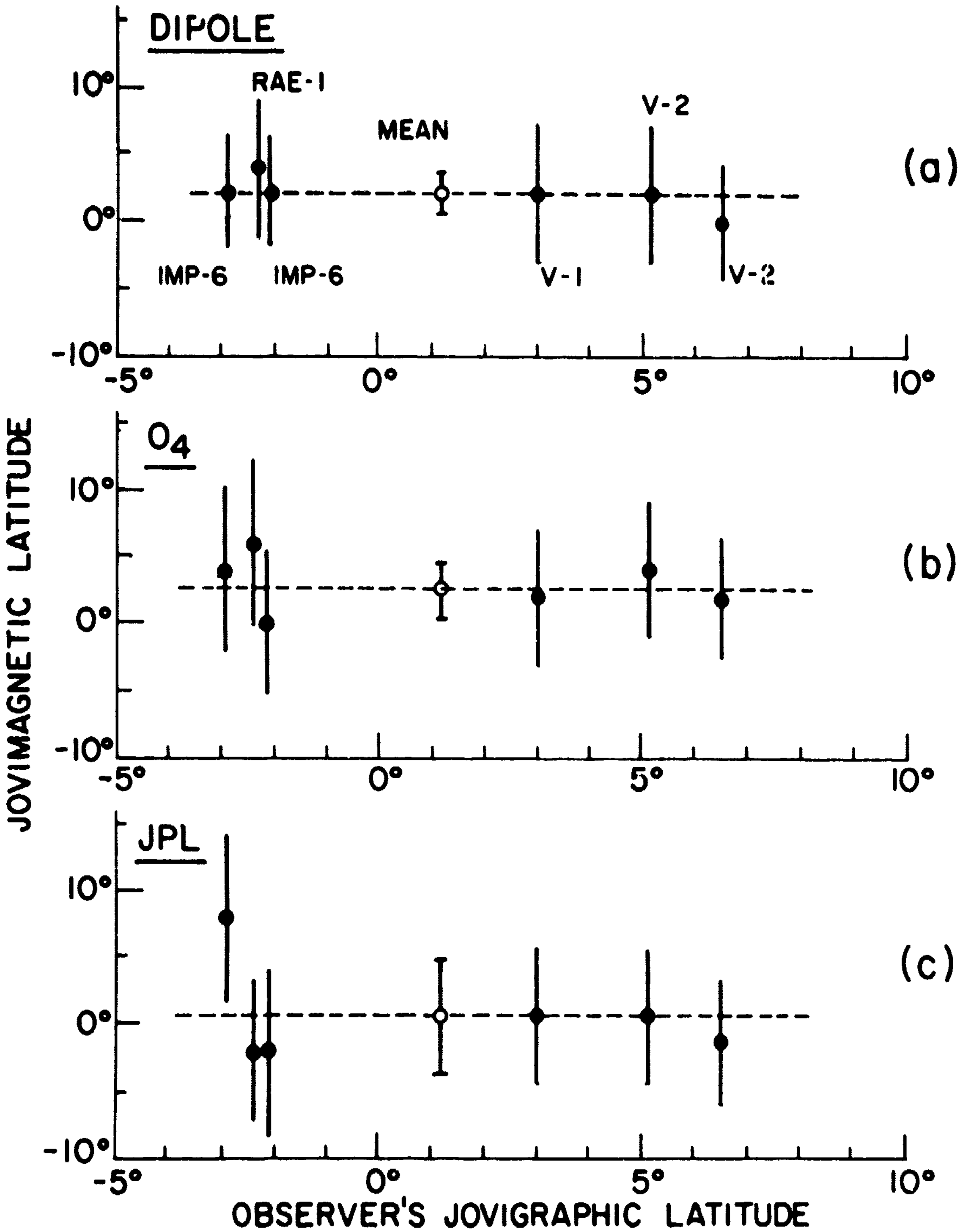
RELATIVE OCCURRENCE PROBABILITY
1.0
0.5
0.0
VOYAGER-2
6.0° < LAT < 6.5°
120 HR ACTIVITY
VOYAGER-2
3.9° < LAT < 6.0°
162 HR ACTIVITY
VOYAGER-1
2.6° < LAT < 3.2°
282 HR ACTIVITY
RAE-1
-2.5° < LAT < -2.1°
27 HR ACTIVITY
IMP-6
-2.5° < LAT < -2.0°
95 HR ACTIVITY
IMP-6
-3.2° < LAT < -2.5°
60 HR ACTIVITY
0°
90°
180°
270°
360°
CENTRAL MERIDIAN LONGITUDE, SYSTEM III (1965)


FEB 5, 1978
V-1
V-2
1250 kHz
750
250
1250
750
250
(a)
0 hr
6
12
18
24 SCET
184°
41°
259°
117°
334° CML
MAR 2, 1978
V-1
V-2
1250 kHz
750
250
1250
750
250
(b)
0 hr
6
12
18
24 SCET
348°
206°
64°
281°
139° CML
MAY 25, 1978
V-1
V-2
1250 kHz
750
250
1250
750
250
(c)
0 hr
6
12
18
24 SCET
37°
255°
113°
330°
188° CML

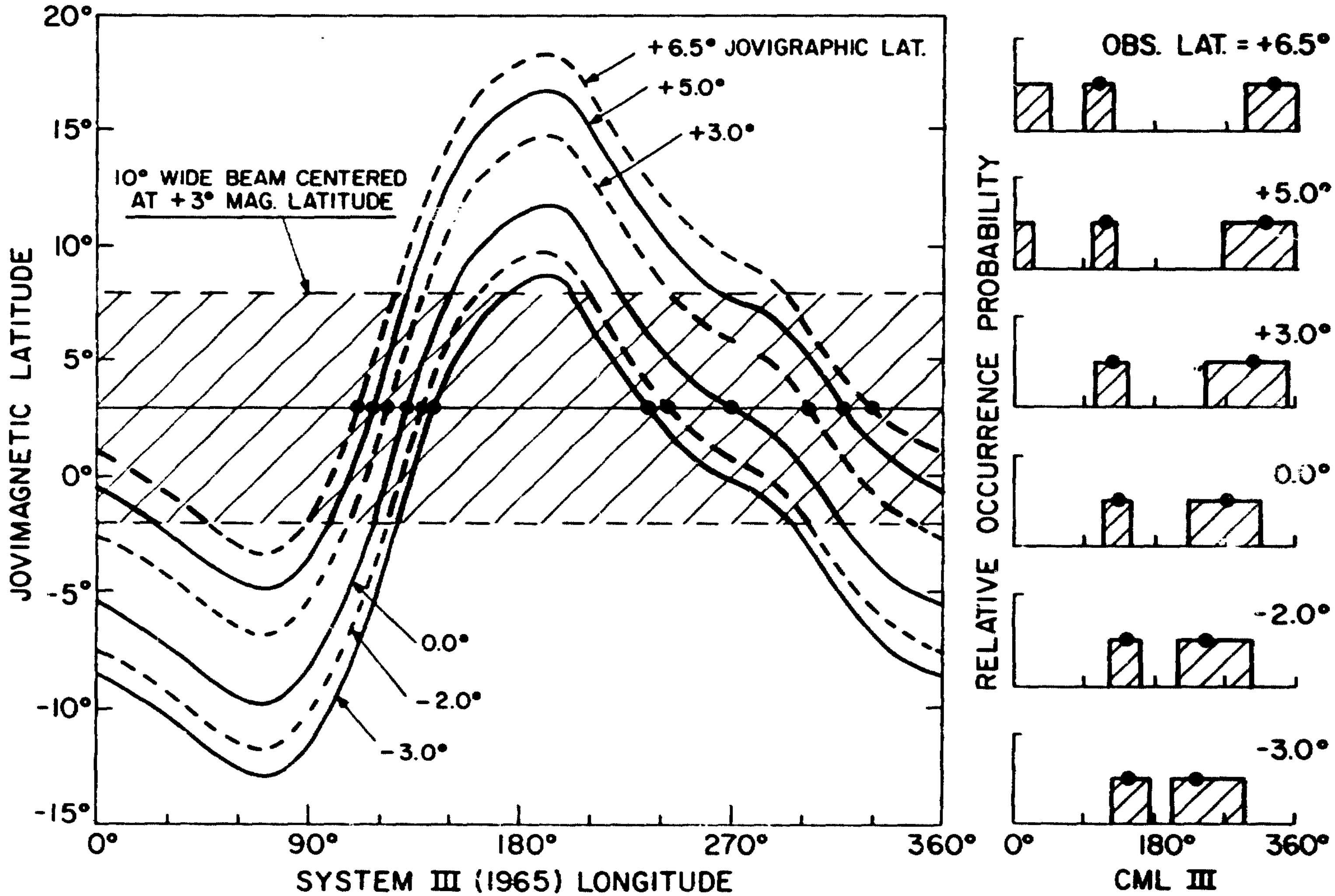

TOTAL JOVICENTRIC ANGULAR SEPARATION
2°
3°
4°
5°
100
80
60
40
20
0
PERCENT V1-V2 DECORRELATION
LEAST SQUARES FIT
1°
2°
3°
4°
JOVIGRAPHIC LATITUDE SEPARATION



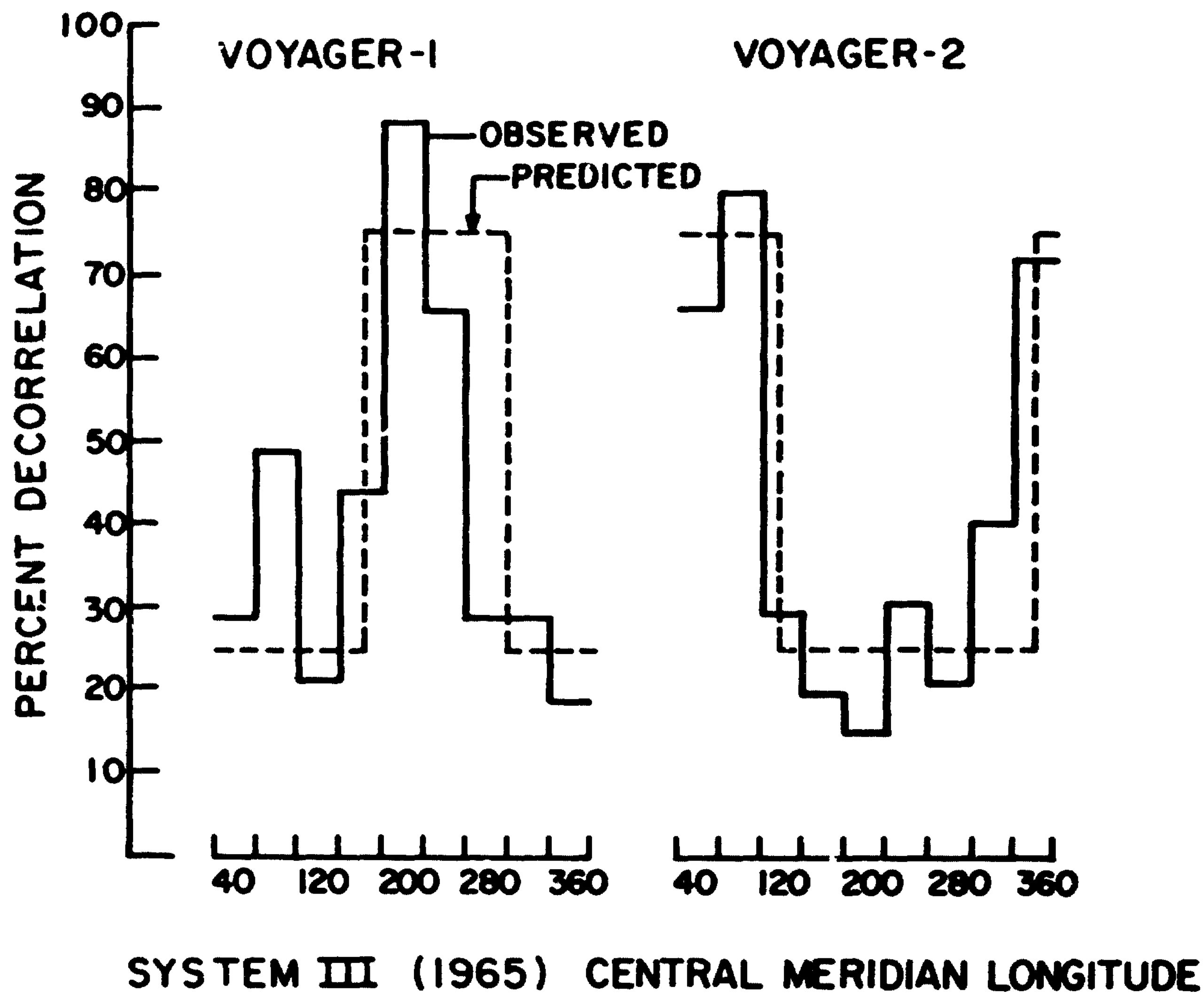
RELATIVE OCCURRENCE PROBABILITY
VOYAGER 2
+6.0°
VOYAGER 2
+5.2°
VOYAGER 1
+3.0°
RAE 1
-2.30°
IMP 6
-2.25°
IMP 6
-2.90°
-16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16°
JOVIMAGNETIC LATITUDE



DIPOLE
RAE-1
MEAN
V-2
(a)
IMP-6
IMP-6
V-1
V-2
10°
0°
-10°
-5°
0°
5°
10°
O4
(b)
JPL
(c)
JOVIMAGNETIC LATITUDE
OBSERVER'S JOVIGRAPHIC LATITUDE



+6.5° JOVIGRAPHIC LAT.
+5.0°
+3.0°
10° WIDE BEAM CENTERED AT +3° MAG. LATITUDE
0.0°
-2.0°
-3.0°
JOVIMAGNETIC LATITUDE
20°
15°
10°
5°
0°
-5°
-10°
-15°
0°
90°
180°
270°
360°
SYSTEM III (1965) LONGITUDE
OBS. LAT. = +6.5°
+5.0°
+3.0°
0.0°
-2.0°
-3.0°
RELATIVE OCCURRENCE PROBABILITY
0°
180°
360°
CML III


100
90
80
70
60
50
40
30
20
10
PERCENT DECORRELATION
VOYAGER-1
VOYAGER-2
OBSERVED
PREDICTED
40
120
200
280
360
40
120
200
280
360
SYSTEM III (1965) CENTRAL MERIDIAN LONGITUDE