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VOYAGER DETECTION OF NONTHERMAL RADIO EMISSION FROM SATURN

M. L. Kaiser and M. D. Desch*
Laboratory for Extraterrestrial Physics
Planetary Magnetospheres Branch
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

and

J. W. Warwick and J. B. Pearce
Radiophysics, Inc.
1885 33rd Street, Suite 210
Boulder, Colorado 80301

* University of Maryland Research Associate

ABSTRACT

The Planetary Radio Astronomy experiment onboard the Voyager spacecraft has detected bursts of non-thermal radio noise from Saturn occurring near 200 kHz with a peak flux density comparable to higher frequency Jovian emissions. The radiation is right-hand polarized and is most likely emitted in the extraordinary magnetoionic mode from Saturn's northern hemisphere. Modulation is apparent in the data which is consistent with a planetary rotation period of 10 hr 39.9 min.

INTRODUCTION

Satellite searches for a nonthermal component to Saturn's radio emission have yielded both positive (1) and, in a somewhat more limited survey, negative results (2). These investigations were conducted from earth-orbiting and lunar-orbiting craft and achieved their greatest sensitivity in the relatively quiet frequency band near 1 MHz, that is, between the spectral peak frequencies of the powerful Jovian and terrestrial radio emitters. This band corresponds very generally to the frequency range predicted for Saturn radio emission on the basis of magnetic Bode's law arguments (e.g., 3) and, more recently, on the basis of in situ measurement by Pioneer 11 of Saturn's magnetic field strength (4, 5).

The present study makes use of the Planetary Radio Astronomy (PRA) instrument (6) onboard the two Voyager spacecraft in order to yield a definitive answer to the question of Saturn's radio emission. By limiting observations to the period of time beginning in Jan. 1980, when the Voyagers' distances to Saturn are less than about 3.7 AU for Voyager 2 (V2) and 2.8 AU for Voyager 1 (V1), we minimize contamination from Jupiter radio noise and gain a factor of at least 8.5 in sensitivity over the near-earth satellite surveys. This has also allowed extension of the low frequency limit of the search to well below 100 kHz. As a result we confirm the existence of Saturn as a source of nonthermal radio emission, but not in the frequency range near 1 MHz where previous earth-orbit identifications were made. Instead, we observe the radio emission to take place below about 300 kHz, i.e., in the kilometer-wavelength range. We thus refer to the emission as Saturnian kilometer-wave radiation or SKR. In this Letter we describe the first polarization and spectral measurements of SKR, propose a working figure for a magnetic field rotation rate, and offer a plausible explanation for the erroneous identification of Saturn made previously.

SELECTION CRITERIA

Aside from solar type III bursts, which are easily identifiable by virtue of their lack of polarization and by their distinctive dynamic spectral signature, Jupiter radio noise remains the principal source of confusion for the Voyagers in properly identifying Saturn bursts. However, we have succeeded in discriminating between Jupiter and Saturn on the basis of the following three selection criteria: Where simultaneous V1 and V2 coverage exists, only those events were counted for which, first, the signal level on V1 (which was closer to Saturn) exceeded that on V2 and, second, the light-time delay between detection by V1 and V2 was plausible ($\sim$10 min). The third criterion was based on experience gained from the dual spacecraft observations. Specifically, SKR became identifiable in single-spacecraft observations by virtue of its spectral character and polarization sense, which differ from the known Jupiter emission components. Jovian nKOM and bKOM emissions have spectral peaks near 100 kHz and 60 kHz, respectively (7, 8), and the Jovian hectometer-wavelength emission generally exhibits a spectral peak far above 600 kHz. With regard to the polarization sense, bKOM is always right-hand (RH) polarized as observed from the night side of Jupiter (8), but appears lefthand (LH) polarized in our records owing to its incidence onto the backside of the PRA antenna. As we shall see, this clearly distinguishes it from SKR. Approximately one third of the events have been identified on the basis of the spectral character and polarization alone. In all, 33 events totaling 24.5 hr of activity have been identified as SKR between Jan. 1, 1980 and Feb. 9, 1980. Our confidence in the correct identification of these events as SKR has grown as the occurrence frequency increases with proximity to Saturn.

RESULTS

In Figure 1 we shown one example of an event detected by both V1 and V2 which we have identified as SKR. Each two-panel display (one for V1 and one for V2) shows frequency-time spectrograms spanning the same 24-hr period and covering the frequency band from 1 to 1320 kHz. Using a black and white code, the top panel of each pair illustrates the polarization sense of the radiation with the convention that black (white) corresponds to LH (RH) polarized emission. The bottom panel of each shows wave total power in terms of a gray scale with black corresponding to maximum intensity. The Saturn event, which takes place at 1300 SCET, is indicated on the spectrograms.
Hectometer-wavelength Jovian emission was still detectable at this time and it

dominates the spectra. A second, weaker SKR event, identified on the basis of its polarization and spectral character alone, is apparent on the V1 spectrum at 2100 SCET.

As is apparent from the figure, the SKR event persists for about 0.5 hr, is sporadic at the 3 min level (our effective resolution limit during this period) and is clearly RH polarized. The event is stronger and occurs slightly earlier on V1, as expected. Although not apparent in the plots shown here, examination of the individual RH and LH circular power levels indicates that SKR is strongly RH polarized, with degree of polarization levels in excess of 60% to 70% on average. All of the events recorded thus far have been RH polarized.

Referring to Figure 2, we show a flux density spectrum of the event in Figure 1 made at 1302 SCET (V1). Note that the spectral peak is near 200 kHz and that the spectrum falls off to radiometer detection threshold at 59 kHz and 350 kHz. This spectral behavior is fairly typical of the events seen thus far; however, we have also seen SKR extend as high as 500 kHz. Terrestrial kilometric radiation (TKR) exhibits similar spectral characteristics (9) suggesting, because earth and Saturn possess surface polar magnetic fields of comparable magnitude, that one might expect similarities between the two planets with regard to the physical situations giving rise to the radiation.

The total range of frequencies ($\sim$ 60 kHz to $\sim$ 500 kHz) over which we have observed SKR is entirely within the range to be expected, based on the Pioneer 11 measurements, if emission is at or near the local electron gyrofrequency. For example, restricting attention to Saturn's equatorial region which has a surface field strength of 0.20 gauss (4, 5), the implied source region would extend from 1.04 R_S to 2.10 R_S. This is comfortably above the planet's surface but within what might be regarded as Saturn's inner magnetosphere.

The peak flux density of the event shown in Figure 2, approximately 10^{-19} W m^{-2} Hz^{-1}, is probably typical of the events we have observed. We have normalized the flux to the standard earth-Jupiter opposition distance of 4.04 AU in order to facilitate comparisons between the two planets and to show that SKR is as intense at 250 kHz as Jupiter is near its 8-MHz spectral peak (10).

Our results show that SKR is on the order of 200 times more intense than the average TKR burst and perhaps 5 times more intense than the peak TKR burst (9).

As mentioned previously, we have thus far observed events of only a single polarization sense -- RH. This probably indicates that all of the emission we observe is issuing from a single magnetic hemisphere on Saturn, either north or south, thus restricting the initial ray vector direction to only one of two situations: the $\mathbf{B}$-parallel or $\mathbf{B}$-antiparallel geometry. This does not necessarily imply, however, that only a single hemisphere is active in stimulating radiation. The Voyager-Saturn geometry is such that our observations have been made at a planetocentric latitude near $+9^{\circ}$, which corresponds to a constant magnetic latitude of $+9^{\circ}$ since the magnetic field has been determined by Pioneer 11 investigators to be rotationally axisymmetric or nearly so (4, 5). This could effectively exclude from our view (LH polarized) radiation beamed from the southern hemisphere. Thus, our results are consistent with extraordinary mode emission beamed from the northern hemisphere because such radiation would have its wave vector initially parallel to $\mathbf{B}$ (Saturn's magnetic moment points in the same sense as Jupiter's) and so would appear RH polarized.

Because of widespread interest in its intrinsic rotation rate, we have attempted to determine Saturn's magnetic rotation period as revealed through the radio occurrence statistics. Similar methods have been used to precisely define System III, the radio rotation rate of Jupiter; however, the data span available for Saturn is greatly limited. With a 40 day baseline, we are able to report a provisional rotation period for use in preliminary analyses only. Our result is based on two methods of analysis. First, we stacked all the events in bins covering 360° of rotation, using different rotation periods, until the data were organized preferentially in the smallest number of bins. The best-organized data set was identified through the application of a chi-square test to each trial run. Second, we used a method of spectral analysis which is applicable to unequally-spaced samples (11). Within the uncertainty of the two methods, both have yielded the same result (see Figure 3). We derive a period of $10^{h}39.9^{m} \pm 0.3^{m}$, where the uncertainty is based on a linear least-squares goodness of fit analysis of the data. This period is within the spread of the measured optical periods for Saturn (12), which range from about 10 hr 02 min at the equator to about 11 h 03 min at 57° latitude. By dividing the analysis interval in half and subjecting each half to the above spectral analysis, we can evaluate the secular change in the rotation period. We find that the period is stable to within $\pm$ 43 sec over the analysis interval, or $\pm$ 1 sec per rotation at the 5% confidence limit.

Although it is difficult to judge definitively because of the limited volume of data at hand, it appears that the Saturn events are not organized in rotation phase as tightly as are the Jupiter radio events which we have been observing for many years. This was predicted by Acuna and Ness (4) on the basis of the Pioneer 11 in situ field measurements which indicate a rotationally axisymmetric magnetic field for Saturn. It is thus unlike both Jupiter and the earth, which have magnetic dipoles tipped at relatively large angles to their rotation axes. Therefore, any modulation which appears in the SKR is likely due to near-surface anomalies in the field which are undetectable from the Pioneer 11 observations.

Finally, in spite of the fact that the $\sim$ 1 MHz Saturn radio events reported by Brown (1) would be more than 20 dB above our present detection threshold, we have failed to record any Saturn emission in the vicinity of 1 MHz. Reexamination of the IMP-6 data used by Brown shows that for much of the period covered by his Figures 1 and 2, TKR was clearly evident below 600 kHz. Additionally, the dynamic spectra for this period are strongly reminiscent of Jovian hectometer-wave emission which was observed often by IMP-6. In a recent study, Fainberg (13) has shown that when two or more radio sources are emitting simultaneously, the IMP-6 direction-finding analysis "points" to the intensity-weighted mean angle between the sources. Thus, we believe that Brown may have observed a signal coincident with the Saturn direction which was formed by a combination of signals from Jupiter and the earth (or perhaps, the sun).

SUMMARY

Using the PRA instruments onboard the Voyager spacecraft we have presented the first conclusive evidence for nonthermal radio emission from Saturn. Based on an initial survey of 33 events totaling 24.5 hr of activity over a 40 day period, we conclude that SKR is strongly RH polarized, has a spectral peak in the vicinity of 200 kHz, and is approximately as intense as Jovian emission is at higher frequencies. We propose a working rotation period of $10^h\ 39.9^m$, which we claim is accurate to ± 0.05% or ± 0.3 min. No secular change greater than ±1 sec per rotation is evident. Radiation in the extraordinary magnetoionic mode is indicated. The ability to determine a rotation period at all implies a deviation from perfect axial symmetry of the planetary magnetic field presumably near the surface.

Closest approach to Saturn for V1 is Nov. 12, 1980 and V2 is Aug. 27, 1981. Thus, during the next year and a half we shall clearly be able to refine the rotation period. We also plan to search for a LH polarized component and investigate the nature of the rotation modulation of SKR.

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FIGURE CAPTIONS

FIGURE 1. Simultaneous 24 hr dynamic spectra from V1 and V2. The bottom panel of each set indicates total power with increasing darkness proportional to increasing intensity. The top panel of each set shows the sense of polarization with white representing right hand and black representing left hand. The indicated Saturn event occurs earlier and is more intense as seen by V1.

FIGURE 2. A normalized flux density spectrum from V1 at 1302 SCET of Fig. 1. The two peaked structure does not appear to be a permanent feature, but rather results in this instance from rapid intensity fluctuations. At the normalized distance of 4.04 AU, Saturn appears as powerful as Jupiter.

FIGURE 3. The spectral power (relative to the standard deviation) between 10 and 11 hours as determined from the method introduced by Deeming (1975). The major peak is surrounded by sidelobes which are caused by heterodyning with a 7.0 day sampling periodicity.

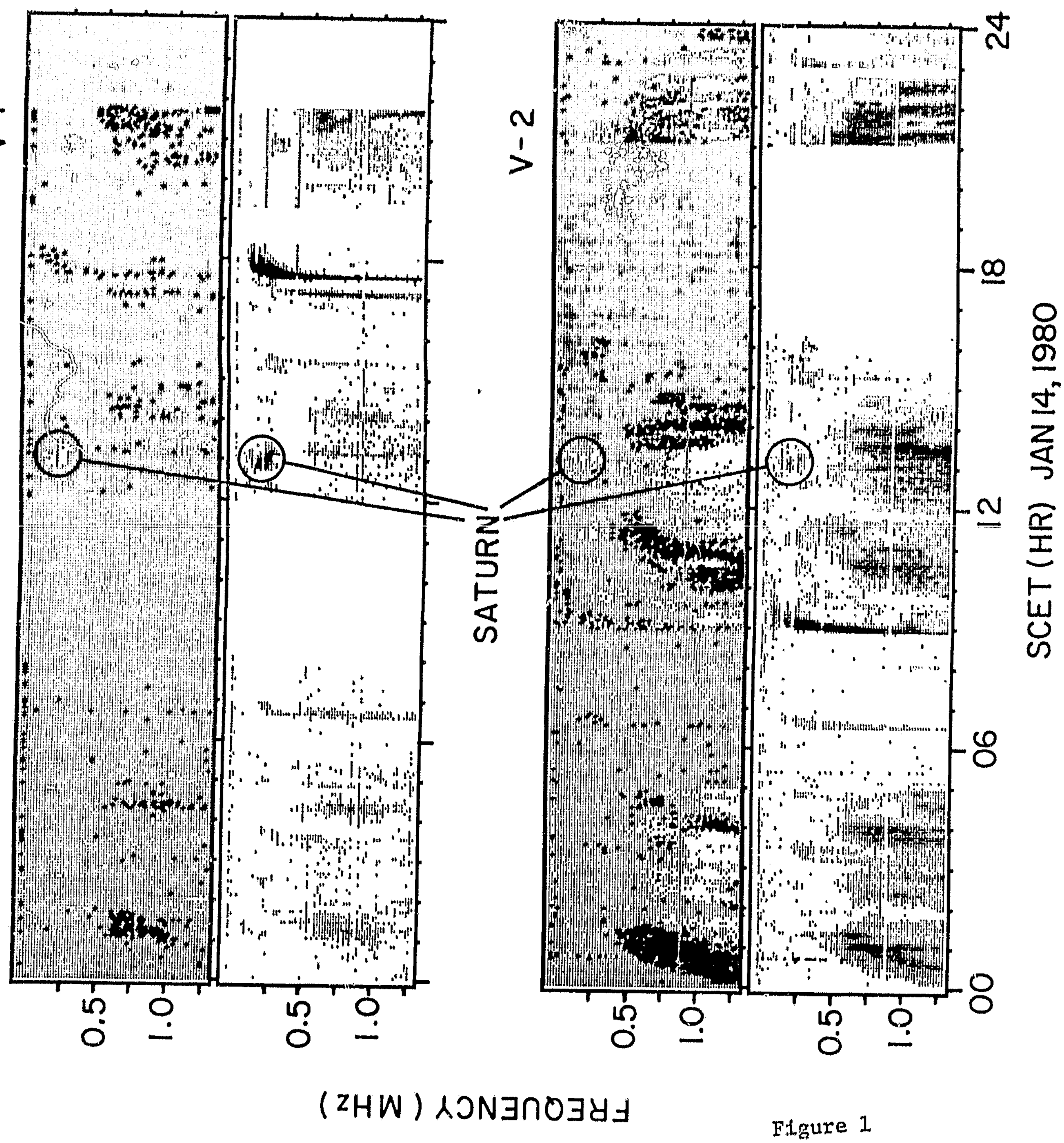
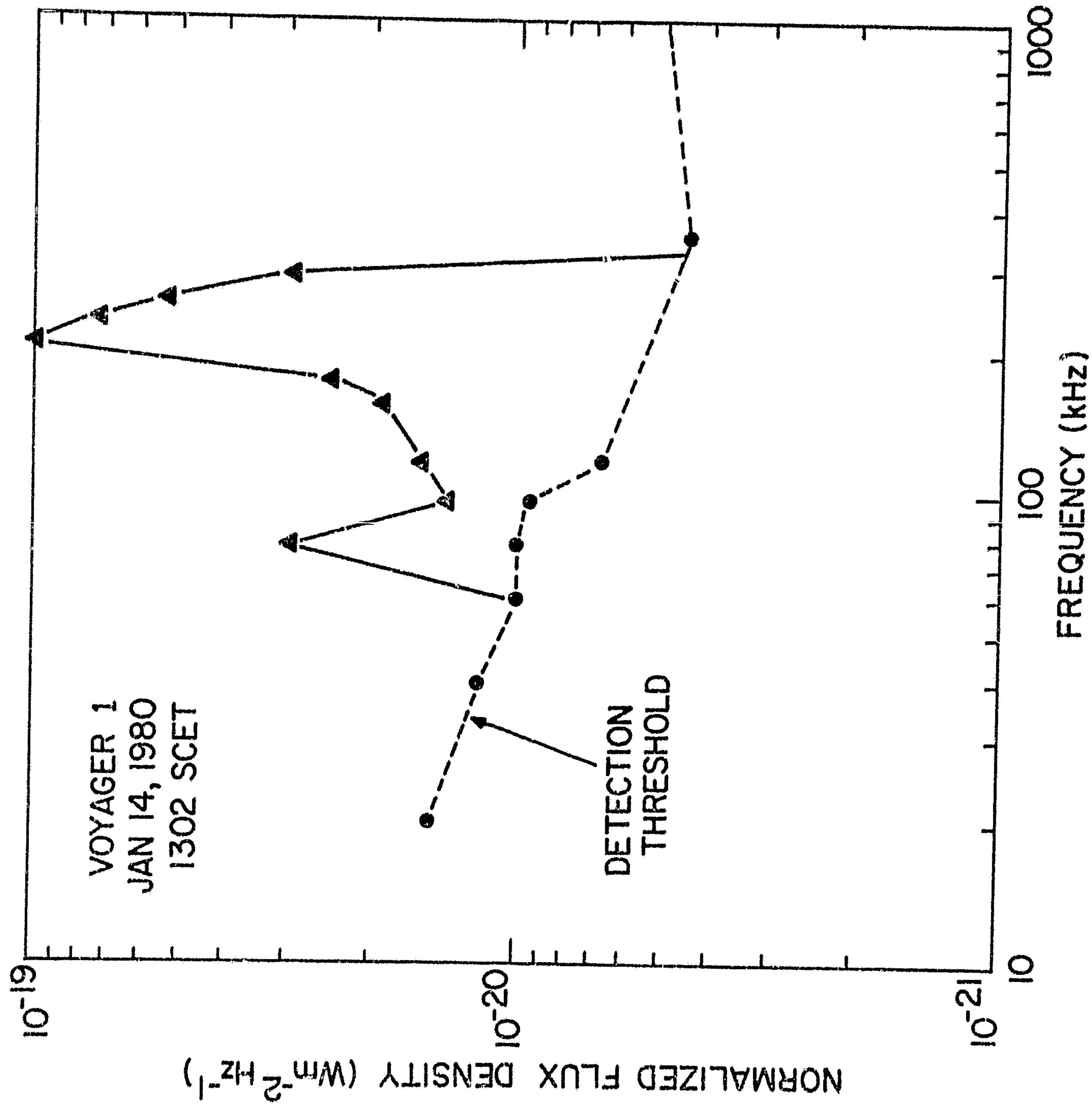

V-1
V-2
SATURN
SCET (HR) JAN 14, 1980
00
06
12
18
24
0.5
1.0
FREQUENCY (MHz)

Figure 1



VOYAGER 1
JAN 14, 1980
1302 SCET
DETECTION THRESHOLD
FREQUENCY (kHz)
10
100
1000
NORMALIZED FLUX DENSITY ($Wm^{-2} Hz^{-1}$)
10^{-19}
10^{-20}
10^{-21}

Figure 2

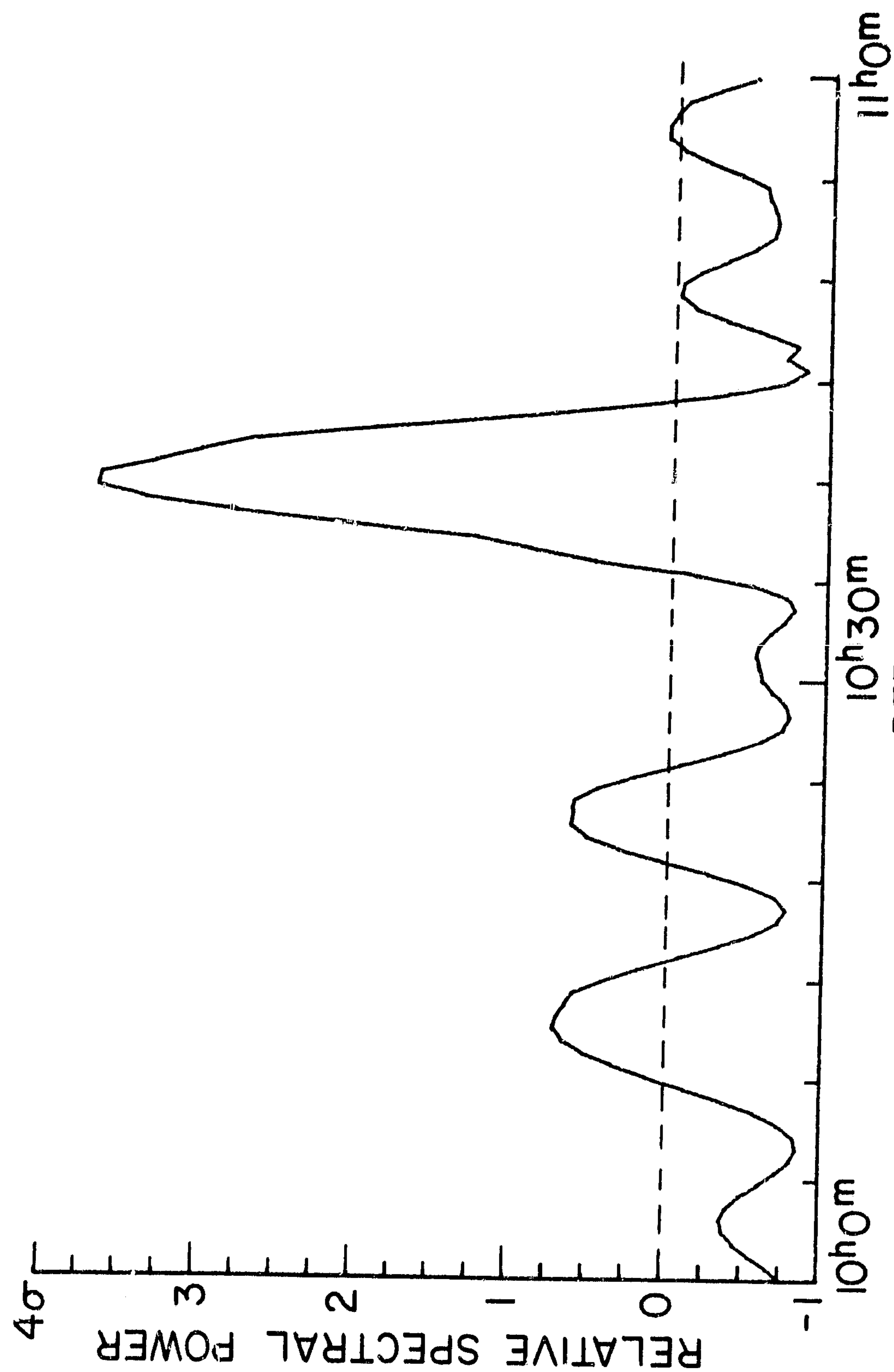

RELATIVE SPECTRAL POWER
4σ
3
2
1
0
-1
PERIOD
10h0m
10h30m
11h0m

Figure 3