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PERIODICITY IN THE RADIOFREQUENCY SPECTRUM OF THE PULSAR CP 0328

P. A. STURROCK,*† S. ANTIOCHOS,*† P. SWITZER,‡ AND J. VALLÉE*
Stanford University, Stanford, California
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ABSTRACT

Long-term averaging of a sequence of wide-band radiofrequency spectra of CP 0328 reveals a periodicity not apparent in the original spectra. This may be caused by a mechanism intrinsic to the source, or by a propagation mechanism distinct from ordinary scintillation.

The precise mechanism by which pulsars produce radio emission is not yet understood and agreed upon. It is agreed that the particle streams responsible for radiation must be bunched, and there is growing unanimity of opinion that radiation occurs near the polar caps due to bunches of electrons (or other particles) moving along curved magnetic field lines (Radhakrishnan 1969; Radhakrishnan and Cooke 1969; Komesaroff 1970; Sturrock 1970, 1971; Tademaru 1971). It therefore appears that, to improve our understanding of pulsar-radiation mechanisms, one of the most important items of information to be obtained is the spectrum of the charged-particle flux which is responsible for radio emission.

It has been suggested (Sturrock, Bracewell, and Switzer 1970) that this spectrum might be obtained by analysis of the optical radiation from the Crab pulsar. Alternatively, if the spectrum has one or more sufficiently sharp peaks of sufficiently high frequency, the structure may show up in the radiofrequency spectrum itself. If, for instance, radiation is due to charge sheets which are emitted with a well defined frequency ν_E (Hz) [or period τ_E (sec)], then the radiofrequency spectrum would be composed of a sequence of delta-functions at multiples of ν_E. Various effects would tend to smooth this structure, but a residual periodicity might exist and seems worth looking for. Calculations published recently (Sturrock 1970, 1971) indicate that ν_E should be of order 1 MHz.

In observations reported by Ewing *et al.* (1970), CP 1919 appears to have a drifting sinusoidal structure in its radiofrequency spectrum. The "period" (in kHz) of this structure is comparable with the typical feature width, which the authors attribute to scintillation. Ewing *et al.* attribute the drifting periodicity to effects of multipath propagation.

Rickett (1970) has published a sequence of 75 spectra of CP 0328, measured at intervals of 50 s and covering a total interval of more than 1 hour. Each spectrum was centered at 408 MHz and covered a bandwidth of 2.5 MHz with a frequency resolution of about 60 kHz. Dr. Rickett has kindly provided us with these data in digital form and the bandpass response of the receiver. Rickett formed from these data an autocorrelation function, in both frequency and time, which shows that the correlation drops to zero for a time separation of about 7 minutes or for a frequency separation of about 250 kHz. (Ewing *et al.* estimate the spectral feature width of CP 0328 to be 111 ± 50 kHz at 405 MHz.) It therefore appears that, as far as scintillation is concerned, we may consider spectra separated by 7 minutes or more to be substantially independent data,

* Institute for Plasma Research.
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and we have formed from Rickett's spectra a sequence of nine average spectra, at 7-minute intervals, as shown in Figure 1. No single spectrum of this series exhibits an obvious periodicity.

In order to test for the possibility that a small periodic component is being masked by scintillation effects, we have proceeded as follows. First, we have corrected for the bandpass response $B(\nu)$ by forming the function $x(\nu)$ defined by

$$x(\nu) = S(\nu)/B(\nu) , \tag{1}$$

where $S(\nu)$ is a spectrum function. Using the sequence of spectra $S_i(\nu)$, $i = 1, \ldots, 9$, we have formed the mean corrected spectrum

$$\langle x(\nu)\rangle = \frac{1}{9}\sum_{i=1}^{9} x_i(\nu) , \tag{2}$$

and the standard error of the mean, defined by

$$\sigma(\nu) = \frac{1}{9}\left[\sum_{i=1}^{9} [x_i(\nu) - \langle x(\nu)\rangle]^2\right]^{1/2} . \tag{3}$$

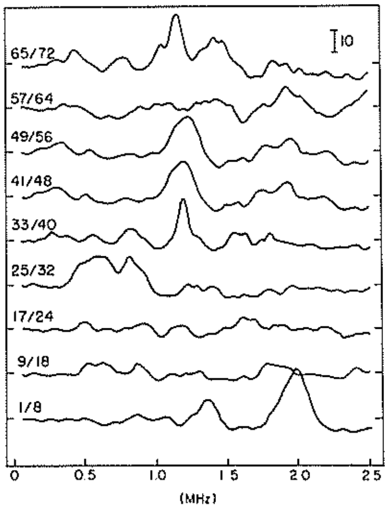
The function $\langle x(\nu)\rangle$ is shown in Figure 2, the error bars denoting $\sigma(\nu)$. It appears that the mean corrected spectrum contains a periodic component.

In order to test for periodicity, we have attempted to fit the data by a least-squares technique. The data are in fact given for discrete values ν_n, $n = 1, \ldots, 80$, where $\Delta\nu = 31.25$ kHz. We have therefore sought to fit the data by the curve

$$f_n = a + b \sin (n\theta + c) , \tag{4}$$

minimizing the function

$$V(a, b, c, \theta) = \sum_{n=1}^{80}\left[\frac{\langle x_n\rangle - f_n}{\sigma_n}\right]^2 . \tag{5}$$



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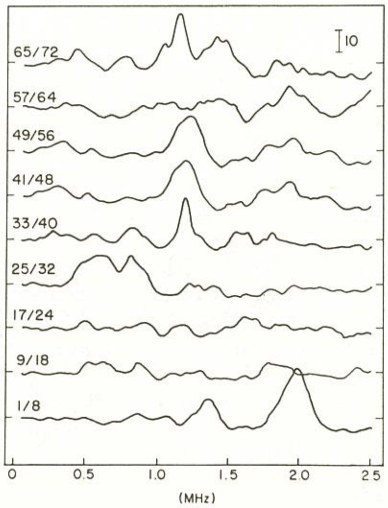

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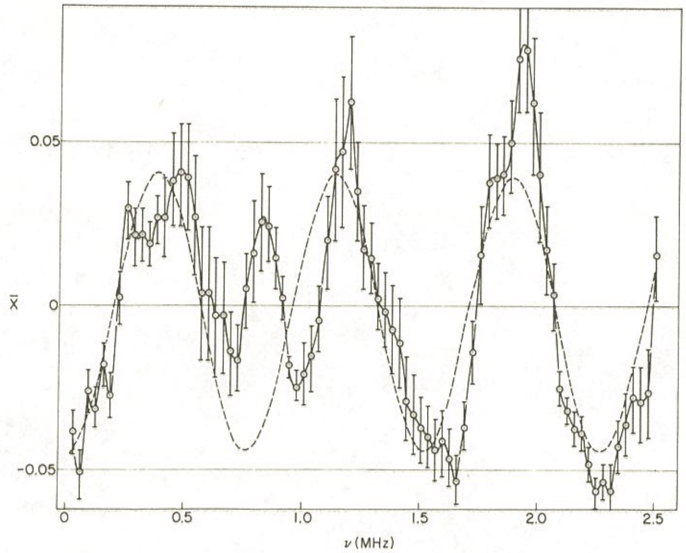

FIG. 2.—The average $\langle x \rangle$ and the standard error of the mean (shown by error bars). The broken line indicates the best-fitting sine wave obtained by least-squares analysis.

For purposes of spectrum analysis, it is convenient to display the quantity $V(\theta)$ obtained by minimizing $V(a, b, c, \theta)$ for successive values of θ. The resulting function is shown in Figure 3 in which, for convenience, the abscissa is taken to be τ defined by

$$\tau = \theta/2\pi\Delta\nu \, . \tag{6}$$

It is seen that the function $V(\tau)$ has a deep and sharp minimum at $\tau = 1.30$ μs corresponding to a frequency of 770 kHz. Less pronounced minima occur as sidebands to the principal minimum, as is typical in spectrum analysis by Fourier techniques (Blackman and Tukey 1959) or least-squares methods (Vaniček 1971).

One may determine the significance of the least-squares fit (Rao 1965) by comparing the least value of V obtained by varying all four parameters, which we write as D_4, with the least value of the right-hand side of equation (5) obtained by varying the one parameter a (setting $b = 0$), which we write as D_1. We then consider the quantity

$$F_{3,N-4} = \frac{N-4}{4-1}\frac{D_1 - D_4}{D_4} \, . \tag{7}$$

Measurements are presented for 80 different frequencies. However, we should remember that the frequency resolution is 60 kHz, whereas data are given at intervals of about 30 kHz. Hence the number of *independent* measurements is more properly taken to be 40. With this choice of N, we find that $F_{3,36} = 9.05$. Extrapolation from published tables (Abramowitz and Stegun 1965) shows that the probability of obtaining such a large F-value by chance from a featureless model ($b = 0$) is less than 0.02 percent.

It appears, from the above analysis, that long-term averaging of a wide-band spectrum of pulsar radiation can bring to light structure which is otherwise submerged by scintillation. The fact that the periodic modulation of the spectrum is derived from a sample lasting 9 times the mean lifetime of scintillation features, over a bandwidth at least 10 times the width of scintillation features, indicates that the structure which is

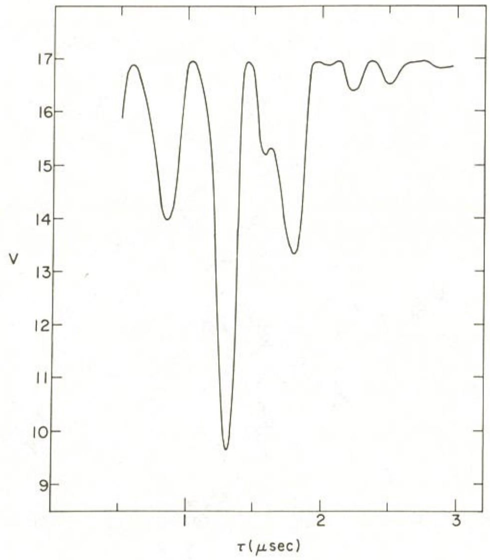

FIG. 3.—The least-squares function V minimized by varying a, b, and c, and shown, for convenience, as a function of τ rather than as a function of θ.

evident in Figure 2 is not a simple scintillation effect. In this regard, the periodic structure presented in this Letter seems different from that noted by Ewing *et al.*

The periodicity which shows up in the spectrum of CP 0328 may originate in the pulsar itself (in which case determination of the periodicity probably comprises a determination of the ejection frequency ν_E), or during propagation through the interstellar medium. It may be possible to resolve this question, and to obtain further information about either pulsars or the interstellar medium, by carrying out similar analyses of similar spectra obtained for CP 0328 and other pulsars in several different frequency bands.

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