II. RADIO ASTRONOMY*

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A. PULSAR OBSERVATIONS

High time resolution observations at 115 MHz and 150 MHz have confirmed the marching subpulse behavior of CP1919 and AP2015+28 reported by Drake and Craft,[1] and have revealed similar behavior in MP0031 and CP0808 (Fig. II-1). The marching patterns for all four pulsars slope in the same sense; i.e., subpulses occur slightly earlier within the average pulse window with each succeeding pulse. Similar, but more ambiguous, results have been obtained for CP0834.

Drake and Craft described the phenomenon by a single parameter, the Class 2 Period P_2, which is the mean separation of the marching or Class 2 pulses and is much shorter than the basic pulsar period P_1 and incommensurate with it. We define a third period, the pattern period P_3, as the time between successive appearances of Class 2 pulses in a given time window of the average pulse. Values of P_1, P_2, and P_3 are given in Table II-1.

Each of the marching patterns in Fig. II-1 can be represented by a series of sloping lines connecting the Class 2 pulses in consecutive pulses. The average separations of these lines, P_2 and P_3, are approximately unchanged from day to day and month to month, but the slopes and separations of individual lines show variations of ~±20%. In the case of MP0031, the width of the Class 2 pulses is approximately 0.2 P_2, which shows that the modulation process is not sinusoidal.

The pulsars MP0031 and CP1919 also exhibit periodicities in pulse intensity of the order of 2 min and 6 min, respectively. The slow periodic variations were first noted in MP0031, as illustrated in Fig. II-2. On this strip chart record the pulse intensities vary, with a period of ~2 min. Examination of several hours of MP0031 data suggests that the effect is often, but not always, evident, and that the period sometimes varies 20% or more over several minutes. The day-to-day variation does not appear to be

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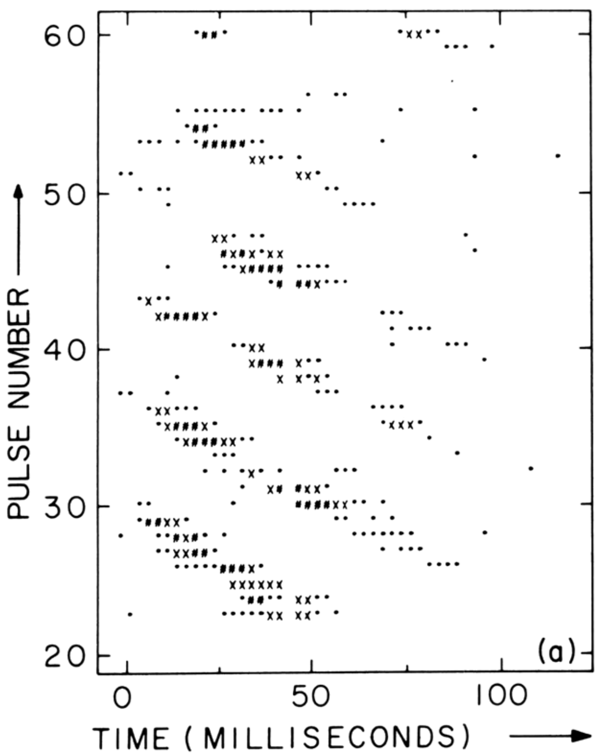

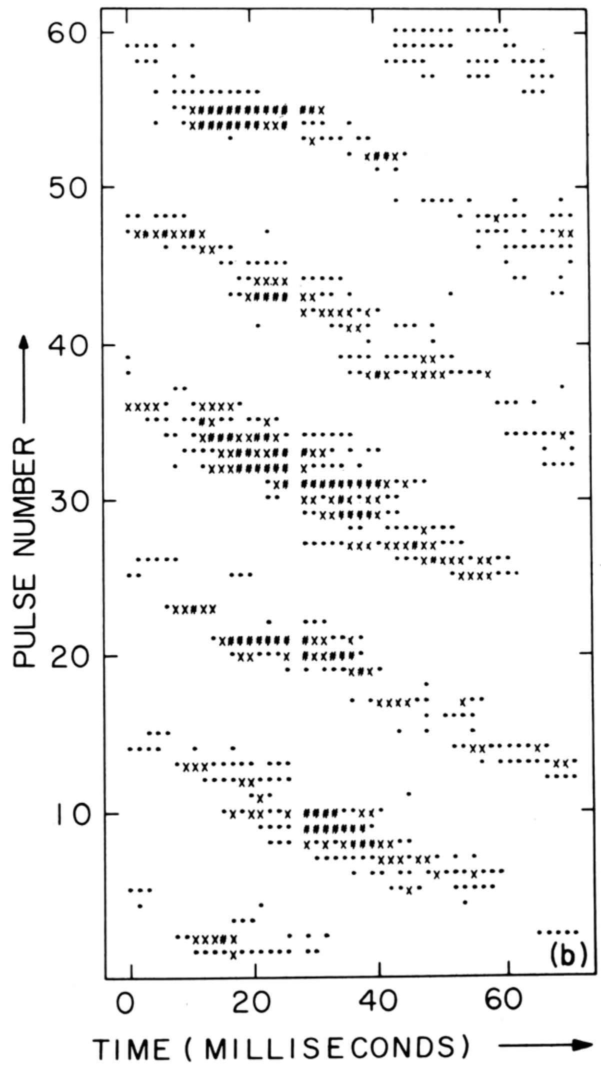

Fig. II-1. Systematic variations of pulse shape observed for (a) MP0031 and (b) CP0808 on August 13, 1969. Each horizontal line represents a time window centered approximately on the average pulse, and successive windows are separated precisely by the pulsar period. Relative intensities: 1 (.), 2 (X), 3 (#). Filter-bank resolution 100 kHz. Sweep ranges: (a) 155-151 MHz, (b) 151-143 MHz.

Table II-1. Periodicities in pulsars.

Pulsar	P_1 (s)	P_2 (ms)	P_3 (s)
0031	0.943	58	6.8
0808	1.292	53	14.4
0834	1.274	110	2.74
1919	1.337	15.5*	5.9
2015	0.558	10.7*	2.62

*F. D. Drake and H. D. Craft, Jr., Nature 220, 231 (1968).

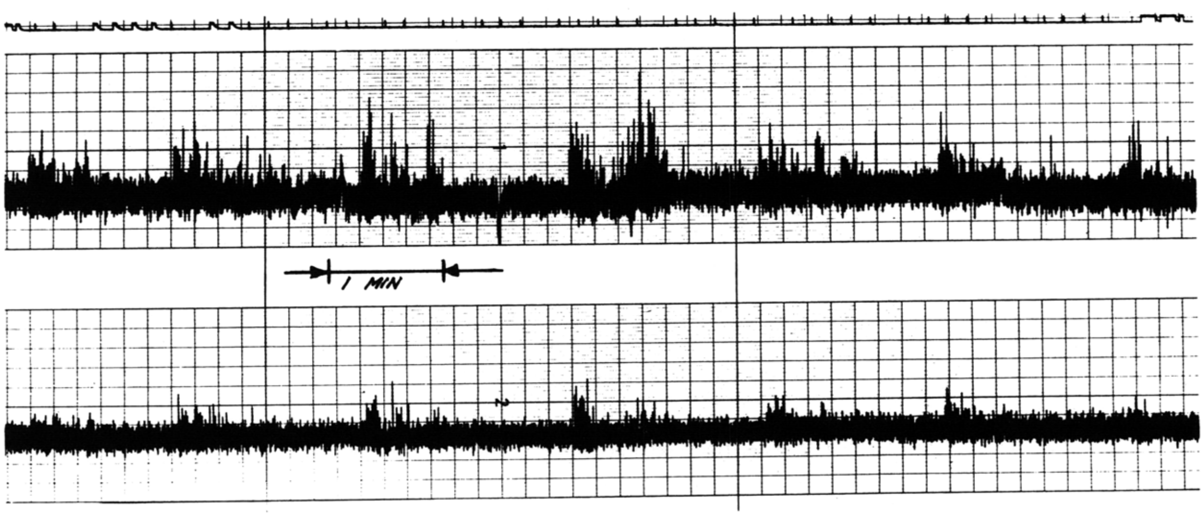

Fig. II-2. Strip chart record of pulses from MP0031 recorded at 158.5 MHz (upper) and 112.5 MHz (lower).

much greater. A suggestion of the short-term variation is evident in Fig. II-2.

The 2-min periodicity is also evident in pulse-intensity spectra. Four pulse-intensity spectra of MP0031, observed at different times and at different frequencies, are shown in Fig. II-3. The spectra were computed by first extracting the strengths

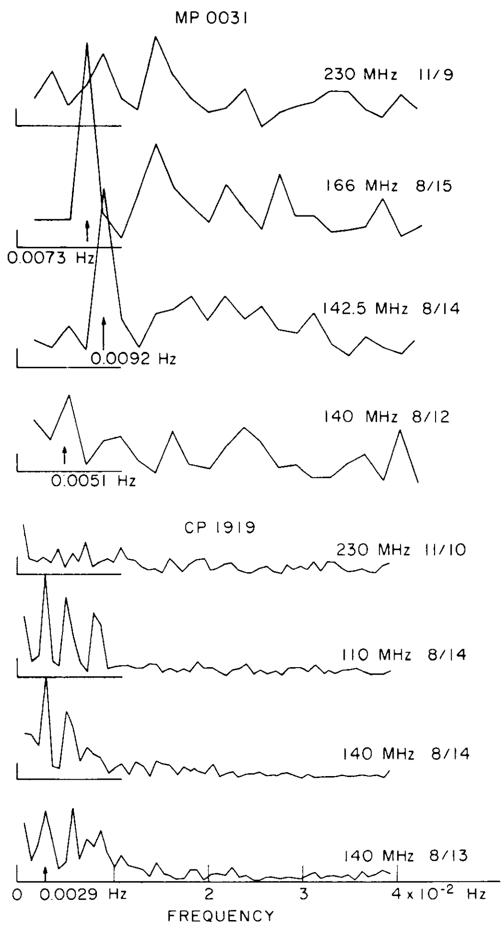

Fig. II-3.

Pulse intensity spectra for MP0031 (upper four spectra), and CP1919 (lower four spectra). Spectra illustrate the periodic behavior of pulse bursts. Spectra were computed using 512 and 1024 pulses for MP0031 and CP1919, respectively. The dates indicate when the data were recorded in 1969.

of 512 consecutive pulses from 30-ms sampled data observed with a 50-channel radiometer. The strengths of each of the 512 pulses were integrated over bandwidths of either 1.5 MHz or 5.0 MHz, after the effects of dispersion were removed by a computer. These 512 numbers were then Fourier-transformed to yield the illustrated spectra. The spectra at 140, 142.5, and 166 MHz peak at frequencies corresponding to periods of 196, 108, and 137 s, respectively. These variations in period appear to be a function of time rather than of observing frequency, and are compatible with those inferred from the strip chart records. At 230 MHz the effect is generally less evident.

Another important feature of this new periodicity is also evident in Fig. II-1, particularly in the upper trace, recorded at 158.8 MHz. That is, the pulse-intensity pattern which repeats at ~2-min intervals is neither sinusoidal nor impulsive; rather, it appears to be composed of more than one burst event, each event repeating at ~2-min intervals and each appearing or fading independently. The upper trace appears to be dominated by two events, each of which survives ~15 min. Detection of the periodicity is sometimes more difficult because the entire 2-min period is active, or at other times because the period may vary more than 20% over many minutes.

A second pulsar exhibiting these properties is CP1919 for which 1024-pulse power density spectra are shown in Fig. II-3. The spectra peak at ~0.0029 Hz, which corresponds to a period of ~345 s. In each case, two or three harmonics are also evident. The harmonics apparently arise from the short duration of the individual burst events. CP1919 is more stable than MP0031, but is similar, in that the effect is less evident at 230 MHz. Pulse strengths vary in a fashion similar to that for MP0031, so that one or two excited regions are typically present, each region surviving approximately 20-30 min. These excited regions may develop or fade either abruptly or slowly, and occasionally only an isolated burst is seen which does not repeat in the following cycle.

The repetitive appearance of pulse-intensity patterns with more than one excited region supports the suggestion that some sort of waves are circulating about the pulsar and modulating the pulse intensity. Although such waves could conceivably reside on the surface of the star, it is more likely that they are waves in the circumpulsar plasma, and although they could circulate along a complex spatial trajectory, it seems more likely that they would travel in an approximately circular orbit. Each burst of pulses then corresponds to a region of this circulating plasma ring which favors pulse emission. These enhancement regions survive approximately 10-20 min and may come or go abruptly. By monitoring the waxing and waning of such regions it may be possible to learn something about the meteorology of the plasma envelope surrounding the star, under the assumption that this plasma circulation model is correct.

One very interesting aspect of the long-period phenomenon is that it may be related to the second periodicity discovered by Drake and Craft.[1]

One possible interpretation of the second-periodicity phenomenon is that those waves circulating about the pulsar producing the long-period variations also have short-period waves associated with them producing the short-term variations. If the long-period and short-period waves circulate about the star at the same angular velocities, then the long period, designated P_4, must be related to the other periods as

$$P_4 = \frac{P_1 P_3}{P_2}.$$

This "period equation" predicts values of the circulation period of P_4 of 111 s and 509 s for MP0031 and CP1919, respectively, based on nonsimultaneous measurements of P_2 and P_3 (Sutton et al.[2]). The predicted P_4 of 111 s for MP0031 is 32% less than the mean of the representative periods evident in Fig. II-2, that is, 196, 108, and 137 s, and the predicted P_4 of 509 s for CP1919 is 47% greater than the observed 345 s. A small amount of data is available which permits P_2, P_3, and P_4 to be measured simultaneously. On one occasion the predicted P_4 for MP0031 was 154 s, 36% more than the observed value.

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References

1. F. D. Drake and H. D. Craft, Jr., Nature 220, 231 (1968).
2. J. M. Sutton, D. H. Staelin, R. M. Price, and R. Weimer, Astrophys. J. 159, L89 (1970).