DUAL-FREQUENCY OBSERVATIONS OF PULSAR MICROSTRUCTURE FROM PSR 1133+16

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Abstract

We have made pulsar microstructure observations of PSR 1133+16 at the Arecibo Observatory. Cross-correlation of linearly polarized microstructure between 111 MHz and 318 MHz results in a value of the dispersion measure of $DM = 4.8462 \pm 0.0004\,\mathrm{pc\,cm^{-3}}$ at epoch 1989.9. This value is consistent with the average profile determination of Phillips and Wolszczan (1990) obtained at epoch 1989.2, but not with the microstructure value found by Popov *et al.* (1987) in early 1980. Time variation of the integrated electron content over this ten-year span is a plausible explanation for the discrepancy.

Observations

We made observations of PSR 1133+16 on 17 December 1989. We obtained simultaneous data in four frequency bands (a single linear polarization): 111.5 MHz, 112.0 MHz, 313.31 MHz, and 318.31 MHz. Faraday rotation between 111.5 MHz and 112.5 MHz is only about 10° (ISM and ionosphere), and similar between 313 and 318 MHz, but the total rotation between the 111-MHz and 318-MHz band is large (~4 turns) and undetermined. A strong single pulse, with a micropulse spike, is shown in figure 1 (no signal was seen at 112.0 MHz, and these data were not used subsequently).

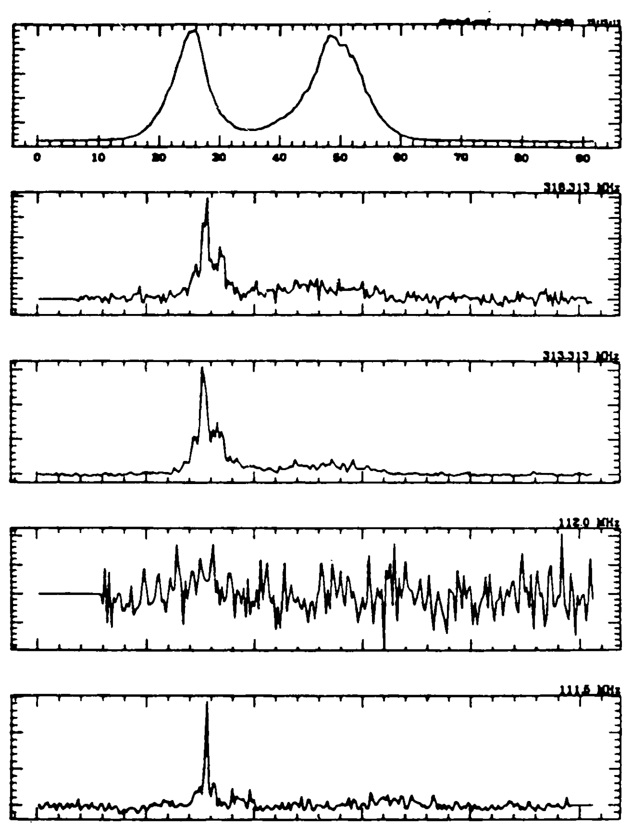

Figure 1 Observations of a single pulse from PSR 1133+16 observed with the 111/318 MHz feed system in December 1989 (P1478). The panels are, from top to bottom: a) 313-MHz average profile, b) 318.3 MHz, c) 313.3 MHz, d) 112.0 MHz (no signal present), and e) 111.5 MHz. An isolated micropulse is seen in panels b, c, and e.

Analysis

We analyzed a 420-pulse sequence obtained in this fashion. We cross-correlated the 111.5-MHz data against both the 313 and 318-MHz data. The cross-correlation function (CCF) between 111 MHz and 313 MHz is shown in figure 2a with a close-up view in figure 2b. The CCF shows a broad subpulse feature (~7 ms width) topped by a micropulse CCF feature with a width of about 1 ms. We estimate the delay peak of the micropulse feature to be 12.4±0.1 ms, to which must be added an instrumental delay of 1408.300 ms. We determined the dispersion measure (DM) between these two frequencies using

$$DM' = \frac{2.410000 \times 10^{-4}(t_2 - t_1)}{(\nu_2^{-2} - \nu_1^{-2})} \quad \mathrm{pc\,cm^{-3}},$$

where ν_1 and ν_2 are in MHz and t_1 and t_2 are in seconds. (The effective center frequencies of the two bands are 111.433 ± 0.0001 and 313.000 ± 0.0001 MHz because of the use of coherent dedispersing equipment. We have used the conventional

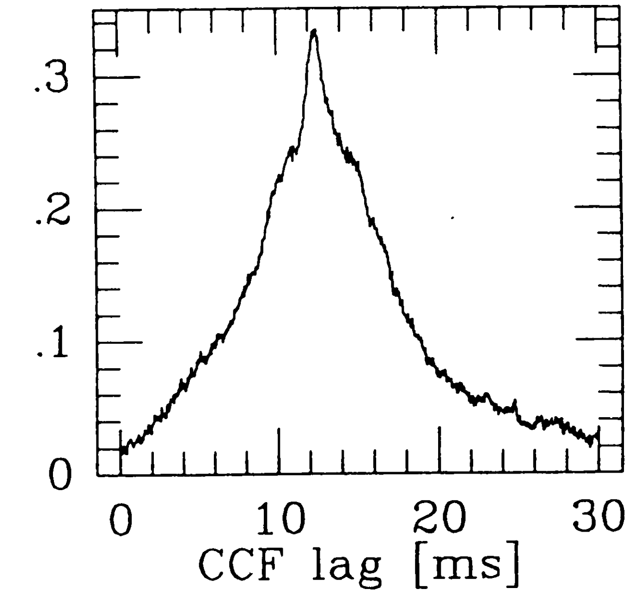

Figure 2a The average cross-correlation function (313 MHz to 111 MHz) of many pulses such as those shown in figure 1. The maximum has a half-width of about 500 μs, characteristic of the microstructure from this pulsar.

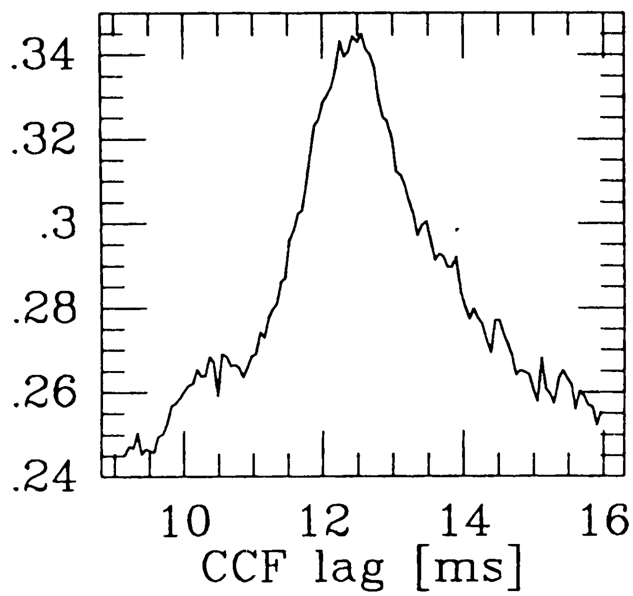

Figure 2b A close-up of the same CCF as shown in figure 2a. The peak was estimated to be at a delay of 12.4±0.1 ms, to which must be added an instrumental delay of 1408.3 ms.

value of 2.410000 in translating delay into DM; a more precise value, based on the recent SI readjustment of fundamental constants, is 2.41033.)

When corrected for the Doppler shift of the Earth's orbital motion using $DM = DM'/(1+\beta)$, where $\beta = v/c$ is positive for motion of the earth toward the pulsar, and the frequencies and times are measured in the topocentric frame, this results in a determination of

$$DM = 4.8463 \pm 0.0004\,\mathrm{pc\,cm^{-3}}$$

for the 111.5-MHz to 313.3-MHz CCF. A similar analysis of the 111.5-MHz to 318.3-MHz CCF yields

$$DM = 4.8461 \pm 0.0004\,\mathrm{pc\,cm^{-3}}.$$

Results

These two points, determined by the microstructure cross-correlation technique, are plotted in figure 3 at epoch 1989.95. Two other microstructure DM determinations are also shown in figure 3: Boriakoff (private communication), 196 to 318 MHz, and Popov, Smirnova, and Soglasnov (1987), 40 to 102 MHz. Two DM determinations obtained by cross-correlating average profiles are also shown: Craft (1973), 40 to 430 MHz, and Phillips and Wolszczan (1990), 25 to 2380 MHz. Note that the lower point next to the Phillips and Wolszczan label uses a conversion constant of 2.41000 rather than the value they used of ≈2.41033 in reporting $DM = 4.8471\,\mathrm{pc\,cm^{-3}}$. This moves their point into agreement with our microstructure DM determination, obtained less than a year later.

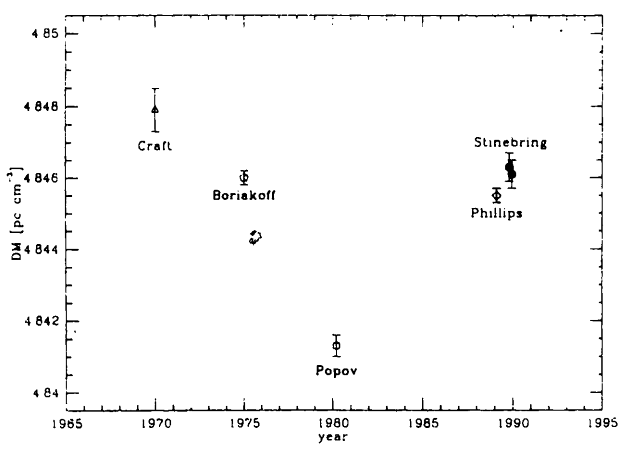

Figure 3 A comparison of DM determinations for PSR 1133+16 obtained over 20 years using two different techniques. The points labelled Boriakoff, Popov, and Stinebring indicate microstructure (single-pulse) cross-correlations. The Craft and Phillips points represent average profile cross-correlations.

Conclusions

We are hesitant to draw sweeping (or sweepback, see Shitov *et al.* 1988) conclusions from these initial results. In particular, we emphasize that our two points are determined from 420 pulses and that neither of two other blocks of pulses observed during the same hour-long session show microstructure CCF features. We are also concerned about the use of linearly polarized feeds at both observing bands. With these caveats in mind, however, we make the following conclusions:

1. Our microstructure DM determination is identical to the average profile determination of Phillips and Wolszczan (1990) obtained at about the same epoch.

2. Our DM determination is consistent with Boriakoff's 1975 microstructure determination, but not with Popov's extensive low-frequency measurements in 1980.

A discrepancy at this level of precision could be due to many things (*e.g.*, use of different constants, small observing frequency errors, a frequency dependence of microstructure DM determinations), and the large amount of time that has elapsed since the earlier observations makes it unlikely that a definitive explanation will be found. A time variation of the integrated electron content (DM) along the line of sight is another plausible cause of the discrepancy. Linear drifts of roughly $0.001\,\mathrm{pc\,cm^{-3}}$ per year are seen in seven years of dual-frequency timing data from the millisecond pulsar, PSR 1937+21 (Rawley, Taylor, and Davis 1988, Stinebring *et al.* 1990). Although the path length to PSR 1937+21 ($DM = 71.04$) is much longer than that to PSR 1133+16, the absolute error should only depend only on $DM^{1/2}$ if the fluctuations are caused by random irregularities in the ISM.

This tabulation of DM values for PSR 1133+16 raises more questions than it answers. But the importance of determining high precision DM values using both microstructure and profile alignment techniques at the same epoch is clear from this study. We have embarked on such a program and hope to be able to clarify what is being measured when we measure DM.