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VLBI OBSERVATIONS OF THE CRAB NEBULA PULSAR

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ABSTRACT

Observations of the Crab Nebula pulsar at meter wavelengths using VLBI techniques have been made. At 196.5 MHz we observe no resolution of the pulsar, all the pulse shapes observed with the interferometers are similar to single dish profiles, and all the power pulsates. At 111.5 MHz besides the pulsing power there is always a steady component, presumably due to interstellar scattering. The pulsar is slightly resolved at 111.5 MHz with an apparent angular diameter of $0\overset{''}{.}07 \pm 0\overset{''}{.}01$. We observe 50% linear polarization of the time-averaged power at 196.5 MHz; at 111.5 MHz, 20% of the total time-averaged power is polarized, 35% of the pulsing power is polarized and the steady component is unpolarized.

I. INTRODUCTION

From 1971 November through 1972 March we observed the Crab Nebula pulsar (PSR 0531+21) at monthly intervals using very long baseline interferometry (VLBI) techniques at meter wavelengths. The results presented in this paper are based on the November and December observations. The purpose of the experiment was to monitor the apparent angular size of the pulsar and to compare variations in the pulse shape, as reported by Rankin and Counselman (1972), to angular size changes. The relation between spatial and temporal broadening can indicate the general location of the scattering screen.

The telescopes used were the 305-m (1000 ft.) Arecibo dish, the 92-m (300 ft.) NRAO dish, and the 46-m (150 ft.) dish at Sugar Grove, W.Va. These telescopes form two long baselines of about 2000 km each and one short baseline about 50 km long. Table 1 shows the interferometer parameters: baseline in wavelengths, minimum detectable flux density, and fringe spacing for the two observing frequencies, 111.5 and 196.5 MHz. The standard NRAO Mark-I recording terminals were used; and the normal Arecibo Crab pulsar timing observations, as described by Rankin et al. (1970), were made simultaneously.

The VLBI data were analyzed into the Fourier components of the pulse shape using the techniques described by Erickson et al. (1972). This technique coherently de-disperses the pulsar and also removes the differential Faraday rotation across the passband. Reconstruction of the pulse shapes is done by adding the components in a Fourier sum. At 196.5 MHz we generally obtained five Fourier harmonics in addition to the fundamental; at 111.5 MHz three or four components were detectable.

II. RESULTS

a) Positional agreement of pulsar and compact source

The 26 pulse profiles derived from the 111.5 MHz data indicate that the average deviation of the phase of the Fourier components (associated with the pulsar) from the fundamental phase (associated with the compact source) is about 1.2 degrees. This corresponds to a positional agreement of about 0".01, and supports the previous conclusion that the compact source in the Crab Nebula must be identified with the pulsar.

b) Timing observations

In determining the epoch of the reconstructed interferometer pulse profiles, we find that it agrees with the time of arrival determined at Arecibo to within about 1% of the pulse period at 196.5 MHz and 2-3% at 111.5 MHz.

c) Profiles

At both frequencies the low resolution interferometer pulse profiles agree in overall shape with those observed with the single dish at Arecibo. This is illustrated in Figure 1 which shows typical 196.5 MHz pulse profiles observed in 1971 December. At this frequency, the pulse profiles observed with high resolution are also similar to the Arecibo profiles; all the profiles at 196.5 MHz have the same shape and height, and all the power pulsates. We conclude there is no resolution of the pulsar at 196.5 MHz and place an upper limit on its apparent size of 0".04. The VLBI observation at 196.5 MHz are essentially identical to those of a single dish.

From the low resolution 111.5 MHz observations we reconstruct a broad pulse shape which always has a steady nonpulsing component. The detection of the steady component illustrates one major advantage of interferometer observations, we are able to measure both the steady and the pulsing flux. Typical pulse profiles observed in 1971 November are shown in Figure 2. The high resolution observations also show a broad pulse shape, implying that the temporal and angular scattering are not simply related and probably do not occur at the same place along the intervening path.

The average fringe visibility at 111.5 MHz is 0.8 ± 0.1, corresponding to an angular diameter of $0''.07 \pm 0''.01$, assuming a gaussian brightness distribution. The apparent angular size predicted on the basis of interstellar scattering by Harris *et al*. (1970) is $0''.09$ at 111.5 MHz, assuming a distance of 2000 pc to the Crab Nebula. This size is consistent with our observations.

We observe that the average value of the ratio of steady to total flux is 0.45 ± 0.1 for both months' observations. The scattering function proposed by Rankin *et al*. (1970) predicts a fraction, 0.5 ± 0.2, of the total flux will be non-pulsing, which is in good agreement with our observations.

d) Total flux

The total flux of the small diameter source was constant during the observing sessions and was the same value in both November and December. Preliminary analysis of the 1972 observations also gives the same total flux. Each of these five epochs yields a time-averaged total flux of 35 $\pm$ 5 f.u. at 111.5 MHz and 6 $\pm$ 1 f.u. at 196.5 MHz. The variations in pulsar strength observed with a single dish at 11.5 MHz should be attributed to different distributions of the power between the pulsing and steady components, not to intrinsic changes in the total flux. We have observed one example of this redistribution in the average profiles observed between 06:00 and 07:00 U.T. on 1971 November 24, as shown in Figure 2. Although the general shape of all the low resolution and Arecibo profiles is the same, the steady component is twice as strong in the later profile. In one hour the power was redistributed, the steady flux increased by a factor of two while the pulsating flux decreased to conserve the total flux.

e) Polarization

In order to show the polarization effects more clearly in Figure 3 we have superposed the 111.5 MHz pulse profiles from Figure 2. Observations made with feeds of opposite circular polarization at the ends of the baselines make the interferometer sensitive to <u>only</u> linearly polarized radiation of <u>any</u> position angle. The instrumental polarization was calibrated by observing several quasars. When crossed circular feeds were used, the steady component of the pulse disappears. This occurs for both the high and low resolution observations and is a polarization, not a resolution, effect. Assuming there is no circular polarization of the pulsar (Campbell <u>et al</u>., 1970), the disappearance of the steady component means that it is unpolarized; only the pulsing component retains partial linear polarization. The polarization of the steady component is evidently destroyed by the multipath scattering effects which cause this component.

We observe 50% linear polarization of the average power at 196.5 MHz. At 111.5 MHz, 20% of the total time-averaged power is linearly polarized. Since the interferometer observes all the power from the small diameter source, some of which is not detected by single dish observers, this is a true measure of the polarization. In order to compare our results to those of other observers, we consider only the pulsing power at 111.5 MHz, and calculate 35% polarization, which agrees with the observations of Manchester <u>et al</u>. (1972).

TABLE 1

INTERFEROMETER PARAMETERS

Baseline	111.5 MHz			196.5 MHz		
	D (wavelengths)	S_{min} (f.u.)	θ (arc-seconds)	D (wavelengths)	S_{min} (f.u.)	θ (arc-seconds)
Arecibo - NRAO	0.9×10^6	0.3	0.20	1.7×10^6	0.3	0.12
Arecibo - Sugar Grove	0.93×10^6	0.5	0.20	1.6×10^6	0.5	0.12
NRAO - Sugar Grove	1.9×10^4	1.5	10	3.3×10^4	0.8	6

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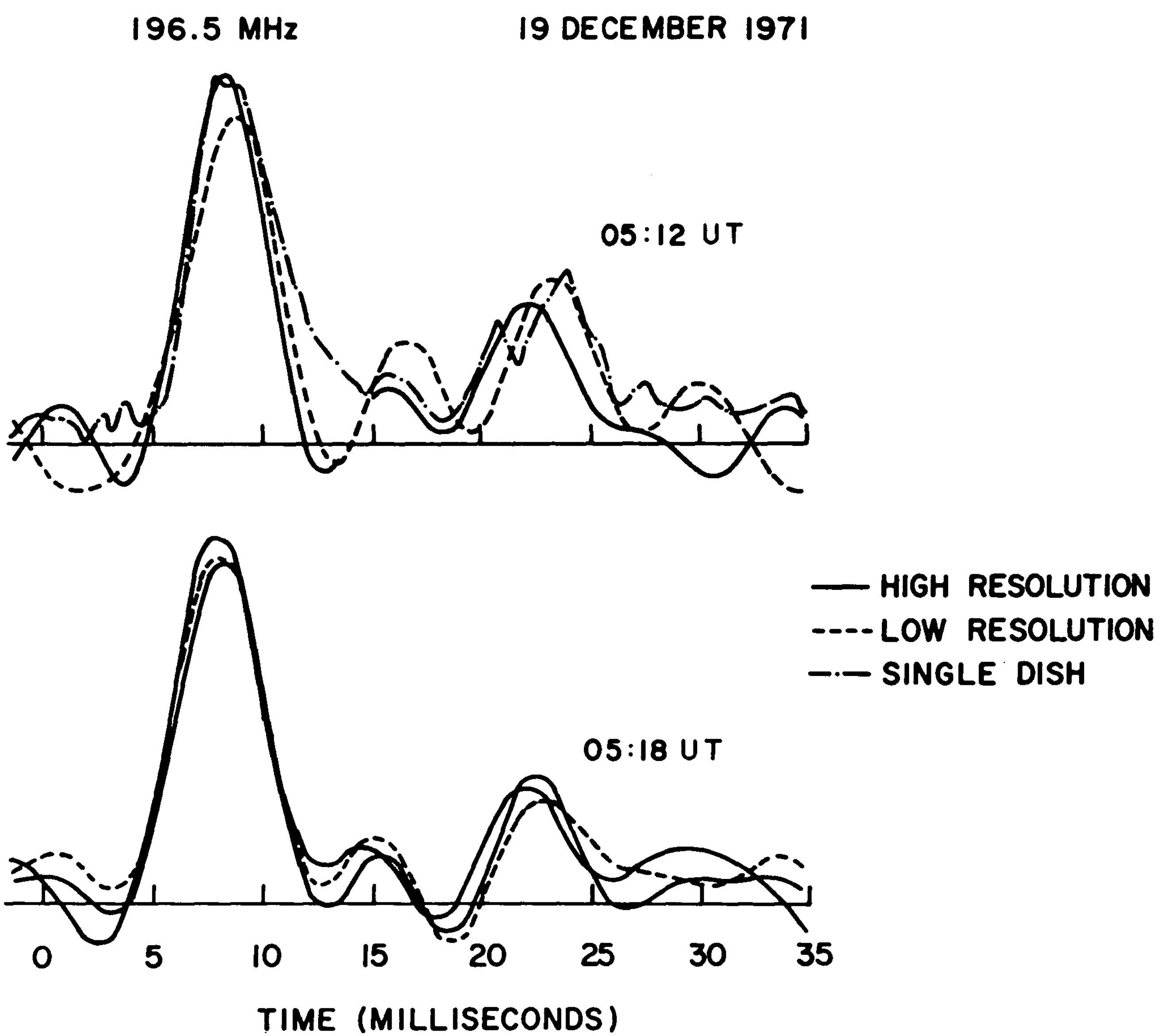

Figure 1 - Typical 196.5 MHz average pulse profiles from 1971 December 19. Observations were averaged for 160 seconds (5000 pulses) beginning at the time indicated on each profile.

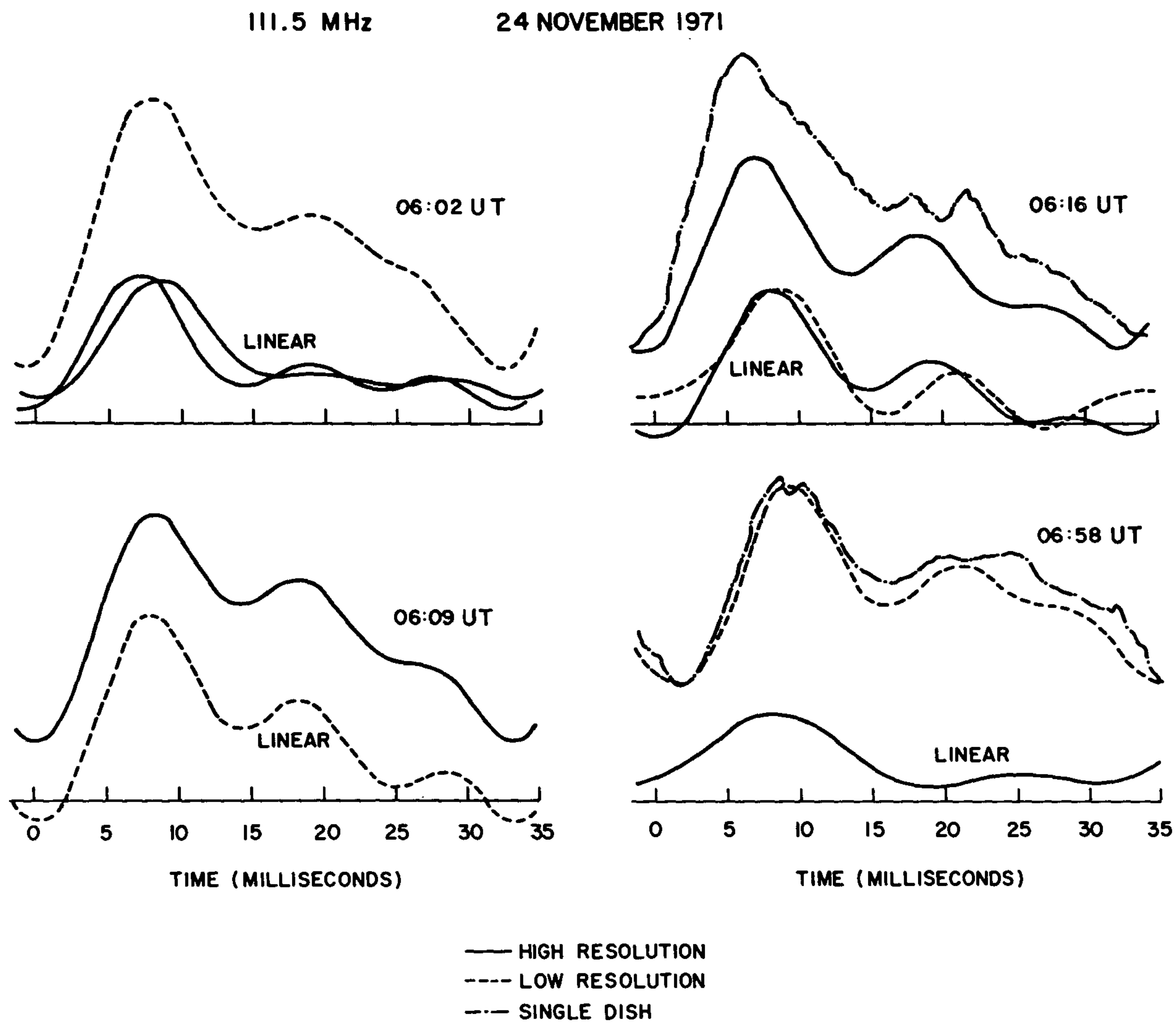

Figure 2 - Typical 111.5 MHz average pulse profiles from 1971 November 24. VLBI observations were averaged for 160 seconds (5000 pulses) beginning at the time indicated on each profile. Observations made with crossed circular feeds are indicated by the word LINEAR next to the appropriate profile. The Arecibo single dish profiles have been raised above the baseline to fit the interferometer profiles.

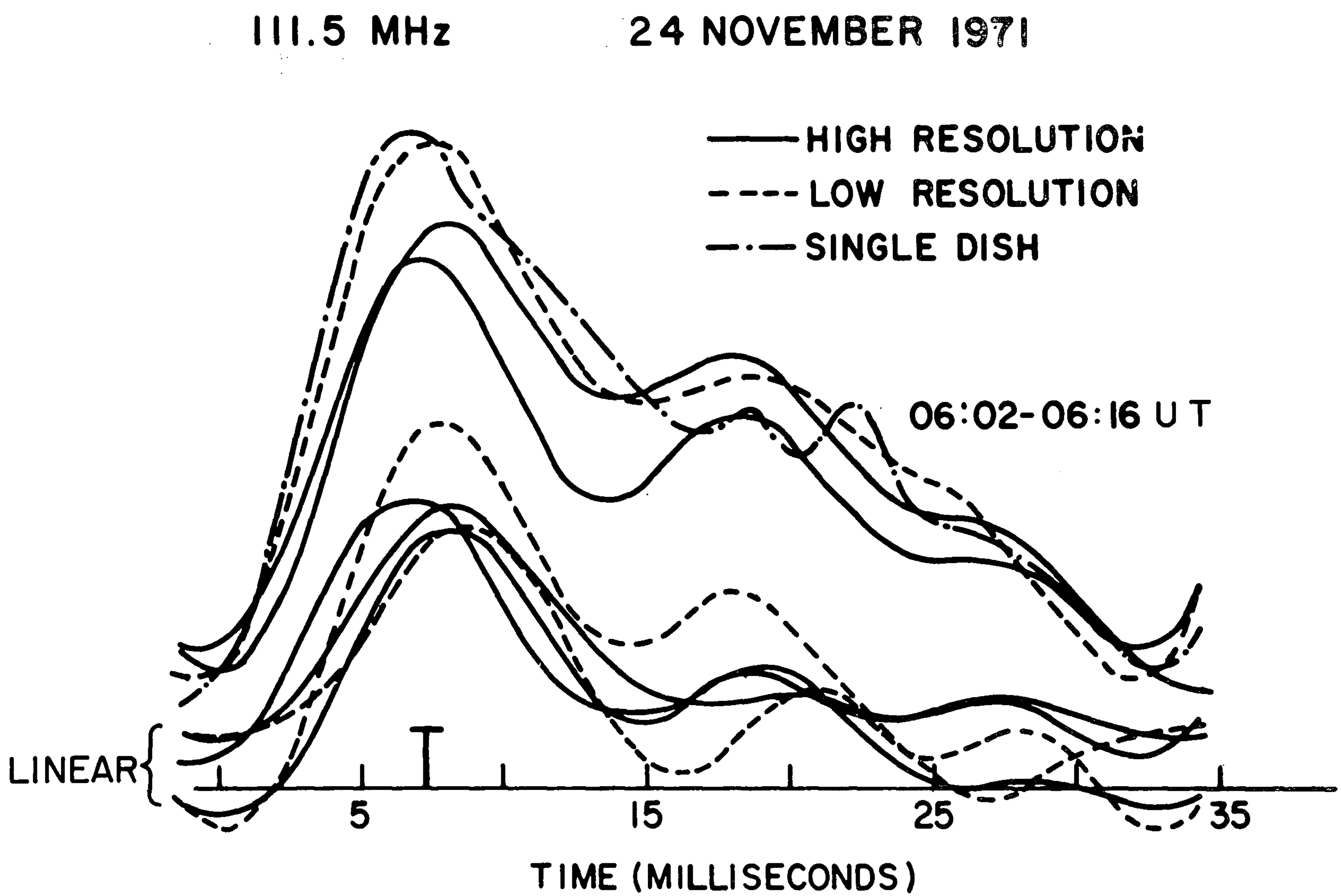

Figure 3 - Superposition of 111.5 MHz average pulse profiles from Figure 2. The height of the bar under the main pulse represents the amplitude of the instrumental polarization.