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Giant Radio Pulses from the Millisecond Pulsar PSR B1937+21 at 327 MHz

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ABSTRACT
Seven giant radio pulses were recorded from the millisecond pulsar PSR B1937+21 during $\approx$ 8.1 minutes observation by the Ooty Radio Telescope (ORT) at 326.5 MHz. Although sparse, these observations support most of the giant pulse behavior reported at higher radio frequencies (430 to 2380 MHz). Within the main component of the integrated profile, they are emitted only in a narrow ($\lesssim$ 47 μs) window of pulse phase, close to its peak. This has important implications for doing super-high precision timing of PSR B1937+21 at low radio frequencies.

Key words: pulsars: general – pulsars: individual (PSR B1937+21): stars – neutron

1 INTRODUCTION

Recently Kinkhabwala and Thorsett (2000) (henceforth KT) studied giant radio pulses from the fastest known millisecond pulsar to date, PSR B1937+21, simultaneously at frequencies 2380 mega hertz (MHz), 1420 MHz and 430 MHz, using total intensity data from the Arecibo Radio Telescope (ART) (see also Sallmen & Backer (1995); Cognard et al. (1996)). They used coherent dedispersion to obtain a time resolution of $\approx$ 0.1 to 0.2 micro seconds (μs). Their main conclusions are (1) " at each frequency, giant pulses are emitted only in narrow ($\lesssim$ 10 μs) windows of pulse phase located $\approx$ 55-70 μs after the main and interpulse peaks", (2) their " ... mean arrival phase appears stable", (3) their cumulative intensity distribution is roughly power law with an exponent of -1.8.

This article reports the result of analyzing seven giant pulses from PSR B1937+21, obtained at 326.5 MHz using ORT; only a single linear polarization was available, and incoherent dedispersion was used. Although the data were observed with a sampling interval of 102.4 μs, the pulse phases of giant pulses were obtained with accuracies of 15 to 20 μs; the instrument, the method of observation, and the several variations of data reduction for diverse purposes are given in Vivekanand et al. (1998), Vivekanand (2000), and Vivekanand (2001). While the above pulse phase accuracies are $\lesssim$ two orders of magnitude lower than those of KT, they are sufficient for the current purpose; they are much smaller than the widths of giant pulses that are affected by interstellar scattering and dispersion broadening at 326.5 MHz (discussed later).

Table 1 lists 5 of the total 7 data files observed during the later half of May 1995, in which giant pulses were found. For technical reasons, the first 6 000 of the 681 984 samples (each of duration 102.4 μs) were ignored in each file. The data were folded at the corresponding period (table 1); 15 times samples were synthesized in each period, whose duration differed from file to file, but is approximately 103.85 μs. In each file, consists of 44 436 useful periods of data, the five highest peaks were found, and giant pulses were identified as those whose peak signal to noise ratio (SNR) was higher than or close to 10.0. Then their pulse phases and their uncertainties were derived as in Vivekanand (2001). Then the integrated profile of each file was cross correlated with that of file observed at UT 22:24:37 on 1995-05-22 (no giant pulses were found in this file), and the data were shifted in each file (using FFT technique) by the corresponding amount of time.

DATE	UT	PERIOD	SNR	POS	ERR
1995-05-16	22:11:28	1.55770189	9.11	0.244	0.010
1995-05-16	22:13:45	1.55770191	8.43	0.235	0.015
1995-05-22	22:26:31	1.55770736	18.44	0.774	0.009
			17.52	0.231	0.010
			10.88	0.248	0.014
1995-05-22	22:28:17	1.55770738	14.20	0.244	0.010
1995-05-22	22:30:06	1.55770740	14.85	0.248	0.010

Table 1. Columns 1 and 2 contain the date and time (UT) of observation; column 3 contains the period (in ms) used for folding, derived from the TEMPO package; column 4 contains the peak signal-to-noise ratio (SNR) of the giant pulse, while the last two columns contain the pulse phases of giant pulses and their errors (in units of phase within the period).

PSR B1937+21 has a very small rotation period; so it

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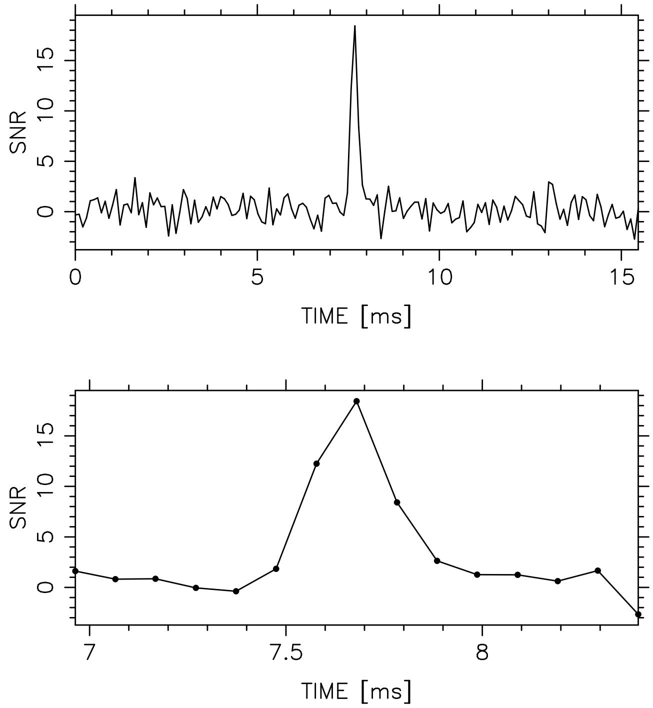

Figure 1. Top panel: Ten periods of data centered on the strongest spike observed in PSR B1937+21 at 326.5 MHz using ORT (file observed at UT 22:26:31 on 1995-05-22). The abscissa is in milli seconds, while the ordinate is in units of the signal to noise ratio. **Bottom panel**: The period containing the giant pulse.

requires fast sampling rates that are not available at ORT. It has a high dispersion measure; so coherent dedispersion technique is required to maintain the required sensitivity; that is also not available at ORT. Therefore observing this pulsar at ORT is a difficult exercise, although ORT is the most powerful telescope operating currently at $\approx$ 327 MHz. The top panel of fig. 1 shows ten periods of PSR B1937+21 centered around the strongest giant pulse observed at ORT. The ordinate was obtained in units of the signal to noise ratio as described in Vivekanand (2001). The effects of dispersion smearing and interstellar scattering are evident in the bottom panel of fig. 1.

2 INTENSITY DISTRIBUTION

These data are too meager to verify the cumulative intensity distribution reported by KT of giant pulses of PSR B1937+21. So only a consistency check will be done here, using their 430 MHz observations. This frequency is appropriate for comparison with current ORT observations since interstellar scattering of giant pulses affects their 430 MHz observations, just as it does the ORT observations, but hardly their 1420 MHz or 2380 MHz observations.

The effective collecting area of ART is $\approx$ 49 700 square meters (m^2), obtained from the antenna gain G value of 18.0 Kelvin per Jansky (K/Jy) quoted by Thorsett & Stinebring ((1990)) for observations of PSR B1937+21. That of ORT is $\approx$ 7 400 (m^2); this is obtained from the $G = 1.9$ (K/Jy) (Selvanayagam et al (1993)) for the correlation mode of operation of ORT, and noting that the current observations have been done in the total power mode, which gains a factor $\sqrt{2}$. This reduces by factor ≈ 6.7 the sensitivity of ORT with respect to that of ART. The system temperature of ART is 170 K towards PSR B1937+21 (Thorsett & Stinebring (1990)); that of ORT is the receiver temperature plus spillover of 110 K (Selvanayagam et al (1993)) plus the galactic background contribution of 202 K, obtained by scaling 117 K (see equation 8-6 of Manchester & Taylor (1977)) by the frequency scaling factor $(400/326.5)^{2.7} \approx 1.73$ (see Salter & Brown (1988) for the exponent 2.7). This reduces ORT's relative sensitivity by the further factor $312/170 \approx 1.84$. The total available bandwidths at the two telescopes contribute a factor $\sqrt{10/8} \approx 1.12$, while a factor $\sqrt{2}$ arises due to the availability of only a single polarization at ORT.

At 430 MHz, KT look for giant pulses by integrating the flux density within a 150 μs window "located on the tails of the main pulse (MP) and the interpulse (IP)"; in this work they are located by means of their peak SNR, measured within a single time sample of duration 102.4 μs. Further, interstellar scattering broadening of giant pulses in KT is ≈ 30 μs at 430 MHz (their table 1), while interstellar dispersion smearing is negligible due to coherent dedispersion. Thus at ART the energy of giant pulses can be assumed to be effectively spread over the detection window width of 150μs. On the other hand, scatter broadening at ORT is $\approx 30 \times (430.0/326.5)^4 \approx 90.0$ μs (see Manchester & Taylor (1977)); and dispersion smearing within each frequency channel is ≈ 165 μs. Now, scatter broadening occurs at each frequency within the observing bandwidth. Thus at ORT the energy of giant pulses can be expected to be spread over $\approx \sqrt{90^2 + 165^2} \approx 188$ μs. Thus the relative sensitivity of ORT is reduced by $\approx 188/150 \approx 1.25$ due to smearing of giant pulse energy over a longer time, and by $\sqrt{150.0/102.4} \approx 1.21$ due to the reduced measurement window.

ORT's relative sensitivity is further affected by two uncertain factors. The first is a reduction by factor α, due to refractive interstellar scintillation, phasing of ORT, etc; α can be ≈ 2 or even more at ORT (see Vivekanand (1995)).

The second is β, due to the relative SNR thresholds chosen in both works. The threshold is ≈ 10 in this work; i.e., at ORT one has observed 7 giant pulses in ≈ 8.1 minutes of observation above a SNR threshold of ≈ 10. In KT this number is not explicitly stated. However, from their fig. 7 one can deduce that a fraction of $\approx 10^{-4}$ of their $\approx 10^6$ total periods (KT mislabel these as "pulses" in the second last para of page 365, which can be confused with the giant pulses) have integrated fluxes greater than ≈ 2000 [Jy$-\mu$s], at 430 MHz, within the 150μs window. The corresponding flux density threshold will be ≈ 2000 [Jy$-\mu$s] / 150 [μs] ≈ 13 [Jy]. Now, the noise of ART within the 150μs window would be 170 [K] / G [K/Jy] / 2 / $\sqrt{10\ [\mathrm{MHz}] \times 150\ [\mu\mathrm{s}]} \approx 0.12$ Jy (the extra factor of 2 in the denominator arises due to the definition of the gain G of an antenna). Thus KT would have observed ≈ 100 giant pulses above the SNR threshold of ≈ 110 (Kinkhabwala (2001)).

Thus the relative sensitivity of ORT is enhanced by a factor $\beta \approx 110/10 \approx 11$ due to the relative SNR thresholds of both works. Finally, the giant pulse flux density scales with observing frequency as $\nu^{-3.1}$ (KT); this would further enhance the sensitivity of ORT with respect to that of ART by the factor $\approx (430.0/326.5)^{3.1} \approx 2.35$.

This leads to an effective sensitivity of ORT that is a factor $6.7 \times 1.84 \times 1.12 \times 1.41 \times 1.25 \times 1.21 \times \alpha/11/2.35 \approx 1.14 \times \alpha$ less than that of ART.

Now, KT claim that the fraction of giant pulses above a flux density S is proportional to $S^{-1.8}$; actually the abscissa in their fig. 7 is intensity I, which is S multiplied by a fixed duration of time. So the number of giant pulses ORT should have recorded in half an hour would be $\approx 100 \times (1.14 \times \alpha)^{-1.8}$. Therefore in the ≈ 8.1 minutes of actual observation, ORT is expected to record $\approx 21/(\alpha)^{1.8}$ giant pulses.

For $\alpha \approx 1$, this is a factor ≈ 3 higher than the number of giant pulses actually observed at ORT; α needs to be ≈ 1.8 for the numbers to match, which is not unreasonable at ORT. Furthermore, small changes in some of the above numbers can cause significant change in the final result. For example, assuming that the scatter broadening is 40 (instead of 30) μs further reduces the number of giant pulses potentially observable by $\approx 14\%$. As another example, if the giant pulse flux density is assumed to scale with observing frequency as $\nu^{-2.6}$, instead of as $\nu^{-3.1}$, since such a possibility exits in fig. 10 of KT, the number of giant pulses potentially observable decreases by $\approx 28\%$. It is therefore concluded that the seven giant pulses of PSR B1937+21 observed in about 8.1 minutes of the current ORT observations are consistent with the cumulative intensity distribution of KT.

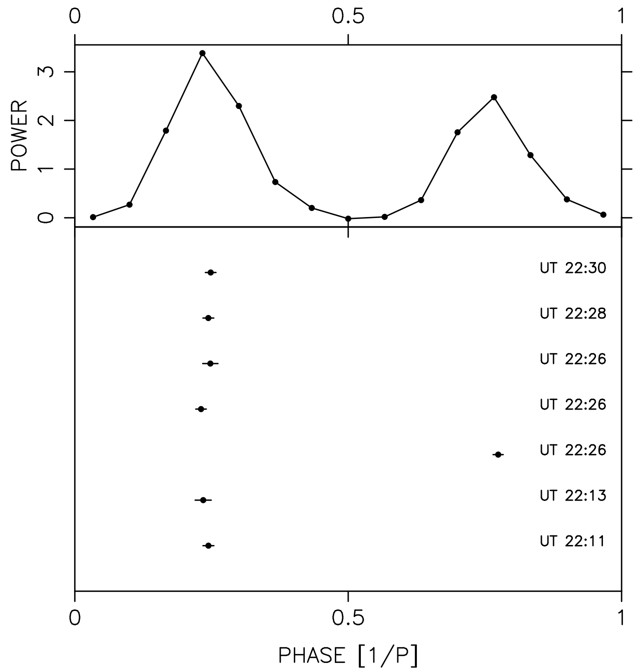

Figure 2. Abscissa is the phase within the integrated profile, in units of the pulsar period. The top panel shows the integrated profile (in arbitrary units) of PSR B1937+21 for the $\approx 311\,052$ periods of useful data in the seven files observed. The bottom panel shows the pulse phases of the seven strongest giant pulses observed in five of those files (table 1). The error bars represent two standard deviations. This figure should be compared with fig. 4 of KT.

3 PHASE DISTRIBUTION

The effective time resolution of these data is so many times worse than that of KT that once again a detailed comparison is not possible with their work. However fig. 2 shows that there is broad agreement.

3.1 Mean Arrival Phase

The mean pulse phase of the 6 giant pulses in the main pulse of the integrated profile of PSR B1937+21 (fig. 2) is 0.242 ± 0.006, in units of the pulsar period (≈ 1.55770 ms). For reference, the phase of the peak of the main pulse in fig. 2 is 0.247 (discussed later). The error on the mean pulse phase is $0.006 \times 1557.7 \approx 9.3\mu$s. This is obtained by taking into account (1) the formal estimation error on the phase of each giant pulse (column 6 of table 1; see Vivekanand (2001) for details), (2) the departure of the estimated phase of each giant pulse from the mean of all six values (column 5 of table 1), and (3) reducing by $\sqrt{6}$ the final answer. Assuming Gaussian statistics one can conclude that most giant pulses (in the main pulse of PSR B1937+21 at 326.5 MHz) arrive within a phase window of $\approx 9.3 \times 5 \approx 47\mu$s; this is consistent with the narrow window of ≤ 10 μs obtained by KT at higher radio frequencies. A corresponding comment can not be made regarding the giant pulses in the inter pulse of PSR B1937+21 at 326.5 MHz, since these data contain only one such; it occurs $\approx 19\mu$s after the inter pulse peak.

A visual inspection of fig. 2 shows that the arrival phases of giant pulses in the main pulse of PSR B1937+21 at 326.5 MHz are "stable" as claimed by KT. Once again this work can not comment on the stability of the arrival phases of giant pulses in the inter pulse.

3.2 Its Separation From Pulse Peak

The mean pulse phase of the peak of the main pulse of PSR B1937+21 in fig. 2, obtained by weighting the abscissa with the ordinate in the top panel, is 0.247 with (comparatively) negligible error. So it is separated from the mean pulse phase of giant pulses by $(0.242 - 0.247) \times 1557.70 \approx -8\mu$s, which is within measurement errors. This implies that the mean arrival phase of giant pulses is coincident with the mean pulse phase of the main component of the integrated profile of PSR B1937+21 at 326.5 MHz. The separation of $\approx -8\mu$s is independent of the scatter broadening at ORT; that is expected to bias both the mean pulse phase of a giant pulse (modeled as a delta function convolved with a truncated exponential function), as well as the mean pulse phase of the main pulse of the integrated profile (modeled as a Gaussian convolved with a truncated exponential function), by the same amount, viz., the scatter broadening width.

This is inconsistent with the $\approx 55 - 70\mu$s separation noted by KT. They mention that the separation has a "lower limit of 49 μs at 430 MHz"; this also appears to be the case from a visual inspection of the bottom panel of their fig. 2. Therefore the best explanation currently is that ORT observations, obtained using only a single linear polarization, might bias the mean pulse phase of the peak of the integrated profile to a greater extent than they do the mean pulse phases of giant pulses. This is plausible if, for example, the mean position angle of the linear polarization vector is different in the two cases; or if it changes across the integrated profile at a rate that is different for the rate of change across the giant pulses, since the former is expected to be dominated by the non-giant pulse (or the so called normal) emission. However this result merits verification by future observations.

This analysis is obviously not possible for the interpulse of PSR B1937+21 in the current data.

4 DISCUSSION

This work supports, at 326.5 MHz, the reported behavior of giant pulses of PSR B1937+21 at higher radio frequencies (KT), although with meager data. It is encouraging that this was possible with data having only a single linear polarization, and which also suffer from severe interstellar scattering.

KT showed that timing the giant pulses of PSR B1937+21 gives precision comparable to that obtained by timing the integrated profile, on the short time scales ($\approx$ hours). Whether this leads to better long term timing precision depends upon the emission characteristics of giant pulses – how fast does their average profile stabilize, etc. (KT). This problem can be studied with actual data, as is currently being undertaken by KT at the higher radio frequencies. Unfortunately this can not be done at 326.5 MHz because of the technical limitations of ORT. It would have been nice if one could theoretically study the problem; but that would require more information on the intrinsic scatter of the giant pulse emission phase.

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