Detailed study of giant pulses from the millisecond pulsar B1937+21

V.I. Kondratiev1,2, M.V. Popov1, V.A. Soglasnov1, Y.Y. Kovalev3,1,4, N. Bartel2, and F. Ghigo3

1 Astro Space Center of the Lebedev Physical Institute, Profsoyuznaya 84/32, Moscow, 117997 Russia
2 York University, Department of Physics and Astronomy, 4700 Keele Street, Toronto, Ontario M3J 1P3 Canada
3 Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany

Abstract. The second fastest millisecond pulsar, B1937+21, is one of several pulsars known to emit giant pulses (GPs). GPs are characterized by their huge energy, power-law cumulative energy distribution, and particular longitudes of occurrence. All these characteristics are different from those of regular pulses. Here, we present a study of GPs from our observations of the pulsar B1937+21 with the GBT at 2.1 GHz in both left and right circular polarization with a time resolution of 8 ns. The Mark5 data acquisition system was used for the first time in single-dish observations with the GBT. This allowed us to obtain continuous and uniform recording for 7.5 hours with a data rate of 512 Mbps. As a result, more than 6000 GPs were found above a detection threshold of 23 K. After the observations the data were transferred from the Mark5 ‘8-pack’ disk modules to a backend. This allowed us to determine the location of the occurrence of GPs. They found that GPs occur in 10-µs windows delayed by 58 µs and 65 µs from the maximum of the MP and IP components, respectively. A thorough analysis of GPs was done in our previous study (Soglasnov et al. 2004) based on 39-min observations at 1.650 GHz at Tidbinbilla with a high time resolution of 31.25 ns. A number of 309 GPs were found, with the strongest one having a peak flux density of 65 kJy. This peak flux density together with a short duration of < 15 ns corresponds to an exceptionally high brightness temperature of > 5 × 10^39 K. We also determined the power-law index of the cumulative distribution of GP energies to be −1.4.

Here, we present preliminary results of our study of GPs from B1937+21 observed with the GBT with a high time resolution.

1. Introduction

Giant pulses (GPs) are one of the most fascinating phenomena in pulsar radio emission. They are manifested as separate huge pulses with intensities hundred, thousand, and even million times larger than the intensity of an average pulse. Only 11 pulsars are known to emit such “giant” pulses. Among them, only two – the Crab pulsar and the original millisecond pulsar B1937+21 – have the strongest giant radio pulses ever observed (e.g., Hankins et al. 2003; Popov et al. 2006a,b; Soglasnov et al. 2004).

Sallmen & Backer (1995) presented the first analysis of GPs and first noted that GPs occurred at 39-min observations at 1.650 GHz at Tidbinbilla with a high time resolution of 31.25 ns. A number of 309 GPs were found, with the strongest one having a peak flux density of 65 kJy. This peak flux density together with a short duration of < 15 ns corresponds to an exceptionally high brightness temperature of > 5 × 10^39 K. We also determined the power-law index of the cumulative distribution of GP energies to be −1.4.

2. Observations and data processing

Observations of giant pulses from the millisecond pulsar B1937+21 were done on June 7, 2005 between 02:30 and 10:40 UTC with the Robert C. Byrd Green Bank Telescope (GBT) at a frequency of 2.1 GHz in both left- and right-hand circular polarization (LCP, RCP) with a time resolution of 8 ns. Four adjacent 16-MHz channels (2052–2116 MHz) at each polarization were digitized simultaneously with 2-bit sampling at the Nyquist rate. The Mark5A data acquisition system was used for the first time in single-dish observations with the GBT (see GBT Commissioning Memo 236 by Kovalev et al. 2005) for information on how to use the GBT with a VLBA+Mark5A backend). This allowed us to obtain continuous and uniform recording for about 7.5 hours with a data rate of 512 Mbps. The quasar 3C286, the radio source 3C399.1 and the planetary nebula NGC 7027 were observed as well, for flux density and polarization calibration. The system temperature in all 8 separate frequency channels was about 23 K. After the observations the data were transferred from the Mark5 ‘8-pack’ disk modules to a
Linux PC server at the observatory site. The continuously recorded Mark5A data were split into individual pieces of 10^9 bytes. The size of the pieces was constrained by the storage capacity. Then, the split data were copied to external 1-TB disks and shipped to home institutions for further processing.

The Mark5A data appear as if they were recorded to VLBA tapes. To get the real 2-bit voltage signal from the Mark5A raw data, decoding software was written. The obtained signal was corrected for bit-statistics, i.e. for the fluctuation of instantaneous rms values which results in a deviation of the signal levels away from the levels for the optimum state of 2-bit sampling (Jenet & Anderson 1998). Following Hankins (1971) we then dedispersed the data and corrected them for amplitude bandpass irregularities. Then we cut the signal with the topocentric pulsar period to search for GPs and folded the signal to produce the average pulse profile.

It is known that GPs from B1937+21 occur in the trailing edges of the MP and IP components of the average profile (Soglasnov et al. 2004). We chose a detection threshold of 17σ in every 16-MHz band and searched for events in 60-μs windows at the trailing edges of the regular MP and IP components. From all events stronger than our threshold we selected “true” GPs if a) they had intensities > 5σ in at least one other frequency channel apart from the channel in which they were detected; b) their intensity when reconstructed in the total 64-MHz passband was > 5σ; and c) they showed a characteristic scattering profile for the pulses reconstructed in the 64-MHz passband.

3. Results

To date, 5.5 from 7.5 hours of pulsar data have been processed. We detected 6 334 GPs stronger than 205 Jy in the 16-MHz bands with the strongest one having a peak flux density of 2 kJy (10 kJy in the total 64-MHz band). The statistics for the GP occurrence are almost the same both in the MP and IP regions as well as in LCP and RCP and in the separate frequency channels. The rate of GP occurrence is about 20 GPs/min for the two different scales, respectively. Making cuts in frequency and time, we measured two different scales. In the frequency domain a small scale was found to be ~1 MHz which is about equal to the expected decorrelation bandwidth.

Are these features related to scattering or do they represent the intrinsic spectrum of GPs? The interstellar scintillation should equally affect both regular and GP emission. Hence, we constructed the dynamic spectra of regular emission in LCP and RCP that contain a number of so-called “scintles,” spots of increased intensity in the time-frequency domain. The 2-D CCF between these dynamic spectra is shown in Fig. 3. Making cuts in frequency and time, we measured two different scales. In the frequency domain a small scale was found to be 3.79 ± 0.04 MHz, and a large one 16.5 ± 0.8 MHz. The characteristic scintillation time is 10.4 ± 0.1 min and 46.2 ± 0.4 min, for the two different scales, respectively. Only statistical standard errors are given. The small frequency scale of 3.8 MHz agrees well with the decorrelation bandwidth found in the average CCF between the spectra of GPs. In the left plot of Fig. 1 the thin curve shows the spectrum of regular emission in a 15-s time interval when a GP occurred. Apart from a scaling factor, the spectrum of

![Fig. 1. The instantaneous spectrum of one of the strongest GPs in LCP shown with a spectral resolution of 0.5 MHz (128 channels).](image)

spectra of strong GPs, we found particular features in them (see Fig. 1). To be precise, we computed the average auto and cross-correlation functions (ACF, CCF) for the spectra in LCP and RCP of 22 strong GPs (Fig. 2). We further measured a frequency scale as the half-width at half the height between the maximum and breakpoint in the CCF. It was found to be ~4 MHz which is about equal to the expected decorrelation bandwidth.
regular emission is very similar to that of the giant pulse. Therefore we conclude that the instantaneous spectrum of the GP reflects scintillation in the ISM rather than the intrinsic spectrum of the GP.

### Table 1. Power-law indexes of the cumulative distribution of GPs

| Pol | Channel (MHz) | $\alpha_1$   | $\alpha_2$   |
|-----|---------------|--------------|--------------|
| LCP | 2100–2116     | $-2.03 \pm 0.02$ | $-1.1 \pm 0.1$ |
|     | 2084–2100     | $-3.73 \pm 0.06$ | $-1.4 \pm 0.3$ |
|     | 2068–2084     | $-2.48 \pm 0.04$ |              |
|     | 2052–2068     | $-2.43 \pm 0.02$ | $-1.38 \pm 0.01$ |
| RCP | 2100–2116     | $-2.63 \pm 0.05$ | $-1.42 \pm 0.04$ |
|     | 2084–2100     | $-2.22 \pm 0.03$ |              |
|     | 2068–2084     | $-3.15 \pm 0.04$ |              |
|     | 2052–2068     | $-2.25 \pm 0.02$ |              |
| Mean|               | $-2.2$        |              |

### 3.2. Energy distribution of GPs
In contrast to regular pulse emission, the GP energies, $E$, are known to obey power-law statistics with the rate of GP occurrence $N_{GP} \sim E^{\alpha}$ (Kinkhabwala & Thorsett 2000) and with a low-energy but no high-energy cut-off (Soglasnov et al. 2004). To study the statistics of low-energy GPs and search for the low-energy threshold we have constructed the cumulative distribution of GPs for every frequency channel and polarization. All determined indexes are summarized in Table 1. It was found that power-law indexes have a large jitter around the mean value of $-2.2$. This seems to be caused by scintillation. The mean value of $-2.2$ differs significantly from the value of $-1.4$ we found in our previous study (Soglasnov et al. 2004). However, we also found that the cumulative distributions for half of the channels may be approximated by power-law functions with two different slopes, $\alpha_1$ and $\alpha_2$ (see Table 1). The values of $\alpha_2$ are close to $-1.4$ from our previous study (Soglasnov et al. 2004) which had less sensitivity. Hence, moving downwards toward lower energies the cumulative energy distribution of GPs gets steeper and also agrees better with the power-law index of $-2.3$ obtained for the Crab pulsar (Lundgren et al. 1995).

### 3.3. Polarization of GPs
We selected 343 strong GPs with a signal-to-noise ratio in a 16-MHz band $> 25$, sufficiently high to study the polarization properties of GPs. In Fig. 4 we present the

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**Fig. 2.** Average ACFs for LCP and RCP separately (top) and CCF between the LCP and RCP data (bottom) for the spectra of 22 strong GPs. The spectral resolution is 0.5 MHz.

**Fig. 3.** The 2-D CCF between dynamic spectra of regular emission in LCP and RCP (center plot). The contours are plotted at 0, 18.4, 26, 36.8, 52, and 3.6 % of the maximum. The plots at the top and left show the central cut of the 2-D CCF in the frequency and time domain, respectively (thick curves). The thin curves in these plots show the fits used for the determination of the frequency and time scales.
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Fig. 4. Histograms that represent the number of GPs versus fractional linear (top) and circular (bottom) polarization. The total number of selected GPs with a signal-to-noise ratio in a 16-MHz band of > 25 is 343. Histograms in gray represent values for the peaks of the GPs, while open histograms represent average values for the whole GP.

distribution of GPs versus linear and circular fractional polarization. It can be seen that the majority of the GPs (> 55%) have circularly polarized peaks with fractional polarization > 0.8 (either left, or right). Only a few of the GPs (15%) have fractional circular polarization < 0.6. The fractional linear polarization of GPs is also very high. Out of the 343 GPs, 165 (48%) have fractional linear polarization of 0.4–0.5. It should be mentioned that the phase of the peak in circular and linear polarization profiles within the same GP could be different. Hence, the same GP can reveal both strong circular and strong linear polarization. The number of GPs with both large circular (> 0.8) and large linear (> 0.4) fractional polarization is 130, or almost 38%. Thus, GPs are very strongly, both, circularly and linearly polarized events.

4. Conclusions

The Mark5 recording system provides an excellent possibility to study properties of GPs with high time resolution at single-dish radio telescopes. Preliminary data reduction of the observations of the millisecond pulsar B1937+21 made with the GBT at a frequency of 2.1 GHz confirms the very short duration of GPs of < 8 ns. The instantaneous spectrum of a GP was found to correspond well to the diffraction spectrum of regular emission. In half of cases the cumulative distribution of GP energies may be represented by a power-law piecewise function with two slopes and indexes of −2.2 and −1.4. For the first time the polarization properties of the GPs of pulsar B1937+21 were analyzed. Almost all strong GPs are highly circularly polarized, with > 55% of GPs having fractional circular polarization > 0.8.

The work reported in these proceedings is in progress. The complete analysis will be published later.

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