Research Article

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Observations of the gamma-ray pulsar J1836+5925 at 111 MHz

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Abstract: We describe the 10-day radio observations of the gamma-ray pulsar J1836+5925. Observations were carried out in the Pushchino Radio Astronomical Observatory at the frequency of 111 MHz using the Large Phased Array of the Lebedev Physical Institute.

Keywords: pulsars, radio observations, gamma-ray pulsars

1 Introduction

The pulsar was discovered during the EGRET mission aboard the NASA Compton Gamma-Ray Observatory (CGRO) by Lin *et al.* (1992) and later by Nolan *et al.* (1994). It is also called as GRO J1837+59, 2EG J1835+5919, 3EG J1835+5918 and GEV J18351+5921. Attempts were made to identify it in optical and radio ranges (Halpern *et al.* 2002 and Halpern *et al.* 2007).

In the Malov and Timirkeeva (2018) we suggested that gamma-ray pulsars with strong magnetic fields at the light cylinder and high rotational energy loss rates could radiate also radio emission. Our article is devoted to the search for radio emission of this pulsar.

2 Geminga and Geminga-like pulsars

This pulsar is called Geminga-like because it has some characteristic features of Geminga. PSR J0633+1746 was discovered as gamma-ray source by Fichtel *et al.* (1975); Kniffen *et al.* (1975). It emits hard radiation but its radio emission has been detected much later (Malofeev and Malov 1997).

There are several pulsars similar to Geminga: J0007+7302 (Lin *et al.* (2010)), J2021+4026 (Lin *et al.* 2013), J1813-1246 (Marelli *et al.* 2014).

Abdo *et al.* (2010) showed the overall similarity of the X-ray spectra of PSR J1836+5925 and Geminga (see Figure 1). The spectrum is seen to be well described by the sum of a pure black-body and a hard power-law components. The tails of their spectra are also well fit by a similar hard power-law component.

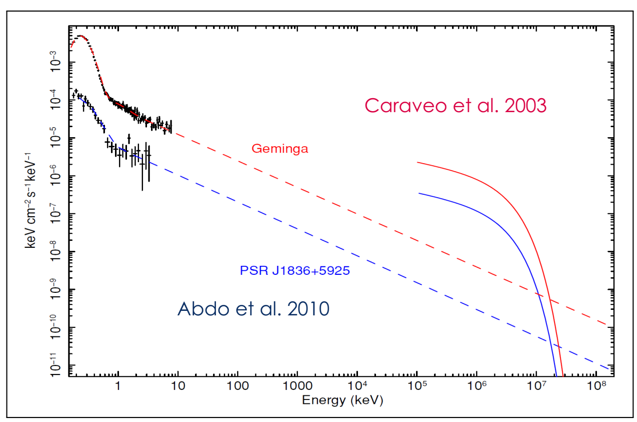

Figure 1. The X-ray spectrum of PSR J1836+5925 (blue line), compared to that of Geminga (red line). Data was prepared by Caraveo *et al.* (2003). Figure was received in (Abdo *et al.* (2010)).

3 Radio observations

Radio observations of the gamma-ray pulsar J1836+5925 were carried out using the meridian radio telescope LPA (Large Phase Array). Its antenna is the phased array com-

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posed of 16384 dipoles. The geometric area of this antenna is more than 70 000 m^2 and the effective area is 47000 ± 2500 m^2. Antenna has 64 space beams with the size of one beam $1^\circ \times 0.5^o$. The duration of an observing session is about $3.5/cos\delta$ minutes (Tyul'bashev *et al.* (2016)). In order to make a more sensitive search for radio pulsations from the gamma-ray pulsar J1836+5925 observations were carried out with the set durations about 5-10 days each on more than 200 days for 4 years at the frequency of 111 MHz. For the processing 460 channels of the 512 channel digital receiver are used. The single channel bandwidth is 4.88 kHz, and the time resolution is 2.46 msec, the total bandwidth is 2.245 MHz. All data is stored in the server. For the processing the special program has been worked out by Malofeev *et al.* (2012). Data processing is carried out in 2 stages. First, there is an accumulation with the pulsar period and a search for dispersion measures from 2 to 20 pc cm^{-3}. Then the search for strong individual pulses with the presence of a dynamic spectrum in the bandwidth of the receiver is carried out. At the first stage to verify the presence of weak signals and enhance the reliability of results we selected observing sessions equal to double or triple periods. To increase the reliability of identification of the pulsar signal during the observing sessions 725 (for triple period window) pulses have been accumulated. After analysing other works (see also Halpern *et al.* (2002, 2007) and Abdo *et al.* (2010)) we proposed to concentrate our efforts in the search for radiation in radio range for dispersion measures from 2 to 20 pc cm^{-3}. We carried out 10-day sessions of observations of the pulsar J1836+5925 in May 2021. We removed the 1-4 May data from the consideration because they had a low quality caused by interferences. After summation of all pulses we get the weak pulsed signal with the signal-to-noise ratio (S/N) no more than 4 for several values of the dispersion measure (DM). The value of this DM is unknown up to now. Unfortunately, we were unable to find a reliable integrated signal on a certain dispersion measure over 6 days of observations.

4 Results

The analysis of the received data shows that there is no any relationship between the values of S/N and the DM after summation of 725 pulses (see Figure 2). It is necessary to consider each pulse in more detail for each dispersion measure (in range from 2 to 20 pc cm^{-3}) and for each day.

We separated the strongest pulses (with a signal-to-noise ratio of more than 4) in the range of dispersion measures from 2 to 20 pc cm^{-3} in the analyzed data set and

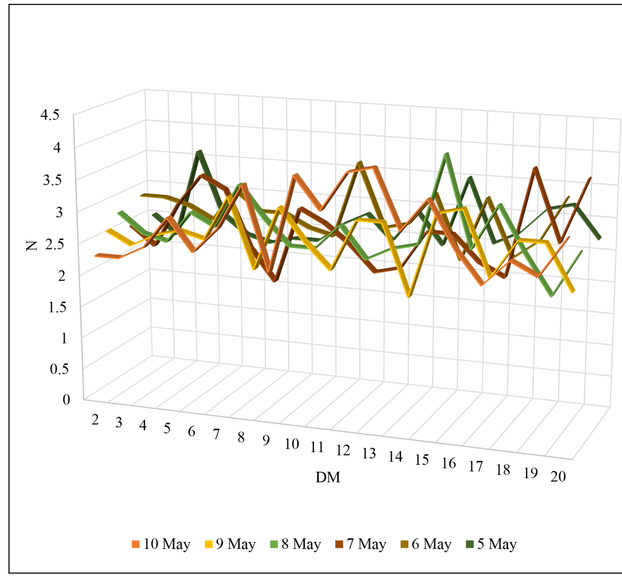

Figure 2. The diagram of S/N versus DM in May 2021.

plotted the following dependencies: the number of such pulses in 10 intervals of the dispersion measures (Figure 3) and the number of strong pulses depending on the phase of their arrival in a certain time interval equaled to 3 pulsar periods (see Figures 3 and 4).

For a deeper analysis of the data and search for the radio emission, we analyzed the distribution of the dispersion measure in the strongest pulses (see Figure 3).

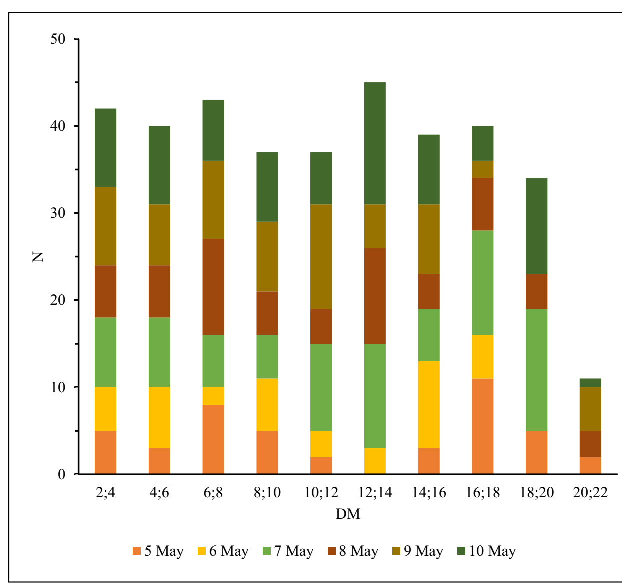

Figure 3. The distribution of the number of individual pulses with the different DM for 6-days observations in May 2021.

After analyzing the data of Figure 3, it became clear that there was not an expected strongly significant range of DM. We do not see an evident maximum.

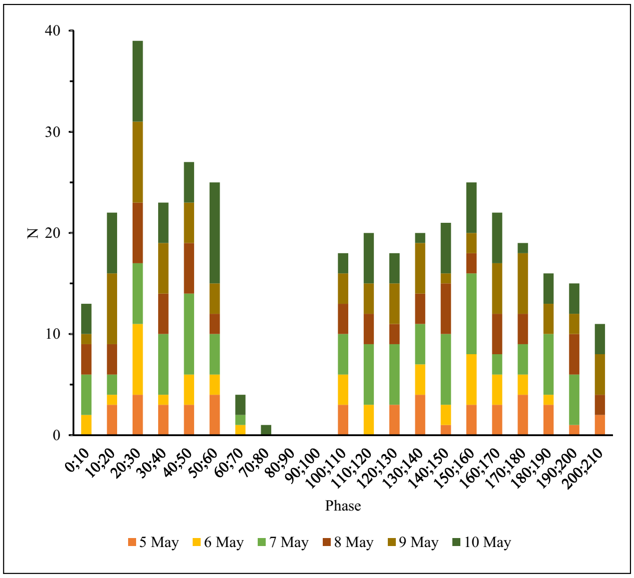

Figure 4. The distribution of phases for 6-days of observations in May 2021.

In the case of presence of several strong individual pulses (observed with the triple period) in one day of observations, we could expect the presence of three maxima (Figure 4) with a phase difference of 70 points after summing up the records for 6 days. We got 2 wide ranges with "collapse" in the phases of 60-90 points. If the number of observed days increases, this collapse becomes more significant.

Thus, we can conclude that during 6 days of observations we fail to detect pulsed periodic radiation at the level of 82 mJy (Timirkeeva *et al.* 2020), and also individual pulses with S/N ≥ 5 with the presence of a dynamic spectrum in the bandwidth of receiver used for our observations are not detected.

Our results have the direct practical relevance for the further search for radio emission from the PSR J1836+5925.

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References

Abdo AA, Ackermann M, Ajello M, Atwood WB, Baldini L, Ballet J, et al. 2010. Fermi Large Area Telescope Observations of PSR J1836+5925. ApJ. 712:1209-1218.

Caraveo PA, Bignami GF, DeLuca A, Mereghetti S, Pellizzoni A, Mignani R, et al. 2003. Geminga's tails: a pulsar bow shock probing the interstellar medium. Science. 301:1345-1348.

Fichtel CE, Hartman RC, Kniffen DA, Thompson DJ, Bignami GF, Oğelman H, et al. 1975. High-energy gamma-ray results from the second Small Astronomy Satellite. ApJ. 198:163-182.

Halpern JP, Gotthelf EV, Mirabal N, Camilo F. 2002. The Next Geminga: Deep Multiwavelength Observations of a Neutron Star Identified with 3EG J1835+5918. ApJ. 573:L41-L44.

Halpern JP, Camilo F, Gotthelf EV. 2007. The Next Geminga: Search for Radio and X-Ray Pulsations from the Neutron Star Identified with 3EG J1835+5918. ApJ. 668(2):1154-1157.

Kniffen DA, Fichtel CE, Hartman RC, Thompson DJ, Ozel ME, Tumer T, et al. 1975. Distribution of Cosmic Gamma Rays in the Galactic Anticenter Region as Observed by SAS-2. in Proc. 14th ICRC; Munich, Germany. 1975;1:100-105

Lin YC, Chiang J, Fierro J, Michelson PF, Nolan PL, Brazier K, Kanbach G, et al. 1992. GRO J1837+59. IAU Circ. 5676:2.

Lin LCC, Huang RHH, Takata J, Hwang CY, Kong AKH., Hui CY. 2010. Detection of an X-ray pulsation for the gamma-ray pulsar centered in CTA 1. ApJL. 725:L1-L5.

Lin LCC, Hui CY, Hu CP, Wu JHK, Huang RHH, Trepl L, et al. 2013. Discovery of X-Ray Pulsation from the Geminga-like Pulsar PSR J2021+4026. ApJL. 770:L9.

Malofeev VM, Malov OI. 1997. Detection of Geminga as a radio pulsar. Nature. 389(6652):697-699.

Malofeev VM, Teplykh DA, Logvinenko SV. 2012. New observations of anomalous X-ray pulsars at low frequencies. Astron Rep. 56:35-44.

Malov IF, Timirkeeva MA. Radio pulsars with expected gamma radiation and gamma-ray pulsars as pulsating radio emitters. RAA. 18(8):89-1 – 89-8.

Marelli M, Harding A, Pizzocaro D, De Luca A, Wood KS, Caraveo P. et al. 2014. On the puzzling high-energy pulsations of the energetic radio-quiet γ-ray pulsar J1813-1246. AJ. 795:168.

Nolan PL, Fierro JM, Lin YC, Michelson PF, Willis TD, Chiang J. et al. 1994. The unidentified gamma ray source GRO J1837+59. AIP Conf Proc. 304:360-364.

Timirkeeva MA, Malov IF., Malov OI. 2020 Observations of the 60 Gamma-Ray Pulsar J1836+5925 at 111 MHz. Ground-Based Astronomy in Russia 21st Century. In: Romanyuk II, Yakunin IA, Valeev AF, Kudryavtsev DO. Editors. Proceedings of the All-Russian Conference. 2020 Sept 21-25; Nizhny Arkhyz, Russia. 187:451-454.

Tyul'bashev SA., Tyul'bashev VS, Oreshko VV, Logvinenko SV. 2016. Detection of new pulsars at 111 MHz. Astron Rep. 60:220-232.