On the Radio Emission of the Geminga Pulsar and RBS 1223 at the Frequency of 111 MHz

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Abstract—Observations on the search for pulsed radio emission from the Geminga pulsar and the close isolated neutron star 1RX J1308.6+2127 (RBS 1223) at the frequency of 111 MHz are performed. No pulsed signals are detected from both sources. Upper limits for the average flux density are determined as 0.4–4 mJy for the Geminga pulsar and 1.5–15 mJy for RBS 1223 depending on the assumed duty cycle (0.05–0.5) at the frequency of 111 MHz.

Keywords: pulsars, radio emission, average profile, single pulses

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1. INTRODUCTION

The Geminga gamma pulsar was discovered using SAS-2 satellite [1]. It is the second brightest gamma source in the sky at energies above 100 MeV and was studied across the entire electromagnetic spectrum. This object was reliably identified as a pulsar after detecting pulsations in X-ray [2] and gamma [3] ranges. In the 1990s, three teams of the Pushchino Radio Astronomy Observatory reported on the detection of pulsed radio emission from the Geminga pulsar (PSR J0633+1746) at a frequency of 102.5 MHz [4–6] with a flux density from 30 mJy to 100 mJy and a dispersion measure of ~3 pc/cm³. In the recent paper [7], it was reported on the detection of several radio bursts from the Geminga pulsar at a relatively low frequency of 34 MHz. However, numerous searches for Geminga radio emission at higher frequencies have not led to a positive result (see, e.g., [8] and references therein).

The 1RX J1308.6+2127 (another name of the object is RBS 1223) is a close isolated neutron star [9] with a rotation period of 10.3 s [10], which was also identified as a very weak optical object [11]. In 2005, it was reported on the detection of pulsed emission from this neutron star at a frequency of 111 MHz with an average flux density of ~50 mJy [12].

2. OBSERVATIONS AND PROCESSING

The Geminga pulsar was observed from November 1999 to January 2007 (MJD from 51505 to 54110), and the isolated neutron star RBS 1223 was observed from October 2001 to March 2007 (MJD from 52203 to 54180). The Large Scanning Antenna (LSA) of the Pushchino Radio Astronomy Observatory with an effective area of ~15000 m² at the zenith was used. One linear polarization was accepted. A 128-channel spectrum analyzer with a channel band of 20 kHz and a center frequency of 110.59 MHz was used. Observations were performed in the search mode, i.e., in the mode of recording individual pulses in all channels without referencing to some ephemerides of these objects. The readout interval was 2.56 ms at time constant of 3 ms for the Geminga pulsar, and 5.0 ms and 10.0 ms for RBS 1223, respectively. The LSA is a transit telescope; therefore, the duration of one observation session was 3.2/cos(δ) min. A total of 600 such sessions containing 441000 periods for the Geminga pulsar and 12000 periods for RBS 1223 were performed. From the mid-2004, the PSR B0626+24 pulsar close to the Geminga (by the sky position) was observed as a test in exactly the same mode.

In the preprocessing of the day observation session, an average value was subtracted from the time series in each frequency channel, and the result was normalized to the root-mean-square in this channel. Then the records were reviewed with respect to interferences, i.e., records of all channels were averaged.
without compensation for dispersion delay (since there is no dispersion delay for terrestrial interferences), and in the presence of interferences (with the signal-to-noise ratio over seven), the corresponding counts in all channels were nullified. Then, folding, i.e., summation of periods in the record of each channel, was performed; in this case, the period and phase for a particular day of Geminga pulsar observations were calculated based on ephemerides [13, 14]. In particular, rotation frequencies and its derivative from [14] were used, \( \nu_0 = 4.21758680078(5) \) Hz, \( \nu_0' = -1.95214(1) \times 10^{-13} \) Hz \cdot s\(^{-1} \), for the epoch \( t_0 = 53630.0 \) (MJD). Parthenetical numbers are errors by the level of 1 \( \sigma \) in the units of last significant digits. The astrometric parameters (coordinates and proper motions) were taken from [13]. If we set the phase (number of rotations) of star rotation by the expression

\[
\varphi = \varphi_0 + \nu_0 \cdot (t - t_0) + \frac{1}{2} \cdot \nu_0' \cdot (t - t_0)^2,
\]

the error of the phase calculated for the time point \( t \) of each observation session, is written as

\[
\delta \varphi = |t - t_0| \cdot \sqrt{((\delta \nu_0)^2 + 1/4 (t - t_0)^2 \cdot (\delta \nu_0')^2)},
\]

where \( \varphi_0, \delta \nu_0, \) and \( \delta \nu_0' \) are the phase and the errors in the rotation frequency and its derivative for the epoch of \( t_0 \) ephemerides. In our observations, the maximum deviation from the epoch of ephemerides, hence, the maximum phase error, is inherent to the first observation session for which \( |t_1 - t_0| = 1.84 \times 10^8 \) s. Thus, the maximum phase error is \( \delta \varphi_{\text{max}} = 0.02 \) of the period for the Geminga pulsar; however, the error is noticeably lower for a significant fraction of observation sessions. For the isolated neutron star RBS 1223, ephemerides from [15] were used; the maximum phase error is \( \delta \varphi_{\text{max}} = 0.013 \) for the first observation session.

In the last stage, dispersion delay was compensated in each channel; in this case, the dispersion measure was searched in the range from 0 to 40 pc/cm\(^3\) with a step of 1 pc/cm\(^3\). The dispersion measure DM = 3 pc/cm\(^3\) corresponds to the expected distance (160 pc) to the Geminga pulsar. No statistically significant (S/N > 5) pulsed radio emission at the frequency of 111 MHz was detected in any observation session.

3. RESULTS

To significantly improve the sensitivity of the search for Geminga pulsar emission, all 600 sessions were coherently averaged over time referencing according to ephemerides from [13, 14]. After such summation and search for the dispersion measure, significant radio emission also was not detected. Examples of the obtained average (for all 600 sessions) pulse profiles for a number of dispersion measures are shown in Fig. 1. The upper limit (S/N = 5) for the peak flux density is 8 mJy; for the period-averaged flux density, it is from 0.4 to 4 mJy, depending on the expected (0.05–0.5) pulse duration. Figure 2 shows the Geminga pulsar profile (for all 600 sessions, it is smoothed over 4 points; two periods are shown) for the dispersion measure of 3 pc/cm\(^3\) along with the average profile of the PSR B0626+24 test pulsar. The period-averaged flux density of the PSR B0626+24 is 60 mJy, i.e., is much the same as was stated for the Geminga pulsar.

For coherent summation of all 600 observation sessions of the RBS 1223, ephemerides from [15] were used. Examples of the obtained average profiles (for all 600 sessions) for a number of dispersion measures are shown in Fig. 3. The upper limit (S/N = 5) for the peak flux density (when smoothing to the time resolution of 20 ms) is 30 mJy. The corresponding period-averaged flux density is in the range from 1.5 to 15 mJy, depending on the expected pulse duration of 0.05–0.5 at the frequency of 111 MHz.

4. DISCUSSION

The radio emission bursts of the Geminga pulsar at a frequency of 34 MHz, detected in [7], can indicate a very nonuniform (in time) radio emission. However, the revealed short-term (of the order of a minute) dispersion measure variations in the range of 1.4–3.6 pc/cm\(^3\) can in no way be attributed to the interstellar medium. In [16], new results on Geminga pulsar observations at three low frequencies from 42 to 111 MHz were presented. The possible causes of disagreement between the results of the present study and the data of [7, 16] are as follows. First, radio emission of many pulsars is rather nonuniform in time; both nullings, i.e., an almost complete absence of radio emission during a large enough number of pulsar periods, and the burst nature, i.e., a substantial increase in the radio emission intensity in comparison with the average level, are possible. It is possible that the case in point in [7, 16] is exactly such radio emission bursts of the Geminga pulsar. Second, selection was performed in [16], i.e., some time intervals were excluded from the consideration even during relatively short isolated observation sessions. In the present
work, no selection was performed, except for noise cleaning, and the radio emission search was performed only on three time scales: individual pulses, average profiles for an observation session, and the average profile over all 600 sessions. It is possible, that the same causes explain the results of the study of the second object, i.e., RBS 1223.

5. CONCLUSIONS

The search for pulsed radio emission of the Geminga pulsar and the isolated neutron star RBS 1223 at the frequency of 111 MHz did not yield positive results. For the Geminga pulsar, the upper limit for the average flux density of 0.4–4 mJy was determined depending on the expected (0.05–0.5) pulse durations.
at the frequency of 111 MHz. For the RBS 1223, the corresponding upper limit is in the range of 1.5–15 mJy. The absence of radio emission from the Geminga pulsar and RBS 1223 for summed data in long-term intervals and emission detection at selected time points can be caused by the burst nature of the activity of these objects.

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