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Pulsed radio emission from two XDINS

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Abstract The result of the detection and the observations of radio emission from two X-ray dim isolated neutron stars (XDINS) 1RXS J1308.6+212708 and 1RXS J214303.7+065419 are reported. The observations were carried out on two sensitive transit radio telescopes at a few low frequencies in the range 42-112 MHz. The flux densities, mean pulse profiles period and its derivative , as well as, the estimation of the dispersion measures, distances and integrated radio luminosities are presented. Comparison with X-ray data shows large differences in the mean pulse widths and luminosities.

PACS

1 Introduction

Recent gamma-ray and X-ray observations have led to the discovery of three interesting groups of pulsars: anomalous X-ray pulsars (AXPs), soft gamma-ray repeaters(SGRs) and nearby dim isolated neutron stars with strong magnetic fields (XDINS) or the magnificent seven. These isolated neutron stars have different parameters than the larger group of "normal" radio pulsars and ordinary X-ray pulsars do. These objects have long periods (5-12 s) and large period derivatives, $10^{-11} - 10^{-13}$ s/s. They are young objects with characteristic ages of up to several million years. Most of AXPs and SGRs objects are located close to the plane of the Galaxy, and nearly half of them are inside supernova remnants. The main problem connected with these objects is the source of their energies, which sometimes imply luminosities that are two to three orders of magnitude higher than can be provided by the rotational kinetic-energy losses. All the models proposed until recently, including the most popular magnetar model of Duncan & Thompson (1992), which proposes the superstrong magnetic fields $10^{14} - 10^{15}$ G to explain this energy source encounter serious difficulties (Malov et al. 2003). XDINSs are not associated with supernova remnants and maybe in these compact stars we can have a clean view of the star surface in X-ray, without contamination from magnetospheric emission (Zane 2005). The presence of the absorption feature in the X-ray spectra of a few XDINSs give the possibility to measure the magnetic field strength independently from spin-dawn measurements.

One of the key arguments in favor of the magnetar model was the absence of radio emission from AXPs, SGRs and XDINSs: this could be naturally explained as a consequence of the absence the

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electron- positron cascades that are responsible for radio emission in some models in the presence of such strong fields (Barring & Harding, 1998). The situation was changed when pulsed radio emission was detected from the SGR 1900+14 (Shitov et al. 2000) and the AXP 1E2259+586 (Malofeev et al. 2001, 2004, 2005). This led to searches for mechanism of pair production, such as two-photon process for the generation of radio emission in the framework of the magnetar model by Zhang (2001), as well as completely new models, such as the action of drift waves at the periphery of the magnetosphere (Malov et al. 2003). The importance of searches for the radio emission of AXPs, SGRs and XDINS is obvious and recently the radio emission from two XDINS: 1RXS J1308.6+212708 (Malofeev et al. 2004, 2005) and 1RXS J2143.7+065419 (Malofeev et al. 2006) has been detected. In this report we present briefly data on the radio emission of both XDINS.

1RXS J1308+21 was discovered in 2001 by Hambaryan et al. (2002) and the rotational period for this pulsar was recently redetermined $P = 10.32$ s (Haberl et al. 2003). The detection of pulsed X-ray emission of XDINS 1RXS J2143.7+065419 was made by Zane et al. in 2005.

2 OBSERVATIONS AND RESULTS

1RXS J1308+21 has been observed since December 2001. The observations of of the second pulsar 1RXS J2143+06 was started in October 2005 and we present data obtained until June 2006. Most of the observations were carried out on the high-sensitivity Large Phased Array (LPA) of the Lebedev Physical Institute (Pushchino) at a frequency of 111 MHz. A few simultaneous observations have been made at 87, 61 or 42 MHz on the East - West arm of the DKR-1000 (Pushchino). This antenna operates at 30-110 MHz. The effective area is $\sim 20000\, m^2$ and ~ 7000 m^2 for LPA and the East-West arm of the DKR-1000, respectively. Both radio telescopes are transit instruments; the durations of each observational session on the LPA were 3.3 min, and those on the DKR-1000 were longer by factor of three for each pulsar. A filter-bank receiver with a bandwidth of 20 kHz and 64 channels at 111 MHz and 32 or 64 channels at 87, 61 and 42 MHz was used. In addition, we used a method to search for pulsed radio emission with unknown period (Malofeev et al. 2005). To increase reliability we carried out numerous observations, using double the period. We have used a technique that has been tested with observations of faint pulsars.

XDINS 1RXS J1308+21. To detected weak periodic pulsed radio emission from 1RXS J1308+21 at 111, 87, 61 MHz (Malofeev et al. 2004; 2005) and 42 MHz (Fig.1) we obtained more than 100 and more than 15 records useful for analysis for 1RXS J1308+21 at 111 MHz, and at every lower frequency (87, 61 and 42 MHz), respectively. We observe a narrow pulse at 111 MHz, which has a duration of 140 ± 20 ms, or 1.35% of the period ($P = 10.32$ s). Fig.1 shows the mean profiles at four frequencies. In addition to a narrow pulse, this pulsar displays an interpulse at a phase of ~ 0.5 of period, which is clearly visible in Fig.1 at all frequencies.

Determination of the dispersion measures is extremely important, since it makes it possible to obtain independent estimates of the distances to the pulsars. We estimated the dispersion measure using the best data in the 111.22 - 110.58 MHz frequency band, which was covered by 64 receiver channels. The signal-to-noise ratio and pulse duration as a function of the dispersion measure for pulsar J1308+21 was shown by Malofeev et al.(2004, 2005).

We measured the fluxes at 111 MHz via calibration using the radio sources with known fluxes. The flux of 1RXS J1308+21 was obtained on the base of 10 days of observations over 1.5 years.

New period and period derivative presented by Kaplan and van Kerkwijk (2005) for J1308+21 gives a much smaller value of the period derivative, that requires us to redetermine our value using data obtained during 2002-2005. We measured the period and its derivative ($P = 10.31434039(6)$s and $\dot{P} = 1.29921(9) \cdot 10^{-11}$ s/s) at MJD 51719.5, during the MJD range 52333-53650.

XDINS 1RXS J2143+06. More 40 good records of 1RXS J2143+06 have been obtained during Oct. 2005-June 2006 at the frequency 111 MHz. About one-fourth of the observations for both pulsars were corrupted by strong interference, and the pulsar signal did not exceed 4σ on more than one-third of the days. The mean profiles are shown at Fig.2-3. This pulsar demonstrates a wider and more complex profile, than first object. Very probable the profile has three components separated on 400 ms and total width of the integration profile at 50 percent of the intensity maximum is about 1000 ms. Some days we observed the interpulse at the phase 0.5 of period (Fig.3).

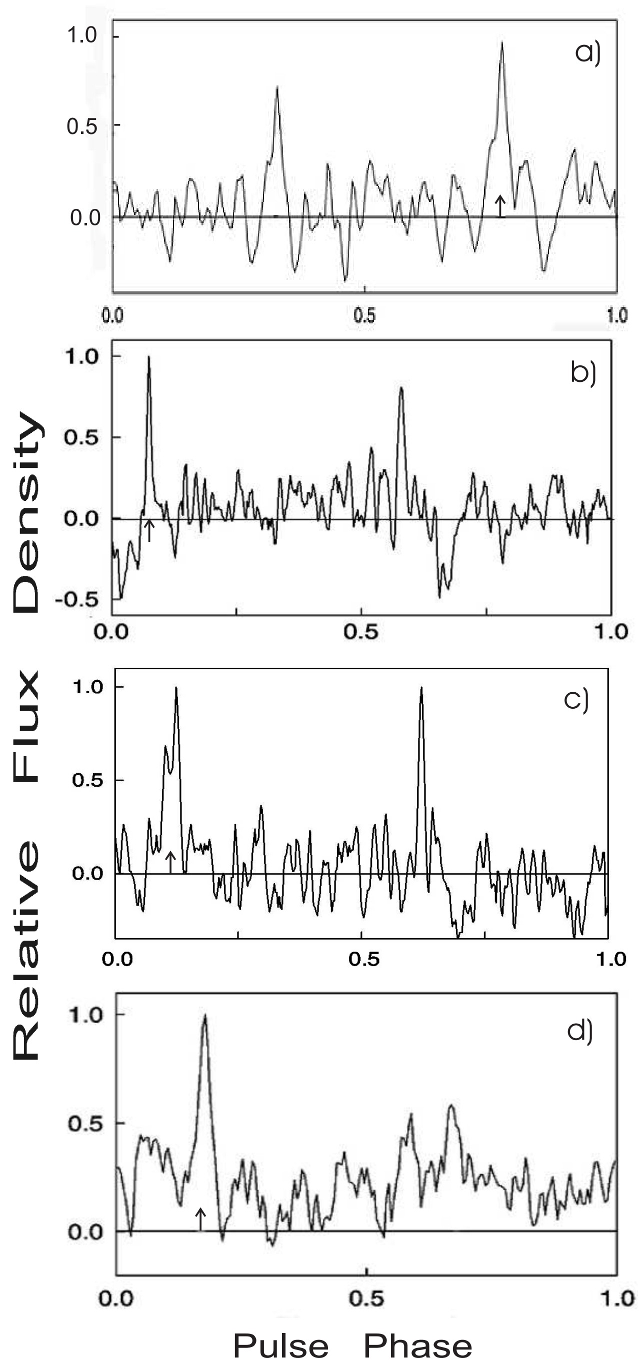

Fig. 1 Mean profiles of 1RXS J1308+21 (a)111.2 MHz (in arbitrary units), the sum of 50 periods; (b)87 MHz, sum of 14 periods; (c) 62 MHz, sum of 100 periods and (d),42 MHz, sum of 206 periods. The phases of main pulses are shown by the arrows.

To confirm the presence of periodic pulsed radio emission we used the search programme. The sum of 11 amplitude spectra is shown on Fig.4. There is few first harmonics at the frequencies suitable to the pulsar period. A few features are shown by the arrows. Tests of this method using observations of known pulsars demonstrate that pulsars with fluxes > 70 mJy can be confidently detected. We were able to obtain good spectra for XDINS 1RXS J1308+21, some examples of which were presented by Malofeev et al. (2004, 2005).

We obtained that the mean profile had the highest signal-to-noise ratio for $DM = 8 \pm 5$ pc/cm^3 in the case of XDINS J2143+06. All values of the the dispersion measures are presented in Table 1. The flux density was obtained as mean value during 6 days of observations (Table 1).

We measured the period and its derivative ($P = 9.437018(6)$s and negative $\dot{P} = -2.2(8) \cdot 10^{-13}$ s/s) at MJD 53680.0, during the MJD range 53657.7-53950.

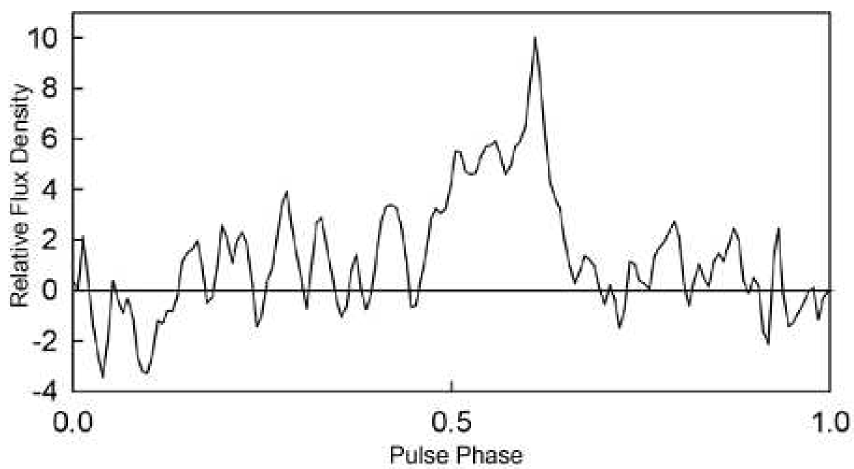

Fig. 2 Integrated profile of the 1RXS J2143+06 at 111.2 MHz (in arbitrary units) obtained by integrating of 20 periods on 16 Feb. 2006.

3 DISCUSSION AND SUMMARY

Table 1 lists the main parameters of the radio emission from the two pulsars. Comparison with the X-ray data shows that the radio measurements both extend our knowledge about these objects and carry fundamentally new information. We have detected strongly differing durations of the mean pulses, and derived independent estimates of the distances to sources based on their dispersion measures. The existence of the radio emission itself represents a fundamentally new fact, which raises doubts about either the magnetar model or our understanding of radio emission in superstrong magnetic fields.

Estimates of the distance to 1RXS J1308+21, or, more precisely, the star RBS 1223, obtained using several methods lie in the broader interval from 0.1 to 1.5 kpc (Hambaryan et al. 2002). Our dispersion measure (Table 1) and the model for the Galaxy yield an estimated distance to the pulsar of $0.25^{+0.2}_{-0.1}$ kpc. This suggests that the pulsar is close to us. In the case of J2143+06 we can estimate the distance as 0.4 kpc, in agreement with the estimate 0.28 kpc given by Zane et al. (2005).

The X-ray luminosity of 1RXS J1308+21 for a distance of 0.25 kpc is $L_x = 2.6 \cdot 10^{31}$ erg/s. If $\dot{P} = 1.310^{-13}$ s/s we obtain $E = 0.4 \cdot 10^{31}$ erg/s, that is less than the X-ray luminosity. To estimate the total radio luminosity, we must know the spectrum of the pulsar, or at least the spectral index. Using our flux density measurement at 111 MHz and the upper limits at 87 MHz and $S_{1400} < 0.94$ mJy (White et al. 1997) for J1308+21, we estimate the spectral index $\alpha > 1.7$.

Given that the spectra of two pulsars are probably steep, we estimated the integral radio luminosities of the pulsars by adopting the value $\alpha = 2.5$; this yeld the value $L_R = 3 \cdot 10^{26}$ erg/s for 1RXS J1308+21 and $L_R = 9 \cdot 10^{26}$ erg/s for J2143+06. Both XDINSs have among the lowest radio luminosities.

Comparison of the radio and X-ray data suggests large differences in two observed parameters. First, the radio and X-ray pulse widths differ by a factor of 16 for J1308+21, and by a factor of only 5 for J2143+06. Second, there is a huge difference in the radio and X-ray luminosities- six orders of magnitude for J1308+21.

1. We have detected periodic pulsed emission from two XDINSs 1RXS J1308+21 and J2143+06 in observations carried out on two low frequency radio telescopes of the Pushchino Radio Astronomy Observatory. The pulsars parameters are listed in the Table 1.

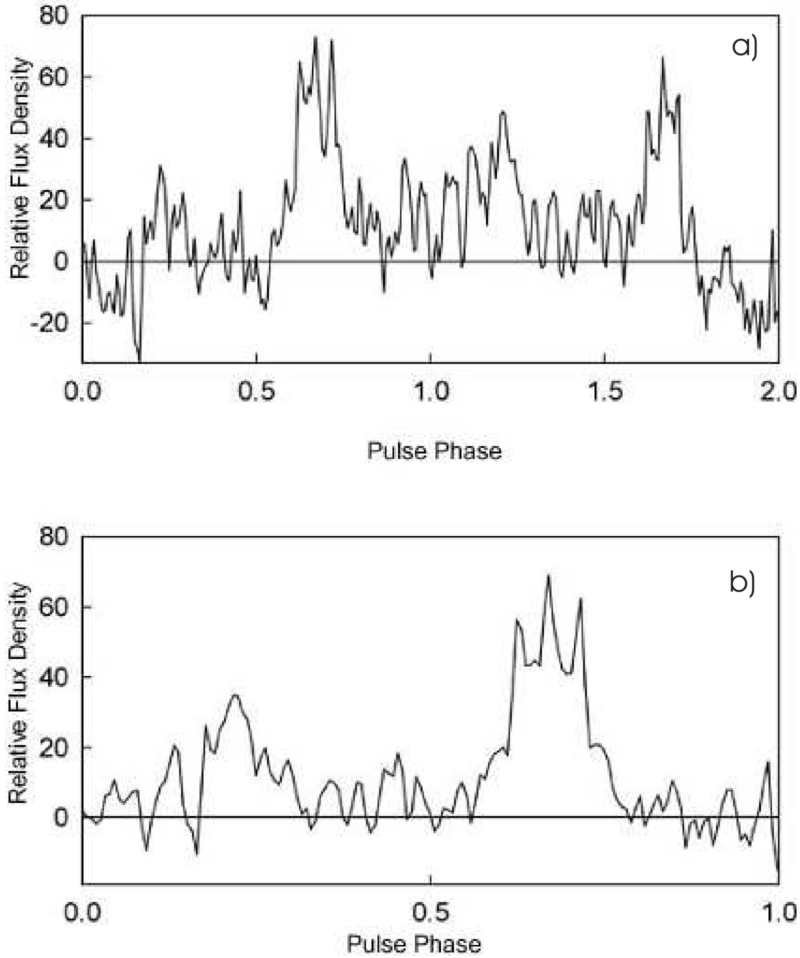

Fig. 3 (a)Integrated profile of the 1RXS J2143+06 at 111.2 MHz (in arbitrary units) obtained by summing 23 days during four month of 2004, when the observing window equals twice the apparent period (225 doubled periods); (b) Integrating profile obtained by the folding of data with one period, i.e., the sum of 450 periods.

Table 1 Measured and calculated parameters of the three pulsars

Parameter	1RXS J1308 +21	1RXS J2143+06
DM, pc/cm^3	5.7 ± 0.5	8 ± 5
S_{111}, mJy	50 ± 20	60 ± 25
$w_5 0$ (111 MHz), ms	140 ± 20	990 ± 60
D, kpc	0.25 ± 0.02	0.4 ± 0.2
L_R, erg/s	$3 \cdot 10^{26}$	$9 \cdot 10^{26}$
L_x, erg/s	$3 \cdot 10^{31}$	
E, erg/s	$0.4 \cdot 10^{31}$	

2. We have obtained independent estimates of the distances to pulsars, which are within the intervals of distances determined using other methods.

3. The main difference between the radio from the X-ray pulsed emission is that the integrated radio pulses of all objects are much narrower. There is radio interpulse for XDINSs 1RXS J1308+21 and J2143+06.

4. Our detection of weak radio emission in AXP 1E 2259+586, two XDINS and SGR (Shitov et al. 2000) at low frequencies and the detection strong one in transient AXP XTE J1810-197 (Camilo et al. 2006) at 0.7-42 GHz, together with detection of a radio pulsar (J1847-0130) with a long period

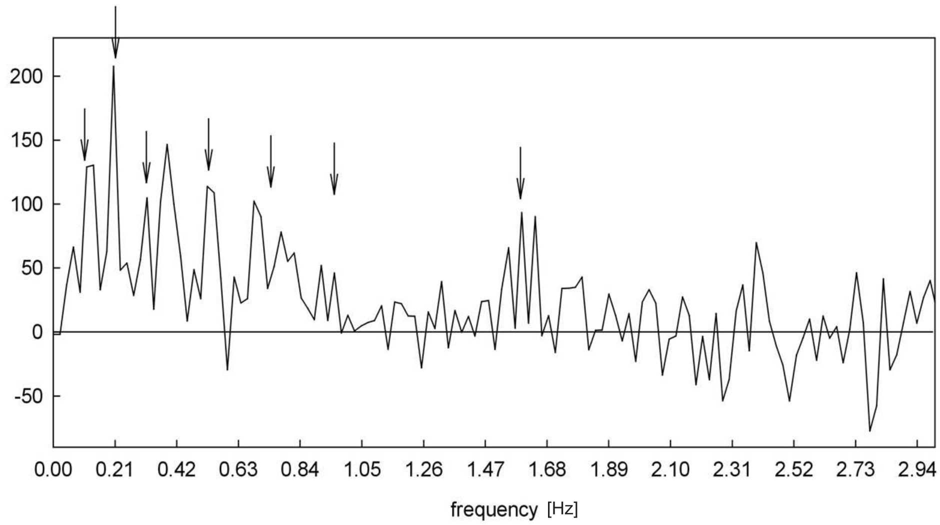

Fig. 4 Amplitude spectrum the 1RXS J2143+06. A few first harmonics are shown by the arrows.

(P = 6.7 s)and period derivative (McLaughlin et al. 2003), suggests the need to re-examine radio emission mechanisms in the magnetar model, or to consider other AXP, SGR and XDINS models that do not involve superstrong magnetic fields.

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