Pulse Emission Properties of the Magnetar XTE J1809-197 During the Flaring Activity in December 2018–April 2019

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Abstract. Measurements of pulsing radiation from the transient X-ray magnetar XTE J1810-197 were made in daily observations since 19 December 2018 to April 21, 2019 with the Northern sector of RATAN-600 radio telescope. Likely events 11 years ago in 2006, after a bright X-ray flare on December 8, 2018, weak radio pulses were detected from the magnetar. From 19 to 27 December we have detected the bright pulses during the consecutive passing source through the telescope's motionless beams of receivers at frequencies 2.3, 4.7, 8.2 and 11.2 GHz, and having bandwidths 80, 600, 970 and 2500 MHz respectively. Signal-to-noise ratio for the single pulses varied from 2 to 20 at different frequencies for a time sampling rate (TSR) of 7.8 ms. Later, we switched to a 132-second tracking through the source using mode when the receiver horns move synchronously with the source. So the magnetar was in the beam of the antenna during 25 rotation periods. The flux and substructure of the pulses varied from pulse to pulse up to 10 times. At last from March 14, 2019, we used one of the three four-channel 4.7 GHz radiometers, used for the FRB search with the atntenna 'Western sector' of RATAN-600. Soon it became clear that TSR of 250 microseconds and narrow channel bandwidth of 150 MHz, the pulses of the substructure of the main pulse become much narrower and brighter than for the wide bandwidth of 600 MHz and TSR=7.8 ms. Using delays of time of arrival of pulses with decrease of frequency of the channel we confirmed the dispersion measure DM=178.5 pc cm$^-$3, which was measured in 2006, although the variable substructure of the pulses at 4.7 GHz with a total width of about 50-200 ms introduced additional errors. Average spectrum of a single pulse in December 2018 was well approximated by a power law with spectral index -1.5 ± 0.2, the value characteristic of radio pulsars. The flux densities of individual pulses reached 8 Jy at 4.7 GHz and 2 Jy at 8.2 GHz. During the measurement program, the magnetar XTE J1809-197 became the brightest radio pulsar in the Milky way, and this state with gradual decrease (near 5 per cent per month) of average flux continued until April 21, 2019, when the observations were interrupted. In May 2019, pulsed radio emission has not already been detected.

Keywords: stars: evolution; pulsars: general; stars: magnetars

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1 Introduction

During the three-year sky survey with the Western sector of RATAN-600 on a three-beam four-channel complex of radiometers at 4.3-4.9 GHz we are looking for short bright pulses from the fast radio bursts (FRB). Such pulses were effected by cosmic dispersion in ionized interstellar and intergalactic medium (Trushkin et al. 2018). We have only detected the some giant pulses (GP) with fluxes of up to hundreds Jy from the Crab nebula pulsar. In 2017 with the Southern sector of RATAN-600 we have detected the quite bright pulses from nearby pulsar PSR 0329+54 on 2.3, 4.7 and 8.2 GHz in the broad bands. Now they considered that GP from young pulsars, and pulsations from neutron star with extremely strong magnetic field, magnetars, can be the most probable sources of FRB.

The source XTEJ1809-197 was detected by a bright X-ray flare in 2003 (Ibrahim et al. 2004). It showed periodic change brightness with the period of 5.5414 seconds (Bernardini et al. 2009). Almost immediately it is attributed to a small sample of anomalous X-ray pulsars (AXP) or transient magnetars. Only 30 AXPs are known in the Milky way. The distance to the magnetar is 3.5 kpc (Helfand et al. 2007). Extremely high luminosity was estimated, and the X-ray spectrum well fitted by two – warm and hot – black-body (bb) radiation or by bb (0.6-07 keV) + a power law with $\Gamma = 3$. Although AXP were not thought to emit pulsing radio emission, in 2005, XTEJ1809-197 had been detected bright (tenths of Jy) variable radio emission with relatively small pulse width (0.2s), interimpulse and high variability of the mean profile Helfand et al. (2007).

Existence of the bright interimpulse indicates that the slope of the magnetic axis to the axis of rotation can be close to 90 degrees. No connection with the known supernova remnant (SNR) has been found, although the estimated age of the magnetar is about 15000 years. It is worth noting that the magnetar locates in a complex region of the Galactic plane with nearby bright HII regions, and it is quite difficult to distinguish a faint SNR. We searched for the non-thermal radiation from possible SNR in the maps of different surveys of the sky, but did not find any bright extended source around XTE J1810-197.

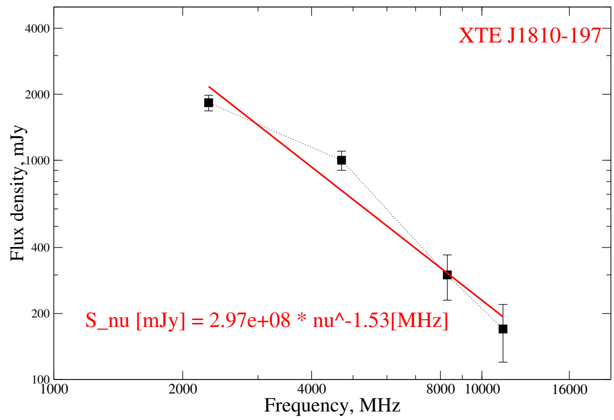

Fig. 1. The spectrum of the mean pulse during 19-25 December 2018

After the 50-fold decrease of the X-ray flux in 2007 XTE J1809-197 became undetectable at radio waves, while it have found weak pulsating radiation at a frequency of 62 MHz using the BSA telescope (PRAO)(Malofeev et al. 2012). Later on the 76-meter telescope Lovell had regularly monitored by magnetar, but from 2008 to October 2018 but no radiation was detected, and on 8 December pulses with a known period were again recorded at a signal-to-noise level of 400 at the frequency 1.4 GHz. On December 11 with a 100-meter telescope in Effelsberg, the flux was found at levels $22.5 + / - 0.2$ mJy at 4.74 GHz and $14.9 + / - 0.2$ mJy at 8.35 GHz, that gave a relatively flat the spectral index is -0.7. Almost 100% linear polarization were discovered with rapid change of positional angle and 10 per cent circular polarization of the pulses, but the interimpulses are missing. Data from the MAXI monitor on the ISS confirmed a significant increase in X-ray flux from the magnetar just on December 8 2018 and later radiation was detected constantly. On December 12 the pulses at 835 MHz were detected at the level of 9 mJy at the telescope UTMOST. Later the pulses of the magnetar were detected at 8.4 and 32 GHz with the 34-meter telescope in Canberra.

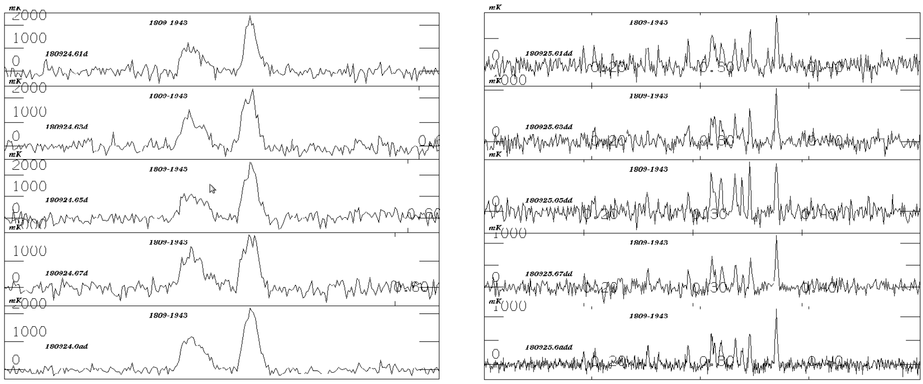

Fig. 2. Two examples of the bright individual pulses of XTE J1809-197 at 4.7 GHz on 24 and 25 March 2019 The panels are at 4.925, 4.725, 4.625 and 4.425 GHz (*from top to bottom*) with the calculated time shifts from the dispersion measure 178.5 pc cm^{-3}. The bottom panels are the mean profiles of pulses.

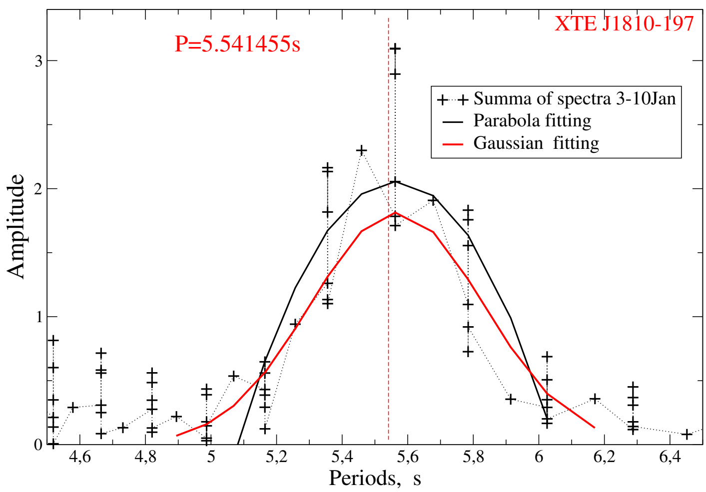

Fig. 3. The mean Fourier spectrum of the some days

2 Discussion

The properties of these pulses – peak flux density and substructure – are exceptionally strong and randomly changed from a pulse to a pulse. frequency at 4.7 GHz with a total duration of about 200 ms consisted of 1-10 different amplitude subimpulses with a duration of 2-10 ms. And these parameters do not depend from the frequency range. According to the results of measurements with a fixed carriage with receiver horns average flux pulses were detected and thus we can plot a radio spectrum. It is well approximated by a power-law dependence with spectral index -1.5 ± 0.2, that is, in general, very similar to the average spectrum radio pulsars (Fig.1). In general, records the light curves for 132 seconds at different frequencies are similar, although the numbers of brighter pulses at 2.3 and 4.7 GHz are significantly higher than at 8.2 GHz. But for full confidence in this conclusion we need to get more meaningful statistics.

For recordings in early January at 4.7 GHz, we performed a Fourier analysis, and then added all the spectra to determine the position of the most accurate a bright harmonic of 0.180 Hz, or a 5.54-second pulsar period. The obtained position of the harmonic maximum corresponded to the period 5.56 ± 0.02 seconds that within errors corresponds to the value 5.541455 s, obtained from data for 20-30 minutes (Maan et al. 2019).

In general, during observations on the RATAN-600 telescope (Trushkin et al. 2019) we have detected about 2000 pulses from the magnetar XTEJ1809-197 at 4.7 GHz and tens at 2.3 and 8.2 GHz. Single pulses reached the values of several Jy, which is characteristic only for giant pulses from some radio pulsars, for example, as from the 33-ms pulsar in the Crab nebula. Average 25 pulses day by day had a flux from 0.5 to 4 Jy at frequency 4.7 GHz. In contrast to the known data in 2005-2007 we could not to detect interimpulse. Interimpulses were not detected on the Effelsberg 100-meter (Del Palacio et al. 2018).

In 2019 the studies of this transient event from XTE J1809-197 were published by Shi Dal et al. about Parkes radio telescope wideband measurements, Gotthelf et al. (2019) about MAXI and NuStar measurements, Levin et al. (2019) about the Effelsberg and Lovell telescopes measurements and Maan et al. about GMRT low frequencies measurements. These papers discussed the radio and X-ray properties of the pulsating emission of the XTE J1809-197.

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