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Discovery of Anomalously Strong (Giant) Pulses from the Pulsar B1133+16 (J1136+1551) at a Frequency of 111 MHz

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Abstract. In the framework of our program of the Northern Hemisphere pulsar survey we have found anomalously strong pulses from the pulsar B1133+16 (J1136+1551). The observations were carried out at a frequency of 111 MHz using the Large Phased Array (LPA) radio telescope and digital pulsar processor. The peak flux density of the strongest observed individual pulse was 86 times as strong as the dynamic averaged (mean) profile, and a typical anomalous pulse has a duration of approximately 0.2 of the duration of the mean profile for the observational session. The flux density of individual pulses has a complex distribution function, different for the 1st and 2nd main components of the pulse and can be fitted with a combination of log-normal and power-law distributions. Thus, we can argue that the pulsar B1133+16 generates pulses having main features of the Giant Pulses (GP).

Keywords: pulsar, Giant Pulse, individual pulse, neutron stars, PSR B1133+16, PSR J1136+1551

Introduction

The pulsar B1133+16 (J1136+1551) is the second period (normal) isolated radio pulsar. It has a quite complex average profile with two well separated main components and a faint sub-component between them. The pulsar demonstrates weak intensity fluctuations of individual components at 147 and 400 MHz (Taylor & Huguenin, 1971). Fluctuations of the peak flux density of an individual pulse have been studied also at 408 and 2695 MHz. It was shown that the pulse intensity histogram at 2695 MHz for B1133+16 is characterized by the maximum probability at zero intensity and its maximum is about 6 in units of dynamic (obtained for the current observational session) mean profile (Hesse & Wielebinski, 1974). A similar shape of the distribution for the pulse energy histogram was obtained at 408 MHz (Ritchings, 1976) (See Figure 1).

Observations of PSR B1133+16 in the decameter wavelength range (18–30 MHz) have demonstrated strong sub-pulses with peak intensity 20 times greater than the peak intensity of the mean profile (Ulyanov et al., 2004). The authors called such sub-pulses Anomalously

Intense Pulses (AIPs). This is very similar to the GP phenomenon. For example, GPs for PSR B0950+08 were defined by (Signal & Vats,2012) as pulses with peak flux densities 10 times as large as the peak flux density of an average pulse. The information about the generation of AIPs from PSR B1133+16 at decameter waves has given us an impetus to investigate its features at meter wavelength (at a frequency of 111 MHz).

Observations and Processing

The observations were carried out at the Pushchino Radio Astronomy Observatory with the Large Phased Array (LPA) radio telescope in one linear polarization of the 1st antenna beam in 2013–2014. The effective area in the zenith direction was estimated as 20000 ± 4000 square meters. The main frequency of the observations was 111 MHz with a bandwidth of 2.3 MHz. The digital pulsar processor was used in the 460×5 kHz mode with post-detector DM removal. There were processed 11091 individual pulses. We calculated peak flux density distributions separately for both main components of the pulsar in units of the dynamic mean profile and $\sigma_{\rm noise}$ (in signal-to-noise ratio).

Results and Conclusions

PSR B1133+16 is an active radio pulsar with a multicomponent profile having two strong and one faint intermediate components and changing mods (two main mods). We have observed strong pulses in all modes of the pulsar and at the phase of both strong main components. We detected about 1 pulse with an intensity >30 of the dynamic mean profile for 833 pulsar periods. Examples of the observed AIPs are shown in Figures 2–5 (for the first and second strong components of the mean profile). A histogram of the pulse distribution *vs* intensity of a dynamic average profile is shown in Figures 6 and 7. The distribution of the peak flux density (in signal to noise ratio units) in the Log-Log scale is shown in Figures 8–9. As we can see, the best-fit solution gives us a distribution of the strong pulses as a combination of two log-normal distributions at the longitude of the first component; two log-normal and power-law distribution at the longitude of the second component of the pulsar. It is worth noting that the widths of the strongest individual pulses are about 20% of the width of the corresponding component or less, which is typical of GPs.

We can conclude that AIPs of PSR B1133+16 observed at 111 MHz at least partially satisfy the main criteria of GPs: peak flux densities are sometimes 30 times or stronger than the average pulse, pulses were detected at the phase of the mean profile, they are significantly narrower than the corresponding components of the mean profile (∼20% at 1/2 intensity). The pulses have a complex peak flux density distribution, different for the first and the second components, including (for the second component) a power-law distribution of the strongest pulses with a power index of -2.39 ± 0.08. The pulsar belongs to a sub-class of pulsars with a low magnetic field on the light cylinder generating GPs at low radio frequencies: J0034−0721, J0659+1414, J0953+0755, J1115+5030, B1237+25, and J1752+2359 (see Kazantsev & Potapov, 2015). Its AIPs have properties of GPs typical of this sub-class.

Acknowledgements

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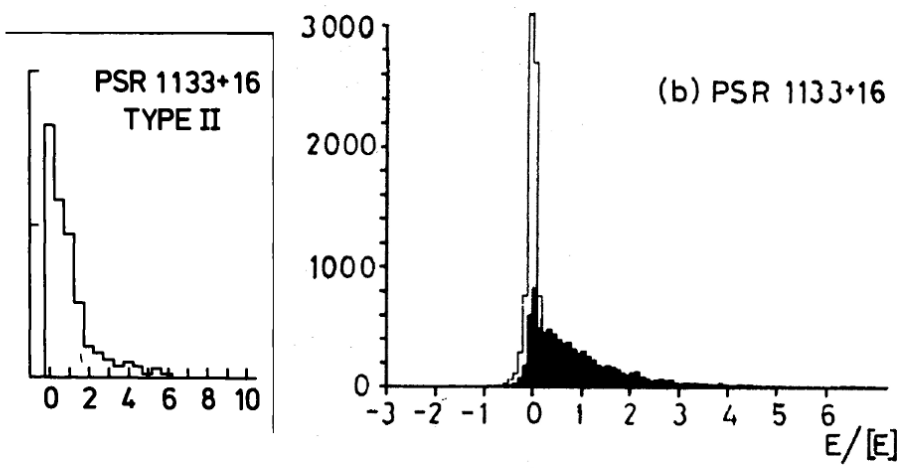

Figure 1: Left panel: pulse intensity histogram at 2695 MHz for B1133+16 in units of the mean profile (Hesse& Wielebinski, 1974). Right: pulse energy histogram (shaded columns) in units of the mean pulse energy (Ritchings, 1976).

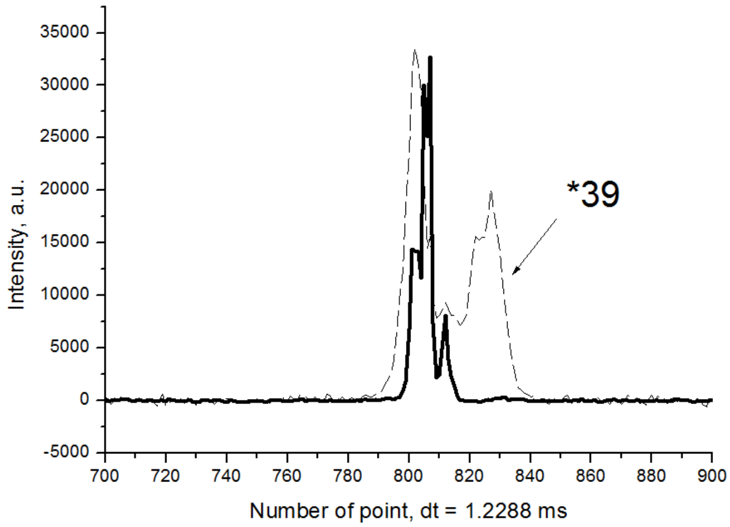

Figure 2: The strongest pulse of PSR B1133+16 observed in the session of March 25, 2014. The averaged pulse is multiplied by 39. First component, second (anomalous) mode.

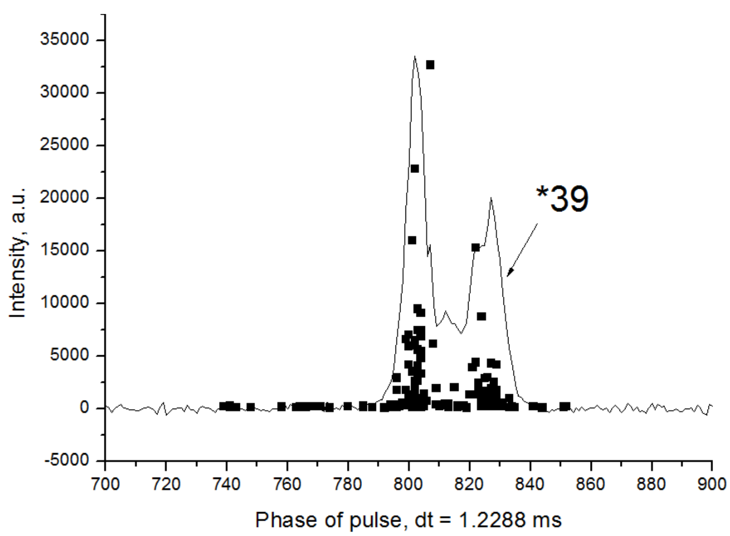

Figure 3: Strong pulses of PSR B1133+16 observed in the session of March 25, 2014. The distribution over the phase of the average profile.

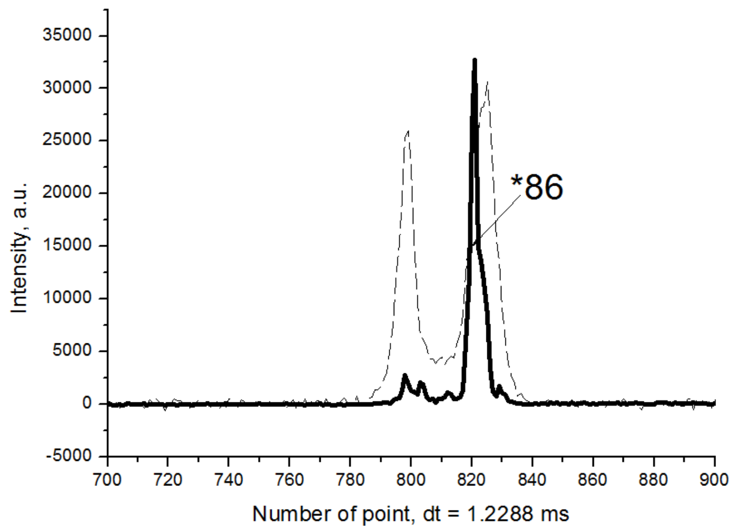

Figure 4: The strongest pulse of PSR B1133+16 observed in the session of March 14, 2014. The averaged pulse is multiplied by 86. Second component, first mode.

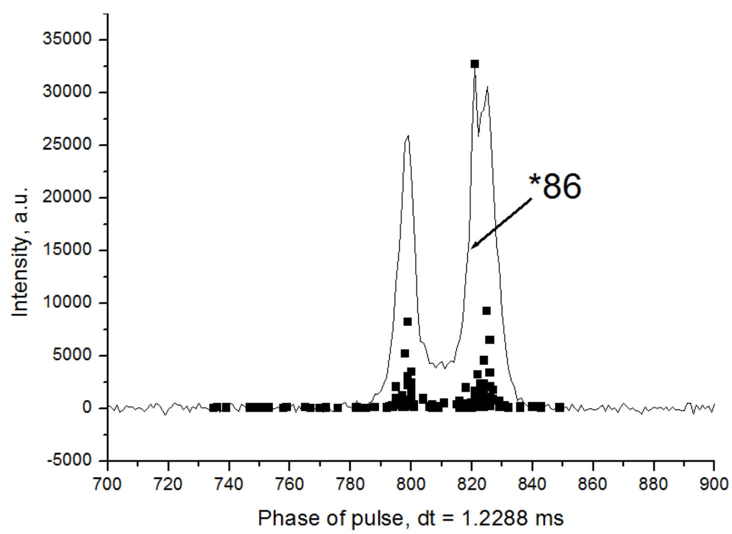

Figure 5: Strong pulses of PSR B1133+16 observed in the session of March 14, 2014. The distribution over the phase of the average profile.

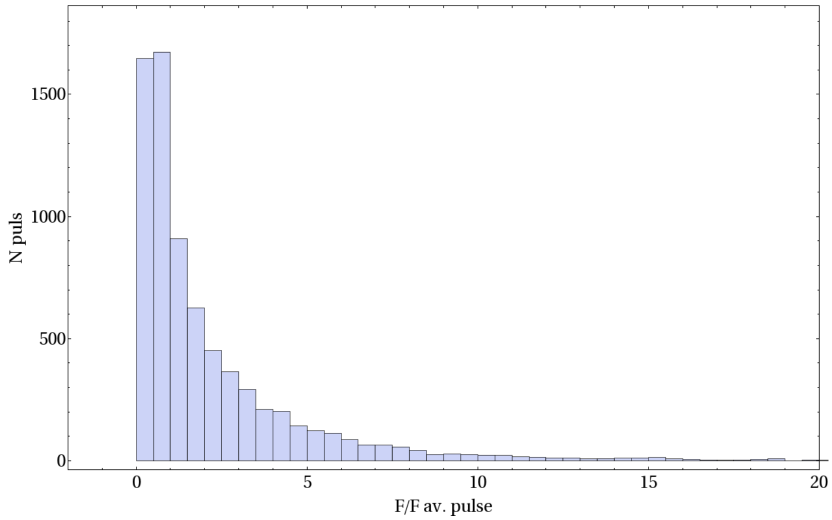

Figure 6: Histogram of the intensity of individual pulses on the longitude of the first (left-hand) component, in units of an average (per session) pulse. The right-hand side of histogram is cut off.

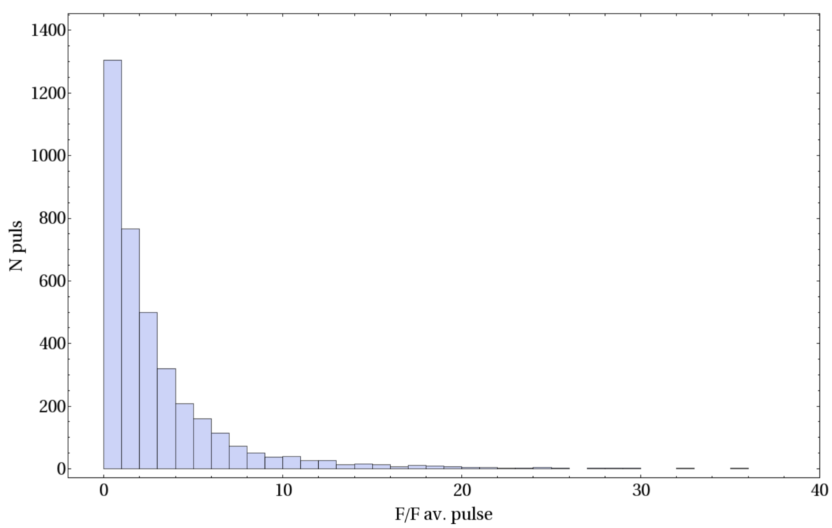

Figure 7: Histogram of the intensity of individual pulses on the longitude of the second (right-hand) component, in units of an average (per session) pulse. The right-hand side of histogram is cut off.

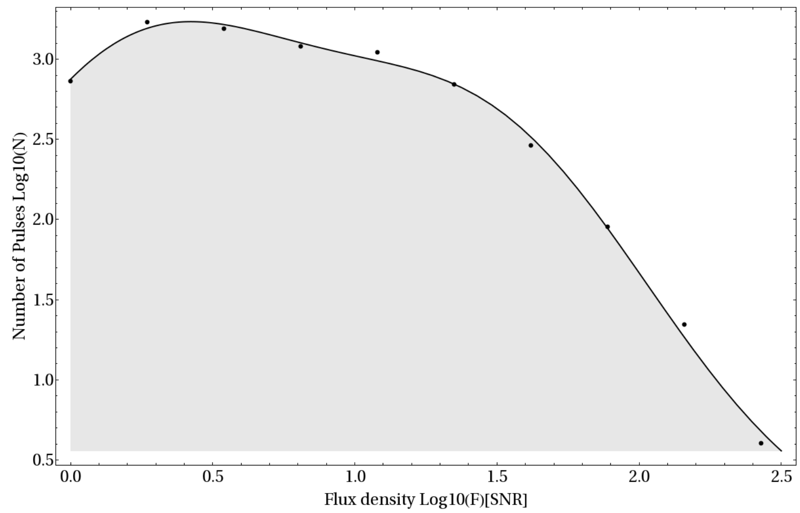

Figure 8: Distribution of the peak flux density of individual pulses on the longitude of the first (left-hand) component in the Log-Log scale (in SNR – signal to noise ratio – units). Fitted by the sum of two log-normal distributions

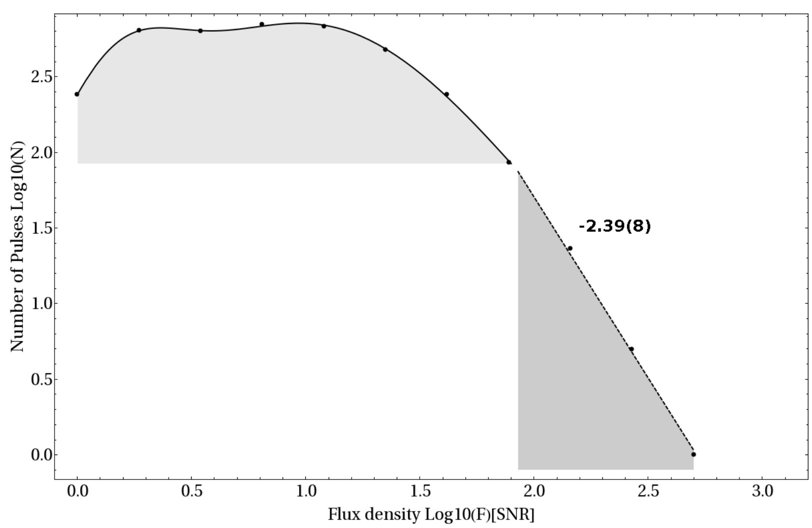

Figure 9: Distribution of the peak flux density of individual pulses over the longitude of the second (right-hand) component(in SNR – signal to noise ratio – units) of the second pulse component in the Log-Log scale (in SNR - signal to noise ratio units). Fitted by the sum of two log-normal distributions and power-law distribution with an exponent of -2.39 ± 0.08

Открытие аномально мощных (гигантских) импульсов пульсара B1133+16 (J1136+1551) на частоте 111 МГц

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Резюме. В рамках программы обзора пульсаров северной полусферы нами были обнаружены аномально сильные импульсы пульсара B1133+16 (J1136+1551). Наблюдения проводились на частоте 111 МГц с использование Большой Сканирующей Антенны (БСА) и цифрового пульсарного процессора. Пиковая плотность потока наиболее сильного из зарегистрированных импульсов была в 86 раз интенсивнее динамичного среднего профиля, а ширина типичного аномального импульса составила около 0.2 от ширины среднего профиля за сеанс. Плотность потока индивидуальных импульсов имеет сложное распределение, которое может быть описано с помощью комбинации логнормального и степенного распределения. Таким образом, мы можем утверждать, что пульсар B1133+16 генерирует импульсы, обладающие основными свойствами Гигантских Импульсов (ГИ).

Ключевые слова: пульсары, гигантские импульсы, индивидуальные импульсы, нейтронные звезды, PSR B1133+16, PSR J1136+1551