Giant Pulses of Pulsar Radio Emission

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Abstract. Review report of giant pulses of pulsar radio emission, based on our detections of four new pulsars with giant pulses, and the comparative analysis of the previously known pulsars with giant pulses, including the Crab pulsar and millisecond pulsar PSR B1937+21.

1. Introduction

Giant pulses (GPs)- a short duration outbursts- are a special form of pulsar radio emission.

This is a most striking phenomenon of the pulsar radio emission. For normal pulsars, the intensity of single pulses varies by no more than one order of magnitude (Hesse & Wielebinski 1974, Ritchings 1976). GPs peak flux densities can exceed hundreds and thousands of times the peak flux density of regular pulses. GPs are the brightest sources of the radio emission observed in the Universe.

This rare phenomenon has been detected only in 11 pulsars among more than 1 500 known ones. The first two of them to be discovered were Crab pulsar PSR B0531+21 (Staelin & Reifenstein 1968; Argyle & Gower 1972; Gower & Argyle 1972) and the millisecond pulsar PSR B1937+21 (Wolszczan, Cordes & Stinebring 1984), and for a long time remain little investigated.

For over 20 years only these two pulsars were known to emit GPs. The last 5 years were marked by a systematic search of GPs that benefit from a fast progress in the detection of nine new pulsars with GPs. They are PSR B1821-24 (Romani & Johnston 2001), PSR B1112+50 (Ershov & Kuzmin 2003), PSR B0540-69 (Johnston & Romani 2003), PSR B0031-07 (Kuzmin, Ershov & Losovsky 2004), PSR J0218+42 (Joshi et al. 2004), PSR B1957+20 (Joshi et al. 2004), PSR J1752+2359 (Ershov & Kuzmin 2005), PSR J1823-3021A (Knight, Bailes et al. 2005) and PSR B0656+14 (Kuzmin & Ershov 2006). GP of the Crab pulsar observed at frequency 111 MHz inside an interval of 150 normal pulses masked by noise.

2. Observations

GPs are observed as a rare very strong pulses of pulsar radio emission standing out of the noise background and underlying ordinary individual pulses. An example of one of 150 normal pulses masked by noise.

2.1. Flux density, energy, spectra and intensity distribution.

GPs are the most extremal phenomena of pulsar radio emission. Their peak flux densities can exceed hundreds and thousands of times the peak flux density of an AP. An example of a GP in comparison with an AP of the millisecond pulsar PSR B1937+21 is shown in Fig.2. The peak flux density of GPs in this pulsar at 1650 MHz ranges up to 65 kJy and exceeds the peak flux density of an AP by a factor of \(3 \times 10^5\) (Soglasnov et al. 2004). An energy of GPs can exceed the energy of the AP by a factor of 60.

The peak flux densities of GPs from the Crab Nebula pulsar PSR B0531+21 at 2228 MHz exceeds the peak flux density of an AP up to a factor of 5 \(\times\) \(10^5\). An energy of the GP exceeds the energy of the AP by a factor of 60 (Kostyuk et al., 2003). GPs of the Crab pulsar have been detected in a very wide frequency range from 23 MHz (Popov et al. 2006) up to 15 GHz (Hankins et al. 2000). Only small part of GPs...
occurs simultaneously in different frequency ranges. Radio spectra of these GPs were studied by simultaneous multi-frequency observations. Sallmen et al. (1999) observations of GPs in pulsar PSR B0531+21 at two frequencies 1.4 and 0.6 GHz show that the GPs spectral indices fall between -2.2 and -4.9, which may be compared to the AP value for this pulsar -3.0. Popov et al. (2006) observations of this pulsar at three frequencies 600, 111 and 43 MHz reveal that the GPs spectral indices fall between -1.6 and -3.1 with mean value -2.7, that also may be compared to the AP value for this pulsar -3.0. Popov et al. (05).

Kinkhabwala et al. (2000) have estimated the average spectral properties of the GPs emission of the pulsar PSR B1937+21. Using the top eight GPs at three frequencies 430, 1420 and 2380 MHz, they find a somewhat steeper slope of -3.1 for the GPs spectrum, compared the -2.6 slope for the normal emission spectrum of this pulsar.

Another distinguishing characteristic of pulsars with GPs, as demonstrated in Fig.3, is their two-mode pulse intensity distribution. At low intensities of ordinary pulses, the pulse strength distribution is Gaussian one, but above a certain threshold the pulse strength of GPs is roughly power-law distributed (Argyle & Gower 1972, Cognard et al. 1996).

The next peculiarity of GPs, as demonstrated in Fig. 2 for PSR B1937+21, is a much shorter time-scale of GP as compared with an AP. The width of this GP is τ ≤ 15 ns (Soglasnov et al. 2004).

Hankins et al. (2003) found in pulsar PSR B0531+21 the pulse structure as short as 2 ns. If one interprets this pulse duration in terms of the maximum possible size of emitting region l ≤ c × τ, where c is the speed of a light, the time-scale τ = 2 ns corresponds to a light-travel size of an emitting body l of only 60 cm, the smallest object ever detected outside our solar system.

The brightness temperature of the GPs is

$$T_B = S_{\text{peak}} \frac{\lambda^2}{2k\Omega}$$

where $S_{\text{peak}}$ is the peak flux density, $\lambda$ is the radio wavelength, $k$ is the Boltzmann’s constant, and $\Omega \approx (l/d)^2$ is the solid angle of the radio emission region.

For observed in Crab pulsar at frequency 5.5 GHz peak flux density of 10^3 Jy with τ = 2 ns (Hankins et al. 2003) the brightness temperature of GPs is as high as 10^{37} K.

Soglasnov et al. (2004) have proved that the majority of GPs from the millisecond pulsar PSR B1937+21 are shorter than 15 ns. At a frequency of 1.65 GHz a peak flux density of 65 x 10^3 Jy with τ = 15 ns show that the brightness temperature of GPs in this pulsar is $T_B \geq 5 \times 10^{39}$ K, the brightest radio emission observed in Universe.

However, these evaluations of size and brightness temperature of an emitting body are not unambiguous. Gil & Melikidze (2004) argued that the apparent duration of the observed impulse $\tau_{\text{obs}}$ may be shorter \(^1\) than the duration of the emitted one as $\tau_{\text{rad}}$ as $\tau_{\text{obs}} = \tau_{\text{rad}} \times \gamma^{-2}$. For Lorentz factor $\gamma \approx 100$, the time-scale of pulse structure for B1937+21 will transformed from observed $\tau_{\text{obs}} = 2$ ns to emitted $\tau_{\text{rad}} = 20 \mu$s. As well as $T_B \propto \Omega^{-1} \propto \tau^{-2}$, the brightness temperature will be reduced to $T_B \approx 10^{31}$ K.

\(^1\) Relativistic shortening of a pulse duration were claimed by Smith (1970) and Zheleznyakov (1971).
Giant pulses is a special form of pulsar radio emission, that is characterized by very large excess of flux density and energy of radio emission relative to an average pulse, the power-law statistic of the energy distribution, giant pulses occur in various types of pulsars in a wide range of periods $P = 1.5 - 1600$ ms and magnetic field at the light cylinder $B_{LC} = 4 - 10^6$ G over a wide range of radio frequencies.

4. Summary

Giant pulses is a special form of pulsar radio emission, that is characterized by very large excess of flux density and energy of radio emission relative to an average pulse, the power-law statistic of the energy distribution, giant pulses occur in various types of pulsars in a wide range of periods $P = 1.5 - 1600$ ms and magnetic field at the light cylinder $B_{LC} = 4 - 10^6$ G over a wide range of radio frequencies.

3. Are giant pulses inherent to some special property of pulsars?

The first detected pulsars with GPs PSR B0531+21 and PSR B1937+21 were among a small group of pulsars with highest magnetic field at the light cylinder $B_{LC} = 10^4 - 10^5$ G. This gave a rise to the suggestion that GPs are inherent to pulsars with very strong magnetic field at the light cylinder and the search of GPs was oriented on those pulsars. As a result GPs were detected in five other pulsars with very strong magnetic field at the light cylinder: PSR B1821-24 (Romani & Johnston 2001), PSR B0540-69 (Johnston & Romani 2003), PSR J0218+42 (Joshi et al. 2004), PSR B1957+20 (Joshi et al. 2004) and PSR J1823-3021 (Knight et al. 2005).

However detection of the GPs in four pulsars with ordinary magnetic field at the light cylinder: PSR B0031-07 (Kuzmin, Ershov & Losovsky 2004), PSR B0656+14 (Kuzmin & Ershov 2006), PSR B1112+50 (Ershov & Kuzmin 2003) and PSR J1752+2359 (Ershov & Kuzmin 2005) have revealed that GPs can occur in ordinary pulsars too.

Johnson & Romany (2004) claimed that GPs may be associated with pulsars which possess a high energy X-ray emission. But the alignment of X-ray pulses with GPs is observed only for four objects among eleven known pulsars with GPs and is not a proper indication for GPs.

Knight et al. (2005) argued that GPs may be indicated by large rotation loss luminosity $\dot{E} \propto P^{-3}$. But in fact the rotation loss luminosity of the known 11 pulsars with GPs are differ by 6 orders of magnitude and is not a proper indication for GPs also.

GPs occur in various types of pulsars in a wide range of periods $P = 1.5 - 1600$ ms and magnetic field at the light cylinder $B_{LC} = 4 - 10^6$ G over a wide range of radio frequencies.

Fig. 4. (top) GP in pulsar PSR B0656+14 at 111 MHz (bold line) together with the AP (dotted line). The plot of AP is presented on a 500 times larger scale and flux densities of GP and AP are shown separately on the left and right sides of the $\nu^2$ scales. (bottom) The phases of the observed GPs relative to the center of the AP. N is the number of GP. (after Kuzmin & Ershov ,2006)
Table 1. Properties of the Giant Pulses

| PSR       | $P_{\text{ms}}$ | $\log B_{LC}$ | $\text{Freq}$ (GHz) | $S_{GP}/S_{AP}$ | $T_B$ (K) | $E_{GP}/E_{GP}$ | References          |
|-----------|----------------|---------------|---------------------|-----------------|-----------|-----------------|---------------------|
| B0031-07  | 943            | 6.9           | 0.04                | 400             | $\geq 10^{28}$ | 75              | Kuzmin & Ershov 2004 |
|           | 0.11           |               | 120                 |                 | $\geq 10^{28}$ | 8               | Kuzmin et al. 2004  |
| J0218+42  | 2.3            | $3.2 \times 10^5$ | 0.61                | 1.3             | 51         |                 | Joshi et al. 2004   |
| B0531+21  | 33.4           | $9.8 \times 10^5$ | 0.14                | 300             | $\geq 10^{36}$ | 75              | Kostyuk et al. 2003 |
|           | 0.59           |               | $6 \times 10^4$     |                 | $\geq 10^{34}$ | 80              | Kostyuk et al. 2003 |
|           | 2.23           |               | $5 \times 10^5$     |                 | $\geq 10^{37}$ |                | Hankins et al. 2003 |
|           | 5.50           |               |                     |                 |           |                 |                     |
| J0540-69  | 50.5           | $3.5 \times 10^5$ | 1.38                | 5 $\times 10^3$ | $\geq 10^{26}$ | 110             | Kuzmin & Ershov 2006 |
| J0656+14  | 385            | 770           | 0.11                | 600             | $\geq 10^{26}$ | 10              | Ershov & Kuzmin 2003 |
| B1112+50  | 1656           | 4.1           | 0.11                | 80              | $\geq 10^{28}$ | 200             | Ershov & Kuzmin 2005 |
| J1752+2359| 409            | 71            | 0.11                | 260             | $\geq 10^{28}$ |                |                     |
| B1821-24  | 3.0            | $7.2 \times 10^5$ | 1.51                |                 | 81         |                 | Romani & Johnston 2001 |
| J1823-3021A | 5.4         | $2.5 \times 10^5$ | 0.68                | 680             | 64         |                 | Knight et al. 2005  |
|           | 1.40           |               | 1700               |                 | 28         |                 |                     |
| B1937+21  | 1.5            | $9.8 \times 10^5$ | 0.11                | 600             | $\geq 10^{35}$ | 65              | Kuzmin & Losovsky   |
|           | 1.65           |               | $5 \times 10^5$     |                 | $\geq 5 \times 10^{39}$ | 60 | Soglasnov et al. 2004 |
| B1957+20  | 1.6            | $3.8 \times 10^5$ | 0.61                |                 |           | 129             | Joshi et al. 2004   |

for different magnetic field at the light cylinder, pulsar periods and frequencies.

A light-travel size of an emitting body indicate the smallest object ever detected outside our solar system.

Giant pulses are the brightest sources of radio emission among the known astronomical objects.

Giant pulses exist in various types of pulsars in a wide range of periods, magnetic field at the light cylinder and broad frequency range.

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