Review of overall parameters of giant radio pulses from the Crab pulsar and B1937+21

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Abstract. We present a review of observed parameters of giant radio pulses, based on the observations conducted by our group during recent years. The observations cover a broad frequency range of about 3 octaves, concentrating between 600 and 4850 MHz. Giant pulses of both the Crab pulsar and the millisecond pulsar B1937+21 were studied with the 70-m Tidbinbilla, the 100-m GBT, 64-m Kalyazin and Westerbork radio telescopes. We discuss pulse energy distribution, dependence of peak flux density from the pulse width, peculiarities of radio spectra, and polarization properties of giant radio pulses.

Keywords: pulsars, giant radio pulses, Crab pulsar, B0531+21, B1937+21
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INTRODUCTION

Giant pulses (GPs) are abnormally short (down to nanoseconds), bright (up to MJy), polarized (up to 100%) bursts of pulsar radio emission. They occur in the very narrow windows and are known only for a handful of pulsars.

Here we present the detailed study of two brightest sources of giant pulses – the Crab pulsar and millisecond pulsar B1937+21.

Both the Crab pulsar and the PSR B1937+21 have many similar characteristics that can be a clue for understanding the giant pulse phenomenon. They both have an interpulse in their regular profiles and highest values of magnetic field at the light cylinder (about 10^6 G). Popov et al.[1] have recently proposed that the Crab regular profile consists of only GPs whereas the precursor observed at the frequencies below 1 GHz represents the regular profile. Hence, for both the Crab pulsar and the pulsar B1937+21 GPs occur at the very trailing edge of the regular emission profile.

Polarization properties are also similar. In general, GPs from the Crab pulsar are wider (up to 100 μs), mainly with some degree of linear polarization. However, Hankins et al. [2] showed that these pulses consist of very narrow (<2 ns) bursts with 100% circular polarization, either left or right. The number of these fundamental bursts in any individual broad GP was estimated by Popov et al.[1] to be about 100. Giant pulses from the B1937+21 reveal the broad spectrum of polarization properties: they can be almost 100% circular polarized, and they may have high linear polarization as well. This means that probably they also consist of narrower pulses.

Many similar properties are undoubtedly manifestations of the same physical process responsible for GP emission. However, there are still some differences, that represent either the individual character of these two pulsars or the influence of the ISM, or both.

ENERGY DISTRIBUTION

Unlike regular emission, which has normal or log-normal energy distribution, giant pulses follow power-law energy distribution:

$$N(\text{GPs with } E > E_0) \sim {E_0}^{\alpha} \tag{1}$$

Both for the Crab pulsar and B1937+21 there is a correlation between GP energy and width: the brightest pulses have the shortest duration. As a consequence, giant pulses with different duration have distributions with different values of α and the distribution in GP width depends on the range of energy used.

One can raise the question: is there any cutoff of power-law distribution at low and at high energies?

The recent 160 hours monitoring campaign[1] of the Crab pulsar carried out by Popov et al.[3] revealed that the energy distributions of GP **do follow a power-law** at both 600 and 4850 MHz **up to the highest energy detected**, namely 5 MJy·μs for 600 MHz and 0.07 MJy·μs for 4850 MHz.

The investigation of energy distribution of Crab GPs with respect to their different widths carried out by

[1] Simultaneous observations at 600, 1650 and 4850 MHz at Kalyazin radio telescope with time resolution 500 μs. Both circular polarizations were recorded at 1650 and 4850 MHz, only RCP – at 600 MHz.

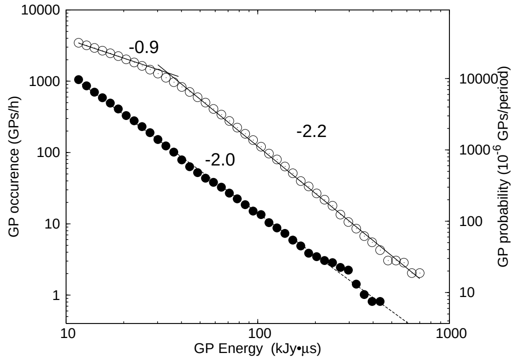

FIGURE 1. Cumulative energy distribution for the Crab pulsar GPs at 600 MHz. Filled circles mark interpulse, open – main pulse.

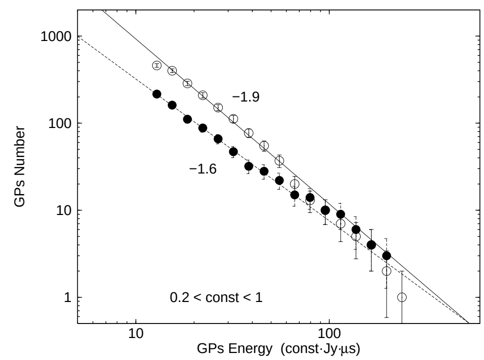

FIGURE 2. Cumulative energy distribution for GPs from B1937+21 at 2100 MHz. Main pulse is marked by open circles, interpulse – by filled circles.

Popov & Stappers [4] at 1200 MHz[2] can shed light on the low-energy part of the distribution. It was disclosed that the distributions manifest notable differences for the different width groups. For main pulse, the wider are GPs, the steeper is their distribution (α varying from -1.7 to -3.2). There are also **breaks in the power-law fits indicating flattening at low energies** (α switches to -1.0 - -1.9). At the same time, the interpulse GPs can be fitted with one power-law function with $\alpha = -1.65$. A similar situation was found at 600 MHz[3] (see Figure 1), although in this case GPs from the interpulse are fitted by power-law with α varying from -1.6 to -3.1 going from the shortest to the longest GP.

The break-point pulse energy found (4 kJy·μs at 1200 MHz and 40 kJy·μs at 600 MHz) suits a power-law frequency dependence presented by Popov & Stappers [4]:

$$E_{break}(f) = 7f^{-3.4} \qquad \text{kJy}\cdot\mu\text{s}, \qquad (2)$$

where f is in GHz.

Giant pulses from B1937+21 are in general fainter than those from the Crab pulsar, so it is more difficult to collect the sufficient number of events.

As a result of observation of B1937+21 at the 70-m Tidbinbilla radio telescope at 1650 MHz[4] we found that GP with energies from 100 to 1000 Jy·μs follow a power law with $\alpha = -1.4$ for both main pulse and interpulse.

Another attempt to found low-energy break was made at 2100 MHz using the 100-m Green Bank telescope[5]. The result is shown in Figure 2. Owing to much better GBT sensitivity, we were able to detect more low-energy GPs at 2100 MHz, but we still did not find the low-energy cutoff.

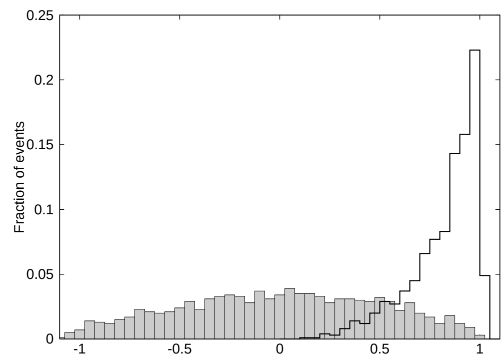

FIGURE 3. Distribution of polarization degree of GPs from Crab pulsar at 2244 MHz. Empty bars represent the degree of linear polariztion, filled – circular (negative for LCP and positive for RCP).

POLARIZATION PROPERTIES

As the result of observations of B1937+21 at 2100 MHz[5] (see [5] for details) we found that the majority of GPs (>55%) have circularly polarized peaks with fractional polarization >0.8 (either left or right). The fractional linear polarization of GPs is also very high, namely 48% have fractional linear polarization of 0.4-0.5.

The position of the peak in circular and linear polarization profiles within the same GP could be different. Hence, the same GP can reveal both strong circular and strong linear polarization. The fraction of GPs with both large circular (>0.8) and linear (>0.4) fractional polarizations is almost 38%. Thus, GPs from B1937+21 are very strongly polarized, both circularly and linearly.

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[2] Westerbork Synthesis RT, total intensity recorded for 3.5 hr with time reolution of 4.1 μs.
[3] Kalyazin RT, 295-min observation with RCP recorded with time resolution of 125 ns.
[4] RCP recorded for 39 min with time resolution of 31.25 ns.
[5] Both circular polarizations were recorded for 7.5 hr with time resolution of 7.8 ns.

Polarization properties of the Crab GPs[6] are displayed in Figure 3. In general, the properties are identical: high degree of linear and circular polarization with random fluctuations in different spikes within the same giant pulse.

PECULARITIES OF RADIO SPECTRA

Eilek & Hankins [6] revealed that interpulse GPs at frequencies more than 3 GHz differ significantly from GPs at main pulse both in profile and spectrum properties. The spectra of high-frequency interpulse GPs show striking regularly spaced structure, while those from main pulse do not. Hence, the hypothesis was proposed that interpulse GPs at frequencies > 3 GHz originate in another region inside the pulsar magnetosphere. During our tri-frequency monitoring of the Crab pulsar[1] we have found 8 GPs on interpulse longitudes occurred simultaneously at 3 frequencies: 600, 1650, and 4850 MHz (see Figure 4). The probability of an occasional coincidence of 2 independent events in the same pulse is 0.0003. Thus, the suggestion about other localization of high-frequency interpulse GP emitters is very unlikely.

In addition, we have found the large number of GPs that occurred simultaneously at 600 and 4850 MHz, but not at 1650 MHz, so GP spectra must have large-scale irregularities with the scale $\delta\nu/\nu$ of about 0.5.

It was revealed (see [3] for details), that GPs at high frequency have flatter indices (even positive) than those at low frequency. In general, radio spectra in this range can not be represented by an unique power-law function, or even power-law function with break.

DISCUSSION

It seems rather unlikely that any plasma mechanism is responsible for GP emission. Extermely short GP duration implies very small GP emission region, $10^2 - 10^3$ cm. For strongest GPs, volume density of the emission exceeds by many orders density of plasma energy, it is comparable with the density of the energy of the magnetic field. Huge peak flux densities for the strongest GPs from the Crab pulsar detected at the Earth means an ultimate field strength of EM wave inside pulsar's magnetosphere. Interaction of such strong wave with plasma is very specific: the wave accelerates charged particles up to relativistic speed over one wave cycle, and the particles emit secondary waves at different frequency in different directions than the incident wave. The process may

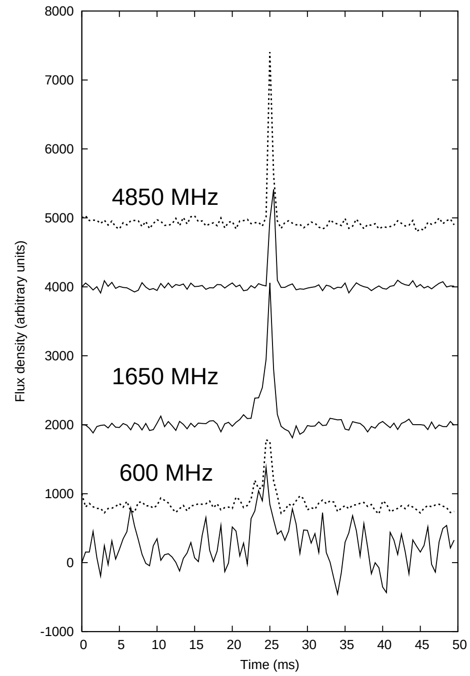

FIGURE 4. An example of GPs found simultaneosly on 600, 1650 and 4850 MHz. Solid line stands for RCP, dotted – for LCP.

explain unusual HFC1 and HFC2 components in the profile of the Crab pulsar.

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[6] Kalyazin RT, 3 hours of recording both RCP and LCP at 2244 MHz with time resolution of 31.25 ns.