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Individual Pulses Behaviour of PSR B0950+08 at 111 MHz

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Abstract We carried out an analysis of the behaviour of individual pulses of PSR B0950+08 based on our observations at a frequency 111.2 MHz. The intensity and phase distribution of pulses at different longitudes of the pulsar average profile was investigated. The intensity of individual pulses can exceed ten times the average profile amplitude. It was shown that the intensity distribution of weak pulses with longitude of their appearance differs strongly from the distribution of strong pulses. The flux density of the average pulse changes by a factor of up to 13 from day to day, due to interstellar scintillation. It was shown that the cumulative distribution function is described by a polynomial fit of the second order in log-log scale.

Key words: individual pulses, variability — stars: individual: PSR B0950+08

1 INTRODUCTION

The main profile of the pulsar obtained by averaging several thousand pulses is a stable characteristic of the pulsar at the frequency of observation. While the average pulse is unique, individual pulses vary widely in intensity by a factor of ten and more from phase to phase and from one pulse to another. The time scale of pulse variability is very large: from nanoseconds in giant pulses (Hankins et al. 2003), tens and hundreds of microseconds for microstructure to tens of milliseconds for substructure in individual pulses, with even greater variability of emission caused by pulse drift, nulling and propagation effects. We study here the behaviour of individual pulses at different longitudes of the mean profile of PSR B0950+08 at a frequency of 111 MHz. Analysis of the intensity variability of pulses is important because this variability reflects emission processes such as microinstabilities or nonlinear processes. Different theories developed recently give different statistics of electric field strengths or intensities. The stochastic growth theory (SGT; Robinson 1992; Robinson & Cairns 2001) predicts log-normal statistics in the electric field (intensity). Processes such as wave collapse and modulation cause a power-law tail with $P(E) \propto E^{-n}$ in which $n = 4 \div 6$, to develop above some critical level E_c (Robinson & Cairns 2001). Other theories such as self-organized criticality (SOC; Bak et al. 1987) produce power-law distributions with indices close to -1. The comparison of observed intensity statistics with theoretical predictions can be used for testing theories and hence the physical processes responsible for pulsar emission.

Pulsar B0950+08 is one of the strongest pulsars at meter wavelengths, having a flux density of S = 2 Jy at 102.5 MHz (Malofeev et al. 2000). It has a strong linear polarization, $P_l = 70\% - 80\%$ at f = 111 MHz (Shabanova & Shitov 2004), a weak interpulse occurring approximately $152°$ ahead of the main pulse and a bridge of emission between interpulse and main pulse.

2 OBSERVATIONS

Observations of individual pulses from the pulsar B0950+08 were carried out at Pushchino Radioastronomy Observatory of ASC FIAN in 2001 September - October at a frequency of 111.2 MHz. The BSA large phased array radiotelescope, making up a linearly polarized transit antenna with 30 000 m^2 effective area, provides observation of 770 pulses in each session ($T = 3.2$ min). A 64 channel × 20 kHz receiver covering a total bandwidth of B = 1.28 MHz was used. The data were sampled at intervals of 0.4096 ms, the

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observation window width each pulse period was 150 ms. The receiver time constant was 0.8 ms and the signal dispersion through one 20 kHz channel causes pulse broading of 0.35 ms.

3 DATA ANALYSIS AND RESULTS

After dispersion removal and subtracting the baseline obtained from the out-of-pulse region, we calculated the mean profile by averaging the 770 individual pulses. For each session we defined σ_N (out-of-pulse) for individual pulses and the average profile and also S/N as the ratio of peak amplitude ($A_{\max}$) of the mean profile to σ_N. The mean profiles for 6 days of observation are presented in Figure 1.

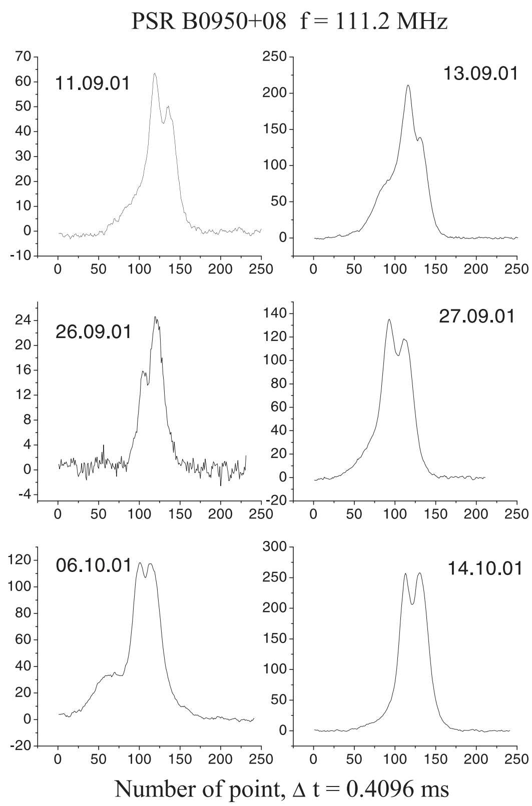

Fig. 1 Average profiles for 6 days of observation.

The shape and S/N of the observed profiles strongly varies from one day to an other, showing both double and triple profiles. Variations in the relative amplitudes of all three components are caused by polarization effects. As it was shown in the paper of Shabanova & Shitov (2004) the rotation measure for pulsar B0950+08, RM = 4 rad m^{-2}, so the rotation of position angle in our bandwidth of 1.28 MHz is $37°$. Lyne et al. (1971) obtained the changing of position angle in $160°$ across the average profile at frequency 151 MHz. Together with a strong linear polarization of all components this causes a strong amplitude variations of them.

PSR B0950+08 is the closest pulsar, with a distance of 262 pc (Brisken et al. 2002) and so its emission should be strongly affected by interstellar scintillation. We obtained the characteristic frequency scale of diffractive scintillation for this pulsar from analysis of spectra, $f_d = 200$ kHz at 111 MHz and put a lower limit on the time scale of scintillation: t_d is larger than observation time (3.3 min) because the spectrum does not change during this time. The ratio of peak amplitude of average profiles to σ_N over time is shown in Figure 2.

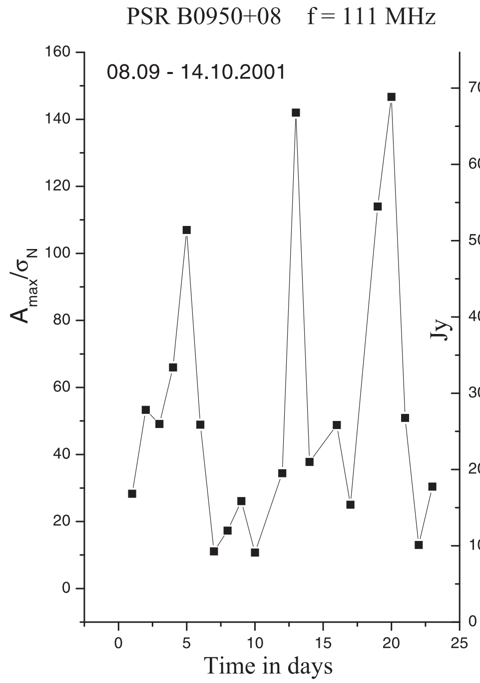

Fig. 2 The ratio of peak amplitude of average profile to σ_N in dependence of time.

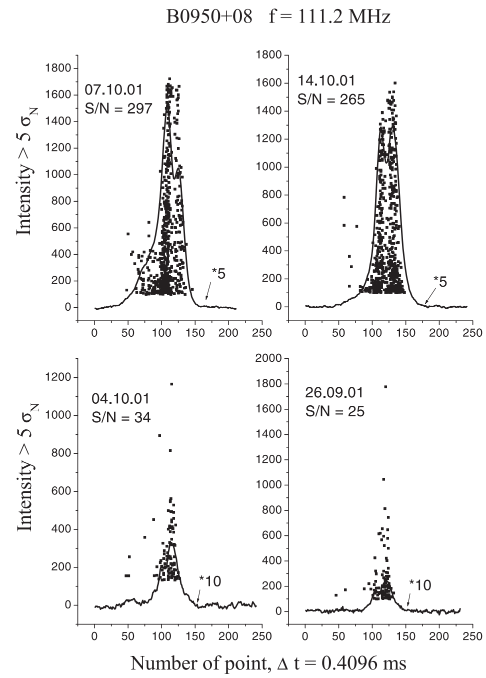

Fig. 3 The distribution of subpulse phases and intensities for 4 days of observation.

We see strong variability in $A_{\max}/\sigma_N$ from day to day (up to 13 times) which is caused by scintillation. We can convert $A_{\max}$ from computer units to Jy using this relation: A [Jy] = 14.7 $\cdot S \cdot A_{\max}/\langle A_{\max}\rangle$, where S = 2 Jy, the constant (14.7) is the scaling ratio of the period-averaged flux density to the peak flux density with allowance made for the shape of the integrated profile and $\langle A_{\max}\rangle$ is the mean value of $A_{\max}$ for the whole duration of observations. The right y-axis is in Jy. The distribution of subpulse phases and intensities (only for pulses with intensity exceeded $5\sigma_N$ level) together with average profiles multiplied by the corresponding coefficients are shown in Figure 3.

We see three distinguished regions of subpulse appearance corresponded to three components of mean profiles. For data with a small S/N ratio, in the average profile the amplitude of strongest pulses can exceed by a factor of 10 the peak amplitude of the profile (the peak amplitude of the strongest pulse for 26.09.01 exceeds the peak amplitude of profile by a factor of 60.

It should be noted that absolute values of the largest subpulse intensities are about the same for days with large S/N as for days with small S/N. It is a consequence of insufficient dynamic range of our analog-digital convertor. We have thus effectively chipped the amplitudes of pulses higher than some level. The distribution function of pulses exceeding some intensity level expressed in σ_N units (σ_N for individual pulses) is shown in Figure 4 for two days of observation.

Straight lines (the top of figure) here show the chipping levels caused for the reason pointed out above. We see rapid steepening of the function for intensities larger than this level. This cutting level depends on S/N and for sessions with low S/N when scintillation strongly decreases flux density we don't have this chipping. We can construct a correct distribution function from different days of observation taking into account the corresponding chipping levels (including only points lower than this level). To exclude influence of scintillation effects on our data we carried out normalization of pulse intensities on the peak amplitude of an average profile.

The corresponding distribution function based on 6 days of observation is shown on Figure 5.

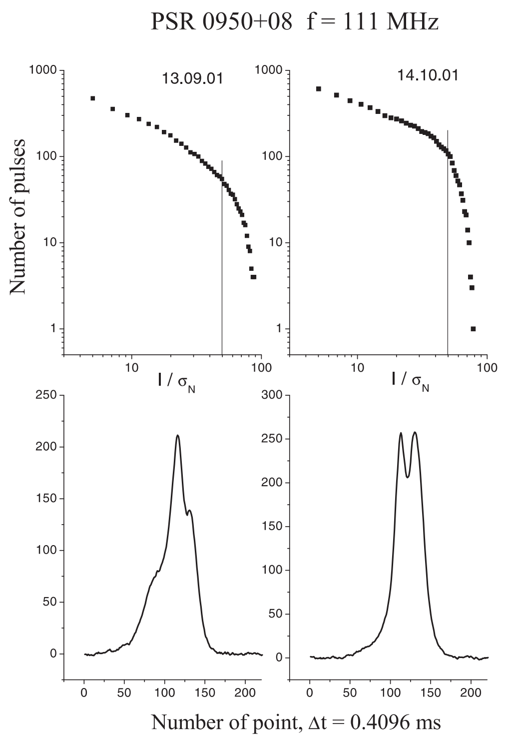

Fig. 4 Top: the number of pulses with intensity exceeding the particular level, shown on the x-axis; Bottom: the corresponding average profiles.

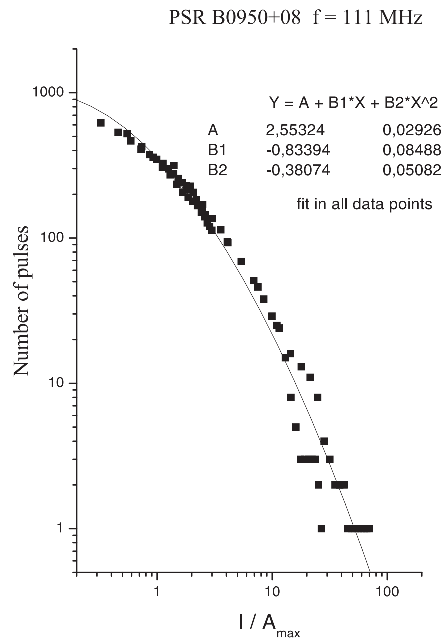

Fig. 5 The distribution function of pulses versus intensity of individual pulses normalized to the peak amplitude of the mean profile. 6 days of observation were used here. The line is a polynomial fit to the data.

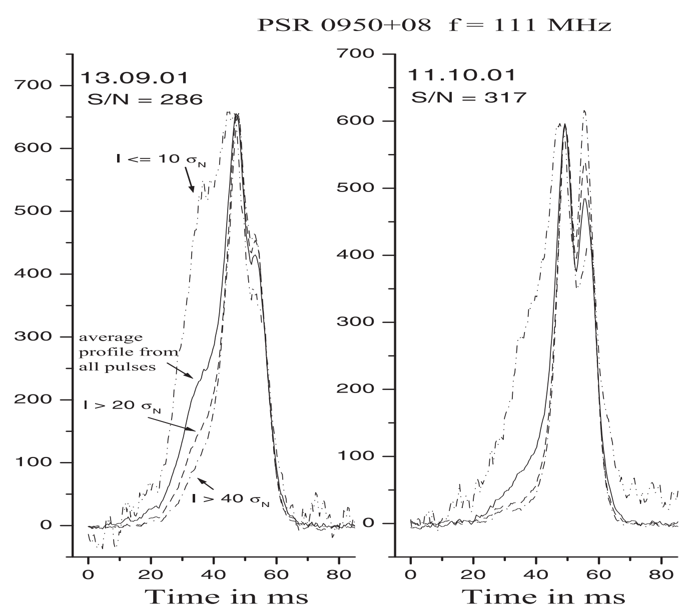

Fig. 6 Profiles obtained by summing of pulses with different intensity limits.

We see that data for different days agree with each other quit well, the spread of points increasing for large I/$A_{\max}$ because of small statistics. The cumulative distribution function doesn't follow log-normal law but can be described well by a polynomial fit of the second order on a log-log scale.

It is very interesting that average profiles obtained by summing of pulses with different intensity limits have different distribution of intensities and phases inside of emission zone. In Figure 6 we see profiles obtained from pulses with $I = (3\div\ 10)\ \sigma_N$ (dash-dot-dot line), $I > 20\sigma_N$ (dash line) and $I > 40\sigma_N$ (dash-dot line) normalized to the same amplitude. Profiles with $I < 10\sigma_N$ are about twice as wide as the profile from strong pulses; the relative amplitude of weak pulses is greater at the longitude of the first component, while strong pulses are centered mainly at the longitudes of 2 and 3 components of the mean profile.

4 CONCLUSIONS

We have shown that large variations of the flux density of PSR B0950+08 by a factor of 13 times at 111 MHz are caused by diffractive scintillation with scintillation time of more than 3 min. The intensity of individual pulses can exceed the peak flux density of the average pulse by factors of a few tens. There are three longitude regions where pulses appear more frequently. It was shown that the intensity distribution of weak pulses with the longitude of their appearance differs strongly from the distribution of strong pulses. The cumulative distribution function is described by a polynomial fit of the second order on a log-log scale. We have to mention that the detection of giant pulses from weak and nearby pulsars can be mistaken because of the strong influence of scintillation effects.

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