DYNAMIC AUTOCORRELATION FUNCTIONS OF MICROPULSE RADIO EMISSION IN PSR 0809+74

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Abstract

Dynamic autocorrelation functions for 2.56-ms adjusted intervals of single pulses of PSR 0809+74 have been analyzed. The observations were conducted at 102.5 MHz with 10 μs resolution. We find that the neighboring 2.56-ms subpulse intervals seem to have independent microstructure parameters, although sometimes the tendency was observed for the occurrence of *quasi*-periodic structures of close or double periods within the same subpulse. The distribution of a number of well ordered micropulses in *quasi*-periodic structures was shown to agree with the hypothesis of a random origin of *quasi*-periodicities. No relation has been found between the microstructure parameters and subpulse longitude.

Introduction

One can distinguish several characteristic time-scales in the temporal structure of pulsar radio signals: integrated profile, subpulses and micropulses. The integrated profile has a stable shape, intrinsic to a given pulsar at a given frequency. It is believed that the integrated profile reflects the general beam geometry of the radio emission for a given pulsar.

The individual pulses, which constitute the integrated profile, consist of one or more subpulses. The characteristics of subpulses—such as drift, pulse nulling and other intensity fluctuations with time and longitude—bring us information about the nature and dynamics of the electric discharge in the potential gap above the polar cap of the neutron star, where the dense electron-positron plasma is produced.

Micropulses are variations in subpulse intensity on time scales smaller than a few milliseconds. There are some observations of micropulses with a duration less than 0.8 μs (Hankins and Boriakoff 1978). Investigation of the statistical properties of pulsar intensity (Rickett 1975, Cordes 1976a, Cordes and Hankins 1979) shows that the emission can be well represented as an amplitude modulation of a complex Gaussian-noise process, the so-called amplitude modulated noise model (AMN). Such an analysis has shown that micropulses are the result of an incoherent superposition of numerous coherent emitters. Thus it became clear that micropulses do not represent a direct look at the coherent radio emission mechanism. However the properties of the micropulses, which remain the shortest physically meaningful fluctuation of the radio emission, can give important information on the physical conditions in the region, where the coherent mechanism of radio emission is developed.

In a number of papers presented by the IKI-FIAN group of investigators, it was shown that there are two types of microstructure with short and long time scales at a frequency of 102.5 MHz. Short time-scale microstructure has a 10 to 100-μs time scale, and the long time-scale microstructure has a 0.5 to 1.5-ms time scale (Soglasnov *et al.* 1981).

In these papers they showed that microstructure of both types shows the phenomenon of *quasi*-periodic modulation. Such modulations were discovered by an autocorrelation function (ACF) analysis applied to a chosen set of strong single pulses. For PSR 0809+74 the mean subpulse time scale is about 15–20 ms. At such a duration different *quasi*-periodic structures with short time scales may be severely averaged and smoothed. For a more detailed investigation of the statistical properties of the *quasi*-periodic modulation and evaluation of its characteristic life time, we present in this report an analysis of the dynamic ACF (DACF)—*i.e.* an ACF which was constructed for short time intervals, one following after another during the duration of the subpulse.

Processing technique

For our analysis we used observations of PSR 0809+74 that were carried out on 23 February 1980 at 102.5 MHz with the BSA radio telescope in Pushchino. During this set of observations numerous single pulses were observed with a good signal-to-noise ratio. These data has already been used in several previous papers, in an analysis of microstructure (Soglasnov *et al.* 1981) and a study of drifting subpulses (Popov and Smirnova 1982).

To compute the DACF we divided each strong subpulse (40.96 ms) into 32 time intervals, 1.28 ms in time duration each. Then we correlated each double interval (2.56 ms) with the neighboring four intervals, thus obtaining a cross-correlation function in the range of ±1.28 ms. In the range of small lags this cross-correlation function corresponds to an ACF, and we call it a dynamic ACF. By this technique we have obtained 15 DACFs for each chosen subpulse. An example of the results of our calculation is presented in figure 1.

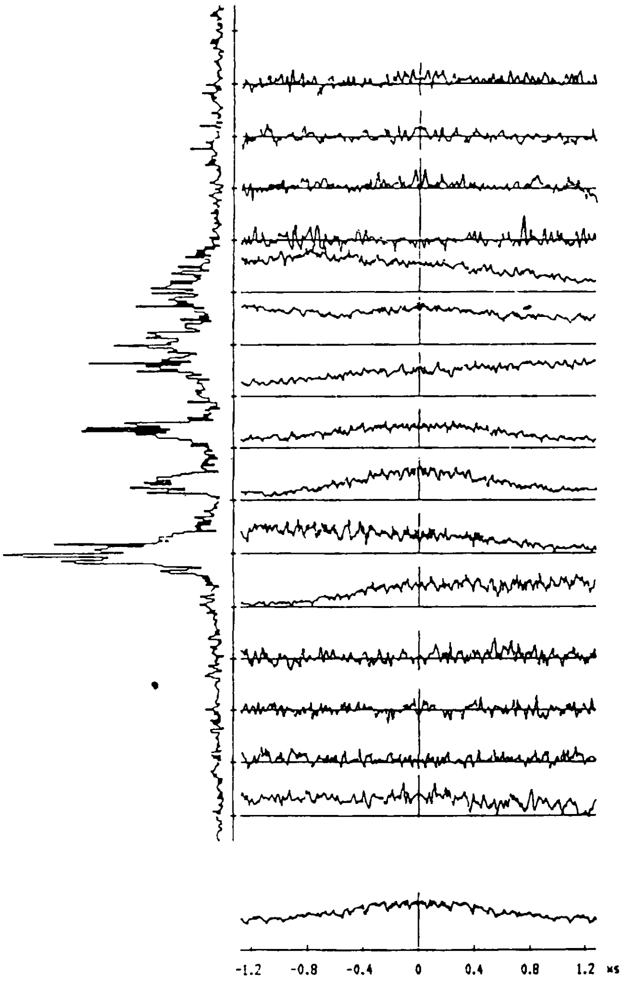

Figure 1 Dynamic ACFs of single pulses from PSR 0809+74 computed in 2.56-ms adjusted intervals (right side), corresponding to the relevant pulse intensity (left side). The ACF values for zero lag and two neighboring lags are not shown. The ACF for the whole subpulse is shown in the bottom. The time scale is in milliseconds.

In the left part of this figure the intensity variations of the subpulse under analysis is shown, and the DACFs are plotted on the right side at the position corresponding to the given part of subpulse. Each DACF was normalized to unity at zero lag, so the vertical axis scale is different for different DACFs. Some DACFs (those which correspond to abrupt changes in the subpulse intensity) show asymmetry relative to the zero lag, since they are in fact cross-correlation functions. The unity zero-lag point as well as two points on either side of it are not shown in the figure so as to better distinguish the microstructure peak from that of the receiver noise.

Thus we have constructed 1635 DACFs for 109 subpulses and 1545 DACFs for the receiver noise (*i.e.* for intervals which do not contain visible subpulses).

The objective of further analysis was to measure the microstructure and *quasi*-periodic modulation time scales. One can see immediately from the figure that in the majority of cases the neighboring DACFs differ drastically from each other. This fact shows that the microstructure parameters change rapidly along the subpulse, and those reflected by the mean ACF (shown in the bottom in figure) represent the most powerful part of the subpulse only. Other time scales and *quasi*-periodicities present in the subpulse structure are thus often veiled in the mean ACF.

Results

In our analysis we are interested in short time-scale microstructure (less than 0.5 ms). Sometimes it is difficult to measure the characteristic time scales of short time-scale microstructure because of the receiver noise peak in the ACF at zero lag. Therefore, we decided to investigate the microstructure properties by measuring the parameters of the *quasi*-periodic modulation which the various peaks of the DACF often represent. A single well distinguished peak in DACF corresponds to the presence of double micropulses in the subpulse structure; two peaks at equal distance indicate the existence of triple structures in the subpulse, *etc.* Sometimes more than a dozen well organized maxima in the DACFs were observed. Such cases provide strong evidence for *quasi*-periodic modulation.

For each DACF we have measured the number of well organized peaks (when they were present) and the corresponding periods of the successive micropulses.

Nearly half (710) of the 1635 DACFs analyzed did not show any *quasi*-periodicity in the sense described above. We classified such cases as having m equal to 1 (single micropulses) in the distribution of the number of micropulses constituting regular structures (figure 2).

Let the probability of a realization of a regular structure consisting of m micropulses be

$$p(m) = \frac{n(m)}{N}. \qquad (1)$$

If the probability of the appearance of a single micropulse structure were p_1 then one may expect that in a random distribution of micropulses the probability of the occurrence of a double micropulse

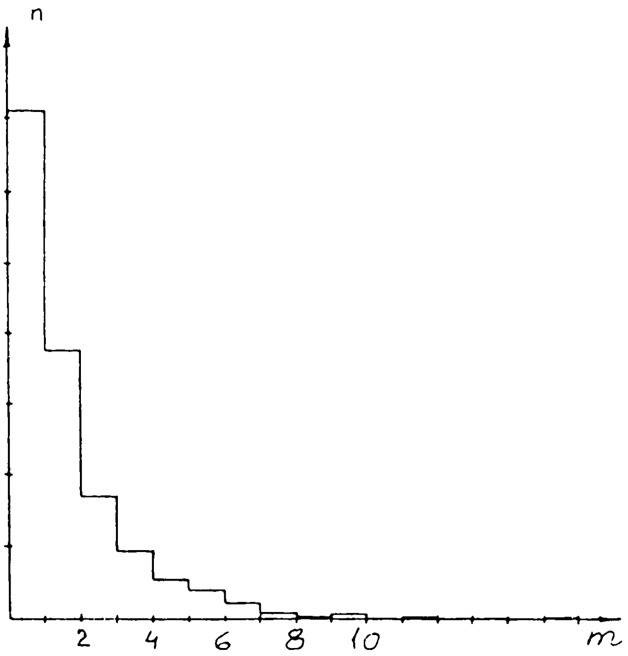

Figure 2 Distribution of the number of micropulses constituting regular structures; $m = 1$ corresponds to single micropulses, $m = 2$ corresponds to double micropulses, *etc.*

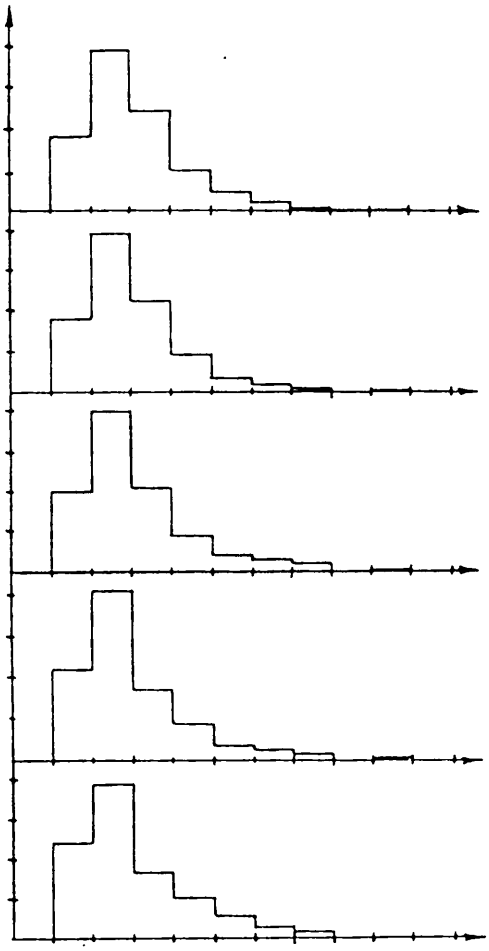

Figure 3 The distributions of periods of *quasi*-periodic modulation as a function of the number of micropulses m, constituting the observed structure. N is the volume of the sample. The time scale is in milliseconds.

structure $p_2 = p_1^2$, triple $p_3 = p_1^3$, and so on. In our analysis $p_1 \approx \frac{1}{2}$, $p_2 \approx \frac{1}{4}$, $p_3 \approx \frac{1}{8}$. Thus the distribution in figure 2 corresponds to the expected distribution for a random occurrence of micropulses remarkably well.

$$p(m) = p_1^m \approx \left(\frac{1}{2}\right)^m \qquad (2)$$

An important departure from this relation is observed for the case of large m—that is, greater or equal 10. The number of such cases are in excess of that predicted by eq.(2), but the statistics of such cases are rather low.

We constructed a distribution of the period of the *quasi*-periodic modulation as a function of the number of micropulses constituting the observed *quasi*-periodic structure. Histograms corresponding to these distributions are shown in figure 3. One can see from the figure that the histograms are very similar, *i.e.*, the distribution of the characteristic distances between the double micropulses (upper case in figure) agrees very well with the distributions of the period of the *quasi*-periodic structures constituting six or more micropulses (bottom case in figure). Therefore these intensity modulations all have a common character, and their occurrence may happen by chance.

All the histograms of figure 3 show a common tendency toward increasing probability of occurrence at smaller distances between the well organized micropulses. The observed decrease in probability for the smallest interval of 33–66 μs is, in our opinion, due to limitations in the observing and data-processing techniques. This conclusion is in good agreement with the results, obtained from the analysis of the mean ACF for PSR 0809+74 (Soglasnov *et al.* 1981).

In contrast with the previous investigation we had the possibility of analyzing the dynamics of the microstructure parameters throughout the duration of the subpulse. The general conclusion of our analysis, which we have already mentioned above, is that the neighboring DACFs usually are very different. This means that the microstructure parameters are independent of lag time on a scale of 2.56 ms.

In order to check this conclusion quantitatively we constructed a distribution of the mutual ratios of observed microstructure period within the same subpulse and compared it with the analogous distribution for successive subpulses.

Histograms corresponding to these distributions are shown in figure 4. Only *quasi*-periodic modulations with m greater than 4 were used in this analysis. The distributions shown in figure 4 are rather similar, but they also have two important

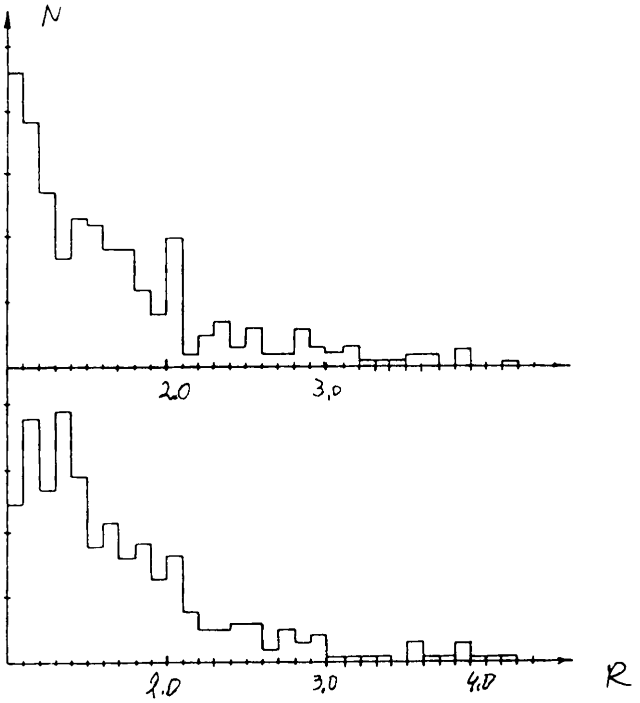

Figure 4 Distribution of the mutual ratios of observed microstructure periods with $m > 4$ within the subpulse (upper part), and for successive subpulses (lower part).

differences. The distribution of the ratios of the periods during the subpulse (upper figure) shows a narrow feature near r equal to 1 and an even narrower peak in range r equal to 2.0–2.1. Neither feature is clearly discernible in the analogous distribution for the successive subpulses (bottom figure).

These features in the upper part of figure are not very outstanding; however they are sufficiently notable to mention. They may be interpreted as evidence that *quasi*-periodic modulations tend to occur with ~ two complete periods. This tendency may be explained as an indication of the similarity of some physical conditions in the plasma outflow on a 15–20-ms time scale and as confirmation of the existence of some bifurcation processes.

The important question is whether the conditions in the plasma outflow vary with the longitude of the observed subpulse. In order to answer this question, we tried to obtain a relation between the period of the *quasi*-periodic modulations and the subpulse longitude. Our analysis showns that no such relation exists. However, we should remark that for PSR 0809+74 the sight line passes near the edge of the tube of magnetic field lines (MFL) at all longitudes. Therefore, an attempt to find such a relationship should be carried out with a pulsar having central traverse of the observer's sight line with the cone of the open MFL. PSR 1133+16 may be a good candidate for such an investigation.

Now let us review briefly the main results of our analysis of DACFs.

1. In the majority of cases those parts of subpulses which are separated by more than 2.56 ms have independent microstructure parameters.
2. There is, however, some tendency for the occurrence of *quasi*-periodic modulations with around two periods within a subpulse duration of 15–20 ms.
3. The distribution of the number of micropulses in well organized structures is in good agreement with the expected random distribution, but the probability of realization of such structures itself is rather high, compared to that which would be normal for a uniform random distribution.
4. The distribution of periods in *quasi*-periodic structures shows a clear increase at shorter periods up to the limit caused by the time resolution of our technique.
5. There is no relation between the parameters of microstructure and subpulse longitude.