Pulsars: Statistics of Pulse Sequences

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Abstract

The four statistical moments: mean, sigma, skewness and kurtosis, have been calculated for 12 pulsars at 1.4 GHz. The calculations were undertaken for both the individual components and the total pulse window of the integrated profile. The characteristics of the statistical moments are compared with the basic properties of pulsars.

In addition a set of simultaneous observations of PSR 0329+54 at 1.41 GHz (Jodrell Bank, UK) and at 2.69 GHz (Effelsberg, Germany) in EPN format has been analysed. The simultaneous observations have revealed that statistical details (variations in the statistical moments) are very similar in the two frequencies.

1 Introduction

It is inevitable that the study of pulsar emission is corroborated by statistical methods, in particular when we are dealing with single pulses.

The procedure is not new. A number of publications have used similar techniques, e.g. Tsakmakis and Seiradakis (1996), who developed the original tools. Earlier consideration of the problem was undertaken by R. Wielebinski (1968), J.M. Rankin (1986), Hesse (1974), and others; but the innovation which began in 1995 takes into account the individual components of the integrated pulsar profile and performs the statistical calculations for each one of them. Hence, it is now possible to examine the various phenomena, which can occur not only in the total pulse, but also in the finer structure of the pulsar emission, i.e. the components.

2 The analysis procedure

Initially the two orthogonal polarizations are added in order to produce the pulsar's integrated profile. In most cases the individual components can be easily distinguished and the correspoding subwindows defined, by a simple examination of the integrated profile. Special care should be taken in order to define a noise window whose length (in phase bins) is equal to the length of the subwindow under examination.

Then the four statistical moments, i.e. mean, sigma, skewness and kurtosis, are calculated for each recording. The calculations are performed for both the total pulse window of the integrated profile and the individual subwindows as well. Furthermore, the respective moments for the noise subwindow are calculated in order to inspect the quality of the data. It should be noted that common calibration factors are calculated for the all components. This secures equal treatment for all the components.

Finally graphical output of the data is created. There are two different types of plots that can be created: (a) sequences of the values of each moment are plotted against time to produce *time-series* diagrams which represent the variation of each moment with time and (b) the same values are treated statistically and *histograms* are produced.

3 The results

It is impossible to present our data for all 12 pulsars that were investigated under this project. Full analysis is presented by Chatzikos (2002, Diploma thesis, University of Thessaloniki, Greece). In §3.1 we shall concentrate on the most interesting pulsar that was examined. In §3.2 we present the results on simultaneous observations on PSR B0329+54. This work is presented by Noutsos (2001, Diploma Thesis, University of Thessaloniki, Greece).

3.1 Statistics of Q-mode pulses from PSR B1822-09

PSR B1822-09 is known for its vivid changes in the shape of the integrated profile, which is governed by a main pulse (MP) with two components, while an interpulse (IP) occurs midway between the MPs. It demonstrates two distinct modes of pulse emission. During the quiet mode (‘Q-mode’) the emission from the leading component (C1) is weak, accompanied by strong emission from the IP. On the other hand, in the burst mode (‘B-mode’) the emission from the MP is strong, i. e. from both the leading (C1) and the trailing (C2) components, while the energy received from the IP seem to be much weaker (Gil et al. 1993).

Our data for PSR 1822-09 consists of 1035 consecutive recordings containing mixed Q- and B-mode data; each recording contains a total of 10 integrated pulses. The observations were carried out at 1.41 GHz with the 100-m Radio Telescope of the Max-Planck-Institut für Radioastronomie located at Effelsberg near Bonn, Germany.

The analysis has revealed that the weaker C1 exhibits a considerable amount (44%) of null pulses (Figure 1b). This is not the case for C2 which exhibits only 0.1% of null pulses. These nulls are due to the Q-mode pulse. This remark has urged us to examine the behavior of the trailing component during this mode. Special care has been taken in order to isolate the recordings that contained only Q-mode pulses. The resultant data contained only 583 not consecutive recordings. In this case only the histogram analysis of the data has been taken into consideration.

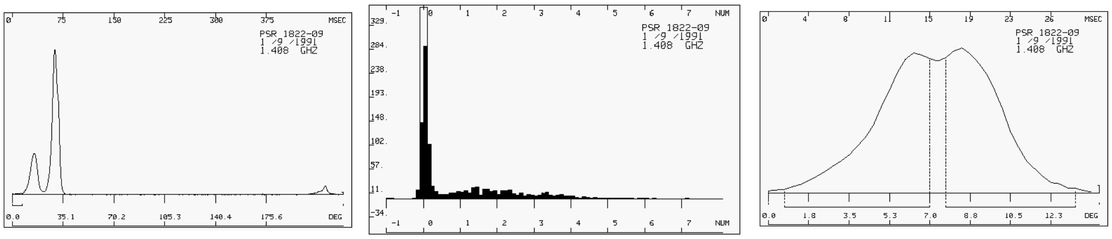

Figure 1: (a) On the left, PSR’s 1822-09 integrated profile. Both MP and IP are present. (b) In the middle, C1’s total power histogram of 1035 pulses; null percentage reaches almost 44%. (c) On the right, the bifurcation of C2’s profile is evident. The left part is labeled as C2a, while the right one as C2b.

The first step was to specify which sections of the integrated profile, and therefore which regions of the magnetosphere, would be examined. The integrated profile contained only C2 and IP; inadequate signal-to-noise ratio does not allow a meaningful examination of the latter. The MP component, i. e. C2, exhibits structure not easily distinguished in the original integrated profile. It consists of two distinct sub-components, which shall be called components C2a, the leftmost one, and component C2b, the other one (Figure 1c). It is interesting to examine whether statistics could indicate the existence of two emission mechanisms in this double component.

We have examined the two sub-components and their histograms are being presented above (Figure 2). Their implications are discussedin §4.

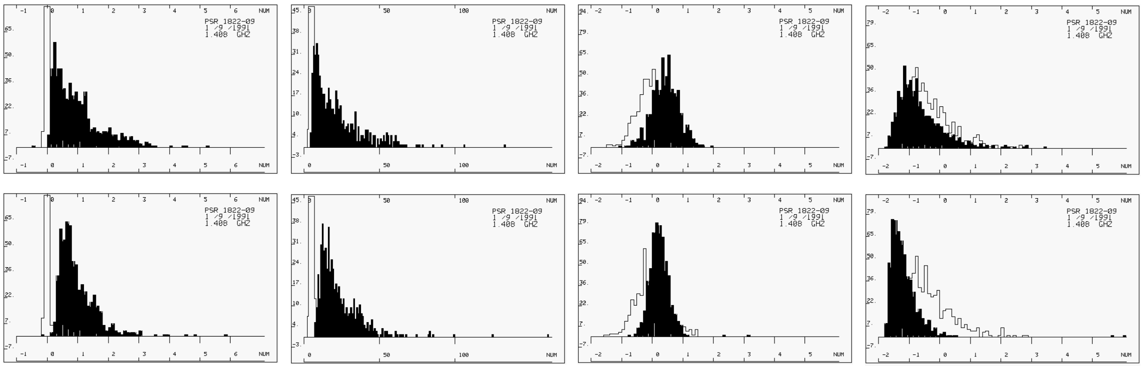

Figure 2: First row plots correspond to C2a's mean, sigma, skewness and kurtosis histograms respectively, while second row's plots depict C2b's statistical histograms.

3.2 Simultaneous observations of PSR B0329+54

PSR B0329+54 is one of the brightest pulsars available for observation. Previous studies of its pulse properties have shown that it exhibits mode changing phenomena but no significant sub-pulse drifting or nulling. Especially at 1.4 and 2.7 GHz, to which frequencies the available data refer, it emits in three different modes. It is classified as a "wide-triple"; its integrated profile displays three well resolved peaks, which correspond to the conal (side peaks) and the core emission (central peak) in agreement with the hollow cone model. The core component is nearly four times as intense as the conal components, while the conal components seem to fade out when moving to higher or lower frequencies.

The data consists of two simultaneous observations conducted at Effelsberg with the 100m RT at 2.69 GHz and with the 76m Lovell RT at Jodrell Bank near Manchester at 1.41 GHz. Both observations were written in a single EPN file which contains a total of 1892 single pulses. Each record contains eight channels; four for each observation. A fairly adequate resolution (700 μsec) and the very good alignment of the data allowed a satisfactory definition of the components.

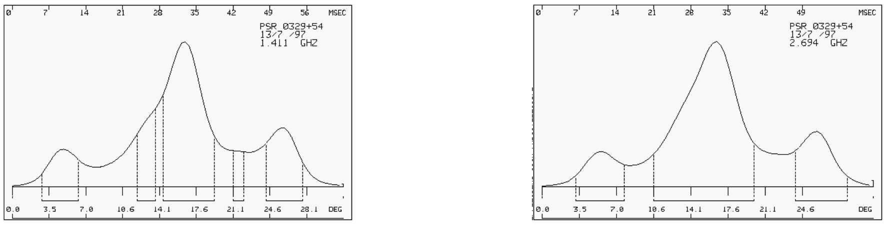

Figure 3: (a) The Lovell observation. Components C1, C2, C3, C5 and C4 consecutively from left to right. (b) The Effelsberg observation. Components C1, C2 and C3 respectively.

As far as the total profiles are concerned, the analysis has shown that only the mean diagrams demonstrate similar patterns for both frequencies. This behavior is illustrated in Figure 4.

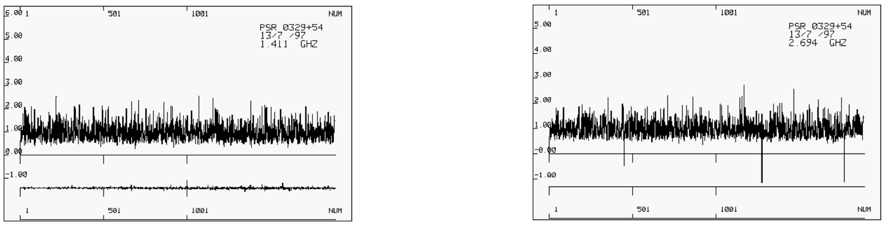

Figure 4: The mean energy fluctuation of the total pulse window at 1.41 (left) and 2.69 GHz (right).

Referring to the components, component C1 exhibits simultaneous variation of the mean intensity at both frequencies, but the other moments do not take the same values simultaneously. However, there are certain similarities between the time-series. The most obvious one has to do with the sigma time diagram, which looks roughly the same for both frequencies (Figure 5).

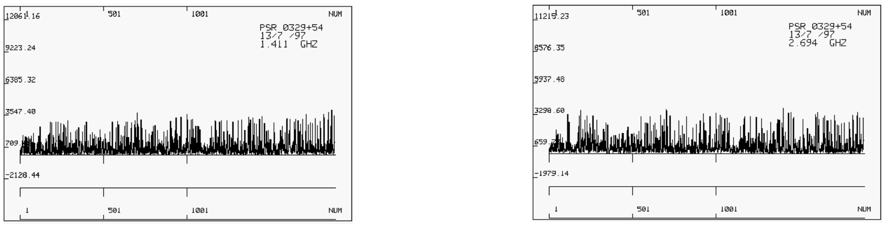

Figure 5: The sigma time series of component 1 at 1.41 (left) and 2.69 GHz (right).

Finally, the time-series for the mean intensity of component C2 at 2.69 GHz seems to have the characteristics of the corresponding graphs for components C2 and C3 at 1.41 GHz, merged together (Figure 6). So, there is an inversely peaked pattern for C3 at 1.41 GHz and a peaked pattern for component C2 at the same frequency.

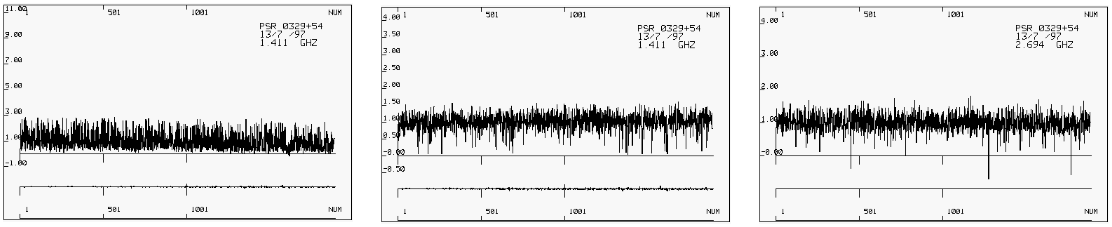

Figure 6: Comperative layout of the mean time-series diagrams for both components 2 (on the left) and 3 (middle) at 1.41 GHz and component 2 (on the right) at 2.69 GHz.

4 Conclusions

As far as PSR B1822-09 is concerned it must be noted that the diagrams reveal some slight differences between the two components. The trailing sub-component exhibits steadier emission, while in the leading one strong pulses manifest their presence through some large sigma values. Furthermore the differences in the skewness and kurtosis histograms are trivial, although the somewhat larger values of the leading sub-components kurtosis corroborate our remark about the existence of strong bursts.

In the case of PSR B0329+54 the diagrams have not revealed any substantial difference between the two frequencies. At higher frequencies the bridge components merge with the main ones. This is evident since neither the time- series analysis nor the histograms displayed any substantial differences between the two observations. In this sense it can be assumed that the emission mechanism at both frequency should be the same.

References

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