Revisiting the rich sub-pulse patterns of B1237+25 : Preliminary Results

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Abstract.
"Sub-pulse drifting", one of the rich phenomena exhibited by many pulsars, have been suggested ([8], Ruderman and Sutherland, hereafter RS) as representing a system of sparks circulating around the magnetic axis in the acceleration zone of the star. Although pulse 'drift' sequences have been studied for a number of pulsars, only in a few cases (i.e, B0943+10 & B0834+06) have the underlying patterns been mapped so far, revealing a well organized system of emission sub-beams and providing a strong support to the R&S model of circulating sparks. The well-known bright pulsar B1237+25, with its multi-component profile resulting from a special viewing geometry combined with its rich variety in pulse-to-pulse fluctuations, represents a challenging case for exploring the underlying circulation pattern. We present preliminary results of our analysis on a number of pulse-sequences from this object, with a view to investigate the following :

1. Are the sub-beam patterns in the two presumed conal rings correlated ?
2. If yes, are the corresponding sub-beam patterns in the two conal rings offset relative to each other in magnetic azimuth ?
3. Can the mode-changing phenomenon be understood as a result of some systematic feature in sub-beam patterns ?
4. Core component : Really a "core" or just another conal ring of suitably small radius ?

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INTRODUCTION

While the usually stable integrated pulse profile of a pulsar hides certain details of emission mechanism, micropulses are generally too variable to define clearly the underlying pattern. Somewhere in between these two extremes of the time-scales of variations, sub-pulses represent the emission entities responsible for the observed structure of single-pulses, and do carry information coded through variation of their location in longitude and fluctuations in intensity. These fluctuations are identified as phase modulations within the profile and/or as amplitude modulations of the pulse component.

The "Nulling" phenomenon can be modeled as a form of amplitude modulation which is correlated and simultaneous across the entire pulse region.

"Drifting Sub-pulses" primarily representing phase modulation within the pulse profile, have been suggested [8] to manifest a system of sparks circulating around the magnetic axis in the acceleration zone of the star. Only in case of a few pulsars an illuminating connection between the drifting sub-pulses and the actual sites of radio emission have been established [2] providing a strong support to the above RS model of circulating sparks. The type of sub-pulse modulation is largely decided by our viewing geometry and the apparent angular size of the polar emission cone of the pulsar.

In the above picture of circulating spark-rings, the tangential sight-line cut is consistent with the single-component average profile, and also "drifting" (phase modulation) being the dominant form of the sub-pulse fluctuation (in addition to any amplitude modulation). The line of sight traversing through/near the magnetic pole would sample the emission cone(s) more than once, as would be manifested in multi-component profiles. Such viewing geometries allow one to sample the emission sub-beams and polar cap more completely, and the circulating sub-beams would result in apparent amplitude modulation of sub-pulses.

PSR B1237+25 : Unique and Challenging

B1237+25 is a classic example of a pulsar having multi-component profile (earlier recognized as a five-component profile and classified as "M"-category pulsar, however presence of sixth component has been proposed and apparently verified; [4] & [9]).

Like many other pulsars, B1237+25 is also known to flip between two modes of emission, 'normal' and 'abnormal', with corresponding emission profiles having different proportions of primary and secondary polarization-mode powers. It has been discovered recently that within the normal-mode of emission itself,

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this pulsar shows two distinct behaviors : a 'quiet-normal' mode with nearly 2.8 period sub-pulse modulation with little or no core activity, and a 'flare-normal' mode with a regular, bright core and perhaps a somewhat longer sub-pulse modulation period ([9],Zuzana & Rankin, hereafter ZR).

The double conal profile of this star has been presumed to be produced by a sight-line which passes almost through the center of two concentric emission cones and a central core beam. This assumption has been verified recently by the 'quiet-normal' average profile exhibiting full conal traverse, where at the center of the traverse, the position-angle sweep rate being exceptionally steep (~ 180°/deg, may well be the largest ever determined), as expected from single-vector-model [6]. With the sight line traversing so close to the magnetic axis, this pulsar provides an ideal case for the study of underlying spark-patterns responsible for the presumed conal rings and any possible relation between them.

In this paper, we describe preliminary results of our analysis of several rich sub-pulse sequences from this object observed with the Arecibo telescope, and discuss the preliminary indications of several properties of the underlying pattern/circulation revealed by our analysis.

ANALYSIS : THE UNDERLYING PATTERNS AND THEIR PROPERTIES

The fluctuation spectra of the pulse sequence from this pulsar clearly shows secondary (amplitude) modulation feature at a period of $P_3 \sim 2.8$ P, but its Q is not high enough to enable us to identify any circulation periodicity as side-bands to this feature. A typical longitude resolved fluctuation spectra for this pulsar can be seen in ZR's [9] Fig. 6. The broad spectral feature might have been resulted from either uneven spacing between the sub-beams or fluctuations in intensity across various sub-beams, making it difficult to isolate or detect a spectral signature associated with period of circulation of the sub-beam pattern(s).

Although auto/cross correlation function of intensity sequences has essentially the same information as in the (cross) power spectrum of the fluctuations, it can still be much more advantageous to find the signature of any tertiary period, particularly when the secondary fluctuations are of very low Q, as we see in the longitude-resolved fluctuation (LRFLUC) spectra of this pulsar, or if the circulation period itself is not constant. A very useful way then is to examine the cross correlation between fluctuations of two pulse components that may be expected to be associated with the same conal-ring, and sharing the same underlying modulation, but with a delay. The Fig. 1 here demonstrates the above.

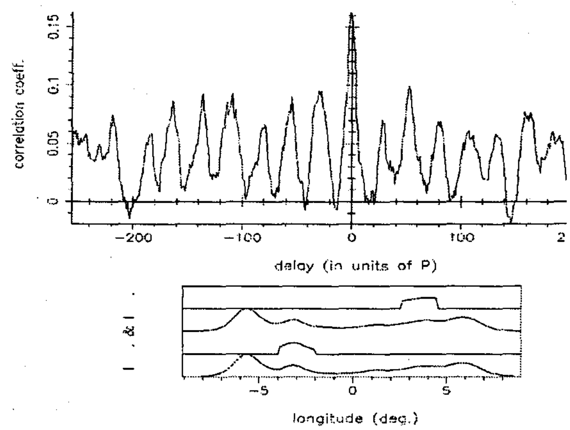

FIGURE 1. Top: A cross correlation between fluctuations at two different longitudes as a function of delay, after suitable smoothing to reduce the corrugation due to the secondary (quasi-) periodicity. Note the presence of overall slow periodicity of 27 P. Bottom: 1^{st} and 3^{rd} line plots show the average profiles, while 2^{nd} and 4^{th} line plots show the corresponding longitude regions(components) of profile, for which the intensity sequence have been cross-correlated.

The use of the two methods discussed here, based on LRFLUC-spectra and the Correlation analysis, and their other forms (Fourier Transform of cross-correlation function, search for phase-gradient in such (cross) power spectra) have resulted in short listing a few candidate circulation periods. Each of these candidate tertiary periods was then used to cartographically map the underlying spark-pattern.

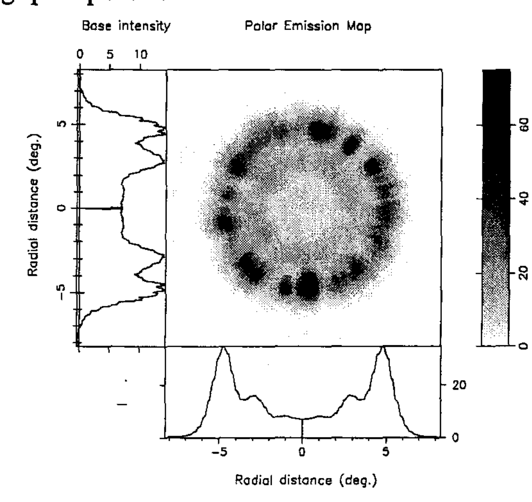

FIGURE 2. Polar cap map synthesized using a set of 512 pulses for the most likely tertiary modulation period. Two rings and individual (bright) sparks can easily be located

Then to quantify the validity of the assumed circulation period, an inverse cartographic transform was used to generate a synthetic pulse-sequence, and was correlated with the original one. We choose here the most likely tertiary period (~ 26.626301 P) to map the underlying spark pattern (see Fig. 2).

To find any correlation between patterns associated with the two conal rings, the radial profiles from the polar-cap map were sampled at uniform intervals of magnetic azimuth(longitude), and then the whole radial profile's azimuth sequence was subjected to correlation analysis, resulting in correlation maps over a span of azimuthal shifts. The maximum correlation for each pair of radii (i.e. magnetic latitude), and the azimuthal shift corresponding to this maximum was found and plotted here in Fig. 3.

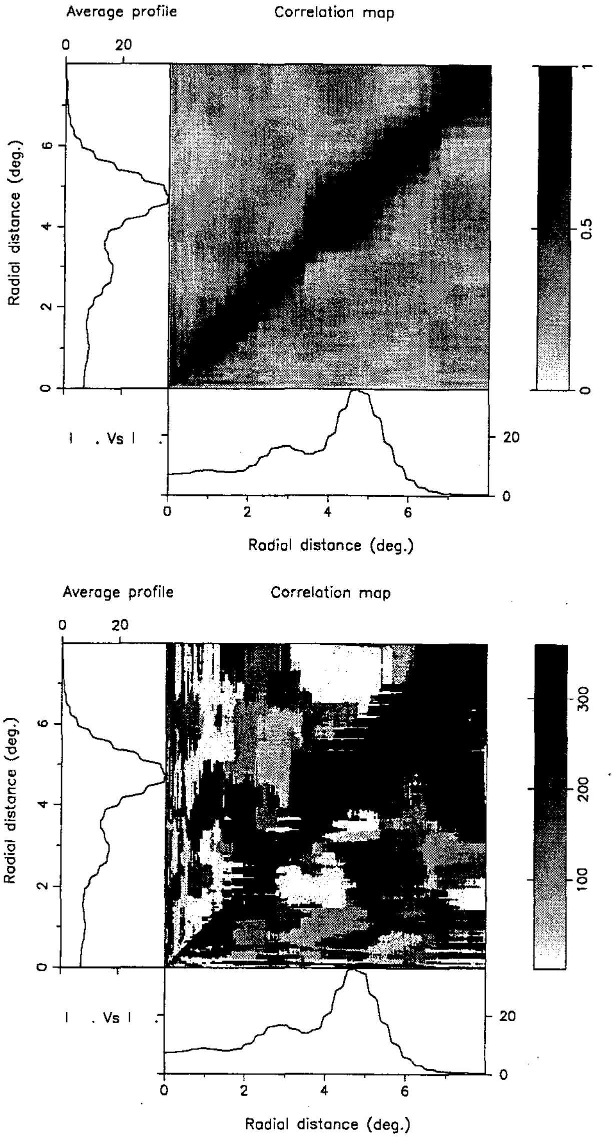

FIGURE 3. Auto-correlation of polar-cap radial profile. Top: The maximum correlation for each pair of magnetic latitude; Bottom: corresponding Azimuthal shift (degrees).

DISCUSSION : PRELIMINARY INDICATIONS

Significant correlation between sub-beam patterns associated with the two cones is apparent, particularly at the component edges (Fig. 3) which indicates that the sub-beam patterns are not independent of each other and may be sharing the same underlying seed pattern. The different conal rings might be associated with emission at different heights (at any given frequency).The sub-beam patterns in the two conal rings are offset relative to each other in magnetic azimuth ($\sim 50-60$ degrees).

The above is inferred from analysis that assumes the most likely value of the circulation period (shown above). The validity of these indications is to be assessed based on further investigations using all the data sets.

It is of interest to see if the above relative offsets in azimuth have any systematic variation across the magnetic latitude or/and with time, and what would be its implications on the normal mode of emission.

From our present analysis, it is yet unclear whether the core component is due to "core" emission or merely another (compact) conal ring. However, the (quasi-periodic) fluctuations exhibited by the core component and the weak (and rare) appearance of the "conjugate" component, may be understood together as a manifestation of a compact central ring with azimuthal modulation similar to that in "conal" rings combined with circulation. Its correlation with other components will help to establish its real origin.

In the next step of this analysis, we are working to establish the circulation period, confirm and quantify precisely the offset in two conal rings and its variation across the magnetic latitude, and investigate whether the "core" component is associated with a conal ring of suitably small radius or not.

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