Frequency Dependence of Profile Changes in Pulsar Emission

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Abstract

The frequency dependence of changes, known to occur in pulsar profiles, is studied using either a fairly high frequency sampling within a narrow band, or a lower sampling within a much wider band. Observations from the 100-m radio telescope at Effelsberg, Germany, and from the 76-m radio telescope at Jodrell Bank, England, were used.

The wide band observations were used to examine the nature of the exponential dependence of the profile width on frequency. A model proposed by Professor F. G. Smith at Jodrell Bank seems to describe the observations of two pulsars (PSR B0525+21 and PSR B1929+10) with high *signal/noise* profiles, fairly accurately. Within this investigation a 7-members group of pulsars was studied.

The narrow band observations reveale a smooth profile transition in most cases (e.g. PSR B1702-19). One pulsar seems to exhibit a fast transition between consecutive profiles (e.g. PSR B1742-30). In total, 6 selected pulsars were studied at this stage.

1 Introduction

The *optical depth's* dependence on the observing frequency implies that different observing frequencies correspond to different depths into the emitting region of the neutron star's magnetosphere (radius-to-frequency mapping). Therefore, studying the development of particular profile features over frequency may lead to some conclusions concerning the emitting region's structure.

The present study concerns two distinct investigations which focus on the dependence of the observed profile changes on frequency though from two different perspectives.

On the one hand, wide range observations of low frequency sampling have been used to examine whether the profile *width* develops over frequency obeying an exponential regularity. The theoretical reflection pointing to such an expectation has as follows (Smith 2000). The configuration of the neutron star's magnetosphere determines that the magnetic field lines diverge as $\theta \propto r^{1/2}$ with θ being a measure of beam-width and r the distance from the surface of the star. Assuming a very general relation between θ and r, such as $\theta \propto f^{-\beta}$, the derived relation between f and r becomes:$f \propto r^{-1/2\beta}$. For dipole radiation, the inductance of the magnetic field is reduced with increasing r, according to $B \propto r^{-3}$. Assuming that the frequency of radiation corresponds to the *gyrofrequency* of electrons radiating in a magnetic field B, one may notice that $f \propto B$. From the above it is expected that $\beta = 1/6$ and therefore, that: $\theta \propto f^{-1/6}$. If a more general relation of the form $f \propto B^n$ is assumed then the relation under investigation, becomes:

$$\theta \propto f^{1/6n} \tag{1}$$

The above equation is investigated in the framework of the wide band study.

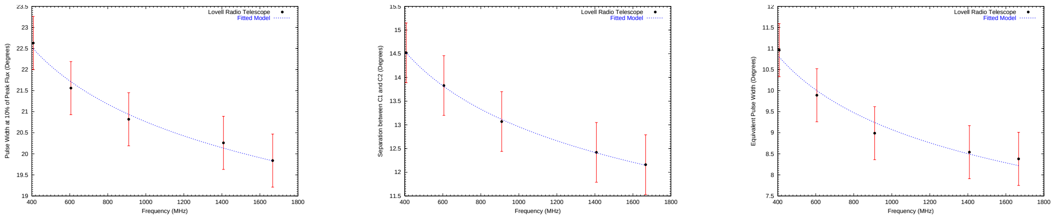

Figure 1. Three characteristic plots with respect to PSR B0525+21. From left to right: correlation between observing frequency and $W_{10\%}$, angular distance between C_1 and C_2 and W_{eq}.

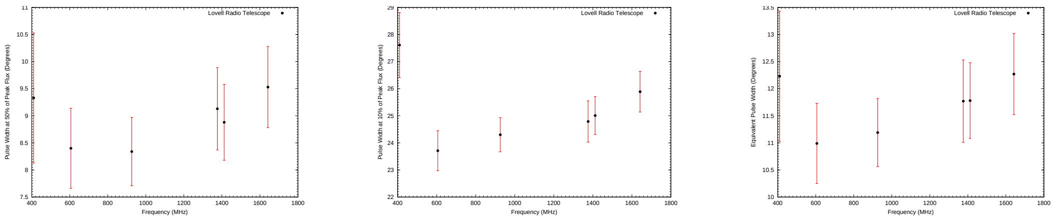

Figure 2. Three characteristic plots with respect to PSR B0540+23. From left to right: correlation between observing frequency and $W_{50\%}$, $W_{10\%}$ and W_{eq}.

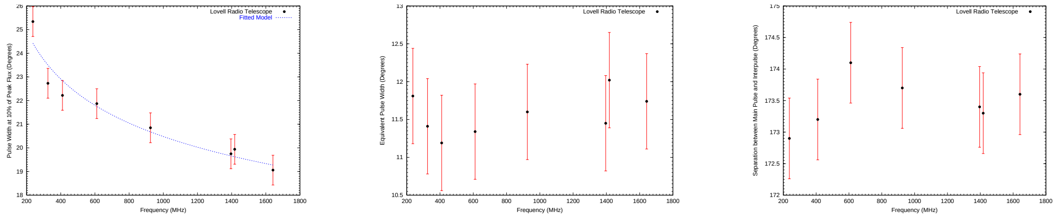

Figure 3. Three characteristic plots with respect to PSR B1929+10. From left to right: correlation between observing frequency and main pulse's $W_{10\%}$, main pulse's W_{eq} and angular distance between main pulse and interpulse.

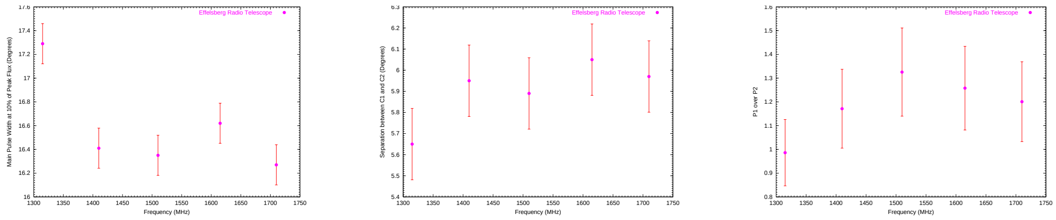

Figure 4. Three characteristic plots with respect to PSR B1702-19. From left to right: correlation between observing frequency and $W_{10\%}$, separation between its two main components and ratio between the associated peak fluxes.

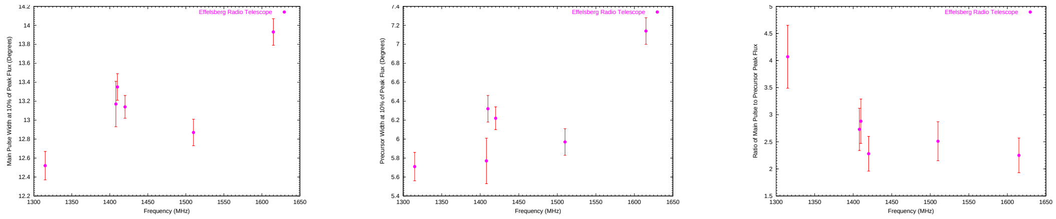

Figure 5. Three characteristic plots with respect to PSR B1742-30. From left to right: correlation between observing frequency and main pulse's $W_{10\%}$, precursor's $W_{10\%}$ and ratio between main pulse's and precursor's peak flux.

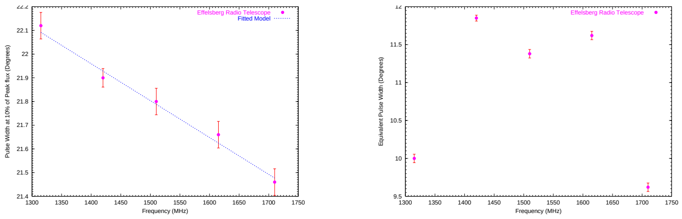

Figure 6. Three characteristic plots with respect to PSR B2319+60. From left to right: correlation between observing frequency and $W_{10\%}$ and W_{eq}.

On the other hand, in order to investigate the question whether the observed changes in the profile happen gradually or rapidly, narrow band observations but of higher frequency sampling have been used. If the profile's changes follow a smooth evolution over frequency, then it is highly unlikely that responsible for this effect is the emission mechanism. On the contrary, if fast changes are observed, either B undergoes a rapid change, or an emission mechanism peculiarity is involved.

At this point it is worth mentioning the particular profile features studied as well as the group of pulsars examined in each stage. For both the narrow and the wide band observations, the following profile properties were studied: (a) Pulse width at 50% of peak flux ($W_{50\%}$), (b) Pulse width at 10% of peak flux ($W_{10\%}$), (c) Pulse equivalent width (W_{eq}), (d) Angular separation between flux peaks, (e) Ratio between flux peaks.

Table 1. The pulsars studied

Low Frequency Sampling (Wide Band)						
B name	J name	l (deg)	b (deg)	DM (cm^{-3})	Distance (kpc)	P (ms)
0525+21	0528+2200	183.9	-6.9	51	2.3	3745.521
0540+23	0543+2329	184.4	-3.3	78	3.5	245.974
0740-28	0742-2822	243.8	-2.4	74	1.9	166.761
1742-30	1745-3040	358.6	-1.0	88	2.1	367.427
1822-09	1825-0935	21.4	1.3	19	1.0	768.979
1831-04	1834-0426	27.0	1.7	83	2.3	290.108
1929+10	1932+1059	47.4	-3.9	3	0.2	226.518
High Frequency Sampling (Narrow Band)						
B name	J name	l (deg)	b (deg)	DM (cm^{-3})	Distance (kpc)	P (ms)
1702-19	1705-1906	3.2	13.0	23	1.2	298.987
1742-30	1745-3040	358.6	-1.0	88	2.1	367.427
1822-09	1825-0935	21.4	1.3	19	1.0	768.979
1831-04	1834-0426	27.0	1.7	83	2.3	290.108
1929+10	1932+1059	47.4	-3.9	3	0.2	226.518
2319+60	2321+6024	112.1	-0.6	95	3.2	2256.488

2 Instrumentation and Software Resources

The data used were obtained with the 76-m Lovell radio telescope (low frequency sampling project), or the 100-m Effelsberg radio telescope (high frequency sampling).

In general, the frequency range was from about 200 MHz up to 4850 MHz for the Lovell radio telescope data and from roughly 1315 MHz up to 1710 MHz for the Effelsberg radio telescope. The frequency sampling varies from case to case.

Concerning the software used for the projects, one should mention that (a) **jhspuls** and **psrprof** were used as data reduction programs and (b)**bfit** which used for fitting a group of gaussians to each integrated profile.

3 Wide Band Observations Results

This part of the analysis was exclusively based on Lovell radio telescope data. The possibility of an exponential decay of several particular profile features with frequency, has been investigated. Figures 1, 2 and 3 summarize characteristic results associated with PSR B0525+21, 0540+23 and 1929+10, respectively.

The parameters a and b of a power law have been calculated whenever such a behavior was obvious. Thus, for PSR B0525+21 it has been estimated that: $W_{10\%} = 38 \cdot f^{-0.089}$, $C_2 - C_1 = 31 \cdot f^{-0.13}$ and $W_{eq} = 35 \cdot f^{-0.19}$. For PSR B1929+10, it has been worked out that: $W_{10\%} = 48 \cdot f^{-0.12}$. A brief discussion of the above results is given below.

4 Narrow Band Observations Results

Figures 4, 5 and 6 present the most interesting results corresponding to PSR B1702-19, 1742-30 and 2319+60 respectively.

It is important to recall that in this project no exponential behavior is examined. The main aim is to study the behaviour of the pulse profile.

The data on which the following analysis is based have exclusively been obtained with the Effelsberg radio telescope.

5 Discussion

Focusing on the low frequency sampling project, it is worth mentioning the obvious regularity in the evolution of PSR B0525+21.The $W_{10\%}$, separation between the two components and the W_{eq} is given prime attention. It is expected that $W_{10\%}$ should follow an exponential decay as that proposed by Smith since it clearly represents a beam-width measure. A power law of an exponent 1/6, that is about -0.17, is what one should observe if the assumptions made in Section 1 are correct. Surprisingly, $W_{10\%}$ decreases as $f^{-0.12}$ which is interestingly close to the expected value. Similar is the situation in the case of the separation between the two profile components which are also a measure of beam-width. Therefore, apparently PSR B0525+21 not only possess a regular behavior but it also displays the expected one.

Although PSR B0540+23 does not display the same behavior, the qualitative similarity in the evolution of $W_{50\%}$, $W_{10\%}$ and W_{eq} should be pointed out. To put it simply, although the exponential regular behaviour is absent still a regularity seems to be present.

Finally, PSR B1929+10 appears to introduce a third sort of interesting frequency dependence. On the one hand $W_{10\%}$ displays an exponential behavior with an exponential parameter of -0.12 (very close to the expected one), whereas W_{eq} and the separation between main and inter-pulse do not. But still the two later features possess a qualitatively similar evolution.

Concerning the narrow band project, most pulsars seem to exhibit a smooth profile transition as a function of frequency. PSR B1702-19 (Figure 4) is a typical example. However, in a few cases fast changes seem to take place around the 21-cm wavelength.

Abrupt profile changes are displayed by PSR B1742-30 (Figure 5) and it is of outstanding importance to examine what could be the reason for this behavior.

PSR B2319+60, the well known moding pulsar, probably exhibits the most peculiar frequency evolution. Its $W_{10\%}$ has a linear frequency dependence in contrast with the rather dramatic irregularity displayed by W_{eq}.

References

F. G. Smith, Personal Communication, 2000.

A. G. Lyne & F. G. Smith, Pulsar Astronomy, Cambridge University Press, 1998.

A. G. Lyne & R. N. Manchester, Mon. Not. R. Astr. Soc., 234: 477-508, 1988.

J. M. Rankin, Ap.J., 274: 333-358, 1983.

S. E. Thorsett, Ap.J., 377:263-267, 1991.

M. Kramer, R. Wielebinski, A. Jessner, J. A. Gil & J. H. Seiradakis, A&AS, 107:1-12, 1994.