Ord, S. M., Edwards, R.T., Bailes, M. (2001). Drifting sub-pulses in two newly discovered pulsars.

Originally published in *Monthly Notices of the Royal Astronomical Society*, 328(3), 911-913

Available from: http://dx.doi.org/doi:10.1046/j.1365-8711.2001.04946.x

This version of the article copyright © 2001 The Authors.

This is the author’s version of the work. It is posted here with the permission of the publisher for your personal use. No further distribution is permitted. If your library has a subscription to this journal, you may also be able to access the published version via the library catalogue.

The definitive version is available at www.interscience.wiley.com.
Drifting sub-pulses in two newly discovered pulsars

S. M. Ord,¹ R. Edwards¹ and M. Bailes¹

¹ Swinburne University of Technology,
Centre for Astrophysics and Supercomputing
Mail 31
P. O. Box 218
VIC 3122
Australia

1 February 2008

ABSTRACT

We have detected the rare phenomenon of stable, drifting sub-pulse behaviour in two pulsars discovered in the recent Swinburne intermediate latitude pulsar survey. The pulsars, PSR J1231–47 and PSR J1919+0134, have approximate periods \( P \) of 1.873 and 1.6039 seconds respectively.

Both pulsars have multi-component profiles, and distinct drifting is observed across them. We have identified a single drift mode in both pulsars: the drift rate for PSR J1231-47 being 5.4(1) ms \( P^{-1} \) and 5.8(2) ms \( P^{-1} \) for PSR 1919+0134. The drifting is linear across the profile with no departure from linearity at the edges within the sensitivity of our observations.

1 INTRODUCTION

The Swinburne intermediate latitude survey (Edwards et al. 2001) has discovered 69 pulsars, 8 of which are recycled. In the process of confirming candidates a number of pulsars were found to display interesting emission behaviour, namely pulse nulling and drifting. Two pulsars in particular, PSR J1231–47 and PSR J1919+0134, exhibit regular drifting sub-pulses.

Drifting sub-pulse behaviour has been considered a litmus test for models of pulsar emission since the discovery of such periodicities in pulsar emission by Drake and Craft (1968). Although many pulsars display sub-pulse intensity variations few present orderly persistent drifting sub-pulses. It is considered by Rankin (1986) to be a purely geometrical effect. Assuming the intensity variations are due to conal sub-beams, then drifting will be apparent if the pulse profile is a result of an almost tangential cut of the line of sight across the cone. This implies that drifting sub-pulses would be more apparent in conal single profiles and that well resolved double profiles should display intensity variations that do not drift. The newly discovered pulsars are both members of an intermediate profile class, that of “barely resolved conal double” (Rankin 1983). They also display the very rare property of a stable drift pattern.

We present both 2 dimensional auto-correlation analysis (Vivekanand and Joshi 1997) and fluctuation spectra (Backer 1973; Taylor Manchester and Huguenin 1975) for both pulsars; providing an initial characterisation of their sub-pulse behaviour. We also present an examination of the drift rate of an average drift band as a function of pulse phase.

2 OBSERVATIONS

All the observations presented here were taken with the Parkes 64 metre radio telescope using the central beam of the 13 beam multi-beam receiver and the 96 × 3 MHz filter bank (Staveley-Smith et al 1996), at a central frequency of 1374 MHz. Both polarisations were summed together and the result one bit sampled. The sample rate varies between the observations, and is 125 µs for PSR J1919+0134 and 500 µs for PSR J1231-47. This time series is folded into 512 phase bins at the topocentric pulsar spin period.

Each period can be represented by a row in a "longitude–time" plot (Taylor, Manchester & Huguenin 1973; Manchester & Taylor 1977). Two such plots are shown in Figure 1 together with average profiles for both pulsars. These arrays form the basis of the following analysis.

Many different methods have been employed to examine drifting behaviour, including cross–correlation (Proszyński & Wolszczan 1986), Fourier phase methods and fluctuation spectra (Backer 1973, Deshpande and Rankin 2001) and auto-correlation methods (Vivekanand and Joshi 1997). Both fluctuation spectra and auto-correlation analyses are presented here.
Figure 1. Longitude–time plot showing the drifting sub-pulses of J1231+47 and J1919+0134. The contour levels have been set to a scale that increases the contrast. Phase 0 has been set arbitrarily. The dotted line indicates the level of spectral power in the fluctuation spectrum at that longitude.

| Name       | R.A. (J2000) | Dec. (J2000) | $P$  | $P$ Epoch (MJD) | $\dot{P}$ (10$^{-15}$) | DM (cm$^{-3}$ pc) |
|------------|--------------|--------------|------|-----------------|-------------------------|------------------|
| J1231–47  | 12$^h$31$^m$40(50) | $-47^\circ46(7)'$ | 1.87304(2) | 52056.3 | ........... | 31(3) |
| J1919+0134 | 19$^h$19$^m$43$^s$62(3) | $+01^\circ34'56"5(7)$ | 1.60398355528(6) | 51650.0 | 0.589(11) | 191.9(4) |

2.1 Fluctuation spectra

Fluctuation spectra were formed by performing a spectral analysis of the longitude–time data. The process is discussed in Backer (1973). The Fourier transform was performed upon each longitudinal column to produce an indication of the level of periodicity as a function of pulse phase. The spectra were then normalised by first subtracting the power spectra of an off-pulse region from all the on-pulse spectra. Each spectrum was then divided by the square of the average signal level in the longitudinal column from which the spectrum was formed. Figure 1 shows the normalised average pulse profile along with the normalised spectral power as a function of longitude measured at the peak of the fluctuation spectrum. Both pulsars are in fact very similar. The fluctuation, although great in longitudinal extent, is concentrated in the stronger of the two components.

Analysis of the spectra themselves provided values for the frequency of the amplitude variations. The values obtained for the frequency of the main spectral feature were: 0.050±0.002 (cycles/period) for PSR J1231–47, and 0.156±0.008 (cycles/period), for PSR J1919+0134.

In order to further investigate this phenomenon, a 1 hour integration of PSR J1231–47 has been obtained. Due to interstellar scintillation effects the 1 hour observation had a signal to noise ratio such that sub-pulses are not directly observable in a longitude–time plot. Furthermore it suffered from a burst of interference approximately half way through. In order to mitigate the interference effects the observation was broken into two sub-integrations. Nevertheless fluctuation spectra formed from these sub-integrations displayed a significant spectral feature at 0.0528±0.0008 (cycles/period) and 0.0515±0.0004 (cycles/period) respectively. This feature is consistent with that found in the shorter observation. The quoted errors are under-estimates being simply half a frequency bin-width. These values are consistent with those presented in Table 2.

2.2 Average properties

In order to examine the features of a “typical” drift band some sort of band averaging had to be performed. This was achieved by the construction of a two dimensional auto-
correlation function (2DACF) of the longitude–time plots (Vivekanand & Joshi 1997). The auto-correlation function was formed in a number of stages. A region of the longitude-time frame was chosen. The region is composed of the on-pulse region in longitude domain and the length of the observation in the time domain. The mean value of this sub-array was then subtracted from each point. The purpose of this was to reduce the height of the zero-lag spike in the auto-correlation. The array was then padded on all 4 sides with a number of zeroes commensurate with the number of lags required in the 2DACF. A forward Fourier transform was then performed. The resultant was then multiplied by its complex conjugate. The product was then inverse transformed, producing the 2DACF.

The 2DACF provides a method for examining the “average” properties of the drifting bands by providing the correlation of each drift band with itself and its neighbours. We can examine the evolution of the drift rate by comparing the slopes and separations of the correlated bands. The values for \( P_2 \) (the phase separation), and \( P_3 \) (period separation) (Backer 1973) can be found by analysis of straight line fits to the peaks in the lag-lag plane. The straight line fits were performed on the central regions of each drift band, where the signal to noise ratio was highest. In order to obtain the parameters of the straight line fit we assumed the data was adequately modeled by a straight line and an initial fit was performed. Then measurement errors of magnitude 1 standard deviation were ascribed to each point, the fit performed again and the chi-square statistic minimised to obtain values and errors for the fitted parameters. This method is described in Press et al. (1986).

The values for the separation between pairs of bands in time (\( P_3 \)) and phase (\( P_2 \)) are given in Table 2. The values were obtained by combining the values for individual drift bands in the lag-lag plane obtained from the straight line fits.

### Table 2. The parameters of a “representative” or “average” drift band for the two pulsars. The parameters were derived from analysis of the straight line fits to peaks in the 2-dimensional auto-correlation functions. \( P_2 \) is the separation of two drift bands in phase. \( P_3 \) is the separation in periods of the drift bands. The drift rate is given as the number of periods required for an average drift band to cross unit phase. The drift rate in milliseconds per period is also given.

| Name     | \( P_2 (\phi) \) | \( P_3 (P) \) | Drift rate \( (P/\phi) \) (ms/P) |
|----------|-----------------|---------------|---------------------------------|
| J1231–47 | 0.0557(9)       | 19.3(2)       | 348(8)                          | 5.4(1)                          |
| J1919+0134 | 0.023(1)       | 6.5(2)        | 277(8)                          | 5.8(2)                          |

2.3 Drift rate across the profiles

Many pulsars which display the property of drifting sub-pulses exhibit a change in sub-pulse drift rate across the pulse profile. This property may be used to test emission models (Krishnamohan 1980; Oster & Sieber 1976; Wright 1981).

We have examined the straight line fits to the peaks in the lag–lag plane in an attempt to identify any clear departure from linearity. No discernible, regular structure indicative of a changing drift rate is apparent in the residuals. Although it should be noted that the “grand averaging” properties of the 2DACF method will remove any non-linearity if the drift rate varies between bands. The low signal to noise ratio of the sub-pulses at the edges of the drift band make investigation of the band behaviour in this region difficult.

3 DISCUSSION

Very regular, stable, persistent drifting pulsars are rare. As such these pulsars represent a welcome addition to the pulsar family. The initial observations are intriguing, the linearity of the drift may provide some information regarding emission geometry (Krishnamohan 1980; Wright 1981). The longitudinal extent of the drift is interesting; it is rare for pulsars of this profile class to display a measurable drift across the whole profile (Rankin 1986; Hankins & Wolszczan 1987). Both of these pulsars display a measurable \( P_3 \) across the majority of the profile and the drift is continuous. Furthermore it is rare for pulsars of this profile class to show such a clear sense of drift, as simple periodic intensity variations at fixed longitudinal positions are more common.

It appears that these pulsars are rare and exemplary exponents of the drifting sub pulse phenomena; as such these pulsars will be of great benefit in investigations of the radio emission mechanism in pulsars.

REFERENCES

Backer D. C., 1973, Astrophys. J., 182, 245

Deshpande A. A., Rankin J. M., 2001, Mon. Not. R. astr. Soc., 322, 438+

Drake F. D., Craft H. D., 1968, Nature, 220, 231

Edwards R. T., Bailes M., van Straten W., Britton M. C., 2001, Mon. Not. R. astr. Soc., 326, 358+

Hankins T. H., Wolszczan A., 1987, Astrophys. J., 318, 410

Krishnamohan S., 1980, Mon. Not. R. astr. Soc., 191, 237

Manchester R. N., Taylor J. H., 1977, Pulsars. Freeman, San Francisco

Oster L., Sieber W., 1976, Astrophys. J., 210, 220

Press W. H., Flannery B. P., Teukolsky S. A., Vetterling W. T., 1986, Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, Cambridge

Proszynski M., Wolszczan A., 1986, Astrophys. J., 307, 540

Rankin J. M., 1983, Astrophys. J., 274, 333

Rankin J. M., 1986, Astrophys. J., 301, 901

Staveley-Smith L. et al., 1996, Proc. Astr. Soc. Aust., 13, 243

Taylor J. H., Manchester R. N., Huguenin G. R., 1975, Astrophys. J., 195, 513

Vivekanand M., Joshi B. C., 1997, Astrophys. J., 477, 431

Wright G. A. E., 1981, Mon. Not. R. astr. Soc., 196, 153+
Figure 2. The 2 dimensional autocorrelations of the longitude–time information. A straight line has been fit to the central peaks in the lag-lag plane in order to characterise the drift band behaviour. The parameters are given in Table 3.