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Inferring a characteristic timescale for pulsar microstructure

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Abstract. We describe a method to extract quasiperiodicities observed in pulsar single pulses reliably, and then to infer their characteristic timescale. The method is applied to PSR B0301+19 data at time resolution of 59.5 μs from Arecibo Observatory.

Keywords : pulse microstructure timescales – nonparametric inference

1. Introduction

Bright single pulses of several pulsars with periods > 60 millisecond, when observed with time resolutions of tens of microseconds, show quasiperiodic intensity variations over timescales of a few hundred microseconds. These structures, first reported by Craft et al. (1968), are commonly known as the pulse microstructure. Microstructure has been observed simultaneously across frequency channels (e.g., Rickett et al. (1975)), which is a strong evidence that they arise due to magnetospheric coherent plasma processes. However, how microstructure relates to pulsar emission processes is yet to be understood. A key quantity that can help bridge the gap between theory and observation is the characteristic timescale for microstructure. Many methods (e.g., Popov et al. (2002), Lang et al. (1998)) attempt to extract microstructure timescales from individual-pulse time series data. However, finding timescales is confounded because of large power at low frequencies, low amplitude of the microstructure signal, and an immense variability in the pulse signal. In this work, we report a method designed to infer a characteristic microstructure timescale reliably.

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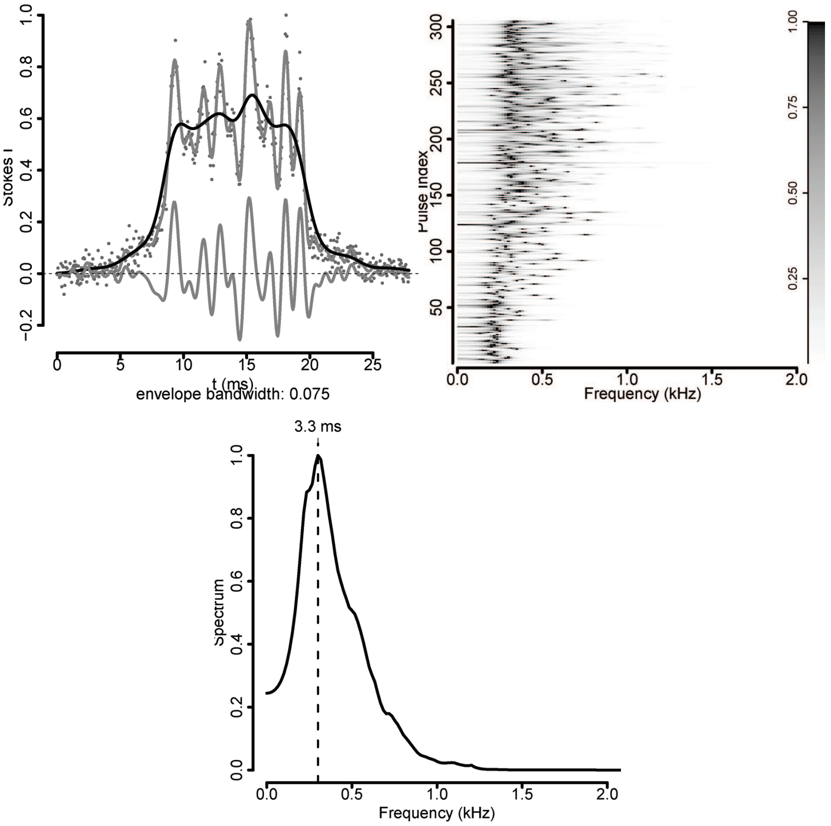

Figure 1. An illustration of our method for inferring microstructure timescales; see text for description.

2. Methodology

Visual inspection of a large number of single pulses (not shown) suggests that the microstructure of interest is a quasiperiodic signal riding on top of a broad pulse envelope with modulating subpulse structures and noise. Hence, we concentrate on finding the dominant periodicity P_μ of the microstructure. Our 3-step procedure extracts this information from each pulse as follows: (1) We de-noise every pulse using a model-independent nonparametric regression method (Aghamousa et al. (2012) and references therein). The fit thus obtained is an optimally smoothed noise-free version of the pulse. (2) We estimate the "envelope" for each pulse using a kernel smoother (Wasserman 2004) using heuristic bandwidth (i.e., smoothing window size). The difference between the fit and this envelope is the estimated microstructure. (3) To extract characteristic timescales in the microstructure, we use three standard estimators (Brockwell & Davies 2002) of the power spectrum: the raw periodogram, the Blackman-Tukey estimator with a Hanning window, and an estimator based on a parametric autoregressive (AR) model. We further scale each power spectrum by its maximum value. P_μ, a characteristic timescale of pulse microstructure, is taken to be the inverse of the frequency-at-peak in the spectrum. This procedure depends on one critical hand-tunable parameter – the smoothing window size for the envelope.

3. An illustrative result

We have applied our methodology to a large set of pulsars (Arecibo observatory; P and L band; time resolution of 59.5 μs). Fig. 1 illustrates it for PSR B0301+19P (period P =1.38 s): The left panel shows the fit (gray, top) = envelope (black) + microstructure (gray, bottom) decomposition for a representative pulse (envelope bandwidth = 0.075 × pulse length); the middle panel shows 305 pulsewise AR power spectra as a grayscale image (grayscale: appropriately normalized power; x-axis: frequency; y-axis: pulse index); the right panel shows the AR power spectrum averaged across the 305 single pulses. An approximate AR-based estimate of the characteristic timescale P_μ for this pulsar is 3.3 ms.

4. Conclusion

We have designed a model-independent methodology to extract a characteristic microstructure timescale from single-pulse data. Our analysis suggests (not shown here) that pulsar period P and microstructure timescale P_μ are positively correlated. This has important implications to understanding the geometry and dynamics of pulsar emission processes.

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