Pulse-to-pulse variations in accreting X-ray pulsars

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Abstract. In most accreting X-ray pulsars, the periodic signal is very clear and easily shows up as soon as data covering sufficient pulse periods (a few ten) are available. The mean pulse profile is often quite typical for a given source and with minor variations repeated and recognisable across observations done years or even decades apart. At the time scale of individual pulses, significant pulse-to-pulse variations are commonly observed. While at low energies some of these variations might be explained by absorption, in the hard X-rays they will reflect changes in the accretion and subsequent emission. The amount of these variations appears to be quite different between sources and contains information about the surrounding material as well as possibly interactions at the magnetosphere. We investigate such variations for a sample of well-known sources.

1 Motivation and data sample

Accreting X-ray pulsars show an easily detectable periodic signal. Their pulse profiles – light curves folded with the pulse period – are usually quite specific for each source, although some common patterns exist [1, 2]. The profiles vary strongly with energy and in some sources with luminosity [1]. Significant variations from one pulse to the next have been observed early on in different sources [e.g., 3, 4]. Studying these variations, especially at higher energies, where absorption becomes negligible, should yield information on the interaction of the magnetosphere with the surrounding material. We have started to do this for a sample of well known sources (Table 1) for which good observational data with relatively long, uninterrupted observations exist in the archives.

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Table 1. Source Sample.

Name	Type	Pulse Period	Instrument	Energy Range
Vela X-1	SgXRB	283.226 s	Suzaku PIN	15–30 keV
GX 304–1	BeXRB	274.884 s	Suzaku PIN	15–30 keV
A 0535+26	BeXRB	103.393 s	RXTE PCA	2–60 keV
GRO J1008–57	BeXRB	93.733 s	Suzaku PIN	15–30 keV
V 0332+53	BeXRB	4.3755 s	RXTE PCA	2–60 keV

Figure 1. Vela X-1 in an active state (left) and going into an off-state (right). In the upper panel the actual light curve is plotted in blue; the repeated mean profile in green and the re-scaled mean profile in red. The lower panel shows the ratio between the observed (blue) and rescaled predicted (green) curve, as well as the scale factor.

2 Comparing light curves and pulse profiles

For each source we extracted light curves and pulse profiles. The pulse profiles were also used to create predicted light curves, repeating the mean pulse profile over the duration of the observation in phase with the light curves. In order to account for variations on longer time scales, a scaled predicted curve was created by applying a rolling scale factor integrating over the observed light curve for the duration of one pulse period. Some examples are shown in Figures 1, 2, 3 and 4.

3 Preliminary Results

The differences between the light curves and the repeated (“unrolled”) mean pulse profiles are at first order driven flux variations on time scales of several pulse periods, presumably driven by the variable inflow of accreting matter. Using the scaled predicted light curves (red curves in the figures), the deviations are reduced to a few 10% of the time-averaged flux with a similar spread across the sources studied so far. On several occasions, a significant change appears to happen from one pulse to the next. Shifts in brightness seem at least in part go hand in hand with different plateaus of pulse minima, while the pulse maxima are somewhat more variable, but this still has to be confirmed and quantified.

Currently, some regular structures in the residuals remain. These may be due to various factors, e.g., a too simple re-scaling approach, evolution of the pulse period within the observation (e.g., for V0332+53) or slight phase shifts in the calculation of the match between pulse profile and lightcurves.

Figure 2. GX 304–1 changing rapidly from a bright state to a normal brightness, plotted as described in Fig. 1.

Figure 3. A 0535+26 varying randomly around the mean brightness, plotted as described in Fig. 1.

Figure 4. V 0332+53 varying randomly around the mean brightness, plotted as described in Fig. 1.

A limiting factor is the rather short typical duration for uninterrupted observation stretches, leading sometimes to a small number of truly consecutive pulses.

4 Further Work

We plan to extend this study by including a larger sample of sources, e.g., Her X-1 or Cen X-3 and a variety of brightness states, where applicable.

The matching of repeated pulse profiles and measured light curves needs to be further refined and the energy dependence of the variations studied for each source.

Based on the improved analysis, the statistical distribution of the residuals and a study of temporal patterns beyond the pulse period can be undertaken and different source types compared.

References

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