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Investigating Long-Term Behaviour of X-ray Binaries Using Archival Data

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Abstract

Long term modulations have been detected in a wide variety of both low and high-mass X-ray binaries. The All Sky Monitor on board the Rossi X-ray Timing Explorer provides the most extensive (∼15 years) and sensitive X-ray archive for studying such behaviour. Since those variations were often intermittent and/or aperiodic, we used a time-dependent Dynamic Power Spectrum method to examine how the modulations themselves vary with time in a systematic way. Some were found to be remarkably stable, while others show a range of properties, from even longer variability time-scales to quite chaotic behaviour.

Keywords: accretion discs - X-ray binaries.

1 Introduction

Kotze & Charles (2012) contains the results of our time-dependent period analysis on 25 X-ray binaries (XRBs) with reported long term variability. For the purpose of these conference proceedings, some of those results are reproduced herein to illustrate the importance of such an approach when dealing with varying periodic and/or aperiodic signals. We also use this opportunity to present some of the highlights contained in our previously published results.

2 Data Analysis

2.1 RXTE/ASM archival data

The Massachusetts Institute of Technology (MIT) operated an All Sky Monitor (ASM) on board the Rossi X-ray Timing Explorer (RXTE) from 1996 to 2012. The ASM observed the X-ray sky with 3 rotating Scanning Shadow Cameras (SSC) which scanned ∼80% of the sky during ∼90 min orbits.

Data were reduced and compiled weekly by the ASM team and made publicly available [1] as dwell-by-dwell or one-day-averages in four energy bands, which includes a Sum-band (1.5-12 keV). One-day-average data [2] are the dwell-by-dwell data binned into 1-day bins. Archival ASM datasets contain the lightcurves of all X-ray sources in the RXTE catalogue. For full details see Levine et al. (1996).

2.2 Time-dependent period analysis

Periods are typically found by variability analysis of time-series/lightcurve datasets. While this approach may allow distinction between periodic and quasi-periodic behaviour, it contains no information regarding the variation or consistency of aperiodic/quasi-periodic signals.

Clarkson et al. (2003) presented results from their time-dependent periodic analysis on 4 X-ray binaries in the form of Dynamic Power Spectra (DPS). The method requires the datasets to be split into windows that are of sufficient length to allow detection of the maximum period considered. Transition from one independent window to the next is smoothed (i.e. increased resolution) by adding sliding windows between the positions of adjacent independent data windows.

Lomb-Scargle (L-S; Lomb 1976 & Scargle 1982) periodograms were produced for every data window and the results of all the periodograms for a source were plotted together in a density map, using the L-S power for each frequency plotted at every window's mid-point along the time-axis. The frequency domain allowed appropri-

[1] http://xte.mit.edu/ and http://xte.mit.edu/ASMlc.html

[2] I have made all their plots available on: http://www.saao.ac.za/∼marissa/LC/LC.html

ate coverage over frequencies associated with previously reported periodic behaviour (Table 1). Since the DPS method requires a significant number of computations, its application has been limited until recent advances in desktop technology allowed it to be employed more readily.

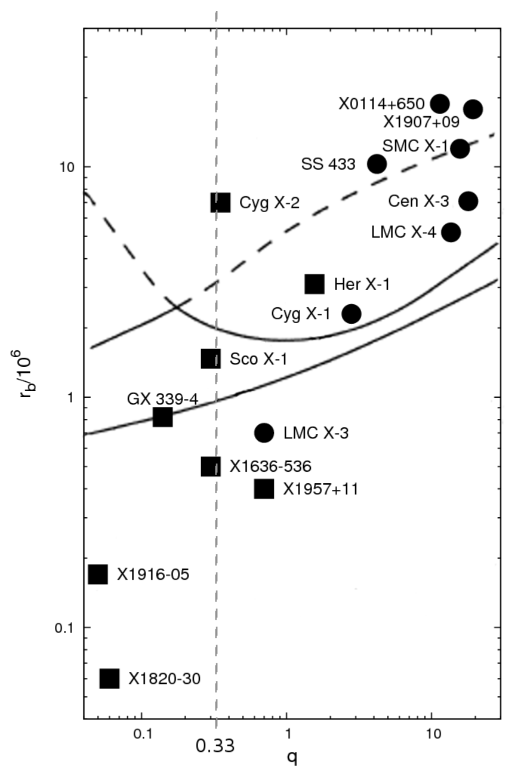

Figure 1: Accretion disc stability to radiation-driven warping in XRBs, as functions of q and r_b ($[\frac{GM_1}{c^2}]$), adapted from Ogilvie & Dubus (2001) to include only XRBs with known super-orbital periods and updated with their latest system parameters (See Table 1). Squares indicate low-mass XRBs (LMXBs) and circles high-mass XRBs (HMXBs). Tidally-induced disc precession (Sec 3.4) may occur left of the dashed line.

3 Results

Several mechanisms have been proposed to account for the super-orbital variations (P_{sup}) observed in XRBs. We list our results according to the mechanisms that have been considered most likely candidates for the cases included here. Please refer to Kotze & Charles (2012) for more details.

3.1 Radiation-induced disc warp/tilting

Ogilvie & Dubus (2001) provided stability predictions for XRB accretion discs against radiation-driven warping/tilting. Therein the binary separation (r_b) and mass ratio ($q = M_2/M_1$) determine the location of a source on their predictive diagram, which is divided into zones where stable warps (between the dashed and solid line), chaotic warps (above the dashed line) or no warps (below lower solid line) are expected. A source near the transition boundary between the stable warp zone and the chaotic warp zone, may experience instability that could result in variable warps.

Table 1: System parameters for included XRBs

Source	P_{sup} [days]	P_{orb} [days]	q $[\frac{M_2}{M_1}]$	$r_b/10^6$ $[\frac{GM_1}{c^2}]$
Her X-1	33-37 [1]	1.700 [2]	1.56	3.1
SMC X-1	50-70 [3]	3.89 [4]	11.0	8.9
LMC X-4	30 [5]	1.41 [6]	10.6	4.5
Cyg X-2	60-90 [7]	9.844 [8]	0.34	8.0
X1820-303	171 [9]	0.008 [10]	[0.1]	0.1
SS433	162 [11]	13.10 [12]	[1.0]	[3.0]
X1916-053	5 [13] 199 [16]	0.035 [14],[15]	[0.1]	0.2

[1] Leahy & Igna (2010), [2] Tananbaum et al. (1972), [3] Clarkson et al. (2003), [4] Schreier et al. (1972), [5] Lang et al. (1981), [6] Chevalier & Ilovaisky 1977, [7] Clarkson et al. (2003), [8] Cowley et al. (1979), [9] Chou & Grindlay (2001), [10] Stella et al. (1987), [11] Margon (1984), [12] Crampton et al. (1980), [13] Homer et al. (2001), [14] Walter et al. (1982), [15] White & Swank (1982), [16] Priedhorsky & Terrell (1984)

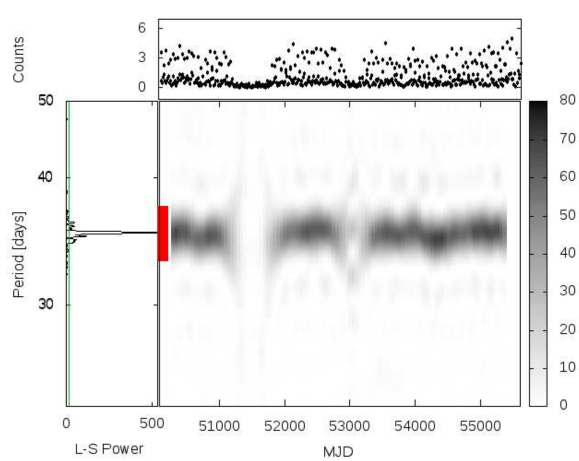

Figure 2: Her X-1: This steady super-orbital period have been associated with a stable radiation-driven warp.

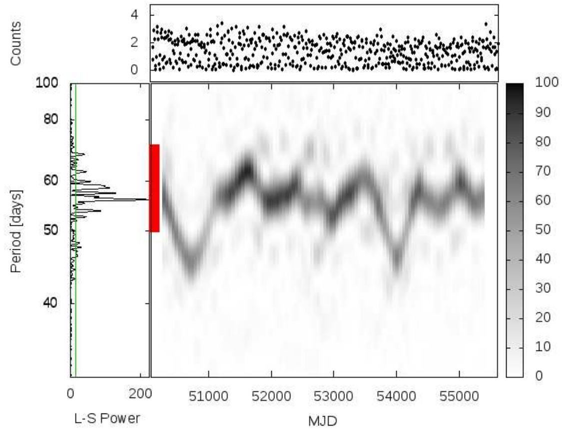

Figure 3: SMC X-1: The super-orbital period that is evolving dramatically over an even longer time-scale, may be associated with a radiation-driven warp that is variable.

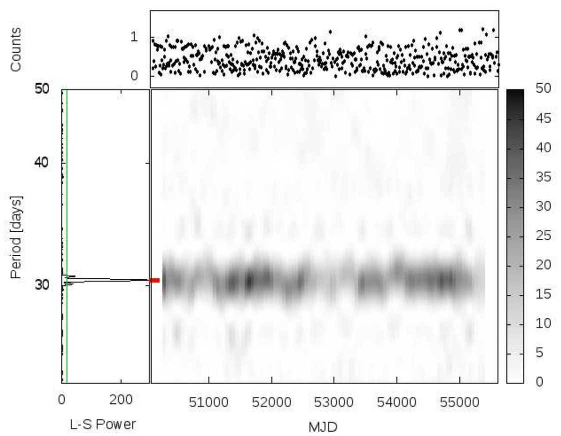

Figure 4: LMC X-4: The steady long-term period may be produced by a stable radiation-driven warp.

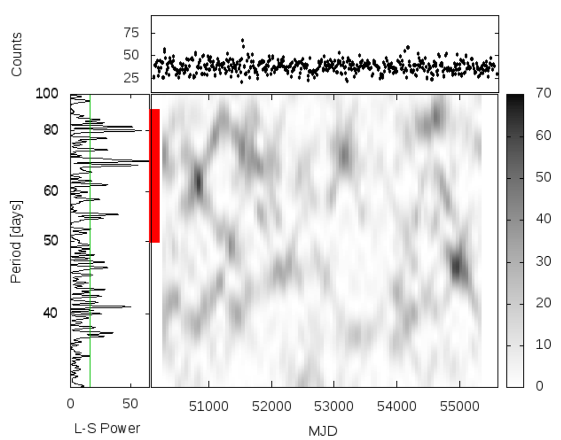

Figure 5: Cyg X-2: The unstable/chaotic behaviour may be associated with chaotic warping.

3.2 Third body

Zdziarski et al. (2007) performed a comprehensive analysis of the triple system scenario and how binary eccentricity oscillations could modulate mass transfer through L_1, finding agreement between theoretical and observed lightcurves for X1820-303.

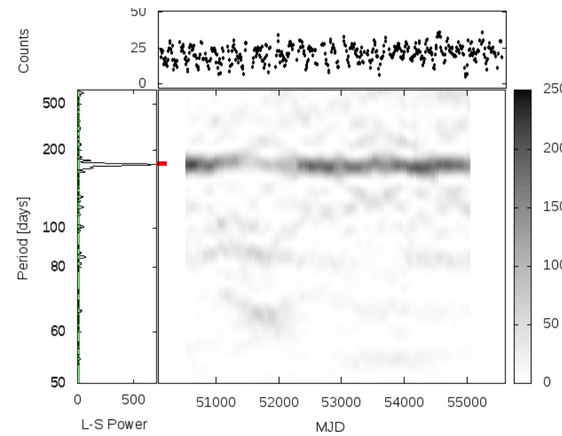

Figure 6: X1820-303.

3.3 Precessing relativistic jets

SS433 is the prototypical microquasar. Its precessing relativistic jets and their resulting $\sim$ 162 day super-orbital period was obtained by Hjellming et al. (1981) and Margon (1984) from variations in the radial velocity measurements from Balmer and He I emission lines.

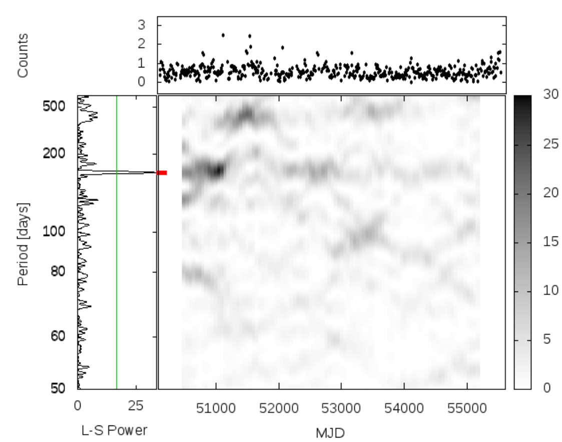

Figure 7: SS433.

3.4 Tidally-induced disc precession

Whitehurst & King (1991) described how tidal interactions with the donor may excite resonances in the accretion disc, causing it to precess and produce quasi-periodic variations in the lightcurve. Essentially the disc becomes elliptical, expanding beyond its critical radius while remaining within its Roche-lobe radius, so that disc precession is effectively the result of changes in the orientation of this elliptical accretion disc with respect to the donor.

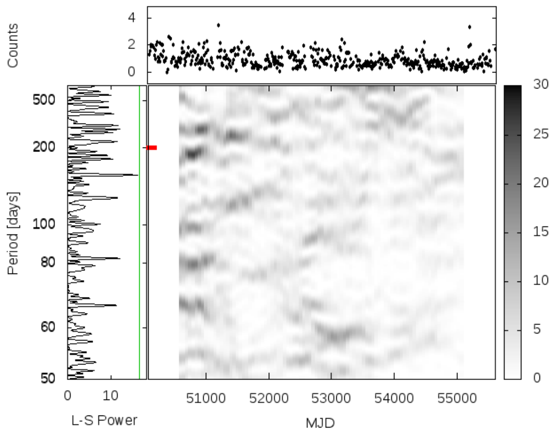

Figure 8: X1916-053.

Tidal disc precession depends on the mass ratio ($q = \frac{M_2}{M_1}$) and will only occur if $q < 0.25 - 0.33$, producing so-called “superhumps”, which have been detected in the SU UMa sub-class of Cataclysmic Variables (CVs). The vertical dashed line on Fig. 1 indicates this boundary, to the left of which XRBs are expected to be susceptible to tidal disc precession (e.g. X1916-053 and X1820-303).

4 Discussion

The composite figure for each source contains a wealth of information to assist interpretation. The lightcurves are shown in the top panels and density maps with the DPS results form the main panels, for which the scales are indicated to the right. The 99.9%-confidence white noise levels (green lines), together with the L-S for the entire datasets, are shown in the left panels.

All included sources show significant (exceeding the white noise levels) periodic signals in their DPS. Previously reported periodicities (listed in Table 1), indicated by red bars, are clearly present in the DPS panels and often also in the L-S (left-hand) panels along with additional variability.

5 Conclusions

Quasi-periodic or aperiodic signals should be investigated using time-dependent period analysis techniques. While these examples focussed on long-term super-orbital behaviour of XBs, it should be immediately apparent how useful such a technique would be for investigating short-term quasi-periodic oscillations in CVs.

Acknowledgement

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DISCUSSION

KOJI MUKAI: Can you clarify what you saw in X1916? It is a low q system, but I thought the disc precessesion period was about 5 days, while your plot showed only longer periods.

MARISSA KOTZE: Our DPS analysis for this source show no significant periodic behaviour below 10 days. But this is not unexpected, since the 5 day period associated with tidal disc precession in X1916-053 was not determined from X-ray flux variations, but rather from optical variability and changes in the structure of the X-ray dips, which our DPS analysis of RXTE ASM data is unable to detect.