Accretion driven spin-up in Be/X-ray binary systems in the Small Magellanic Cloud

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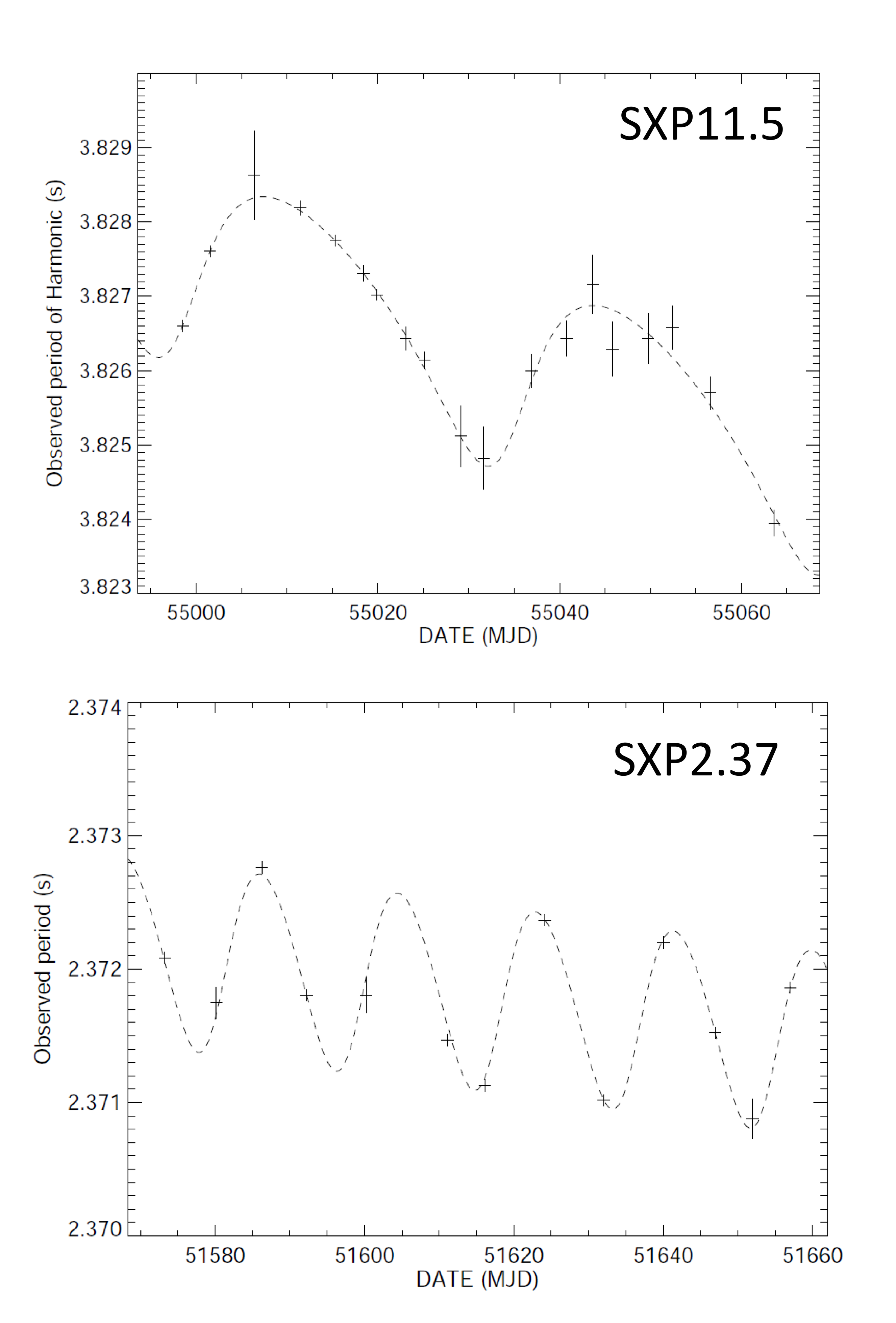

Figure 1: Spin period evolution and orbital fit to SXP11.5 & SXP2.37

Abstract

In recent years it has been discovered that the Magellanic Clouds are home to a plethora of accreting binary systems. In particular, the Small Magellanic Cloud (SMC) has an exceptional population of Be/X-ray binaries (BeXRB). Being at a known distance, in an environment of known metallicity and spatially very close, this population is ideal for studying star formation, binary evolution and accretion onto compact objects. Born out of our long-term monitoring programme with RXTE, it is becoming clear that many SMC BeXRB systems exhibit substantial spin-up during phases of accretion onto the neutron star. We examine the spin period evolution of four BeXRB's in the SMC (SXP11.5, SXP2.37, SXP8.80 and SXP74.7), modelling the observed spin-up to separate the intrinsic, accretion driven spin-up from any Doppler modulation of the spin period. In the case of SXP11.5 & SXP2.37 we fit an orbital solution and find that the spin-up, spin period and X-ray luminosity agree nicely with current theory on binary accretion. The two other sources were more luminous and seem to exhibit unusual timing properties at the most luminous point in the X-ray outburst.

Introduction and Background

BeXRBs are systems in which a neutron star (NS) orbits a massive, early type star that at some stage has shown evidence of line emission in the Balmer series. The NS accretes via interactions with an extended envelope of material in the equatorial plane of the Be star. These systems typically have wide, eccentric orbits meaning most X-ray outbursts are due to the NS passing through periastron where the density of accretable material is greatest. These outbursts are denoted Type I outbursts and are generally in the luminosity range 10^{36}-10^{37} erg s^{-1} and last from a few days to a few weeks. The less common Type II outbursts are brighter (>10^{37} erg s^{-1}) and have no correlation with orbital phase. They can last from a few days to several months. During phases of accretion, the pulse period of the pulsar is seen to decrease, suggesting that large transfer of angular momentum from the companion to the NS is taking place. This is known as *spin-up.*

Data and Model Fitting

Over the duration of our RXTE monitoring programme of the SMC, we have detected several sources in a Type II outburst. Depending on the coverage of the satellite and the duration of the outburst, we have approximately a dozen systems with data sufficiently long enough to make orbital fitting a possibility. So far only two systems in the SMC have been fit with an orbital model such that we have a complete orbital solution, describing all the parameters of the binary system; these are SXP18.3 (Schurch et al. 2009, MNRAS, 392, 361) and SXP11.5 (Townsend et al. 2010, arXiv:1008.3361). The figures show four examples of recent fits to the detected pulse period of the system using our orbital fitting code. The oscillatory nature of the spin period is most easily explained by the Doppler shifting of the spin period by the binary orbital motion in the system. However, a general spin-up trend may be induced by angular momentum transfer during the accretion of matter onto the neutron star. Consequently the observed data were fit with a simple spin-up model, convolved with a standard orbital model which calculates the line of sight velocity of the neutron star. This combined model iterates over some input parameters until a best fit for a Levenberg-Marquardt least-squares fit is achieved.

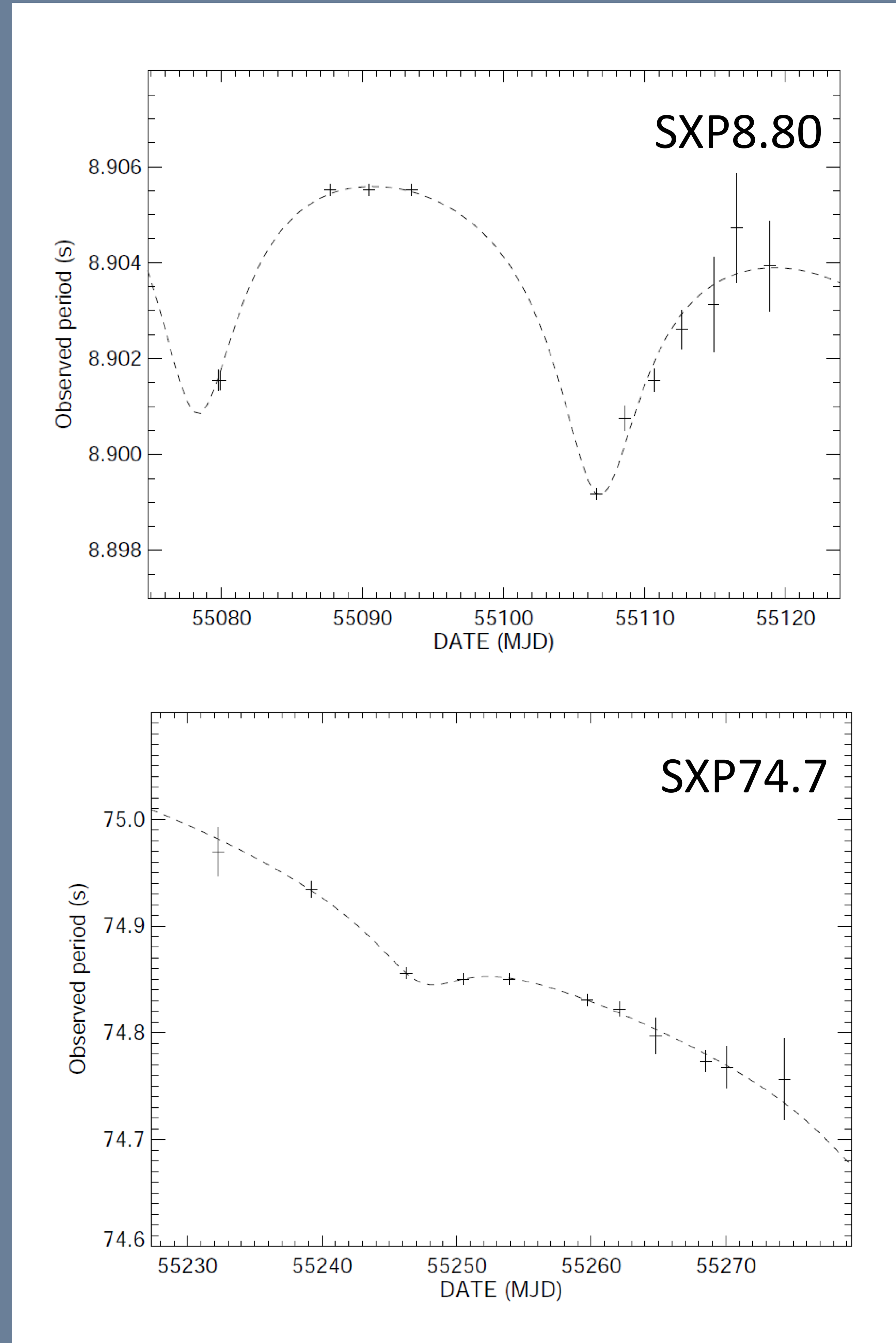

Figure 2: Spin period evolution and orbital fit to SXP8.80 & SXP74.7

Parameter		SXP11.5	SXP2.37	SXP8.80	SXP74.7
Orbital period	$P_{orbital}$ (d)	36.3 ± 0.4	18.46 ± 0.04	28.51 *(frozen)*	33.38 *(frozen)*
Projected semimajor axis	$a_x \sin i$ (light-s)	167 ± 7	74.6 ± 2.4	111 ± 4	147.3 ± N/A
Longitude of periastron	ω (^{o})	224 ± 10	238 ± 5	178 ± 4	186 ± 18
Eccentricity	e	0.28 ± 0.03	0.09 ± 0.02	0.41 ± 0.04	0.40 ± 0.23
Orbital epoch	$\tau_{periastron}$ (MJD)	55034.3 ± 1.0	51617.2 ± 0.3	55135.2 ± 0.2	55280.9 ± 1.5
Spin period	P (s)	11.48143 ± 0.00001	2.37182 ± 0.00001	8.9038 ± 0.0001	74.867 ± 0.002
First derivative of P	$\dot{P}$ (ss^{-1})	$(-4.67 \pm 0.31)^{-10}$	$(-8.79 \pm 0.45)^{-11}$	$(-6.89 \pm 0.57)^{-10}$	$(-6.35 \pm 0.37)^{-8}$
Goodness of fit	χ^2_ν	0.82	4.90	2.60	0.33

Table 1: The orbital parameters from fits to the four BeXRB systems presented above.

Results and Conclusions

❑ SXP11.5 was the first time in which the Doppler modulation of the spin period of the NS has been seen so apparent in a binary system in the SMC, and only the second source to have a binary solution through orbital model fits. The correct solution was easily found in this system and the spin-up, X-ray luminosity and pulse period agree well with the equations that describe accretion in binary star systems (Ghosh & Lamb, 1979, ApJ, 234, 296).

❑ Although the SXP2.37 data presented here is over 10 years old, the length of this Type II outburst has made it quite easy to fit. The uncertainty in the proposed orbital period from optical data seems to have been removed with the confirmation of this periodicity in our fit, although the poor chi-squared of the fit is peculiar and will be looked into further. Again, the spin-up, luminosity and period found in the fit agree with the equations of Ghosh & Lamb.

❑ SXP8.80 and SXP74.7 have well known orbital periods found from analysis of optical data. Given the data on these systems are sparser than the previous sources, we have frozen the orbital period to the known values in the fit – allowing for easier fitting. As can be seen in Table 1, the lack of data still gives unsatisfactory goodness of fits. In these cases, parameters such as eccentricity and projected semimajor axis may not be accurate as they are much more sensitive to the initial fitting parameters.

❑ Is there evidence of spin-up freezing at points of high flux? All three sources presented here (not SXP11.5 which has an L_{MAX} = 2 x 10^{37} ergs/s) show two subsequent detections at exactly the same spin period when the luminosity exceeds 5 x 10^{37} ergs/s, the approximate Eddington limit for a 1.5 solar mass NS accreting onto 20% of it's surface. Is this coincidence and do other systems show this phenomenon?

Summary: Through several years of X-ray monitoring of the SMC, we are starting to uncover orbital details of BeXRB systems that were previously unobtainable. Finding these binary parameters will help in our understanding of how these binary systems form and how they evolve, as well as giving an insight into how different binary parameters are linked and how they affect each other. The discovery or confirmation of orbital periods is also important, allowing systems to be classified or refined on the Corbet diagram of binary pulsars. These orbital parameters are also a key component of SPH simulations of the circumstellar disk being performed in our research group, allowing us to probe the dynamics of the disk and how this affects accretion onto the compact object.