Long-term properties of HMXBs in the SMC

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Abstract

We have studied the very long-term temporal properties of the optical emission from Be X-ray binaries (BeX) in the Small Magellanic Cloud over a ~ 16 yr baseline, using light curves from the MACHO and OGLE databases. All the BeX in our sample display super-orbital variations, many of them quasi-periodic on timescales of ~ 200-3000 d. These long-term variations are believed to be related to the formation and depletion of the circumstellar disc around the Be star and we compare and contrast their behaviour with that of the LMC's prototypical BeX, A0538-66. The great majority of sources show a correlation of outburst amplitude with brightness (the opposite to that seen in A0538-66) although the amplitudes are mostly small (<0.1 mag). We suggest this is an orbital inclination effect. In addition, we have also detected many of their optical orbital periodicities, visible as a series of precisely regular outbursts. Furthermore, the amplitude of these periodic outbursts can vary through the long-term super-orbital cycle, and we discuss mechanisms which can produce this effect, as well as examining an apparent correlation between these periodicities. As a by-product of this variation survey we have compiled a list of all the reported SMC BeX orbital and super-orbital periodicities at optical and X-ray wavelengths.

Introduction

- BeX: neutron star orbiting a Be star in a wide (period ~months) and eccentric orbit
- Rapid rotating Be stars → outflows/equatorial disc .
- Neutron star/ Be equatorial disc interaction during the periastron passage → periodic outbursts/ Orbital modulation (Okazaki & Negueruela, 2001).
- Formation and depletion of the equatorial disc → long-term super-orbital modulations (~ hundreds of days to years). (McGowan & Charles, 2003).

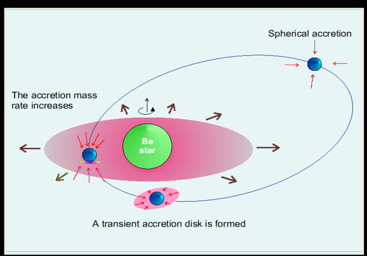

Figure 1 : Typical Be/X-ray binary

Light-curves from the MACHO and OGLE projects

- MACHO (MAssive Compact Halo Objects) project observed the Magellanic Clouds for 7 years in two passbands, a red band (~ 6300-7600 A), and a blue band (~ 4500-6300 A).
- OGLE (Optical Gravitational Lensing Experiment) projects runs from January 1997 until now (13 years). The photometric data are taken in the I-band.
- MACHO + OGLE → 18 years light curves

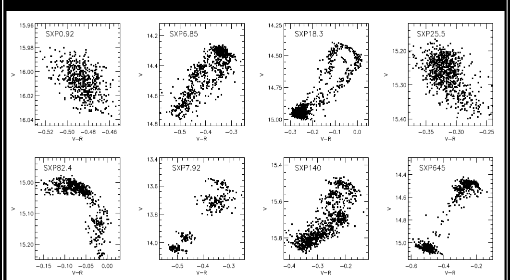

Figure 2 : V vs. V-R diagram of selected SMC BeX sources showing that they are redder when brighter; the 3 exceptions being SXP0.92, SXP25.5, and SXP82.4 which are redder when fainter (Rajoelimanana et al. 2010, submitted)

Some results

- Periodicities from as short as hours (non-radial pulsation of the Be star) to tens of days (orbital modulation, NS/Be equatorial disc interaction) to many hundreds of days (formation and depletion of the Be equatorial disc) (Figure 4).
- Correlation between the observed super-orbital and orbital periods (linear correlation coefficient = 0.73)(Figure 3).
- Increase of outburst amplitude with brightness of the source. The only exception is SXP7.92 (Figure 5).
- Sources with an inclination i < 90º- α get redder when it brightens (α is the opening angle of the disc).
- P (i < 90º- α) = *1 - cos(90º- α)*. *If we assume that* α ~ *10,* then P(> 80º) ~ 0.17.
- 31 sources with MACHO counterparts → 4 or 5 sources with an inclination i > 80º (in good agreement with the number of sources (3 sources) that become redder when fainter (Figure 2).

Short ID	$P^{\star}_{sup}$	P_{orb}	Previously reported P_{orb} X − ray†	Previously reported P_{orb} Optical
SXP0.09	247±5	...	...	...
SXP0.92	2654±298	...	...	51[1]
SXP2.37	...	18.58± 0.01	...	...
SXP2.76	2800±700	82± 0.07	...	82.1[2]
SXP3.34	495±2	11.09± 0.01	...	...
SXP6.85	621±4	110± 0.20	112	114[4]
SXP7.78	1116±56	44.9± 0.20	44.9	44.8[5]
SXP7.92	397±2	36.4± 0.02	...	36.8[14]
SXP8.9	1786±32	28.5± 0.01	28.4	33.4[6]
SXP9.13	1886±35	80.1± 0.06	77.2	40.1[8]
SXP15.3	1515±23	74.5± 0.05	28	75.1[8]
SXP18.3	...	17.9± 0.01	17.7	17.7[15]
SXP22.1	...	75.9± 0.06	...	...
SXP25.5	...	22.5± 0.01	...	...
SXP31.0	...	90.5± 0.08	...	90.4[2]
SXP34.1	...	598± 3.60	...	...
SXP46.6	...	136± 0.20	137	137[9]
SXP59	...	62.1± 0.04	122	60.2[10]
SXP74.7	1220±64	33.3± 0.01	61.6	33.4[11]
SXP82.4	...	171± 0.30	362	...
SXP91.1	...	88.3± 0.10	117	88.2[7]
SXP101	758±6	21.9± 0.01	25.2	21.9[12]
SXP138	2700±304	143± 0.20	103	122[6]
SXP140	492±2.4	...	...	197[6]
SXP172	...	67.9±0.04	70	69.9[6]
SXP202A	1220±61	71.9± 0.05	91	...
SXP202B	~ 3000	224± 0.50	...	...
SXP264	~2000	49.1± 0.02	...	49.1[10]
SXP280	~2000	127± 0.20	64.8	127[2]
SXP293	...	59.7± 0.03	151	59.7[7]
SXP304		344± 1.20	...	520[6]
SXP327	1274±143	45.9± 0.20	...	45.9[16]
SXP348	...	94.4± 0.09	...	93.9[6]
SXP455	1886±145	74.9± 0.05	...	74.7[7]
SXP504	3448±119	272± 0.70	265	273[10]
SXP564	~ 3000	152± 0.20	151	95.3[7]
SXP645	2857±81	135± 0.50	...	...
SXP701	...	412± 5.00	...	412[10]
SXP755	...	391± 2.00	389	394[7]

[1]: Kaspi et al. (1993); [2]: Schmidtke & Cowley (2006); [3]: Coe et al. (2005); [4]: McGowan et al. (2008); [5]: Cowley & Schmidtke (2004); [6]: Schmidtke, Cowley, & Udalski (2006); [7]: Schmidtke et al. (2004); [8]: Edge (2005a); [9]: McGowan et al. (2008); [10]: Schmidtke & Cowley (2005b); [11]: Schmidtke & Cowley (2007b); [12]: McGowan et al. (2007); [13]: Edge et al. (2005b); [14]: Coe et al. (2009); [15]: Schurch et al. (2009); [16]: Udalski & Coe (2008)

⋆Superorbital orbital period.
†X-ray orbital period from Galache et al. (2008).

Table 1 : The list of all super-orbital and orbital periods as well as the previously reported X-ray and optical periods (Rajoelimanana et al. 2010, submitted)

Orbital and super-orbital period correlation

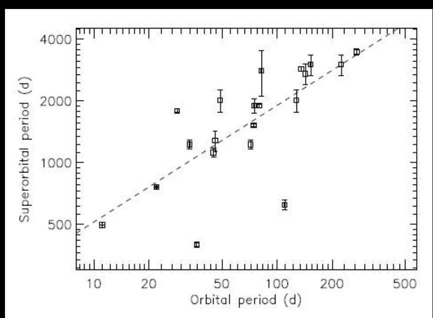

Figure 3 : Plot of the BeX super-orbital periods against orbital periods. The dashed line represents the best linear fit. (Rajoelimanana et al. 2010, submitted)

Some results (Orbital and super-orbital periods seen in SXP6.85)

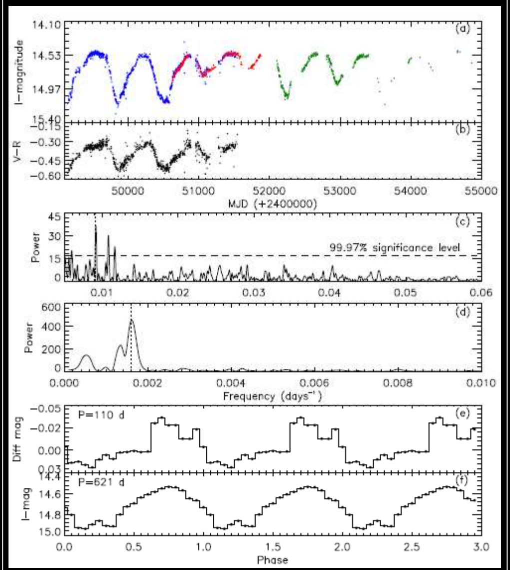

Figure 4 : SXP6.85 : (a): MACHO and OGLE light curves. (b) MACHO colour variation (V - R). (c) and (d): Power spectrum of the detrended and combined light curves showing significant peaks at 110 d and 621 d respectively. (e) and (f): Light curve folded on the 110 d and 621 d (Rajoelimanana et al. 2010, submitted) .

Variation of outbursts amplitude

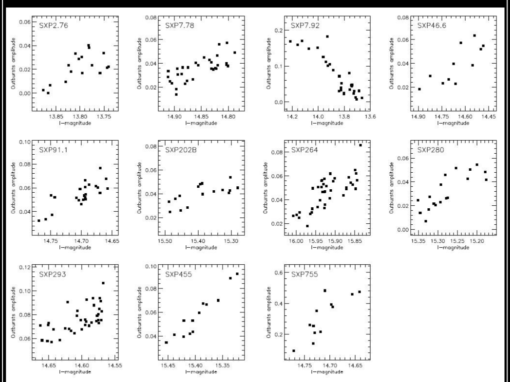

Figure 5 : Variation of outburst amplitude of selected SMC BeX sources as a function of the brightness of the sources. (Rajoelimanana et al. 2010, submitted)

Summary

We have found 19 super-orbital periods which are related to the variation in the size of the Be circumstellar disc, with timescales very similar to the V/R variations found spectroscopically. This suggests that the long-term variation in Be star emission line profiles may be related to the long-term variations we see in the optical light curves.

In addition to that, we have presented an update of the orbital periods of 35 BeX sources using the complete MACHO, OGLE observations, which are seen as a periodic outburst in the light curves. Furthermore, the amplitude of these outbursts vary through the super-orbital cycle. They are very strong either at optical maxima or at optical minima, depending on the inclination of the source (Figure 5).

References

Okazaki A. T., Negueruela I., 2001, *A&A* , 377, 161
McGowan K. E., Charles P. A., 2003, *MNRAS* , 339, 748
Galache J.L et al., , 2008, *ApJS*, 177, 189
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