COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 6030

Konkoly Observatory
Budapest
10 July 2012

HU ISSN 0374 – 0676

PHOTOMETRIC BEHAVIOR OF EIGHT Be/X-RAY BINARIES IN THE SMC

SARRAJ, I.[1]; SANDERS, R.J.[1]; SCHMIDTKE, P.C.[1]

[1] School of Earth and Space Exploration, Arizona State University, Box 871404, Tempe, Arizona 85287 USA

E-mail: Ibrahim.Sarraj@asu.edu, Raymond.J.Sanders@asu.edu, Paul.Schmidtke@asu.edu

We have examined the photometric behavior of eight Be/X-ray binaries in the SMC. Systems like these contain a mass-accreting neutron star in orbit with a Be star and show a variety of optical signatures (see Schmidtke & Cowley 2006; Coe et al. 2005). For binaries in which the neutron star pierces the Be star's envelope, recurring outbursts are observed that mark the orbital period. Non-radial pulsations of the Be star itself are apparent in some systems (see Balona 2010). Our sample is listed in Table 1 and consists of eight systems from the surveys of Antoniou et al. (2009b), Haberl & Pietsch (2004), and Laycock et al. (2010). None of the X-ray sources is known to be a pulsar. The magnitudes of all optical counterparts are consistent with B-type stars in the SMC. Except for object 2 (CXOU J005047.9−731817), the spectrum of each source was discussed by Antoniou et al. (2009a). They classified the stars as type B1.5e or earlier, with strong Hα emission. Hence, the observed $B-V$ colors (between -0.10 and 0.00) imply large contributions to the light from cooler circumstellar disks surrounding the primary stars.

Table 1. Source Identifications, Magnitudes, Colors, and Spectral Types

Object	X-ray Source	OGLE-II	MACHO	[M2002][a]	V^a	$B-V^a$	Sp.Typ.[b]
1	XMMU J004834.5−730230	smc_sc5_43566[c]	212.15851.9	11182	14.84	−0.05	B1.5e
2	CXOU J005047.9−731817	smc_sc5_180008	...	17703	14.50	−0.03	...
3	CXOU J005057.2−731008	smc_sc5_271074	...	18200	14.33	0.00	B0.5e
4	CXOU J005245.0−722844	...	207.16145.12[d]	24501	14.65	−0.10	O9-B0e
5	CXOU J005252.2−724830	smc_sc6_147662	208.16140.14[e]	24914	14.19	0.00	O2((f))+OBe
6	CXOU J005446.2−722523	smc_sc7_70843	207.16259.37	31155	15.25	−0.10	B1e
7	XMMU J010030.2−722035	smc_sc8_204456[f]	207.16603.13	49014	14.60	−0.07	B1.5e
8	XMMU J010435.7−722143	smc_sc10_61612	206.16887.12	59680	15.15	−0.03	B1.5e

[a]From Massey (2002) [b]From Antoniou et al. (2009a)
[c]Also smc_sc4_178950 [d]Also 208.16145.10 [e]Also 207.16140.17 [f]Also smc_sc9_35989

Photometric data for all objects were obtained from the MACHO and OGLE web sites. Long-term trends in the observations were removed by subtracting low-order polynomial fits from segments of data. The flattened values were then searched for periodicities in the frequency range $0-3$ day^{-1}, using the Period04 analysis package (Lenz & Breger 2005).

For sources in this study, significant one-day aliasing is present in the Fourier spectra due to the character of the data sampling. This problem can be further complicated for short-period signals if the fundamental frequency is itself changing, as discussed by Schmidtke & Cowley (2012). They find that small variations in a pulsation period have the effect of reducing the significance of a short-period signal while artificially increasing the apparent significance of a long-period alias. Hence, the highest peak in a Fourier plot might not be the proper choice. In selecting the most likely period for each object studied here, we considered not only the relative strengths of peaks in the Fourier spectrum of the entire data set but also the Fourier spectrum from each individual season, the shape of the resulting (folded) light curve, and the agreement of data taken in different bandpasses.

Periodic signals were found in four systems. We did not identify a meaningful signal for objects 3, 5, 7, and 8. The maximum amplitude in each of these stars was <0.01 mag. The results are summarized in Table 2, and individual systems are discussed below.

Table 2. Photometric Periods and Amplitudes

	OGLE-II *I*		MACHO Blue		MACHO Red	
Object	Period (days)	Amplitude (mag)	Period (days)	Amplitude (mag)	Period (days)	Amplitude (mag)
1	1.053	0.037	1.025	0.022	...	...
2	1.050	0.017	...	...	...	...
4	...	...	...	...	17.541	0.042
6	0.731	0.015	0.730	0.008	0.730	0.010

Object 1 (XMMU J004834.5−730230): A periodic signal with P=1.053 days was found in season 1 of the OGLE-II *I* data. The folded light curve, shown in Figure 1, is sinusoidal in shape with a full amplitude of 0.037 mag. This behavior is consistent with non-radial pulsations of the Be star. Similar variations, with a period of 1.025 days and an amplitude of 0.022 mag, are present in MACHO blue-bandpass data.

Object 2 (CXOU J005047.9−731817): The high-precision position of the *Chandra* X-ray source is coincident with OGLE-II star smc_sc5_180008, but not with emission-line object [MA93]396 (Meyssonnier & Azzopardi 1993), which lies $\sim5''$ to the north. Although the X-ray spectral parameters are consistent with a Be/X-ray binary (Antoniou et al. 2009b), Hα emission has not yet been confirmed in smc_sc5_180008. A weak optical periodicity, however, is present in season 4 of the OGLE-II *I* data for this star, as shown in Figure 2. These variations, with P=1.050 days and an amplitude of 0.017 mag, are approximately sinusoidal and might be due to non-radial pulsations of the primary star.

Object 4 (CXOU J005245.0−722844): A signal with a period of 17.541 days and an amplitude of 0.042 mag is clearly present in all seasons of the MACHO red-bandpass data. The folded light curve, shown in Figure 3, has a non-sinusoidal shape. The distinct brightening might represent an orbital outburst lasting $\sim$0.4P.

Object 6 (CXOU J005446.2−722523): Periodic variations, with P=0.731 days and an amplitude of 0.015 mag, are present in season 4 of the OGLE-II *I* data. Although the amplitude is small, see Figure 4, the folded light curve is roughly sinusoidal and might be caused by non-radial pulsations. Similar signals were found in both red and blue MACHO data, reinforcing this interpretation.

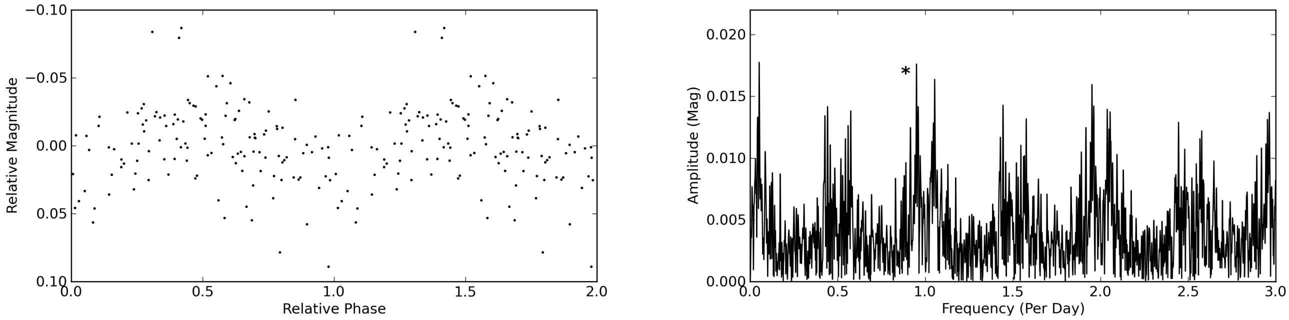

Figure 1. Light curve of detrended OGLE-II data and Fourier spectrum for object 1. The data are folded with P=1.053 days, which is the period marked by $*$ in the Fourier spectrum.

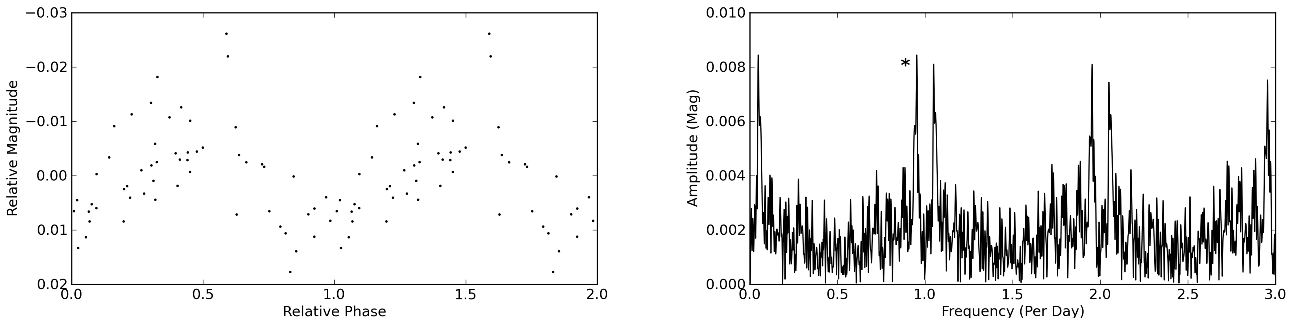

Figure 2. Light curve of detrended OGLE-II data and Fourier spectrum for object 2. The data are folded with P=1.050 days, which is the period marked by $*$ in the Fourier spectrum.

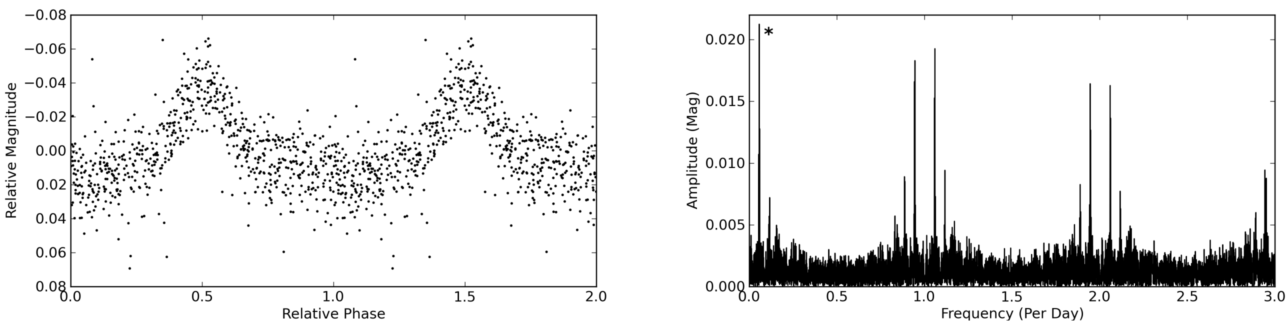

Figure 3. Light curve of detrended MACHO data and Fourier spectrum for object 4. The data are folded with P=17.541 days, which is the period marked by $*$ in the Fourier spectrum.

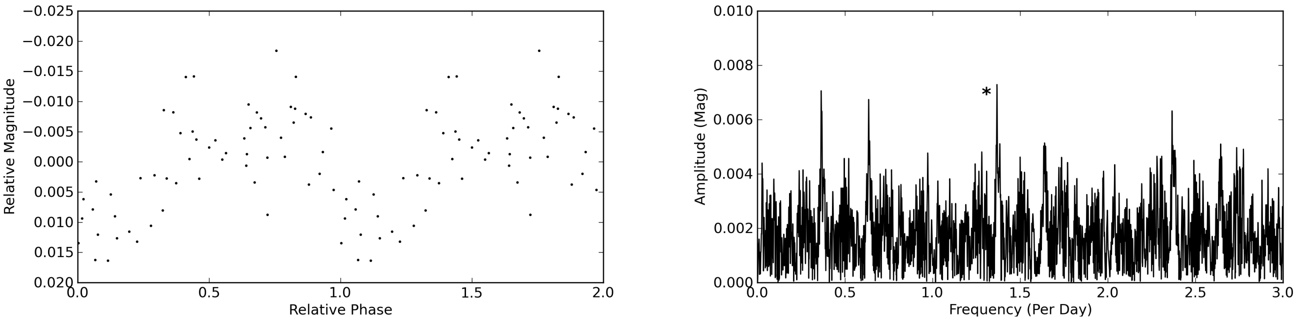

Figure 4. Light curve of detrended OGLE-II data and Fourier spectrum for object 6. The data are folded with P=0.731 days, which is the period marked by $*$ in the Fourier spectrum.

Acknowledgments: This paper utilizes public domain data obtained by the MACHO Project, jointly funded by the US Department of Energy through the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48, by the National Science Foundation through the Center for Particle Astrophysics of the University of California under cooperative agreement AST-8809616, and by the Mount Stromlo and Siding Spring Observatory, part of the Australian National University.

The OGLE-II database, as described by Udalski et al. (1997), Zebrun et al. (2001), and Szymanski (2005), was also used in this investigation.

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