Periodicities in X-ray Binaries from Swift/BAT Observations

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The Burst Alert Telescope (BAT) on board Swift has accumulated extensive light curves for 265 sources (not including GRBs) in the energy range 14 to 200 keV. We present here a summary of searches for periodic modulation in the flux from X-ray binaries. Our results include: determination of the orbital periods of IGR J16418-4532 and IGR J16320-4751; the disappearance of a previously known 9.6 day period in 4U 2206+54; the detection of a 5 hour period in the symbiotic X-ray binary 4U 1954+31, which might be the slowest neutron star rotation period yet discovered; and the detection of flares in the supergiant system 1E 1145.1-6141 which occur at both periastron and apastron passage with nearly equal amplitude. We compare techniques of weighting data points in power spectra and present a method related to the semi-weighted mean which, unlike conventional weighting, works well over a wide range of source brightness.

§1. Introduction

The Swift satellite was launched November 20, 2004. It carries 3 instruments: the X-ray Telescope (XRT), the Ultraviolet/Optical Telescope (UVOT), and the Burst Alert Telescope (BAT). Swift is primarily a gamma-ray burst mission. After the BAT detects a GRB Swift slews rapidly to enable UVOT and XRT observations.

The BAT consists of a coded aperture mask with 0.52m² CdZnTe detectors.¹ It has a wide field of view (1.4 sr half-coded) and covers the 14 - 195 keV energy range. The BAT typically observes 50% - 80% of sky each day. Sky coverage is “random” because of GRB followups. Although the primary BAT purpose is to detect GRBs, it has also obtained light curves for 265 other sources. We give here a brief summary of searches for periods in X-ray binaries using BAT light curves.

§2. Weighting Power Spectra

To search for periodic signals we calculate power spectra of the light curves. There is large variability in the size of BAT error bars. The errors depend on the length of each observation and the location of a source in the field of view. When computing power spectra of data with non-uniform errors it can often be advantageous to weight data points by their errors.¹⁴ This is analogous to the weighted mean and we calculate the power spectrum of \( \frac{y_i}{\sigma_i^2} \). We term this “standard weighting”. However, if the scatter in data values is large compared to the error bar sizes weighting by error bars can be inappropriate. We find that weighting bright sources can actually reduce the sensitivity of the power spectrum (Fig. 1).

A modified type of weighting is to treat source variability as an additional “er-
ror”, i.e. calculate the power spectrum of $\frac{\nu}{(\nu^2 + V_s^2)}$ where $f$ is a correction to nominal error bar size and $V_s$ is the estimated variance due to source variability. Details are given in Corbet et al. (2007). This procedure is related to Cochran’s semi-weighted mean, and hence may be termed “semi-weighting”. We find that semi-weighting works well for sources across a wide range of brightness providing that the correction factor $f$ is applied. We advocate that semi-weighting should always be considered when dealing with data with non-uniform error bars.

§3. IGR J16418-4532 and IGR J16320-4751

INTEGRAL has found many new highly absorbed high-mass X-ray binaries. The BAT is well suited for studying these because of its high-energy sensitivity. Two sources for which we have determined orbital periods are IGR J16418-4532, for which no pulsations have been seen, and the 1303s pulsar IGR J16320-4751. We find orbital periods of $P = 3.753 \pm 0.004$ days and $P = 8.96 \pm 0.01$ days respectively. For both of these sources, the strong absorption means that the BAT is much more sensitive to orbital modulation than the RXTE ASM which covers lower energies.

§4. An Ultra-Slow X-ray Pulsar in the Symbiotic System 4U 1954+31

Symbiotic binaries contain an object (typically a white dwarf) accreting from an M giant. 4U 1954+31 was first thought to be a high-mass X-ray binary, but an M giant counterpart has now been found. 4U 1954+31 is thus a member of the rare “symbiotic X-ray binary” class along with GX 1+4 and 4U 1700+24. 4U 1954+31 is very variable, but no orbital period or pulse period were previously known.

From BAT observations we discovered a strong 5 hour “pulse” period that decreased in period during an outburst lasting hundreds of days. This period is too
short to be either an orbital period or an M star pulsation period. The period change excludes triple star models and also a white dwarf rotation period. The spin-up rate is consistent with a neutron star pulse period if $L_X \sim 5 \times 10^{35}$ ergs/s. This would be one of the slowest X-ray pulsars known, currently only exceeded by the 6.67 hr period source in RCW 103 for which the origin is not yet clear.\(^9\)

§5. Disappearance of the 9.6 Day Period in 4U 2206+54

4U2206+54 was previously thought to be a Be star X-ray pulsar. However, RXTE observations (and a reanalysis of EXOSAT data) showed no pulsations. Further optical observations suggest the optical counterpart is a very peculiar active O type star. 5.5 years of RXTE ASM data showed a 9.6 day period.\(^4\) If due to orbital variability, this would be one of the shortest orbital periods known for a “Be-like” system.

The BAT data do not show modulation at 9.6 days. Instead the strongest peak in the power spectrum is at 19.25 days, twice the ASM period.\(^8\) Recent ASM data folded on 19.25 days also show similar modulation to the BAT light curve. The 9.6 day period is thus not a permanent strong feature of the light curve and the orbital period thus may be twice the previously proposed value. Possibly the circumstellar envelope and orbit may not lie in the same plane.

§6. The Supergiant High-Mass X-ray Binary 1E 1145.1-6141

1E 1145.1-6141 is an X-ray pulsar with a 297 s pulse period. The optical counterpart is a B2 supergiant and accretion takes place from a stellar wind. The orbital period was not determined until recently. Ray & Chakrabarty\(^12\) find from RXTE...
PCA pulse timing $P = 14.365 \pm 0.002$ days, and an eccentricity of $0.20 \pm 0.03$.

Fig. 4. Power spectrum of the BAT light curve of 1E 1145.1-6141. The orbital period (dashed line) and harmonics are marked.

Fig. 5. The BAT and ASM light curves of 1E 1145.1.6141 folded on the orbital period.

1E 1145.1-6141 shows flares at apastron which are of similar size to the periastron flares. Apsastron flares have also been reported from the supergiant systems 4U 1223-624$^{11}$ and 4U 1907+09.$^{13}$ However, in these two systems the apastron flares are much smaller than the periastron flares. Apsastron flare sources have low inclination angles, suggesting that variability such as eclipses in high inclination angle systems may mask apastron flares. The origin of apastron flares is still unclear.

References

1) S. Barthelmy et al., Space Science Reviews 120 (2005), 143.
2) W. G. Cochran, Supplement to the Journal of the Royal Statistical Society 4 (1937), 102.
3) W. G. Cochran, Biometrics 10 (1954), 101.
4) R. H. D. Corbet and A. G. Peele, Astrophys. J. 562 (2001), 936.
5) R. Corbet et al., ATEL 649 (2005), 1.
6) R. Corbet et al., ATEL 779 (2006), 1.
7) R. Corbet et al., ATEL 797 (2006), 1.
8) R. H. D. Corbet, C. B. Markwardt and J. Tueller, Astrophys. J. 655 (2007), 458.
9) A. De Luca et al., Science 313 (2006), 814.
10) N. Masetti et al., Astron. & Astrophys. 453 (2006), 295.
11) S. H. Pravdo and P. Ghosh, Astrophys. J. 554 (2001), 383.
12) P. S. Ray and D. Chakrabarty, Astrophys. J. 581 (2002), 1293.
13) M. S. E. Roberts et al., Astrophys. J. 555 (2001), 967.
14) J. D. Scargle, Astrophys. J. 343 (1989), 874.