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The 17 min orbital period in the Ultra Compact X-ray Binary 4U 0513-40 in the X-ray energy band

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The principal motivations for studying the X-ray binaries is that the accretion onto neutron stars and black holes provides a unique window on the physics of the strong gravity and dense matter. For this reason, a renewed interest has developed in ultracompact X-ray binaries and their identification is very important, albeit complex because of the difficulty in measuring orbital periods in low mass X-ray binaries. The ultracompact low-mass X-ray binary 4U 0513-40 in the globular cluster NGC1851 reveals a clear sinusoidal periodic signal with a period of ~17 minutes when the source is in a typical high/soft state with a dominant soft thermal component (using BeppoSAX and Chandra data). The periodicity disappears when the source is in a low/hard state and the thermal soft component is no longer required any more to model the data (using XMM-Newton and INTEGRAL observations). These properties indicate the orbital nature of the detected signal and imply an high inclination angle of the binary system ($> 80°$).

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1. Introduction

Ultracompact X-ray binaries (UCXBs) are systems with orbital periods ($P_{\rm orb}$) shorter than ≈1 hr in which a neutron star or black hole accretes matter from a companion low mass star. UCXBs are rare objects and their identification is very difficult because of the difficulty to measuring $P_{\rm orb}$ in LMXBs. The most recent compilation of ultracompact X-ray binaries lists 27 candidates (in 't Zand et al., 2007). Eight out of 52 LMXBs with measured orbital period are in the ultracompact regime (in 't Zand et al. 2007, Nelemans & Jonker 2006). IBIS results from long-term monitoring of the UCXBs showed that these sources spend most of the time in the canonical low/hard state, with X-ray luminosities $\lesssim 7\times10^{36}$ $erg\ s^{-1}$, plasma temperature $kTe \gtrsim$ 20 keV and $\tau \lesssim 4-5$ (Fiocchi et al. 2008).
4U 0513-40 is an X-ray binary in the Galactic globular cluster NGC 1851 with a 17-minute orbital modulation first observed with the *Hubble Space Telescope* (Zurek et al. 2009). It is a persistent source showing evidence for variability of a factor of ∼ 10 in X-ray luminosity on timescales of ∼ weeks, and a factor of more than 20 overall (Maccarone et al. 2010).

2. Observations and Data Analysis

Table 1 gives a summary of source observations performed with instruments on board *BeppoSAX*, *Chandra*, *XMM-Newton* and *INTEGRAL* satellites.

The LECS, MECS and PDS/*BeppoSAX* (Boella et al. 1997) event files and spectra were generated with the Supervised Standard Science Analysis (Fiore, Guainazzi & Grandi 1999). Both LECS and MECS spectra were accumulated in circular regions of 8 arcmin radius. The PDS spectra were extracted using the XAS version 2.1 package (Chiappetti & Dal Fiume 1997). The *Chandra* (Weisskopf 1999) data were processed with the CIAO (*Chandra* Interactive Analysis of Observations) software, version 4.1.2, i.e. the same version of CALDB (Calibration Data Base), provided by the *Chandra* X-ray Center and following the science threads listed on the CIAO website[1]. We extracted source photons from a circular region centered on the source with an extraction region of 8 arcsec. For the background, we used circular source-free regions in the same CCD of the studied source.
XMM-Newton (Turner et al. 2001) data have been processed starting from the observation files with `SAS 7.0.0`. X-ray events corresponding to patterns 0-4 were selected in the EPIC-pn camera. Source light curves and spectra were extracted from circular regions of 10 arcsec centered on the source, while background products were obtained from off-set regions close to the source.
The analyzed *INTEGRAL* (Winkler et al. 2003) data consist of all public observations in which 4U 0513–40 was within the field of view of the IBIS and JEM-X detectors. Broad-band spectra, ∼5–80 keV, are obtained using data from the high-energy instruments, JEM-X (Lund et al. 2003) and IBIS (Ubertini et al. 2003). The IBIS and JEM-X data have been processed using the Off-line Scientific Analysis (OSA v. 9.0) software released by the *INTEGRAL* Science Data Center (ISDC, Courvoisier et al. 2003). These runs were performed with AVES cluster, designed to optimize performances and disk storage for the INTEGRAL data analysis (Federici et al. 2010).

[1] Available at http://cxc.harvard.edu/ciao/

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Table 1: Summary of the X-ray binary 4U0513-40 observations

Instrument	Tstart MJD	Exposure ks
BeppoSAX/LECS	51597.6	31.5
BeppoSAX/MECS	51597.6	73.6
BeppoSAX/PDS	51597.6	34.9
XMM Newton/EPIC-pn	52730.0	23.5
CHANDRA/ACIS	54560.6	18.8
INTEGRAL/JEM-X	53917.6	102.8
INTEGRAL/IBIS	53380.4	601.5

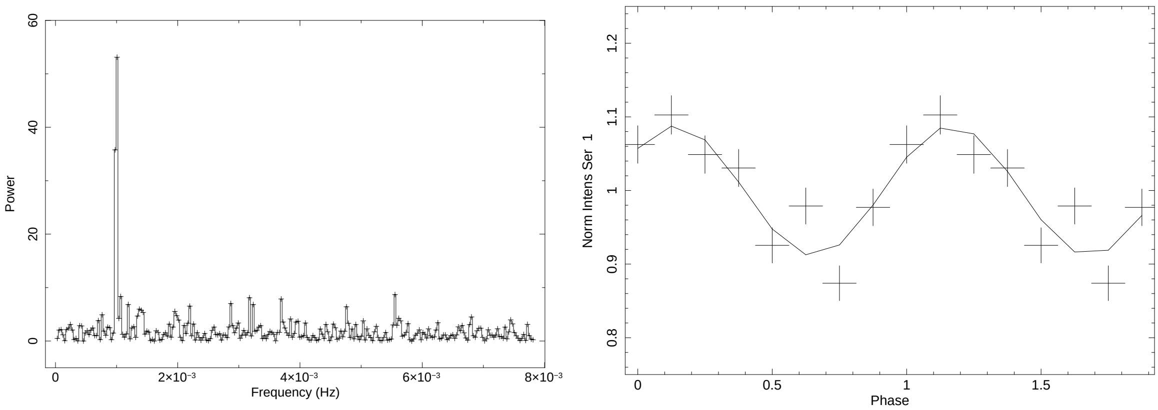

Figure 1: The power spectrum and efolding phase diagram using ACIS 0.3-5 keV data

3. Temporal analysis

Using the ACIS/*Chandra* data, we accumulated a 16s bin light curve in the 0.3-5 keV energy band of 4U 0513–40 detected at $\sim 140\sigma$ in this energy range and calculated a power spectrum over the whole observation following the method outlined by Israel & Stella (1996). The power spectrum is shown in Figure 1 (left panel) where a peak at 0.00099 Hz is clearly observed. The 4U 0513–40 period was obtained with an epoch-folding technique. The best-fit period is (1004±18) s with uncertainties at 1 σ confidence level. Using this period value, we folded the light curve and a sinusoidal shape of the modulation was found (see Figure 1, right panel) with a pulsed fraction of $\sim$ 11% (i.e. the semi amplitude of the modulation divided by the mean source count rate).

During the *BeppoSAX* observation, a type-I thermonuclear burst was detected at the time 51597 MJD - 15:29:55s (see below for details). The same procedure used for *Chandra* data was applied to 10s bin MECS/*BeppoSAX* light curve in the 3-5 keV energy band, with exclusion of the burst data. The best-fit period is (1013±14) s with uncertainties at 1 σ confidence level. Using this period value, we folded the light curves and a sinusoidal shape of the modulation was found (see figure 2) with a pulsed fraction of $\sim$ 4%.

We have also searched for periodicity in the *XMM-Newton* and *INTEGRAL* X-ray light curves, but no periodic signals were detected.

Table 2: Spectral analysis results. A N_H fixed to the Galactic column density was included in the fit. Error are given at 90% confidence level for one parameter of interest ($\Delta\chi^2 = 2.71$). The absorbed 1–10 keV flux are reported in units of 10^{-11} erg cm^{-2} s^{-1}. 1: BeppoSAX spectrum before the burst event; 2:BeppoSAX spectrum after the burst event; 3: *XMM-Newton* average spectrum; 4:*Chandra* average spectrum: 5: *INTEGRAL* average spectrum

	kT_{BB}	T_0	kT_e	τ	n_{BB2}	n_{COMPTT}	Flux	χ^2/d.o.f
	keV	*keV*	*keV*			10^{-3}	10^{-11} erg cm^{-2} s^{-1}	
1	...	0.22 ± 0.04	7^{+41}_{-3}	$3.6^{+2.6}_{-3.3}$	...	$8.6^{+15.3}_{-8.5}$	15.2	156/127
2	0.49 ± 0.04	0.18 ± 0.02	2.6 ± 0.2	6.8 ± 0.6	21 ± 16	38 ± 4	18.9	155/128
3	...	0.068 ± 0.002	15^{+2}_{-10}	2^{+9}_{-1}	...	86 ± 20	8.9	573/387
4	0.34 ± 0.04	0.13 ± 0.05	5^{+24}_{-2}	6 ± 2	$3.9^{+2.7}_{-2.5}$	0.7 ± 0.4	0.7	280/284
5	...	< 1.1	21^{+32}_{-16}	< 2.4	...	< 50	11.0	3/7

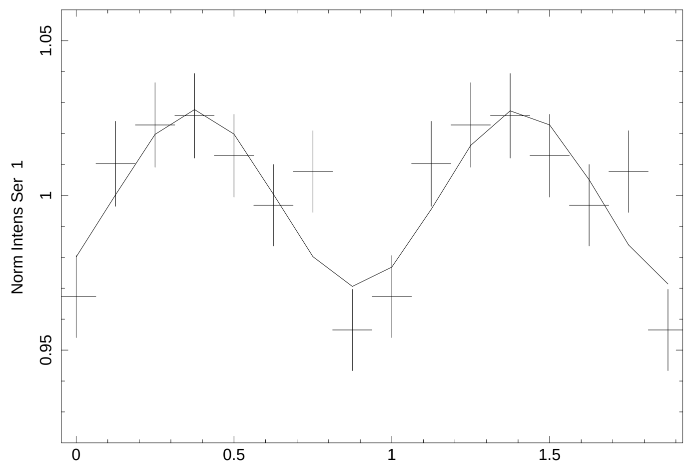

Figure 2: The efolding phase using MECS 3-5 keV data

In the soft X-ray band, two thermonuclear X-ray bursts have been detected, during the *Chandra* and *BeppoSAX* observations. The first HRC/*Chandra* burst event was described by Homer et al. (2001). For the second, not yet reported in the literature, we extracted the MECS/*BeppoSAX* light curve in the 1.5-10 keV keV energy band and we detected an X-ray burst starting at 51597 MJD (15:29:55 s), with a decay time of τ ~22 s, computed from exponential fits to the burst decay profile. Fitting the spectrum (extracted at the burst peak with exposure time of ~10 s) with a simple black-body model, a thermal temperature of 1.6±0.1keV with a extrapolated flux of $3.3\times10^{-9} erg\ cm^{-2} s^{-1}$ in 0.1-30 keV energy band has been derived.

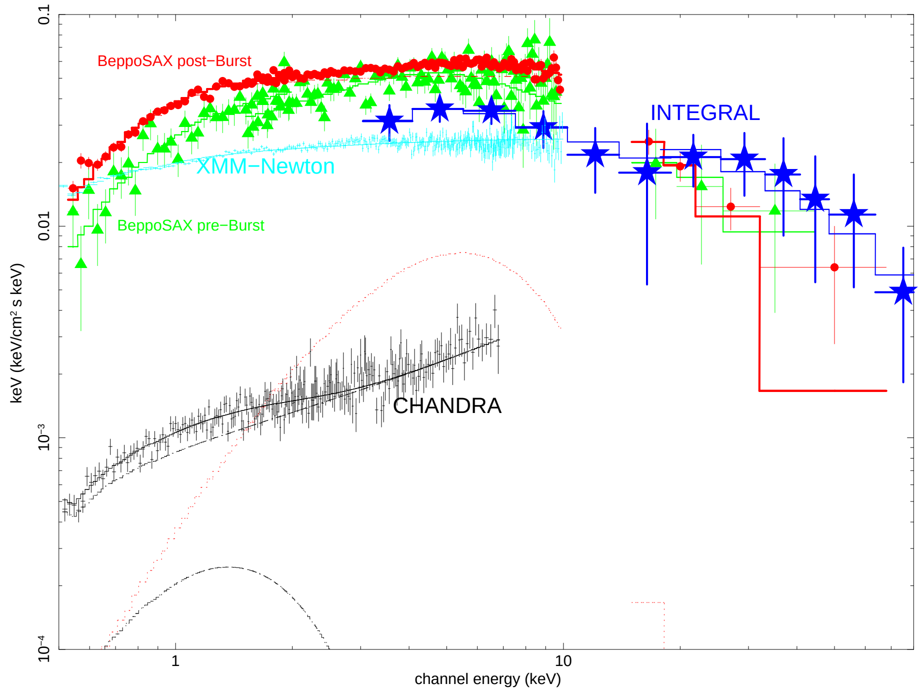

Figure 3: The *BeppoSAX*, *Chandra*, *XMM-Newton* and *INTEGRAL* spectra are shown together with the total model and its components.

4. Spectral behavior of the persistent emission

We extracted the *BeppoSAX* spectra before the burst event with the LECS, MECS and PDS exposure times of 1.6, 3.4 and 1.5 ks, and after the burst event with the LECS, MECS and PDS exposure times of 30.1, 67.5 and 31.2 ks, respectively.
IBIS and JEM-X spectra are produced summing up spectra of the source from each science windows in the period for which both instrument data are available and source was detected above 5σ. The exposure times are 103 ks and 36 ks for IBIS and JEM-X, respectively. For *Chandra* and *XMM-Newton* observations, to extract the spectra we use the total exposure time, 18.8 and 23.5 ks, respectively.

Each spectrum was fitted with a model of thermal Comptonization, in XSPEC by COMPTT (Titarchuk 1994; a spherical geometry was assumed), absorbed by a column density, $N_{\rm H}$. Adding a blackbody component (modeled in XSPEC by BBODYRAD model) resulted in a substantial fit improvement for *Chandra* and *BeppoSAX* (after the burst) data. This reduces χ^2/d.o.f. from 452/310 to 374/308 for the *Chandra* data and from 173/130 to 155/128 for the *BeppoSAX* data, with the low corresponding F-test chance probabilities of 4×10^{-13} and 9×10^{-4}, respectively.

The spectral fit results are reported in Table 2 and spectra are shown in Figure 3 in different colors.

5. Discussion

The binary system 4U 0513-40 in NGC 1851 exhibits a clear periodic signal with $P \simeq 17$ min in soft X-ray. This signal is sinusoidal and has an amplitude from ~4% to ~10%. It is observed only in two observations (*Chandra* and *BeppoSAX* after the burst) when the source is in a typical high/soft state. This result is independent from the extrapolated luminosity of the system, which spans from 0.7 to 5.2 $\times$ 10^{36} erg s^{-1} in the 0.5-50 keV energy band, for *Chandra* and *BeppoSAX* (after the burst), respectively. This periodicity is not seen when the source is in a low/hard state (*XMM-Newton* and *INTEGRAL* data).

The far-ultraviolet photometry obtained with the *Hubble Space Telescope* has shown the same periodicity described here (Zurek et al. 2009). These timing properties seen in UV/optical observations and the eclipse observed in the X-ray band imply that the origin of this modulation is of orbital nature and the inclination angle is higher than 80 ° (Arons and King 1993).

Acknowledgments

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