A&A 579, A22 (2015)
DOI: 10.1051/0004-6361/201425225

Astronomy & Astrophysics

Searching for coherent pulsations in ultraluminous X-ray sources (Research Note)

V. Doroshenko[1], A. Santangelo[1], and L. Ducci[1,2]

[1] Institut für Astronomie und Astrophysik, Sand 1, 72076 Tübingen, Germany
e-mail: doroshv@astro.uni-tuebingen.de
[2] ISDC, Department of Astronomy, Université de Genève, chemin d'Écogia, 16, 1290 Versoix, Switzerland

Received 27 October 2014 / Accepted 10 March 2015

ABSTRACT

Luminosities of ultraluminous X-ray sources (ULXs) are uncomfortably large when compared to the Eddington limit for isotropic accretion onto stellar-mass object. Most often either supercritical accretion onto stellar mass black holes or accretion onto intermediate mass black holes is invoked the high luminosities of ULXs. However, the recent discovery of coherent pulsations from ULX M82 X-1 with NuStar has shown that another scenario implying accretion onto a magnetized neutron star is possible for ULXs. Motivated by this discovery, we re-visited the available *XMM-Newton* archival observations of several bright ULXs with a targeted search for pulsations to check whether accreting neutron stars might power other ULXs as well. We have found no evidence for significant coherent pulsations in any of the sources including the M82 X-2. We provide upper limits for the amplitude of possibly undetected pulsed signals for the sources in the sample.

Key words. X-rays: binaries – X-rays: galaxies – stars: neutron – stars: black holes

1. Introduction

Ultraluminous X-ray sources (ULX) are empirically defined as non-nuclear extragalactic sources with luminosities exceeding $\sim 10^{39}$ erg s^{-1}, i.e. the Eddington limit for isotropic accretion on stellar-mass black holes (Feng & Soria 2011). These sources are considered, therefore, the best candidates to host intermediate mass black holes (IMBHs, Colbert & Mushotzky 1999). This interpretation is also supported by observations of quasi-periodic oscilations in several ULXs (Strohmayer & Mushotzky 2009), which might imply blackhole masses exceeding several thousands of solar mass. However, interpretation is not straighforward (Middleton et al. 2011) and super-Eddington accretion onto stellar mass black holes like in the case of the well-known source SS 433 (King et al. 2001; Fabrika 2004) might still be an option. Emission from young rotation-powered pulsars (Medvedev & Poutanen 2013) has also been suggested as a possible mechanism powering ULXs.

Recently, the discovery of coherent X-ray pulsations from ULX M82 X-2 (or X-1) (Bachetti et al. 2014), with a period of $\sim$1.37 s and the associated orbital motion, provided a new explanation for the very bright emission of at least some of these objects. Based on the X-ray timing Bachetti et al. (2014) have derived a mass function of $f = 2.1\ M_{\odot}$. The accretion would then proceed from a low-mass companion via Roche-lobe overflow, likely the only mechanism to feed enough matter to explain the observed luminosity. This implies a strong spin-up torque imposed onto the neutron star in agreement with the observed short spin-up timescale ($P/\dot{P} \sim 300$ yr) and spin period of the pulsar. In principle, other ULXs powered by an accreting neutron star could exist and are expected to have spin periods of the order of $\lesssim$10 s as well.

Currently there is a lack of detailed studies of the variability in ULXs at short timescales (i.e. $\leq$100 s) as illustrated by the surprising discovery of the pulsations in M82 X-2, which is a rather well-studied system. Motivated by this, we performed a targeted search for coherent pulsations with periods in the range 0.15–15 s in archival *XMM-Newton* data to understand whether other ULXs might host accreting pulsars. In the present note, we report the results of this systematic search.

2. Source sample and available data

The number of ULXs and candidates has been steadily increasing since the launch of the *Einstein* satellite (Feng & Soria 2011). Many of them are, however, not sufficiently bright for detailed timing analysis. As an initial step, we limited our analysis to a sample of fifteen bright ULXs observed with *XMM-Newton*. This sample was used by Heil et al. (2009) to characterize ULX variability in a broad frequency range and no significant periodicities were reported by these authors. However, Heil et al. (2009) did not search for coherent pulsations.

We searched for pulsation in archival *XMM-Newton* data of the EPIC PN camera as it is one of the few instruments with adequate timing resolution to investigate variability down to sub-second timescales. Our analysis is based on a larger dataset compared to the one considered by Heil et al. (2009) since many additional observations have become available since their publication. Most of the observations were performed in full-frame read-out mode with time resolution of $\sim$0.07 s. The list of the sources in our sample, and the summary of available observations are presented in Table 1.

3. Data analysis and results

Low-level data reduction was carried out using the XMM SAS 13.5 package, current calibration files, and standard filtering criteria[1]. Periods of high background flaring activity were filtered using the *espfilt* task based on the observed count-rate of the non-exposed detector corners and

[1] http://xmm.esac.esa.int/sas/current/doc

Table 1. Sources included in the analysis.

Source	Exp.(ks)/obs.	f_{pulsed} limit, %
M82 X-1/X-2	143/11	2.2
NGC 55 ULX	130/3	4.4
NGC 253 PSX-2	69/7	9.8
NGC 1313 X-1	315/18	4.4
NGC 2403 X-1	66/4	8.8
Holmberg II X-1	76/7	3.7
Holmberg IX X-1	195/13	4.6
NGC 3628 X-1	40/1	17.1
NGC 4395 X-1	91/3	8.6
NGC 4559 X-1	31/1	11.7
NGC 4861 ULX	19/3	30.7
NGC 4945 X-2	39/2	25.7
NGC 5204 X-1	82/8	8.1
M83 ULX	31/2	30.5
NGC 5408 X-1	473/10	3.6

Notes. Upper limits on the pulsed fraction represent the strongest (among all observations) limits at the 3σ confidence level.

visual inspection of the detector lightcurves above 10 keV for periods of high background. Source photons with energies in 0.3–10 keV range were then extracted using the source-centred circles with radius of 20″ in all cases except M82 X-2, where to match the original NuStar observation more closely we used a radius of 40″ centred in between the two nearby ULXs, X-1 and X-2, where the pulsations could potentially originate from (Bachetti et al. 2014). We note that even with a larger extraction region the observed power spectrum remains dominated around pulsation frequency by the white noise due to the limited photon statistics, so increasing the extraction region size is not expected to change the sensitivity to the coherent signal.

The arrival times of individual photons were then corrected to solar barycentre using the *barycen* task. To search for pulsations, we used the H-test (de Jager et al. 1989) applied to unbinned source events. Taking into account that in M82 X-2 the pulsed fraction showed large variations with time (suggesting the possible transient nature of the pulsations), we analysed individual observations separately. Our results are summarized in Table 1.

We have found no evidence for significant periodic signals in any of the sources. Therefore, we followed the approach suggested by Brazier (1994) for deriving the upper limits on amplitude of potentially present but undetected periodic signals f_{pulsed}. For each source and observation we calculated the upper limit on the amplitude of a sinusoidal signal with period in the range 0.15–15 s at a 3σ confidence level (for details see Eq. (3) and accompanying text in Brazier 1994). We report in Table 1 the highest upper-limit among all the observations available for a given source.

We note that for M82 X-2 our limit is below the lowest pulsation amplitude value reported by Bachetti et al. (2014). To illustrate this point, in Fig. 1 we present the periodogram for the longest *XMM-Newton* observation along with two periodograms for two simulated signals with amplitudes of 2.2% and 5% (corresponding to the derived upper limit and lowest amlitude reported by Bachetti et al. 2014, respectively). We note that a pulsed signal is not detected in *XMM-Newton* lightcurve and is easily detectable in simulated lightcurves, so the pulsations would be easily detectable if the pulsed fraction during the *XMM-Newton* observation was comparable to that reported for NuStar.

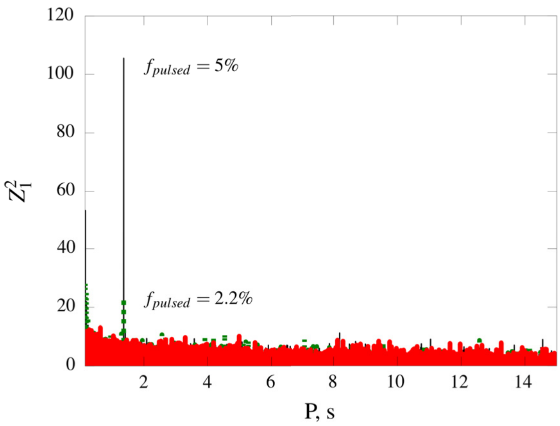

Fig. 1. Periodogram for the longest observation of the pulsating in ULX in M82 (thick red line, obsid 0206080101, exposure of 46 ks), and periodograms for simulated sinusoidal signal with pulsed fractions of 5% (thin black line, only visible at the peak) and 2.2% (dotted green line) with the same exposure, observation duration, and total number of photons as observed.

4. Conclusions

Inspired by the recent discovery of the pulsations from the M82 X-2 with NuStar, we revisited the available archival *XMM-Newton* observations of several bright ULXs in order to systematically search for pulsations whose detection escaped previous investigations. We found no significant pulsed signal in the range of periods from 0.15 to 15 s in any of the considered sources including M82 X-2. We provide, therefore, upper limits for pulsed fraction of potentially non-detected pulsations. We note that in many cases these limits are rather weak owing to limited statistics and could be significantly improved with additional observations.

For M82 X-2 our upper limit turns out to be a factor of two lower than the lowest value $f_{\text{pulsed}} \sim 5\%$ reported by Bachetti et al. (2014), and therefore, we exclude pulsations with amplitude similar to that observed by NuStar in the *XMM-Newton* data. The amplitude of the pulsations in this source, however, has been reported to vary with time, hence it cannot be excluded that at the time of the *XMM-Newton* observation it remained intrinsically low. This would imply that pulsations in ULXs powered by accreting neutron stars might be transient and highlights the importance of regular monitoring of ULXs, particularly at higher energies where the pulsed fraction is expected to be larger. Still, an independent confirmation of pulsations in M82 X-2 would be indispensable.

Acknowledgements. The authors thank the Deutsches Zentrums für Luft- und Raumfahrt (DLR) and Deutsche Forschungsgemeinschaft (DFG) for financial support (grants DLR 50 OR 0702, FKZ 50 OG 1301, SA2131/1-1).

References

Bachetti, M., Harrison, F. A., Walton, D. J., et al. 2014, Nature, 514, 202
Brazier, K. T. S. 1994, MNRAS, 268, 709
Colbert, E. J. M., & Mushotzky, R. F. 1999, ApJ, 519, 89
de Jager, O. C., Raubenheimer, B. C., & Swanepoel, J. W. H. 1989, A&A, 221, 180
Fabrika, S. 2004, Astrophys. Space Phys. Rev., 12, 1
Feng, H., & Soria, R. 2011, New Astron. Rev., 55, 166
Heil, L. M., Vaughan, S., & Roberts, T. P. 2009, MNRAS, 397, 1061
King, A. R., Davies, M. B., Ward, M. J., Fabbiano, G., & Elvis, M. 2001, ApJ, 552, L109
Medvedev, A. S., & Poutanen, J. 2013, MNRAS, 431, 2690
Middleton, M. J., Roberts, T. P., Done, C., & Jackson, F. E. 2011, MNRAS, 411, 644
Strohmayer, T. E., & Mushotzky, R. F. 2009, ApJ, 703, 1386