Discovery of a 0.42-s pulsar in NGC 7793 P13

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ABSTRACT
NGC 7793 P13 is a variable (luminosity range > 1000) ultraluminous X-ray source (ULX) proposed to host a stellar-mass black hole of less than 15 M⊙ in a binary system with orbital period of 64 d and a 18–23 M⊙ B9Ia companion. Within the EXTras project we discovered pulsations at a period of ~0.42 s in two XMM–Newton observations of NGC 7793 P13, during which the source was detected at $L_X \sim 2.1 \times 10^{39}$ and $5 \times 10^{39}$ erg s$^{-1}$ (0.3–10 keV band). These findings unambiguously demonstrate that the compact object in NGC 7793 P13 is a neutron star accreting at super-Eddington rates. While standard accretion models fail to account for the pulsar X-ray luminosity, the presence of a multipolar magnetic field with $B \sim$ few $\times 10^{13}$ G close to the base of the accretion column appears to be in agreement with the properties of the system.

Key words: galaxies: individual: NGC 7793 – X-rays: binaries – X-rays: individual: CXOU J235750.9–323726 (XMMU J235751.1–323725, NGC 7793 P13)

1 INTRODUCTION
Ultraluminous X-ray sources (ULXs) are extra-nuclear point-like X-ray objects located in nearby galaxies with X-ray luminosities exceeding the Eddington limit of $>10^{39}$ erg s$^{-1}$ for a $\sim 10$ M⊙ black hole (BH). Based on their spectral and timing properties, it has been proposed (see Roberts et al. 2016 for a recent review) that most ULXs are stellar-remnant black holes (with masses possibly reaching $\sim 100$ M⊙; Zampieri & Roberts 2009; Belczynski et al. 2010) accreting at super-Eddington rates. The salient ULX features revealed by XMM–Newton and NuSTAR observations and supporting the scenario of super-Eddington accretion onto BHs is a downturn of the X-ray spectrum at energies of $\sim 5–10$ keV and a soft excess at lower energies (Roberts et al. 2016 and references therein). Despite evidences in favour of the BH nature of the compact remnant in ULXs (Liu et al. 2013), there are also two notable exceptions of pulsating ULXs testifying to the presence of accreting neutron stars (Bachetti et al. 2014). Israel et al. 2016, submitted). This shows that spectral properties alone are not an unambiguous way for a correct identification of the compact remnant in ULX (Bachetti 2016).

Within the framework of the EXTras project (Exploring the X-ray Transient and variable Sky; De Luca et al. 2015), we searched for coherent periodic signals in the about 290,000 time series of sources, with more than 50 counts, detected by XMM–Newton in all EPIC public data. Among dozens of new X-ray pulsators found so far with periodic signals detected at high confidence ($>4.5\sigma$), there is XMMU J235751.1–323725 = CXOU J235750.9–323726, also known as the ULX P13 in NGC 7793.

NGC 7793 P13 was first observed in 1979 by the Einstein satellite as a bright, $L_X \sim 2 \times 10^{39}$ erg s$^{-1}$ (in the 0.3–10 keV range), X-ray stellar-like object in the nearby ($D = 3.9$ Mpc; Karachentsev et al. 2003) reasonably face-on ($i = 53.7^\circ$) galaxy NGC 7793 in the Sculptor group (Fabbiano et al. 1992). It was also detected by ROSAT in 1992 at an $L_X \sim 3.5 \times 10^{39}$ erg s$^{-1}$ (value extrapolated in the 0.3–10 keV band; Read & Pietsch 1999). A Chandra pointing carried out in 2003 September re-

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Table 1. Logbook of the XMM–Newton observations used in this work.

| Obs. ID    | Start date | Exp. (ks) | Off-axisa (arcsec) | Count rateb (cts s⁻¹) |
|------------|------------|-----------|-------------------|----------------------|
| 0693760101 | 2012-05-14 | 35        | 77                | <0.002               |
| 0693760401 | 2013-11-25 | 45        | 77                | 0.29 ± 0.02          |
| 0748390901 | 2014-12-10 | 47        | 249               | 0.53 ± 0.02          |

a Radial off-axis angle of NGC 7793 P13 from the boresight of the telescope.

b Net source count rate or 3σ upper limit in the 0.1–10 keV energy band, using the extraction regions described in the text; the values are not corrected for point spread function and vignetting effects.

we revealed two sources at the ROSAT position of NGC 7793 P13, separated by 2 arcsec, namely CXOU J235750.9–323726 and CXOU J235750.9–323728 (Panmuti et al. 2011). The latter source is thought to be unrelated to NGC 7793 P13 and is more than an order of magnitude less luminous than NGC 7793 P13 itself. The luminosities are $\sim 1.2 \times 10^{39}$ and $\sim 6.2 \times 10^{37} \text{ erg s}^{-1}$, respectively. The compact object in NGC 7793 P13 is orbiting around a B9Ia spectral-type star of 18–23 M$_\odot$, in a binary system with an orbital period of about 64 days and a moderate eccentricity $e$ of 0.3–0.4 (Motch et al. 2014). By modelling the strong optical and UV orbital modulation, likely arising from the heating of the donor star, a mass for the suspected BH of less than about 15 M$_\odot$ has been inferred for NGC 7793 P13 (Motch et al. 2014).

Here we report on the discovery of coherent pulsations at a period of 0.42 s in the EPIC pn lightcurves of XMMU J235751.1–323725, with a secular first period derivative of $P_{\text{sec}} \sim -4 \times 10^{-11} \text{ s}^{-1}$ (sect. 2.3). These findings clearly indicate that NGC 7793 P13 hosts an accreting neutron star (NS) in a binary system and not a stellar-mass BH as previously assumed. We discuss the nature of this new ultraluminous X-ray pulsar (sect. 3), the third discovered so far, and also the fastest-spinning one.

2 OBSERVATIONS AND DATA ANALYSIS

2.1 XMM–Newton

The region of NGC 7793 P13 was observed by XMM–Newton with the EPIC detectors in full imaging mode (Full Frame). The source position was always off-axis, at angles from $\sim 1.2$ to 4.1 arcmin. The 0.42-s pulsations were detected in the pn data only (MOS cameras time resolution $\sim 2.6$ s; pn time resolution $\sim 73$ ms). The public pn data sets covering the position of NGC 7793 P13 are listed in Table 1. During the first pointing, a faint source was detected at a flux level of $\sim 4 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$, corresponding to a luminosity of $\sim 7 \times 10^{37} \text{ erg s}^{-1}$ and providing only about 120 events. We note that this luminosity is consistent with that detected with Chandra from CXOU J235750.9–323728, suggesting that during the first XMM–Newton observation NGC 7793 P13 was not active. Assuming that the observed XMM–Newton flux could be all ascribed to CXOU J235750.9–323728, we set a 0.3–10 keV flux and luminosity 3σ upper limit of $< 9 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$ and $< 2 \times 10^{37} \text{ erg s}^{-1}$, respectively.

As part of the EXTraS reduction pipeline, the raw observation data files (ODF) were processed with the Science Analysis Software (SAS) v.16. No time periods with high particle background were found. Photon event lists and spectra were extracted in a radius of 32 arcsec for the source, while to estimate the background we used a nearby region with radius of 45 arcsec, far from other sources and avoiding CCD gaps. Event times were converted to the barycentre of the Solar system with the SAS task BARYCEN using the Chandra source position (RA = 23°57′50″, Dec. = −32°37′26″). Spectra were rebinned so as to obtain a minimum of 30 counts per energy bin, and for each spectrum we generated the response matrix and the ancillary file using the SAS tasks RMFGEN and ARFGEN.

2.2 Swift

We analysed the 78 observations of NGC 7793 performed with the Swift X-Ray Telescope (XRT; Burrows et al. 2005) between 2010 August 16 and 2016 August 24, for a total exposure of 210 ks. We processed and analysed the observations performed in photon counting (PC) mode using the standard software (HEASoft v. 6.19) and calibration files (CALDB v. 20160609). We extracted source photons in a 20-px radius (equivalent to 47.2 arcsec) around the source position; background was extracted from close-by source-free regions. Photons with grade between 0 and 12 were retained in the analysis.

2.3 Discovery of the period and timing analysis

A periodic signal at about 0.42 s was first detected in the pn data set 0748390901 (2014 December) at a confidence level larger than 15σ by the power spectrum peak detection algorithm of the automatic analysis (Israel & Stella 1996) see Fig. 1 and Table 2. By a phase fitting analysis, we honed the period at 0.4183891 ± 0.0000001 s (with uncertainty at 1σ confidence level). No significant first period derivative was found, with 3σ limits of about $\pm 5 \times 10^{-11} \text{ s}^{-1}$. Pulsations at about 0.42 s were also detected in the pn data of Obs. 0693760401, carried out one year before (2013 November). The refined period value was 0.4197119 ± 0.0000002 s. Also in this data set, no first period derivative was found (with 3σ limits of about $\pm 10^{-10} \text{ s}^{-1}$), but the difference between the two
measures implies a long-term average (‘secular’) period derivative $P_{\text{sec}} = -\frac{\Delta P}{\Delta T} = -\frac{4.031 \pm 0.004}{10^{11}} \text{ s}^{-1}$.

The pulse profiles are almost sinusoidal, with an averaged pulsed fraction of $18 \pm 1\%$ and $22 \pm 1\%$ for the 2013 and 2014 observation, respectively (see inset in Fig. 1). While the pulse profile is single-peaked at all energies, the pulsed fraction is increasing from $10$–$20\%$ below $1.5 \text{ keV}$ up to about $40\%$ above $8 \text{ keV}$ (see Fig. 2).

### 2.4 Spectral analysis and long-term variability

The spectral fitting was performed in $0.1$–$10 \text{ keV}$ using XSPEC v.12.8; the abundances used are those of Wilms, Allen, & McCray (2000). Different spectral models have been used in literature to fit the 2013 XMM–Newton spectrum of NGC 7793 P13 (Motch et al. 2014). Bearing in mind the nature of the compact object, we simply notice that a good fit can be also obtained assuming an empirical model often used for accreting X-ray pulsars in our Galaxy: an absorbed power-law with a high energy cut-off (the multiplicative component HIGHECUT in XSPEC) plus, sometimes, a soft thermal component at low energies, which we modelled with a blackbody (BB). A similar model has been successfully tested on the X-ray spectra of a sample of ULXs with broadband XMM+NuSTAR data by Pintore et al. (2016, in preparation). We note that, regardless of the model used, the fluxes and luminosities derived do not change significantly. The model PHABS[HIGHECUT\(^*\)POWERLAW\(+\)BBODYRAD\)] gave the following parameters (we assumed that the two datasets have the same absorption): $N_{\text{H}} = (9.60 \pm 0.01) \times 10^{20} \text{ cm}^{-2}$, $\Gamma^{2013} = 1.2 \pm 0.1$ and $\Gamma^{2014} = 1.14 \pm 0.06$, $E_{\text{cut}}^{2013} = 5.5^{+0.8}_{-0.5} \text{ keV}$ and $E_{\text{cut}}^{2014} = 6.5^{+0.4}_{-0.6} \text{ keV}$, $E_{\text{fold}}^{2013} = 5.0 \pm 1.7 \text{ keV}$ and $E_{\text{fold}}^{2014} = 4.6^{+1.5}_{-0.9} \text{ keV}$, $kT_{\text{BB}}^{2013} = 0.18 \pm 0.02 \text{ keV}$ and $kT_{\text{BB}}^{2014} = 0.23 \pm 0.04 \text{ keV}$, $R_{\text{BB}}^{\text{2013}} = (1.2 \pm 0.3) \times 10^9 \text{ km}$ and $R_{\text{BB}}^{\text{2014}} = (0.7 \pm 0.1) \times 10^9 \text{ km}$ (90% confidence level uncertainties are reported; see also Table 2 for fluxes and luminosities). We note that the size of the black body is of the order of the corotation radius of the pulsar (see below). The probabilities, as inferred through the Fisher test (F-test), that the inclusion of the HIGHECUT component (with respect to the power-law alone) and of the blackbody component (with respect to HIGHECUT+POWERLAW), are not needed are $7 \times 10^{-17}$ and $9 \times 10^{-12}$, respectively. The reduced $\chi^2$ for the simultaneous fit of the two data sets is $1.13$ for $373$ degrees of freedom (dof).

The data from the Swift monitoring proved useful to study the long-term variability of NGC 7793 P13. We fit the spectra observed in the $0.3$–$10 \text{ keV}$ band using Cash (C) statistics and adopting an absorbed power law model, forcing the absorption column to take the same value in all the observations. The C statistics we obtained was 3995 for 4595 dof. We measured an absorption column density of $N_{\text{H}} = (5.7 \pm 0.2) \times 10^{20} \text{ cm}^{-2}$. The average value of the index of the power law was $<\Gamma> = 1.03$, with a standard deviation of $0.18$. The observed $0.3$–$10 \text{ keV}$ unabsorbed fluxes are plotted in Fig. 3, the right scale of the plot represents the isotropic luminosity in the same energy band for a distance to the galaxy of $3.9 \text{ Mpc}$. When the source was not significantly detected, we set an upper limit on the $0.3$–$10 \text{ keV}$ count rate at $3 \sigma$ confidence level following Gehrels (1986). Then, we converted the count rate into a flux estimate with WebPIMMS assuming that the spectrum is described by an absorbed power law with absorption column $N_{\text{H}} = 5.7 \times 10^{20} \text{ cm}^{-2}$ and photon index $\Gamma = 1$. Upper limits are plotted in Fig. 3 with red arrows.

NGC 7793 P13 was detected in X-ray outburst during observations performed in 2010, and from late 2013 to 2016. The maximum and minimum observed $0.3$–$10 \text{ keV}$ flux are $9.5^{+4}_{-3} \times 10^{-12}$ and $0.5 \pm 0.2 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ observed on 2016 June 6 and 2010 October 15, respectively. Assuming a distance of $3.9 \text{ Mpc}$ we can estimate the luminosity on the right axis assumes isotropic radiation and a distance to the source of $3.9 \text{ Mpc}$. Arrows mark the $3\sigma$ upper limits derived from individual Swift (red) and XMM–Newton (green) observations.

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### Table 2. Main properties of the NGC 7793 P13 pulsar.

| Epoch (MJD TDB) | $P$ (s) | $\nu$ (Hz) | $|P'|$ (10$^{-11}$ s$^{-1}$) | $P_{\text{sec}}$ (10$^{-11}$ s$^{-1}$) | Pulsed fraction (%)$^a$ | $F_{X}^{0.3–10}$ (erg cm$^{-2}$ s$^{-1}$) | $L_{X}^{0.3–10}$ (erg s$^{-1}$) |
|----------------|--------|-----------|-----------------|----------------|----------------|----------------|-----------------|
| 56621.0        | 0.4197119(2) | 2.382586(1) | <10             | <5             | 18(1)          | 1.1(1)×10$^{-12}$ | 2.1(2)×10$^{39}$ |
| 57001.0        | 0.4183891(1) | 2.3901207(6) |                |                | 22(1)          | 2.7(1)×10$^{-12}$ | 5.0(2)×10$^{39}$ |

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$^a$ Pulsed fraction defined as the semi-amplitude of the sinusoid divided by the average source count rate in the 0.1–10 keV range.
The properties of the optical counterpart are consistent with a distance of 3.9 Mpc, these fluxes translate into 0.3–10 keV isotropic luminosity of \( \sim 1.6 \times 10^{39} \) and \( \sim 9 \times 10^{38} \) erg s\(^{-1}\). A bolometric correction factor of \( \sim 3 \) is obtained if it is assumed that the spectrum is cut off at 30 keV. The source was not detected by Swift between 2011 August 29 and 2013 June 13. Considering that the spacing between consecutive observations was similar than during the outbursts, the source likely remained in quiescence at least during the whole interval. The most stringent upper limit set on the 0.3–10 keV flux was \( 1.5 \times 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\), obtained on 2012 September 10 during a 3-ks-long observation. This value translates into an upper limit of \( \sim 3 \times 10^{38} \) erg s\(^{-1}\) on the 0.3–10 keV luminosity.

### 3 Discussion

Motch et al. (2014) found that the orbital period of NGC 7793 P13 is 64 d and that, if contamination from X-ray irradiation is not severe, the properties of the optical counterpart are consistent with those of a B9a supergiant companion with mass in the range \( M_2 = 18–23 M_\odot \). The radius of such a star is \( R_2 = 50–60 \) R\( \odot \).

The same authors assume that the star fills its Roche lobe, as the stellar wind from a B9a supergiant cannot provide the accretion rate needed to produce the maximum observed X-ray luminosity \( 10^{39–10^{40}} \) g s\(^{-1}\), see below). All acceptable orbital solutions obtained from fitting the orbital modulation of the optical light curve require a significant eccentricity, in the range \( e = 0.27–0.41 \). From this constraint, Motch et al. (2014) conclude that, at periastron, the large companion can fill the Roche lobe of a BH with a mass \( 3.4 M_\odot < M_{\text{BH}} < 15 M_\odot \), with the upper limit being fixed by the requirement that the Roche lobe is not too small to accommodate the star.

The discovery of a pulsar in NGC 7793 P13 allows us to place an independent and even tighter constraint on the orbital eccentricity of the system. Assuming a mass \( M_1 = 1.4 M_\odot \) for the NS, the Roche lobe of the companion is bigger than that for a BH. Therefore, even a B9a supergiant cannot fill it unless the eccentricity is \( e = 0.46–0.55 \), so that, at periastron, the separation is sufficiently small to allow for a contact phase.

Following Motch et al. (2014), we assume that the mass transfer in the system proceeds on a thermal timescale \( t_{\text{th}} \): 

\[
t_{\text{th}} = 2.4 \times 10^5 (M_2/20 M_\odot)^2 \times (R_a/50 \text{ R}_\odot)^{-1} (L_a/10^4 \text{ L}_\odot)^{-1} \text{ yr},
\]

where \( L_a \) is the luminosity of the companion. The mass transfer rate is then:

\[
\dot{M}_2 \approx \frac{M_2}{t_{\text{th}}} = 3.7 \times 10^{33} (M_2/20 M_\odot)^{-1} \times (R_a/50 \text{ R}_\odot)^{-1} (L_a/10^4 \text{ L}_\odot)^{-1} \text{ g s}^{-1}.
\]

Owing to the large mass ratio \( q = M_2/M_1 \gg 1 \), the evolution is expected to be non-conservative. Part of the mass is likely to be removed from the binary through hydrodynamical instabilities, although the system may possibly be stabilized by the significant mass loss of the companion (Fragos et al. 2015). Even considering all the mass lost, \( M_2 \) is so high to easily account for the accretion rate \( \dot{M} \) implied by the maximum observed X-ray luminosity: \( L_{\text{max}} \approx 6 \times 10^{38} \) erg s\(^{-1}\), \( M = L_{\text{max}}/(q \dot{m}) \approx 10^{28} b (0.1/\eta) \) g s\(^{-1}\), where \( b \) is the beaming factor and \( \eta \) the accretion efficiency.

When detected, the source displayed a factor of \( \sim 15 \) flux variation during the X-ray monitoring described in Sect. 2.3, attaining a maximum isotropic luminosity of \( L_{\text{max}} \approx 1.6 \times 10^{39} \) erg s\(^{-1}\), about 100 times higher than the Eddington limit. We note that the \( \sim 0.42 \) s pulsations were observed at the top and close to the bottom of this range, implying that accretion onto the neutron took place over the entire interval of variation. The tightest upper limit on the luminosity was a factor of \( \sim 1000 \) lower than \( L_{\text{max}} \) (see Fig. 3), indicating that the source is likely transient.

In our discussion here we assume that accretion onto the neutron star takes place unimpeded (at least) over the above mentioned luminosity variation. The \( \sim 4.0 \times 10^{-11} \) s\(^{-1}\) period derivative inferred from the two one-year-apart observations during which pulsations were detected, is virtually unaffected by orbital Doppler shift given that the two XMM–Newton pointings are almost at the same orbital phase (assuming \( P_{\text{orb}} = 63.52 \) d; Motch et al. 2014).

Neutron stars may attain accretion luminosities exceeding the Eddington limit by orders of magnitude if their surface magnetic field \((B)\) is very high, so that electron scattering cross sections for extraordinary mode photons below the cyclotron energy \( E_c \approx 12(B/10^{12} \text{ G}) \) keV is much lower than the Thomson cross-section.
section, Mushotukov et al. (2015) show that column-accretion onto a $> 10^{12}$ G magnetic pole may give rise to a luminosity of $L \sim 10^{41}$ erg s$^{-1}$. However, for a magnetic NS to accrete at a very high rate, other conditions must be met. First, the accretion flow outside the magnetosphere must take place through a disk that remains geometrically thin (i.e. height/radius ratio $< 1$), such that the bulk of the flux emitted close to the bottom of the accretion column can escape. This translates into the condition that the accretion energy released in the disk down to the magnetospheric radius $r_m$ is sub-Eddington. An additional condition is that the neutron star angular velocity is smaller than the (Keplerian) angular velocity of the disk at $r_m$, so that the drag exerted by the rotating magnetic field lines as matter enters the magnetosphere is weaker than gravity and matter can accrete onto the surface. This is equivalent to requiring that $r_m < r_{cor}$, where $r_{cor} = \left( \frac{GM^2}{\Omega^2} \right)^{1/3}$ is the corotation radius (Illarionov & Sunyaev 1975; Stella et al. 1986). When $r_m > r_{cor}$, centrifugal forces at $r_m$ exceed gravity and only little accretion, if any, can take place when the so-called propeller regime ensues. For NGC 7793 P13 to emit isotropically a maximum luminosity of $L_{\text{iso}}^{\text{max}} = 1.6 \times 10^{40}$ erg s$^{-1}$ according to the model of Mushotukov et al. (2015) the neutron star surface dipolar magnetic should be at least $B \sim 2 \times 10^{14}$ G. However, for such value of $B$ and $P \sim 0.42$ s, accretion would be inhibited by magnetospheric drag and the neutron star would be deep in the propeller regime.

Therefore we relax the assumption of isotropy, and consider that the neutron star emission beam is emitted by a factor $b < 1$. In this case the isotropic equivalent luminosity is $L_{\text{iso}} = L_{\text{acc}} / b$ and the accretion luminosity $L_{\text{acc}} = GM / R$ is reduced correspondingly (here $R$ and $M$ are the neutron star radius and mass). We assume that the minimum (detected) isotropic luminosity of $L_{\text{iso}}^{\text{min}} \sim 1.6 \times 10^{40}$ erg s$^{-1}$ arising according to the model of Mushotukov et al. (2015) the neutron star surface dipolar magnetic should be at least $B \sim 2 \times 10^{14}$ G. However, for such value of $B$ and $P \sim 0.42$ s, accretion would be inhibited by magnetospheric drag and the neutron star would be deep in the propeller regime.

In order to ease this problem, and in analogy with the other two known pulsating ULXs (Bachetti et al. 2014; Israel et al. 2016, submitted), we consider the possibility that close to the neutron star surface (and thus the base of the accretion column) the magnetic field is dominated by higher than dipole magnetic multipoles. Close to the magnetospheric radius ($r_m \sim 10^4$ cm) the field is virtually the dipolar by virtue of its less steep radial dependence. This is done by analogy with the case of magnetars (Thompson & Duncan 1995; Tiengo et al. 2013) and the two already known pulsating ULXs. The conditions that the accretion disk is thin for $L_{\text{iso}}^{\text{max}} / L_{\text{acc}}^{\text{max}} / b$ and that the neutron star is in the accretion regime for $L_{\text{iso}}^{\text{min}} / L_{\text{acc}}^{\text{min}} / b$ depend on the $B$-field strength at $r_m$, where only the dipole component matters. Both conditions are satisfied for a $B \sim 3 \times 10^{12}$ G and $b \sim 1/3$. A (multipolar) $B$ of $> 5 \times 10^{13}$ G at the base of the accretion column would be required to give rise to corresponding maximum accretion luminosity of $L_{\text{acc}}^{\text{max}} = 7 \times 10^{43}$ erg s$^{-1}$. A maximum spin-up of $P \sim -5 \times 10^{-11}$ s s$^{-1}$ is derived in this case (owing to the higher time-averaged accretion rate resulting from $b \sim 1/3$), which is in good agreement with the value inferred from the observations. For a $P \sim 0.42$ s spin period we expect that the isotropic luminosity in the propeller regime is $< L_{\text{iso}}^{\text{min}} / 100 \sim 10^{37}$ erg s$^{-1}$ (Corbet et al. 1997), a value consistent with the upper limit derived by the 2012 XMM–Newton observation when the source was not detected.

The discovery of three PULXs previously classified as stellar mass BH based on their spectral properties, strongly suggests that this class might be more numerous than suspected so far, and that other know ULXs might host an accreting neutron star. The large first period derivative, the intermittence of the pulsations and their relatively small pulsed fraction make their detection a difficult task.

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