X-ray properties of two transient ULX candidates in galaxy NGC 7090

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ABSTRACT
We report the X-ray data analysis of two transient ultraluminous X-ray sources (ULXs, hereafter X1 and X2) located in the nearby galaxy NGC 7090. While they were not detected in the 2004 XMM-Newton and 2005 Chandra observations, their 0.3–10 keV X-ray luminosities reached \( > 3 \times 10^{39} \text{ erg s}^{-1} \) in later XMM-Newton or Swift observations, showing increases in flux by a factor of > 80 and > 300 for X1 and X2, respectively. X1 showed indications of spectral variability: at the highest luminosity, its X-ray spectra can be fitted with a powerlaw (\( \Gamma = 1.55 \pm 0.15 \)), or a multicolour disc model with \( T_{\text{in}} = 2.07^{+0.30}_{-0.35} \text{ keV} \); the X-ray spectrum became softer (\( \Gamma = 2.67^{+0.69}_{-0.64} \)) or cooler (\( T_{\text{in}} = 0.64^{+0.28}_{-0.17} \text{ keV} \)) at lower luminosity. No strong evidence for spectral variability was found for X2. Its X-ray spectra can be fitted with a simple powerlaw model (\( \Gamma = 1.61^{+0.55}_{-0.50} \)) or a multicolour disc model (1.69\( ^{+1.17}_{-0.48} \text{ keV} \)). A possible optical counterpart for X1 is revealed in HST imaging. No optical variability is found, indicating that the optical radiation may be dominated by the companion star. Future X-ray and optical observations are necessary to determine the true nature of the compact object.

Keywords: X-rays: binaries – X-rays: individual: NGC 7090 X1, NGC 7090 X2 – galaxies: individual: NGC 7090

1 INTRODUCTION
Ultraluminous X-ray sources (ULXs) are point-like off-nuclear extragalactic sources with X-ray luminosity higher than \( \sim 10^{39} \text{ erg s}^{-1} \) (Fabbiano 1989; Feng & Soria 2011). The apparent X-ray luminosity of ULXs exceeds the Eddington limit of a stellar black hole (BH) with a typical mass of \( \sim 10 M_{\odot} \) found in Galactic BH X-ray binaries (BHXBs, Remillard & McClintock 2006). It has been generally believed that ULXs are powered either by super-Eddington accretion onto stellar-mass black holes, or by intermediate mass black holes (IMBHs) with sub-Eddington accretion rate (e.g. Colbert & Mushotzky 1999; Feng & Soria 2011). Observational evidence for stellar-mass BHs have been found in a few ULXs (e.g. M101 ULX-1, Liu et al. 2013), while ESO 234-49 HLX1 (Farrell et al. 2009) and M82 X-1 (Feng & Kaaret 2010; Pasham et al. 2014), both with relatively high peak X-ray luminosity (\( L_X \gtrsim 10^{41} \text{ erg s}^{-1} \)), are promising IMBH candidates. However, the detection of pulsations in the X-ray data of four ULXs (M82 X-2: Bachetti et al. 2014; NCG 5907 ULX-1: Israel et al. 2017a; NGC 7793 P13: Fürst et al. 2016; Israel et al. 2017b; NGC 300 ULX-1: Carpano et al. 2018) show clear evidence that the accretors in those systems are neutron stars (NS), indicating that the apparent X-ray luminosities in those ULXs are at least \( \geq 10 \) times the Eddington limit for a standard NS of mass 1.4\( M_{\odot} \).

Some ULXs show low level short-term variability with fractional variability \( \lesssim 10 \)\% per cent, while some may be highly variable with fractional variability \( \gtrsim 10 \)–30 per cent (e.g. Heil et al. 2009; Sutton et al. 2013; Middleton et al. 2015). ULXs with long-term flux variability by a factor of \( \sim 40 \)–1000, though quite rare, have also been found, e.g. NGC 3628 (Strickland et al. 2001), M101 ULX-X1 (Mukai et al. 2005), M82 X2 (Feng & Kaaret 2007), NGC 1365 ULX X2 (Soria et al. 2009), CXOM31 J004253.1+411422 (Kaar et al. 2012) and XMMU J004243.6+412519 (Esposito et al. 2013) in M31 and NGC 5907 ULX-2 (Pintore et al. 2018). All the four pulsar ULXs discovered so far are also highly variable (even transient) X-ray sources.

The X-ray spectra of many luminous ULXs (\( L_X > 3 \times 10^{39} \text{ erg s}^{-1} \)) can generally be fitted with either a two component model (the ultraluminous state, UL), i.e., a multicolour disc blackbody (DBB) plus a Comptonisation or a single Comptonisation component (Gladstone et al. 2009; Sutton et al. 2013). For the less luminous ULXs (\( L_X < 3 \times 10^{39} \text{ erg s}^{-1} \)), their spectra can be well described with a single p-free disc model (the broadened disk, BD; Sutton et al. 2013) for which the local disc temperature \( T(r) \) is proportional to \( r^{-3/2} \). Some ULXs with luminosity higher than \( 10^{40} \text{ erg s}^{-1} \) also show a spectral shape consistent with the BD model Pintore et al. 2016. Spectral variability has been revealed in some individual ULXs through detailed X-ray spectral or colour analysis (e.g. Kubota et al. 2001; Roberts et al. 2006; Feng & Kaaret 2009; Kajava & Poutanen 2009). Some ULXs, similar to the Galactic X-ray binaries (XRBs), can change their spectral state dramatically.

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(Sutton et al. 2013; Marlowe et al. 2014), e.g. Holmberg IX X-1 showed a two component disc plus power-law spectrum at lower luminosity, while the spectral shape changed to a broadened disc at higher luminosity (Walton et al. 2014; Luangtip et al. 2016). The spectral properties of the four pulsar ULXs are similar to typical ULXs, although pulsar ULXs show a further excess at high energy whose origin may be associated to the accretion column above the NS surface. However, even though less robustly, indications of such an excess are observed also in other non-pulsating ULXs, suggesting that the ULX population can host a larger number of neutron stars than previously expected (Walton et al. 2018a).

In this letter, we report the X-ray properties of two transient ULXs (Fig. 1, hereafter X1, X2) found in the nearby star-forming galaxy NGC 7090. X1 is classified as an ULX candidate in Lin et al. (2012) based on XMM-Newton observations. X2 was detected in the 2012 Swift/XRT observations and included in the first Swift-XRT point source catalogue (1SXPS Evans et al. 2014). In this work we identify it as an ULX with peak 0.3–10 keV X-ray luminosity higher than $3 \times 10^{39}$ erg s$^{-1}$. We adopted a distance to NGC 7090 of 6.6 Mpc (Tully et al. 1992) throughout this work.

2 DATA ANALYSIS

NGC 7090 was observed by XMM-Newton, Chandra, Swift and Hubble in the past decades. The observation log can be found in Table 1. In this section, we describe the details of the data analysis.

2.1 XMM-Newton

NCG 7090 was observed by XMM-Newton on 2004 April 18 (ObsID: 0200230101), 2004 May 13 (ObsID: 0200230201) and 2007 October 5 (ObsID: 0503460101) with exposure time 28 ks, 19 ks and 31 ks, respectively. The first observation was severely affected by high background flaring, and thus was excluded from this work. The XMM-Newton Science Analysis System (SAS) version 16.1 (Gabriel et al. 2004) was used to reduce XMM-Newton data. We ran SAS tasks emchain and epchain to generate the event lists for the European Photon Imaging Camera (EPIC) MOS (Turner et al. 2001) and pn (Strüder et al. 2001) detectors, respectively. Flaring background periods were identified and filtered from the event lists. The effective exposure time of the EPIC pn, M1 and M2 cameras, after filtering the high background periods, were 6024, 10390, 10290 s (4270, 12790, 12980 s) for the 2004 (2007) observation, respectively. Source detection was performed on all the individual EPIC image as well as the combined EPIC image for each observation using the SAS task edetect_chain. The parameters likemin (minimum detection likelihood) and mlmin (minimum likelihood) of 8 and 10 were adopted as suggested by the SAS guide. We found X2 was not detected in the individual EPIC image or in the combined image of the two observations, while X1 was only detected in the October 2007 observation (both in the individual image and the combined image). We thus only extracted the X-ray spectra for the combined image.

\[1\] https://xmm-tools.cosmos.esa.int/external/sas/current/doc/edetect/node3.html
Table 1. Observation logs

| Mission | Observation/proposal ID | Observation date  | Exposure time (s) | Instrument/filters | Used in work |
|---------|-------------------------|-------------------|-------------------|-------------------|-------------|
| XMM-Newton | 0200230101 | 2004-04-08 | 27981 | — | N |
| | 0200230201 | 2004-05-13 | 6024/10390/10290 | pn/M1/M2 | Y |
| | 0200230101 | 2004-09-15 | 4270/12790/12980 | pn/M1/M2 | Y |
| Chandra | 7060 | 2005-12-18 | 26410 | ACIS-S | Y |
| | 7252 | 2006-04-10 | 31020 | ACIS-S | Y |
| Swift | 35883001 | 2006-09-24 | 2349 | XRT | Y |
| | 35883002 | 2006-10-31 | 2191 | XRT | Y |
| | 32287001 | 2012-02-27 | 3856 | XRT | Y |
| | 32287002 | 2012-03-12 | 3350 | XRT | Y |
| | 32287003 | 2012-03-26 | 3161 | XRT | Y |
| | 32287004 | 2012-04-09 | 3673 | XRT | Y |
| | 32287005 | 2012-04-23 | 4091 | XRT | Y |
| | 32287006 | 2012-05-07 | 4124 | XRT | Y |
| | 32287007 | 2012-05-21 | 3952 | XRT | Y |
| | 32287008 | 2012-06-04 | 2897 | XRT | Y |
| | 32287009 | 2012-06-18 | 2681 | XRT | Y |
| | 32287010 | 2012-06-21 | 1592 | XRT | Y |
| | 32287011 | 2012-07-02 | 3852 | XRT | Y |
| | 35883003 | 2012-07-24 | 2171 | XRT | Y |
| | 32287012 | 2012-07-30 | 1972 | XRT | Y |
| | 32287013 | 2012-08-02 | 602 | XRT | Y |
| | 32287014 | 2012-08-02 | 2093 | XRT | Y |
| | 32287015 | 2012-08-20 | 1953 | XRT | Y |
| | 84548001 | 2014-06-15 | 1188 | XRT | Y |
| | 84548002 | 2014-07-24 | 221 | XRT | Y |
| | 84548003 | 2014-07-26 | 728 | XRT | Y |
| HST | 5446 | 1994-06-20 | 160 | WFC2/F606W | N |
| | 9042 | 2001-09-24 | 460, 460 | WFC2/F485W, F814W | Y |
| | 10416 | 2005-06-23 | 2508, 7496 | ACS/F625W, F658N | N |
| | 10889 | 2007-05-17 | 4000 | WFC2/F814W | N |
| | 12546 | 2012-04-09 | 900, 900 | ACS/F606W, F814W | Y |
| | 14095 | 2016-03-08 | 298, 1802 | WFC3/F110W, F128N | N |

source X1. A circular region with a radius of 12 arcsec was used to extract the source spectra. Apart from X2, we note that X1 is also about 19 arcsec away from the closest source, and it is ~5 times brighter than that source during the 2007 XMM-Newton observation. X-ray events with pattern ≤12 and ≤4 were selected to extract the MOS and pn spectrum, respectively. The background spectra were extracted from a source-free region with a circle of radius 100 arcsec located on the same CCD chip as the source for MOS, while a circular region centred at the same CCD read-out column as the source position was selected for pn. The arfgen and rmfgen tasks were used to generate the response files.

2.2 Chandra

*Chandra* observed NGC 7090 on 2005 December 18 (26ks, ObsID: 7060) and 2006 April 10 (31ks, ObsID: 7250) with the Advanced CCD Imaging Spectrometer (ACIS). Chandra data were reduced with CIAO (Fruscione et al. 2006, ver 4.10) software package and calibration files CALDB (ver 4.7.6). We ran wavdetect tool on the Chandra observations to generate a source list. X2 was not detected in the two Chandra observations, while X1 was only detected in the 2006 observation. The overall 90 per cent absolute astrometric uncertainty of Chandra is ~0.8 arcsec.2 Following the online data analysis guide,3 we corrected the absolute astrometry by cross-matching Chandra sources with the GAIA DR2 catalogue (Gaia Collaboration et al. 2018) using a correlation radius of 1 arcsec. Three sources were selected to perform absolute astrometry correction. The CIAO task WCS_MATCH and WCS_UPDATE were used to correct and update the aspect ratio. The residual rms scatter in the corrected X-ray positions of the GAIA sources is 0.26 arcsec, which corresponds to a 90 per cent position error of ≈0.53 arcsec (assuming Rayleigh distribution).

To extract the source spectrum for X1, we selected a circular region with a radius of 2 arcsec. The background spectrum was extracted from an annulus (concentric with the source) region with an inner and outer radius of 6 and 24 arcsec, respectively. The regions surrounding the events from the X2 (a circle with radius of 2.7 arcsec) and the other close by source (a circle with radius of 5.2 arcsec) were excluded from the annulus background region. The CIAO task DMELECT was used to extract the source and background spectra. The response files are generated using the MKACIS-RMF and MKARF tasks.

2.3 Swift/XRT observations

NGC 7090 was observed by the X-ray Telescope (XRT, Burrows et al. 2005) of the Neil Gehrels Swift Observatory (Swift) from 2006 to 2014. All the XRT data (21 observations) were analysed with the XRT online data analysis tool4 (Evans et al. 2009). We

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2 http://cxc.cfa.harvard.edu/cal/ASPECT/celmon
3 http://cxc.harvard.edu/ciao/threads/reproject_aspect
4 http://www.swift.ac.uk/user_objects
ran source detection using ximage task detect. Source X1 was not detected in either individual observations or the combined observation with signal-to-noise ratio (S/N) more than 2, while source X2 was detected in observations performed on 2012 June 4 and July 2 (ObsIDs: 00032287008, 00032287011) with S/N higher than 3.7 (Evans et al. 2014). To increase the S/N, we extracted the source and background spectra from a combined image of the four observations performed between 2012 June 4 and July 2 (ObsIDs: 00032287008-11, total exposure: 11 ks, S/N > 9, hereafter Swift/X1). X2 was also detected in the combined image of observations performed from 2012 July 30 to August 20 (ObsIDs: 00032287011-15, total exposure: 8.7 ks, S/N > 5, hereafter Swift/X2). Source and background spectra were also extracted for this combined observation.

2.4 NGC 7090 was observed six times by HST from 1994 to 2016. In this work, the observations with better S/N carried out on 2001 September 24 with the Wide Field and Planetary Camera 2 (WFPC2, filter F814W), on 2005 June 23 with the Wide Field Camera 3 (ACS/WFC3, filter 625W) and on 2012 April 9 with ACS/WFC3 (filters: F814W and F606W) were used. The HST images were retrieved from the Hubble Legacy Archive\(^5\) (HLA). The absolute astrometry for the 2012 observations (which have the best spatial resolution and S/N) was corrected by aligning the HST images with the source positions found in the GAIA DR2 catalogue. The absolute astrometry accuracy of HST after correction is \(\sim 1\) mas (68 per cent confidence level), consistent with the position accuracy obtained at HLA.

3 RESULTS

The position of X1 was obtained from the 2006 Chandra observation using the wavdetect task, which gives RA = \(21^h 36^m 31.8^s\) and Dec. = \(-54^\circ 33\arcmin 57.82\arcsec\), within the error circle of the position measured from the XMM-Newton 2007 observation. Following Evans et al. (2014), we improved the position accuracy of Swift/XRT by aligning the XRT image with the sources detected by Chandra. The improved position of X2 given by XRT is then: RA = \(21^h 36^m 29.11\) and Dec. = \(-54^\circ 33\arcmin 48.31\arcsec\) (with 90 per cent uncertainty of 1.8 arcsec), which is about 25.3 arcsec away from X1.

3.1 X-ray variability

Fig. 2 shows the long-term X-ray variability of the two ULXs. The unabsorbed 0.3–10 keV X-ray luminosities of X1, estimated by fitting the X-ray spectra with an absorbed power-law model (see Sec. 3.2.1 for more details), are \(L_X \sim 1 \times 10^{38}\) and \(\sim 4 \times 10^{39}\) erg s\(^{-1}\) for the 2006 April Chandra and 2007 October XMM-Newton observations, respectively. The 3\(\sigma\) upper limits, estimated by fitting the best-fitting absorbed power-law model of the 2007 XMM-Newton observation, are plotted for the other observations (or the Swift/XRT combined observations) for which X1 was not detected.

\(^5\) Note that the 2007 HST observation had a very long exposure time. However, no photometric measurements were given on the Hubble Source Catalogue website. Thus this observation is not used in this work.

\(^6\) http://hla.stsci.edu

![Figure 2](image.png)

**Figure 2.** The long-term unabsorbed 0.3–10 keV light curves of X1 (top) and X2 (bottom). The errors on the luminosities are at 90 per cent confidence level, while the upper-limits (in grey) are at 3\(\sigma\) confidence level.

The lowest X-ray luminosity was given by the 2005 Chandra observation with a 3\(\sigma\) upper limit of \(\sim 5 \times 10^{37}\) erg s\(^{-1}\).

Source X2 was significantly detected by Swift/XRT in the observations made on 2012 June 4 (\(> 3\sigma\)) and July 2 (\(> 5\sigma\)). It was also seen in the other two observations performed in 2012 June, albeit with less significance (\(> 2.6\sigma\)). The average X-ray luminosity estimated by fitting the average X-ray spectrum of those four observations with an absorbed power-law model is \(\sim 4 \times 10^{39}\) erg s\(^{-1}\) (see Fig. 2). X2 was not detected in any of the other individual observations. But it was clearly seen in the combined image of the Swift/XRT data observed between 2012 July 30 and August 20 (Swift/X2) with an estimated X-ray luminosity of \(7 \times 10^{38}\) erg s\(^{-1}\). (see Fig. 2). The lowest X-ray luminosity was calculated from the 2006 Chandra observation with a 3\(\sigma\) upper limit of \(8 \times 10^{36}\) erg s\(^{-1}\).

From Fig. 2, it is clear that both X1 and X2 showed dramatic long-term X-ray variability. Comparing to the 2005 Chandra observation, the highest X-ray luminosity of X1 (the 2007 XMM-Newton observation) and X2 (the 2012 Swift/XRT observations) increased by a factor of \(> 80\) and \(> 300\), respectively. We also analysed the temporal properties of X1 within the 2007 XMM-Newton data. No significant short-term (e.g. minutes to hours) variability was found in the 31 ks exposure time. We did not find any coherent signal in the power spectrum created using the 0.3–10 keV XMM-Newton data. Assuming a sinusoidal modulation, a 3\(\sigma\) upper limit of \(\sim 60\) per cent on the pulsed fraction (defined as the semi-amplitude of the sinusoid divided by the source average count rate) was derived using the XMM-Newton data for periods in the range of \(0.4 – 150\) s.

3.2 X-ray spectral analysis

X-ray spectral analysis was carried out for the 2006 Chandra (background-subtracted 0.3–10 keV photon counts \(C_{\text{sub}} = 34\)) and 2007 XMM-Newton (\(C_{\text{sub}} = 350\), 353 and 283 for EPIC M1, M2 and pn, respectively) observations of X1, as well as the two X-ray spectra of X2 (\(C_{\text{sub}} = 110\) and 15 for Swift/X1 and Swift/X2, respectively). Xspec (Arnaud 1996 ver 12.10) is used to fit the X-ray spectra. The cash statistic (wstat in Xspec) is used due to the relatively low photon counts. Galactic and host galaxy absorption are included.
in all models (model tbars and ztbars in Xspec, abundances are set to w1lm, Wilms et al. 2000). The Galactic absorption is fixed at $5.4 \times 10^{20} \text{cm}^{-2}$ (Kalberla et al. 2005). Quoted uncertainties on spectral parameters are the 90 per cent confidence limits unless stated otherwise.

### 3.2.1 Source X1

The EPIC 0.3–10 keV M1, M2 and pn spectra were fitted simultaneously. A normalization factor is included to account for the calibration differences between the detectors. We fitted the data with two simple models: powerlaw model (const*tbars*ztbars*powerlaw in Xspec) and diskbb model (const*tbars*ztbars*diskbb). Both models can fit the data well (see Fig. 3) with $\Gamma = 1.55 \pm 0.15$ in the powerlaw model and inner disc temperature $T_{\text{in}} = 2.1^{+0.3}_{-0.4}$ keV for diskbb model. Best-fitting values of the intrinsic absorption are $5.0^{+1.0}_{-1.0} \times 10^{21} \text{cm}^{-2}$ (powerlaw) and $3.0^{+1.0}_{-1.0} \times 10^{21} \text{cm}^{-2}$ (diskbb). The estimated unabsorbed 0.3-10 keV X-ray luminosity is higher than $3 \times 10^{39} \text{erg s}^{-1}$. We also tried to fit the data with two component models, i.e., a powerlaw plus a diskbb, which gave $T_{\text{in}} = 0.22^{+0.08}_{-0.08}$ keV and $\Gamma = 1.44^{+0.26}_{-0.20}$ or a blackbody plus a diskbb ($T_{\text{BB}} = 1.41^{+0.24}_{-0.16}$ keV, $T_{\text{in}} = 0.40^{+0.14}_{-0.09}$ keV). Those two component models improve the fit slightly comparing with a single powerlaw model ($\Delta C = 5.4$ and 11.3 for 2 d.o.f, see Table 2). The best-fitting models as well as the data-to-model ratios for the powerlaw and diskbb models are shown in Fig. 3. The 2006 Chandra data were fitted with the two simple models. The intrinsic column was fixed at values found by XMM-Newton data. Although with large uncertainties, the data suggest a steeper photon index ($\Gamma = 2.67^{+0.09}_{-0.64}$) or a lower disc temperature ($T_{\text{in}} = 0.64^{+0.28}_{-0.17}$ keV), indicating a change in spectral shape. The best-fitting parameters of different models can be found in Table 2.

### 3.2.2 Source X2

The same simple models were fitted to the Swift/XRT spectra for X2. Both models can fit the Swift/XRT spectrum well, with best-fitting temperature $T_{\text{in}} = 1.69^{+1.17}_{-0.58}$ keV or photon index $\Gamma = 1.61^{+0.55}_{-0.48}$ due to the low S/N, we did not fit the X-ray spectrum with more complicated models. The best-fitting results of the Swift/XRT spectrum were consistent with the Swift/XRT data, though with large uncertainties (intrinsic column was fixed at the values found by Swift/XRT) and relatively small change in flux (by a factor of ~ 4).

### 3.3 Optical counterpart

We found one optical counterpart (see Fig. 1) within the position uncertainty of X1 in the HST images. The AB magnitudes of the X1 counterpart (obtained from the Hubble Source Catalogue) are: $23.27^{+0.06}_{-0.07}$, $23.32^{+0.01}_{-0.02}$, $23.28^{+0.02}_{-0.02}$ and $23.45^{+0.02}_{-0.02}$ mag for the $\text{WFPC2/F814W}$ (2001), $\text{ACS/F625W}$ (2005), $\text{ACS/F814W}$ (2012) and $\text{ACS/F606W}$ (2012), respectively. Assuming $N_\text{H} = 2.21 \times 10^{21} \text{cm}^{-2}$ (Güver & Özel 2009) and $A_V = E(B-V)/3.1$, the estimated extinction for $\text{ACS/F814W}$, $\text{ACS/F625W}$ and $\text{ACS/F606W}$ are $A_{\text{F814W}} = 1.3, A_{\text{F625W}} = 1.9$ and $A_{\text{F606W}} = 2.1$ (Sirianni et al. 2005) with $N_{\text{H, host}} = 3 \times 10^{21} \text{cm}^{-2}$. Respectively. The estimated $V$, $R$ and $I$ band magnitudes, transformed from the ACS/WFC AB magnitude (Sirianni et al. 2005), are 21.28, 21.24 and 21.49 mag, respectively. No significant variability is found for the F814W flux in the two HST observations.

Multiple optical counterparts were found within the position uncertainty of X2 in the HST images. The magnitudes of the brightest source in the 2012 HST observation were 24.86 and 25.93 mag in F814W and F606W band, respectively. Assuming $N_{\text{H, host}} = 3 \times 10^{21} \text{cm}^{-2}$, the upper limit magnitudes for the X2

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**Table 2. Best-fitting parameters**

| Model | $N_{\text{H, host}}$ | $\Gamma/T_{\text{BB}}$ | $T_{\text{in}}$ | $C_{\text{stat/d.o.f}}$ |
|-------|-----------------|-----------------|-----------------|-----------------|
|       | $10^{22} \text{cm}^{-2}$ | keV | keV | erg s$^{-1}$ cm$^{-2}$ |
| PO    | $0.3^{+0.1}_{-0.1}$ | $1.55^{+0.15}_{-0.15}$ | $-12.09^{+0.04}_{-0.04}$ | 708.67/815 |
| DISKBB| $0.3^{+0.1}_{-0.1}$ | $2.07^{+0.30}_{-0.23}$ | $-12.19^{+0.05}_{-0.05}$ | 722.32/815 |
| PO+DISKBB | $0.8^{+0.4}_{-0.3}$ | $1.44^{+0.26}_{-0.29}$ | $-11.93^{+0.45}_{-0.19}$ | 703.23/813 |
| BB+DISKBB | $0.6^{+0.2}_{-0.2}$ | $1.41^{+0.24}_{-0.16}$ | $-12.07^{+0.12}_{-0.09}$ | 697.34/813 |

**Figure 3.** Top panel: the X-ray spectra of X1 during the 2007 observation: open circle for EPIC-M1, filled circle for EPIC-M2, square for EPIC-pn. The grey solid and dashed lines show the best-fitting powerlaw and diskbb model, respectively. The lower two panels show the data/model ratio for different models.
counterpart are 24.0 and 23.1 mag in the V and I bands, respectively.

4 DISCUSSION

In this letter, we report the X-ray properties of two highly variable ULXs in the nearby star-forming galaxy NGC 7090. Source X1 has been classified as an ULX candidate in the catalogue compiled by Lin et al. (2012) using *XMM-Newton* data. Source X2 is a new ULX detected in the 2012 Swift/XRT observations. The long-term X-ray light curves show that both sources are highly variable: flux changed by a factor of > 80 for X1 and > 300 for X2. AGNs are known to be highly variable especially in the X-ray bands. However, variability by a factor of more than 80 are rare in AGNs (e.g. Stroetjohann et al. 2016). We further explore the possibility that the two sources are background AGNs by considering the log N − log S of extragalactic X-ray sources. The expected number of AGN, with X-ray flux higher than ∼ 10^{−13} erg cm^{−2} s^{−1} covering by the approximate 7.0 × 1.5 arcmin^{2} area by NGC 7090 is smaller than 0.04 (Moretti et al. 2003), suggesting that X1 and X2 are unlikely to be background AGNs.

Most Galactic BHXRBs are transient X-ray sources with dramatic X-ray variability. If X1 and X2 are similar to BHXRBs, i.e. stellar massive BH with sub-Eddington accretion rate, then the mass of the BH should be around 30M_⊙, assuming the observed peak luminosity are close to the Eddington luminosity (i.e. in the soft state, Remillard & McClintock 2006). However, the temperature (2.0^{+0.30}_{−0.23} − 1.69^{+1.17}_{−0.48} keV for X1 and X2, respectively) obtained from X-ray spectral analysis is inconsistent with the prediction for a disc around a 30M_⊙ BH. The X-ray data of X1 have slightly better S/N, and can be fitted with a two component model. The powerlaw+diskbb model showed a hard (1.44^{+0.26}_{−0.29}) photon index with a weak and cool disc (the ratio of the disc flux to the total flux f_{disc} ∼ 0.19, T_{in} = 0.22^{−0.08}_{+0.08}), which is consistent with the low/hard state of BHXRBs. If this is the case, the peak luminosity of X1 could be even higher, thus the BH mass should be much larger (e.g. an IMBH). But we note that the powerlaw+diskbb model does not improve the fit significantly comparing to the single component models. X1 also showed a transition in spectral shape with a much softer or cooler spectrum in 2006. This is reminiscent of the quiescent state (Γ = 1.5−2.1, Remillard & McClintock 2006) in BHXRBs.

Alternatively, super-Eddington accretion onto an NS or a BH with mass less than 10M_⊙ cannot be ruled out. High X-ray variability, though rare, has been found in some ULXs (e.g. Pintore et al. 2018 and references therein). All the four pulsating ULXs also showed high level flux variability. In a recent paper, Walton et al. (2018b) showed that the broadband X-ray spectra of the bright ULXs can be fitted with a model consistent with super-Eddington accretion onto NSs, which may suggest that the compact object in many ULXs are neutron stars. The photon index and the disc temperature of X2, when fitted with the two simple models, are in agreement with the typical values found in ULXs with low S/N data (e.g. Makishima et al. 2000) as well as the transient pulsar M82 X2 at a similar luminosity range (Brightman et al. 2016). Similar to the other ULXs, the spectra of X1 in the high luminosity state can be described with a hot blackbody component plus a cool multi-colour disc component. Though X1 did not show strong variability or pulsation during the 2007 *XMM-Newton* observation, it is known that short-term variability and pulsation in some pulsar ULXs is transient. To further confirm the nature of the compact object of those two ULXs, future high S/N X-ray observations are necessary.

We did not find significant variability in *F814W* flux for the X1 optical counterpart in the two *HST* observations, which may suggest that the optical emission is from the companion star. Future simultaneous optical and X-ray observations are needed to confirm the nature of the companion star as well as the optical emission, however.

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