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# Unveiling the nature of compact object in the LMXB MAXI J1957+032 using *Swift*-XRT

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## ABSTRACT

MAXI J1957+032 is a transient low-mass X-ray binary (LMXB) that underwent four short outbursts in 1.5 yr since its discovery in 2015. The nature of the compact object in MAXI J1957+032 is not clear, but it was proposed to be a neutron star (NS) based on the short duration of its outbursts. Here, we report the results obtained after performing spectral analysis using data obtained with the X-ray telescope aboard the Neil Gehrels *Swift* satellite. When describing the spectrum with an *absorbed power law*, we found that the spectra softens (the power-law index increases from  $\sim 1.8$  to 2.5) as the luminosity decreases. Near the end of its outbursts the observed value of power-law index ( $\Gamma$ ) is  $\sim 2.5$ . To identify the nature of the compact object in this system, we used  $\Gamma$  as a tracer of the spectral evolution with luminosity. We found that for the distance of 4 kpc, our results suggest that the source harbours a NS.

**Key words:** binaries: spectroscopic – stars: neutron – X-rays: binaries – X-rays: individual: MAXI J1957+032.

## 1 INTRODUCTION

Low-mass X-ray binaries (LMXBs) contain a black hole (BH) or neutron star (NS) that accretes matter from a companion star that typically has a mass lower than that of the accretor. Most LMXBs are transients that mean they undergo outbursts sporadically while spending most of their time in a quiescent state with X-ray luminosity below  $\sim 10^{34}$  erg s<sup>-1</sup>. During an outburst, the X-ray luminosity can increase up to a few times  $10^{36}$ – $10^{39}$  erg s<sup>-1</sup>. In the last 15 yr, it has been found that there are LMXBs that show sub-luminous accretion outbursts, i.e. having peak outburst luminosities within a range of  $10^{34}$ – $10^{36}$  erg s<sup>-1</sup>. This class of LMXBs is known as very faint X-ray transients (VFXTs; see e.g. Wijnands et al. 2006).

One of the challenging aspects in the study of LMXB – and in particular of these VFXTs – is to understand the nature of a compact object. There are only a few observational methods to unambiguously constrain it. If the source shows coherent pulsations or thermonuclear X-ray bursts, then it is a NS. If the mass function (typically from optical/infrared spectroscopy) is measured, then one can generally state if the binary system hosts a NS or a BH. In cases where we lack these measurements, the possible nature of its compact object is inferred from the comparison of its spectral and

timing signatures with those observed from systems for which we know the nature of their compact objects (see e.g. Porquet et al. 2005). Studies carried out during the quiescent state can also be used to infer the nature of the accretor (see e.g. Gelino et al. 2006).

The faint luminosities of VFXTs make them difficult to find with all-sky monitors whose sensitivity is typically not sufficient to detect those systems beyond the peak of their outburst. When followed-up and monitored with more sensitive instruments, especially with *Swift*, the VFXTs often appear to show brief (few days to few weeks) outbursts, hence allowing only for a limited time opportunity to study these systems (e.g. Armas Padilla et al. 2011, 2014; Degenaar et al. 2015). In addition, many are found in the Galactic plane and have thus large distances and typically have large column densities towards them. This does not allow for detailed studies of their optical or near-infrared properties and hence not much is known about their companion stars either.

MAXI J1957+032 (also sometimes referred to as IGR J19566+0326) is an X-ray binary that was first observed in outburst on May 11, 2015 with the Gas Slit Camera (GSC) aboard *Monitor of All Sky X-ray image* (MAXI; Negoro et al. 2015). It was later also detected using *Integral* in 20–60 keV band (Cherepashchuk et al. 2015). *Chandra* also observed the source giving the best known position to date (Chakrabarty, Jonker & Markwardt 2016). Since its discovery, MAXI J1957+032 exhibited four outbursts; each outburst decayed quite rapidly

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**Table 1.** Log of observations made with *Swift*-XRT in response to the outbursts of MAXI J1957+032. All errors and upper limits are at  $3\sigma$  confidence level.

Obs ID	Time (MJD)	Mode	Exp time (ks)	0.3–10 keV count rate (count s <sup>-1</sup> )
33770001	57156.03	PC	3.0	0.55 ± 0.02
33770002	57157.67	PC	2.0	0.013 ± 0.003
33770005	57162.06	PC	2.8	0.006 ± 0.001
33770006	57164.76	PC	0.9	0.008 ± 0.004
33770007	57165.78	PC	2.2	0.006 ± 0.002
33770009	57304.68	PC	1.0	0.65 ± 0.04
33770010	57305.62	PC	1.0	0.060 ± 0.008
33770011	57306.67	PC	1.0	< 0.008
33770012	57307.68	PC	1.0	< 0.013
33770013	57308.63	PC	1.0	< 0.008
33770014	57309.27	PC	1.0	< 0.015
33770015	57310.54	PC	0.8	< 0.016
33770016	57311.43	PC	1.0	0.005 ± 0.003
33770017	57660.69	WT	1.0	26.3 ± 0.8
33770018	57661.35	WT	0.8	19.0 ± 0.1
33770019	57662.75	WT	0.4	4.7 ± 0.6
33770020	57663.08	WT	0.036	3.5 ± 0.4
33770020	57663.35	PC	1.7	1.3 ± 0.05
33770021	57664.18	PC	1.7	0.109 ± 0.008
33770022	57665.61	PC	1.4	< 0.008
33770023	57667.52	PC	0.6	< 0.016
33770024	57668.09	PC	2.0	0.002 ± 0.001
33770025	57669.76	PC	1.7	< 0.007

(within a few days, see e.g. Mata Sánchez et al. 2017). These authors showed that the optical spectrum of MAXI J1957+032 during its outburst is consistent with other LMXB transients. The same authors also proposed that the source is a NS system based on the resemblance of the system with the accreting millisecond X-ray pulsar (AMXP) in NGC 6440 X–2. Both systems have exhibited a period during which they displayed frequent outbursts that only lasted several days. For a reasonable range (2–8 kpc) of distances, MAXI J1957+032 classifies as a VFXT.

So far, no BH system has been identified that also exhibits such short, frequent outbursts. However, it is unclear whether short outbursts are characteristic only for NS X-ray binaries or that they can also indeed be observed in BH systems. Knevitt et al. (2014) argued that for BHs with short orbital periods ( $P_{\text{orb}} < 4$  h), the peak outburst luminosity drops close to the threshold for radiatively inefficient accretion, and BH LMXBs can have lower outbursts luminosities and shorter outburst durations compared to NS systems. However, there exist systems like Swift J1357.2–0933 (see e.g. Armas Padilla, Degenaar & Wijnands 2013a; Mata Sánchez et al. 2015) and Swift J1753.5–0127 (see e.g. Ramadevi & Seetha 2007; Zurita et al. 2008) that are believed to have short orbital periods, but they do not exhibit short outbursts. Moreover, MAXI J1659–152 is a short orbital period BH but it exhibits bright outbursts (Kuulkers et al. 2013).

Wijnands et al. (2015) searched the literature for reports on the spectral properties of NS and BH LMXBs studied using an absorbed *power-law* model. They compared the spectra of NS and BH transients when they have accretion luminosities between  $10^{34}$ – $10^{36}$  erg s<sup>-1</sup>. The authors found that NSs are significantly softer than BHs below an X-ray luminosity (0.5–10 keV) of  $10^{35}$  erg s<sup>-1</sup> (fig. 1 of Wijnands et al. 2015). Thus, the spectral shape between 0.5 and 10 keV at these low luminosities can be a useful tool to distinguish LMXBs hosting NSs from those harbouring BHs. In this paper, we present the evolution of all the outbursts observed with *MAXI* and

*Swift*, and we used the results obtained by Wijnands et al. (2015) to try to get more insights into the nature of MAXI J1957+032.

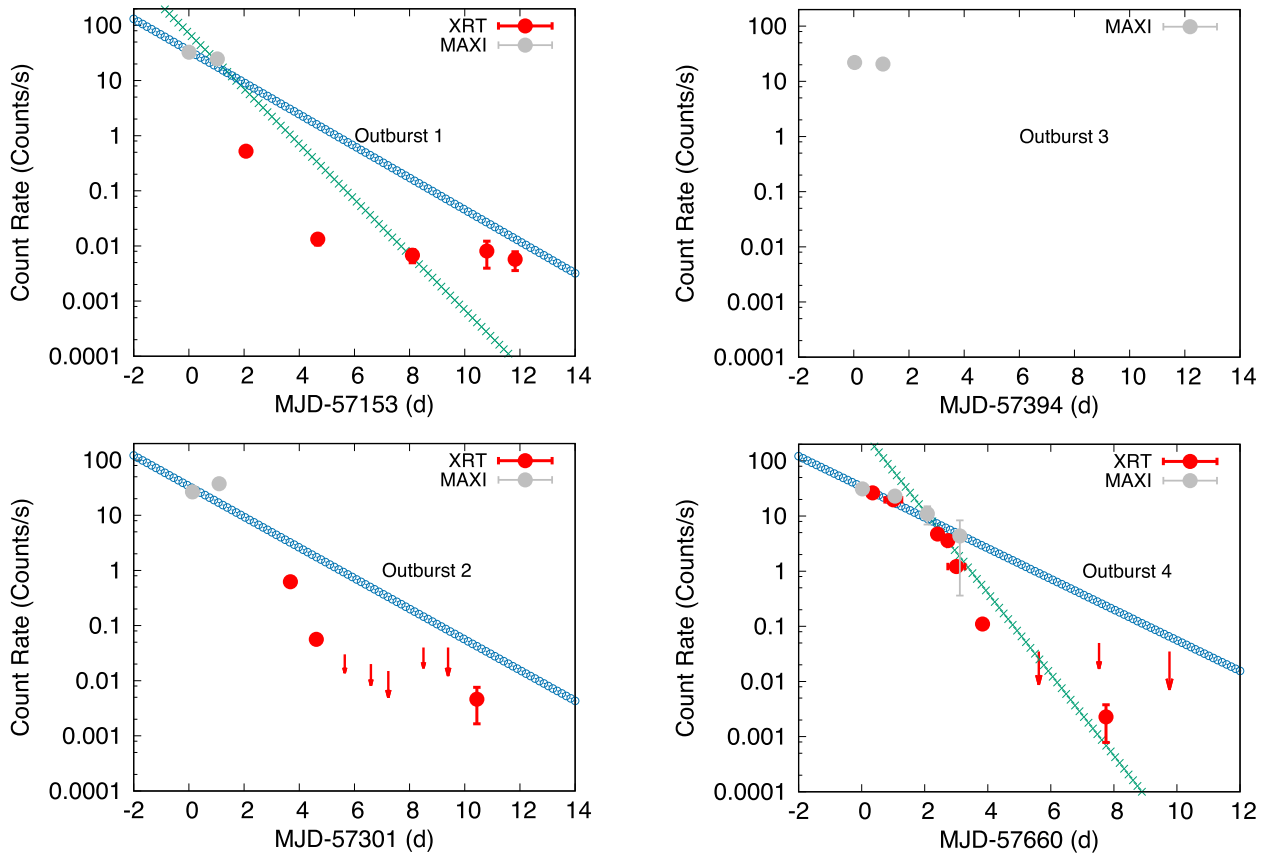
## 2 OBSERVATIONS

The Neil Gehrels *Swift* observatory, launched in 2004 November (Gehrels et al. 2004), has three instruments on board: (a) the Burst Alert Telescope that operates in the energy range of 15–150 keV (Barthelmy et al. 2005); (b) the X-ray telescope (XRT), operating in the range of 0.2–10 keV (Burrows et al. 2007); (c) the Ultraviolet and Optical Telescope that covers UV and optical bands (170–600 nm; Roming et al. 2004). In our paper, we have used the observations of MAXI J1957+032 performed with *Swift*-XRT during the 2015 and 2016 outbursts of the source. The details of observations used are given in Table 1. Due to the rapid decay of the source during the outbursts, only during eight observations enough photons were detected to allow for meaningful spectral analysis to be carried out.

The XRT observations were performed in photon counting (PC) and windowed timing (WT) modes depending on the brightness of the source. We have used the online tools provided by the UK Swift Science Data Centre<sup>1</sup> (Evans et al. 2009) to obtain the spectrum of each observation. Some of the spectra showed low number of photons therefore did not allow us to use  $\chi^2$  statistics. To maintain the homogeneity in our analysis, we grouped the obtained spectra using the ftools task GRPPHA (HEASOFT v6.19) to have at least one count per bin. Spectra were fitted using the XSPEC 12.9.1 (Arnaud 1996). We have used W-statistics which is background subtracted Cash statistics (Wachter, Leach & Kellogg 1979).

To obtain insight in the nature of the accretor in our target we compared our results with that of Wijnands et al. (2015). We fitted an absorbed power law to our spectra. TBABS was used to model the

<sup>1</sup><http://www.swift.ac.uk/>



**Figure 1.** The four outbursts observed in MAXI J1957+032. The plot at the top-left corresponds to the first outburst that began on 2015 May 11 (MJD 57153), the bottom-left shows the second outburst (beginning on 2015 October 6, MJD 57301), the top-right is for the third outburst (started on 2016 January 7, MJD 57394) that was only observed with *MAXI*, and the fourth outburst that starting on 2016 September 29 (MJD 57660) is shown in the bottom-right panel. The arrows correspond to the upper limits of the detection with XRT. We show XRT count rate in log scale. The values of flux measured with *MAXI* were converted to XRT count rates and are shown in grey. For the *MAXI* data, we have included only those data points that show significant detection (above  $4\sigma$ ). We also plot exponential decays where the crossed line (green) shows the fast decay while the empty circles (blue) is for the slow decay (see Section 3.1 for e-folding time-scales).

hydrogen column density ( $N_{\text{H}}$ ) using WILM abundances (Wilms, Allen & McCray 2000). The values of  $N_{\text{H}}$  used are discussed in the next section. For the observations made in PC mode, we fitted the spectra between 0.5 and 10 keV. The WT spectra are fitted in the range of 0.7–10 keV as there exist low energy spectral residuals below 0.7 keV in the WT mode spectra.<sup>2</sup> All the fluxes reported are the unabsorbed fluxes and we have used the convolution model ‘CFLUX’ to measure the fluxes in the 0.5–10 keV range. In the Appendix, we show that an absorbed power law provides a good fit to the XRT observations of MAXI J1957+032 where we have used only spectra of sufficient quality that allowed us to use  $\chi^2$  statistics to determine the goodness of the fits. Fig. A1 in the Appendix shows the best spectral fit obtained with the brightest observation made with XRT. Table A1 gives the fit parameters obtained using an absorbed power law.

The *MAXI* is an all sky monitor (Matsuoka et al. 2009) that has two instruments on board: the Solid state Slit Camera (SSC), operating between 0.7–10 keV (Tomida et al. 2011) and GSC, operating in the energy range 2–20 keV (Mihara et al. 2011). GSC has a wider field of view and much larger collecting area than SSC. MAXI J1957+032 was detected with the *MAXI*-GSC during all

the four outbursts. We have used *MAXI*-GSC light curves extracted in the 2–10 keV energy band using the *MAXI* on-demand data processing<sup>3</sup> (Nakahira et al. 2010).

## 3 RESULTS

### 3.1 Light curves

MAXI J1957+032 underwent four outbursts that started on 2015 May 11 (outburst 1; ATel 7504; Negoro et al. 2015), 2015 October 6 (outburst 2; ATel 8143; Sugimoto et al. 2015), 2016 January 7 (outburst 3; ATel 8529; Tanaka et al. 2016) and 2016 September 29 (outburst 4; ATel 9565; Negoro et al. 2016b). The four outbursts of MAXI J1957+032 were observed with *MAXI* but only three of these were monitored with *Swift*. The third outburst (outburst 3) was not covered with *Swift*-XRT due to the Sun angle constraint. In Fig. 1, we show combined light curves of MAXI J1957+032, obtained using *MAXI*-GSC and *Swift*-XRT data, however, for the third outburst we show only the *MAXI* light curve. We have used MJD 57153, MJD 57394, MJD 57301, MJD 57660 as the reference time for outburst 1, outburst 2, outburst 3, outburst 4, respectively.

<sup>2</sup>For example, see <http://www.swift.ac.uk/analysis/xrt/>.

<sup>3</sup><http://maxi.riken.jp/mxondem/>

**Table 2.** Best-fitting parameters of MAXI J1957+032 obtained using the *Swift*-XRT data. Spectral fitting was performed using W-statistics.

Outburst	Obs ID	$N_{\text{H}}$ (free) ( $10^{21}$ atoms $\text{cm}^{-2}$ )	$\Gamma$	$N_{\text{PL}}$ (photons $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$ ) at 1 keV	Unabsorbed flux (0.5–10 keV) ( $10^{-10}$ erg $\text{cm}^{-2} \text{s}^{-1}$ )
Outburst 1	00033770001	$3.6 \pm 0.7$	$2.5 \pm 0.2$	$0.007 \pm 0.001$	$0.15 \pm 0.01$
Outburst 2	00033770009	$3.7 \pm 0.8$	$2.8 \pm 0.3$	$0.010 \pm 0.003$	$0.33 \pm 0.02$
	00033770010	$4.9^{+3.9}_{-2.7}$	$4.87^{+2.2}_{-1.5}$	$0.002 \pm 0.001$	$0.07 \pm 0.02$
Outburst 4	00033770017	$1.1 \pm 0.2$	$1.78 \pm 0.04$	$0.175 \pm 0.008$	$10.1 \pm 0.1$
	00033770018	$1.7 \pm 0.2$	$2.01 \pm 0.05$	$0.146 \pm 0.008$	$6.9 \pm 0.1$
	00033770019	$4.7 \pm 2.0$	$2.2 \pm 0.2$	$0.04 \pm 0.01$	$1.7 \pm 0.1$
	00033770020	$3.1 \pm 0.7$	$2.49 \pm 0.22$	$0.017 \pm 0.003$	$0.61 \pm 0.03$
	00033770021	$2.0 \pm 1.0$	$2.6 \pm 0.4$	$0.0013 \pm 0.0004$	$0.045 \pm 0.005$

Note. Errors quoted are for the 90 per cent confidence range. The energy range used is 0.5–10 keV.  $N_{\text{PL}}$  is the normalization of power law (PL).

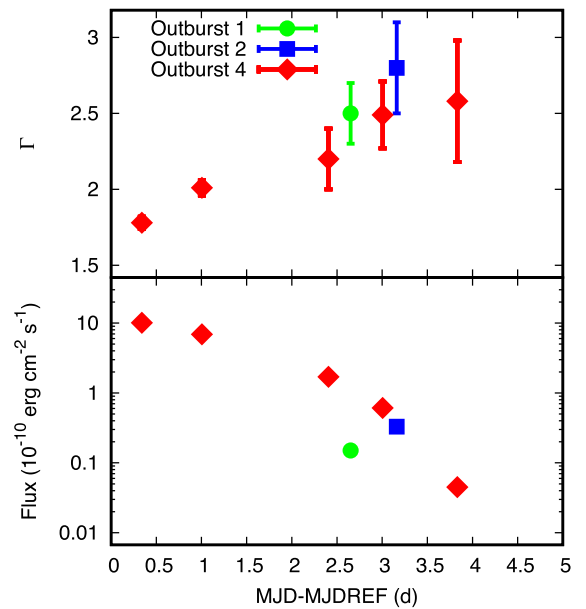
We have used WEBPIMMS HEASARC tool to convert *MAXI*-GSC count rates obtained in the 2–10 keV energy band to *Swift*-XRT count rates in the 0.3–10 keV energy band. The best-fitting values of  $N_{\text{H}}$  and  $\Gamma$  obtained using the spectral fitting of the brightest observation made with XRT during each outburst were used for this conversion (refer Table 2). However, for the third outburst, we assumed the value of  $N_{\text{H}}$  and  $\Gamma$  as observed during its outburst 4.

Fig. 1 shows the evolution of four outbursts observed in MAXI J1957+032 and it can be seen that all the four outbursts were equally bright. However, only during the fourth outburst (outburst 4) XRT observations were made close to the peak of the outburst. The peak count rate during the fourth outburst observed with *Swift*-XRT is  $\sim 26 \text{ count s}^{-1}$  that is almost a factor of 50 higher than observed during the other two outbursts. These outbursts do not last more than a few days, and in all cases *Swift*-XRT observations sample (part of) the outburst decay (Ravi 2017). We fitted an exponential decay function to the decay to obtain the e-folding time of these outbursts. The decay time-scale obtained for outburst 2 is  $0.64 \pm 0.08$ . Here, the exponential decay function was fitted starting from the peak of the outburst. Outbursts 1 and 4 indicated the presence of two e-folding times. Therefore, we fitted these two outburst curves using an exponential decay function in two different time ranges. This allowed us to determine slow and fast declines during these outbursts (see Fig. 1). The e-folding time-scales of outburst 1 are  $1.16 \pm 0.22$ , and  $0.66 \pm 0.11$  d corresponding to the slow and fast declines, respectively. For the outburst 4, we obtained  $1.7 \pm 0.4$  and  $0.64 \pm 0.08$  d to be the slow and fast decay time-scales, respectively.

These obtained decay time-scales are consistent with that reported by Mata Sánchez et al. (2017). For the third outburst (outburst 3) it is difficult to determine the decay time-scale using the GSC data. The errors quoted on the decay time-scales are within 90 per cent confidence range.

### 3.2 Absorption column density ( $N_{\text{H}}$ )

From the spectral fitting we found that, when it was left free in the fits, the value of  $N_{\text{H}}$  showed a large variation throughout the brightest outburst observed in 2016. To investigate, if the higher value of column density is due to the requirement of a thermal X-ray component, we tried fitting the spectra with a model composed of a soft thermal component (*bbodyrad*) and a power-law component. We noticed, however, that thermal component was not required in all these spectra. During the brightest outburst of MAXI J1957+032, only one of the observations showed the presence of a soft component (for details see Section 4). Thus,



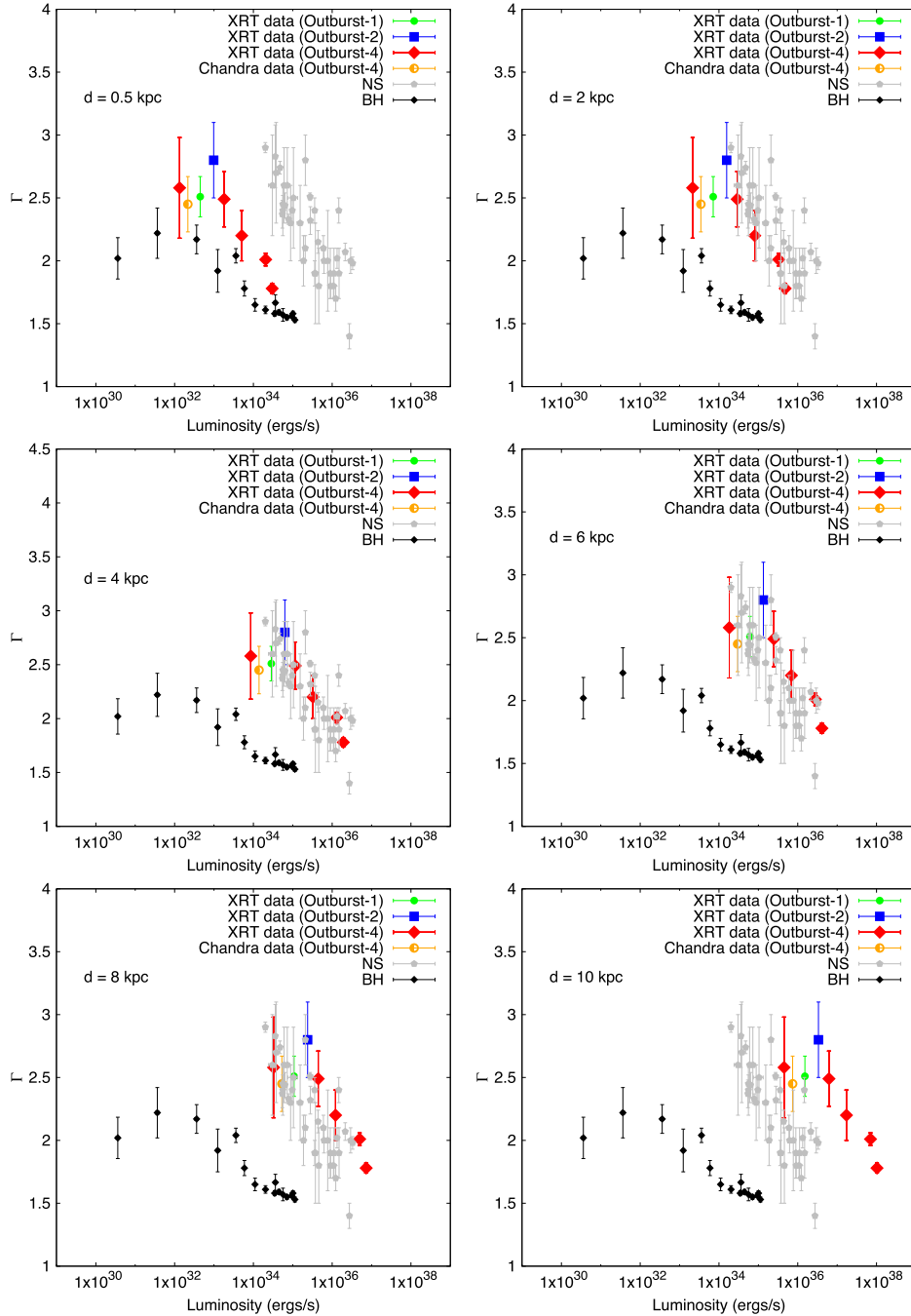
**Figure 2.** Variation of the index, and the unabsorbed flux (0.5–10 keV) of the power-law model during the three outbursts observed with *Swift*-XRT in 2015 and 2016. The power-law index was estimated keeping  $N_{\text{H}}$  as a free parameter. The spectrum obtained during the *Swift*-XRT observation made on MJD 57305.62 (outburst 2) had low statistics and consequently the errors on the obtained photon index were very large ( $\Gamma$  has an error greater than 0.5). Therefore, this point was not plotted.

a higher value of  $N_{\text{H}}$  might indicate the increase in the intrinsic absorption with an decreasing X-ray luminosity. Another possibility could be that at higher X-ray luminosities the source is far away from a true power-law shape. This was also suggested by Cherepashchuk et al. (2015) when the authors found that the simple extrapolation of the XRT spectrum of MAXI J1957+032 to the 20–60 keV energy band resulted into five times lower value of X-ray flux compared to that measured with *INTEGRAL*.

### 3.3 Spectral evolution during outbursts of MAXI J1957+032

In Fig. 2, we show the spectral evolution of MAXI J1957+032 during the three outbursts as observed with *Swift*-XRT. The two panels (from top to bottom) are for the power-law index, and the





**Figure 3.** The photon index versus the 0.5–10 keV X-ray luminosity for MAXI J1957+032, including the data presented by Wijnands et al. (2015) for NS and BH binaries.

unabsorbed flux in the 0.5–10 keV band, respectively. We found that while  $\Gamma$  generally increases with time, and the 0.5–10 keV absorbed flux decreased; clearly there is an anticorrelation between power-law index and observed flux. During the brightest outburst of MAXI J1957+032 in 2016, the values of power-law index ( $\Gamma$ ) increased from  $\sim 1.8$  to  $\sim 2.5$  when the fluxes decreased (outburst 4, Fig. 1). From the spectral analysis of MAXI J1957+032, we found that  $\Gamma$  reaches the value close to 2.5 during its three outbursts observed with *Swift*-XRT (see also Kennea et al. 2017; Mata Sánchez et al. 2017; Ravi 2017).

### 3.4 Photon index versus luminosity

We converted the unabsorbed fluxes in the 0.5–10 keV band (given in Table 2) to X-ray luminosities. The distance to MAXI J1957+032 is not known; therefore, below we discuss different interpretations of our data based on a wide range of distances. Fig. 3 shows  $\Gamma$  as a function of X-ray luminosity in the 0.5–10 keV band. This plot includes all the data points used by Wijnands et al. (2015) and also the values we have obtained for MAXI J1957+032. The black and the grey points of the Fig. 3 corresponds to BH and the NS binary systems, respectively. The red, blue, and green points are of

MAXI J1957+032, obtained using *Swift*-XRT data while the orange point corresponds to the photon index obtained using the *Chandra* observation of MAXI J1957+032 during outburst 4 (Chakrabarty et al. 2016).

#### 4 DISCUSSIONS

In our work, we have used *Swift*-XRT observations during three of four outbursts of MAXI J1957+032. MAXI J1957+032 is believed to be a VFXT and the nature of its compact object is still not established. We observe that the light curves of MAXI J1957+032 during its outbursts show a very short exponential decay time-scales of less than a day. Based on these characteristics like short outbursts and short recurrence time of outbursts, MAXI J1957+032 was proposed to be an AMXP similar to NGC 6440 X-2 by Mata Sánchez et al. (2017). However, there are several VFXTs in the Galactic centre that are not AMXPs but show short duration outbursts (see e.g. Degenaar et al. 2015) and there are also several bright NS X-ray transients (not AMXPs) that show outbursts that last only for a few days with a peak luminosity of  $<10^{36}$  erg s $^{-1}$  for example, GRS 1741-2853 (Degenaar & Wijnands 2010), XTE J1701-407 (Fridriksson et al. 2011), Aql X-1 (Coti Zelati et al. 2014), SAX J1750.8-2900 (Wijnands & Degenaar 2013).

Outbursts are often believed to be due to accretion disc instabilities. According to standard accretion disc instability models e.g. Lasota (2001) one would expect brighter outbursts to be longer. If MAXI J1957+032 is a short-period binary system then one would expect a long interval between outbursts (also see Heinke et al. 2010, for details). MAXI J1957+032 showed an increased activity in a year and half starting from June 2015. It showed outbursts once every few hundred days. *MAXI*/GSC nova alert system (Negoro et al. 2016a) has triggered on four outbursts from MAXI J1957+032. To search for other brightening episodes of MAXI J1957+032, we checked the publicly available *MAXI*-GSC light curves that include data before its first outburst (starting from August 2009), however, we did not find any flaring event prior to the its first X-ray outburst (outburst 1). Another possible cause of these outbursts is mass-transfer variations from the donor similar to that suggested for NGC 6440 X-2 (Heinke et al. 2010). If MAXI J1957+032 is a triple star system as proposed by Ravi (2017) one might expect to observe change in the orbital parameters, induced by the distant companion. However, this would need monitoring of future outbursts with more sensitive instruments like *XMM-Newton*, *Chandra*.

We have studied the spectra (using an absorbed power-law model) and we observed an anticorrelation between  $\Gamma$  and the total flux similar to what has been observed in the spectra of many other LMXBs (see e.g. Armas Padilla et al. 2011, 2013a; Reynolds et al. 2014). The spectra become softer as the source luminosity decreases (see also Kennea et al. 2015, 2016). After comparing the spectra of several LMXBs (NSs and BHs) Wijnands et al. (2015) reported that NS binary systems tend to be much softer compared to the BH systems at low luminosities. These authors found that in the case of NS X-ray binaries at low luminosities ( $10^{34}$ – $10^{35}$  erg s $^{-1}$ ) the value of  $\Gamma$  can be as high as 3. We explore different possible scenarios based on the assumption of different values of source distance of MAXI J1957+032. Fig. 3 shows how different distances affect our conclusions that we discuss in more detail here. If the distances of MAXI J1957+032 is as low as 0.5 kpc, our data lay closer to the track of BHs rather than a NS. In addition, at the lowest X-ray luminosities, the two data points of MAXI J1957+032 are significantly softer than the BH data points. We also note that

although the errors on  $\Gamma$  estimated for rest of the data points of MAXI J1957+032 are large, the trend clearly shows higher values of  $\Gamma$  than seen for the BH data points. Moreover, we note that Ravi (2017) proposed the source distance to be  $\sim 5$  kpc using the *R*-band magnitude for the MAXI J1957+032 counterpart. The authors also suggested that the *V*-band extinction and measured hydrogen column density are consistent with the proposed source distance.

For the source distance between 2 and 8 kpc, our data better follows the track of the NS LMXBs. At 4 kpc, MAXI J1957+032 falls in the regime of VFXTs that have maximum X-ray luminosities in outburst between  $10^{34}$  and  $10^{36}$  erg s $^{-1}$  (Wijnands et al. 2006). In that case, at around  $10^{35}$  erg s $^{-1}$  thermal emission from the NS surface might become visible and the spectrum should then be described with an absorbed *bbodyrad*+*power-law* model (see discussions in Wijnands et al. 2015). Therefore, we re-fitted the spectra by adding *bbodyrad* component. We found that on adding the *bbodyrad* component, the value of  $\chi^2$  decreased from 50 to 43 for the observation with ID 00033770001 and for the observation with ID 00033770020, the value of  $\chi^2$  decreased from 17 to 13 for 2 degrees of freedom (dof) less. Thus, the spectra of two observations (ID 00033770001 and 00033770020; MJDs: 57156.03 and 57663.35, respectively) showed a potential contribution of thermal emission in the form of blackbody. The best-fitting parameters are given in Table 3. However, we would like to mention that some of the fit parameters are not well constrained owing to the limited statistics. These observations corresponds to the green and fourth red point from the left (between  $10^{34}$  and  $10^{35}$  erg s $^{-1}$ ) of Fig. 3 at  $d = 4$  kpc. We observe that  $\Gamma$  is harder when a blackbody component is included.

This has also been seen in other VFXTs such as XTE J1709-267, IGR J17494-3030 which have both been proposed to be NSs based on their X-ray spectral properties (Armas Padilla, Wijnands & Degenaar 2013b; Degenaar, Wijnands & Miller 2013) (see also Wijnands et al. 2015, for a discussion). Moreover, the confirmed NS VFXT and AMXP IGR J17062-6143 also shows a thermal component in its spectrum (Degenaar et al. 2017). The obtained *kT* values and power law that we obtained for MAXI J1957+032 are consistent with studies of these systems. We note that in the BH LMXB and VFXT, namely, Swift J1357.2-0933 the high-quality *XMM-Newton* data also required a blackbody component but the contribution of the soft (thermal) component to the total flux is less than 10 per cent (Armas Padilla et al. 2013a), while we find that it contributes about 30-40 per cent of the total flux observed for MAXI J1957+032.

We also note that Armas Padilla et al. (2013b), Shidatsu et al. (2017), Degenaar et al. (2017) suggested the possible origin of the observed thermal emission in the X-ray spectra to be NS surface or the accretion disc. From Table 3, we observe that the obtained values of blackbody radius (2-3 kpc) are very similar to that have been found in other systems that are either proposed to be NS or are confirmed NS systems. Thus, the origin of the thermal emission can be a part of the NS.

There are systems even as far as 20-50 kpc (e.g. the BHC GS 1354-64 at a distance of about 25 kpc, NS MAXI J0556-332 at a distance  $\sim 46$  kpc see; Casares et al. 2004; Homan et al. 2014). However, we note that a very recent distance measurements performed by Gandhi et al. (2019) using data obtained with *Gaia* suggests that GS 1354-64 is a nearby system ( $\sim 0.6$  kpc). If we assume that MAXI J1957+032 is at about 8-10 kpc, then the highest flux levels we measured would correspond to a source accreting at  $\sim 10^{38}$  erg s $^{-1}$ . The softening we observed could

**Table 3.** Best-fitting parameters obtained after fitting the spectra (with an absorbed  $bbbodyrad+power-law$  model) of two observations that showed a contribution of thermal emission. Errors quoted are with 90 per cent confidence range.

Outburst	Obs ID	$N_{\text{H}}$ (free) $10^{21}$ atoms $\text{cm}^{-2}$	$kT_{\text{bb}}$ keV	$R_{\text{bb}}$ km/4 kpc	$\Gamma$	$N_{\text{PL}}$ photons $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$	Total unabsorbed flux (0.5–10) keV $10^{-11}$ erg $\text{cm}^{-2} \text{s}^{-1}$	PL flux/total flux	$\chi^2_{\nu}$ (dof)
Outburst 1	00033770001	$0.02^{+1.97}_{-0.02}$	$0.42^{+0.03}_{-0.05}$	$1.9 \pm 1.4$	$1.3 \pm 1.0$	$0.0009^{+0.0035}_{-0.0003}$	$1.72 \pm 0.05$	$0.57 \pm 0.04$	1.28 (34)
Outburst 4	00033770020	$0.0^{+0.8}_{-0.0}$	$0.41^{+0.02}_{-0.04}$	$3.4^{+2.0}_{-1.7}$	$0.42^{+1.17}_{-2.03}$	$0.0008^{+0.0023}_{-0.0007}$	$4.8 \pm 0.2$	$0.67 \pm 0.05$	0.71 (18)

*Note.*  $kT_{\text{bb}}$  is the blackbody temperature.  $R_{\text{bb}}$  is the blackbody radius in km. PL stands for power law.

correspond to the softening that it is sometimes seen in some BH and NS systems at high luminosities (see e.g. Remillard & McClintock 2006; Lin, Remillard & Homan 2007; Soleri et al. 2013; Fridriksson, Homan & Remillard 2015, and references therein; however note that these works generally use multicomponent models, making it difficult to make precise comparisons). We also note that the possibility of MAXI J1957+032 to be a distant source contradicts the measured value of extinction via optical observations and  $N_{\text{H}}$ . However, these measurements are based on several assumptions e.g. extinction does not significantly vary between active and quiescent states and if so, then with the current data it is not possible to conclusively state whether this system contains a NS or a BH.

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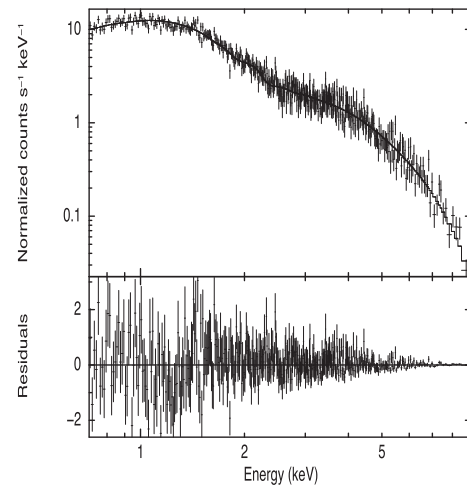
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## APPENDIX: BEST FIT WITH AN ABSORBED POWER LAW USING CHI-SQUARED STATISTICS

Here, we show the spectral fitting using an absorbed power-law model of the spectra with good statistics that allowed us to use  $\chi^2$  statistics to estimate the goodness of the fit. We grouped the obtained spectra using the `ftools` task `GRPPHA` to have at least 25 counts per bin.



**Figure A1.** This plot shows the residuals obtained using an absorbed power-law model to the *Swift* observation of MAXI J1957+032 made on 2016 September 29 during the onset of its brightest outburst in 2017 (outburst 4).

**Table A1.** Best-fitting parameters of MAXI J1957+032 obtained using the high statistics *Swift*-XRT data. Errors quoted are for the 90 percent confidence range. Energy range used is 0.5–10 keV.

Outburst	Obs ID	$N_{\text{H}}$ (free) ( $10^{21}$ atoms $\text{cm}^{-2}$ )	$\Gamma$	$N_{\text{PL}}$ (photons $\text{cm}^{-2}$ $\text{s}^{-1}$ $\text{keV}^{-1}$ ) at 1 keV	$\chi_{\nu}^2$ (dof)
Outburst 1	00033770001	$2.8 \pm 0.4$	$2.5 \pm 0.2$	$0.007 \pm 0.001$	1.38 (36)
Outburst 2	00033770009	$0.3 \pm 0.1$	$2.8 \pm 0.3$	$0.010 \pm 0.002$	0.87 (26)
	00033770017	$0.08 \pm 0.01$	$1.82 \pm 0.02$	$0.176 \pm 0.005$	0.96 (341)
Outburst 4	00033770018	$0.07 \pm 0.01$	$1.81 \pm 0.03$	$0.127 \pm 0.004$	0.89 (262)
	00033770019	$0.29 \pm 0.12$	$2.1 \pm 0.3$	$0.06 \pm 0.01$	0.75 (12)
	00033770020	$0.27 \pm 0.07$	$2.4 \pm 0.2$	$0.016 \pm 0.003$	0.85 (20)

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