Multi-epoch spectroscopy of the globular cluster black hole in NGC 4472

I. C. Shih,1⋆ T. J. Maccarone, 2 A. Kundu1 and S. E. Zepf1

1Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
2School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ

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ABSTRACT

We present a study of the X-ray spectral properties of the highly variable X-ray emitting black hole in a globular cluster in the elliptical galaxy NGC 4472. The X-ray Multiple Mirror–Newton (XMM–Newton) spectrum of the source in its bright epoch is well described by a multiple blackbody model with a characteristic temperature $kT_{\text{bb}} \approx 0.2$ keV. The spectrum of an archival Chandra observation of the source obtained 3.5 yr before the XMM data gives similar estimates for the blackbody parameters. We confirm that the fainter interval of the XMM–Newton observation has a spectrum that is consistent with the brighter epoch, except for an additional level of foreground absorption. We also consider other possible mechanisms for the variability. Based on the time-scale of the X-ray flux decline and the estimated size of the X-ray emission region, we argue that an eclipsing companion is highly unlikely. We find the most likely means of producing the absorption changes on the observed time-scale is through partial obscuration by a precessing warped accretion disc.

Key words: accretion, accretion disc – binaries: close – X-rays: binaries.

1 INTRODUCTION

Maccarone et al. (2007, hereafter MKZR07) identified a luminous ($4 \times 10^{39}$ erg s$^{-1}$) X-ray point source, XMMU 122939.7 +075333, in a globular cluster around the Virgo elliptical galaxy NGC 4472. Its count rate varied by a factor of 7 over a few hours during a 28-h observation made by the X-ray Multiple Mirror–Newton (XMM–Newton) satellite. This X-ray luminosity is well beyond the Eddington limit ($\sim 10^{38}$ erg s$^{-1}$) for accretion on to a neutron star. While accretion-powered pulsars are sometimes seen to exceed the Eddington limit for long stretches, low-magnetic field neutron stars can tolerate only very short excursions above the Eddington luminosity. High-magnetic field neutron stars of the former variety are not expected to exist in the old stellar environment of a globular cluster. The strong X-ray variability of this source rules out the possibility that the X-ray emission could come from multiple sources. In fact, variability is one of the only ways to show convincingly that an extragalactic globular cluster X-ray source is a black hole (e.g. Kalogera, King & Rasio 2004). Finally, the optical counterpart is spectroscopically confirmed to be a globular cluster with a redshift appropriate for a cluster in NGC 4472, eliminating the possibility that this source might be a background active galactic nuclei (AGN) (for details of the optical spectroscopy, see Zepf et al. 2007).

This object exhibits two remarkable features – its X-ray intensity shows very high amplitude variability, and its X-ray spectrum peaks at a lower X-ray energy than the spectra of typical X-ray sources in galaxies. The initial spectral analysis indicated that the variation is predominantly at lower energies (<0.7 keV) and hence it may be due to the increase of the absorption column in front of the X-ray source (MKZR07). While the softer X-ray spectrum might suggest an accreting intermediate-mass black hole (IMBH) in the object (Miller et al. 2003), as noted in MKZR07, other mechanisms are also capable of producing a soft X-ray spectrum at high luminosity from stellar-mass black holes, for example, accretion on to slim discs at very high accretion rates (Abramowicz et al. 1988; Begelman, King & Pringle 2006). Similar phenomenology has been seen in other systems in the past. For example, the Galactic black hole candidate V404 Cyg showed rapid variations in its foreground absorption level (Oosterbroek et al. 1997), while cool accretion discs have been found in a subset of ultraluminous X-ray sources (see Stobbart, Roberts & Wilms 2006).

In this paper, we use the XMM–Newton data in conjunction with archival ROSAT and Chandra observations to study further the X-ray spectrum and variability of XMMU 122939.7 +075333. We present the spectral analysis results in Section 3, extending the spectral analysis already presented in MKZR07. We show that the luminosity and spectrum observed in the Chandra data are similar to the bright interval of the XMM–Newton data, and confirm that the X-ray flux decline is most likely due to an increase in the absorption column. In Section 4, we use the observed decline time-scale of $\sim 13$ ks from the bright epoch to the faint epoch of the XMM–Newton observation to put constraints on the geometry of the foreground absorption.

*E-mail: shihs@pa.msu.edu

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2 OBSERVATIONS AND DATA REDUCTION

2.1 XMM–Newton

NGC 4472 was observed for 1.1 × 10^5 s by the XMM–Newton on 2004 January 1. All three European Photon Imaging cameras (EPIC), including two Metal Oxide Semiconductor (MOS) and pn, were simultaneously operating with full frame mode and thin filter. The data analysis procedures are essentially the same as those used in MKZ807, but we outline the analysis procedure in the interest of completeness. We use standard procedures to analyse the XMM–Newton data. The observation date files (ODF) were reprocessed using the latest version of Science Analysis Software (SAS) v.7.0 and Current Calibration Files (CCF) to create an updated calibrated and concatenated event lists. To generate science products such as images, light curves and spectra, a set of selection criteria were applied to the concatenated event files (Loiseau 2006). High background flares interval is filtered out if the count rate at the pattern zero is higher than 0.35 and 1.0 counts/s in the MOS and the pn cameras, respectively. As higher number patterns are not created by X-rays or are highly contaminated by cosmic rays, only event patterns 1–12 and 0–4 are selected for the MOS and the pn camera, respectively. FLAG = 0 omits parts of the detector area like border pixels, columns with higher offsets, etc., and XMMEA_EP, XMMEA_EM are used to filter out artefact events. The good time intervals (GTIs) of the bright and faint parts of the data are defined by 0.015 counts/s. For spectral analysis, the created spectra were regrouped into bins of at least 20 photons.

2.2 Chandra

NGC 4472 was observed by Chandra ACIS-S on 2000 June 12 for ∼40,000 s. The data were obtained from the Chandra Data Archive and reprocessed to generate improved calibrated level = 2 event files using the Chandra Interactive Analysis of Observations (CIAO) software package v.3.3 (Fruscione 2006).

The globular cluster black hole source is located on the ACIS-S2 (CCD 6). After the time intervals with background flares were filtered, we obtained a total exposure time of ∼38 ks. An examination of the light curve shows that the X-ray intensity of the object is steadily bright. The CIAO dmextract task is used to create source and background spectra, a circular background region is selected in the same CCD where no significant X-ray source is presented. The mkacisrmf and mkarf tasks create the instrument models of RMF and ARF, respectively. Finally, in order to have good statistics, the source and background spectra are regrouped to have a minimum number of 15 and 20 counts per new channel, respectively.

2.3 ROSAT

ROSAT observed NGC 4472 for about 27,000 s of live time in 1994 June and July. The quality of spectra from the ROSAT high-resolution imager is quite poor, so these data cannot be used for spectral fitting to test models. XMUMU 122939.7+075333 was already reported as an intermediate-luminosity X-ray object (Colbert & Ptak 2002) – it is I XO 60 in their catalogue. They estimated a source luminosity of 10^{39} erg s^{-1} from 2–10 keV, based on an assumed spectrum of a power law with photon index $\Gamma = 1.7$, where $L_{\text{X}} \propto E^{-\Gamma}$ – a considerably harder spectrum than what we have fit from the XMM–Newton data during the bright epoch. The source count rate of about 4 × 10^{-3} counts/s is consistent within a factor of a few of both the fainter and brighter states seen from XMUMU 122939.7+075333 with XMM – because a harder spectrum was assumed by Colbert & Ptak (2002) than what we have found, they infer a higher luminosity for the source than what we have found despite the fact that the XMM–Newton spectrum, folded through pimms for ROSAT, gives a higher count rate than what the ROSAT High Resolution Imager saw. The ROSAT data are useful for helping to demonstrate that the source has likely been on as a bright source for at least the 9 yr period between the ROSAT and XMM observations, but are not sufficient for helping to determine whether the bright or faint part of the XMM–Newton observation is typical of the source’s behaviour.

3 SPECTRAL ANALYSIS

The primary goals of the analysis are to investigate the nature of the flux decline in the XMM–Newton observation, and to compare the XMM and Chandra spectra. In MKZ807, a restricted set of spectral fits were presented, and fits were presented only to the XMM–Newton data. It was shown there that the spectrum extracted from the bright part of the XMM–Newton light curve is consistent with the multiple blackbody disc model [often referred to as a multicolour disc (MCD)] which models a multiple blackbody from an accretion disc, parametrized in term of the temperature (keV) at inner disc radius (Mitsuda et al. 1984), with foreground Galactic absorption only. The spectrum during the faint part of the observation was found to be consistent with the same underlying model, but with a higher value for the absorption. Here, we present a more detailed discussion, considering alternative models for the spectrum, and also fit the Chandra spectrum. The effect of Galactic absorption was taken into account by using phabs in xspec (Arnaud 1996). The Galactic absorption at the direction of the object is $N_H \approx 1.6 \times 10^{20} \text{cm}^{-2}$ which was frozen in most of the fits.

First, the spectra of the Chandra data and the XMM observations in both the bright and faint epoch were fitted with an absorbed MCD model. The fitting result is marginally acceptable for the XMM–Newton spectra but is statistically a poor fit to the Chandra spectrum. Two notable features, however, can be drawn from the result. First, the peak temperature ($kT_\text{in} \approx 0.2 \text{ keV}$) of all the spectra is significantly lower than typical X-ray binaries ($kT_\text{in} \approx 1.0 \text{ keV}$). Secondly, there appears to be a ‘hard tail” in the >1 keV band indicating that an additional second component may be required.

Next, we fit the X-ray spectra (0.1–10 keV) with a MCD plus power-law model, as is often done for low-mass X-ray binaries. It shows a great improvement for the Chandra spectrum and a slight improvement for the bright epoch XMM–Newton one. However, it is worth mentioning that the Chandra data are taken far off axis, where the response matrix is not well calibrated, so that the difference should be taken cautiously. To verify that the power-law component is really required for the bright epoch XMM–Newton spectrum, we performed the f-test by comparing the values of $\chi^2$ and numbers of degrees of freedom (d.o.f.) from both models. The null hypothesis probability for adding the power-law component is ≈10 per cent, indicating that the evidence for the extra component is suggestive but not conclusive. For the faint epoch XMM–Newton data, the parameters of the additional component, i.e. $\Gamma$, are poorly defined because of very large error contours (<68 per cent confidence level), and it is most likely due to few data points in the >1 keV band.

The radial temperature dependence of the MCD model follows a power-law form $kT \propto R^{-\rho}$, where $\rho = 0.75$. The peak temperature refers to the temperature at the inner accretion disc radius. The
characteristic temperature derived from the ULXs’ (Ultraluminous X-ray Source) spectra has led some to suggest that an IMBH is contained in these sources (Miller et al. 2003), since more massive black holes will have lower inner disc temperatures at a given luminosity, under the assumptions that go into the MCD model (Shakura & Sunyaev 1973). On the other hand, an $\rho$-free multiple blackbody disc model, assuming super-Eddington accretion onto a stellar-mass black hole (i.e. slim disc), can also explain the same spectra successfully (i.e. Vierdayanti et al. 2006). When the source enters the ‘slim disc’ or optically thick advection-dominated accretion disc state, $\rho$ reduces to $\approx 0.5$. Thus, we tried to fit the spectra with DISKBB model in xspec. For the bright epoch XMM–Newton and for the Chandra data, the parameter values for this model converge to values quite similar to those obtained from the MCD model. For the faint epoch XMM–Newton data, the model produces a good fit without variation of the absorption, but the value of $\rho$ required is 1.0. This is indicative of an accretion disc with a steeper temperature gradient than in a standard Shakura–Sunyaev accretion disc, a result with no clear physical interpretation.

We then consider that the X-ray flux decline may be due to an increase of absorption column $N_f$ as suggested in MKZR07. An absorbed MCD model with frozen $kT_\text{in}$ and normalization derived from the bright epoch XMM–Newton spectrum was fitted to the faint epoch XMM–Newton one. The result clearly shows that the absorption column increases by an order of magnitude from bright to faint epochs, and that the fit is acceptable, despite having only one free parameter, since the other parameters were specified by the fit to the bright epoch.

Conclusively, the absorbed MCD model is our best effort to describe the XMM–Newton spectra in the $<1$ keV band. For bright epoch XMM–Newton, the $F$-test suggests that a second component might be necessary to the spectrum in the $>1$ keV band, but the relatively low single-to-noise ratio data in this energy band prevent further constraining of the parameters.

Table 1 lists details of spectral fitting results discussed above, and Fig. 1 plots two epochs of the XMM–Newton spectra and the best fit of the single absorbed MCD model.

### 3.1 X-ray colour

X-ray colour is a useful tool to reveal spectral variability in X-ray binaries (see e.g. Lewin & van der Klis 2006). We created X-ray light curves of the EPIC-pn camera in three energy ranges: 0.2–0.5, 0.5–2.0 and 2.0–10.0 keV (see Fig. 2). The X-ray flux decline is clearest in the soft energy (i.e below 2 keV) as already indicated by the spectral differences between the bright and faint epochs. In the high-energy band (2.0–10.0 keV), the source was scarcely detectable and has no obvious variation throughout the observation.

### 4 DISCUSSION

A few key results come from the spectral fitting.

(i) It suggests that bright epoch XMM–Newton and Chandra spectra can generally be described by a conventional MCD model with similar characteristic temperature $kT_\text{in}$. The X-ray state of the object during the Chandra observation is consistent with the bright epoch XMM–Newton.

(ii) The slim disc-like $\rho$-free model fails to be an alternative interpretation of the spectra in both observations, especially in the brighter epochs.

(iii) The fitting result and X-ray colour do not support the scenario that the X-ray decline is caused by an X-ray state change.

#### Table 1. Spectral fitting results. Numbers in parenthesis emphasize that the parameters are frozen during the fitting, and all errors quoted in the table are above 90 per cent confidence level. The error contours may be slightly underestimated for the fits where $\chi^2_r > 1$. All the fits have a null hypothesis probability of more than 1 per cent except the Chandra fit, for which there are likely to be significant systematic errors unaccounted for, since the spectrum is taken far off axis. If $\chi^2_r > 2$, then xspec does not provide error estimation.

| Parameter | XMM bright | Chandra | XMM\(^a\) faint | XMM\(^b\) faint |
|-----------|------------|---------|----------------|----------------|
| $N_f$\(^c\) | (0.016) | (0.016) | (0.016) | 0.35 ± 0.04 |
| $kT_\text{in}$\(^d\) | 0.16 ± 0.01 | 0.15 | 0.29 ± 0.07 (0.16) |
| Norm.\(^e\) | 10.08 ± 5.77 | 16.92 | 0.07 ± 0.05 (10.07) |
| $\chi^2$/d.o.f. \(^f\) | 44.10/26 | 81.60/22 | 13.04/18 | 18.25/19 |
| DISKBB+PL\(^g\) | | | |
| $N_f$\(^c\) | (0.016) | (0.016) | (0.016) | |
| $kT_\text{in}$\(^d\) | 0.16 ± 0.01 | 0.11 ± 0.01 | 0.29 ± 0.19 (0.19) |
| Norm.\(^e\) | 11.24 ± 7.43 | 65.33 ± 14.55 \(^{32}\) | 0.07 ± 0.06 (0.06) |
| $\Gamma$ | 0.34 ± 0.91 | 1.61 ± 0.42 \(^{21}\) | 1.45* |
| Norm.\(^h\) | 7.86 ± 7.75 | 52 ± 30 \(^{24}\) | 1.60* |
| $\chi^2$/d.o.f. | 36.07/24 | 29.64/20 | 12.98/16 |

\(^{a}\)Absorption column is frozen.

\(^{b}\)Absorption column is free to vary.

\(^{c}\)Multiple blackbody disc (MCD) model.

\(^{d}\)MCD plus power-law model.

\(^{e}\)Absorption column in unit of $10^{22}$ atoms cm$^{-2}$.

\(^{f}\)Inner accretion disc temperature in unit of keV.

\(^{g}\)[($R_{\text{in}}$)($D$/10 kpc)]$^2$ cos$\theta$, where $R_{\text{in}}$ is the inner disc radius, $D$ is the distance to the source and $\theta$ is the disc declination angle

\(^{h}\)Photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$ at 1 keV in unit of 10$^{-7}$.

\(\ast\)See the text in Section 3.

X-ray transients, many of which are black hole X-ray binaries, exhibit distinct X-ray spectral behaviour at different X-ray flux. In the high state, the soft, thermal component dominates the spectrum, while in the low state, this component reduces to less than 20 per cent and the hard component becomes dominant $>80$ per cent (see Remillard & McClintock 2006). We did not see any such qualitative changes in the spectrum between the bright and the faint epochs. Additionally, these state transitions are not typically seen to take place in a few hours in stellar-mass black holes, but rather over days or weeks. Because these transitions typically happen at 2 per cent of the Eddington luminosity (Maccarone 2003), the black hole mass would have to be about 1000 M$_\odot$ for the observed spectral variability to be soft-to-hard state transition, and the increase in mass by a factor of 100 would be expected to lead to an increase in characteristic variability time-scale by a factor of 100. For these reasons, we can be confident that the observed spectral variability is due to a subtler cause than spectral state transitions.

(iv) We consider the possibility that the X-ray decline is an actual eclipse, and the faint epoch XMM–Newton data represent the residual emission coming from other sources within the globular cluster. This spectrum is soft ($kT \approx 0.29$ keV) and its X-ray luminosity in the 0.2–10 keV band is $\lesssim 10^{39}$ erg s$^{-1}$. If the residual emission is from a collection of LMXBs, then these LMXBs will be much softer than the typical galactic LMXB. On the other hand, it is not bright enough to be classified as an ULX ($\gtrsim 10^{39}$ erg s$^{-1}$, see Fabbiano 2006). No currently known stellar-type X-ray sources have such exotic spectral characteristics. Furthermore, the residual emission...
Figure 1. *XMM–Newton* EPIC pn spectra and $\Delta \chi^2$ residuals for an absorbed MCD model fit for bright (solid circle, solid line) and faint (open diamond circle, dashed line) epochs. The *Chandra* spectrum (open triangle) is also overlapped to demonstrate its likeness to the bright epoch *XMM–Newton* data.

Figure 2. The *XMM–Newton* light curves in three colours: 0.2–0.5, 0.5–2.0 and 2.0–10.0 keV. The integration time is 600 s and dash lines in each panels emphasize the zero counts/s level.

of eclipsing X-ray binaries, such as Her X-1 and extragalactic X-ray binary M33 X-7 (Day, Tennant & Fabian 1988; Pietsch et al. 2006), is at most $\sim$10 per cent of the uneclipsed flux, and can be explained by reprocessing of primary photons from the compact X-ray source in an extended accretion disc corona or by scattering in the companion atmosphere/stellar wind. On the other hand, at flux minimum, the black hole candidate is still luminous, and appears to be only absorbed, rather than to be scattered light. As a result, we suggest that the eclipse scenario is not a suitable explanation.

4.1 Nature of the decline

An increasing absorption column is thus a more consistent and simpler explanation of the X-ray decline so far. A few key possibilities
for the origin of the excess absorption are a stellar wind from the donor star (although this should reveal sinusoidal modulation of $N_{\text{H}}$ around the entire orbit, contrary to observations), a grazing eclipse by the donor star, a disc wind from the accretion disc around the black hole or a grazing eclipse by a precessing, warped accretion disc. A strong diagnostic of the possible cause is the time-scale of the X-ray decline. To obtain the time-scale $\Delta t$, the light curve in the 0.2–2.0 keV band was fitted by three straight line segments to find out two vertices; first ($t_{1\text{st}}$) and secondly ($t_{2\text{nd}}$) contacts (here we just borrow the terminology of eclipse), thus $\Delta t = t_{\text{secondly}} - t_{\text{1st}} \sim 12\,600 \pm 1\,600$ s.

First, we test if this is an occultation by a Roche lobe filling secondary star by calculating the possible orbital period $P$ depending on $\Delta t$ and the size of the X-ray emission region $D = 2R_{\odot} \approx 10\,000$ km derived from the MCD model. Assuming a circular orbit as the simplest case, the ingress time of $\Delta t$ that the secondary star crossing over the linear dimension of the X-ray source $D$ is proportional to the binary separation $a$ and the orbital period $P$,

\[
\frac{2\pi a}{P} = \frac{D}{\Delta t}
\]

then combining with the Kepler's third law, we derive the equation for the orbital period:

\[
P = 2\pi GM \left( \frac{\Delta t}{D} \right)^{3/2},
\]

where $M$ is the total mass of the binary system and $G$ is gravitational constant.

For a X-ray binary containing a stellar-mass black hole, $M \approx 10\,M_{\odot}$, much of the total mass of the binary can be attributed to the black hole. From equation (2) above, it is clear that this leads to an unphysically long orbital period of $\sim 10^4$ h. This not only refers to an unrealistic size for a Roche lobe overflowing binary system (Eggleton 1983), but also means that the size of semimajor axis of the orbit is at a similar scale to the tidal radius of typical globular clusters. Increasing the mass of the black hole to say an IMBH compounds the problem by increasing the inferred orbital period.

Therefore, an eclipse by the donor star cannot explain the change in flux.

4.2 Precessing warped accretion disc?

From both the observational and theoretical viewpoints, it is possible that the X-ray source can be quasi-periodically obscured by a tilted accretion disc precessing around it roughly on a long period $P_{\text{long}}$, such as Her X-1, SS 433 and LMC X-4 (see White, Nagase & Parmetr 1995). Accretion discs can be tilted by the tidal force of the companion star [i.e. in Cataclysmic Variables (CVs), Whitehurst 1988], or warped if the central radiation source exerts non-axisymmetric radiation pressure on an initially flat disc, and the warping is driven in the outer part of accretion disc (i.e. in X-ray binaries Pringle 1996). The precession period of a warped accretion disc is much longer than the orbital period of the binary system (Wijers & Pringle 1999), e.g. the orbital period of Cyg X-1 is 5.6 d and its precession period is 294 d (Priedhorsky, Terrell & Holt 1983). It is clear that XMMU 122939.7+075333 generally fulfills the conditions required for a precessing warped accretion disc – as one of the brightest known X-ray binaries, its X-ray luminosity is sufficiently strong to induce warping. Additionally, given its long outburst, it is likely to have a long orbital period, and long period systems are more susceptible to the irradiation-driven warping than short-period systems.

Next consider whether the precession period that would be required to produce the observed results are reasonable. Applying equation (1), and solving for $P$, we estimate that a $\sim 90$-d precession period would be inferred for a warp located at about $10^{11}$ cm from the black hole (a reasonable distance if we assume an orbital period of $\sim 10^5$ d, also a stellar-mass black hole). This is well in the range of precession periods from the currently known X-ray binaries (see Ogilvie & Dubus 2001). While the ratio of precession period to orbital period is a bit lower than that typically seen from X-ray binaries, the precession period is expected to be shorter for higher X-ray luminosities (Maloney & Begelman 1997; Wijers & Pringle 1999), so again, the data are, at the very least, consistent with this picture’s predictions. We note that if the black hole is of intermediate mass, the characteristic radius will be considerably larger than $10^{11}$ cm, requiring a similarly longer precession period.

A few alternative hypotheses exist. For example, the change in absorption could come from an outflow generated by super-Eddington accretion (e.g. Proga, Stone & Drew 1998; Begelman, King & Pringle 2006). If the wind itself is variable, then different column densities could be in front of the accretor at different times. This would be a possibility in either the case where the system shows long outbursts due to a highly evolved donor star, or where the system is truly persistent, due to accretion from a white dwarf with a sufficiently short orbital period that the entire accretion disc is ionized. However, it would require some degree of fine tuning for the spectrum to be consistent with only foreground absorption during the part of the observation when the source is bright, while changing by a factor of about 10 when the source becomes fainter.

5 CONCLUSION

We analyse the X-ray spectrum of the black hole X-ray binary candidate XMMU 122939.7+075333 from the XMM–Newton and Chandra observations. The variation in the XMM–Newton observation is dramatic but the X-ray colour lacks the spectral signature usually seen in X-ray state change.

The event can simply be explained by an increase in an absorption column, as MKZR07 has mentioned earlier. The spectral properties of the Chandra data are similar to those of the bright epoch XMM–Newton data, suggesting it is the ‘normal’ state for the object. According to the time-scale of the variation in the X-ray luminosity during the XMM–Newton observation, we suggest that a precessing warped accretion disc is the source to obscure the central X-ray emission region.

As a warped disc surface can tilt off from the orbital plane for up to 40° (Wijers & Pringle 1999; Ogilvie & Dubus 2001), an observer must be at a high enough inclination angle (>50°–70°) to see the warped accretion disc crossing his line of sight to the central X-ray source. If the object has a rather stable precessing warped accretion disc, we should be able to see more similar variation events by carefully programming further observations to the time-scale of the precession period. The most plausible alternative model is that a disc wind from the accretion disc is varying. A monitoring campaign on this source could discriminate between the two possibilities, since the variations in $N_{\text{H}}$ should follow a regular pattern if they are due to precession of the accretion disc, and should be aperiodic, rather than quasi-periodic, if they are due to a variable disc wind.

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