XMM-Newton Observations of TW PIC incomparison with the Archival SWIFT and RXTE data

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Abstract

We present ∼ 40 ks (2 observations) of *XMM-Newton* data of the magnetic cataclysmic variable candidate TW Pic, suggested as an Intermediate Polar (IP) at a low inclination angle. The XMM EPIC spectrum (pn+MOS) can be best modeled by an absorption for interstellar medium (tbabs) along with partial covering absorber (pcfabs) and a multi-temperature plasma emission component (cevmkl). In addition, we find two Gaussian lines at 6.4 and 6.7 keV. We find intrinsic absorption differences between two observations with a difference of 54 days at 90% confidence level. If the interstellar absorption in the direction of the source is assumed (Willingale et al. 2013 or Dickey and Lockman 1990), there is soft excess which may be modeled with a blackbody emission $kT_{BB} \sim 20$ eV. We utilize the serendipitous SWIFT observations obtained ∼ 60 days prior to the first *XMM-Newton* observation and an earlier RXTE observation in 1999 for comparisons on energy and power spectral analysis.

TW Pic

TW Pic is known as 14th magnitude cataclysmic variable suggested as an Intermediate Polar (IP), but unconfiremd in the X-rays. Identification of several periodic oscillations in the optical band hint it as an IP (Mouchet et al 1991). The optical photometric study of TW Pic by Patterson and Moulden (1993) revealed an orbital period of 6.06 hours with the ephemeris HJD = 2448207.785(14) + 0.2525(12)E . The system is located at a distance of ∼ 617 pc (Ozdonmez and Bilir 2015) from the Earth.

XMM-Newton Observations

TW Pic was observed using the *XMM-Newton* on 2 March, 2008 (Observation ID (OBS-ID): 0500970101) with a 47 ksec of exposure time and on 25 April, 2008 (Observation ID (OBS-ID): 0500970301) with a 18 ksec of exposure time. The standard SAS analysis tasks SAS, version 14.0, were used to extract three light curves from a single data set for the three X-ray CCDs with a bin time of 0.1 s. The EPIC data were cleaned (time filtering) for any superfluous flarings detected in the background. The light curves of the two *XMM-Newton* observations are in Figure 1. To study of the variation of the X-ray light curves over the orbital period, we used FTOOLS analysis tasks folded them over the orbital period (Fig. 2). For TW Pic, we used the orbital period ephemerides of 2448207.785(14) + 0.2525(12)E (HJD).

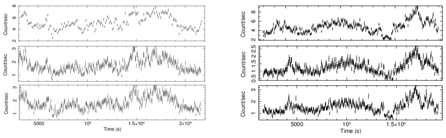

Figure 1: The *XMM-Newton* light curve of TW Pic for the first observation (left) and for the second observation (right), extracted from EPIC pn (top), MOS1 (middle), and MOS2 (bottom) CCDs with the bin size of 100 s for pn and 55 s for MOS data.

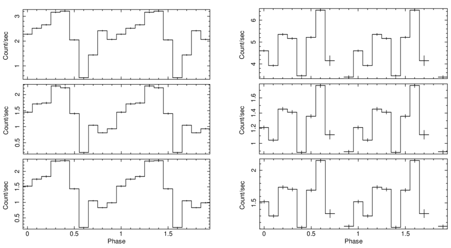

Figure 2: The *XMM-Newton* light curves of TW Pic folded over the orbital period of 21816 s for the first observation (left) and for the second observation (right) and from top to bottom: EPIC pn, MOS1, and MOS2, respectively.

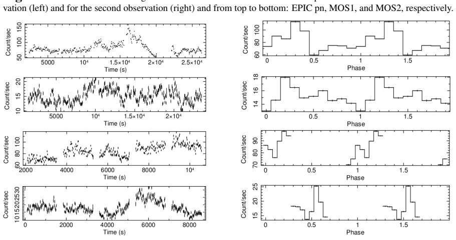

Figure 3: Light curves (left panels) and folded light curves (right panels) in two energy filters (B and UVM2) for two different observations. First and second row panels belong to first observation in filter B and UVM2 respectively. Third and forth row panels belong to second observation in filters B and UVM2.The binning time is 50 s in both bands and the orbital period of 21816 s.

The OM data of TW Pic was collected in two photometric bands using first the B filter, centred at 4500 Å and then the UVM2 filter, centered at 2310 Å. The OM time series were obtained using SAS task, *OMFCHAIN*, with a bin time of 0.5 s and rebinned for further analysis. We simultaneously fitted all EPIC spectra (pn + MOS) using a composite model of absorption for interstellar medium (*tbabs*) with a partial covering absorber (*pcfabs*) including a multitemperature plasma emission component (*CEVMKL*). In addition, we compared this fit including an extra blackbody emission component for both observations. The spectra are best modeled with two Gaussian emission lines at 6.4 keV and 6.7 keV. The system has a maximum plasma temperature of ∼ 34 keV with an X-ray luminosity around 1.6×10^{33} ergs $^{-1}$ at an accretion rate of $\sim 4\times10^{-10}$ $M_\odot yr^{-1}$ for the first observation and a maximum plasma temperature of ∼ 27 keV with an X-ray luminosity around 1.33×10^{33} ergs $^{-1}$ at an accretion rate of $\sim 3.1\times10^{-10}$ $M_\odot yr^{-1}$ for the second observation.

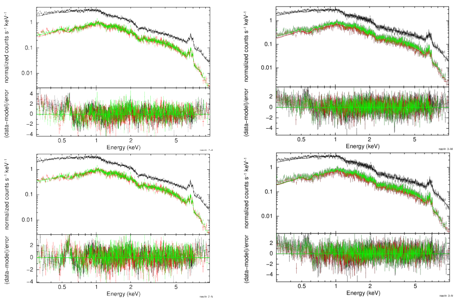

Figure 4: The top panels show the combined EPIC pn, MOS1 and MOS2 spectra of TW Pic fitted with the composite model (tbabs*pcfabs*(CEVMKL+Gaussian+Gaussian)) and with an additional blackbody model component (tbabs*pcfabs*(CEVMKL+bbody+Gaussian+Gaussian)) on the bottom. The left panels correspond to the first observation and the right panels correspond to the second observation. The lower panels show the residuals in standard deviations.

Table 1: Spectral Parameters of the Fits to the TW Pic Spectra

Model	Component	1^{st} obs.*1	1^{st} obs.*2	2^{nd} obs.*3	2^{nd} obs.*4
tbabs	$N_H(\times10^{22}cm^{-2})$	0.05 (Fixed)	0.05	0.05	0.05
pcfabs	$N_H(\times10^{22}cm^{-2})$	$3.59^{+0.18}_{-0.17}$	$3.84^{+0.211}_{-0.196}$	$5.13^{+0.585}_{-0.497}$	$4.78^{+0.48}_{-0.45}$
	CoverFrac	$0.36^{+0.003}_{-0.003}$	$0.35^{+0.003}_{-0.003}$	$0.374^{+0.020}_{-0.019}$	$0.38^{+0.02}_{-0.02}$
cevmkl	kT_{max} (keV)	$33.37^{+0.69}_{-0.68}$	$34.18^{+0.632}_{-0.728}$	$29.84^{+1.973}_{-1.768}$	$27.16^{+2.11}_{-1.50}$
	K_{CEVMKL} $(\times10^{-2})$	$3.41^{+0.01}_{-0.01}$	$3.43^{+0.015}_{-0.015}$	$3.04^{+0.06}_{-0.06}$	$3.14^{+0.06}_{-0.06}$
bbody	$kT\ (eV)$	$19.9^{+0.27}_{-0.32}$	N/A	$19.6^{+0.28}_{-0.33}$	N/A
	K_{bbody}	0.042 (Fixed)	0.042	0.042	0.042
Gaussian1(6.4keV)	$K_{Gaussian}(\times10^{-5})$	$3.05^{+0.43}_{-0.43}$	$3.01^{+0.43}_{-0.429}$	$2.89^{+0.427}_{-0.428}$	$2.55^{+0.40}_{-0.40}$
Gaussian2(6.7keV)	$K_{Gaussian}$ $(\times10^{-5})$	$3.16^{+0.52}_{-0.52}$	$3.17^{+0.526}_{-0.527}$	$2.19^{+0.593}_{-0.577}$	$2.59^{+0.95}_{-0.94}$
χ^2_ν (dof)		1.27 (1612)	1.35 (1605)	1.24 (1963)	1.13 (1962)

Notes. *1 The composite model with *bbody* for the first observation. *2 The composite model without the *bbody* model for the first observation. *3 The composite model with *bbody* for the second observation. *4 The composite model without *bbody* model for the second observation. N_H is the absorbing neutral hydrogen column density for the *tbabs* and *pcfabs* models, kT_{max} is the maximum temperature for the *CEVMKL* model, and CoverFrac is the covering fraction of the absorber. K_{CEVMKL} is the normalization for the CEVMKL model. K_{bbody} $(\frac{L_{39}}{D^2_{10}})$, where L_{39} is the source luminosity in units of 10^{39} erg^{-1}, D_{10} is the distance to the source in units of 10 kpc. $K_{Gaussian}$ is the total photons cm^{-2} s^{-1}in the line. All errors are given at 90% confidence limit for a single parameter. Also, *tbabs* N_H and bbody norm were fixed at 0.05 and 0.042, respectively, to improve the quality of the fit.

Swift XRT Observations

We used five different observations of *Swift* XRT to extract the spectrum of TW Pic. The observations were operated on 07 April 2008 (Observation ID (OBS-ID): 0502640201) with 51 ksec of exposure time. The observations were done on 31 December 2007 (OBSID: 00037120003), 13 November 2007 (00037120001), 25 December 2007 (00037120002), 19 December 2015 (00034215002) and again 19 December 2015 (00034215001).

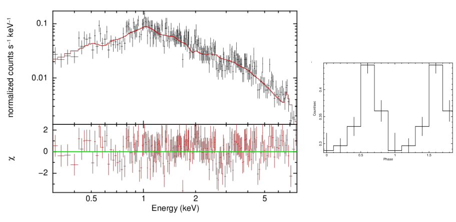

Figure 5: Left: The top panel shows the Swift-XRT spectrum of TW Pic fitted with the composite model TBABS*PCFABS*(CEVMKL). The lower panel shows the residuals in standard deviations. Right: The XRT light curve of TW Pic folded over the orbital period of 21816 s using the ephemeris HJD = 2448207.785(14) + 0.2525(12)E.

Using all the archival observations, we prepared an XRT spectrum using XSELECT version 2.4b and standard extraction procedures as outline in the webpage (http://www. swift.ac.uk/analysis/xrt/). The spectrum of TW Pic was fitted with an absorption model *tbabs* for the interstellar medium set to 5×10^{20} cm $^{-2}$ (Willingale et al. 2013) and a partial covering absorber model *pcfabs* for the intrinsic absorption together with a multi-temperature plasma emission model *CEVMKL*. We did not include any *Gaussian* used for the modeling of *XMM-Newton* data because the XRT spectrum did not indicate any line from the source. The fitted spectrum is presented in Fig. 5 and the spectral parameters are displayed in Table 2. TW Pic has a maximum plasma temperature of ∼ 27 keV with an X-ray luminosity around 5.23×10^{34} ergs $^{-1}$ at an accretion rate of $\sim 1.25\times10^{-8}$ $M_\odot yr^{-1}$. The standard XSELECT light curve extraction procedures were used to extract the light curve of the source with a bin time of 2.6 s and an energy range of 0.3 - 10.0 keV. To study of the variation of the X-ray light curve, we folded it over the orbital period of the system using 5 phase bin. The FTOOLS task *efold* was used to create the folded light curve (Fig. 5).

Model	Component	Value
tbabs	$N_H(\times10^{22}cm^{-2})$	0.05
pcfabs	$N_H(\times10^{22}cm^{-2})$	$0.216^{+0.0274}_{-0.0242}$
	CoverFrac	$0.755^{+0.0412}_{-0.0412}$
cevmkl	kT_{max} (keV)	$26.57^{+4.05}_{-3.69}$
	K_{CEVMKL}	$0.926^{+0.028}_{-0.028}$
χ^2_ν (dof)		1.11 (225)

Table 2: Spectral parameters derived for the XRT observation of TW Pic in the 0.3-8 keV energy range.

RXTE Observations

We used Rossi X-ray Timing Explorer (*RXTE*; Bradt, Rothschild & Swank 1993) archival data of TW Pic obtained in 1999 May 7 with an exposure of 20.3 ksec for comparison. The data were obtained by the Proportional Counter Array (PCA; Jahoda et al. 1996)13 instrument aboard *RXTE*. The PCA units are sensitive in the range 2-60 keV, the energy resolution is 17% at 5 keV, and the time resolution capability varies depending on the data files in the science array or science event format. RXTE/PCA background was estimated with help of the model appropriate for faint sources. Light curves and spectra were extracted using standard procedures (i.e., SAEXTRCT) from data mainly in the entire PCA energy band using "Standard 1" data with 0.125 sec time resolution (has no energy resolution) and "Standard 2" data with 16 sec resolution that also has 129 energy channels to create a spectrum. All light curves were background subtracted for the analysis. We converted all event arrival times to the solar system barycenter. All data were analyzed using HEASOFT version 6.13 and tasks/software within.

Figure 6 shows the spectrum obatined from the *RXTE* Standard 2 data fitted with a composite model of *tbabs×pcfabs×(CEVMKL+ Gauss)* similar to the other two observatory data analysis. *tbabs* is set to 5×10^{20} cm^{-2} as determined from interstellar hydrogen absorption in the line of sight (Willingale et al. 2013). The fits indicate a kT_{max} in a range 19-31 keV with a normalization in a range 0.040-0.052. The partial covering absorber is (2.5-7.0)$\times10^{22}$ cm^{-2} with a covering fraction of about 70%. *RXTE* detects a line at 6.4 keV as the best fit results indicate at a normalization (2.5-11)$\times10^{-5}$ phot cm^{-2} s^{-1}. These ranges correspond to 90% confidence level and most *XMM-Newton* results are within these ranges. The unabsorbed X-ray flux in the 1.5-80 keV range is 5.4×10^{-11} erg cm^{-2} s^{-1} translating to a luminosity of 2.5×10^{33} erg s^{-1} at the source distance , again consistent with *XMM-Newton* results.

Figure 6 right hand panel shows the X-ray light curve (see Figure 7 left hand panel) folded over the optical ephemerides used for the *XMM-Newton* and *Swift* analysis. The recovered orbital modulation is similar to the first observation of *XMM-Newton* and *Swift* data. Figure 7 right hand panel shows averaged power spectrum (PDS) in the units of rms^2 following the Miyamoto normalization (see Miyamoto et al. 1991). The PDS indicates a flat noise component originating (as expected) from the optically thick accretion disk. However, we detect a break in the PDS at 3±1.5 mHz where the optically thick disk subsides and the inner regions of the disk have a different type of flow as in a hot flow. This was discussed and shown for several dwarf nova systems and the break frequency we detect is very similar to nonmagnetic CVs rather than magnetic CVs (see Balman & Revnivtsev 2012, Balmnan 2015, see review in Balman 2016).

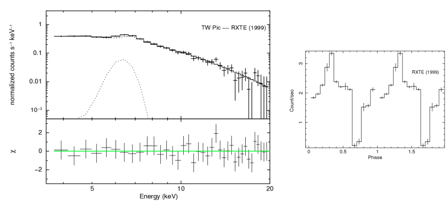

Figure 6: *RXTE* standard 2 data spectrum of TW Pic fitted with the composite model*tbabs×pcfabs×*(CEVMKL+ Gauss) is shown on the left hand panel. The right hand panel is the *RXTE* light curve obtained from the standard 2 data folded over the binary period.

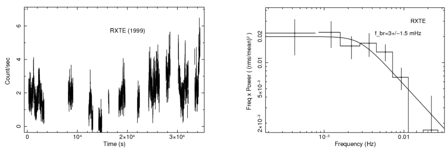

Figure 7: Left: *RXTE* light curve of TW Pic (standard2 data) Right: Stacked and averaged (9 PDS averaged) power spectrum of *RXTE* standard2 data.

Discussion

- The Spectral analysis of the source using all three X-ray observatories, *XMM-Newton*, *Swift* and *RXTE* suggests that TW Pic is consistent in *XMM-Newton* and *RXTE* with an X-ray luminosity (unabsorbed) in a range 1-3$\times10^{33}$ and an accretion rate around 3-5$\times10^{-10}$ $M_\odot yr^{-1}$. However, *Swift* detects this source at an X-ray luminosity of 5×10^{34} (unabsorbed) and an accretion rate around 1.2×10^{-8} $M_\odot yr^{-1}$. This indicates that TW Pic is going trough high and low states without detected outbursts. The accretion rate as determined by *Swift* is more typical of Nova-like systems.
- The spectral parameters of TW Pic resembles to magnetic CVs that are IPs with the high partial covering absorber in the *XMM-Newton* and *RXTE* data. However, the partial covering absorber revealed in the *Swift* data have a factor of 10 less hydrogen column decreasing the intrinsic absorption, a typical of IPs. The hardness of the TW Pic spectrum also resembles to VY Scl type of Nova-like systems (e.g. MV Lyr or BZ Cam) that indicates high and low states as well.
- We will further our power spectral analysis to determine flow structure and look for any periodicity. Using *RXTE*, we have determined that TW Pic shows a break frequency (∼ 3 mHz) similar to dwarf nova in quiescence and thus the system PDS resembles to nonmagnetic CVs. The IP PDS indicate higher break frequencies (see Revnivtsev et al. 2009 and 2010 and 2011). The averaged PDS of the first *XMM-Newton* observation shows a similar break frequency of around 1-2 mHz. The high state *Swift* data reveal a flat noise level of about 2 (white noise). Thus, the system seems at a different source state without any breaks or red noise.
- We used the optical orbital ephemerides by Patterson & Moulden (1993) to phase lock the X-ray mean light curves folded over the orbital period. However, the accumulated phase error as a result of the error in the orbital period was large and we can not lock the phases of the different observatory data to the optical ephemerides. However, the phases of the orbital variation is phase-locked for the X-rays, B-band and the UVW2 band folded light curves. In general in all three X-ray observatory mean light curves we find a similar modulation profile (sinusoidal) for TW Pic (except for the second *XMM-Newton* observation where the profile seems to have more dips and peaks). The optical B-band and the UVW2 mean light curves folded over the orbital period shows phase-shifted minima and maxima with respect to each other and the X-rays. This may be caused if there is a hotspot effect at the accretion impact zone as seen in nonmagnetic CVs.

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