XMM–Newton confirmation of a new intermediate polar: XMMU J185330.7–012815

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ABSTRACT

We report on the results of a detailed spectro-imaging and temporal analysis of an archival XMM–Newton observation of a new intermediate polar XMMU J185330.7–012815. Its X-ray spectrum can be well described by a multitemperature thermal plasma model with the K lines of heavy elements clearly detected. Possible counterparts of XMMU J185330.7–012815 have been identified in optical and ultraviolet (UV) bands. The low values of the inferred X-ray-to-UV and X-ray-to-optical flux ratios safely rule out the possibility of its being an isolated neutron star. We confirm the X-ray periodicity of ∼238 s but, differently from the previous preliminary results, we do not find any convincing evidence of phase shift in this observation. We further investigate its properties through an energy-resolved temporal analysis and find that the pulsed fraction monotonically increases with energy.

Key words: stars: individual: XMMU J185330.7–012815 – novae, cataclysmic variables – X-rays: stars.

1 INTRODUCTION

XMMU J185330.7–012815 is an X-ray object of which the emission nature is not yet completely confirmed. It has been detected in the ROSAT All-Sky Survey (RASS). Based on its extent inferred from the RASS data (i.e. 11 × 7 arcmin2), Schaudel (2003) has suggested that XMMU J185330.7–012815, which was designated as G31.9−1.1 in their work, is a supernova remnant (SNR) candidate in our Galaxy. Schaudel (2003) has further analysed the X-ray properties of XMMU J185330.7–012815 by using an archival ASCA observation in which XMMU J185330.7–012815 is located at an off-axis angle of ∼14 arcmin. Although they found that XMMU J185330.7–012815 appears to be elongated in an ASCA GIS image, the large off-axis angle precludes any constraining spatial analysis. Examining the spectral data collected by ASCA, Schaudel (2003) found that the X-ray spectrum of XMMU J185330.7–012815 is featureless and can be fitted with an absorbed power-law model with a photon index of $\Gamma = 1.84^{+0.21}_{-0.22}$ (cf. table 5.2 in Schaudel 2003). Together with the apparently centrally brightened X-ray morphology, the author claimed that the power-law spectral fit strongly supports the interpretation of a centre-filled SNR or a Crab-like SNR. However, with only ∼1100 source counts from the ASCA data, one cannot unambiguously distinguish between the power-law model and a single-temperature thermal plasma model with $kT = 5.23^{+1.88}_{-1.35}$ keV

Schaudel (2003). Also, the non-detection of any radio emission from the position of XMMU J185330.7–012815 makes the SNR interpretation questionable.

In an archival search for the Galactic magnetars, Muno et al. (2008) have made use of 506 archival Chandra data and 441 archival XMM–Newton data. This search has included a dedicated XMM–Newton observation of XMMU J185330.7–012815 with an off-axis angle of only ∼0.4 arcmin. Interestingly, the authors have detected a signal with a period of ∼238 s from this observation. With this discovery, instead of being a magnetar candidate, Muno et al. (2008) have suggested that this source is probably an accreting white dwarf. The cataclysmic variable nature of this source is further supported by the optical spectroscopy performed by Halpern & Gotthelf (private communication reported in Muno et al. 2008).

Although Muno et al. (2008) have identified XMMU J185330.7–012815 as a promising candidate of cataclysmic variable, they have not further analysed and discussed the nature of this object as this is out of the scope of their work. To confirm the X-ray emission properties of XMMU J185330.7–012815, a detailed spectro-imaging and temporal analysis of the aforementioned XMM–Newton observation is required and this provides the motivation for this investigation. In Section 2, we are going to describe the details of this XMM–Newton observation of XMMU J185330.7–012815 as well as the procedure of the data reduction. The method and the results of the data analysis are presented in Section 3. Finally, we will discuss the implication and the possible nature of XMMU J185330.7–012815 as an accreting white dwarf.

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2 OBSERVATION AND DATA REDUCTION

XMMU J185330.7−012815 was observed by XMM–Newton on 2004 October 25–26 (Observation ID: 0201500301). The X-ray data used in this investigation were obtained with the European Photon Imaging Camera (EPIC) on board XMM–Newton (Jansen et al. 2001). EPIC consists of two metaloxide semiconductor (MOS1/2) CCD detectors Turner et al. (2001) from which half of the beam from two of the three X-ray telescopes is reflected. The other two halves of the incoming photon beams are reflected to a grating spectrometer (RGS) (den Herder et al. 2001). The third of the three X-ray telescopes is dedicated to expose the EPIC-PN CCD detector solely Strüder et al. (2001). The EPIC-PN CCD was operated in small-window mode with a medium filter to block optical stray light. These data provide imaging spectral and temporal information. All recorded events are time-tagged with a temporal resolution of 5.7 ms. The MOS1/2 CCDs were set up to operate in full-window mode with a medium filter in each camera. The MOS1/2 cameras provide imaging, spectral and timing information, though the later with a temporal resolution of 2.6 s only.

The aim point of the satellite in this observation is RA = 18h53m29.7s and Dec. = −01°28′31.8″ (J2000). With the most updated instrumental calibration, we generate the event lists from the raw data obtained from all EPIC instruments with the tasks emproc and epprocf of the XMM Science Analysis Software (XMAS version 9.0.0). Examining the raw data from the EPIC-PN CCD, we did not find any timing anomaly which was observed in many of the XMM–Newton data sets (cf. Hui & Becker 2006 and references therein). This provides us with opportunities for an accurate timing analysis. We then created filtered event files for the energy range of 0.2–12 keV for all EPIC instruments and selected only those events for which the pattern was 0–12 for MOS cameras and 0–4 for the EPIC-PN camera. We further cleaned the data by accepting only the good times when sky background was low and removed all events potentially contaminated by bad pixels. After the filtering, the effective exposures are found to be 19.5 and 13.5 ks for MOS1/2 and EPIC-PN, respectively.

Apart from the X-ray data, we have also made use of the Optical Monitor (OM, Mason et al. 2001) data obtained in standard imaging mode with two filters UVW1 (an effective wavelength of 2910 Å) and UVM2 (2310 Å). The OM data are reduced by using the standard xmasas omichain task. For imaging and source detection, the track history was created, bad pixels were removed and the resulting image was subsequently used for source detection. Since individual photons were centered to one-eighth of detector pixel by on-board electronics which produces a noise pattern known as modulus 8, spatial fixed pattern noise and hence this noise was overcome using the ommodmap task. The source detection was performed by using the task omdetect and counts were converted into magnitudes for the corresponding filters with the aid of the task ommag. The ultraviolet (UV) bandpass counts were converted into fluxes using the recipe provided by Alice Breeveld.1

3 DATA ANALYSIS

3.1 Spatial analysis

The composite MOS1/2 image of a 6 × 6 arcmin² field around XMMU J185330.7−012815 is shown in Fig. 1. XMMU J185330.7−012815 is observed as the brightest object in this field. We determined its position and significance by means of a wavelet detection algorithm. The X-ray position is found to be RA = 18h53m30.7s, Dec. = −01°28′16″ (J2000), where the numbers in the parentheses indicate the 1σ statistical uncertainties of the last digit. The signal-to-noise ratio of XMMU J185330.7−012815 is found to be 32σ. This MOS1/2 image clearly rules out extended source as suggested by the RASS data Schaudel (2003). There are two serendipitous X-ray sources found in the vicinity of XMMU J185330.7−012815, where are labeled as sources A and B in Fig. 1. The wavelet detection reports the locations and the significances of these sources to be [RA=18h53m30.7s, Dec. = −01°28′16″] [J2000]; signal-to-noise ratio (S/N) = 6σ and [RA = 18h53m32′24″, Dec. = −01°26′29″9] [J2000]; S/N = 17σ for sources A and B, respectively. Since our focus is on characterizing the emission nature of XMMU J185330.7−012815, we will not discuss the properties of these two sources further in this paper.

3.2 Spectral analysis

We estimated the effects of the pile-up on all of the EPIC data by using the xmasas task epatplot. Our results showed that all the EPIC data were not affected by CCD pile-up. In order to maximize the signal-to-noise ratio for XMMU J185330.7−012815, we extracted its source spectrum from circles with a radius of 50 and 30 arcsec in the MOS1/2 and EPIC-PN cameras, respectively. This choice of extraction regions corresponds to the encircled energy fraction of 90 per cent in all cameras2 and at the same time it minimizes the contamination from the nearby X-ray sources. The background spectra were sampled from the nearby regions with circles of a radius of 60 and 40 arcsec in MOS1/2 and EPIC-PN, respectively.

Figure 1. The raw X-ray image of the 6 × 6 arcmin² field of view centered at XMMU J185330.7−012815 generated by merging the MOS1 and MOS2 data in the energy range of 0.2–12 keV. Two serendipitous unidentified sources are also detected in this FOV.

1 http://xmm.esac.esa.int/sas/7.0.0/watchout/Evenet_performance/uvflux.shtml

2 The source significances quoted in this paper are in the unit of Gehrels error: σ0 = 1 + √σB + 0.73 where C_B is the background count.

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that suggest K lines of heavy elements, in particular the features at \(\sim 6.7\) and \(\sim 6.9\) keV. This has led us to examine the spectrum with the emission model of hot plasma that includes line emissions from different elements. First, we attempted to fit the spectrum with MEKAL which is a code that models the plasma in collisional ionization equilibrium (Mewe, Gronenschild & van den Oord 1985). With the metal abundances fixed at the solar values, a single-temperature MEKAL model results in a hydrogen equivalent column density of \(n_H = (4.6 \pm 0.3) \times 10^{20} \text{ cm}^{-2}\) and a plasma temperature of \(kT = 6.4 \pm 0.2\) keV with a goodness of fit of \(\chi^2 = 1.89\) (583 d.o.f.). The large \(\chi^2\) indicates that this model is unlikely to be the adequate description of the data. In examining the fitting residuals, we have identified the systematic deviations at energies larger than \(\sim 5\) keV and smaller than \(\sim 1\) keV. This prompts us to examine the spectrum with a multitemperature plasma model.

With a two-temperature MEKAL model, the best fit yields a similar absorption of \(n_H = 4.7^{+0.4}_{-0.3} \times 10^{20} \text{ cm}^{-2}\) and the plasma temperatures of \(kT_1 = 1.00^{+0.04}_{-0.03}\) keV and \(kT_2 = 8.34^{+0.40}_{-0.42}\) keV. In comparison with the single-temperature model, the goodness of fit, \(\chi^2_1 = 1.27\) (581 d.o.f.), is found to be improved significantly. Statistically, the additional component is required at a confidence level >99.9 per cent. Although the systematic residuals at energies >5 and <1 keV are not observed in this two-temperature model, we notice that this model appears to overpredict the emission at the energies around \(\sim 1\) and \(\sim 6.7\) keV. This leads us to speculate that either the abundances of the metals that give rise to the line emissions at these energies are different from their solar values or the data require an additional component for modelling. For testing the first hypothesis, we further analysed the X-ray spectrum of XMMU J185330.7–012815 by taking metal abundance as a free parameter in the fitting. As the residuals at these energies are likely to be due to Fe K\(\alpha\) lines, we have entangled the free parameters of Fe abundances in both components, we found that the residuals at \(\sim 1\) and \(\sim 6.5\) keV can be minimized. The goodness of fit is improved (\(\chi^2 = 1.20, 580\) d.o.f.). The model yields a column density of \(n_H = (5.7 \pm 0.4) \times 10^{20} \text{ cm}^{-2}\), plasma temperatures of \(kT_1 = 0.81 \pm 0.03\) keV and \(kT_2 = 7.75^{+0.44}_{-0.65}\) keV, as well as an iron abundance of Fe = 0.72 ± 0.08. Although the residuals of the lines can be reduced with this model,

**Figure 2.** Energy spectrum of XMMU J185330.7–012815 as observed with the EPIC-PN (upper spectrum) and MOS1/2 detectors (lower spectra) and simultaneously fitted to an absorbed three-temperature MEKAL model (upper panel) and contribution to the \(\chi^2\) fit statistic (lower panel).

Response files were computed for all data sets by using the XMMAS tasks rmfgen and arfgen. After the background subtraction, we have 9130 ± 97, 9314 ± 98, and 19282 ± 140 counts collected for the spectral analysis from MOS1, MOS2 and EPIC-PN cameras, respectively.

In order to constrain the spectral parameters tightly, we fitted the data obtained from three cameras simultaneously. For the spectrum extracted from each camera, we grouped the data so as to have at least 50 count bin\(^{-1}\). We found fluctuations in the spectral data below 0.3 keV, which can be ascribed to the undesirable spectral response. Therefore, we limited all the spectral analyses to the energy range of 0.3–12 keV. All the spectral fits were performed with XSPEC 12.5.1. The parameters of the best-fitting models are summarized in Table 1. All the quoted errors are 1σ for the two parameters of interest.

The X-ray spectrum of XMMU J185330.7–012815 as observed by XMM–Newton is displayed in Fig. 2 which shows line features

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### Table 1. Best-fitting spectral parameters of XMMU J185330.7–012815.

| Component | MEKAL | MEKAL+MEKAL | MEKAL+MEKAL | MEKAL+MEKAL | MEKAL+MEKAL | PL |
|-----------|-------|-------------|-------------|-------------|-------------|----|
| \(n_H\) (10\(^{20}\) cm\(^{-2}\)) | 4.60 ± 0.31 | 4.74\(^{+0.34}_{-0.35}\) | 5.67\(^{+0.42}_{-0.38}\) | 5.46\(^{+0.40}_{-0.38}\) | 12.08\(^{+0.57}_{-0.56}\) |
| \(kT_1\) (keV) | 6.42 ± 0.23 | 1.00\(^{+0.04}_{-0.03}\) | 0.81 ± 0.03 | 0.65 ± 0.04 | - |
| \(kT_2\) (keV) | - | 8.34\(^{+0.40}_{-0.42}\) | 7.75\(^{+0.44}_{-0.65}\) | 1.78\(^{+0.39}_{-0.15}\) | - |
| \(kT_3\) (keV) | - | - | - | - | - |
| Fe \(^{a}\) | - | 1.0 (fixed) | 0.72 ± 0.08 | 1.0 (fixed) | - |
| \(\Gamma\) | - | - | - | - | 1.84 ± 0.02 |
| \(\text{Norm}_{1}\) \(^{b}\) | (2.92 ± 0.03) \times 10\(^{-3}\) | (1.46\(^{+0.18}_{-0.16}\) \times 10\(^{-4}\) | (1.55\(^{+0.22}_{-0.20}\) \times 10\(^{-4}\) | (8.56\(^{+0.12}_{-0.07}\) \times 10\(^{-5}\) | - |
| \(\text{Norm}_{2}\) \(^{b}\) | - | (2.70\(^{+0.03}_{-0.04}\) \times 10\(^{-3}\) | (2.78 ± 0.04) \times 10\(^{-3}\) | (3.56\(^{+0.15}_{-0.14}\) \times 10\(^{-4}\) | - |
| \(\text{Norm}_{3}\) \(^{b}\) | - | - | - | (2.46\(^{+0.07}_{-0.07}\) \times 10\(^{-3}\) | - |
| \(\text{Norm}_{\text{PL}}\) \(^{c}\) | - | - | - | - | (1.07 ± 0.02) \times 10\(^{-3}\) |
| \(\chi^2\) | 1099.53 | 737.50 | 698.87 | 621.20 | 1003.51 |
| d.o.f. | 583 | 581 | 580 | 579 | 583 |

\(^{a}\)The abundance of iron relative to the solar photospheric values.

\(^{b}\)The normalization of MEKAL model is expressed as \((10^{15}/4\pi D^2)\int N_eN_HdV\) where \(D\) is the source distance in cm and \(N_e\) and \(N_H\) are the electron and hydrogen densities in \(\text{cm}^{-3}\).

\(^{c}\)The normalization of the power-law model (PL) at 1 keV in units of photons \(\text{keV}^{-1}\text{ cm}^{-2}\text{ s}^{-1}\).

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with a more careful examination we found that there are still discrepancies between the observed data and this model at energies larger than \( \sim 7 \) keV. This led us to consider the other possibility, namely whether any additional spectral component is required to model these data.

A comparison between the best-fitting three-temperature plasma model and the observed data is shown in Fig. 2. There is no systematic deviation between the data and this model within the entire adopted energy range. The goodness of fit is further improved \( (\chi^2_r = 1.07, 579 \text{ d.o.f.}) \). Different from the two-temperature model, we do not find any significant deviation of the Fe abundance from the solar value in this adopted model. Therefore, we fixed all the metal abundances at the solar values in the three-temperature plasma model. It results in the column density of \( n_H = (5.5 \pm 0.4) \times 10^{20} \text{ cm}^{-2} \), the plasma temperatures of \( kT_1 = 0.65 \pm 0.04 \text{ keV}, kT_2 = 1.78 \pm 0.19 \text{ keV} \) and \( kT_3 = 10.84^{+0.40}_{-0.96} \text{ keV} \). The unabsorbed flux inferred by this model is \( f_X = (6.4 \pm 0.5) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1} \) in 0.3–12 keV.

We notice that there is a class of cataclysmic variable which contains a soft blackbody component (cf. Evans & Hellier 2007). Statistically the soft blackbody component is only required at a confidence level of \( \sim 10 \) per cent in this observed spectrum. Therefore, we do not consider this spectral contribution in this work.

The ASCA and XMM–Newton spectra of XMMU J185330.7–012815 appear to be qualitatively different. ASCA observations show no line emission features and the spectrum has a single power-law model, and a reasonable goodness of fit has been obtained with the ASCA data \( (\chi^2_r = 0.86, 40 \text{ d.o.f.}) \) Schaudel (2003). However, with the photon statistic improved by a factor of \( \sim 34 \), the spectral data obtained by XMM–Newton clearly show the presence of the emission line features. Fitting a power law to the EPIC spectrum does not result in an acceptable goodness of fit \( (\chi^2_r = 1.72, 583 \text{ d.o.f.}) \). Similar to the single-temperature plasma model, it cannot describe the data below \( \sim 2 \) keV and above \( \sim 5 \) keV. Such a discrepancy between the inferences drawn from these two observations can be ascribed to the relatively poor quality of ASCA data.

### 3.3 Temporal analysis

#### 3.3.1 Modulation period

To confirm the X-ray period by Muno et al. (2008), we did a periodicity search by using an epoch-folding method after converting the X-ray arrival times to the barycentric times of the Solar system. The best period, which was determined by fitting a Gaussian function to the centroid of the \( \chi^2 \) peak, is \( P = 238.1 \pm 0.1 \text{ s} \) for both PN and MOS data under the assumption that the pulses are coherent (where the errors in \( \chi^2 \) are included and the MOS1 and MOS2 data are combined). This period is consistent with the result reported by Muno et al. (2008). If we take the possible irregularity of the pulses into account, then the error should increase to \( P = 238.1 \pm 1.1 \text{ s} \) in which the error is the standard deviation \( \sigma \) of the Gaussian function fitted to the full \( \chi^2 \) profile.

Muno et al. (2008) have also pointed out that the phases vary by \( \sim 0.1 \) cycles with a time-scale of \( \sim 5000 \text{ s} \) which suggests the incoherent nature of the source. We have also carried out the phase analysis by dividing the PN light curve into four segments with a time-scale of \( \sim 5000 \text{ s} \) and folded each segment at the period of 238.1 s over the epoch MJD 53303.98674 (Fig. 3). By fitting a sinusoidal model to the data (see below), we obtained the following peak positions in time order: 1.13\( ^{+0.02}_{-0.03}, 1.05^{+0.06}_{-0.07}, 1.06^{+0.01}_{-0.04} \) and 1.14\( ^{+0.02}_{-0.05} \) in phases (where the errors are at the 90 per cent confidence level). Taking the uncertainties into account, we are not able to unambiguously state whether there is a clear, systematic phase shift. Furthermore, by running a \( \chi^2 \) test in each pair of the time-sliced light curves in Fig. 3, their distributions are found to be consistent with each other at a confidence level >99.9 per cent. Therefore, we conclude that no convincing evidence for the incoherence can be found in our independent analysis.

#### 3.3.2 Energy-resolved folded light curves

A pulse or modulation profile folded at the period of 238.1 s shows a single broad peak over one cycle of the data. It can be approximated by a sinusoidal model plus a constant unpulsed level:

\[
A \sin(2\pi[\phi - \phi_0]) + C.
\]

To see how the profiles vary with energy, we investigate the energy-resolved profiles obtained in three different energy bands, 0.2–1.2, 1.2–3.0 and 3.0–10 keV. For this analysis, we focus on the PN data set as it provides a superior photon statistic in each of the considered energy bands. Fig. 4 shows the profiles (plus signs) where the backgrounds are not subtracted (the extracted backgrounds from a photon-deficit region in the same CCD chip are very small and they are at most \( \sim 2 \) per cent level compared to their source count rates). We fit the sinusoidal model to the profiles by allowing all the parameters to be free and obtain the following results from the best-fitting parameters. The goodness of the model fit is given in each panel of the Fig. 4. These profiles show no significant phase shift in the chosen energy bands. The pulse amplitude \( A \) (cf. equation 1) is found to increase with increasing energy: 0.16 \( \pm 0.03 \) (0.2–1.2 keV), 0.34 \( \pm 0.04 \) (1.2–3.0 keV), and 0.46 \( \pm 0.06 \) (3.0–10 keV). In the other words, a pulsed (or modulation) fraction

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The intensity in each panel was normalized by the average count rates of the same energy band. The pulse phase has been repeated over two cycles. A sine curve plus a constant (dotted curve) was fitted to the profiles (plus signs).

Figure 4. Energy-resolved pulse profiles of XMMU J185330.7—012815 for PN data. The data were folded in 238.1 s from the observation start time. The quoted errors for the temporal results are at the 90 per cent confidence level.

3.4 Analysis of optical monitor (OM) data

Within 10′ arcsec from the X-ray position of XMMU J185330.7—012815, we have detected two UV sources in the OM data. One of these UV sources (hereafter U1) has been found to have the magnitudes of $m_{\text{UVW1}} = 15.99 \pm 0.02$ and $m_{\text{UVM2}} = 16.49 \pm 0.03$ with the corresponding significances of 68.31σ and 53.46σ, respectively. On the other hand, the other source (hereafter U2) has the magnitudes of $m_{\text{UVW1}} = 15.98 \pm 0.03$ and $m_{\text{UVM2}} = 18.86 \pm 0.26$ with the corresponding significances of 43.81σ and 6.70σ, respectively. The corrected count rate for U1 and U2 for the two filters are $c_1 = 3.06 \pm 0.06$ count s$^{-1}$ (UVW1), $c_1 = 0.82 \pm 0.03$ count s$^{-1}$ (UVM2), and $c_2 = 1.92 \pm 0.05$ count s$^{-1}$ (UVW1), $c_2 = 0.06 \pm 0.01$ count s$^{-1}$ (UVM2), respectively. We subsequently use these count rates to calculate the UV fluxes. For the conversion factors in the UVW1 and UVM2 bandpasses of $4.76 \times 10^{-16}$ and $2.20 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$, we obtain the fluxes of $(4.36 \pm 0.06) \times 10^{-12}$ and $(4.16 \pm 0.03) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for U1 in the corresponding filters. For U2, the fluxes are found to be $(2.66 \pm 0.05) \times 10^{-12}$ and $(0.30 \pm 0.01) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in UVW1 and UVM2, respectively. Of these two detected UV sources, U1 has been found to have its position coincided with the nominal X-ray position of XMMU J185330.7—012815. Furthermore, while no optical counterpart can be found for U2, we have identified an optical source in B band at the position of U1 (see Section 4). The X-ray-to-UV flux ratio has been found to have the same order of magnitude as the X-ray-to-optical flux ratio. In view of these properties, we suggest that U1 is more likely to be the counterpart of XMMU J185330.7—012815.

4 DISCUSSION AND SUMMARY

In this paper, we present a detailed spectro-imaging and temporal analysis of an archival XMM–Newton observation of XMMU J185330.7—012815, which has its emission nature not yet identified unambiguously.

We found that the energy spectrum of XMMU J185330.7—012815 obtained by the EPIC can be well described by an absorbed multitemperature plasma model. The inferred column density is $n_H \sim 5 \times 10^{20}$ cm$^{-2}$ which is far lower than the total Galactic neutral hydrogen absorption, $n_H \sim 10^{22}$ cm$^{-2}$, in the direction of XMMU J185330.7—012815 (Dickey & Lockman 1990; Kalberla et al. 2005). This leads us to rule out the extragalactic origin of XMMU J185330.7—012815.

The unabsorbed X-ray flux inferred from the best-fitting model is found to be $f_X \sim 6 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. Together with the UV counterpart identified in OM, the inferred X-ray-to-UV flux ratio is $f_X/f_{\text{UV}} \sim 1.5$. To further constrain the source nature, we also search for any optical identification of XMMU J185330.7—012815 in the United States Naval Observatory (USNO)-B1.0 catalogue (Monet et al. 2003). Within the 20σ X-ray positional uncertainty of XMMU J185330.7—012815 (see Section 3.1), we have identified one optical counterpart with $B = 17.11$. The position of this source is also found to be consistent with that of U1. By using the $n_H$ inferred from the X-ray analysis to estimate the foreground extinction, we calculate the extinction-corrected optical flux in B band as $f_B = 1.8 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ which implies $f_X/f_B \sim 3.8$. Such a low value of X-ray-to-optical flux ratio safely rules out the possibility of there being an isolated neutron star with $f_X/f_B > 10^3$ (cf. Haberl 2007).

Through our independent search for the periodic X-ray signal from XMMU J185330.7—012815, we have identified a peak at $\sim 238.1$ s in the power density spectrum. This has confirmed the periodicity first reported by Muno et al. (2008). Nevertheless, different from the result reported by Muno et al. (2008), we do not find any convincing phase shift in our phase analysis. In any case, it is unlikely that this signal with such a long period comes from rotation-powered pulsars (cf. Manchester et al. 2005). Instead, we speculate that this periodic signal is possibly from a white dwarf. By comparing the uncovered period with the typical values of accreting white dwarf binaries, we further suggest that it is likely to be the spin period of the white dwarf and that it does not correspond to an orbital period. This interpretation is further supported by the spectral properties. The X-ray spectrum of XMMU J185330.7—012815 can be described by a three-temperature plasma model clearly showing the presence of iron lines, which have often been seen in one type of accreting white dwarf binaries, namely the intermediate polars (IPs) (e.g. Patterson 1994; Cropper et al. 2002). The additional frequencies in the X-ray power spectra, which corresponds to orbital or the beat period, is absent in XMMU J185330.7—012815. In the context of an IP interpretation, this suggests that material accretes on to the pole via a disc.

Although the spin period and the spectral properties strongly favour the IP interpretation, the observed property of monotonically
increasing modulation with increasing energy in the light curves requires a further discussion. In contrast to XMMU J185330.7−012815, many IPs show an opposite trend of decreasing modulation with energy (e.g. Norton & Watson 1989) which is generally explained by the variation of photoelectric absorption in the accretion curtain across the observer’s line of sight (Rosen, Mason & Córdova 1988). The accretion rate is expected to have the maximum from the sector of the disc that is closest to the magnetic pole and fall off with deviation from this sector. This gives rise to a continuous variation of column density along the cross-section of the curtain and hence results in the modulation by photoelectric absorption. The minimum of the light curve is thus at the phase when the accreting pole, where the absorption is the largest, is pointing towards the observer. As the effect of photoelectric absorption is more prominent in the soft band than in the hard band, a trend of decreasing pulsed fraction with increasing photon energy is not unexpected in this scenario (cf. fig. 9 in Rosen et al. 1988).

Although the behaviour of decreasing amplitude with increasing energy has been observed in many IPs, a number of them do deviate from this general trend. For example, a clear increase in amplitude modulation with increasing energy is also found in V2306 Cygni (WGA J1958.2+3232) by the ASCA observation Norton et al. (2002). Norton & Mukai (2007) found that an IP candidate XY Ari also shows an increasing modulation with increasing energy in the XMM–Newton data, whereas it shows a decreasing behaviour with increasing energy in the RXTE data (see figs 1 and 5 in Norton & Mukai 2007). Another IP that shows a modulation different from the general trend is IGR J00234+6141 in the RXTE observations (see table 2 in Butters et al. 2011). However, the XMM–Newton/EPIC-PN observation of this object shows no modulation above 2 keV Anzolin et al. (2009). There is another IP, PQ Gem, which shows an increasing modulation in subdivided low-energy bands and a decreasing modulation in high-energy bands of ASCA and RXTE observations (James Cynthia et al. 2002). On the other hand, a few other IPs show a constant modulation in RXTE observations (e.g. Butters et al. 2007, 2008) and some show no amplitude modulation in the EPIC-PN energy band (e.g. de Martino et al. 2005). Since a diversity of temporal behaviour has been observed, the energy dependence of amplitude modulation is a weaker criterion to constrain the property of an IP.

To further probe the temporal behaviour of XMMU J185330.7−012815, we have also analysed the archival RXTE observations for this source (ObsIDs: 90070-04-01-00, 90070-04-01-01, 90070-04-01-02, 90070-04-02-00, 90070-04-02-01 and 90070-04-02-02). However, no pulsed signal from XMMU J185330.7−012815 was detected from all these data sets. On the other hand, we found that the emission line features at ~6.5 keV in the RXTE PCA spectrum. Hence, we speculate that the non-detection of pulsation in the RXTE data can be ascribed to the lack of imaging capability in resolving the source in a crowded region. The upcoming missions with focusing optics for hard X-rays, such as NuSTAR Harrison et al. (2010), will certainly provide the appropriate instruments for further investigation of this interesting IP candidate.

The X-ray spectra of many IPs are described by a complex absorption model as expected in the context of accretion curtain (e.g. Ramsay et al. 2008). However, such an additional absorption component is not required in modelling the spectrum of XMMU J185330.7−012815. The lack of complex and high absorption in XMMU J185330.7−012815 might indicate a low inclination angle such that the observed X-rays are not passing through the accretion curtains. On the other hand, the observed hydrogen column density (i.e. $n_H \sim 5 \times 10^{20} \text{cm}^{-2}$) is much lower than typically observed in other IPs (cf. Euzka & Ishida 1999). The absence of high values of absorption can possibly due to the low accretion rate. Such low absorption have also been seen in several cases, such as HT Cam de Martino et al. (2005), EX HYa Mukai et al. (2003) and V1025 Cen Hellier, Beardmore & Buckley (1998) along with a few other IP sources in which a strong soft component was always prominent (Evans & Hellier 2007). Nevertheless, such a soft component is not observed in the case of XMMU J185330.7−012815. In the scenario of a low inclination angle, the missing soft component may be so simply due to the geometrical effect (Evans & Hellier 2007). Alternatively, this component might be much softer than the spectral coverage of XMM–Newton EPIC so that it is not revealed in this observation.

The spectral results of XMMU J185330.7−012815 suggest a relatively low shock temperature of ~11 keV (cf. Table 1). Very recently, Yuasa et al. (2010) have investigated the shock temperatures of 15 IPs and found two sources also with low temperatures, FO Aqr (~14 keV) and EX Hya (~12 keV). In another systematic study of 23 IPs, the lowest temperature is found to be ~12 keV for the source DO Dra Brunschweiger et al. (2009). Furthermore, we notice that the temperature of a new IP RX J0704 has exhibited a change from a high value of >44 to ~11 keV in 8 months Anzolin et al. (2008). There is an IP, AE Aqr, which shows exceptionally low temperature plasma of 0.1–7 keV (e.g. Choi, Dotani & Agrawal 1999; Choi & Dotani 2006a; Mauche 2009). However, for AE Aqr, it is widely believed that most of the transferred material from the companion does not reach the magnetic poles due to a magnetic propeller effect (e.g. Wynn, King & Horne 1997; Choi & Dotani 2006). Based on aforementioned temperature distribution in IPs, it is clear that the observed temperature of XMMU J185330.7−012815 is not significantly different from a few other IPs and also the observed low plasma temperature may not be persistent. A frequent monitoring of this source is encouraged.

In summary, based on our temporal and spectral analysis, we suggest that XMMU J185330.7−012815 belongs to the IP subclassification of cataclysmic variables. We would like to stress that, including XY Ari, there are only eight IPs/IP candidates which show spin period less than 240 s. Owing to this small population, the exact selection criteria to classify a source as an IP is not well defined for this short-period subclass, which so far could only have been constrained on the basis of the six observational criteria given by Patterson (1994). It is not certain if all six of these characteristics should be exhibited by an IP. For a further investigation of this new IP, a multiwavelength observation campaign is required to unveil the physical and geometrical configuration of this system. In particular, the determination of the orbital period of this source through a dedicated optical observation will definitely play a key role in determining the system parameters such as orbital inclination. Furthermore, a dedicated series of X-ray observations is desirable to search for the possible eclipses from XMMU J185330.7−012815. Through the timing of the eclipse ingress and egress, one is able to determine the size of the X-ray emitting region and hence put an additional observational constraint on the emission nature of this system.

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REFERENCES
Anzolin G., de Martino D., Bonnet-Bidaud J. M., Mouchet M., Gansicke B. T., Matt G., Mukai K., 2008, A&A, 489, 1243
Anzolin G., de Martino D., Falanga M., Mukai K., Bonnet-Bidaud J.-M., Mouchet M., Terada Y., Ishida M., 2009, A&A, 501, 1047
Brunschweiger J., Greiner J., Ajello M., Osborne M., 2009, A&A, 496, 121
Butters O. W., Barlow E. J., Norton A. J., Mukai K., 2007, A&A, 475, L29
Butters O. W., Norton A. J., Hakala P., Mukai K., Barlow E. J., 2008, A&A, 487, 271
Butters O. W., Norton A. J., Mukai K., Tomsick J. A., 2011, A&A, 526, 77
Choi C. S., Dotani T., Agrawal P. C., 1999, ApJ, 525, 399
Choi C. S., Dotani T., 2006, ApJ, 646, 1149
Cropper M., Ramsay G., Hellier C., Mukai K., Mauche C., Pandel D., 2002, Proc. R. Soc. Lond. A, 360, 1951
den Herder et al., 2001, A&A, 365, 7
de Martino D. et al., 2005, A&A, 437, 935
Dickey J. M., Lockman F. J., 1990, ARA&A, 28, 215
Evans P. A., Hellier C., 2007, ApJ, 663, 1277
Ezuka H., Ishida M., 1999, ApJS, 120, 277
Haberl F., 2007, Ap&SS, 308, 181
Harrison F. A. et al., 2010, in Arnaud M., Murray S. S., eds, Proc. SPIE Vol. 7732, Space Telescopes and Instrumentation 2010: Ultraviolet to Gamma Ray, SPIE, Bellingham, 77320S
Hellier C., Beardmore A. P., Buckley D. A. H., 1998, MNRAS, 29, 851
Hui C. Y., Becker W., 2006, A&A, 454, 543
James Cynthia H., Ramsay G., Cropper M., Branduardi-Raymont G., 2002, MNRAS, 336, 550
Jansen F. et al., 2001, A&A, 365, L1
Kalberla P. M. W., Burton W. B., Hartmann D., Arnal E. M., Bajaja E., Morras R., Pöppel W. G. L., 2005, A&A, 440, 775
Manchester R. N., Hobbs G. B., Teoh A., Hobbs M., 2005, AJ, 129, 1993
Mason K. O. et al., 2001, A&A, 365, L36
Mauche C. W., 2009, ApJ, 706, 130
Mewe R., Gronenschild E. H. B. M., van den Oord G. H. J., 1985, A&AS, 62, 197
Monet et al., 2003, AJ, 125, 984
Mukai K., Kinkhabwala A., Peterson J. R., Kahn S. M., Paerels F., 2003, ApJ, 586, L77
Muno M. P., Gaensler B. M., Nechita A., Miller J. M., Slane P. O., 2008, ApJ, 680, 639
Norton A. J., Watson M. G., 1989, MNRAS, 237, 853
Norton A. J., Quaintrell H., Katajainen S., Lehto H. J., Mukai K., Negueruela I., 2002, A&A, 384, 195
Norton A. J., Mukai K., 2007, A&A, 472, 225
Patterson J., 1994, PASP, 106, 209
Ramsay G., Wheatley P. J., Norton A. J., Hakala P., Baskill D., 2008, MNRAS, 387, 1157
Rosen S. R., Mason K. O., Cordova F. A., 1988, MNRAS, 231, 549
Schaudel D., 2003, PhD thesis, Ludwig-Maximilians Univ. München
Strüder L. et al., 2001, A&A, 365, L18
Turner M. J. L. et al., 2001, A&A, 365, L27
Wynn G. A., King A. R., Horne K., 1997, MNRAS, 286, 436
Yuasa T., Nakazawa K., Makishima K., Saitou K., Ishida M., Ebisawa K., Mori H., Yamada S., 2010, A&A, 520, 25

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