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TWO RAPIDLY VARIABLE GALACTIC X-RAY TRANSIENTS OBSERVED WITH *CHANDRA*, *XMM-NEWTON*, AND *SUZAKU*

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ABSTRACT

We have identified two moderately bright, rapidly variable transients in new and archival X-ray data near the Galactic center. Both objects show strong, flaring variability on timescales of tens to thousands of seconds, evidence of N_H variability, and hard spectra. XMMU J174445.5–295044 is seen at 2–10 keV fluxes of 3×10^{-11} to $< 10^{-12}$ erg cm⁻² s⁻¹, with N_H at or above 5×10^{22} cm⁻², by *XMM-Newton*, *Chandra*, and *Suzaku*. A likely Two Micron All Sky Survey (2MASS) counterpart with $K_S = 10.2$ shows colors indicative of a late-type star. CXOU J174042.0–280724 is a likely counterpart to the fast hard transient IGR J17407–2808. *Chandra* observations find $F_X(2\text{--}10\text{ keV}) \sim 10^{-12}$ erg cm⁻² s⁻¹, with large N_H variations (from 2×10^{22} to $> 2 \times 10^{23}$ cm⁻²). No 2MASS counterpart is visible, to $K_S > 13$. XMMU J174445.5–295044 seems likely to be a new symbiotic star or symbiotic X-ray binary, while CXOU J174042.0–280724 is more mysterious, likely an unusual low-mass X-ray binary.

Key words: stars: neutron – X-rays: binaries

Online-only material: color figures

1. INTRODUCTION

The wide field of view, sensitivity to hard X-rays, and program focused on the Galactic plane of the *International Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*) IBIS telescope has unveiled new kinds of hard X-ray transient behavior (Sguera et al. 2005). Many of these systems are high-mass X-ray binaries containing neutron stars (NSs), either eccentric Be systems where the NS feeds from an excretion disk, or supergiant fast X-ray transient systems (Negueruela et al. 2006) where the NS feeds from a (clumpy) stellar wind (Walter & Zurita-Heras 2007). A number of new *INTEGRAL* sources have now been identified with supergiant fast X-ray transients, showing rapid flaring behavior and variable N_H , and in some cases (slow) pulsations (Patel et al. 2004; Walter et al. 2006; Chaty et al. 2008).

However, some rapidly variable X-ray transient behavior may be produced by other systems, such as symbiotic stars (with white dwarf accretors, e.g., Smith et al. 2008), symbiotic X-ray binaries (with NS accretors, e.g., Masetti et al. 2007), some unusual black hole X-ray binaries (in’t Zand et al. 2000), or magnetars (Castro-Tirado et al. 2008; Stefanescu et al. 2008). Identifying the optical/infrared (IR) counterparts of rapidly variable X-ray transients is important for understanding these systems, and requires accurate positions from focusing X-ray instruments.

The *INTEGRAL* hard X-ray source IGR J17407–2808 was first identified by Kretschmar et al. (2004) as a hard X-ray flaring source, positionally consistent with the faint *ROSAT* source 2RXP J174040.9–280852. Sguera et al. (2006) described the X-ray activity as three fast (few minute timescale) bright (up to 0.8 Crab) flares, and refined the position to a 1.7 radius. A 23 keV bremsstrahlung model was an acceptable fit to the 20–60 keV spectrum. Sguera et al. (2006) noted that IGR J17407–2808’s outburst was unusually strong and brief compared to known supergiant fast X-ray transients, and refrained from ruling out alternative interpretations.

We have identified two spectrally hard, rapidly variable, X-ray transients in archival *Chandra*, *XMM-Newton*, and *Suzaku* data near the Galactic center. Our likely counterpart to the *INTEGRAL* IBIS fast transient IGR J17407–2808 detected in 2004, CXOU J174042.0–280724, showed strong flaring activity in early 2007. X-ray transient behavior has not been previously identified from the other, XMMU J174445.5–295044, for which we identify hard X-ray flaring in late 2006 and early 2007.

2. XMMU J174445.5–295044

2.1. Data

We observed the supernova remnant G359.1–0.5 on 2006 September 24 (ObsId 0400340101) for 42 ks with *XMM-Newton*’s EPIC camera, using two MOS CCD detectors (Turner et al. 2001) with medium filters and one pn CCD detector (Strüder et al. 2001) with a thin filter. (The time resolution was 2.6 s for the MOS cameras and 73.4 ms for the pn camera.) All data were reduced using HEASOFT 6.5⁵ and SAS version 8.0.0.⁶ The data were moderately affected by soft proton flares. For spectral analysis, we chose a compromise between retaining photon statistics and excluding background, using limiting 0.2–10 keV rates of 5, 6, and 40 counts s⁻¹ for MOS1, MOS2, and pn cameras, respectively. This left 25.0, 26.2, and 23.4 ks of time for the MOS1, MOS2, and pn cameras. We excluded event grades higher than 12 for MOS, and higher than 4 for the pn. The brightest point source was so much brighter than the background that all data could be used to produce light curves (see below).

We used *Chandra* archival ObsIDs 658, 2278, 2289 (all with the ACIS-I imaging CCD array), and 2714 (using the HRC-I high-resolution camera). The data were reduced with

⁵ <http://heasarc.gsfc.nasa.gov/docs/software/lheasoft>

⁶ <http://xmm2.esac.esa.int/sas/>

Table 1
X-ray Observations of XMMU J174445.5–295044 and CXOU J174042.0–280724

Mission/Instrument	ObsID	Date (yyyy-mm-dd)	Exposure	Notes
XMMU J174445.5–295044				
<i>Chandra</i> /ACIS-I	658	2000-08-30	9235	
<i>XMM-Newton</i> /MOS	0112971701	2001-03-31	7003	Nondetection
<i>Chandra</i> /ACIS-I	2278	2001-07-20	11611	At chip edge
<i>Chandra</i> /ACIS-I	2289	2001-07-21	11611	Nondetection
<i>Chandra</i> /HRC-I	2714	2002-03-02	29709	Nondetection
<i>XMM-Newton</i> /MOS	0144630101	2003-09-11	4477	Marginal detection
<i>XMM-Newton</i> /MOS	0303210201	2005-10-02	21823	
<i>XMM-Newton</i> /MOS	0400340101	2006-09-24	41028 (25026)	Source flaring
<i>XMM-Newton</i> /pn	0400340101	2006-09-24	35337 (23378)	Source flaring
<i>Suzaku</i> /XIS	501056010	2007-03-13	26545	Variable
CXOU J174042.0–280724				
<i>Chandra</i> /ACIS-I	8199	2007-07-30, 01:31	14682	Source flaring
<i>Chandra</i> /ACIS-I	8200	2007-07-30, 05:57	14566	At chip edge
<i>Chandra</i> /ACIS-I	8202	2007-07-30, 14:41	14300	Source flaring
<i>Chandra</i> /ACIS-S	7526	2007-08-01, 13:04	5108	

Note. For ObsID 0400340101, we give the exposure with background flares removed in parentheses (these data are used for spectral analysis).

CIAO 4.1 and CALDB 4.1, following standard data analysis threads.⁷ We used archival X-ray Imaging Spectrometer (XIS) data from *Suzaku* ObsID 501056010, reduced following the *Suzaku* Data Reduction Guide.⁸ We used the cleaned event files in the HEASARC archive, extracted spectra and backgrounds with XSELECT,⁹ and produced response files with the *xisresp* task. Finally, we included archival *XMM-Newton* data from three previous observations of 1E 1740.7–2942, in 2001, 2003, and 2005. These observations were conducted with the pn camera in timing mode, so only the MOS detectors were useful for our imaging. We performed standard filtering, as discussed above. All of these data are described in Table 1.

2.2. Discovery of XMMU J174445.5–295044

XMMU J174445.5–295044 is the brightest point source in the 2006 *XMM-Newton* data. We extracted its spectrum (from the data with high background excluded) and light curve (from the full data set) from 20'' circles, with background regions nearby on the same chip.

XMMU J174445.5–295044 shows a very hard absorbed spectrum (Figure 1, Table 2), indicating it is not a nearby coronal source. A power-law fit to the pn and combined MOS data is acceptable, and finds an intrinsically hard spectrum ($\Gamma = 1.18^{+0.08}_{-0.07}$) with substantial extinction ($N_H = 8.6 \pm 0.4 \times 10^{22} \text{ cm}^{-2}$). The spectrum is apparently featureless, with limits on the equivalent width of Fe lines at 6.4 and 6.7 keV at 26 and 9 eV, respectively. Its average unabsorbed 2–10 keV X-ray luminosity would be $1.7 \times 10^{35} \text{ erg s}^{-1}$ if it were located at an 8 kpc distance.

We produced barycentered light curves for XMMU J174445.5–295044, and found strong flaring on timescales of hundreds of seconds (Figure 2). The hardness of the spectrum does not vary strongly, indicating that the flaring is intrinsic and not due to varying N_H . Power spectra, with a binning timescale of 0.4 s, did not produce clear evidence of any periodicity, only red noise (rms variability of 24%, from 2×10^{-4} to 0.1 Hz).

Figure 1. Upper panel: spectra of XMMU J174445.5–295044 from 2006, with *XMM-Newton* EPIC pn (top) and MOS (below; red online), fit with an absorbed power law (Table 2). Lower panel: residuals to the fit.

(A color version of this figure is available in the online journal.)

We use an error radius of $2''^{10}$ for comparing the *XMM-Newton* position with accurate optical/IR catalogs (though we note that others, e.g., Walter et al. (2006), tend to use $4''$). A potential Two Micron All Sky Survey (2MASS)¹¹ counterpart (2MASS J17444541–2950446) is only $1''.78$ from the *XMM-Newton* position, with $K_S = 10.2$ and $J - K_S = 4.7$ (Figure 3, Tables 3 and 4). Only 12 2MASS stars with magnitude $K_S < 10.2$ lie within $50''$ of XMMU J174445.5–295044, indicating that the probability of finding a star of this brightness within $2''$ (our search radius) is only 2%. Thus, the 2MASS star is the likely counterpart of XMMU J174445.5–295044.

Since intrinsic $J - K$ colors range from -0.2 for O stars to 1.2 for M giants, $E(J - K)$ must be within 3.5 – 4.9 . For standard interstellar reddening laws, $A_V = 20$ to 28 , and $N_H = 3.6 \times 10^{22}$ to $5 \times 10^{22} \text{ cm}^{-2}$. These values suggest that if this star is the true counterpart, the X-rays probably suffer additional local absorption.

⁷ <http://xc.harvard.edu/ciao/threads>

⁸ <http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/>

⁹ <http://heasarc.gsfc.nasa.gov/docs/software/ftools>

¹⁰ XMM-SOC-CAL-TN-0018, from <http://xmm.esac.esa.int>

¹¹ See <http://irsa.ipac.caltech.edu/>

Table 2
Spectral Fits to XMMU J174445.5–295044

Mission/Instrument	ObsID	Flux (erg cm ⁻² s ⁻¹)	Γ	N_H (10 ²² cm ⁻²)	χ^2/dof	kT (keV)	N_H (10 ²² cm ⁻²)	χ^2/dof
Power-law fit					Bremsstrahlung fit			
<i>Chandra</i> /ACIS-I	658	$1.6^{+0.6}_{-0.7} \times 10^{-12}$	$3.0^{+0a}_{-1.1}$	15^{+3}_{-6}	0.68/10	$1.8^{+5.0}_{-1.0}$	19^{+14}_{-9}	0.57/10
<i>XMM-Newton</i> /MOS	0112971701	$< 3 \times 10^{-13}$						
<i>Chandra</i> /ACIS-I	2278	$2.8^{+1.5}_{-1.1} \times 10^{-13}$	$0.5^{+2.5a}_{-0a}$	$5.1^{+21}_{-2.7}$	146/15 ^b	> 2.3	11^{+8}_{-7}	146/85 ^b
<i>Chandra</i> /ACIS-I	2289	$< 5 \times 10^{-13}$						
<i>Chandra</i> /HRC-I	2714	$< 1.6 \times 10^{-12}$						
<i>XMM-Newton</i> /MOS	0144630101	$1.3^{+0.3}_{-0.5} \times 10^{-12}$						
<i>XMM-Newton</i> /MOS	0303210201	$6^{+6}_{-2} \times 10^{-13}$	$1.8^{+1.2a}_{-1.3a}$	8^{+9}_{-5}	0.54/11	> 1.8	$7.8^{+9.5}_{-3.3}$	0.54/11
<i>XMM-Newton</i> /EPIC	0400340101	$2.29 \pm 0.05 \times 10^{-11}$	$1.18^{+0.08}_{-0.07}$	$8.6^{+0.4}_{-0.4}$	0.91/368	> 126	$8.8^{+0.2}_{-0.2}$	0.92/368
<i>Suzaku</i> /XIS	501056010	$5.2^{+2.8}_{-1.2} \times 10^{-12}$	$2.4^{+0.6a}_{-0.6}$	16^{+5}_{-4}	0.65/111	$6.6^{+11}_{-2.9}$	$13.9^{+3.9}_{-3.2}$	0.66/111

Notes. Photon indices are restricted to the physically reasonable range of 0.5–3. Fluxes are unabsorbed, for 2–10 keV, using the best-fit absorbed power-law model, or a power-law spectrum with $\Gamma = 2$ and $N_H = 1 \times 10^{23}$ cm⁻² for upper limits.

^a Error calculation reached hard limit.

^b Used C-statistic, reporting C-statistic and “goodness” (see the text) instead of χ^2 and degrees of freedom.

Figure 2. 2006 *XMM-Newton* pn background-subtracted 1.5–9 keV light curve of XMMU J174445.5–295044, binned at 100 s resolution. Below it (in red online), we plot the background (appropriately scaled) extracted from a nearby region on the same chip.

(A color version of this figure is available in the online journal.)

We use the system of Negueruela & Schurch (2007) to compare the near-IR colors of the 2MASS counterpart with those expected for high-mass X-ray binaries. Following Comerón & Pasquali (2005), we define the reddening-free parameter $Q = (J - H) - 1.70(H - K_S)$. Supergiants should have $K_S < 11$ and $Q < 0.2$, Be stars should have $K_S < 12$ and $Q < 0$, and typical late-type stars have $Q \sim 0.5$. We find $Q = 0.81$ for the 2MASS counterpart, which is redder than expected even for late-type stars.

2.3. XMMU J174445.5–295044 at Lower Fluxes

The location of XMMU J174445.5–295044 ($l = 359.13$, $b = -0.31$), at the edge of the *Chandra* wide Galactic center survey field (Wang et al. 2002), and within 15' of the

LMXB 1E 1740.7–2942, has been observed numerous times by X-ray satellites. We have searched the HEASARC archive¹² for detections or constraining upper limits. We report here archival detections of XMMU J174445.5–295044 at lower fluxes by *Suzaku*, *XMM-Newton*, and *Chandra*, and upper limits from *Chandra* and *XMM-Newton* (Table 2, Figure 4). Observations by *ROSAT*, *ASCA*, *EXOSAT*, and *Einstein* do not detect it, but the upper limits are not particularly constraining, so we do not discuss those observations further.

XMMU J174445.5–295044 is consistent with the position of CXOGC J174445.5–295042 (Muno et al. 2006), seen in *Chandra* ObsID 2278. (The *Chandra* position is at the edge of a chip, so its positional uncertainty of 2'8, while consistent with XMMU J174445.5–295044, may not be fully trustworthy.) We have attempted spectral fitting to an absorbed power law and absorbed bremsstrahlung spectrum, using the unbinned data and the C statistic (Table 2). Testing the acceptability of a C-statistic fit is done through Monte Carlo simulations (we use 1000) of the model. The percentage of those simulations having a larger C-statistic than the data is reported as the “goodness”; a high value (e.g., 95%) indicates a poor fit. Its 10-count detection at the very edge of the chip makes conclusions tentative.

A second *Chandra* ACIS-I observation (ObsID 658) identifies XMMU J174445.5–295044 on the off-axis S2 chip, with over 100 counts. We extracted a spectrum (binning the data with 10 counts bin⁻¹) and a light curve with 200 s bins. Chi-square and KS tests found no evidence of variability in the light curve. We fit the spectrum (Figure 5) with absorbed power law and bremsstrahlung models (Table 2). Fitting the unbinned data with the C-statistic gave similar results (within the errors).

A third *Chandra* ACIS-I observation (ObsID 2289) did not detect XMMU J174445.5–295044, at the extreme corner of the off-axis S2 chip. Neither did a *Chandra* HRC-I observation where XMMU J174445.5–295044 was far off-axis (ObsID 2714). To determine upper limits for nondetections of XMMU J174445.5–295044 in this paper, we assume a spectrum similar to its faintest detections; an absorbed power law with photon index 2 and $N_H = 10^{23}$ cm⁻². We extract the number of photons in a circle corresponding to the 50% encircled energy radius for photons of 4.5 keV at XMMU J174445.5–295044's off-axis angle, using an energy range of 1.5–6 keV. Using a

¹² <http://heasarc.gsfc.nasa.gov/db-perl/W3Browse/w3browse.pl>

Figure 3. Images in 2MASS K band (left) and GLIMPSE $4.5\ \mu\text{m}$ band (right) of the XMMU J174445.5–295044 field. Generous $4''$ error circles are plotted around the *XMM-Newton* position, containing only one possible counterpart.

Table 3
Positions of XMMU J174445.5–295044, CXOU J174042.0–280724, and Possible Counterparts

Name	R.A.	Decl.	Δ	Notes
XMMU J174445.5–295044	17:44:45.55	–29:50:44.3	$\pm 2.0^a$	<i>XMM-Newton</i> pos.
XMMU J174445.5–295044	17:44:45.54	–29:50:42.1	$\pm 2.8^b$	Muno+06
2MASS J17444541–2950446	17:44:45.41	29:50:44.6	$\pm 0.07^a$	
CXOU J174042.0–280724	17:40:42.05	–28:07:24.6	$\pm 0.6^b$	<i>Chandra</i> pos.

Notes. Positions of detected (X-ray or optical/IR) source and error.

^a 1σ error.

^b 90% confidence error.

Table 4
Magnitudes and Fluxes of 2MASS J17444541–2950446

Band	Magnitude	Flux
J	14.89(5)	1.77
H	11.62(4)	23.1
K_S	10.17(3)	57.2
$3.6\ \mu\text{m}$	9.06(5)	66(3)
$4.5\ \mu\text{m}$	8.87(5)	51(2)
$5.8\ \mu\text{m}$	8.67(4)	40(2)
$8.0\ \mu\text{m}$	8.67(5)	22(1)

Note. Fluxes in mJy. Magnitudes from 2MASS and GLIMPSE.

larger nearby background region free of sources, we compute the expected number of background photons in this circle, scale it to the source region, and compute the 90% confidence lower limit (Gehrels 1986) on the number of expected background photons in the source region. The upper limit on the source count rate is derived by subtracting this lower limit from the observed photons, accounting for the encircled energy fraction and the vignetting of the telescope. Finally, we calculate flux upper limits using PIMMS.¹³

A recently archived *Suzaku* observation (ObsID 501056010, 2007) clearly detects XMMU J174445.5–295044 in all three operational XIS (Koyama et al. 2007) cameras (due to source confusion in the Galactic center, we do not consider the PIN data here). We extract spectra from a $100''$ region of the cleaned data, combining the spectra from XIS CCDs 0 and 3, and binning the data at 40 photons bin^{-1} (Figure 6). The variations in thermal emission from the Galactic center and large point-spread

function of *Suzaku* make background subtraction difficult below 2 keV. Since XMMU J174445.5–295044 shows little emission below 2 keV, we choose to ignore data below 2 keV for spectral fitting. The flux is a factor of 5 lower than observed by *XMM-Newton*, with a softer spectrum, and slightly higher N_H . We created a light curve from all detectors, in the energy range 1.5–6 keV, at 16 s binning. Variability, suggesting continued flaring, is best seen at 500 s binning (Figure 7).

We retrieved three prior *XMM-Newton* observations of 1E1740.7–2942 from the archive (Table 1), taken in 2001, 2003, and 2005. In each case, the pn camera was in timing or small window mode, so we used only MOS data. The 2001 and 2003 data were heavily affected by background flaring, forcing us to use partly contaminated data. A combined MOS image of the 2001 data produced only an upper limit on the existence of XMMU J174445.5–295044. The 2005 data produced a clear detection of XMMU J174445.5–295044 (Figure 4, lower left), with a flux comparable to the *Chandra* detections (Table 2). In the 2003 data, the position of XMMU J174445.5–295044 falls off the MOS2 chips, but lies on a MOS1 chip. Although the source is not detected with a blind detection algorithm, our upper limit method described above calculates $11^{+2.2}_{-4.8}$ counts (at 90% confidence). Thus, we consider this as a marginal detection (see Figure 4, upper right).

3. CXOU J174042.0–280724: AN *INTEGRAL* SOURCE?

Sguera et al. (2006) give the revised *INTEGRAL* error circle as R.A. = $17^{\text{h}}40^{\text{m}}40^{\text{s}}.08$, decl. = $-28^{\circ}08'24''$ (J2000), with error radius of $1'.7$. Bird et al. (2007) give the error circle as $17^{\text{h}}40^{\text{m}}42^{\text{s}}$, $-28^{\circ}12'1''$, with a $4'.2$ error radius. The Galactic Bulge Latitude Survey (J. E. Grindlay et al. 2009, in

¹³ <http://asc.harvard.edu/toolkit/pimms.jsp>

Figure 4. 1.5–6 keV images of all six observations with detections or marginal detections of XMMU J174445.5–295044. All images are on the same scale (dimensions 6.3×8.7), though the binning and stretch vary. Two observations (2001 July and 2003 September) have been smoothed to more clearly identify XMMU J174445.5–295044. The 2003 September MOS observation is only at best a marginal detection. Note that four of the observations place XMMU J174445.5–295044 near or at the edge of the detector.

(A color version of this figure is available in the online journal.)

Figure 5. *Chandra* spectrum of XMMU J174445.5–295044, from 2000 data (ObsID 658), fitted with an absorbed power-law model (Table 2).

preparation) covers both error circles thoroughly, between four overlapping 15 ks ACIS-I observations. We downloaded these four observations, plus the ACIS-S observation of Tomsick et al. (2008). We searched for periods of enhanced background, but found none. We created a mosaic image in the 0.5–7 keV energy band (Figure 8).

Figure 6. *Suzaku* spectrum of XMMU J174445.5–295044, fitted with an absorbed power-law model (fit only above 2 keV). XIS1 data (diagonal crosses, red online) are lower above 4 keV than the combined XIS0 and XIS3 data (boxes, black online).

(A color version of this figure is available in the online journal.)

The mosaic image shows 18 sources in one or the other of the two overlapping error circles. (Note that no *Chandra* source is visible in the error circle for the *ROSAT* source

Figure 7. *Suzaku* combined XIS 1.5–6 keV light curve of XMMU J174445.5–295044, using 500 s bins.

Figure 8. Mosaic of five *Chandra* observations in the 0.5–7 keV range, showing the large (green online) error circles for IGR J17407–2808 from Bird et al. (2007) and Sguera et al. (2006), and (red online) ellipses around detected sources. The candidate counterpart CXOU J174042.0–280724 is indicated by two black ticks. The small thick (green online) error circle indicates the location of 2RXP J174040.9–280852; note that no *Chandra* sources lie near it. SLX 1737–282 is the brightest source producing a readout streak, near the bottom of the image.

(A color version of this figure is available in the online journal.)

2RXP J174040.9–280852.) The brightest of these sources, CXOU J174042.0–280724 (indicated), shows marked flaring variability and a hard spectrum showing strong variations in absorption, which suggest that this source is the soft X-ray counterpart to IGR J17407–2808. None of the other sources within the IGR J17407–2808 error circles show these behaviors,

Figure 9. Spectrum of CXOU J174042.0–280724 in *Chandra* ObsID 8202, fit with an absorbed bremsstrahlung spectrum.

so we focus on CXOU J174042.0–280724. (Tomsick et al. (2008) identify the brightest source visible in Figure 8 as the low-mass X-ray binary SLX 1737–282, which is not a likely counterpart for IGR J17407–2808.)

CXOU J174042.0–280724 is in the field of view of ObsIDs 8199, 8200 (on the edge of the chip), 8202, and 7526, all of which were observed between 2007 July 30 and August 1 (Table 1). The count rate is much higher in ObsID 8202 than the others, by almost a factor of 10. None of these data sets showed background flaring, so we used all the data, and extracted spectra and light curves using CIAO tools.

A power-law spectral fit of CXOU J174042.0–280724 in ObsID 8202 finds a hard, absorbed spectrum, with photon index $\Gamma = 0.9^{+0.4}_{-0.6}$ and $N_H = 1.7^{+0.7}_{-0.9} \times 10^{22} \text{ cm}^{-2}$ (Table 5; Figure 9). A light curve (binned at 100 s) shows irregular sharp, short flares (Figure 10(a)), reaching at least 100 times the lowest flux. No periodicities are detected in the overall power spectrum. Although the count rates between flares are low, there is some indication that part of the variability is due to variable absorption, as the emission is systematically softer during the brightest periods (Figure 10).

We test this by extracting spectra from bright and faint parts of ObsID 8202, and fitting the (ungrouped) spectra with an absorbed power-law model, with photon index constrained between 0 and 3. Our spectral fit to the brightest 220 s of the first flare finds $N_H = 0.8^{+1.5}_{-0.7} \times 10^{22} \text{ cm}^{-2}$, and a 2–10 keV flux of $F_X = 8^{+4}_{-2} \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$. (We note that there is no evidence for pileup in the spectrum or image of this flare, due to the source’s off-axis location.) This is still 3 orders of magnitude fainter than the peak *INTEGRAL* flux from IGR J17407–2808. A similar fit to the data below 0.04 counts s^{-1} (excluding the last 5 ks) gives $N_H = 2.0^{+2.4}_{-1.6} \times 10^{22} \text{ cm}^{-2}$, and a flux of $F_X = 3.6^{+2.2}_{-1.3} \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$. This exercise strongly supports intrinsic source variation, and does not prove N_H variations during ObsID 8202.

CXOU J174042.0–280724’s substantially smaller count rate in the other three observations is explained by comparison of the spectra from ObsIDs 8199 and 8202. The spectrum observed in 8199 is substantially harder than that in 8202, showing a low-energy cutoff near 4 keV versus 1.5 keV (compare Figure 9 with Figure 11). Fitting bremsstrahlung models to both spectra confirms that the N_H value changed dramatically between the two observations, from $N_H = 29^{+36}_{-7} \times 10^{22} \text{ cm}^{-2}$

Table 5
X-ray Spectra of CXOU J174042.0–280724

Mission/Instrument	ObsID	Flux (erg cm ⁻² s ⁻¹)	Γ	N_H (10 ²² cm ⁻²)	χ^2/dof	kT (keV)	N_H (10 ²² cm ⁻²)	χ^2/dof
Power-law fit					Bremsstrahlung fit			
<i>Chandra</i> /ACIS-I	8199	$7^{+24}_{-3} \times 10^{-13}$	$0.5^{+2.5a}_{-0a}$	24^{+37}_{-7}	1.5/3	> 2.4	29^{+36}_{-7}	1.7/3
<i>Chandra</i> /ACIS-I	8200	$2.1^{+2.2}_{-1.6} \times 10^{-12}$	$3^{+0j}_{-2.5a}$	48^{+24}_{-27}	147/30 ^b	> 0.5	58^{+69}_{-20}	146/99 ^b
<i>Chandra</i> /ACIS-I	8202	$1.3^{+0.2}_{-0.2} \times 10^{-12}$	$0.8^{+0.5}_{-0.3}$	$1.5^{+0.8}_{-0.6}$	1.23/16	> 25	$2.2^{+0.5}_{-0.3}$	1.39/16
<i>Chandra</i> /ACIS-S	7526	$1.7^{+1.0}_{-0.8} \times 10^{-13}$	$0.5^{+0.6}_{-0a}$	$2.8^{+4.7}_{-1.7}$	148/62 ^b	> 10	$3.6^{+6}_{-1.8}$	152/85 ^b

Notes. Fluxes are unabsorbed, 2–10 keV, using the best-fit absorbed power-law model (constraining photon index to range 0.5–3).

^a Error calculation reached hard limit.

^b Used C-statistic, reporting C-statistic value and “goodness” (see the text) instead of χ^2 and degrees of freedom.

Figure 10. Top: light curve of CXOU J174042.0–280724 in *Chandra* ObsID 8202, 0.5–7 keV, binned at 100 s resolution. Bottom: hardness ratio of CXOU J174042.0–280724 in ObsID 8202, 4–8 keV counts over 1–4 keV counts, in 500 s bins.

Figure 12. Light curve of CXOU J174042.0–280724 in *Chandra* ObsID 8199, 0.5–7 keV, binned at 500 s resolution.

Figure 11. Spectrum of CXOU J174042.0–280724 in *Chandra* ObsID 8199, fit with an absorbed bremsstrahlung spectrum. Note the higher low-energy cutoff in comparison with Figure 9.

to $N_H = 2.2^{+0.5}_{-0.3} \times 10^{22}$ cm⁻², while the unabsorbed 2–8 keV fluxes are consistent (Table 5). Thus, the inter-observation

variability may be ascribed entirely to varying N_H , although the flaring (present in ObsID 8199 also; Figure 12) cannot. The remaining two observations (ObsIDs 8200 and 7526) offer less information (in 8200 the source lies on a chip edge, while 7526 was a shorter observation), producing spectra which are poorly constrained. However, the spectrum from ObsID 8200 is as hard as that from 8199 (only 3 of 27 photons are below 4 keV in ObsID 8200, compared to 7 of 63 in ObsID 8199), giving support to our explanation of the variability. The spectrum from ObsID 7526 is rather softer (7 of 19 counts below 4 keV), which might be due to intrinsic spectral evolution, or to N_H variations. Future observations could probe CXOU J174042.0–280724’s spectral evolution.

The best *Chandra* position for CXOU J174042.0–280724 is R.A. = 17:40:42.05 ± 0.01, decl. = −28:07:24.6 ± 0.1. Without astrometric matching of nearby X-ray sources to other wavelengths, we must add a systematic uncertainty of 0′.6 (90% conf.). We have searched for possible counterparts in the 2MASS catalog, but the nearest star is 1′.9 away, at a magnitude of 11.8. Based on the faintest 2MASS sources detected within 1′, rough limits of $J > 14$ and $K_S > 13$ can be set for the error circle. No counterparts exist in SIMBAD or the USNO catalog.

Figure 13. Fluxes, photon indices, and N_H measurements for XMMU J174445.5–295044 from constrained ($0.5 < \Gamma < 3.0$) absorbed power-law spectral fits to *XMM-Newton*, *Chandra*, and *Suzaku* data over 8 years (see Table 2).

4. DISCUSSION

We show the fluxes, photon indices, and N_H measurements for XMMU J174445.5–295044 in Figure 13. Clearly, XMMU J174445.5–295044 spends most of its time at lower fluxes, below $F_X = 3 \times 10^{-12}$ erg cm² s^{−1}. The 2006 *XMM-Newton* and 2007 *Suzaku* observations clearly show differences in photon index and N_H . The *Chandra* results also suggest a softening of the intrinsic spectrum, and increased N_H , at lower fluxes. The variable absorption and hard spectrum seem to rule out a coronal nature for the X-ray emission, suggesting an accreting compact object.

The evidence of rapid variability on timescales of minutes, the hard spectrum, and the intrinsic and variable absorption suggest a high-mass X-ray binary nature for XMMU J174445.5–295044 (White et al. 1995). However, the red colors of the IR counterpart for XMMU J174445.5–295044 are inconsistent with a high-mass X-ray binary nature, suggesting a red giant companion. The spectrum and variability are similar to those of, e.g., 4U 1954+31 (Masetti et al. 2007), suggesting a symbiotic X-ray binary nature. However, some symbiotic stars also show hard spectra and rapid variability (Luna & Sokoloski 2007), so a white dwarf accretor is also a viable explanation. We note that there are strong similarities between accretion from the clumpy stellar wind of high-mass stars versus that from giant stars onto a compact object. Indeed, several *INTEGRAL* sources with X-ray properties similar to high-mass X-ray binaries have recently been identified as symbiotic X-ray binaries (Masetti et al. 2007; Nespoli et al. 2008; Tomsick et al. 2008).

The substantial extinction to XMMU J174445.5–295044’s IR counterpart suggests a distance of at least 1 kpc, and thus X-ray luminosities of $> 10^{32}$ erg s^{−1} in quiescence, and $> 10^{33}$ erg s^{−1} at maximum. The flux range and strong variability of XMMU J174445.5–295044 suggest it may fit into the category of very faint X-ray transients (Wijnands et al. 2006; Degenaar & Wijnands 2009), although it may reach higher

fluxes at other times. Inspection of the All-Sky Monitor (ASM) and *Rossi X-Ray Timing Explorer* (*RXTE*) bulge scan data finds no evidence of outbursts from this source, with the bulge scan providing typical upper limits of 2–10 mCrab (C. Markwardt 2008, private communication; R. Remillard 2008, private communication). Some of the other known very faint X-ray transients may be symbiotic systems; this possibility might be ruled out with deep IR observations.

CXOU J174042.0–280724 has a more mysterious nature than XMMU J174445.5–295044, due to its lack of an optical counterpart. Even if it were not associated with IGR J17407–2808 (which we think it is), its varying N_H and rapid variability suggest accretion onto a compact object. The high flux attained by IGR J17407–2808 indicates an NS or black hole nature. The distance to this source is unknown, as we do not have a measurement of the interstellar reddening, and at least some of the observed (variable) absorption must be intrinsic. This direction ($l = 0.12$, $b = 1.35$) is sufficiently reddened (N_H up to 1.4×10^{22} cm^{−2}; Marshall et al. 2006) that interstellar reddening could explain the observed N_H in ObsID 8202, which has the lowest observed N_H value. The K_S limit implies $M_K > -2.2$ for a distance of 10 kpc, excluding main-sequence stars with spectral types earlier than B1 and giant stars with spectral types later than K2. At a distance of 15 kpc, these limits shift to excluding main-sequence stars earlier than O9 and giants later than K4, while supergiants are ruled out for either distance.

Some low- or intermediate-mass X-ray binaries, such as V4641 Sgr (in’t Zand et al. 2000; Revnivtsev et al. 2002; Chaty et al. 2003) or XTE J1901+014 (Smith et al. 2007; Karasev et al. 2007), show rapid flaring similar to that seen from IGR J17407–2808. Alternatively, this object could be a Be-type binary at a distance over 10 kpc. We note that for a distance of 10 kpc, the peak *INTEGRAL* flux corresponds to $L_X(20\text{--}60 \text{ keV}) = 1.1 \times 10^{38}$ erg s^{−1}, suggesting a bolometric flux above the Eddington limit for an NS.

Further studies of these mysterious sources are strongly encouraged to improve our understanding of their nature and of fast X-ray transient behavior. The most critical need is for deep optical and IR imaging to search for CXOU J174042.0–280724’s expected donor star. Spectroscopy of such an object (if possible) would be very valuable. Optical and/or IR spectroscopy of XMMU J174445.5–295044’s optical counterpart is also needed, to identify its spectral type and surface gravity and search for evidence of accretion. This will test the hypothesis presented here that XMMU J174445.5–295044 is a symbiotic system. If the distance can be constrained, the nature of the accreting object (white dwarf or NS?) may be determined. Additional X-ray observations of both objects will also be useful to monitor their long-term activity, especially if CXOU J174042.0–280724 produces additional outbursts detectable by *INTEGRAL*.

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