

**Study of Thermally Driven Disk Wind
in X-ray Black Hole Binary 4U 1630–47 and
7 Year *MAXI*/GSC Source Catalog
of Low Galactic-Latitude Sky**

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Abstract

This thesis consists of two main parts: a study of the origin of an accretion disk wind from a Galactic black hole X-ray binary (Chapter 2) and construction of the first complete Galactic X-ray catalog utilizing the 7 year data of Gas Slit Cameras (GSCs) on Monitor of All X-ray Image (MAXI) (Chapter 3). The latter work is intended to provide a new sample for studies of disk wind phenomena in Galactic X-ray binaries to be observed with future missions including the X-ray Astronomy Recovery Mission (XARM).

In Chapter 2, we present the results from the simultaneous observations with *Suzaku* and *NuSTAR* of the Galactic black hole binary 4U 1630–47 in the high/soft state (HSS) during the 2015 outburst. To compare our results with those observed in the HSS at lower luminosities, we re-analyze the *Suzaku* data taken during the 2006 outburst. The continuum can be well explained by thermal disk emission and a hard power-law tail. All spectra show strong iron-K absorption line features, suggesting that a disk wind is always developed in the HSS. We find that the degree of ionization of the wind dramatically increased at the brightest epoch in 2015, when the continuum became harder. Detailed XSTAR simulations show that this cannot be explained solely by an increase of the photoionization flux. Instead, we show that all observed behavior in the HSS is consistent with theory of thermally-driven disk winds, where the column density and the ionization parameter of the disk wind are proportional to the luminosity and the Compton temperature, respectively.

In Chapter 3, we present the first *MAXI*/GSC X-ray source catalog in the low Galactic latitude sky $|b| < 10^\circ$ outside the Galactic center region ($|b| < 5^\circ$, $l < 30^\circ$, and $l > 330^\circ$) based on 7-year data from 2009 August 13 to 2016 July 31. To overcome source confusion in crowded regions, we have accurately calibrated the position-dependent shape of the point spread function of the *MAXI*/GSC by analyzing the onboard data. We have also taken into account the Galactic ridge X-ray emission. Using a maximum likelihood image-fitting method, we have detected 221 sources with a significance of $> 6.5\sigma$, 7 of which are transients only detected in 73-day time-sliced images. The faintest source has a flux of 5.2×10^{-12} erg cm $^{-2}$ s $^{-1}$ (or an intensity of 0.43 mCrab) in the 4–10 keV band. We have identified the counterparts for about 81% of the detected sources, by cross-matching with *Swift*, *Uhuru*, *RXTE*, *XMM-Newton*, MCXC, and

ROSAT all sky survey catalogs. Our catalog contains the source name, position and its error, flux and detection significance in 3–4 keV, 4–10 keV, and 10–20 keV band, hardness ratios, and the information of the likely counterpart for the individual detected sources. We have obtained 73-day-bin light curves of all the cataloged sources over 7 years and have calculated their periodograms. The unidentified sources show large variability, which suggests that the majority are X-ray binaries or blazars. We also present the $\log N - \log S$ relations at different Galactic longitudes and for different source populations.

Finally, in Chapter 4, we summarize the conclusions of these studies.

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Chapter 1

General Introduction

1.1 X-ray Binaries

The X-ray binaries (XRB) are the binary system consist from a compact star (such as neurons stars and black holes) and a donor star (Fig 1.1). They are classified into two categories: low-mass X-ray binaries (LMXB) and high-mass X-ray binaries (HMXB). The donor star of the low-mass X-ray binaries (LMXB) are later than A-type and always fills its Roche lobe. Therefore, a accretion disk around the central compact star is always formed. If the donor star is a massive star (O or B type), they are classified into HMXB. In the case of HMXB, accretion also can forms a accretion disk if the companion star overflows its Roche lobe. On the other hand, sometimes an accretion disk is not formed if the dense stellar wind directly accrete onto the central star through the Bondi accretion or the HMXB contains a Be companion star.

1.1.1 Black Holes

In the general relativity, the black hole (BH) is specified by two parameters; its mass M and the dimensionless spin parameter $a^* = a/R_g$. Here, a and $R_g \equiv GM/c^2$ are the specific angular momentum and the gravitational radius, where G and c is the the gravitational constant and the light speed, respectively. In the Schwarzschild BH ($a^* = 0$), the radius of the event horizon R_S and the innermost stable circular orbit (ISCO) are $R_S = 2R_g = 30(M/10M_\odot)$ km and $R_{\text{ISCO}} = 6R_g$, respectively. For an extreme Kerr BH ($a^* = 1$), the radius of the event horizon and the

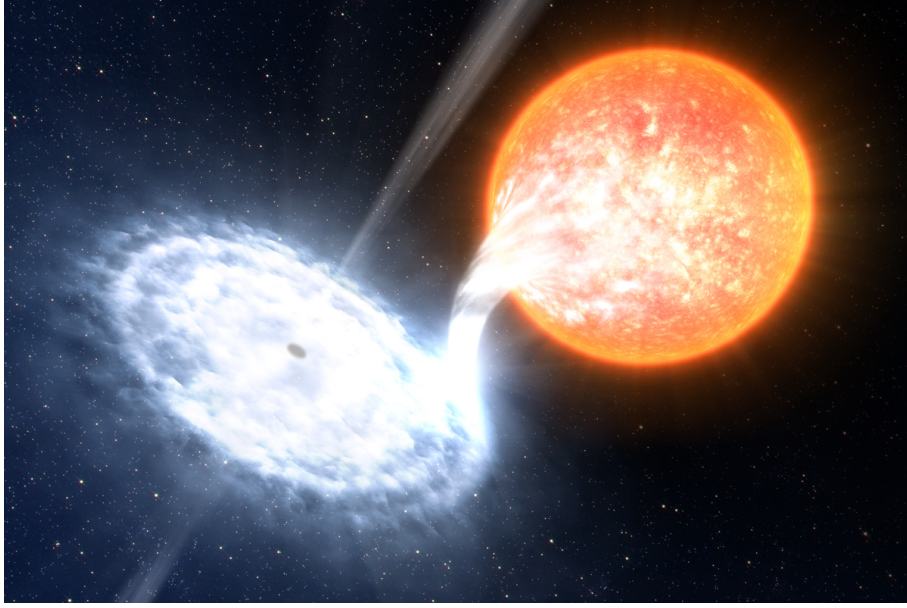


Figure 1.1. An image of the X-ray binary (ESO/L. Calçada)

ISCO becomes identical ($R_K = R_{\text{ISCO}} = R_g$).

1.1.2 Spectral State

Many XRBs are discovered when they go into first outburst, which is triggered by the hydrogen ionization instability (see e.g., Kato et al., 1998). At a material temperature of $10^4 - 10^5$ K, a small increase of a temperature are able to ionize some of hydrogen because the opacity of the hydrogen rises steeply at these temperature. The capture of ionizing photons causes a increase of the temperature still further (Fig 1.3). This thermal runaway, which triggered at a certain radius, only stops when the Hydrogen completely ionized. The mass accretion rate becomes larger with increasing temperature, so that a huge amount mass accrete onto a central black hole.

The evolution of the state of a XRB during an outburst is complex, and not solely determined by mass accretion rate. In typical outbursts, a XRB shows hysteresis with a q-shaped curve on a hardness-intensity diagram (Fig 1.2). Sources start from the Low/Hard State (LHS), where the

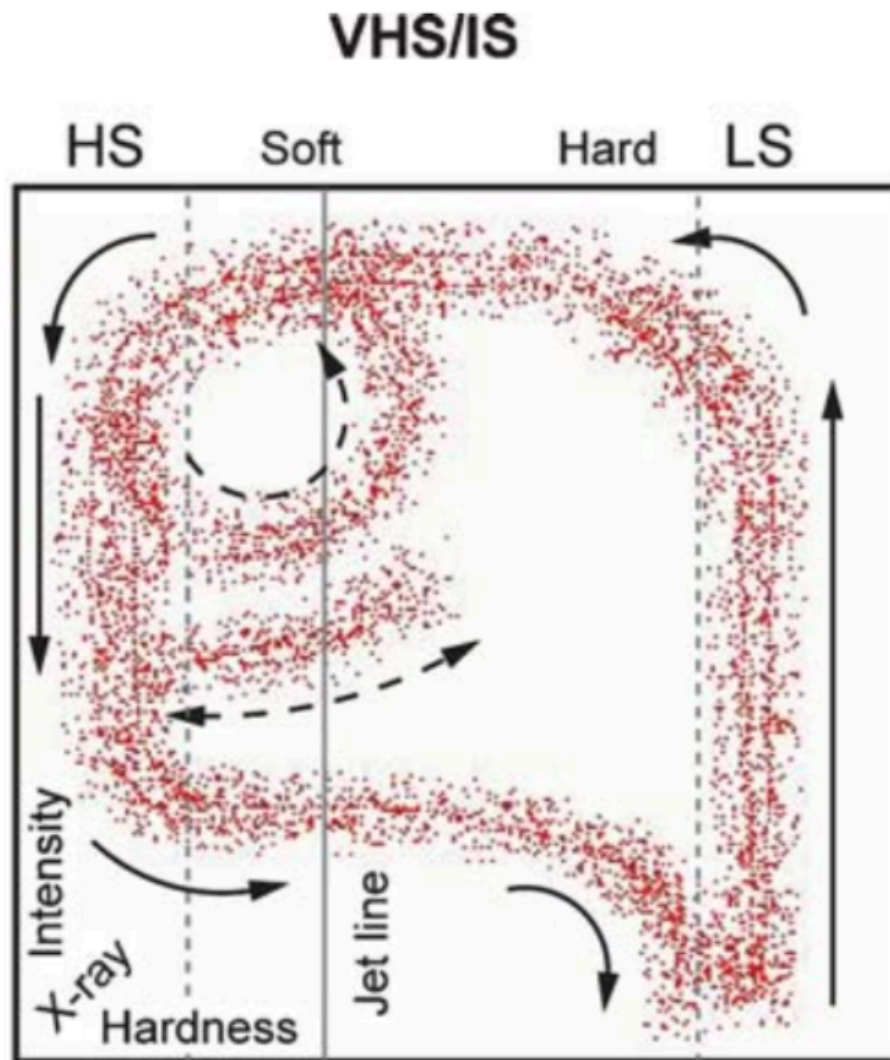


Figure 1.2. A schematic view of evolutionary track during outburst (Remillard & McClintock, 2006).

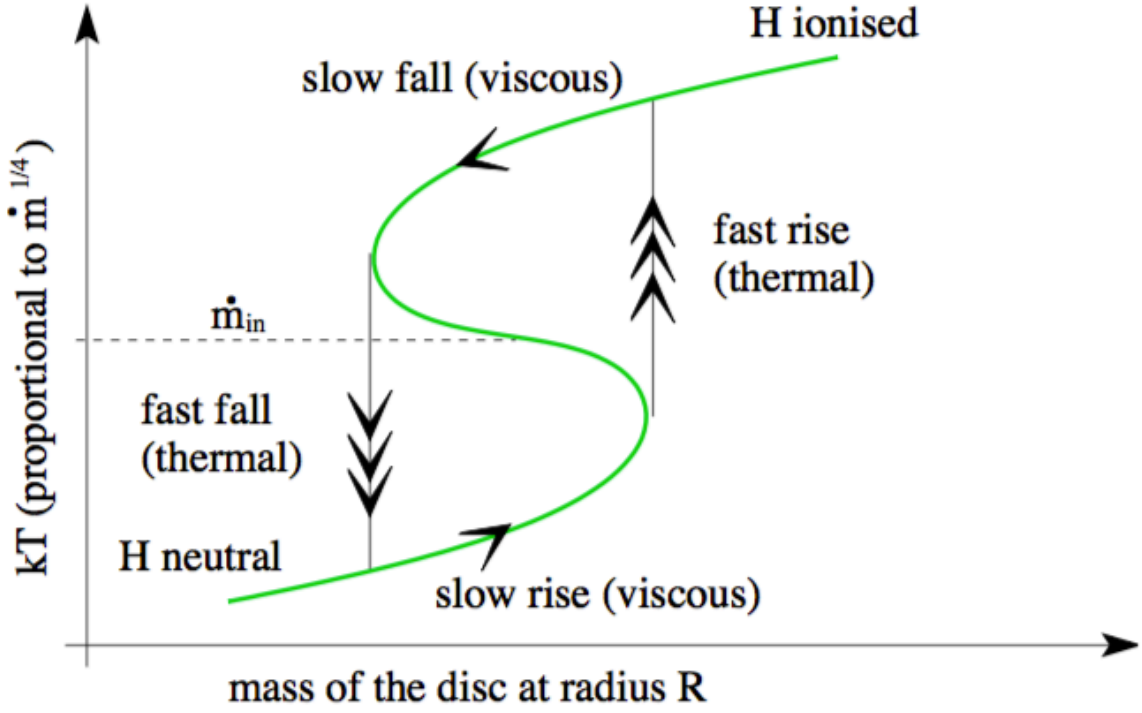


Figure 1.3. The hydrogen ionization instability (Done et al., 2007). The mass accretion rate jumps discontinuously at a certain radius.

spectrum is dominated a power law with a photon index of $\Gamma \sim 1.7$ and a high energy cut-off at ~ 100 keV. At a higher mass accretion rate, they make a transition into the High/Soft State (HSS), where the spectrum is dominated by optically thick, thermal emission from the accretion disk, which is well represented by the Multi-Color Disk (MCD) model (Mitsuda et al., 1984; Makishima et al., 1986). Fig 1.4 shows the typical spectra of LHS and HSS together with relatively rare states (the very high and ultrasoft state). The source remains in the HSS while the luminosity declines, and then turns back to the LHS, at a luminosity which can be a factor of 2-20 times smaller than the initial LHS-HSS transition. This hysteresis behavior probably originates from the accretion rate changing faster than the viscous timescale in the geometrically thin disk (Gladstone et al., 2007). However, BHBs in outbursts do not always exhibit similar evolutionary tracks on this diagram (e.g., Nakahira et al. (2014); Hori et al. (2014)), implying that the physical processes governing the spectral evolution in BHBs may be even more complicated.

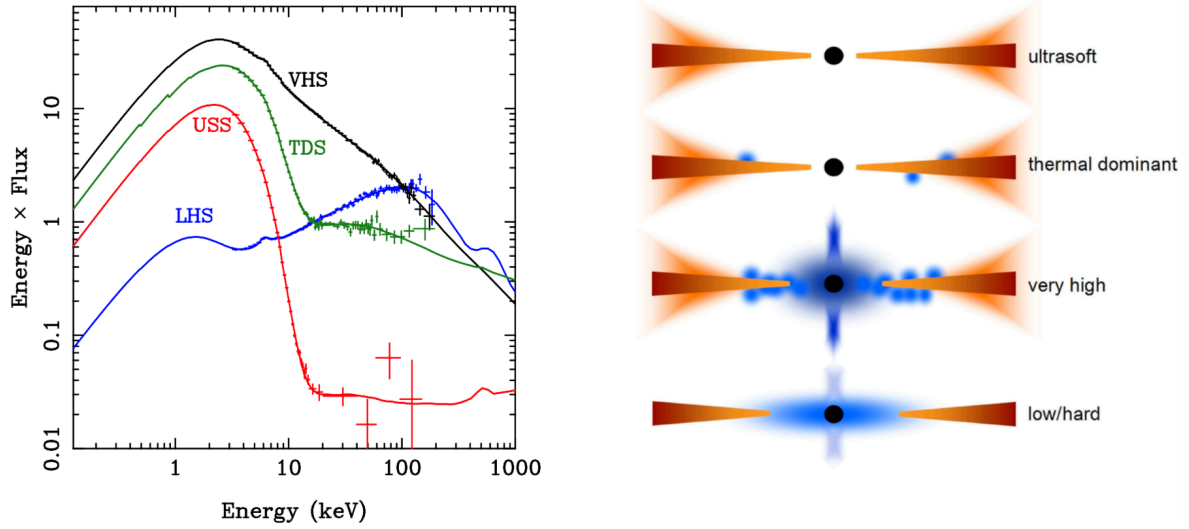


Figure 1.4. The X-ray spectrum taken from the 2005 outburst of GRO J1655 – 40 (left) and the schematic sketch of geometry of accretion disk for each state (right) (Done et al., 2007).

1.1.3 Disk Wind

Modern X-ray spectroscopy has revealed that highly ionized disk winds are a ubiquitous feature in accreting Black Hole Binaries (BHBs). Disk winds interrupt X-ray photons emitted from the central source and produce absorption lines from highly ionized ions in the observed spectra (e.g., Ueda et al., 1998; Kubota et al., 2007). Since these absorption lines are mainly observed in high inclination angle systems, it is thought that these winds are aligned along the disk plane with an opening angle of few tens of degrees (Ponti et al., 2012). While disk winds seem to always present in the High/Soft State (HSS), the absorption line features disappear in the low/hard state (Fig 1.5) with a few exceptions (Shidatsu et al., 2013). Understanding of the nature of disk winds is indispensable to build the whole picture of accretion-disk dynamics in BHBs since a huge amount of accreted matter is carried away by them (e.g., Ueda et al., 2009).

Three major theoretical models have been proposed as the origin of the disk wind in XRB; radiatively driven, thermally driven, and magnetically driven winds (see, e.g., Done et al., 2007). Radiatively driven winds can be produced when the radiation pressure is sufficiently large. As the source luminosity L approaches the Eddington limit L_{edd} , the “effective” gravity

decreases by a factor of $1 - L/L_{\text{edd}}$; Ueda et al. (2004) showed that a wind can be launched when a gas in Keplerian motion is exposed to the radiation with $L > 0.5L_{\text{edd}}$. Thermally driven winds can be launched even at lower luminosities. When X-rays from the central source heat up an upper layer of the accretion disk to the Compton temperature T_{IC} that is higher than the gravitational binding potential at that radius, the gas will be released from the system by its thermal pressure (Begelman et al., 1983). Here, T_{IC} is calculated from the X-ray spectra by considering the equilibrium of Compton-heating and Compton-cooling photons:

$$T_{\text{IC}} = \frac{1}{4k_{\text{B}}} \frac{\int_0^\infty h\nu L_\nu d\nu}{\int_0^\infty L_\nu d\nu}. \quad (1.1)$$

Finally, magnetically driven winds may be formed by magnetohydrodynamics effects, where magnetic field transports the angular momentum from the disk outward (Penna et al., 2010).

1.2 X-ray Source Catalog

Demographic studies of Galactic X-ray sources provide us important clues to understand the evolutionary history of our Galaxy. Many of X-ray emitters over the sky, such as X-ray binaries, supernova remnants, and cataclysmic variables, form classes of objects at their last evolutionary stages, and their formation and evolution must have been influenced by their environment. This is reflected in the current spatial and luminosity distributions of each class of Galactic X-ray sources. Complete X-ray source catalogs in the Galactic plane become the base for such statistical studies.

1.2.1 Comparison with Other Catalogs

Since the majority of Galactic sources are subject to heavy interstellar absorption, observations in hard X-rays above a few keV are essential. Deep imaging observations of the Galactic plane have been conducted by various X-ray observatories covering energies above 2 keV, such as *ASCA* (Sugizaki et al., 2001), *Chandra* (Grindlay et al., 2005; Ebisawa et al., 2005), *XMM-Newton* (Hands et al., 2004; Nebot Gómez-Morán et al., 2013). While these observa-

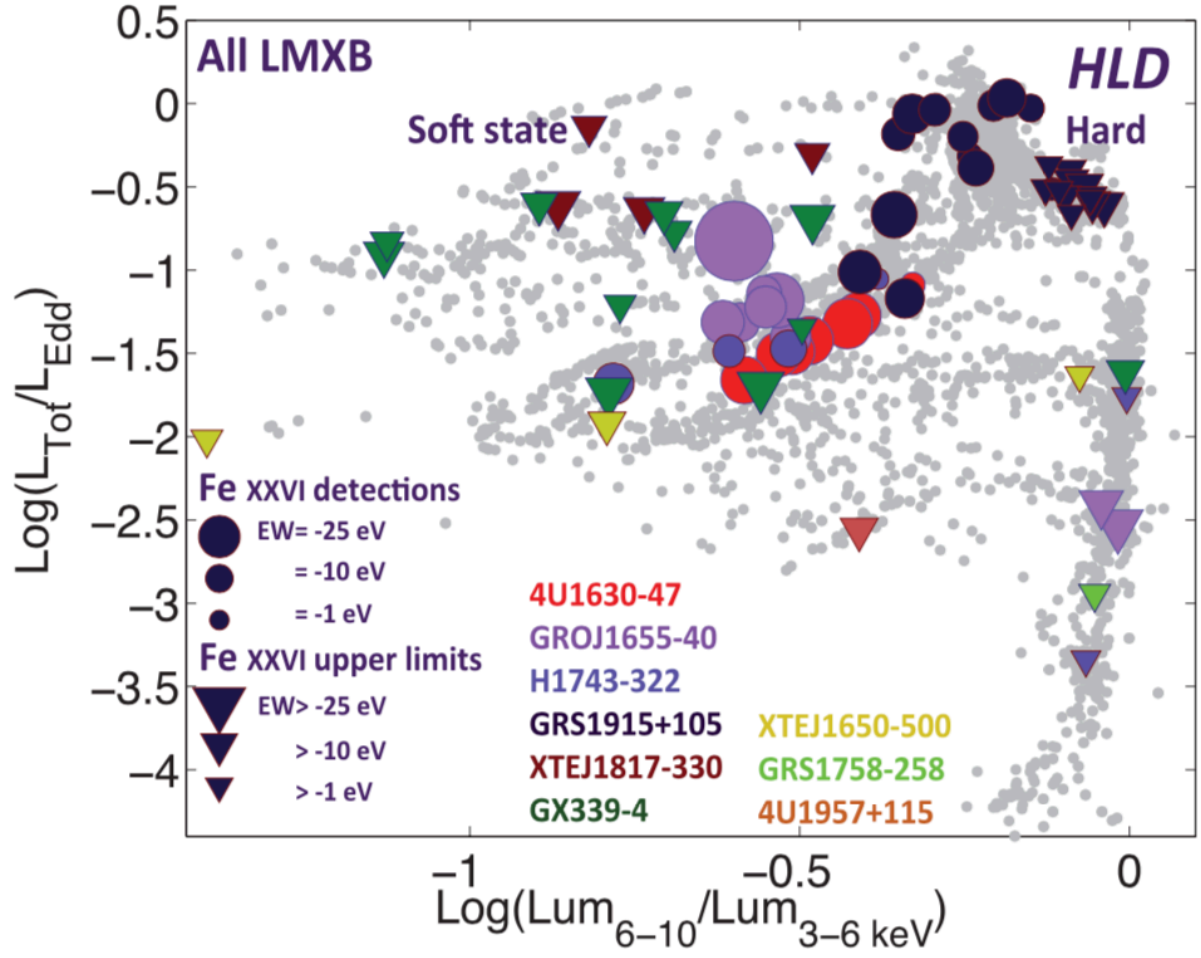


Figure 1.5. The hardness-intensity diagram for several BHBs (Ponti et al., 2012). Circle and triangle indicate the detection and non-detection of Fe XXVI absorption line, respectively.

tions achieve high sensitivities, they cover only limited regions around the Galactic center or at very low Galactic latitudes. Wider area surveys that completely cover the low Galactic latitude region are necessary to provide a complete picture of Galactic X-ray populations.

1.2.2 MAXI

Monitor of All-sky X-ray Image *MAXI* (Matsuoka et al., 2009) is an all-sky X-ray monitor onboard International Space Station (ISS), and have been operating for more than 8 years since 2009 August. Its main instrument, the Gas Slit Camera (GSC; Mihara et al., 2011), covers the energy band of 2–30 keV and scans nearly the entire sky every 92 minutes with an instant field of view of $3.0^\circ \times 160^\circ$. The GSC is composed of 12 one-dimensional gas counters (GSC0 to GSC9, GSCA, and GSCB) with slat collimators attached on the individual counters. Six of the 12 units are placed in front of MAXI, and the others are on the top of it, producing the wide rectangular field-of-views in the horizontal and zenithal directions (see Fig 1.6 or Mihara et al., 2011, for more detailed information). The exposure time of a point source is $\sim 40\text{--}140$ s for 1 counter and 1 scan. The scan duration of a counter is longer for a source located closer to the pole of the ISS rotation (Sugizaki et al., 2011). The effective area of a point source is proportional to $\cos(\phi)$, where ϕ is the photon incident angle along the collimators. The typical value is $\sim 5\text{ cm}^2$ at the scan angle of 0° (Sugizaki et al., 2011).

1.3 Motivation and Strategy

It is not clear whether or not all disk winds in BHBs have a common, unique origin. Previous studies suggested that most of disk winds are consistent with thermally driven ones on the basis of their estimated locations (e.g., Kubota et al., 2007). By contrast, evidence for a magnetically driven wind was reported in GRO 1655–40 by Miller et al. (2006), who found that the launching radius is much smaller than that expected from a thermally driven wind by using diagnostic of the density sensitive lines. The interpretation of this particular case is still under debate, however (e.g., Netzer, 2006; Miller et al., 2008; Kallman et al., 2009; Shidatsu et al., 2016; Done et al., 2018). Thus, it is very important to do more observational tests to identify the

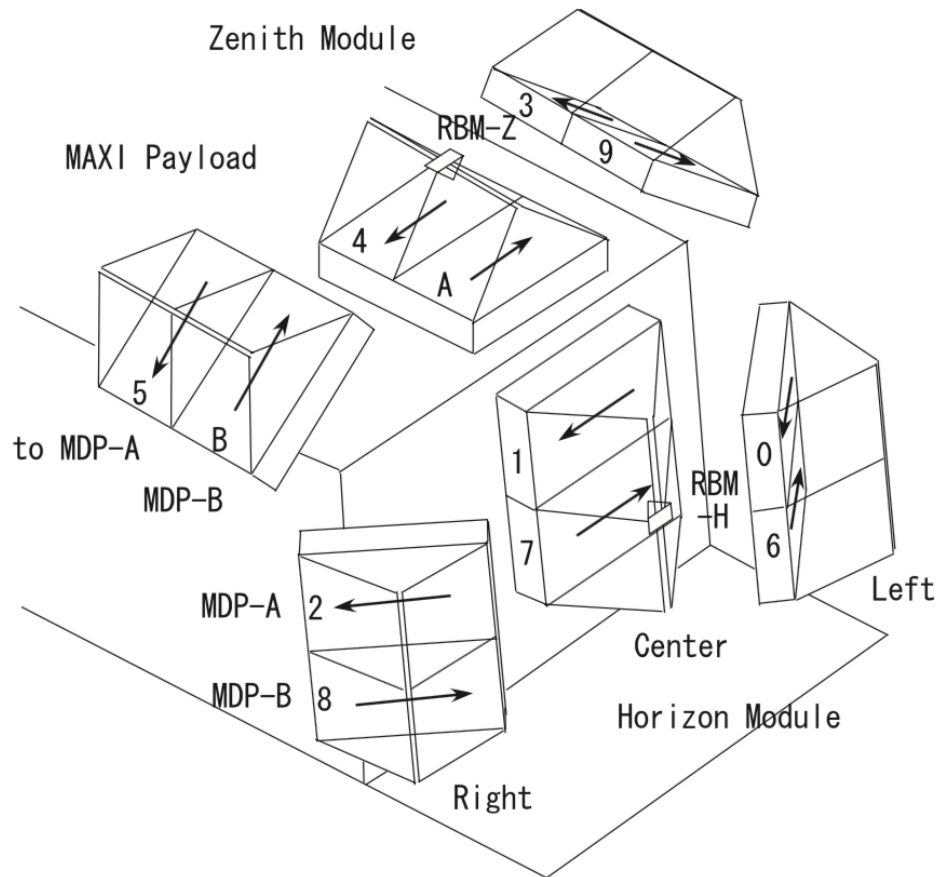


Figure 1.6. A schematic view of the GSC cameras on the MAXI payload. (Mihara et al., 2011).

origin of disk winds. In addition, it is not clear whether or not a long term variability can be explained by the theory of the thermal wind. Hence, the first main goal of this thesis is settled to certify that the thermal wind theory can explain the evolution of the disk wind observed in 4U 1630-47.

There are only a few tens of BH sources or candidate in the Galaxy (Remillard & McClintock, 2006) and only 1 candidate for the magnetically driven wind (Miller et al., 2006). The *MAXI*/GSC catalog, which is the second goal of this thesis, is expected to provide a larger BHB sample since the *MAXI*/GSC achieves the highest sensitivity in the 4–10 keV band among the previous and on-going all-sky surveys, such as *Uhuru* (Forman et al., 1978), *HEAO-1* (Wood et al., 1984), and *RXTE* slew survey (Revnivtsev et al., 2004) and is complementary to those in the soft X-ray band below 2 keV (*ROSAT*: Voges et al., 1999) and above 10 keV (*INTEGRAL*: Bird et al., 2007, 2010, 2016; Ebisawa et al., 2003); (*Swift*: Baumgartner et al., 2013; Oh et al., 2017). In particular, the 4–10 keV band survey has an advantage for detecting X-ray populations with soft spectra without suffering from absorption as long as the hydrogen column density is smaller than $\sim 10^{23} \text{ cm}^{-2}$. In addition, *MAXI* provides us a unique opportunity to study long-term variability of each object, thanks to its almost continuous all-sky monitoring for >7 years.

This thesis constructed by 4 chapters. Chap 2 gives the results from simultaneous observations with *Suzaku* and *NuSTAR* of the Galactic black hole binary 4U 1630–47 in the HSS during the 2015 outburst. We show that all observed behavior in the HSS is consistent with a theory of thermally-driven disk winds. Chap 3 gives the first *MAXI*/GSC X-ray source catalog in the low Galactic latitude sky $|b| < 10^\circ$ outside the Galactic center region ($|b| < 5^\circ$, $l < 30^\circ$, and $l > 330^\circ$) based on 7-year data from 2009 August 13 to 2016 July 31. We suggest that the majority of the unidentified sources are XRB or blazars. Finally, we give a conclusion at Chap 4.

Chapter 2

Evolution of Thermally Driven Disk Wind in the Black Hole Binary 4U 1630–47

2.1 Introduction

4U 1630–47 is an ideal BHB to investigate the properties of the disk wind thanks to its brightness and frequent outbursts. Outbursts of 4U 1630–47 are observed with many missions since 1980s, including *EXOSAT* (Parmar et al., 1986), *Einstein/Ginga/ASCA* (Parmar et al., 1997), *Beppo-SAX* (Oosterbroek et al., 1998), *RXTE* (e.g., Tomsick et al., 1998; Kuulkers et al., 1998; Tomsick & Kaaret, 2000; Trudolyubov et al., 2001; Abe et al., 2005), *INTEGRAL* (Tomsick et al., 2005), *Suzaku* (Kubota et al., 2007), *XMM-Newton* (Díaz Trigo et al., 2013), and *NuSTAR* (King et al., 2014). Figure 2.1 shows the overall light curve of 4U 1630–47 obtained with the All Sky Monitor (ASM) onboard Rossi X-ray Timing Explorer (*RXTE*; Levine et al., 1996) and with the Gas Slit Camera (GSC) onboard MAXI (Matsuoka et al., 2009). Here the count rates of the *RXTE*/ASM light curve are converted to the energy fluxes by using Equation (A1) in Zdziarski et al. (2002), and those of the MAXI light curve in the 4–10 keV band are converted to the 3–12 keV fluxes by assuming the Crab spectra. As noticed, 4U 1630–47 exhibits quasi-periodic outbursts with a 600–700 day cycle. Kubota et al. (2007) detected H-like and He-like iron absorption lines from six observations in the HSS with *Suzaku* during the 2006 outburst (indicated by the down arrow in Figure 2.1). They found that these absorption lines

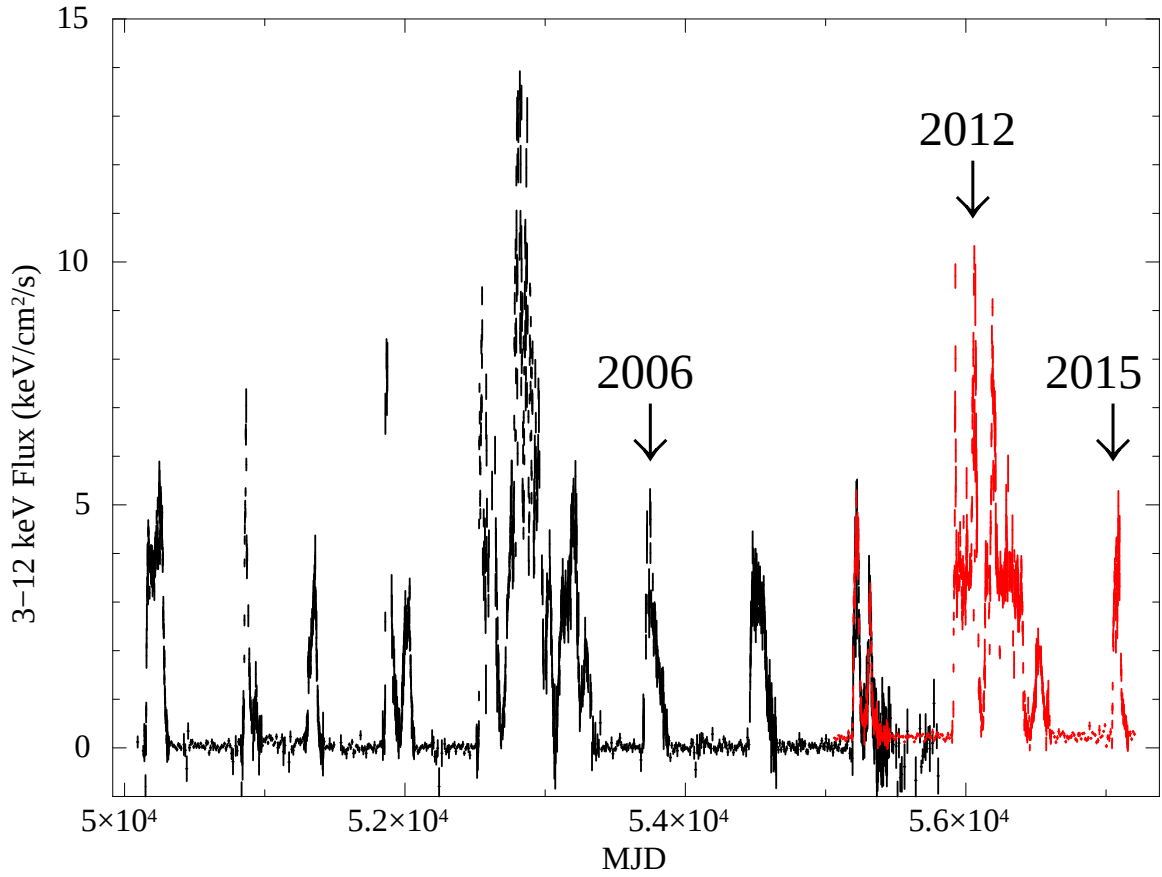


Figure 2.1. Long term light curves of 4U 1630–47 in the 3–12 keV band obtained with *RXTE*/ASM (black) and *MAXI*/GSC (red). Two long outbursts occurred around MJD= 53000 and MJD= 56000. The 2006, 2012, and 2015 outbursts are indicated by the down arrows.

became weaker with increasing luminosity, which is consistent with a photoionization scenario. King et al. (2014) also reported the highly ionized absorption lines during the 2012 outburst when the source was in a very similar state to those observed by Kubota et al. (2007). Hori et al. (2014) observed 4U 1630–47 in the very high state (VHS) around the peak of the 2012 outburst with *Suzaku*, and found that the iron-K absorption lines disappeared in this state. The absence of these features in the VHS was also reported by Díaz Trigo et al. (2014) by using the *XMM-Newton* data.

In this chapter, we report the results of simultaneous observations of 4U 1630–47 with *Suzaku* and *NuSTAR* on 3 occasions during the 2015 outburst. Combining with the *Suzaku* results in the 2007 outburst, we examine the evolution of the iron-K absorption lines in the HSS. Section 2 describes the observation and data reduction. The results of the spectral analysis are presented in Section 3. We discuss the origin of the disk wind by comparison with a theoretical model in Section 4, and summarizes our conclusions in Section 5. For convenience of discussion, we

always assume the distance of $D = 10$ kpc, inclination angle of $i = 70^\circ$, and black hole mass of $M_{\text{BH}} = 10 M_\odot$ as reference values, which are all unknown for this target. Solar abundances by Anders & Grevesse (1989) are adopted. The errors in spectral parameters are given at 90% confidence limits for a single parameter of interest.

2.2 Observation and Data Reduction

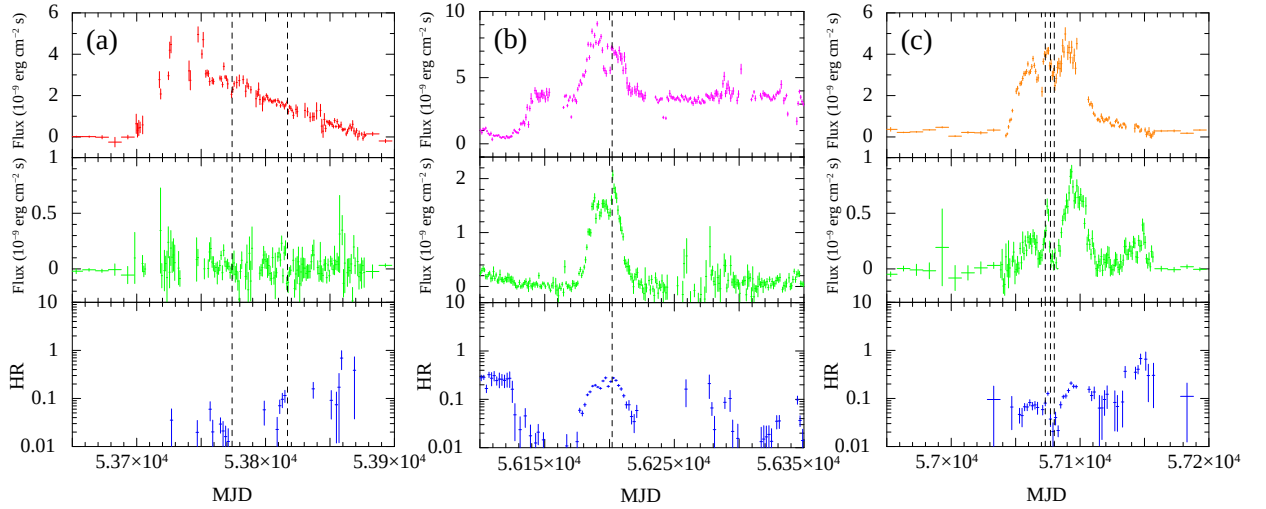


Figure 2.2. (Top) Expanded light curves of 4U 1630–47 in the 3–12 keV band during 2006 (a), 2012 (b), and 2015 (c) outburst, observed with *RXTE*/ASM for (a) and *MAXI*/GSC for (b) and (c). (Middle) Those in the 15–50 keV obtained with *Swift*/BAT. (Lower) The hardness ratio between the two bands. The dashed lines represent the epochs of the *Suzaku* observations.

Figure 2.2 shows blowups of the X-ray light curve of 4U 1630–47 during the 2006 (a), 2012 (b), and 2015 (c) outbursts. The top, middle, and bottom panels plot those in the 3–12 keV band obtained with *RXTE*/ASM (a) or with *MAXI*/GSC (b and c, converted from the 4–10 keV count rate by assuming the Crab spectrum), those in the 15–50 keV band obtained with Burst Alert Telescope (BAT) onboard *Swift* (Burrows et al., 2005), and their hardness ratio (3–12 keV/15–50 keV), respectively. Three ToO (Target of Opportunity) observations of 4U 1630–47 are performed with *Suzaku* on 2015 February 20, 24, and 27, simultaneously with *NuSTAR* (Harrison et al., 2013) for the first two epochs. The overall behavior of the 2015 outburst was quite complex, showing several spiky peaks around the maximum luminosity. Our

ToO observations, whose epochs are indicated by the dotted lines in Figure 2.2(c), were made around the second peak of the outburst. The luminosity in the 2–6 keV band was the highest in the first epoch among the three, and those in the second and third ones were similar to each other (Table 2.1).

Table 2.1. obsevation log

OBSID	Suzaku Observation Date		XIS Option	Exposure (ks)			Flux (erg cm ⁻² s ⁻¹)	
	Start	End		Suzaku XIS	PIN	NuSTAR	2–6 keV	12–30 keV
6	2006 Feb 8 15:09	Feb 9 3:20	1/4 window + 1s burst	11.1	20.5	—	3.4×10^{-9}	1.5×10^{-10}
5	2006 Feb 15 23:29	Feb 16 13:08	1/4 window + 1s burst	10.7	16.0	—	2.5×10^{-9}	1.2×10^{-10}
4	2006 Feb 28 23:18	Mar 1 16:43	1/4 window + 1s burst	10.7	17.9	—	2.4×10^{-9}	7.3×10^{-11}
3	2006 Mar 8 1:49	Mar 8 17:31	1/4 window	10.6	19.1	—	2.1×10^{-9}	5.0×10^{-11}
2	2006 Mar 15 5:26	Mar 15 17:51	1/4 window	23.2	17.7	—	1.9×10^{-9}	4.2×10^{-11}
1	2006 Mar 23 10:13	Mar 23 22:21	1/4 window	21.7	21.3	—	1.7×10^{-9}	3.7×10^{-11}
8	2015 Feb 20 5:41	Feb 21 9:52	1/4 window + 0.3s burst	5.3	—	16.5 ^a	4.4×10^{-9}	6.0×10^{-10}
7	2015 Feb 24 1:30	Feb 25 2:44	1/4 window + 0.3s burst	5.5	—	16.1 ^b	3.7×10^{-9}	1.4×10^{-10}
0	2015 Feb 27 2:28	Feb 28 3:42	1/4 window + 0.3s burst	5.1	—	—	3.7×10^{-9}	—
α	2012 Oct 2 0:24	Oct 2 20:38	1/4 window + 1s burst	2.9	39.5	—	6.6×10^{-9}	3.5×10^{-9}

^aObserved between 2015 Feb 20 11:36 and Feb 20 23:31

^bObserved between 2015 Feb 24 10:46 and Feb 24 21:46

Suzaku carries two types of detectors, the X-ray Imaging Spectrometer (XIS) and the Hard X-ray Detector (HXD). At the time of our observations, two front-side-illuminated XISs (FI-XISs) XIS0 and XIS3, and one back-side-illuminated XIS (BI-XIS), XIS1, were available, whereas the HXD was turned off due to the power shortage of the spacecraft. All XISs were operated with the 1/4 window mode and the 0.3 s burst option to avoid pileup effects. We utilized the “cleaned” event files reduced by the pipeline processing version 2.8.20.37 and analyzed them in a standard manner with HEASOFT version 6.16 and calibration database released on 2015 March 12. To avoid any pileup effect, the XIS spectra were integrated within an annular region with inner and outer radius of 0′.3 and 1′.3, respectively. The background spectra were taken from a circular region with a radius of 1′.3 away from the source by 7′. Further details about these observations are listed in Table 2.1.

NuSTAR has two Focal Plane Modules (FPM), A and B. The *NuSTAR* data were reduced with the standard pipeline NUPIPELINE version 0.4.3 and were analyzed with NUSTARDAS software version 1.4.1 included in HEASOFT version 6.16. The source spectra were extracted

from a central $100''$ circular region around the target by using the standard tool NUPRODUCTS. We extract the background spectra from an annular region with an inner and an outer radius of $240''$ and $260''$, respectively. The exposure times are listed in Table 2.1.

We found that the FI-XIS spectra were apparently harder than the BI-XIS spectra, most probably due to the cross calibration error, as reported in recent *Suzaku* data (e.g., Shidatsu et al., 2013). Hence, these differences were approximately corrected by multiplying the FI-XIS spectra by a power-law function with a photon index of -0.10 in spectral fitting. This procedure made much better agreement of the FI spectra with the BI-XIS and NuSTAR spectra. We note that the BI-XIS spectrum could also be possible to contain some calibration errors.

We re-analyzed the *Suzaku* archive data taken during the 2006 outburst (obsid=400010010 through 400010060), which were analyzed and published by Kubota et al. (2007), to compare our results to those of previous *Suzaku* observations. The shape of the light curves (Figure 2.2(a)), characterized by a fast rise and a gradual decay, were less complex than that of the 2015 outburst. The right and left dashed lines in this figure represent the epochs of the first (obsid=400010010) and the last (obsid=400010060) observations, respectively. The details of these observations are also listed in Table 2.1. Because all observations in 2006 suffer from serious pileup effect, these spectra were extracted within an annular region with inner and outer radius of $1'$ and $1'.7$, respectively.

Figure 2.3 shows the time-averaged spectra in the 2006 and 2015 outbursts. The overall spectral shapes are almost same in these observations, except for that in the brightest observation in the 2015 outburst (orange), which showed a stronger hard power-law tail. Hereafter, we refer to the 1st to 6th observations in 2006, the 2nd observation in 2005, and the 1st one in 2015 as OBS 1 to 6, 7, and 8, respectively (in order of increasing luminosity). We refer to the 3rd observation during the 2015 outburst as OBS A and treat it separately because no hard X-ray data above 10 keV are available. We note that the spectra in OBS 7 (blue) became slightly softer than that in OBS 6 (red).

For comparison, we also plot the VHS spectra observed in the 2012 outburst, which was published by Hori et al. (2014). The flux responsible for photoionization of iron ions (i.e., above ~ 9 keV) in this observation was much higher than in the HSS. The spectrum did not

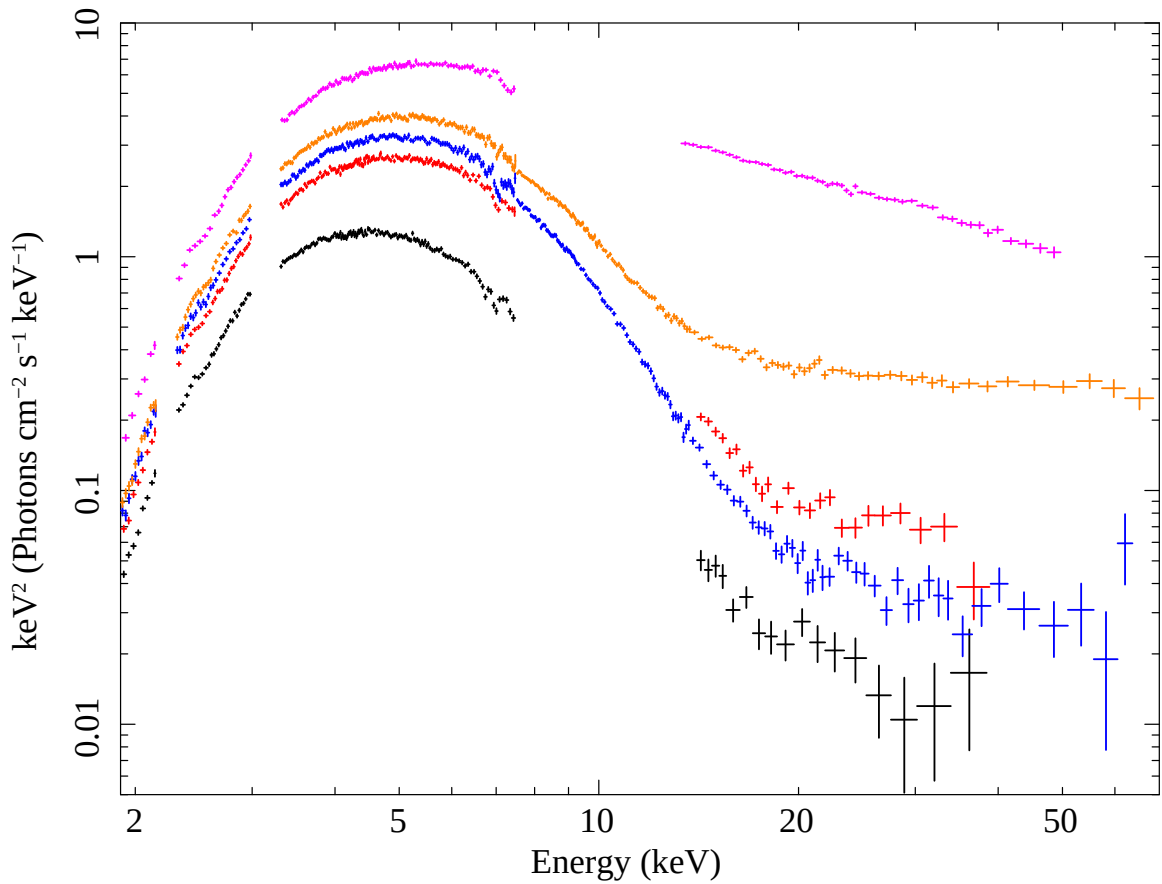


Figure 2.3. The broad-band spectra of 4U 1630–47 in the 2006 (black and red), 2012 (magenta), and 2015 (blue and orange) outbursts. We plot the time-averaged *Suzaku*/XIS1 and HXD spectra in the range of 2–7.5 keV and 12–40 keV, respectively. The HXD was not operated during the 2015 outburst. The *NuSTAR*/FMPA spectra in the 2015 outburst are also plotted, which cover the 7.5–70 keV range. The black, red, green, and orange data correspond to OBS 1, 6, 7, and 8, respectively. The observation during 2012 outburst (magenta) was operated when its state was in the VHS.

show any iron-K absorption line features, although it cannot be explained the photoionization effect alone (Hori et al., 2014).

2.3 Spectral Analysis

2.3.1 Effect of Dust Scattering

Since 4U 1630–47 suffers from heavy absorption by the interstellar matter ($N_{\text{H}} \sim 8 \times 10^{22} \text{ cm}^{-2}$), effects by the dust scattering (Ueda et al., 2010) is not ignorable. Interstellar dust scatters out a part of photons that directly come into our line-of-sight, whereas other photons with slightly different directions are scattered in the line-of-sight, producing a dust-scattering halo around the source. Since the field-of-view of *Suzaku*/XIS and *NuSTAR*/FMP cannot fully cover this dust-

scattering halo, the scattered-in and scattered-out photons are not canceled each other. Hence, we have to estimate the fraction of the scattered-out photons (hereafter "scattering fraction") and to correct for this effect in the spectral analysis. The situation becomes even more complex for a variable source because of the time delay between the direct and scattered-in components.

In this chapter, we follow the same procedure as in (Hori et al., 2014). First, for all *Suzaku*/XIS spectra, we estimate the scattering fraction to be 87% and 67% for observations during 2006 and 2015 outbursts, respectively, with the FTOOL `xissimarfgn` by assuming the image profile of the dust-scattering halo obtained by Smith et al. (2002). For the *NuSTAR*/FMP data, we approximately estimate it to be 66% by ignoring the point spread function. Then, in the spectral fit, we utilize the `Dscat` model, which is a local model developed by (Ueda et al., 2010), to take into account the effects of dust-scattering. It calculates the fraction of the scattered-in and scattered-out components as a function of energy, by referring to the cross section of dust scattering given by Draine (2003). We check effects by time variability of 4U 1630–47 during the 2015 observations. The maximum time delay at the outer integration radius $1'.2$ is estimated to be ~ 1 day by assuming that the scatterers are located at the half distance of 10 kpc. The source shows a flux decay of $\sim 20\%$ around the *Suzaku* observations on this time scale (Figure 2.2(c)), which would lead to an enhancement of the scattering fraction by $< 4\%$ in OBS 8. We confirm that it does not affect our final results (sec 2.4). Hence, for simplicity, we ignore time variability in estimating the scattering fraction in the following analysis.

2.3.2 Continuum Modeling

Spectral analysis is performed separately to the data of OBS 1 through 8. We use the spectra of *Suzaku*/XIS, *Suzaku*/PIN, and *NuSTAR*/FMP in the energy range of 1.9–7.5 keV, 12–40 keV, and 6–80 keV, respectively. Conservatively, the XIS data above 7.5 keV are not utilized to minimize pileup effects, and those in the 2.1–2.3 keV and 3.0–3.4 keV are also excluded to avoid calibration uncertainties. The spectra of the two FI-XISs (XIS0 and 3) are summed together. Spectral fit is performed by using XSPEC version 12.8.2.

We apply a conventional model consisting of a MCD component and a power law with a low energy cutoff (`diskbb` and `simpl` in XSPEC terminology, respectively). The `simpl` model

has two free parameters, the photon index Γ and the fraction of the seed photons f_{PL} . To take into account adsorption by interstellar medium, we use the `tbabs` model with the Wilms et al. (2000) abundances and the Verner et al. (1996) cross section. To estimate the column density of iron ions in a simple manner, we utilize the “kabs” model (Ueda et al., 2004), an *XSPEC* local model calculating the Voigt profile from multiple fine-structure lines. The kabs model has three free parameters, the column density of each ion $N_{\text{ion}}^{\text{wind}}$, the velocity dispersion, which is fixed at 500 km s^{-1} in this analysis (Kubota et al., 2007), and the redshift z . The model is thus expressed as `tbabs*Dscat*kabs*kabs*simpl*diskbb` in the *XSPEC* terminology, where the first and second kabs terms represent the absorption lines of H-like and He-like iron ions, respectively. We apply this model to all XIS spectra in the 2006 and 2015 outbursts.

Table 2.2. Best-fit parameters for spectral modeling.

Component	TBabs	diskbb	simpl			kabs			
Parameter	N_{H}^1	$T_{\text{in}}(\text{keV})$	$R_{\text{in}}(\text{km})$	Γ	$f_{\text{PL}}(\%)$	$N_{\text{FeXXVI}}^{\text{wind}}{}^2$	$N_{\text{FeXXV}}^{\text{wind}}{}^2$	$v_{\text{wind}}(\text{km s}^{-1})$	χ^2/dof
OBS 1	$7.89^{+0.03}_{-0.05}$	$1.12^{+0.01}_{-0.01}$	$27.5^{+0.5}_{-0.4}$	$2.95^{+0.42}_{-0.36}$	$1.1^{+0.7}_{-0.4}$	$1.43^{+0.39}_{-0.32}$	$0.53^{+0.18}_{-0.13}$	400^{+400}_{-400}	522/684
OBS 2	$7.88^{+0.05}_{-0.02}$	$1.19^{+0.01}_{-0.01}$	$27.6^{+0.4}_{-0.4}$	$2.00^{+0.37}_{-0.36}$	$0.3^{+0.2}_{-0.1}$	$1.10^{+0.28}_{-0.22}$	$0.35^{+0.10}_{-0.10}$	700^{+600}_{-600}	539/699
OBS 3	$8.00^{+0.06}_{-0.06}$	$1.20^{+0.01}_{-0.01}$	$28.6^{+0.5}_{-0.6}$	$2.38^{+0.30}_{-0.28}$	$0.5^{+0.3}_{-0.2}$	$1.15^{+0.41}_{-0.31}$	$0.32^{+0.14}_{-0.12}$	700^{+700}_{-800}	603/699
OBS 4	$8.06^{+0.05}_{-0.07}$	$1.22^{+0.01}_{-0.01}$	$25.1^{+0.4}_{-0.5}$	$2.44^{+0.22}_{-0.24}$	$0.8^{+0.3}_{-0.3}$	$1.09^{+0.39}_{-0.27}$	$0.25^{+0.11}_{-0.09}$	1400^{+600}_{-600}	557/696
OBS 5	$7.97^{+0.06}_{-0.05}$	$1.30^{+0.01}_{-0.01}$	$27.5^{+0.5}_{-0.4}$	$2.75^{+0.20}_{-0.19}$	$1.8^{+0.6}_{-0.4}$	$1.43^{+0.41}_{-0.31}$	$0.29^{+0.11}_{-0.09}$	1300^{+500}_{-500}	558/699
OBS 6	$8.08^{+0.05}_{-0.05}$	$1.34^{+0.01}_{-0.01}$	$27.3^{+0.3}_{-0.4}$	$2.29^{+0.14}_{-0.14}$	$0.9^{+0.3}_{-0.2}$	$1.00^{+0.26}_{-0.21}$	$0.07^{+0.06}_{-0.06}$	1300^{+600}_{-700}	576/713
OBS 7	$8.34^{+0.04}_{-0.02}$	$1.32^{+0.01}_{-0.01}$	$31.1^{+0.2}_{-0.3}$	$2.92^{+0.08}_{-0.08}$	$1.4^{+0.1}_{-0.2}$	$1.19^{+0.23}_{-0.19}$	$0.16^{+0.07}_{-0.05}$	1400^{+100}_{-100}	1422/1497
OBS 8	$8.41^{+0.04}_{-0.03}$	$1.34^{+0.01}_{-0.01}$	$32.5^{+0.2}_{-0.3}$	$2.25^{+0.02}_{-0.02}$	$3.3^{+0.1}_{-0.2}$	$0.26^{+0.06}_{-0.06}$	< 0.02	1300^{+500}_{-400}	1454/1497
OBS 0	$8.46^{+0.04}_{-0.05}$	$1.32^{+0.01}_{-0.01}$	$31.7^{+0.3}_{-0.4}$	2.5(fixed)	1.0(fixed)	$0.90^{+0.21}_{-0.18}$	< 0.04	2600^{+700}_{-700}	846/843

¹Hydrogen column densities in the unit of 10^{22} cm^{-2} .

²Ion column densities in the unit of 10^{18} cm^{-2} .

Table 2.2 summarizes the best-fit parameters and chi-squared value for each observation. Reasonably good fits are obtained with this model yielding the best-fit disk temperature of $T_{\text{disk}} \approx 1.2\text{--}1.4 \text{ keV}$ and photon index of $\Gamma \approx 2\text{--}3$. For OBS A, Γ and f_{PL} are fixed to be 2.5 and 1.0%, respectively, because the spectrum only covered the energy range below 7.5 keV. We find that a higher disk temperate is favored with a larger luminosity during 2006 outburst, which is expected from the standard accretion disk model (Shakura & Sunyaev, 1973). The column

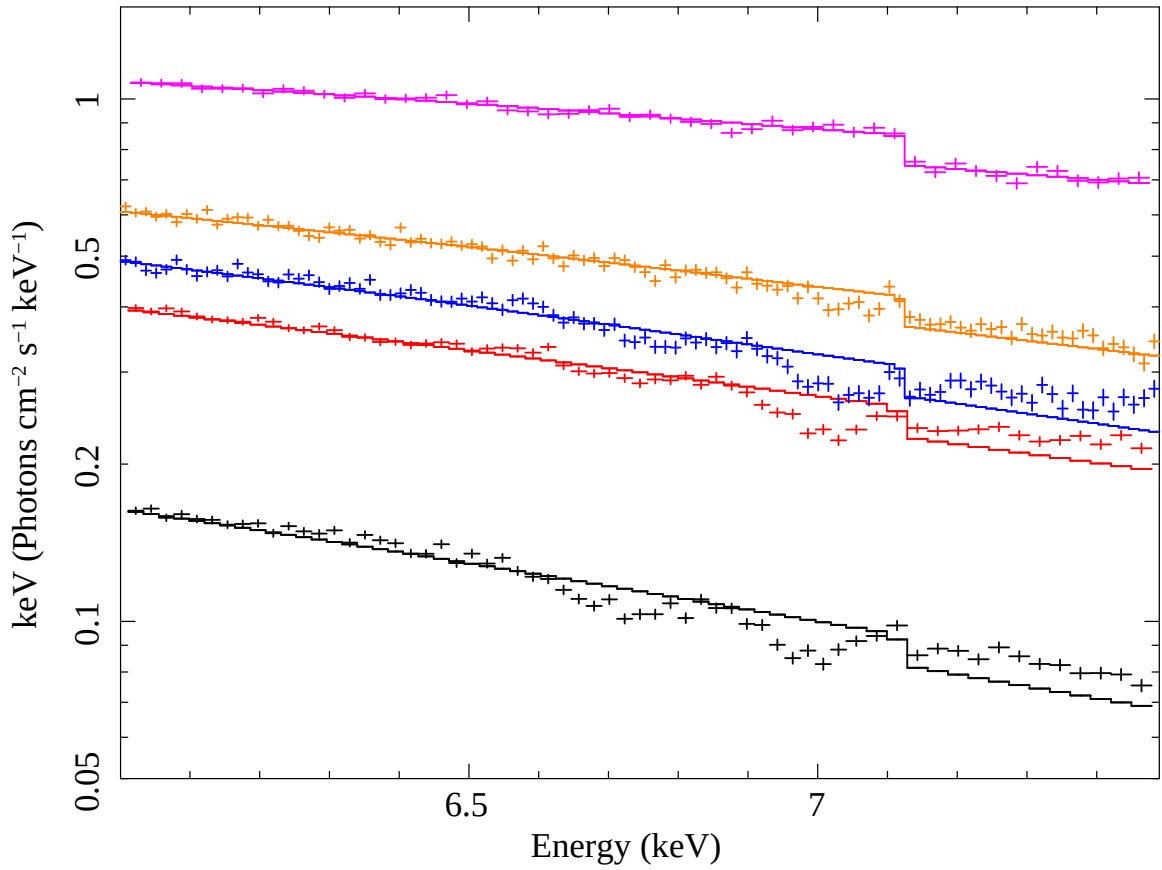


Figure 2.4. The unfolded spectra in the energy range of 6–7.5 keV during the 2006 (black and red), 2012 (magenta), and 2015 outbursts (blue and orange). Data of all XISs (XIS0, 1, and 3) are summed. The solid lines show the best-fit continuum model (see text).

density of the interstellar medium N_{H} and the inner radius estimated from the normalization of the `diskbb` were nearly constant during the 2006 outburst, while they became larger in the 2015 observations. We do not discuss these possible changes in this chapter, because the XIS spectra in 2015 could be subject to time-dependent calibration uncertainties. We find that f_{PL} was almost constant during OBS 1 through 7 but suddenly increased in OBS 8.

2.3.3 Long Term Variability of the Disk Wind

In this subsection, we focus on the iron-K absorption line features in OBS 1–8. Figure 2.4 shows the XIS unfolded spectra of OBS 1, 6, 7, and 8 in the 6–7.5 keV range together with the best-fit continuum model corrected for the interstellar absorption and dust scattering. For comparison, we also plot the spectra in the VHS obtained in the 2012 outburst, which does not show any absorption-line features. Here we adopt the continuum model described in Hori et al. (2014).

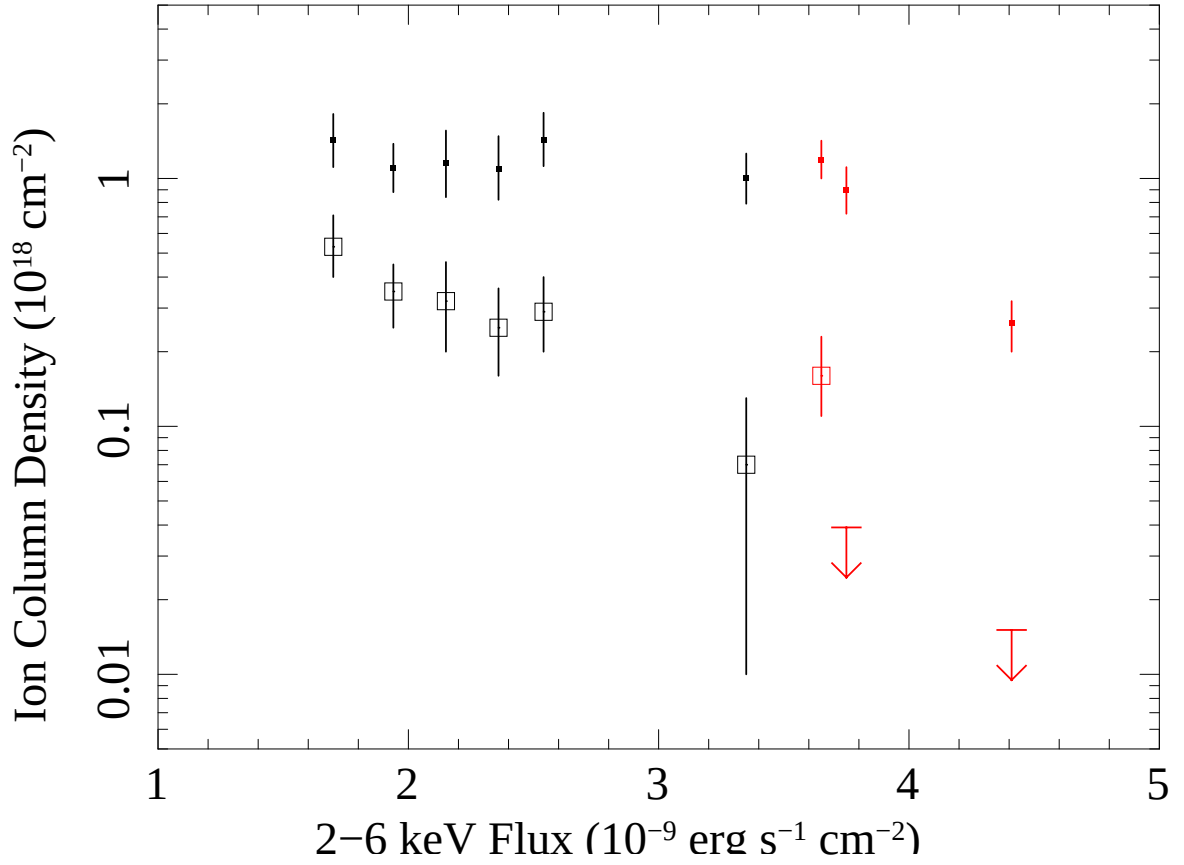


Figure 2.5. Correlation between the 2–6 keV flux and the column densities of iron ions obtained from the HSS spectra in the 2006 (black) and 2015 (red) outbursts. The filled and squared dots represent the column densities of H-like and He-like iron ions, respectively.

Figure 2.5 plots the column density of He-like and H-like irons against the 2–6 keV flux in the HSS during the 2006 (black) and 2015 outbursts (red). OBS 1 and OBS 6 are the faintest and brightest observations in the 2006 outburst, while OBS 7 and OBS 8 are the faintest and brightest observations in the 2015 outburst, respectively. The degree of ionization of the disk wind gradually increased with luminosity in the 2006 outburst as the ratio of the column density between H-like iron ions and He-like iron ions became larger. In the 2015 outburst, the degree of ionization rapidly increased above 2–6 keV flux $\sim 3.5 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$. This result might be explained by photoionization of the disk wind because the observed X-ray spectrum shows significant hardening in the brightest observation owing to the increase of the hard tail component; we will quantitatively examine this possibility in the next section. We also note that the absorption lines in OBS 6 is weaker than that in OBS 7 as expected from the harder spectrum in OBS 6.

2.4 Discussions

Our *Suzaku* and *NuSTAR* observations of 4U 1630–47 during the 2015 outburst confirm the presence of absorption-line features of highly ionized iron ions in the HSS spectra, which were reported by previous observations in the HSS during the 2006 outburst. This strongly suggests that a highly (but not fully) ionized disk wind is always developed in the HSS. These data enables us to investigate the evolution of the disk wind according to the change of luminosity and spectrum from a single source in detail.

2.4.1 A Simple Photoionized Simulation

We find that the ratio between the column densities of H-like and He-like iron ions increased at fluxes above $F_{2-6 \text{ keV}} \sim 3.5 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ where their spectra became harder with increasing contribution from the hard tail (Figure 2.3). In order to examine whether an increase of photoionizing photons solely explains the observed increase of the ionization degree or not, we perform simulations of a photoionized gas, using XSTAR version 2.3. In XSTAR simulations, the ionization parameter of the absorber at the nearest point (i.e., the launching radius for a disk wind), ξ_0 , is defined as

$$\xi_0 = \frac{L_{\text{bol}}}{n_0 R_0^2}, \quad (2.1)$$

where L_{bol} is the luminosity in the 0.0136–13.6 keV band, R_0 is the distance of the absorber from the central source, and n_0 is the density. We use the observed continuum corrected for absorption and dust scattering in the 0.01–1000 keV range as the input of the source spectrum. To consider a self-similarly expanding wind with a constant velocity (Begelman et al., 1983), we assume a density (n) profile with respect to radius $R(> R_0)$ as $n = n_0(R/R_0)^{-1.9}$, which gives an almost constant ionization parameter profile ($\xi = \xi_0(R/R_0)^{-0.1}$)¹. The turbulent velocity is set to be $V_{\text{turb}} = 500 \text{ km s}^{-1}$ in this simulation as a representative value, which has not been measured in this source (but not less than 100 km s^{-1} ; Kubota et al., 2007). To directly apply the simulation results to the *Suzaku*/XIS spectra, we make a grid *XSPEC* model of absorption

¹Here we adopt an index of -1.9 instead of -2.0 for the density profile because XSTAR calculations do not converge if we set $n \propto R^{-2}$ due to technical reasons. We have confirmed that our results are little affected by its choice within a range between -1.5 and -1.9 .

by utilizing the XSTAR2XSPEC tool. Through the fitting, we are able to obtain the column density $N_{\text{H}}^{\text{wind}}$ and the ionization parameter ξ_0 .

We find that the higher ionization degree in OBS 8 than in the other HSS observations cannot be explained solely by the change of the source spectrum and luminosity if we assume that the wind launching radius and density were the same as in the other epochs. In OBS 8, we are able to obtain only lower limits for ξ_0 and $N_{\text{H}}^{\text{wind}}$ because of the non detection of He-like iron absorption-line and of strong coupling between ξ_0 and $N_{\text{H}}^{\text{wind}}$. If we fix the column density at $N_{\text{H}}^{\text{wind}} = 1.5 \times 10^{23} \text{cm}^{-2}$, which is a typical value obtained in OBS 1 to 7, the ionization parameter in OBS 8 becomes $\xi_0 = 5.09^{+0.20}_{-0.17}$. This is significantly higher at a $> 90\%$ confidence level than the value expected from the photoionization effect alone (i.e., the), $\xi_0 = 4.68^{+0.08}_{-0.08}$, which is converted from the result of OBS 7 by replacing the luminosity with that of OBS A. This result indicates that other physical parameters of the wind, such as wind launching radius R_0 and/or density at the launching radius n_0 , must have changed from OBS 7 to OBS 8.

2.4.2 Simulations of Photoionized Disk Wind

In the following, we show that these results can be explained by a theory of thermally driven winds. The Compton temperature T_{IC} and the wind escape velocity V_{wind} depend on the wind launching-radius (or Compton radius, R_{IC}) as

$$kT_{\text{IC}} \propto \frac{GM_{\text{BH}}}{R_{\text{IC}}} \quad (2.2)$$

and

$$\frac{1}{2}V_{\text{wind}}^2 \propto \frac{GM_{\text{BH}}}{R_{\text{IC}}} \propto T_{\text{IC}}. \quad (2.3)$$

Here, k , G , and M_{BH} are the Boltzmann constant, the gravitational constant, and the mass of the BH, respectively. From numerical simulations, Woods et al. (1996) showed that the mass flux per unit area of an isothermal disk wind, $\dot{m}$, is given by

$$\dot{m} \sim 0.5 \left(\frac{kT_{\text{IC}}}{\mu} \right)^{-0.5} \frac{L}{4\pi R^2 c \Xi_{c,\text{crit}}}, \quad (2.4)$$

where μ , c , and $\Xi_{c,\text{crit}}$ are the mean mass per particle, the light speed, and the critical pressure ionization parameter determined by the spectrum, respectively. The mass-loss rate of disk wind $\dot{M}$ and the density at the base of the wind n_0 given as

$$\begin{aligned}\dot{M} &= 2 \int_{R_{\text{IC}}}^{R_{\text{max}}} \dot{m} 2\pi R dR \\ &= \left(\frac{kT_{\text{IC}}}{\mu} \right)^{-0.5} \frac{L}{4\pi c \Xi_{c,\text{crit}}} (\log(R_{\text{max}}) - \log(R_{\text{IC}})) \\ &\propto L \times T_{\text{IC}}^{-0.5},\end{aligned}\tag{2.5}$$

$$\begin{aligned}n_0 &= \frac{\dot{M}}{\Omega R_{\text{IC}}^2 V_{\text{wind}} m_p} \\ &\propto L \times T_{\text{IC}},\end{aligned}\tag{2.6}$$

Here, R_{max} is the maximum radius where the disk wind is ejected, m_p is the proton mass and Ω is the solid angle of the disk wind, which is assumed to be constant against the distance from the BH. The n_0 value in the OBS 1 is set to be $1.0 \times 10^{13} \text{ cm}^{-3}$, which yields the mean number density of $\bar{n} \sim 5 \times 10^{12} \text{ cm}^{-3}$ estimated by Kubota et al. (2007). In the following XSTAR simulations, n_0 for each observation is calculated from Equation (2.6) (see Table 2.3). From these equations, we finally obtain the dependence of the column density $N_{\text{H}}^{\text{wind}}$ and the ionization parameter at the base of wind ξ_0 on luminosity and Compton temperature as

$$\begin{aligned}N_{\text{H}}^{\text{wind}} &= \int_{R_{\text{IC}}}^{\infty} n dR \\ &\propto L\end{aligned}\tag{2.7}$$

and

$$\begin{aligned}\xi_0 &= \frac{L}{n_0 R_{\text{IC}}^2} \\ &\propto T_{\text{IC}},\end{aligned}\tag{2.8}$$

respectively.

The green solid lines in Figure 2.6(a) and 2.6(b) plots the relations of Equations (2.7) and

Table 2.3. Fitting results

Parameter	OBS 1	OBS 2	OBS 3	OBS 4	OBS 5	OBS 6	OBS 7	OBS 8
$L_{\text{bol}} (10^{38} \text{ erg s}^{-1})$ ¹	1.20	1.34	1.48	1.61	1.63	2.13	2.61	3.14
$T_{\text{IC}} (\text{keV})$ ²	0.70	1.37	0.92	0.99	0.95	1.38	0.83	3.25
$n_0 (10^{13} \text{ cm}^{-3})$ ³	1.0	2.1	1.6	1.9	1.8	3.5	2.6	12.0
$\log(\xi_0)$	$4.62^{+0.13}_{-0.11}$	$4.61^{+0.11}_{-0.11}$	$4.64^{+0.15}_{-0.14}$	$4.62^{+0.14}_{-0.14}$	$4.55^{+0.18}_{-0.10}$	$4.74^{+0.29}_{-0.17}$	$4.66^{+0.14}_{-0.12}$	> 4.38
$N_{\text{H}}^{\text{wind}} (10^{23} \text{ cm}^{-2})$	$1.23^{+0.31}_{-0.24}$	$1.03^{+0.27}_{-0.23}$	$1.06^{+0.37}_{-0.30}$	$0.99^{+0.37}_{-0.29}$	$1.48^{+0.65}_{-0.37}$	$1.58^{+0.49}_{-0.47}$	$2.31^{+0.71}_{-0.55}$	> 0.40
$V_{\text{wind}} (\text{km s}^{-1})$	500^{+400}_{-400}	800^{+500}_{-600}	800^{+700}_{-700}	1400^{+600}_{-600}	1400^{+500}_{-500}	1500^{+600}_{-600}	2200^{+500}_{-500}	2100^{+1200}_{-1100}

¹Unabsorbed luminosities in the range of 0.0136–13.6 keV assuming isotropic emission.

²Calculated by Equation (1.1) with the integration range of 0.01–1000 keV.

³Calculated by Equation (2.6). n_0 in OBS 1 is set to be $1.0 \times 10^{13} \text{ cm}^{-12}$.

(2.8), respectively. The data points calculated from the best-fit parameters (Table 2.3) are also shown. As noticed, all the data in OBS 1 through 8 are consistent with the theoretical relation, although only lower limits of $N_{\text{H}}^{\text{wind}}$ and ξ_0 are obtained in OBS 8. If we assume $N_{\text{H}}^{\text{wind}} = 2.56^{+0.37}_{-0.37} \times 10^{23} \text{ cm}^{-2}$ for OBS 8, the ionization parameter is estimated to be $\log(\xi_0) = 5.31^{+0.18}_{-0.14}$ from the spectral fit, which is consistent with the prediction. We note that the possible increase of the scattering fraction in OBS 8 (discussed in Sec 2.3.1) does not affect our final results. The maximum increase of the scattering fraction (4%) leads to an only $\sim 1\%$ luminosity decrease and a $\sim 2\%$ Compton-temperature increase.

The non-detection of the iron-K absorption lines in the VHS during the 2012 outburst does not contradict with this theory. The column density and ionization parameter are predicted to be $N_{\text{H}}^{\text{wind}} = 4.39^{+0.64}_{-0.63} \times 10^{23} \text{ cm}^{-2}$ and $\log(\xi_0) = 5.37^{+0.07}_{-0.07}$ by using $L_{\text{bol}} = 5.36 \times 10^{38} \text{ erg s}^{-1}$ and $T_{\text{IC}} = 5.57 \text{ keV}$ with Equations (2.7) and (2.8). Analyzing the VHS spectra in the same way as for the HSS data, we obtain a lower limit of the ionization parameter of $\xi_0 > 5.38$ at a 99% confidence level. This is still consistent with the theoretical prediction (see Figure 2.6(b)). We do not rule out, however, the possibility that the geometrical configuration between the central source and outer disk might have changed in the VHS, leading to a more efficient ionization of the disk wind in the VHS than in the HSS.

The measured wind velocity is also consistent with Equation (2.3). Figure 2.7 plots the cor-

relation between the best-fit wind velocity V_{wind} and the Compton temperature T_{IC} in the 2006 outburst. The green line, representing the best-fit relation of $V_{\text{wind}} \propto T_{\text{IC}}^{0.5}$, is consistent with the observed velocities. We note that V_{wind} has a systematic error of $\sim 200 \text{ km s}^{-1}$ due to a possible energy-gain uncertainty of *Suzaku*/XIS, which became more serious in the 2015 observations ².

From these results, we conclude that the evolution of the observed iron-K absorption line features in the spectra of 4U 1630–47 is consistent with a simple theory of thermally-driven disk winds. We have shown that it is important to consider the dependence of the launching radius of a disk wind on the Compton temperature T_{C} , which is determined by the shape of the continuum. Further observational studies with high resolution spectroscopy that enable us to more accurately determine the outflow velocity would be useful to confirm our scenario.

²https://heasarc.gsfc.nasa.gov/docs/astroe/prop_tools/suzaku_td/node10.html

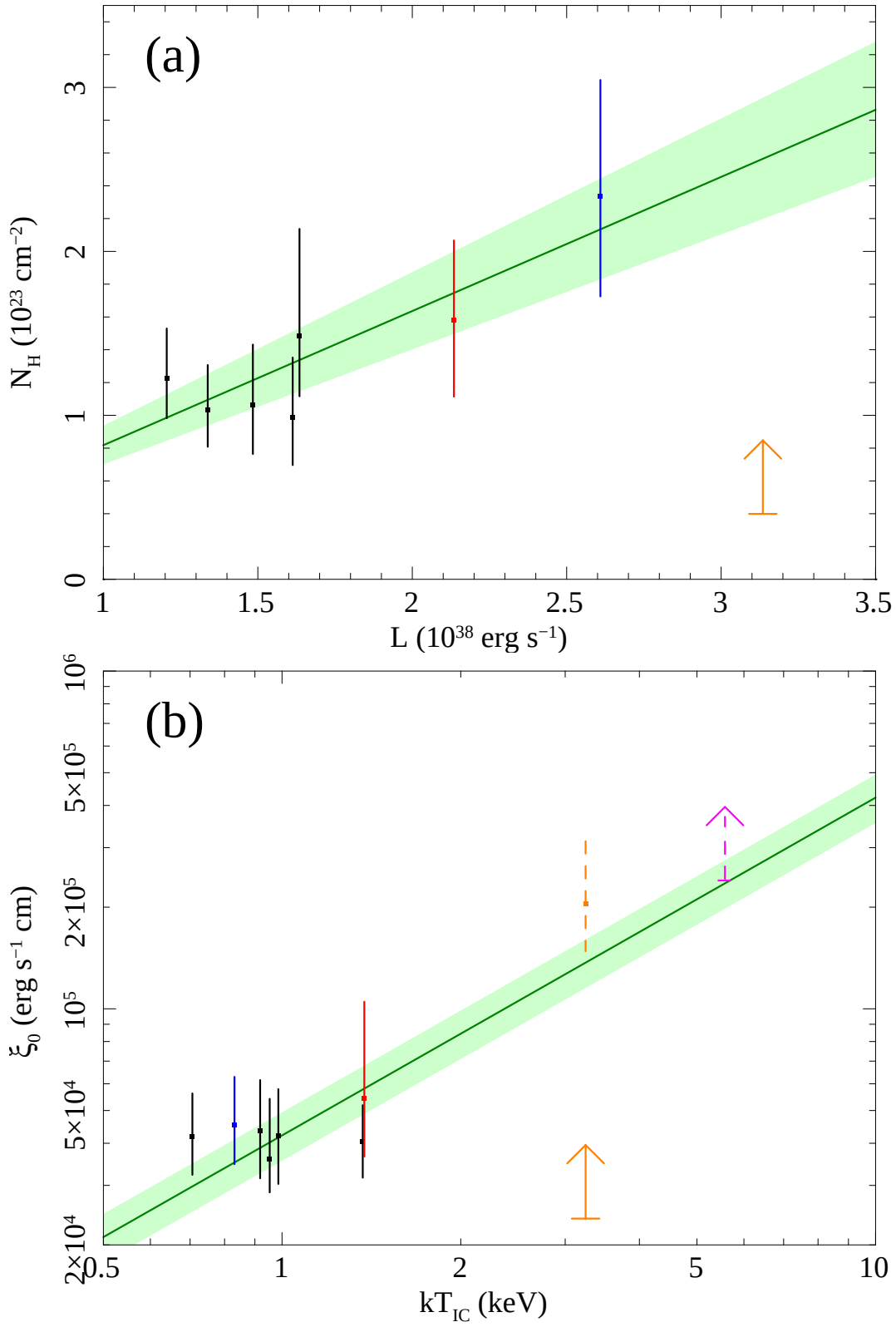


Figure 2.6. (a) The L_{bol} dependence of the ion column density $N_{\text{H}}^{\text{wind}}$ and (b) the T_{IC} dependence of the ionization parameter ξ_0 . The black, red, and blue points represent the spectral fitting results for OBS 1–5, 6, and 7, respectively. We only obtain the lower limit with OBS 8 (orange) due to the non-detection of the He-like iron absorption line. The green solid lines in (a) and (b) show the best-fit relation of Equations (2.7) and (2.8), respectively. The light green regions correspond to the 90% confidence interval. The orange dashed curve plots the best-fit ionization parameter by assuming a column density of $N_{\text{H}}^{\text{wind}} = 2.6 \times 10^{23} \text{ cm}^{-2}$. The magenta dashed arrows represent the lower limits for the VHS spectra in 2012 with an assumption of $N_{\text{H}}^{\text{wind}} = 4.4 \times 10^{23} \text{ cm}^{-2}$.

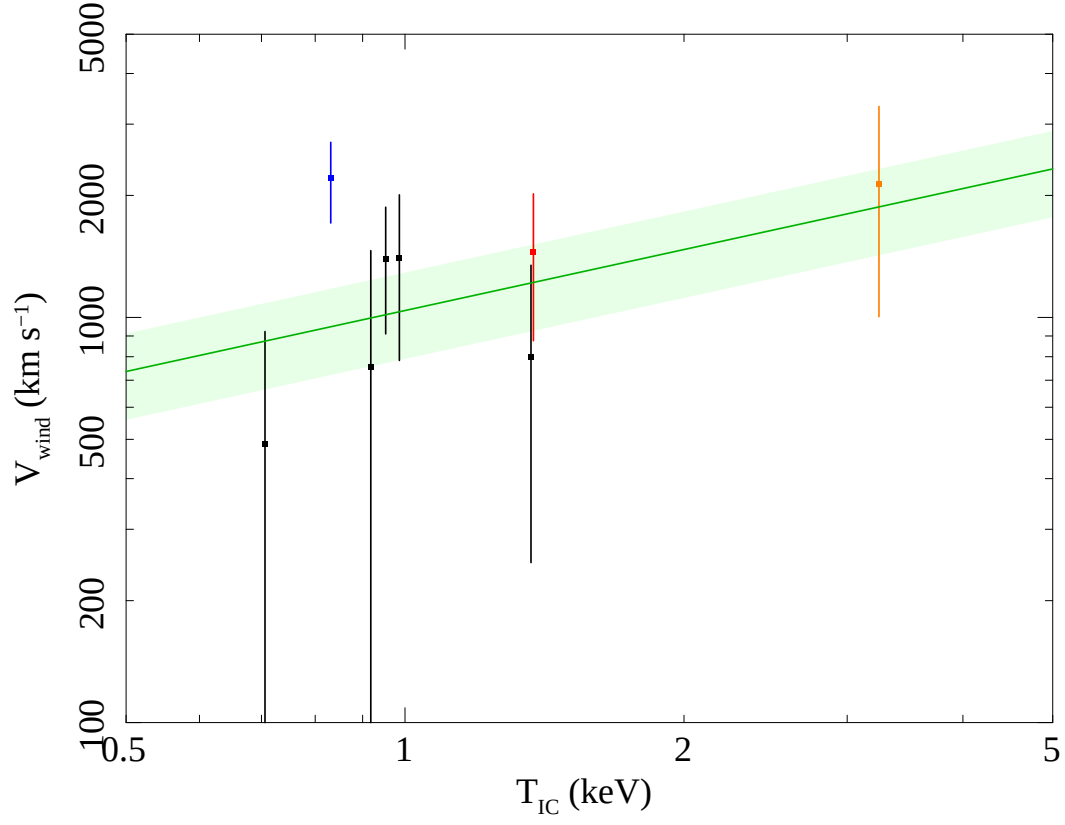


Figure 2.7. Correlation between the best-fit wind velocity V_{wind} and the Compton temperature T_{IC} . The black, red, blue, and orange points show that of OBS 1 to 5, and 6, respectively. The green line shows the relation of Equation (2.3). We note that there is a systematic error of $\sim 200 \text{ km s}^{-1}$ due to some calibration uncertainties.

Chapter 3

The 7 Year *MAXI*/GSC Source Catalog of the Low Galactic-Latitude Sky (3MAXI)

3.1 Introduction

While the *MAXI*/GSC source catalogs in the high Galactic latitude region, $|b| > 10^\circ$, were released by Hiroi et al. (2011) and Hiroi et al. (2013) from the first 7-month and 38-month data, respectively, the catalog in the low latitude region below $|b| = 10^\circ$ has not been produced yet. This was mainly because the Galactic plane region is heavily crowded with sources and is contaminated by the Galactic Ridge X-ray Emission (GRXE), making it difficult to separate signals from individual X-ray sources and determine their positions and fluxes accurately. In this case, it is crucial to accurately estimate the spatial distribution of the GRXE and to reduce systematic uncertainties in the point spread function (PSF) of the GSC.

In this chapter, we present the first *MAXI*/GSC source catalog for $|b| < 10^\circ$ in the 4–10 keV band produced by integrating the 7-year data from 2009 August 13 to 2016 July 31. We utilize the same image-fitting technique as that employed in the 37-month catalog (Hiroi et al., 2013). To overcome source confusion, we calibrate the position-dependent shape of the GSC PSF and estimate the contribution of the GRXE. We also determine the 3–4 keV and 10–20 keV fluxes of the individual detected sources, to calculate their hardness ratios (HRs). For the remaining sky area ($|b| > 10^\circ$), a new source catalog, which is an updated version of (Hiroi et al., 2013) and

complementary to ours, will be provided in another paper (Kawamuro et al., in preparation).

Sections 3.2 and 3.3 describe data reduction and analysis, respectively. The PSF calibration is summarized in Appendix 1. The resultant source catalog and its properties are described in Section 3.4, and the conclusions are given in Section 4. We define the fluxes of the MAXI sources in Crab units (i.e., relative to the 7-year averaged flux of the Crab nebula) unless otherwise stated. The Crab-nebula spectrum is assumed to be an absorbed power-law model ¹ with a column density of $2.6 \times 10^{21} \text{ cm}^{-2}$, a photon index of 2.1, and a normalization at 1 keV of $10.0 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$, which corresponds to 3.98×10^{-9} , 1.21×10^{-8} , and $8.51 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the 3–4 keV, 4–10 keV, and 10–20 keV bands, respectively.

3.2 Data Reduction

We used the *MAXI*/GSC cleaned event data version 1.8 from 2009 August 13 to 2016 July 31, and reduced them with essentially the same method as that in the *MAXI*/GSC 37-month high-latitude catalog (Hiroi et al., 2013). The data reduction was carried out with MXSOFT, which is an original software package developed by the MAXI team, and Heasoft version 6.15. We ignored the cameras operated at the nominal high-voltage levels (1650 V or 1550 V) for only less than 1 year (GSC6, GSC9, GSCa). The GSC0 data after 2013 June 15, when the detector was leaking its gas, were not used either. We also discarded the data from GSC3, which have large systematic uncertainties in position calibration and suffer from high background level due to damages of its veto cells (Sugizaki et al., 2011).

The data screening was performed with mostly the same selection criteria as those adopted in Hiroi et al. (2013). The only differences from the previous work were that (1) we found that the contamination of the calibration sources is not negligible in the edge of some GSC counters, and thus imposed a tighter restriction on the incident angles of photons, $|\phi| < 36.8^\circ$, where the incident angle ϕ is defined by the photon detected position on the detector (see Mihara et al., 2011, for more detail), and that (2) we excluded the events acquired when the attitude data files,

¹ The spectral parameters are adopted from INTEGRAL General Reference Catalog (version 40): <http://www.isdc.unige.ch/integral/science/catalogue>. One has to bear in mind that the X-ray flux of the Crab nebula is not constant (Wilson-Hodge et al., 2011), which could cause a systematic uncertainty of a few percent level in the absolute flux calibration.

which are needed in the source/background simulations described below, were unavailable or contained incorrect values². These changes were made to remove any possible systematic errors and improve the sensitivity for detecting faint sources in the crowded regions on and around the Galactic plane. They only negligibly affect the results from the previous high-latitude catalogs.

Figure 3.1 presents the coverage map created after the data screening. We utilized the MAXI event simulator “*maxisim*” (Eguchi et al., 2009), which generates events from X-ray point/diffuse sources based on the input energy spectra and source position (and spatial distribution for extended sources). Referring to the calibration database and the attitude, orbit, and time data included in the auxiliary files provided by the MAXI team, it correctly considers the angle dependence of the slit area, the collimator field-of-view, and the responses of the individual GSC cameras. The large-scale patterns seen in the coverage map reflect the difference in the duty cycles and the operation periods of the individual GSC cameras and dependence of the directions of their field-of-view on the ISS orbit.

3.3 Analysis

We performed an image analysis in basically the same way as that described in Hiroi et al. (2013), fully taking into account the image response and background contribution. We first divided the entire sky into 768 square regions with a size of $7^\circ.3 \times 7^\circ.3$ in the sky coordinates (see Hiroi et al., 2013, for the definition), whose central positions were determined through the Healpix software package (Górski et al., 2005), and produced tangentially projected images from the screened event data. We next made the list of source candidates in each image, and constructed the models of the PSFs of these sources. Finally we estimated their positions and fluxes by fitting the individual images with the model composed of the PSFs and the other contributors: the non X-ray background (NXB), the cosmic X-ray background (CXB), and the GRXE. The normalizations of the PSFs give the source fluxes in Crab units, because we measure

² We ignored the event data taken when (a) the interval of two neighboring attitude data is >60 s, and/or (b) the attitude quaternions of two neighbouring data, $\vec{q} = (q_1, q_2, q_3, q_4)$ and $\vec{q}' = (q'_1, q'_2, q'_3, q'_4)$ have unusually large or small differences. For the latter condition, we defined $\Delta q = \sqrt{\sum_{i=1}^4 (q_i - q'_i)^2} \geq 2.5 \times 10^{-4}$ and $\Delta q \leq 1.5 \times 10^{-3}$, considering the trend in Δq in the whole period of the MAXI operation. The data taken in 30 s before and after the periods with these bad condition were additionally removed.

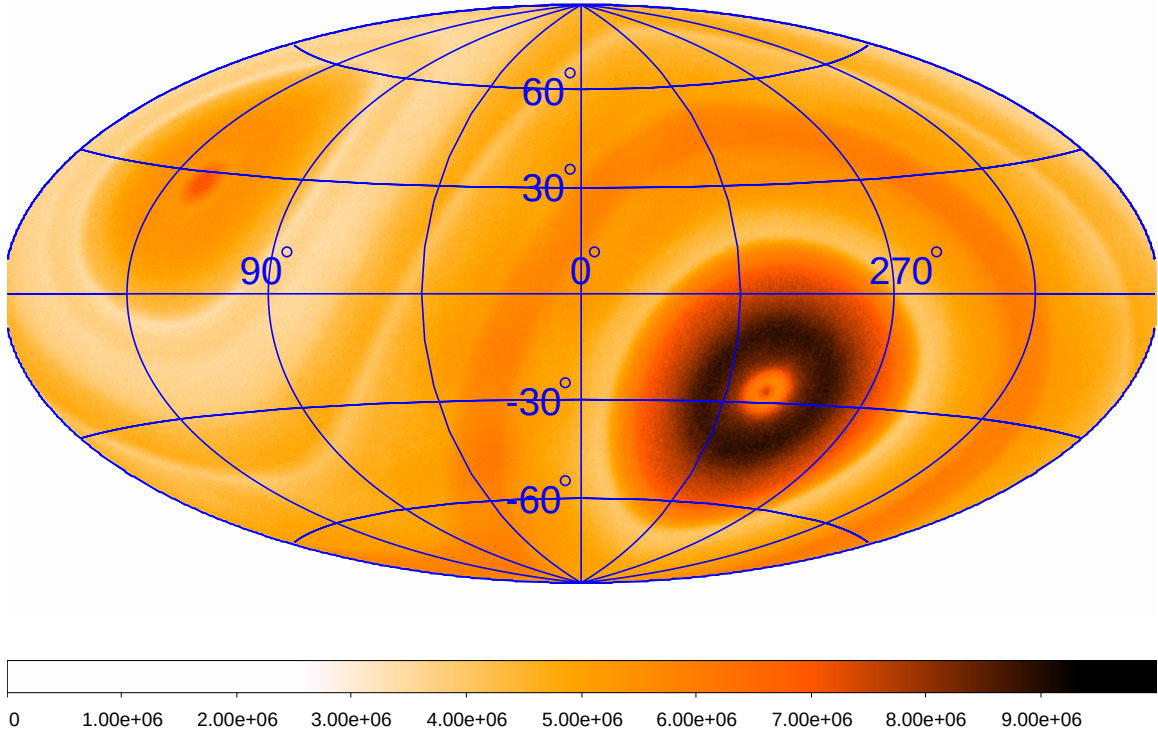


Figure 3.1. Coverage map for the 7-year MAXI/GSC data for $|b| < 10^\circ$ in Galactic coordinates projected with the Hammer-Aitoff projection. The unit is $\text{cm}^2 \text{ s}$.

the total count rates relative to those of the PSFs simulated on the basis of the Crab-Nebula spectrum. To make the source search complete, the last two steps were iterated by including additional sources that appeared as positive residual signals in the previous image fitting. We found, however, serious source confusion was unavoidable in the Galactic center region within $|b| < 5^\circ$, $l < 30^\circ$, and $l > 330^\circ$. Because faint sources with significances of $\sim 6.5\sigma$ were difficult to detect, we excluded the images in that region in this image analysis. The complete catalog in this region will be provided in a future paper.

Following Hiroi et al. (2013), the data in 4–10 keV, where a high signal-to-noise ratio can be achieved, were used to detect X-ray sources, while energy fluxes in the 3–4 keV and 10–20 keV bands were also estimated for all the detected sources, to derive their spectral information. In the next subsections, we describe the details of our analysis, mainly focusing on the procedures that are different from those adopted in Hiroi et al. (2013).

3.3.1 Background Modeling

We constructed the model of the GSC background, by which we mean the combination of the NXB and the CXB, in the same manner as Hiroi et al. (2013) using the so-called “VC” count rate (the rate of the coincident events between a carbon anode for signal detection and a veto anode) as a tracer of the intensity and energy distribution of the GSC background. Unlike the previous works, we created the background models separately for the periods when the ISS moves northward and southward. Figure 3.2 demonstrates the difference in the correlation of the background rate and the VC count rate between the direction of ISS motion; the background rate tends to be higher when the ISS travels from north to south than from south to north. This trend was found to be seen in all the cameras. More detailed properties of the GSC background will be described in a future paper (Shidatsu et al., in preparation).

We produced simulated background data based on our newly created model, utilizing *maxsim*. We found that our new background model improved the reproducibility of the GSC background strength especially above ~ 5 keV. The simulated data were processed in exactly the same way as the real event data, before being used in the image fitting. We produced 10 times more events than what was predicted from the actual background level, so that the statistical errors in the model became negligible compared with the real data.

3.3.2 GRXE Modeling

To detect faint sources in the low Galactic latitude region, we have to estimate the contribution of GRXE accurately. The GRXE can be separated into two emission components: the Galactic bulge (or bar) and disk (Cooke et al., 1970; Yamauchi & Koyama, 1993). Following Revnivtsev et al. (2006), we modeled these components with an ellipsoid plus disk profile, adopting the parameters given in Table 1 of that work. On the basis of this model, we created the simulated GRXE data through *maxsim*, processed them with the same criteria as the real data and simulated background data, and incorporated them in the image analysis. Because the intensity of the GRXE is much lower than the level of NXB+CXB, we adopted 50 times higher intensity than the that of the actual GRXE in the simulation, to reduce statistical errors. Because the GRXE model cannot reproduce detailed structures on a spatial scale of $\lesssim 10^\circ$, its normalization

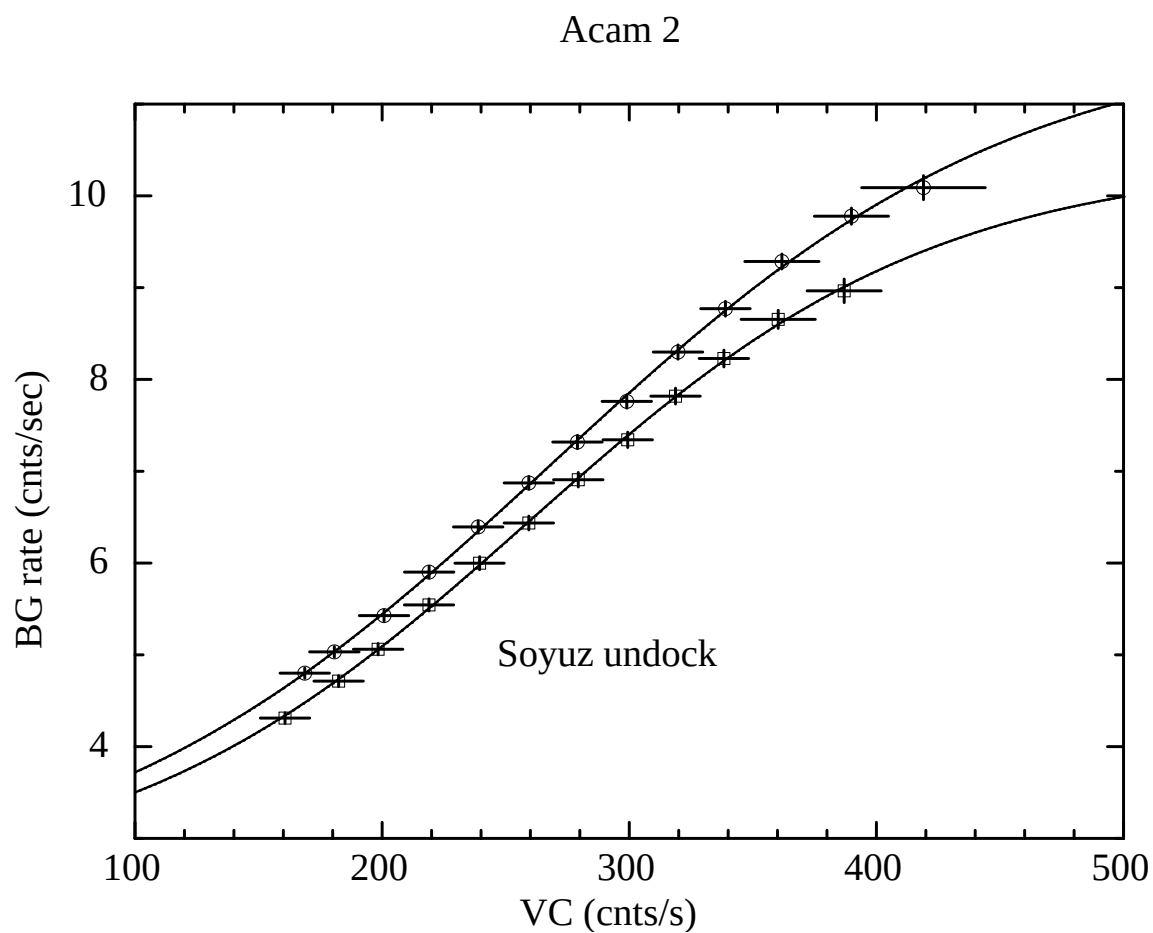


Figure 3.2. Correlations between the VC count rates versus the 3–20 keV background event rates of GSC2, when the Russian spacecraft Soyuz is not present on the docking port close to MAXI. The open circles and squares plot the data when the ISS travels northward and southward, respectively.

was left as a free parameter in the image analysis.

3.3.3 PSF Modeling, Source Finding, and Position/Flux Measurements

To minimize the complexity by source confusion, which is more severe at lower Galactic latitudes, we searched for new sources after identifying those listed in the *Swift*/BAT 105 month catalog³ (hereafter BAT105 Oh et al., 2017), instead of blind source search as performed by Hiroi et al. (2013). We adopted the *Swift*/BAT catalog, which covers the hard X-ray band in 14–195 keV, as a reference catalog, instead of catalogs in the soft X-ray band below 10 keV, because hard X-rays have stronger penetrating power than soft X-rays and give a more complete catalog. We first prepared the PSF models for all the sources in the *Swift*/BAT 105 month catalog by simulation of their photon distributions with *maxisim*, assuming the same conditions as the actual observations with the GSC. Here we used our newly created calibration database for the PSF of the GSC (see Appendix 1 for details). As the input source positions and spectra, we adopted the coordinates of the optical counterparts and, for simplicity, the canonical model of the Crab nebula (see Section 1) for all the sources, respectively. We also assumed that the flux was constant in the PSF simulation; this means that we would obtain a time-averaged flux when the source was variable. We have confirmed that the spectral difference from the Crab nebula and the observed time variability has little effect on the integrated PSF shape and hence do not affect our results.

We fit the individual images created from the real data, with a model consisting of the background, GRXE, and PSF components, using the MINUIT package⁴ in root version 6.06/08. Besides the fluxes of the sources, we also made the normalization of the background and that of the GRXE free parameters, to take into account possible small spatial variation of the CXB and GRXE levels. Because the peak positions of the PSF models could be shifted from the actual positions in the GSC images by $\sim 0.05^\circ$, presumably due to systematic errors in the alignment of attitude data, we allowed the source positions to vary within 0.1° from the original coordinates. The best-fit parameters were determined on the basis of the Poisson likelihood algo-

³ Twelve MAXI sources in our final catalog are associated with *Swift*/BAT 105 month sources that were not detected in the *Swift*/BAT 70 month catalog (Baumgartner et al., 2013).

⁴CERN Program Library Long Writeup D506; <https://cern-tex.web.cern.ch/cern-tex/minuit/minmain.html>

rithm (so-called C -statistics; Cash, 1979). As the source detection significance, we adopted the “MINOS” negative error calculated with the MINUIT package: $s_{D,4-10 \text{ keV}} = (\text{best-fit } 4-10 \text{ keV flux}) / (\text{its } 1\sigma \text{ statistical error})$, where $s_{D,4-10 \text{ keV}}$ is the significance in 4–10 keV. The flux was obtained in Crab units, because we basically measure the count rate relative to that of the Crab nebula through the PSF fitting.

Table 3.1. Conversion factors in the energy bands of 3–4 keV, 4–10 keV, and 10–20 keV in units of $10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ mCrab}^{-1}$

		photon index in powerlaw (Γ)							
		1.0	1.5	1.7	1.9	2.1	2.3	2.5	3.0
3–4 keV	$\log(N_H)=21$	0.409	0.404	0.402	0.399	0.396	0.392	0.389	0.380
	$\log(N_H)=22$	0.413	0.409	0.407	0.404	0.401	0.398	0.395	0.386
	$\log(N_H)=23$	0.440	0.446	0.446	0.446	0.445	0.443	0.442	0.437
4–10 keV	$\log(N_H)=21$	1.288	1.264	1.249	1.231	1.212	1.192	1.171	1.119
	$\log(N_H)=22$	1.292	1.271	1.255	1.238	1.219	1.199	1.179	1.127
	$\log(N_H)=23$	1.330	1.323	1.312	1.298	1.282	1.265	1.247	1.200
10–20 keV	$\log(N_H)=21$	0.917	0.895	0.882	0.867	0.851	0.835	0.818	0.776
	$\log(N_H)=22$	0.918	0.896	0.883	0.868	0.852	0.836	0.819	0.777
	$\log(N_H)=23$	0.928	0.907	0.894	0.879	0.864	0.848	0.831	0.788

Table 3.2. HR1(3–4 keV, 4–10 keV), HR2(4–10 keV, 10–20 keV) in powerlaw like spectrum

		photon index in powerlaw (Γ)							
		1.0	1.5	1.7	1.9	2.1	2.3	2.5	3.0
HR1	$\log(N_H)=21$	0.32	0.17	0.11	0.05	-0.01	-0.06	-0.11	-0.24
	$\log(N_H)=22$	0.35	0.20	0.15	0.09	0.03	-0.02	-0.08	-0.20
	$\log(N_H)=23$	0.62	0.51	0.47	0.42	0.37	0.33	0.28	0.15
HR2	$\log(N_H)=21$	0.40	0.23	0.15	0.08	-0.00	-0.08	-0.16	-0.35
	$\log(N_H)=22$	0.41	0.24	0.17	0.09	0.01	-0.07	-0.15	-0.34
	$\log(N_H)=23$	0.48	0.33	0.27	0.20	0.13	0.05	-0.03	-0.21

As a next step, we searched for source candidates that were not detected in the *Swift*/BAT catalog, utilizing the residual map of the previous image fitting, in the same manner as Hiroi et al. (2013). We smoothed the residual map with a circle of $r = 1^\circ$ with a constant weight of unity, and calculated the excess-signal significance as “ $S t / \sqrt{S t + B t}$ ” at each point, where S and B are the count rate of the source and background signals, respectively, and t is the exposure time. Here we adopted a conservative criterion, $> 4\sigma$, in finding new source candidates. We then

constructed the PSF models for those candidates and added them in the model to be used for the next image fitting. We repeated these procedures (source search, PSF modeling, and image fitting) 2 times, not to miss any nearby sources, and obtained the final source list with $s_{D,4-10 \text{ keV}}$. We ignored, however, the circular region with a radius of 3° around Vela supernova remnant. Because its size is substantially larger than that of the PSF, significant residuals remained after the image fitting and it was difficult to detect any other sources in that region. Also, in the final catalog we excluded sources detected close to much brighter ones if their flux levels are lower than possible systematic errors in the PSF model of the nearby target (if the flux is $<1\%$ and $<0.4\%$ of the latter at a distance of 1–2 and 2–3 degrees, respectively; see Appendix 1).

We chose $s_{D,4-10 \text{ keV}} = 6.5$ as the detection threshold to reduce the number of fake sources caused by background fluctuation (both statistical and systematic ones). In order to estimate it, we searched for negative signals in the smoothed residual map and performed image fitting to them using negative PSF models. Assuming that the systematic errors in the background model are symmetric in positive and negative sides, we estimate that ~ 5 spurious sources may be detected in the Galactic plane region ($|b| \leq 10^\circ$) with a significance of $\geq 6.5\sigma$. We note that 11 spurious sources will be found in the case of $s_{D,4-10 \text{ keV}} \geq 6.0$, which is too many to be accepted. The number of spurious sources was reduced to 3 and 1 in the case of $s_{D,4-10 \text{ keV}} \geq 7.0$ and ≥ 8.0 , respectively.

3.3.4 Transient Sources

It is essential for making a complete catalog to search for transient sources that are not detected with $s_{D,4-10 \text{ keV}} > 6.5$ in the 7-year integrated map. To find these transient sources, we applied our image analysis method (Section 3.3.3) to 73-day (i.e., 0.2-year) integrated GSC images and obtained the light curve of each source with that time bins. We searched for sources with $s_{D,4-10 \text{ keV}} > 6.5$ in the 73-day integrated images, and found 7 additional sources. Hereafter, we refer to these 7 sources as “transient sources”.

3.3.5 Estimation of Hardness Ratio

We measured the 3–4 keV and 10–20 keV fluxes of the sources with a significance of $s_{D,4-10 \text{ keV}} > 6.5$ via image fitting, to obtain their spectral information. The screened event data, simulated background, GRXE, and PSF data in the 3–4 keV and 10–20 keV bands were produced in the same way as those in the 4–10 keV band. The source positions were fixed at those determined in the analysis for the 4–10 keV data. Hardness ratios (HRs) were defined by the fluxes in any two of the three bands:

$$\text{HR(H,S)} = \frac{F_H - F_S}{F_H + F_S}, \quad (3.1)$$

where F_H and F_S correspond to the fluxes in the higher and lower energy bands, respectively. For the transient sources, we adopted the fluxes in one of the 73-day time bins when the 4–10 keV flux was the highest (the column (15) of Table 3.5b). We defined HR1 as that between the 4–10 keV and 3–10 keV bands, and HR2 between the 10–20 keV and 4–10 keV bands.

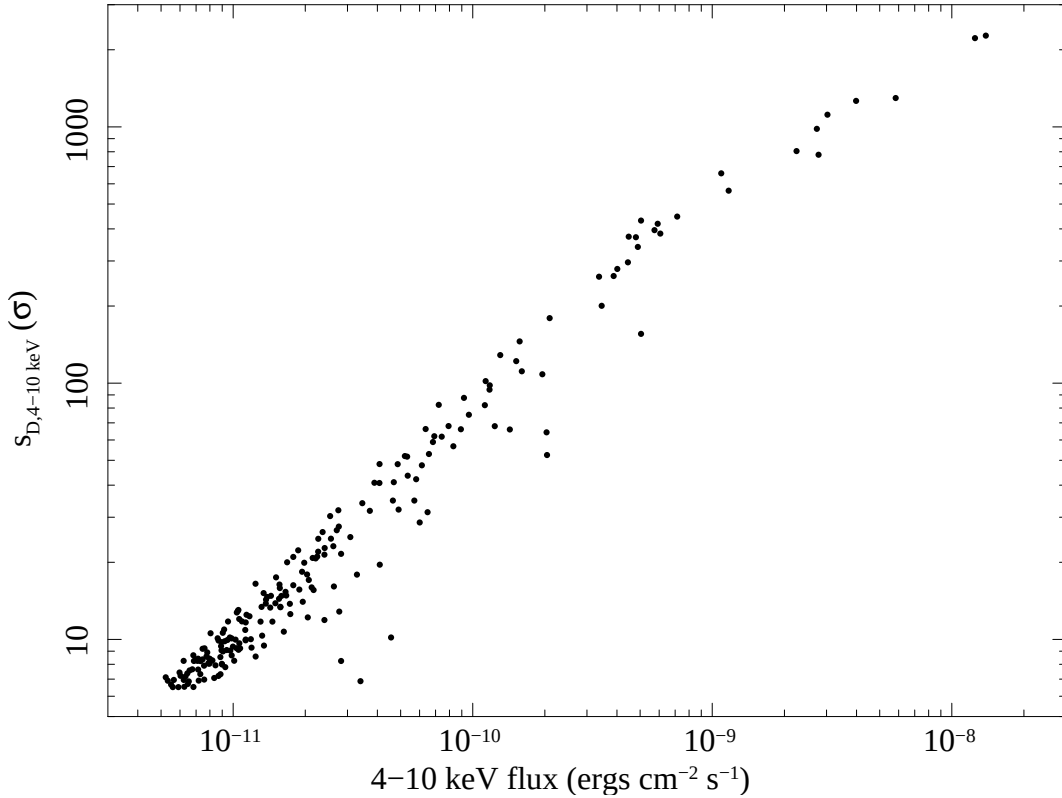


Figure 3.3. Correlation between the source flux and the detection significance for all the 7-year sources (in the unit of σ), in the 4–10 keV band.

3.4 Catalog

In this section, we present the catalog and discuss the statistical properties of the detected sources. In Table 3.5a, we provide the 7-year *MAXI*/GSC catalog in the Galactic plane region $|b| < 10^\circ$ (except for the Galactic center region $|b| < 5^\circ$ and $|l| < 30^\circ$), obtained from the GSC data in the 4–10 keV band. We detected 214 sources in total with a significance of $s_{D,4-10 \text{ keV}} > 6.5$ in the 7-year integrated image, 143 of which are identified with sources listed in BAT105. Hereafter, these 214 sources are referred to as the “7-year sources”. Seven sources are additionally detected in the 73-day time-sliced images (“transient sources”; Table 3.5b), 1 of which is identified with BAT105. The lowest source flux above $s_{D,4-10 \text{ keV}} = 6.5$ in the 7-year integrated image is 0.43 mCrab, which corresponds to $5.2 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the 4–10 keV band for a Crab-like spectrum. Note that the conversion factor from a flux in Crab unit to a physical unit depends on the spectral shape. Table 3.1 summarizes those factors for various combinations of parameters of an absorbed power-law model. The corresponding values of HR1 and HR2 are listed in Table 3.2 (by definition HR1=0 and HR2=0 for a Crab-like spectrum).

Fig 3.3 shows the correlation between the 4–10 keV flux and the detection significance $s_{D,4-10 \text{ keV}}$ for the 7-year sources. The observed trend can be understood by considering that the detection significance is approximately expressed as $s_{D,4-10 \text{ keV}} = St / \sqrt{St + Bt}$. At low fluxes, background events are dominant ($s_{D,4-10 \text{ keV}} \sim S \sqrt{t/B}$), and hence we predict a linear correlation. By contrast, the source counts are dominant at high fluxes, $s_{D,4-10 \text{ keV}}$ should be proportional to the square root of the source counts; $s_{D,4-10 \text{ keV}} \sim \sqrt{St}$. The data in Figure 3.3 indeed follow the trend. Note that our definition of $s_{D,4-10 \text{ keV}}$ does not represent the statistical significance of deviation from the background level in the source-photon limited case. There are a few tens of sources that deviate from the trend and have relatively small detection significances, due to contamination by nearby bright sources.

3.4.1 Cross Matching with Other X-ray Catalogs

For statistical studies of cataloged sources, it is important to find the counterparts and identify the object types of the detected sources. For this purpose, it is necessary to estimate the position accuracy of the detected sources. Figure 3.4 plots the detection significance in the 4–10 keV

Table 3.3a. Number of Matched Sources for the 7-year sources

Catalog Name	BAT105	4U	XTEASMLONG	XMMSL2	MCXC	1RXS	One catalog only ^a
BAT105	143	...	...	...	...	...	143
4U	...	4(4) ^b	3	3	1	2	0
XTEASMLONG	...	...	8(9) ^b	2	1	2	5
XMMSL2	...	...	...	12(16) ^b	1	8	7
MCXC	...	...	...	...	8(9) ^b	2	6
1RXS	...	...	...	...	...	14(14) ^b	4

^a Numbers of MAXI sources matched only with one catalog given in the first column.

^b Numbers in parentheses represent those of total matched counterparts in each catalog.

Table 3.3b. Number of Matched Sources for the transient sources

Catalog Name	BAT105	4U	XTEASMLONG	XMMSL2	MCXC	1RXS	One catalog only ^a
BAT105	1	...	...	...	...	...	1
4U	...	1(1) ^b	1	0	0	0	0
XTEASMLONG	...	...	4(4) ^b	0	0	0	3
XMMSL2	...	...	...	1(1) ^b	0	0	1
MCXC	...	...	...	...	0(0) ^b	0	0
1RXS	...	...	...	...	...	0(0) ^b	0

^a Numbers of MAXI sources matched only with one catalog given in the first column.

^b Numbers in parentheses represent those of total matched counterparts in each catalog.

band and the 1σ positional errors of the 71 7-year sources that are not listed in BAT105. They are roughly inversely proportional, as expected from statistics in determining the center of the PSF with limited source counts. The typical 1σ error at $s_{D,4-10 \text{ keV}} \sim 7$ is $\sim 0.2^\circ$.

As a next step, we attempted to identify the sources without BAT105 counterparts, using other catalogs. The positional error σ_{posi} is defined as $\sigma_{\text{posi}} \equiv \sqrt{\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2}$, where σ_{stat} and σ_{sys} are the statistical and systematic errors, respectively. We adopted $\sigma_{\text{sys}} = 0.05^\circ$, which is typical systematic uncertainty associated with GSC alignment calibration (Hiroi et al., 2011). We searched for sources in the reference catalogs located within a $2.5\sigma_{\text{posi}}$ error circle, which corresponds to the 95% confidence level. We utilized the data when the highest 4–10 keV flux was obtained among the individual 73-day-bin images to estimate σ_{stat} for the transient sources (Table 3.5b).

Because of the large positional errors, it is difficult to find the counterparts in optical or infrared catalogs, which have a much higher number density of sources with a much better position accuracy. We therefore performed cross matching with major X-ray catalogs. We first

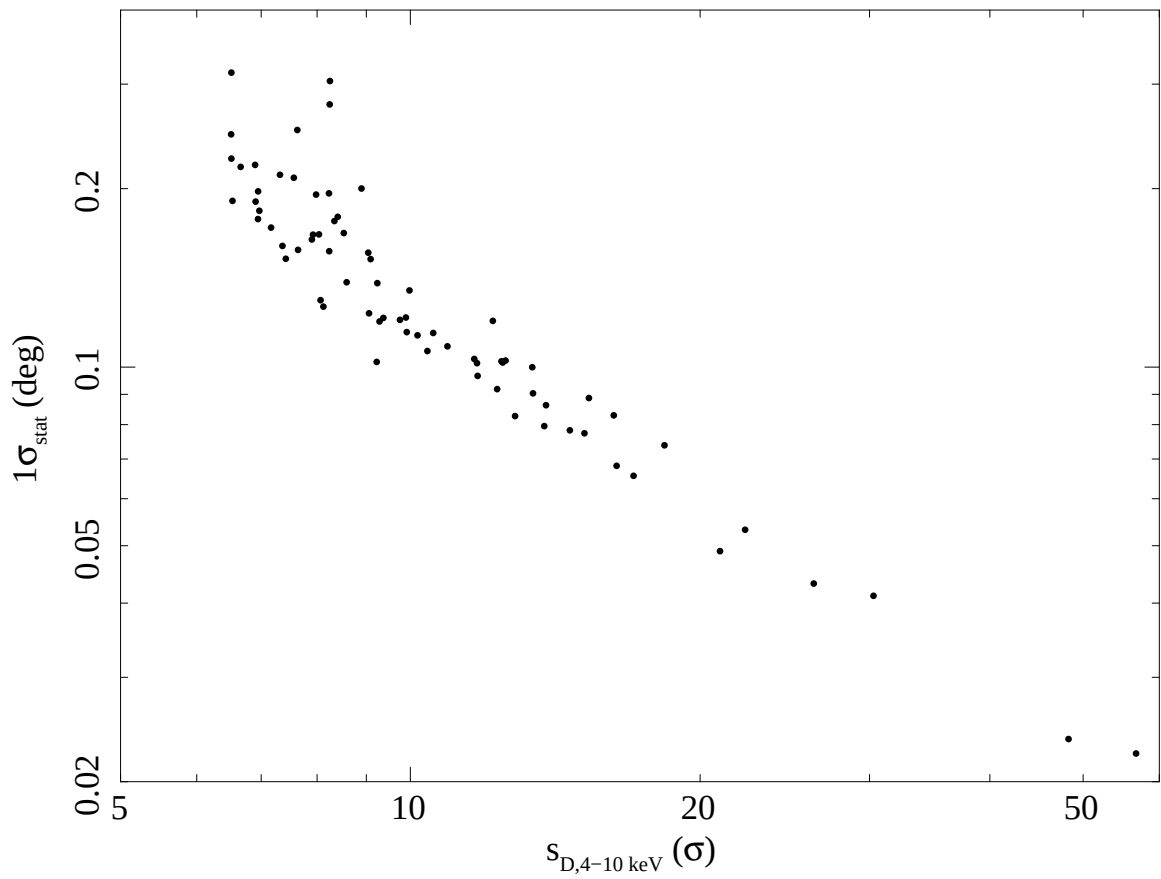


Figure 3.4. Correlation between the 4 – 10 keV detection significance and the 1σ positional error of the 71 7-year sources without BAT105 counterparts.

matched *Uhuru* fourth catalog (Forman et al., 1978, hereafter 4U) and found the counterparts of 4 sources. Then, we searched the *RXTE* All-Sky Monitor (ASM) long-term observed source table (hereafter XTEASMLONG), which is based on ASM light curve data products ⁵, for the remaining sources that have no counterparts in BAT105 and 4U. Finally, we carried out cross-matching with the *XMM-Newton* slew survey catalog (hereafter XMMSL2; Saxton et al., 2008), Meta-Catalog of X-ray Detected Cluster of Galaxies (hereafter MCXC; Piffaretti et al.,

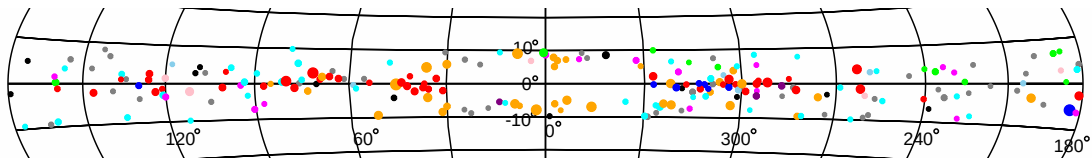


Figure 3.5. Location of the 7-year and transient sources in Galactic coordinates. The source fluxes on the logarithmic scale are indicated by the radii of the circles. The colors represent the object types: blazars and Seyfert galaxies (cyan), galaxy clusters (green), cataclysmic variables (magenta), stars (sky blue), pulsars (blue), supernova remnants (pink), high-mass and low-mass X-ray binaries (red and orange, respectively), X-ray binaries (purple), sources whose types are unidentified in BAT105, 4U, XTEASMLONG, and XMMSL2 (black), and sources without any counterparts (gray).

⁵https://heasarc.gsfc.nasa.gov/docs/xte/asm_products.html

2011), and *ROSAT* all-sky survey bright source catalog (hereafter 1RXS; Voges et al., 1999). For XMMSL2 and 1RXS, we only referred to the sources with fluxes of $> 1.0 \times 10^{-12}$ erg cm $^{-2}$ s $^{-1}$ and > 0.30 cts s $^{-1}$, which correspond to 0.3 mCrab for the Crab spectrum. Finally, as for the sources with BAT105 counterparts that are optically unidentified (“unidentified”) and those without BAT105 counterparts that are not matched with any objects in the above 5 X-ray catalogs (“unmatched”), we also checked the MAXI transient source catalog summarized by Negoro et al. (2016).

As a result, 36 out of the 77 sources were matched with at least 1 counterpart. Tables 3.3a and 3.3b show the number of MAXI sources that were matched with the reference catalogs for the 7-year and transient sources, respectively. If multiple sources were found within the error circles, we adopted the closest object to the position in our catalog as the most likely counterpart. For BAT105 sources, we did not attempt to find counterparts in other catalogs, because their positional errors were not estimated. The typical positional errors of the 4U, XMMSL2, and 1RXS counterparts are 0.5° , $3''$, and $10''$ respectively. The expected numbers of erroneous identification by chance are estimated to be 0.88, 1.48, 1.78, 0.31, and 2.45 for 4U, XTEASMLONG, XMMSL2, MCXC, and 1RXS, respectively, based on the mean number densities of the cross-matched sources in our survey region and the total area of the error circles (2.5σ) of the MAXI sources without BAT105 counterparts. Figure 3.5 plots the location of the MAXI sources in Galactic coordinates. Table 3.4 (second column) lists the number of each source type. The fluxes of the MAXI sources were found to be consistent with those of their counterparts in 4U, XTEASMLONG, XMMSL2, MCXC, and 1RXS catalogs within a factor of 4. In Figure 3.6, we present the correlation between the 4–10 keV flux and the HR (HR1 or HR2), and that between HR1 and HR2, for different object types.

3.4.2 Time Variabilities

Long-term variability is essential information to understand the nature of the detected objects. Figures 3.10a and 3.10b show the light curves for all objects. We added a systematic error of 1.6% in each flux due to incomplete instrumental calibration, which was estimated from the variation seen in the 73-day-bin light curve of the Crab Nebula.

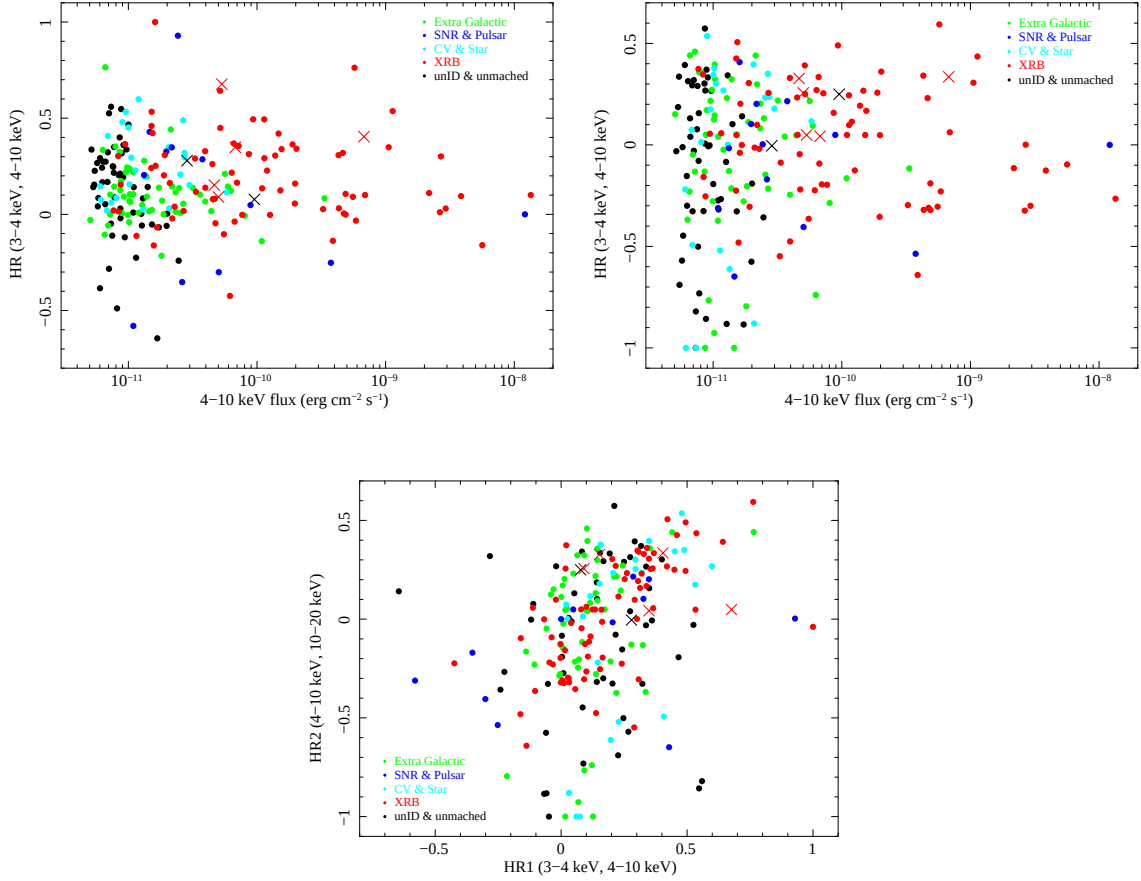


Figure 3.6. Scatter plots of HRs to the 4–10 keV flux (Upper panel). The colors represent the object types: blazars, galaxy clusters, and Seyfert galaxies (green), supernova remnants and pulsar (blue), cataclysmic variables and star (sky-blue), X-ray binaries (red), unidentified and unmatched sources (black). The transient sources are indicated by the cross marks.

Table 3.4. Properties for Each Source Type

Category	Number of Sources ^a	σ_{rms}^2 ^{a,b}	HR1 ^{a,c}	HR2 ^{a,d}
Unidentified	13	0.126	0.13±0.05	−0.13±0.11
Blazars	12	0.111	0.04±0.02	−0.11±0.11
Galaxy Clusters	11	−0.018	0.02±0.03	−0.45±1.35
Seyfert Galaxies	29	0.028	0.18±0.03	0.12±0.04
Cataclysmic Variables	16	0.048	0.25±0.04	0.06±0.11
Star	7	0.027	0.24±0.07	−0.25±1.47
Isolated Pulsar	8	0.038	0.22±0.12	0.05±0.04
Super Nova Remnants	5	0.001	−0.32±0.24	−0.30±0.21
High Mass X-ray Binaries	42	0.205	0.31±0.03	0.13±0.04
Low Mass X-ray Binaries	34	0.127	0.09±0.04	−0.09±0.05
X-ray Binaries ^f	3	0.131	−0.06±0.04	−0.16±0.15
Unmatched	42	0.119	0.10±0.04	−0.06±0.23

^aTransient sources are included.

^bThe median of excess variance calculated by equation 3.2.

^cThe mean and its standard deviation of HR(3–4 keV, 4–10 keV) calculated by equation 3.1.

^dThe mean and its standard deviation of HR(4–10 keV, 10–20 keV) calculated by equation 3.1.

^fX-ray binaries whose donar star is not firmly identified.

To quantify the variability of each source, we use the excess variance (σ_{rms}^2) normalized by the square of the mean flux (Vaughan et al., 2003);

$$\sigma_{\text{rms}}^2 = \frac{1}{N\bar{x}^2} \sum_{i=1}^N [(x_i - \bar{x})^2 - \epsilon_i^2], \quad (3.2)$$

where N is the total number of the lightcurve points, $\bar{x}$ is the mean of the flux, and x_i and ϵ_i are the flux and its error for each data point, respectively. The σ_{rms}^2 value becomes larger in stronger variability. The error on σ_{rms}^2 ($\Delta\sigma_{\text{rms}}^2$) can be calculated via the following equation

$$\Delta\sigma_{\text{rms}}^2 = \sqrt{\left(\sqrt{\frac{2}{N}} \frac{\overline{\epsilon^2}}{\bar{x}^2}\right)^2 + \frac{\overline{\epsilon^2}}{N} \frac{4\sigma_{\text{rms}}^2}{\bar{x}^2}}, \quad (3.3)$$

where $\overline{\epsilon^2}$ is the mean of the square of ϵ_i . These values for each source are listed in the 14th column of Tables 3.5a and 3.5b.

Periodograms are commonly used to quantify the variability of X-ray sources. Employing the

same method as Isobe et al. (2015), we made the periodograms of the individual MAXI sources from their 73-day-bin light curves. We adopted the following formula to estimate the PSD for each source;

$$\begin{aligned}
P(f) &= \frac{[a^2(f) + b^2(f)]T}{\mu^2}, \\
a(f) &= \frac{1}{n} \sum_{j=0}^{n-1} x_j \cos(2\pi f t_j), \\
b(f) &= \frac{1}{n} \sum_{j=0}^{n-1} x_j \sin(2\pi f t_j),
\end{aligned} \tag{3.4}$$

where f is the frequency of the flux variation, x_i is the source flux at time t_j , n is the number of data points, T is the total duration, and μ is the unweighted average of the source flux. A frequency range of 5×10^{-9} Hz to 2×10^{-8} Hz can be investigated from these light curves. Figures 3.11a and 3.11b show the normalized periodograms for all objects. We note that the result of Cyg X-1 is consistent with those obtained in Sugimoto et al. (2017).

3.4.3 Mean Properties of Each Source Type

Here we discuss the overall properties of each source type. Table 3.4 (3rd to 5th columns) lists the median values of the flux, the excess variance, and the means and its standard deviations of hardness ratios. Galactic sources constitute the largest population (<50%) in our catalog. As expected, galaxy clusters, (isolated) pulsars, and supernova remnants show stable light curves, while X-ray binaries and blazars have large variabilities. Galaxy clusters, stars, and supernova remnants tend to show softer spectrum. The majority of high mass X-ray binaries are X-ray pulsars, which have hard spectrum below 20 keV because of non-thermal emission characterized by a hard power-law like spectrum (Nagase, 1989). Low mass X-ray binaries show a softer spectrum in the bright state, characterized by blackbody emission from the surface of a neutron star and multi-color disk emission (Mitsuda et al., 1984).

The unidentified and unmatched sources show, on average, large variability amplitudes ($\sigma_{\text{rms}}^2 \sim 0.1 - 0.2$), which are observed from blazars and X-ray binaries in our catalog. Since their mean HR2 values are not large, we infer that the majority are not high mass X-ray binaries. In fact,

the mean values of HR1 and HR2 of the unidentified and unmatched sources are similar to those of blazars or low mass X-ray binaries, which are good candidates.

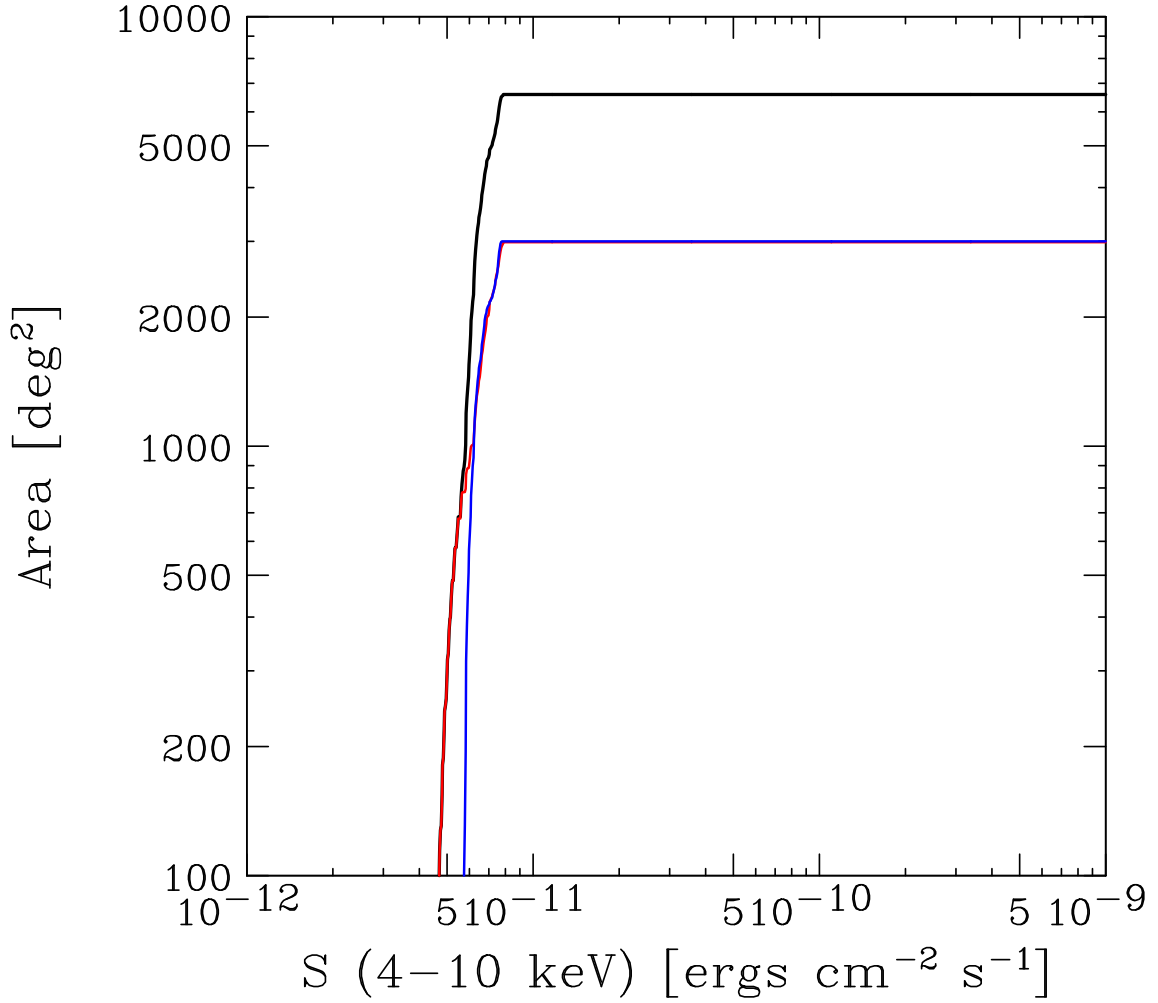


Figure 3.7. Survey area as a function of limiting sensitivity in the 4–10 keV band for $s_{D,4-10 \text{ keV}} > 6.5$ (black: the whole survey area, red: $l = 30^\circ\text{--}105^\circ$ and $l = 255^\circ\text{--}330^\circ$, blue: $l = 105^\circ\text{--}255^\circ$).

3.4.4 $\log N$ - $\log S$ Relation

The $\log N$ - $\log S$ relation (number counts) represents a basic statistical property of sources detected in a survey observation. To derive this relation, we need to create the sensitivity map, which gives the minimum flux of a source detectable with the adopted significance threshold ($s_{D,4-10\text{keV}} > 6.5$) as a function of sky position. Following our previous works (Hiroi et al., 2011, 2013), we estimated the sensitivity at each position by using the coverage map (Figure 3.1) and

the background+GRXE map. Here we utilized simple analytical formula that are calibrated with the actual relations among flux, significance, exposure, and background from the cataloged sources. The sensitivity map enables us to calculate the survey area as a function of limiting sensitivity (area curve, Figure 3.7). By dividing the observed flux distribution of sources by the area curve, the $\log N - \log S$ relation in the differential form is obtained, where the surface number density $n(S)dS$ of sources with fluxes between S and $S + dS$ is given. In this section, considering the low number statistics, we represent it in the integral form $N(> S) \equiv \int_S n(S)dS$, i.e., the total surface number density of sources with fluxes larger than S .

Figure 3.8 plots the spatially averaged $\log N - \log S$ relation in the 4–10 keV band of the MAXI sources at $|b| < 10^\circ$ obtained from the whole survey area (excluding the Galactic center and Vela SNR regions). Unlike the case of high Galactic latitude sky, where extragalactic populations are dominant, we expect large variation of source number density among different directions at low Galactic latitudes. To demonstrate this, we also calculated the $\log N - \log S$ relations from two separate Galactic longitude regions, (1) $l = 30^\circ - 105^\circ$ and $l = 255^\circ - 330^\circ$, and (2) $l = 105^\circ - 255^\circ$, both at $|b| < 10^\circ$. The results and corresponding survey area are also plotted in Figures 3.8 and 3.7, respectively.

We find that the slope of the $\log N - \log S$ relation is flat regardless of the Galactic longitude, which can be roughly approximated by $N(> S) \propto S^{-0.5}$. To evaluate the contributions from different populations, in Figure 3.9 we compare the $\log N - \log S$ relations of the identified extragalactic objects (AGNs and galaxy clusters), LMXBs, and HMXBs, which are the most dominant ones in our Catalog. As noticed, the $\log N - \log S$ slopes for LMXBs and HMXBs are even flatter than 0.5, and they are consistent with the results by Grimm et al. (2002) using the RXTE/ASM data at $|b| < 20^\circ$. As a future work, our catalog will be useful to constrain the X-ray luminosity function of Galactic-disk sources covering low luminosity ranges down to $L_X \sim 10^{34-35} \text{ erg s}^{-1}$ (assuming a mean distance of 10 kpc).

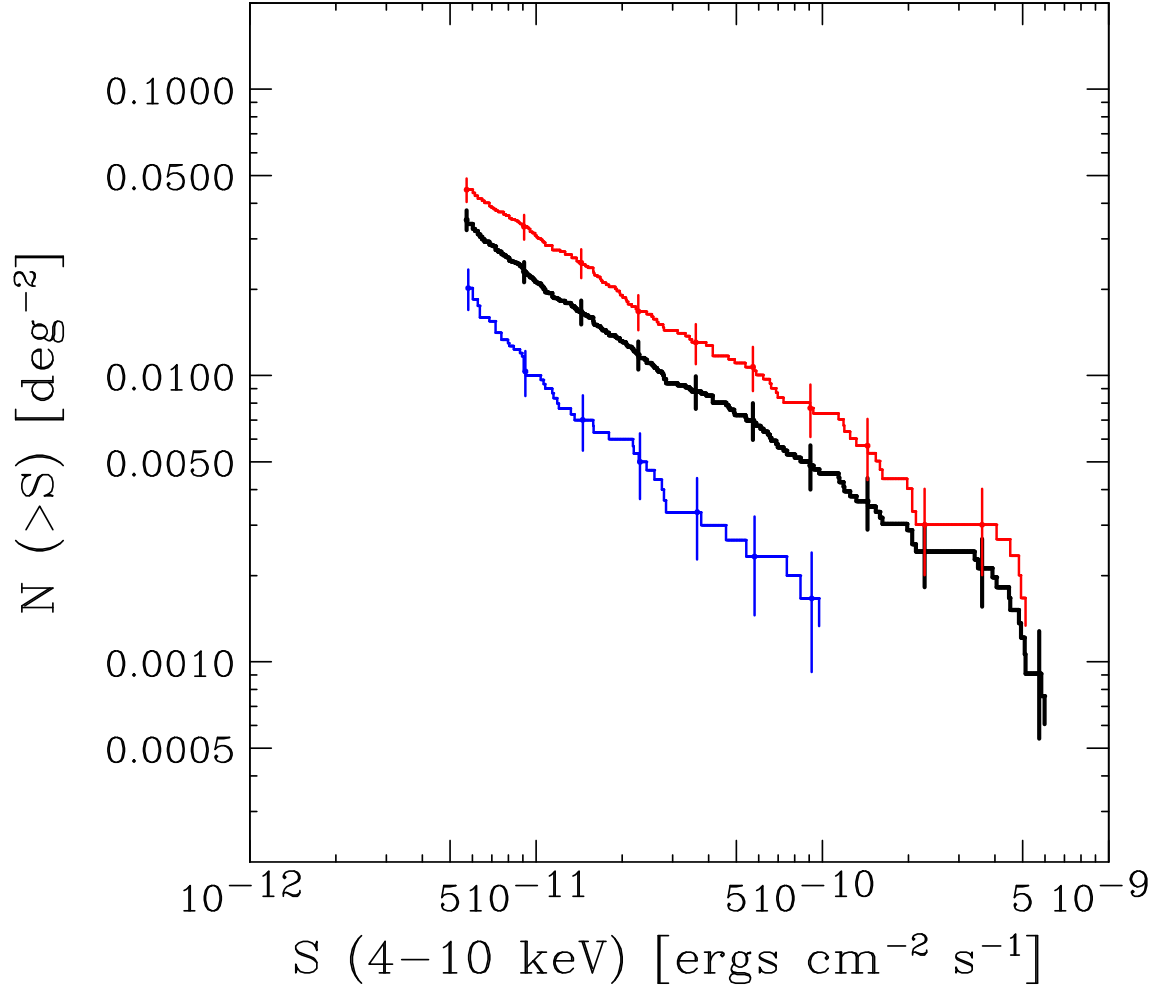


Figure 3.8. Spatially-averaged log N - log S relations in the 4-10 keV band of the 7-year sources at $|b| < 10^\circ$ (black: from the whole survey area, red: from the $l = 30^\circ - 105^\circ$ and $l = 255^\circ - 330^\circ$ region, blue: from the $l = 105^\circ - 255^\circ$ region). The attached error bars correspond to 1σ .

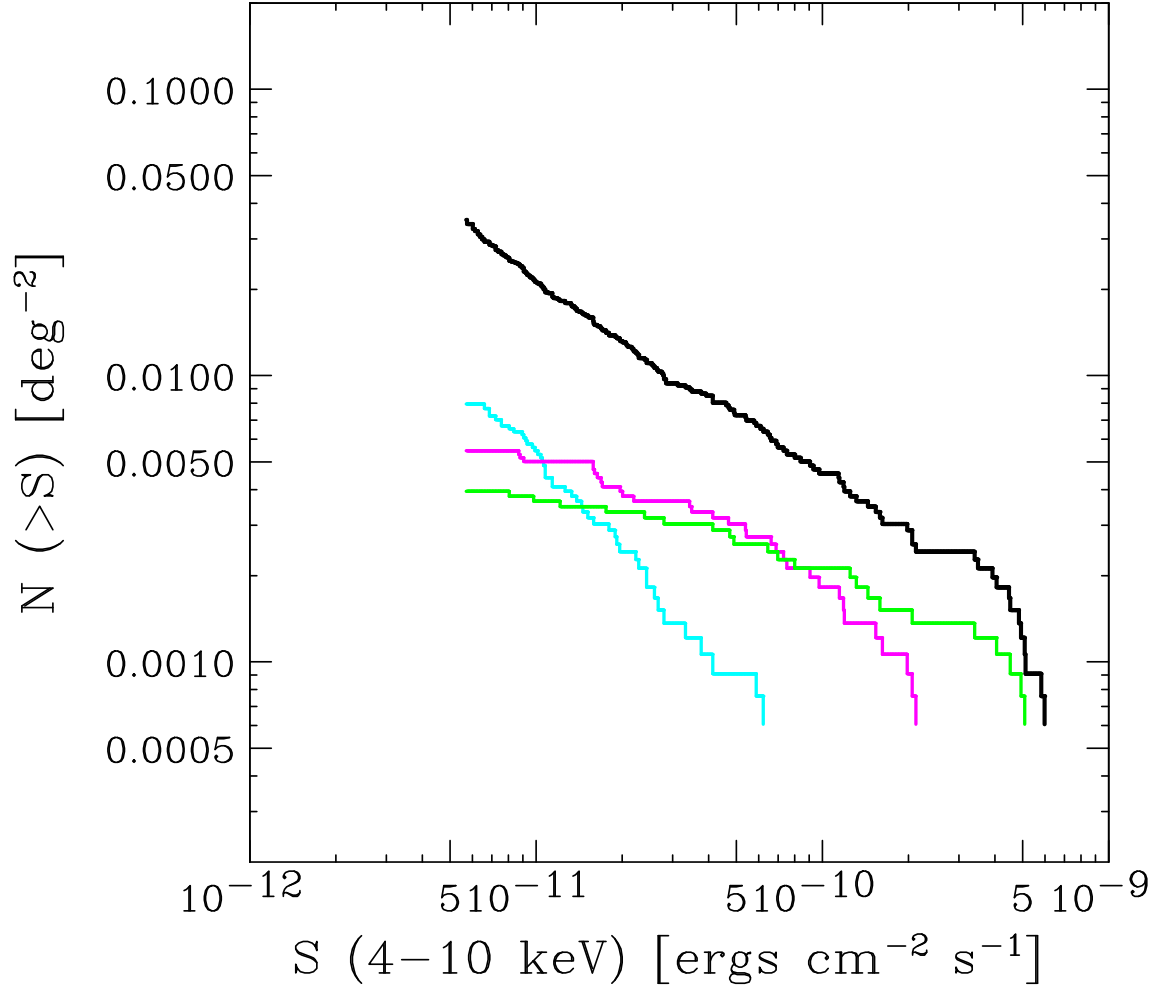


Figure 3.9. Spatially-averaged log N - log S relations in the 4-10 keV band obtained from the whole survey area for different populations (black: total, green: LMXBs, magenta: HMXBs, cyan: extragalactic).

Table 3.5a. Properties of the 7-year Sources in the *MAXI*/GSC Catalog at $|b| < 10^\circ$

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR1^e	(13) HR2^f	(14) σ_{rms}^g
1	J0000+674	0.006	67.449	0.173	7.2	6.3±0.9	6.5	1.7±0.3	0.0	<1.7	0.08±0.13	-1.00±0.20	0.136±0.126
2	J0025+641	6.308	64.132	...	51.9	52.1±0.9	80.4	30.9±0.4	4.3	15.0±3.5	-0.30±0.01	-0.40±0.09	-0.005±0.005
3	J0029+592	7.280	59.252	...	8.2	28.2±4.6	11.6	4.6±0.4	6.8	31.1±4.6	0.32±0.14	0.24±0.14	0.053±0.023
4	J0035+598	8.938	59.802	...	10.2	45.6±4.7	32.3	14.1±0.4	7.3	34.1±4.7	0.02±0.07	0.05±0.11	0.441±0.007
5	J0036+614	9.082	61.417	...	14.4	15.6±1.1	9.3	3.0±0.3	1.7	6.7±3.8	0.24±0.07	-0.23±0.28	-0.005±0.041
6	J0056+606	14.155	60.692	...	101.9	113.3±1.1	72.0	27.5±0.4	22.9	85.1±3.7	0.14±0.01	0.05±0.03	0.011±0.002
7	J0117+652	19.492	65.268	...	61.8	74.3±1.0	34.0	11.2±0.3	23.1	85.1±3.7	0.36±0.02	0.25±0.03	0.031±0.003
8	J0118+637	19.566	63.711	...	43.5	53.5±1.0	19.6	6.5±0.3	16.1	60.8±3.8	0.45±0.02	0.25±0.05	13.081±0.006
9	J0140+583	25.072	58.319	0.121	8.1	8.0±1.0	4.1	1.2±0.3	2.0	7.5±3.9	0.35±0.14	0.16±0.37	0.232±0.089
10	J0146+616	26.543	61.651	...	26.7	27.1±1.0	50.0	18.0±0.4	3.5	13.1±3.7	-0.35±0.02	-0.17±0.15	0.008±0.016
11	J0210+525	32.509	52.512	...	11.9	24.0±1.4	20.5	7.5±0.4	5.6	24.7±4.4	0.01±0.05	0.20±0.14	0.003±0.020
12	J0227+619	36.845	61.918	0.153	8.1	7.9±1.0	5.1	1.5±0.3	0.0	1.8±3.7	0.25±0.13	-0.50±0.67	0.148±0.089
13	J0241+611	40.354	61.137	...	7.2	8.7±1.2	8.1	2.7±0.3	1.1	4.3±4.0	0.02±0.11	-0.16±0.50	0.199±0.078
14	J0244+624	41.190	62.418	...	22.0	22.6±1.0	16.6	5.4±0.3	7.4	28.5±3.8	0.14±0.05	0.30±0.11	0.067±0.024
15	J0252+571	43.099	57.190	0.094	8.5	8.8±1.0	3.8	1.2±0.3	2.8	11.2±4.0	0.40±0.14	0.30±0.29	0.151±0.067
16	J0334+531	53.696	53.147	...	75.3	96.4±1.3	28.0	10.4±0.4	42.3	191.8±4.5	0.49±0.02	0.49±0.02	18.699±0.008
17	J0342+636	55.606	63.608	0.099	12.5	11.4±0.9	9.7	2.7±0.3	1.2	4.0±3.4	0.14±0.08	-0.32±0.37	-0.042±0.059
18	J0404+572	61.187	57.287	0.203	6.5	6.8±1.1	6.4	2.0±0.3	1.5	6.1±3.9	0.05±0.14	0.13±0.46	0.294±0.095
19	J0408+632	62.163	63.212	0.219	6.5	5.9±0.9	3.9	1.1±0.3	0.0	1.1±3.4	0.27±0.17	-0.57±0.87	-0.074±0.124
20	J0418+380	64.522	38.055	...	31.8	37.2±1.2	27.4	9.7±0.4	6.6	27.5±4.2	0.10±0.03	0.04±0.10	0.024±0.010
21	J0427+354	66.757	35.471	0.102	11.7	13.0±1.1	12.6	4.1±0.3	1.8	7.5±4.1	0.00±0.07	-0.08±0.32	-0.009±0.049
22	J0441+445	70.289	44.589	...	15.6	21.7±1.4	13.6	5.0±0.4	3.2	14.4±4.5	0.16±0.06	-0.01±0.19	2.415±0.026
23	J0450+450	72.505	45.037	0.022	56.8	83.0±1.5	58.9	26.8±0.5	6.5	31.4±4.8	-0.01±0.01	-0.29±0.07	-0.005±0.003
24	J0452+496	73.138	49.643	...	9.2	10.7±1.0	8.8	3.0±0.3	3.2	14.3±4.5	0.06±0.09	0.32±0.26	-0.030±0.068
25	J0456+523	74.065	52.367	0.090	13.4	15.7±1.2	15.9	5.6±0.3	1.3	5.4±3.6	-0.05±0.06	-0.33±0.29	0.119±0.046
26	J0457+455	74.428	45.517	...	9.5	13.4±1.4	10.9	4.1±0.4	1.9	9.2±4.8	0.03±0.09	0.00±0.32	0.015±0.074
27	J0459+272	74.874	27.202	...	8.3	8.2±1.0	4.4	1.2±0.3	3.1	11.8±3.7	0.35±0.13	0.36±0.27	0.150±0.072
28	J0525+241	81.451	24.124	...	20.8	21.5±1.0	20.4	6.4±0.3	0.0	0.9±3.7	0.03±0.04	-0.88±0.33	0.018±0.017
29	J0534+220	83.624	22.012	...	2222.4	12493.7±5.6	1507.1	3980.0±2.6	997.7	8510.0±8.5	0.00±0.00	0.00±0.00	-0.000±0.000
30	J0534+285	83.627	28.557	...	9.0	9.1±1.0	2.9	0.8±0.3	0.0	0.5±2.8	0.55±0.15	-0.86±0.58	0.337±0.062
31	J0538+263	84.732	26.309	...	296.3	444.3±1.5	153.3	74.9±0.5	141.9	616.0±4.3	0.31±0.00	0.34±0.01	8.004±0.005
32	J0547+379	86.902	37.929	...	8.0	9.0±1.1	9.1	3.0±0.3	2.5	10.6±4.2	-0.02±0.10	0.27±0.32	1.511±0.059
33	J0601+130	90.443	13.009	0.156	7.9	7.6±1.0	9.9	2.7±0.2	0.0	<2.7	-0.05±0.10	-1.00±0.18	0.302±0.063

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR1^e	(13) HR2^f	(14) σ_{rms}^g
34	J0602+285	90.659	28.573	...	24.7	25.6±1.0	18.5	6.2±0.3	5.8	22.7±4.0	0.14±0.04	0.13±0.12	0.002±0.026
35	J0602+230	90.710	23.052	0.166	6.9	7.2±1.0	9.3	2.6±0.3	1.2	4.4±3.7	-0.06±0.11	-0.05±0.49	-0.045±0.100
36	J0605+299	91.253	29.988	0.076	16.3	17.8±1.1	19.4	6.5±0.3	0.0	0.7±3.2	-0.07±0.05	-0.88±0.36	-0.014±0.035
37	J0616+225	94.155	22.576	0.100	11.7	11.3±1.0	42.4	13.5±0.3	1.1	4.0±3.5	-0.58±0.03	-0.31±0.38	0.054±0.055
38	J0617+091	94.278	9.137	...	383.5	606.6±1.6	306.4	206.4±0.7	73.0	259.0±3.5	-0.03±0.00	-0.23±0.01	0.023±0.001
39	J0631+251	97.863	25.176	0.128	9.1	8.9±1.0	7.9	2.2±0.3	0.0	<2.3	0.13±0.10	-1.00±0.16	0.082±0.079
40	J0633+049	98.423	4.949	0.112	9.8	8.9±0.9	10.3	2.7±0.3	1.9	6.2±3.2	0.03±0.09	0.01±0.33	-0.044±0.071
41	J0635+225	98.851	22.527	...	27.6	27.6±1.0	26.3	7.9±0.3	3.3	12.1±3.6	0.06±0.03	-0.22±0.15	-0.023±0.014
42	J0635+077	98.941	7.764	0.091	12.3	11.7±1.0	8.8	2.3±0.3	0.0	2.5±2.9	0.23±0.08	-0.52±0.37	0.027±0.059
43	J0640-127	100.133	-12.788	...	9.2	7.5±0.8	10.6	2.4±0.2	1.3	3.9±3.1	-0.00±0.09	-0.13±0.42	0.067±0.073
44	J0641+098	100.416	9.850	0.054	6.5	6.3±1.0	5.5	1.5±0.3	0.0	2.7±3.5	0.15±0.15	-0.22±0.62	0.388±0.137
45	J0645-169	101.415	-16.910	...	7.1	8.3±1.2	10.0	2.2±0.2	1.9	5.8±3.0	0.09±0.11	0.01±0.33	0.016±0.056
46	J0648+152	102.211	15.273	0.108	10.0	10.2±1.0	11.4	3.3±0.3	1.0	3.9±3.9	-0.00±0.08	-0.28±0.45	0.194±0.072
47	J0656-035	104.007	-3.599	0.159	6.9	6.2±0.9	4.4	1.1±0.2	3.1	9.7±3.1	0.29±0.15	0.39±0.29	0.349±0.081
48	J0704-114	106.045	-11.418	0.162	6.9	5.7±0.8	5.0	1.1±0.2	0.0	0.7±2.8	0.23±0.14	-0.69±0.83	0.025±0.110
49	J0708-155	107.249	-15.551	...	12.9	10.5±0.8	15.7	3.6±0.2	3.0	9.2±3.0	0.09±0.12	0.13±0.23	0.276±0.039
50	J0714-254	108.644	-25.445	...	7.2	6.0±0.8	7.1	1.6±0.2	0.0	1.6±3.2	0.09±0.12	-0.45±0.72	-0.116±0.095
51	J0717-114	109.309	-11.476	0.053	21.0	17.8±0.9	17.9	4.3±0.2	0.0	6.9±3.0	0.14±0.04	-0.28±0.20	-0.014±0.020
52	J0725-064	111.473	-6.451	0.155	8.2	7.1±0.9	6.7	1.6±0.2	2.8	8.9±3.1	0.17±0.12	0.29±0.28	0.036±0.081
53	J0728-206	112.129	-20.696	0.150	7.4	6.0±0.8	7.9	1.8±0.2	1.3	4.0±3.1	0.04±0.11	-0.01±0.47	0.207±0.068
54	J0729-262	112.269	-26.205	...	20.0	16.8±0.8	13.6	3.2±0.2	5.5	17.3±3.2	0.25±0.05	0.20±0.14	0.109±0.023
55	J0733-135	113.259	-13.568	...	12.7	10.4±0.8	5.6	1.2±0.2	4.7	14.4±3.0	0.45±0.10	0.34±0.18	-0.117±0.052
56	J0745-162	116.465	-16.220	...	13.0	10.5±0.8	10.9	2.4±0.2	5.2	15.9±3.0	0.16±0.07	0.38±0.17	0.063±0.040
57	J0747-192	116.919	-19.257	...	48.3	40.9±0.8	45.1	11.4±0.3	5.6	16.9±3.0	0.07±0.02	-0.25±0.09	-0.003±0.005
58	J0752-442	118.198	-44.215	0.150	7.9	8.4±1.1	6.8	7.8±1.2	2.4	36.7±15.0	-0.49±0.15	0.73±0.47	0.068±0.081
59	J0753-459	118.425	-45.974	0.170	7.0	7.6±1.1	2.3	0.7±0.3	0.0	0.5±2.5	0.56±0.19	-0.82±0.62	0.332±0.084
60	J0758-221	119.596	-22.103	0.097	11.7	9.5±0.8	11.2	2.5±0.2	0.0	0.9±3.1	0.09±0.08	-0.77±0.57	-0.030±0.054
61	J0759-387	119.857	-38.721	...	14.3	13.7±1.0	9.3	2.5±0.3	2.0	7.2±3.5	0.28±0.07	-0.13±0.27	0.088±0.042
62	J0802-496	120.649	-49.679	...	10.1	9.9±1.0	7.2	2.0±0.3	2.9	10.4±3.6	0.22±0.10	0.22±0.26	-0.004±0.071
63	J0804-276	121.109	-27.681	0.138	8.2	6.9±0.8	5.5	1.2±0.2	1.6	5.1±2.9	0.27±0.12	0.04±0.38	0.007±0.097
64	J0809-406	122.309	-40.676	0.143	8.0	8.0±1.0	5.9	1.6±0.3	1.3	4.6±3.7	0.22±0.13	-0.08±0.45	0.325±0.065
65	J0823-430	125.758	-43.052	0.070	15.3	16.6±1.0	66.9	92.7±1.4	1.9	26.8±13.8	-0.89±0.02	0.41±0.46	0.016±0.029
66	J0839-358	129.758	-35.899	...	8.4	8.0±0.9	7.6	1.9±0.3	3.4	11.5±3.4	0.14±0.11	0.36±0.26	0.104±0.060

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR1^e	(13) HR2^f	(14) σ_{rms}^g
67	J0841-562	130.295	-56.247	0.203	6.7	5.5±0.8	5.4	1.3±0.2	1.7	5.5±3.1	0.14±0.14	0.19±0.42	0.266±0.099
68	J0844-378	131.231	-37.834	0.078	14.6	13.9±0.9	11.3	3.0±0.3	0.0	2.3±2.5	0.20±0.07	-0.61±0.29	-0.002±0.038
69	J0902-481	135.505	-48.130	...	13.3	14.3±1.1	9.9	3.1±0.3	1.6	6.3±4.0	0.20±0.07	-0.21±0.31	0.046±0.044
70	J0902-405	135.533	-40.550	...	564.2	1170.4±2.1	204.0	112.3±0.6	371.2	2027.3±5.4	0.54±0.00	0.44±0.00	0.015±0.001
71	J0910-526	137.637	-52.606	...	6.7	6.5±1.0	5.6	1.5±0.3	0.0	2.4±2.7	0.17±0.14	-0.30±0.51	0.073±0.089
72	J0916-623	139.008	-62.309	...	10.3	13.2±1.3	14.0	3.8±0.3	4.6	14.4±3.2	0.05±0.08	0.23±0.17	0.118±0.034
73	J0920-552	140.104	-55.216	...	128.7	130.3±1.0	116.0	41.7±0.4	21.0	68.9±3.3	-0.00±0.01	-0.13±0.03	0.156±0.001
74	J0922-632	140.749	-63.268	...	19.6	40.9±1.3	35.0	9.9±0.3	3.2	9.9±3.1	0.14±0.03	-0.48±0.11	0.013±0.006
75	J1009-582	152.426	-58.285	...	108.4	195.2±1.8	80.4	29.0±0.4	61.7	225.0±3.7	0.36±0.01	0.26±0.01	5.229±0.004
76	J1018-582	154.582	-58.207	0.080	12.2	20.5±1.7	21.6	7.4±0.3	1.0	3.8±3.7	-0.06±0.06	-0.58±0.28	0.086±0.022
77	J1031-621	157.773	-62.152	0.132	6.9	5.3±0.8	3.5	0.8±0.2	1.2	3.4±2.9	0.34±0.17	-0.03±0.51	0.165±0.082
78	J1036-568	159.210	-56.848	...	10.1	8.6±0.9	5.6	1.5±0.3	3.9	12.1±3.0	0.30±0.11	0.35±0.21	0.588±0.029
79	J1038-497	159.736	-49.762	...	6.9	6.5±1.0	3.8	1.0±0.2	0.0	2.1±2.6	0.34±0.15	-0.37±0.52	0.087±0.090
80	J1044-596	161.220	-59.694	...	34.8	57.1±1.8	64.3	22.4±0.3	5.2	18.1±3.6	-0.10±0.02	-0.36±0.08	0.131±0.003
81	J1121-606	170.292	-60.629	...	658.8	1090.2±1.7	300.6	167.8±0.6	337.5	1398.0±4.1	0.35±0.00	0.31±0.00	0.205±0.001
82	J1139-653	174.766	-65.399	...	32.1	49.0±1.2	58.3	17.1±0.3	7.3	21.4±2.9	-0.05±0.02	-0.22±0.07	0.101±0.004
83	J1141-639	175.434	-63.966	0.155	8.4	7.1±0.9	3.3	1.0±0.3	0.0	1.7±2.8	0.41±0.15	-0.49±0.56	0.252±0.072
84	J1144-698	176.133	-69.820	...	7.1	5.2±0.7	7.8	1.8±0.2	1.9	4.8±2.6	-0.03±0.12	0.15±0.38	0.171±0.095
85	J1144-610	176.158	-61.042	...	14.0	19.5±1.4	11.7	4.1±0.4	6.4	24.9±3.9	0.20±0.07	0.30±0.13	0.090±0.027
86	J1147-619	176.829	-61.978	...	121.9	151.9±1.2	49.5	19.8±0.4	42.0	178.7±4.2	0.42±0.01	0.27±0.02	0.037±0.001
87	J1156-566	179.019	-56.675	0.090	9.2	7.6±0.8	8.7	2.1±0.3	0.0	<2.6	0.06±0.10	-1.00±0.15	0.005±0.086
88	J1203-538	180.868	-53.844	...	12.0	10.6±0.9	8.0	2.1±0.3	2.9	9.7±3.3	0.24±0.09	0.15±0.25	-0.001±0.055
89	J1213-648	183.349	-64.844	...	82.3	72.1±0.9	55.9	16.5±0.3	11.7	33.1±2.8	0.16±0.01	-0.19±0.04	1.011±0.003
90	J1226-627	186.642	-62.789	...	419.1	591.6±1.4	69.6	25.4±0.4	353.0	1580.2±4.0	0.76±0.00	0.59±0.00	0.020±0.001
91	J1235-646	188.792	-64.667	...	31.9	27.5±0.9	10.9	3.0±0.3	12.9	38.9±3.0	0.49±0.04	0.35±0.07	0.012±0.010
92	J1237-667	189.312	-66.722	0.117	10.6	8.0±0.8	8.9	2.1±0.2	0.0	0.9±2.6	0.09±0.09	-0.73±0.56	0.126±0.069
93	J1240-577	190.168	-57.791	...	9.7	10.6±1.1	10.4	2.7±0.3	5.3	16.7±3.2	0.10±0.09	0.40±0.17	0.192±0.042
94	J1243-630	190.931	-63.076	...	19.9	19.8±1.0	10.3	3.3±0.3	2.1	7.2±3.0	0.31±0.06	-0.30±0.19	0.044±0.018
95	J1249-590	192.401	-59.071	...	62.1	69.1±1.1	75.9	23.8±0.3	12.7	39.2±3.1	-0.04±0.01	-0.09±0.05	0.338±0.002
96	J1257-692	194.396	-69.292	...	431.0	504.4±1.2	325.5	161.1±0.5	65.1	176.8±2.7	-0.00±0.00	-0.32±0.01	0.001±0.000
97	J1301-615	195.300	-61.595	...	371.1	479.9±1.3	180.1	78.8±0.4	146.7	522.8±3.4	0.32±0.00	0.23±0.01	1.444±0.002
98	J1302-639	195.602	-63.908	...	40.9	38.9±0.9	21.0	6.9±0.3	12.7	41.0±3.2	0.29±0.03	0.22±0.06	0.114±0.005
99	J1314-602	198.672	-60.240	0.162	8.3	7.0±0.8	7.9	2.2±0.3	1.8	5.5±3.0	0.02±0.11	0.07±0.37	0.207±0.067

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR1^e	(13) HR2^f	(14) σ_{rms}^g
100	J1317-629	199.432	-62.995	...	10.7	16.3±1.5	20.4	7.2±0.3	1.1	3.9±3.4	-0.16±0.06	-0.48±0.31	0.027±0.015
101	J1325-577	201.279	-57.725	0.053	22.3	18.7±0.8	33.7	9.2±0.3	0.0	1.5±3.0	-0.22±0.03	-0.80±0.29	-0.018±0.022
102	J1326-621	201.616	-62.147	...	67.9	123.6±1.6	66.8	24.8±0.4	30.5	105.9±3.5	0.23±0.01	0.11±0.02	0.024±0.001
103	J1331-549	202.914	-54.947	0.122	9.9	8.7±0.9	7.0	1.8±0.3	0.0	3.0±3.3	0.20±0.10	-0.33±0.46	0.177±0.065
104	J1345-623	206.256	-62.382	0.089	13.4	13.1±1.0	13.9	4.7±0.3	0.0	0.6±3.7	-0.06±0.06	-0.88±0.54	-0.006±0.020
105	J1347-606	206.840	-60.648	...	17.9	32.9±0.8	27.3	8.0±0.3	11.2	34.9±3.1	0.14±0.03	0.22±0.07	0.027±0.007
106	J1356-645	209.147	-64.503	0.069	12.8	27.7±2.1	27.5	8.5±0.3	9.6	31.9±3.3	0.02±0.05	0.26±0.09	7.967±0.009
107	J1359-633	209.958	-63.352	...	13.8	13.7±0.8	8.7	2.9±0.3	2.5	9.0±3.6	0.20±0.07	-0.02±0.25	0.044±0.037
108	J1407-618	211.782	-61.891	...	23.1	25.0±1.1	0.0	0.3±-0.3	4.8	17.2±3.6	0.93±0.08	0.00±0.13	1.481±0.012
109	J1412-653	213.095	-65.310	...	20.7	22.1±1.1	10.9	2.7±0.2	14.0	38.7±2.8	0.44±0.05	0.44±0.07	0.011±0.015
110	J1419-610	214.835	-61.011	...	21.1	22.4±1.1	9.5	3.5±0.4	5.9	23.0±4.0	0.35±0.06	0.20±0.13	0.032±0.011
111	J1420-626	215.199	-62.680	...	40.8	40.8±1.0	20.6	6.6±0.3	17.2	55.1±3.2	0.33±0.03	0.33±0.05	5.236±0.009
112	J1423-541	215.977	-54.177	0.158	7.6	6.8±0.9	10.0	2.7±0.3	0.0	2.9±2.1	-0.11±0.10	-0.23±0.37	-0.090±0.106
113	J1442-626	220.687	-62.635	0.039	30.3	25.4±0.8	45.4	13.2±0.3	2.7	8.2±2.7	-0.24±0.02	-0.36±0.14	-0.010±0.012
114	J1446-641	221.687	-64.128	...	8.7	6.8±0.8	1.1	0.3±0.3	4.1	12.0±2.9	0.76±0.19	0.44±0.22	-0.002±0.092
115	J1449-598	222.369	-59.808	...	15.9	15.7±1.0	4.6	1.5±0.3	3.5	11.7±3.3	0.53±0.09	0.05±0.19	0.132±0.028
116	J1453-553	223.284	-55.389	...	23.1	26.2±1.1	19.9	5.5±0.3	8.8	28.7±3.1	0.21±0.04	0.23±0.09	0.251±0.010
117	J1455-516	223.981	-51.673	...	9.8	9.2±0.9	10.4	2.9±0.3	2.5	8.9±3.4	0.01±0.08	0.17±0.28	0.141±0.064
118	J1502-601	225.726	-60.182	...	9.9	9.5±0.9	4.8	1.4±0.3	2.0	6.4±3.1	0.36±0.11	-0.01±0.30	0.210±0.048
119	J1509-667	227.378	-66.723	...	16.5	12.4±0.7	4.4	1.0±0.2	5.5	14.6±2.6	0.60±0.08	0.27±0.14	0.086±0.039
120	J1513-461	228.479	-46.122	0.084	13.8	15.0±1.1	14.6	4.6±0.3	0.0	<1.7	0.02±0.06	-1.00±0.10	-0.031±0.047
121	J1514-591	228.532	-59.124	...	87.6	91.9±0.9	70.0	26.6±0.4	21.1	69.1±3.3	0.05±0.01	0.05±0.03	0.008±0.002
122	J1520-571	230.129	-57.195	...	395.5	574.2±1.5	255.2	152.4±0.6	54.7	208.5±3.8	0.09±0.00	-0.30±0.01	3.712±0.004
123	J1533-658	233.309	-65.862	0.133	8.3	6.2±0.7	5.5	4.5±0.8	3.6	27.3±7.7	-0.38±0.16	0.73±0.32	0.405±0.075
124	J1542-523	235.573	-52.373	...	179.4	209.4±1.2	87.0	32.8±0.4	81.6	303.6±3.7	0.34±0.01	0.36±0.01	0.003±0.001
125	J1547-625	236.951	-62.563	...	373.0	447.7±1.1	272.9	133.9±0.5	52.5	157.1±3.0	0.03±0.00	-0.32±0.01	0.043±0.001
126	J1548-455	237.126	-45.505	...	21.6	28.2±1.2	15.8	4.9±0.3	8.1	32.3±4.0	0.30±0.04	0.25±0.10	0.043±0.016
127	J1548-476	237.229	-47.698	0.135	9.0	9.7±1.1	4.7	1.4±0.3	1.8	7.4±4.1	0.37±0.12	0.06±0.36	0.181±0.072
128	J1551-543	237.910	-54.399	...	17.9	20.4±1.2	8.4	3.3±0.4	4.2	17.0±4.0	0.33±0.07	0.10±0.16	0.112±0.053
129	J1601-607	240.313	-60.750	...	64.3	203.3±1.5	136.3	57.9±0.4	20.7	66.0±3.2	0.06±0.01	-0.35±0.02	0.001±0.001
130	J1612-607	243.168	-60.732	...	82.1	112.4±1.4	108.8	47.4±0.4	15.3	54.9±3.5	-0.14±0.01	-0.16±0.03	0.000±0.001
131	J1617-595	244.460	-59.558	...	8.6	12.4±1.4	12.4	3.9±0.3	2.4	8.1±3.4	0.01±0.08	-0.02±0.26	0.066±0.054
132	J1629-613	247.312	-61.314	0.161	7.3	7.3±1.0	15.8	4.2±0.3	3.3	9.6±2.9	-0.28±0.08	0.32±0.25	0.001±0.033

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR^e	(13) HR^f	(14) σ_{rms}^g
133	J1640-324	250.222	-32.469	0.095	7.4	6.4±0.9	5.1	1.3±0.2	0.0	3.2±3.2	0.24±0.14	-0.15±0.53	0.253±0.090
134	J1641-346	250.358	-34.670	0.141	8.2	7.3±0.9	3.0	0.7±0.2	1.4	4.7±2.6	0.53±0.16	-0.03±0.34	0.096±0.088
135	J1650-601	252.530	-60.154	0.065	17.1	20.7±1.2	19.2	6.5±0.3	2.4	9.6±4.0	0.00±0.05	-0.19±0.21	0.006±0.024
136	J1650-330	252.549	-33.018	...	11.8	10.9±0.9	7.5	1.9±0.2	4.1	13.8±3.3	0.30±0.09	0.30±0.20	0.068±0.043
137	J1653-593	253.365	-59.328	...	16.1	26.3±1.6	23.8	8.3±0.3	3.3	13.3±4.1	0.01±0.05	-0.15±0.17	0.028±0.017
138	J1655-519	253.995	-51.965	...	14.8	14.4±1.0	12.8	3.8±0.3	5.3	19.1±3.6	0.09±0.06	0.32±0.16	0.002±0.047
139	J1702-299	255.506	-29.978	0.043	26.3	23.6±0.9	25.5	7.0±0.3	4.8	15.5±3.2	0.04±0.03	-0.02±0.13	7.846±0.008
140	J1709-266	257.424	-26.605	...	68.1	79.3±1.1	74.6	25.4±0.3	10.8	36.3±3.4	-0.00±0.01	-0.20±0.05	8.776±0.004
141	J1710-280	257.543	-28.084	...	41.1	46.8±1.1	41.0	12.7±0.3	10.4	35.2±3.4	0.08±0.02	0.05±0.06	0.046±0.005
142	J1712-233	258.079	-23.333	...	200.5	345.5±1.7	160.4	93.1±0.6	40.7	186.4±4.6	0.08±0.00	-0.12±0.01	-0.001±0.000
143	J1713-241	258.262	-24.146	...	28.6	60.0±1.9	31.4	15.2±0.5	11.3	51.7±4.6	0.12±0.03	0.12±0.06	0.004±0.005
144	J1730-215	262.564	-21.579	...	17.5	15.1±0.9	7.6	1.9±0.3	0.0	2.2±3.2	0.43±0.07	-0.65±0.34	-0.006±0.047
145	J1731-169	262.935	-16.961	...	1116.8	3026.2±2.7	775.6	907.8±1.2	266.4	1109.7±4.2	0.03±0.00	-0.30±0.00	0.009±0.001
146	J1738-444	264.728	-44.445	...	804.7	2247.6±2.8	507.2	573.1±1.1	238.5	1216.7±5.1	0.11±0.00	-0.11±0.00	0.057±0.001
147	J1741-122	265.477	-12.244	...	10.6	9.0±0.9	8.5	2.0±0.2	2.2	6.8±3.1	0.17±0.09	0.05±0.30	-0.052±0.071
148	J1750-370	267.548	-37.062	...	155.8	504.1±4.4	196.4	129.8±0.7	53.9	233.9±4.3	0.11±0.01	-0.19±0.01	0.107±0.001
149	J1803-344	270.927	-34.422	0.024	48.3	48.6±1.0	41.5	13.2±0.3	9.0	30.2±3.4	0.08±0.02	-0.05±0.07	17.000±0.006
150	J1806-089	271.656	-8.967	0.090	8.9	7.8±0.9	6.0	1.5±0.2	3.1	9.7±3.2	0.25±0.11	0.29±0.27	0.159±0.105
151	J1807-369	271.989	-36.943	...	8.4	7.9±0.9	8.9	2.4±0.3	3.4	11.9±3.0	0.02±0.10	0.37±0.22	13.354±0.021
152	J1810-041	272.576	-4.160	0.077	15.2	13.4±0.9	14.2	3.6±0.2	5.9	18.6±3.2	0.08±0.06	0.34±0.14	-0.022±0.039
153	J1814+022	273.502	2.201	0.132	8.6	7.7±0.9	11.8	3.1±0.3	1.9	6.2±2.8	-0.11±0.09	0.08±0.31	-0.034±0.085
154	J1823-347	275.824	-34.796	0.112	10.2	9.7±1.0	13.7	3.9±0.3	1.9	6.6±3.4	-0.12±0.07	-0.00±0.32	0.184±0.068
155	J1823-303	275.914	-30.358	...	1264.5	3982.4±3.1	796.1	1048.8±1.3	420.1	2104.3±5.0	0.09±0.00	-0.13±0.00	0.024±0.001
156	J18250000	276.352	-0.012	...	260.4	336.8±1.3	204.6	101.6±0.5	38.6	124.5±3.2	0.03±0.00	-0.30±0.01	0.135±0.001
157	J1828-253	277.249	-25.355	0.079	13.8	17.2±1.3	18.6	6.3±0.3	3.4	11.7±3.2	-0.07±0.05	-0.00±0.17	14.016±0.012
158	J1829-238	277.362	-23.817	...	446.7	713.9±1.6	298.0	186.0±0.6	140.6	550.7±3.9	0.10±0.00	0.06±0.00	0.196±0.001
159	J1834-210	278.523	-21.081	...	8.4	7.5±0.9	7.6	1.9±0.2	4.2	13.7±3.3	0.10±0.11	0.46±0.23	0.112±0.082
160	J1836-194	279.039	-19.400	...	24.7	22.7±0.9	27.9	7.5±0.3	5.7	18.8±3.3	-0.02±0.03	0.10±0.12	10.379±0.008
161	J1839+050	279.994	5.029	...	983.1	2731.4±2.8	685.2	851.6±1.2	227.0	950.1±4.2	0.01±0.00	-0.32±0.00	0.015±0.001
162	J1849-171	282.420	-17.163	0.177	6.5	5.6±0.9	5.4	1.3±0.2	2.3	7.7±3.3	0.15±0.15	0.34±0.37	-0.229±0.138
163	J1855-026	283.869	-2.607	...	51.7	53.3±1.0	13.0	3.7±0.3	25.8	83.0±3.2	0.64±0.03	0.39±0.03	-0.003±0.004
164	J1855+157	283.900	15.733	...	10.9	11.2±1.0	8.0	2.3±0.3	0.0	3.5±2.8	0.22±0.09	-0.37±0.33	0.091±0.053
165	J1858+033	284.579	3.335	...	14.8	16.7±1.1	0.0	<0.2	2.9	10.5±3.3	1.00±0.10	-0.04±0.19	1.437±0.042

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HRI^e	(13) HR2^f	(14) σ_{rms}^g
166	J1858+082	284.656	8.261	0.070	16.4	15.6±0.9	6.6	1.8±0.3	8.0	26.4±3.3	0.46±0.08	0.43±0.11	13.844±0.012
167	J1901+014	285.442	1.475	...	34.0	34.6±1.0	27.3	8.7±0.3	6.1	19.8±3.3	0.12±0.03	-0.09±0.09	0.089±0.010
168	J1904-108	286.119	-10.885	0.041	7.6	6.6±0.2	4.9	1.2±0.2	2.6	8.6±3.3	0.27±0.09	0.31±0.31	0.144±0.077
169	J1904-131	286.205	-13.166	0.104	10.9	9.2±0.8	6.5	1.5±0.2	4.3	13.6±3.1	0.32±0.10	0.37±0.20	0.088±0.062
170	J1910+097	287.509	9.729	...	52.4	204.3±2.7	74.8	47.1±0.6	37.0	153.2±4.1	0.16±0.01	0.05±0.02	0.124±0.001
171	J1910-057	287.560	-5.760	...	66.2	63.6±1.0	129.5	50.1±0.4	8.7	27.5±3.1	-0.42±0.01	-0.22±0.06	14.905±0.005
172	J1910+076	287.675	7.684	...	94.4	117.5±1.2	33.2	12.7±0.4	35.2	131.8±3.8	0.49±0.01	0.24±0.02	0.008±0.002
173	J1911+005	287.824	0.577	...	340.1	488.9±1.4	264.0	154.3±0.6	52.6	175.4±3.3	0.00±0.00	-0.31±0.01	6.973±0.004
174	J1911+049	287.989	4.939	...	98.1	117.8±1.2	54.0	20.6±0.4	29.7	97.6±3.3	0.29±0.01	0.10±0.02	0.079±0.002
175	J1915+109	288.806	10.938	...	2271.6	13858.9±6.1	1398.5	3611.5±2.6	726.7	5484.9±7.6	0.10±0.00	-0.26±0.00	0.082±0.003
176	J1918-052	289.707	-5.232	...	145.6	156.9±1.1	107.4	38.9±0.4	36.1	117.8±3.3	0.12±0.01	0.05±0.02	0.109±0.001
177	J1928+204	292.148	20.411	0.134	9.1	9.4±1.1	6.7	2.0±0.3	3.3	12.8±3.9	0.19±0.11	0.33±0.26	0.066±0.068
178	J1929+184	292.377	18.411	...	14.8	15.9±1.1	6.2	2.1±0.3	8.9	33.1±3.7	0.42±0.08	0.51±0.11	0.691±0.055
179	J1930+096	292.713	9.692	0.069	18.4	19.4±1.0	20.7	6.2±0.3	4.8	16.6±3.5	0.00±0.04	0.11±0.15	0.265±0.023
180	J1941+301	295.322	30.183	0.130	9.2	10.3±1.1	3.8	1.2±0.3	1.2	4.8±4.1	0.47±0.12	-0.19±0.44	0.136±0.097
181	J1941+258	295.488	25.861	0.129	9.4	10.0±1.1	5.1	1.6±0.3	3.0	11.7±3.9	0.34±0.12	0.27±0.27	0.211±0.054
182	J1942+224	295.602	22.466	...	8.7	9.9±1.2	2.8	1.0±0.3	2.2	9.6±4.2	0.53±0.16	0.17±0.32	0.027±0.076
183	J1944+212	296.092	21.207	...	10.0	11.3±1.1	9.2	2.9±0.3	2.1	8.3±3.9	0.10±0.09	0.04±0.31	0.051±0.059
184	J1945+274	296.365	27.410	...	58.9	68.2±1.2	29.1	10.0±0.3	22.6	93.2±4.1	0.37±0.02	0.33±0.04	7.415±0.005
185	J1946+449	296.688	44.920	...	7.3	8.9±1.2	4.2	1.4±0.3	0.0	4.6±4.7	0.32±0.14	-0.13±0.55	0.438±0.117
186	J1949+301	297.423	30.160	...	52.9	65.6±1.2	37.0	13.5±0.4	18.8	77.7±4.1	0.22±0.02	0.27±0.04	8.259±0.005
187	J1955+321	298.885	32.116	...	65.9	142.9±2.0	47.2	24.2±0.5	27.2	143.9±5.3	0.31±0.01	0.19±0.03	0.486±0.003
188	J1958+352	299.596	35.201	...	1297.3	5828.0±4.5	1053.6	2564.8±2.4	466.4	3272.8±7.0	-0.16±0.00	-0.10±0.00	0.019±0.001
189	J1959+408	299.848	40.804	...	47.8	61.4±1.3	37.2	14.6±0.4	11.4	50.5±4.5	0.14±0.02	0.09±0.06	0.002±0.005
190	J1959+117	299.860	11.712	...	279.3	401.4±1.4	264.8	168.7±0.6	16.9	59.8±3.5	-0.14±0.00	-0.64±0.01	0.118±0.001
191	J1959+322	299.975	32.290	...	6.9	34.0±3.4	12.1	6.0±0.5	1.3	6.8±5.3	0.29±0.09	-0.55±0.25	0.240±0.015
192	J2008+325	302.075	32.528	...	11.7	14.6±1.2	9.1	3.5±0.4	2.6	12.2±4.7	0.14±0.08	0.10±0.27	0.051±0.064
193	J2015+370	303.996	37.083	...	15.7	18.9±1.2	13.3	5.2±0.4	1.8	8.5±4.7	0.07±0.06	-0.20±0.28	0.076±0.054
194	J2022+371	305.510	37.138	0.089	12.6	17.3±1.3	15.3	25.5±1.7	0.0	15.7±16.5	-0.64±0.07	0.14±0.74	0.023±0.045
195	J2032+376	308.041	37.644	...	111.3	160.3±1.4	56.8	25.2±0.4	33.4	153.2±4.6	0.34±0.01	0.17±0.02	0.628±0.002
196	J2032+409	308.097	40.954	...	779.0	2777.3±3.5	389.6	475.2±1.2	280.3	1894.8±6.8	0.30±0.00	0.00±0.00	0.122±0.002
197	J2037+418	309.409	41.897	...	31.4	64.8±2.0	25.2	16.1±0.6	1.2	6.6±5.0	0.12±0.03	-0.74±0.14	0.055±0.006
198	J2052+443	313.074	44.376	0.121	9.3	11.9±1.3	12.2	4.8±0.4	1.9	9.1±4.6	-0.11±0.08	0.06±0.33	0.104±0.064

Table 3.5a. *continued*

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) HR1^e	(13) HR2^f	(14) σ_{rms}^g
199	J2056+497	314.114	49.732	...	13.3	15.7 $\pm$ 1.2	13.5	4.8 $\pm$ 0.4	2.6	11.9 $\pm$ 4.5	0.02 $\pm$ 0.06	0.05 $\pm$ 0.25	0.106 $\pm$ 0.044
200	J2103+456	315.844	45.674	...	34.8	46.4 $\pm$ 1.3	21.4	8.7 $\pm$ 0.4	11.1	50.9 $\pm$ 4.6	0.26 $\pm$ 0.03	0.23 $\pm$ 0.07	1.196 $\pm$ 0.006
201	J2123+423	320.999	42.339	...	7.8	9.3 $\pm$ 1.2	3.1	1.0 $\pm$ 0.3	4.7	20.9 $\pm$ 4.4	0.48 $\pm$ 0.16	0.54 $\pm$ 0.21	0.464 $\pm$ 0.146
202	J2124+509	321.142	50.995	...	42.2	58.1 $\pm$ 1.2	30.1	12.1 $\pm$ 0.4	13.3	61.3 $\pm$ 4.6	0.21 $\pm$ 0.02	0.22 $\pm$ 0.06	0.009 $\pm$ 0.006
203	J2128+570	322.082	57.027	...	21.4	24.0 $\pm$ 1.1	17.9	6.1 $\pm$ 0.3	4.7	19.3 $\pm$ 4.0	0.11 $\pm$ 0.04	0.08 $\pm$ 0.14	0.077 $\pm$ 0.022
204	J2134+511	323.593	51.180	...	16.0	21.3 $\pm$ 1.3	8.7	3.3 $\pm$ 0.4	7.3	33.5 $\pm$ 4.6	0.35 $\pm$ 0.07	0.40 $\pm$ 0.12	0.013 $\pm$ 0.032
205	J2136+475	324.025	47.575	...	8.3	10.1 $\pm$ 1.2	5.8	2.0 $\pm$ 0.3	2.6	12.0 $\pm$ 4.6	0.24 $\pm$ 0.12	0.27 $\pm$ 0.30	0.035 $\pm$ 0.089
206	J2142+435	325.685	43.516	...	25.1	30.8 $\pm$ 1.2	19.8	7.2 $\pm$ 0.4	6.8	30.2 $\pm$ 4.5	0.15 $\pm$ 0.04	0.18 $\pm$ 0.11	0.235 $\pm$ 0.022
207	J2143+572	325.772	57.286	0.149	8.0	9.0 $\pm$ 1.0	6.4	2.1 $\pm$ 0.3	0.0	3.6 $\pm$ 4.1	0.15 $\pm$ 0.12	-0.25 $\pm$ 0.53	0.202 $\pm$ 0.082
208	J2207+545	331.957	54.556	...	66.1	89.3 $\pm$ 1.4	36.6	14.9 $\pm$ 0.4	17.9	83.6 $\pm$ 4.6	0.31 $\pm$ 0.02	0.16 $\pm$ 0.04	0.205 $\pm$ 0.004
209	J2228+611	337.039	61.102	0.159	7.6	7.1 $\pm$ 0.9	4.1	1.2 $\pm$ 0.3	0.0	2.5 $\pm$ 3.6	0.32 $\pm$ 0.15	-0.33 $\pm$ 0.61	0.139 $\pm$ 0.085
210	J2235+634	338.912	63.401	...	9.4	8.9 $\pm$ 0.9	6.4	1.8 $\pm$ 0.3	6.3	22.4 $\pm$ 3.6	0.21 $\pm$ 0.11	0.57 $\pm$ 0.17	0.066 $\pm$ 0.087
211	J2245+534	341.294	53.402	0.120	9.9	11.3 $\pm$ 1.1	10.4	3.5 $\pm$ 0.3	1.0	4.4 $\pm$ 3.4	0.01 $\pm$ 0.09	-0.27 $\pm$ 0.36	0.149 $\pm$ 0.067
212	J2253+626	343.290	62.617	...	10.0	11.8 $\pm$ 1.2	19.4	6.0 $\pm$ 0.3	1.3	4.7 $\pm$ 3.6	-0.23 $\pm$ 0.06	-0.27 $\pm$ 0.36	-0.023 $\pm$ 0.047
213	J2323+588	350.855	58.824	...	261.9	387.4 $\pm$ 1.5	280.5	206.4 $\pm$ 0.7	20.9	79.7 $\pm$ 3.8	-0.25 $\pm$ 0.00	-0.54 $\pm$ 0.01	0.001 $\pm$ 0.001
214	J2346+517	356.609	51.716	...	9.1	10.5 $\pm$ 1.2	8.5	2.9 $\pm$ 0.3	0.0	0.3 $\pm$ 1.1	0.07 $\pm$ 0.10	-0.93 $\pm$ 0.25	0.109 $\pm$ 0.077

^aThe 1σ statistical position error in units of degrees.^bThe observed 4–10 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 1.21×10^{-11} erg cm $^{-2}$ s $^{-1}$.^cThe observed 3–4 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 3.98×10^{-12} erg cm $^{-2}$ s $^{-1}$.^dThe observed 10–20 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 8.51×10^{-12} erg cm $^{-2}$ s $^{-1}$.^eHR(3–4 keV, 4–10 keV) calculated with equation 3.1^fHR(4–10 keV, 10–20 keV) calculated with equation 3.1^gExcess variance calculated with equation 3.2

Table 3.5b. Properties of the Transient Sources in the MAXI/GSC Catalog at $|b| < 10^\circ$

(1) No.	(2) 3MAXI	(3) R.A.	(4) Decl.	(5) σ_{stat}^a	(6) $s_{\text{D},4-10\text{keV}}$	(7) $f_{4-10\text{keV}}^b$	(8) $s_{\text{D},3-4\text{keV}}$	(9) $f_{3-4\text{keV}}^c$	(10) $s_{\text{D},10-20\text{keV}}$	(11) $f_{10-20\text{keV}}^d$	(12) $\text{HR}1^e$	(13) $\text{HR}2^e$	(14) σ_{rms}^2, f	(15) Period ^g
215	J0716-196	109.060	-19.695	0.144	8.0	29.5 $\pm$ 3.7	5.2	5.3 $\pm$ 1.0	1.4	19.9 $\pm$ 13.6	0.28 $\pm$ 0.13	-0.00 $\pm$ 0.42	2.980 $\pm$ 0.053	2010/10/25 $\sim$ 2011/01/05
216	J0836-432	129.022	-43.223	0.016	58.2	700.0 $\pm$ 12.1	24.4	94.6 $\pm$ 3.9	27.7	957.7 $\pm$ 34.4	0.40 $\pm$ 0.02	0.34 $\pm$ 0.03	7.989 $\pm$ 0.011	2012/03/31 $\sim$ 2012/08/11
217	J1619-382	244.769	-38.250	0.066	12.3	98.5 $\pm$ 8.1	10.5	26.9 $\pm$ 2.6	4.2	111.8 $\pm$ 26.6	0.08 $\pm$ 0.08	0.25 $\pm$ 0.19	11.551 $\pm$ 0.104	2014/10/24 $\sim$ 2015/01/04
218	J1719-284	259.804	-28.410	0.135	7.9	48.1 $\pm$ 6.0	6.1	11.3 $\pm$ 1.9	3.1	64.6 $\pm$ 20.8	0.15 $\pm$ 0.12	0.33 $\pm$ 0.27	10.463 $\pm$ 0.200	2012/03/31 $\sim$ 2012/08/11
219	J1846+007	281.560	0.800	0.077	11.8	70.0 $\pm$ 6.0	5.9	10.8 $\pm$ 1.8	2.9	51.9 $\pm$ 18.2	0.35 $\pm$ 0.10	0.04 $\pm$ 0.23	1.621 $\pm$ 0.045	2009/10/25 $\sim$ 2010/01/05
220	J1903+031	285.847	3.162	0.114	10.0	51.8 $\pm$ 4.9	7.6	13.8 $\pm$ 1.8	3.6	59.6 $\pm$ 16.5	0.09 $\pm$ 0.10	0.26 $\pm$ 0.22	12.779 $\pm$ 0.192	2011/10/25 $\sim$ 2012/01/05
221	J2023+336	305.919	33.698	0.165	6.6	55.0 $\pm$ 8.4	1.4	3.4 $\pm$ 2.4	1.5	41.3 $\pm$ 27.7	0.68 $\pm$ 0.23	0.05 $\pm$ 0.44	11.136 $\pm$ 0.368	2015/10/24 $\sim$ 2016/01/04

^aThe 1σ statistical position error in units of degrees.

^bThe observed 4–10 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 1.21×10^{-11} erg cm $^{-2}$ s $^{-1}$.

^cThe observed 3–4 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 3.98×10^{-12} erg cm $^{-2}$ s $^{-1}$.

^dThe observed 10–20 keV flux in units of 10^{-12} erg cm $^{-2}$ s $^{-1}$, converted from Crab units by assuming a Crab-like spectrum; 1 mCrab = 8.51×10^{-12} erg cm $^{-2}$ s $^{-1}$.

^eHR calculated with equation 3.1

^fExcess variance calculated with equation 3.2

^gThe period when these source properties are measured.

Table 3.6a. Possible Counterparts for the 7-year Sources in the *MAXI*/GSC Catalog at $|b| < 10^\circ$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart						
		Name	R.A.	Decl.	Δposi^a	Type ^b	Flag ^c	Note ^d
1	J0000+674	BD+66 1664	359.544	67.568	0.213	Star	NR	
2	J0025+641	Tycho SNR	6.284	64.165	...	SNR	B	
3	J0029+592	V709 Cas	7.204	59.289	...	CV	B	
4	J0035+598	1ES 0033+595	8.969	59.835	...	Blazar	B	
5	J0036+614	BD +60 73	9.290	61.360	...	HMXB	B	
6	J0056+606	Gamma Cas	14.177	60.717	...	HMXB	B	
7	J0117+652	2S 0114+650	19.511	65.292	...	HMXB	B	
8	J0118+637	4U 0115+634	19.633	63.740	...	HMXB	B	
9	J0140+583							
10	J0146+616	PSR J0146+61	26.593	61.751	...	Pulsar	B	
11	J0210+525	LEDA 138501	32.393	52.443	...	Sy1	B	
12	J0227+619							
13	J0241+611	LS I +61 303	40.132	61.229	...	HMXB	B	
14	J0244+624	[HB89] 0241+622	41.240	62.468	...	Sy1.2	B	
15	J0252+571							
16	J0334+531	BQ Cam	53.749	53.173	...	HMXB	B	
17	J0342+636	1RXS J034002.0+635210	55.008	63.870	0.372	unID	R	
18	J0404+572							
19	J0408+632							
20	J0418+380	3C 111.0	64.589	38.027	...	Sy1.2	B	
21	J0427+354							
22	J0441+445	RX J0440.9+4431	70.247	44.530	...	HMXB	B	
23	J0450+450	4U 0446+44	72.435	45.046	0.050	Galaxy Cluster	UXM	
24	J0452+496	1RXS J045205.0+493248	73.021	49.546	...	Sy1.5	B	
25	J0456+523							
26	J0457+455	1RXS J045707.4+452751	74.285	45.464	...	CV	B	
27	J0459+272	4C +27.14	74.984	27.101	...	Sy2	B	
28	J0525+241	1RXS J052523.2+241331	81.344	24.226	...	CV	B	
29	J0534+220	Crab	83.633	22.015	...	Pulsar	B	
30	J0534+285	SWIFT J053457.91+282837.9	83.740	28.477	...	unID	B	
31	J0538+263	1A 0535+262	84.727	26.316	...	HMXB	B	
32	J0547+379	NVSS J054706+375236	86.774	37.874	...	unID	B	
33	J0601+130							
34	J0602+285	IRAS 05589+2828	90.545	28.473	...	Sy1.2	B	
35	J0602+230	RXC J0602.1+2309	90.531	23.166	0.200	Galaxy Cluster	M	
36	J0605+299							
37	J0616+225	IC 443	94.200	22.467	0.117	SNR	XR	
38	J0617+091	4U 0614+091	94.280	9.137	...	LMXB	B	
39	J0631+251	RXC J0631.3+2500	97.839	25.016	0.162	Galaxy Cluster	M	
40	J0633+049							
41	J0635+225	CIZA J0635.0+2231	98.764	22.525	...	Galaxy Cluster	B	
42	J0635+077	TYC 733-2098-1	98.993	7.922	0.166	Star	N	
43	J0640-127	PMN J0640-1253	100.030	-12.888	...	Blazar	B	
44	J0641+098	1RXS J064059.3+095330	100.247	9.892	0.172	Star	R	
45	J0645-169	V* HL CMa	101.322	-16.860	...	Nova	B	
46	J0648+152	1RXS J064847.8+151626	102.199	15.274	0.012	Blazar	R	
47	J0656-035							
48	J0704-114							
49	J0708-155	PKS 0706-15	107.301	-15.450	...	Blazar	B	
50	J0714-254	SWIFT J0714.7-2521	108.655	-25.290	...	unID	B	

Table 3.6a. *continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart			Δposi^a	Type ^b	Flag ^c	Note ^d
		Name	R.A.	Decl.				
51	J0717–114	RXC J0717.4–1119	109.362	–11.331	0.154	Galaxy Cluster	M	
52	J0725–064							
53	J0728–206							
54	J0729–262	4U 0728–25	112.223	–26.108	...	HMXB	B	
55	J0733–135	SWIFT J073237.6–133109	113.156	–13.518	...	CV	B	
56	J0745–162	1RXS J074616.8–161127	116.570	–16.191	...	CV	B	
57	J0747–192	PKS 0745–19	116.881	–19.294	...	Galaxy Cluster	B	
58	J0752–442							
59	J0753–459							
60	J0758–221	RXC J0757.9–2157	119.495	–21.962	0.170	Galaxy Cluster	M	
61	J0759–387	2MASS J07594181–3843560	119.924	–38.732	...	Sy1.2	B	
62	J0802–496	ESO 209- G 012	120.492	–49.777	...	Sy1.5	B	
63	J0804–276							
64	J0809–406							
65	J0823–430	4U 0821–42	125.826	–42.907	0.153	SNR	UXNR	
66	J0839–358	Fairall 1146	129.628	–35.993	...	Sy1.5	B	
67	J0841–562							
68	J0844–378	CD-37 5063B	131.140	–37.963	0.148	Star	NR	
69	J0902–481	2MASX J09023729–4813339	135.656	–48.226	...	Sy1	B	
70	J0902–405	Vela X-1	135.529	–40.555	...	HMXB	B	
71	J0910–526	SWIFT J0911.3–5229	137.773	–52.547	...	unID	B	
72	J0916–623	IRAS 09149–6206	139.039	–62.325	...	Sy1	B	
73	J0920–552	4U 0919–54	140.111	–55.207	...	LMXB	B	
74	J0922–632	V395 Car	140.644	–63.295	...	LMXB	B	
75	J1009–582	GRO J1008–57	152.446	–58.293	...	HMXB	B	
76	J1018–582							
77	J1031–621							
78	J1036–568	4U 1036–56	159.391	–56.799	...	HMXB	B	
79	J1038–497	2MASX J10384520–4946531	159.688	–49.782	...	Sy1.5	B	
80	J1044–596	Eta Carina	161.265	–59.684	...	XRB	B	
81	J1121–606	Cen X-3	170.316	–60.623	...	HMXB	B	
82	J1139–653	GT Mus	174.873	–65.398	...	XRB	B	
83	J1141–639	V* V1033 Cen	175.346	–64.172	0.209	CV	N	
84	J1144–698	PKS 1143–696	176.473	–69.900	...	Blazar	B	
85	J1144–610	IGR J11435–6109	175.967	–61.150	...	HMXB	B	
86	J1147–619	1E 1145.1–6141	176.869	–61.954	...	HMXB	B	
87	J1156–566	V* V1040 Cen	178.863	–56.698	0.089	CV	NR	
88	J1203–538	LEDA 38038	180.699	–53.835	...	Sy2	B	
89	J1213–648	SWIFT J121314.7–645231	183.321	–64.880	...	HMXB	B	
90	J1226–627	GX 301–2	186.657	–62.771	...	LMXB	B	
91	J1235–646	RT Cru	188.724	–64.566	...	Symbiotic Star	B	
92	J1237–667	XMMSL2 J123629.8–664549	189.125	–66.764	0.085	unID	N	
93	J1240–577	WKK 1263	190.357	–57.834	...	Sy1.5	B	
94	J1243–630	1H 1249–637	190.709	–63.058	...	HMXB	B	
95	J1249–590	4U 1246–58	192.414	–59.087	...	LMXB	B	
96	J1257–692	4U 1254–690	194.405	–69.289	...	LMXB	B	
97	J1301–615	GX 304–1	195.322	–61.602	...	HMXB	B	
98	J1302–639	2RXP J130159.6–635806	195.494	–63.968	...	Pulsar	B	
99	J1314–602	HD 114630B	198.238	–59.820	0.472	Star	NR	
100	J1317–629	IGR J13186–6257	199.607	–62.971	...	HMXB	B	

Table 3.6a. *continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart			Δposi^a	Type ^b	Flag ^c	Note ^d
		Name	R.A.	Decl.				
101	J1325–577	RXC J1324.7–5736	201.180	–57.614	0.123	Galaxy Cluster	MNR	
102	J1326–621	4U 1323–619	201.650	–62.136	...	LMXB	B	
103	J1331–549							
104	J1345–623							
105	J1347–606	4U 1344–60	206.900	–60.618	...	Sy1.9	B	
106	J1356–645	Ginga 1354–644	209.550	–64.733	0.288	LMXB	X	
107	J1359–633	IGR J14003–6326	210.190	–63.429	...	Pulsar	B	
108	J1407–618	MAXI J1409–619	212.011	–61.983	...	Pulsar	B	
109	J1412–653	Circinus Galaxy	213.291	–65.339	...	Sy2	B	
110	J1419–610	Rabbit	214.678	–60.967	...	Pulsar	B	
111	J1420–626	4U 1416–62	215.303	–62.698	...	HMXB	B	
112	J1423–541	RXC J1423.7–5412	215.930	–54.203	0.038	Galaxy Cluster	M	
113	J1442–626							
114	J1446–641	IGR J14471–6414	221.617	–64.233	...	Sy1	B	
115	J1449–598	SWIFT J1448.4–5945	222.179	–59.704	...	HMXB	B	
116	J1453–553	1RXS J145341.1–552146	223.456	–55.362	...	CV	B	
117	J1455–516	WKK 4438	223.823	–51.571	...	Sy1.5	B	
118	J1502–601	SWIFT J1503.7–6028	226.067	–60.356	...	unID	B	
119	J1509–667	IGR J15094–6649	227.358	–66.823	...	CV	B	
120	J1513–461	RXC J1514.6–4558	228.651	–45.981	0.184	Galaxy Cluster	MR	
121	J1514–591	PSR B1509–58	228.481	–59.136	...	Pulsar	B	
122	J1520–571	Cir X-1	230.170	–57.167	...	LMXB	B	
123	J1533–658							
124	J1542–523	H 1538–522	235.597	–52.386	...	HMXB	B	
125	J1547–625	4U 1543–62	236.976	–62.570	...	LMXB	B	
126	J1548–455	NY Lup	237.061	–45.478	...	CV	B	
127	J1548–476	4U 1543–47	236.855	–47.714	0.252	LMXB	UXN	
128	J1551–543	PSR J1550–5418	237.725	–54.307	...	Pulsar	B	
129	J1601–607	1H 1556–605	240.260	–60.738	...	LMXB	B	
130	J1612–607	WKK 6092	242.964	–60.632	...	Sy1.5	B	
131	J1617–595	WKK 6471	244.652	–59.455	...	Sy1	B	
132	J1629–613							
133	J1640–324							
134	J1641–346							
135	J1650–601							
136	J1650–330	IGR J16500–3307	252.482	–33.117	...	CV	B	
137	J1653–593	NGC 6221	253.193	–59.217	...	Sy2	B	
138	J1655–519	1RXS J165605.6–520345	254.024	–52.061	...	Sy1.2	B	
139	J1702–299	XB 1658–298	255.525	–29.950	0.033	LMXB	X	
140	J1709–266	XTE J1709–267	257.377	–26.656	...	LMXB	B	
141	J1710–280	XTE J1710–281	257.552	–28.131	...	LMXB	B	
142	J1712–233	Oph Cluster	258.108	–23.376	...	Galaxy Cluster	B	
143	J1713–241	V2400 Oph	258.152	–24.246	...	CV	B	
144	J1730–215	Kepler’s SNR	262.673	–21.480	...	SNR	B	
145	J1731–169	GX 9+9	262.934	–16.962	...	LMXB	B	
146	J1738–444	4U 1735–44	264.743	–44.450	...	LMXB	B	
147	J1741–122	2E 1739.1–1210	265.476	–12.197	...	Sy1	B	
148	J1750–370	4U 1746–37	267.553	–37.052	...	LMXB	B	
149	J1803–344	1RXS 180408.9–342058	271.052	–34.313	0.150	LMXB		T
150	J1806–089							

Table 3.6a. *continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart			Δposi^a	Type ^b	Flag ^c	Note ^d
		Name	R.A.	Decl.				
151	J1807–369	SAX J1808.4–3658	272.115	–36.979	...	LMXB	B	
152	J1810–041							
153	J1814+022							
154	J1823–347	2E 4061	275.910	–34.904	0.129	unID	NR	
155	J1823–303	4U 1820–30	275.919	–30.361	...	LMXB	B	
156	J18250000	4U 1822–000	276.342	–0.012	...	LMXB	B	
157	J1828–253	MAXI J1828–249	277.243	–25.030	0.325	LMXB		T
158	J1829–238	Ginga 1826–24	277.367	–23.791	...	LMXB	B	
159	J1834–210	PKS 1830–21	278.416	–21.061	...	Blazar	B	
160	J1836–194	MAXI J1836–194	278.931	–19.320	...	XRB	B	
161	J1839+050	Ser X-1	279.990	5.036	...	LMXB	B	
162	J1849–171							
163	J1855–026	XTE J1855–026	283.877	–2.605	...	HMXB	B	
164	J1855+157	2MASX J18560128+1538059	284.002	15.632	...	Sy1.2	B	
165	J1858+033	XTE J1858+034	284.679	3.434	...	HMXB	B	
166	J1858+082	XTE J1859+083	284.750	8.233	0.097	HMXB	X	
167	J1901+014	XTE J1901+014	285.421	1.438	...	HMXB	B	
168	J1904–108							
169	J1904–131							
170	J1910+097	4U 1907+09	287.408	9.830	...	HMXB	B	
171	J1910–057	MAXI J1910–057	287.595	–5.799	...	LMXB	B	
172	J1910+076	4U 1908+075	287.700	7.596	...	HMXB	B	
173	J1911+005	Aql X-1	287.817	0.585	...	LMXB	B	
174	J1911+049	SS 433	287.957	4.983	...	HMXB	B	
175	J1915+109	GRS 1915+105	288.798	10.946	...	LMXB	B	
176	J1918–052	4U 1916–053	289.699	–5.238	...	LMXB	B	
177	J1928+204							
178	J1929+184	SWIFT J192955.7+181839	292.482	18.311	...	HMXB	B	
179	J1930+096	1RXS J193109.5+093714	292.790	9.621	0.103	Blazar	R	
180	J1941+301							
181	J1941+258							
182	J1942+224	HD 344800	295.712	22.563	...	Star	B	
183	J1944+212	SWIFT J1943536.21+211822.9	295.984	21.306	...	Blazar	B	
184	J1945+274	XTE J1946+275	296.414	27.365	...	HMXB	B	
185	J1946+449	2MASX J19471938+4449425	296.831	44.828	...	Sy2	B	
186	J1949+301	KS 1947+300	297.377	30.207	...	HMXB	B	
187	J1955+321	4U 1954+31	298.926	32.097	...	LMXB	B	
188	J1958+352	Cyg X-1	299.590	35.202	...	HMXB	B	
189	J1959+408	Cygnus A	299.868	40.734	...	Sy2	B	
190	J1959+117	4U 1957+115	299.851	11.709	...	LMXB	B	
191	J1959+322	SWIFT J2000522.0+320731	300.091	32.189	...	HMXB	B	
192	J2008+325	SWIFT J2008.8+3225	302.196	32.430	...	multiple	B	
193	J2015+370	QSO B2013+370	303.870	37.183	...	Blazar	B	
194	J2022+371							
195	J2032+376	EXO 2030+375	308.063	37.638	...	HMXB	B	
196	J2032+409	Cyg X-3	308.107	40.958	...	HMXB	B	
197	J2037+418	SSTSL2 J203705.58+415005.3	309.273	41.835	...	Blazar	B	
198	J2052+443	4U 2048+44	312.589	44.562	0.393	LMXB	UNR	
199	J2056+497	RX J2056.6+4940	314.178	49.668	...	Blazar	B	
200	J2103+456	SAX J2103.5+4545	315.899	45.751	...	HMXB	B	

Table 3.6a. *continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart		Decl.	Δposi^a	Type ^b	Flag ^c	Note ^d
		Name	R.A.					
201	J2123+423	V2069 Cyg	320.937	42.301	...	CV	B	
202	J2124+509	4C 50.55	321.164	50.973	...	Sy1.2	B	
203	J2128+570	SWIFT J212745.6+565636	321.937	56.944	...	Sy1	B	
204	J2134+511	RX J2133.7+5107	323.432	51.124	...	CV	B	
205	J2136+475	2MASX J21355399+4728217	323.975	47.473	...	Sy1.5	B	
206	J2142+435	SS Cyg	325.678	43.586	...	CV	B	
207	J2143+572	Cep X-4	324.875	56.983	0.573	HMXB	X	
208	J2207+545	4U 2206+54	331.984	54.519	...	HMXB	B	
209	J2228+611							
210	J2235+634	SWIFT J223703.9+632338	339.156	63.492	...	unID	B	
211	J2245+534							
212	J2253+626	IGR J22534+6243	343.480	62.727	...	unID	B	
213	J2323+588	Cas A	350.850	58.815	...	SNR	B	
214	J2346+517	2MASX J23470479+5142179	356.770	51.705	...	Blazar	B	

^aAngular separation between the MAXI position and that of possible counterpart in the unit of degree.

^bSy: Seyfert galaxy, AGN: active galactic nucleus, L(H)MXB: low(high)-mass X-ray binary, XRB: X-ray binary, SNR: supernova remnant, CV: cataclysmic variable, unID: unidentified source.

^cCross-matching flag: B, U, X, N, M, and R represent that the source has one or more counterparts in the BAT105, 4U, XTEASMLONG, XMMSL2, MCXC, and 1RXS, respectively. The counterpart name listed in column (3) is quoted from the catalog expressed by the leftmost letter in this column.

^dT: Transient or new MAXI source.

Table 3.6b. Possible Counterparts for the Transient Source in the *MAXI*/GSC Catalog at $|b| < 10^\circ$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No.	3MAXI	Possible Counterpart						
		Name	R.A.	Decl.	Δposi^a	Type ^b	Flag ^c	Note ^d
215	J0716–196	XMMSL2 J071531.3-193957	108.880	–19.666	0.172	unID	N	
216	J0836–432	Ginga 0834–430	128.979	–43.185	0.050	HMXB	X	
217	J1619–382	MAXI J1619–383	244.925	–38.375	0.175	unID		T
218	J1719–284	IGR J17191–2821	259.808	–28.327	0.083	LMXB	X	
219	J1846+005	Ginga 1843+00	281.403	0.863	...	HMXB	B	
220	J1903+031	4U 1901+03	285.905	3.192	0.065	HMXB	UX	
221	J2023+336	Ginga 2023+338	306.016	33.867	0.187	LMXB	X	

^aAngular separation between the MAXI position and that of possible counterpart in the unit of degree.

^bSy: Seyfert galaxy, AGN: active galactic nucleus, L(H)MXB: low(high)-mass X-ray binary, XRB: X-ray binary, SNR: supernova remnant, CV: cataclysmic variable, unID: unidentified source.

^cCross-matching flag: B, U, X, N, M, and R represent that the source has one or more counterparts in the BAT105, 4U, XTEASMLONG, XMMSL2, MCXC, and 1RXS, respectively. The counterpart name listed in column (3) is quoted from the catalog expressed by the leftmost letter in this column.

^dT: Transient or new MAXI source.

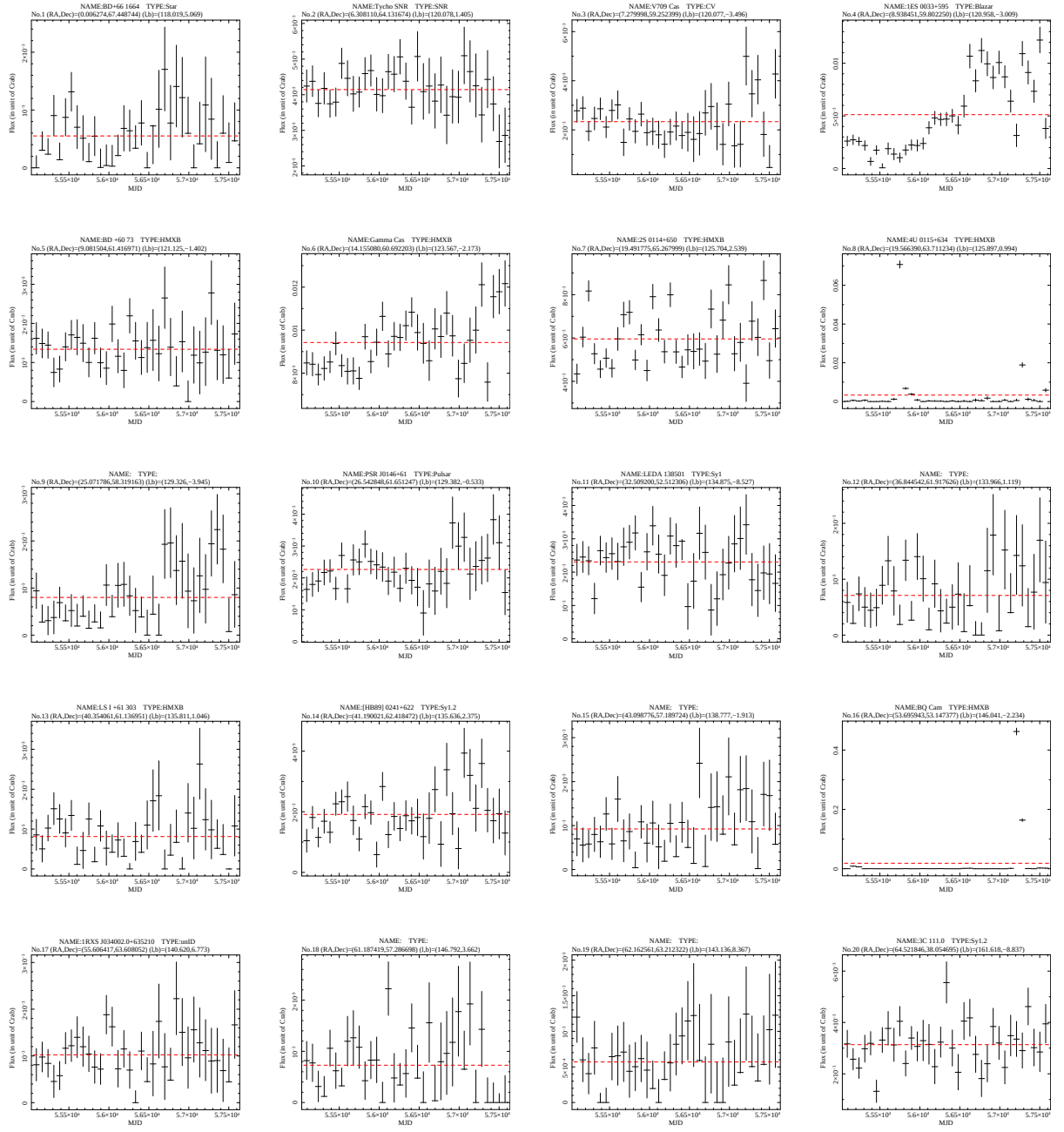


Figure 3.10a. 7-year light curves with 73 day bins. The mean flux of each source is plotted with red-dotted line.

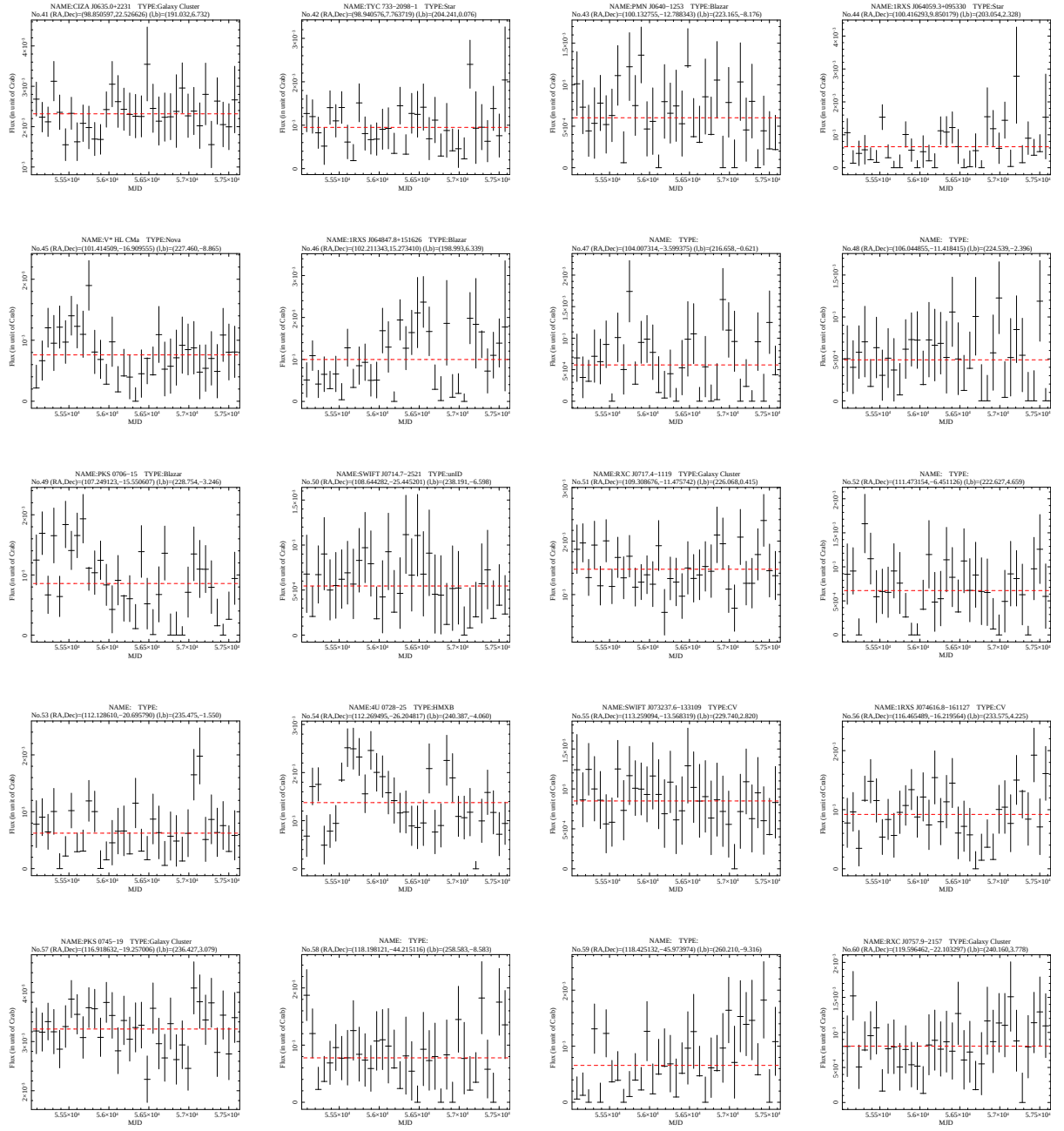


Figure 3.10a. *continued*

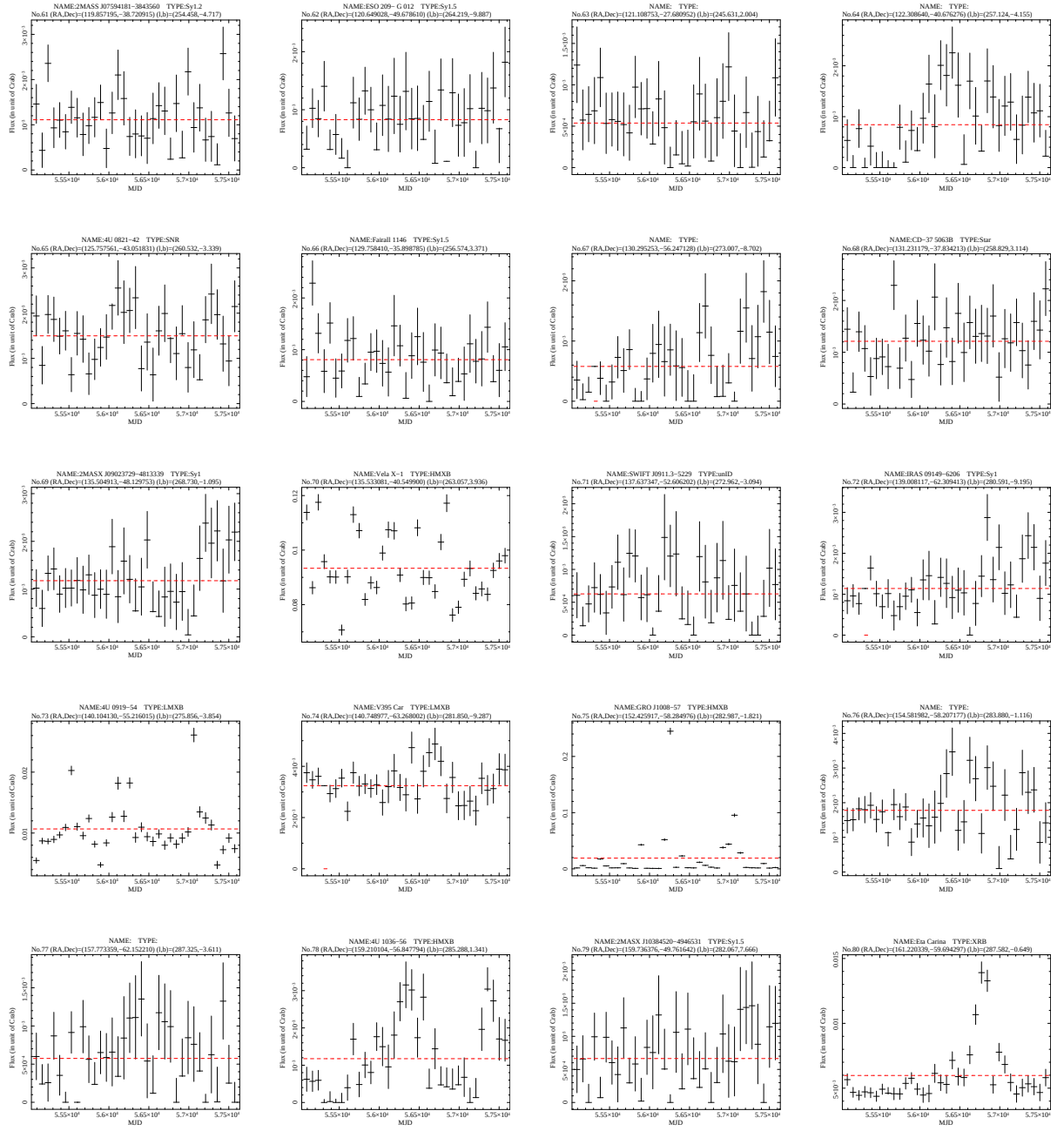
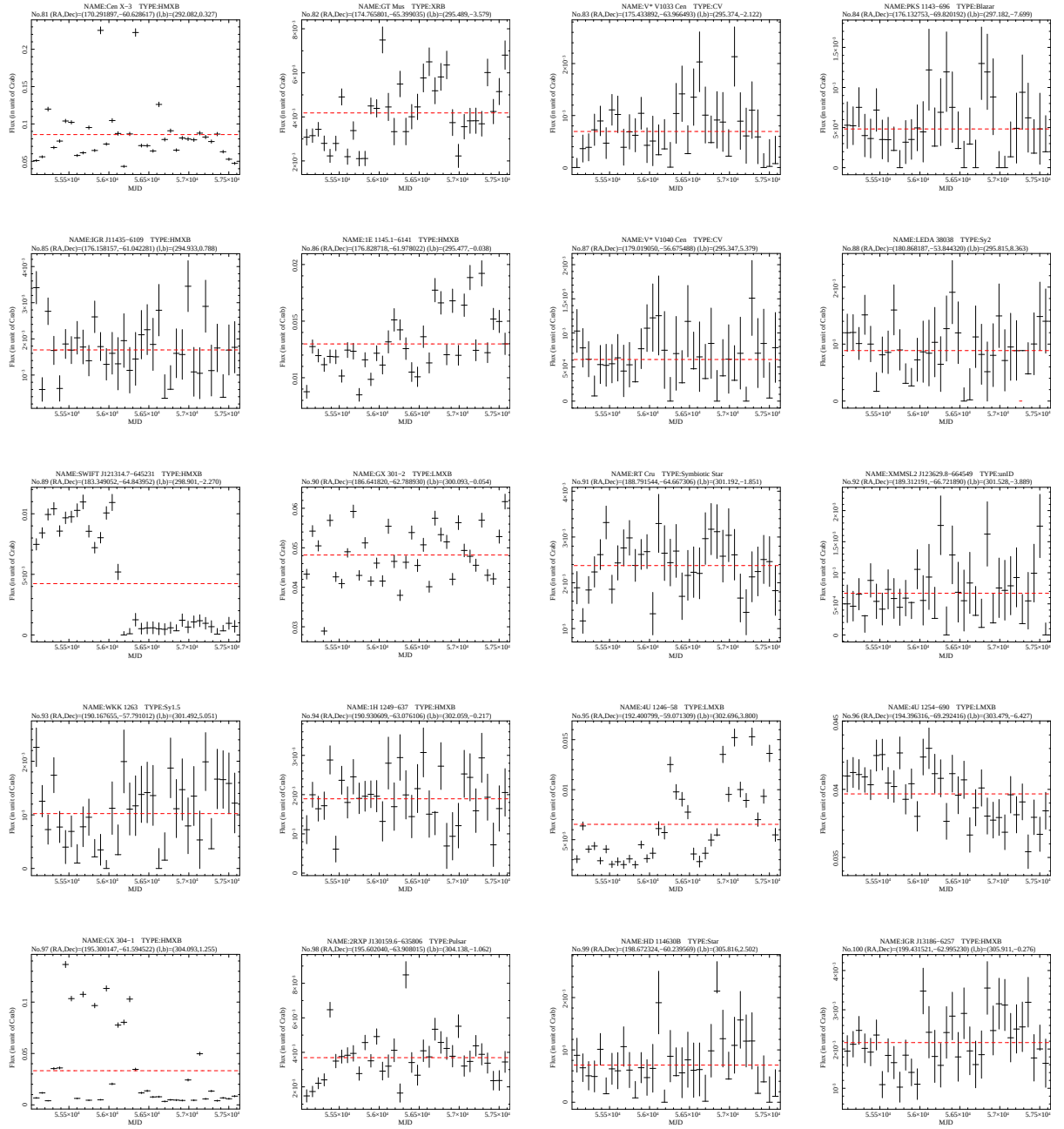


Figure 3.10a. *continued*



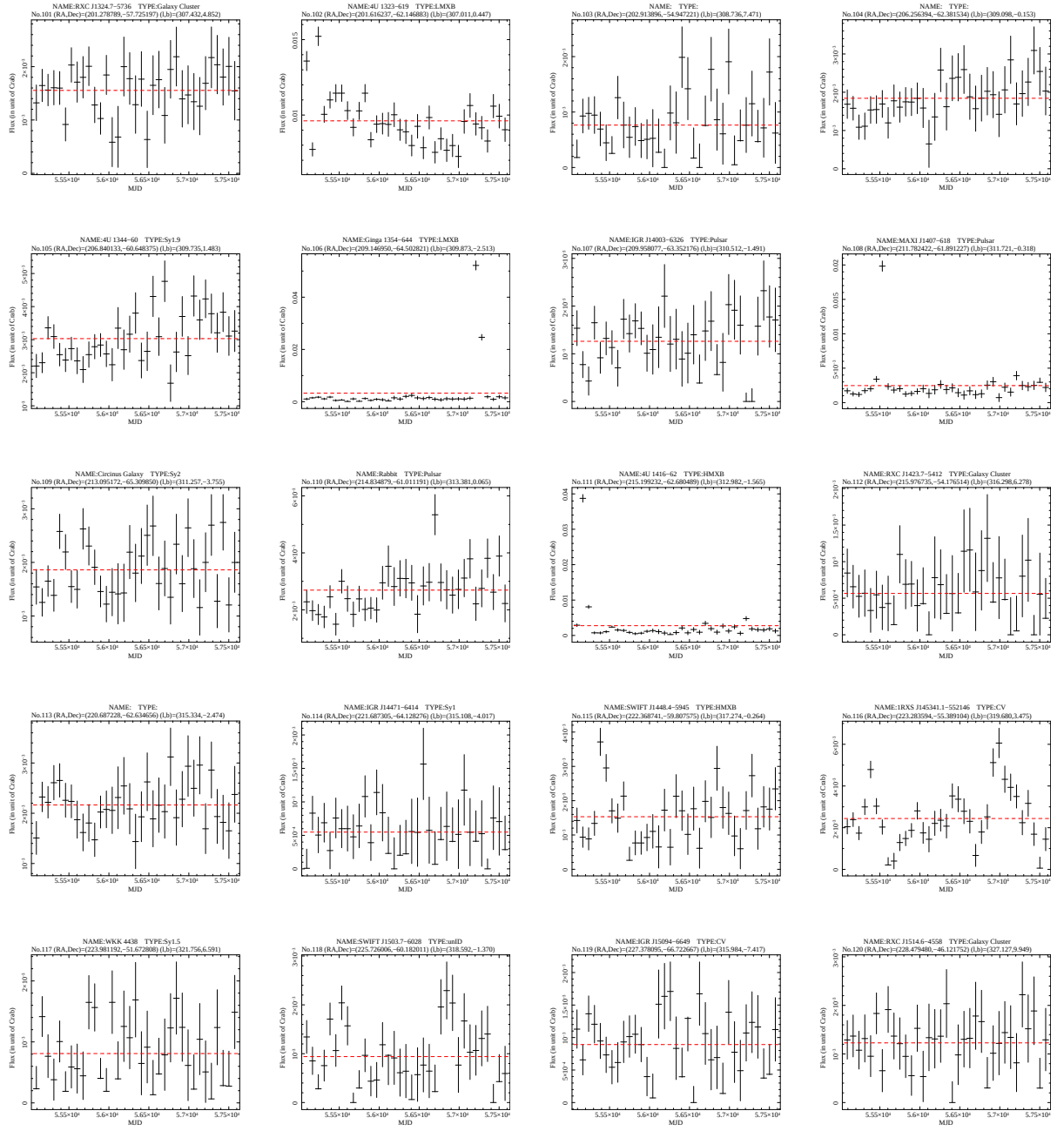


Figure 3.10a. *continued*

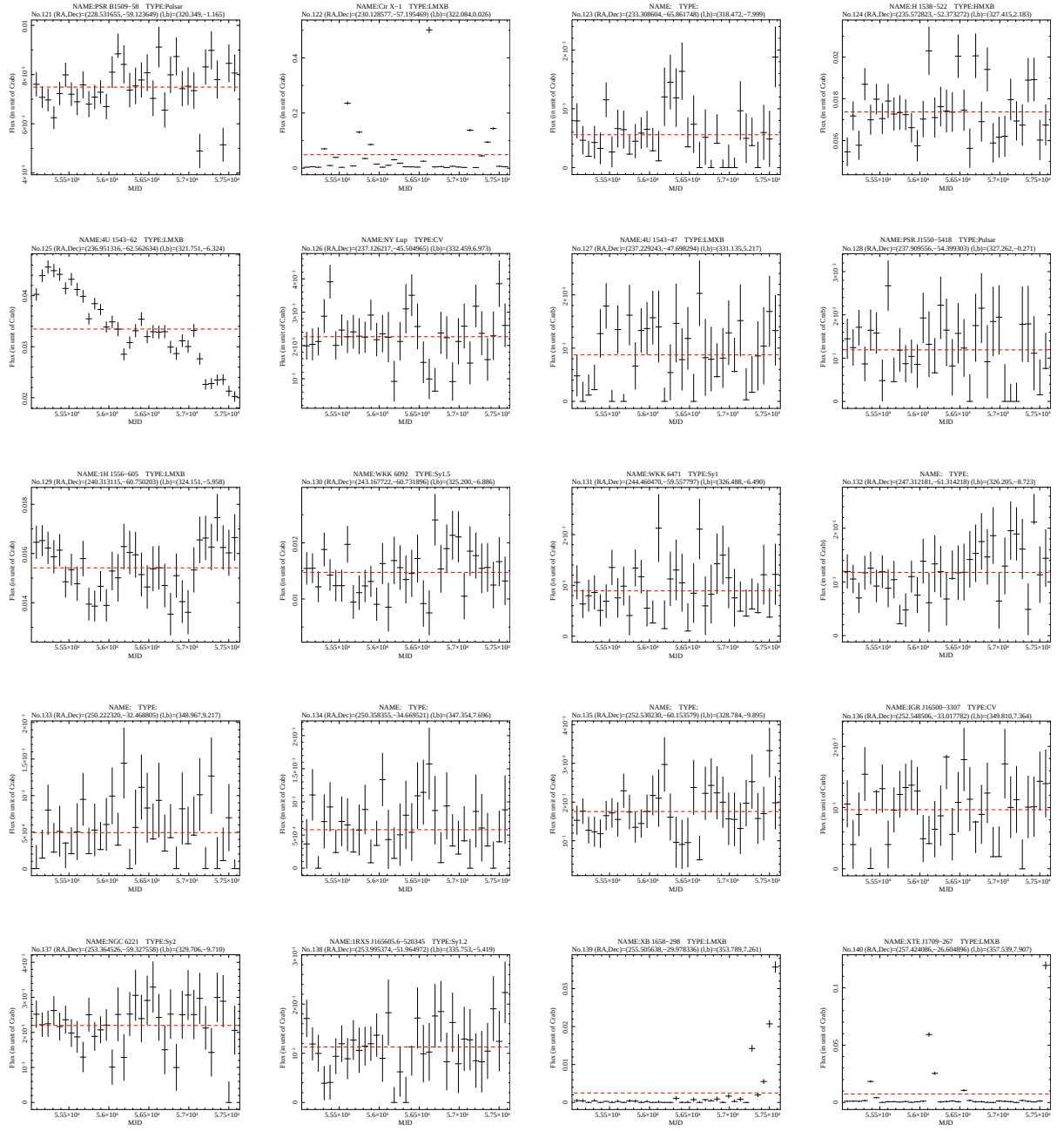


Figure 3.10a. *continued*

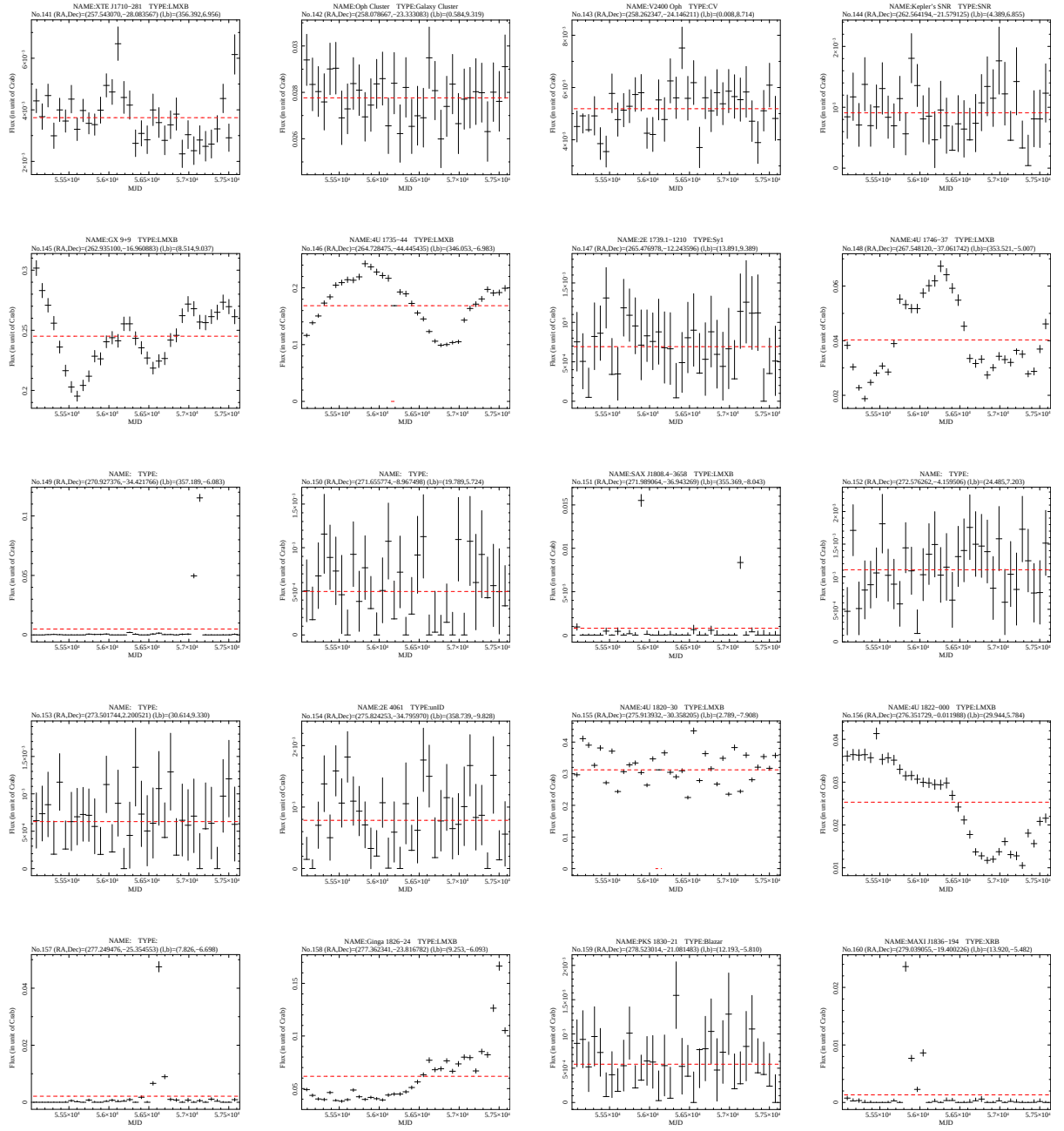


Figure 3.10a. *continued*

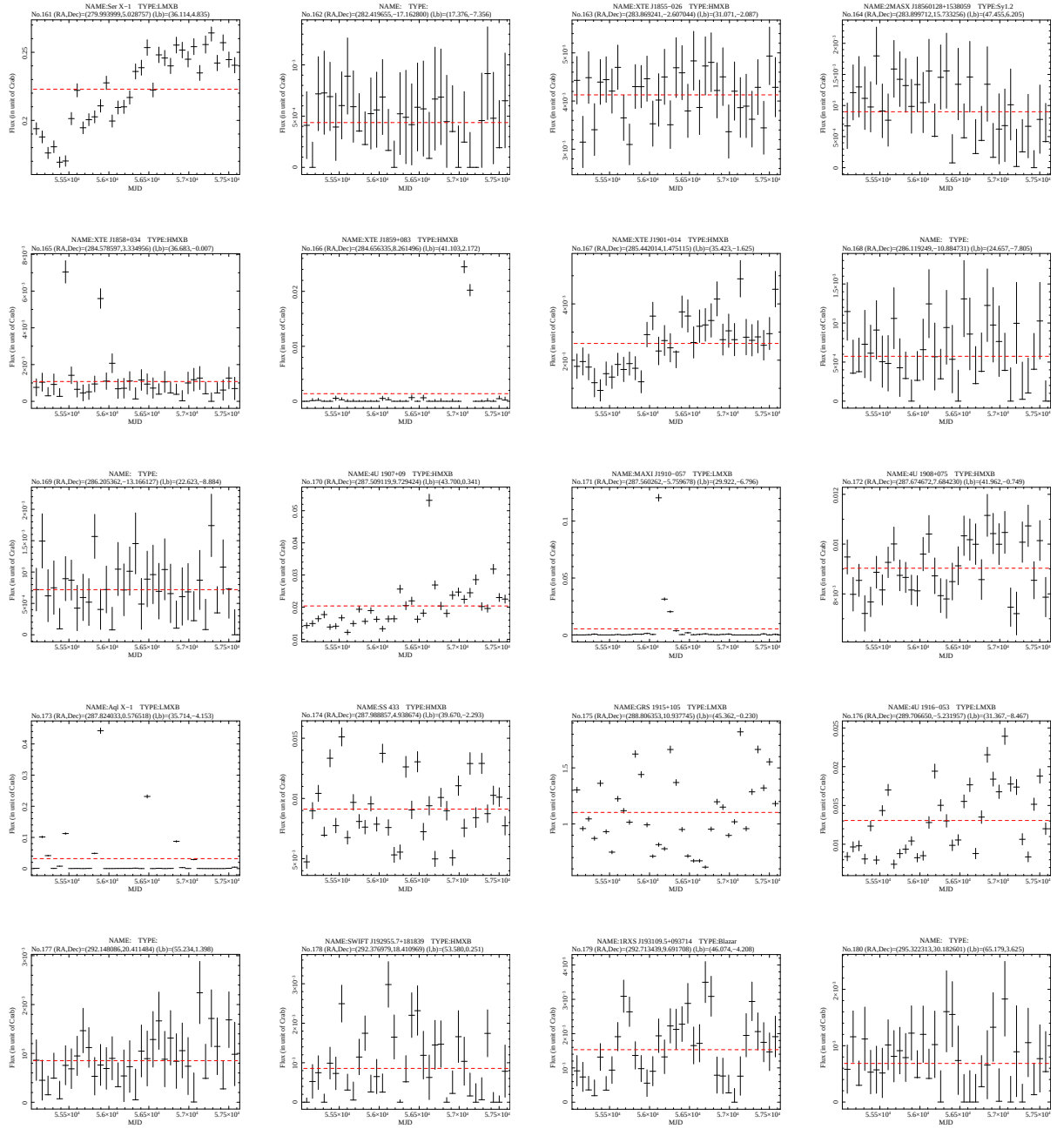
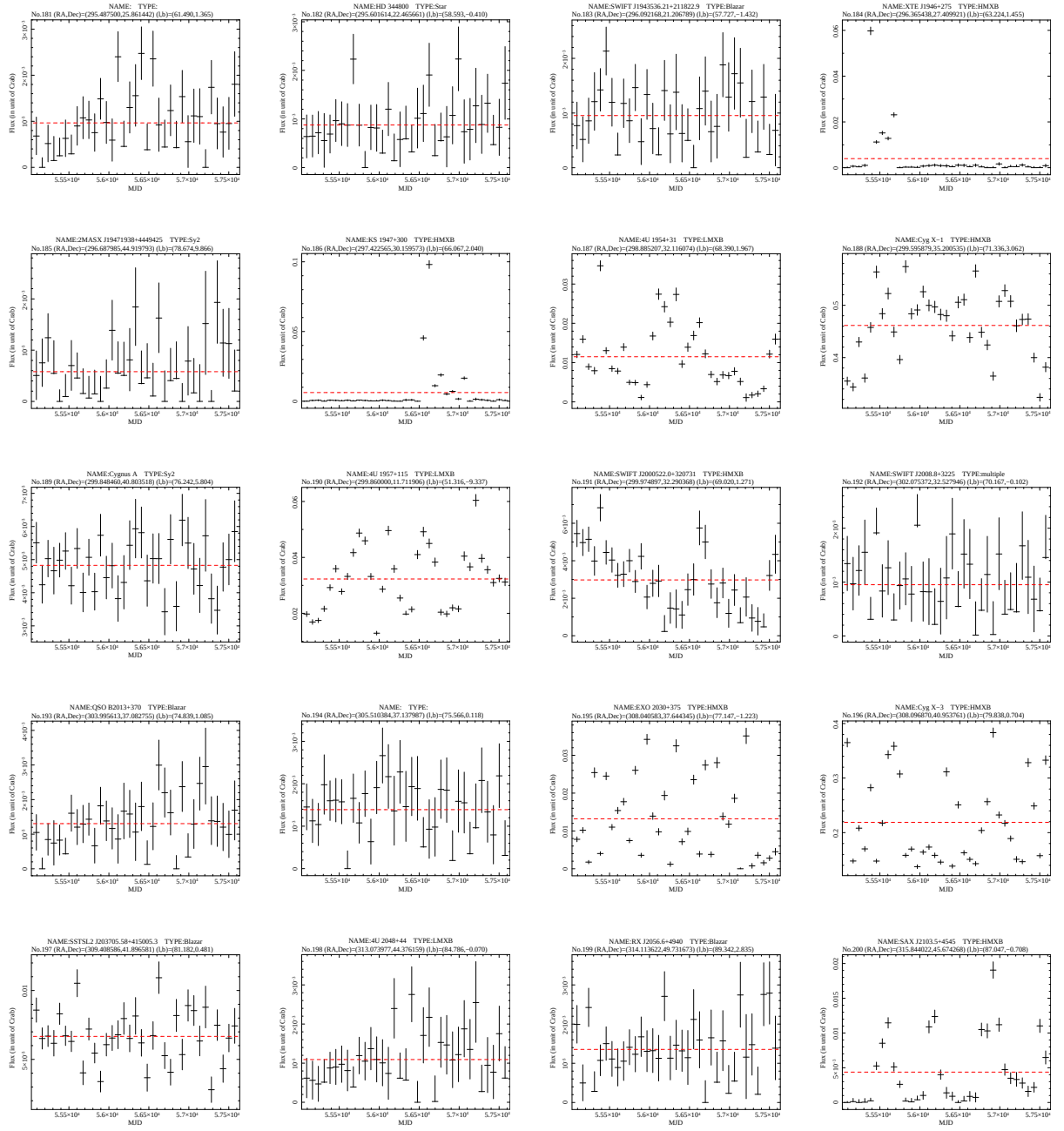
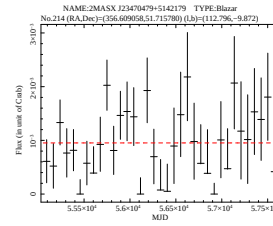
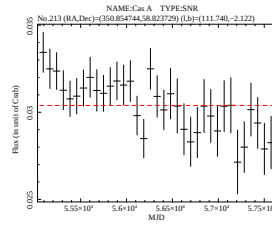
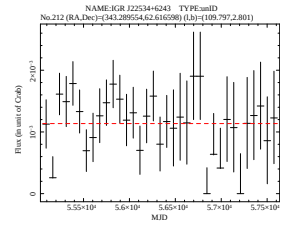
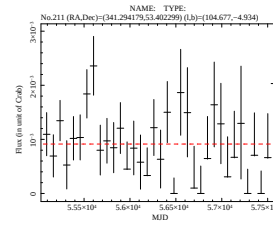
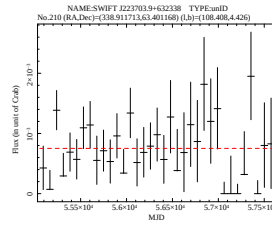
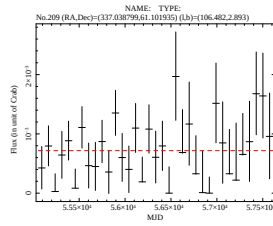
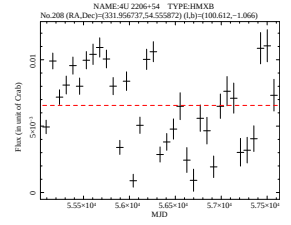
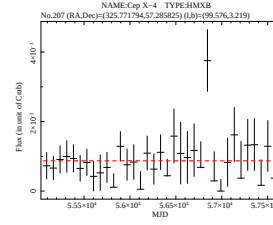
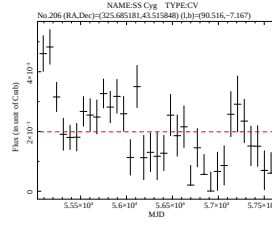
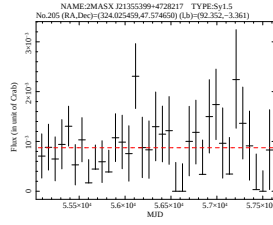
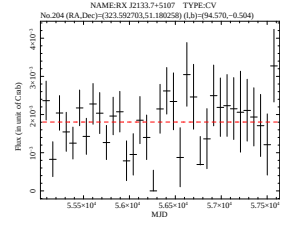
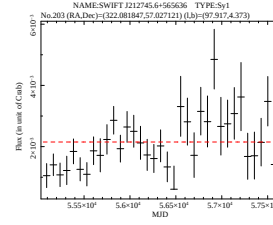
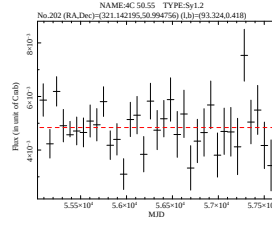
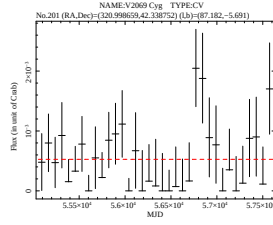


Figure 3.10a. *continued*





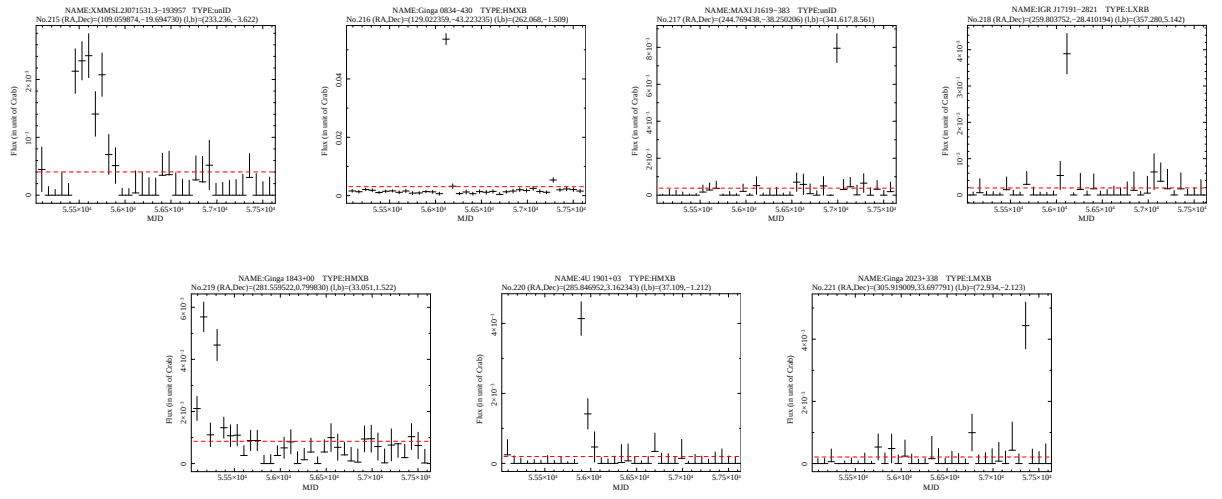


Figure 3.10b. 7-year light curves for transient sources with 73 day bins. The mean flux of each source is plotted with red-dotted line.

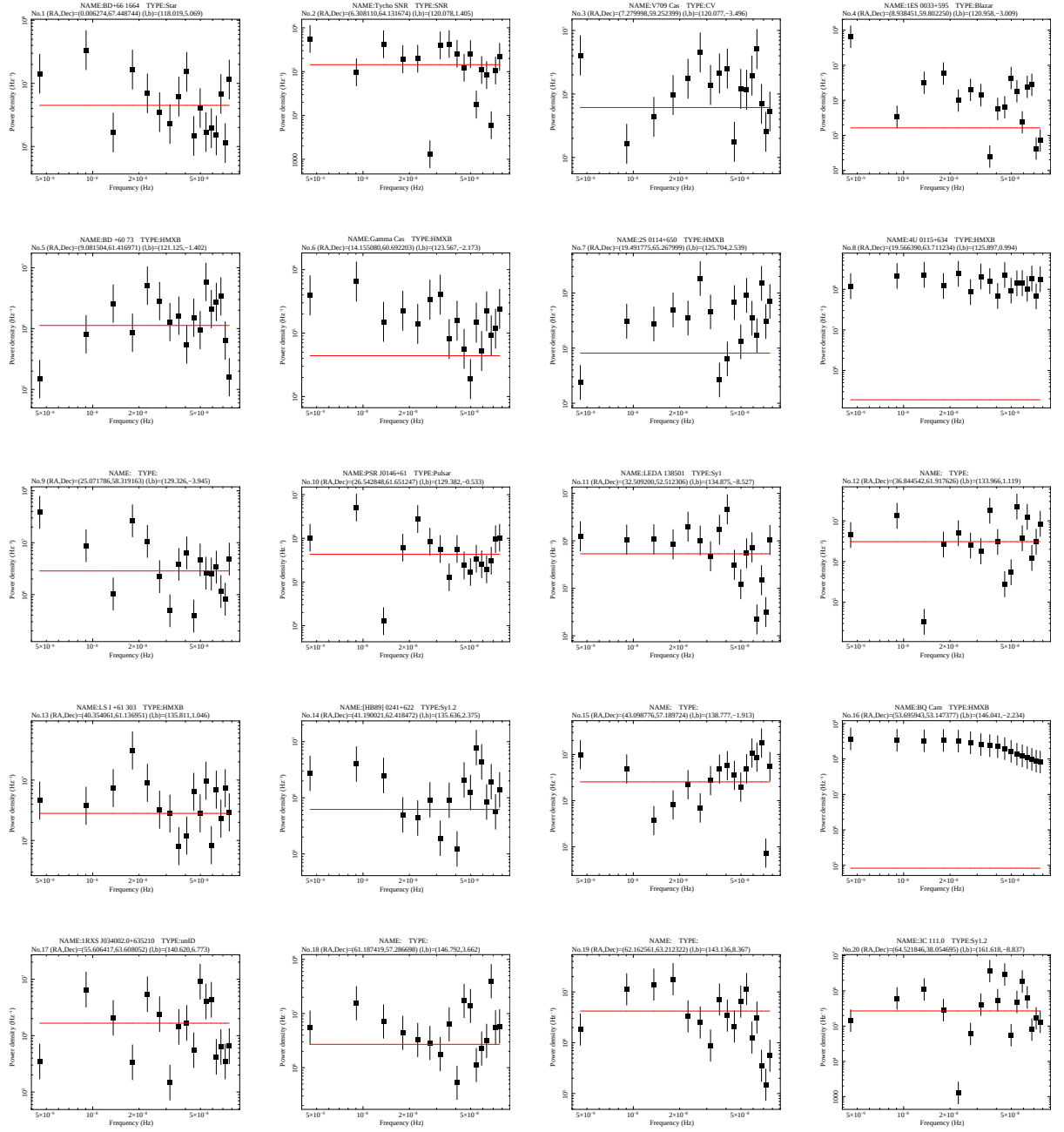


Figure 3.11a. The normalized periodograms. The red dotted lines show the level of Poisson fluctuations. The errors refer to the constant variance of 0.31 (Papadakis & Lawrence, 1993; Isobe et al., 2015).

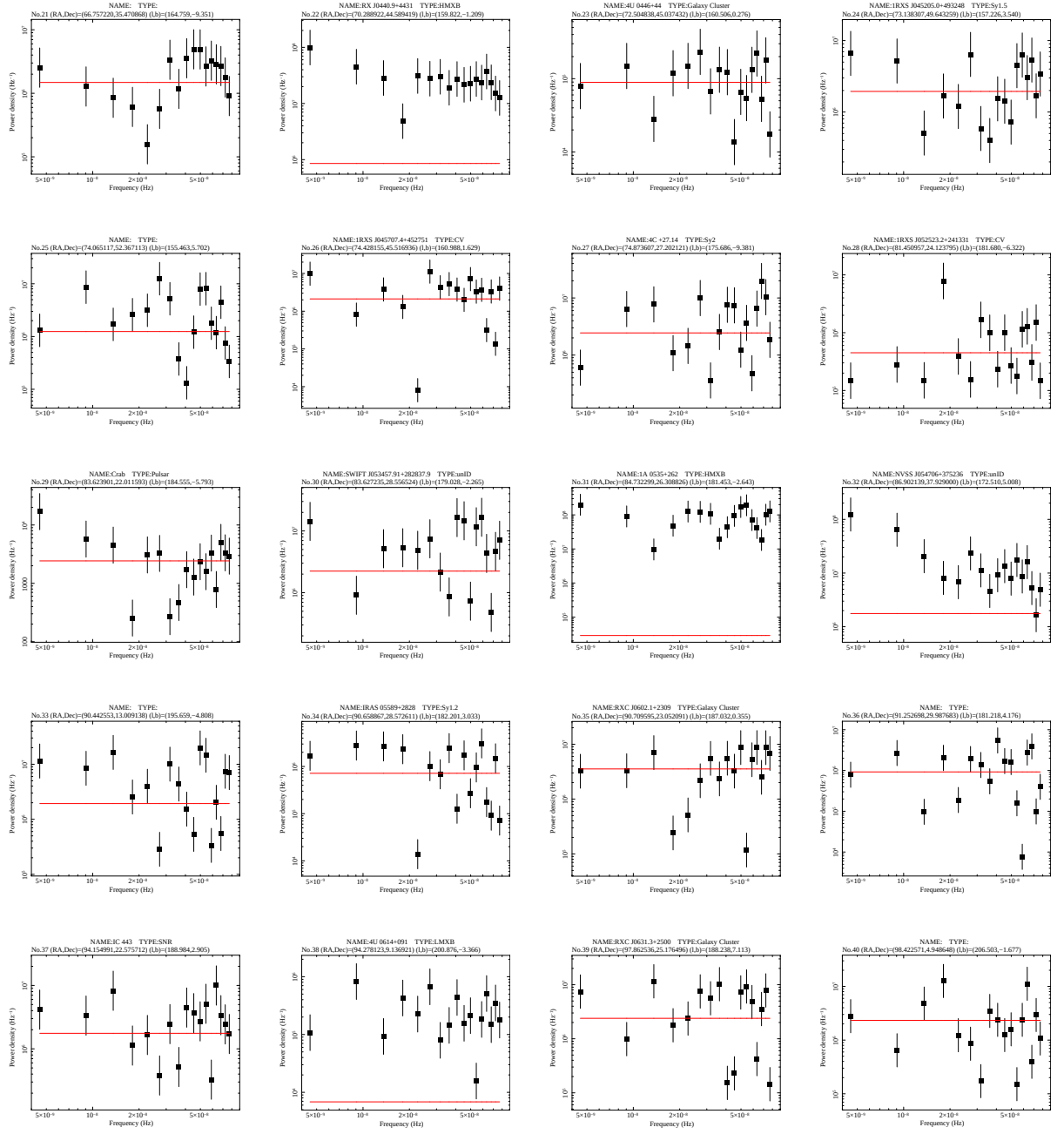
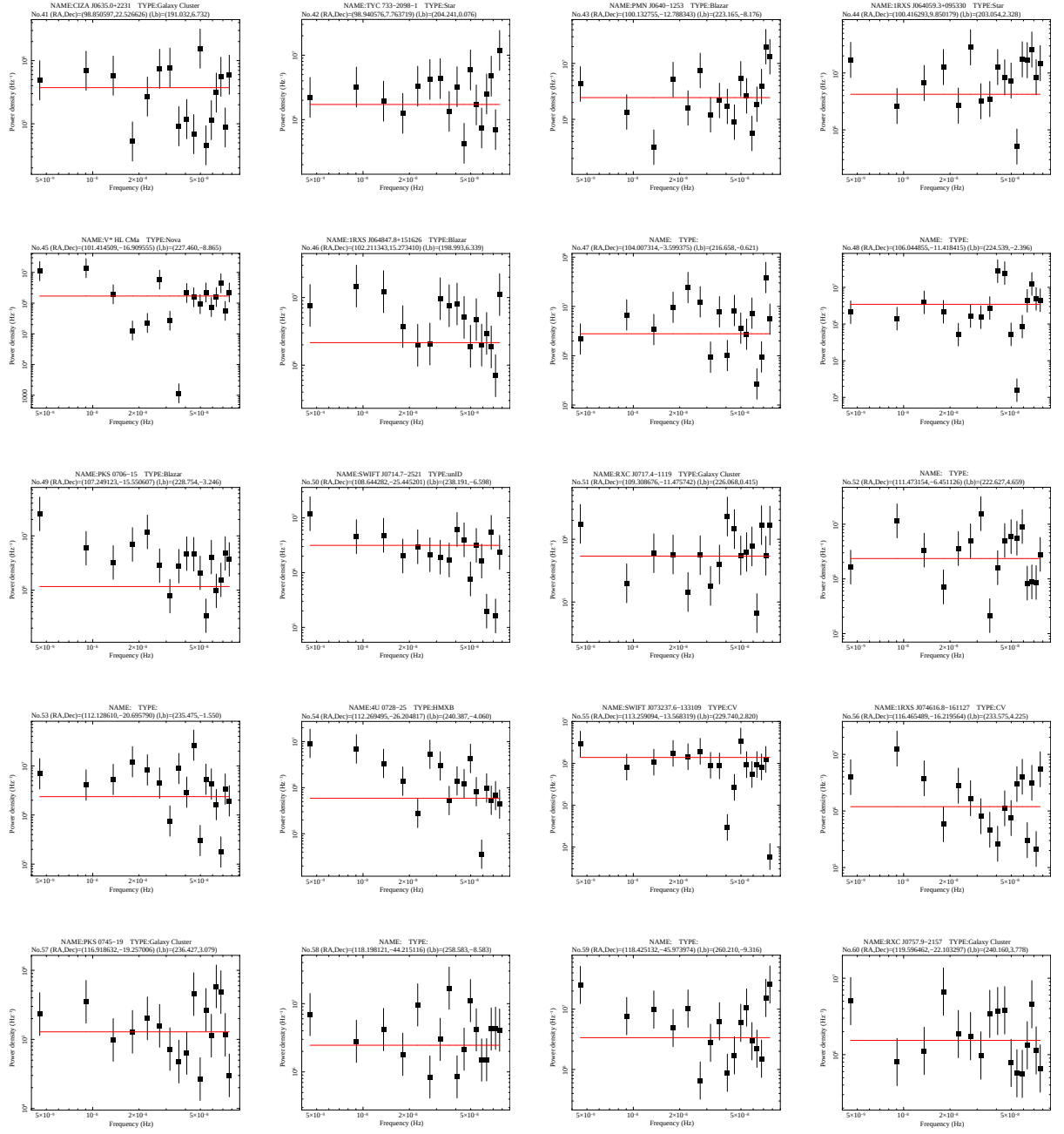
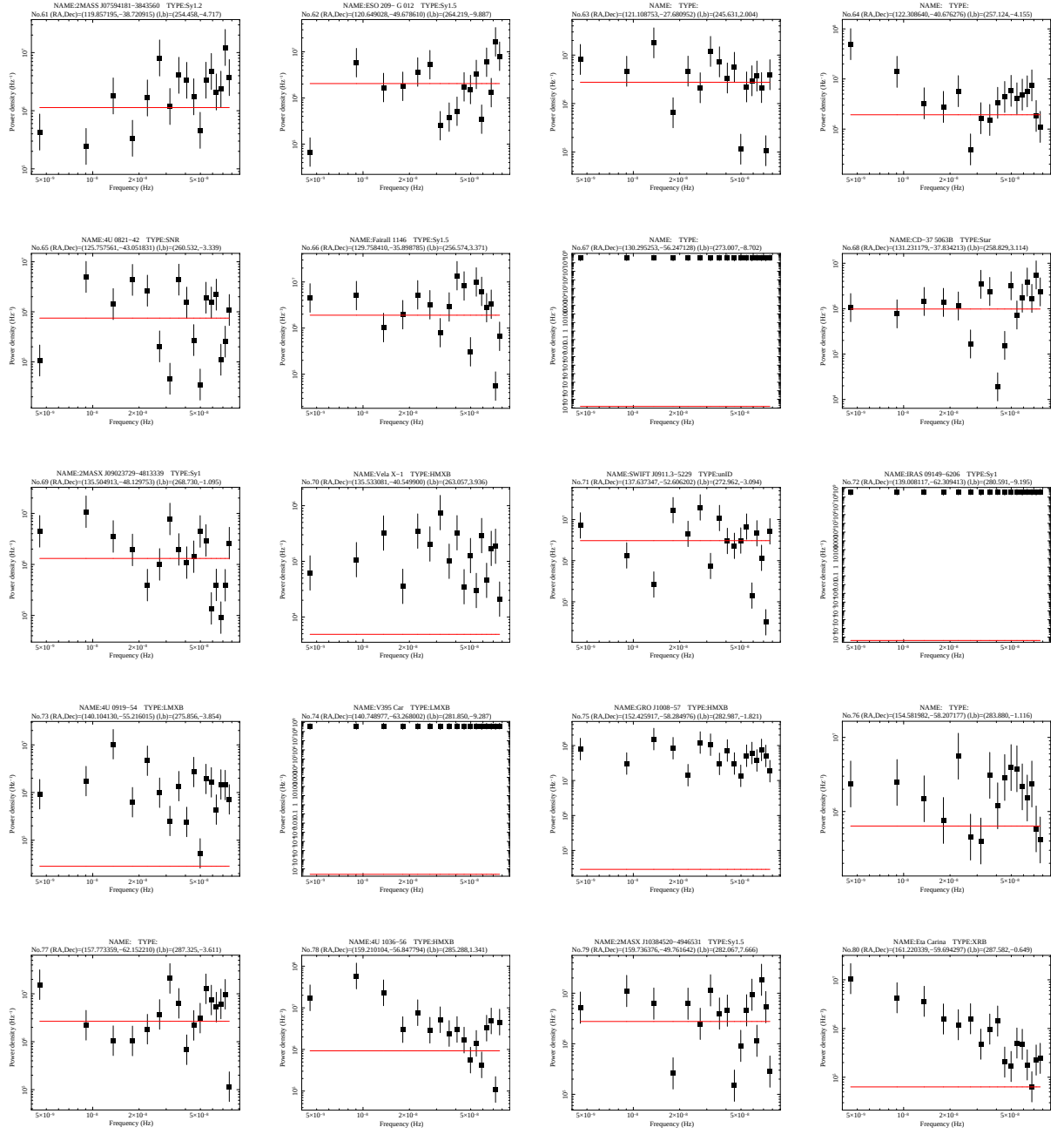


Figure 3.11a. *continued*





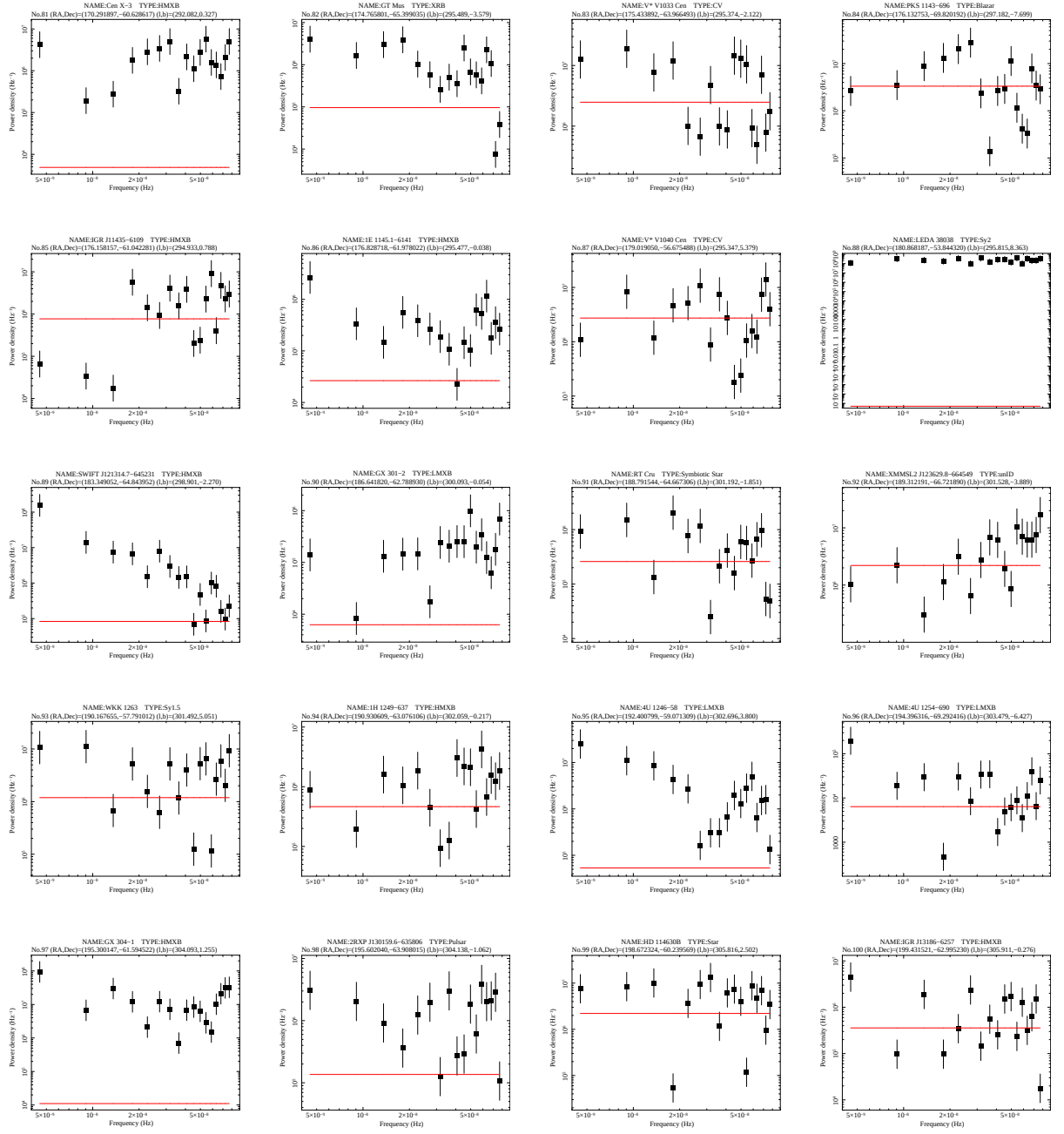
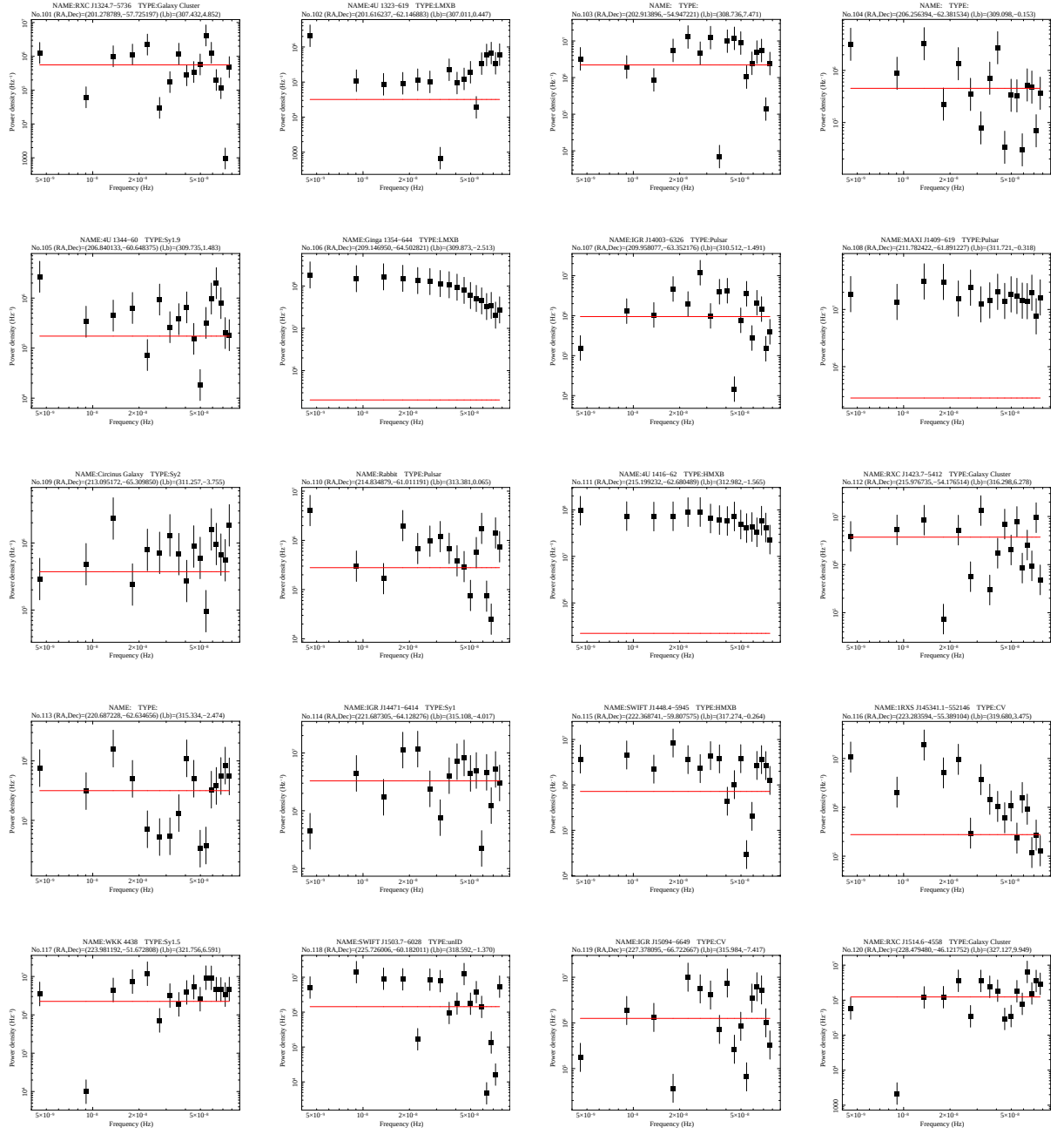


Figure 3.11a. *continued*



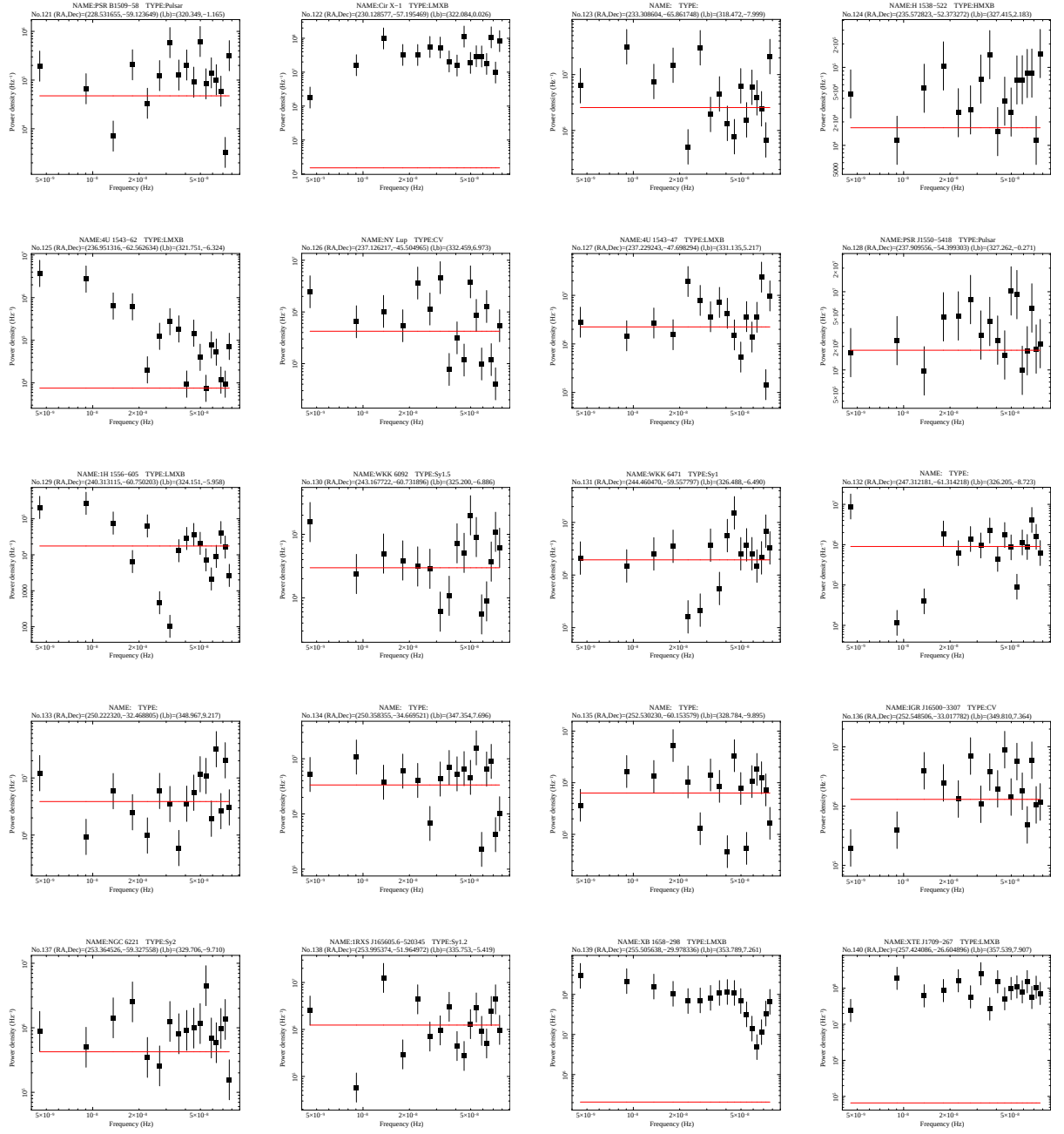


Figure 3.11a. *continued*

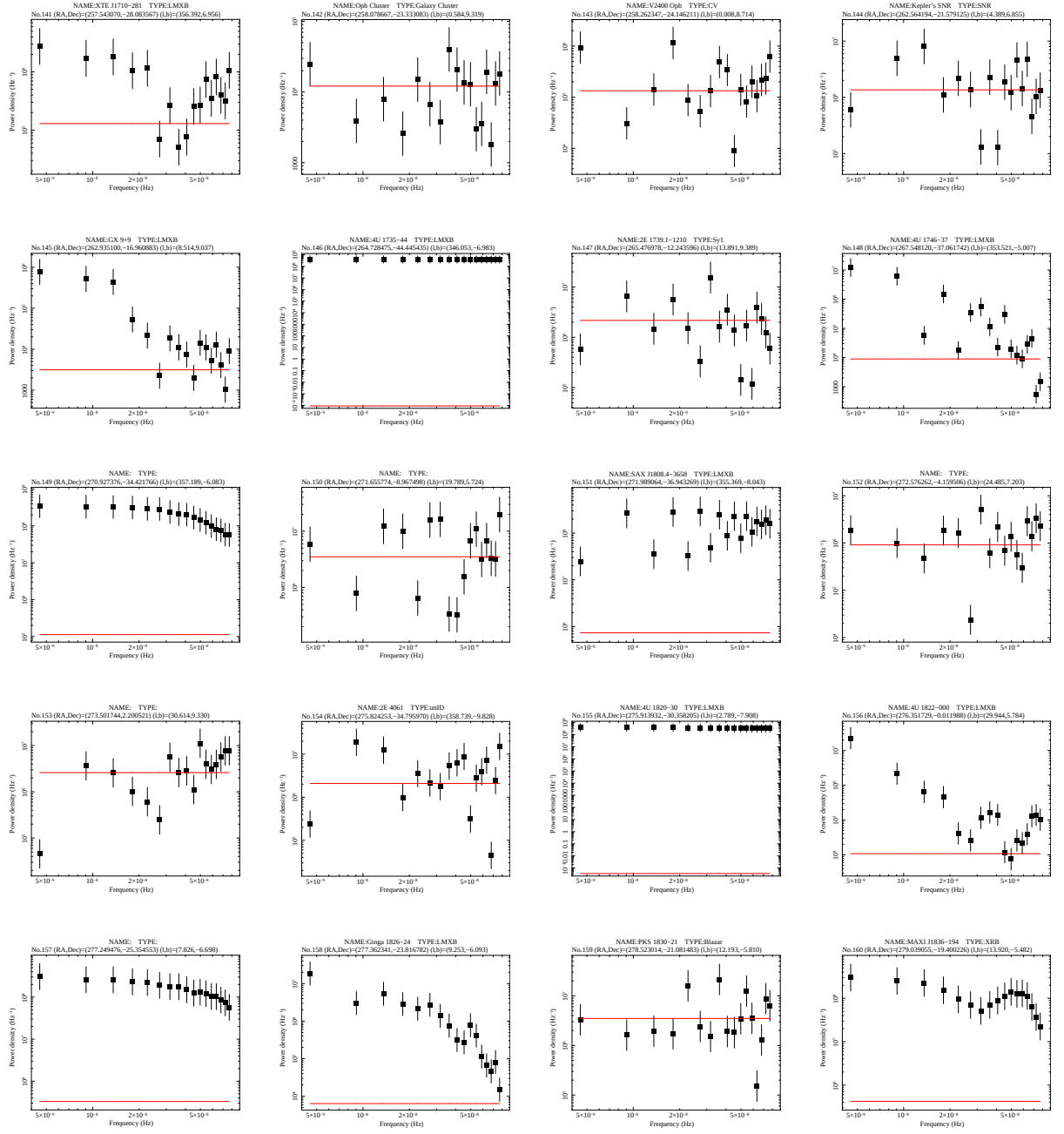


Figure 3.11a. *continued*

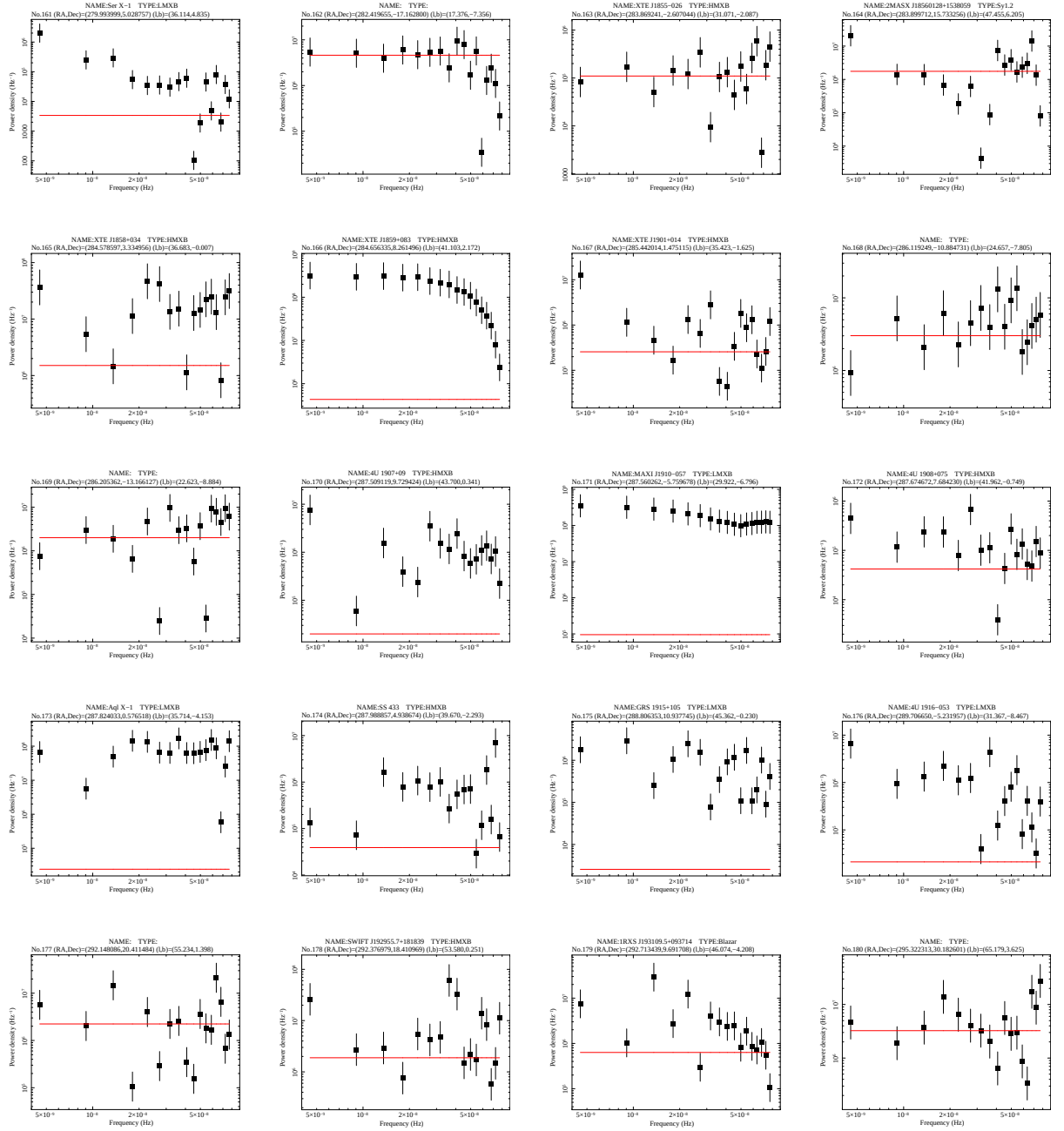


Figure 3.11a. *continued*

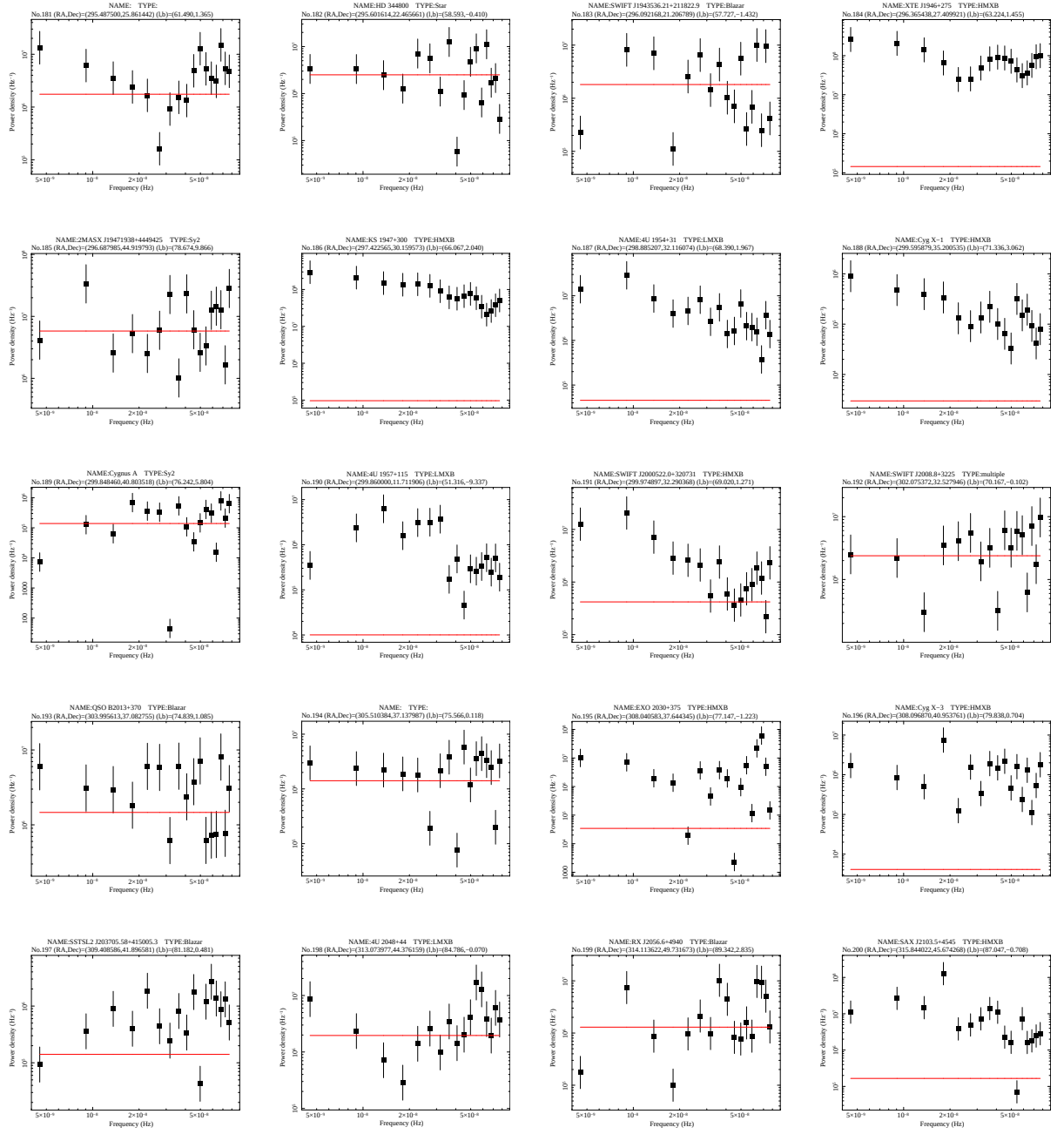
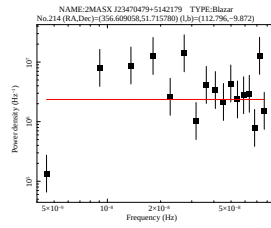
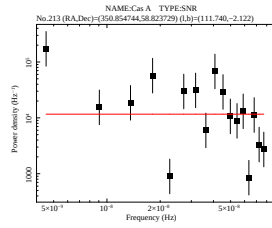
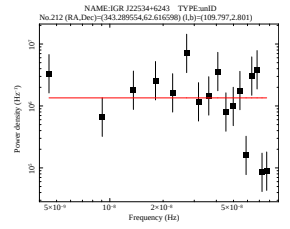
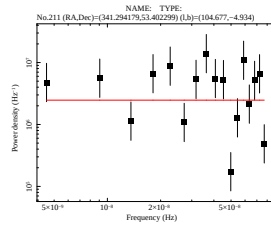
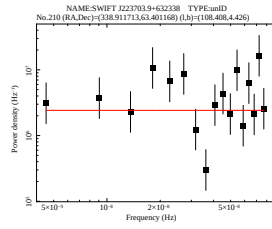
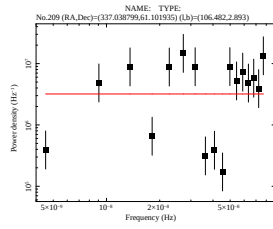
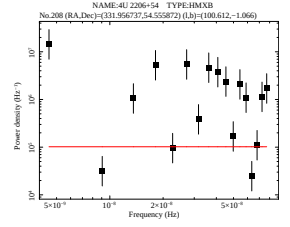
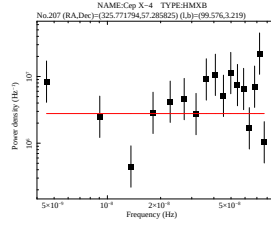
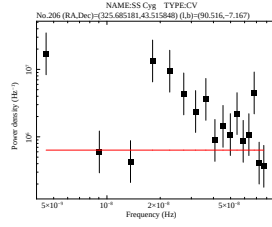
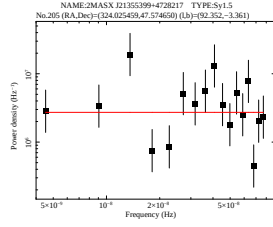
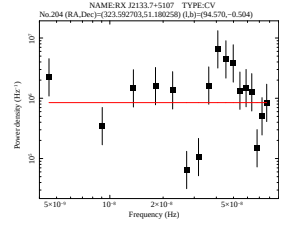
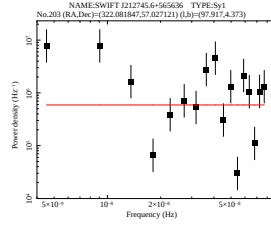
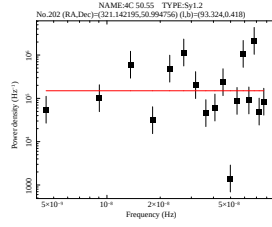
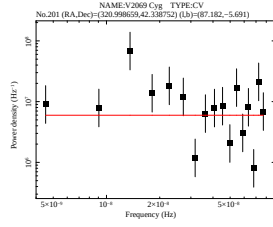


Figure 3.11a. *continued*



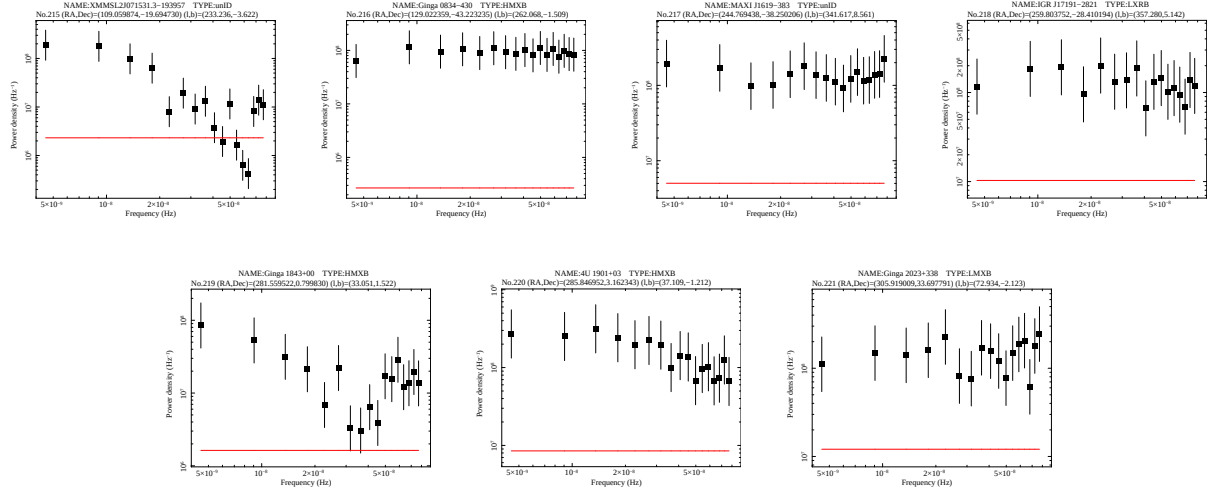


Figure 3.11b. The normalized periodograms for transient sources. The red dotted lines show the level of Poisson fluctuations. The errors refer to the constant variance of 0.31 (Papadakis & Lawrence, 1993; Isobe et al., 2015).

Chapter 4

Conclusions

We performed three observations of 4U 1630–47 with *Suzaku* during the 2015 outburst, simultaneously with *NuSTAR* in the first two epochs. For comparison, we also re-analyze the *Suzaku* data taken during the 2006 and 2012 outburst. The conclusions are summarized below.

1. The continuum in the HSS is well described by thermal disk and a weak power-law tail produced by Comptonization of the disk photons. The K-absorption lines from highly ionized iron are detected in all observations in the HSS during the 2006 and 2015 outbursts.
2. We investigate the evolution of the disk-wind parameters as a function of luminosity and spectrum. The degree of ionization dramatically increased at the brightest state during the 2015 outburst. The XSTAR simulations show that this change cannot be explained solely by photoionization effects if we assume constant launching radius and density of the wind.
3. We find that a simple theory of thermally driven winds can explain our observational results. We point out that the column density and ionization parameter are proportional to the luminosity and Compton temperature, respectively, which must be taken into account when interpreting the disk wind parameters.

In Chapter 3, we have provided the first *MAXI*/GSC source catalog at low Galactic latitudes, $|b| < 10^\circ$, outside the Galactic center region ($|b| < 5^\circ$, $l < 30^\circ$, and $l > 330^\circ$), based on the data obtained in 7 year from 2009 August 13 to 2016 July 31. To overcome source confusion in crowded regions, we have accurately calibrated the point spread function of each GSC camera and improved the background model by utilizing the onboard data. We have also taken into account the contribution of the Galactic ridge X-ray emission employing the model in Revnivtsev et al. (2006). Finally we have detected 221 sources with a detection significance of $s_{D,4-10 \text{ keV}} > 6.5$, 180 of which have one or more counterpart(s) after cross-matching with other X-ray catalogs. The 73-days-bin light curves over 7 years and their periodograms for all the cataloged sources are presented. To complete sample information, we are working for the identification of the remaining sources, whose results will be reported in future papers.

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Appendix

PSF CALIBRATION

In Hiroi et al. (2013) the PSF of the GSC was assumed to have a two-dimensional Gaussian profile in the coordinate system based on collimator angle (ϕ and θ ; see Sugizaki et al., 2011, for the definition) around the original source positions. However, the actual profile deviates from the Gaussian in the direction of the anode wires (i.e., the ϕ axis), due to the variation in the position where photons are absorbed in the gas counters, which depends on their incident angles and the energy of photons. In addition, the finite slit width makes the profile broader Sugizaki et al. (see 2011). These effects are negligible for most X-ray sources compared with their statistical errors, but significant in brightest Galactic sources, such as Sco X-1, Crab Nebula, and Cyg X-1.

To measure the actual PSF profile in each camera, we collected the event data from several brightest isolated sources, such as Sco X-1, and Crab, and integrated them separately for each incident angle and energy band. Figure 4.1(a), (b), and (c) show the PSF cross-sectional profiles obtained from the real event data, with their best-fit models in the 3 – 4 keV, 4 – 10 keV, and 10 – 20 keV bands, along the anode wire direction for incident angles (ϕ) of -32° to -30° , 4° to 6° , and -1.1° to -1.0° , respectively. As noticed in Fig. 4.1(a), the PSF shape at larger ϕ become more asymmetric at higher energies, because higher energy photons travel deeper before being absorbed in the gas counter and the effects of variation in the photon-absorption position become more significant. Narrower PSFs are formed at $\phi \sim 0^\circ$ (Fig. 4.1(c)), due to the shielding effect by the support structure of the counter’s beryllium window, perpendicular to the anode wires. We note that the width of the PSF profile also depends on the voltage of the anode

wires, 1650 V or 1550 V.

Considering the results above, we constructed a PSF database and used it in the simulation for the sources detected in the image analysis Section 3.3. The database consists of FITS files of PSF data for each camera and each voltage of anodes (1550 V and 1650 V). In these files the PSF profiles along the wire anodes are tabulated as histograms separately for each ϕ ranges and in energy bands of 3–4 keV, 4–10 keV and 10–20 keV, in a proper format that maxisim can refer to.

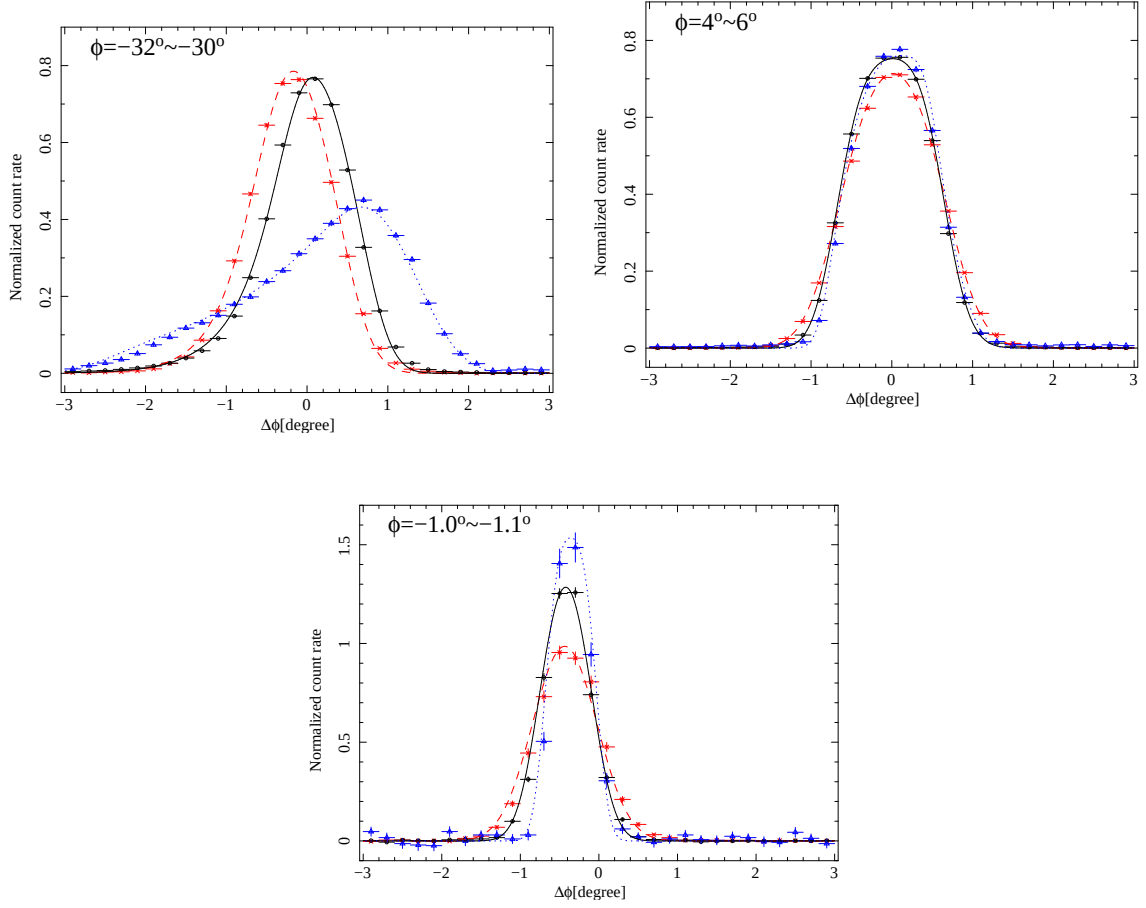


Figure 4.1. PSF cross-section profiles of GSC5 with the anode voltage of 1650 V and their best-fit models along the detector anode-wire direction at (a) $\phi = -32^\circ \sim -30^\circ$, (b) $4^\circ \sim 6^\circ$, (c) $-1.1^\circ \sim 1.0^\circ$ in 3 – 4keV (crosses and red dashed line), 4 – 10keV (circles and black solid line), and 10 – 20keV (triangles and blue dotted line).

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