INTEGRAL AND BeppoSAX OBSERVATIONS OF THE TRANSIENT ATOLL SOURCE 4U 1608–522: FROM QUIESCENT TO HARD SPECTRAL STATE

A. Tarana, A. Bazzano, and P. Ubertini

Received 2007 December 20; accepted 2008 July 15

ABSTRACT

We report on the spectral evolution of 4U 1608–522 using observations performed as part of the long-term Galactic bulge monitoring program with INTEGRAL. The data set includes the 2005 April outburst. BeppoSAX archival data (two observations, from 1998 and 2000) are also analyzed and compared with the INTEGRAL data. Three different spectral states have been identified from the hardness-intensity diagram derived from INTEGRAL: the canonical hard and soft states, as well as an intermediate state. The hard-state spectrum is well described by a weak blackbody component plus a Comptonized plasma with high electron temperature ($kT_e \approx 60$ keV) extending up to 200 keV without any additional cutoff. The soft spectra are characterized by a cold Comptonized plasma ($kT_e = 2–3$ keV; 7 keV for the intermediate state) and a strong disk blackbody component. A reflection component, indicating reflection of the X-rays from the accretion disk, is also present in the soft state seen by BeppoSAX in 1998. The 2000 BeppoSAX observation reveals the source to have been in its quiescent state, which can be modeled with a neutron star atmosphere (assuming a neutron star radius of 10 km and mass $1.4M_\odot$) with an effective temperature $kT_{eff}$ of 0.1 keV, plus a power-law component with $\Gamma \approx 3$, detected for the first time in this source. This spectrum can also be modeled with a simple blackbody compatible with emission originating from a small fraction of the neutron star’s surface, of radius 0.4 km.

Subject headings: stars: individual (4U 1608–522) — stars: neutron — X-rays: binaries

Online material: color figures

1. INTRODUCTION

A low-mass X-ray binary (LMXB) is a stellar system composed of a late-type star and a compact object that accretes material from the companion star via Roche lobe overflow. The neutron star (NS) LMXBs are classified as Z or atoll sources based on the shape of their tracks in a color-color diagram (Hasinger & van der Klis 1989), corresponding to different X-ray spectral and variability properties. The atoll sources move from the “island branch,” which corresponds to the hard spectral state, to the “banana branch,” corresponding to the soft state.

Many LMXBs are soft X-ray transient sources (SXRTs), showing spectral state changes possibly driven by accretion instability phenomena. In fact, they often reside in a quiescent state with a low luminosity of $10^{34}$ ergs s$^{-1}$ and abruptly undergo X-ray outbursts that consist of a fast flux increase reaching luminosities $L_X \sim 10^{37}–10^{38}$ ergs s$^{-1}$, followed by a slower, nearly exponential decay (lasting weeks or months) (Campana et al. 1998). During such outbursts, these sources exhibit spectral state transitions from the hard (onset of the outburst) to the soft (at the peak of the outburst), passing through intermediate spectral states. The mass accretion rate is the main parameter responsible for the spectral changes (hardening and softening). NSs in the quiescent state on average are more luminous than black holes (BHs) in quiescence. This observational property may be used to distinguish the NS or BH nature of the compact object (Rutledge et al. 2000; Campana et al. 2001). Unfortunately, so far few sources have been detected during the quiescent state, namely, Aql X-1, Cen X-4, EXO 0748–676, and 4U 2129+47 (Campana et al. 1998), XTE J2123–058 (Tomsick et al. 2004), and 4U 1608–522 itself (Asai et al. 1996).

The atoll source 4U 1608–522 is a LMXB with a NS as compact object, as deduced from the presence of type I X-ray bursts and superbursts (Nakamura et al. 1989; Remillard & Morgan 2005). It is one of the SXRTs that show long periods of quiescence (such as EXO 0748–676 and 4U 2129+47) spaced out by periodic outbursts (Lochner & Roussel-Dupré 1994; Simon 2004), like Aql X-1 (Tanaka & Shibazaki 1996).

In the past decade, the broadband capabilities of BeppoSAX and the Rossi X-Ray Timing Explorer (RXTE) have allowed a step forward in the study of NS LMXBs, establishing their high-energy behavior well above the standard X-ray band ($\leq 20$ keV). More recently, reflection components and high-energy tails have been reported, for example, in 4U 1820–30, 4U 1705–44 (Tarana et al. 2007; Fiocchi et al. 2007; Piraino et al. 2007), and 4U 1608–522 itself (Gierliński & Done 2002). For 4U 1608–522, a radio flux density upper limit of 0.19 mJy at 8.5 GHz is available (Migliari & Fender 2006).

We report here on recent data from INTEGRAL (Winkler et al. 2003) to characterize the high-energy emission and spectral variation of 4U 1608–522. For this purpose, we analyze the data in the 4–200 keV energy range from JEM-X (Lund et al. 2003) and IBIS (Ubertini et al. 2003). Two noncontemporaneous observations with BeppoSAX (Boella et al. 1997) are also analyzed. We combine three methods of analysis: temporal, using the light curves in different energy bands; photometric, with the hardness-intensity diagram; and spectral, through spectral modeling.

2. OBSERVATIONS AND DATA ANALYSIS

The INTEGRAL observations span a noncontinuous period from 2004 February 18 to 2005 September 8, during revolutions...
164–354. We analyzed all the public data from JEM-X (within 7° × 7° of the field of view) and IBIS (with a 9° × 9° field of view), which resulted in 192 and 420 pointings (or Science Windows [SCWs]), respectively, each lasting about 2000 s. Data were extracted with the Offline Scientific Analysis software (ver. 5.1; Goldwurm et al. 2003) released by the INTEGRAL Science Data Centre (Courvoisier et al. 2003). For the spectral analysis, which was performed with the XSPEC package (ver. 11.3), systematic errors of 2% were added to both the JEM-X and IBIS data sets.\(^6\) Fluxes were normalized to the IBIS/ISGRI value.

The two public observations from BeppoSAX\(^5\) were performed on 1998 February 28 and 2000 August 1. The spectra from the LECS (0.1–10 keV), MECS (1–10 keV), and PDS (15–200 keV) instruments were generated within a radius of 4\(\times\)2000 s. Each point corresponds to the count rate in millicrabs, with a time binning of 1 SCW for INTEGRAL and 1 day averaging for ASM.

3. LIGHT CURVES AND HARDNESS-INTENSITY DIAGRAM

In Figure 1, we present the public 1.5–12 keV RXTE All-Sky Monitor (ASM) light curve\(^6\) of 4U 1608–522 for the period 2004 February–2005 September and overplot the light curves from JEM-X (4–10 and 10–20 keV bands) and IBIS (20–30, 30–60, and 60–120 keV bands). Each INTEGRAL point corresponds to a single SCW. Figure 2 zooms in on the light curve during the outburst of the source that started in 2005 February (MJD 53,400). Different colors in Figure 2 correspond to different spectral properties. Colors in the hardness-intensity diagram shown in Figure 3 are used accordingly. This figure shows the hard color versus intensity from the JEM-X and IBIS data. “Hard color” here is defined as the ratio of the 10–20 and 20–30 keV fluxes, while the intensity is the sum of the 10–20 keV and 20–30 keV fluxes (all fluxes are in units of millicrabs). The dark and light blue data points correspond to the hard (island) spectral state, while purple, red, and green correspond to soft (banana) states.

The hard spectral states appear at the beginning and the end of the outburst (see Fig. 2), as is typical for transient sources.

In Figure 4, we show the ASM light curve with the two BeppoSAX observations marked (vertical bars). For the 1998 observation the source was in a soft state, while in 2000 it was in a quiescent phase, as discussed below.

4. SPECTRAL ANALYSIS

Spectra for the INTEGRAL data have been derived with pointings grouped according to the colors used in the hardness-intensity diagram (Fig. 3). In Table 1, we report the log of the INTEGRAL and BeppoSAX data sets and identified spectral states. Data sets S1 and S5 correspond to hard states, S3 and S4 correspond to soft states, and S2 corresponds to the soft/intermediate state.

4.1. Soft and Intermediate States

The S2, S3, and S4 spectra were first modeled with a Comptonized component, \(\text{compTT}\) in XSPEC (Titarchuk 1994). For S2 and S3, and to a minor extent for S4, it was necessary to add a soft component because of a soft excess below 6 keV and the poor values of the reduced \(\chi^2\) (\(\chi^2\) of 1.4 and 1.2, respectively). A multi-color disk blackbody component, \(\text{diskbb}\) in XSPEC (Mitsuda et al. 1984), was used, although a simple blackbody component (\(\text{bbody}\)) gives similar results. In Table 2, the parameters of the \(\text{compTT+diskbb}\) model are listed for these spectral states.

The Comptonization model has three main parameters: \(kT_e\), the temperature of the electrons in the corona—that is, a hot region near the disk; the optical depth of this region, \(\tau\); and \(kT_{in}\), the temperature of the input seed photons that are upscattered to higher energies by the hot electrons of the corona. The temperature of the disk blackbody depends on the radius as \(T \propto R^{-3/4}\), and the fit parameter of the \(\text{diskbb}\) model, \(kT_{in}\), is the temperature at the inner disk radius, \(R_{in}\), corresponding to the inner last stable orbit of the material of the disk.

The results from the \(\text{compTT+diskbb}\) model fitting in Table 2 show that the temperature of the Comptonized region \(kT_e\) decreases from the “left” to the “right” banana state (S2 to S4) and becomes optically thick \(\tau\) increases), whereas the inner disk blackbody temperature \(kT_{in}\) undergoes a small increase. Moreover,
for spectra S2 and S3, the temperature of the input photons required for the Comptonization model, $kT_0$, has a value different from the inner disk temperature of the photons, $kT_{in}$. This indicates that the seed input photons should be coming from a region with a higher temperature with respect to the inner disk region, such as a boundary layer or the neutron star’s surface. On the contrary, for S4 the temperature of the inner disk is compatible (within the errors) with the $kT_0$ value. In the fitting procedure, when trying to fix the parameters $kT_0$ and $kT_{in}$ at the same value for all the spectral data, only spectrum S4 yielded an acceptable $\chi^2$ value. On the other hand, we are aware that these parameters are well outside the instrumental energy coverage.

A better estimate of the soft-state parameters can be obtained with a BeppoSAX observation from 1998 that covers energies well below 4 keV (below JEM-X’s operating range). Results of a fit with the addition of an absorption model with a column density $N_H = 1.2 \times 10^{22}$ cm$^{-2}$ (compatible with that previously found by Penninx et al. 1989) are reported in Table 2. Also, on this occasion the source exhibited an input photon temperature higher than that of the inner disk photons. We discuss this further in § 5.

A reflection component (Wardziński et al. 2002) was tentatively added to all the observed soft states and proved to be required only for the BeppoSAX soft-state data. In fact, for spectra S3 and S4 the $F$-test result does not improve, whereas for S2 a better fit was obtained but with a low chance probability (10%). The reflection component contributes to the fit with a sort of bump in the 10–20 keV band, and as a consequence we get a better fit to the high-energy data (>30 keV). Moreover, the best-fit parameter values do not really change from the previous fit. The parameters are listed in Table 2 and the energy and count

![Fig. 2.—A zoom in on the outburst of 2005 February–April. The colored bands correspond to different spectral states. Note that the hardening appears just at the beginning and the end of the outburst (see the blue bands). These data are reported with the same colors in the hardness-intensity diagram of Fig. 3.](image1)

![Fig. 3.—Hard color vs. intensity with IBIS and JEM-X data. Each point corresponds to one SCW.](image2)
spectra are shown in Figure 5. For the BeppoSAX data we also need to add a Gaussian model to fit an excess below 10 keV, as shown in Figure 6, where the quiescent spectrum is also reported. An Fe reflection line at an energy of 6.4 keV with a large FWHM is required to obtain the best fit.

Assuming a source distance of 3.6 kpc (Nakamura et al. 1989), the value of the bolometric luminosity ranges from $6 \times 10^{37} \text{ to } 1.5 \times 10^{37}$ ergs s$^{-1}$ from the soft to the intermediate state.

4.2. Hard States

Hard states were detected at the beginning and at the end of the 2005 outburst, as derived from the light curves and hardness-intensity diagram shown in Figures 1, 2, and 3. The S1 and S5 data sets were modeled with the same model and the same spectral parameters, so they were combined into a single spectrum to increase the signal-to-noise ratio.

First, a Comptonization model was used to fit the data; the parameters are $kT_e = 57.4^{+54.3}_{-21.3}$, optical depth $\tau = 0.49^{+0.41}_{-0.31}$, and input photon temperature $kT_0 = 0.5$ keV, with $\chi^2 = 0.91$ ($\nu = 50$). A diskbb component was added to take into account the higher residuals below 6 keV. Table 3 reports the values obtained from this fit, and Figure 5 shows the spectrum extending up to 200 keV. Moreover, an acceptable fit was also obtained with the temperature of the seed photons frozen at the blackbody temperature. In this case, the soft temperature is 0.5 keV and the coronal temperature and optical depth are similar to the previous model.

It is evident in all cases that the value of the temperature of the coronal electrons is not well constrained, indicating that a real cutoff in this spectrum is not detected. We also checked the data from the Spectrometer on INTEGRAL (SPI) for the same period, and there is agreement with our values (E. Jourdain 2007, private communication).

Finally, we tried fitting this spectrum with the compPS model (Poutanen & Svensson 1996), which includes a reflection parameter, with no improvement, as shown in Table 3. The unabsorbed

| TABLE 1 | LOG OF THE DATA USED FOR SPECTRAL FITTING |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Data Set | Start Time (MJD) | Exposure (ks) | Spectral State |
| INTEGRAL: | | | |
| S1 (light blue) | 53,433.0 | 10.2, 10.7 | Hard |
| S2 (purple) | 53,435.2 | 56.5, 32.0 | Soft/intermediate |
| S3 (red) | 53,438.0 | 64.5, 36.7 | Soft |
| S4 (green) | 53,462.7 | 74.6, 63.5 | Soft |
| S5 (blue) | 53,598.8 | 45.6, 53.7 | Hard |
| BeppoSAX: | | | |
| Spe1998 | 50,872 | 30.4, 13.2, 14.1 | Soft |
| Spe2000 | 51,757 | 47.8, 23.3, 22.7 | Quiescent |

$^a$ The colors are used in the light curves, Fig. 2, and hardness-intensity plots, Fig. 3.

$^b$ For INTEGRAL, the values are for IBIS and JEM-X, respectively; for BeppoSAX, they are LECS, MECS, and PDS, respectively.

![Fig. 4.—ASM 1.5–12 keV light curve. The vertical bars indicate the BeppoSAX observations.](image)

4.2. Hard States

Hard states were detected at the beginning and at the end of the 2005 outburst, as derived from the light curves and hardness-intensity diagram shown in Figures 1, 2, and 3. The S1 and S5 data sets were modeled with the same model and the same spectral parameters, so they were combined into a single spectrum to increase the signal-to-noise ratio.

First, a Comptonization model was used to fit the data; the parameters are $kT_e = 57.4^{+54.3}_{-21.3}$, optical depth $\tau = 0.49^{+0.41}_{-0.31}$, and input photon temperature $kT_0 = 0.5$ keV, with $\chi^2 = 0.91$ ($\nu = 50$). A diskbb component was added to take into account the higher residuals below 6 keV. Table 3 reports the values obtained from this fit, and Figure 5 shows the spectrum extending up to 200 keV. Moreover, an acceptable fit was also obtained with the temperature of the seed photons frozen at the blackbody temperature. In this case, the soft temperature is 0.5 keV and the coronal temperature and optical depth are similar to the previous model.

It is evident in all cases that the value of the temperature of the coronal electrons is not well constrained, indicating that a real cutoff in this spectrum is not detected. We also checked the data from the Spectrometer on INTEGRAL (SPI) for the same period, and there is agreement with our values (E. Jourdain 2007, private communication).

Finally, we tried fitting this spectrum with the compPS model (Poutanen & Svensson 1996), which includes a reflection parameter, with no improvement, as shown in Table 3. The unabsorbed
bolometric luminosity of the hard spectrum corresponds to $5 \times 10^{37}$ ergs s$^{-1}$.

4.3. Quiescent State

During the 2000 observation by BeppoSAX, the source was in a quiescent state as derived with LECS and MECS only, and the bolometric luminosity corresponded to $\sim 1.4 \times 10^{33}$ ergs s$^{-1}$. This quiescent state was fitted with different models: a simple power law, a blackbody, a blackbody plus a power law, a neutron star atmosphere model (nsa in XSPEC; Zavlin et al. 1996), and finally nsa plus a power law. For all the fits we assumed an absorption $N_H$ fixed at $1.2 \times 10^{22}$ cm$^{-2}$.

The single power-law component gives a photon index of 3.3 with a $\chi^2$ value of 0.82 ($\nu = 65$). The blackbody model gives a
temperature of 0.5 keV, with $\chi^2 = 1.18$ ($\nu = 65$). From the value of the blackbody normalization (assuming a distance of 3.6 kpc), we derive the size of blackbody emission region as $\sim 0.4$ km, which is incompatible with the typical NS radius of 10 km. This could be explained by assuming that the X-ray emission originates from a smaller emission region such as the polar caps of the neutron star. A better fit is obtained by adding a power-law component ($\chi^2 = 0.74$, $\nu = 63$), but this implies a blackbody temperature of 0.07 keV and a blackbody emission region larger than the NS radius ($\sim 100$ km).

We also tried to fit the quiescent spectra with a pure hydrogen atmosphere spectrum. The neutron star H atmosphere model (nza) uses the mass and radius of the NS and the unredshifted effective temperature of the surface of the star ($kT_{\text{nsa}}$) as parameters. The model normalization is equal to $1/D^2$, where $D$ is the distance to the source. Note that the blackbody model temperature (the temperature to infinite distance) is different from $kT_{\text{nsa}}$ by the redshift factor, which is 0.76 for the standard mass and radius values of a NS (1.4 $M_\odot$ and 10 km). We froze the mass and the radius at the standard values and the normalization to 7.716 x $10^{-8}$ (for $D = 3.6$ kpc) and left the effective temperature as a free parameter. The NS radius was frozen at 10 km to overcome the underestimate of the emission region resulting from the blackbody model, as has been done for previous NS quiescent-state data (Rutledge et al. 1999; Tomsick et al. 2004). The obtained effective temperature of the neutron star is 0.17 keV, but the value of $\chi^2$ is still too high (1.7, with $\nu = 66$).

The best-fitting model was obtained by adding a power law to the nza component: in this case, the effective temperature corresponds to 0.12 keV, and the photon index of the power law is 3 ($\chi^2 = 0.83$, $\nu = 64$). The 0.5–10 keV unabsorbed luminosity is $1.9 \times 10^{33}$ erg s$^{-1}$ (Asai et al. 1996) and $(7.3–8.3) \times 10^{32}$ erg s$^{-1}$ (Rutledge et al. 1999). These values were also obtained by modeling the quiescent spectrum of this source with the same models (blackbody, single power law, or nza), although a power-law component was never required in the fits.

5. DISCUSSION AND CONCLUSIONS

We have reported on a study of the spectral behavior, as derived with the INTEGRAL and BeppoSAX satellites, of the SXRT source 4U 1608–522 in different spectral states characterized by luminosities ranging from $4 \times 10^{33}$ to $6 \times 10^{37}$ ergs s$^{-1}$ from the quiescent up to the soft state. The soft and hard spectra have been modeled with a soft component, described by a disk blackbody emission or just blackbody emission, plus a Comptonization component, which is described by a Comptonized corona. The BeppoSAX soft-state spectra in addition show a reflection emission from the disk.

During the spectral hardening (from the banana to the island branch of the color-intensity diagram), the inner disk blackbody temperature decreases from 0.7 to 0.4 keV, while the temperature of the Comptonized corona increases and the optical depth decreases, becoming optically thin and very hot in the hard state ($kT_e$ changes from 2 to 60 keV).

Despite the difficulty of precisely determining the soft-state parameters (because of the limited instrumentation bandwidth, often sensitive at $E > 4$ keV) and the need to often freeze the seed photons’ temperature in our fits, we can still arrive at some remarks and explanations regarding this source.

From the diskbb normalization model we have estimated the inner disk radius. For the soft spectra, a radius ranging from 20 to 60 km has been obtained, indicating that the disk extends to near the NS. On the contrary, for the hard spectrum the inner radius extends up to 120 km, as expected to allow the formation of the hot plasma corona. This implies that a change in the spectral state corresponds to a different disk-corona geometry of the system, as already observed in NS and also BH transient systems (Zdziarski & Gierlinski 2004).

Moreover, we observed a seed input photon temperature higher ($T_0$ ranging from 0.6 to 1.2 keV) than the inner disk temperature. In view of the fact that $kT_{\text{in}}$ is representative of the latest/inner part of the accretion disk, the seed photons must be provided from a hotter inner region, which could either be close to the neutron

---

TABLE 3

| Parameter        | compTT+diskbb | compPH+diskbb |
|------------------|---------------|---------------|
| $kT_0$ (keV)     | 1.2           | 1.1 ± 0.5     |
| $kT_{\gamma}$ (keV) | 62.6 ± 26.0  | 38.5 ± 9.7    |
| $\gamma$         | 0.4 ± 0.9     | 2.6 ± 0.8     |
| $\Omega/2\pi$    |               | 0.1 ± 0.2     |
| norm             | 0.003 ± 0.002 | 74.3 ± 138.3  |
| $kT_{\text{in}}$ (keV) | 0.4 ± 0.63 | 0.5 ± 0.6     |
| $\chi^2 (\nu)$   | 0.79 (49)     | 1.06 (47)     |

---

7 Estimated with the formula given by Gierliński & Done (2002).
star, that is, an optically thick boundary layer heated by friction effects (suggested as a possibility for the source GRS 1724–30; Barret et al. 2000) or the neutron star’s surface itself.

The boundary layer model predicts a temperature ranging from 0.5 to 2.0 keV (Lin et al. 2007 and references therein), whereas the predicted temperature for the “spreading boundary layer model” of a NS LMXB (with NS radius of 15 km and mass $1.4 M_\odot$) is 2.4 keV (Revnivtsev & Gilfanov 2006; Suleimanov & Poutanen 2006; Lin et al. 2007), well above the temperature of 0.6–1.2 keV observed for 4U 1608–522. In this case that the seed photons are provided by the stellar surface of the NS, the temperature is higher than the NS temperature estimated during quiescence, as a result of the NS’s cooling during the quiescent state at low accretion rate (Done et al. 2007).

In the hard state, the energy spectrum does not show any high-energy cutoff. Such behavior is usually attributed either to non-thermal emission processes, probably related to jet formation, as for 4U 0614+091 (Migliari et al. 2006), or to hybrid thermal-nonthermal emission, as for 4U 1820–30 (Tanaka et al. 2007). In any case, the spectral characteristics and models of 4U 1608–522 are different from those for 4U 1820–30. Also, the large uncertainties on the value for the coronal electron temperature would prevent us from deriving the presence of a cutoff. The lack of any firm detection in the radio band supports this scenario, although nonthermal processes cannot be ruled out. Indeed, in any case, for 4U 0614+091 also only an upper limit was derived in the radio band, but later the presence of a jet was detected (Migliari & Fender 2006; Migliari et al. 2006).

We have also investigated the spectrum of 4U 1608–522 during a quiescent state that exhibited a luminosity higher than those previously reported. This state was modeled with thermal neutron star atmosphere emission, and for the first time, a power law with $\Gamma \simeq 3$ was required. The thermal emission is due to the cooling NS (with $R = 10$ km and $M = 1.4 M_\odot$), with an effective temperature of 0.12 keV, comparable to the previously observed temperature of 0.17 keV (Rutledge et al. 1999). The nature of the power-law tail is still unclear. This component has also been observed as the dominant one above 2–3 keV in the quiescent X-ray spectra of transient NSs such as Aql X-1 and Cen X-4 (Asai et al. 1996; Campana et al. 2000; Rutledge et al. 2000) and KS 1731–260 (Rutledge et al. 2002). Such a component can originate from a residual low-level accretion onto the NS magnetosphere, also in the quiescent state, (Campana et al. 1998) or in the interaction of a pulsar wind or surrounding gas such as in PSR 1259+63 (Tavani & Arons 1997). This last case does not apply to 4U 1608–522, which is not a pulsar-like system. This power-law component was never detected in previous quiescent spectra of 4U 1608–522, suggesting that it appears only occasionally and also suggesting a variability in the quiescent emission.

This research has made use of data obtained with INTEGRAL, an international collaboration. The authors thanks M. Federici for continuous efforts to update the INTEGRAL archive and software in Rome, and G. De Cesare and L. Natalucci for scientific and data analysis support. The authors also thank E. Jourdain for information and discussions about the SPI data, and C. O. Heinke for useful discussions about the quiescent-state spectrum observed.

We acknowledge financial support from the Agenzia Spaziale Italiana through grants ASI-INAF I/008/07 and I/088/06.

REFERENCES

Asai, K., Dotani, T., Mitsuda, K., Hoshi, R., Vaughan, B., Tanaka, Y., & Inoue, H. 1996, PASJ, 46, 257
Barret, D., Olive, J. F., Boirin, L., Done, C., Skinner, G. K., & Grindlay, J. E. 2000, ApJ, 533, 329
Boella, G., Butler, R. C., Perola, G. C., Piro, L., Scarsi, L., & Bleeker, J. A. M. 1997, A&A, 322, 399
Campana, S., Colpi, M., Mereghetti, S., Stella, L., & Tavani, M. 1998, A&A Rev., 8, 279
Campana, S., Parmar A. N., & Stella, L. 2001, A&A, 372, 241
Campana, S., Stella, L., Mereghetti, S., & Cremonesi, D. 2000, A&A, 358, 583
Courvoisier, T. J.-L., et al. 2003, A&A, 411, L53
Done, C., Gierlinski, M., & Kubota, A. 2007, A&A Rev., 15, 1
Fiocchi, M., Bazzano, A., Ubertini, P., & Zdziarski, A. A. 2007, ApJ, 657, 448
Gierlinski, M., & Done, C. 2002, MNRAS, 337, 1373
Goldwurm, A., et al. 2003, A&A, 411, L223
Hasinger, G., & van der Klis, M. 1989, A&A, 225, 79
Lin, D., Remillard, R. A., & Homan, J. 2007, ApJ, 667, 1073
Lochner, J. C., & Roussel-Dupré, D. 1994, ApJ, 435, 840
Lund, N., et al. 2003, A&A, 411, L231
Migliari, S., & Fender, R. P. 2006, MNRAS, 366, 79
Migliari, S., Tomsick, J. A., Maccarone, T. J., Gallo, E., Fender, R. P., Nelemans, G., & Russell, D. M. 2006, ApJ, 643, L41
Mitsuda, K., et al. 1984, PASJ, 36, 741
Nakamura, N., Dotani, T., Inoue H., Mitsuda, K., Tanaka, Y., & Matsuoka, M. 1989, PASJ, 41, 617
Penninx, W., Damen, E., Tan, J., Lewin, W. H. G., & van Paradijs, J. 1989, A&A, 208, 146
Piraino, S., Santangelo, A., Di Salvo, T., Kaaret, P., Horns, D., Iaria, R., & Burderi, L. 2007, A&A, 471, L17
Poutanen, J., & Svensson, R. 1996, ApJ, 470, 249
Remillard, R., & Morgan, E. 2005, ATel, No. 482
Revnivtsev, M. G., & Gilfanov, M. R. 2006, A&A, 453, 253
Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., & Zavlin, V. E. 1999, ApJ, 514, 945
———. 2000, ApJ, 529, 985
Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., Zavlin, V. E., & Ushomirsky, G. 2002, ApJ, 580, 413
Simon, V. 2004, A&A, 418, 617
Suleimanov, V., & Poutanen, J. 2006, MNRAS, 369, 2036
Tanaka, Y., & Shibazaki, N. 1996, ARA&A, 34, 607
Tavani, A., Bazzano, B., Ubertini, P., & Zdziarski, A. A. 2007, ApJ, 654, 494
Tavani, M., & Arons, J. 1997, ApJ, 477, 439
Tictarchuk, L. 1994, ApJ, 434, 570
Tomsick, J. A., Gelino, D. M., Halpern J. P., & Kaaret, P. 2004, ApJ, 610, 933
Ushomirsky, G. 2002, ApJ, 580, 413
Winkler, C., et al. 2003, A&A, 411, L1
Zavlin, V. E., Pavlov, G. G., & Shibian, Yu. A. 1996, A&A, 315, 141
Zdziarski, A. A., & Gierlinski, M. 2004, Prog. Theor. Phys. Suppl., No. 155, 99