THE EVOLUTION OF THE HIGH-ENERGY TAIL IN THE QUIESCENT SPECTRUM OF THE SOFT X-RAY TRANSIENT AQUILA X-1

S. Campana\textsuperscript{1} and L. Stella\textsuperscript{2}

Received 2002 December 23; accepted 2003 July 9

ABSTRACT

A moderate level of variability has been detected in the quiescent luminosity of several neutron star soft X-ray transients. Spectral variability was first revealed by Chandra observations of Aql X-1 in the 4 months that followed the 2000 X-ray outburst. By adopting the canonical model for the quiescent spectrum of soft X-ray transients, i.e., an absorbed neutron star atmosphere model plus a power-law tail, in 2002 Rutledge et al. concluded that the observed spectral variations could be ascribed to temperature variations of the neutron star atmosphere. These results can hardly be reconciled with the neutron star cooling that is expected to take place in between outbursts (after deep crustal heating in the accretion phase). Here we reanalyze the Chandra spectra of Aql X-1, together with a long BeppoSAX observation in the same period, and propose a different interpretation of the spectral variability: that it is due to correlated variations of the power-law component and the column density (>5, a part of which might be intrinsic to the source), while the temperature and flux of the neutron star atmospheric component remain unchanged. This lends support to the idea that the power-law component arises from emission at the shock between the radio pulsar wind and inflowing matter from the companion star.

Subject headings: accretion, accretion disks — binaries: close — stars: individual (Aquila X-1) — stars: neutron

1 INTRODUCTION

The large luminosity swing of transient X-ray binaries allows the sampling of a variety of physical conditions that are inaccessible to accreting compact objects in persistent sources. The very low luminosity that characterizes the quiescent state of neutron star soft X-ray transients (SXRTs; \( L_X \sim 10^{32} - 10^{33} \) ergs s\(^{-1}\)) opens up the possibility of studying these old, fast-spinning neutron stars in different and yet-unexplored regimes such as accretion onto the neutron star magnetosphere (propeller), resumed millisecond radio pulsar (MSP) activity, and/or low-level atmospheric emission from the cooling of the neutron star in between the accretion intervals of the outbursts (e.g., Campana et al. 1998a; Brown, Bildsten, & Rutledge 1998; Rutledge et al. 2002b).

In recent years the quiescent properties of a handful of SXRTs have been studied in some detail. The main outcome of these investigations is that the quiescent X-ray spectra of SXRTs display a soft component plus a hard (power-law) component contributing a comparable flux in the 0.5–10 keV band (Campana 2001; Bildsten & Rutledge 2000; Wijnands 2002). The soft component has been frequently modeled with a blackbody model of 0.1–0.3 keV temperature and a few kilometer radius. Especially promising is the idea that the soft component of SXRTs may be produced from the cooling of the neutron star heated during the repeated outbursts (van Paradijs et al. 1987; Stella et al. 1994; Campana et al. 1998a). The theory of deep crustal heating by pycnonuclear reactions compares well with observations (Brown et al. 1998; Campana et al. 1998a; Rutledge et al. 1999; Colpi et al. 2001). In particular, Rutledge et al. (1999) fitted neutron star atmospheric models to the soft component of the quiescent spectra of SXRTs and derived slightly smaller temperatures (0.1–0.3 keV) and larger radii (10–15 km, consistent with the neutron star radius) than those inferred from simple blackbody fits.

Observationally, the hard component is well described by a power-law tail. In the quiescent spectra of Aql X-1 and Cen X-4 observed by ASCA and BeppoSAX, this component is statistically significant (Asai et al. 1996, 1998; Campana et al. 1998b, 2000), with a photon index in the 1–2 range. The same power law is needed (even if not statistically significant) in the analysis of Chandra data in order to achieve an emitting radius of the cooling component consistent with the neutron star radius (otherwise, the inferred radius would be smaller; Rutledge et al. 2001a, 2001b). The nature of this hard component is still uncertain. Models range from Comptonization to advection/convection-dominated accretion flows to shock emission from the neutron star that resumes its radio pulsar activity in quiescence. The latter model envisages a situation similar to that of the eclipsing radio pulsar PSR B1259–63 or of the “black widow” pulsar PSR B1957+20: a shock at the boundary between the relativistic MHD wind from the radio pulsar and the matter outflowing from the companion star (Tavani & Arons 1997; Tavani & Brookshaw 1991; Campana et al. 1998a). For the model to explain the observed luminosity in the hard power-law component of quiescent SXRTs, some few percent of the pulsar spin-down luminosity must be converted into shock emission. The shock-emission model predicts synchrotron emission with power-law photon indexes in the 1.5–2 range and extending over a wide range of frequencies. There are also indirect indications for the presence of this emission from UV observations of Cen X-4.

\textsuperscript{1} INAF-Osservatorio Astronomico di Brera, Via Bianchi 46, I-23807 Merate (LC), Italy.
\textsuperscript{2} INAF-Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monteporzio Catone (Rome), Italy.

\(^3\) Ongoing deep searches in the radio band have not yet revealed any steady or pulsed emission from quiescent SXRTs (Burgay et al. 2003); however, free-free absorption due to matter in the binary system might be an important limiting factor in these searches (Stella et al. 1994; Burgay et al. 2003).
with the *Hubble Space Telescope*, revealing a flat spectrum (i.e., $\Gamma \sim 2$) that matches well the extrapolated X-ray power-law component (McClintock & Remillard 2000). Power-law indexes outside the above range are indications of strong (inverse Compton) cooling.

In a way similar to what is routinely done in the optical, a promising tool to probe the X-ray-emitting regions is through a rough eclipse mapping technique (e.g., Horne 1985). *Chandra* observations of the eclipsing SXRT 4U 2129+47 were the first to exploit the potential of this technique by looking at the extension of the emitting regions through eclipses (Nowak, Heinz, & Begelman 2002). During eclipses the soft component gets totally eclipsed, whereas the hard component is too faint to be revealed. This implies an upper limit on the emission size of $\lesssim 10\%$ of the orbital separation (Nowak et al. 2002). The inclination of Aql X-1 has been estimated, from ellipsoidal variations in the $R$- and $I$-band light curves, to be greater than 36$^\circ$ (Welsh, Robinson, & Young 2000).

In this paper we investigate in more detail the quiescent spectrum of one of the best-studied SXRT sources: Aql X-1. We take advantage of four *Chandra* exposures (Rutledge et al. 2002a) and one 76 ks long (unpublished) *BeppoSAX* exposure. All these data were collected just after the 2000 November outburst. Based on the *Chandra* data, Rutledge et al. (2002a) claimed that the soft component decreased by $\sim 50\%$ over 3 months, increased by $\sim 35\%$ in 1 month, and then remained constant ($<6\%$ change) over the last month. The variability of these observations was ascribed to an intrinsic variability of the soft component, hinting at accretion onto the neutron star surface. Here we discuss in more detail these observations together with the *BeppoSAX* long exposure, probing the shock-emission model.

In § 2 we deal with the data. In § 3 we describe the spectral fitting and related results. A discussion and conclusions are given in § 4.

2. DATA

### 2.1. Chandra

Aql X-1 was observed by *Chandra* after the 2000 November outburst on four occasions (see Table 1). Observations were carried out with the backside-illuminated ACIS-S detector (S3) at an off-axis position of 4$'$ and limited readout area of 1/8 (achieving a time resolution of 0.44 s) in order to limit problems connected to pile-up (see Rutledge et al. 2002a). As expressly required, Aql X-1 fell on the same physical pixels in order to avoid problems with the CCD’s quantum efficiency (see Rutledge et al. 2002a). For the analysis we use CIAO, version 2.2.1, with CALDB, version 2.15 (these are later versions than what were used by Rutledge et al. 2002a). In all observations, we extracted the source counts from an elliptical $47.5 \times 3\arcsec$ region centered on the source with a position angle matching the source. Background photons were extracted from an annular region with inner and outer radii of 10$''$ and 20$''$, respectively. Data were extracted, using *psextract*, into pulse-invariant spectra. We grouped all the spectra to have (at least) 30 photons channel$^{-1}$. We also corrected all the ancillary response files (ARFs) with the recently released *corrf* tool to account for the continuous degradation in the ACIS CCD’s quantum efficiency.

#### 2.2. BeppoSAX

We analyzed data from the two imaging instruments on board the *BeppoSAX* satellite: the Low Energy Concentrator Spectrometer (LECS; 0.1–10 keV; Parmar et al. 1997) and the Medium Energy Concentrator Spectrometer (MECS; 1.6–10.5 keV; Boella et al. 1997). Nonimaging instruments provided only upper limits. Only two of the three MECS units were operating at the time of the observations. LECS data were collected only during satellite nighttime, resulting in shorter exposure times. For a summary of the observations, see Table 1. The observation took place on 2001 April 14, observing Aql X-1 for a net exposure time of 76 ks with the MECS and 30 ks for the LECS.

Products were extracted using the FTOOLS package (ver. 5.1). LECS and MECS events were extracted from a circle of 4$'$ radius. The background was subtracted using spectra from blank-sky files at the same detector coordinates (after checking that the background of the observation was comparable). We rebinned the LECS and MECS spectra in order to have 80 counts per spectral bin each.

### 3. OVERALL SPECTRAL ANALYSIS

#### 3.1. Spectral Model

Rutledge et al. (2002a) analyzed the four *Chandra* spectra together. The spectra are different; e.g., a hard power-law tail has been detected during only two of the four observations. To account for these differences, Rutledge et al. (2002a) considered a model made from an absorbed atmosphere model plus a power law and let vary single parameters (fixing all others), trying to account for the variations. They found that differences in the spectra could not be explained as being entirely due either to a changing

| Satellite         | Sequence Number | Start Time   | Exposure | Orbital Phase $\phi_{\text{orb}}$ |
|-------------------|-----------------|--------------|----------|----------------------------------|
| *Chandra*         | 400075          | 2000 Nov 28  | 6628     | 0.02–0.15 (±0.02)                |
| *Chandra*         | 400076          | 2001 Feb 19  | 7787     | 0.20–0.36 (±0.02)                |
| *Chandra*         | 400077          | 2001 Mar 23  | 7390     | 0.19–0.34 (±0.02)                |
| *Chandra*         | 400078          | 2001 Apr 20  | 9245     | 0.22–0.39 (±0.02)                |
| *BeppoSAX LECS*   | 212380011       | 2001 Apr 14  | 30390    | 0.38–0.50 (±0.02)                |
| *BeppoSAX MECS*   | 212380011       | 2001 Apr 14  | 76301    | 0.38–0.50 (±0.02)                |

Notes.—Orbital phase is relative to minimum light (inferior conjunction of the secondary); the ephemeris is from Garcia et al. 1999. For *Chandra* data these are taken from Rutledge et al. 2002a.
power-law flux and/or index or to a variable column density. On the contrary, differences could be accepted (in terms of $\chi^2$ statistics) explained as being entirely due to a (nonmonotonic) temperature variability of the thermal emission component. These variations could not be explained within the deep crustal heating model, and the authors suggested that these might originate from quiescent accretion onto the neutron star surface.

As discussed in § 1, we want to test here the hypothesis that the quiescent emission of SXRTs (and Aql X-1 in particular) is produced by a soft thermal component, likely arising from cooling of the neutron star, plus a power-law hard tail, arising from shock emission due to an active MSP. In theory, the soft component is steady on a relatively short timescale, whereas the hard component can likely vary depending on the geometry and density of the outflowing matter. Hydrodynamic simulations (Brookshaw & Tavani 1993) as well as radio observations of MSPs in binary systems with a sizeable mass transfer show complex geometries and, more importantly, variations from one orbital cycle to another. The example of the recently discovered MSP PSR J1740–5340 (D’Amico et al. 2001; Ferrario et al. 2001) is enlightening. This is a 3.7 ms MSP orbiting a main-sequence companion every 32.5 hr. The source is located in the globular cluster NGC 6397 at 2.5 kpc. The radio pulsar gets partially and totally eclipsed over a wide range of orbital phases. It emits X-rays as observed by Chandra (Grindlay et al. 2001), likely arising from shock emission. As testified by this source, the MSP is eclipsed for a large part of the orbit, and variations from orbit to orbit are seen.

This case motivates us to consider a spectral model for fitting the quiescent X-ray spectra of Aql X-1 made from a soft thermal component from the entire neutron star, a variable power-law component (the strength of which depends on the interaction with the surrounding matter), and a variable column density due to variations intrinsic to the source (over a fixed interstellar column density).

### 3.2. Spectral Analysis

Spectral analysis was carried out with the XSPEC software (ver. 11.2.0). The spectral model we adopted consisted of a (fixed) cooling spectrum (we use here the hydrogen atmosphere model by Gänsicke, Braje, & Romani 2002, HYD_SPECTRA.MOD in XSPEC) plus a variable power law. A variable column density was also adopted (TBABS in XSPEC; Wilms, Allen, & McCray 2000). We fitted all five spectra (four Chandra and one BeppoSAX. LECS plus MECS) together. For the BeppoSAX data, we used the public response matrices available in 2000 January. During the fit, a variable normalization factor between the LECS and MECS was included to account for the mismatch in the absolute flux calibration of the BeppoSAX instruments (see the Cookbook for BeppoSAX NFI Spectral Analysis). A variable normalization factor was also included to account for the mismatch between BeppoSAX and Chandra. The spectrum provides a statistically acceptable description of the entire data set with a reduced $\chi^2$ of 1.00 (null hypothesis probability 49.0%, see Table 2 and Fig. 1). This indicates

TABLE 2
Spectral Fit of Chandra and BeppoSAX
Aql X-1 Observations

| Parameter | Value (90% CL) |
|-----------|---------------|
| Component Flux 1.5 | |
| Temperature (eV) | $157^{+31}_{-33}$ |
| Radius (km) | $11.1^{+2.5}_{-4.8}$ |
| S, Component Flux 0.4 (22%) | |
| $N_H$ | $1.2^{+1.3}_{-0.9}$ |
| Power law | $0.9^{+0.4}_{-0.7}$ |
| C1, Component Flux 6.2 (81%) | |
| $N_H$ | $6.1^{+1.2}_{-1.0}$ |
| Power law | $4.0^{+0.5}_{-0.3}$ |
| C2, Component Flux 0.3 (16%) | |
| $N_H$ | $3.5^{+0.6}_{-0.5}$ |
| Power law | $1.3^{+0.3}_{-0.2}$ |
| C3, Component Flux 1.5 (51%) | |
| $N_H$ | $4.6^{+1.1}_{-1.4}$ |
| Power law | $3.4^{+0.4}_{-0.6}$ |
| C4, Component Flux 0.9 (38%) | |
| $N_H$ | $3.2^{+0.4}_{-0.5}$ |
| Power law | $1.8^{+0.5}_{-0.6}$ |

Notes.—“S” indicates the BeppoSAX observations, and “C1”—“C4” the four Chandra observations. Column density values are in units of $10^{24}$ cm$^{-2}$, and the component flux is in units of $10^{-12}$ ergs cm$^{-2}$ s$^{-1}$. Confidence levels have been computed for one parameter of interest at 90% (i.e., $\Delta \chi^2 = 2.71$); this is at variance with the distribution in the text and is motivated to allow a comparison between all parameters. Fluxes are unabsorbed and in the 0.5–10 keV energy band. Numbers in parentheses indicate the percentage of the total flux in the power-law component. Observation C1, for which the power law is steep, can be equally well fitted with a bremsstrahlung model with temperatures $kT = 2.0_{-0.3}^{+2.4}$ keV and $N_H = 4.0_{-1.2}^{+1.3} \times 10^{23}$ cm$^{-2}$.

$^a$ The temperature and radius are given at the neutron star. The radius is at a distance of 4 kpc.

---

4 Available at ftp://ftp.asdc.asi.it/pub/sax/doc/software_docs/saxabc_v1.2.ps.gz.

5 We find a ratio of the BeppoSAX over the Chandra normalization of $1.9^{+1.4}_{-0.6}$, consistent with previous determinations (e.g., Piro et al. 2001).

---

Figure 1.—Aql X-1 spectra of the five observations described in the text. The Chandra spectra are in the top part of the figure. LECS and MECS spectra are indicated with filled circles. The best-fit model is overlaid on the data.
that, at least at first sight, all the data concerning the quiescence following the 2000 November outburst of Aql X-1 are consistent with a model made by a cooling neutron star and variable power-law and absorption components.

A detailed theory of the shock emission mechanism has been developed by Tavani & Arons (1997), tailored to the young radio pulsar PSR B1259–63 orbiting a Be star. A more detailed discussion on SXRTs is within Campana et al. (1998a). The expected spectrum is a power-law spectrum with a photon index in the 1.5–2 range, with a positive correlation between the quantity of matter at the shock region (possibly traced by the column density) and the power-law index. This behavior has been observed in PSR B1259–63, which showed a photon index of ~2 at periastron and hardened toward apastron. However, the column density to PSR B1259–63 is larger than the one to Aql X-1, and we expect that variations in the column density are therefore highly suppressed. This correlation might provide us with a further check on the shock emission mechanism. In Figure 2 we show the column density and power-law indexes for the five observations. A correlation is indeed present, suggesting that this mechanism might be at work. We note, however, that the column density and the power-law index are correlated parameters, and for this reason we derived the errors (68% confidence level [CL] in Fig. 2) for the two parameters together ($\Delta$N = 2.30). The correlation is tight. A fit with a constant provides a $\chi^2_{\text{red}} = 5.4$ with a null hypothesis probability of $2 \times 10^{-4}$, whereas a linear fit gives $\chi^2_{\text{red}} = 0.2$ (with an F-test probability of 99.9%). We also carried out a weighted linear correlation test, finding a correlation probability of $r_w = 0.9$ (95% probability). A further correlation can be tested between the power-law flux and the column density. A weighted Pearson correlation test gives $r = 0.8$ (90% probability).

A similar correlation has also been found in the quiescent emission of the transient black hole candidate V404 Cyg (Kong et al. 2002). Kong et al. (2002), however, suspected that the correlation is not intrinsic to the source but is an artifact of the fitting process. In their case the slope of the correlation is nearly (to within 5%) the same as the slope of the major axis of the parameter confidence contours. Moreover, they did not find a correlation between flux and column density. This is contrary to our findings. In Figure 2 we also include the confidence contours, showing that this alignment effect is not present.

We then considered a cutoff power-law model in addition to the neutron star atmosphere one. The overall fit is as good as the others ($\chi^2_{\text{red}} = 1.05$, null hypothesis probability of 35%). The cutoff energy is only loosely constrained, and only an upper limit for each observation can be placed. Drawing contour plots in the cutoff energy–column density plane, we find an anticorrelation between the two quantities: the lower the energy of the cutoff, the larger the column density. From a Pearson correlation test, we obtain $r = -0.9$, corresponding to a significance of ~96%. This might indicate an (almost) constant luminosity that is shared among different quantities of matter.

To further test this idea, we fitted the data with a different model with a smaller emission at low energies. We consider a model consisting of a Comptonized component (COMPTT; Titarchuk 1994) plus an atmosphere component. We found a large degree of freedom with this model, which forced us to freeze the input soft photon temperature to the temperature of the neutron star atmosphere (which is the same for all the observations), take the same amount of optical depth for all the observations (which turns out to be 7.7), and leave the plasma temperature free to vary. The fit is as good as the one with the power law ($\chi^2_{\text{red}} = 1.00$). We derive an anticorrelation between the column density and the plasma temperature. A weighted Pearson correlation test gives $r = -0.9$ (~93% probability).

4. DISCUSSION

Rutledge et al. (2002a), analyzing Chandra data of the Aql X-1 quiescent phase after the 2000 November outburst, found a variable flux and X-ray spectrum. They interpreted these variations in terms of variations of the neutron star effective temperature, which changed from 130$^{+73}_{-39}$ eV (C1), down to 113$^{+117}_{-84}$ eV (C2), and finally increased to 118$^{+79}_{-49}$ eV (C3, C4). Interestingly, during observation C4 they also found short-term variability (at 32% rms) and a possible absorption feature near 0.5 keV (even if this feature can also be explained as being due to a time-variable response in the ACIS detector; Rutledge et al. 2002a).

Short-term variability is a powerful tool for the study of the emission mechanism(s) responsible for SXRT quiescent emission. A factor of 3 variability over timescales of days (Campana et al. 1997) and 40% over 4.5 yr (Rutledge et al. 2001b) has been reported in Cen X-4. Several other neutron star systems have also been found to be variable in quiescence by factors of 3–5 (e.g., Rutledge et al. 2000), but data have been collected over several years and with different instruments. Chandra data on Aql X-1 are the first that show a clear luminosity variation and, more importantly, an increase during quiescence. No known mechanism associated with crustal heating can account for this variability (Rutledge et al. 2002a).

Here we approach the same Chandra data plus an unpublished long BeppoSAX observation of Aql X-1 in quiescence carried out in the same period to probe a different spectral model. Deep crustal heating (Brown et al. 1998; Rutledge et al. 1999; Colpi et al. 2001) has been proposed as a...
physically sound mechanism powering the soft component of the quiescent spectra of SXRTs. Several mechanisms have been proposed to explain the hard tail component often observed in quiescent SXRTs. One of them, physically motivated by the recent observations of the MSP PSR J1740–5340 (D’Amico et al. 2001; Grindlay et al. 2001), relies on the shock emission between the relativistic MSP wind and matter outflowing from the companion (Tavani & Arons 1997; Campana et al. 1998a). These two components are not exclusive. With this physical scenario, we fitted the spectra fixing the soft component for all the observations and leaving free to vary the hard component and the column density (which changes by a factor of $\sim 5$). This model is consistent with the entire data set ($\chi^2_{\text{red}} = 1.00$, for 109 degrees of freedom [dof] and with a null hypothesis probability of 49.0%). Fitting the same data set with the best-fit model by Rutledge et al. (2002a) with the addition of the BeppoSAX data, we obtain a slightly worse fit ($\chi^2_{\text{red}} = 1.17$, for 113 dof and with a null hypothesis probability of 11.1%). An equally good fit is provided by a neutron star atmosphere plus a COMPTT. This model provides a high degree of freedom with a $\chi^2_{\text{red}} = 0.99$ fit (for 104 dof and with a null hypothesis probability of 50.5%) obtained fixing the soft Wien temperature to atmosphere temperature and the plasma temperature kept the same in all the observations. We conclude that the scenario proposed is (at least) equally well consistent with the data, meaning that a shock-emission scenario can account for the spectral variability observed in Aql X-1. We also note that Rutledge et al. (2002a) found 32% (rms) variability in observation C4. In their case, the power-law component contributed only 12% of the flux. From our fit, the power-law component contributes 38% of the total flux, so it can in principle account for all of the short-term variability.

Despite the low number of points, spectral parameters derived for the power-law index show some correlation with the column density (interpreted as a measure of the variable mass around the system, over a fixed interstellar amount) as well as with the power-law flux. This correlation might be expected in the shock-emission scenario (Tavani & Arons 1997). What is not expected is a large value for the power-law index in the last observations. This might then provide an indication of a different regime in the system, possibly underlying a larger inverse Compton cooling. The hard part of the spectrum is in fact also consistent with a thermal bremsstrahlung spectrum.

Further observations can shed light on this new interesting field, namely, variability in the quiescent phase of SXRTs, which up to now has often not been considered.

We thank the anonymous referee and G. Ghisellini for useful comments.

REFERENCES

Asai, K., et al. 1996, PASJ, 48, 257
———. 1998, PASJ, 50, 611
Bildsten, L., & Rutledge, R. 2000, in The Neutron Star–Black Hole Connection, ed. C. Kovouliotou, J. Ventura, & E. P. J. van den Heuvel (NATO ASI Ser. C, 567; Dordrecht: Kluwer), 254
Boella, G., et al. 1997, A&AS, 122, 327
Brookshaw, L., & Tavani, M. 1993, ApJ, 410, 719
Brown, E. F., Bildsten, L., & Rutledge, R. E. 1998, ApJ, 504, L95
Burgay, M., et al. 2003, ApJ, 589, 902
Campana, S. 2001, in AIP Conf. Proc. 599, X-Ray Astronomy 1999: Stellar Endpoints, AGN, and the Diffuse X-Ray Background, ed. N. E. White, G. Malaguti, & G. G. C. Palumbo (New York: AIP), 63
Campana, S., et al. 1997, A&A, 324, 941
———. 1998a, A&A Rev., 8, 279
———. 1998b, ApJ, 499, L65
———. 2000, A&A, 358, 583
Colpi, M., Geppert, U., Page, D., & Possenti, A. 2001, ApJ, 548, L175
D’Amico, N., et al. 2001, ApJ, 561, L89
Ferrario, F., Possenti, A., D’Amico, N., & Sabbia, E. 2001, ApJ, 561, L93
Giacintucci, B. T., Braje, T. M., & Romani, R. W. 2002, A&A, 386, 1001
Garcia, M. R., Callanan, P. J., McCarthy, J., Eriksen, K., & Hjellming, R. M. 1999, ApJ, 518, 422
Grindlay, J., Heinke, C. O., Edmonds, P. D., Murray, S. S., Cool, & A. M. 2001, ApJ, 563, L53
Horne, K. 1985, MNRAS, 213, 129
Kong, A. K. H., et al. 2002, ApJ, 570, 277
McClintock, J. E., & Remillard, R. A. 2000, ApJ, 531, 956
Nowak, M., Heinz, S., & Begelman, M. 2002, ApJ, 573, 778
Parmar, A. N., et al. 1997, A&AS, 122, 309
Piro, I. L., et al. 2001, ApJ, 558, 442
Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., & Zavlin, V. E. 1999, ApJS, 124, 265
———. 2000, ApJ, 529, 985
———. 2001a, ApJ, 551, 921
———. 2001b, ApJ, 559, 1054
———. 2002a, ApJ, 577, 346
Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G., Zavlin, V. E., & Ushomirsky, G. 2002b, ApJ, 580, 413
Stella, L., et al. 1994, ApJ, 433, L47
Tavani, M., & Arons, J. 1997, ApJ, 477, 439
Tavani, M., & Brookshaw, L. 1991, ApJ, 381, L21
Titarchuk, L. 1994, ApJ, 434, 570
Van Paradijs, J., Verbunt, F., Shafer, R. A., & Arnaud, K. A. 1987, A&A, 182, 47
Welsh, W. F., Robinson, E. L., & Young, P. 2000, AJ, 120, 943
Wijnands, R. 2002, in ASP Conf. Ser. 262, The High Energy Universe at Sharp Focus: Chandra Science, ed. E. M. Schlegel & S. B. Vrtilek (San Francisco: ASP), 235
Wilms, J., Allen, A., & McCray, R. 2000, ApJ, 542, 914