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Letter to the Editor

An XMM-Newton observation of IGR J16320−4751 = AX J1631.9−4752

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Abstract. The hard X-ray sensitivity and arcminute position accuracy of the recently launched International Gamma-Ray Laboratory (INTEGRAL) has lead to the (re-)discovery of a class of heavily absorbed hard X-ray sources lying in the Galactic plane. We report on the analysis of an XMM observation of such a source IGR J16320−4751 = AX J1631.9−4752. Our analysis allowed us to obtain the most accurate X-ray position to date (Rodriguez et al. 2003), and to identify a likely infrared counterpart (Tomsick et al. 2003). We present the detailed analysis of the IGR J16320−4751 XMM spectra. The PN spectrum can be well represented by a single powerlaw or a comptonized spectrum with a high equivalent absorption column density of $\sim 2 \times 10^{23}$ cm^{-2}. The current analysis and the comparison with the properties of other sources favor the possibility that the source is a Galactic X-Ray Binary (XRB). The identification of two candidate IR counterparts is in good agreement with this identification. The hard spectrum previously seen with ASCA, and the brightness of the candidate counterparts indicate that IGR J16320−4751 is most probably a highly absorbed High Mass X-ray Binary, hosting a neutron star.

Key words. accretion, accretion disk – stars: individual: IGR J16320−4751 – X-rays: binaries – X-rays: general

1. Introduction

The International Gamma-Ray Laboratory (INTEGRAL) has been launched on October 17, 2002. Since then, the high sensitivity and position accuracy of the IBIS imager has allowed for detections and determinations of arcminute positions for faint hard X-ray sources (e.g. IGR J16318−4848, Courvoisier et al. 2003; IGR J16358−4726, Revnivtsev et al. 2003, in addition to IGR J16320−4751). It is interesting to note that these sources belong to a class of highly absorbed low luminosity X-ray sources, which renders their detection in the soft X-rays (≤10 keV) difficult. In fact, some of them were missed with the All Sky Monitors of past X-ray missions, especially those sensitive in the 1−10 keV spectral range. As a result, these sources have remained poorly studied until the advent of INTEGRAL, and there may be many more than previously realized. In that view the IBIS/ISGRI detector on board INTEGRAL appears perfectly suited since it works in a spectral range (≥15 keV) not affected by absorption. Once such a source is detected, given the good position accuracy of the IBIS/ISGRI detector, it is possible to use highly sensitive soft (1−10 keV) X-ray telescopes, such as XMM-Newton or CHANDRA, to 1) obtain a more precise position and allow for counterpart search, and 2) obtain a soft X-ray spectrum and try to identify the type of the source. Such studies should then allow for a better understanding of the nature of these highly absorbed sources and the physics underlying the emission/absorption processes (e.g. Revnivtsev et al. 2003b).

IGR J16320−4751 was detected on Feb. 1.4 UT (Tomsick et al. 2003a), as a hard X-ray source with the IBIS/ISGRI detector (Lebrun et al. 2001) on board INTEGRAL at $\mathrm{RA_{J2000}} = 16^{\mathrm{h}}32^{\mathrm{m}}\!.0$, $\delta_{\mathrm{J2000}} = -47°51'$ (±2′), during an observation of the Galactic Black Hole Candidate (BHC) 4U 1630−47 (PI Tomsick). The source was observed to vary significantly in the 15−40 keV energy range on time-scale of ∼1000 s, and was detected in some occasions above 60 keV (Tomsick et al. 2003a). This source has a position consistent with that of AX J1631.9-4752, which was observed with ASCA in 1994, and 1997. The ASCA spectrum was fitted with a powerlaw with a hard photon index (0.2 ± 0.2, Sugizaki et al. 2001), which may suggest that the source belongs to the High Mass X-ray Binary (HMXB) class. Analysis of archival BeppoSAX-WFC data revealed that this source was persistent for at least 8 years (in't Zand et al. 2003). Their 2−28 keV spectral analysis shows a quite different result, since they obtain a soft photon index (2.5 ± 0.3) for the powerlaw. This evolution and the persistence of the source may indicate the presence of an absorbed

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XRB. Two possible infrared counterparts have been identified (Tomsick et al. 2003b).

We report here the detailed spectral analysis of an XMM public Target of Opportunity (ToO) observation of IGR J16320−4751, and compare it to the former observations of the source. In Sect. 2 we provide details about the XMM observation and data reduction methods that were employed for the analysis. We describe the spectral analysis in Sect. 3, and present results on the time variability of the source in Sect. 4. The infrared counterparts will be discussed in Sect. 5, and the results of our analysis will be discussed in the last section of this paper.

2. XMM data reduction and analysis

IGR J16320−4751 was observed with XMM-Newton on March 4, during a public ToO pointing on the INTEGRAL position that started around 21 h UTC. The data were processed using the Science Analysis Software v.5.4.1. Images were then obtained both from the EPIC MOS (Turner et al. 2001) and EPIC PN (Strüder et al. 2001) cameras. The EPIC-PN was operating in imaging mode with large window and a medium filter, the EPIC MOS2 in imaging mode with a full window and a medium filter. The EPIC-MOS1 was operating in timing mode (medium filter). During the processing, the data were screened by rejecting periods of high background, and by filtering the bad pixels. Correction for vignetting (Lumb 2002) has not been applied, because the source is close to the center of the field of view (<2′). One source was detected by the MOS2 within the 1 arcmin INTEGRAL error circle. The source position (obtained following the procedures given in the Introduction to XMM-Newton Data Analysis[1]) is $\alpha_{J2000} = 16^h\ 32^m\ 01.9^s$ and $\delta_{J2000} = -47°\ 52'\ 29''$ ($\pm4''$ at the 90% confidence level, Rodriguez et al. 2003). It should be noted that this position is also consistent with the ASCA (at 0.4′ from the XMM position with an uncertainty of 1′), and BeppoSAX (at 0.7′ from the XMM position, uncertainty of 1.7′) positions of AX J1631.9−4752.

Due to soft proton flares during this observation, the MOS2 data are not usable for spectral and timing analysis, and only ∼4.9 ks out of a total of 25 ks are exploitable for scientific (spectral and timing) studies with the PN camera. The spectrum and light curve for the source were extracted from a circular region centered on the source with a radius of 45″ (which gives an encircled energy fraction of about 85%). The background spectrum and light curve were extracted from a source free region, with a radius of 2 arcmin. The response matrices were generated with the SAS package (arfgen, rmfgen). The spectrum was grouped with a minimum of 25 counts per channels and was fitted with the XSPEC v11.2 package.

3. Spectral studies

The PN spectrum was fitted with different models. In a first run, only single component models were tested. An absorbed powerlaw gives a good representation of the spectrum, with a reduced χ^2 of 0.81 (Rodriguez et al. 2003 and Fig. 1). An absorbed blackbody or disc blackbody give acceptable fits, with a reduced χ^2 of 0.81 (bbody) and 0.83 (diskbb), but the temperature returned from the fits ($kT = 2.1$ keV for the bbody and 3.8 keV for the diskbb) is a bit higher (especially for the diskbb component) than what is observed in general for accreting compact objects, even during the high luminosity states where a thermal component contributes strongly to the spectrum (see Tanaka & Shibazaki 1996 for a review). Furthermore, the detection of the source at higher energies (≥15 keV, Tomsick et al. 2003a) indicates the need for an additional component to account for this hard part. A comptonized spectrum (comptt, Titarchuk 1994) gives a good representation of the spectrum, with a reduced χ^2 of 0.83. The spectral parameters are not well constrained, however, if they are all left free. Fixing the electron temperature to 10 keV (which is an reasonable value, Barret 2001), leads to a reduced χ^2 of 0.84, with spectral parameters compatible with what is commonly observed in accreting neutron stars (Table 1 and Barret 2001). Since both models are strongly correlated to N_H, the 68% and 90% confidence intervals are shown in Fig. 2, for the photon index and the absorption column density.

We have re-analysed the publicly available ASCA data, and fitted the SIS and GIS energy spectra simultaneously in

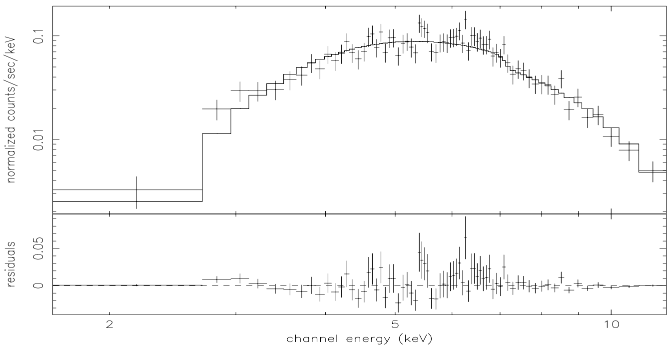

Fig. 1. EPIC-PN spectrum of IGR J16320−4751 and residuals to the absorbed powerlaw model.

Table 1. Spectral fit parameters. The given fluxes are corrected for an encircled energy fraction of 85%. The errors are the 1σ confidence level.

Power-law Model	
N_H	$21^{+4}_{-1} \times 10^{22}$ cm^{-2}
Γ	$1.6^{+0.2}_{-0.1}$
χ^2	55.9 (69 d.o.f.)
2−10 keV unabsorbed flux	1.7×10^{-11} erg/s/cm^2
Comptt	
N_H	$14 \pm 2 \times 10^{22}$ cm^{-2}
kT_{seed}	$1.6^{+0.5}_{-0.3}$ keV
kT_e	10 keV fixed
τ	≤3.35 (3 σ)
χ^2	56.2 (68 d.o.f.)
2−10 keV unabsorbed flux	1.1×10^{-11} erg/s/cm^2

[1] Snowden et al. http://xmm.vilspa.esa.es/external/xmm_sw_cal/sas_frame.shtml

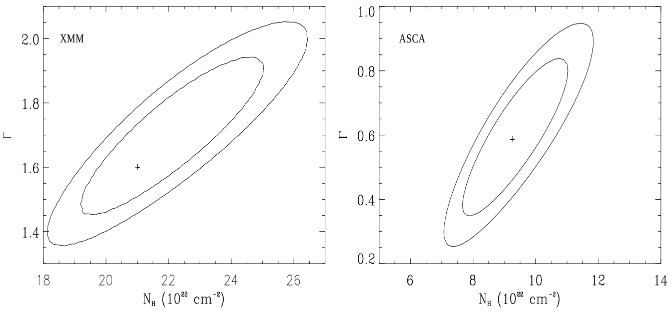

Fig. 2. Left: error contours for the column density (N_H), and the photon index (Γ) obtained from the XMM-Newton observation. The cross marks the location of the best fit values, and the 68% ($\Delta\chi^2 = 2.30$) and 90% ($\Delta\chi^2 = 4.61$) contours are shown. **Right:** same plot for the ASCA observation.

XSPEC, with a simple model of an absorbed powerlaw. Our best result gives an equivalent absorption column density of $N_H = (9.2 \pm 1.1) \times 10^{22}$ cm^{-2}, and a photon index of ~0.6 ± 0.2 (errors at 1σ), somewhat softer than that obtained by Sugizaki et al (2001). The error contour plot is shown in Fig. 2, allowing for a direct comparison with that of the XMM observation. The BeppoSAX spectrum was fitted with an absorbed powerlaw of photon index 2.5, and $N_H = 20 \times 10^{22}$ cm^{-2} (in't Zand et al. 2003).

4. Timing behavior

The PN light curve is displayed in Fig. 3. The source shows variability on a time scale of ~50−100 s. A slow decrease and a period of relatively quiet emission is first observed until ~2000 s. Then, the source undergoes two flares: the first starts at 2000 s after time 0 (begining of the good time intervals), reaches its maximum about 300 s later. The flux increases by a factor of 2.3 in the mean time. This flare lasts for ~900 s. The second flare starts around 3050–3100 s, and reaches the maximum around 3450 s, the flux increases by a factor of ~3.3, during this time. A third flare may start around 4500 s, but our observation stops soon after, and does not allow us to follow it.

We produced light curves in two different energy bands (2−5 keV and 5−12 keV, Fig. 3), and the hardness ratio between these two. The flare episodes occur in the two ranges in a similar manner (Fig. 3). With the time binning of 200 s, the flux increases by a factor of ~4 between 2 and 5 keV, and ~3 between 5 and 12 keV during a time interval of 400 s (first flare), and by a factor of ~3 between 2 and 5 keV, and ~2 between 5 and 12 keV during 400 s (second flare)[2] This similarity indicates that the flares are related to broadband flux increase rather than variations of the absorption (since the hard band would be much less affected in this case). The hardness ratio does not show significant changes between the low flux periods and the flares. The same behavior is observed if the light curves are produced in other energy bands (e.g. 2−3 keV and 2−4 keV).

[2] Note that the differences of the variation rates compared to those of the total range light curve, are simply due to the different time binnings used for the light curves.

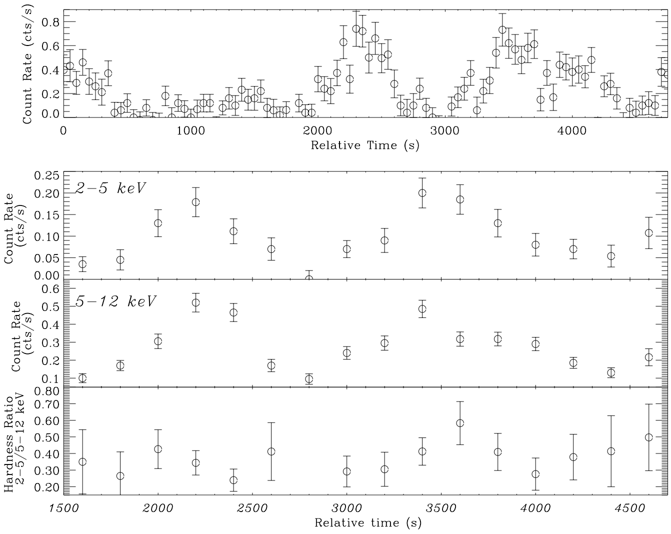

Fig. 3. Upper panel: 0.5–12 keV PN light curve of IGR J16320−4751 measured after background subtraction. The time sampling is 50 s, which shows the fast rise during the flare episodes. The lower panels represent a zoom on the region of the flares (starting around relative time 1500 s). The 2–5 keV, 5–12 keV and hardness ratio between 2–5 and 5–12 keV are shown. The time sampling is 200 s.

We searched for pulsations and quasi-periodic oscillations in the power spectra of the source. However, the low counting statistics and short exposure time does not enable us to obtain strong constraints. Indeed taking into account a net average counting rate of 0.22 cts/s for the source, and 0.16 cts/s for the background, during a 4.8 ks observation, leads to a 3σ upper limit on the amplitude of a periodic signal between ~5 mHz and 10 Hz (where the power spectrum is dominated by Poissonian noise) of 12.25%. The 3σ upper limit for QPOs is higher than this value in the given frequency range (due to the non-zero width of the QPO).

5. Infrared counterpart

From the improved position obtained with XMM−Newton (Rodriguez et al. 2003), two candidate infrared counterparts have been identified (Tomsick et al. 2003b, Fig. 4). The first one is located at $\alpha_{J2000} = 16^h\,32^m\,01^s.75$, $\delta_{J2000} = -47°\,52'\,28''.9$ (1″ uncertainty) with magnitudes[3] $K_s = 10.99 \pm 0.03$, $H = 13.03 \pm 0.04$, $J > 14.08$ (97 % confidence). The second source ($K_s = 10.82 \pm 0.04$, $H = 11.24 \pm 0.03$, $J = 12.13 \pm 0.02$) is on the southeast edge of the X-ray error circle. From the Palomar Observatory Sky Survey (POSS) epoch I and II, we can derive $R > 21$ for the first source, and $R = 14.6$ (±0.3, 1σ error POSS epoch I, period 1949–1965) and $R = 15.4$ (±0.3, 1σ error POSS epoch II, period 1985–2000), for the second one (note that the evidence for variability is only marginal). To estimate the equivalent absorption column density along the line of sight we used a web-based tool that uses data from Dickey & Lockman (1990). For the position

[3] the magnitudes come from the "2MASS All-Sky Point Source Catalog" http://www.ipac.caltech.edu/2mass/

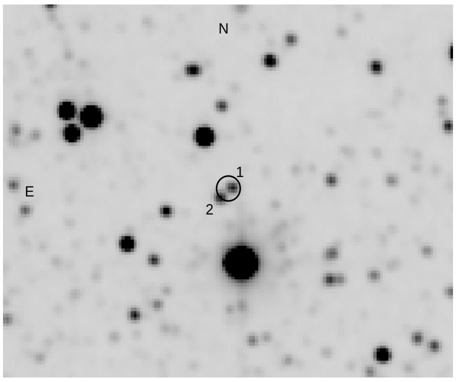

Fig. 4. 2-MASS K-band $2.5 \times 2'$ image of IGR J16320−4751 field, the XMM error circle is superimposed. One can clearly see the two possible counterparts. 1 stands for the most probable one, and 2 for the second.

of IGR J16320−4751, the average value is $\sim 2.1 \times 10^{22}$ cm^{-2}. Then, assuming $A_V = 5.6 \times 10^{-22} \times N_{\rm H}$ (Predehl & Schmitt 1995), we derived $A_V = 11.7$. With this value, we can calculate the dereddened fluxes in the three bands, and compare them to tabulated objects. The second source appears to be a star with a peak in the J band. The colors $(J - H) = 0.9$ and $(H - K) = 0.4$ are typical for a M−type star with a temperature around 3000 K.

With this visual extinction, the first source, the faintest and most probable counterpart, presents some very interesting features. The dereddened flux increases toward radio wavelenghts (from J to K band) and the colors $(J - H) > 3.1$ and $(H - K) = 2.0$ suggest an infrared excess that is likely to be due to circumstellar matter (probably hot plasma or warm dust). However, the absorption column density along the line of sight may be different from this value. The $N_{\rm H}$ returned from XMM spectral fits leads to an extinction of $A_V = 106$, giving a dereddened $K_{\rm s}$ magnitude close to 0 for both objects. In addition, some molecular clouds and inhomogeneities in the ISM can make the A_V increase. If, for example, we take a value of $A_V = 30$ (i.e. $N_{\rm H} = 5 \times 10^{22}$ cm^{-2}), the dereddened magnitudes would suggest a K-giant or supergiant, rendering the object more usual. Furthermore, the wavelength dependence of the interstellar extinction is poorly constrained when studying sources close to the Galactic ridge. We thus cannot exclude other types for the companion star. We remark for example that the color, and magnitude of the second candidate counterpart could indicate a high mass star (O or B spectral type).

6. Discussion

From their analysis of ASCA data, Sugizaki et al. (2001) suggested that AX J1631.9−4752 was an HMXB with a pulsar, given the flat spectrum they obtained. Our best model, a powerlaw or a comptt spectrum, is also consistent with the source being a Galactic XRB. A comptonized spectrum would not be surprising for such an object, but alone it is not a sufficient argument since extragalactic sources have similar X-ray spectra. For a distance range of 5−15 kpc (the latter giving an upper limit on the distance for the object to be Galactic), the powerlaw model leads to unabsorbed 2−10 keV isotropic luminosities of 0.5−4.5×10^{35} erg/s, which may be compatible with the observe luminosity of either a neutron star or a black hole in a low hard state. The spectral parameters we obtain are also compatible with those commonly observed for this kind of objects (e.g. Tanaka & Shibazaki 1996). The persistence of the source over 8 years (in't Zand et al. 2003), and the evolution of the spectral parameters resembles the spectral transitions seen in XRBs.

It is interesting to note the similarities of IGR J16320−4751 with the persistent X-ray source 1E 1743.1−2843 whose primary type is still a matter of debate. Both sources are persistent, heavily absorbed, and undergo XRB-like spectral transitions between hard states (Porquet et al. 2003), and softer ones (Cremonesi et al. 1999). Although for 1E 1743.1−2843 the neutron star hypothesis could not be ruled out, Porquet et al. (2003) have suggested that this object might be a black hole in a hard state. In the case of IGR J16320−4751, the BeppoSAX and XMM observations alone would rather indicate a persistent black hole undergoing spectral transitions between hard states and softer ones. However, the low value of the photon index during the ASCA observation, and its large variations between ASCA (Sugizaki et al. 2001), BeppoSAX (in't Zand et al. 2003), and XMM (current study) observations are rather unusual for a black hole. On the other hand, such very hard photon indices and large variations (from 0 to 2.4) have already been observed in the neutron star system Sco X−1 (D'Amico et al. 2001), but also in some other sources (Sugizaki et al. 2001). In addition, the powerlaw model gives extrapolated 1−20 keV luminosities (between 5−15 kpc), of 0.93−8.4×10^{35} erg/s, and extrapolated 20−200 keV luminosities of 0.23−2.1×10^{36} erg/s (the comptt model leads to slightly lower values). With these values, the source would lie in the neutron star box in Fig. 1 of Barret et al. (1996). The relatively good fit obtained with the comptt model is compatible with a Comptonization of soft photons on hot electrons surrounding the compact object. However, the lack of data above 12 eV, does not allow us to obtain a good constraint on the cutoff energy. The detection of hard emission with INTEGRAL (Tomsick et al. 2003a) appears in good agreement with a comptonized spectrum. The hard photon index obtained during the ASCA observation, however, is not easy to understand in the framework of thermal Comptonization.

The identification of the infrared counterpart remains difficult given the proximity of the two candidates. The faintest one (number 1 in Fig. 4), however, is more likely related to the X-ray source. This candidate could either favor a reprocessing of high energy photons by a cloud or some dust, or the emission from a supergiant or K-giant star depending on the visual extinction on the line of sight. Both hypothesis are in good agreement with the high absorption obtained from the X-ray spectrum, and the spectral parameters obtained from our fits, which are similar to those observed in the case of HMXB (e.g. GX 301−2, Saraswat et al. 1996, 4U1700−37, Boroson et al. 2003), although we do not detect lines in IGR J16320−4751 with a 3σ upper limit on the equivalent width of a narrow 6.4 keV Iron (emission) line of 112 eV. The position of IGR J16320−4751 in the Galactic plane, and along a spiral arm (the Norma arm), a region of star formation, where a number of young (massive) stars can be found, appear in good agreement with the system being an HMXB. It is interesting to note the change of equivalent absorption density between the different observations, (from $\sim 9 \times 10^{22}$ cm^{-2} to $\sim 20 \times 10^{22}$ cm^{-2}). This strongly favors an absorption intrinsic to the source, similar to what observed in heavily absorbed sources (e.g. Revnivtsev et al. 2003 and reference therein). In the case of a Galactic XRB, the absorption could be due to the accretion flow, and the changes could be associated with variations of the accretion rate.

Although the source appears more likely to be a Galactic XRB (given its similarities with known neutron stars or black holes XRB) we can not exclude totally an extragalactic source, e.g. an ULX seen through the Galactic plane. Assuming a typical luminosity of 10^{40} erg/s (Foschini et al. 2002), the simple power law model would lead to a distance to the source of about 2.2 Mpc. Although compatible with an extragalactic origin, this hypothesis appears not to be favored given such a short distance. Longer X-ray observations and more multiwavelength studies (e.g. infrared spectra), should allow for more precise answers to all the above mentioned points. Note that a better X-ray position would be useful to select a unique IR counterpart, allowing for a better understanding of the nature of the source.

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References

Barret, D., McClintock, J. E, & Grindlay, J. E. 1996, ApJ, 473, 963
Barret, D. 2001, Adv. Space Res., 28, 307
Boroson, B., Vrtilek, S. D., Kallman, T., & Corcoran, M. 2003, ApJ, submitted [astro-ph/0303277]
Courvoisier, T., Walter, R., Rodriguez, J., et al. 2003, IAUC, 8063
Cremonesi, D. I., Mereghetti S., Sidoli L., Israel G. L. 1999, A&A, 345, 826
D'Amico, F., Heindl, W. A., Rotschild, R. E., et al. 2001, Adv. Space Res., 28, 389
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Foschini, L., Di Cocco, G., Ho, L. C., et al. 2002, A&A, 392, 817
in't Zand, J. J. M, Ubertini, P., Capitanio, F., Del Santo, M. 2003, IAUC, 8077
Kong, A. K. H., McClintock, J. E., Garcia, M. R., et al. 2002, ApJ, 570, 277
Lebrun, F., et al. 2001, Proceedings of the 4th INTEGRAL Workshop, ed. A. Gimenez, V. Reglero, & C. Winkler
Lumb, D. H. 2002, Proc. Symp. New Visions of the X-ray Universe in the XMM-Newton and Chandra Era, ed. F. Jansen, ESA SP488 [astro-ph/0203278]
Predehl, P., & Shmitt, J. H. M. 1995, A&A, 293, 889
Porquet, D., Rodriguez, J., Corbel, S., et al. 2003, A&A, 406, 299
Revnivtsev, M., Turler, M., Del Santo, M., et al. 2003, IAUC, 8097
Revnivtsev, M., Sazonov, S., Gilfanov, M., & Sunyaev, R 2003b, Astr. Lett., accepted [astro-ph/0304353]
Rodriguez, J., Tomsick, J. A., Foschini, L., et al. 2003, IAUC, 8096
Saraswat, P., Yoshida A., Mihara T., et al. 1996, ApJ, 463, 726
Strüder, L. et al. 2001, A&A, 365, L18
Sugizaki, M., Mitsuda, K., Kaneda, H., et al. 2001, ApJS, 134, 77
Tanaka, Y., & Shibazaki, N. 1996, ARA&A, 34, 607
Titarchuk, L. 1994, ApJ, 434, 313
Tomsick, J. A., Lingelfelter, R., Walter, R., et al. 2003a, IAUC, 8076
Tomsick, J. A., Rodriguez, J., Foschini, L., et al. 2003b, IAUC, 8096
Turner, M., et al. 2001, A&A, 365, L27