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ASCA X-ray observations of the Galactic bulge source SLX 1735-269

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Abstract. SLX 1735−269 is among the 10 persistent, high energy, SIGMA sources which contribute significantly to the last five year averaged γ/X-ray emission from the direction of the Galactic Center. Detailed study of the source has only been carried out recently from data collected by SIGMA in the 35-150 keV range without successfully establishing the nature of SLX 1735−269, consequently observations with ASCA from 0.6-10 keV were performed with the aim of determining the nature of this source. The spectrum of SLX 1735−269 can be described by a powerlaw-absorber model, of photon index ~ -2. No period was determined from the data by epoch folding in the range 10 to 1000 s nor from a power spectrum analysis in the range 125 ms to 64 s and upper limits to pulsation are derived. Yet the nature of SLX 1735−269 remains to be determined.

Key words: X-rays: stars - individual: SLX 1735-269 – gamma rays: observations

1. Introduction

In the soft γ-ray band of the SIGMA telescope aboard *GRANAT*, 16 out of some 60 previously known X-ray sources have been detected in the direction of the Galactic Bulge. Six exhibit transient behaviour and thus have a negligible impact on the long term averaged γ/X-ray emission from this region (Vargas et al. 1996, Goldwurm et al. 1994, Churazov et al. 1994). SLX 1735−269 is one of the remaining ten which are, instead, characterized by "persistent" high energy emission. Within this group, some sources show temporal variations (burst or pulsations) while others, also through analysis at other wavelengths, are suspected to be associated with blackholes (1E 1740.7-2942 and GRS 1758-258). However, the physical nature of SLX1735−269 remained unknown. In order to evaluate what type of object is associated with SLX1735−269, a low energy spectrum was obtained using the ASCA telescope and the results of these observations are reported here.

SLX 1735−269 was first detected in the range 3-30 keV in 1985 in a survey performed by Skinner et al. (1987) during the *Spacelab 2* mission. This source was later observed between October 1988 and February 1992 by the TTM telescope in the energy band 2-28 keV (Int 't Zand 1992). The TTM spectra were modeled by a thermal bremsstrahlung with a plasma temperature of 11^{+8}_{-3} keV. The total integrated flux was given as 5.5 10^{-10}ergs cm^{-2}s^{-1}. Although the TTM results did not show any significant variability, the reported flux level is roughly twice that obtained by the *Spacelab 2* XRT, $\sim$ 2.3 10^{-10}ergs cm^{-2}s^{-1}. Further observations from 1990 March 24 to 1992 April 7 between 4-20 keV with the ART-P telescope resulted in a total averaged flux of $\sim$ 2.7 10^{-10}ergs cm^{-2}s^{-1}, close to that measured by *Spacelab 2* (Pavlinsky et al. 1994). SLX 1735−269 was first detected by the SIGMA telescope above 35mCrab in 1992 in the 35-150 keV band (Goldwurm et al. 1996). Spectral fits by a simple powerlaw yield a photon index of -2.87 $\pm$0.23 while a thermal bremstrahlung resulted in a plasma temperature of 53^{+12}_{-10} keV. The SIGMA data showed no significant long term variations.

2. Observations and data analysis

SLX 1735−269 was observed by the ASCA satellite on 1995 March 15. The observing instruments on ASCA consist of four identical thin foil mirrors which focus X-rays onto two Solid-state Imaging Spectrometers (SIS) and two Gas Imaging Spectrometers (GIS). The GIS observed in the PH mode where the on board CPU calculates the event position and discards background events using rise time and positional information. SIS data was acquired at a high bit rate and in the Faint data mode, i.e. the pixel position of the center of the event is given along with the pulse height recorded in the nine surrounding pixels. The data were converted to bright mode using the same algorithm as used on the spacecraft. Only one of the four CCD chips available in the SIS sensor was exposed. Screening of bad events was

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Table 1a. Best fit parameters to spectra for powerlaw plus absorber model

Det	N_H (*a*)	photon index	*F* (*b*)	χ^2_ν
SIS0	1.44 (± 0.017)	-2.16 (± 0.016)	9.02 (± 0.20)	1.61
SIS1	1.49 (± 0.020)	-2.14 (± 0.019)	8.93 (± 0.23)	1.16
GIS2	1.42 (± 0.028)	-2.13 (± 0.021)	8.13 (± 0.24)	1.19
GIS3	1.54 (± 0.027)	-2.17 (± 0.019)	8.79 (± 0.25)	1.21
mean	1.47 (± 0.023)	-2.15 (± 0.019)	8.72 (± 0.23)	

(*a*) equivalent hydrogen column ($\times 10^{22}$ atoms)
(*b*) Flux at 1 keV in units of 10^{-2} photons cm^{-2} s^{-1} keV^{-1}

Table 1b. Best fit parameters to spectra for bremsstrahlung plus absorber model

Det	N_H (*a*)	kT_e (*c*)	*G* (*d*)	χ^2_ν
SIS0	1.16 (± 0.012)	4.85 (± 0.095)	3.18 (± 0.07)	1.43
SIS1	1.21 (± 0.014)	4.99 (± 0.118)	3.13 (± 0.08)	1.35
GIS2	1.06 (± 0.020)	5.71 (± 0.148)	2.49 (± 0.07)	1.52
GIS3	1.13 (± 0.019)	5.58 (± 0.131)	2.61 (± 0.07)	1.70
mean	1.16 (± 0.017)	5.12 (± 0.108)	2.90 (± 0.18)	

(*c*) in keV
(*d*) Gaunt factor at 1 keV $\times 10^{-2}$
319 d.o.f. for the SIS and, 202 d.o.f. for the GIS detectors in both Tables 1a and 1b.

performed using the ASCA GOF recommended values (Day et al. 1995). The minimum elevation angle was set to 10 for both the SIS and GIS instruments.

2.1. Spectral analysis

Spectra for each instrument were extracted from circular regions centered on the source. The radii of these regions were $\sim 4'$ for the SIS and $\sim 6'$ for the GIS images. Background spectra were obtained from a region of the same size using the background files made available by ASCA GOF. Because the diffuse X-ray emission from the Galactic ridge is high towards the position of SLX1735−269 (e.g. Koyama 1994), the GIS background used was checked against the background obtained from a source free region in the GIS image. In this latter case, background spectra were extracted from an annulus centered on the source within which source emission is absent. No notable effects were seen due to diffuse emission; spectra obtained by subtracting one or the other background gave statistically equal results when compared.

The sensitivity of the GIS instrument is more than 10% of its maximum value in the energy range of 0.8-12 keV. However, because no good calibration data base above 10 keV is available for ASCA, GIS spectral analysis was restricted to 0.8-10 keV. The pass band used for the SIS data was 0.6-10 keV, this avoids the O K-edge in the SIS response but the Al and Si K-edges, along with the Au M-edge, due to the instrument are present in the 2-3 keV region. However, no obvious absorption features due to the source are discernible in this region so detailed analysis was not necessary between 2-3 keV. The models employed in fitting the data were a powerlaw, a thermal bremsstrahlung, and a comptonization spectrum (Sunyaev and Titarchuk 1980).

Absorption by the interstellar medium was modeled using the photoelectric absorption cross-sections of Morrison & McCammon (1983). Best fit parameters for the powerlaw and thermal bremsstrahlung are summarized in Table 1. The χ^2_ν are relatively high but this is probably due to imprecise calibration at lower energies. The powerlaw model plus absorber provides a more satisfactory fit to the data although only at a level of a few percent. To fit the comptonization spectrum, the electron temperature was fixed at 26 keV following the results from SIGMA (Golwurm et al. 1996) and the resulting optical depth was ~ 3 in agreement with that obtained for the SIGMA data. This can be clearly seen in Fig. 1 where the best fit comptonization plus absorber model is plotted along with the ASCA and SIGMA data and if the SIGMA points are renormalized by a factor of $\sim 1/3$. The jump between the ASCA and SIGMA spectra might be due to the fact that the latter is averaged over several years. On the date of the ASCA observation the SIGMA telescope was not operating in pointing mode. On this occasion SLX 1735−269 might have been in a "low" state (see Fig. 2 of Goldwurm et al. 1996). The comptonization model fits the data to within the same confidence level as the powerlaw. In the same figure is plotted for comparison the best fit thermal bremsstrahlung model obtained from the TTM experiment.

The K-iron emission line centered at ~ 6.4 keV and typically with equivalent width ≥ 100 eV and intrinsic line width $\sigma \leq 0.5$ keV frequently observed in the spectra of binary pulsars (Nagase 1989) does not appear in the data. In fact, a fit between $\sim$ 4-10 keV by a powerlaw plus gaussian line, centered at 6.4 keV with σ = 0.1 and 0.5, model does not reveal this feature nor show any significant improvement to a simple powerlaw fit. Upper limits to the equivalent line width have been determined, using the SIS data, assuming a gaussian line shape, by fixing σ and varying the intenstity until χ^2_ν became unacceptable in an F-test at a confidence level of 95%. For σ = 0.1 the equivalent line width is ~ 150 eV while for σ = 0.5 it is ~ 340 eV.

2.2. Source position

The source position was derived from the SIS images which provide a more reliable position than the GIS. Indeed, the SIS images are solely limited by the point spread function and the SIS focal plane calibration is more accurate than that of the GIS (Gotthelf 1996). ASCA situates SLX 1735−269 at R.A. = 17h 35m 8.9s, Dec. = -26° 57.87′ (equinox 1950) with error radius of 40″. This position is compatible with the original position from *Spacelab 2* (Skinner et al. 1987), the Einstein source 1ES 1735-26.9, (Elvis et al. 1992), the SIGMA position, (Goldwurm et al. 1996) as well as with the *Rosat* PSPC catalogue position (Zimmermann 1994). The recently available *Rosat All-Sky Survey Bright Source Catalogue (1RXS)* position, R.A. = 17h 35m

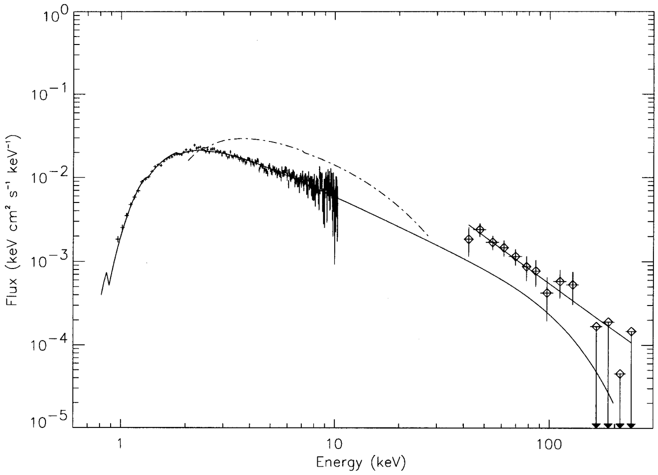

Fig. 1. Spectrum of SLX 1735−269 obtained from the GIS3 detector and the corresponding best fit Sunyaev-Titarchuk plus absorber model. The SIGMA data is also plotted, circles, along with the corresponding best fit powerlaw model. The dot dashed line represents the best fit bremsstrahlung plus absorber model derived from the TTM data.

9.43s, Dec. = -26° 57′ 58.4″ with an error box of radius 8″ (Voges W. et al. 1996) falls within the ASCA determination. All these X-ray sources are undoubtly the same object.

2.3. Timing analysis

The data were submitted to a timing analysis employing the epoch folding method described by Leahy et al. (1983). The GIS data has a higher time resolution than the SIS (62.5 ms and 4s respectively) with roughly equal integration time. Data from both instruments was submitted to the timing analysis separately. The number of bins chosen was 10. The original GIS arrival times were binned into 1 s intervals. Because a pulsation period has never been determined for SLX 1735−269, an attempt was made to limit the number of trials. The protocol followed was: first a systematic period search was effected on the arrival times from the GIS2 detector in the range 10 to 1000 s and, from the SIS0 detector over 40-1000 s. Any possible detection at a confidence level ≥90% was noted and, then checked for, using the data from the GIS3 or SIS1 detector in order to confirm that period. Proceeding as above, no periodic behaviour was found for SLX 1735−269 in the range searched. Assuming a sinusoidal pulse profile of amplitude A, the instantaneous count rate is written as, $r(t) = r_0[1+A\sin(\omega t+\phi)]$. Upper limits for the parameter A, not accounting for background counts and imposing a confidence level for detection and sensitivity greater than 90%, are listed in Table 2.

When binned into 1s intervals, the GIS data does not easily allow period searches below 10s by epoch folding because, in this case, too few photons per phase bin would result. Likewise, the SIS data only permitted period searches above $\sim$ 40 s. Thus, to search for periods in the millisecond to second range a more appropriate method is provided by Fourier analysis. The method applied here is detailed in Leahy et al. (1983). A total of 225 continuous sections of length 64 s, within a total time span, including gaps, of 43036 s from the GIS3 detector were analyzed to obtain the total power spectrum. Imposing a confidence level for detection of 90%, no pulsation period was found. The upper limit to pulsations in the period range 125 ms to 64 s is listed in Table 2. Pulse periods for binary X-ray pulsars range from $\sim$ 0.07 to $\sim$ 1500 s with roughly two thirds of known pulsars having a period exceeding 10 s (Nagase 1989, Mereghetti et al. 1996). Solitary neutron stars have periods less than one second, at most a few seconds. Thus a fairly reasonable range of possible periods was searched.

Table 2. Upper limits to pulsation A

	GIS2 (a)	SIS0 (a)	GIS3 (b)
total time ($\times 10^4$)	4.9407	4.9216	4.3036
integration time ($\times 10^4$)	1.5733	1.7436	1.4400
number of photons	45492	62493	55114
number of periods searched	17676	18800	1024
range (s)	10-1000	40-1000	0.125-64
A ($\times 10^{-2}$)	3.53	3.56	5.75 (c)

more periods were searched in the SIS0 data due to overlap.
(a) epoch folding.
(b) FFT
(c) quoted value is $A\sin(x)/x$, where $x = \pi j/N$, N being the total number of bins which is twice the number of periods searched (see Leahy et al. 1983).

3. Discussion and conclusion

The photon index obtained by SIGMA, -2.87 ± 0.23, is more consistent with those of binary neutron star systems rather than with blackhole candidates such as 1E1740.7-2942 or GRS 1758-258. The derived mean photon index from ASCA, -2.15 ± 0.019 is markedly higher. It is softer than that expected for accretion-powered pulsars (APP), the majority of which have photon indices between -1.5 and -0.8 (Nagase 1989) although some can present rather soft spectra, as e.g. 4U1258-61 with a photon index of ~ -2 between 1 and 60 keV (White et al. 1983) close to that of SLX 1735−269, 1E 2259+586 with a photon index of ~ -3.7 in the 1.5-5 keV region has an extremely steep spectrum (Koyama et al. 1987). The K-iron emission feature at 6.4 keV displayed by most APPs is absent in the spectrum of SLX 1735−269. Thus the observed spectral characteristics do not follow the general trend of those of APPs. Furthermore, no rotational period was found, expected unless SLX 1735−269 has its magnetic and rotational axii aligned, further weakening the APP hypothesis.

The column density measurements are consistent with a source location situated close to the Galactic center. Thus, if a distance of 8.5 kpc is assumed, the X-ray luminosity of SLX 1735−269 is $\sim 3\ 10^{36}$ erg s^{-1}. Assuming such a low luminosity excludes SLX 1735−269 from the class of high-luminosity low mass X-ray binaries (LMXRB) which have typical luminosities of $\sim 10^{38}$ ergs s^{-1}. Moreover, the spectra of these systems exhibit a blackbody component accounting for 10% - 70% of the total luminosity (White et al. 1988). The addition of blackbody emission to the spectral model for SLX 1735−269 does not improve the fits to the ASCA data. The derived upper limit to blackbody emission at 3 keV is found to be only $\sim 5\ 10^{34}$ ergs s^{-1}, i.e. at most 2% of the total luminosity. But SLX 1735−269 might also be another type of LMXRB, namely an "X-ray burster" since all the results of the spectral analysis are compatible with this hypothesis. Moreover, SLX 1735−269 is among the 11 soft γ-ray sources within the Galactic bulge detected by SIGMA of which 50% are LMXRB bursters. However, the light curve of SLX1735−269 shows no signature of burst activity, evidence for which was also not observed either by ART-P or TTM. This tends to weaken the case for an X-ray burster, but the data present a number of gaps and the integration time over which data have been collected might have been too short to allow the detection of bursts.

An unambiguous association with a companion star would settle the binary nature of SLX 1735−269. A search in the SIMBAD data base of sources within $2'$ of the ASCA position did not reveal any convincing associations with SLX 1735−269 at other wavelengths since the error boxes associated with the four objects found do not intersect those of ASCA and *Rosat*. The high column density obtained from the ASCA data implies strong absorption along the line of sight (typically $A_V \sim 7$ e.g. Gorenstein and Tucker 1976) and thus an optical counterpart for SLX 1735−269 will be difficult to detect, especially in such crowded regions of the Galaxy. However, thanks to the small error box associated with the *Rosat All-Sky Survey* position, meaningfull optical/IR observations are now possible, particularly in the I and K bands for which extinction is lower. Considering a distance modulus of 14.6 for SLX 1735−269, even setting an upper limit to the visual magnitude of ∼18-21 would effectively exclude a high mass early type companion (e.g. Chen et al. 1994, Mereghetti et al. 1992).

The lack of long term variability reported by TTM and SIGMA points to a more stable system. Thus, the possibility that SLX 1735−269 is an isolated pulsar powered by its rotational energy loss should also be explored. SLX 1735−269 is not listed among the 706 radio pulsars in the catalogue of Taylor et al. (1993). The few radio pulsars observed in the X-ray domain (only 16, see Caraveo 1995), have photon indices falling between -4 and -1 (Mereghetti et al. 1994). The young pulsar PSR 1951+32 has a photon index of -1.9 in the 0.05-6 keV region close to that of SLX 1735−269. Unfortunately no data is available at higher energies. Only three isolated pulsars have been detected in the hard X and soft γ-rays, namely PSR 1509−58, the Crab pulsar and Vela. The photon indices obtained for these are -1 (Laurent et al. 1994), ~ -2 (Ulmer et al. 1994) and -1 (Hermsen et al. 1993) respectively. No data between 2 and 60 keV is available for the Vela pulsar, for the other two, very young, isolated neutron stars, there is no significant break between the soft and hard X-ray spectra and broken powerlaw fits do not provide an improved model to their spectra, in contrast to SLX 1735−269 where a break appears to occur in the interval 12-35 keV. But the paucity of X-ray data on isolated pulsars makes it difficult to conclude that all isolated neutron stars have spectra discribed by a single powerlaw. Note that PSR 1509−58 and the Crab pulsar do not exhibit line emission at 6-7 keV. Although no rotational period of less than a few seconds was found, it can still be argued that SLX 1735−269 is an isolated neutron star on the basis of the spectral data.

The spectrum of SLX 1735−269 displays characteristics which can be attributed both to binary or isolated pulsars, however, the derived upper limits to pulsations tend to disfavour the pulsar hypothesis. The possibility that this source is an X-ray burster is left open. Based on the available data to date, the nature of SLX 1735−269 still remains elusive. To further elucidate to what category this object belongs, more data must be collected.

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