A&A 452, 431–437 (2006)
DOI: 10.1051/0004-6361:20054207

Astronomy & Astrophysics

Supersoft sources in *XMM-Newton* Small Magellanic Cloud fields*

A symbiotic and a close binary or cooling neutron star

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Received 15 September 2005 / Accepted 10 February 2006

ABSTRACT

We report the detection and study of two faint *ROSAT* supersoft X-ray sources in the SMC field with *XMM-Newton*, RX J0059.1−7505 and RX J0059.4−7118. Due to the larger effective area of *XMM-Newton* we can constrain the X-ray spectra of both sources. RX J0059.1−7505 is optically identified with the symbiotic LIN 358 in the SMC. A ∼20 eV blackbody component dominates the observed spectrum. The soft blackbody component is consistent with steady nuclear burning in a shell although the spectrum is more complex than a simple blackbody continuum. RX J0059.4−7118 is not optically identified and we derive with the Optical Monitor (*OM*) a *V* magnitude $\gtrsim$19.3 assuming an M0 spectral type. The X-ray spectrum is fitted with a blackbody component with a temperature of ∼90 eV and an additional spectrally hard component which can be reproduced with a powerlaw. The luminosity of RX J0059.4−7118 would be $\sim 4 \times 10^{34}$ erg s^{-1} at the distance of the SMC. This is too large for a Cataclysmic Variable (CV). The spectral appearance is not in agreement with a supersoft source in the SMC. Thus we suggest that RX J0059.4−7118 is a Galactic source. As the optical magnitude derived from the *OM* data may be too faint for a normal Galactic CV we examined the possibility that RX J0059.4−7118 is a polar CV in the Galaxy, an isolated cooling neutron star (INS) at distance ∼(1−2) kpc, a pulsar with a brown dwarf companion, or a Galactic quiescent low-mass X-ray binary (qLMXB). We favor the hypothesis of a Galactic CV because of variability in the *EPIC-pn* data with a timescale of ∼1 h. A third supersoft *ROSAT* source, RX J0050.5−7455, is not detected with *XMM-Newton*.

Key words. Magellanic Clouds – X-rays: stars – stars: binaries: general – binaries: close – stars: neutron – stars: general

1. Introduction

The first supersoft X-ray sources (SSS) CAL83, CAL87, and 1E0035.4-7230 were discovered with the Einstein satellite in the fields of the Magellanic Clouds (Long et al. 1981; Seward & Mitchell 1981). During the *ROSAT* all-sky survey (*RASS*) additional SSS were found in the Magellanic Clouds and the first SSS were discovered in the Galaxy (Trümper et al. 1991; Greiner et al. 1991; Beuermann et al. 1995; Motch et al. 1994; see also Kahabka & Trümper 1996; Kahabka & van den Heuvel 1997). With *ROSAT*, *XMM-Newton* and *Chandra* several (candidate) SSS were found in more than 10 external galaxies (Di Stefano & Kong 2003, 2004; see also Kahabka 2005).

Although accreting black hole and neutron star models at the Eddington limit have been proposed in the beginning, the steady nuclear burning white dwarf (WD) model introduced by van den Heuvel et al. (1992) was worked out most extensively and was supported by many observational studies. The steady nuclear burning model which can also apply to a post-nova stage (e.g. Pietsch et al. 2005) is the most favored model for SSS presently. A SSS was defined to have basically no observed counts above 0.5 keV in the *ROSAT PSPC* detector. This is consistent with the emission of hot WD atmospheric models. Hot steady nuclear burning WD models can also produce somewhat harder spectra (e.g. Starrfield et al. 2004). In addition a spectrally harder emission component may contribute to the X-ray spectrum (e.g. colliding winds in a symbiotic binary or shocks in nova ejecta). Some Galactic objects show an additional spectrally hard component (RR Tel, Jordan et al. 1994 and Nova Cyg 1992; Krautter et al. 1996). Such a component is too faint to be observed with *ROSAT* in more distant SSS like the Magellanic Cloud SSS. Due to the large effective area of *XMM-Newton* a faint spectrally hard component may be detected in some of the Magellanic Cloud SSS.

It is also known that other types of sources show blackbody like spectra with temperatures typical of a SSS but with a considerably lower luminosity (e.g. INSs, Becker & Pavlov 2001). The optically identified INSs are nearby as they are optically faint. So far no INS was known in the direction of the Magellanic Clouds. Also Galactic foreground polars have a very soft blackbody like component. Several faint SSS in the fields of the Magellanic Clouds which were poorly studied and were not identified optically (Haberl et al. 2000; Kahabka 2002), were observed with *XMM-Newton* in an effort to reveal their characteristics. Here we report on the study of three such objects in the field of the SMC, RX J0059.1−7505, RX J0059.4−7118, and RX J0050.5−7455.

2. *XMM-Newton* observations of the RX J0059.1–7505, RX J0059.4–7118, and RX J0050.5–7455 fields

We were granted *XMM-Newton* (Jansen et al. 2001) observing time during the AO2 guest observer program for the SMC pointings towards RX J0059.1−7505, RX J0059.4−7118,

* Based on observations with XMM-Newton, an ESA Science Mission with instruments and contributions directly funded by ESA Member states and the USA (NASA).

Table 1. *XMM-Newton* EPIC observations.

Target	Instrument	Read-out Mode	Filter	Sat. Revol./ Obs.-ID	Observation Date	Start	End (UT)	Exp. [ks]
RX J0059.1−7505	EPIC-MOS1/2	FF, 2.6 s	Thin	721	Nov. 16/17, 2003	21:49	03:03	18.7
	EPIC-pn	FF, 73 ms	Thin	0142660401		22:12	03:04	17.0
RX J0059.4−7118	EPIC-MOS1/2	FF, 2.6 s	Thin	721	Nov. 17, 2003	03:55	09:09	12.2
	EPIC-pn	FF, 73 ms	Thin	0142660801		04:18	09:09	11.8
RX J0050.5−7455	EPIC-MOS1/2	FF, 2.6 s	Thin	721	Nov. 16, 2003	16:55	21:10	15.1
	EPIC-pn	FF, 73 ms	Thin	0142661001		17:19	21:10	13.4

and RX J0050.5−7455. We used data collected with the European Photon Imaging Camera based on a pn (*EPIC-pn*, Strüder et al. 2001) CCD detector, mounted behind one of the three X-ray telescopes (Aschenbach et al. 2000). We also used data from the *EPIC-MOS* (*EPIC-MOS1* and *EPIC-MOS2*, Turner et al. 2001) CCDs of sources RX J0059.1−7505 and RX J0059.4−7118 detected during the observations. The observations are summarized in Table 1.

Tools from the XMM-Newton analysis software SAS version 6.5 were used to generate event files and to calculate effective area and redistribution matrices for the *EPIC-pn* (and *EPIC-MOS*) data which were used for spectral fitting. In the case of the *EPIC-pn* analysis we created the event files using "epchain" with the parameter screenlowthresh = 0 to also include events below 150 eV which is important for very soft sources. For the extraction of the spectra we use single and double pixel events to increase the statistics at higher energies (the contribution of double pixel events to the soft components which we see in the spectra described below is negligible, but increases with energy). Background spectra were extracted from circular regions near the source at similar distance to the readout node of the EPIC-pn detector (similar RAWY detector coordinates) to avoid variations in the detector electronic noise which is an important background contribution at the lowest energies. We performed spectral fits using XSPEC v11.3.2 and utilized energies down to 130 eV for EPIC-pn data. The soft X-ray calibration source RX J1856.5−3754 shows a perfect blackbody-fit down to this energy, although the calibration of the spectral response of the EPIC-pn is less certain at energies below ~200 eV. Source net count rates were derived for EPIC-pn from the energy spectra in the given energy bands. *OM* data (Mason et al. 2001) were used to determine (constrain) the countrate and flux in the optical.

2.1. RX J0059.1–7505, the symbiotic star LIN 358

RX J0059.1−7505 was found by Mürset et al. (1997) to be a SSS which coincides in position with the symbiotic SMC star LIN 358. X-ray emission of LIN 358 was also marginally detected by Bickert et al. (1996) with a maximum likelihood ratio of 4.5 ($\approx 2.5\sigma$) in *RASS* data. RX J0059.1−7505 is classified in the catalog of Haberl et al. (2000) as a SSS.

RX J0059.1−7505 was observed with *XMM-Newton* on Nov. 16/17, 2003. From a maximum likelihood source detection analysis we derived an *EPIC-pn* position of RA (J2000) = $0^h59^m12\overset{s}{.}3$, Dec (J2000) = $-75°5'17''$. The positional error is $2''$ including $1\overset{''}{.}5$ systematic astrometric error (*XMM-Newton* User's Handbook Sect. 1.1.1) which improves the *ROSAT* position with an error of $20''$ (Haberl et al. 2000).

We extracted the source and background counts within circular regions with radii of $20''$. We applied a blackbody + bremsstrahlung spectral model to the data modified by Galactic absorption (using Galactic elemental abundances, Anders & Grevesse 1989) and absorption in the SMC (assuming metallicities 0.2 times Galactic). In the direction of RX J0059.1−7505 the Galactic foreground $N_{\rm H}$ is 3.7×10^{20} cm^{-2} and the total SMC $N_{\rm H}$ 3.0×10^{20} cm^{-2} (Brüns et al. 2001). Keeping the Galactic foreground $N_{\rm H}$ fixed we determine best-fit SMC $N_{\rm H}$, effective blackbody temperature $kT_{\rm bb}$, blackbody radius $R_{\rm bb}$ and the absorbed and unabsorbed fluxes (Table 2). We stress that the unabsorbed flux for the very soft spectrum is strongly dependent on the $N_{\rm H}$ value, which is subject to systematic errors and the choice of the spectral model. To estimate the systematic uncertainty of the $N_{\rm H}$ value we performed spectral fits starting at different lower energies between 0.13 and 0.20 keV. We find best-fit $N_{\rm H}$ values between 0 and 4×10^{20} cm^{-2} (and best-fit $kT_{\rm bb}$ values between ~20 and ~24 eV), which leads to an uncertainty in the unabsorbed flux by a factor of 10. In addition, using more detailed WD atmosphere models Heise et al. (1994) found that the blackbody model can overestimate the luminosity by typically a factor of 10. Due to the insufficient energy resolution we restrict our spectral analysis of the soft spectrum to the blackbody model. We force all spectral parameters to be the same for the spectra from the three instruments, *EPIC-pn*, *EPIC MOS1* and *MOS2*, except relative normalizations. The spectra with the best-fit model are shown Fig. 1. The low statistics in the MOS spectra does not influence the spectral parameters.

Table 2. *XMM-Newton* EPIC spectral fit results for RX J0059.1−7505.

Parameter[a]	Unit	Value[b]
	blackbody + bremsstrahlung	
Net exposure	s	15463
Count rate (0.13–1.0 keV)	cts s^{-1}	0.139 ± 0.004
$N_{\rm H}^{\rm gal}$	10^{20} cm^{-2}	3.7 (fixed)
$N_{\rm LMC}$	10^{20} cm^{-2}	3.9 ± 0.6
$kT_{\rm bb}$	eV	19.6 ± 2.6
flux$^{\rm abs}$	erg cm^{-2} s^{-1}	1.92×10^{-13}
flux$^{\rm unabs}$	erg cm^{-2} s^{-1}	2.51×10^{-10}
$L^{\rm unabs}$	erg s^{-1}	1.0×10^{38}
$R_{\rm bb}$	cm	$1.6 \pm^{0.6}_{0.3} \times 10^{10}$
$kT_{\rm brems}$	keV	2 (fixed)
flux$^{\rm abs}_{\rm brems}$	erg cm^{-2} s^{-1}	2.64×10^{-15}
flux$^{\rm unabs}_{\rm brems}$	erg cm^{-2} s^{-1}	3.82×10^{-15}
$L^{\rm unabs}_{\rm brems}$	erg s^{-1}	1.6×10^{33}
$\chi^2_{\rm red}$		1.2
d.o.f.		35

[a] Fluxes and luminosities are given for the 0.1–10 keV range. A distance of 60 kpc to the SMC is assumed. [b] 90% confidence errors are given.

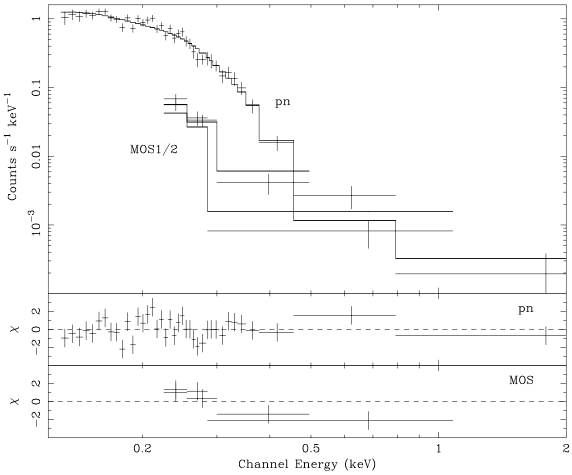

Fig. 1. *Upper panel*: *EPIC-pn*, *MOS1* and *MOS2* spectra of RX J0059.1−7505 together with the best-fit model as histograms. *Lower two panels*: residuals of the data compared to the model in terms of sigmas for *EPIC-pn* and *MOS*.

Although the bremsstrahlung component is very weak, it improves the spectral fit at energies above 0.5 keV. A single blackbody component yields a temperature of 20.0 ± 2.6 eV and a χ^2 of 47.1 for 36 degrees of freedom (DOF). Comparison of the two models (with and without bremsstrahlung component) yields an ftest probability of 0.084 to be spurious. Therefore, the existence of a hard emission component should be treated with caution. Because the low statistics does not allow us to determine the temperature, we kept the bremsstrahlung temperature fixed to 2 keV, a temperature which is consistent with the temperature of the spectrally hard component observed in the Galactic symbiotic nova RR Tel. The best-fit absorbed flux, unabsorbed flux and luminosity of the bremsstrahlung component is given in Table 2.

We used the *EPIC-pn* derived spectral parameters to simulate a *ROSAT PSPC* spectrum of RX J0059.1−7505. From this simulation we derive a *ROSAT PSPC* count rate of 0.081 s^{-1}, which is a factor of 2.9 larger than the count rate of $(2.76 \pm 0.12) \times 10^{-2}$ s^{-1} observed with the *PSPC* from this source. Despite calibration uncertainties at low energies in both instruments, this indicates that the X-ray flux of RX J0059.1−7505 during the *XMM-Newton* observation was larger than during the *ROSAT* observation.

We also detected the source in the *XMM-Newton OM U* band image at the *EPIC-pn* position. From the image with 5000 s exposure we derive in the area of the optical point-spread function a count rate of 0.88 cts s^{-1}. This converts to a *V* magnitude of 14.7 for an M0 spectral type (Sect. 3.5.6 of *XMM-Newton* User's Handbook).

2.2. RX J0059.4–7118, a candidate INS, qLMXB or polar detected with XMM-Newton

RX J0059.4−7118 was detected by Haberl et al. (2000) with *ROSAT* as a candidate SSS in the SMC field with a *PSPC* count rate of 0.003 s^{-1}. The object was observed with *XMM-Newton* on Nov. 17, 2003. We detect the source in the *EPIC-pn* data at a position RA (J2000) = $0^h59^m27\overset{s}{.}3$, Dec (J2000) = −71°18′28″ (positional error ∼2″).

We used *EPIC-pn* data and extracted the source counts within a circular radius of 15″. For the background region we used a radius of 25″. We removed time intervals of high background which occurred in particular during the second half of the observation. We used a blackbody + powerlaw spectral model to the data modified by Galactic absorption (using solar elemental abundances, Anders & Grevesse 1989).

Table 3. *XMM-Newton* EPIC-pn spectral fit results for RX J0059.4–7118.

Parameter[a]	Unit	Value[b]
	blackbody + powerlaw	
Net exposure	s	8243
Count rate (0.13–1.0 keV)	cts s^{-1}	0.016 ± 0.002
$N_{\rm H}$	10^{20} cm^{-2}	$1.3^{+5.2}_{-1.3}$
$kT_{\rm bb}$	eV	90 ± 29
D (for R = 20 km)	kpc	32^{+30}_{-19}
flux$^{\rm abs}$	erg cm^{-2} s^{-1}	8.7×10^{-14}
flux$^{\rm unabs}$	erg cm^{-2} s^{-1}	9.7×10^{-14}
Γ		$0.17^{+0.88}_{-0.44}$
flux$^{\rm abs}_{\rm bb}$	erg cm^{-2} s^{-1}	1.7×10^{-14}
flux$^{\rm unabs}_{\rm bb}$	erg cm^{-2} s^{-1}	2.7×10^{-14}
flux$^{\rm abs}_{\rm powl}$	erg cm^{-2} s^{-1}	7.0×10^{-14}
flux$^{\rm unabs}_{\rm powl}$	erg cm^{-2} s^{-1}	7.0×10^{-14}
$\chi^2_{\rm red}$		1.14
d.o.f.		8
	neutron star atmosphere + powerlaw	
$N_{\rm H}^{\rm gal}$	10^{20} cm^{-2}	$3.3^{+5.7}_{-3.3}$
D	kpc	$0.81^{+0.84}_{-0.62}$
log T$_{\rm eff}$		5.54 ± 0.26
flux$^{\rm abs}$	erg cm^{-2} s^{-1}	8.6×10^{-14}
flux$^{\rm unabs}$	erg cm^{-2} s^{-1}	1.3×10^{-13}
L (810 pc)	erg s^{-1}	1.0×10^{31}
Γ		$0.13^{+0.84}_{-0.65}$
$\chi^2_{\rm red}$		1.16
d.o.f.		8

[a] Fluxes and luminosities are given for the 0.1–10 keV range. [b] 90% confidence errors are given.

In the direction of RX J0059.4−7118 the Galactic foreground $N_{\rm H}$ is 2.3×10^{20} cm^{-2} and the total SMC $N_{\rm H}$ 2.1×10^{21} cm^{-2} (Brüns et al. 2001). We can derive only a 90% upper limit of 6.5×10^{20} cm^{-2} for $N_{\rm H}$ (for the best-fit parameters see Table 3), which does not allow us to constrain the distance of the object.

The blackbody norm given by XSPEC is $K = \frac{R^2_{\rm km}}{D^2_{10}}$, with $R_{\rm km}$ the radius in units of km and D_{10} the source distance in units of 10 kpc. If we constrain the absorbing column density towards RX J0059.4−7118 to be at the Galactic value of 2.3×10^{20} cm^{-2} then we derive $K = 39.8^{+233}_{-10.4}$. Assuming an upper limit for the radius of 20 km, we infer an upper limit for the source distance (keeping the Galactic absorbing column constant, Table 3). Such a distance is smaller than the distance to the SMC and a neutron star with a radius ≲20 km would be less distant than the SMC. For the powerlaw component we derive the photon index Γ. We also infer the absorbed (unabsorbed) best-fit flux of the blackbody component and the best-fit absorbed (unabsorbed) flux of the powerlaw component (Table 3). This gives an unabsorbed flux ratio blackbody to powerlaw of 0.39.

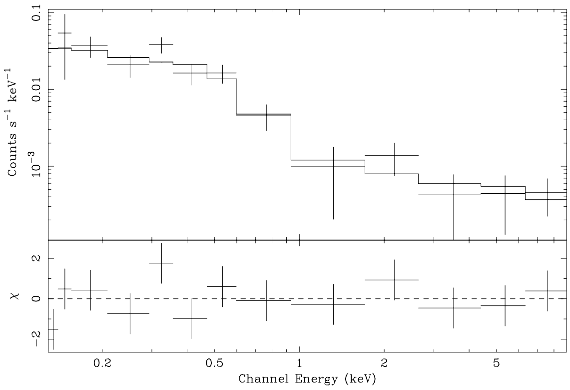

Fig. 2. EPIC-pn best-fit spectrum of RX J0059.4−7118 (*upper panel*). In the lower panel residuals of the data compared to the model in terms of sigmas are given.

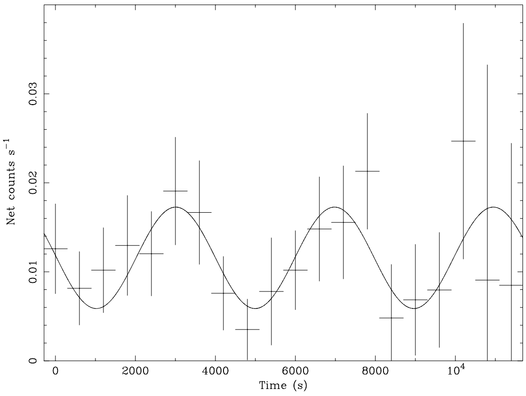

Fig. 3. Background subtracted *EPIC-pn* (0.14–2.0 keV) lightcurve of RX J0059.4−7118 with a binsize of 10 min. Also given is a sinusoidal modulation with a period of 66 min fitted to the data.

We also applied a neutron star atmosphere model (nsa in *XSPEC*, Zavlin et al. 1996) plus a powerlaw to fit the *EPIC-pn* spectrum of RX J0059.4−7118. We kept the neutron star mass fixed to 1.4 $M_{\odot}$ and the neutron star radius to 10 km and derive the distance to the neutron star, Galactic $N_{\rm H}$ as upper limit, the effective temperature of the neutron star atmosphere log $T_{\rm eff}$, absorbed flux and the unabsorbed flux and luminosity (for the best-fit distance). The best-fit model parameters are summarized in Table 3.

We investigated the *EPIC-pn* observation for source variability. We derived the binned and background subtracted source lightcurve. We choose a background circle which is well separated from the source circle and which has a radius three times larger than the radius of the source circle (Fig. 3). We do not screen for high background intervals because the lightcurve is dominated by emission at very low energies where the hard background flares do not contribute much.

There is variability seen in the lightcurve. A fit of a constant to the lightcurve gives a chi-squared of 15.3 for 20 degrees of freedom, while a fit of a sinusoidal gives a chi-squared of 5.7 for 17 degrees of freedom. The period of this sinusoidal modulation is 66^{+14}_{-7} min. This period is consistent with a peak of low significance in the region 50−70 min from a power spectral analysis. Although the quality of the data and length of the observation do not allow us to infer a periodic variability from this observation, it may indicate source variability with such a timescale.

In order to investigate whether the X-ray flux of the source did vary from the *EPIC-pn* to the much earlier *ROSAT PSPC* observation, we used the *EPIC-pn* derived spectral parameters to simulate a *ROSAT PSPC* spectrum of RX J0059.4−7118. From this simulation we derive a *ROSAT PSPC* count rate of 3.2×10^{-3} s^{-1}, which is consistent with the count rate of $(3.0 \pm 0.8) \times 10^{-3}$ s^{-1} observed with the *PSPC* from this source.

We also investigated the *XMM-Newton OM U* band image and did not find a source at the *EPIC-pn* position of RX J0059.4−7118. For the 5400 s exposure we derive in the area of the optical point-spread function a 3σ upper limit of 66.5 counts which gives a count rate of 1.23×10^{-2} s^{-1} and a V magnitude > 24.0 mag assuming a WD spectral type (*XMM-Newton* User's Handbook, Sect. 3.5.6). Assuming an M0 spectral type we infer a V magnitude >19.3 mag respectively. This estimate is consistent with a limiting magnitude of ~20 in the B and R band as constrained with the USNO-B1.0 catalog in the field of RX J0059.4−7118. We find a star from the Magellanic Cloud Photometric Survey (MCPS, Zaritsky 2002) at a distance of 3.7″ from the position of RX J0059.4−7118 with B = 21.5, V = 21.2, and I = 20.9. But we consider it as unlikely that this is the optical counterpart of RX J0059.4−7118 as other MCPS objects have positions which agree within ∼1″ with the positions of X-ray sources in the field of fiew of the same *XMM-Newton* observation.

2.3. RX J0050.5–7455, non detection and upper limits

RX J0050.5−7455 has been detected by Haberl et al. (2000) in the field of the SMC with the *PSPC* (64.4 ks exposure) as a candidate SSS with a count rate of $(2.1 \pm 0.3) \times 10^{-3}$ s^{-1}. The source was not detected in the 13.4 ks *EPIC-pn* observation. We derived a 3σ (equivalent to a maximum likelihood ratio of 5.9) upper limit source count rate of 1.5×10^{-3} s^{-1} (0.2–1 keV) from the sensitivity map (using the SAS task "esensmap").

Assuming for RX J0050.5−7455 the same *EPIC-pn* spectral parameters as for RX J0059.1−7505, we derived from the 3σ upper limit *EPIC-pn* count rate of RX J0050.5−7455 and the *EPIC-pn* count rate of RX J0059.1−7505 an upper limit *ROSAT PSPC* count rate of 9×10^{-4} s^{-1}, which is comparable to the count rate observed with the *PSPC*. This indicates that the *EPIC-pn* observation was less sensitive than the *PSPC* observation. No *OM* exposure was available at the position of the source.

3. Search for candidate SSS in the fields of other archival *XMM-Newton* observations

We also investigated 14 archival *XMM-Newton* pointed observations towards the SMC. We applied the standard detection procedure in 3 spectral bands and compiled the maximum likelihood source detection list. We inspected the *HR*1–*HR*2 diagram for extremely soft sources (with the hardness ratio $HRi = \frac{B_{i+1}-B_i}{B_{i+1}+B_i}$, $i = 1, 2$, with the counts in the PI channel ranges B_1 = 200−500, B_2 = 500−1000, and B_3 = 1000−2000). We simulated tracks in the *HR*1–*HR*2 plane by taking the Galactic foreground absorption and the total SMC intrinsic absorption from the Parkes H I map into account. We did not find any source from the *EPIC-pn* observations with *HR*1 $\lesssim$ 0.0 and *HR*2 $\lesssim$ −0.5, which would characterize a SSS. We note that RX J0059.1−7505 has *HR*1 = −0.99 and *HR*2 = −1.0. RX J0059.4−7118 has *HR*1 = −0.355 and *HR*2 = −0.379, the higher *HR*2 is consistent with a spectrally hard component in addition to a supersoft component. We checked for the known classical novae in the SMC field but none of these novae was contained in the observed *EPIC-pn* fields.

4. Discussion

4.1. The symbiotic LIN 358

LIN 358 is identified with a symbiotic binary in the SMC which is strongly variable on time scales of years (e.g., it was absent in the Henize 1956 survey). The cool component is a mid to late K type star (Mürset et al. 1996). The temperature and luminosity of the hot component was constrained from *HST* data to (1.5–1.75) × 10^5 K and (0.9–1.4) × 10^{37} erg s^{-1}. One explanation for the overabundance of N is a thermonuclear (nova) event (Vogel & Nussbaumer 1995).

The *XMM-Newton EPIC-pn* spectrum of LIN 358 can be fitted with a blackbody spectrum with a temperature of 2.3 ± 0.3 × 10^5 K and a bolometric luminosity of $4.7^{+6.7}_{-3.6} \times 10^{38}$ erg s^{-1}, which is much higher than the value inferred with *HST*. These values were derived assuming a blackbody type flux distribution. As a WD atmosphere spectrum is a better approximation to the observed spectrum and blackbody type spectra may overestimate the true bolometric luminosity by a factor of ∼10, the true luminosity of LIN 358 is probably lower.

LIN 358 is the second symbiotic system in the SMC with a supersoft spectrum in X-rays. The other SMC symbiotic system is SMC 3 which showed strong X-ray variability during *ROSAT* observations covering about 7 years which might be related to the orbital period (Kahabka 2004). LIN 358 has a mid to late K giant while the giant in SMC 3 is classified as M0. The blackbody temperature and luminosity derived from the *XMM-Newton EPIC-pn* spectral fit can be compared with the values expected from a steady nuclear burning WD in the Hertzsprung-Russell diagram (Mürset et al. 1996). A WD with a mass of ∼0.9 $M_\odot$ appears to be consistent with the evolutionary track (temperature and luminosity from the blackbody fit) of a symbiotic.

In a simple model we assume a binary orbital period of 1000 days. We assume for the donor a K8 giant with a mass of 0.9 $M_\odot$ and a radius of 190 $R_\odot$. The blackbody flux distribution inferred from the X-ray spectrum of LIN 358 and extrapolated into the UV may well explain the UV flux distribution observed with *HST* although the X-ray flux distribution has large uncertainties (in the bolometric luminosity and the exact spectral shape). In Fig. 4 we show a blackbody model with a temperature of 2.3 × 10^5 K and a bolometric luminosity of 4.7 × 10^{38} erg s^{-1} which can explain the X-ray flux distribution.

The contribution of an additional component like an accretion disk or a nebula in the UV cannot be excluded. A binary model with a giant donor can reproduce the *B* to *K* magnitudes observed from the symbiotic system. The lower X-ray flux during the *ROSAT* observation compared to the *XMM-Newton* observation could indicate that the spectral shape is not blackbody like. But we cannot exclude a change in the luminosity (and/or temperature) of the hot component.

The *V* magnitude derived with the *OM* is consistent with a 15–16 mag mid to late K spectrum (Mürset et al. 1996).

The *XMM-Newton EPIC-pn* spectrum can be reproduced with a supersoft and in addition a hard spectral component which is fitted with a bremsstrahlung model with a temperature of 2 keV (kept fixed) and a best-fit unabsorbed luminosity (0.1–10 keV) of 1.6 × 10^{33} erg s^{-1}. A similar spectrally hard component has been observed in the Galactic symbiotic nova RR Tel although with a much lower luminosity of ∼(2–4) × 10^{32} erg s^{-1} (Jordan et al. 1994). The origin of the spectrally hard component could be due to a colliding wind or due to shocks in the WD wind and/or ejecta.

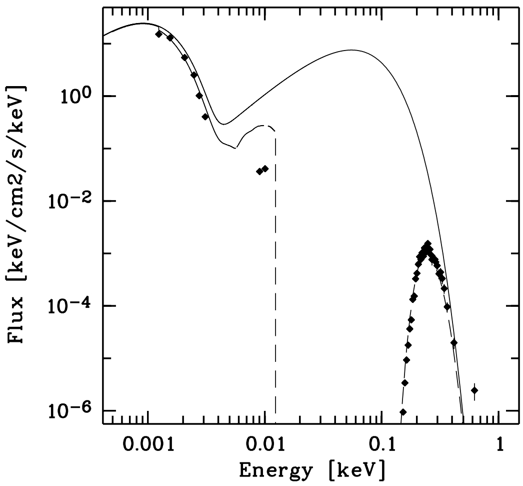

Fig. 4. Model spectrum of LIN 358 (WD with temperature 2.3 × 10^5 K and bolometric luminosity 4.7 × 10^{38} erg s^{-1} and giant donor) with the 2003 unfolded EPIC-pn spectrum, the blackbody model with a temperature of 1.75 × 10^5 K and a luminosity of 1.4 × 10^{37} erg s^{-1} derived from the 1994 *HST* observation and the 1993 optical data. The model spectrum corrected for extinction and X-ray absorption is shown with dashed line.

4.2. The candidate INS, qLMXB or polar RX J0059.4−7118

RX J0059.4−7118 has a low absorbing column density, a best-fit distance smaller than the distance to the SMC for an emitting region with a radius <20 km, and a composite spectrum with a supersoft blackbody spectrum and an additional hard spectral component which is not consistent either with a SSS or a (magnetic) CV at SMC distance. The unabsorbed luminosity of the spectrally hard component of ∼3 × 10^{34} erg s^{-1} is too large for a SSS at SMC distance, although it may be explained by a colliding wind or shocks in nova ejecta. For a CV the luminosity is far too large for SMC distance. Thus, unless RX J0059.4−7118 is an unusual type of SMC X-ray binary, these arguments are in favor of a Galactic object.

In order to evaluate the probability that an X-ray source without optical counterpart is observed, we compare this result with those of the deep *ROSAT* surveys like the Lockman Hole survey (e.g. Lehmann et al. 2001) and the RIXOS survey (e.g. Mason et al. 2000). While the Lockmann Hole survey covered only a small area of the sky (∼0.12 square degrees), it was quite deep (limiting flux ∼(1−10) × 10^{-15} erg cm^{-2} s^{-1}). The RIXOS survey covered an area of 15.8 square degrees and was less deep (limiting flux ∼3 × 10^{-14} erg cm^{-2} s^{-1}). For comparison the *ROSAT* SMC survey (Haberl et al. 2000) covered a field of ∼18 square degrees and had a limiting flux of ∼10^{-14} erg cm^{-2} s^{-1}. 5% of the X-ray sources in the Lockman Hole field are identified with stars and (4–8)% have no optical identification. About one M dwarf star per square degree with a flux in excess of 2 × 10^{-14} erg cm^{-2} s^{-1} is expected in the RIXOS survey. As the *ROSAT* SMC survey covered an area somewhat larger than that of the RIXOS survey the chance to cover a Galactic foreground source is accordingly somewhat higher. Interestingly, Schmidtke et al. (2002) optically identified one X-ray source in the LMC field (CAL 86 which is already known since *Einstein* observations) using *MACHO* data with a Galactic dwarf nova with a *V* magnitude of ∼19 mag and an outburst amplitude of 5 mag. Thus RX J0059.4−7118 could also be a Galactic CV. For RX J0059.4−7118 we derive with the *OM* for an M0 spectral type a considerably lower

V magnitude of >19.3 mag. Therefore we consider it as unlikely that the source is a normal Galactic CV. Although a distant magnetic CV cannot be completely excluded it appears unlikely as the high blackbody temperature of ~90 eV is atypical for a magnetic CV. As optical CVs with brown dwarf companions were found also such a type of CV cannot completely be excluded.

There remains the likely option that RX J0059.4−7118 is a Galactic INS. An INS nature would be supported by the fact that the X-ray luminosity of the source did not change significantly from the *ROSAT* to the *XMM-Newton* observation. Such INSs have X-ray spectra which show a blackbody-like and an additional powerlaw component in several cases (e.g. Zavlin & Pavlov 2003). For some INSs the powerlaw component extends into the optical regime and can explain the optical flux of the source (e.g. due to synchrotron emission). But there are INSs which have optical fluxes well below the powerlaw extension (e.g. Geminga, see Kargaltsev et al. 2005). The upper limit *V* band flux derived from the *OM* data is consistent with the extrapolated powerlaw from the X-ray band and cannot further constrain it.

In Fig. 5 we show the blackbody plus powerlaw model of RX J0059.4−7118 for the best-fit $\Gamma = 0.17$ and the 90% upper limit $\Gamma = 1.05$. Also shown is the upper limit *V* band flux derived from the *OM* data (equivalent to a powerlaw slope $\Gamma = 2.1$). The ratio of the luminosity (0.1–10 keV) of the powerlaw component to the total luminosity (blackbody + powerlaw, assuming the best-fit $\Gamma = 0.17$) is ~72% and larger than observed from other pulsars (e.g. this ratio is 7% for Geminga and ~1% for PSR B0656+14, Zavlin & Pavlov 2003). Comparison with the spectrum of Geminga (Zavlin & Pavlov 2003), shows that RX J0059.4−7118 is about a factor of 100 fainter, which puts it about a factor 10 more distant than Geminga assuming the same luminosity. For a distance to Geminga of 200 pc (Kargaltsev et al. 2005) we would obtain a distance to RX J0059.4−7118 of ~2 kpc. We can also estimate the distance if we apply a neutron star atmosphere model to the spectrally soft component (assuming a neutron star radius of 10 km). We infer a distance of $0.81^{+0.84}_{-0.62}$ kpc and a luminosity at a distance of 810 pc of 1.0×10^{31} erg s^{-1}.

A puzzle in the scenario of an INS is the variability seen in the source flux (Fig. 3). If this variability is real then it could be due to binarity. The variability time scale of ~1 h is quite short for a binary system containing a main-sequence star companion if it is the orbital period of the system (Politano 2004). If RX J0059.4−7118 would be an X-ray binary with a short orbital period of ~1 h, then it could be a CV with a substellar companion. As the upper limit *V* band flux inferred for RX J0059.4−7118 is low (V > 19.3), a CV containing an accretion disk would have to be distant. If it is a magnetic CV (polar) then the optical magnitude is far smaller and the system can be less distant. Comparison with the *V* magnitude of the polar EF Eri during its low-state ($V \approx 18.2$, e.g. Harrison et al. 2003 and assuming a distance to EF Eri of 113 pc) puts RX J0059.4−7118 at a distance of ≳190 pc. An upper bound of the distance to the source is ~3 kpc if the luminosity of the source does not exceed ~10^{32} erg s^{-1}. The blackbody temperature of ~90 eV of RX J0059.4−7118 is outside the range of blackbody temperatures observed for polars of ~(20−40) eV (Ramsay et al. 2004). Higher blackbody temperatures were derived from soft intermediate polars (cf. discussion in Rana et al. 2005). The ratio of the soft blackbody luminosity to the spectrally hard luminosity (total luminosity) is ~39% (~28%) and consistent with a polar (e.g. Ramsay et al. 1994; Ramsay & Cropper 2004). We note that such a ratio may not necessarily

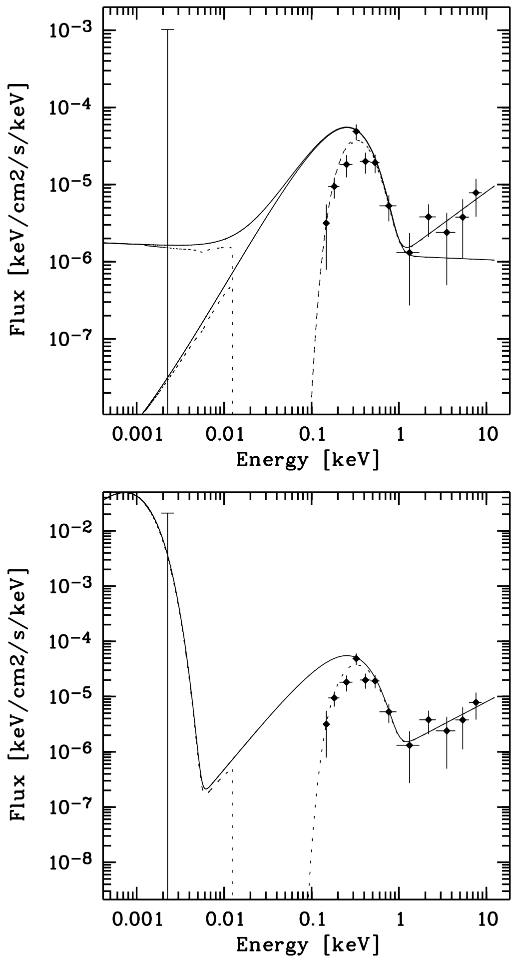

Fig. 5. Model spectra of RX J0059.4−7118 together with unfolded *EPIC-pn* spectrum. *Upper panel*: model spectra are shown for an INS with a blackbody and two powerlaw slopes $\Gamma = 1.05$ (*lower curve*) and $\Gamma = 0.17$ (*upper curve*). The assumed distance is 1 kpc. The model spectrum including extinction and X-ray absorption is shown as dotted line. Also the upper limit *V* band flux derived from the *OM* data is shown. *Lower panel*: model spectra are shown for a CV with a blackbody and a powerlaw slope $\Gamma = 0.17$ and a 0.07 $M_\odot$ sub-stellar companion with a radius of 0.1 $R_\odot$ and with an orbital period of 1.1 h, distance 500 pc.

require a low magnetic field like in EF Eri. The effective temperature of the soft component in RX J0059.4−7118 is much higher than in EF Eri.

There is still the possibility that RX J0059.4−7118 is a cooling neutron star with a brown dwarf companion. But the age of a cooling neutron star may be too low to be consistent with the radius of a brown dwarf if the orbital period is ~1 h (Politano 2004, Fig. 1). A much higher age of ~1 Gyr is required, consistent with millisecond pulsars containing a brown dwarf companion (e.g. SAX J1808-3658, Bildsten et al. 2001). There appears to be a third option to explain the observational appearance of RX J0059.4−7118 in terms of a Galactic qLMXB. For such qLMXBs indeed similar spectra were found, i.e. a soft blackbody and a hard powerlaw component (Heinke et al. 2005). The source W37 in 47 Tuc shows a blackbody like spectrum with an effective temperature of ~82 eV, derived with a neutron star atmosphere model. The luminosity of qLMXBs is in the range ~(0.5−1.0) × 10^{32} erg s^{-1}. We infer a distance to RX J0059.4−7118 of ~3 kpc assuming a blackbody and ~1 kpc assuming a neutron star atmosphere model for a luminosity of 10^{32} erg s^{-1}. The low *V* band flux requires a small orbital period and a low accretion rate which may also be consistent with a qLMXB. This is confirmed by the optical identification of another qLMXB in the globular cluster ω Cen (at a distance of ~5 kpc) with a faint blue object reminiscent of an accretion disk (Haggard et al. 2004).

Thus with the present quality of the observational data the nature of RX J0059.4−7118 cannot be clarified. In order to settle the nature of the source, the variability with a timescale of ∼1 h has to be confirmed and strengthened by future X-ray observations which cover several of these cycles.

5. Conclusions

We have observed three faint *ROSAT* detected SSS in the field of the SMC with *XMM-Newton*.

The first source, RX J0059.1−7505, is optically identified with the symbiotic LIN 358 in the SMC. The *XMM EPIC-pn* spectrum of the source is fitted with a blackbody spectrum with an effective temperature of ∼20 eV. We find that in comparison to the *ROSAT* observation the X-ray flux of RX J0059.1−7505 increased by a factor of ∼3. This could be due to orbital variability or a change in the temperature. If the UV HST spectrum is the lower energy portion of a blackbody, the bolometric luminosity of the hot component is $\sim 10^{38}$ erg s^{-1}. The blackbody temperature and luminosity of RX J0059.1−7505 are consistent with the parameters of a symbiotic. An additional spectrally hard component with a luminosity of $\sim 2 \times 10^{33}$ erg s^{-1} (which is statistically not very significant) may be due to a colliding wind and/or shocks in the WD wind or ejecta.

For the second source, RX J0059.4−7118, no optical counterpart was detected in the *OM* data (assuming a WD spectral type yields a limiting magnitude $V > 24.0$). The X-ray spectrum can be reproduced with a blackbody plus powerlaw component. The properties are in favor of a Galactic nature of the source. For comparison the short period Magellanic Cloud SSS RX J0537.3−7035 and 1E 0035.4−7230 have $V \sim 19.7$ and $V \sim 20.3$ (Greiner et al. 2000; van Teeseling et al. 1998). As the source is optically very faint a normal Galactic CV which has an accretion disk can be excluded. The relatively high blackbody temperature of ~90 eV is not consistent with temperatures inferred for magnetic CVs. The best-fit distance to the source, assuming a source radius of <20 km, would be smaller than the distance to the SMC which also favors a Galactic object. Thus an INS may be consistent with the X-ray and optical properties of RX J0059.4−7118. Assuming the same X-ray luminosity as observed from Geminga a distance to RX J0059.4−7118 of ~2 kpc is inferred. This would be consistent with the distance to the Galactic plane obtained for RX J0059.4−7118. Assuming a maximum age of 10^6 yr and a velocity of (100−1000) km s^{-1} a maximum distance to the Galactic plane of ~(0.1−1) kpc is obtained which would be consistent with a distance to RX J0059.4−7118 of (0.2−1.5) kpc.

The observed variability in the X-ray flux of RX J0059.4−7118 with a timescale of ∼1 h may be difficult to understand in this scenario if it is due to the orbital period of the system. The scenario of a cooling neutron star with a brown dwarf companion is unlikely as the radius of a brown dwarf with an age of the cooling neutron star of $<10^6$ years would be too large for such an orbital period. Alternatively RX J0059.4−7118 is a distant Galactic qLMXB (such as W37 in 47 Tuc, although it appears to be quite unlikely to observe such a rare object in the direction of the SMC). Due to the low accretion rate the system may be optically faint. It is more likely that RX J0059.4−7118 is a CV with a short orbital period and a stellar component at the lower end of the main-sequence. The constraint on the optical magnitude $V > 19.3$ would require a magnetic CV (polar) and a large distance of ≈(0.2−3) kpc. RX J0059.4−7118 thus could be a Galactic halo magnetic CV. This would be naturally explained by the evolutionary age of such a system of ∼1 Gyr. Assuming a stellar velocity of 5 km s^{-1} a maximum distance from the Galactic plane of 5 kpc is obtained, which puts the source into the Galactic halo. From the stellar evolutionary point of view it is also required that the system has an age of ∼1 Gyr as then the radius of the sub-stellar component is small enough to allow Roche lobe filling for such an orbital period.

A third *ROSAT* SSS, RX J0050.5−7455, is not detected with *XMM-Newton*.

Acknowledgements. The *XMM-Newton* project is supported by the Bundesministerium für Bildung und Forschung/Deutsches Zentrum für Luft- und Raumfahrt (BMBF/DLR), the Max-Planck-Gesellschaft and the Heidenhain Stiftung. We made use of the USNO-B1.0 catalog, Stephen Levine and Dave Monet, USNO Flagstaff. This research has made use of the VizieR catalog access tool, CDS, Strasbourg, France. We thank the referee for helpful comments.

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