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A multi-frequency identification study of the SMC X-ray binary AX J0049-732

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Abstract. We present a high-resolution multi-frequency identification study of the Small Magellanic Cloud (SMC) region around the newly discovered X-ray pulsar AX J0049-732. ROSAT PSPC images show three X-ray sources near the ASCA source position. We combine X-ray, radio-continuum and optical data to identify these sources. RX J0049.2-7311 and RX J0049.5-7310 did not show long-term time variability nor pulsations during the ROSAT observations and both are not detected in the radio. We identify RX J0049.5-7310 with an emission line star in the catalogue of Meyssonier & Azzopardi (1993). This catalogue contains several known Be/X-ray binaries strongly suggesting the ROSAT source as new Be/X-ray binary. RX J0049.5-7310 is therefore very likely the counterpart of the ASCA X-ray pulsar AX J0049-732. The third source RX J0049.1-7314 is associated with the supernova remnant (SNR) DEM S49 (B0047-735).

Key words: galaxies: Magellanic Clouds – ISM: individual objects: AX J0049-732, SNR B0047-735 – ISM: supernova remnants – stars: binaries: general – X-rays: galaxies

1. Introduction

Imanishi et al. (1998) reported coherent pulsations from a new ASCA X-ray source in the SMC named as AX J0049-732. They measured a pulse period of 9.1321±0.0004 s (observations made on 13 November 1997) from the source at RA(J2000)=$00^h49^m23^s$ and Dec(J2000)= $-73°12'38''$. The positional error from their observations is estimated to be $\sim 1'$ radius (at 90% confidence) and the X-ray flux at 2-10 keV was $\sim 8 \times 10^{-13}$ erg s^{-1} cm^{-2}.

This SMC region has been surveyed at Hα wavelengths by Davies et al. (1976) who named DEM S49 and classified it as a irregular shell with diameter of $4' \times 4'$. Bica & Schmitt (1995) classified DEM S49 using the ESO/SERC R and J Sky Survey as an SNR with a diameter of $2.'9 \times 2.'3$ (position angle = 45°).

The first X-ray source in this region were reported from the Einstein satellite observations. Inoue et al. (1983) detected an X-ray source, IKT 5, and due to positional coincidence (within the X-ray positional error) with DEM S49 they classified this source as SNR. SNR B0047-735 is also included in the Einstein SMC catalogues of Bruhweiler et al. (1987) and Wang & Wu (1992) as BKGS 2 and WW 22, respectively. Mathewson et al. (1984) investigated optical properties of this SNR. Two nearby extended X-ray sources were found in the ROSAT PSPC catalogue of Kahabka et al. (1999): RX J0049.0-7314 (source 68) and RX J0049.4-7310 (source 70). Also, this region was surveyed with the MOST radio telescope at 843 MHz (Turtle et al. 1998; Ye 1988). For more details of all these earlier observations see Table 1.

Haberl et al. (2000) produced an improved X-ray source catalogue based on the complete set of ROSAT PSPC pointed data of the SMC. It includes in particular an observation centered only $6'$ from AX J0049-732. This observation was not analyzed by Kahabka et al. (1999) and allows a study of the AX J0049-732 area with good spatial resolution. The catalogue contains three sources in the vicinity of the ASCA source indicating the complexity of X-ray emission in that area. Here, we present new results from ROSAT PSPC X-ray and Australia Telescope Compact Array (ATCA) radio-continuum studies of the region around AX J0049-732.

2. Observations and data analysis

2.1. X-ray data

The ROSAT archive contains several pointed PSPC and HRI observations centered close to the field of AX J0049-732. More details on the ROSAT mission can be found in Trümper (1982). The two nearest ROSAT PSPC (energy range 0.1–2.4 keV) observations which have best angular resolution were used in this study. For more details of the PSPC observations see Table 2. In Fig. 1 we show the ROSAT PSPC images ("hard1" energy range 0.5–0.9 keV and "hard2" energy range 0.9–2.0 keV) of the AX J0049-732 region. They were obtained by combining the two PSPC observations binned to $5''$ pixels and smoothed with a Gaussian sigma of $10''$ for better representation. Several ROSAT HRI observations were performed within the field of AX J0049-732 but larger offsets from the source and lower ex-

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Table 1. Details of previously reported sources in the region near AX J0049-732.

Source Name	Frequency	Instrument	RA (J2000) h m s	Dec (J2000) ° ′ ″	Reference
DEM S49	Hα	UK Schmidt 1.2m	00 49 16.8	–73 15 40	Davies et al. (1976)
DEM S49	R and J Band	ESO/UK Schmidt	00 49 03.1	–73 14 37	Bica & Schmitt (1995)
SNR B0047-735	Hα/[S II]	AAO 3.9m	00 49 03.1	–73 14 37	Mathewson et al. (1984)
B0047-735	Radio-843 MHz	MOST	00 49 04.1	–73 14 31	Ye (1988)
SMC B0047-7332	Radio-8550 MHz	Parkes	00 49 26.2	–73 16 30	Filipović et al. (1997)
IKT 5	X-ray	Einstein IPC	00 49 02.1	–73 13 54	Inoue et al. (1983)
BKGS 2	X-ray	Einstein IPC	00 49 11.9	–73 14 09	Bruhweiler et al. (1987)
WW 22	X-ray	Einstein IPC	00 49 06.5	–73 14 06	Wang & Wu (1992)
RX J0049.0-7314	X-ray	ROSAT PSPC	00 49 05.9	–73 14 06	Kahabka et al. (1999)
RX J0049.4-7310	X-ray	ROSAT PSPC	00 49 27.6	–73 10 53	Kahabka et al. (1999)
AX J0049-732	X-ray	ASCA	00 49 23.0	–73 12 38	Imanishi et al. (1998)

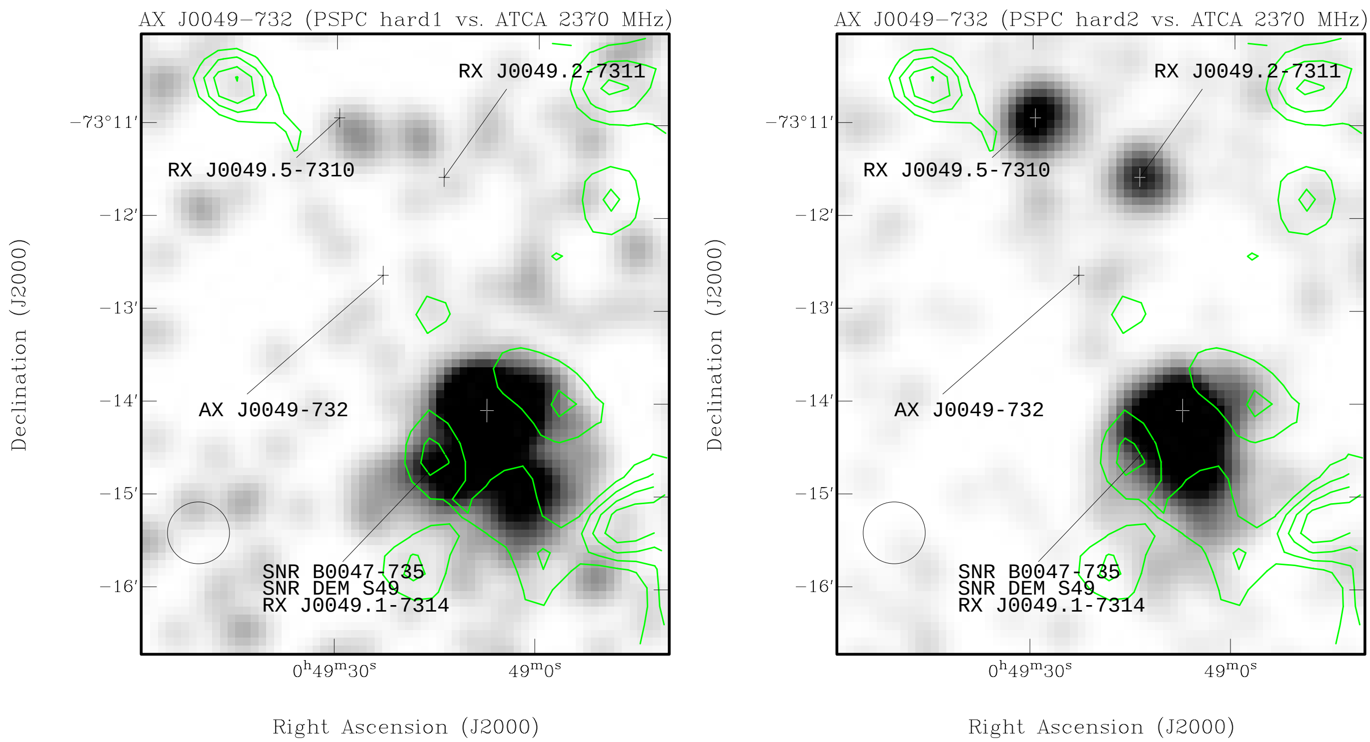

Fig. 1. ROSAT PSPC 0.5–0.9 keV (hard1) and 0.9–2.0 keV (hard2) images (gray-scale) of the region around AX J0049-732. Contours represent the radio continuum image at 2370 MHz. The synthesized beam of the ATCA observations is 45″ × 45″ (lower left corner) with r.m.s. noise (1σ) of 0.8 mJy. Contours are 5σ, 6σ, 7σ and 8σ

posure times did not allow deeper quantitative study than was obtained from the PSPC observations.

The ROSAT PSPC catalogue of the SMC of Haberl et al. (2000) contains three sources in the AX J0049-732 region which are marked in Fig. 1 and listed in Table 3 with properties taken from that catalogue. Source positions, RA and Dec, are given in J2000 coordinates. The statistical (90%) positional error is given in Column 4 (a systematic error of 7″ should be added). Count rate (0.1–2.4 keV, Column 5), source extent (Column 8) and hardness ratios (HR1) and (HR2) (Columns 6 and 7, respectively) are extracted from Haberl et al. (2000) where also their definitions can be found. X-ray sources with very hard spectrum are indicated by HR2 near 1.0. Few photons are detected in the soft band, causing relatively large errors on HR1. The distance to AX J0049-732 is given in Column 9.

2.2. Radio-continuum data

The region around AX J0049-732 was observed as part of the ATCA mosaic observations of the SMC with a baseline of 375 m at frequencies of 1420 and 2370 MHz with angular resolution of ∼ 90″ and 45″ (Table 2). Similar ATCA observations at 4790/8640 MHz were undertaken for specific regions of interest. More information about these observations can be found in Filipović & Staveley-Smith (1998; hereafter FS98). The radio

Table 2. Summary of new X-ray and radio-continuum observations of the region of AX J0049-732.

X-ray Obs. Date	Seq. Number	RA (J2000) h m s	Dec (J2000) ° ′ ″	Exp (sec)
15 April 1992	600196p	00 50 45	–73 13 48	23526
5 November 1993	500249p	00 46 40	–73 12 36	19262

Radio Telescope	Freq. (MHz)	Beam Size	rms Noise (mJy/b.a.)	Reference
MOST	843	45″	0.5	Turtle et al. (1998)
ATCA	1420	90″	0.8	FS98
ATCA	2370	45″	0.8	FS98
ATCA	4790	30″	0.5	FS98
ATCA	8640	15″	0.5	FS98

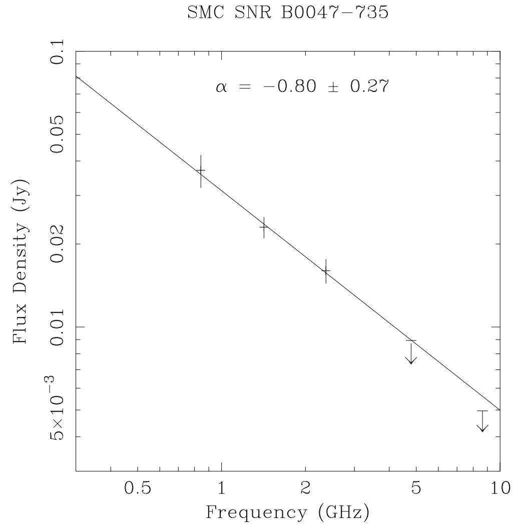

Fig. 2. The radio spectral index plot of SNR B0047-735 (DEM S49). Two points at 4790 and 8640 MHz represent flux upper limits and were excluded from the spectral index fit. The spectrum of SNR DEM S49 (α=–0.80$\pm$0.27) is steeper (but within error) than most of the Galactic SNRs (Green 1998) and other SMC SNRs (Filipović 1998)

contours of 2370 MHz observations are shown in Fig. 1. The MOST data used in this study were part of the SMC survey at 843 MHz (Ye 1988; Turtle et al. 1998).

A radio-continuum emission is detected south-east from the centre of the error region of AX J0049-732. The radio emission coincides with DEM S49 (Fig. 1) and we fitted one source, SNR B0047-735, in that area within a diameter of 100″. The flux density at a given radio frequency was determined as a sum of flux density in a box of $\sim$50″ from the center of SNR B0047-735. The integrated flux density at 843 MHz were estimated to be 37$\pm$5 mJy. Similarly, we estimate the SNR integrated flux density at 1420/2370 MHz to be 23$\pm$2 and 16$\pm$2 mJy, respectively. This was achieved using the IMFIT algorithm in the MIRIAD software package (Sault & Killeen 1999). We did not detect radio emission in and around SNR B0047-735 at 4790 and 8640 MHz. This is due to the low surface brightness of the SNR at these frequencies caused by the synchrotron emission and represented in the steep radio-continuum spectrum of the source. Upper limits for the SNR flux are $<$9 mJy at 4790 MHz and $<$5 mJy at 8640 MHz.

An estimate of the spectral index (α) of SNR B0047-735 is based on flux densities obtained from 843, 1420 and 2370 MHz radio-frequencies. The spectral index α is defined by the relation $S_\nu \sim \nu^\alpha$, where S_ν is the integrated flux density and ν is frequency. The error on the spectral index was deduced from the scatter in flux density. In Fig. 2, we plot the spectrum of this radio source.

3. Discussion

We analyzed ROSAT PSPC, radio-continuum and optical images (Figs. 1 and 3) of the region around the ASCA pulsar AX J0049-732. We found three ROSAT PSPC sources within or near the AX J0049-732 error circle: RX J0049.1-7314, RX J0049.2-7311 and RX J0049.5-7310. Only source RX J0049.1-7314 is seen in radio-continuum wavelengths as SNR B0047-735 /DEM S49.

The emission nebula *DEM S49 (SNR B0047-735)* shows a prominent steep radio-continuum spectrum of α=–0.80$\pm$0.27 (Fig. 2) which is generally somewhat steeper for SNRs (Filipović et al. 1998). SNR DEM S49 coincides with the extended X-ray source RX J0049.1-7314 which exhibits hardness ratio HR1 and HR2 typical for SNRs (Haberl & Pietsch 1999). No significant X-ray flux variations were found between the two ROSAT PSPC observations, which is also consistent with an SNR nature and unlike a compact stellar X-ray source. The ratio of the [S II] to Hα emission in SNR B0047-735 is measured to be 0.7 (Mathewson et al. 1984). Therefore, indicators from three different wave-bands independently confirm the SNR nature proposed by Mathewson et al. (1984). The radio diameter of the SNR DEM S49, as measured along an east-west line, is about 100″ or 32 pc at the distance of the SMC (65 kpc; Feast 1999). This result is far smaller than the optical measurements of Mathewson et al. (1984) who estimated an optical diameter of SNR DEM S49 of 51 pc. From the radio-continuum images, the SNR DEM S49 can be classified as a so called barrel-shaped (bilateral) remnant (Gaensler 1998). We note that the radio-continuum and also X-ray emission from SNR DEM S49 could be contaminated with a point-like background source which is located at the south limb of the SNR.

About 3′ north from DEM S49, we found two X-ray sources *RX J0049.2-7311* and *RX J0049.5-7310*. The X-ray spectra of both objects are hard as indicated by their HR2 (for more details see Table 3). Also, it can be seen from Fig. 1 (right) that both sources appear only on the ROSAT-PSPC hard2 image. We investigated long term time variations in the flux of those two X-ray sources by comparing the two PSPC observations which were performed about 18 months apart. RX J0049.2-7311 and RX J0049.5-7310 did not show significant changes in count rate between the April 1992 and November 1993 observations. Unfortunately, due to the poor statistics, the archival ROSAT

Table 3. Measured ROSAT PSPC properties of objects near AX J0049-732

Source X-ray Name	RA (J2000) h m s	Dec (J2000) ° ′ ″	P_e (″)	Count Rate cts sec^{-1}	HR1	HR2	EXT (″)	d_{ASCA} (″)	Type
RX J0049.1-7314	00 49 06.9	–73 14 05.0	5	0.0177±0.0011	1.00±0.06	0.15±0.06	44	112	SNR
RX J0049.2-7311	00 49 14.0	–73 11 34.5	6	0.0036±0.0004	1.00±0.94	1.00±0.16	—	75	?
RX J0049.5-7310	00 49 29.6	–73 10 56.4	6	0.0032±0.0005	1.00±0.53	1.00±0.20	19	106	Be/X

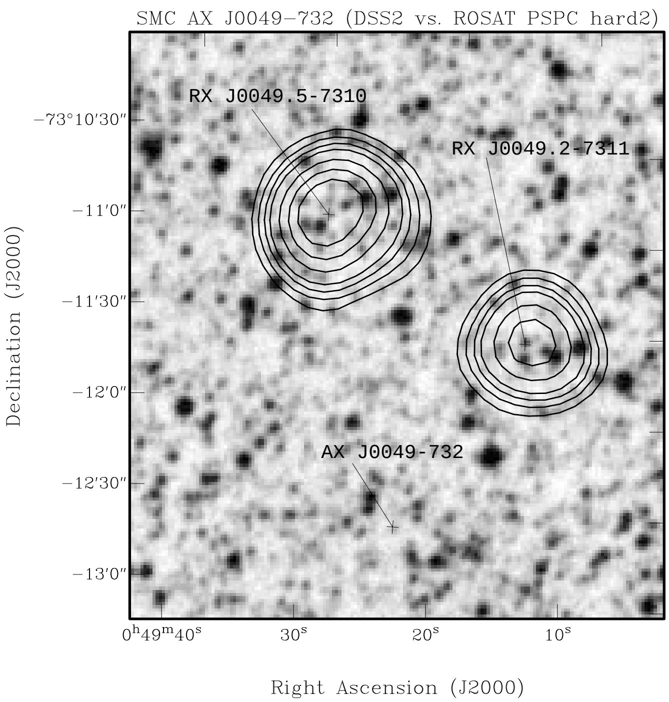

Fig. 3. Optical (DSS2) image (gray-scale) of the SMC region AX J0049-732. Contours represent the ROSAT PSPC (hard2) image of Fig. 1. Contours are: 0.15, 0.2, 0.25, 0.3, 0.4, 0.5, 0.6 and 0.8 cts $ksec^{-1}$. The emission line star (No. 300; MA93) is the bright object 2.″6 to the SE of the X-ray source RX J0049.5-7310

PSPC/HRI data cannot confirm the pulsations from any of those two X-ray sources. For both of these X-ray sources no radio-continuum emission is detected.

In Fig. 3, we present a Digital Sky Survey 2 (DSS2) image with ROSAT-PSPC X-ray contours for the two hard sources. One of them (RX J0049.5-7310) is identified with the emission line star (No. 300) in the catalogue of Meyssonier & Azzopardi (1993, MA93) located 2.″6 to the SE from the X-ray position, well within the X-ray errors circle. From the finding chart in MA93 we identify the emission line object with the star seen on the DSS2 image just below the cross which indicates the X-ray position of RX J0049.5-7310 (see also Fig. 5 in Haberl & Sasaki 2000). The catalogue of MA93 contains most of the other already identified Be/X-ray binaries in the SMC. In a parallel study of the area of ASCA pulsar AX J0105-722, we also found ROSAT counterpart identified with an MA93 object (Filipović et al. 2000). This strongly suggests RX J0049.5-7310 as the most likely counterpart of the ASCA pulsar AX J0049-732. The mbox X-ray luminosity during the ROSAT observations estimated from the count rate (Haberl et al. 2000) was about 5×10^{34} erg s^{-1}, a level often found for persistent Be/X-ray binaries. However, the unambiguous identification of RX J0049.5-7310 with AX J0049-732 has to await the confirmation of the X-ray pulsations in further new high-resolution X-ray observations.

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