FIRST DEEP XMM-NEWTON OBSERVATIONS OF THE LMC: IDENTIFYING LMC INTRINSIC SOURCE POPULATIONS

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ABSTRACT

The first X-ray survey of the Large Magellanic Cloud (LMC) was performed with the Einstein satellite, revealing diffuse X-ray emission from hot gas and discrete X-ray sources. The ROSAT observations between 1990 and 1998 supplied the most sensitive survey with imaging instruments in the soft X-ray band (0.1 - 2.4 keV). The PSPC and HRI observations covered 59 square degrees of the LMC and yielded a catalogue of about 1000 sources. Large efforts were undertaken to identify and classify the X-ray sources according to the nature of their X-ray emission. X-ray properties were used together with information from other electro-magnetic wavelength bands to screen out foreground stars and background objects from the LMC intrinsic X-ray source population which comprises X-ray binaries, supernova remnants and supersoft sources. However, the vast majority of sources still remains of unknown nature.

First deep XMM-Newton observations of selected regions in the LMC demonstrate a large step forward in the identification of LMC X-ray sources. The large collecting area together with imaging detectors covering energies 0.1 - 15 keV with far improved spectral resolution allows to determine the nature of an object directly from the X-ray properties down to low flux levels of a few $10^{-14}$ erg cm$^{-2}$ s$^{-1}$. First results of a deep observation north of LMC X-4 are presented, which reveal the presence of new supernova remnants and X-ray binaries.

Key words: Galaxies: LMC – Galaxies: stellar content

1. INTRODUCTION

First X-ray surveys of the Large Magellanic Cloud with imaging instruments were performed by the Einstein Observatory between 1997 and 1981 (Long et al. 1981, Wang et al. 1991) and resulted in the discovery of diffuse X-ray emission from hot interstellar gas and a catalogue of about 100 discrete X-ray sources. The most sensitive and most complete survey was carried out by ROSAT from 1990 to 1998 in the energy range 0.1–2.4 keV. The large field of view of the ROSAT PSPC detector yielded a large coverage of the LMC area by combining the data from hundreds of pointings to various targets in the LMC (Haberl & Pietsch 1999a). Due to monitoring programs some fields were covered more than 30 times during the lifetime of ROSAT. One such region is located between the high mass X-ray binary (HMXB) LMC X-4 and the foreground star AB Doradus. Besides the known EXOSAT transient EXO053109-6609 which was detected again by ROSAT in outburst (Haberl et al. 1995a), two new HMXBs (the Be/X-ray pulsar RX J0529.8-6556, Haberl et al. 1997 and the OB supergiant system RX J0532.5-6551, Haberl et al. 1995b) were discovered by ROSAT. Their nature was recently confirmed by Negueruela & Coe (2002). The EPIC instruments cover all three HMXBs simultaneously in their field of view and, therefore, this region was selected for deep observations in the guaranteed time programme of XMM-Newton.

2. THE XMM-NEWTON OBSERVATION

The LMC deep field observation was performed by XMM during satellite revolution 152. The total of 60 ks observing time was split into two parts (ids 0104060101 and 0104060201) interrupted by a gap of about 90 minutes (start and end of the exposures vary somewhat between the EPIC instruments. For the analysis the two observations were merged. The Optical Monitor was not used because of bright star constraints. The EPIC instruments covered the field around RA (2000) 05h31m20s and Dec -65°57'38" with ~13' radius.

Images were created in different energy bands (0.3–1.0 keV, 1.0–2.0 keV, 2.0–5.0 keV) and combined to a colour image as shown in Fig. 1 for the EPIC-pn camera. The broad arc-shaped structures in the east of the image are caused by X-rays single-reflected by the mirrors from the nearby bright supernova remnant (SNR) N63A. A preliminary source detection analysis of the broad energy band revealed about 150 X-ray sources down to fluxes of $10^{-14}$ erg cm$^{-2}$ s$^{-1}$. A more detailed analysis is, however, still required to produce a reliable source catalogue from this field. ROSAT detected about 35 sources in the field.

2.1. NATURE OF X-RAY SOURCES

An extended source just NW of the arcs, marked by similar colours, is immediately conspicuous as new SNR candidate. Another, weaker SNR candidate is located NE of the image centre. Both of the new SNR candidates were
also detected by ROSAT and are found in the PSPC catalogue of the LMC as extended sources (PSPC sources 190 and 205). The lower statistical quality of the PSPC data however, resulted in a low extent likelihood and did not allow the classification as SNR candidates by Haberl & Pietsch (1999b).

The majority of sources appear as blue in Fig. 1 which indicates a hard X-ray spectrum. These may either be hard X-ray binaries or AGN, the latter considerably absorbed by the interstellar gas of the LMC. In the restricted 0.1–2.4 keV ROSAT energy band X-ray binaries and AGN could not be distinguished from their spectrum using hardness ratio criteria (Haberl & Pietsch 1999b). At least for the brighter sources the high statistical quality of the XMM-Newton data allows to create broad band, 0.1–12 keV spectra. A typical example for an AGN candidate is a source W to the arcs (also detected by ROSAT PSPC, 202). It exhibits a strongly absorbed power-law spectrum with a photon index typical for an AGN. Foreground stars appear yellow in the image, their X-ray spectra show low absorption and little emission above 2 keV. Example X-ray spectra for one of the new candidate SNRs, AGN and a foreground star are plotted in Fig. 2. The 0.1–12 keV energy coverage of the EPIC instruments easily allows to differentiate between these three types of X-ray sources and to identify their nature. In particular power-law spectra can be easily distinguished from spectra of thermal plasma emission with temperatures up to a few keV.

Additional information about the source nature can be obtained from correlations with other wavelength bands in order to identify possible counterparts. Already for the currently achieved accuracy in the X-ray source positions (systematic uncertainties are ~3") finding charts produced from Digitized Sky Survey images allow to identify optical counterparts for foreground stars and HMXBs in the LMC which are both relatively bright in the optical. Fig. 3 shows the finding charts for the AGN and foreground star as identified from their X-ray spectra in Fig. 2. While a bright stellar object is found in the error circles of the foreground star, no obvious counterpart is visible for the AGN, consistent with their proposed nature.

Figure 1. EPIC-pn image of the LMC deep field. The colours represent X-ray intensities in different energy bands (red: 0.3–1.0 keV, green: 1.0–2.0 keV, blue 2.0–5.0 keV). North is to the top, east to the left.
Figure 2. EPIC spectra of different types of X-ray sources in the deep LMC field (red, black: pn, green: MOS1, blue: MOS2). The best fit models are shown as histograms. Left: The spectra of a new candidate SNR are well represented by a thermal plasma emission model (VMEKAL) with a temperature of 0.71 keV. Middle: EPIC spectra of a new candidate AGN, best fit by a power-law with photon index 1.86 and absorbing column density of \(5.5 \times 10^{21} \text{ cm}^{-2}\). Right: EPIC-pn spectrum of a foreground star. The spectrum can be represented by a VMEKAL model with a temperature of 0.63 keV and little absorption.

Among the X-ray brightest sources in the investigated field are HMXBs. They usually show power-law spectra with photon indices typically between 1.1 and 1.5, harder than most AGN (Fig. 4). Moreover the high mass, early type star in these accretion powered binary systems is sufficiently luminous to be seen as bright star with typical magnitudes of 12–15. Figure 4 presents the DSS images for the three known HMXBs with the error circles obtained from the EPIC instruments over-plotted. Also shown are the ROSAT PSPC error circles. The hard power-law spectrum of ROSAT source 183 and the presence of a possible counterpart with \(B = 14.2\) mag strongly suggest this source to be a HMXB.

A timing analysis was performed for the known HMXBs and the new candidate. For the two Be/X-ray pulsars pulse periods of 13.667 s (EXO053109-6609) and 69.23 s (RX J0529.8-6556) were derived, the latter confirming the ROSAT discovery as X-ray pulsar (Fig. 6). In this first preliminary analysis no significant pulsations were found for RX J0532.5-6551 and for the new HMXB candidate.

The long term light curve of RX J0529.8-6556 during the ROSAT observations between 1990 and 1994 was presented by Haberl et al. (1997). Figure 7 shows this light curve with the XMM-EPIC point added. The flux during the XMM-Newton observation was the lowest ever de-
Figure 5. DSS2 (R) images with X-ray error circles obtained from the three EPIC instruments (green: pn, blue: MOS). The red circle marks the ROSAT PSPC position. EXO053109-6609 (top left) is located on a CCD gap in the pn detector which causes the source split into two parts with distorted positions. The nature of the Be/X-ray pulsar RXJ0529.8-6556 (top right) and the OB supergiant system RXJ0532.5-6551 (bottom left) were recently confirmed by Negueruela & Coe (2002) using optical spectroscopy. Based on the X-ray spectrum and the possible optical counterpart found on the DSS image, which is of similar brightness than the counterparts of the known HMXBs in the LMC, a new candidate HMXB is found (bottom right).

...ected from this source and a factor of ~250 lower than during the outburst in one of the ROSAT observations when the X-ray pulsations were discovered.

2.2. X-RAY SOURCE CLASSIFICATION

The sample of brighter sources observed in the deep LMC field can be used to define distinct source properties which allow to classify sources down to lower flux levels. The classification of the sources according to their X-ray properties provides useful information for subsequent identification work. As demonstrated with the colour image of Fig. 2 and the X-ray spectra of the brighter sources, “X-ray colours” derived from ratios of count rates in different energy bands (hardness ratios) can be used to distinguish sources with different emission mechanisms and absorption column densities. Hardness ratios were defined as HR1 = (B+A)/(B-A) and HR2 = (C+B)/(C-B) with A, B and C as count rates in the energy bands 0.3–1.0 keV, 1.0–2.0 keV and 2.0–5.0 keV, respectively. Given the foreground absorption to the observed part of the LMC and intrinsic LMC and source absorption the observed column densities derived from the spectra are between ~6·10^{20} cm^{-2} and ~6·10^{21} cm^{-2}. Such column densities mainly affect the spectrum below 1 keV and therefore HR1, while HR2 characterizes the source intrinsic spectrum above 1 keV. In Fig. 8 HR1 is plotted versus HR2 for those sources with error on both hardness ratios of less than 0.2. HR1 is directly correlated with the absorption column densities and foreground stars are therefore found on the left side of the diagram while AGN, absorbed by the galactic and the LMC interstellar absorption are expected to be located towards the right side. Most of the unknown...
sources found with HR1 values larger than $\sim 0.2$ are most likely AGN. Their hardness ratios are compatible with absorbed power-law spectra with photon index of $\sim 1.8$. The HMXBs exhibit the hardest X-ray spectra and highest values of HR2. A large number of unknown sources is found with HR1 below 0 which implies absorption column densities below the sum of galactic and LMC absorption. To be explained as AGN a soft spectral component would be required. However from log N – log S considerations a smaller AGN contribution is expected. The sensitivity limit of the observation (the faintest sources detected have fluxes $\sim 3.7 \cdot 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ which correspond to luminosities of $\sim 1.1 \cdot 10^{33}$ erg s$^{-1}$ at the distance of the LMC, 50 kpc) should allow to detect the brightest cataclysmic variables (CVs) in the LMC. However it remains unclear if CVs and low mass X-ray binaries (LMXBs) can explain the large number of unknown sources.

First results revealed the presence of a relatively large number of unknown sources, too soft to be explained by AGN with power-law spectra absorbed through the LMC. Further investigations are needed to see if they can be explained by either background AGN with soft excess or sources intrinsic to the LMC like low mass X-ray binaries or cataclysmic variables.

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3. SUMMARY

In a preliminary analysis of a 60 ks XMM-Newton observation, pointed to an area in the Large Magellanic Cloud, new candidates for supernova remnants and a high mass X-ray binary were discovered. The high sensitivity and broad energy band of the EPIC instruments allows to determine the type of the X-ray sources to much lower flux levels as was possible before. While most of the high mass X-ray binaries in the Magellanic Clouds so far were discovered during X-ray outburst these systems can now be detected and identified during periods of quiescence. This will allow to reach a more complete census of this source population in our neighboring galaxies.