New Views of the Magellanic Clouds
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ROSAT Survey of X-ray Sources in the Magellanic Clouds

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Abstract. More than 250 pointed observations of the Magellanic Clouds were performed with the ROSAT PSPC during its nominal operation phase. From an analysis of the images we obtained a list of about 750 point-like sources in the LMC and more than 500 sources in the SMC region. In combination with the ROSAT all-sky survey this large amount of data offers the unique opportunity to study the detailed physical properties of individual X-ray sources as well as the global statistical properties of different types of X-ray sources of a small galaxy as a whole. We report on the first results obtained from cross-correlations of our PSPC source catalogues with catalogues from other wavelength bands. Proper selection criteria, based on comparisons with known sources, permits the identification of new candidates for various source classes in the Magellanic Clouds such as supersoft sources, X-ray binaries and supernova remnants, and makes it possible to discriminate them from foreground stars and background objects.

1. Introduction

The Magellanic Clouds are among the very few galaxies sufficiently close to allow the major fraction of their X-ray sources to be resolved by imaging instruments. The first soft X-ray surveys performed with the Einstein satellite (LMC: Long et al. 1981, Wang et al. 1991; SMC: Wang & Wu 1992) revealed more than 100 discrete X-ray sources in the LMC and about 70 in the SMC regions. Due to the vicinity to the south ecliptic pole the LMC was covered with high sensitivity during the ROSAT (Trümper 1983) all-sky survey. This revealed more than 500 point(-like) sources and large-scale diffuse emission in a 13.5° × 13.5° field centered on the LMC (Pietsch & Kahabka 1993). ROSAT pointed observations using the PSPC detector (Pfeffermann et al. 1986) have covered large parts of the Magellanic Clouds (LMC: Snowden & Petre 1994; SMC: Kahabka & Pietsch 1996). Here we present the first results of cross-correlations of X-ray source catalogues for the LMC and SMC with catalogues from other wavelength bands with the aim to derive classification schemes for the new, unidentified sources.

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2. ROSAT PSPC catalogues of LMC and SMC

More than 250 pointed observations of the Magellanic Clouds were performed with the ROSAT PSPC during the nominal operation of the detector between June 1990 and September 1994. From the analysis of all individual PSPC images we obtained a list of about 750 point-like sources in a $10° \times 10°$ field of the sky centered on the LMC. A preliminary analysis of a $6° \times 6°$ field including the SMC yields more than 500 X-ray sources. Our catalogues include various properties of the X-ray sources (and their associated uncertainties) such as celestial coordinates, count rates in different energy bands, and hardness ratios which are useful as indicators for the spectral shape and source extent. From multiple detections of a source in different observations only the one with the best position (smallest error) entered the catalogues which were visually screened to remove spurious detections like e.g. multiple sources in diffuse emission regions or false detections near the support structure of the detector entrance window. The catalogues will be published separately.

3. First results from correlations with other catalogues

We cross-correlated the LMC PSPC catalogue with the SIMBAD database which contains catalogues from various wavelength bands from radio to optical and X-rays. For the current work we only use positional coincidence within 60″ as identification criterion. So far we found 137 "identifications" for PSPC sources in the LMC catalogue. The majority originate from galactic foreground stars ($\sim 45\%$) and supernova remnants (SNR) in the LMC ($\sim 28\%$).

Seventeen X-ray binaries (XRBs) including five new candidates from a variability study of the PSPC sources (Haberl & Pietsch 1999, hereafter HP99) are found which are mostly high mass X-ray binaries (HMXBs). HP99 also suggest 2 new candidates for supersoft sources (SSSs) increasing the number of these systems to 9. The fraction of background objects such as AGNs and galaxies ($\sim 9\%$) is expected to increase after careful identification work since SIMBAD is biased towards stellar identifications.

In Fig. 1 the hardness ratios of LMC sources are shown, which corresponds to a colour-colour diagram. The identified sources are marked with different symbols, excluding the new, not yet confirmed candidates from HP99. Only sources with sufficiently small errors in the hardness ratios are shown. Most of the foreground stars cluster around HR1 and HR2 of 0 and X-ray point sources near this location are strong candidates for foreground stars. XRBs, SNRs and some AGNs are hard ROSAT sources and cover partly overlapping regions in the hardness ratio diagram. Additional information is required for their classification.

Fig. 2 presents source extent and its likelihood. The class of SNRs is separated from the majority of sources. However, finding point sources with extent likelihood up to ~ 50 shows that a source extent can only be treated as secure for a likelihood above that value. Point sources with very high statistics appear extended (lower left part) when deviations of the real point-spread-function to the assumed Gaussian shape become highly significant. Sources detected in the outer part of the detector are found to have artificial extent, which increases

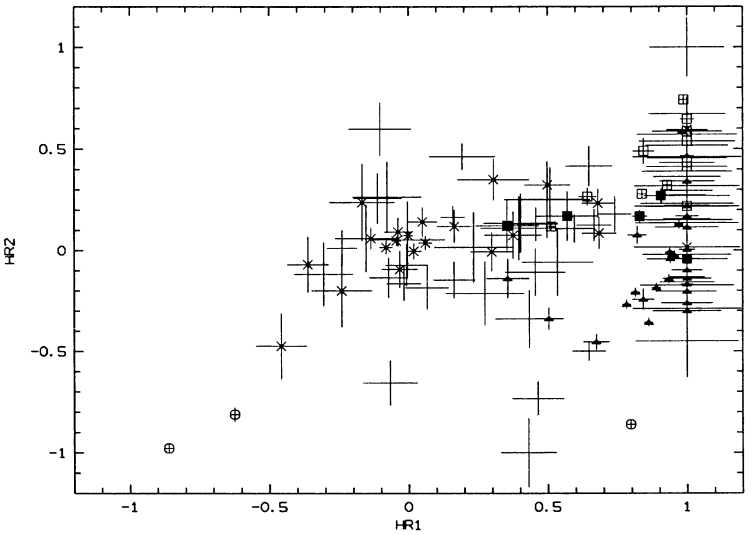

Figure 1. The location of different source classes in the hardness ratio diagram. Softest sources are found in the lower left part of the figure while hardest sources have HR1 and HR2 near +1. Plotted are only LMC sources that have 1σ errors on HR1 and HR2 < 0.2. Identified sources are marked with different symbols: X-ray binaries - open squares, SNRs - filled triangles, foreground stars - ×, SSS - o, and AGN - filled squares.

with off-axis angle and are not shown in Fig. 2. One new source with very likely extent is found. The hardness ratios indicate a somewhat harder spectrum than the average SNR but are still compatible with an SNR classification. The position of the source is 6.7″ from an entry in the Hubble GSC which is also flagged as extended. Follow-up studies are required to distinguish between an SNR or a possible background object (galaxy cluster?).

4. Discussion

Correlations of our ROSAT PSPC source catalogues of the Magellanic Clouds with SIMBAD yield first identifications with known sources from various classes like XRBs, SNRs, SSSs, AGNs and foreground stars. These samples permit a definition of selection criteria for the classification of previously unknown X-ray sources. Using these criteria together with time variability studies of the PSPC sources in the LMC, HP99 find new candidates for X-ray binaries, SSSs and foreground stars.

The spatial distribution of foreground stars in the LMC region is uniform across the observed field. A significant concentration of evolutionary young HMXBs is found in the area of the supergiant shell LMC4 (HP99) while only one known HMXB is located in the bar region. In contrast supersoft sources are

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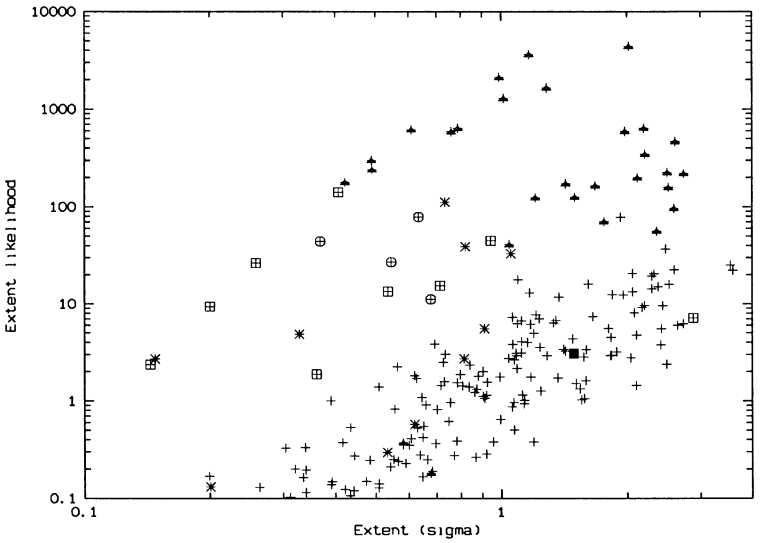

Figure 2. Source extent and extent-likelihood for LMC sources with off-axis angles less than 18′. Identified sources are marked as in Fig. 1. The extent is given in units of 15″.

so far only detected around the bar of the LMC. Due to the higher absorption the bar itself hides SSSs (as it is observed in M31, Supper et al. 1997). This is consistent with the age structure of the LMC derived from stellar formation history studies (Grebel & Brandner 1999).

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Discussion

Tetsuo Hasegawa: Can the lack of binary sources in the region near SN 1987A be due to confusion by diffuse emission?

Haberl: Very unlikely. The diffuse emission only increases the background. The hard X-ray binaries should easily be detected even if embedded inside the gas (HMXBs are observed throughout our own Galaxy).

Yuri Efremov: If I properly understood that there is a concentration of X-ray binaries just in the area of the supershell LMC4?

Haberl: Yes.

Daniel Wang: Could you elaborate a bit more on how you distinguish X-ray binaries from background AGNs? A comment on background QSOs suitable for absorption studies: from our optical identifications of X-ray sources for other nearby galaxy fields, we find that typically a couple of QSOs brighter than V $\sim$ 18 m are present. So you may expect about a dozen of such objects in the entire field of the LMC.

Haberl: Hardness ratios near +1 and high variability favour the selection of X-ray binaries.

Dominik Bomans: How many of the X-ray binaries are actually inside the supergiant shell LMC4 and how many are outside the Hα/HI boundary?

Haberl: From the 9 high mass X-ray binaries (including 4 new candidates in the LMC4 area) 3 are outside the Hα/HI boundary.

Hans Zinnecker: How many new quasars has ROSAT found behind the LMC/SMC? Log N - Log S statistics would predict lots of them (Hasinger et al. 1993, AA 275, 1).

Haberl: We so far have only done correlations with existing catalogues of various kinds (e.g., SIMBAD). This yields 11 positional coincidences from our LMC catalogue with background objects. No attempt was made to investigate these in more detail, nor have we looked for further candidates due to the mentioned difficulties to select them.

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