The Magellanic System: Stars, Gas, and Galaxies
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The Magellanic system X-ray sources

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Abstract. Using archival X-ray data from the second XMM-Newton serendipitous source catalogue, we present comparative analysis of the overall population of X-ray sources in the Large and Small Magellanic Clouds. We see a difference between the characteristics of the brighter sources in the two populations in the X-ray band. Utilising flux measurements in different energy bands we are able to sort the X-ray sources based on similarities to other previously identified and classified objects. In this manner we are able to identify the probable nature of some of the unknown objects, identifying a number of possible X-ray binaries and Super Soft Sources.

Keywords. surveys: XMM, Magellanic Clouds, X-rays: binaries, X-rays: stars

1. Introduction

The Magellanic Clouds (MCs) provide an ideal location for the study of source populations of all types. At a distance of 48.5 kpc for the Large Magellanic Cloud (LMC; Macri et al., 2006) and 61 kpc for the Small Magellanic Cloud (SMC; Hilditch et al., 2005) it is entirely possible to resolve individual components of stellar populations with modern detectors. For the study of X-ray sources (XRS), there are a number of other features of these systems that are beneficial. Their comparatively small size on the sky means that observations of the entire systems are feasible with a small number of observations. The low absorption towards the MCs, $n_{\mathrm{H}} = 1.5 \times 10^{21}\,\mathrm{cm}^{-2}$† towards the LMC and $n_{\mathrm{H}} = 3.0 \times 10^{21}\,\mathrm{cm}^{-2}$† towards the SMC benefits observations of sources, especially those which emit the bulk of their flux in the $0.1-3$ keV soft band. The Large Magellanic Cloud has a metallicity of about forty per cent of the Milky Way, $Z = 0.0091 \pm 0.0007$, while the Small Magellanic Cloud has a metallicity of about ten per cent of the Milky Way, $Z = 0.0050 \pm 0.0005$ (Keller & Wood, 2006) and their numerous epochs of star formation mean they are ideal laboratories for exploring the formation processes and evolution of stellar populations.

Prior to the launch of XMM-Newton and Chandra, the most complete X-ray surveys of the MCs were performed by the ROSAT observatory (Haberl & Pietsch 1999; Haberl et al. 2000). These surveys detected ∼750 and ∼500 sources in the LMC and SMC respectively. The improved sensitivity and spatial resolution of the XMM-Newton observatory (Jansen et al. 2001) means that with a comparatively small number of observations it has already increased the number of XRS in the region of the MCs threefold (see Section 2) without approaching full coverage of the MC fields. In addition, there is a vast array of datasets

† http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl

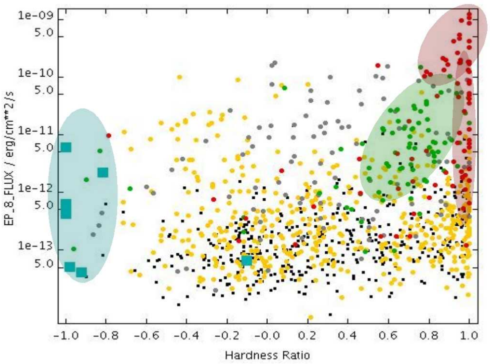

Figure 1. Hardness ratio vs. EPIC total band 8 ($0.2 - 12\,\mathrm{keV}$) flux, X-ray colour-magnitude diagrams (XCMD, see text for details) of identified variable XRSs in 2XMM. XRBs are marked in red, CVs in green, AGN in grey, stars in yellow and SSSs as turquoise squares. The figure shows selected regions of XRB, CV and SSS populations (see Section 3 for details).

at other wavelengths for the MCs making follow-up of identified XRS easier without the need to await targeted observations to identify and analyse counterparts.

2. The sources

We selected the sources from the second XMM-Newton serendipitous source catalogue (2XMM; Watson et al. 2008) that were coincident with the positions and extent of the LMC and SMC. The 2XMM catalogue is the largest X-ray source catalogue ever produced, containing almost twice as many discrete sources as previous all-sky surveys or other pointed catalogues, with preliminary studies indicating that approximately 35% of the real sources in the catalogue have not previously been identified (Farrell et al. *in prep.*). The catalogue provides an effective dataset for generating large, well-defined samples of various types of astrophysical object. The large sky area covered by the serendipitous survey also means that 2XMM is a rich resource for exploring the variety of the X-ray source populations and identifying new examples of rare sources.

We used a strict selection criteria from the catalogue to discard spurious detections and multiple detections of a single source. We only selected those sources which had a `SUM_FLAG`< 3 (an automated pipeline flag indicating likely real sources), or with the `EPIC_FLAG12` value set to True (a flag for sources which were flagged as potentially spurious by the pipeline software but which were determined to be real after manual inspection). In 2XMM there are 45 fields (a total of 208 observations) in the region of the LMC containing 2069 discrete X-ray sources, and 12 fields (a total of 59 observations) in the region of the SMC containing 1204 discrete X-ray sources.

3. Identifying X-ray source types

Figure 1 shows comparative flux diagrams used to identify differences in XRS populations for a selection of identified XRSs from 2XMM variable source studies (Farrell et al. *in prep.*). The two panels compare the Hardness Ratio (HR) to the total (band 8) EPIC flux (European Photon Imaging Camera; Jansen et al. 2001), hereby referred to as an X-ray colour-magnitude diagram (XCMD). HR is defined as $hard - soft/soft + hard$, where $soft$ is the EPIC low energy flux: $0.2 - 1\,\mathrm{keV}$, and $hard$ is the EPIC high energy

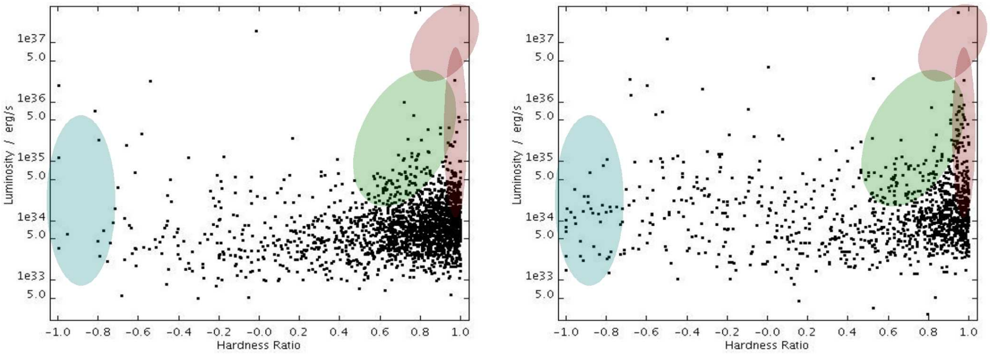

Figure 2. XCMDs (Hardness ratio vs. Luminosity in the $0.2-12$ keV band) for the LMC (left) and the SMC (right). These show the different XRS population locations from Figure 1 overlaid and scaled to the Magellanic Cloud XRS populations. From these we have identified up to 20 new, unidentified sources of interest (with no listings in SIMBAD) in the first stages of our work.

flux: $1-12$ keV. Total EPIC flux is measured in the $0.2-12$ keV energy band. As can be seen in Figure 1, sources of similar type are found in specific regions of the XCMD.

Based on the positions of the different sources in Figure 1, we have selected X-ray colour and magnitude properties that correspond to the different source populations. The two red regions correspond to the bright, hard sources, mostly X-ray binaries (XRBs). Close to this region and with some overlap is the green region which contains fainter, softer sources such as Cataclysmic Variables (CVs). Super Soft Source (SSSs; turquoise region), predominantly thought to be white dwarfs undergoing steady thermonuclear burning (Kahabka & van den Heuvel 2006), are relatively faint in the $0.2-12$ keV range but have extremely soft colours. Each indicated region contains at least 50% of the proposed source type for that region.

4. The Magellanic X-ray source population

By using the localisation of the different identified source populations shown in Figure 1, we can suggest the X-ray type of the unidentified X-ray sources in the MCs, see Figure 2. The LMC appears to have less sources that exhibit extremes of HR. The proportion of SMC sources that are bright and soft is higher than in the LMC despite the absorption towards the LMC being approximately half that towards the SMC. However, as we have exploited a catalogue composed of sources from requested pointings of preferred regions and proportionally more of the SMC has been covered than the LMC, our results could suffer from selection effects. Further coverage of both MCs will be required to verify this. We also note that the SMC contains a higher fraction of sources that fall into the region dominated by XRBs and CVs than the LMC. Comparison of the coordinates of the bright hard sources in the SMC to the SIMBAD database shows that a significant fraction of the sources are identified HMXBs, most likely to have formed in the most recent epoch of star formation (Dray, 2006). The fraction of the total populations of the LMC and SMC that fall into the regions indicating them to be likely XRBs appears to be smaller than the fraction of the variable source population in these same regions in Figure 1. This is partly due to selection effects; of the 7 brightest XRBs in the MCs, only 5 have been observed and of these only 1 is included in our population. The others are flagged as potentially spurious by the pipeline software (i.e. `SUM_FLAG`>2) due to numerous false detections surrounding them, a result of the comparatively high flux of these XRBs. It may also be linked to the lower metallicities of the MCs. Low metallicity stars are known to evolve quicker so the population of high mass stars in the MCs will be short lived compared to similar mass stars in our Galaxy, reducing the number of possible bright, hard, HMXB systems (Dray, 2006). This may have a secondary effect of increasing the number of LMXB systems in the MCs as there will be a higher proportion of the compact remnants of these high mass stars in the MCs. This is one of the questions that we hope to address in studying the total XRS population of the MCs.

We have thus tried to determine the nature of some of the unknown sources. We have identified two potential new SSSs in the LMC and one potential new SSS in the SMC. We have identified eight possible new XRBs in the LMC and four possible new XRBs in the SMC. None of these sources are coincident with identified sources in the SIMBAD database or the associated literature.

5. Conclusions and further work

From the properties of identified sources in the 2XMM catalogue, we have defined criteria to identify the likely nature of unidentified X-ray sources in the LMC and SMC. Using these properties, we have outlined the differences in the two populations. We show that in the observed populations, there are proportionally more soft and bright hard sources in the SMC than in the LMC. Some of these features can be attributed to selection effects. However, it appears that others may be the result of the different metallicities and star formation histories of the two systems.

We have identified up to 20 new sources of interest in the MCs. We intend to perform full analysis and follow-up of all of these sources including cross-matching of positions with optical and infrared sources to identify candidate companions.

This work is in its preliminary stages and we expect to be able to identify many new sources in the existing observations. We have already identified a number of sources as candidate X-ray Binaries, Cataclysmic Variables and Super Soft Sources. We also intend to carry out further observations of the MCs to obtain a more complete catalogue of all the X-ray sources.

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