Chandra XVP Observation of Low-mass X-ray Binaries in NGC 3115

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Abstract: We present our study of low-mass X-ray binaries (LMXBs) in NGC 3115 using the Ms Chandra X-ray Visionary Project (XVP) observation. By systematically comparing their spectral dependence on luminosity with those of Galactic X-ray binaries, we show that most bright sources in NGC 3115 are neutron star (NS) LMXBs in the soft state, except ten candidate black hole (BH) LMXBs showing very soft spectra. We construct the X-ray luminosity function (XLF) down to the limit of ~10^{36} erg/s, and show significant flattening of the overall XLF from $dN/dL \propto L^{-2.2}$ above 6×10^{37} erg/s to $dN/dL \propto L^{-1.0}$ below it. The XLF of globular cluster (GC) LMXBs is flatter than that of field LMXBs, indicating their different origins.

Introduction

Chandra carried out 1 Ms XVP observation of the nearby lenticular galaxy NGC 3115 in 2012. With a limiting $L_X \sim 10^{36}$ erg/s, it is one of the best observed early-type galaxies by Chandra and is ideal for addressing two long-standing problems in understanding LMXBs in nearby galaxies: the source identification and X-ray luminosity function in the low luminosity limit.

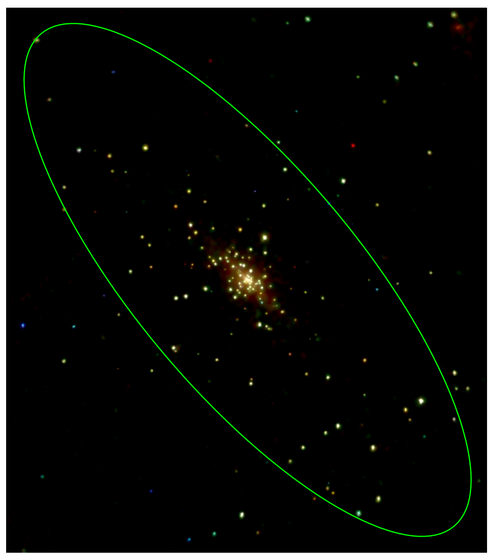

Figure 1. Chandra X-ray image of NGC 3115. The image is false-colored (0.5-1.2 keV in red, 1.2-2.0 keV in green, and 2.0-7.0 keV in blue), adaptively smoothed, and exposure-corrected. The D_{25} eclipse of the galaxy is also shown.

Source Identification

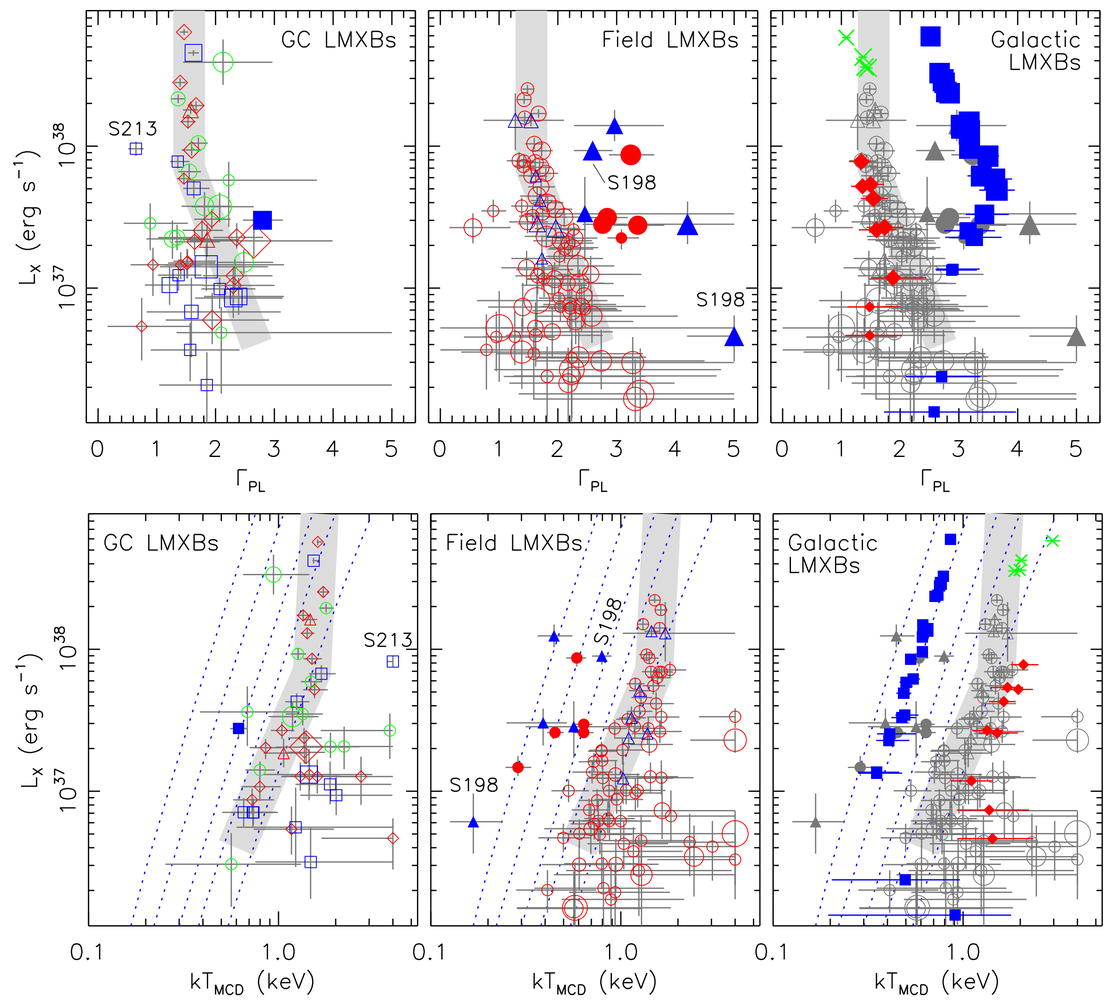

Figure 1. Top panels: simple PL fits to GC LMXBs (left panel, red diamonds and blue squares for HST/ACS red/metal-rich and blue/metal-poor GCs, respectively, green circles other GC candidates), to field LMXBs (middle panel), and to three representative Galactic LMXBs (right panel, red diamonds for the atoll source 4U 1705-44 (Lin et al. 2010), green crosses for the Z source GX 17+2 (Lin et al. 2012), and blue squares for the BH LMXB candidate XTE J1817-330 (Rykoff et al. 2007), assumed to be in NGC 3115). The light gray region marks the NS LMXB soft-state track. In the left and middle panels, filled symbols mark candidate BH LMXBs, and triangles mark transients. Bottom panels: similar to top panels but for MCD fits.

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Our source identification method: compare the collective spectral properties of our sources with the spectral evolution expected for representative Galactic LMXBs in the Chandra bandpass (0.3-8 keV), based on simple power law (PL) fits and multicolor disk (MCD) fits. Our main findings include (Lin et al. 2014a):

⇨ dominance of sources in the NS LMXB soft-state track in the L_X-Γ_{PL} and L_X-kT_{MCD} plots (gray region in Figure 1):

✻ $L_X \lesssim 7\times10^{37}$ erg/s: harder spectra at higher luminosity, dominated by atolls (the low-L_X class of NS LMXBs) in the soft state, in which the thermal disk and NS emission follow $L \propto T^4$ evolution (Lin et al. 2007, 2009, 2010),

✻ $L_X \gtrsim 7\times10^{37}$ erg/s: relatively constant spectral shape (Γ_{PL} ~1.5 or kT_{MCD} ~1.5 keV), dominated by Z sources (the high-L_X class of NS LMXBs), in which the inner disk and NS emission reach local Eddington limit, resulting in relatively constant temperature (Lin et al. 2009, 2012);

⇨ ten BH LMXBs with significantly softer spectra than NS LMXBs.

X-ray Luminosity Function

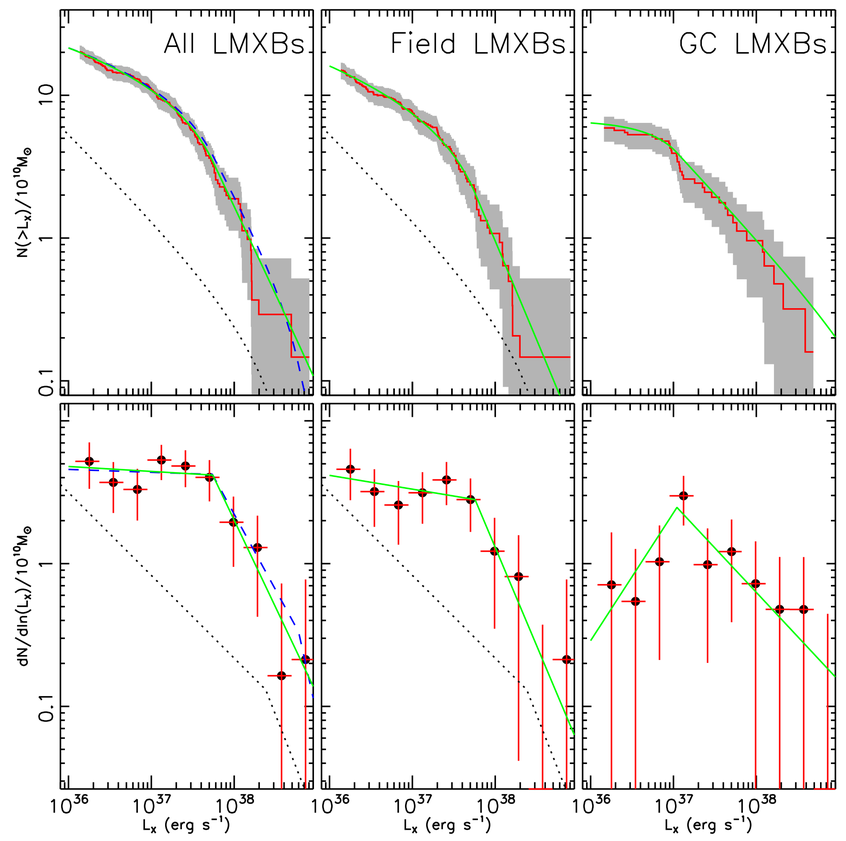

Figure 2. Incompleteness corrected and cosmic X-ray background (CXB) contribution subtracted XLFs for all LMXBs (left panels), field LMXBs (middle panels) and GC LMXBs (right panels). We plot both the cumulative (upper panels, the red solid line with the shaded area representing 1σ Poissonian uncertainty) and differential forms (lower panels). The green lines are our best broken PL fits. The dashed blue lines in the left panels are the fit to the average XLF of 20 early-type galaxies by Zhang et al. (2012), with the normalization decreased by 24%. The black dotted line is the expected CXB distribution.

Our main findings concerning XLFs in NGC 3115 include (Lin et al. 2014b):

⇨ significant flattening of the overall LMXB XLF from $dN/dL \propto L^{-2.2\pm0.4}$ above 5.5×10^{37} erg/s to $dN/dL \propto L^{-1.0\pm0.1}$ below it, agreeing with, e.g., Zhang et al. 2012 for other galaxies;

⇨ the XLF of LMXBs in GCs is overall flatter than the XLF of LMXBs in the field, which does not support the idea that all LMXBs in this galaxy are formed in GCs, agreeing with, e.g., Zhang et al. 2011 for other galaxies.

References: Lin, D., et al., 2014a, "The Megasecond Chandra X-Ray Visionary Project Observation of NGC 3115 (II): properties of point sources", submitted to ApJ; Lin, D., et al., 2014b, "The Megasecond Chandra X-Ray Visionary Project Observation of NGC 3115 (III): luminosity functions of LMXBs and dependence on stellar environments", submitted to ApJ; Lin, D., Remillard, R., Homan, J., 2007, ApJ, 667, 1073; Lin, D., Remillard, R., Homan, J., 2009, ApJ, 696, 1257; Lin, D., Remillard, R., Homan, J., 2010, ApJ, 719, 1350; Lin, D., et al., 2012, ApJ, 756, 34; Rykoff, E.S., et al., 2007, ApJ, 666, 1129; Zhang, Z., et al., 2011, A&A, 533, A33, Zhang, Z., et al., 2012, A&A, 546, A36