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CHANDRA MONITORING OBSERVATION OF THE ANTENNAE GALAXIES: THE X-RAY SOURCE POPULATIONS AND THE SHAPE OF THEIR LUMINOSITY FUNCTION

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RESUMEN

Presentamos la función de luminosidad en rayos-X (XLF) de las galaxias de La Antena, basada en 8 observaciones llevadas a cabo con *Chandra*. Detectamos entre 37 y 49 fuentes en cada observación. Después de combinar todas las observaciones detectamos un total de 120 fuentes por debajo de una luminosidad límite de $\sim 2 \times 10^{37}$ erg s^{-1}. La comparación entre las XLFs de las observaciones individuales muestra que no están afectadas por la variabilidad de la fuente. La XFL acumulativa de las observaciones añadidas está bien representada por una ley de potencias con una pendiente ~ -0.5.

ABSTRACT

We present the X-ray luminosity function (XLF) of the Antennae galaxies based on 8 observation performed with *Chandra*. We detect between 37 and 49 sources in each observation. After combining all observations we detect a total of 120 sources down to a limiting luminosity of $\sim 2 \times 10^{37}$ erg s^{-1}. Comparison between the XLFs of the individual observations shows that they are not affected by source variability. The cumulative XLF of the coadded observations is well represented by a single power-law with a slope of ~ -0.5.

Key Words: **GALAXIES: ANTENNAE (NGC 4038/39) — X-RAYS: BINARIES — X-RAYS: GALAXIES**

1. INTRODUCTION

The Antennae (NGC 4038/9), the nearest (19 Mpc) pair of galaxies undergoing a major merger, provide an excellent environment for studing the X-ray binary populations in star-forming galaxies. The first *Chandra* observations of the Antennae revealed a large population of discrete X-ray sources (43 sources down to a luminosity of 5×10^{37} erg s^{-1}), of which roughly 1/4 are in the luminosity range of Ultraluminous X-ray sources (ULXs; $L_X > 10^{39}$ erg s^{-1}). These X-ray sources are located in the active star-forming regions in the Antennae, indicating that they are mainly High Mass X-ray binaries (HMXBs; Zezas *et al.* 2002). The X-ray luminosity function (XLF) of this population can be fitted well with a single power-law $N(>L) \propto L^{-0.52^{+0.08}_{-0.33}}$, which is similar to fits obtained for other star-forming galaxies (e.g. Zezas & Fabbiano, 2002, Kilgard *et al.* 2002, Grimm *et al.* 2003).

In order to study the X-ray source population at lower luminosities as well as their variability, we obtained 7 additional *Chandra* observations between January 2001 and November 2002, yielding a total exposure of 411 Ks (Fabbiano *et al.* 2004).

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2. X-RAY SOURCE POPULATION

For each exposure we searched for sources using the *wavdetect* detection algorithm (Freeman *et al.* 2002). We detect between 37 and 49 sources in each individual exposure and 120 sources in the coadded observation. The intensity of each source was measured using apertures encompassing typically $\sim 90\%$ of the energy of a point-like source. We identified 14 extended sources (based on comparison of their radial profiles with the point-spread function) which we did not include in our subsequent analysis. The luminosity of each source is calculated assuming a power-law spectrum ($\Gamma = 1.7$) absorbed by the Galactic line-of-sight column density (3.4×10^{20} cm^{-2} Stark *et al.* 1992). In this calculation we also took into account spatial and temporal variations of the ACIS-S sensitivity (e.g. because of vignetting and the accumulation of absorbing material on the ACIS window).

Comparison between the different observations shows that the majority of the point-like sources are variable. We also find 14 sources which show outbursts, 6 of which are possibly transients (sources which are only detected in one or two observations). As in the first observation, we find X-ray sources predominantly in regions of recent star-formation. The ULXs are in areas rich in young star-clusters but not always associated with them.

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2.1. *X-ray luminosity function*

In Fig. 1 we present the XLFs from the 7 individual observations. In these XLFs, apart from Poisson errors, we include errors due to uncertainties in the flux determinations of each sources (which dominate over Poisson noise at the faint end of the XLF; see Zezas & Fabbiano 2002, for details). The typical errors for one exposure are shown by the hatched band. From this figure is clear that all XLFs are consistent with each other. This conclusion is supported by a comparison between the XLFs using a KS test, which showed that they are consistent at $> 99\%$ confidence level. Similarly, power-law fits to the different XLFs yield consistent slopes (~ -0.5) within the errors. To perform these comparisons and fits we exclude the part of the XLFs which is affected by incompleteness (as determined from detailed simulations; e.g. Zezas & Fabbiano 2002). This result shows that X-ray binary variability does not affect the shape of their XLF. Therefore, one observation of a galaxy gives a representative picture of the luminosity distribution of its X-ray sources.

In Fig. 2 we present the XLF from the coadded data (down to a limiting luminosity of $\sim 2\times10^{37}$ erg s^{-1}). which in a sense gives the mean luminosity of the X-ray sources in the Antennae in the course of two years. The best fit slope of ~ -0.5, is consistent with the slopes of the individual XLFs. There is a indication for a 'bump' at $\sim 10^{38}$ erg s^{-1} but at this point its significance is not clear. If this bump is statistically significant it could be evidence for Eddington limited accretion on compact objects (e.g. Kalogera *et al.* 2004, in prep) or anisotropic emission from the accretion disk (e.g. Zezas & Fabbiano 2002)

Even at this lower luminosity limit the shape of the Antennae XLF is consistent with the XLFs of other star-forming galaxies and the Galactic HMXBs, supporting the idea that ULXs are part of the 'normal' young X-ray binary population (e.g. Grimm *et al.* 2003).

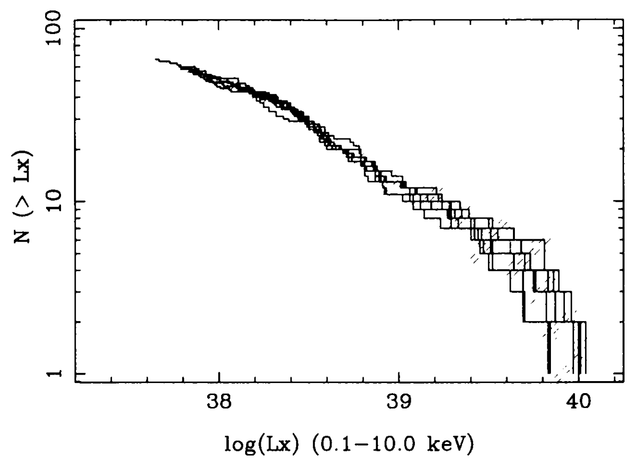

Fig. 1. The XLFs of the point-like sources detected in the 7 Chandra observations of the Antennae. The hatched band shows the typical errors including Poisson uncertainties as well as uncertainties in the source fluxes.

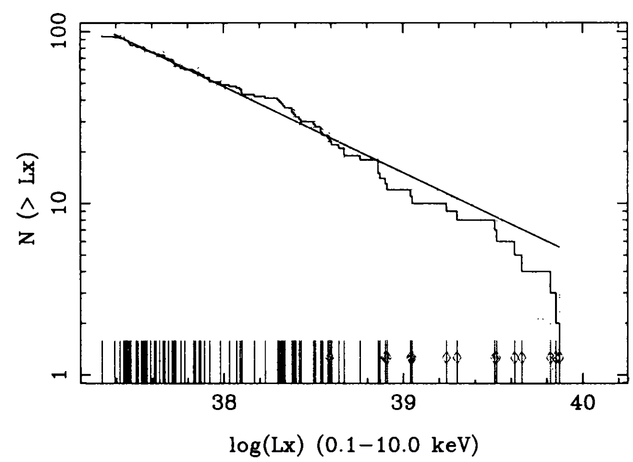

Fig. 2. The XLF of the point-like sources detected in the coadded observation of the Antennae. The straight line show the best fit power-law. The vertical lines in the bottom show the differential XLF, where diamonds indicate sources which appear as ULXs in any of the 7 observations. As in Fig. 1 the band defined by the dashed lines show the typical errors including Poisson uncertainties as well as uncertainties in the source fluxes.

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