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The logN-logS relationship of normal X-ray emitting galaxies

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Abstract. We have selected a flux limited serendipitous sample of galaxies from the cross-correlation of the BMW (Brera Multiscale Wavelet) ROSAT HRI and the LEDA (Lyon - Meudon Extragalactic Database) Catalogues. This sample is used to study the X-ray properties of normal galaxies in the local universe.
We also find that the logN-logS distribution we derived for a serendipitous subsample, optically and X-ray flux limited, is consistent with the euclidean slope in the flux range $F_{X(0.5-2)} \sim 1.1 - 110 \times 10^{-14}$ erg cm^{-2} s^{-1}. We further show that the same law is valid over 4 decades, from the bright sample derived from the RASS data to the very faint detections in deep *XMM - Newton* fields.

Key words. Galaxies: general – X-rays: galaxies

1. Introduction

Detailed x studies of normal galaxies have been possible only with the advent of imaging instruments aboard the *Einstein* observatory. The *Einstein* results were summarized in the catalogue and atlas published by Fabbiano et al. (1992). Elliptical galaxies were found to retain large amounts (10^8 – 10^{11} $M_\odot$) of hot gas (T $\sim 10^7$ K) whose thermal emission dominates their x luminosities, while in normal spirals the integrated contribution of the evolved stellar sources, such as supernova remnants and x binaries, is generally the dominant component (see Fabbiano 1989; Fabbiano et al. 1992; Kim et al. 1992).

Subsequent observations on individual sources made by *ROSAT* and *ASCA* confirmed most of the *Einstein* results and added interesting information on the x properties of normal galaxies (see among others Roberts & Warwick 2000; Read et al. 1997; Brown & Bregman 1998; Beuing et al. 1999) in the local universe.

With the launch of *XMM - Newton* and *Chandra* satellites, the study of the x properties of "normal" galaxies at intermediate ($z \sim 0.1$) or cosmological distances (Brandt et al. 2001; Hornschemeier et al. 2002, 2003; Georgakakis et al. 2003, 2004) was made possible, thanks to significantly improved sensitivity, spatial and spectral resolution of the instruments. In spite of the large number of papers, however, a truly complete sample of x emitting normal galaxies in the local universe has so far not been properly discussed in the literature.

The large database provided by ROSAT has been so far exploited only marginally to derive unbiased and complete samples of galaxies.

We have used the X-ray data from the BMW (Brera Multi-scale Wavelet) *ROSAT* HRI catalogue and optical data from LEDA (Lyon-Meudon Extragalactic Database) to define a sample of normal galaxies. Details can be found in **?**). Here we discuss mainly the results from the complete serendipitous subsample.

2. The X-ray flux limited sample

To obtain a representative sample of galaxies we included only serendipitous detections in the BMW – HRI Catalogue, avoiding the targets (we selected only sources with off-axis angle > 3′). We then cross - correlated the positions of the *x* sources in the BMW – HRI catalogue with those of galaxies present in the LEDA database, with a tolerance of 20″. The cross-correlation yields 399 X-ray sources associated with 281 galaxies. Being constructed field-by-field, the BMW – HRI catalogue contains multiple detections of the same source. We then eliminate spurious coincidences, AGNs and clusters.

These selection criteria yielded a total of 143 normal galaxies with associated X-ray emission. For this sample we computed count rates in pulse height analyzer (PHA) channels 1 – 10 of HRI. They are converted into 0.1 – 2 keV fluxes using a conversion factor corresponding to a bremsstrahlung spectrum with kT = 5 keV plus the line of sight absorption appropriate for each source from Dickey & Lockman (1990). The resulting flux range is $\sim 10^{-14} - 10^{-11}$ erg cm^{-2} s^{-1}. The corresponding range in luminosities is $\sim 10^{38} - 10^{43}$ erg s^{-1} (H_0 = 50 km s^{-1} Mpc^{-1}).

To verify whether the total sample of 143 objects is representative of the X-ray properties of normal galaxies, we compared the F_X/F_B distribution with those of other samples in the literature, namely the normal galaxies observed by the *Einstein* satellite (Eskridge et al. 1995; Shapley et al. 2001), the candidate normal galaxies found by Zimmermann et al. (2001) in the ROSAT All Sky Survey (Voges et al. 1999) and the normal galaxies found in the *Einstein* Extended Medium Sensitivity Survey (EMSS; Gioia et al. 1990).

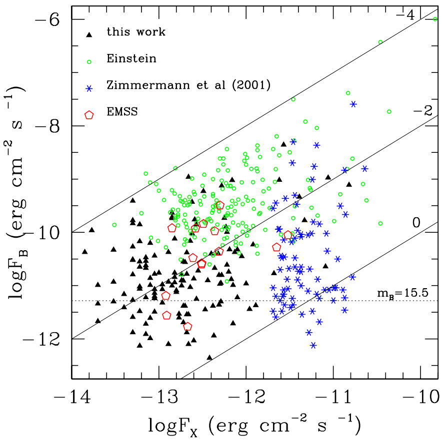

Fig. 1. B flux versus X-ray flux for our total sample (solid triangles), for the *Einstein* samples (empty circles), for the Zimmermann et al. 2001 sample of condidate galaxies (asterisks), and for the EMSS galaxies (empty pentagons). Solid lines correspond to $\log(F_X/F_B)$= 0, −2, −4; the horizontal dashed line is the m_B = 15.5 limit.

The distribution of F_X and F_B values from all samples considered are plotted in Fig. 1. All fluxes are converted to the 0.1 – 2 keV band. Galaxies belonging to different samples appear to populate different regions in the plot:

- Our sample (solid triangles) has $\log(F_X/F_B)$ between −4 and 0.
- The bulk of the galaxies observed by *Einstein* (empty circles) is tipically at higher average fluxes and at lower values of $\log(F_X/F_B)$ (between −4 and −2). This sample is the largest, it is effectively optically selected and reasonably clean of the contamination from AGN (Shapley et al. 2001). However, since it is not complete, it might be not representative of the true distribution of the X-ray - to - optical ratios.
- The distribution of candidate galaxies of Zimmermann et al. (2001) (asterisks) is significantly different from that of the *Einstein* sample and extends at $\log(F_X/F_B)$ > 0; this sample is likely to contain AGNs.

- The F_X/F_B distribution for EMSS galaxies (empty pentagons) is at intermediate values and more consistent with that of our sample. It is the only truly complete sample, since it is serendipitously X-ray selected and virtually completely identified (Gioia et al. 1990; Stocke et al. 1991; Maccacaro et al. 1994), however it is very small (only 15 galaxies with known B-magnitude).

3. The serendipitous complete sample

To study the general properties of the sample we need to derive a subsample with well known completeness criteria and limits. To this end we must consider both the X-ray and the optical completeness criteria. The X-ray completeness is related to the BMW – HRI catalogue, that includes all sources with a significance $\geq 4.2\,\sigma$. To take into account the optical limits, we excluded galaxies fainter than $m_B = 15.5$ (see Paturel et al. 1997).

We have also excluded objects at low galactic latitude ($|b| \leq 10°$) and X-ray sources with off-axis angle $\theta \geq 18'$. We then excluded all sources known or suspected to be associated with the target (e.g. galaxies in pairs, groups or clusters). The complete, serendipitous sample of 32 galaxies thus obtained has been used calculate the logN-logS distribution in the local universe.

The integral logN-logS distribution of the sample (histogram in Fig. 2) covers two decades in flux, from ~ 1.1 to $\sim 110{\times}10^{-14}$ erg cm^{-2} s^{-1} and is consistent with the euclidean slope of -1.5 (dashed line).

We compare in Fig. 2 our logN-logS with those of candidate galaxies of Zimmermann et al. (2001), of EMSS galaxies and of normal star forming galaxies in the XMM/2dF Survey (Georgakakis et al. 2003, 2004). All fluxes are now in the 0.5 – 2 keV band.

- The Zimmermann et al. (2001) points (squares) appear to connect smoothly with the euclidean extrapolation of the BMW – HRI logN-logS above 10^{-12} erg cm^{-2} s^{-1}.
- The EMSS (empty circles) appears to be euclidean and consistent with our curve.

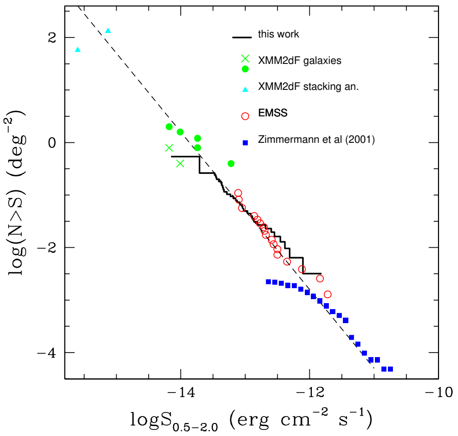

Fig. 2. The logN-logs distribution for the present sample (histogram) compared with the euclidean relationship (dashed line), the logN-logS for galaxies in the EMSS (empty circles), that of *candidate galaxies* of Zimmermann et al. 2001 (squares), the density of galaxies in the XMM/2dF survey as reported by Georgakakis et al. (2004) (crosses) and including LLAGN (solid circles), together with results of their stacking analysis (triangles).

- Crosses are the two normal star forming galaxies found by Georgakakis et al. (2004) in the XMM/2dF survey. Their sample contains however three additional galaxies with $L_{0.5-8} \sim 10^{42}$ erg s^{-1} that are likely to host Low Luminosity AGNs. Since we cannot exclude that our sample also contains a few Low Luminosity AGNs, given that several objects with $L_X \sim 10^{42}$ erg s^{-1} do not have published optical spectra, we include these objects in the XMM/2dF sample. The resulting logN-logS with all five objects (solid circles) is very close to the extrapolation of the euclidean slope.
- Also shown in Fig. 2 as solid triangles are the constraints from the stacking analysis results of Georgakakis et al. (2003) in the XMM/2dF survey. They also are consistent with the extrapolation of the euclidean slope.

We find quite remarkable that all samples considered, derived from different criteria and instruments, give surface densities consistent with a uniform euclidean distribution for more than 4 decades.

4. Conclusions

We have obtained a sample of 143 X-ray emitting normal galaxies from the cross-correlation of the BMW – HRI and LEDA Catalogues, whose general properties have been compared with those of other samples in the literature.

We have also computed the integral logN-logS relationship for a complete, serendipitous subsample of 32 galaxies in the flux range $1.1 - 110 \times 10^{-14}$ erg cm^{-2} s^{-1}, finding that it is consistent with an euclidean slope. We also find a remarkable agreement between the data from 4 different samples selected from *Einstein, ROSAT* and *XMM - Newton* observations in the flux range $\sim 10^{-15} - 10^{-11}$ erg cm^{-2} s^{-1}.

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