THE CLUSTERING OF XMM-NEWTON HARD X-RAY SOURCES

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We present the clustering properties of hard (2-8 keV) X-ray selected sources detected in a wide field (≈ 2 deg²) shallow \[ f_X(2-8\text{ keV}) \approx 10^{-14} \text{ erg cm}^{-2} \text{s}^{-1} \] and contiguous XMM-Newton survey. We perform an angular correlation function analysis using a total of 171 sources to the above flux limit. We detect a \( \sim 4 \sigma \) correlation signal out to 300 arcsec with \( w(\theta < 300'' \) ≃ 0.13 ± 0.03. Modeling the two point correlation function as a power law of the form \( w(\theta) = (\theta/\theta_0)^{\gamma-1} \) we find: \( \theta_0 = 48.9_{+15.8}^{-24.5} \) arcsec and \( \gamma = 2.2 \pm 0.30 \). Fixing the correlation function slope to \( \gamma = 1.8 \) we obtain \( \theta_0 = 22.2_{+9.4}^{-8.6} \) arcsec. Using Limber’s integral equation and a variety of possible luminosity functions of the hard X-ray population, we find a relatively large correlation length, ranging from \( r_0 \approx 9 \) to 19 \( h^{-1} \) Mpc (for \( \gamma = 1.8 \) and the concordance cosmological model), with this range reflecting also different evolutionary models for the source luminosities and clustering characteristics.

1. Introduction

The overall knowledge of the AGN clustering using X-ray data comes mostly from the soft X-ray band (Boyle & Mo 1993; Vikhlinin & Forman 1995; Carrera et al. 1998; Akylas, Georgantopoulos, Plionis, 2000; Mullis 2002), which is however biased against absorbed AGNs. Recently, Yang et al. (2003) performing a counts-in cells analysis of a deep \( (f_{2-8\text{ keV}} \sim 3 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}) \) Chandra survey in the Lockman Hole North-West region, found that the hard band sources are highly clustered with \( \sim 60\% \) of them being distributed in overdense regions.

In this study we use a hard (2-8 keV) X-ray selected sample, compiled from a shallow (2-10 ksec per pointing) XMM-Newton survey near the North

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and South Galactic Pole regions. A total of 18 pointings were observed out of which only 5 were discarded due to elevated particle background at the time of the observation. A full description of the data reduction, source detection and flux estimation are presented by Georgakakis et al. (2003). Here we just note that it comprises of 171 sources above the $5\sigma$ detection threshold to the limiting flux of $f_X(2-8\text{ keV}) \approx 10^{-14}\text{ erg s}^{-1}\text{ cm}^{-2}$.

2. Correlation function analysis

In the present study we use as the estimator of the 2-point correlation function the following:

$$w(\theta) = f(N_{DD}/N_{DR}) - 1,$$

where $N_{DD}$ and $N_{DR}$ is the number of data-data and data-random pairs respectively at separations $\theta$ and $\theta + d\theta$. In the above relation $f$ is the normalization factor $f = 2N_{R}/(N_{D} - 1)$ where $N_{D}$ and $N_{R}$ are the total number of data and random points respectively. To account for the different source selection and edge effects, we have produced 100 Monte Carlo random realizations of the source distribution within the area of the survey by taking into account variations in sensitivity which might affect the correlation function estimate. Indeed, the flux threshold for detection depends on the off-axis angle from the center of each of the XMM-Newton pointings. Since the random catalogues must have the same selection effects as the real catalogue, sensitivity maps are used to discard random points in less sensitive areas (close to the edge of the pointings). This is accomplished, to the first approximation, by assigning a flux to the random points using the Baldi et al. (2002) 2-10 keV log $N - \log S$ (after transforming to the 2-8 keV band assuming $\Gamma = 1.7$). If the flux of a random point is less than 5 times the local rms noise (assuming Poissonian statistics for the background) the point is excluded from the random data-set. We note that the Baldi et al. (2002) log $N - \log S$ is in good agreement with the 2-8 keV number counts estimated in the present survey.

The results of our analysis are shown in Figure 1, were the line corresponds to the best-fit power law model $w(\theta) = (\theta/\theta_c)^{\gamma-1}$ using the standard $\chi^2$ minimization procedure in which each correlation point is weighted by its error. We find a statistically significant signal with $w(\theta < 300\arcsec) \approx 0.13 \pm 0.03$ at the $4.3\sigma$ confidence level using Poissonian errors. The best fit clustering parameters are: $\theta_c = 48.9^{+15.3}_{-8.6} \arcsec$ and $\gamma = 2.2 \pm 0.30$, where the errors correspond to 1$\sigma$ uncertainties. Fixing the correlation function slope to its nominal value, $\gamma = 1.8$, we estimate $\theta_c = 22.2^{+9.4}_{-6.8} \arcsec$.

Our results show that hard X-ray sources are strongly clustered, even more than the soft ones (see Vikhlinin & Forman 1995; Yang et al. 2003;
Figure 1. The 2-point angular correlation function of the hard (2-8 keV) X-ray sources.

Insert: Iso-$\Delta\chi^2$ contours in the $\gamma$-$\theta_0$ parameter space.

Basilakos et al. in preparation. Our derived angular correlation length $\theta_0$ is in rough agreement, although somewhat smaller (within 1$\sigma$) with the Chandra result of $\theta_0 = 40 \pm 11$ arcsec (Yang et al. 2003). The stronger angular clustering with respect to the soft sources could be either due to the higher flux limit of the hard XMM-Newton sample, resulting in the selection of relatively nearby sources, or could imply an association of our hard X-ray sources with high-density peaks.

3. The spatial correlation length using $w(\theta)$

The angular correlation function $w(\theta)$ can be obtained from the spatial one, $\xi(r)$, through the Limber transformation (Peebles 1980). If the spatial correlation function is modeled as $\xi(r, z) \propto (r/r_o)^{-\gamma}(1 + z)^{-\gamma}(3+z)^{\epsilon}$. The angular amplitude $\theta_0$ is related to the correlation length $r_o$ in three dimensions via Limber’s equation. Note that if $\epsilon = \gamma - 3$, the clustering is constant in comoving coordinates (comoving clustering) while if $\epsilon = -3$ the clustering is constant in physical coordinates. We perform the Limber’s inversion in the framework of the concordance $\Lambda$CDM cosmological model ($\Omega_m = 1 - \Omega_\Lambda = 0.3$, $H_o = 70$ km s$^{-1}$ Mpc$^{-1}$).

The expected redshift distribution and the predicted total number, $N$, of the X-ray sources which enters in Limber’s integral equation can be found using the hard band luminosity functions of Ueda et al. (2003). We also use different models for the evolution of the hard X-ray sources: a pure luminosity evolution (PLE) or the more realistic luminosity dependent
density evolution (LDDE; Ueda et al 2003). The LDDE model with respect to the PLE gives an expected redshift distribution shifted to larger redshifts, with a median redshift of $\bar{z} \simeq 0.75$.

For the comoving clustering model ($\epsilon = \gamma - 3$) and using the LDDE evolution model, we estimate the hard X-ray source correlation length to be: $r_0 = 19 \pm 3 \ h^{-1} \text{Mpc}$ and $r_0 = 13.5 \pm 3 \ h^{-1} \text{Mpc}$ for $\gamma = 1.8$ and $\gamma = 2.2$ respectively. While if $\epsilon = -3$ the corresponding values are: $r_0 = 11.5 \pm 2 \ h^{-1} \text{Mpc}$ and $r_0 = 6 \pm 1.5 \ h^{-1} \text{Mpc}$, respectively.

The estimated clustering lengths (for $\gamma = 1.8$) are a factor of $\gtrsim 2$ larger than the corresponding values of the 2QZ QSO's (Croom et al. 2001). However, the most luminous, and thus nearer, 2QZ sub-sample ($18.25 < b_J < 19.80$) has a larger correlation length ($\sim 8.5 \pm 1.7 \ h^{-1} \text{Mpc}$) than the overall sample (Croom et al. 2002), in marginal agreement with our $\epsilon = -3$ clustering evolution results.

The large spatial clustering length of our hard X-ray sources can be compared with that of Extremely Red Objects and luminous radio sources (Roche, Dunlop & Almaini 2003; Overzier et al. 2003; Röttgering et al. 2003) which are found to be in the range $r_0 \simeq 12 - 15 \ h^{-1} \text{Mpc}$.

References