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PROPOSAL: UNAMBIGUOUS DETERMINATION OF THE CLUSTERING OF HIGH-Z X-RAY AGN, THEIR LOCAL ENVIRONMENT AND COSMOLOGICAL CONSTRAINTS

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ABSTRACT

We propose that a large-area relatively shallow XMM survey, reaching $f_x \sim 2 \times 10^{-15}$ erg/sec cm^2 in the 0.5-2 keV band, and $f_x \sim 10^{-14}$ erg/sec cm^2 in the 2-10 keV band, is essential to unambiguously determine the clustering pattern of $\bar{z} \sim 1$ X-ray AGNs, especially in light of the large scatter of clustering results based on a number of recent X-ray surveys (see Plionis et al. 2008 and references therein). Since, these surveys span individual areas between 2 and 10 deg^2, we believe that in order to effectively suppress *cosmic variance* effects, the proposed survey should cover an area between 40 and 60 deg^2. Furthermore, we propose that the survey area should coincide with that of SWIRE (or with the SDSS deep strip), in order to (a) utilize the existing optical and IR imaging (in the case of SWIRE) data to determine accurate photometric redshifts and thus allow also a 3-D analysis, and (b) complement the clustering study with an investigation of the local and large-scale environment of high-z X-ray selected AGNs, which will provide an independent test of their apparent large clustering length (eg. Basilakos et al 2005; 2006, Puccetti et al. 2006, Plionis et al. 2008).

Finally, the resulting, well defined, clustering pattern of X-ray $z \sim 1$ AGNs can be used, as demonstrated by Basilakos & Plionis (2005; 2006), Plionis & Basilakos 2007), to put strong constraints on the X-ray selected AGN bias evolution and on cosmological parameters.

Subject headings: galaxies: active — quasars: general — surveys — cosmology: observations — large-scale structure of the universe

1. BACKGROUND

X-ray selected AGNs provide a relatively unbiased census of the AGN phenomenon, since obscured AGNs, largely missed in optical surveys, are included in such surveys. Furthermore, they can be detected out to high redshifts and thus trace the distant density fluctuations providing important constraints on supermassive black hole formation, the relation between AGN activity and Dark Matter (DM) halo hosts, the cosmic evolution of the AGN phenomenon (eg. Mo & White 1996, Sheth et al. 2001), and on cosmological parameters and the dark-energy equation of state (eg. Basilakos & Plionis 2005; 2006).

The earlier ROSAT-based analyses (eg. Boyle & Mo 1993; Vikhlinin & Forman 1995; Carrera et al. 1998; Akylas, Georgantopoulos, Plionis, 2000; Mullis et al. 2004) provided conflicting results on the nature and amplitude of high-z AGN clustering. With the advent of the XMM and *Chandra* X-ray observatories, many groups have attempted to settle this issue, but in vaine. Different surveys have provided again a multitude of conflicting results, intensifying the debate (eg. Yang et al. 2003; Manners et al. 2003; Basilakos et al. 2004; Gilli et al. 2005; Basilakos et al 2005; Yang et al. 2006; Puccetti et al. 2006; Miyaji et al. 2007; Gandhi et al. 2006; Carrera et al. 2007). However, the recent indications of a flux-limit dependent clustering appears to lift most of the above inconsistencies (Plionis et al. 2008; see also Figure 1).

Furthermore, their are indications for a quite large high-z AGN clustering length, reaching values $\sim 15 - 18\ h^{-1}$ Mpc at the brightest flux-limits (eg., Basilakos et al 2005; 2006, Puccetti et al. 2006, Plionis et al. 2008), a fact, which if verified, has important consequences for the AGN bias evolution and therefore for the evolution of the AGN phenomenon (eg. Miyaji et al. 2007; Basilakos, Plionis & Ragone-Figueroa 2008). An independent test of these results, if verified, will be to establish that the environment of high-z AGN is associated with large DM haloes, which being massive should be more clustered.

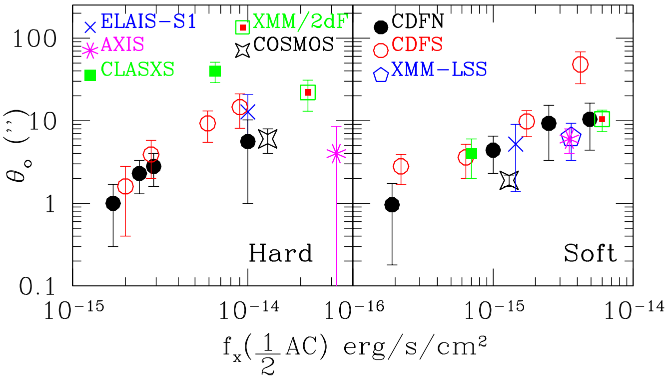

FIG. 1.— The angular correlation scale, θ_0, as a function of different survey characteristic flux, defined as that corresponding to half the respective survey area-curves. Most results appear to be consistent with the clustering flux-limit dependence, found from the CDF-N and CDF-S (from Plionis et al. 2008).

Below we justify the necessity for a large-area (~ 50 deg^2) relatively shallow XMM survey in order to unambiguously determine the clustering pattern and local environment of high-z ($z \sim 1$) X-ray AGNs. We further show that such measurements can be used to put strong cos-

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mological constraints (see for example Basilakos & Plionis 2005; 2006).

2. OBSERVING STRATEGY

It is important to understand and overcome the shortcomings and problems that one is facing in order to reliably and unambiguously determine the clustering properties of the X-ray selected AGNs. A major problem, which can be rectified by increasing considerably the X-ray survey area, is related to the *Cosmic Variance*, which boils down to the question: "Is the volume surveyed large enough to smooth out inhomogeneities of the large-scale distribution of AGNs ?" (see for example Stewart et al. 2007). Closely related to this problem is the so-called *integral constraint*, which is due to imposing as the true mean density of the cosmic sources under study their observed value. If the survey area is small enough, then the mean density, estimated from the survey itself, is way-out of its true value (as for example is the case of the CDF-S, were a large number of superclusters at $z \sim 0.7$ are found; see Gilli et al. 2003). This usually results into an underestimation of the true correlation amplitude and a shallower $\xi(r)$ or $w(\theta)$ zero-crossing (due to the volume-filling nature of cosmic voids). One of the source of the observed scatter between the presently available surveys (see Fig. 1) could well be *cosmic variance*.

In order to minimize such effects and unambiguously determine the soft and hard-band X-ray AGN clustering pattern we propose to perform an XMM survey, increasing the number of large contiguous areas by a factor of 5. We propose to focus on regions of the sky that have been previously covered by the Spitzer SWIRE (Spitzer Wide-Area Infrared Extragalactic Survey). SWIRE covers 50 deg^2 in 6 non-contiguous areas on the sky. These are divided over the North ELAIS-N1,N2 (14 deg^2), Lockman Hole (11 deg^2) and the South hemisphere XMM-LSS (9 deg^2), CDF-S (8 deg^2), ELAIS-S1 (7 deg^2). Since for one of these regions (the XMM-LSS) there are already 10 ksec XMM observations available per field, the necessary XMM observations regard only the remaining 40 deg^2 area. It is important to notice that the SWIRE survey has also excellent optical imaging coverage. For example, the Northern fields are covered by the SDSS, the ELAIS fields have been extensively surveyed to typical depths of 22-25 in a variety of Gunn filters, while the SWIRE consortium has also acquired KPNO, CTIO and Palomar observations for optical identification of the entire Lockman and Chandra-S fields to $r^{'} \sim 25$. The excellent quality optical data in combination with the mid-IR data ascertain that good accuracy photometric redshifts can be obtained.

In order to reach a flux-limit above which the soft-band clustering results appear to converge to their final value (due to the flux-limit clustering correlation revelaed in Plionis et al. 2008; see also Figure 1) we suggest 10 ksec XMM pointings, with which we will reach a flux-limit of $\sim 2\times10^{-15}$ erg/sec/cm^2 in the soft (0.5-2 keV) and $\sim 10^{-14}$ erg/sec/cm^2 in the hard (2-10 keV) bands, respectively. The resulting total exposure time of the proposed survey is $\sim$ 2 Msec's. Note that at the proposed flux-limits the survey will provide a large number of X-ray sources, which according to the $\log N - \log S$ of Baldi et al. (2002) give $\sim$ 30000 and $\sim$ 15000 soft and hard-band sources, respectively. Taking into account vignetting one may expect a reduction by a factor of two of these numbers (however this will depend on the area-filling observing strategy, and one may envision a compact filling with 9 pointings per deg^2 that will reduce the effects of vignetting but increase the total exposure time to 3.6 Msec's).

An alternative survey target could be to observe part of the SDSS deep strip (Jiang et al. 2006). This equatorial strip will eventually cover an area of 270 deg^2 with deep imaging in the five SDSS bands as well as spectroscopy for QSOs down to $g \sim$22.5. The advantage of this choice is that it offers a contiguous area to be observed, and thus the possibility to detect the signal of baryonic oscillations in the high-z AGN LSS distribution (Plionis et al. 2008, in preparation). The problem however is that there are no mid-IR data available and thus there will be a problem in determining high accuracy photo-z.

3. X-RAY AGN BIAS-EVOLUTION AND COSMOLOGICAL CONSTRAINTS

The expected well determined correlation function of the $z \sim 1$ X-ray AGNs will allow us to determine (a) their relation to the underlying matter fluctuations at $z \sim 1$ (ie., their bias: $b(z \simeq 1)$), (b) the evolution of their bias and therefore the mass of the DM haloes which they inhabit (eg., Miyaji et al. 2007; Basilakos, Plionis & Ragone-Figueroa 2008) and (c) put strong cosmological constraints on the Ω_m, h or Ω_m, σ_8 planes, while with the help of the SN Ia Hubble relation (eg. Tonry et al. 2003, Riess et al. 2004) on the Ω_m, w plane.

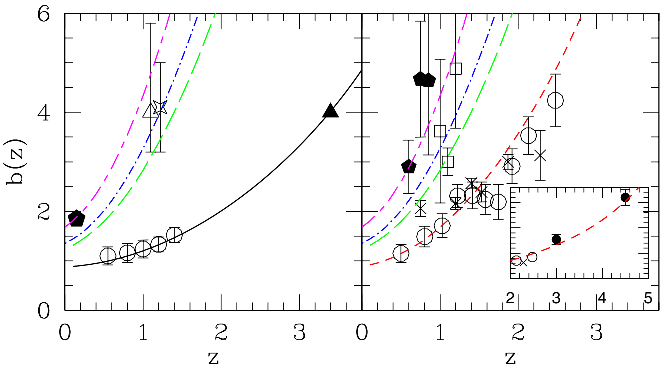

FIG. 2.— Comparison of the Basilakos et al (2008) $b(z)$ evolution model with different observational data. Different line types represent different halo masses. *Left Panel:* optical galaxies (open points) with solid line corresponding to $M_{\rm DM} \sim 10^{12}\ h^{-1}\ M_{\odot}$, Lyman break galaxies (solid triangle), EROs (star), DRGs (open triangle) and 2dF radio sources (filled pentagon). The dot-dashed line corresponds to 7.7 $\times 10^{13}\ h^{-1}\ M_{\odot}$. *Right Panel:* optically selected quasars (open points and crosses), soft and hard X-ray point sources (open squares and solid diamonds; the large scatter corresponds to the uncertainty of the present day clustering results; see Plionis et al. 2008 and references therein). In the insert we plot, as solid points, the high-z SSRS DR5 QSOs and the same $b(z)$ model that fits their lower redshift counterparts (ie., $M_{\rm DM} \simeq 10^{13}\ h^{-1}\ M_{\odot}$).

It is well known (Kaiser 1984; Benson et al. 2000) that according to linear biasing the correlation function of the AGN (or any mass-tracer) ($\xi_{\rm AGN}$) and dark-matter one ($\xi_{\rm DM}$), are related by:

$$\xi_{\rm AGN}(r,z) = b^2(z)\xi_{\rm DM}(r,z) \ , \qquad (1)$$

where $b(z)$ is the bias evolution function (eg. Mo & White

1996, Matarrese et al. 1997, Basilakos & Plionis 2001; 2003; Basilakos, Plionis & Ragone-Figueroa 2008)

A first outcome of the proposed correlation function analysis will be the accurate determination of the AGN bias at their median redshift (in our case $\bar{z} \simeq 1$), utilizing:

$$b(z) = \left(\frac{r_0}{r_{0,m}}\right)^{\gamma/2} D^{3+\epsilon}(z) \;\text{ with } \gamma = 1.8 \;\&\; \epsilon = -1.2 \;,$$

where r_0 and $r_{0,m}$ are the AGN (measured) and dark-matter (from $P(k)$) clustering lengths, respectively and $D(z)$ is the fluctuations linear growing mode. Then using a bias evolution model one will be able to determine the mass of the DM halo within which such AGN live (eg. see Figure 2). To this end a detailed investigation of the local environment of the X-ray AGNs, using the available optical and IR data (SWIRE), will be of the outermost importance to verify the corresponding results of the bias-evolution analysis.

Furthermore, we can compare the observed AGN clustering with the predicted, for different cosmological models, correlation function of the underlying mass, $\xi_{\rm DM}(r,z)$. To this end we can use the Fourier transform of the spatial power spectrum $P(k)$:

$$\xi_{\rm DM}(r,z) = \frac{(1+z)^{-(3+\epsilon)}}{2\pi^2} \int_0^\infty k^2 P(k) \frac{\sin(kr)}{kr} {\rm d}k \;\;, \quad (2)$$

where k is the comoving wavenumber, $P(k) = P_0 k^n T^2(k)$ the CDM power-spectrum with scale-invariant ($n = 1$) primeval inflationary fluctuations, while the transfer function parameterization is as in Bardeen et al. (1986), with the corrections given approximately by Sugiyama (1995). It has been shown that in order to constrain the cosmological parameters a standard χ^2 likelihood procedure can be used to compare the measured XMM source angular correlation function with the prediction of different spatially flat cosmological models, using eq. (**??**) (eg. Plionis & Basilakos 2007 and references therein).

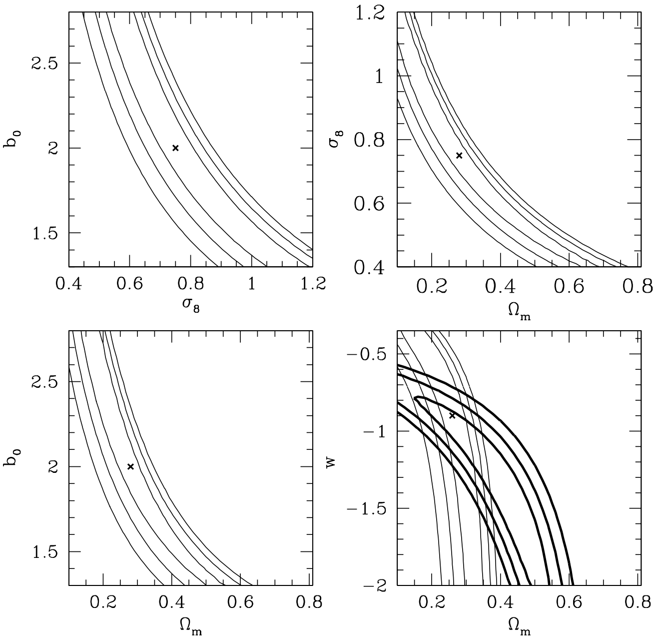

FIG. 3.— Likelihood contours in the following planes: $(\Omega_{\rm m}, \sigma_8)$ (upper right panel), (σ_8, b_0) (upper left panel), $(\Omega_{\rm m}, b_0)$ (bottom left panel) and the $(\Omega_{\rm m}, {\rm w})$ (bottom right panel). The contours are plotted where $-2{\rm ln}\mathcal{L}/\mathcal{L}_{\rm max}$ is equal to 2.30, 6.16 and 11.83, corresponding to 1σ, 2σ and 3σ confidence level. Finally, the thick contours corresponds to the SNIa likelihoods (taken from Basilakos & Plionis 2006).

In figure 3 we present some results from a preliminary analysis of Basilakos & Plionis (2006), marginalizing over different parameters. The lower right panel shows the 1σ, 2σ and 3σ confidence levels (continuous lines) in the $(\Omega_{\rm m}, w)$ plane by marginalizing over the σ_8 and the bias factor at the present time. It is evident that w is degenerate with respect to $\Omega_{\rm m}$ and that all the values in the interval $-2 \leq w \leq -0.35$ are acceptable within the 1σ uncertainty. Therefore, in order to break the degeneracies they additionally used the SN Ia data (eg. Tonry et al. 2003; Riess et al. 2004). and join their likelihoods. A preliminary joint likelihood analysis has provided: $\Omega_{\rm m} = 0.26 \pm 0.04$ with $w = -0.90^{+0.10}_{-0.05}$ (corresponding to $t_0 \simeq 13.5$ Gyr using $H_0 = 72$ km/s/Mpc).

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