What can we learn from AGN clustering measurements with eROSITA?

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Abstract

In the last decade, large area surveys (e.g., SDSS, 2dF, XMM-COSMOS) significantly improved AGN clustering measurements, which now provide tight constraints on the mass of the hosting dark matter halos (as a function of AGN luminosity, type, and redshift), the environment in which super massive black hole accretion takes place, and the co-evolution of galaxies and AGNs. eROSITA is expected to detect up to ~3 million AGNs. With a dedicated spectroscopic follow-up program, eROSITA will, for the first time, yield AGN clustering measurement with such low uncertainties to not only essentially improve our picture of AGN and galaxy co-evolution but also significantly constrain cosmological parameters, which is eROSITA's core scientific goal.

We demonstrate the potential of high-precision AGN clustering measurements using the eROSITA's precursor ROSAT. The ROSAT All Sky Survey (RASS) is currently the most sensitive X-ray all sky survey. Although relatively shallow, this data set has still a huge potential for science, especially when combined with other large-area spectroscopic surveys such as SDSS. Using a series of recently published papers that measure and analyze the clustering of RASS AGNs, we show the constraints from AGN clustering measurements. In the future, eROSITA will yield a complete picture of AGN clustering with unprecedented significance and discriminate between different AGN/galaxy co-evolution models. Furthermore, eROSITA clustering measurements have the potential to measure a Baryonic Acoustic Oscillation (BAO) signal at z~1, a redshift range that is not probed by any other BAO program such as BOSS or BigBOSS.

Introduction

In the era of ultra deep and large surveys, the clustering of galaxies is relatively well-measured compared with that of AGNs. The poor knowledge is mainly due to the lack of observable co-moving volume and the low number density of AGNs. eROSITA will detect up to ~3 million AGNs and allow clustering measurements with unprecedented high precision. Over the past decade the theory of large-scale structure formation together with measurement of auto- and cross-correlation functions of statistical samples of objects has become a key way to determine the total masses of bound objects such as galaxies and clusters of galaxies. A series of recently published papers studies the clustering of ROSAT (eROSITA's direct precursor) All Sky Survey AGNs and illustrates what can be learnt from these measurements.

Since the studies focus on the low redshift Universe (z<0.5) where the number density of AGN is very low, the cross-correlation technique is used. The method measures the cross-correlation function (CCF) between RASS AGN and a well-defined, large number sample of SDSS Luminous Red Galaxies (LRGs) and then infers the auto-correlation function (ACF) of the AGNs. Assuming a linear bias, we make use of Coil et al. (2009):

$$w_p(AGN|AGN) = [w_p(AGN|LRG)]^2 / w_p(LRG|LRG).$$

X-ray luminosity dependence on the clustering

The low uncertainties of the inferred broad-line AGN ACF from the RASS/SDSS combination allows us to split our sample into subsamples according to their X-ray luminosities. We report in Krumpe et al. (2010) an X-ray luminosity dependence of the broad-line AGN clustering in that higher luminosity AGNs cluster more strongly (~2.5σ, see Fig. 1) than their lower luminosity counterparts. We conclude that, on average, low luminosity broad-line RASS/SDSS AGNs cluster similarly to blue galaxies at the same redshift, while high luminosity RASS/SDSS AGNs cluster similarly to red galaxies.

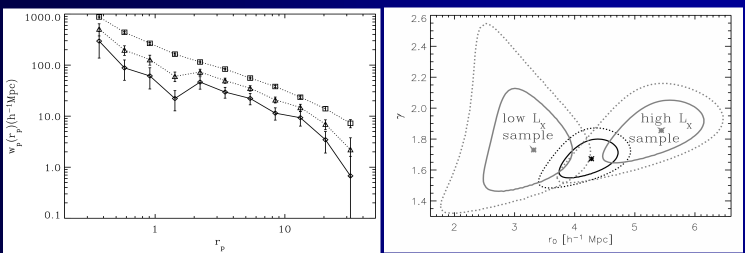

Figure 1: **left:** LRG-ACF (squares), RASS/SDSS AGN and LRG CCF (triangles), and inferred RASS/SDSS AGN ACF (diamonds) for the total RASS/SDSS AGN sample. **right:** Contour plot for the fit of r_0 and γ for the total RASS/SDSS AGN (black, central contour), low L_X sample (grey, left contour), and high L_X sample (grey, right contour). The solid contours represent the 1σ confidence intervals for a one-parameter, while the dotted lines illustrate the corresponding intervals for a two-parameter fit.

Halo Occupation distribution

In our second paper (Miyaji et al. 2011, ApJ, 726, 83) we develop a novel technique to apply a halo occupation distribution (HOD, Fig. 2) modeling directly to the AGN-LRG CCF. This allows us to constrain the full distribution of AGNs as a function of DMH mass (Fig. 3). One of the important results of this analysis is that at 0.16<z<0.36 models where the AGN fraction among satellites decreases with DMH mass is preferred beyond M_{DMH}~ 10^{12} h^{-1} M_{SUN}. This is in contrast to what is found for satellites galaxies.

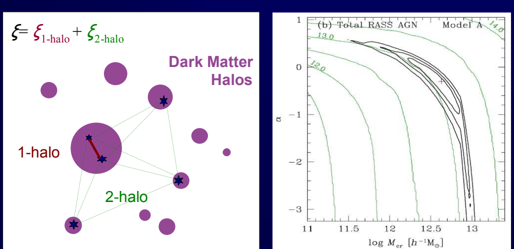

Figure 2: left: Sketch of the pairs contributing to the 1- & 2-halo terms in the HOD model. **right: The confidence contours (Δχ²=1; 2.3; 4.6) of the AGN HOD model parameters. The green contours represent the mean DMH mass of the model.**

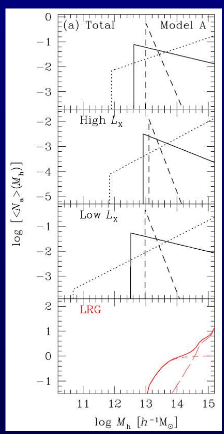

Figure 3: The HODs (<N_A>(M_h)) for three representative points in the parameter space that are acceptable (Δχ2 < 2.3) from our fits. For reference, the bottom panel shows the LRG HOD for the central galaxies (short-dashed line), satellites (long-dashed line), and their sum (solid line).

Current picture of AGN clustering

In the third paper (Krumpe et al. 2011, submitted to ApJ), we extend the redshift range of our CCF method to 0.07<z<0.50 and measure the clustering amplitudes of both X-ray and optically-selected broad-line AGNs. This adds more broad-line AGN clustering data points to the poorly studied low-redshift range and together with the high-redshift measurements from other studies allows us to identify some general findings for broad-line AGNs in the last few years (Fig. 4).

low redshift (z < 0.5):

- AGN cluster similarly to inactive galaxies, occupying M_{DMH} ~ $10^{12-13.5}$ h^{-1} M_{SUN}.
- Luminous broad-line X-ray AGN, red galaxies and lower X-ray luminosity AGNs and blue galaxies cluster similar.

high redshift (z > 0.7):

- X-ray selected (lower luminosity) AGNs seem to cluster more strongly than optically-selected AGNs

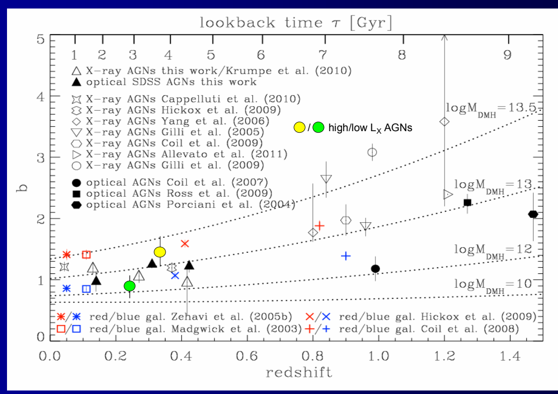

Figure 4: Bias parameter as a function of redshift for various AGN and galaxy samples (see text for details). Grey empty symbols and yellow/green filled circles represent X-ray selected AGNs, while filled symbols show optically selected AGNs. The dotted lines show the expected (simulations) b(z) of typical dark matter halo masses M_{DMH} based on Sheth et al. (2001). The masses are given in log M_{DMH} in units of h^{-1} M_{SUN}.

eROSITA AGN clustering measurements

We estimate the number density of AGNs detected with eROSITA from the log N/log S distribution using Gilli, Comastri, & Hasinger (2007). Assuming a dedicated spectroscopic follow-up program of 10,000 deg^2 and a spectroscopic completeness of 90%, we then infer the co-moving number density of objects for AGN clustering measurements as a function of redshift. We compare these value to the co-moving number density of SDSS Luminous Red Galaxies, which have been extensively used for galaxy clustering measurements and HOD modeling. Rescaling the LRG clustering uncertainties by using the co-moving density ratio yields rough but conservative estimates of the uncertainties of expected AGN clustering measurements with eROSITA. For more detailed studies extensive simulations are required. Below z<0.5 CCF measurements will allow further improvement of the errors.

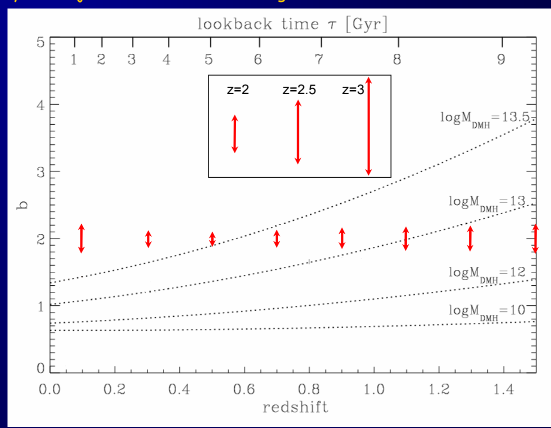

Figure 5: **Plot similar to Fig. 4. Now showing the expected uncertainties of eROSITA AGN clustering measurements using only 1/3 of the full eROSITA sample in each redshift bin of Δz=0.2 (allowing us to test for both luminosity dependences and redshift evolution).**

BAO signal from eROSITA AGN measurements?

eROSITA's detection rate of AGN will peak between z~1. The co-moving number density in this redshift range will be up to ~0.4 times the one of SDSS LRGs. Eisenstein et al. (2005) detected a Baryonic Acoustic Oscillation (BAO) signal using SDSS LRGs from 3816 deg^2. Depending on the final survey area (10,000-15,000 deg^2) of an extensive spectroscopic follow-up program, eROSITA has the potential to yield a BAO measurement in a redshift range not accessible by any other currently funded and planned project. Knowing the BAO scale at different cosmological epochs is of utmost importance to constrains the evolution of the dark energy's equation of state parameter.