Spatial Correlation Function of X-ray Selected AGNs in the Chandra Lockman Hole Fields

Why is clustering of AGNs interesting?
- Clustering of AGNs carries the information of the dark halos that host the supermassive blackholes.
- AGNs are probes of large scale structure at high redshifts because they are intrinsically brighter and abundant at high redshifts.

Previous Studies
- Optical: 2QZ, SDSS, z > 68 Mpc at z ~ 1-2
- Most recent: Soft X-ray, 80 square degree ROSAT NEP survey (Mullis et al. 2003); very similar to the optical results. Not surprising; most are broadline AGNs.
- Hard X-ray: CDFS similar in number but at 1; CDFS > higher than CDF, cosmic variance (Gilli et al. 2003).
- CLASH (0.4 square degree) (Yan et al. 2006): The correlation strength similar to that of optically selected quasars, even though the intrinsic luminosity is much lower than quasars in the 2QZ or SDSS sample.

Advantage of using X-ray
- X-ray selected AGNs have higher spatial density than optical selected AGNs (10x at z1). This gives the edge to X-ray in studying clustering because the correlation function is usually larger at the scales probed by X-ray than typically probed by optical surveys.
- While the visual optical of deep 2MASS surveys are not much smaller than the X-ray selected optical surveys, reasonably good results could still be obtained.
- X-ray could be capable of detecting the non-linear regime of clustering.
- X-ray survey probe much more luminosity range than optically selected quasars, and can help to understand the whole life cycle of supermassive blackholes.

Summary of data
- X-ray selected deep fields: 4 square degree followed up spectroscopically, and 156 redshifts obtained (Shi et al. 2005). The two fields are only 2 square degree, apart, allowing for joint analysis for 3D correlation function.
- CHANDRA (CDFS, LH)
  - CD (M15) 0.12 square degree - 360 spectroscopic redshifts (Shi et al. 2005).
  - The field is used to better probe void scales and c1
  - CDFS (M10) 0.16 square degree - 130 spectroscopic redshifts (Shen et al. 2005).

Redshift-Space Correlation Functions in the LH-NW Chandra Fields
- The 2-point correlation function, excess probability of finding a pair of objects at a given separation. In this paper, we calculated only the redshift-space separation:
- On a large range of mass scales, the correlation function has the form:
- $\xi(r) \propto \frac{1}{1 - r^2}

Combining the Chandra Deep and Wide Fields
- Combining the Chandra wide fields in the LH-NW region and the ultra-deep fields can give us so far the best constraint of correlation function X-ray selected AGNs.
- LH-NW: z < 0.75 (1.85, 1.45), R = 2.19 (1.29, 0.49).
- ALL: z > 0.75 (1.45, 0.95), R = 1.78 (1.39, 1.15).

Discussions
- The correlation function derived using ALL the Chandra fields is higher than that derived using only the two LH-NW fields but still within the margin of error. This is due to the redshift spike in the CDFS.
- There is a clear trend of flattening of the power-law index at small separations. The trend is mainly set by the cluster power-law seen in the two CDFS. More deep fields are needed to clarify the issue. If the trend is genuine, there is a very interesting possibility that the ultra-deep surveys are seeing a different population of AGNs than the shallower surveys do.

Conclusions
- The correlation functions X-ray selected AGNs from Chandra wide fields in the LH-NW region and the ultra-deep surveys are consistent with being at the same mass dependence.
- The correlation functions have been derived from the correlation function of the combined CDFS and LH-NW fields agree very well with that of the 2QZ quasars.
- The evolution of the X-ray selected AGNs clustering is z ~ 2-3 is still poorly constrained.

Evolution of AGN clustering
- The evolution of the correlation function in 4 redshift bins between 0.1 and 3.
- The correlation functions in CLASS and SVWELF fields agree very well with that of the 2QZ quasars.
- The redshift evolution in the clustering of X-ray selected AGNs; the correlation function at z ~ 2-3 is still poorly constrained.

Bias and typical mass of AGN hosts
- Bias = (2.3 + 0.5)2, underling measures how luminous matter tracks the mass distribution.
- On scales of 20 Mpc, the clustering of the dark matter in this mass regime and is well understood.
- CDFS hierarchical structure scenario is consistent with the results on larger scales. Using the formation time of the AGN host (200), the halo mass of the AGN host are found to be:
- HMa = 1.3 x 10^{12}

Conclusions
- The correlation functions of X-ray selected AGNs from Chandra wide fields in the LH-NW region and the ultra-deep surveys are consistent with being at the same mass dependence.
- The correlation functions of the Chandra fields used in this study can be mostly described by a power-law with x ~ 1.05 (0.45, 0.95) h (Mpc)^{-1} for x ~ 1.48 (1.14, 1.59). The power-law tends to be flatter at small separations. More deep observations are needed to address the full range of scales.
- The clustering evolution is very mild. This implies the bias factor increase rapidly with redshift, leading the halo mass of the AGN host is almost constant, indicating AGN evolution in a special epoch of massive galaxies and are probably low.