Clustering of X-ray Selected AGNs in the Chandra Deep Fields (and Implications for the XMM-XXL survey)

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Why AGN clustering is interesting?

LSS and Cosmology: Beacons at high redshift;

Since we know our universe “better” we can use clustering to study AGNs.

1. In CDM cosmology, large scale clustering of AGNs carries information about the dark halos that host the super massive black holes and how they evolve.
2. Combined with the luminosity function, we can also obtain the “duty cycle” of AGN activity.
3. The correlation function on small scale is useful in understand the AGN environment.

Dark matter halos and bias

- Structures form through collapses of over dense regions in the density field. Collapsed systems (galaxies, galaxy clusters) traces the underlying density field in a biased way. The bias parameter b is defined as

$$\frac{\delta n}{n}(x) = b\frac{\delta\rho}{\rho}(x)$$

The auto correlation function of galaxies is $\xi_G = b^2 \xi_{DM}$

- In the CDM cosmology, small halos collapse first and merge to form larger halos. Press-Schechter (1974) introduced a simple semi-analytical model which relates the number density of collapsed halos to the mass of the halos. Mo & White (1996) extended the formalism to calculate the correlation function of halos on large scales where halo-halo correlation dominates.

Halo mass and bias

- Various improvements to the Mo & White (1996) formalism were made (e.g. Jing 1998; Sheth & Tormen 1999; Jenkins et al. 2001; Heitmann et al. 2006) to better match the numerical simulations. In this work we adopt the formalism from Sheth, Mo & Tolmen (2001).

$$b(M,z) = 1 + \frac{1}{\sqrt{a}\delta_c(z)}[a\nu^2\sqrt{a} + 0.5\sqrt{a}(a\nu^2)^{(1-c)} - \frac{(a\nu^2)^c}{(a\nu^2)^c + 0.5(1-c)(1-c/2)}]$$

where $\nu \equiv \delta_c(z)/\sigma(M,z); a = 0.707; c = 0.6$ and δ_c is the critical over-density. $\sigma(M,z)$ is the rms density fluctuation in the linear density field and evolves as

$$\sigma(M,z) = \sigma_0(M)D(z) \quad , \quad \sigma_0 = \frac{1}{2\pi^2}\int dk k^2 P(k)\,|W(k)|^2$$

Clustering of AGNs in optical and radio surveys

Optical selected quasars: Until now most of the studies on AGN clustering focus on optically selected quasars, particularly those from the 2DF and SDSS.

- Scale dependent bias?
  - On scales > 20/h Mpc, quasars have similar clustering properties as those of bright galaxies.
  - On scales < 20/h Mpc, “anti-bias” is found in SDSS AGN samples at z< 0.3 (Li et al. 2006)
- Evolution of quasar clustering:
  - Croom et al. 2005: b~1 at z=0 and b ~ 4 at z=3;
  - Shen et al. 2007: b ~ 8 at z=3, b~16 at z=4.5;
  - Myers et al. 2006, 2007: no evolution in clustering below z=2;

Radio loud AGNs:

The radio loud AGNs are known to be more strongly clustered (Magliocchetti et al. 2004). They are also more likely to be found in galaxy clusters (Best 2004; Croft et al. 2007; Lin & Mohr 2007) .

Importance of X-ray selected AGNs

If we want to understand the AGN population as a whole, we need to study X-ray selected samples.

- X-ray directly probes the accretion onto black holes in AGNs.
- All known AGNs are X-ray emitters, but not all X-ray selected AGNs show optical activity. X-ray selected AGNs a superset of the optically selected AGNs (Mushotzky 2004)
- The spatial density of AGNs accessible with Chandra and XMM is much higher than using optical selection AGNs.
  - This gives the edge to X-ray in studying clustering because clustering signal is significantly higher at the scales probed by X-ray than typically probed by optical surveys.
  - Also allows study of clustering on small scales where nonlinear process become important.
- X-ray survey probe much broader luminosity range than optically selected quasars, and can help to understand the life cycle of super massive black holes.

Data used in this study

Chandra surveys and optical follow-ups

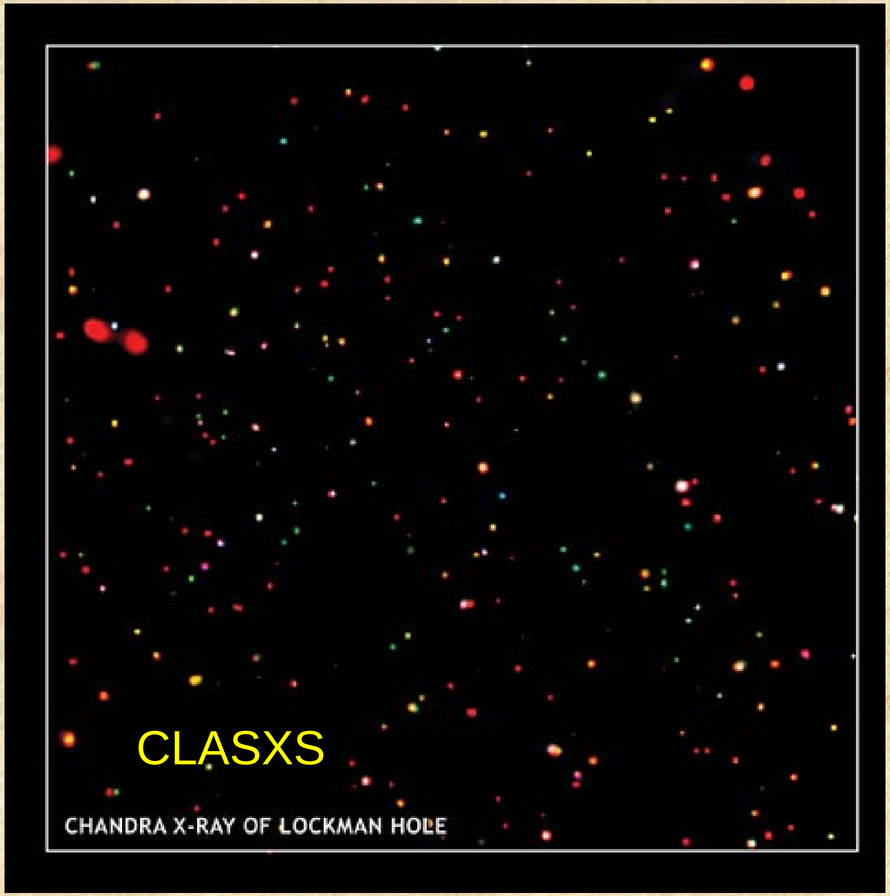
Wide moderate deep field surveys:

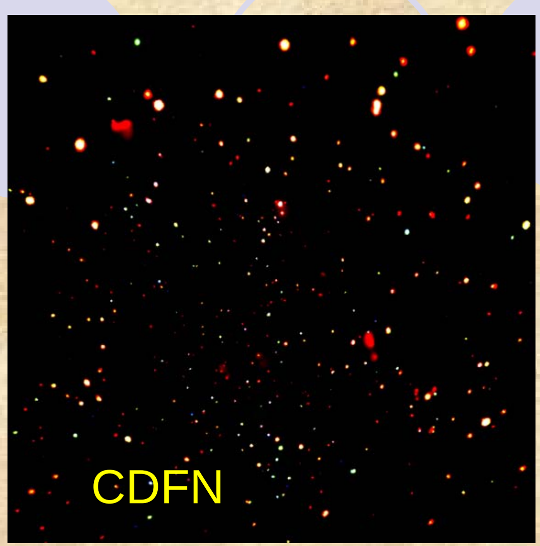
- CLASXS: 0.4 square degree, 40 - 70 ks exposure; 272 spectroscopic redshifts (Yang et al. 2005, Steffen et al 2005);
- SWIRE-LH: 0.6 square degree, 70 ks expsure ~0.4 square degree followed up spectroscopically, and 196 redshifts obtained. (Trouille et al 2008 submitted).
- The two fields are only ~ 2 degree apart, allows for joint analysis for 3D correlation function.

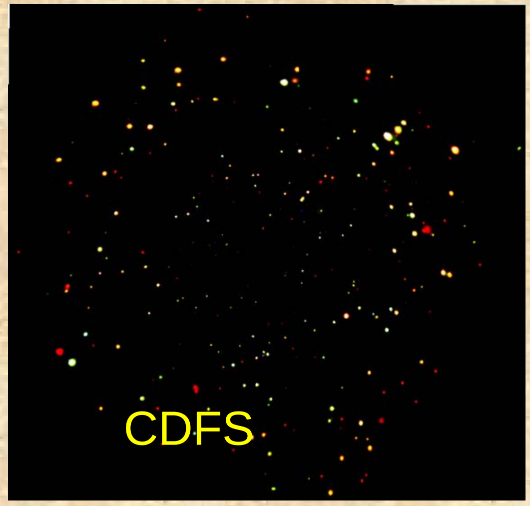
Ultra Deep fields:

- CDFN (2Ms): 0.12 square degree, 306 spectroscopic redshifts (Barger et al 2003). The field is used to better probe small scales and z<1.
- CDFS (1Ms): 0.11 square degree, 133 spectroscopic redshifts (Szokoly et al. 2005).

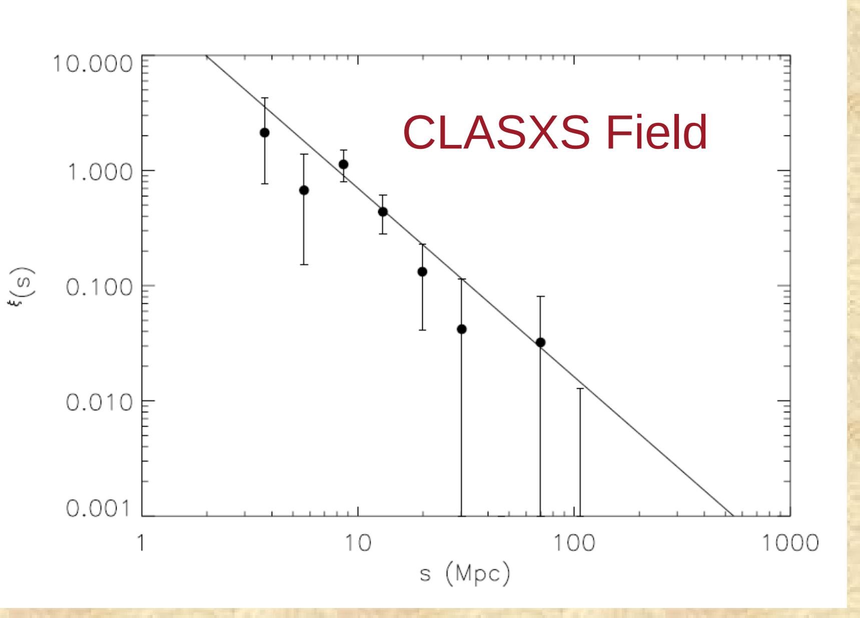
Survey data

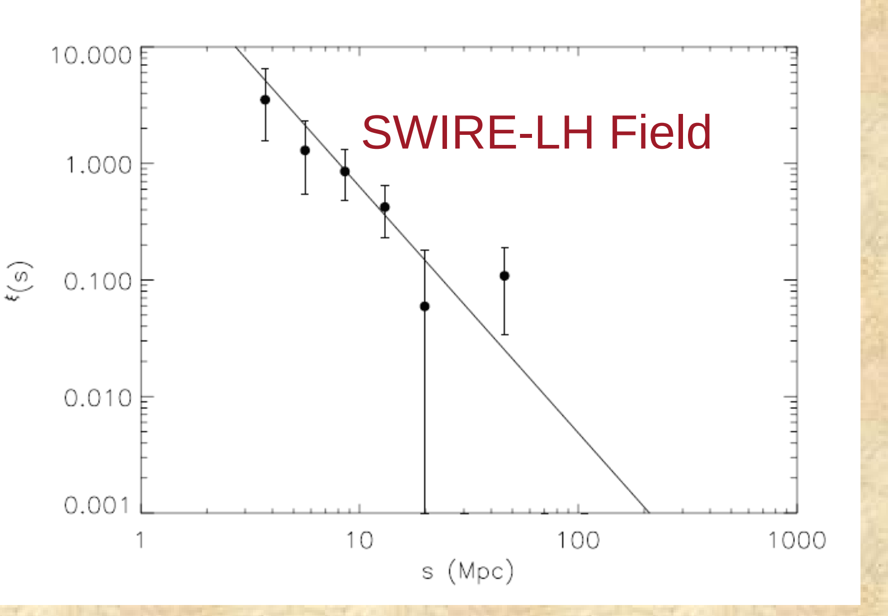






Redshift-Space Correlation Functions in the LH-NW Chandra Fields



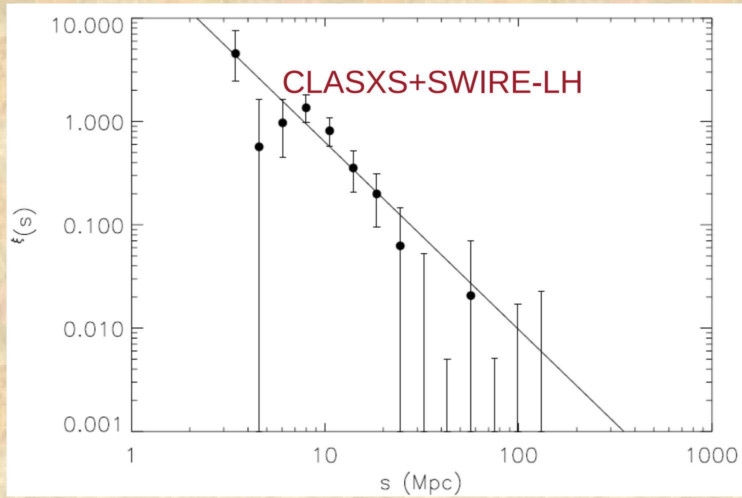


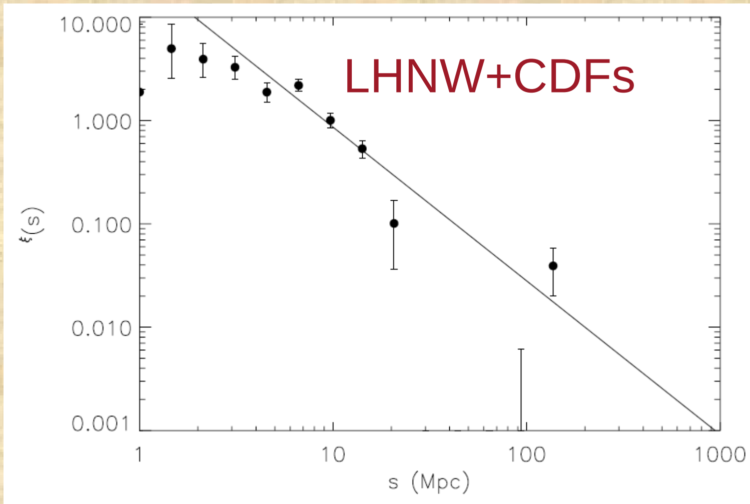
1. Z-space correlation function for the two wide fields in LH region are calculated in the redshift range of 0.3 to 3, and in the separations of 3 to 200 Mpc .
2. CF fitted with power-law

$$\xi(s) = \left(\frac{s}{s_0}\right)^{-\gamma}$$

3. CLASXS: s0 = 5.64 (4.29, 6.42) h^-1 Mpc; γ = 1.58 (1.26, 1.96) ; Numbers in the parenthesis are the 1 σ upper and lower limits.
4. SWIRE-LH: s0 = 5.86 (4.72, 6.85) h^-1 Mpc; γ = 2.08 (1.61, 2.68)
5. The correlation function in the two fields agree very well.

Combining the Chandra Deep and Wide Fields





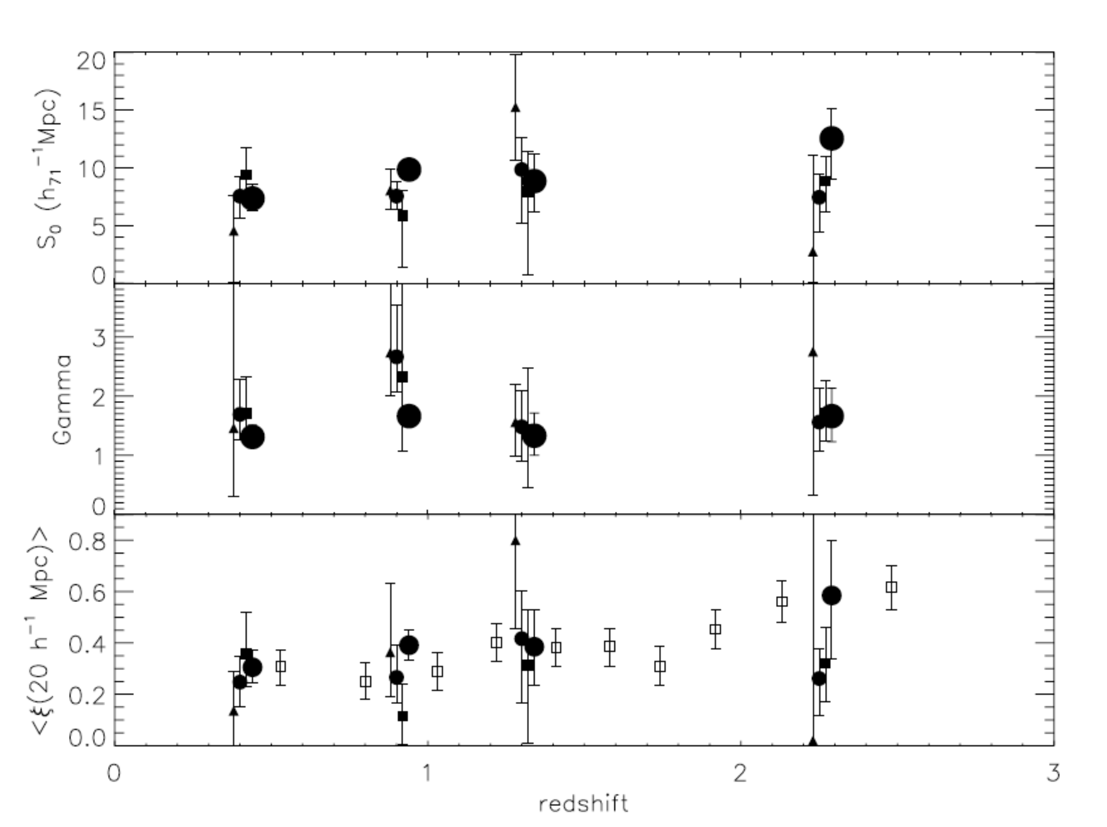
- Combining the Chandra wide fields in the LHNW region and the ultra-deep fields can give us so far the best constrain of correlation function of X-ray selected AGNs.
- LHNW: s0 = 5.50 (4.72, 6.28) h^-1 Mpc; γ = 1.81 (1.54, 2.13)
- ALL: s0 = 6.42 (6.00, 6.85) h^-1 Mpc; γ = 1.48 (1.41, 1.59)
- The higher correlation function in the LHNW+CDFs is caused by a large scale structure found in CDFS.
- The correlation function flatter at small separations.

Comparing with other observations

- Chandra XBootes field (Hickox et al. 2006), 9 deg^2, 3D z-space 2PTCF; s0~6.2 h^-1 Mpc;
- XMM-LSS (Gandhi et al. 2006), 4.3 deg^2, Angular CF and Limber inversion: r0 = (6+/-3) h^-1 Mpc;
- XMM-COSMOS (Miyaji et al. 2007) 2 deg^2 Angular CF and Limber inversion: r0 = (6-12) h^-1 Mpc;
- XMM 2dF (Basilakos et al 2004, 2005), 2 deg^2, Angular CF and Limber inversion: r0 = (7-19) h^-1 Mpc;

- Are highly obscured AGNs more clustered? Cosmic variance? Integral constraint uncertainty in angular correlation function?

Evolution of AGN clustering



Small square: CLASXS; Small triangle: SWIRE-LH;
Small Dot: LH-NW 2 fields; Large Dot: All 4 Chandra fields;
Small boxes: 2dF/2QZ;

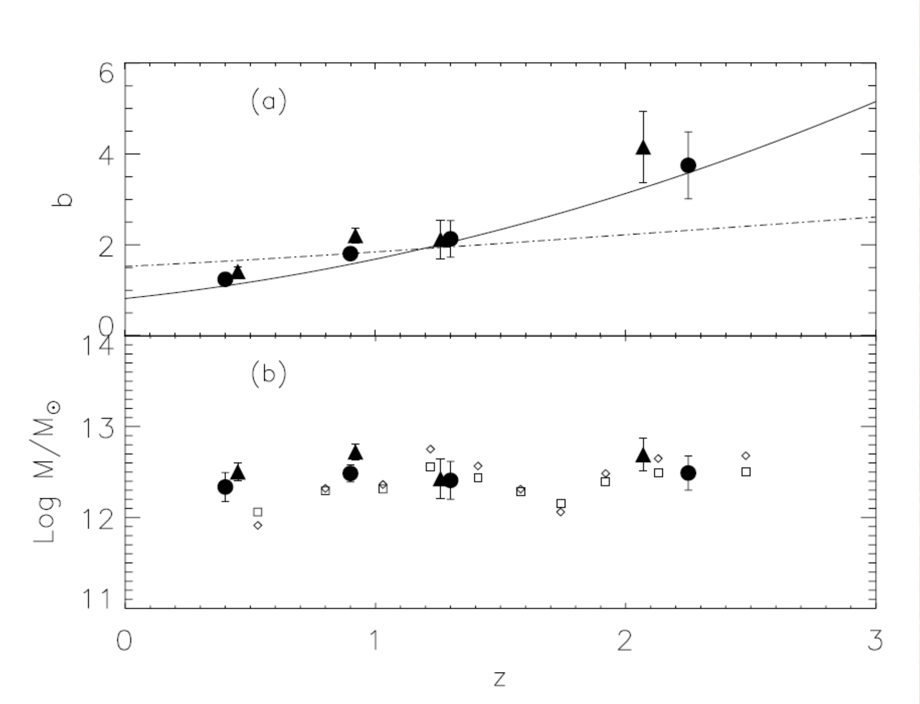
The evolution of correlation function in 4 redshift bins between 0.1 and 3.

- The correlation functions in CLASXS and SWIRE-LH fields agrees within large statistical errors.
- The correlation function of the combined 4 chandra fields agrees very well with that of the 2QZ quasars.
- Only mild evolution in the clustering of X-ray selected AGNs, the clustering at z=2-3 is still poorly constrained;

Bias and typical mass of AGN hosts

- We use the formalism of Sheth, Mo & Tormen (2001) to estimate the averaged halo mass of the AGN hosts.
- The evolution of bias agrees very well with that from 2DF quasars.
- The average mass of halos do not appear to evolve with redshift.

$$\langle M_{halo} \rangle = 2.5 \times 10^{12} M_{Sun}$$



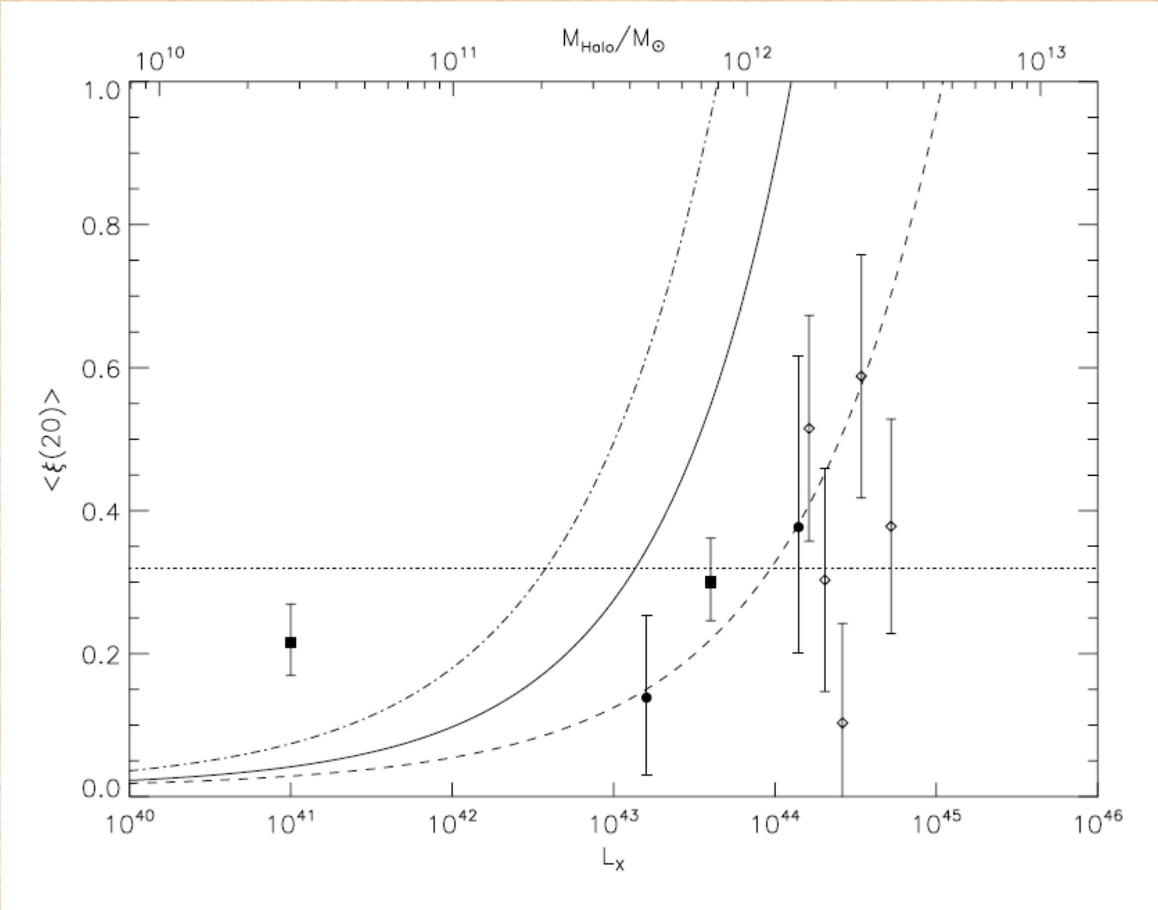
Dots: All samples; Trangles: Yang et al. 06 Boxes: Croom et al 2005; Dashed line: linear evolution of bias; Solid line: the empirical best-fit bias evolution from Croom et al 2005.

Luminosity dependence of clustering

- The luminosity of AGNs evolve strongly with cosmic time as suggested in recent surveys (e.g. Barger et al. 2005), but we see very little evolution in the average mass of the AGN hosts. This is consistent with some recent simulation inspired models that suggest the luminosity of an AGN is mainly determined by its evolutionary stage of the host galaxy (Lidz et al. 2006; Hopkins et al. 2008): quasars are at the peak of AGN activity, while AGNs spend most of their lives in low luminosity states.

- It is still surprising that little correlation exists between (bolometric) luminosity and clustering in quasar samples for the following reason.
  - Observation show that the mass of the supermassive black holes show strong correlated with the galaxy bulge and also with the mass of the halo (Ferrarese 2002);
  - It has also been demonstrated that the blackhole mass is correlated with the X-ray or bolometric luminosity of at least broad line AGNs (Barger et al. 2005)
  - These suggest X-ray luminosity should be correlated with the halo mass of the AGN host and hence the clustering amplitude.

Test for luminosity dependence



CLASXS and CDFN, Yang et al 2006

- We use sources with 0.3<z<1.5 so the evolution effect is small.
- Only mild correlation between Lx and correlation amplitude.
- If the 2dF quasars are also included, there is no correlation at all!
- The models assumes:
  - Fractional BH mass from Ferarese 02;
  - BH mass – Lx relation from Barger et al. 05;
- The outlier at the low end of the luminosity may be LINERS.

Open questions in AGN clustering

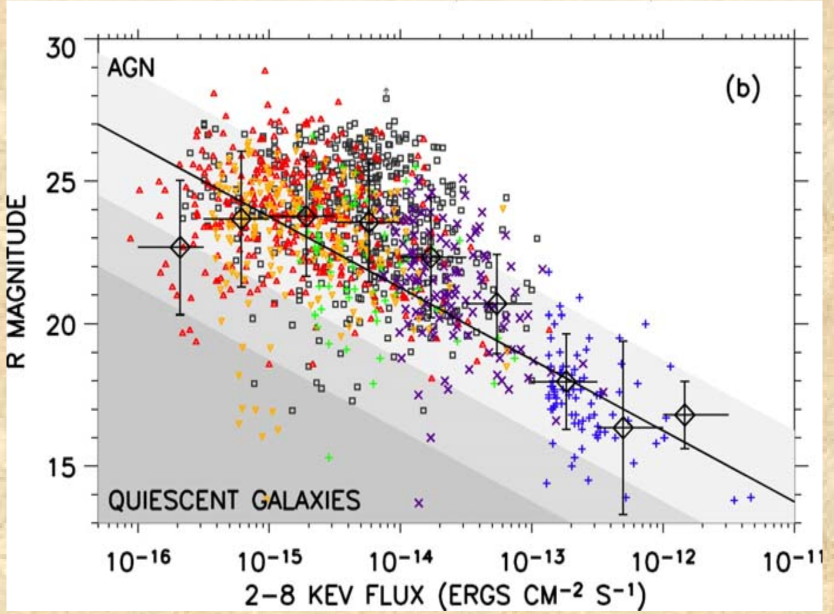
- What is the clustering properties of AGNs at z>3?
  - X-ray survey so far has not produce a high red shift sample that is useful for study AGN clustering at z > 3.
  - SDSS study show the bias of quasars at high red shift can be higher than expected (Shen et al 2007). It is unclear if this is a selection effect.
- Is there a scale dependent bias?
  - “Anti-bias” on small scales has been observed in low red shift AGNs in SDSS (Li et al. 2007).
  - Chandra data also seem to suggest scale dependent bias.
  - This could be an environment effect that reduces AGN activity in very high density regions.
  - Indeed, passive (“red”) and active (“blue”) show different scale dependent bias. Better constrain the scale dependent bias of AGNs could help better understanding of AGN activity and star formation.

Cosmology with AGNs

- An obstacle to use AGNs as a cosmology tool is their strong evolution. However, the very weak evolution of AGN hosts in the LCDM cosmology may suggest an invariant and may have an applications in cosmology.
- If one could determine bias independently, then the redshift distortion can be used to constrain Ω_M (Kaiser 1987).
- Strong gravitational magnification of high-z AGNs can also be very useful in constraining dark matter.
- Probe baryon acoustic oscillation (standard rod) at z=1? Spectroscpic follow-up is definitely needed.

Implications for the design of XMM-XXL Survey

- Large area ~100 sq deg to acquire a large sample of galaxy clusters at z~1; Such a survey reaches 2-8 keV flux limit of 5E-15 – 1E-14 cgs unit that will generate ~10,000 – 30,000 AGNs.
- Contiguous or semi-contiguous fields are needed for clustering study.
- Optical ID critical, which limits the depth of XMM observation because the large PSF could increase false ids.
- Optical data should allow ID for majority of AGNs hosts at z~2 and bright quasars at z>5.
- Multi-wavelength data desired;

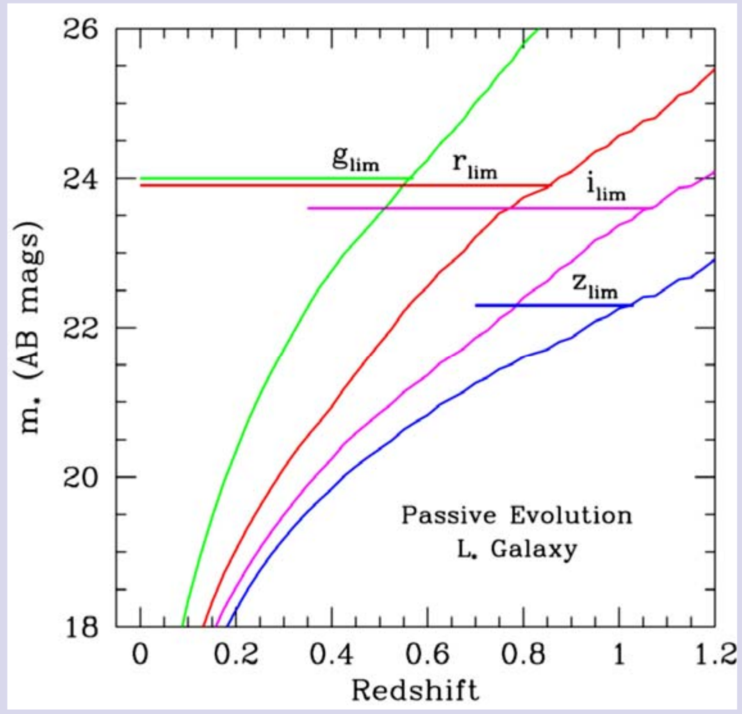


Steffen et al. 2004

The X-ray optical correlation become very scattered at fx < 1E-14 cgs, mainly caused by the increased fraction of optically normal galaxies.

Blanco Cosmology Survey

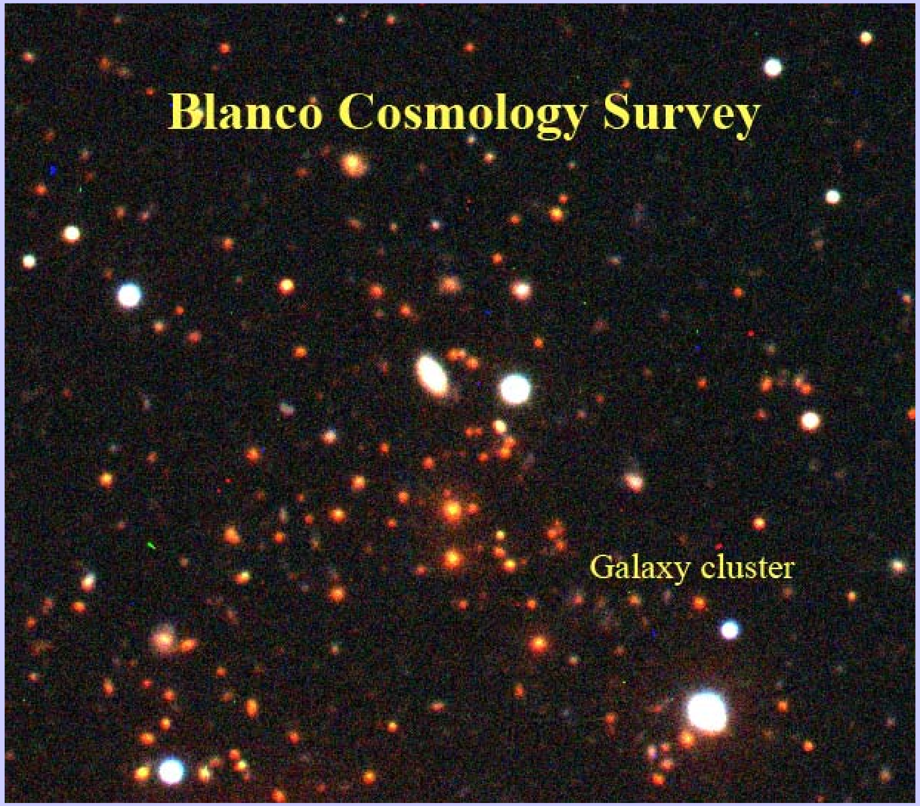
- Primary science goal is to enable cluster and AGN science in combination with SPT.
- Data from Spitzer and XMM approved for part of the field.
- Two 50 deg^2 BCS Fields to allow efficient observing (75% observed)
  - Target depths (10σ in 2.3 arcsec aperture)
    - *g,r,i,z*=24,23.9,23.6,22.3
    - L_* to z=1 for passively evolving population.
- Will provide photo-z for 3 million galaxies for power-spectrum or correlation functon up to z~1.
- The filter choice suitable for detection of high-z quasars. .

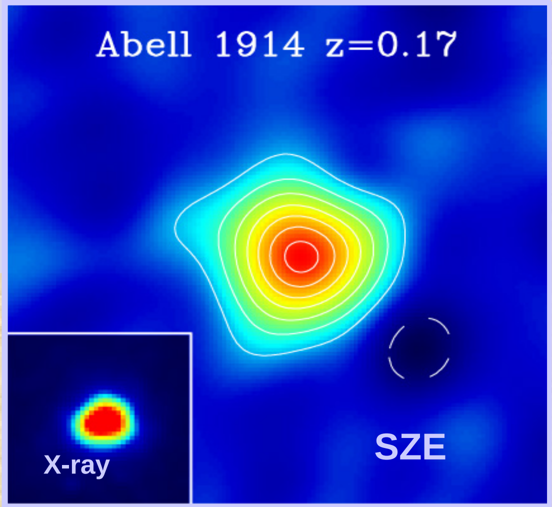


The data processing use the same Pipeline built for DES data management.

Blanco Cosmology Survey

http://cosmology.uiuc.edu/BCS





Concluding remarks

- Clustering of AGNs is useful for statistically constraining the host galaxies of AGNs.
- X-ray surveys provide unbiased sample of AGNs as a population.
- The spatial density of AGNs that can be achieved with XMM and Chandra is much higher than the current large optical surveys. This allows better S/N in correlation function with much smaller survey area.
- The spatial correlation function using the combined samples from CLASXS, SWIRE LH and CDFN/S agree with the clustering properties of optically selected AGNs. The bias factor increase quickly with red shift. The average mass of the halos of AGN hosts is ~2.5x10^12 M_sun. The mass does not change with redshift between z=0 to 3. Luminosity dependence of clustering is weak, indicating the X-ray LF is dominated by AGN activity rather than the mass of the black hole.
- The XXL survey should be able to answer questions about the clustering properties of AGNs at z>3, and how bias depend on scale. Large sample of AGNs can provide good probe of large scale structure at z~1.
- XXL can provide the best constrain of the AGN LF at z>4.
- With the rich multi-wavelength coverage, BCS is a option to conduct the XXL survey.