The Clustering of Optical and X-ray AGN to z=1

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The Spatial Clustering of ROSAT All-Sky Survey AGN:

I. The cross-correlation function with SDSS Luminous Red Galaxies
Krumpe, Miyaji & Coil 2010, ApJ, 713, 558 arXiv: 1002.3598

II. Modeling with Dark Matter Halo Occupation Distribution
Miyaji, Krumpe & Coil ApJ submitted

AGN Clustering: Why?

Can test AGN evolution models by measuring the observed clustering of AGN, ideally as a function of luminosity, redshift, BH mass, accretion rate.

Clustering measurements can constrain:

- host dark matter halo mass / large-scale environment
- host galaxy type
- AGN lifetime
- fraction of AGN in central vs satellite galaxies
- quantitatively constrain models

AGN Clustering: How?

Measure clustering using the 2-point correlation function, $\xi(r)$, which measures the probability of finding 2 objects with separation r in excess of a Poisson distribution:

$$dP = n\,(1 + \xi(r))\,dV$$

In practice, compute by counting pairs of objects with a given separation compared to a random catalog:

$$\xi(r) = (DD(r) / DR(r)) - 1$$

auto-correlation : same object sample

cross-correlation : two different object samples

AGN Clustering: How?

To robustly measure clustering, you need:

- spectroscopic redshifts
- large volumes
- a well-defined and replicable selection function (spatial + z)

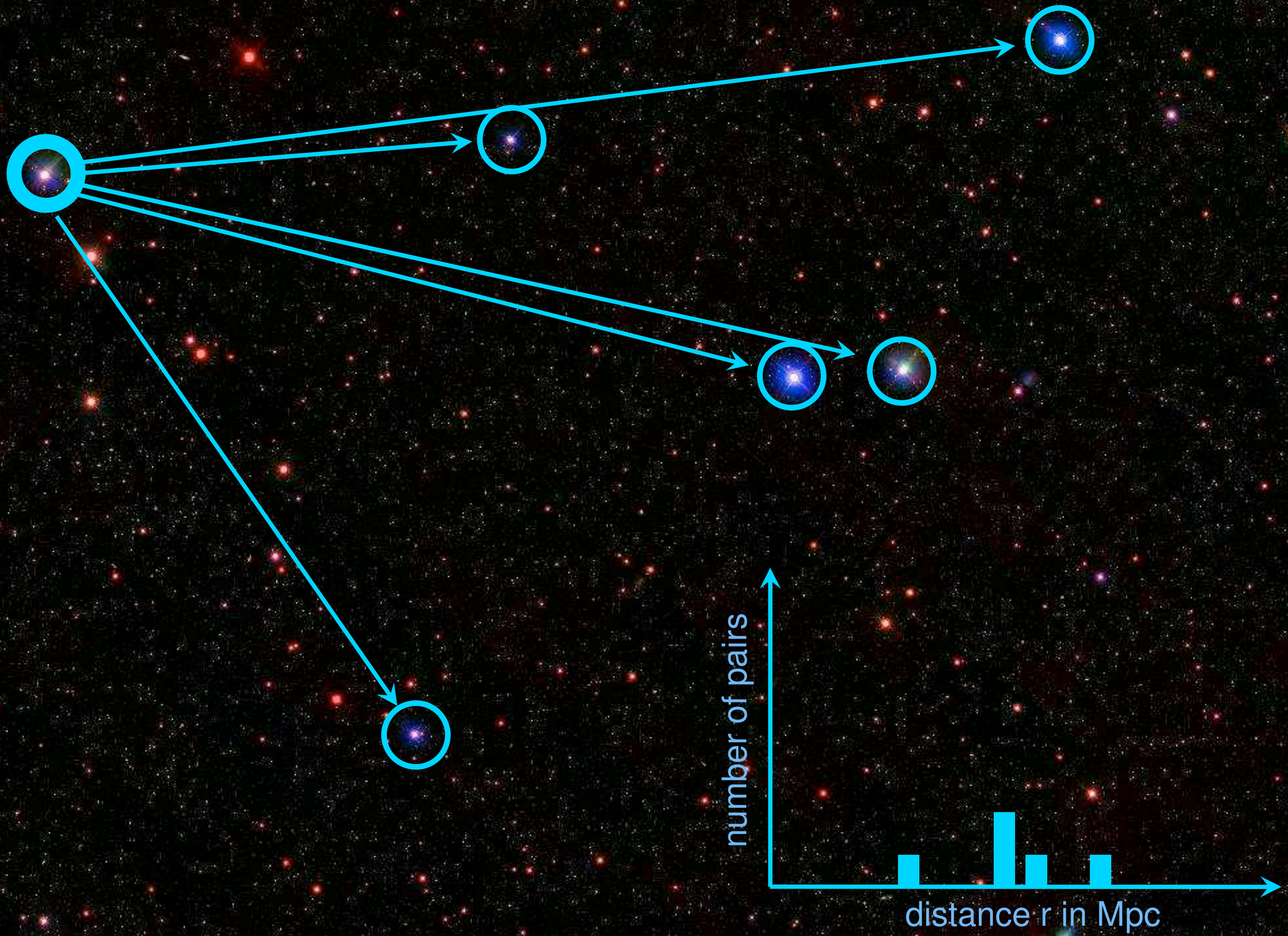
Large surveys such as SDSS, 2dF, AGES, DEEP2, zCOSMOS, etc. provide samples of 10s-100s thousands of galaxies which trace the cosmic web.

Galaxy clustering depends on color, luminosity, morphology:
- brighter / redder / elliptical galaxies are more clustered than fainter / bluer / spiral galaxies

More clustered means reside in more massive dark matter halos (quantified through dark matter simulations).

auto-correlation function

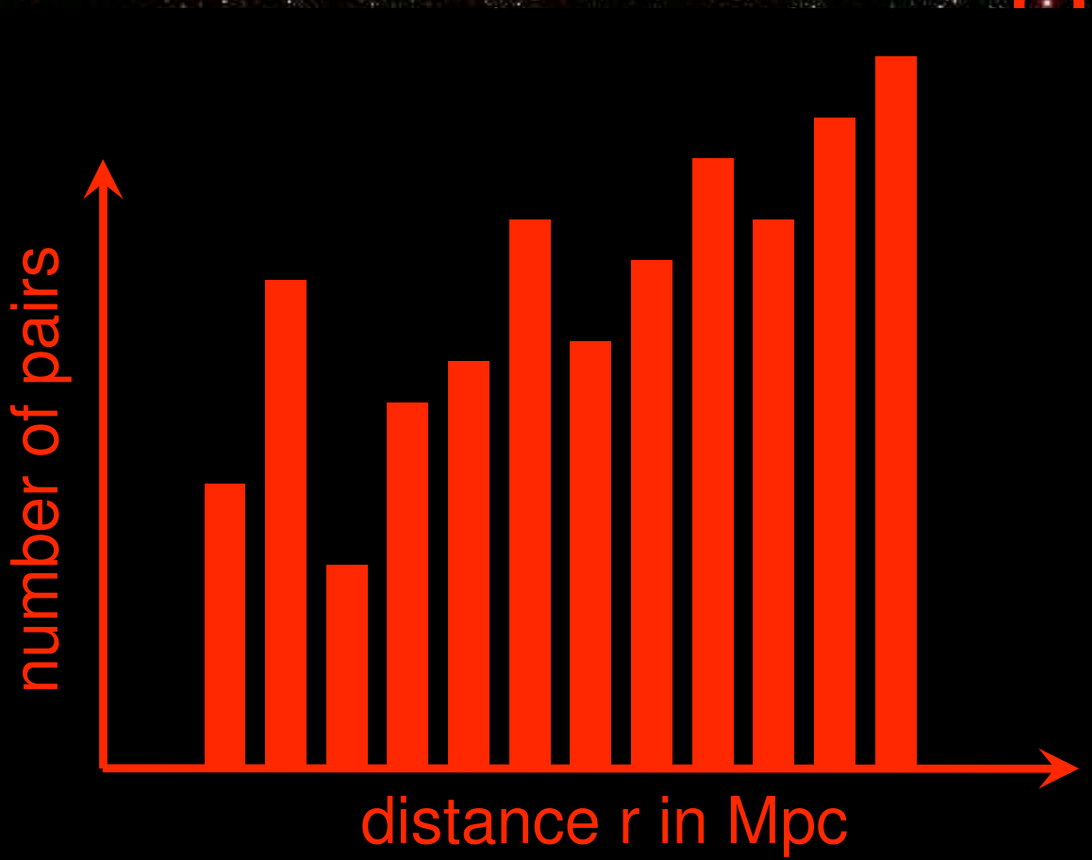
AGN



tracer set

cross-correlation function

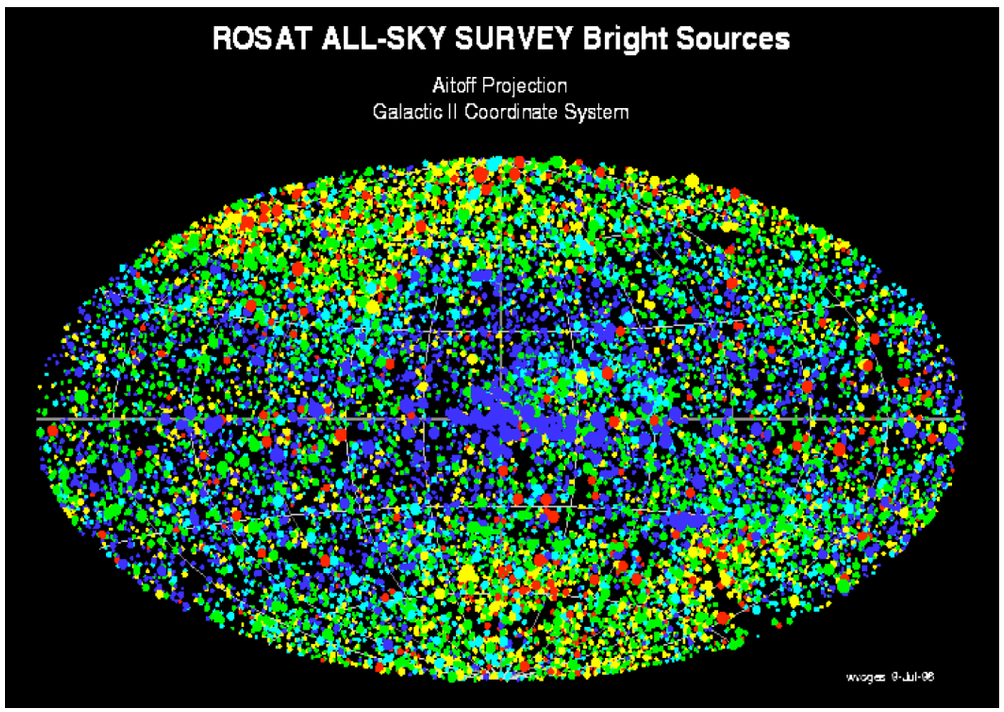
AGN



RASS AGN Sample

AGN sample: ROSAT All-Sky Survey (RASS)

(RASS: Voges et al. 1999, SDSS z's: Anderson et al. 2003, 2007)

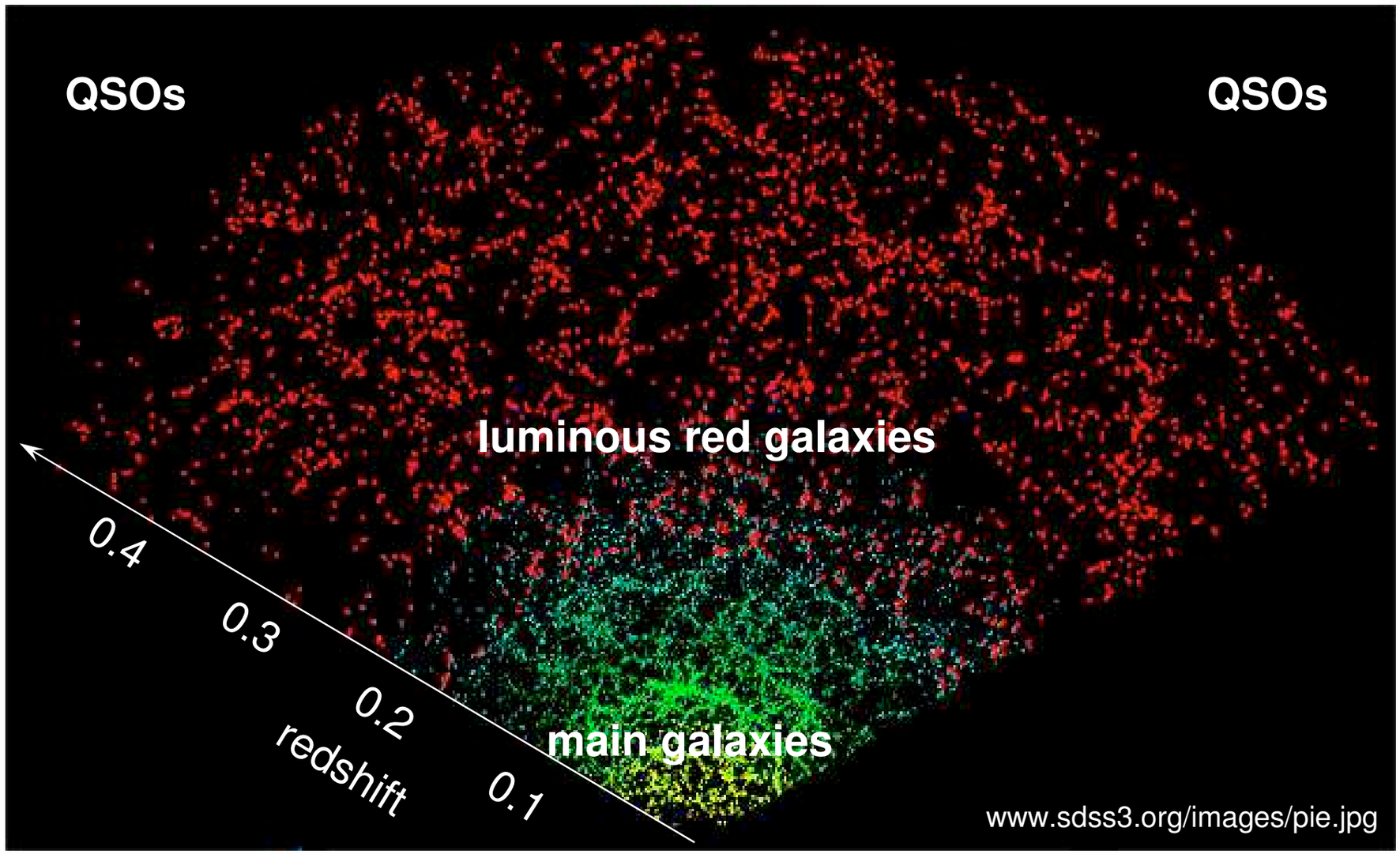


color = soft-band hardness ratio

- Selected in the soft 0.1-2.4 keV band
- Spectroscopic redshifts from SDSS
- 6224 *broad-line* AGN (we use 1552)
- $0.01 < z < 4$ (we use $0.16 < z < 0.36$)
- our L_X range ~ 10^{43} - 10^{45} erg s^{-1}
- our average L_X =$10^{44.3}$ erg s^{-1}

Tracer Sample

For the tracer sample, you want high number density (>> AGN)
and a well-defined and replicable selection



Clustering → Bias

From the AGN-LRG cross-correlation measurement:

→ divide by the measured auto-correlation of LRGs

→ infer the AGN auto-correlation function

From the AGN auto-correlation function:

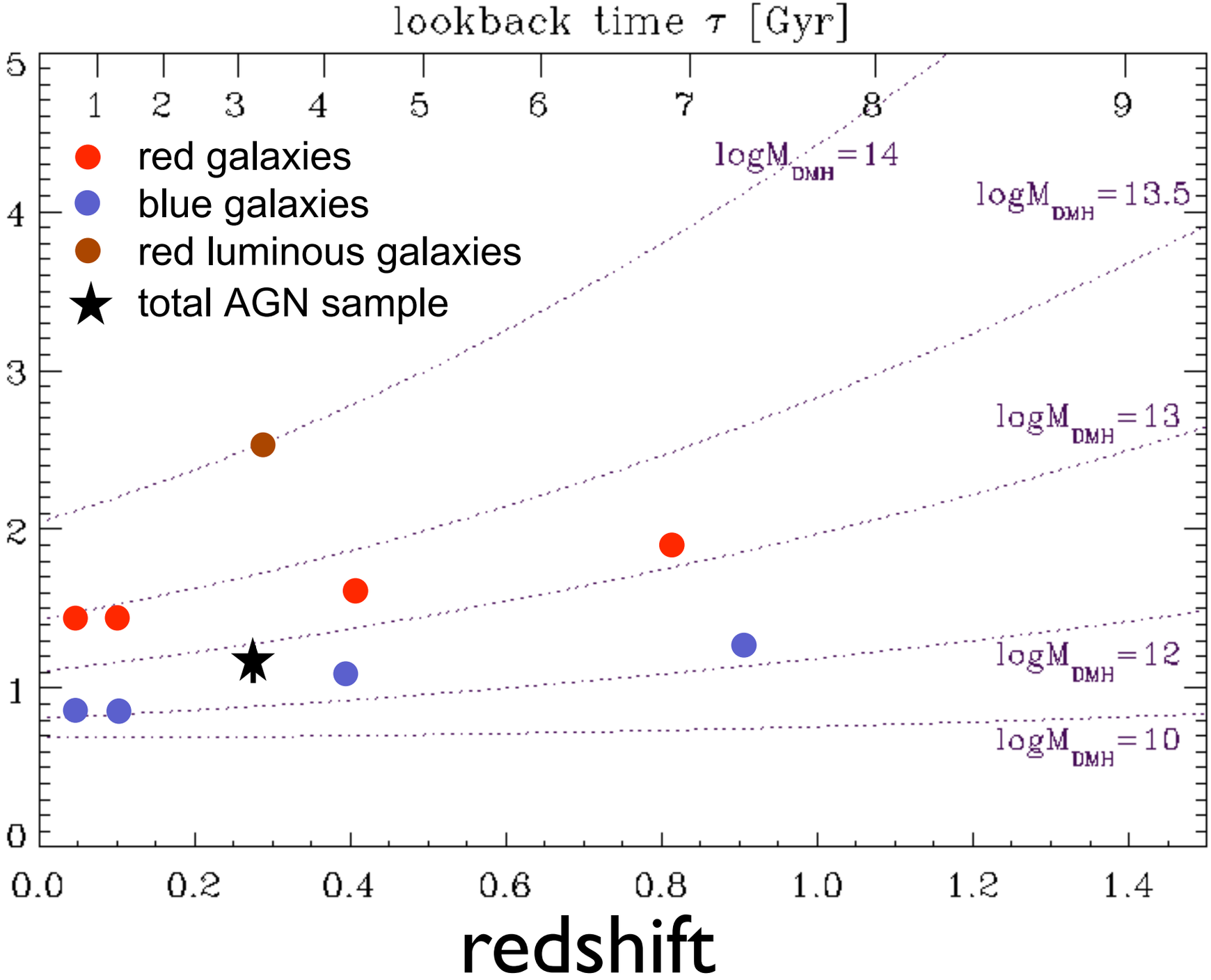
→ derive the bias (how strongly a particular class of objects is clustered relative to dark matter)

→ infer the average host dark matter halo mass

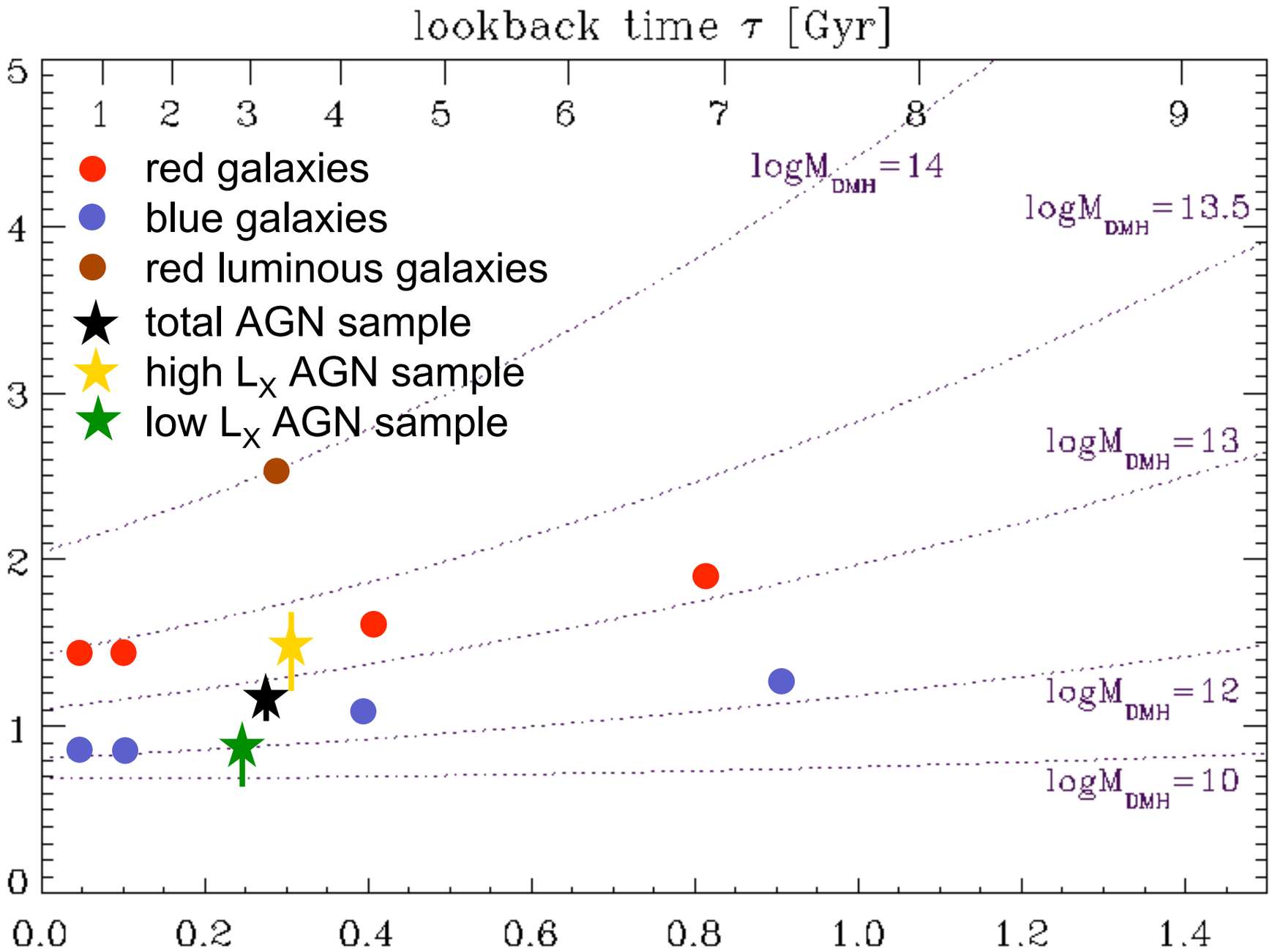
→ compare with clustering of galaxies to constrain host galaxy type

RASS AGN and galaxy bias vs. redshift

bias

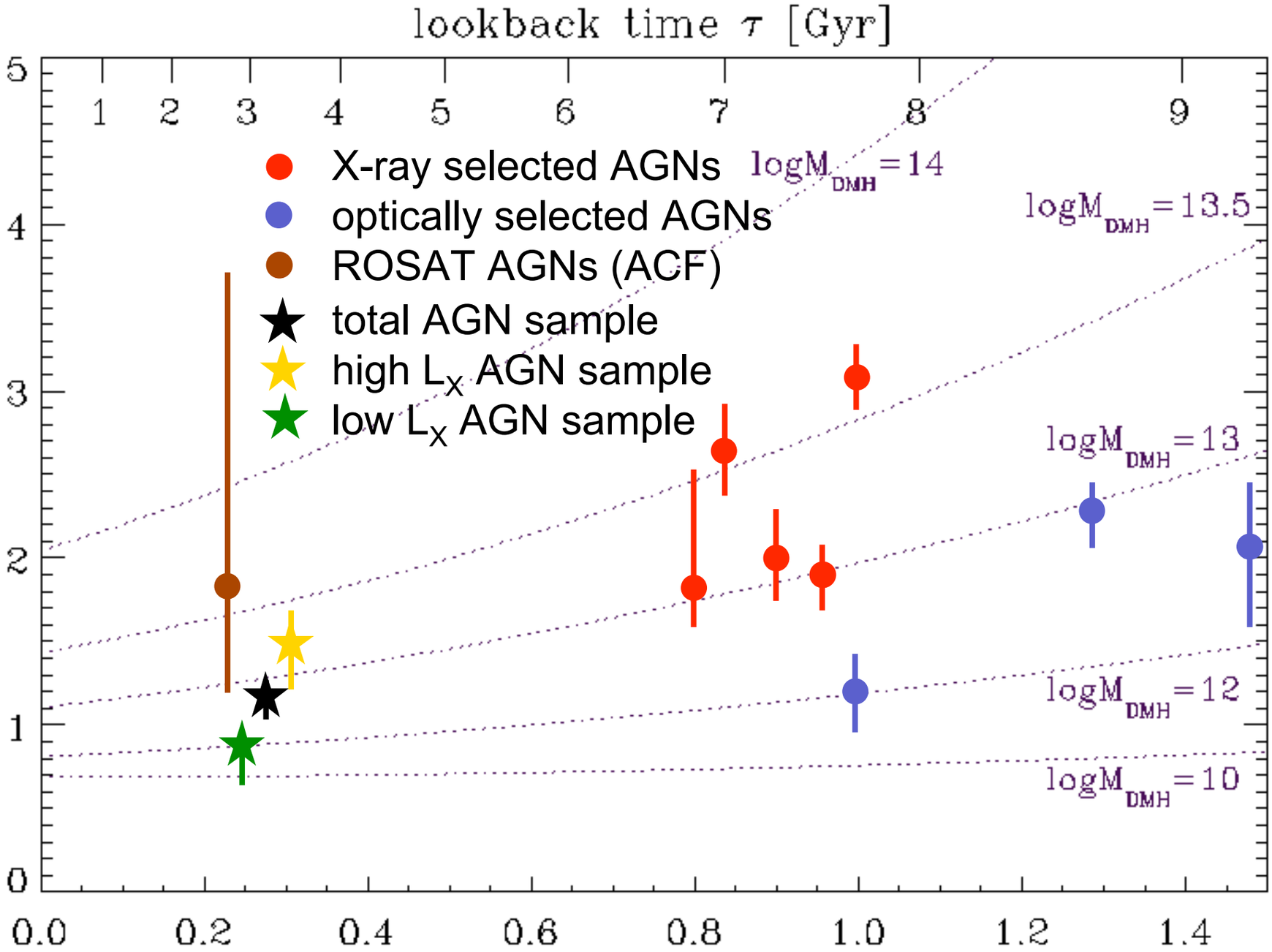


RASS AGN and galaxy bias vs. redshift



RASS AGN and other AGN bias vs. redshift

bias



Halo Occupation of RASS AGN

Which halos do RASS AGN live in?

$<M_{halo}>=10^{13.1}\ M_\odot/h$ (ie, **groups**)

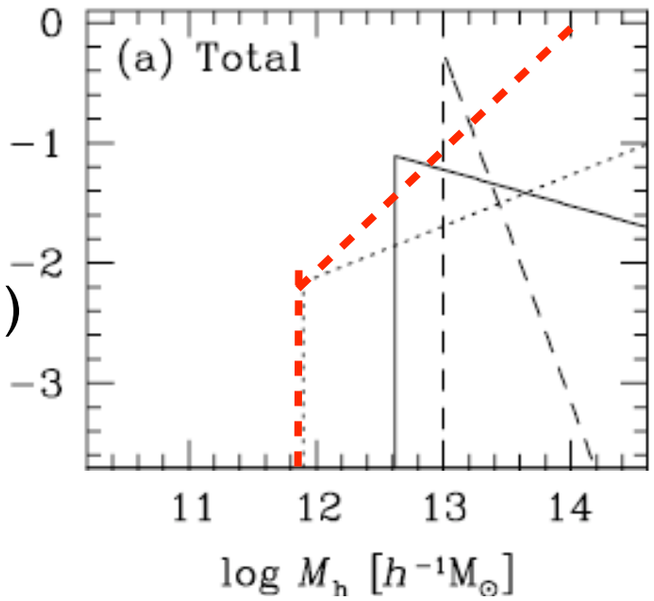
Lower fraction of AGN in clusters!

Halo mass range is *narrower* than for galaxies!!

galaxies

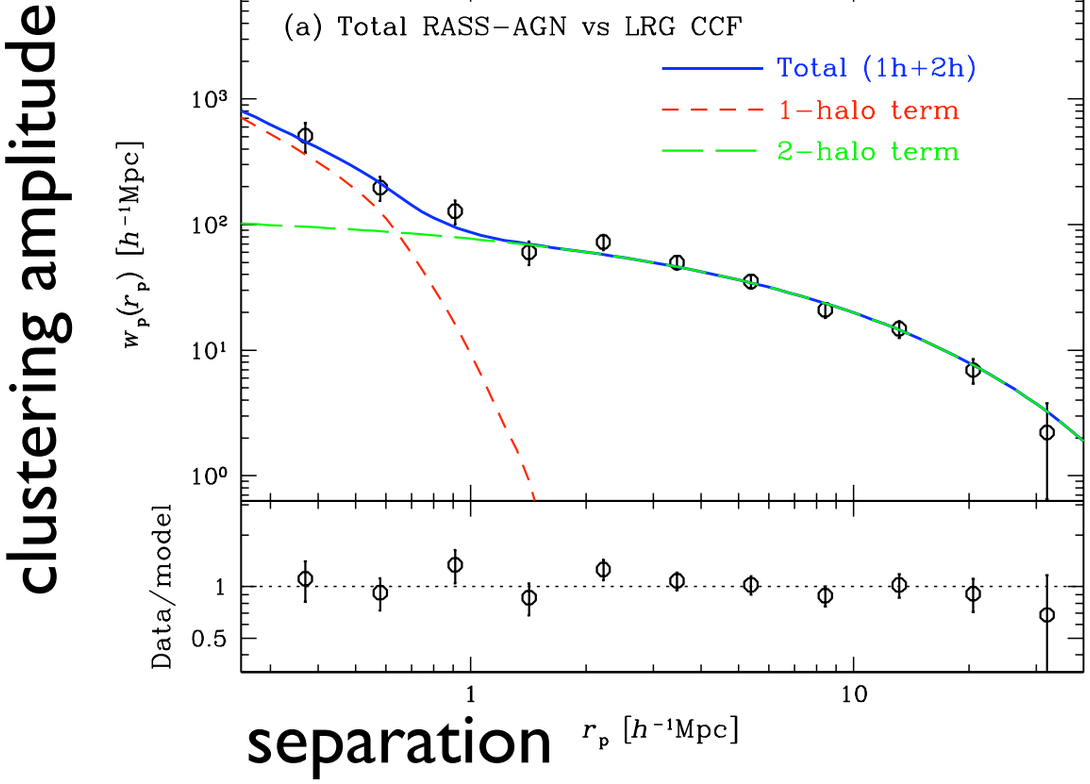
HOD:

$<N_{AGN}>$
$(h^3\ Mpc^{-3}\ \log M_h^{-1})$



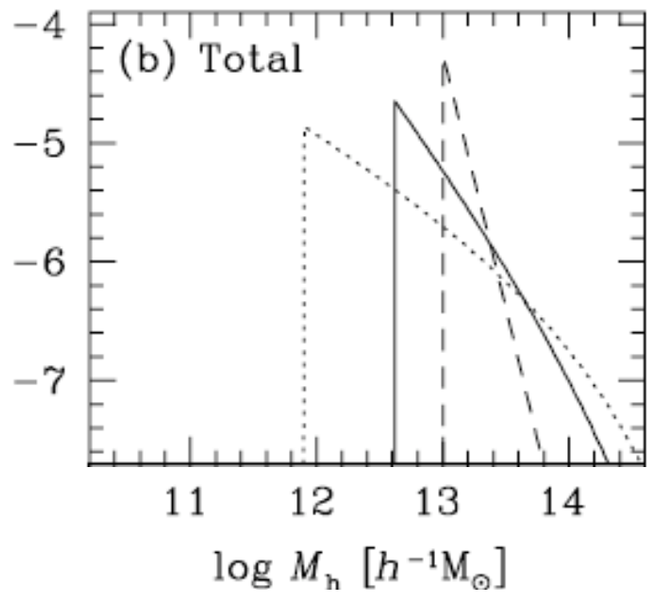
halo mass

clustering amplitude



number density:

n_{AGN}
$(h^3\ Mpc^{-3})$



Current and Future Work

• We are currently extending our redshift and luminosity baselines by measuring the cross-correlation of RASS X-ray AGN with both lower-redshift main SDSS galaxies (z~0.1) and higher redshift LRGs (z~0.45), as well as measuring the clustering of fainter AGN using optically-selected broad-line AGN in the same redshift range (z~0.1-0.45) (paper III, in prep.)

• We will then measure the clustering amplitude of the RASS AGN and SDSS QSOs as a function of black hole mass (typically ~10^8) and Eddington ratio (range 1-50%) (paper IV).

Current work of close collaborators

• James Aird (postdoc, UCSD) has quantified the evolution of the hard X-ray AGN LF to z~5 (see poster and arXiv: 0910.1141). He finds that the XLF retains the same shape but evolves in luminosity and density to z=3. There is *no* flattening of the faint-end slope at high-z. Has new results for low-luminosity AGN at z~4-5 from AEGIS-XD (800ks depth).

• Renbin Yan (postdoc, U Toronto) has proposed a new AGN optical line ratio diagnostic that does not require H-alpha and can be used at high redshift (see poster and arXiv: 1007.3494). He finds that X-BONGS (X-ray bright, optically normal galaxies) are *not* a distinct population in terms of their OIII/X-ray ratio, and also finds that the Compton-thick fraction among Seyferts at z~0.6 is at least as high as that in the local Universe.

Conclusions

- With the broad-line RASS sample, we have detected for the first time an **X-ray luminosity dependence** in AGN clustering.

- The clustering properties of z=0.25 high L_X AGN are consistent with their host galaxies being red (quiescent), while low L_X AGN are consistent with their host galaxies being blue (star-forming).

- The HOD of the RASS sample constrains the average dark matter halo mass to be $M_{halo}=10^{13.1}\ M_\odot/h$ (ie, **groups**), with higher mass halos (ie, clusters) having a **lower** AGN fraction. The halo mass range populated by AGN is **narrower** than that of galaxies. This is a very constraining result for models of AGN accretion and evolution.