Clustering of hard X-ray selected AGN

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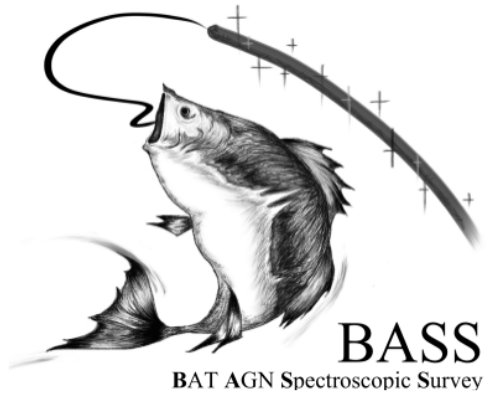


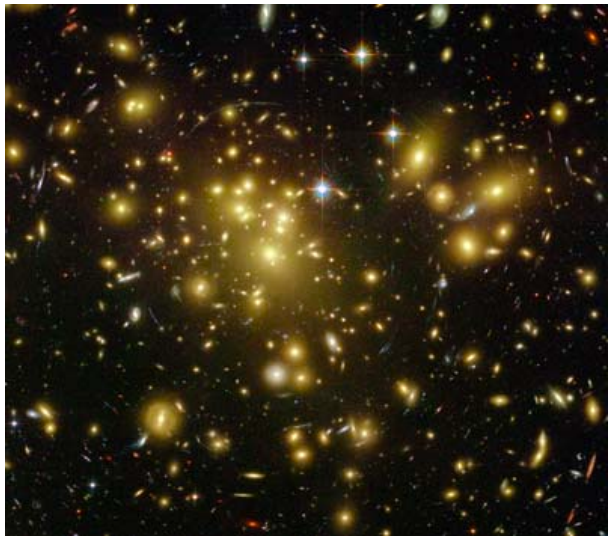
Clustering → environments

Halo mass

Field galaxies

Galaxy groups

Galaxy clusters



Large-scale clustering strength

Previous measurements

Are Obscured (type 2) or Unobscured (type 1) AGN more clustered?

Obscured

- IR AGN, z~1
  Hickox et al. 2011, Elyiv et al. 2012, Donoso et al. 2014, Dipompeo et al. 2014, 2017
- X-ray AGN, z~0
  Krumpe et al. 2018
- Optical AGN, z<0.09
  Jiang et al. 2016

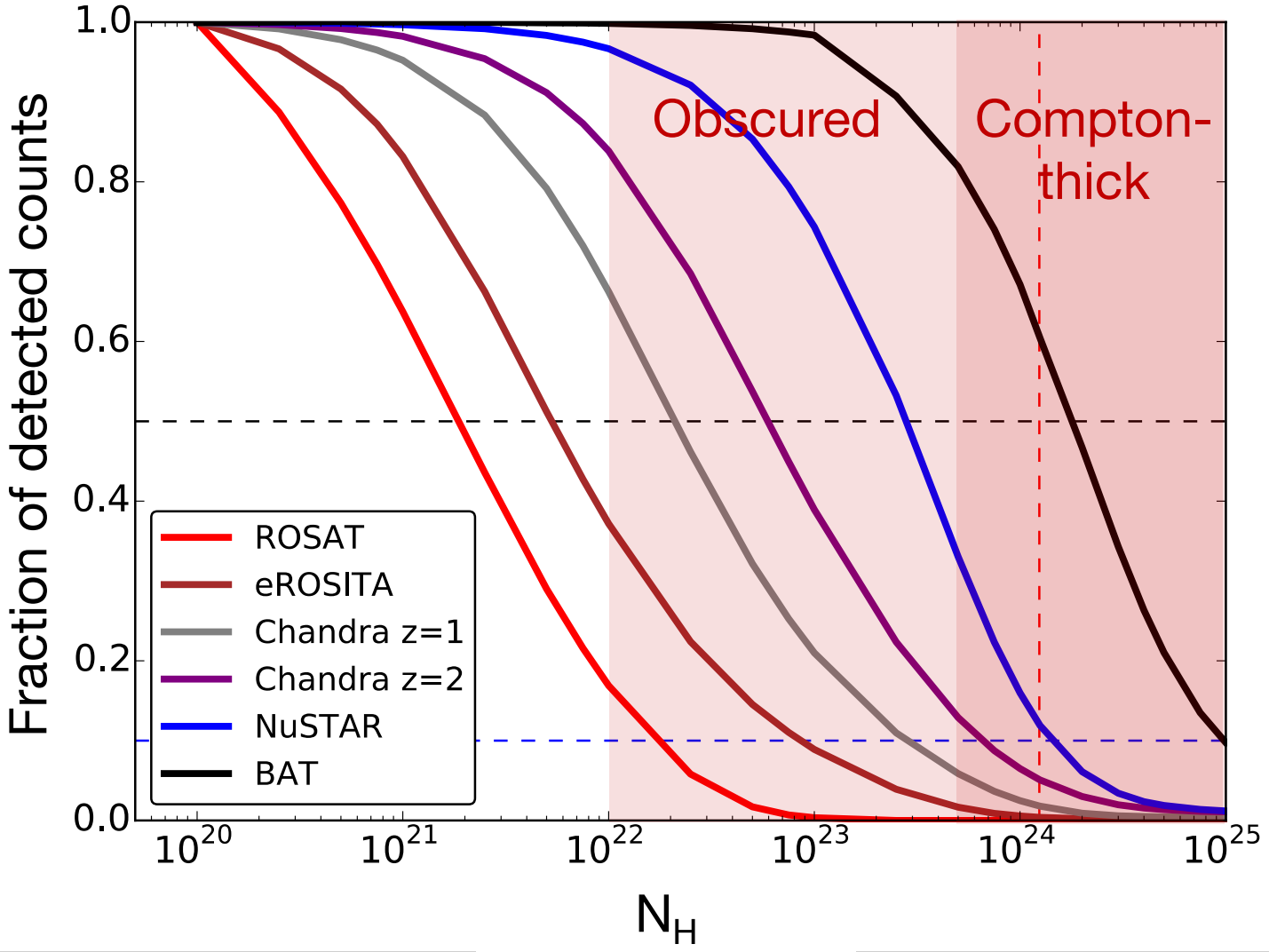
Consistent

- IR AGN, z~1
  Mendez et al. 2016, Geach et al. 2013
- X-ray AGN, z~0.3
  Krumpe et al. 2012

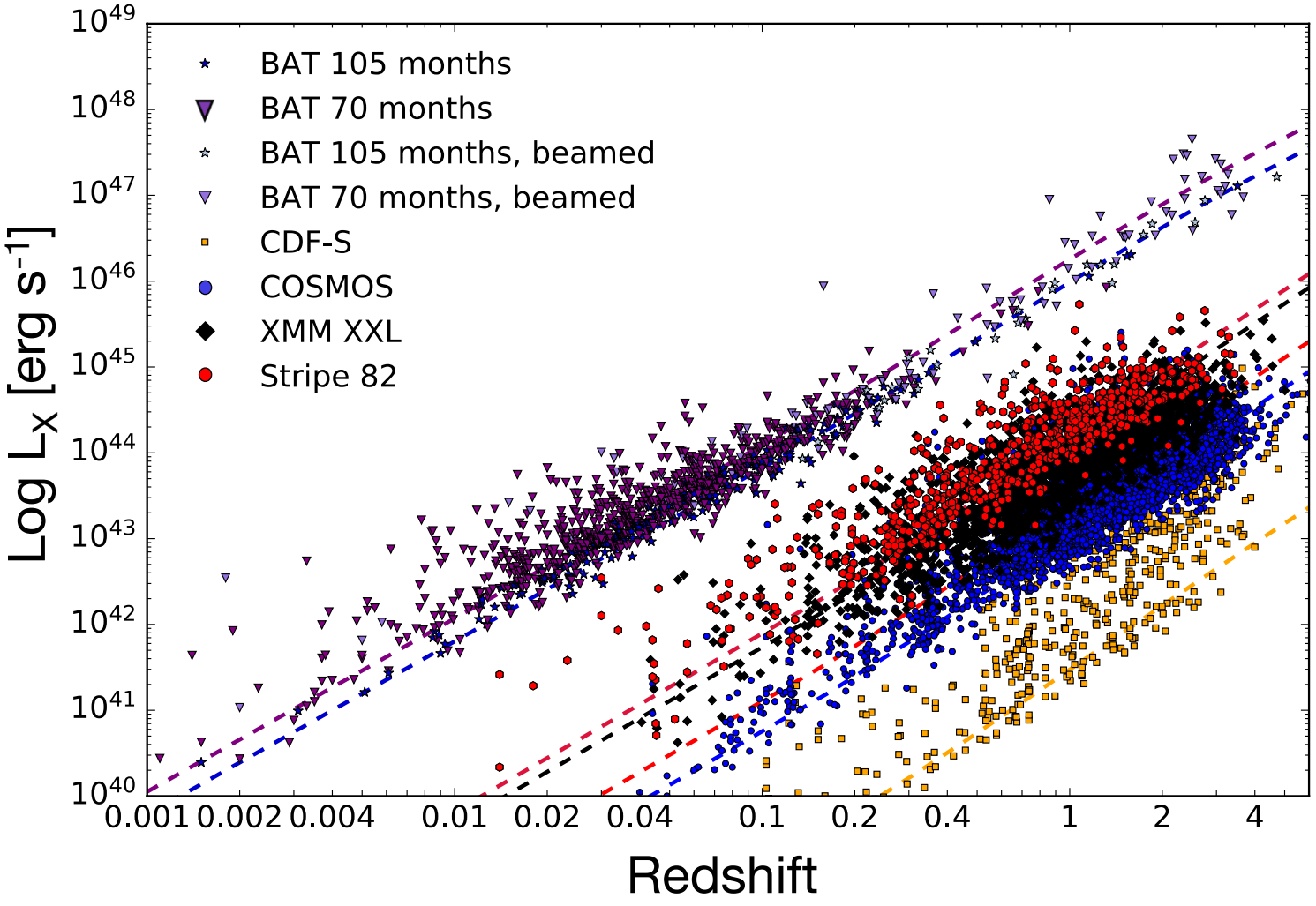
Unobscured

- X-ray AGN, 0.5<z<3
  Allevato et al. 2011, 2014
- X-ray AGN, z~0
  Cappelluti et al. 2010

Swift/BAT hard X-ray selection – an unbiased sample!



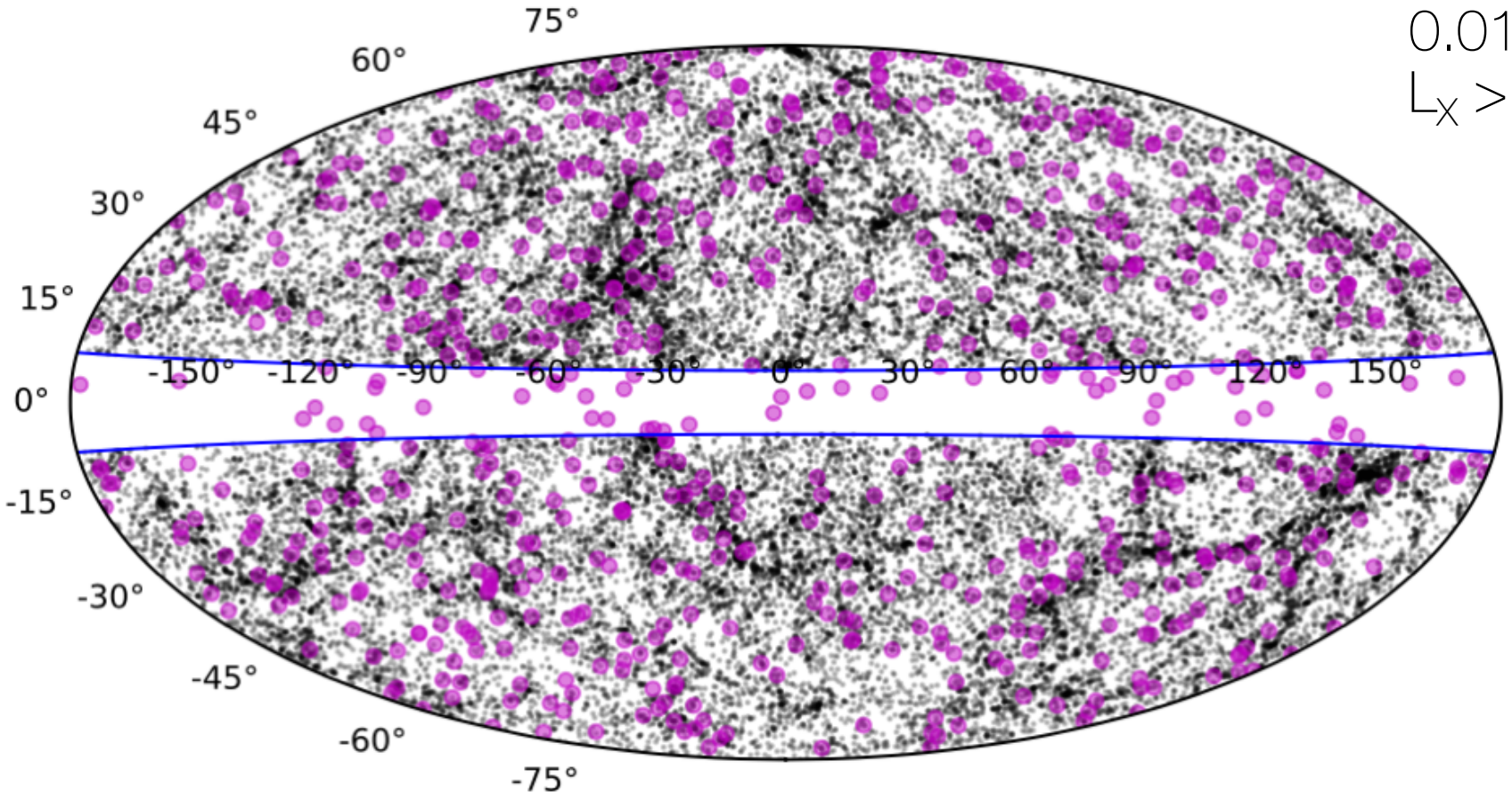
Swift/BAT AGN Spectroscopic Survey (BASS)



- Follow-up optical spectroscopy of *Swift/BAT* all sky AGN catalog
- Abundance of ancillary multiwavelength data
- Luminosity range similar to well studied AGN at z~1-2

Bass-survey.com; Koss et al. 2017

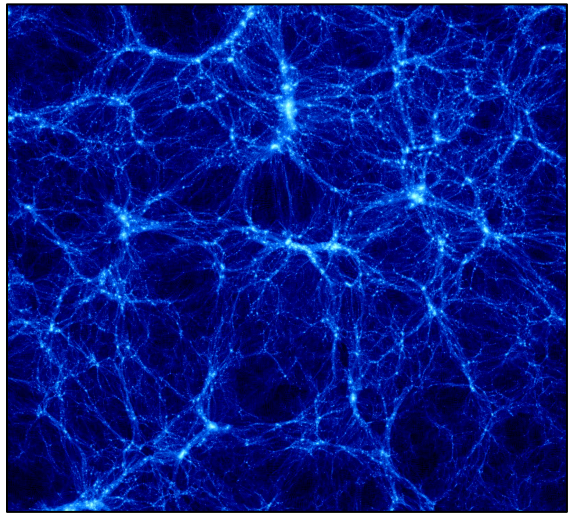
Swift/BAT AGN Spectroscopic Survey (BASS)



$0.01 < z < 0.1$
$L_X > 10^{42.5}$ erg/s

Measure clustering of BASS AGN via cross correlation with 2MASS galaxies

Galaxy (AGN) - halo connection



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Empirical Halo Model

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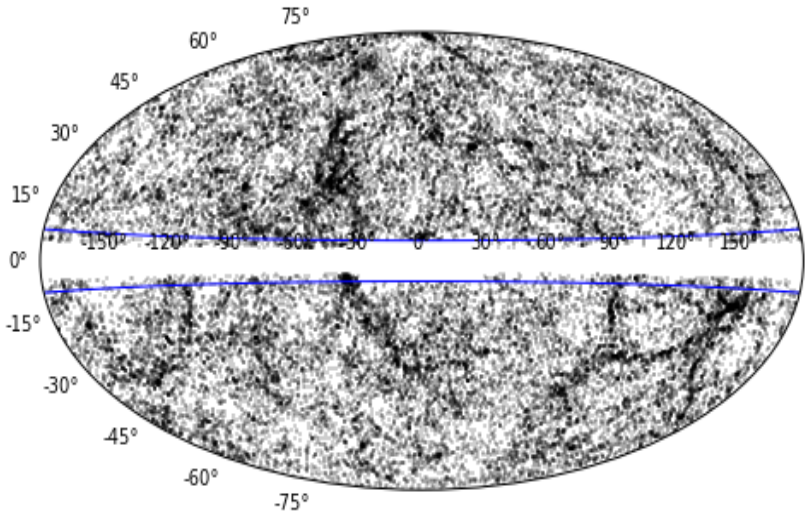
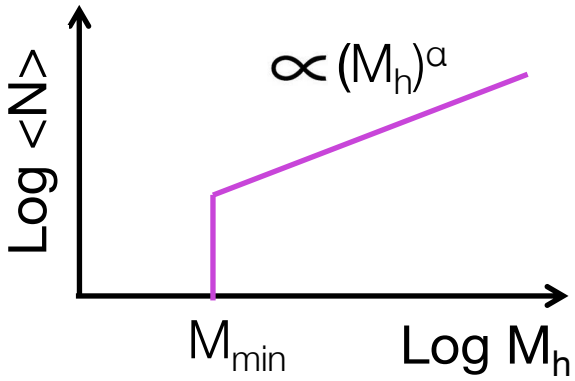




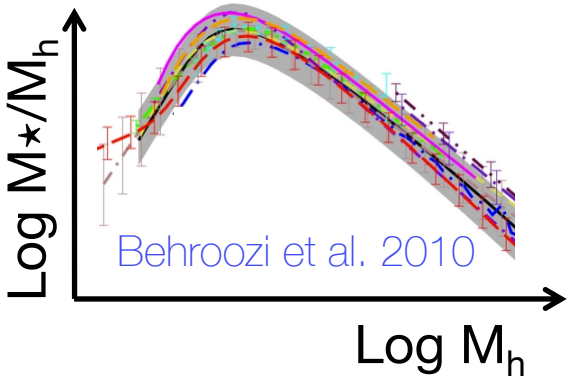
1. HOD model

AGN per largest virialized halo

$\langle N \rangle = \langle N_C \rangle + \langle N_S \rangle$

2. Subhalo model

(sub)halo ←→ galaxy

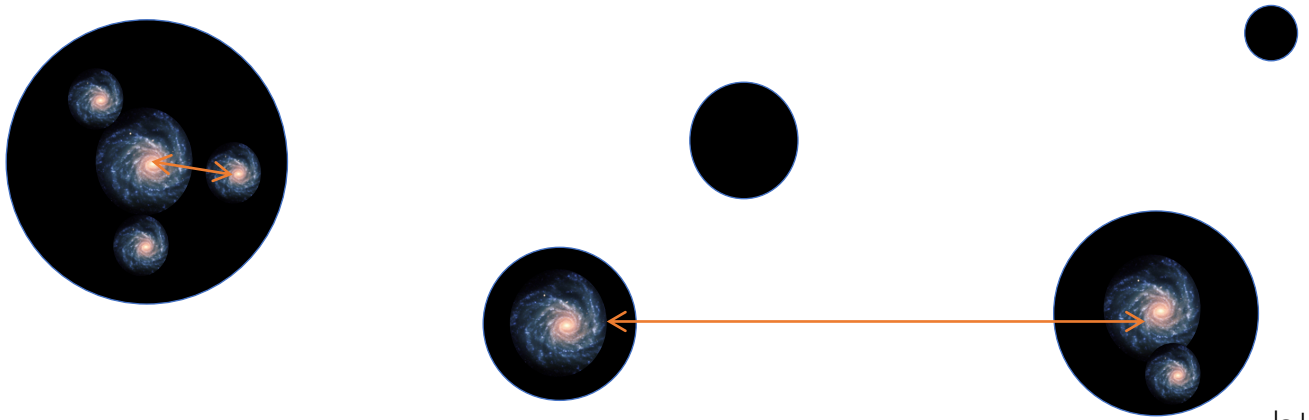


Halotools (Hearin et al. 2016)

1. Obtains halo catalog from DM simulation

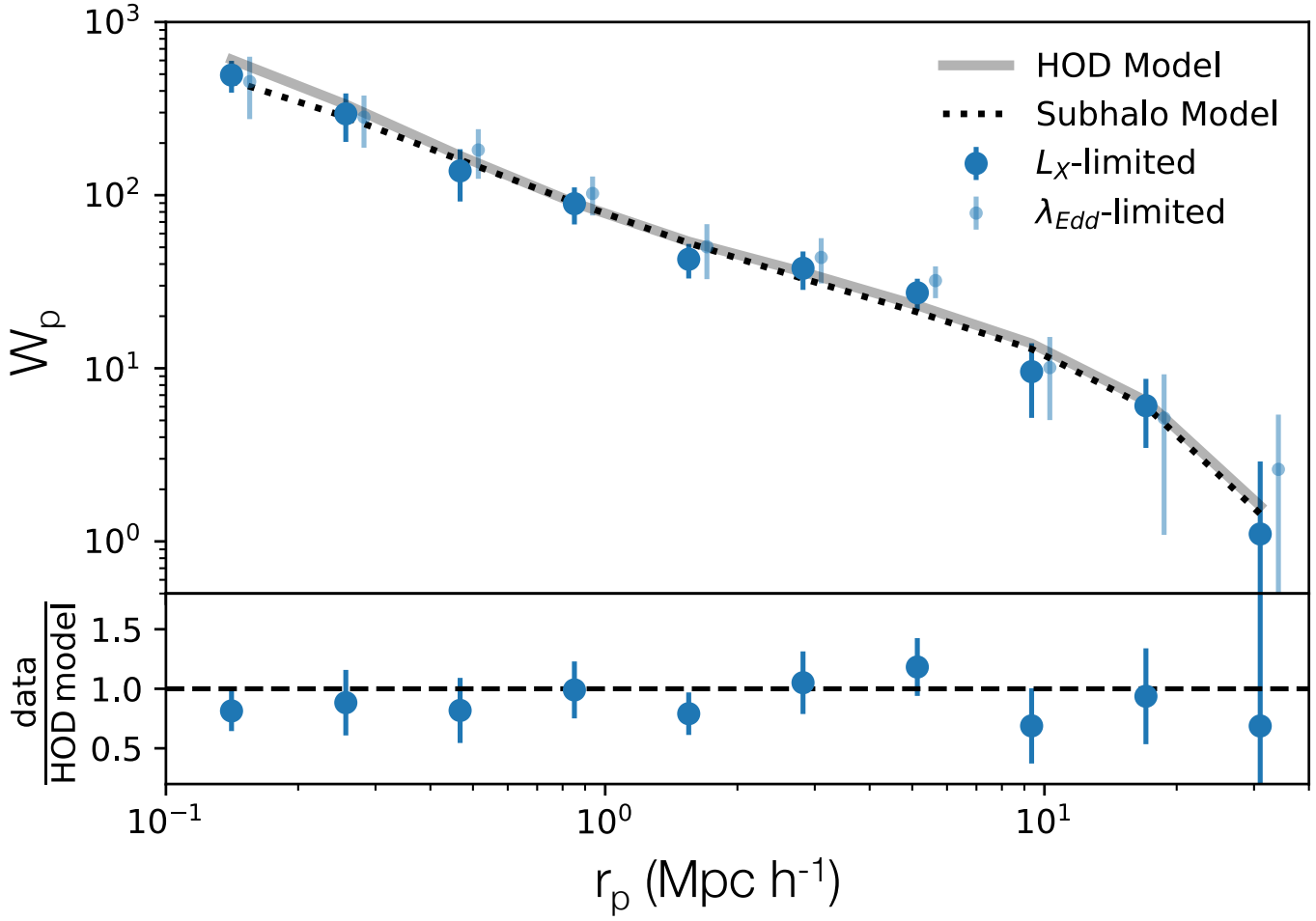
2. Populates halo catalog with defined model

3. Computes 2-pt. statistics ($w_{p\,GG}$, etc.)



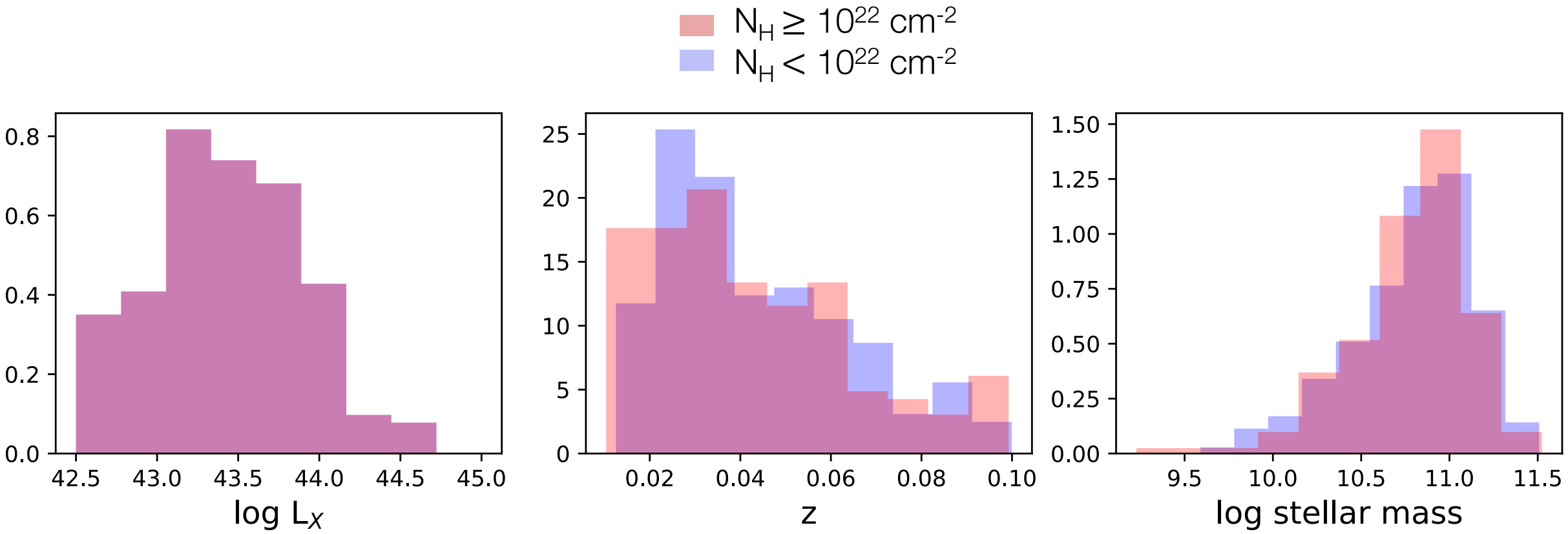
https://github.com/astropy/halotools

AGN-galaxy cross-correlation

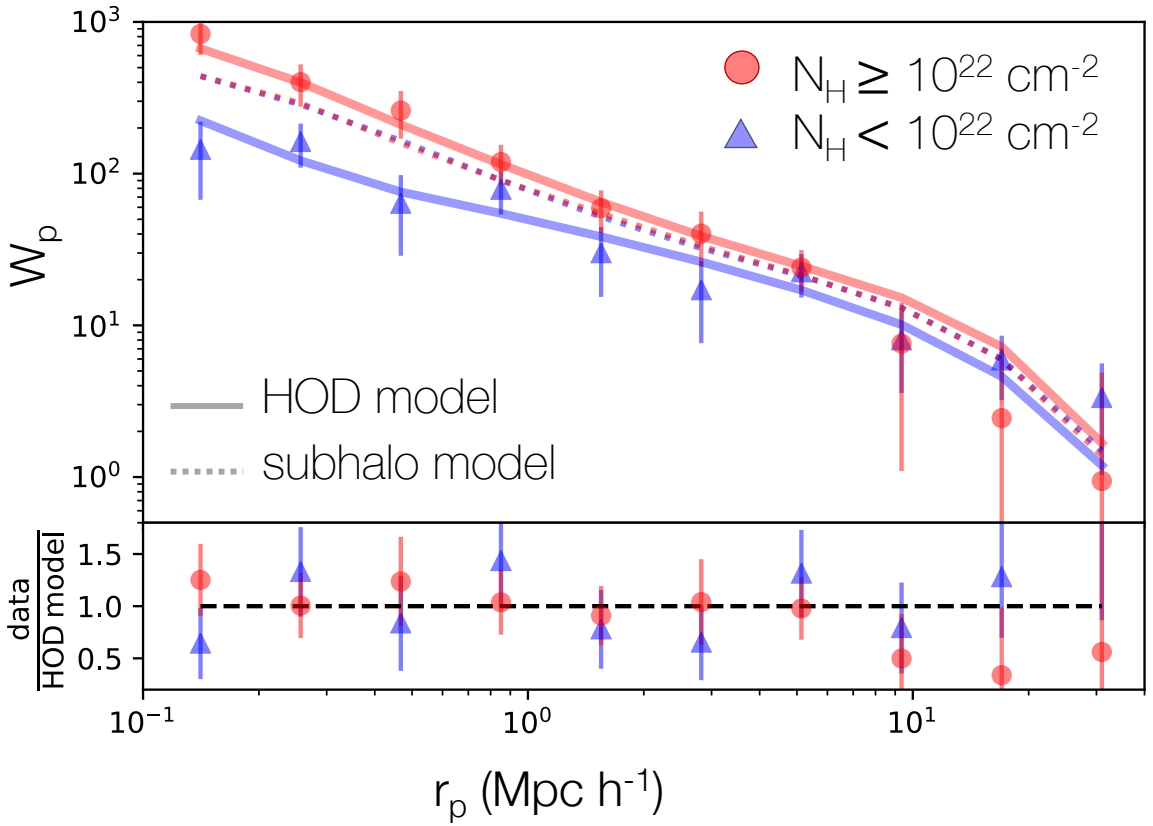


AGN cluster like galaxies of the same stellar mass

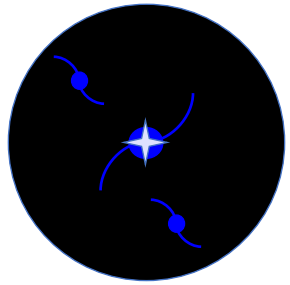
Environmental dependence of Obscuration



Environmental dependence of Obscuration



$M_h \sim 10^{12.9}\ M_\odot h^{-1}$



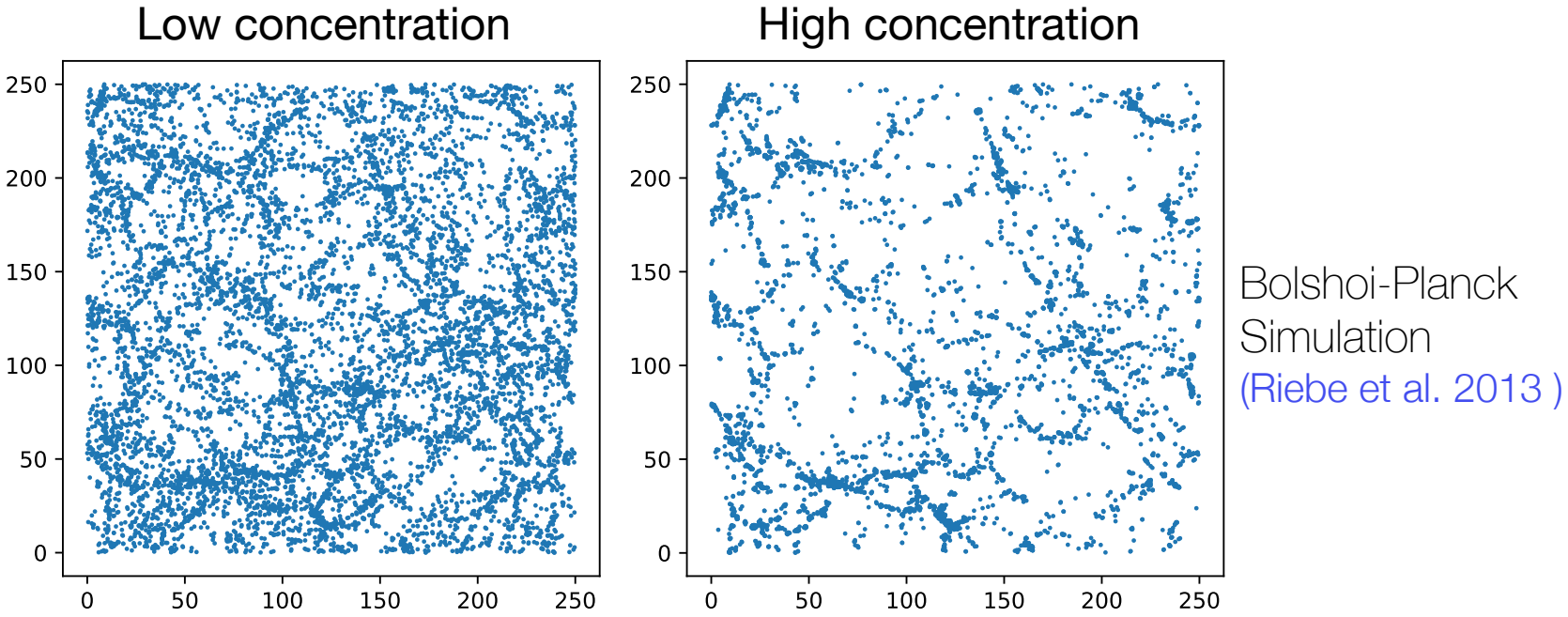
$M_h \sim 10^{12.1}\ M_\odot h^{-1}$

Obscured AGN→ denser environments

Powell et al. 2018; see also Krumpe et al. 2018

What about assembly bias?

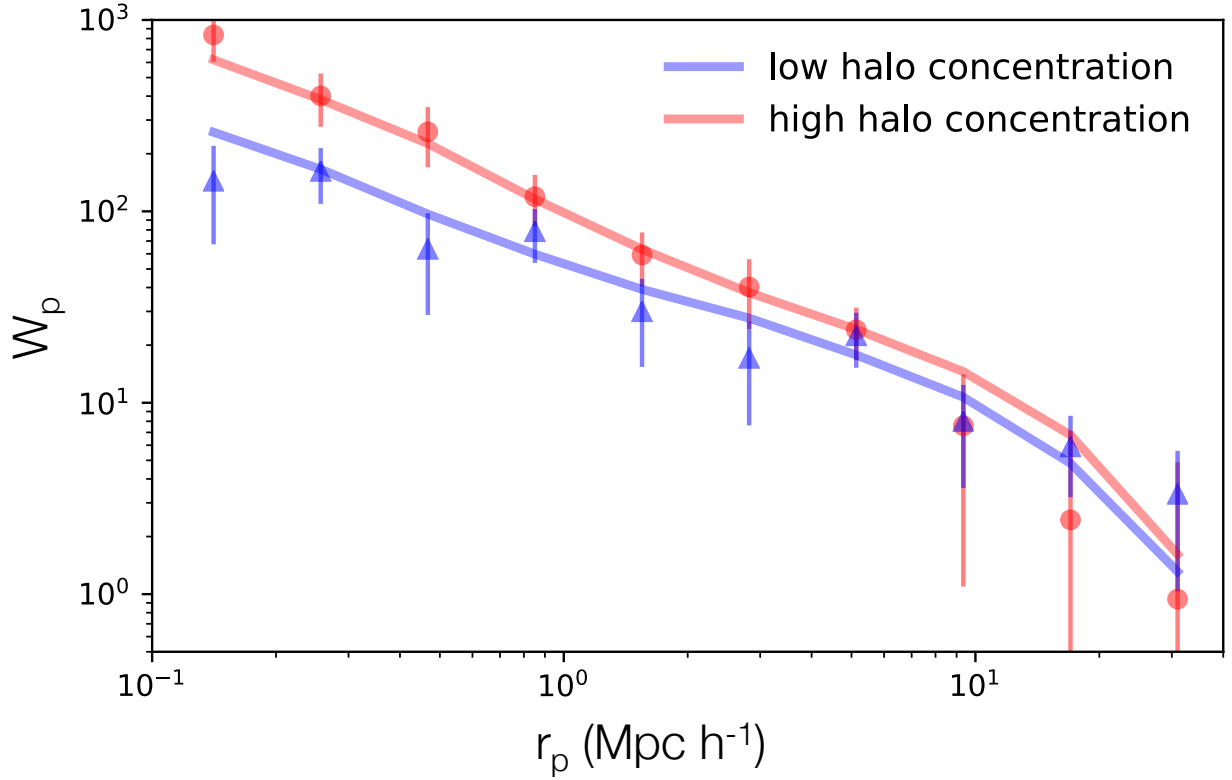
- Halo clustering also depends on **formation epoch**
  - Old halos cluster more strongly then young halos
  - Correlated with concentration

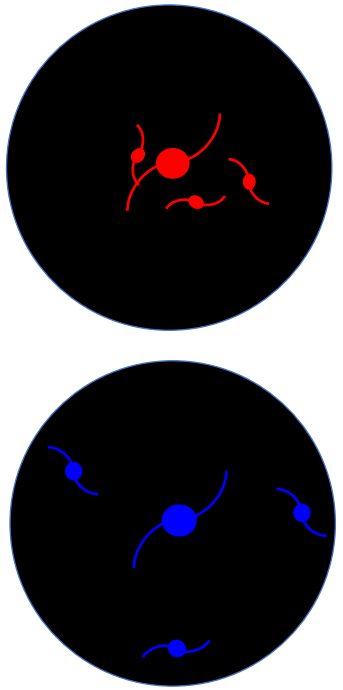


Bolshoi-Planck Simulation (Riebe et al. 2013)

- different host halo concentrations → different small-scale *and* large-scale clustering

What about assembly bias?



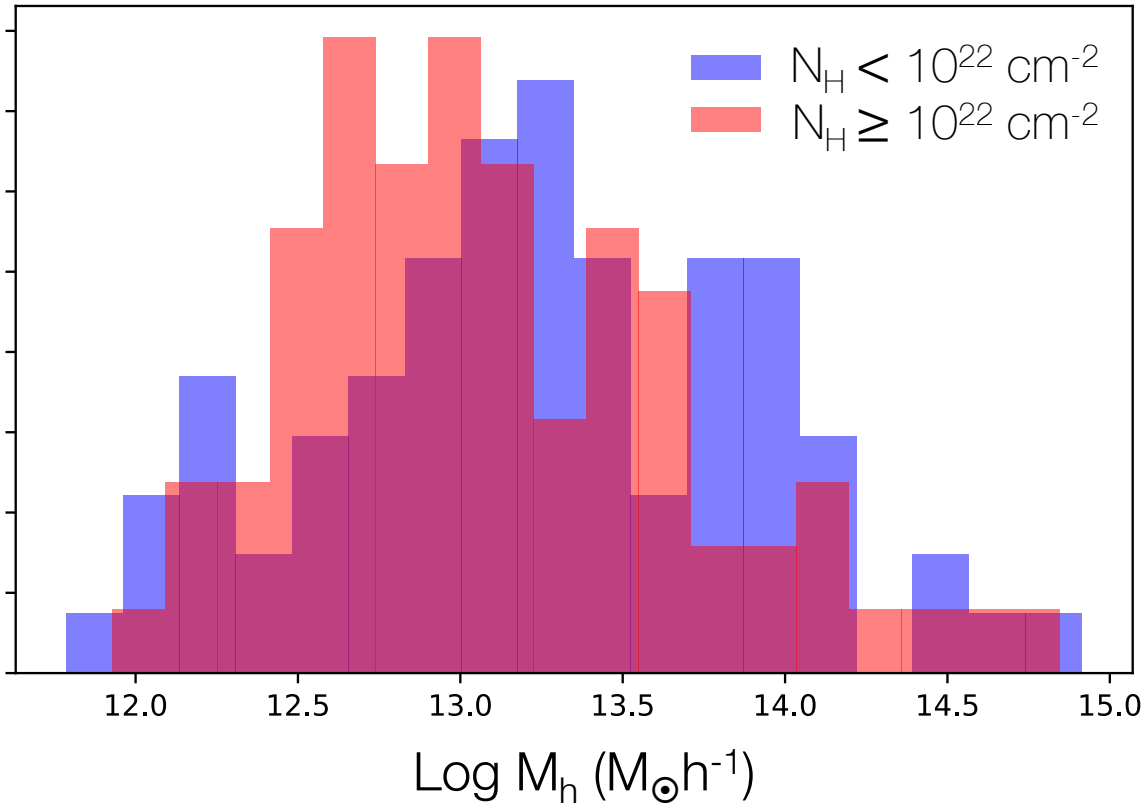


Obscured: $\langle c_{vir} \rangle = 27$ → halo formation epoch $z \sim 5$

Unobscured: $\langle c_{vir} \rangle = 8.5$ → halo formation epoch $z \sim 1$

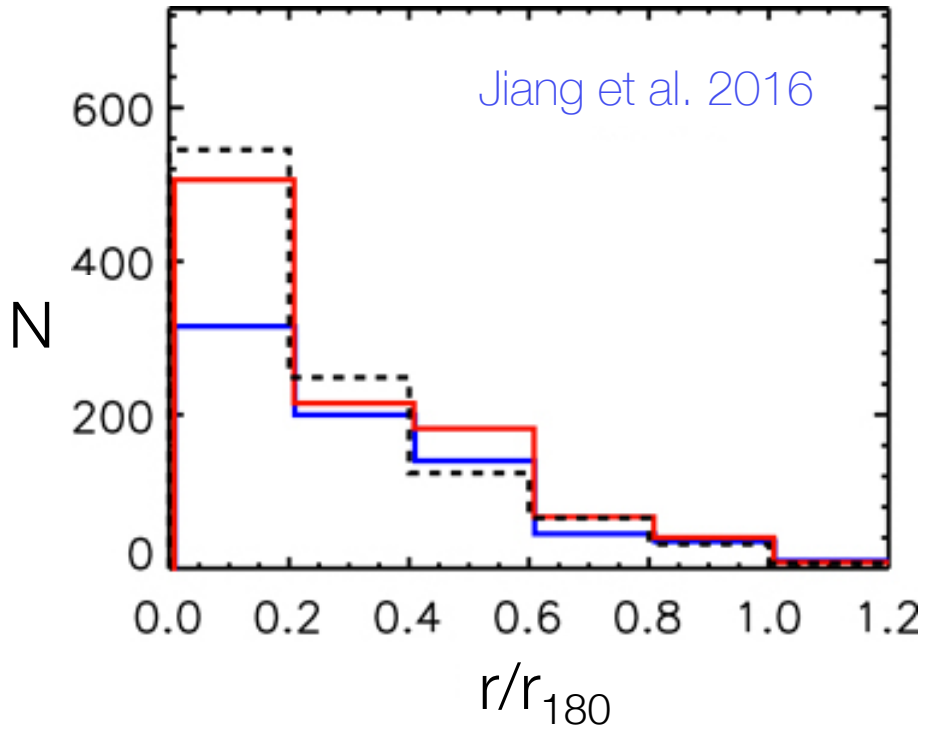
Hints for assembly bias

- 2MASS group catalog (Lu et al. 2016) : similar halo mass distributions

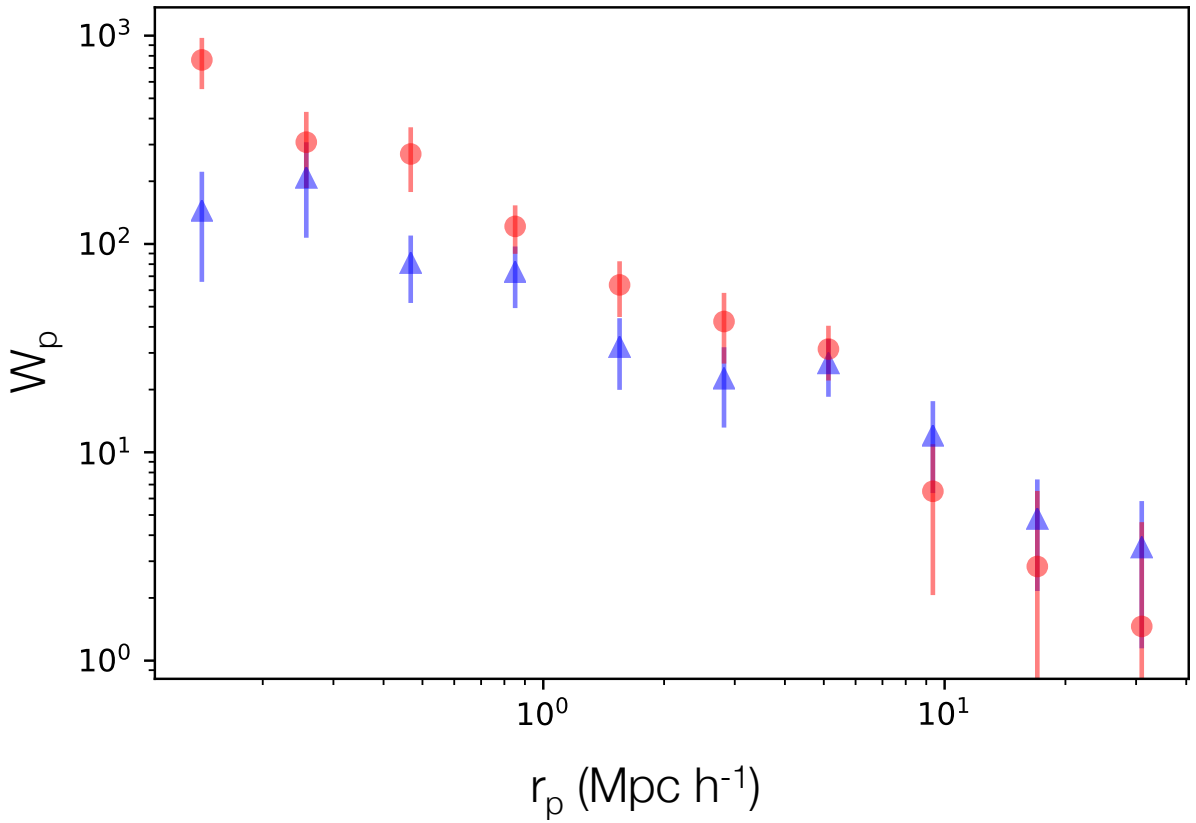


Hints for assembly bias

- 2MASS group catalog (Lu et al. 2016) : similar halo mass distributions
- Evidence that SDSS Type 1 AGN have fewer close pairs
  (Jiang et al. 2016, Villarroel & Korn 2014)



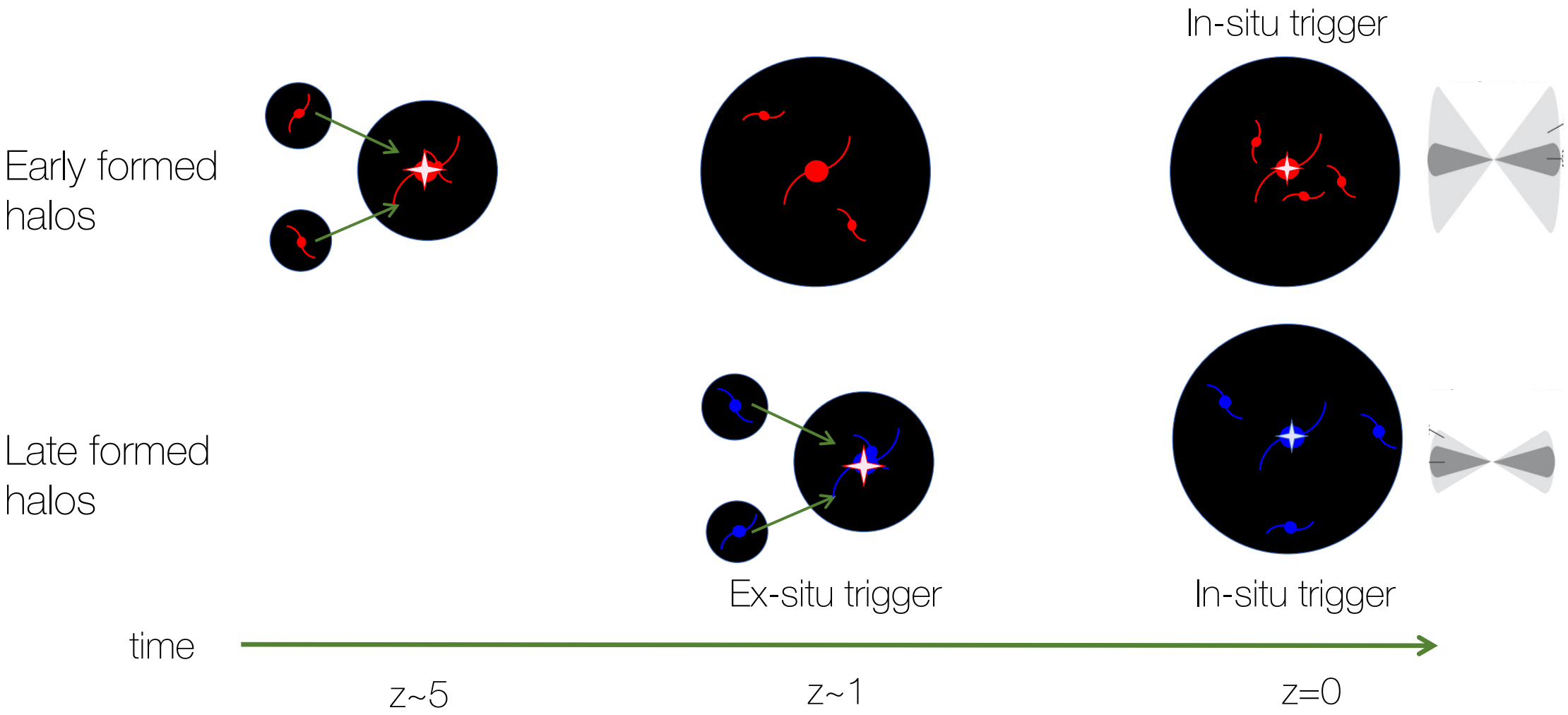
Host galaxy obscuration?



- Obscured AGN with merging and edge-on galaxies eliminated
- Unobscured AGN

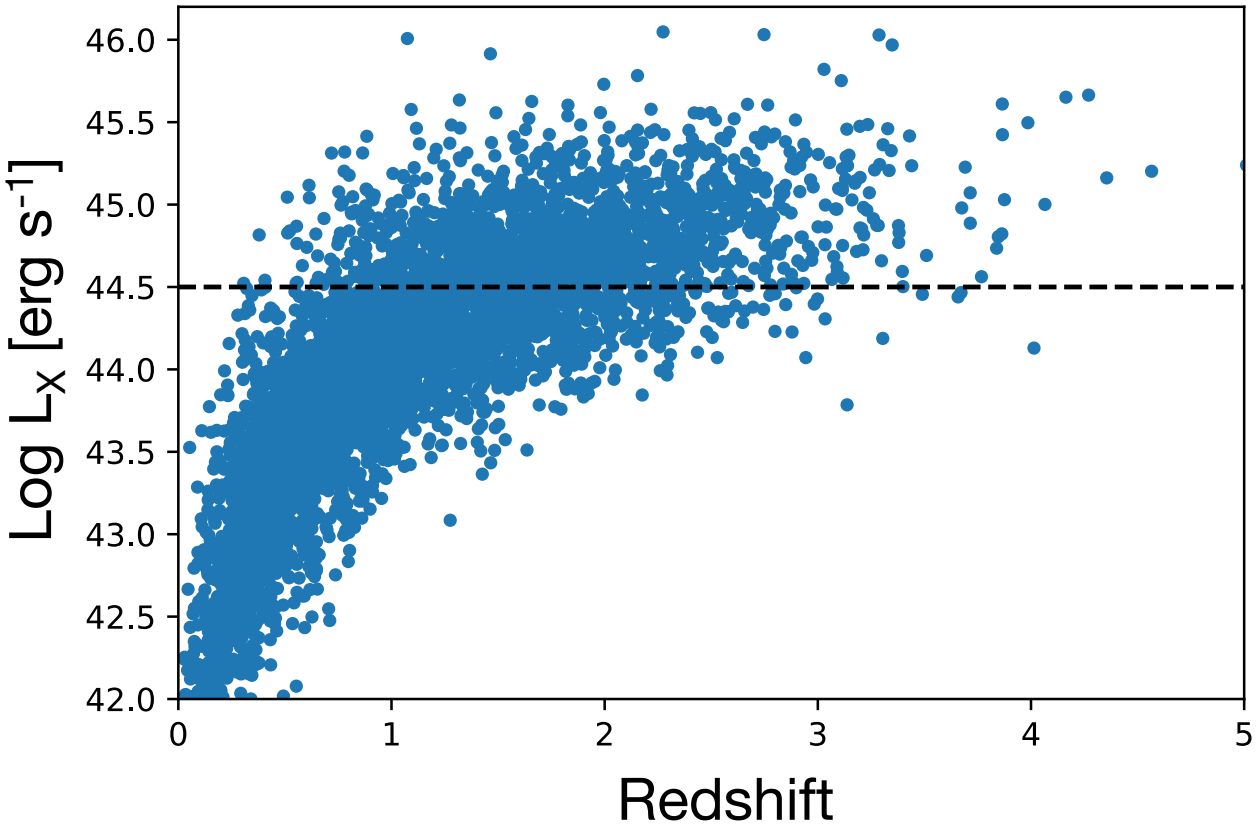
Taking out clear cases of mergers, galaxy interactions, and host galaxy obscuration in obscured AGN did not change clustering difference

Different halo assembly histories?



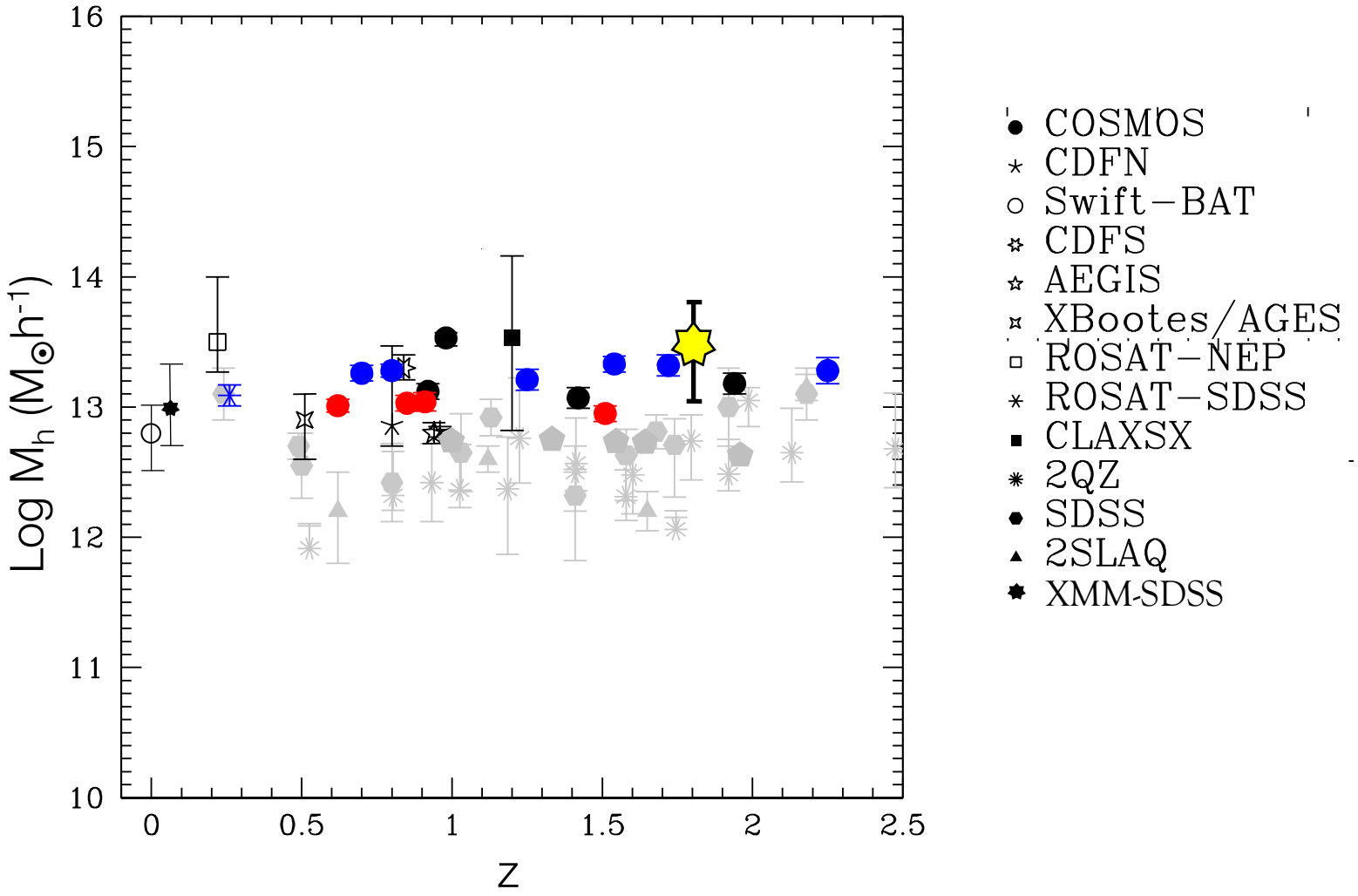
Stripe82X + XMM-XXL-N

- High-L_X AGN at moderate redshifts
  - ~50 deg^2
- Completion of N_H estimates coming soon
- Environmental luminosity dependence beyond $M_\star$?



*with Justin Johnson (University of Miami)

Stripe82X + XMM-XXL-N



(Preliminary)

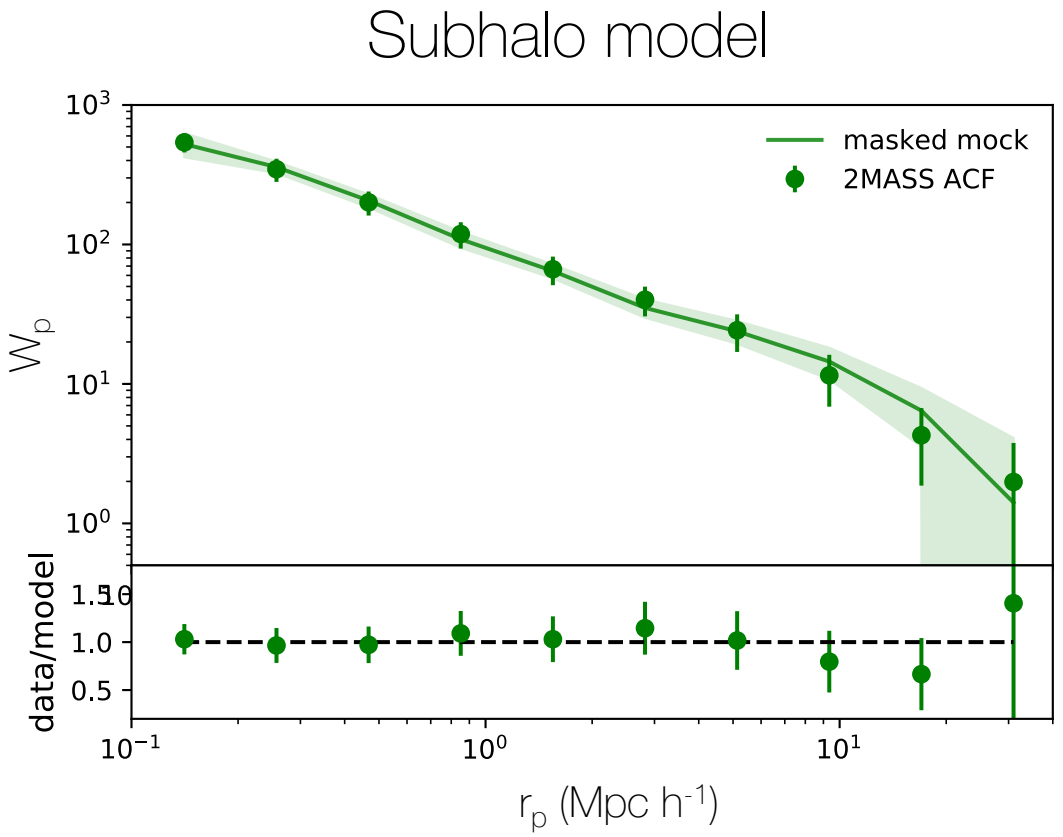
Summary

- Local *Swift*/BAT AGN (L_X ~ $10^{43.5}$ erg/s) live in environments similar to inactive galaxies of same stellar mass

- Obscured AGN live in denser environments than unobscured AGN. Either:
  - They reside in halos of different masses & occupation statistics, or
  - They reside in halos of different concentrations/ages

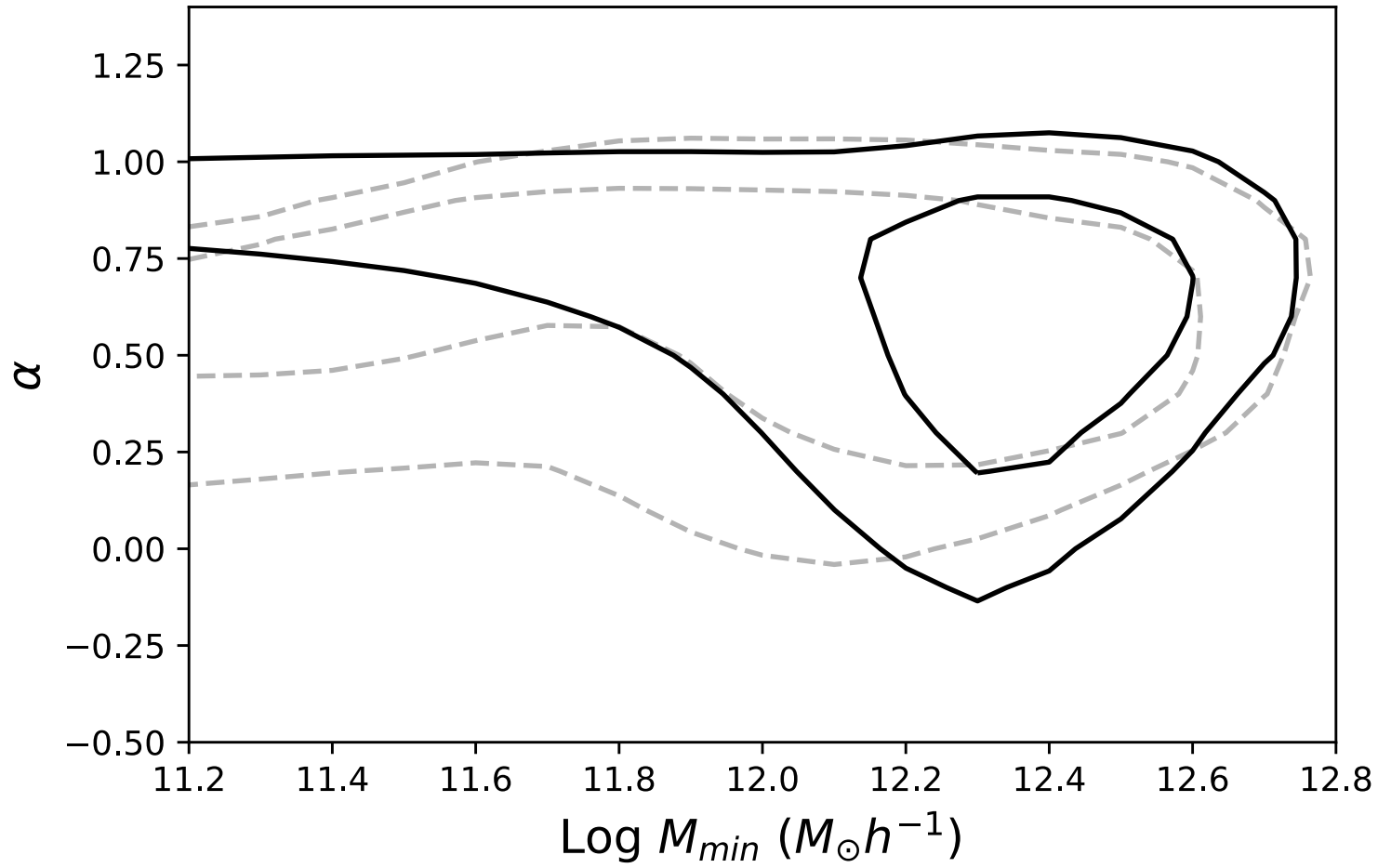
- New high L_X clustering measurements at z~1-2 coming soon!

2MASS autocorrelation function

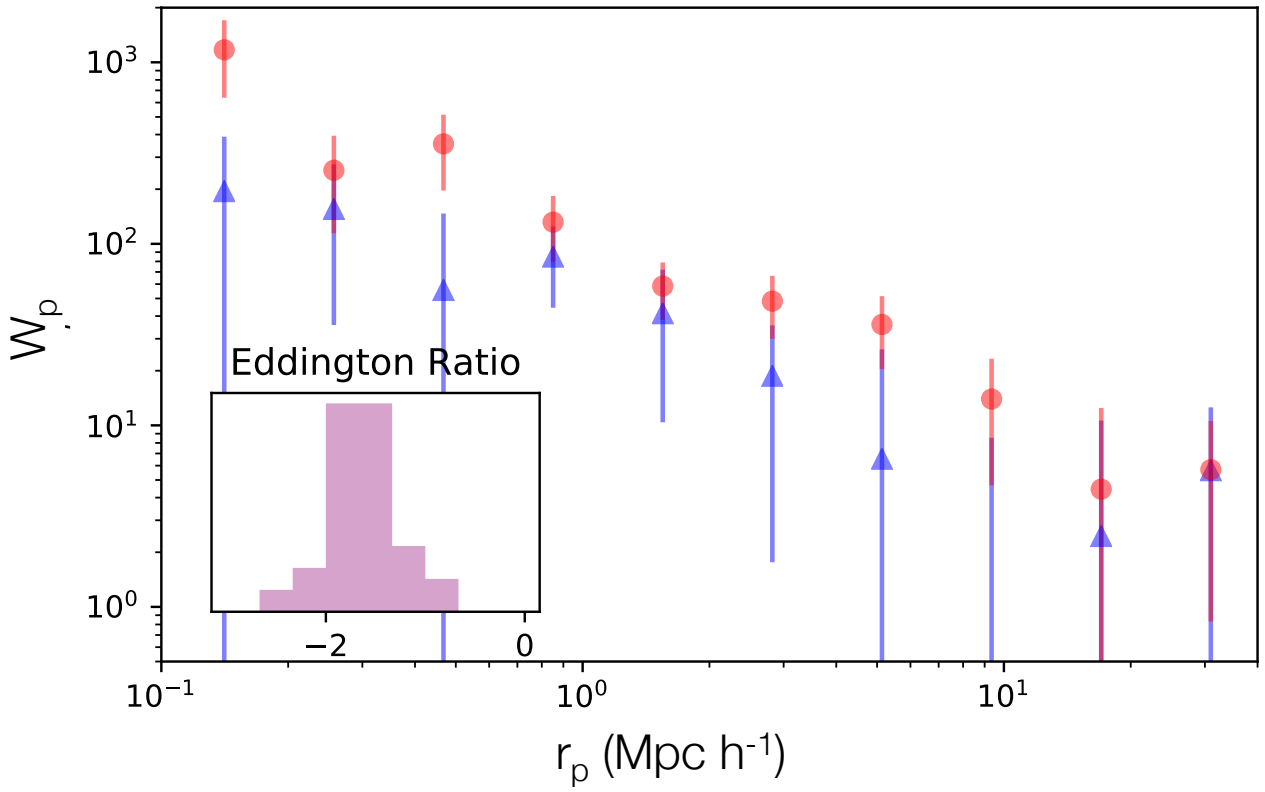


Stellar Masses: Using K_s-band luminosities, fit for M_*/L_K

HOD results


1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
α
11.2
11.4
11.6
11.8
12.0
12.2
12.4
12.6
12.8
Log M_{min} ($M_\odot h^{-1}$)

Obscured vs. Unobscured AGN



Clustering Differences persist after matching Eddington ratio distributions