Where does AGN activity occur within the cosmic web?

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DM Halo ⟷ Galaxy

AGN Clustering

Black Hole

Cosmology

↓

Halo clustering

+

Galaxy/SMBH formation & evolution

↓

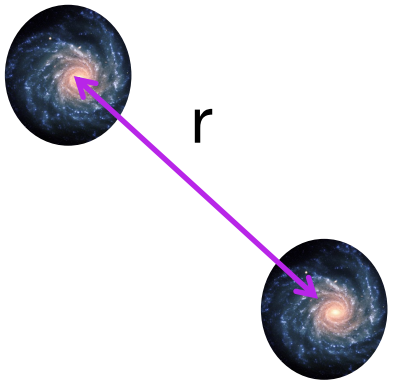
AGN halo occupation

=

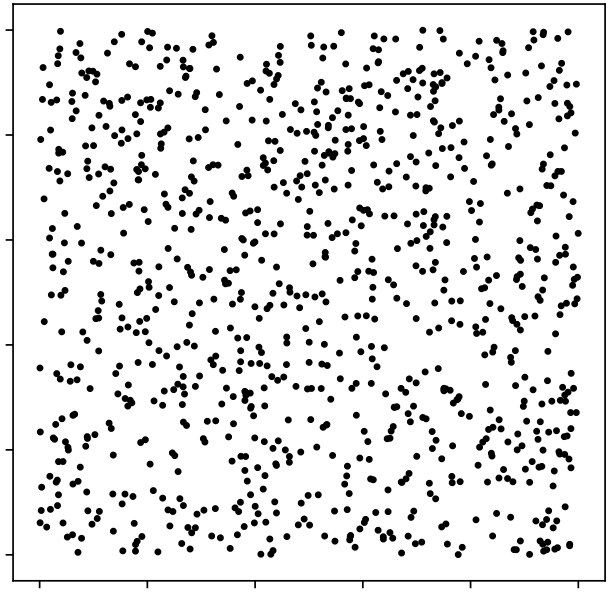
AGN clustering

One way clustering is measured: the Correlation function

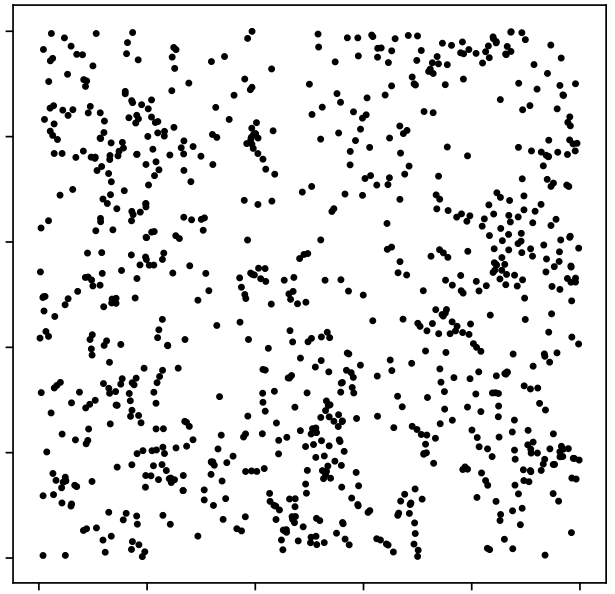
- $dP = n^2 [\ 1 + \mathbf{w(r)}\ ]\ dV_1\ dV_2$



w = 0



w > 0



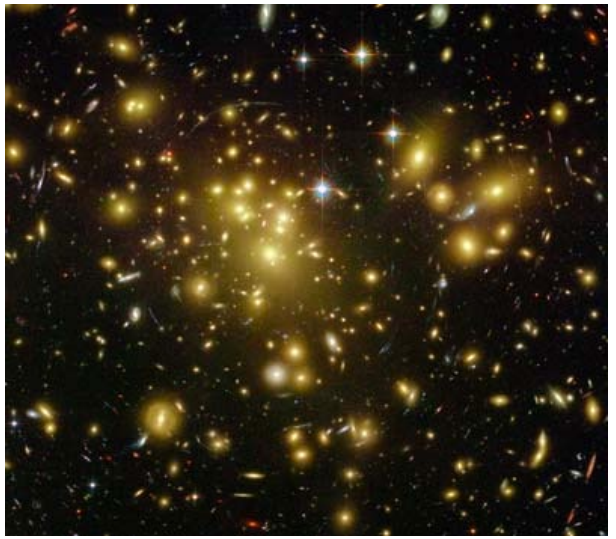
Clustering → environments

Parent halo mass

Field galaxies

Galaxy groups

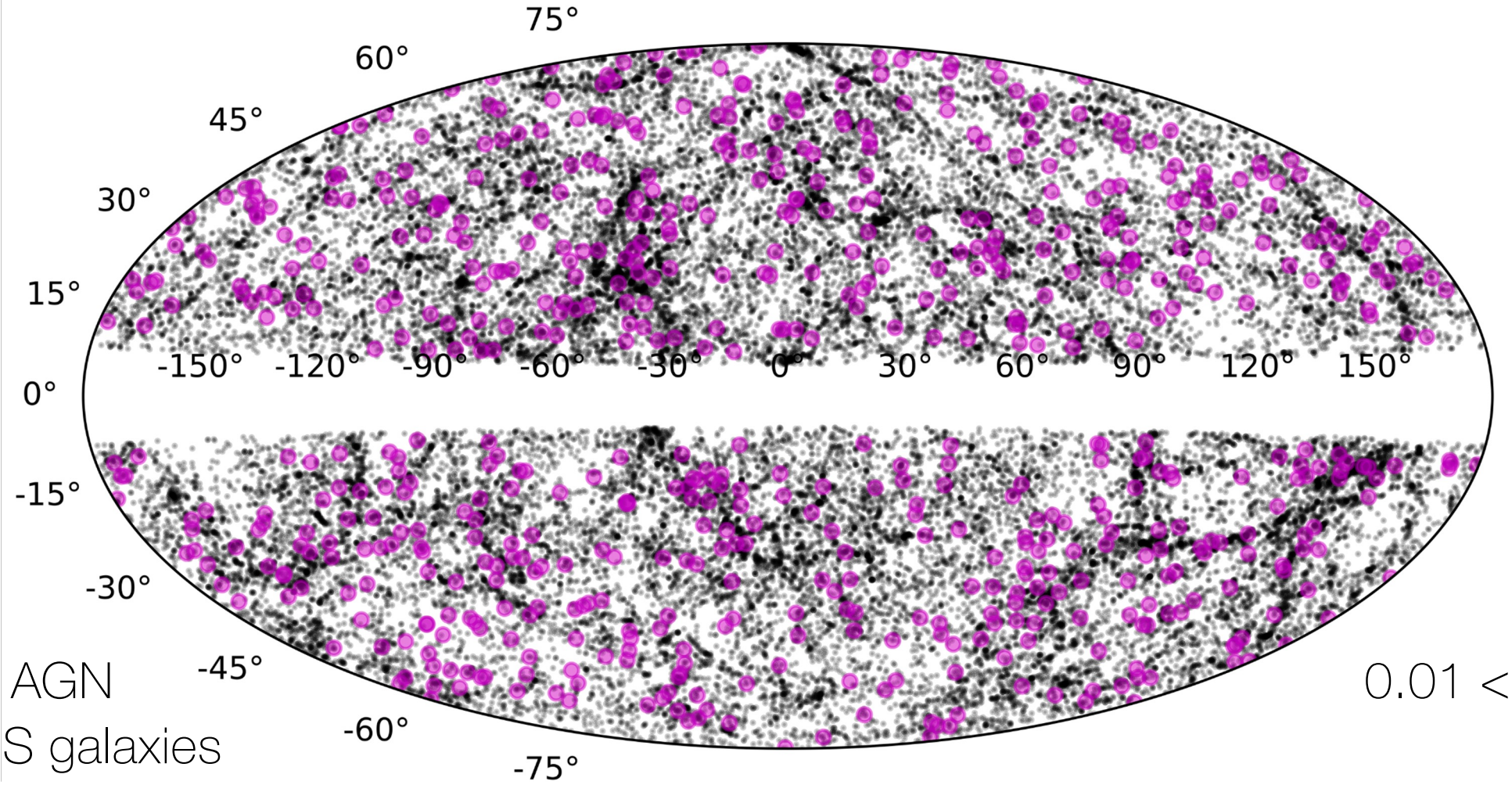
Galaxy clusters



clustering strength

Do AGN reside in special cosmic environments?

Swift/**B**AT **A**GN **S**pectroscopic **S**urvey **(BASS DR2)**

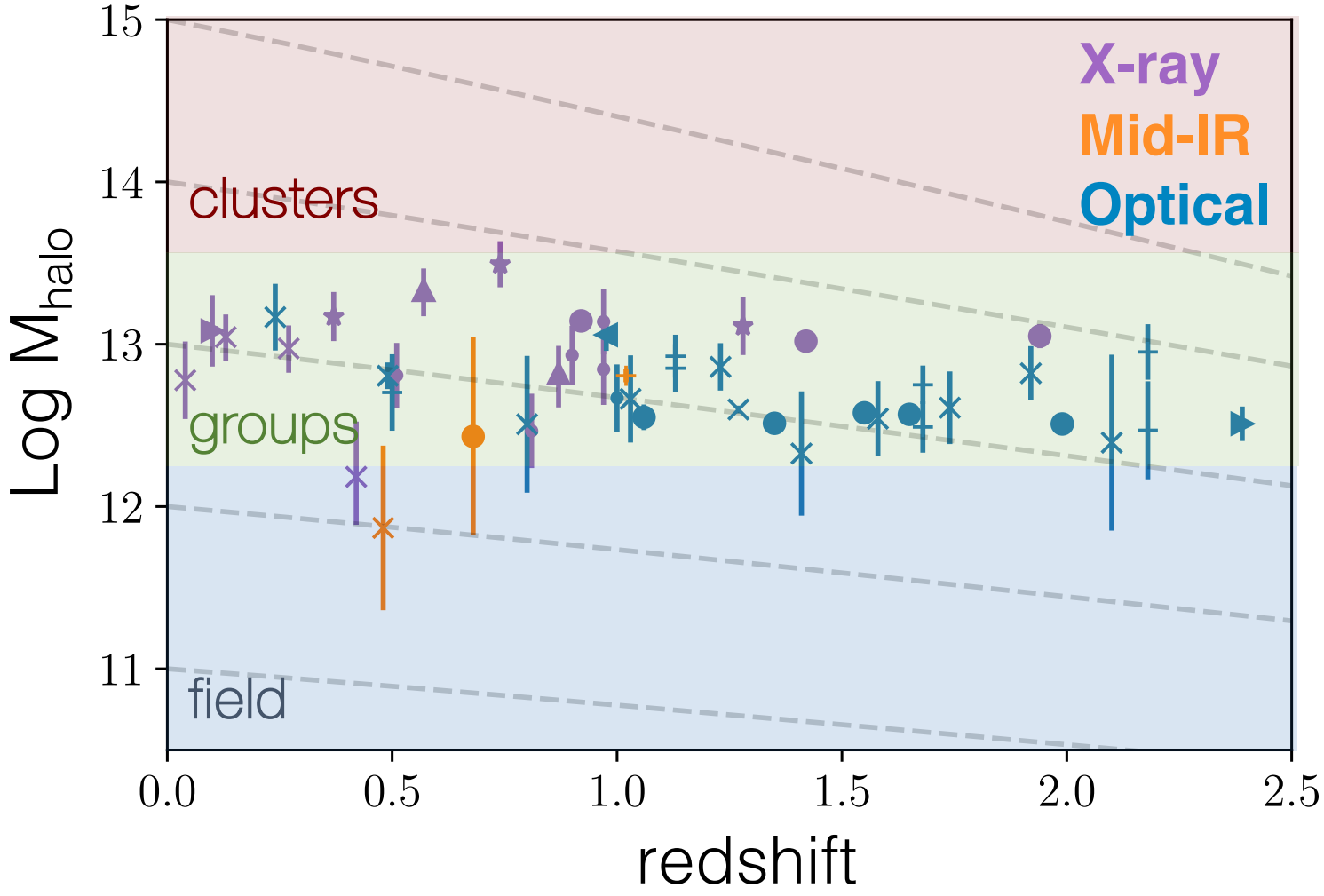


- BASS AGN
- 2MASS galaxies

$0.01 < z < 0.1$

Koss et al. 2022, ApJS; bass-survey.com

Previous: do AGN prefer group environments?



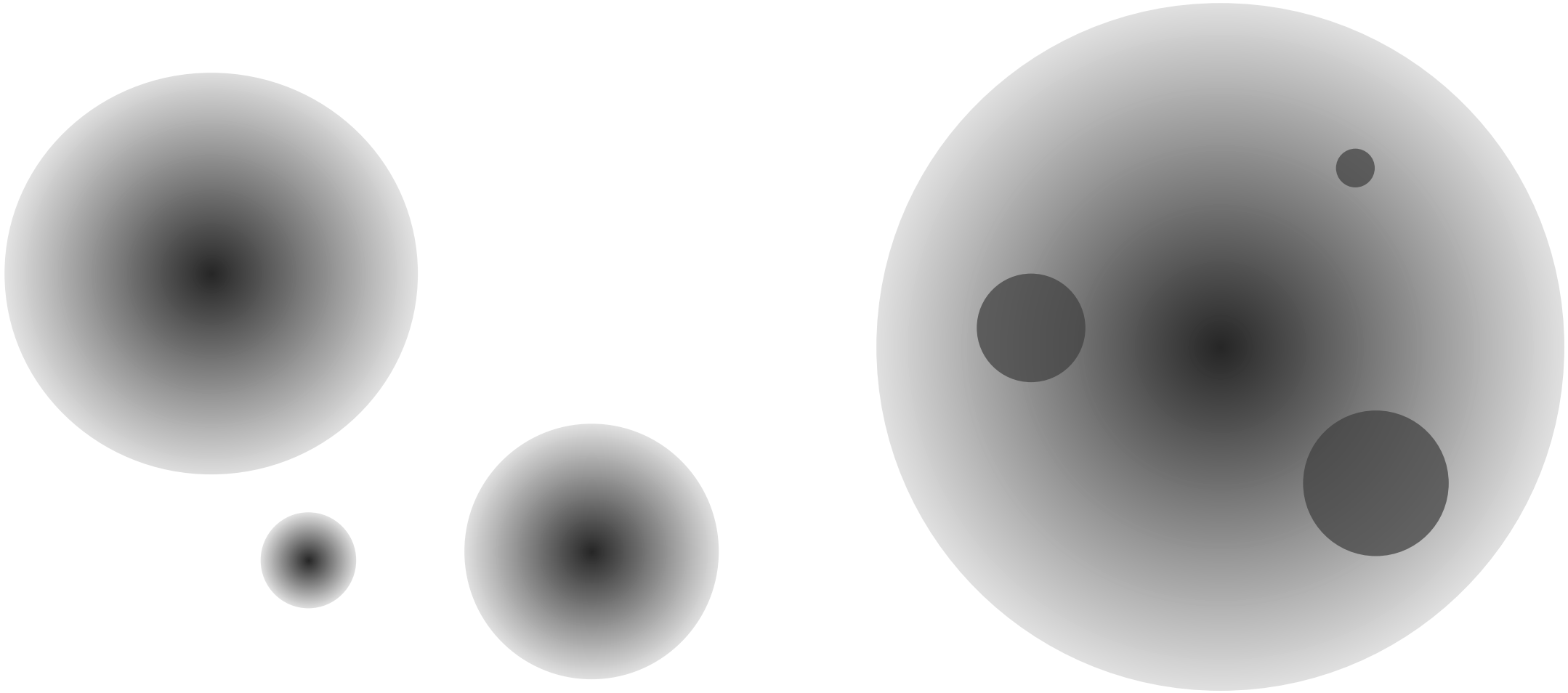
Coil+ 2009
Gilli+ 2009
Hickox+ 2011
Allevato+ 2011, 2014
Mendez+ 2016
Starikova+ 2012
White+ 2012
Mountrichas+ 2012, 2013
Krumpe+ 2012, 2017
Koutoulidis+ 2013

Coil+ 2007
Hickox+ 2009
Shen+ 2009
Ross+ 2009
Laurent+ 2017

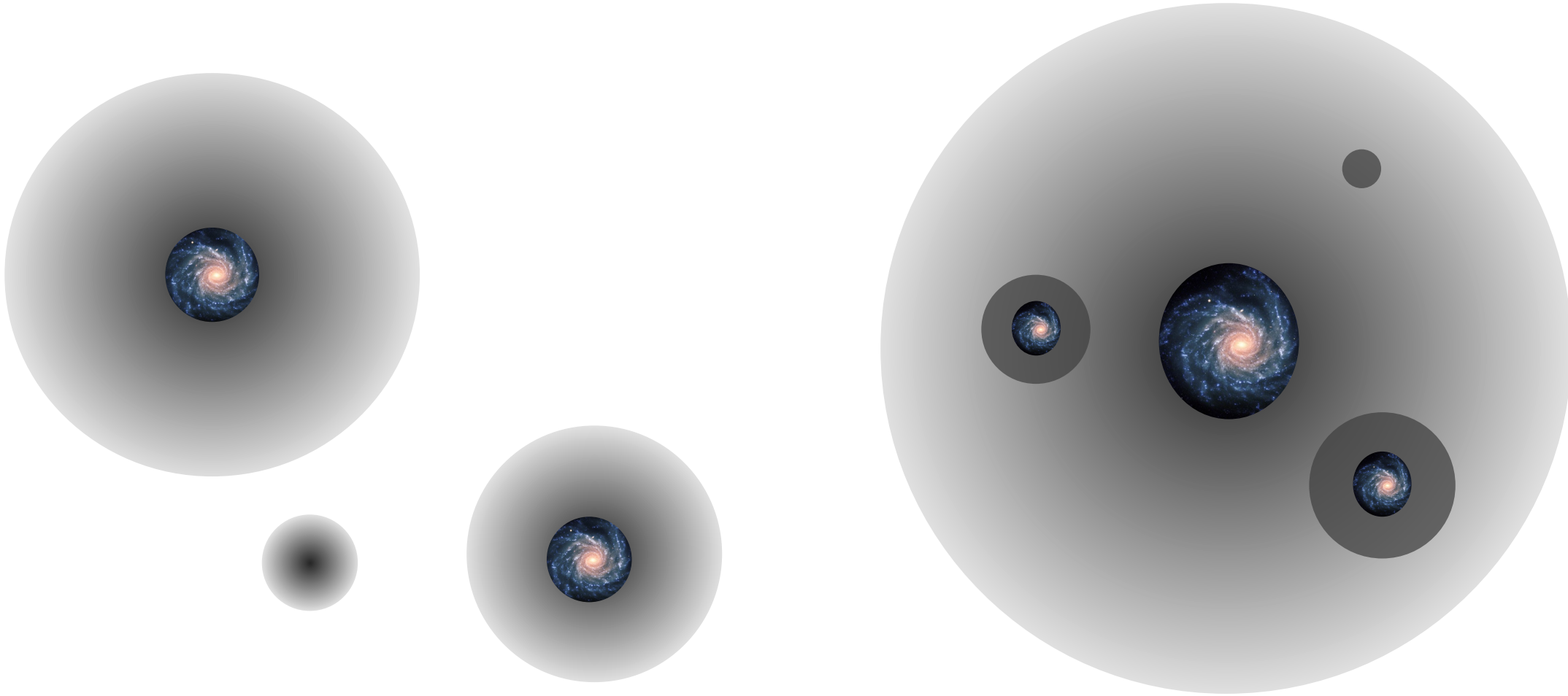
Hickox+ 2009
Mendez+ 2016
DiPompeo+ 2017

HOWEVER: selection effects need to be considered

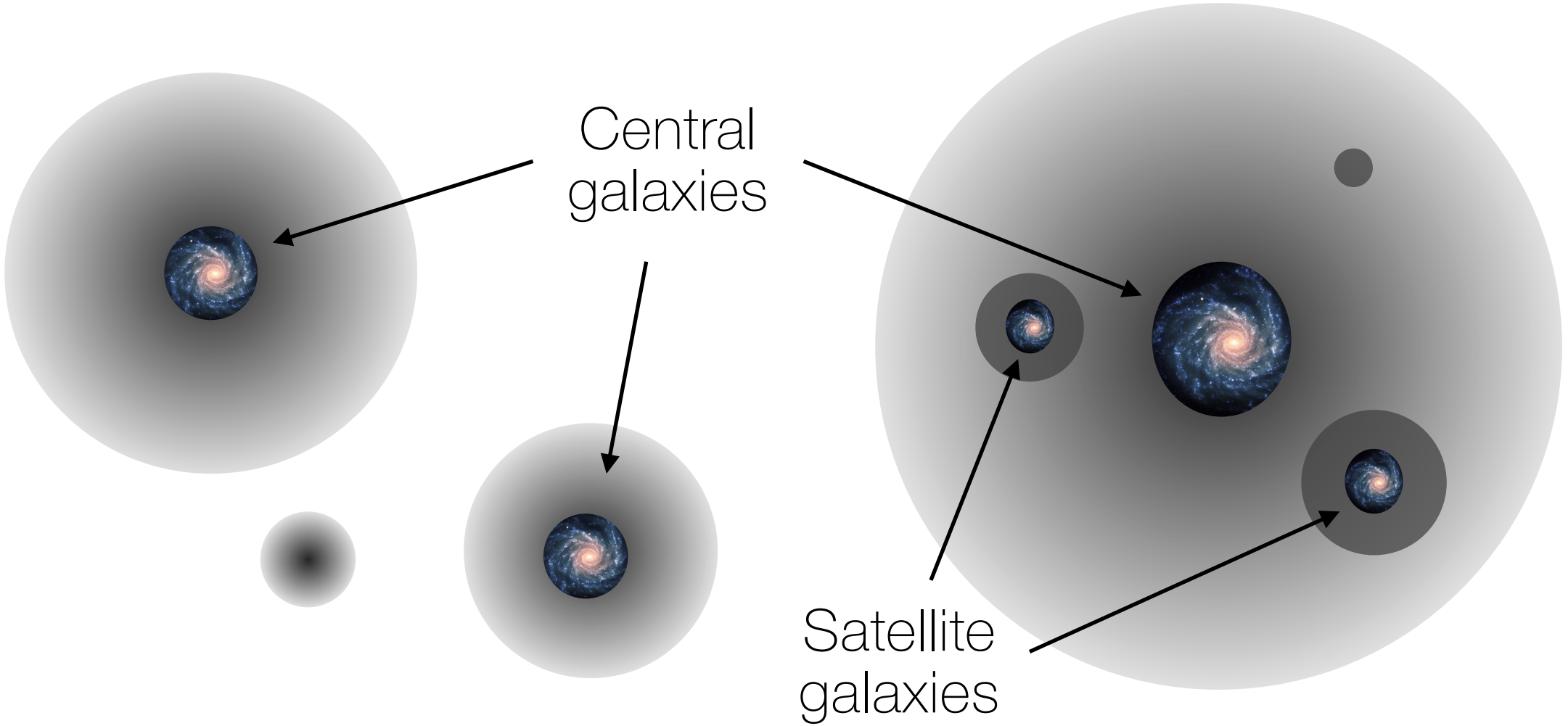
Populating a halo catalog with *galaxies:*



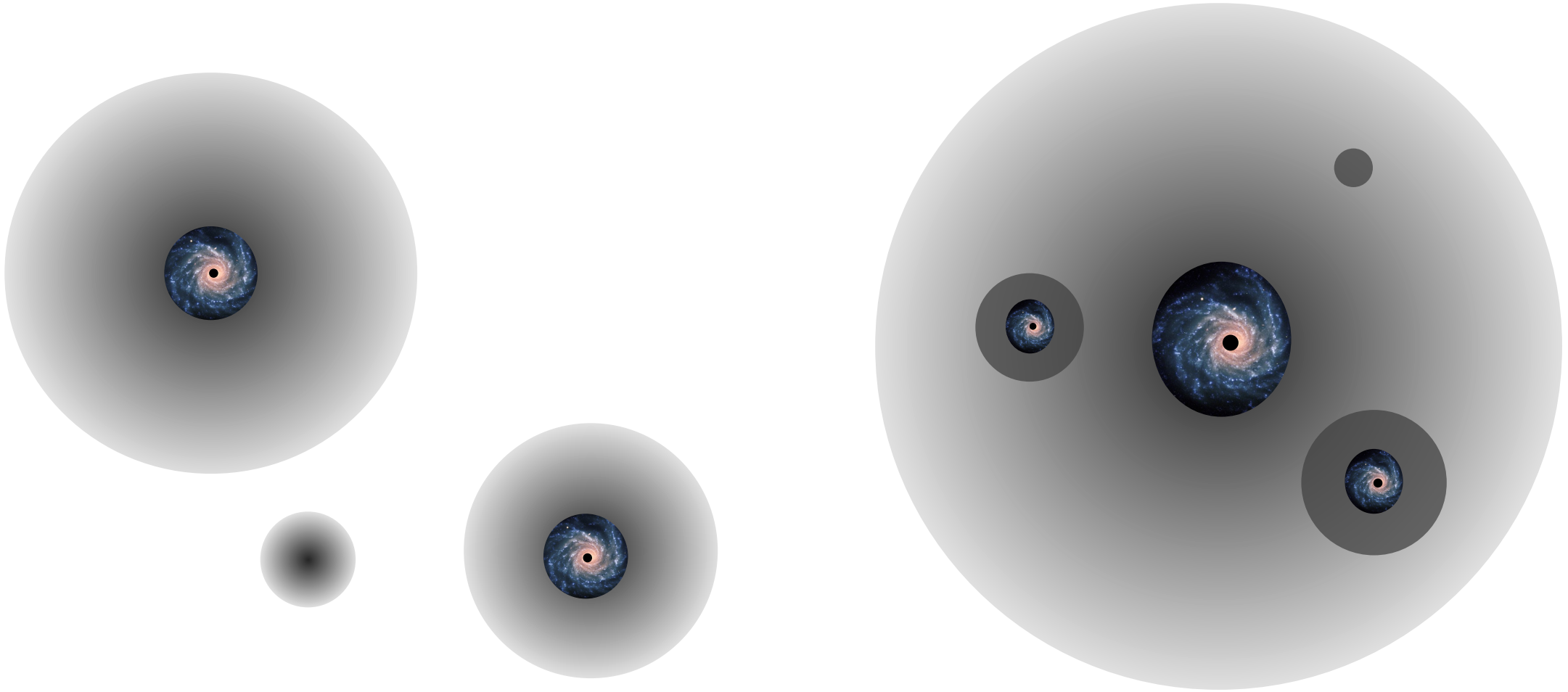
Populating a halo catalog with *galaxies:*



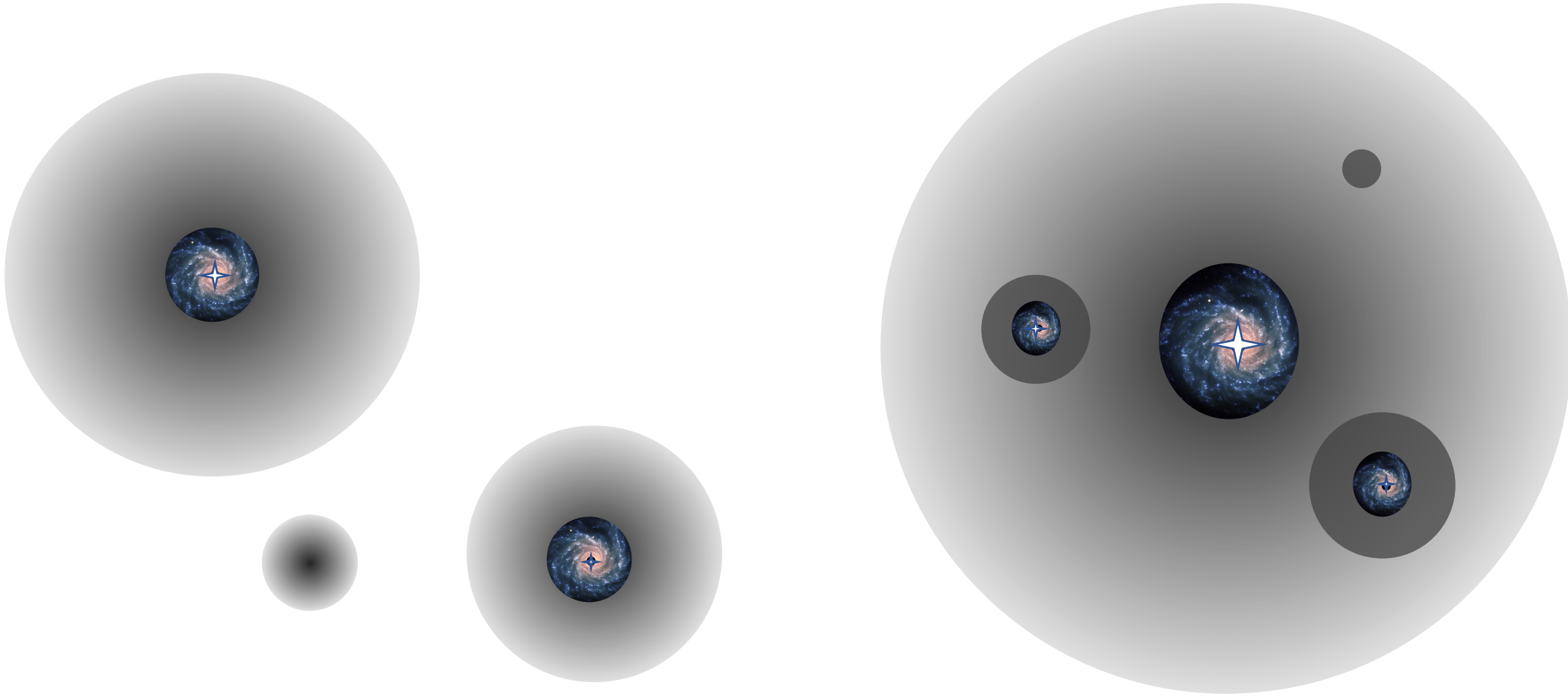
Populating a halo catalog with *galaxies:*



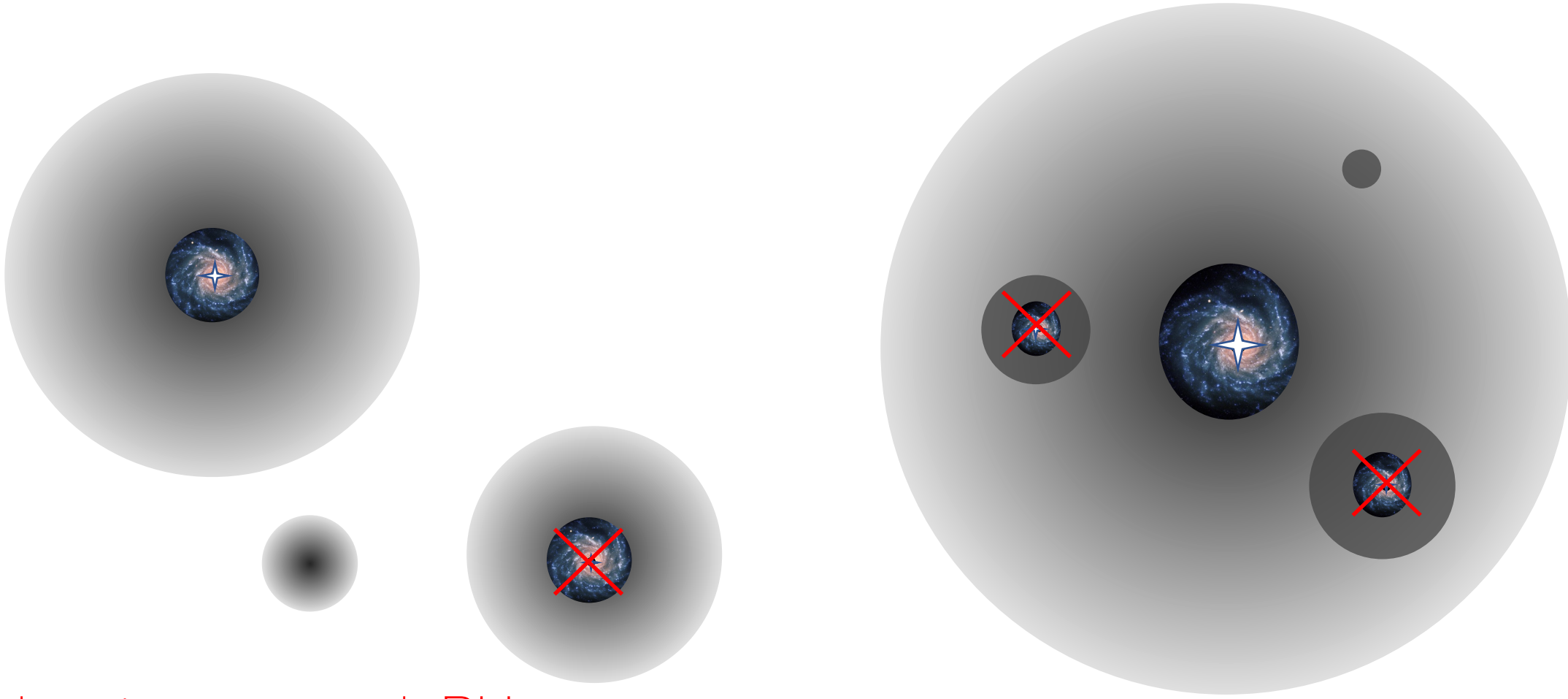
Populating a halo catalog with *SMBHs:*



Populating a halo catalog with *AGN:*



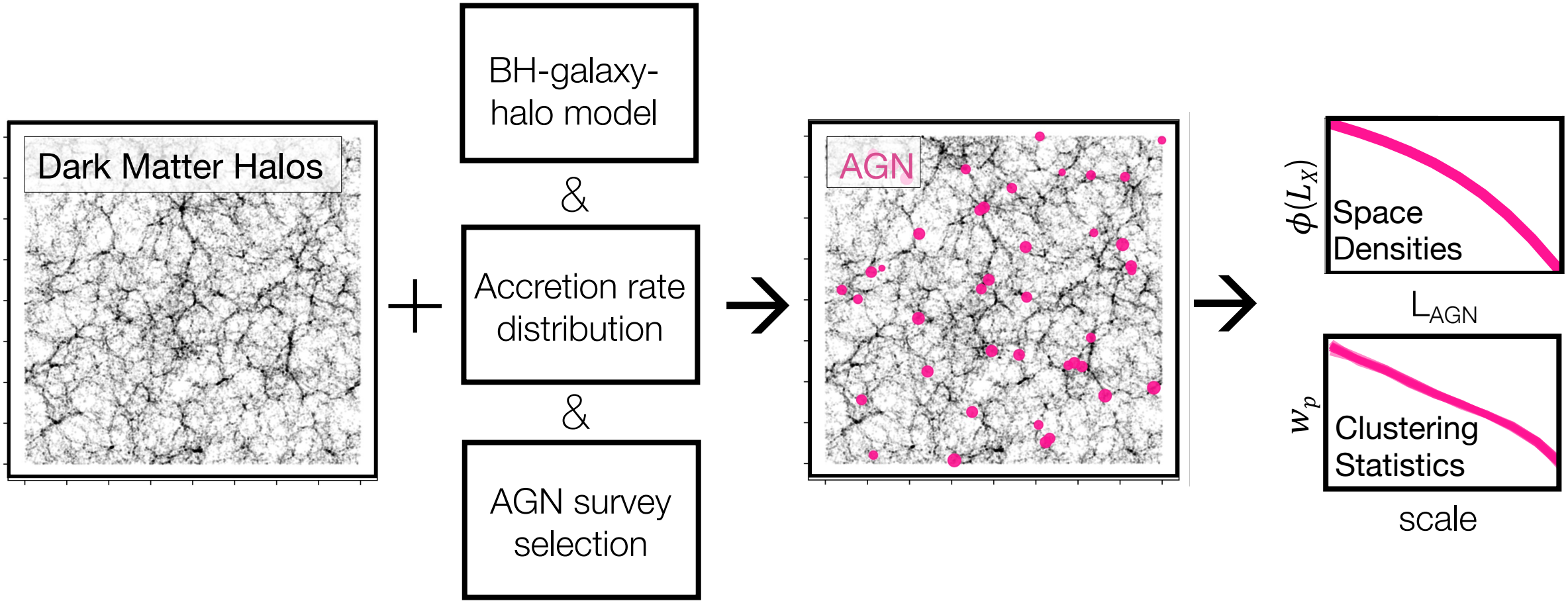
Populating a halo catalog with *AGN:*



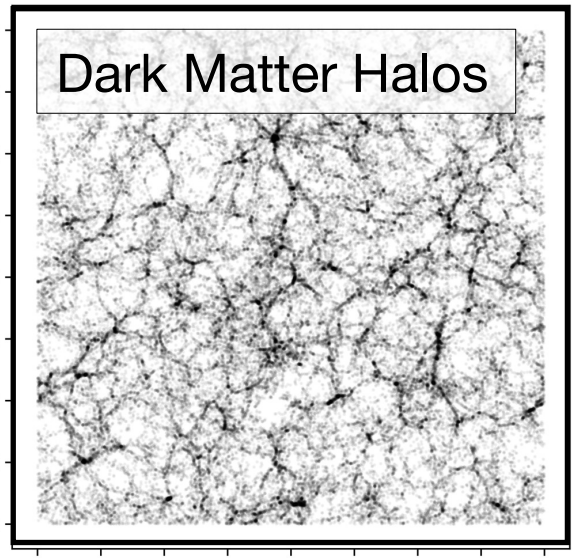
Mask out some mock BHs:

Select AGN based on luminosity

Forward-modeling AGN into DM sims



Forward-modeling AGN into DM sims



+

BH-galaxy-halo model

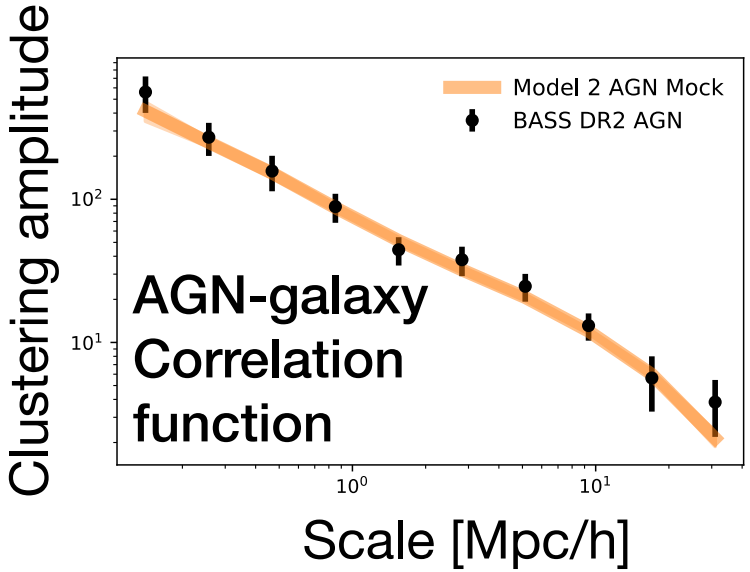
&

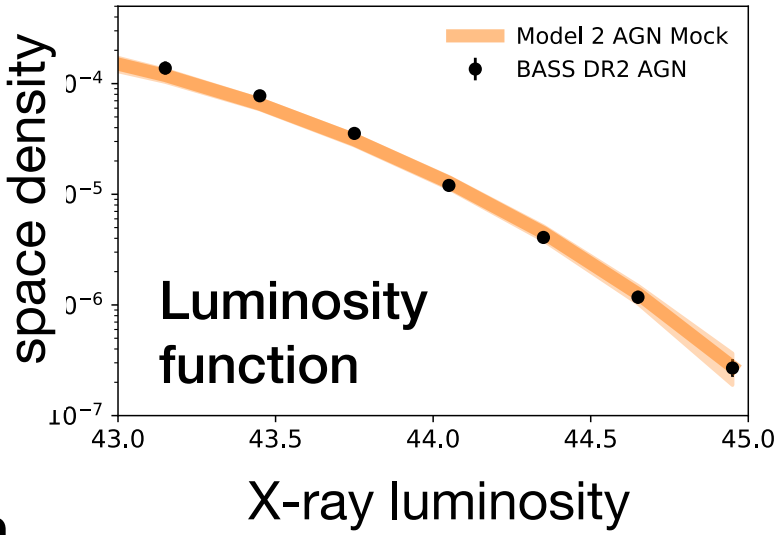
Accretion rate distribution

&

AGN survey selection

→



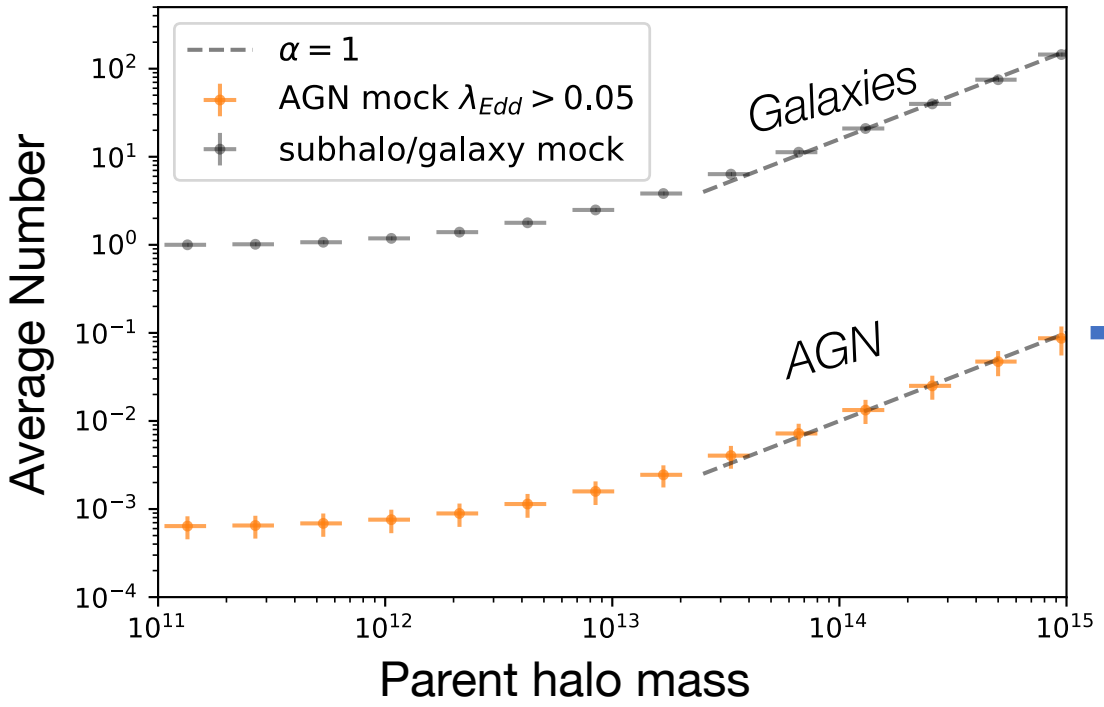


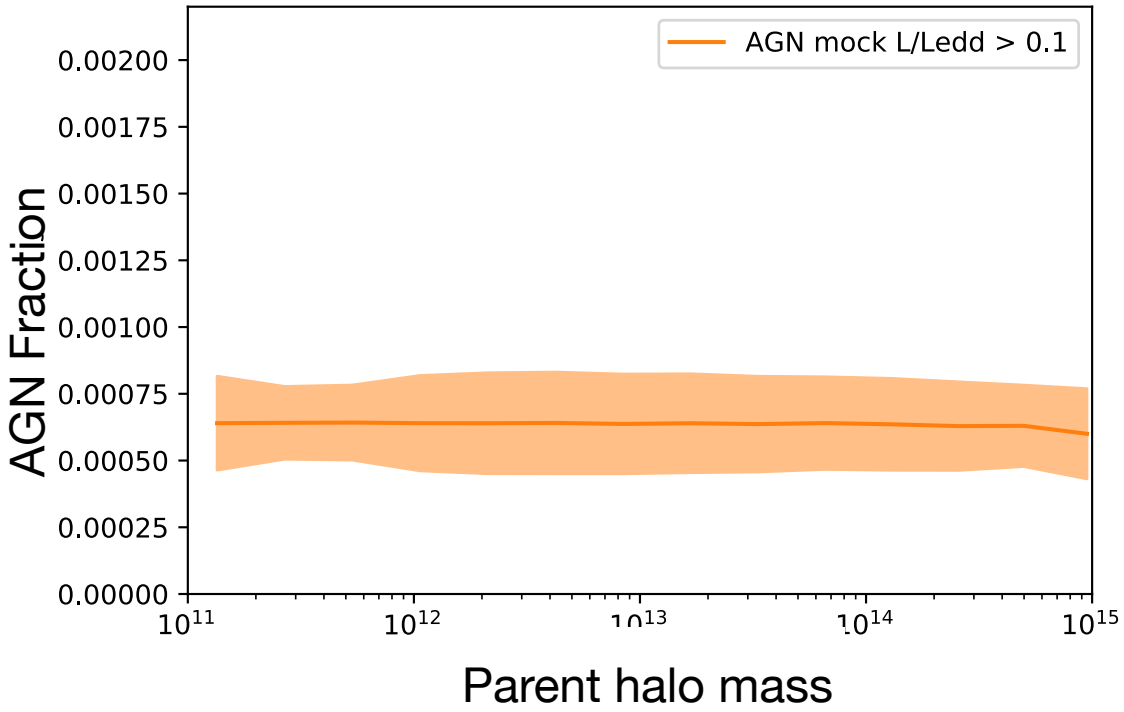
No special environments for BH accretion

Powell et al. 2022

Impact of AGN selection on halo distribution

Forward-modeling AGN with no triggering dependence on environment, selecting based on L/L_{Edd}:

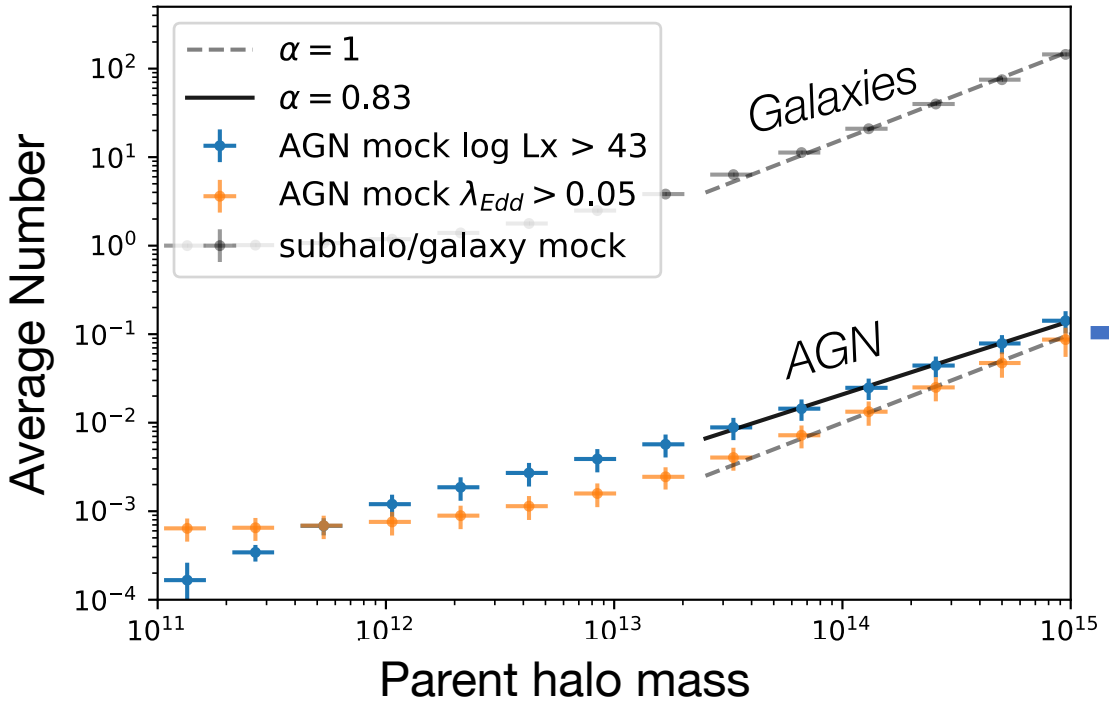


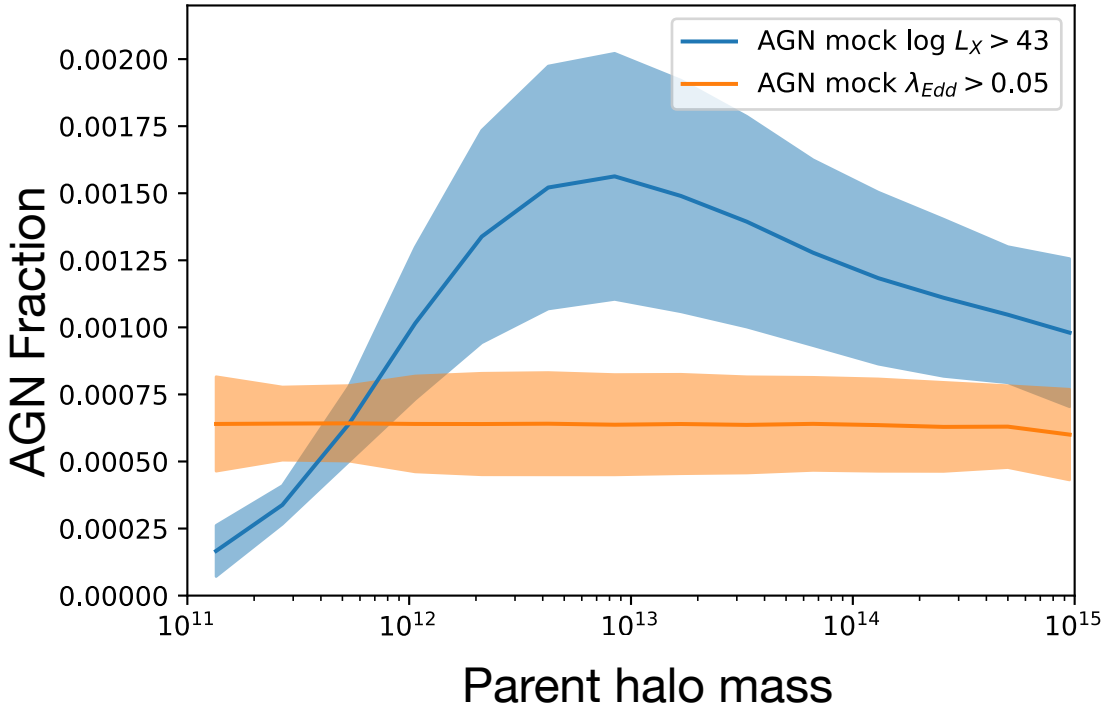


➢By construction, Eddington ratio-limited selection produces unbiased AGN fraction

Impact of AGN selection on halo distribution

Forward-modeling AGN with no triggering dependence on environment, selecting based on luminosity:

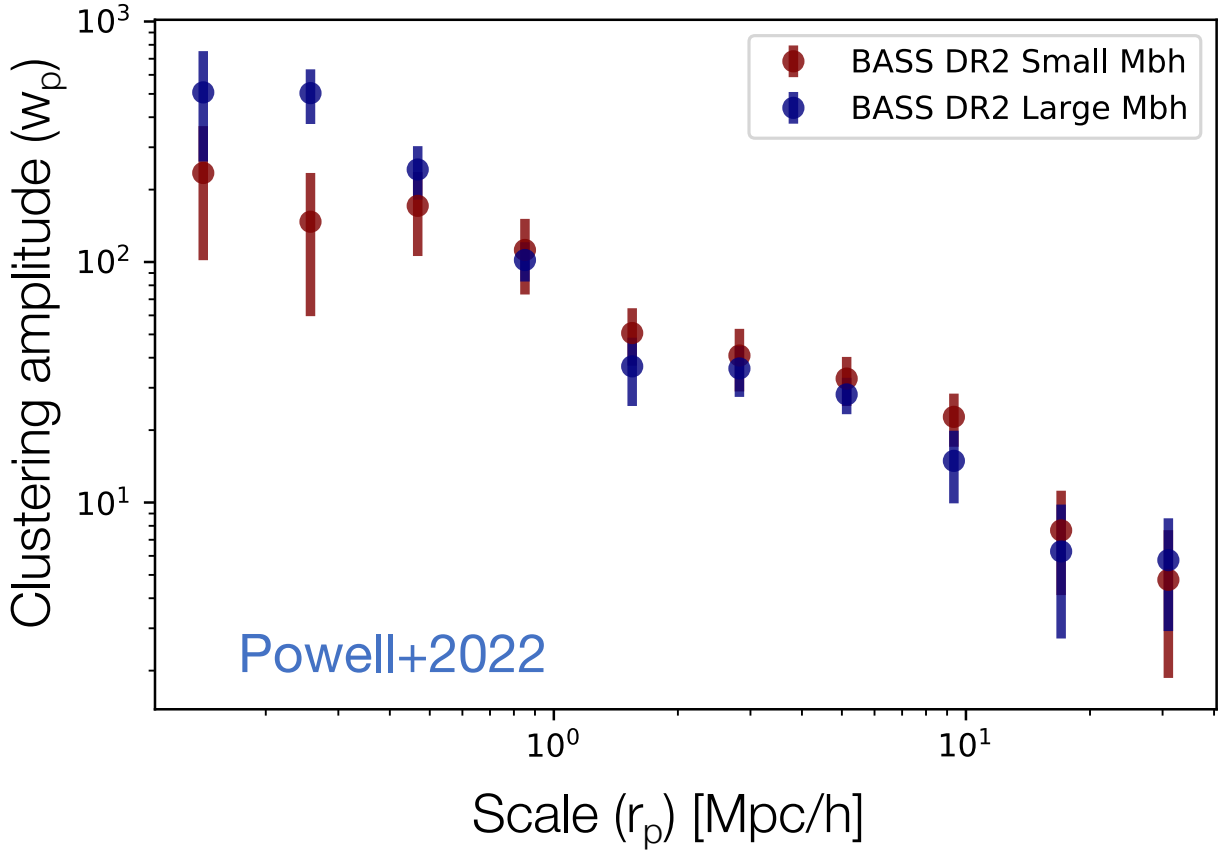




➢Previously measured differences between AGN and galaxy halo distributions may be due to *selection effects* rather than anything physical

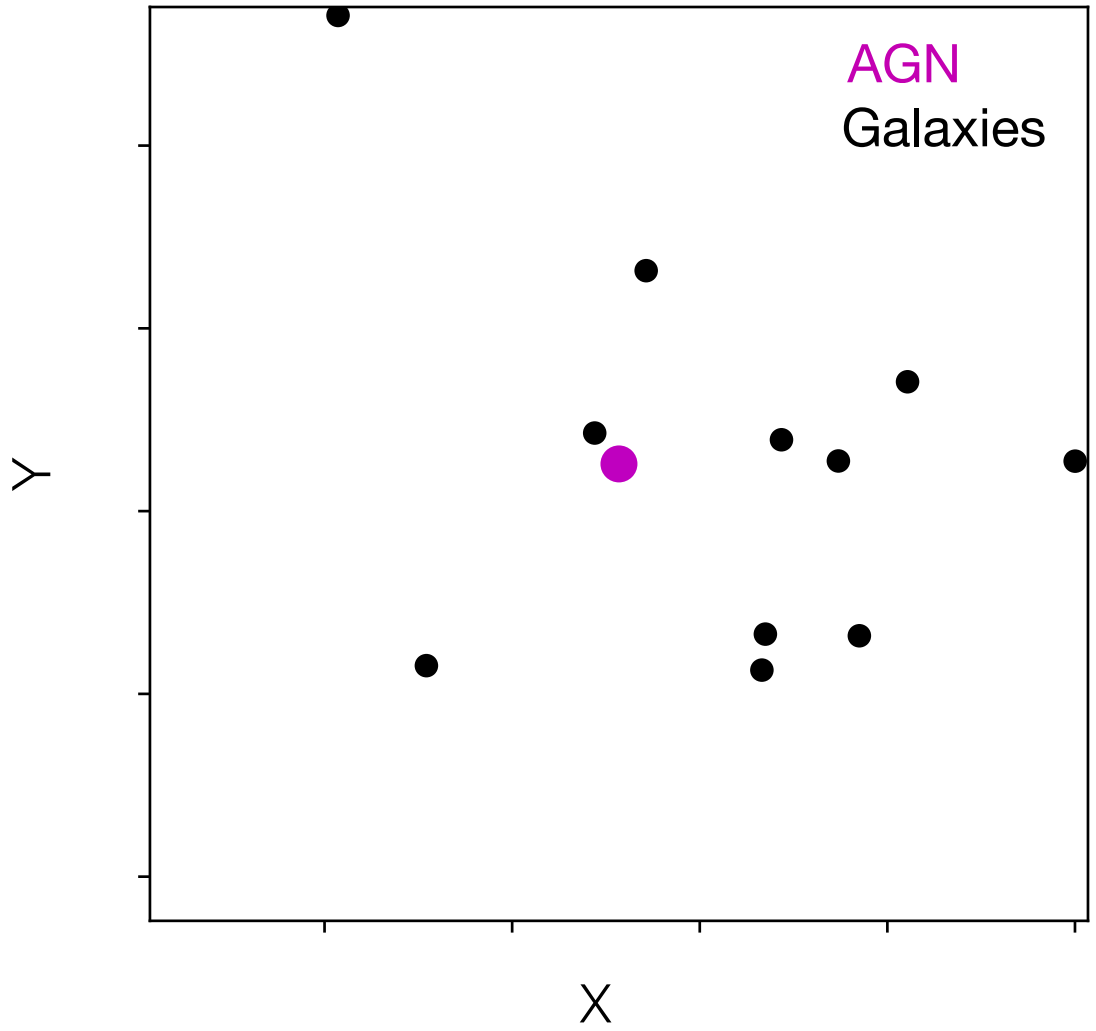
Powell et al. 2024

z=0: Clustering trends with black hole mass



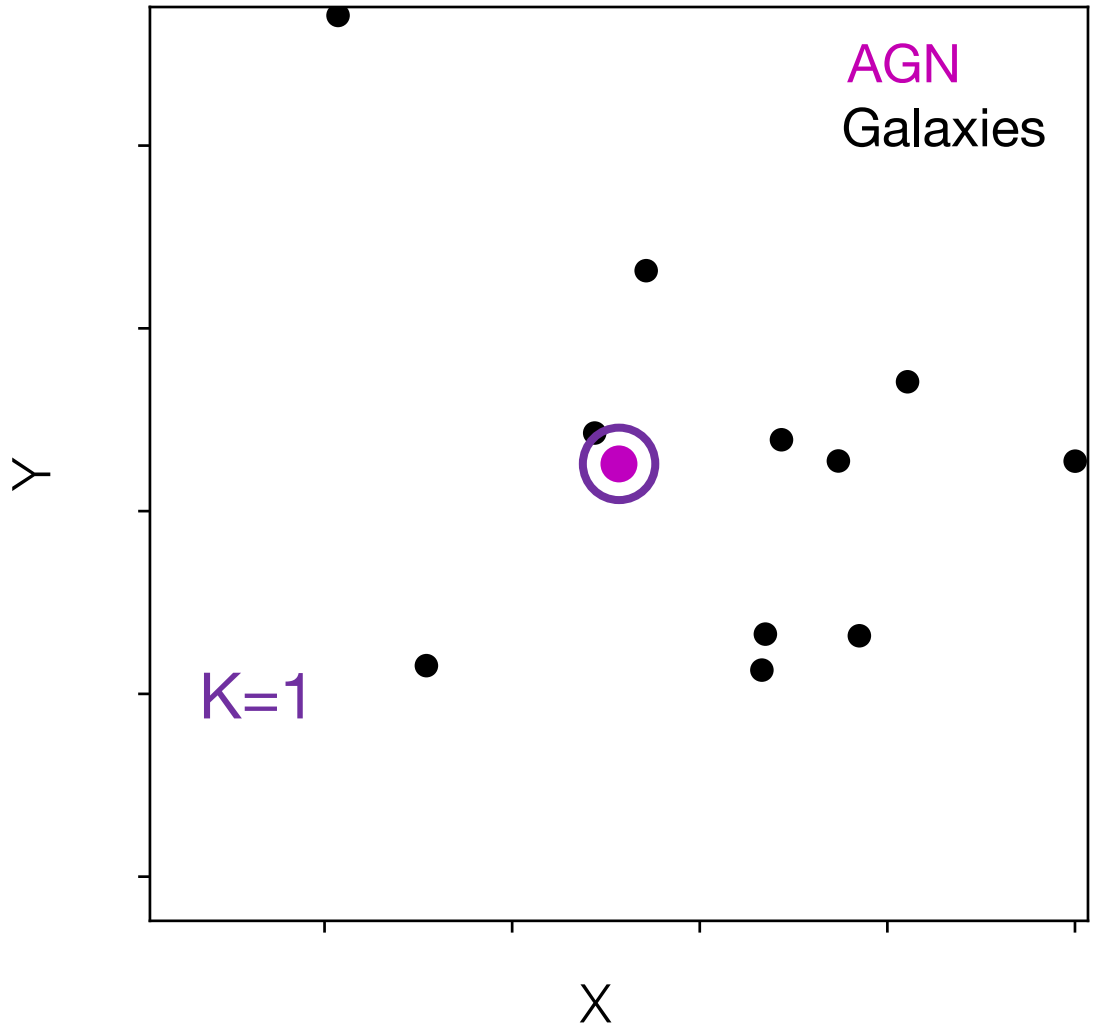
- 2.3σ clustering difference for 2 bins of M_{BH}
- AGN with massive SMBHs→ more clustered on small scales?

Alternative probe of clustering:
K^{th} Nearest-neighbor statistics



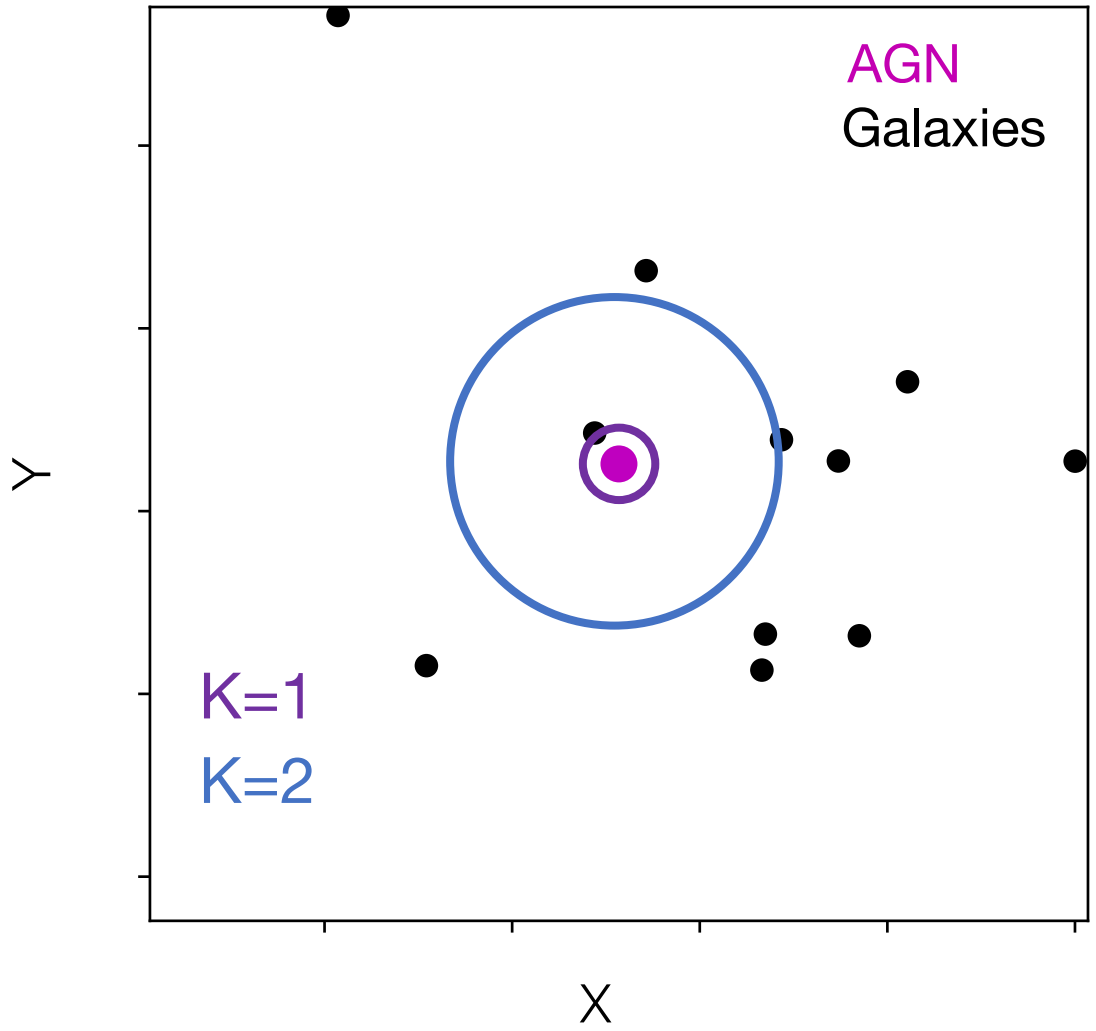
e.g., Banerjee et. al, 2022

Alternative probe of clustering:
K^{th} Nearest-neighbor statistics



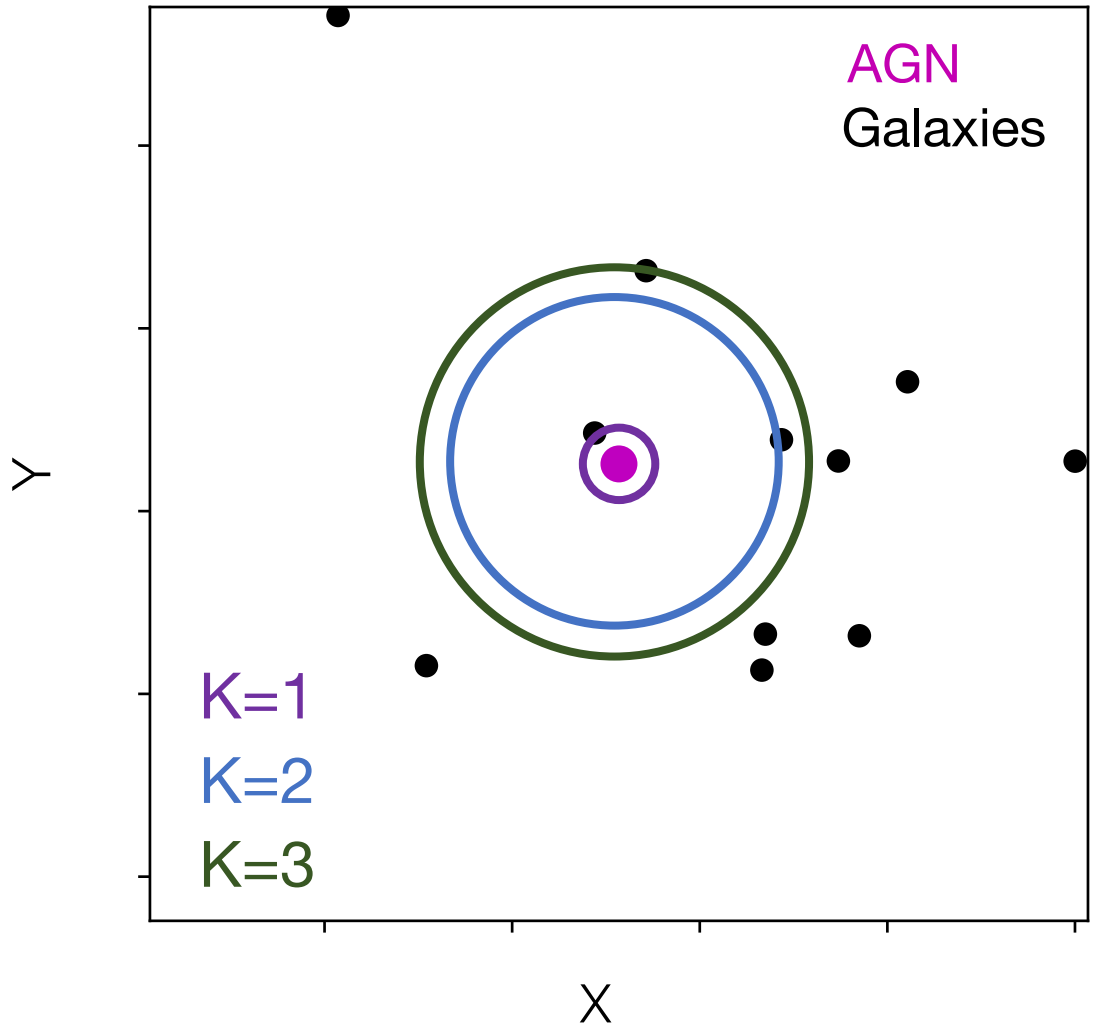
e.g., Banerjee et. al, 2022

Alternative probe of clustering:
K^{th} Nearest-neighbor statistics



e.g., Banerjee et. al, 2022

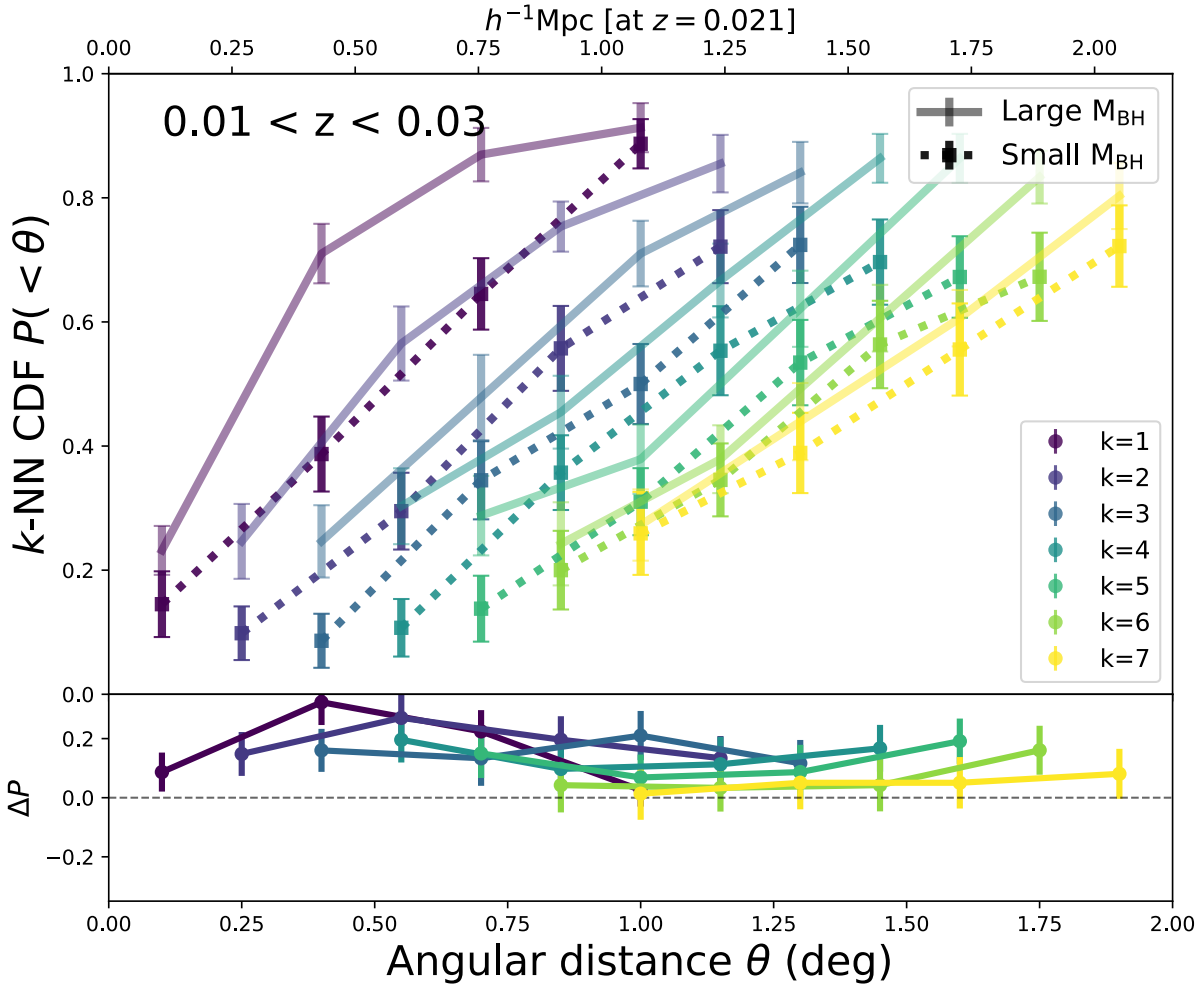
Alternative probe of clustering:
K^{th} Nearest-neighbor statistics



e.g., Banerjee et. al, 2022

K-NN trends with black hole mass

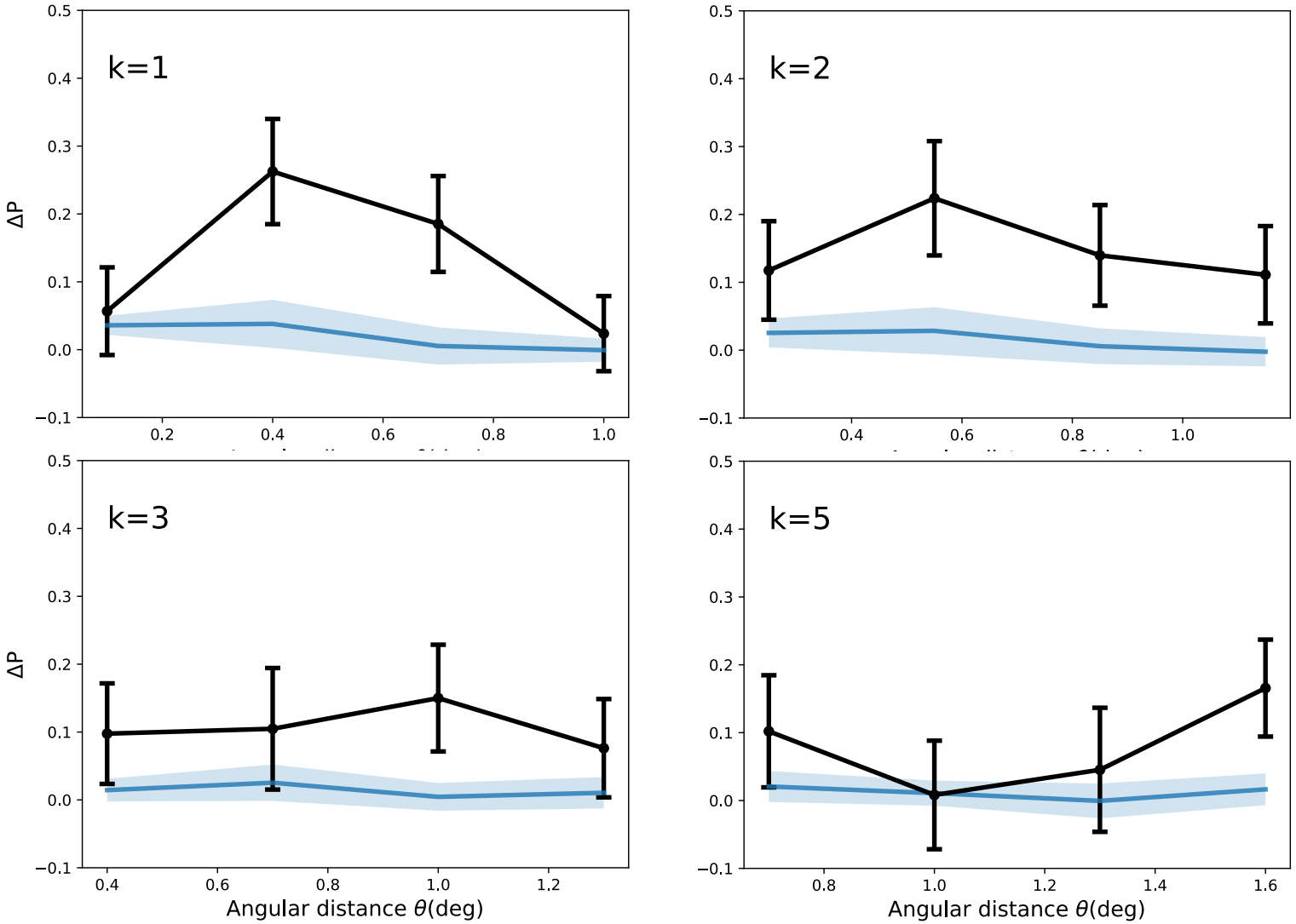
Stanford undergraduate Adam Mhatre



- 4.68 σ clustering difference for 2 bins of M_{BH}
- More massive SMBHs have closer neighbors than less-massive SMBHs

Mhatre, Powell, et al. *in prep*.

KNN M_{BH} trends: Comparing to mocks **(preliminary)**



BASS AGN nearest-nieghbor trends with M_{BH} are stronger in the data than in mocks

→ MBH clustering differences go beyond stellar mass correlations?

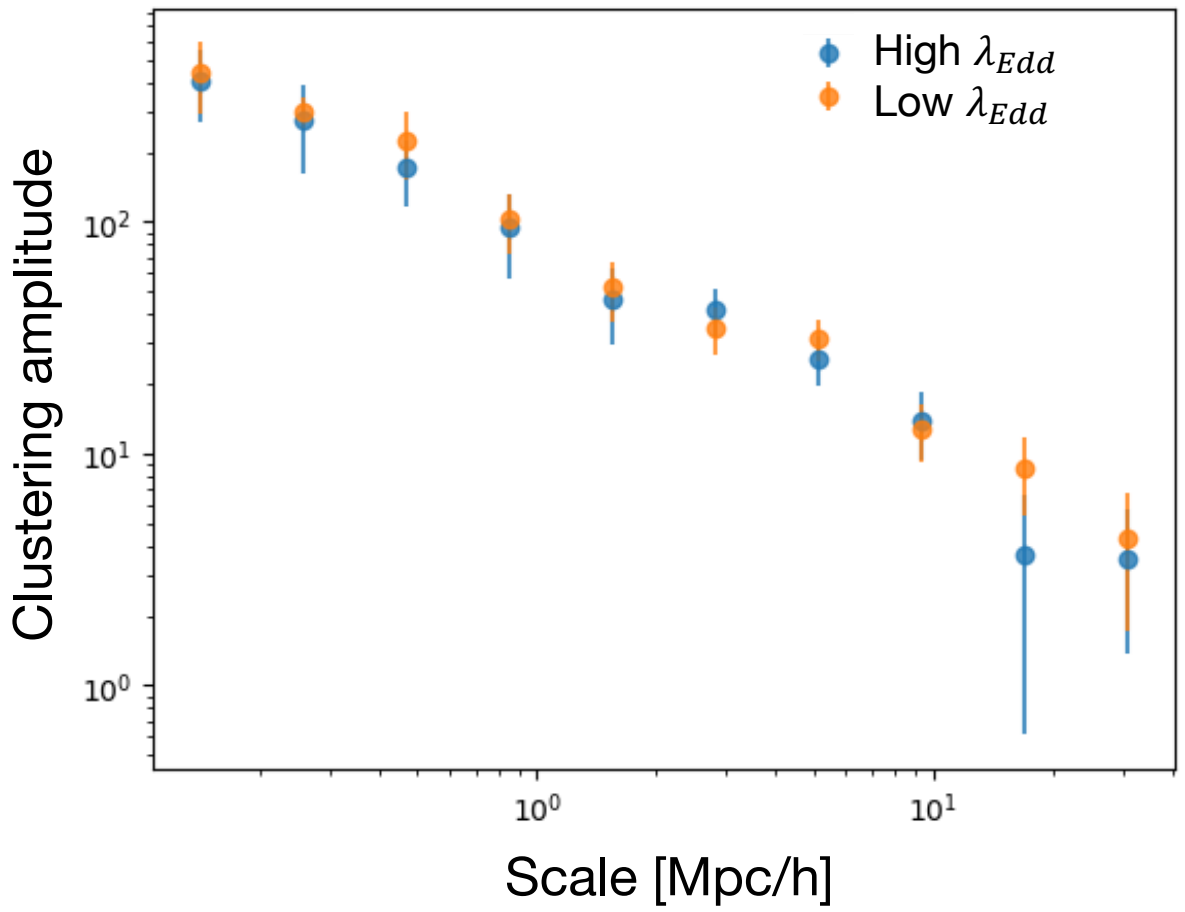
Summary

- AGN clustering measurements are powerful probes of the linked assemblies of SMBHs, galaxies, and their halos. But understanding selection effects are important

- At z=0, there's no evidence that X-ray AGN activity occurs in special environments.

- AGN with more massive black holes reside in denser cosmic environments
  - Differences in K-NN are more significant than previous measurements performed with the correlation function
  - Trends seem to go beyond correlations with stellar mass - denser cosmic environments facilitated earlier SMBH growth?

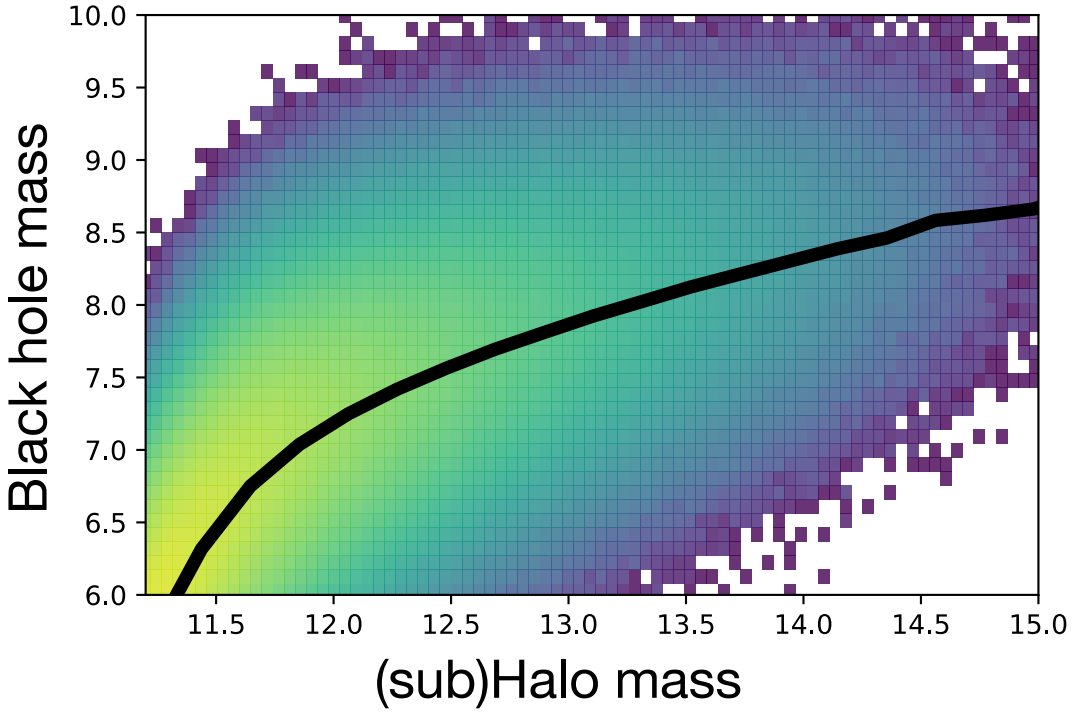
z=0: Clustering trends with L/Ledd



No environmental dependence on Eddington ratio

Models: SMBH mass-halo mass relations

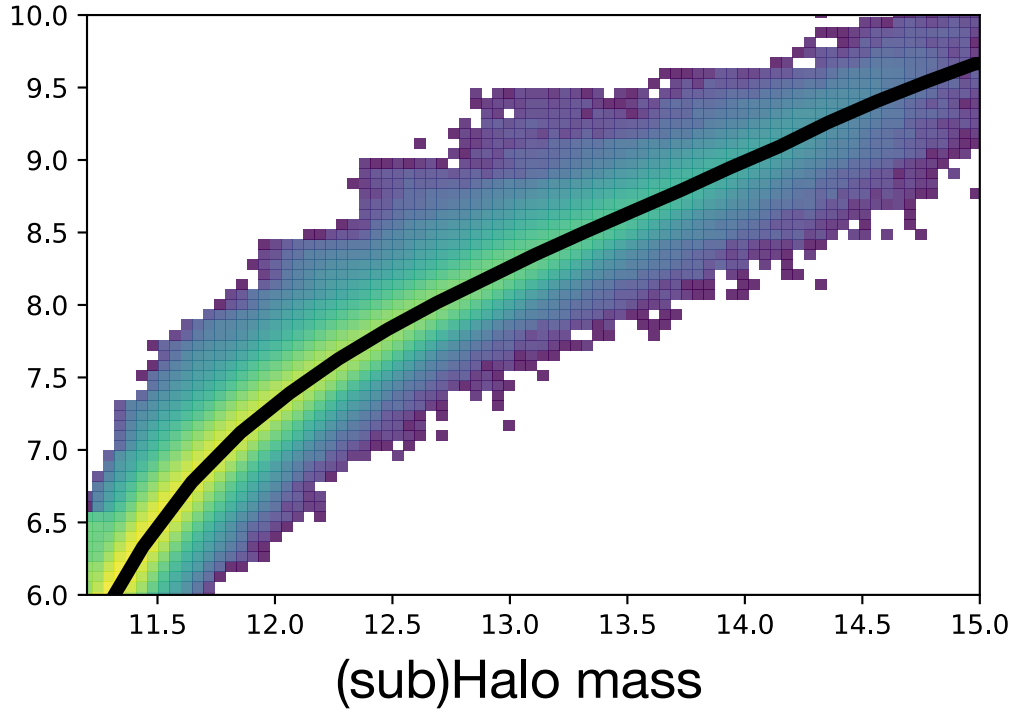
Model 1



SMBH-galaxy and galaxy-halo relations only

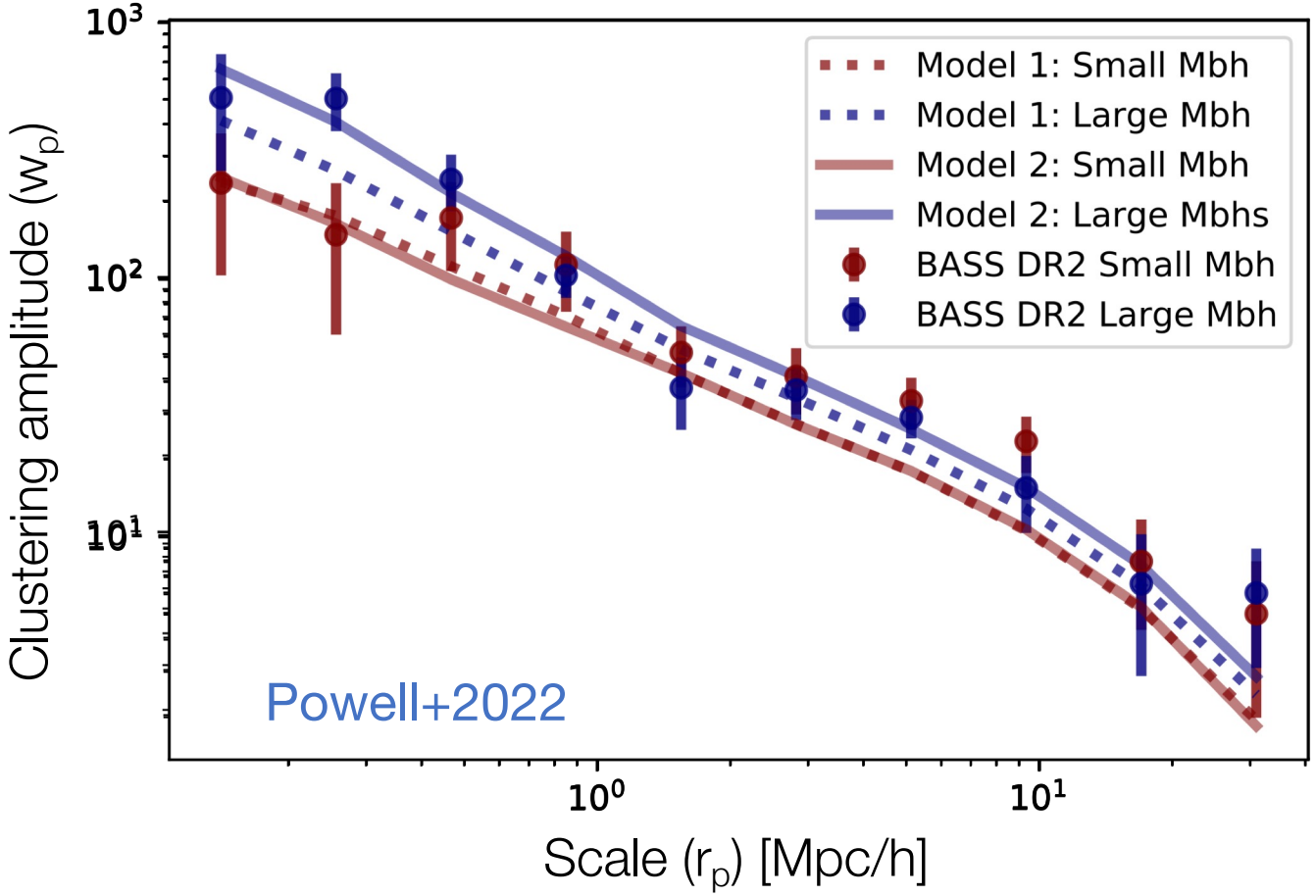
Or

Model 2



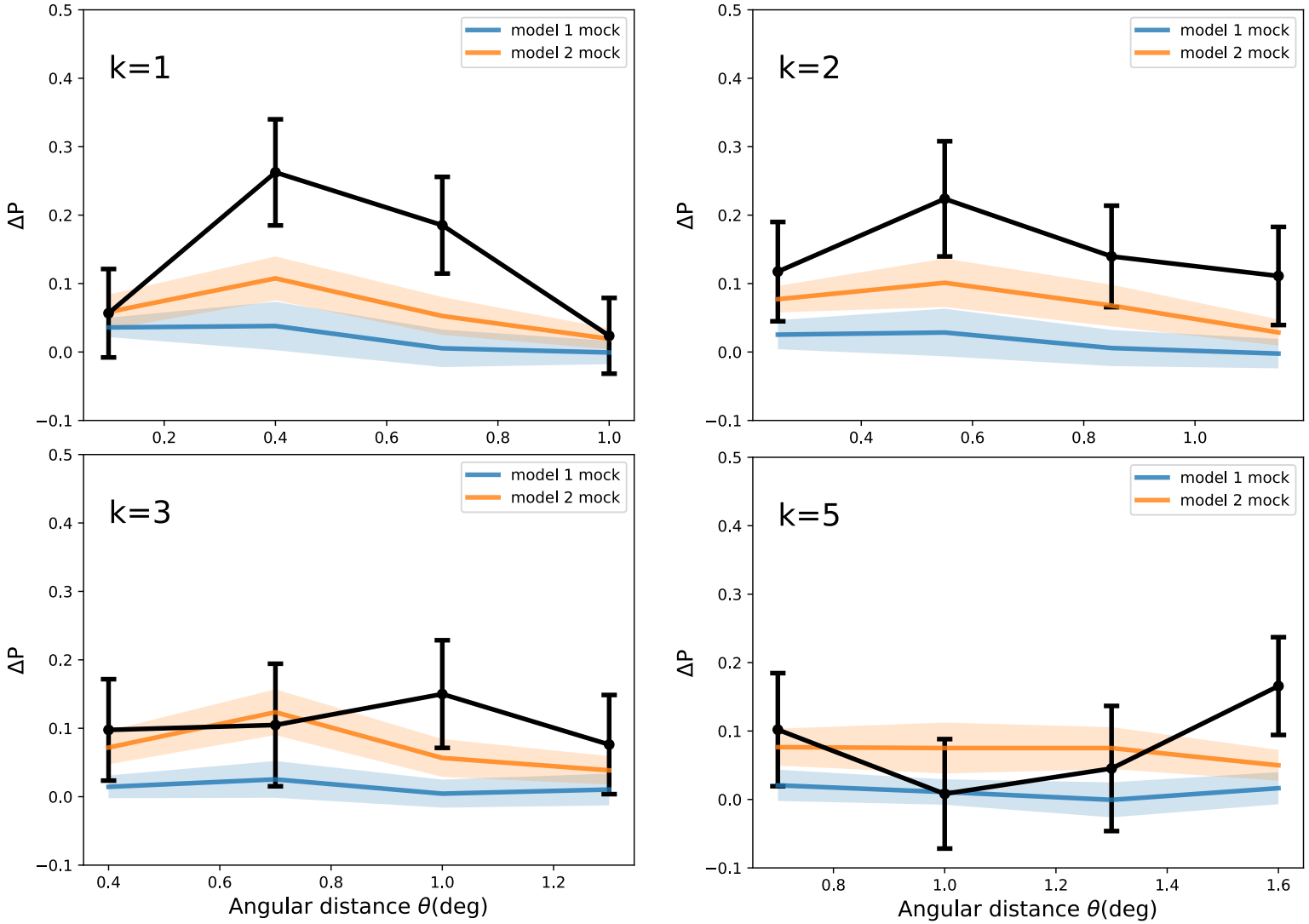
With additional BH-halo correlation

z=0: Clustering trends with black hole mass



$\Longrightarrow$ model with BH mass - (sub)halo mass reproduces wp vs. Mbh differences

KNN M_{BH} trends: Comparing to mocks **(preliminary)**

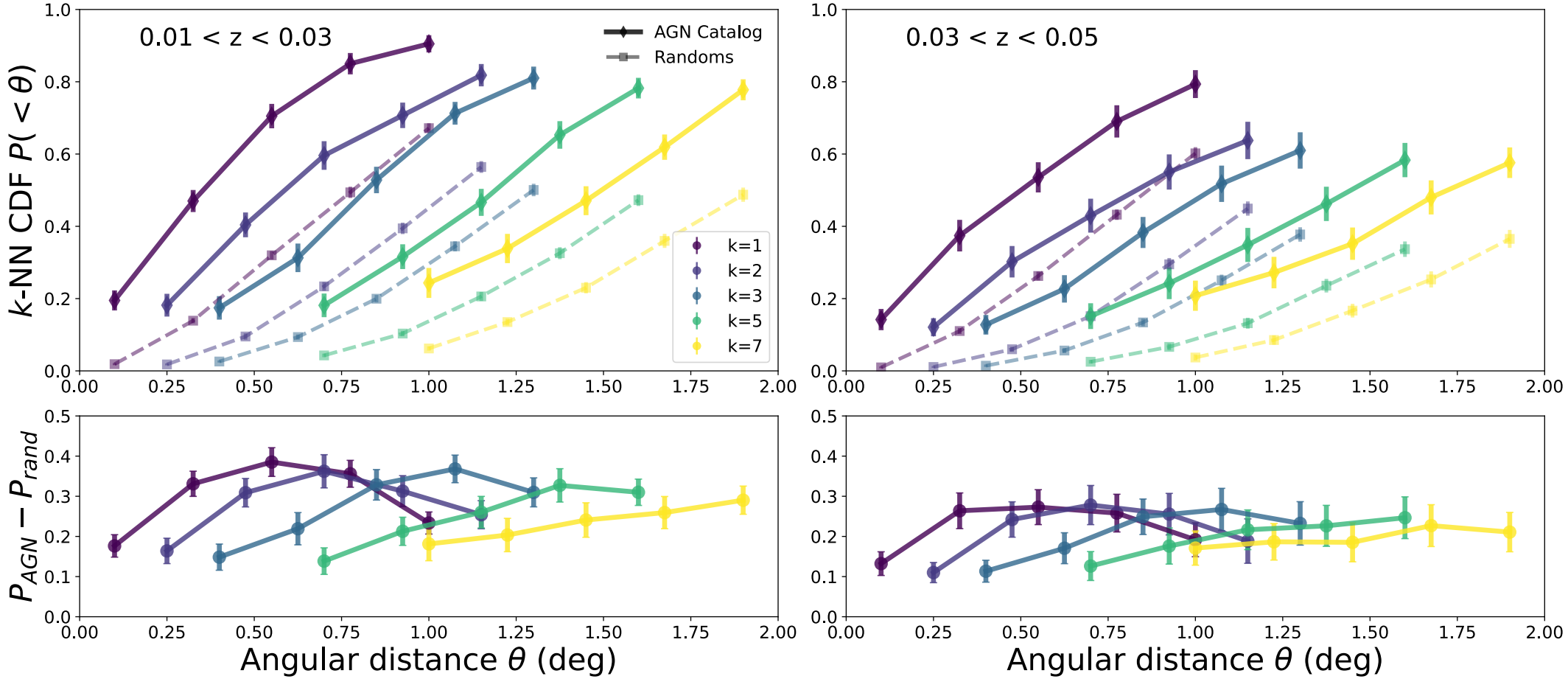


BASS AGN nearest-nieghbor trends with M_{BH} are stronger in the data than in mocks

→ model with BH mass - (sub)halo mass correlation more consistent with data?

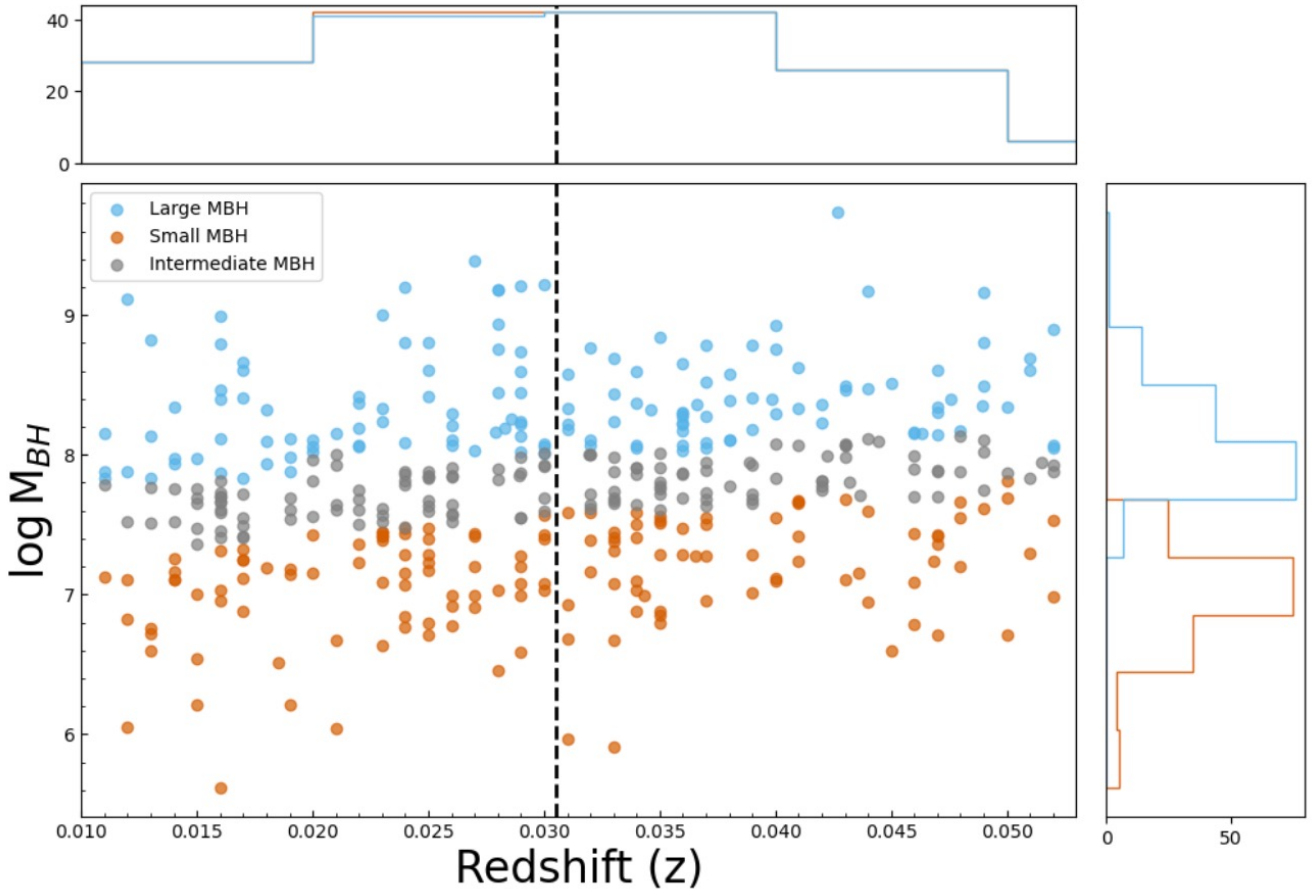
BASS AGN K-NN measurement

Stanford undergrad Adam Mhatre

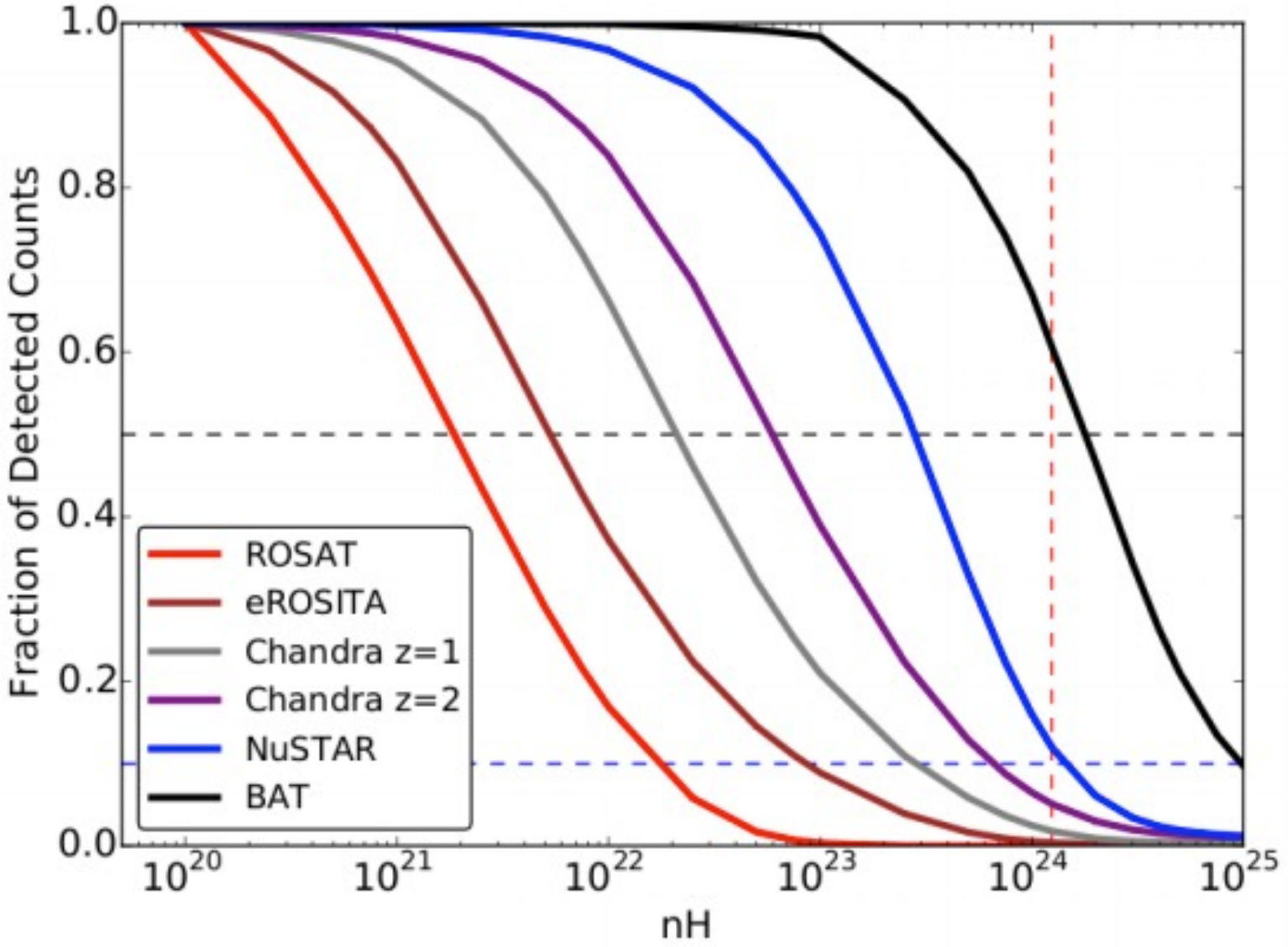


Mhatre, Powell, et al. *in prep*.

Binning BH mass



- 2 bins of black hole mass
- Controlled for redshift



Koss et al. 2017