AGN in dense environments:
Cluster AGN Topography Survey (CATS)

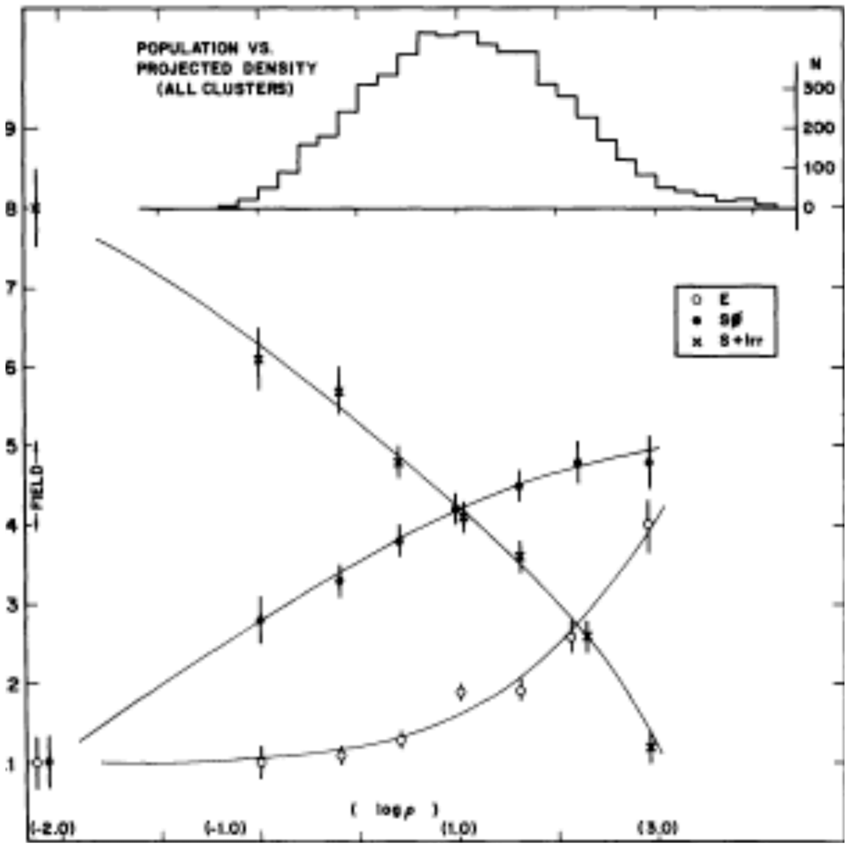
Becky Canning

Allen, Brandt, Ehlert, King, von der Linden, Luo, Mantz, Morris, Noordeh, Xue + SPT

Environmental effects

Dressler 1980

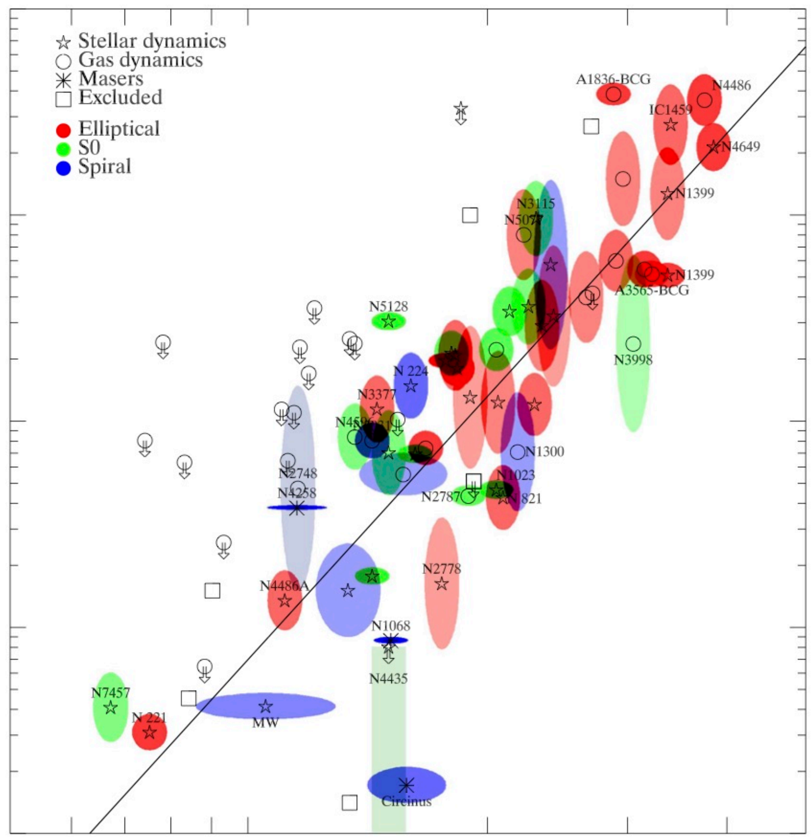
Fraction of population



Density

Gultekin et al. 2009

Black Hole Mass



Stellar Velocity Dispersion

NASA/CXC/Werner et al. 2010

What dominates?
Where/When/How these evolve?

Where/When established?
Whether/How connected?

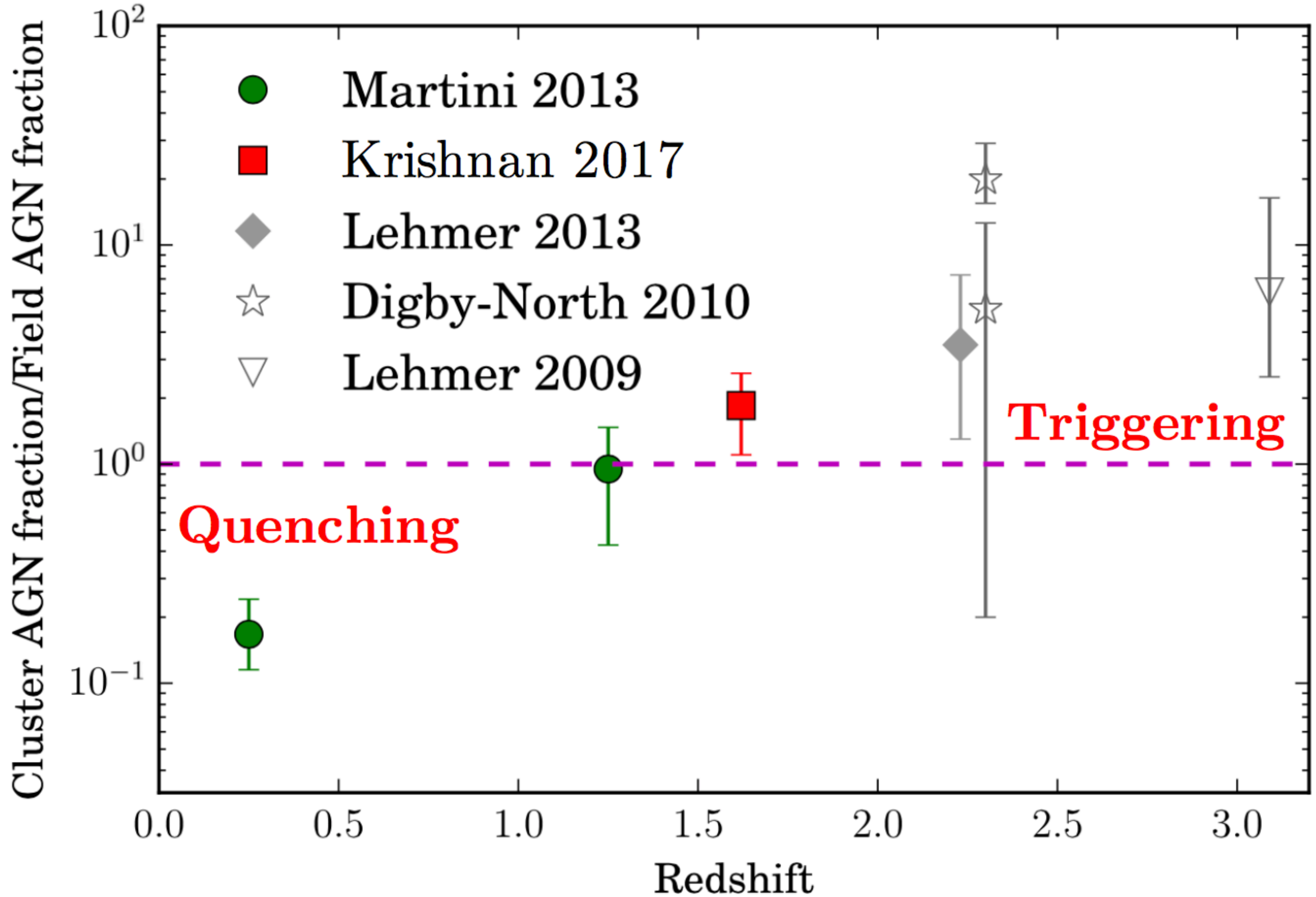
AGN in dense environments

- Ram pressure stripping, evaporation, starvation, tidal effects
- Rates of mergers and interactions

Depend on:

- Position within host cluster
- Mass of host cluster

Adapted from Krishnan+2017



Challenges

Cluster AGN rare - background dominated

Incomplete redshifts = differential measurements

→ Need large survey but can leverage cluster self similarity

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Fortunately people enjoy looking at clusters with Chandra!

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Abundant X-ray data!

Blessing: Can use X-ray data to characterize environment and AGN.

Challenges

Cluster AGN rare - background dominated

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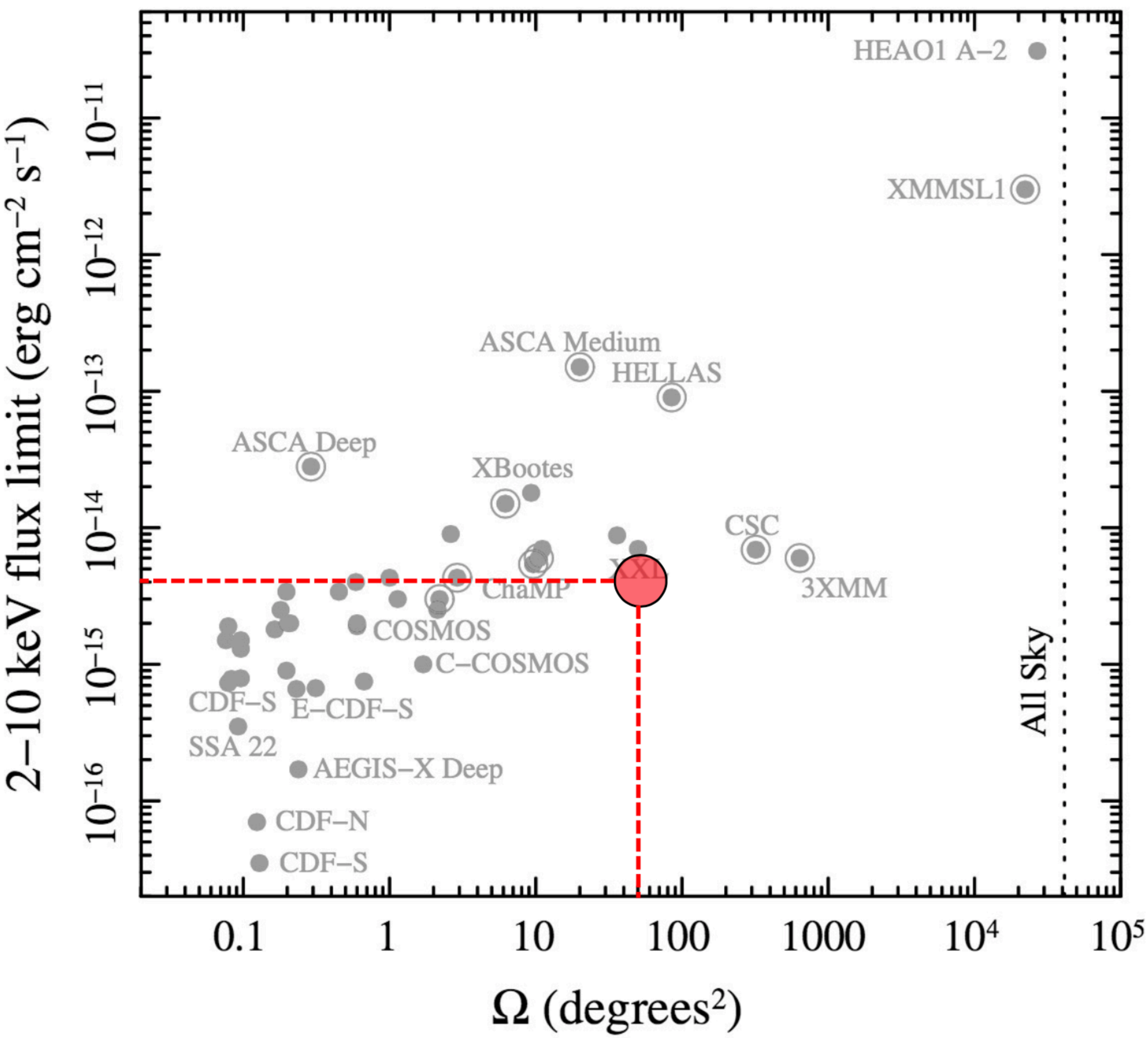
Abundant X-ray data!

Blessing: Can use X-ray data to characterize environment and AGN.

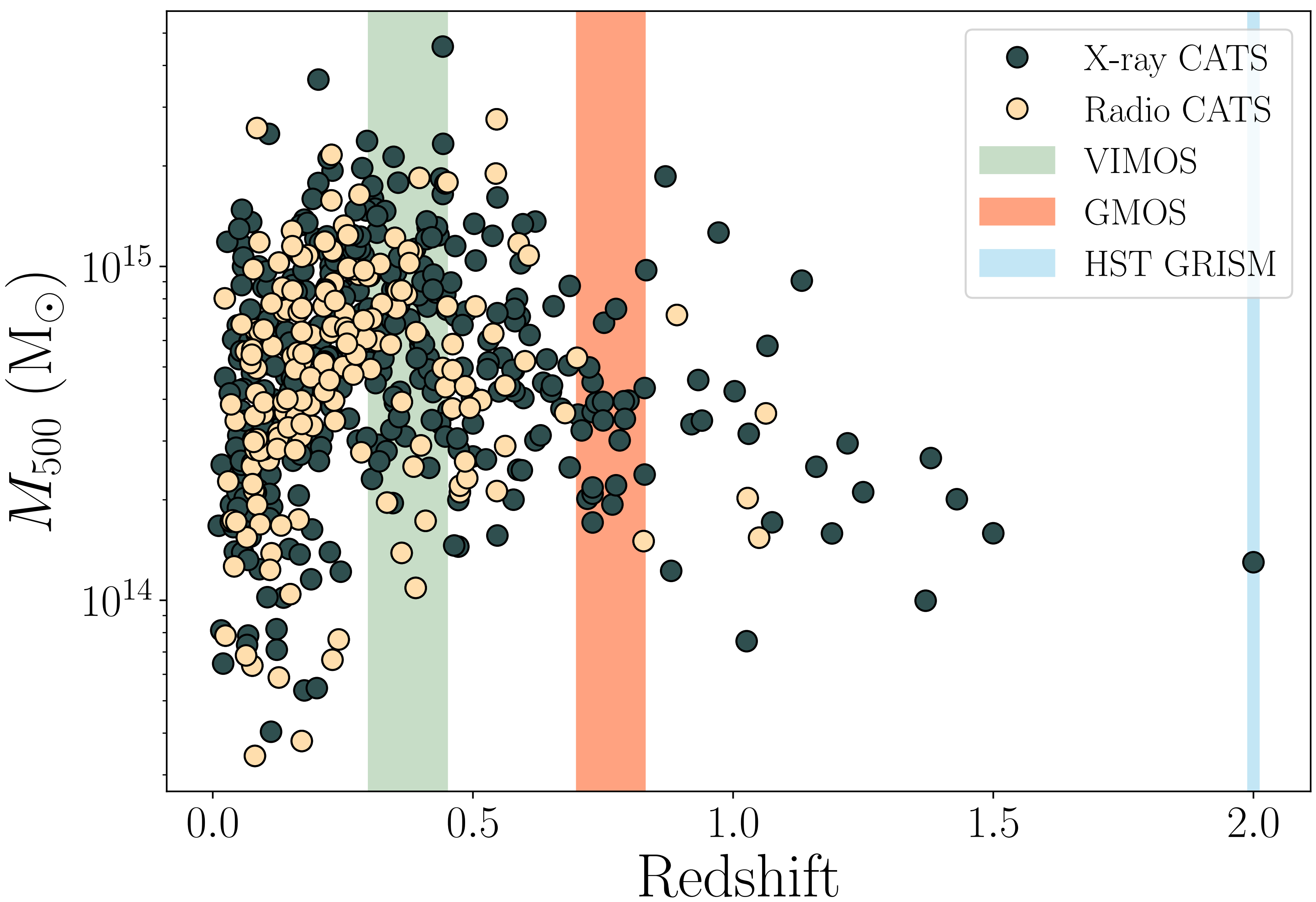
Curse: Diffuse X-ray emission increases background. Affects both completeness and purity of AGN sample.

CATS - Cluster AGN Topography Survey

Adapted from Brandt & Alexander 2015



CATS Selection



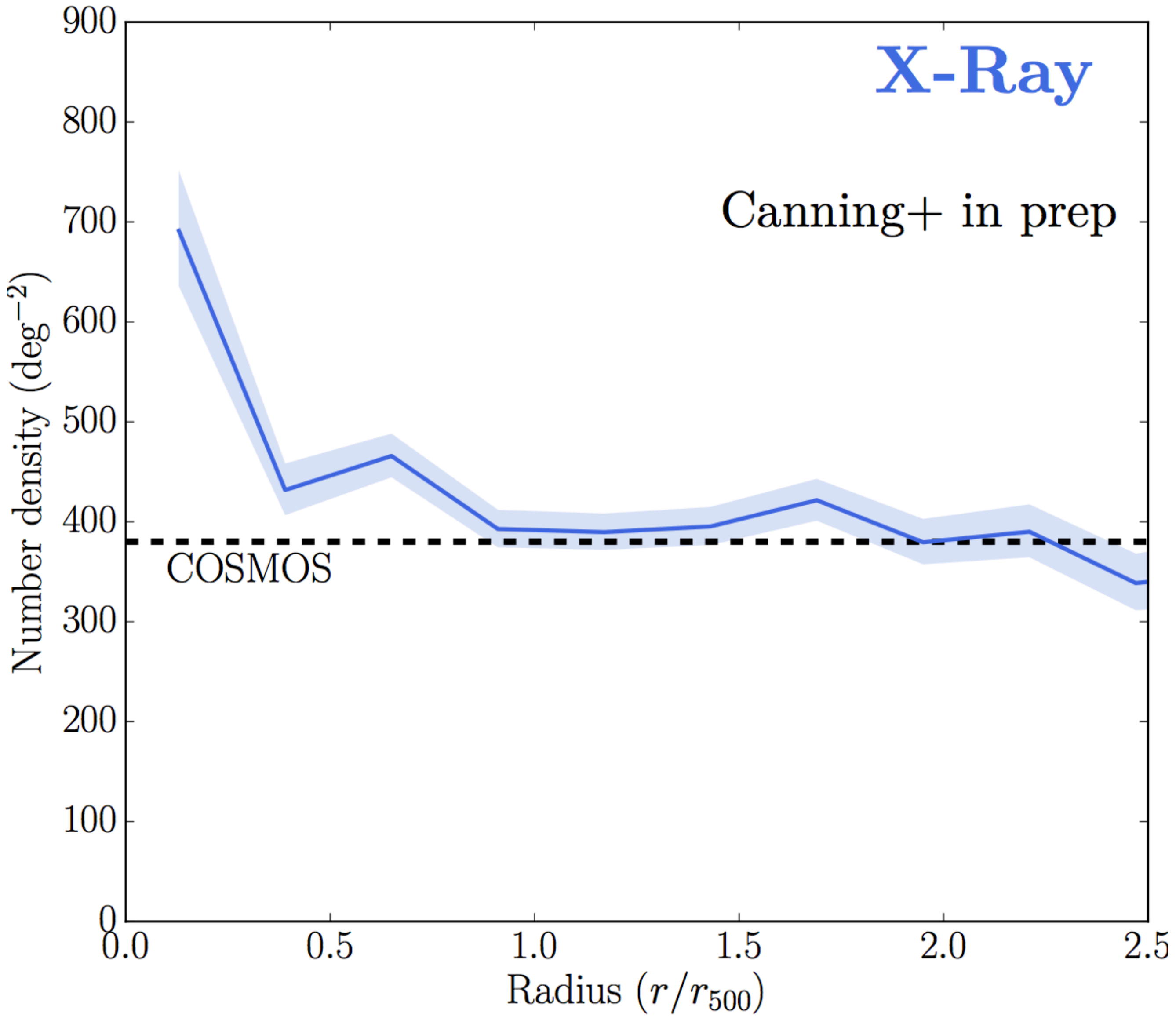
X-ray: 550 clusters ~40,000 point sources (27 Ms Chandra Data)

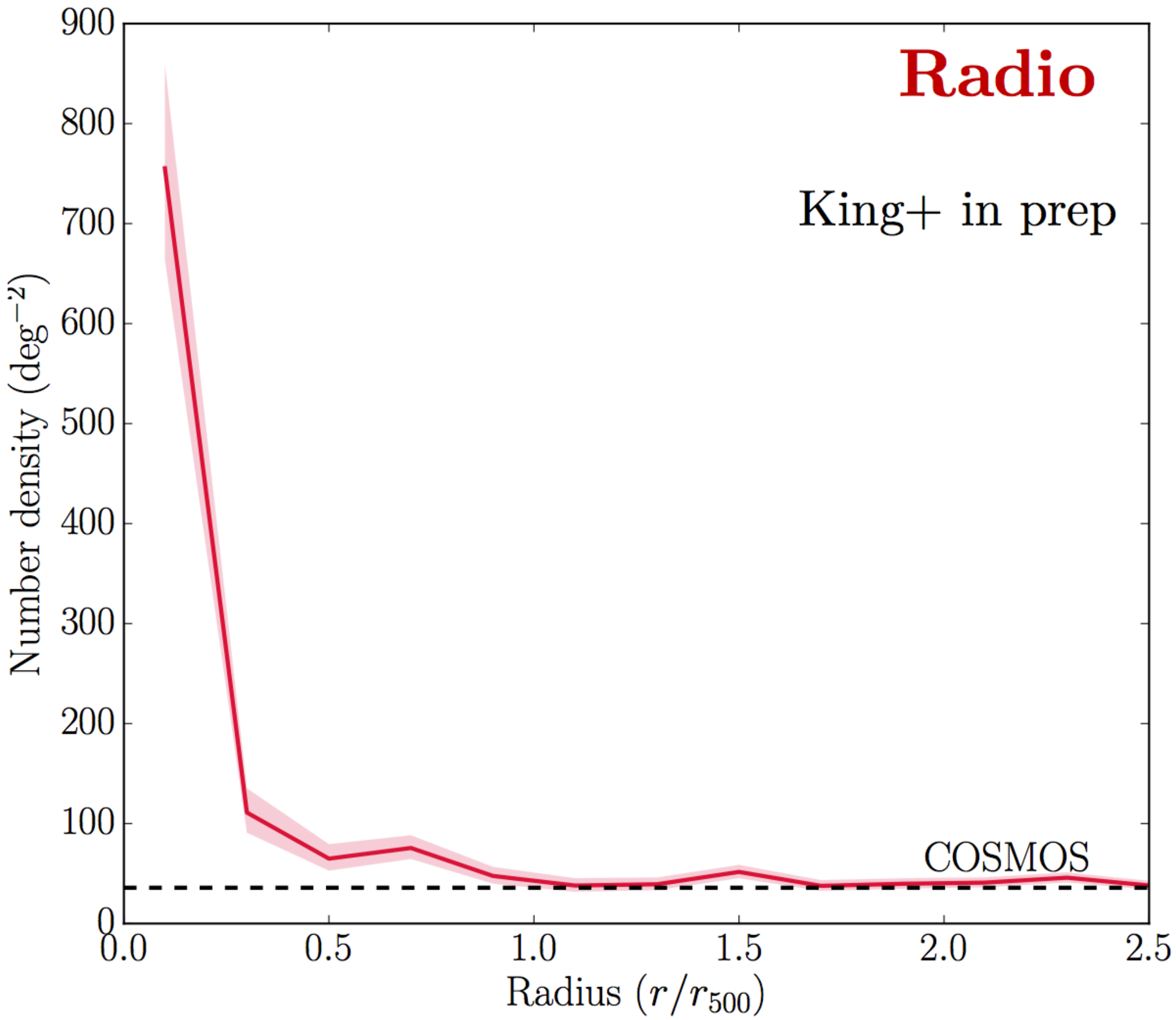
Radio: 183 clusters (FIRST survey)
Ashley's talk

IR and UV: WISE 550 clusters; Spitzer 320 clusters; Galex 550

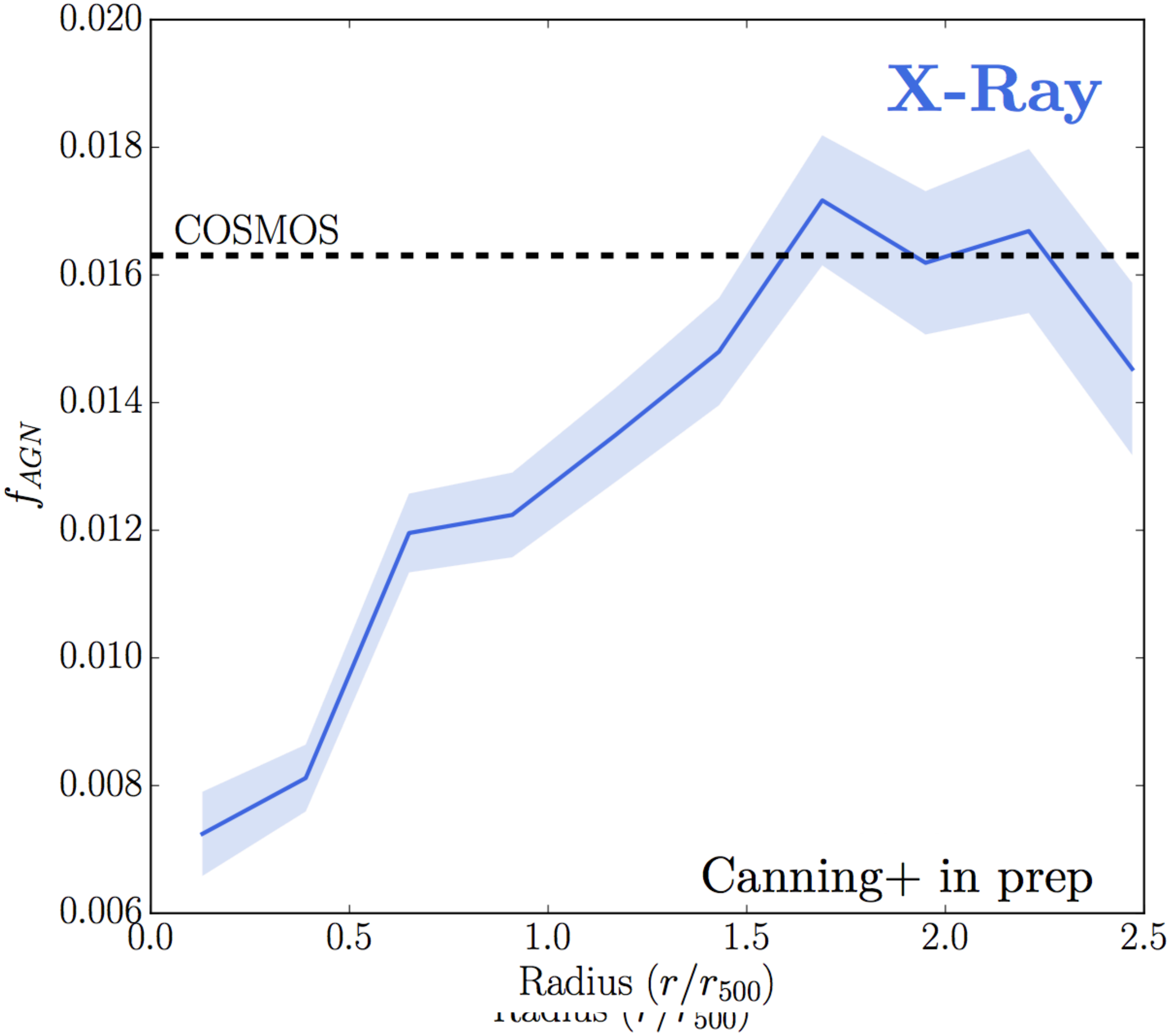
Spectroscopy: 7 z=0.4, 12 z=0.8, 1 z=2 clusters
Noordeh. in prep

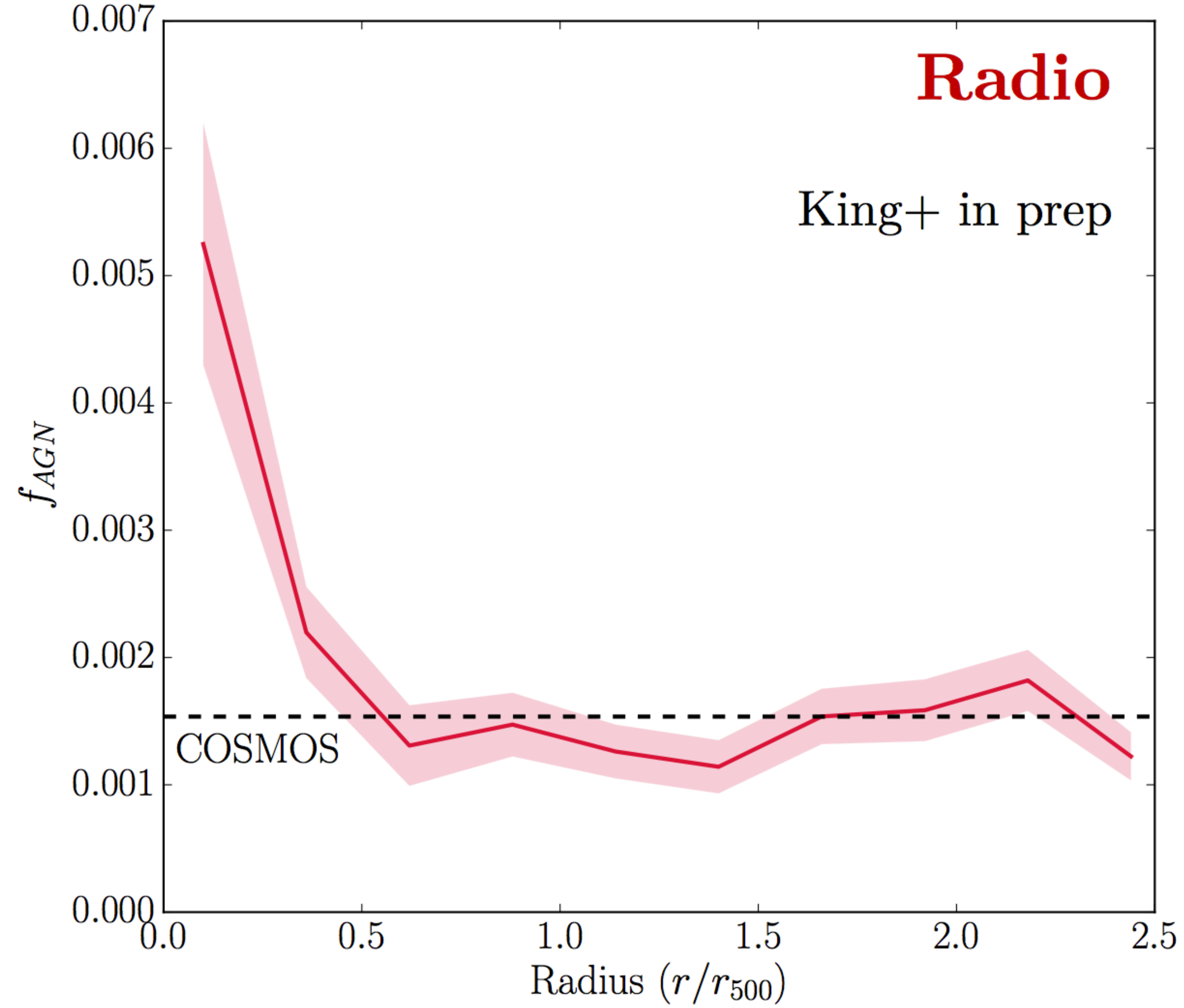
AGN number densities



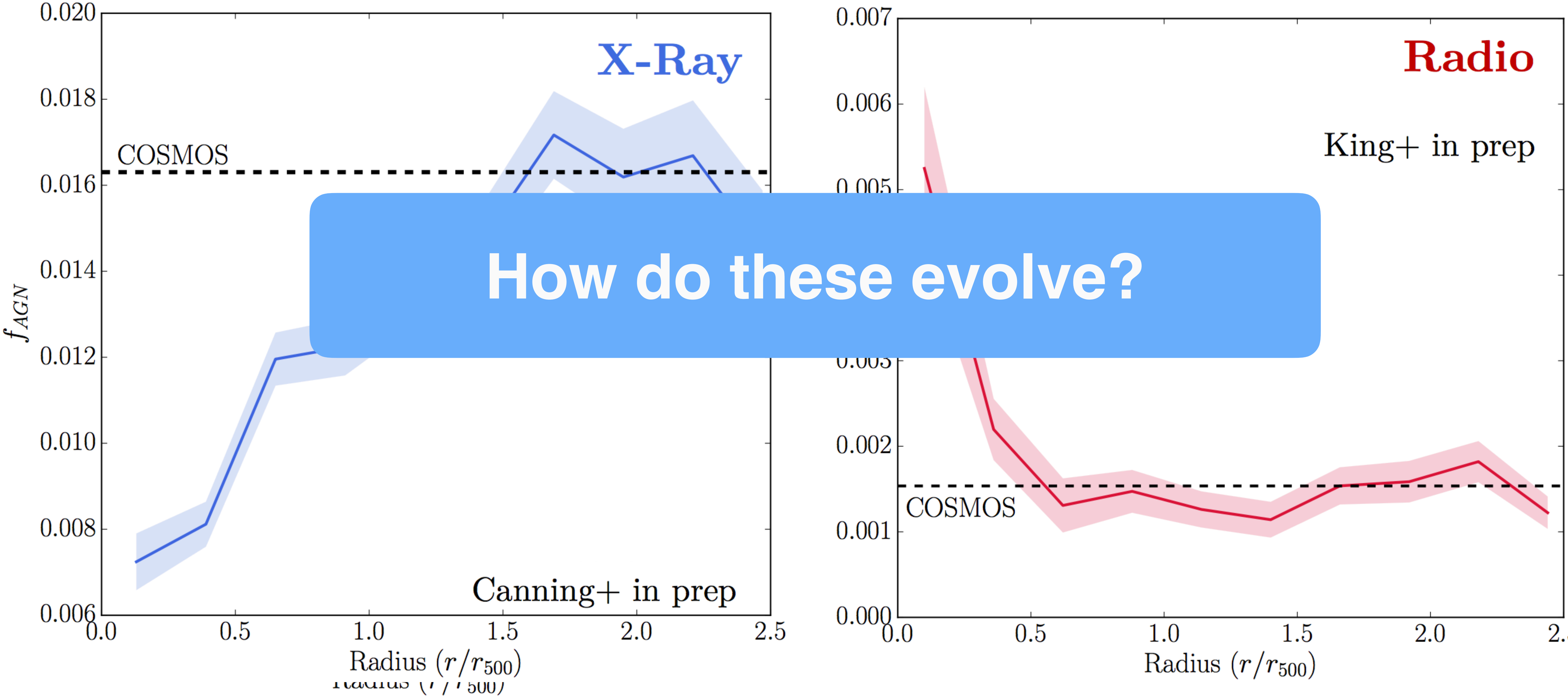


AGN fractions

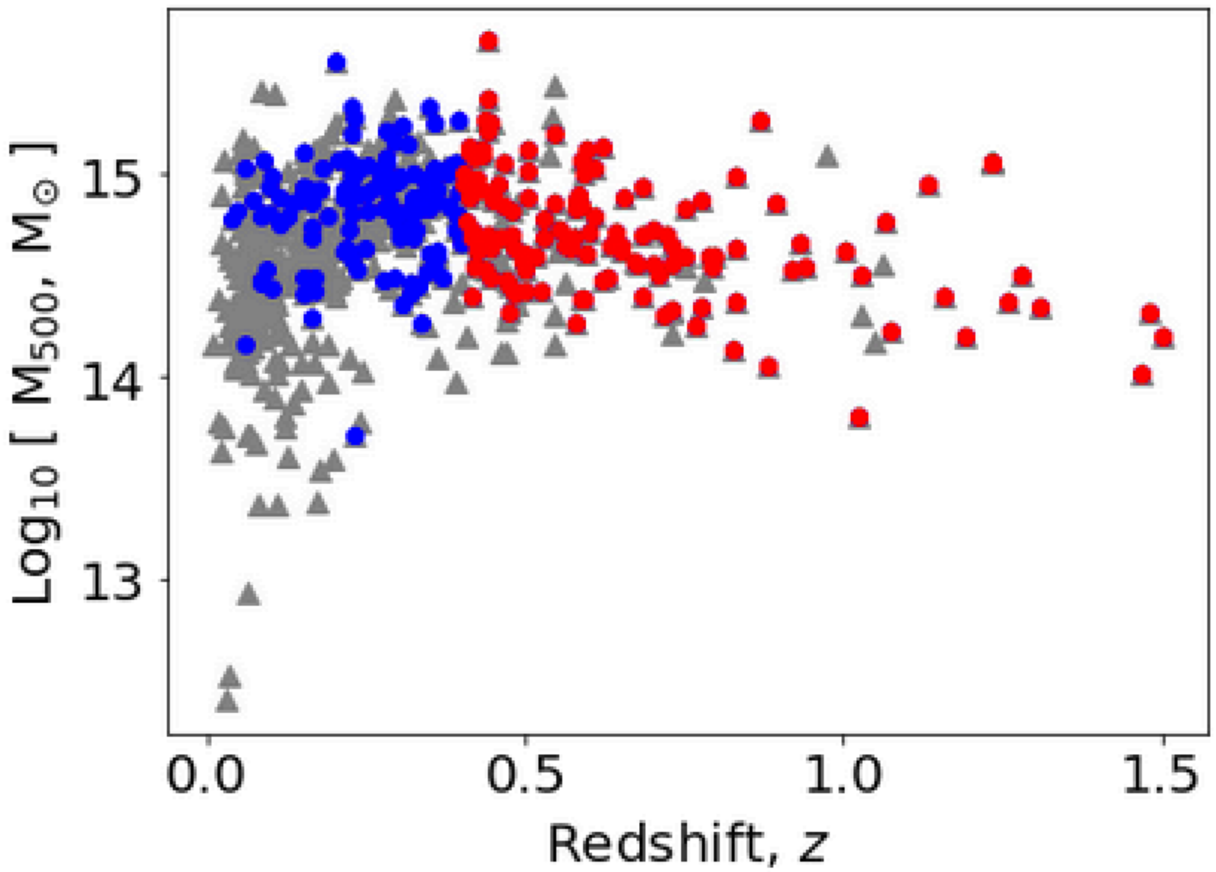




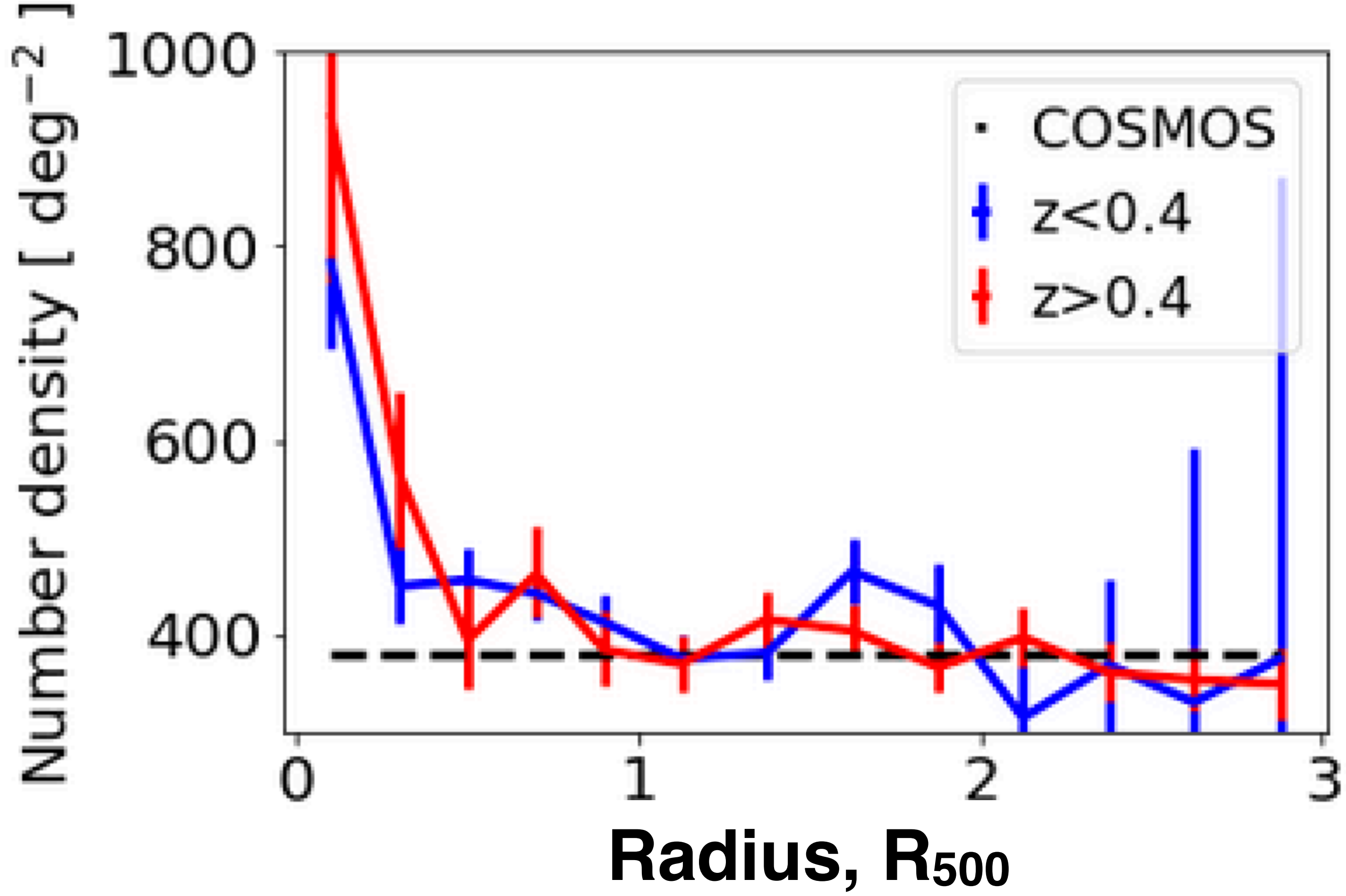
AGN fractions



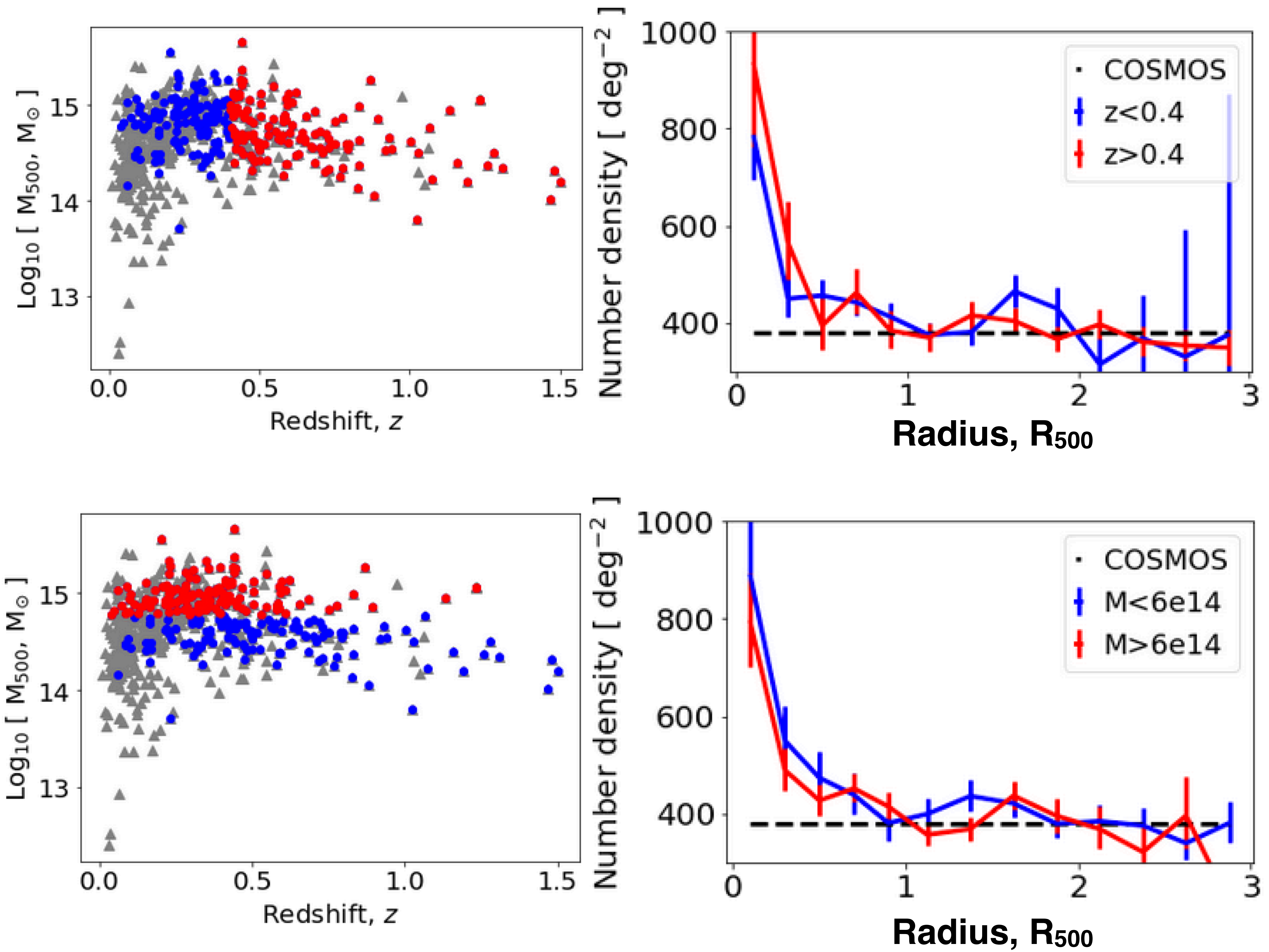
How do these evolve?



Log10 [M500, M⊙]
15
14
13
0.0
0.5
1.0
1.5
Redshift, z



Number density [deg−2]
1000
800
600
400
COSMOS
z<0.4
z>0.4
0
1
2
3
Radius, R500



Log10 [M500, M⊙]
Redshift, z
Number density [deg−2]
Radius, R500
COSMOS
z<0.4
z>0.4
M<6e14
M>6e14

Model

Is increased number density related to the mass or redshift of the host cluster?

$$N_{\rm obs}(> f, r, z) = A D_A^2 r_{500} \Phi(> L, z) \left(\frac{r}{r_{500}}\right)^{\beta} + N_{\rm field}$$

Projected number density of observed X-ray AGN in a cluster field at a given cluster z, r and above flux limit f = **Projected number density of X-ray AGN expected in cluster** above flux limit + **Projected number density of all field AGN** above flux limit

'Scale factor' which allows number density to exceed co-moving field AGN X Scaled by radius X Co-moving field AGN number density at z and above luminosity related to flux limit X Some radial dependence

$$A \rightarrow A_0 (1+z)^{\eta} \left(\frac{M_{500}}{10^{15} M_{\odot}}\right)^{\zeta} \qquad \beta \rightarrow \beta_0 + \beta_z (1+z) + \beta_{\rm m} \left(\frac{M_{500}}{10^{15} M_{\odot}}\right)$$

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$$N_{\mathrm{obs}}(>f,r,z) = A D_A^2 r_{500} \Phi(>L,z)\left(\frac{r}{\quad}\right)^{\beta} + N_{\mathrm{field}}$$

Null hypothesis - same as field

Projected number d
of observed X-ray A
a cluster field at a
given cluster z, r and above
flux limit f

=

AGN expected in cluster above
flux limit

+

l number density
of all field AGN above
flux limit

Ashley's talk next!

'Scale factor'
number dens
co-moving field AGN

related to flux limit

he radial
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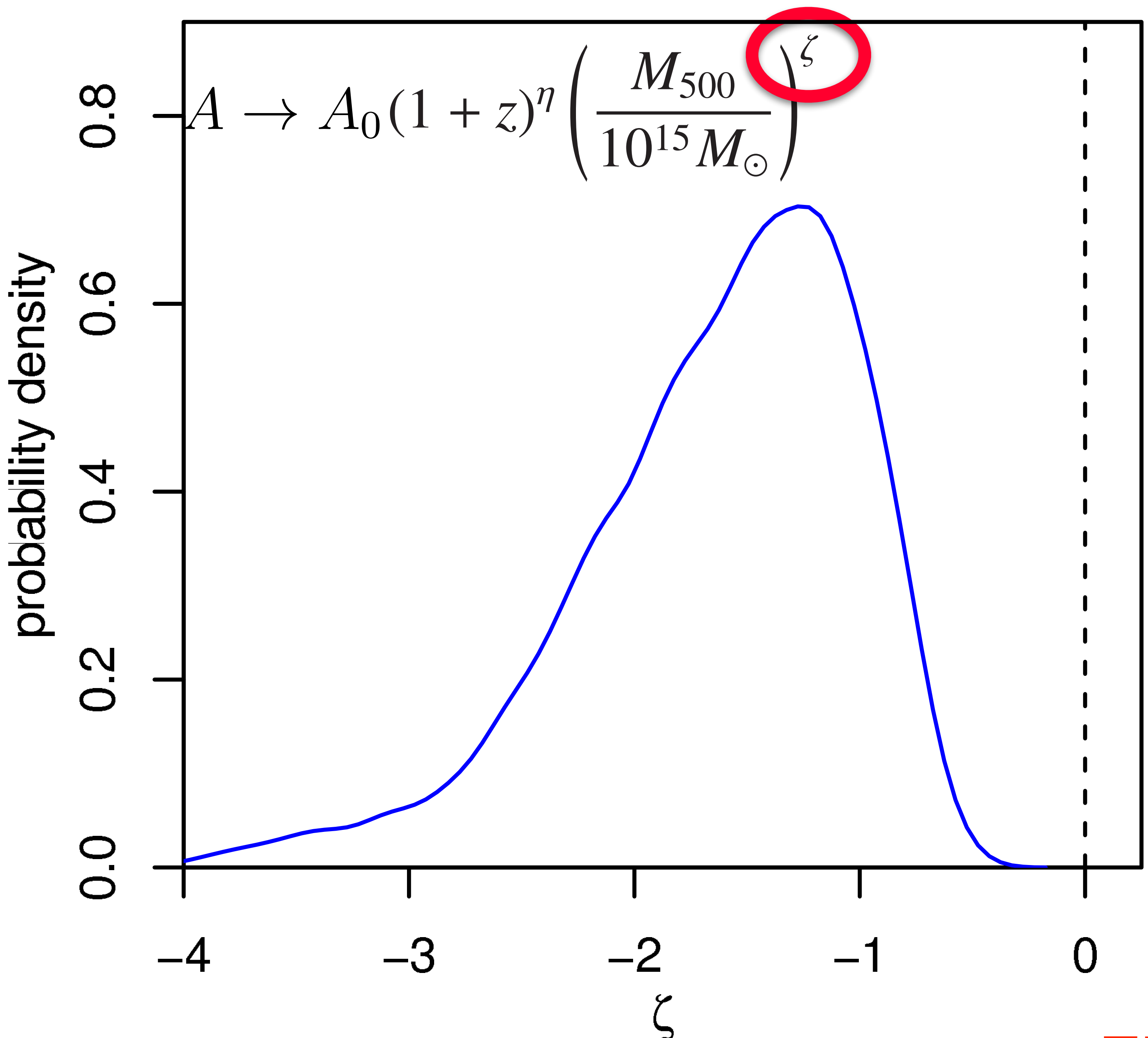
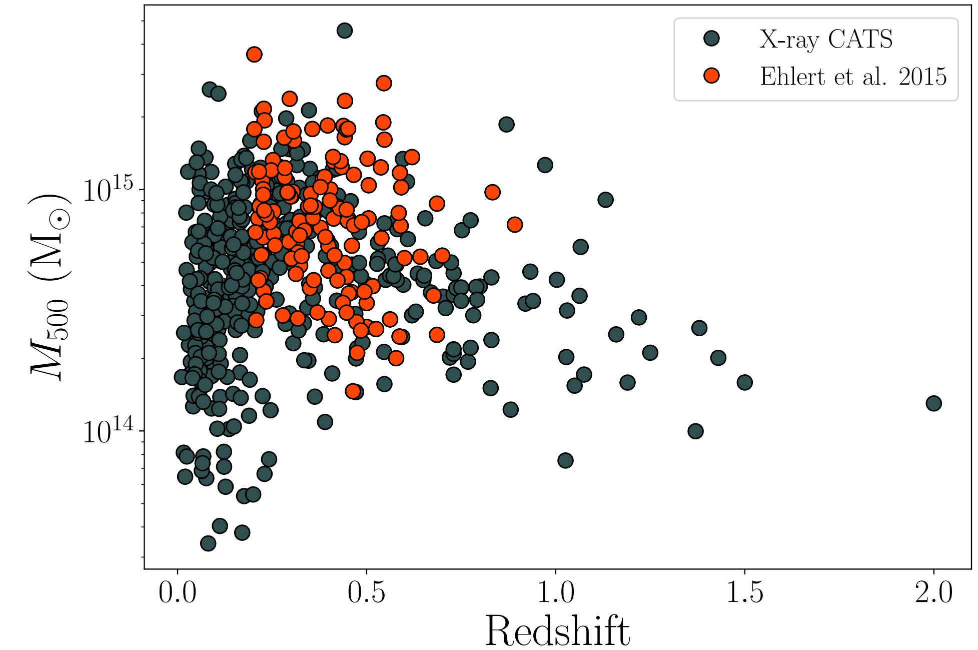
$$A \rightarrow A_0(1+z)^{\eta}\left(\frac{M_{500}}{10^{15}M_\odot}\right)^{\zeta} \qquad \beta \rightarrow \beta_0 + \beta_z(1+z) + \beta_m\left(\frac{M_{500}}{10^{15}M_\odot}\right)$$

Model

No evolution beyond the field X-ray AGN population with redshift.

No radial variation. But…



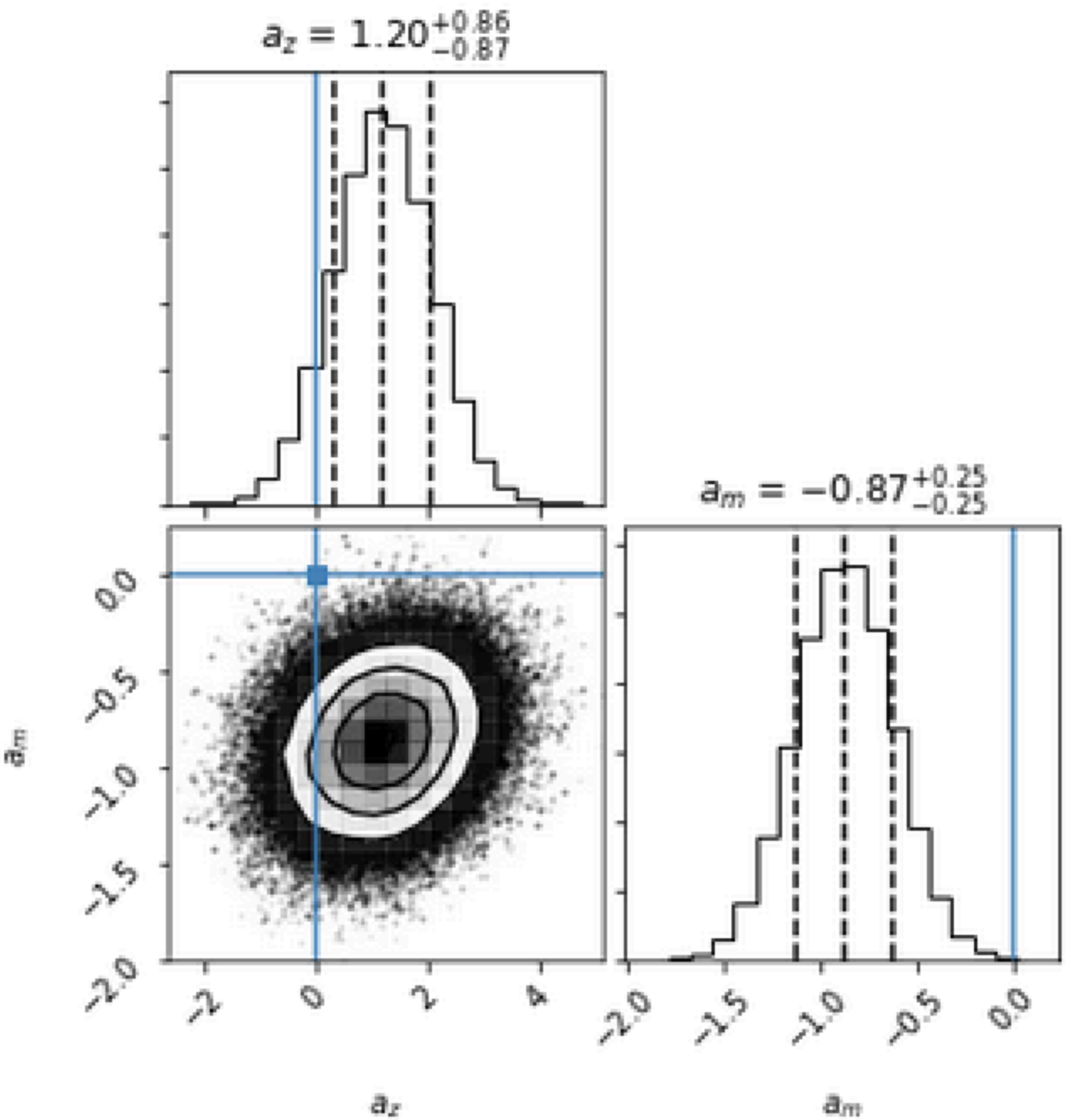


Observed mass scaling $\zeta = -1.2$

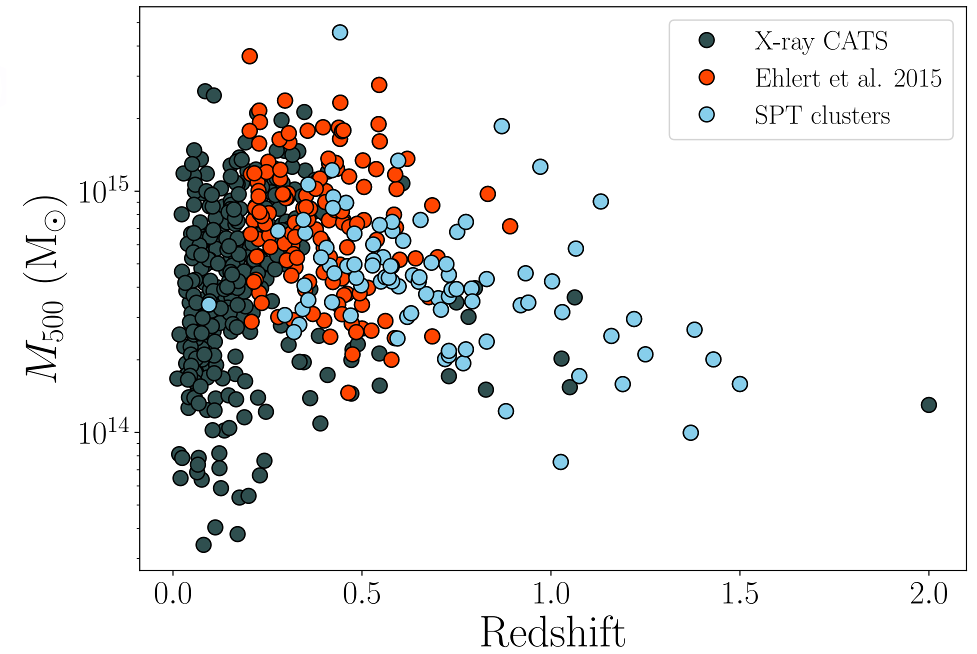
$\zeta = 0$ rejected at > 99.9%

Ehlert et al. 2015 (135 clusters)

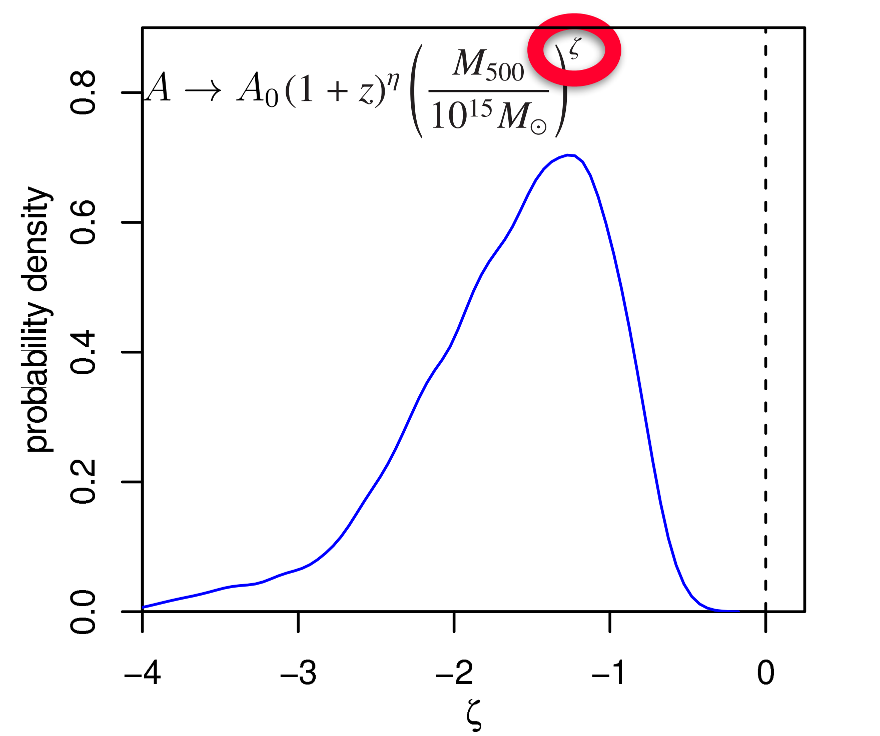
Model



$a_z = 1.20^{+0.86}_{-0.87}$
$a_m = -0.87^{+0.25}_{-0.25}$
0.0
−0.5
−1.0
−1.5
−2.0
a_m
−2
0
2
4
a_z
−2.0
−1.5
−1.0
−0.5
0.0
a_m

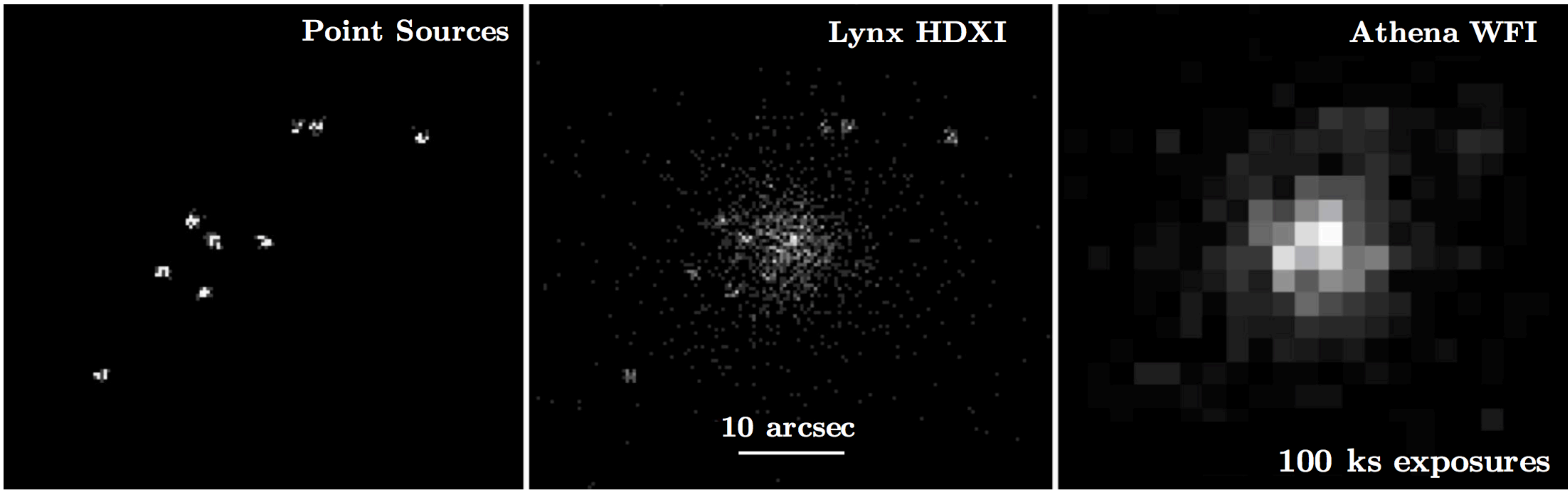


X-ray CATS
Ehlert et al. 2015
SPT clusters
10^{15}
10^{14}
M_{500} ($M_\odot$)
0.0
0.5
1.0
1.5
2.0
Redshift



$A \rightarrow A_0(1+z)^\eta \left(\frac{M_{500}}{10^{15} M_\odot}\right)^\zeta$
probability density
0.0
0.2
0.4
0.6
0.8
−4
−3
−2
−1
0
ζ

Future…X-ray side - high-z not really possible without Lynx…



2 keV, $\boxed{z = 3 \text{ cluster}}$ + AGN (5×10^{-17} erg/cm^2/s)

Summary

1. X-ray AGN selection can easily vary with cluster parameters.

2. Mass and redshift degeneracies (and others) complicate our conclusions about environmental quenching.

3. **PRELIMINARY:** Initial results consistent with no evolution beyond that of the field population but evidence for a variation in number density with cluster mass

Future…

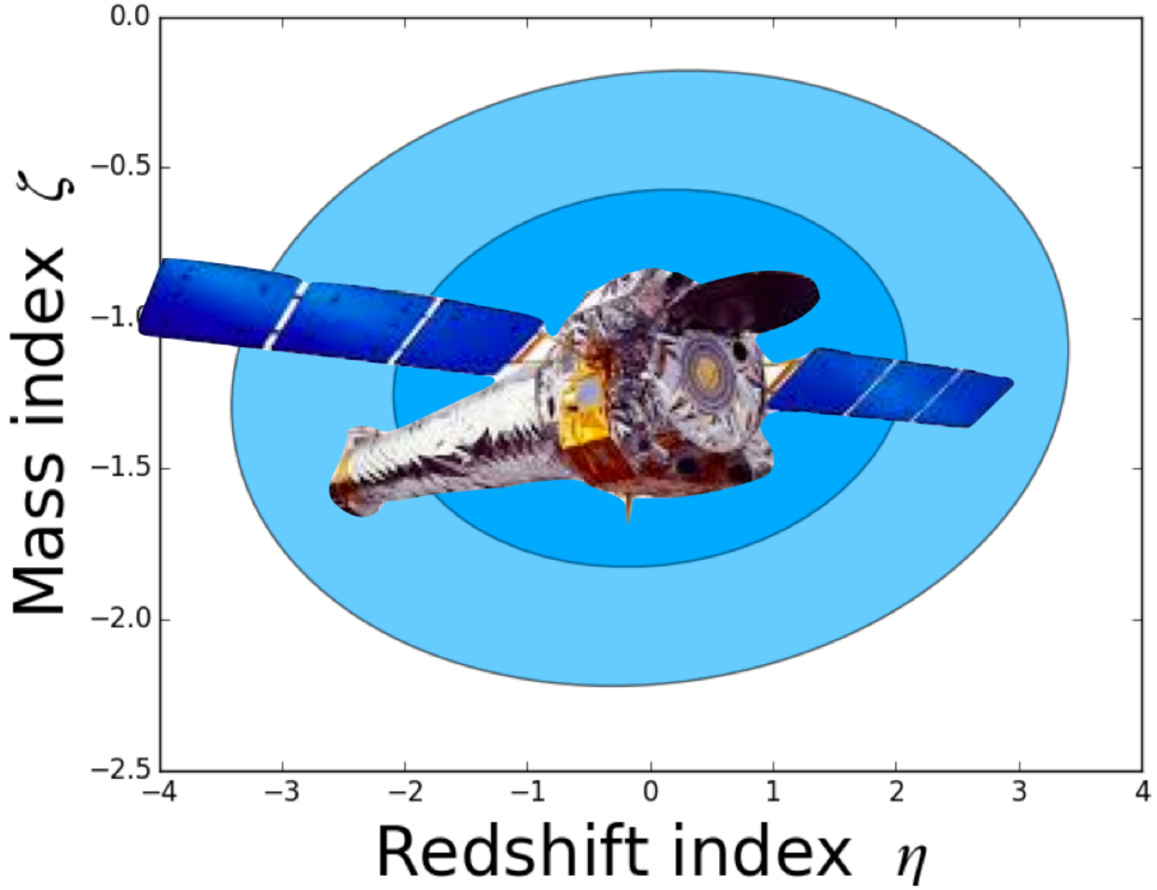
How well will Lynx do?

$$A = A_0(1+z)^{\eta}\left(\frac{M_{500}}{10^{15}\mathrm{M}_{\odot}}\right)^{\zeta}$$

Current constraints

Assuming:

- Same exposure as current model results (6.3 Ms)
- 10 ks exposure per cluster (630 clusters)
- Flux limit of 5×10^{-15} erg/cm^2/s (conservative)
- Cluster $M_{500} > 10^{14}\mathrm{M}_{\odot}$ and $z < 2$



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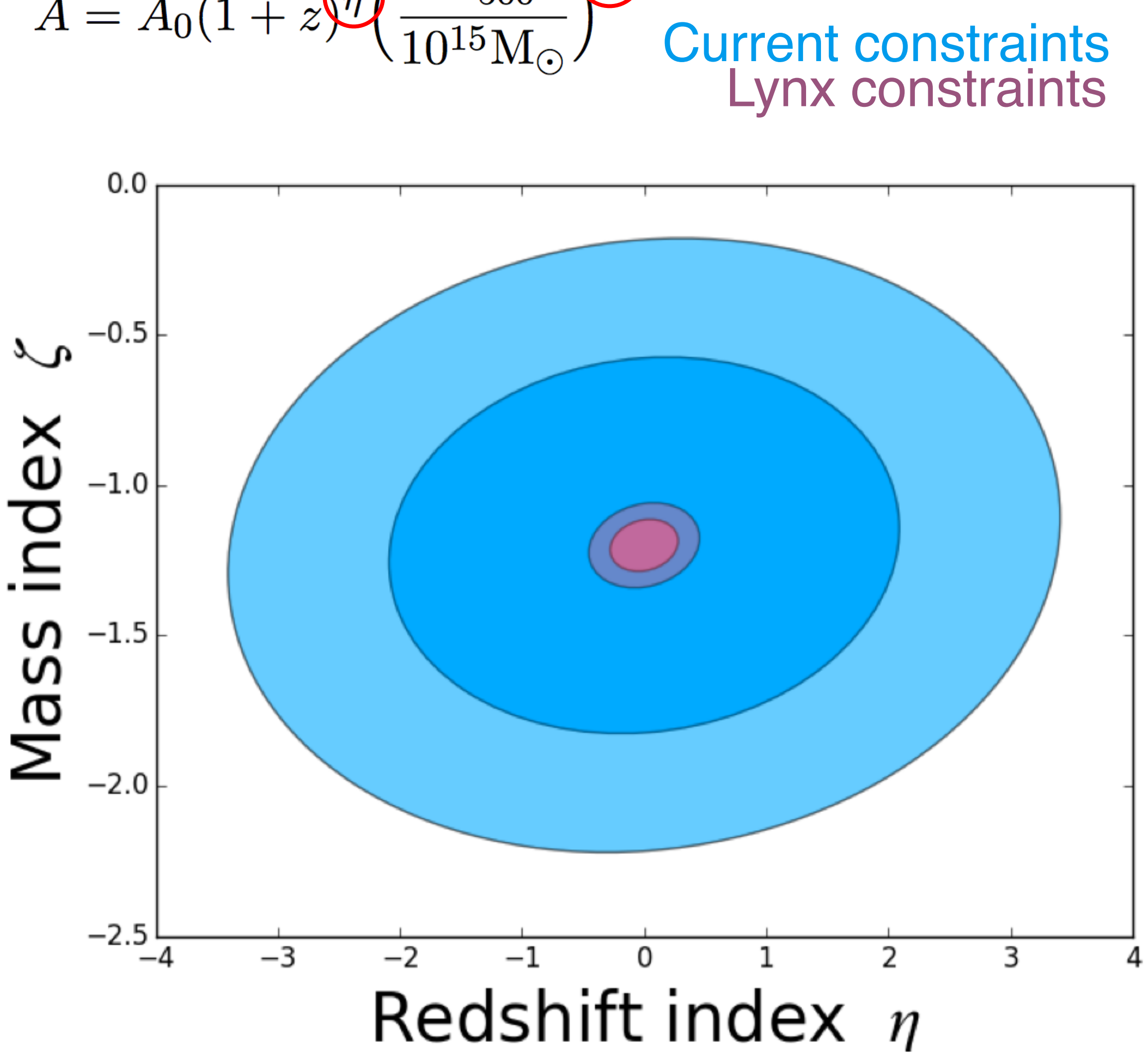
Factor of ~10 better constraints!

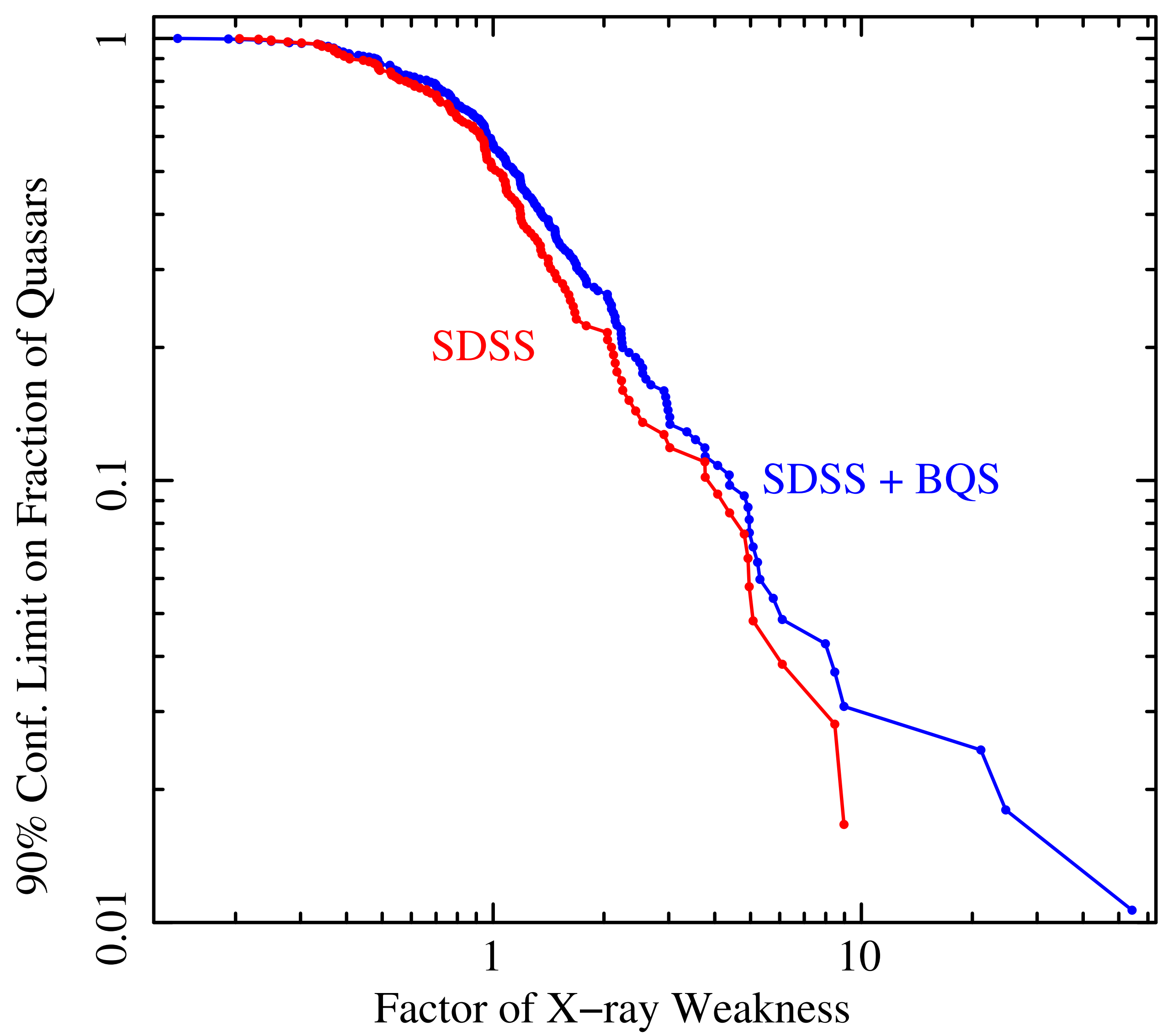
Real strength is pushing to high *z*, low mass clusters

$$A = A_0 (1+z)^{\eta} \left(\frac{M_{500}}{10^{15} \mathrm{M}_\odot} \right)^{\zeta}$$

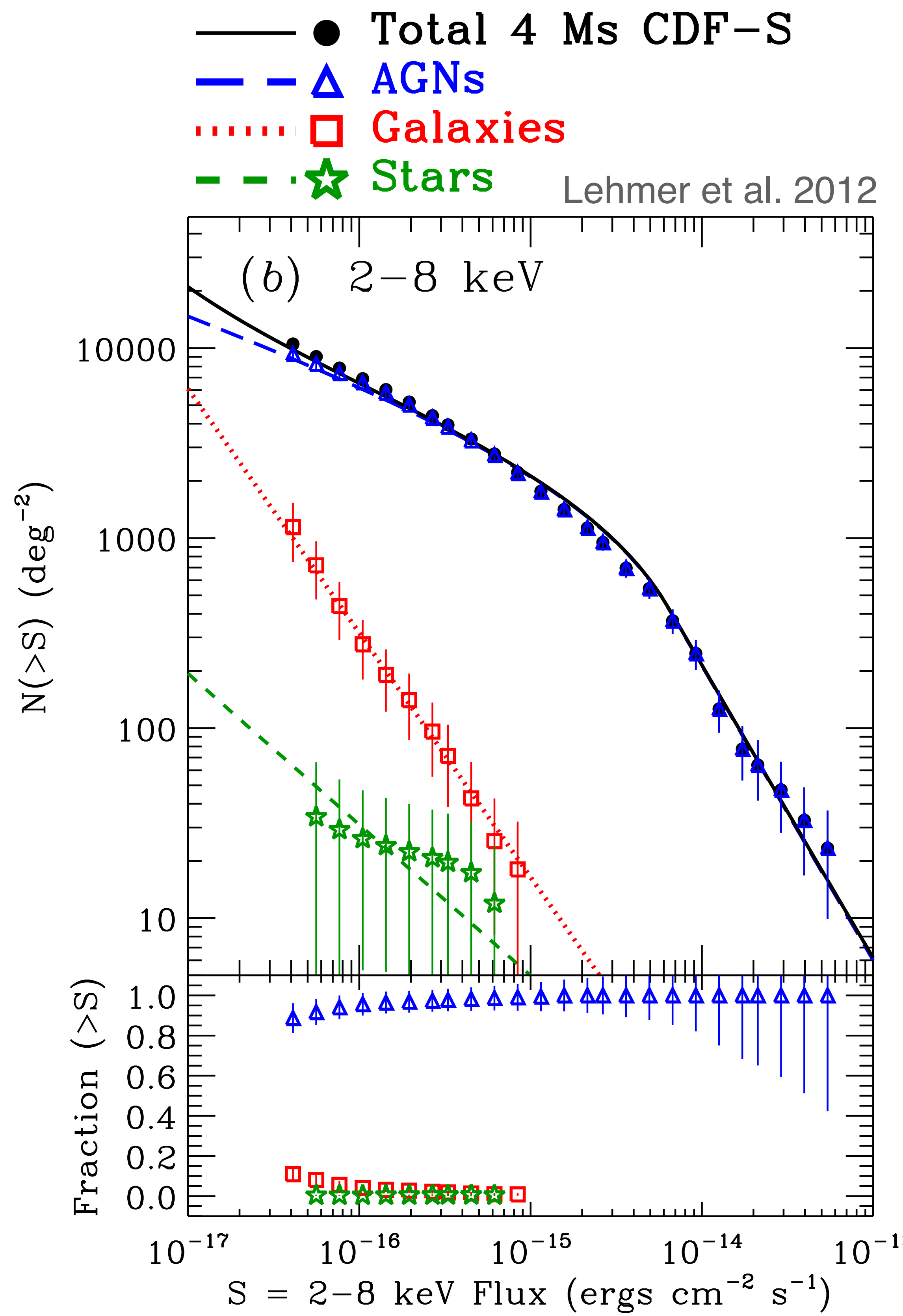


Detecting Black Holes

Gibson et al. 2008; Brandt & Alexander 2015



X-rays can penetrate to columns of $N_H \sim 10^{24}$ cm^{-2}



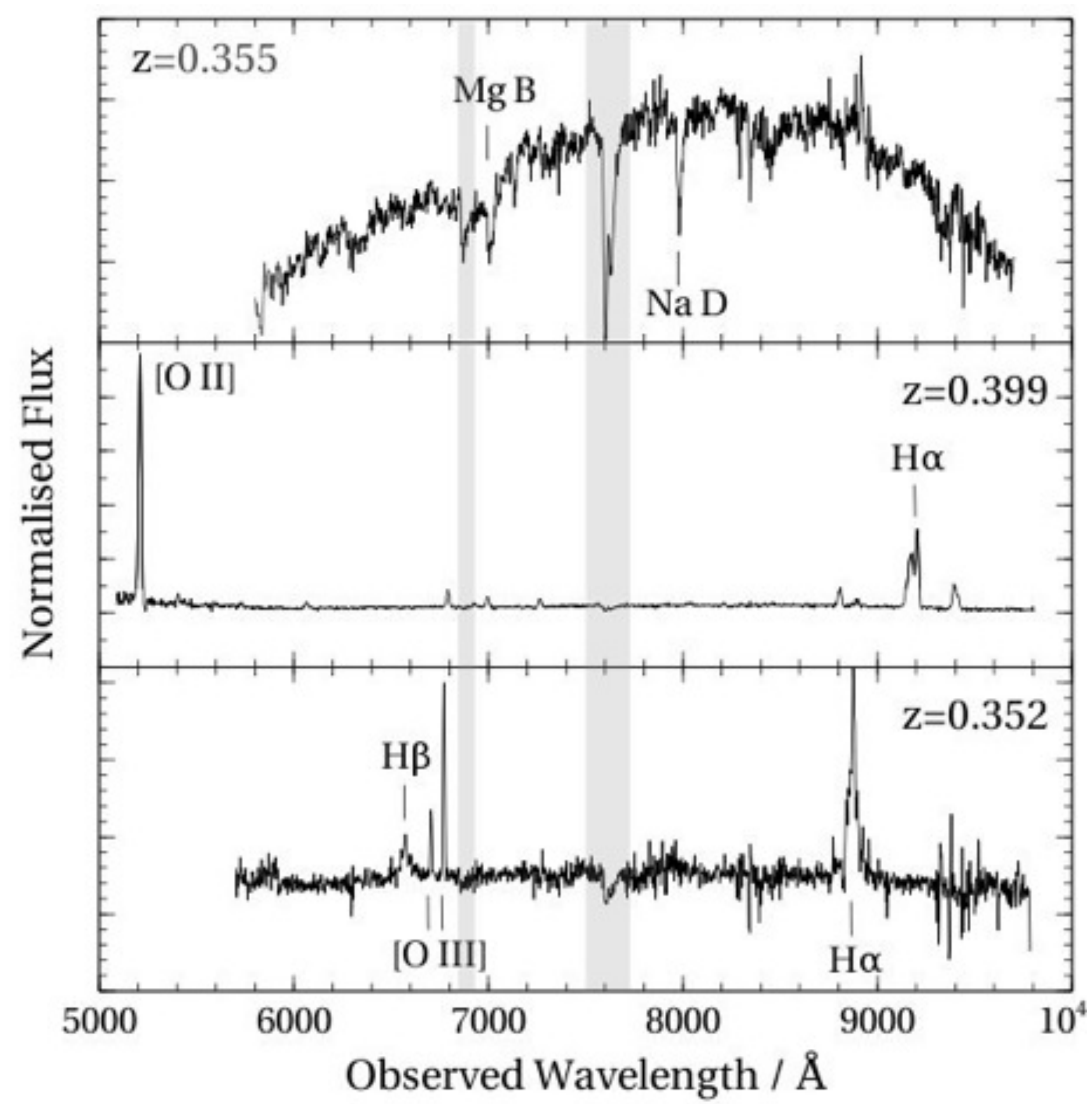
Spectroscopy

VIMOS follow-up program:

Expect: 500-700 targets per cluster (~6000 targets)
~860 X-ray AGN
>50 within ~2x r_{500},
(15 so far)

Matched by magnitude and cluster centric distance for V<23

2700 seconds on target



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=

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'Scale factor' which allows number density to exceed co-moving field AGN

X

Scaled by radius

X

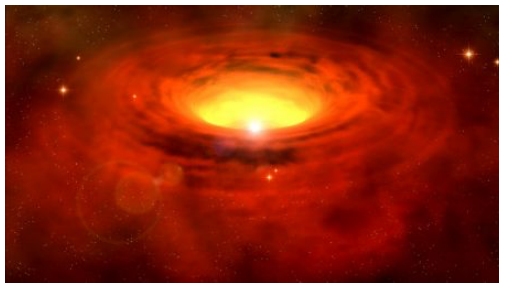
Co-moving field AGN number density at z and above luminosity related to flux limit

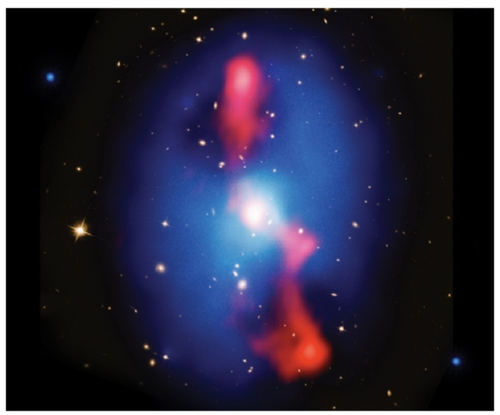
X

Some radial dependence

Multi-Spectral Analysis

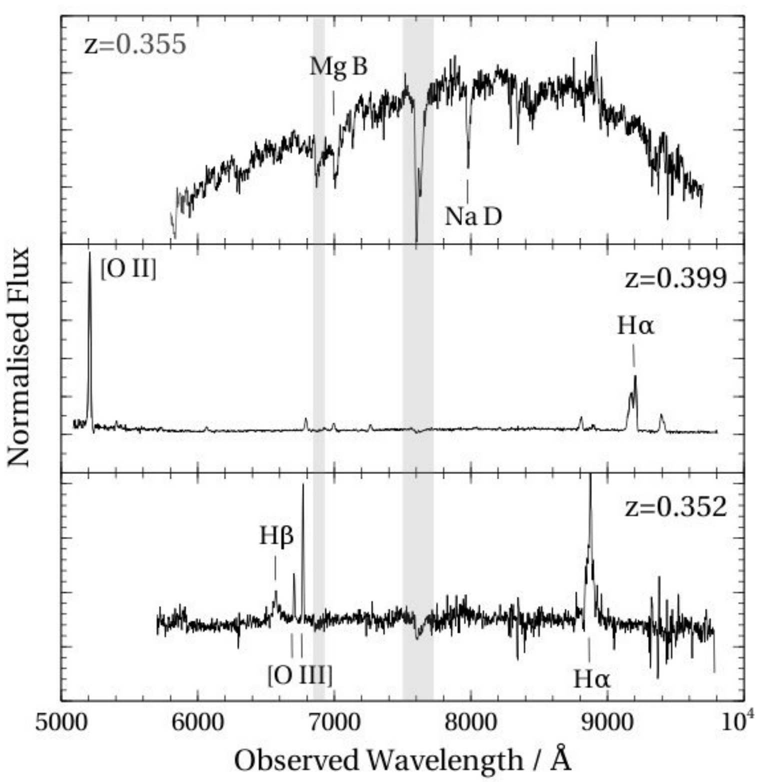
Towards a more complete census of cluster AGN and host galaxy properties





1. Differences in accretion modes: Radio/IR and Optically selected AGN number densities as a function of host cluster properties. **Radio AGN work led by A. King, IR studies in collaboration with SPT.**

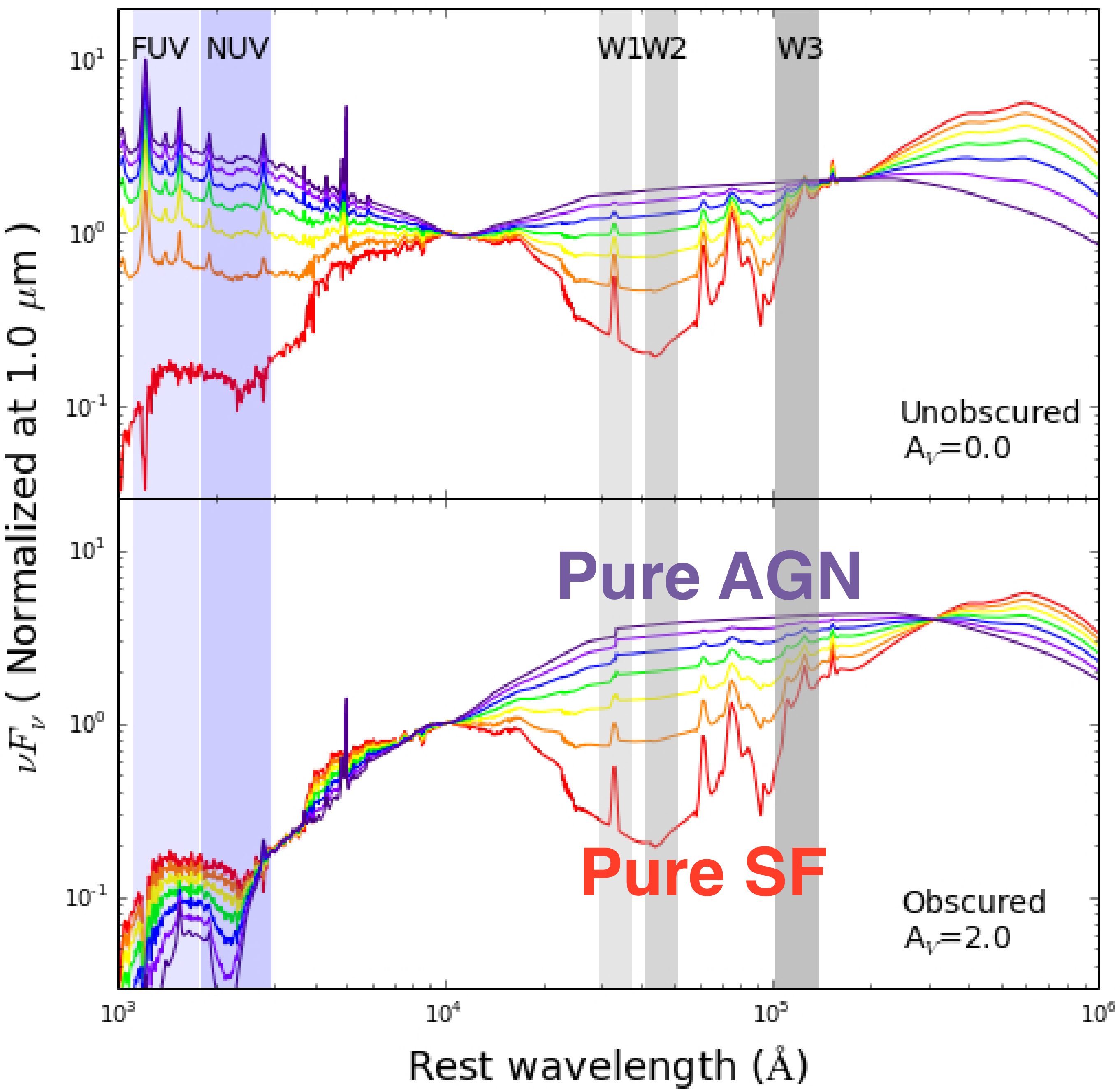
2. Spectroscopic redshift classification - greatly lowers AGN 'background' and enables measurement of AGN fractions as a function of host galaxy stellar mass. **VIMOS survey of 10 clusters led by E. Noordeh.**



3. Can also use spec-z to train photo-z for large sample. **In collaboration with G. Yang and N. Brandt.**

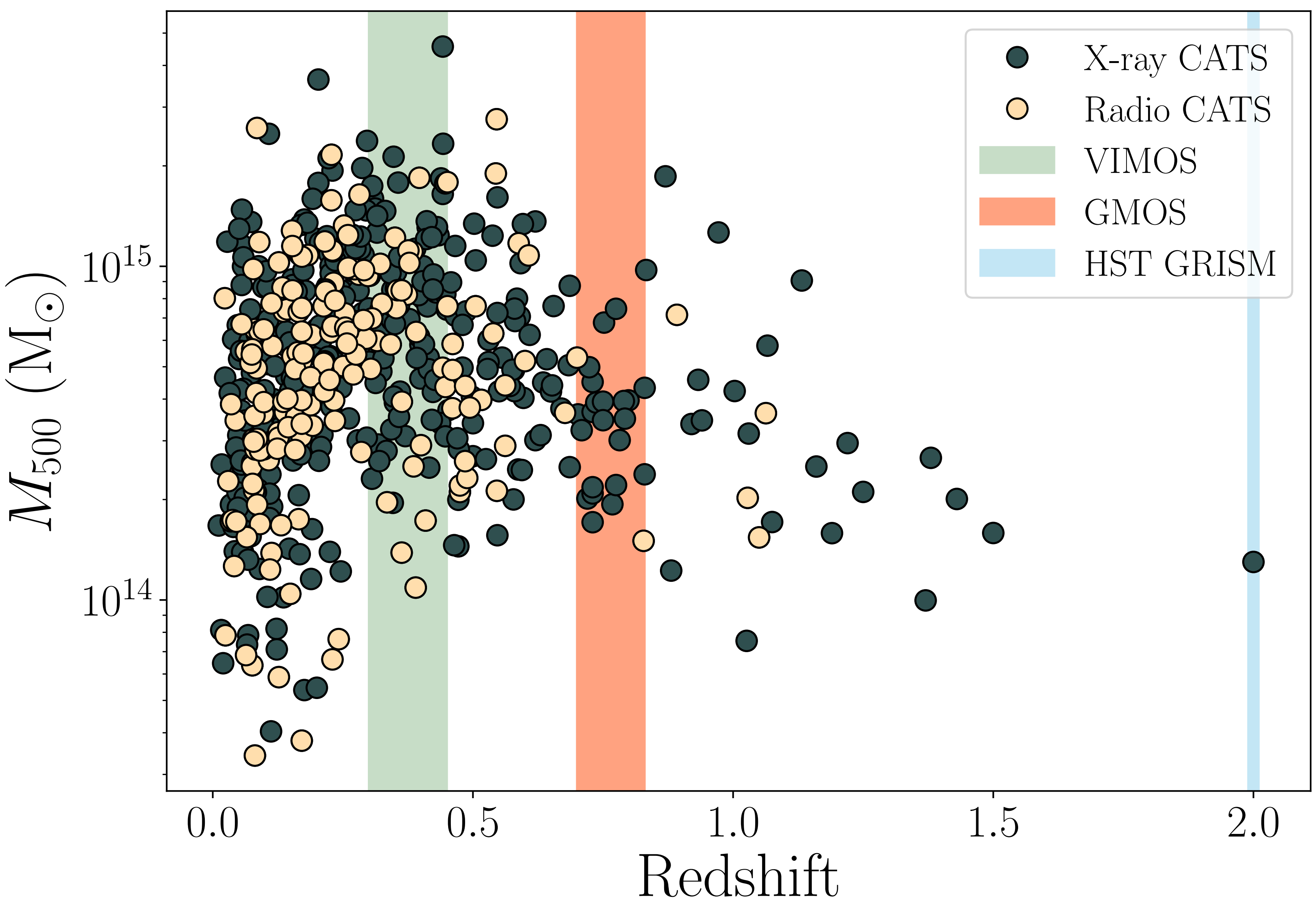
Multi-Spectral Analysis

Towards a more complete census of cluster AGN and host galaxy properties



1. Are the obscuration properties of AGN in cluster fields different from field galaxies?
2. How do the number densities of obscured and unobscured AGN in clusters vary with the mass, radial position and redshift of clusters?
3. Are AGN in clusters more or less likely to reside in star-forming hosts.
4. How does the number density of star-forming AGN vary with the cluster radius and redshift?

CATS Selection



X-ray: 550 clusters (27 Ms Chandra Data)

Radio: 183 clusters (FIRST survey)
Ashley's talk

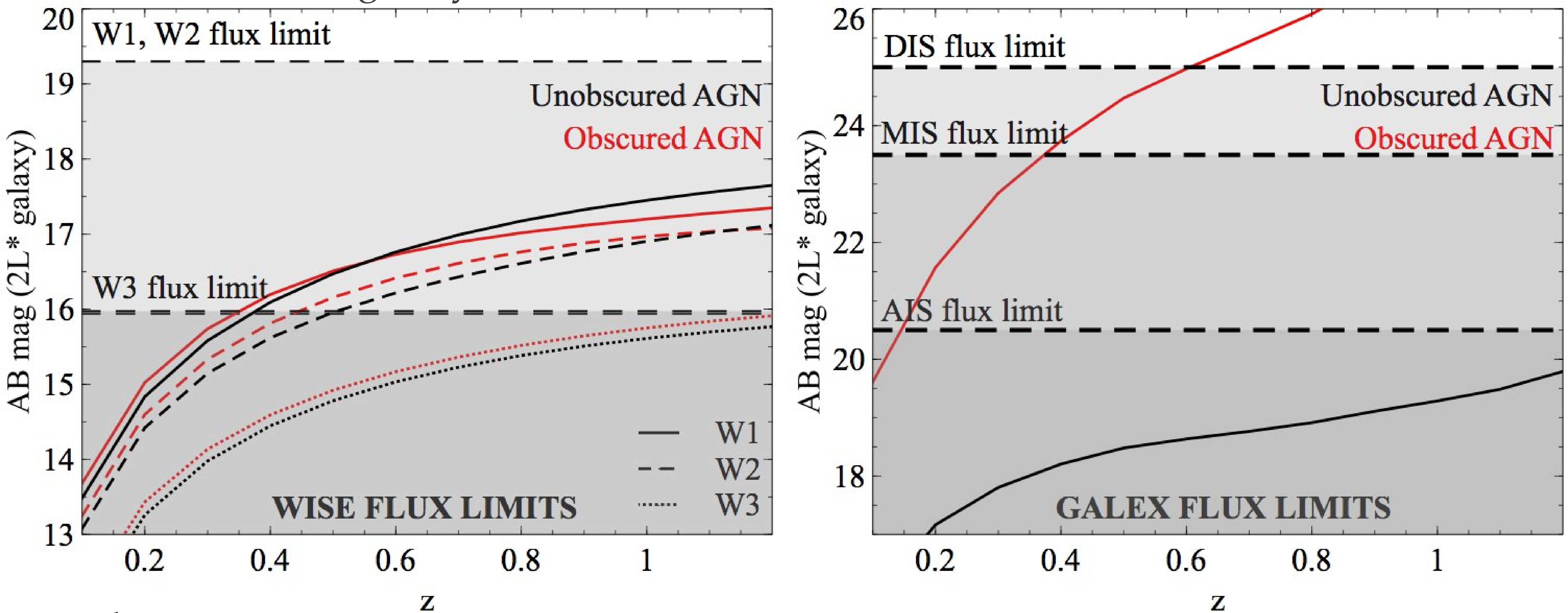
IR and UV: WISE 550 clusters; Spitzer 320 clusters; Galex 550

Spectroscopy: 7 z=0.4, 12 z=0.8, 1 z=2 clusters

IR selected AGN and host gal SF

	Chandra	GALEX			WISE	*Spitzer*			Total
		AIS	MIS	DIS	W1-W4	IRAC	MIPS 24μm	MIPS 70μm	
Cluster fields	435	312	70	13	435	275	179	90	435

2L* galaxy redshifted and convolved with filter functions



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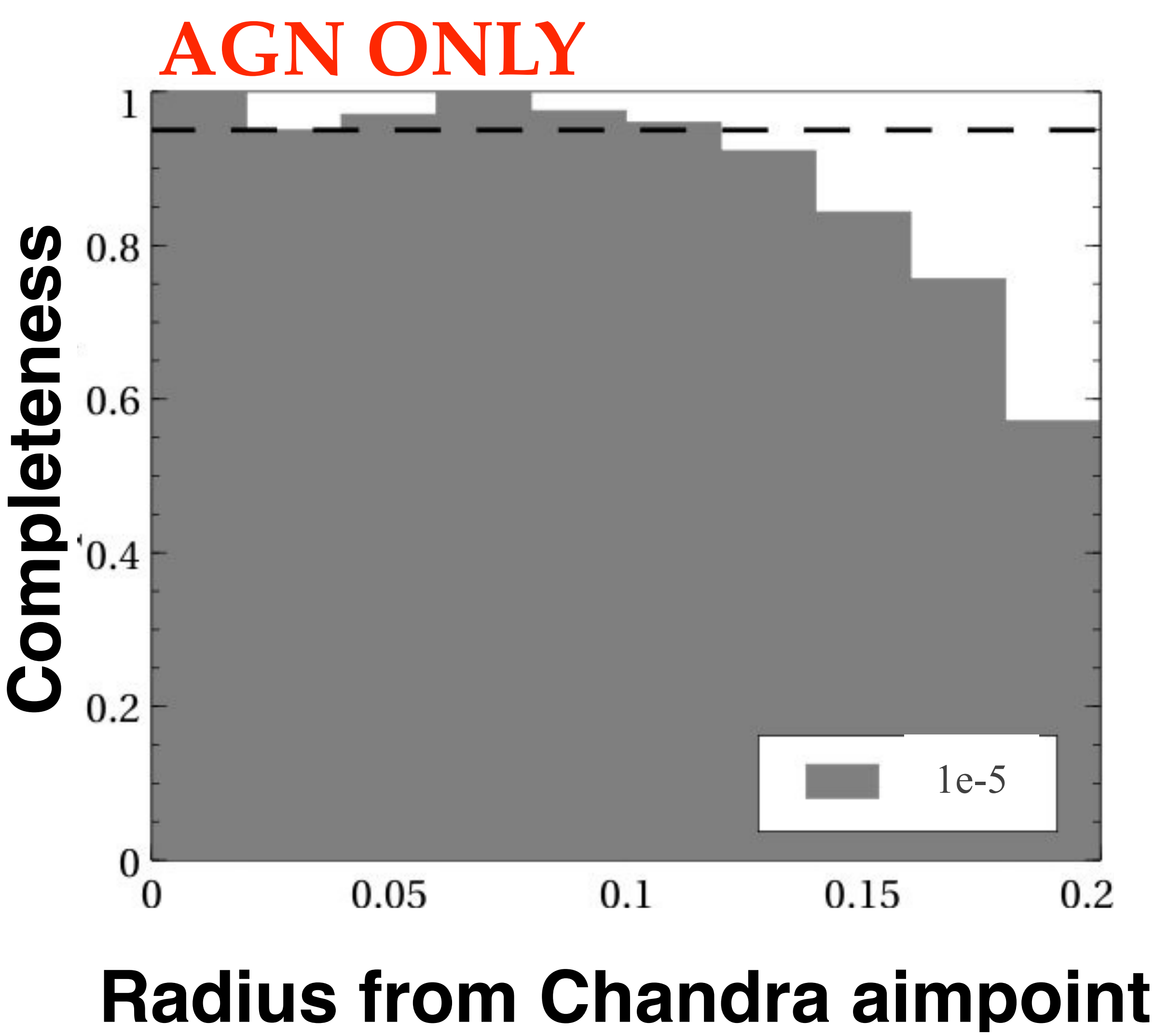
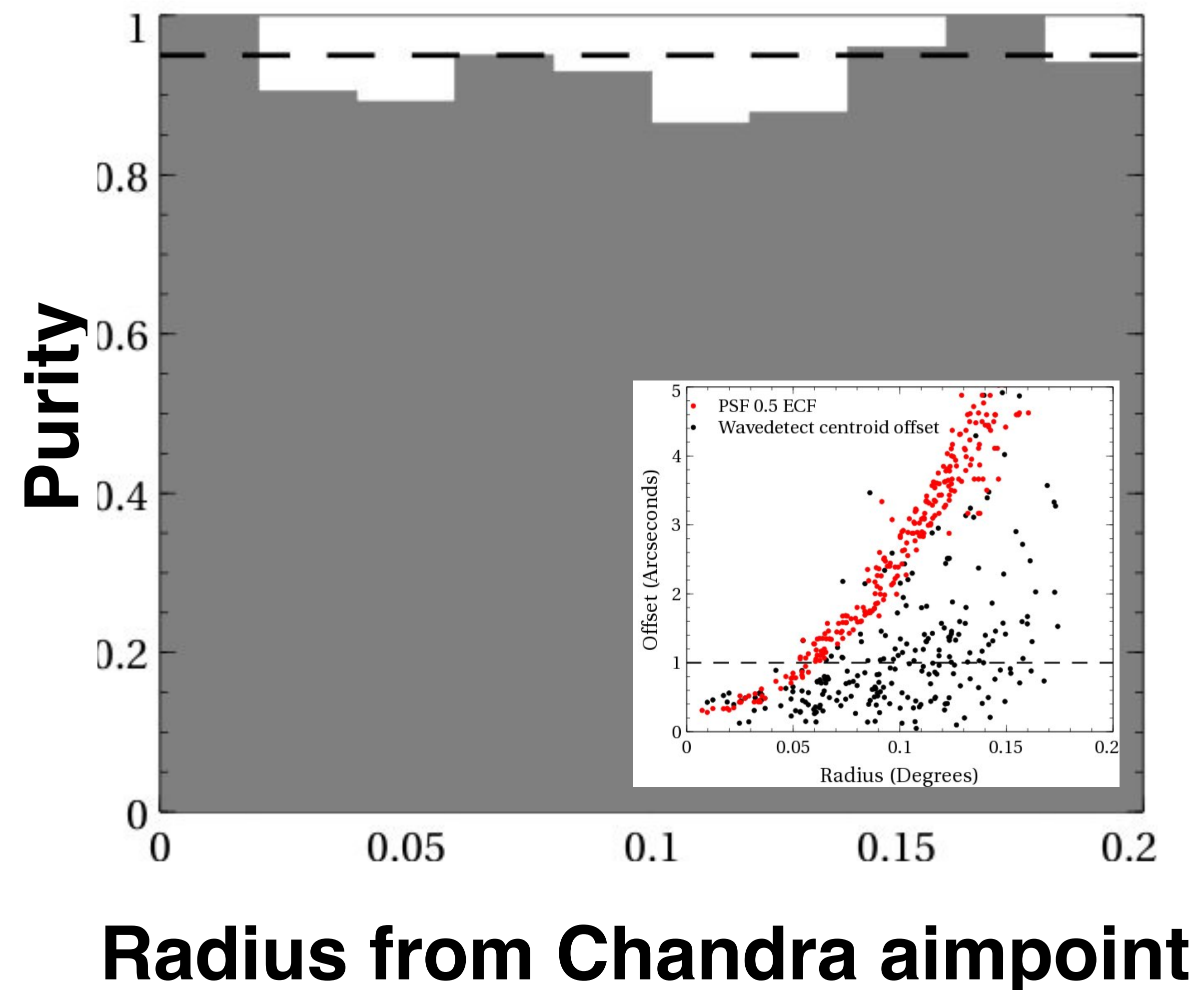
X-ray detection - blessing and curse

Completeness and purity of the AGN sample
Need to both efficiently and cleanly find point sources in cluster fields.





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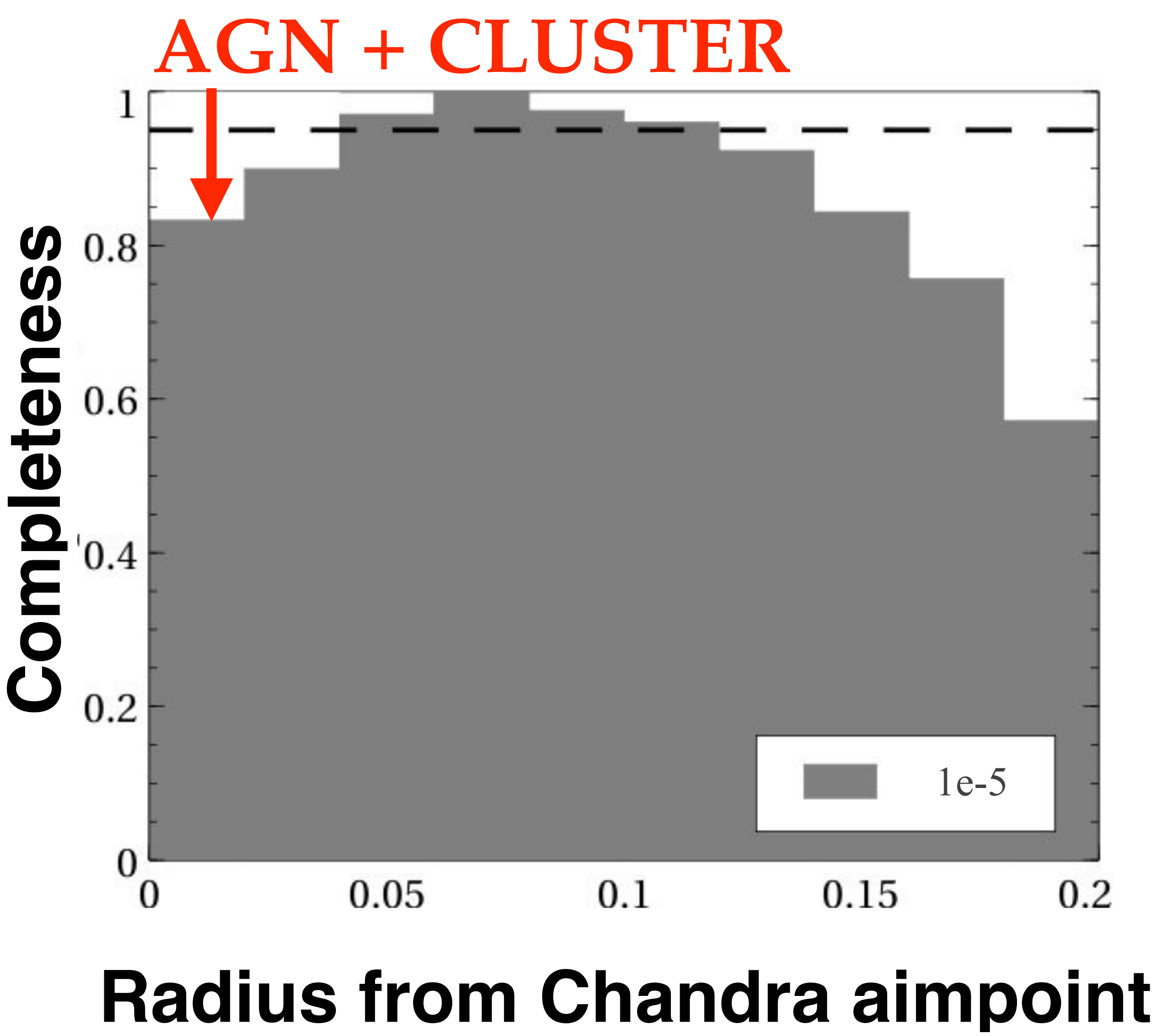

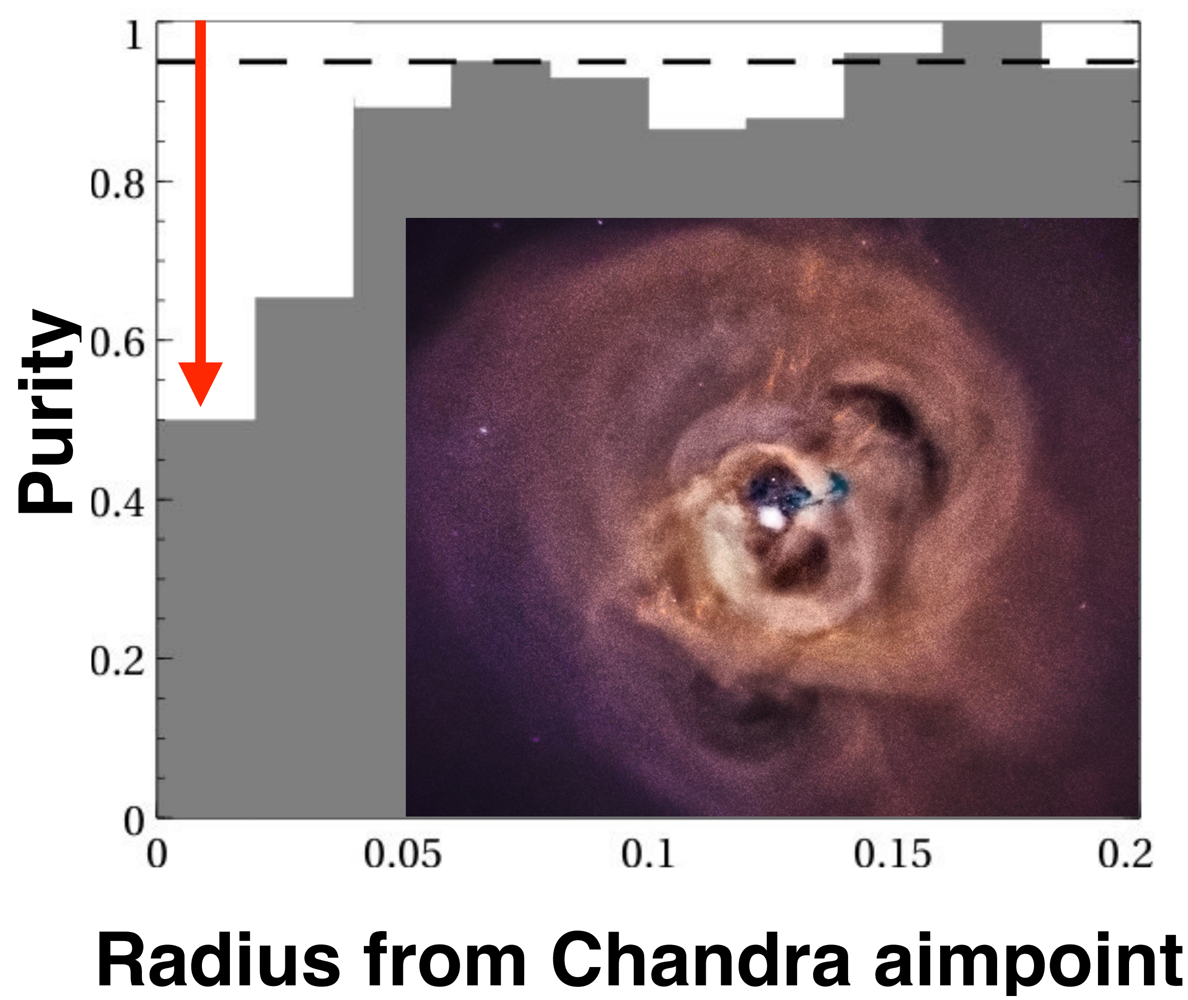

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