AGN in dense environments:
How does the evolution of Black Holes relate to the evolution of cosmic structure?

Becky Canning, Stanford University

Allen, Ehlert, **King**, von der Linden, Mantz, Morris, **Noordeh**

Overview

1. AGN in clusters: Big picture

2. X-ray AGN: A statistical approach and 1st generation results

3. X-Ray AGN: 2nd generation progress

4. A multi-spectral analysis (Radio/IR/Optical/UV/X-ray)

AGN in clusters: Big Picture

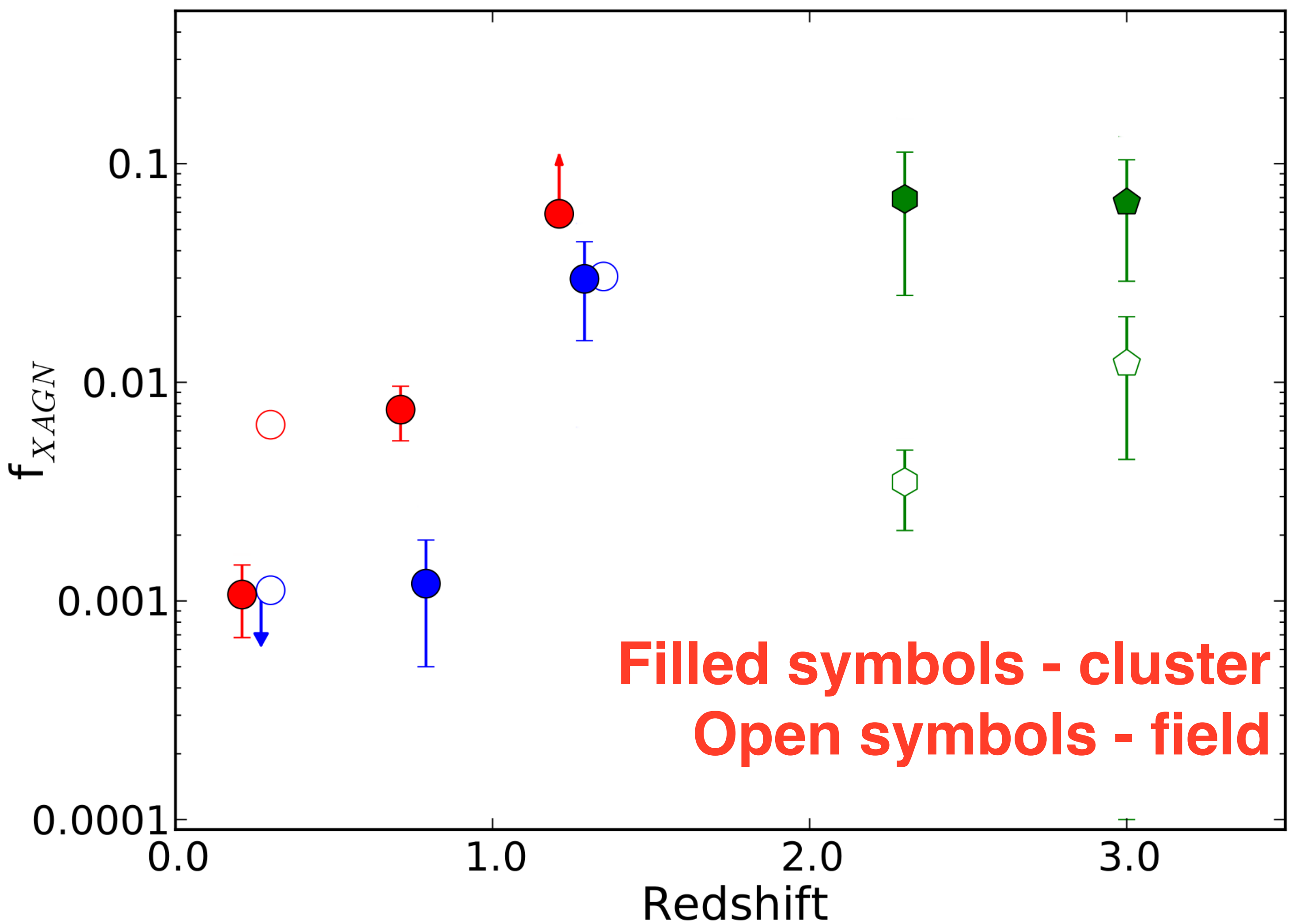
LSS has significant effect on AGN activity

Low z: Luminous AGN fraction in clusters lower than field. Similar to star-forming galaxies and optical AGN.
(e.g. Eastman et al. 2007; Martini et al. 2009; Haines et al. 2012; Elhert et al. 2014)

High z: Suppression of luminous AGN fraction in dense environments may invert.
(e.g. Lehmer et al. 2009; Digby-North et al. 2010; Martini et al. 2013)

Dependence with cluster mass, AGN luminosity, cluster radii, AGN and cluster selection.
(e.g. Popesso & Biviano 2006; Sivakoff et al. 2008; Georgakakis et al. 2008; Silverman et al. 2009; Ehlert et al. 2012; 2016; Koulouridis et al. 2014)

Martini et al. 2013



AGN evo $(1+z)^{5.3+-2}$; SF evo $(1+z)^{5.7+-2}$

Martini et al. 2009; Haines et al. 2009

AGN in clusters: Big Picture

How does the evolution of Black Holes relate to the evolution of cosmic structure?

Conceptually simple:

1) Detect BHs
2) Identify their environments

But…

1) Large areas of sky required
2) Spectroscopic follow-up is expensive
3) X-ray bright AGN are rare in clusters (< 3 per cluster)

Statistical model for cluster AGN

Can mitigate these challenges using:

1) Pointed X-ray observations of clusters

2) Making differential measurements

$$N_{\rm obs} = N_{\rm clus} + N_{\rm field}$$

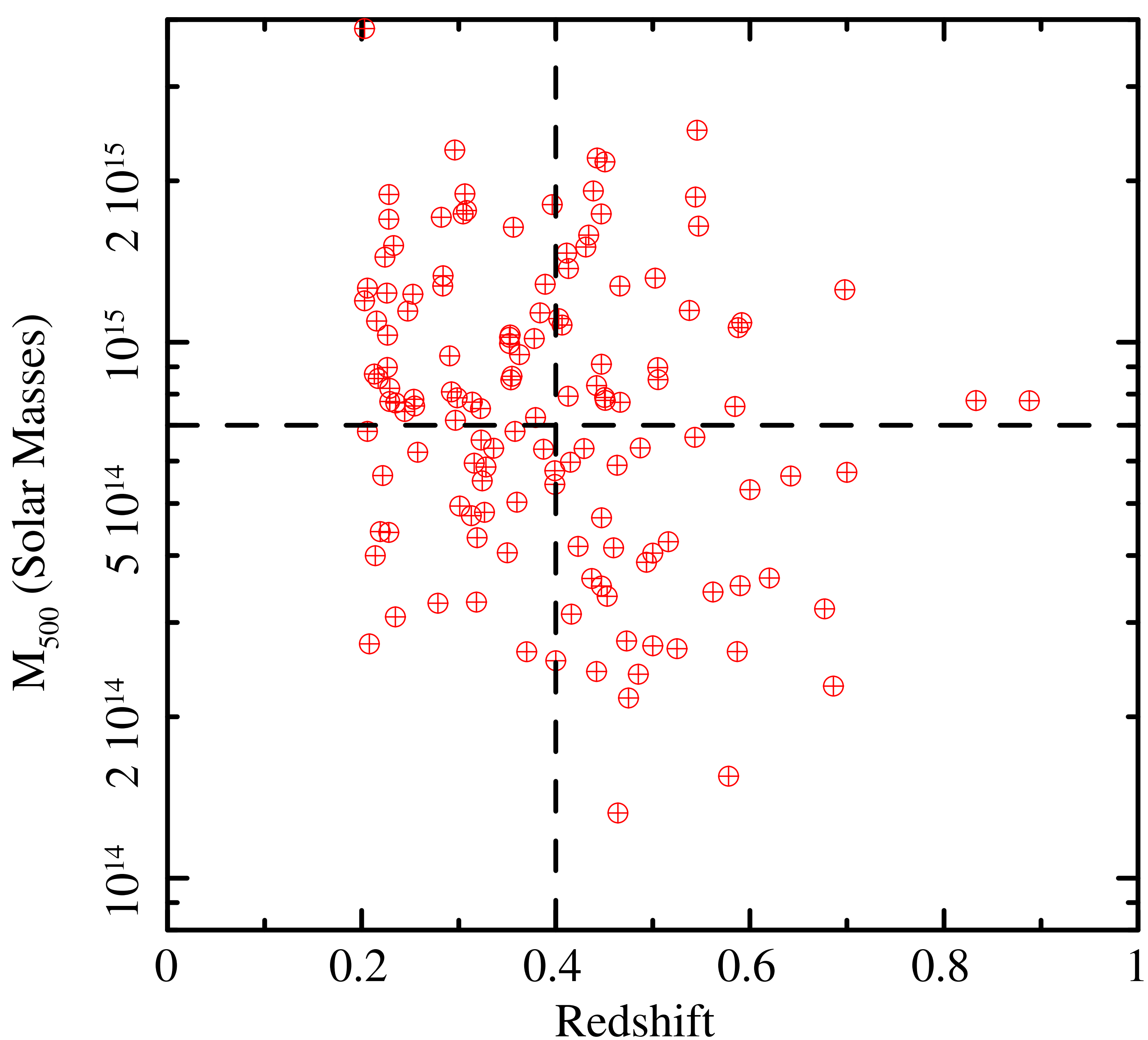
3) Utilize our knowledge of how large scale structure evolves to statistically combine signals - needs robust $z_{\rm clus}$, r_{500}, M_{500}

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

$$A \rightarrow A_0 f(M_{500}, z) \qquad \beta \rightarrow \beta_0 g(M_{500}, z)$$

Ehlert et al. 2015

1st generation results



135 X-ray selected galaxy clusters
(Mantz et al. 2010)

11,671 X-ray AGN in cluster fields

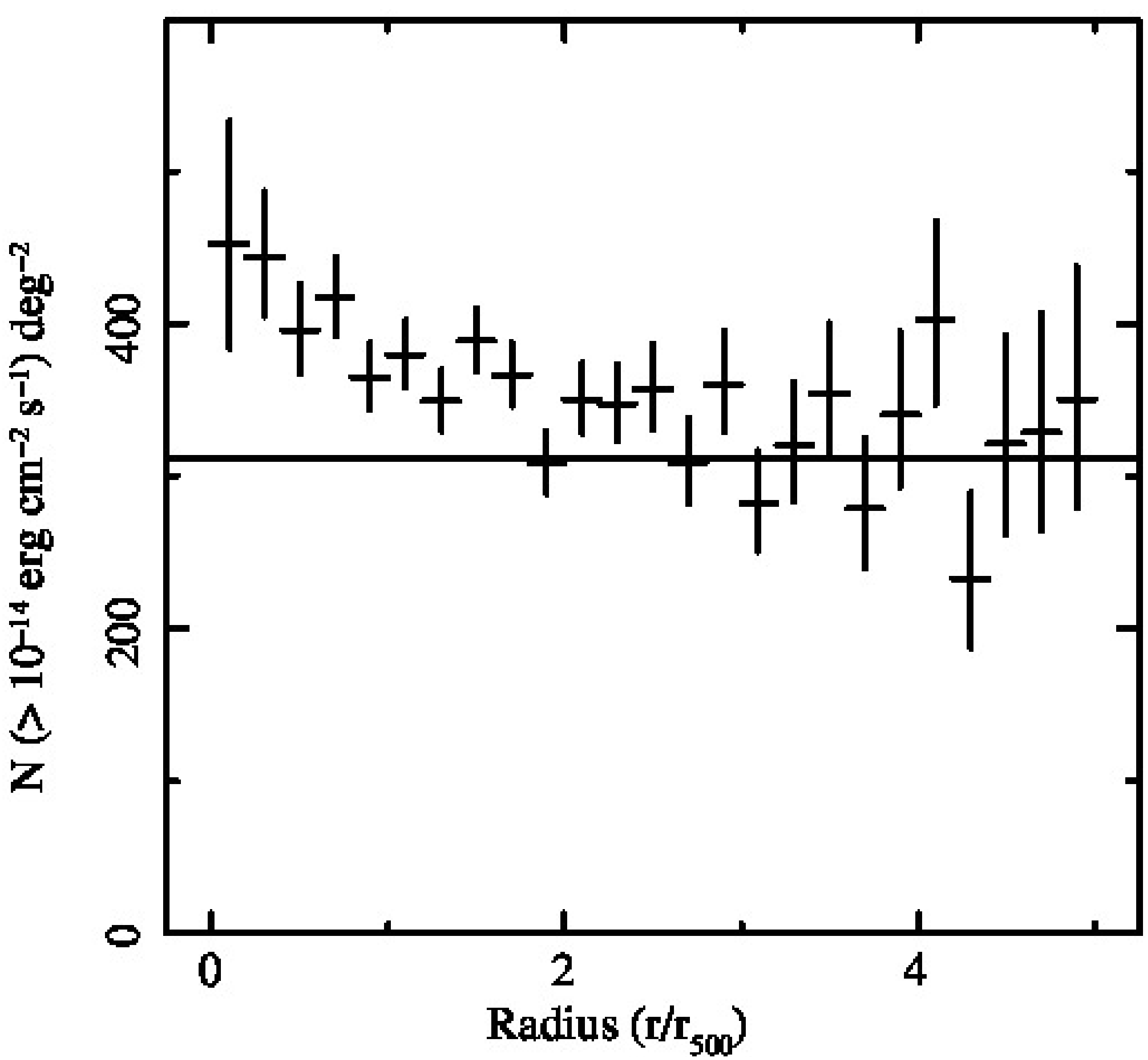
Cluster fields cover ~12 sq degree area

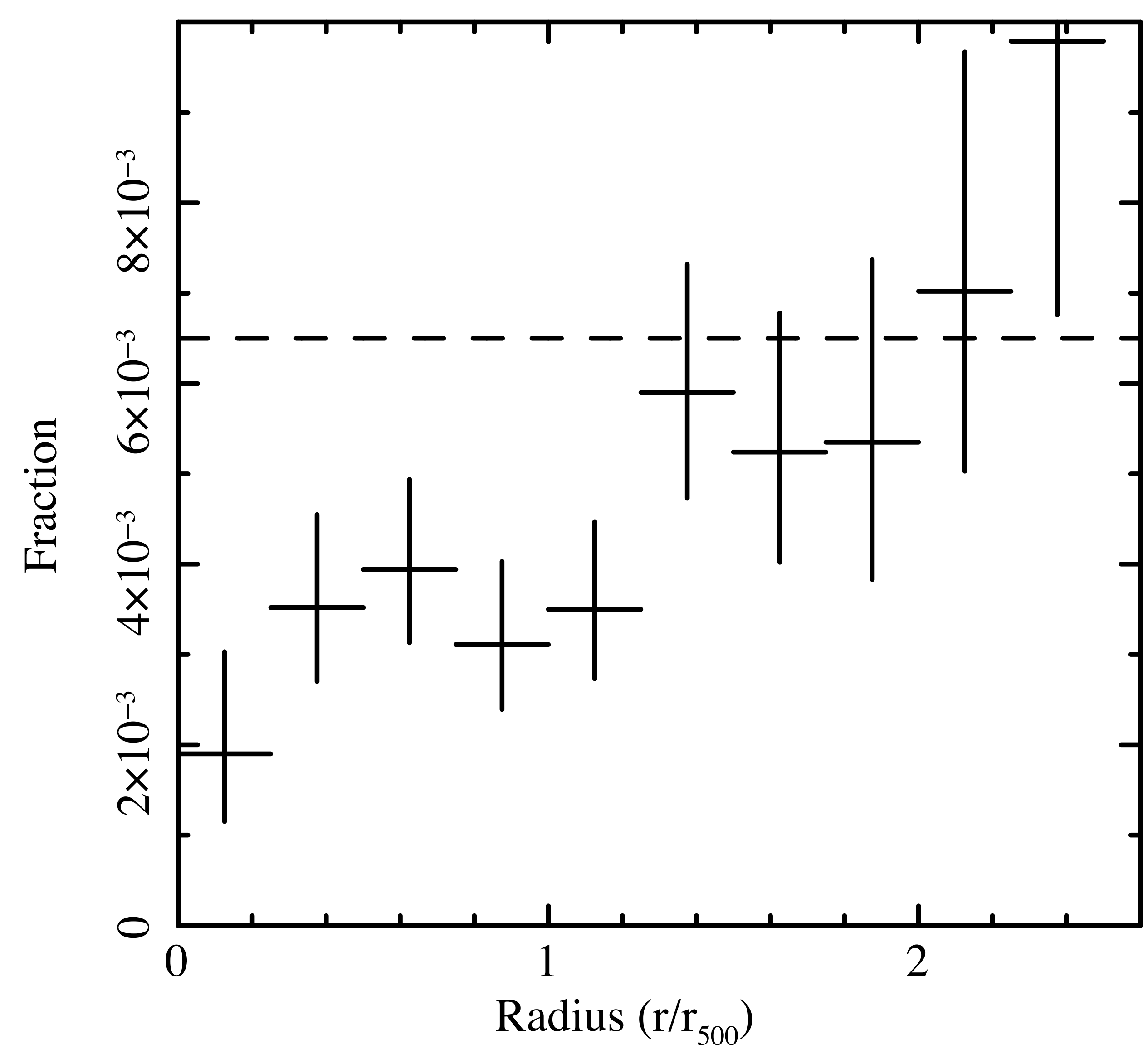
Total Chandra exposure time was 6.3 Ms

3x larger than previous surveys

Ehlert et al. 2015

1st generation results





Projected number density of AGN increases towards the cluster centre while the AGN fraction declines.

Ehlert et al. 2015

1st generation results

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

Null hypothesis = no difference between evolution of cluster AGN and field AGN

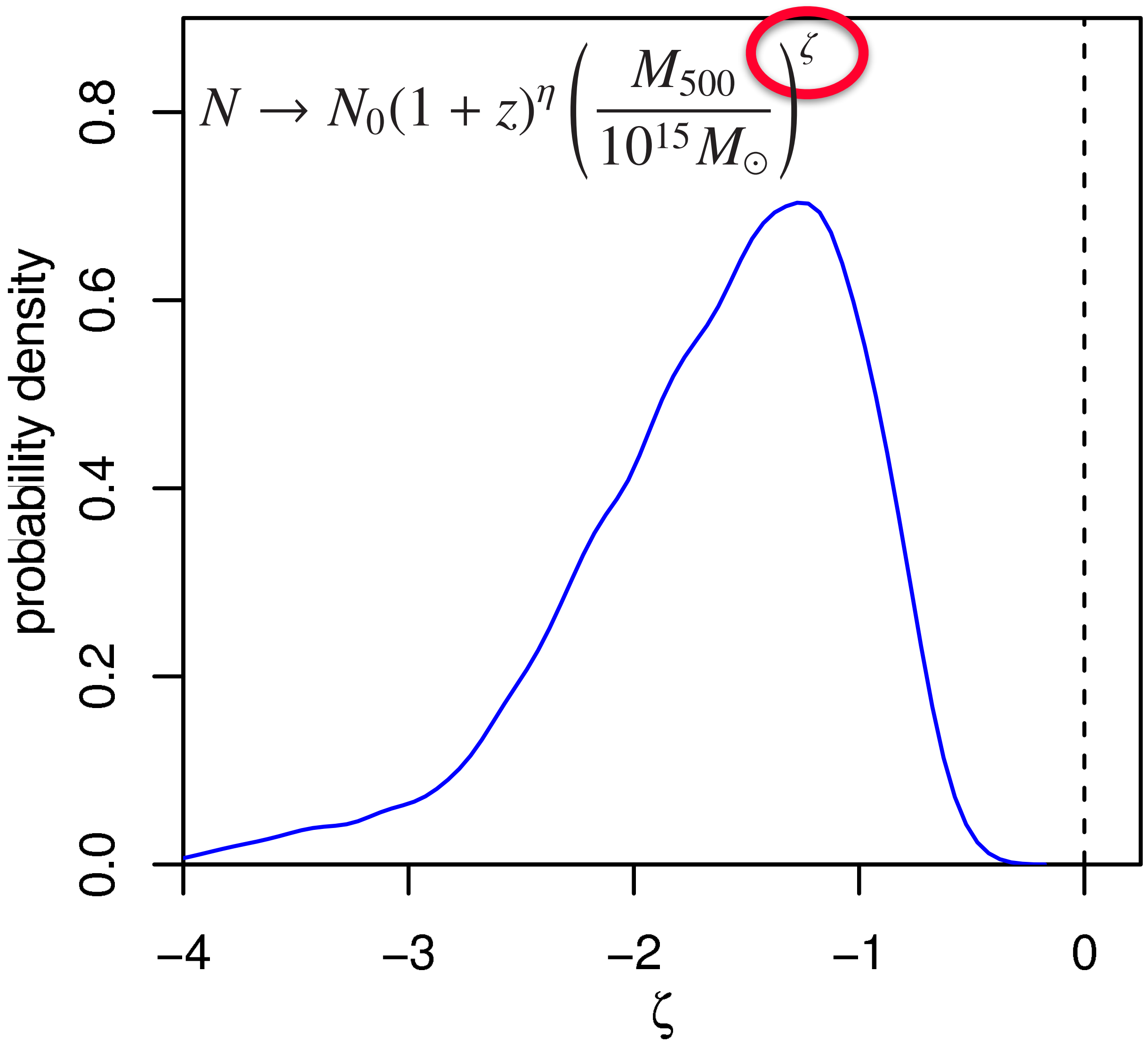
$$N_{\mathrm{obs}}(> f, r, z) = A D_A^2 r_{500} \Phi(> L, z) (\frac{r}{r_{500}})^{\beta} + N_{\mathrm{field}}$$

$$A \rightarrow A_0 f(M_{500}, z) \qquad \beta \rightarrow \beta_0 g(M_{500}, z)$$

No evolution beyond the field AGN population with redshift.
No radial variation with cluster properties. But…

Ehlert et al. 2015

1st generation results



Approximately inverse scaling of AGN number density with host cluster mass.

Observed mass scaling ζ=-1.2

ζ= 0 rejected at >99.9%

No evidence (yet) for evolution of radial scaling - so process occurs on same length scales irrespective of mass

Mergers? Rate of galaxy mergers in massive clusters scales as $\sim \sigma^{-3} \sim M^{-1}$ (e.g. Mamon 1992)

AGN triggering/suppression: Ram pressure? Harassment? Strangulation? May lead to different radial profiles (e.g. Treu et al. 2003).

Limited by statistics and short lever arms in cluster mass and redshift

Ehlert et al. 2015

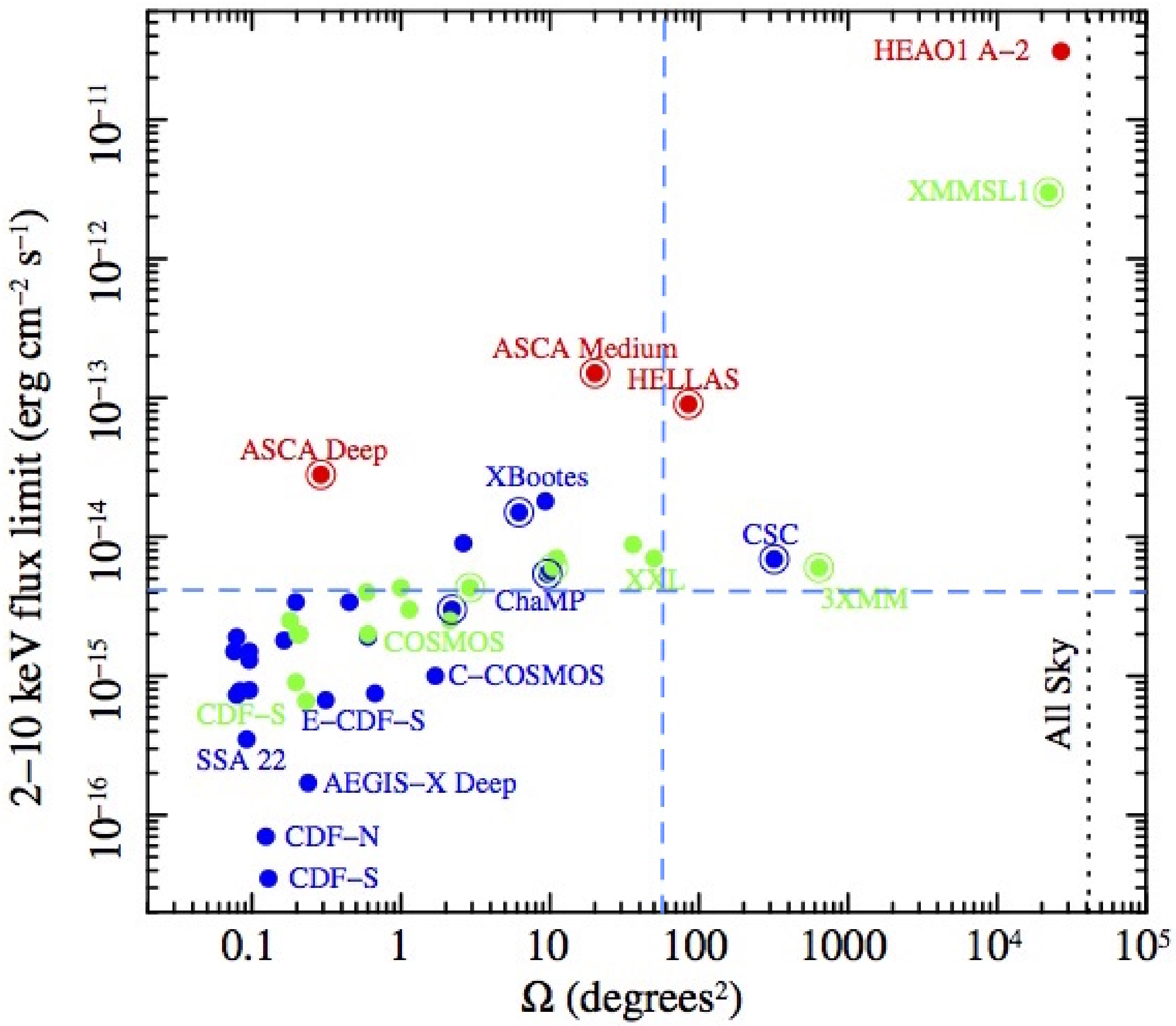
2nd generation

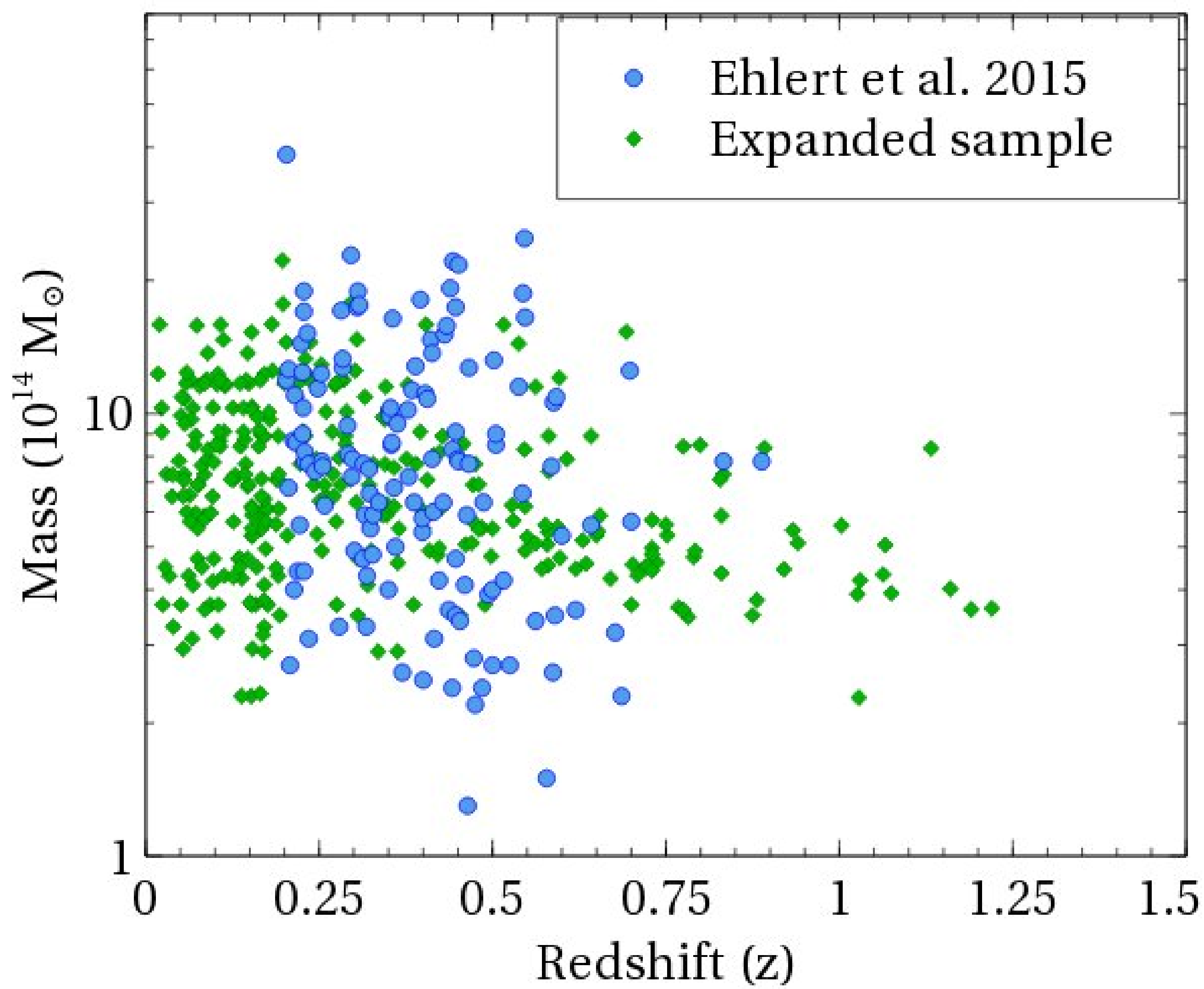
1. Greater statistics

2. Greater lever arm

480 clusters. Depth >10ks.

Total exposure = 25.7 Ms   Total Area = ~40 degrees^2

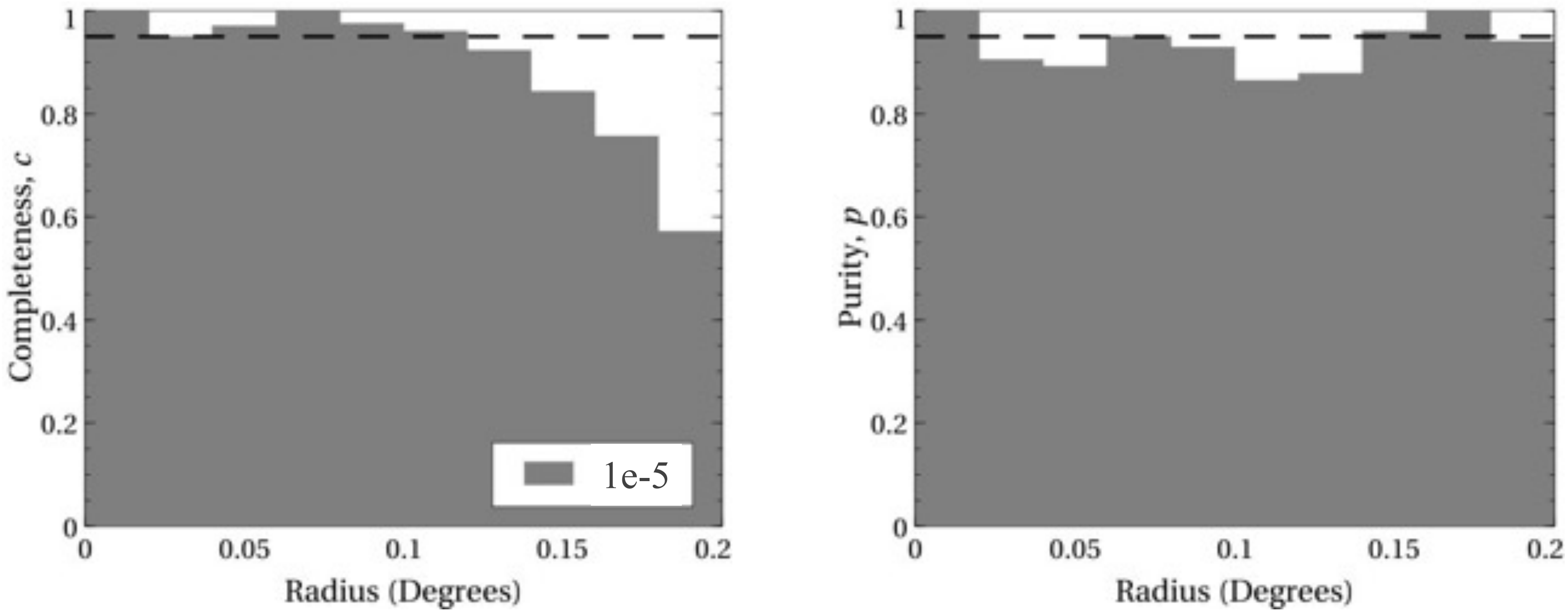




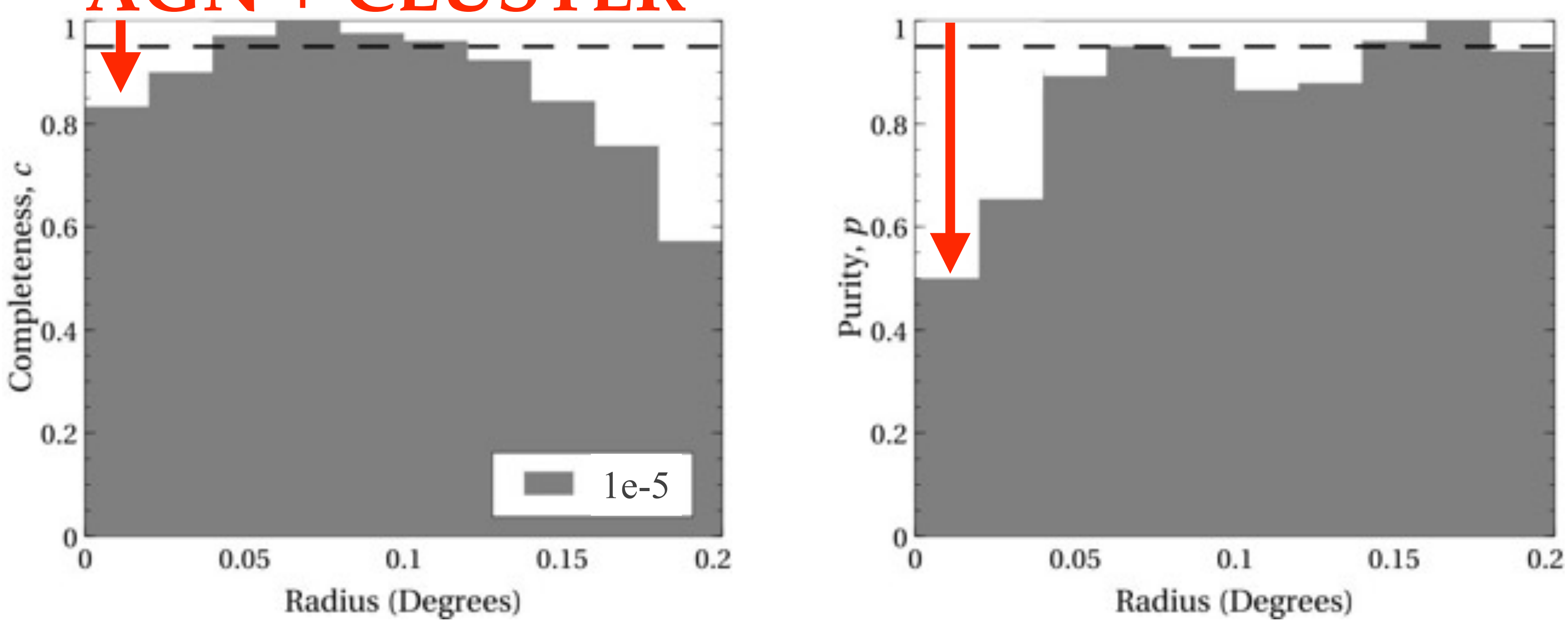
2nd generation

Completeness **Purity**

AGN ONLY



AGN + CLUSTER

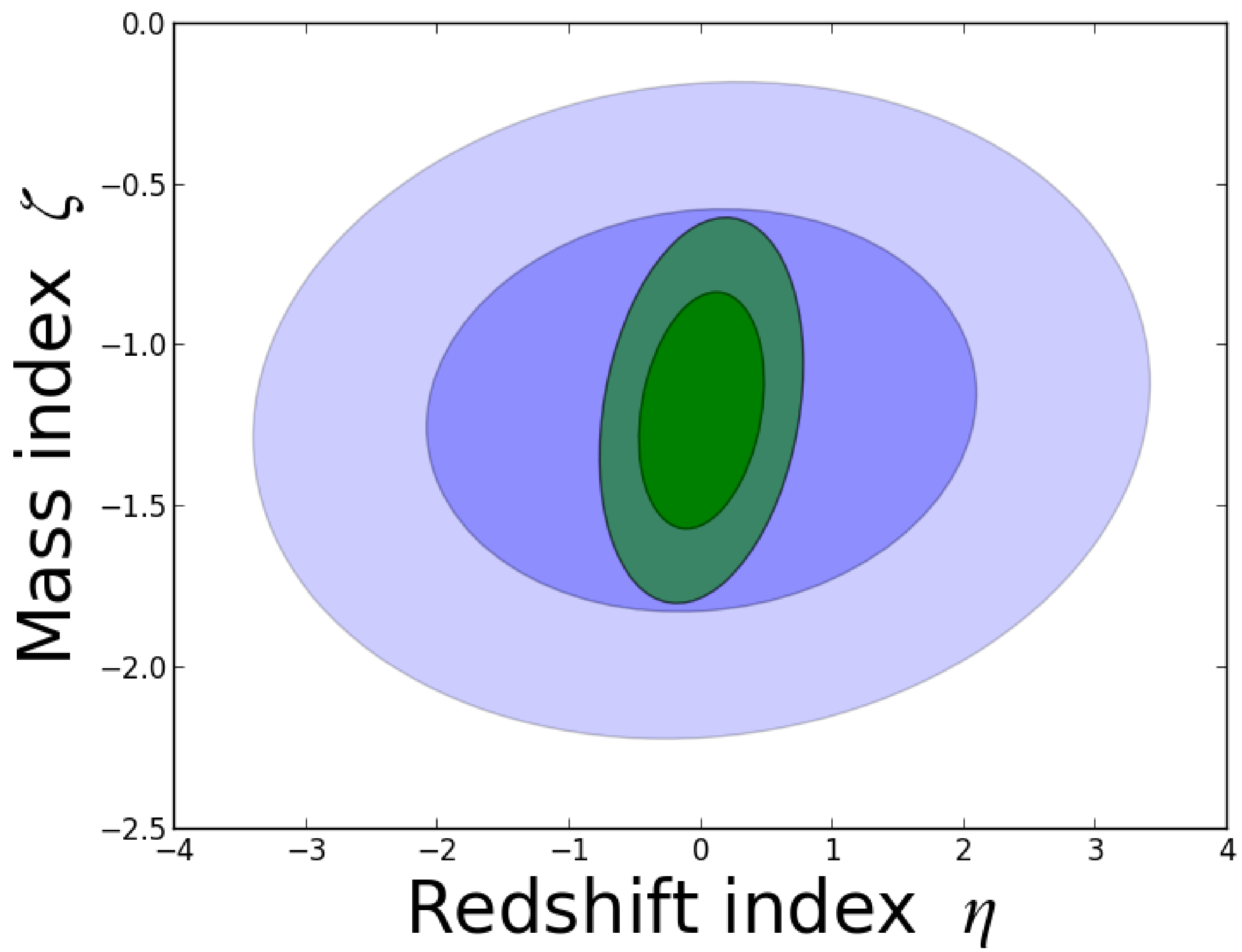


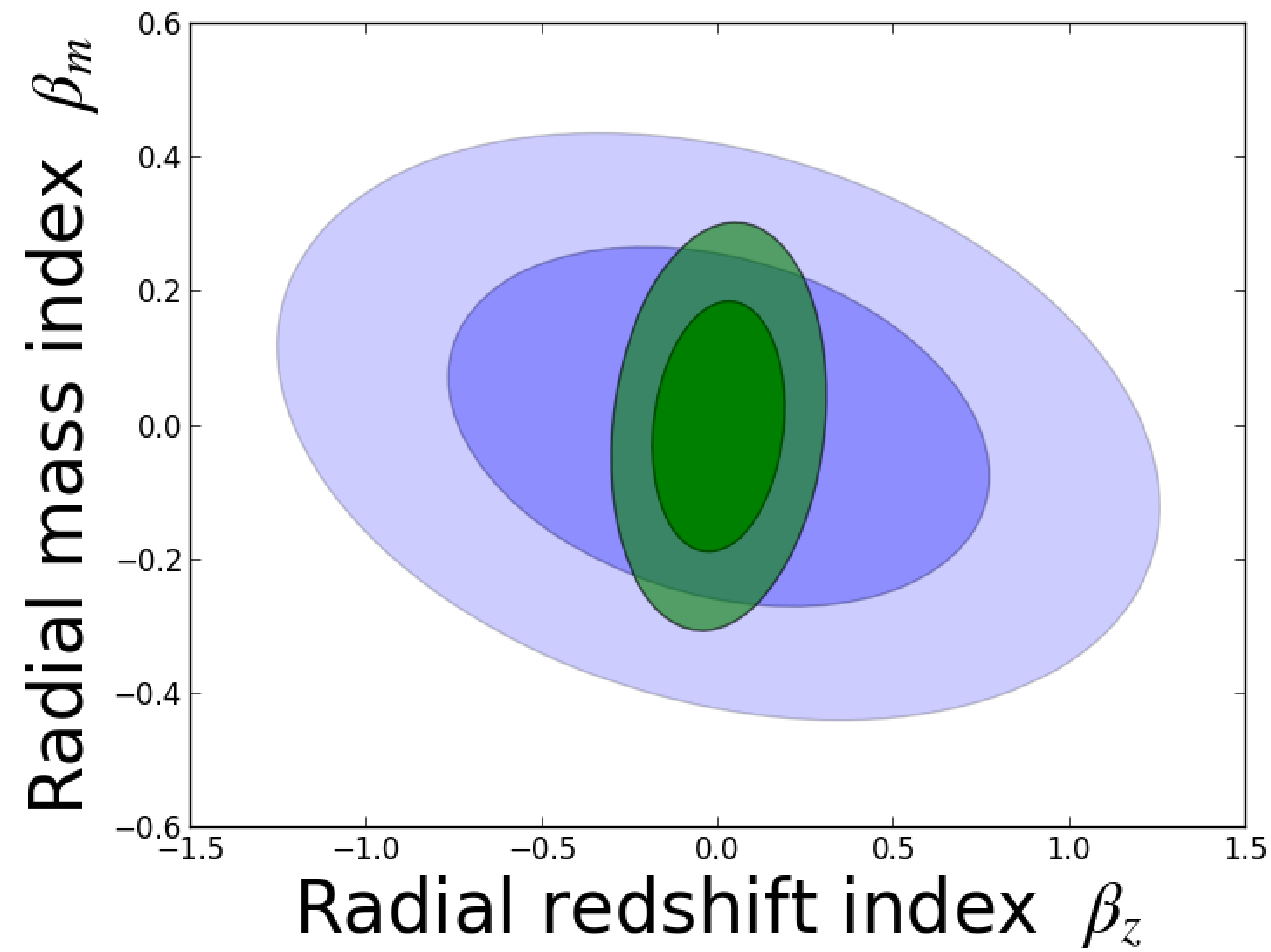
Completeness and purity of the AGN sample: Need to both efficiently and cleanly find point sources in cluster fields.

We use a 2-step process (wavdetect+Acis Extract) with settings optimized using simulations of cluster fields.

2nd generation

Forecast results for 2nd generation of 480 galaxy cluster:

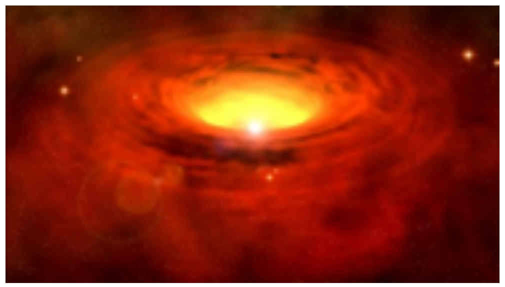


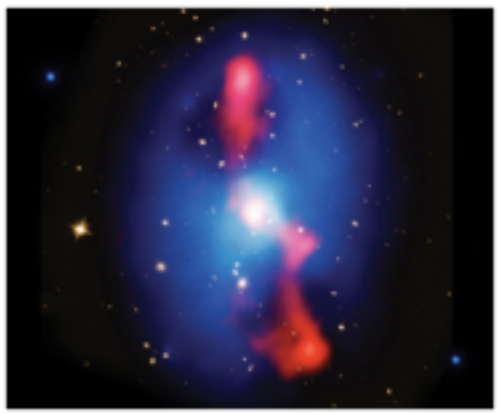


Factor 4 better in redshift evolution; factor 2 better in variation with host galaxy cluster mass (watch out for results in early 2017).

Multi-Spectral Analysis

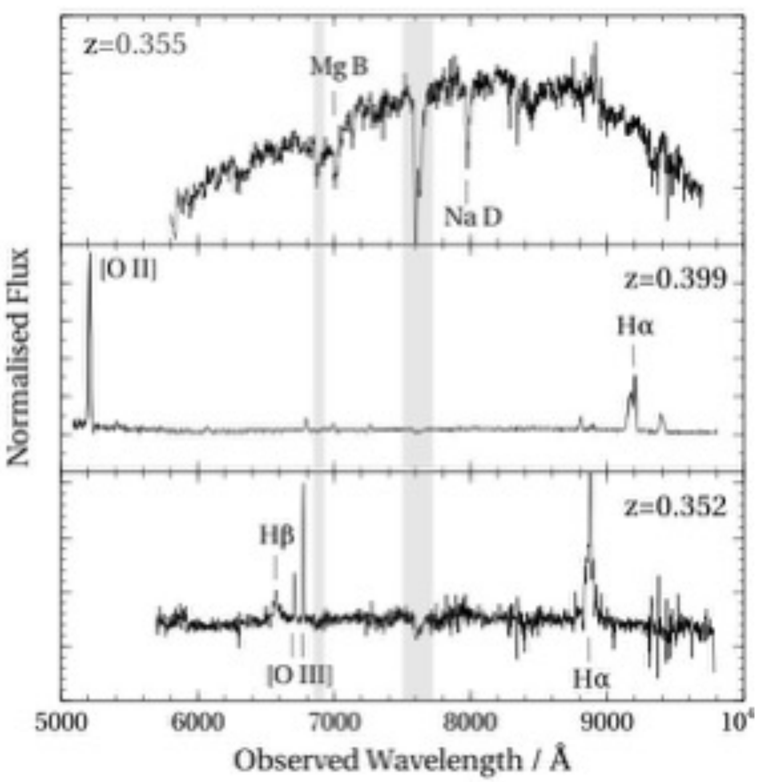
Towards a more complete census of cluster AGN and host galaxy properties





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.**

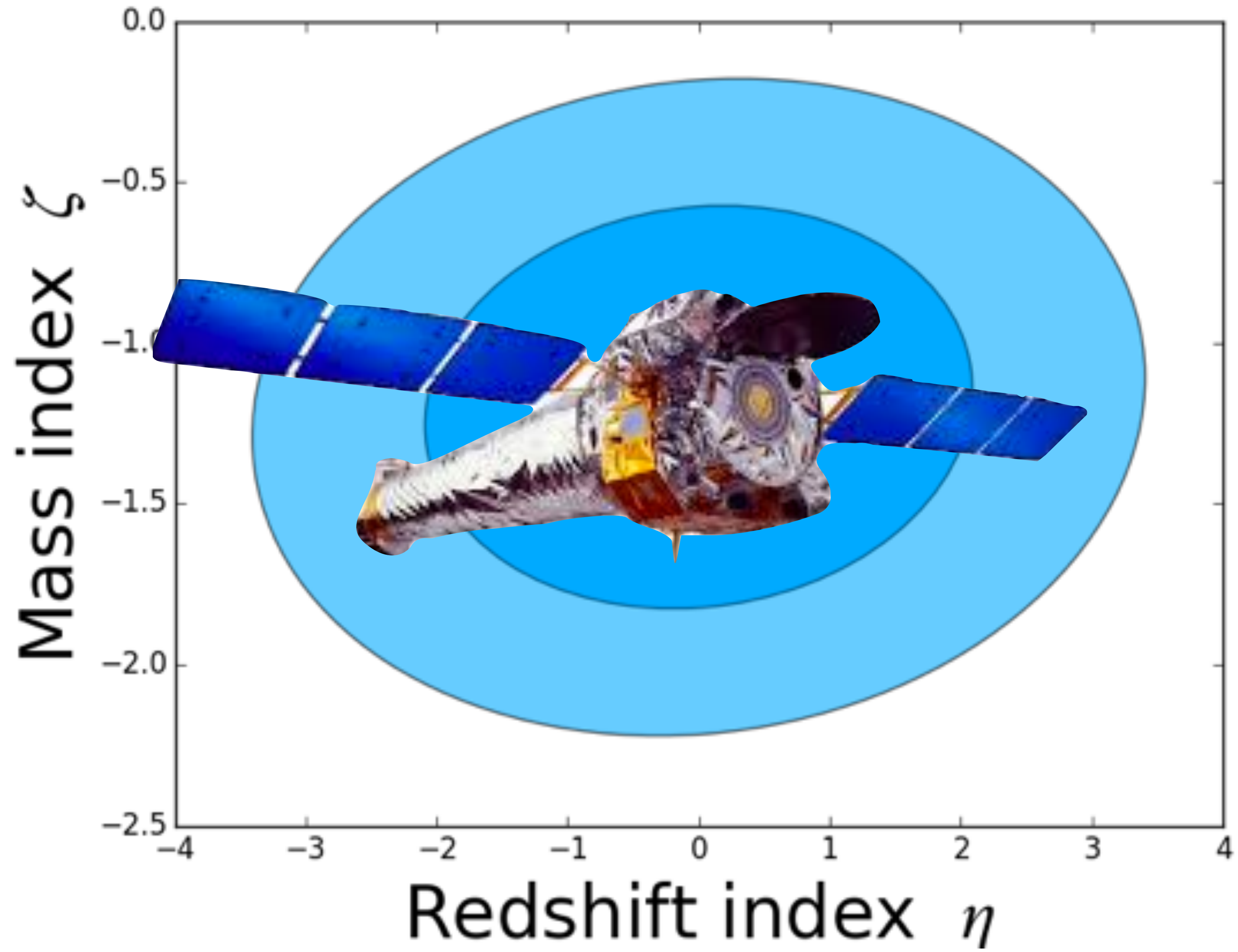


3. Can also use spec-z to train photo-z for large sample. **In collaboration with G. Yang and N. Brandt.**

How will X-ray Surveyor do?

Non-optimized case study:

Assuming:
1) same exposure as current Chandra 1st generation results (6.3 Ms)
2) single flux limit (~5×10^{-15} erg/cm^2/s - should do >factor 10 better in flux)
3) 10 ks obs (630 clusters)
4) Drawing from $M_{500}>10^{14}$ Msun and z<2.0



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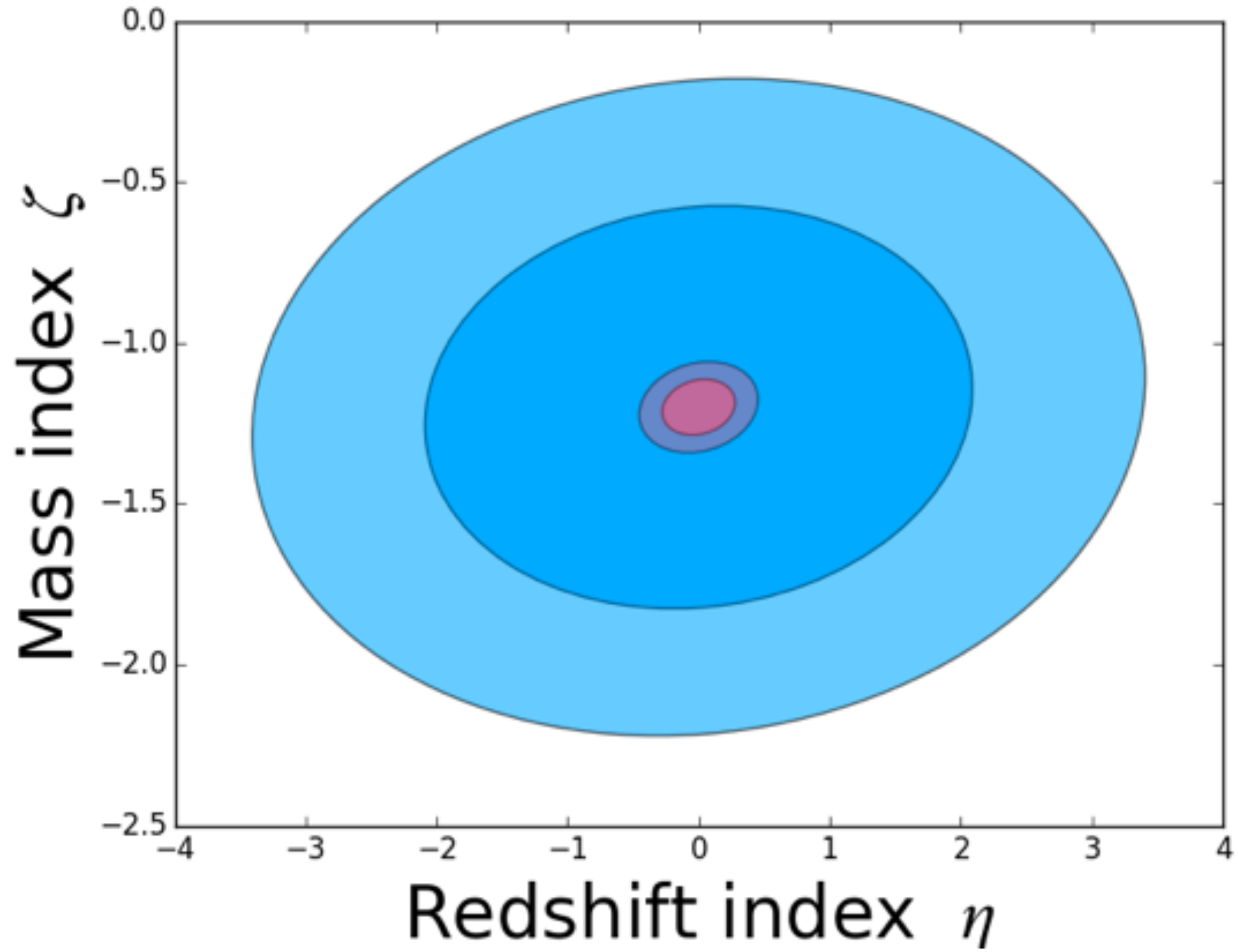


Naivest experiment ~factor 10 better constraints than Chandra

NEXT DECADE:
Host of excellent cluster finders (Athena, eRosita, Euclid and CMB-S4). Combine with Euclid/LSST/DESI/WFIRST/SKA to learn about evolution of SF and AGN in dense environments and understand the transition between radiatively efficient and inefficient AGN in clusters.

Summary:

1st generation: The number density of X-Ray AGN in clusters depends inversely on the host cluster’s mass.

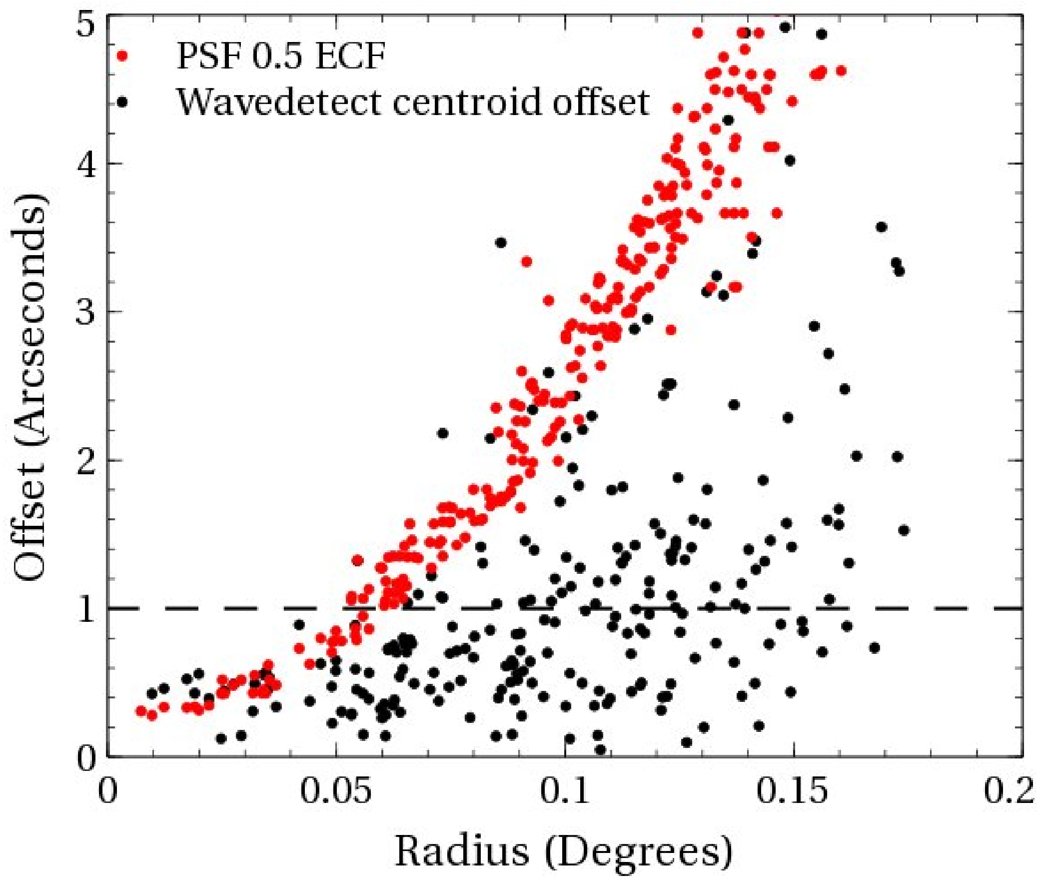
The next generation will improve uncertainties by a factor of 4 in the current state-of-the-art for redshift evolution of X-Ray AGN in clusters.

We can continue to improve with higher statistics and longer redshift lever arms - ideally one needs a large FOV with sub-arcsecond PSF to efficiently answer the question of how AGN and large-scale-structure co-evolve (X-ray Surveyor).

Combining with observations at other wavelengths is very powerful for 1) decreasing the AGN background and 2) learning about the AGN host galaxy properties and examining the transition between radiatively efficient and inefficient accretion.

Extra slides

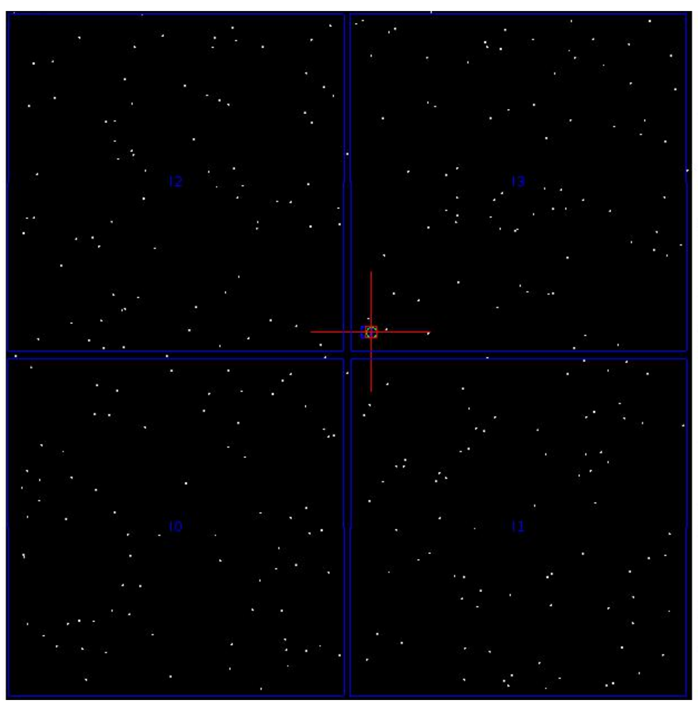
Second generation CATS project - X-ray AGN

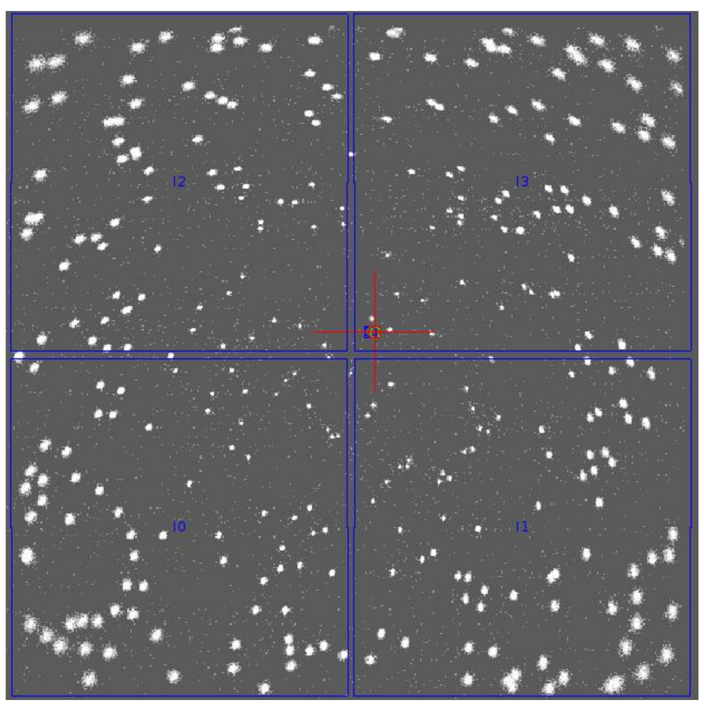


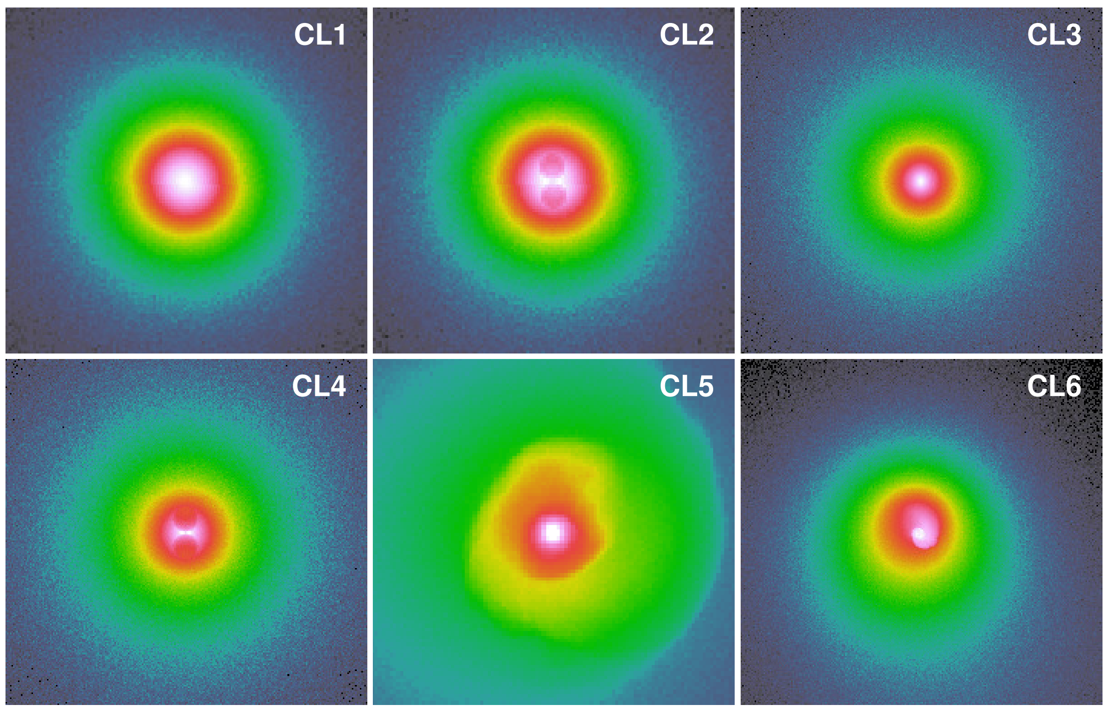
Chandra PSF grows quickly off axis

1. Generate fake AGN and clusters

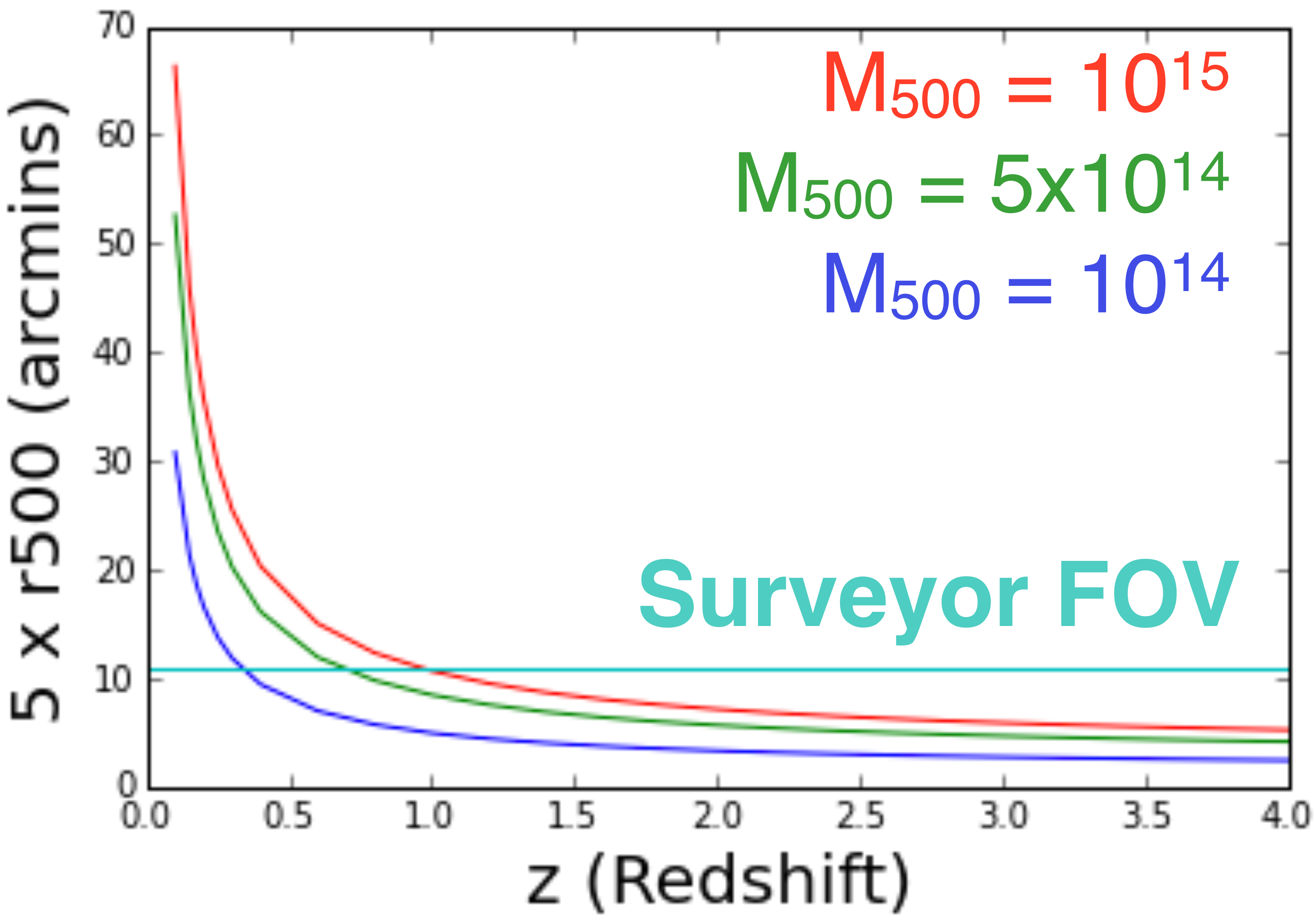
2. Test completeness and purity of the catalogue

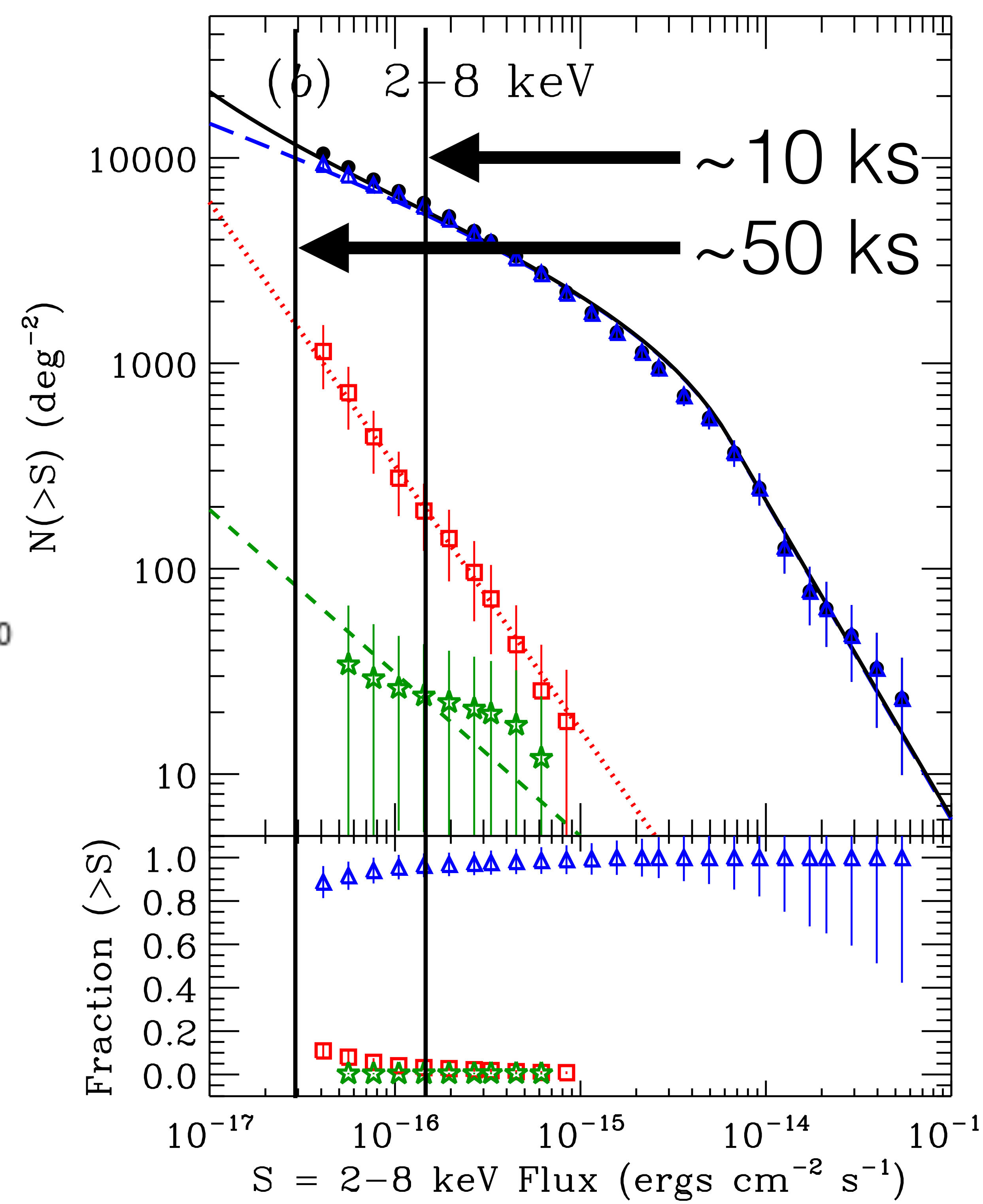






How will X-ray Surveyor do?



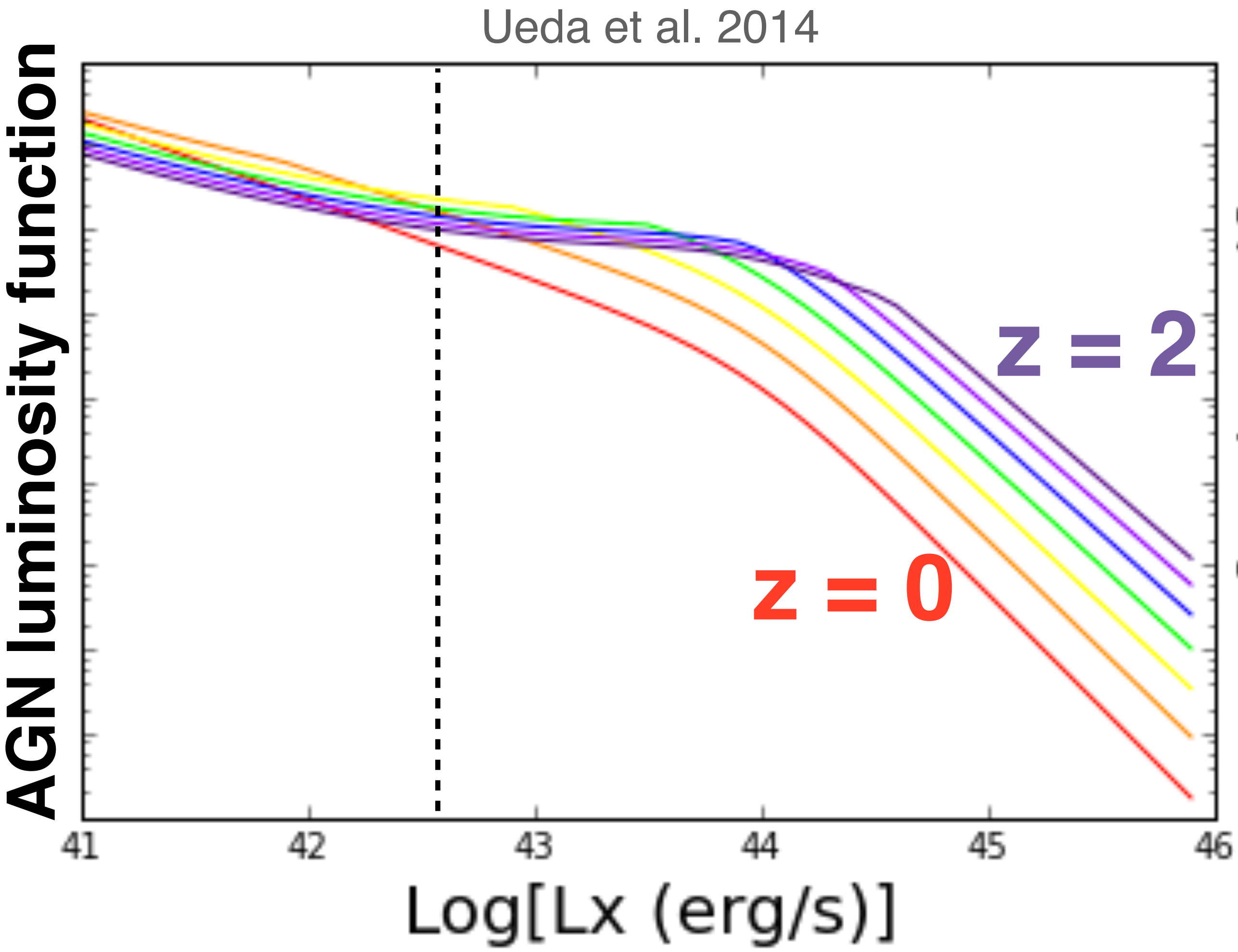


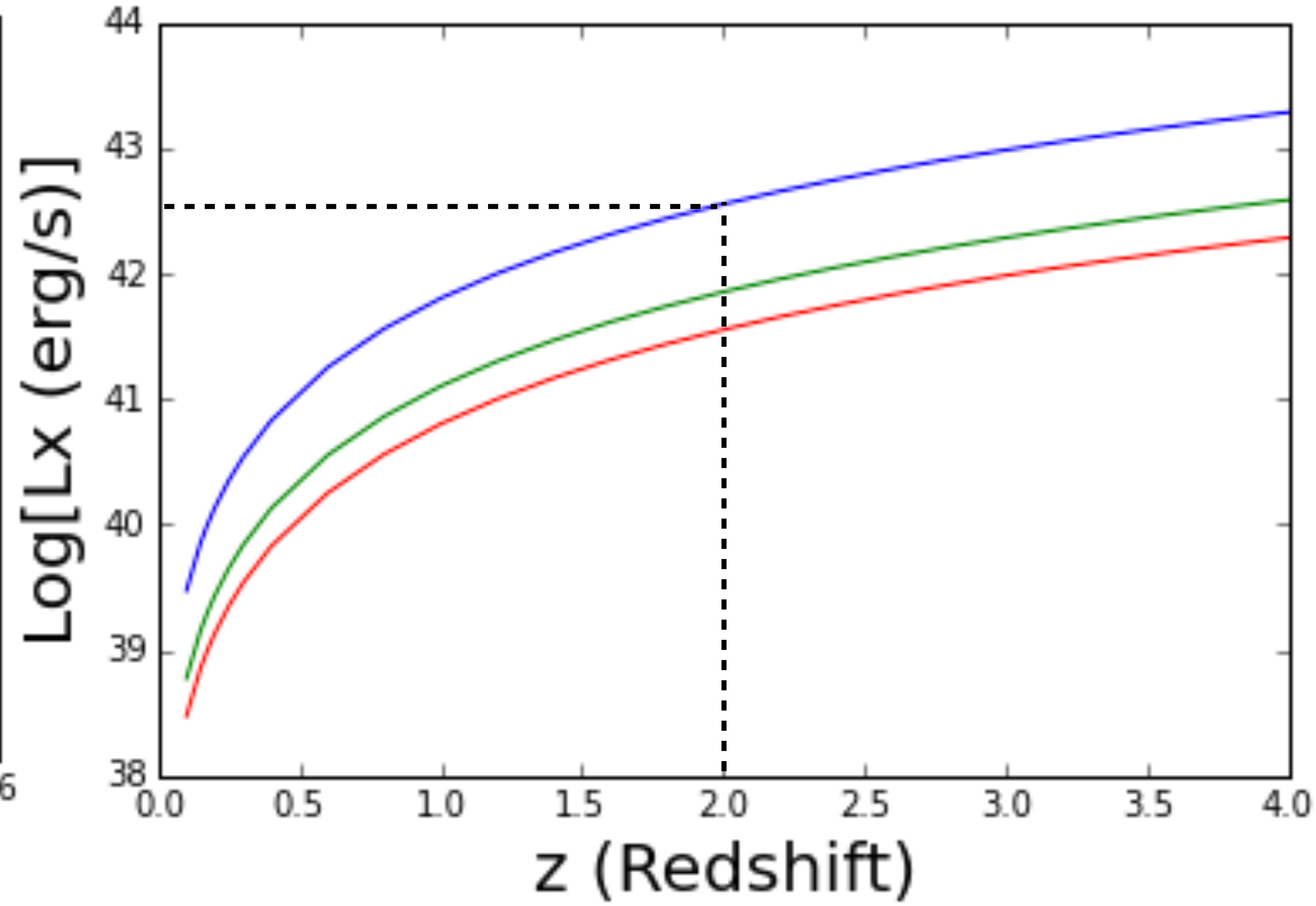
High angular resolution needed to:

1) Enable source matching (for host gal properties and for purity of AGN sample)
2) Distinguish AGN and peaked (often clumpy) cluster light
3) Explore radial AGN fractions

Must have good PSF across whole FOV

How will X-ray Surveyor do?





10 ks = 1.2e-16 erg/cm²/s

50 ks = 2.4e-17 erg/cm²/s

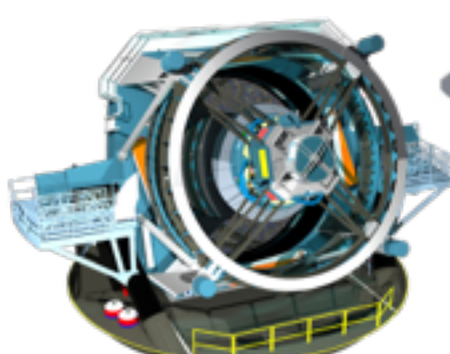
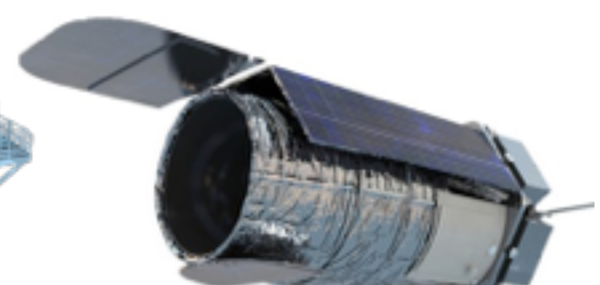
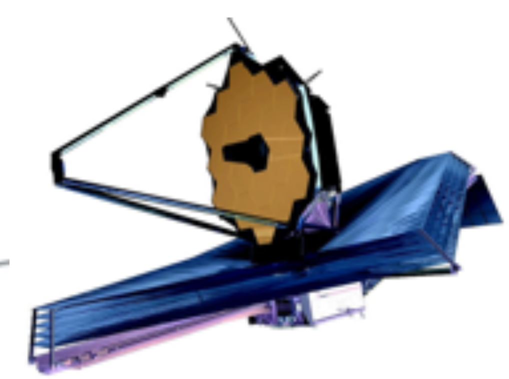
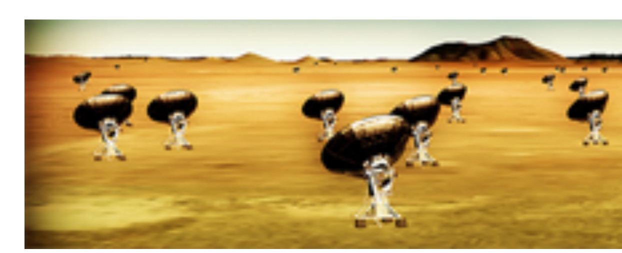
100 ks = 1.2e-17 erg/cm²/s

With 10ks exposure probe to or below knee at all redshifts

Future: Synergy with other observatories

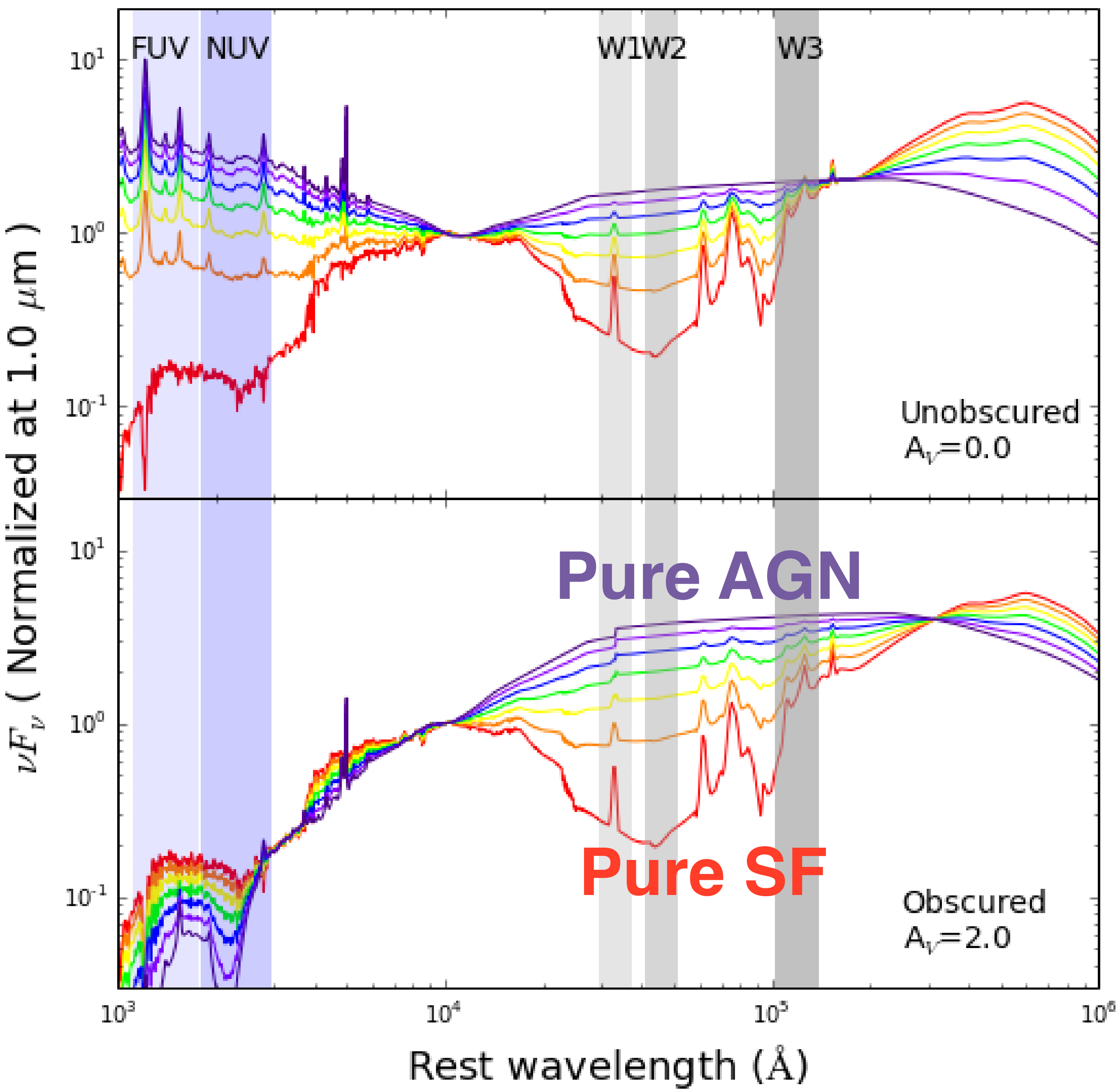
X-ray surveyor - wide FOV and good PSF crucial
Athena, eRosita, Euclid and CMB-S4 - excellent cluster finders

Also great synergy with other observatories:
Number density of AGN in cluster fields - highly background dominated.
1) JWST, Euclid, LSST, WFIRST, DESI : IR/optical - greatly reduce this background component - spec-z’s, photo-z’s, simple magnitude cuts.
2) Allow AGN *fraction* as function of galaxy properties such as stellar mass. Comparison with SF fraction evolution and with morphology of hosts.
3) Radio SKA AGN properties can be compared with X-ray AGN to examine the transition between radiatively efficient and inefficient accretion

Multi-Spectral Analysis

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

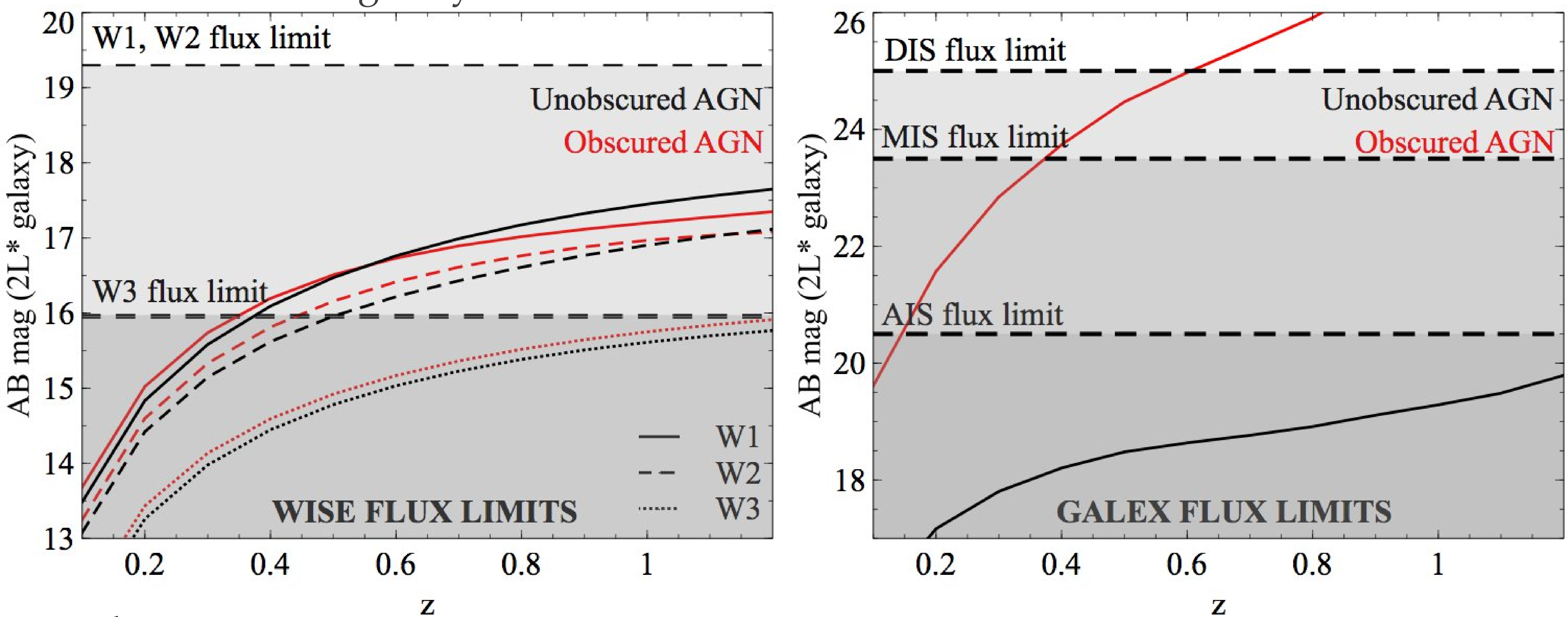


1. Are the obscuration properties of AGN in cluster fields different from field galaxies?
2. How do the number densities of obscured and unobscured AGN in clusters vary with the mass, radial position and redshift of clusters?
3. Are AGN in clusters more or less likely to reside in star-forming hosts.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

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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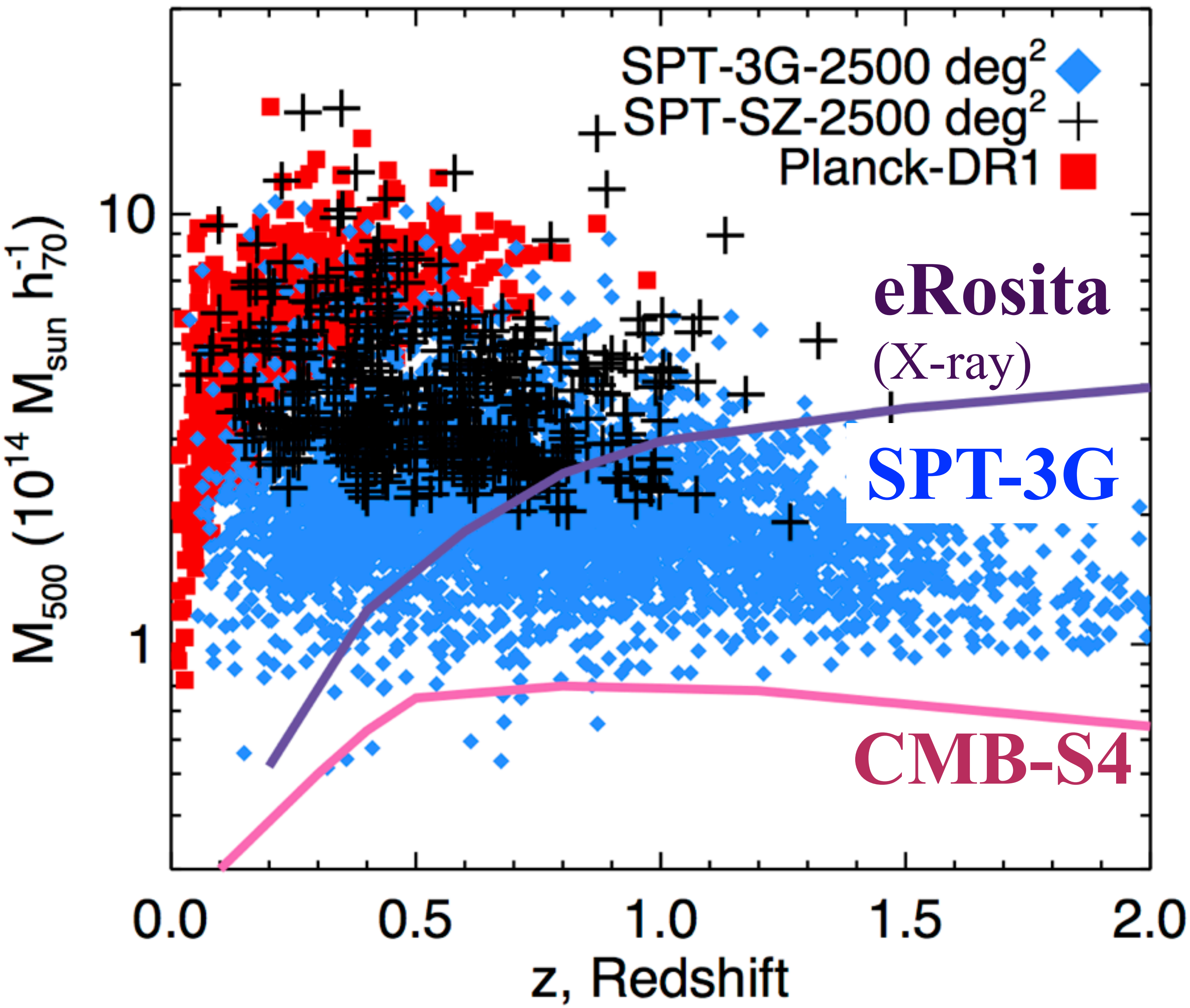
A multi-spectral analysis

2020/30s: Finding clusters not a problem

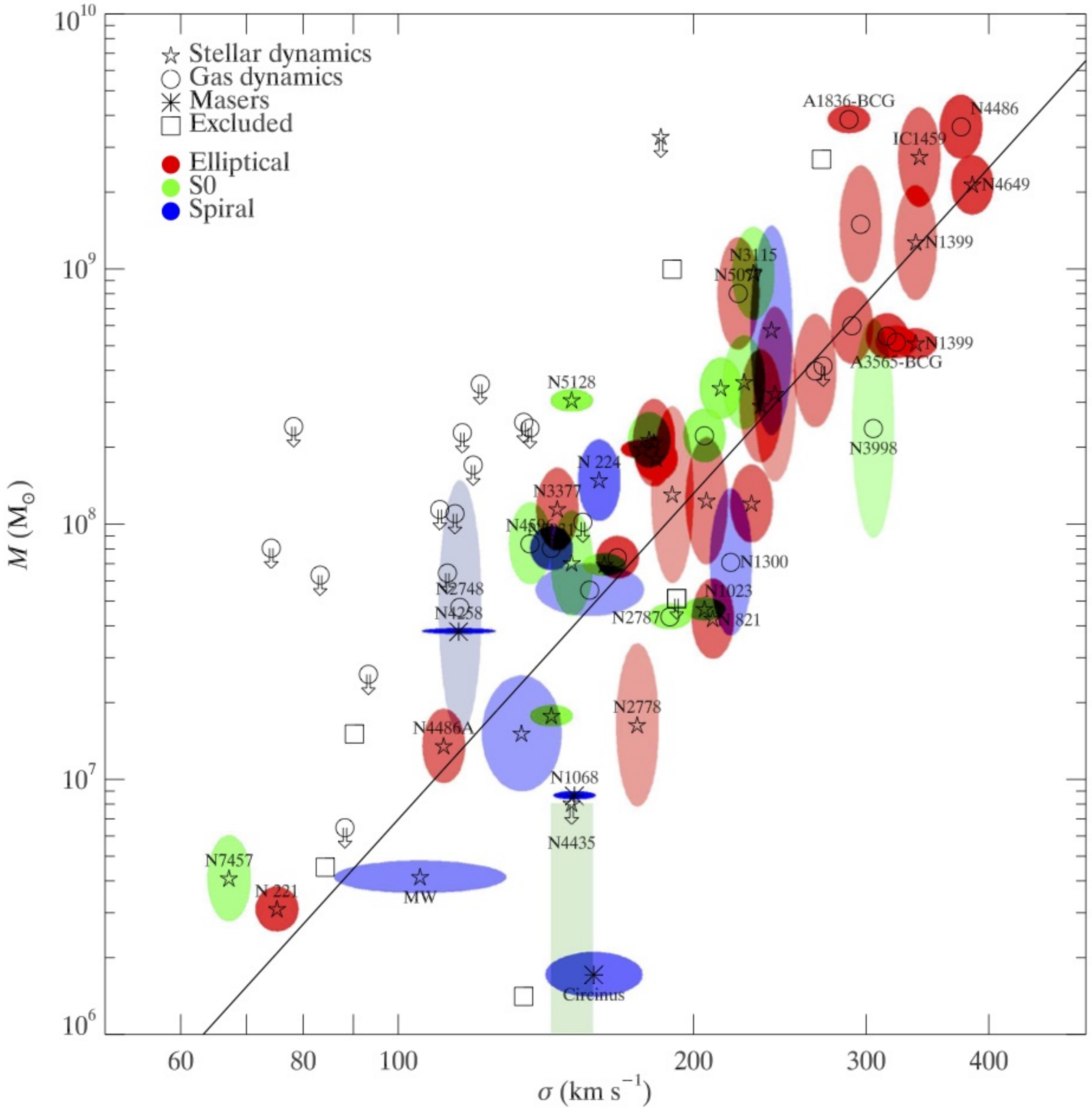


CMB-S4: N_{clus} > 100,000 (higher z and lower M, 20,000 deg^2)

eRosita (All sky), LSST (20,000 deg^2) and Euclid (15,000 deg^2)

Big Questions?

Gultekin et al. 2009



NASA/CXC/Werner et al. 2010

Galaxy and BH evolution is intimately connected

Extra slides

Extra slides

JWST - 6.5 meter, October 2018, 5-10 years duration, 0.1 arc-seconds, 0.6-28.5 microns (NIRCam imaging 0.6-5 micron- FOV 2.2x4.4 arcmin) (NIRSpec spec 0.6-5 micron MOS 100 sources 9x9 arcmin IFU 900 spectra 3x3 arc seconds and a SLIT) (NIRISS 2.2x2.2 arcmins imaging and slitless spectroscopy in various ways) (MIRI making and spec 5-28.5 microns, 3 to 7 arcsec on a side)

Euclid - 1.2 meter telescope, launch 2020, (VIS 5500-9000 A, 0.787x0.709 degrees, 0.1 arcsec pixels) (NISP, 0.763x0.722 degrees, imaging in Y (920 - 1146 nm) J (1146 - 1372 nm) and H (1372 - 2000 nm) and spectroscopy between 1100 - 2000 nm all with 0.3 arcsec pixels)

WFIRST - early 2020's, 2.4 m, (wide field instrument, 0.76-2 microns in imaging and 1.35-1.95 in spectroscopy in 0.281 degrees squared and an IFU but only 3x3.15 arcsec) (coronagraph)

LSST - first light in 2019, 8.4 meter mirror, 3.5 degrees or 9.6 square degrees, u, g, r, i, z, y

SKA - construction in 2018 and early science in 2020. Angular resolution of 0.1 arc second with a imaging field of view of 1 degree at 0.03-20 GHz

Athena - launch in 2028, (XIFU, 2.5eV spectral resolution, 5'' pixels, 5 arcsin fov) (WFI, 0.2-15keV energy band, 40x40 arc min fov pixels size of about 2.5'' and psf is 5'' on axis half energy width)

E-Rosita - launch 2017 - L2 - 0.3-10 keV, 16 to 28'' on axis, 138 eV resolution at 6 keV, FOV about a degree in diameter (0.833 degree^2 ???)

CMB-S4 - ???

DESI -

40m 'scopes?