X-ray AGN in dense environments: Cluster AGN Topography Survey

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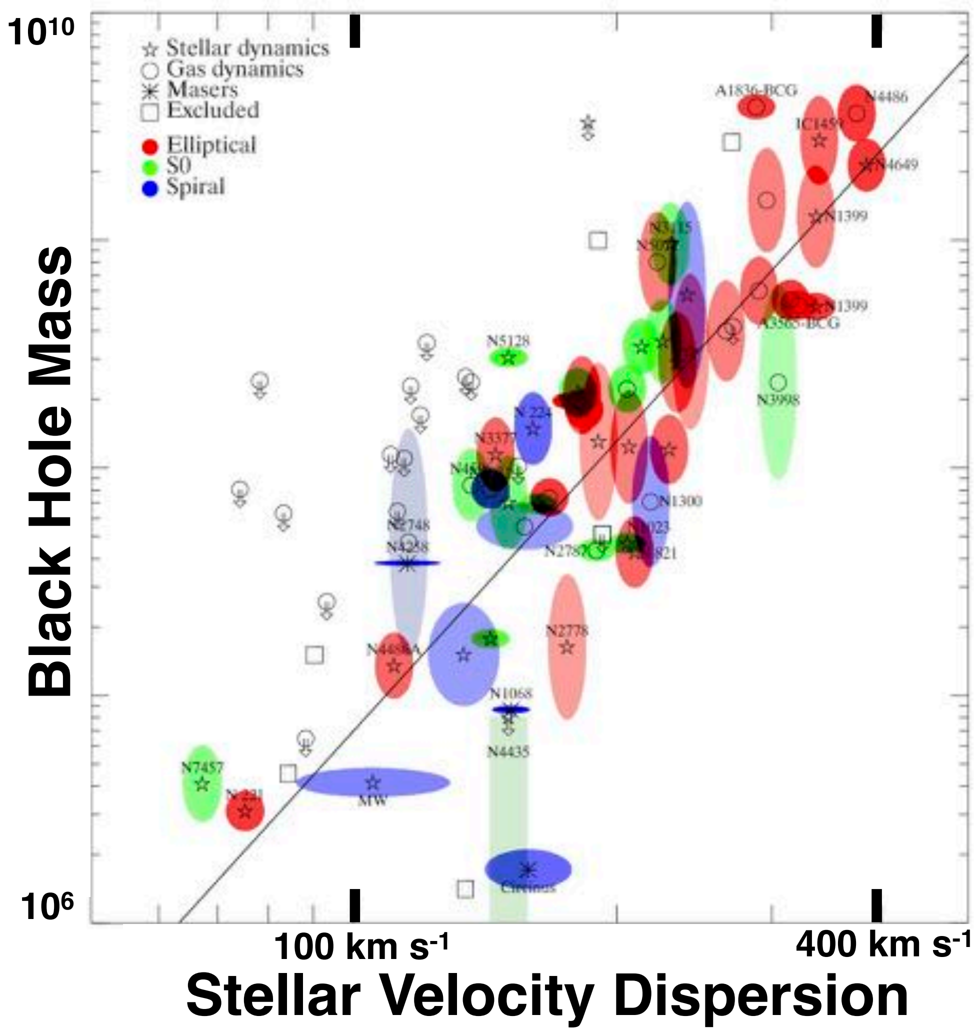
How/Do AGN influence galaxy evolution?

Gultekin et al. 2009



NASA/CXC/Werner et al. 2010

Galaxy and BH evolution is intimately connected

AGN in clusters

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

↳ **Depend on:**

- Position within host cluster
- Mass of host cluster

AGN in clusters

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) Diversity of AGN
2) Large areas of sky required
3) AGN are rare in clusters

AGN in clusters - Challenges

- AGN and host galaxy characteristics differ (see Ashley King's talk)

But…

1) Diversity of AGN
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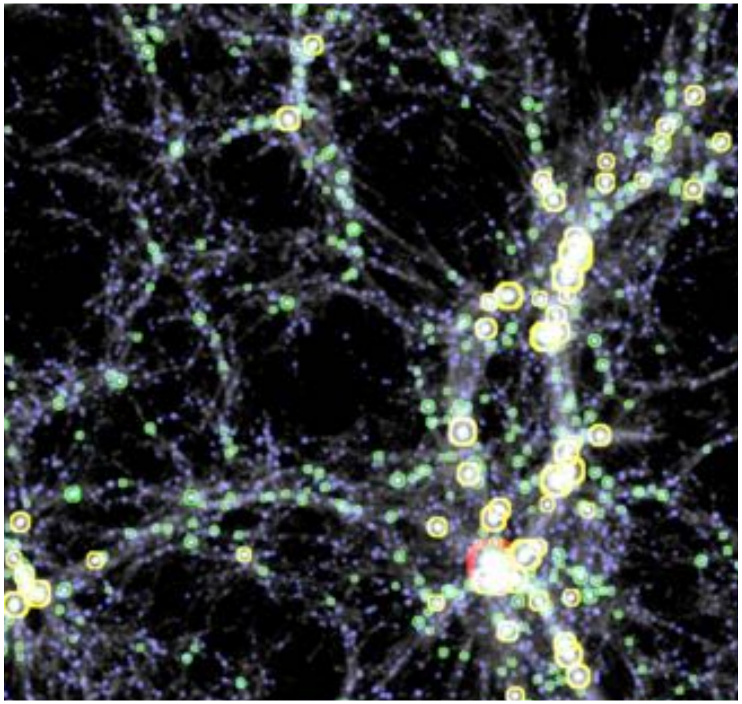
AGN in clusters - Challenges



- Most massive clusters best but rarer.
- Need to sample large area of sky to probe differing environments.

But…

1) Diversity of AGN
2) Large areas of sky required
3) AGN are rare in clusters

Movies: Matt Becker, Ralf Kaehler, Yao-Yuan Mao, Rachel Reddick, Risa Wechsler (Stanford/SLAC)

AGN in clusters - Challenges

- Typically < 3 per cluster for bright X-ray AGN
- But with reasonable depth X-ray observation expect ~50-80 AGN in the field.
- Spectroscopic follow-up is expensive

But…

1) Diversity of AGN
2) Large areas of sky required
3) AGN are rare in clusters

AGN in clusters - Solutions

Can mitigate these challenges using:

1) Pointed X-ray observations of clusters

2) Making differential measurements

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

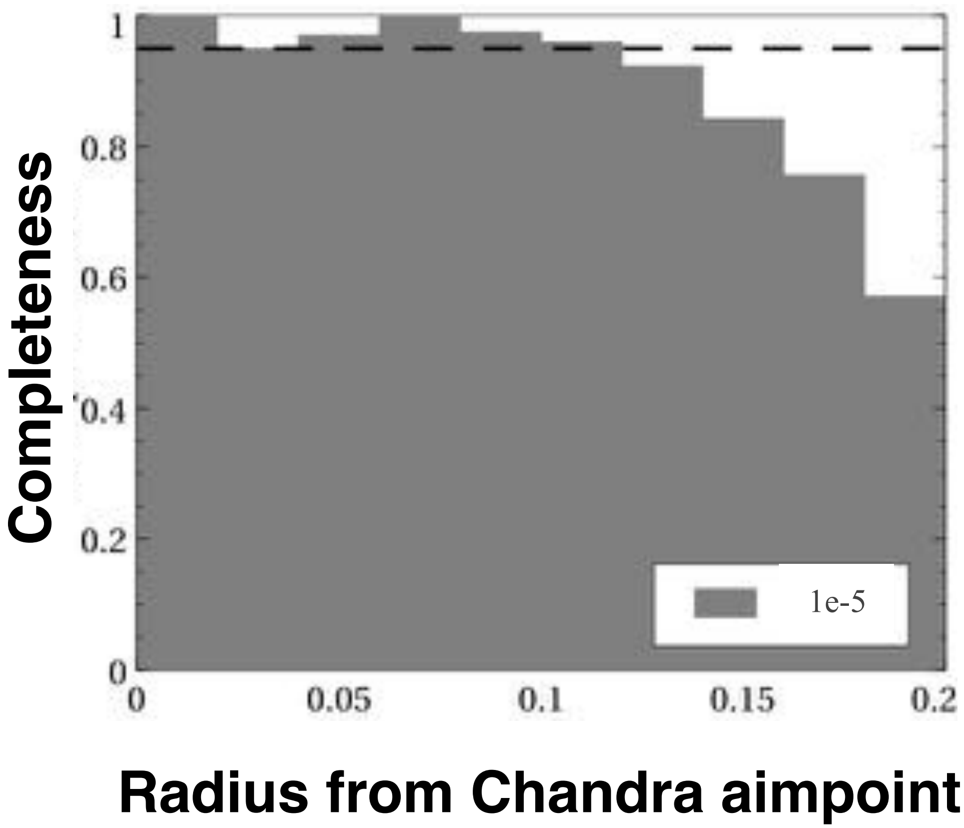
3) Utilize our knowledge of how large scale structure evolves to statistically combine signals - crucially needs robust host cluster z_{clus}, r_{500}, M_{500}

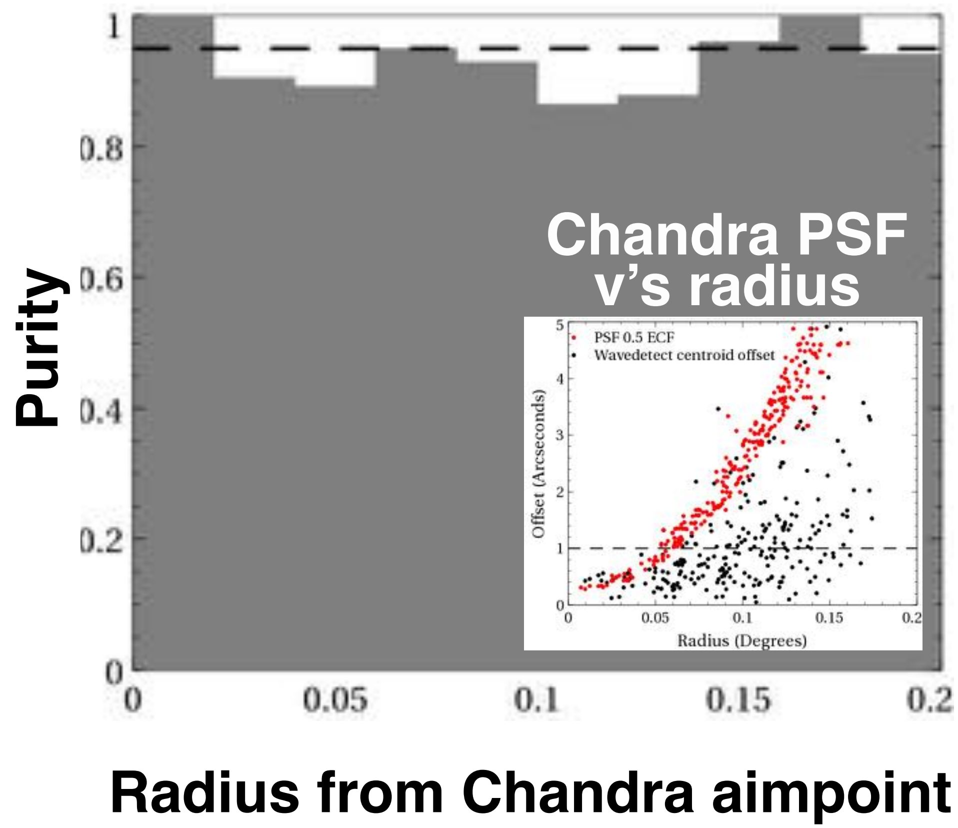
Ehlert et al. 2015

Identifying X-ray AGN

Completeness and purity of the AGN sample
Need to both efficiently and cleanly find point sources in cluster fields. Must understand any dependence on cluster properties.

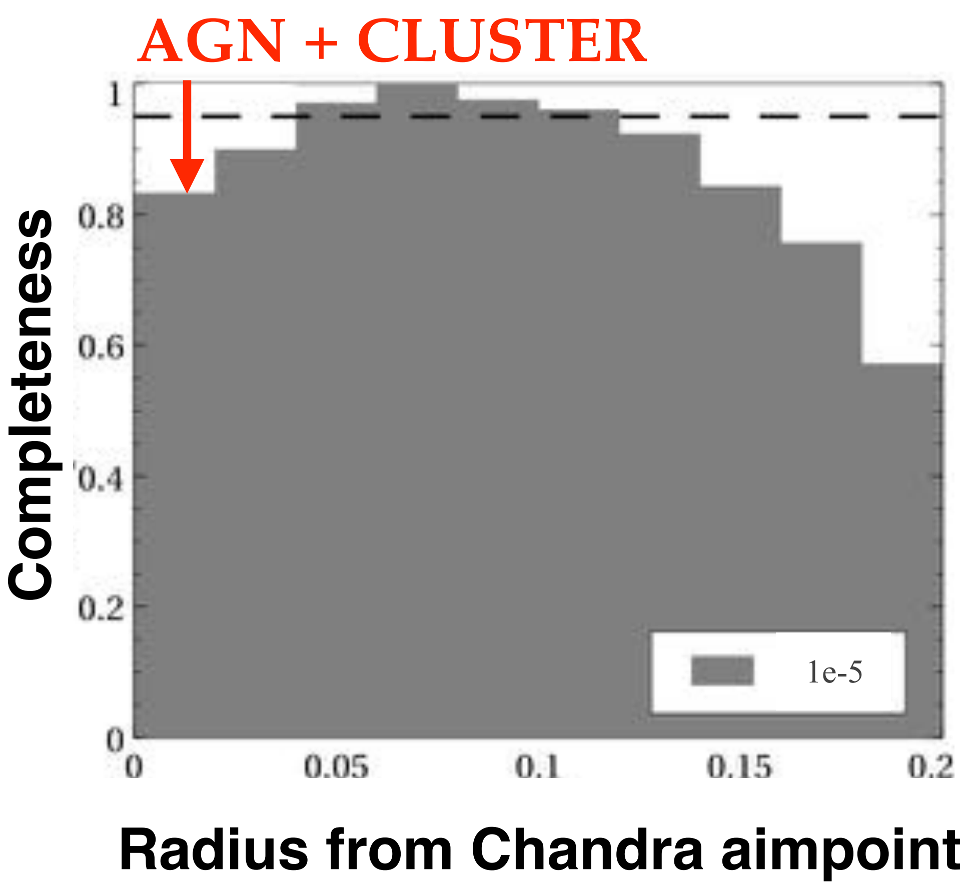
AGN ONLY

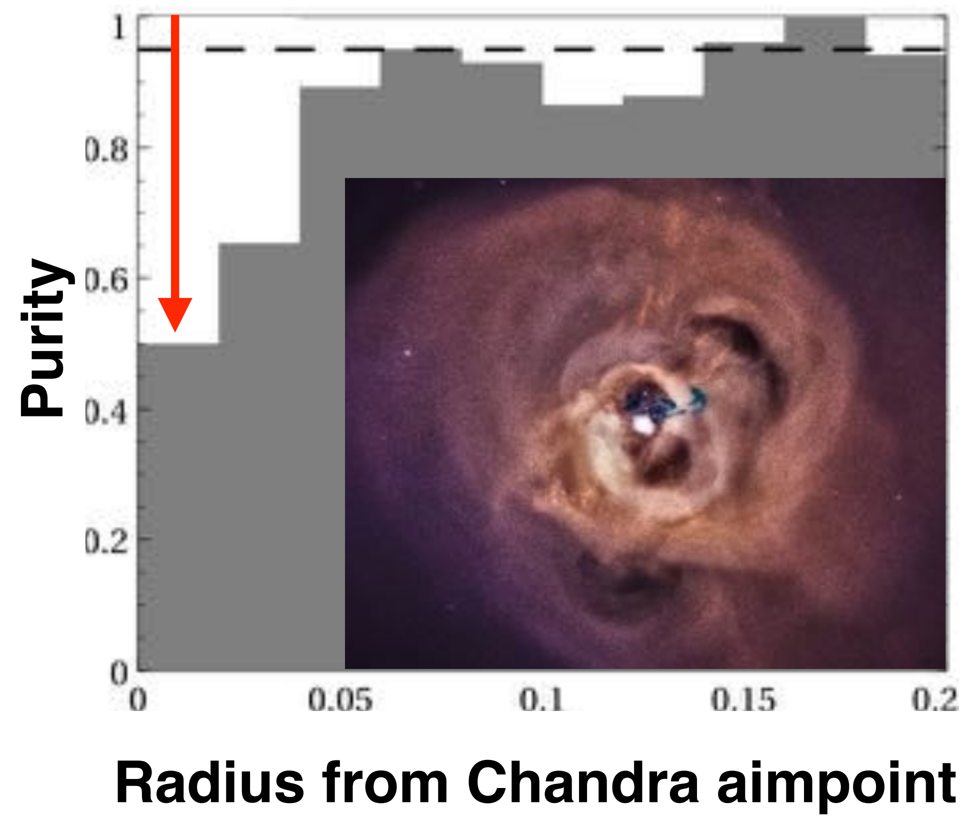




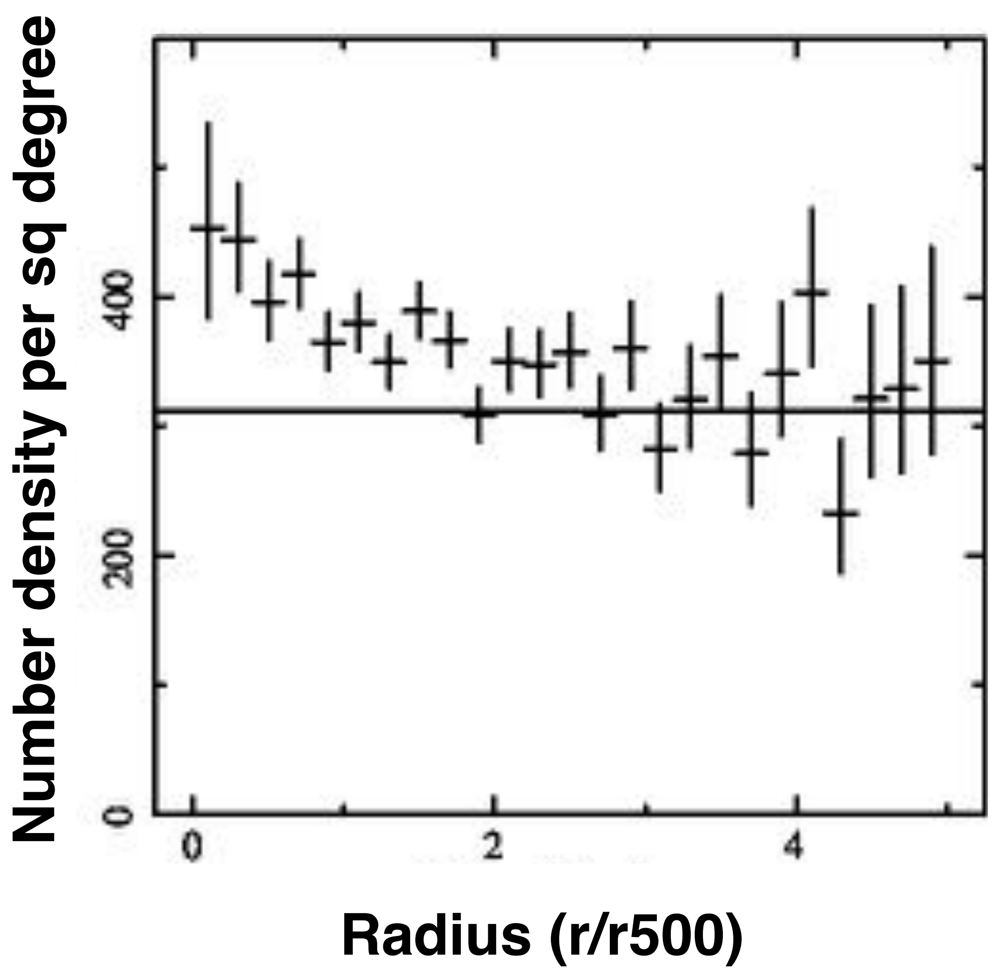
Identifying X-ray AGN

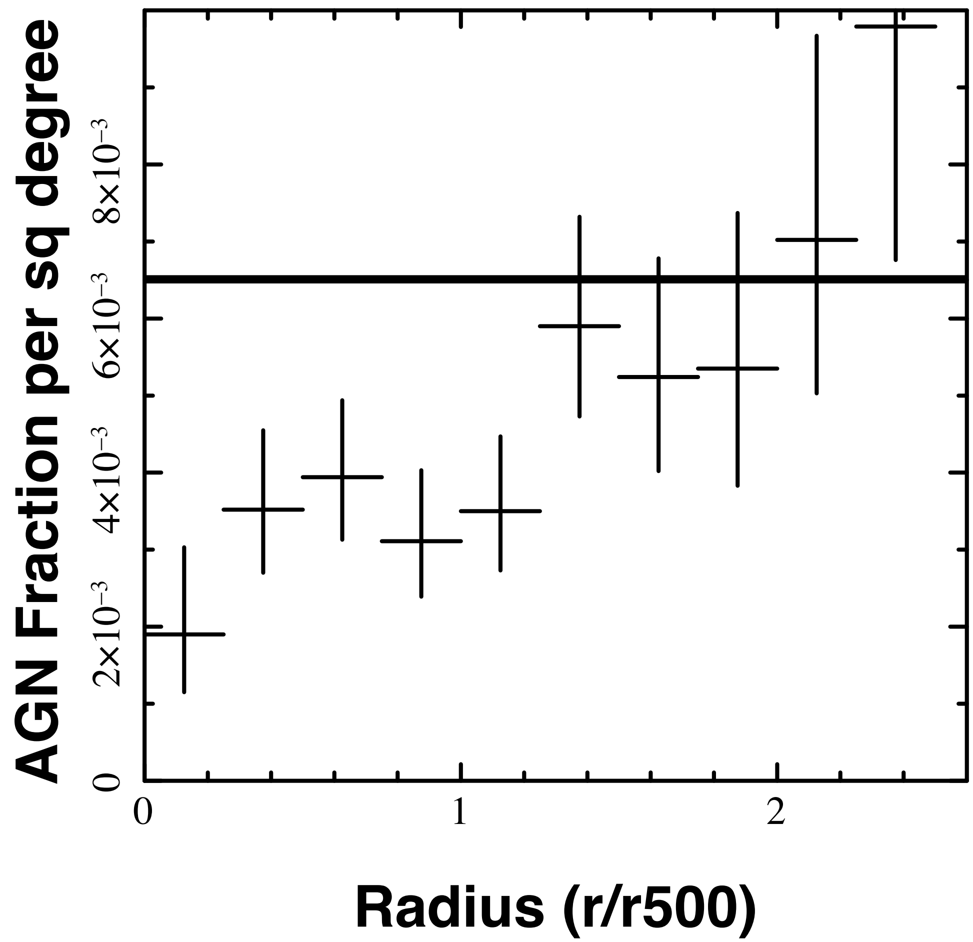
Cluster background affects completeness and purity. We use a 2-step process (wavdetect+Acis Extract) with settings optimized using simulations of cluster fields.





1st generation results





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

Ehlert et al. 2012, 2014

1st generation results

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

Null hypothesis: No difference in evolution of cluster and field AGN

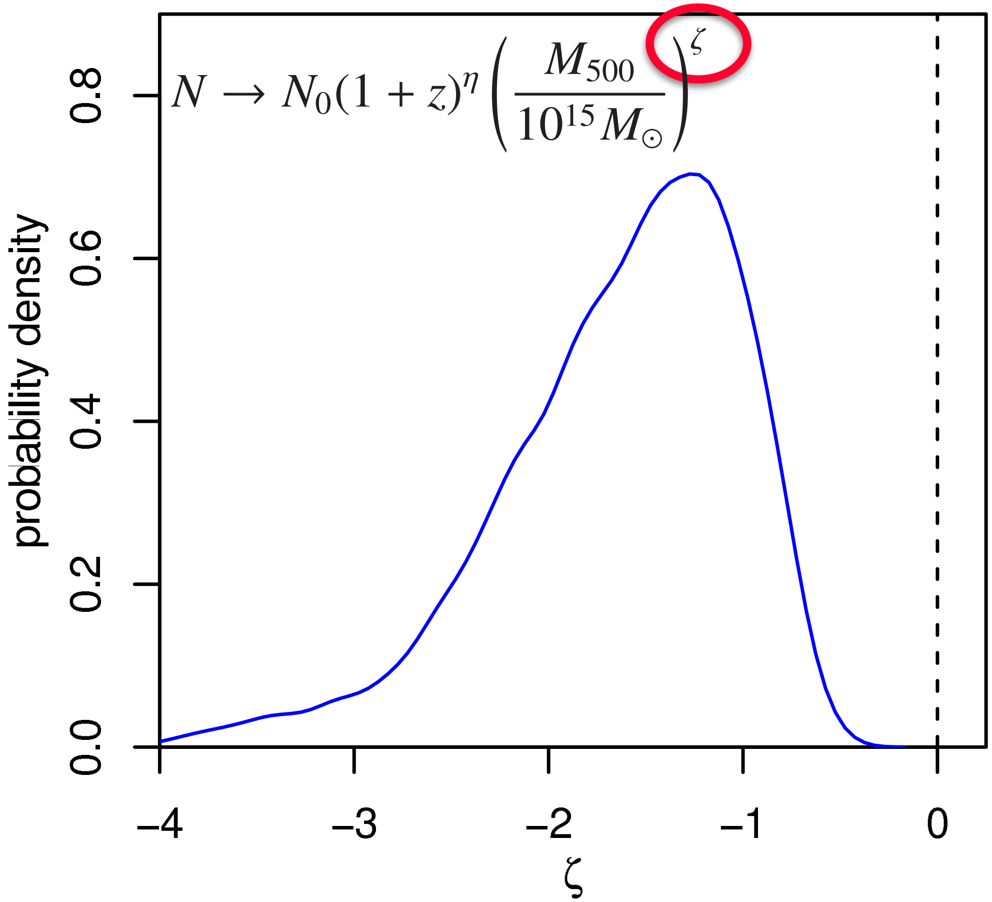
$$N_{\rm obs}(>f,r,z) = AD_A^2 r_{500}\Phi(>L,z)(\frac{r}{r_{500}})^{\beta} + N_{\rm field}$$

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

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

Ehlert et al. 2015

1st generation results



Observed mass scaling ζ=-1.2

ζ= 0 rejected at >99.9%

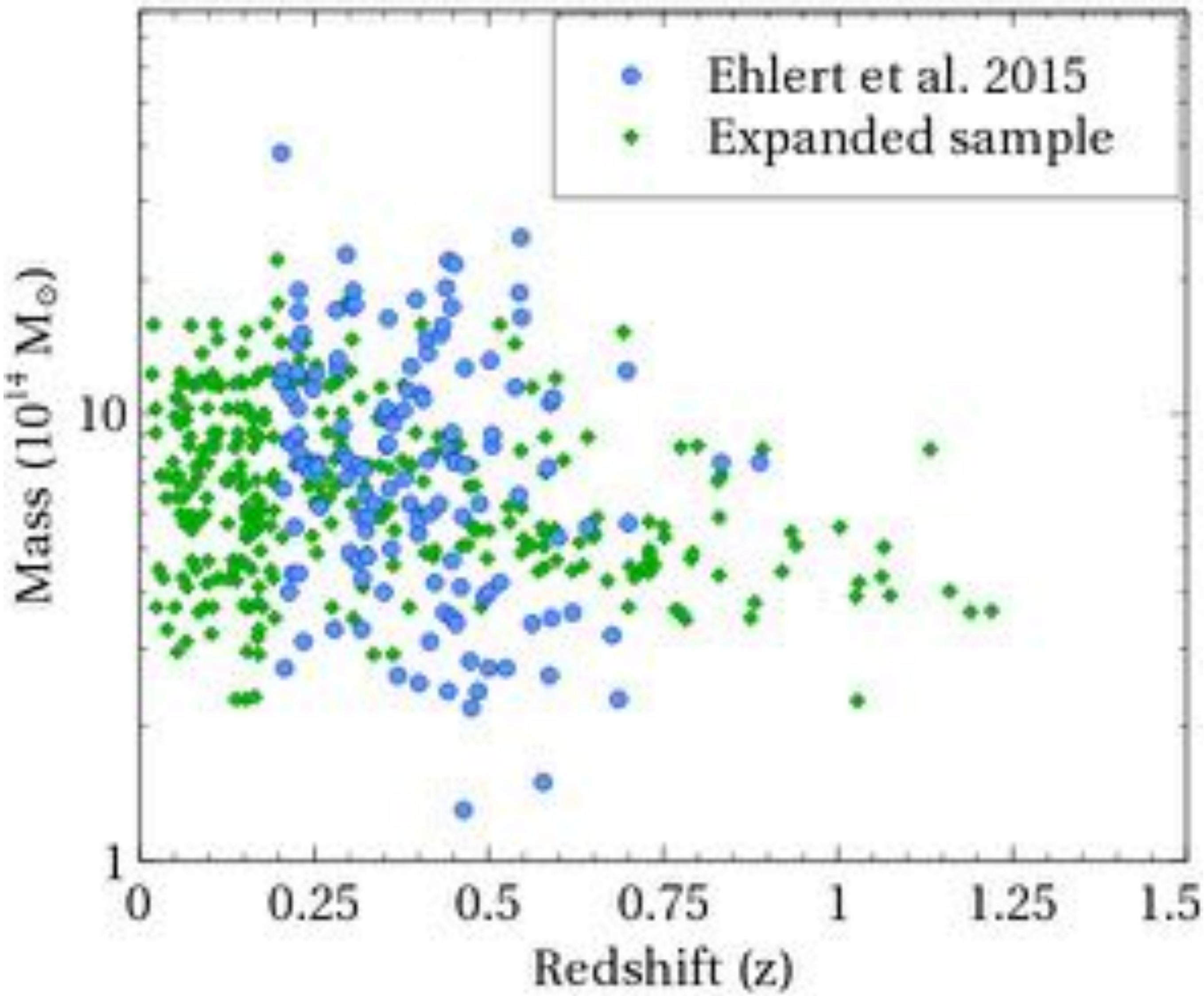
No evidence for evolution of radial scaling - so process occurs on same length scales irrespective of mass

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).

Ehlert et al. 2015

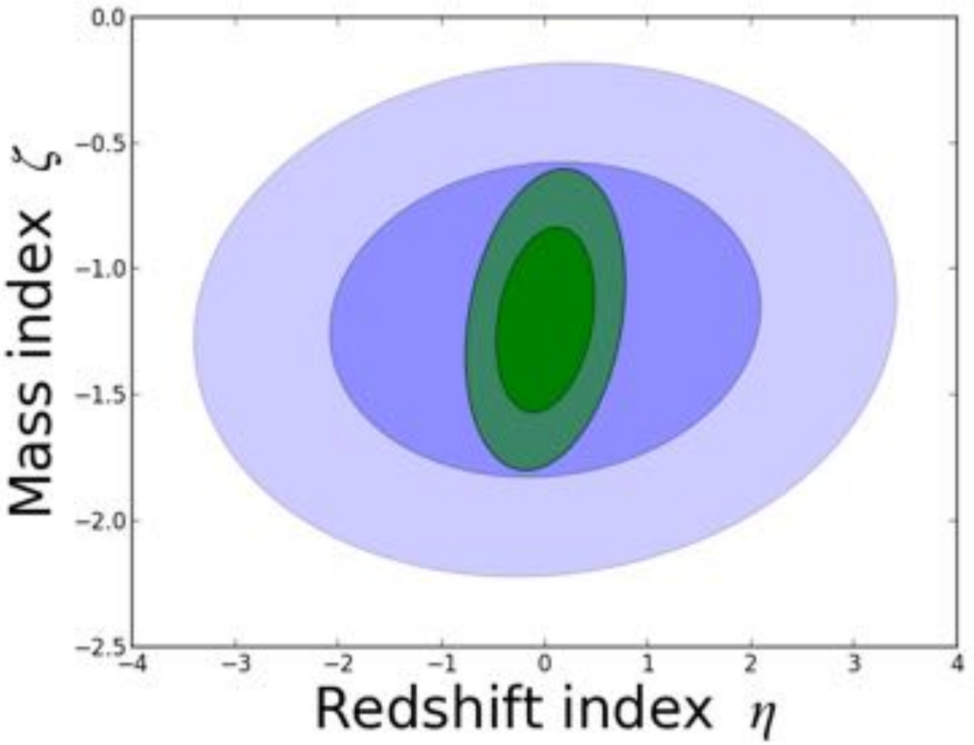
X-ray - 2nd generation

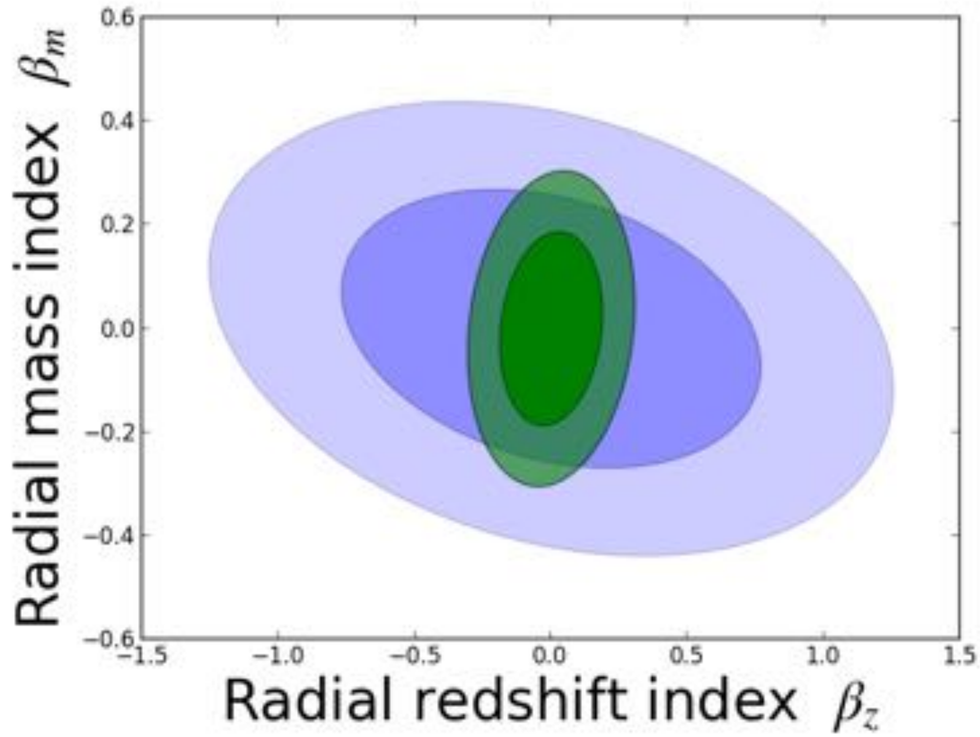


- 480 clusters.
- Depth >10ks.
- Total exposure = 25.7 Ms.
- Total Area = ~40 degrees^2

X-ray - 2nd generation

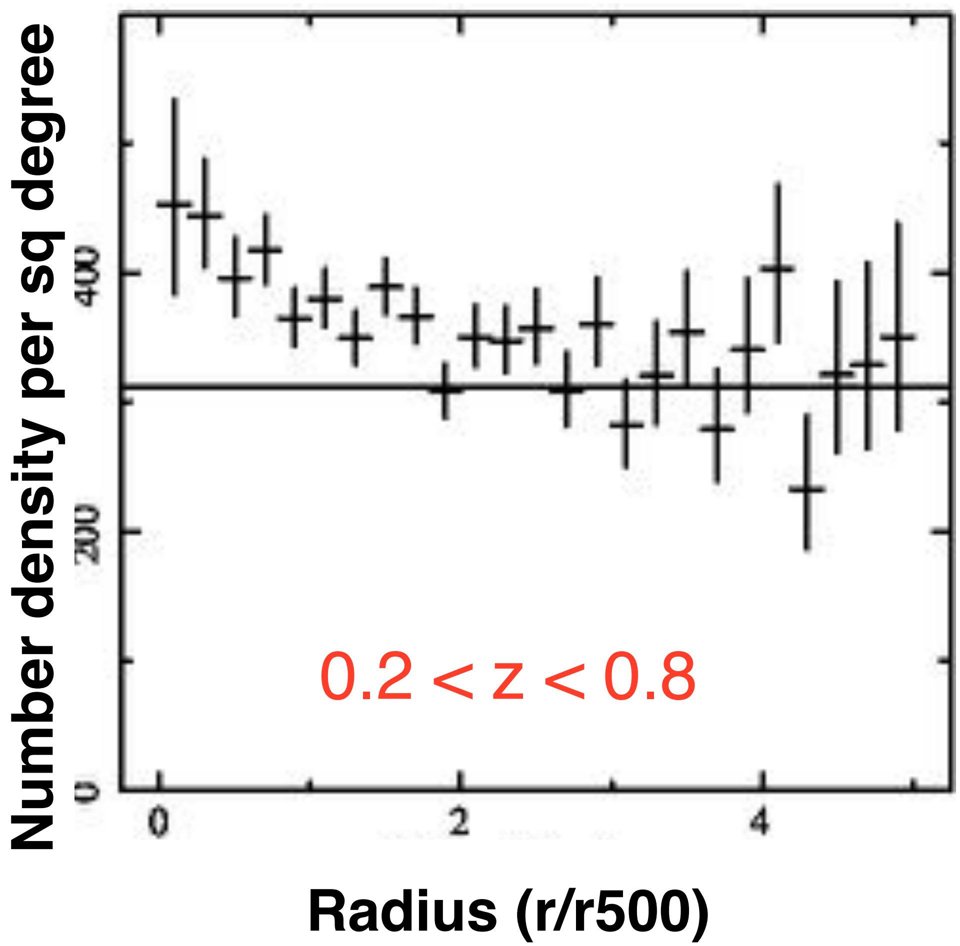
Forecast results for 2nd generation of 480 galaxy cluster:

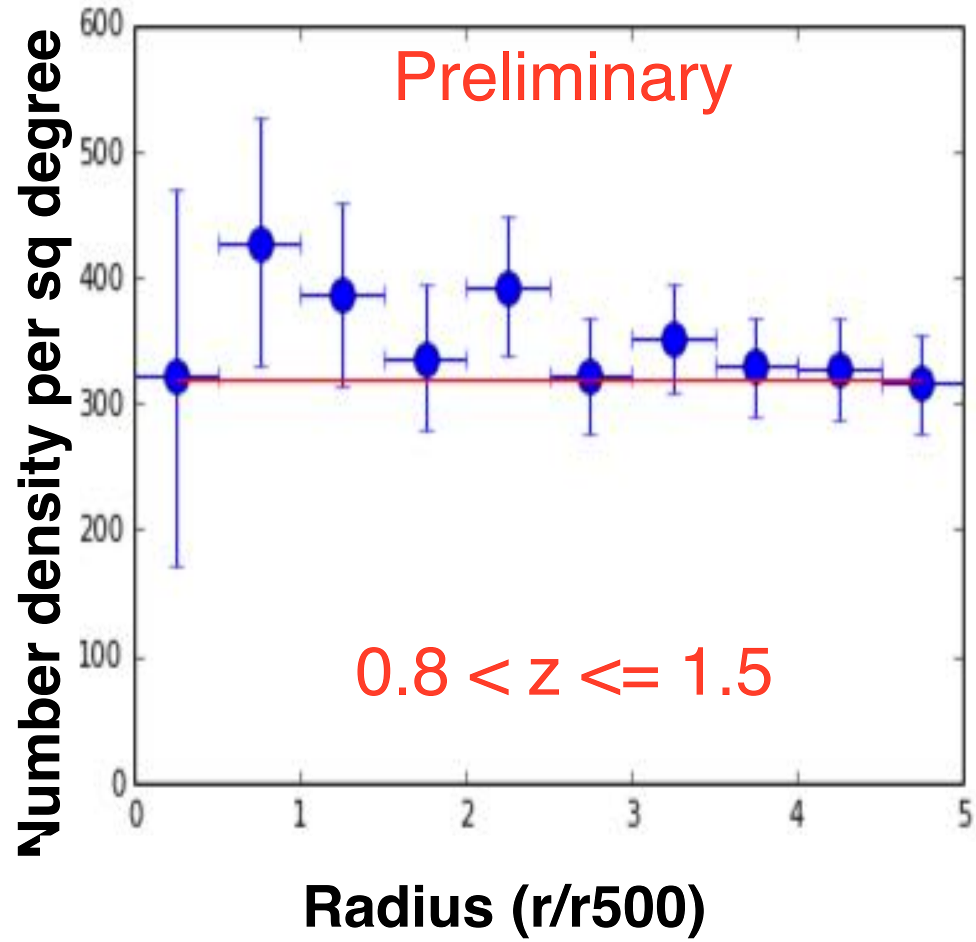




Factor 4 better in redshift evolution; factor 2 better in variation with host galaxy cluster mass (watch out for results in early 2017).

X-ray - 2nd generation





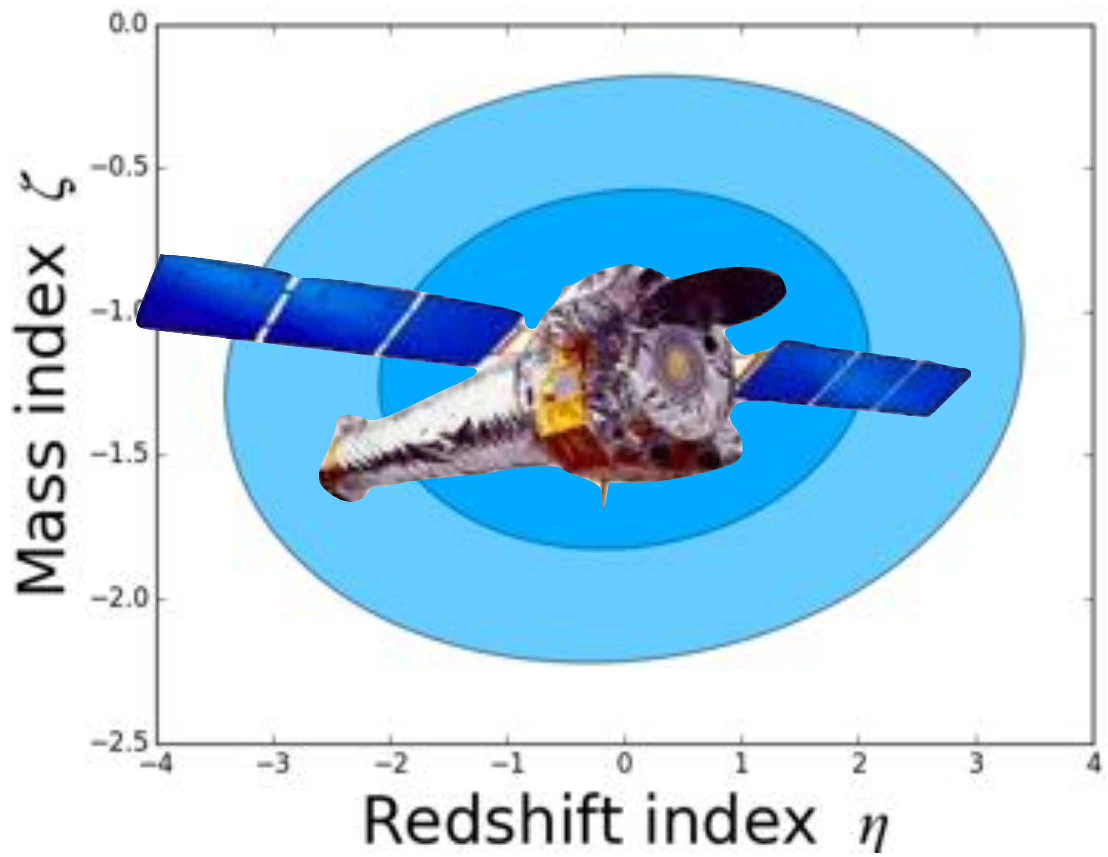
Similar increase - no evidence for extreme evolution beyond that of the field in our ~20 z > 0.8 clusters

Canning et al. in prep

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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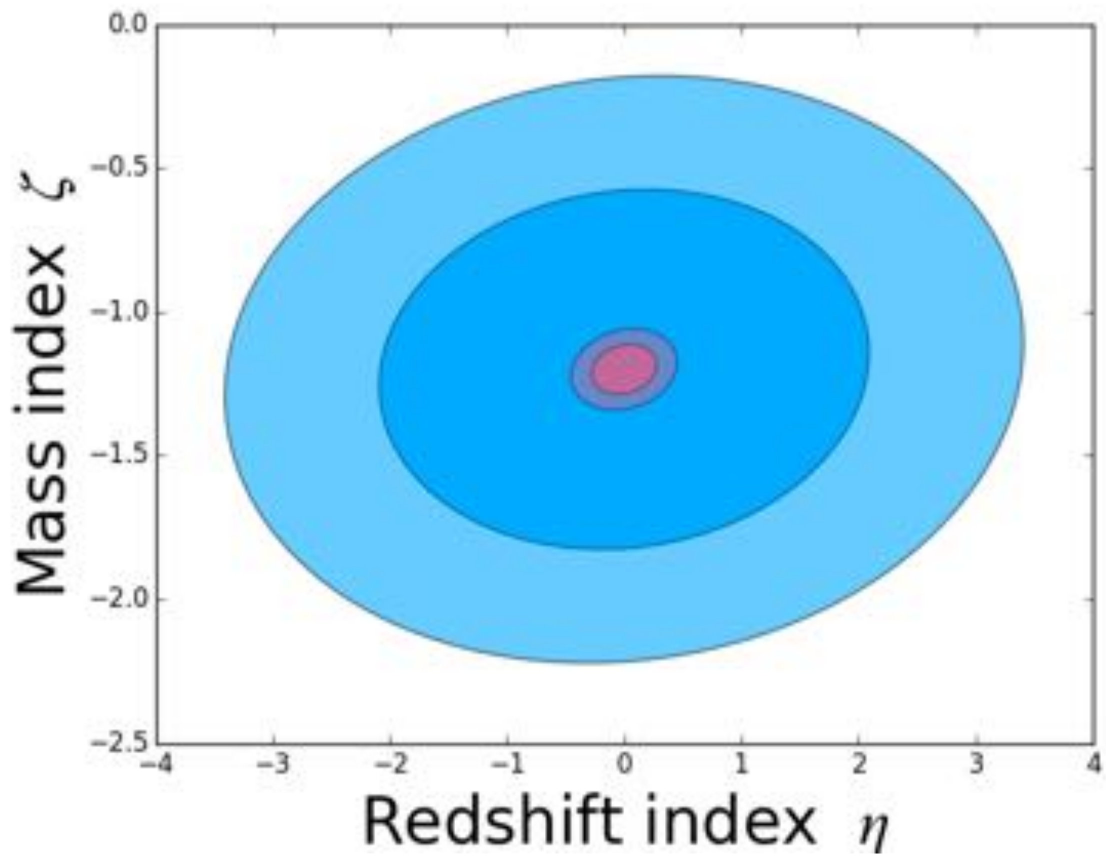

Naivest experiment ~factor 10 better constraints than Chandra

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:

- Challenges of studying AGN in clusters can be mitigated by modeling ensemble together but *crucially depends on robust cluster masses, redshifts, centers* and on a *rigorous understanding of the AGN selection function* in each cluster field and across the field-of-view.

- The fraction of X-ray bright AGN declines towards the center of the cluster.
- The number density of X-ray AGN has an inverse dependence with the host galaxy cluster mass.

- Results consistent with mergers being responsible for AGN triggering in clusters - 2nd generation CATS will test this further as well as comparing the evolution of X-ray, radio and IR AGN and AGN fractions as a function of host galaxy properties.

Combination of next generation X-ray and Optical/IR telescopes will make huge strides in this field.