AGN in massive galaxy clusters: Cluster AGN Topography Survey (CATS)

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

Overview

Virgo

1. AGN in clusters: Big picture

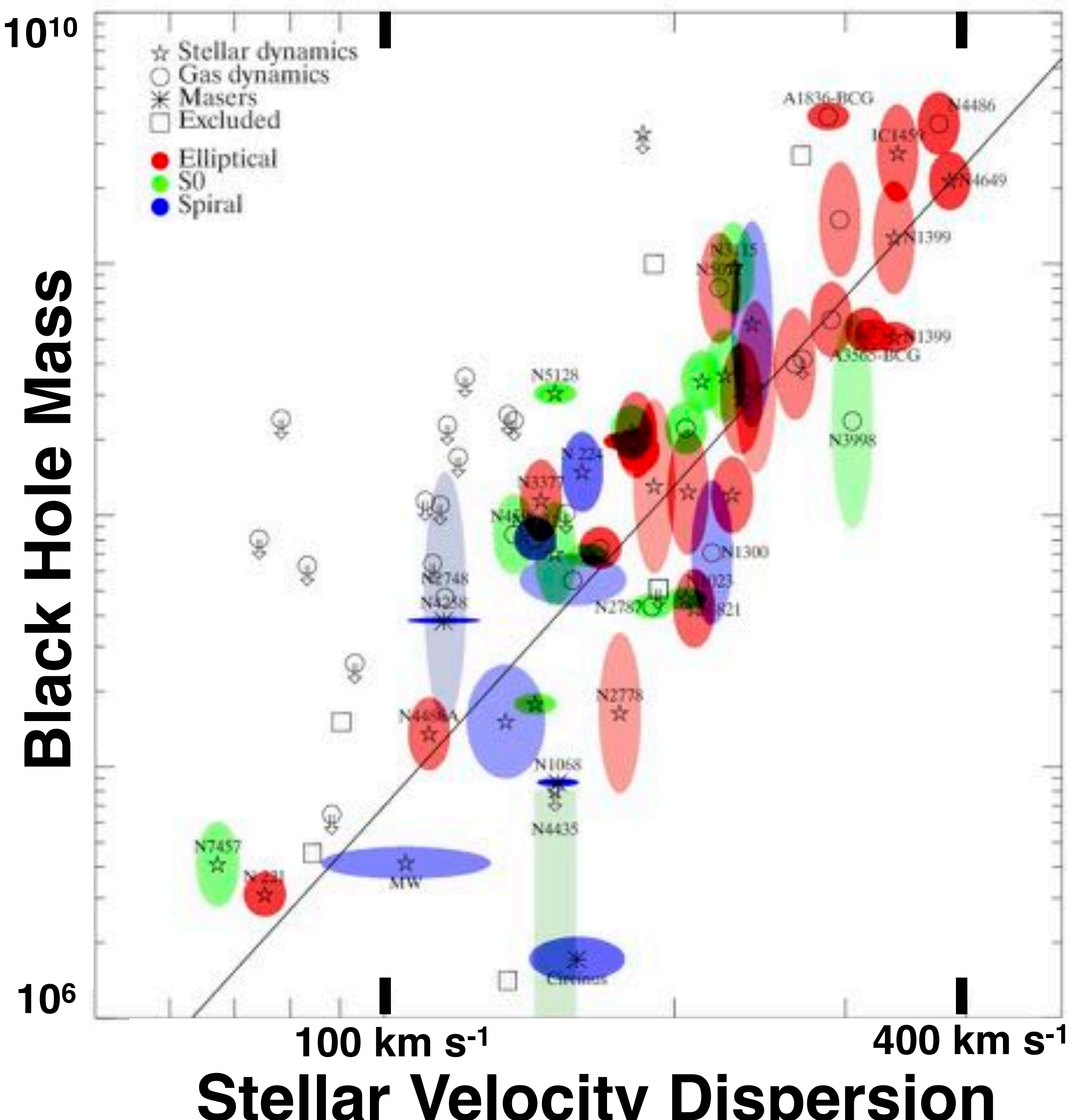
2. CATS: Cluster AGN Topography Survey

3. Current and ongoing results

4. Future

How/Do AGN influence galaxy evolution?

Gultekin et al. 2009

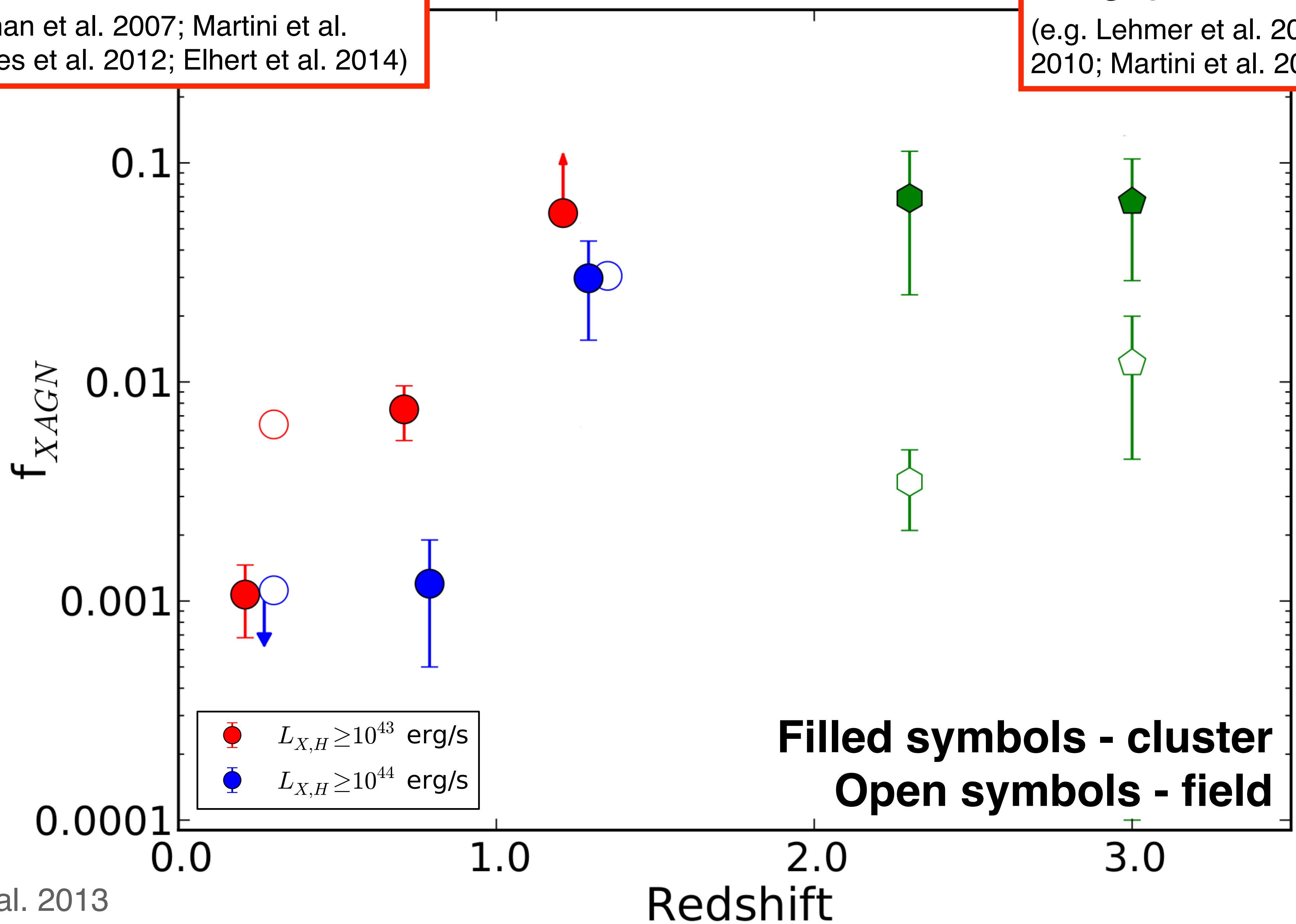


NASA/CXC/Werner et al. 2010

How/Do AGN influence galaxy evolution?

Low z: Luminous AGN fraction in clusters lower than field.
(e.g. Eastman et al. 2007; Martini et al. 2009; Haines et al. 2012; Elhert et al. 2014)

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

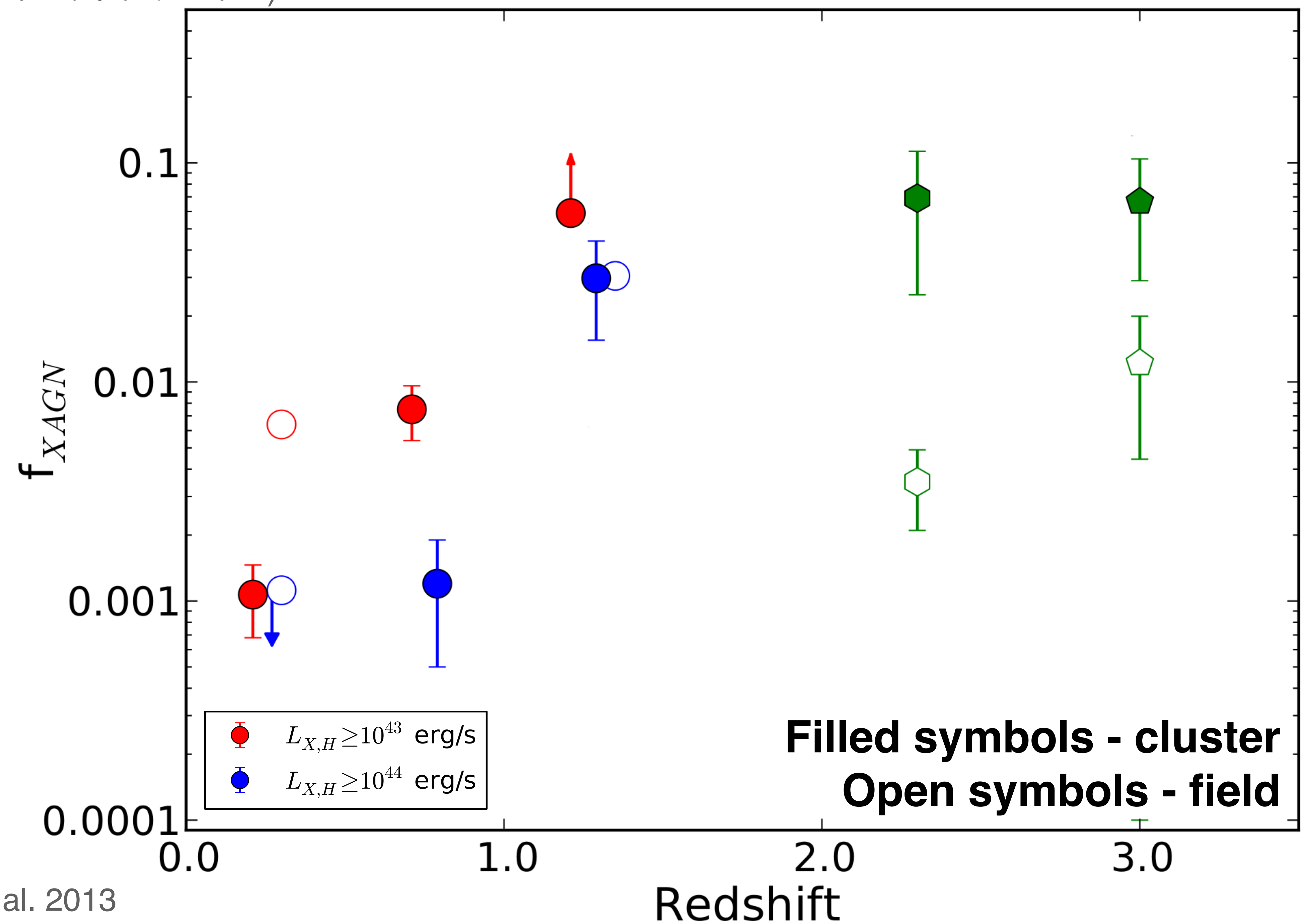


Martini et al. 2013

How/Do AGN influence galaxy evolution?

But… Dependence with cluster mass & radii, AGN luminosity, and 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 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

Noordeh et al. in prep

But…

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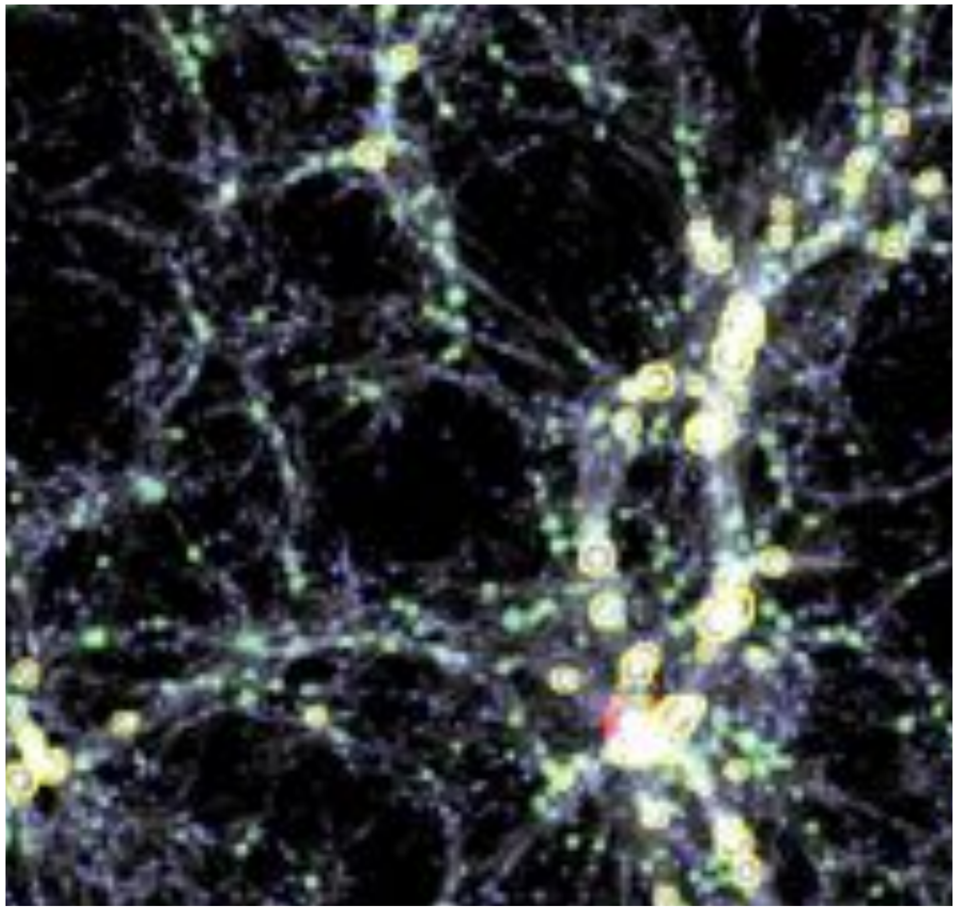
AGN in clusters - Challenges



- 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

But…

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

- 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

AGN in clusters - Solutions

1) Pointed X-ray observations of clusters

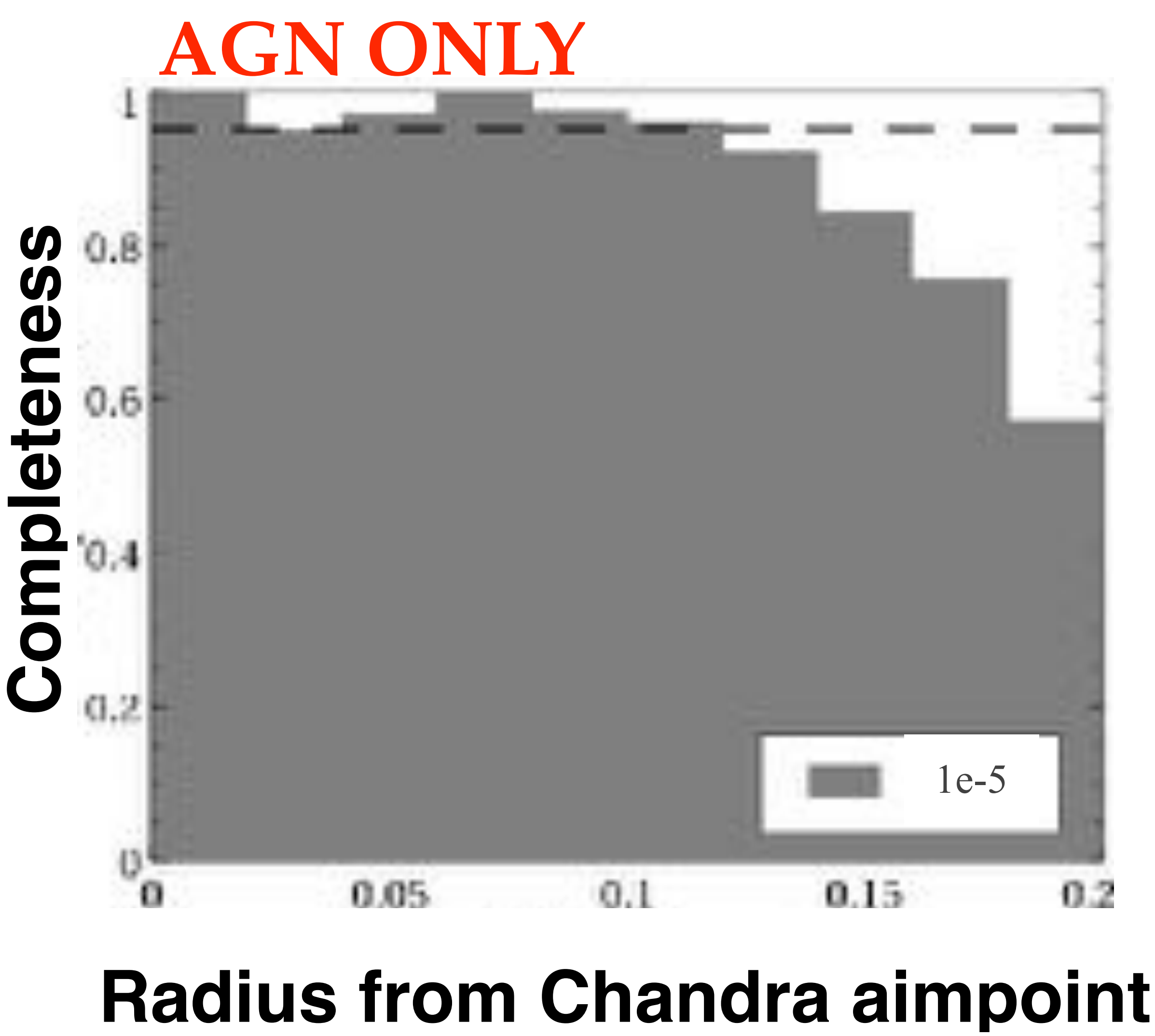
Good for AGN detection and for cluster properties.

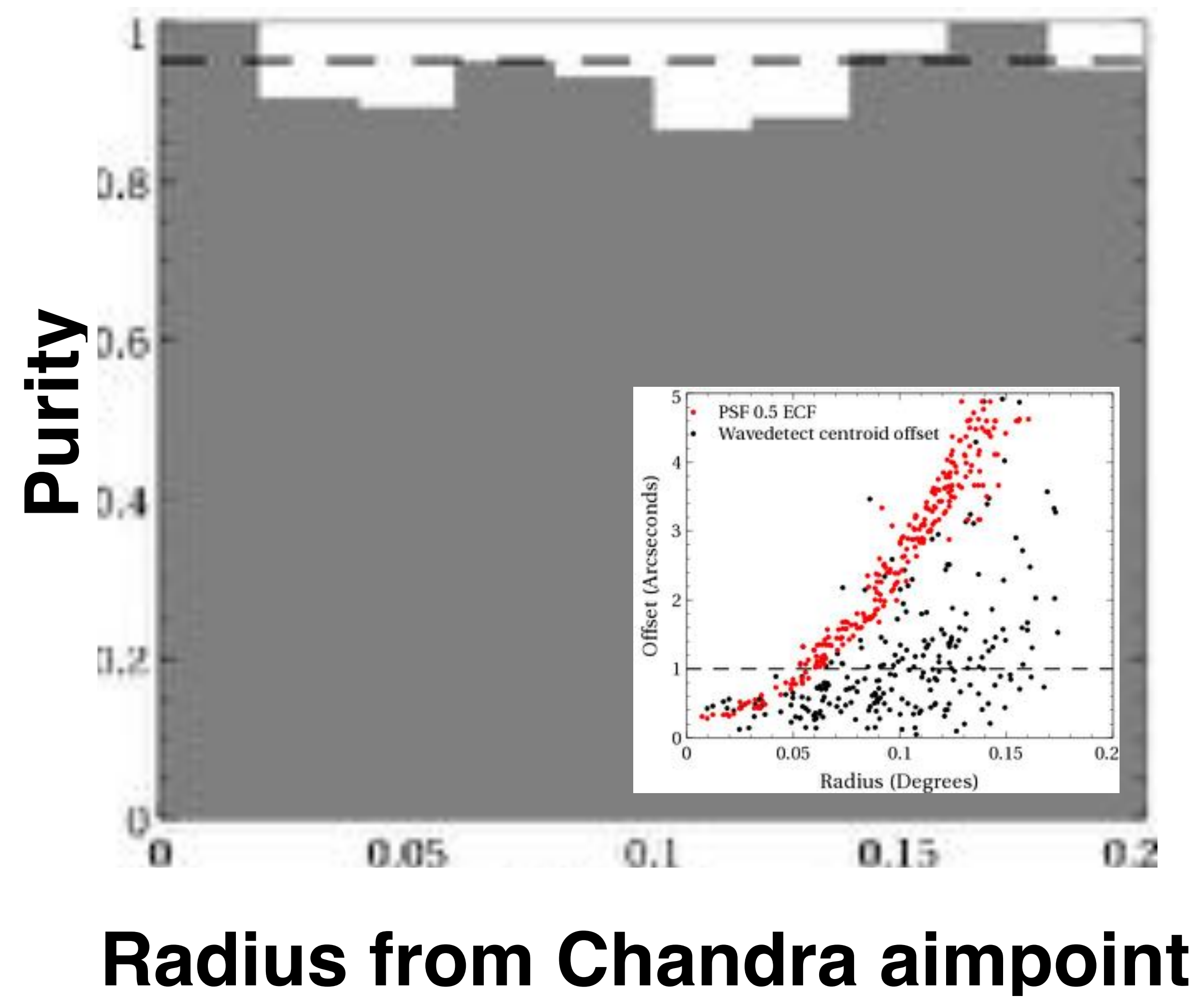
Chandra PSF
v's radius

AGN in clusters - Solutions

1) Pointed X-ray observations of clusters

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





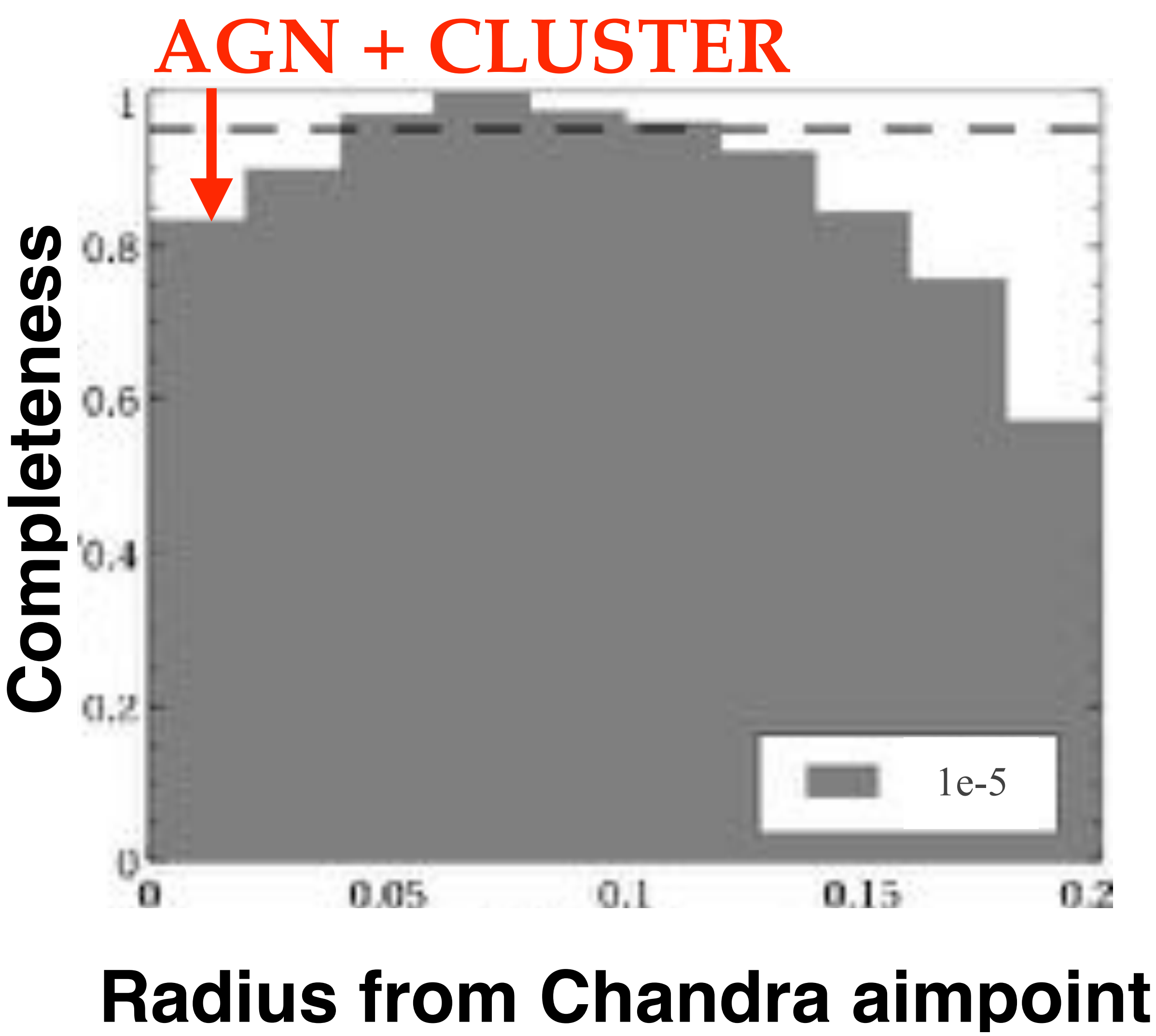
AGN in clusters - Solutions

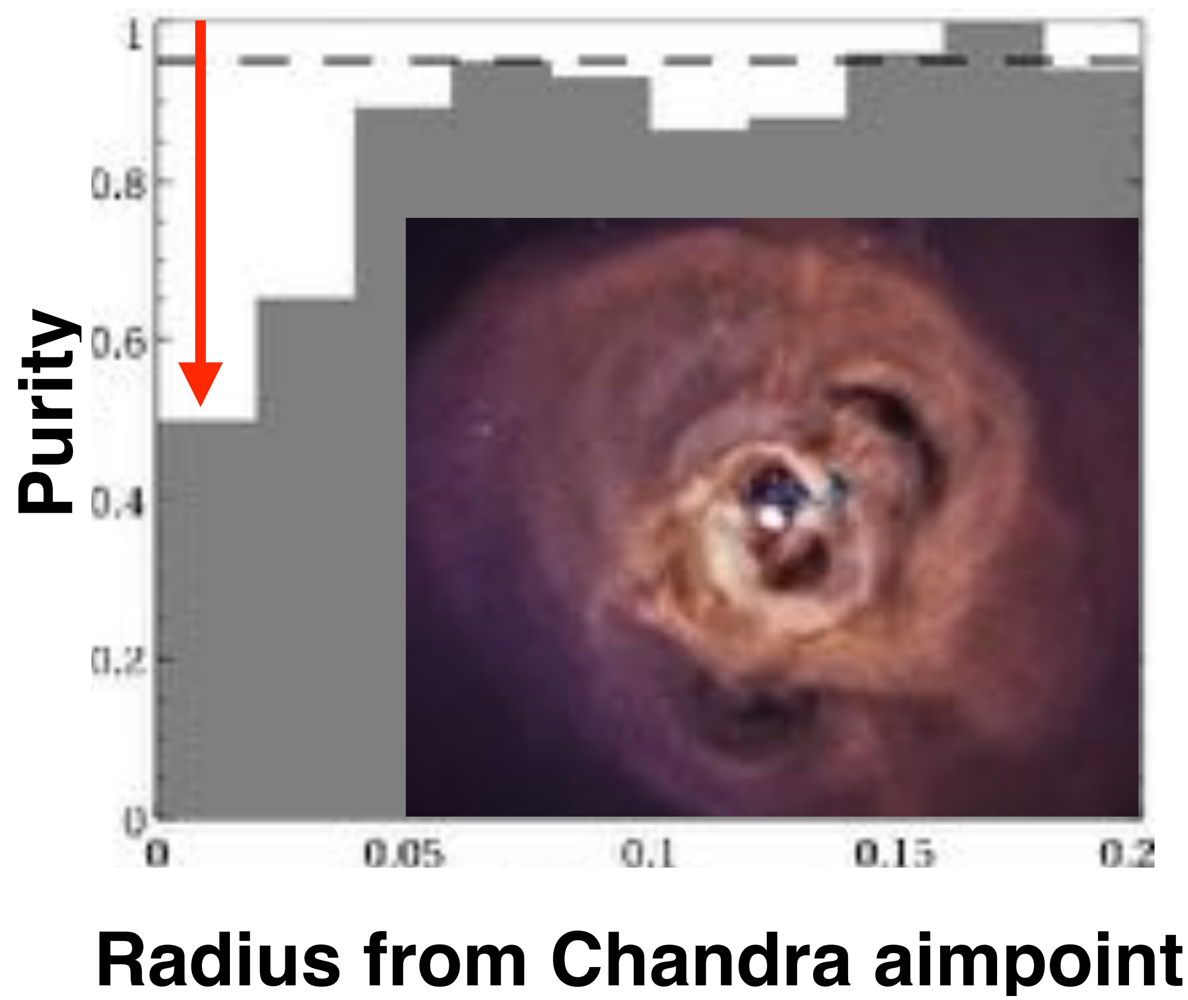
1) Pointed X-ray observations of clusters

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.





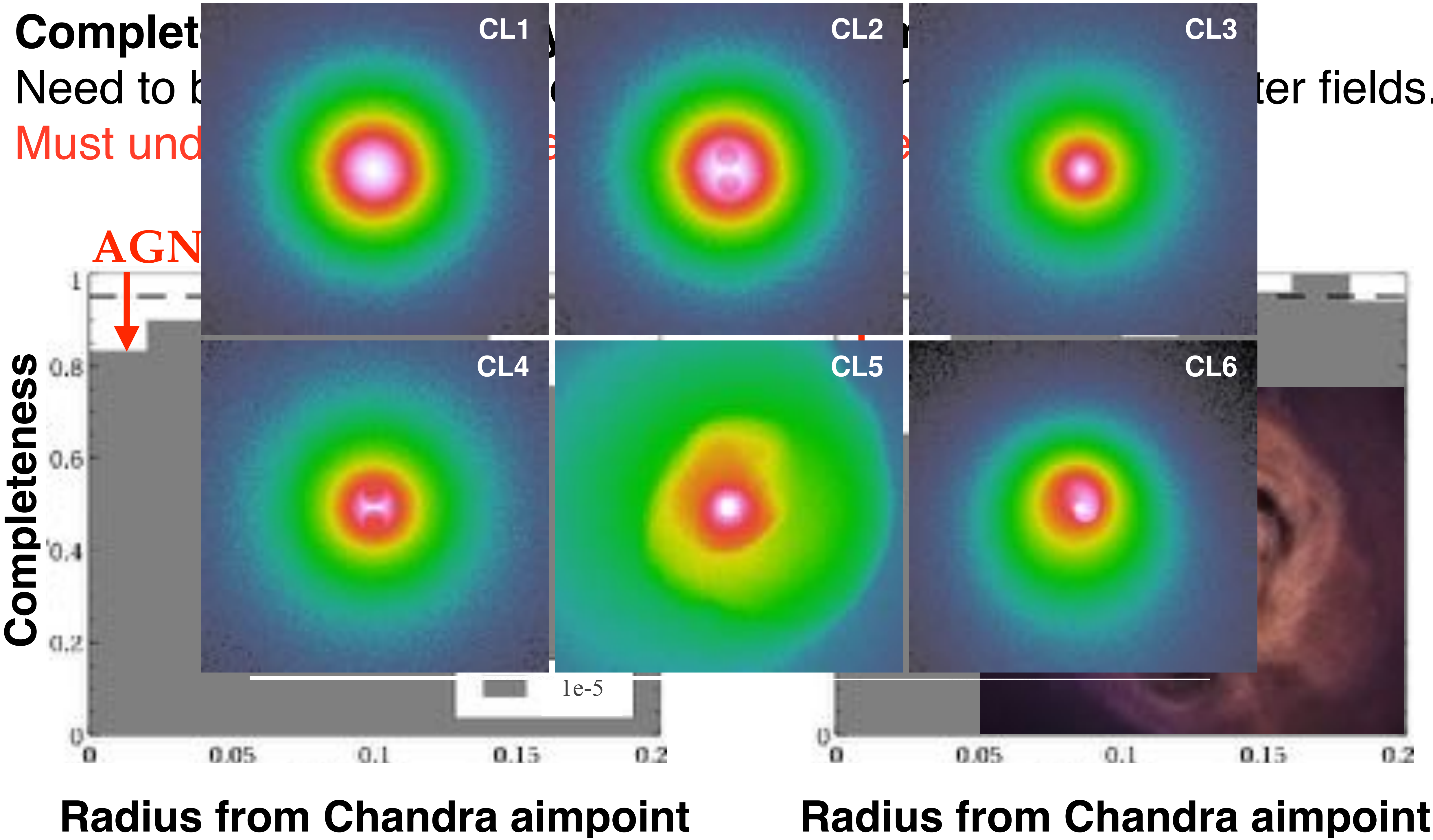
AGN in clusters - Solutions

1) Pointed X-ray observations of clusters

Complet

Need to b ter fields.

Must und



AGN in clusters - Solutions

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

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X-ray AGN
Radio AGN - A King
IR AGN - M Brodwin + his team
Optical spectroscopy - E Norrdeh

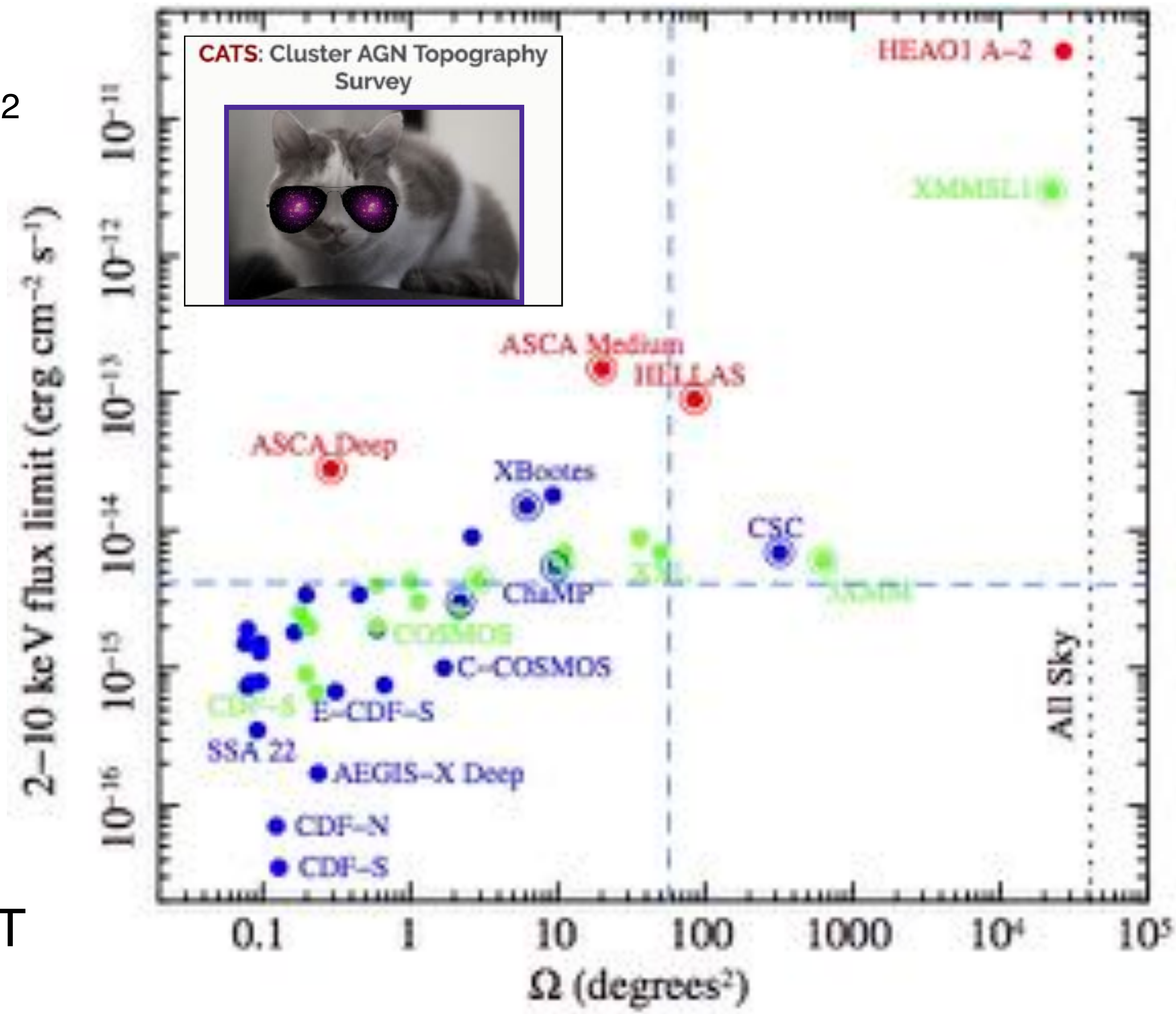
Ehlert et al. 2015

CATS - Cluster AGN Topography Survey

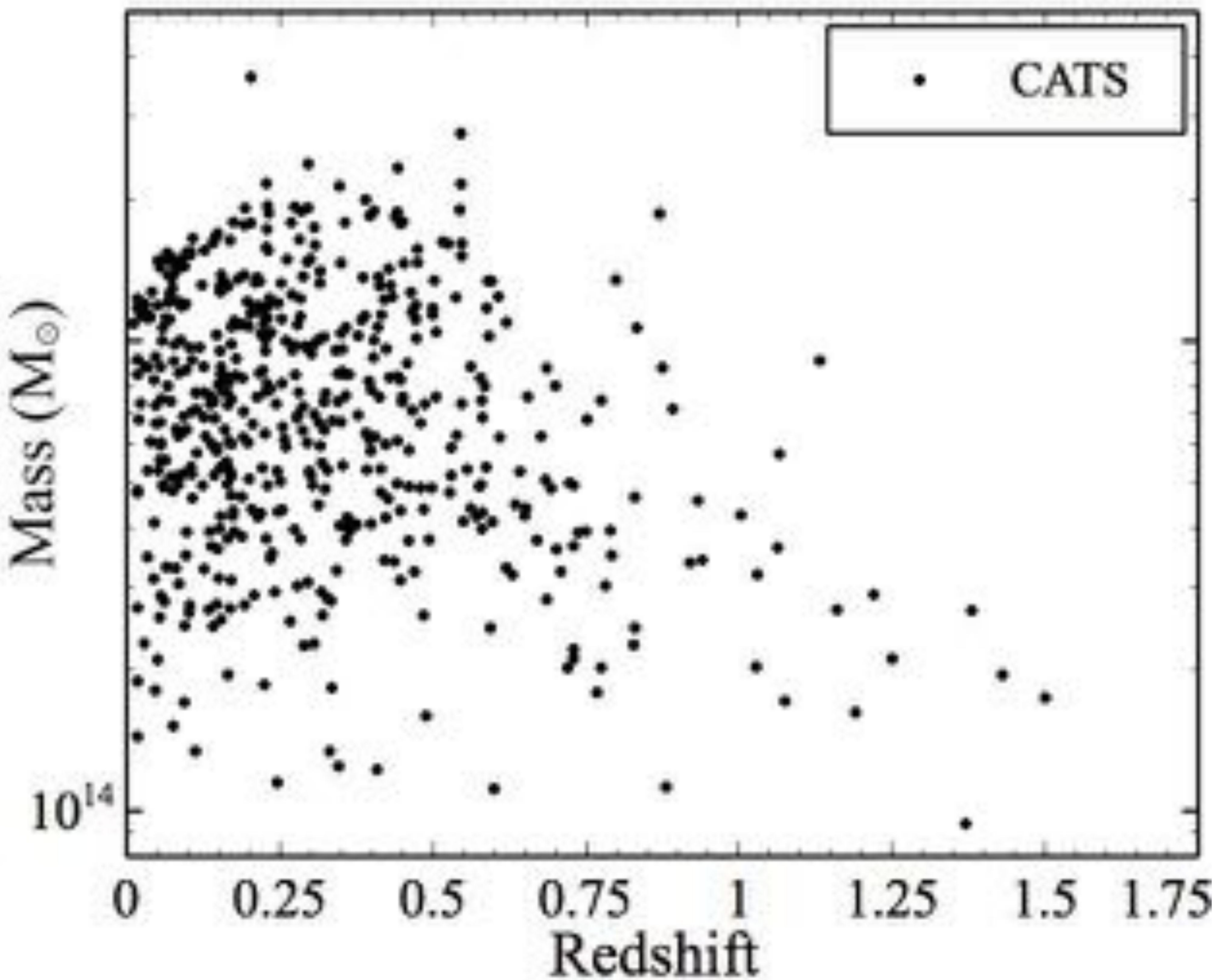
> 650 clusters.
Total Area >40 degrees²

X-ray
- Depth > 10ks of Chandra.
- Total exposure = 25.7 Ms (so far).

Radio
- $S_{1.4GHz}$ > 3mJy
- Only Radio-loud AGN and avoid star formation contribution
- ~100 clusters in FIRST + 20 or our own



CATS



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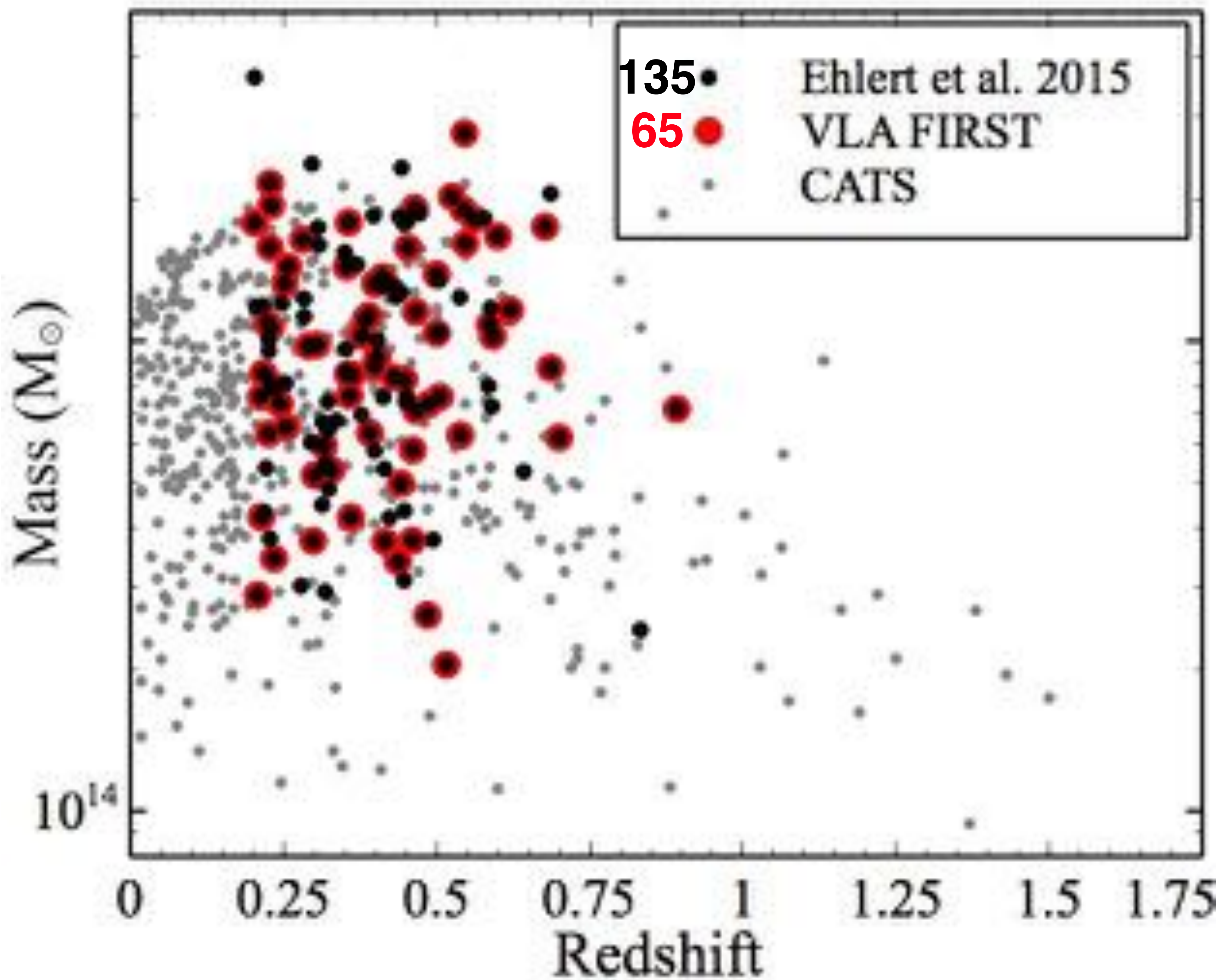
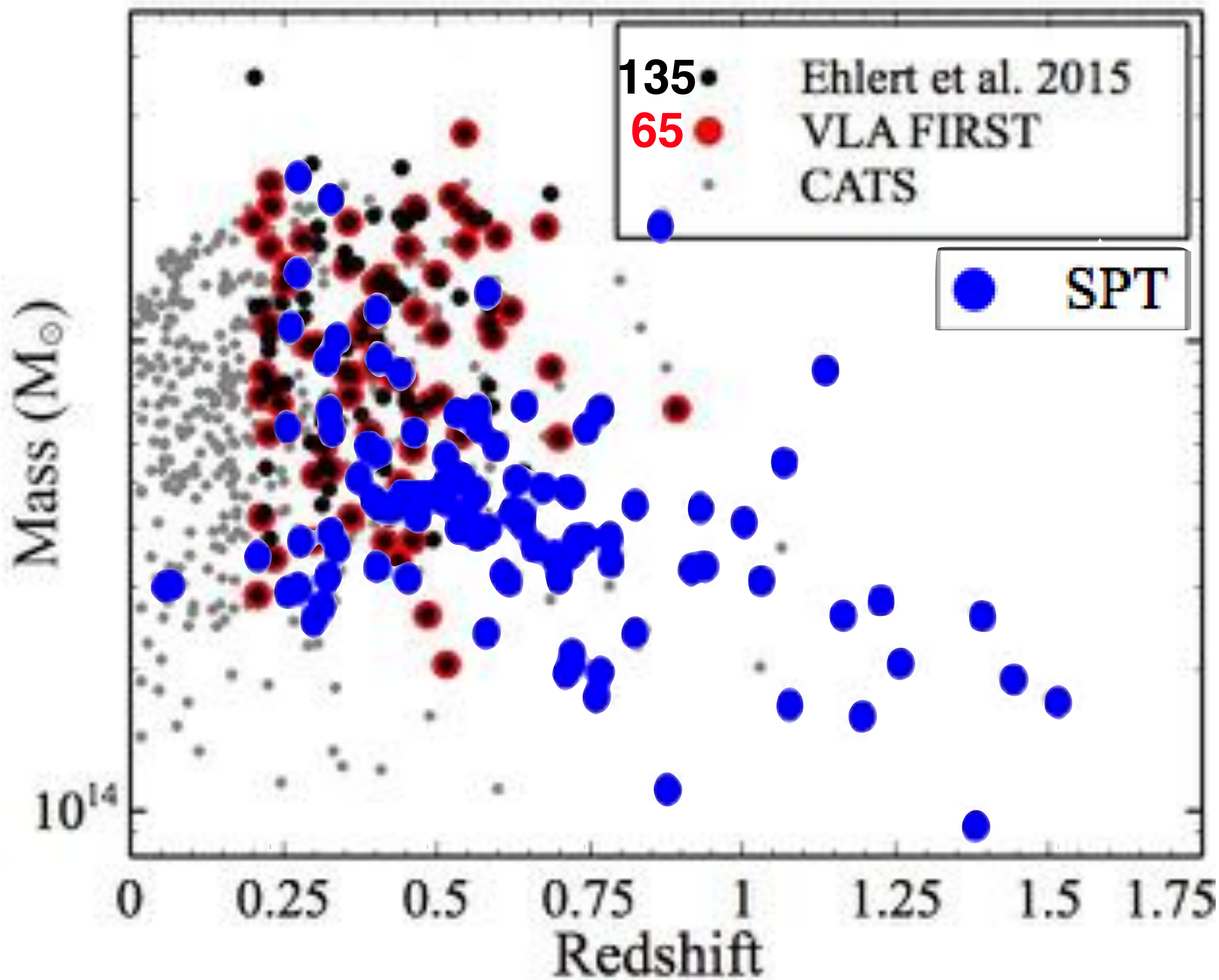

135
65
Ehlert et al. 2015
VLA FIRST
CATS
Mass ($M_\odot$)
10^{14}
0
0.25
0.5
0.75
1
1.25
1.5
1.75
Redshift

CATS



135
Ehlert et al. 2015
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SPT
Mass (M☉)
10^{14}
0
0.25
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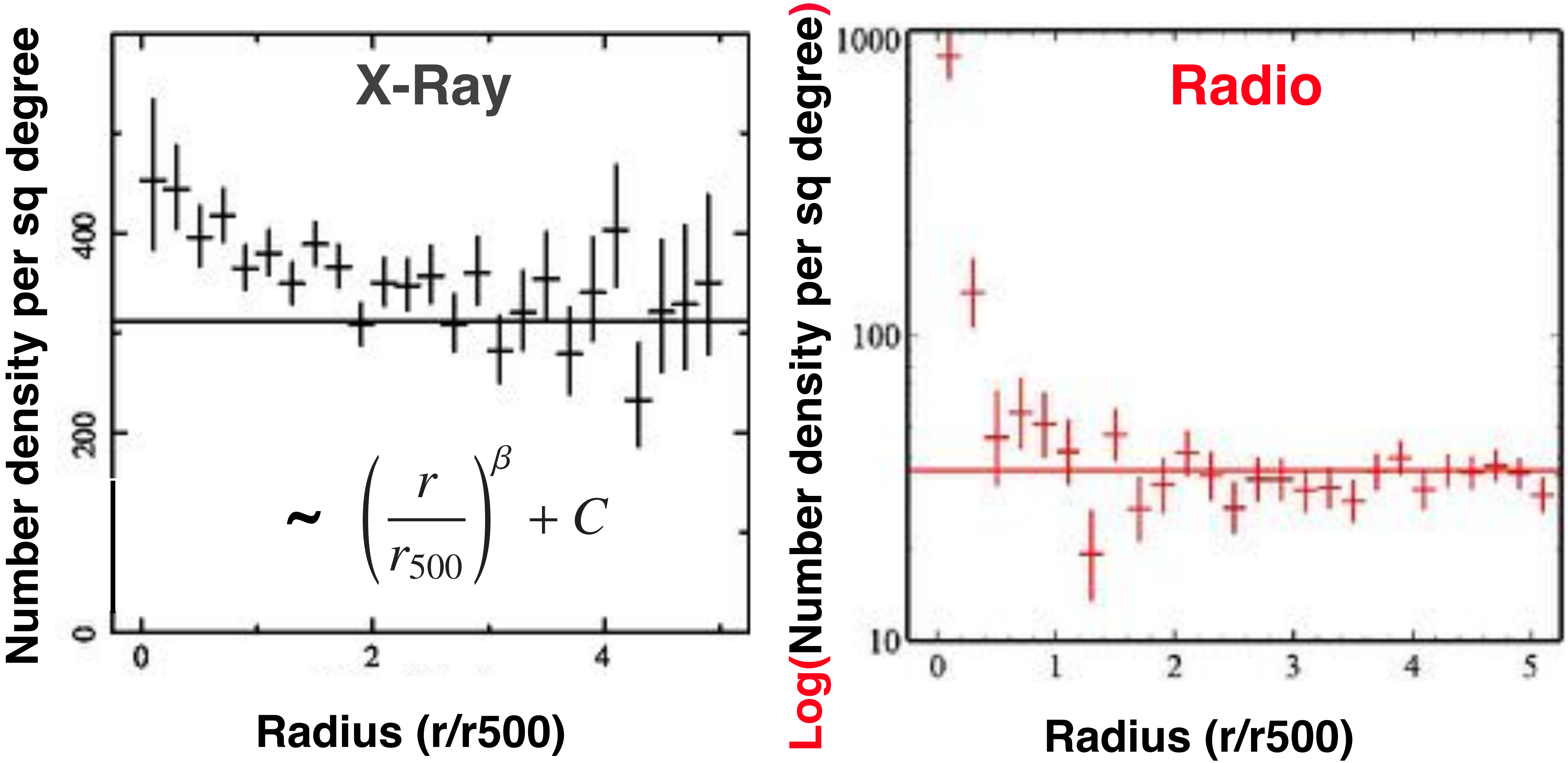
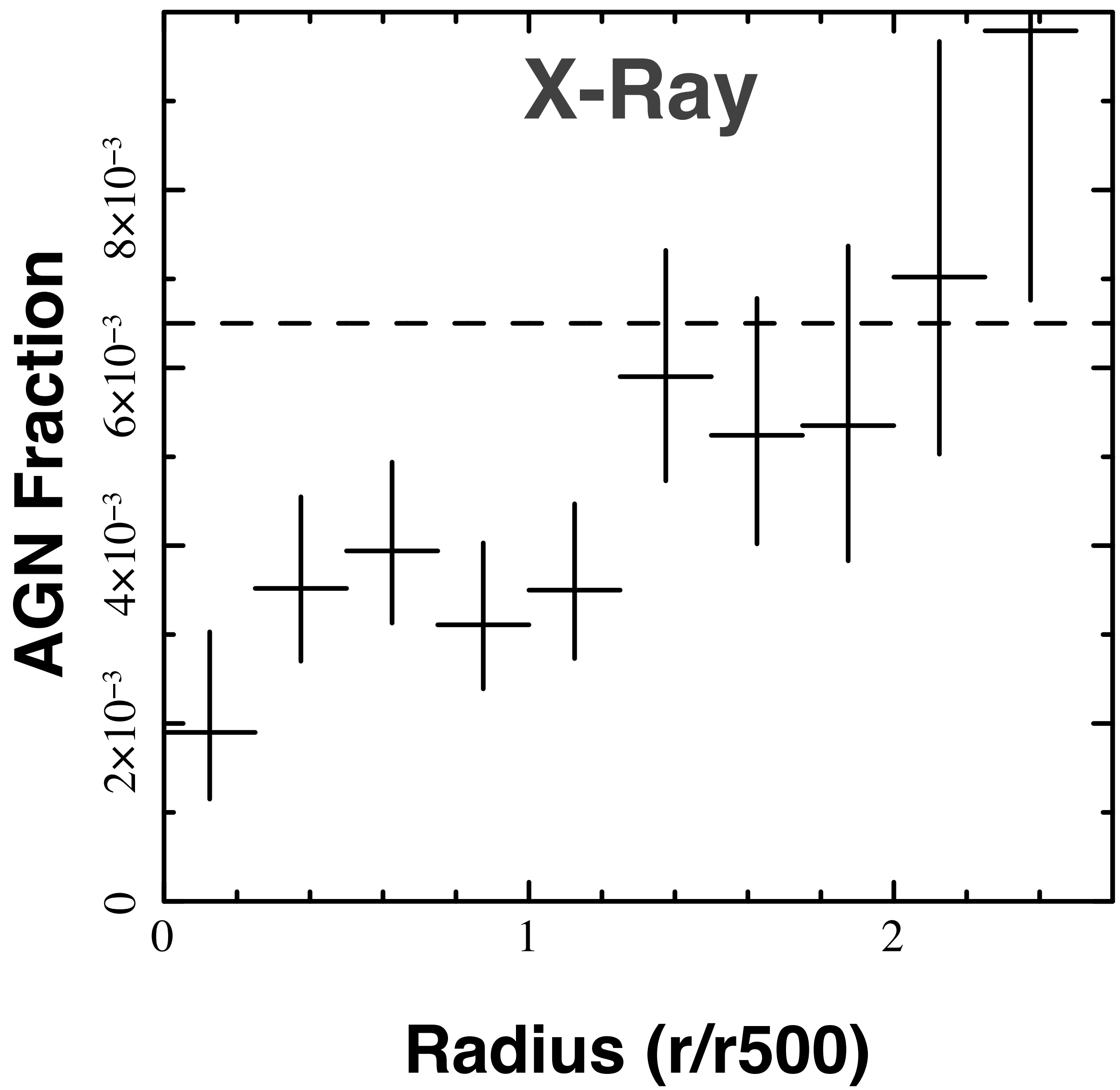
AGN Number Density

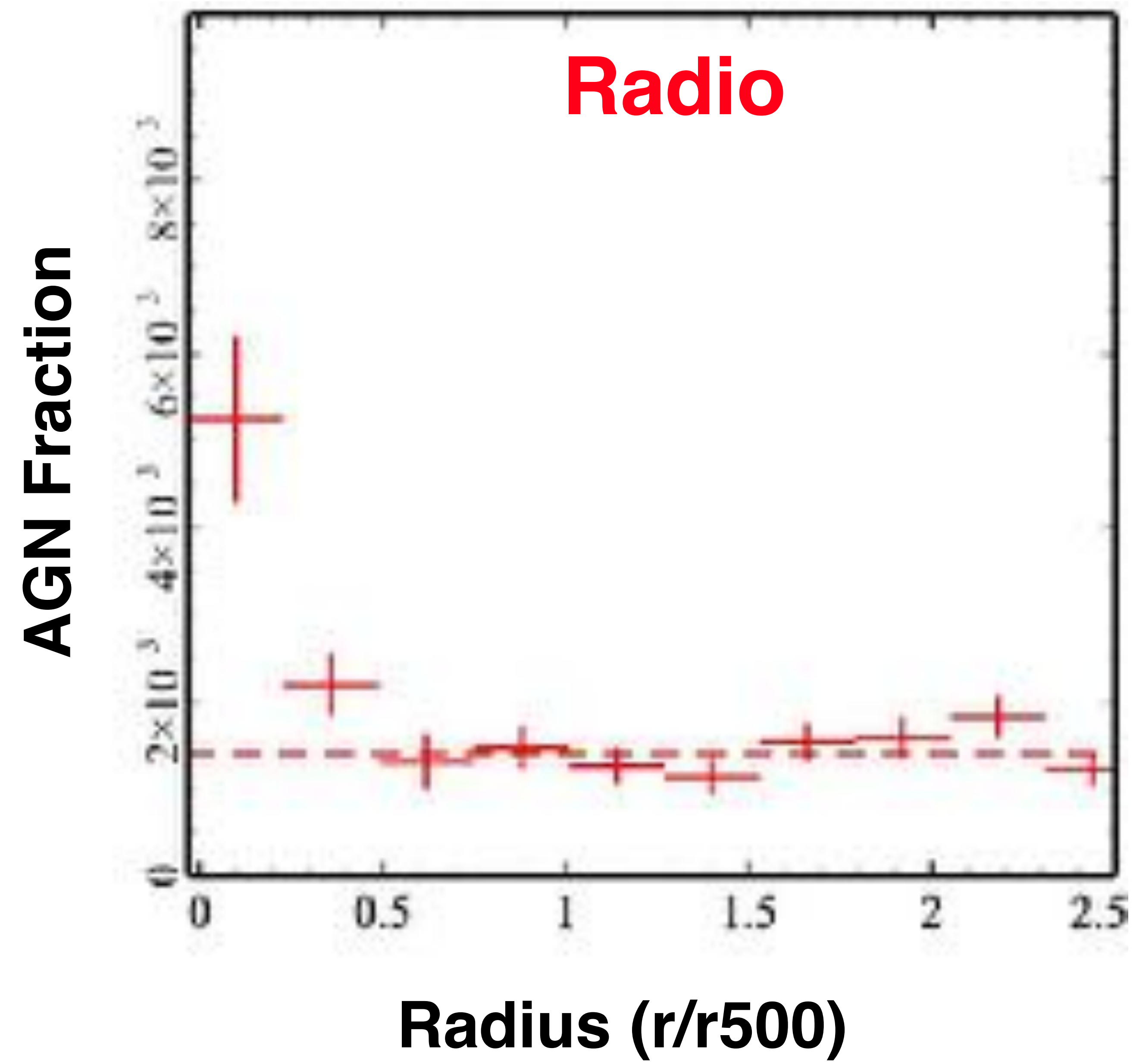


Projected number density of AGN increases towards the cluster centre.

Ehlert et al. 2012, 2014, King et al. in prep

AGN Fraction





X-ray AGN fraction decreases towards the cluster centre while the radio AGN fraction increases.

Ehlert et al. 2012, 2014, King et al. in prep

Model

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

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

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

Ehlert et al. 2015

Model

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

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

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

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

$$\beta \rightarrow \beta_0 + \beta_z (1+z) + \beta_m \left(\frac{M_{500}}{10^{15} M_{\odot}} \right)$$

Ehlert et al. 2015

Model

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

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

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

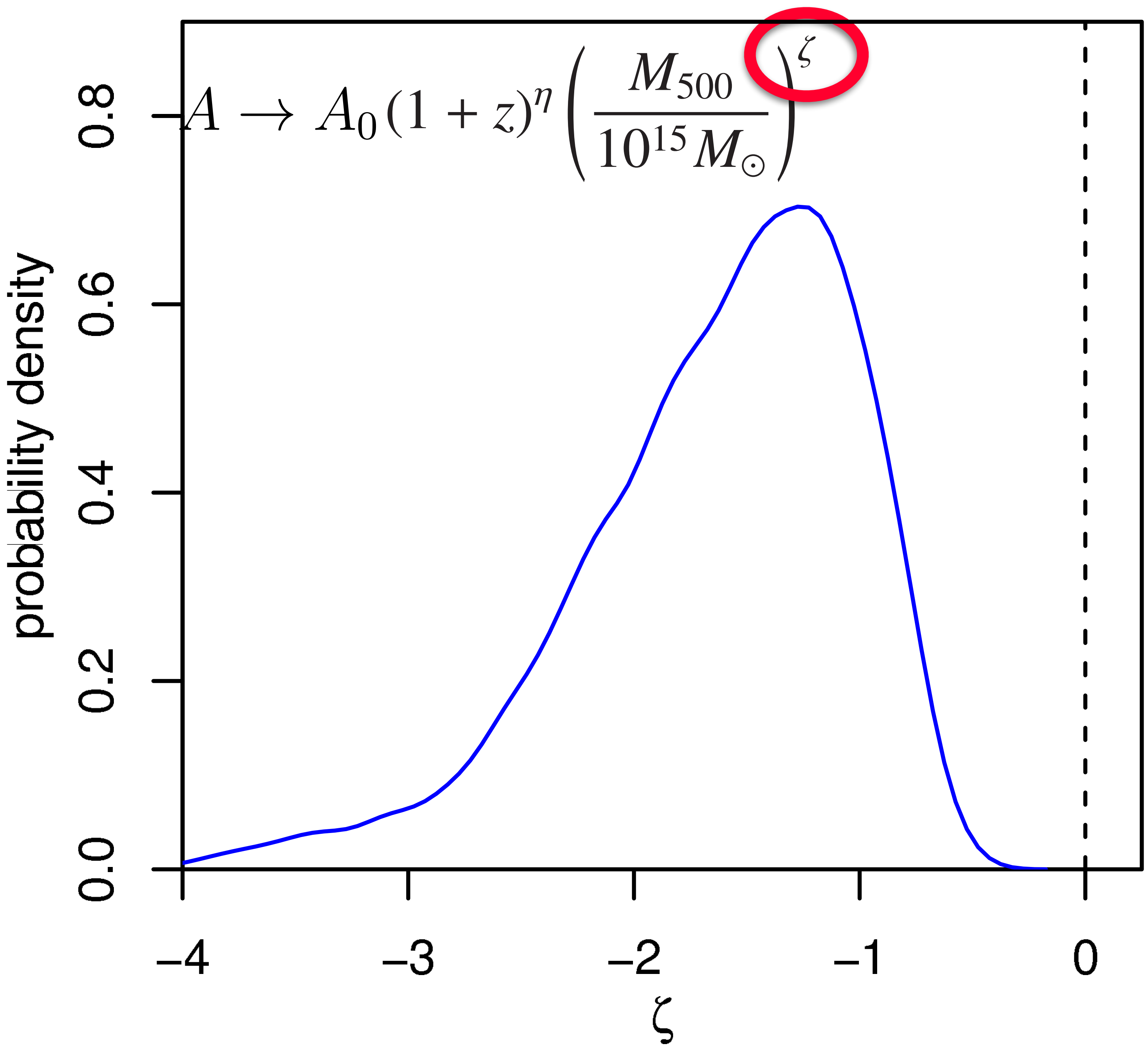
'Scale factor' which allows number density to exceed co-moving field AGN X Scaled by radius X Co-moving field AGN number density at z and above luminosity related to flux limit X Some radial dependence

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

Ehlert et al. 2015

1st generation X-ray results

No evolution beyond the field X-ray AGN population with redshift.
No radial variation. But…



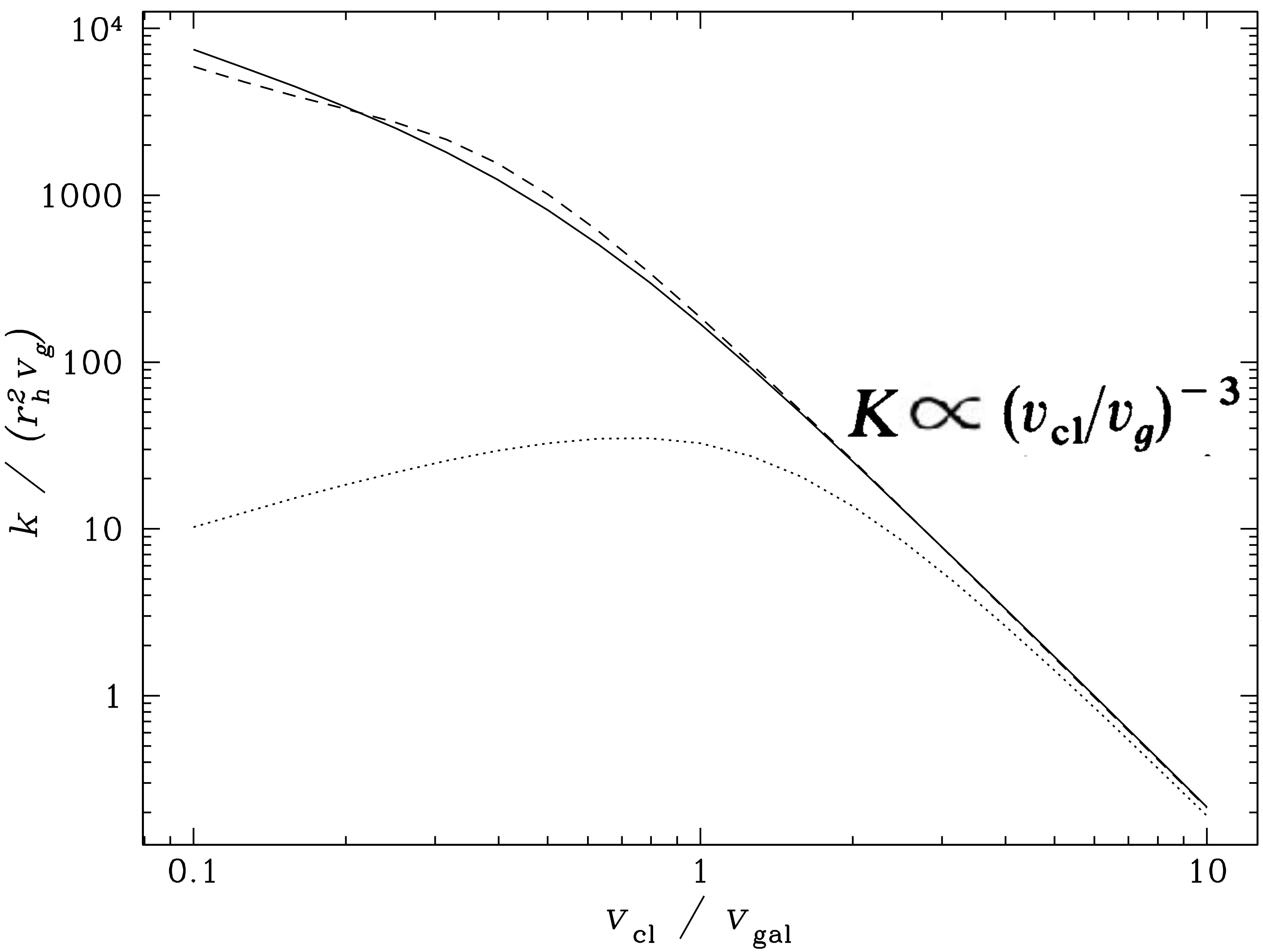
Observed mass scaling $\zeta = -1.2$

$\zeta = 0$ rejected at > 99.9%

Ehlert et al. 2015

1st generation X-ray results

No evidence for evolution of radial scaling - process may occur on same length scales irrespective of mass



AGN triggering/suppression:

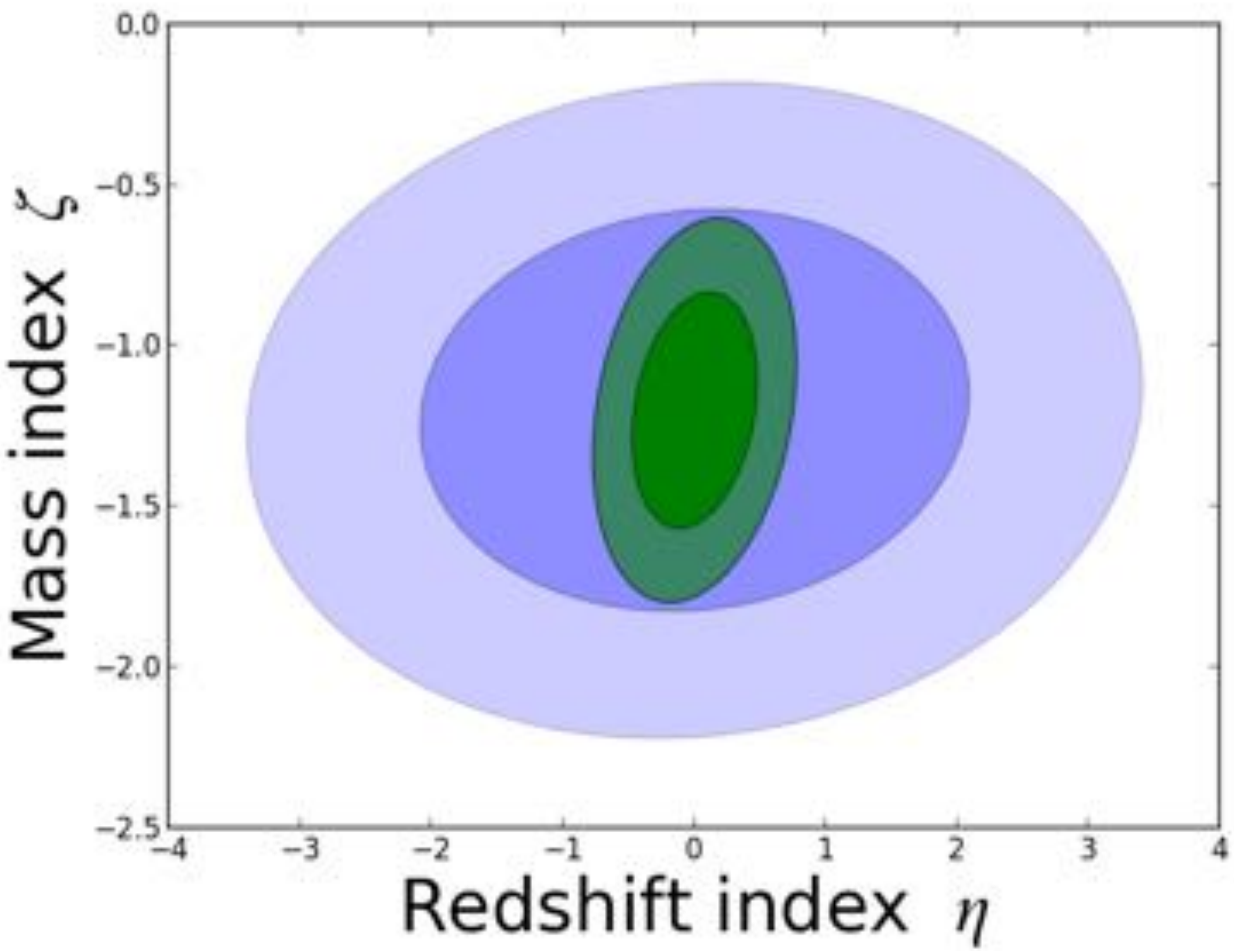
Mergers? Rate of galaxy mergers in massive clusters scales as $\sim M^{-1}$ (e.g. Mamon 1992)

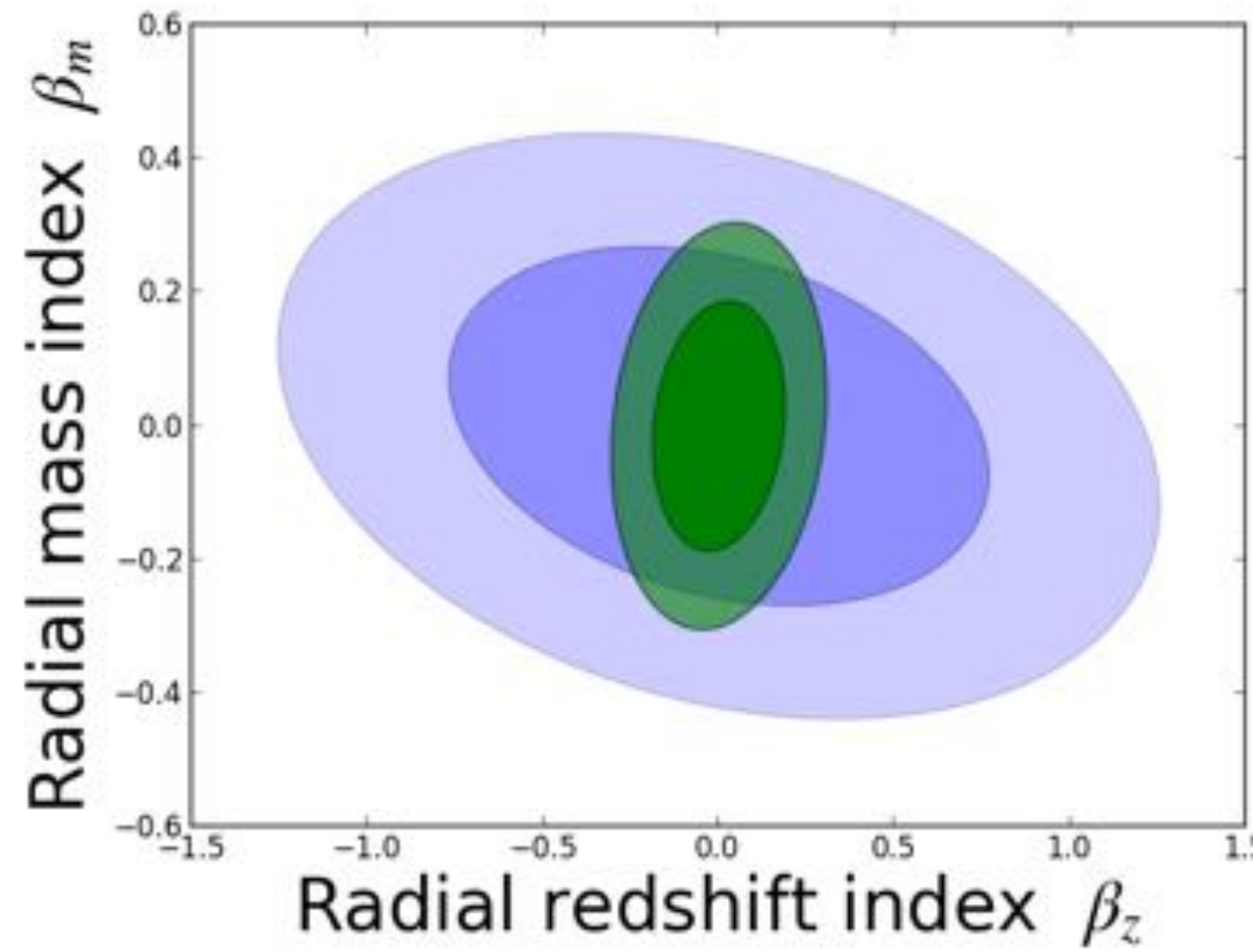
Ram pressure? Harassment? Strangulation?

May all lead to different radial and/or redshift profiles (e.g. Treu et al. 2003).

X-ray - 2nd generation

Forecast results for 2nd generation including SPT galaxy clusters:





Factor 4 better in redshift evolution; factor 2 better in variation with host galaxy cluster mass.

Canning et al. in prep

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 while Radio bright AGN increase.
- The number density of X-ray AGN has an inverse dependence with the host galaxy cluster mass (radio results soon).

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