AGN EVOLUTION IN THE UNIVERSE'S DENSEST ENVIRONMENTS

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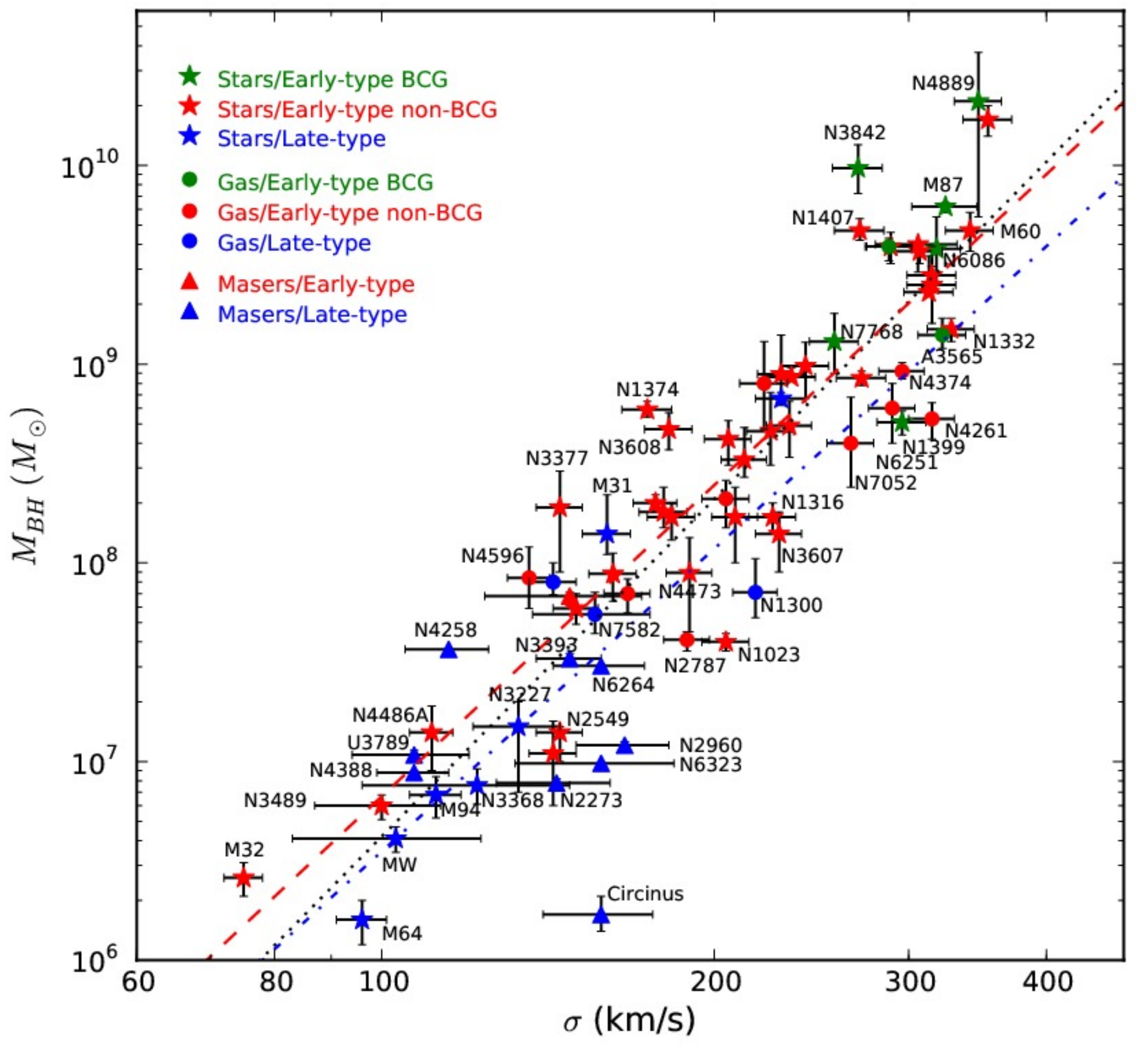
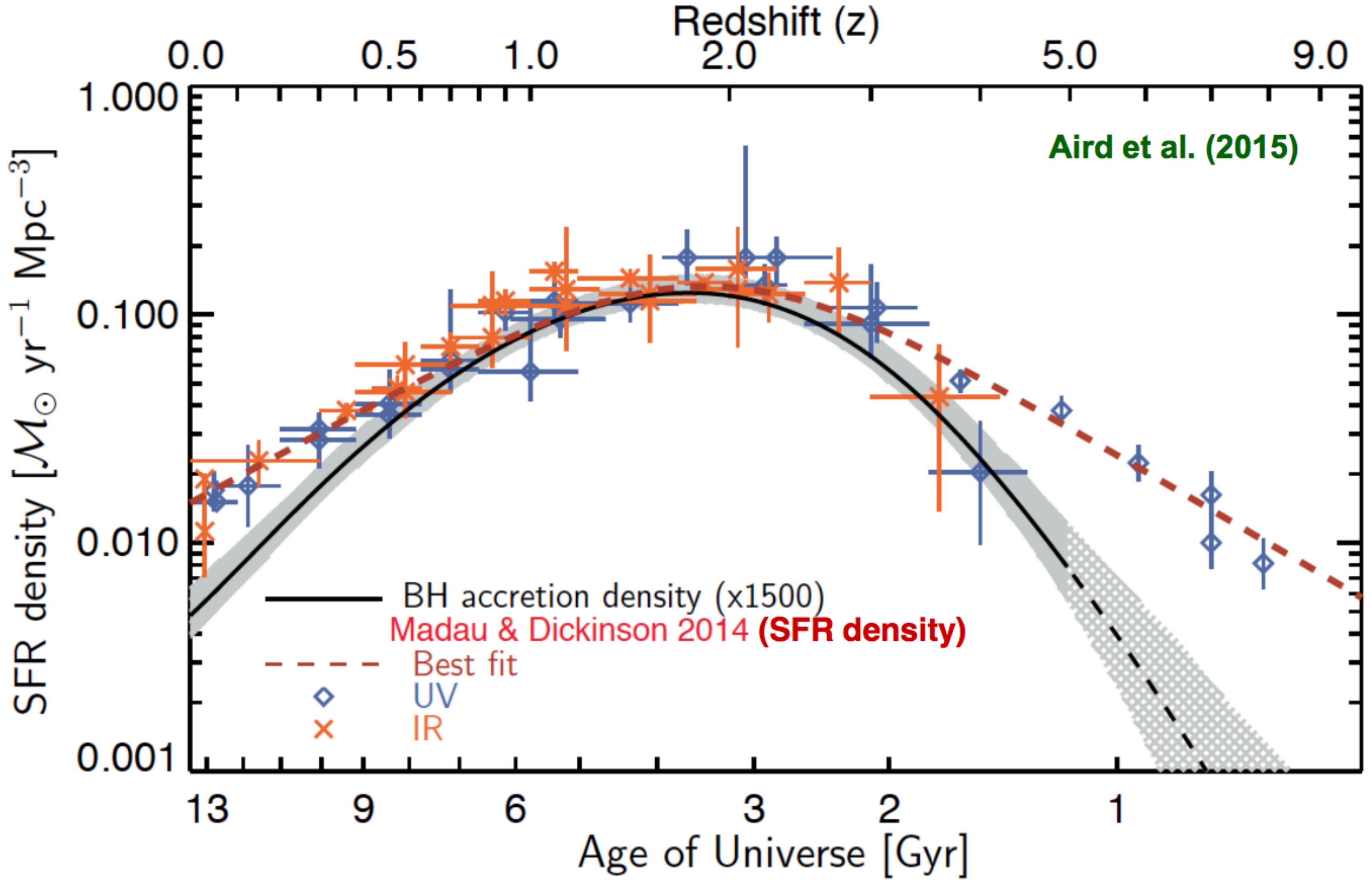
MOTIVATION

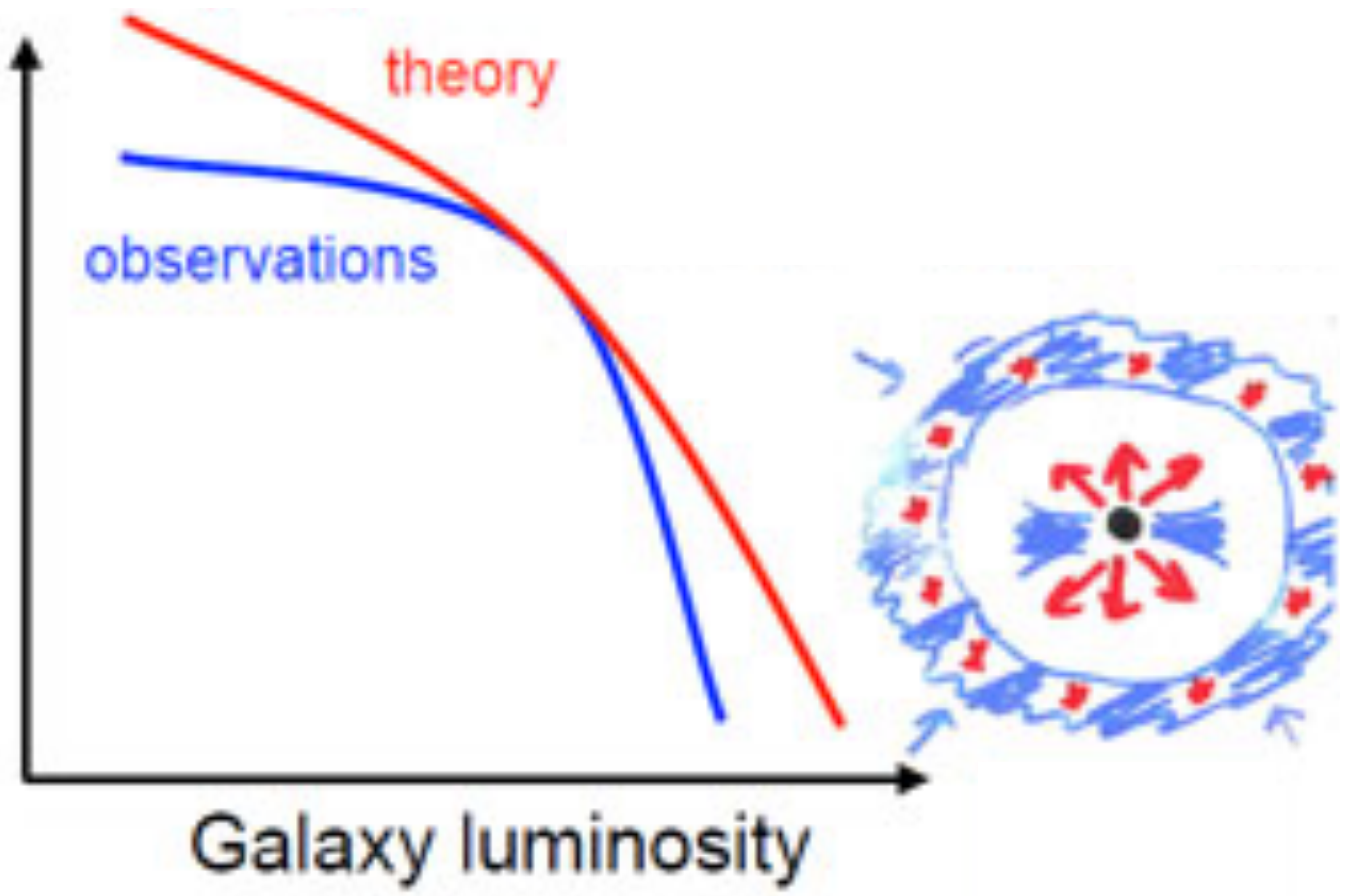
- **SMBHs play a fundamental role in galaxy evolution.**
- SMBHs affect their larger environment.
- Environment is inextricably linked to galaxy/SMBH evolution.
- AGN can also be a contaminant for ICM studies.

McConnell & Ma 2013





Aird et al. 2015



Silk & Mamon 2012

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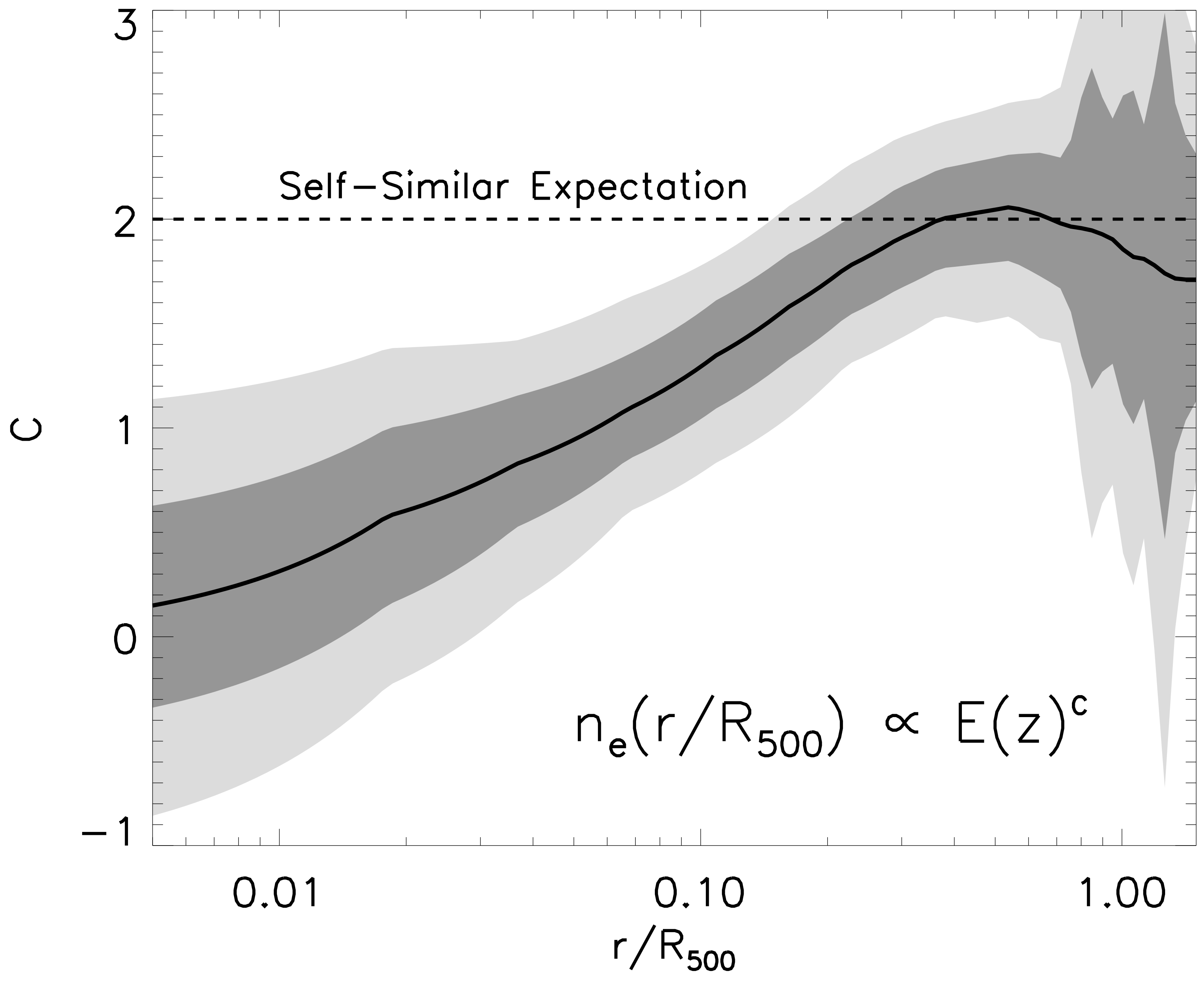
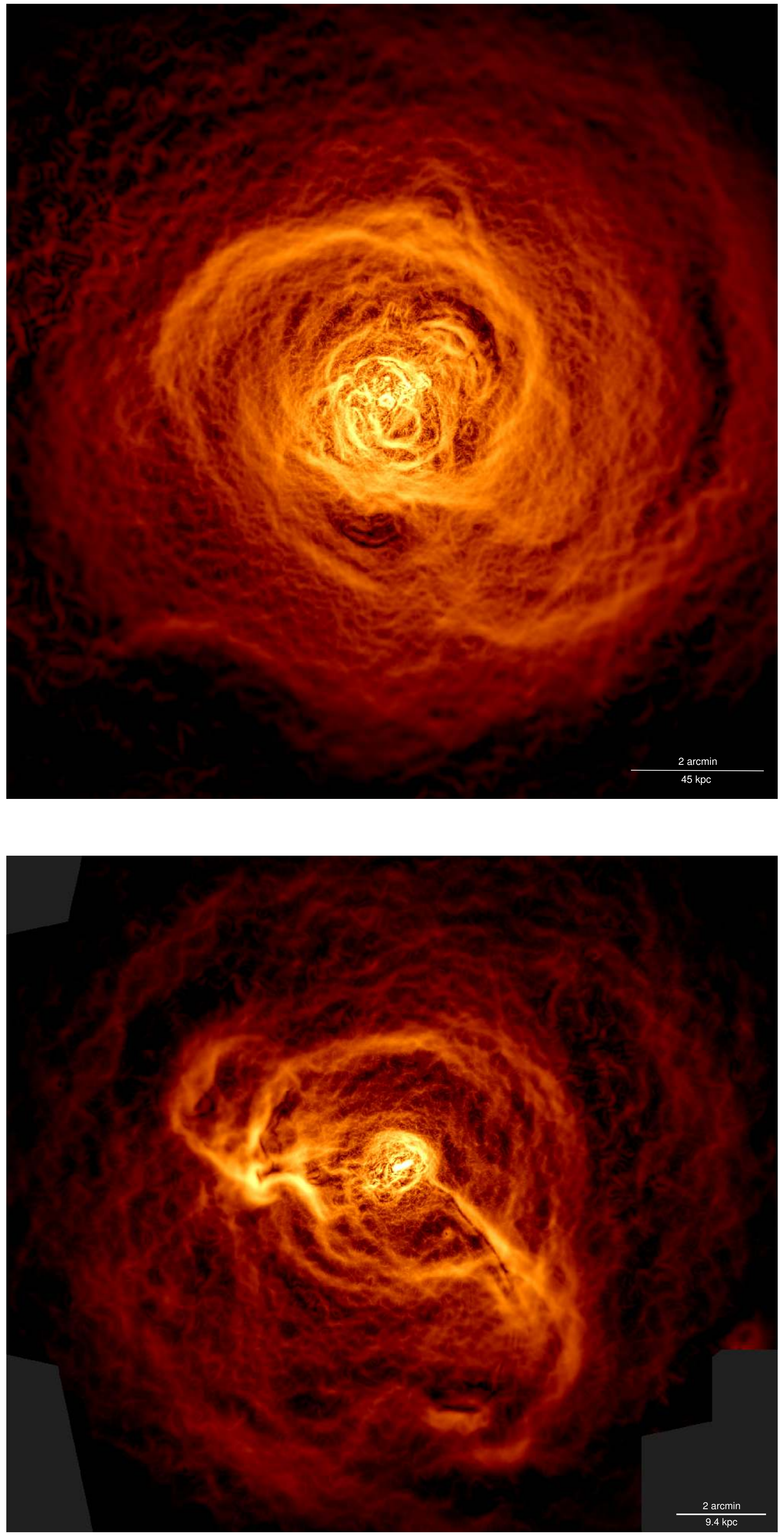
McDonald et al. 2017



Saunders et al. 2016



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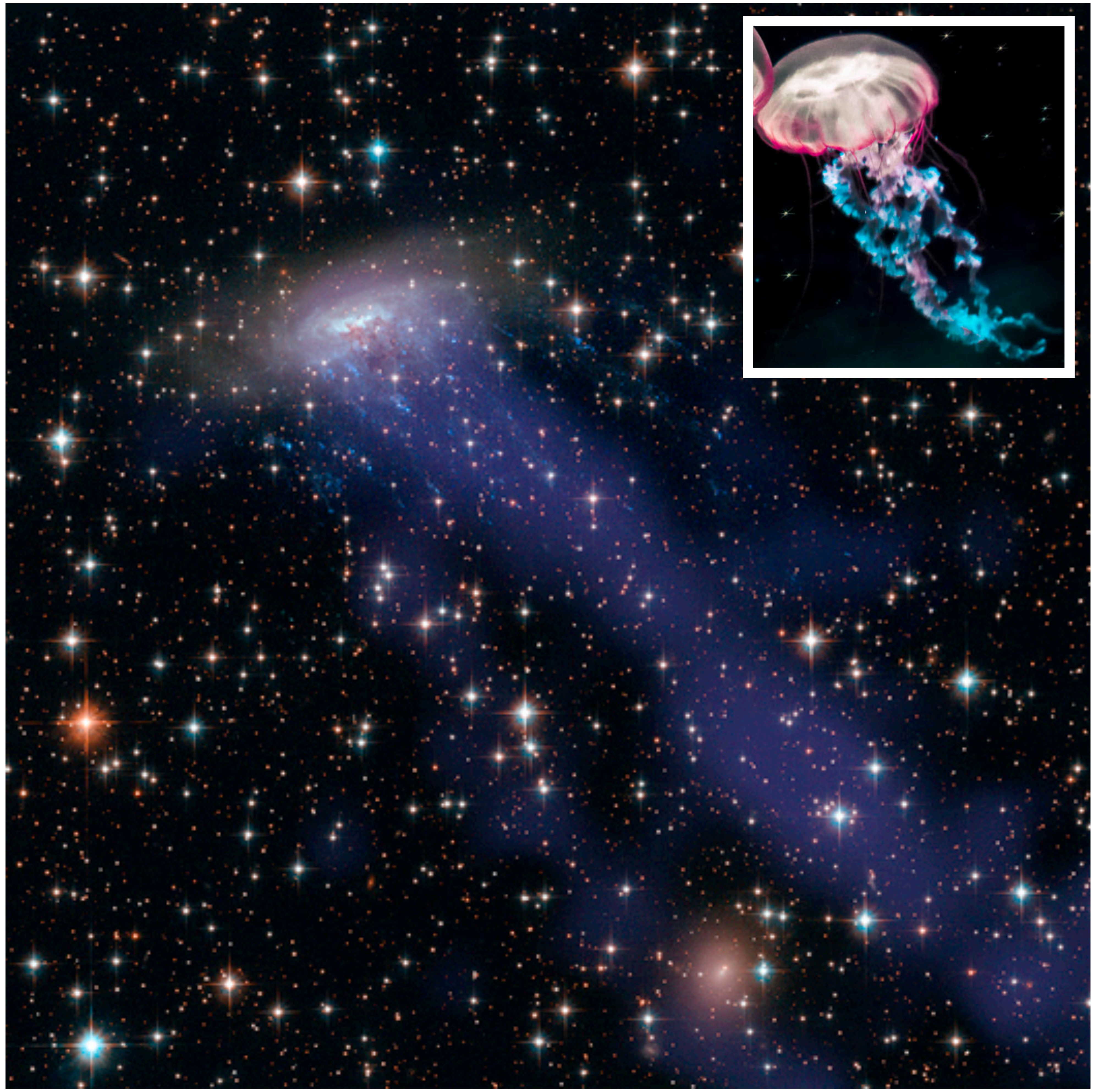

Sun et al. 2007

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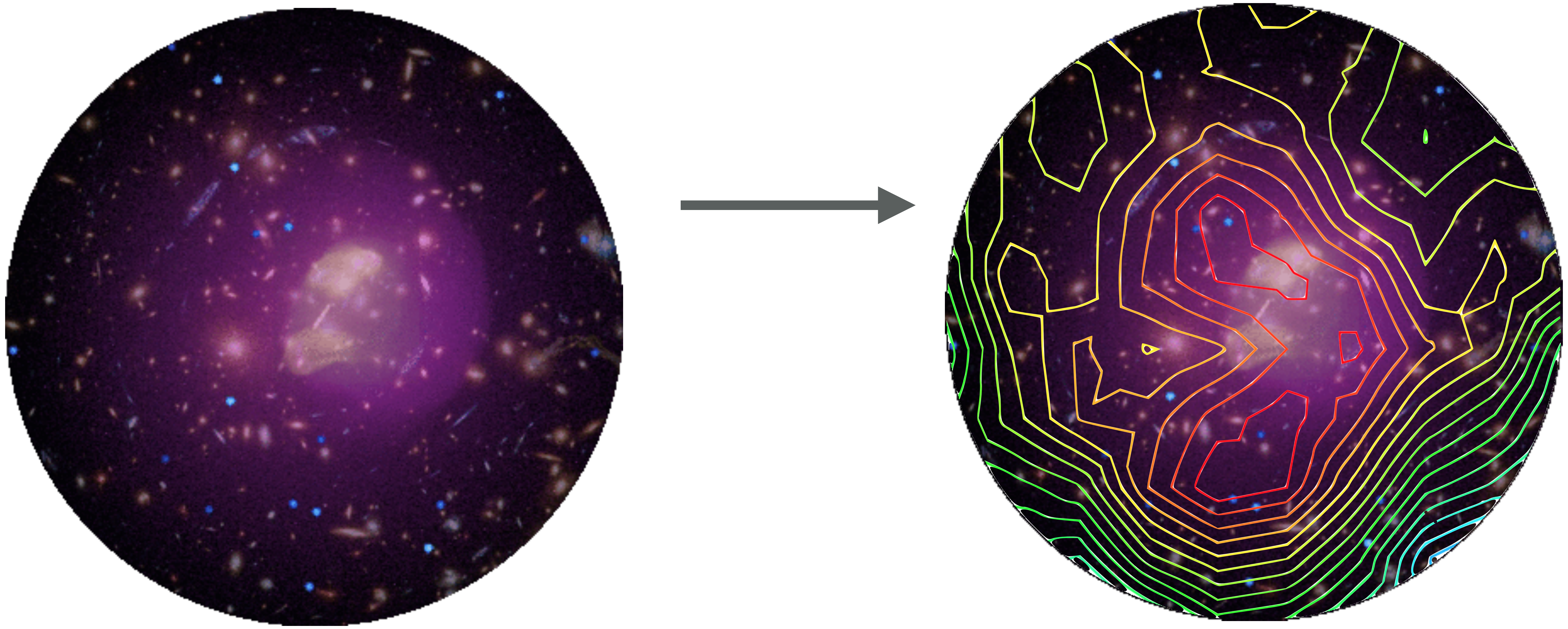
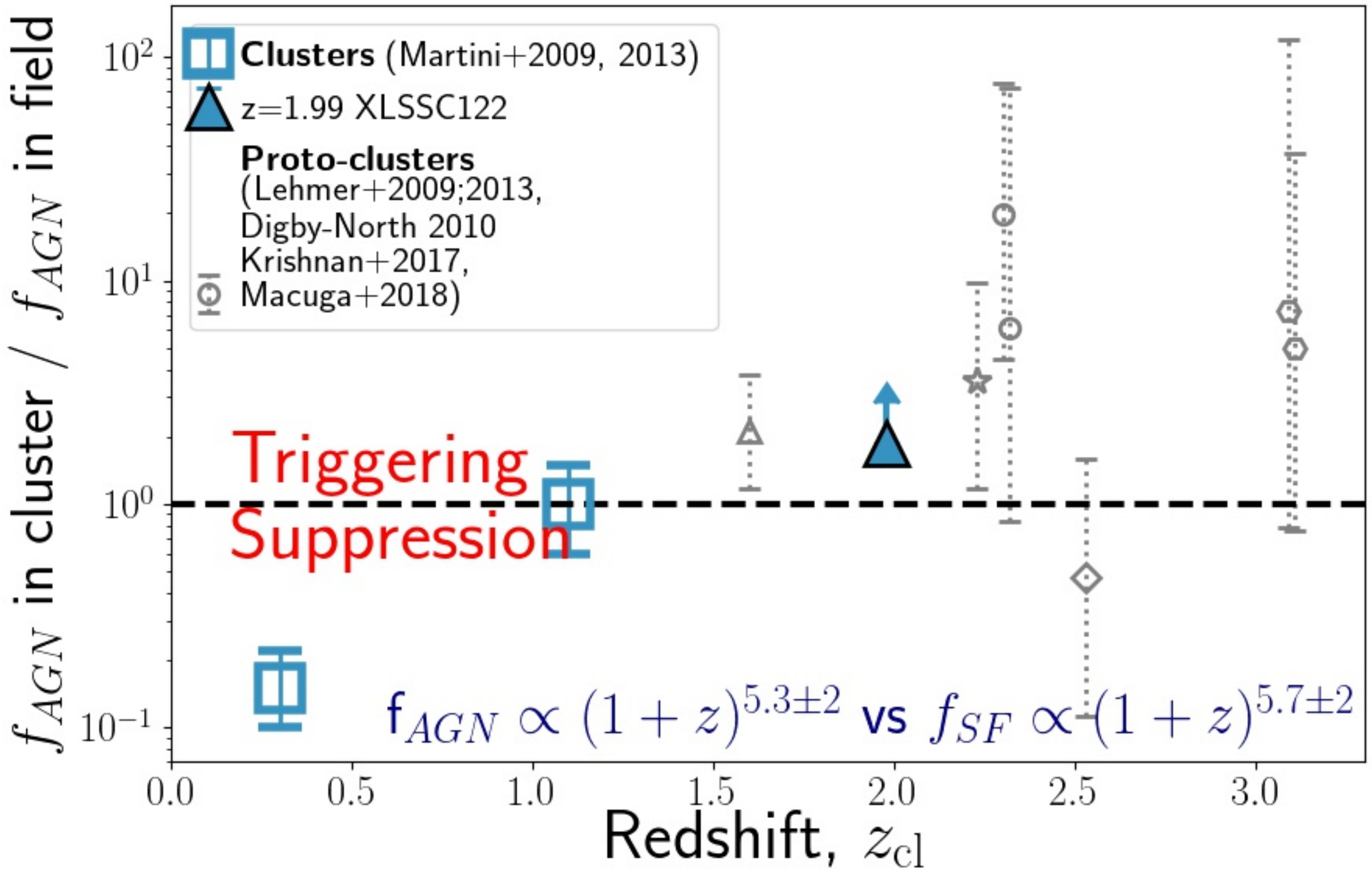
Mapping where SMBH live and their host galaxy properties can tell us about the conditions required to trigger them



WHAT DO WE KNOW?

- X-ray AGN quenched in low-z clusters.
- Are X-ray AGN triggered at high-z?

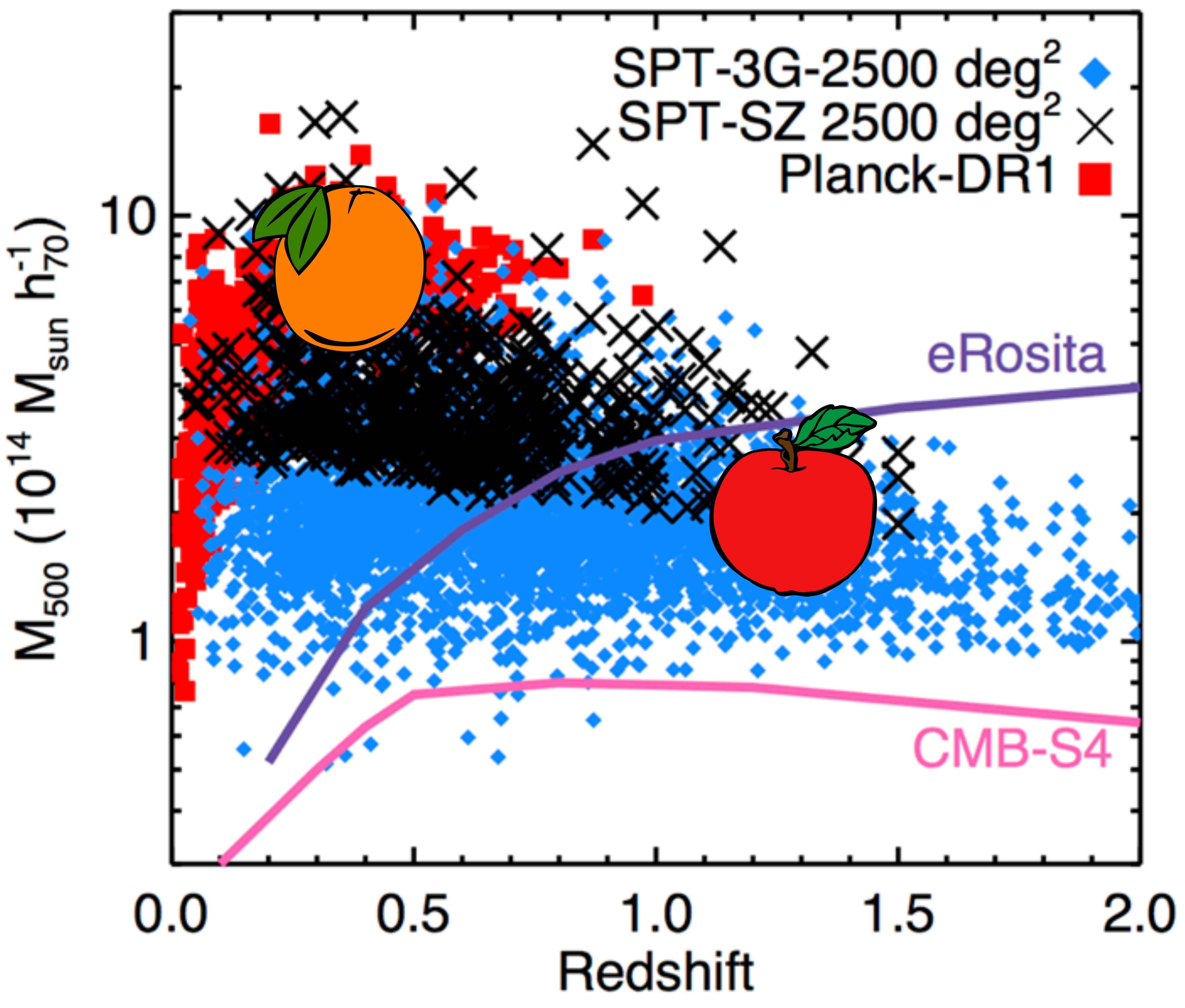
Adapted from Krishnan et al. 2017



See Martini et al. 2009, 2013; Haines et al. 2009

WHAT DO WE KNOW?

Benson et al.



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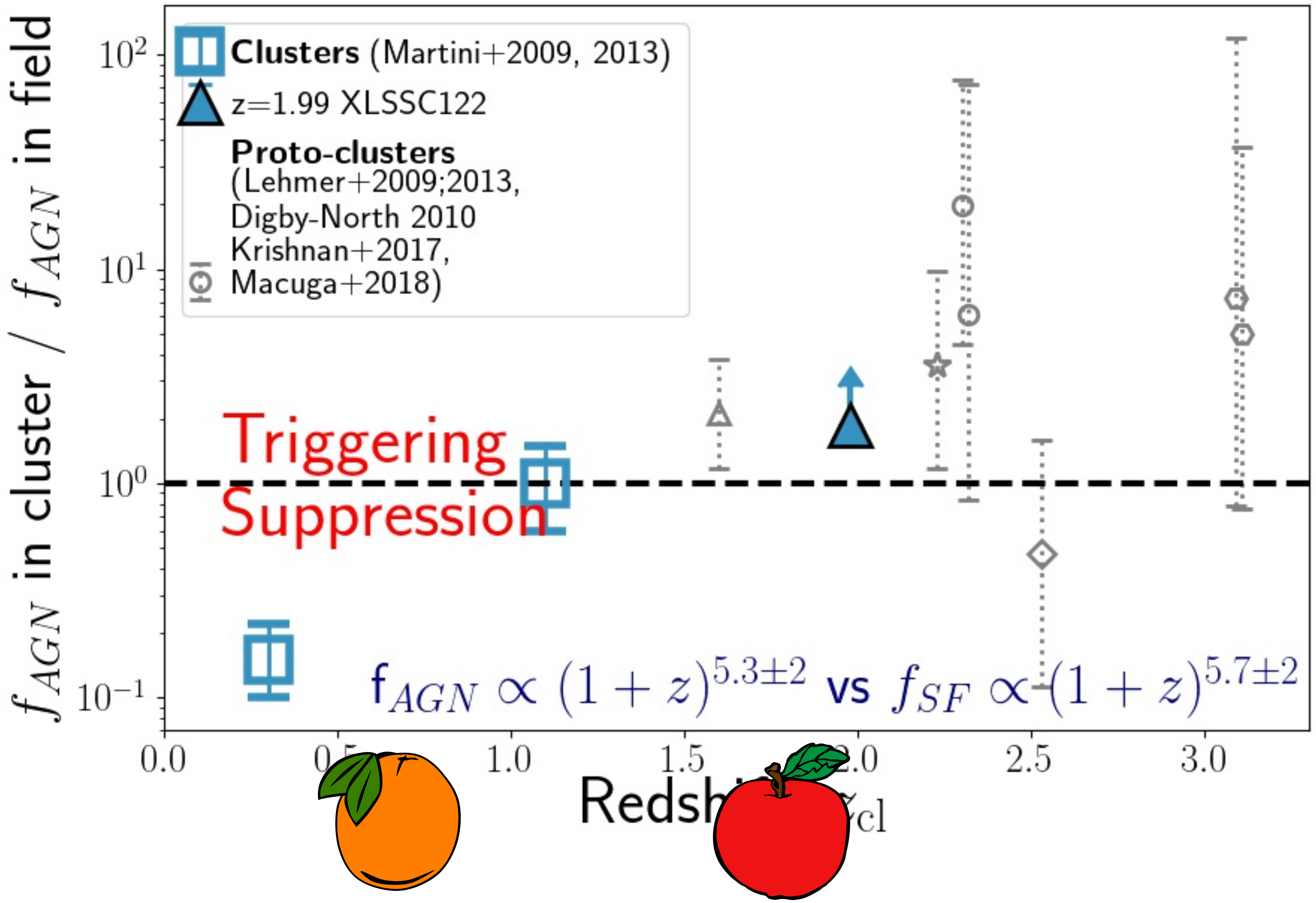
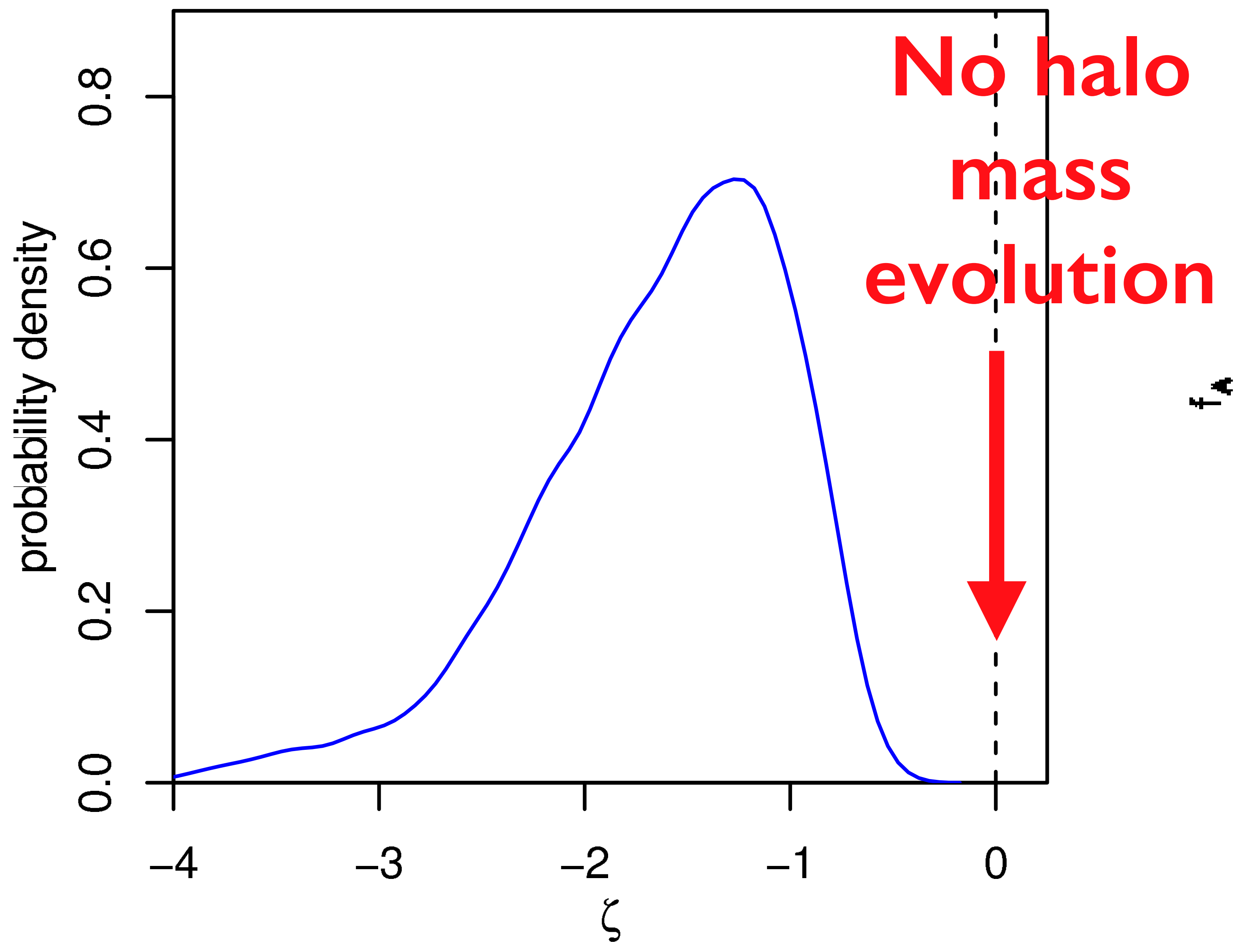
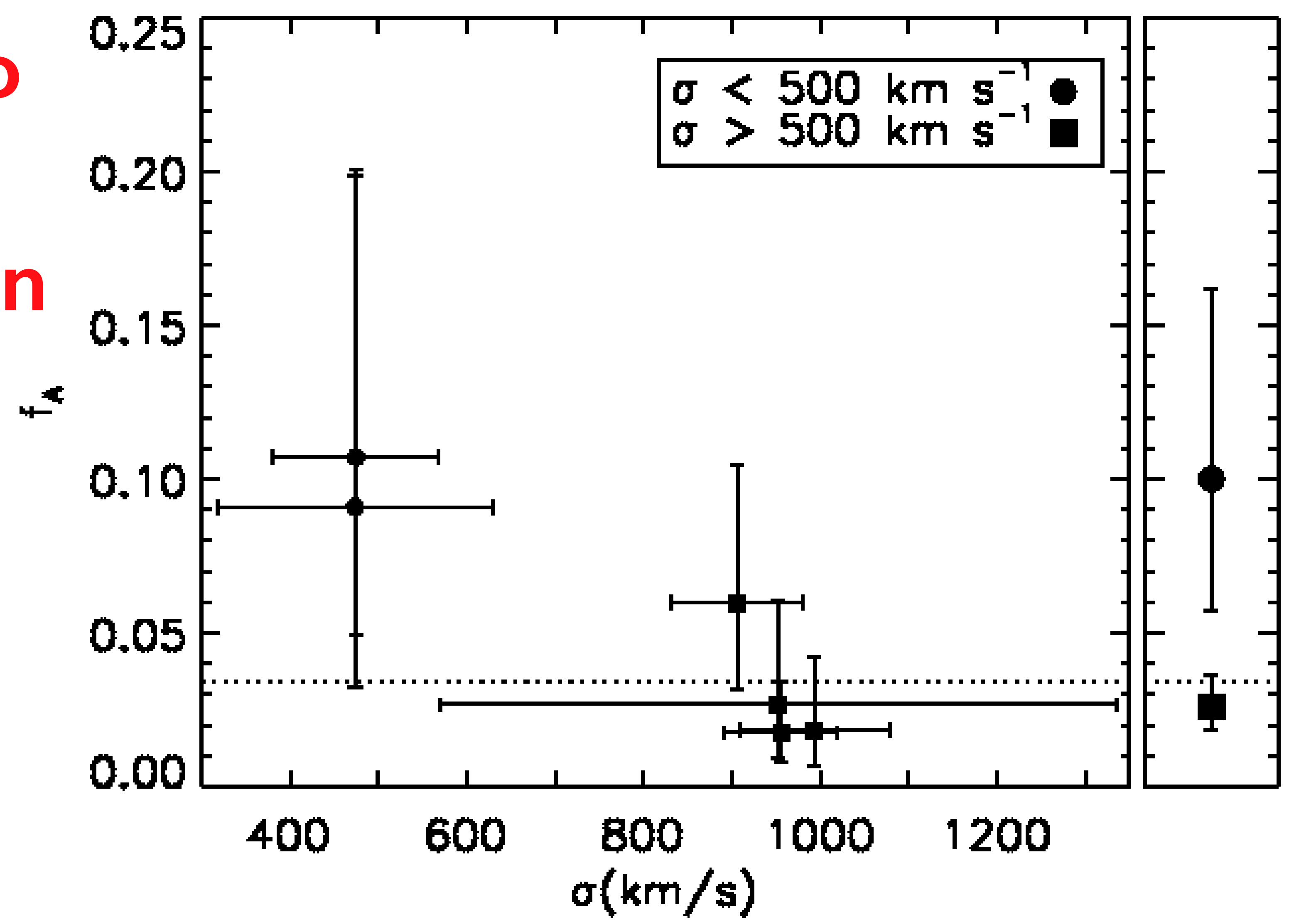


WHAT DO WE KNOW?

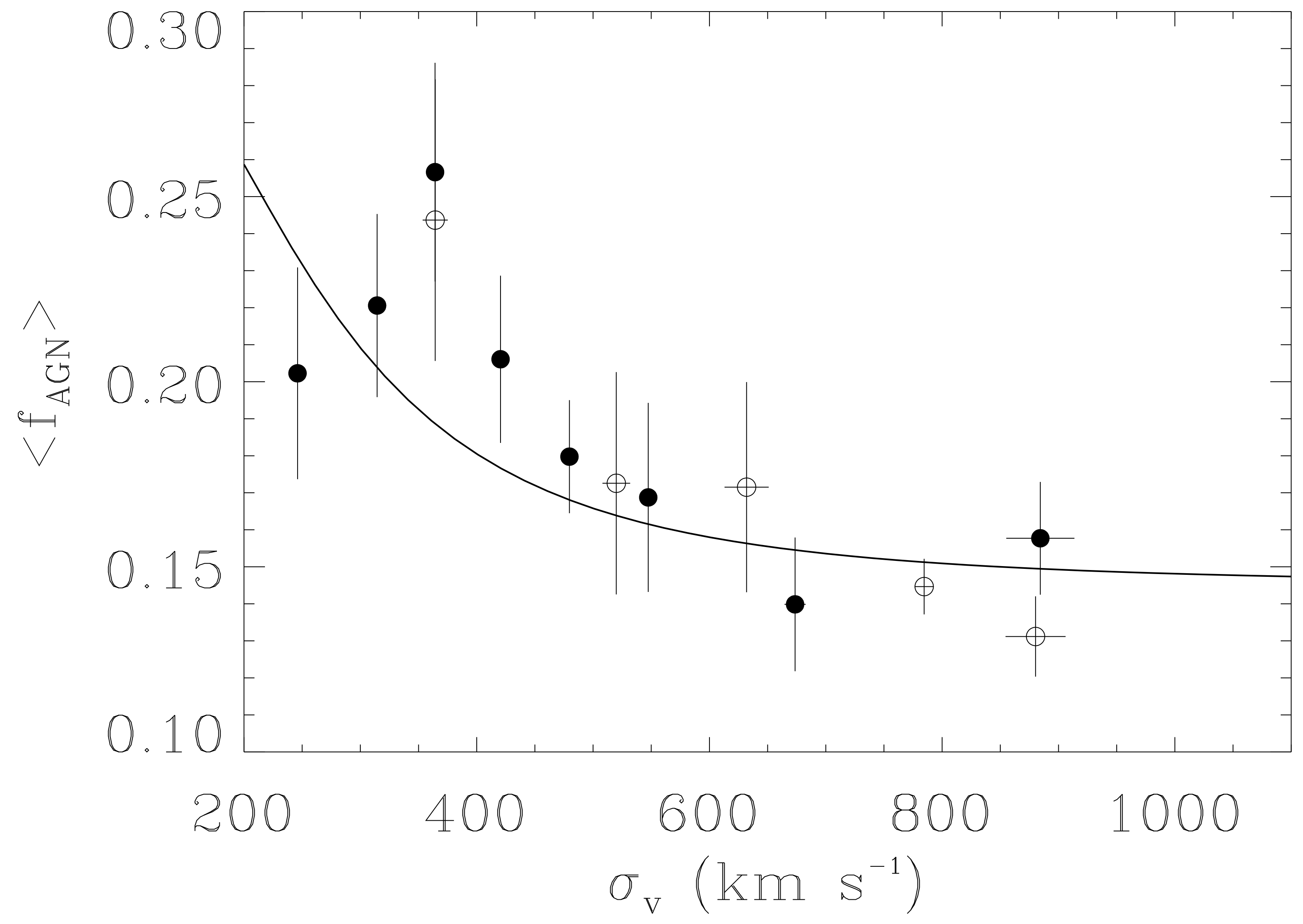
Elhert et al. 2015



Sivakoff et al. 2008



Popesso & Biviano 2006

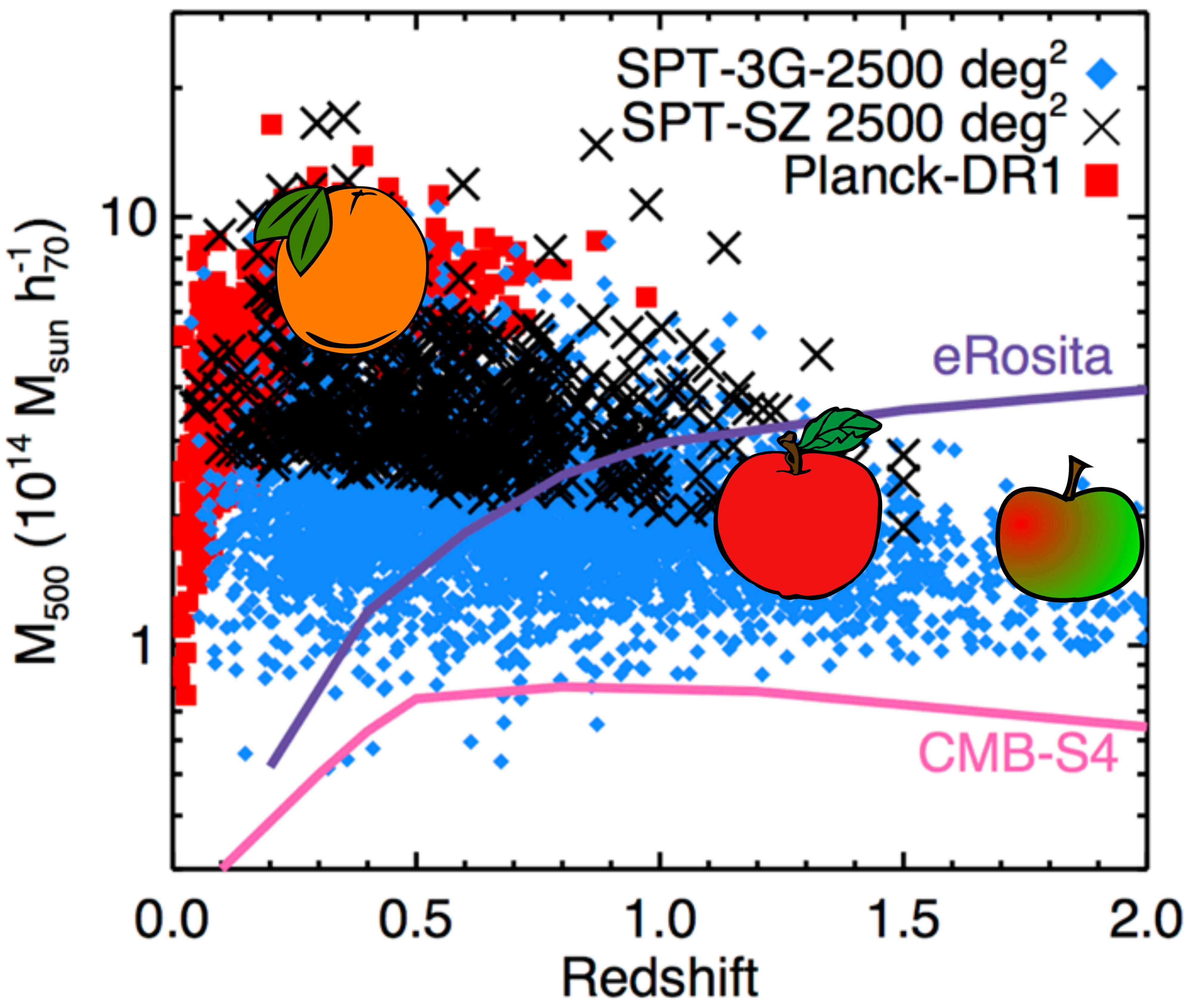


Cluster X-ray AGN number densities have been shown to have some cluster mass dependence as have optical AGN.

See also Poggianti et al. 2006; Koulouridis et al. 2018…

WHAT DO WE KNOW?

Benson et al.



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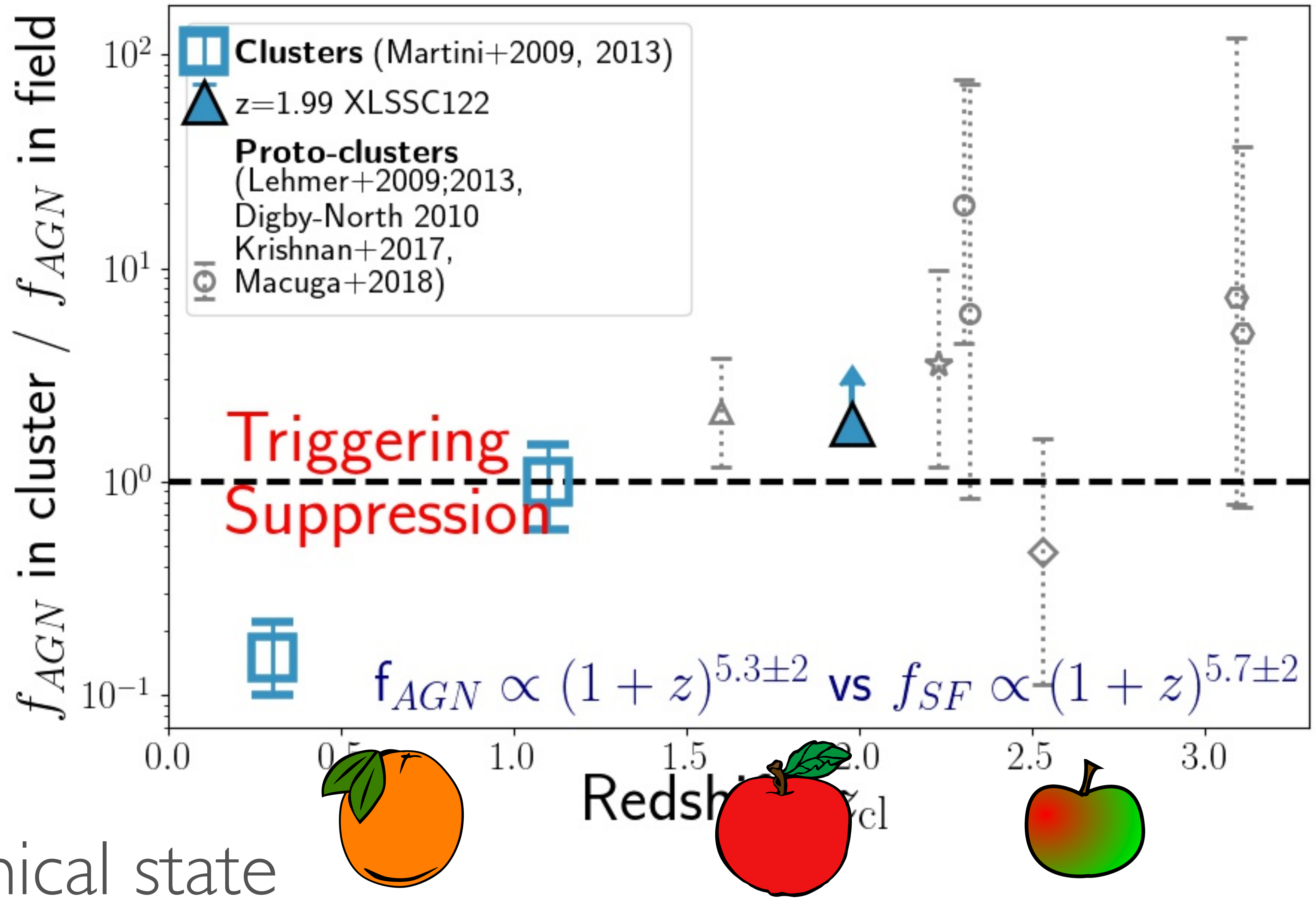

- Consider mass, redshift, dynamical state

WHAT DO WE WANT TO KNOW?

Quantitatively how do AGN depend on host cluster and host galaxy properties?

Challenging as:

- Most massive clusters are best (easily characterized+large variation in ICM density) but lots of clusters would require a large area survey
- AGN and host galaxy properties are diverse
- AGN are rare in clusters yet abundant in background and spectroscopically identifying them is expensive
- For X-ray AGN cluster itself presents a challenging background

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Our solutions:

- Use pointed observations in Chandra archive
- Multi-wavelength AGN selection and data for host galaxies
- Make differential measurements. Utilize knowledge of how large scale structure evolves to statistically combine signals.
- Requires high-spatial res X-ray obs. Developed metric to determine whether source on cluster background is point-like or extended

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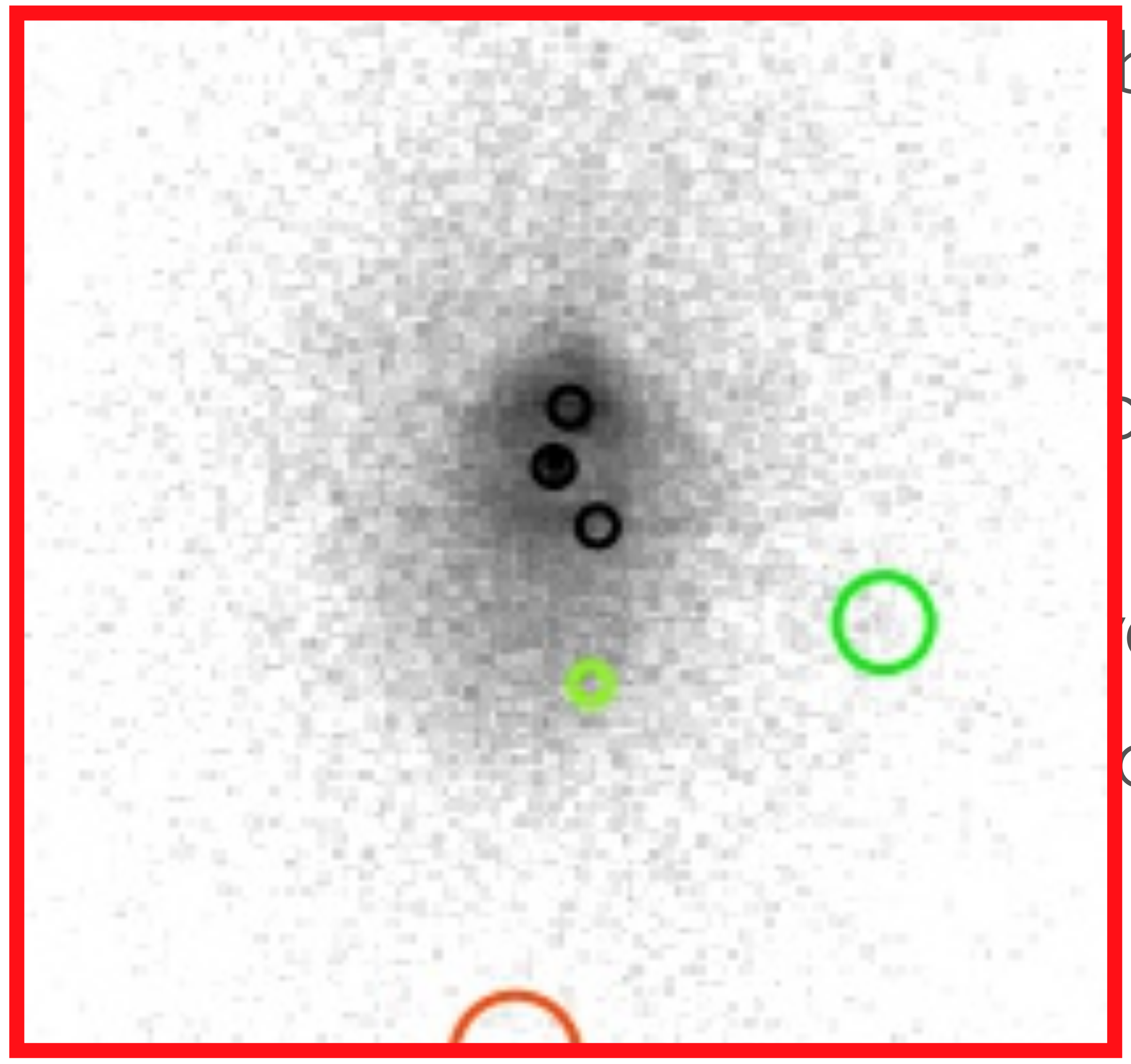

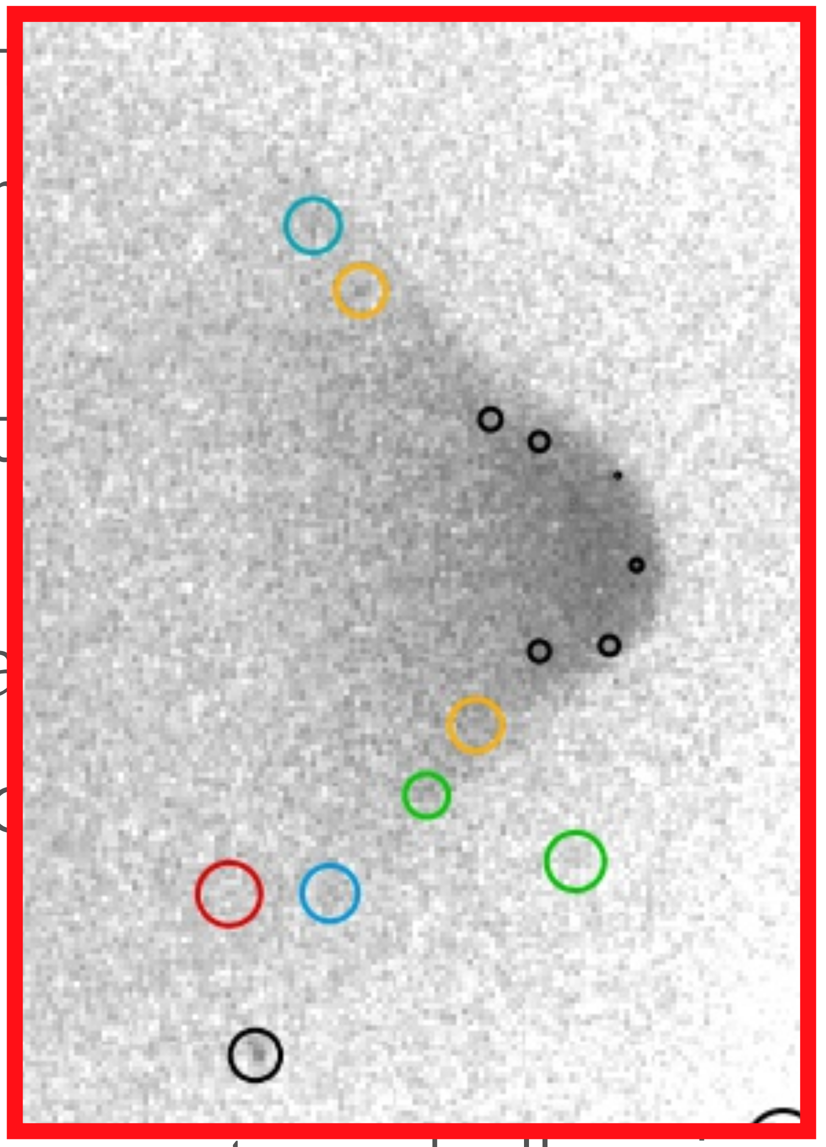

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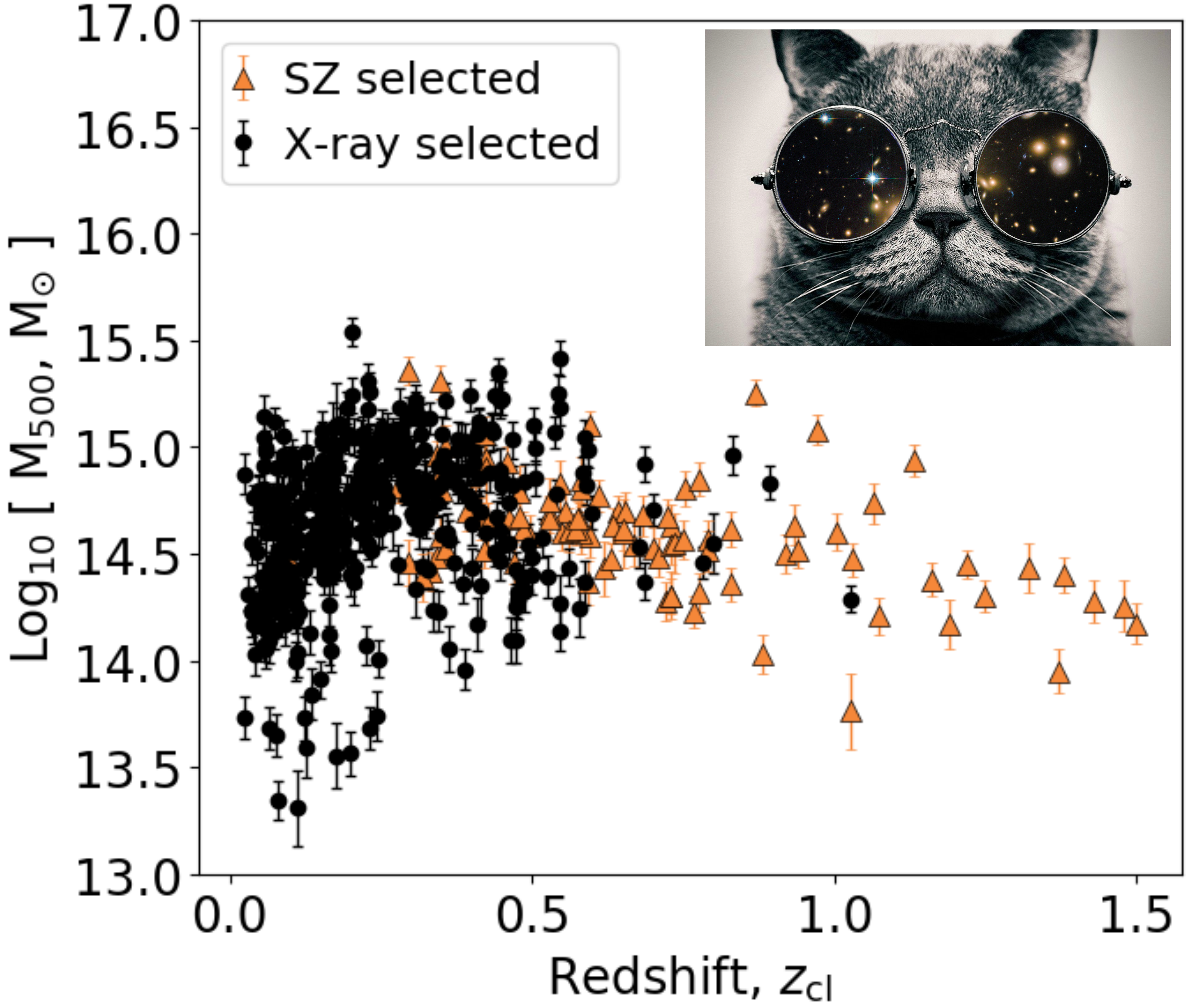
CATS - **C**LUSTER **A**GN **T**OPOGRAPHY **S**URVEY



- > 25 Ms of Chandra data (~500 clusters), VLA FIRST+ATCA, Spitzer+Wise, 293 orbit HST…
- ~40,000 X-ray AGN. ~11,000 radio AGN sources (~4,000 point sources, ~7000 extended)
- Differential analysis of superposition of cluster + field population. Cluster population is split into satellites and BCGs.
- 'No evolution' means 'no evolution beyond that of the field' population

Canning et al.; King et al.; Noordeh et al.

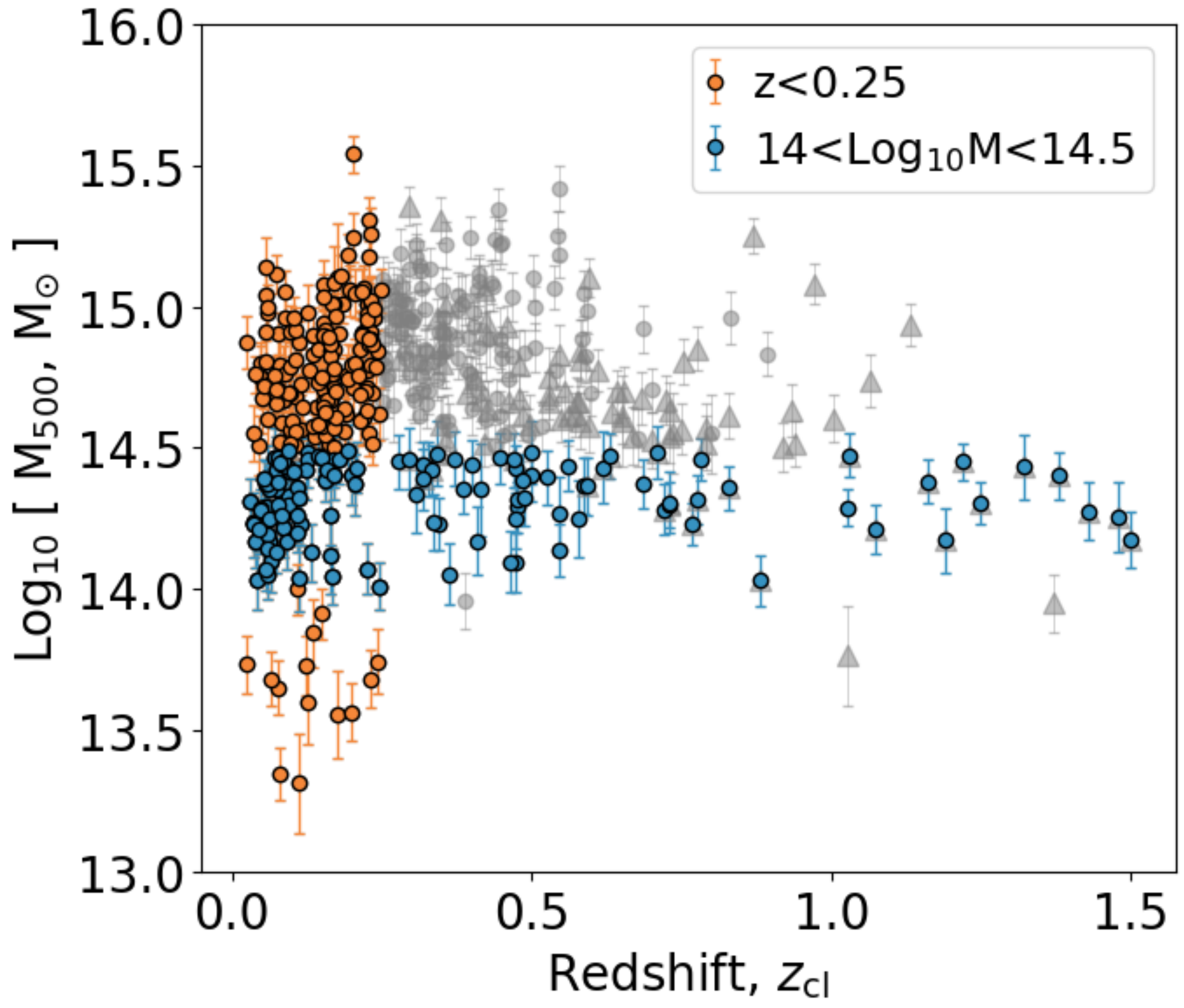
WHAT HAVE WE FOUND?

- I will present binned X-ray results but for the radio I will present the unbinned full model results

MASS AND REDSHIFT

X-RAY AGN

MASS V'S REDSHIFT



Canning et al.

X-RAY AGN

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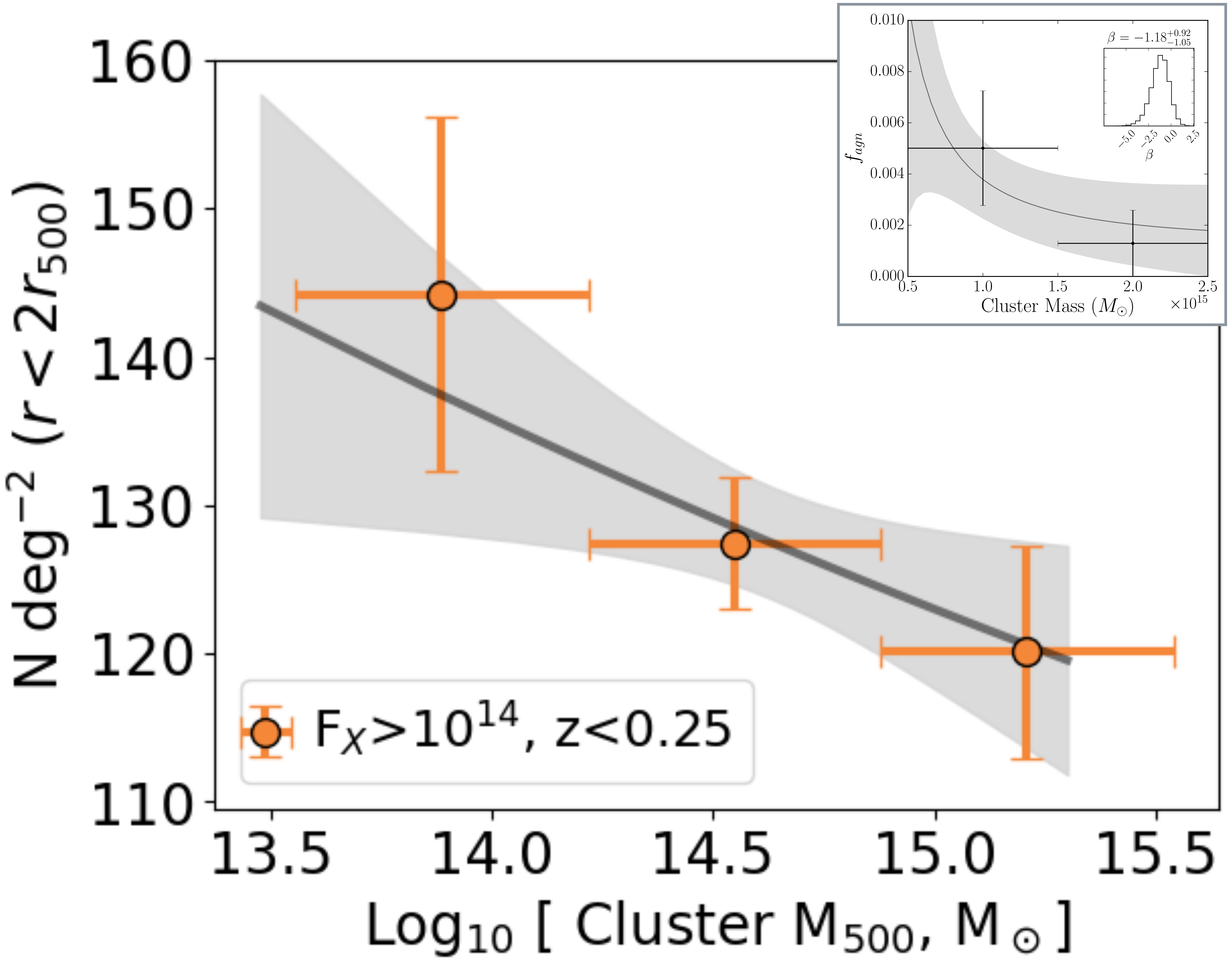
Noordeh et al.



Canning et al.

X-RAY AGN

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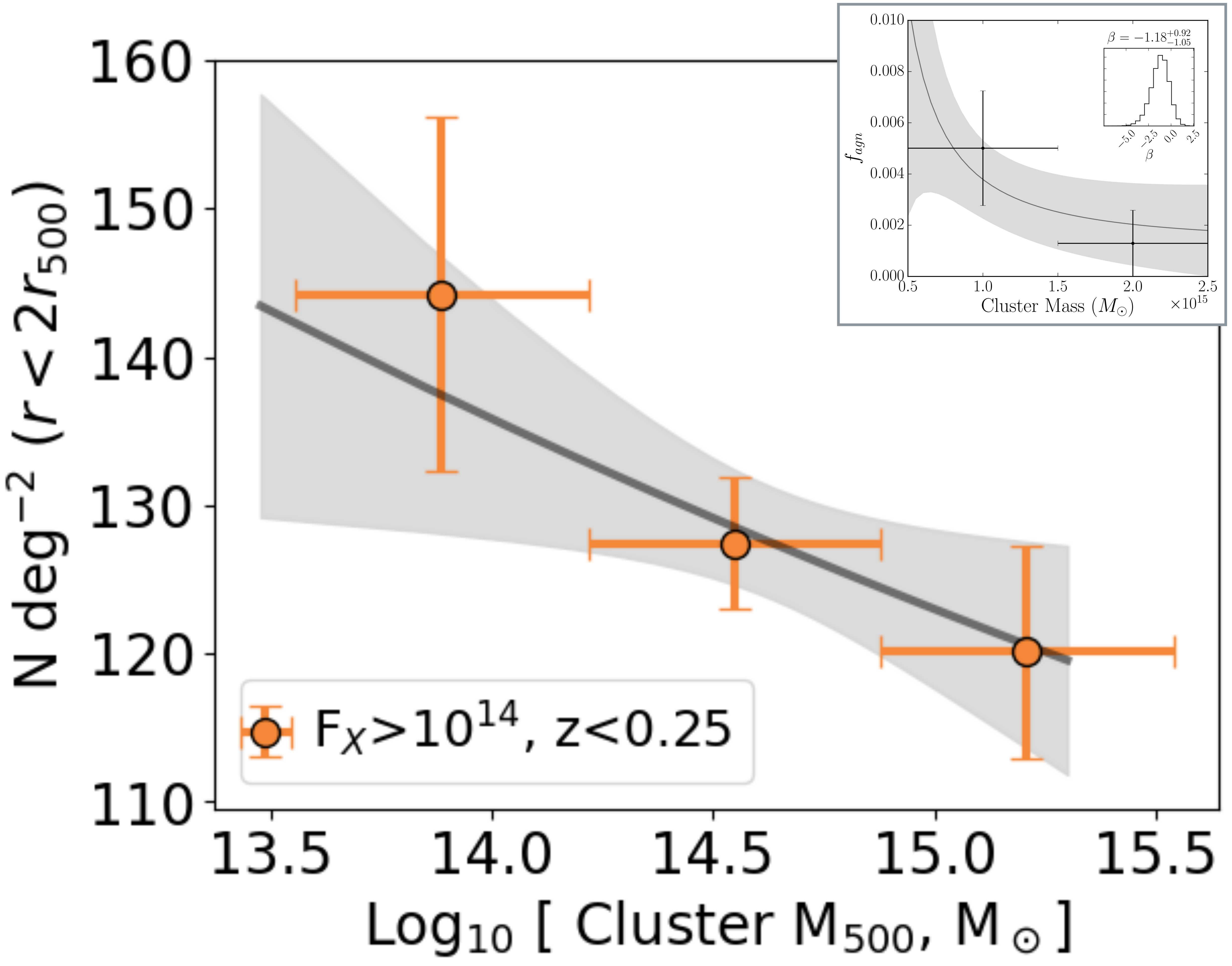
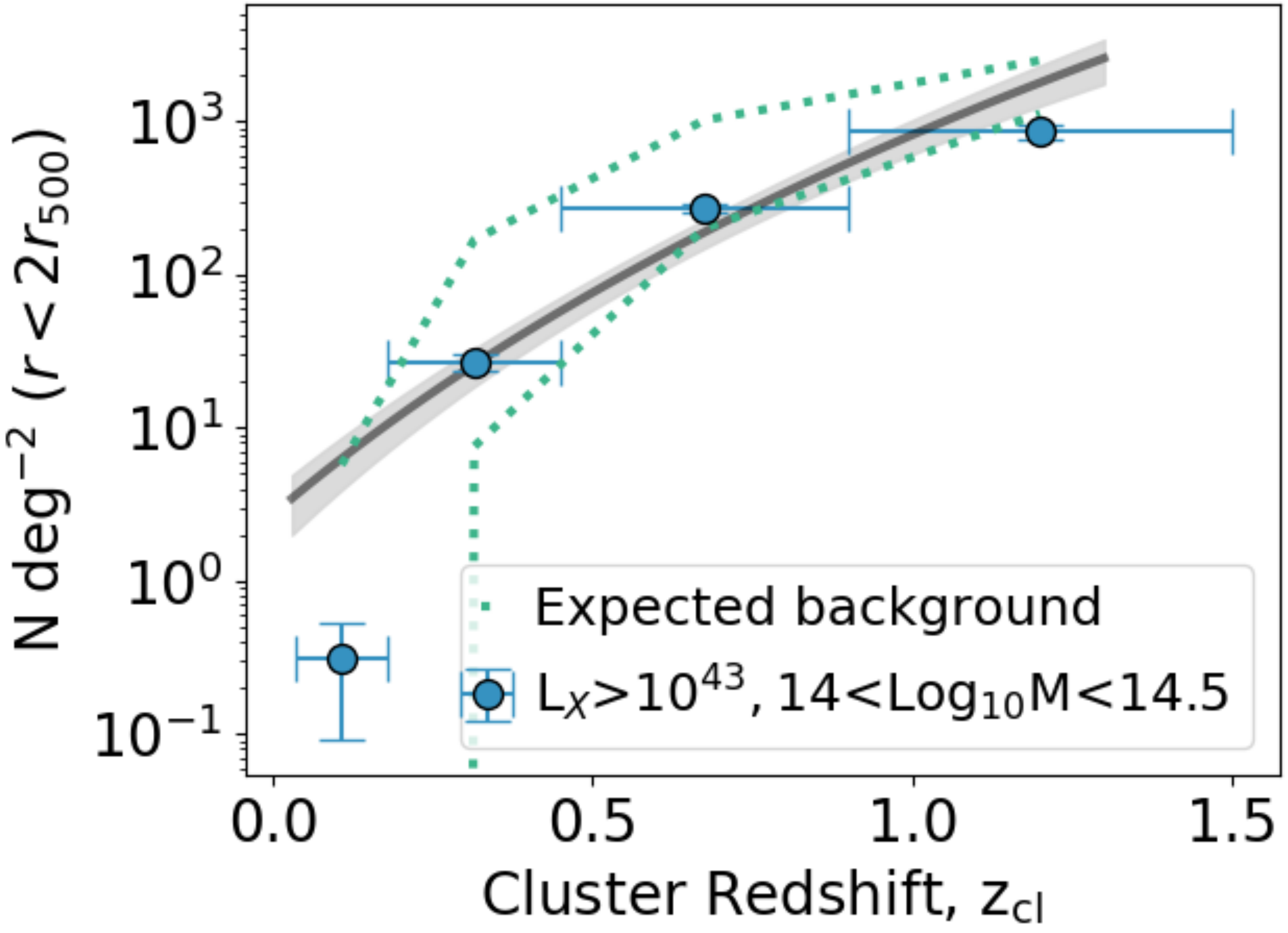




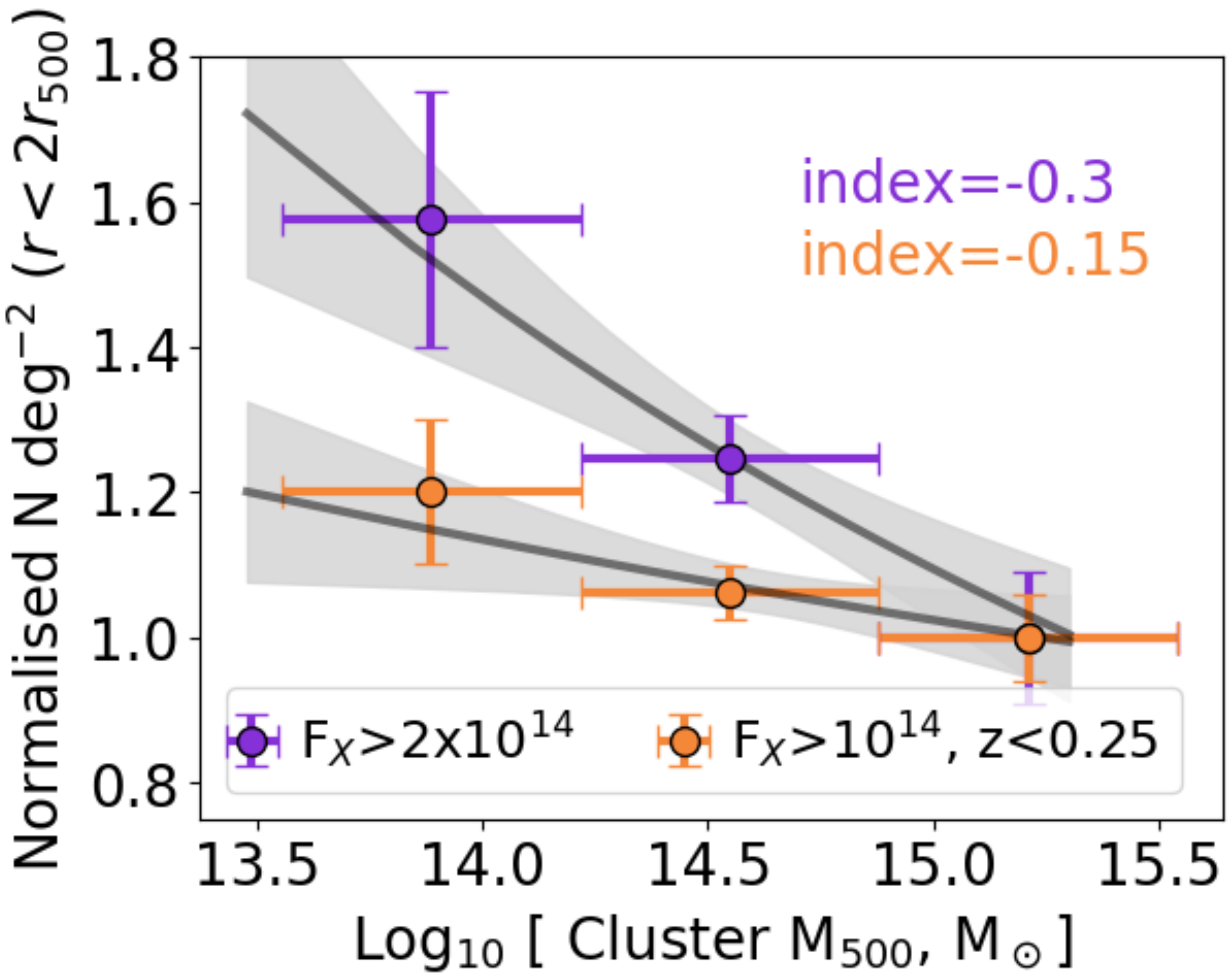
Canning et al.

X-RAY AGN

SO FAR… MASS DEPENDENCE… BUT

- No simple relation: Steepness of number density v’s cluster mass relation is dependent on AGN flux.

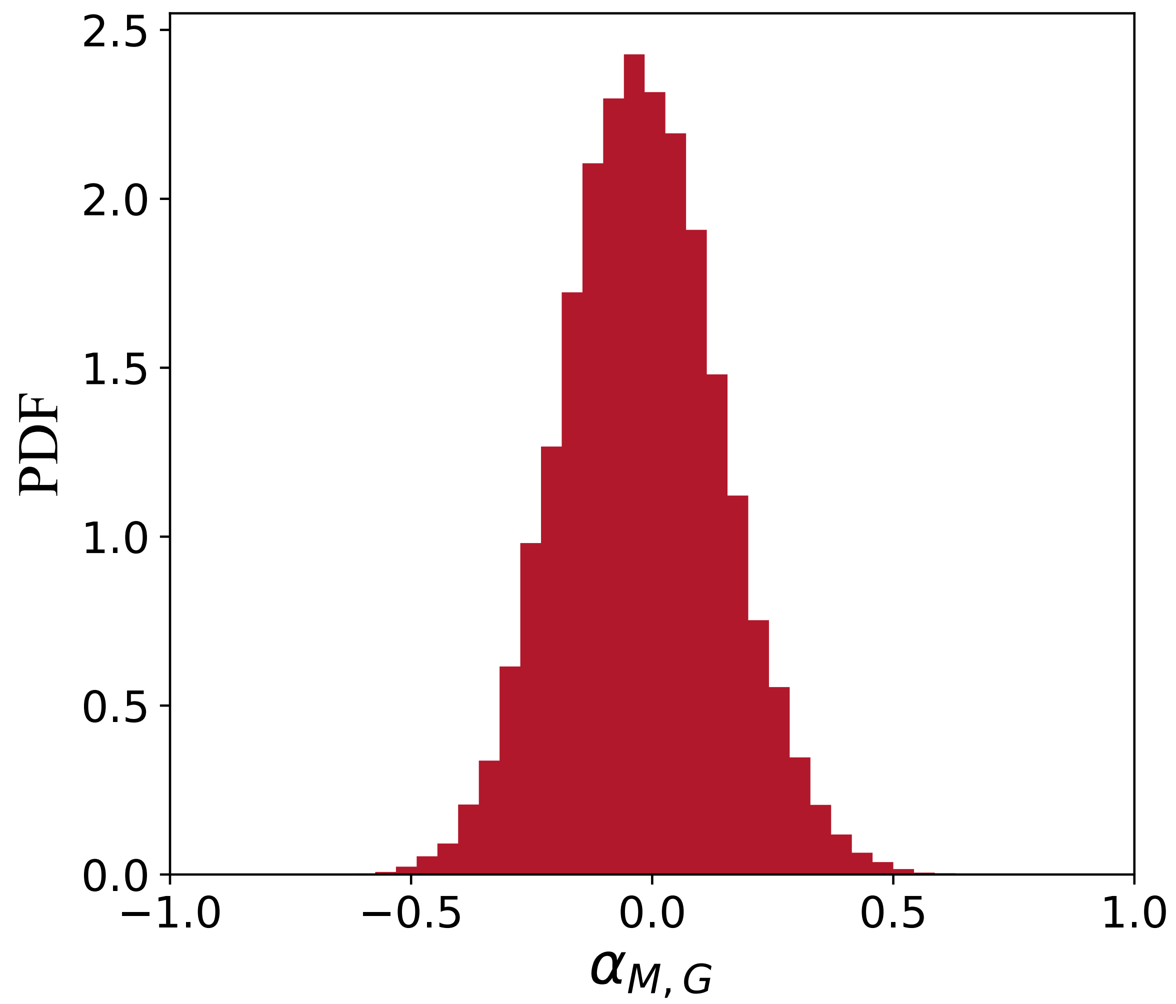
- Codes now running which allow this flexibility.



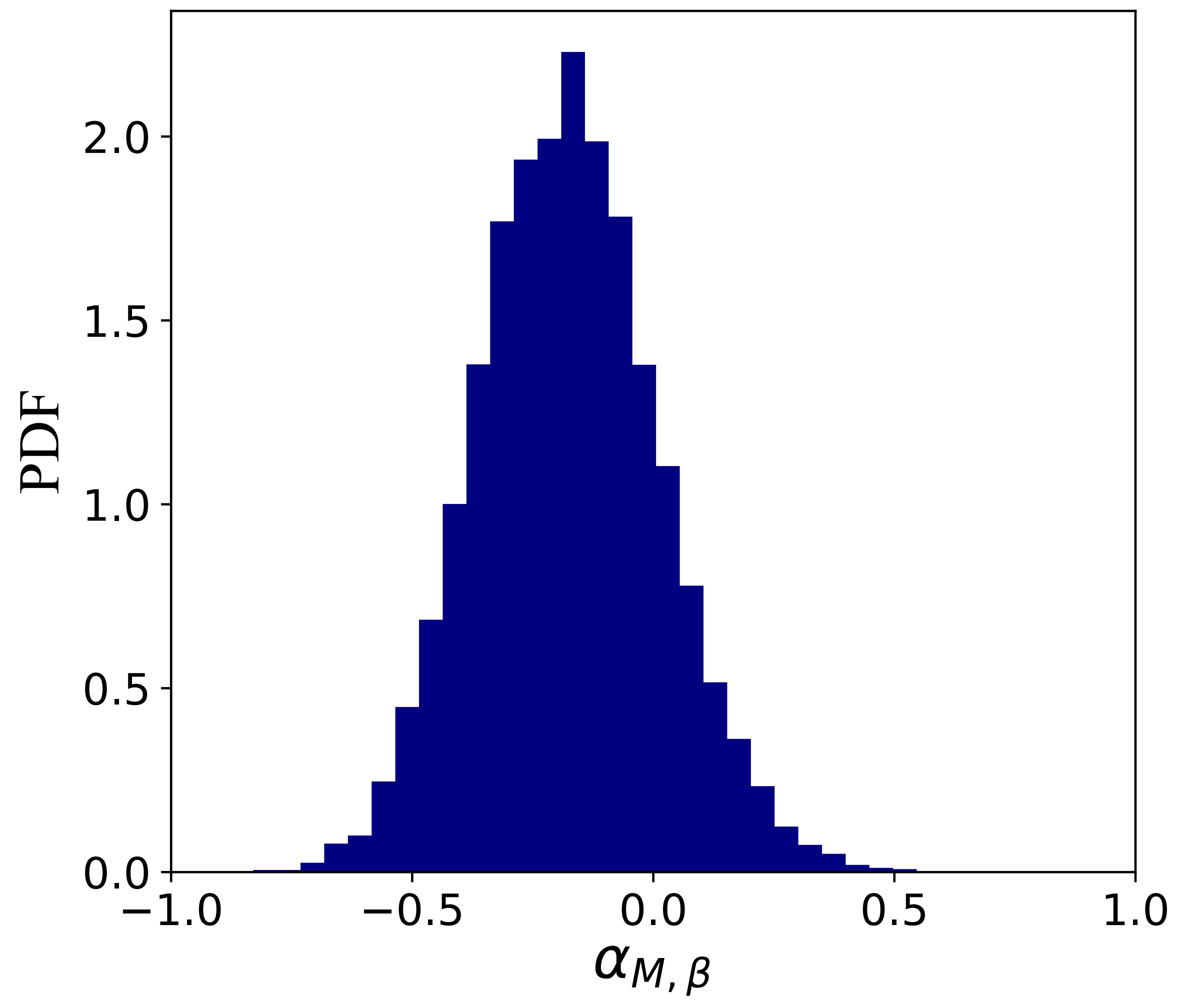
Canning et al.

MASS V'S REDSHIFT

Number density AGN, $Nden \propto (M_{500})^{\alpha_M} \times (1+z)^{\alpha_z}$

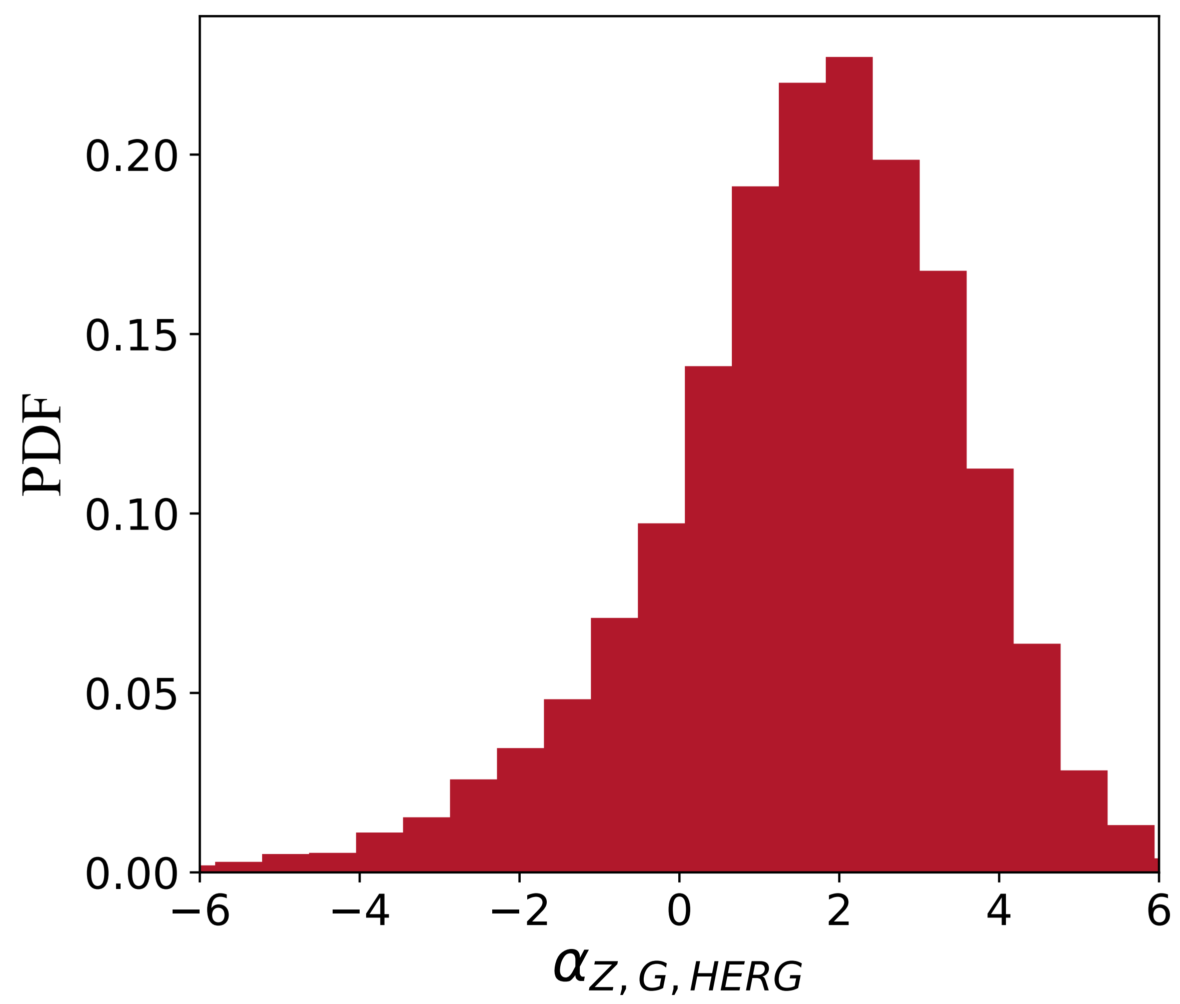


BCG



Satellite

Weak evidence for Satellite mass dependence. No BCG mass dependence.



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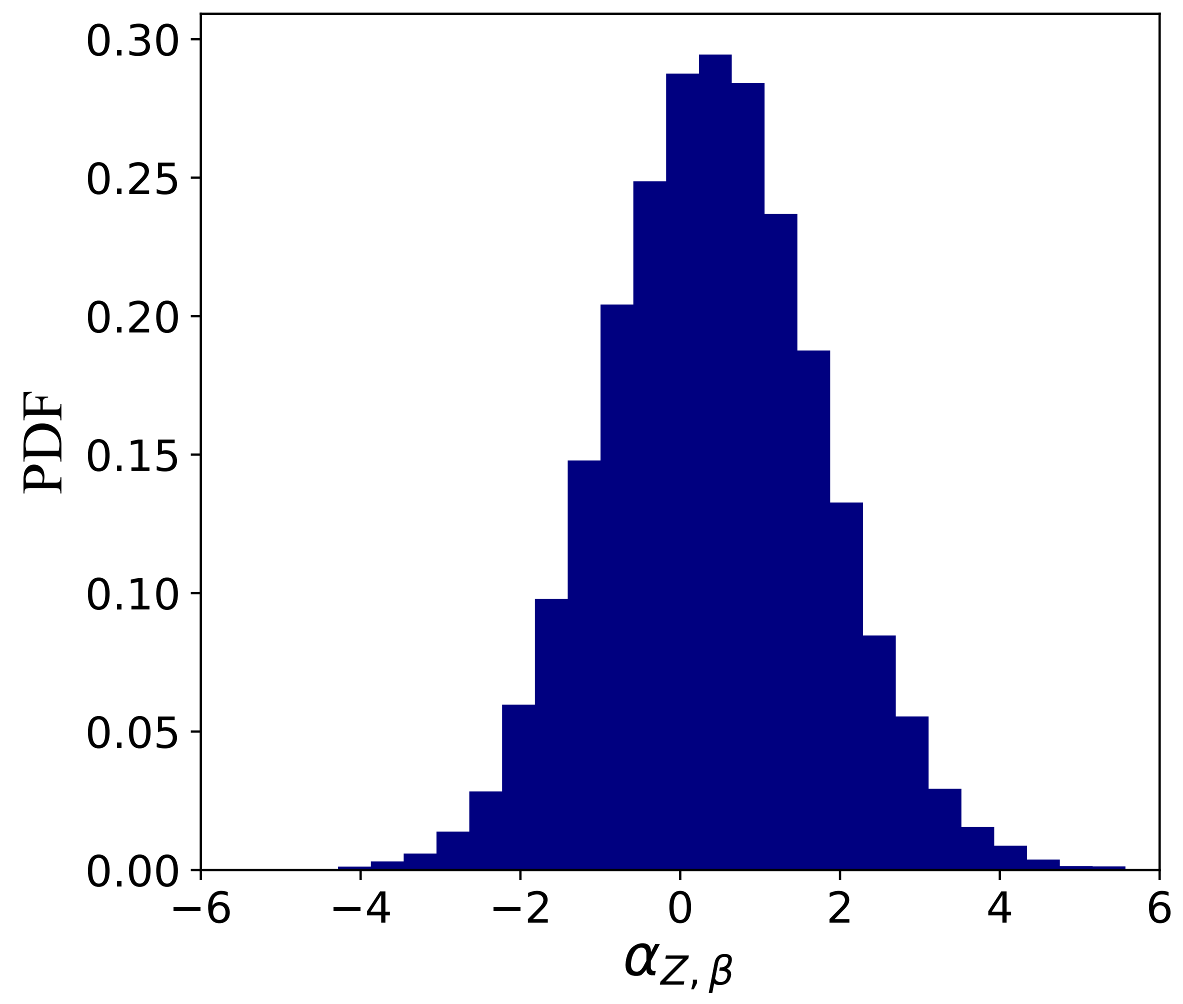


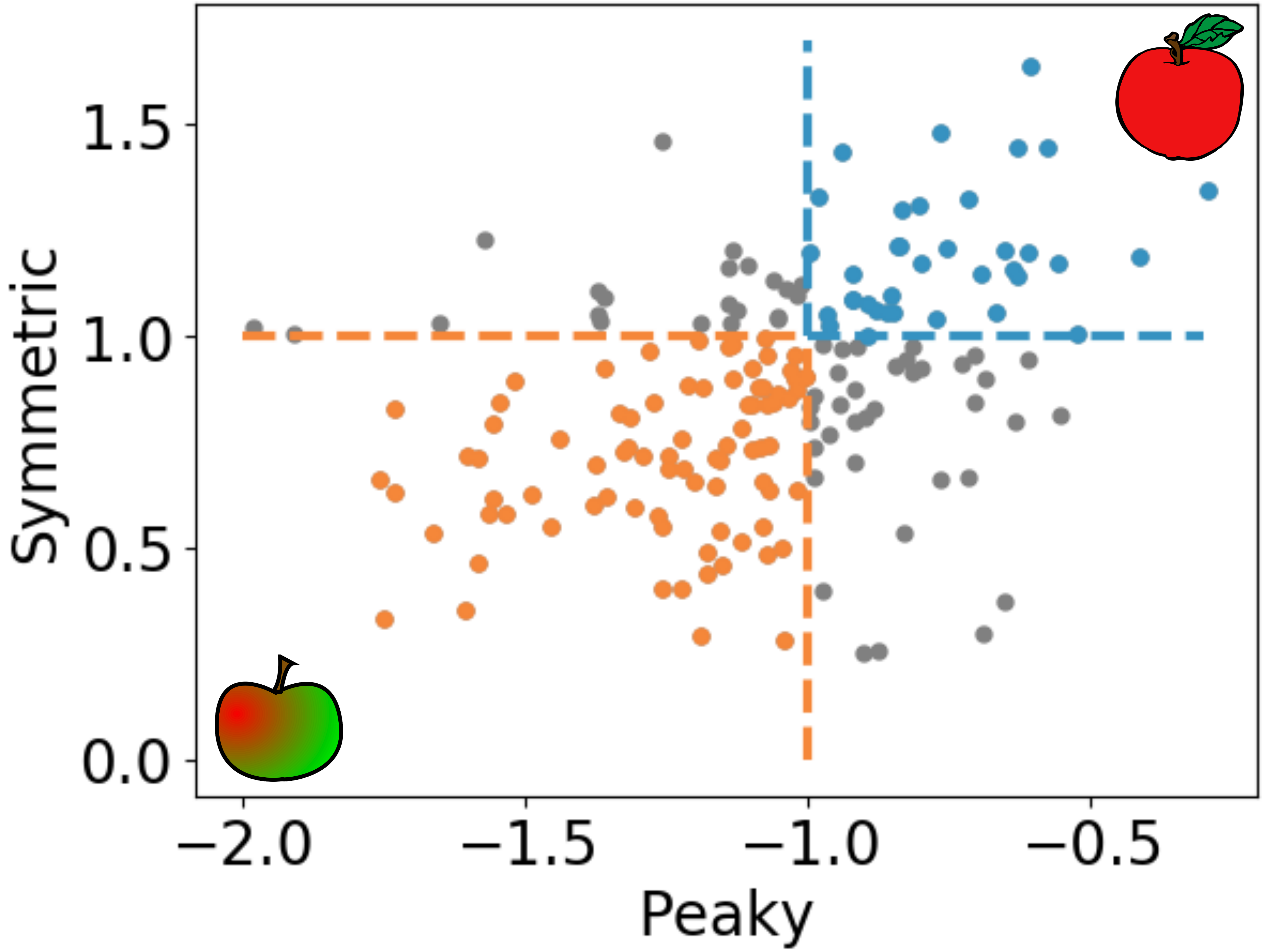
Satellite

Weak evidence for BCG evolution. No Satellite evolution.

King et al.

DYNAMICAL STATE

CLUSTER DYNAMICAL STATE

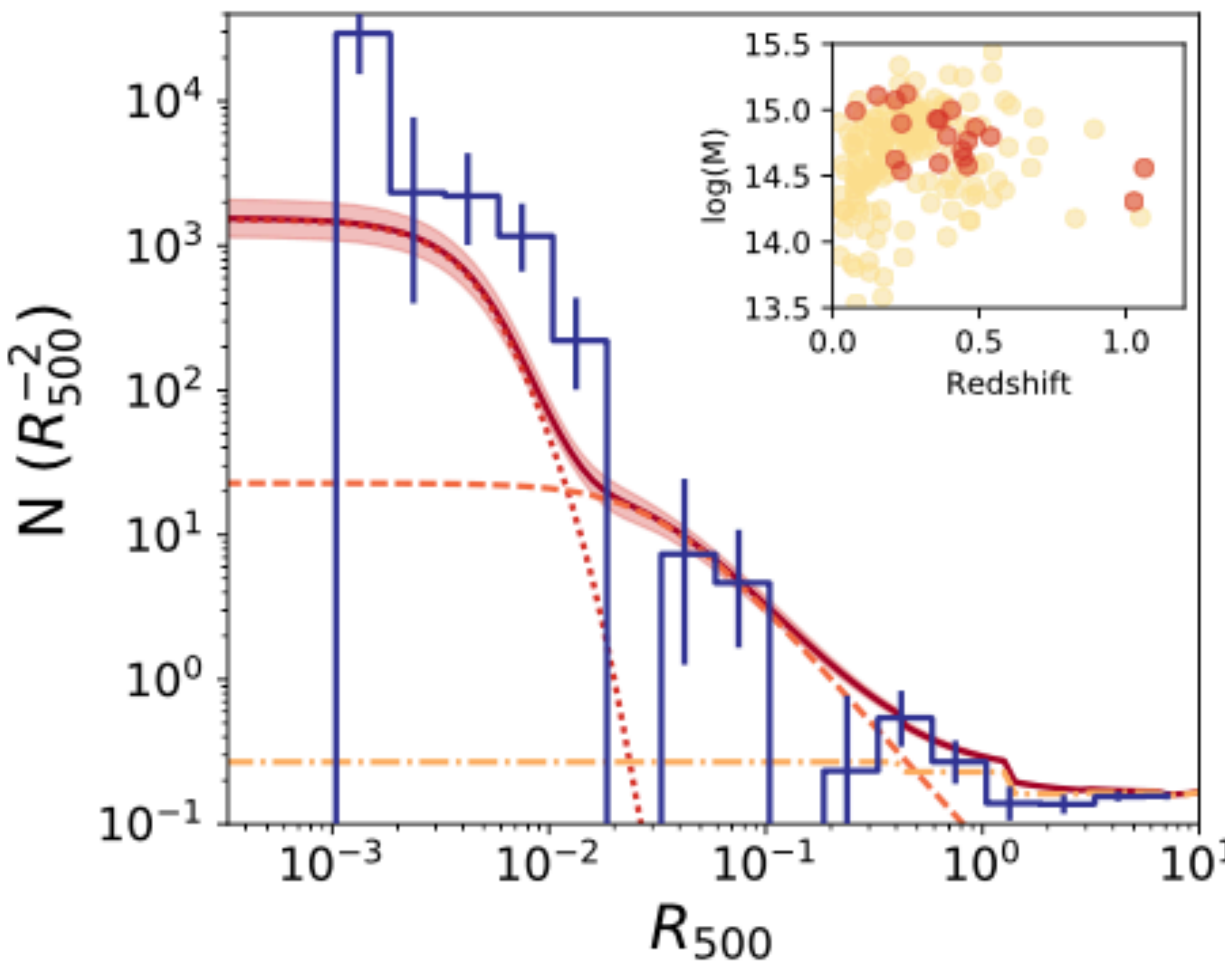


Cluster morphology **S**ymmetry-**P**eakiness-**A**lignment see Mantz et al. 2015

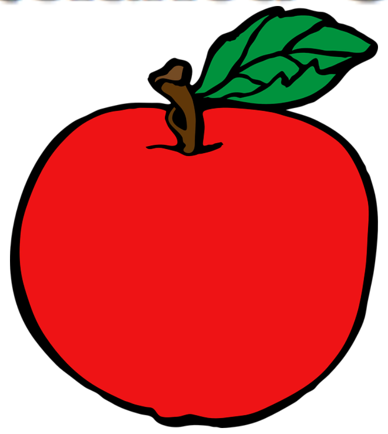
Canning et al.

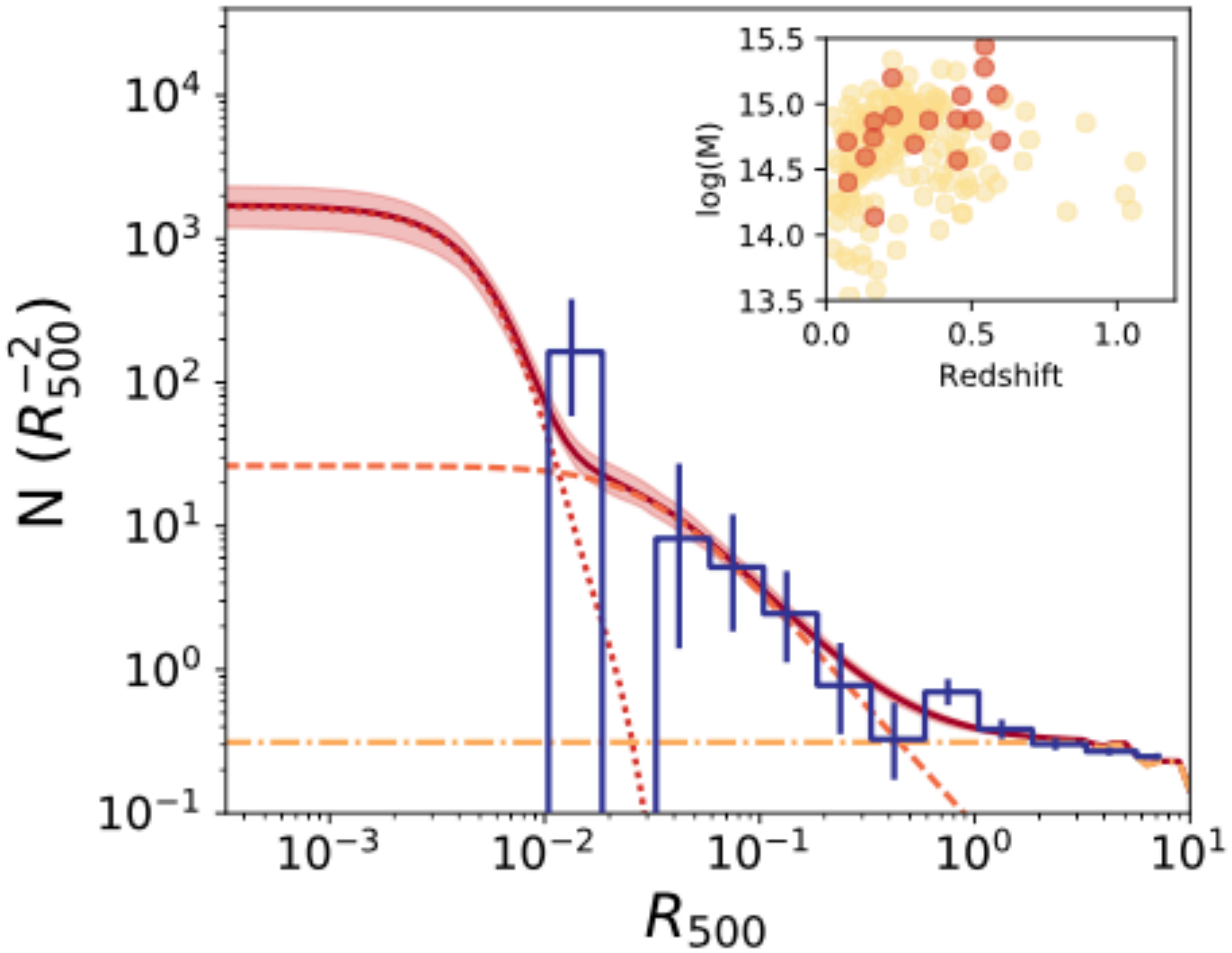
RADIO AGN

CLUSTER DYNAMICAL STATE

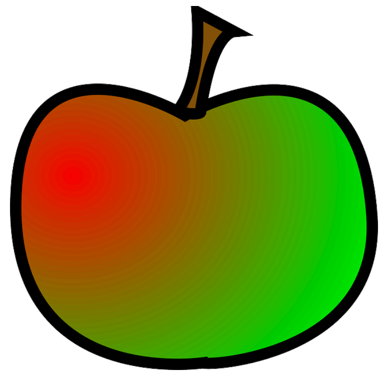


(a) Relaxed Clusters





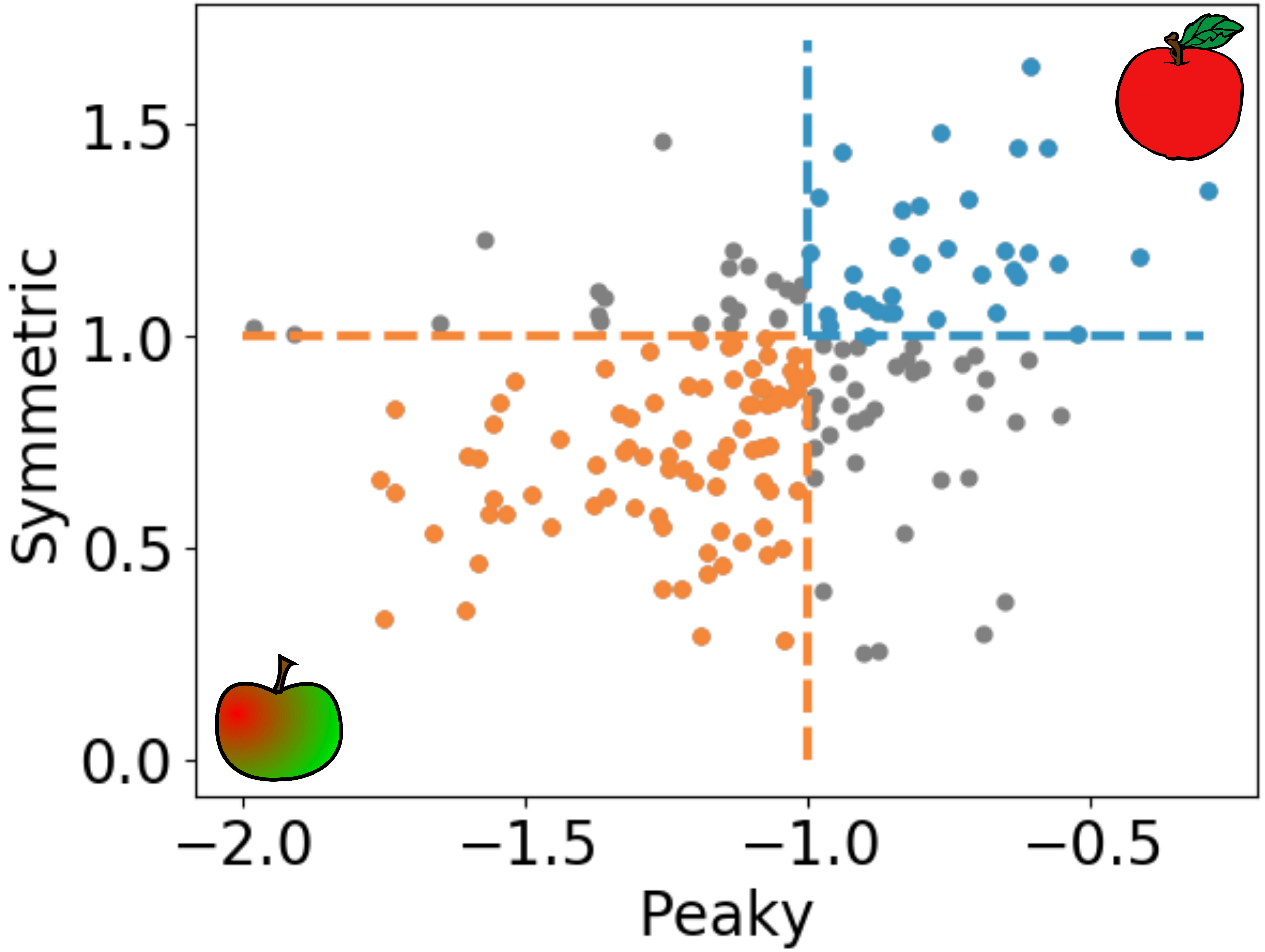
(c) Least Relaxed Clusters

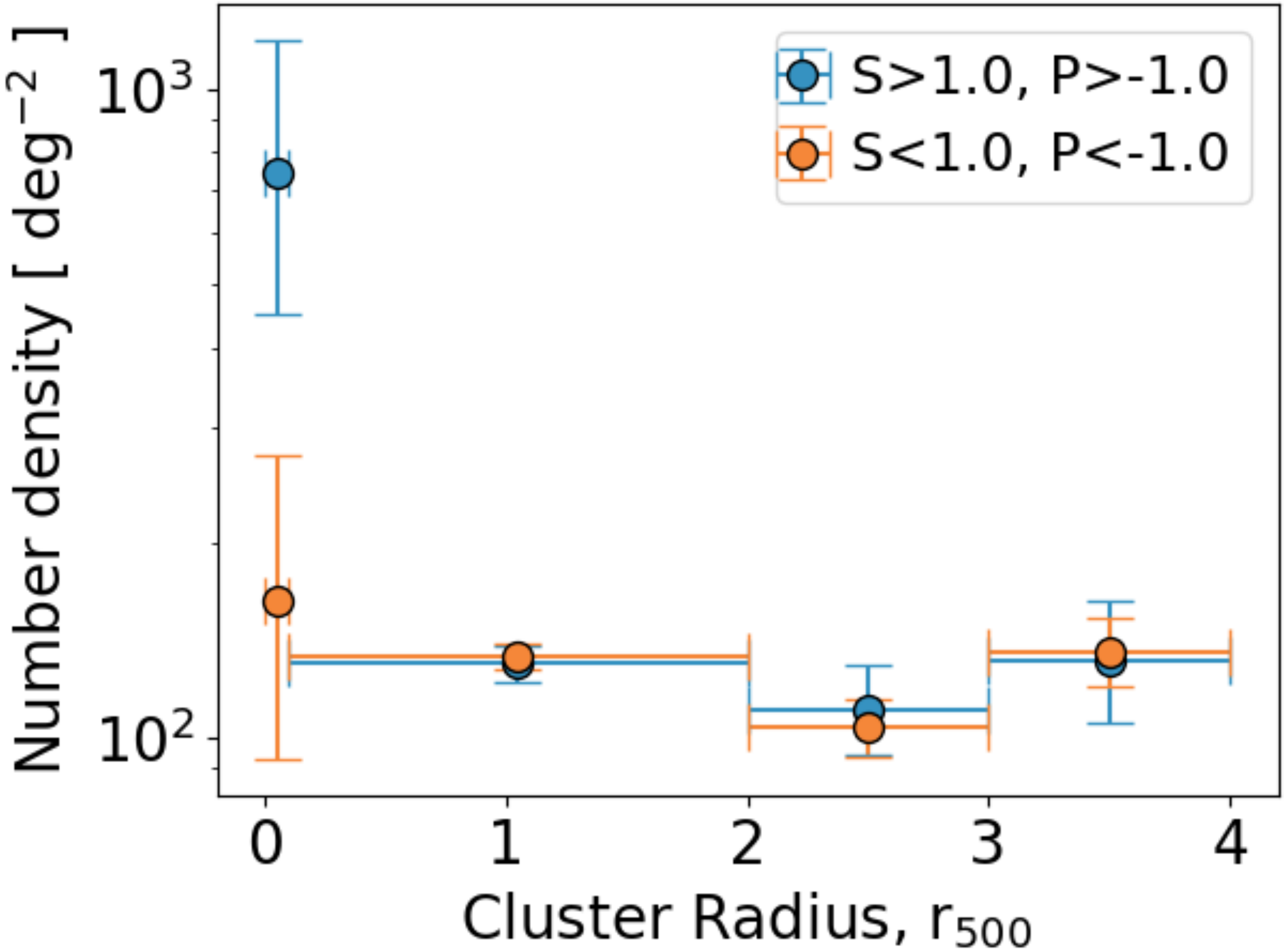


Canning et al.

X-RAY AGN

CLUSTER DYNAMICAL STATE





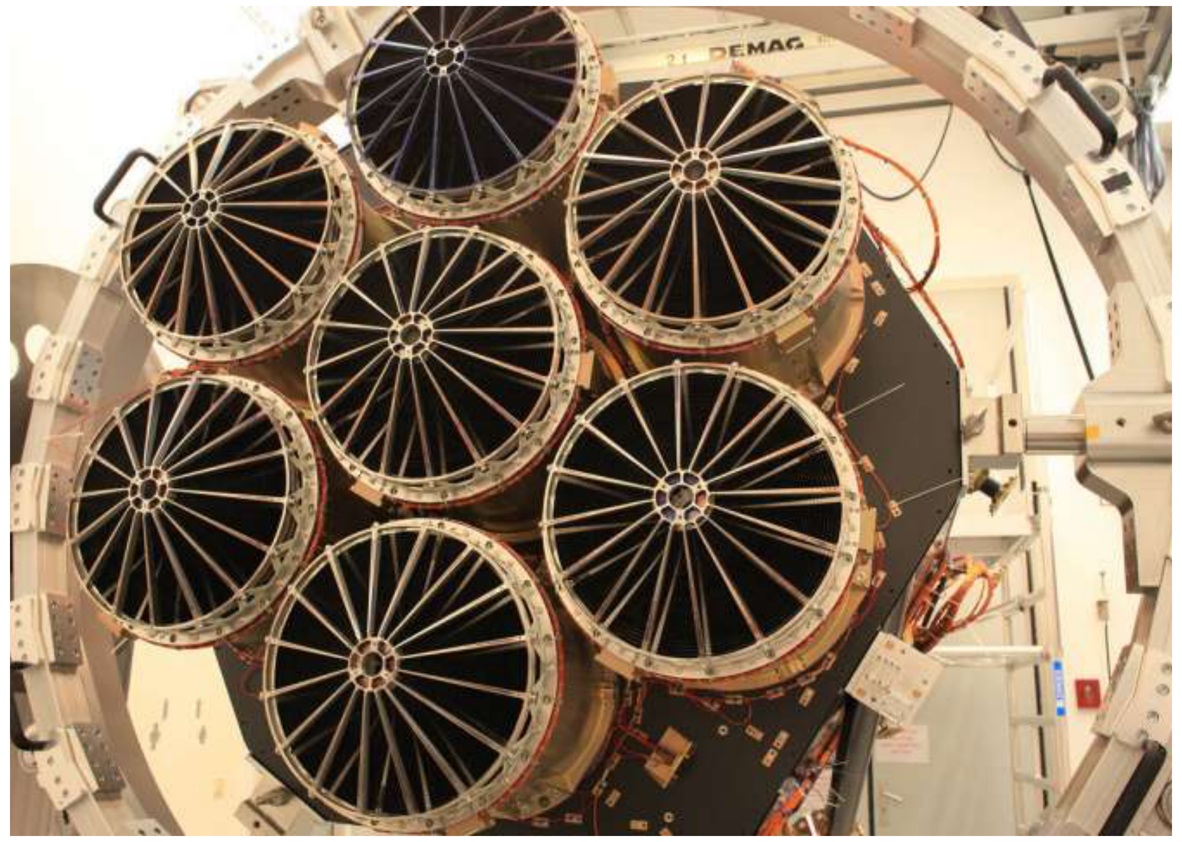
Cluster morphology **S**ymmetry-**P**eakiness-**A**lignment see Mantz et al. 2015

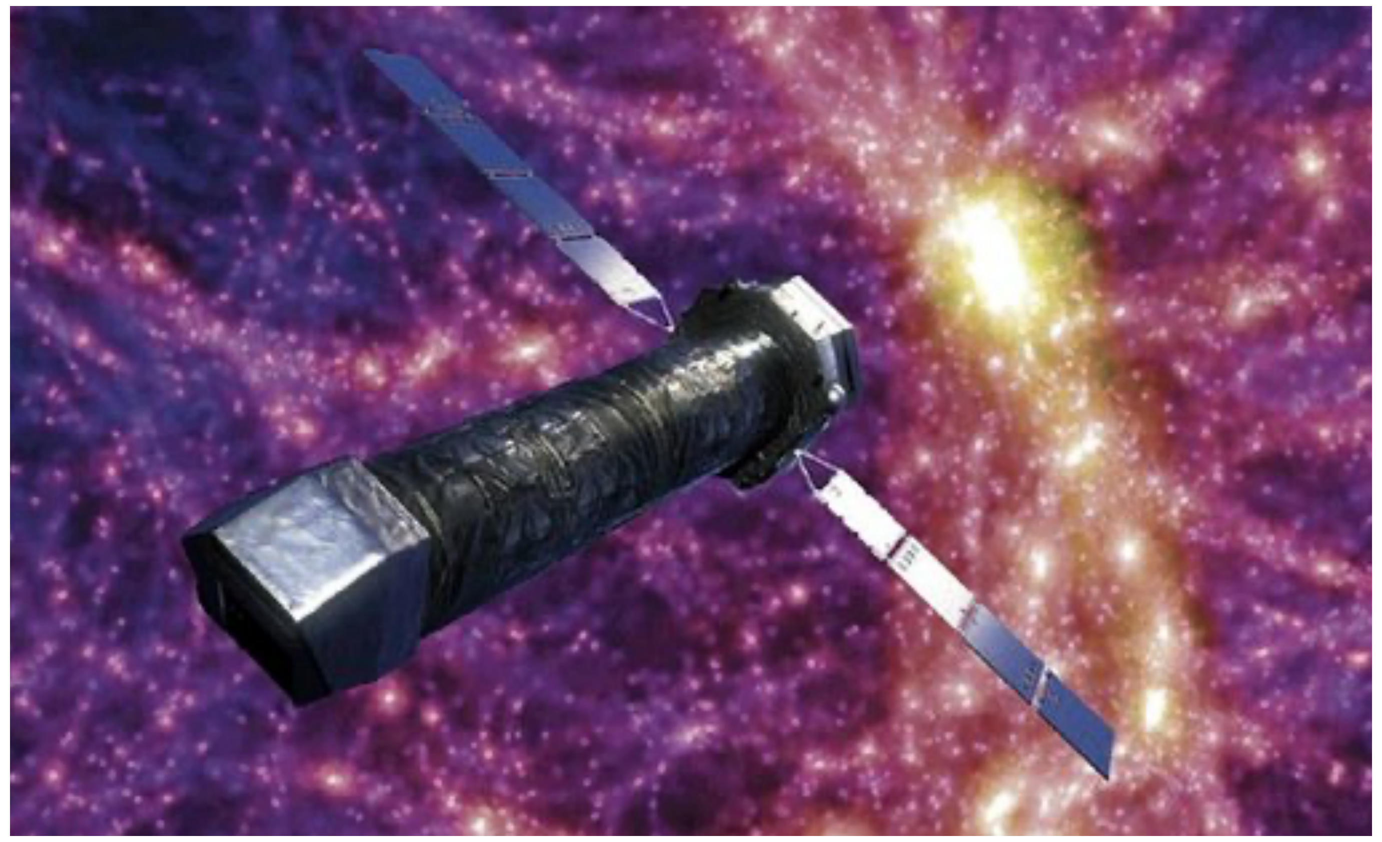
Canning et al.

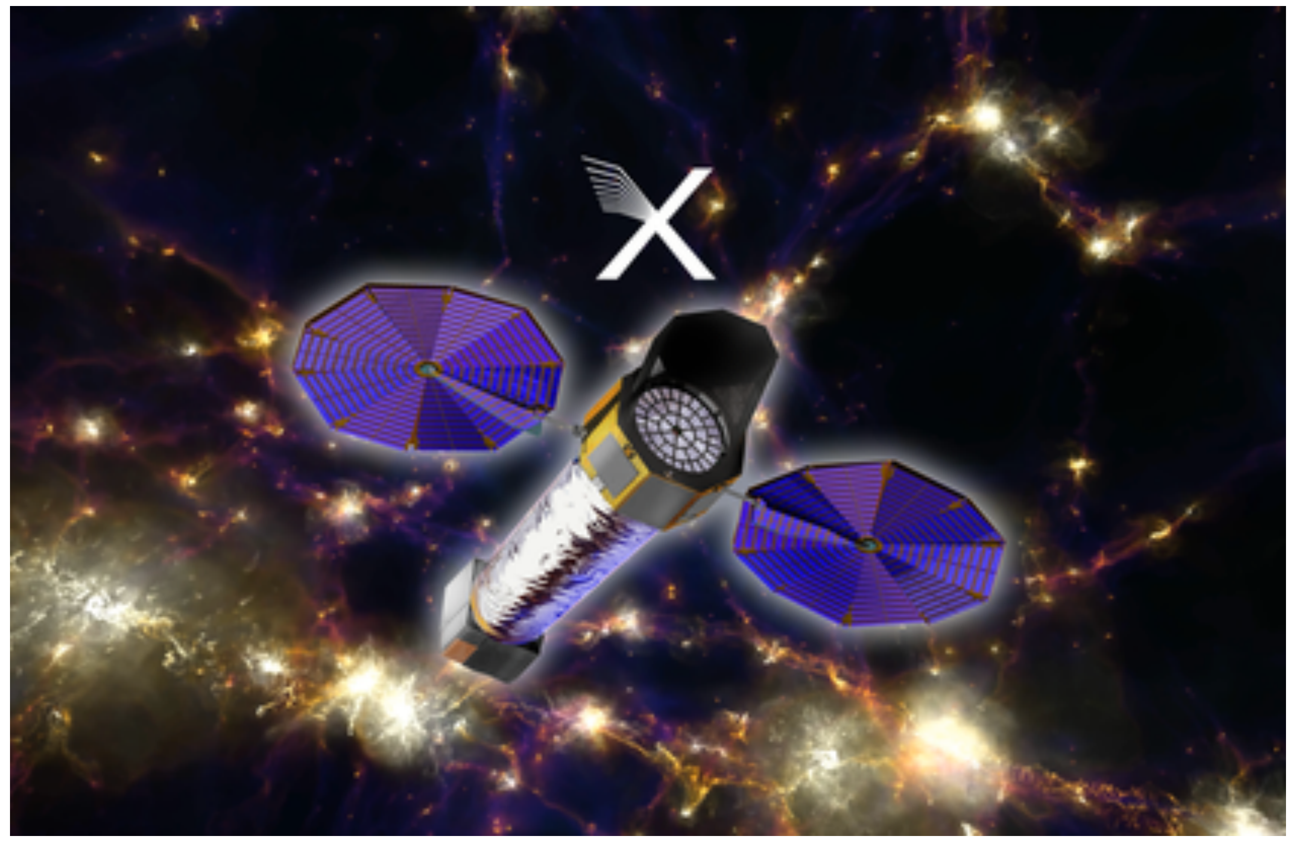
WHAT'S NEXT?

- Full dataset for X-ray, radio and IR AGN.
- Comparison with galaxy population distributions particularly star formation.
- Comparison to models of merger rates and environmental processes in clusters.

WHAT'S NEXT?

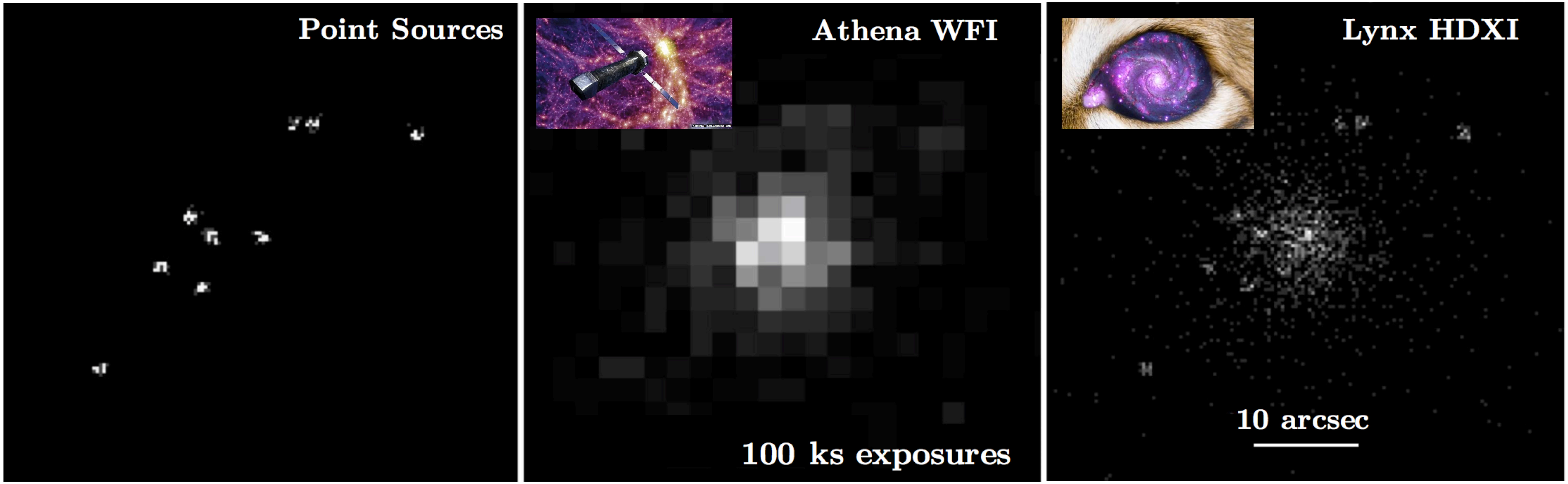






- eROSITA: superb understanding of low-z halo mass dependence
- Athena: great statistics on higher redshift (z~1) AGN in clusters
- Lynx: AGN at the epoch of cluster formation

WHAT'S NEXT?



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