Discovery of a galaxy cluster with a violently starbursting core at z=2.506

—AND WHAT WE HAVE LEARNED SO FAR?

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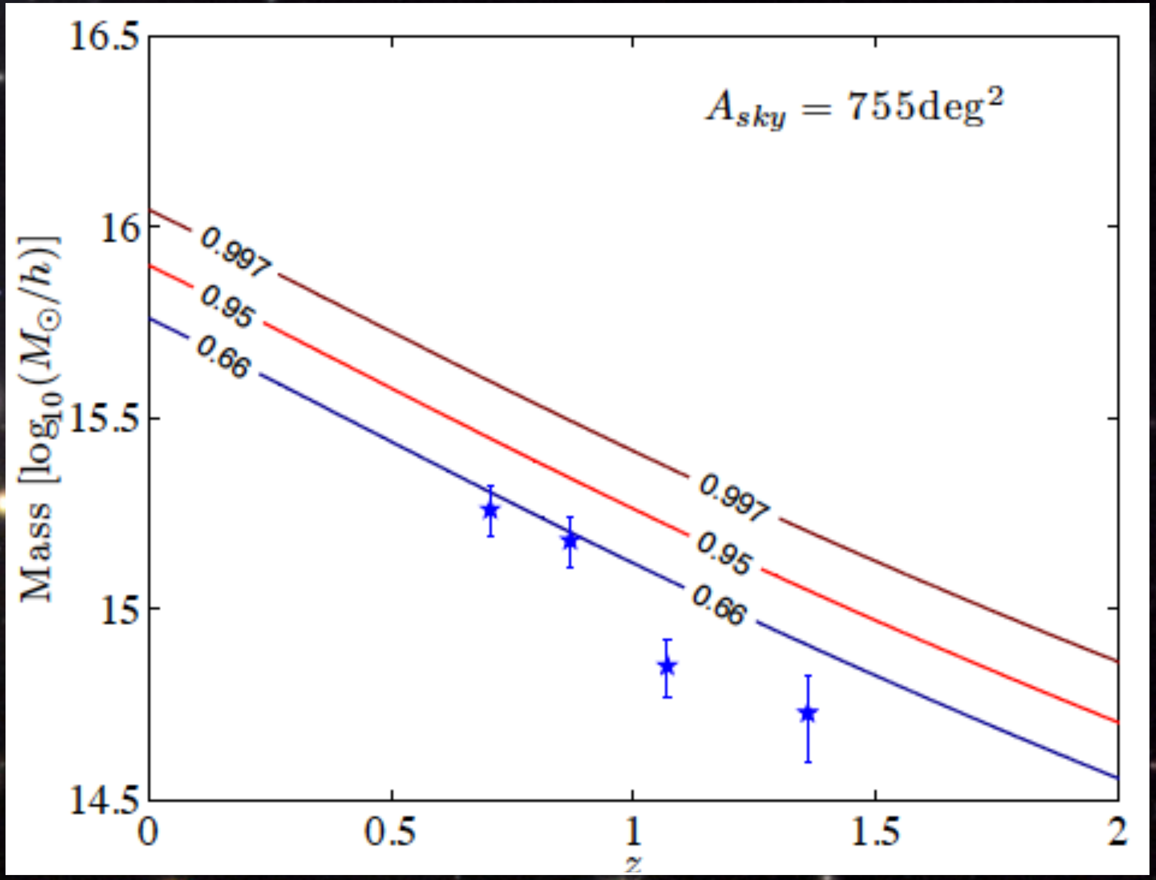
Galaxy clusters trace the most massive halos

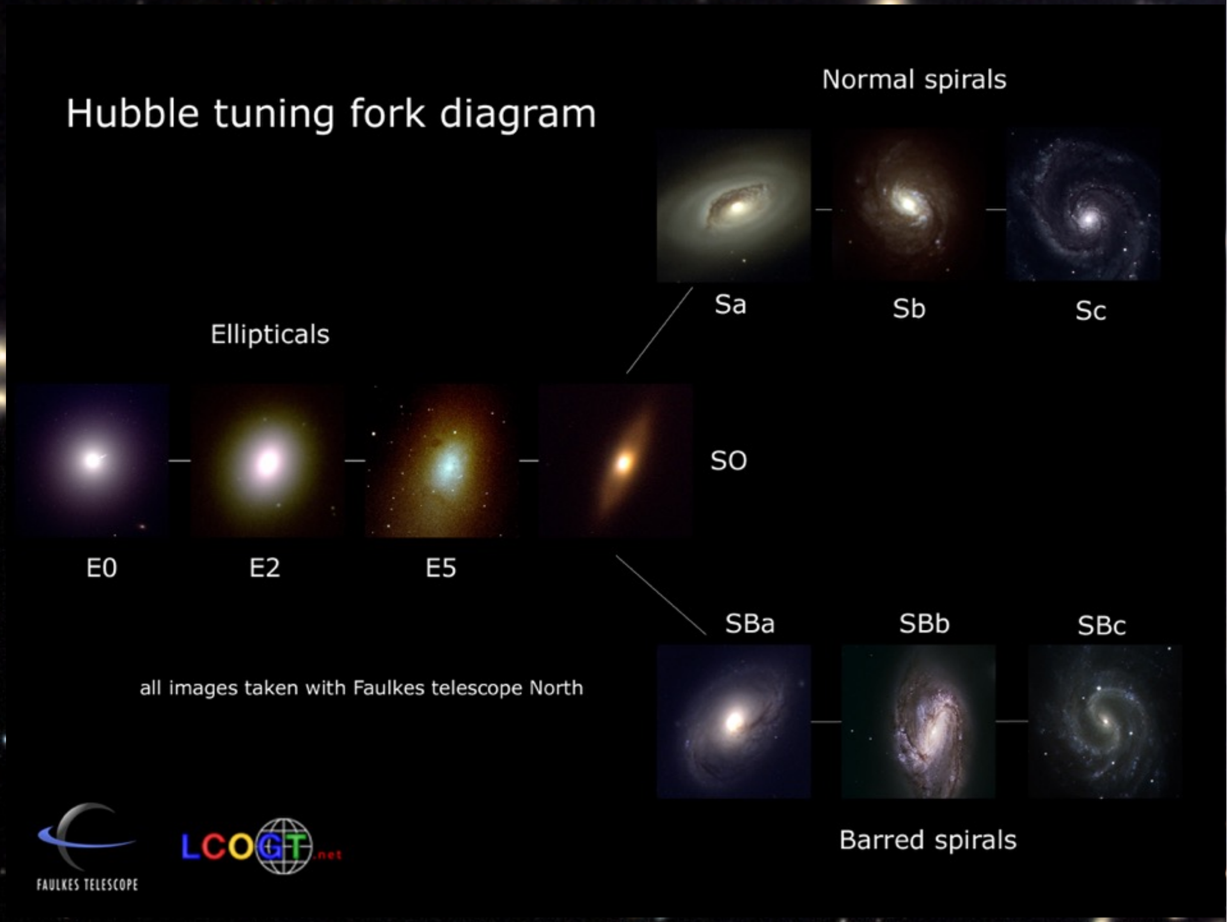
$$\langle N_{>m>z} \rangle = \left[\int_z^\infty \int_m^\infty dz\, dM\, \frac{dV}{dz} \frac{dn(M,z)}{dM} \right]$$

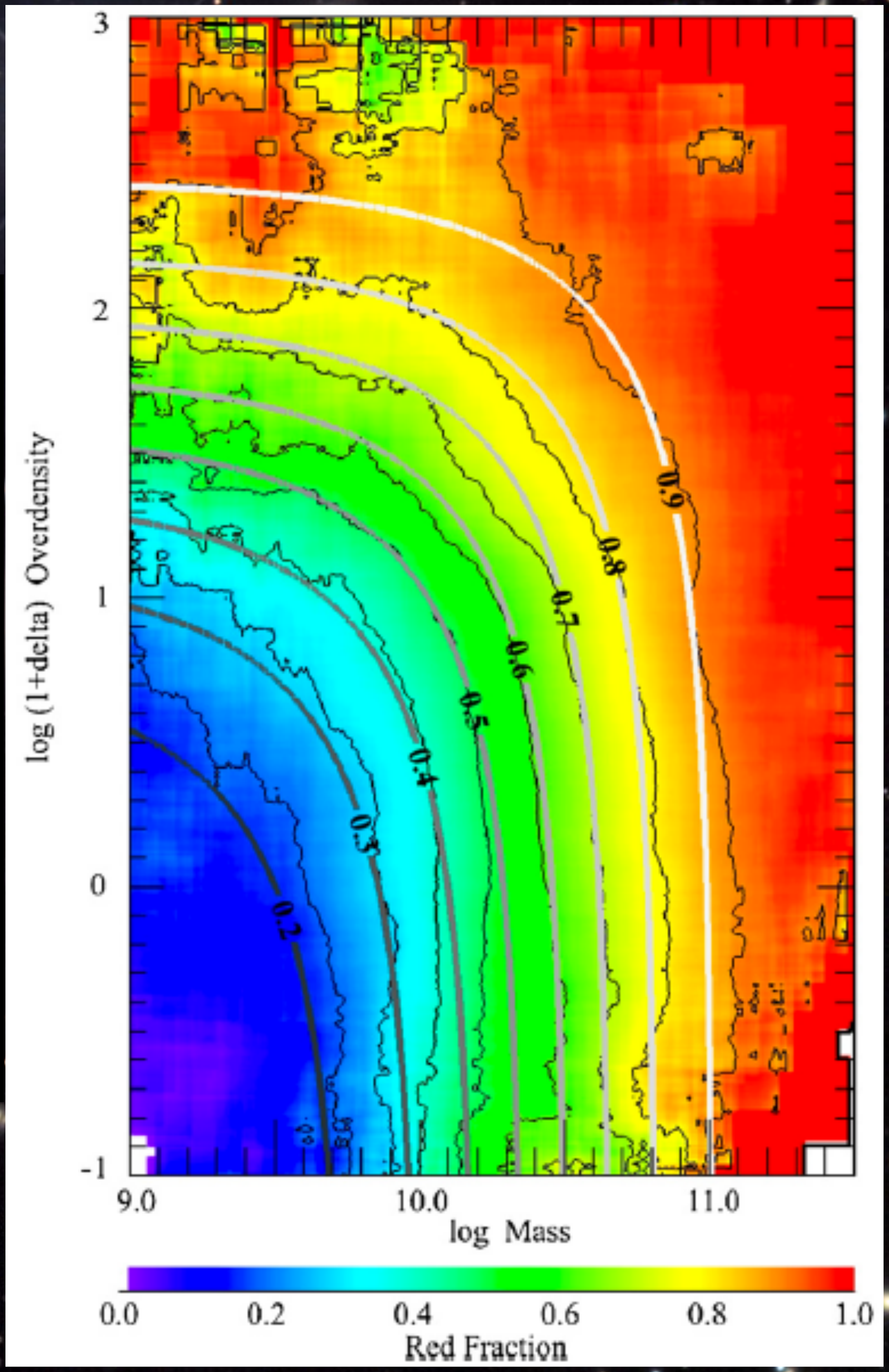
$$\langle N_{>mdV} \rangle = \left[\int_m^\infty dM\, \frac{dn(M,z)}{dM} \right]$$



Harrison+2013

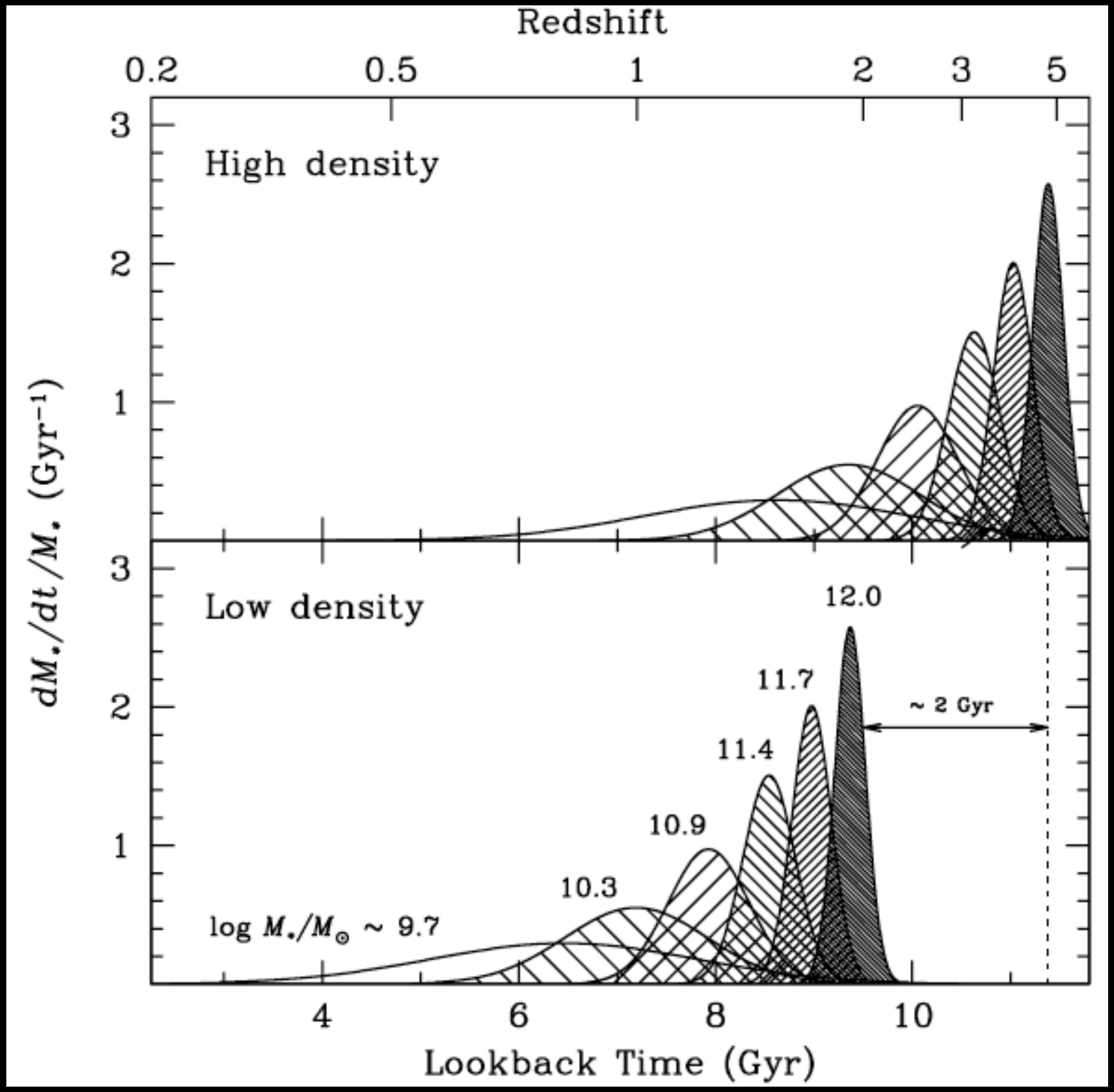
Galaxy clusters trace the densest galaxy environment

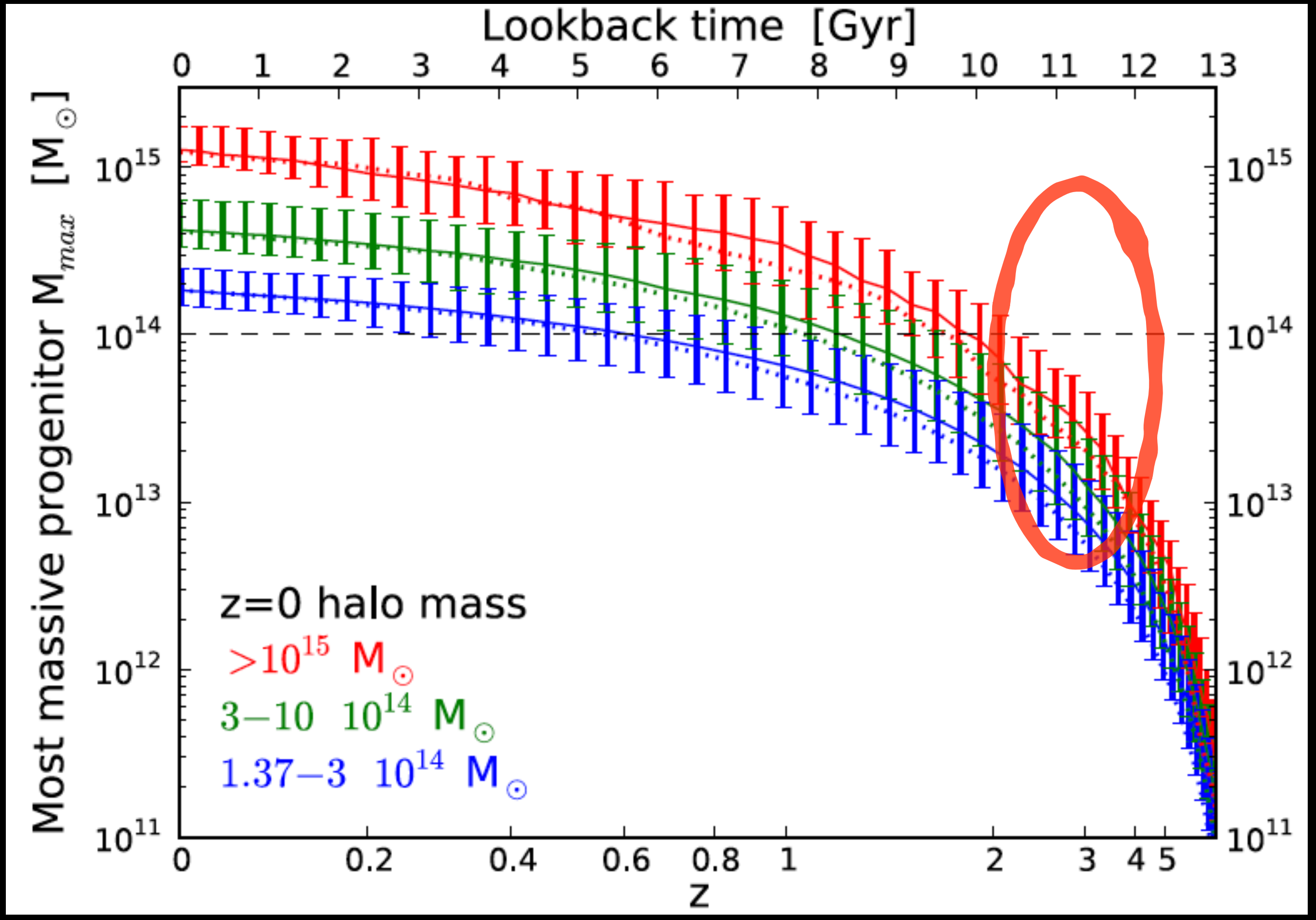




Peng+2010

Hunting for distant galaxy clusters



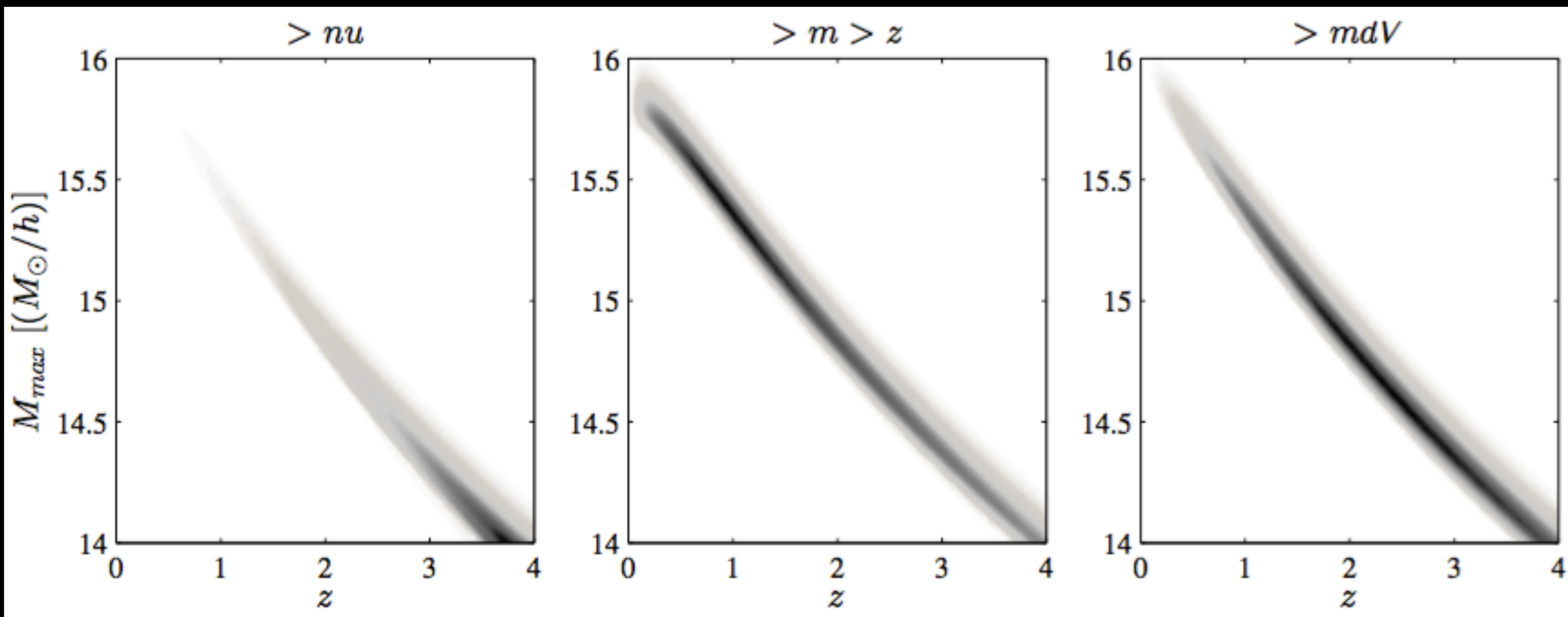


Thomas et al. 2005

Chiang+2013

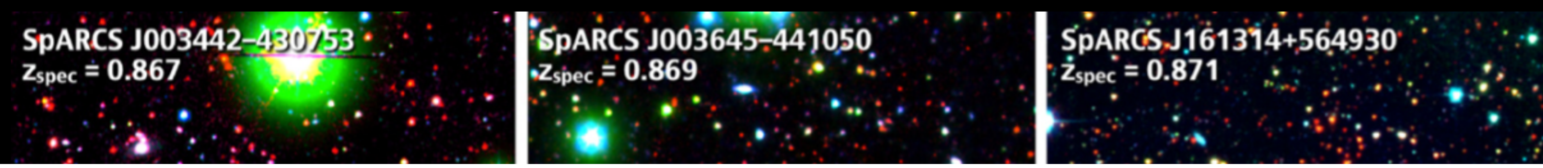
The most massive progenitor of a present-day Coma-like cluster ($M_{200c} > 10^{15}\ M_\odot$) reached $10^{14}\ M_\odot$ at z ~2.

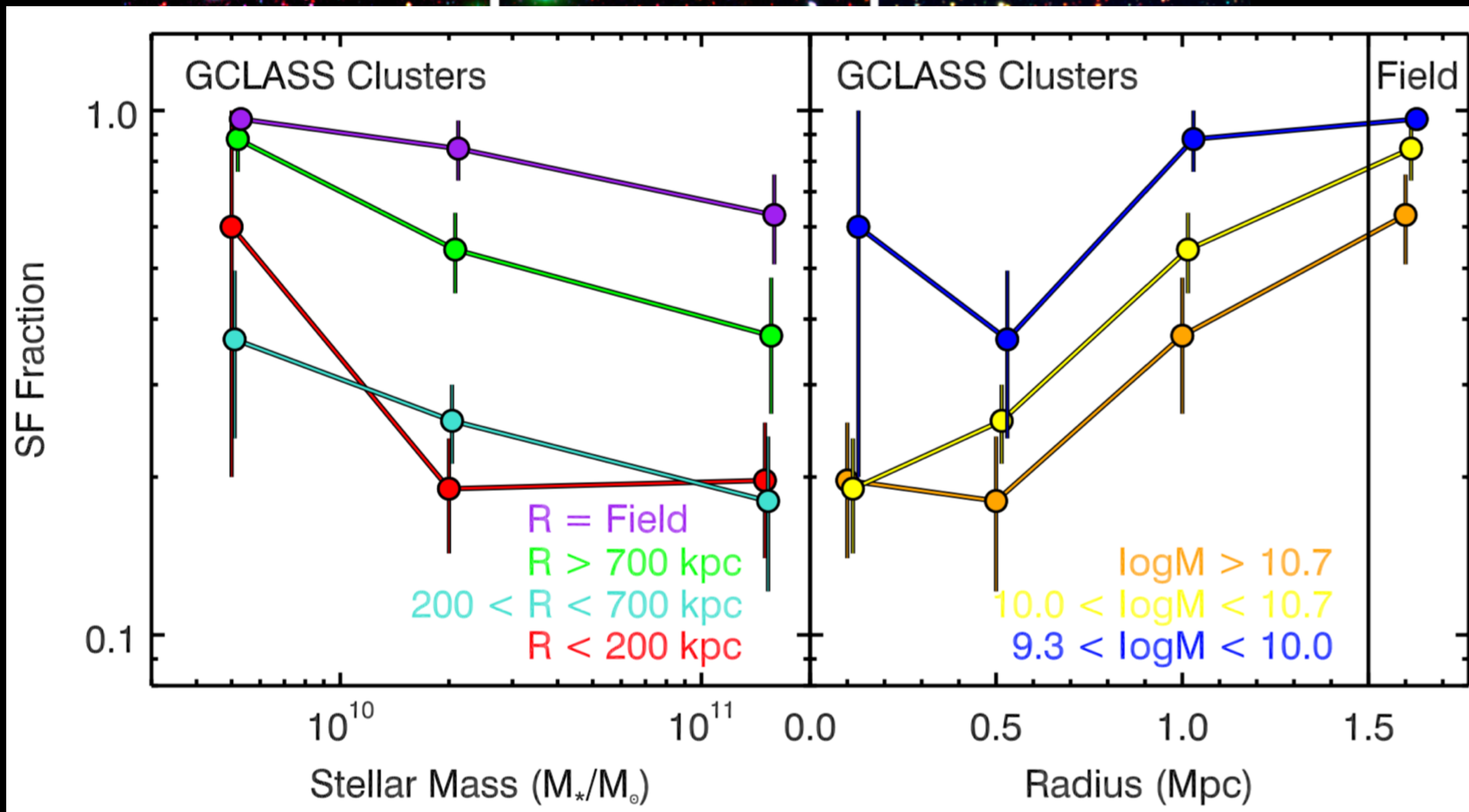
Hunting for distant galaxy clusters

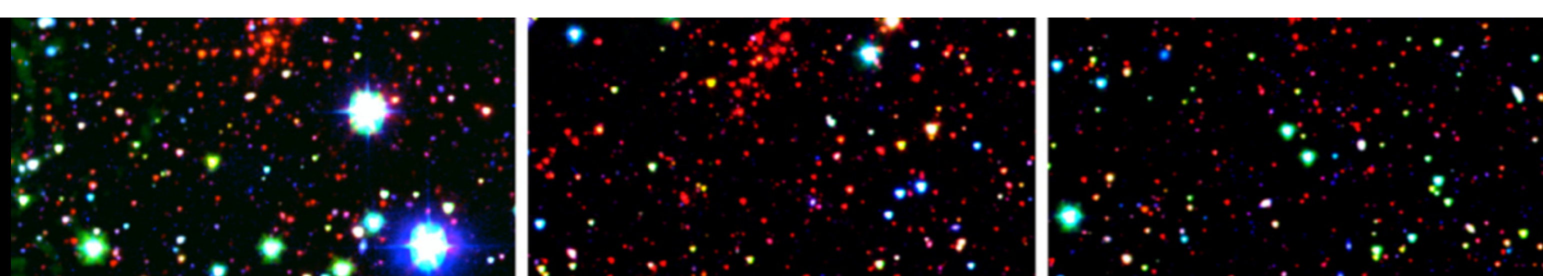


Harrison+2013

z~1

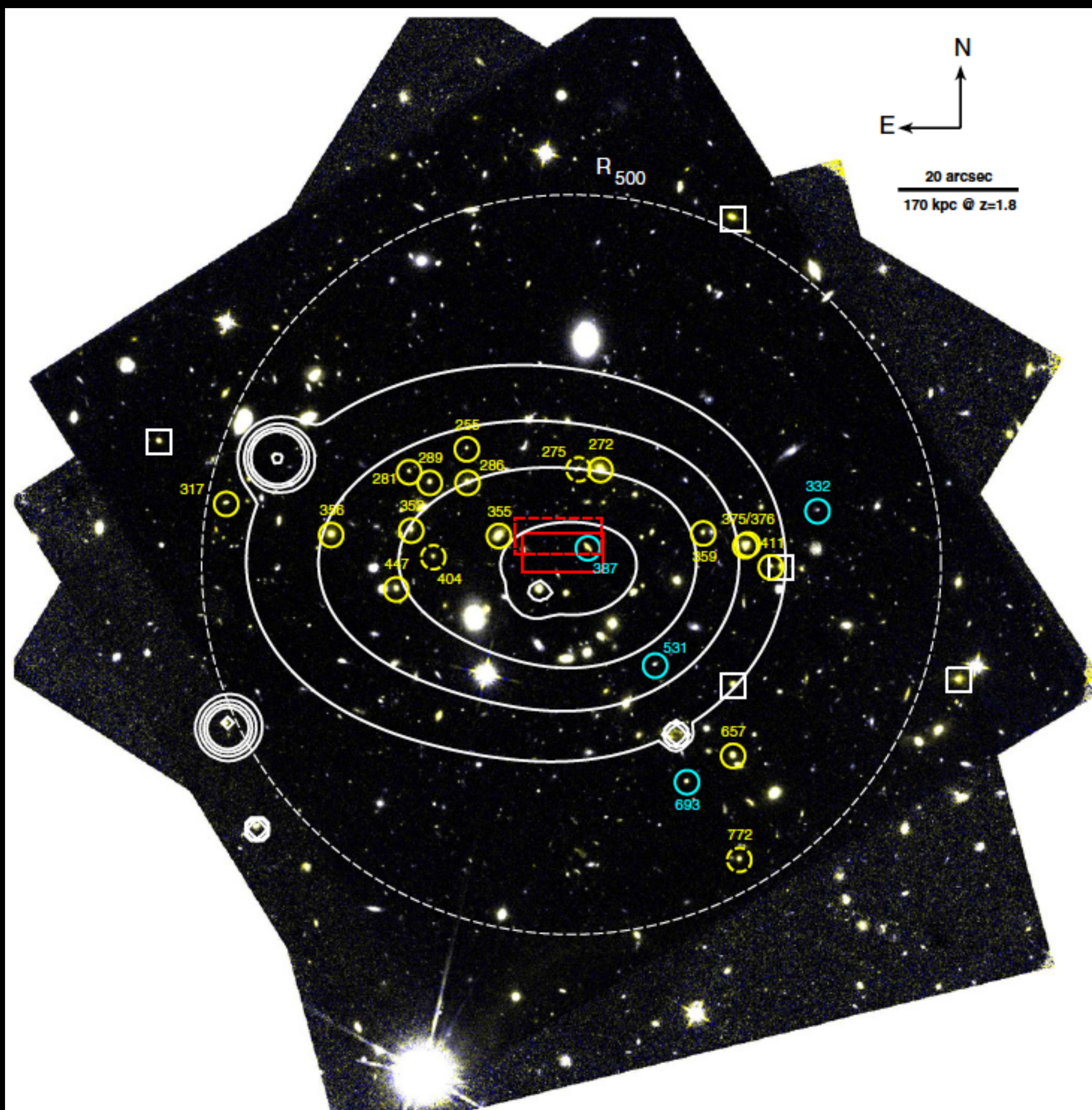


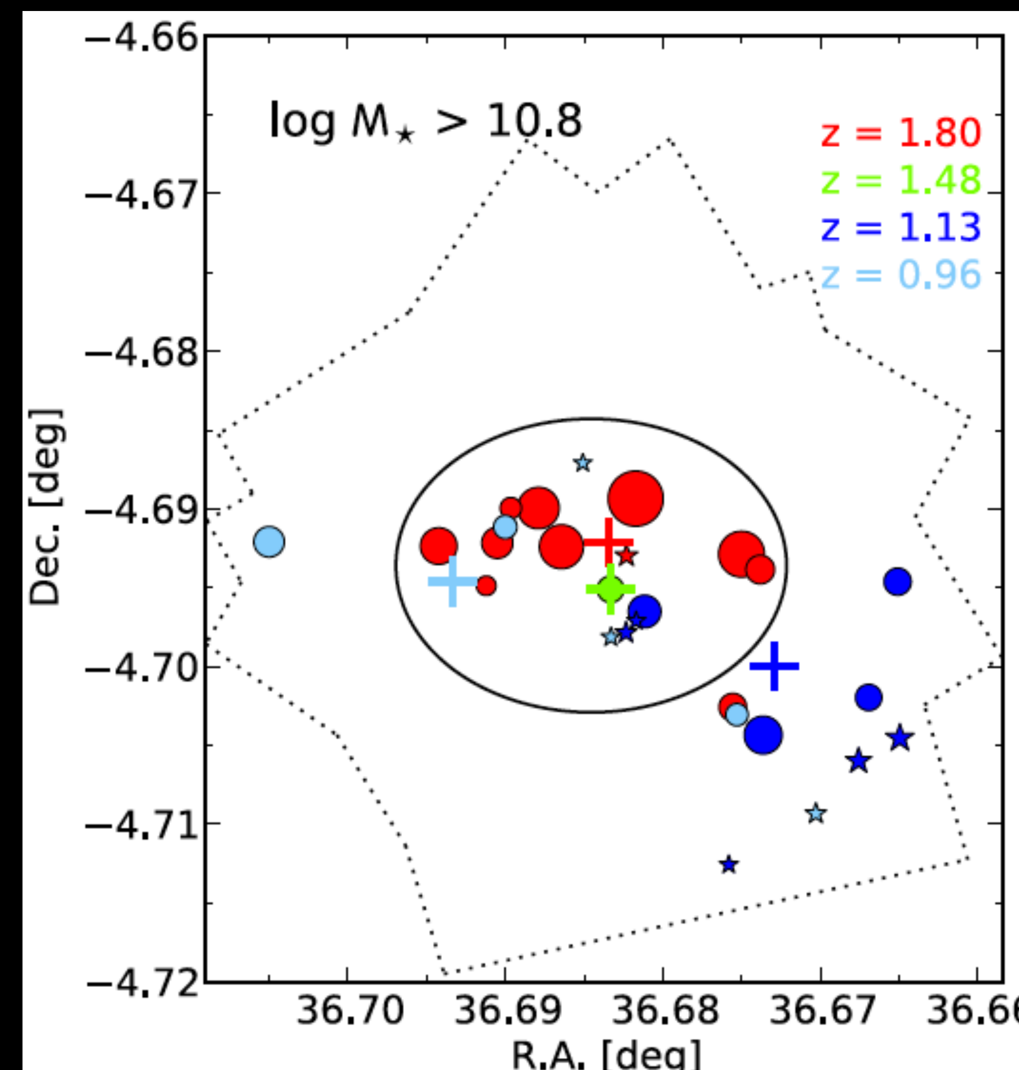




Muzzin+2012

z~2

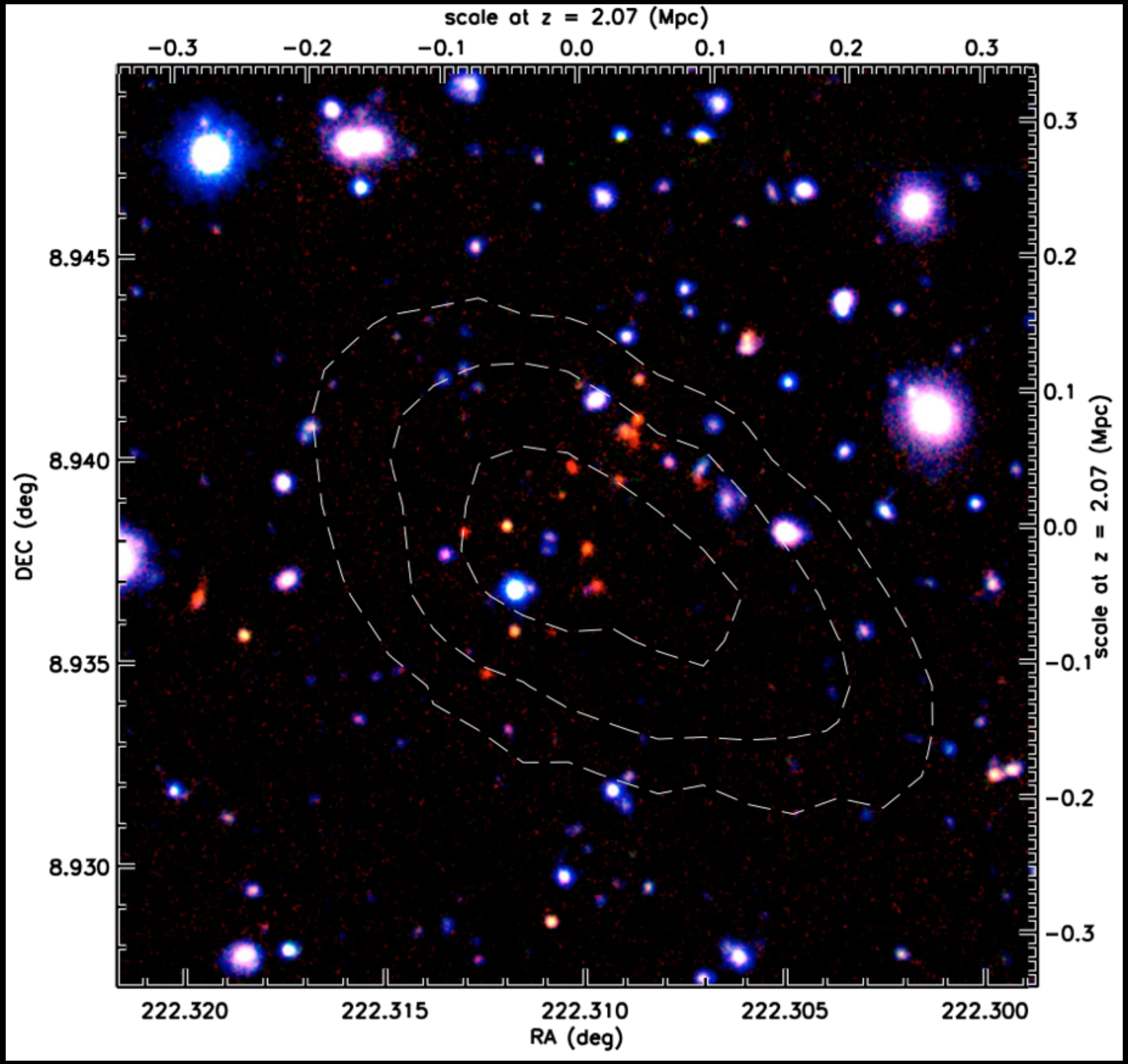


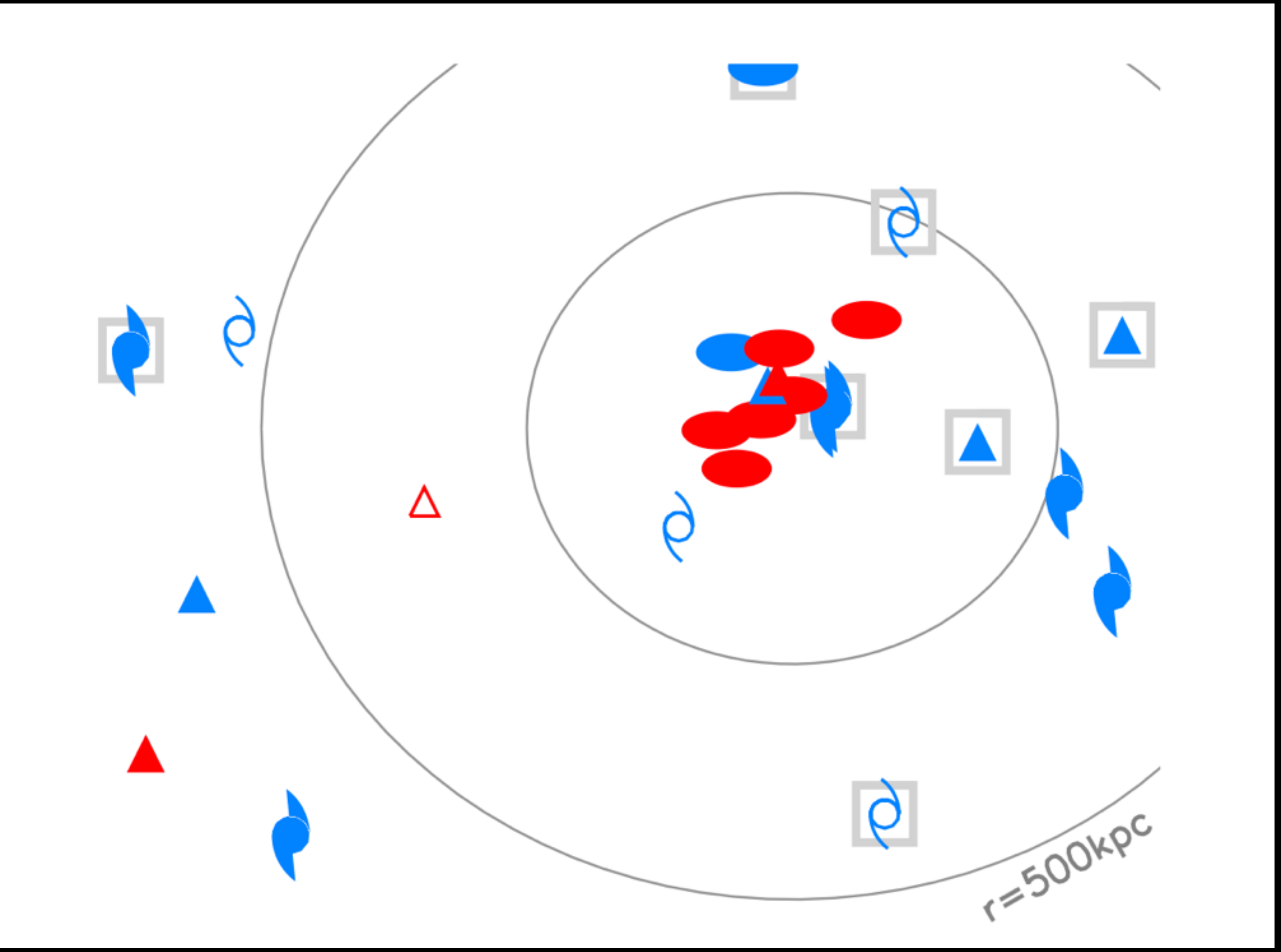


JKCS 041@z=1.803

Newman+2014

z~2





Gobat+2011

Strazzullo+2013

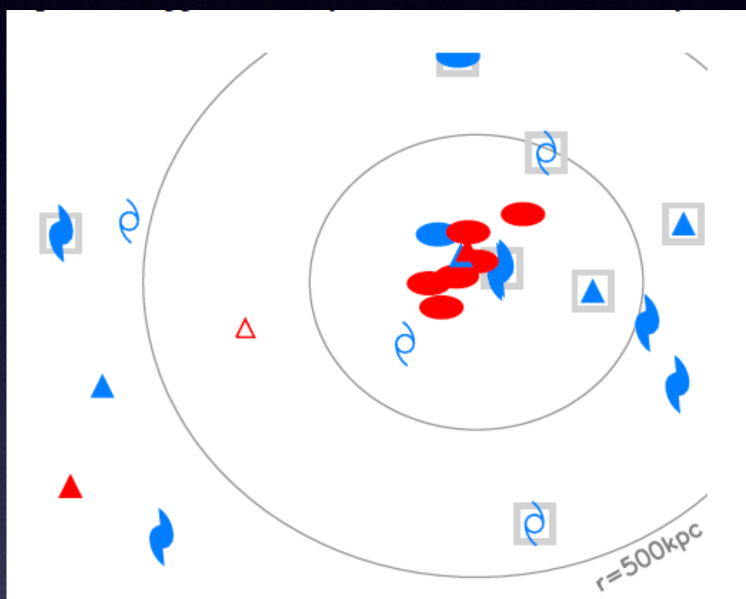
Hunting for high-z galaxy (proto)clusters

mature clusters:

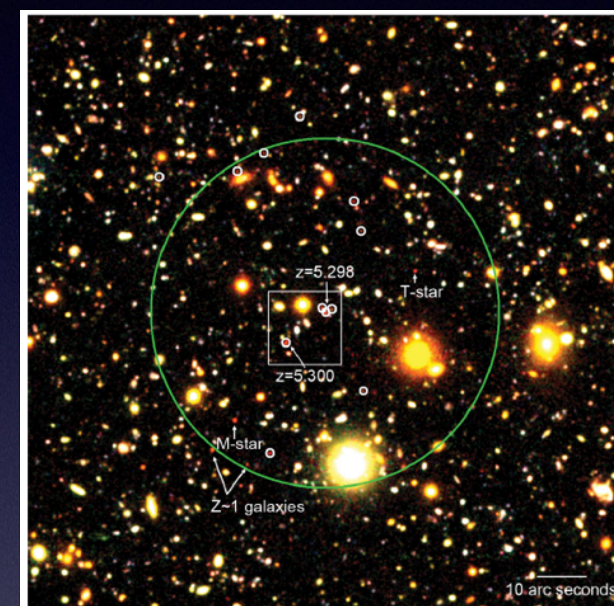
a massive, collapsed halo;
concentration of ellipticals

protoclusters:

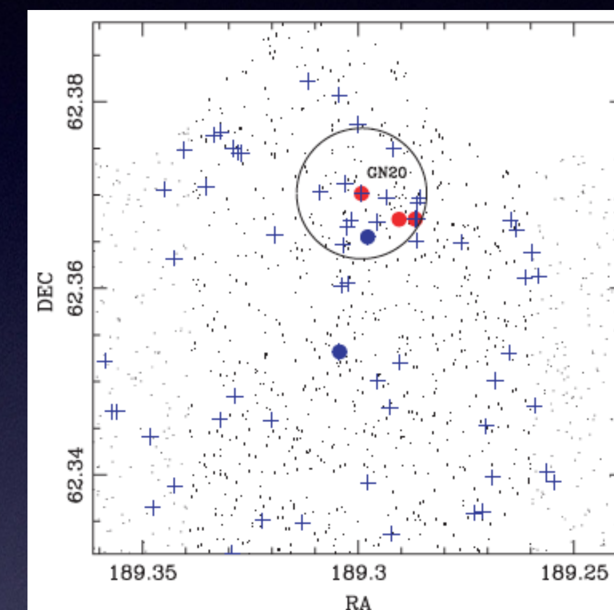
low (star-forming)galaxy densities;
extended, multiple halos



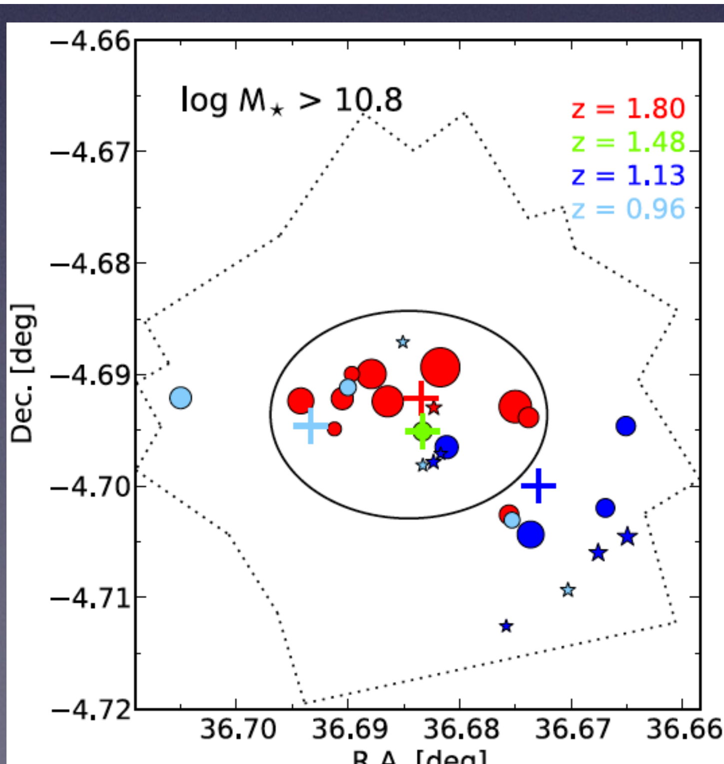
z=2.0,
Strazzullo+2013



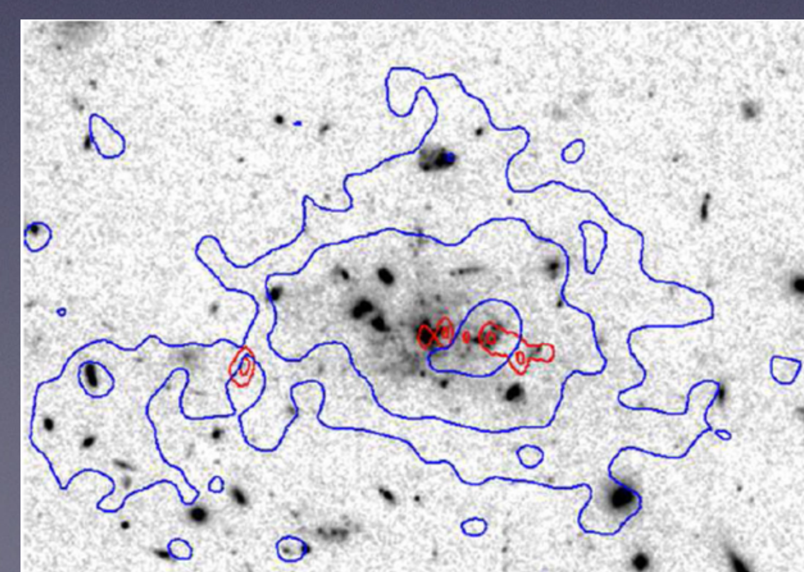
0, Capak+2011



z=4.05,Daddi+2010



z=1.8,
Newman+2014

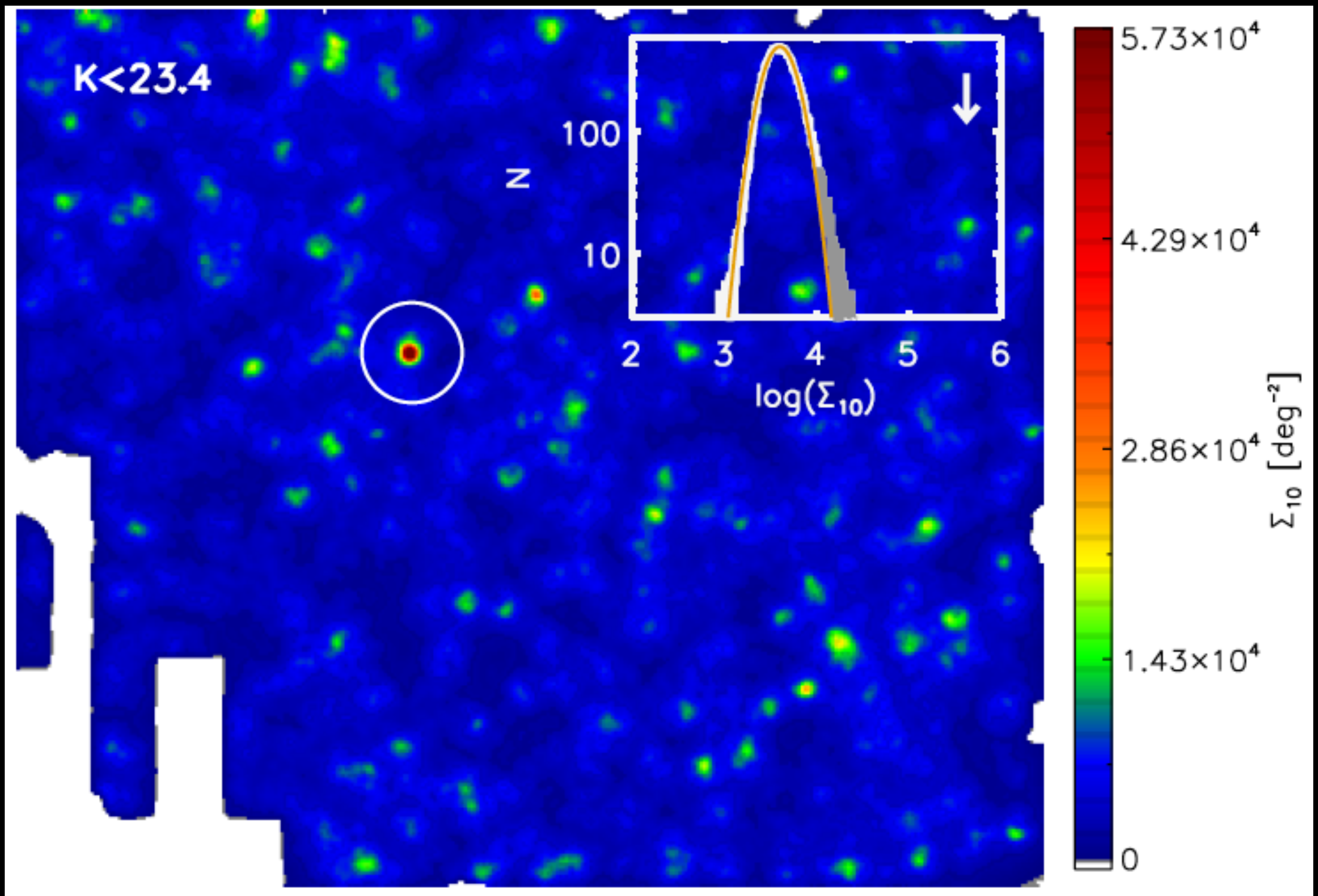


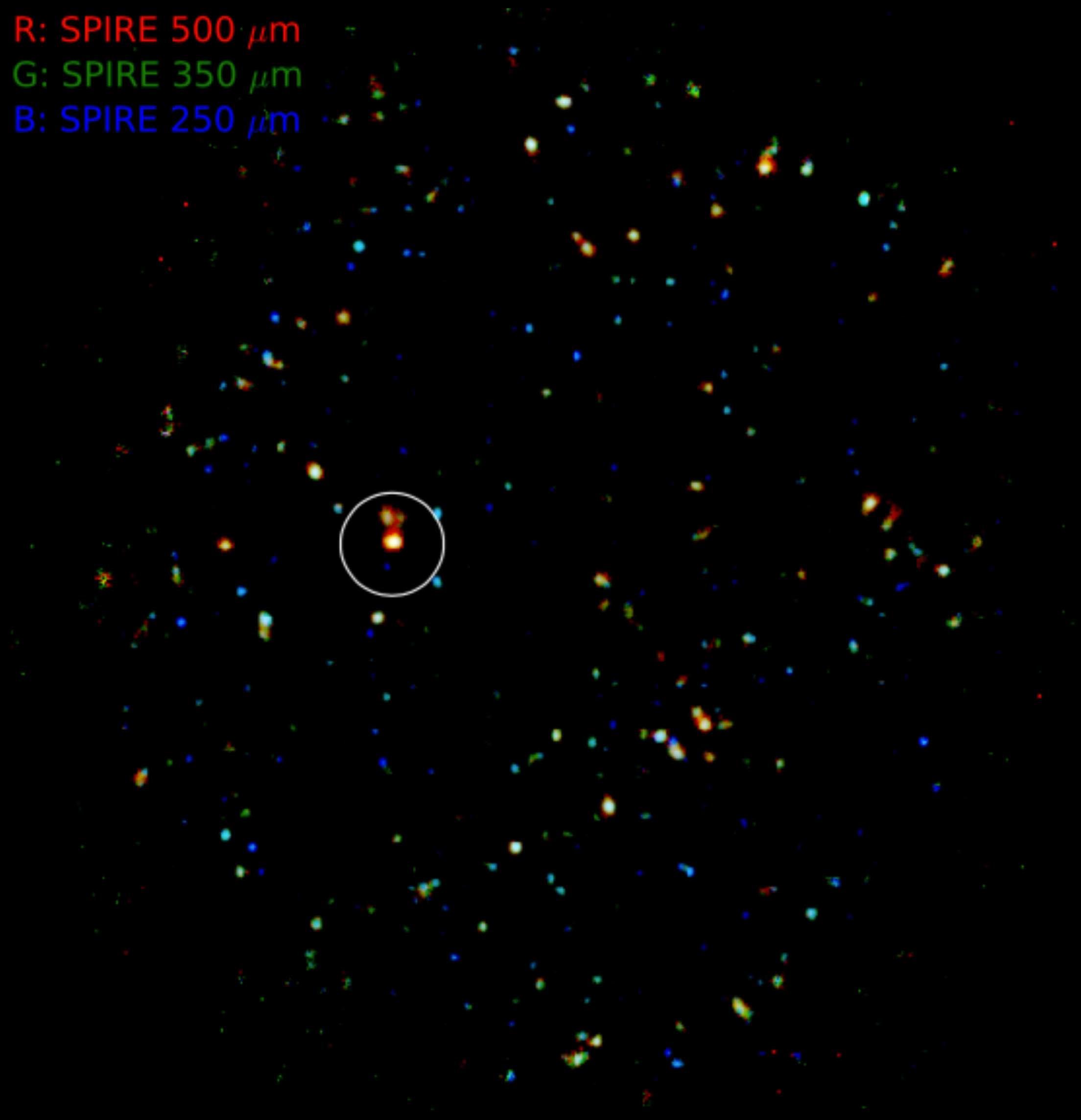
Spiderweb Galaxy
z=2.2
Miley+2006,Koyama+2013

Questions to be addressed

- When do cluster ellipticals form, before or after the collapse of the host halo (constraining on the role of “pre-processing”)?
- How do cluster ellipticals form? Are there any evidence for environmental effects on massive galaxy formation in clusters (star formation, AGN s, structure/morphologies)?
- Cosmology

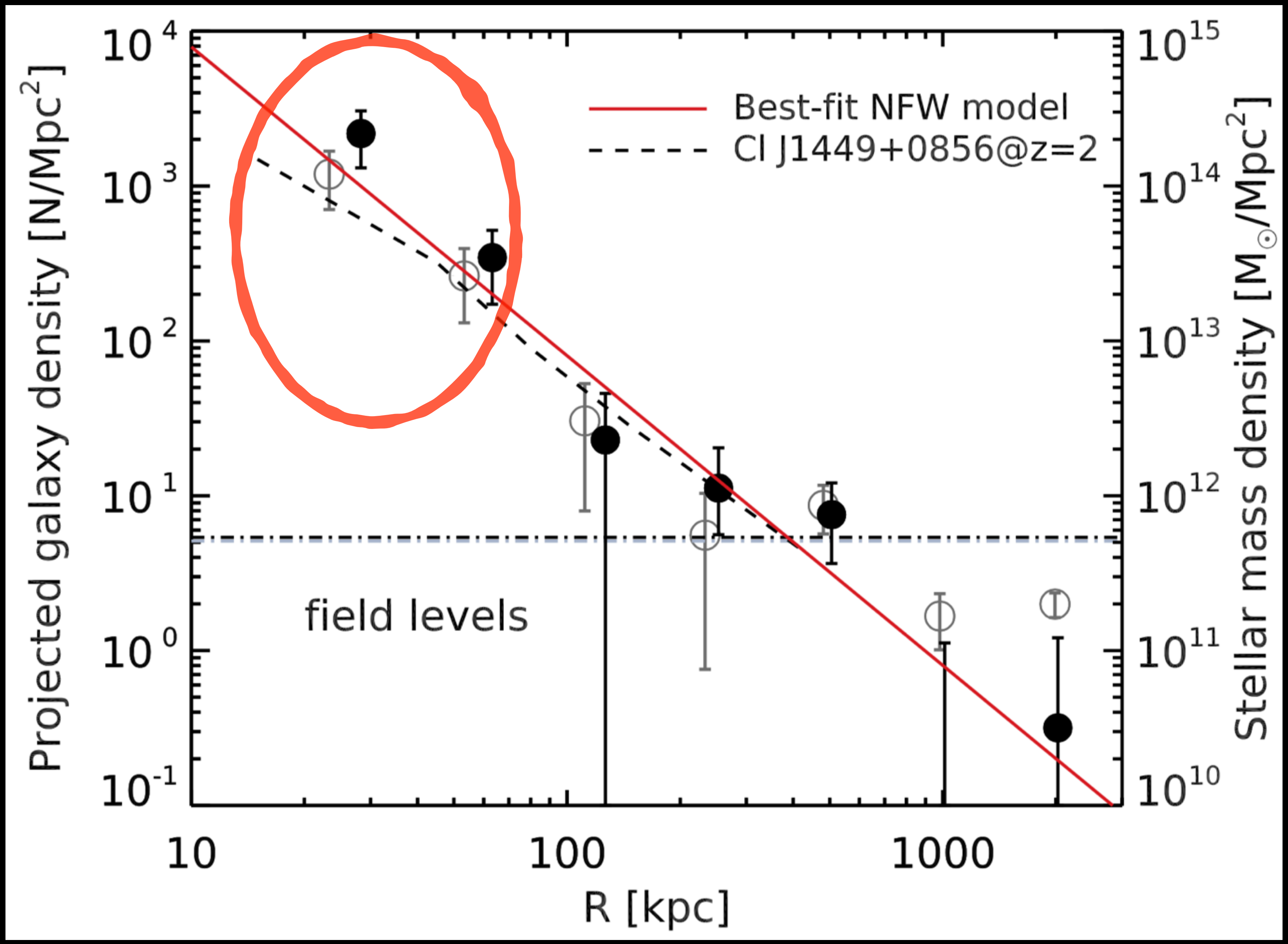
Discovery of an X-ray cluster at z=2.506





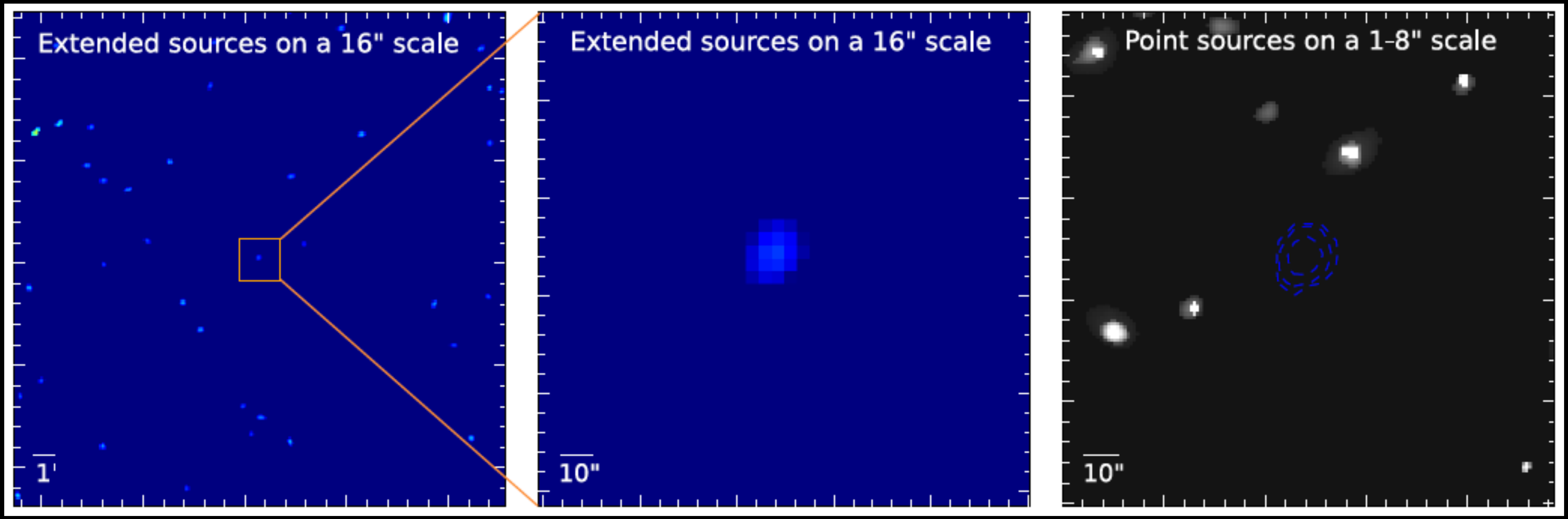
Herschel/SPIRE

Evidence for the presence of a massive, collapsed halo: Stellar mass density profile



Total stellar mass within 100 kpc ~ 2e12 Msun

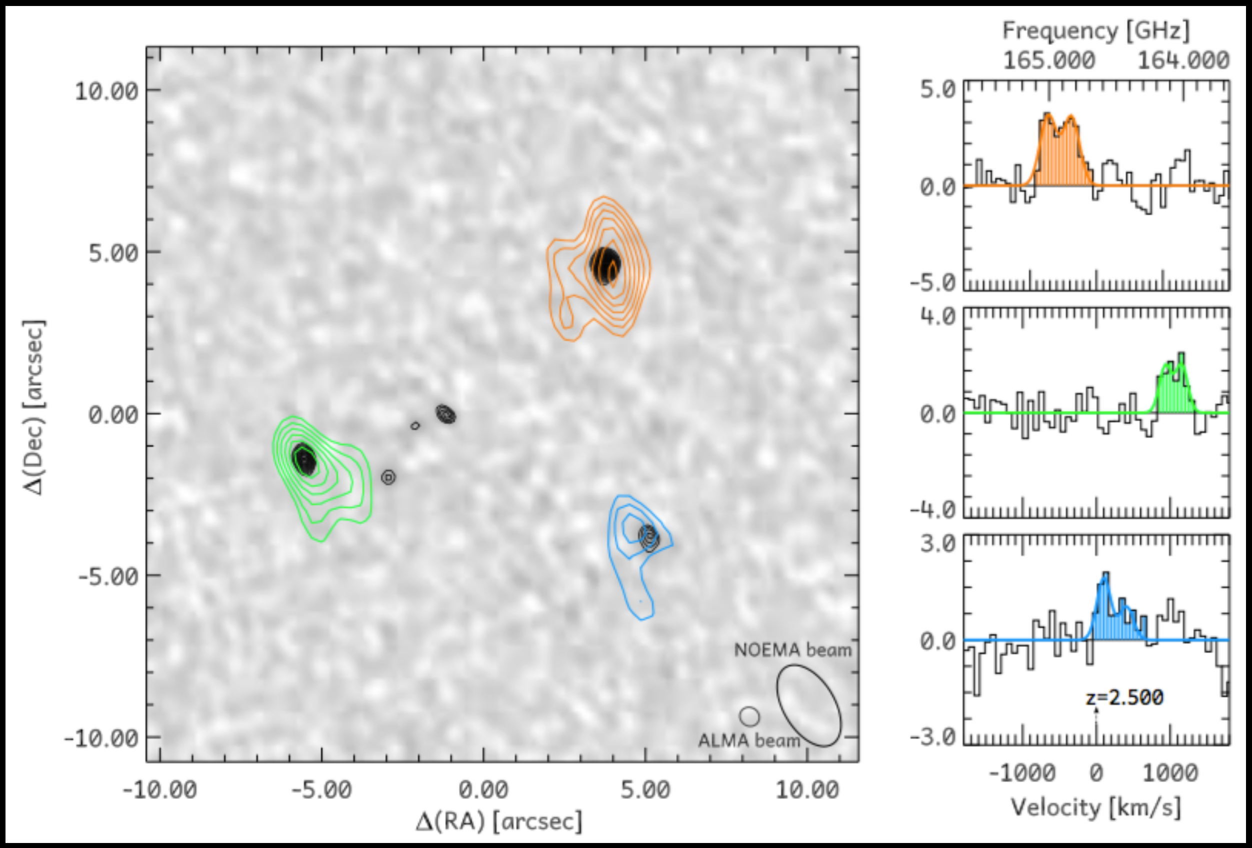
Evidence for the presence of a massive, collapsed halo: X-ray emitting gas

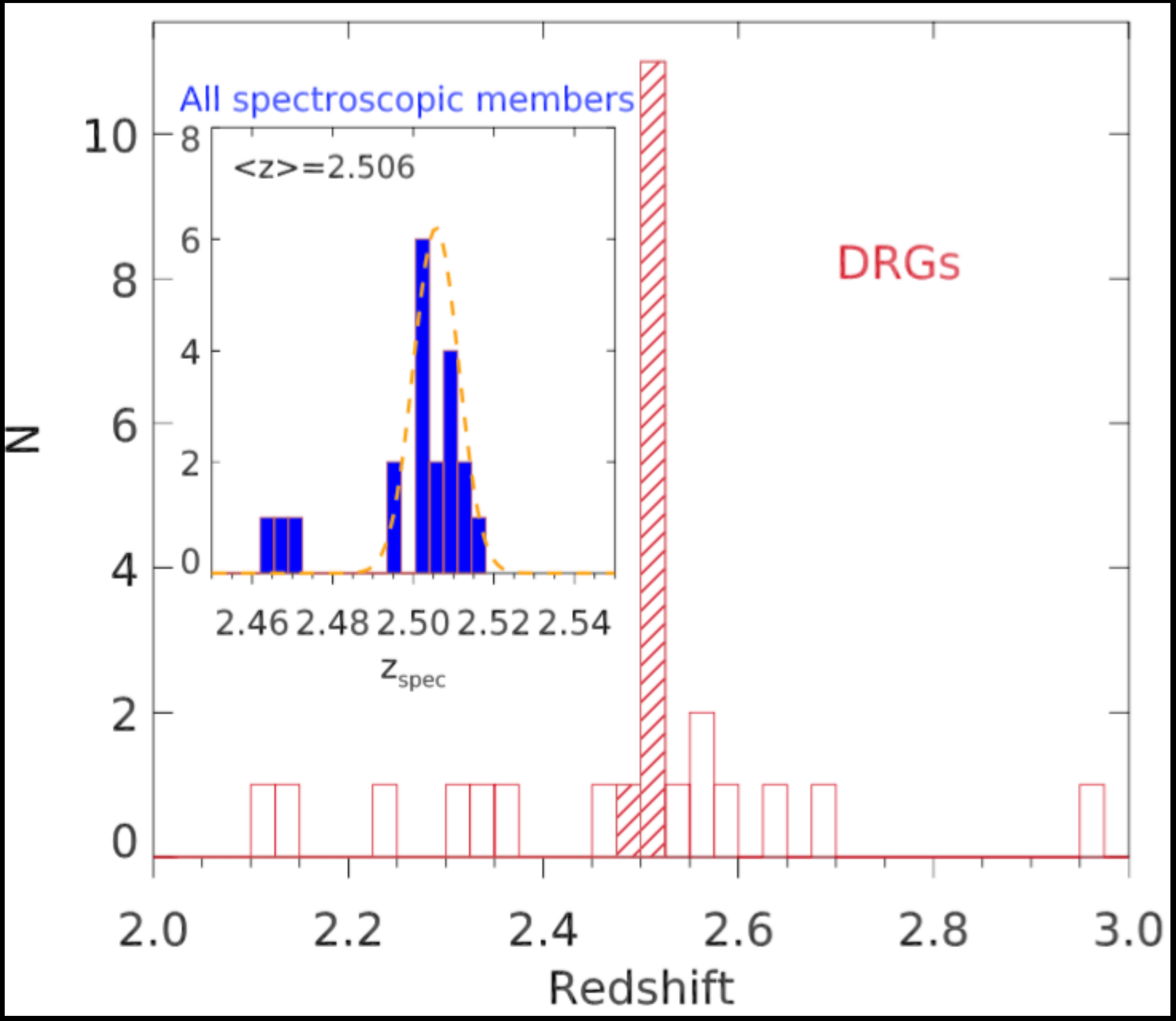


$$L_{0.1-2.4\,\mathrm{keV}} = 8.8 \pm 2.6 \times 10^{43}\ \mathrm{erg\ s^{-1}}$$

Spectroscopic confirmation:

NOEMA(CO(5-4)) + VLT/KMOS (Ha) + JVLA (CO(1-0))

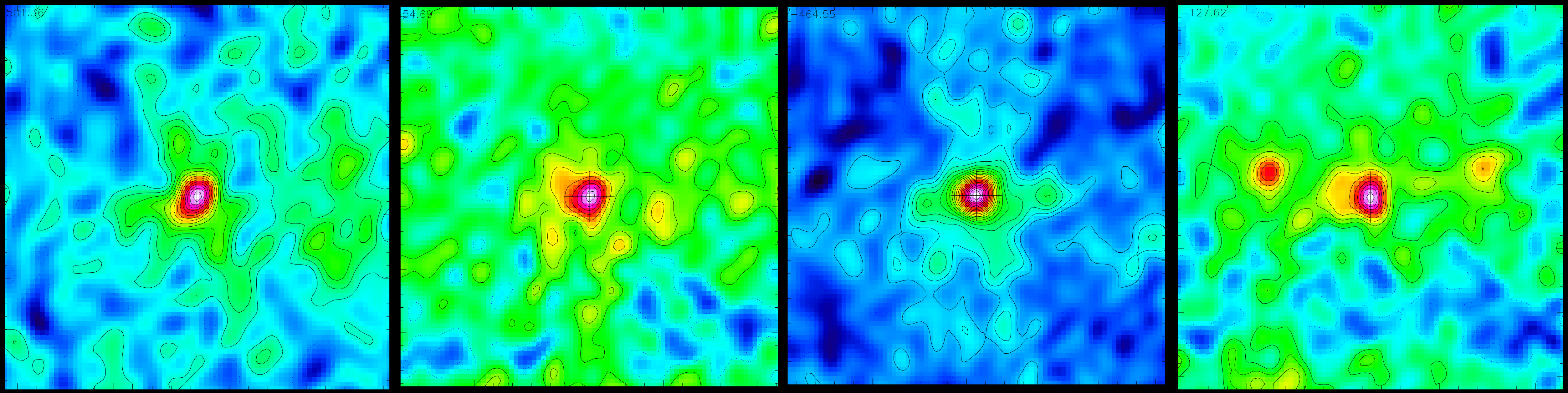




velocity dispersion: ~530 km/s

17 spectroscopic members

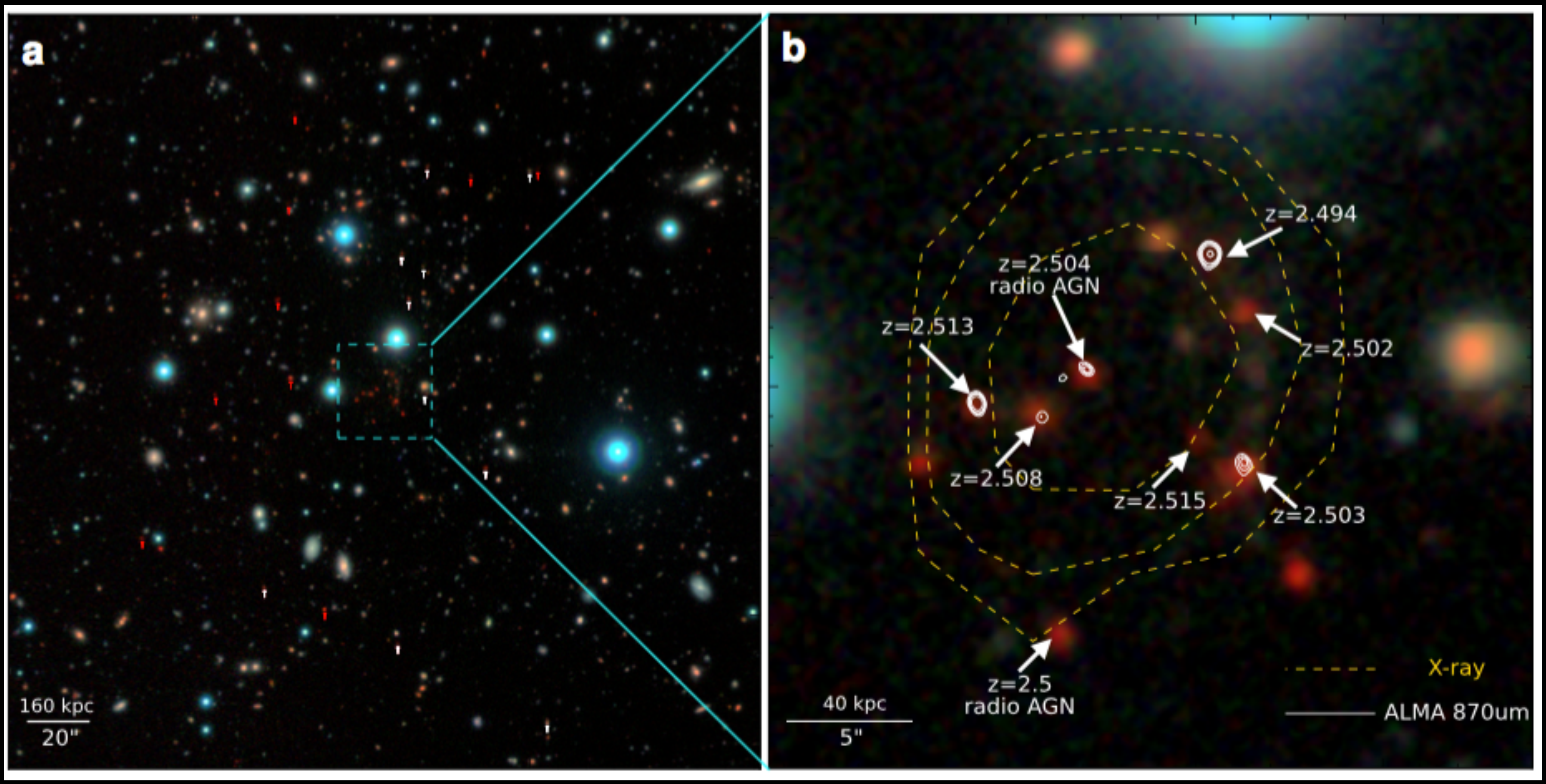
JVLA CO(1-0)



Measured physical properties of spectroscopically confirmed members

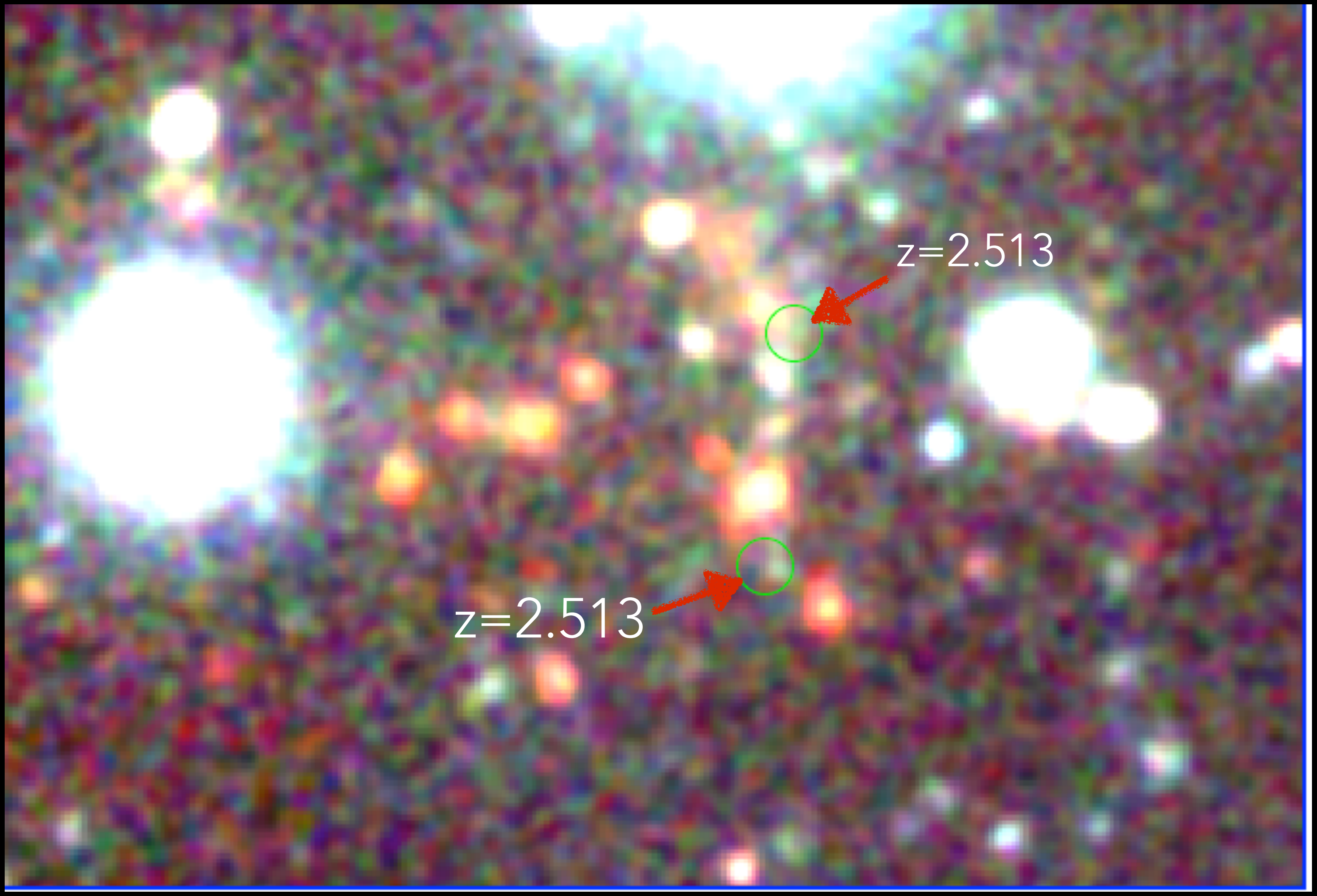
ID[a]	RA (J2000)	DEC (J2000)	$z_{\rm zpec}$	$z_{\rm phot}$	$J-K_s$	$\log M_*$ $[M_\odot]$	Redshift determination	Type
128484	150.22348	2.30719	2.495	2.55	0.70	10.82	$H\alpha$	SF
129305	150.23940	2.31750	2.512	2.65	0.71	10.19	$H\alpha$	SF
129444	150.24875	2.31921	2.510	2.57	1.59	10.77	$H\alpha$	SF
131661	150.23584	2.34488	2.501	2.64	1.57	11.03	$H\alpha$	SF
131864	150.23454	2.34770	2.511	2.64	0.53	10.38	$H\alpha$	SF
132636	150.22505	2.35620	2.510	2.55	0.49	10.68	$H\alpha$	SF
130359	150.22899	2.32978	2.507	2.47	1.93	11.26	$H\alpha$, CO(1-0)	SF
130842	150.23746	2.33612	2.515	3.04	1.77	11.12	CO(1-0)	SF
130891	150.23987	2.33645	2.513	2.68	2.09	11.06	CO(1-0), CO(5-4)	SF
130901	150.23923	2.33637	2.508	2.20	1.74	11.58	CO(1-0)	SF
130933	150.23869	2.33683	2.504	2.28	2.23	11.29	CO(1-0)	SF (radio AGN)
130949	150.23701	2.33571	2.503	2.49	1.66	11.57	CO(1-0), CO(3-2), CO(5-4)	SF
131077	150.23735	2.33814	2.494	2.82	1.39	11.16	CO(1-0), CO(3-2), CO(5-4)	SF
131079	150.23695	2.33748	2.502	2.57	1.46	11.36	CO(1-0)	SF
132044	150.23650	2.34881	2.504	2.35	1.47	11.13	CO(1-0)	SF
132627	150.23421	2.35659	2.506	2.36	1.34	10.90	CO(1-0)	SF
–[b]	150.23419	2.33647	2.504	–	0.7	11.0	CO(1-0)	SF

A galaxy cluster at z=2.506 (CLJ1001)

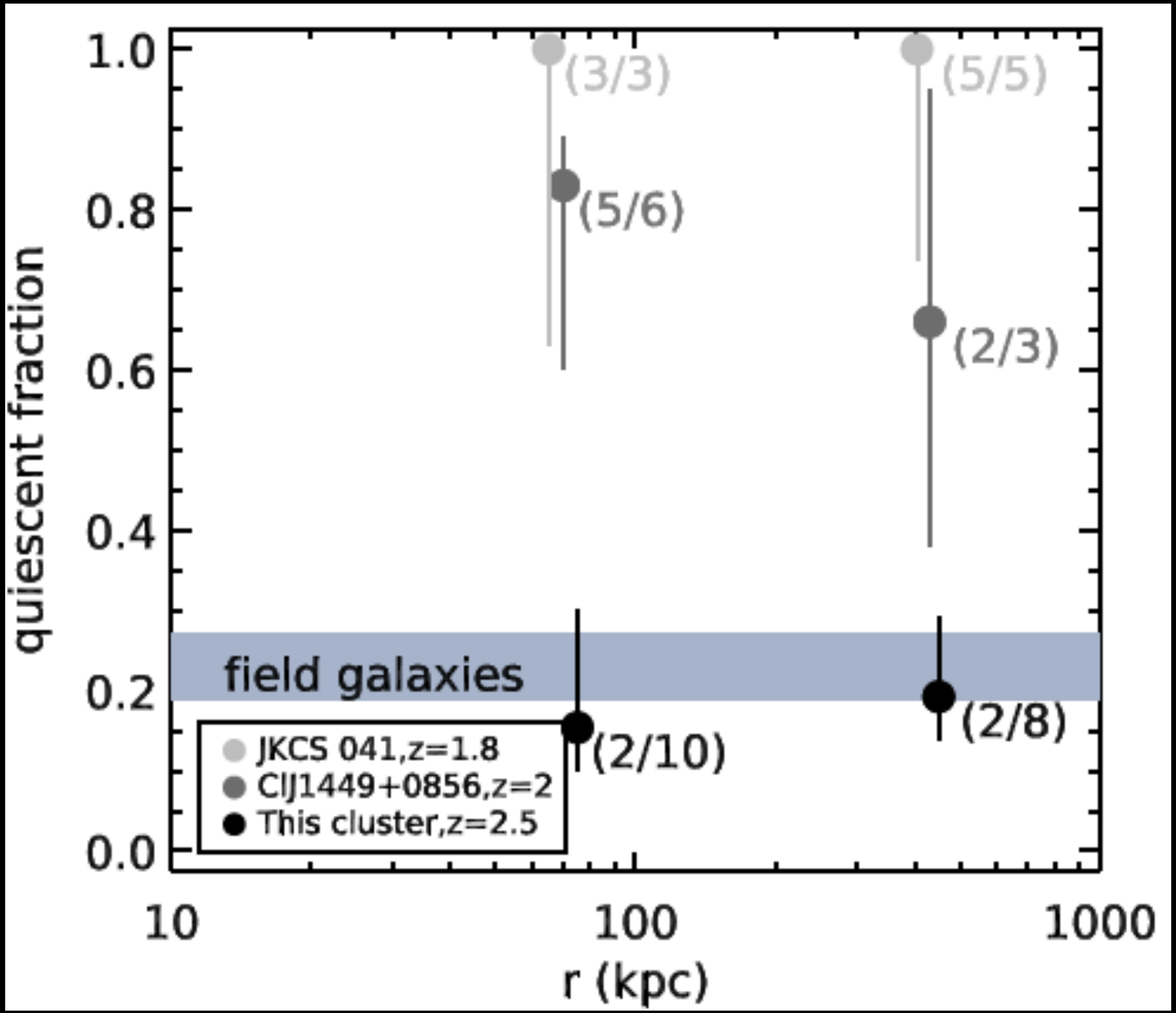


$$M_{200c} = 10^{13.9 \pm 0.2}\ M_{\odot}$$

More confirmed members



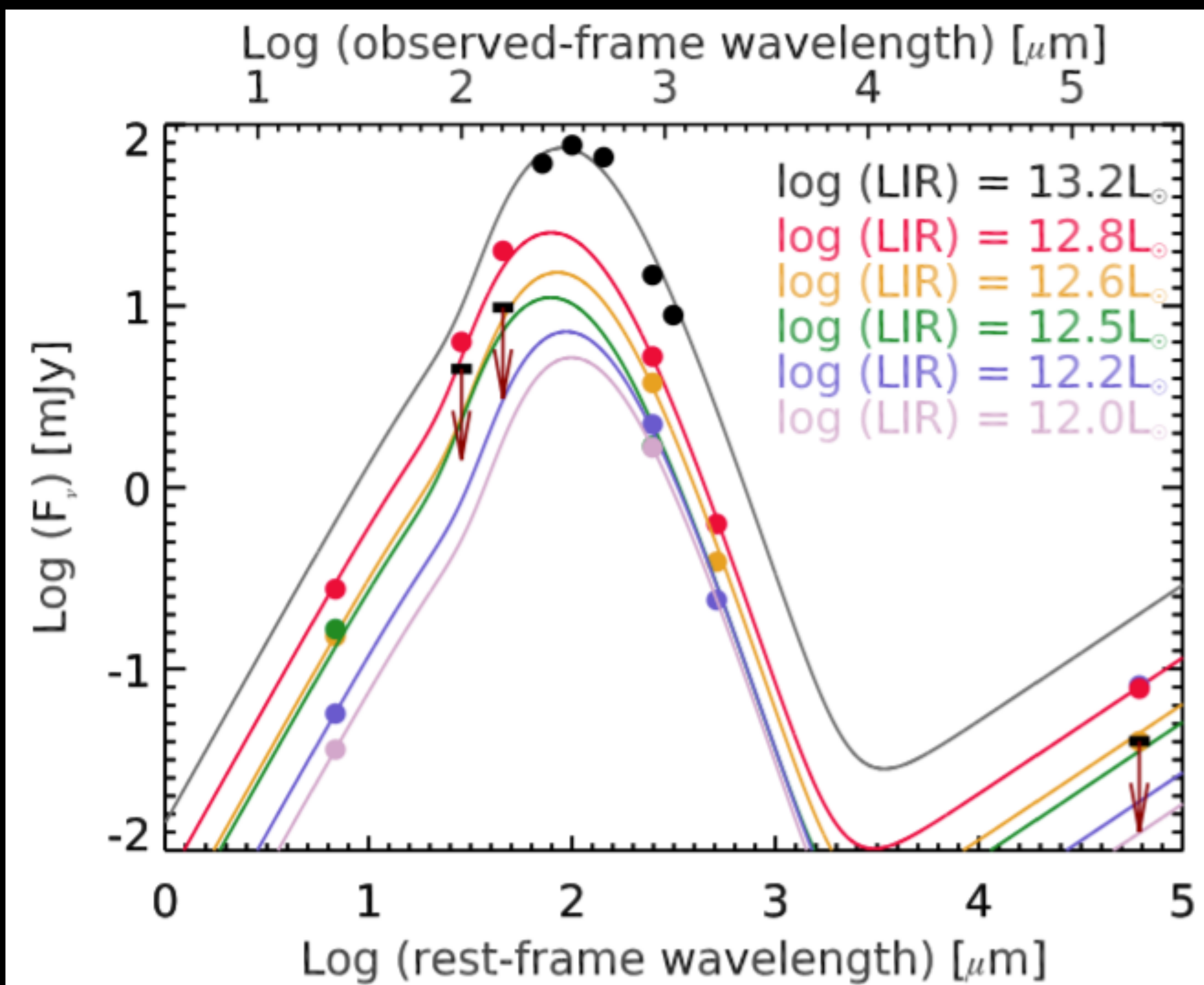
Uniqueness of CLJ1001: A high abundance of massive star-forming galaxies in a massive, collapsed halo

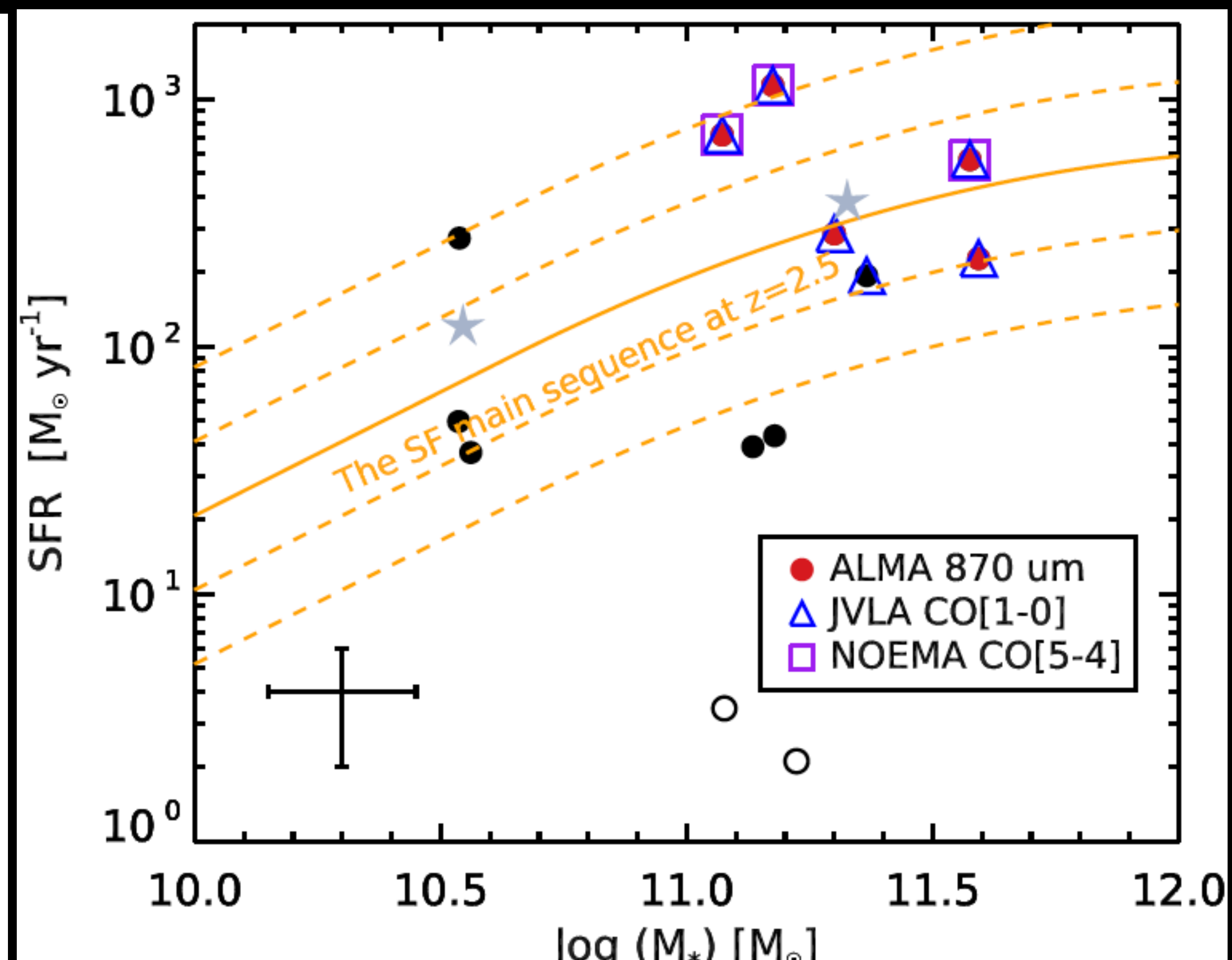


When do cluster ellipticals form:

formed after their accretion onto the cluster halo

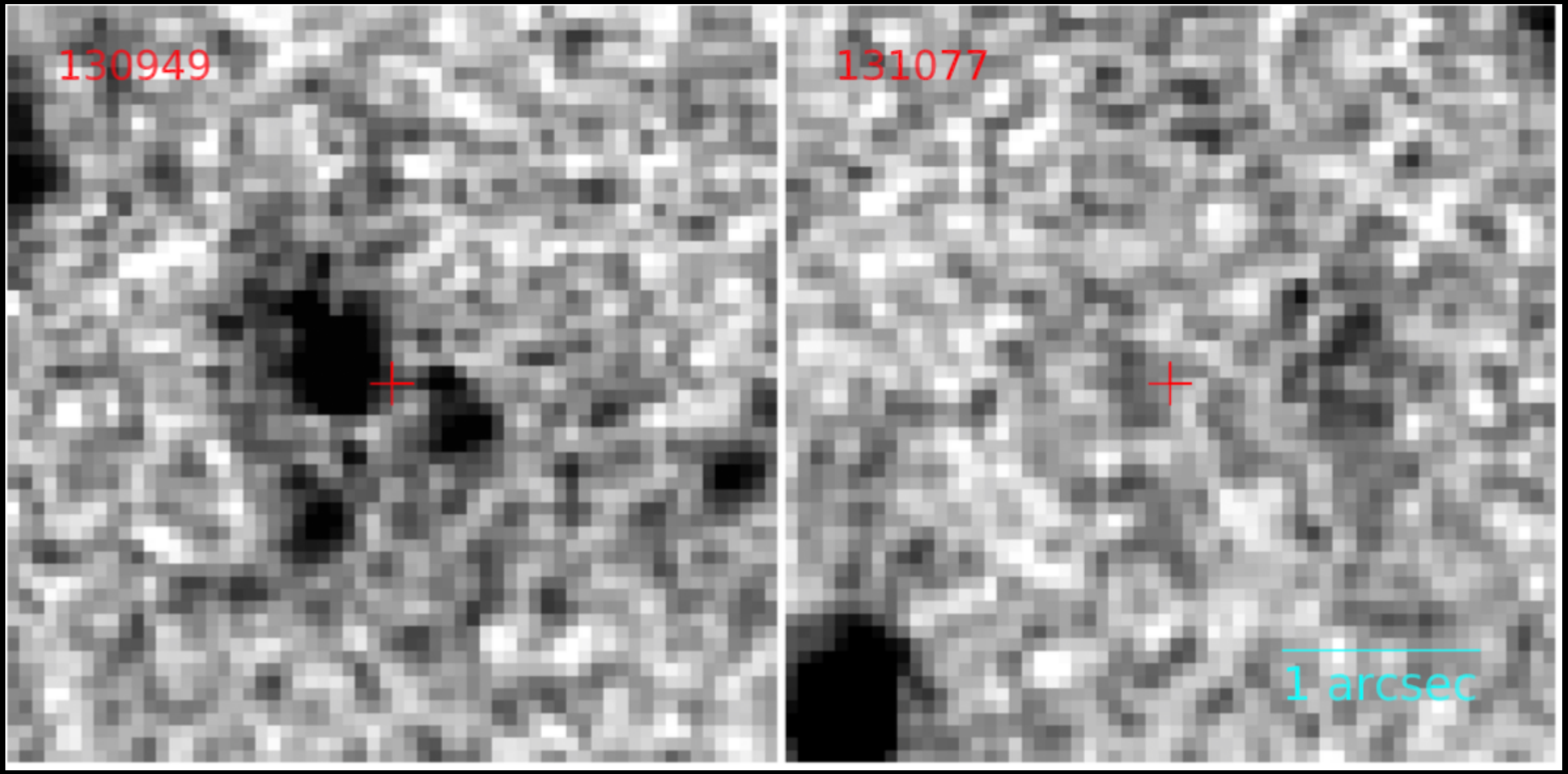
Properties of member galaxies:
A high fraction of starburst galaxies



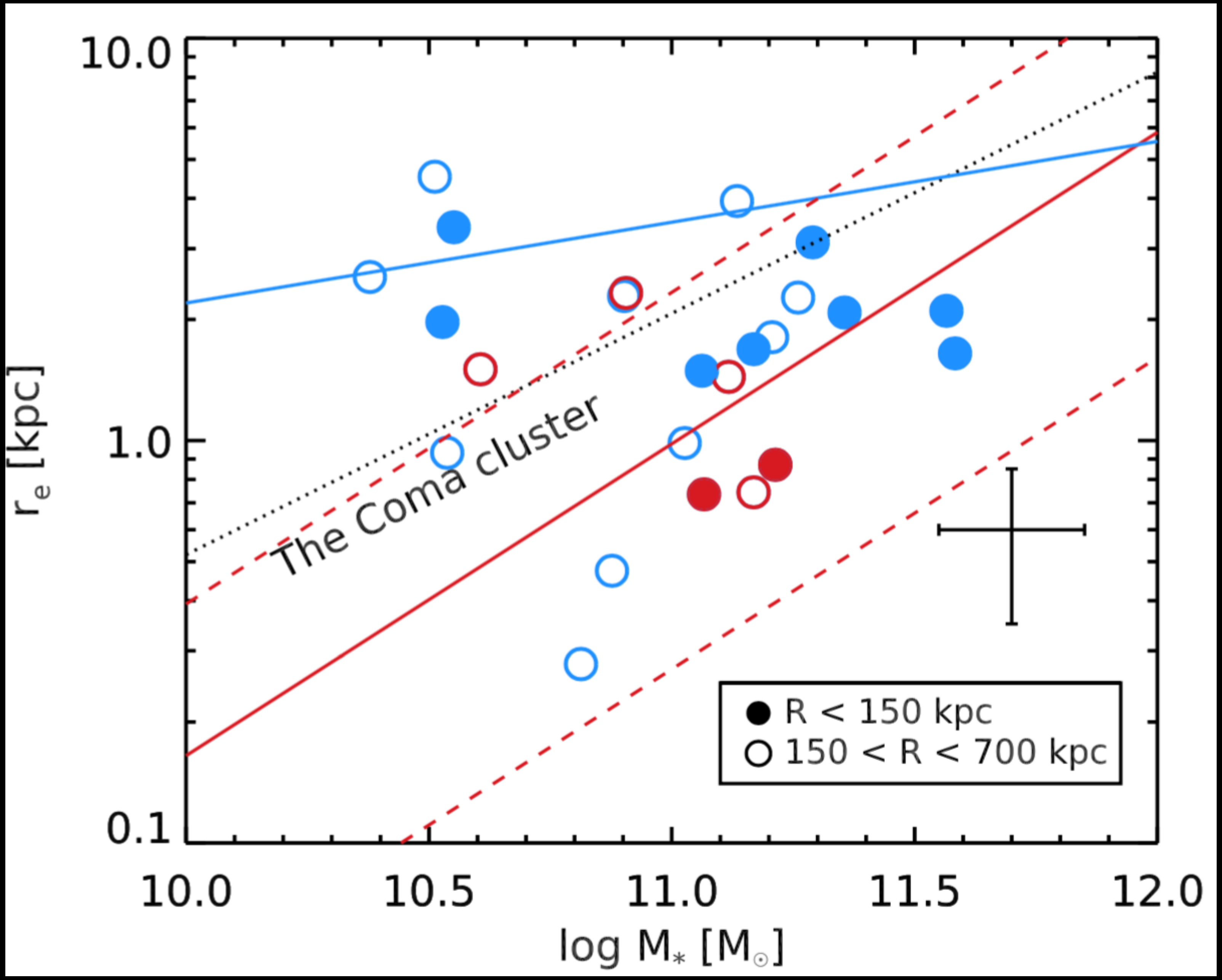


Total SFR~3400 M⊙/yr in the central ~200kpc
gas depletion time ~200 Myr

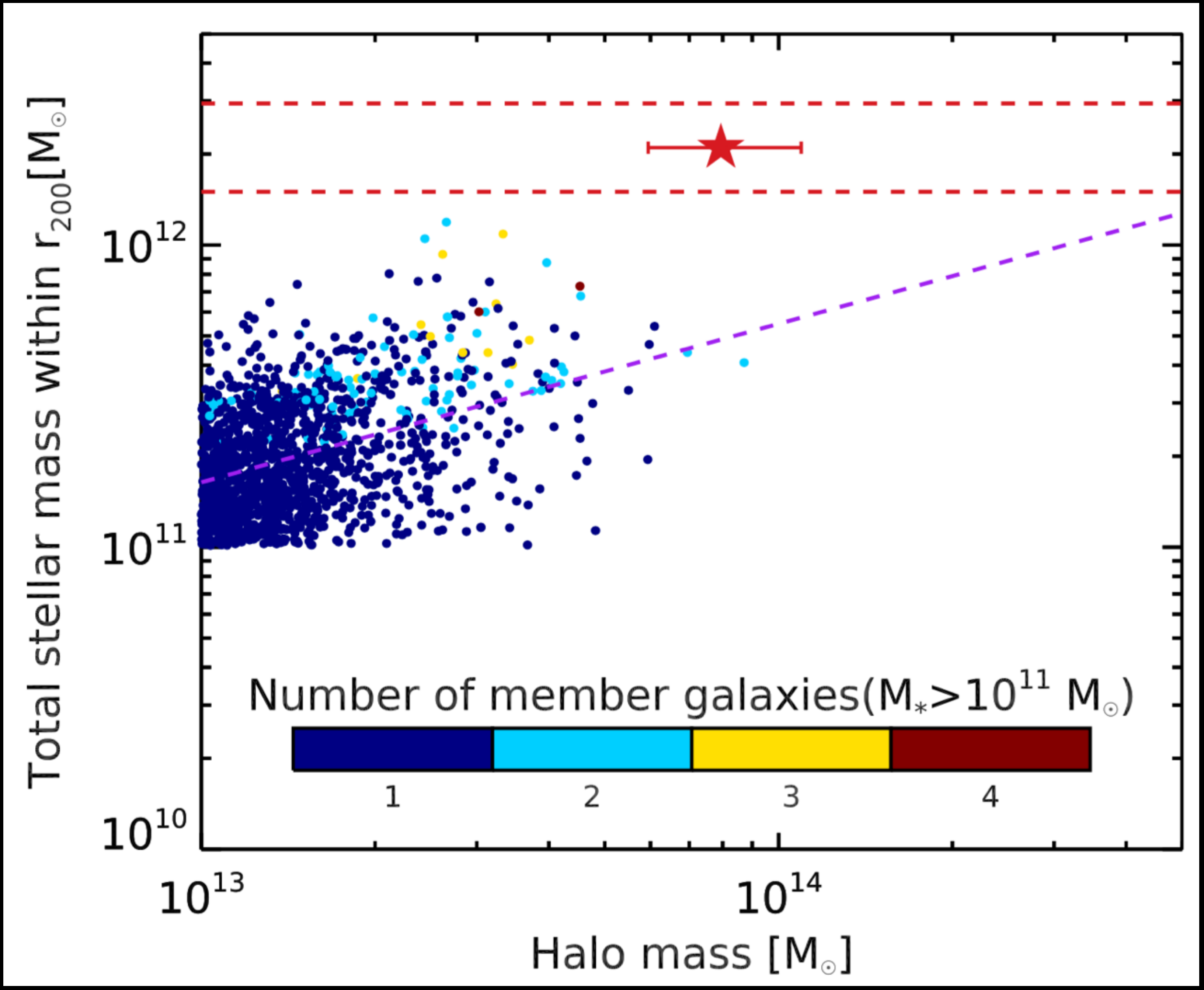
Morphologies of the two starbursts



Properties of member galaxies:
A high abundance of compact star-forming galaxies

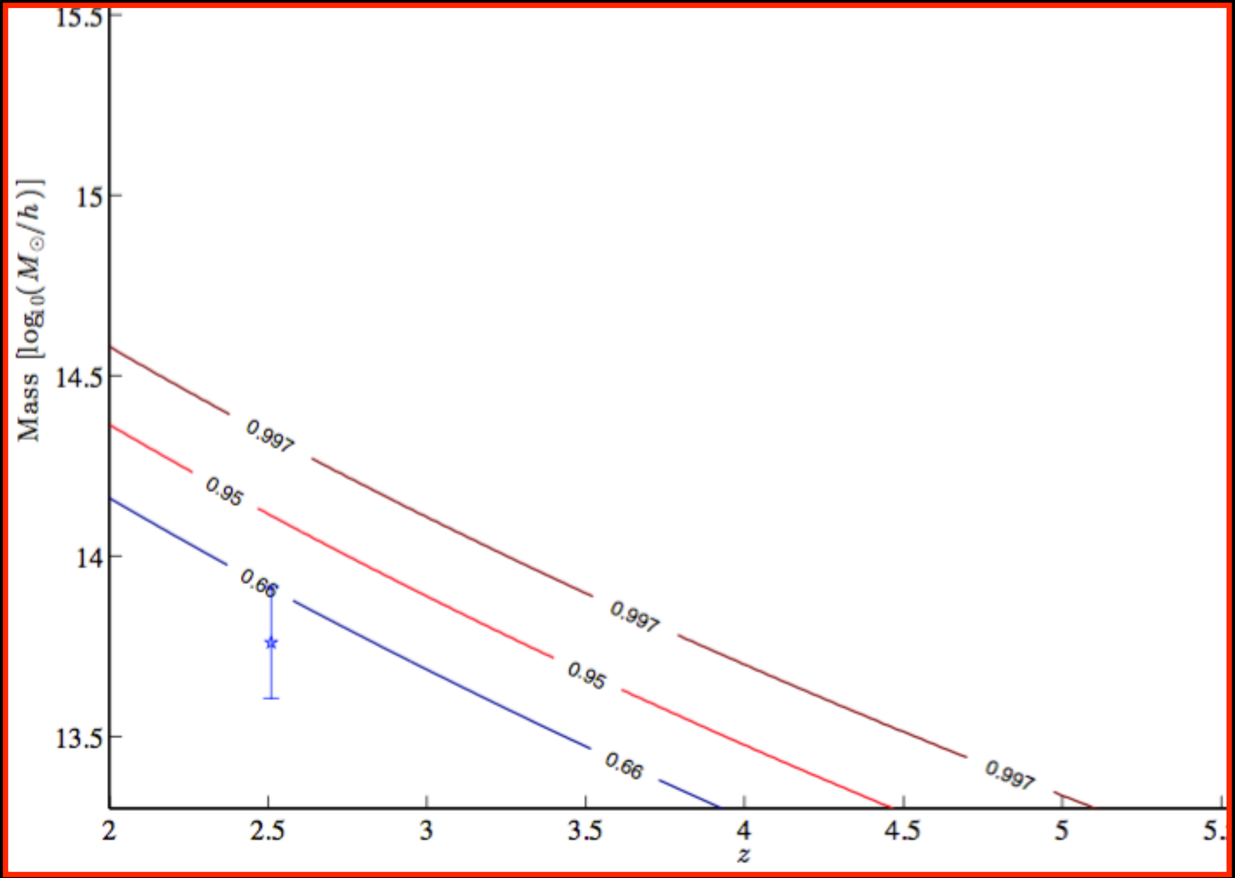


Cosmological context:
A high stellar mass content

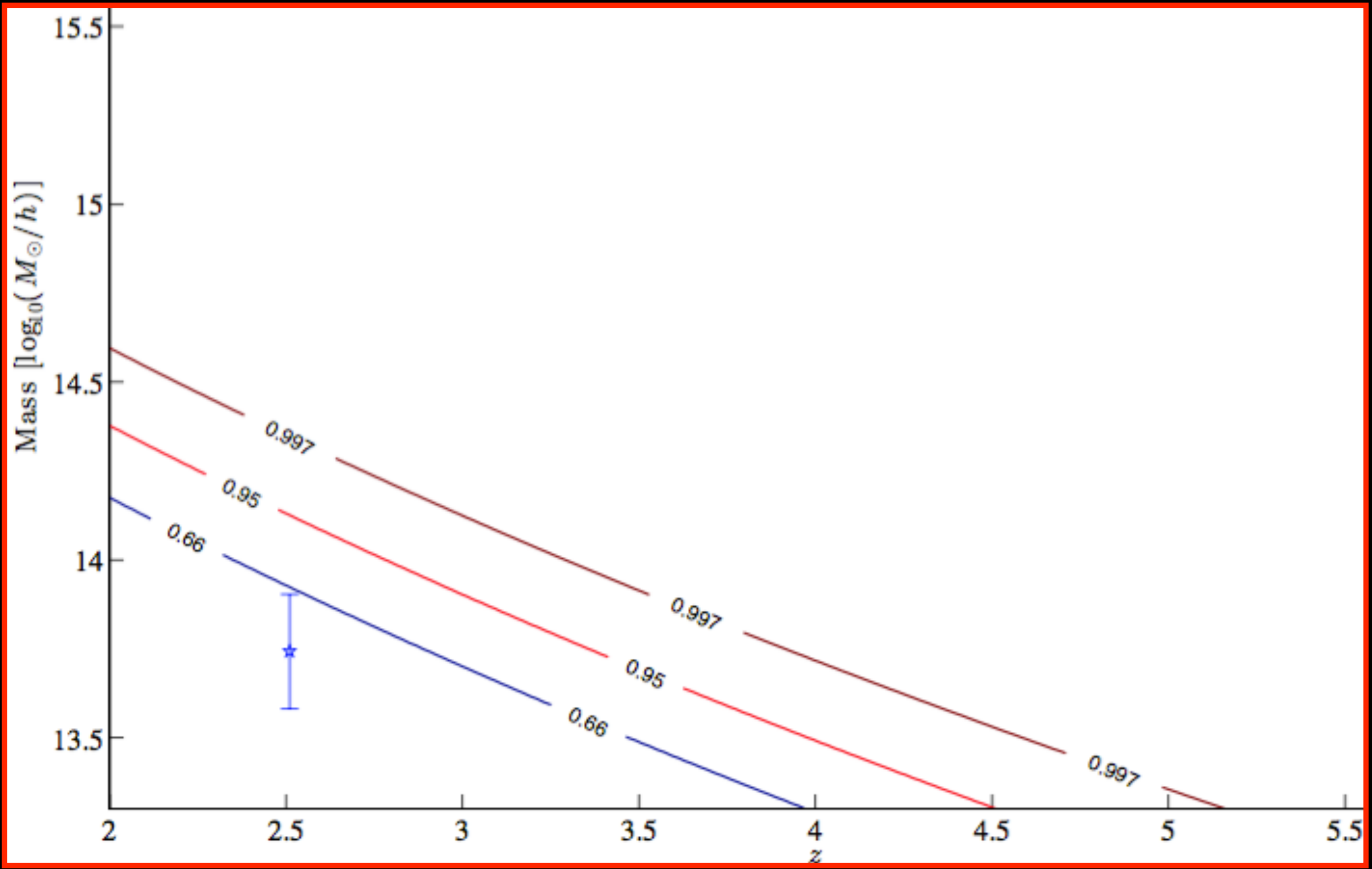


Constraints on cosmology

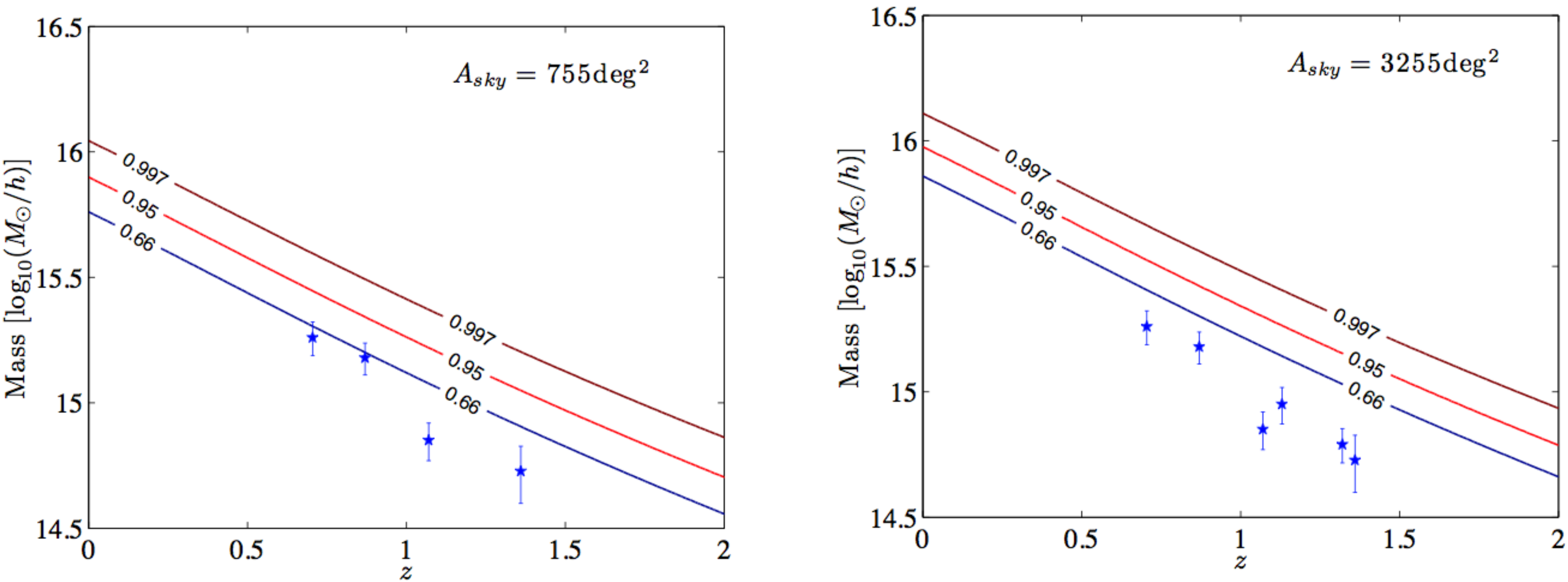
WMAP7



Planck15



Wang et al, in preparation



Harrison+2013

Summary

- We have discovered the most distant (X-ray) galaxy cluster known to date at z=2.506. Its unique properties provide a rare chance to witness the rapid build-up of a dense cluster core.
- The presence of both a collapsed, cluster-sized halo and a predominant population of massive star-forming galaxies provides evidence that the main phase of massive galaxy passivization will take place after galaxies accrete onto the cluster.
- Galaxies in the cluster core exhibit elevated starburst and (radio) AGN activities.
- Both quiescent galaxies and star-forming galaxies in the cluster core are compact, suggesting that compaction likely precedes quenching.
- The high stellar mass content challenges current theoretical models of massive cluster formation at high redshift.