Galaxy Evolution and Environment
Kuala Lumpur, Malaysia, 31 March – 3 April, 2009

The Spatial Distribution of Starburst and Post-Starburst Galaxies in Clusters at z>0.5

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Outline

- Review of post-starburst galaxies
- Wide field spectroscopic survey of MACS ($z>0.5$)
- Spectroscopic analysis
- Results:
  - Post-starburst galaxies in clusters
  - Starburst galaxies around the clusters

Outline

- Wide field spectroscopic survey of MACS ($z>0.5$)
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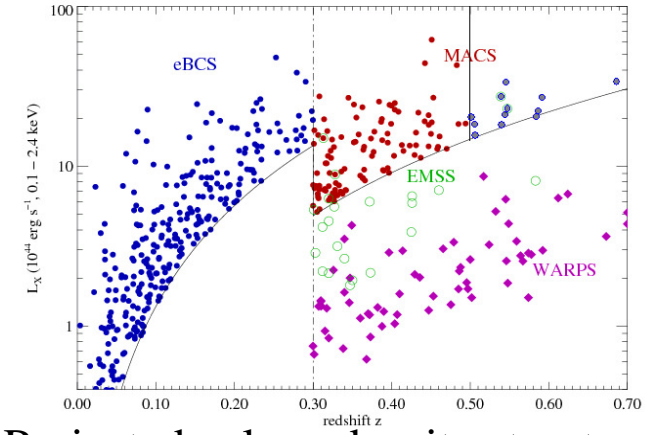
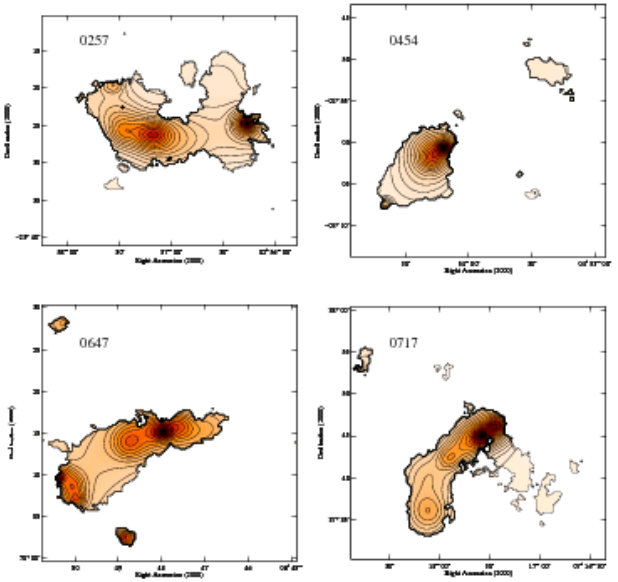
I. Wide-Field Spectroscopic Survey of Galaxies in MACS at z>0.5

Goals:

- Cluster dynamics
- Confirmation of large scale structure
- **Galaxy properties and evolution in the densest environment.**
- Spectroscopic redshift template to calibrate photometric redshift for weak-lensing study

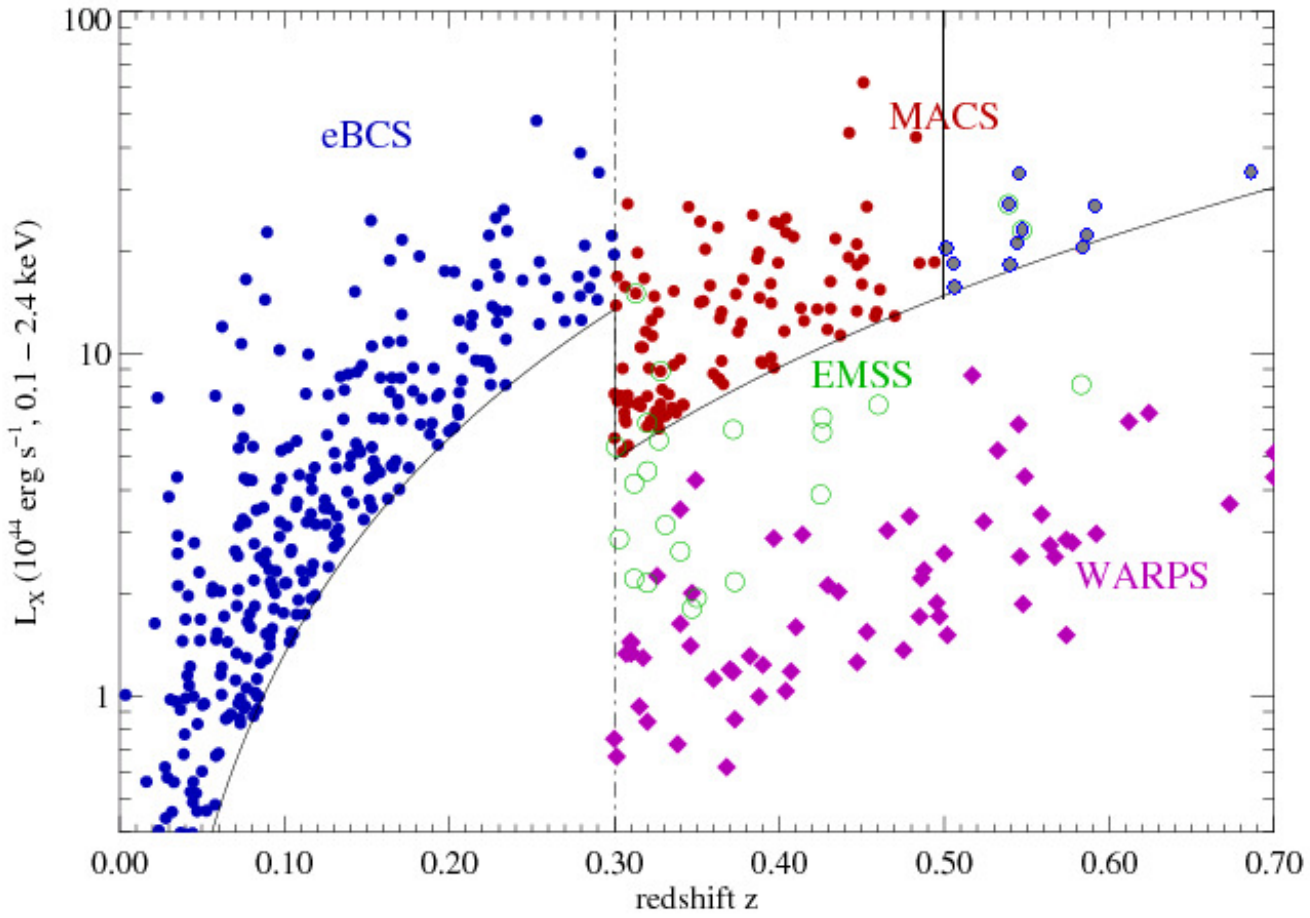


Projected galaxy density structure

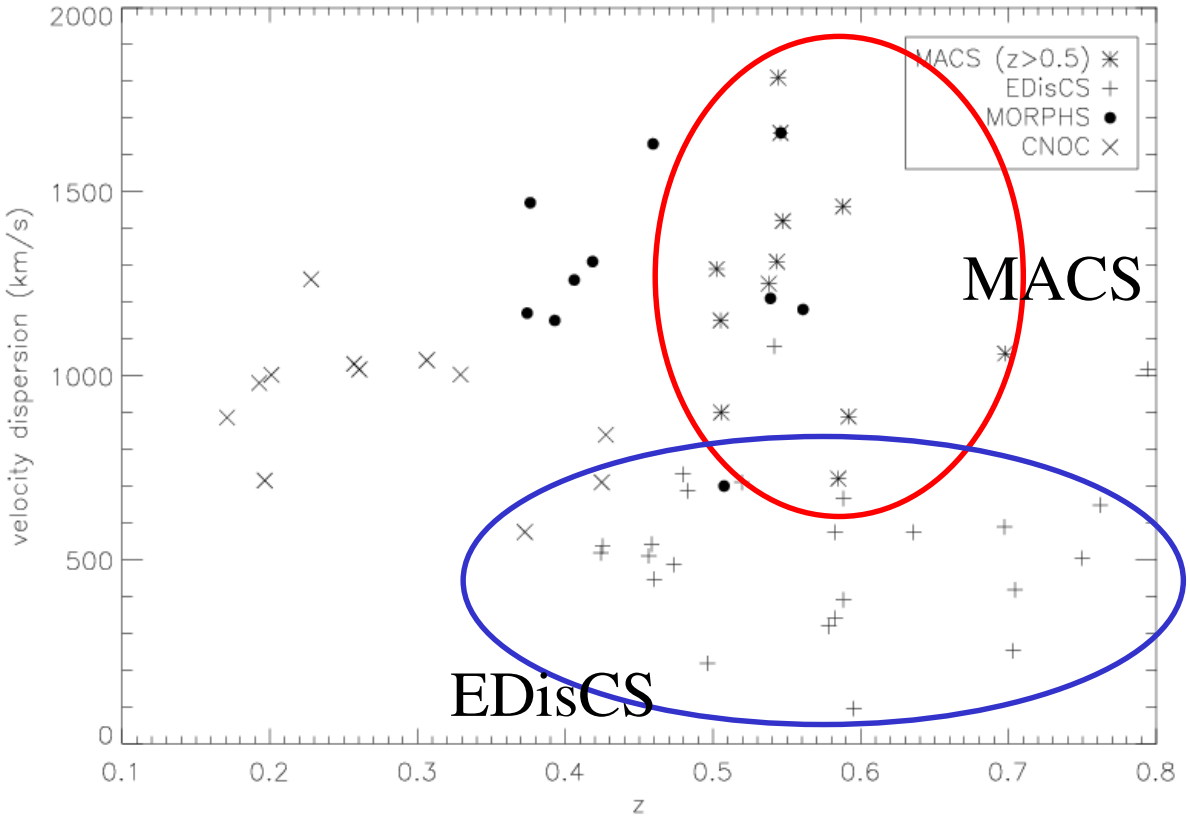


I. Wide-Field Spectroscopic Survey of Galaxies in MACS at z>0.5

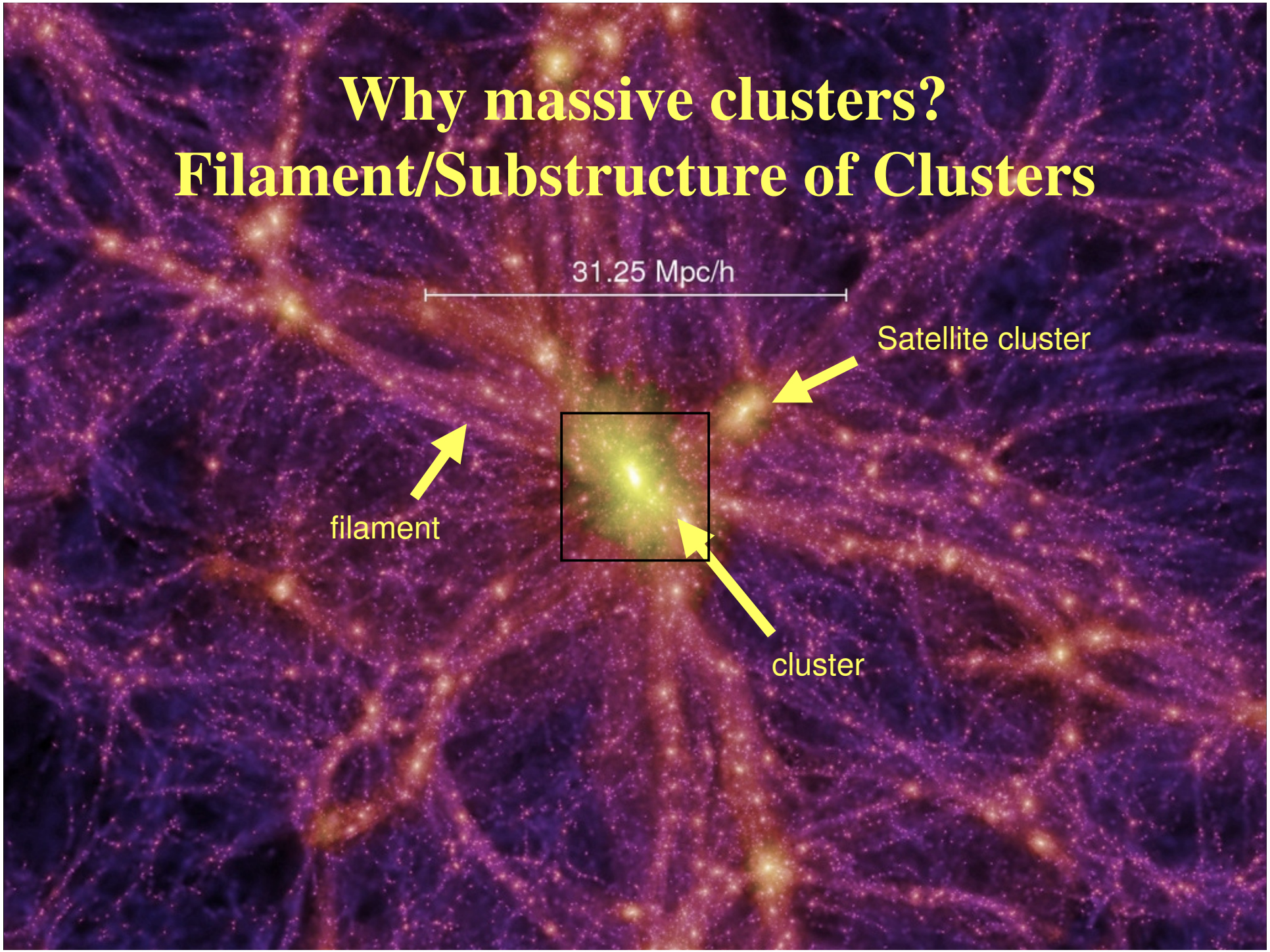
Selection of clusters:

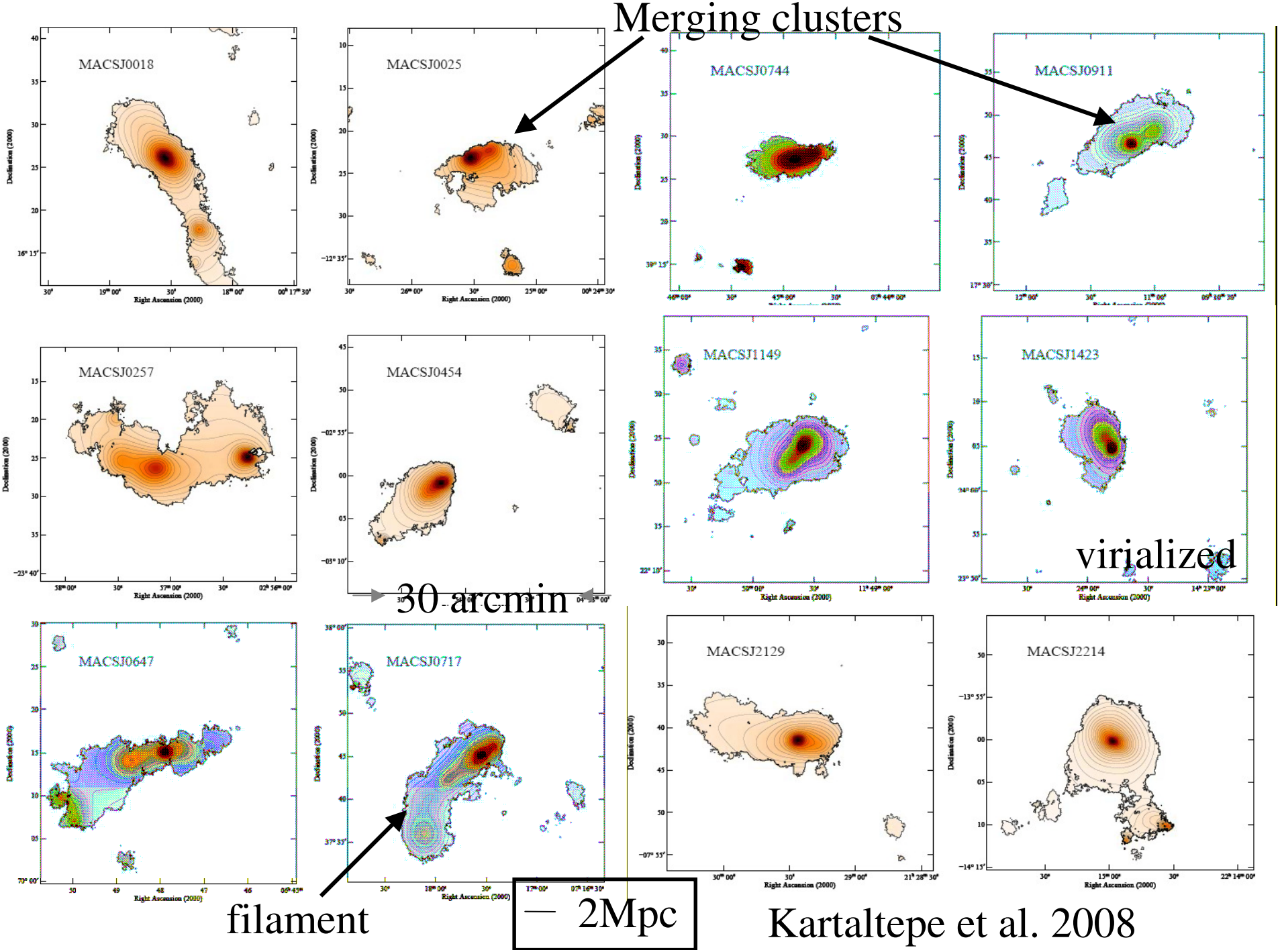


I. Wide-Field Spectroscopic Survey of Galaxies in MACS at z>0.5

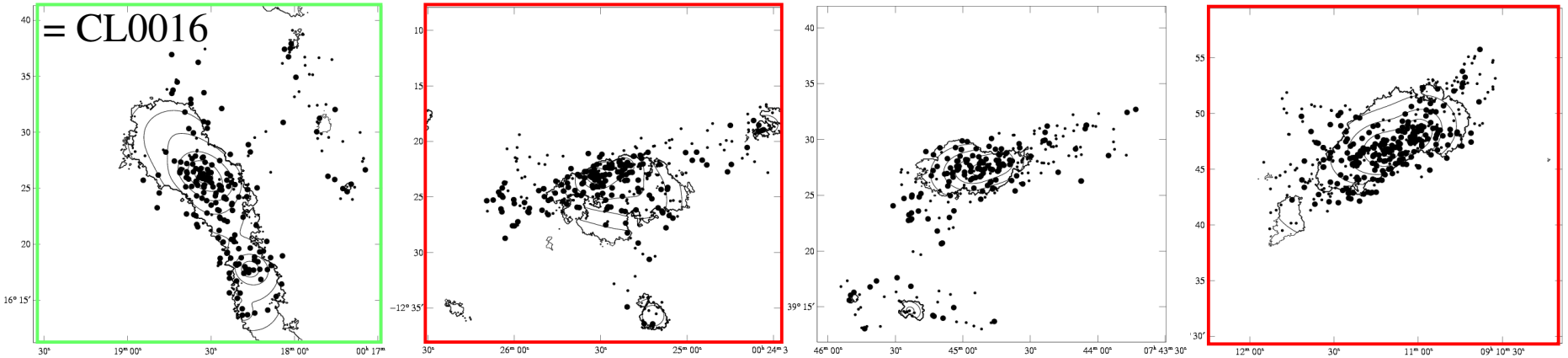


- Complementary to EDisCS --- we selected the most massive and X-ray luminous clusters in a narrower redshift range.

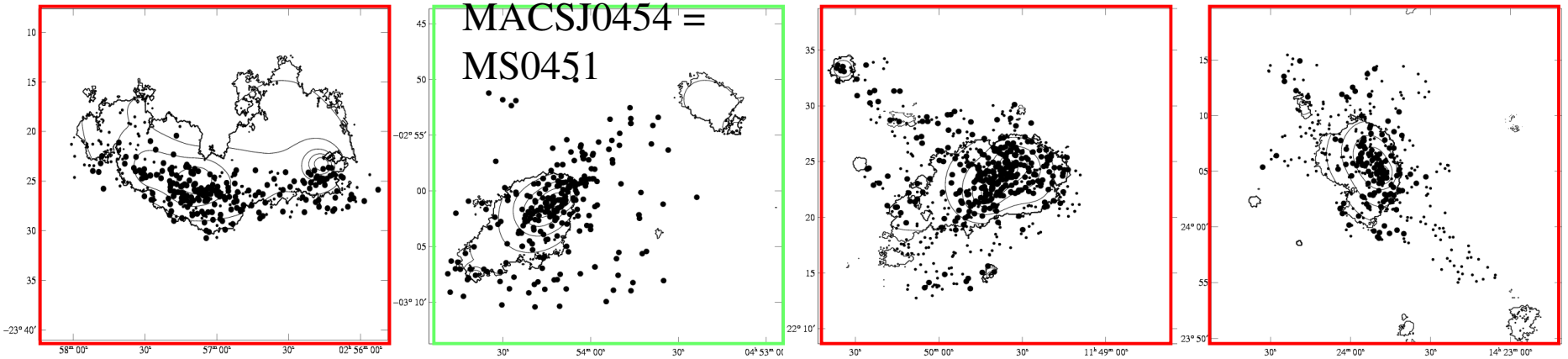

Why massive clusters?
Filament/Substructure of Clusters
31.25 Mpc/h
Satellite cluster
filament
cluster

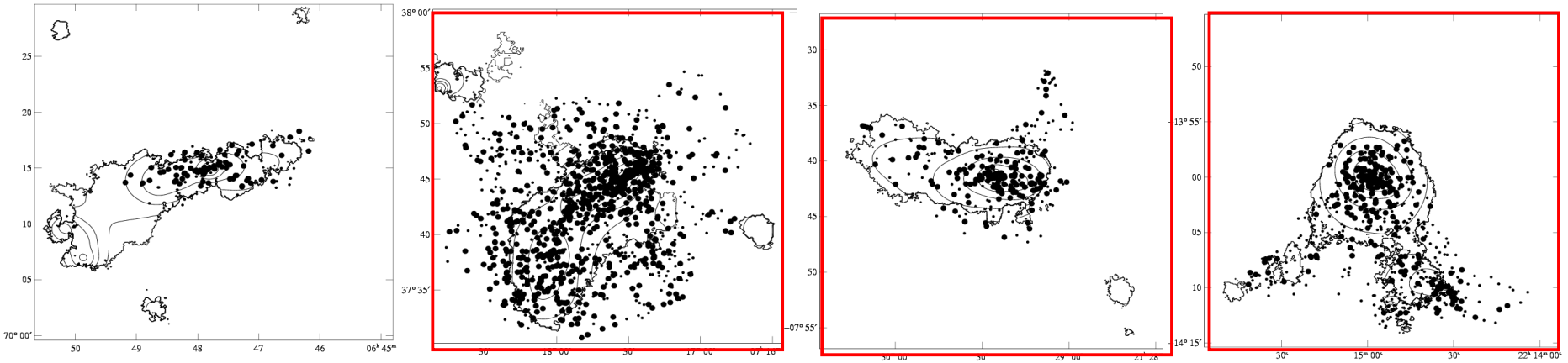

Merging clusters
MACSJ0018
MACSJ0025
MACSJ0744
MACSJ0911
MACSJ0257
MACSJ0454
MACSJ1149
MACSJ1423
virialized
30 arcmin
MACSJ0647
MACSJ0717
MACSJ2129
MACSJ2214
filament
2Mpc
Kartaltepe et al. 2008

MACSJ0018 = CL0016



MACSJ0454 = MS0451





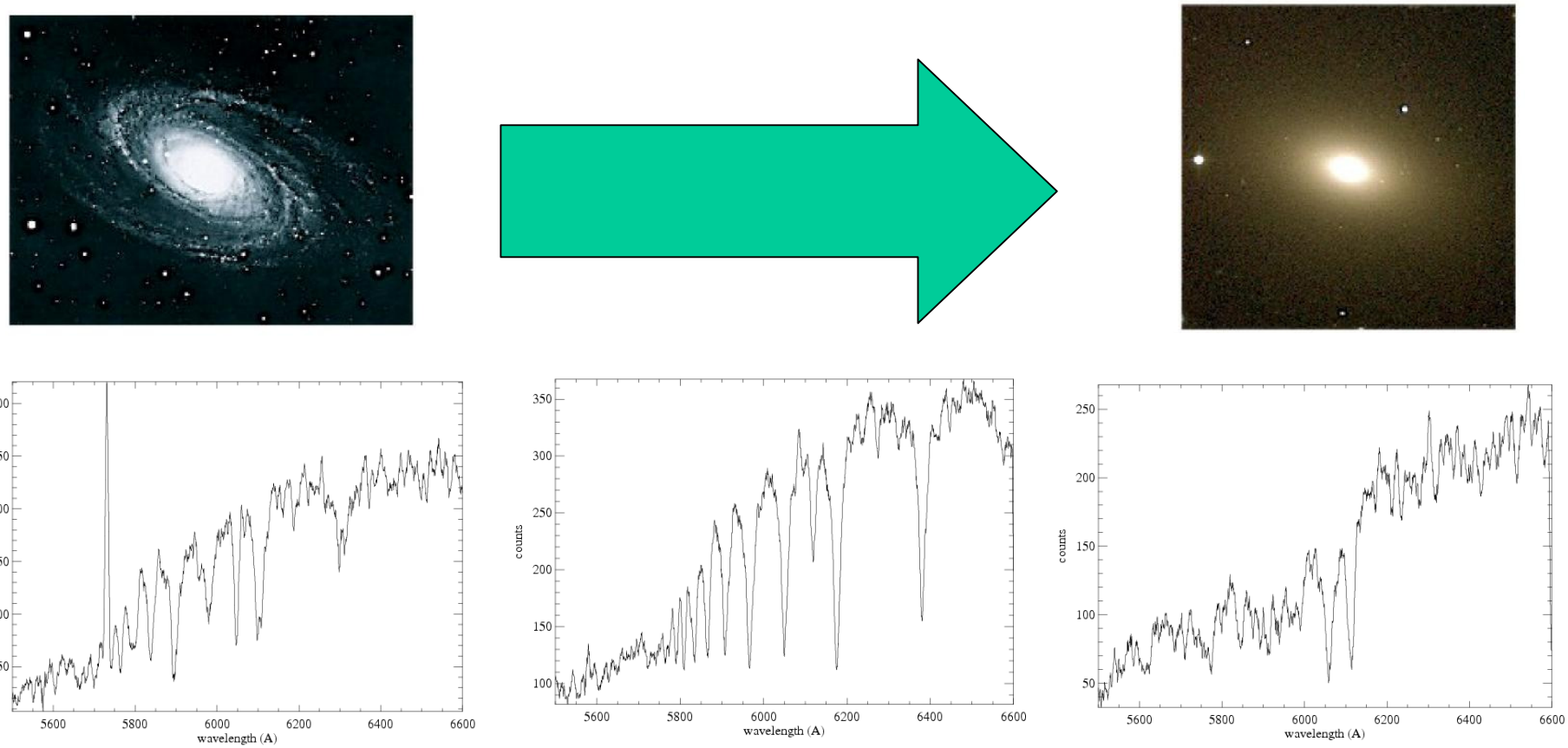
cluster	all spectra	redshift measurements		high S/N spectra	
		all	at cluster redshift	all	at cluster redshift
M0018**	414	219	164	212	160
M0025	564	286	151	270	142
M0257	412	313	202	307	200
M0454*	1639	1514	242	1514	242
M0647**	138	116	74	87	51
M0717	1752	1055	543	1042	535
M0744**	599	264	140	198	100
M0911	562	346	210	340	209
M1149	773	559	309	495	271
M1423	490	372	124	356	117
M2129**	441	262	147	237	129
M2214	818	531	239	517	228
total	8602	5837	2545	5575	2384

*: from Sean Moran (http://www.astro.caltech.edu/~smm/clusters/)

**: Data collection is not complete.

II. Review:

post-starburst galaxy (E+A)



Post-starburst galaxy is one of the important missing links.

II. Review:

FAQ of E+A

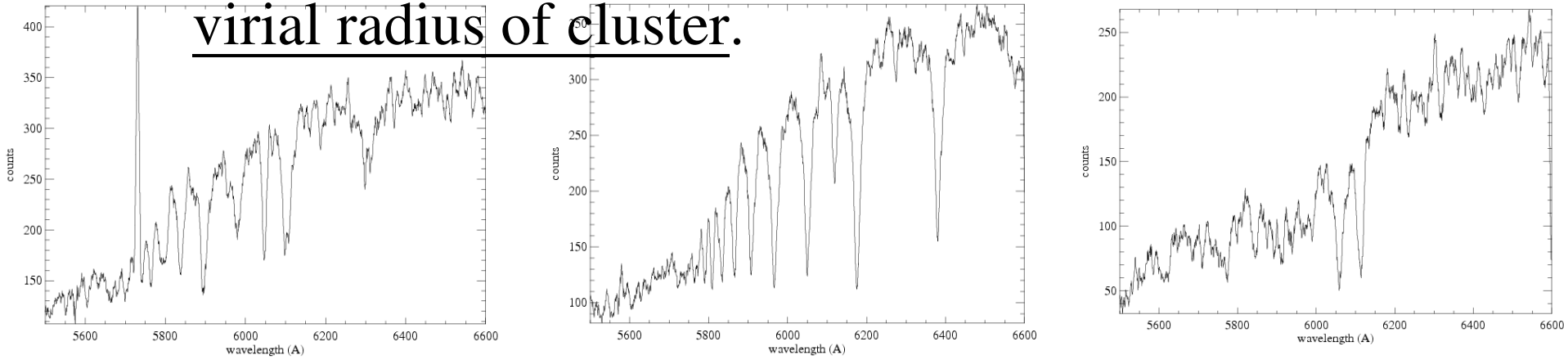
- Q1: How does the star formation terminate?
- Q2: What triggers the starburst?
  - Just major merger?
  - Galaxy cluster related?

II. Review:

Post-starburst galaxies and galaxy clusters

Low redshift:

- Goto et al. 2005 (SDSS): Almost all of the "bright" E+A galaxies live in the field. (see also Poggianti et al. 2004)
- Hogg et al. 2006 (SDSS): The environment of post-starburst galaxies are similar to star-forming galaxies, although there is a small excess inside virial radius of cluster.

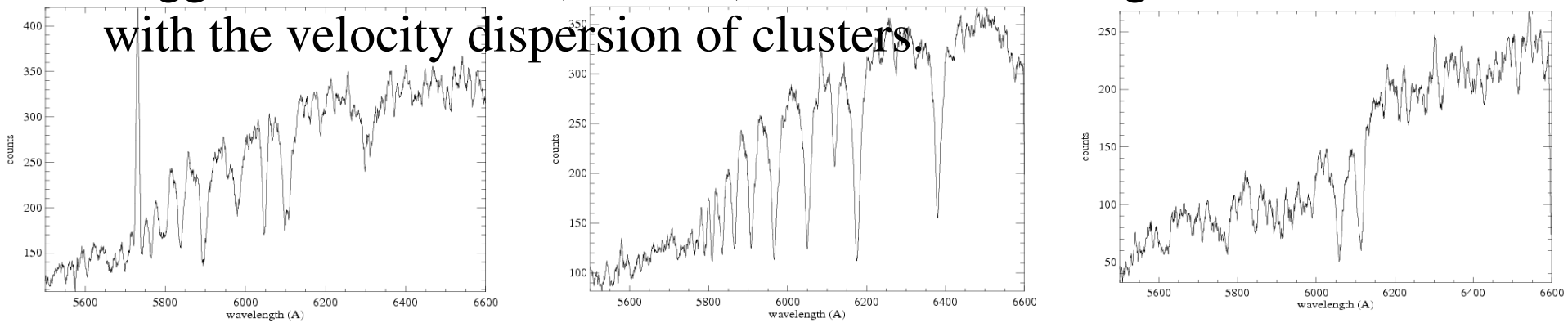


II. Review:

Post-starburst galaxies and galaxy clusters

Intermediate redshift:

- Tran et al. 2005 (4 clusters): Fraction of E+A in clusters > Fraction of E+A in field
- Yan et al. 2008 (DEEP2): Many of the post-starburst galaxies are missed because of [OII] emission related to AGN. Most of the post-starburst galaxies are in the field, instead of the densest region. (see also Balogh et al. 1999)
- Poggianti et al. 2009 (EDisCS): fraction of E+A galaxies correlates with the velocity dispersion of clusters.



III. Spectral Analysis

EW measurements:

- Inverse-variant weighted integration of flux
- Integration windows: Fisher et al. 1998
- For emission line -- Best fit spectrum templates subtracted

Uncertainty of EW: ~1Å

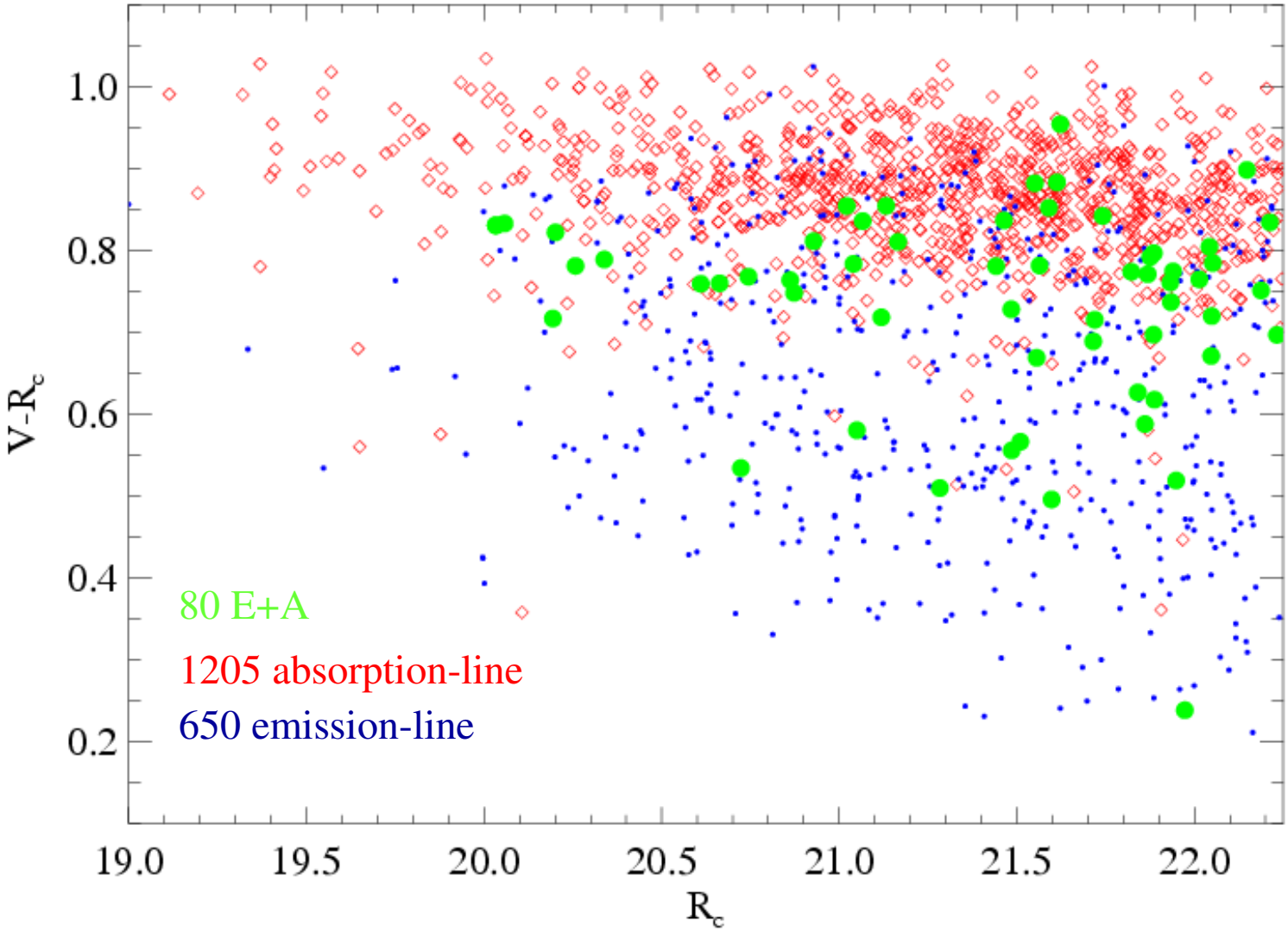
III. Spectral Analysis

TABLE 2
DEFINITION OF SPECTRAL TYPES

Type		Criteria
Emission-line		$[OII] < -5$Å or $H_{\beta,em} < -5$Å
Absorption-line		$[OII] > -5$Å $H_{\beta,em} > -5$Å and $\frac{(H_\delta + H_\gamma)}{2} < 4$Å
post-starburst	E+A	no detection of $[OII]$ and $H_{\beta,em}$, and $\frac{(H_\delta + H_\gamma)}{2} > 4$Å
dusty starburst	e(a)	Emission-line galaxies with $H_\delta > 4$Å and -25Å$< [OII] < -5$Å
starburst	e(b)	Emission-line galaxies with $[OII] < -25$Å
	e(c)	Emission-line galaxies with $H_\delta < 4$Å and -25Å$< [OII] < -5$Å

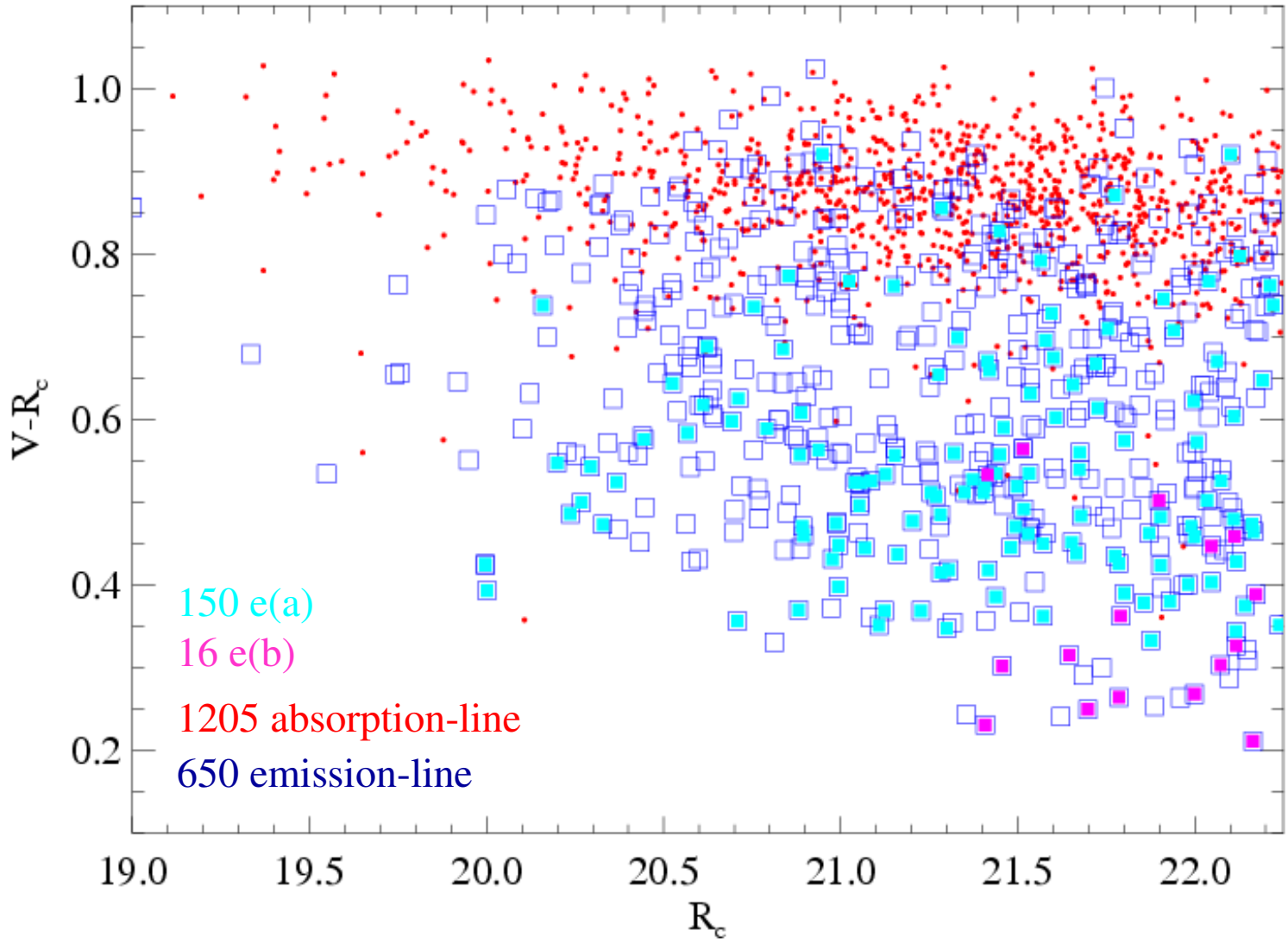
Ma et al. 2008, see also Poggianti et al. 2006, 2009

Color-Magnitude Diagram of cluster members

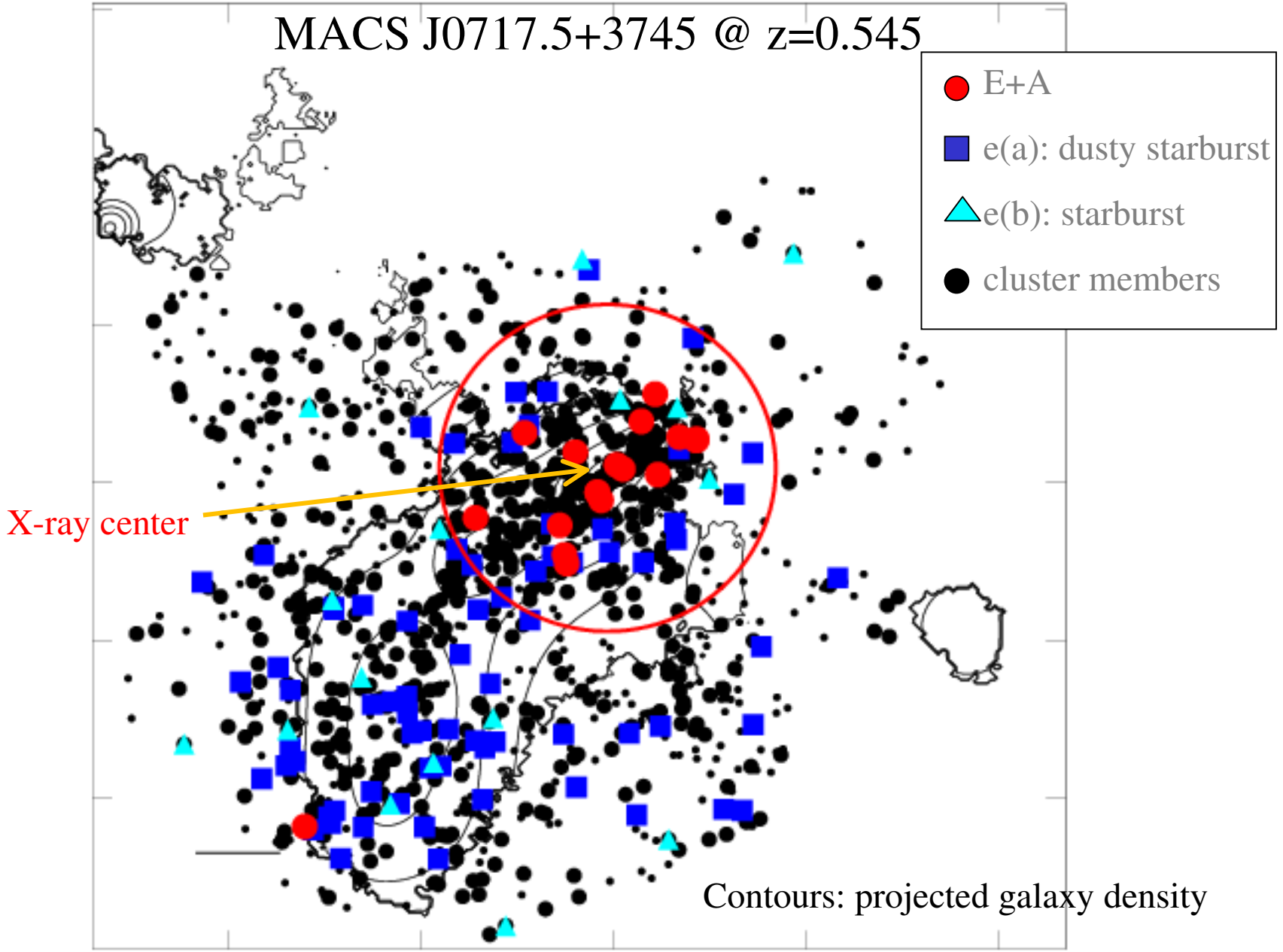


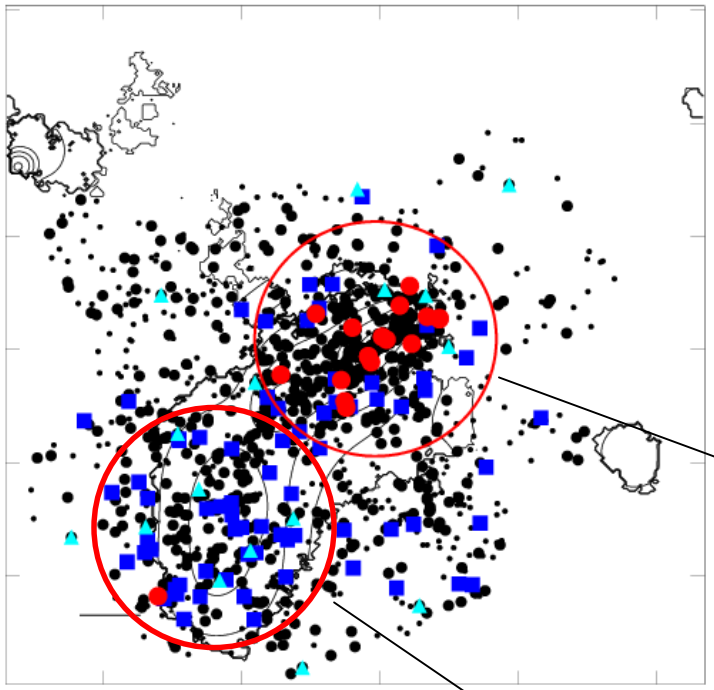
Limit magnitude $m_{Rc} = 22.25 \sim M_{Rc}^{*}+2$ at $z = 0.55$

Color-Magnitude Diagram of cluster members

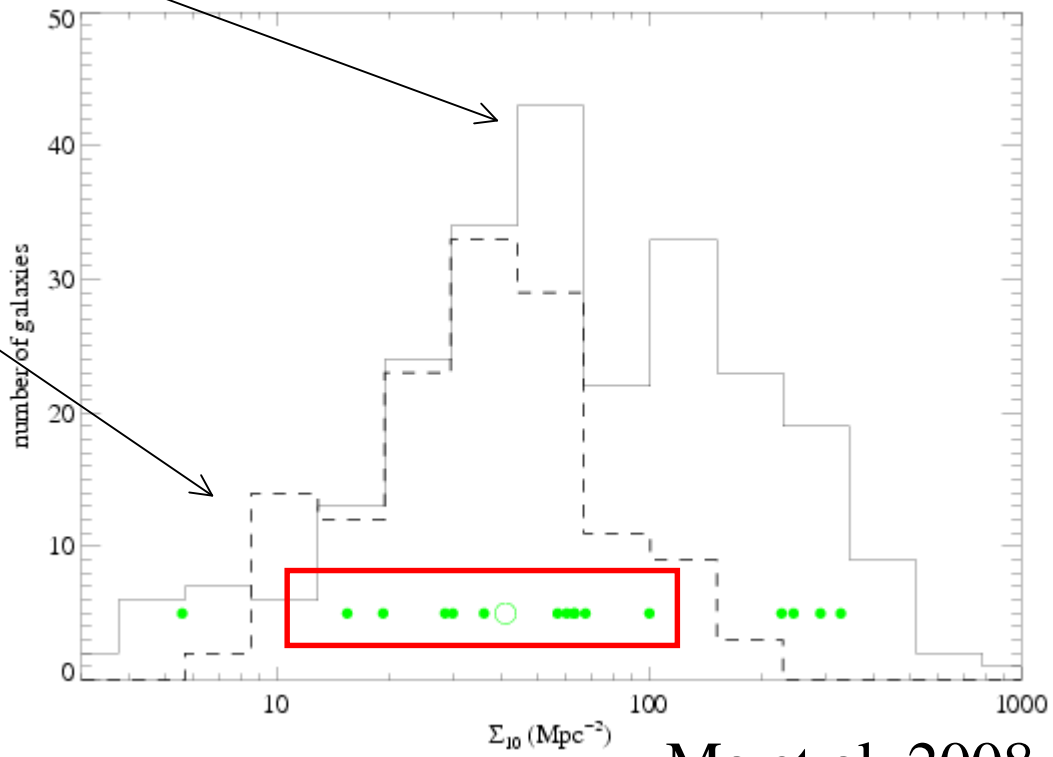


IV. Results

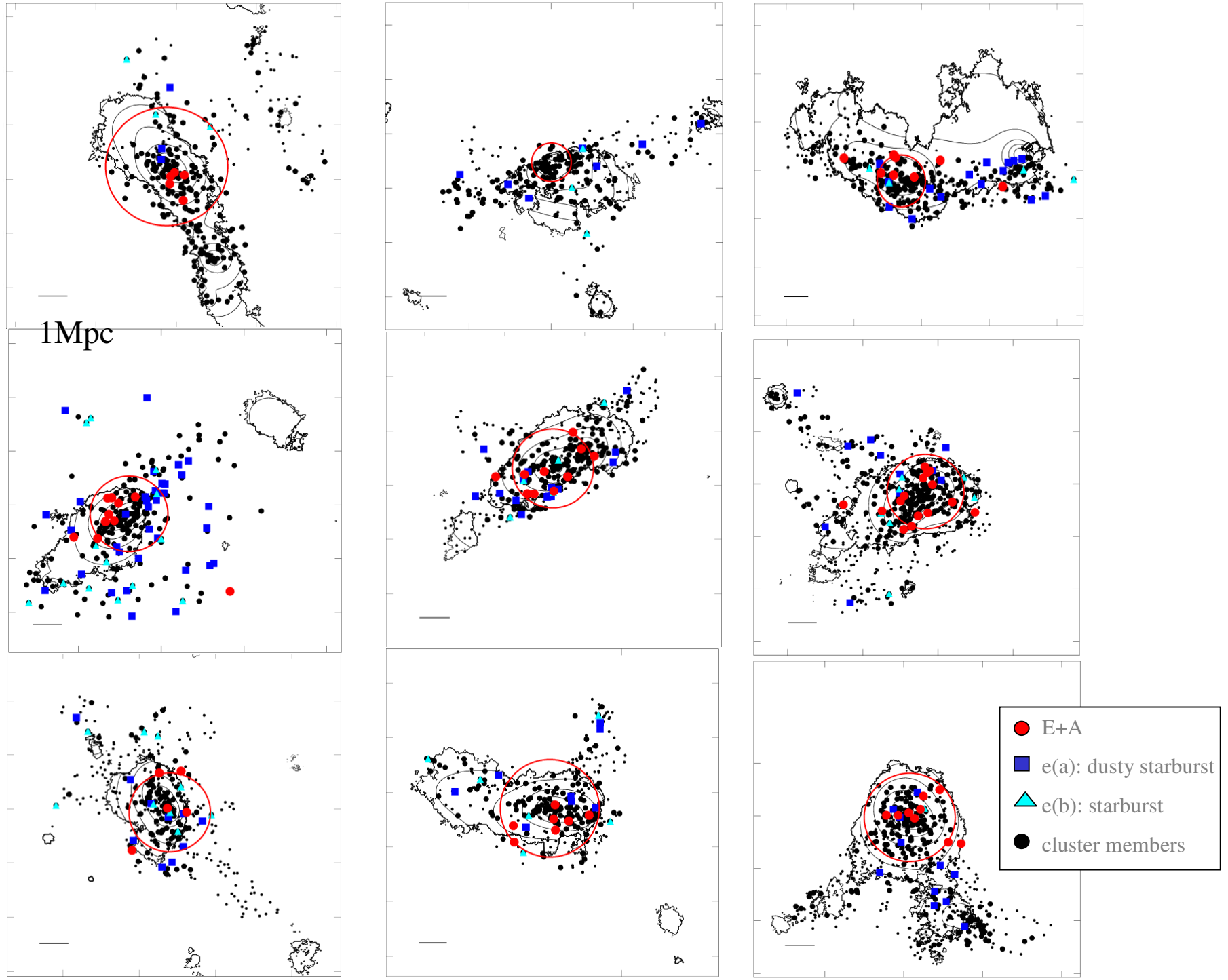

MACS J0717.5+3745 @ z=0.545
E+A
e(a): dusty starburst
e(b): starburst
cluster members
X-ray center
Contours: projected galaxy density



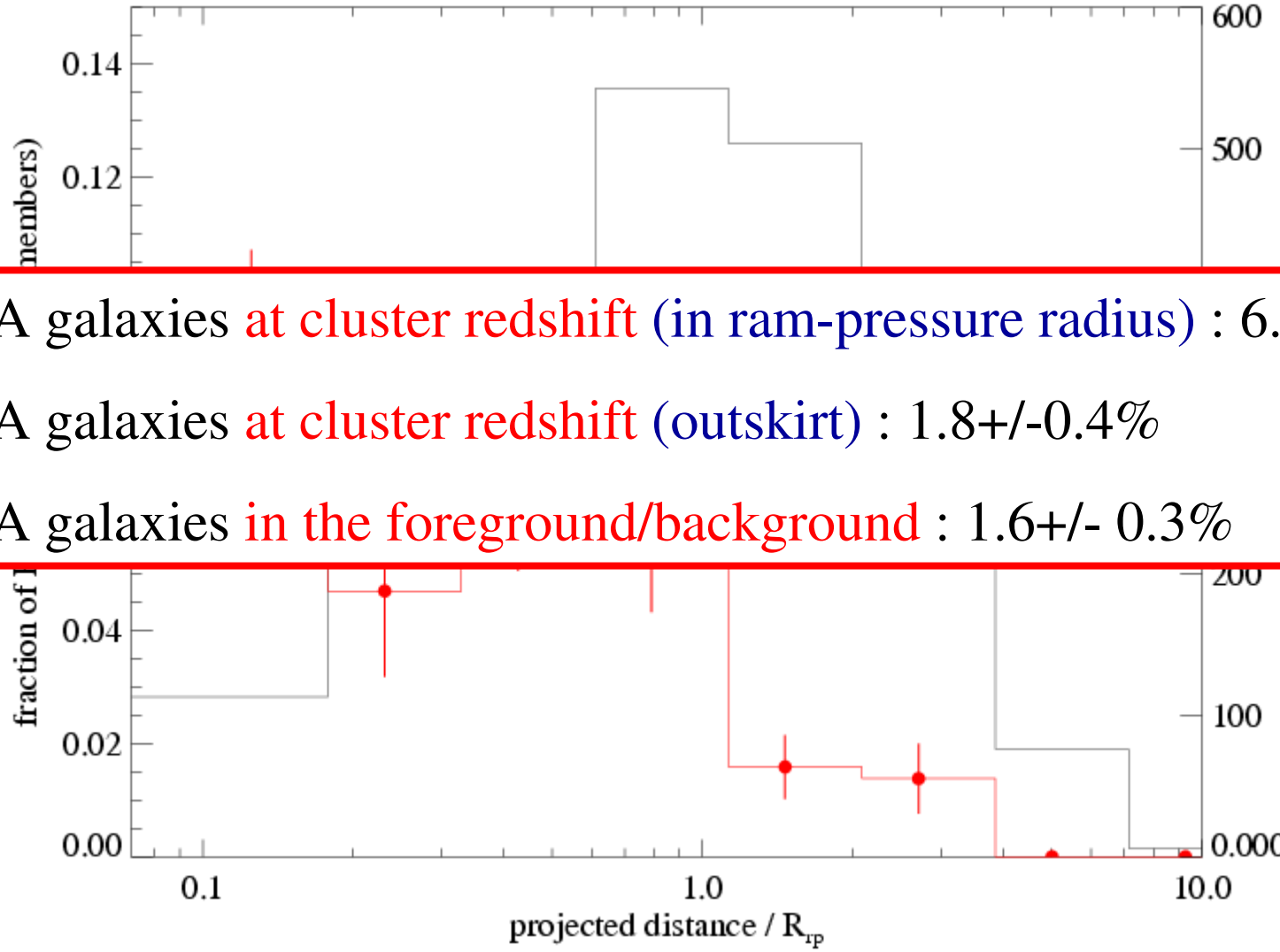
The hypothesis that density is the dominant factor of E+A galaxy distribution is **rule out** with 3σ confidence level.



Ma et al. 2008


1Mpc
E+A
e(a): dusty starburst
e(b): starburst
cluster members

Radial distribution of E+A in clusters



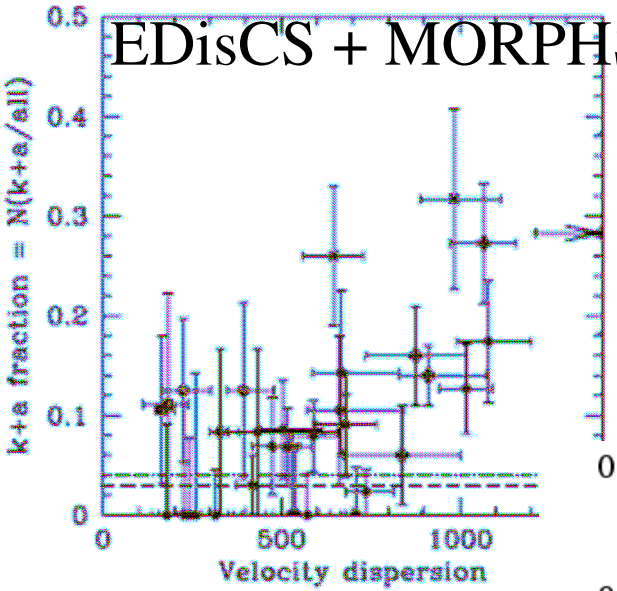
E+A galaxies at cluster redshift (in ram-pressure radius) : 6.0+/-0.8%

E+A galaxies at cluster redshift (outskirt) : 1.8+/-0.4%

E+A galaxies in the foreground/background : 1.6+/- 0.3%

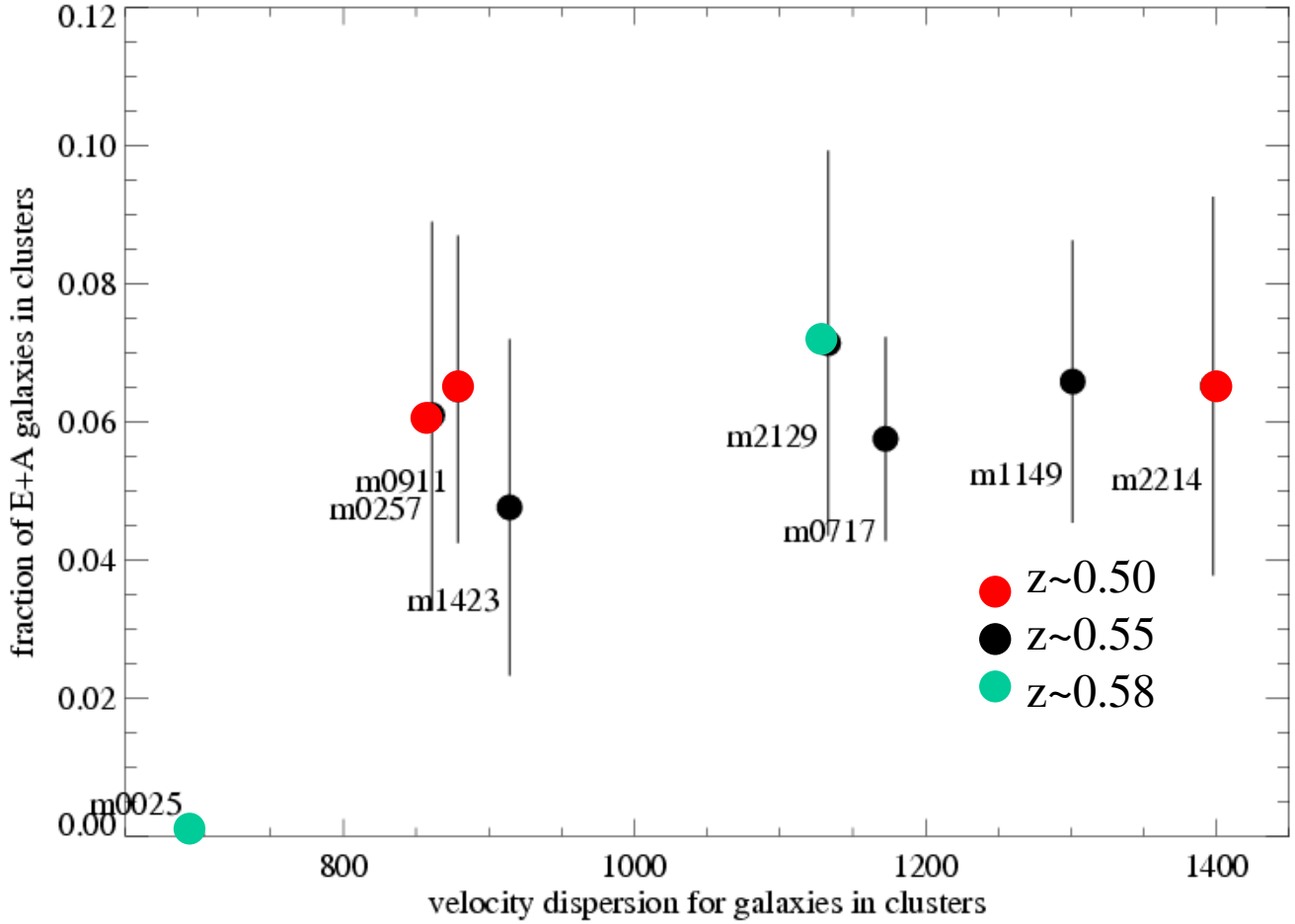
Projected distance (ram-pressure radius)

EDisCS + MORPHS

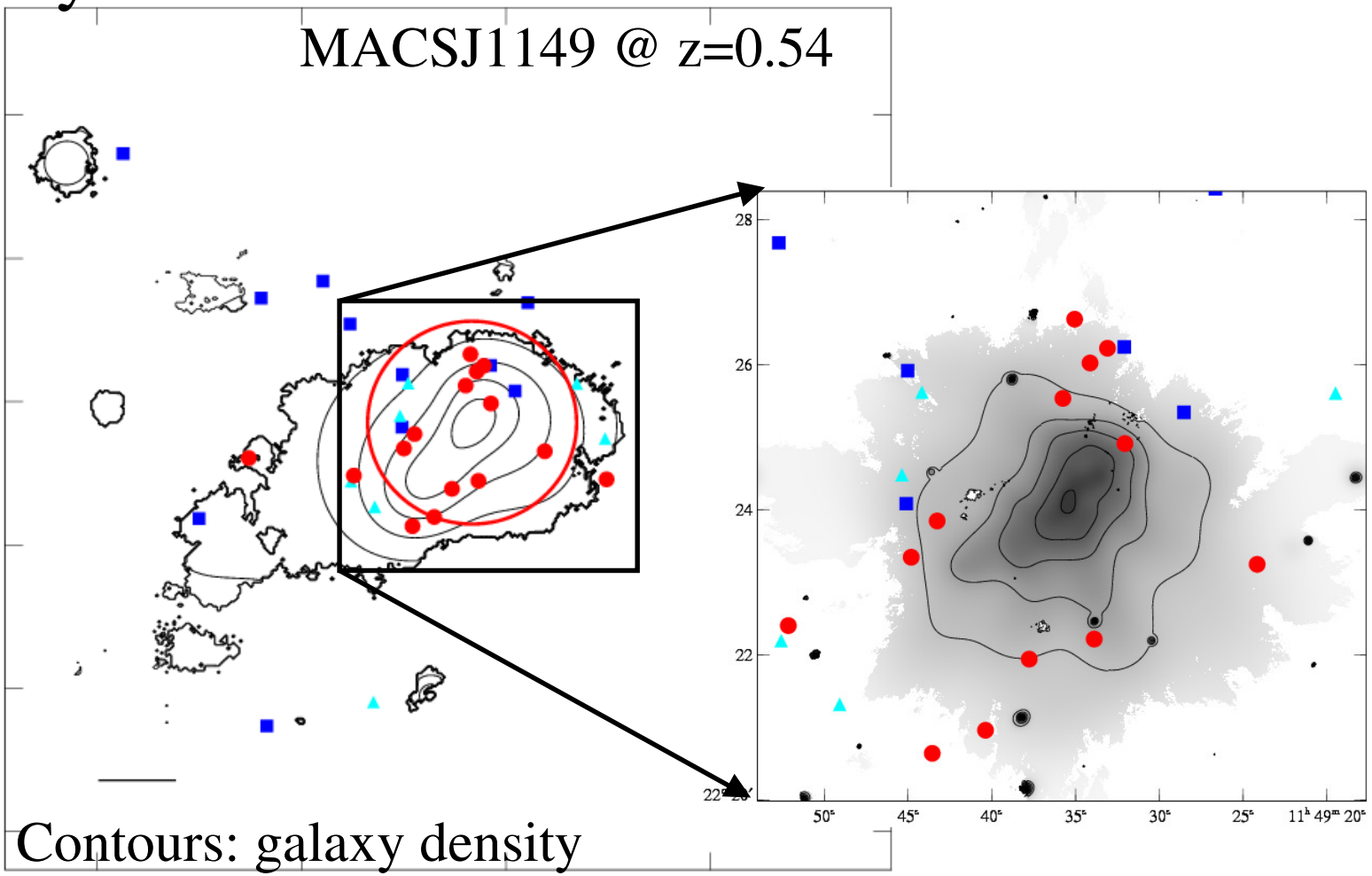


Poggianti et al. 2009

Correlation to the velocity dispersion of clusters

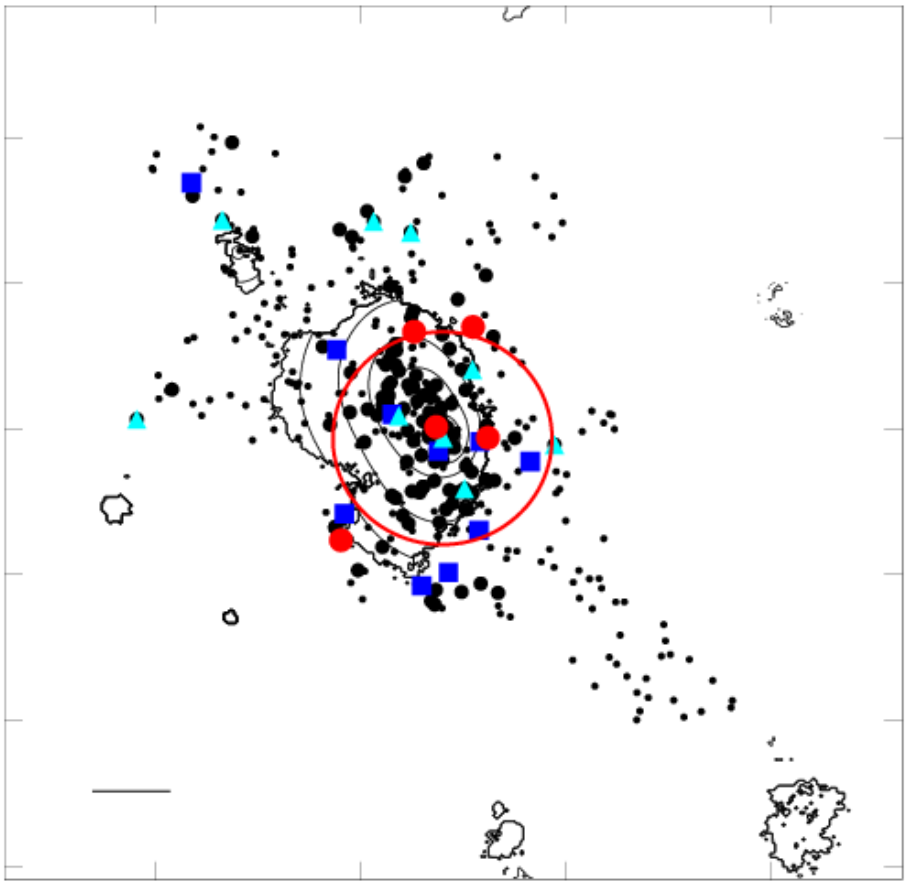


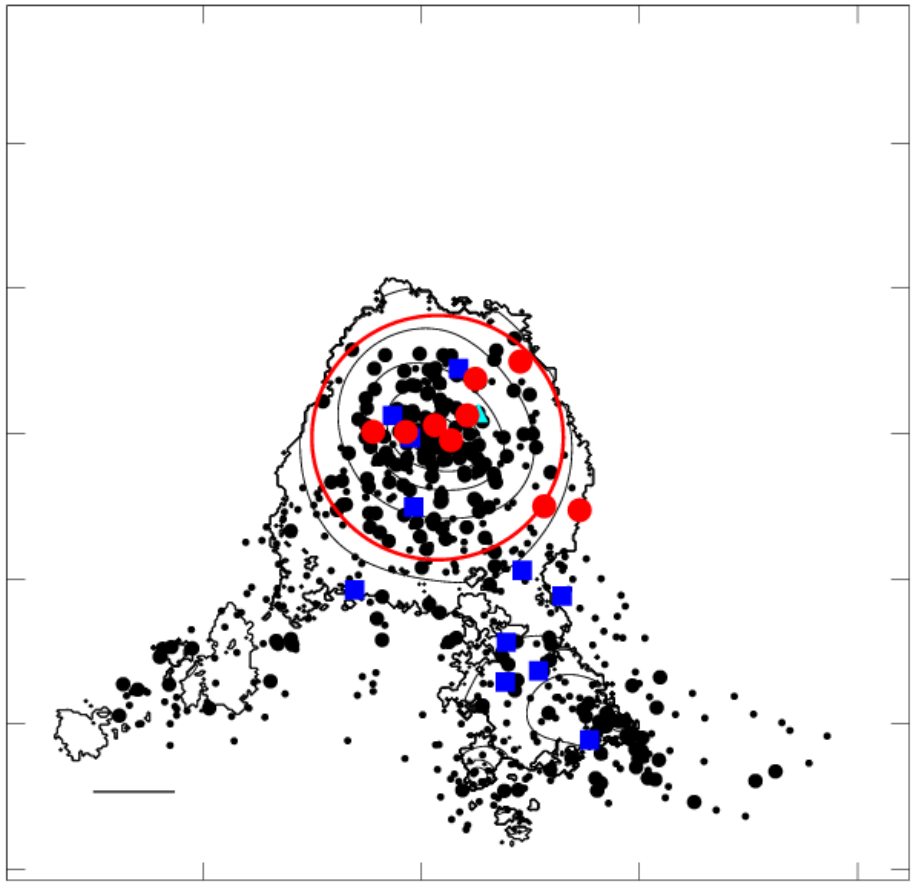
Individual cluster: Do the E+As avoid the very center of clusters?



Individual cluster: Do the E+As avoid the very center of clusters?

Not necessary.



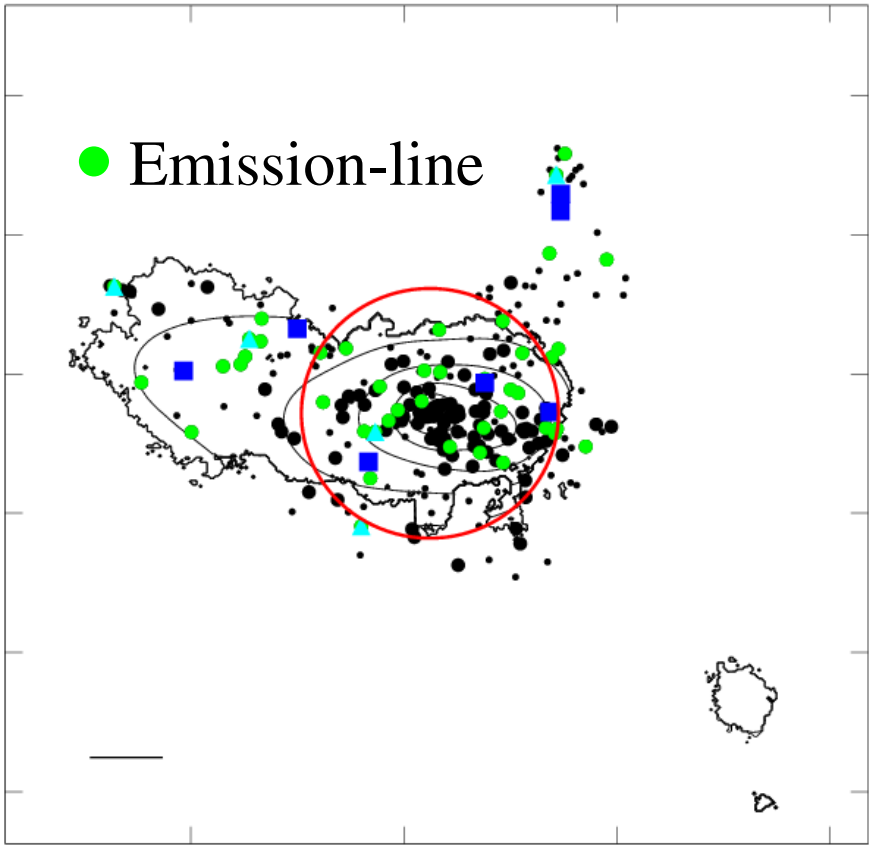


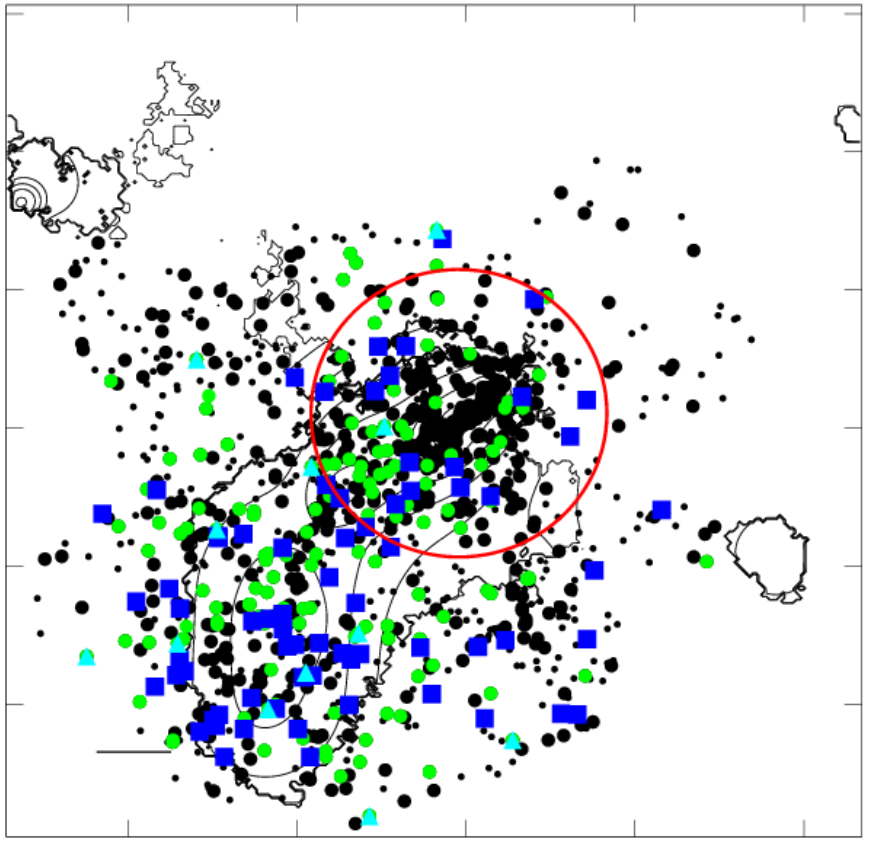
Could be projection effect

Individual cluster: Do the emission-line galaxies avoid the center?

In most cases, yes.

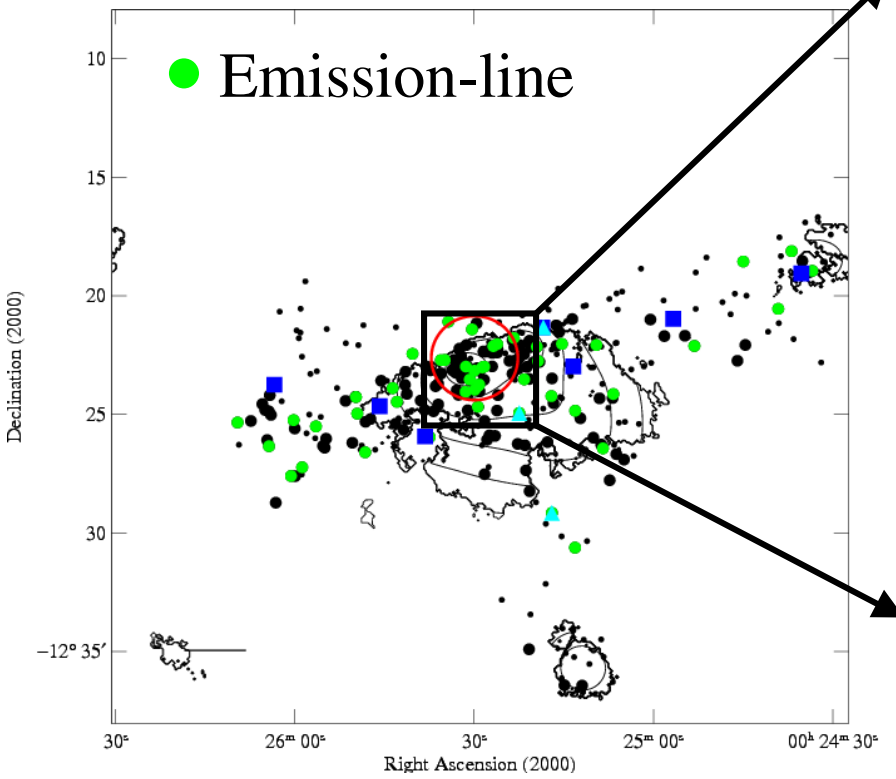
Two examples:

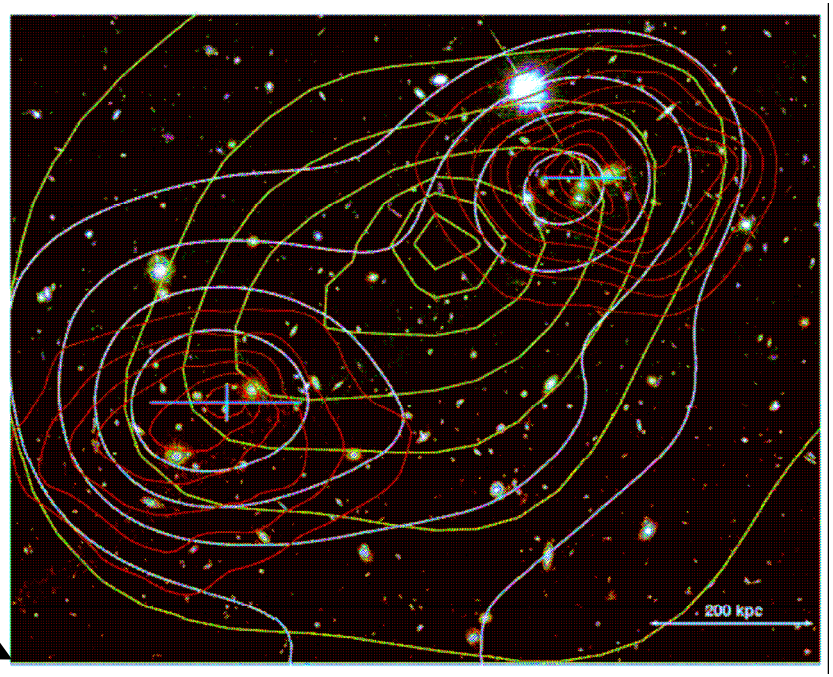




Individual cluster: Does the emission-line galaxies avoid the center?

But, there is an exception!





red: lensing

yellow: x-ray

Brodâc et al. 2008

MACSJ0025

Conclusion

- The fraction of E+A at z~0.5 inside ram-pressure radius of clusters is higher than any other environment.
  - It is consistent with field spectroscopic survey (Yan et al. 2008) that the E+A fraction does not depend strongly on galaxy density, unless we are looking at inside of massive clusters.
  - We are not saying the ram-pressure stripping is the only mechanism to quench the starburst, but we suggest the ram-pressure stripping is more effective to terminate starburst rather than merger.
- No correlation between velocity dispersion and fraction of E+A galaxies at the extreme high velocity dispersion end. The fraction are actually consistent with each other.