time invariance of total stellar mass–cluster mass relation

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with
Bau-Ching Hsieh, Masamune Oguri, and the HSC collaboration

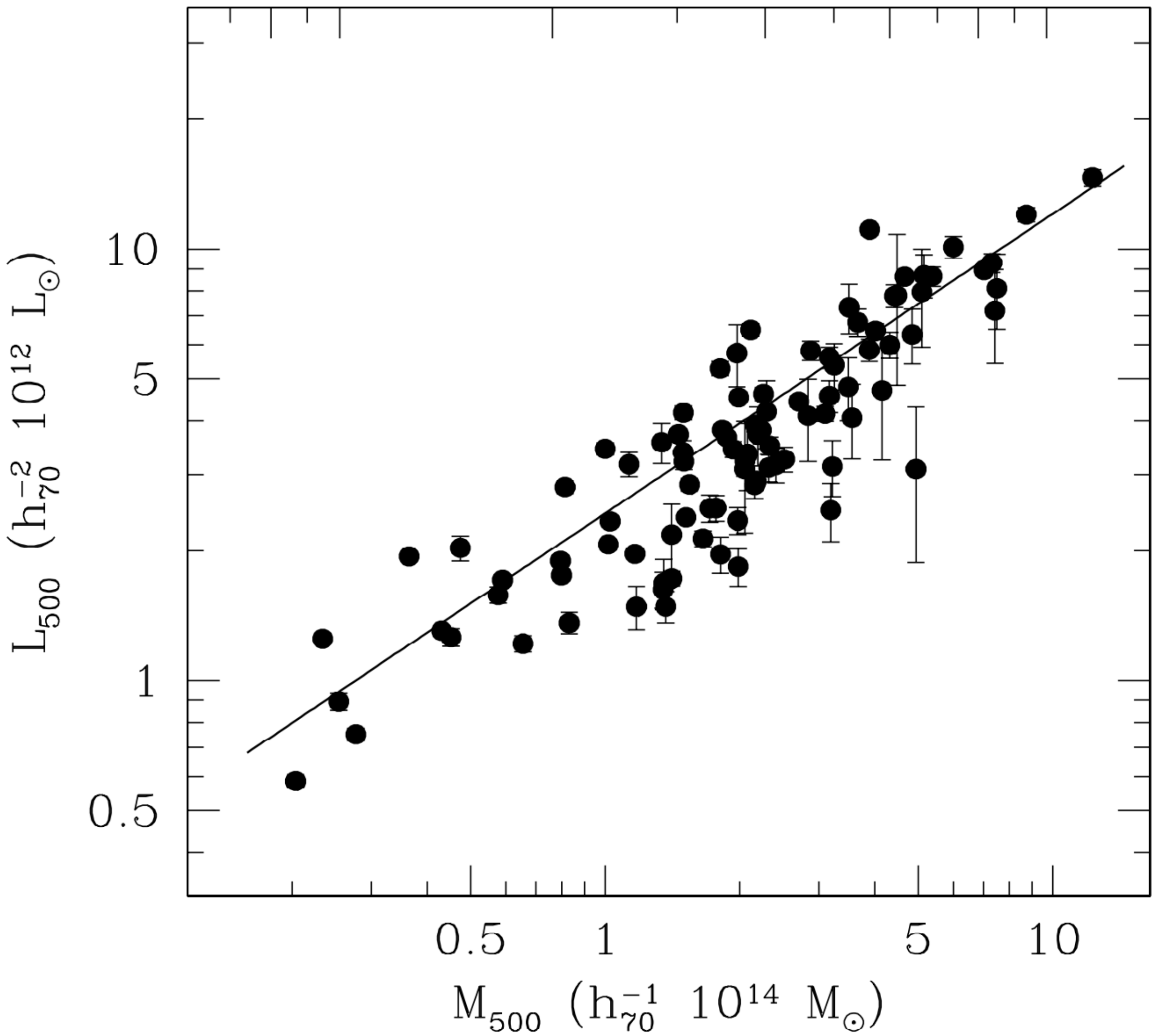
outline

- total stellar mass–cluster mass correlation
    - insights from Subaru Hyper Suprime-Cam (HSC) survey
- more fun with the HSC survey
    - stellar mass function in clusters vs field
    - redshift evolution of cluster radio galaxy population
    - star formation activity in high-z clusters
    - ...

total near-IR K-band light

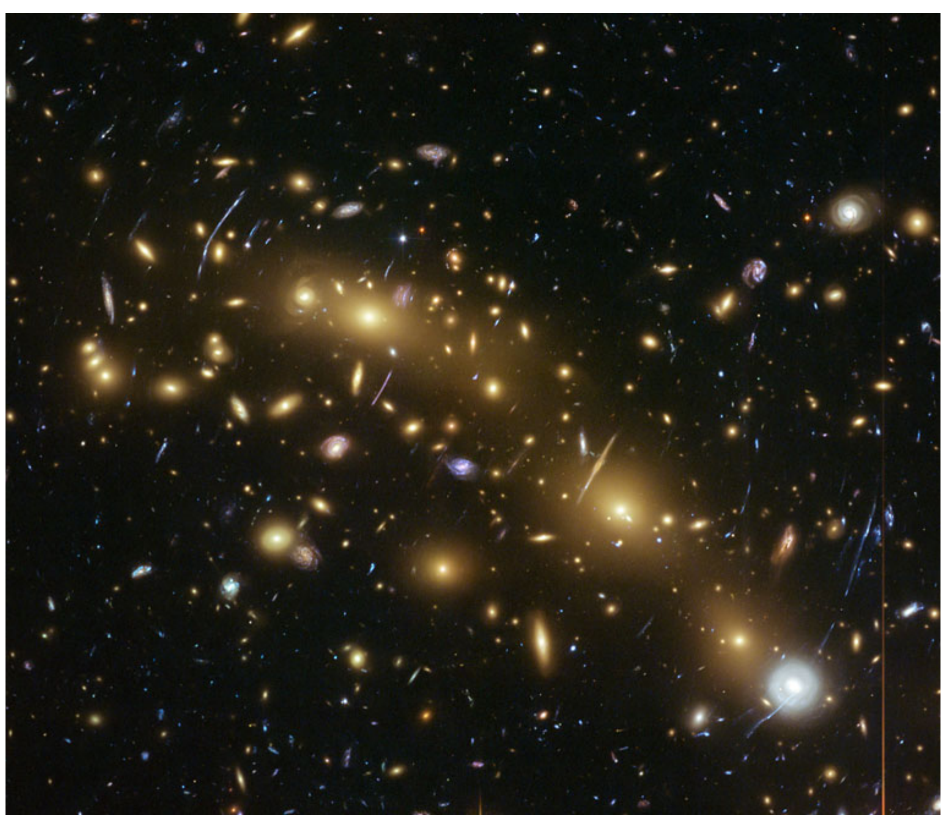
total stellar mass–cluster mass correlation

- the scaling is far from linear!
- clusters are *not* self-similar — you don't build massive clusters simply by combining smaller ones together
- total galaxy stellar mass per unit halo mass has to decrease as clusters become more massive
  - tidal stripping ⇒ intracluster light?!



$$\frac{L_{200}}{10^{12}\ h_{70}^{-2}\ L_\odot} = 5.64 \pm 0.16 \left(\frac{M_{200}}{2.7 \times 10^{14}\ h_{70}^{-1}\ M_\odot}\right)^{0.72 \pm 0.04}$$

$L_{200} \propto M_{200}^{0.7}$
$(L/M) \propto M^{-0.3}$



Lin+04, HST

total near-IR K-band light

total stellar mass–cluster mass correlation

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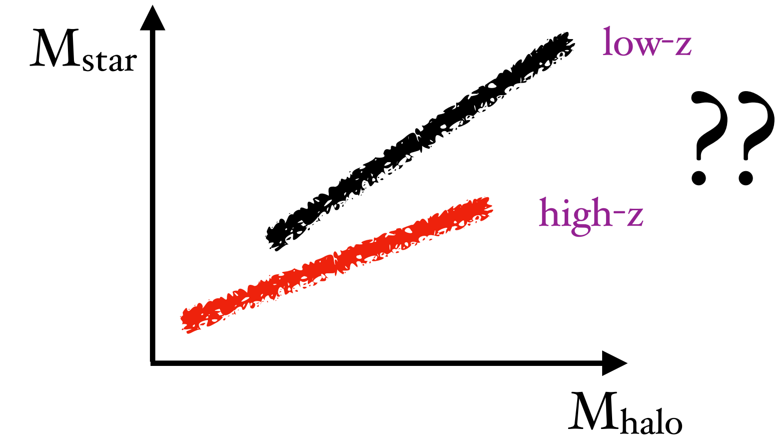
- clusters are *not* self-similar — you don't build massive clusters simply by combining smaller ones together
- total galaxy stellar mass per unit halo mass has to decrease as clusters become more massive
  - tidal stripping ⇒ intracluster light?!
  - perhaps the progenitors of z~0 high-mass clusters (=lower mass clusters at high-z) are different (in terms of L/M) from the low-z low-mass ones?
    - change in the scaling relation may be expected...
    - varying galaxy formation efficiency as a function of cluster mass??

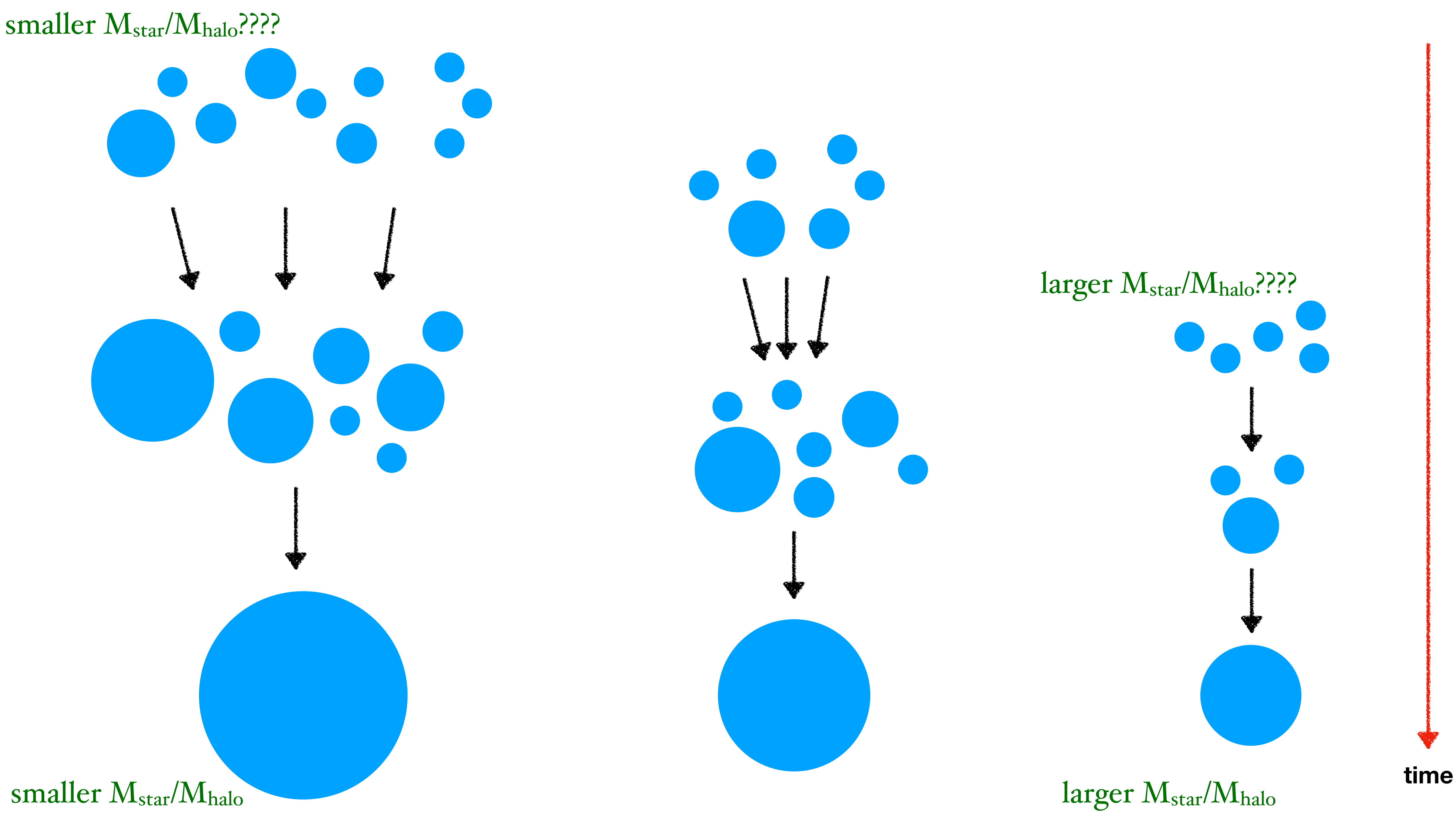
RDCS1252
z=1.24
M_{200}~3x$10^{14}M_{sun}$

Abell2107
z=0.041
M_{200}~3x$10^{14}M_{sun}$

HST, SDSS

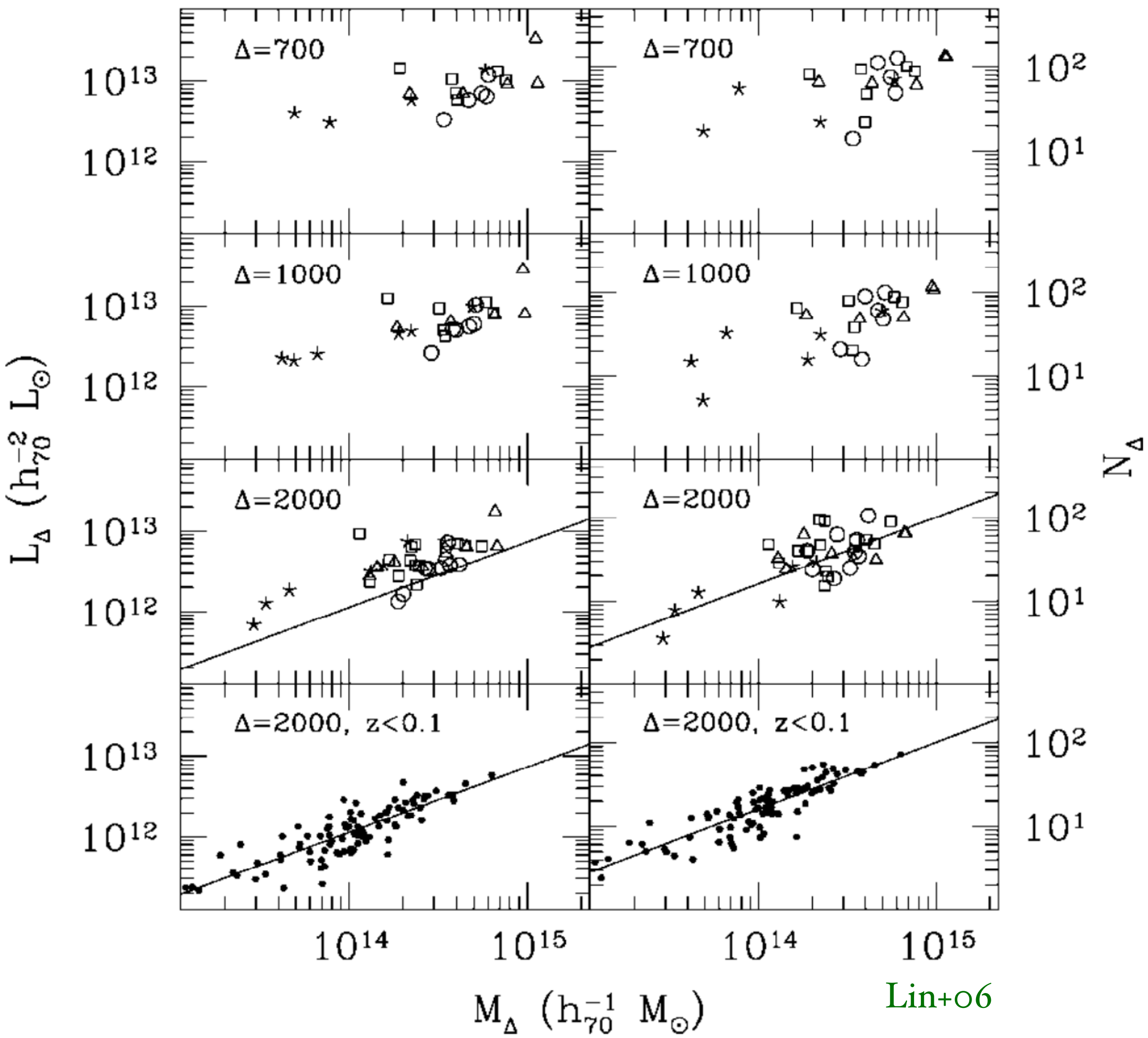
- change in the scaling relation may be expected…
- varying galaxy formation efficiency as a function of cluster mass?? somehow halos must know where/what will they end up with?





does the relation evolve?

27 clusters, z=0-0.9

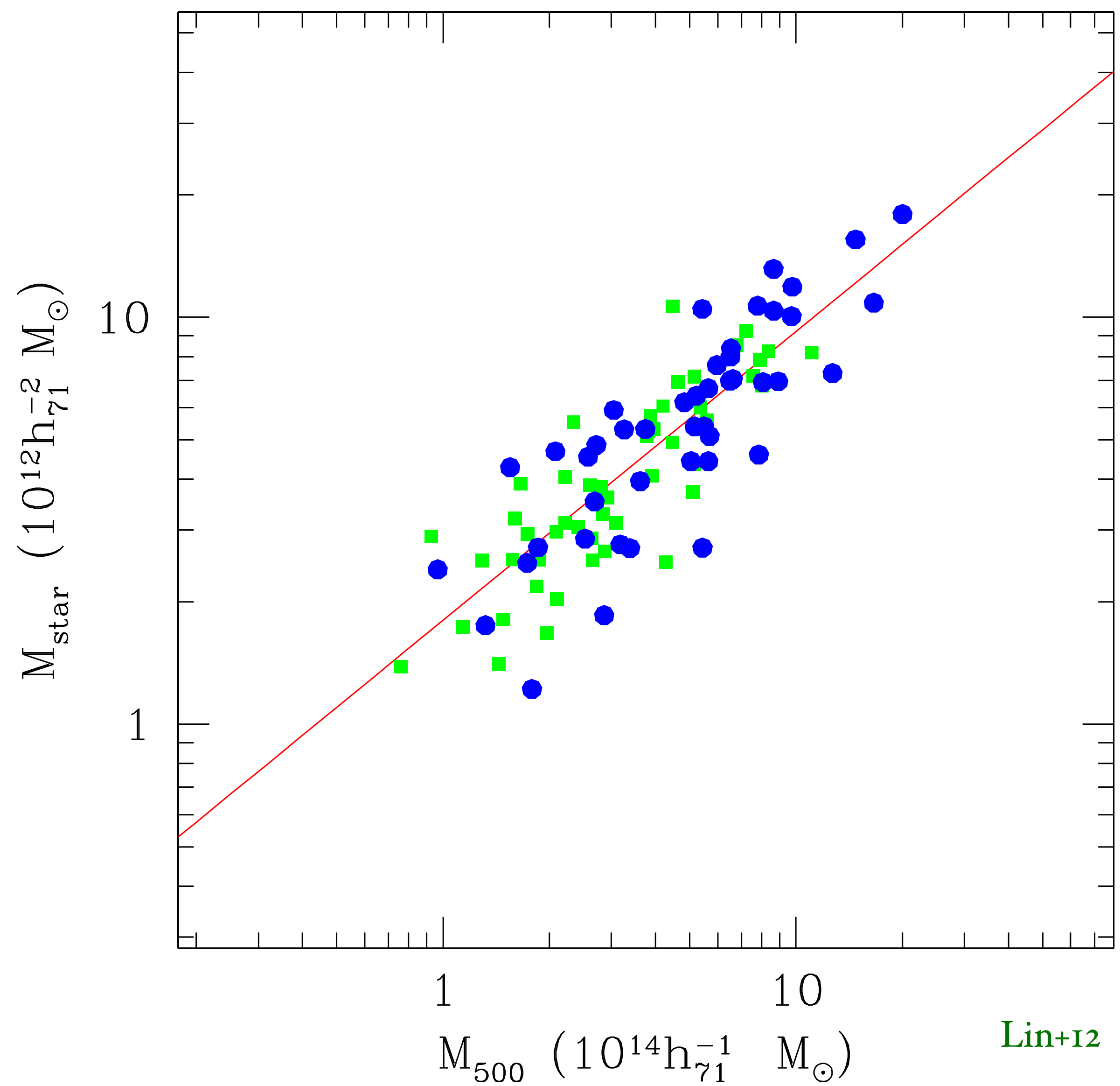


$$N(M, z) = N_0(1+z)^\gamma (M/M_0)^s$$

$$\gamma = -0.03 \pm 0.27$$

scaling with near-IR L similar once
passive evolution has been taken into account

94 clusters, z=0-0.6



$$M_{\rm star} \propto M_{500}^{s_2} (1+z)^{\gamma_2}$$

$$s_2 = 0.71 \pm 0.04$$

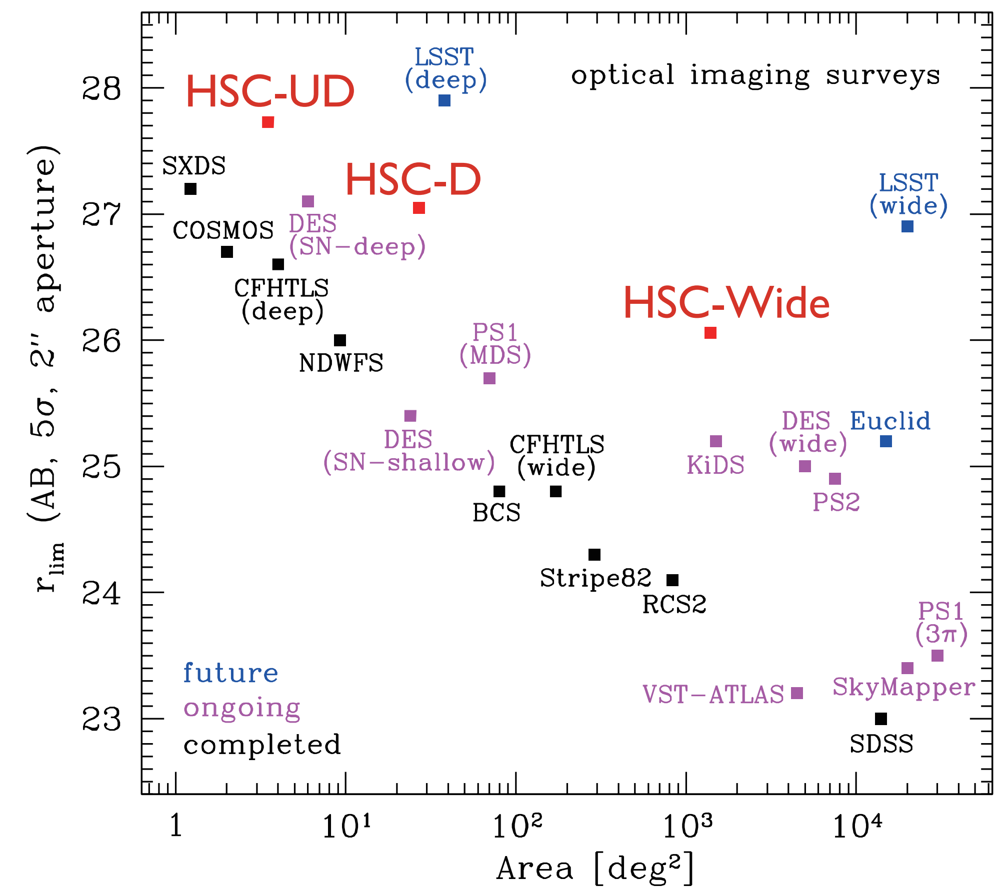
$$\gamma_2 = -0.06 \pm 0.22$$

insights from the HSC survey

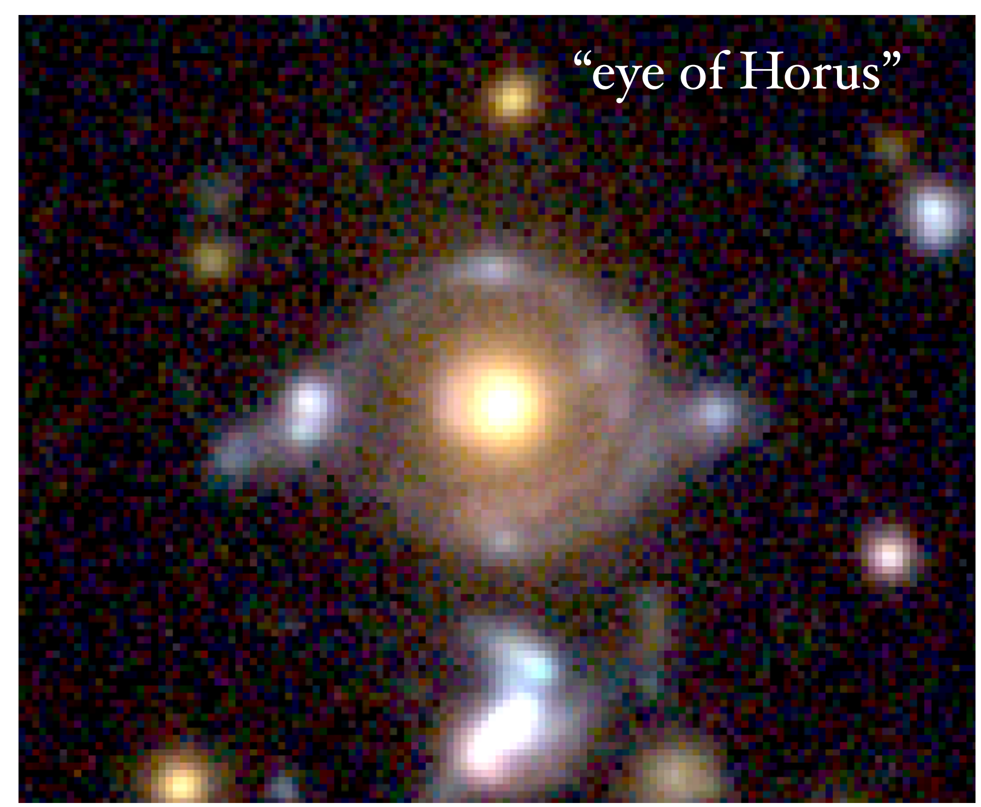
the HSC survey

- not just yet another imaging survey
  - superb imaging quality (median seeing 0.6″)
  - narrow-band filters in deep+ultradeep layers
- complete census of clusters at key phases
  - proto-clusters as Lyman break galaxy overdensities at z=4-6
  - clusters at z=1-2 from broad & narrow bands
  - z<1 clusters from red sequence or shear selection
- 1st public data release in 02/2017; 2nd in mid-2019

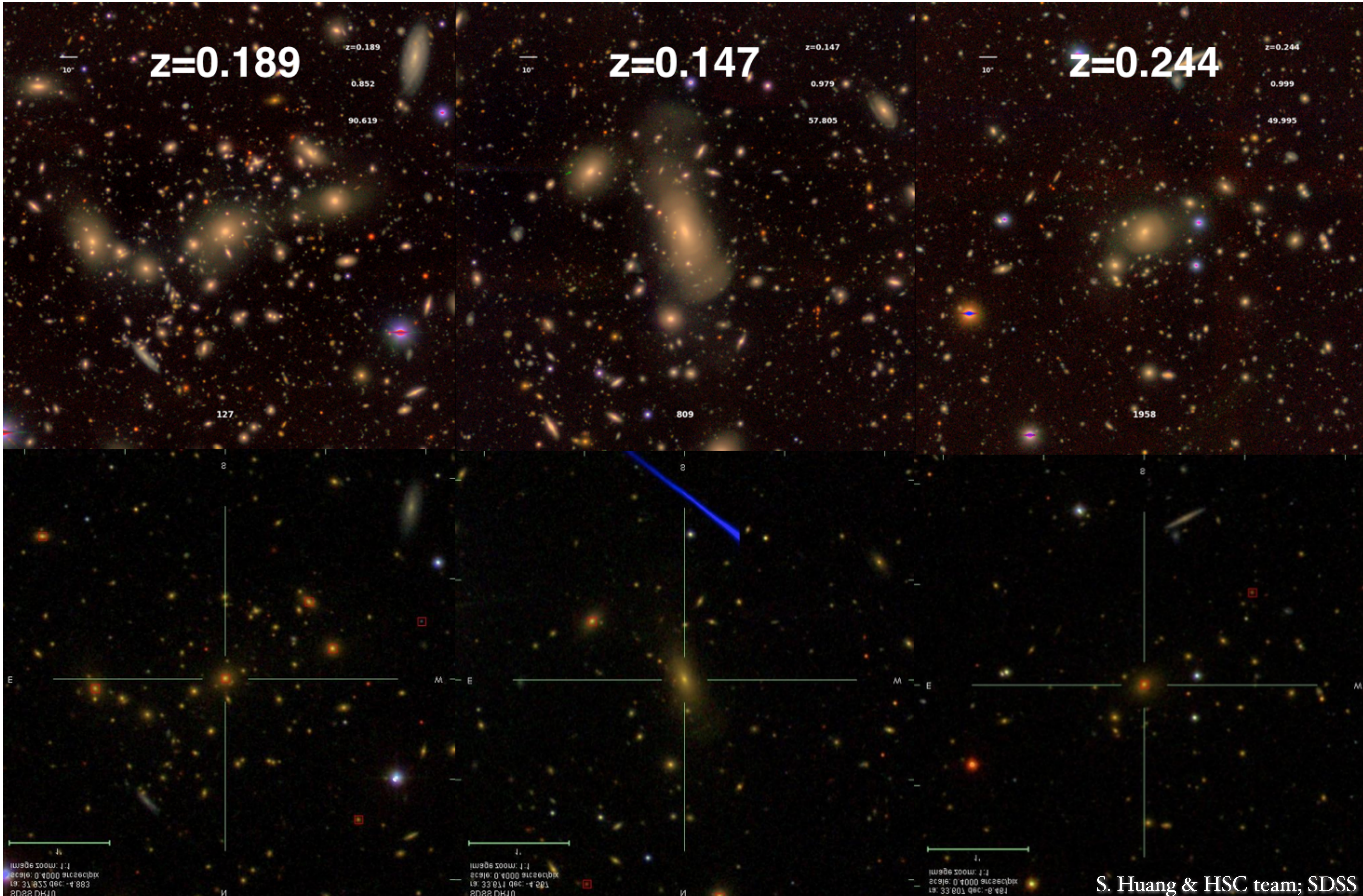
Layer	Area [deg^2]	Number of pointings	Filters and depth
Wide	1400	916	$grizy (i \simeq 26)$
Deep	26	15	$grizy$ + 3NBs ($i \simeq 27$)
UltraDeep	3.5	2	$grizy$ + 3NBs ($i \simeq 28$)



credit: M. Tanaka, K. Wong, K. Thanjavur



the HSC cluster sample

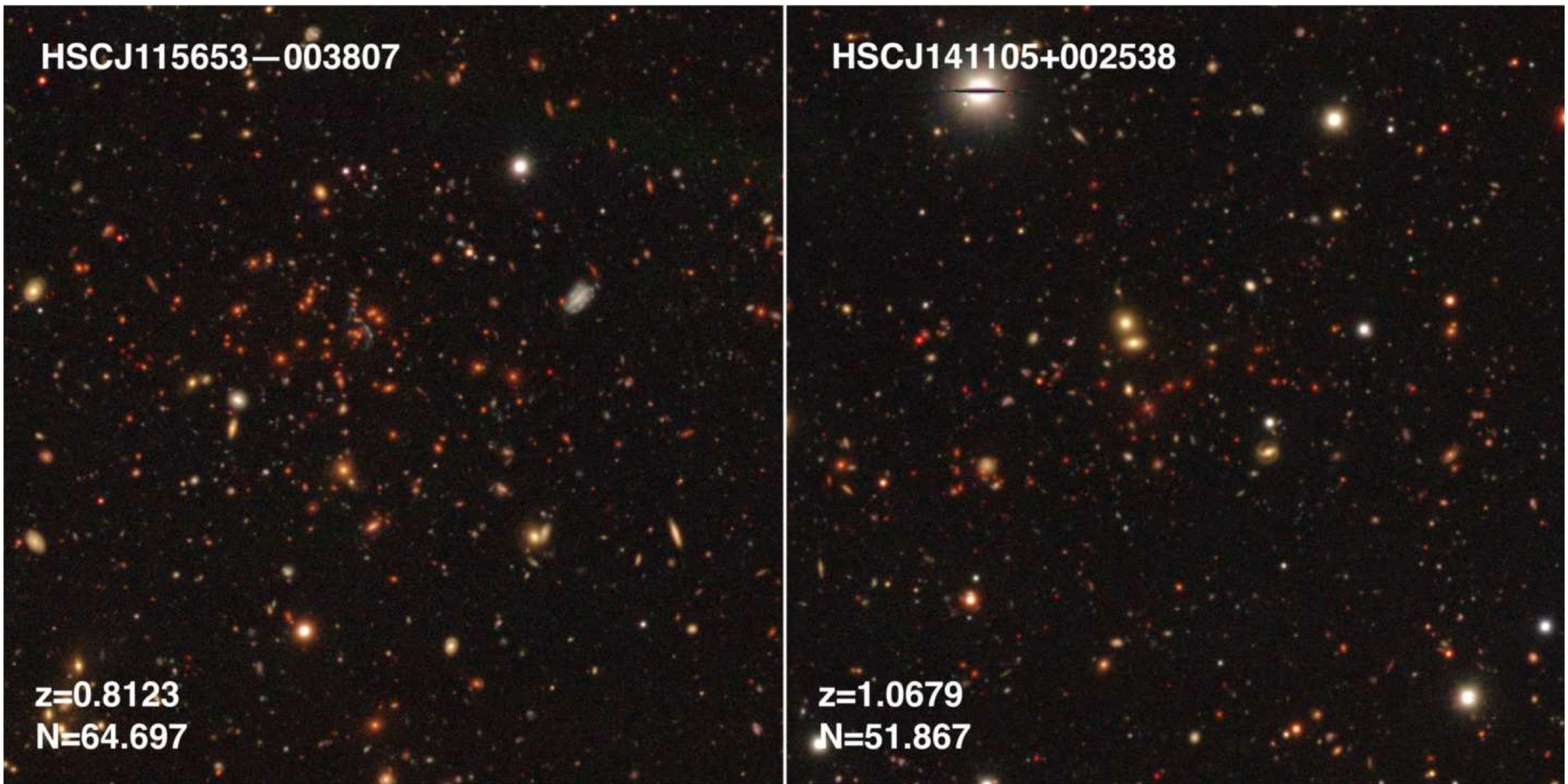


S. Huang & HSC team; SDSS

the HSC cluster sample

targeting clusters with prominent red sequence, *camira* (**c**luster finding **a**lgorithm based on **m**ulti-band **i**dentification of **r**ed sequence g**a**laxies) has found ~1900 clusters at z=0.1-1.1 over 230 deg^2 with richness N≥15 in the HSC survey

Oguri, Lin+18

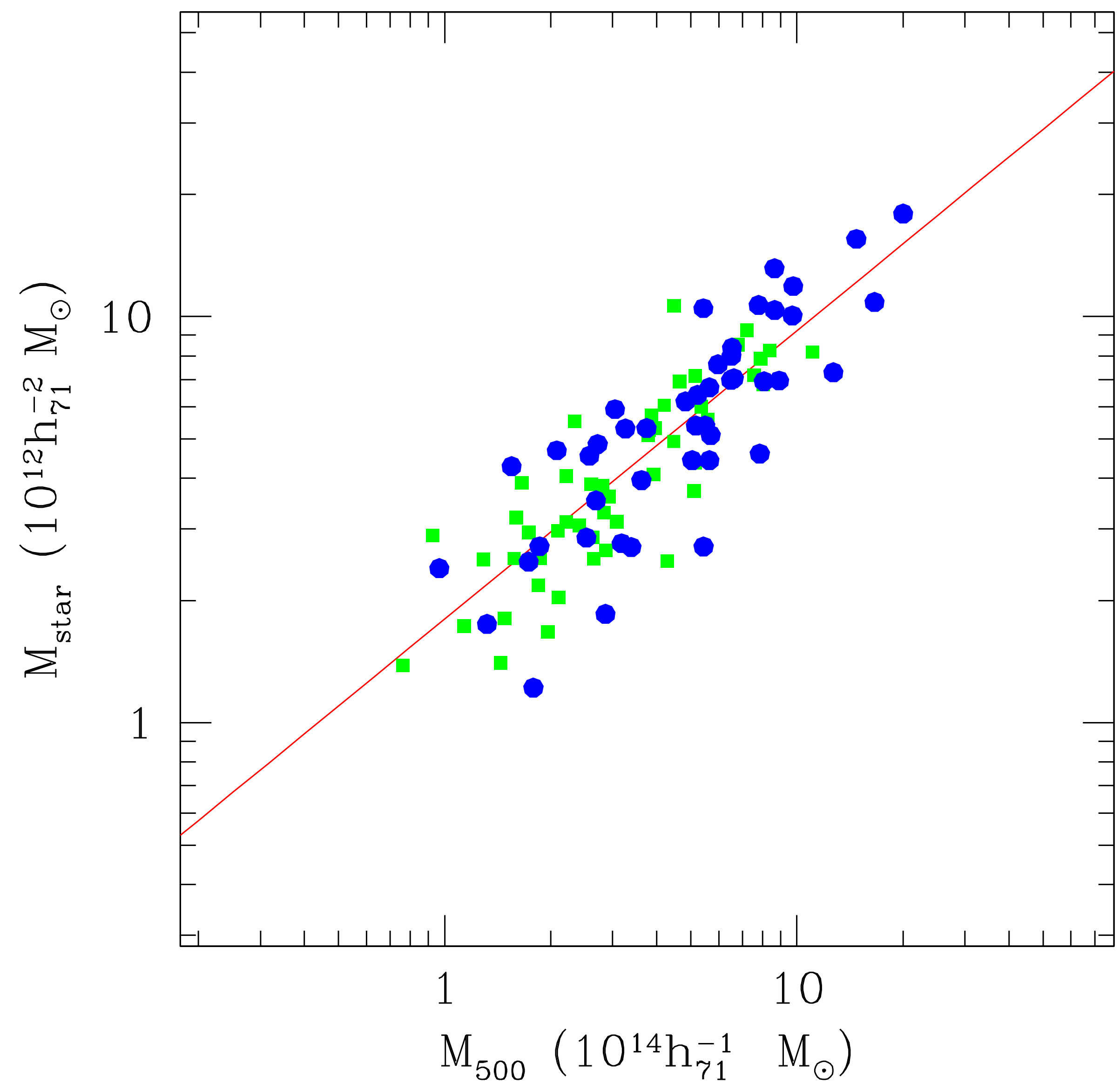


elements of analysis

stellar mass: derived with a machine-learning algorithm

stellar mass distribution: constructed using a statistical background correction scheme

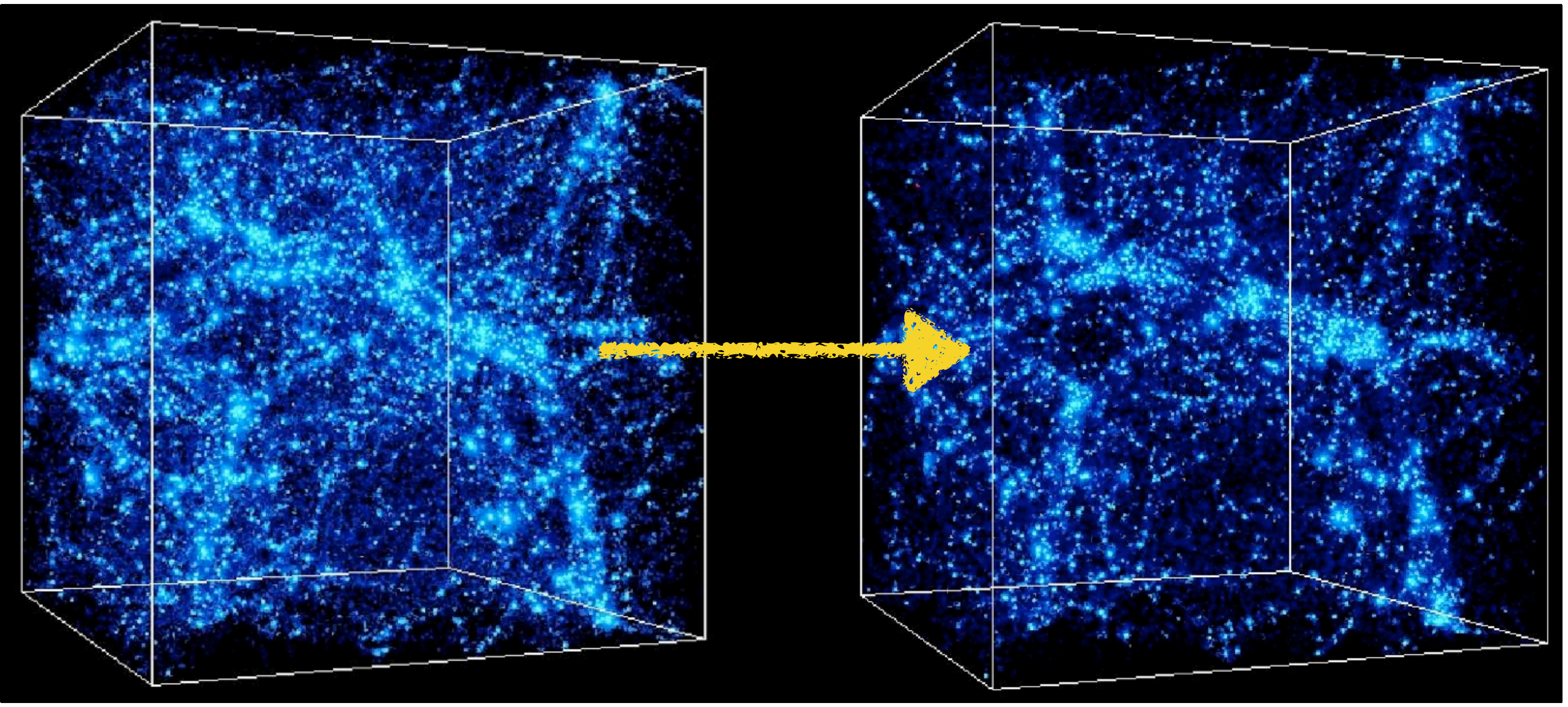
M_{star}: obtained by integrating the SMD



cluster selection: use cluster (sub)samples that can be considered to form an evolutionary sequence: high-z cluster (sub)sample to have properties consistent with progenitors of low-z (sub)samples ⇒ *top N* selection

cluster mass: weak lensing / abundance-based estimates

top N selection of halos



A. Kravtsov

	Remaining Fraction (%)					
initial z	final z (no scatter)			final z (25% scatter)		
	0.83	0.68	0.45	0.83	0.68	0.45
0.98	86	76	66	62	67	58
0.83	–	86	70	–	64	55
0.68	–	–	79	–	–	58

for N=100 over 60% Millennium volume; 4 redshift bins from 0.3 to 1.02

- construct cluster samples that represent progenitor-descendant relationship *statistically*
- Ansatz: given comoving volume, the most massive N halos will remain among the most massive N at a later time
- similar in spirit to the fixed cumulative number density selection for field galaxies
- tests with Millennium simulation suggest above holds to *~65%* (including scatter in mass-observable relation), even with Δz~0.6

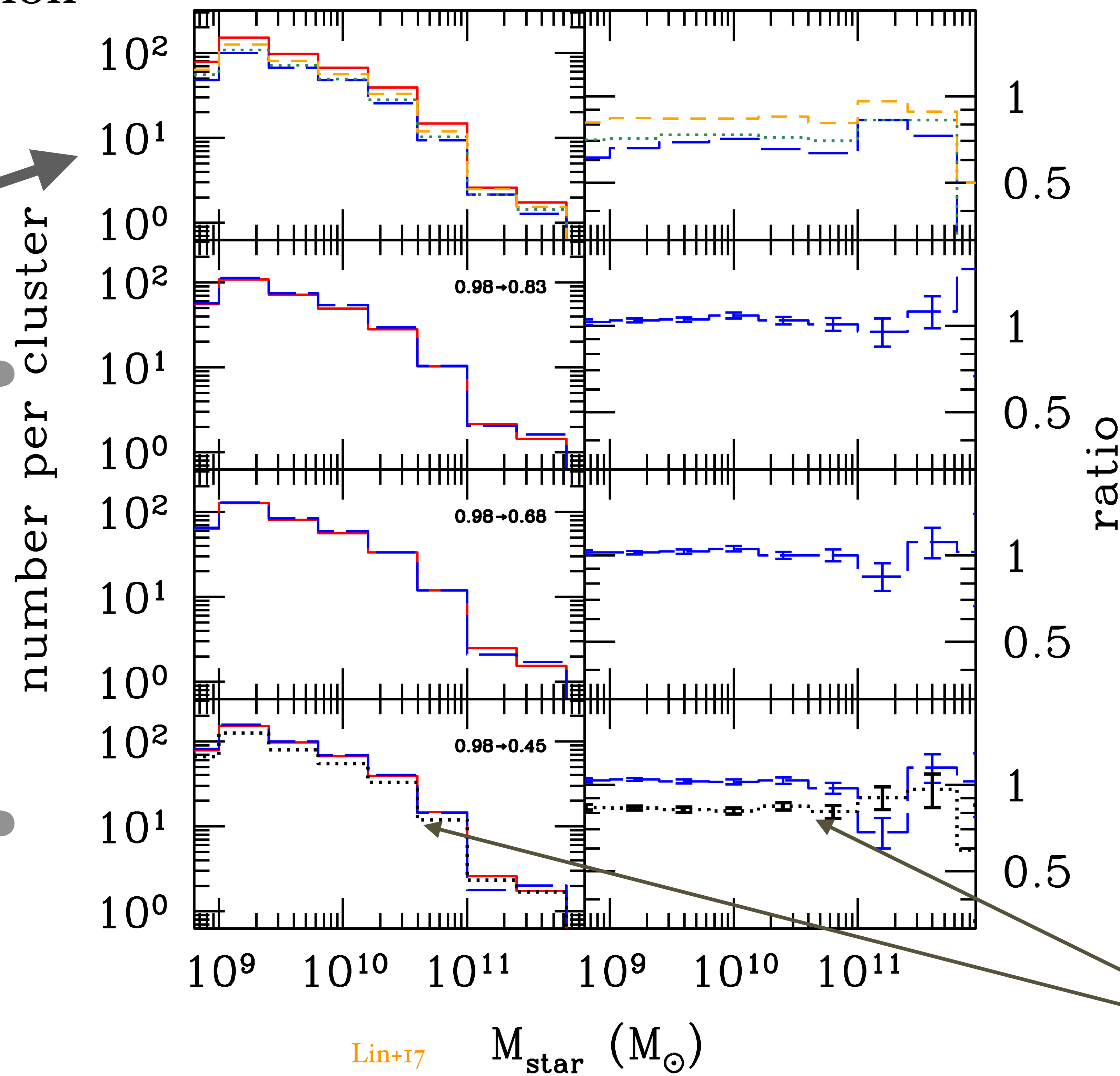
top N selection of halos

tests with semi-analytic models show good recovery of galaxy population

top 100 in 4 bins:
blue: 0.98
green: 0.83
orange: 0.68
red: 0.45

dashed/blue: descendants of top 100 selected at z=0.98

solid/red: top 100 selected at lower-z



Lin+17

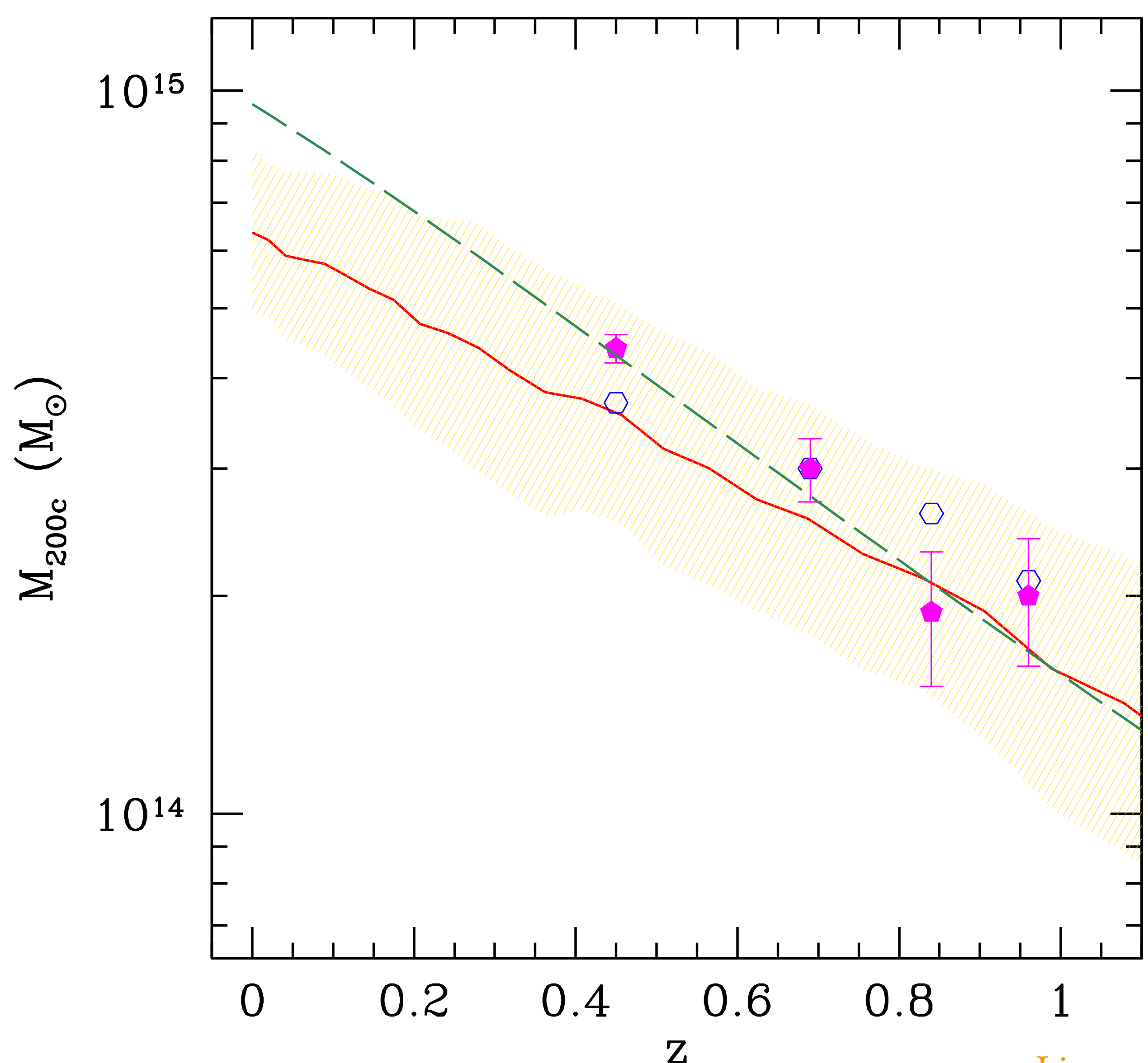
top 200 halos

halo mass estimates

- two methods
  - mean mass of top 100 halos over $(420h^{-1}Mpc)^3$ in Millennium, with reasonable assumptions in mass−observable relation (open circles)
  - stacked weak lensing (solid points)
- from $\sim 2\times10^{14} M_{sun}$ at $z\sim1$ to $\sim 4\times10^{14} M_{sun}$ at $z\sim0.45$
- descendant mass at $z\sim0$ likely in $(6\text{-}10)\times10^{14} M_{sun}$

Basic Cluster Properties

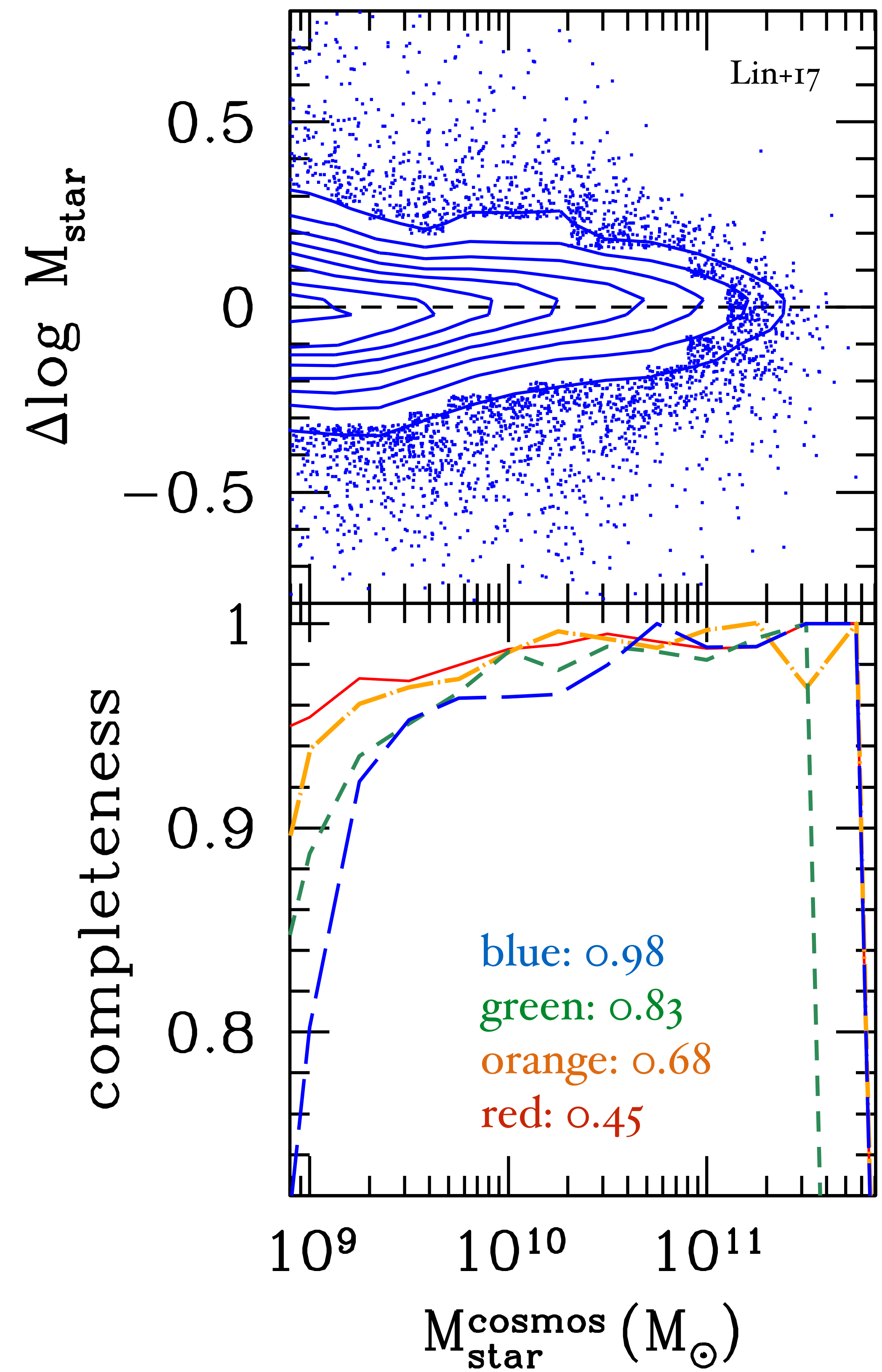
bin	redshift range	mean z	stacked lensing M_{200} ($10^{14} M_\odot$)	stacked lensing r_{200} (Mpc)	abundance M_{200} ($10^{14} M_\odot$)	abundance r_{200} (Mpc)	$\hat{N}_{\rm lim}$
1	0.30 − 0.60	0.45	4.4 ± 0.2	1.33	3.7	1.27	30.0
2	0.60 − 0.77	0.69	3.0 ± 0.3	1.07	3.0	1.09	22.7
3	0.77 − 0.90	0.84	1.9 ± 0.4	0.86	2.6	0.98	21.6
4	0.90 − 1.02	0.96	2.0 ± 0.4	0.84	2.1	0.87	18.0



Lin+17

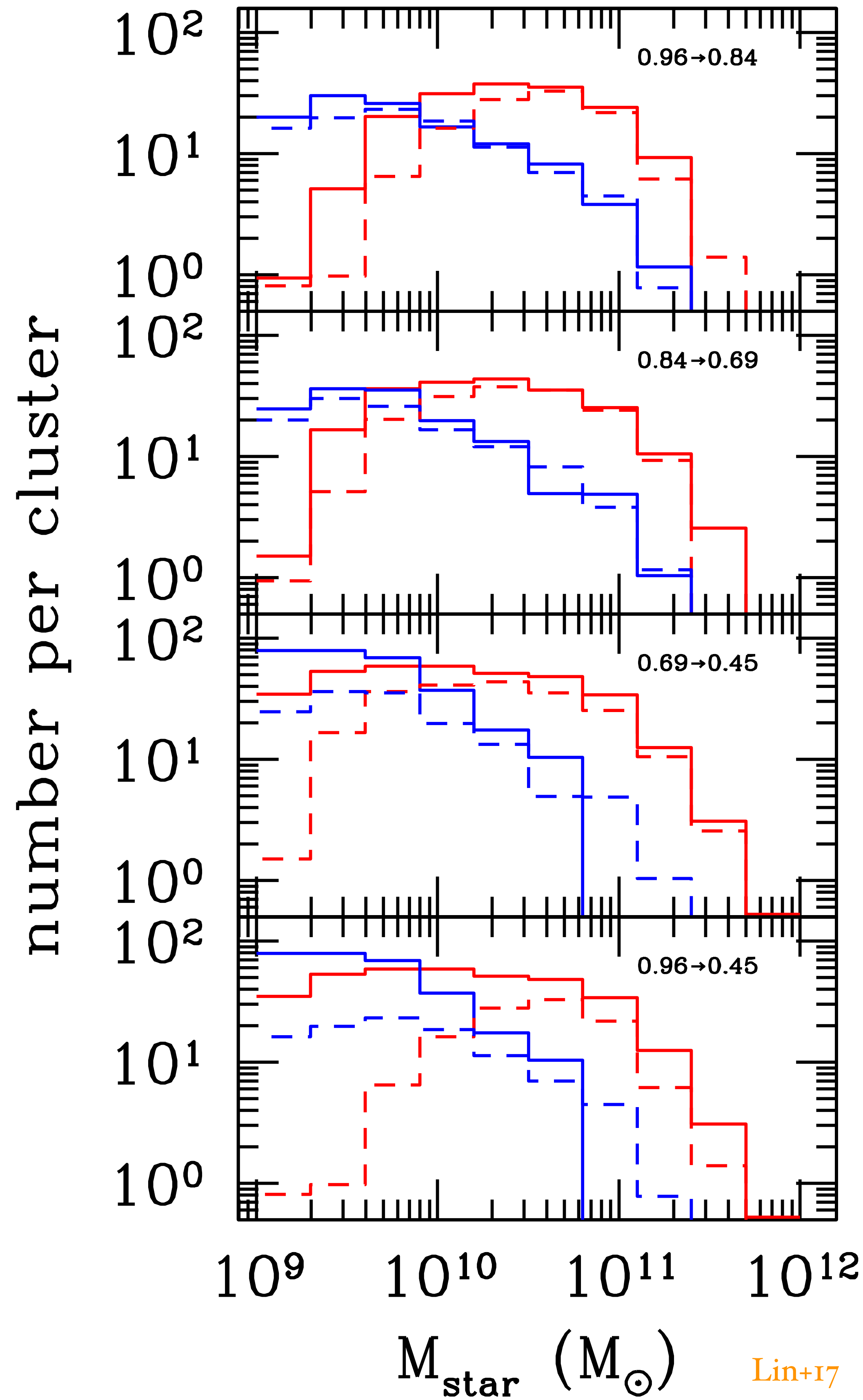
stellar mass estimates

- for galaxies at z>0.8, the HSC *grizy* photometry does not sample much of restframe optical, resulting in biases in stellar mass estimates based on SED fitting
- we thus use a machine learning algorithm, Direct Empirical Method (DEmP, Hsieh & Yee 2014), for the task
- hybrid of linear regression and nearest neighbor
- COSMOS2015 and HSC ultra-deep catalogs used as training set, applied to HSC wide data
- our estimates are unbiased with low scatter
- highly complete above $10^{10} M_{sun}$



stellar mass distribution

- each panel shows pairwise comparison of SMDs (no BCGs) in two redshift bins for red and blue galaxies
  - dashed = higher-z; solid = lower-z
- completeness corrections applied
- apparent growth at both very high mass and low mass ends
  - (except for disappearance of massive blue galaxies)
  - for $M > 10^{10} M_{sun}$ red galaxies, abundance at z=0.45 is 2x that at z=0.96
  - for lower mass red galaxies, difference is 7x (down-sizing!)
  - ratios for blue ones are 1.5x and 3x



Lin+17

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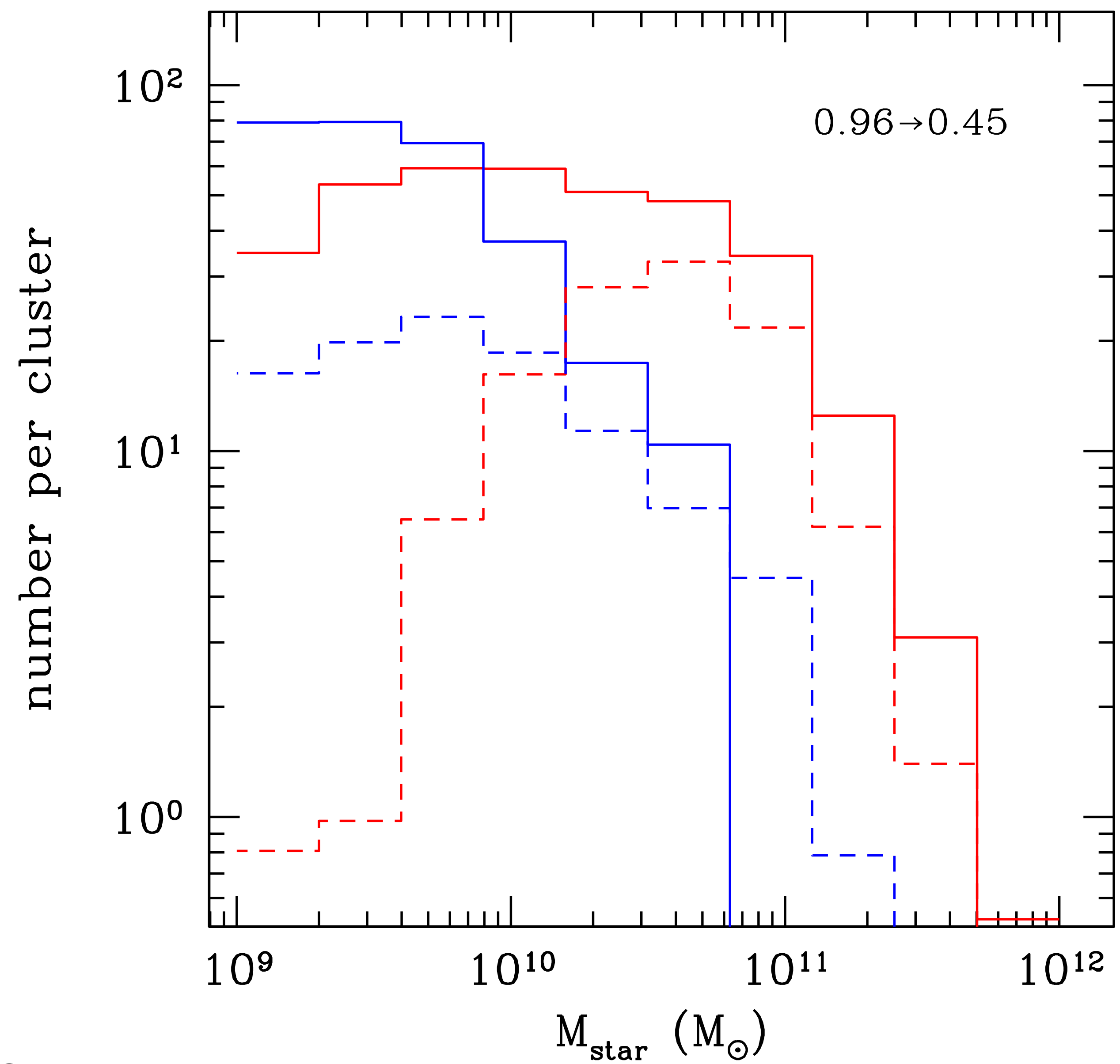
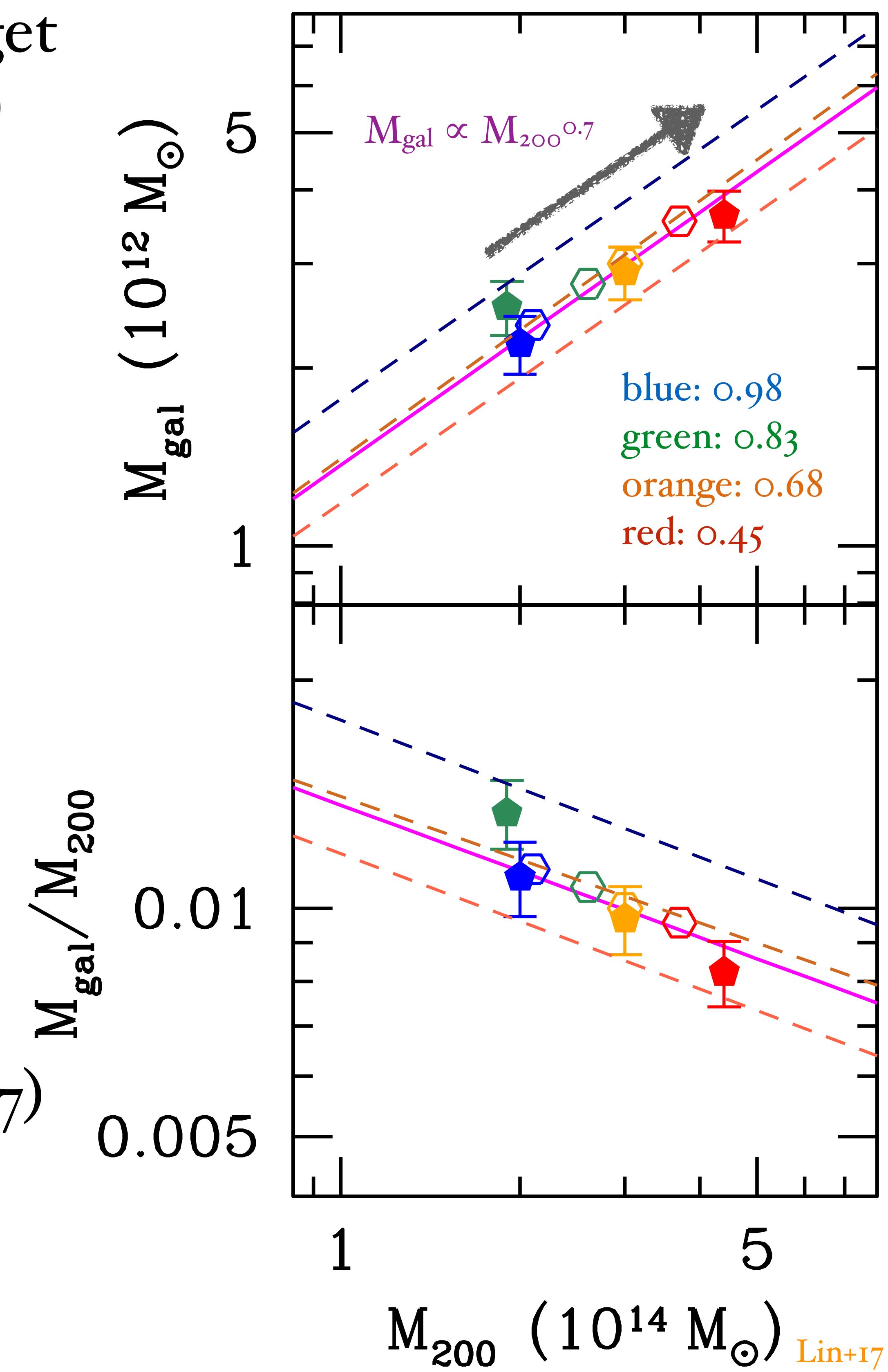


Lin+17

stellar mass contents of clusters

- integrate the SMD down to $10^{10} M_{sun}$ to get "total" stellar mass M_{gal} (including BCGs)
- clusters move along the $M_{gal} \propto M_{200}^{0.7}$ locus (solid line, taken from Lin+12 for a totally different sample)
- why is there no/little evolution of the M_{gal}–M_{200} relation?
    - lots of stripping required?
    - preferentially accreting high M/L objects?
    - operating at all redshifts!
    - would $M_{gal} \propto M_{200}$ at any early epoch?
- also seen in SPT-selected clusters (Chiu+17) & COSMOS groups (Giodini+09)



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  - prefere ts?
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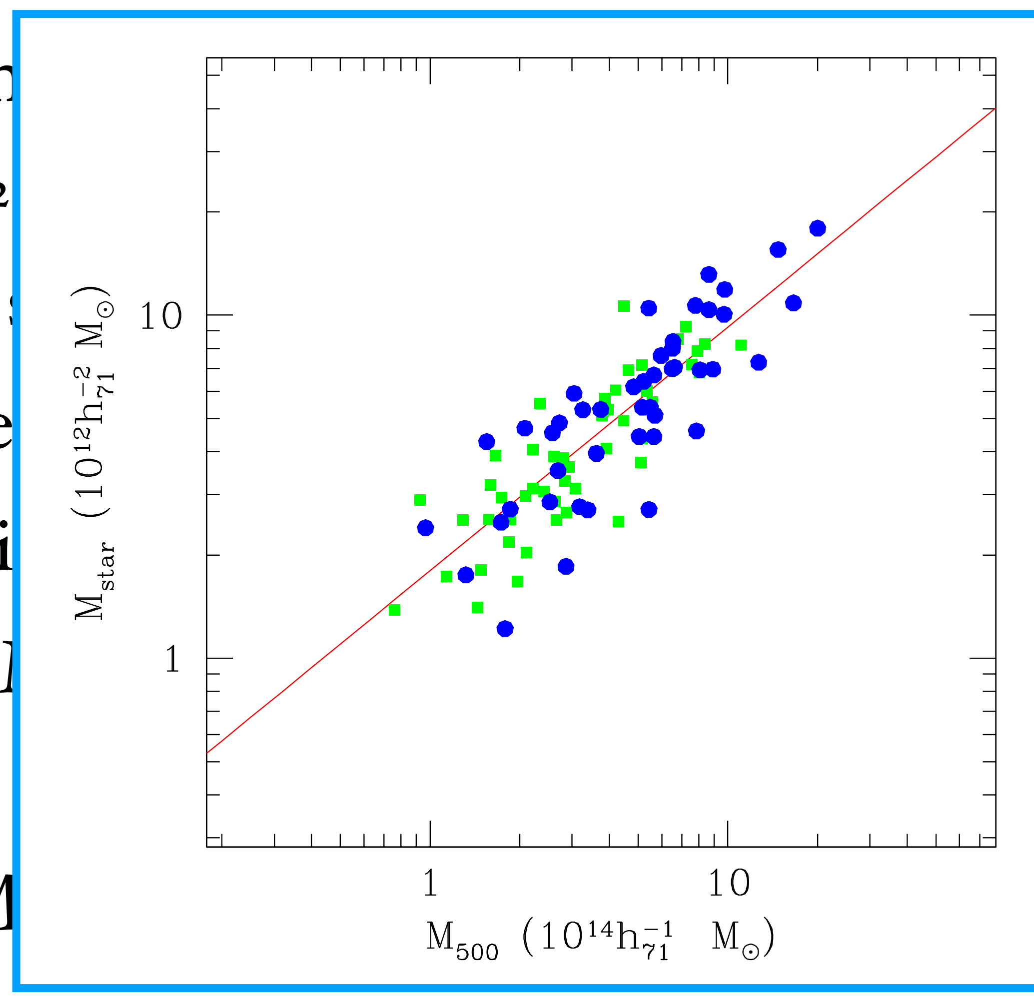

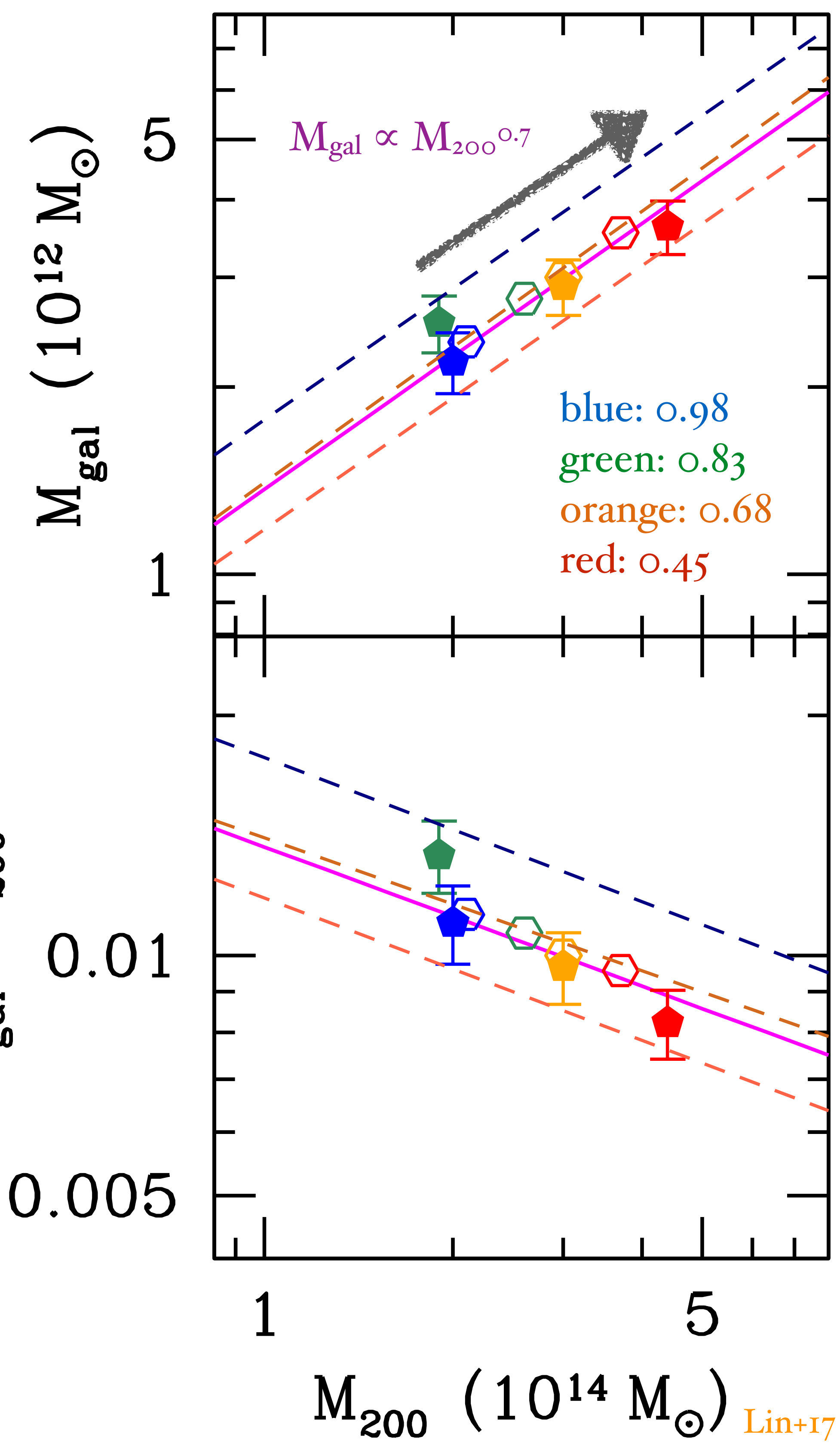

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  - wo ?
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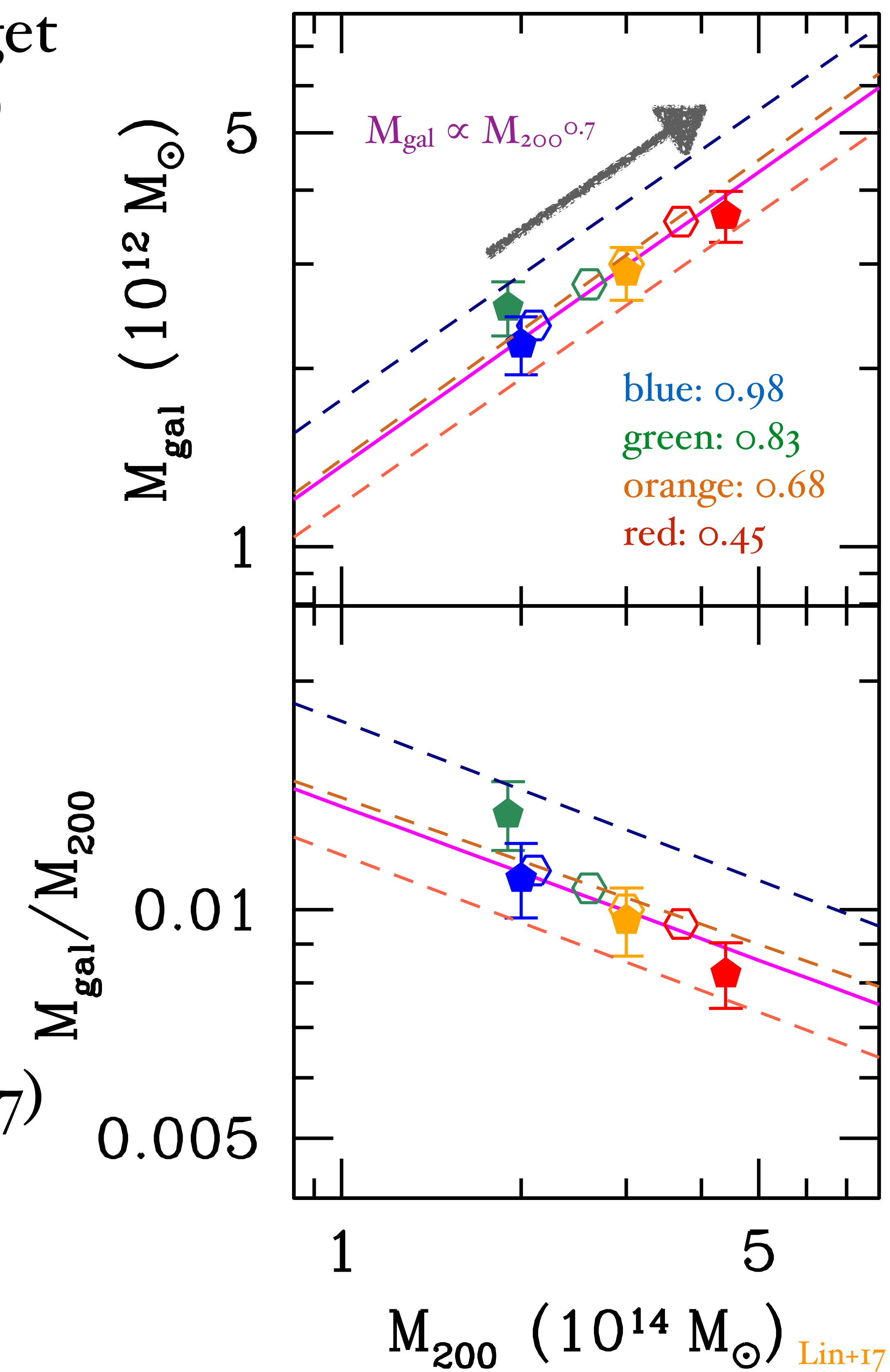
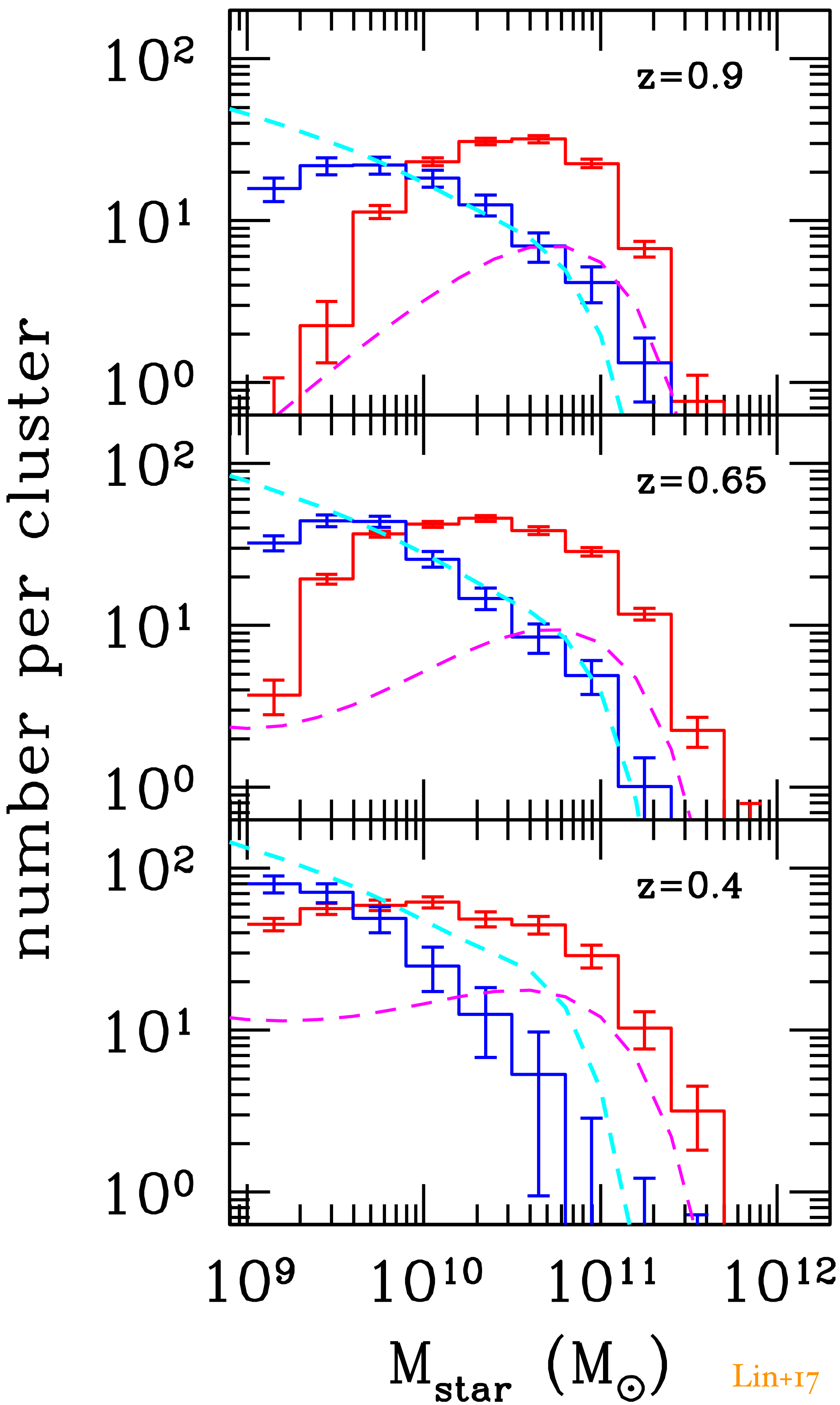
Taking merger trees of massive halos from Millennium; for every halo that forms, we assign some stellar mass to it (following a simple M_{star}-M_{halo} prescription). When two halos merge, some fraction f_{loss} of stars are assumed to be lost to intrahalo or interhalo space.

It is found that, to produce a slope of ~0.7, f_{loss}~0.4 is needed; even so, the model cannot produce a constant amplitude of the scaling relation…



more fun with HSC clusters

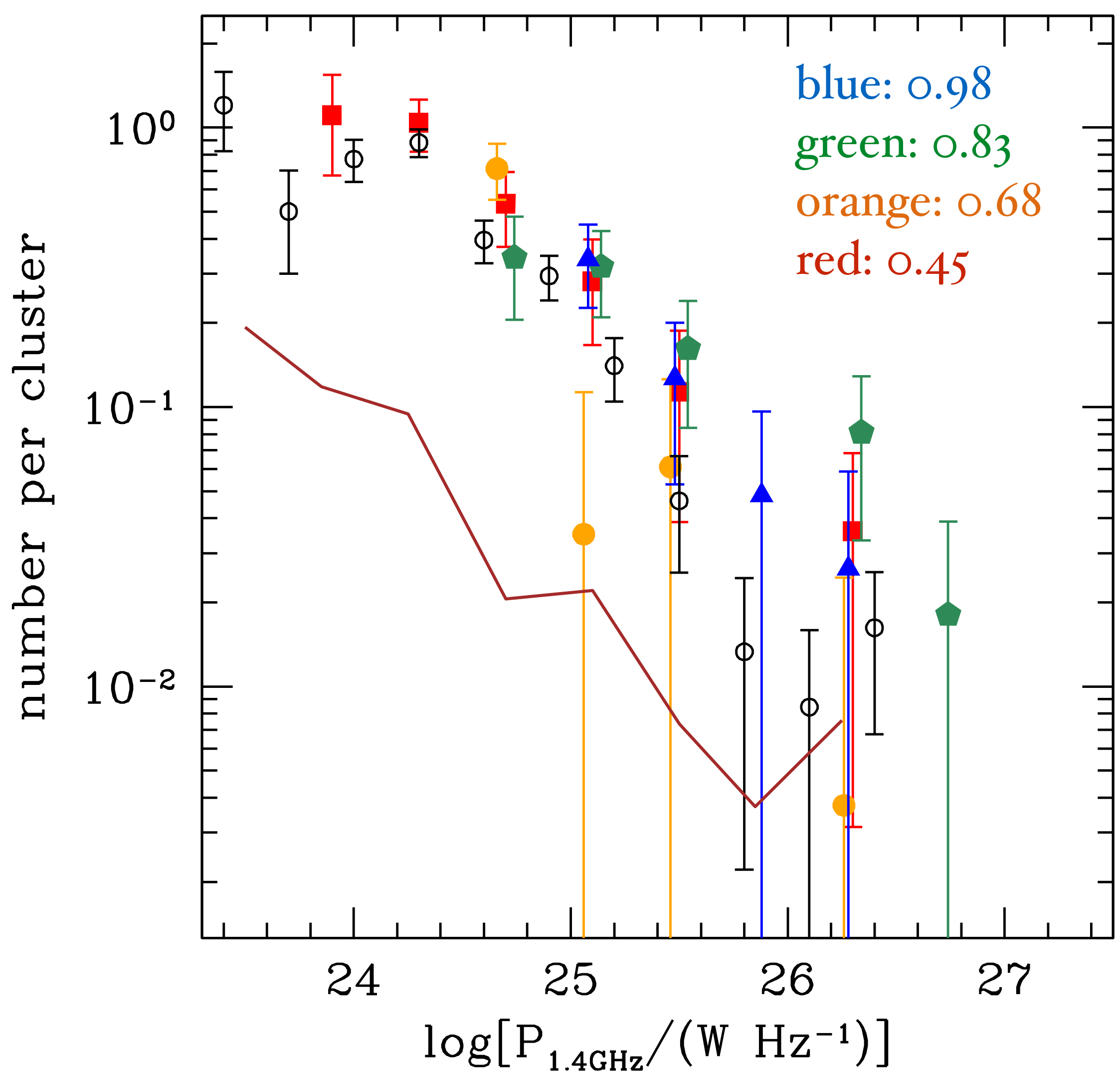
comparison with field



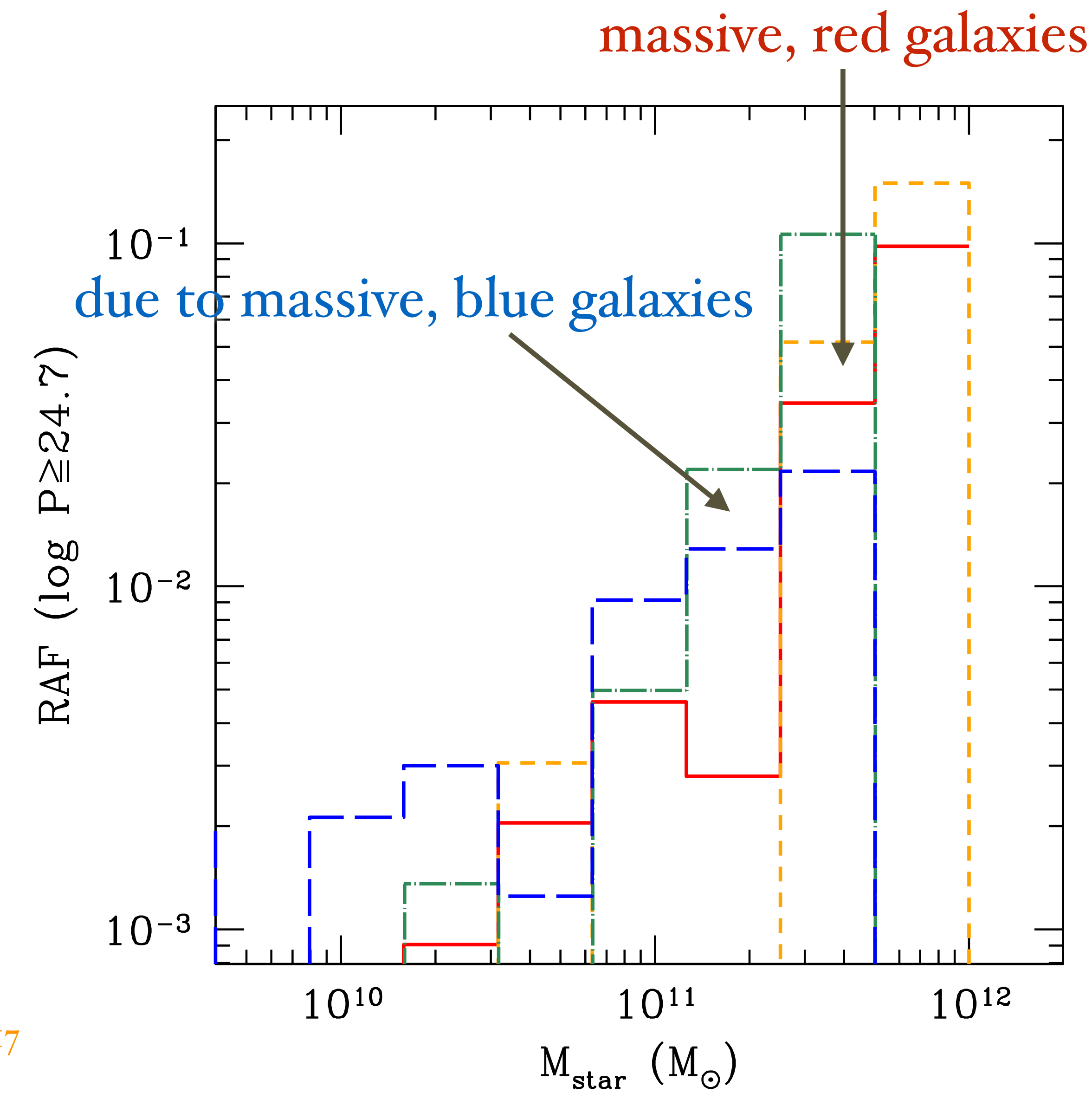
Lin+17

- Davidzon+17 SMF from COSMOS shown as dashed curves
    - multiplied by cluster comoving volumes
- clusters always over-abundant in red galaxies
    - cluster (or group) environment must have enhanced quenching
    - *a similar comparison between group and field may inform the degree of pre-processing in groups (?)*
- except at low-z, blue galaxy number density comparable
    - down-sizing of quenching kicked in at z<0.5?!

radio galaxies

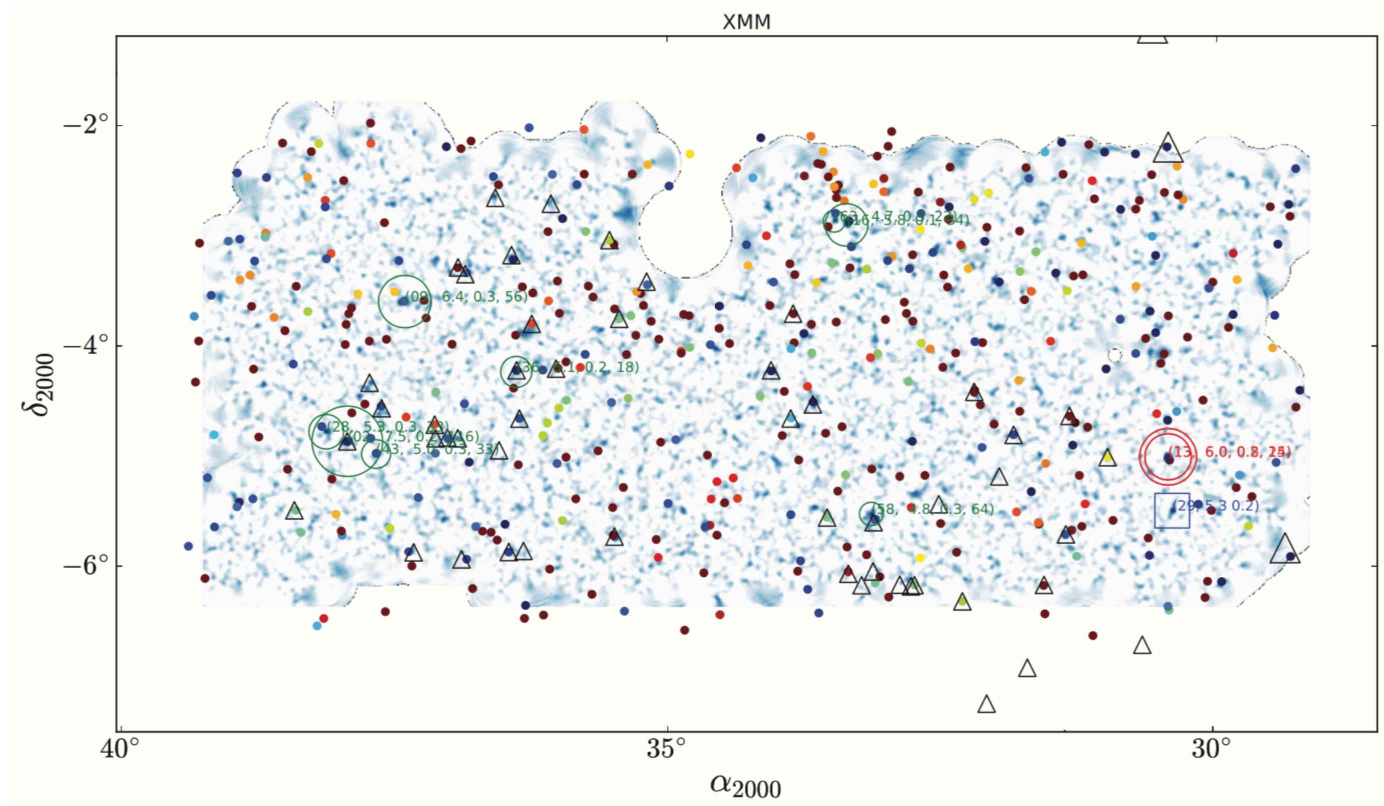


Lin+17

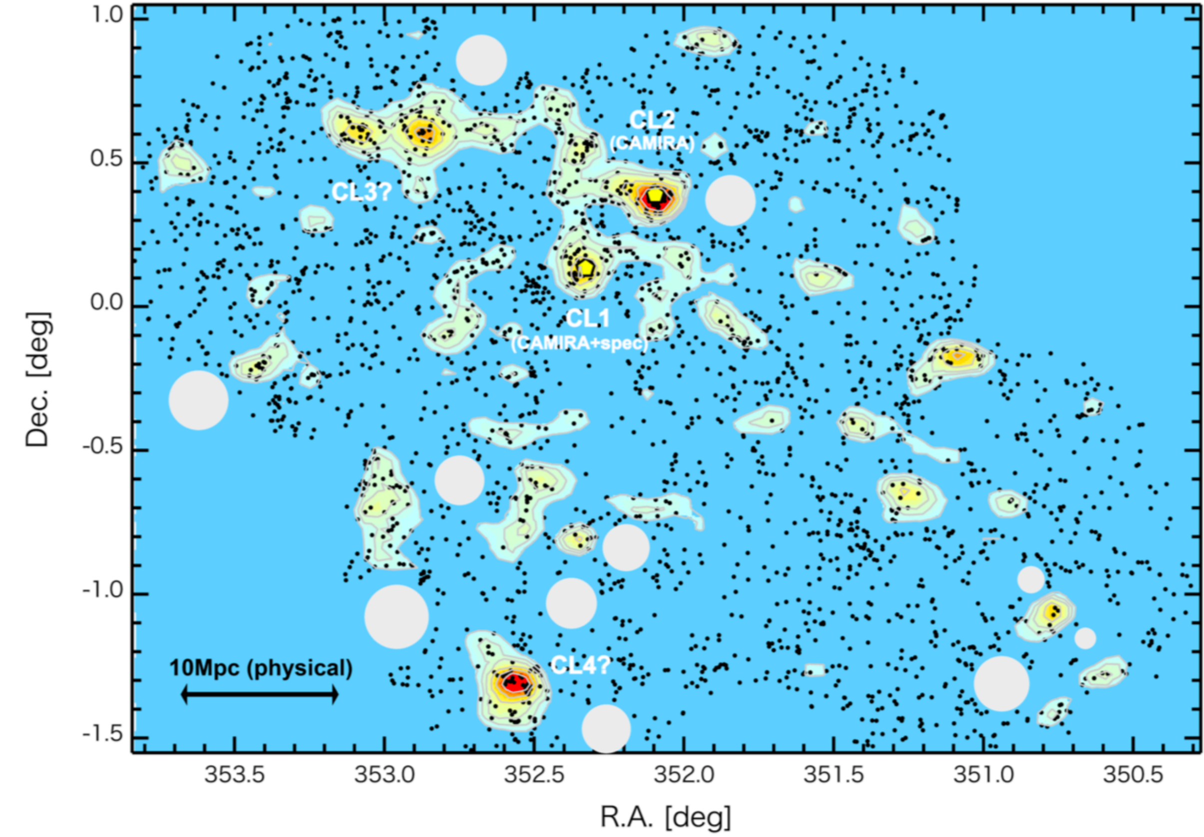


- count FIRST sources around clusters, then do global background subtraction
- cluster RLD ~10x higher than scaled field RLF (Smolčić+09)

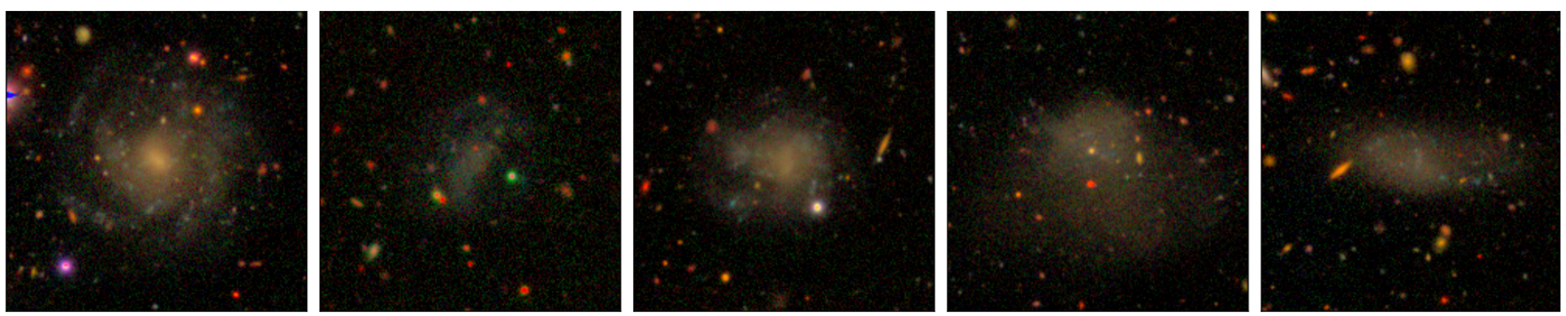
- RAF = fraction of galaxies above certain radio power
- strong function of stellar mass
- possible change in the mode of accretion to SMBH at z~0.8?!



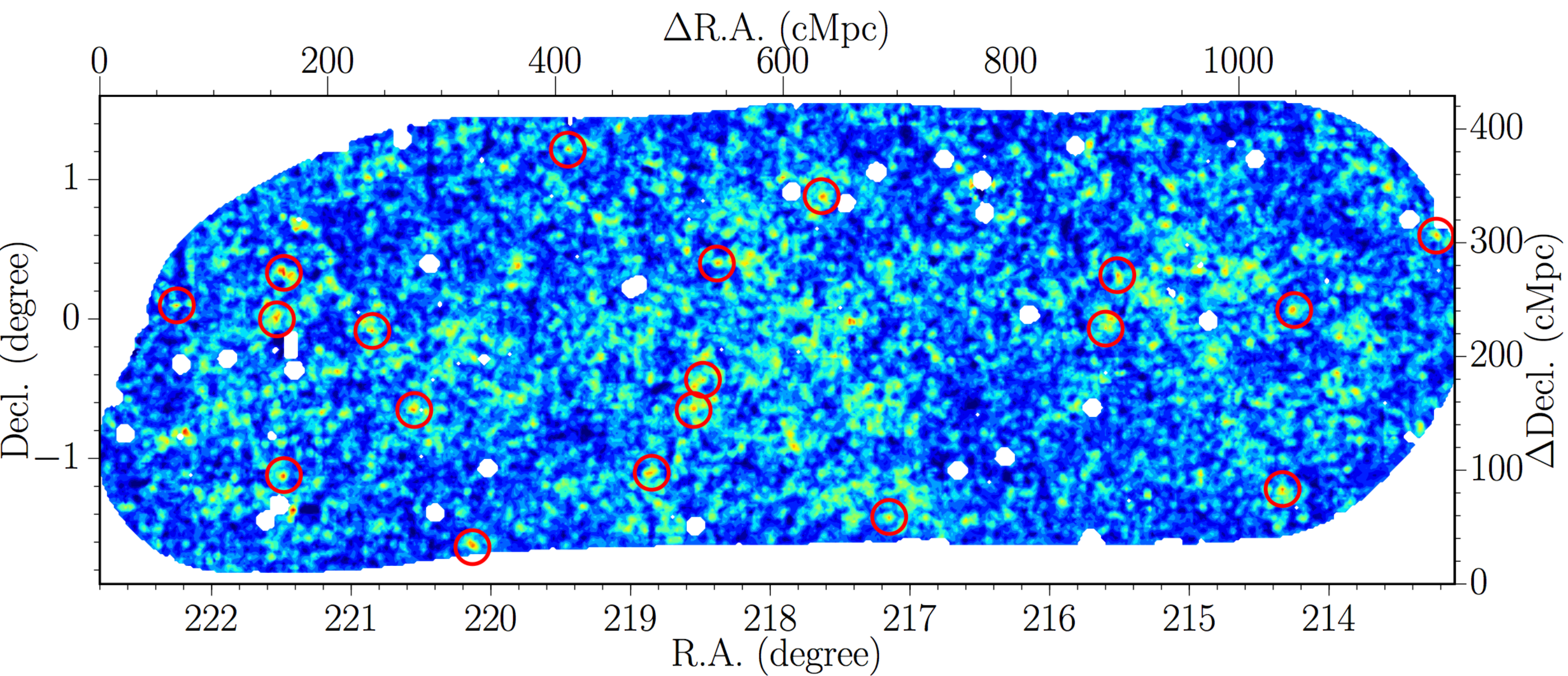
65 mass peaks with S/N>4.7 (Miyazaki+18)



twin cluster at z~0.4 from NBs (Koyama+18)



781 LSBGs (Greco+18)



179 proto-cluster candidates at z~4 as >4σ LBG overdensities (Toshikawa+18)

Panchromatic Panoramic Studies of Galaxy Clusters: from HSC to PFS and ULTIMATE

March 11-13, 2019

ASIAA, Taipei, Taiwan

Owing to its large aperture and wide field-of-view, Subaru telescope has played key roles in advancing our understanding of the formation and evolution of galaxy clusters. With the 300-night Hyper Suprime-Cam (HSC) survey, the largest ever undertaking of Subaru, the HSC collaboration is conducting a unique survey of all key phases in the lives of clusters. The deep and wide areal coverage and the superb imaging quality have enabled us to publish the first large sample of shear-selected clusters, as well as the largest distant cluster and proto-cluster samples beyond redshift of 1.

As a prelude to the second public data release of the HSC survey, we will hold a 3-day workshop on March 11-13, 2019 at Institute of Astronomy and Astrophysics, Academia Sinica (ASIAA) in Taipei, which is part of the Subaru International Partnership workshop series. Researchers working in all aspects of cluster science are cordially invited to participate in the workshop, where latest results from the HSC survey will be presented. The workshop will be a venue for presenting and discussing results from all large-scale cluster surveys, as well as for brainstorming and preparation for cluster studies with the upcoming instruments on Subaru and other telescopes, such as Prime Focus Spectrograph, ULTIMATE-Subaru, AdvACT, SPT-3G, DESI, eROSITA, Euclid, Moons, LSST, and 30-meter class telescopes.

The topics of the workshop include:

- The HSC cluster samples
- Galaxy evolution in clusters
- Cosmology with clusters
- Challenges and new ideas in cluster detection and characterization
- Multi-wavelength studies of clusters
- Prospects with future facilities.

https://events.asiaa.sinica.edu.tw/workshop/20190311/

We shall also have discussion sessions on themes such as "Cluster mass calibration", "Machine learning in cluster detection".

conclusion

- it remains a puzzle as to why the total stellar mass–cluster mass relation does not evolve with time
  - should include intracluster light in the measurements of "total" stellar mass
  - should measure this relation in bins of optical richness at several redshifts, to really constrain the (no-)evolution
  - or, to measure the scaling relation within the splashback radius instead of fixed overdensity radii?

- HSC data is great for a wide array of topics in galaxy/cluster formation and cosmology
  - stay tuned for the next public data release (May 2019)!