cluster galaxy evolution from z=1 to 0.3: an HSC view

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Bau-Ching Hsieh, Masamune Oguri, Sheng-Chieh Lin, Kai-Feng Chen, I-Non Chiu, Surhud More, Masayuki Tanaka, Taddy Kodama, Song Huang, Aleaxie Leauthaud, Lihwai Lin, Kevin Bundy, Satoshi Miyazaki, and the HSC collaboration

outline

- Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP)
- a preview of power of HSC-SSP on cluster galaxy evolution
    - novelties
        - machine learning-derived stellar mass
        - *top N* cluster selection
    - brightest cluster galaxy (BCG)
    - stellar mass distribution
    - radio galaxies
    - (spatial distribution, luminosity distribution)

Lin et al., ApJ, in press (arXiv:1709.04484)


first-year results from
the HSC survey

HSC survey

- collaboration: Japan, Taiwan, and Princeton University
- PI: Satoshi Miyazaki (NAOJ)
- awarded 300 nights over 6 years (2014-2019)
  - have so far observed 340 deg^2 (full color, full depth)
- growth of cosmic structure through gravitational lensing, nature of dark matter & dark energy, formation & evolution of galaxies
- three layer, wedding cake-like design
  - wide (1400 deg^2, 3 fields, grizy, r~26): cosmology, galaxy evolution, AGN census
  - deep (27 deg^2, 4 fields, grizy+3NB, r~27): galaxy evolution with SDSS precision and statistical power at z>1
  - ultradeep (2 pointings, grizy+3NB, r~28): cosmic reionization, supernovae cosmology

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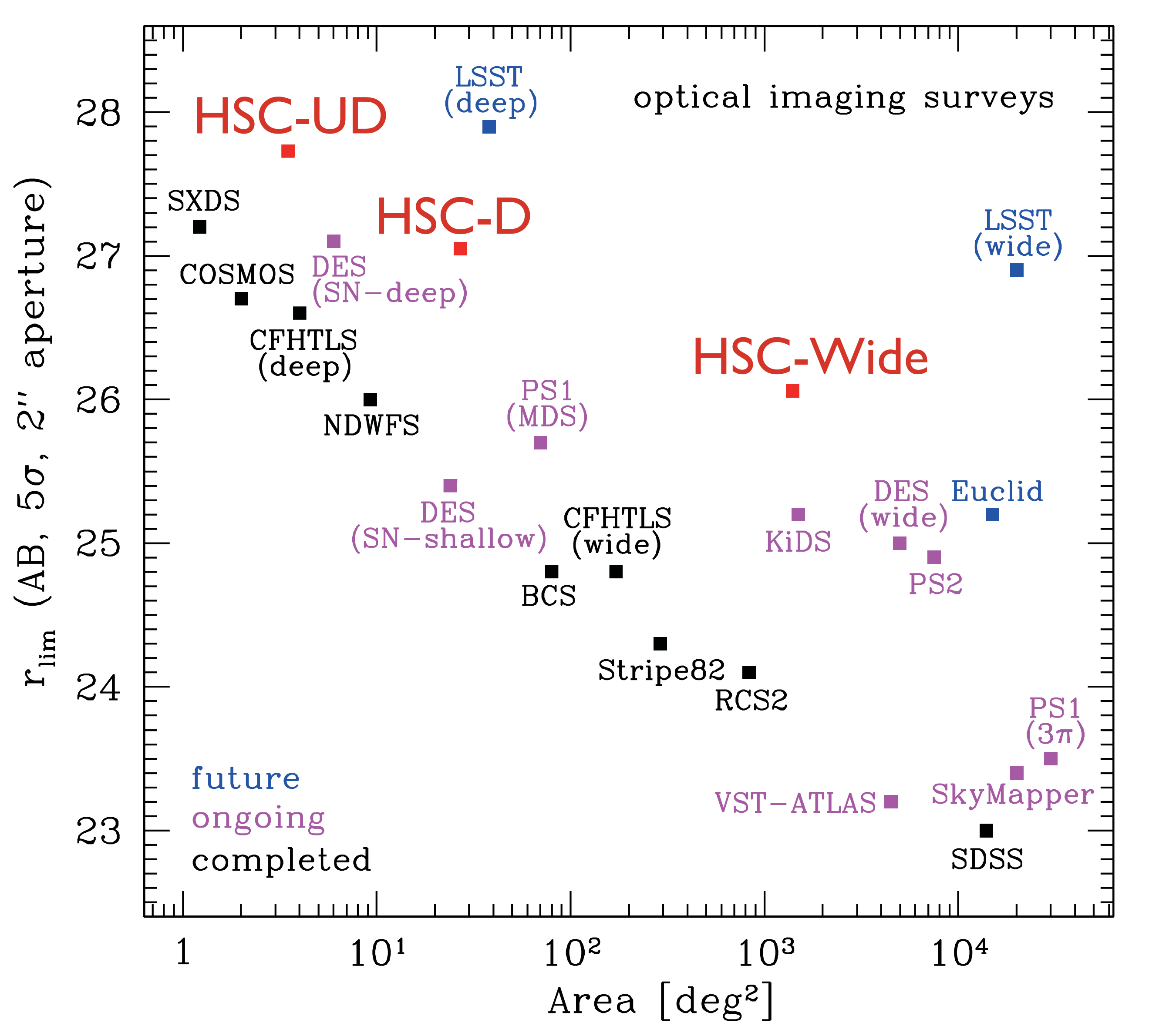

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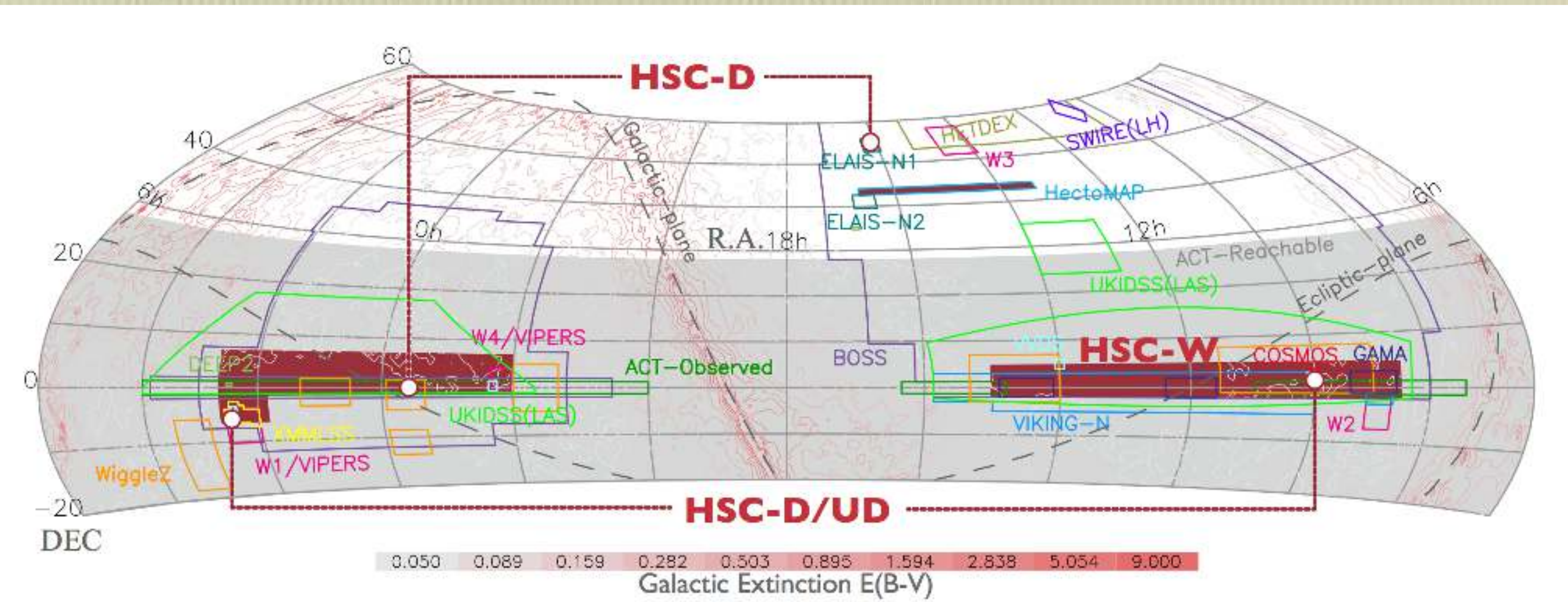

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depth

Aihara+17

Wide	g	r	i	z	y			
exposure (min)	10	10	20	20	20			
seeing (arcsec)	0.72	0.67	0.56	0.63	0.64			
depth (mag)	26.8	26.4	26.4	25.5	24.7			
target exposure (min)	10	10	20	20	20			
target depth (mag)	26.8	26.4	26.2	25.4	24.7			
Deep	g	r	i	z	y	$NB387$	$NB816$	$NB921$
exposure (min)	20	15	30	35	20	—	45	60
seeing (arcsec)	0.83	0.68	0.55	0.69	0.59	—	0.53	0.65
depth (mag)	26.8	26.6	26.5	25.6	24.8	—	25.9	25.6
target exposure (min)	84	84	126	210	126	84	168	252
target depth (mag)	27.8	27.4	27.1	26.6	25.6	24.8	26.1	25.9

UltraDeep	g	r	i	z	y	$NB816$	$NB921$	$NB101$
exposure (min)	70	70	130	130	210	200	270	—
seeing (arcsec)	0.74	0.62	0.64	0.59	0.74	0.60	0.76	—
depth (mag)	27.5	27.3	27.2	26.5	25.7	26.3	25.9	—
target exposure (min)	420	420	840	1134	1134	630	840	1050
target depth (mag)	28.4	28.0	27.7	27.1	26.6	26.8	26.5	25.1

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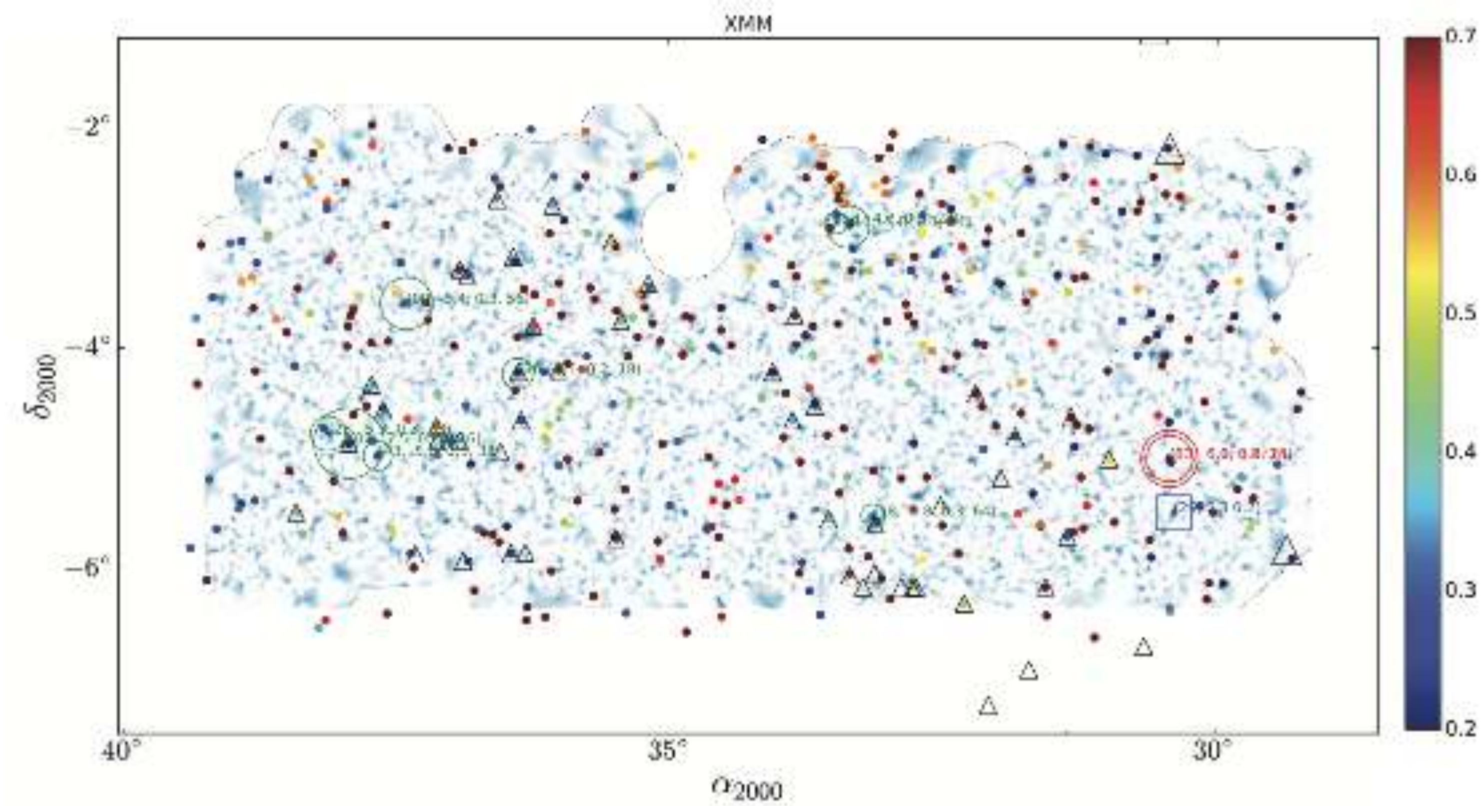
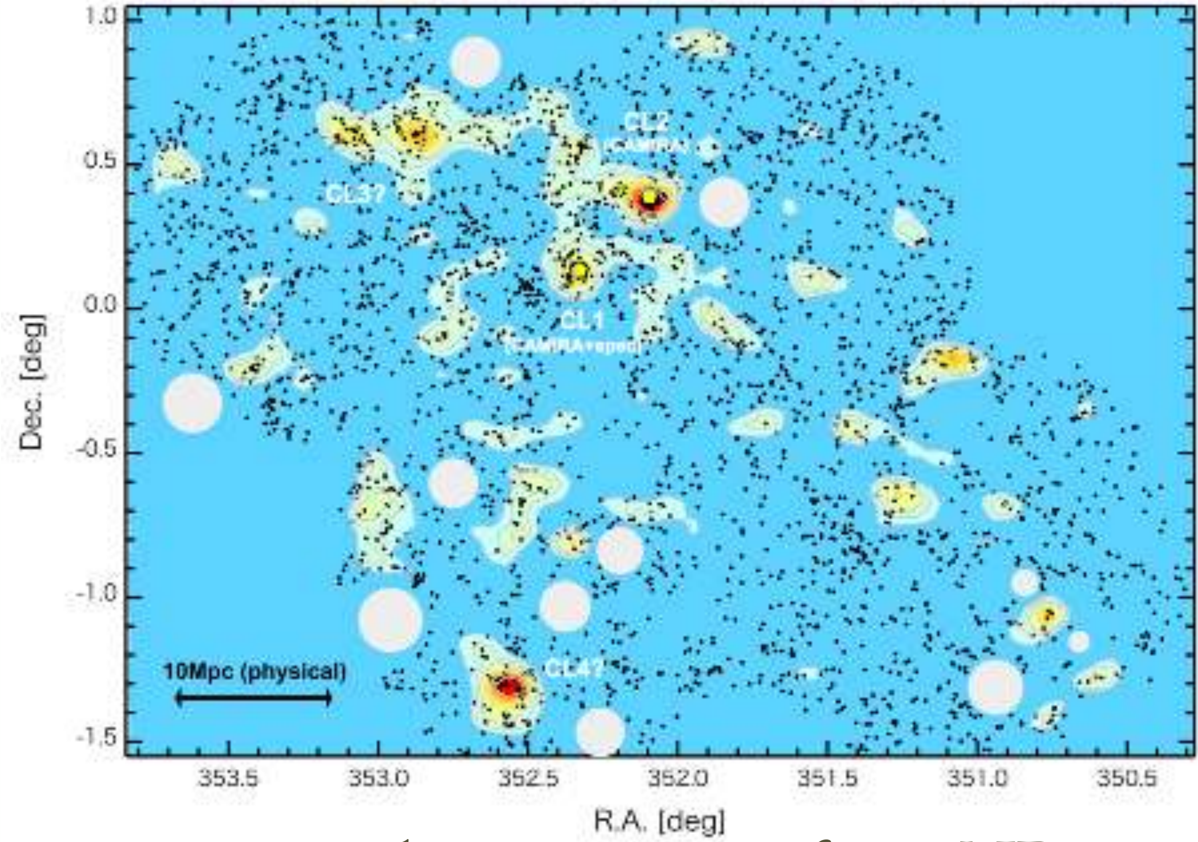
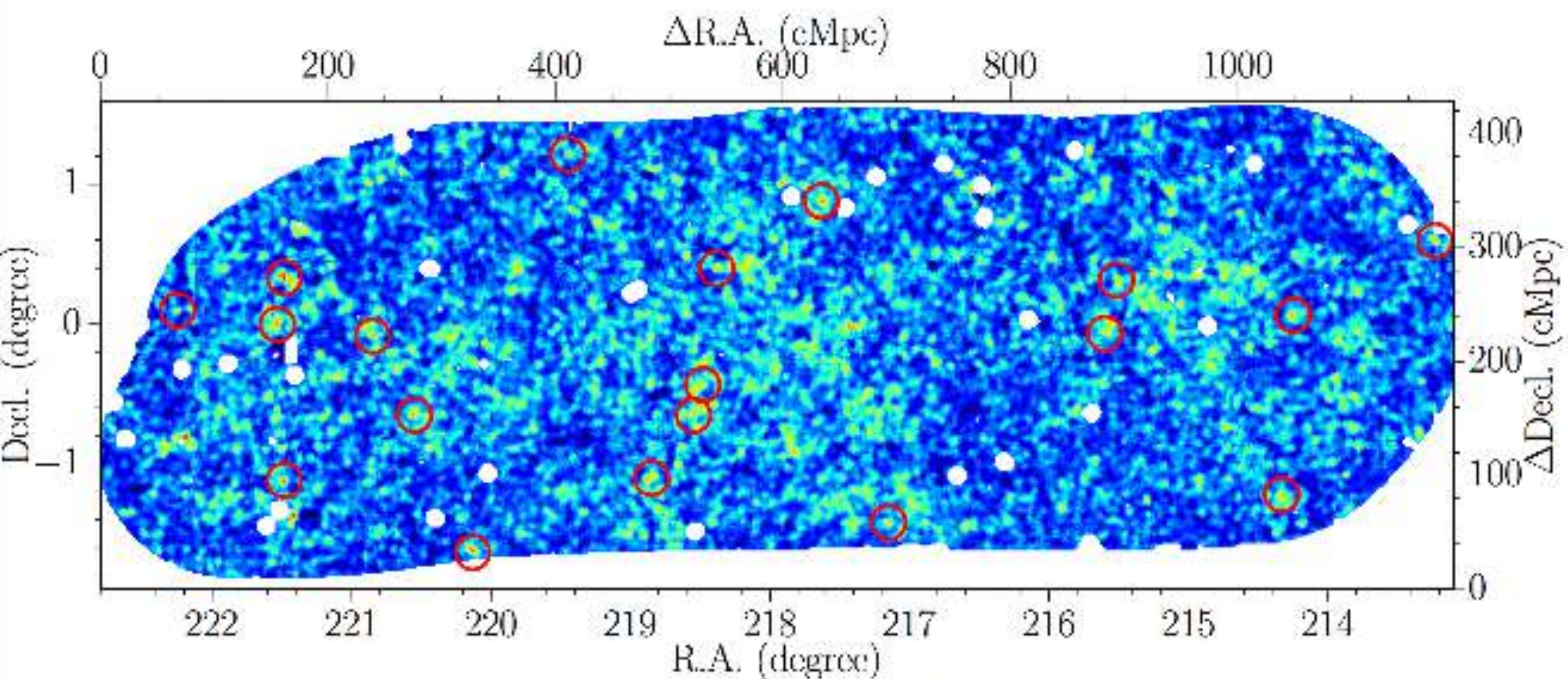


65 mass peaks with S/N>4.7 (Miyazaki+18)



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

781 LSBGs (Greco+18)

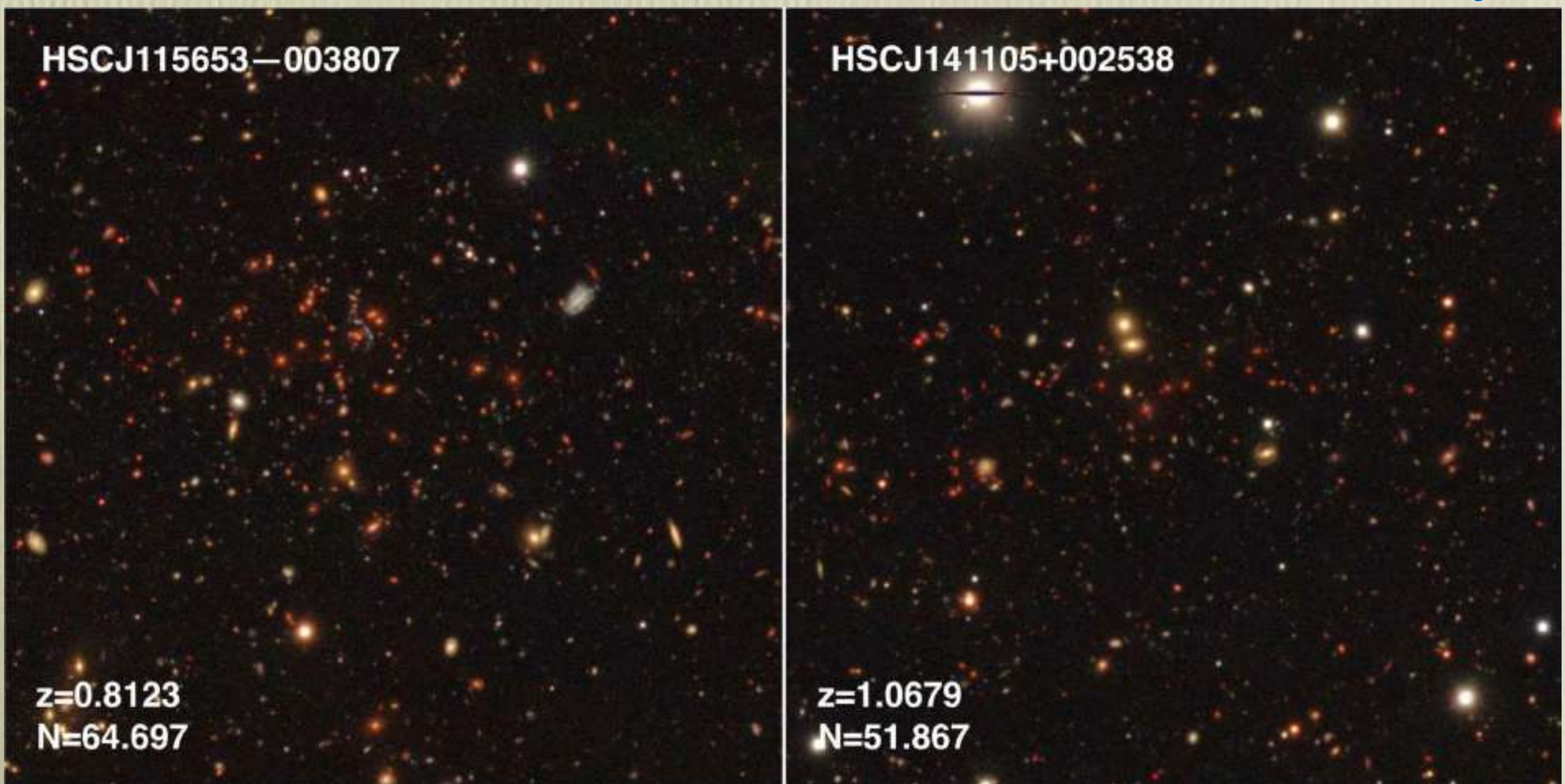


179 proto-cluster candidates at z~4 as >4σ LBG overdensities (Toshikawa+18)

seeing red

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 $N \geq 15$

Oguri+17



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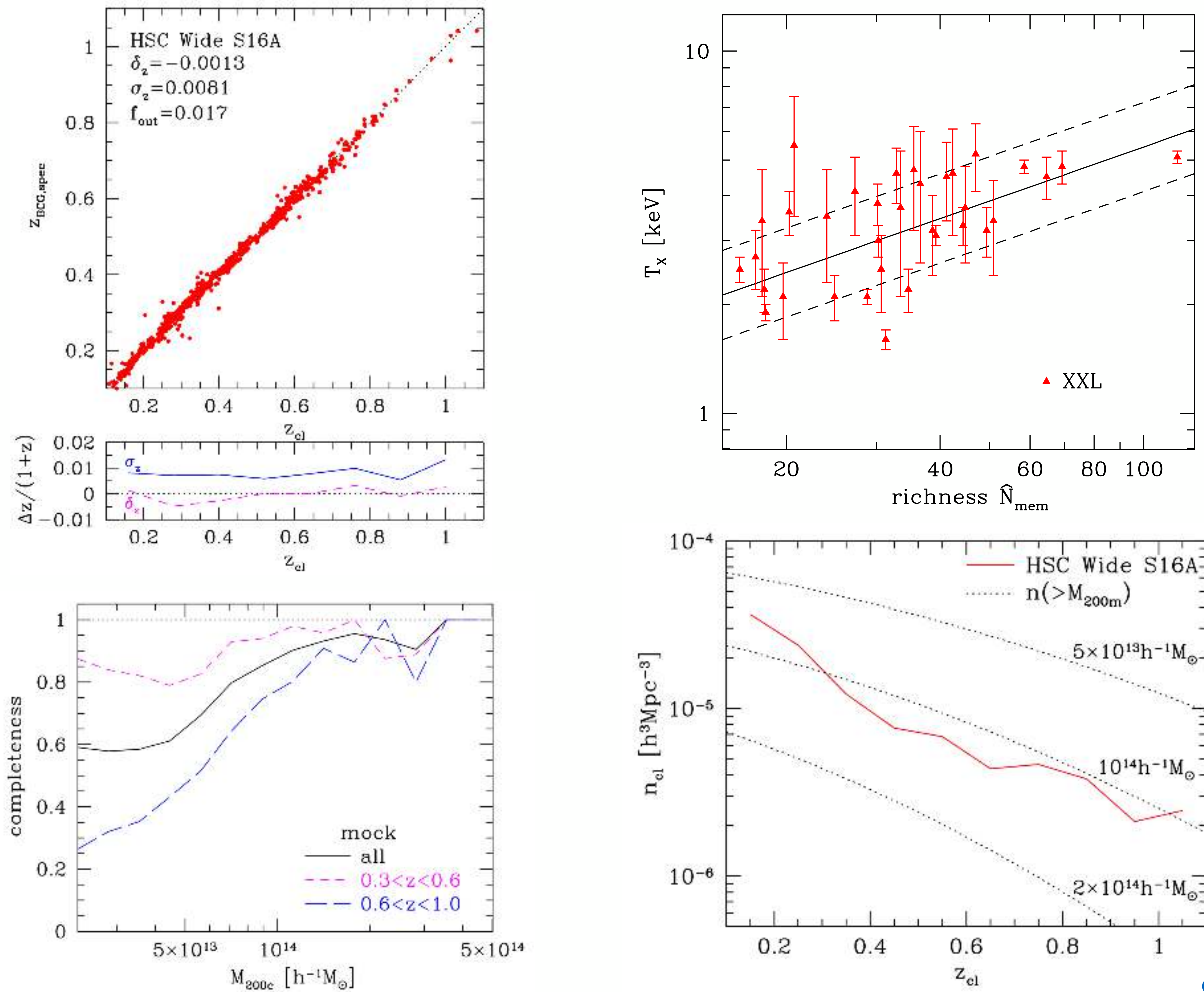
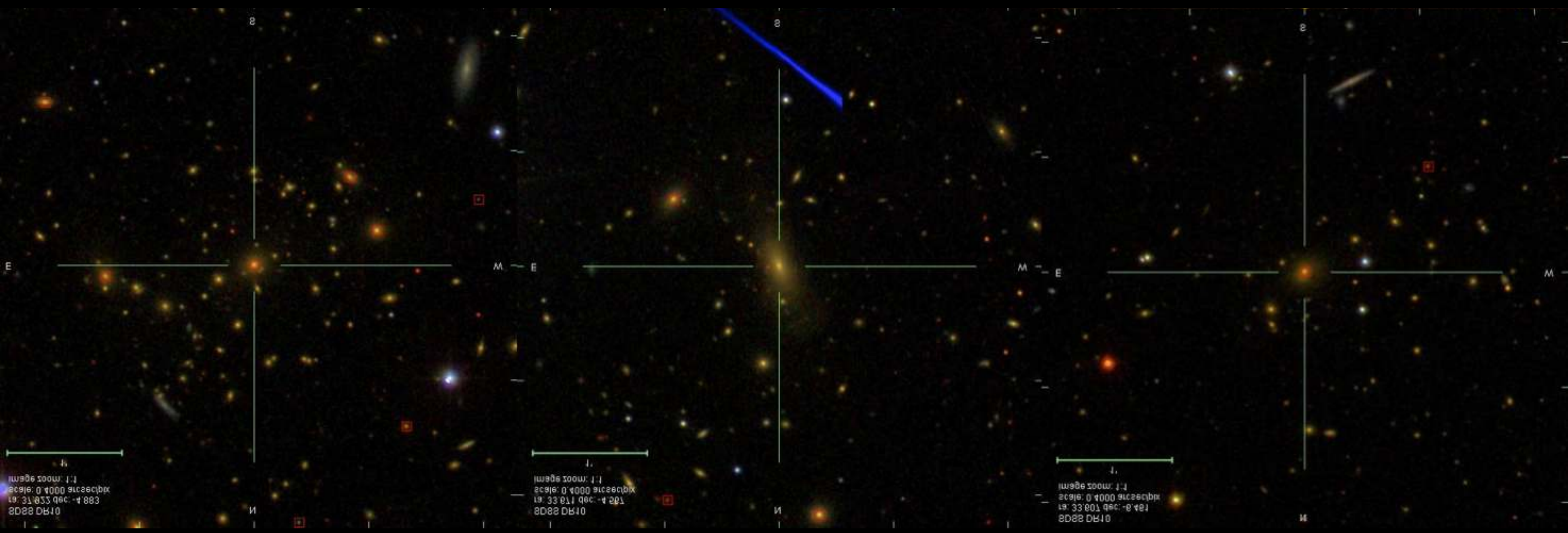
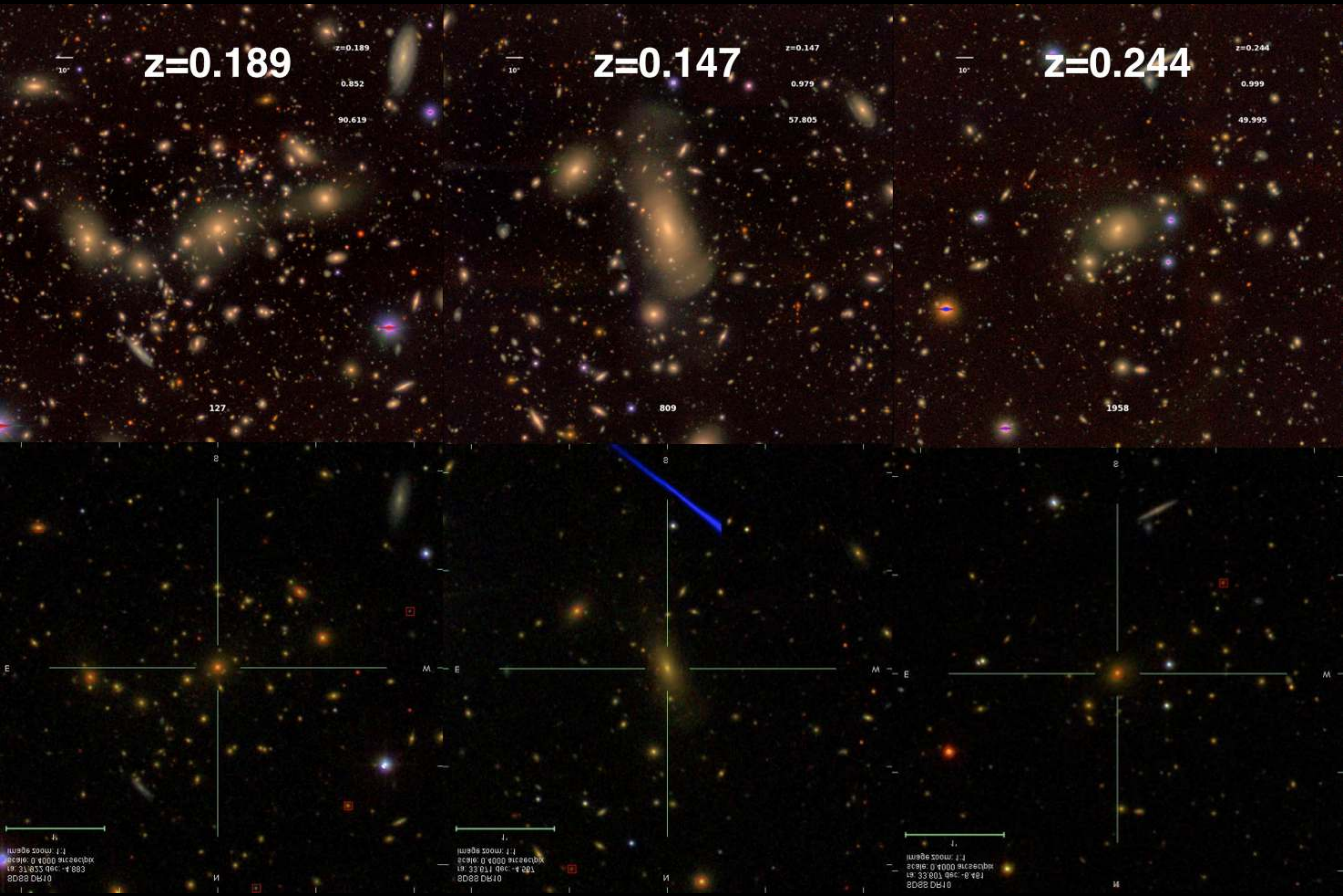

HSC Wide S16A
δz=−0.0013
σz=0.0081
fout=0.017
zBCG,spec
zcl
Δz/(1+z)
σz
δz
Tx [keV]
XXL
richness N̂mem
completeness
mock
all
0.3<z<0.6
0.6<z<1.0
M200c [h⁻¹M⊙]
ncl [h³Mpc⁻³]
HSC Wide S16A
n(>M200m)
5×10¹³h⁻¹M⊙
10¹⁴h⁻¹M⊙
2×10¹⁴h⁻¹M⊙

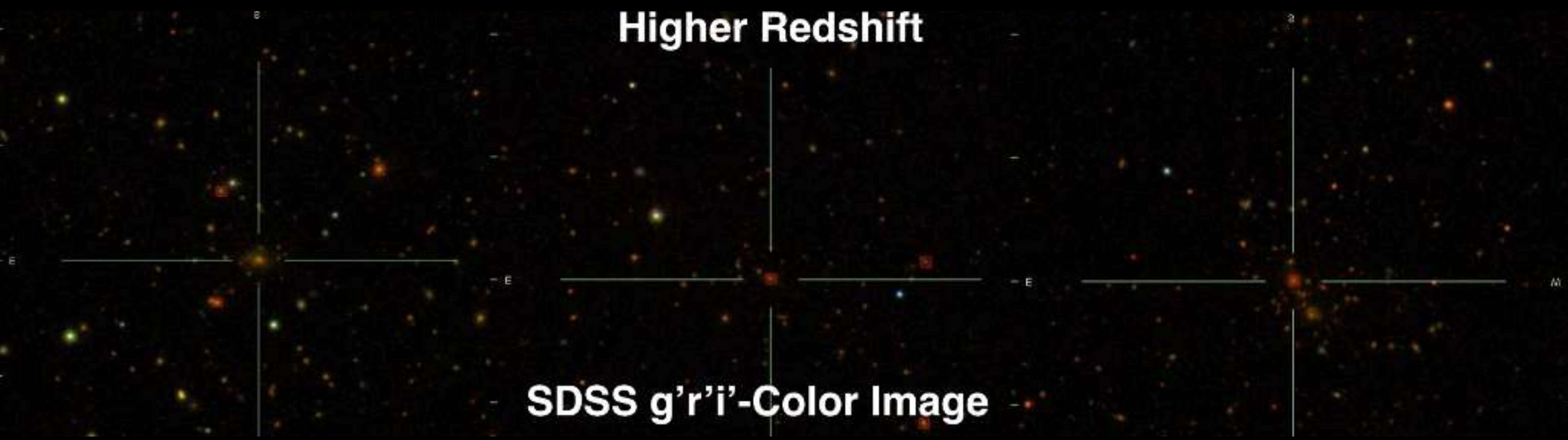
Oguri+17



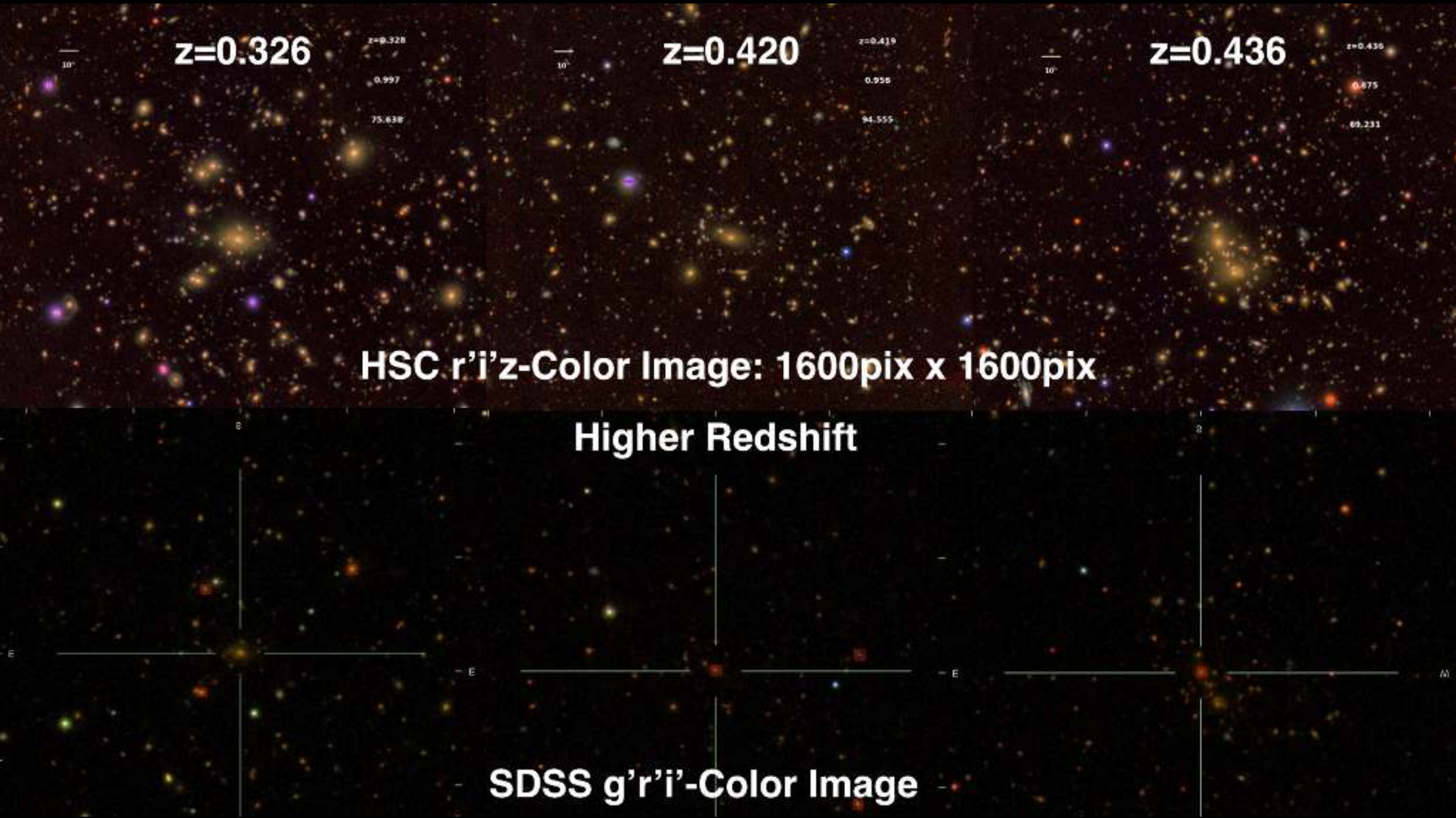
credit: Song Huang & HSC, SDSS



credit: Song Huang & HSC, SDSS



credit: Song Huang & HSC, SDSS

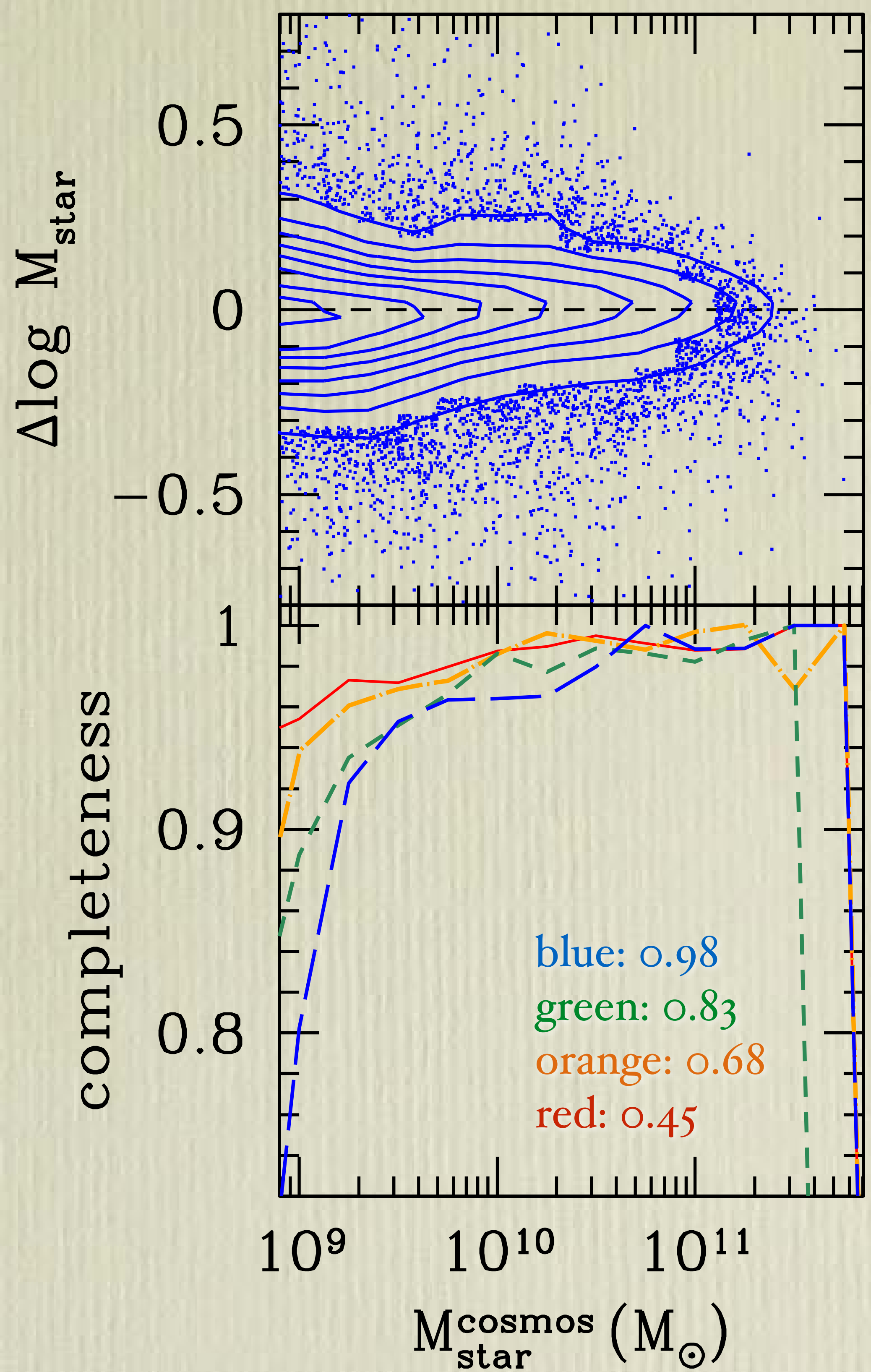


credit: Song Huang & HSC, SDSS

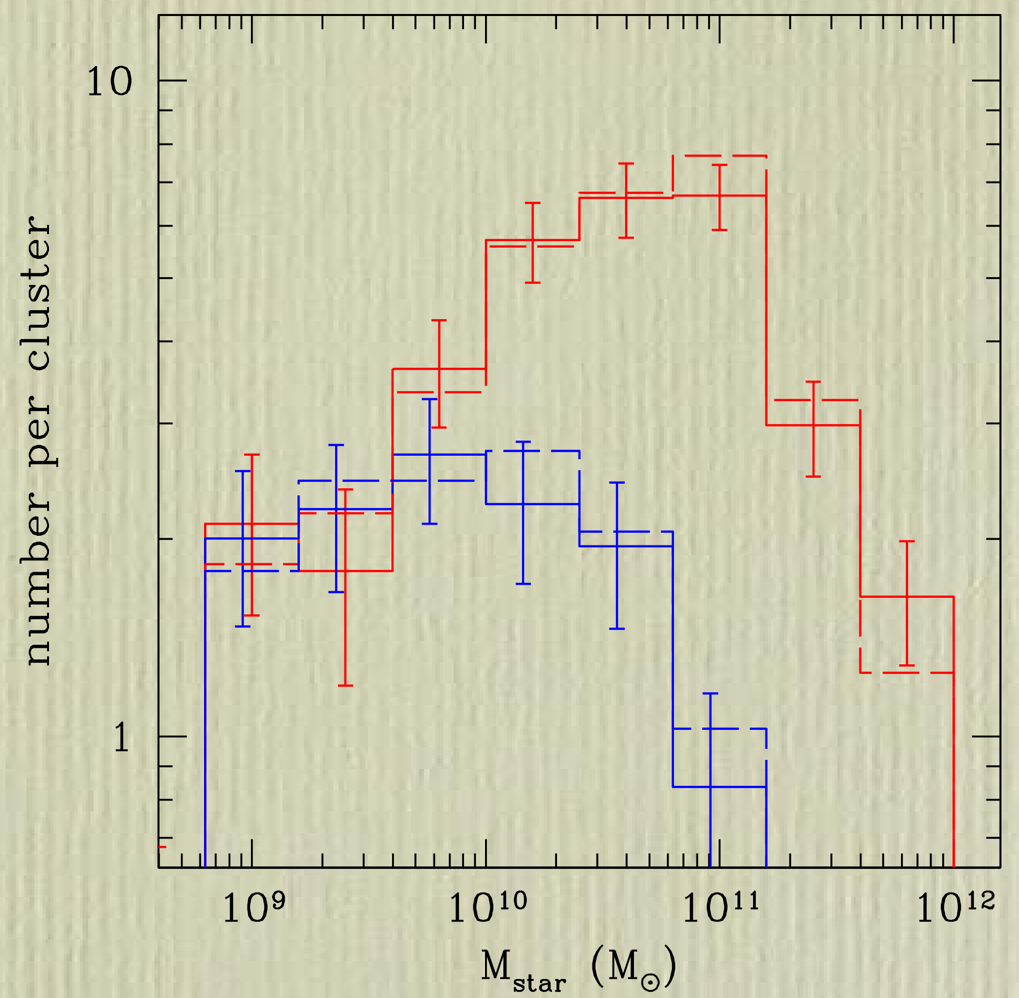

power of HSC: a preview

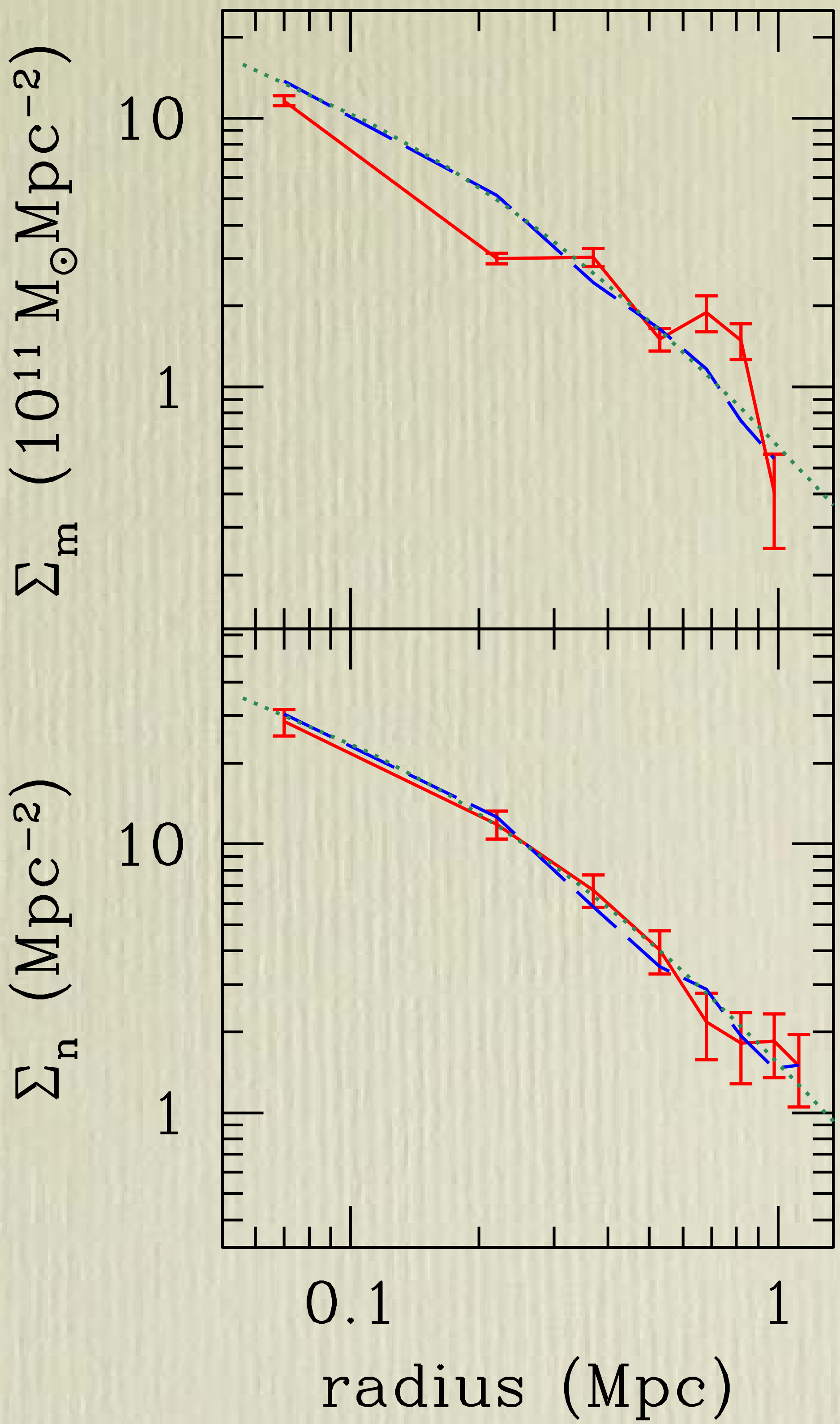
stellar mass estimates

- 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 UD catalogs used as training set, applied to HSC wide data
- our estimates are unbiased
- highly complete above $10^{10}M_{sun}$



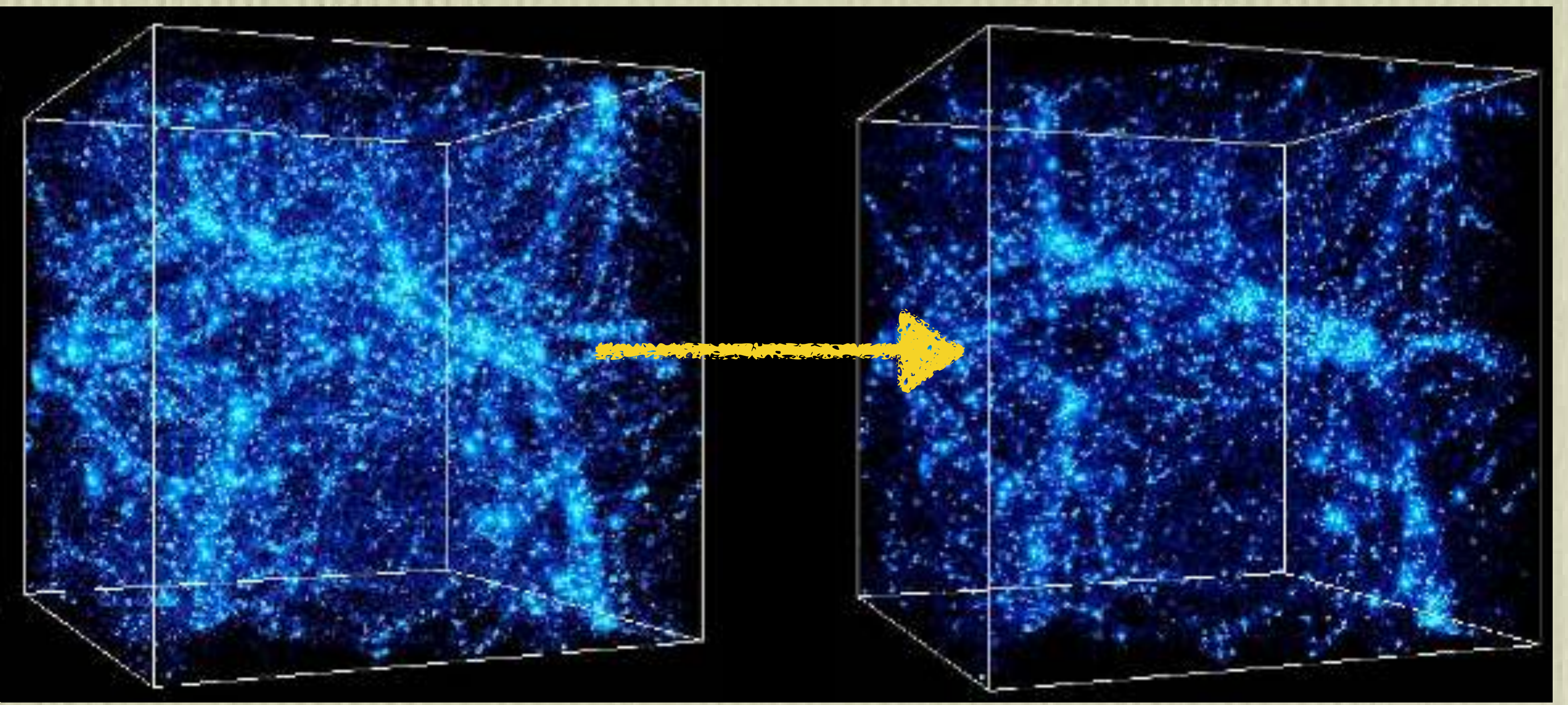
background subtraction scheme





- tests with MICE mock catalog
- background counts estimated from an annulus 5-7Mpc from cluster center
- skipped clusters with large holes in the annulus
- dashed = truth

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

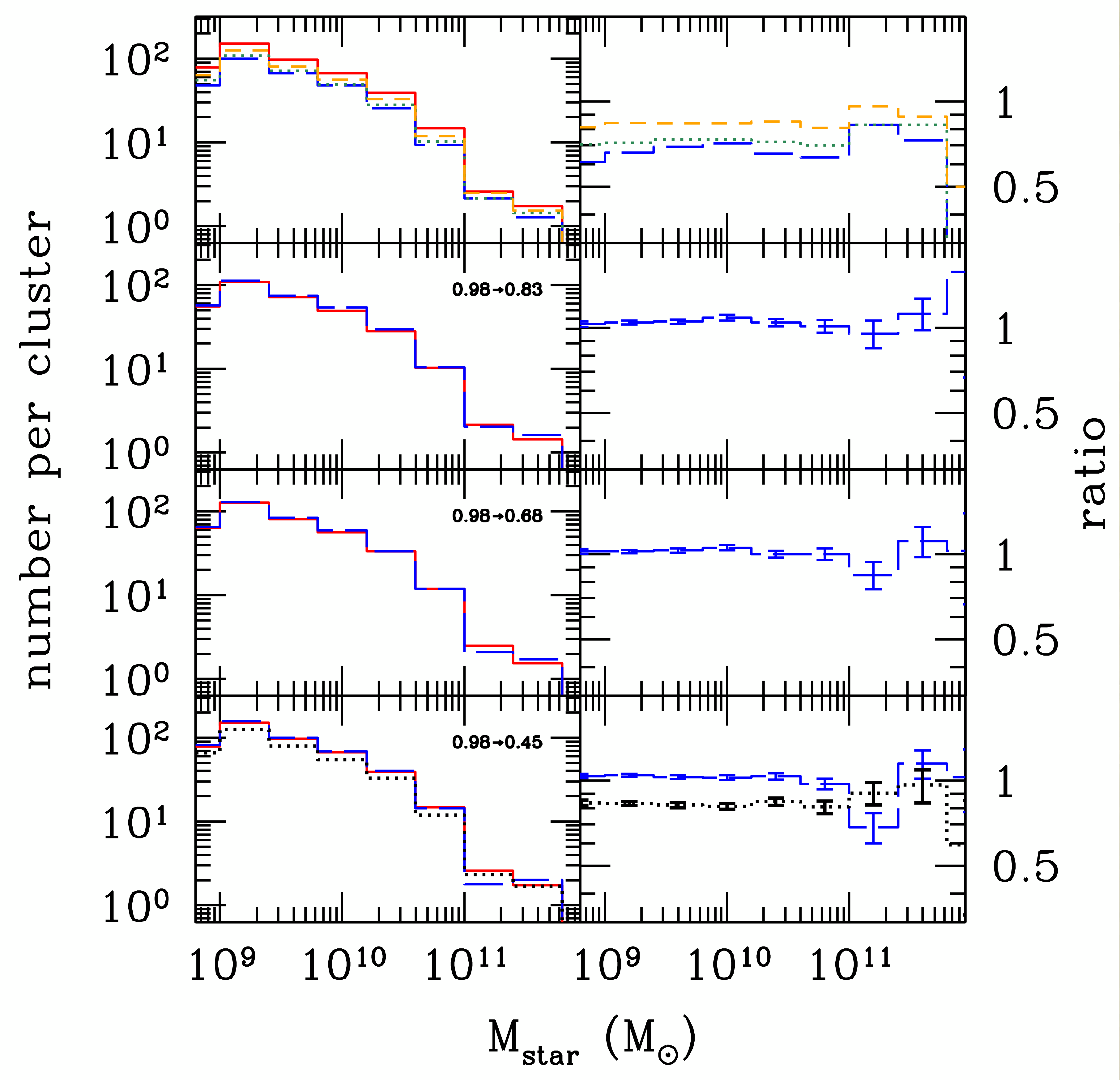
- construct cluster samples that represent progenitor-descendant relationship statistically
- Ansatz: given comoving volume, the most massive N halos will remain among the most massive N at a later time
- similar in spirit to the fixed cumulative number density selection for field galaxies
- tests with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

top N selection of halos

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

dashed = descendants of top 100 selected at z=0.98

solid = top 100 selected at lower-z



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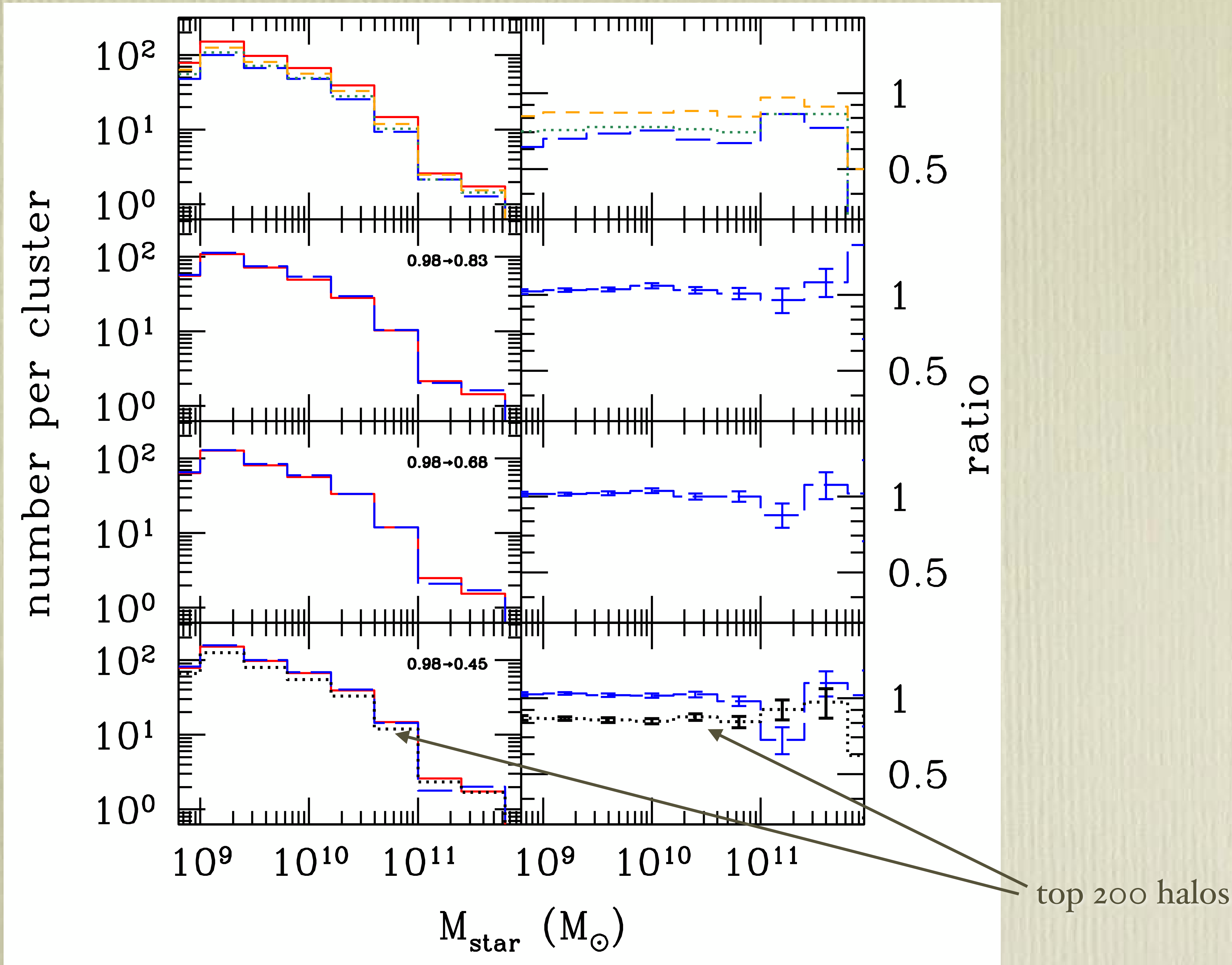
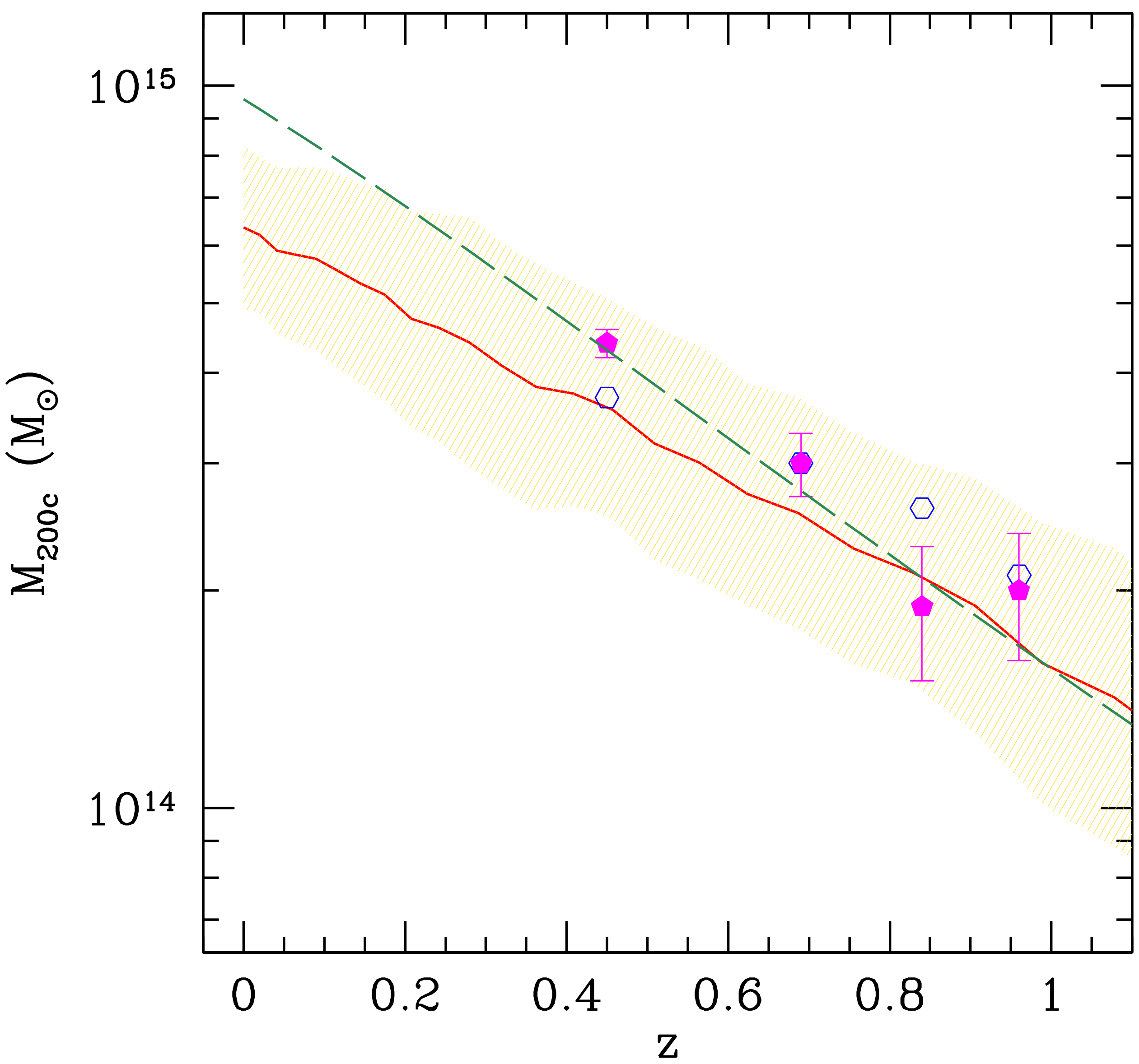


halo mass estimates

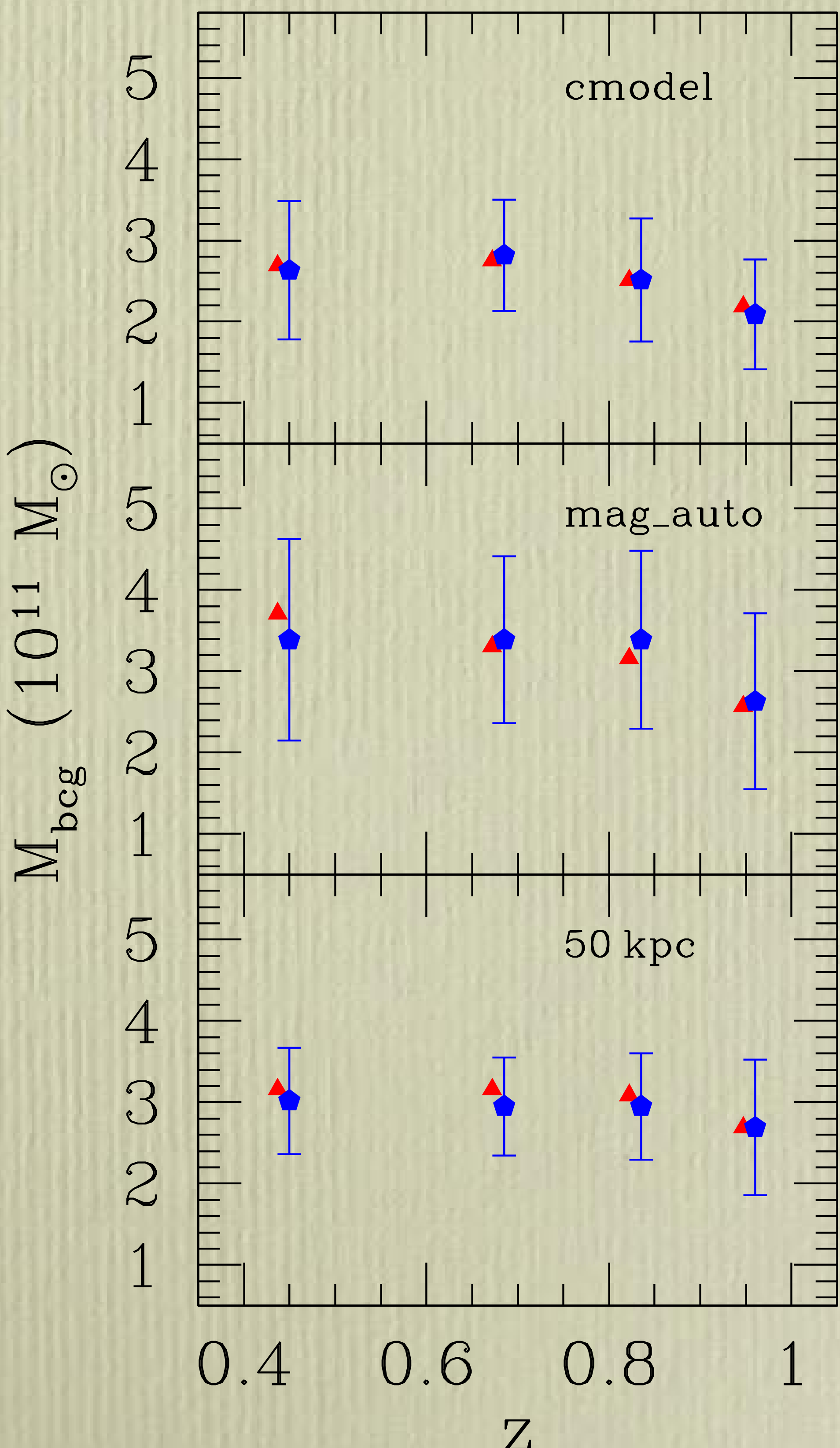
- two methods
  - mean mass of top 100 halos over $(420h^{-1}Mpc)^3$ in Millennium, with reasonable assumptions in mass–observable relation (open circles)
  - stacked lensing (solid points)
- from ~$2x10^{14}M_{sun}$ at z~1 to ~$4x10^{14}M_{sun}$ at z~0.45
- descendant mass at z~0 likely in $(6\text{-}10)x10^{14}M_{sun}$

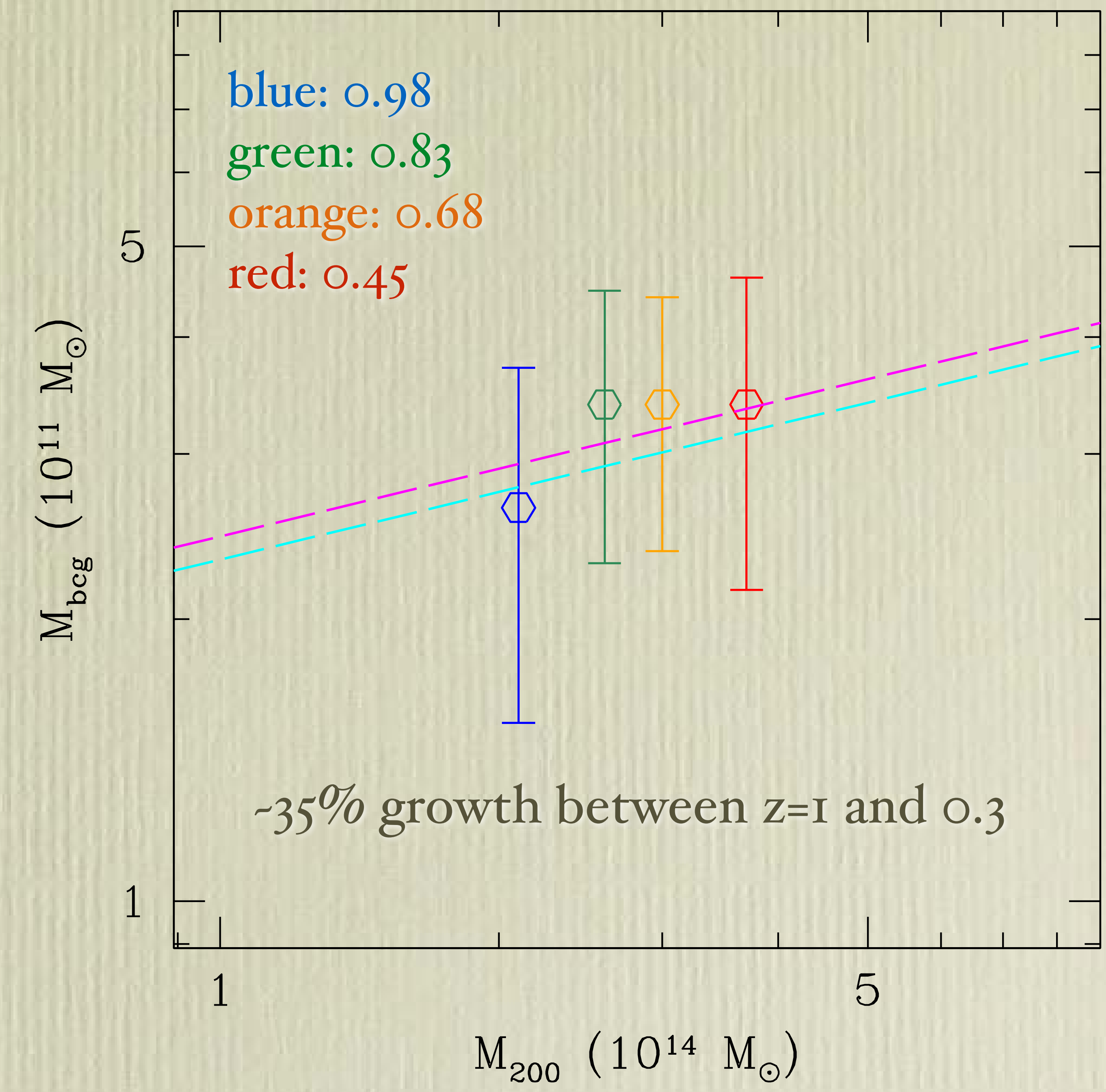
Basic Cluster Properties

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)	$\hat{N}_{lim}$
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



BCG growth: a simplified analysis

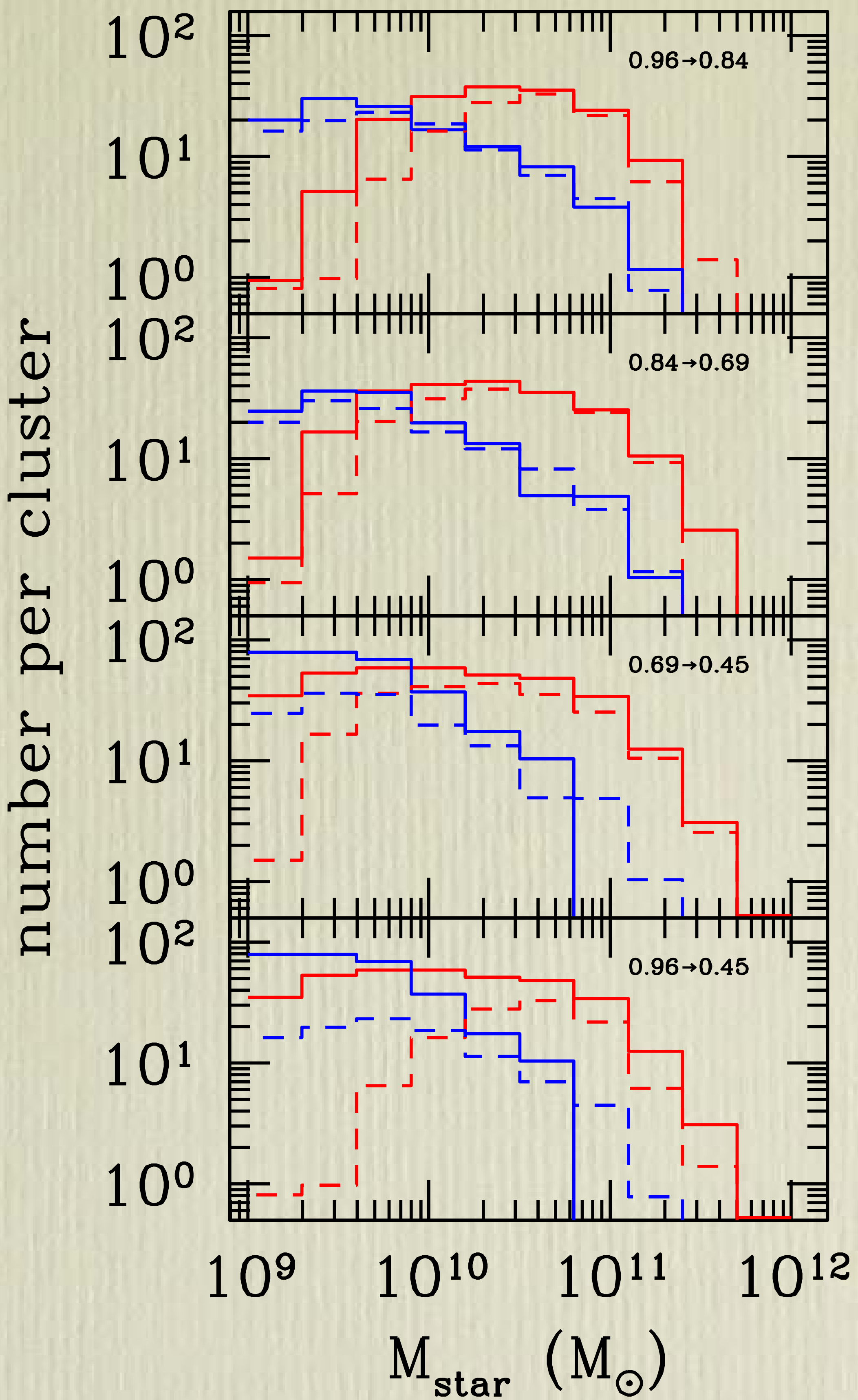




Zhang+16: $M_{\rm bcg} \propto M_{200}^{0.24}(1+z)^{-0.19}$

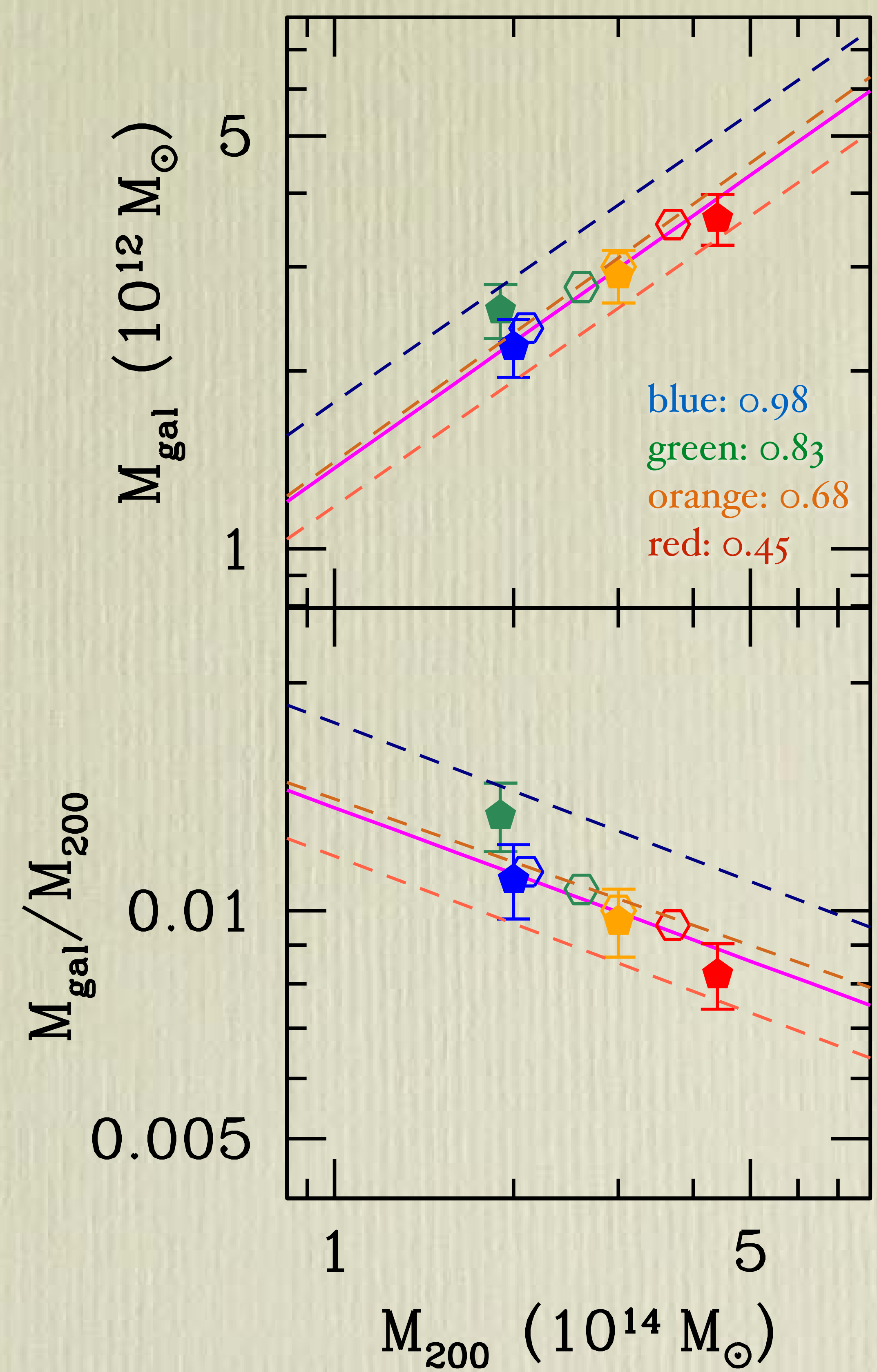
stellar mass distribution

- 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 (consistent with $N \propto M^{0.8}$ scaling)
  - for lower mass red galaxies, difference is 7x
  - ratios for blue ones are 1.5x and 3x



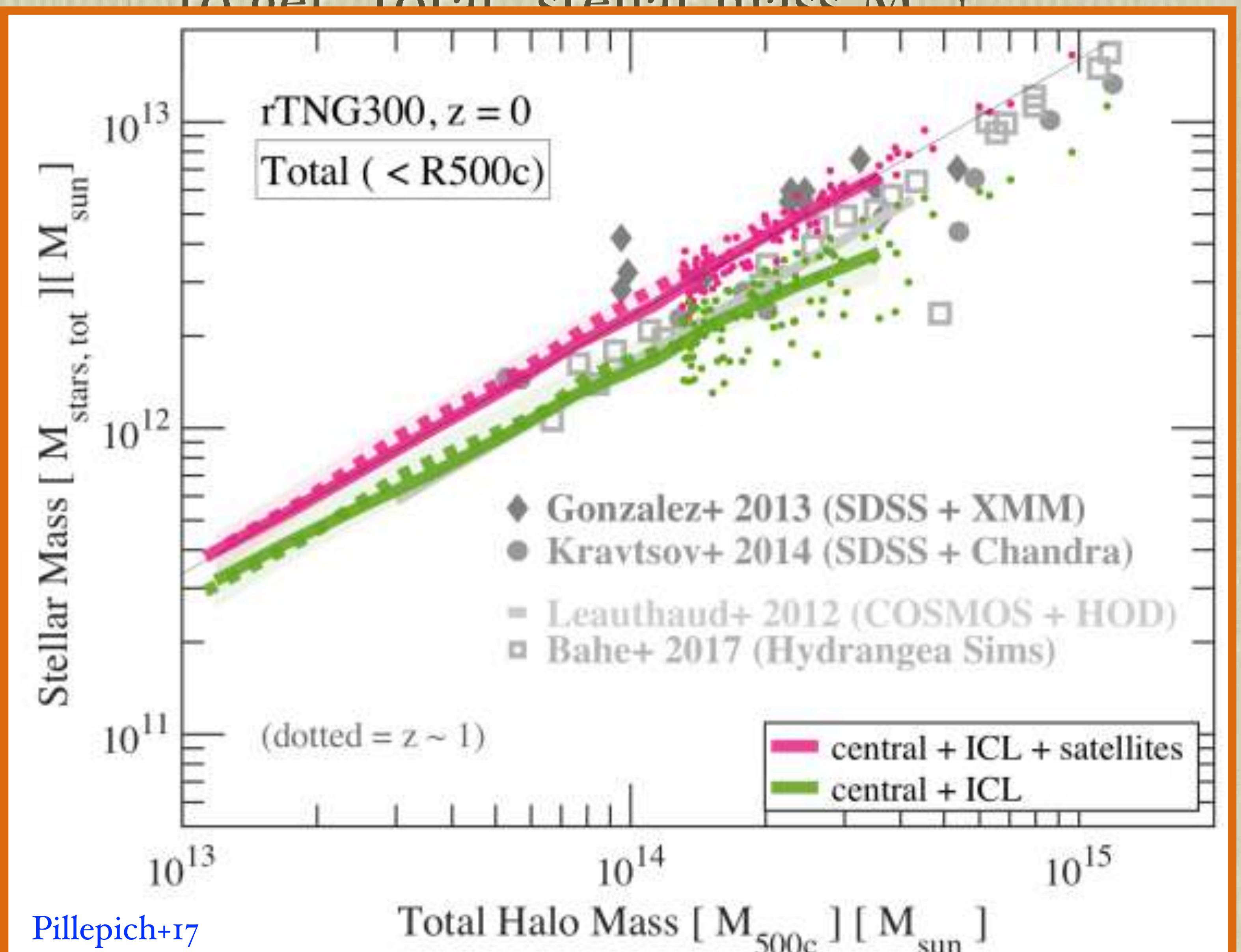
stellar mass contents of clusters

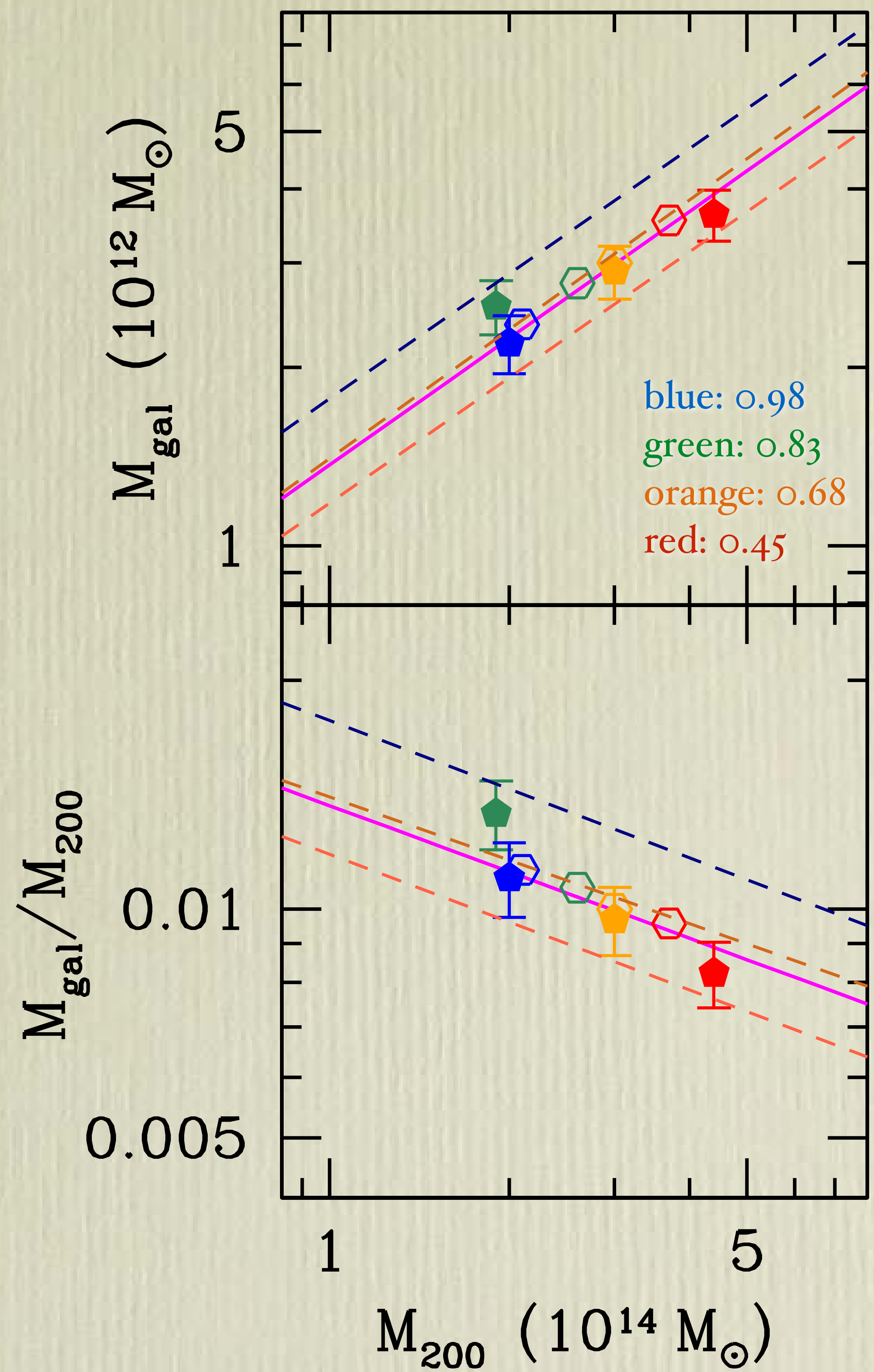
- integrate the SMD down to $10^{10} M_{sun}$ to get "total" stellar mass M_{gal} (including BCGs)
- clusters appear to move along the $M_{gal} \propto M_{200}^{0.7}$ locus (solid line, taken from Lin+12 for a totally different sample)
- why is there no/little evolution of the M_{gal}–M_{200} relation?
  - lots of stripping required?
  - same for N–M_{200}
  - would $M_{gal} \propto M_{200}$ at any early epoch?
- also found by Chiu+17 for SPT-selected clusters



stellar mass contents of clusters

- integrate the SMD down to $10^{10} M_{sun}$ to get “total” stellar mass M





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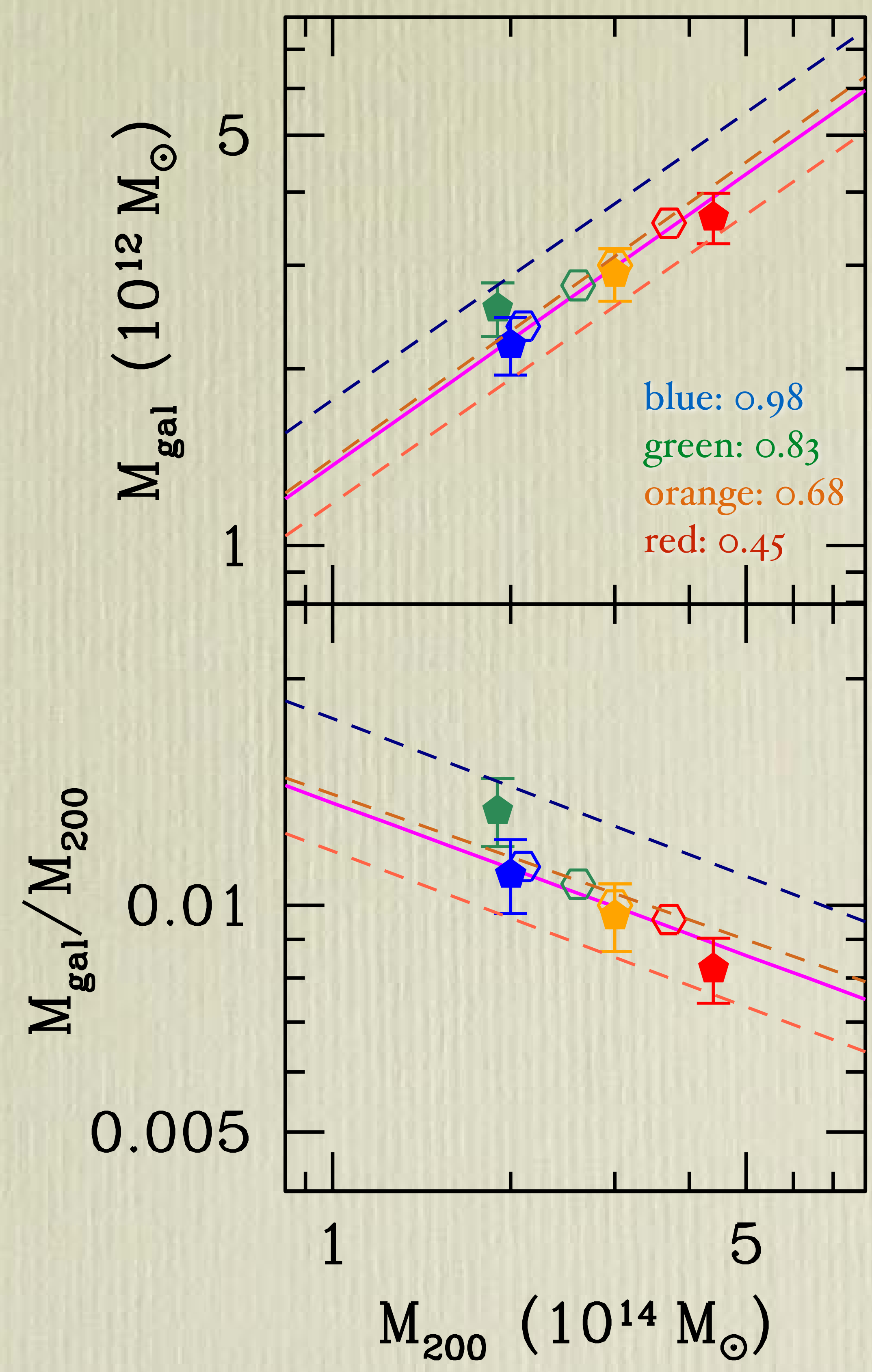
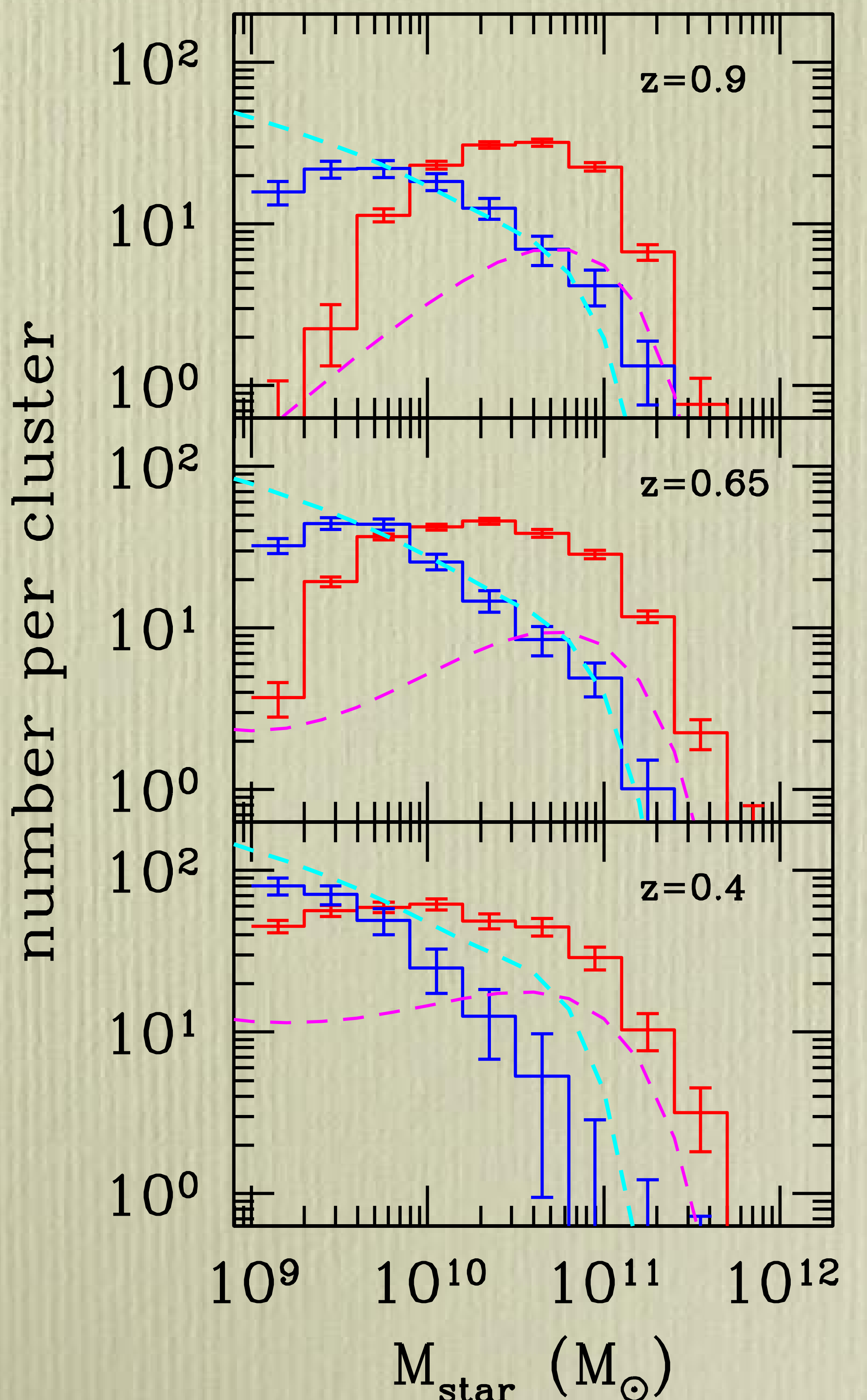
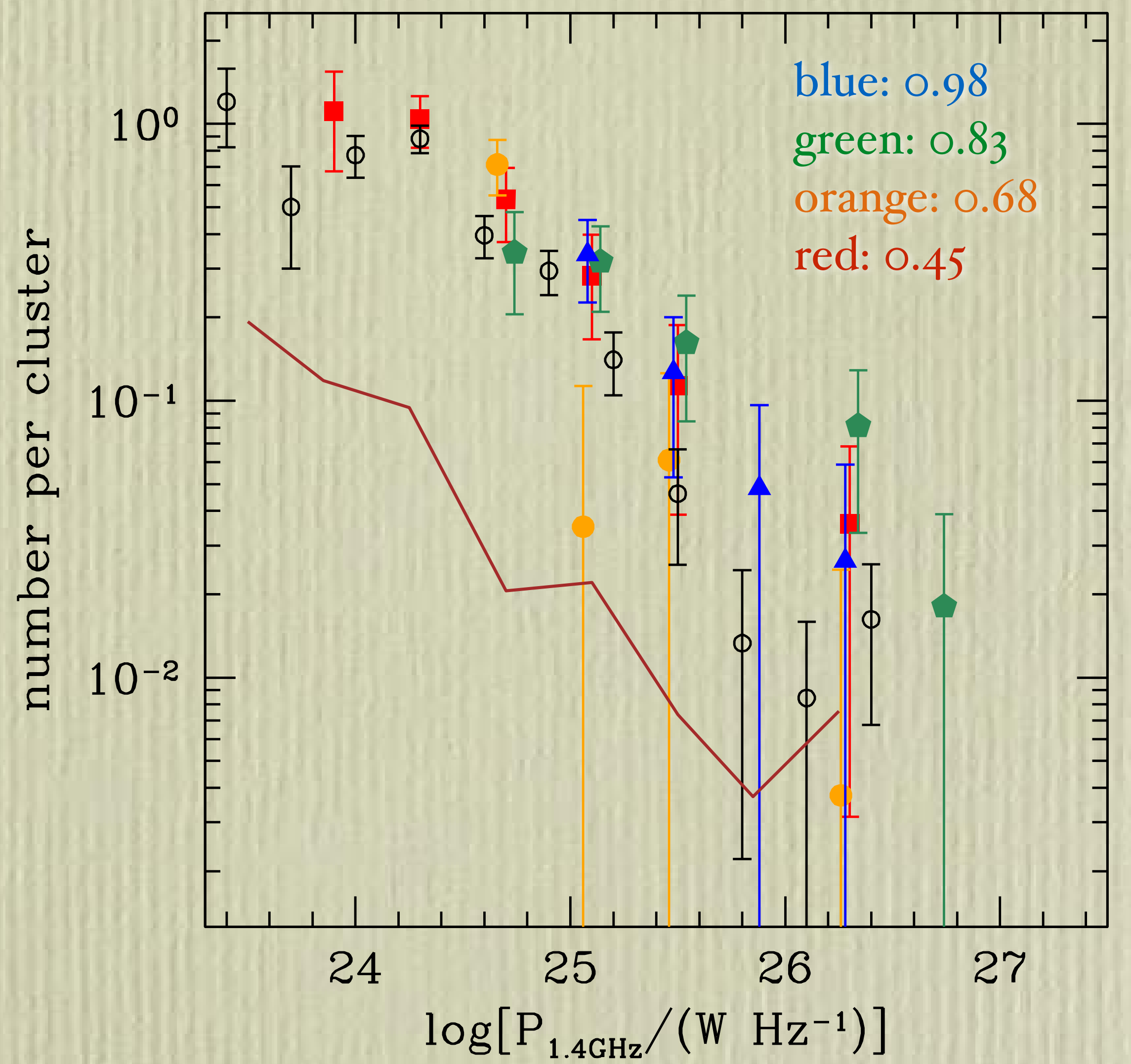


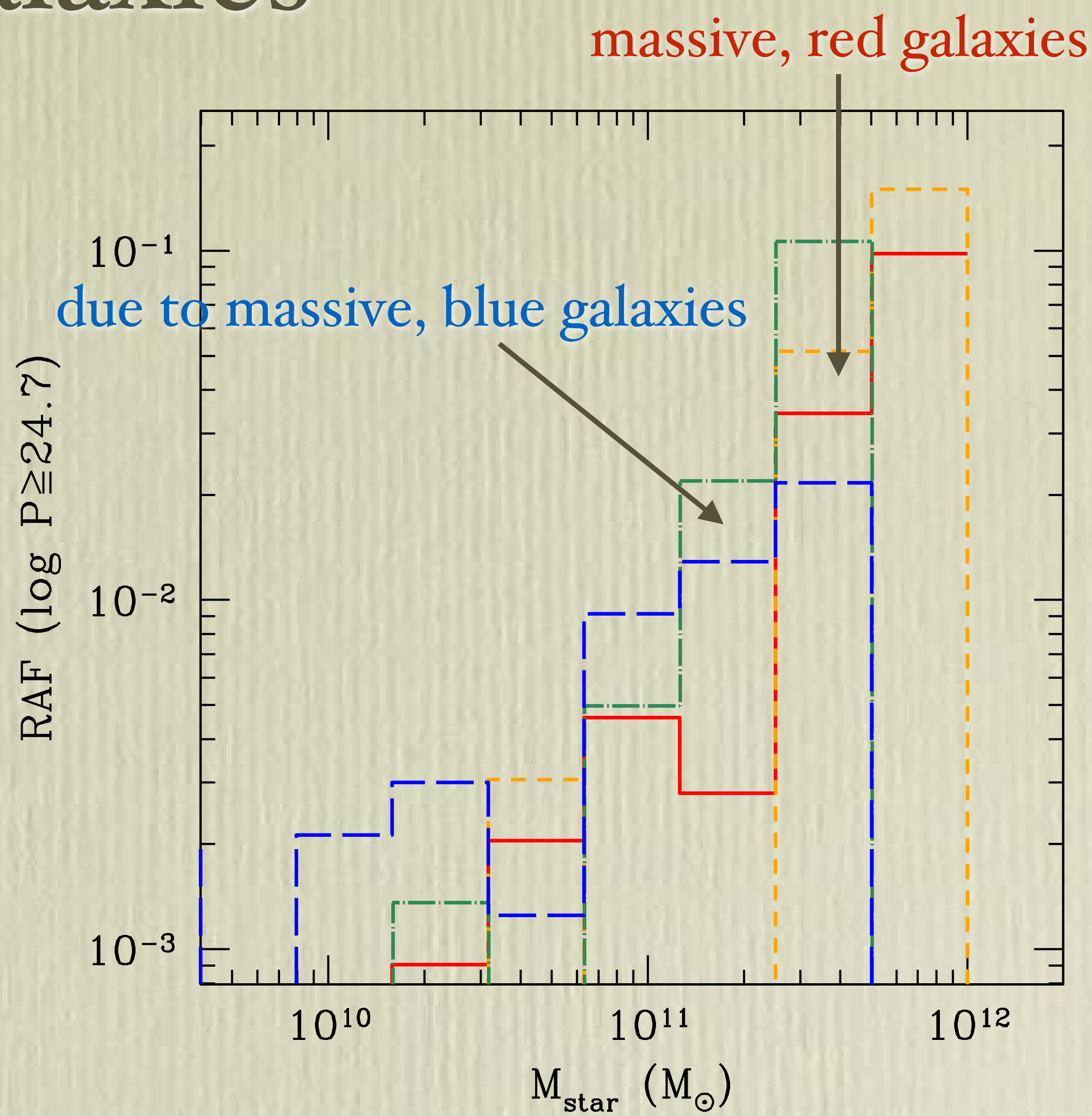
comparison with field



- 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



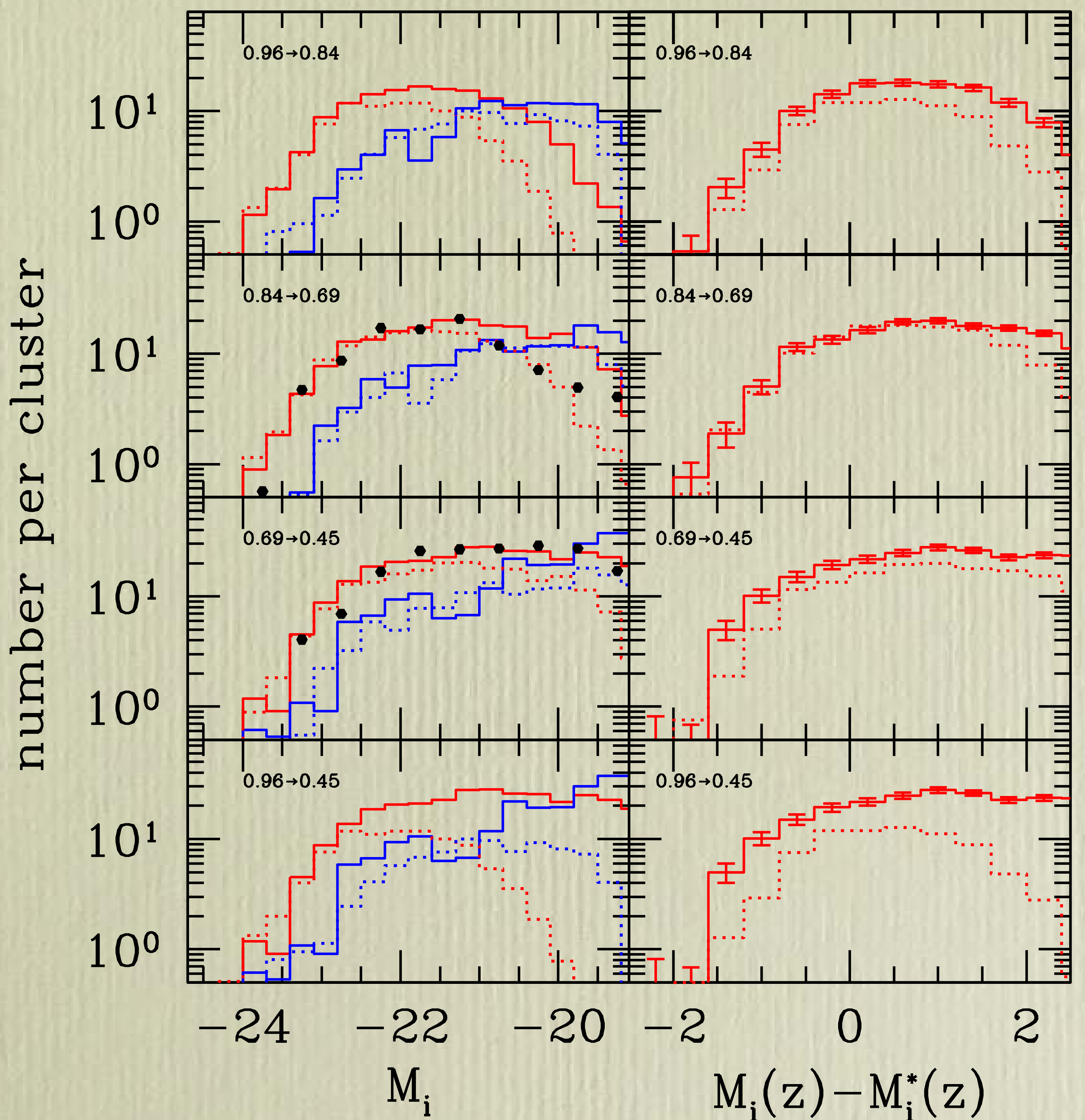


- count FIRST sources around clusters, then do global background subtraction
- cluster RLD ~10x higher than scaled field RLF (Smolčić+09)
- RAF = fraction of galaxies above certain radio power
- strong function of stellar mass
- possible change in the mode of accretion to SMBH at z~0.8?!

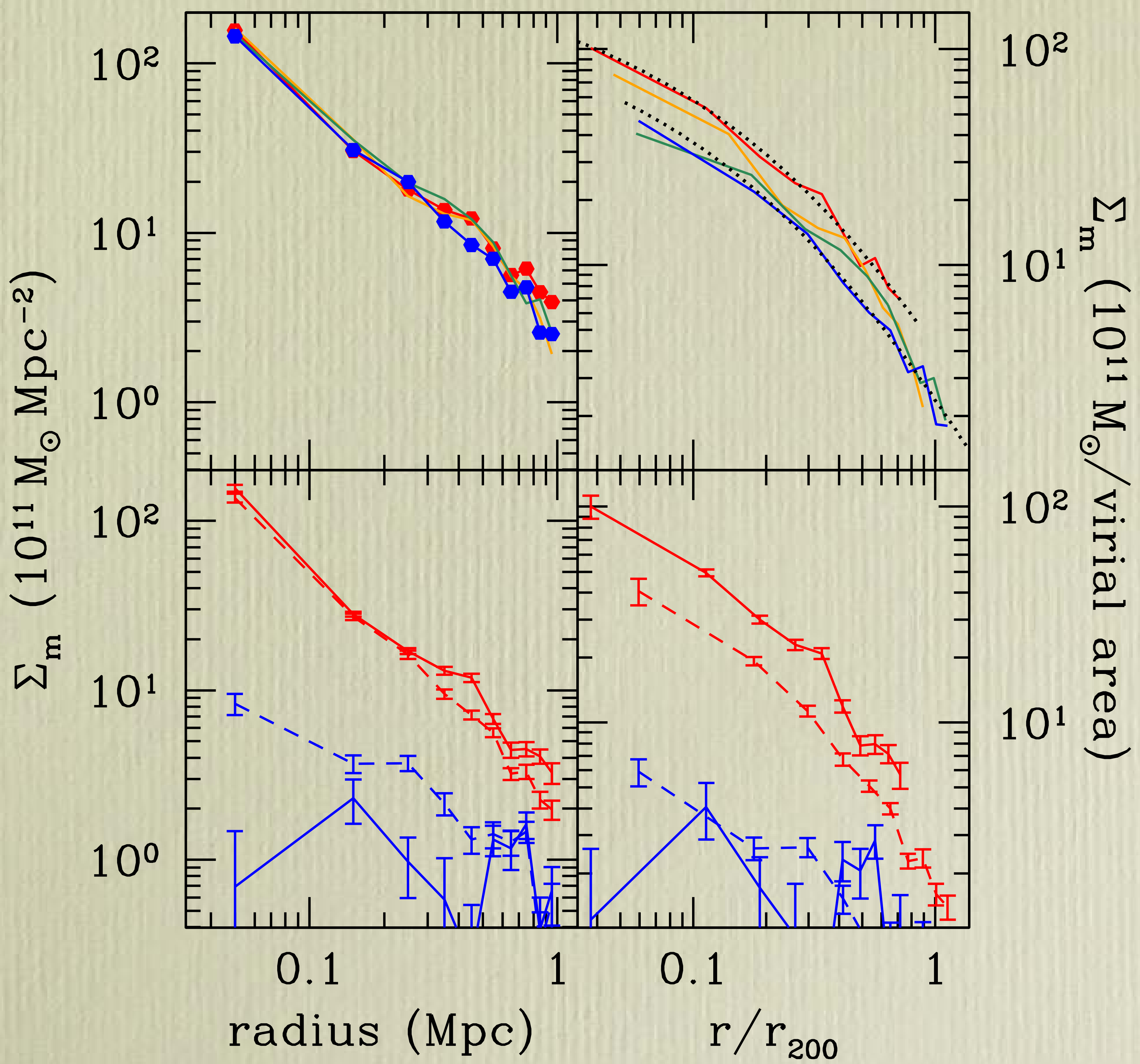
summary

- machine learning applied to stellar mass estimates
- *top N* cluster selection shown as useful way of studying cluster galaxy population evolution
- mild degree of growth in BCGs
- stellar mass distribution
  - down-sizing in galaxy content buildup confirmed
  - M_{gal}-M_{200} relation seems invariant in time; why?
  - clusters are overabundant in red galaxies ⇒ pre-processing?
- radio galaxies
  - clusters are overabundant in RGs too
  - at $z>0.8$, cluster RGs mainly blue; at lower-z red galaxies take over
- all the data this analysis is based is now publicly available (just google "HSC SSP")

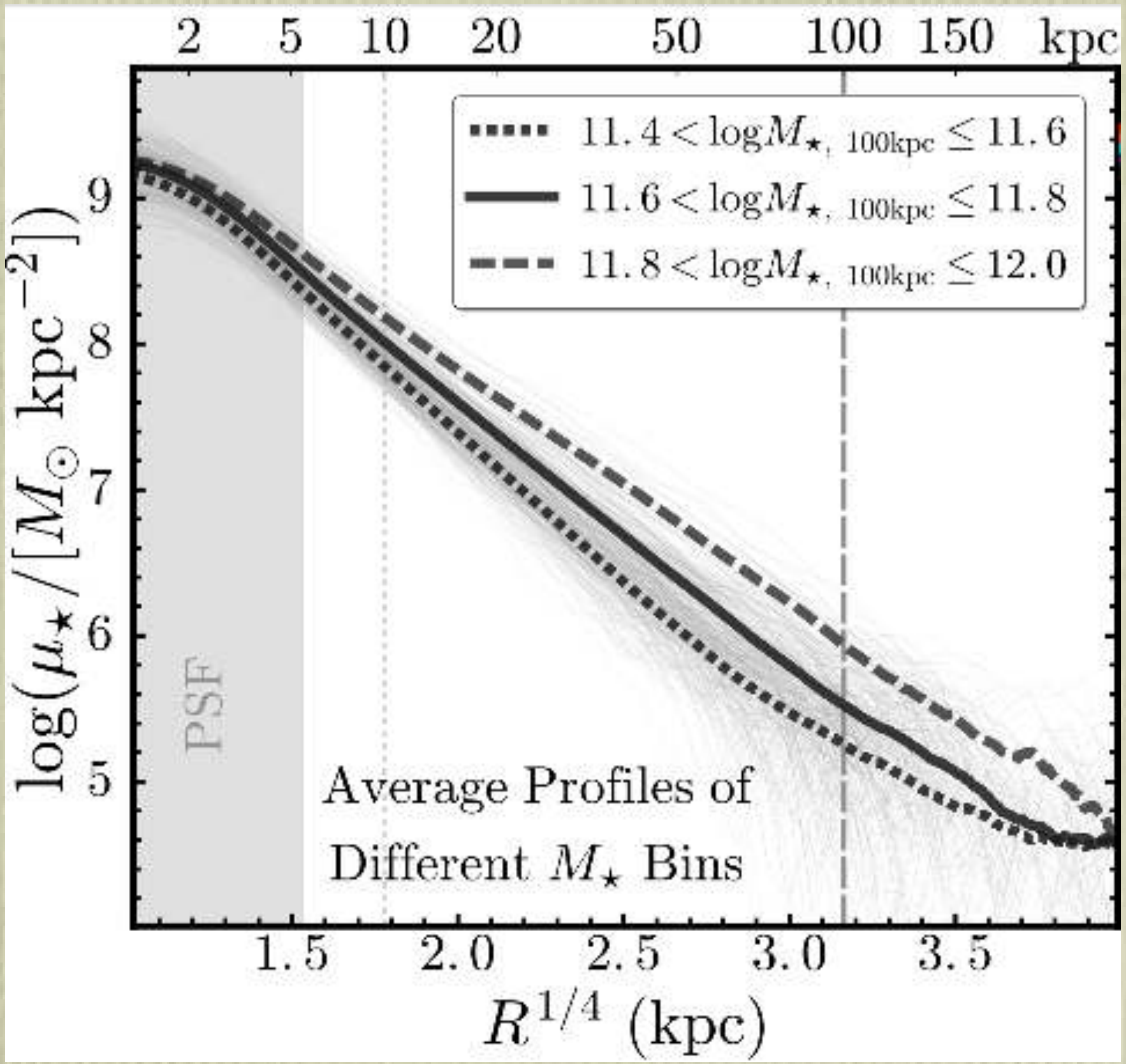
luminosity distribution

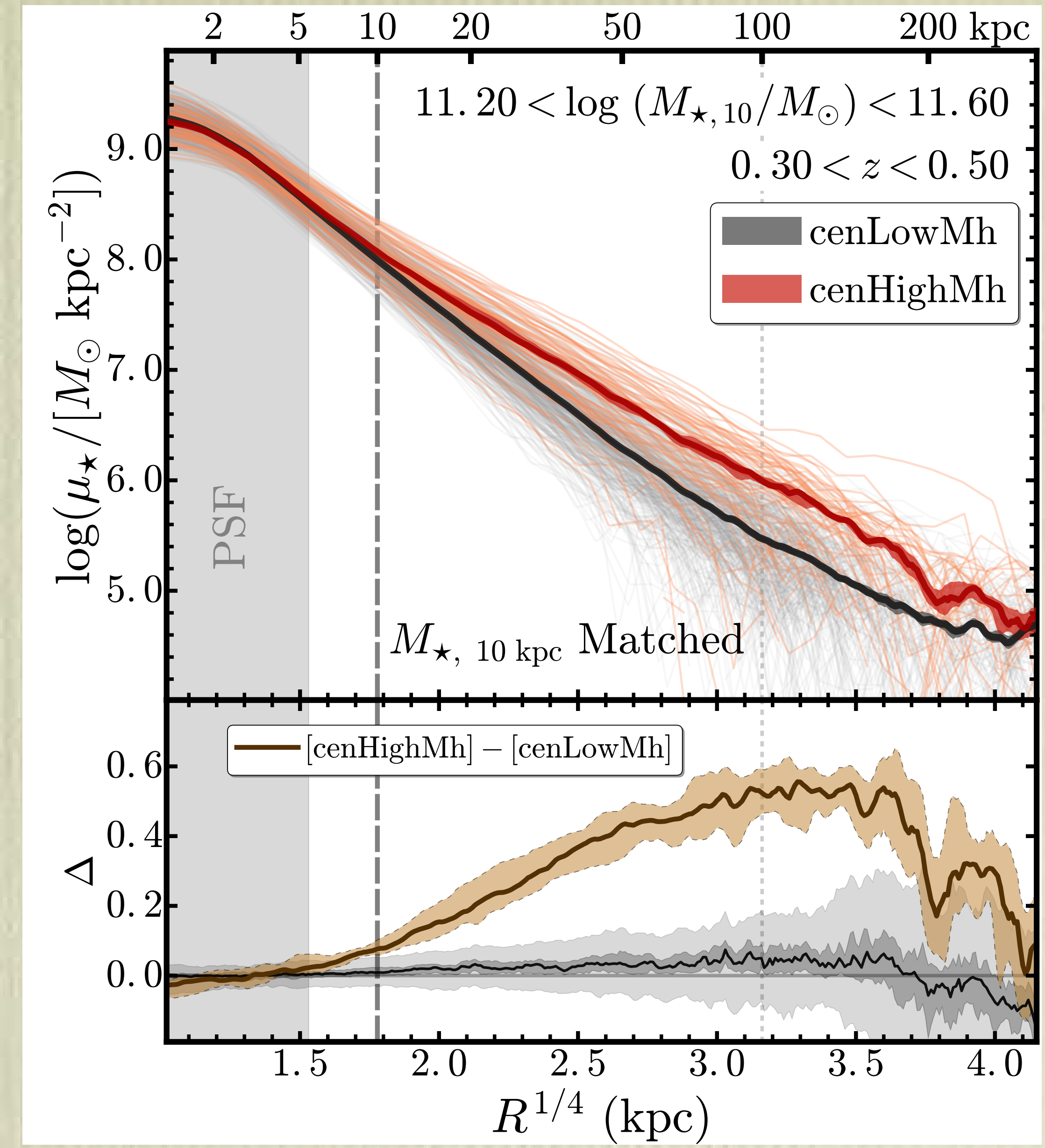


spatial distribution



BCG stellar mass profiles





- profile of individual BCGs measurable to at least ~100 kpc
- when stellar mass within 10kpc matched, outer envelop shows strong dependence on halo mass
- more accretion/mergers allowed in high mass halos

Huang+17a,b