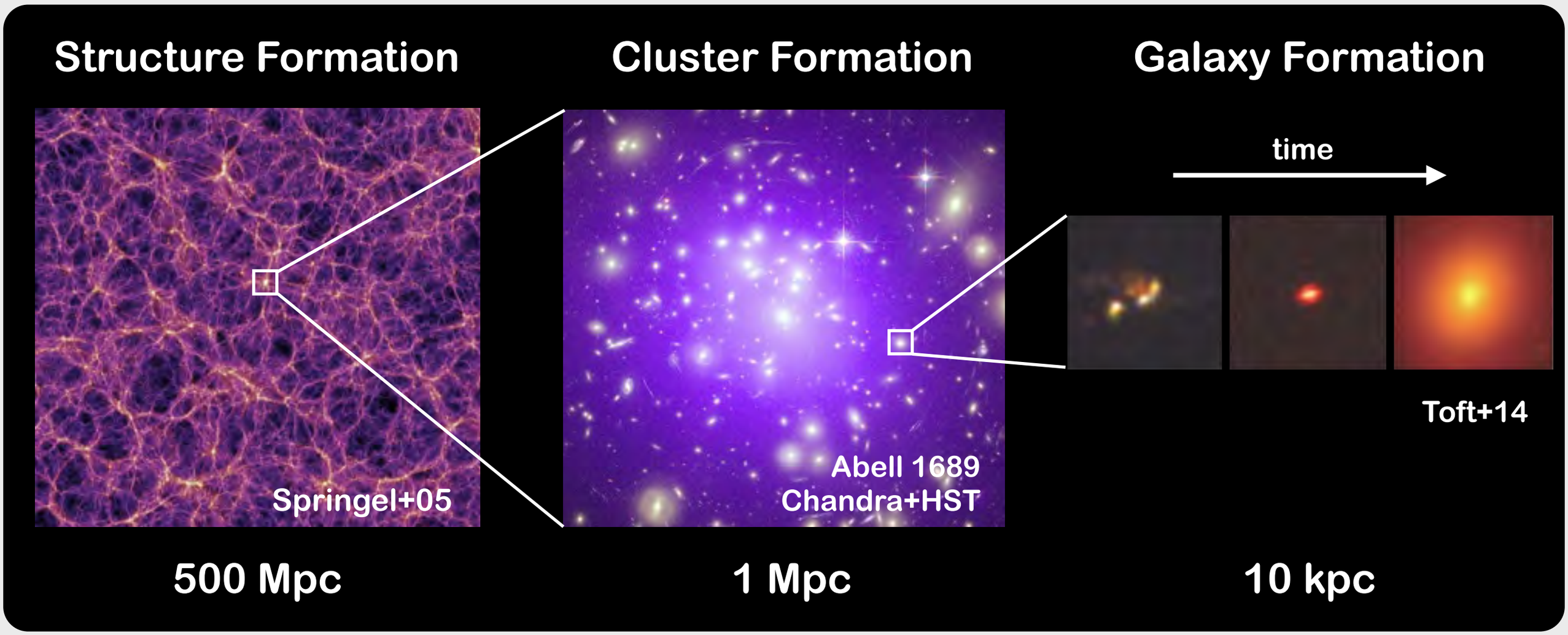
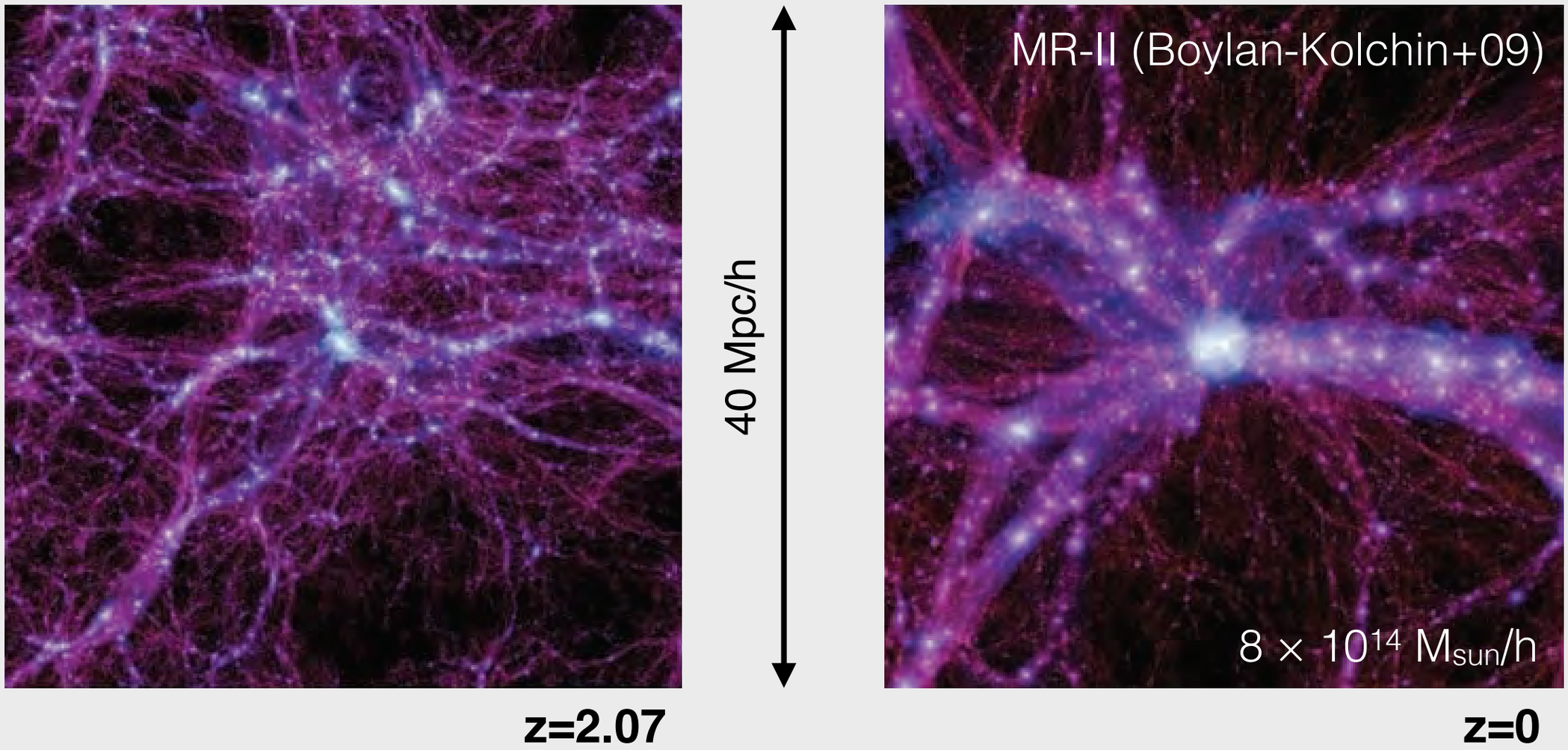
Protoclusters, Galaxy–DM Connection, and Galaxy–IGM Connection at z~2



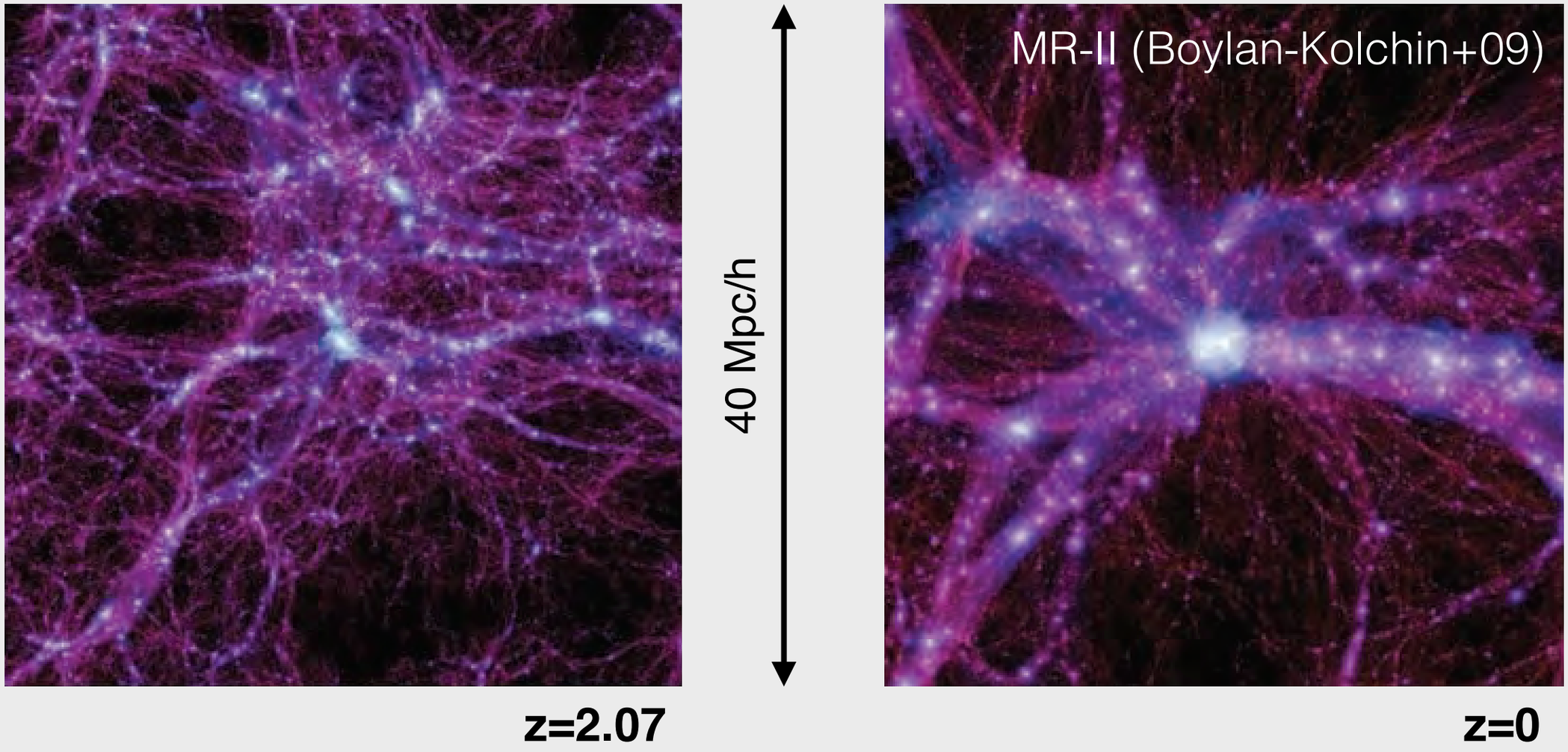
Yi-Kuan Chiang
University of Tokyo, ICRR

Cluster formation on cosmological timescale in DM *N*-body simulations

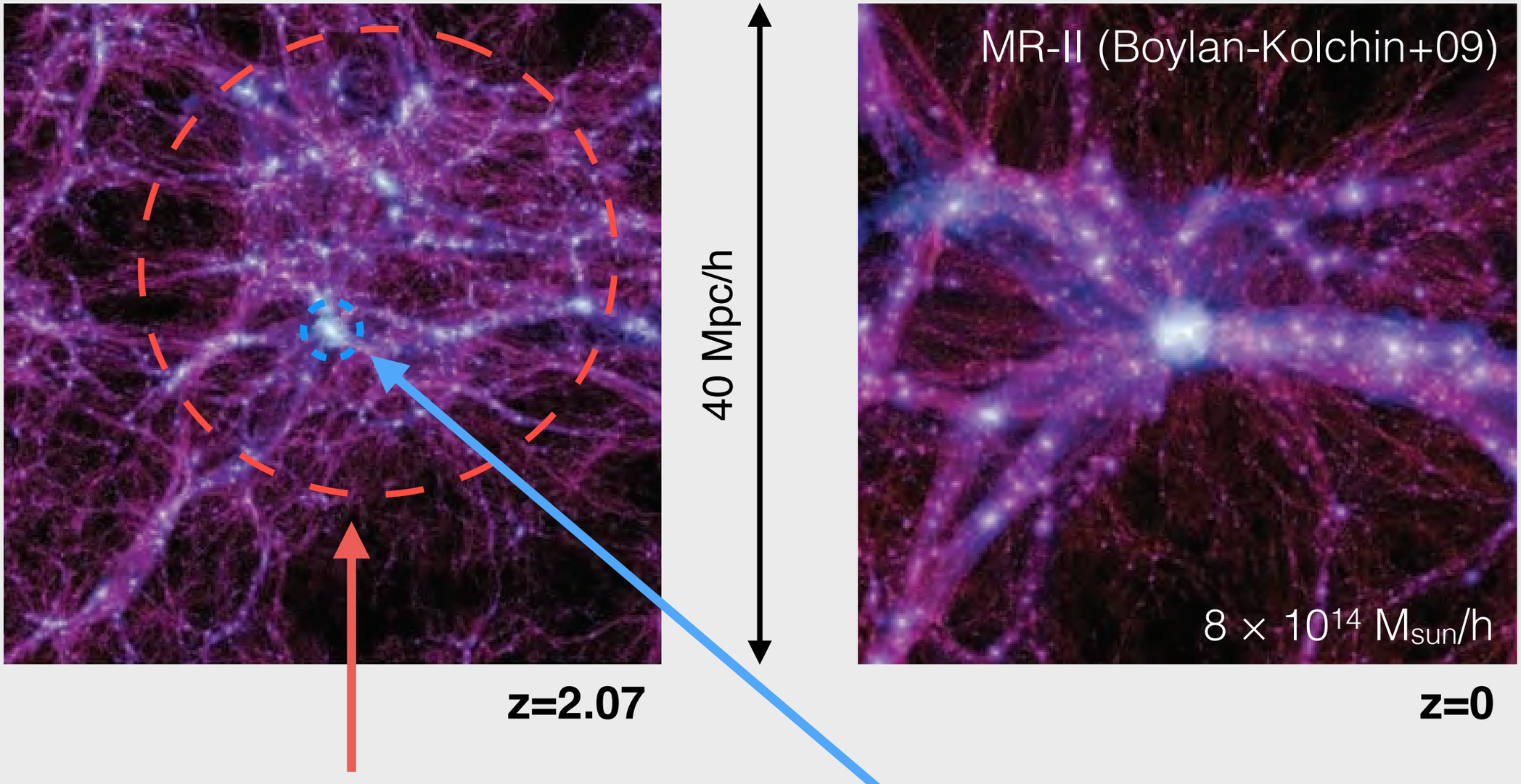


An unique case where galaxy progenitor bias can be largely eased

Messy small-scale astrophysics happens in a confined region of LSS, of which the evolution is governed by clean dissipationless DM processes



For an evolutionary view beyond a dynamical time, one should pay attention to the full Lagrangian volume, which boundary is carried along with the cosmic fluid



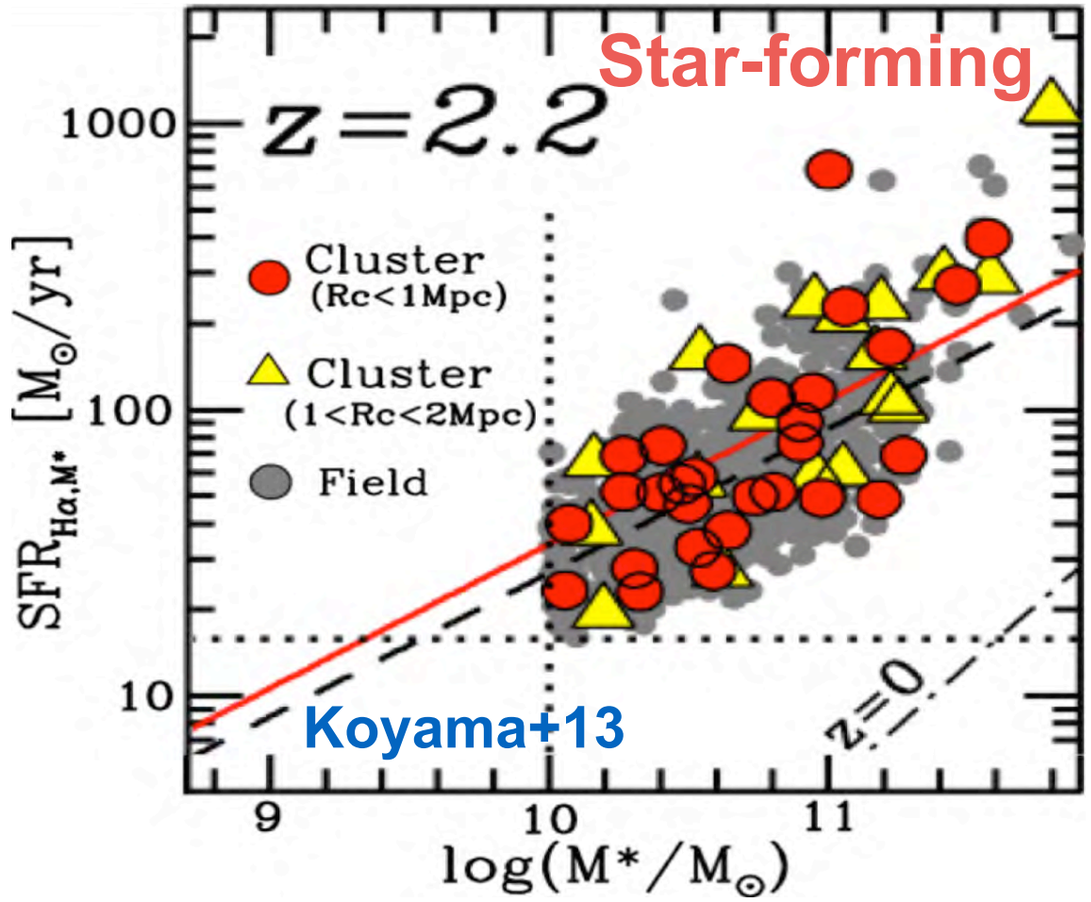
Proto-cluster (Lagrangian)
A collection of halos/galaxies/diffuse gas that will be assembled into a z=0 cluster

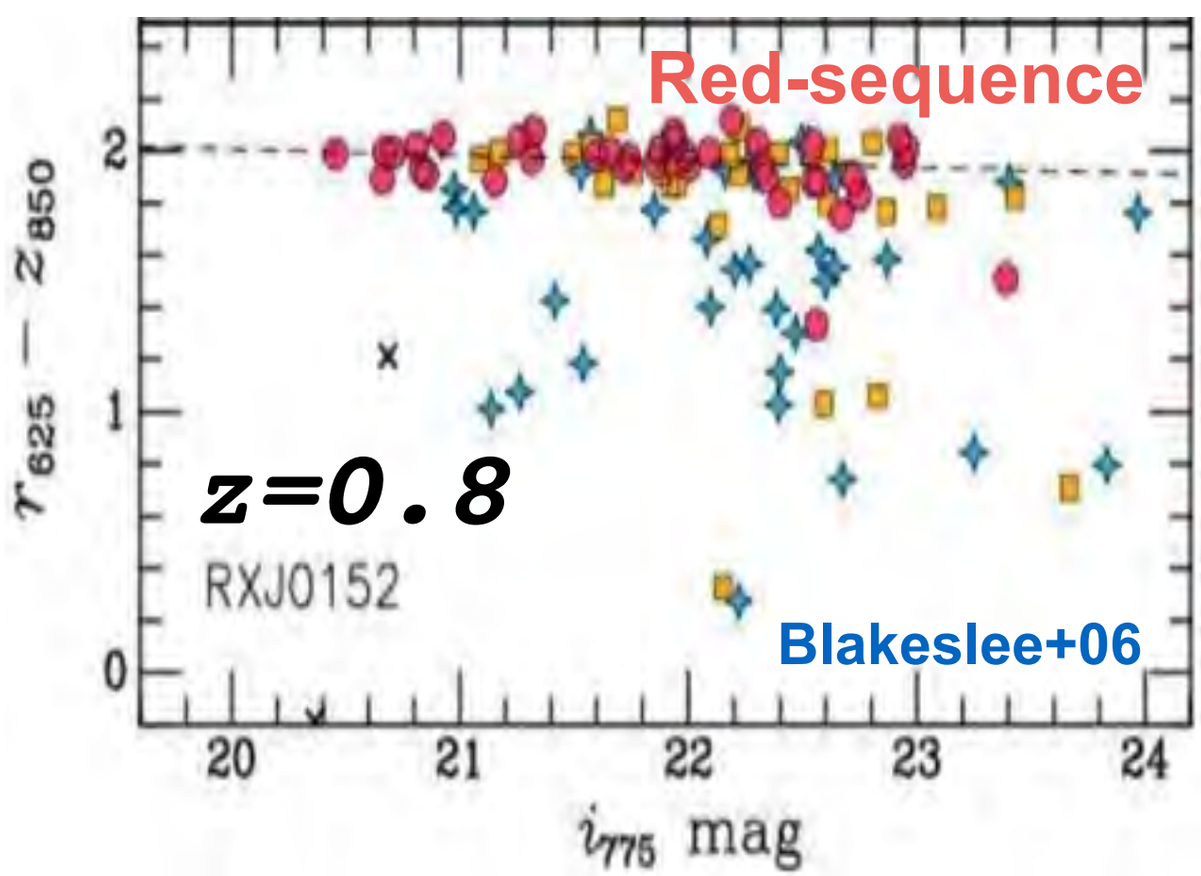
Proto-cluster core (Eulerian)
The most massive halo in a PC

The Roles of Protoclusters in Galaxy Formation

a. Extreme galaxy life cycles with traceable progenitor/descendant-ship

SF quenching and structural transformations must happen therein





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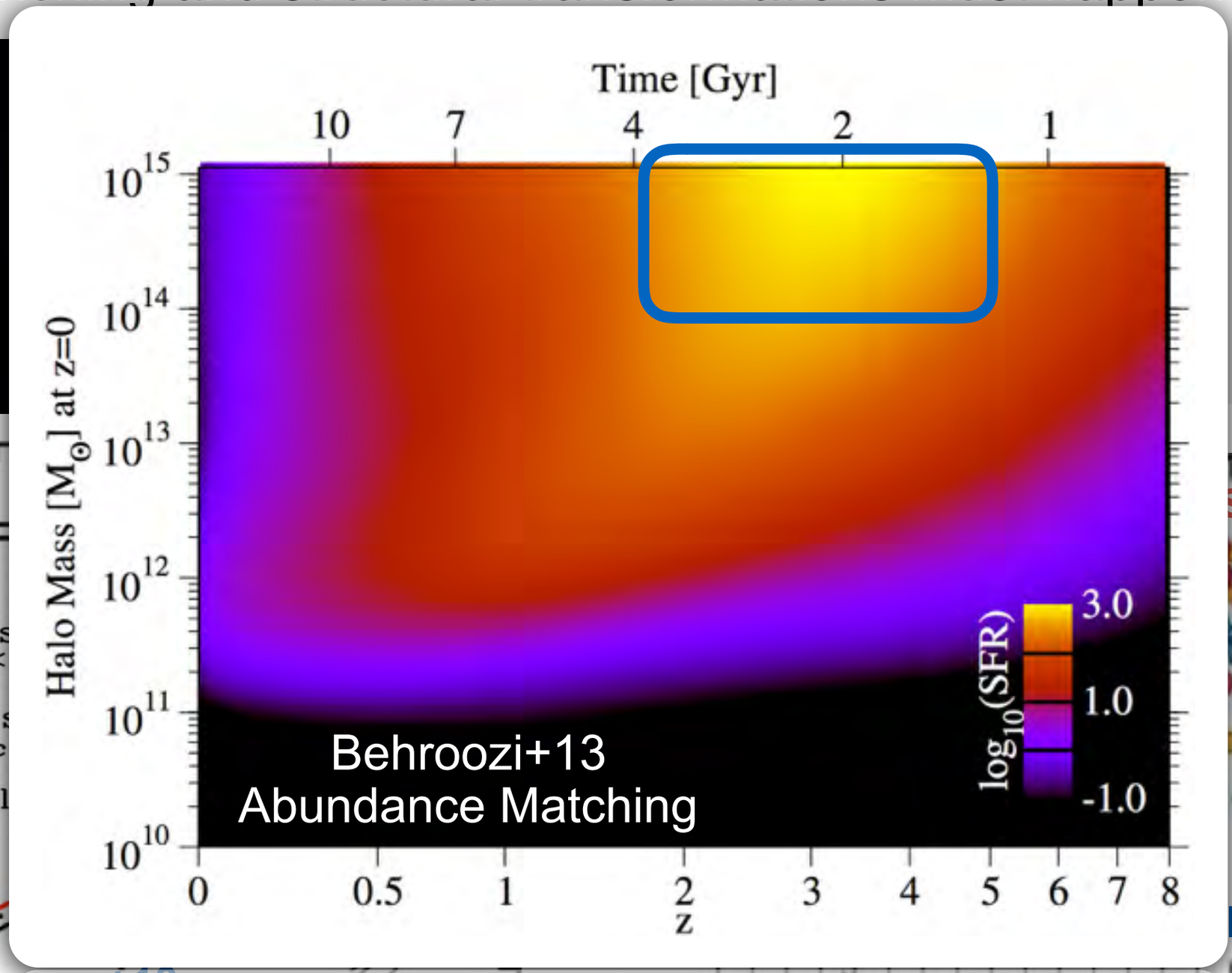
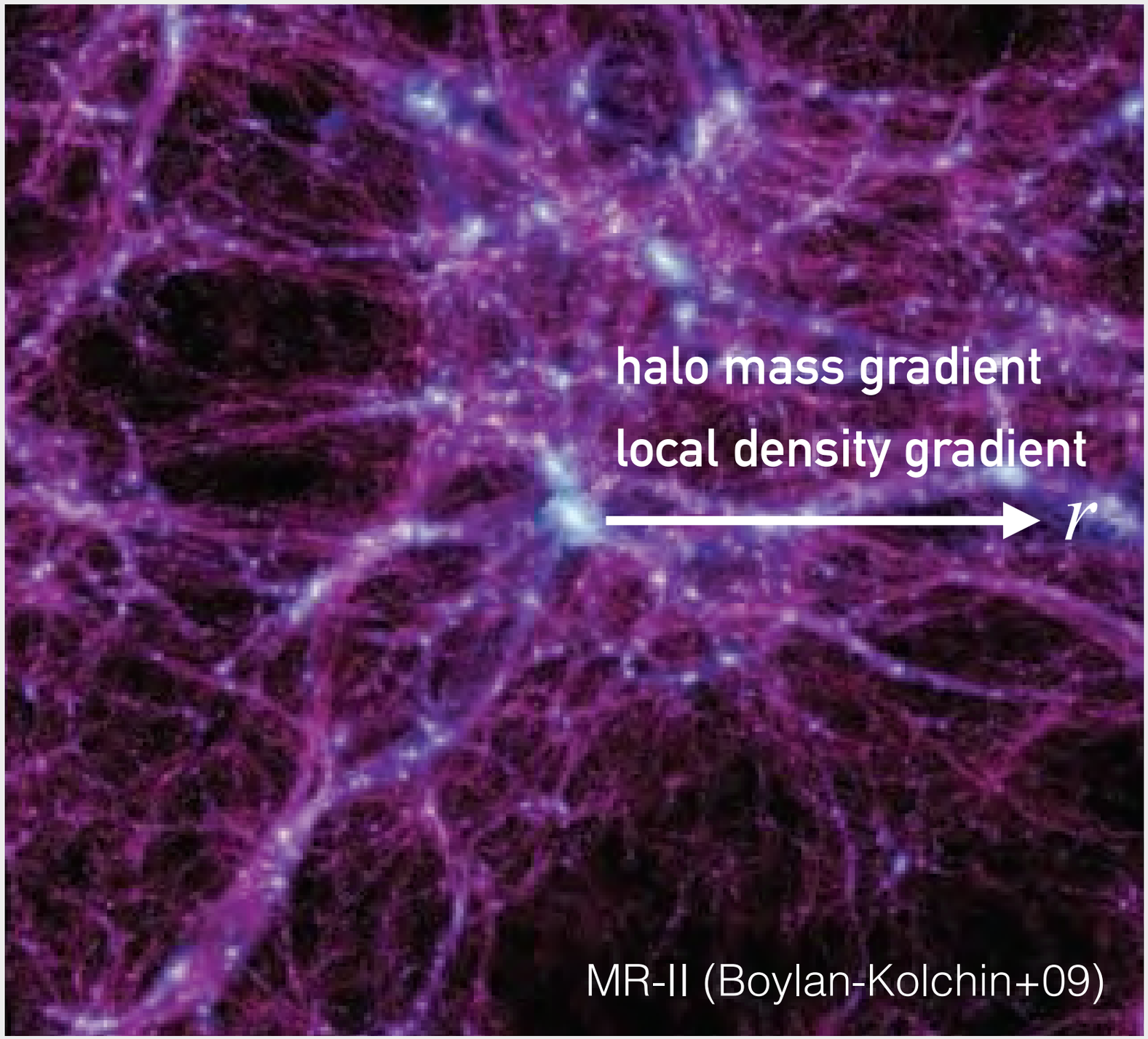


b. Large concentrations of coeval galaxies w/ a high dynamic range of activities and local environment



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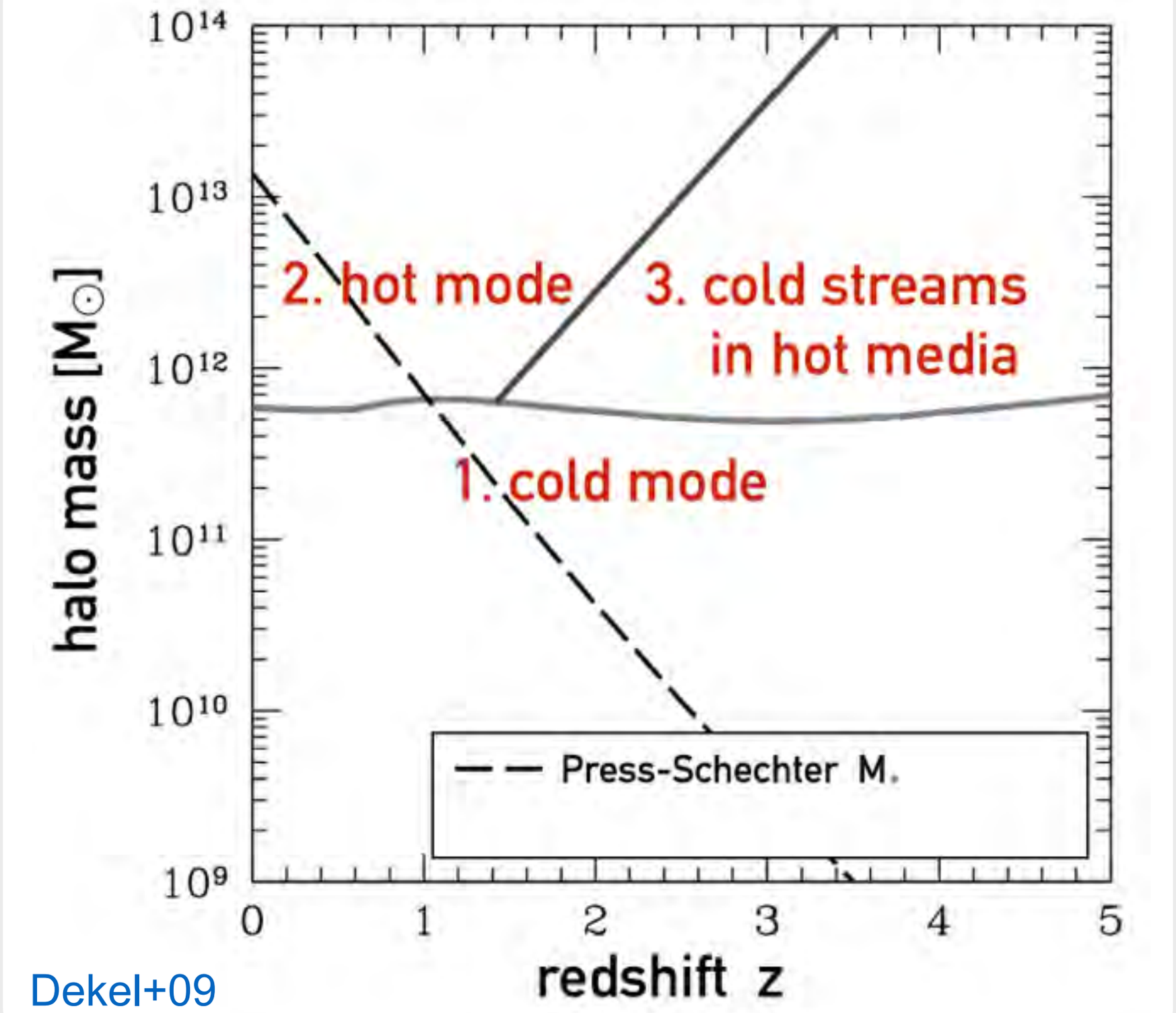

Dekel+09

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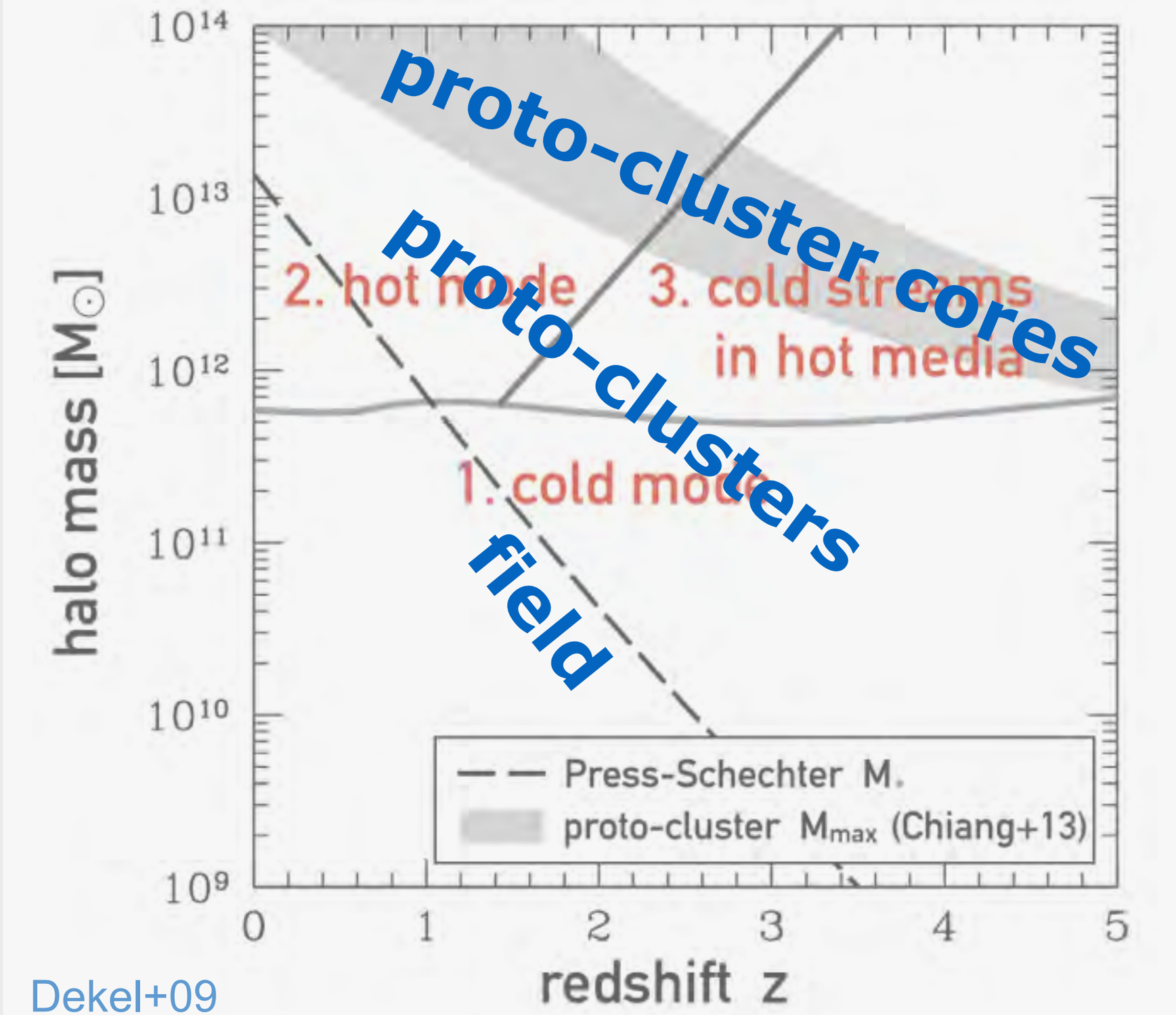
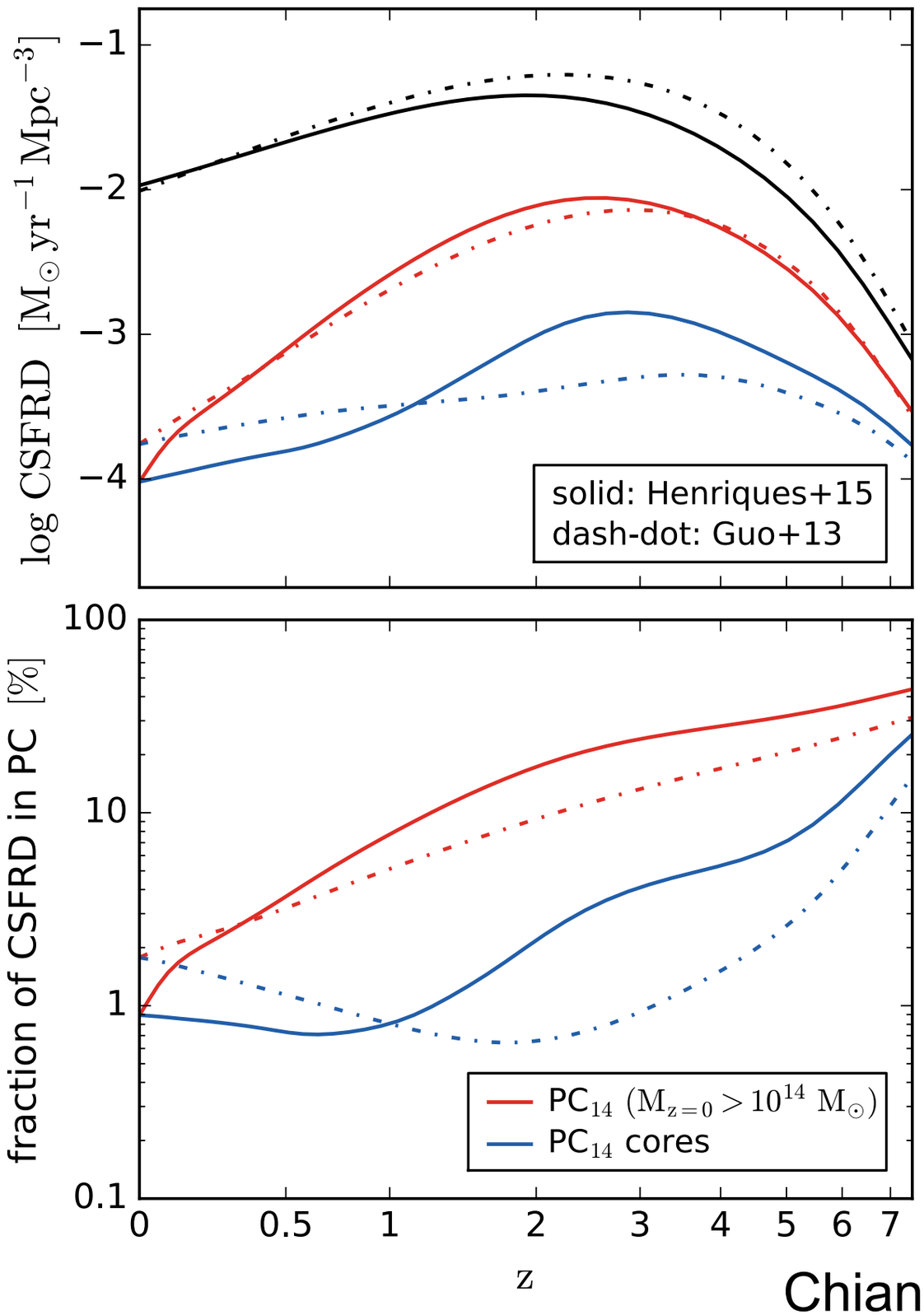
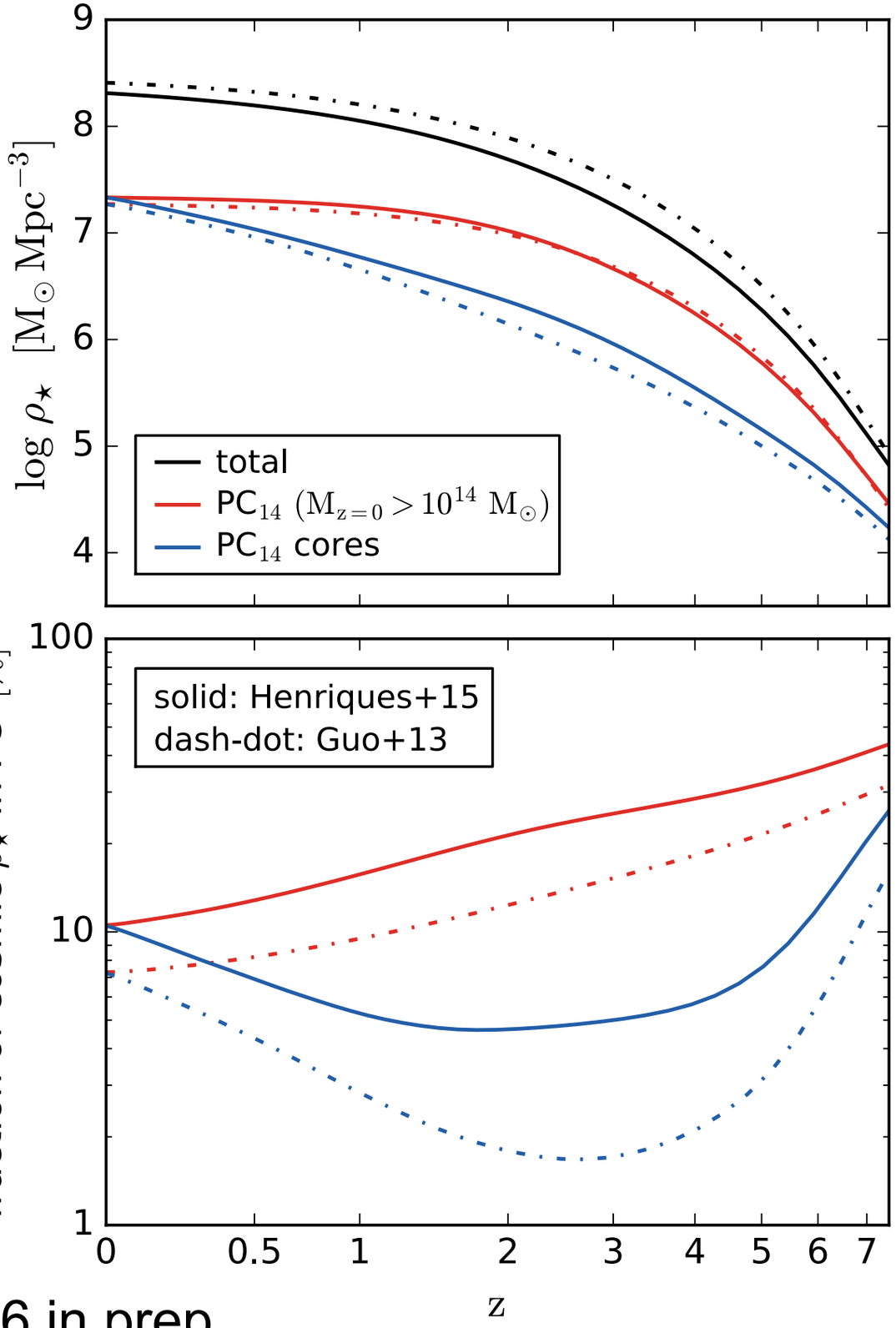


Dekel+09

c. High global contribution to the cosmic SF budget





Chiang+16 in prep.

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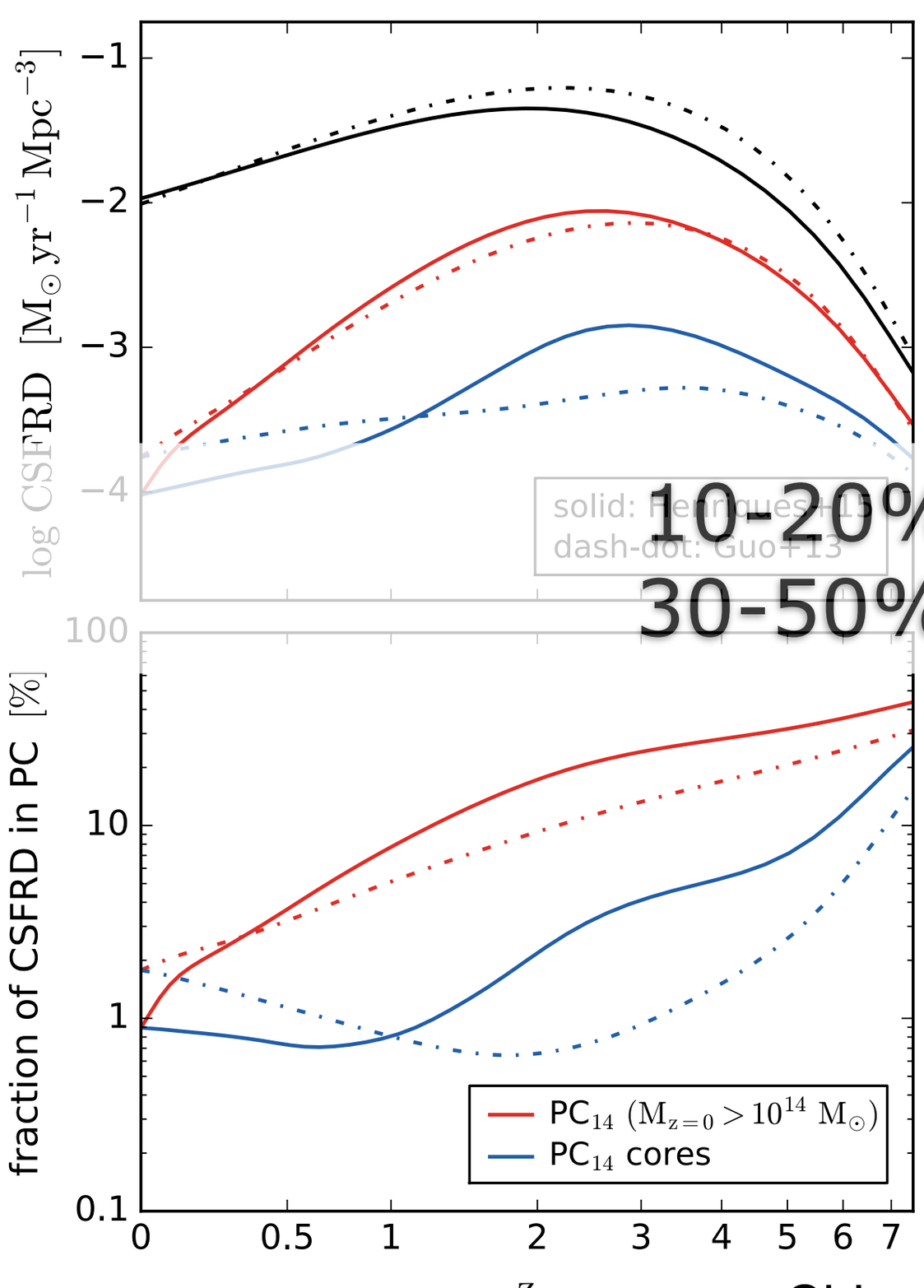
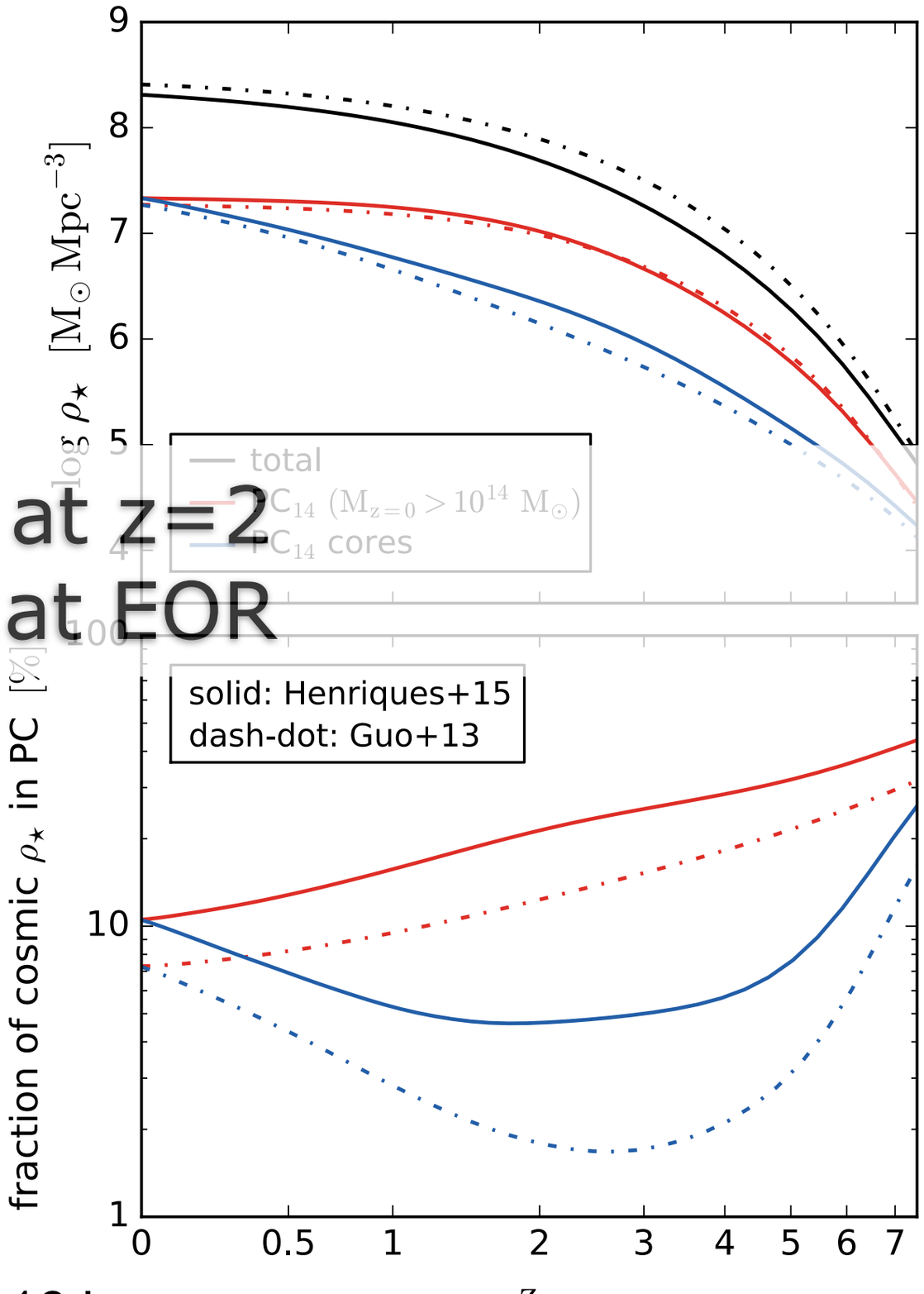




10-20% at z=2

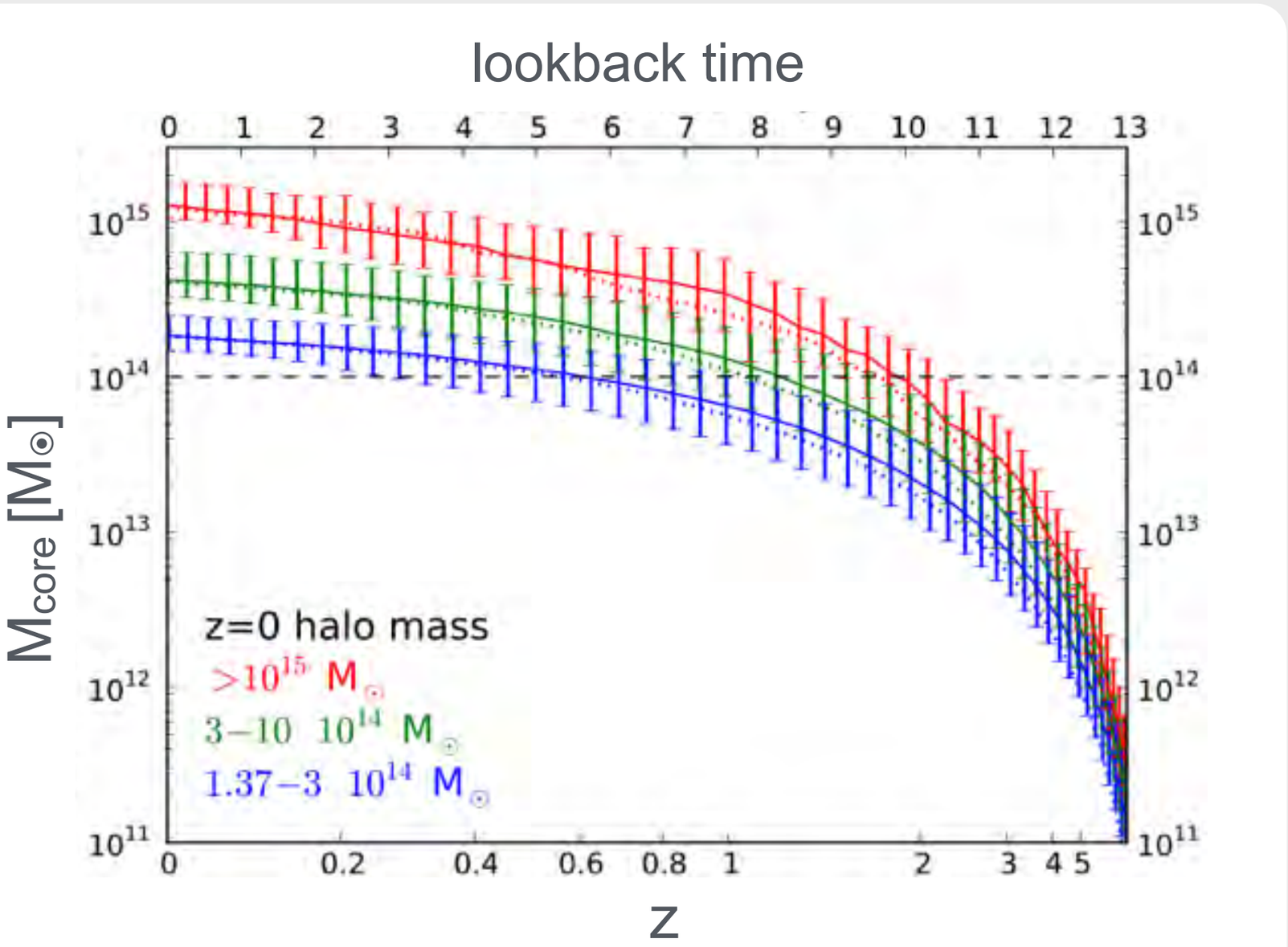
30-50% at EOR

Chiang+16 in prep.

Structural Properties

Core Mass Growth

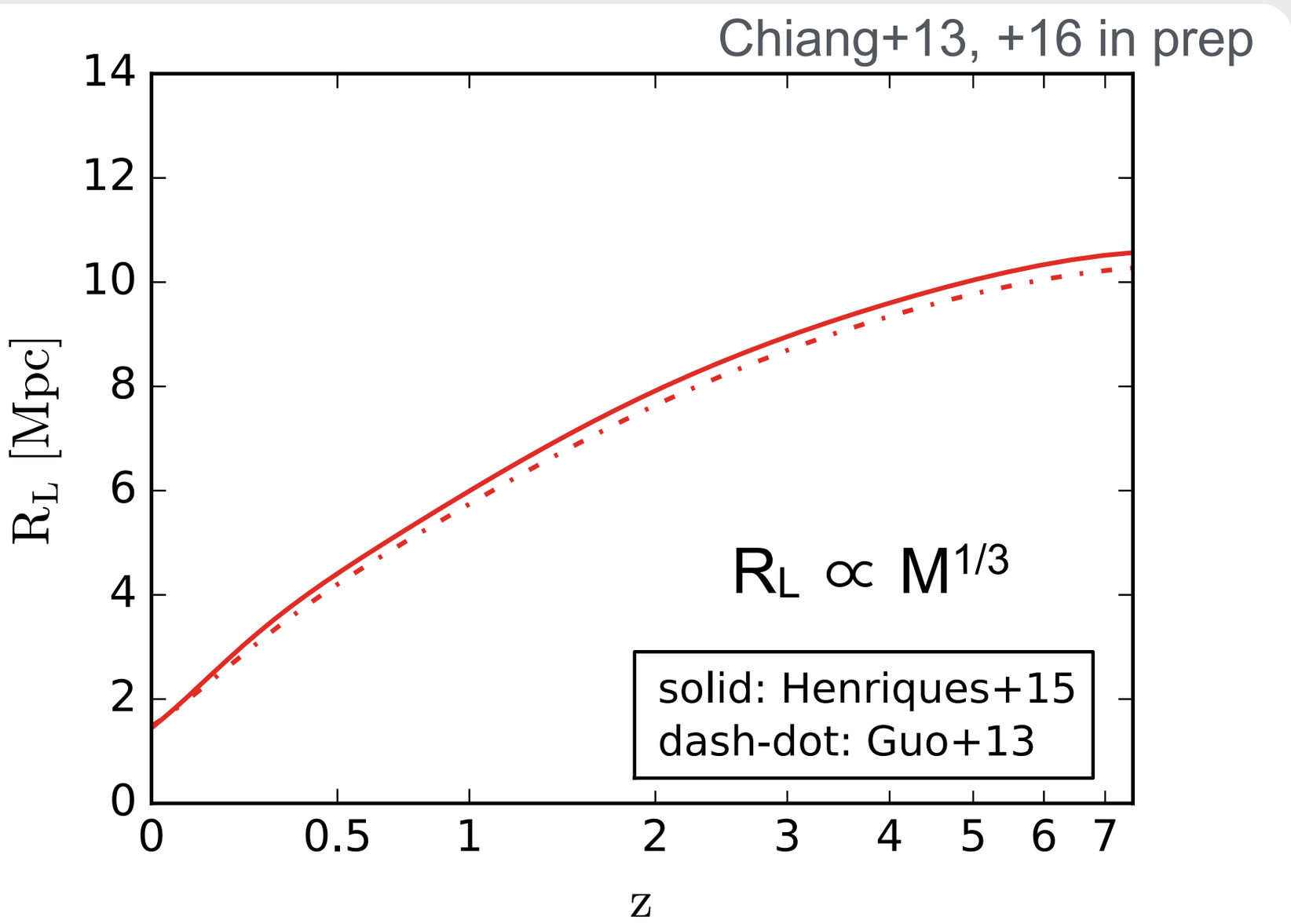
- Proto-clusters: by definition, no evolution (closed-box system)
- PC cores: an order of magnitude smaller at z=2 (open-box system)



Chiang+13

Collapse in Size

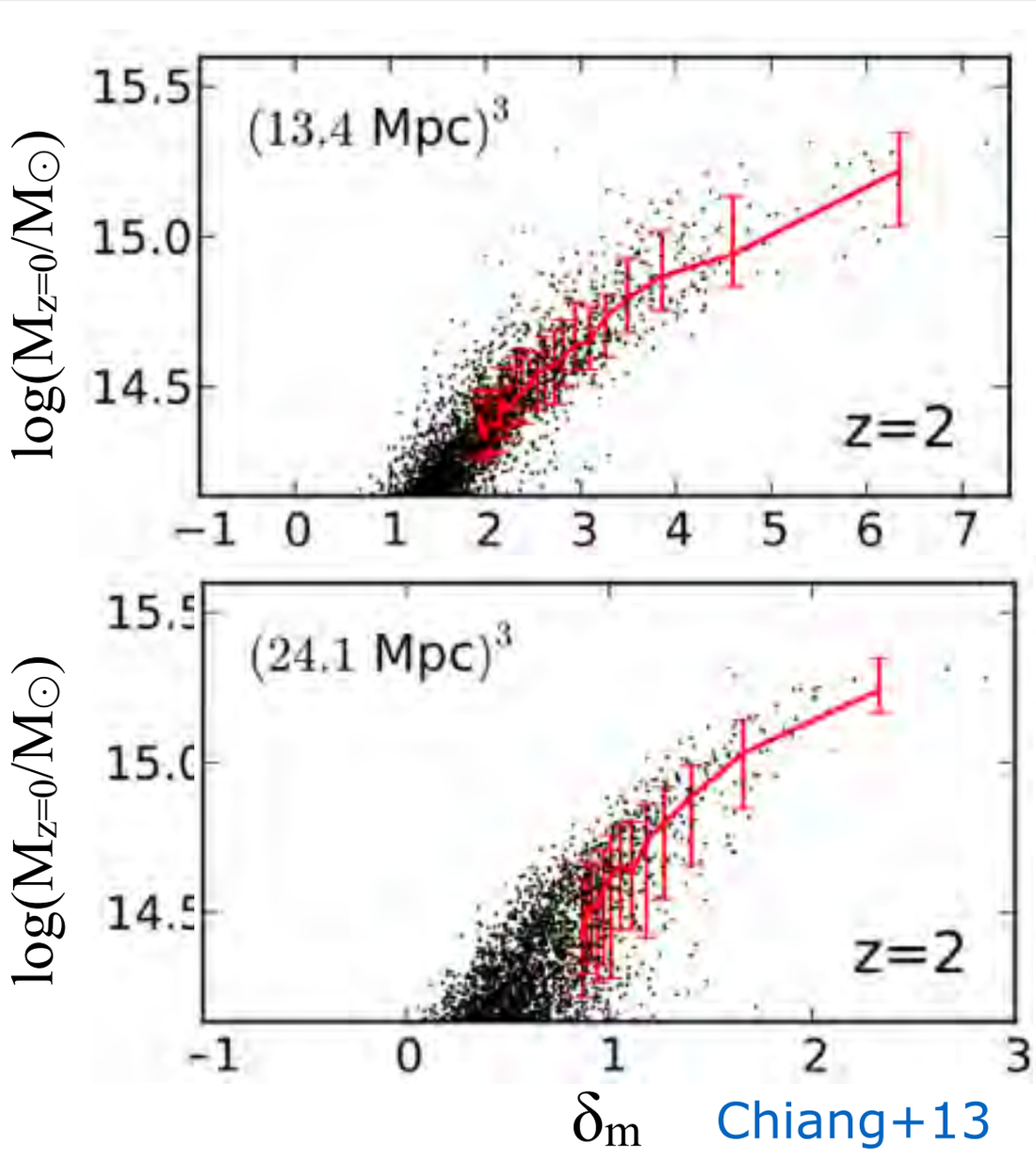
	$\log(M_{z=0}/M_\odot)$	$\log(n/Mpc^{-3})$	$2R_L$ at z=2.3
		Planck1	cMpc / arcmin
proto-Coma	>15	-7.1	32 / 19
proto-Virgo	14.5−15	-5.8	22 / 13
proto-Fornax	14−14.5	-5.1	15 / 9
total	>14	-5.0	



Protocluster identification

High-z Overdensity — z=0 Halo Mass Relation

Simply mass conservation in the Lagrangian volume

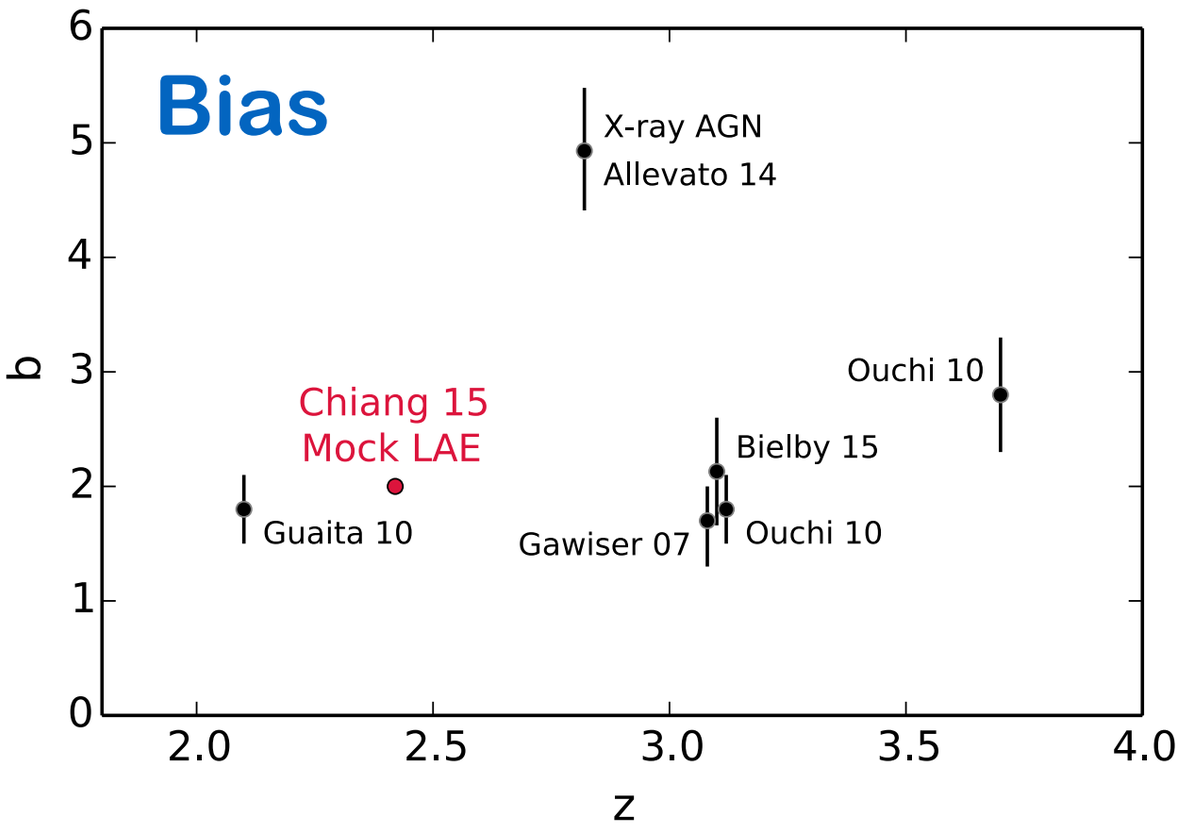


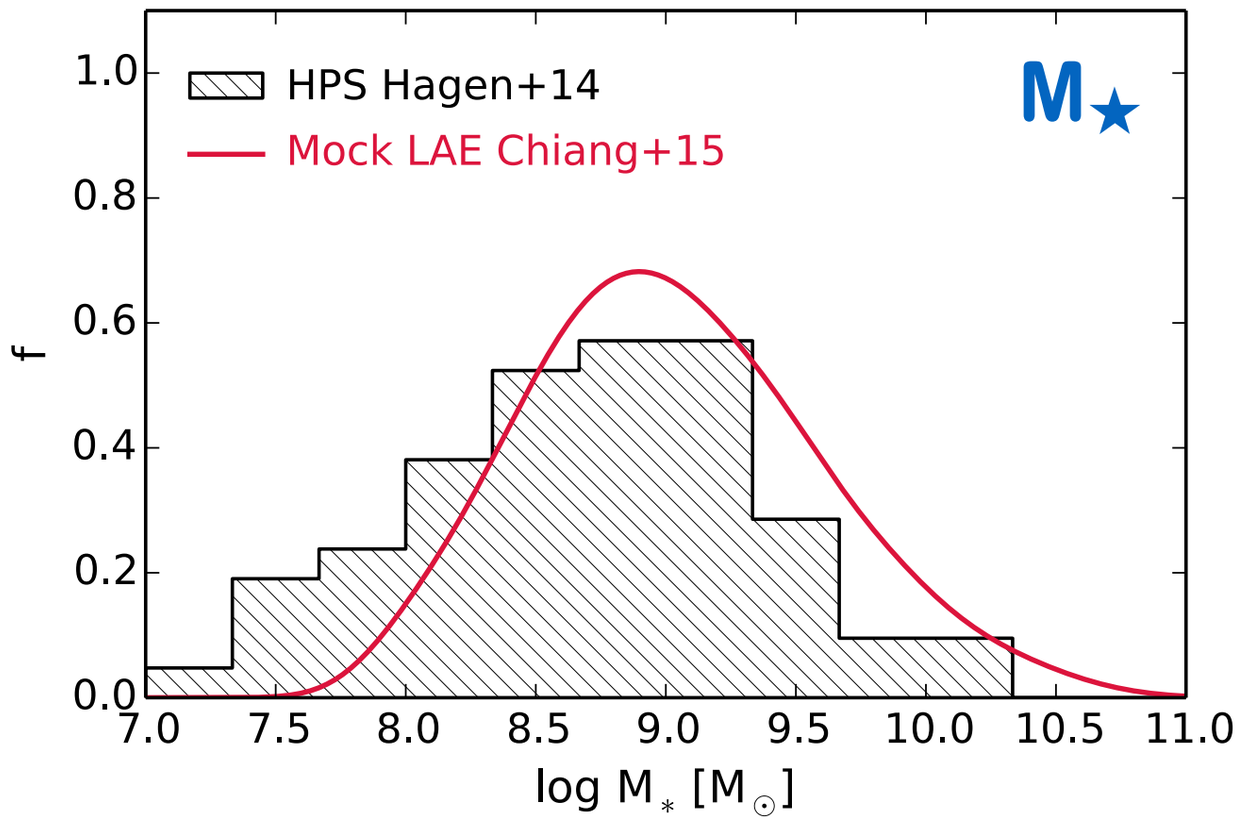
Chiang+13

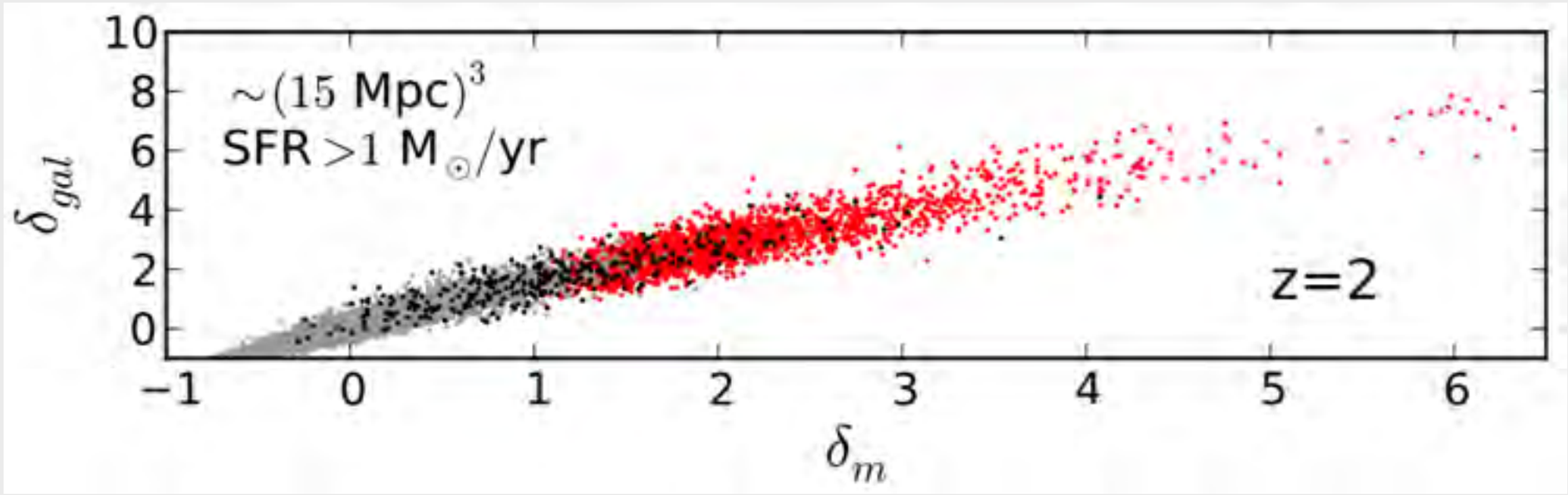
Galaxy—DM Connection

Example: HETDEX Mock LAEs

Chiang+15







Galaxy—DM connection

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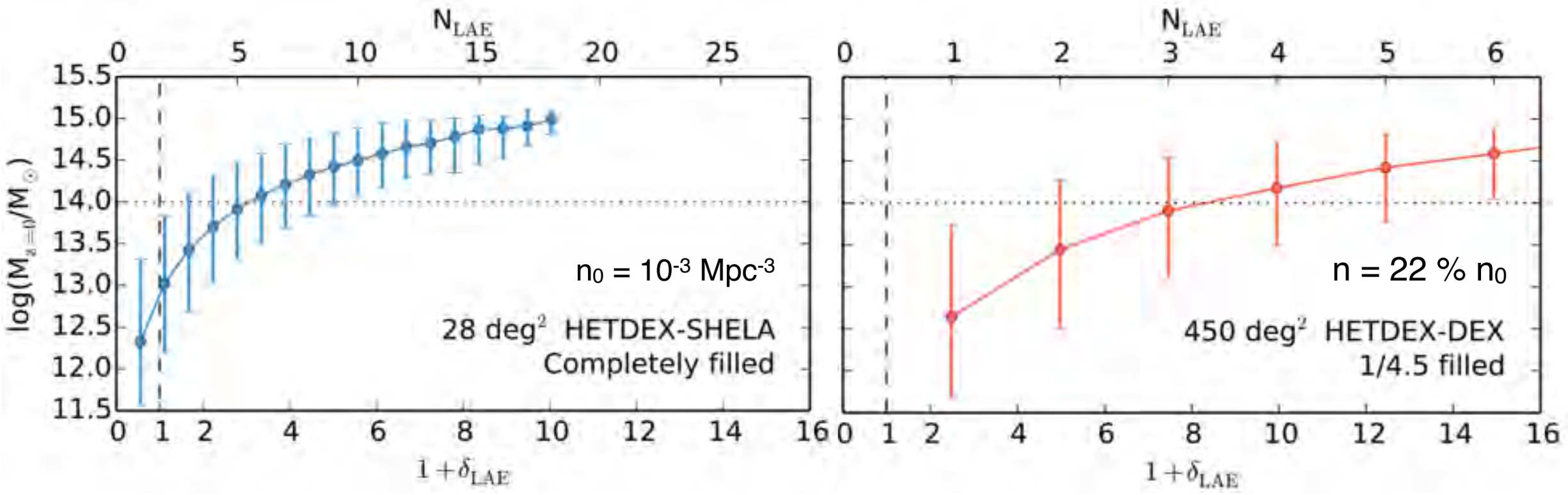
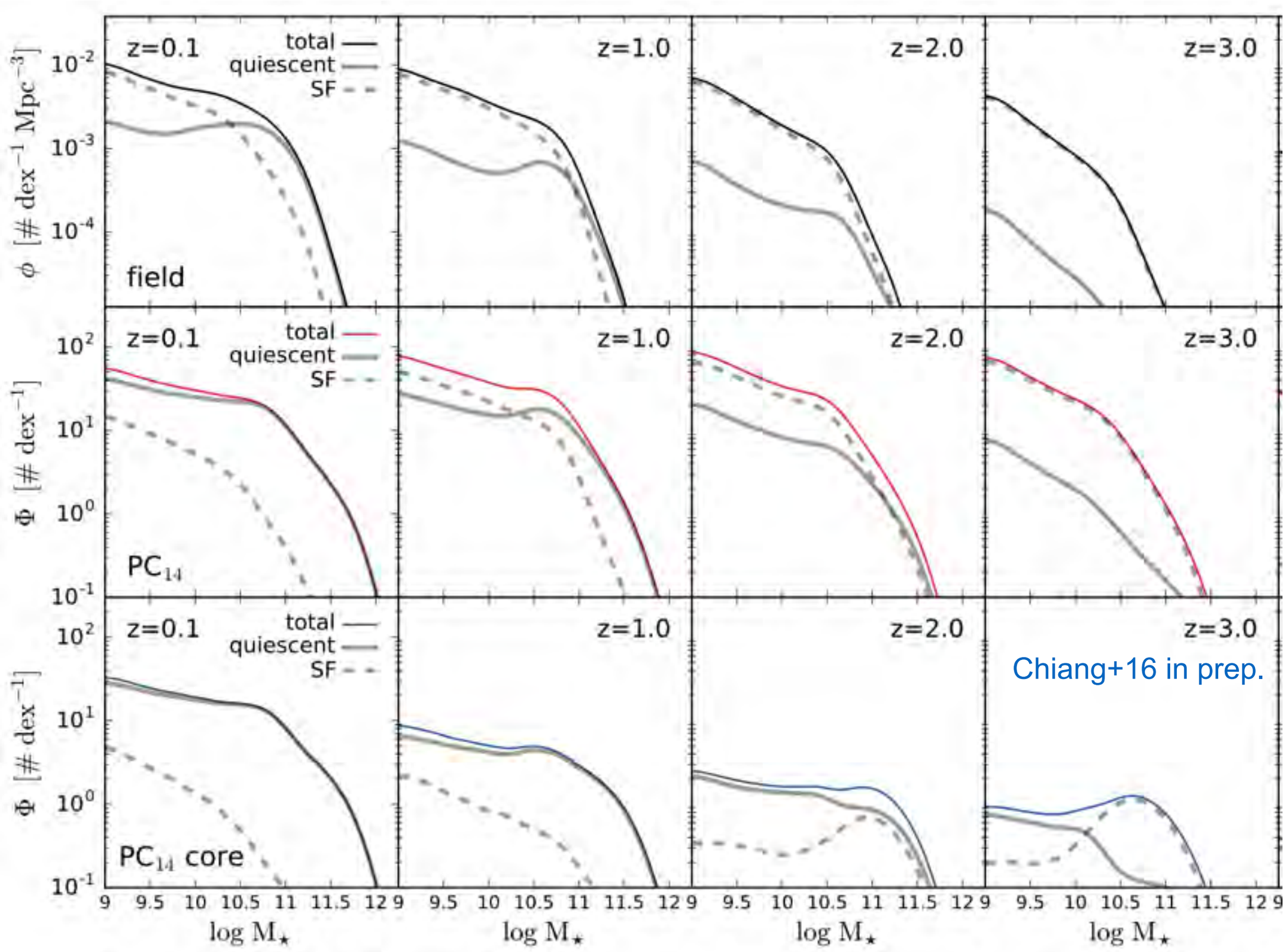
Chiang+15



shot noise induced Eddington bias in the posterior $M_{z=0}$ distributions

PC Cores / Group Catalog at z>1

Requirements from stellar mass function predictions in PC cores



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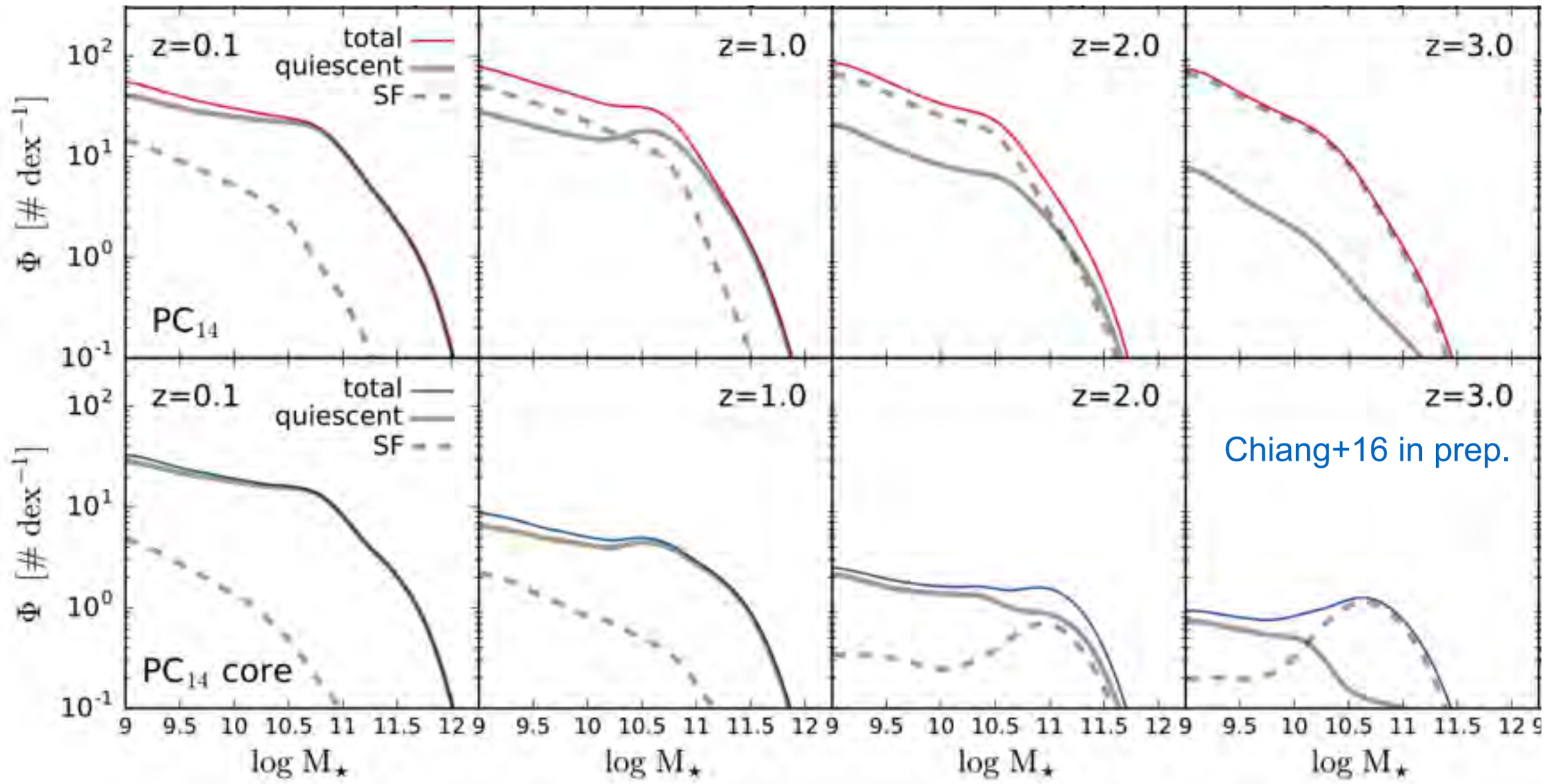


galaxies in PC cores (r_{vir} ~ fiber collision scale 0.5')

z	$\log(M_{core}/M_\odot)$	$N(>10^9 M_\odot)$	$N(>10^{10} M_\odot)$
1	13.5–14.5	15–75	6–30
2	13–14	5–25	3–15

Galaxy-IGM connection in the z=2.44 COSMOS PC

HETDEX Pilot Survey (HPS)

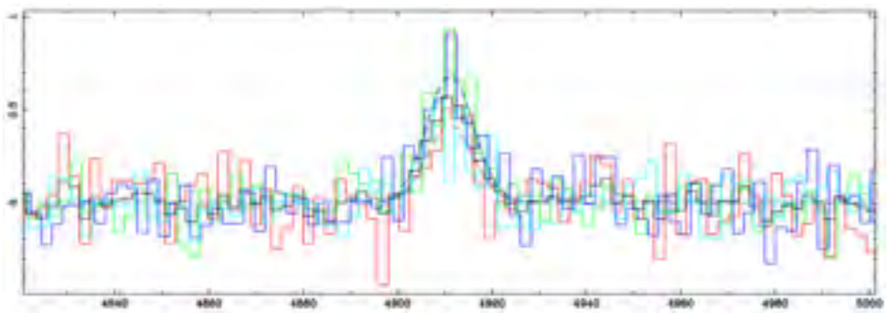
Adams+11
Blanc+11

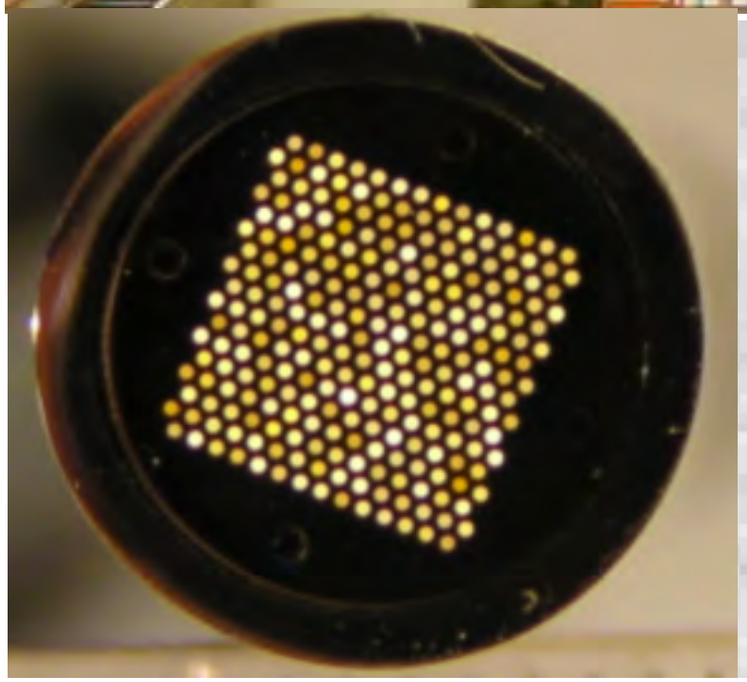
IFU Blind Spectroscopy
Homogeneous Selection Function in 3D

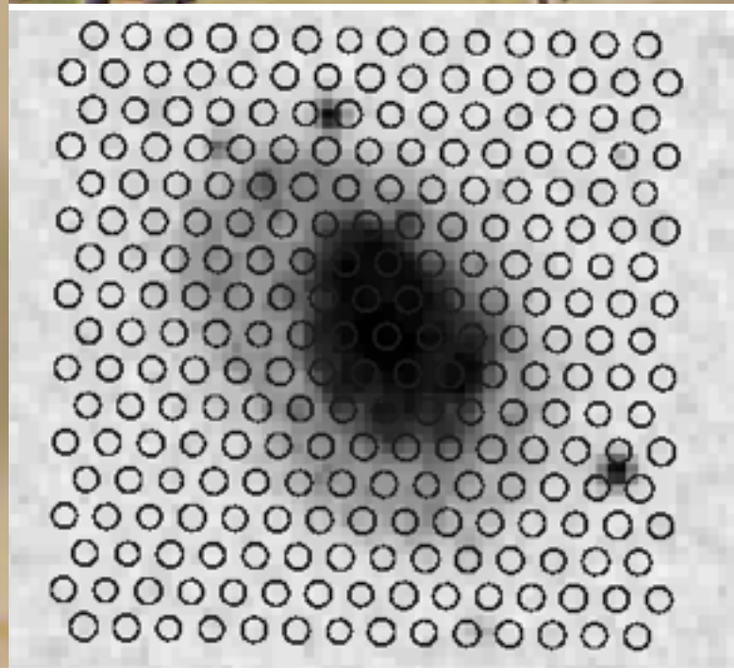
2.7m Harlan J. Smith Telescope

246 Fibers (4”)
1.7 x 1.7 arcmin^2 FoV

Lya emitters at 1.9 < z < 3.8

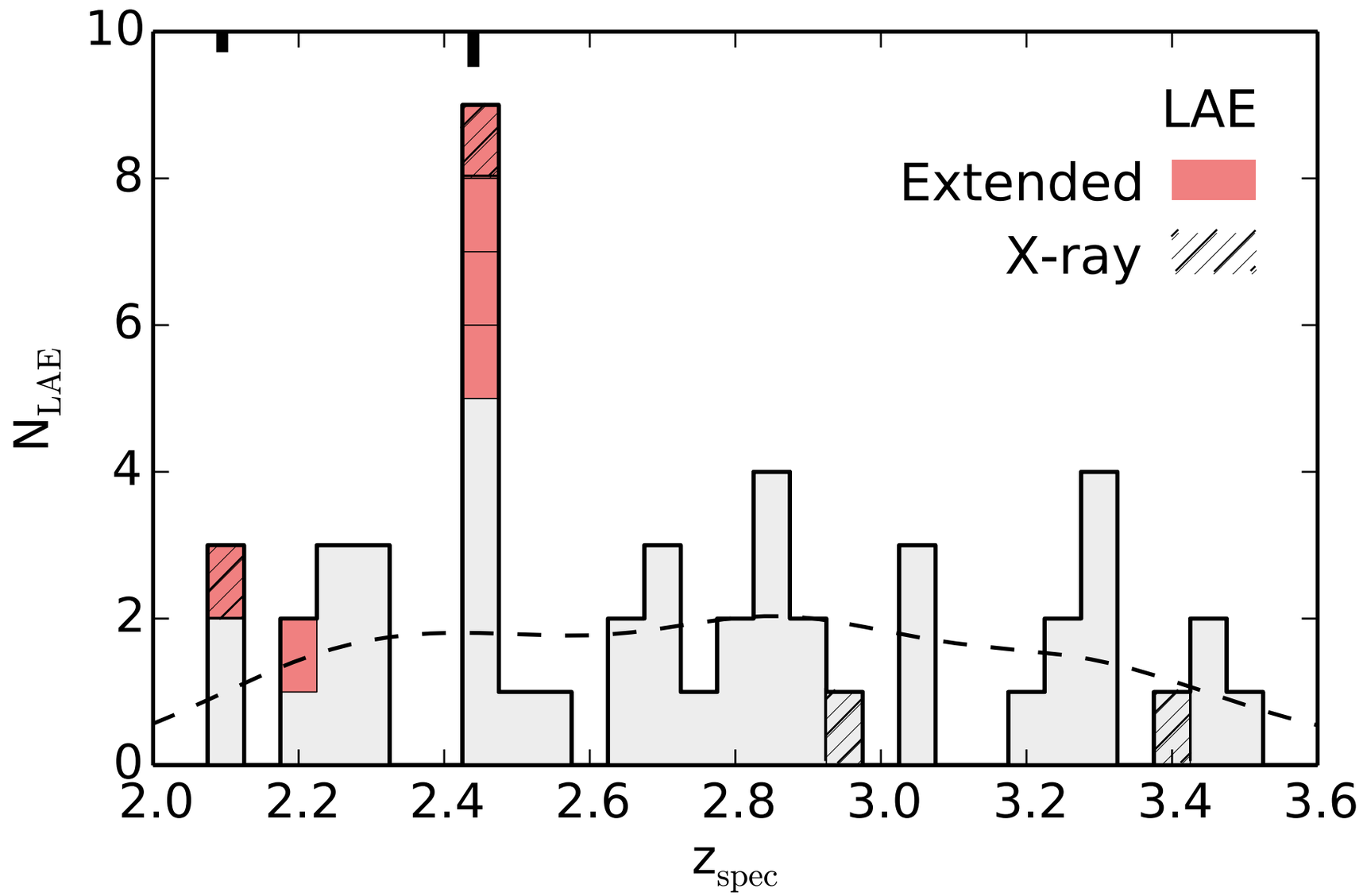






Extreme LAE Concentration at z=2.44 in 8’×10’ HPS-COSMOS

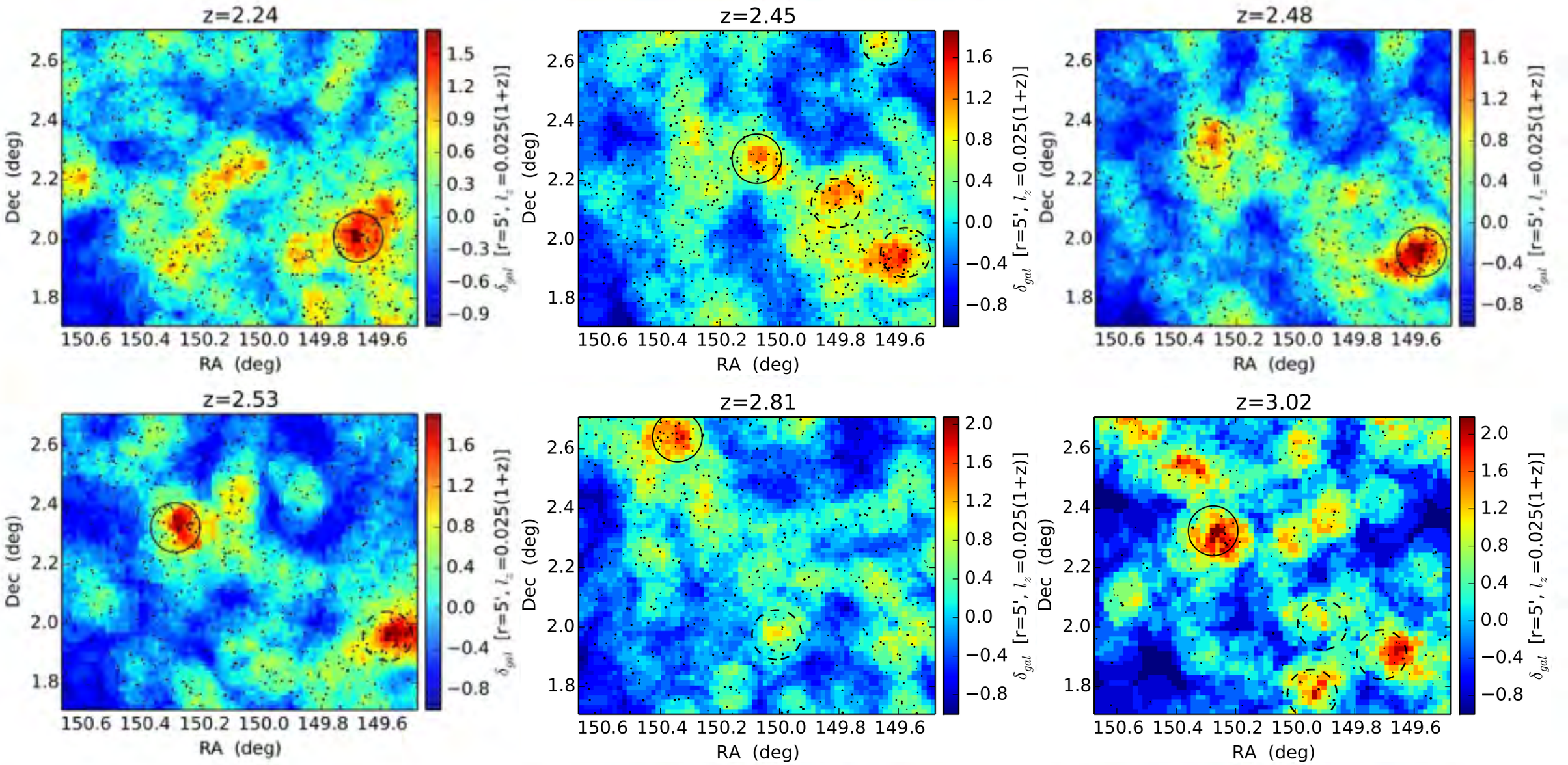
Chiang+15



LAB — LSS correlation is highly significant (p-value ~ 3×10^{-4})

The same z=2.44 structure was already picked out as on of the 36 proto-cluster candidates in COSMOS using photo-z

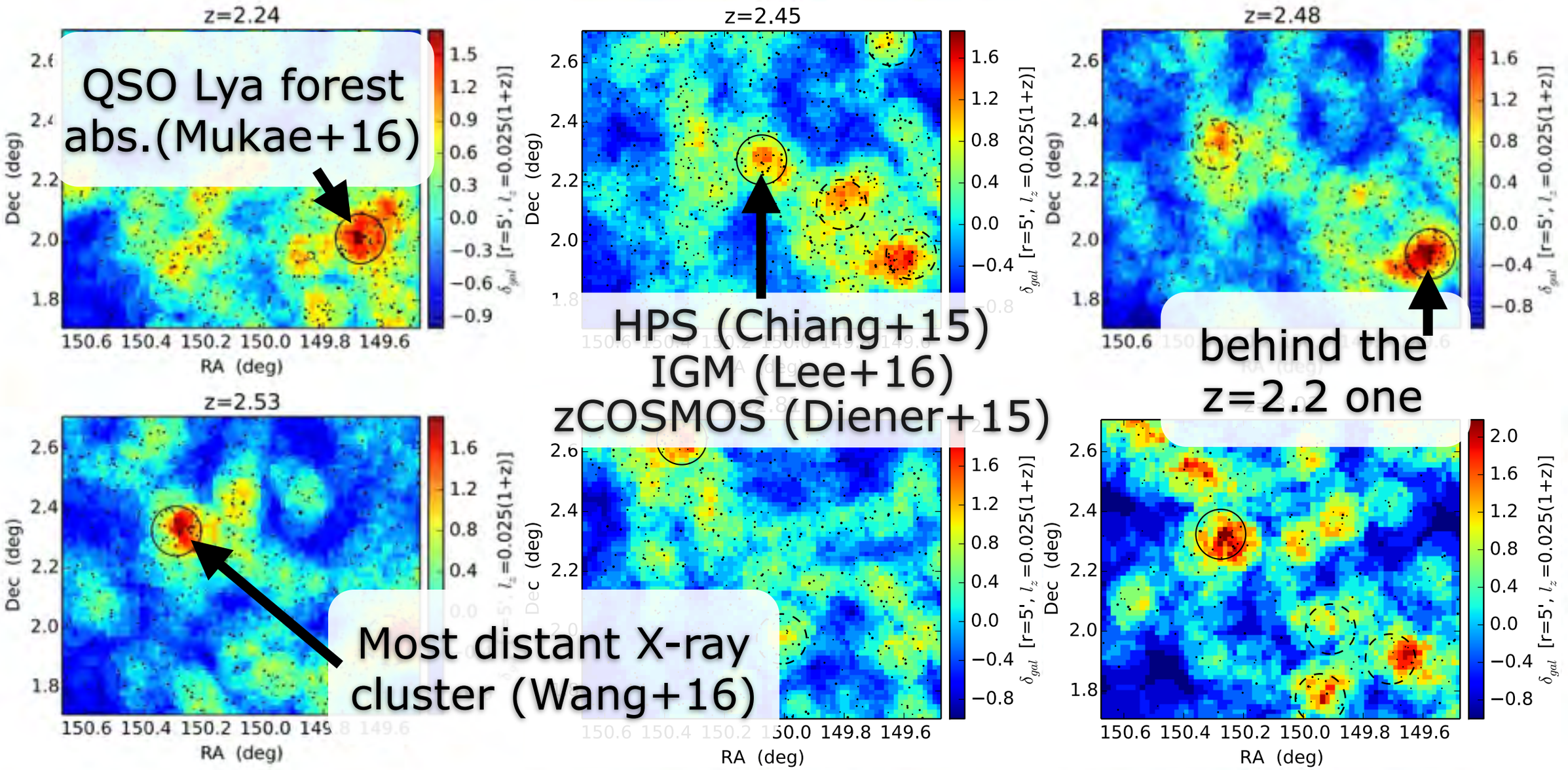
Chiang+14



COSMOS PC candidates selected using~15 cMpc scale photo-z galaxy overdensity

The same z=2.44 structure was already picked out as on of the 36 proto-cluster candidates in COSMOS using photo-z

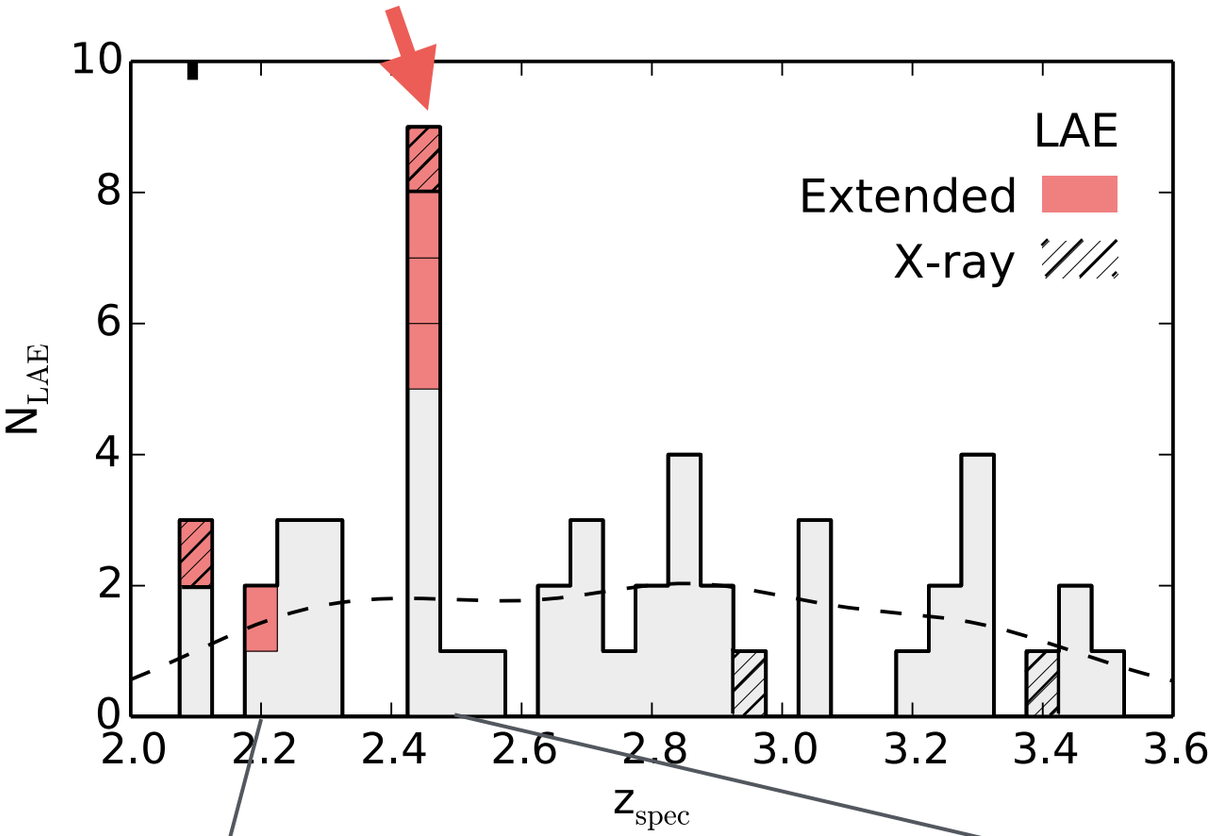
Chiang+14

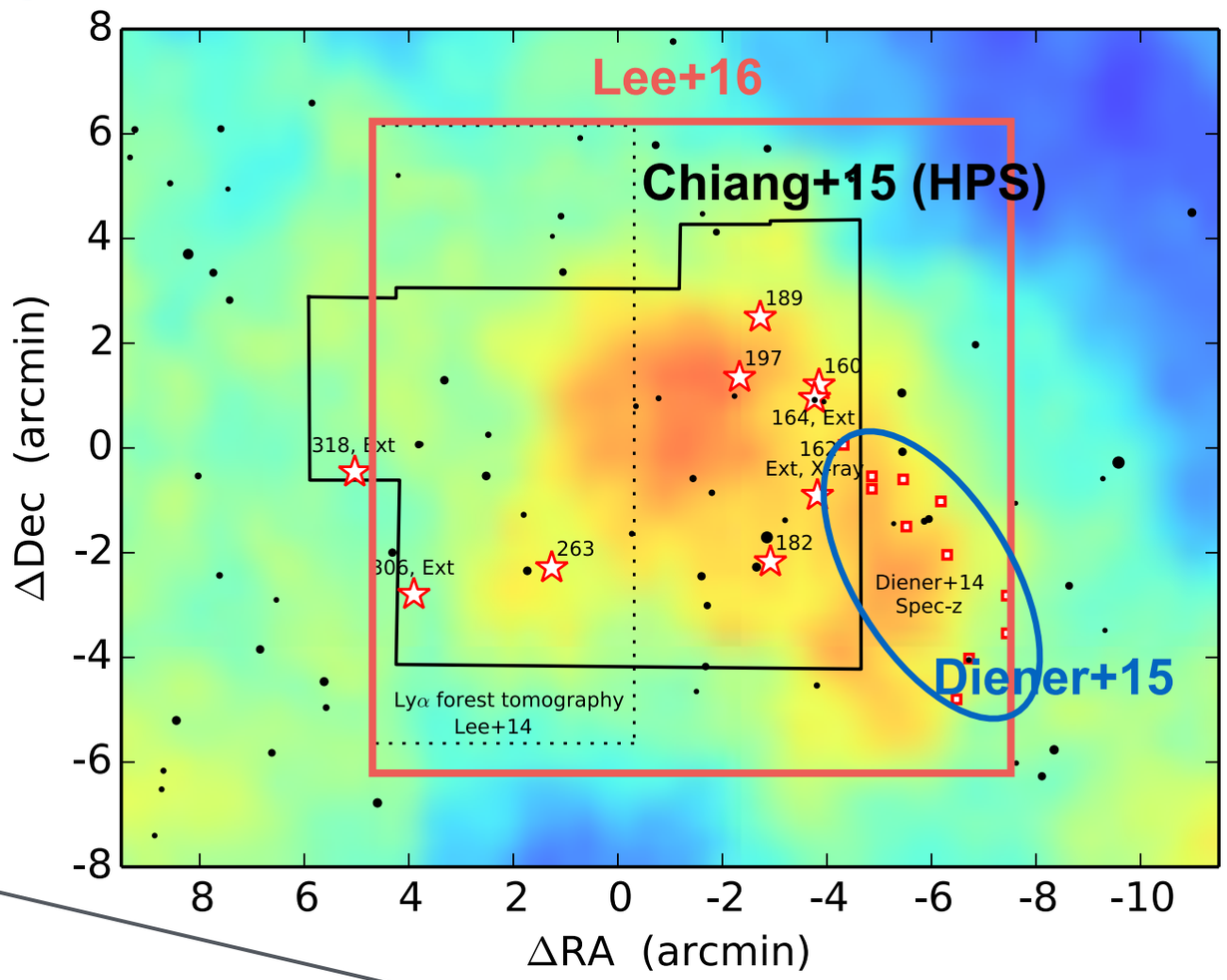


COSMOS PC candidates selected using~15 cMpc scale photo-z galaxy overdensity

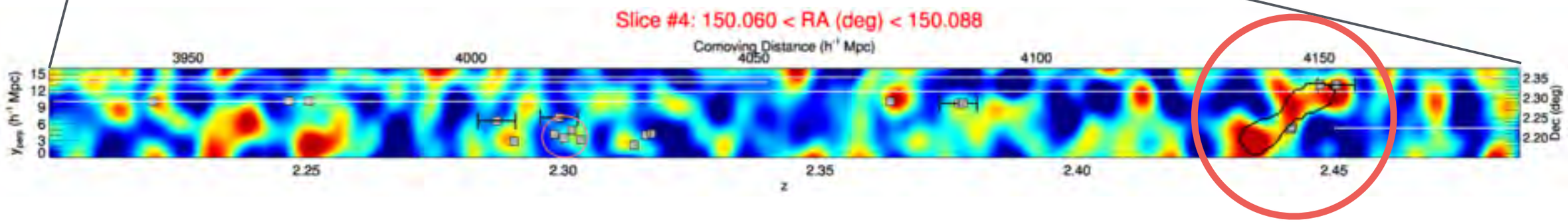
The structure is seen in overdensities of LAEs, Lya blobs, LBGs, and neutral gas in IGM tomography

LAEs in HPS-COSMOS Chiang+15





Lya forest tomography K.G. Lee+16

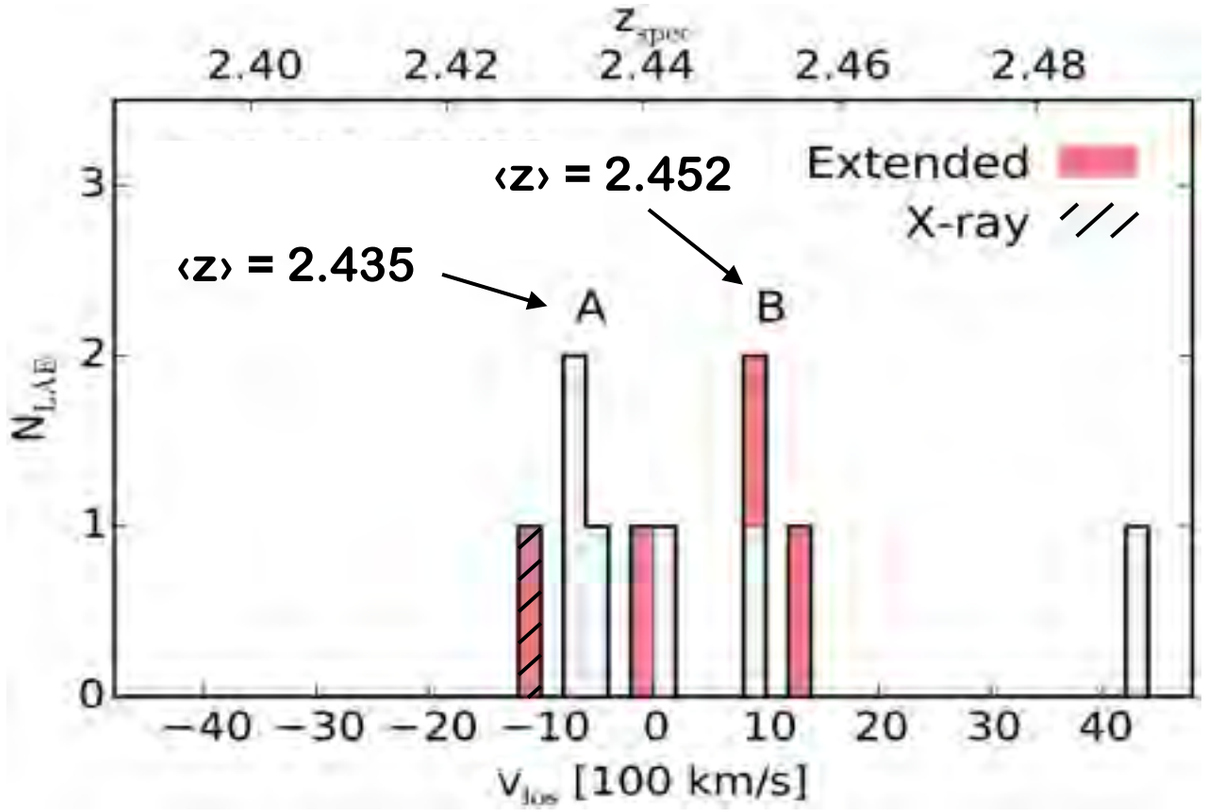


Remarkably consistent substructures and descendant cluster mass estimates using LAEs and IGM tomography

LAE, LAB

HETDEX Pilot
Chiang+15

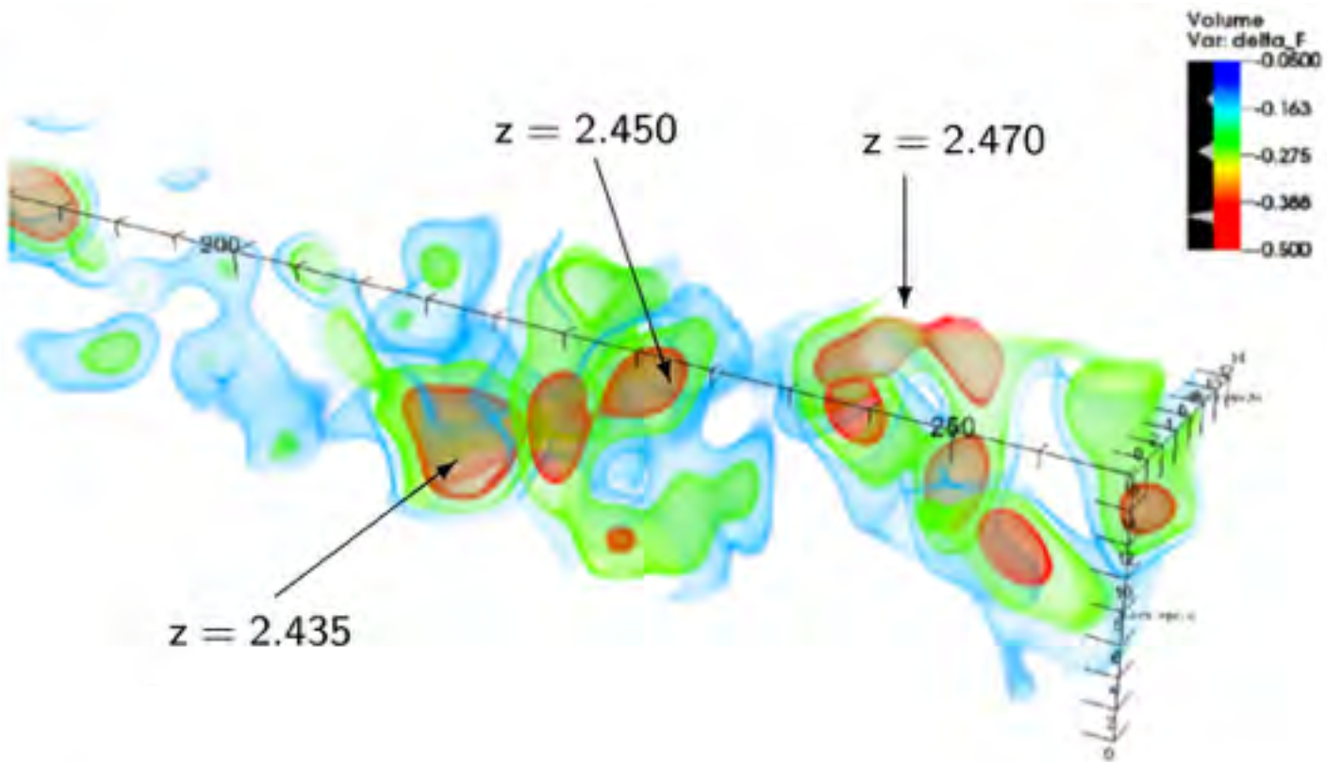
log $M_{z=0}$ = 14.5 $^{+0.4}_{-0.4}$



IGM

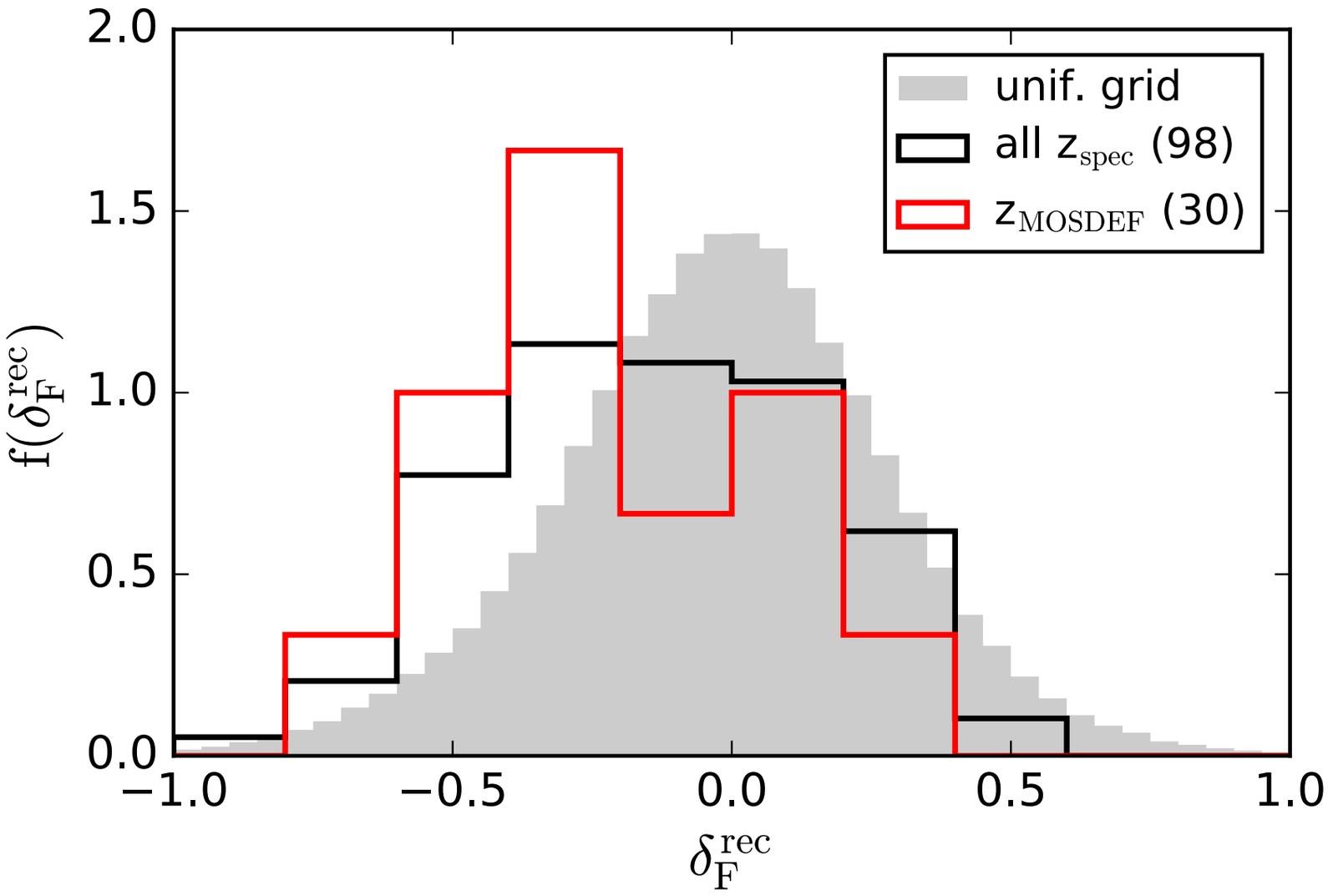
CLAMATO
Lee+16

log $M_{z=0}$ = 14.6 $^{+0.2}_{-0.3}$



Galaxies tend to be surrounded by overdensity of neutral IGM on ~3.5 cMpc scale

see Lee+15 for the original figure

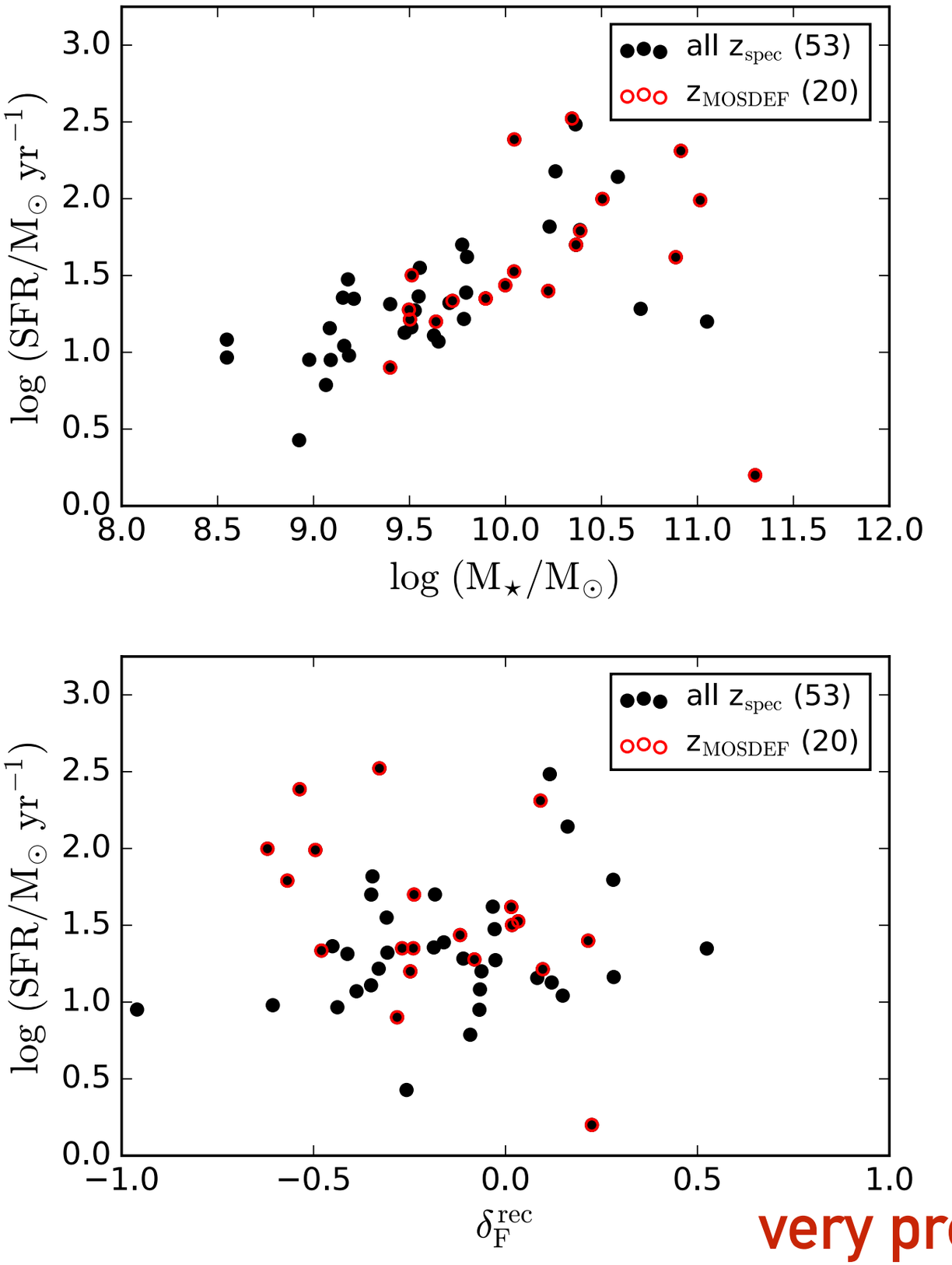


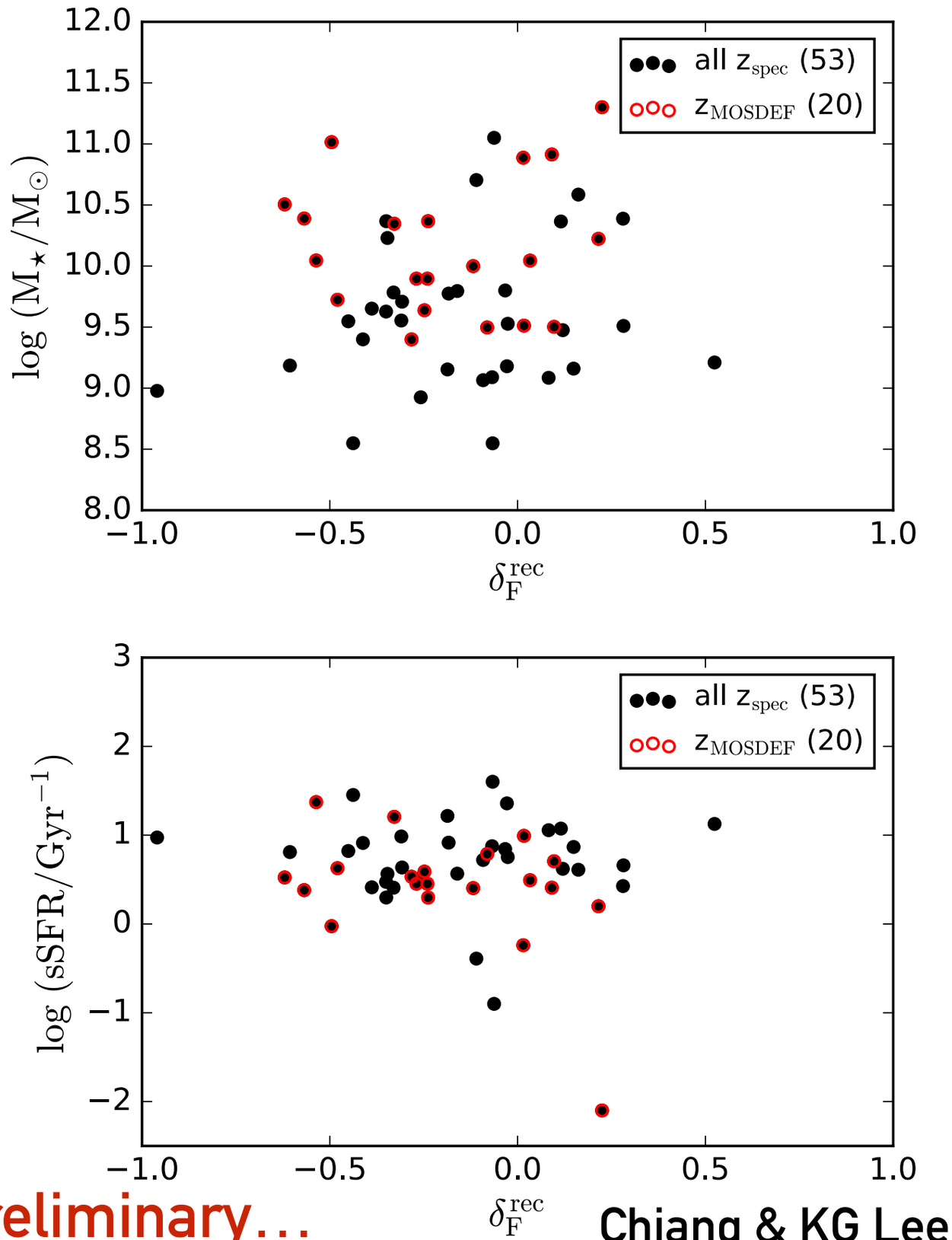
σ_v=300 km/s, σ_{los}=5 cMpc

σ_v=60 km/s, σ_{los}=1 cMpc

MOSDEF (Kriek+15) does not cover the z=2.44 density peak due to 3D HST selection ([OIII] shifts out of the HST WFC3 g141 grism at z>2.35)

Correlations between galaxy properties and 3.5 cMpc IGM transmission?





very preliminary…

Chiang & KG Lee

My Proposal for the PFS Survey

LSS Abundance Matching

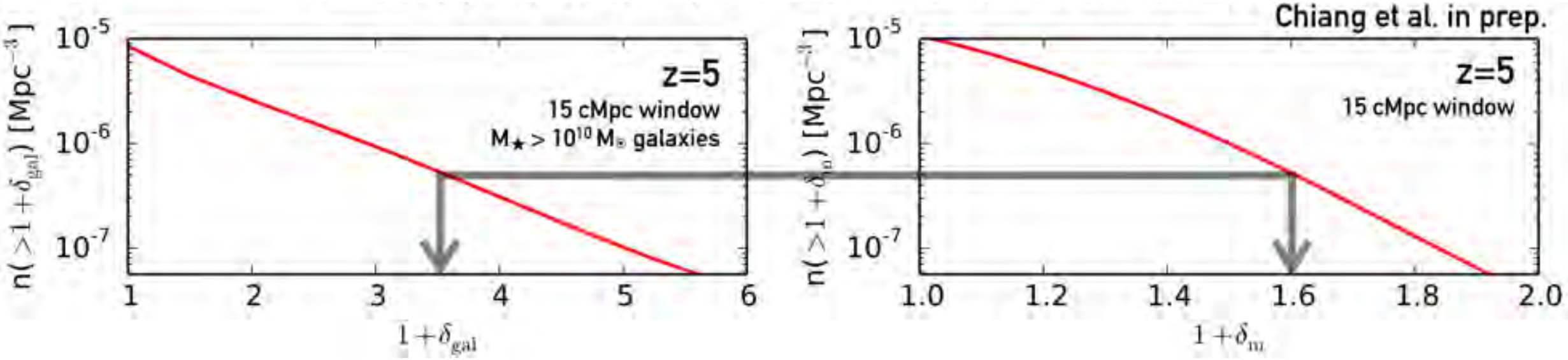
1. Overdense galaxy structures should live in overdense DM structures

2. Rank order should be preserved with time if one follows the Lagrangian volumes

3. Works if the survey probe a large enough volume to sample the high end of density peaks

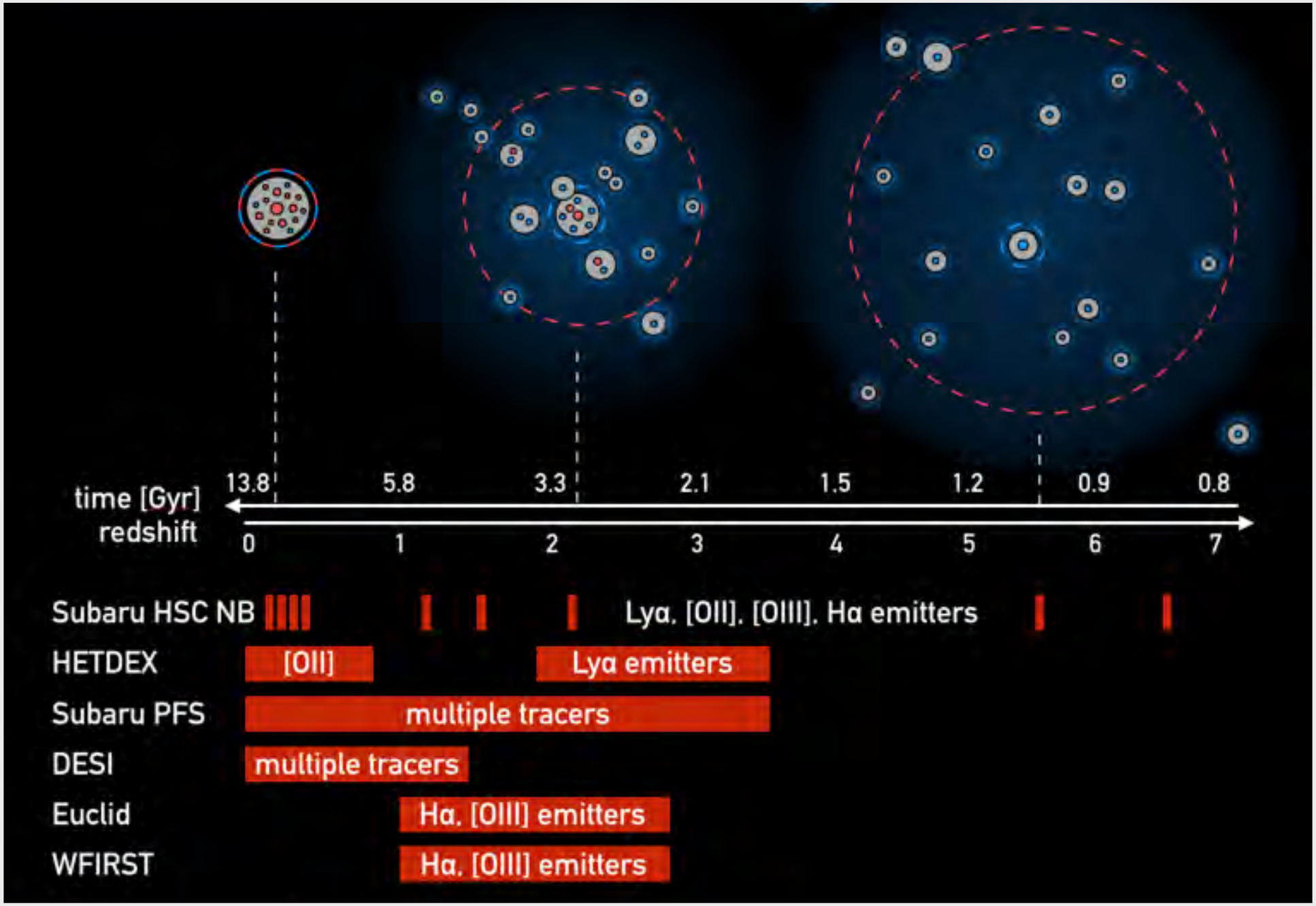
4. Works for any matter tracers, e.g., LBGs, LAEs, IGM, DLAs, MgII abs…

Galaxy overdensity **DM overdensity**



Key questions that LSS AM can help:

1. What is the cosmic evolution for baryons end up in clusters, i.e., *x(t)* and *ẋ(t)*?
   x = $M_\star$, SMF, LF, M_{BH}, *f*_passive, morphology, dynamics, BCG, ICM, ICL…
2. What is the physical mechanisms for these evolutions?
3. What processes are universal for galaxy formation but not cluster specific?



Summary

- Large-scale structural evolution of cluster assembly can be cleanly predicted by cosmological N-body simulations.

- Cluster progenitors across cosmic time can be found by LSS surveys of luminous matter in various phases (galaxy, IGM…), provided that their connections to DM is well modeled or empirically constrained.

- More to be done in understanding IGM—Galaxy connections beyond spatial correlation

- LSS abundance matching for PFS and other complimentary surveys

Thanks