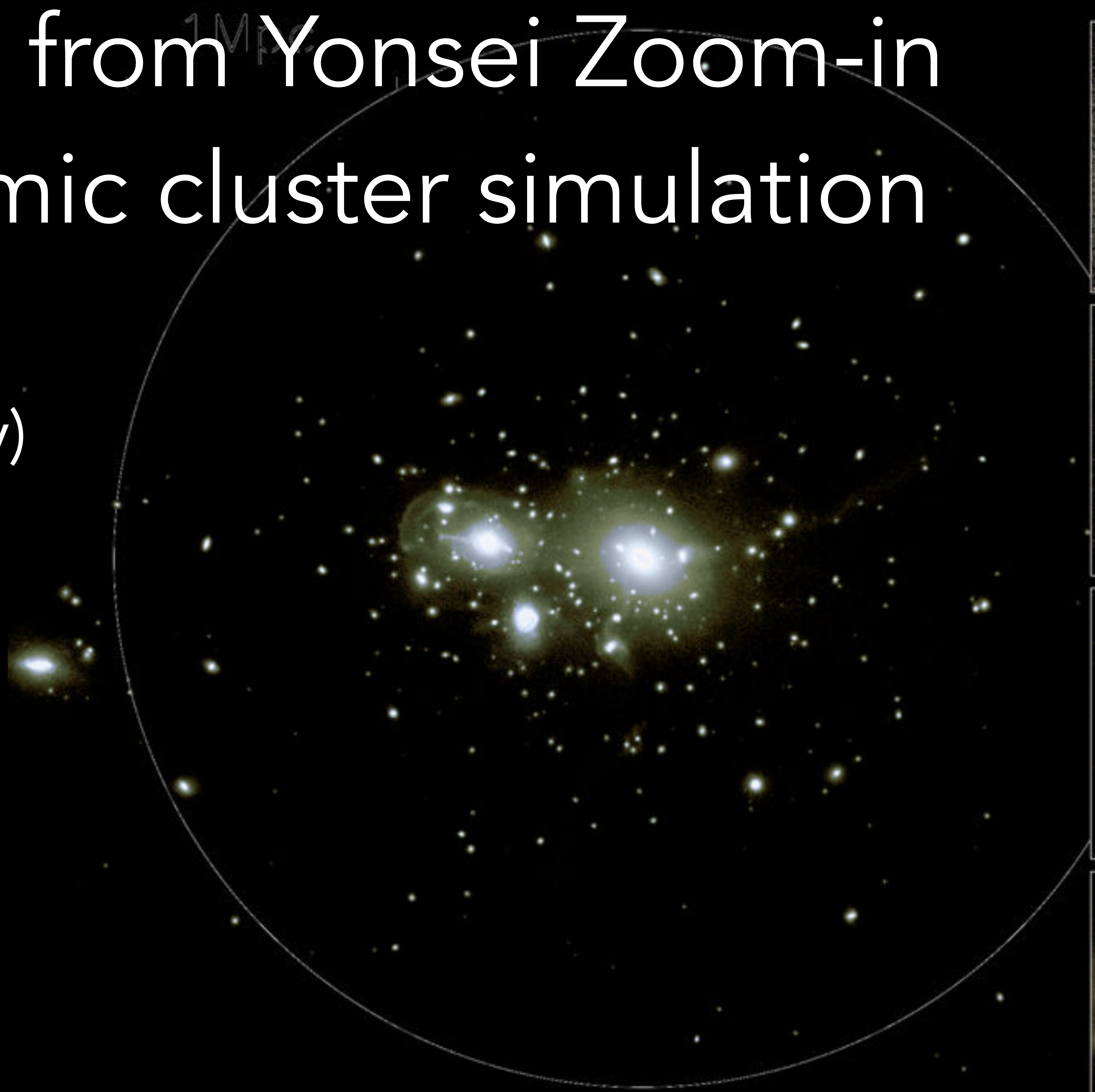
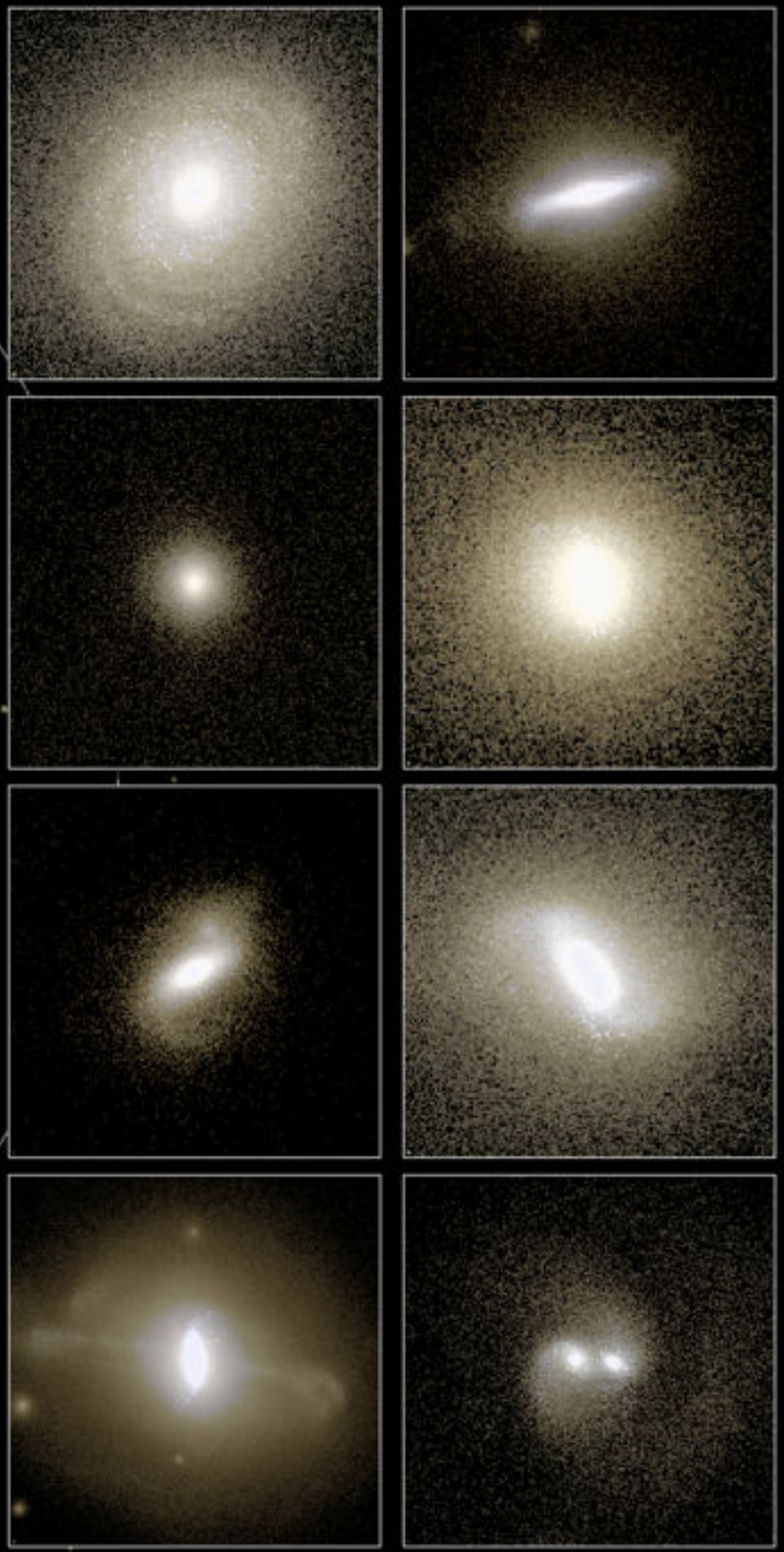
First results from Yonsei Zoom-in hydrodynamic cluster simulation

Sukyoung K. Yi
(Yonsei University)



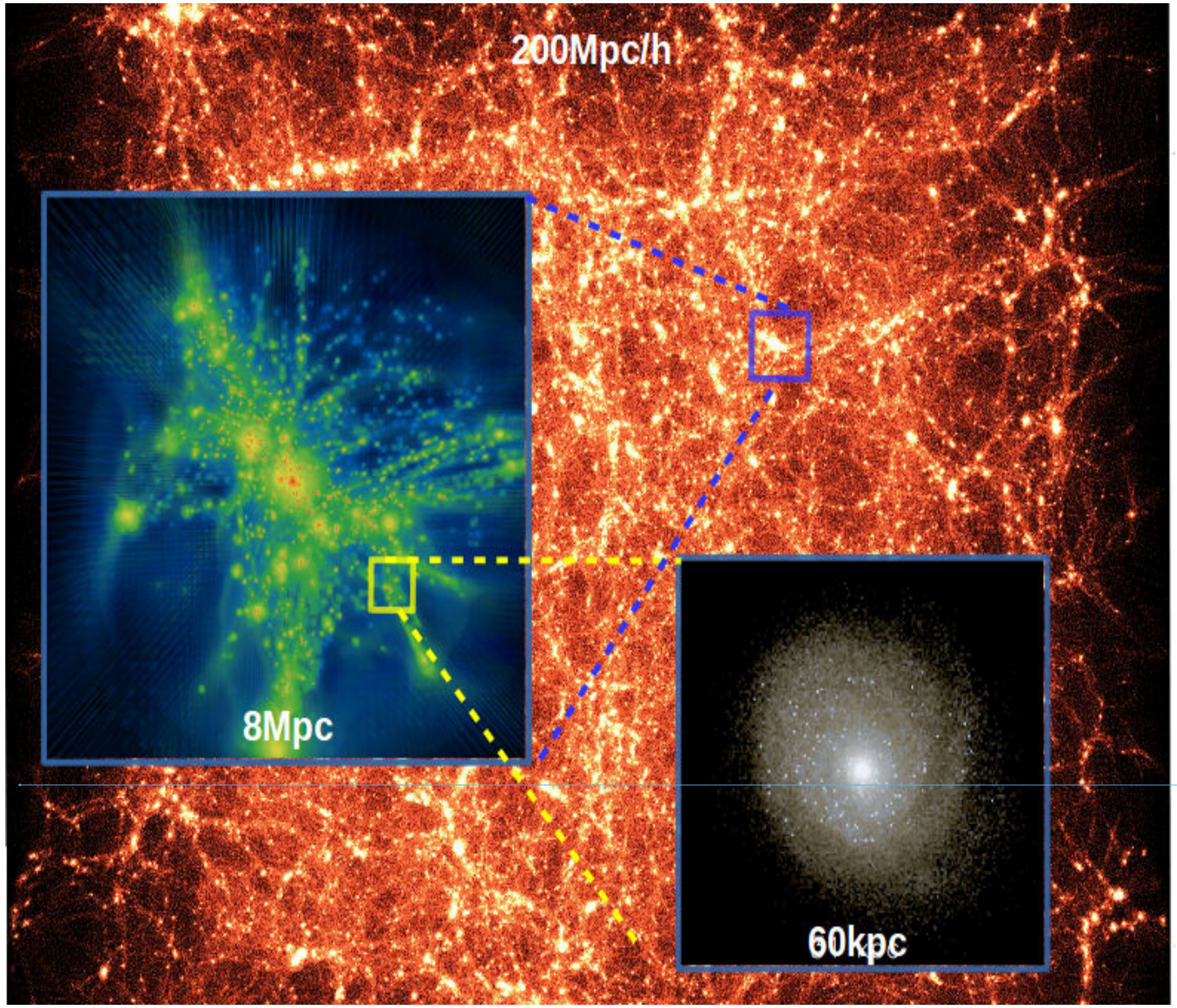


Mock image of a cluster
Image credit: Hoseung Choi

Yonsei Zoom-in Cluster Simulation (YZiCS)

- PI: Sukyoung Yi
- RAMSES (AMR, Teyssier 2002)
- DM+hydro: baryon prescription of Horizon-AGN
- cosmological: 16 clusters in 200Mpc/h
- cluster mass: log $M_{200}/M_{\odot}$ ~ 13.5 - 15.0
- DM particle resolution: dm=8e7
- stellar mass resolution: dm*=5e6
- spatial resolution: dx~kpc

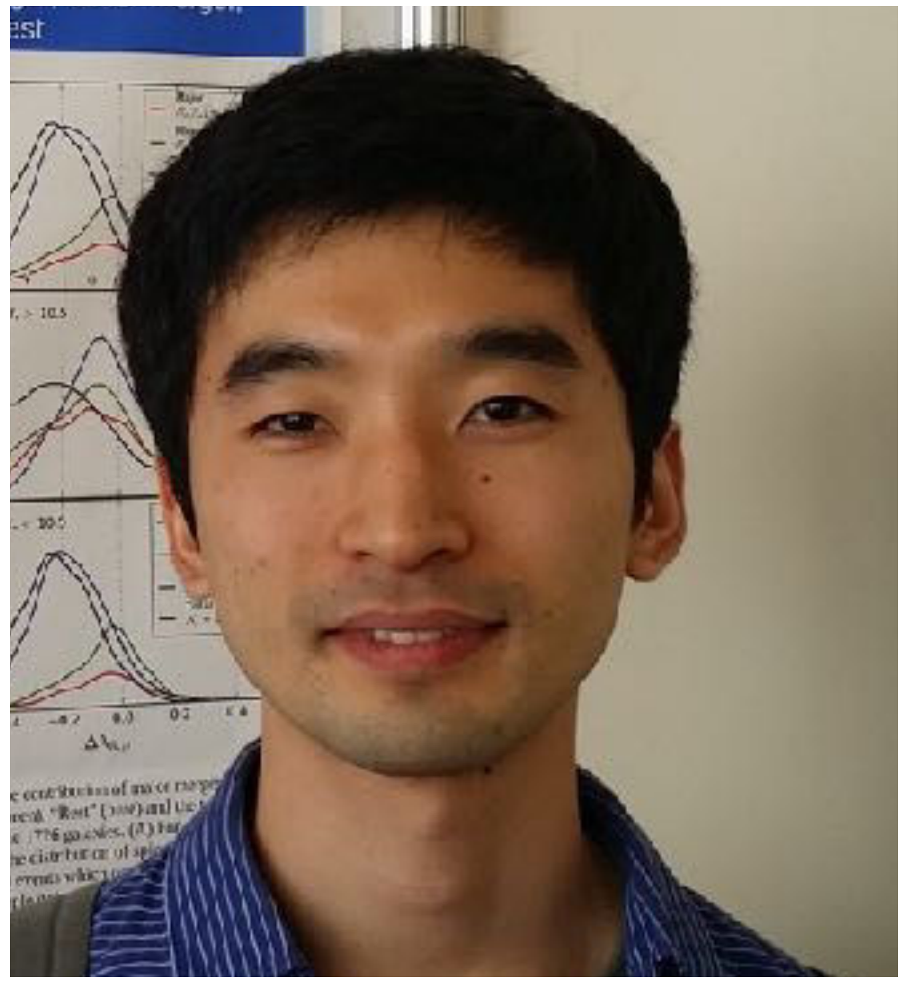
Choi & Yi 2017, ApJ, 837, 68



200Mpc/h

1. SPIN of galaxies

The Astrophysical Journal, 837:68 (6pp), 2017 March 1
https://doi.org/10.3847/1538-43



On the Evolution of Galaxy Spin in a Cosmological Hydrodynamic Simulation of Galaxy Clusters

Hoseung Choi and Sukyoung K. Yi
Department of Astronomy and Yonsei University Observatory, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea; choi.h@yonsei.ac.kr, yi@yonsei.ac.kr
Received 2016 September 28; revised 2017 January 31; accepted 2017 February 1; published 2017 March 3

Abstract

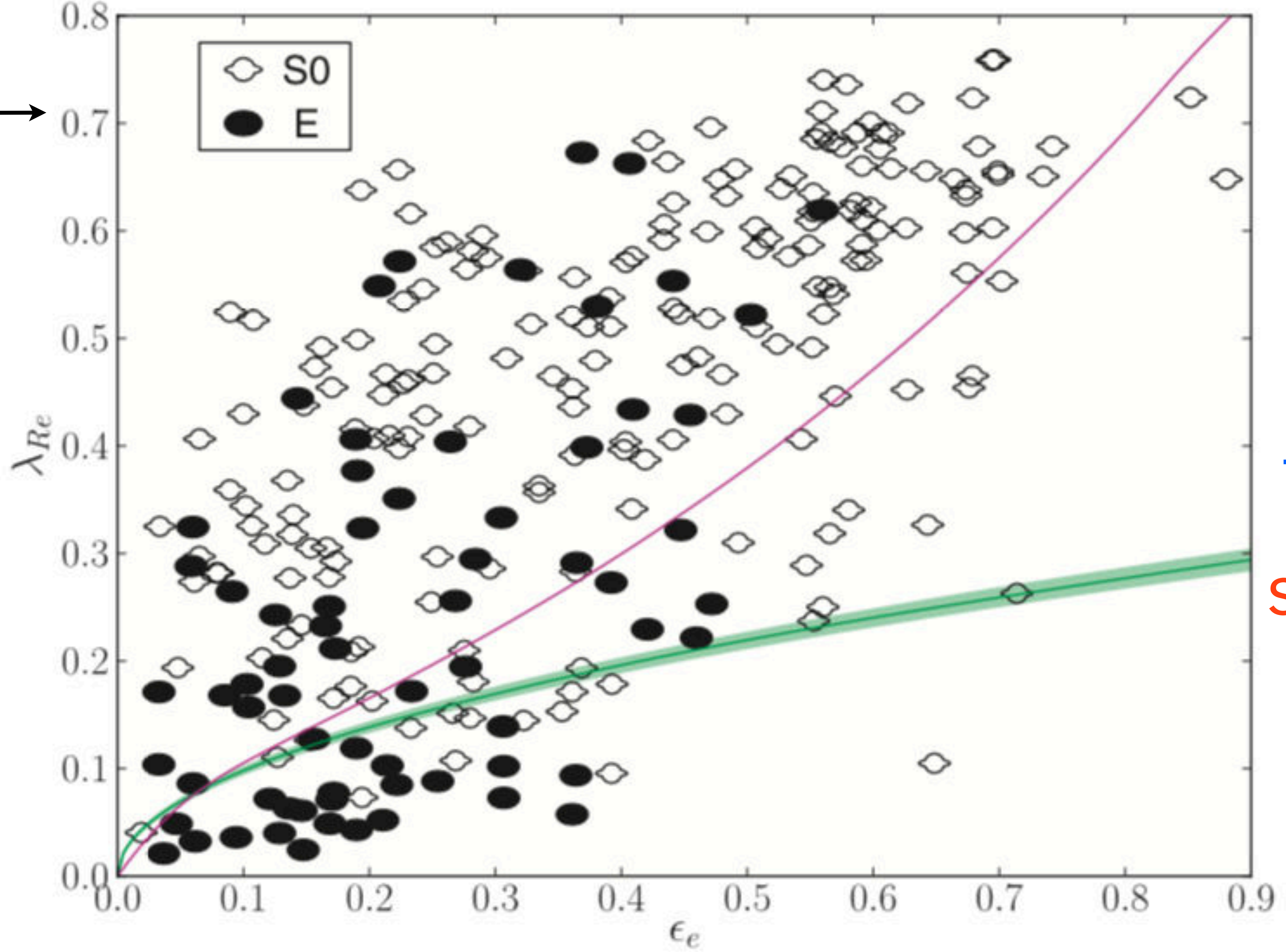
The traditional view of the morphology–spin connection is being challenged by recent integral field unit observations, as the majority of early-type galaxies are found to have a rotational component that is often as large as a dispersion component. Mergers are often suspected to be critical in galaxy spin evolution, yet the details of their roles are still unclear. We present the first results on the spin evolution of galaxies in cluster environments through a cosmological hydrodynamic simulation. Galaxies spin down globally with cosmic evolution. Major (mass ratios $> 1/4$) and minor ($1/4 \geqslant$ mass ratios $> 1/50$) mergers are important contributors to the spin-down in particular in massive galaxies. Minor mergers appear to have stronger cumulative effects than major mergers. Surprisingly, the dominant driver of galaxy spin-down seems to be environmental effects rather than mergers. However, since multiple processes act in combination, it is difficult to separate their individual roles. We briefly discuss the caveats and future studies that are called for.

Spin-ellipticity from IFU

$\sigma \approx v_{\rm rot}$ →

$$\lambda_R \equiv \frac{\langle R\,|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle}$$

luminosity-weighted specific angular momentum



fast rotator

slow rotator

~10-15%

Emsellem+ 2011 Atlas3D

See also SAMI (van de Sande+ 2017)

Theories

- Tidal torque theory (Peebles 1969)
- Disc **mergers** result in spheroids and spin down (Toomre & Toomre 1972, etc.)
- SAM reproduces f_slow through **mergers** (Khochfar et al. 2011)
- 1:1 **merger** simulations reproduces $\lambda - \epsilon$ (Jesseit et al. 2009; Bois et al. 2010 & 2011)
- Multi-**merger** simulations reproduce slow rotators (Moody+ 2014)
- Cosmological simulations
  - reproduces slow rotating BCGs (Naab+ 2014)
  - EAGLE reproduces galaxy angular momentum (Lagos+ 2017)
  - YZiCS reproduces $\lambda - \epsilon$(Choi & Yi 2017)
  - Illustris reproduces $\lambda - \epsilon$(Penoyre+ 2017)

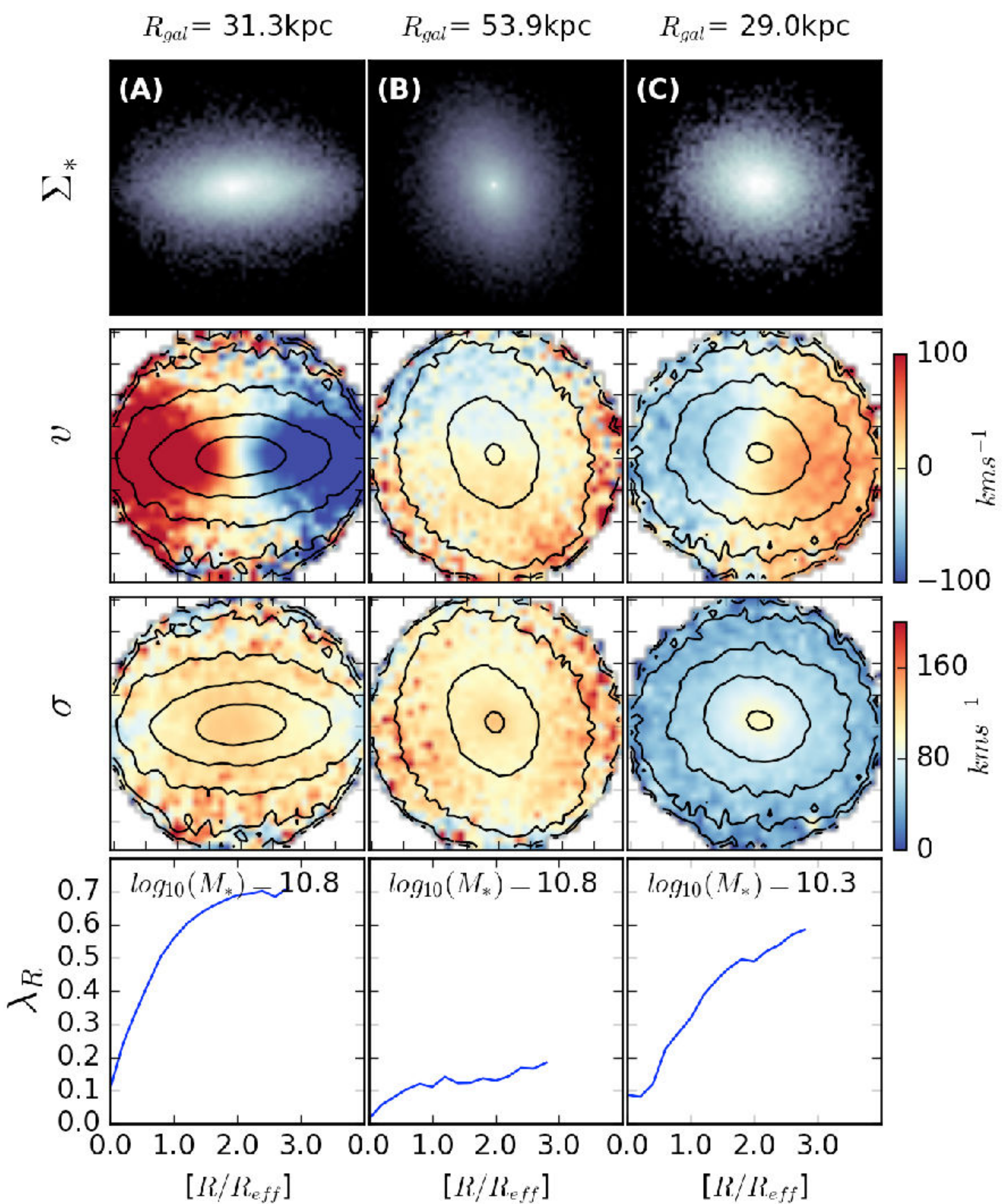
Some **model** ellipticals do rotate fast

stellar density

rotation

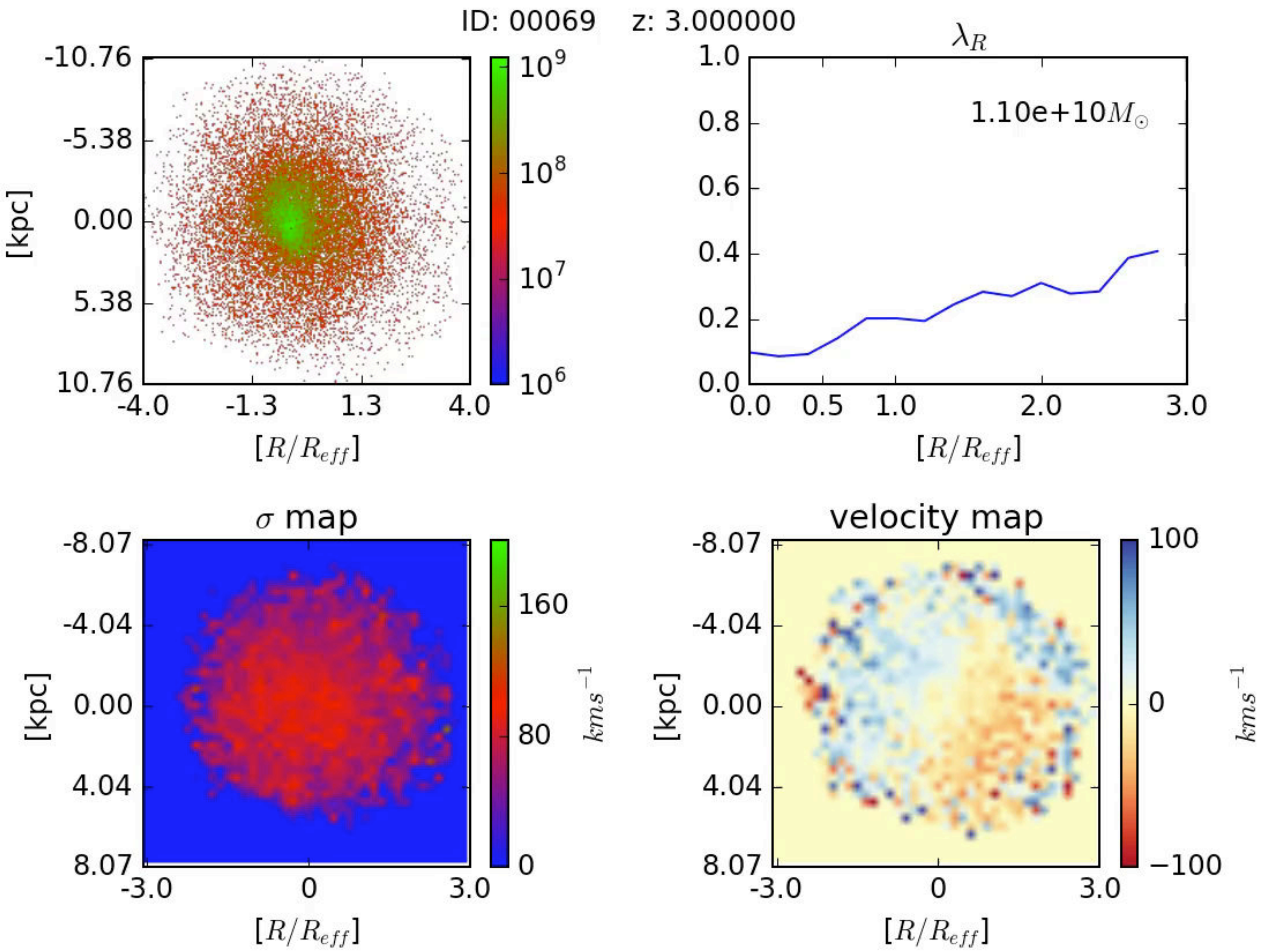
dispersion

rotation profile



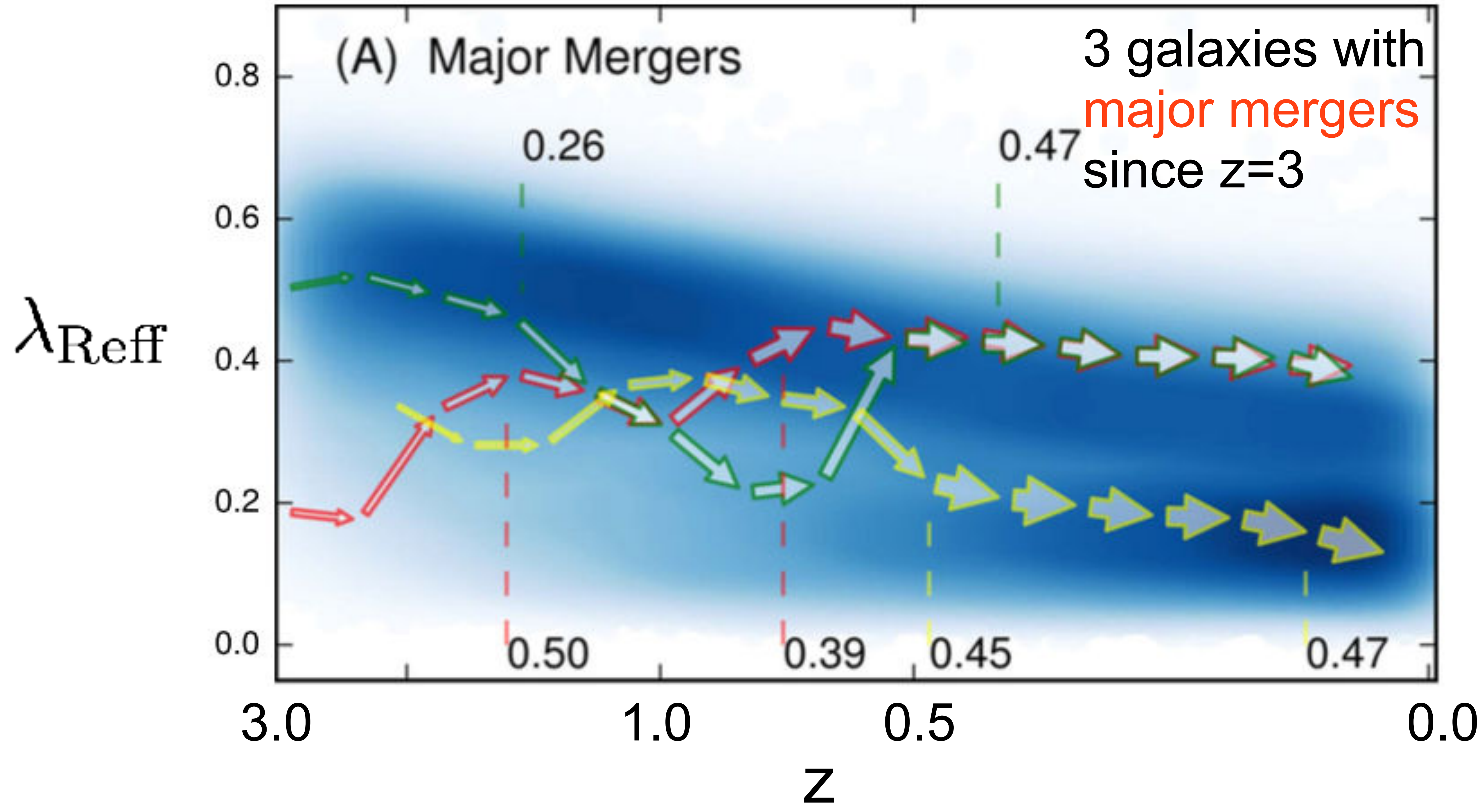
Choi & Yi 2017, ApJ, 837, 68

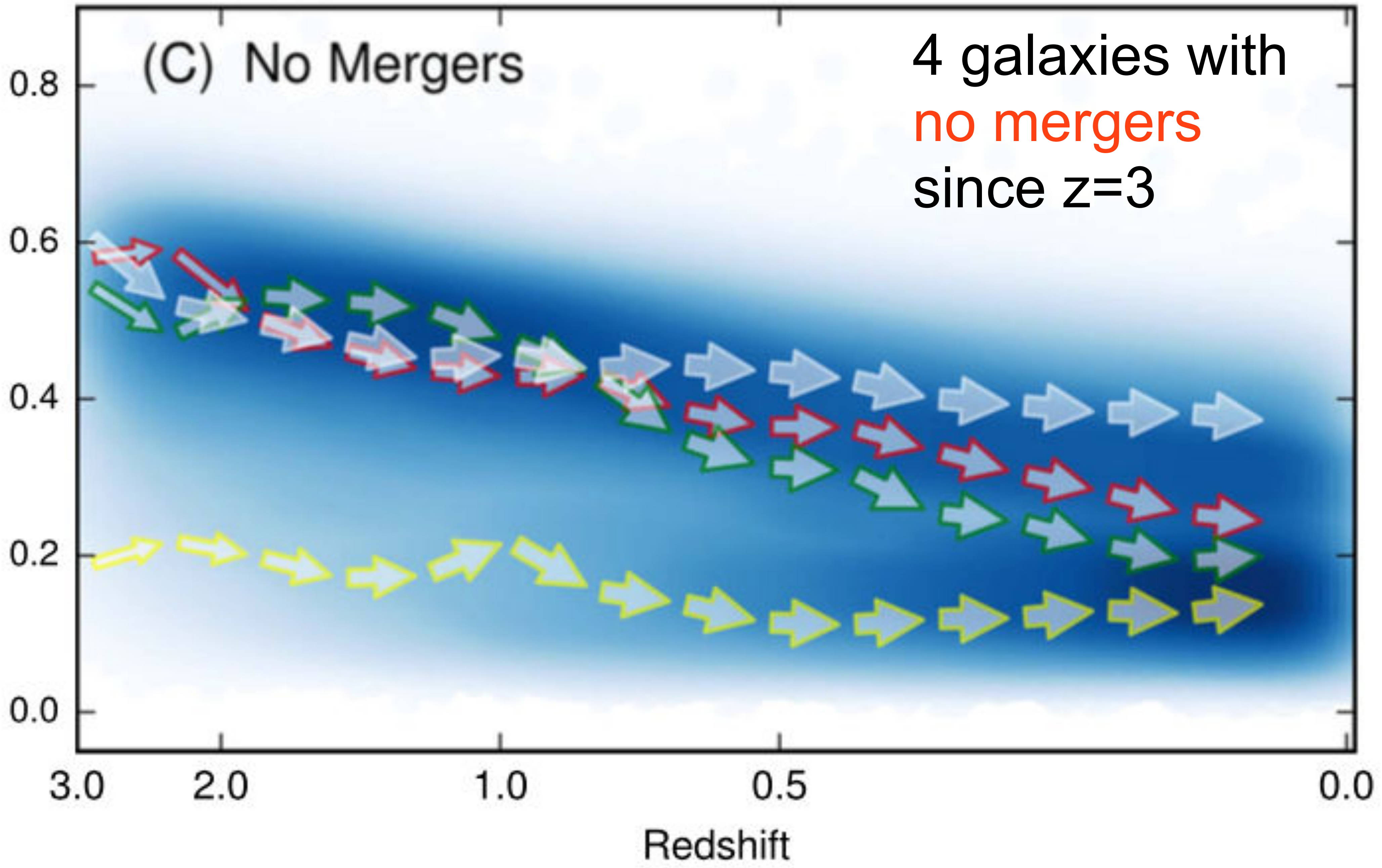
Interaction important



Origin of spin change

Blue shade: total of 1726 galaxies in 16 clusters

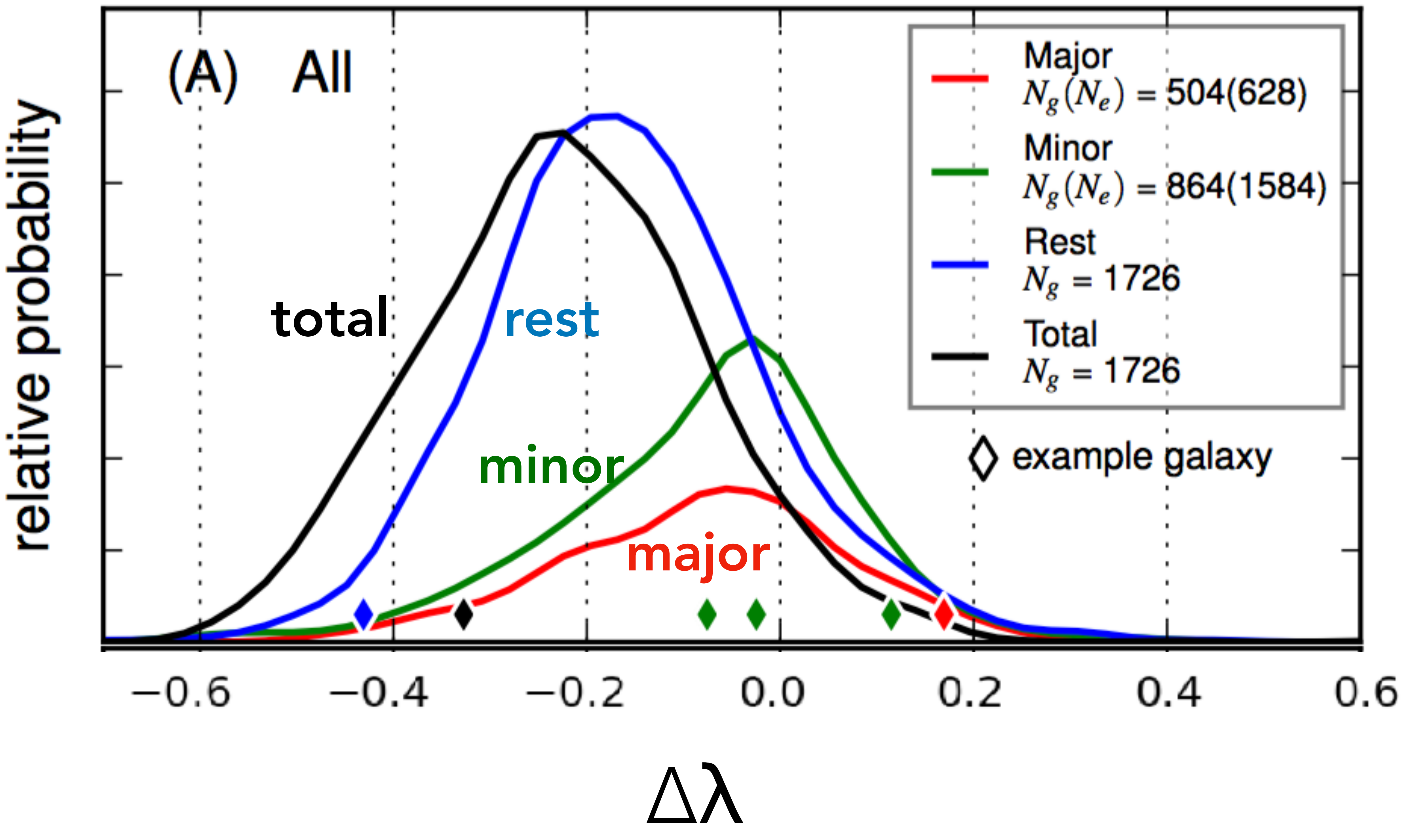


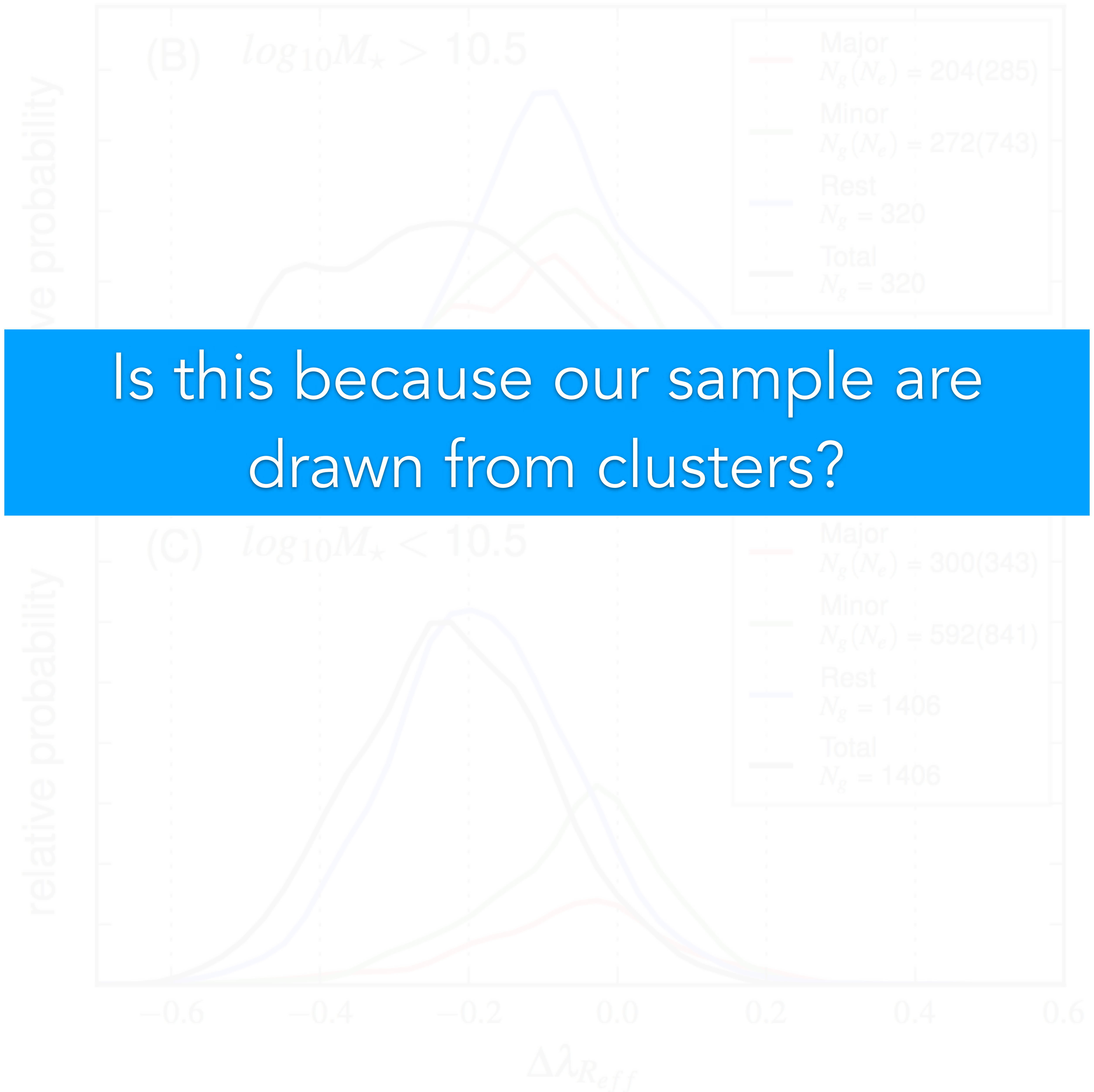


Major merger: 1/4 < m2/m1 < 1.0

minor merger: 1/50 < m2/m1 < 1/4

Origin of spin change





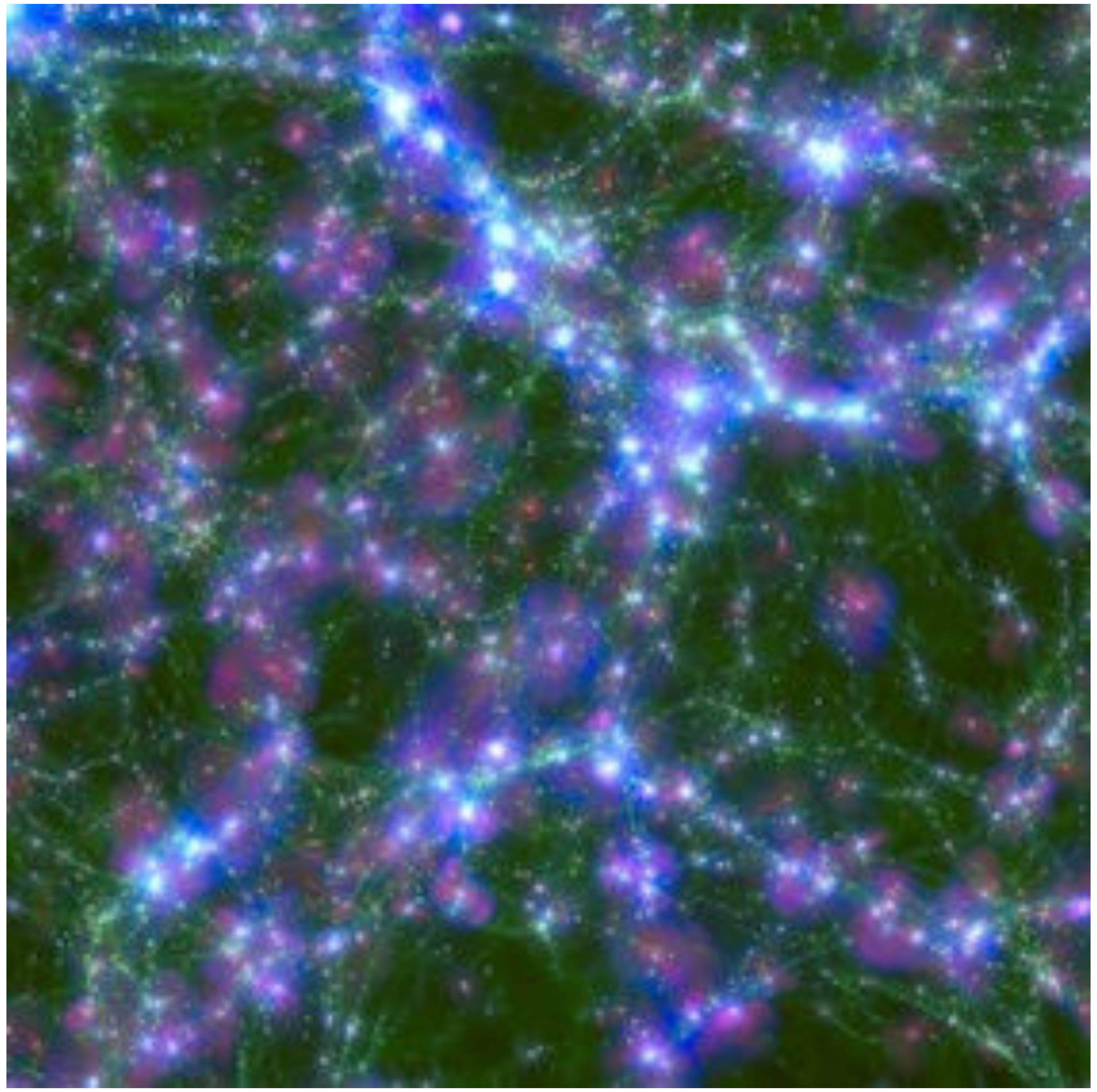
Is this because our sample are drawn from clusters?

Major merger: 1/4 < m2/m1 < 1/1
minor merger: 1/50 < m2/m1 < 1/4

To cover all environments

Horizon-AGN

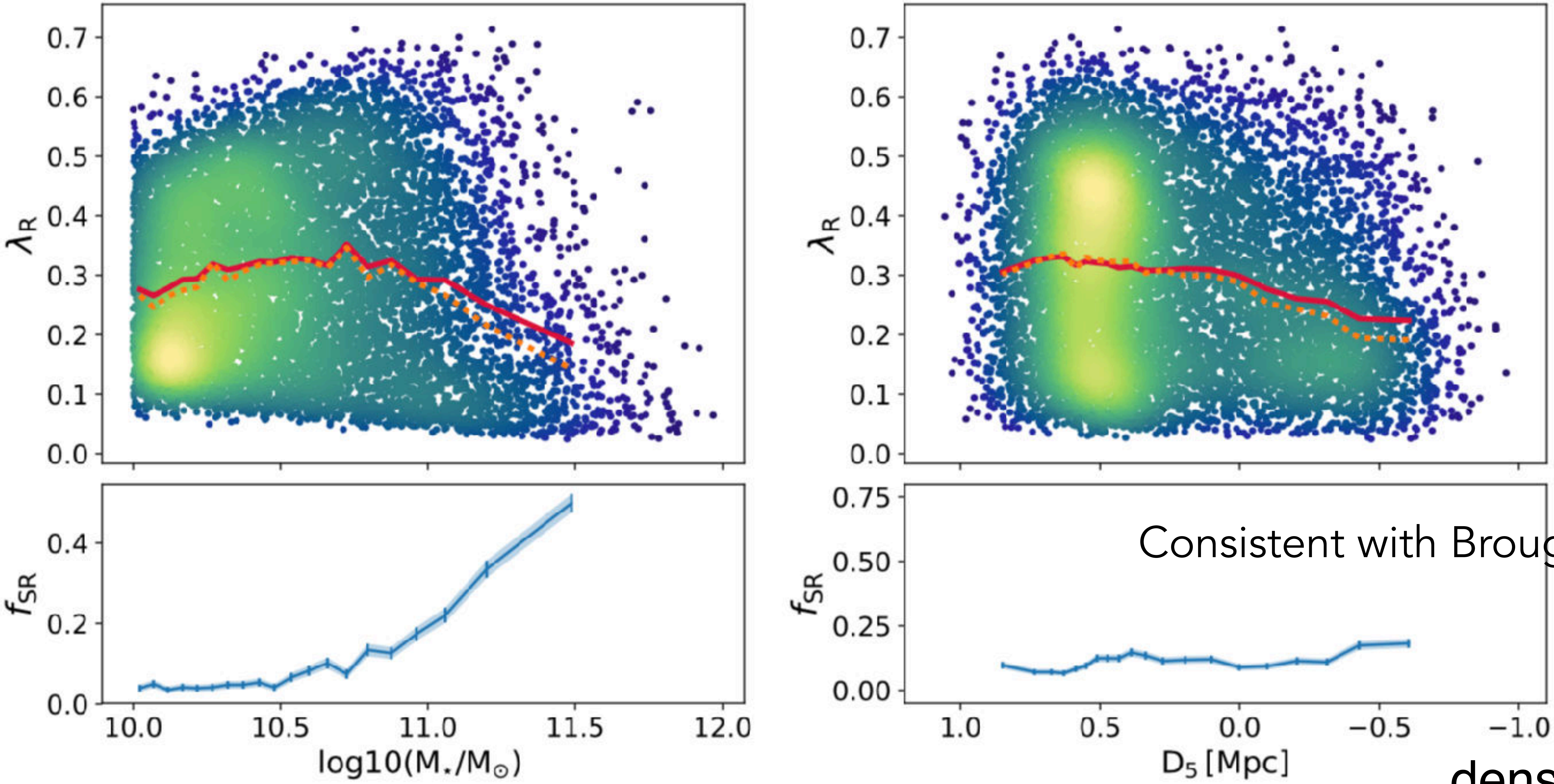
- RAMSES AMR
- 100 h^{-1} Mpc
- 1024^3
- dm=$8x10^7$ $M_\odot$
- dx~1kpc
- 6.7M hrs, 4096cores



(Dubois + 14)

Mass and density

Slow rotator fraction



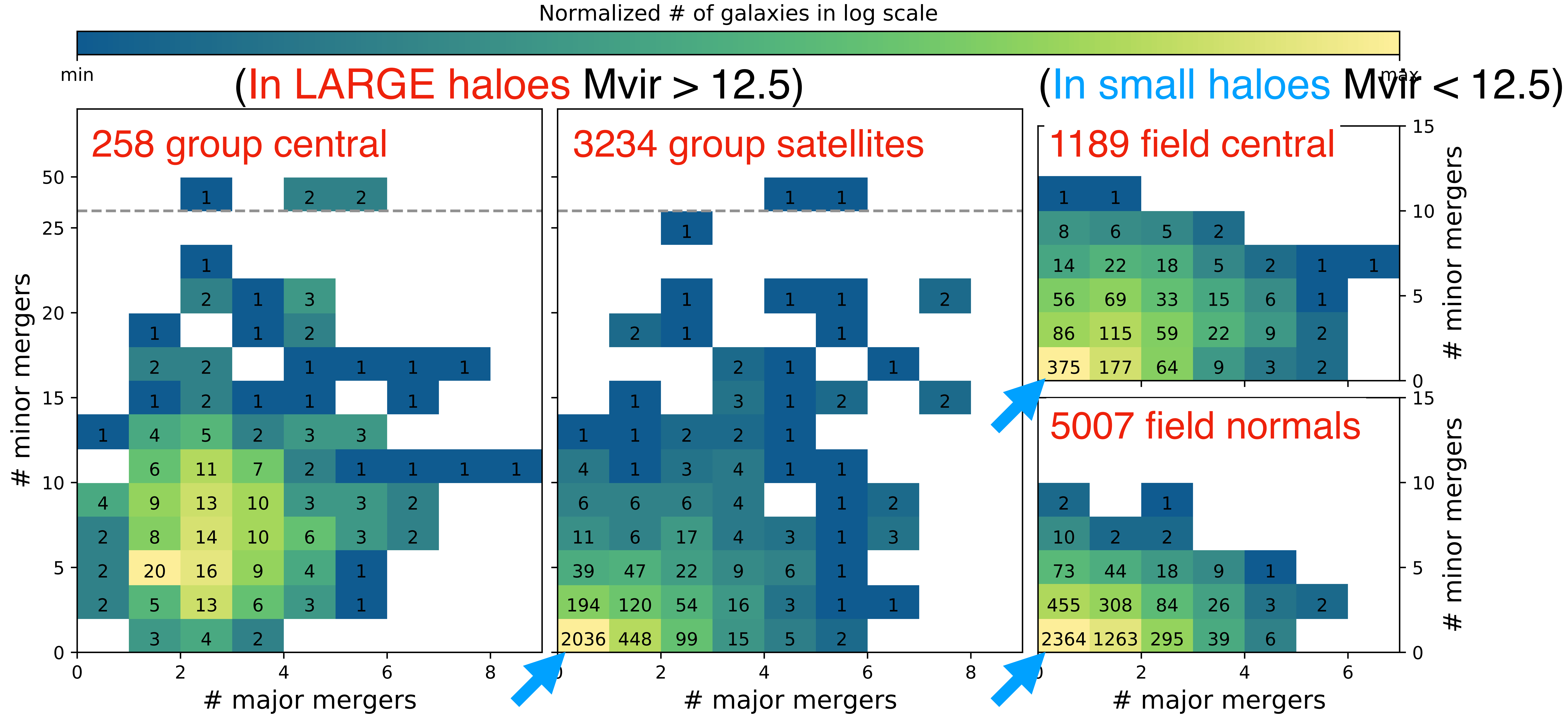
Consistent with Brough et al. 2017

denser

Choi, Yi, Dubois, Kimm 2017, ApJ, submitted

Horizon-AGN early type galaxies

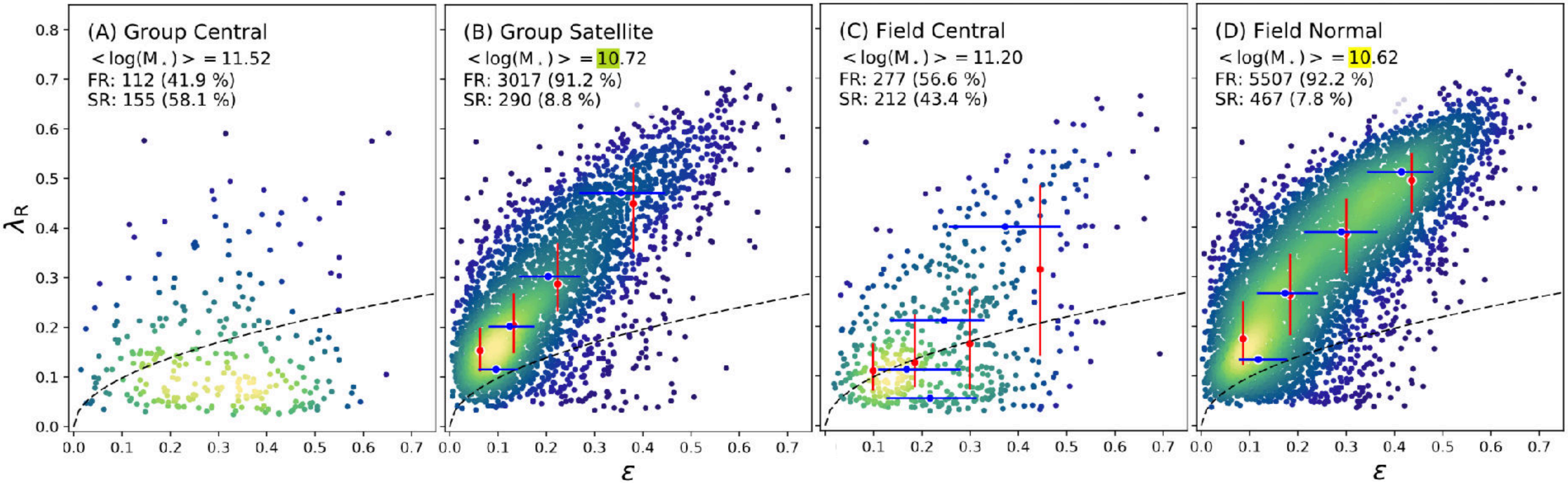
Merger frequency since z=1



Choi, Yi, Dubois, Kimm 2017, ApJ, submitted

Horizon-AGN early type galaxies

Spin-ellipticity



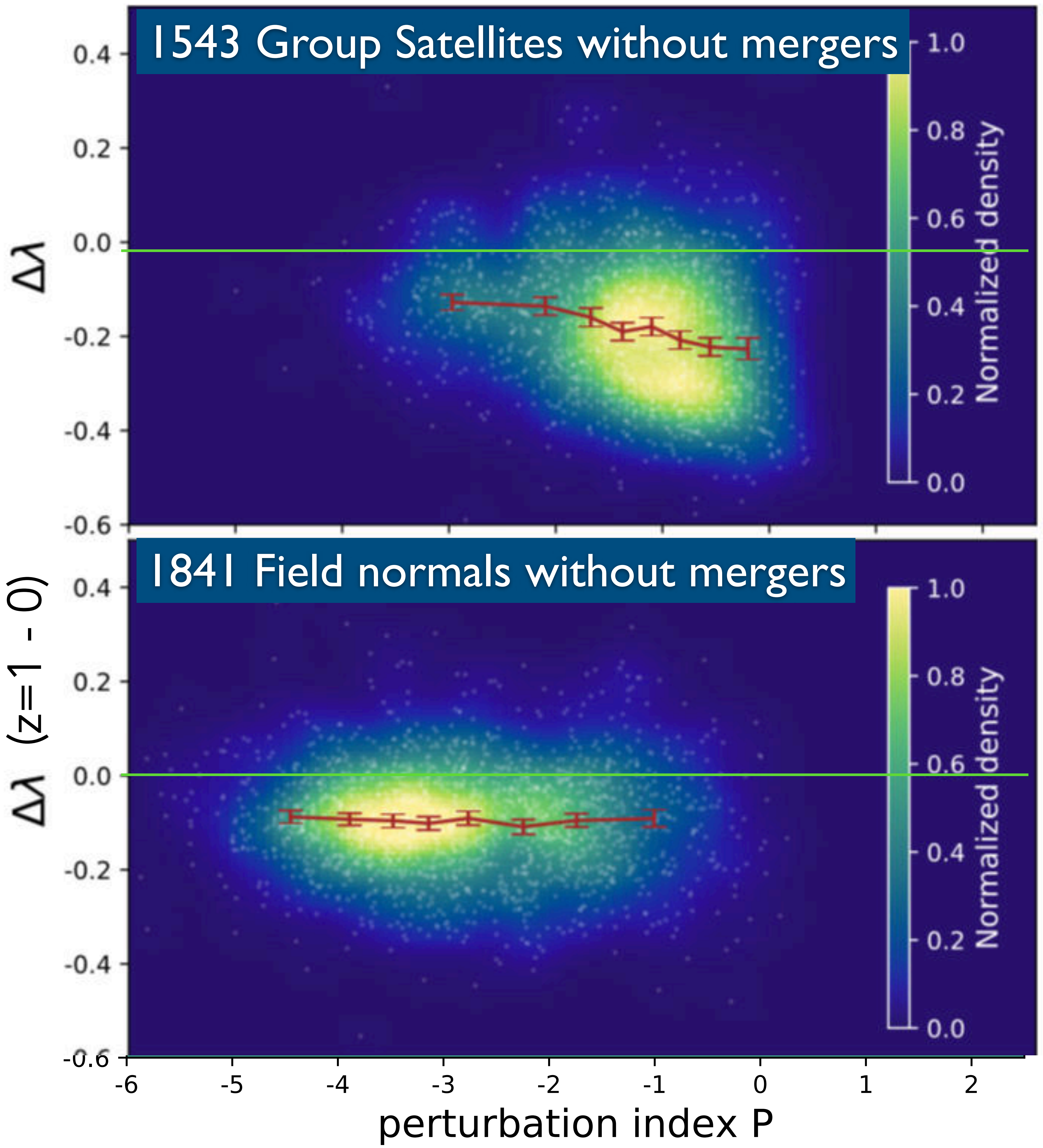
Choi, Yi, Dubois, Kimm 2017, ApJ, submitted

Horizon-AGN early type galaxies

Perturbation

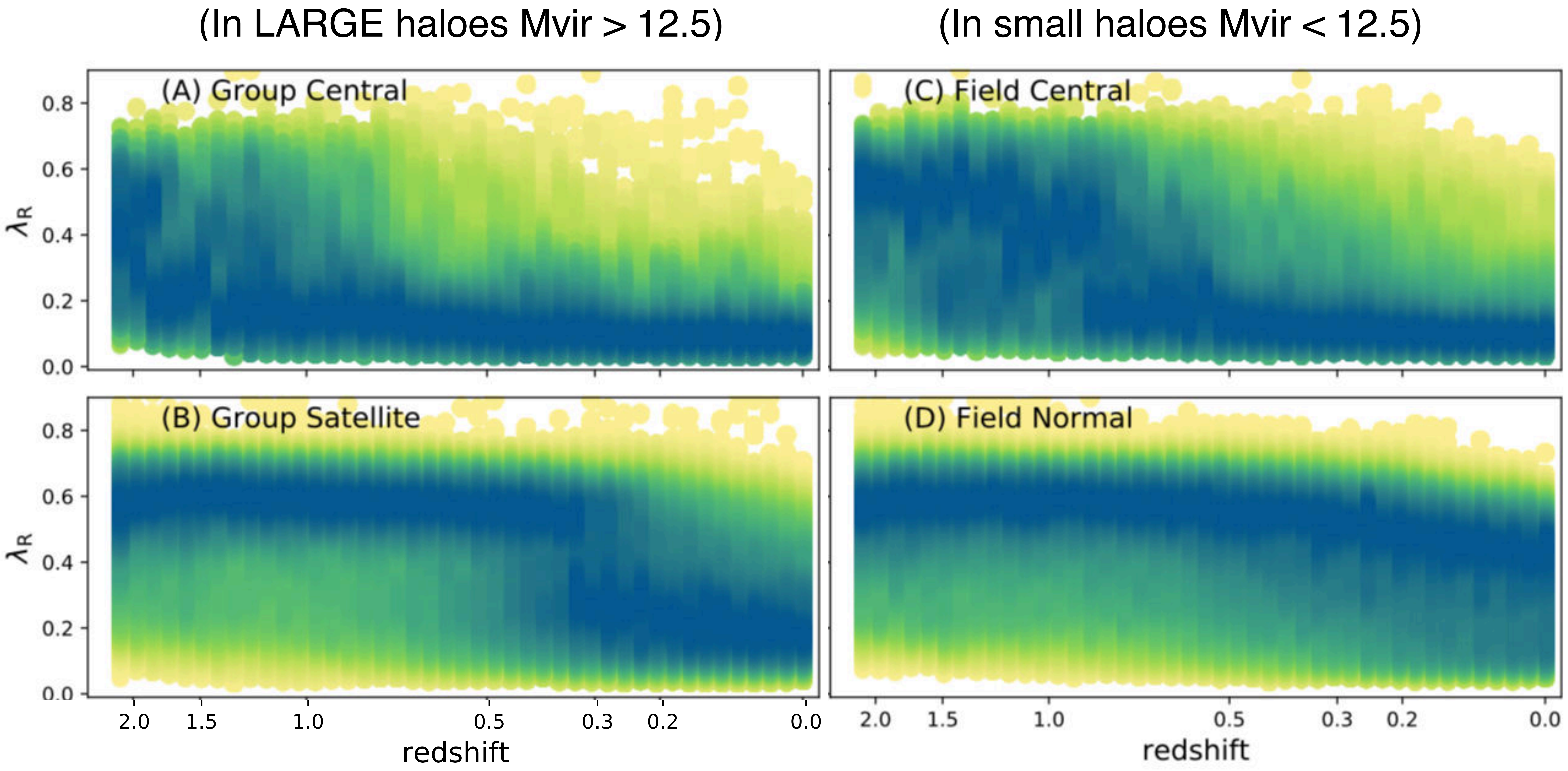
$$P = \log \int_0^{t_{\rm Rvir}} \sum_{i=0}^{n} \left(\frac{M_{{\rm P},i}}{M_{\rm gal}}\right) \times \left(\frac{R}{d_i}\right)^3 dt,$$

- measured P since the last merger (i.e., while there is no merger)
- higher P, more spin down
- Field normals still show spin down (0.1) but no P dependence.



Choi, Yi, Dubois, Kimm 2017, ApJ, submitted

Horizon-AGN early type galaxies



Choi, Yi, Dubois, Kimm 2017, ApJ, submitted

In summary: spin

- Massive galaxies ($M^*>10^{10}$) have spun down globally since z=3.
- Any galaxy can spin down by 0.1 without mergers or obvious perturbation.
- If central in large halos (2.5%), mergers dominate spin down.
- If central in small haloes (12%), mergers and perturbation.
- If satellite (86%), perturbation seems more important.

- Resolution sufficient?

Resolution

NGC 891 (~MW)

YZiCS

New Horizon

(Dubois, Devriendt, Gavazzi, Hahn, Kaviraj, Kimm, Le Borgne, Peirani, Pichon, Silk, Slyz, Volonteri, Yi)

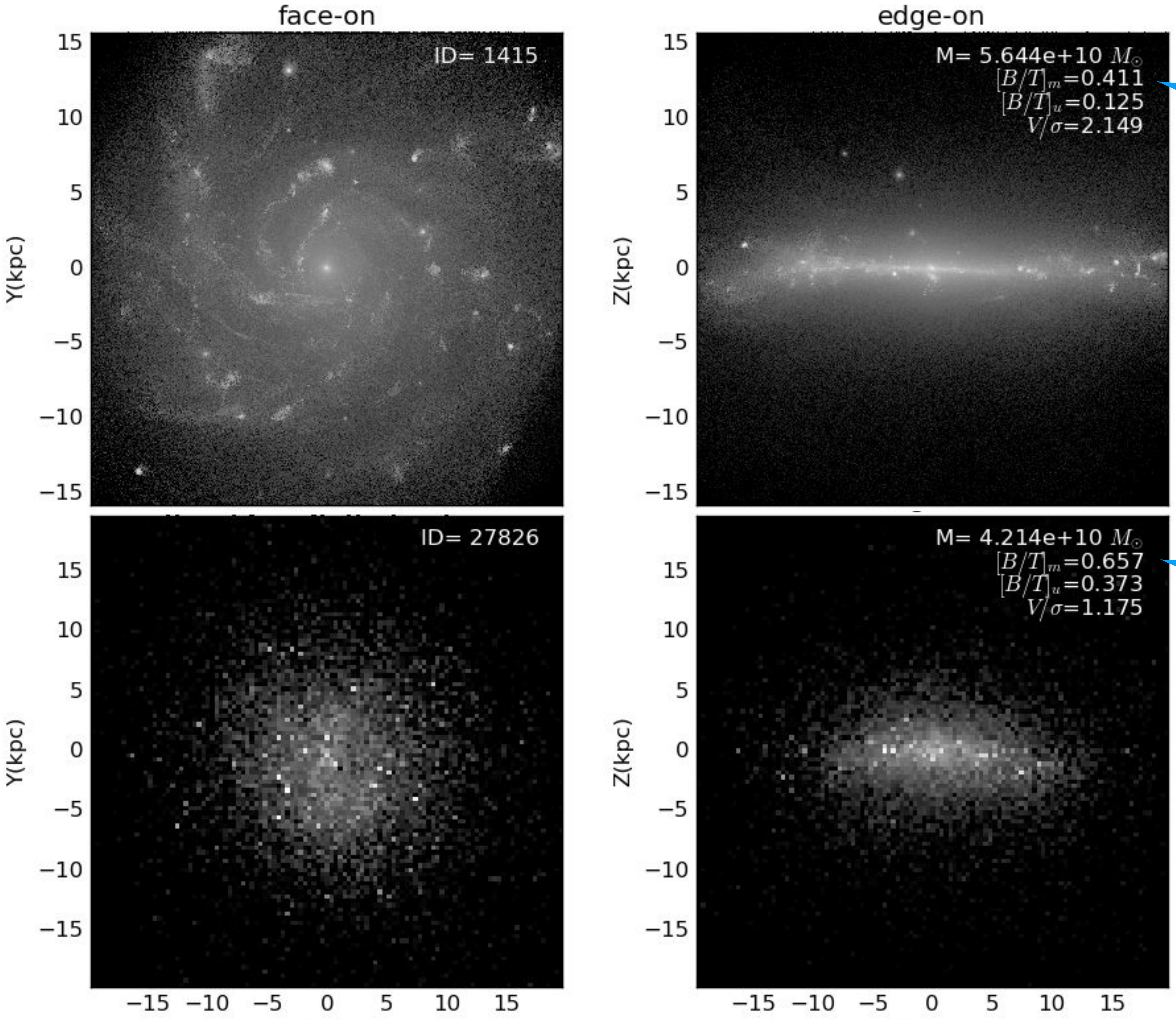
10Mpc sphere inside Horizon-AGN volume

high res (**40pc**) simulation

New Horizon

z=1
M*=5e10

Horizon-AGN



B/T=0.41

B/T=0.66

New Horizon
at z=1
(Dubois, Yi, et al.)

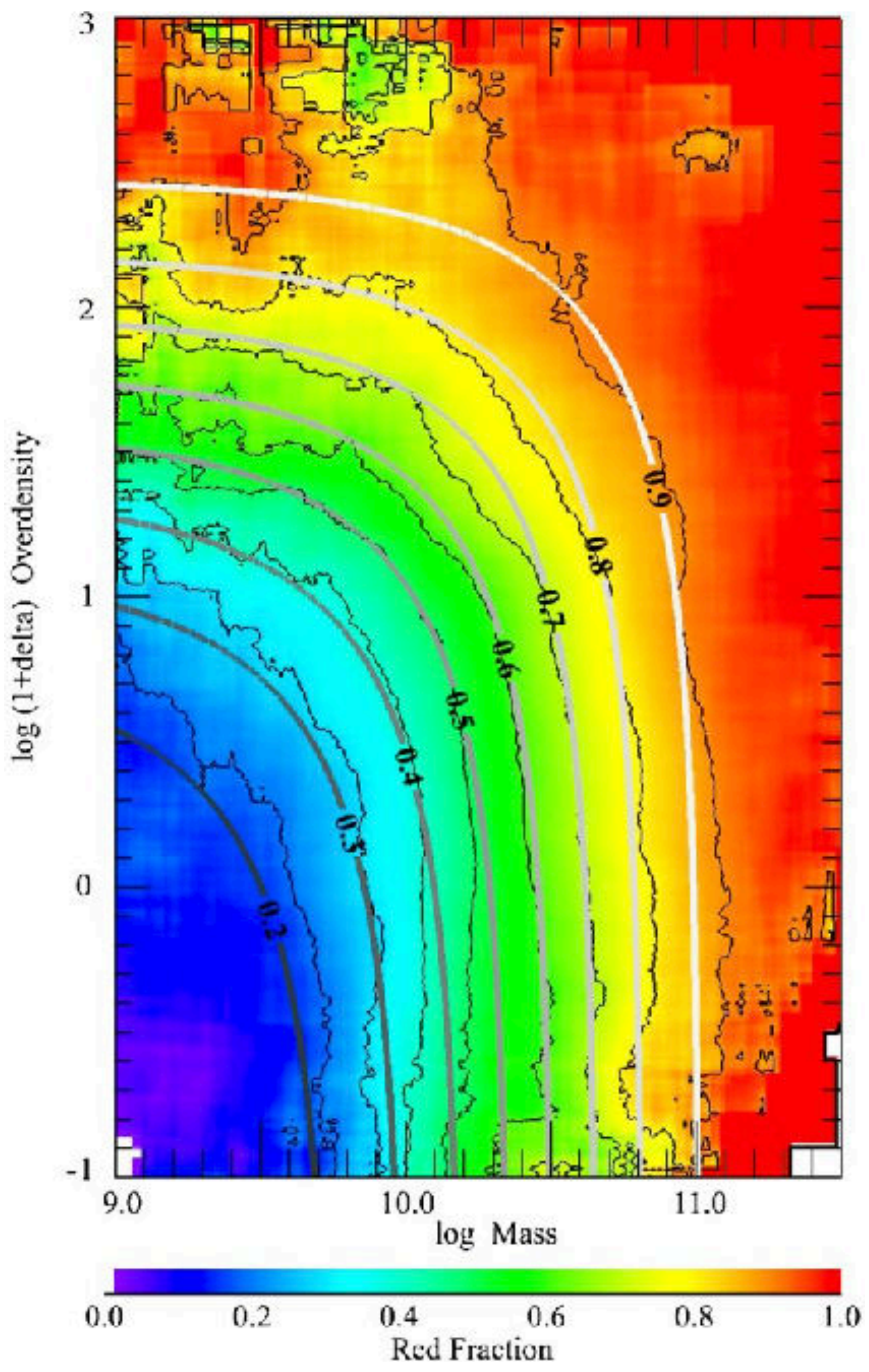
SKIRT image:
Jongwon Park

2. SF quenching of cluster galaxies

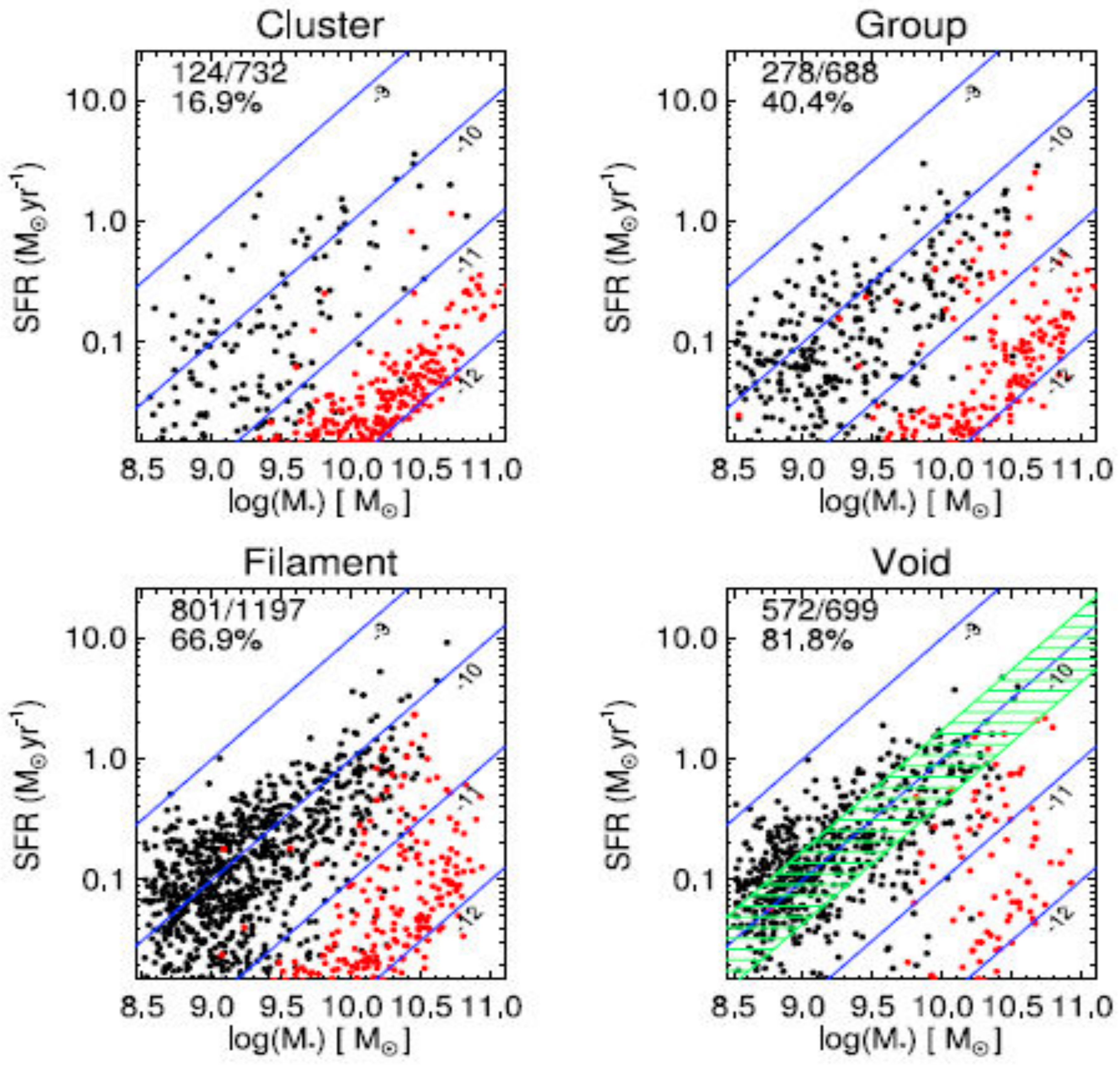
Seoyoung Jung

YZiCS simulation

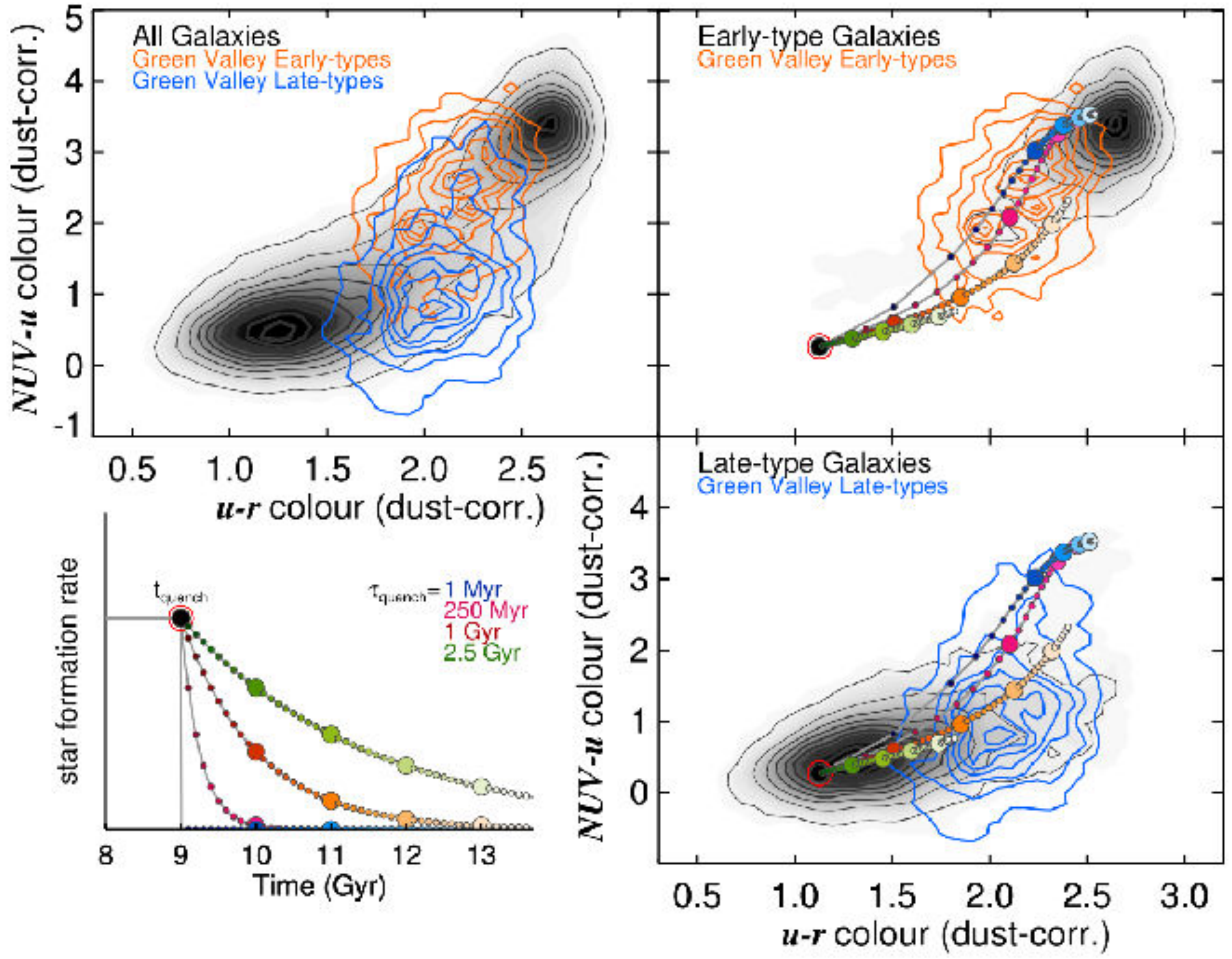
Star formation quenching



Peng+ 2010

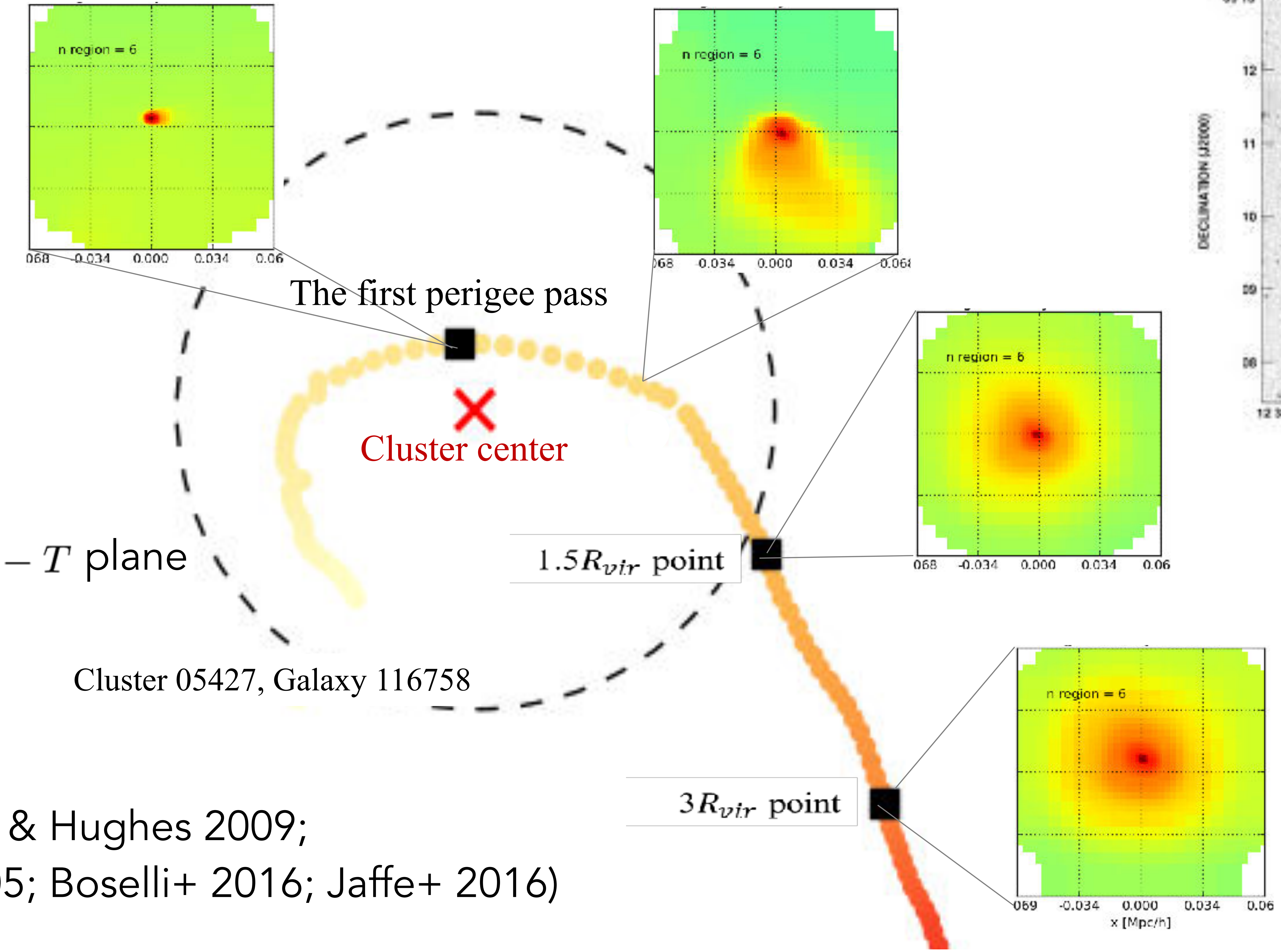


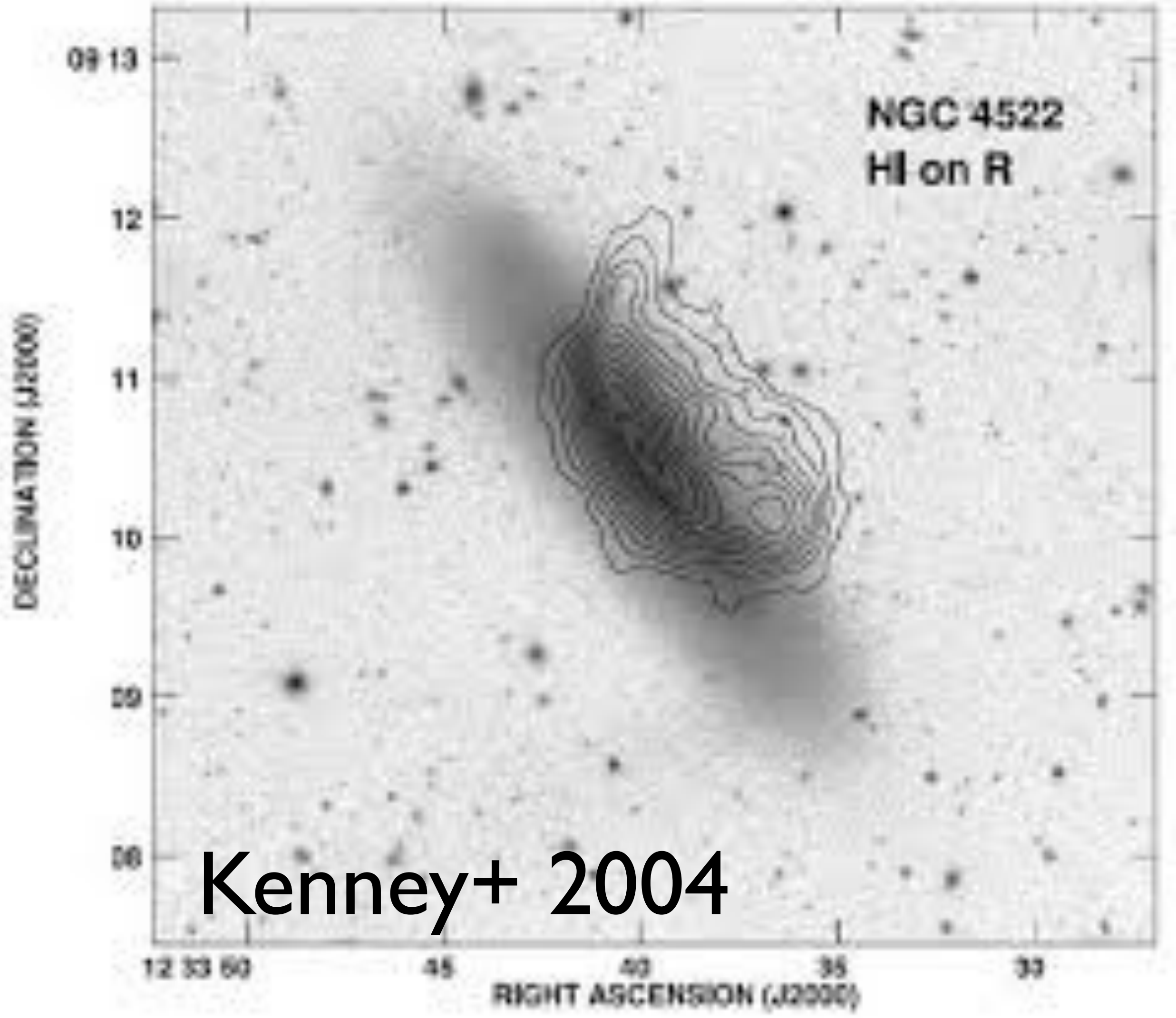
SFing galaxy fraction
Cybulski+ 2014



Green valley galaxies
Schawinski+ 2014

Ram pressure stripping

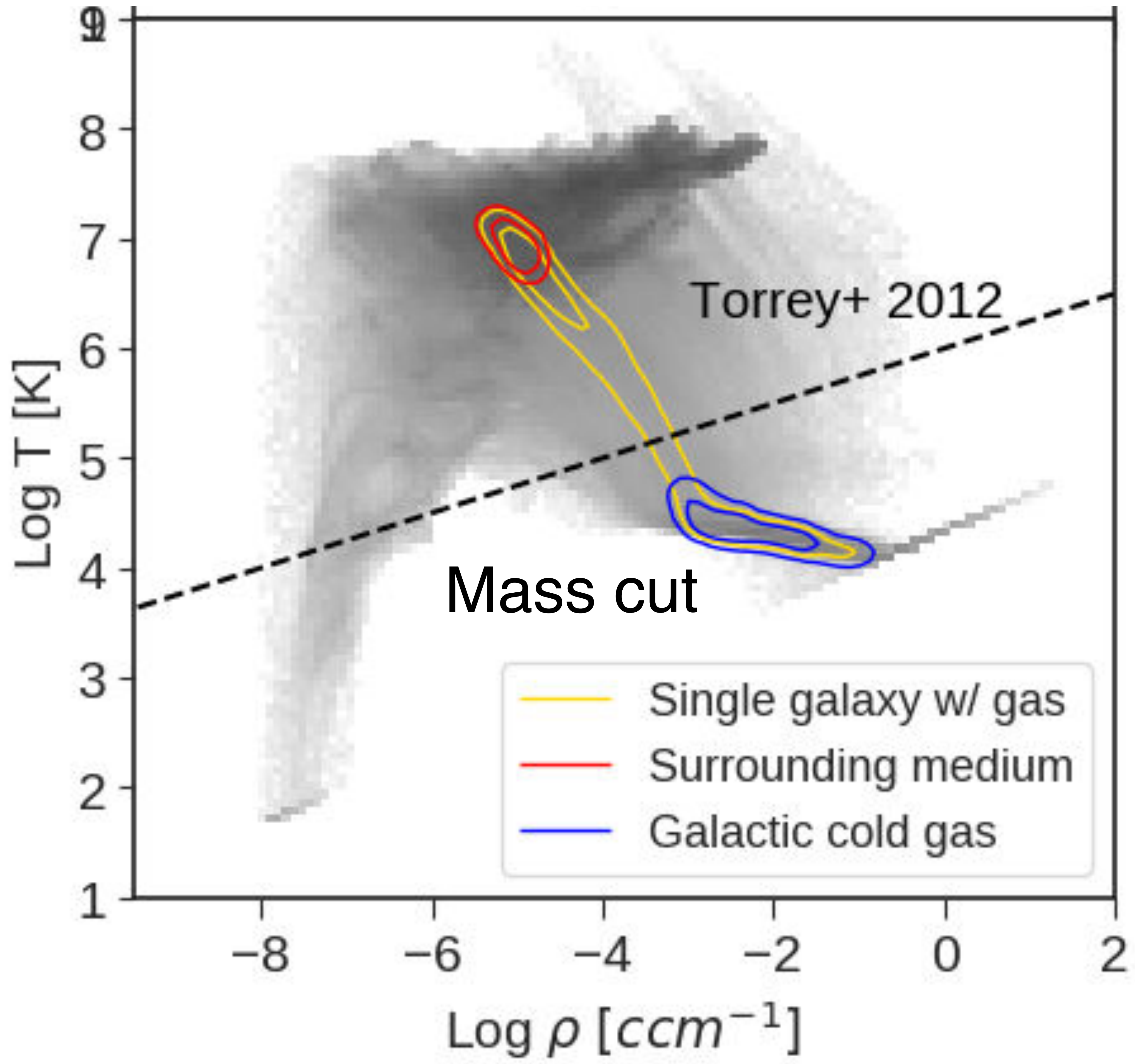


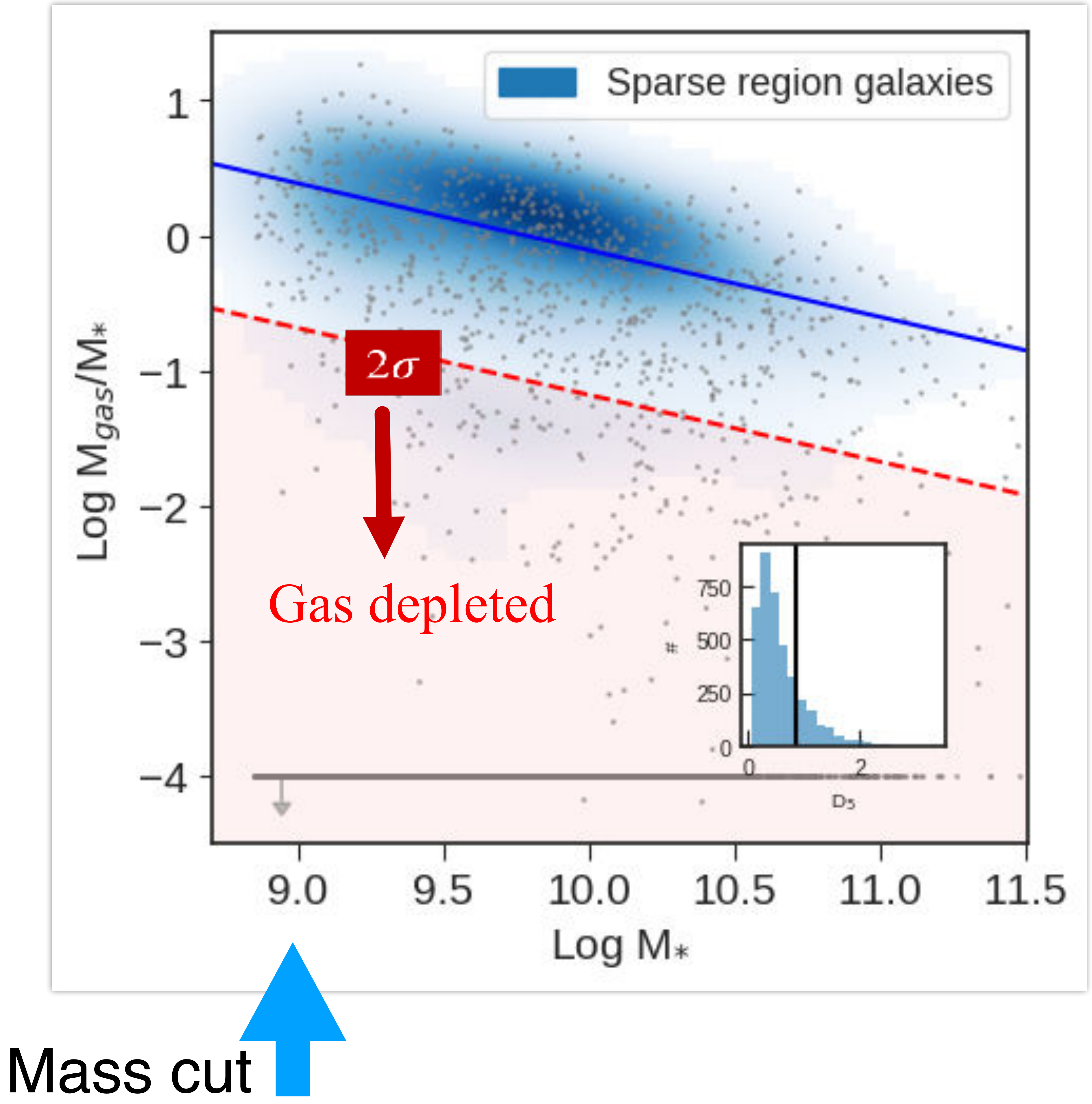


galactic gas defined in $\rho - T$ plane
(Rasera & Teyssier 2006)

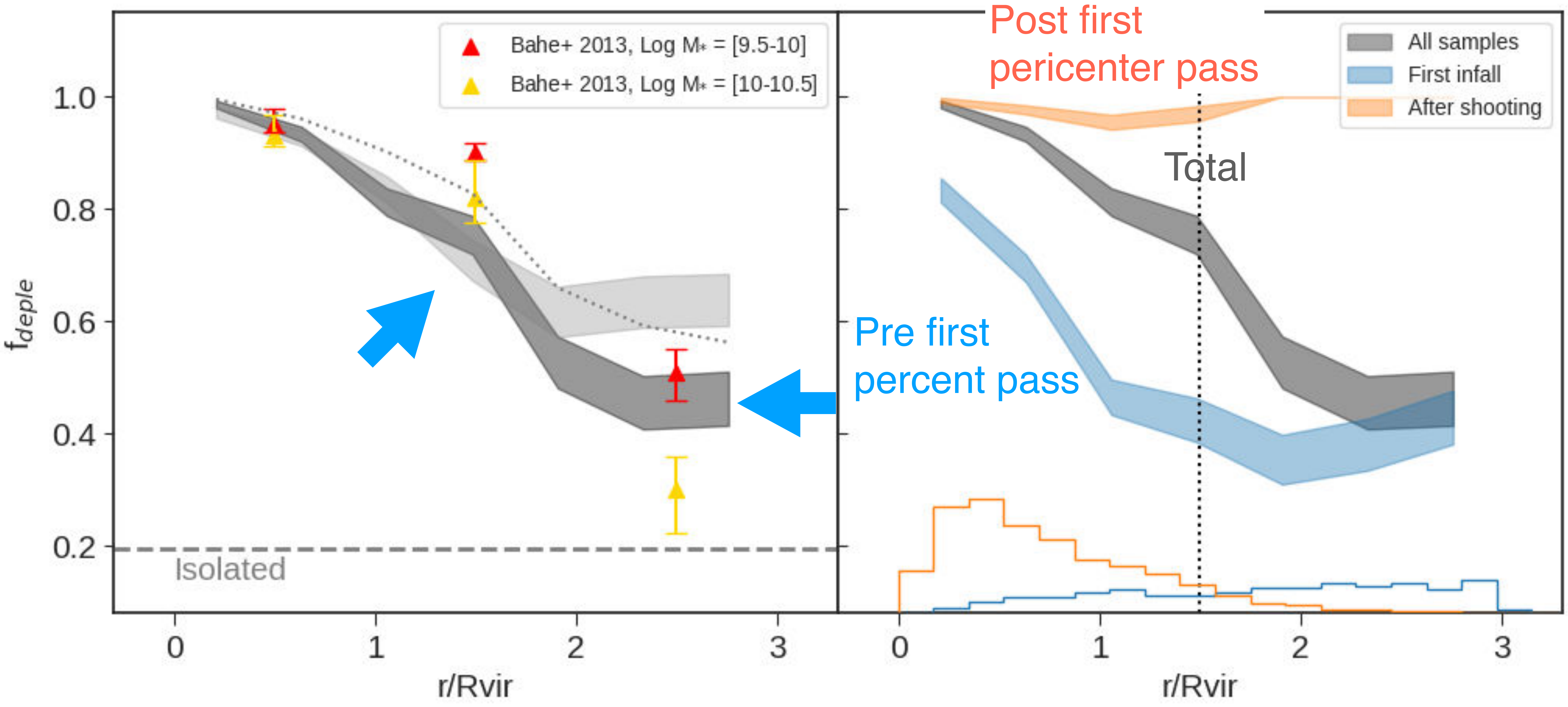
RPS significant (Cortese & Hughes 2009;
Roediger & Hensler 2005; Boselli+ 2016; Jaffe+ 2016)

Definition of gas depletion

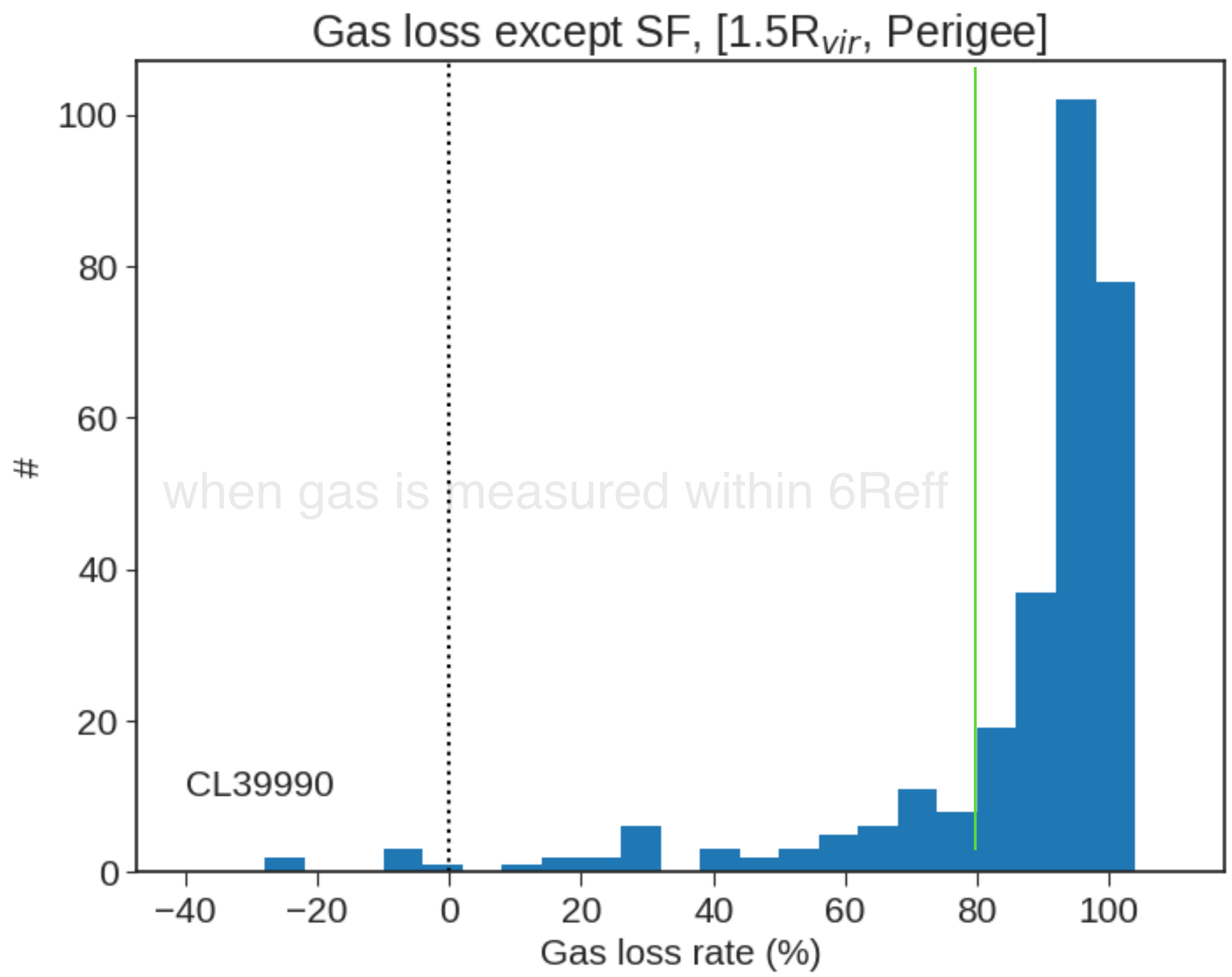




Radial distribution of gas-depleted galaxies

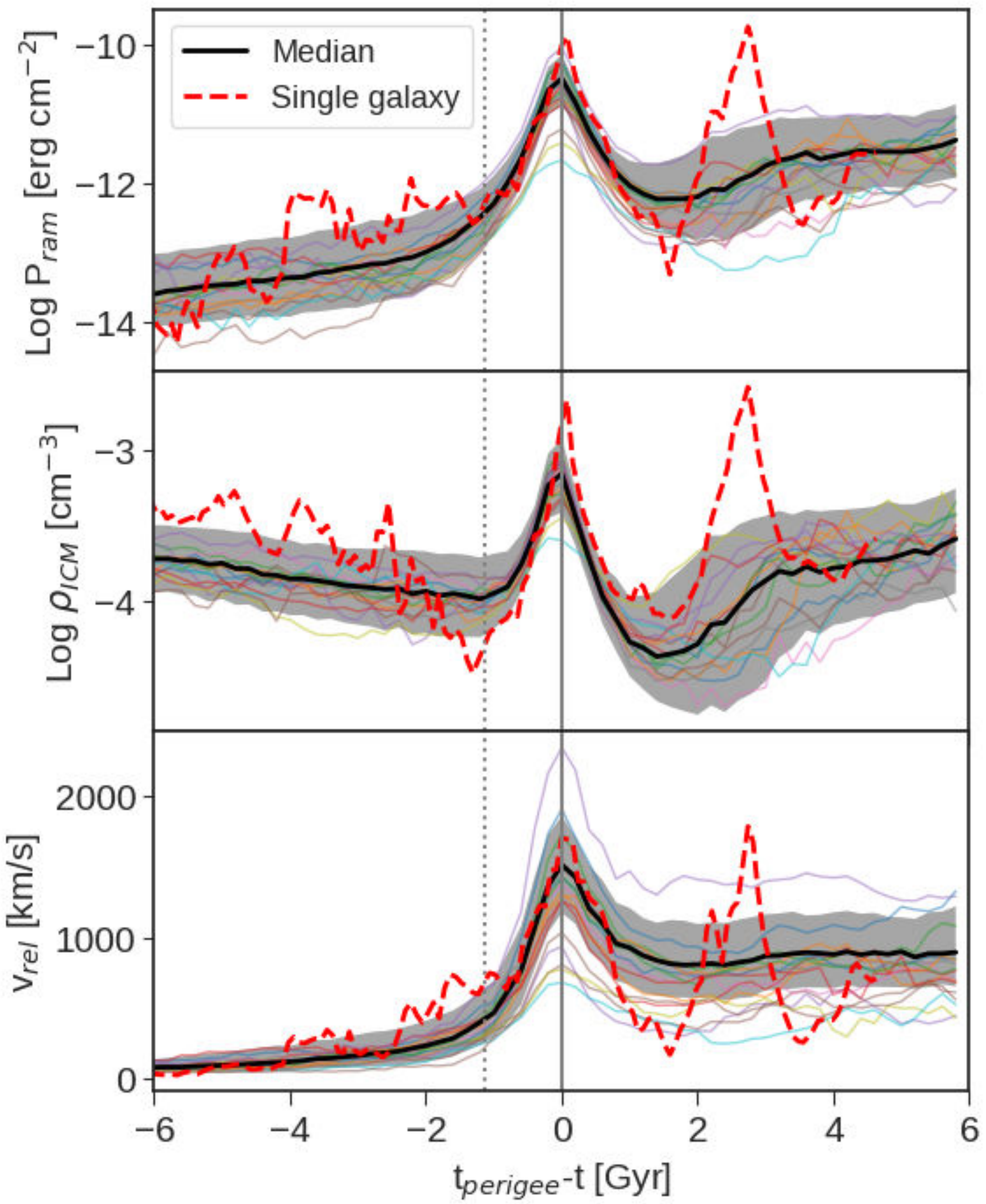


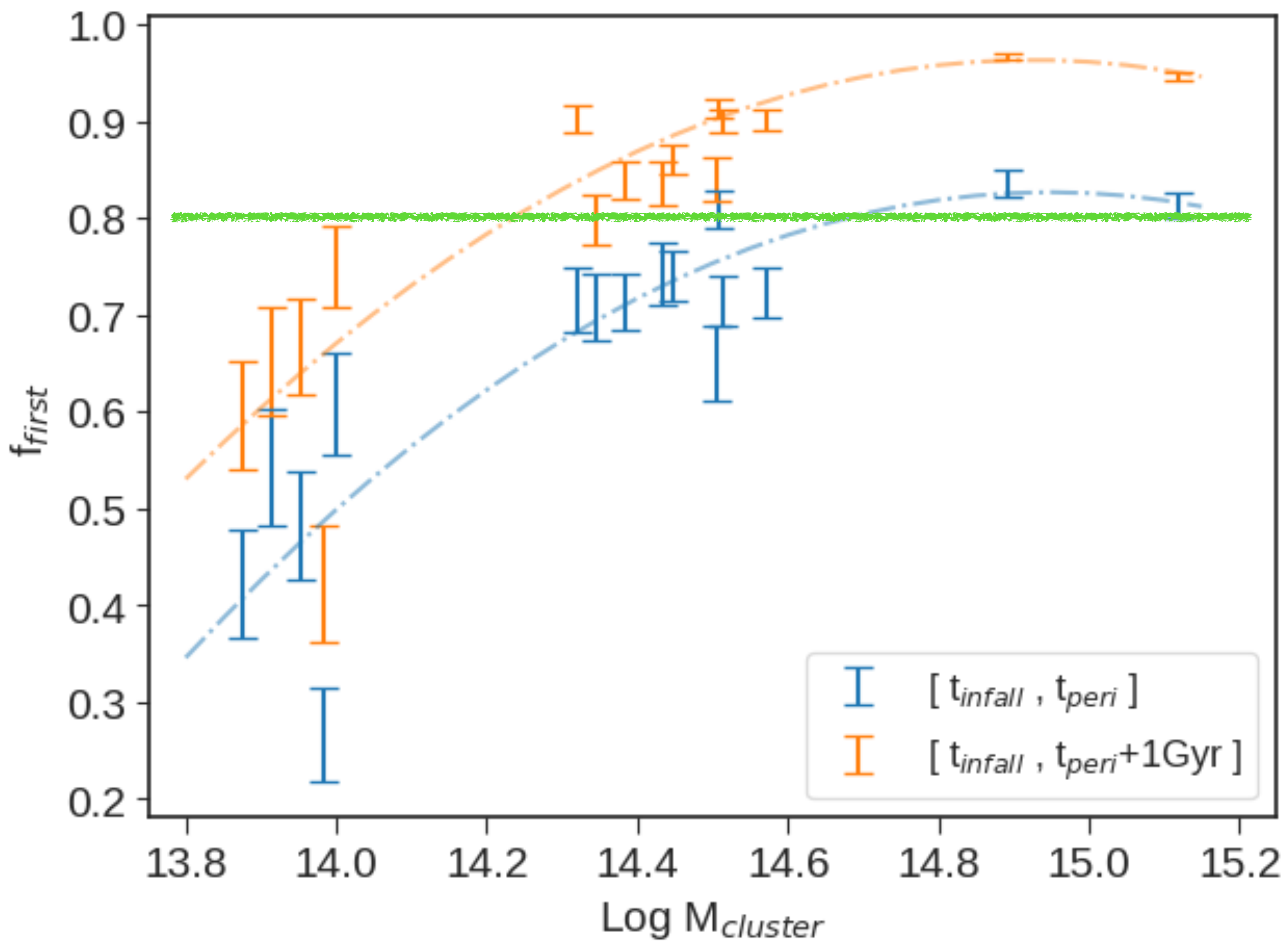
Gas loss inside cluster



- 80% of the galaxies lose >80% of cold gas during the first infall into the cluster (see also Cen+ 2014).

Cluster mass dependence

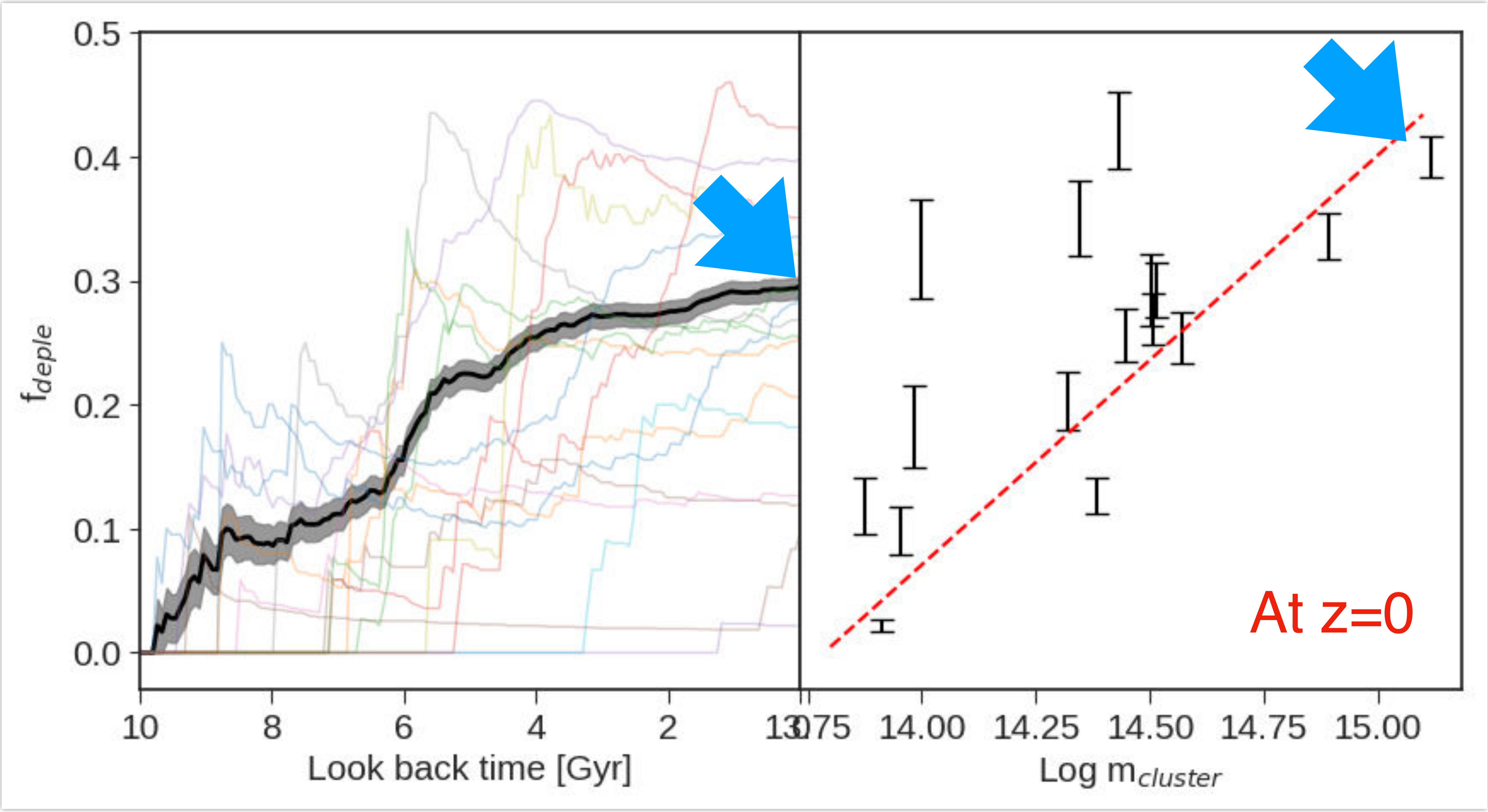




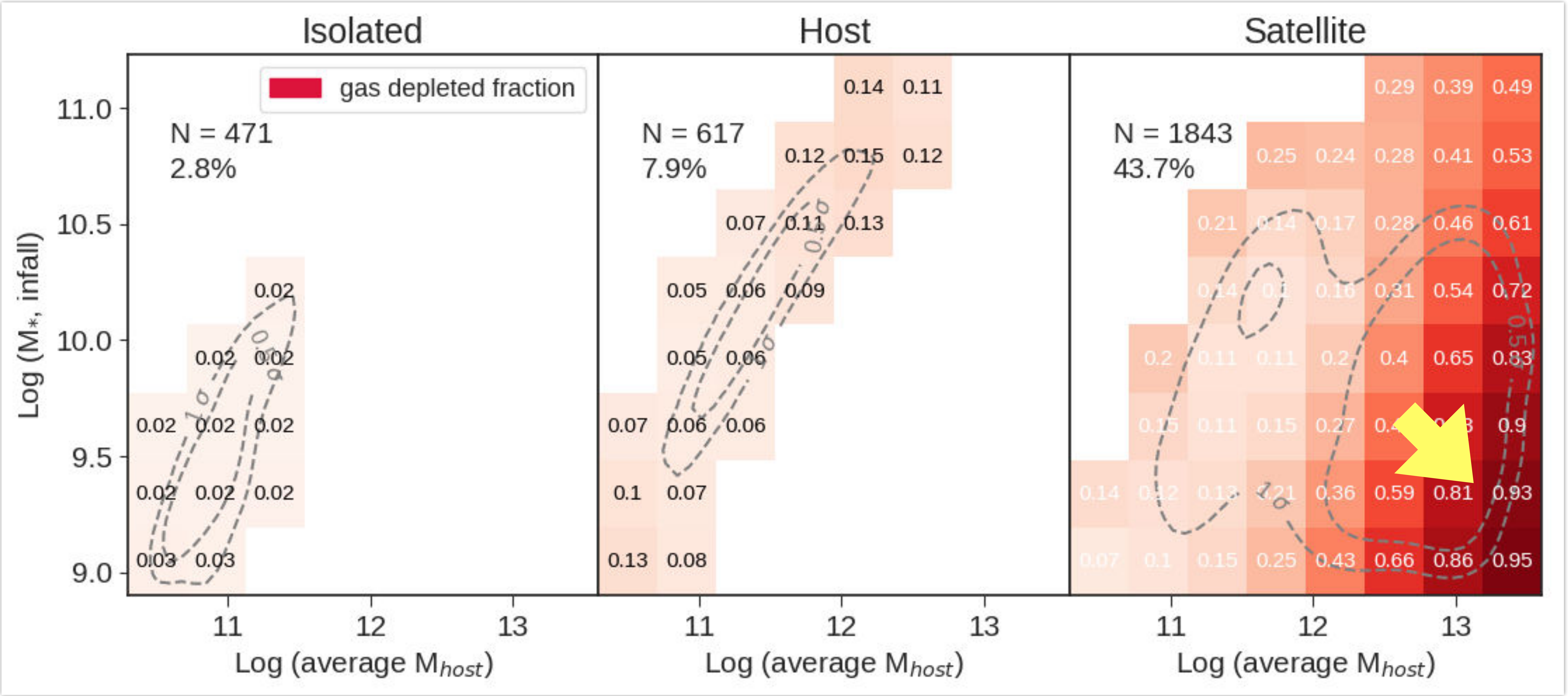
~80% of galaxies become gas-depleted during the first infall to the cluster
(c.f., Mahajan+ 2011, Cen+ 2014, Jaffe+ 2016)

Preprocessing

- Over the last 10Gyr, 30% of galaxies arrived at the clusters gas-depleted.
- At z=0, 40% of galaxies arrive preprocessed in massive clusters.



Pre-processed galaxies are mostly small galaxies from large groups



At z=0, Total ~30% of galaxies are arriving gas poor via reprocessing.
~90% of them are group satellites. (Fujita 2004, Wetzel+ 2013, Jaffe+ 2015)

In summary: quenching

- ~30% arrive at cluster gas-depleted via pre-processing.
- ~70% arrive with gas and SF.
- ~80% of them lose >80% of gas through the first perigee pass (~1Gyr).
- Halo quenching very effective! Pre-processing important to consider.

Conclusions

- Today's cosmological hydro simulations reproduce many basic properties of galaxies (spin, mass, SF, etc).
- Improvement expected in spatial resolution (e.g., New Horizon).
  - NH does not have clusters.
  - Zoom-in technique useful: YZiCS, C-Eagle (Barnes+2017), and more…