Merger relics in galaxy clusters

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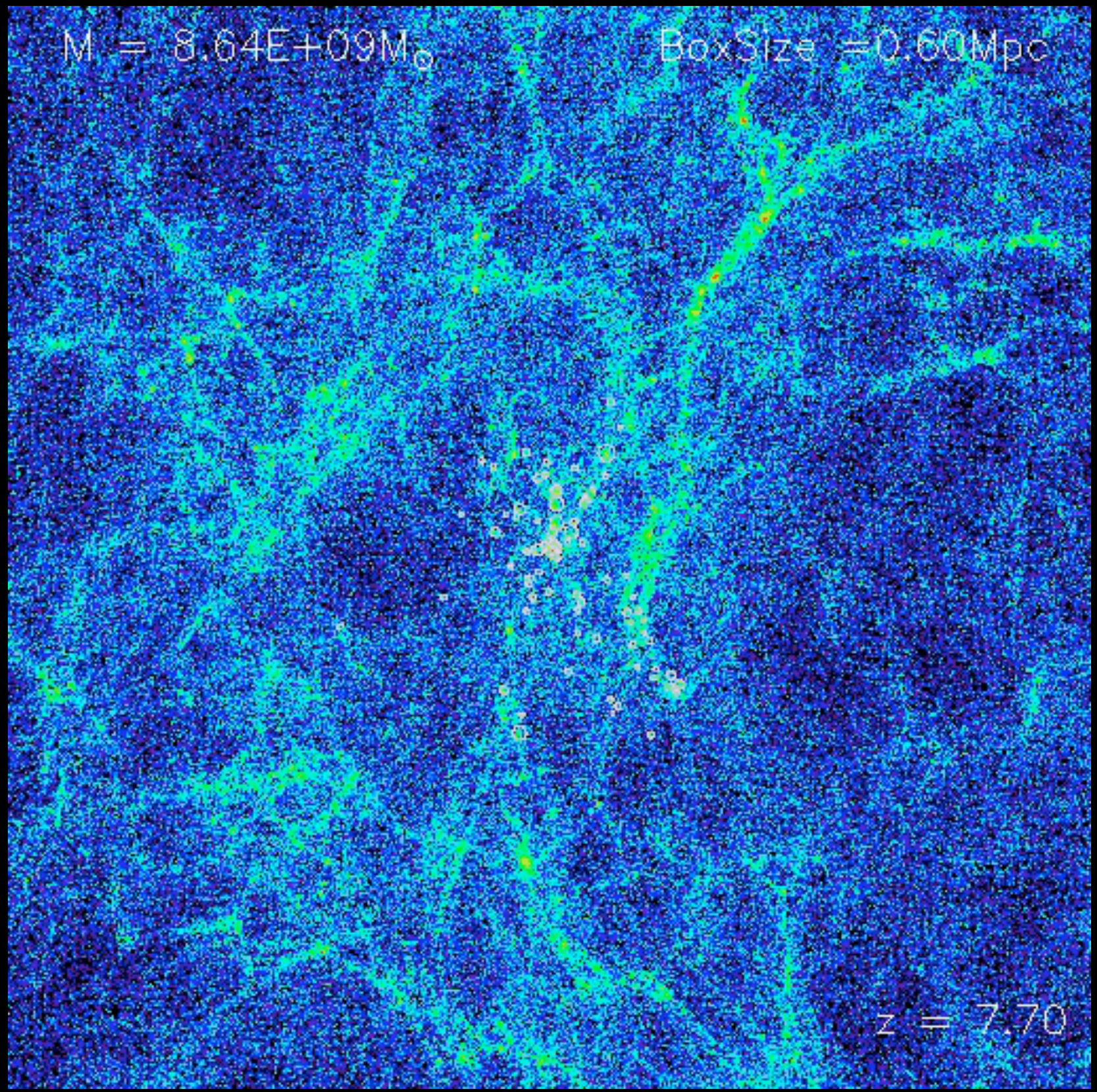
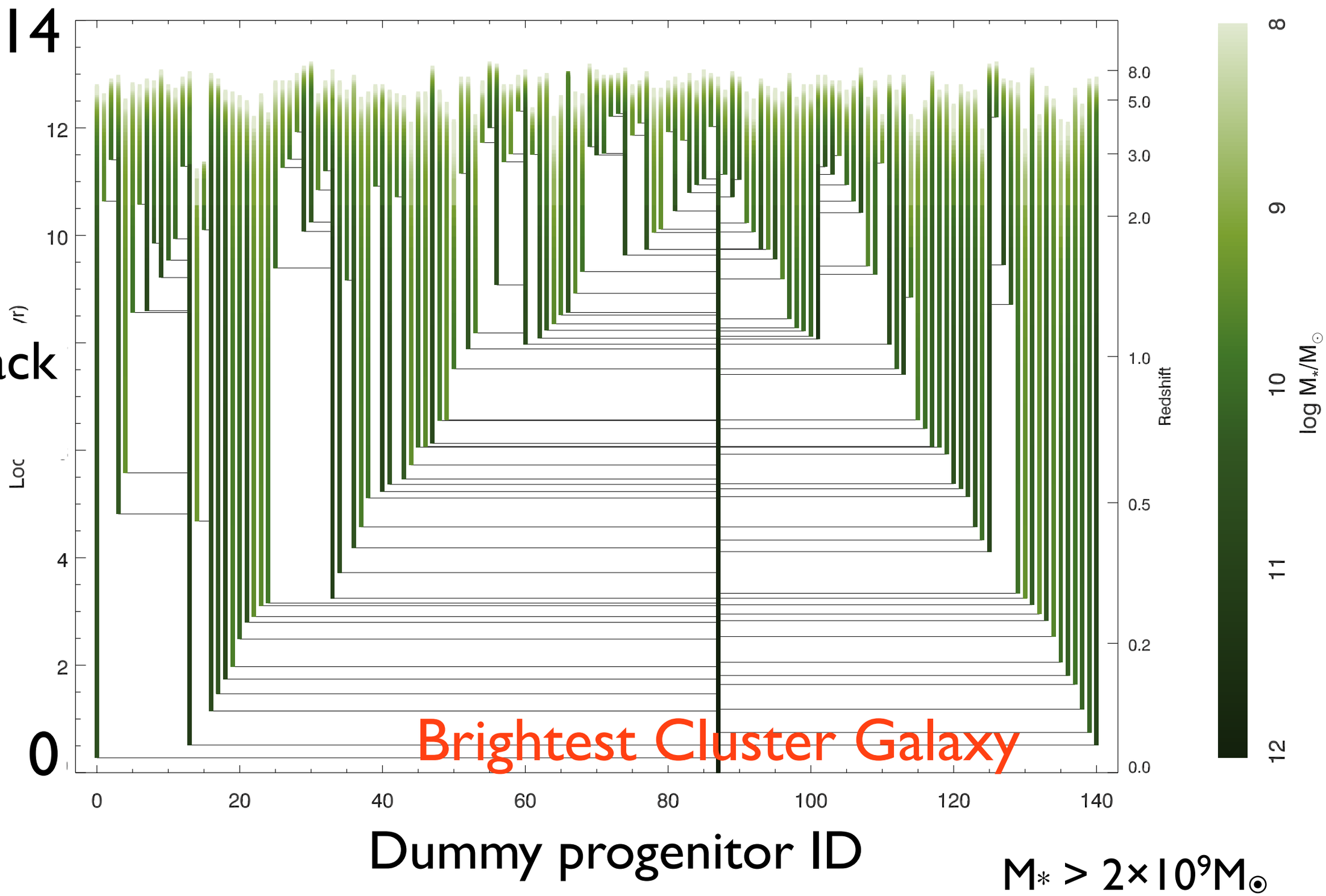
Dark halos grew via mergers



So did galaxies



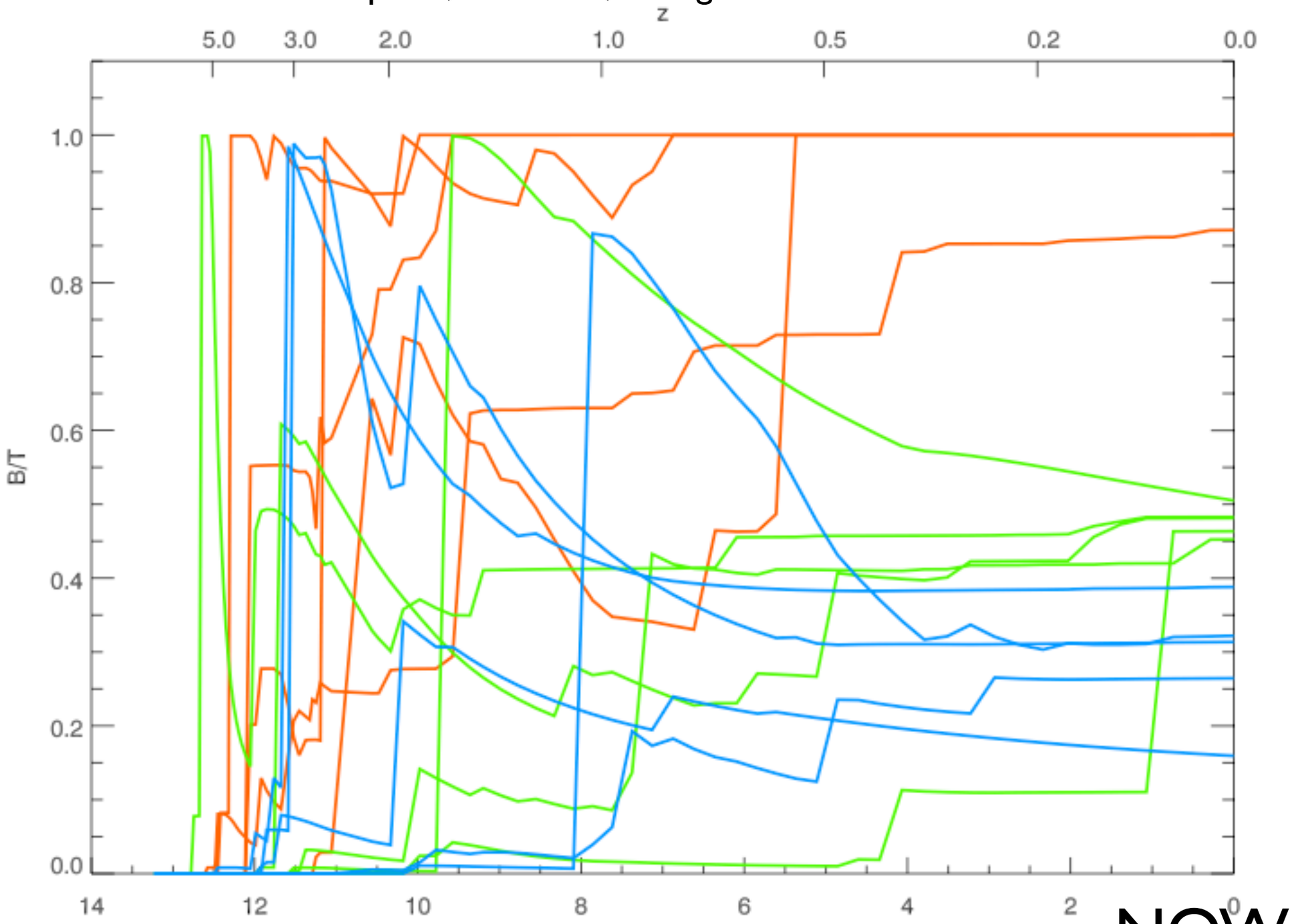
Look-back time

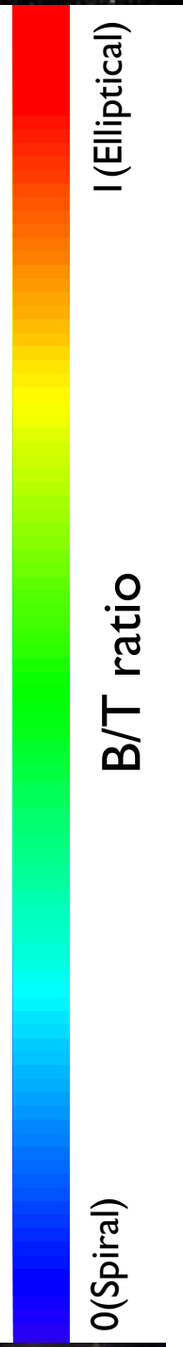
Dummy progenitor ID

$M_* > 2\times10^9 M_\odot$

Mergers affect morphology

5 Elliptical, Lenticular, Disc galaxies random





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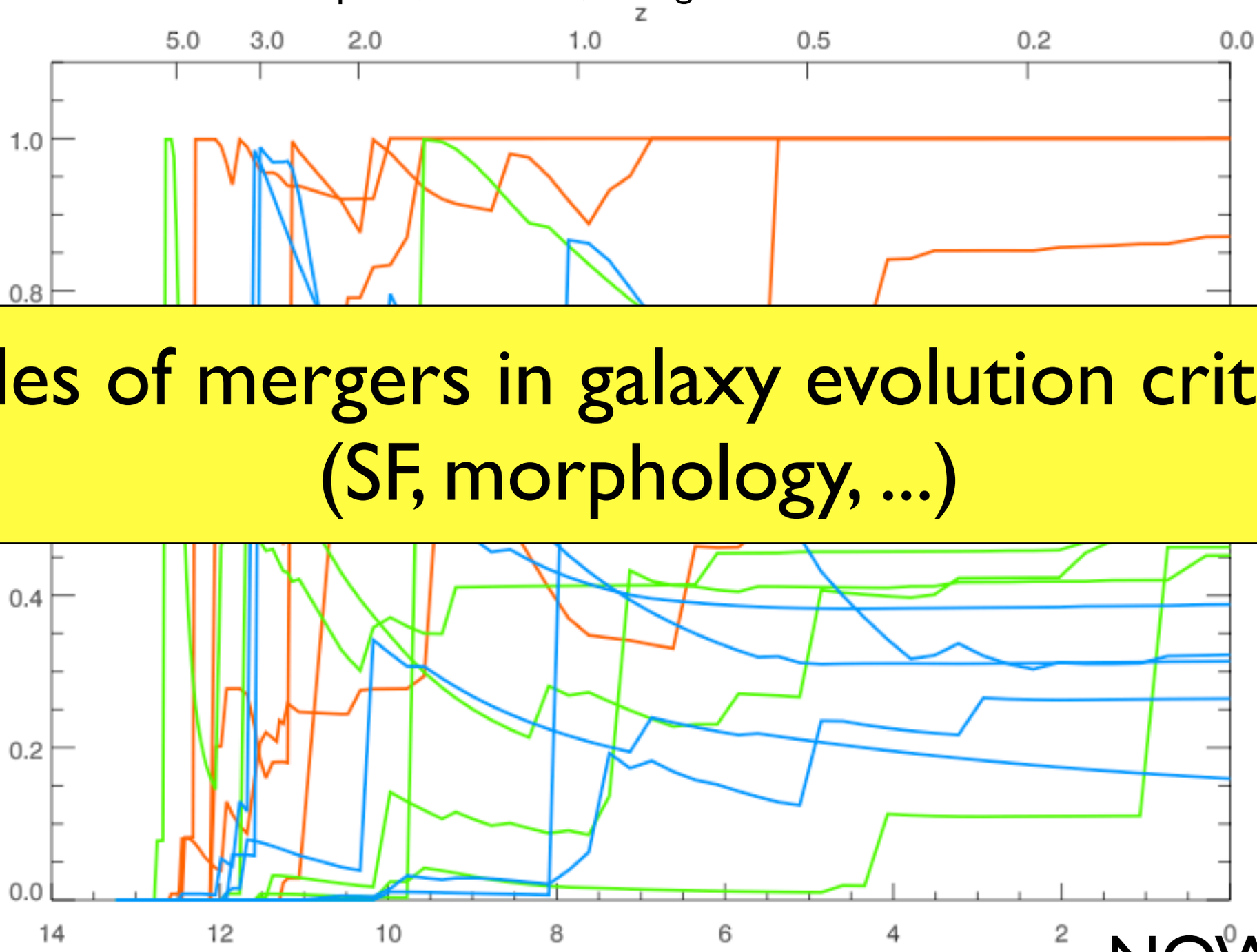
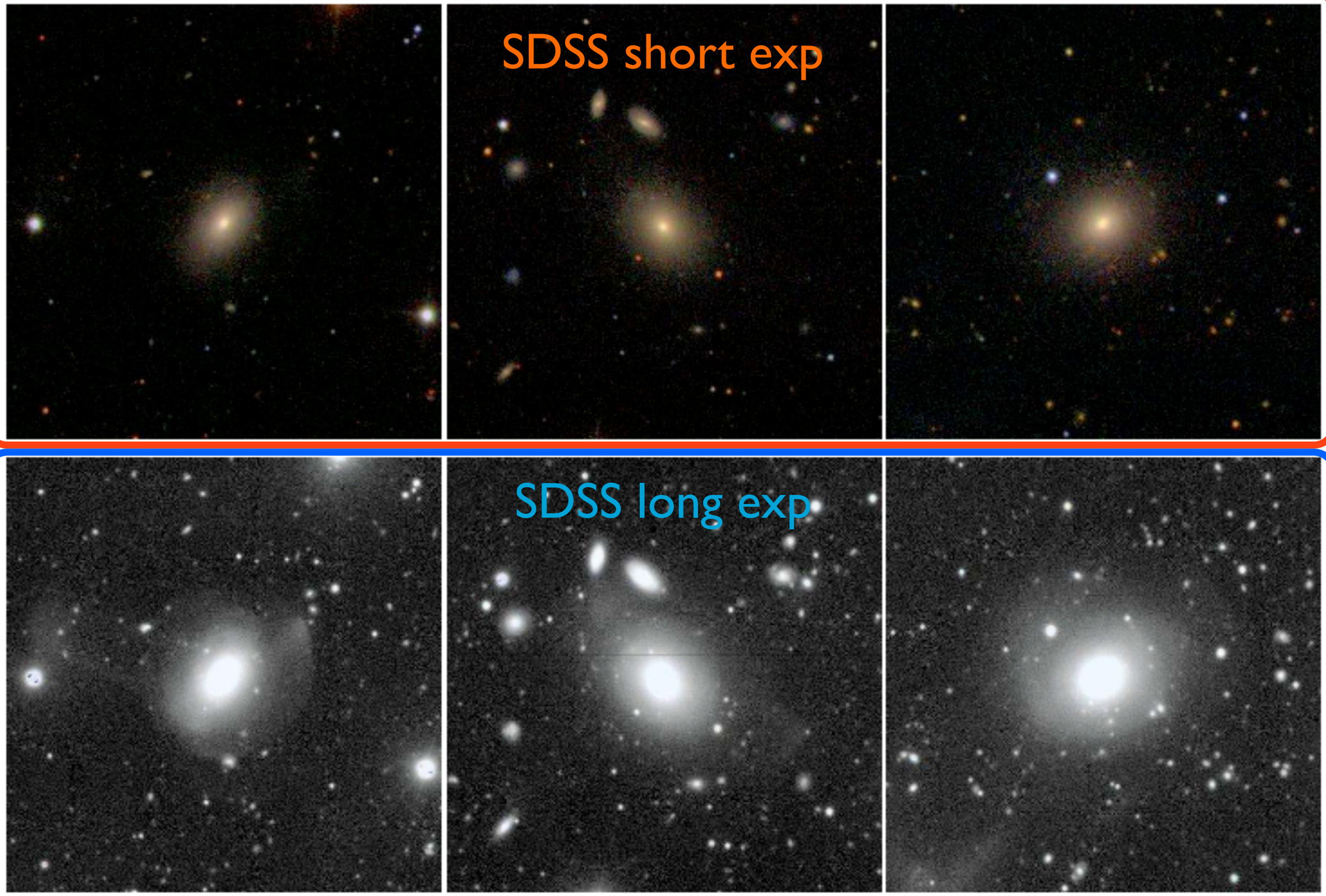


Roles of mergers in galaxy evolution critical. (SF, morphology, ...)

Deep imaging reveals mergers.

Kaviraj et al. 2010



Credit: CFHTLS: P.-A. Duc

Early-type Galaxy Mergers

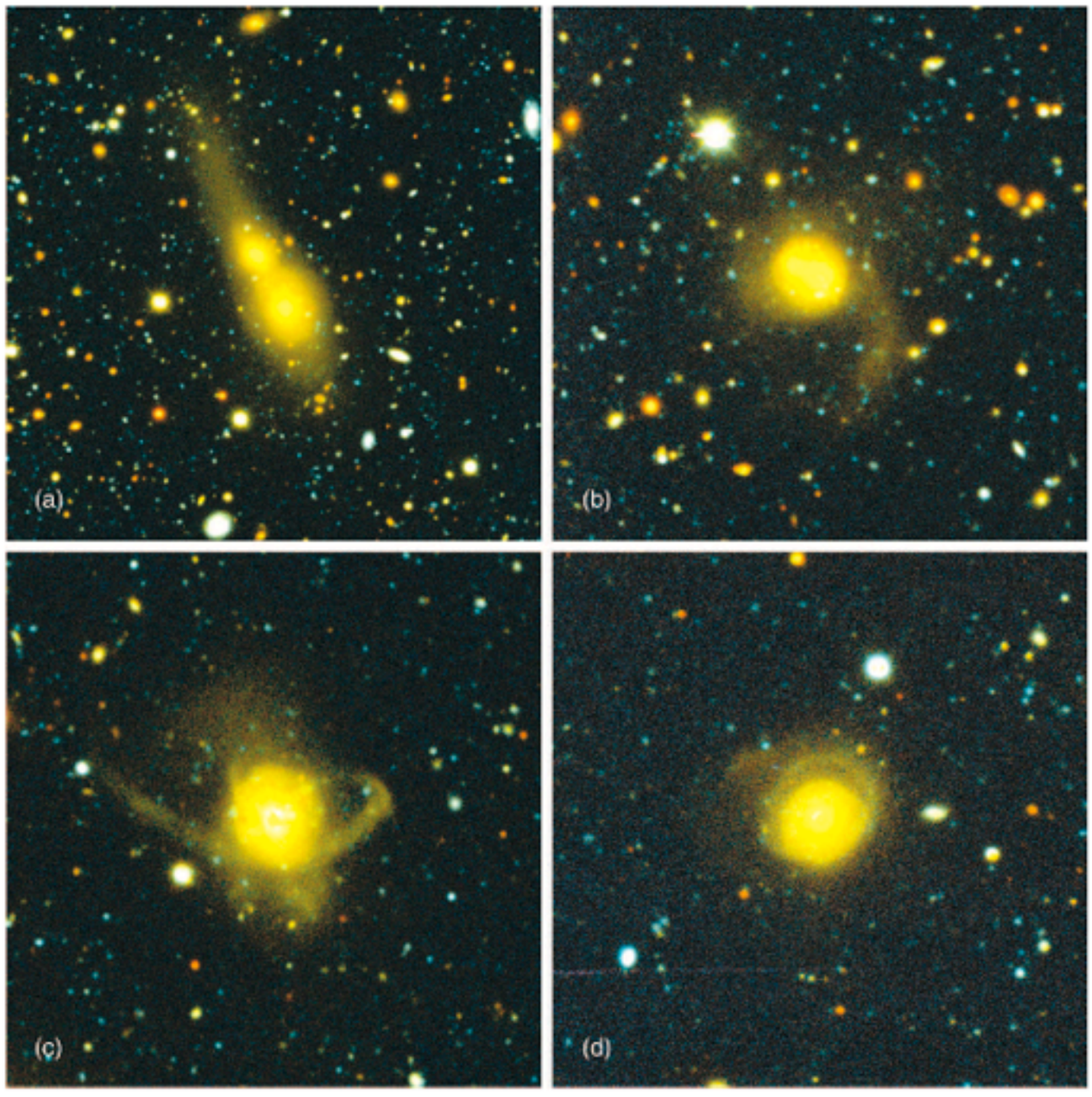


FIG. 3.—Examples of red mergers, ordered by the progression of the interaction. The images were generated by combining the *B* and *R* frames. The objects are (*a*) 17-596 and 17-681; (*b*) 19-2206 and 19-2242; (*c*) 1256-5723; and (*d*) 6-1302. Panel *a* spans $5' \times 5'$; panels *b*–*d* span $2'.5 \times 2'.5$. The tidal features are faint, red, and generally barely visible in *B*. Similar features are seen in a large fraction of our sample of 123 red galaxies, in particular among the bulge-dominated early-type galaxies; images of all objects are given in the Appendix.

~50% of field bulge-dominant galaxies show merger features in deep (μ=28) images (van Dokkum 2005).

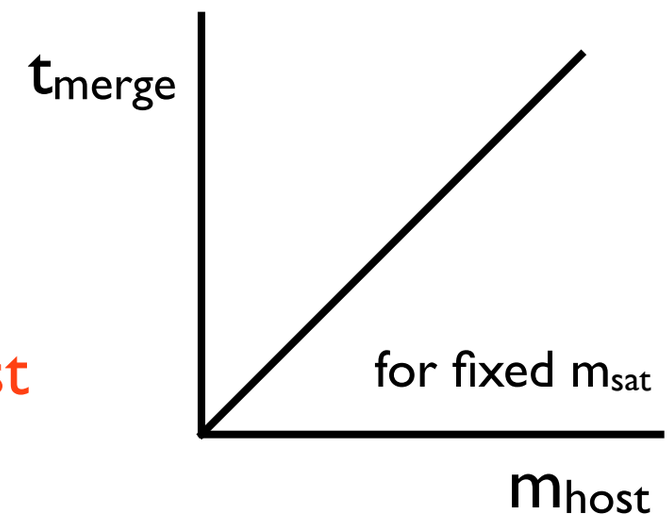
How about in clusters?

Merger timescale in a "frozen halo"

Chandrasekhar merger timescale (Lacey & Cole 1993)

$$t_{merge} = \frac{1}{2}\frac{f(\epsilon)V_c r_c^2}{CGm_{sat}ln\Lambda} \propto \frac{V_c r_c^2}{m_{sat}} \propto \frac{r_c V_c^2}{m_{sat}}\frac{r_c}{V_c} \propto \frac{m_{host}}{m_{sat}}\rho^{-1/2} \propto \frac{m_{host}}{m_{sat}} t_{dyn} \propto \frac{m_{host}}{m_{sat}}$$

For given m_sat,
Chandrasekhar merger time scales with m_host



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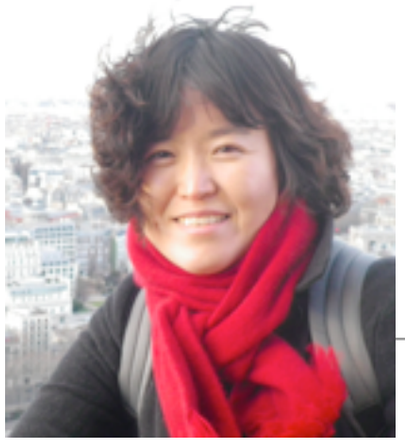
In a large halo,
galaxy density is high
but spatial velocity is also high
and galaxy *merger* becomes highly unlikely!



Sheen et al. 2012, ApJS, 202, 8

Clusters at z~0.1

- FOV covers R_{virial}

  A389 R_{virial} = 2.3 Mpc

  A3330 R_{virial} = 1.9 Mpc

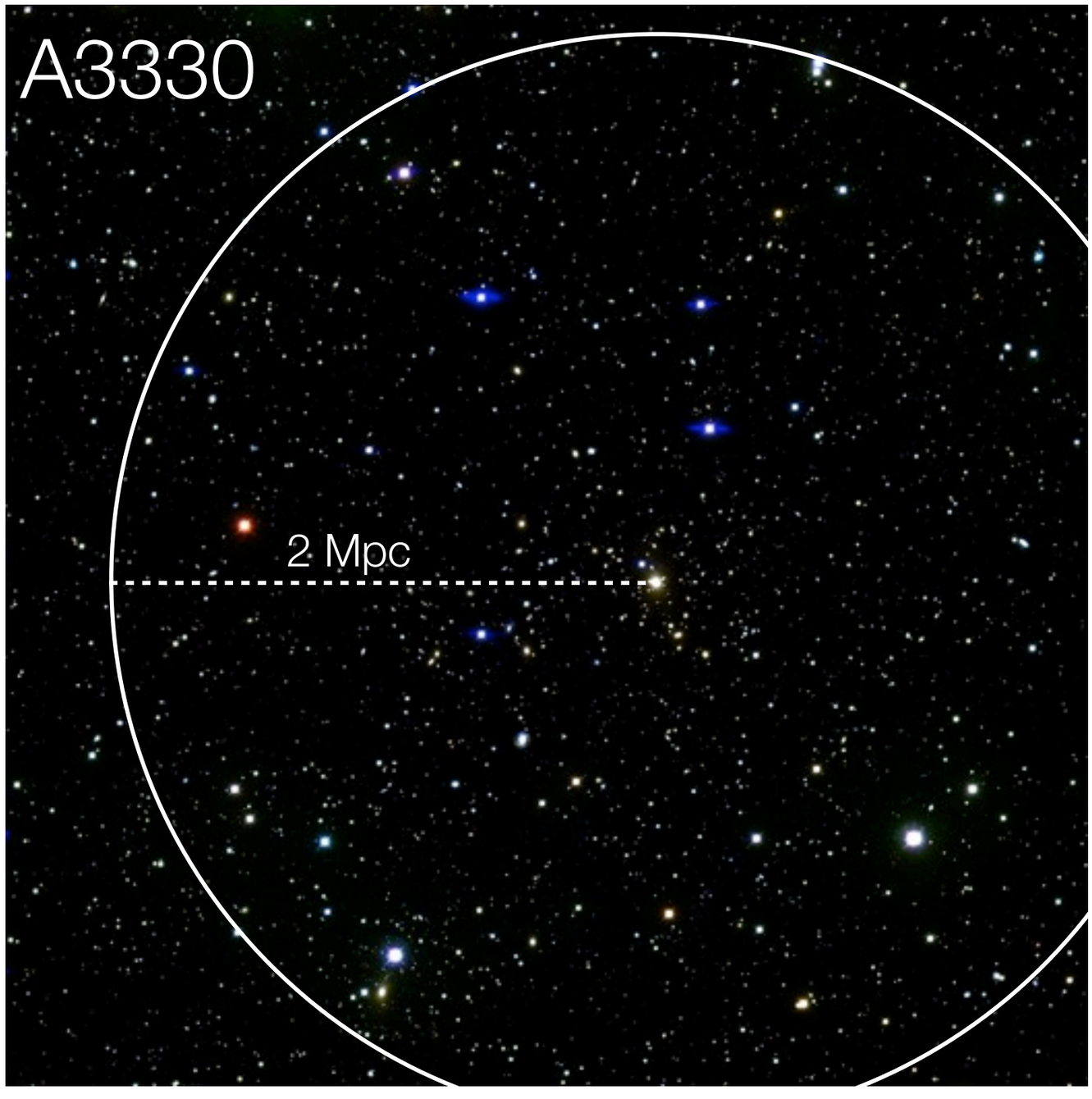
  A2670 R_{virial} = 1.6 Mpc

  A119 R_{virial} = 1.0 Mpc

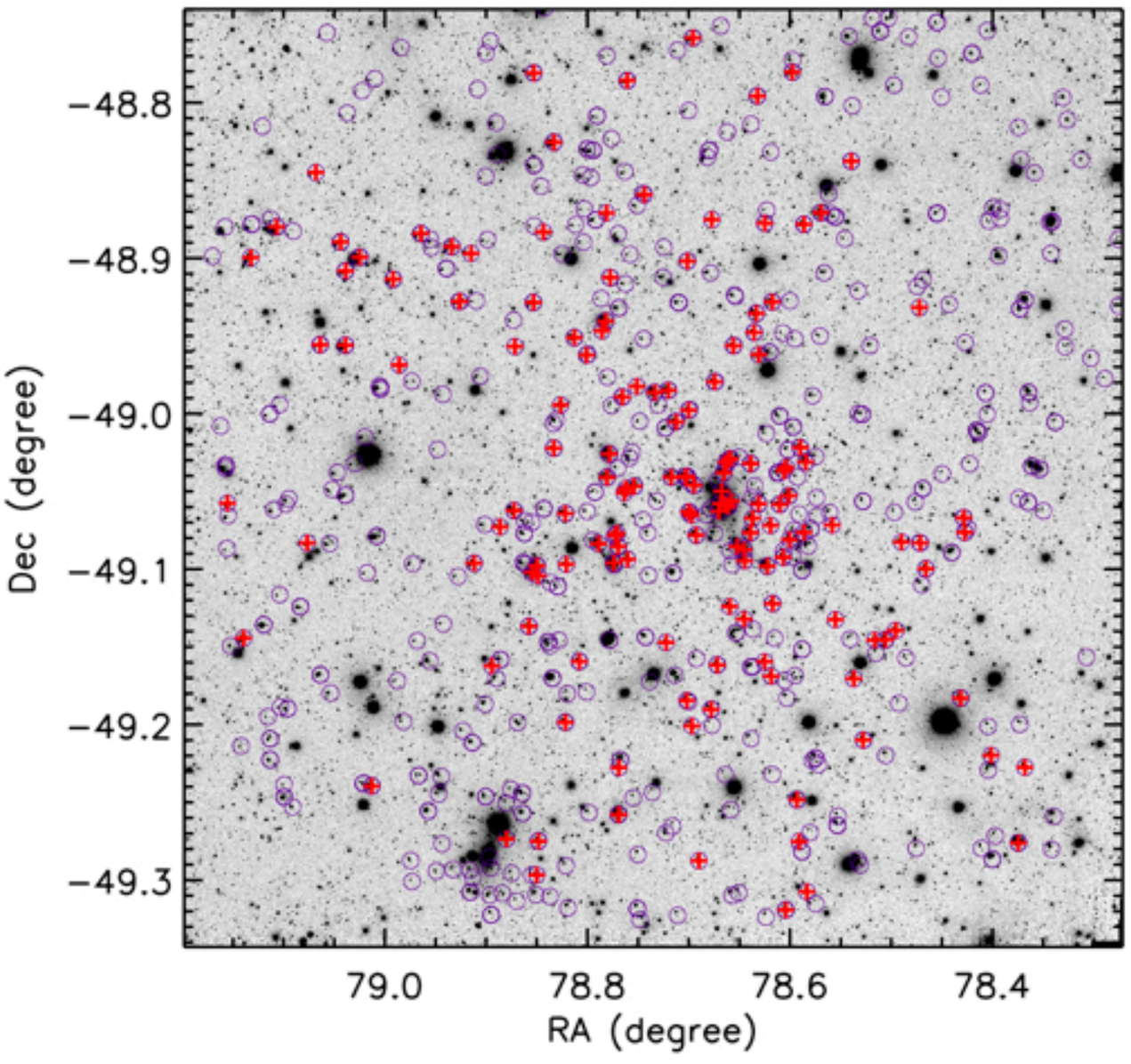
- R_{vir} ~ CTIO Blanco 4m MOSAIC FOV (36‘x36’)

- exposure ~ 2hr

- All with deep GALEX images

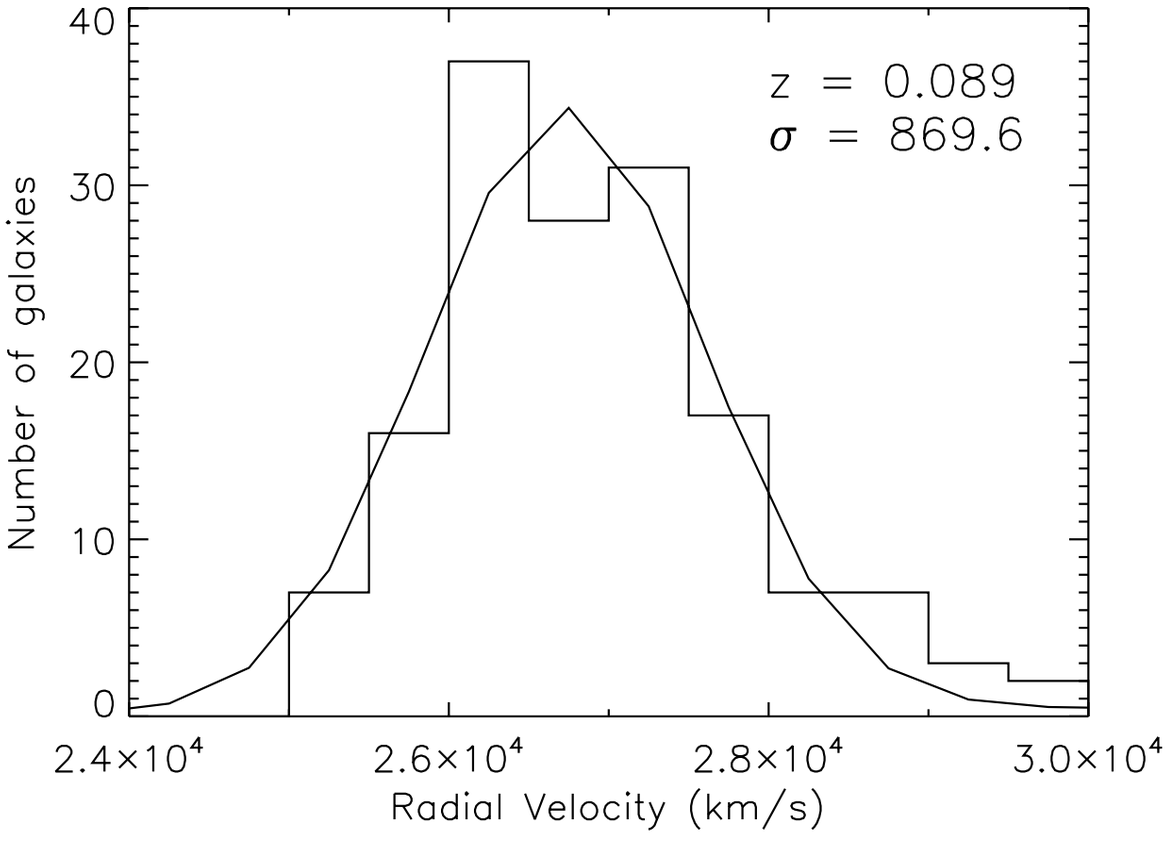


Hydra Spectroscopic Survey



Abell 3330 (○ : Targets, + : Members)

- 200~250 galaxies (r < 19) were observed for each galaxy cluster



Merger Signatures in Red-sequences in A2670

composite r

High post-merger fraction

[a] van Dokkum 2005

	Class	Cluster	Field[a]
	PM	38 *	49%
Bulge-dominated[c]	I	4	21%
	Total	42	70%

Sheen et al. 2012, ApJS, 202, 8

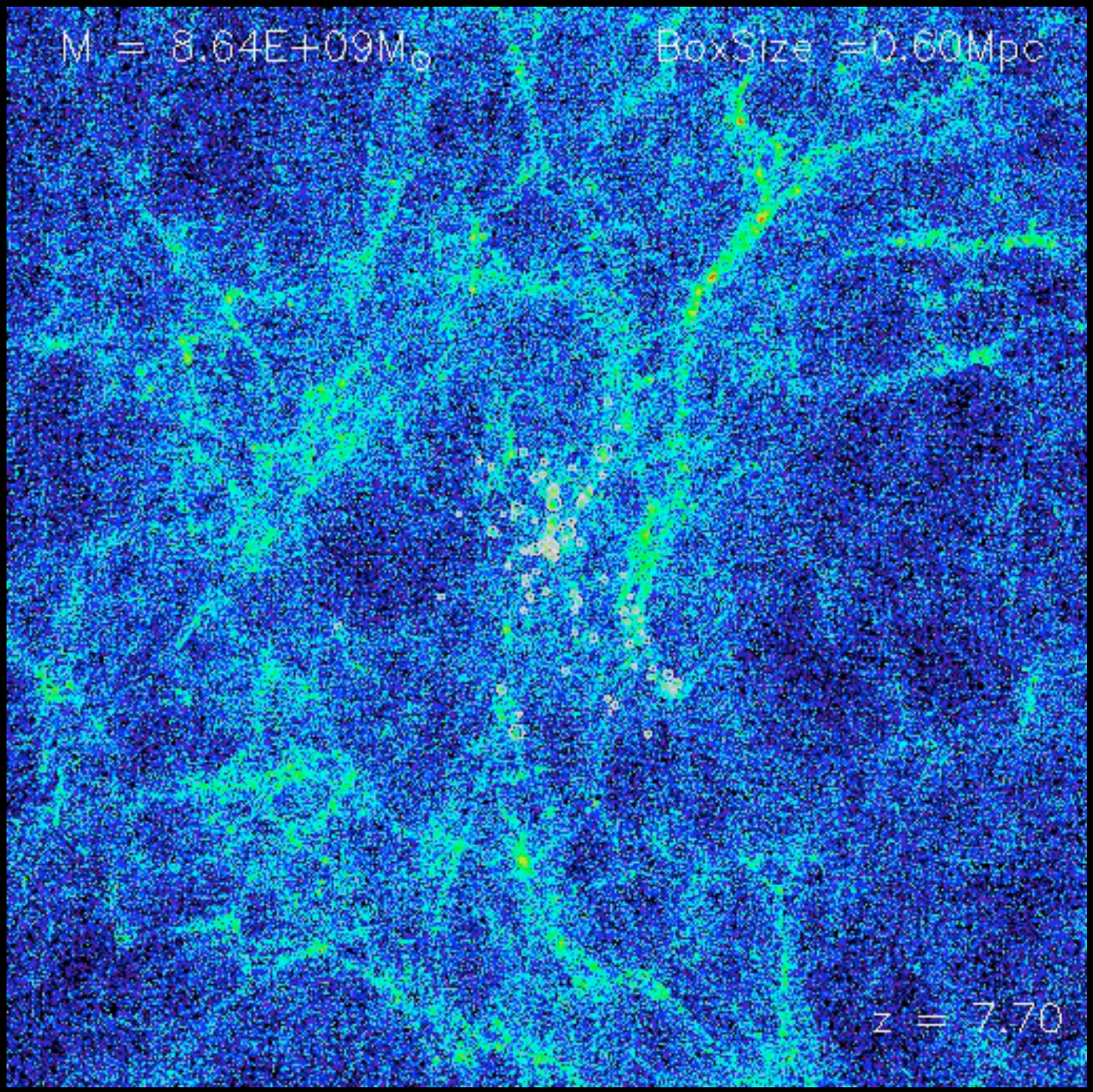
* N.B.
~10-20% on ETGs (CFHTLS)

Yi et al. 2013, A&A

Merger relics!

- build halo merger history from DM simulations
- semi-analytic tracking of subhalos in dense regions (Binney & Tremaine GD; Jiang et al. 2008)
- build model galaxies using SAM
- estimate “post-merger feature time” from galaxy merger simulations
- calculate the number of merger relics showing post-merger features in each halo

Subhalo tracking tough!



Jung, Lee, Yi 2014,
ApJ, in press

GADGETII

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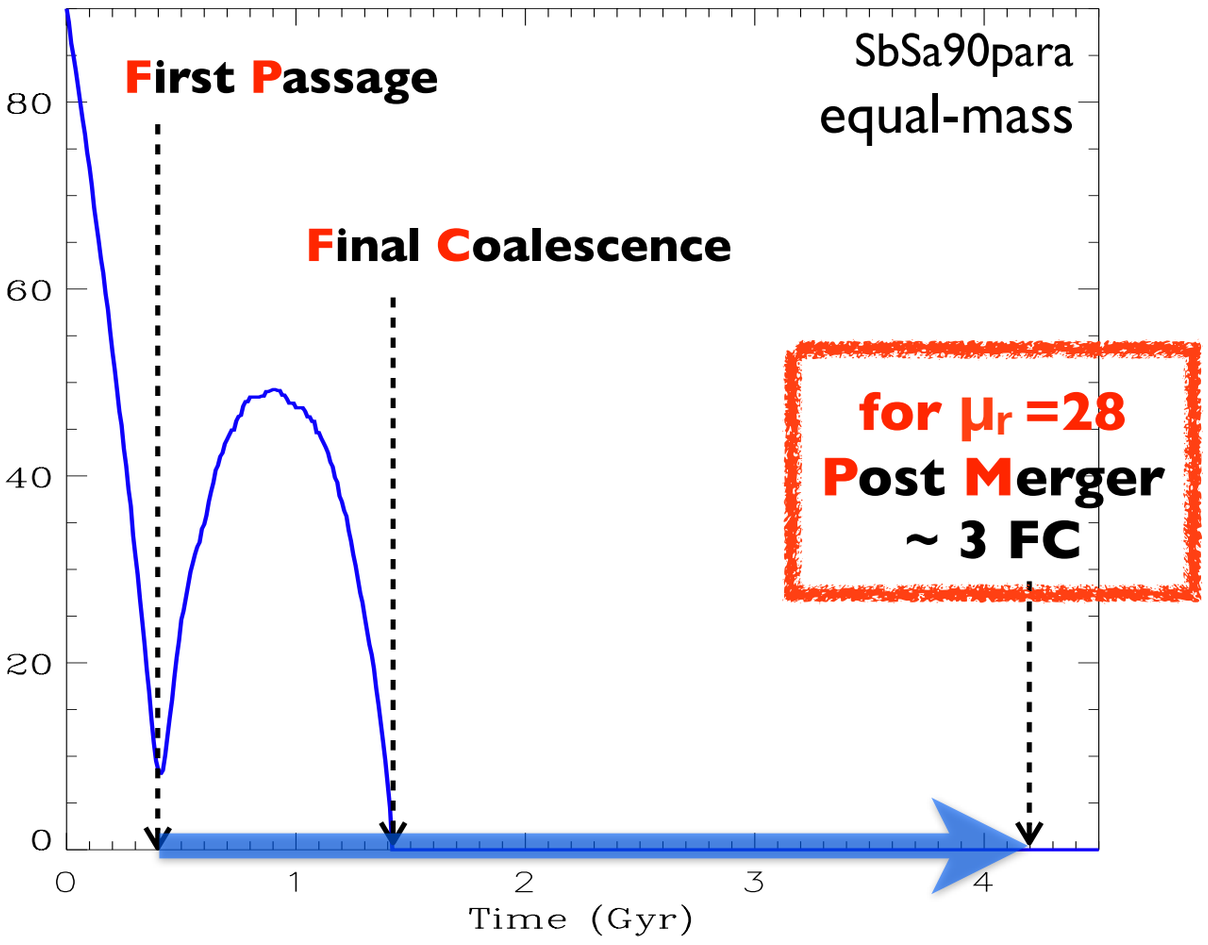
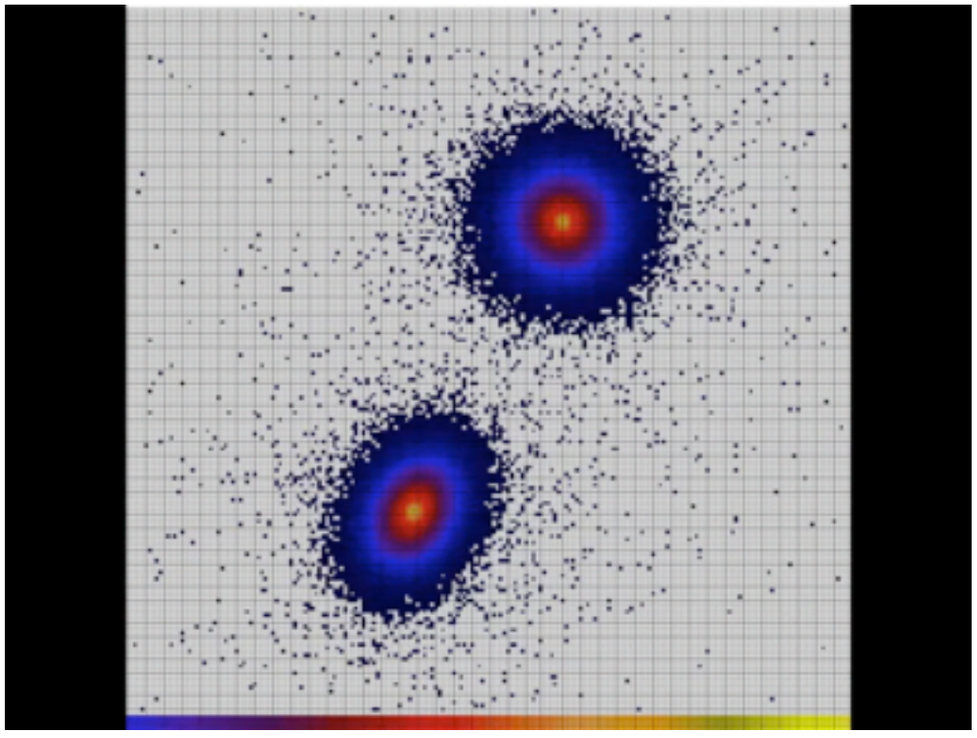
Post-merger feature time

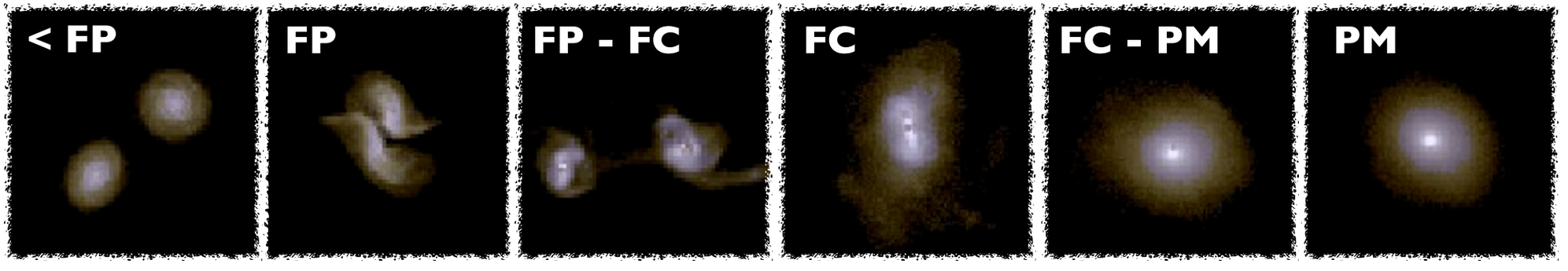
Ji, Peirani, Yi
2014, A&A



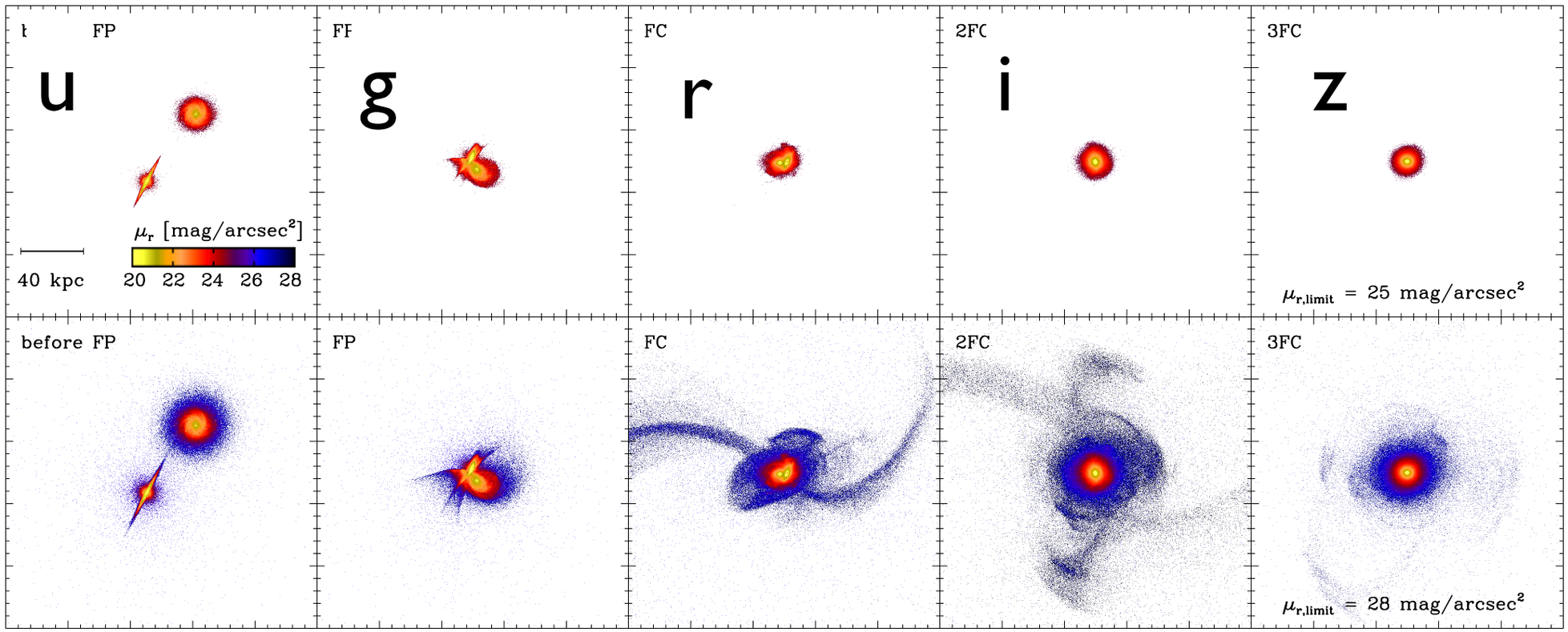
for μ_r =28
Post Merger
~ 3 FC



equal-mass disc+disc merger

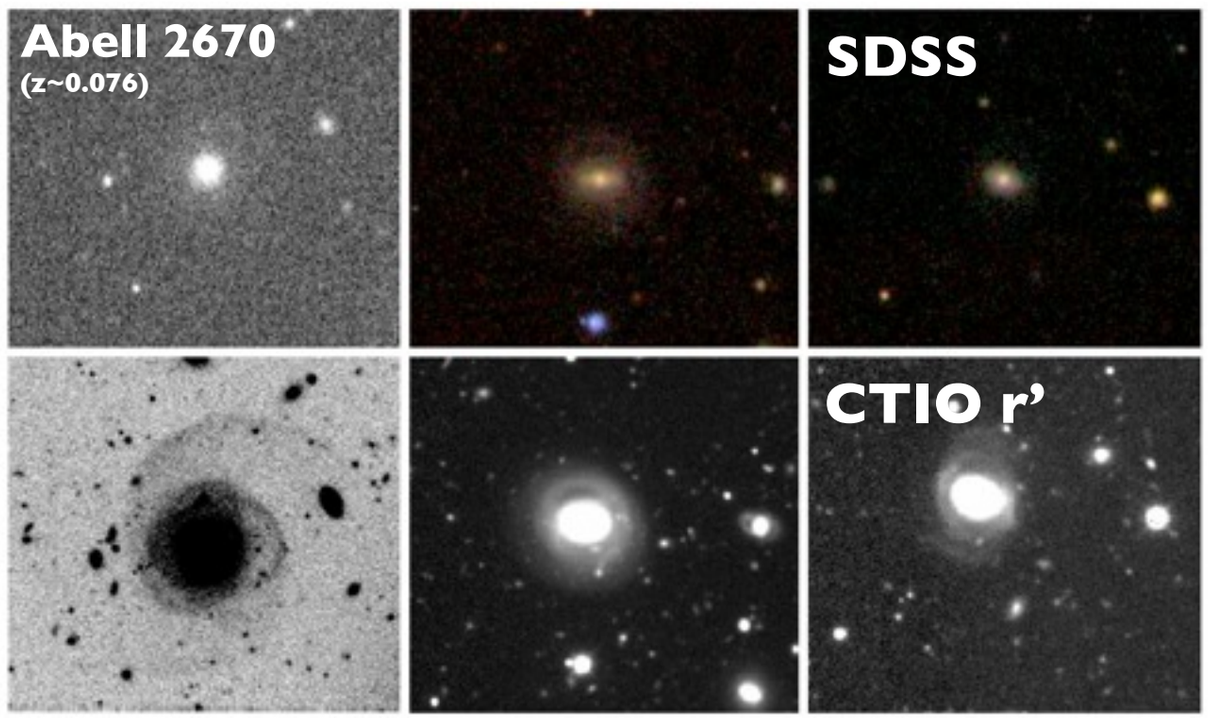


Post-merger features



25 mag arcsec^{-2}

28 mag arcsec^{-2}



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Courtesy of Y.K. Sheen

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Subhaloes with a resident galaxy with PM feature

red: bulge-dominant

blue: disc

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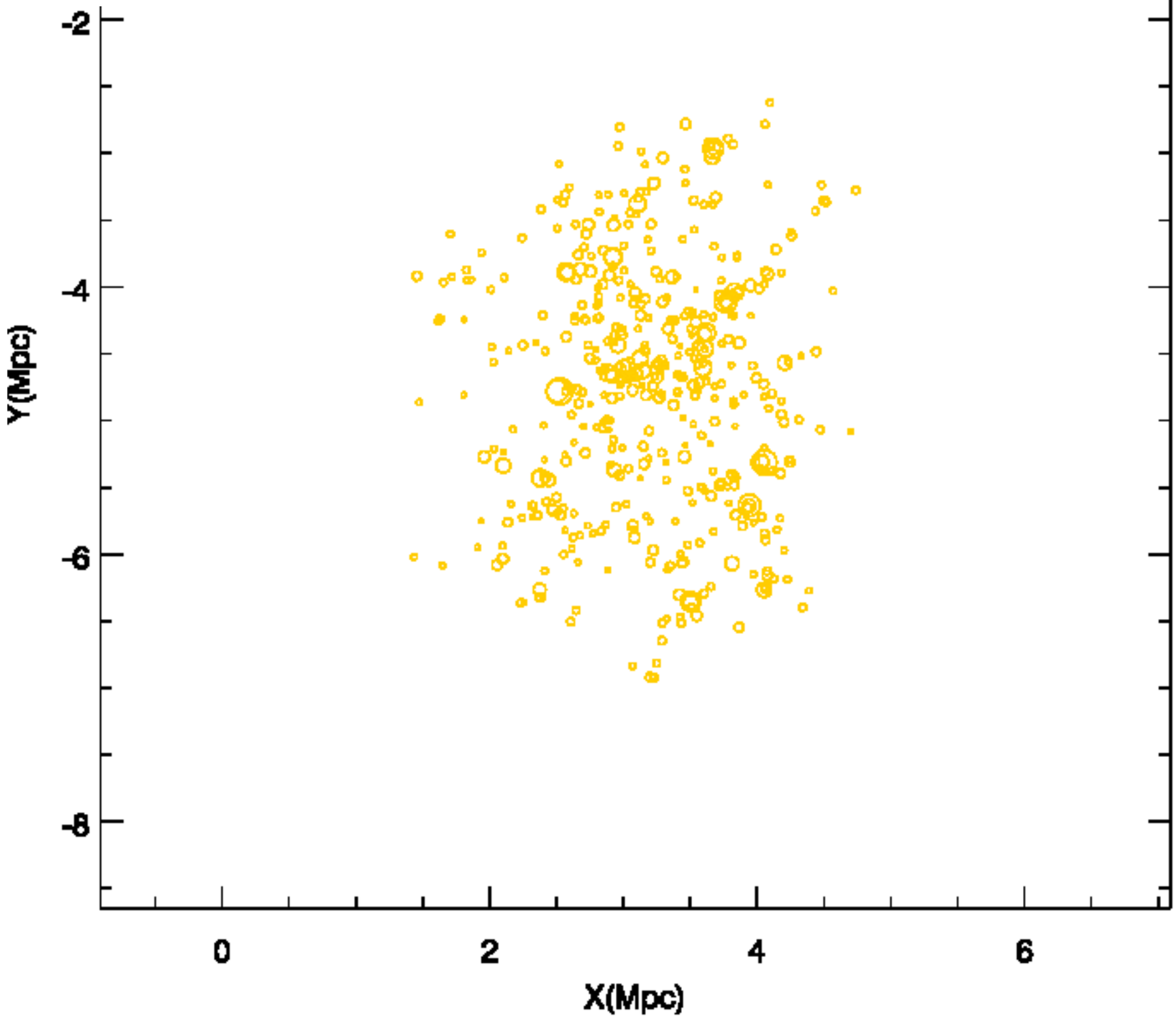
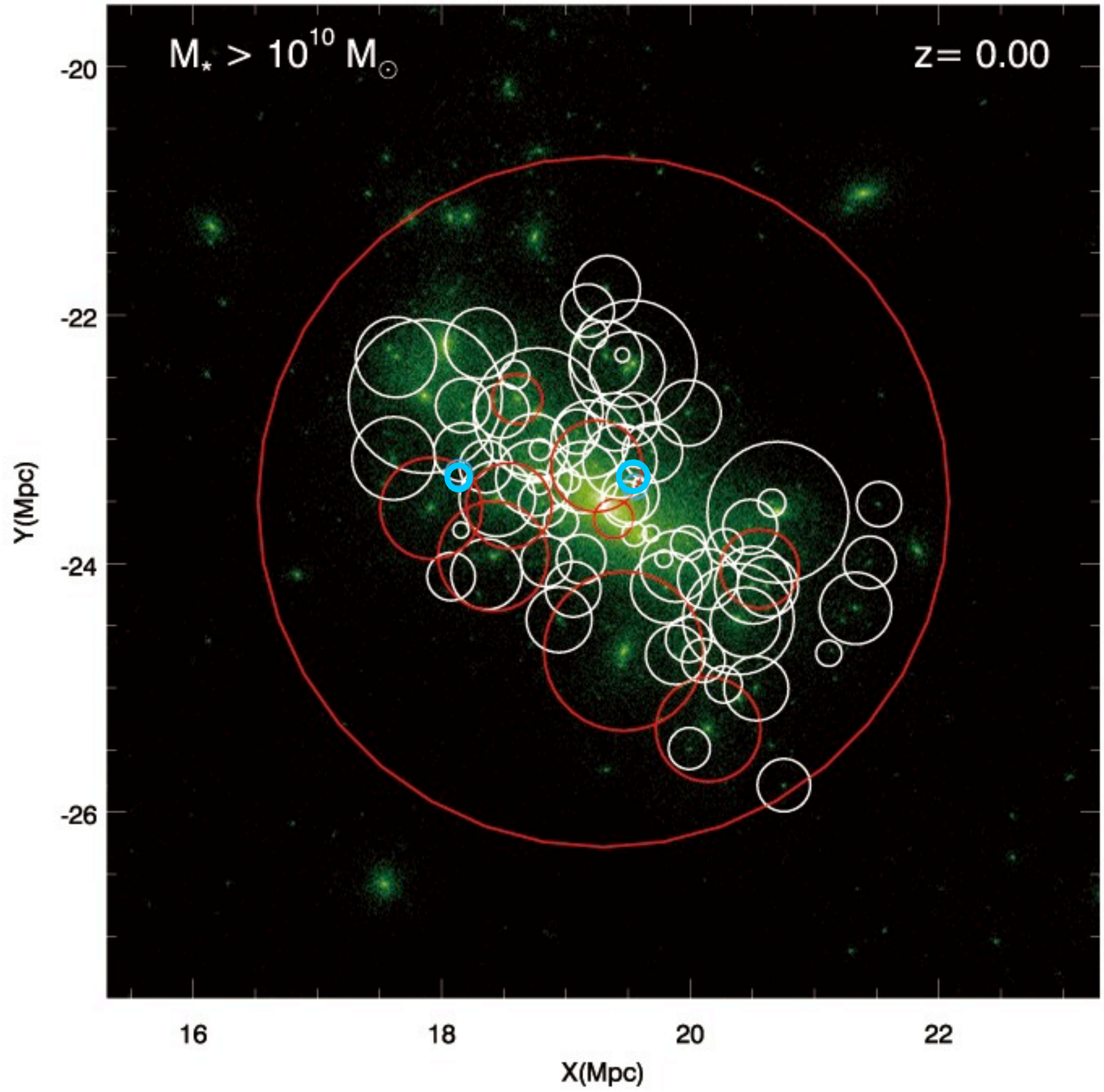
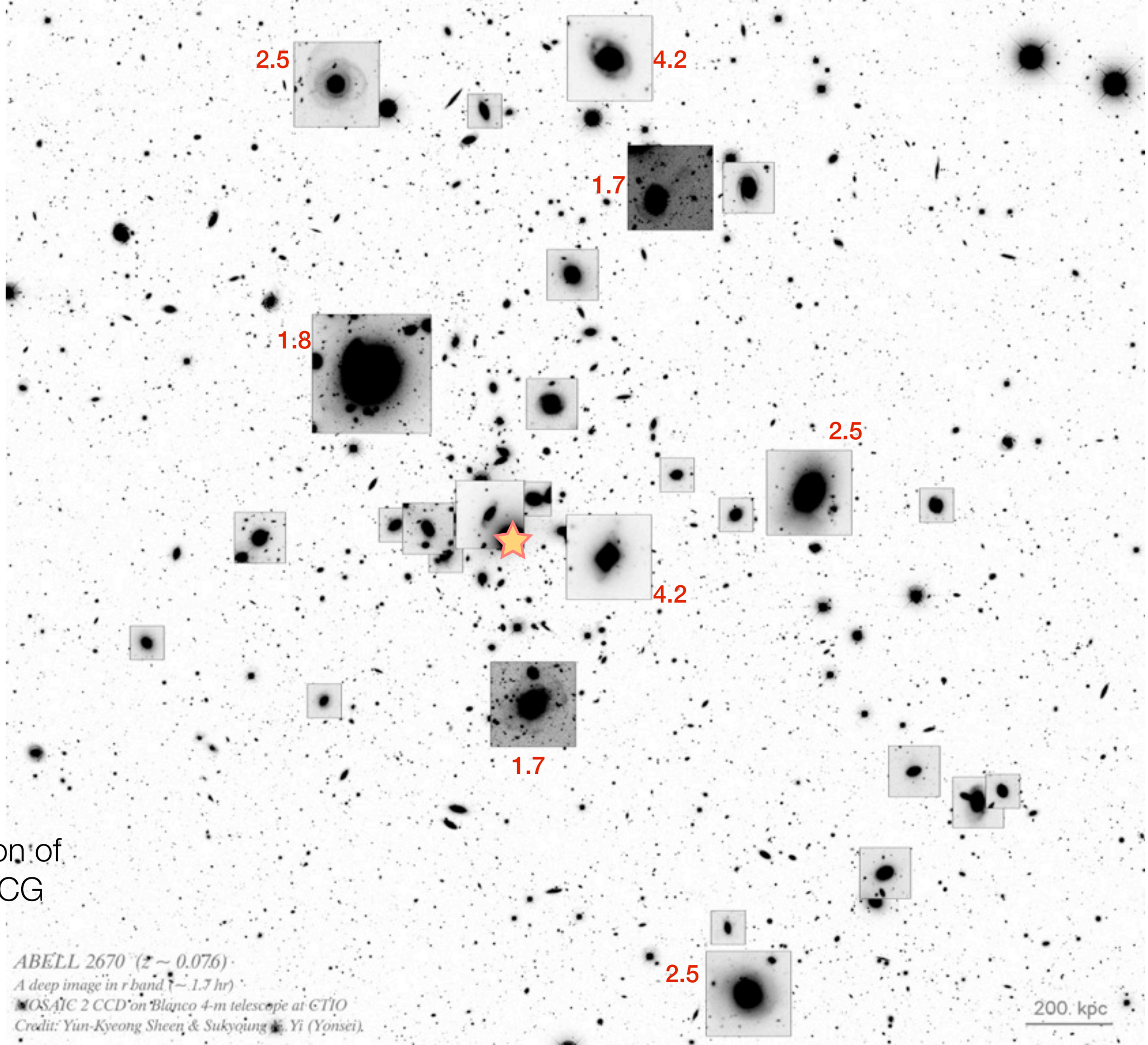
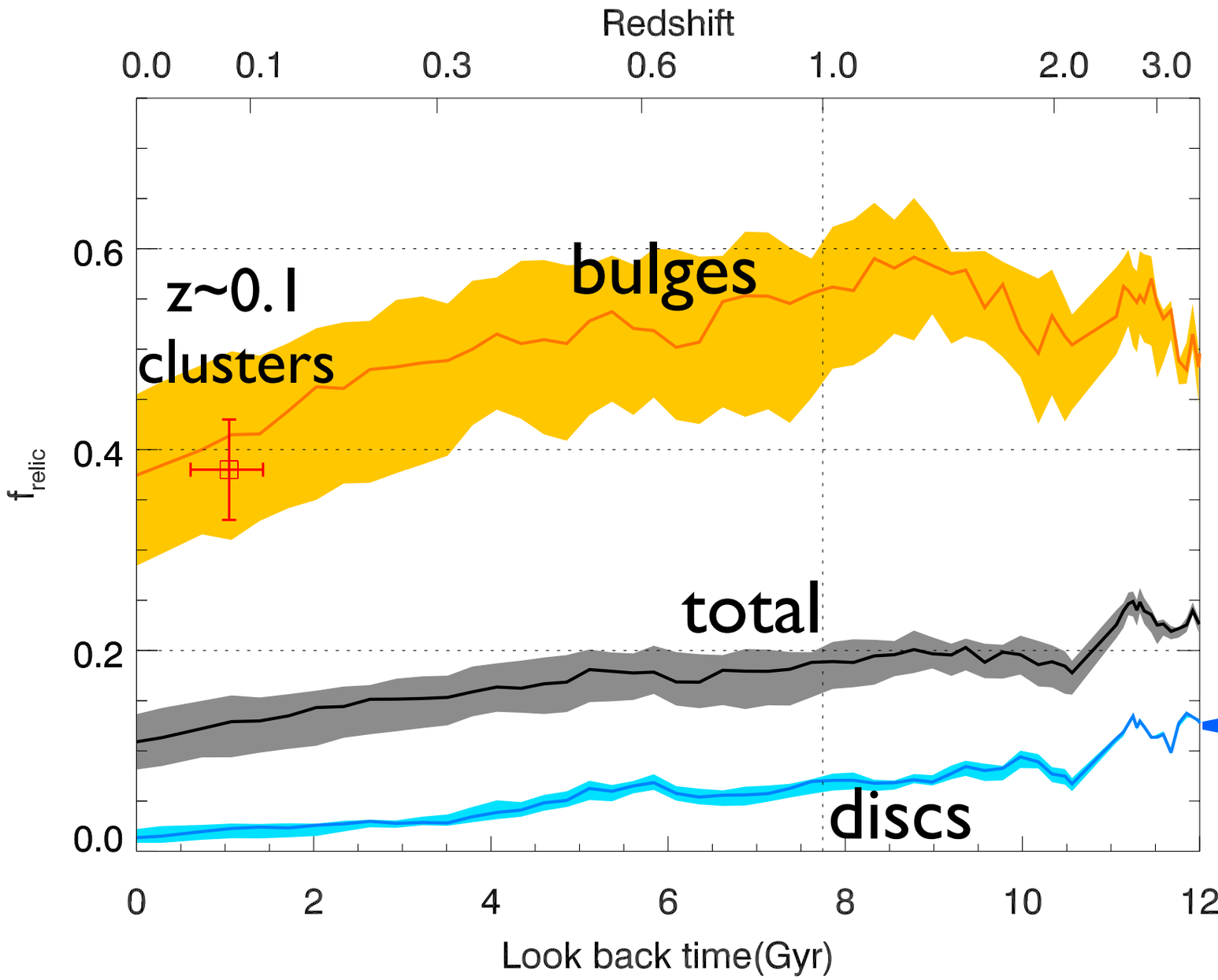



$M_\star > 10^{10}\ M_\odot$
z= 0.00
-20
-22
-24
-26
Y(Mpc)
16
18
20
22
X(Mpc)



Location of the BCG

Merger Relic Fraction

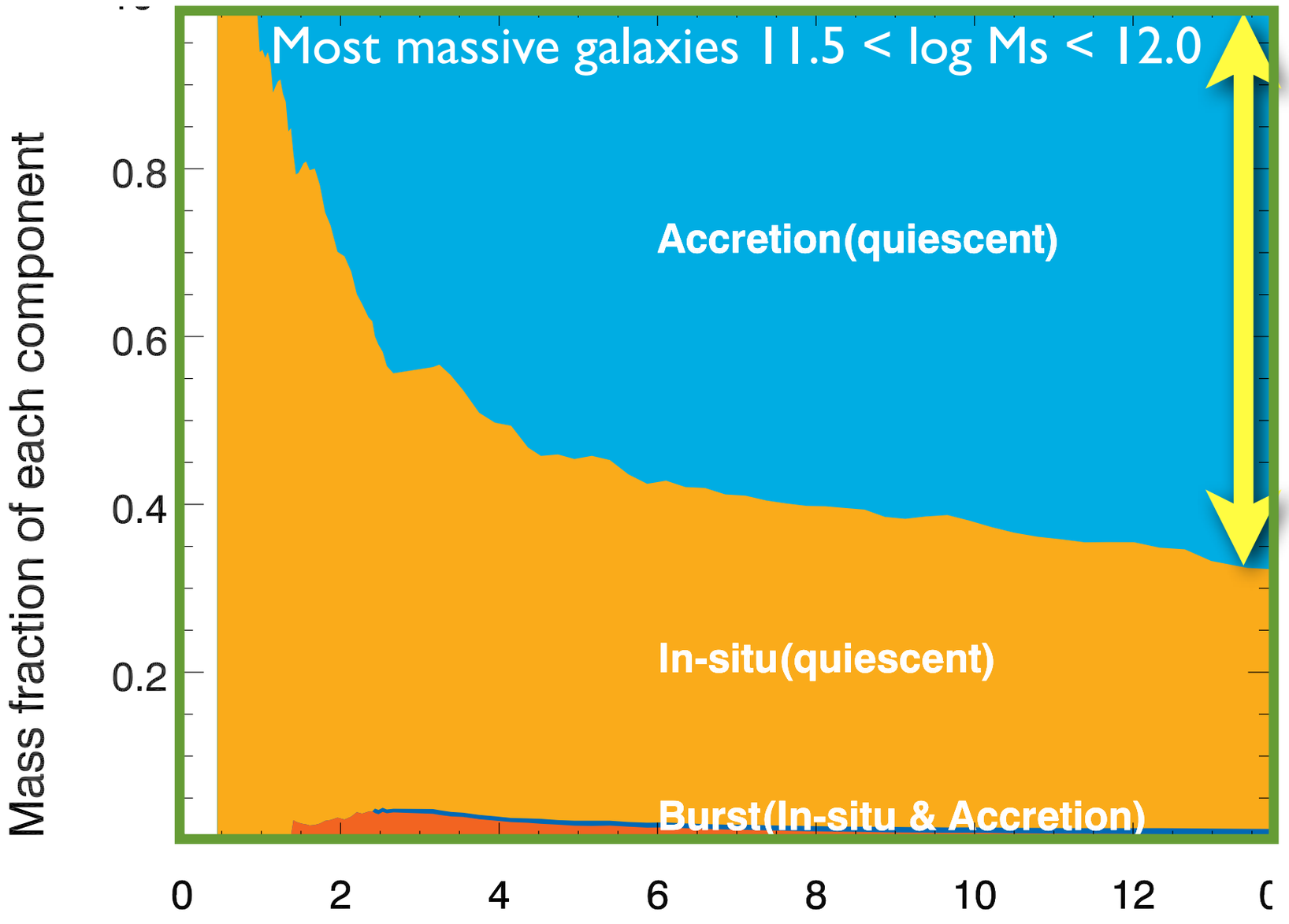


discs show merger features less frequently (c.f., Ferguson)

$t_{PM\ feature}$=2-4 t_{merge} (fiducial 3)

Lee & Yi 2013, ApJ

Merger accretion dominates stellar mass growth in the most massive galaxies



70% (10L*)

10% (1L*)

For Direct progenitors

Summary

- caveats
  - *merger feature*, mass ratio determination subjective
  - *baryon effects* on halo merger tree
  - *post-merger feature time* (larger parameter space to explore)
- galaxy mergers
  - found to be frequent in clusters too
  - may be *merger relics* from previous halo environments
- cluster deep imaging campaign: 20 clusters with CTIO/Magellan/CFHT
- new approach of galaxy evolution studies
- full hydrodynamic simulation (Hoseung Choi's poster)

Hoseung Choi

Ramses
Zoom-in
simulations
on clusters