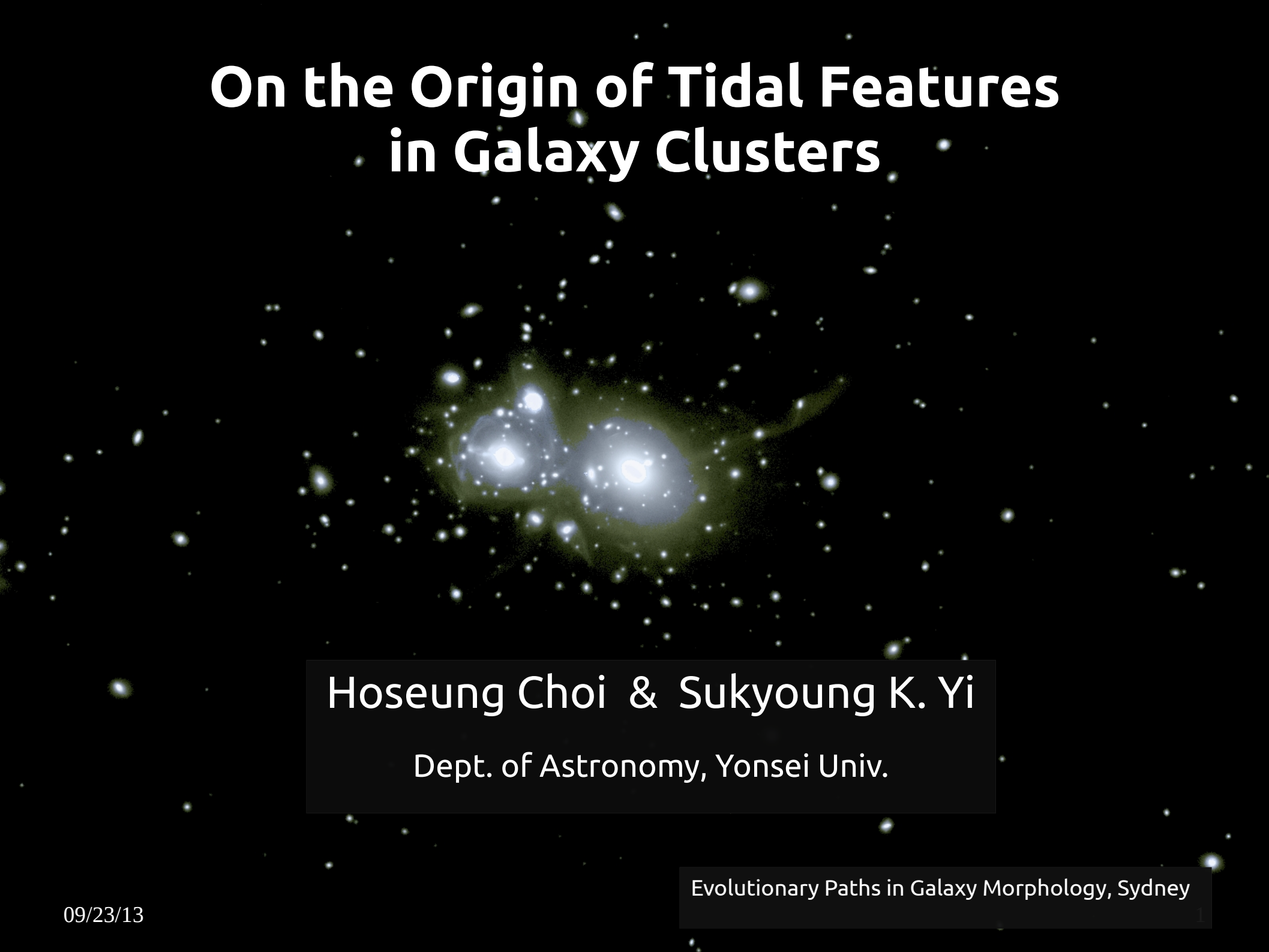
On the Origin of Tidal Features in Galaxy Clusters



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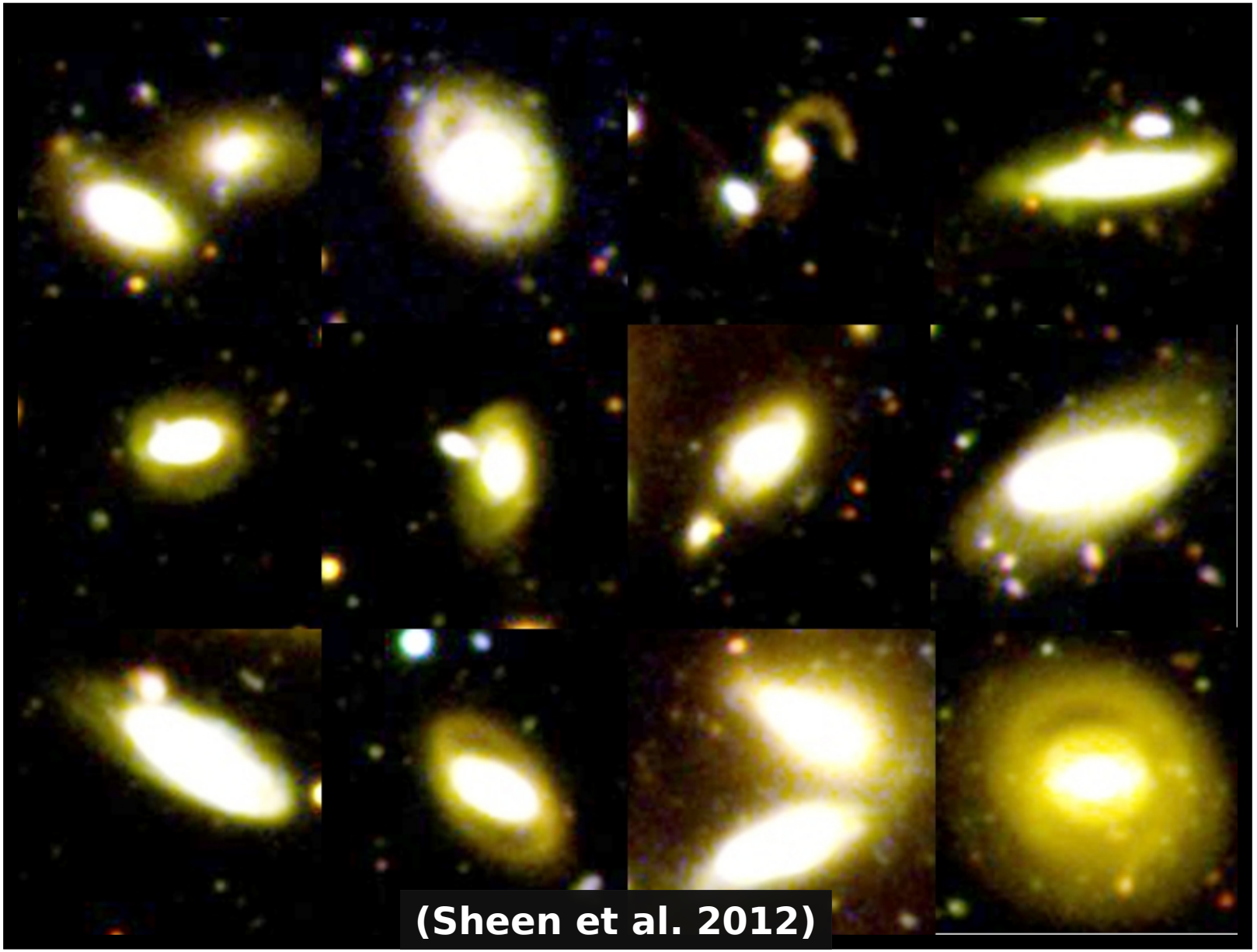
09/23/13

INTRODUCTION

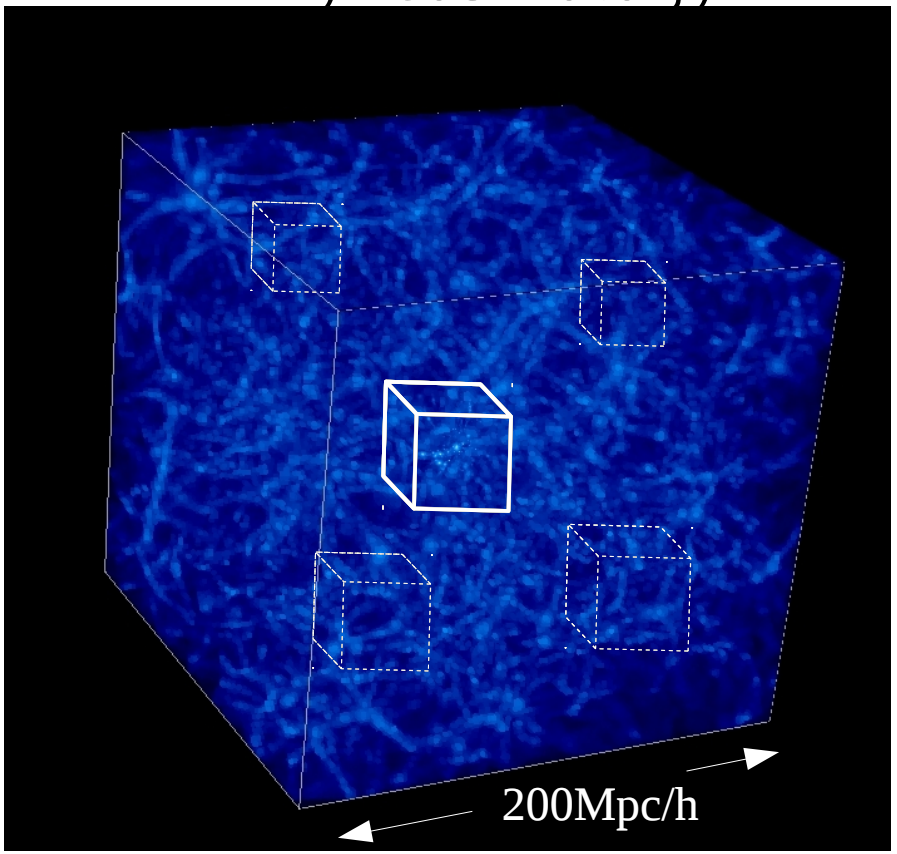


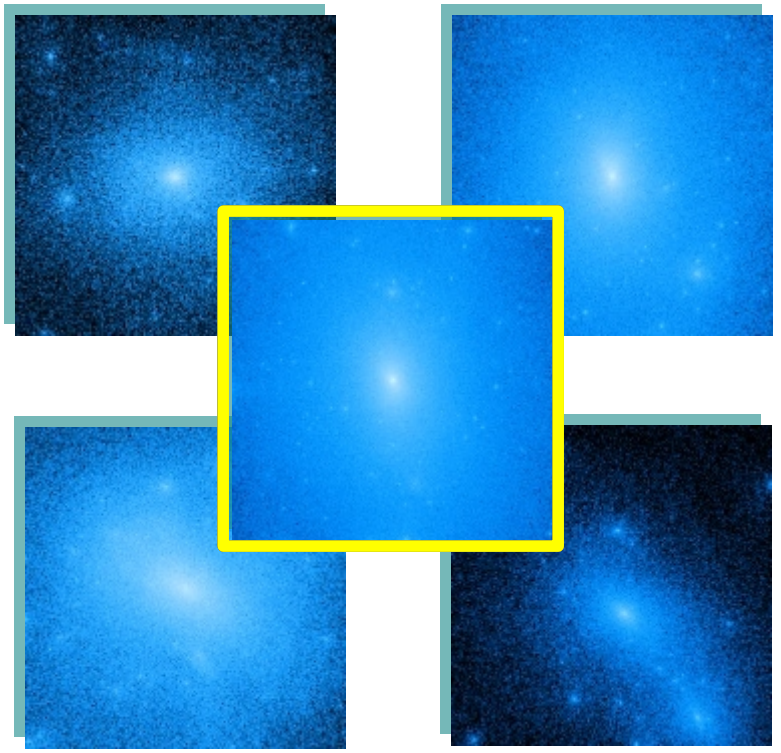
Q: Why do we see **merger features** in **cluster** environments?

→ Hydrodynamic simulation

Simulations of clusters

- RAMSES (AMR, Hydrodynamics)
- WMAP 7yr cosmology

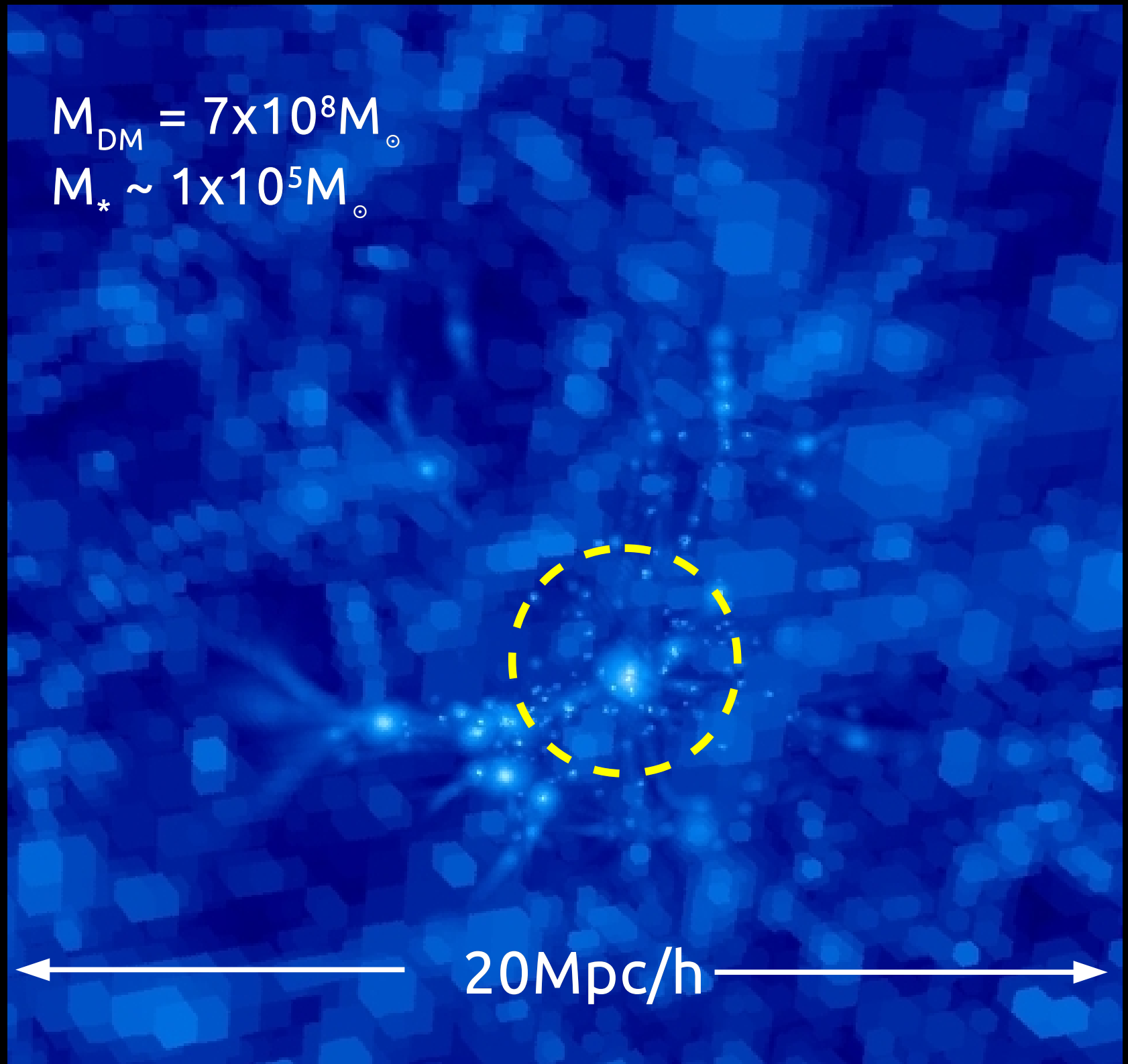




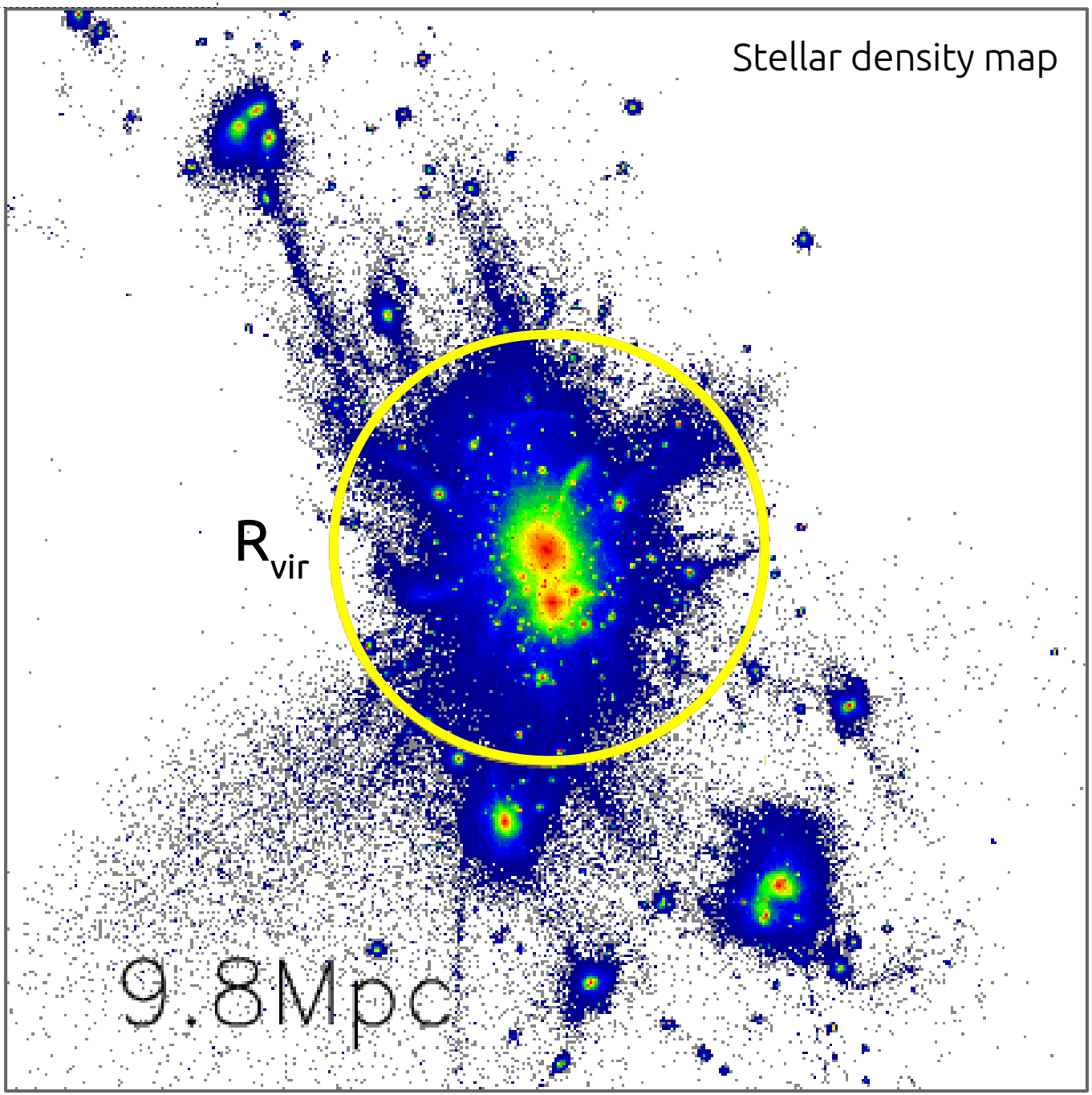
5+ clusters, $10^{14} \sim 10^{15} M_{\odot}$

A cluster simulation

- Previous works - Attempts to simulate clusters
  - Maller +06, Crain +09, Feldmann +10
- (People think) finally, we can make 'good' galaxies.
  - Booth & Schaye 09, Dubois +11, Scannapieco +12
- Needs lots of computational power
  - 240CPU x 4 months, 1TB memory / 1 cluster

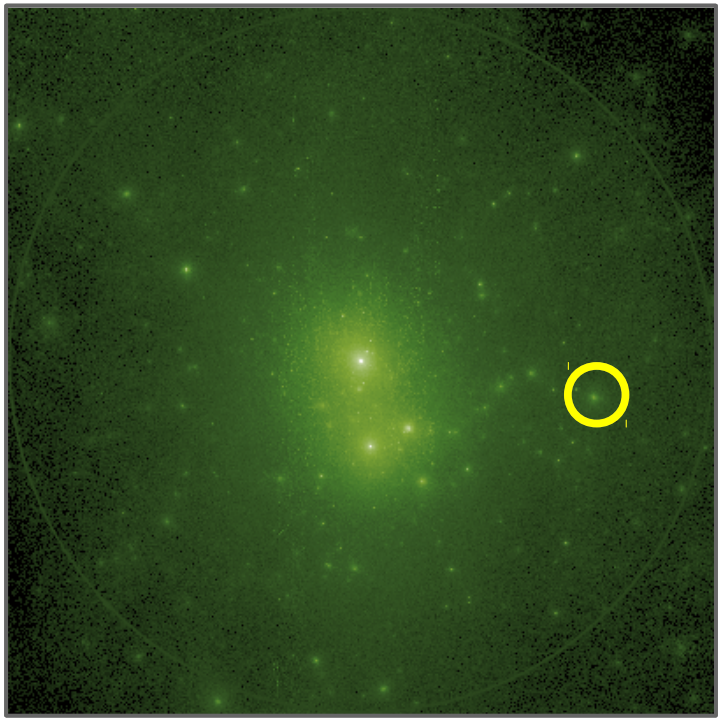

$M_{DM} = 7x10^8 M_\odot$
$M_* \sim 1x10^5 M_\odot$
20Mpc/h

NUMERICAL SIMULATION



Halo & galaxy identification

- Halo finding (AdaptaHOP, Aubert +04)
  - # DM halo : 1598
  - $M_* > 10^{10} M_\odot$: 183



Dark matter density map of the cluster

Halo & galaxy identification

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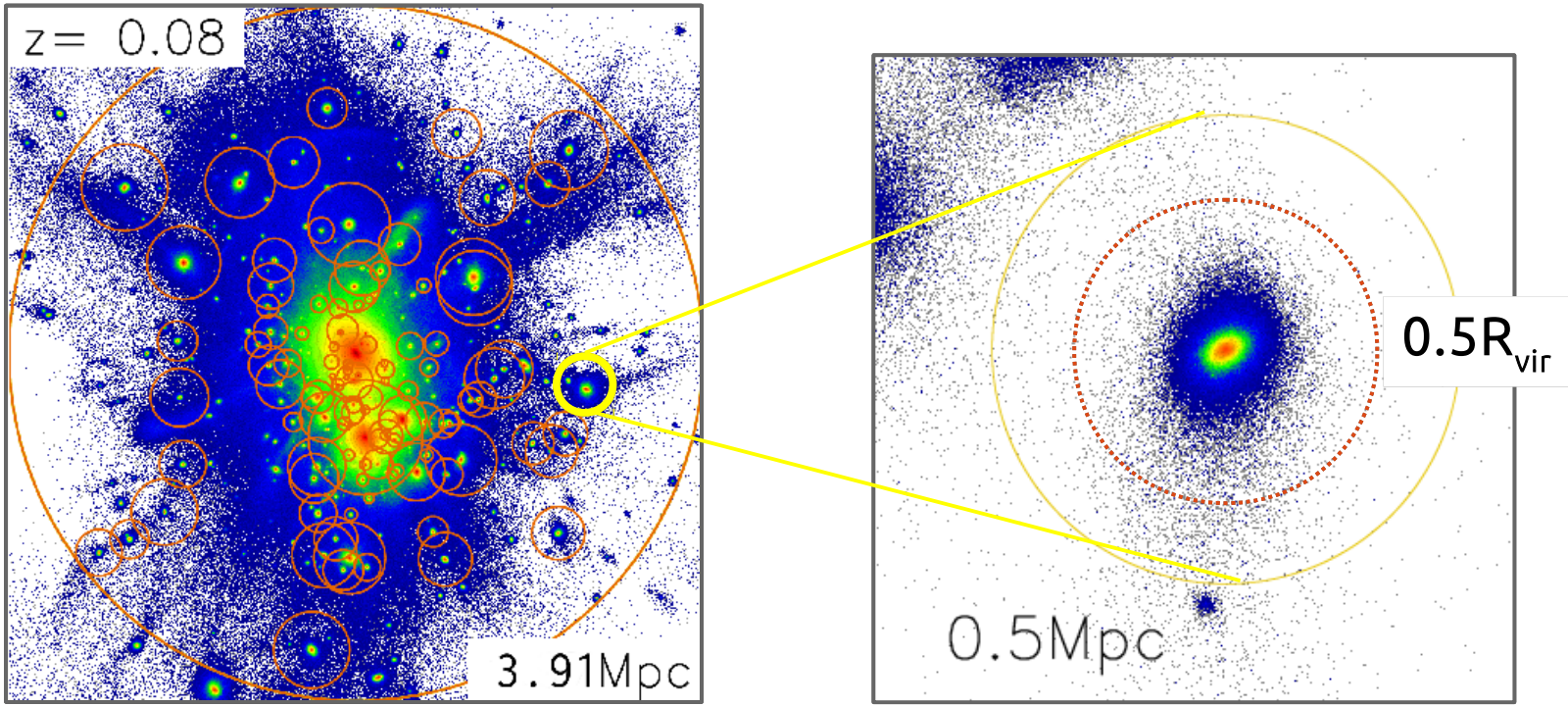
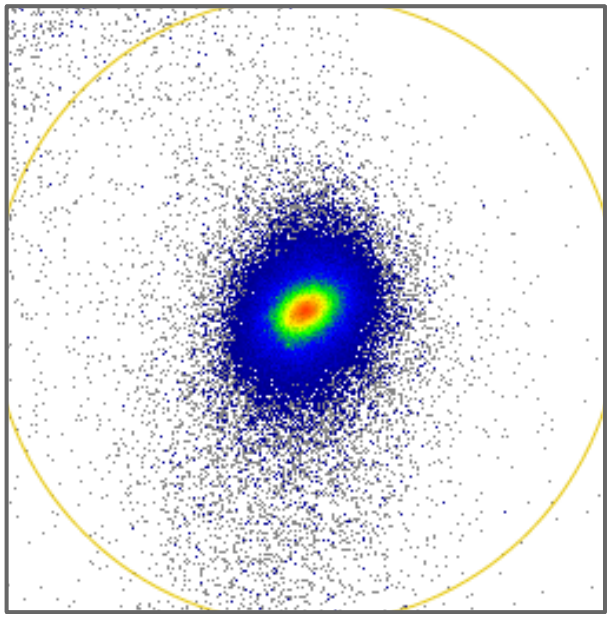


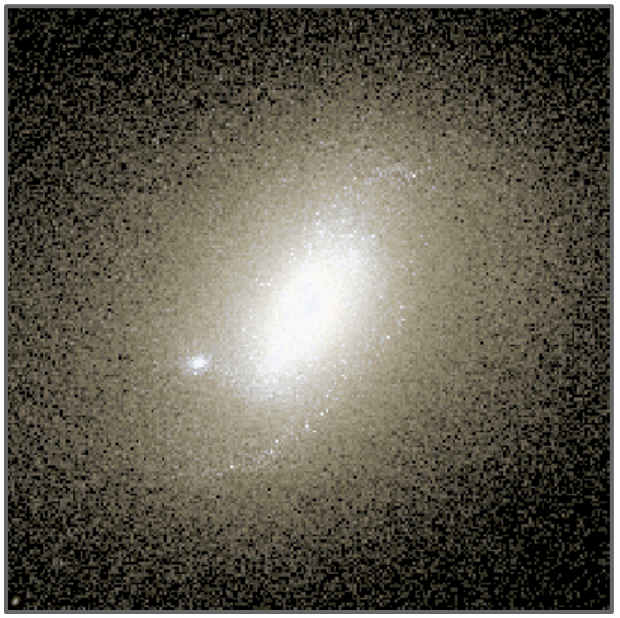
Stellar density map of the cluster

Mock image

- SED synthesis (Ji et al. Submitted, Bruzual & Charlot 2003)
  - D_L=362Mpc (z = 0.08), μ_r=28 mag/arcsec^2, 0.24'' / pixel
  - $M_r < -20 \rightarrow 112$



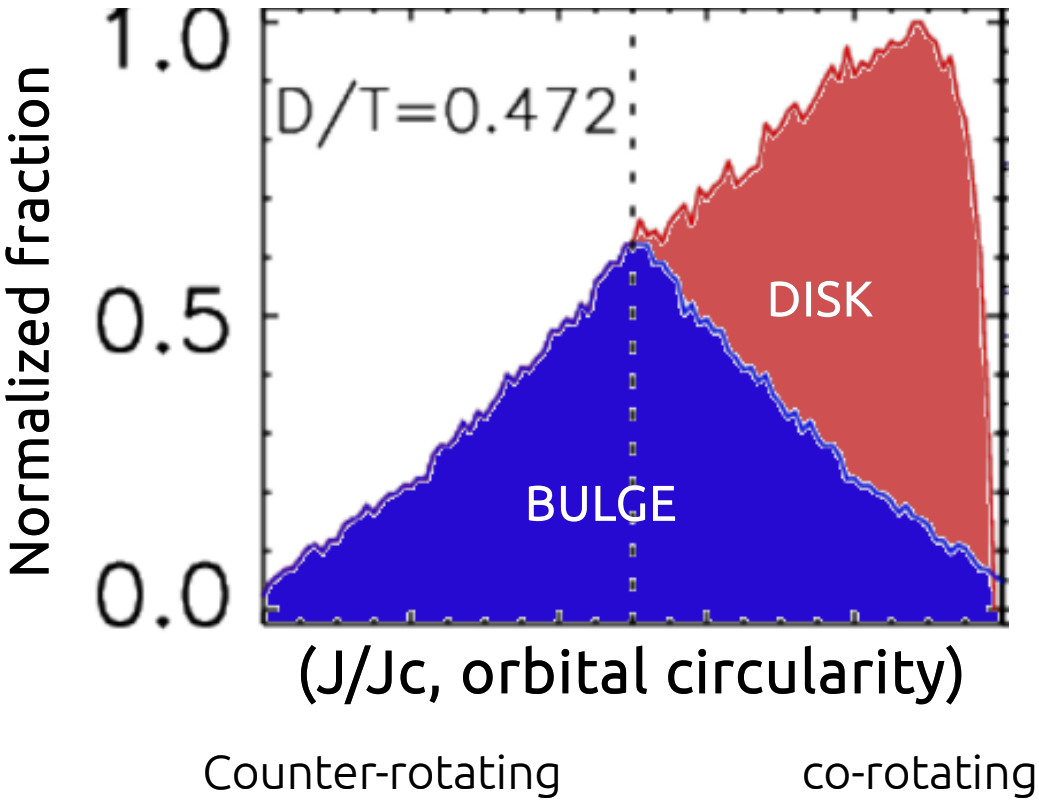
Age & metallicity



(synthetic color mock image)

Morphology classification

- D/T decomposition (Abadi 2003)



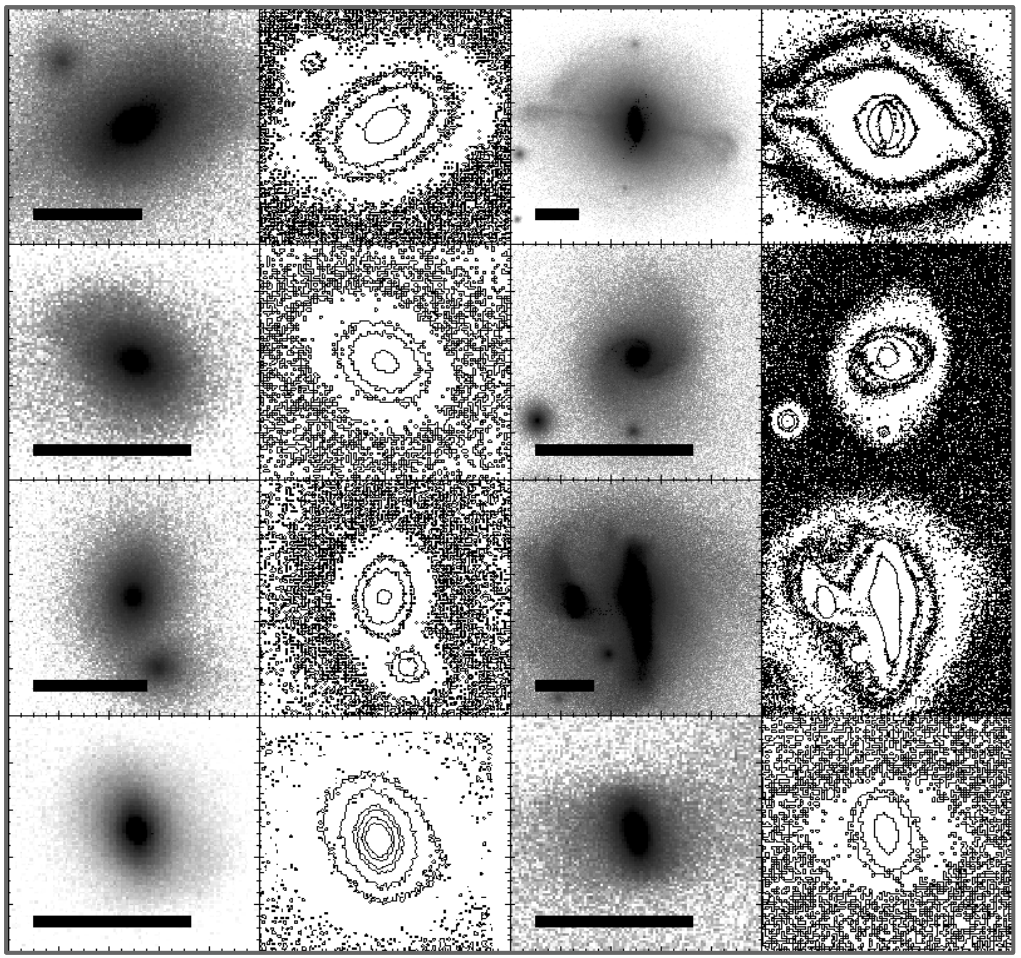
+ Visual inspection

= **78 massive Es**

RESULTS

RESULT

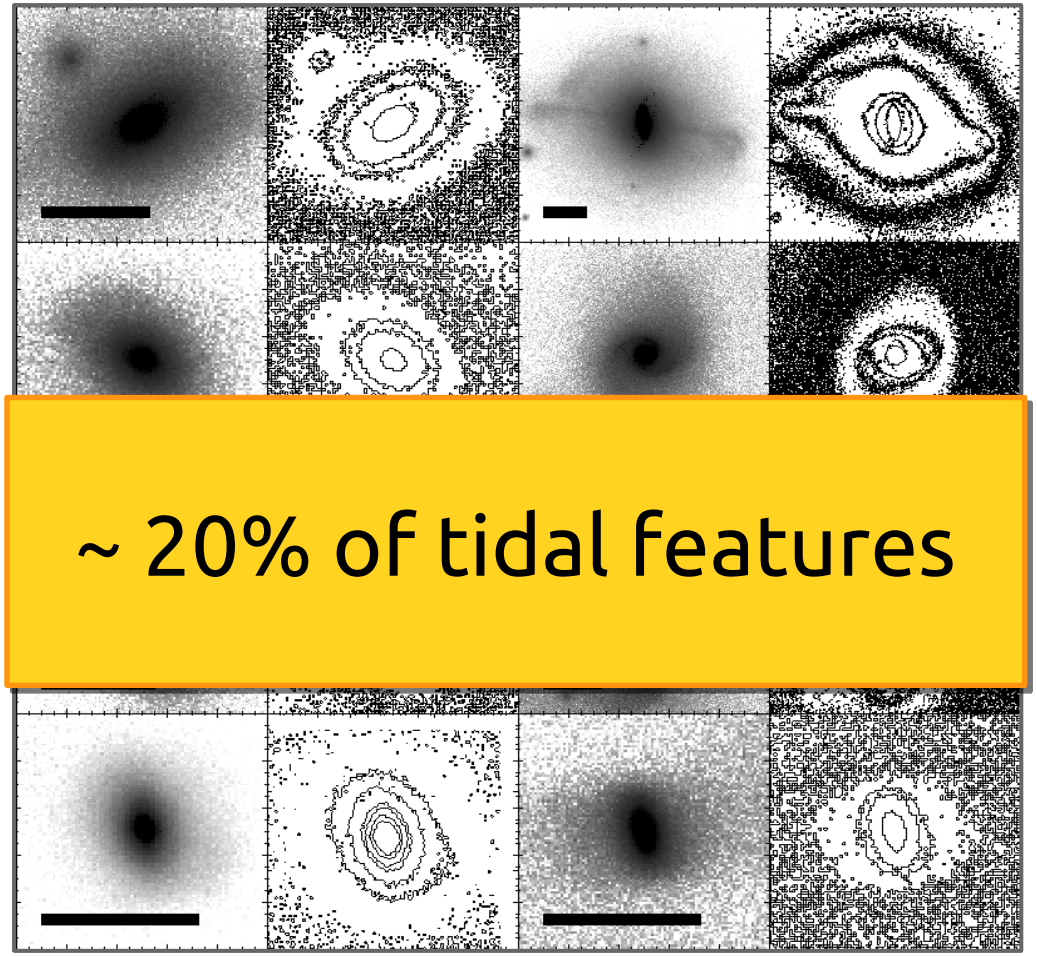
Tidally Disturbed galaxy fraction



* Some of the tidally disturbed galaxies
** Each bar represents 50kpc

RESULT

Tidally Disturbed galaxy fraction

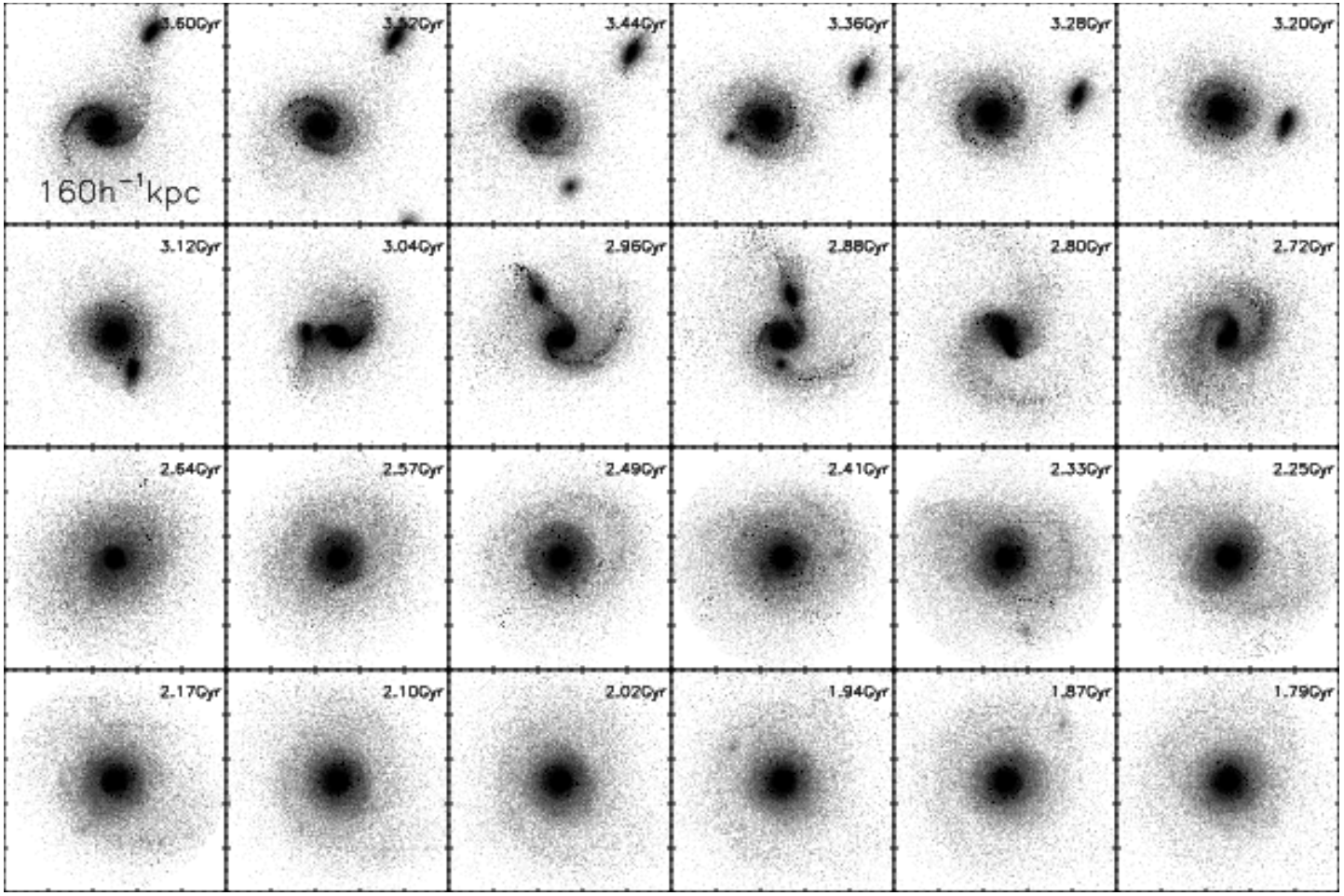


~ 20% of tidal features

* Some of the tidally disturbed galaxies
** Each bar represents 50kpc

RESULT

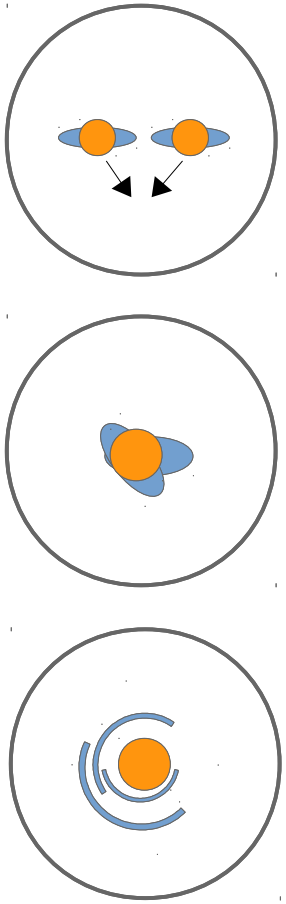
Interaction history



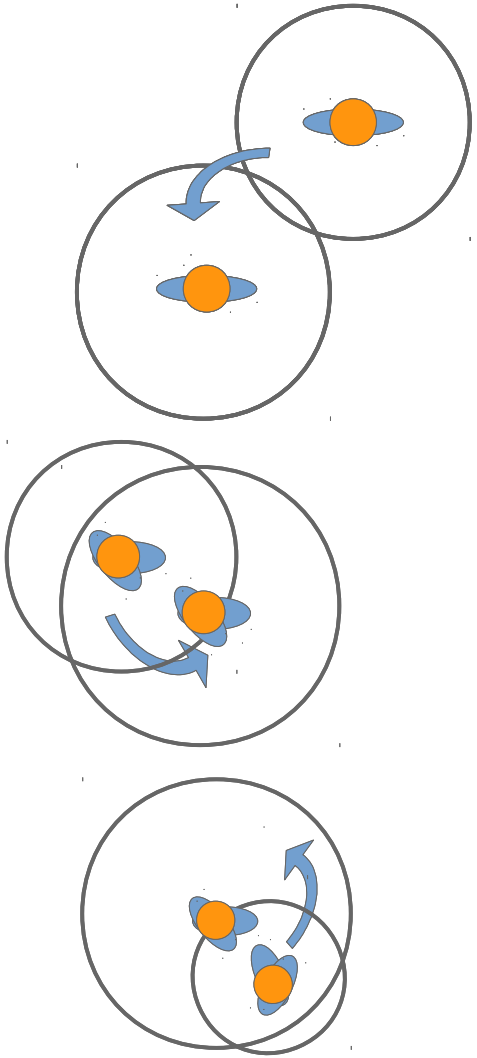
* Part of the interaction history of a TD galaxy.
** Z=0.5 (4.3Grys ago) ~ t_{now} in 75 snapshots

RESULT

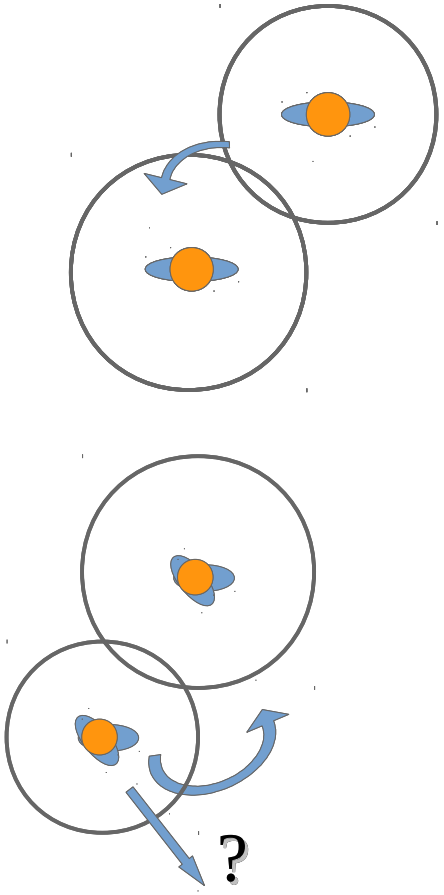
Interaction types



Galaxy Merger
(5 galaxies)



Halo Merger
(4 galaxies)

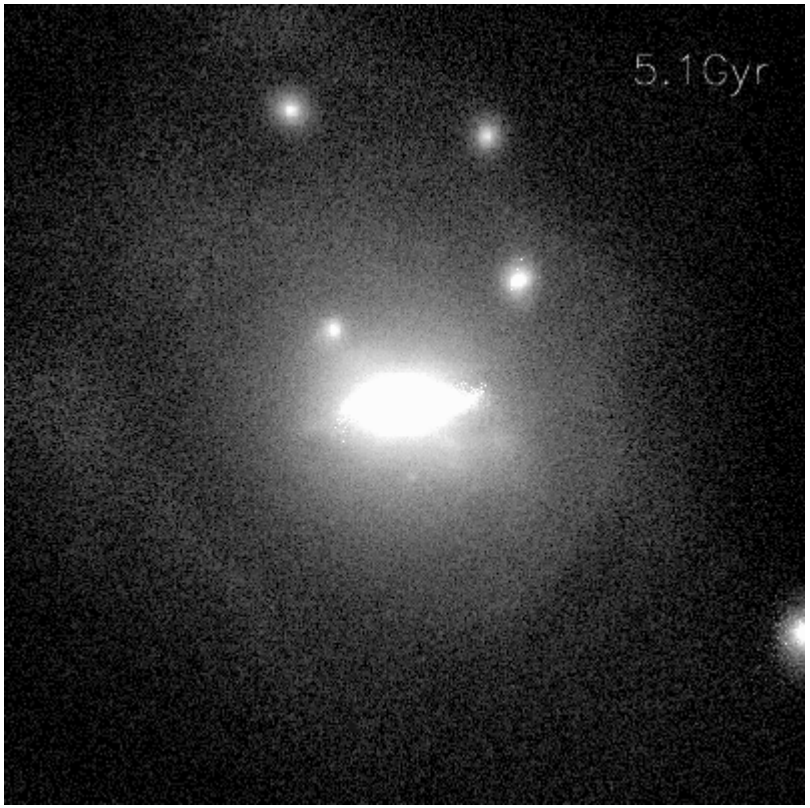


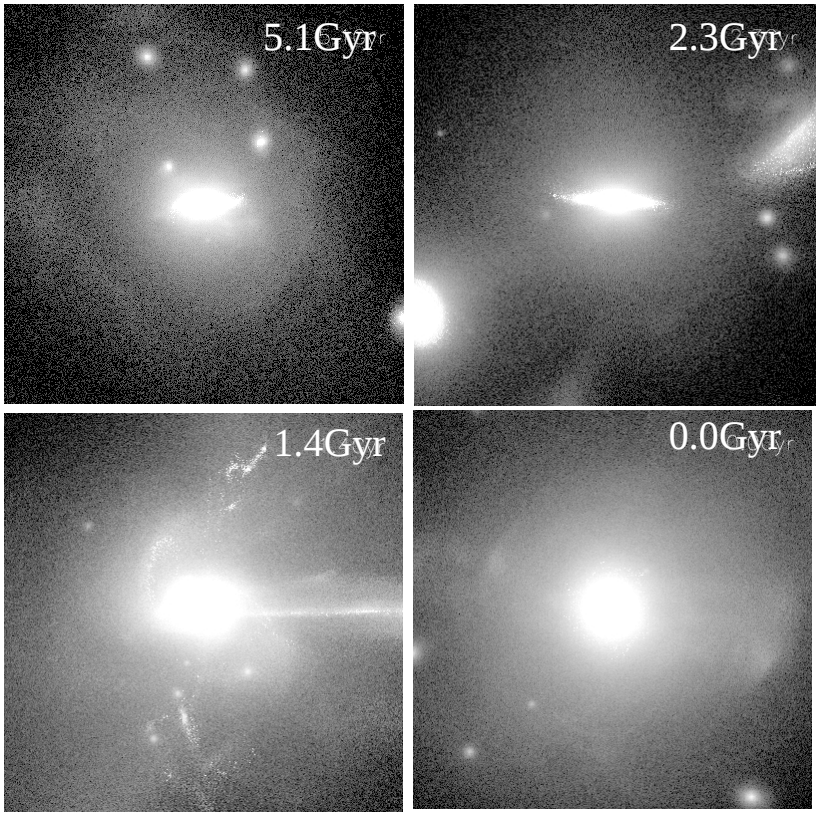
Fly-by
(4 galaxies)

RESULT

Evolutionary history

Example 1) post merger





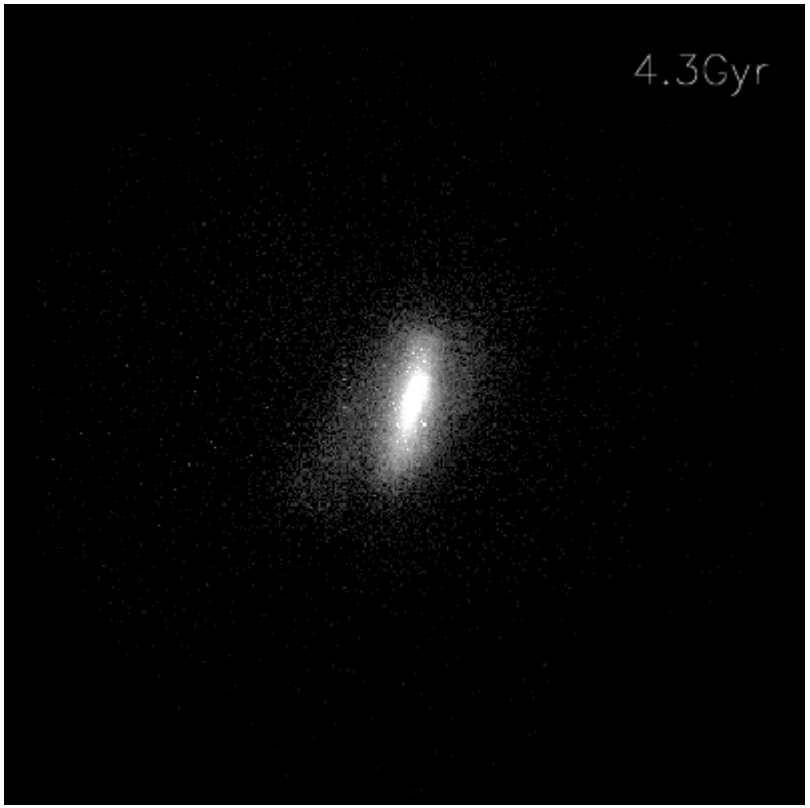
Merger Merger features

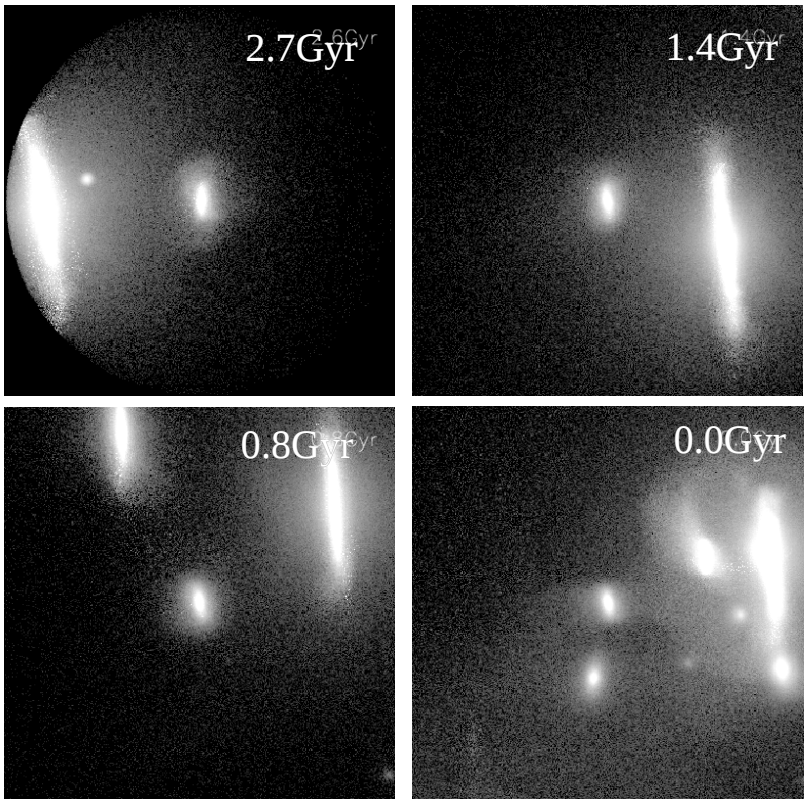
2.3 1.4 0.0 (Gyrs ago)

RESULT

Evolutionary history

Example 2) halo merger





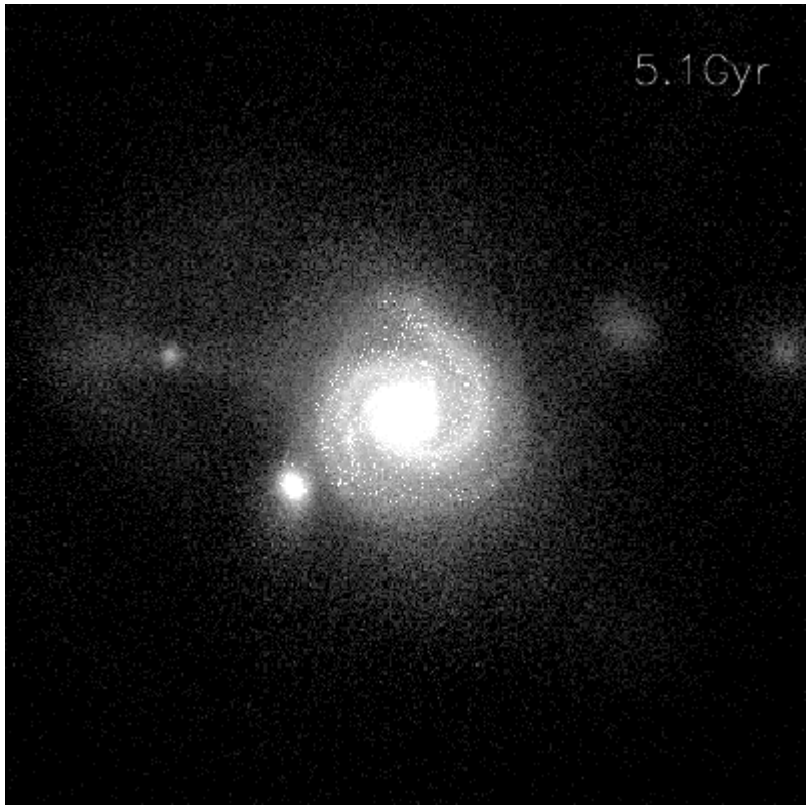
Halo merger (tidal feature)

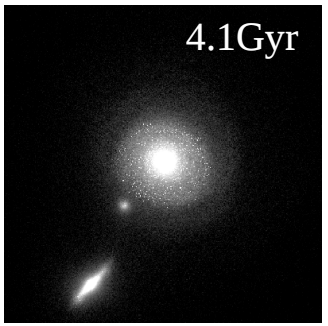
4.1 0.0 (Gyrs ago)

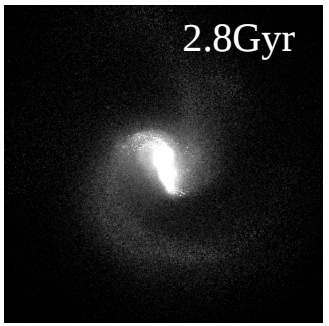
RESULT

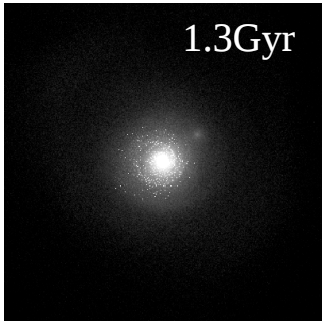
Evolutionary history

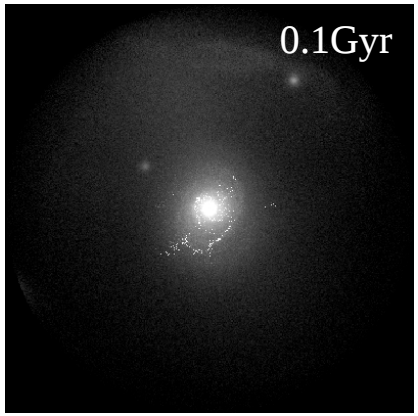
Example 3) fly-by encounter

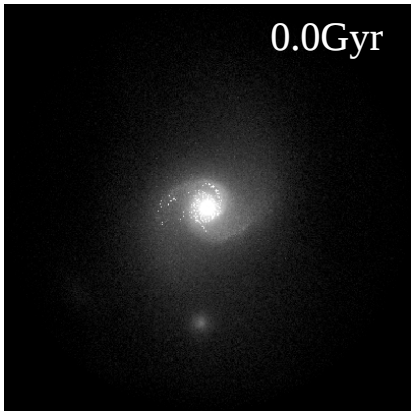










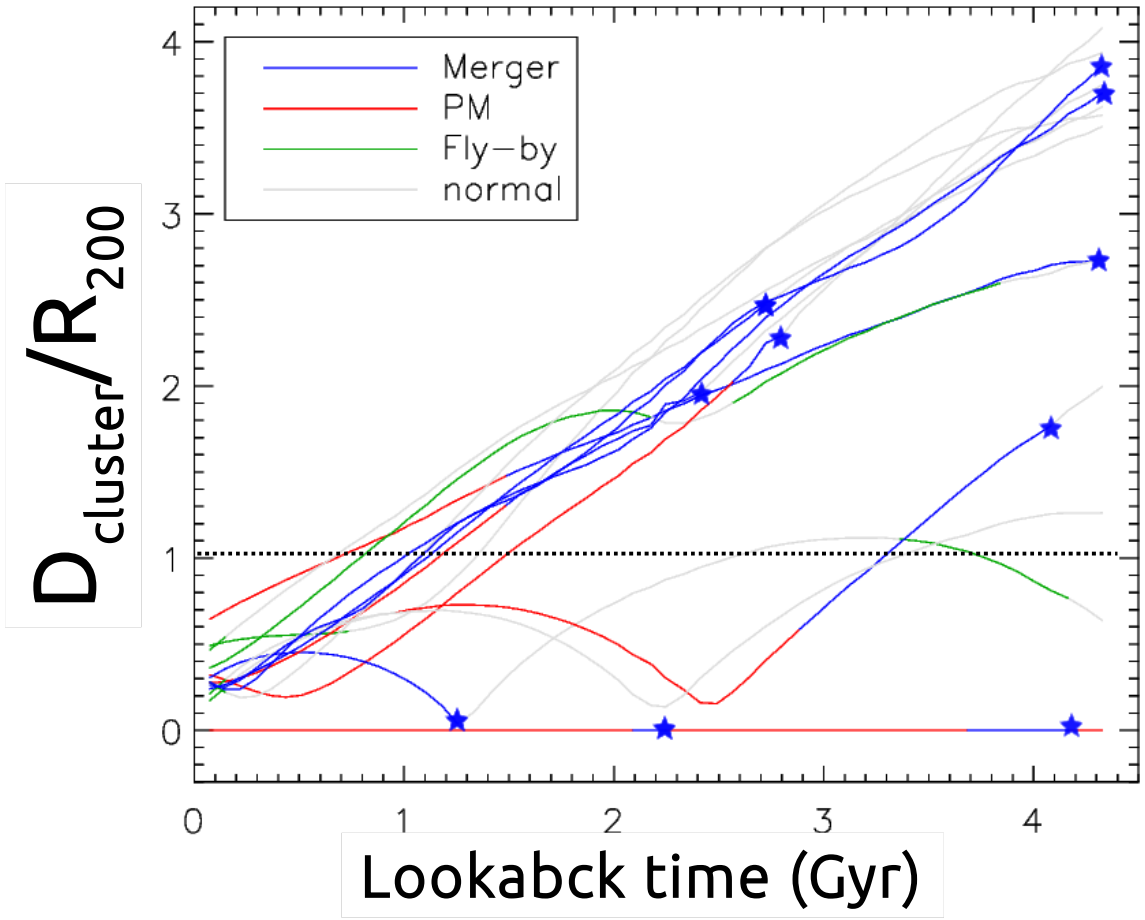


Merger PM normal fly-by

4.1 2.8 1.0 0.1 0.0 (Gyrs ago)

RESULT

Sites of mergers



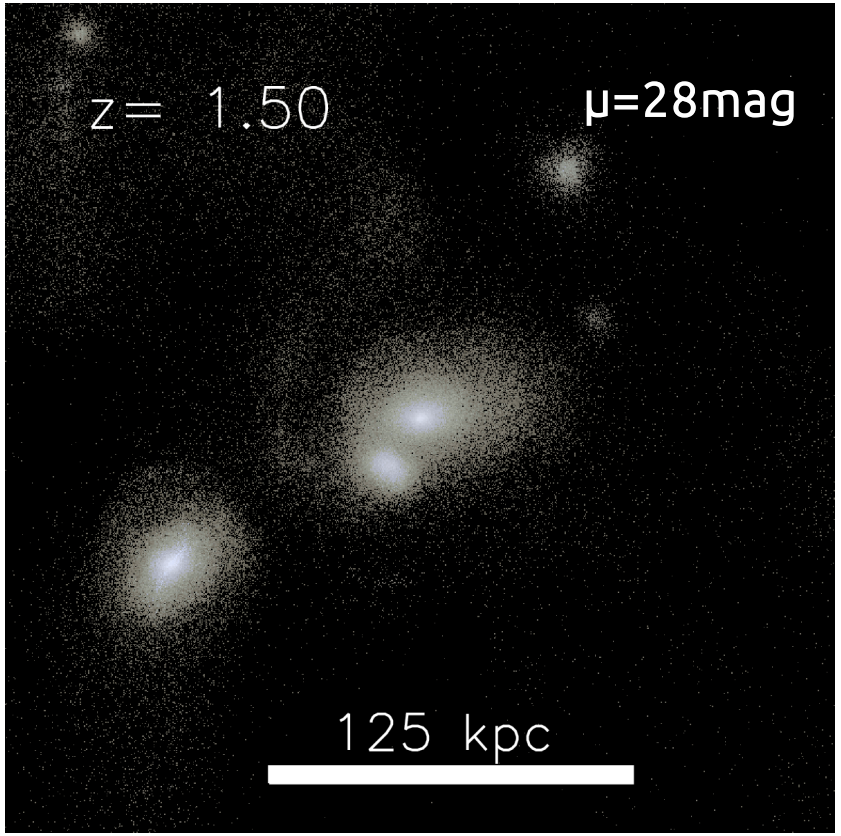
- Most of the mergers have started outside the cluster.
- Some features survive ~ 2 Gyr or more*.
- Some mergers take long times.

† For every merger after Z=0.5 (4.3Grys ago), except unknowns

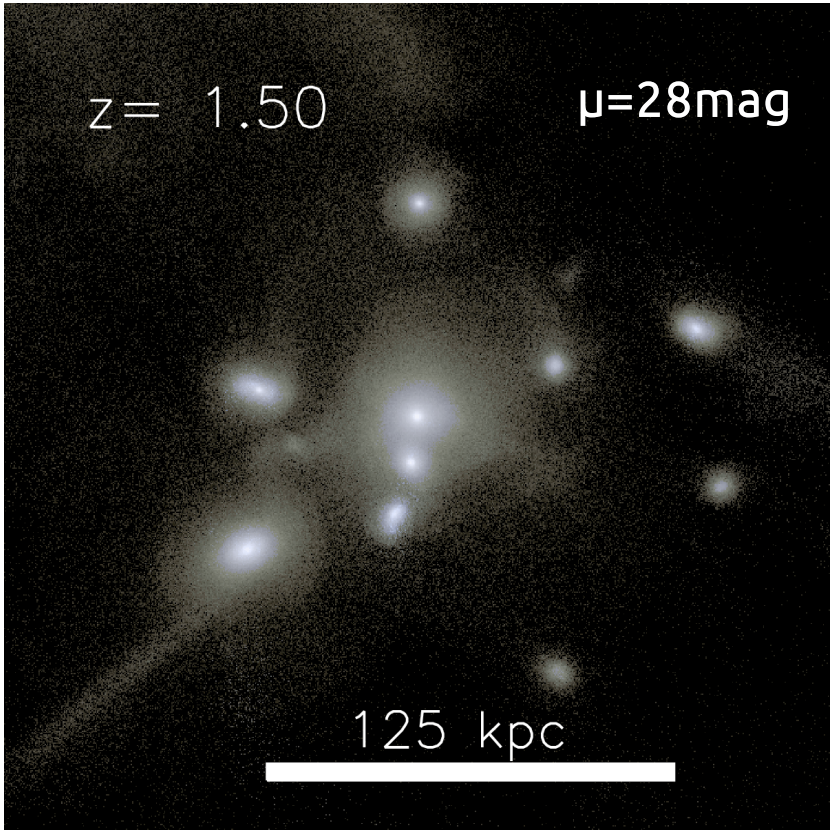
RESULT

Discussion – Resolution effect

- Insufficient resolution smooths out fine features
- Merger timescales are lower bounds.



This study

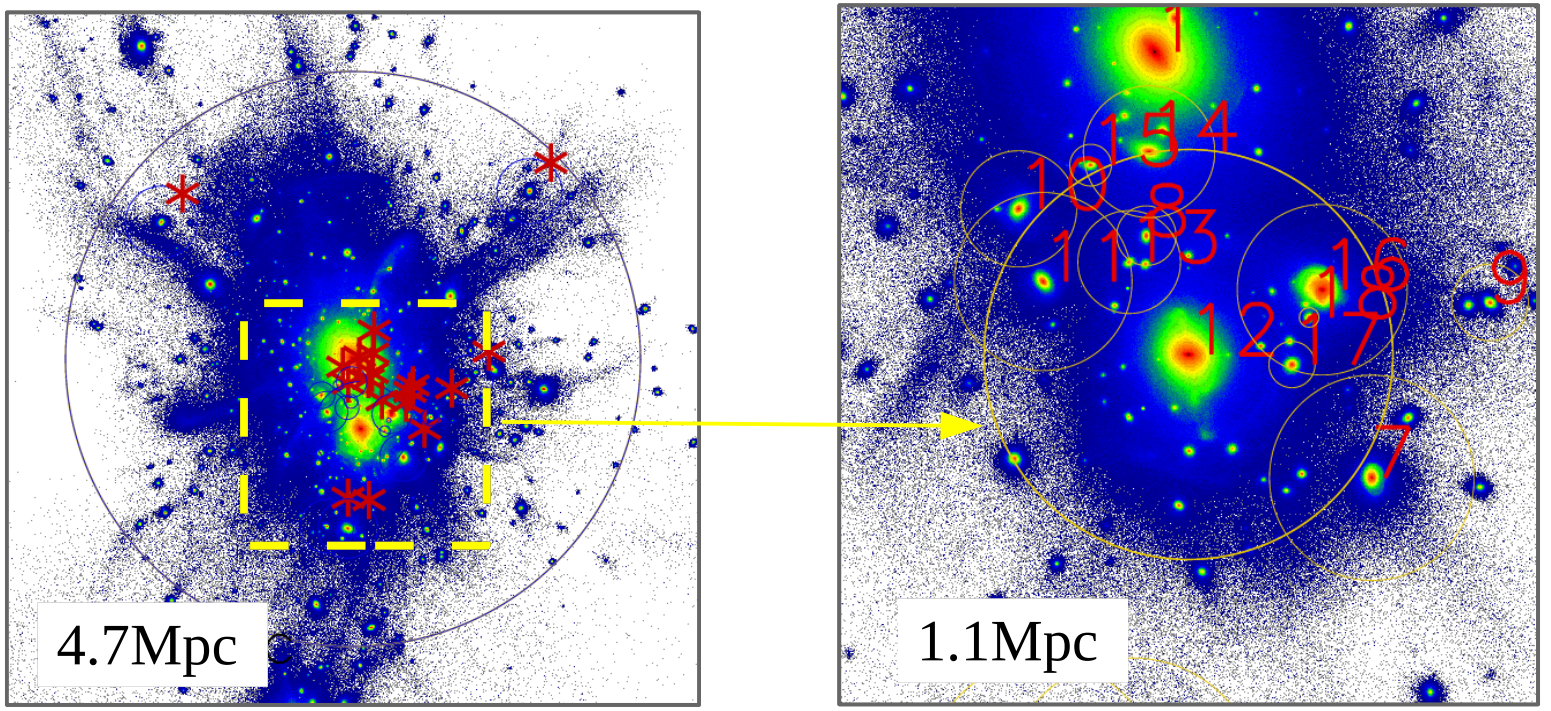


Higher resolution run

RESULT

Discussion - An infalling group

- Many (9/18) of the galaxies with tidal feature are near an infalling group.
- Group is preferred merger site.



Summary

- Considerable amount of tidal features are found in the cluster. (~ 20%)
- Most of the mergers start before the infall.
- Merger feature survive > 2Gyrs.
- Group environments seem to be preferred.
- Future direction
  - Consider Mass / LSS dependence with more sample.
  - Systematic feature detection scheme is needed.

Thank you

How can you measure or quantify that the galaxies in near the group are coherent?

- Feldmann 2011 have found that elliptical galaxies found in group environments at z=0.1 had already been 'pre-processed' at z > 1 before their infall into the group halo.

Is the absence of AGN means AGN is not an important mechanism of elliptical generation?

- (Refer to Feldmann 2011)
- d

How about selection effect?

- What if the group is one very special case?

1) How do you treat Noise, fore/background contamination, and so on?

Resolution of the simulation

- particle numbers of 4 × 106 in a MW type galaxy, as in Governato et al. (2008), we see some differences

Have you tested effects of image resolution?

- Plate scale
  - EYE.... auto corrects.. no obvious effect on the VI result.

- Mass assignment kernel
  - NGP. But higher order kernels do not make any noticeable changes because enough number (~100) of particles are in each pixel already.

How reliable is your simulation?

- Two issues are important.
  - How precise the galaxy formation recipe is?
  - And, do I have enough resolution?
- For the resolution issue, we have briefly tested the effect of resolution with twice higher resolution in length or 8 times in mass, only for high redshift because it takes too long to get to the final redshift. The impression is that a L_* galaxy resolved with an order of magnitude more particles show fine features much better and for much longer period. (How much?) Therefore, merger time scale in this work must be the lower limit.
- In the past one or two years, Galaxy formation recipes have been “converging“ at least for the scale of this simulation. Sub-grid models for SF, SN, AGN in different simulations all share roughly the same idea and results. 'The results' are : size, mass, SFR of the simulated galaxies in recent universe roughly reproduces what we know from observations of 'normal spiral and elliptical galaxies' in the local universe.

Studies showed that mergers that result elliptical galaxies preferentially occurred at z >1. Why are you focusing on the rather recent epoch?

1) Primary goal is to address that the tidal features in clusters can tell us about evolution of cluster galaxies. This work can be the bridge b/w z >1 and z < 1 and eventually will be merged into one big picture throughout the evolution history of elliptical galaxies. From high redshift when SF and galaxy merger peaked, to the current universe around us.

2) d

Cosmological Cluster simulations (…?)

- (Introduce them what this field is like these days)
- Maller 2006, Croft 09, Crain 09, Feldmann 10, (Evolution of the 'GALAXIES' inside the cluster, not focusing on the cluster itself. (Like T/S profile, weak lensing...)
  - Cosmological simulations recently become capable of reproducing observed galaxy properties.
  - These all lacks resolution or for groups ~ 10^13, not clusters.

Is AMR better than SPH?

- Because the most popular simulation code in the field is GADGET-2/3, you may be curious about that. It is known that SPH has _??__??__??___ problem. Their choice likely be for practical issues.