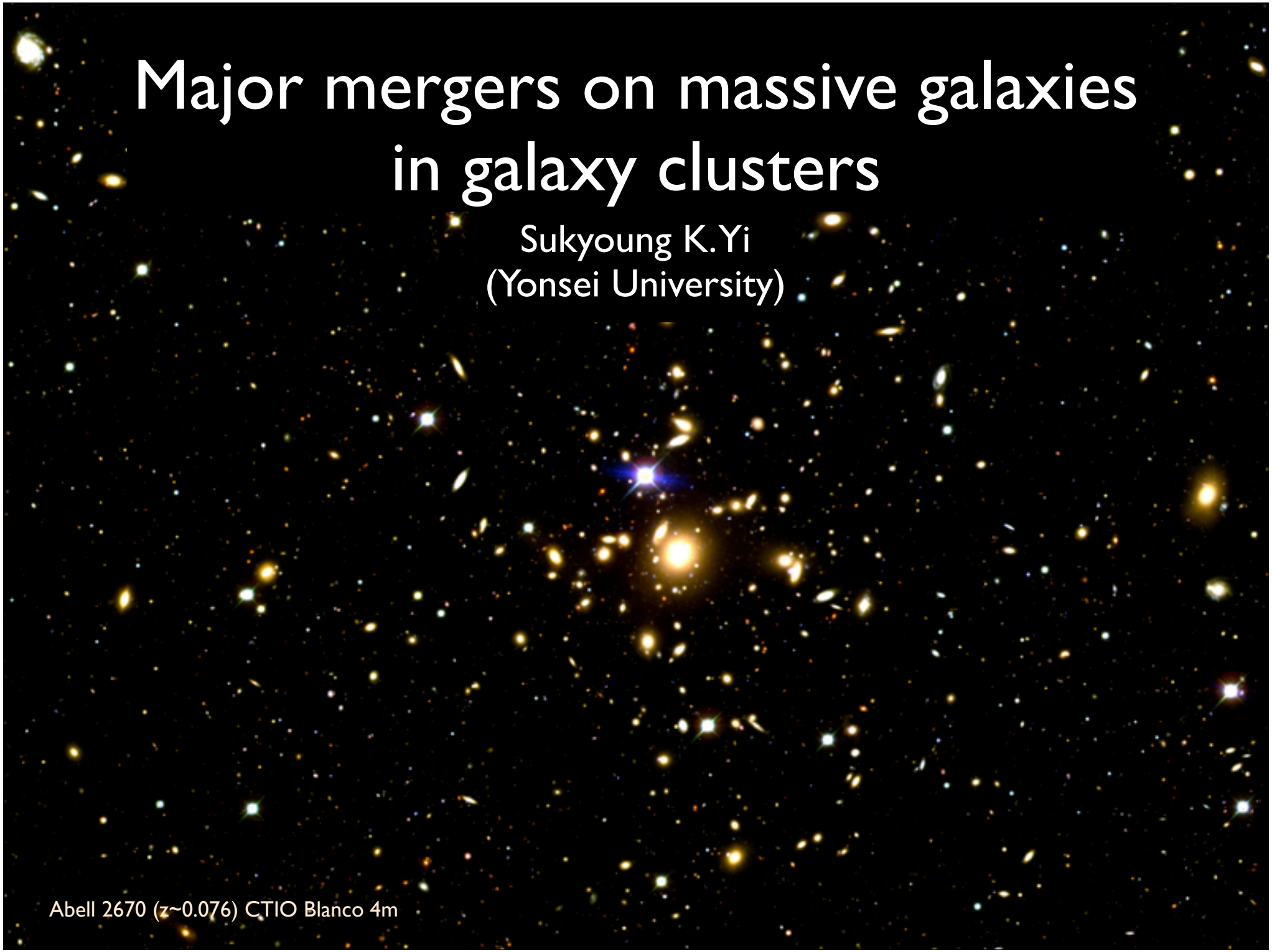
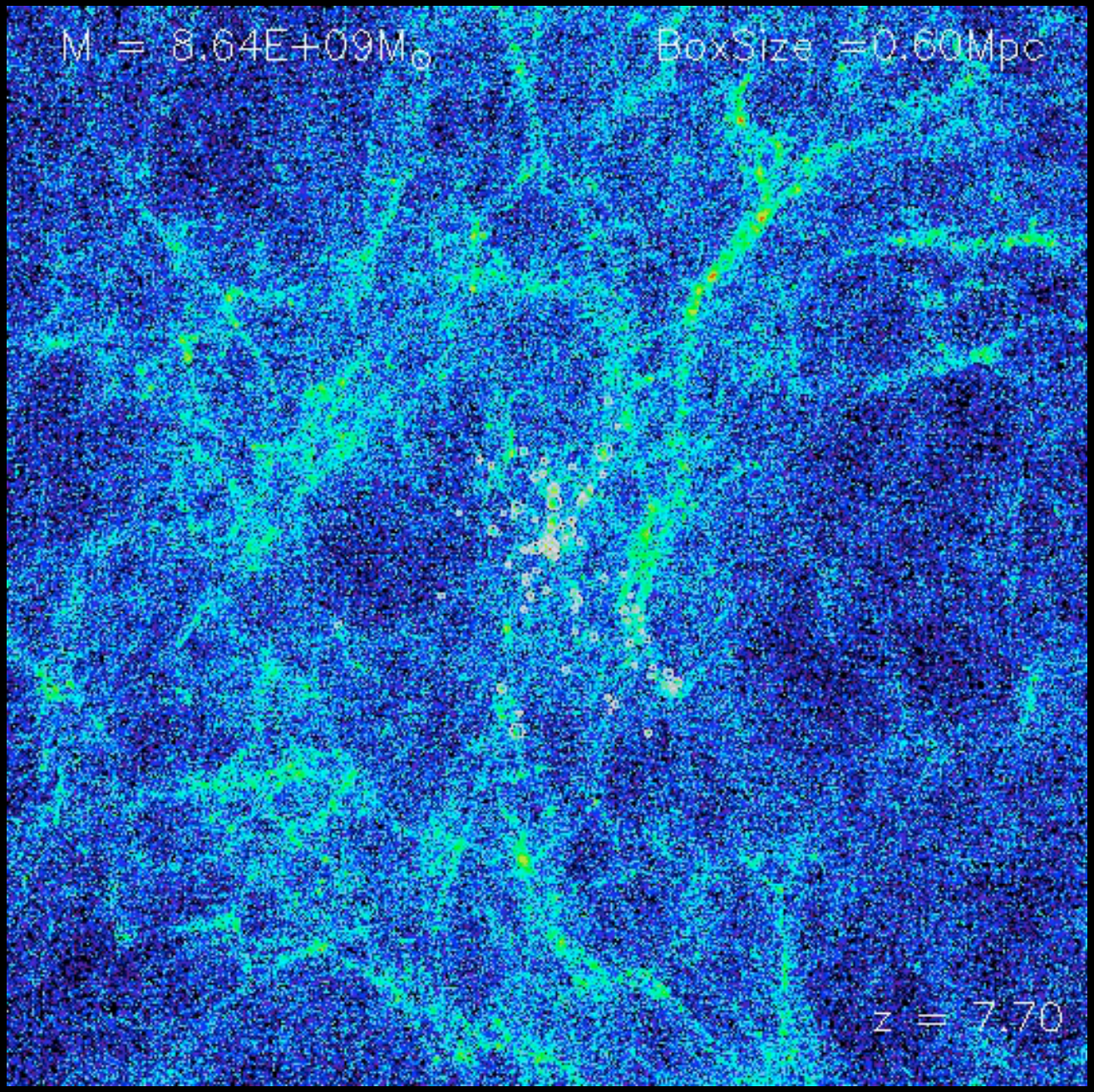
Major mergers on massive galaxies in galaxy clusters

Sukyoung K. Yi
(Yonsei University)



Abell 2670 (z~0.076) CTIO Blanco 4m

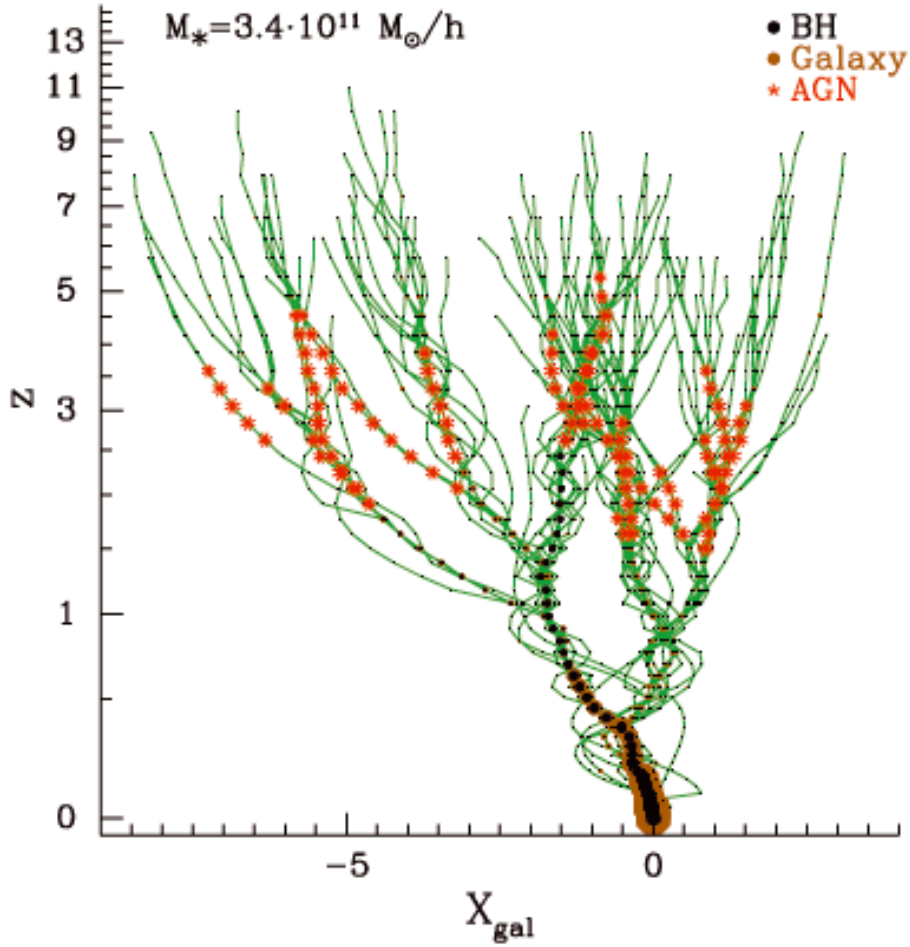
Dark halos grew via mergers



Intae Jung
now at UT Austin

GADGETII

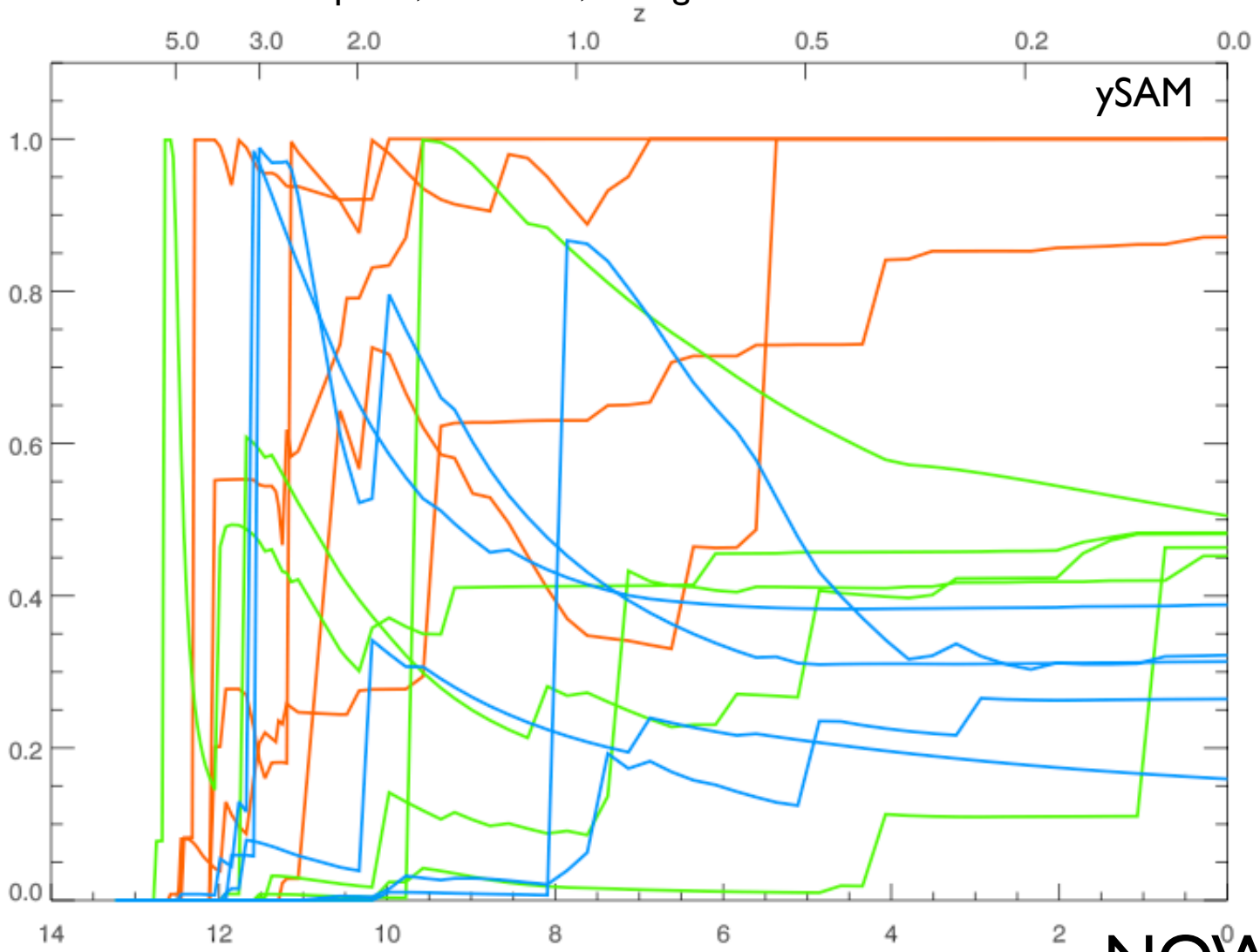
So did galaxies, especially in the early universe.

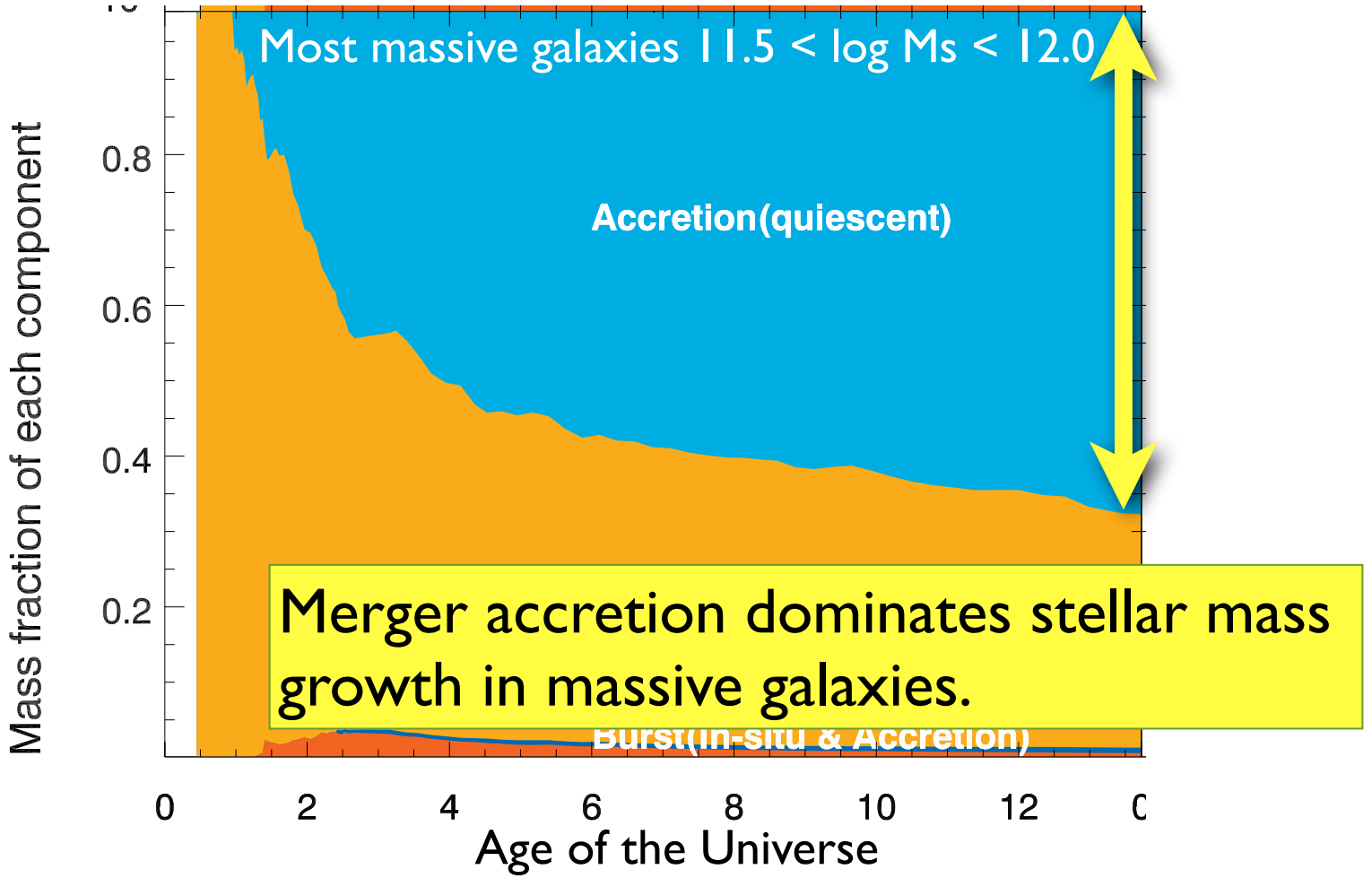


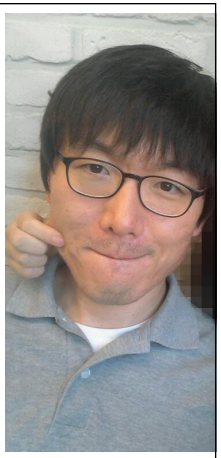
Merger tree from Marulli et al. (2009)

Mergers affect morphology

5 Elliptical, Lenticular, Disc galaxies random







Jay Lee

Lee & Yi 2013, ApJ, 766, 388

doi:10.1088/0004-637X/766/1/38

ON THE ASSEMBLY HISTORY OF STELLAR COMPONENTS IN MASSIVE GALAXIES

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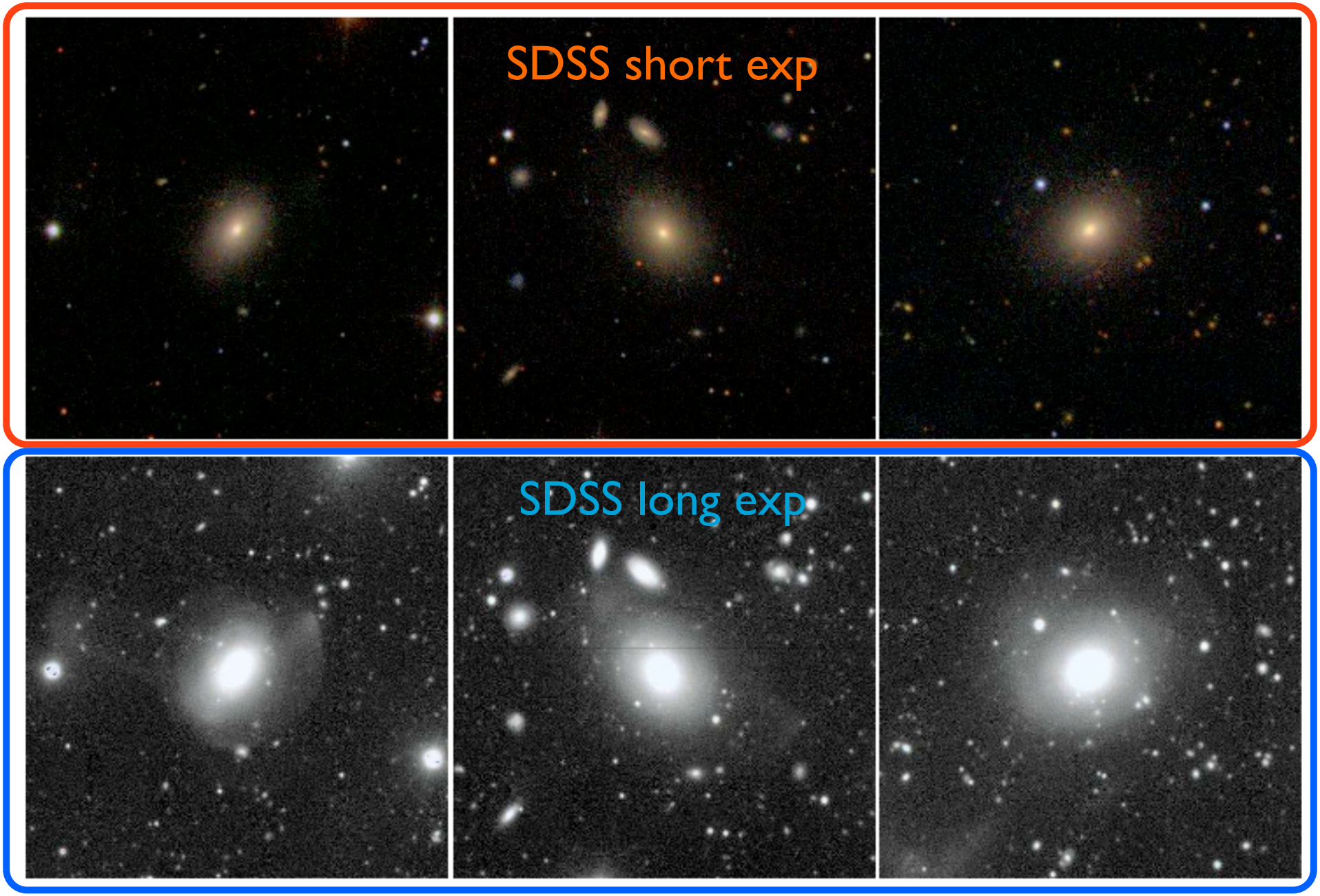
Received 2012 August 24; accepted 2013 February 4; published 2013 March 5

Roles of mergers in galaxy evolution critical.

Long exposures reveal mergers (Kaviraj et al. 2010)



Early-type Galaxy Mergers

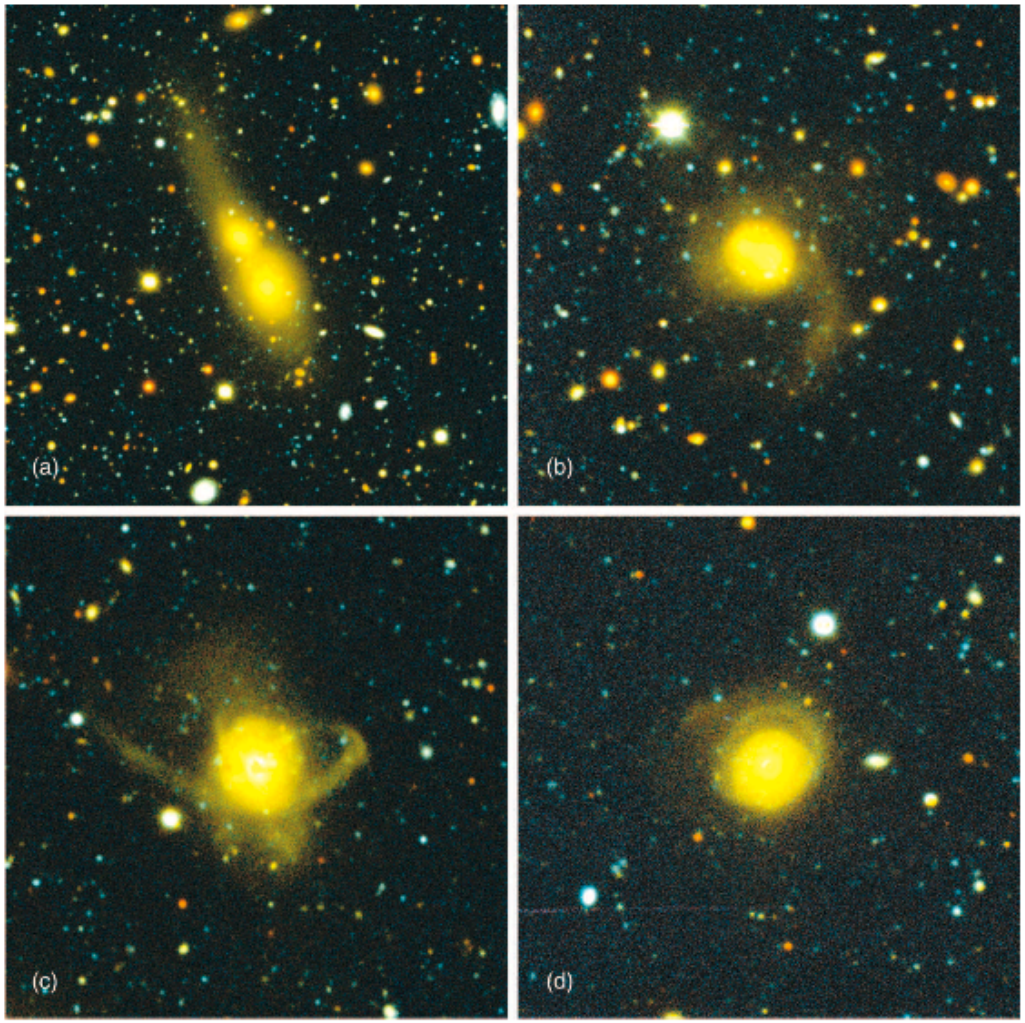


FIG. 3.—Examples of red mergers, ordered by the progression of the interaction. The images were generated by combining the *B* and *R* frames. The objects are (*a*) 17-596 and 17-681; (*b*) 19-2206 and 19-2242; (*c*) 1256-5723; and (*d*) 6-1302. Panel *a* spans $5' \times 5'$; panels *b*–*d* span $2'.5 \times 2'.5$. 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).

Yun-Kyeong Sheen
now at Concepcion

Deep Imaging of Galaxy Clusters

Sheen et al. 2012, ApJS, 202, 8

doi:10.1088/0067-0049/202/1/8

POST-MERGER SIGNATURES OF RED-SEQUENCE GALAXIES IN RICH ABELL CLUSTERS AT $z \lesssim 0.1$

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Received 2011 November 14; accepted 2012 July 8; published 2012 August 28

ABSTRACT

We have investigated the post-merger signatures of red-sequence galaxies in rich Abell clusters at $z \lesssim 0.1$: A119, A2670, A3330, and A389. Deep images in u', g', r', and medium-resolution galaxy spectra were taken using MOSAIC II CCD and Hydra MOS mounted on a Blanco 4 m telescope at Cerro Tololo Inter-American

Textbooks say

mergers should be rare in clusters!

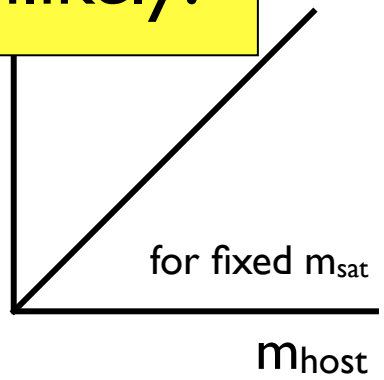
Merger timescale in "Frozen halo" model

Chandrasekhar merger timescale (Lacey & Cole 1993)

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

In a large halo, galaxy merger is highly unlikely!

For given m_sat,
Chandrasekhar merger time scales with m_host



First campaign: Clusters at z~0.1

- FOV covers R_{virial}

  A389 R_{virial} = 2.3 Mpc

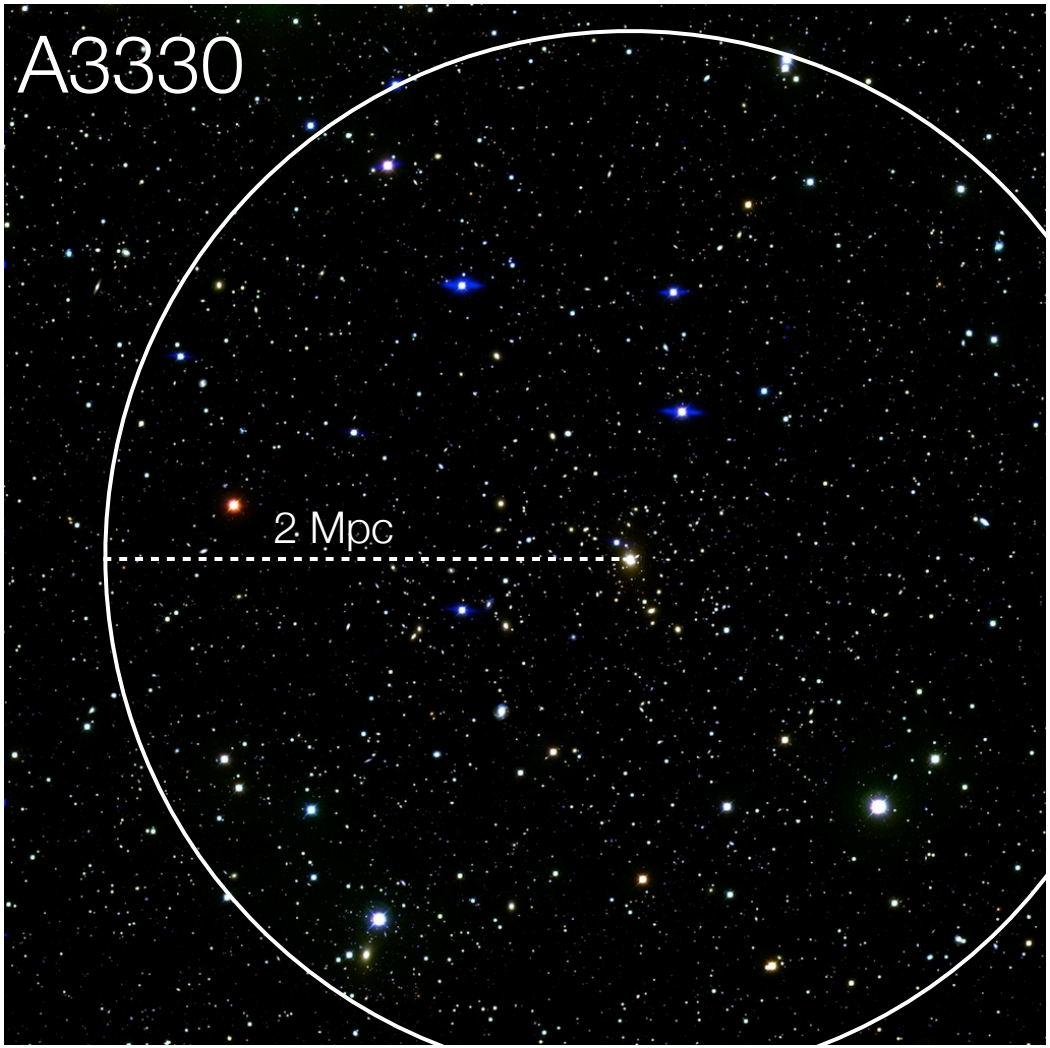
  A3330 R_{virial} = 1.9 Mpc

  A2670 R_{virial} = 1.6 Mpc

  A119 R_{virial} = 1.0 Mpc

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

- All with deep GALEX images



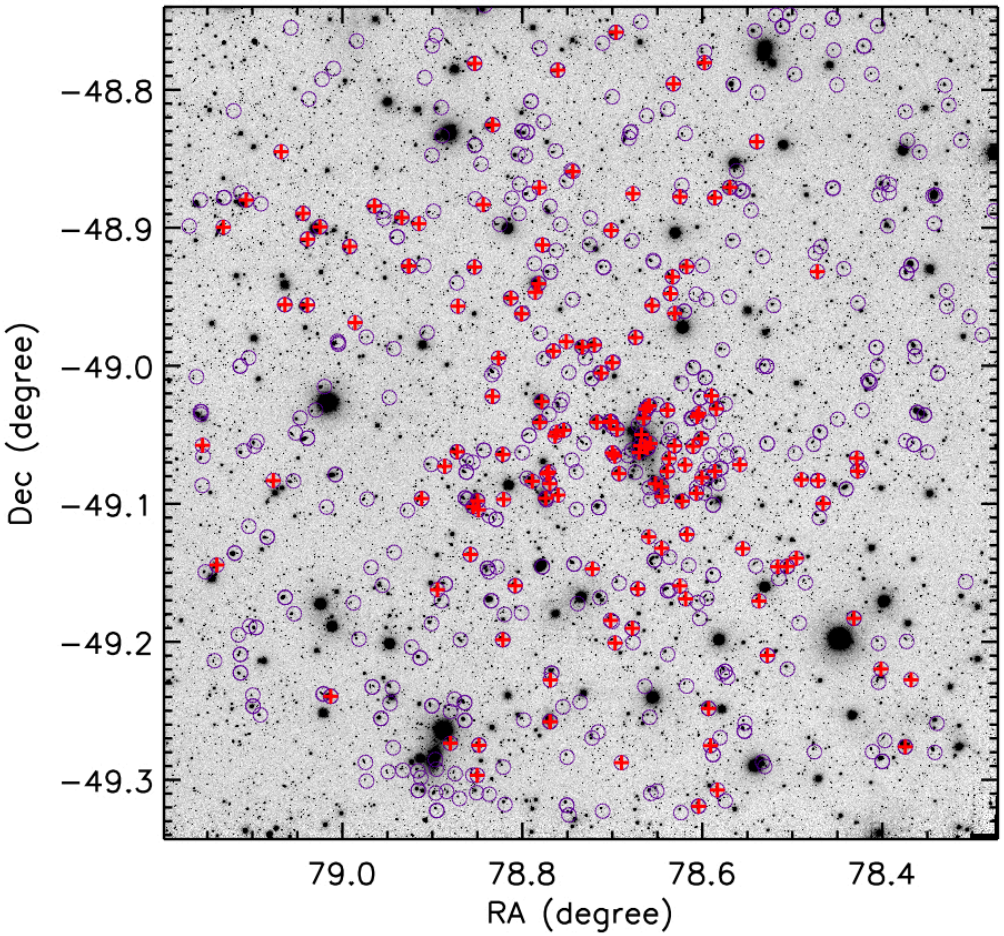
CTIO Blanco 4m Deep Imaging

- $\mu_r \sim 28$ mag/arcsec^2

(unit: hours)

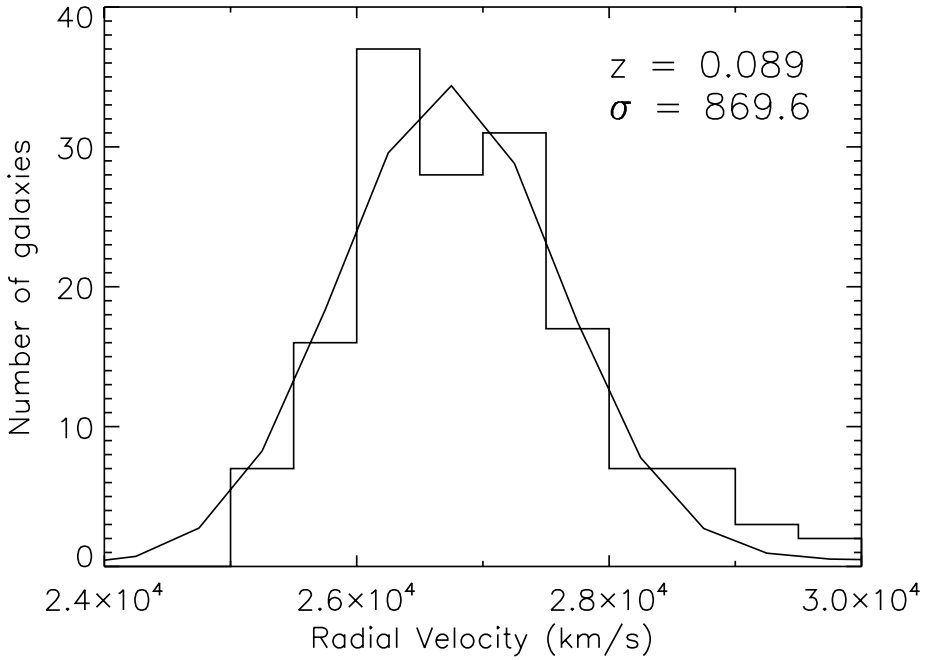
	A3330	A2670	A389	A119
Optical Imaging	u ~ 1.3 g ~ 1.4 r ~ 1.7	u ~ 1.3 g ~ 1.4 r ~ 1.7	u ~ 1.7 g ~ 2 r ~ 2	u ~ 1.7 g ~ 1.6 r ~ 1.6
Optical Spectroscopy	~ 4	~ 1.5	~ 3	~ 2.5
GALEX UV	FUV ~ 6.3 NUV~ 16.7	FUV ~ 6 NUV ~ 6	FUV ~ 6 NUV ~ 8.7	FUV ~ 0.9 NUV ~ 0.9

Hydra Spectroscopic Survey

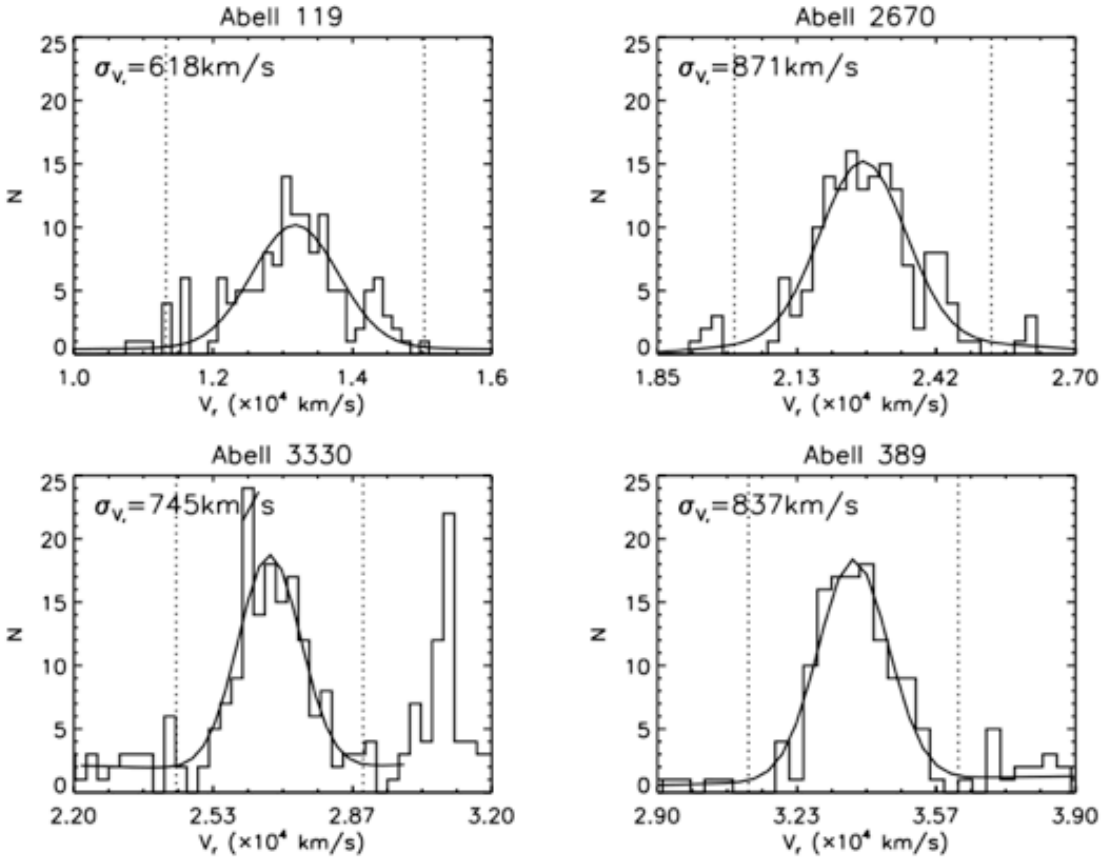


Abell 3330 (○ : Targets, + : Members)

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

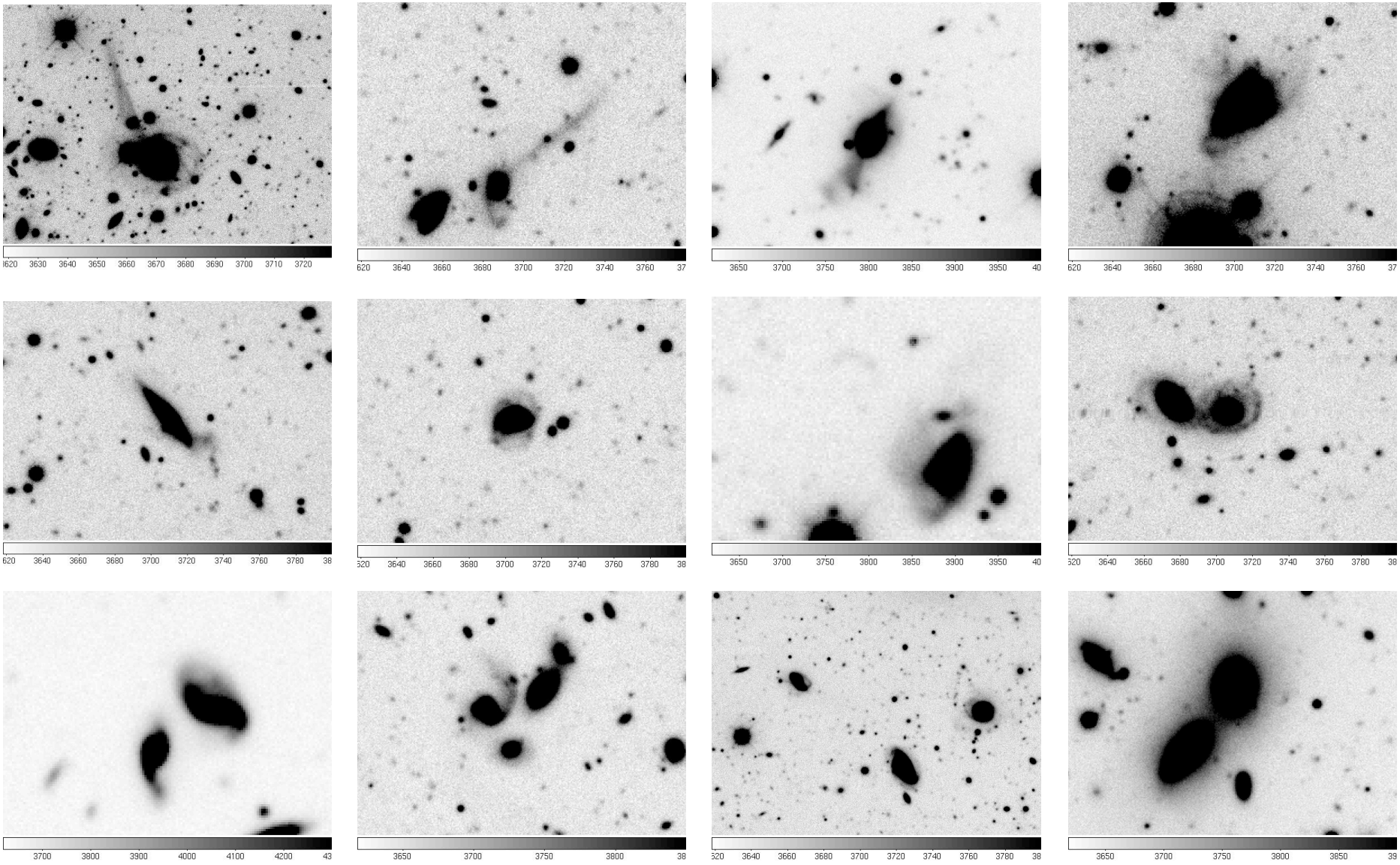


Hydra Spectroscopic Survey



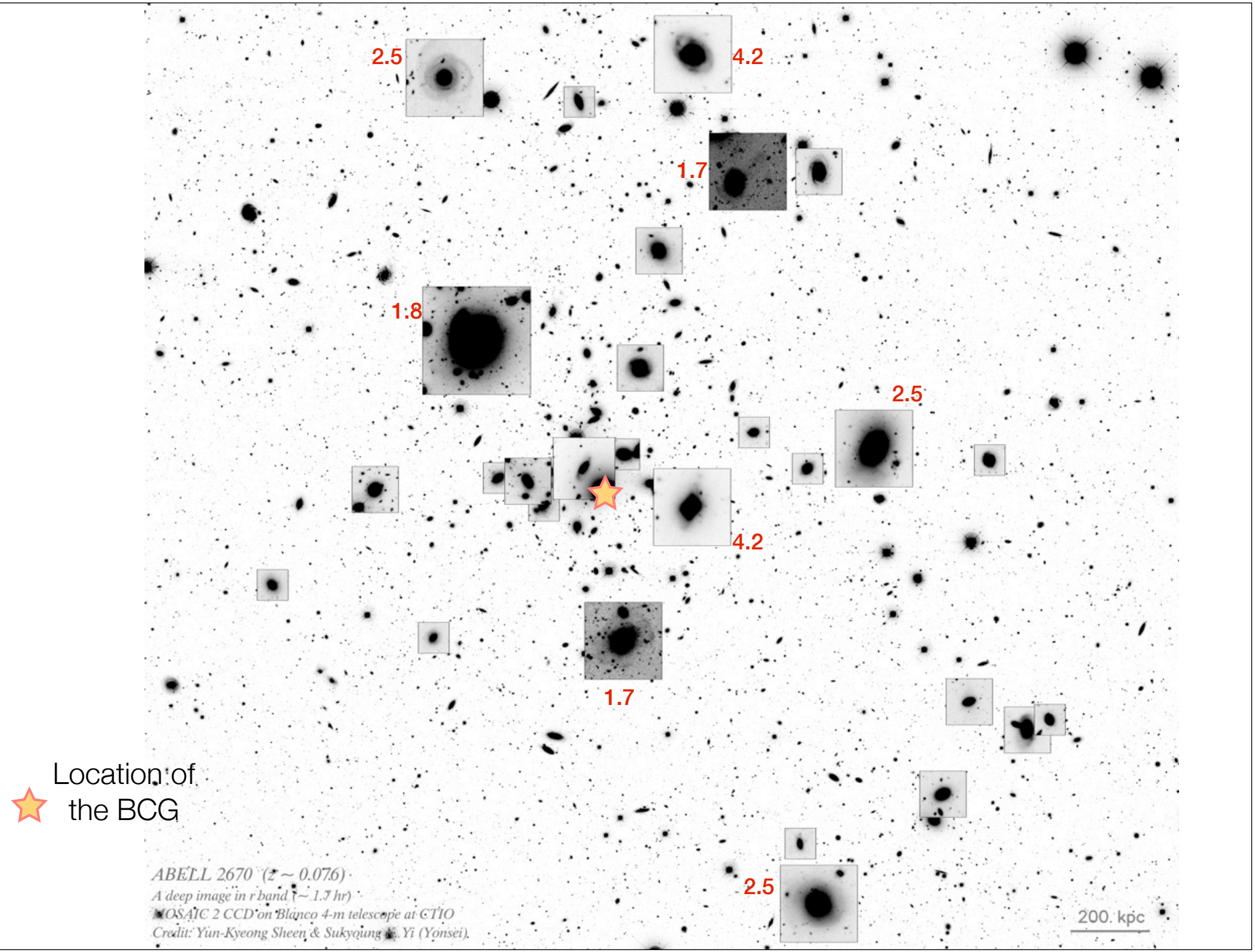
ID	$V_{r,center}$ (km/s)	σ_{V_r} (km/s)	z	member (SDSS)	R_{200} (Mpc)
A119	13177.6	618.14	0.0439	135 (30)	1.53
A2670	22676.9	871.07	0.0756	154 (39)	2.16
A3330	26684.9	745.58	0.0889	147	1.84
A389	33688.1	837.22	0.1123	119	2.07

Post-mergers and Interacting Systems in A3330



Merger Signatures in Red-sequences

composite r


2.5
4.2
1.7
1.8
2.5
4.2
1.7
2.5
Location of the BCG
ABELL 2670 (z ~ 0.076)
A deep image in r band (~ 1.7 hr)
MOSAIC 2 CCD on Blanco 4-m telescope at CTIO
Credit: Yun-Kyeong Sheen & Sukyoung K. Yi (Yonsei)
200 kpc

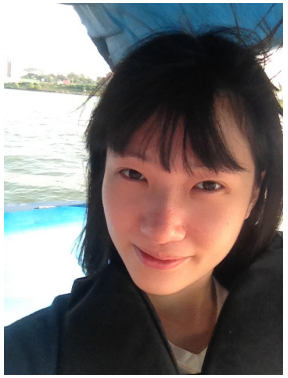
High post-merger fraction

[a] van Dokkum 2005

	Class	Cluster	Field[a]
Bulge-dominated[c]	PM	$38 \pm 5\%$	49%
	I	$4 \pm 1\%$	21%
	Total	$42 \pm 6\%$	70%

Sheen et al. 2012, ApJS, 202, 8

Cf.
A. Ferguson's June Paris talk: 10-20% on ETGs (CFHTLS)

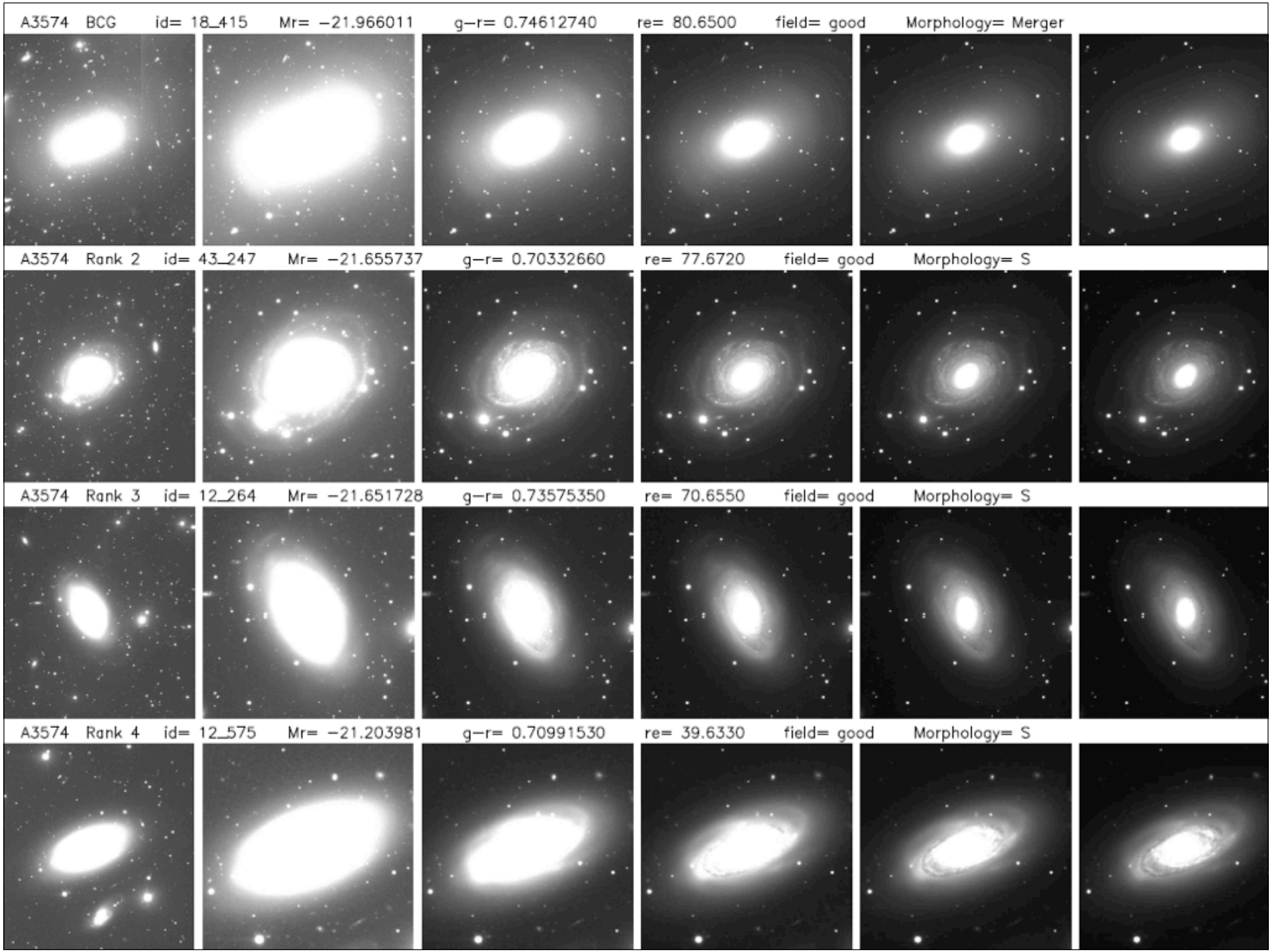


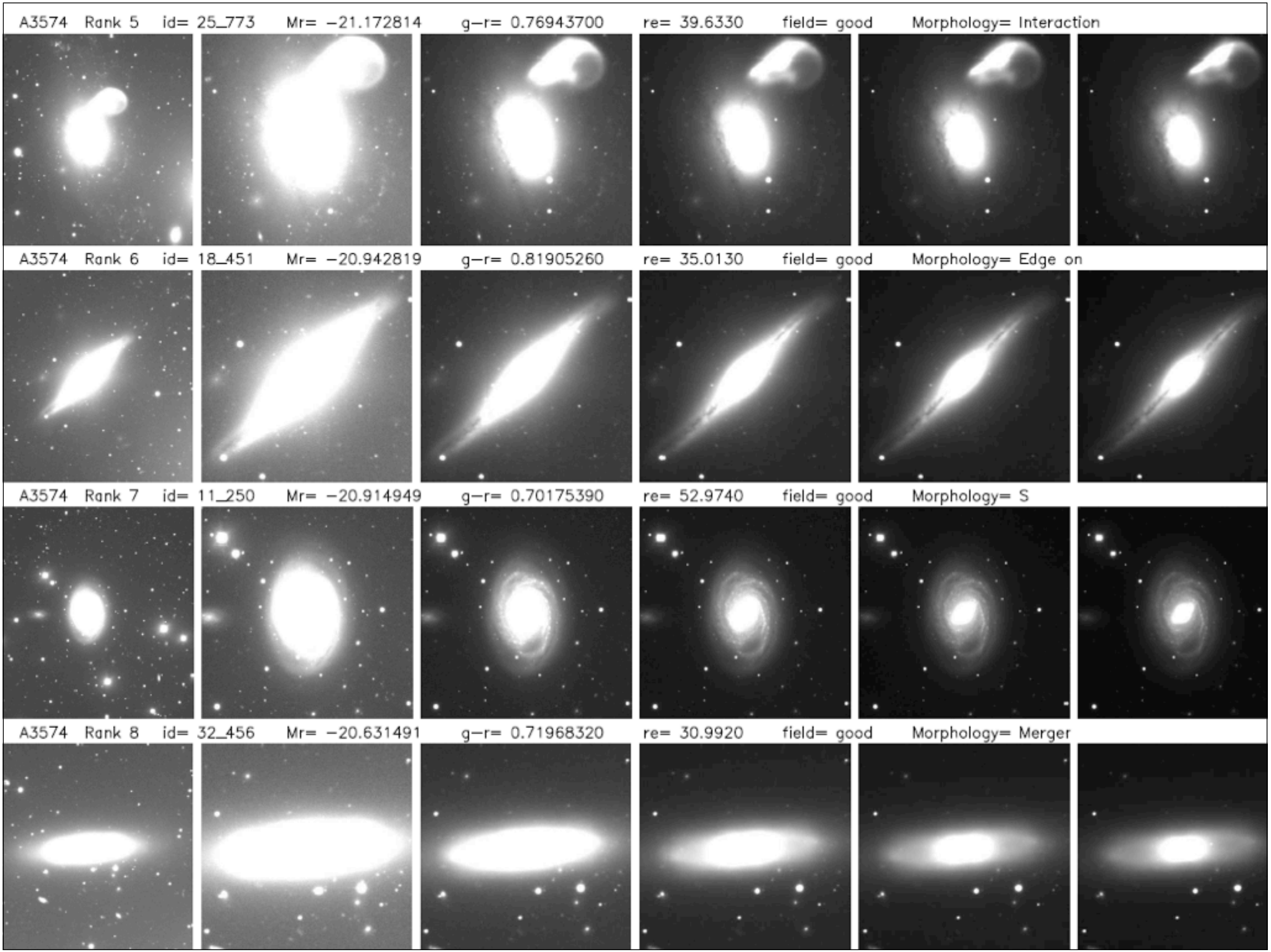
Seulhee Oh

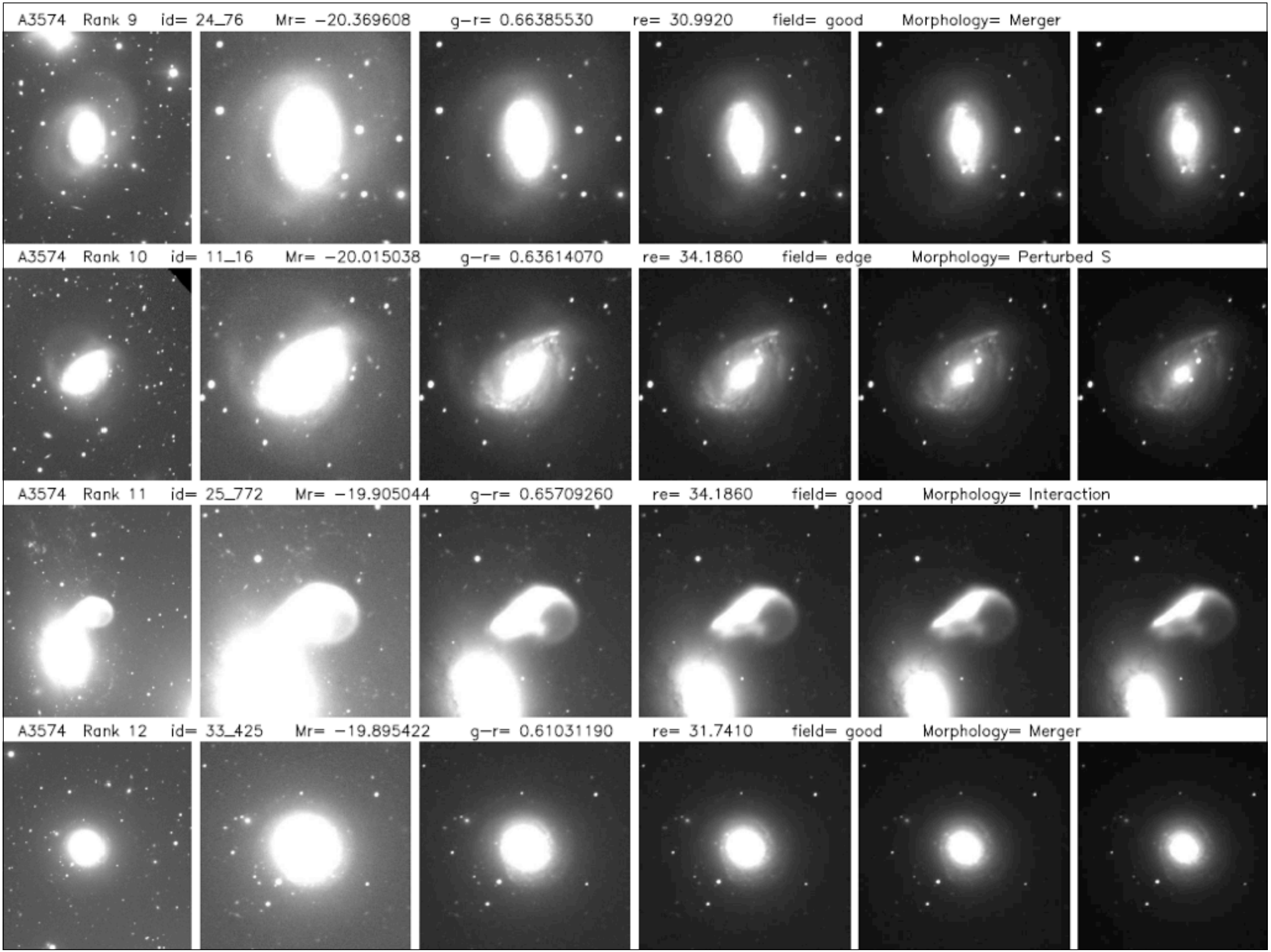
Deep imaging campaign continued:

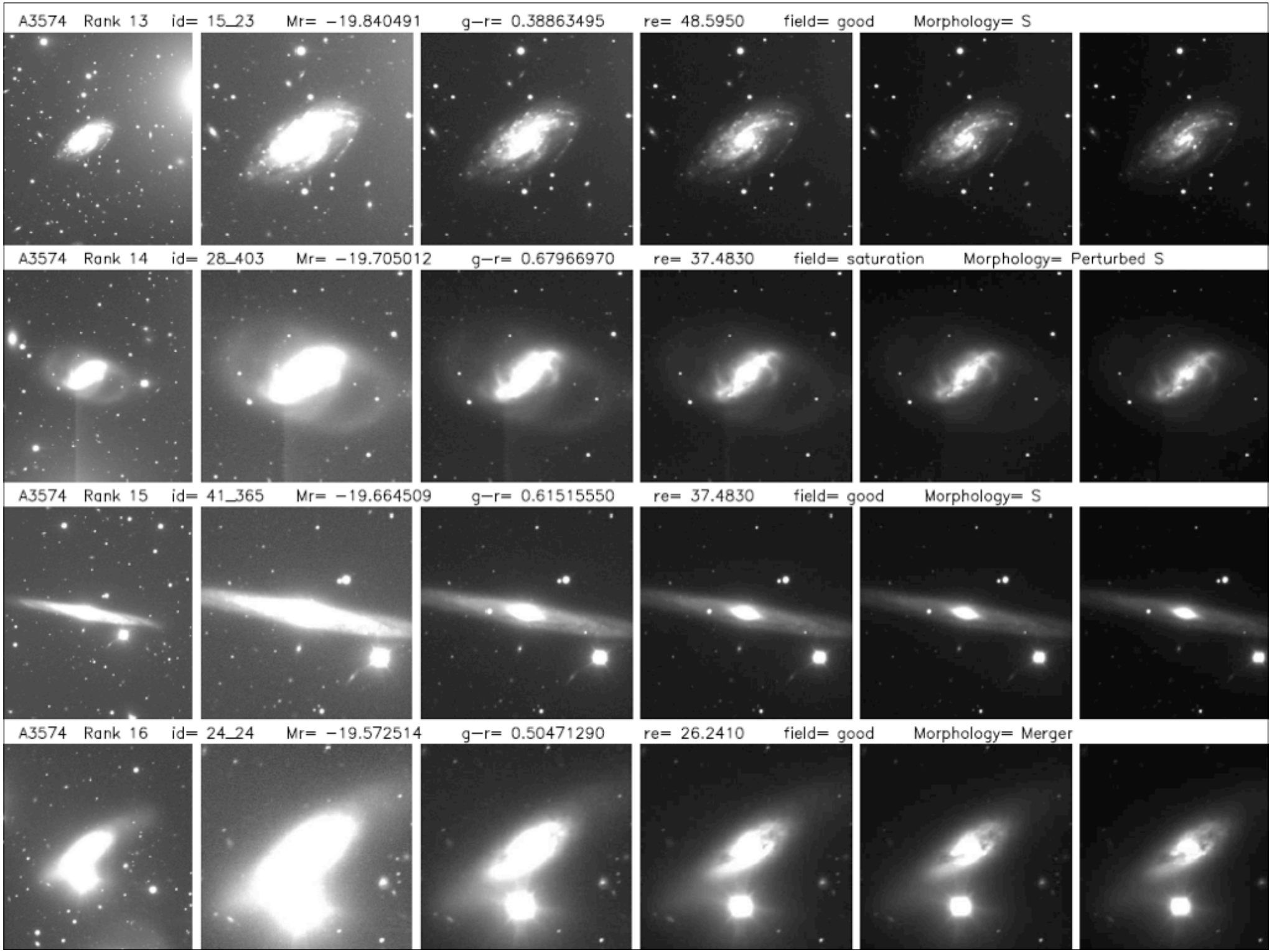
16 clusters using Magellan and CFHT

(e.g. A3574)


A3574 BCG id= 18_415 Mr= −21.966011 g−r= 0.74612740 re= 80.6500 field= good Morphology= Merger
A3574 Rank 2 id= 43_247 Mr= −21.655737 g−r= 0.70332660 re= 77.6720 field= good Morphology= S
A3574 Rank 3 id= 12_264 Mr= −21.651728 g−r= 0.73575350 re= 70.6550 field= good Morphology= S
A3574 Rank 4 id= 12_575 Mr= −21.203981 g−r= 0.70991530 re= 39.6330 field= good Morphology= S


A3574 Rank 5 id= 25_773 Mr= −21.172814 g−r= 0.76943700 re= 39.6330 field= good Morphology= Interaction
A3574 Rank 6 id= 18_451 Mr= −20.942819 g−r= 0.81905260 re= 35.0130 field= good Morphology= Edge on
A3574 Rank 7 id= 11_250 Mr= −20.914949 g−r= 0.70175390 re= 52.9740 field= good Morphology= S
A3574 Rank 8 id= 32_456 Mr= −20.631491 g−r= 0.71968320 re= 30.9920 field= good Morphology= Merger


A3574 Rank 9 id= 24_76 Mr= −20.369608 g−r= 0.66385530 re= 30.9920 field= good Morphology= Merger
A3574 Rank 10 id= 11_16 Mr= −20.015038 g−r= 0.63614070 re= 34.1860 field= edge Morphology= Perturbed S
A3574 Rank 11 id= 25_772 Mr= −19.905044 g−r= 0.65709260 re= 34.1860 field= good Morphology= Interaction
A3574 Rank 12 id= 33_425 Mr= −19.895422 g−r= 0.61031190 re= 31.7410 field= good Morphology= Merger


A3574 Rank 13 id= 15_23 Mr= −19.840491 g−r= 0.38863495 re= 48.5950 field= good Morphology= S
A3574 Rank 14 id= 28_403 Mr= −19.705012 g−r= 0.67966970 re= 37.4830 field= saturation Morphology= Perturbed S
A3574 Rank 15 id= 41_365 Mr= −19.664509 g−r= 0.61515550 re= 37.4830 field= good Morphology= S
A3574 Rank 16 id= 24_24 Mr= −19.572514 g−r= 0.50471290 re= 26.2410 field= good Morphology= Merger

Yi et al. 2013, A&A, 554, A122

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

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t}_{\mathrm{dynf}} = -\frac{GM_{\mathrm{sat}}(t)}{r^2}\ln\Lambda\left(\frac{V_c}{v}\right)^2 \left\{\mathrm{erf}\left(\frac{v}{V_c}\right) - \frac{\sqrt{\pi}}{2}\left(\frac{v}{V_c}\right)\exp\left[-\left(\frac{v}{V_c}\right)^2\right]\right\}\vec{e}_{v}$$

Yi et al. 2013, A&A, 554, A122

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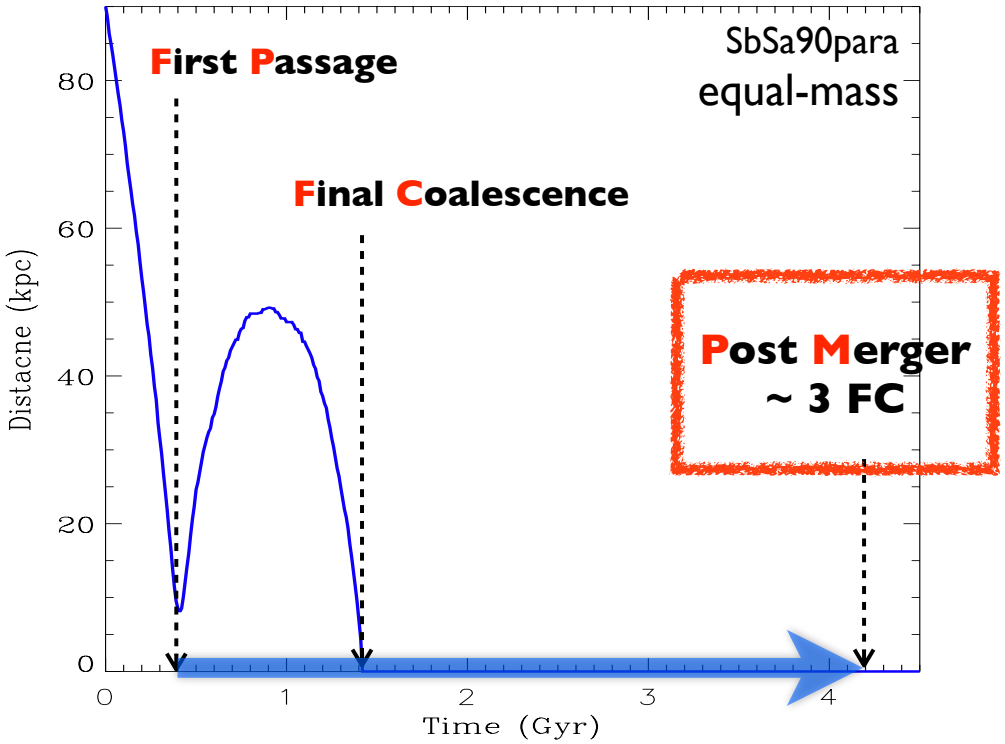
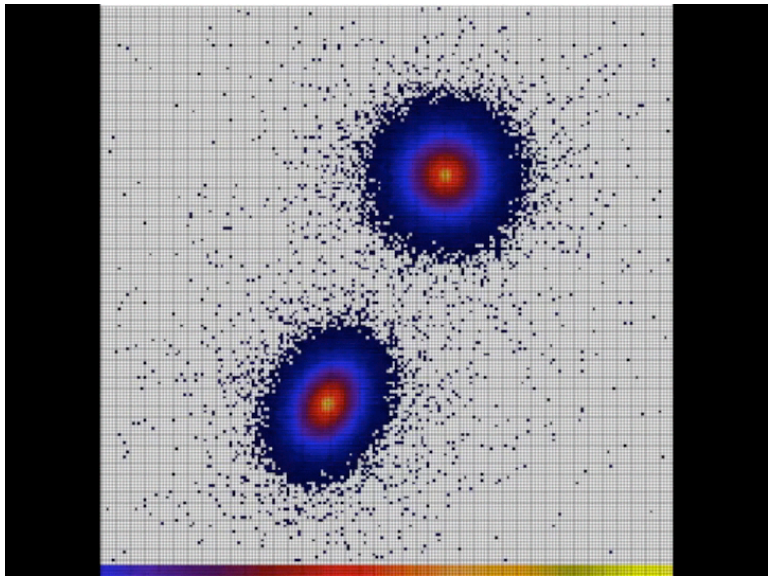
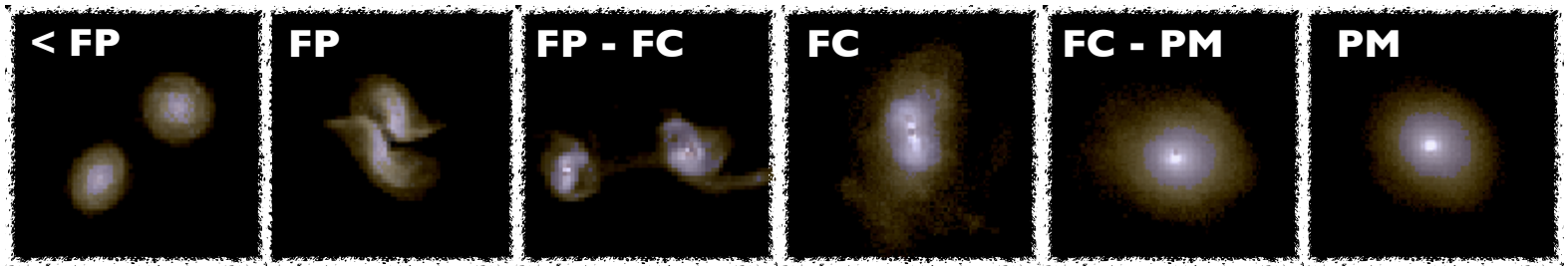
Post-merger feature time

Inchan Ji



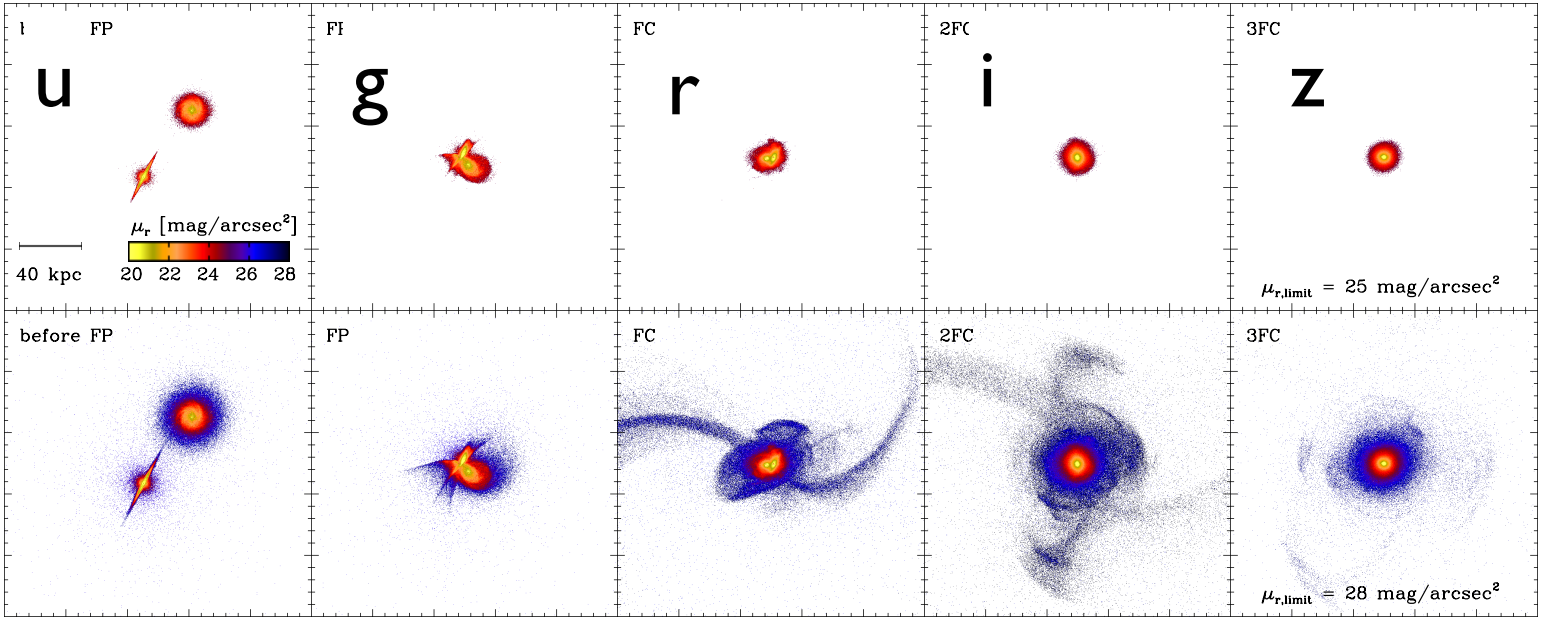


equal-mass disc+disc merger



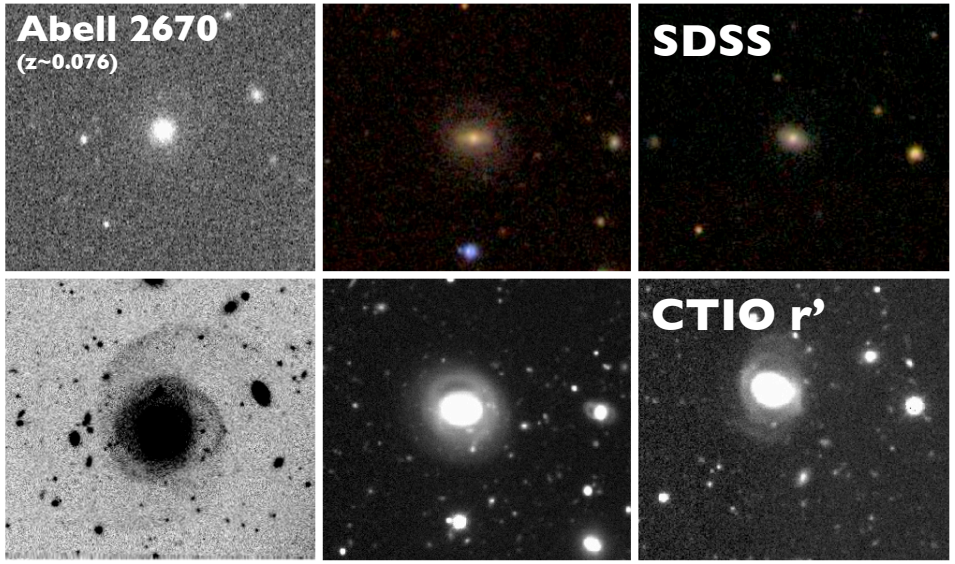
Post-merger features

Ji, Peirani, Yi 2013, ApJ, submitted



25 mag arcsec^{-2}

28 mag arcsec^{-2}



25 mag arcsec^{-2}

28 mag arcsec^{-2}

Courtesy of Y.K. Sheen

Yi et al. 2013, A&A, 554, A122

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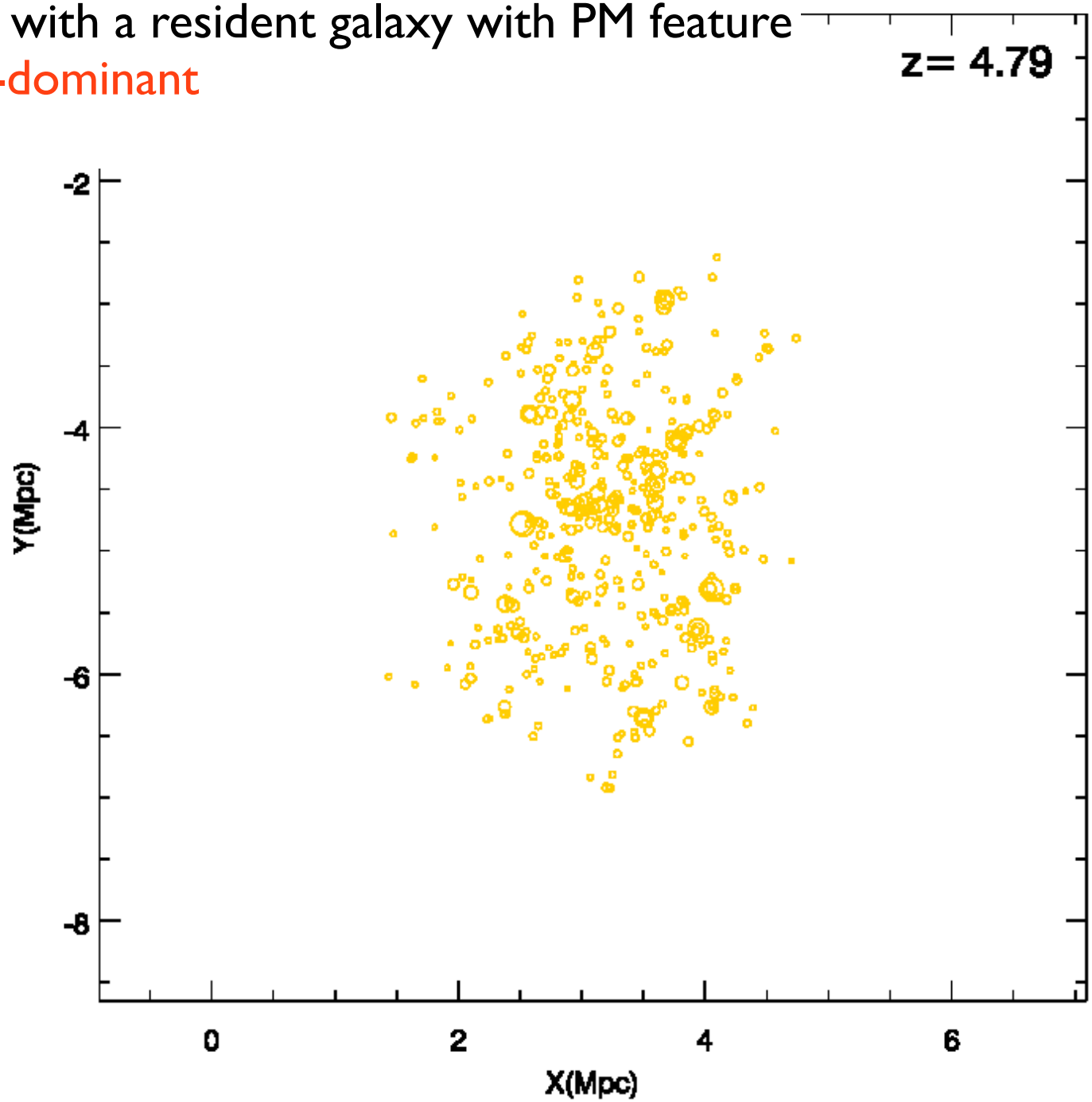
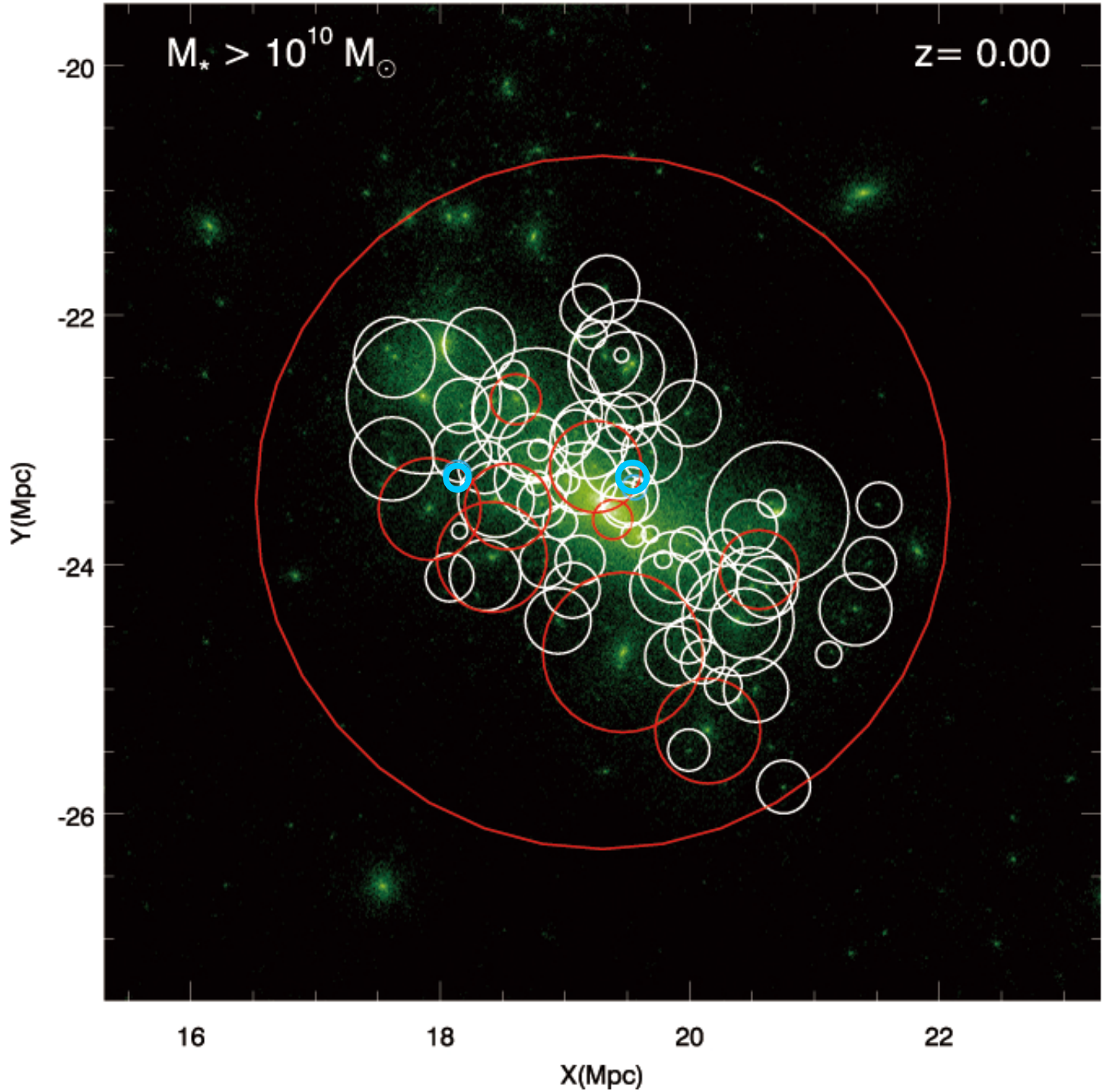
Subhaloes with a resident galaxy with PM feature

red: bulge-dominant

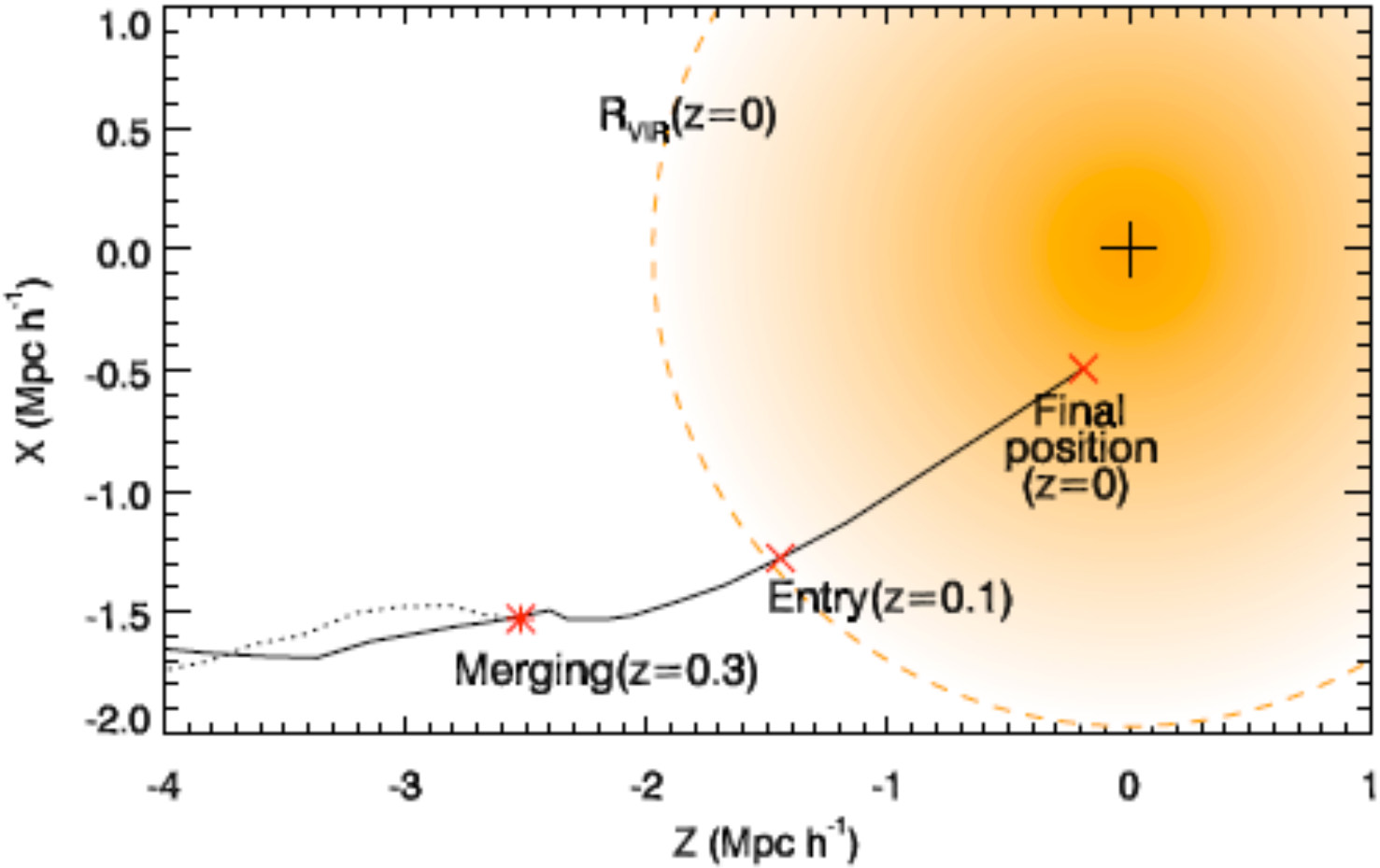
blue: disc




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

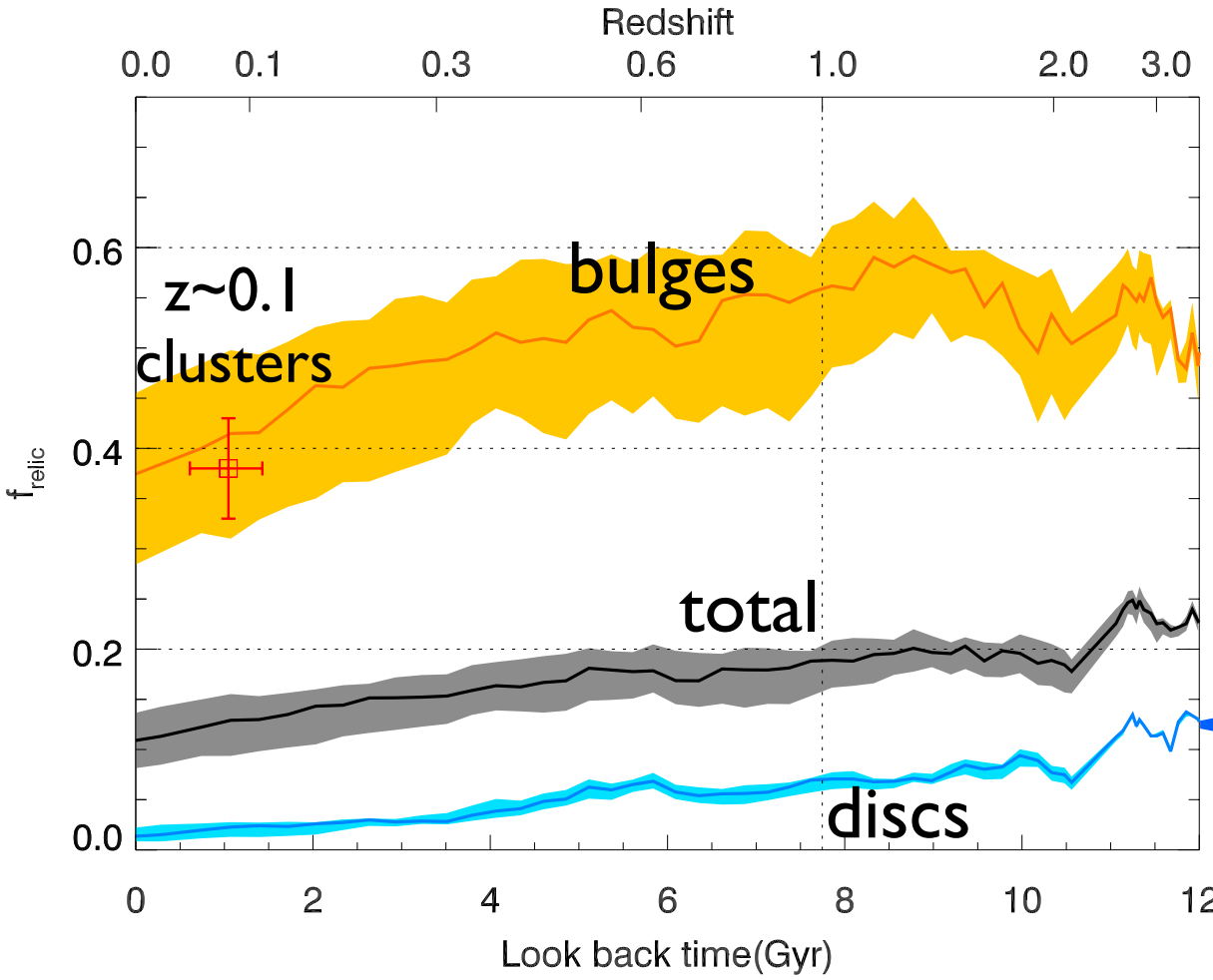
Merger relics of cluster galaxies
(Research Note)

S. K. Yi[1], J. Lee[1], I. Jung[1], I. Ji[1], and Y.-K. Sheen[2]



Cf. Mihos (2004), Fujita (2004)

Merger Relic Fraction



discs show merger features less frequently (Cf. A.Ferguson)

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

Summary

- galaxy mergers
  - found to be frequent in real clusters
  - some may be merger relics from previous halo environments
- Having realistic information on halo assembly history is critical to understanding the galaxy evolution
- cluster deep imaging campaign (CTIO/Magellan/CFHT)
- related issues (BOE, DMR)
- caveats
  - merger feature, mass ratio determination subjective
  - satellite-satellite mergers (zoom-in simulations)
  - baryon effects on halo merger tree
  - post-merger feature time (larger parameter space to explore)

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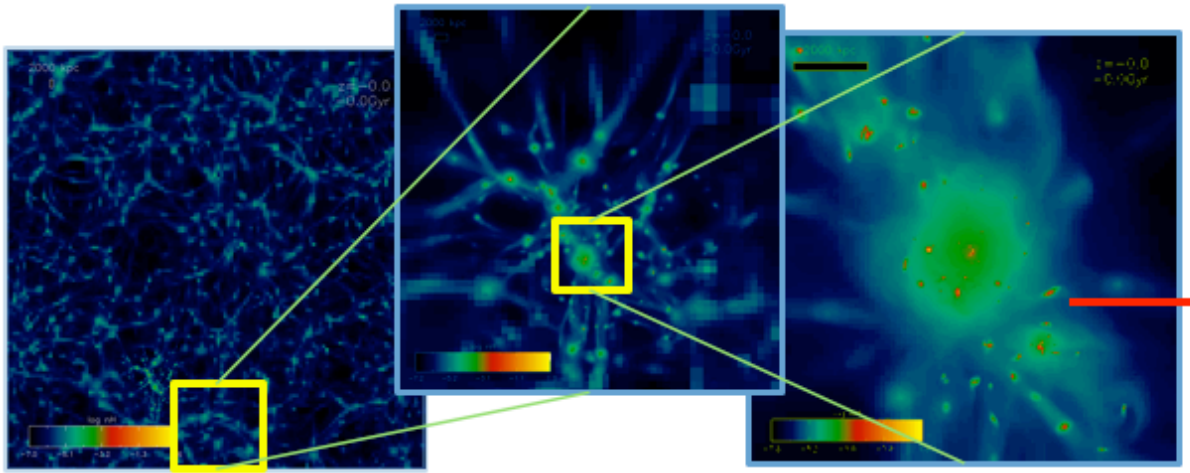
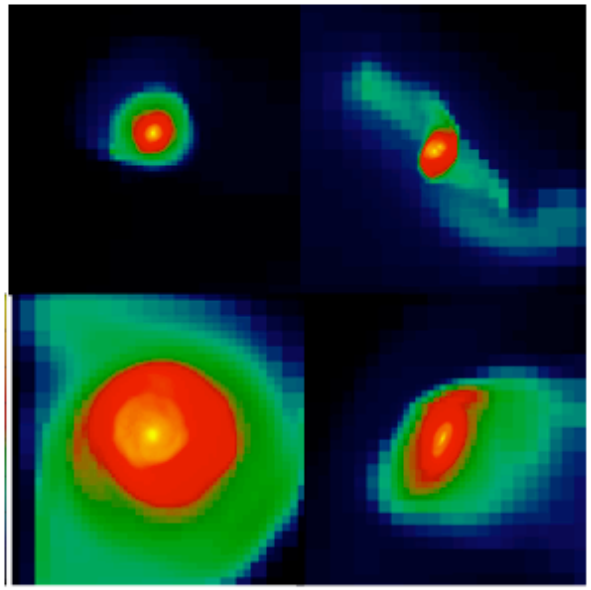
Research interest: MERGER HISTORY OF CLUSTER GALAXIES

1. Zoom-in hydrodynamic simulation on a cluster



200Mpc/h

4Mpc/h



Individual galaxies