A massive cD galaxy at z~1.1 and its implications

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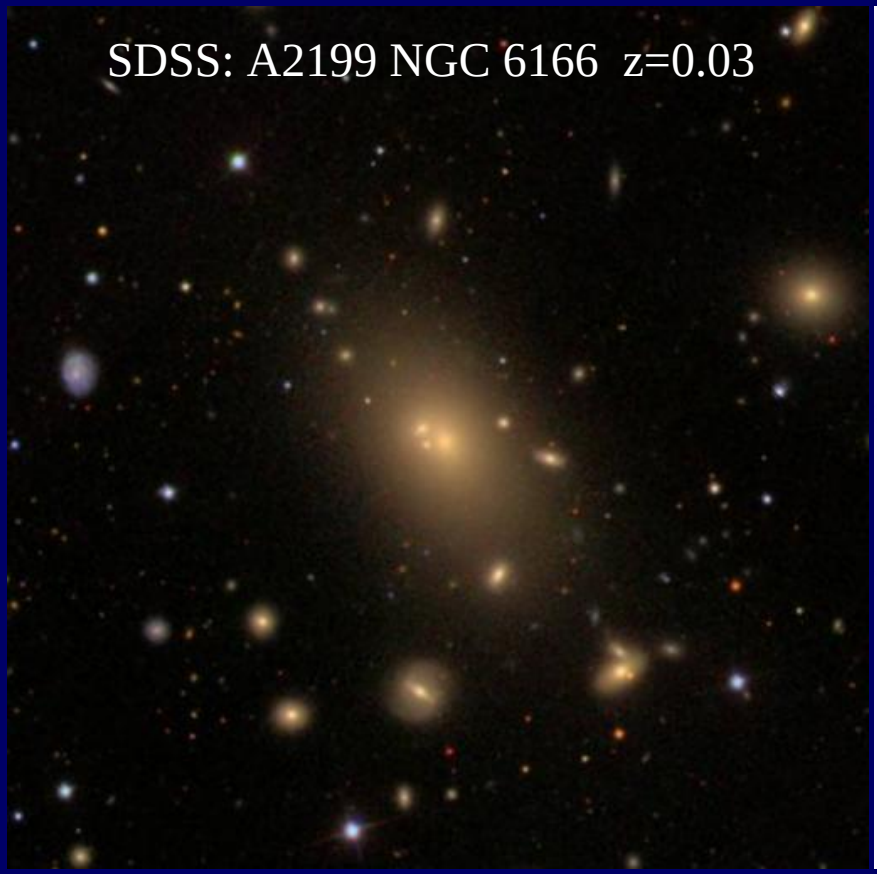
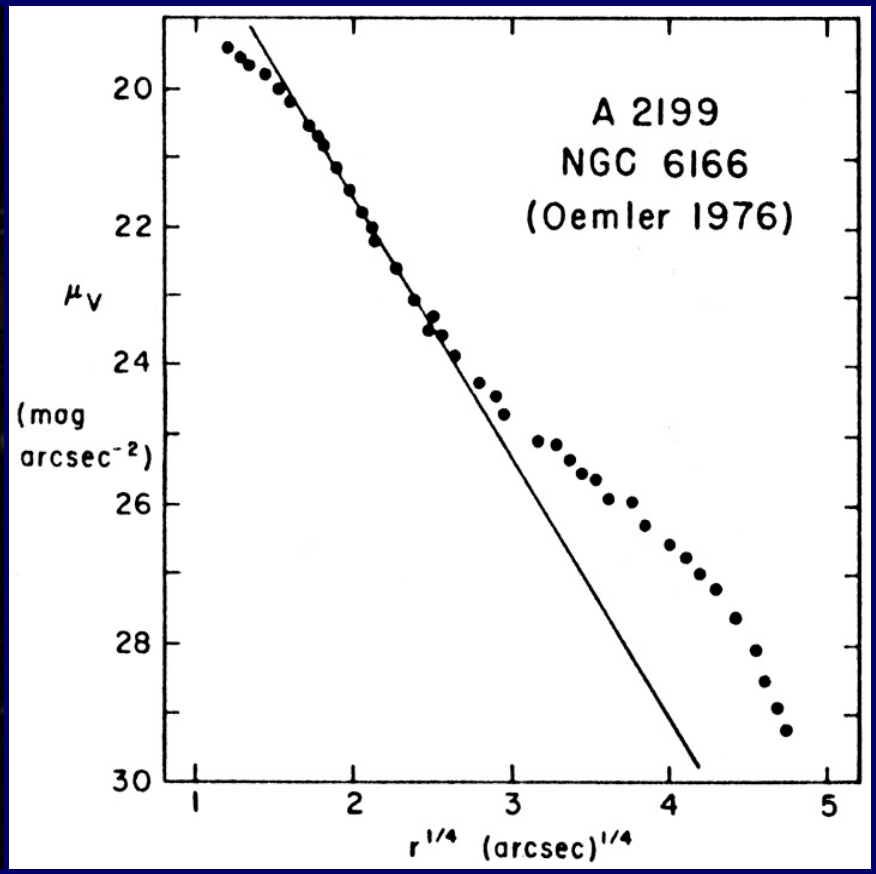
Outline

- *The structure of local Brightest Cluster Galaxies (BCGs): radial light profiles*
- *The role of major dry mergers in the late (z<1) mass assembly of BCGs and cD halo formation*
- *A massive cD galaxy at z~1.1 and its implications for an early (z>1) dry merger history*

0. Background: Basic properties





(see Matthews et al. 1976; Oemler 1976; Schombert 1988; Graham et al. 1996)

0. Background: The formation mechanisms of BCGs/cDs

Early mechamisms:

- *Galactic cannibalism (Ostriker & Tremaine 1975; White 1976)*
- *Tidal stripping (Gallagher & Ostriker 1972; Merritt 1985)*
- *Cooling flow (Fabian 1994)*

Recent semi-analytic models and simulations: two-phase process

An initial collapse with rapid cooling and star formation at z>1~2 is followed by late (z<1) growth through multiple dissipationless (dry) mergers of pre-existing progenitors

This is not correct totally!

Present-day BCGs have built up half of stellar mass since z~1. Minor mergers can be responsible for late (z<1) mass assembly.

(e.g., De Lucia & Blaizot 2007; Ruszkowski & Springel 2009; Naab et al. 2009; Laporte et al. 2012)

No observational evidence

Very recently, Laporate et al. simulation shows that BCGs may enter the dry merger phase at epochs earlier than z=1 (Laporte et al. 2013)

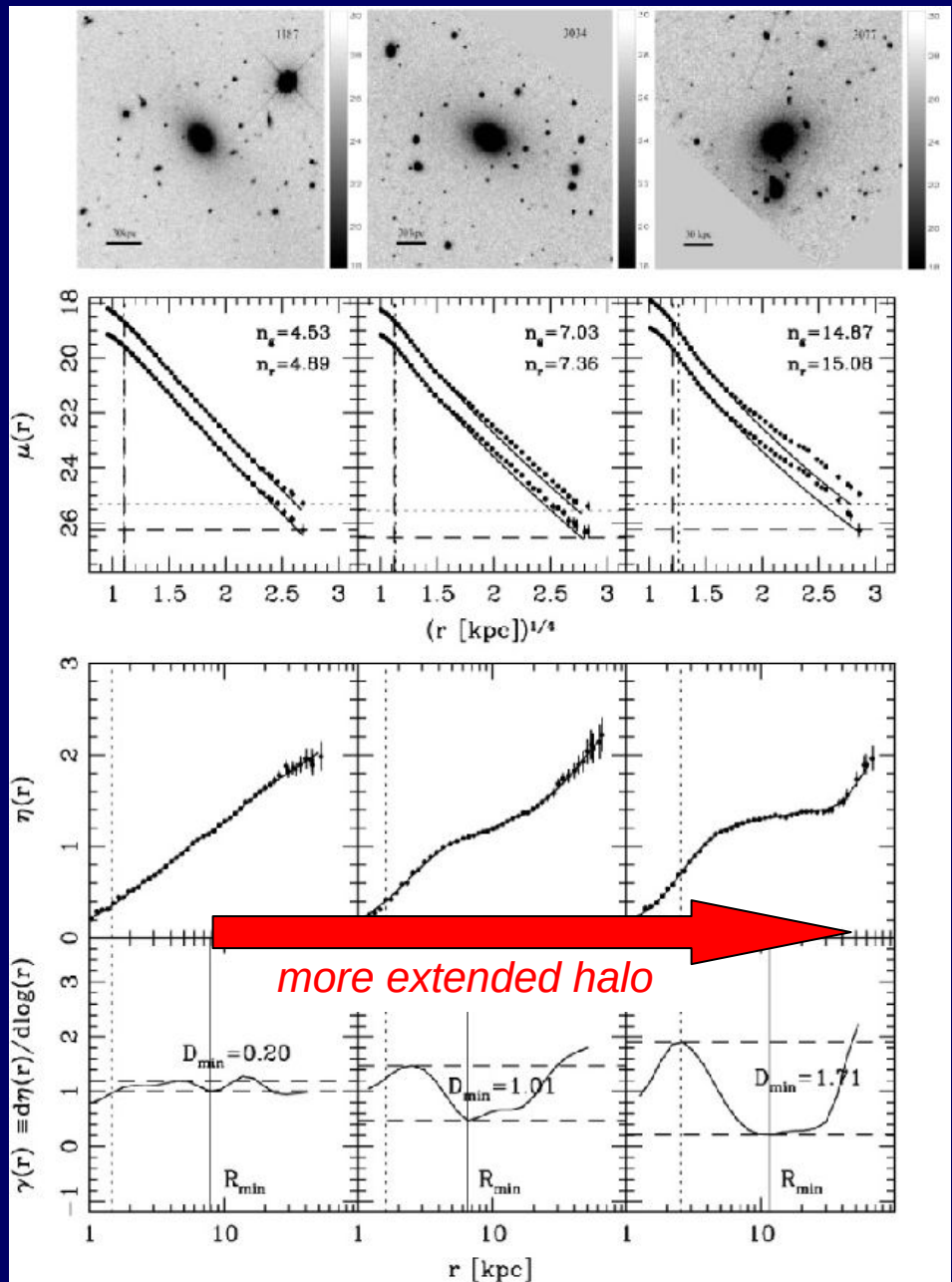
1 The structure of local BCGs: light profiles: A new, objective method

Sloan r-band images

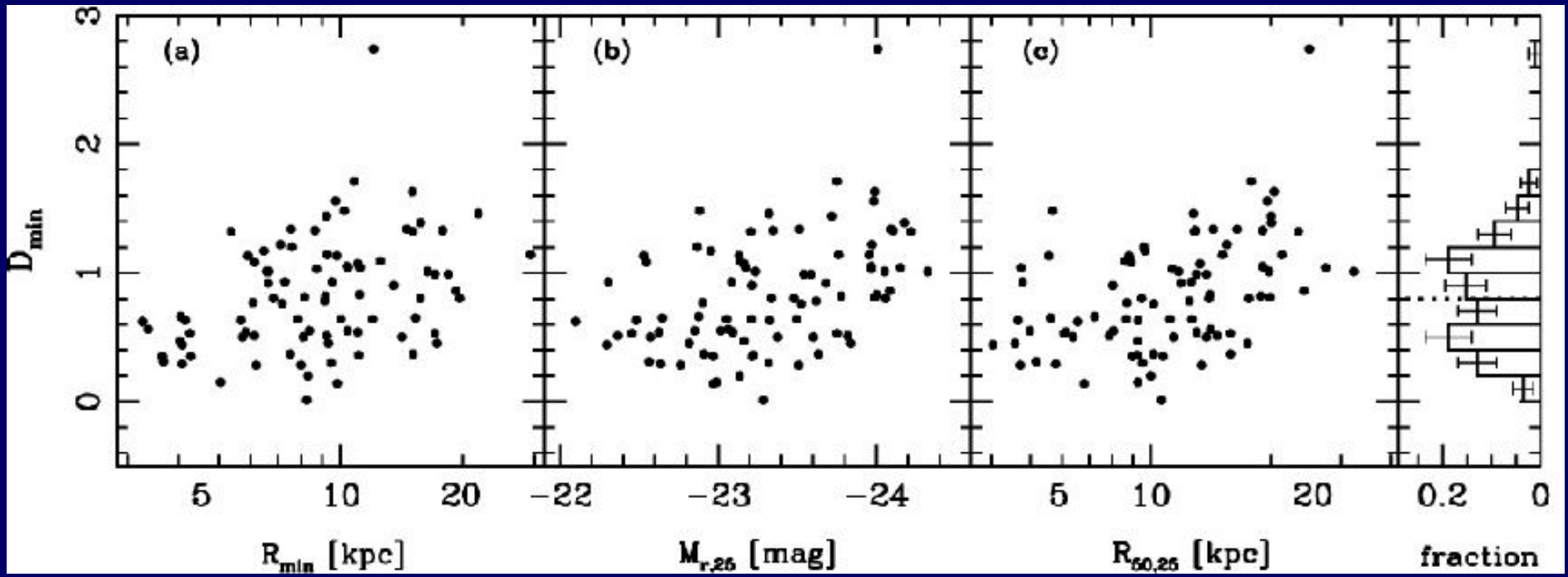
light profiles: $\mu(r)$

$$\eta(r) \equiv \mu(r) - \langle \mu(r) \rangle$$
(Petrosian 1976)
(Brough et al. 2005)

$$\gamma(r) \equiv d\eta(r) / d\log(r)$$
(Liu et al. 2008)



Correlated with galaxy properties (Liu et al. 2008)



These correlations demonstrate that more luminous and larger BCGs tend to have more extended stellar halos and are more likely to be classified as cD galaxies.

2.1 Growth of the BCGs via major dry mergers since z=1: Direct evidence

Nearby sample (z < 0.12, Liu et al. 2009)

A well-selected BCG sample from SDSS-C4 cluster catalog (Miller et al. 2005)

18 Pairs (triples) in merging out of 515 BCGs:

Redshift range: $0.03 < z < 0.12$

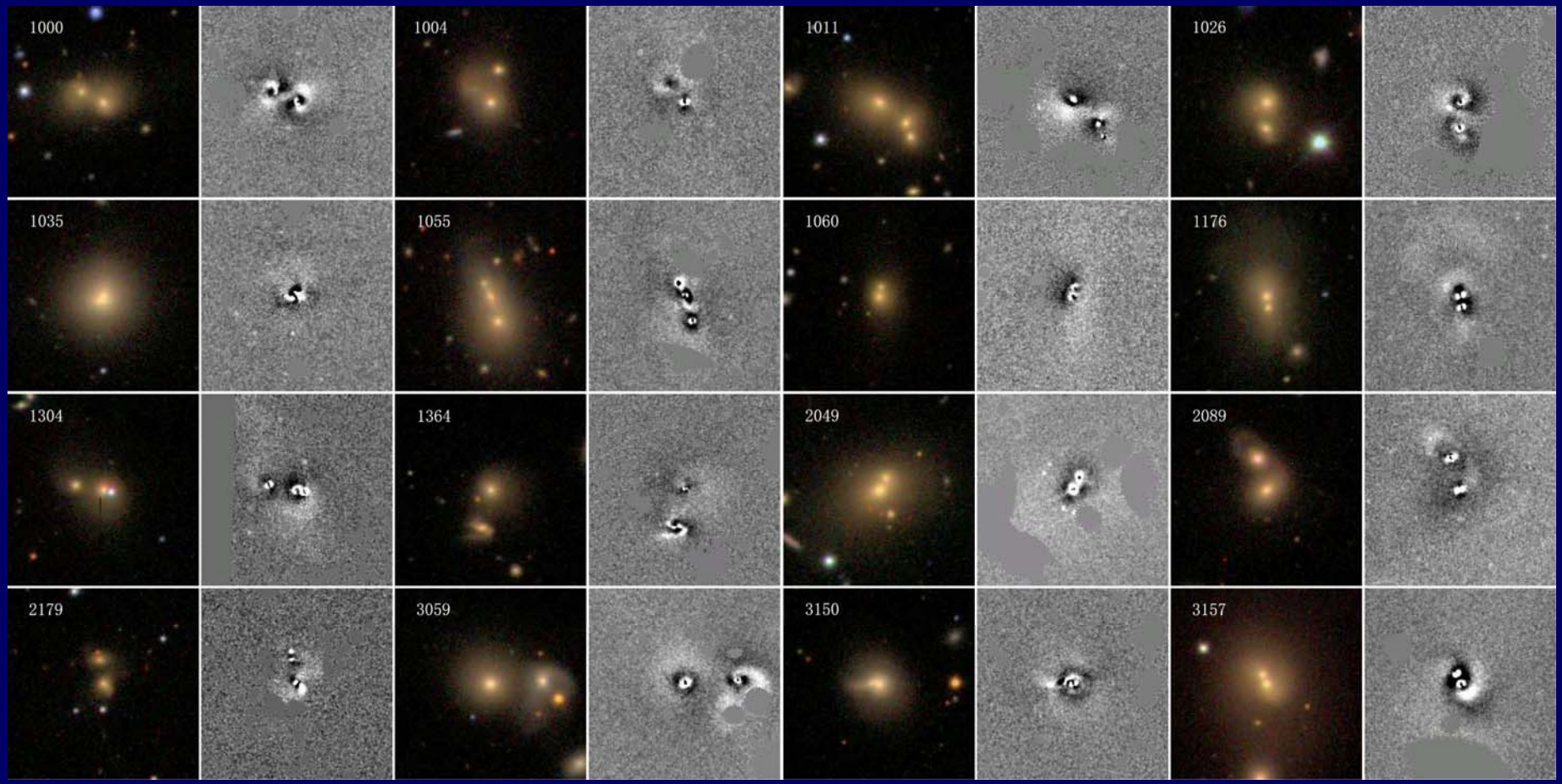
Magnitude differences: $\delta m_r < 1.5 mag$

Projected separation: $r_p < 30 kpc$

Interaction features: broad plumes at the outskirts, short tidal tails, bridges, or asymmetries

2.1 Growth of the BCGs via major dry mergers since z=1: Direct evidence

Nearby sample (z < 0.12, Liu et al. 2009)



2.1 Growth of the BCGs via major dry mergers since z=1: Direct evidence

Intermediate-z sample (0.3 < z < 0.6, Liu et al. 2013, in prep.)

X-ray clusters of galaxies in the COSMOS field (Finoguenov et al. 2007)

4 Pairs (triples) in merging out of 28 BCGs:

Redshift range: $0.3 < z < 0.6$

Magnitude differences: $\delta m_{F814} < 1.5 mag$

Projected separation: $r_p < 10 kpc$

Interaction features: broad plumes at the outskirts, short tidal tails, bridges, or asymmetries

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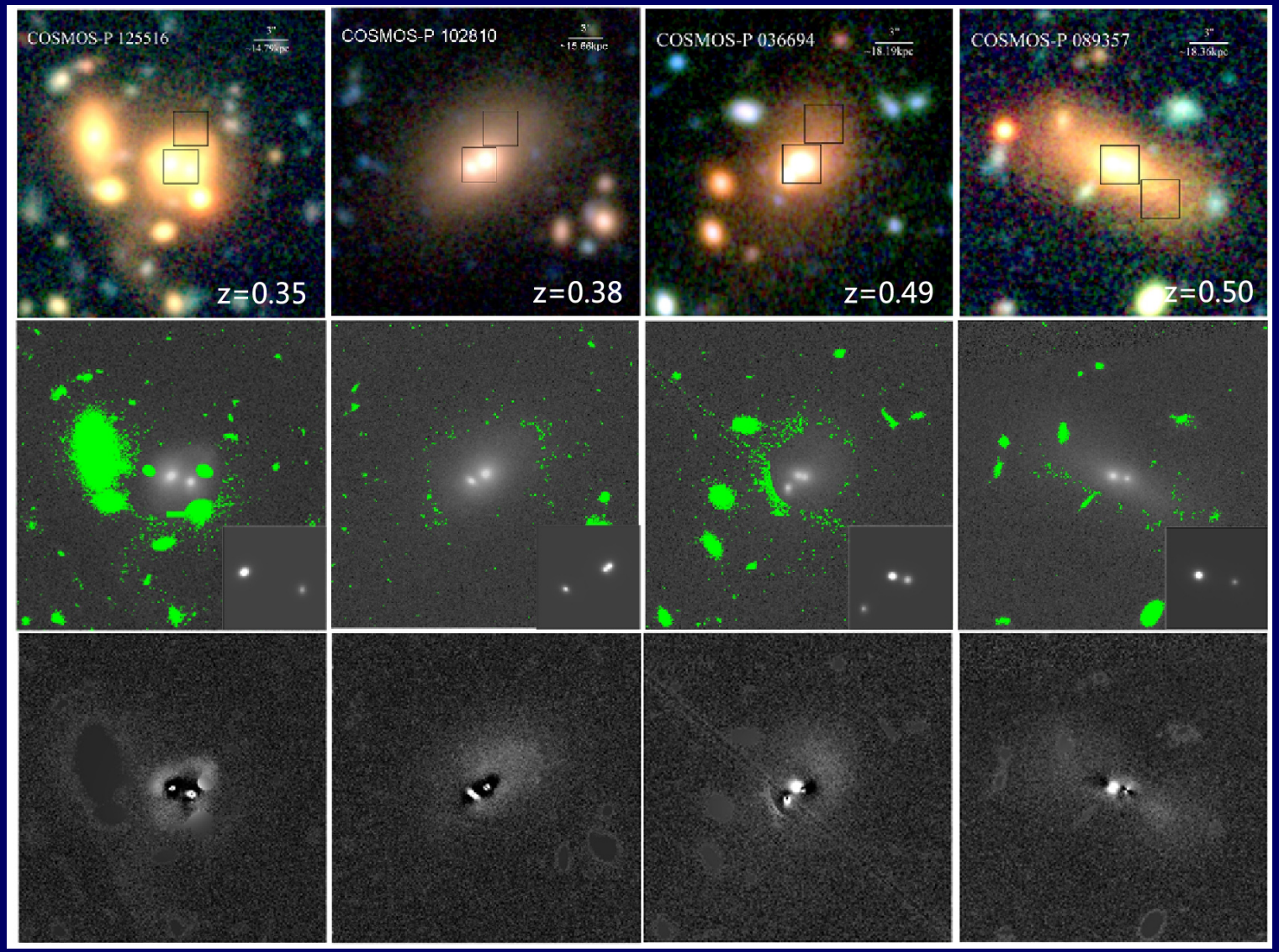


2.1 Growth of the BCGs via major dry mergers since z=1: Direct evidence

z~1 sample (0.84 < z < 1.46, Lidman et al. 2013,MNRAS,433,825.)

3 of the 14 BCGs are likely to experience a major merger within 0.6 Gyr from spectroscopic observations. (RDCS 1252, RCS 2319, SpARCS 1616)

$$8kpc < r_p < 28kpc, \Delta v < 500km/s, 0.25 < \mu_* < 1$$

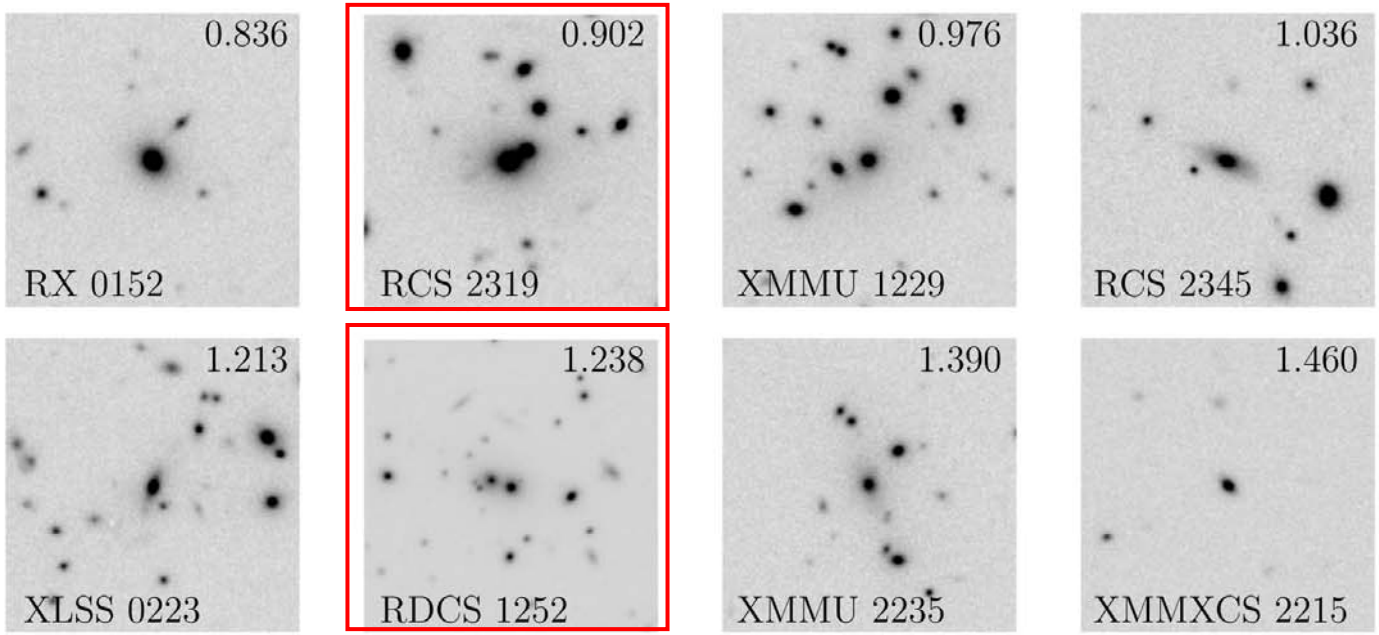
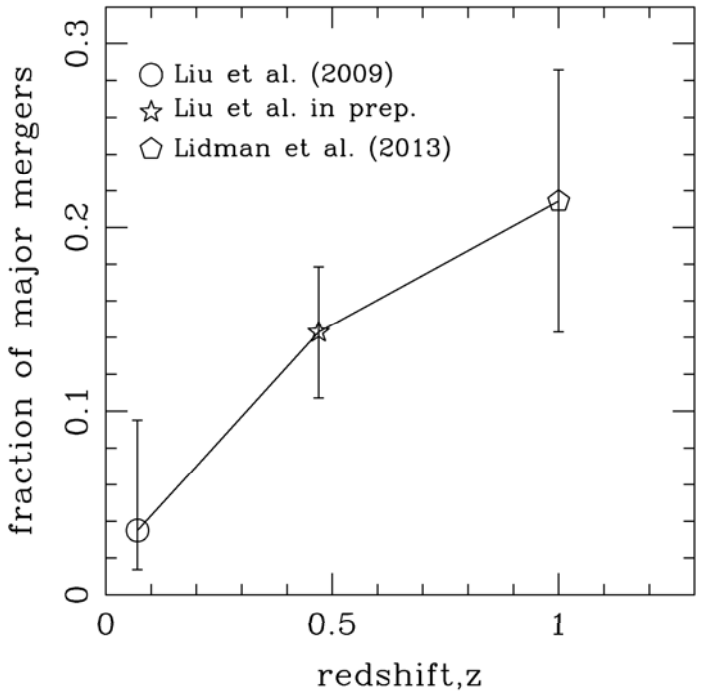
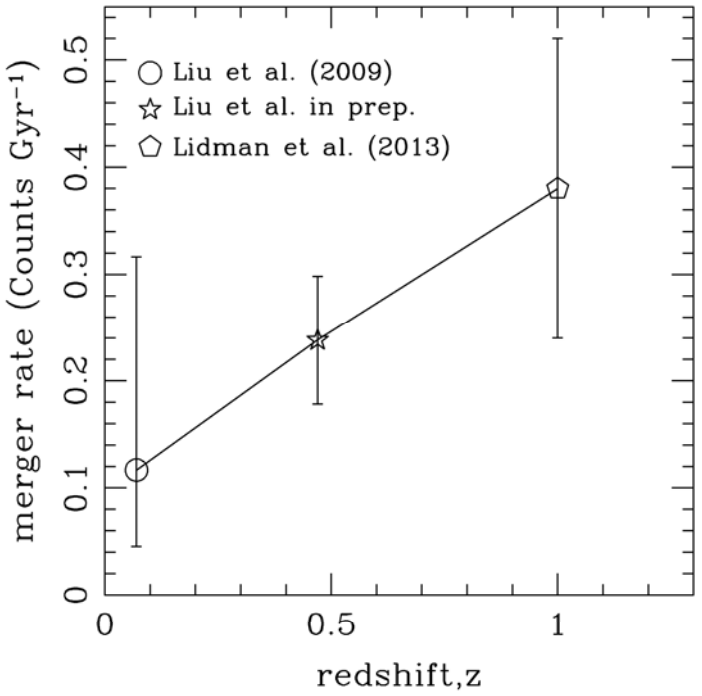


Figure 1. Ks-band image cutouts centred on the HCS BCGs. With the exception of RDCS 1252, the images are 18″ on a side, which corresponds to 140 kpc for the nearest BCG and 155 kpc for the most distant. For RDCS 1252, the image covers twice the area. Annotating each image are the shortened version of the cluster name and the redshift of the cluster. From left to right and from top to bottom, clusters are ordered in redshift. North is up and east is to the left.

2.1 Growth of the BCGs via major dry mergers since z=1: Direct evidence

(Liu et al. 2013, in prep.)

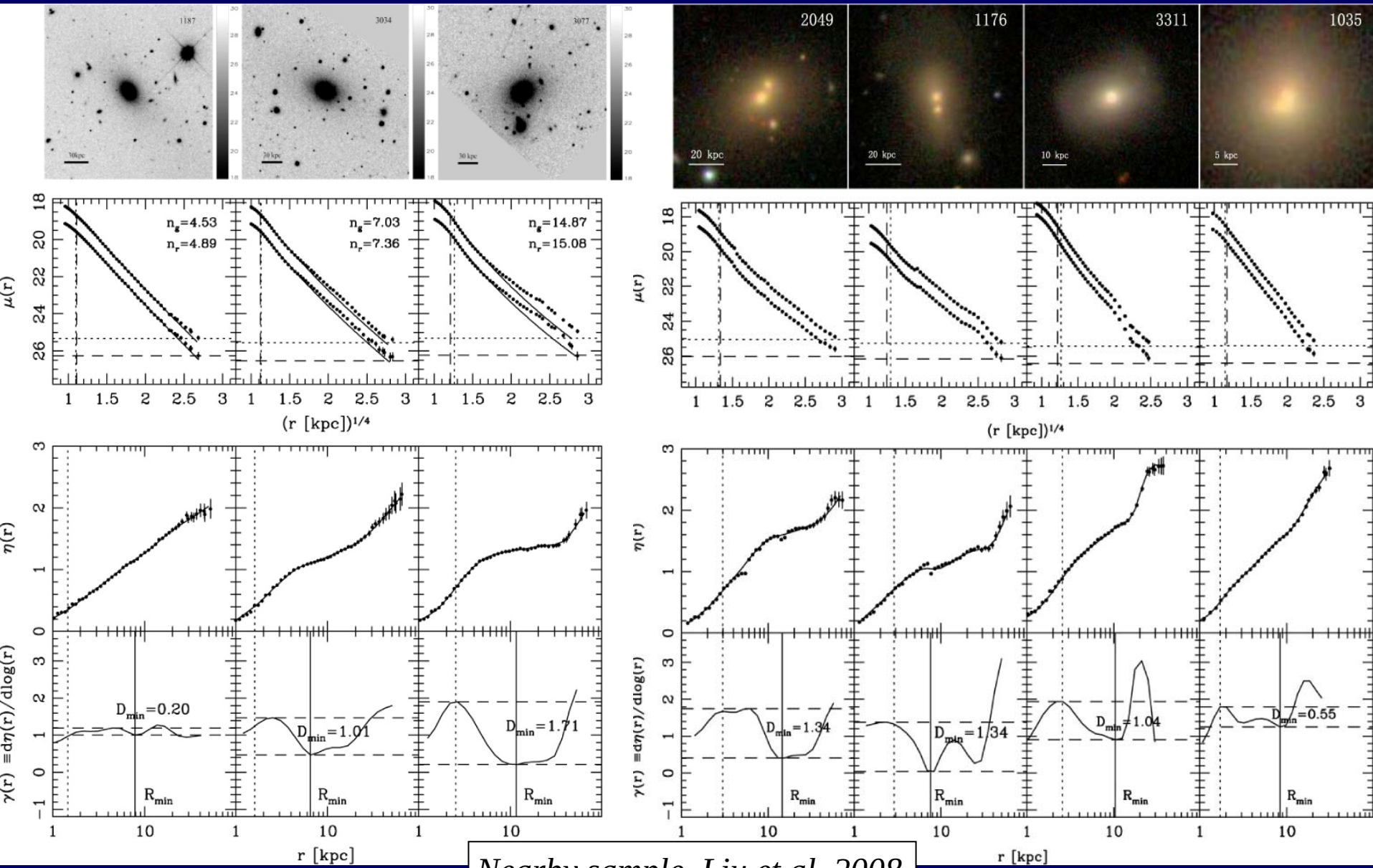




Today's BCGs may increase their stellar mass by $\sim 35\% \pm 12\%(f_{mass}/0.5)$ *since z=1. However, minor dry mergers may also play an important role.*

(f_{mass} *~ mass ratio added to central galaxy by merger)*

2.2 Connections between major dry mergers and outer cD halo formation



Nearby sample, Liu et al. 2008

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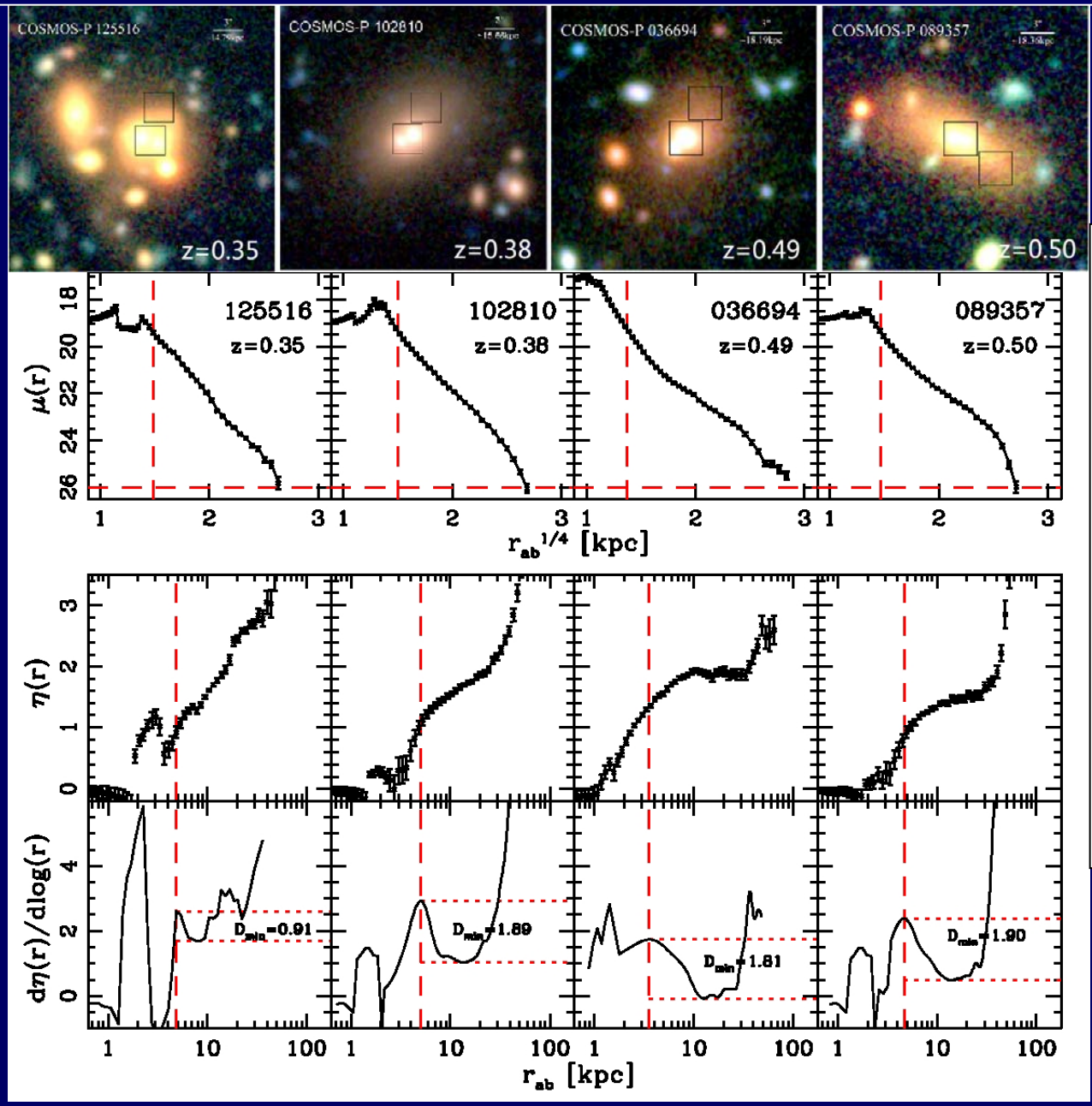
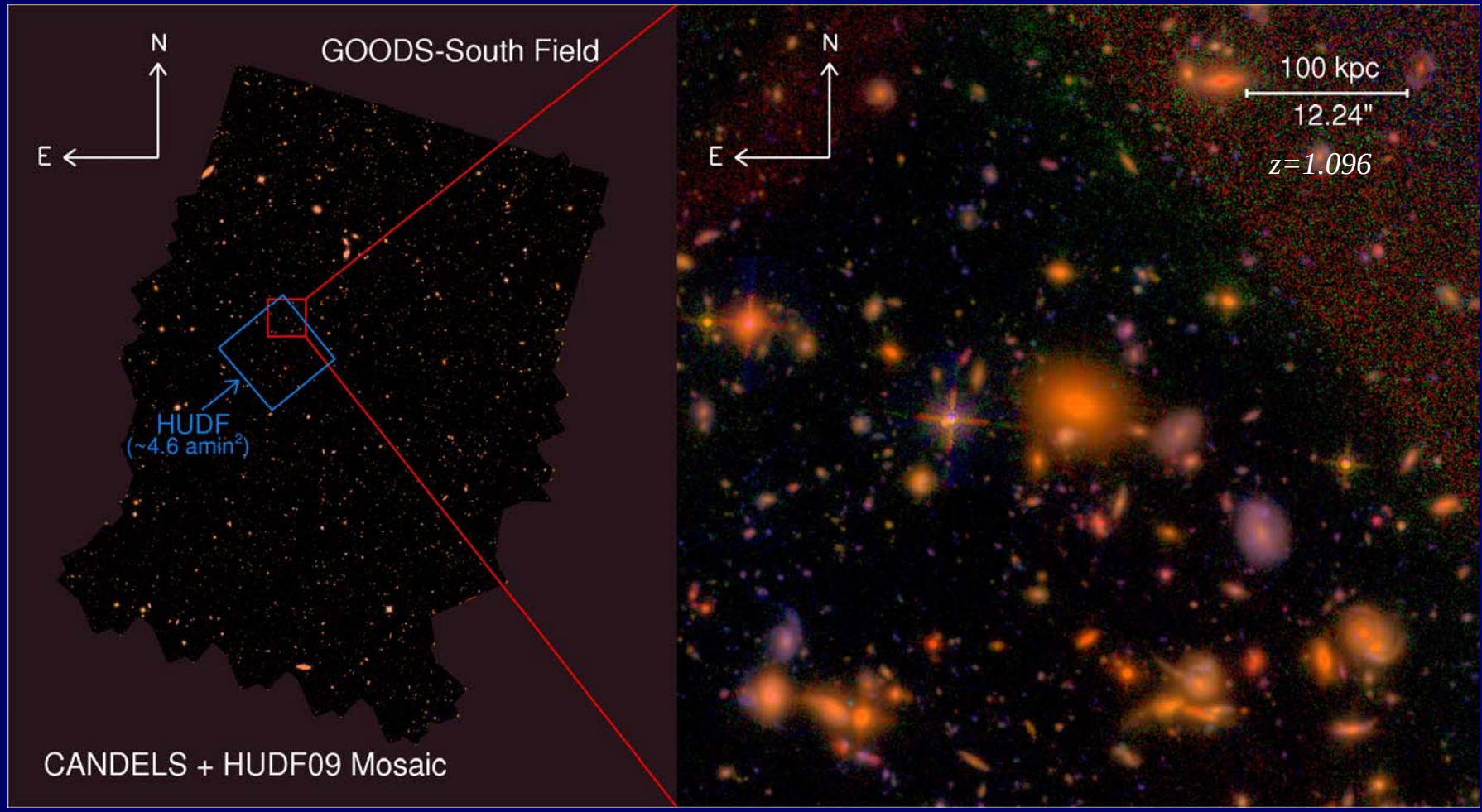


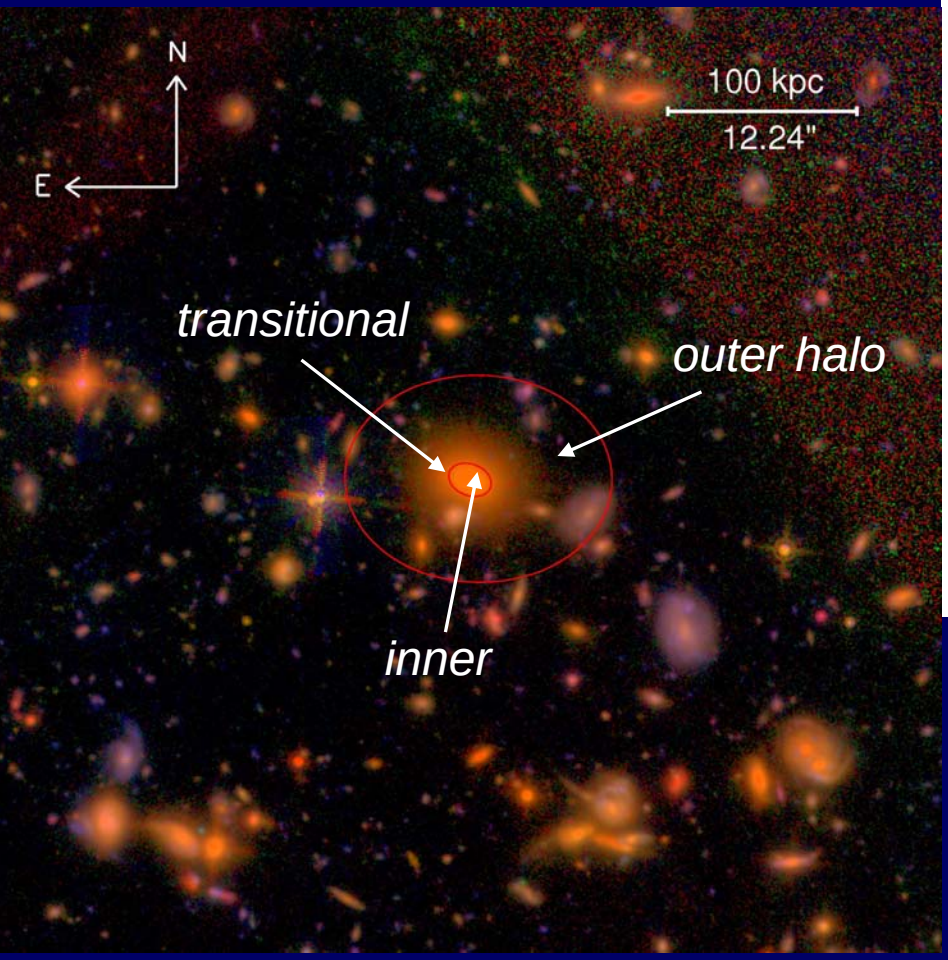
Intermediate-z sample (Liu et al. 2013,in prep.)

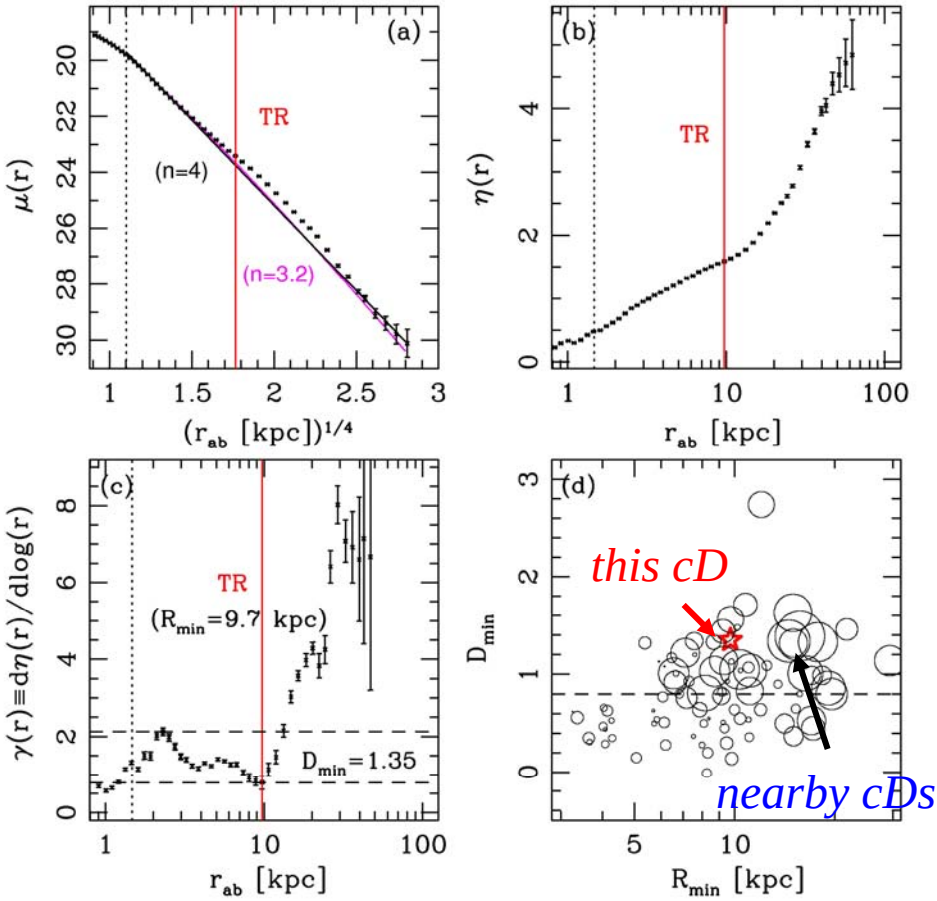
cD halos (envelopes) in BCGs are from major dry mergers and they appear shortly after merging take place.

3. A massive cD galaxy at z=1.096 in the HUDF region of GOODS-South



3.1 Identification





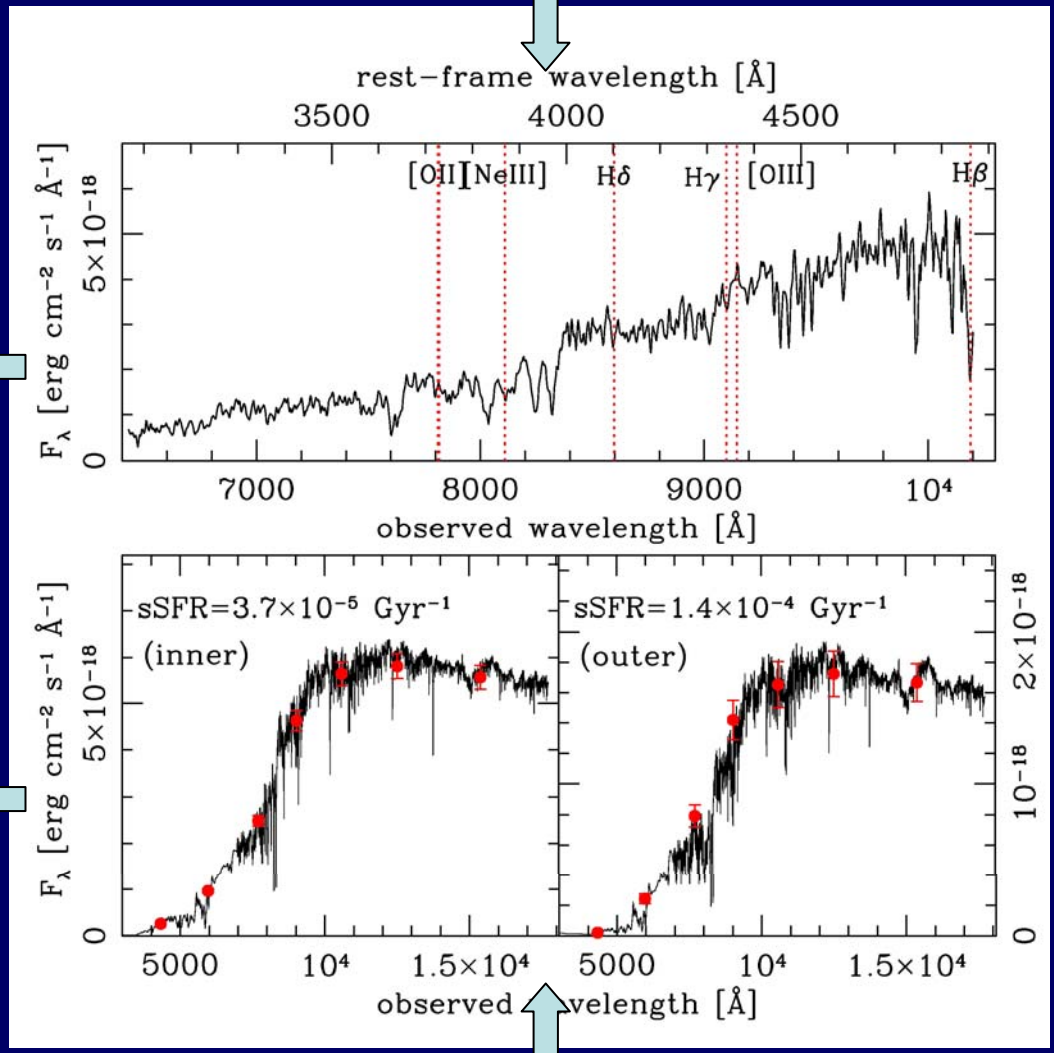
(See Liu et al. 2008,2013 for more details about the method)

3.2 Stellar population

Optical spectroscopy observed by the VLT/FORS2

Weak emission lines (e.g., [OII]):
old population

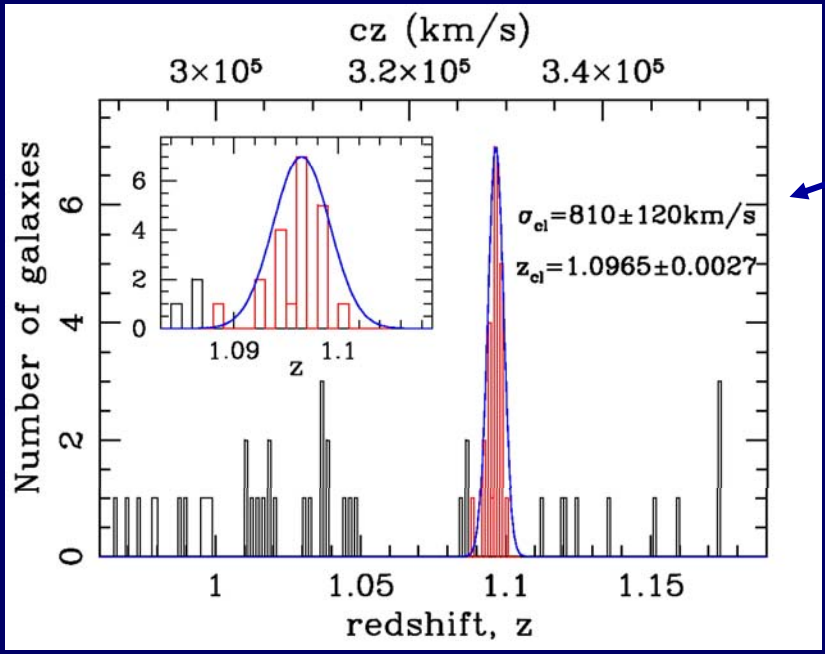
Extremely low sSSFRs:
passively-evolving populations



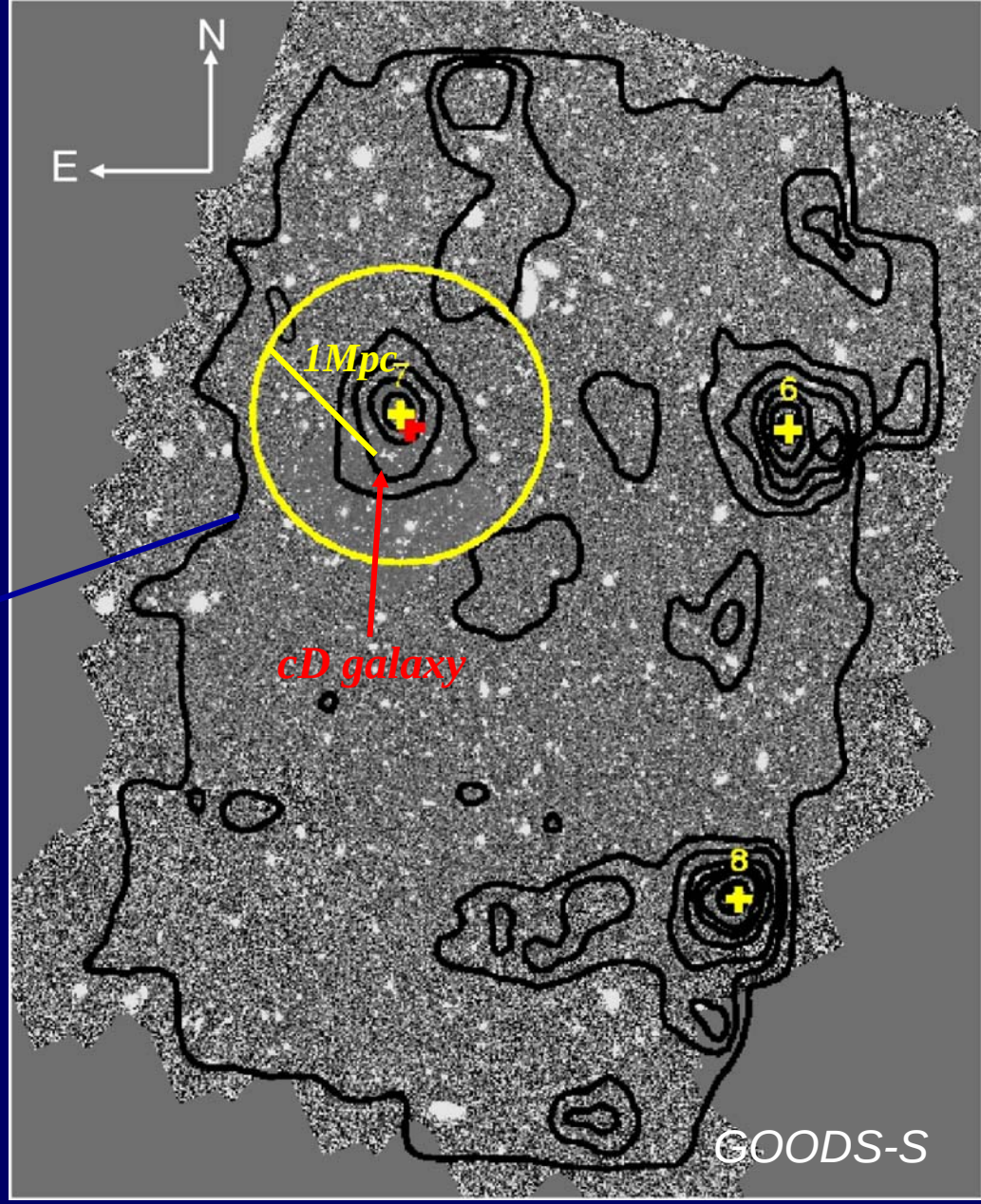
SEDs of inner and outer components

3.3 Environment

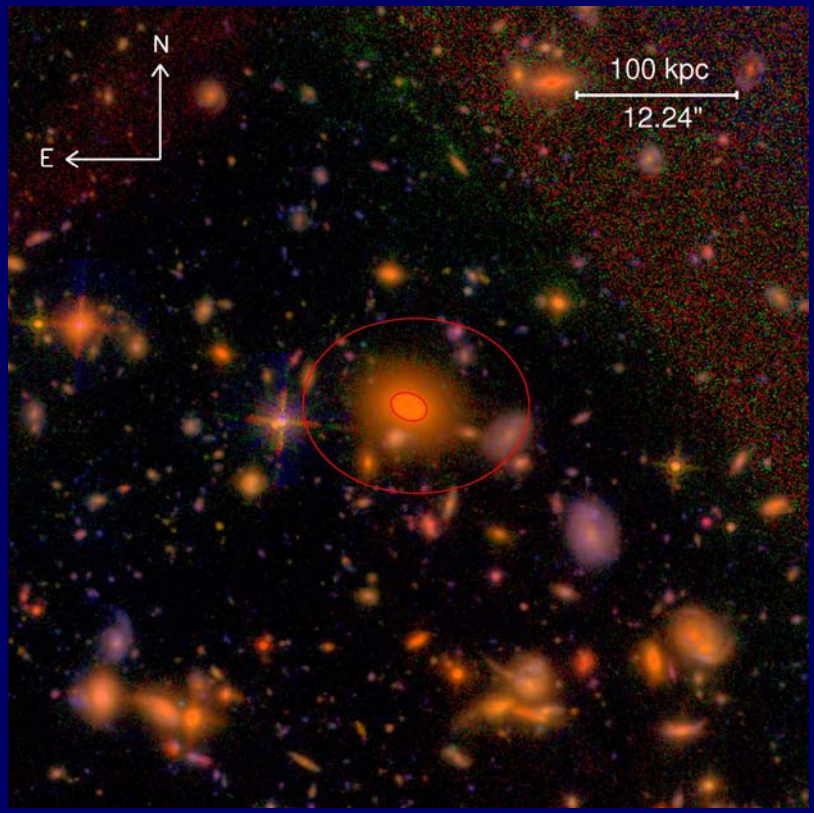
This high-z cD is located close to the centre of a candidate cluster!

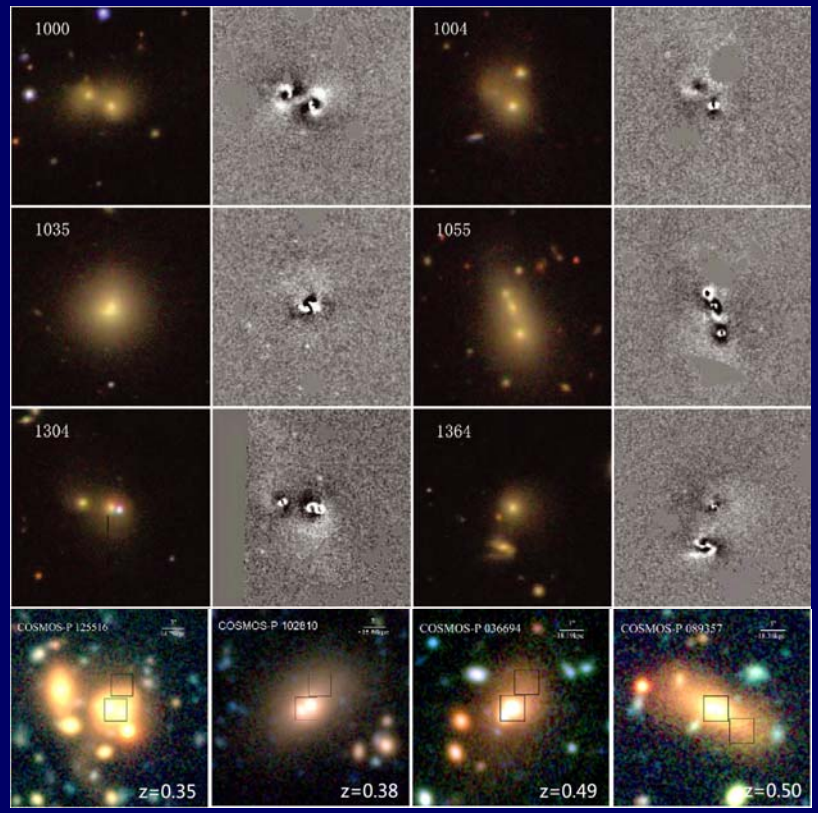


21 member galaxies spectroscopically confirmed



3.4 Implications: early dry merger history (z>1)



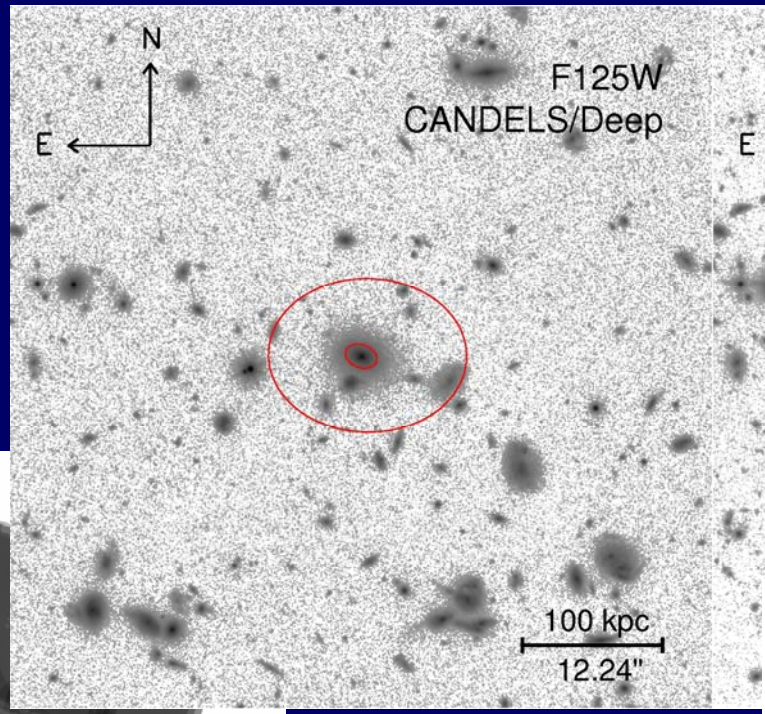


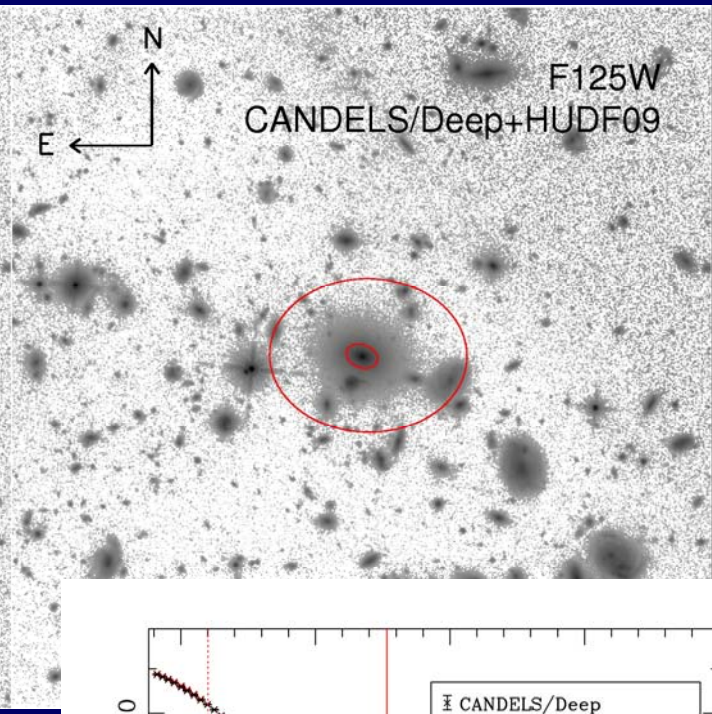
z=1.096, old population

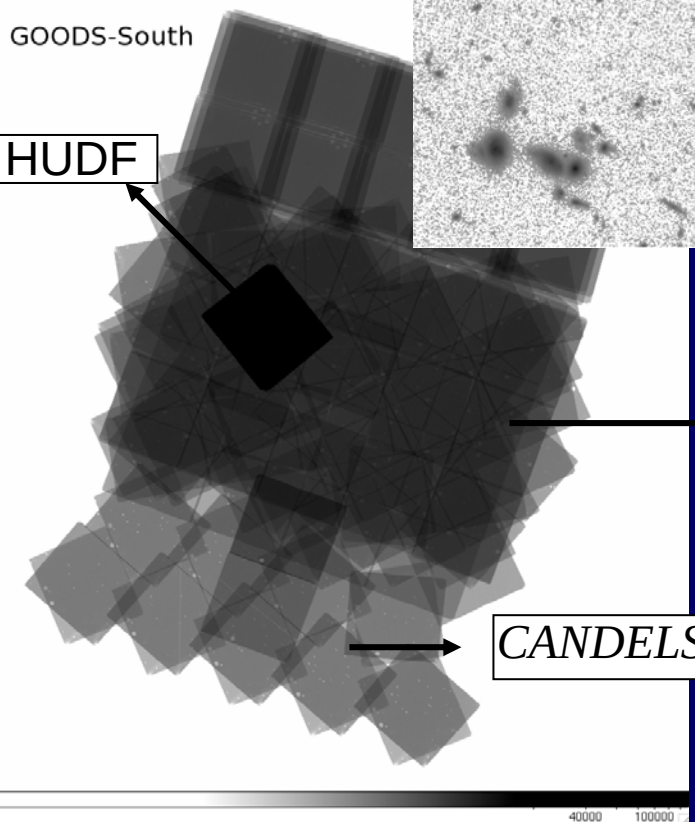
cD envelopes may originate from dry mergers

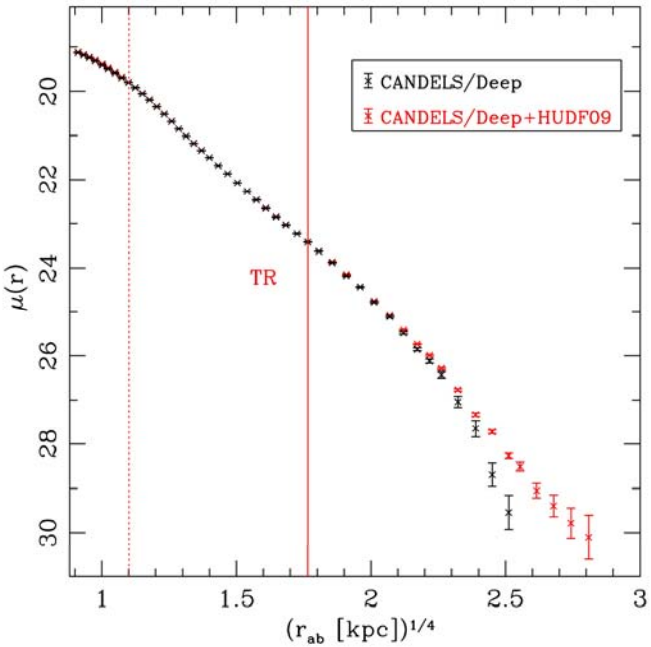
Some BCGs entered the dry merger phase at epochs earlier than z=1

3.4 Implications: such high-z cDs are more common than expected?









UCSC, 12 August 2013

Conclusions

- *We developed a relatively subjective method to determine how a radial light profile of a BCG deviates from the Sersic profile.*
- *Direct observational evidence shows that almost 1/3 of stellar mass of present-day BCGs is assembled via major dry merger since z~1.*
- *Both major and minor dry mergers do play an important role in the build up of stellar mass in BCGs at z<1.*
- *cD halos (envelopes) in BCGs may originate from major dry mergers.*
- *We discovered a massive cD galaxy at z~1.1, which indicates that some BCGs may enter dry merger stage at epochs earlier than z=1.*

Thank you!