# Caught in the Act: the assembly of massive cluster galaxies at z=1.62

*Jennifer Lotz*

*STScI*

*with C. Papovich, R. Bassett, K.-V. Tran, A. Saintonge, C. Willmer, I. Momcheva, S. Finkelstein, G. Rudnick, + CANDELS team (S. Faber, H. Ferguson, A. Koekemoer, Y. Guo, K.S. Lee, D. Kocevski, A. van der Wel...)*

Durham - 20 July 2011

# Caught in the Act:
# the assembly of massive cluster galaxies at z=1.62

-- Formation of Brightest Cluster Galaxies

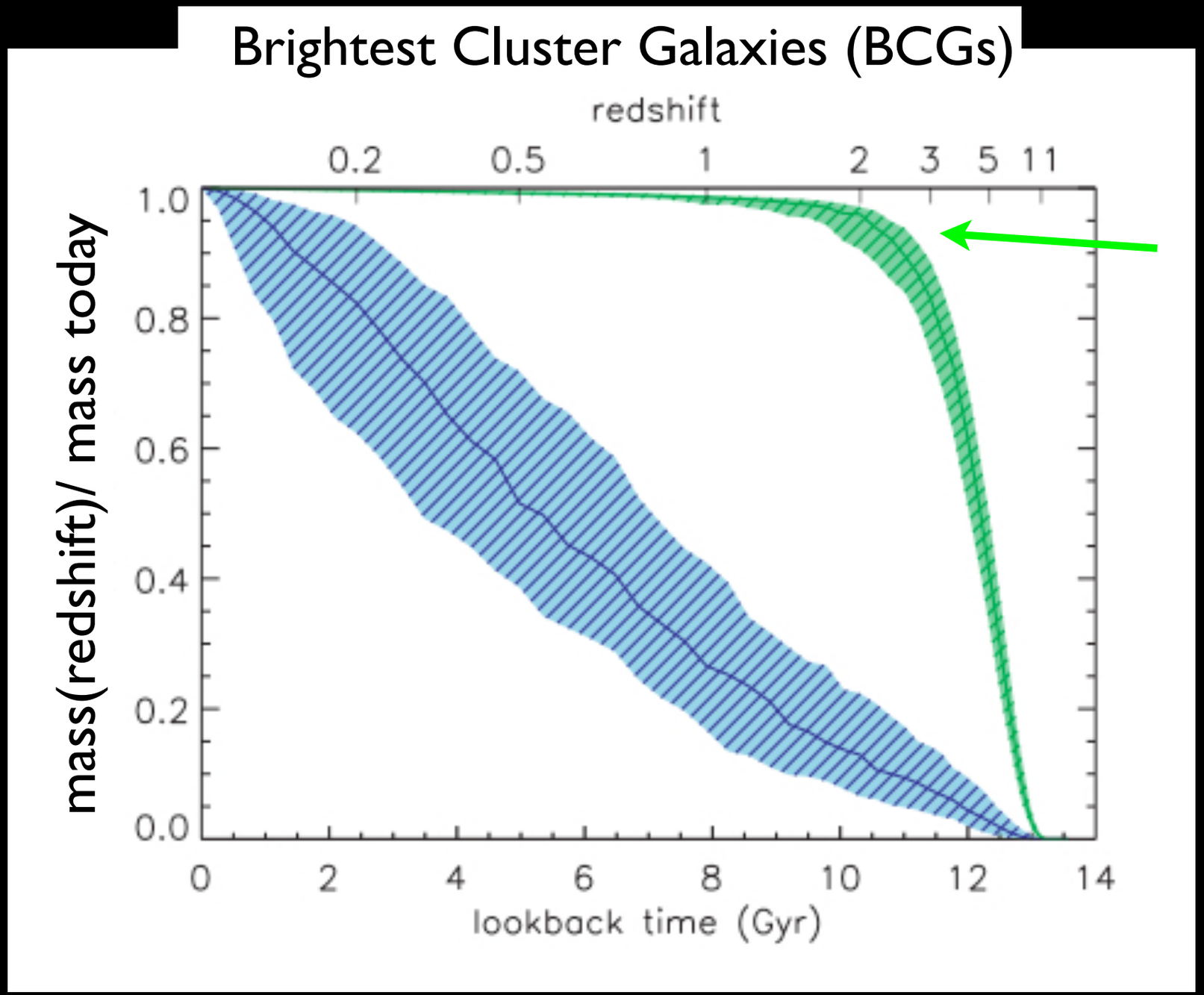
-- z=1.62 proto-cluster in UDS/CANDELS

-- proto-cluster galaxy sizes, morphologies

-- Mergers in cluster v. field

Durham - 20 July 2011

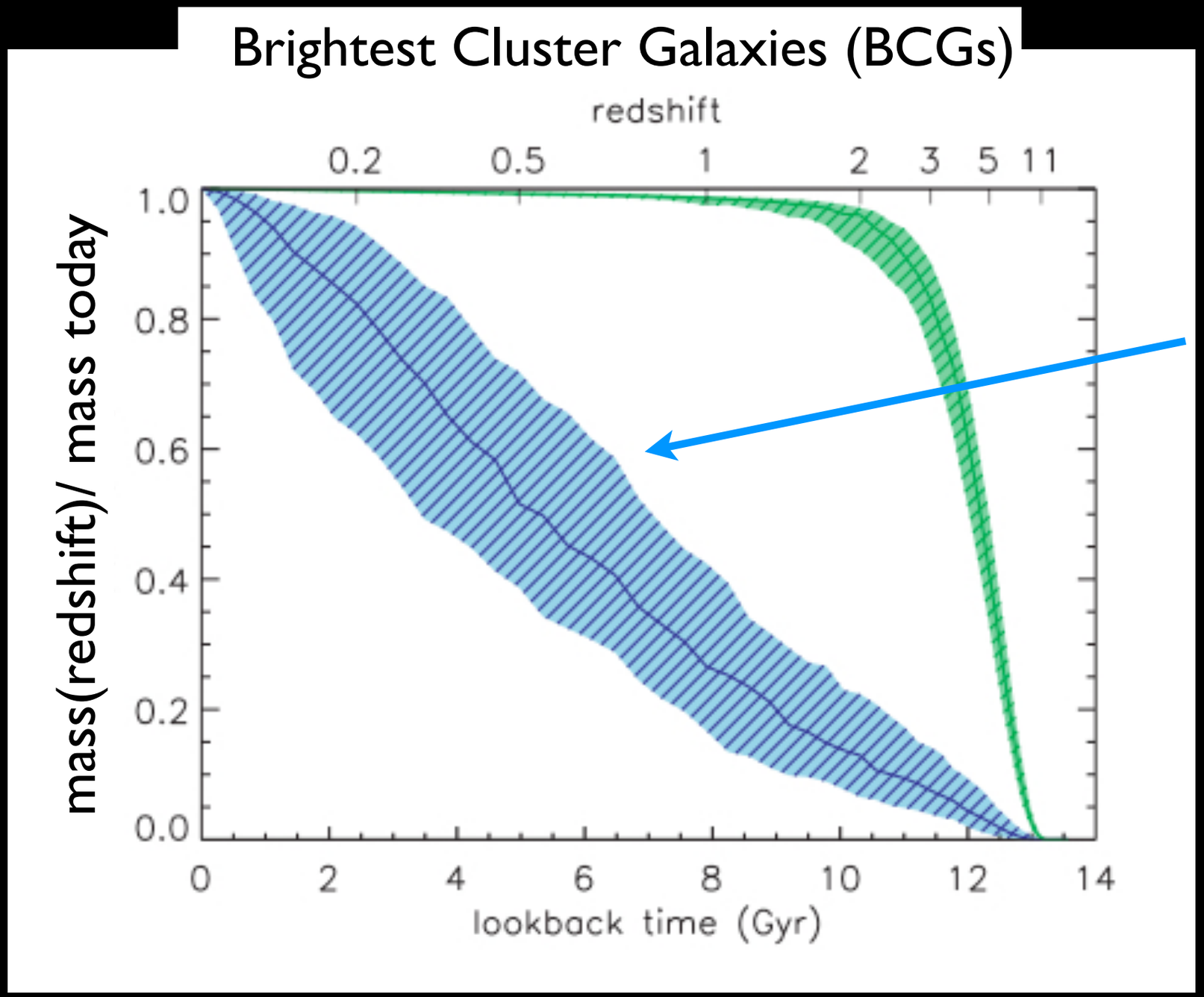
# Massive Cluster Galaxy Formation




the stars that end up in most massive galaxies form early

de Lucia & Blaziot 2007

# Massive Cluster Galaxy Formation

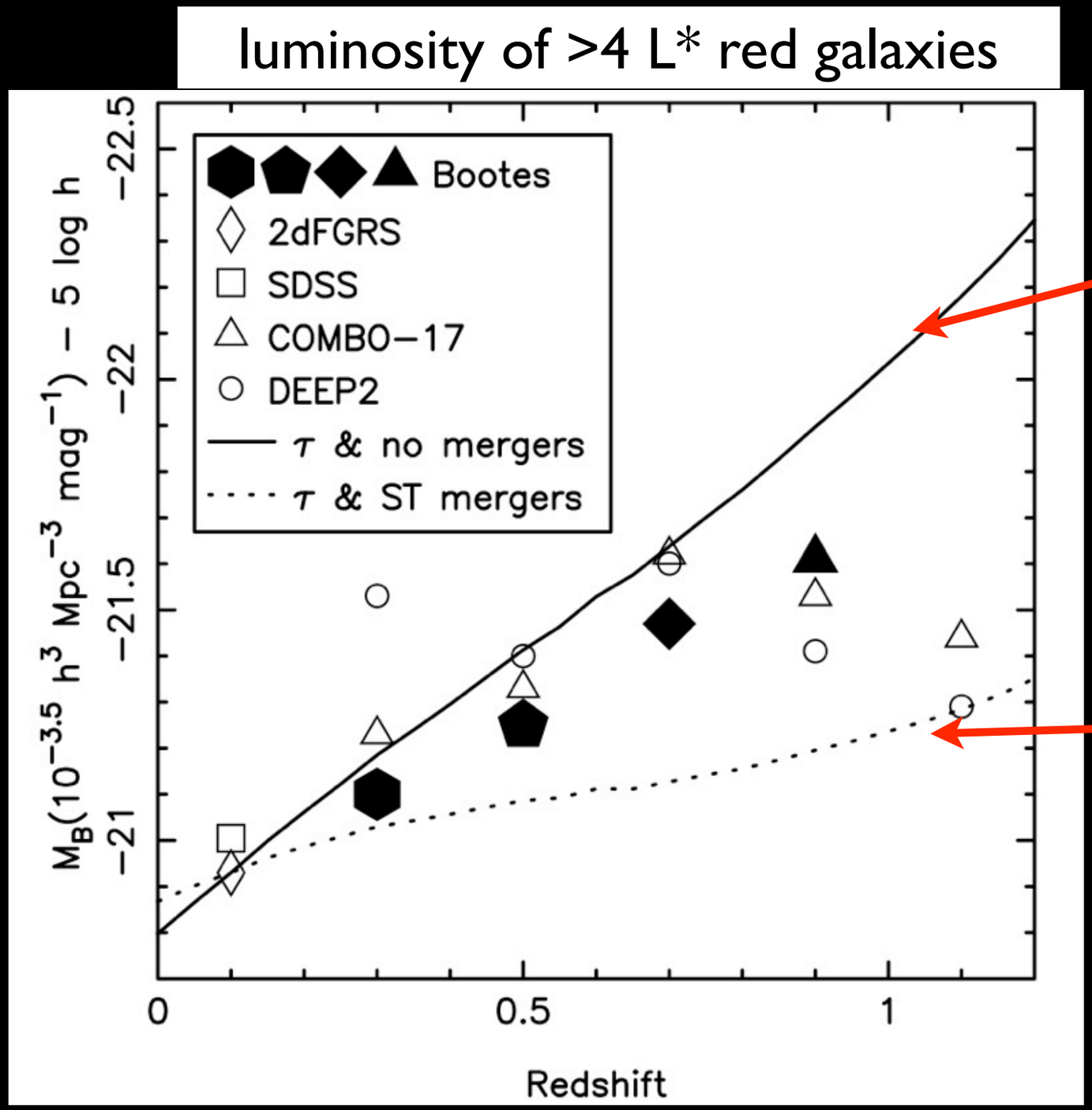



but those stars merge onto central galaxy late

< 50% of total mass by z~0.7

de Lucia & Blaziot 2007

# Massive Cluster Galaxy Formation

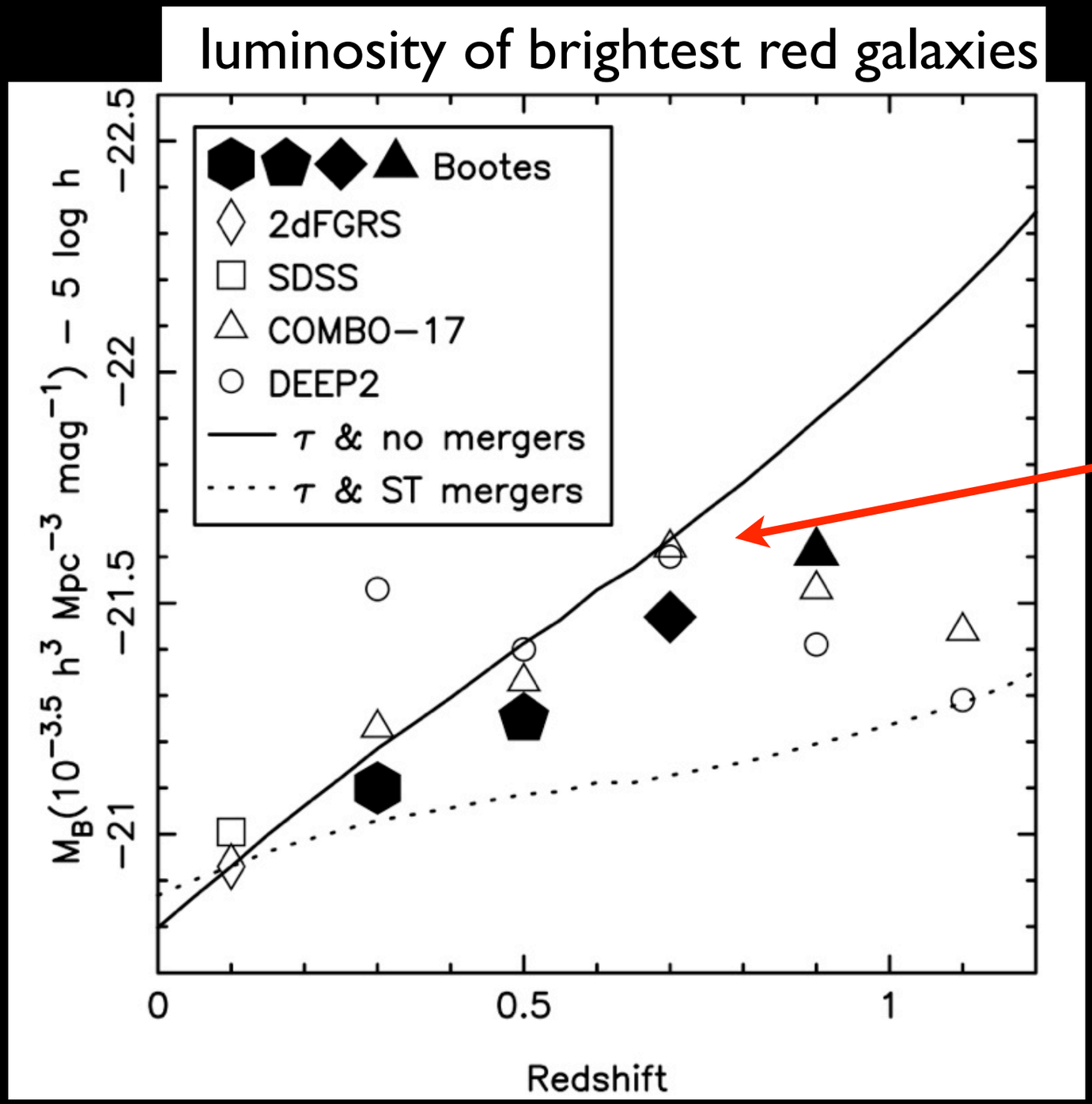



# stars in brightest red galaxies does not change

# stars in brightest red galaxies grow via mergers

Brown et al. 2007

# Massive Cluster Galaxy Formation




most massive galaxies already fully formed at z~0.7

so when did they form?

Brown et al. 2007

# Massive Cluster Galaxy Formation

need to look at the right time, in the right place:

-- mergers are unlikely in virialized massive clusters because relative velocities are too high (>> 200 km/s)

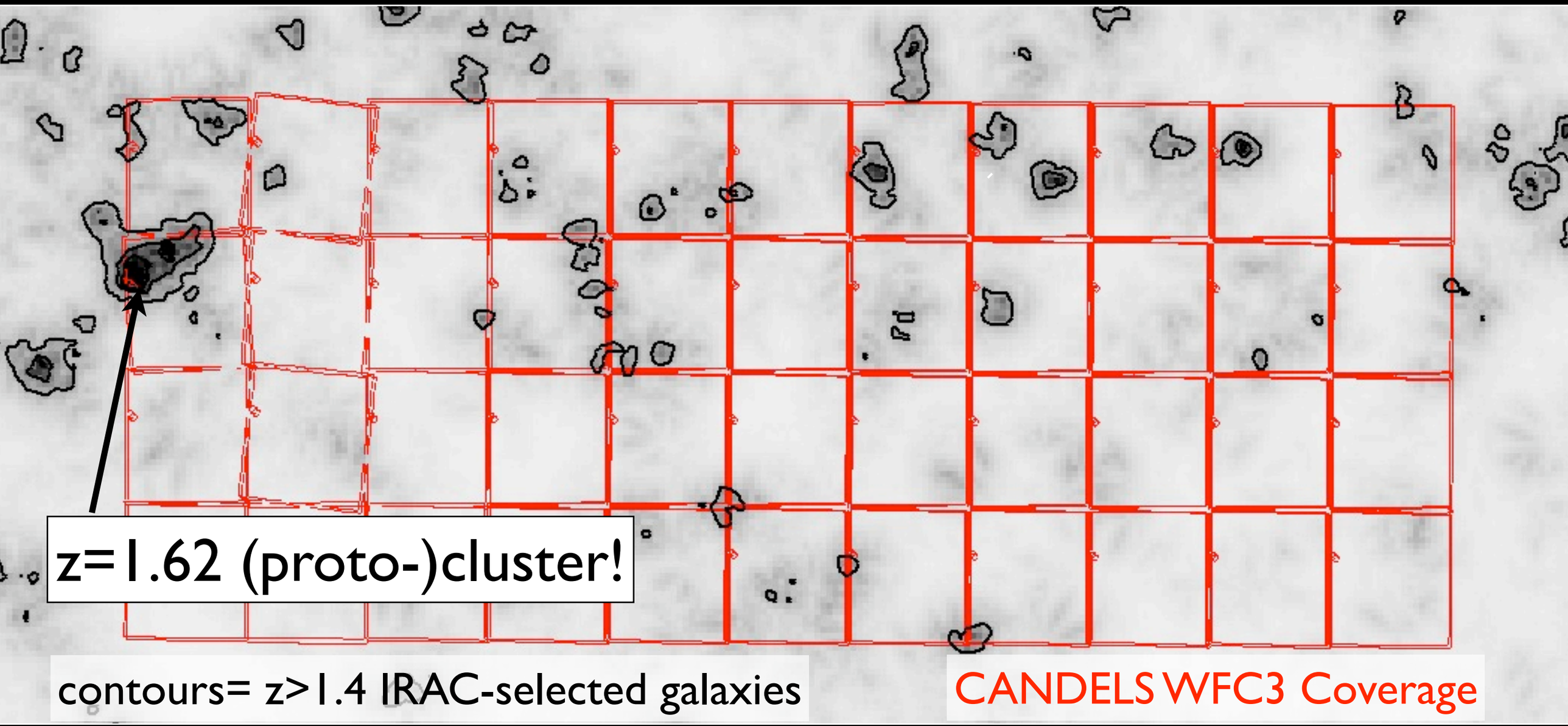
⇒ proto-cluster/ group environments (e.g. Tran et al. 2008)

-- no little observed evolution in LRGs at z< 1

-- stellar ages give formation times ~10 Gyr ago

⇒ massive proto-clusters at z > 1

# CANDELS: UKIDSS Deep Survey Field




13 spectroscopic confirmations, clear red sequence

$\sigma$ ~360 km/s; $M_{200} \sim 2 \times 10^{13}\ M_{\odot}$ (if virialized)

Papovich et al. 2007, 2010; Tanaka et al 2010

# Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey

PIs Faber + Ferguson

HST WFC3 NIR imaging

wide fields: EGS + COSMOS + UDS

~1 orbit depth J + H

over ~ 0.2 sq. degrees

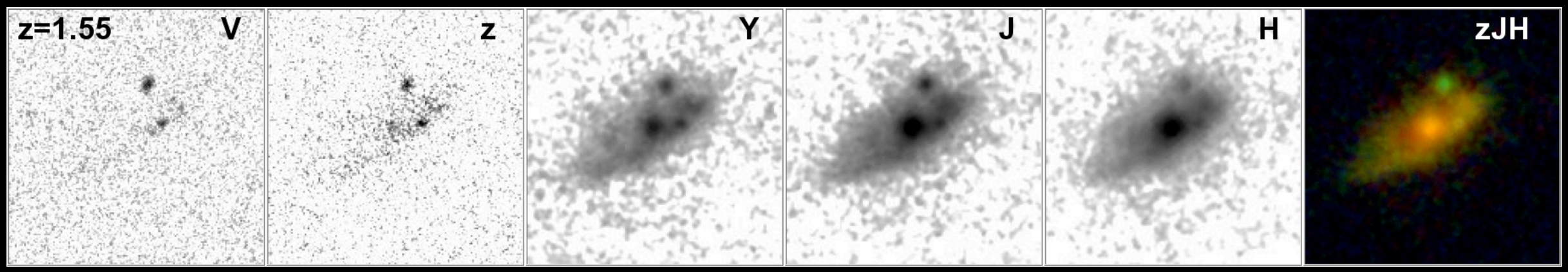
deep fields: GOODS N + S

~4 orbit depth Y + J + H

over ~0.04 sq. degrees

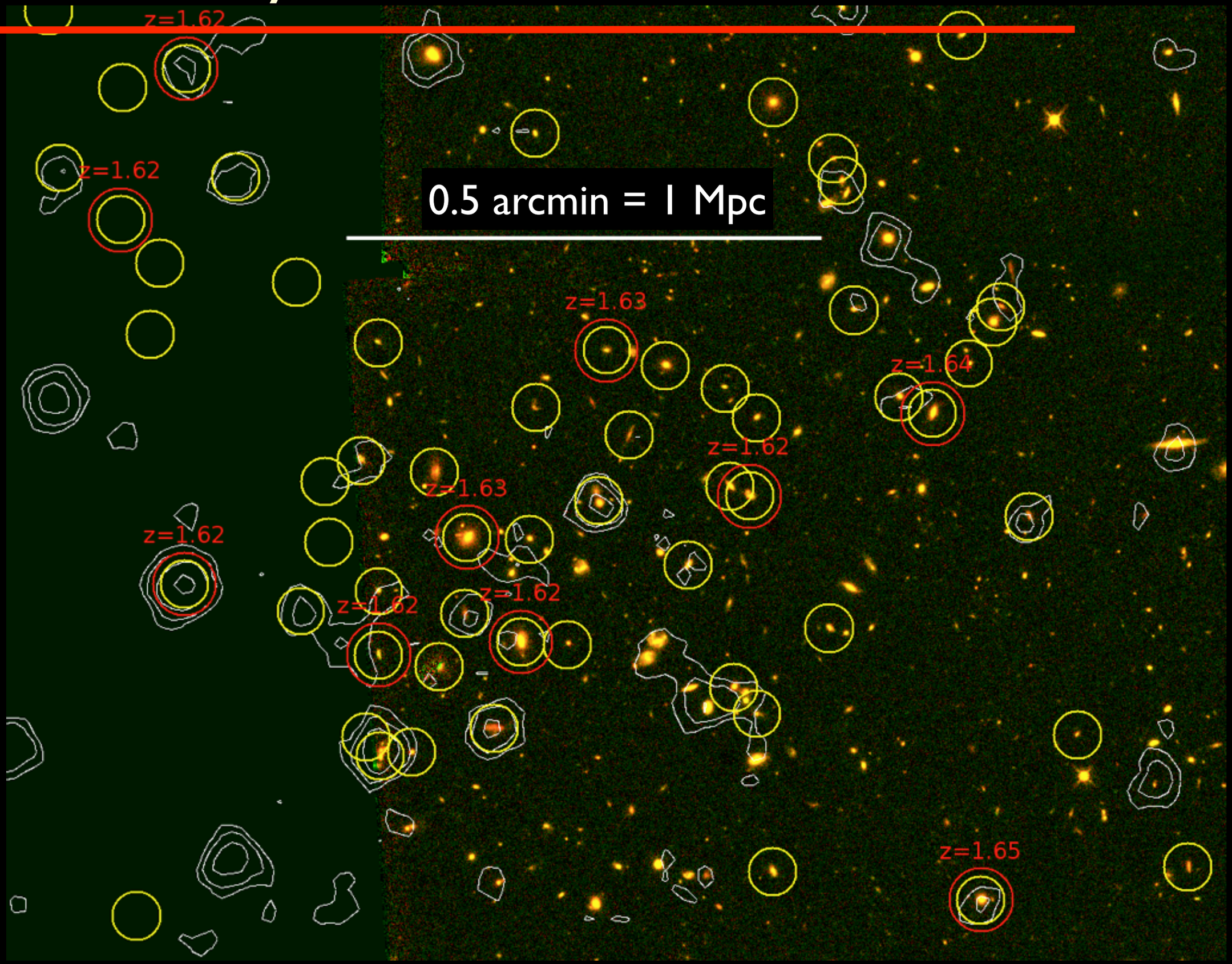
candels.ucolick.org

# Galaxy Structures and Mergers at z> 1

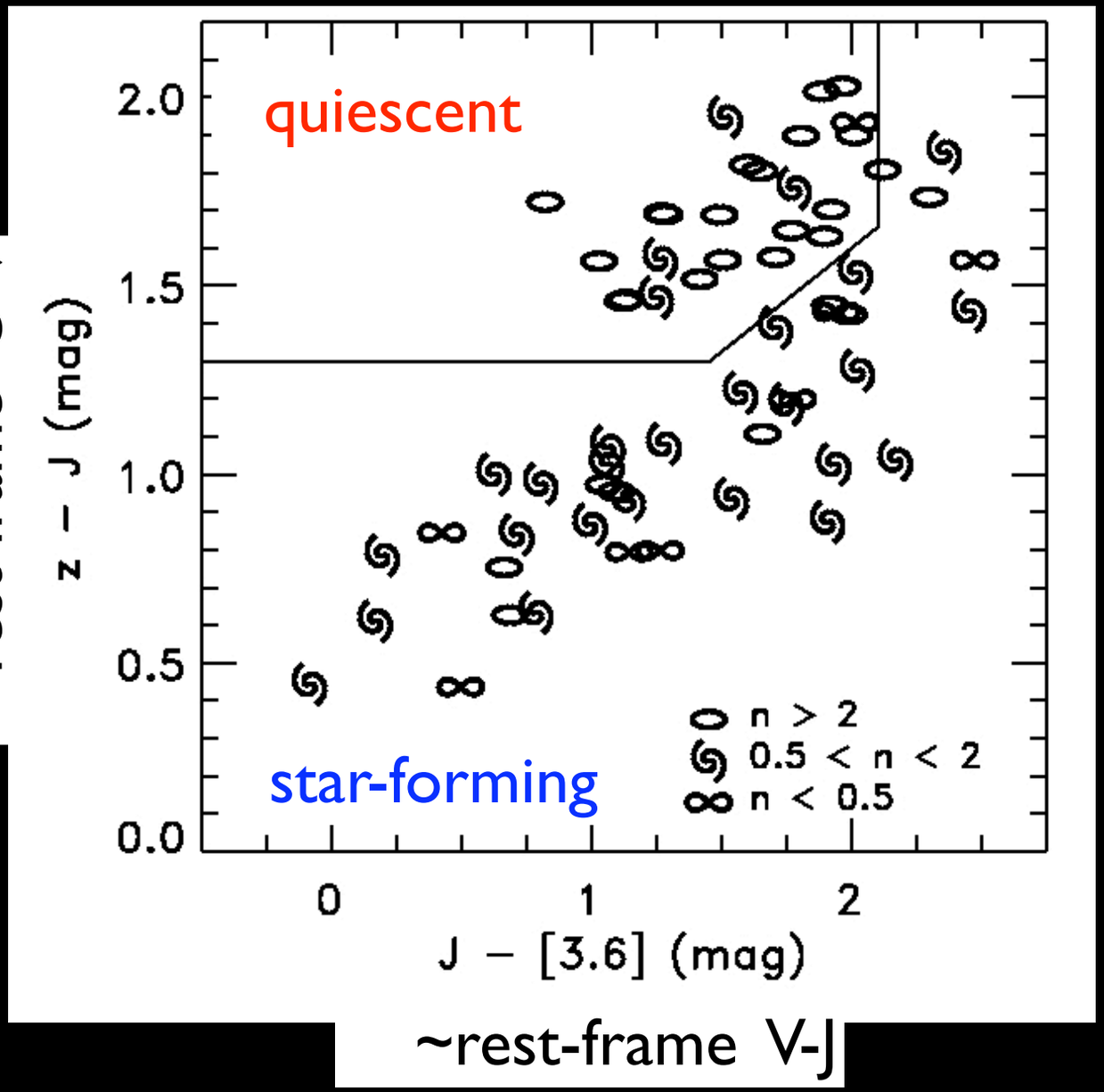


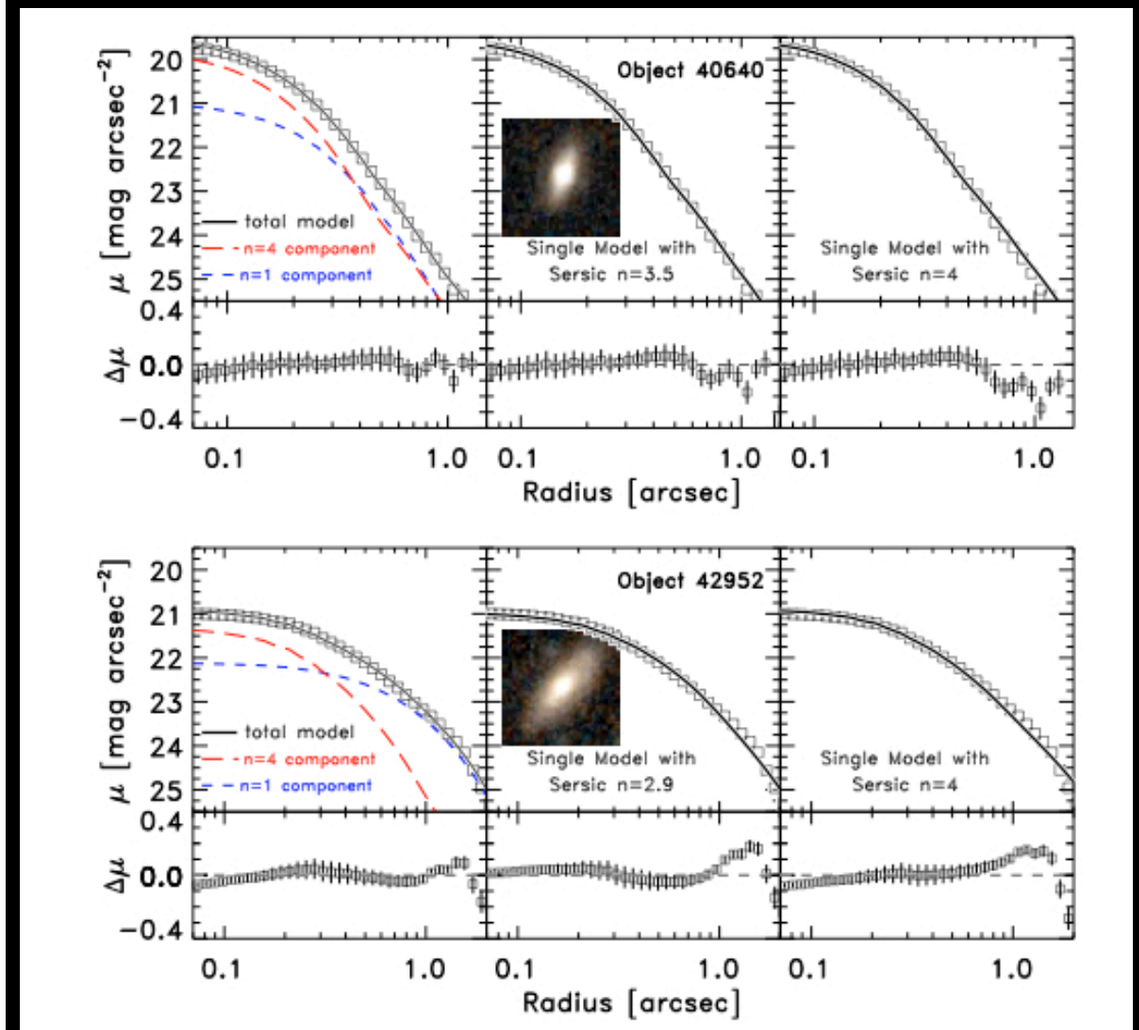

need high resolution NIR imaging to probe
rest-frame optical structures of z > 1 galaxies

# Massive Galaxy Formation in z=1.62 cluster



# Color-Morphology in z=1.62 proto-cluster

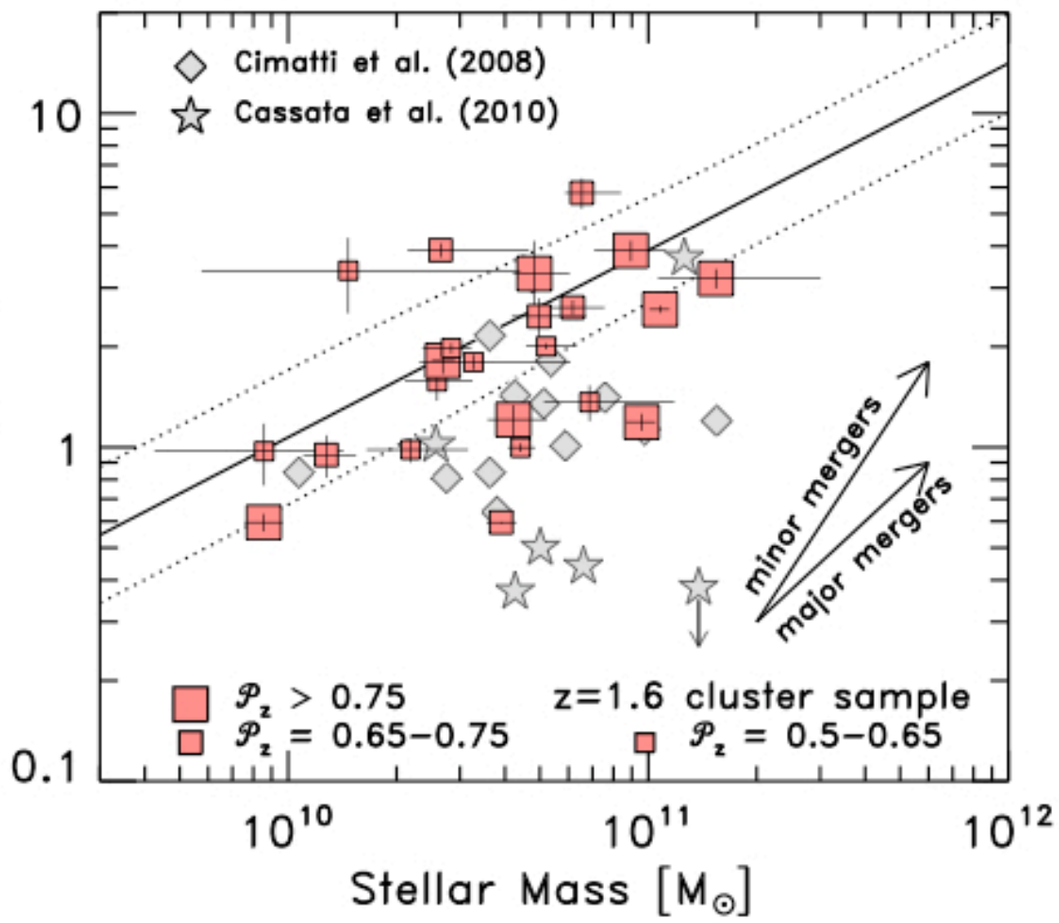


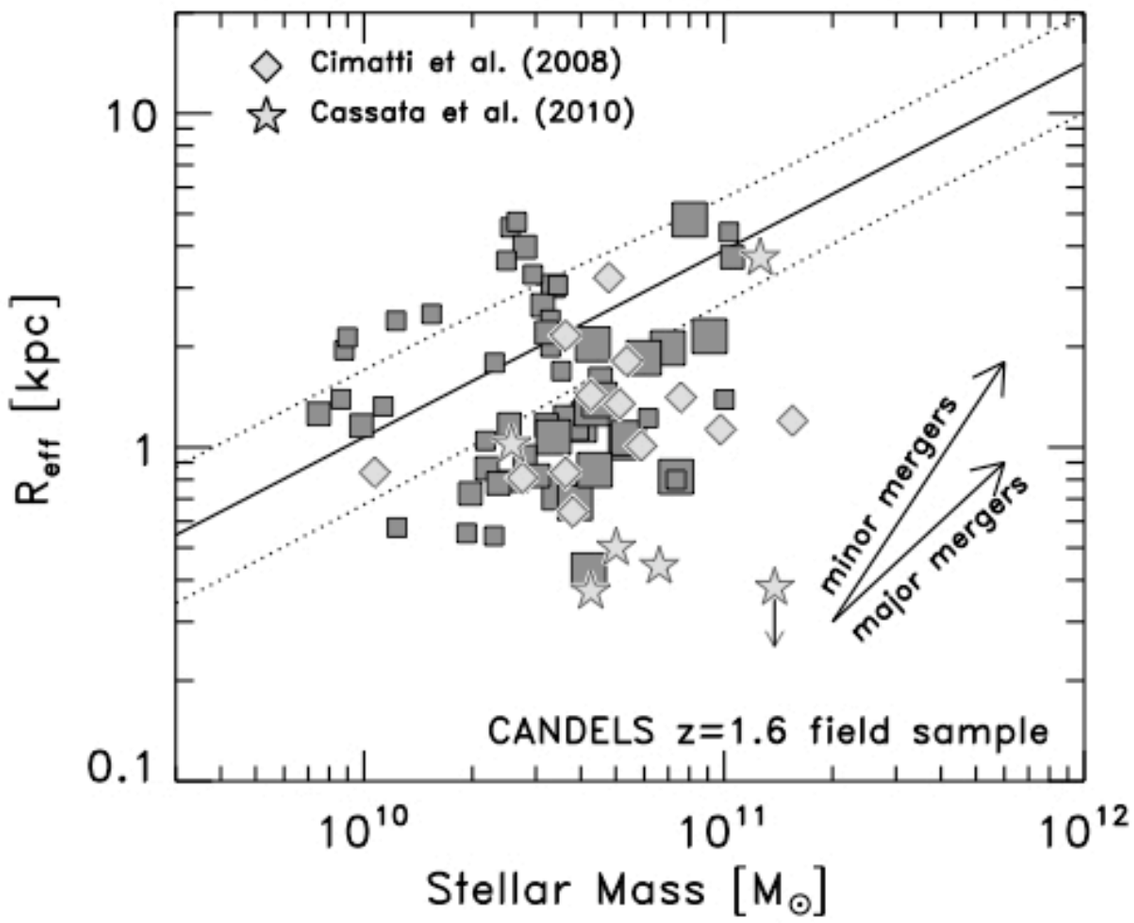

- cluster galaxies have color-morphology relationship
- quiescent galaxies are spheroid-dominated w/ disk component (Papovich et al. 2011; field galaxies: van der Wel et al. 2011)

# Size-Mass relationship in z=1.62 proto-cluster

z=1.62 proto-cluster




z~1.6 CANDEL/UDS field

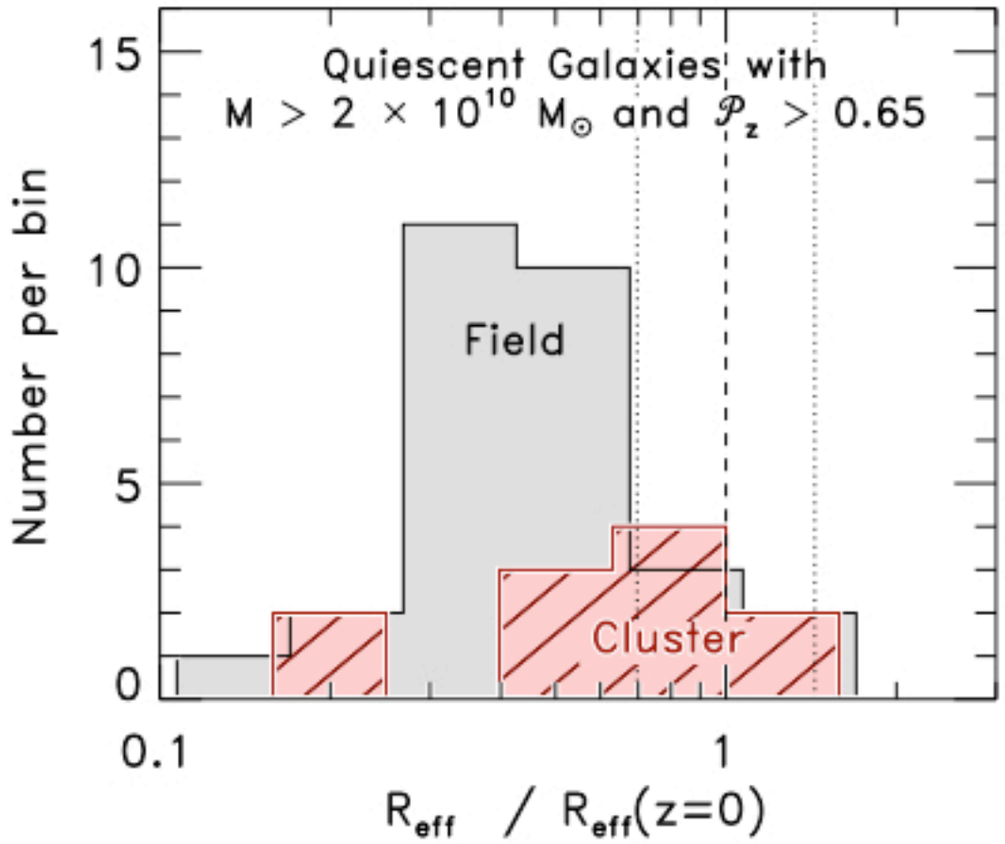


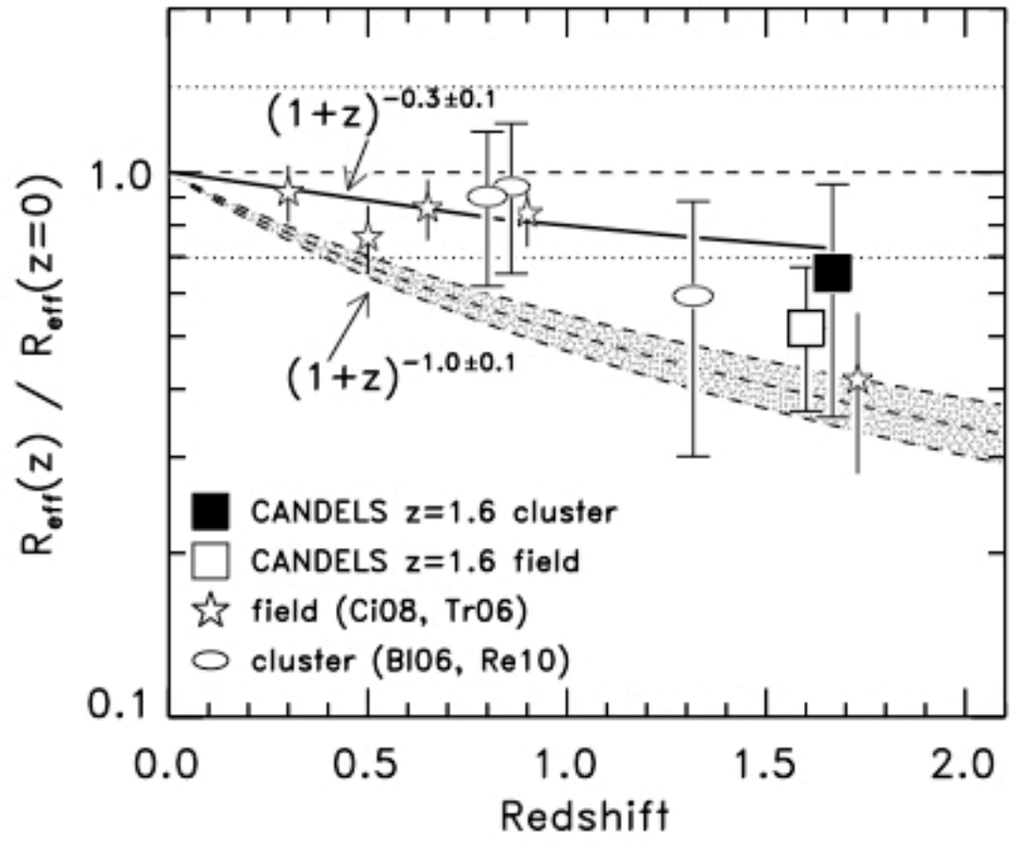

- quiescent cluster galaxies have larger sizes than field
[massive proto-cluster galaxies ~ 1/5 today's BCG mass]

(Papovich et al. 2011, in prep)

# Size evolution in clusters v. field

size(z=1.6)/size(z=0)

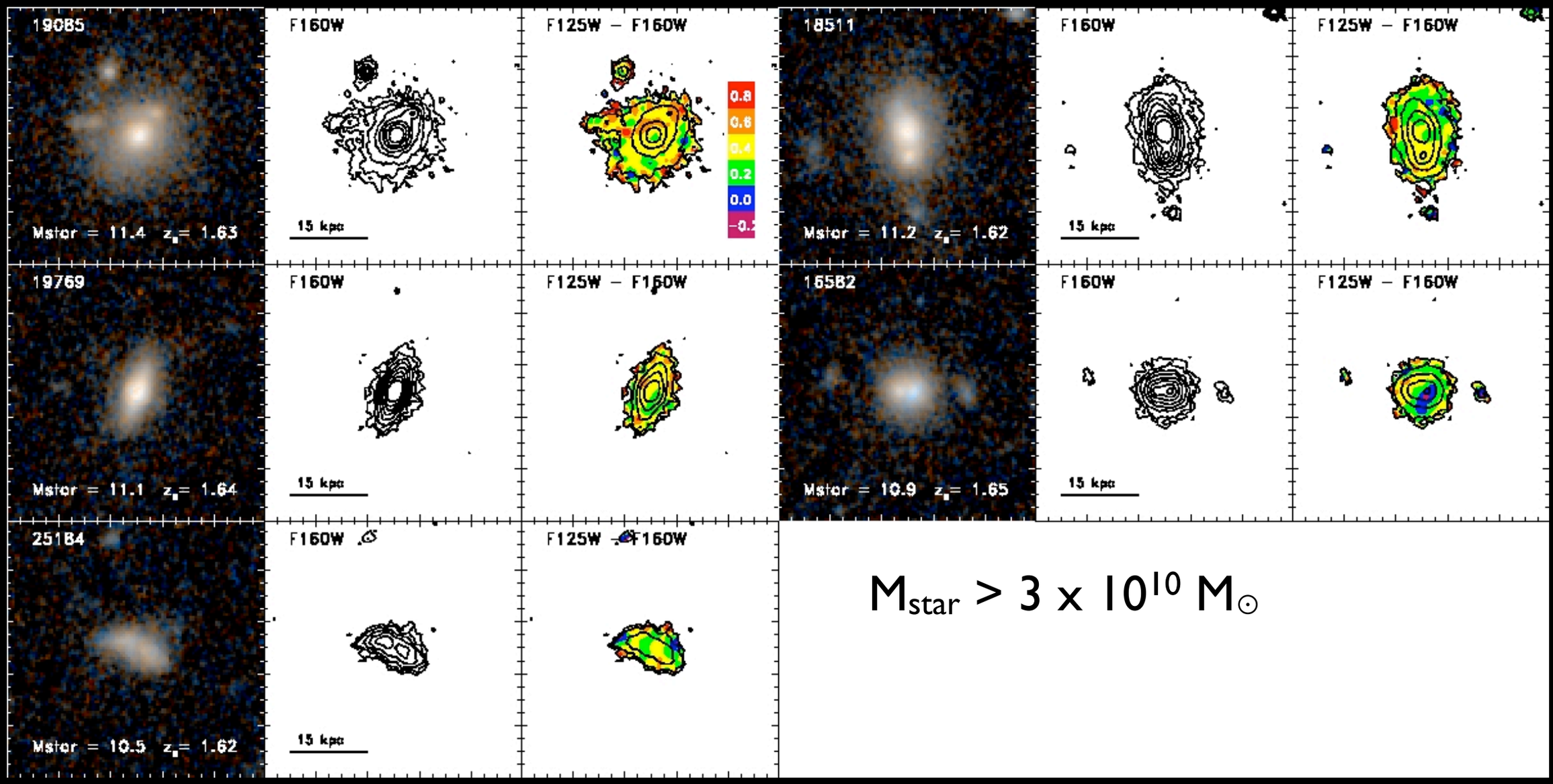



- weaker size evolution for cluster galaxies ?

(Papovich et al. 2011, in prep)

# Mergers in z=1.62 proto-cluster




$M_{star} > 3 \times 10^{10} M_{\odot}$

4/5 of spectroscopically-confirmed massive cluster galaxies have multiple nuclei at <15 kpc (Lotz et al. 2011, in prep)

# Pair Fraction Cluster v. Field at z=1.62

HST WFC3 double nucleus or
companion < 15 kpc (co-moving), H< 24 AB
+ $M_* > 3 \times 10^{10} M_\odot$
+ high probability of cluster redshift (1.55 < zphot < 1.70)

($M_*$, zphot calculated with UKIDSS public data:
Furusawa et al. 2007, Lawrence et al. 2007)

zspec cluster: 4/5 multiple nuclei = 80%
zspec + zphot + < 1 Mpc : 8/19 = 43 ± 14%

UDS Field: 18 / 139 = 13 ± 3 %

⇒ cluster pair fraction 4-8 x larger than the field !!

# Rapid Galaxy Assembly at 1 < z < 1.6

cluster pair fraction at z < 1 much lower

17% MS1054 z=0.83 van Dokkum et al. 1999, Tran et al. 2005;

1-4% at z~0.1 McIntosh et al. 2008

⇒ rapid assembly of BCGs at 1 < z < 1.6 ?

# Rapid Galaxy Assembly at 1 < z < 1.6

cluster pair fraction at z < 1 much lower

17% MS1054 z=0.83 van Dokkum et al. 1999, Tran et al. 2005;

1-4% at z~0.1 McIntosh et al. 2008

⇒ rapid assembly of BCGs at 1 < z < 1.6 ?

if $T_{merge}$ ~ 0.2 - 0.5 Gyr, merger rate ~ 2 - 4 per Gyr

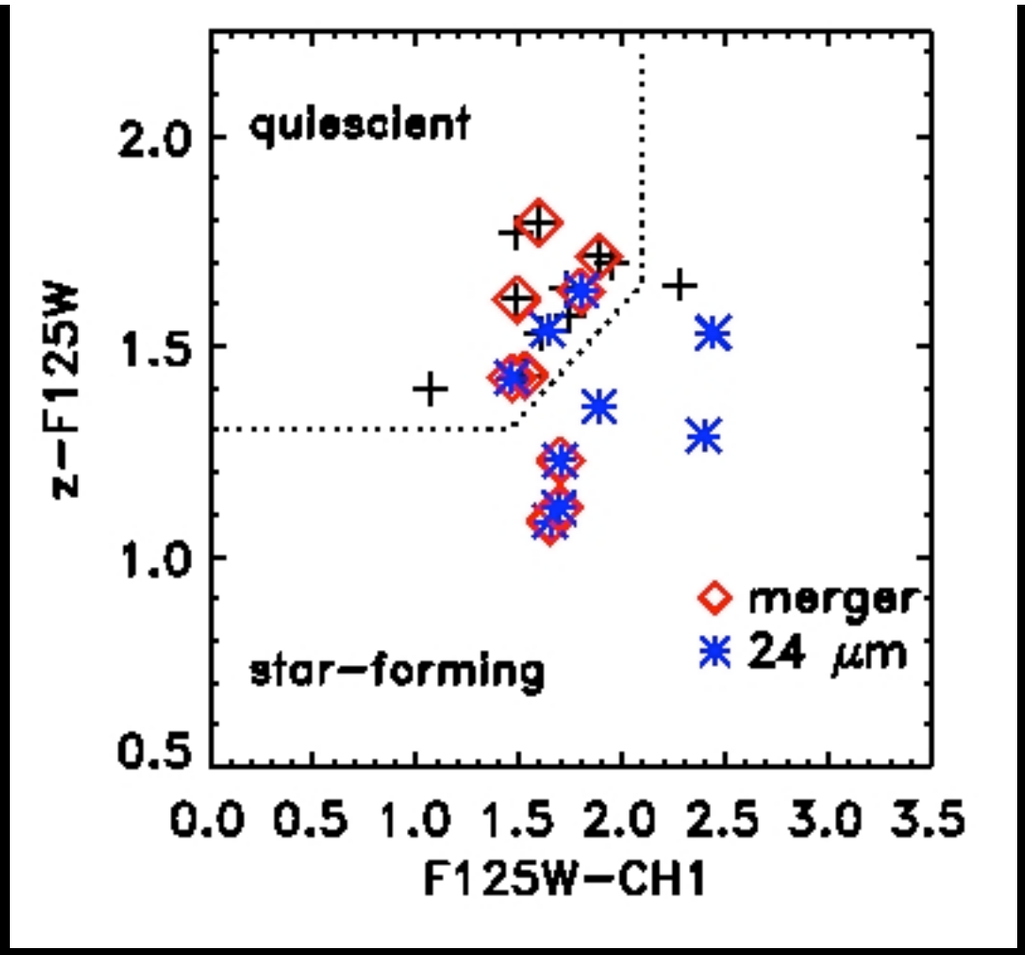
if typical mass ratio ~ 1:4 , ~ double mass by z ~ 1

most massive proto-cluster z=1.62 galaxies ~2 x $10^{11}$ $M_\odot$

⇒ z~1 BCG ~ 3-4 x $10^{11}$ $M_\odot$ ~ 60-80% today's mass

# Not Dead Yet

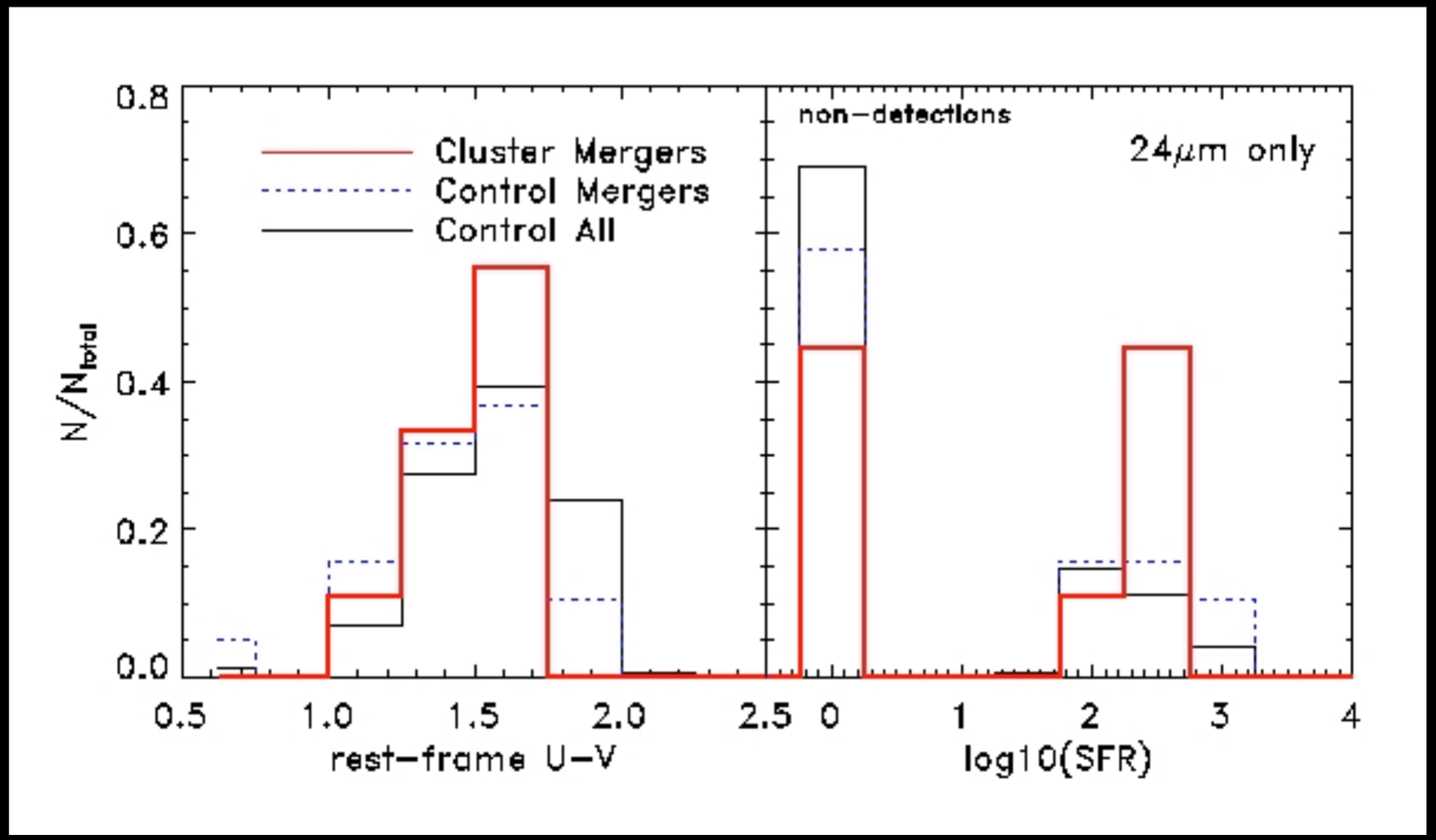
$M_{star} > 3 \times 10^{10} M_{\odot}$ proto-cluster galaxies




- half of mergers are red, quiescent; half are star-forming

(Lotz et al. 2011, in prep)

# Not Dead Yet




- color distribution similar to field at same stellar mass

(Lotz et al. 2011, in prep)

# Summary

- quiescent cluster galaxies have sizes larger than the field
  ⇒ already undergone more mergers?

- massive cluster galaxies have merger rate 4-8x the field
  ⇒ can build up BCG mass by z~1

BCG assembly ~ cluster virialization?

but < 50% of mergers are ‘dry’
colors, SFR distribution of cluster mergers ~ field
⇒ merger/ environmental quenching not in place (yet?)