Cl J1449+0856: an old cluster in the young Universe ?

R. Gobat[1]

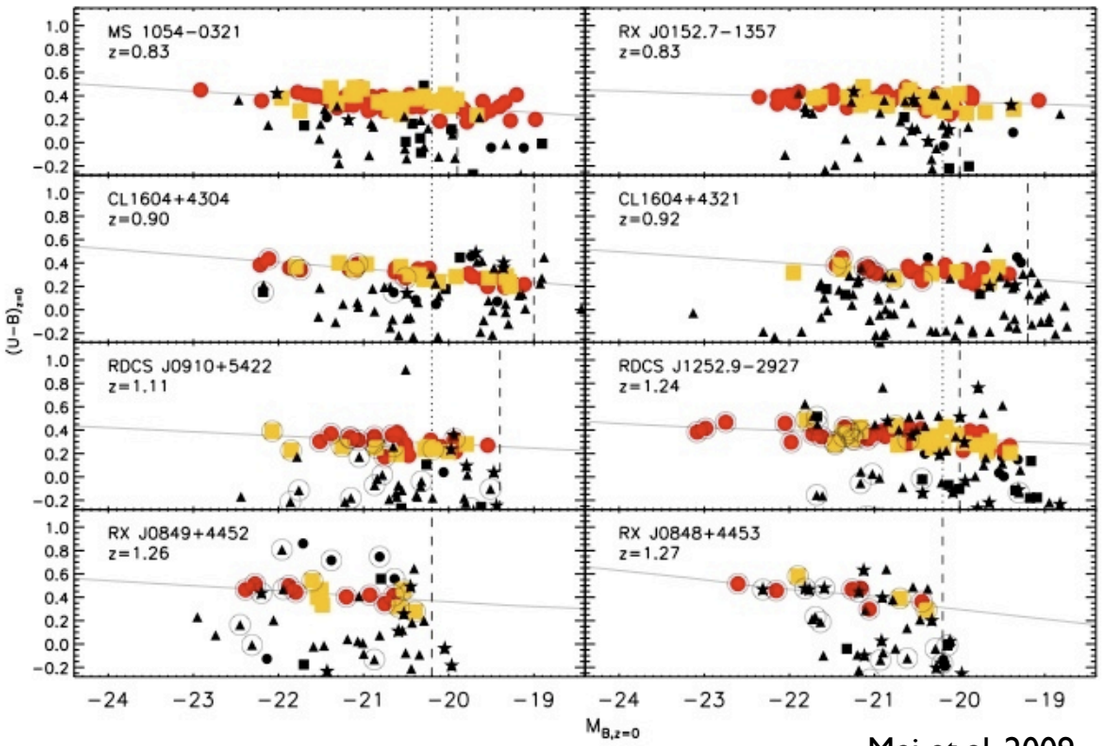
E. Daddi[1], M. Onodera[1], A. Finoguenov[2], A. Renzini[3], N. Arimoto[4], R. Bouwens[5], M. Brusa[2], R.-R. Chary[6], A. Cimatti[7], M Dickinson[8], X. Kong[9], M. Mignoli[10], H. Dannerbauer[1], V. Strazzullo[1]

[1]CEA/Saclay, [2]MPE, [3]INAF-OAPD, [4]NAOJ, [5]UCO/Lick, [6]Caltech, [7]UniBo, [8]NOAO, [9]USTC, [10]INAF-OABO

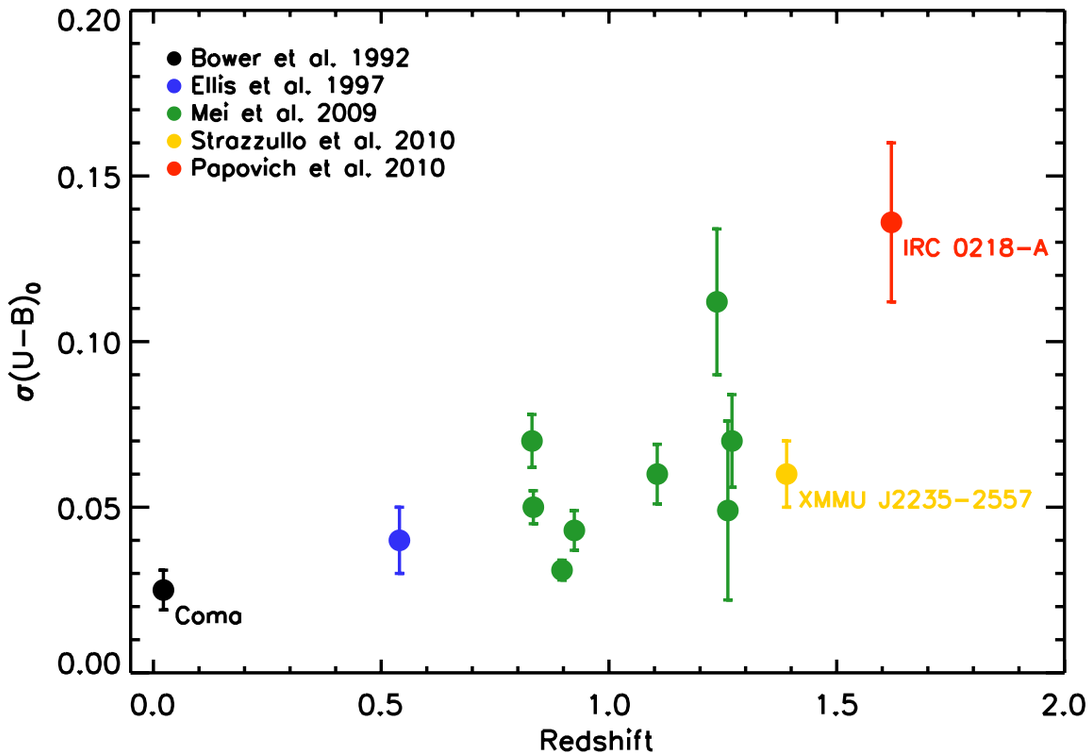
(Gobat et al. 2011, A&A 526, 133)

The interest of high-z clusters

Galaxy evolution, role of environmental processes



Mei et al. 2009



but the core ETGs quenched at z > 2-3

⇒ interest in looking as close as possible to the early stages of formation (z ≥ 2)

star-forming population, not yet virialised



NASA/ESA



Blakeslee et al. 2003



Miley, G. & Overzier, R.

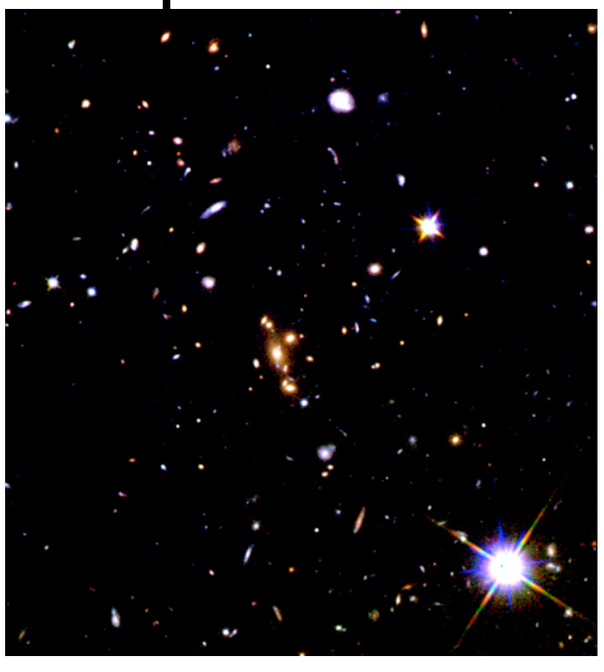
"cluster desert"

proto-clusters

0 0.5 1 1.5 2 2.5 3 z



NASA/ESA



quenching of the most massive ETGs

core dominated by giant ellipticals
X-ray atmosphere

Finding galaxy clusters at z > 1

Hot ICM

X-ray

XCS
XDCP
XMM-LSS
(eROSITA)
etc

(flux/surface brightness limited)

SZE

APEX
SPT
ACT
Planck
etc

(massive halos)

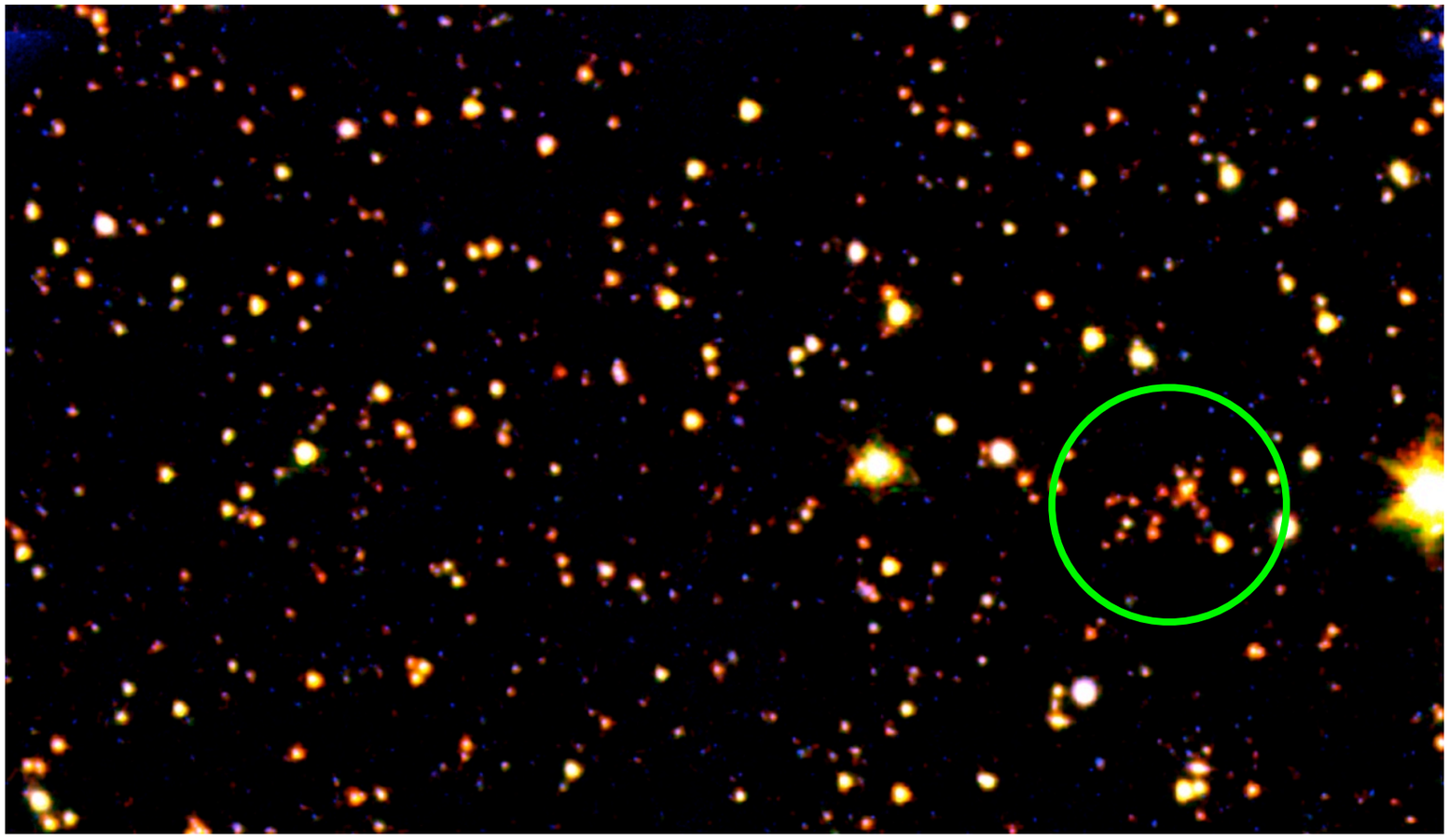
Core galaxy population

Red sequence

RCS2
SpARCS
UKIDDS
etc

(up to z~2)

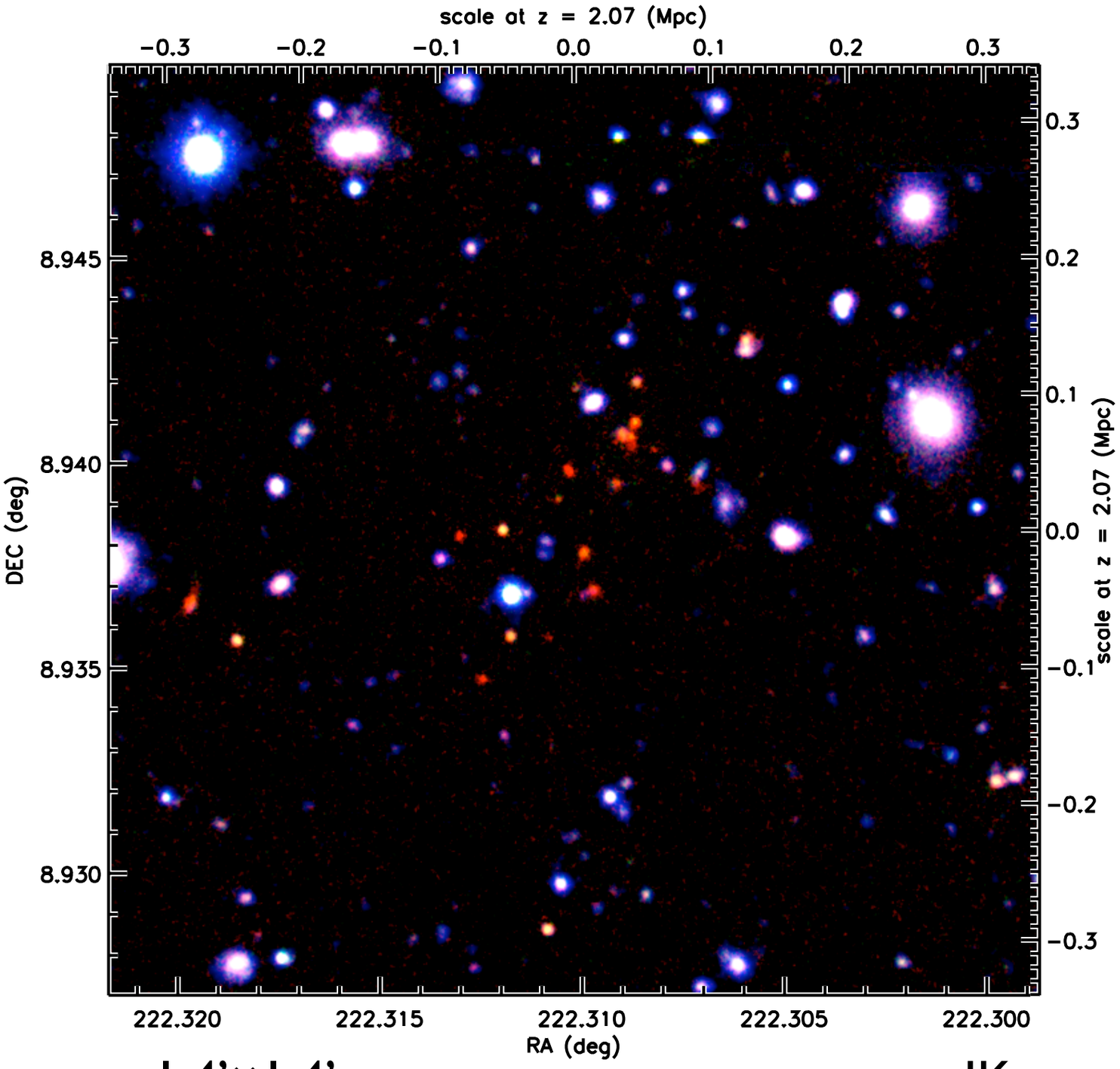
Cl J1449+0856: a "mature" X-ray detected cluster at z ~ 2.1



K_s3.6μ4.5μ

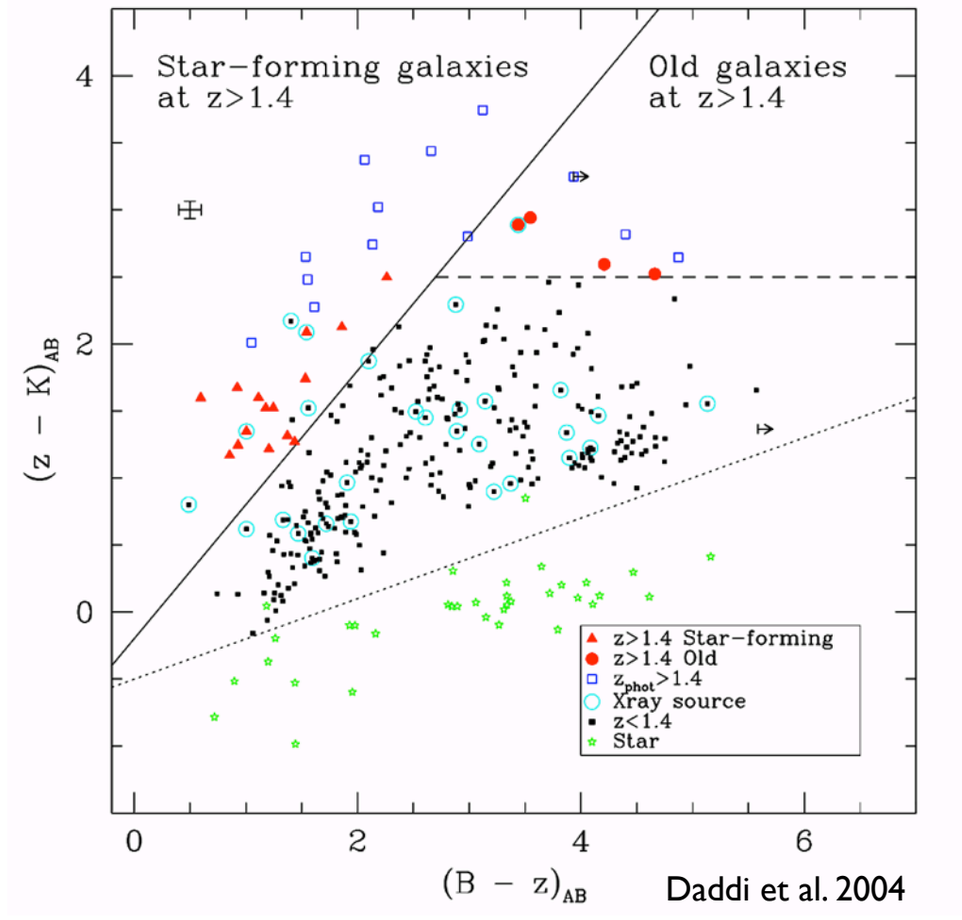
Initial discovery in the "Daddi Field" as an overdensity of galaxies with $m_{3.6} - m_{4.5} > 0$ (AB)

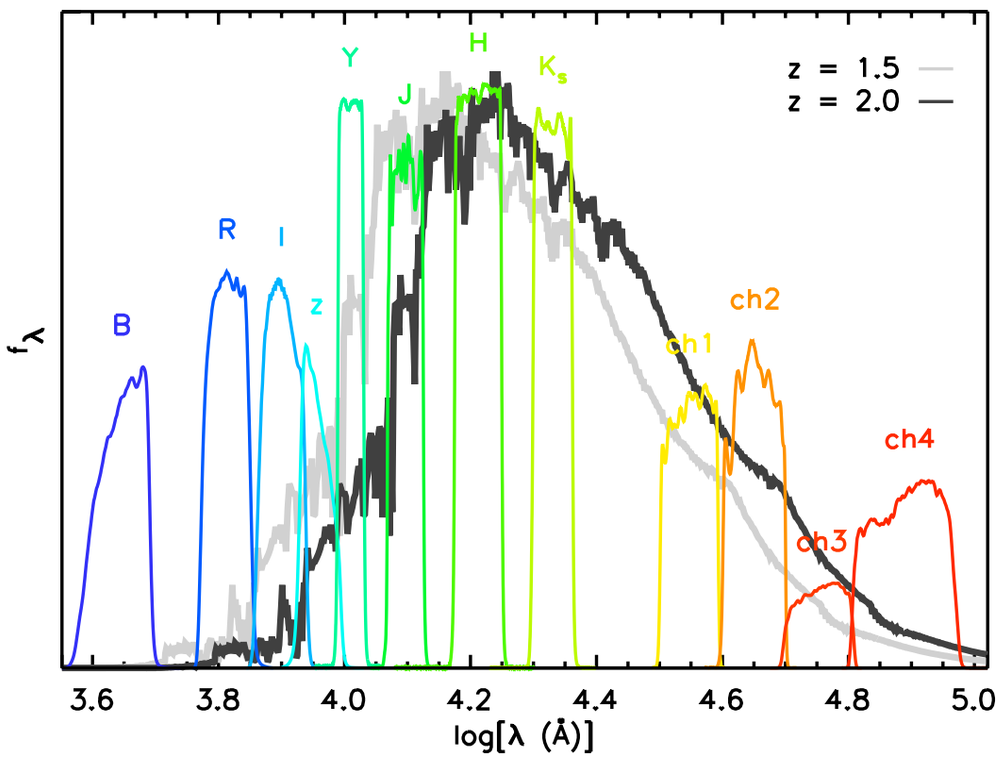
follow-up observations revealed a dense core of red, passive-looking galaxies at z = 2.07 with an extended X-ray emission



1.4'×1.4'

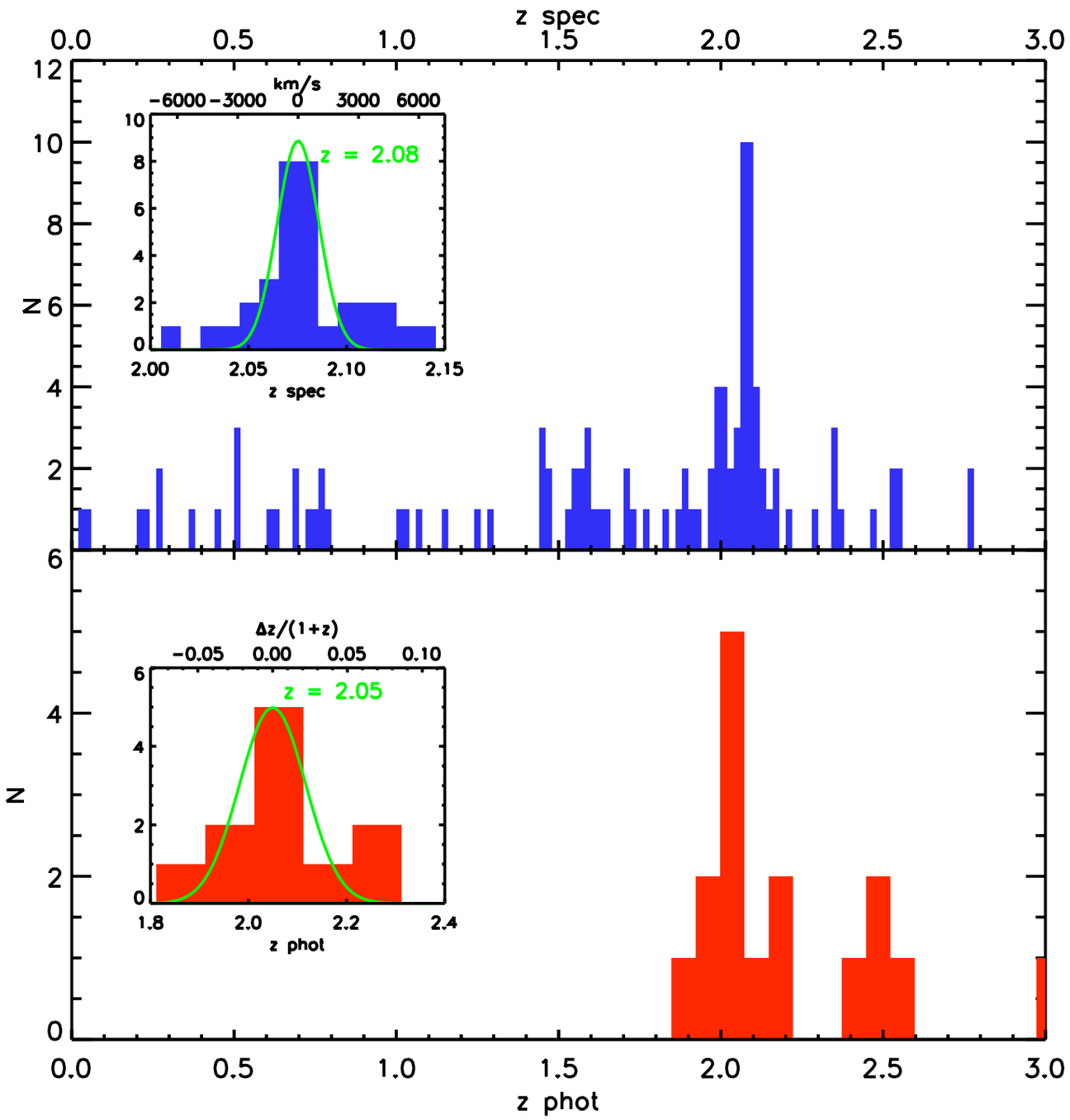
zJK_s





$Y-K_s > 2$ selects passive galaxies at $z > 1.5$

Blue ($Y-K_s < 2$) galaxies: VLT spectroscopic redshifts
Red ($Y-K_s > 2$) galaxies: 8 to 12-band photometric redshifts



$z_{spec} = 2.07$

$\sigma = 780 \pm 90$ km/s

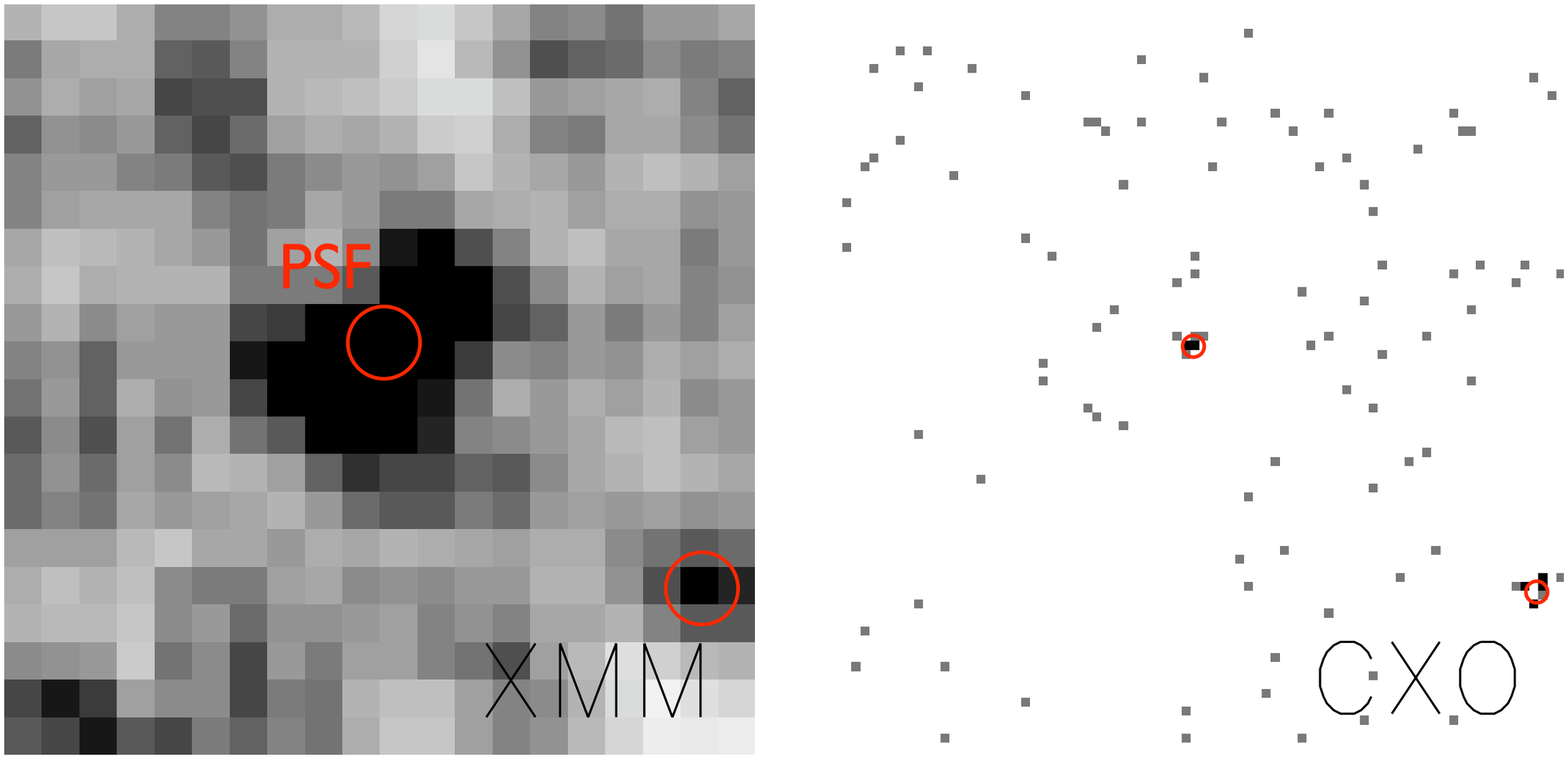
(~ late-type galaxies in Virgo)

$z_{phot} = 2.05$

$\Delta z = 0.07$

(typical for ETGs)

X-ray observations with XMM and Chandra



XMM-Newton
80 ks

soft (0.5-2 keV)

Chandra
80 ks

~50 photons , 3.5σ significance

Total mass

From X-ray analysis:

$L_X = (7\pm2)\times10^{43}$ erg/s $\Rightarrow$ **$M_{200} > 6\times10^{13}\ M_\odot$**

not yet virialised ?

$R_{200} \sim 0.4$ Mpc

kT ~ 2keV

(based on L_X-M , Leauthaud et al. 2010)

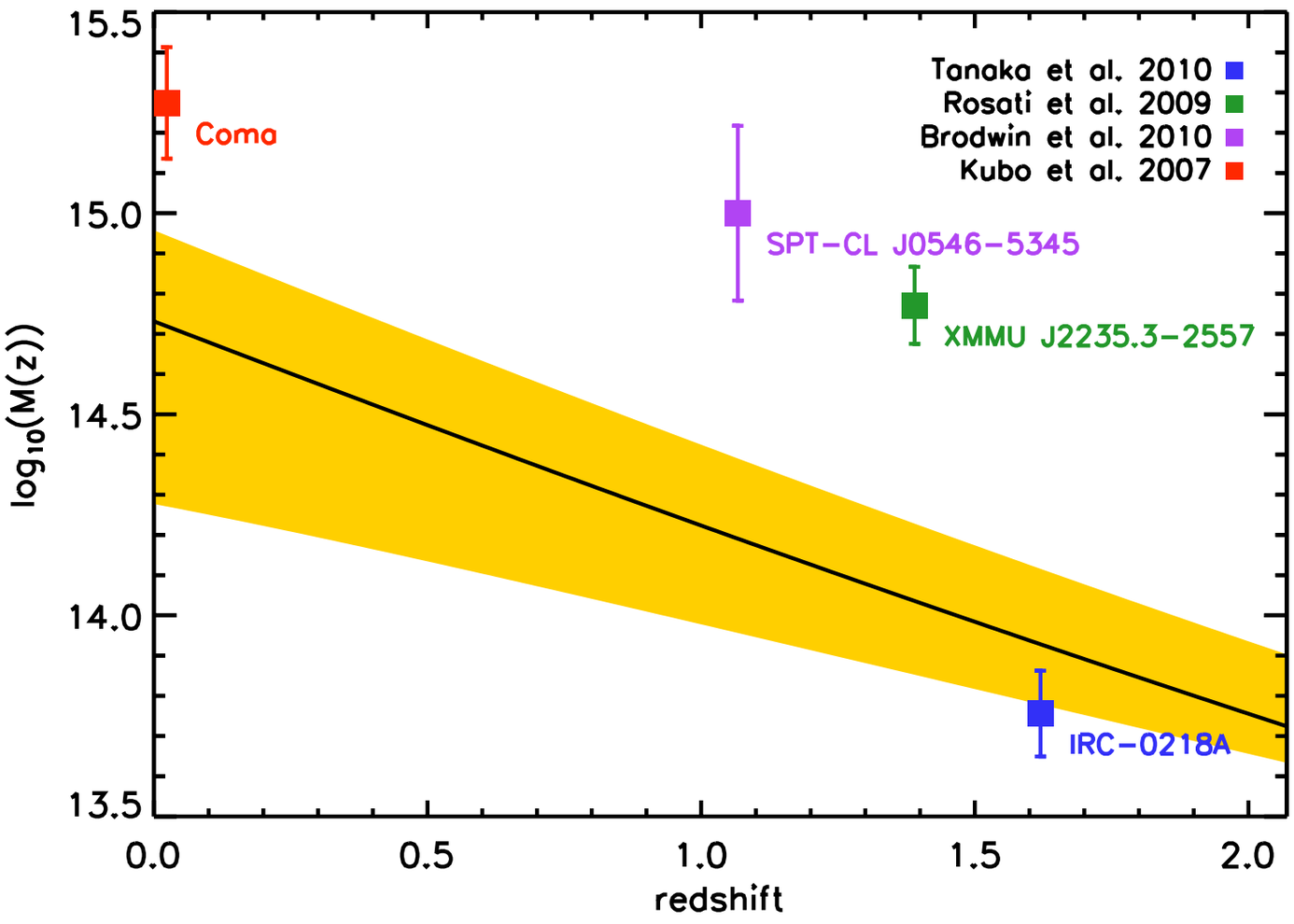
From SED fitting:

$M_\star(r < 20'', 1.9<z<2.2) \sim 5\times10^{11}\ M_\odot \Rightarrow$ **$M_{halo} > 8\times10^{13}\ M_\odot$**

only core galaxies

($M_\star$-M_{halo} , Moster et al. 2010)

$\Rightarrow$ comparable to Virgo



Mass at z = 0:
(from the Millenium simulations; Fakhouri et al. 2010)

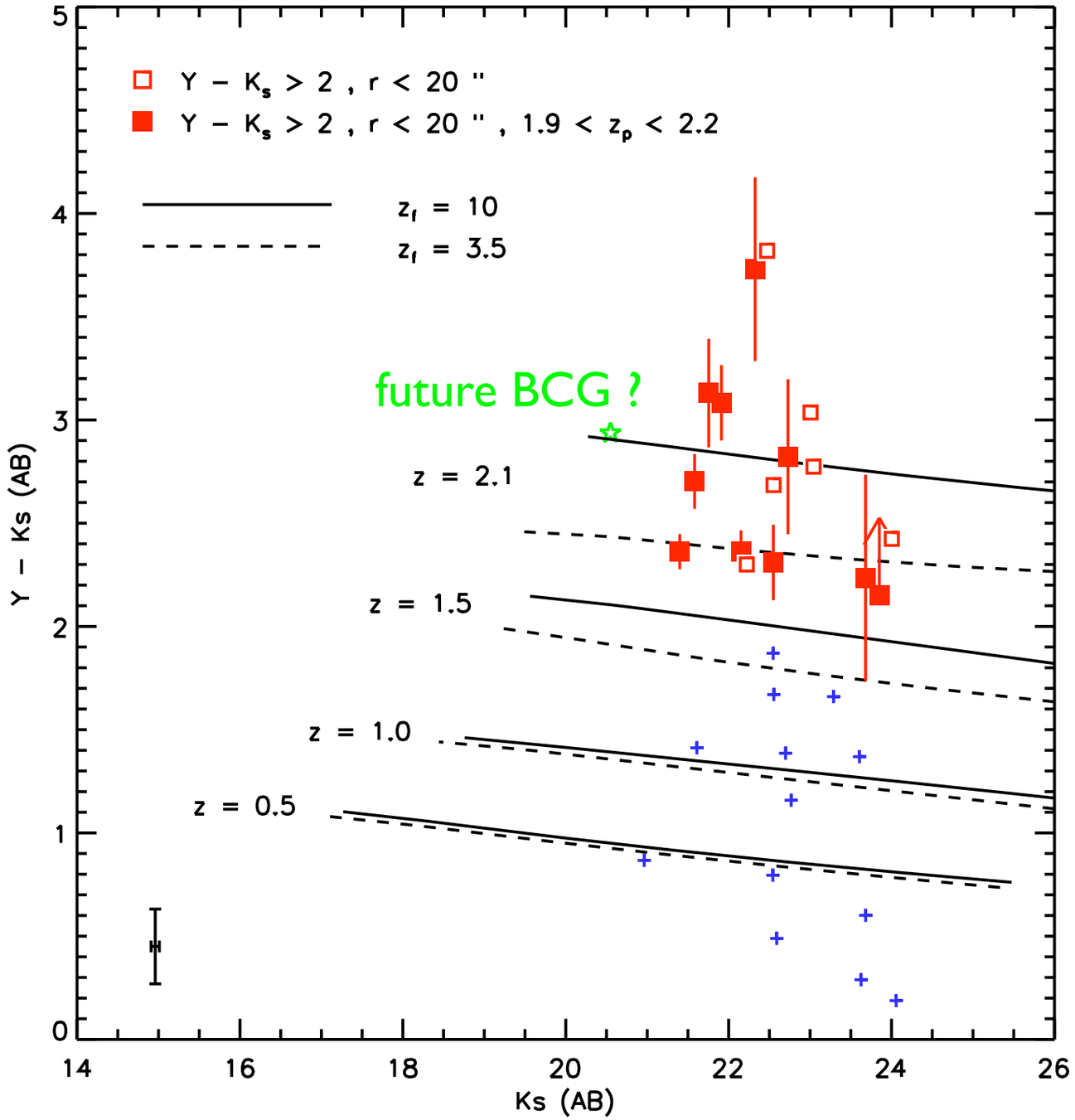
$\sim 6\times10^{14}\ M_\odot$

$P(z>2.07, M>5\times10^{13}, 400\ \text{arcmin}^2) = 0.033\ (\sigma_8 = 0.8)$
$0.01\ (\sigma_8 = 0.77)$

$\times\ 0.3$ if $z_f = 2.3$ (i.e. 0.3 Gyr to allow the gas to settle)

$\Rightarrow$ rare but not exceedingly so

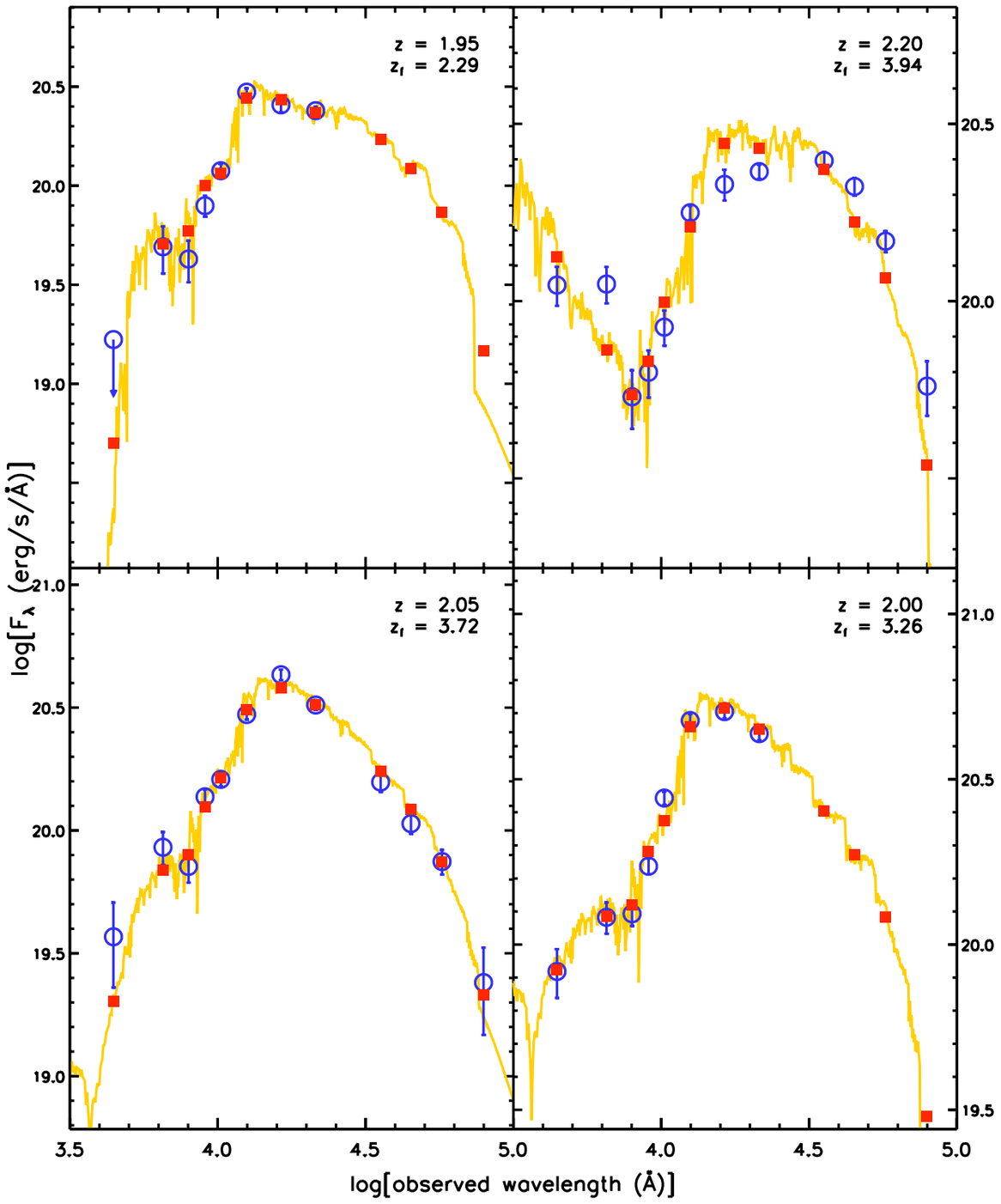
The nature of the red galaxy population



Colours:

- consistent with a z = 2.1 passive population
- no established red sequence
- no BCG but assemblage of 3 interacting galaxies

The nature of the red galaxy population

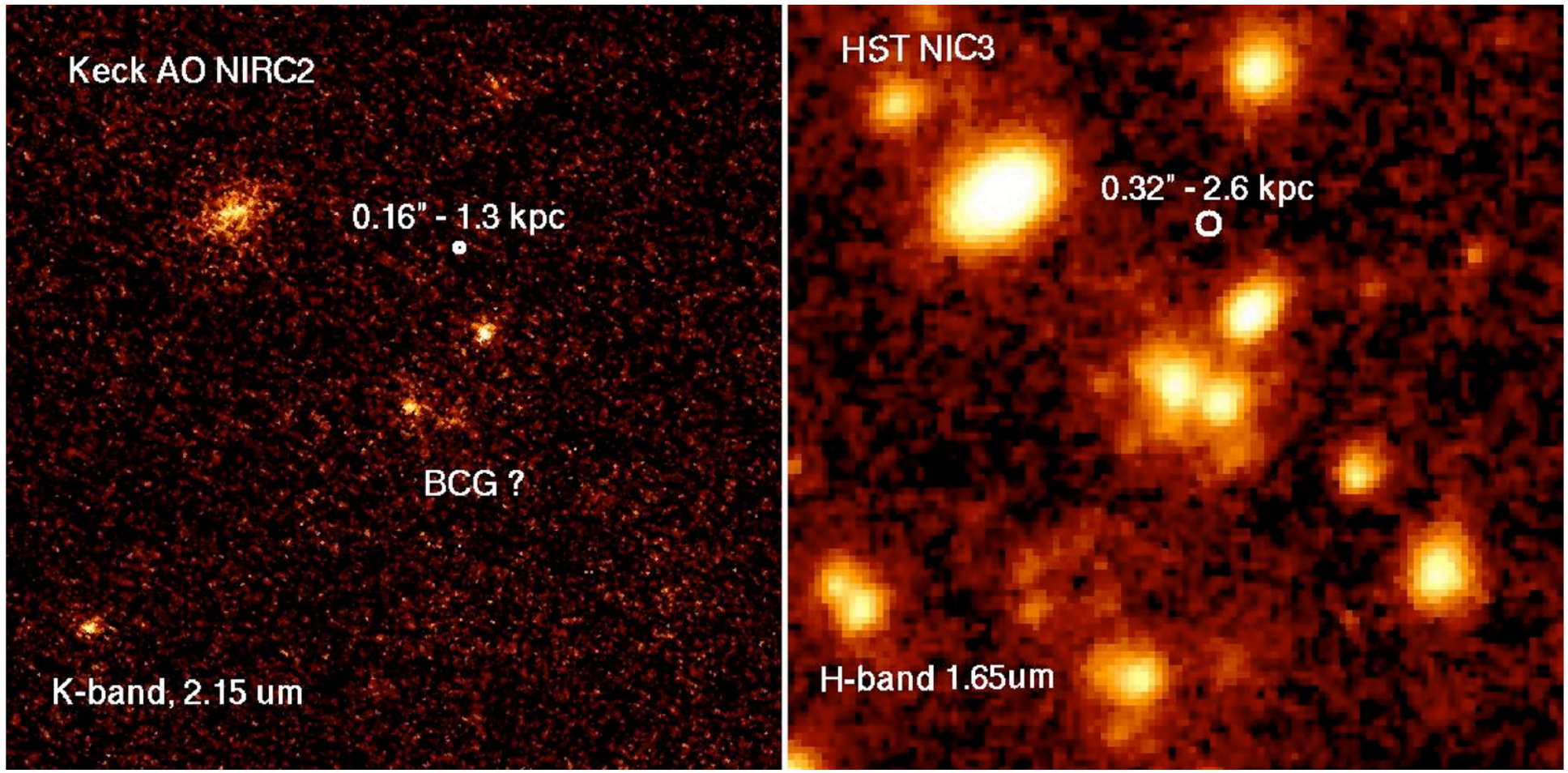


SEDs:

- fit with low to no redidual star formation
- little or no dust
- t_{SF} ~ 1.1 Gyr , z_f ~ 3.3

⇒ passive galaxy population at z~2 ?

The nature of the red galaxy population

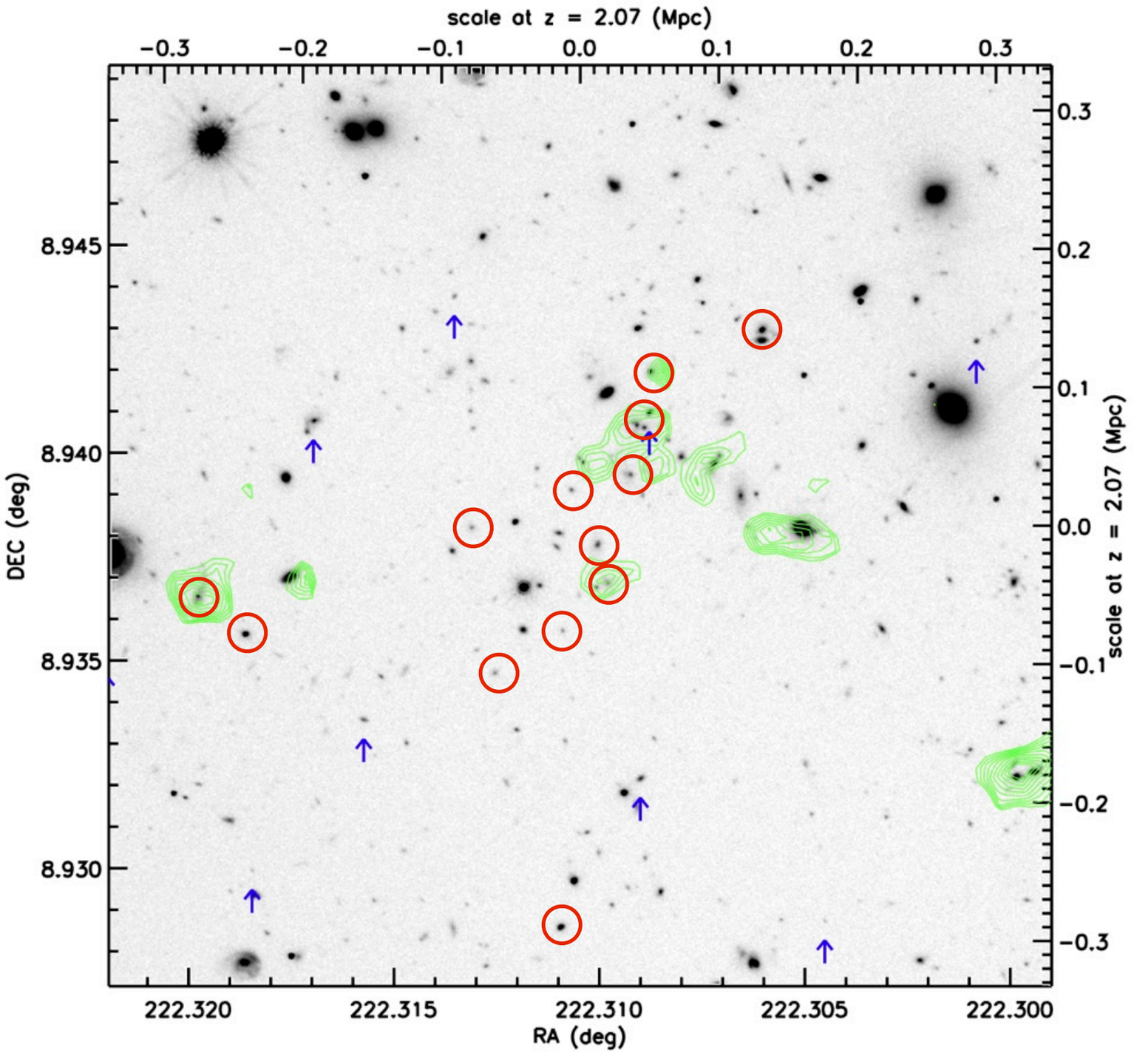


red galaxies have mostly $n \geq 3$

Ground-based AO imaging shows that
the red, high-n galaxies have very compact cores

The nature of the red galaxy population

MIPS 24μm data



z-spec members

z-phot candidates

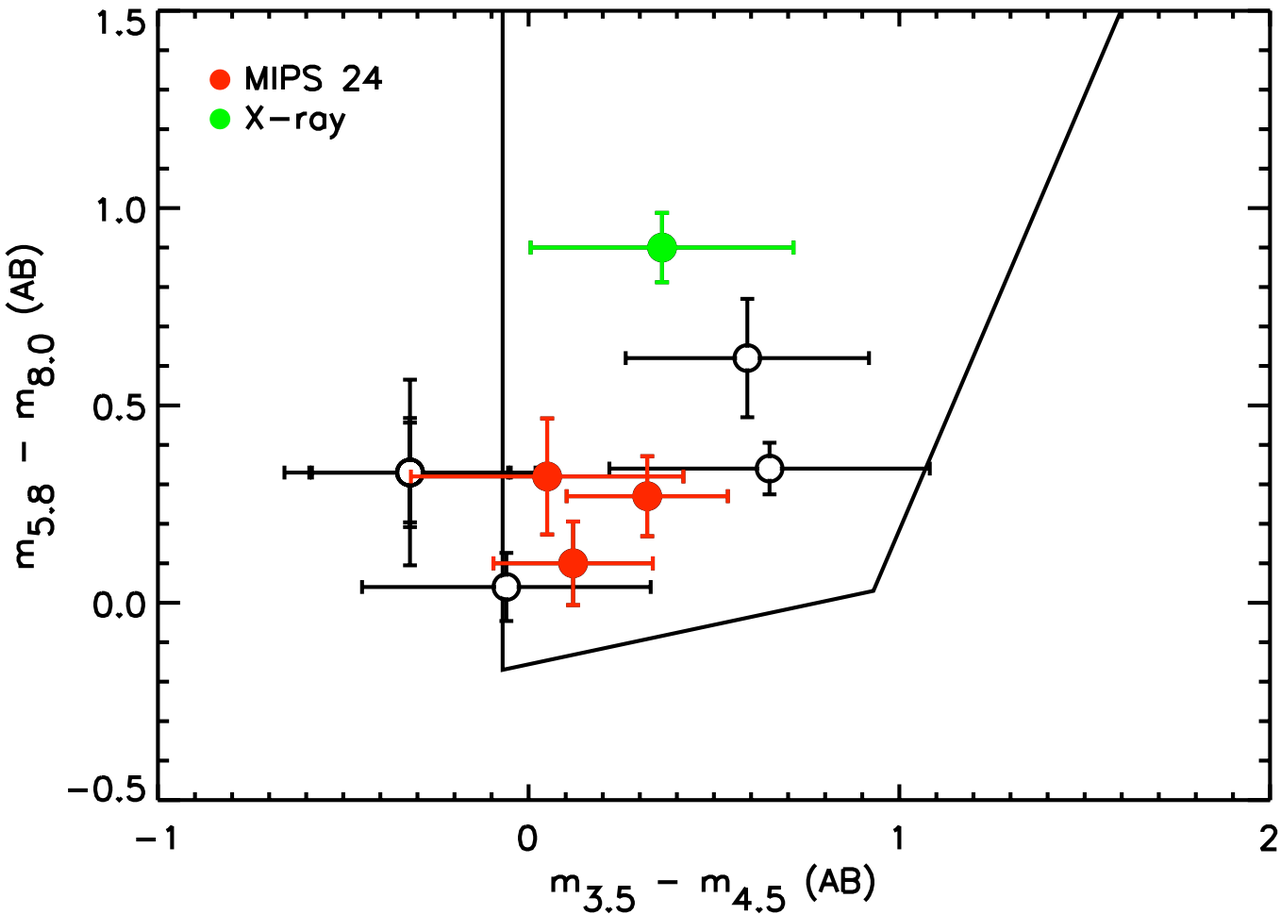
some red member galaxies are detected at 24μm:

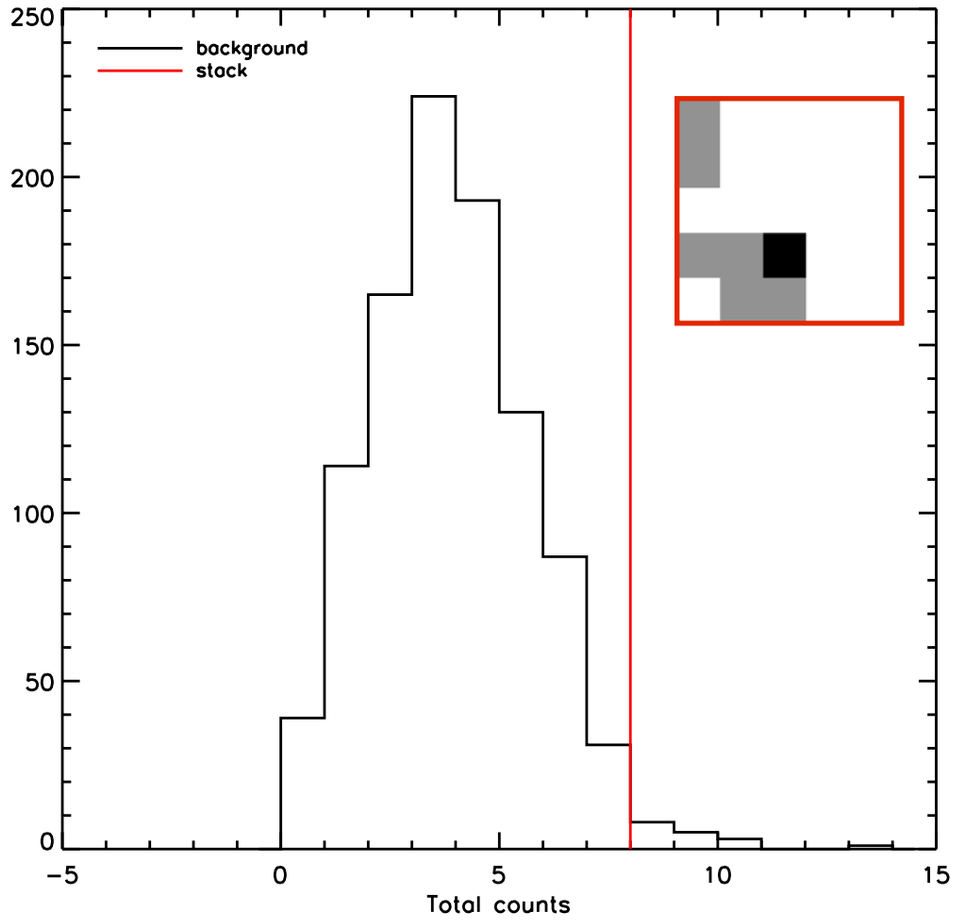
dusty starbursts ?

(> 100 $M_{\odot} yr^{-1}$ if purely SF)

The nature of the red galaxy population

IR-excess galaxies: SF or AGN ?





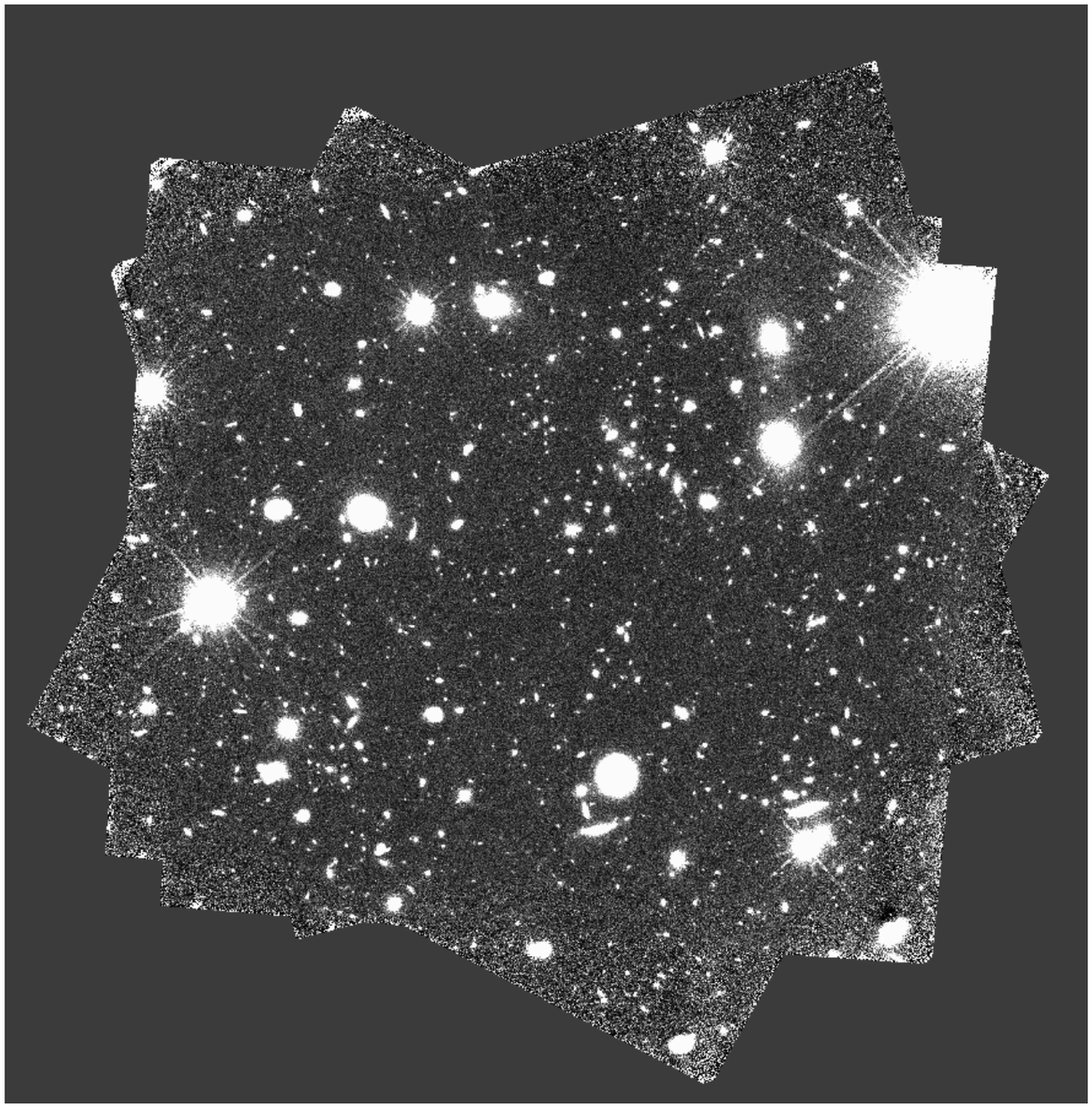
(very incomplete IRAC photometry)

some red galaxies show excess in the IRAC bands

weak (2.3σ) excess in the hard Chandra band

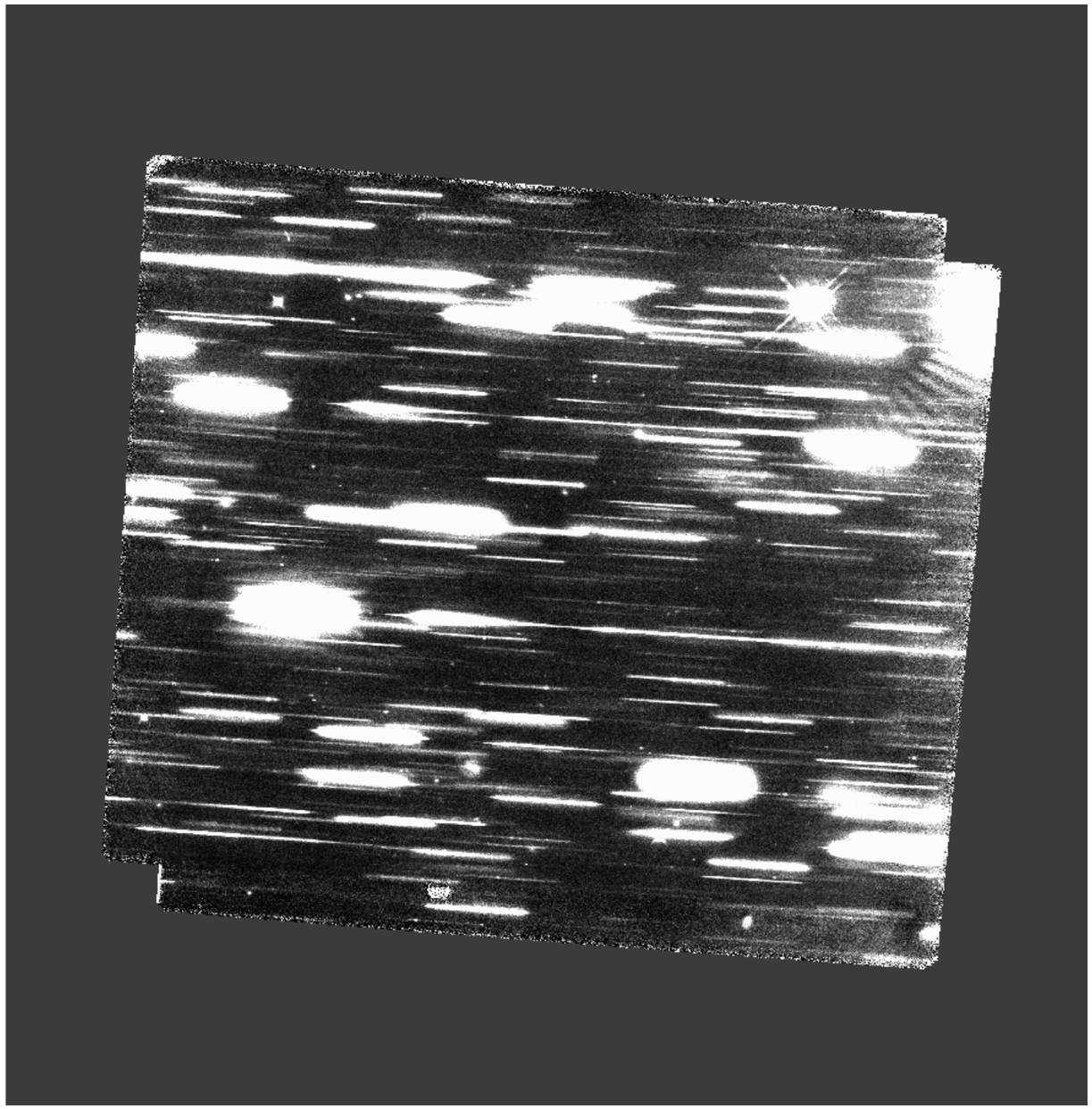
HST/WFC3 observations

F140w imaging



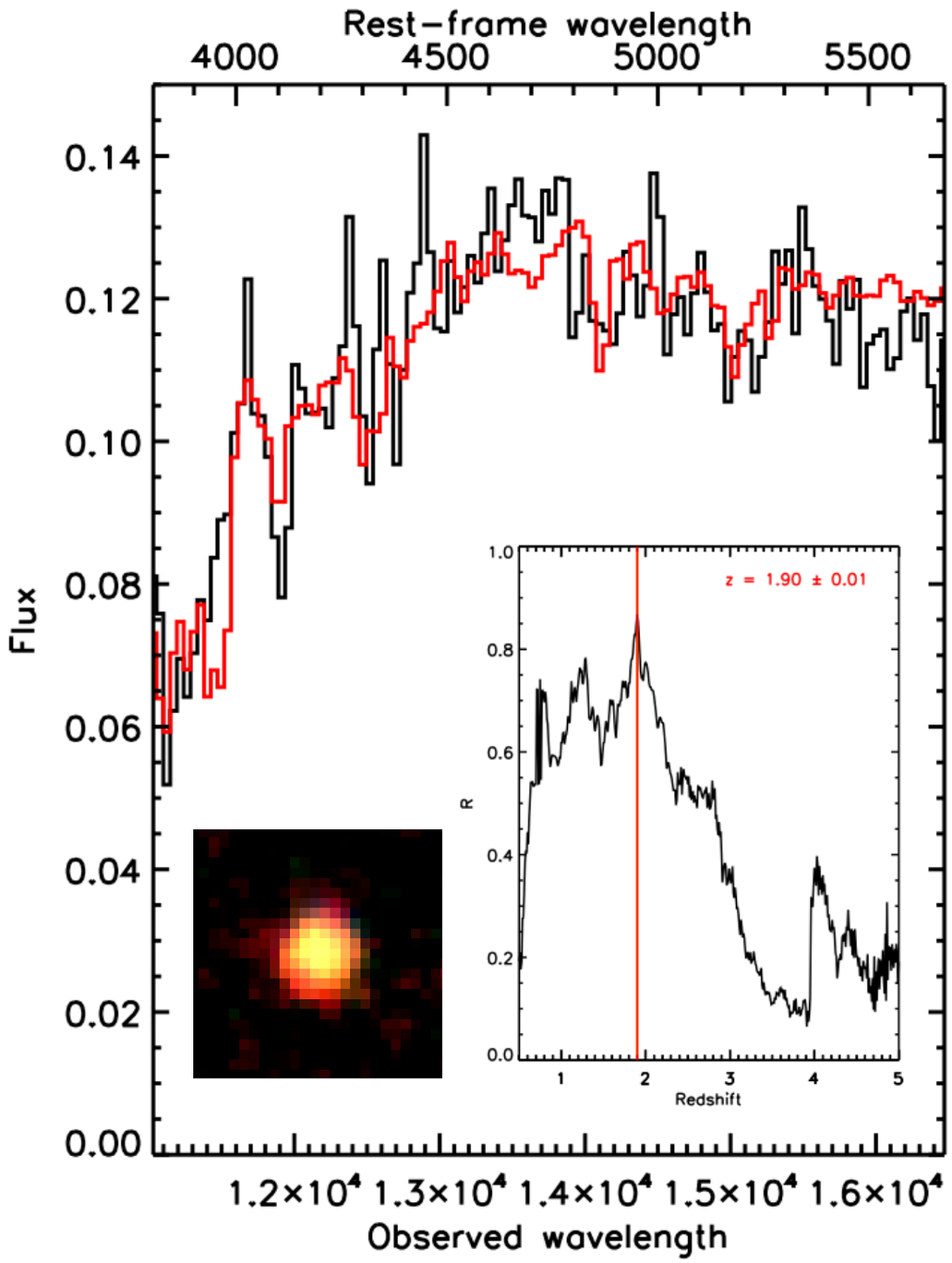
2 orbits

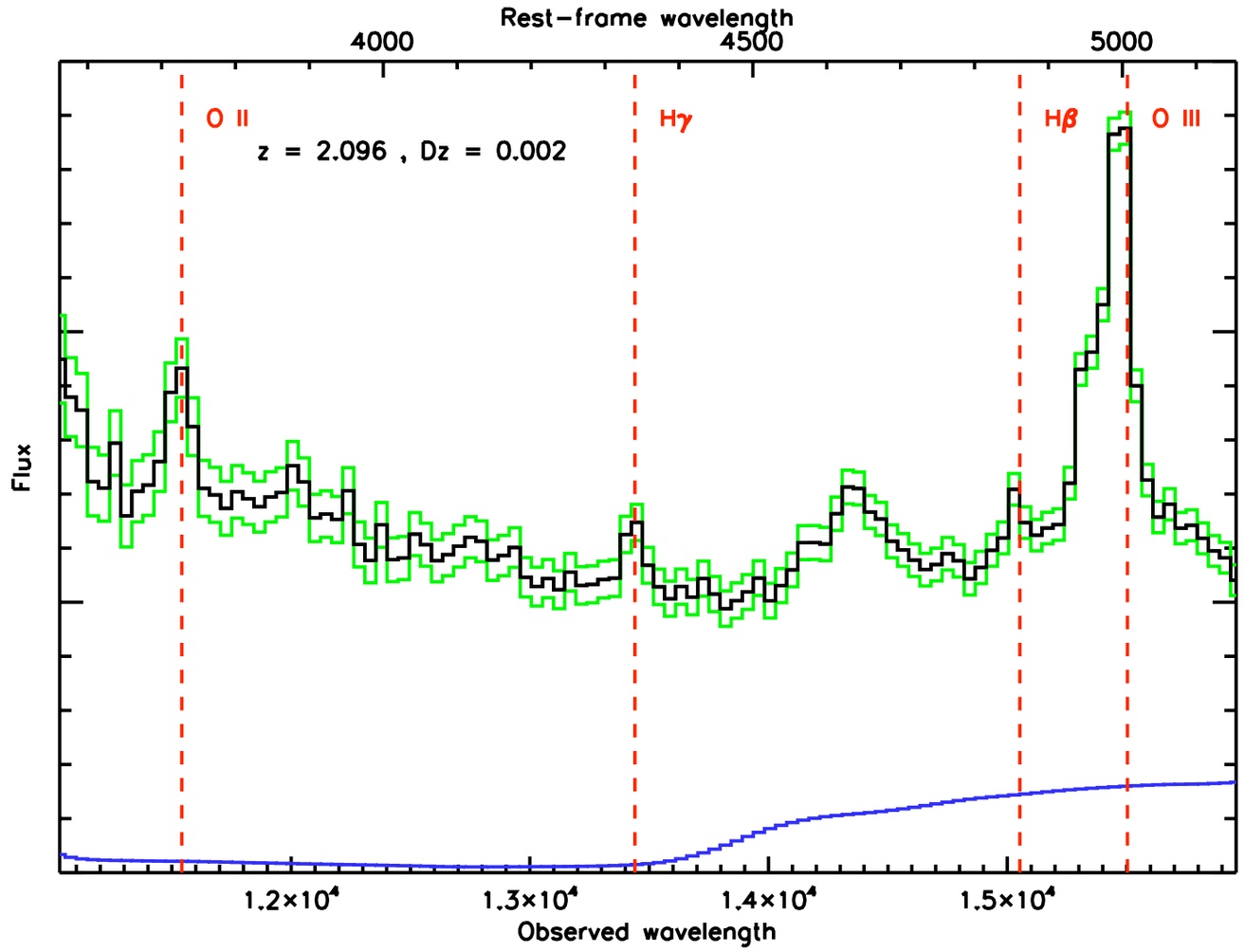
G141 grism spectroscopy



10 orbits

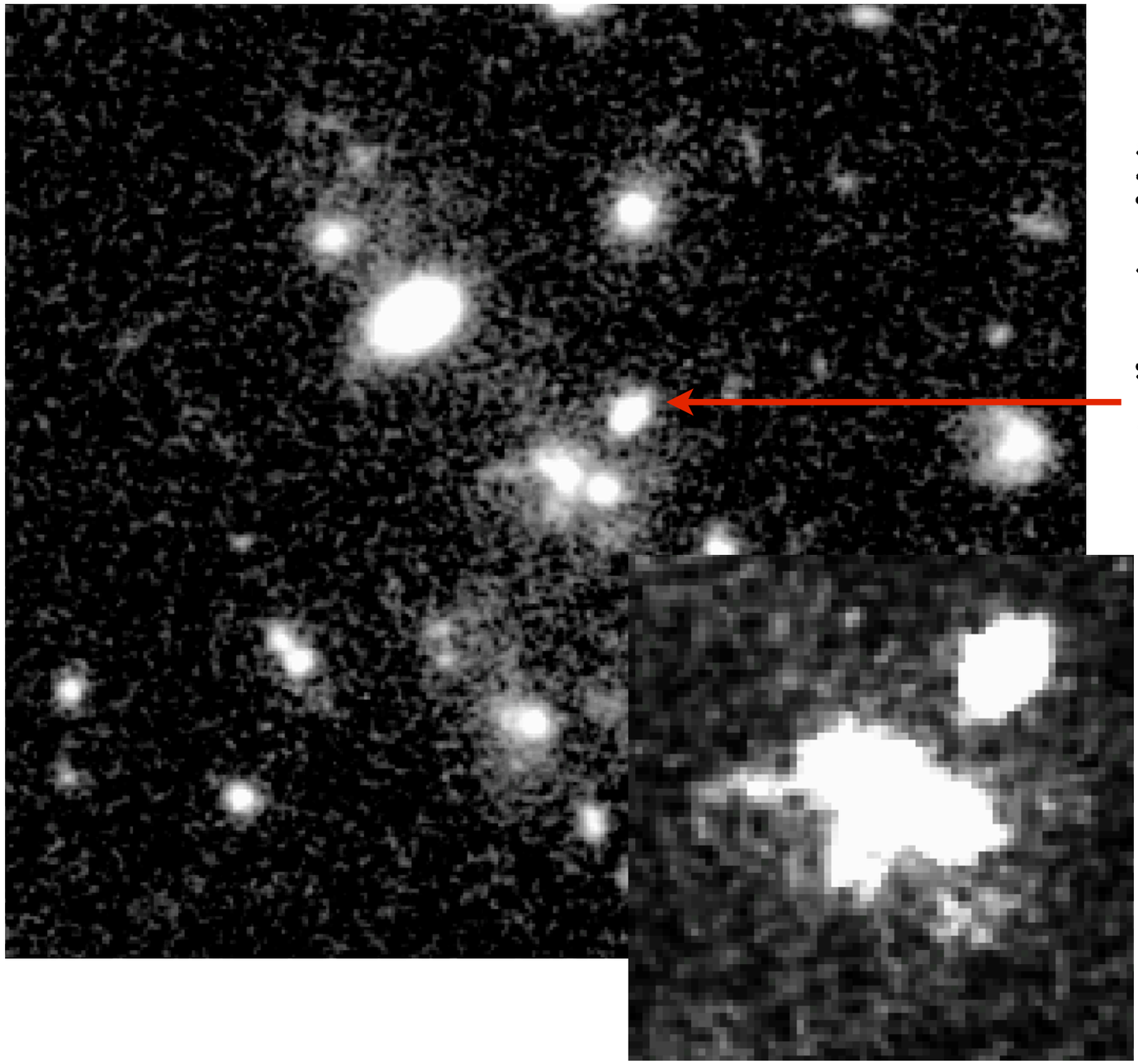
HST/WFC3 redshifts

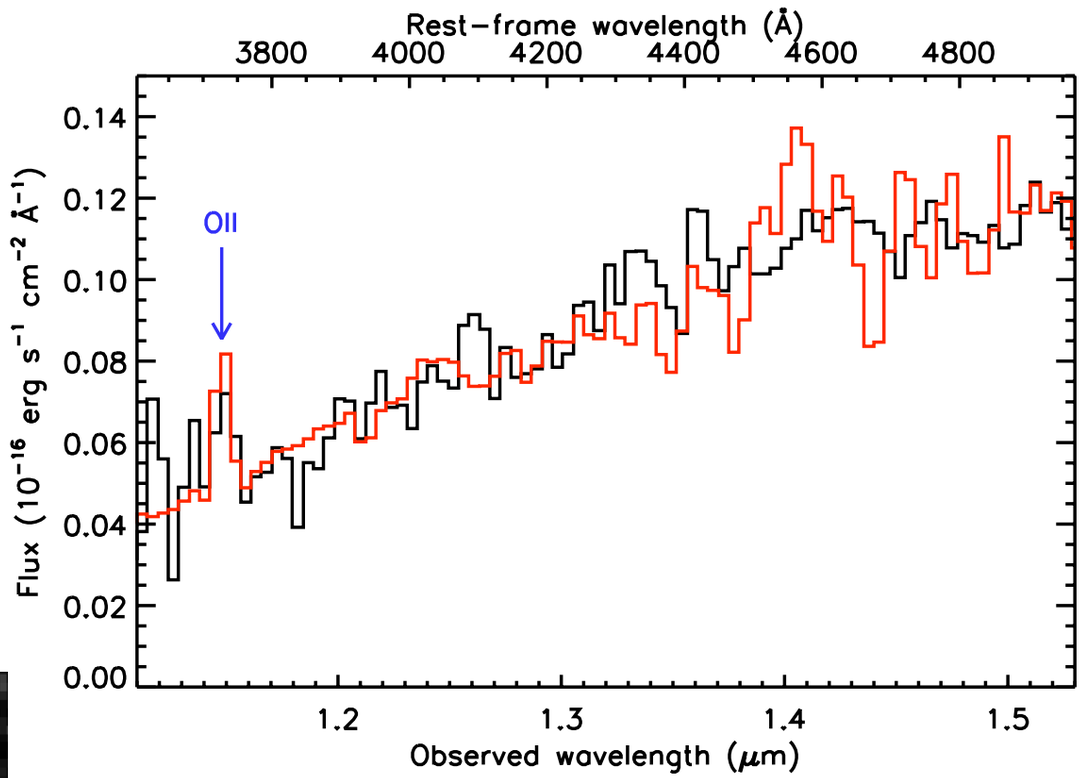




+9 members
(8 em + 1 abs)

Galaxy merging in the core





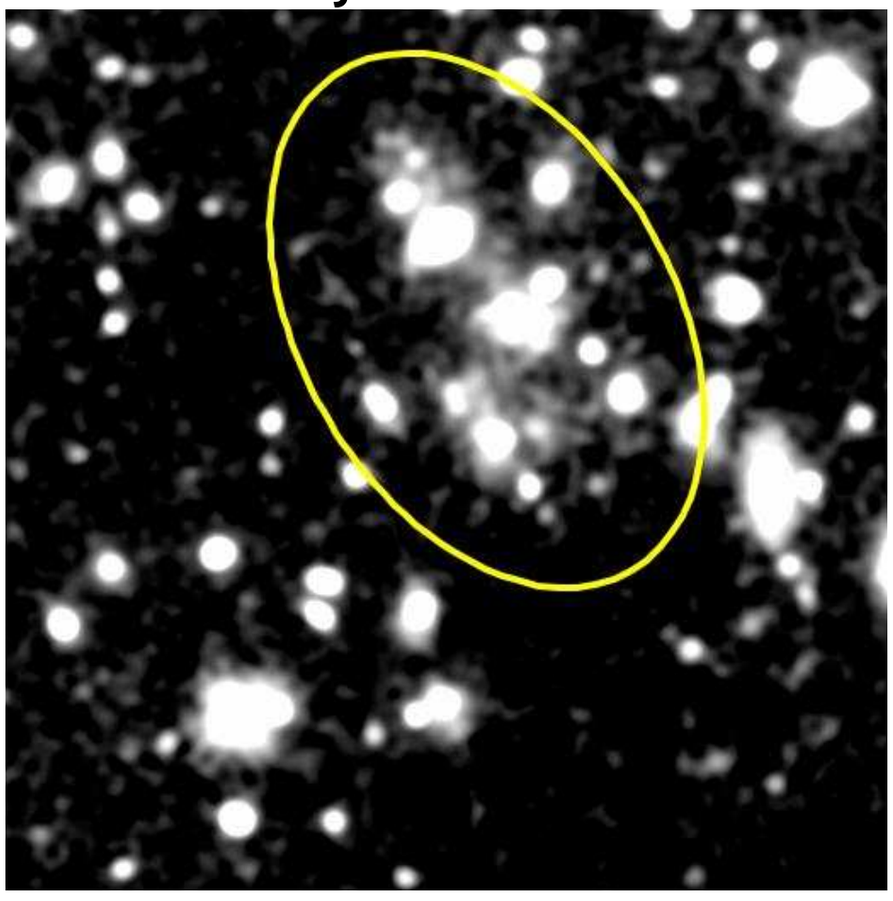
- spectrum best fit by an ERO template (Cimatti et al. 2002) with z = 2.08 and E(B-V) = 1.1
- very compact
- MIPS 24 source

⇒ dusty startburst, late-stage merger

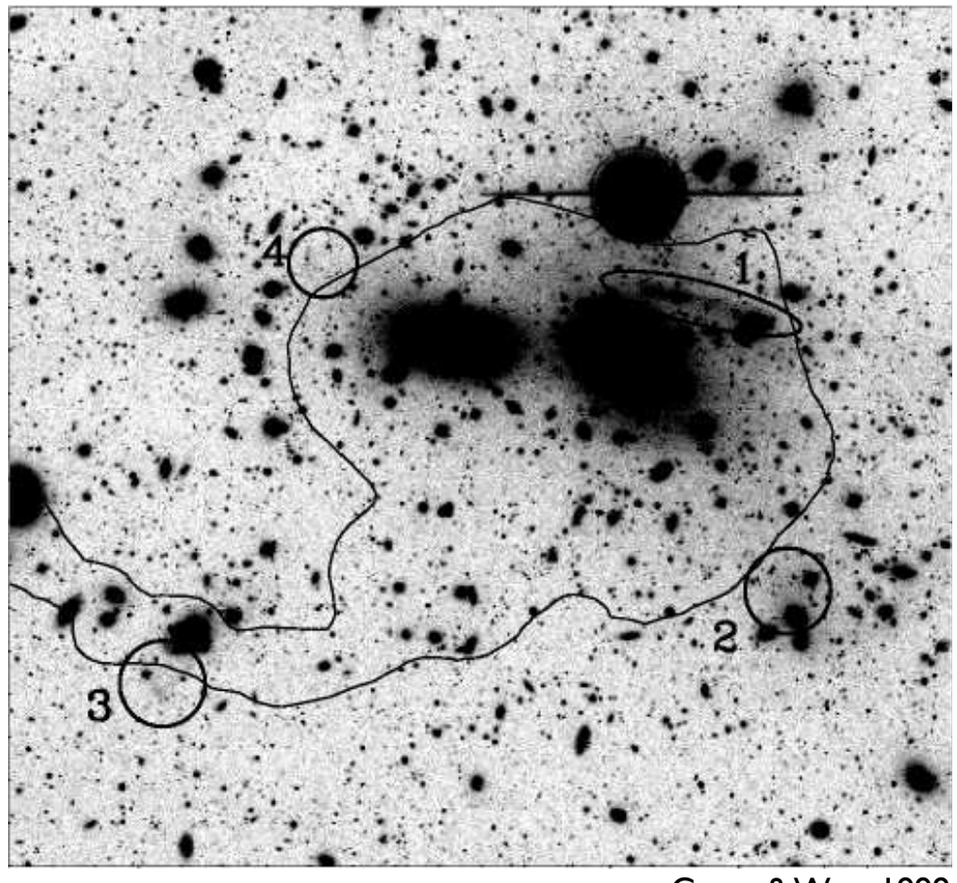
Galaxy merging in the core

Intracluster light

Cl J1449+0856



Coma



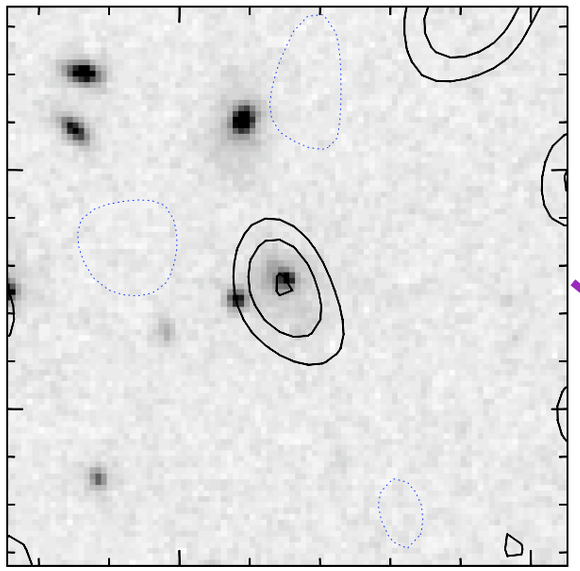
Gregg & West 1998

WFC3 1.4μm imaging reveals diffuse emission around core galaxies
broad filter ⇒ likely continuum rather than emission

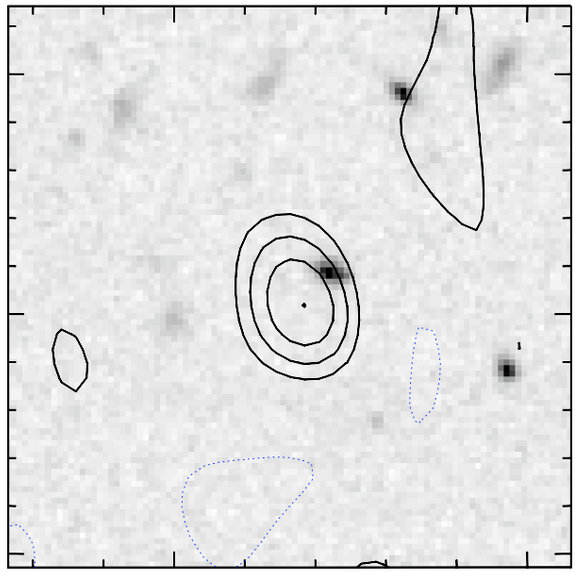
if stellar light, this implies high merging activity

PdBI CO(3-2) observations

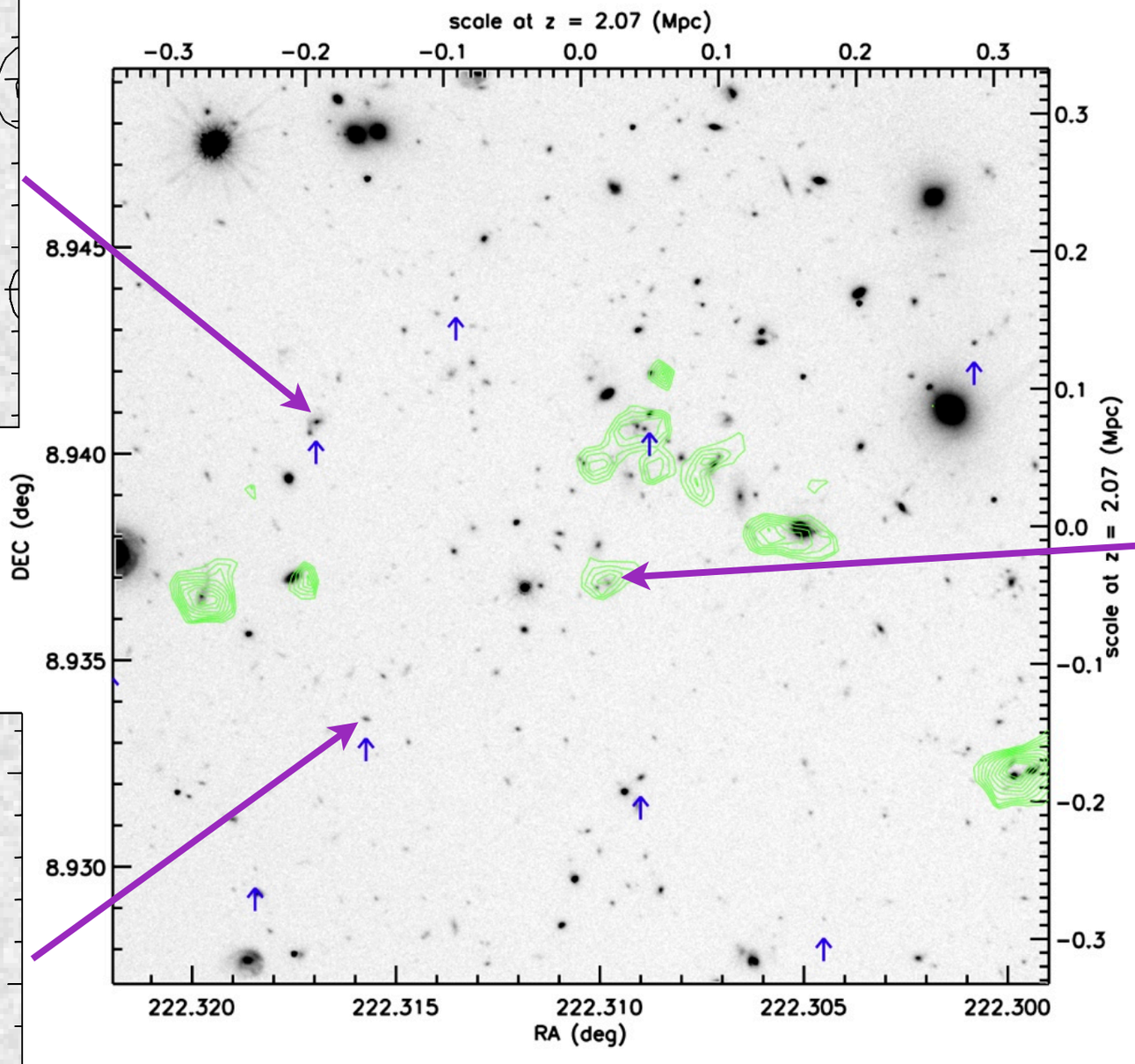
(very preliminary)



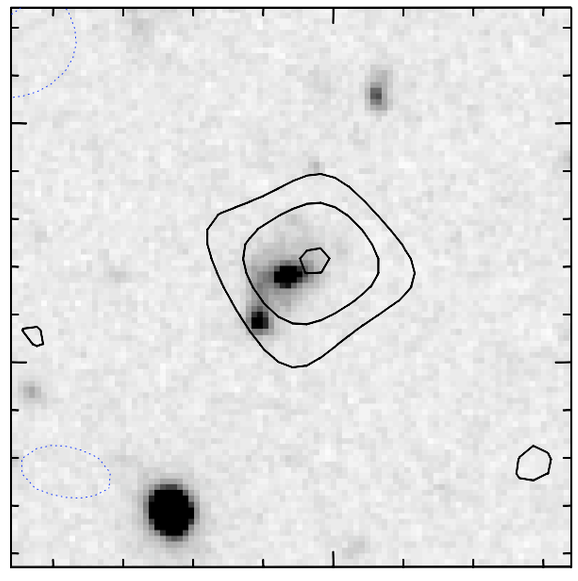
z = 2.077 , 4.8σ



z = 2.079 , >5σ

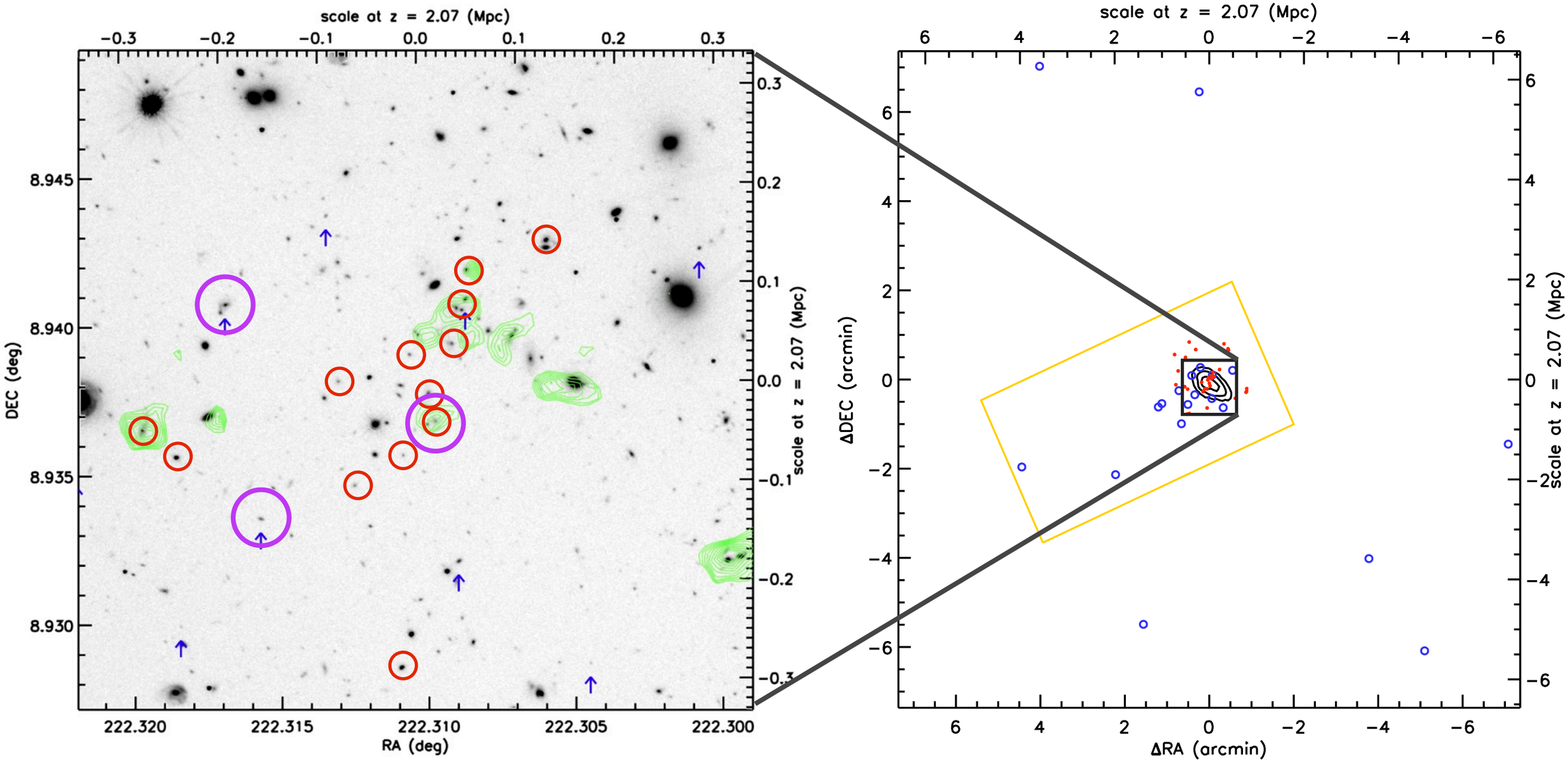


z = 2.08 , 4.2σ



3 tentative detections at z ~2.08

Passive and active members in Cl J1449+0856



z-spec members

z-phot candidates

CO(3-2) detections

24μm sources: > 100 $M_\odot yr^{-1}$

emission line members: 30–130 $M_\odot yr^{-1}$

Cl J1449+0856 is a “mature” galaxy cluster with detectable X-ray emission at $z \geq 2$ (i.e. ~3 Gyr after the Big Bang).

The core appears to host a high level of activity as well as an established early-type galaxy population.

Follow-up observations

- sub-mm (cold gas, SF efficiency)
- Herschel PACS (star formation and AGNs)
- narrow-band VLT imaging (census of SF members, large-scale structure)