EVOLUTION OF THE GALAXY RED SEQUENCE IN COSMOLOGICAL SIMULATIONS OF CLUSTERS AND GROUPS

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Why are we interested in modelling the Red Sequence ?

RS constrains epoch and duration of star formation activity → help to solve the puzzle:
More massive ellipticals are the last to get assembled... but their stellar populations are the oldest (= *fossil/archaeological* ***DOWNSIZING***)

The early-type CMR is a useful discriminant between the two competing theories of elliptical galaxy evolution:

- **Passive evolution/Monolithic** collapse at high redshift

a tight, constant slope CM up to high *z* consistent with a synchronous starburst and then passive evolution = slow ageing & reddening (Kodama et al. 1998)

- **Dynamic evolution/Hierarchical merger**

RS slope flattens with *z* because more massive Ell. form from the (selective) mergers of more massive (metal rich) discs (Kauffmann & Charlot 1998)

Caveat *(Kaviraj et al. 2005): the elliptical-only CMR (monolithic biased) does not take into account the late-type progenitors at high z…*

COSMOLOGICAL + HYDRODYNAMICAL SIMULATIONS

- ΛCDM "standard" model, N-body code

(*Fly*, Catania group):

$\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$, $z_i = 40$, $f_b = 0.15$

+

- TreeSPH (Lagrangian) hydro-dynamical code

(Copenhagen group):

mass resolution m_{DM}=18 (2.3) x10^8 h^{-1} M_{sun} , m_{SPH}=m_*=2.5 (0.3) x10^8 h^{-1} M_{sun}

Completeness limit: M_V = -17 /-15, M_K = -20 /-17.5

softening: 1.4-2.8 (stars) and 2.7-5.4 (DM) h^{-1} kpc

Gas hydrodynamics (thermal & chemical):

non-gravitational heating + radiative cooling

$\leftrightarrow$

coupled "self-consistently" with **galaxies**:

Star formation

↓

stellar feedback

↓

energy & metals outflow: galactic winds

- radiative metal-dependent cooling: Bremsstrahlung + lines
- star formation: Salpeter or Arimoto-Yoshii (top-heavier) IMF
- SN-II & Ia feedback
- stochastic chemical evolution: recycling of H, He, C, N, O, Mg, Si, S, Ca, Fe

Top-heavy IMF
+
Strong feedback

(70% SN II → galactic “super” winds)

balance cooling → reproduce ICM properties: L_X-T, S(r), f_{cold} , Z_{Fe}(r) , ICMLR

by removing low-S, over-X-ray emitting central gas

& spreading more efficiently metals up in the ICM
(Romeo et al., 2006, MNRAS 371, 548)

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Bottom-line: no unique model for both gas and galaxies

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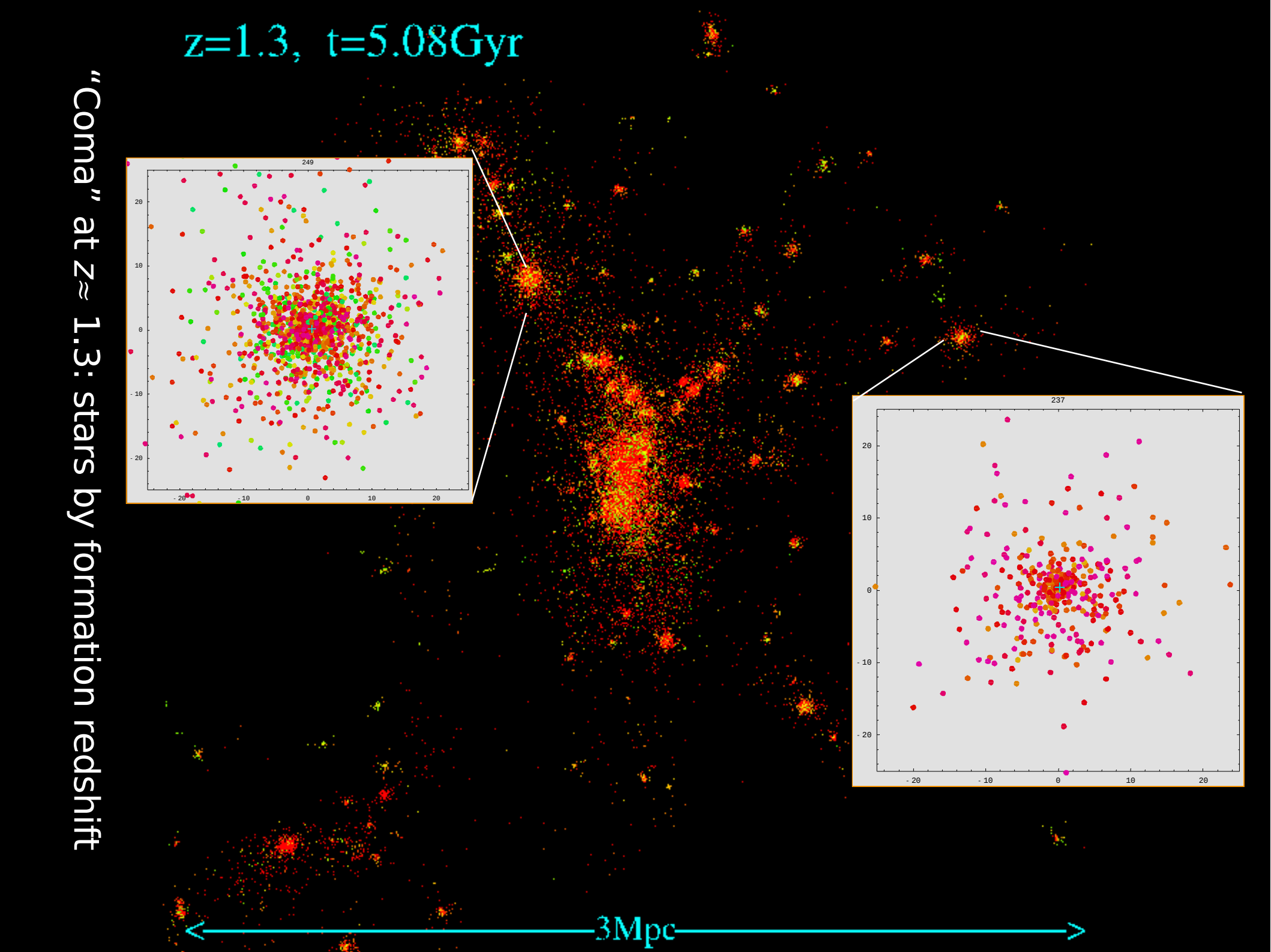
solution: AGN feedback ?!?


z=1.3, t=5.08Gyr
"Coma" at z≈ 1.3: stars by formation redshift
3Mpc

Which driver for RS build-up? Metallicity, SSFR…

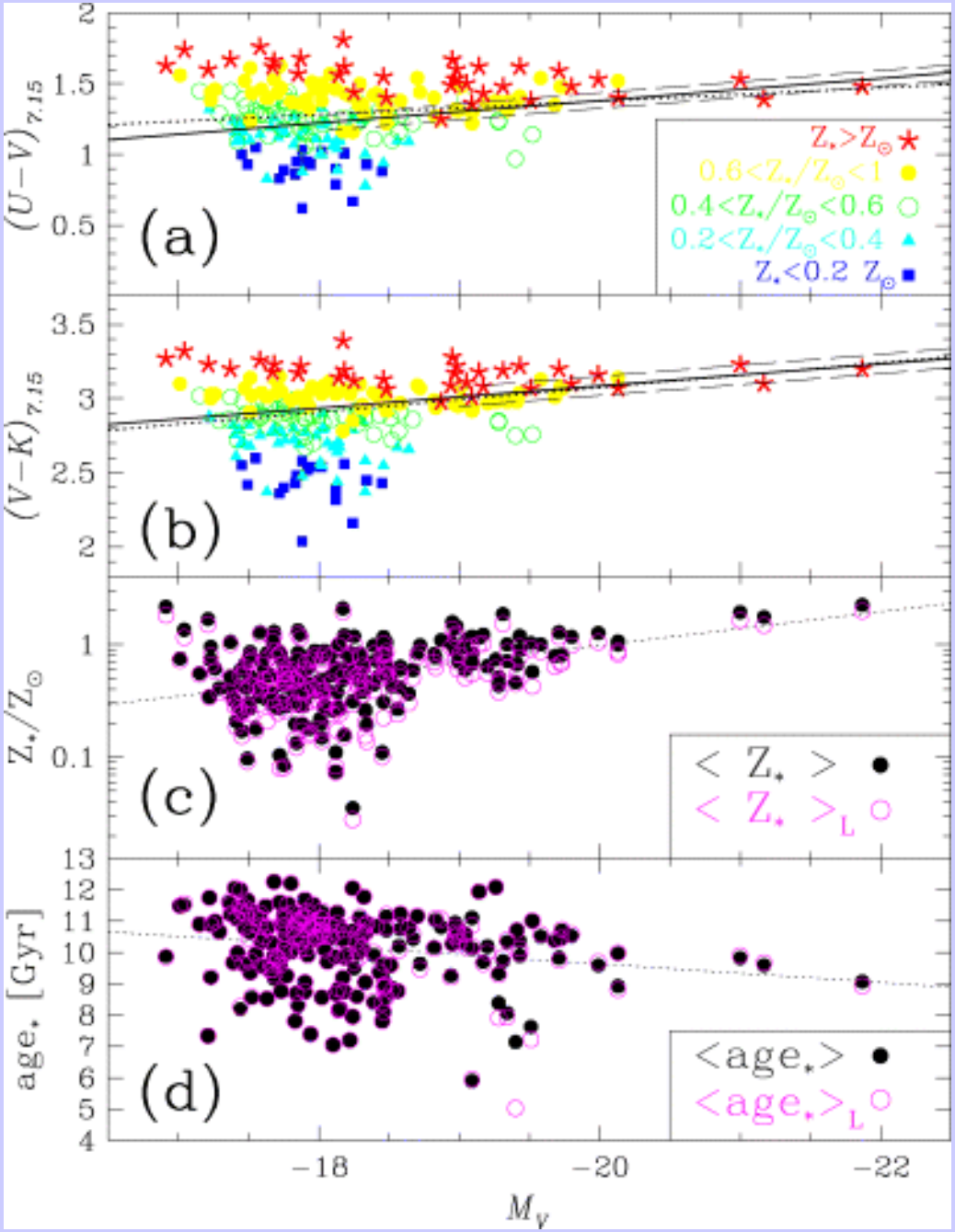
Colour-Magnitude

⇕

Metallicity-Mass

(cfr. Bower et al. 1992, Terlevich et al. 2001)

***z*=0**



(Romeo et al., 2005, MNRAS 361, 983)

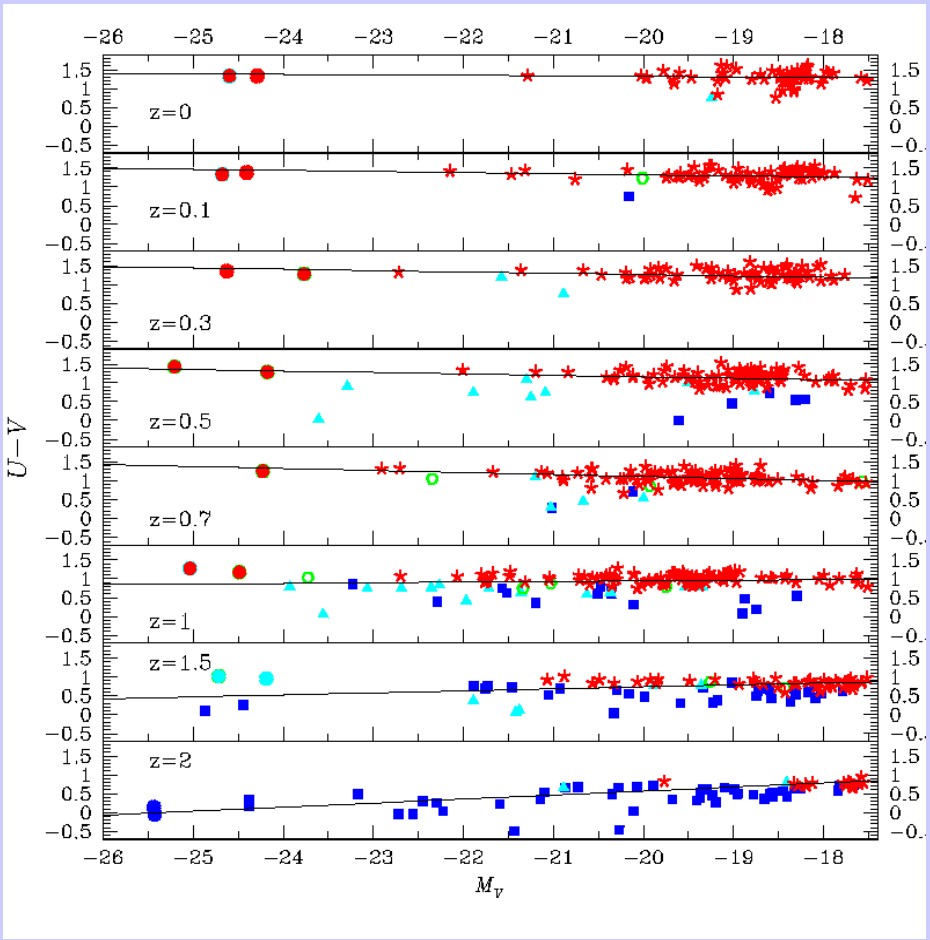
Metallicity alone does **not** shape the RS as a peculiar locus in the CM plane

The tight CMR might be a combination of age/metallicity if younger are metal rich

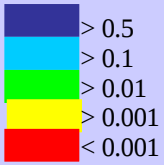
Ferreras, Charlot, Silk (1999)

Which sample for defining the RS ? The “tale of two sequences”…

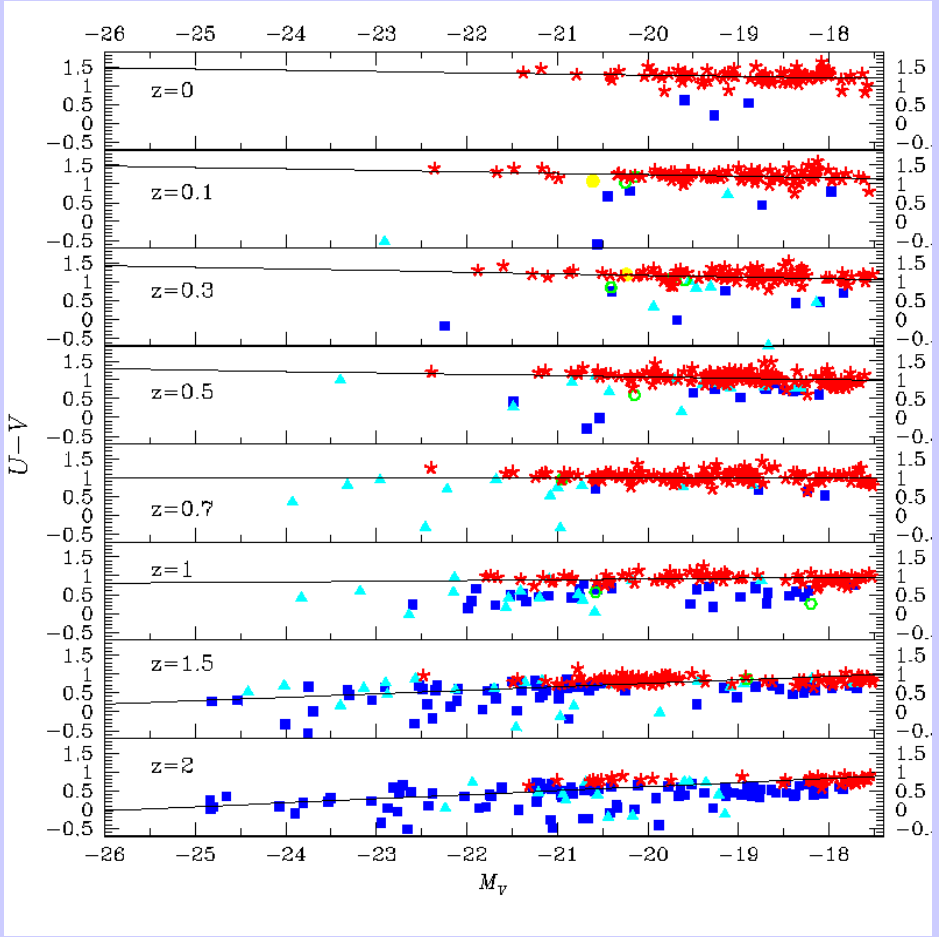
CORE



CLUSTERS



OUT

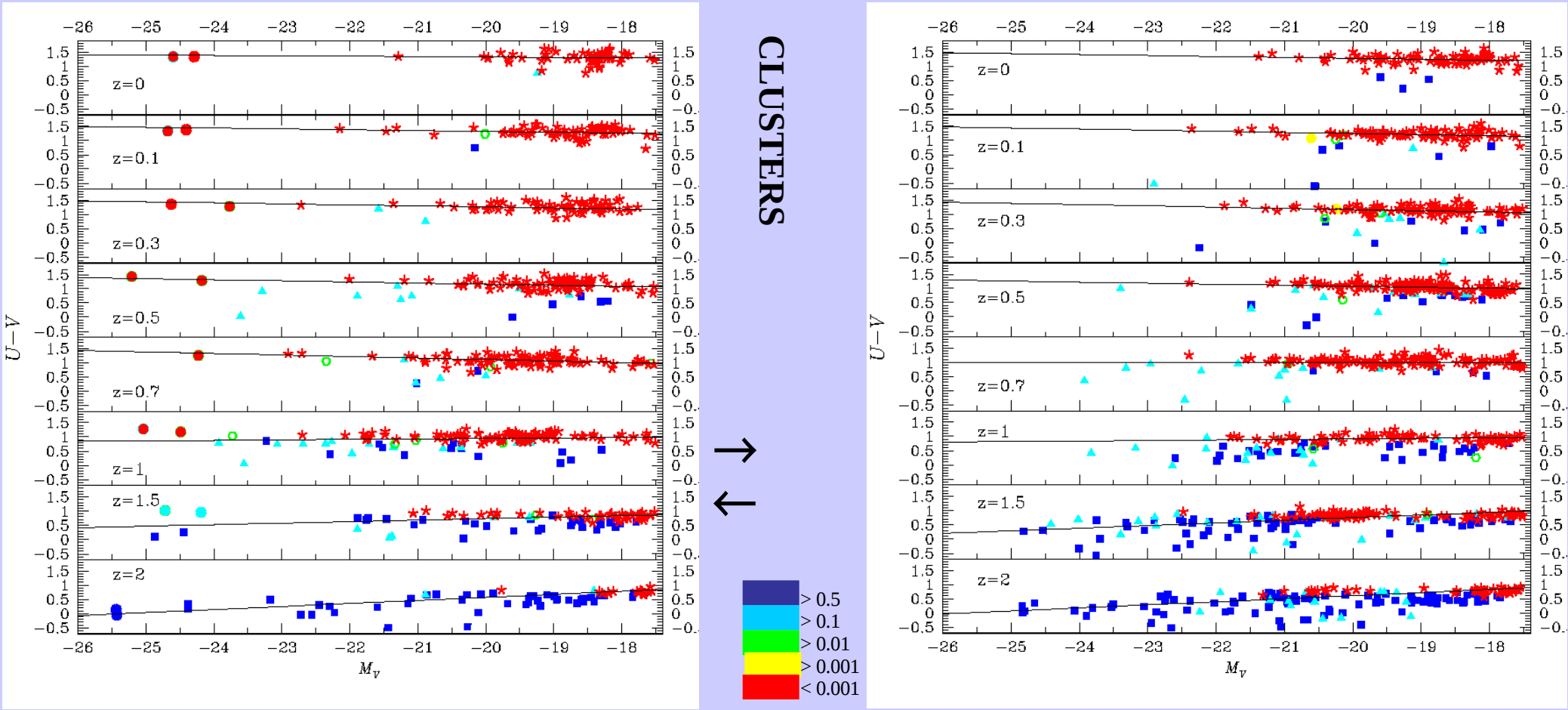


SFR/M$_*$=M$_\odot$ yr^{-1}/10^{10}M$_\odot$

- **RS** fit: early-type selection from σ_v – colour plane, with 2-sigma clipping
- “Dead sequence” (**DS**): all galaxies with no SF over the last Gyr

➢ Since *z*~1, most of s.f. occurs in less massive galaxies (*downsizing !)* and all star-forming galaxies lie below the RS fits

- Cluster cores complete the RS first

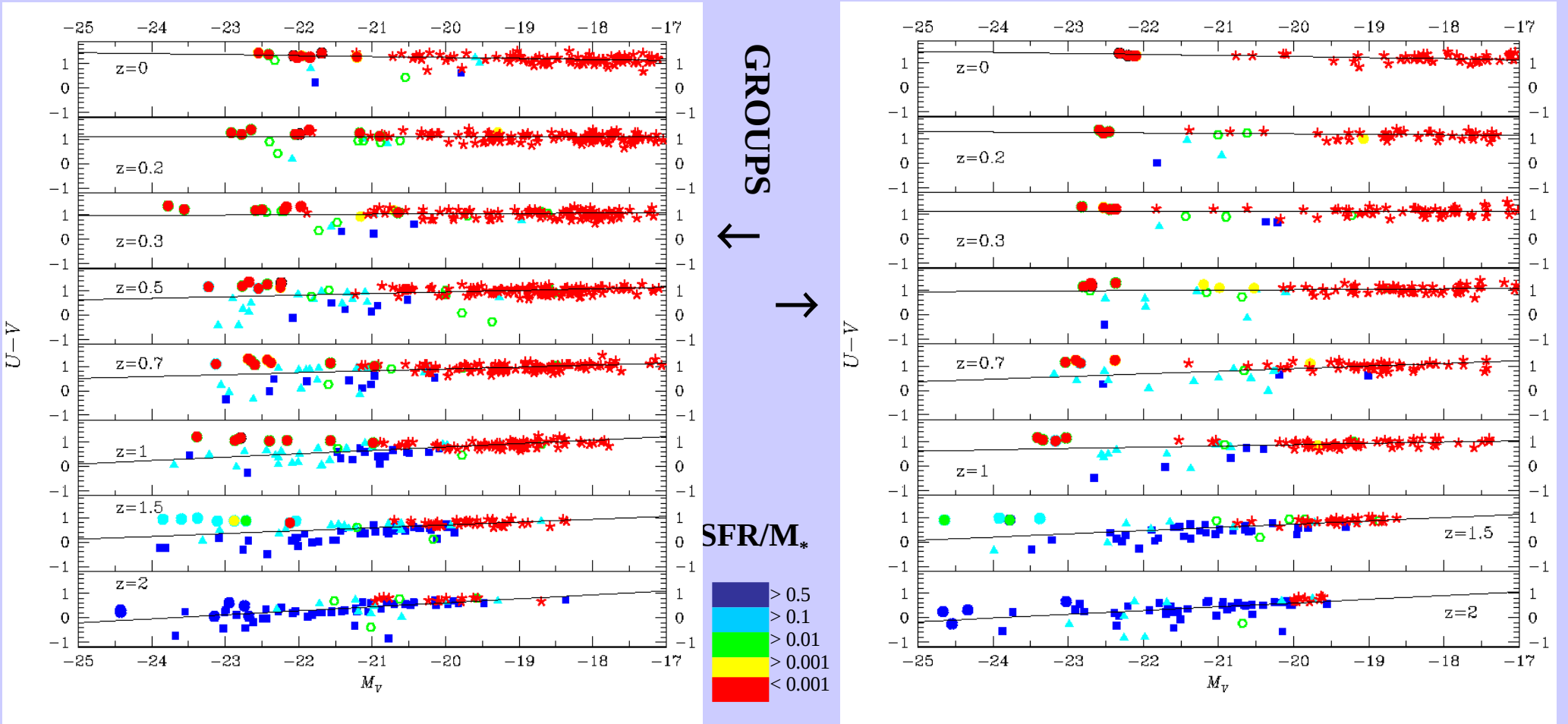


CORE **SFR/M$_*$=M$_\odot$ yr^{-1}/10^{10}M$_\odot$** **OUT**

"Transfusion" from blue cloud to red peak :
Star formation moves towards less-massive galaxies

Environmental sequence in building the RS

- Normal groups: s.f. activity lasts down to z=0
- FG: earlier shutoff; “universal” CD mass since z~1



NORMAL **FOSSIL**

“Transfusion” from blue cloud to red peak :
Star formation moves towards less-massive galaxies (slower in groups)

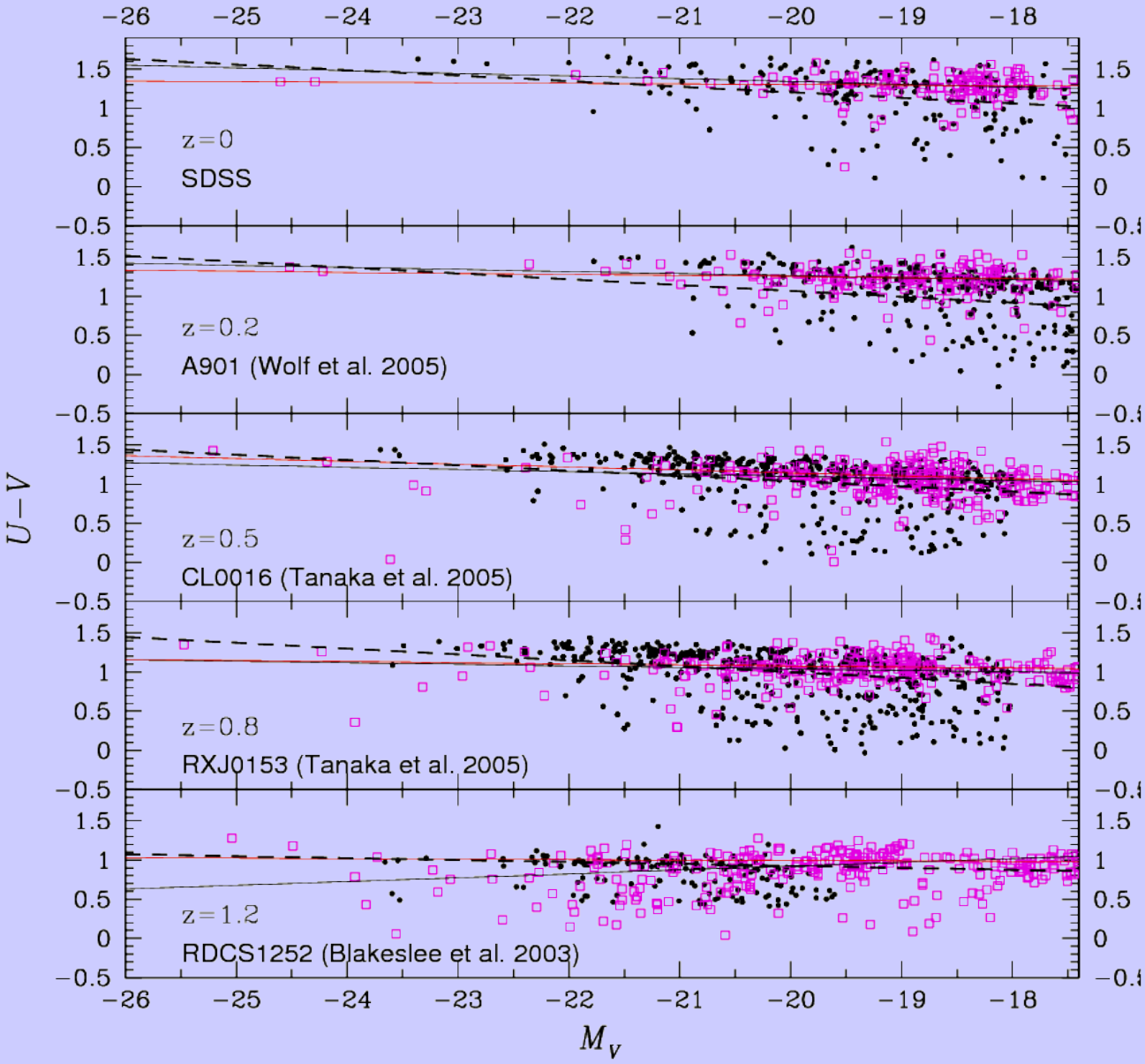
Model vs. observations

Best-fits:

Obs.

RS

DS

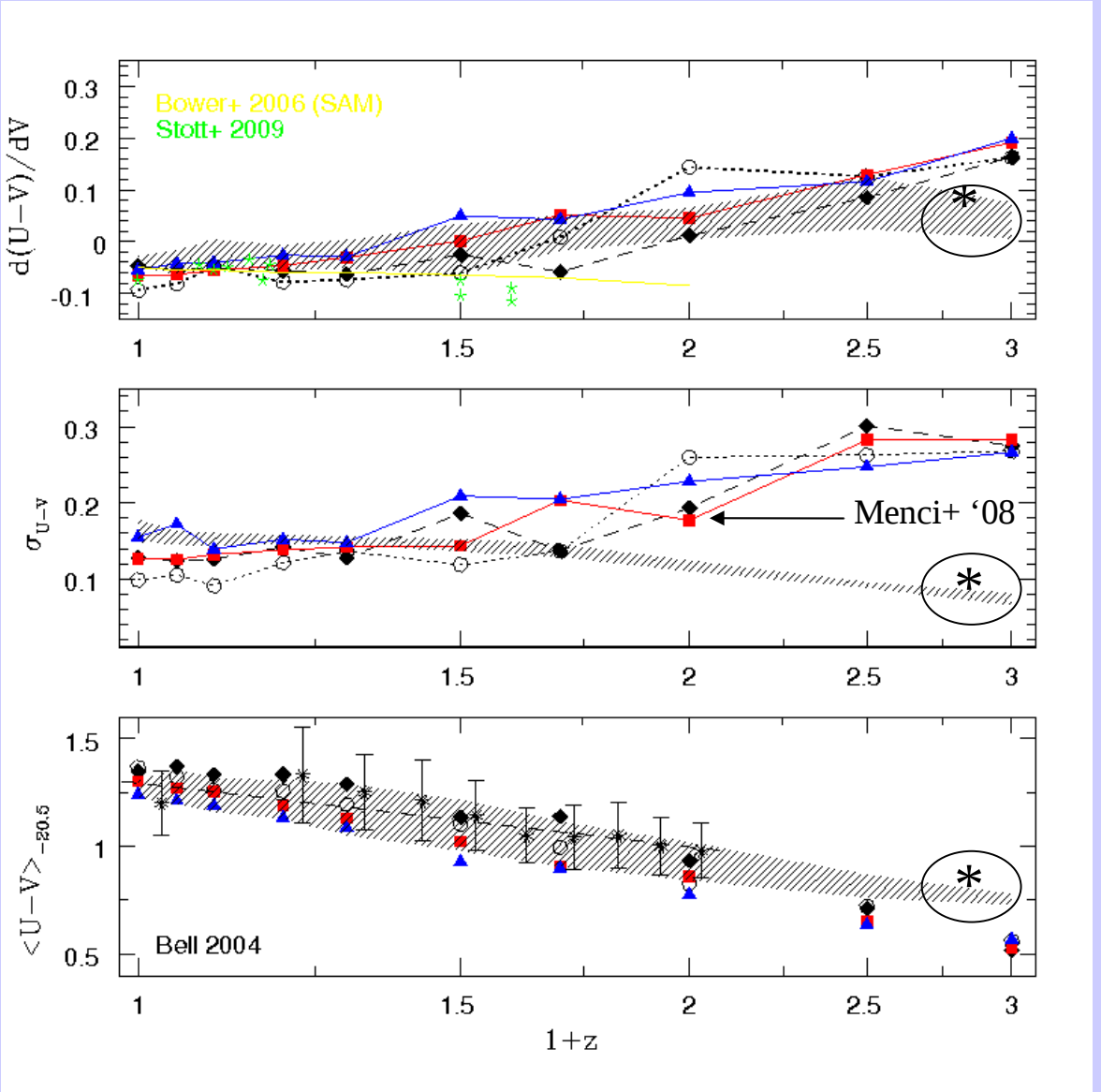


Romeo et al., MNRAS 389, 13 (2008)

Slope, scatter and zero-point of the RS & DS

- change of slope → constraints the epoch of RS breaking-out
- scatter → measure of duration of s.f. activity

DS: always tight, flatter slope



cluster cores

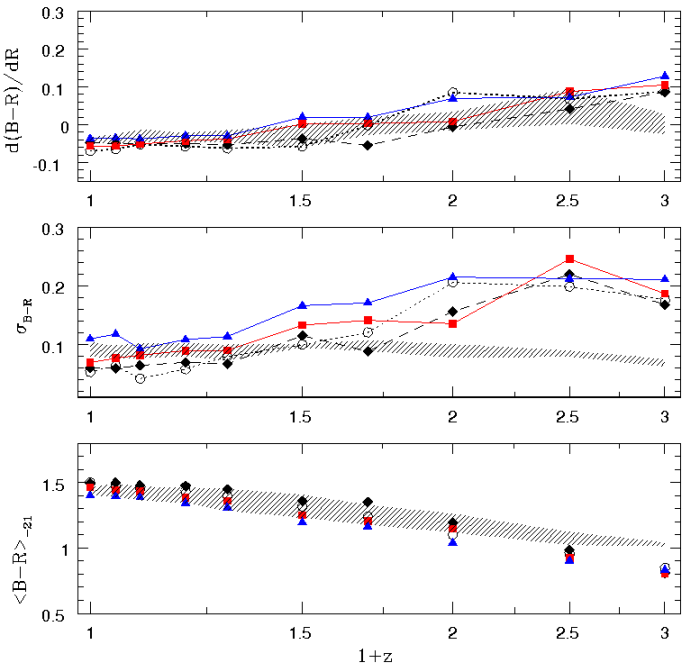
clusters outskirts

fossil groups

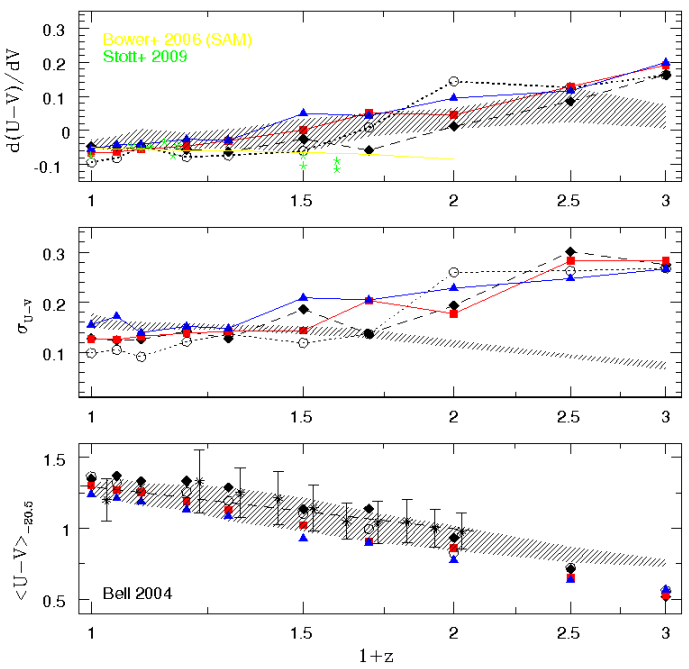
normal groups

all quiescent galaxies (* under-populated at z=2)

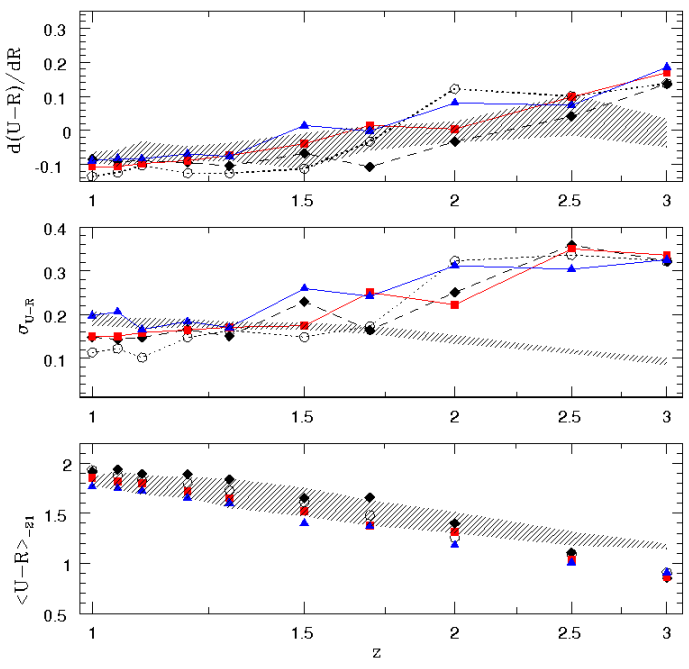
B-R



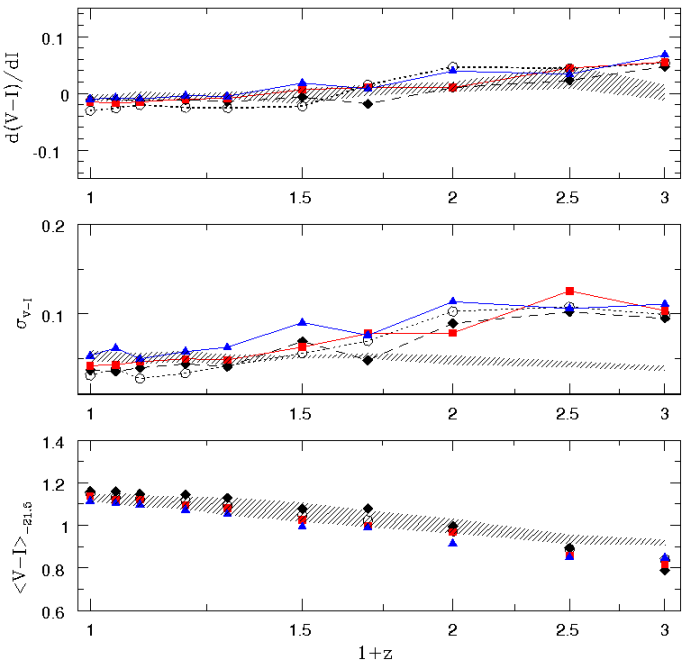
U-V



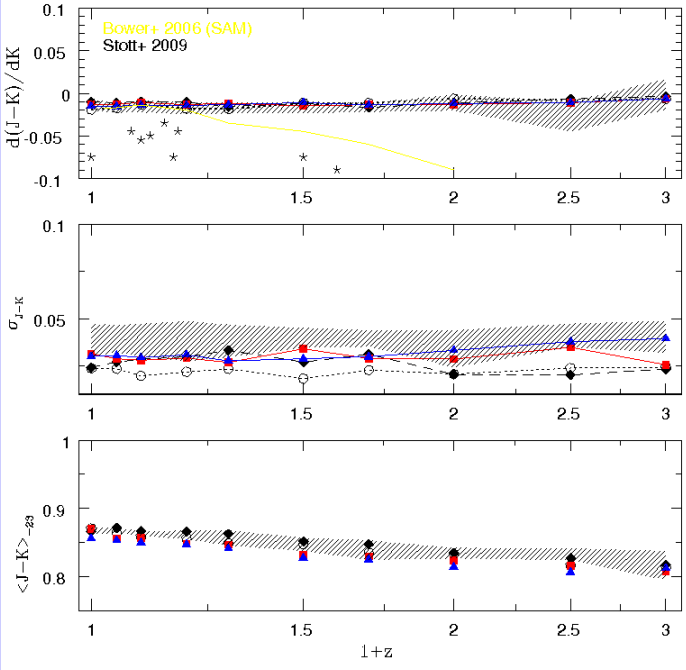
U-R



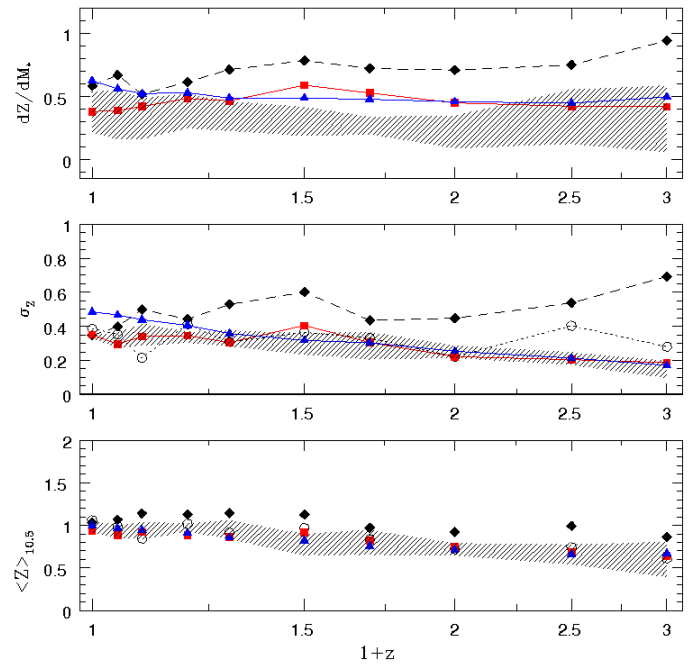
V-I



J-K



Z-mass



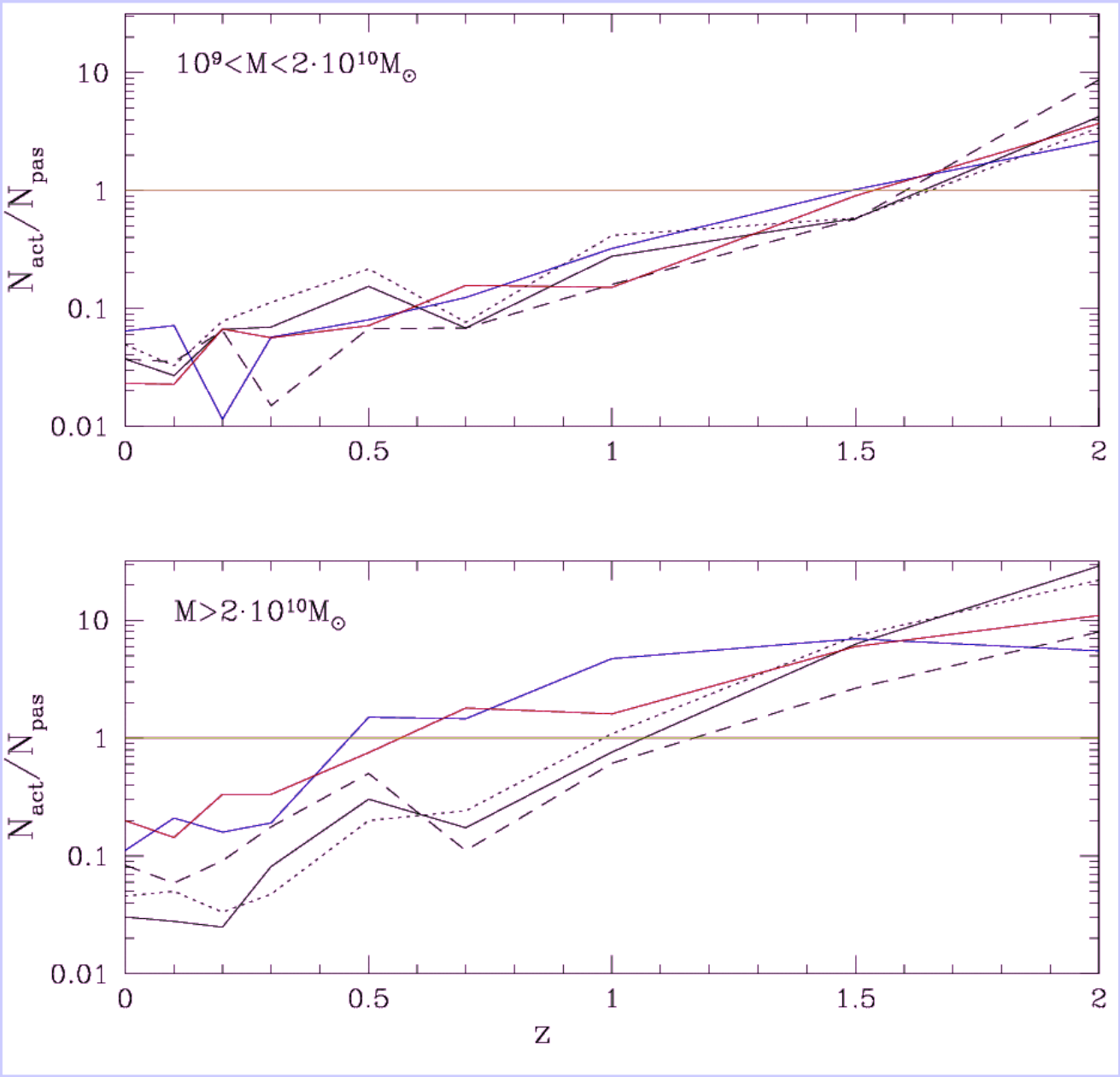
The slope of the slope…

	$\partial\alpha/\partial z$	$\partial\sigma/\partial z$	$\partial col/\partial z$	
RS	~0 up to z=0.7 >0 earlier	~0 up to z=0.3 >0 earlier	<0	
DS	~0 up to z=1 Indef. earlier	<0	<0	
J-K	0	0	<0	
Z-mass	~ 0	~ 0	~ 0	

Depends on the selected sample and on the waveband !

The RS active to passive ratio

cl. IN
cl. OUT
cl. tot.
NG
FG



Less massive:

universal turnaround at z ~1.5

More massive:

environmental sequence

➢ $z \approx 1$ (clusters) $\rightarrow$ 0.5 (groups) : transition epoch between active and quiescent regimes

Environment dependency of the transition redshift

	$\alpha = \alpha_{DS}$	$N_{ac}=N_{pas}$	$N_{ac}=$ 50% N_{pas}	redshift
cluster cores	0.9	1.1	0.85	
cluster outskirts	0.7	1	0.8	
Fossil Groups	0.4	0.6	0.4	
Normal Groups	0.2	0.4	0.3	

$M > 2x10^{10}M_{\odot}$

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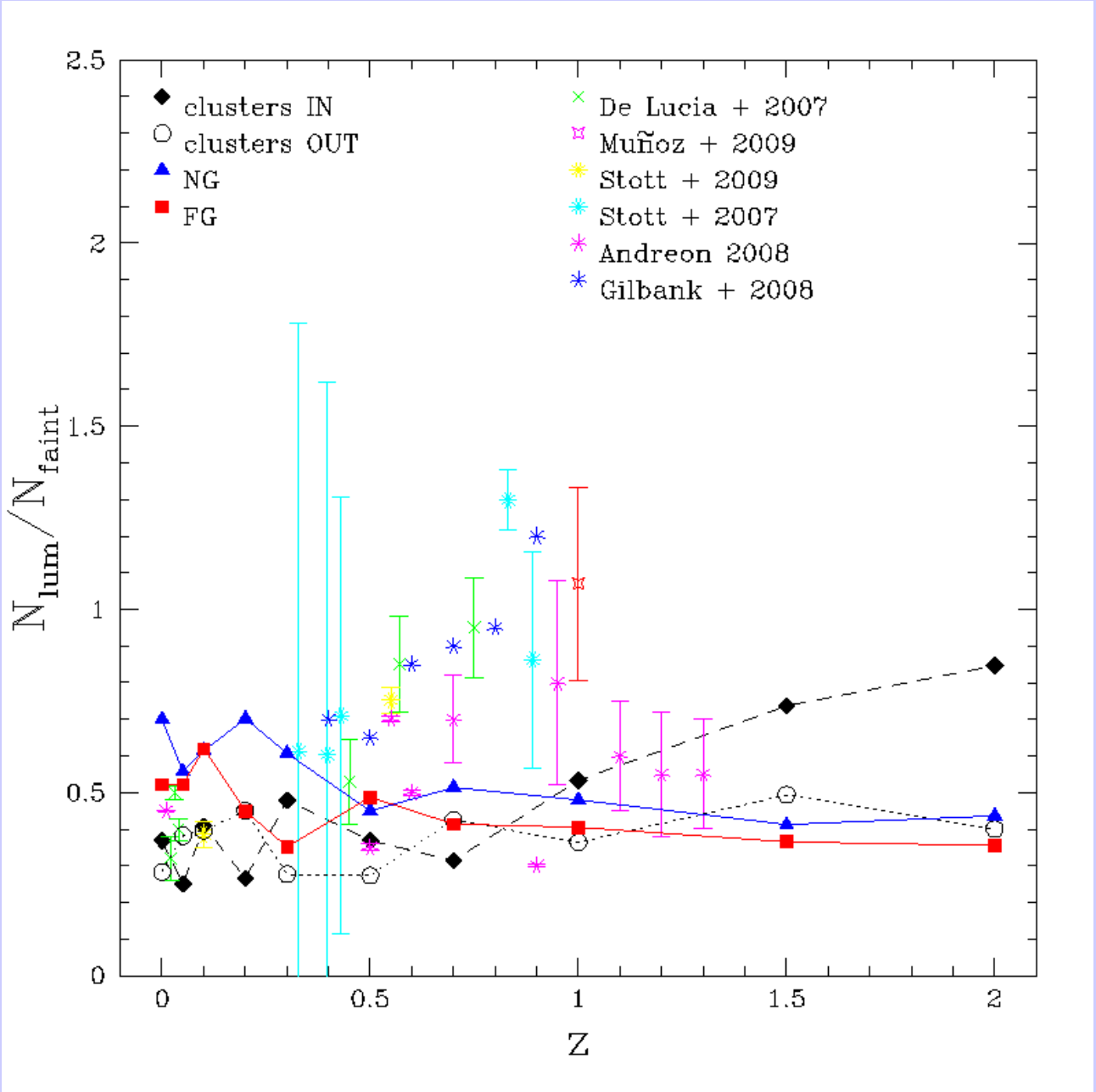
Arnouts et al. 2007

transition redshift ⇔ epoch when RS approaches DS

The overall luminous-to-faint ratio



(*) cfr. between non-homogeneous samples

Mean Poissonian error

Threshold=2×10^{10} M_{sun} Limit=3×10^{9} M_{sun}

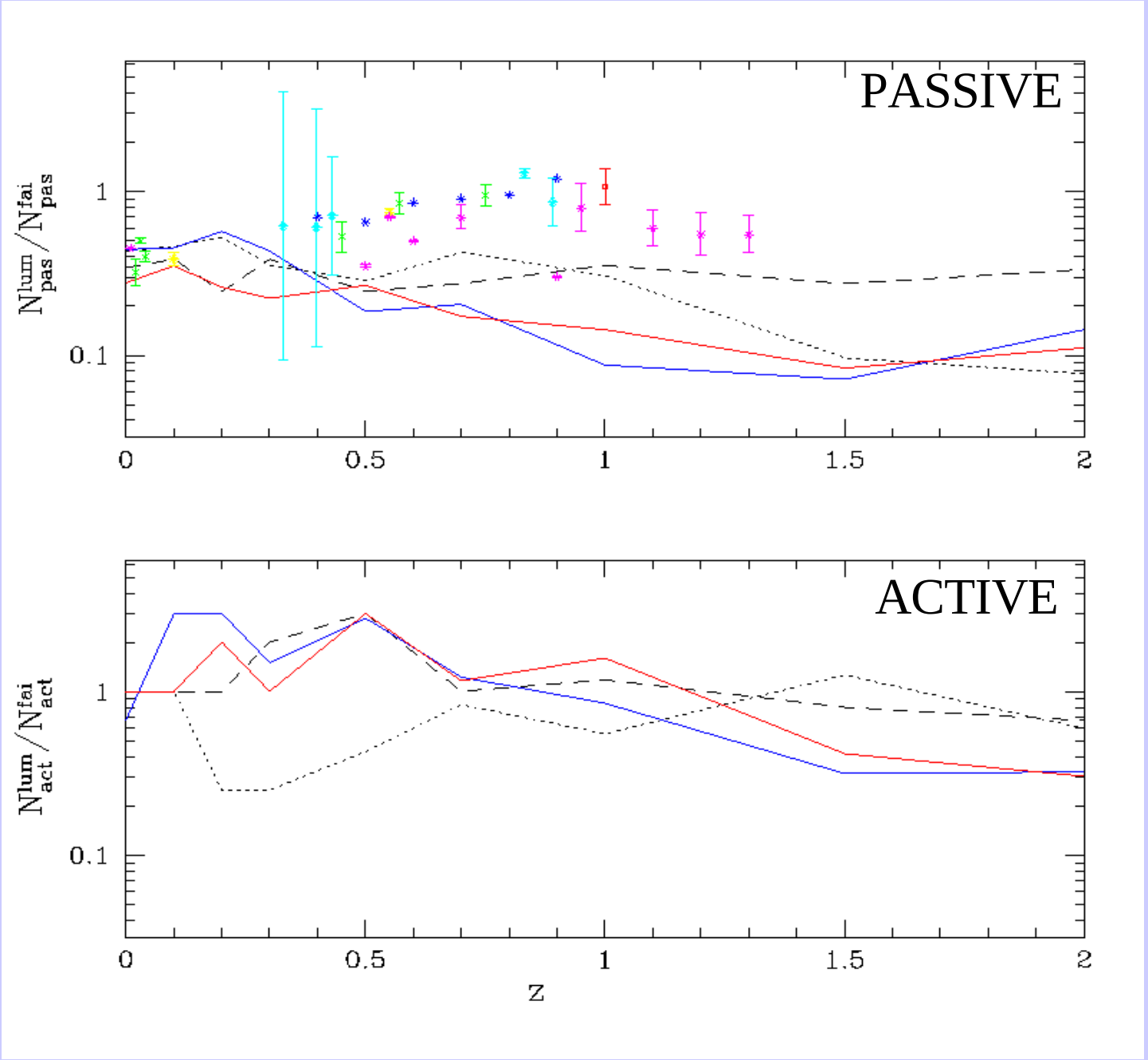
The DS luminous to faint ratio

cl. IN

cl. OUT

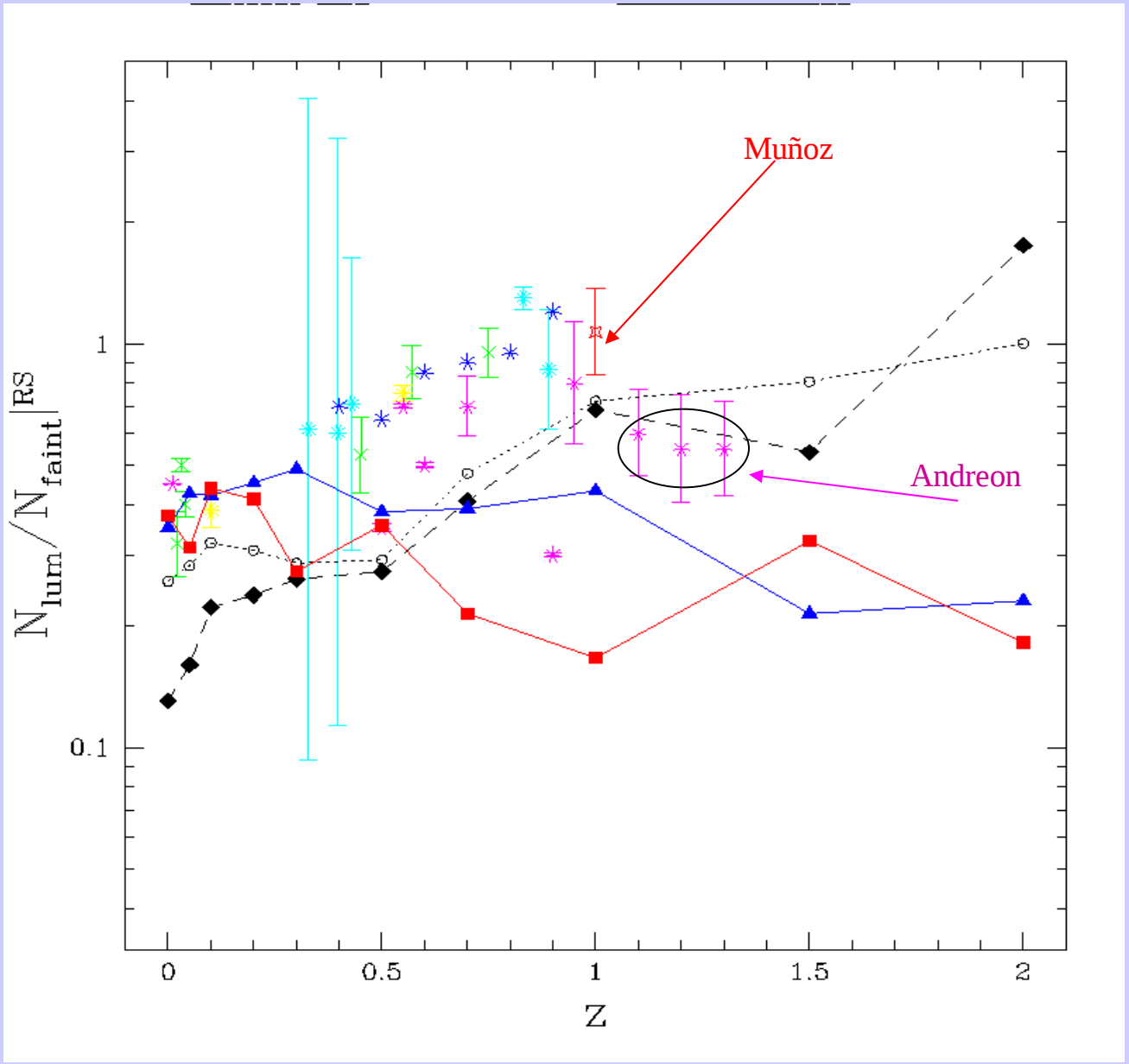
NG

FG



(*) cfr. between non-homogeneous samples

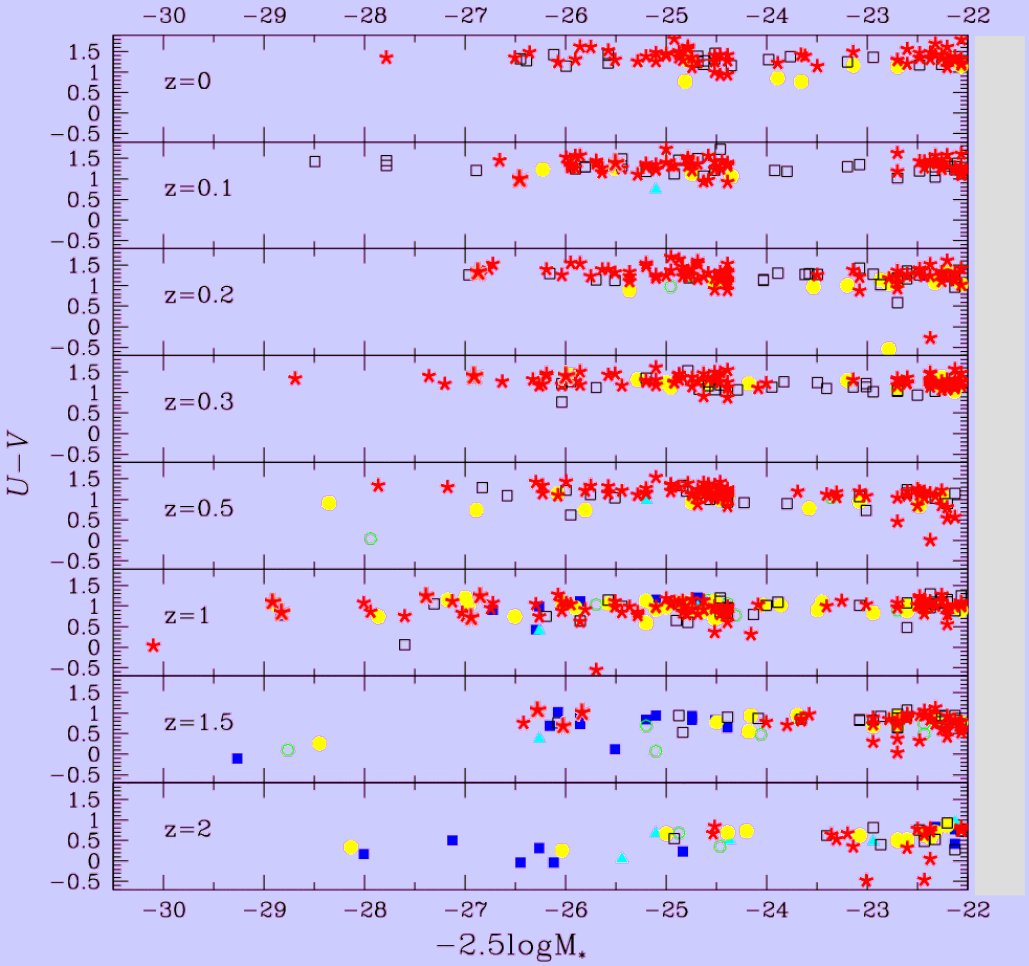
The RS luminous to faint ratio



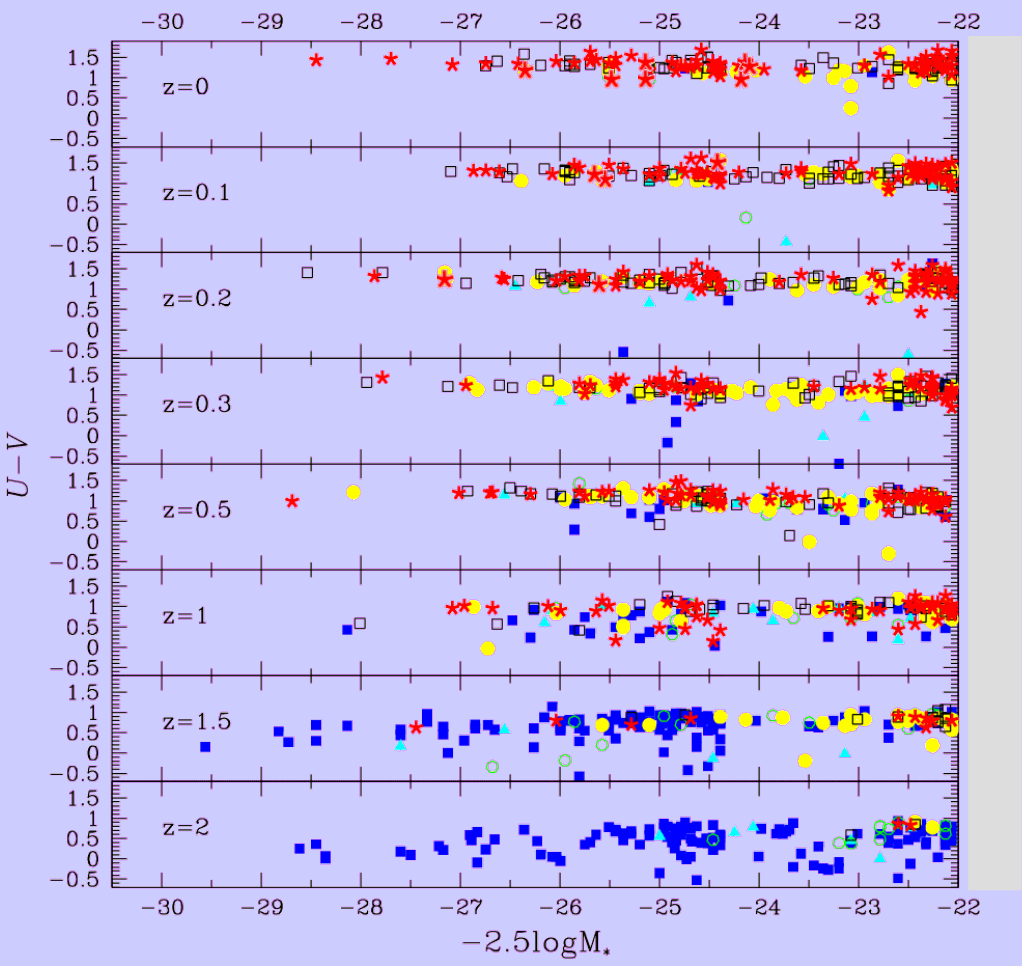
Threshold M_v=-20 Limit M_v=-18 at z=0 → pass.evol. z>0

Red sequence and (cold) gas fraction

Cluster core



Outskirts



M_{gas}/M_*

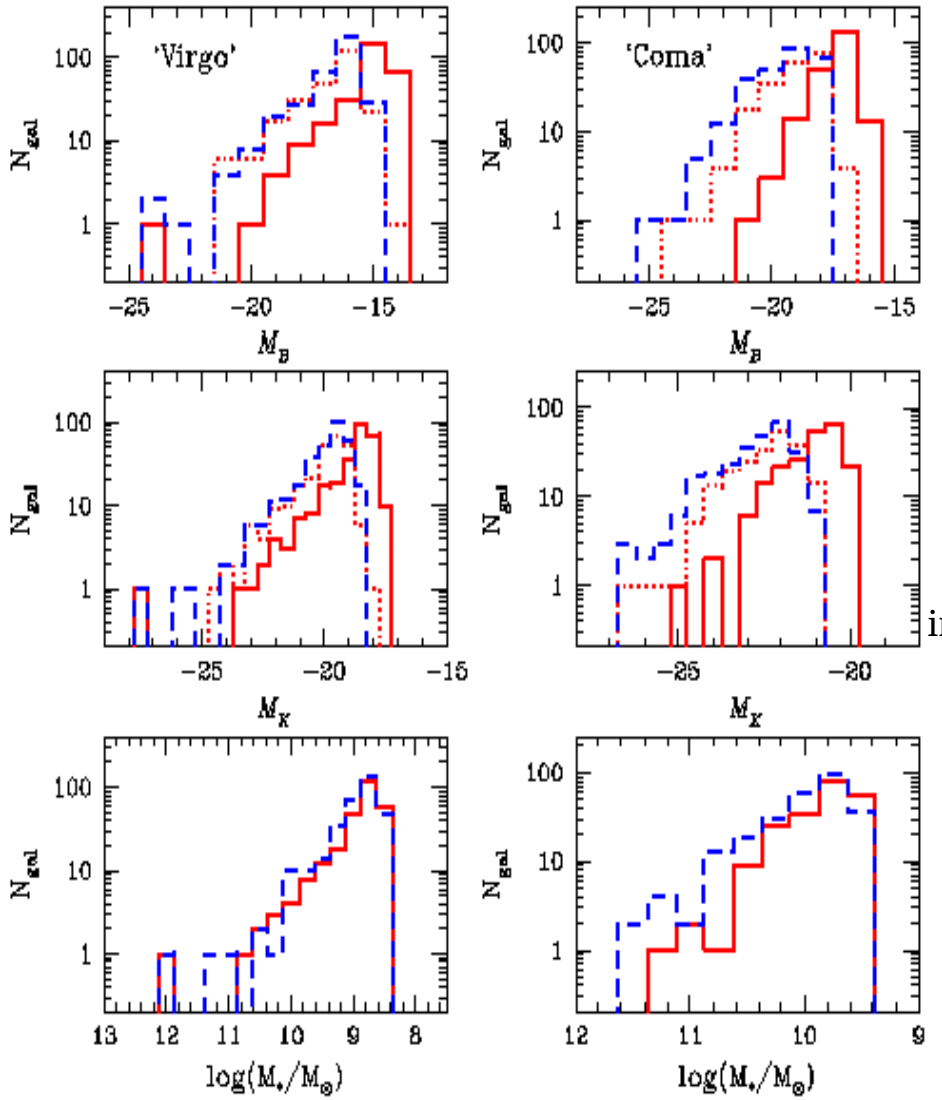
A way to reconciliation...

- Quenching of star formation due to lack of cold gas, especially in cluster cores

- Evolution of stellar populations in galaxies is mostly passive (age reddening) at least since z ~1, except from merging on to the BCG

- merging plays a role in the very late epochs through **“dry mergings”** which do not produce major features on the RS. The only regions significantly interested are the external BGC envelopes, where merging are mainly involving dwarfs. These latter might be also just destroyed participating to the ICM enrichment (metals and ICL).

Constraints from LF evolution



LF in B & K

MF

z=0 z=1

cfr. expected *z*=1 LF if pure p.e. applied back to *z*=0

passive (L) vs. dynamic (M)

Monolithic Hierarchical

Bright-end gal. merged onto CD

CONCLUSIONS

- **SSFR** (more than Z or age) drives the RS evolution within the CM plane
- **DS** is the asymptotic, universal locus of “final rest” of galaxies once inactive
- Transition epoch at $z \approx 1$ from active to passive regimes $\Leftrightarrow$ slope’s change
- It does exist an environmental sequence in building the RS:
  - Cluster cores complete the RS first
  - Normal groups: s.f. activity lasts longer
  - FG: more quiescent, earlier assembled: “fossilness” (gap) widens at $z \sim 0.7$