THE RED SEQUENCE OF HIGH-RESHIFT CLUSTERS
A COMPARISON WITH GALAXY FORMATION MODELS

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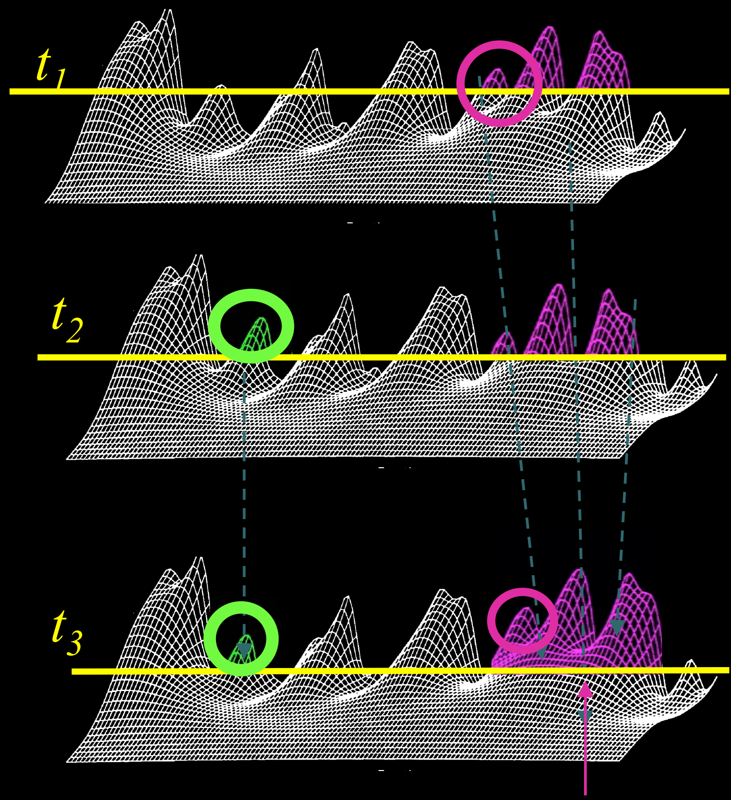
Motivations: testing basic Hierarchical Clustering expectations for the color properties of galaxies as a function of environment

- Clusters are the last structures to collapse and virialize:
- Earlier star formation due to
  - biased galaxy formation
  - starbursts from merging + fly-by
  + quenching in massive glxs due to AGN feedback
- Accelerated assembly of massive galaxies in dense environment due to higher merging rate

Galaxies in Clusters constitute a testing ground for the balance between star formation histories, galaxy assembly, and galaxy inclusion into larger halos

High–redhsift (z ≈ 1.2) rich clusters constitute the most biased environments We expect them to provide the most strigent constrains on such a balance



Galaxies residing in massive halos originate from the clumps collapsed in biased, high-density regions of the density field, hence at higher redshift compared to ''isolated'' galaxies

Testing the BH growth model

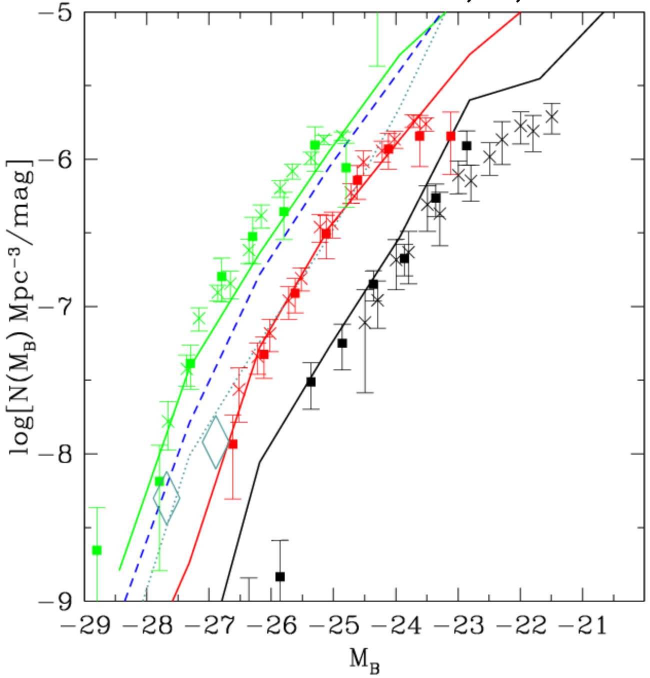
DETAILED PREDICTIONS BASED ON SEMI-ANALYTIC MODEL
(NM et al. 2004, 2005, 2006)

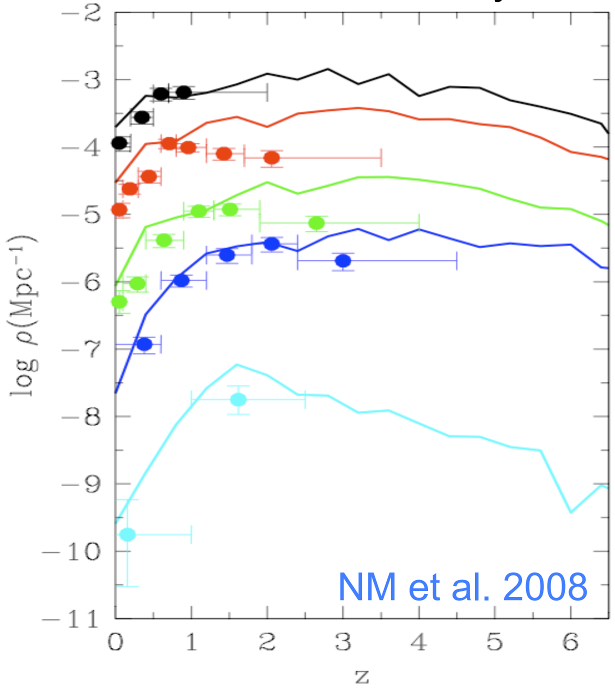
- DM merging trees: Monte Carlo realizations
- Dynamical Processes involving galaxies within DM haloes
- Cooling, Disc Properties, Star formation and SNae feedback
- Star bursts triggered by (major+minor) merging and fly-by events
- Growth of SMBH from BH merging + accretion of galactic gas destabilized by galaxy encounters (merging and fly-by events)
  - Rate of encounters
  - Fraction of galactic gas accreted by the BH
  - Duty cicle

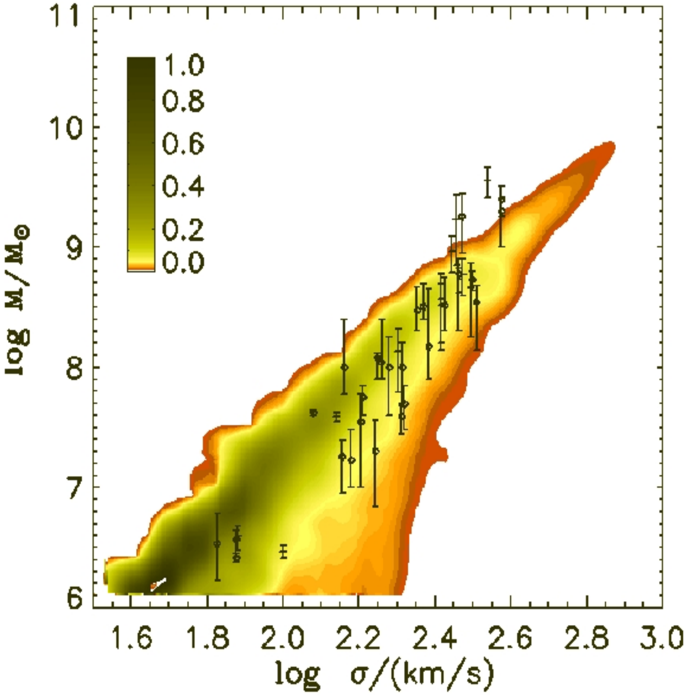
Physical, non parametric Model.
Computed from galactic and orbital quantities

- Feedback from AGNs associated to the active, accretion phase.
  Blast wave model for energy transport in the ISM

Testing the BH growth model







- Growth of SMBH from BH merging + accretion of galactic gas destabilized by galaxy encounters (merging and fly-by events)

Rate of encounters

Fraction of galactic gas accreted by the BH

Duty cicle

Physical, non parametric Model.
Computed from galactic and orbital quantities

$$\dot{m}_{accr} = \left\langle \frac{f_{accr} m_{cold}}{\tau_r} \right\rangle$$

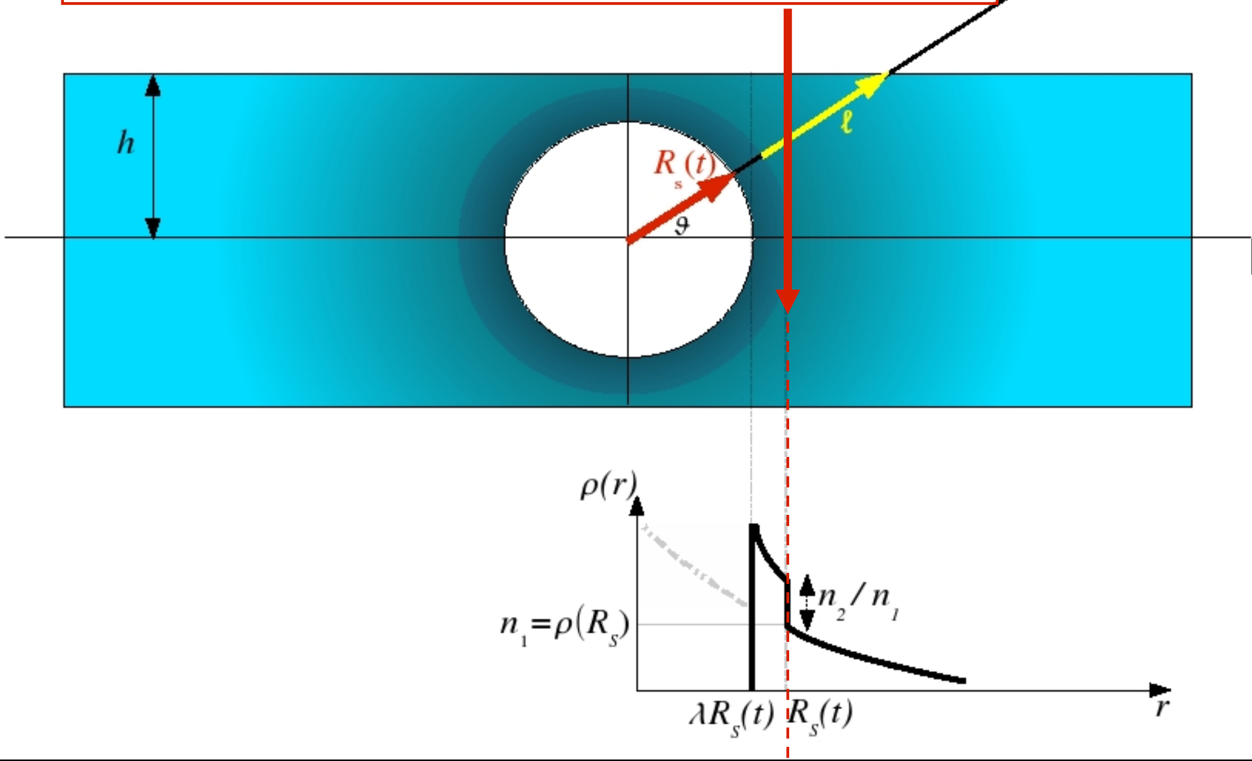
Fraction of cold galactic gas destabilized by encounters and funnelled to the BH

$$f_{accr} \approx 0.1 \left\langle \frac{m' \, r_d \, v_d}{m \, b \, V} \right\rangle$$

The AGN feedback model: a QUASAR MODE

AGN feedback corresponds to the expulsion of galactic gas due to an expanding blast wave, promptly following the start of the AGN active phase. The expansion of the shock radius $R_s(t)$ and the width of the shocked shell are computed analytically for given AGN energy ΔE (Lapi et al. 2005).

$$R_s(t) = v_d t_d \left[\frac{5\pi\omega^2}{24(\omega-1)}\right]\left[1+\frac{\Delta E}{E}\right]^{1/\omega}\left[\frac{t}{t_d}\right]^{2/\omega}$$



$\Delta E/E$ energy injected by AGN relative to thermal energy in ISM

Mainly effective at high z

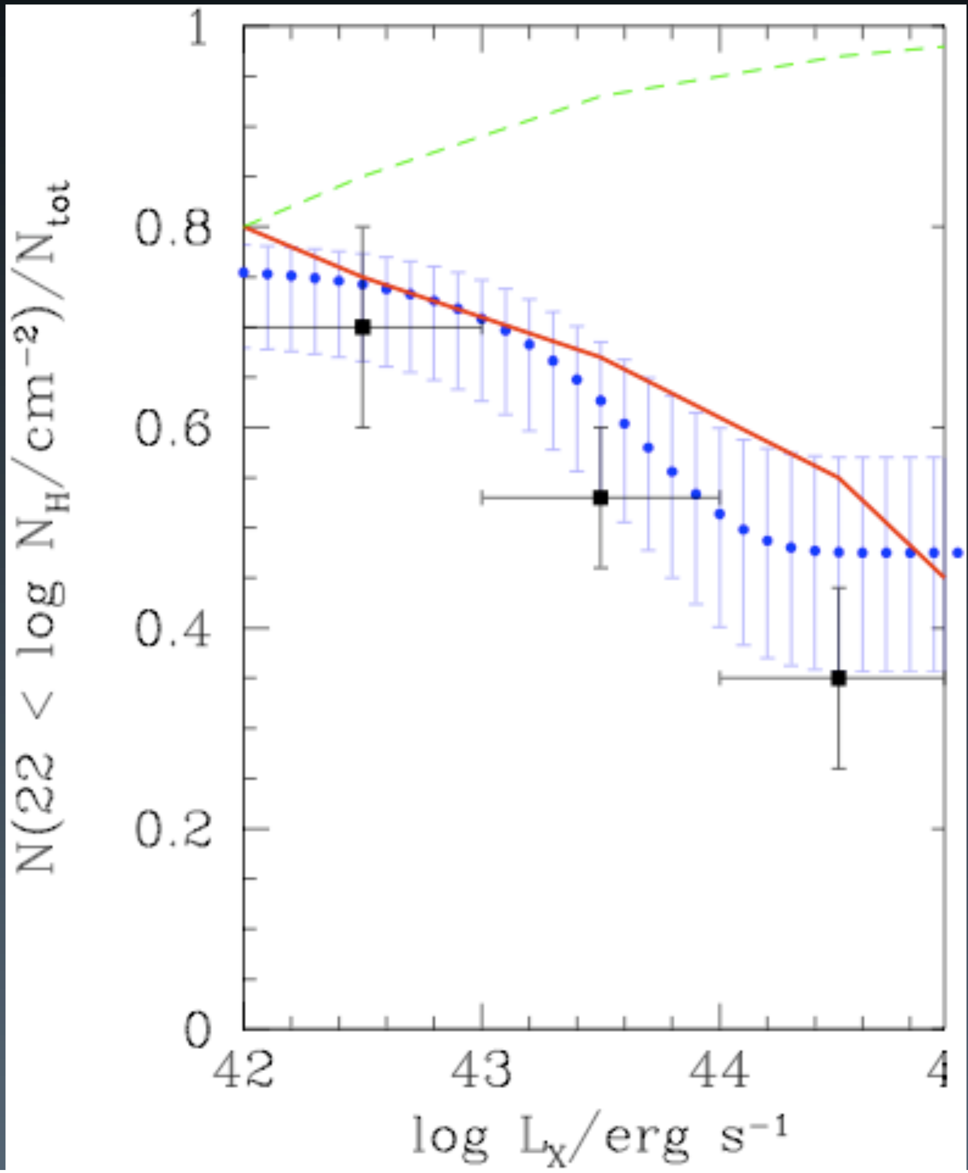
Mass expulsion faster and larger for luminous AGNs

- Feedback from AGNs associated to the active, accretion phase.

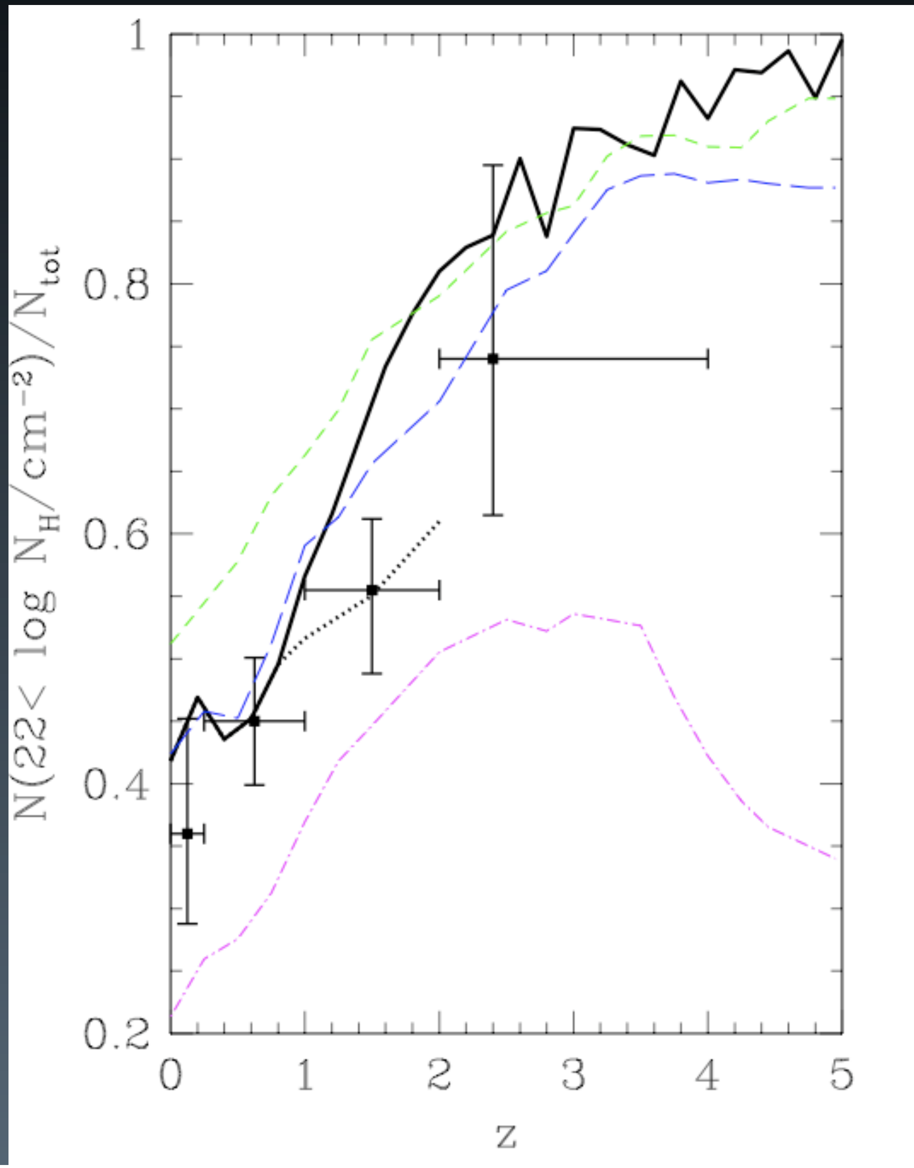
  Blast wave model for energy transport in the ISM

Testing the AGN feedback model: the absorption properties

Obscured Fraction as a function of X-ray Luminosity at z<1



Obscured Fraction as a function redshift



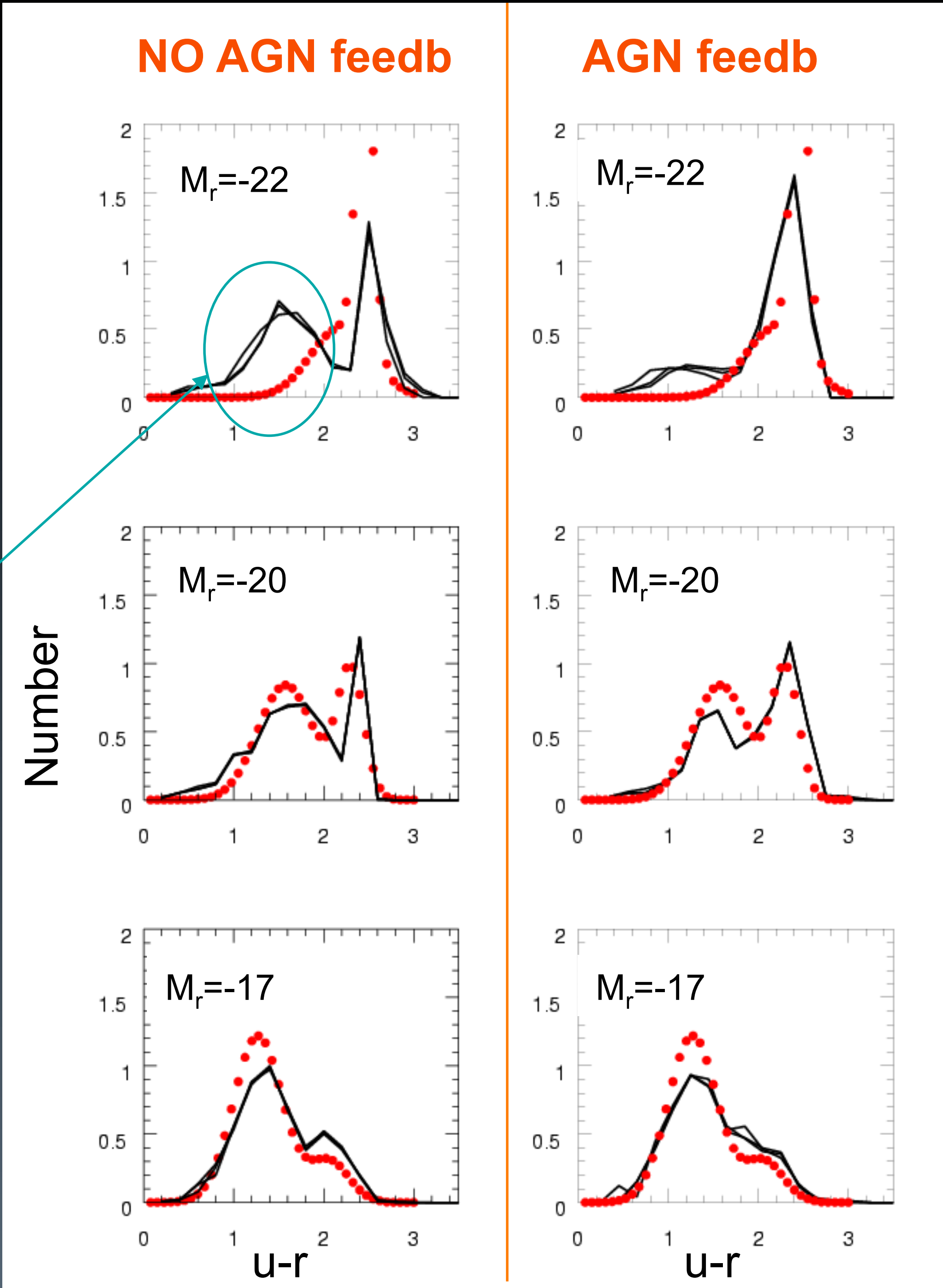
The Local Color Distribution: the effect of the AGN feedback

The u-r color distribution of galaxies for different R magnitudes in field and clusters

1) Massive galaxies redder than low-mass objects

2) In the absence of AGN feedback a sizeble fraction of large-mass galaxies has blue colors

NM06; data from Baldry et al. 04



The Color Distribution: The effect of environment on the Red/Blue Fraction

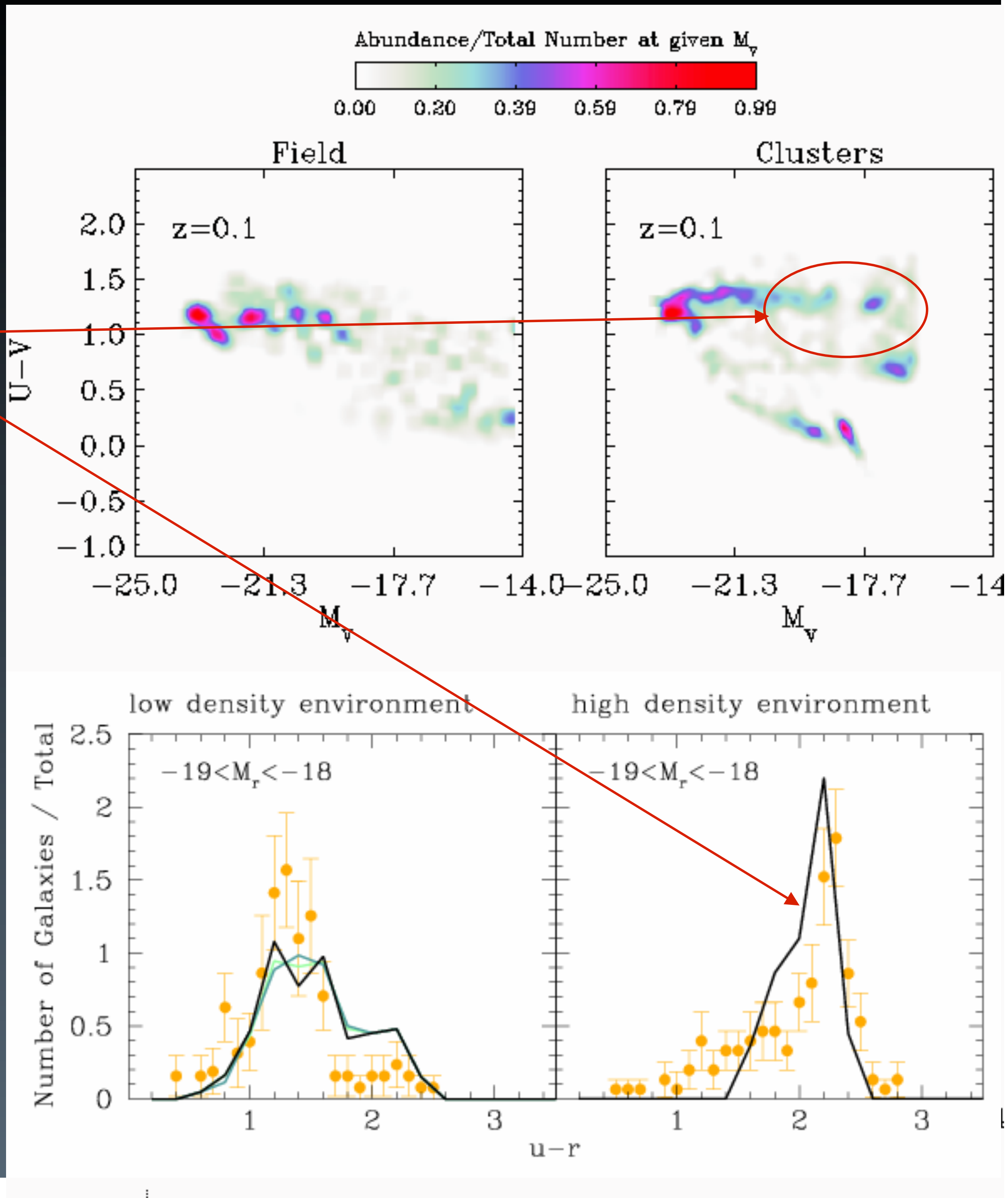
The CM diagram of field vs, cluster galaxies

Larger fraction of red objects in cluster galaxies

Mainly contributed by low-mass objects with $M_r \geq -19$

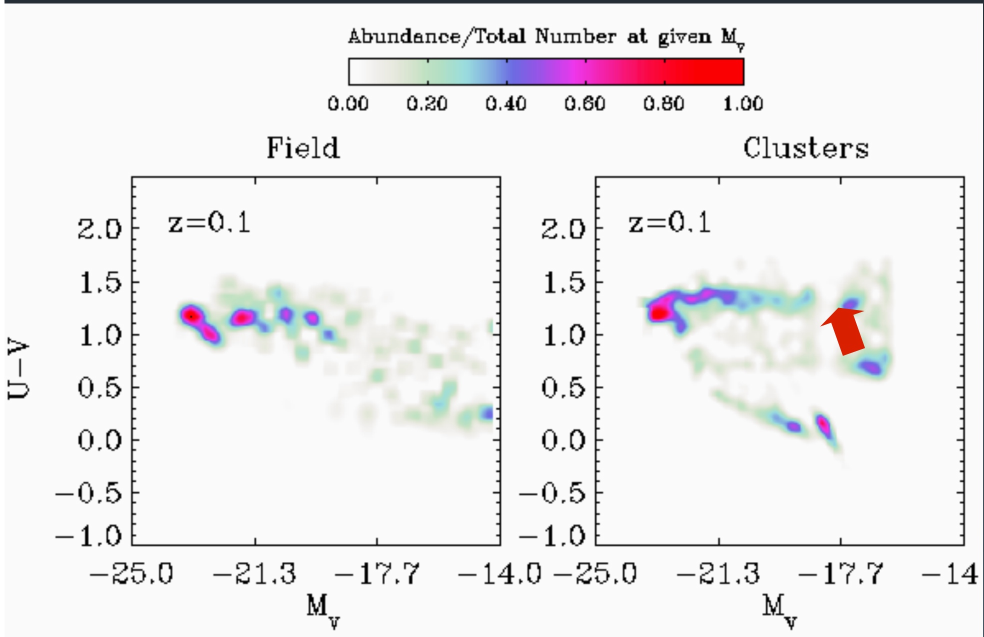
Clusers defined as halos with $M \geq 5\ 10^{14}\ M_{\odot}$

Dots: SDSS data from Baldry et al. (04)

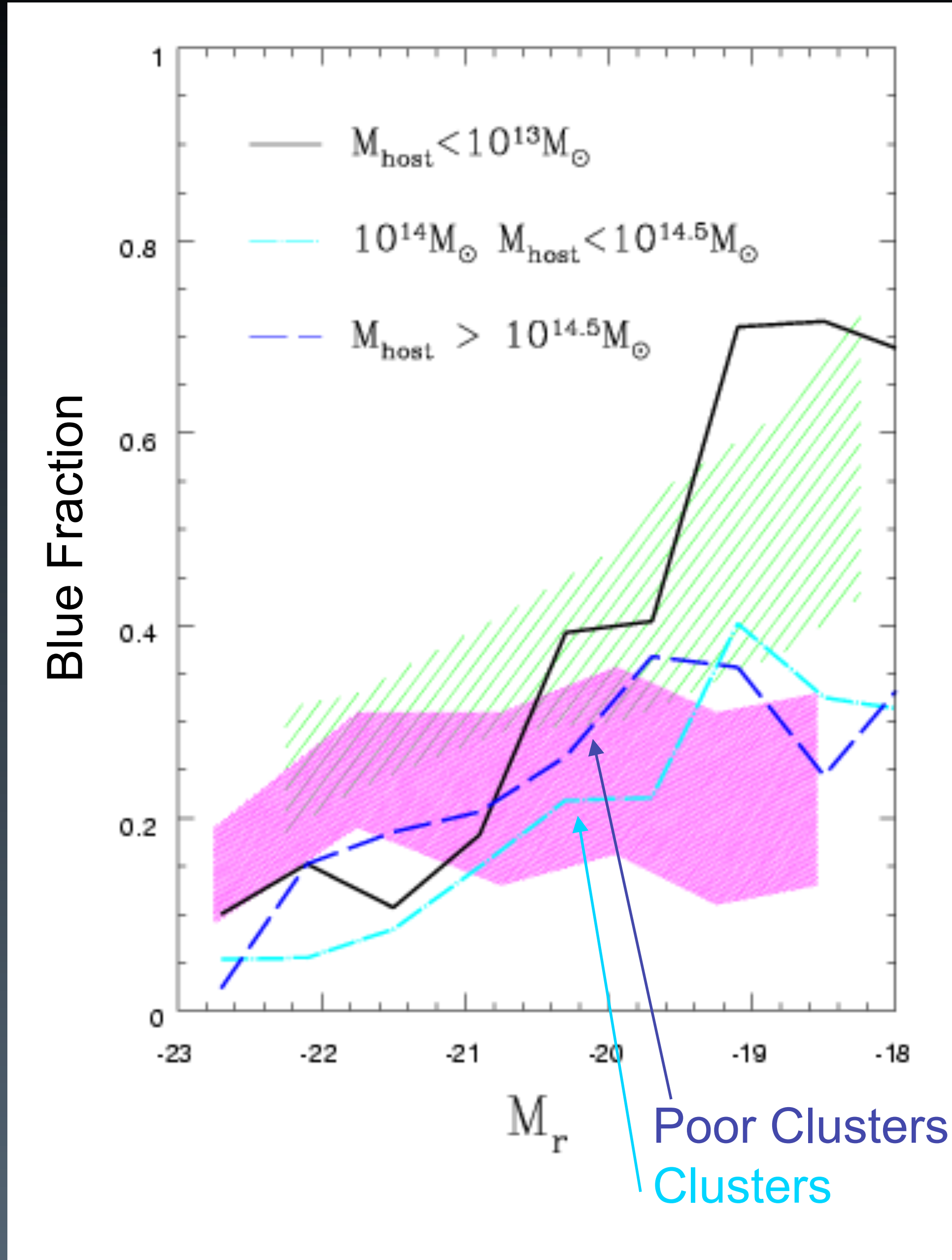


The color distribution: the effect of the environment on the fraction of red/blue galaxies

The environment speeds up the <u>transition</u> of <u>low-mass galaxies</u> to the <u>passive</u> state (they formed on top of high-density biased regions of the DM Density fied)

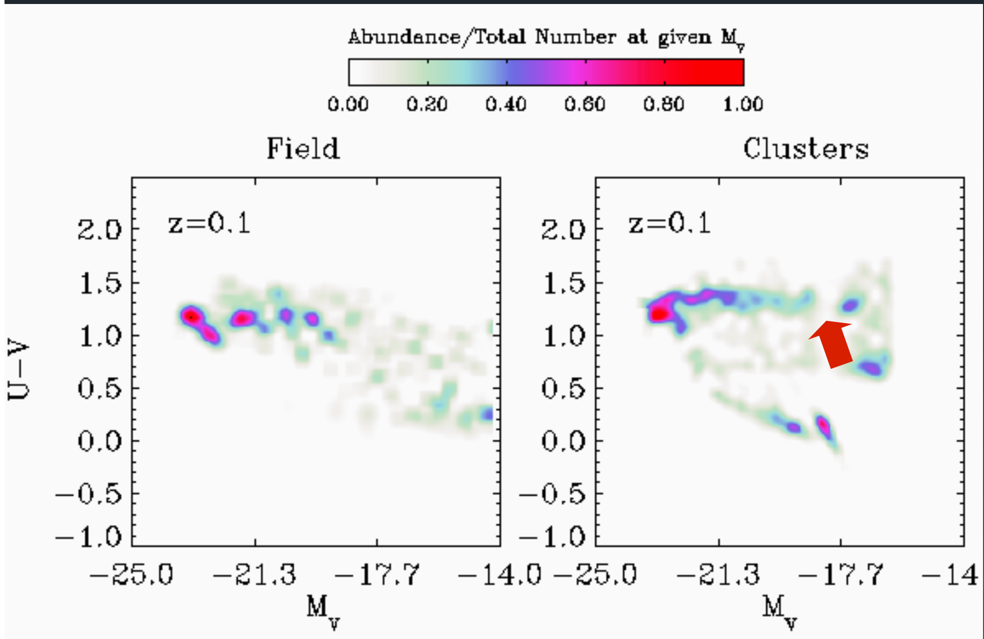


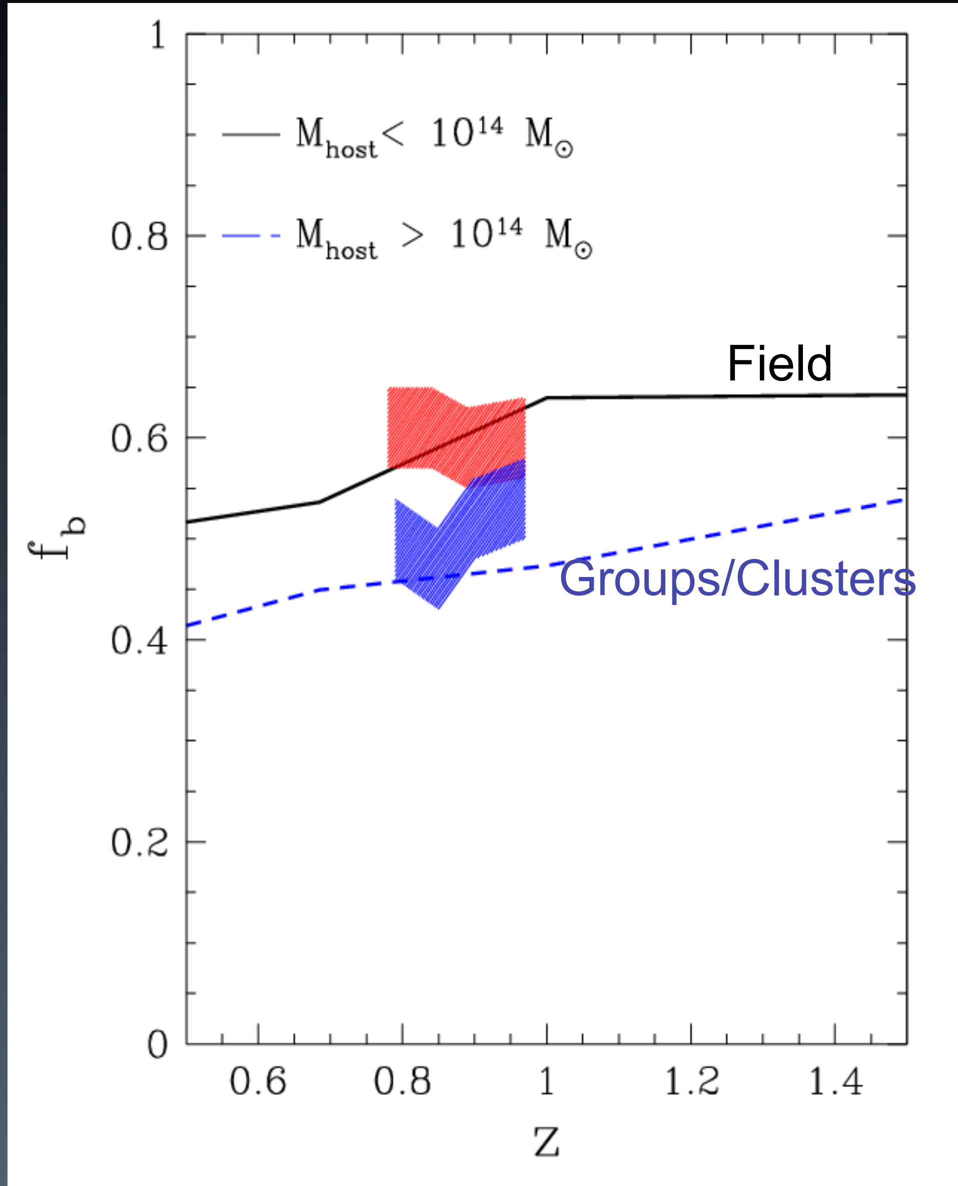
Shaded areas: rendition of analysis of Weinmann et al. (06) on SDSS
Magenta:Groups/Clusters Green: Field



The color distribution: the effect of the environment on the fraction of red/blue galaxies

The environment speeds up the transition of low-mass galaxies to the passive state





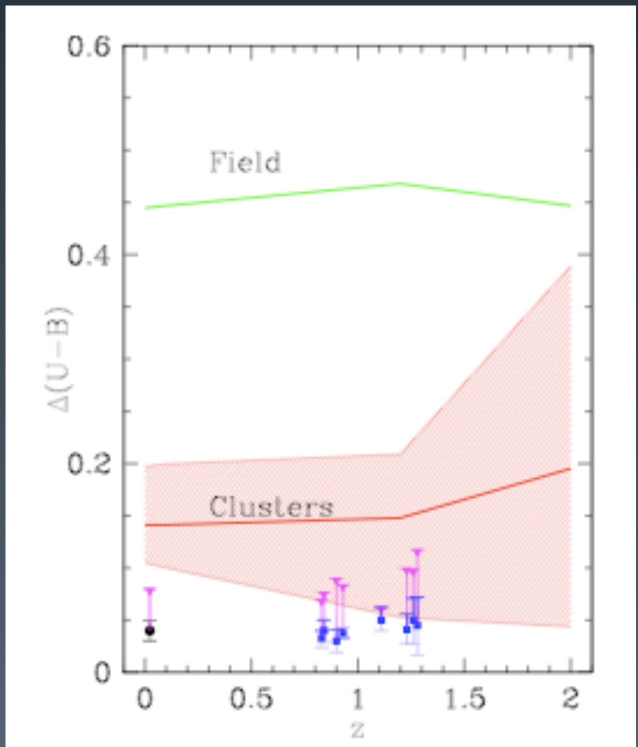
Shaded areas: DEEP2 data from Gerke et al.. (07)

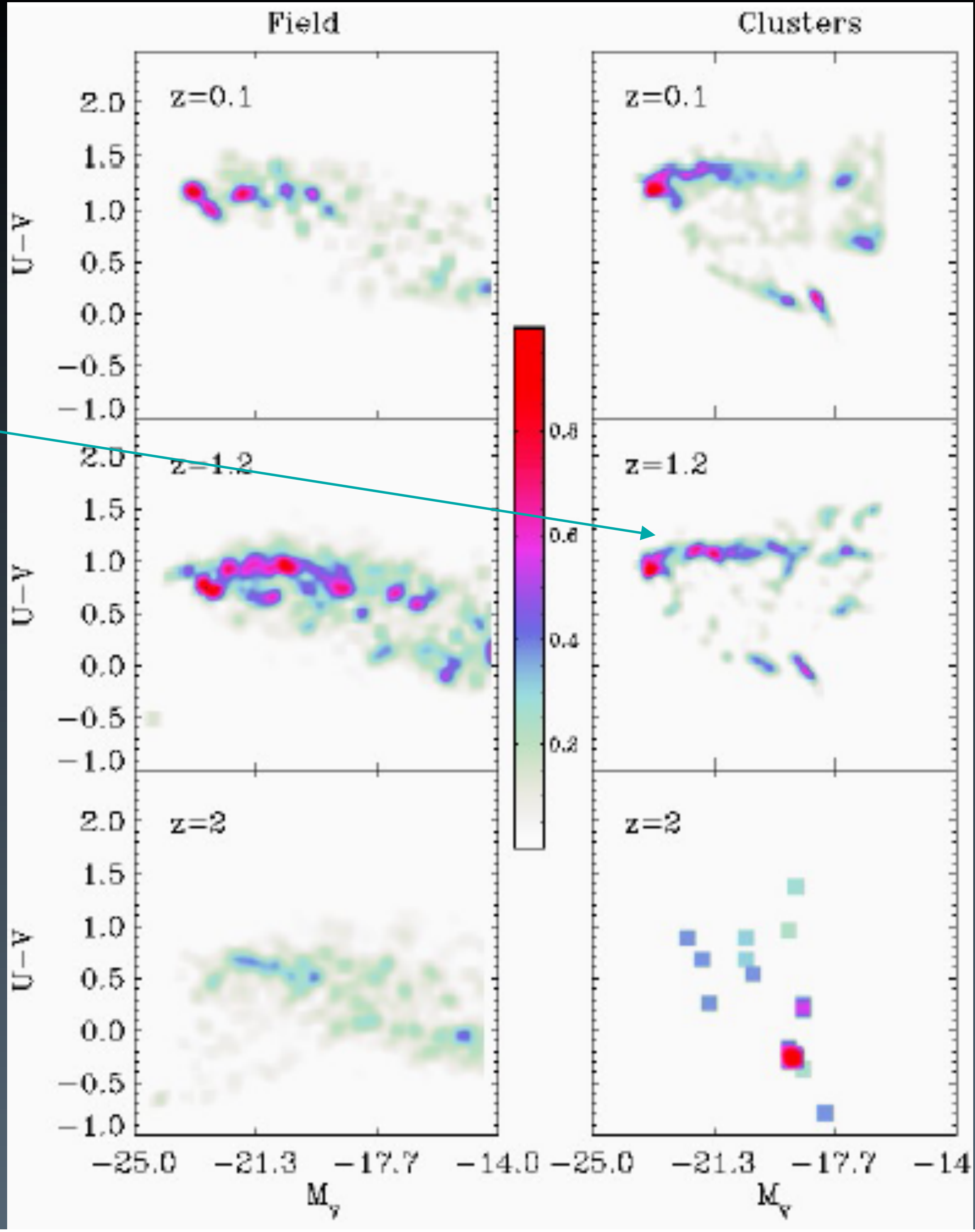
Red:Field Blue: Groups/Clusters

The color distribution : the properties of the Red Sequence

Focus on massive galaxies

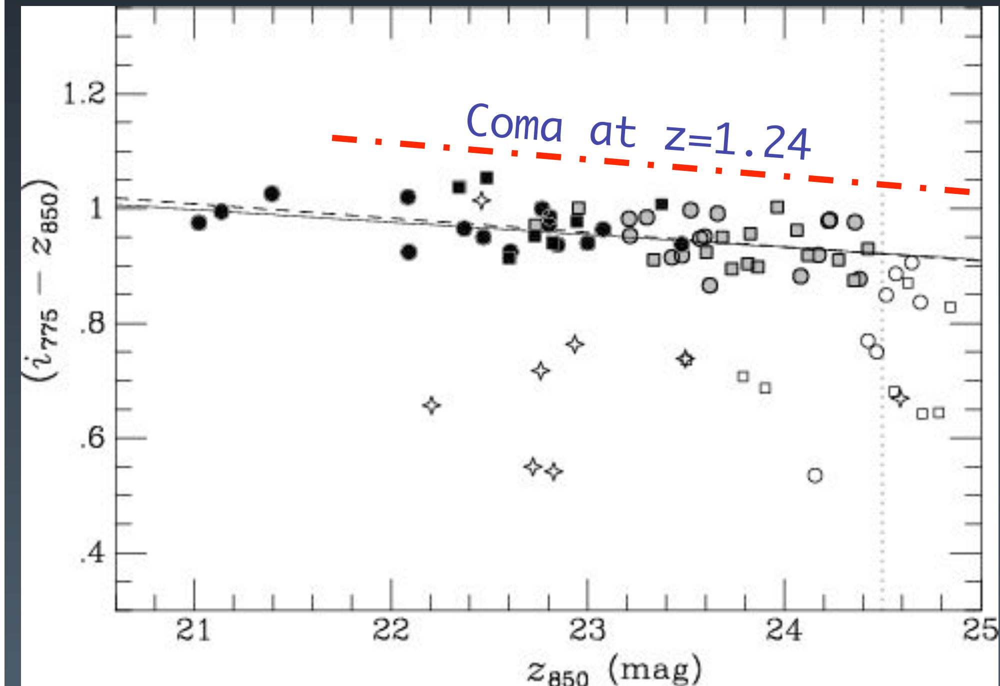
Well defined, tight red-sequence in cluster already in place by z=1.5



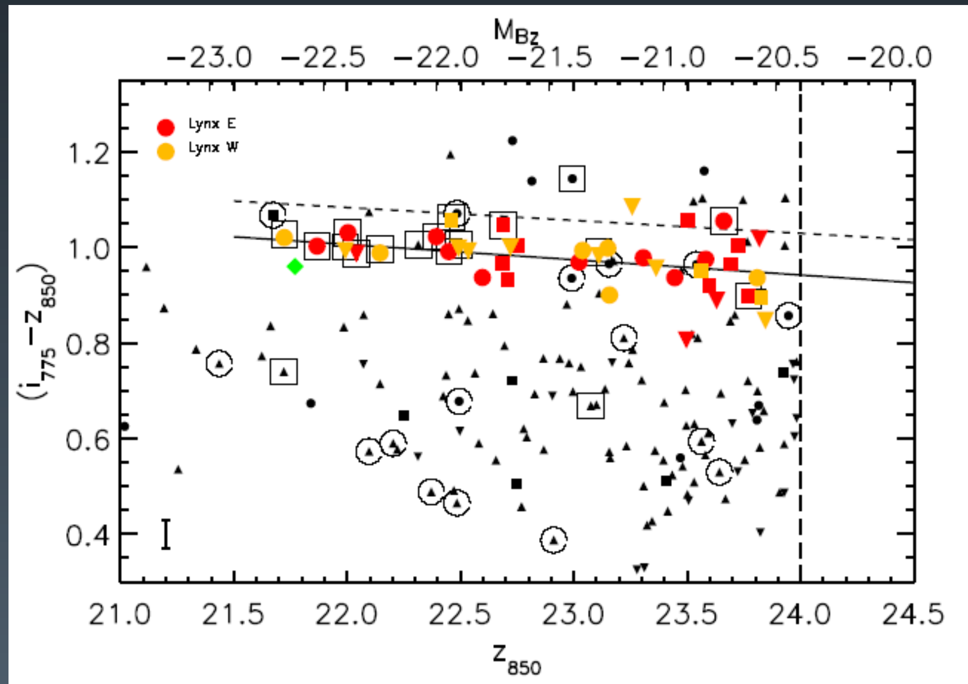


Observations show that the RS of high-redshift clusters is
a) already in place by z ~ 1.5
b) characterized by a tight dispersion (width δ ≤ 0.05 mag)

RDCS1252 (z = 1.24) C-M Relation with HST/ACS and VLT/ISAAC (Blakeslee et al. 03; Lidman et al. 03; Rosati et al . 04)



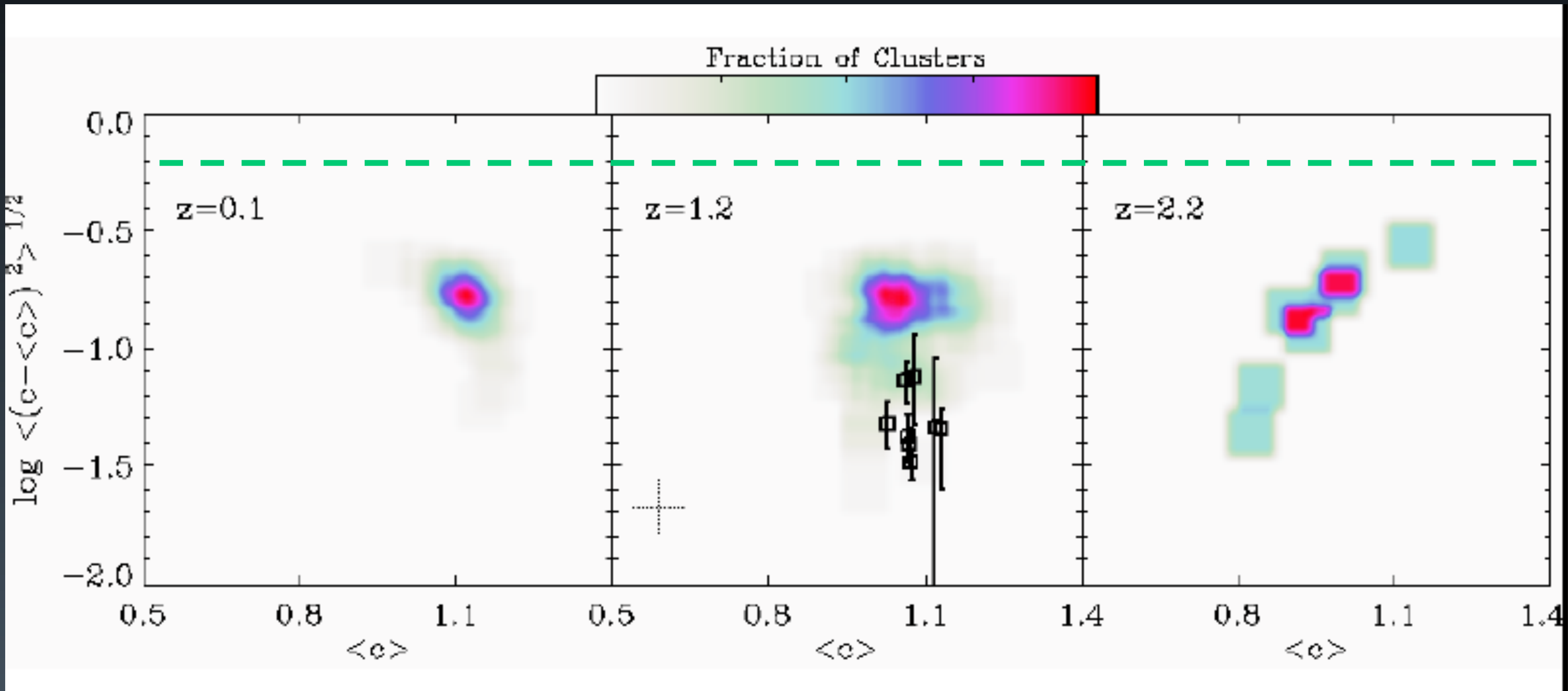
Mei et al. 2006: RX J0849+4452 and RX J0848+4453 in the Lynx SuperCl. (Lynx E, Lynx W); HST ACS + Keck



The Scatter and the Normalization of the RS: comparison with observations.

Large-Mass galaxies $M_* \geq 5 \, 10^{10} \, M_\odot$

Color Code: Fraction of model clusters with given RS scatter and normaliz.



Field

δ ≈ 0.4

δ ≈ 0.1

δ ≈ 0.05

Predicted colors for the RS agree with observations

Scatter of the RS: predicted δ ≈ 0.1. Much smaller (factor ~ 5) than the field value
observed δ ≈ 0.05.

THE CM RELATION for MASSIVE GALAXIES: $M_* \geq 5 10^{10} M_\odot$

The origin of the tightness of the RS

The star formation history

Massive galaxies in dense environment form much earlier than the ''field'' counterparts

The assembly history

The reduced scatter results from intrinsic lower variance in the assembly history of massive galaxies in highly biased, overdense regions

Probing the star formation history of stellar populations

The age of stellar populations for $M_* \geq 5\ 10^{10}$ M⊙ galaxies at z=1.2

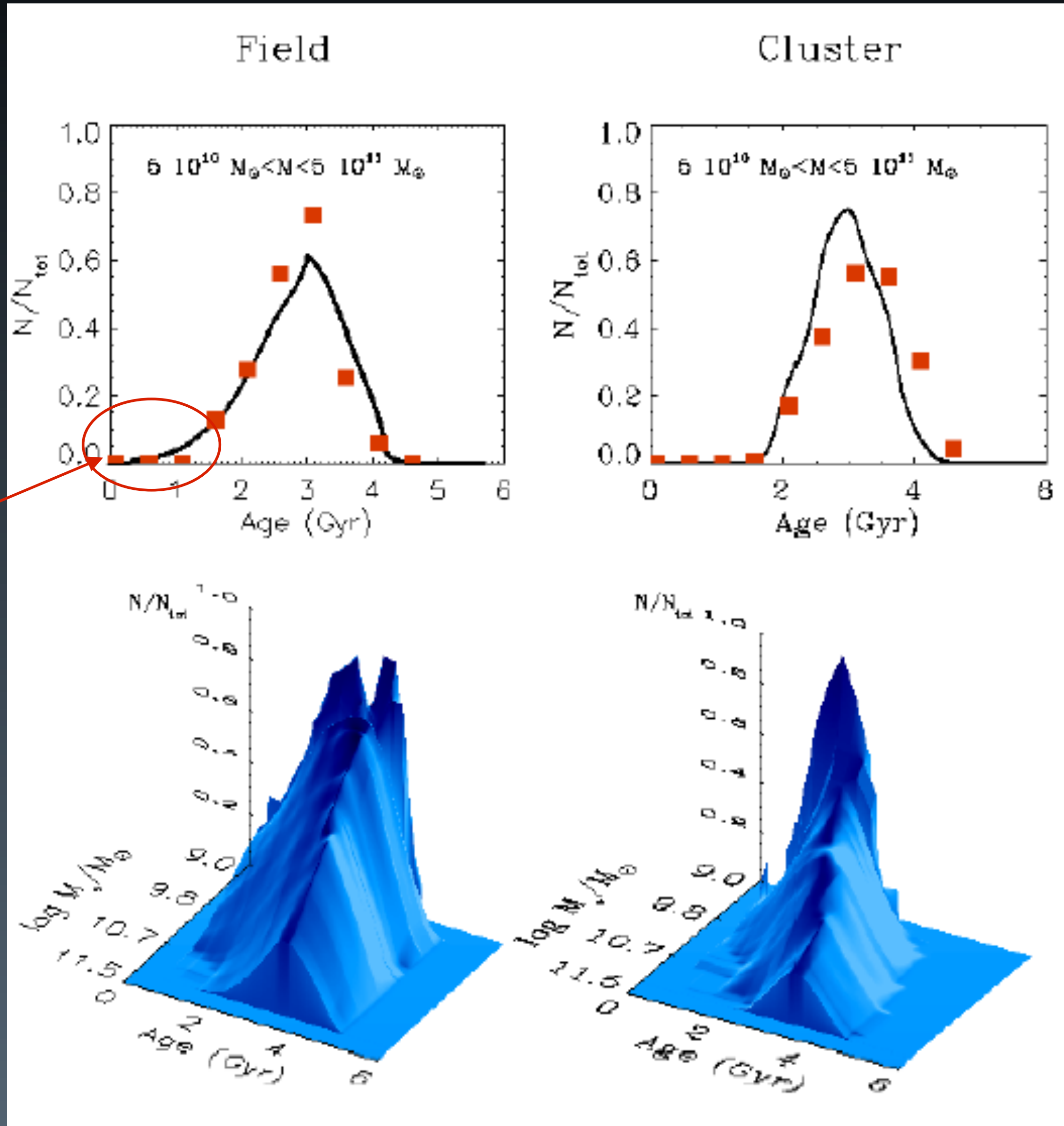
$$\tau(t) = \frac{\int_0^t (t - t')\, \dot{m}_*(t')\, dt'}{\int_0^t \dot{m}_*(t')\, dt'}$$

Average values $\tau \approx 3$ Gyr similar for clusters and field

However, for field galaxies the distribution is skewed toward younger ages

The tightness of the RS in clusters is not due to older average ages for cluster

Existence of an intrinsic lower spread in ages/st. form. histories of cluster galaxies

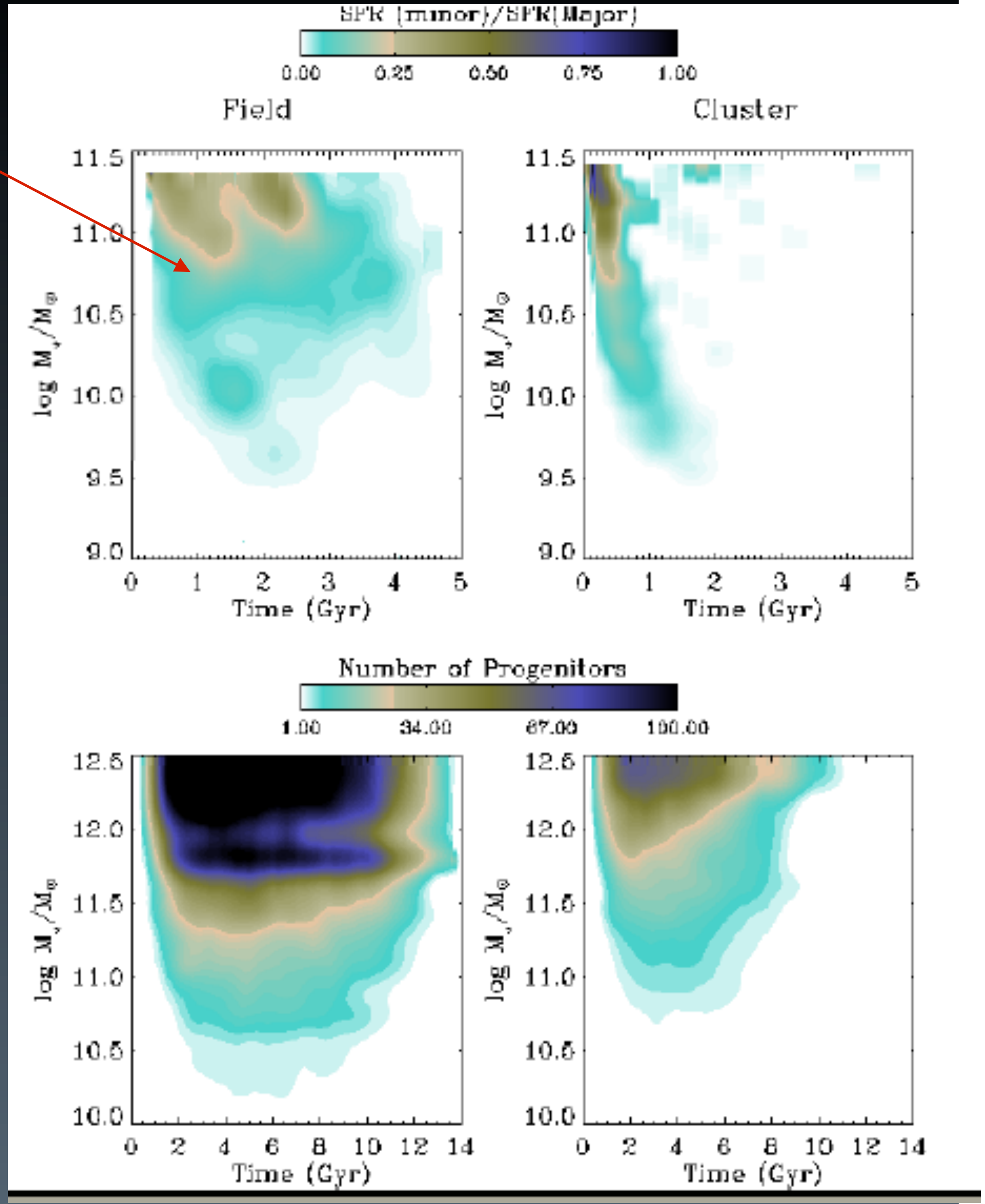


Probing the assembly history of galaxies

COLOR CODE

Star Formation in MINOR PROGENITORS

Star Formation in MAIN PROGENITOR



Cluster galaxies

Rapidly assembled into a unique, main progenitor.

Most of the star formation takes place In such a main progenitor

Field galaxies

The formation of stars is distributed among all progenitors; this increases the variance associated the different SF histories

CONCLUSIONS: Robust features of HC models vs observations:

Cluster galaxies assembled from clumps collapsed in biased, overdense regions

- the fraction of red galaxies increases in dense environment

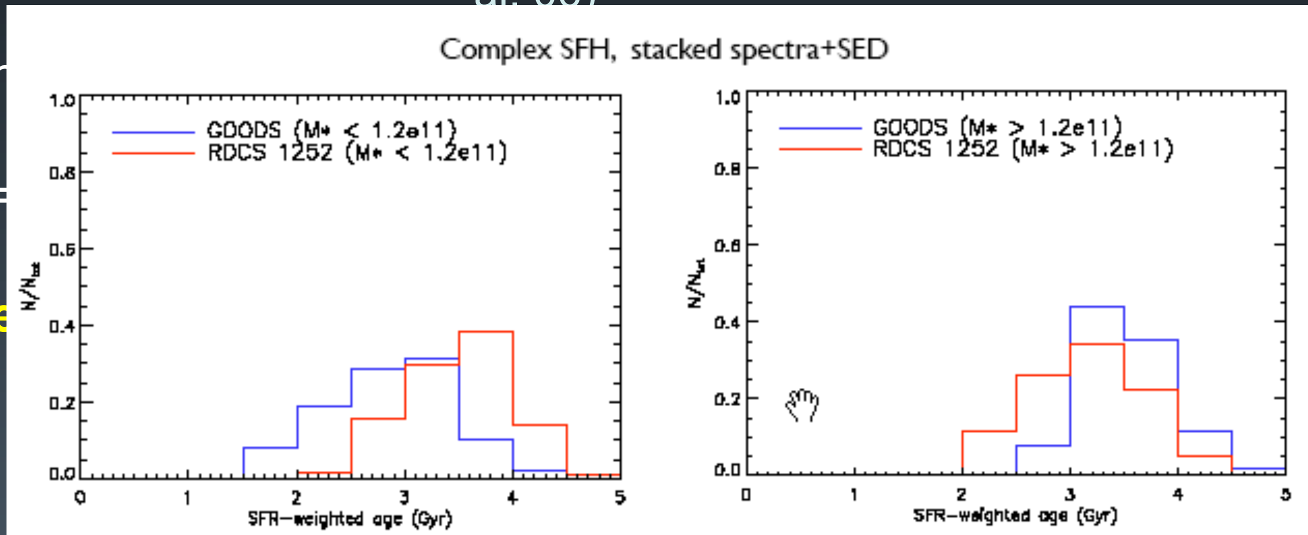
CF. density dependence of color distributions, see, e.g., Baldry et al. 04,

- mainly due to earlier transition to the red population of $M_* \leq 5\ 10^{10} M_\odot$ galaxies

CF observational results by Gobat et al.
Test for AGN feedback models (Weinmann et al. 06)

- For massive galaxies th
clusters is ~ 0.1, about
than in the field up to z=

Rapid assembly of cluste
a main progenitor where
takes place



- Average ages of stellar pop. of RS galaxies similar in clusters and field

Critical issue: current obs. results from extrapolation of past star form hist. from final colors. See also Rettura et al. 07

- scatter in the age of stellar population larger for field galaxies: distribution skewed to lower values

CF Gobat et al. 07, Rosati et al. 04

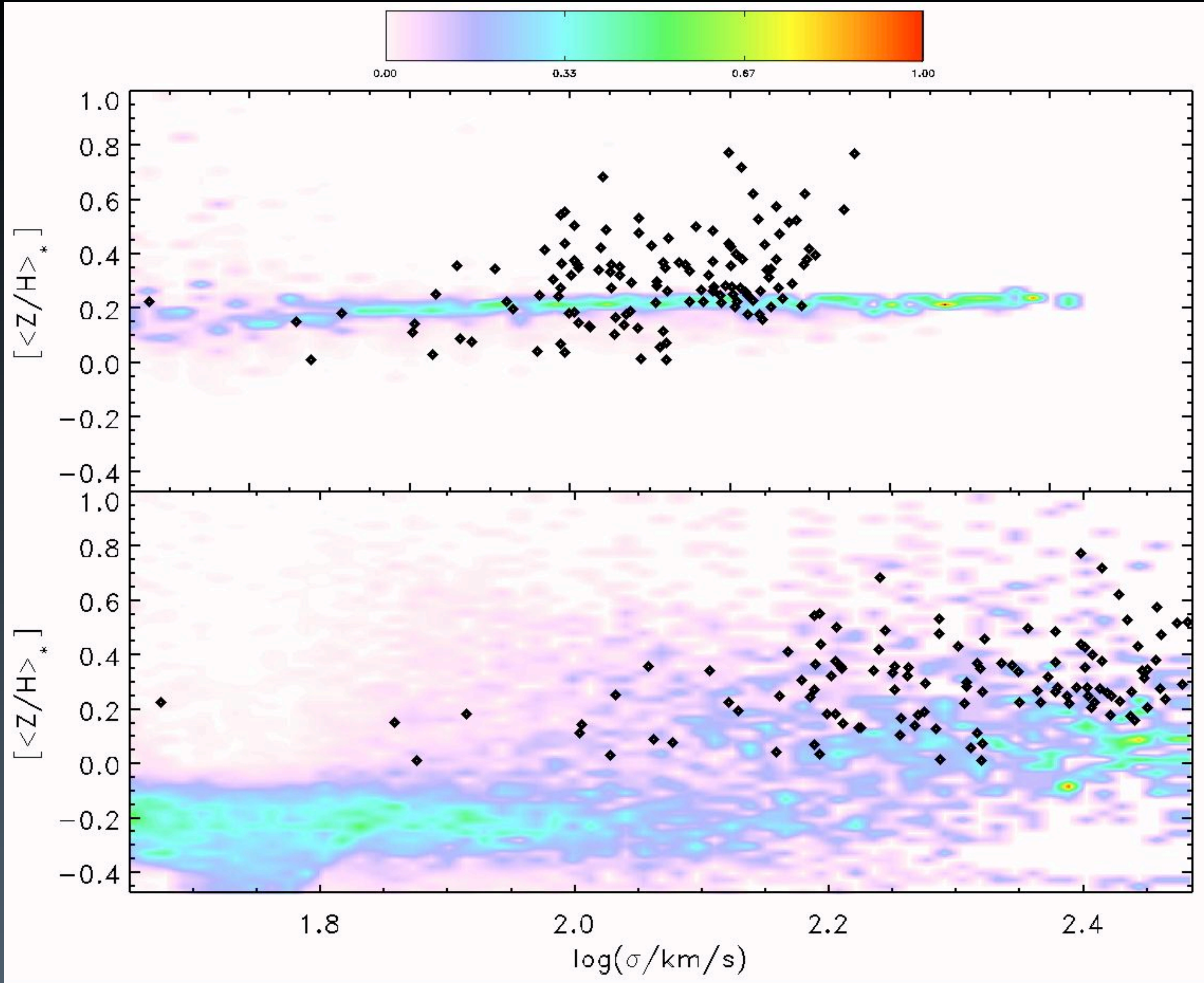
Old model Metallicity

Computed From galaxy past SFHs of stellar populations

New model Metallicity

Computed taking into account the Metal contribution from every single progenitor

Calura & NM 2009, in preparation



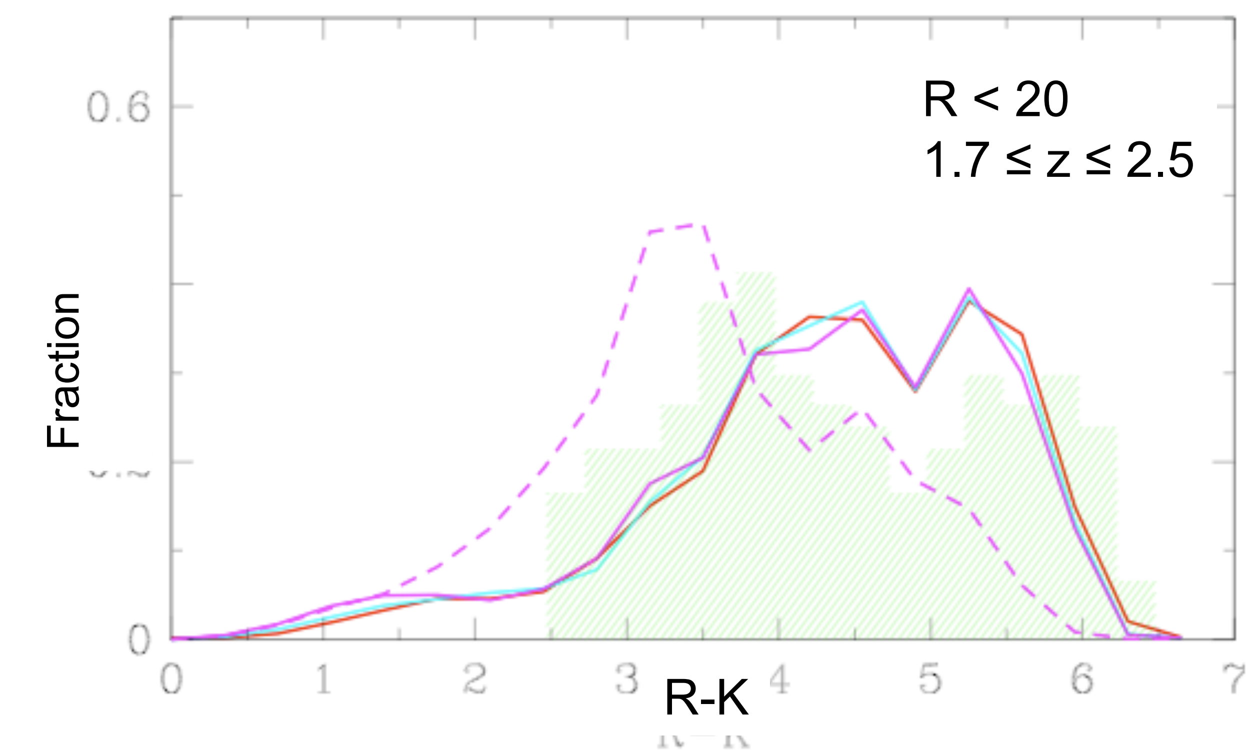
The Color Distribution at High z: the effect of the AGN feedback

The implemented AGN feedback is related to the QSO phase: particulary effective at high z≈2-3. Yield a fraction of EROs comparable to that observed

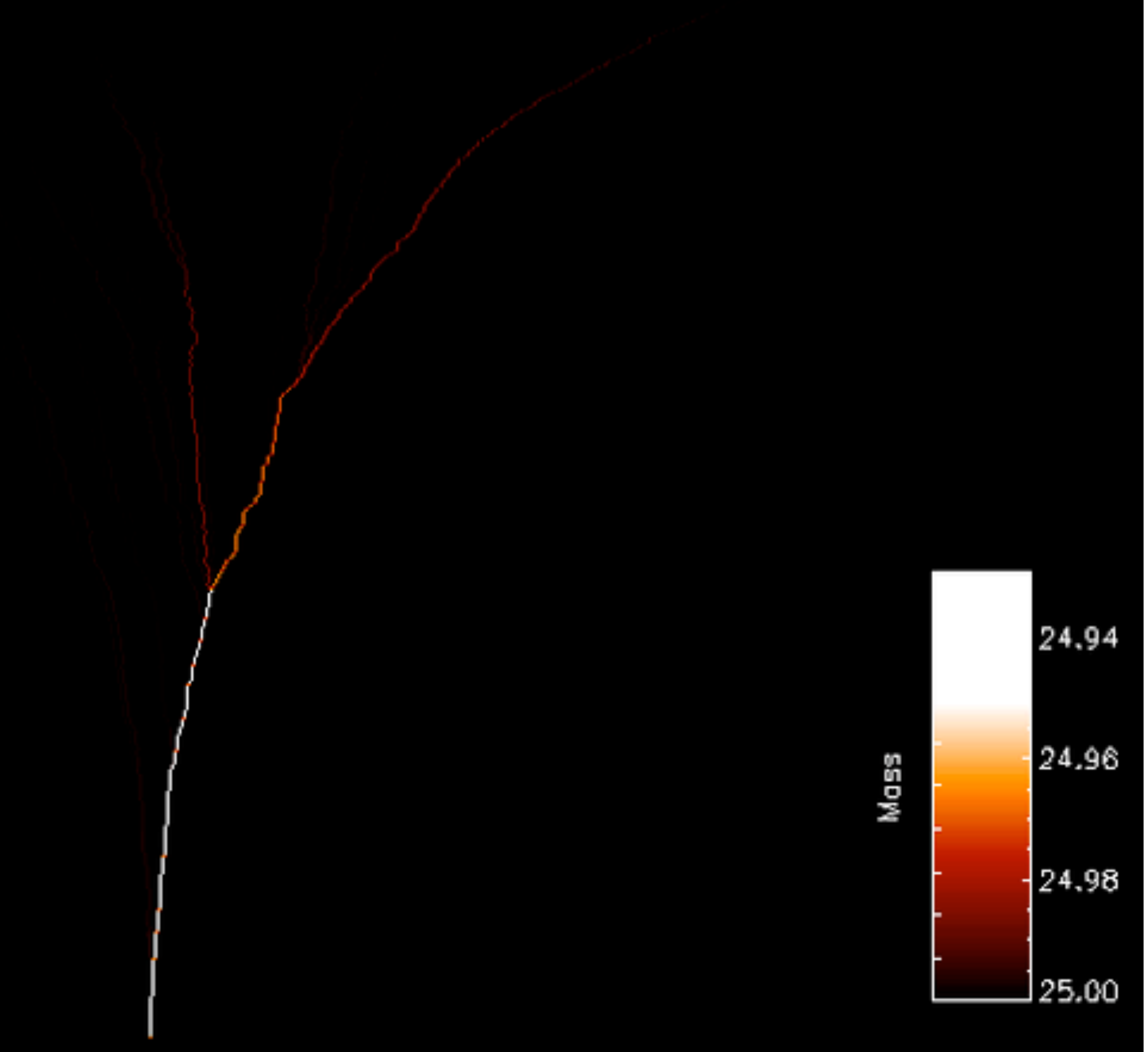
Fraction of EROs at $1.7 \leq z \leq 2.5$ underpredicted in models without AGN feedback (dashed line)

The fraction of preditcted EROs (R-K>5) is 0.31 when AGN feedback is included (solid lines)

NM06;
GOODS data (shaded region) taken from Somerville et al. 2004)

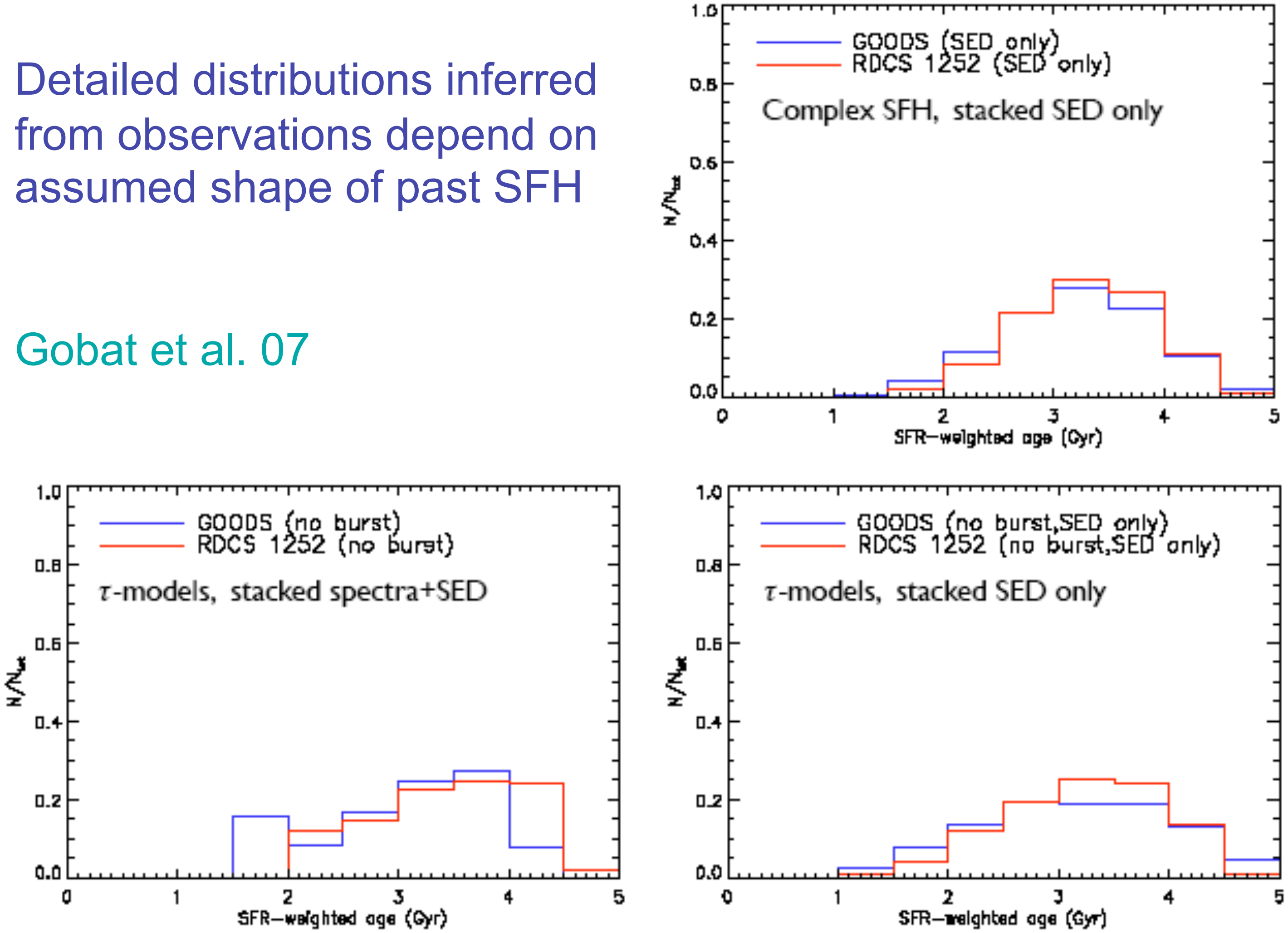


Probing the assembly history of galaxies



Detailed distributions inferred from observations depend on assumed shape of past SFH

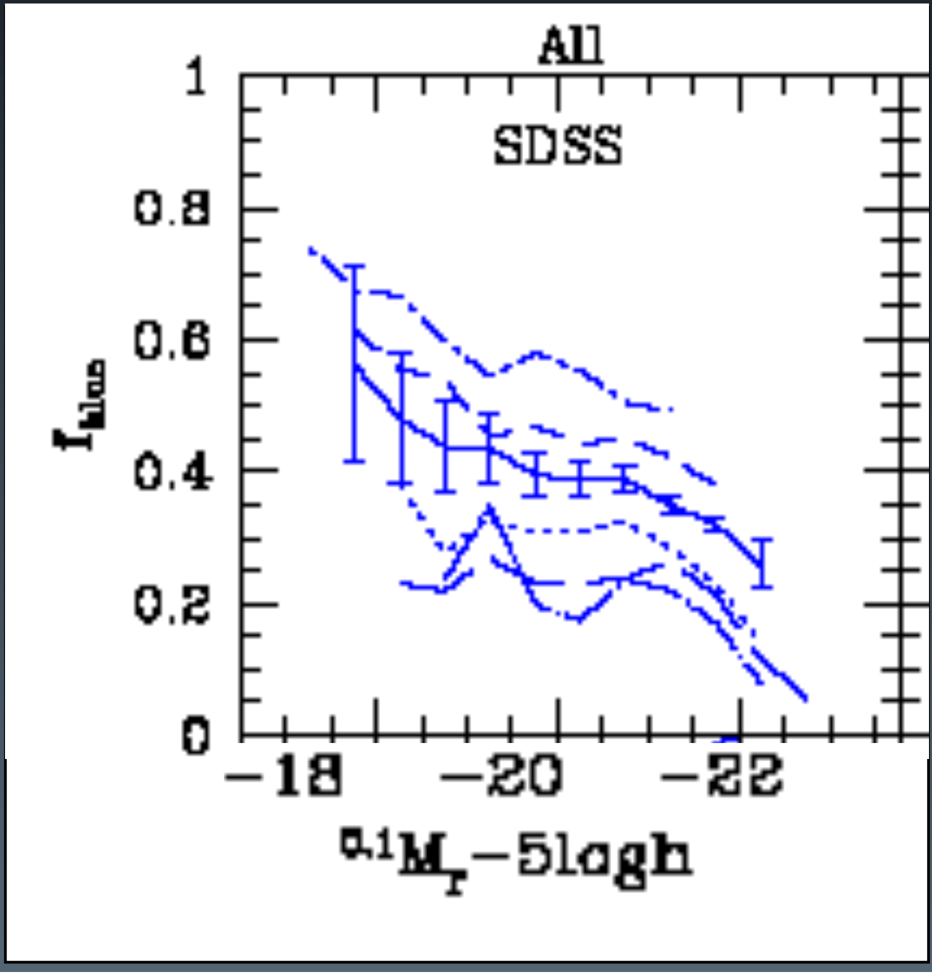
Gobat et al. 07



Weinmann et al. 06

Group finding algorithm:

1) Select candidate groups using friend-of-friend method
2) Estimate virial mass and virial radius assuming a M/L ratio
3) Estimate membership using the obtained virial radius
4) Iterate until convergence



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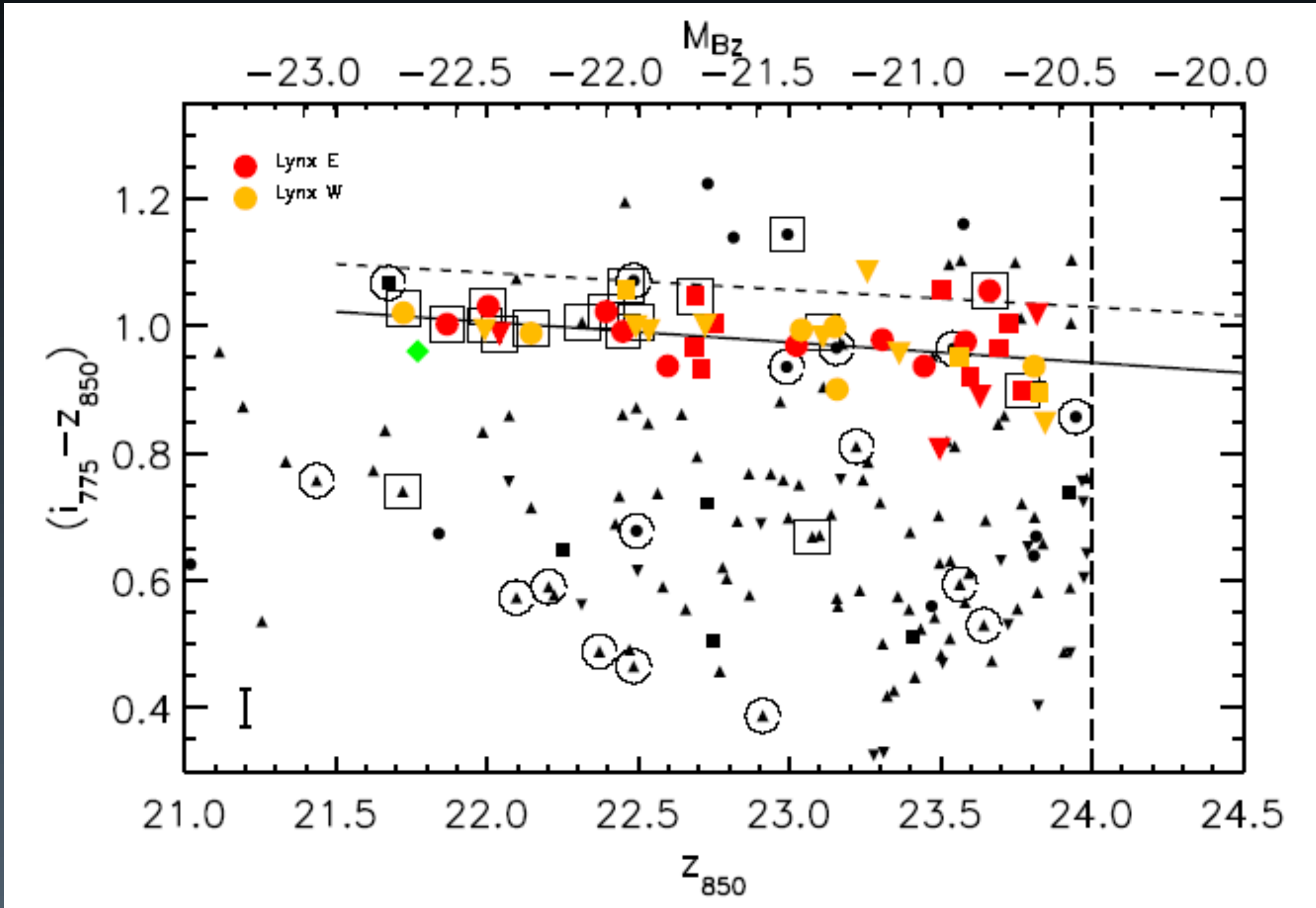
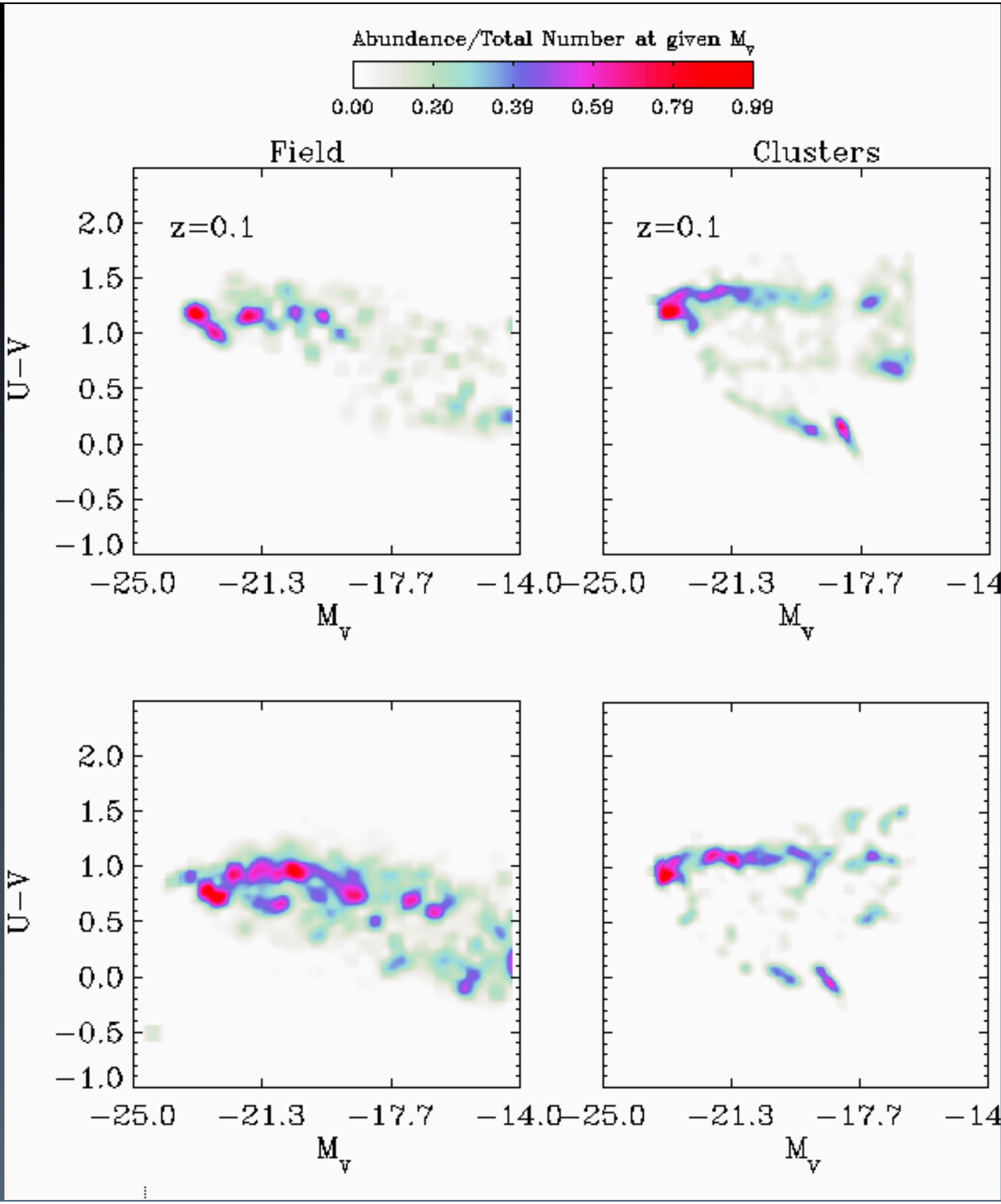
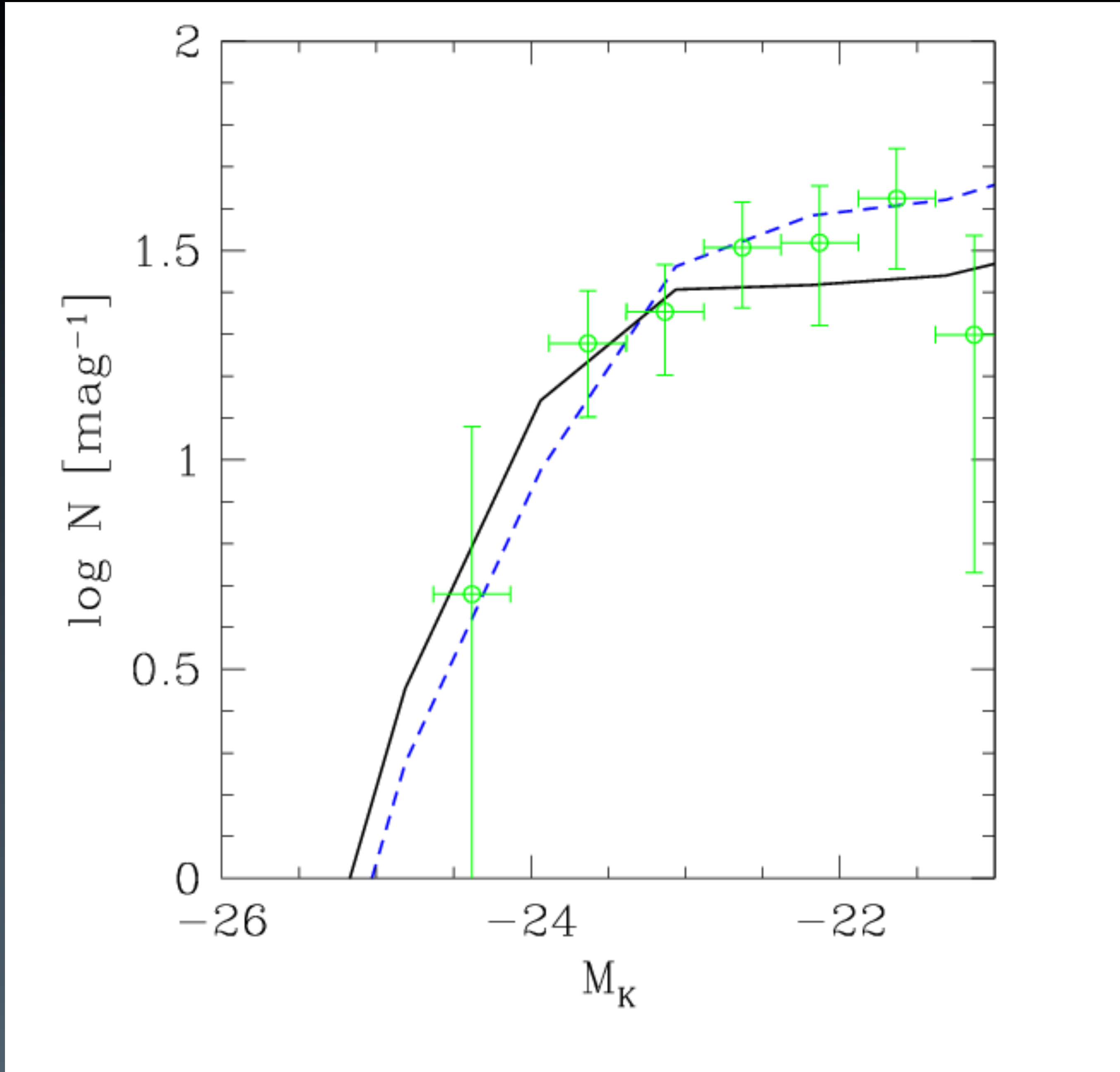
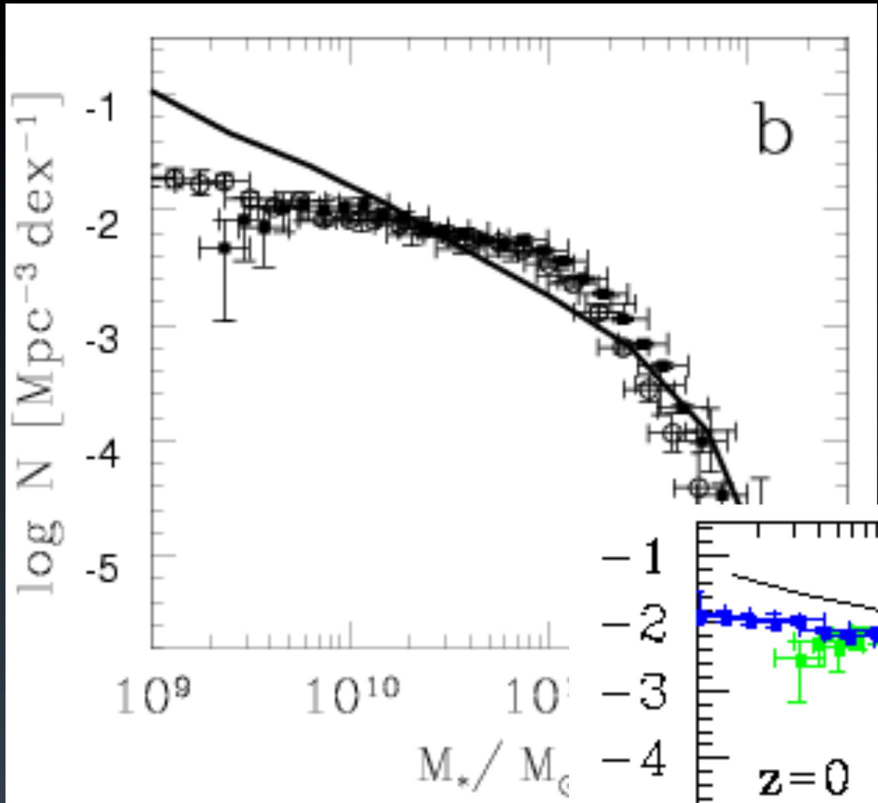


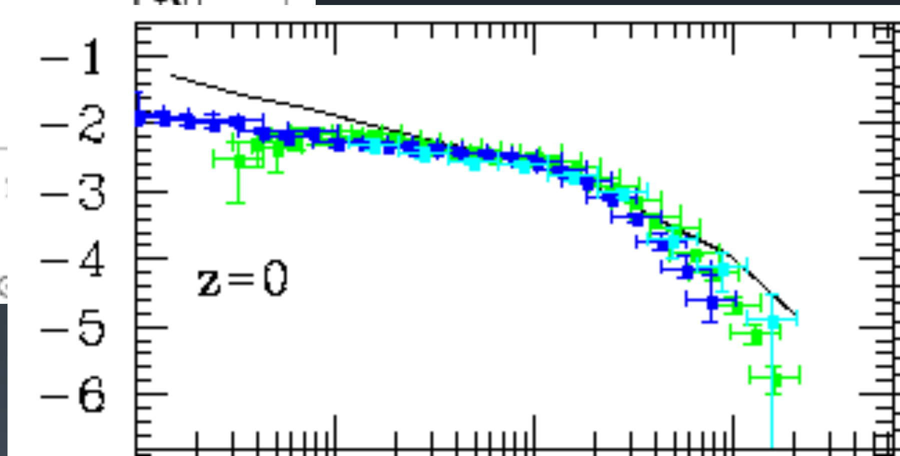


Abundance/Total Number at given M_V
0.00
0.20
0.39
0.59
0.79
0.99
Field
Clusters
z=0.1
z=0.1
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
U−V
−25.0
−21.3
−17.7
−14.0
−14
M_V



2
1.5
1
0.5
0
−26
−24
−22
log N [mag⁻¹]
M_K


b
log N [Mpc⁻³ dex⁻¹]
-1
-2
-3
-4
-5
10^9
10^{10}


−1
−2
−3
−4
−5
−6
z=0

color cut: SDSS g-r=0.7-..
DEEP2 U-B=1.2