RED SEQUENCE AND ENVIRONMENT: IMPLICATIONS FOR THE STAR FORMATION HISTORY IN PROTOCLUSTERS

Martínez, Coenda & Muriel
IATE-OAC
Córdoba, Argentina

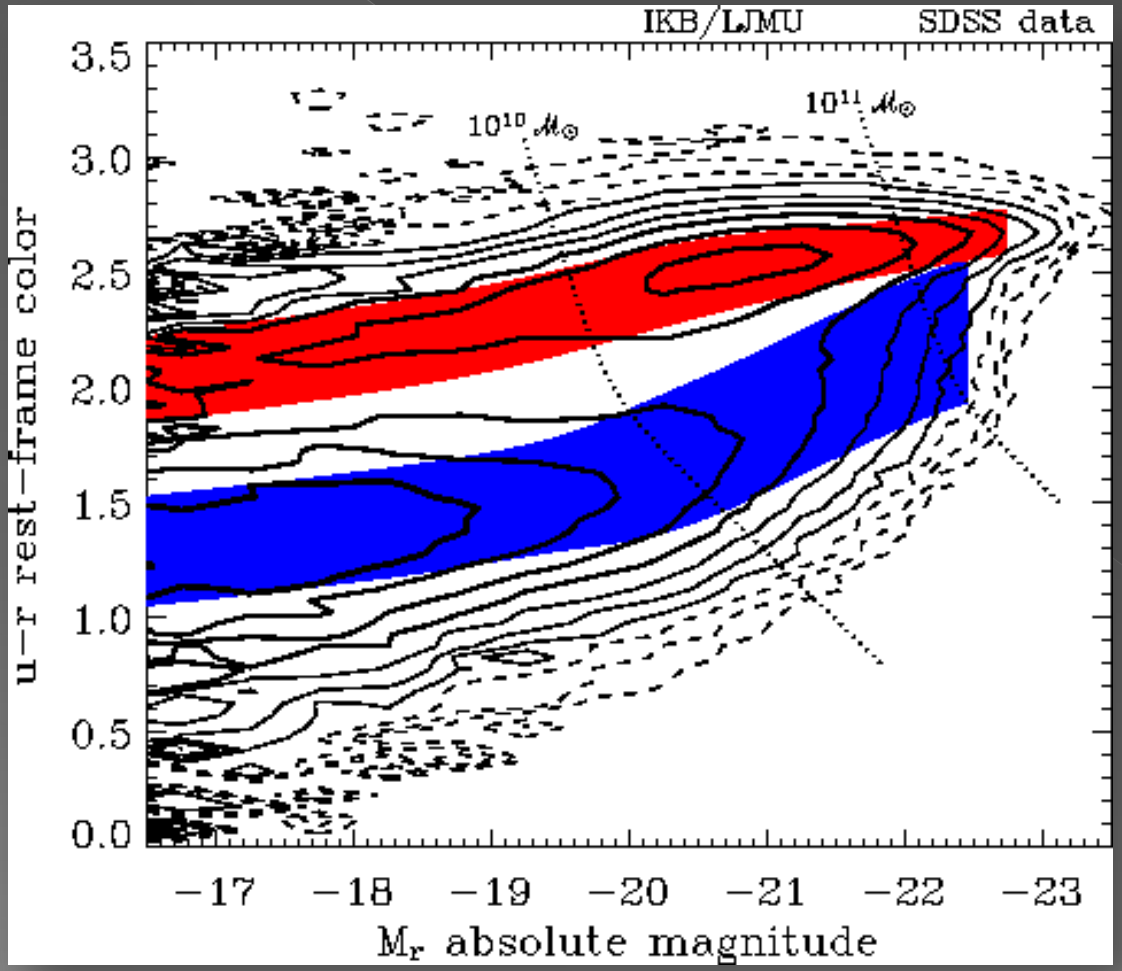
Properties of Galaxies

Three fundamental parameters:

- Mass
- Time
- Environment

Different galaxy properties are related in different ways with these three fundamental parameters

Colour Magnitude Relation



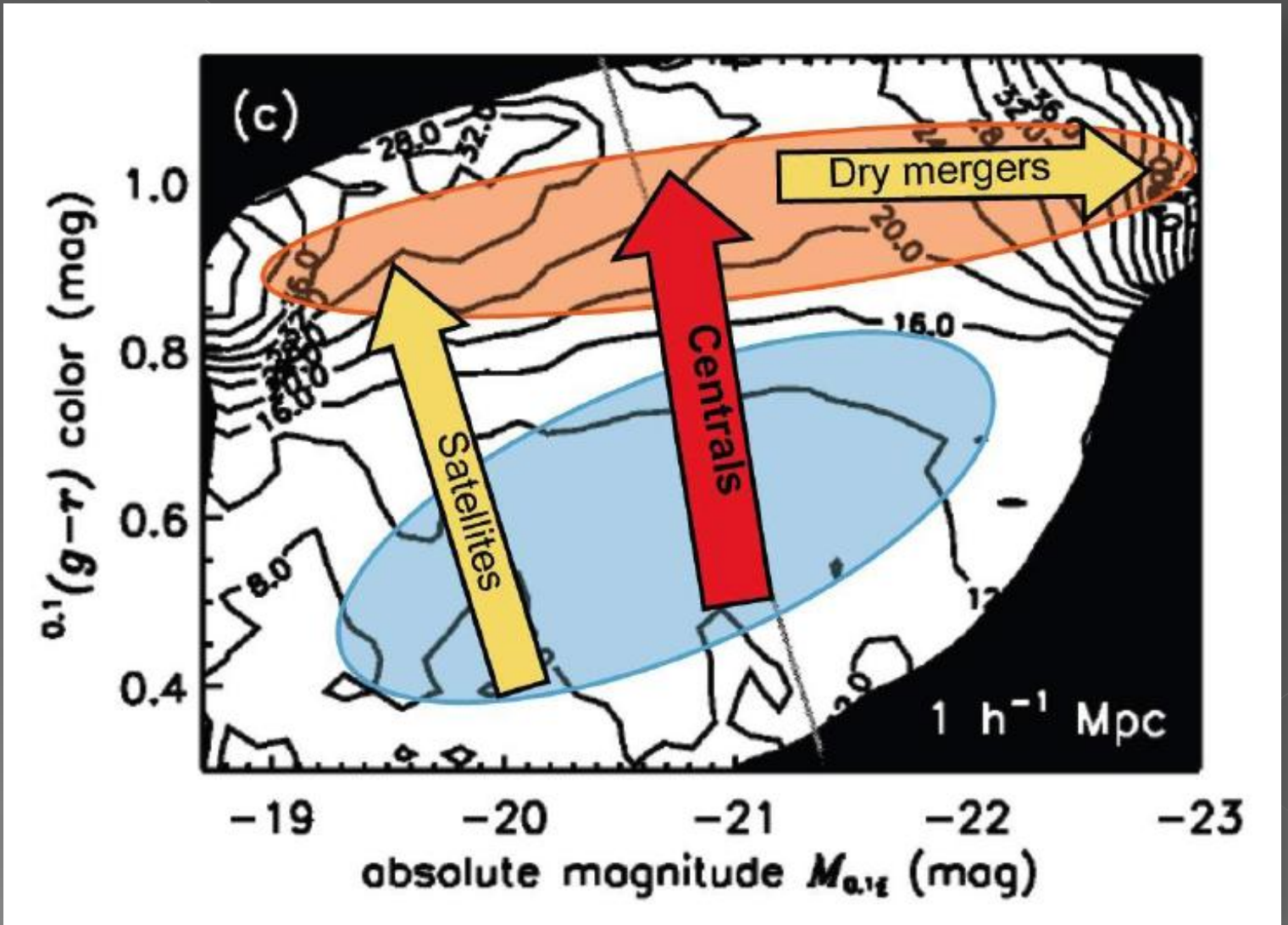
The colour of a galaxy correlates with the ratio of the present star formation rate (SFR) to the overall mass of stars in the galaxy.

Nearly half of the stellar mass of the universe is in galaxies that populate the RS (Bell 2004).

The Red Sequence

- The RS is primarily the result of a relation between mass and metallicity.
- Age variations may also play a role (reddest galaxies → older population).
- Faber et al. 1973 and Bower et al. 1992 found a high degree of universality for this relation comparing early type galaxies in clusters, groups and the field.

Populating the RS



- Several authors suggest that the bright end of the cluster RS is already in place at $z \approx 1$ while this relation for field galaxies has been built all the way down to the present day.

Environment vs. RS

Different environments seem to show similar RSs:

- Hogg et al. 2004: (galaxies taken from the SDSS): the CMR is independent of the of environmental overdensity.
- Cassata 2007: (galaxies at z~0.7): the slope of the RS is independent of the local density.
- Stott 2009: No strong correlation between this slope and the cluster environment at a given redshift.
- McIntosh et al. 2005 (three Abell clusters of different masses): similar CMRs and narrow limits of intrinsic color scatter and slope.
- López-Cruz et al. 2004 (57 X-ray-detected Abell clusters of different richness and cluster types): similar CMRs.

Environment vs. RS

Different environments show different RSs:

- Mei et al. 2009: Relation between CMR and the environment in clusters .
- Haines et al. 2006 (the core of the Shapley supercluster): The CMR is 0.015mag redder in highest-density regions. [They interpret this result in terms of ages, suggesting a population being 500-Myr older in the cluster cores].
- Pimbblet et al. 2002 and Pimbblet et al. 2006: (11 low redshift X-ray luminous clusters): Found also a dependencies of CMR properties as a function of the projected radius of clusters.
- Wake et al. 2005 (12 intermediate-redshift X-ray Clusters): Similar results also interpreted in terms of age gradients.

The scatter around the RS

- If the most massive galaxies in the RS are the result of the merger of galaxies already in the RS (van Dokkum 2005 (AJ 130,264)), a significant scatter is expected (Bower, Lucey & Ellis 1992).
- Nevertheless, Bernardi et al 2007 and Skelton et al. 2009 argued that a small scatter is not against the dry merger scenario.
- The intrinsic scatter could also be the result of a spared in the age of the stellar population.
- Mei et al. 2008 (high-redshift clusters): the CMR scatter for bright elliptical galaxies (M_B<-21) increases with distance from the cluster center. On the other hand, all the elliptical galaxies of fainter magnitudes show similarly larger scatter (results are interpreted in terms of differences of ages).

Our work

Mean colour and scatter of the RS

- In samples of galaxies in the field, in groups and in X-ray clusters.
- The clue of this work is to determine a precise RS for galaxies in different environments using a uniform sample of galaxies.

- Two types of analysis: we analyse how the RS depends on mass and the projected distance to the centres of systems.

Galaxies

- Main Galaxy Sample SDSS (DR7).
- We classify galaxies into early and late types according to their concentration parameter.
- $0.02 \leq z \leq 0.12$.

Groups of Galaxies

- Groups of galaxies in the DR7 MGS used in this work were identified by Dr. Ariel Zandivarez (private communication) using a standard *fof*.
- Number of groups: 11028 with at least 4 members.

X-ray Clusters

- C-P04-I (Coenda & Muriel 2009) that selected clusters from the ROSAT-SDSS Galaxy Cluster Survey of Popesso et al. 2007.
- 36 regular galaxy clusters in the redshift range $0.05<z<0.12$.

Identification of cluster members in two steps:

- First, *fof* algorithm, then an eyeball examination of the structures detected by *fof*.

Field Galaxies

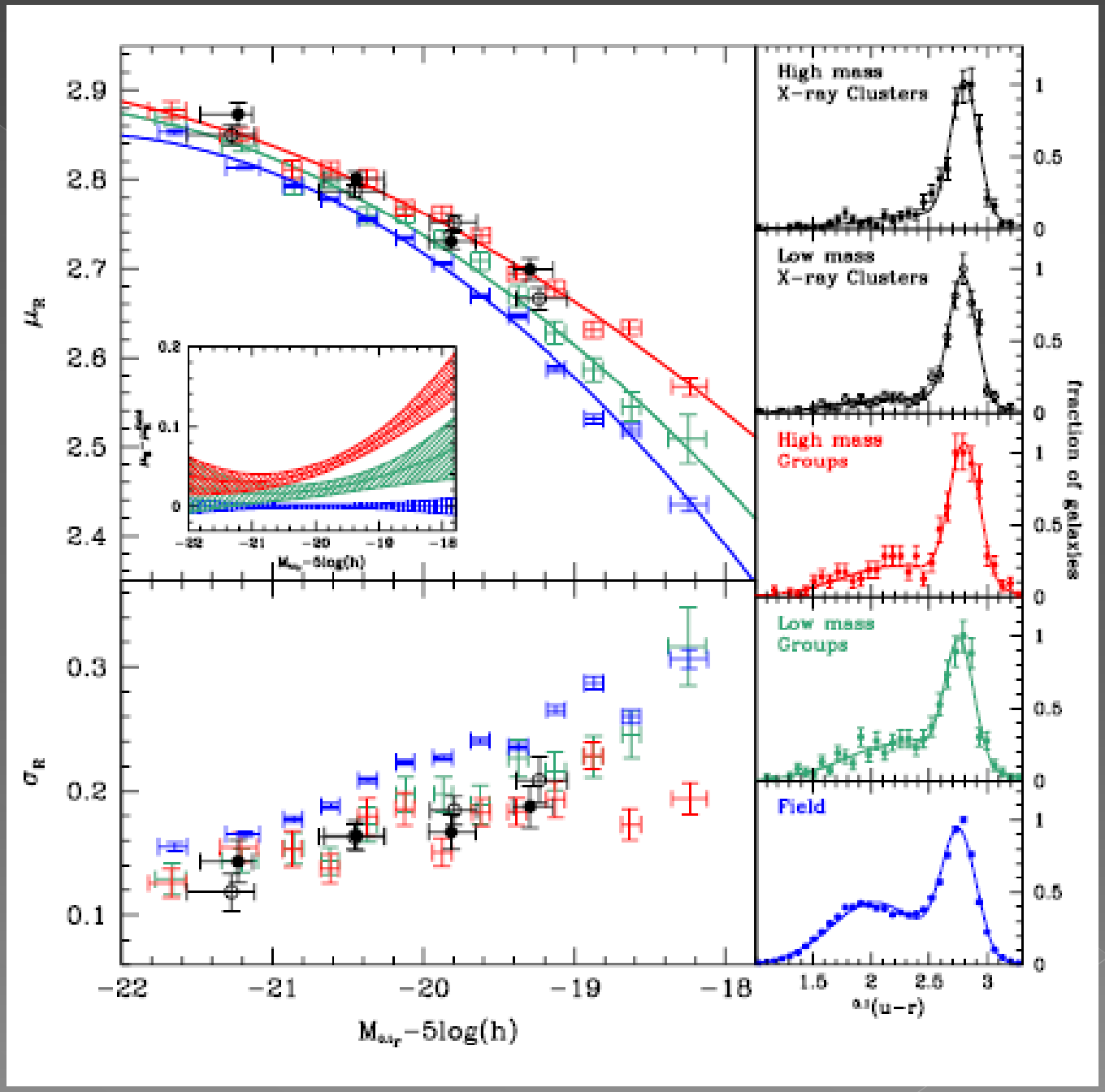
- All DR7 MGS galaxies that were not identified as belonging to *fof* groups nor to Coenda & Muriel 2009 clusters.

1. The Mass Dependence of the RS

- We split groups and clusters into low and high mass according to the median of their mass distribution:

$M=1.3\times10^{13}\ M_{sun}\ h^{-1}$ [groups]

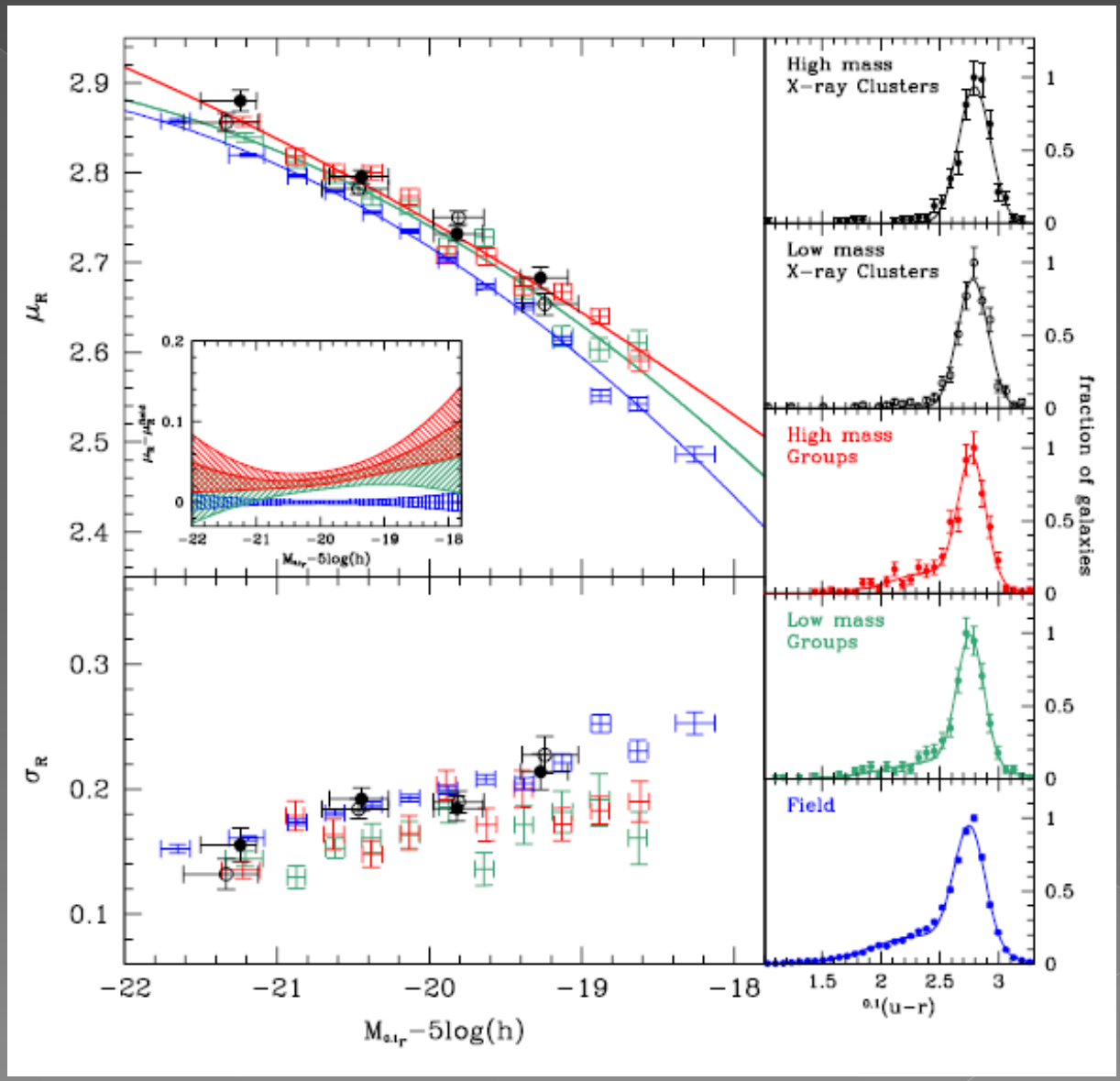
$M=5.0\times10^{14}\ M_{sun}\ h^{-1}$ [X-ray clusters]


High mass
X-ray Clusters
Low mass
X-ray Clusters
High mass
Groups
Low mass
Groups
Field
fraction of galaxies
μ_R
σ_R
$M_{0.1r}-5\log(h)$
$^{0.1}(u-r)$

- The μ_R of field galaxies is bluer than its group and cluster counterparts.

- Among groups, μ_R is systematically redder for the high mass subsample for galaxies fainter than $M_r \sim -20.5$.

Red Early type galaxies



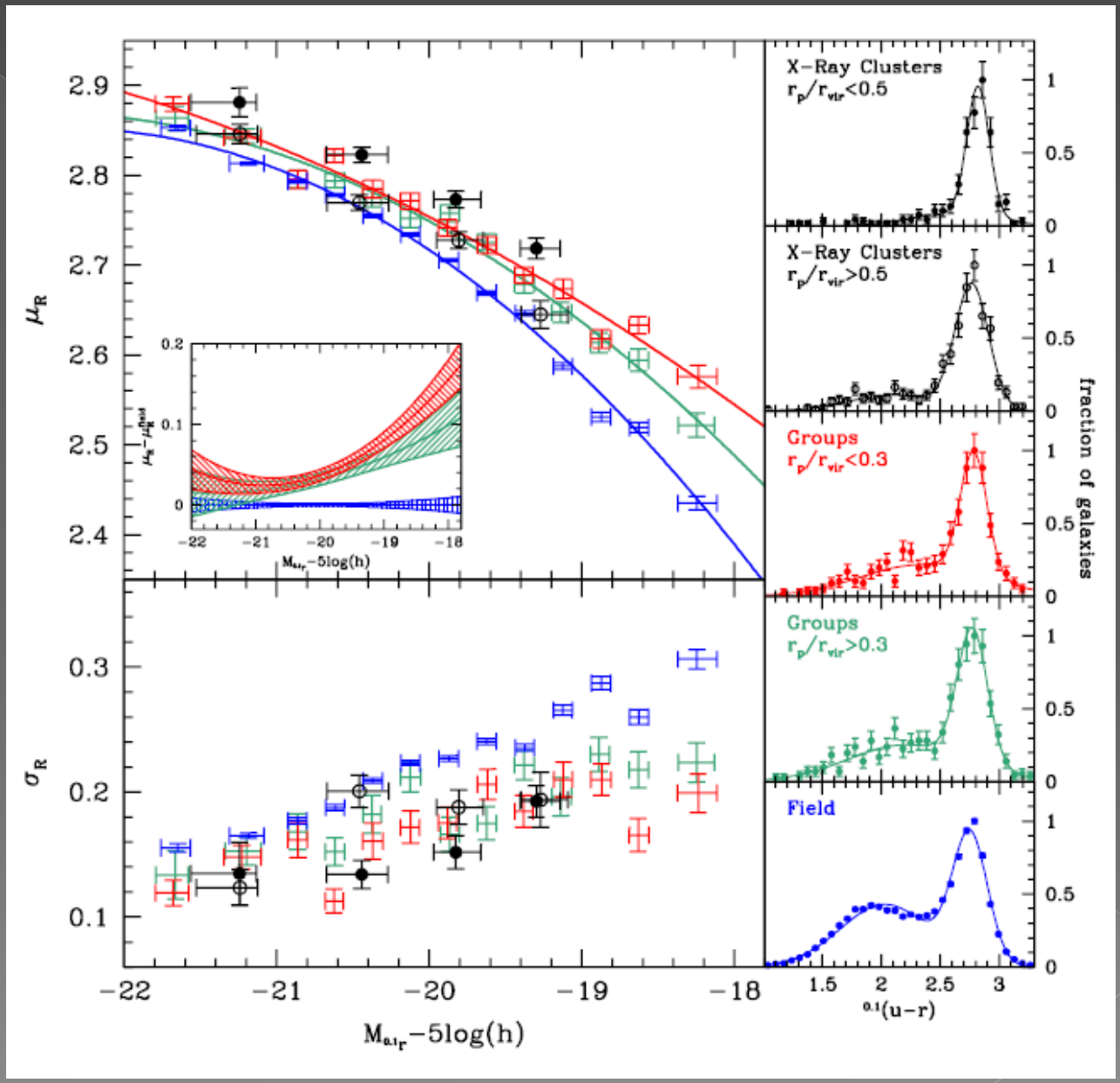
- [Groups]: the differences between low and high mass subsamples are not clear anymore.
- [X-ray clusters]: results not affected by the C cut-off, since only a few galaxies in the sample have $C<2.5$.
- [Field galaxies]: have μ_R values that are systematically bluer that their counterparts in systems of galaxies.

2. The System-Centric dependence of the RS

- We split galaxies using r_p/r_{vir} (above or below the sample's median):

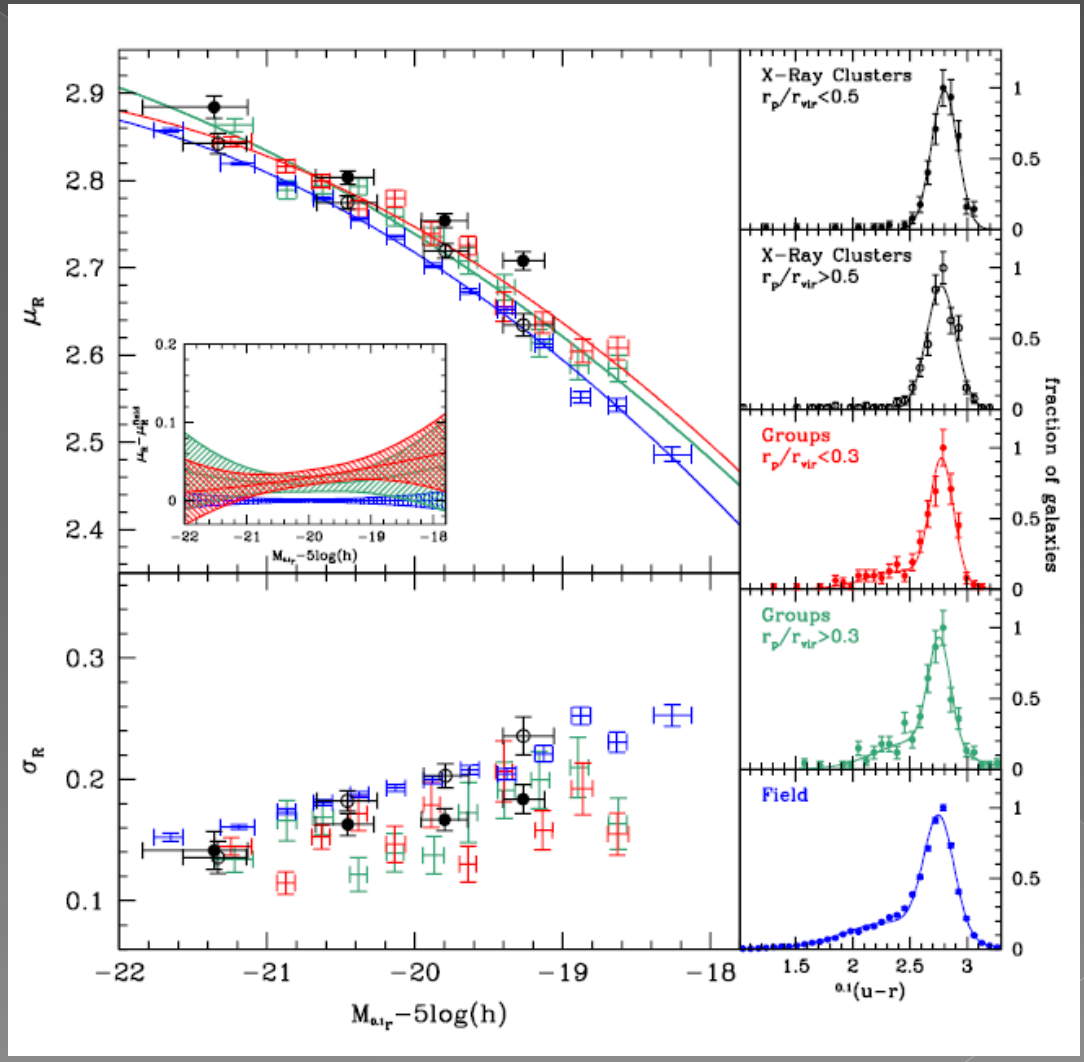
r_p/r_{vir} =0.3 [groups]

$r_p r_{vir}$ =0.5 for [X-ray clusters]


X-Ray Clusters
r_p/r_{vir}<0.5
X-Ray Clusters
r_p/r_{vir}>0.5
Groups
r_p/r_{vir}<0.3
Groups
r_p/r_{vir}>0.3
Field
fraction of galaxies
μ_R
σ_R
$M_{0.1r}-5\log(h)$
$^{0.1}(u-r)$

- μ_R in the inner regions of clusters is significantly redder than in the outer regions for all luminosities probed.
- It is also clear that μ_R in the field is distinctively bluer than in groups and in the inner regions of clusters for $M_r \sim -20.5$.
- It is interesting to note that the μ_R in the outer regions of clusters is consistent with that of field galaxies.

The System-Centric dependence of the RS: red early-type galaxies



Discussion

- Our results indicate that the RS depends on the present time environment. Nevertheless, most of the stars that place a galaxy in the RS were formed when the universe was very young, moreover, most of the physical processes acting at z~0 were not necessarily present at times when the bulk of the stellar populations were forming.
- Therefore, the origin of the dependence of the RS on the present time environment should be looked for at high redshift.

- Steidel et al 2005 found that galaxies in protoclusters have mean ages ~2 times larger than identical galaxies outside the protocluster structures.
- This is in agreement with the Λ-CDM model where denser dark matter concentrations collapse earlier and form an important fraction of their stellar mass in early short events Springel et al. 2005.

Discussion

- These differences in age will imply subtle differences in the present day colours.

- In order to test this hypothesis, we have used the code GALAXEV by Bruzual & Charlot 2003 to construct the SED of a solar metallicity Salpeter IMF stellar population with a star formation rate of the form $\psi(t) \propto e^{-t/\tau}$, and assumed τ=1 Gyr.
- This model SED allows us to relate colour differences in the RS of different environments with age differences, assuming that all galaxies in the RS are represented by such a simple model.

Discussion & Conclusions

- The colour differences between field and high mass group galaxies imply age differences ranging from 200 to 600 Myr in the magnitude range -22 to -18.
- These differences are of the same order of magnitude of those found by De Lucia et al. 2006 when they compare the formation history of elliptical galaxies in halos of different masses.
- *We conclude that the RS of galaxies shows dependencies with environment that could be mostly interpreted in terms of the typical age of the bulk of their stellar population.*

Discussion & Conclusions

- Field galaxies and cluster members in the outskirts have values of scatter equal or larger than the corresponding values for groups and galaxies in the core of clusters, also consistent with the scenario of field galaxies falling into clusters.

- ***[RETG] bright galaxies (M_r <-21) have the same RS (ages) irrespective of the environment. In other words, bright RETG are the only objects that reached nearly the same evolutionary state in groups, clusters and in the field.***

- *The clear difference between RS galaxies in the core and the outskirts of clusters, suggests that the cluster environment could be playing a roll in the drift of galaxies of intermediate magnitudes towards redder colours, producing and increase of the fraction of red galaxies.* ***Nevertheless, the fact that galaxies in groups and in the core of X-ray clusters populate nearly the same RS (the cluster RS is slightly redder), suggests that the cluster environment is not necessary to populate the RS.***