THE GROWTH OF THE RED-SEQUENCE IN CLUSTERS SINCE Z=1

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Scientific objectives

- Determine the age of the Universe at which cluster galaxies acquired most of their stellar content through bursts of star formation.
- Determine when the red-sequence in clusters was first established and how do cluster galaxies populate the red-sequence.

PART I

Introduction

Galaxy formation

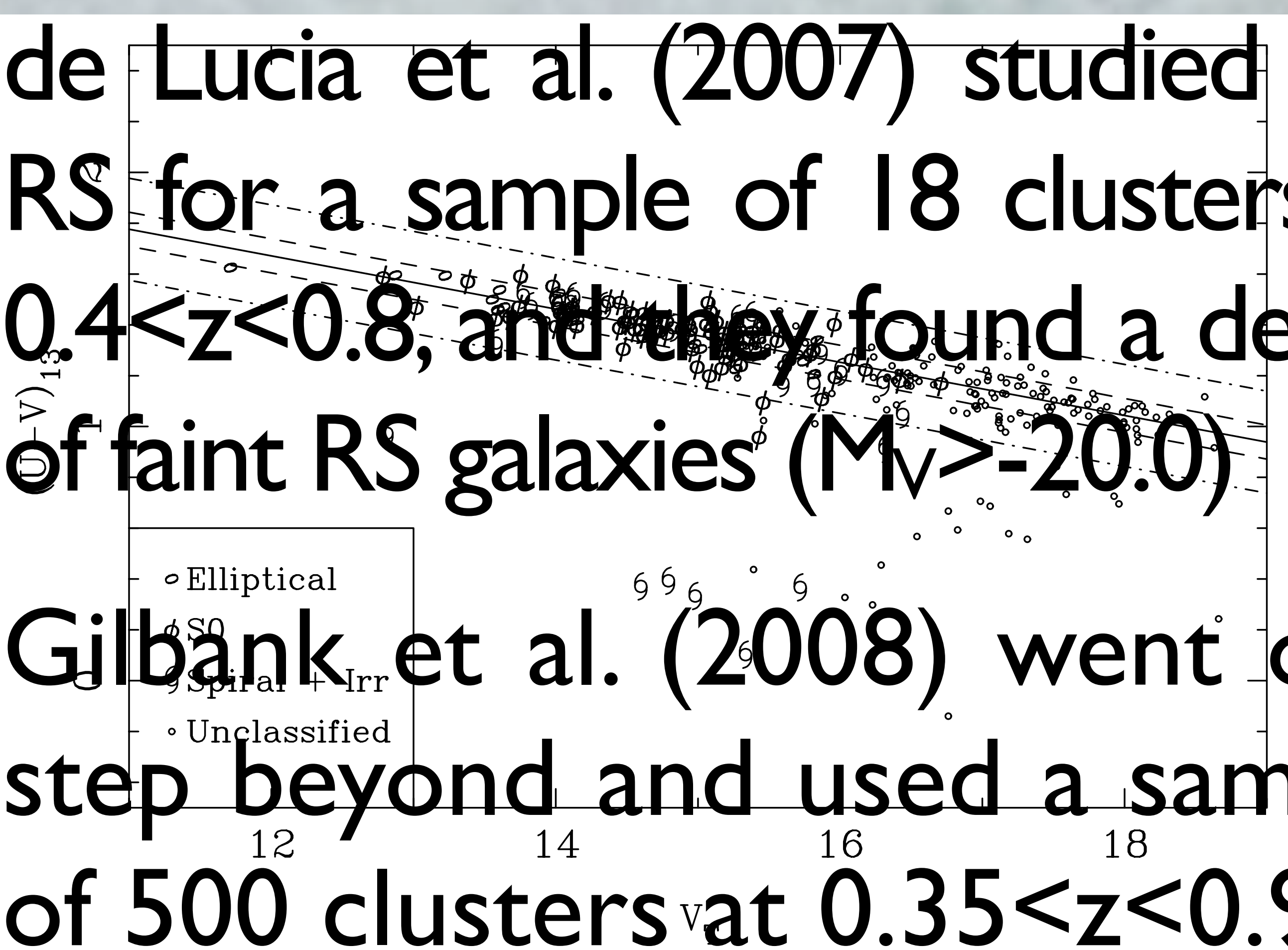
- The central Mpc of clusters is dominated by early-type galaxies (ETGs).
- Two main views for the formation of giant ETGs:
  1) A protogalactic monolithic collapse with dissipational star formation.
  2) A product of mergers in a hierarchical scenario of structure formation.
- Clusters contain a large number of galaxies.

Red-sequence

- ETGs form a well defined sequence in the color-magnitude diagram (CMD), which is known as the Red-Sequence (RS)

- de Lucia et al. (2007) studied the RS for a sample of 18 clusters at 0.4<z<0.8, and they found a deficit of faint RS galaxies (M_V>-20.0)

- Gilbank et al. (2008) went one step beyond and used a sample of 500 clusters at 0.35<z<0.95



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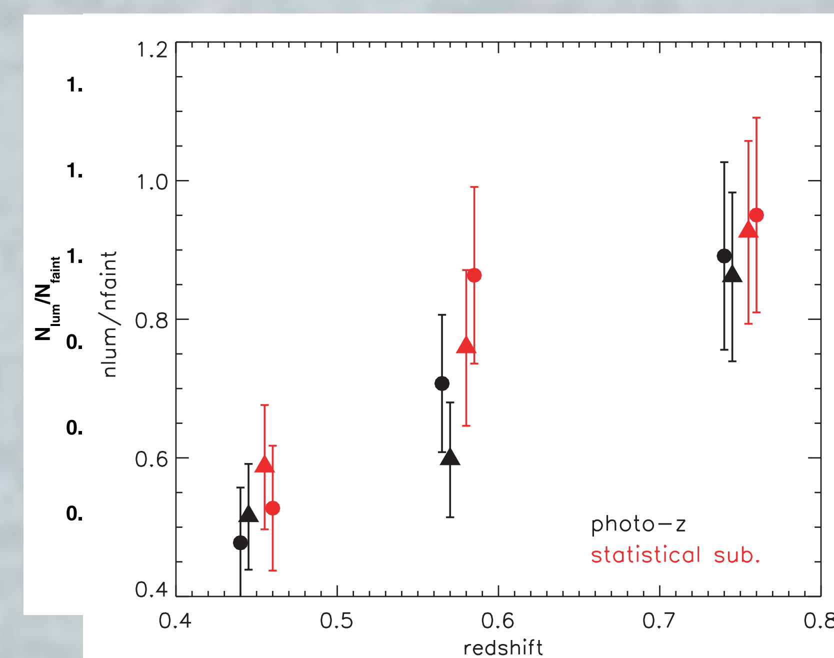
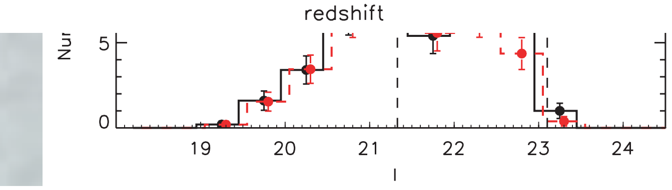
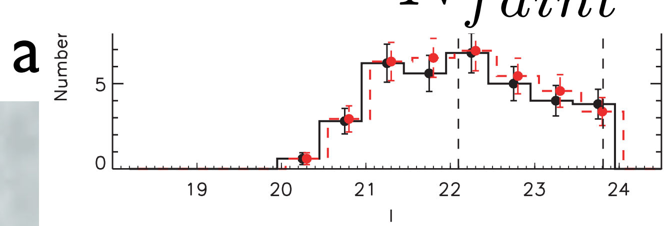




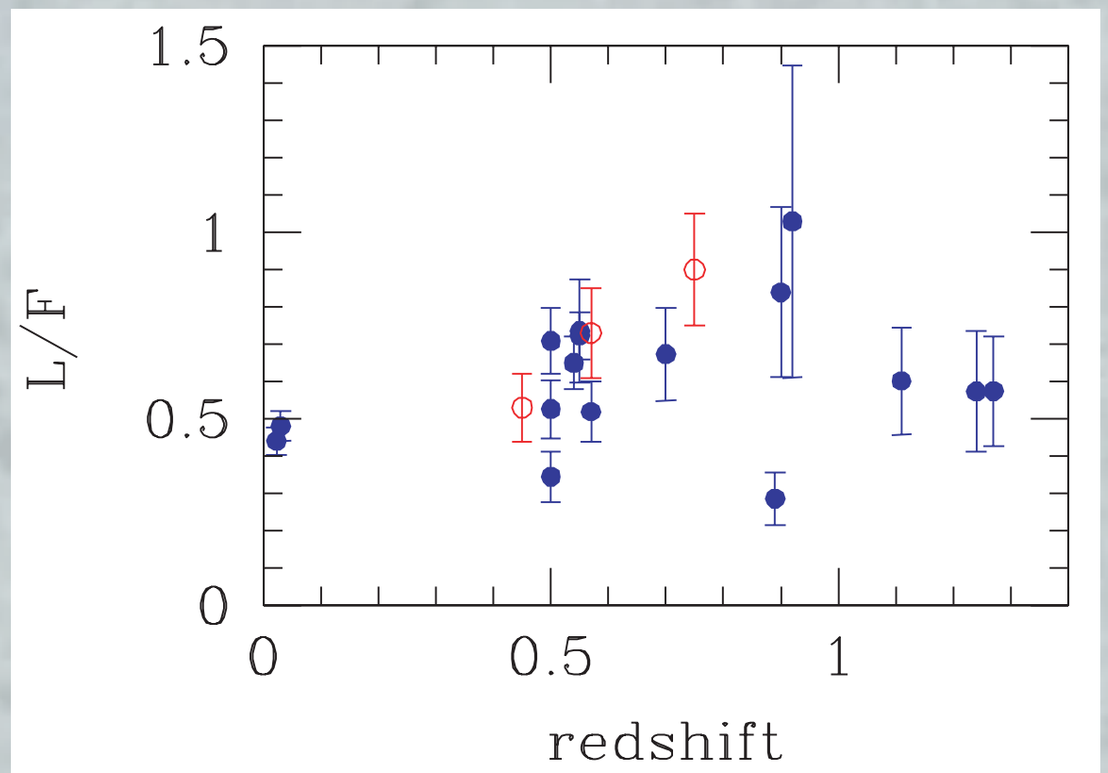
$$L/F\ ratio = \frac{N_{luminous}}{N_{faint}}$$



Increasing trend ?

- Andreon (2008) studied a sample of 28 clusters. Most of his z>0.5 clusters were selected from the MACS survey.

- He concluded that the abundance of faint RS galaxies is constant over 0<z<1.3



PART II

Data

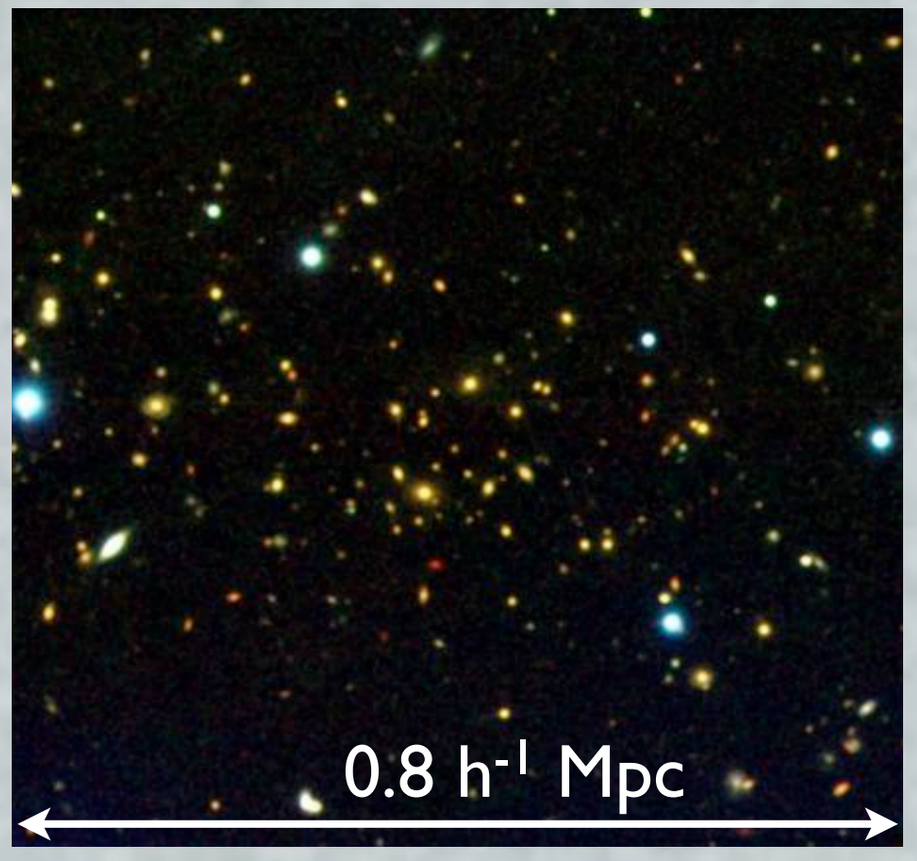
Cluster sample

- 21 cluster candidates with z_{phot}~1 were selected from the Red-sequence Cluster Survey catalogs (RCS-1; Gladders & Yee, 2005)
- We chose only those clusters which showed an overdensity in the redshift space at z_{spec}~1 and had optical richness B_{gcR}>300.
- The cluster sample used in this thesis work consists of 15 clusters located between redshifts 0.85 and 1.10.

VLT and HST data

- The observations were carried out at the ESO Very Large Telescope (VLT) with ISAAC, and at the Hubble Space Telescope (HST) with ACS.

- We have deep J_s and K_s-band imaging of 15 clusters, and F775W (i_{775}) and F850LP-band (z_{850}) imaging for 5 of these clusters.

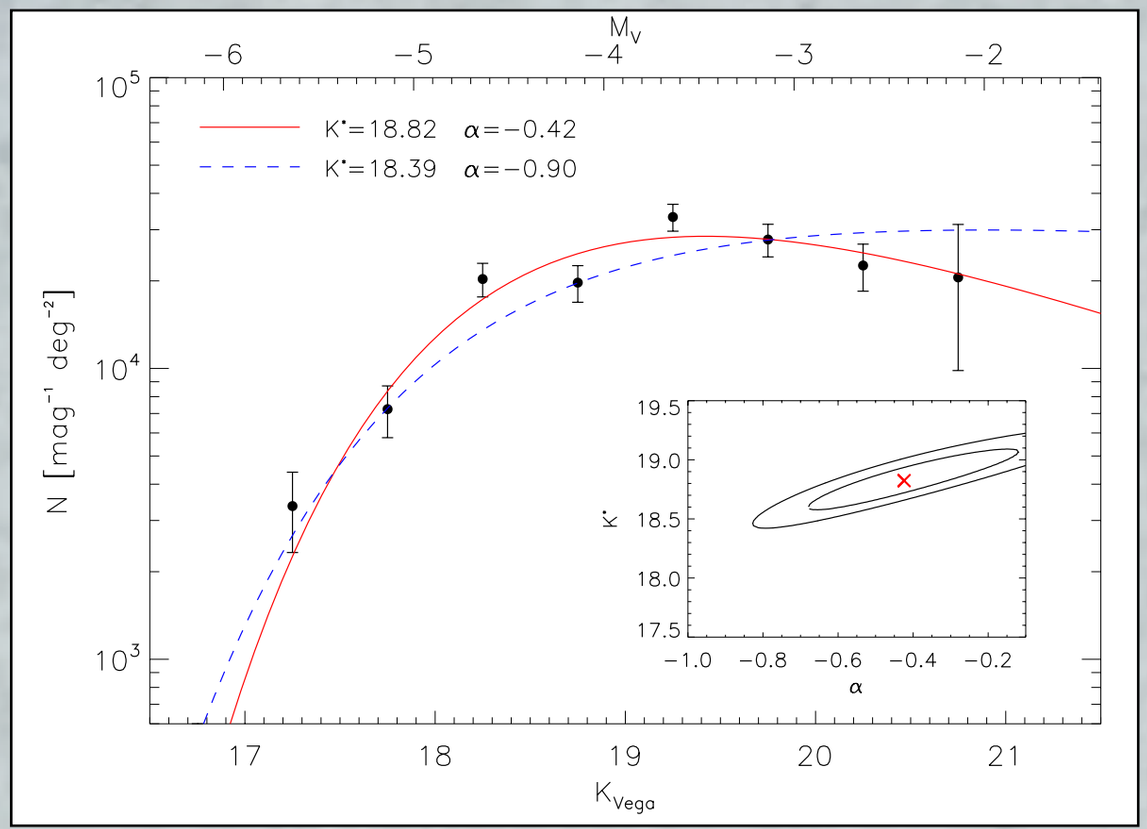


PART III

Formation epoch of cluster galaxies

K_s-band LF

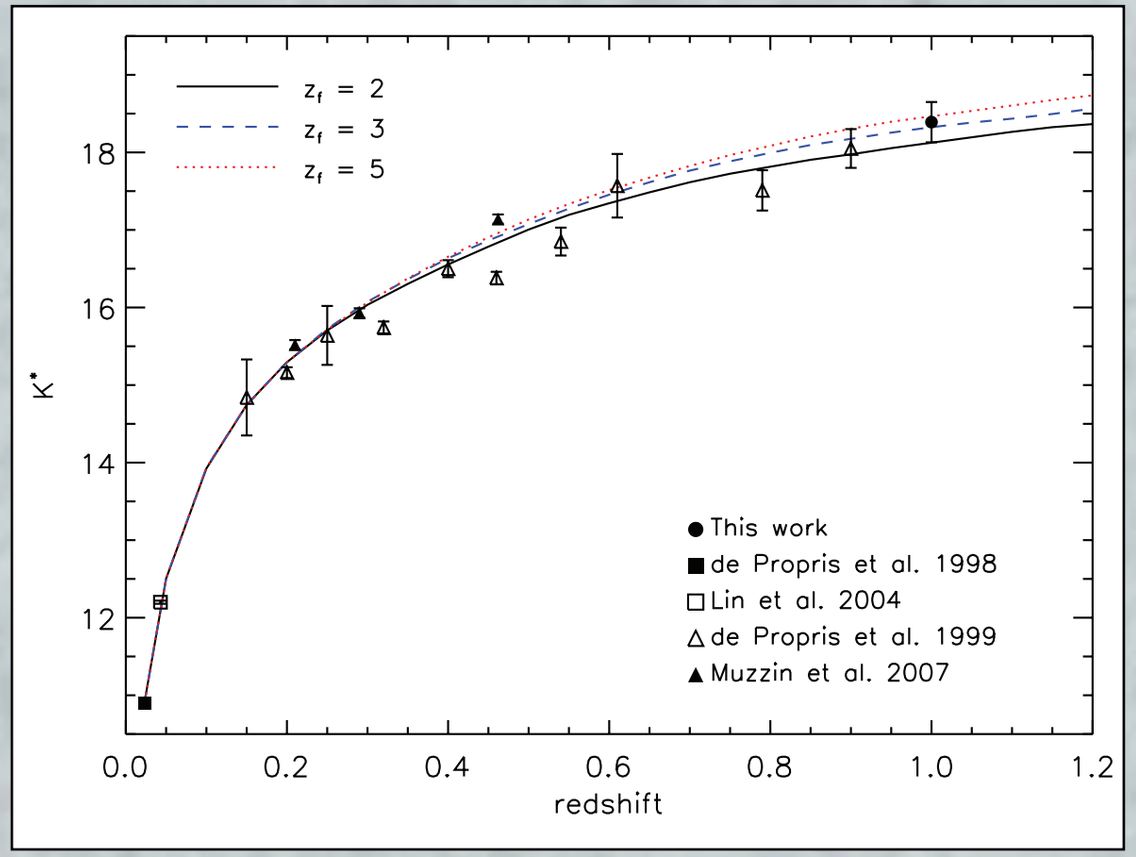
- We built the K_s-band LF for the combined cluster sample at z=1 through the application of the B+Z method (Muñoz et al 2009).
- It can be described by a Schechter function with $K_s^*=18.82\pm0.25$ and $\alpha=-0.42\pm0.28$.
  By fixing $\alpha=-0.9$ we obtained $K_s^*=18.39\pm0.10$.



Evolution of K_s*

- We adopted the passive evolution models by Kodama & Arimoto (1997) in order to reproduce the observed evolution of K_s* as function of z.

- We concluded that bright cluster galaxies formed most of their stellar content at z_f=3.5.

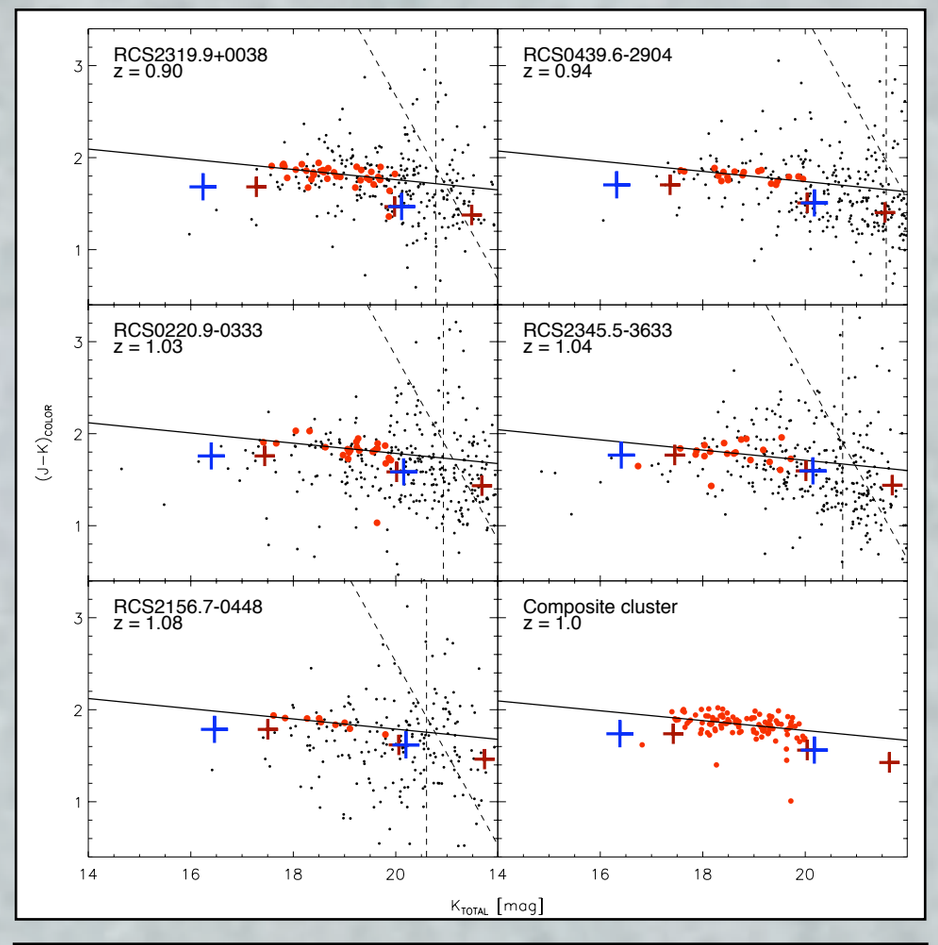


PART IV

Growth of the red-sequence in clusters since z=1

CMR of early-type

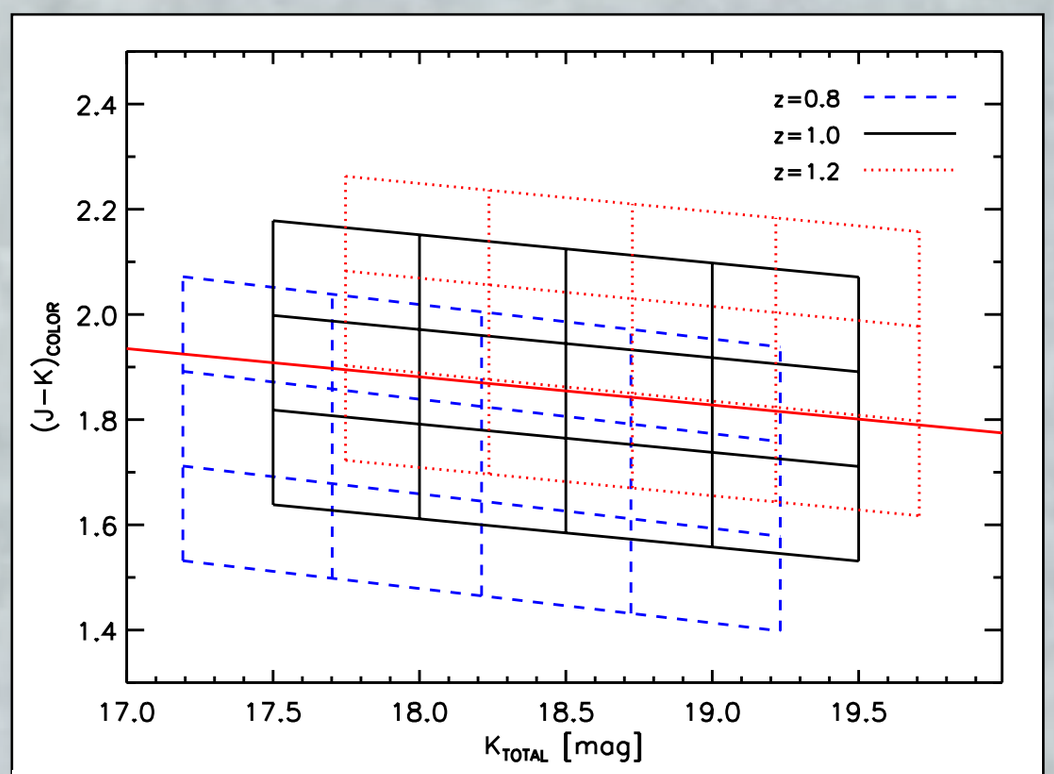
- The ACS morphological catalogs of 5 RCS-1 clusters were kindly provided by Benjamin Koester.
- The classification was performed with MORPHEUS software (Abraham et al., 2007), and we could distinguish between bulge and disk-type galaxies.



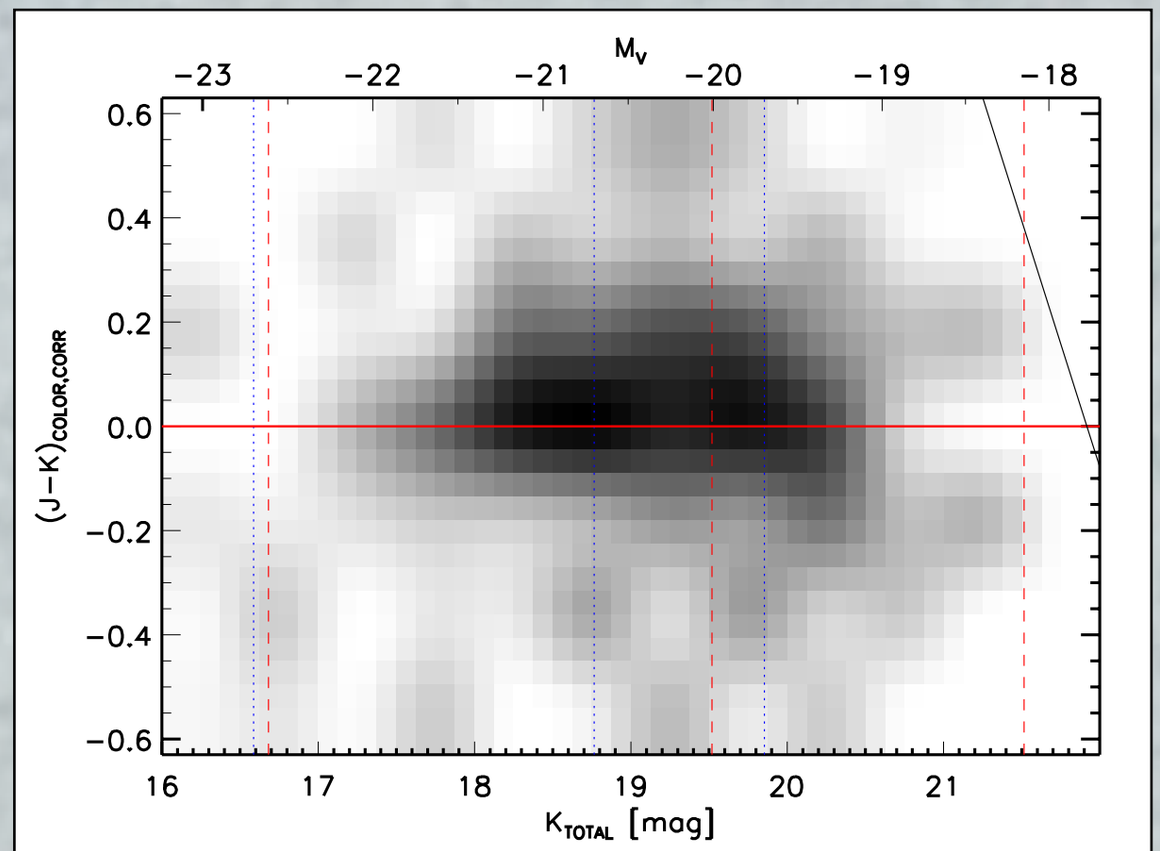
best-fit straight line
δ (J-K) / δ K = -0.05

Background subtracted CMD

- We defined a regular grid in the observed color-magnitude space at z=1 of bin size 0.5 mag in K_{TOTAL} and 0.18 mag in J-K_{COLOR}.



2-D grid on the CMD used to compute the background-subtracted CMD.



CMD for the combined cluster sample at z=1. Best-fit relation was subtracted.

L/F ratio of RS

- In order to study how cluster galaxies populate the RS, we computed the ratio between the number of bright and faint RS galaxies, hereafter L/F ratio.

$$L/F\ ratio = \frac{N_{luminous}}{N_{faint}}$$

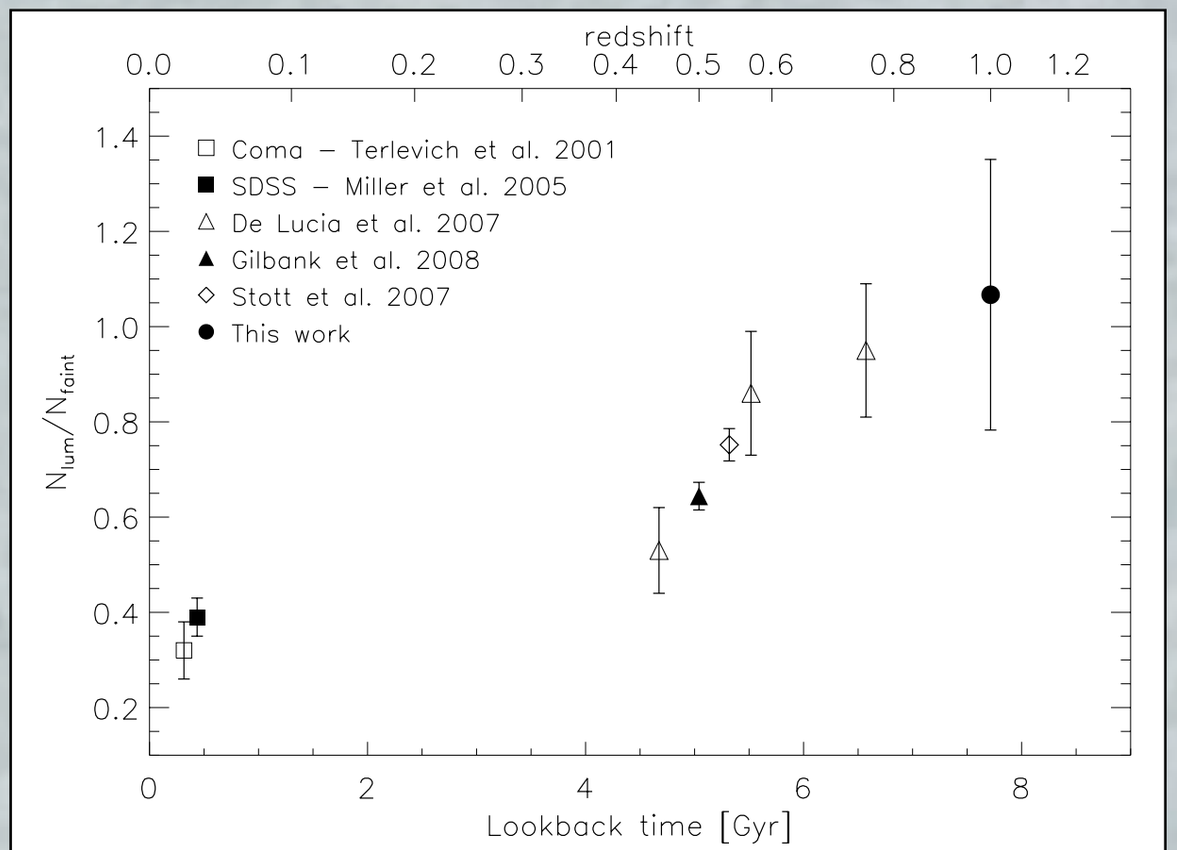
De Lucia et al. (2007)

$$\begin{aligned} \text{luminous} \quad & M_V \leq -20.0 \\ \text{faint} \quad -20.0 < & M_V \leq -18.2 \end{aligned}$$

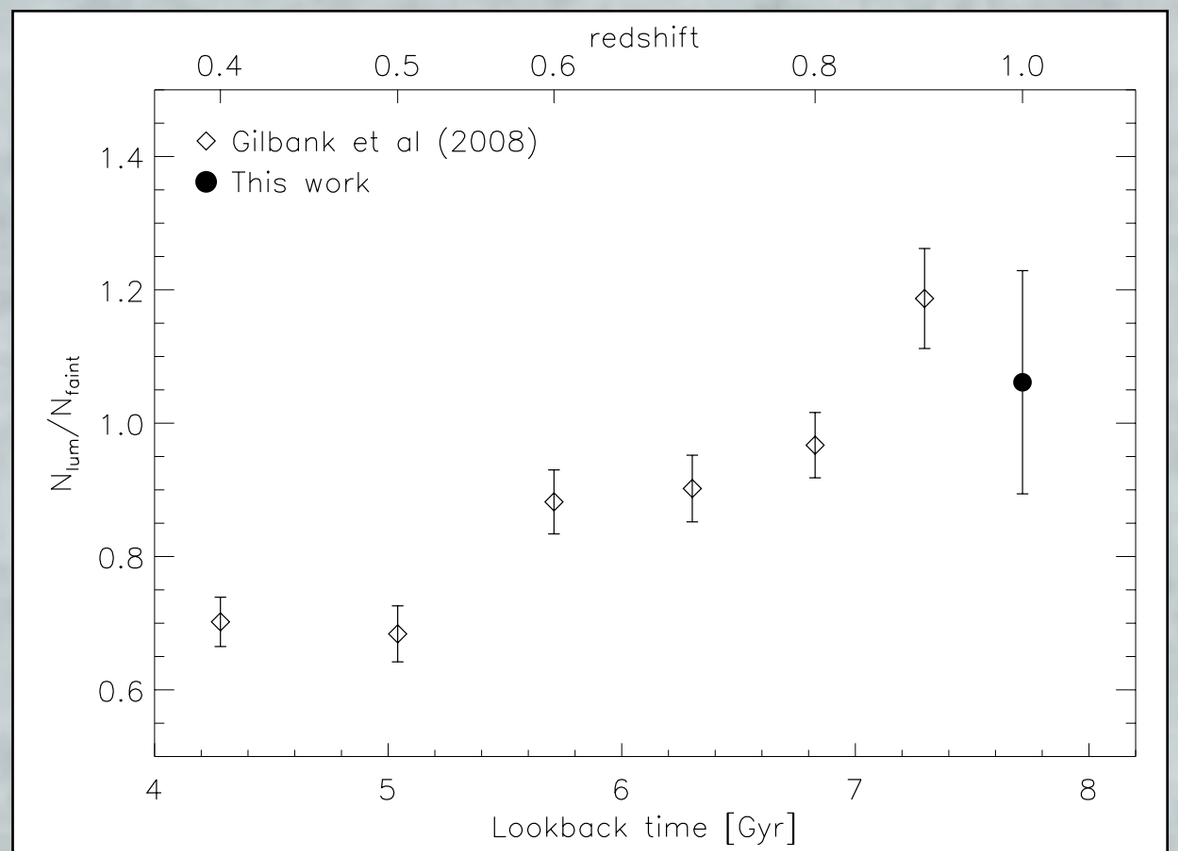
Gilbank et al. (2008)

$$\begin{aligned} \text{luminous} \quad -22.7 < & M_V \leq -20.7 \\ \text{faint} \quad -20.7 < & M_V \leq -19.7 \end{aligned}$$

Evolution of L/F ratio



Evolution of the L/F ratio of RS galaxies since z=1 for the magnitude limits defined by De Lucia et al. (2007).



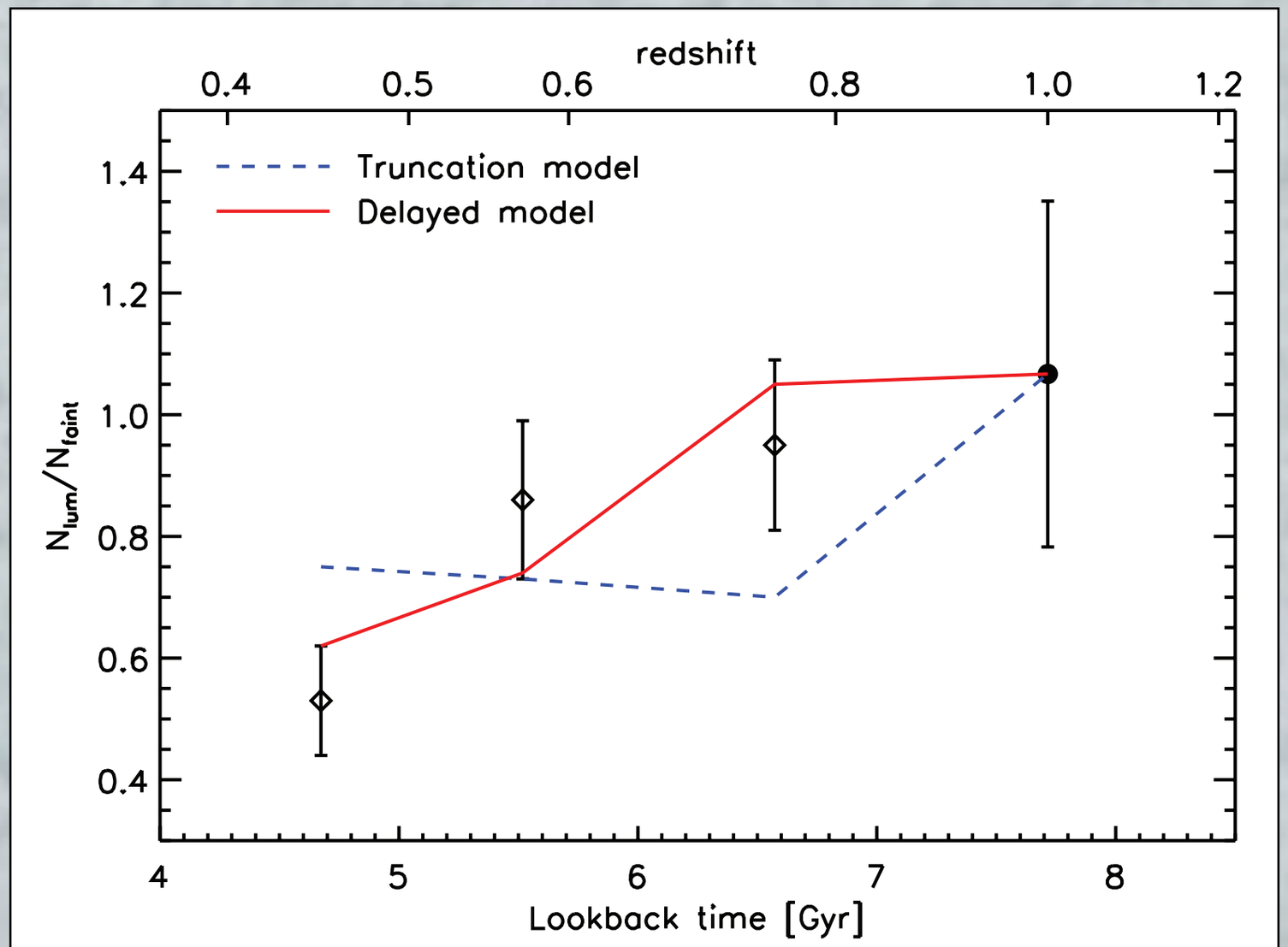
Evolution of the L/F ratio of RS galaxies since z=1 for the magnitude limits defined by Gilbank et al. (2008).

REDGROWTH model

- We developed a toy-model for the color evolution of cluster galaxies since z=1. This model predicts the change in the number of RS galaxies as function of redshift.

- REDGROWTH consists of a set of model galaxy SEDs computed using the population synthesis code by Bruzual and Charlot (2003) for two SF histories: a single burst SF at z_f=3 and an exponentially declining SF of e-folding timescale τ=1, 2, and 7 Gyr.

REDGROWTH results



Predicted evolution of the L/F ratio of RS galaxies since z=1, following the magnitude limits defined by De Lucia et al. (2007).

Conclusions

- That bright cluster galaxies formed most of their stellar content at z_f=3.5.
- That progenitors of present-day M_V>-20 RS galaxies have undergone a recent burst of star formation at z=1.
- That the SF histories of M_V>-20 depends strongly on galaxy luminosity: 19.5<K_s<20.2 have a delay time of 1.5 Gyr, while 20.9<K_s<21.5 have a delay time of 2.9 Gyr.