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Cluster Ellipticals at $z \approx 1$ from the Red-Sequence Cluster Survey

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Abstract

We present the first results from follow up observations for a sample of newly discovered clusters of galaxies at $z \sim 1$ from the Red-Sequence Cluster Survey. Deep IR imaging is used to study the color-magnitude relation, the size-magnitude relation and a measurement of the color gradient distributions for the morphologically selected E/S0 galaxies.

1.1 Introduction

Clusters of galaxies are massive systems that can be used as tools for cosmological and galaxy formation and evolution studies. The number density of galaxy clusters as a function of mass and redshift is strongly dependent on the cosmological parameters Ω_m and σ_8, therefore a measurement of $N(M,z)$ provides a powerful constraint on the cosmological model. Similarly, clusters of galaxies are extreme environments that can be traced to high redshifts, and in them galaxy populations such as E/S0s can be followed during a significant fraction of the age of the universe.

The Red-Sequence Cluster Survey (RCS) is a collaborative effort focused on finding a large number of clusters of galaxies up to $z \sim 1.4$. This survey uses the unambiguous signature of the homogeneous colors of the red sequence of early-type galaxies, present in all the clusters found to date. The survey has been carried out in two programs: 45 sq. degrees in the northern hemisphere using CHFT and approximately 40 sq. degrees in the southern skies using the CTIO4m+MOSAIC. Moderate deep images have been taken in two optical bands ($R_{AB} = 25.4$ and $z'_{AB} = 23.9$ at 4σ) to detect overdensities in the position and color space. For more details on the survey see the contributed talk by M.D. Gladders on these proceedings.

The color information for the red-sequence also provides a first estimate of the redshift of the clusters, accurate typically to 7%. The RCS search method is complementary to other important search techniques such as those based on X-rays.

Preliminary results from the analysis of the first patches of the RCS indicate there are nearly 10 clusters Abell richness 0 or higher per sq. deg. at $z > 1$. A first example of a rich cluster found in the southern RCS is RCS0439.6-2905 (Barrientos et al. 2004). Multi-object spectroscopy at the Magellan 6.5m telescope shows that this cluster is at z=0.97. This is a normal cluster and it shares many properties with those found locally, or at similar redshifts as it is shown below.

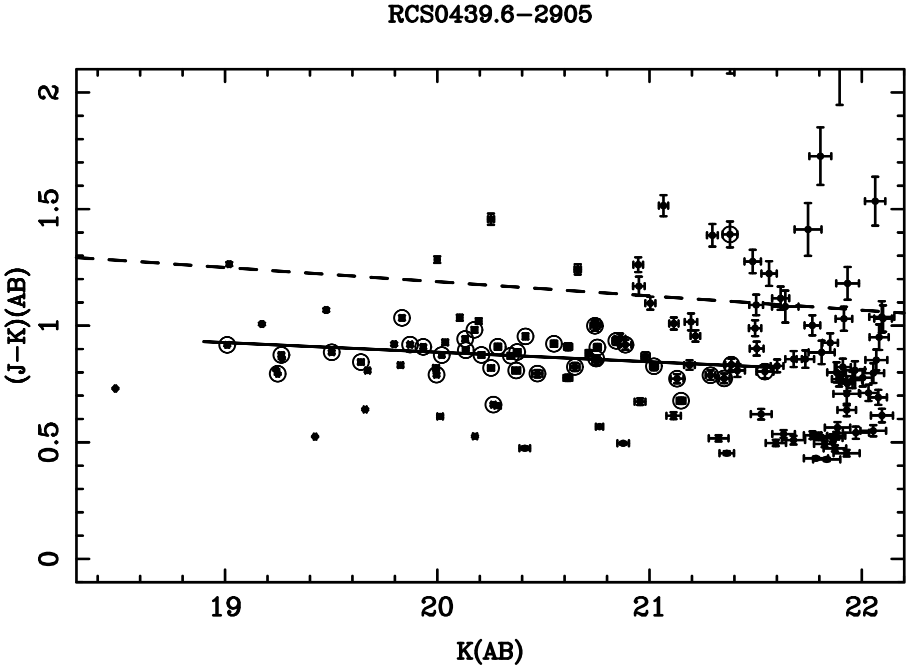

Fig. 1.1. Color-magnitude diagram in the 2.5×2.5 arcmin field of the cluster of galaxies RCS0439.6-2905 at $z = 0.97$. The morphologically selected E/S0 are shown as solid symbols.The solid line represents the best linear fit for the E/S0 galaxies. The broken line represents a similar relation for Coma at it would be seen $z = 0.97$.

1.2 The Color-magnitude Relation

Figure 1.1 shows the IR color-magnitude diagram for the galaxies in the central 1 Mpc of the cluster RCS0439.6-2905. The observed $(J-K)$ color corresponds approximately to restframe $(R-J)$ at the cluster redshift. A 2-D galaxy light profile fitting technique has been applyied to the galaxies in this field allowing us to select morphologically the E/S0 population, i.e. those better represented by an $r^{1/4}$-law. The galaxies selected in this way, highlighted with open circles in the figure, define an extremely tight sequence with a negative slope, consistent with what is seen in clusters at lower redshifts. The solid line corresponds to the best linear fit to the morphologically selected E/S0 galaxies in this high redshift cluster. The broken line corresponds to the locus of the unevolved E/S0 galaxies in Coma (Bower, Lucey and Ellis 1992) as they would be seen at $z = 0.97$. This figure shows that the colors of the E/S0 population in RCS0439.6-2905 are ~ 0.25 mag bluer than their counterparts in Coma, consistent with population synthesis models and a formation redshift $z_f > 2$. There is an indication for a small flattening in the color-magnitude relation at this earlier epochs. This can be interpreted as the differential evolution between brighter and fainter galaxies in the color-magnitude relation, which also have different metallicity contents.

Therefore, we find that at this much earlier epoch there is a well established E/S0 population with red and homogeneous colors in this cluster, suggesting early formation of their stellar populations.

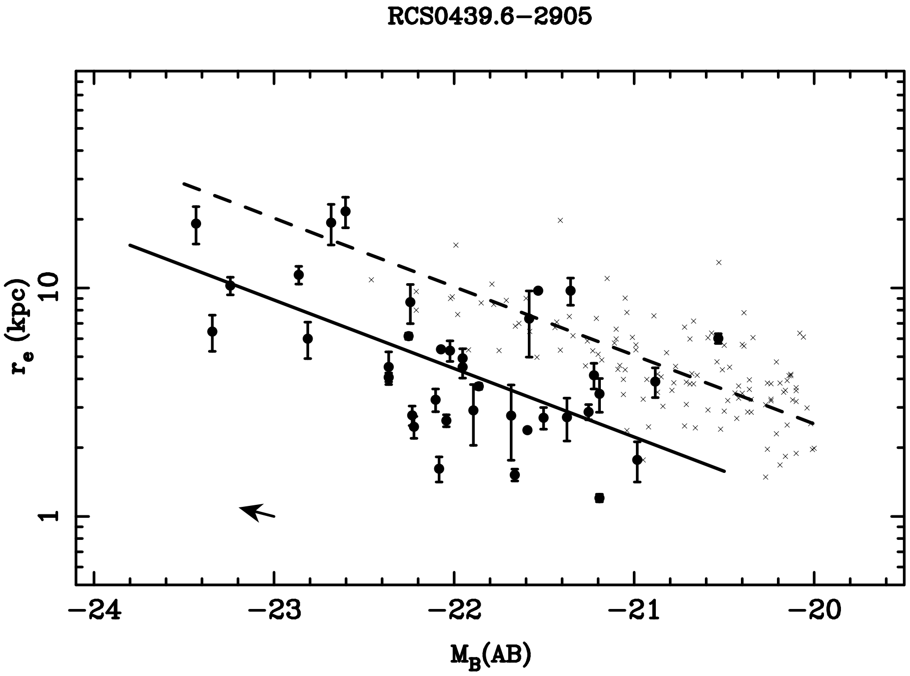

Fig. 1.2. The size-magnitude relation for all the morphologically selected E/S0 galaxies in the field of RCS0439.6-2905 (solid large symbols). A local sample is also shown as small stars and its best linear fit is shown as a broken line. The solid line represents the best linear fit for the galaxies in RCS0439.6-2905, keeping the slope fixed at the value for the local relation.The arrow shows the effect of changing the cosmology from $\Omega_m = 0.2$ and $\Omega_\Lambda = 0$ to $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

1.3 The Size-magnitude Relation

The size-magnitude relation for the E/S0 galaxies in the field of RCS0439.6-2905, and that for a local counterpart are shown in Figure 1.2. This relation is a projection of the Fundamental Plane, which also includes the velocity dispersion in these galaxies. The half-light radius has been obtained using a 2-D galaxy profile fitting software. This software accounts the seeing that has been superb in these images. The dashed line correspond to the best fit for local E/S0 cluster galaxies, while the solid line corresponds to the fit to the E/S0 galaxies in RCS0439.6-2905, keeping the same slope as that for the local galaxies. The offset between the two relations can be interpreted as an increase of $\Delta M_B = -1.2 \pm 0.1$ mag in brightness at $z = 0.97$, when compared to local galaxies. This means that for two galaxies of the same size, one in Coma and the other in RCS0439.6-2905, the high redshift one is 1.2 mag brighter than its corresponding in Coma. This is consistent with a population that formed early and is evolving passively. This is also consistent with previous studies at these redshifts (e.g., Schade, Barrientos and Lopez-Cruz 1997). This result is not sensitive to cosmological parameters as its change is nearly parallel to the observed relations.

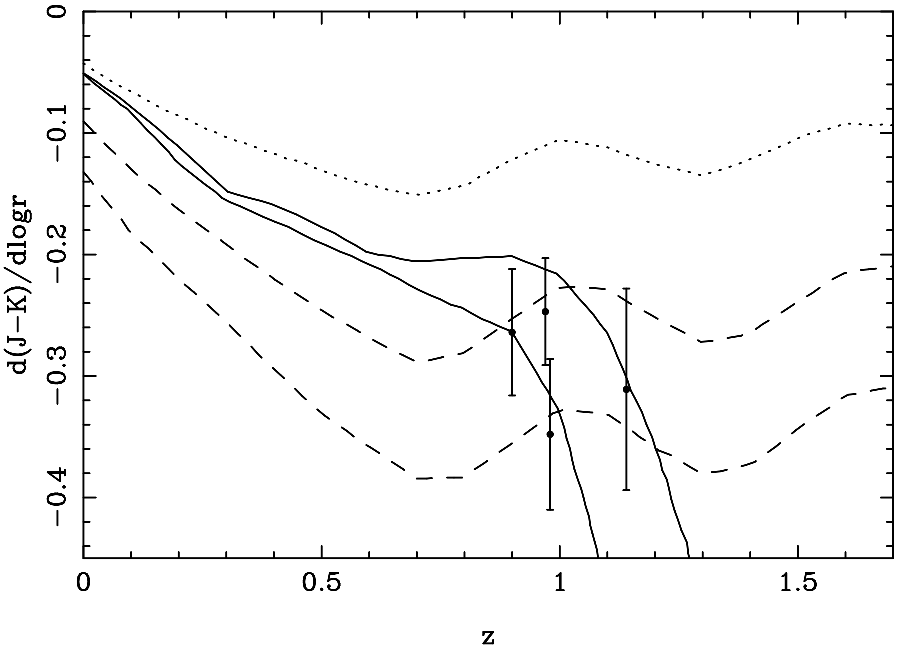

Fig. 1.3. Mean color gradients for the E/S0 galaxies in four $z \sim 1$ clusters found in the RCS. The lines represent different models for the color gradient evolution from Tamura (2003). The models are explained in the text.

1.4 Color Gradients in E/S0s at $z \sim 1$

The Figure 1.3 shows the mean color gradient and dispersion for the E/S0 galaxies in each of the first 4 $z \sim 1$ clusters studied. These color gradients have been computed from the small systematic differences found in the effective radii measured in the J- and K-bands, for the morphologically selected E/S0s. The color gradient distributions for these galaxies (not shown here) are similar in the 4 clusters. Preliminary simulations indicate that these color gradient distributions are real and can be measured to this accuracy.

Models for the observed $(J-K)$ color gradient evolution (Tamura et al. 2000, 2003) for passively evolving ellipticals are also shown. The color gradients found here are well represented by these models. The dashed lines represent models that consider pure metallicity gradients along the radius, with a metallicity gradient in the range $[-0.60, -0.85]$. The solid lines represent models that consider a metallicity and an age gradient. These include a fixed metallicity gradient (dotted line) of $dlogZ/dlogr = -0.35$ and a radial gradient in the age $(dlogt/dlogr)$ of the stellar population in the range $[-0.10, -0.13]$ at $z = 0$.

For the models where the age gradient dominates, the external regions would be only 2 Gyrs at z=1. Being the galaxies well represented by the de Vaucouleurs profile and their colors consistent with passive evolution, the models of pure metallicity gradient are more plausible, even though they are steeper than the ones found locally. Extending these studies to high and intermediate redshifts would help to discriminate between these two competing scenarios.

1.5 Summary

We have presented the first results on the IR follow up for the $z \sim 1$ clusters of galaxies from the RCS. We find clusters with a well populated red-sequence, that is enchanced when morphology is used to select the E/S0 galaxies. The high image quality of VLT allows us also to measure the effective radius for those galaxies well described by an $r^{1/4}$-law. We find that the size-magnitude relation at $z \sim 1$ is similar to that found in local clusters, but it appears shifted by about 1.2 mag. This means that galaxies at $z \sim 1$ would be brighter than their local counterparts in about 1.2 mag. This results are consistent with models of early formation and passive evolution for the stellar population in these galaxies and with previous studies at similar redshifts.

Preliminary analysis of the systematic differences found in the effective radius measured in two bands show that this can be interpreted as a color gradient for the E/S0 galaxies. We find that the color gradient distributions for the E/S0 galaxies are similar in 4 clusters at $z \sim 1$ and stepper than what is observed for local galaxies. These color gradients are in good agreement with models including either a metallicity gradient alone or a mix between a metallicity and an age gradient.

The preliminary results presented here show a consistent picture of a well developed population of E/S0 galaxies present in these first RCS clusters at $z \sim 1$. We are now in the process of obtaining spectroscopic redshifts for some of the $z \sim 1$ clusters and also deep optical-IR imaging to characterize the E/S0 population at different epochs.

References

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