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The Structure and Galaxy Population of the Most Distant Massive Clusters in the Southern Sky

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Abstract

In this work, we present first results of an unprecedented study of the galaxy populations of the two most distant massive clusters known to date in the southern sky, RXJ 0152 at $z = 0.837$ and RDCS 1252 at $z = 1.237$, selected from the ROSAT Deep Cluster Survey (Rosati et al., 1998). As part of a VLT large program, very deep wide-area near-IR imaging with VLT and NTT have been obtained, as well as extensive spectroscopy, which has yielded so far 78 secure cluster members for RXJ 0152 (Demarco et al. 2004, in prep.) and 28 secure members for RDCS 1252 (Rosati et al., 2004, in prep.).

Supporting observations for this project include: deep Chandra and XMM pointings which give detailed information on the physics and structure of the ICM; HST-ACS observations as part of a GTO program, which will deliver unprecedented morphological information of the member galaxies.

1.1 Introduction

Galaxy clusters are ideal laboratories to study the effects of enviroments on the formation and evolution of galaxies. An outstanding question is to understand the mode and epoch of formation of elliptical galaxies, which dominate present-day clusters. Predictions on the spectro-photometric properties of early-type galaxies in clusters based on hierarchical models of galaxy formation (Kauffmann 1996, Kauffmann & Charlot 1998) differ significantly at $z > 1$ from models in which ellipticals formed at high redshift in a monolithic collapse (Eggen et al., 1962). The lack of clusters discovered at redshift ≥ 1 has not enabled to properly address these issues. However, in the past few years the new generation of ground-based and space-based telescopes, such as VLT, Keck, HST and Chandra, have allowed the confirmation of more distant clusters and also a more detailed study of their internal structure. Two of these high redshift clusters are RXJ 0152 (Della Ceca et al., 2000) and RDCS 1252 (Rosati et al., 2004, in prep.), whose structure and galaxy population are the subject our study. In the following section we present our first results on these two distant clusters.

Table 1.1. *Data in hand for RXJ 0152 and RDCS 1252*

Cluster	z	X-ray Imaging	Optical and NIR imaging	Optical Spectroscopy
RXJ 0152.7-1357	**0.837**	Chandra (37 ks)	Keck+LRIS : B, V, R, I VLT+FORS : R NTT+SOFI : J, K HST+ACS : i, z (27 orbits)	VLT+FORS : 19h 141 redshifts **78 Cluster members**
RDCS 1252.9-2927	**1.237**	Chandra (190 ks) XMM (130 ks)	VLT+FORS : B, V, R, I, z NTT+SOFI : J, K **VLT+ISAAC : J ($5\sigma_{lim}$: 25.7AB)** **: K ($5\sigma_{lim}$: 24.3AB)** HST+ACS : i, z (32 orbits)	VLT+FORS : 30h 161 redshifts **28 Cluster members**

1.2 Results

1.2.1 The data set

The data in hand for both clusters are summarised in table 1.1. Both clusters have been targeted with Chandra and XMM. Ground-base photometry in B, V, R, I, J and K have been obtained for RXJ 0152 with Keck, VLT and NTT. On the other hand, the B, V, R, I, z, J and K photometry of RDCS 1252 comes from VLT and NTT observations, where very deep imaging in J ($5\sigma_{lim}$: 25.7 AB) and K ($5\sigma_{lim}$: 24.3 AB) was obtained with ISAAC in very good seeing (0.48) conditions. These observations are complemented by HST/ACS imaging in the *i* and *z* bands obtained by the ACS Science Team as part of the GTO program to study the formation and evolution of clusters (see contributions by Rosati and Postman at this meeting).

Our extensive spectroscopic survey on both clusters have been carried out with FORS on VLT. MOS and MXU masks were designed to target cluster candidates and the 150I and 300I grisms were used. A total of 19h (9 masks) for RXJ 0152 and 30h (10 masks) for RDCS 1252 have been observed.

1.2.2 RXJ 0152.7-1357

RXJ 0152 is one of the most distant massive clusters of galaxies known in the southern sky, akin to MS1054-03 (Donahue et al., 1998; van Dokkum et al., 1999). The statistical analysis based on 141 secure redshifts, from which 78 correspond to confirmed cluster members, gives a median redshift of $z = 0.837$ and a global velocity dispertion of $\sigma_v \sim 1300$ km/s (Figure 1.2), with significant velocity substructure (Girardi et al., 2004, in prep.). The galaxy distribution and the X-ray structure are shown in Figure 1.1. The complex structure of both galaxy and X-ray distribution (see Maughan et al., 2003) is clearly seen : the central part of the cluster is devided in two main clumps, North and South, while a third structure at ~ 1 Mpc to the East of the main one, is also visible. The emergent picture based on the clumps distribution on the plane of the sky and redshift, indicates that RXJ 0152 is a forming cluster in a merging phase. The spectrum of the 4 AGNs visibles in the FORS fov was obtained, indicating that one of them is a cluster member (Demarco et al. 2004, in prep.).

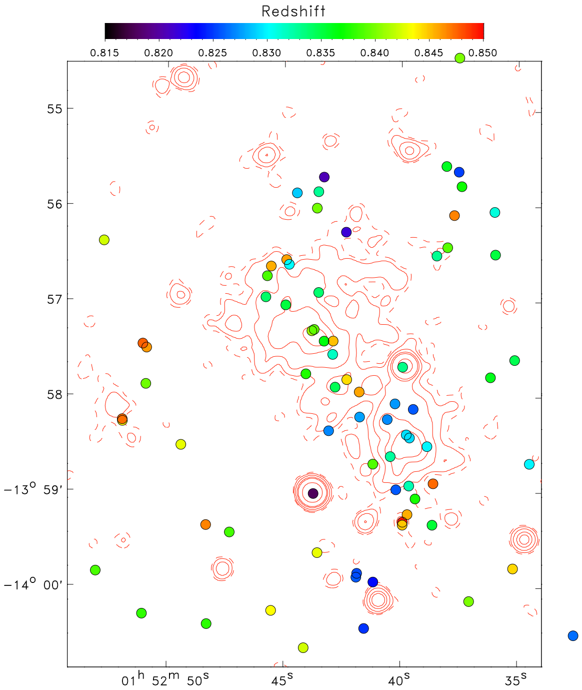

Fig. 1.1. **RXJ 0152.7-1357:** The color circles are member galaxies as seen on the plane of the sky, and individual reshifts has been color-coded as shown in the color table. Chandra X-ray contours (3, 5, 10, 20 and 30 sigma over the background) are also overlaid on the galaxy distribution. From the colors it is clear that the southern clump is at lower redshift than the northern one, being the clump to the East the farther. This picture indicates that RXJ 0152.7-1357 is a forming cluster in a merging phase.

1.2.3 RDCS 1252.9-2927

RDCS 1252 is one most distant clusters known. So fare we have been able to obtain 161 redshifts, and confirm 28 cluster members with a median redshift of $z = 1.237$ and a global velocity dispertion of $\sigma_v \sim 760^{+117}_{-69}$ km/s for the members distribution. This cluster presents a more relaxed structure than RXJ 0152, although it is elongated as well, and several OII(3727) emission line member galaxies, where star formation is on-going , have been detected (Figure 1.3). The combined spectra of the 10 brightest early type member galaxies indicate the existance of a relatively young ($\sim$ 1 Gyr) stellar population in bright early type galaxies, although no on-going star formation has been detected (see contribution by Rosati at this meeting; Rosati et al. 2004, in prep.).

1.3 Conclusions

In the present work, we present firs results of an unpresedented study of the two most distant massive clusters in the southern sky: RXJ 0152 ($z = 0.837$) and RDCS 1252

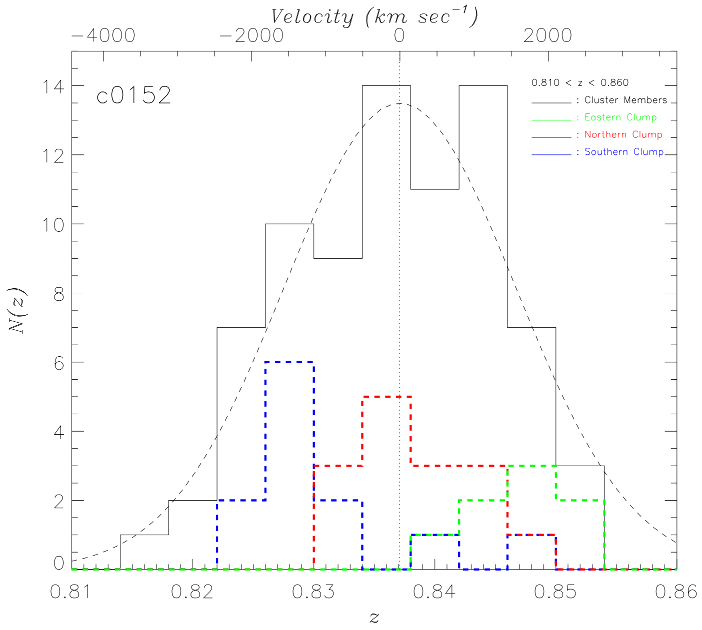

Fig. 1.2. **RXJ 0152.7-1357:** Redshift distribution of galaxy members. The color dashed lines show the position of the three main clumps: North (red) with 15 members, South (blue) with 12 members and East (green) with 8 members. The solid line corresponds to the histogram of the whole set of 78 cluster members. The gaussian shows the best fit of the overall distribution. The statistical analysis of the data gives a global velocity dispertion of $\sigma_v \sim 1300$ km/s and a median redshift of $z = 0.837$, with significant velocity substructure (Girardi et al., 2004, in prep.).

($z = 1.237$). The confirmation of 78 spectroscopic members in RXJ 0152 (Demarco et al., 2004, in prep.) and 28 spectroscopic members in RDCS 1252 (Rosati et al., 2004, in prep.) is the result of an extensive spectroscopic follow-up of both clusters and an efficient selection criteria based on the galaxy distribution in color space. The high quality of our spectroscopic data (see contribution of Rosati at this meeting) enables us to firmly characterize the underlying stellar populations of galaxies in these high redshift systems, thus allowing us to better constrain the mode and formation epoch of cluster early types. X-ray, optical and near-IR imaging, together with spectroscopic information, is providing a comprehensive picture of the internal structure and dynamics of these clusters.

Although RDCS 1252 presents a more relaxed structure compared to RXJ 0152, both clusters are clearly elongated. In the case of RXJ 0152, the filamentary structure observed in its galaxy distribution agrees very well with the X-ray distrubution (Maughan et al. 2003) of the ICM. There is strong evidence for significant substructure in this system (Girardi et al., 2004, in prep.), which supports the picture of a young cluster in a merging phase. On the other hand, HST+ACS imaging obtained by the ACS-GTO team have made it possible to obtain unprecedented morphological information of such a distant systems, which is of great

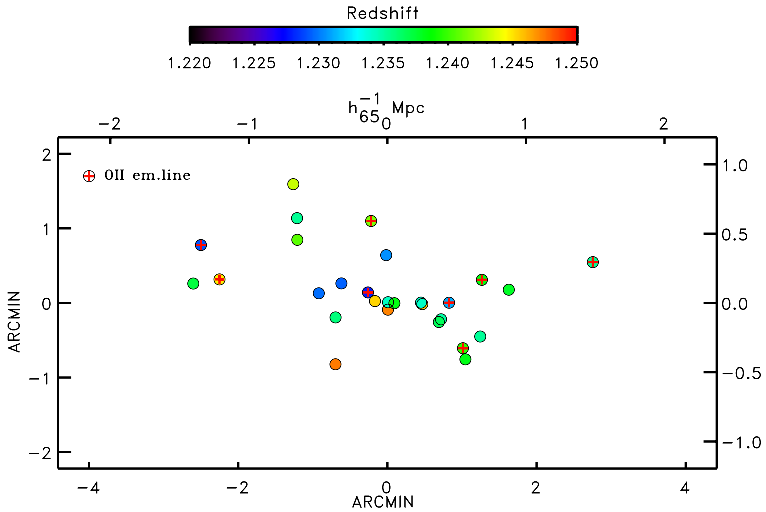

Fig. 1.3. **RDCS 1252.9-2927:** Color circles are spectroscopic member galaxies as seen on the plane of the sky, and individual reshifts have been color-coded as shown in the color table. The overall shape of the galaxy distribution is an elongated one in a East-West direction. The red crosses on top of the circles indicate galaxies with OII emission lines.

importance to understand environmental effects on the galaxy population and evolutionary effects according to galaxy type.

References

Della Ceca, et al. 2000, A&A, 353, 498
Demarco, R., et al. 2004, in preparation
Donahue, M., et al. 1998. ApJ, 502, 550
Eggen, O., et al. 1962, ApJ, 136, 748
Girardi et al. 2004, in preparation
Kauffmann, G. 1996, MNRAS, 281, 487
Kauffmann, G., & Charlot, S. 1998, MNRAS, 297, 23
Maughan, B. J., et al. 2003, ApJ, 587, 589
Postman, M. 2004, in Carnegie Observatories Astrophysics Series, Vol. 3: Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution, ed. J. S. Mulchaey, A. Dressler, & A. Oemler (Pasadena: Carnegie Observatories, http://www.ociw.edu/ociw/symposia/series/symposium3/proceedings.html)
Rosati, P. 2004, in Carnegie Observatories Astrophysics Series, Vol. 3: Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution, ed. J. S. Mulchaey, A. Dressler, & A. Oemler (Cambridge: Cambridge Univ. Press), in press
Rosati, P., et al. 2004, in preparation
Rosati, P., Della Ceca, R., Norman, C., & Giacconi, R. 1998, ApJ, 492, L21
van Dokkum, P., et al. 1999, ApJ, 520, L95