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Early-type galaxy formation: understanding the role of the environment

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Abstract. One of the most characteristic features of galaxy clusters is the so-called "red sequence" (RS) of early-type galaxies. Since these galaxies are, in general, devoid of gas and dust, their red colors are mainly a consequence of their passive nature. However, the physical mechanisms responsible for quenching their star formation, thus originating the RS, are poorly understood. Environmental effects should play a significant role in the formation of the RS by transforming the observed galaxy properties from late to early-type ones. In this respect, we have initiated a KMOS program aimed at studying the kinematical structure of cluster galaxies at $0.8 < z < 1.7$ in an effort to disentangle the physical mechanisms responsible for cluster galaxy evolution and the formation of the RS.

Keywords. galaxies: early-type - galaxies: formation - galaxies: clusters of galaxies

1. Introduction

Observations indicate that the RS begins to form at $z \sim 2.5$ and that by $z \sim 1.4$ is already well established, becoming more apparent in clusters than in the field (Tanaka *et al.* 2005; Kodama *et al.* 2007; Zirm *et al.* 2008; Hilton *et al.* 2009). However, how this actually happens is still unclear. Are early-type galaxies formed directly as such in proto-cluster or field environments through self-quenching mechanisms regulated by their halo mass (nature)? Or do early-type galaxies get into the RS when located in cluster outskirts or group environments in in-falling matter filaments (nurture)? When and where do the effects of ram-pressure stripping and galaxy-galaxy interactions (e.g. harassment, mergers, low-speed encounters; Treu *et al.* 2003) become the dominant way in which galaxies become passive and enter the RS in color-magnitude space? All these processes, whatever their relative importance, should affect the kinematics, spatial distribution and content of the (molecular and ionized) gas component of galaxies. The available observational evidence shows that it is possible, when comparing with numerical models, to establish the most likely cause of any observed kinematical and structural anomaly (Puech *et al.* 2009; Hammer *et al.* 2009). However, these analyses have been done mostly for field galaxies, with systematic and comprehensive studies of the kinematics and detailed structure of baryons in cluster galaxies being still scarce.

Cluster Name	Redshift	Selection	Photometry	Spectroscopy
RXJ0152-13	0.84	X-Ray	ACS/WFC-3, Hawk-I/ISAAC, Spitzer Chandra, VLA, Herschel	yes (FORS2)
XMMJ1229+01	0.98	X-Ray	ACS/WFC-3, Hawk-I/ISAAC	yes
RDCSJ1252-29	1.24	X-Ray	ACS/WFC-3, Hawk-I/ISAAC Spitzer, Chandra	yes (FORS2)
XMMJ2235-25	1.39	X-Ray	ACS/WFC-3, Hawk-I/ISAAC	yes (FORS2)
XMMJ2215-17	1.45	X-Ray	ACS/WFC-3, Hawk-I/ISAAC	yes
ClGJ0218-05	1.62	IR	ACS/WFC-3, Hawk-I/ISAAC	yes

Table 1. Sample of galaxy clusters in our KMOS program. A total of 44 hours of KMOS time has been assigned to this program. Observations are in progress.

2. Datasets and the KMOS observations

Here we aim at exploiting the capabilities of KMOS on the ESO VLT to map out the kinematical structure, spatial distribution and overall properties of the ionized gas components of cluster galaxies at $0.8 < z < 1.7$ (see Table 1). We will search for the presence (or lack) of signatures of the different environmental (galaxy-ICM and galaxy-galaxy) interactions to better understand the physical mechanisms responsible for stellar quenching and the formation of the RS in clusters of galaxies.

The galaxy clusters selected for this program already have extensive spectroscopic and multi-wavelength photometric datasets available (see Table 1). Observational evidence indicates that the most likely place where galaxy transformation and star formation quenching in clusters can occur is their intermediate density regions (e.g. Nantais *et al.* 2013). Star forming galaxies in these regions may show the effects of environmental interactions on their gas content and, therefore, provide key piece of information to understand how galaxies can speed up gas consumption and/or induce gas loss. We focus on the rest-frame Hα emission as a more robust star formation rate (SFR) indicator. We hence select galaxies with [OII] emission to be observed in the YJ- and H-band gratings of KMOS depending on the redshifts. Observations, still in progress, are designed to detect Hα down to a SFR limit of $\sim 5\ M_\odot\ yr^{-1}$ with a signal-to-noise ratio of 10 Å^{-1}, which translates into observing times between 5 and 10 hours (including overheads) depending on the target. The information obtained on the kinematical structure of the hot (ionized) gas component of galaxies will be integrated with that from the cold (molecular) gas structure provided by ALMA (future proposals). All this information will be used to achieve a comprehensive view of cluster galaxy quenching and the formation of the RS.

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