We present first results on the use of a colour space filter for detecting galaxy clusters at cosmological redshifts in the XMM Large Scale Structure Survey. All clusters studied, but one, are successfully colour–detected in spite of their large redshift (0.3 < z < 1.0), X–ray selection and intrinsic low richness (R = 0 or below). We experimentally show that the cluster redshift can be derived, with good accuracy, from the colour of the red sequence, at 0.06 < z < 1 using a sample of about 160 clusters.

1 Introduction

The XMM–Large Scale Structure (XMM–LSS) is a unique project, currently gathering a multi-\lambda coverage over a single area of some 6 deg$^2$: X–ray (XMM), optical/near–infrared (CFHTLS, CTIO, UKIDSS), Mid/Far–infrared (Spitzer Legacy: SWIRE), Radio continuum (VLA survey), UV (Galex) (Pierre et al.\cite{Pierre}, Andreon & Pierre\cite{Arendon}). Since the cluster number density and correlation function depend on key cosmological parameters, such as the matter density, $\Omega_m$, and, even more sensitively, the present–day amplitude of density fluctuations on scale of 8 Mpc, $\sigma_8$ (see Refregier et al.\cite{Refregier}, Evrard et al.\cite{Evrard}), an efficient cluster detection is very important. Several techniques (X–ray, optical, Sunayev–Zeldovich effect, lensing) are being used with success to efficiently detect clusters of galaxies out to $z \approx 1$ and above. The use of many methods should give us an insight on the selection effects of each technique, and correspondingly the impact of the derived cluster characteristics.

One of the methods used for cluster detection makes resemblance to the ”red sequence” method (Gladders & Yee\cite{Gladders}), but differs in several key areas (see Andreon\cite{Arendon} for details). Both methods exploit the observed trend that the majority of galaxies in clusters display similar
colours, while non–cluster galaxies located along the line–of–sight display considerable variation of observed colours, both because they are drawn from a larger interval of redshift and because the field galaxy population at a given redshift displays a larger variation in colour than a typical cluster galaxy population (see Fig 1).

Here we focus on 18 clusters at $z \gtrsim 0.3$, most of which drawn from the XMM–LSS survey. Out of the 18 clusters, 16 are X-ray selected. Observations have been performed in $R$– and $z'$–band ($\lambda_c \sim 9000\AA$) at the Cerro Tololo Inter–American Observatory (CTIO) 4m Blanco telescope during two observing runs (2000–2001) with the Mosaic II camera. Mosaic II is a $8k \times 8k$ camera with a $36 \times 36$ arcminute field of view. Typical exposure times were 1200 seconds in $R$ and $2 \times 750$ seconds in $z'$. A throughout discussion of most of the results presented here can be found in Andreon et al. When noted, this sample is supplemented by 140 clusters at $0.06 < z < 0.3$ colour–detected using SDSS photometry (see Andreon 2003 for details).

2 Results

The colour distribution of galaxies brighter than the $z'$–band completeness limit within each cluster field is displayed in Figure 1 for the $18 z \gtrsim 0.3$ clusters. The colour distribution along the cluster line of sight is compared to the colour distribution measured in a $0.3 \text{ deg}^2$ control field and normalized to the cluster area to which it is compared. All clusters within the sample display a significant numerical excess over a limited colour interval (typically $\pm 0.3$ mag), indicating that clusters may be identified effectively by methods that employ colour selection to suppress background galaxy signals. All clusters, with the exception of XLSSC 007, were in fact colour–detected at high significance.

The clusters shown in Fig. 1 display a range of masses (as determined by either dynamical or
Figure 2: Left: Histogram of the difference between $z_{\text{spect}}$ and $z_{\text{phot}}$ the latter derived from the $g - r$ colour of the red sequence, for 140 clusters in the $0.06 < z < 0.30$ redshift range (Andreon 11). The curve is a Gaussian of the same scatter (0.018 in $z$). Right: Spectroscopic vs photometric redshift, the latter derived from the $R - z'$ colour of the red sequence for 18 clusters, mostly in the XMM–LSS survey.

X–ray information, or both). In particular, XLSSC clusters at $z < 0.6$ display X–ray luminosities comparable to low richness clusters or groups (see Andreon et al 3 and Willis et al 12). Therefore, the detection of galaxy overdensities in the 3D–space defined by colour and sky location, at the location of extended X–ray sources, indicates that such techniques may provide a promising route to confirm the nature of low mass X–ray selected clusters.

However, the failure to combine X–ray data with colour selected cluster samples could lead to a number of sources of bias, as colour plus position selection alone does not constrain the extension in redshift of the identified structure. A filamentary structure of galaxies seen along the line of sight is, without spectroscopic data, hard to distinguish from a cluster and both scenarios can in principle give rise to the “cluster” detection. Spectroscopic observations of a sample of colour selected structures are therefore required to measure the frequency of each type of structure (clusters versus non–virialised large–scale structure).

The spectroscopic cluster sample presented in this paper contains one colour selected cluster undetected in X–ray (RzCS 011, at $z = 0.494$). This system is confirmed spectroscopically and displays a well–defined mean redshift and distribution of rest–frame velocities. It is, therefore, a cluster in the sense of being a gravitationally bound systems of galaxies, although undetected in X–rays. Therefore, colour selection techniques provide a method to identify clusters displaying a broad range of X–ray properties, possibly sampling the cluster mass function deeper than X–ray observations.

Figure 2 shows a measure of the performance of photometric redshifts derived from the colour of the red sequence. The right panel of Fig. 2 shows the photometric vs spectroscopic redshift comparison for 18 clusters shown in Figure 1. The photometric redshift assumes that the colour of the red sequence evolves as a passive “elliptical” galaxy, i.e. following the colour track of Kodama & Arimoto 6, as detailed in Andreon et al 3. The agreement is good. Error bars are larger at the two redshift ends because the photometric redshift accuracy is proportional to the inverse of the derivative of the colour–redshift relationship, which is flatter at the two redshift extrema than in between. At these ends, another choice of filters would be more effective for the photometric redshift determination, such as those allowed by the upcoming CFHLS and UKIDSS projects. On the left panel, the $g' - r'$ SDSS colour is used, for 140 colour–detected
clusters in the $0.06 < z < 0.30$ redshift range (Andreon). The scatter amounts to only 0.018 in redshift, at least three time better than most photometric redshift estimates. Puddu also show a similar comparison for a small, but X-ray selected, cluster sample.

The extremely good performance of the red sequence colour as a redshift indicator is hardly surprising, because of the implicit selection of one single type of galaxies with a distinctive 4000 Å break (spectrophotometric bright early–type galaxies) and of the colour homogeneity of the early–type galaxy class (e.g. Stanford, Eisenhardt, & Dickinson, Kodama et al., Andreon, Andreon et al.). Therefore, the red sequence colour is a good redshift estimator, modulo the poorly sampled region $0.6 < z < 0.9$. Recent spectroscopic observations performed at VLT, as well optical photometry at CTIO, by the XMM–LSS Survey have already filled this region.

Conclusions

All clusters studied in Andreon et al. with one exception, are successfully colour–detected (Fig 1). Most of the clusters are identified in X–rays, largely independent of the optical luminosity and colour of the cluster galaxies. Therefore, their colour–detection is non–trivial. The majority of the clusters are optically poor (Abell richness class 0 or lower) consistent with the low computed X–ray luminosities and velocity dispersions. We have therefore demonstrated, using real clusters, that a colour plus spatial overdensity search technique can effectively identify optically poor systems at intermediate to high redshifts (at least those previously identified in X–rays).

The colour selection techniques provide a method to identify clusters possibly sampling the cluster mass function deeper than (our) X–ray observations (typically, 10 to 20 ks with XMM).

The cluster redshift can be derived, with good accuracy, from the colour of the red sequence (Fig 2). However, astrometry and photometry do not constrain the extension in redshift of the identified structure (a cluster–sized structure, or a much larger one?), and, therefore, attention should be paid to systematics introduced by the uncertain nature of such purely colour selected systems in cosmological applications. Ultimately, a spectroscopic survey of a random subsample of high redshift colour–detected clusters is needed to ascertain the frequency of each structure.

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