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SIMULATING MOCK CATALOGUES TO PROVIDE ACCURATE CLUSTER SELECTION FUNCTIONS.

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Abstract. Galaxy clusters are one of the main probes to constrain dark energy parameters in the present theories of formation and evolution of the Universe. Many present and future surveys are expected to provide large number of clusters ranging both a wide range of mass and redshift. In this summary, we introduce recent results on present galaxy cluster and groups samples extracted from datasets with different properties. In particular, we demonstrate that datasets with similar depth are able to detect clusters and groups with high reliably down to lower masses if the photometric redshift resolution is higher. We also present preliminary work performed on predicting the cluster selection function for clusters in next generation surveys. We first describe the main mock catalogue, transformed to make the photometry more realistic for each different survey and we finally report some results regarding the photometric redshift accuracy obtained for the next-generation surveys considered and their corresponding cluster selection functions obtained.

Keywords: Galaxies: clusters: general, Galaxies: groups: general, Cosmology, Cosmology: cosmological parameters, Cosmology: observations, Cosmology: dark matter, Cosmology: dark energy, Cosmology: large-scale structure of Universe, Galaxies: evolution

1 Introduction

Galaxy cluster surveys are very powerful tools to constrain cosmological scenarios and study evolutionary trends on galaxy evolution in dense environments. At present, a wide range of surveys exists in the literature, many of which have been detecting galaxy clusters with a variety of optical/IR methods (see Ascaso 2013 and references herein), as well as other non-optical techniques such as X-rays, SZ techniques, Weak Lensing, etc (e.g. Allen et al. 2011). With the advent of the next-generation surveys, a large percentage of the observable sky will be completed and we need to estimate the selection function of the future cluster samples with high accuracy to exploit at maximum their potential at setting constraints on cosmology and galaxy evolution scenarios.

In this summary, we start in section §2 by reviewing some results on present cluster samples detected with the Bayesian Cluster Finder (sect §2). Then, in section §3, we introduce a representative sample of next-generation surveys and the numerical simulation used in this work to reproduce realistically the properties of these surveys. Finally, in section §4, we mention briefly some results on the photometric redshift performance and selection function of these next generation surveys.

2 Galaxy cluster samples in present surveys

2.1 The Bayesian Cluster Finder

The Bayesian Cluster Finder (BCF, Ascaso et al. 2012, 2014) is a technique developed to detect galaxy clusters based on the matched filter algorithm (Postman et al. 1996) from a Bayesian point of view. The method is able to determine the position, redshift and richness of the cluster through the maximization of a filter depending on galaxy luminosity, density and photometric redshift combined with a galaxy cluster prior that accounts for color-magnitude relations and brightest cluster galaxy-redshift relation. One of the main advantages of this method is that galaxy clusters and groups without a well-formed red sequence can still be detected.

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2.2 Considered present surveys

Currently, we have applied the BCF to three present surveys: the CFHTLS-Archive Research survey (CARS, Erben et al. 2009), the Deep Lens Survey (DLS, Wittman et al. 2002) and the Advanced Large, Homogeneous Area Medium Band Redshift Astronomical (ALHAMBRA) Survey (Moles et al. 2008). Each of these surveys was designed with different purposes and therefore, they have very different features.

The CARS is a wide-area (37 deg^2) relatively deep (I$\leq$25.5 mag/arcsec^2), five-band optical survey, providing a expected photometric resolution, $\Delta z/(1+z)$, of $\sim$ 0.06 (Erben et al. 2009). The DLS is a 20 deg^2 very deep (R$\leq$27.5 mag/arcsec^2), four ($BVRz^{'}$) optical survey, with an expected photometric resolution of $\sim$ 0.08 (Schmidt & Thorman 2013). Finally, the ALHAMBRA survey is a smaller area (4 degrees square survey divided in 8 different regions), imaged with 20 narrow-band filter and three infrared JHK bands, providing a photometric resolution of $\sim$ 0.01 (Molino et al. 2014) and an estimated depth of $F_{814W} \leq 24.5 mag/arcsec^2$.

We have applied the BCF to these different surveys to detect galaxy clusters and groups (see Ascaso et al. (2012), Ascaso et al. (2014) and Ascaso et al. in prep for the CARS, DLS and ALHAMBRA survey respectively). The resulting cluster and group samples are spread within different redshift and masses ranges and we have demonstrated that all the detections agree well (>80%) with overlapping optical, spectroscopy, weak lensing and X-ray samples confirming the reliability of the methodology.

One remarkable result extracted from the comparison of these surveys is the fact that, for a similar depth survey, the photometric resolution of the survey is directly related to the minimum mass threshold that we expect to detect galaxy clusters with high completeness and purity. For instance, based on simulations, we obtain that for the ALHAMBRA survey, we can reliably detect groups down to $10^{13.7} M_\odot$ whereas for the CARS survey, the mass threshold we obtained was $10^{14.2} M_\odot$. This discovery has motivated us for investing effort in investigating the performance of the photometric redshift of next-generation surveys and developing techniques to improve their performance, if possible (see next section).

3 Galaxy cluster samples in next generation surveys

While present optical cluster samples do not allow to significantly set constrains on dark energy models such as the dark energy equation of state; this is not the case for samples extracted from next generation surveys where unexplored ranges of redshift and mass are going to be explored. We then present here a project consisting of studying consistently the photometric redshift performance of different next-generation surveys to measure their cluster selection function. We will eventually set cosmological constraints on dark energy parameters with a variety of models.

3.1 Next generation surveys considered

We have selected three of the most relevant next-generation stage IV surveys (Albrecht et al. 2006). Following a chronological order of starting date, we have first considered the Javalambre-Physics of the Accelerated Universe Astrophysical Survey* (J-PAS, Benitez et al. 2014). This survey, starting in 2015, is a 54-narrow band, very wide field cosmological survey covering 8600 square degrees of the northern sky imaged from the Javalambre Observatory in Teruel (Spain). The depth of the survey is expected to be $\sim$23.5 AB in all bands and the overall photometric redshift performance of 0.003(1+z) down to 22.5 AB according to simulations (Benitez et al. 2014, Ascaso et al. 2014 in prep, Zandivarez et al. (2014)).

Secondly, we have considered the Large Synoptic Survey Telescope† (LSST, Ivezic et al. 2008), starting in 2018. The LSST will become a large, wide-field ground-based survey, imaging the whole visible southern sky from an 8.4m telescope Cerro Pachon (Chile) with six broad-band optical bands *ugrizy* down to r=27.5 AB after coadding 10 years of operations.

Finally, in 2020 the Euclid survey‡(Laureijs et al. 2011) will be started. The Euclid Wide Field will cover 15,000 square degrees of the sky in the near IR (YJH), down to $\sim$24 mag in H band providing also near-IR spectroscopy and the survey will also include two Deep Fields, about 2 magnitude deeper than the wide survey which will cover around 20 square degrees each. The Euclid space observations will be combined with other space and ground-based observations to obtain the source photometric redshifts and physical properties.

*http://j-pas.org/
†http://www.lsst.org/lsst/
‡http://www.euclid-ec.org/

Among the optical surveys that will be available from the ground, one is already available, the Sloan Digital Sky Survey (SDSS), and two are planned: the LSST and the Dark Energy Survey (DES, The Dark Energy Survey Collaboration 2005). Hence, we will consider two cases for this survey: the case where the optical counterpart will come from the DES + LSST and the case where the optical counterpart will only come from the DES survey.

3.2 *Creating realistic mock catalogues*

We have developed a method that, given an input mock catalogue, is able to recalibrate the photometry by using a fully representative empirical set of realistic templates and simulate the expected conditions for a particular survey (Ascaso et al. in prep). This methodology was already applied in Arnalte-Mur et al. (2014), where we showed that obtaining photometric redshifts directly from mock photometry mimicking the ALHAMBRA survey provided a mean photometric redshift dispersion three times higher than the expected for the real data (Molino et al. 2014).

As a basis to create our mock catalogues, we have used a mock catalogue based on the publicly available light cone mock catalogues by Merson et al. (2013). These catalogs are extracted from an N-body simulation from the Millennium simulation, (Springel 2005) and semi-analytic model of galaxy formation from GALFORM (Cole et al. 2000; Bower et al. 2006). The chosen mock catalogue covers 500 deg^2 down to very deep magnitudes (K$\sim$24). It is well known that semi-analytic galaxy formation models are not fully representing the observational universe. Some of the inconsistencies between those models and the observations are related to the inconsistency with the stellar mass function (see Mitchell et al. (2013) and references herein), luminosity function (e.g. Gonzalez-Perez et al. 2014), chemical abundances (e.g. De Lucia & Borgani 2012) and colors (e.g. Henriques et al. 2012), consequently producing a wrong tilt of the color-magnitude relation, 'plume' effects of redder galaxies belonging to the cluster spread within 1-2 bright magnitudes, absence of a smooth-transitory green valley and other related effects. These effects generally lead to an underestimation of the photometric redshift uncertainties.

We have applied the methodology described above to the Merson et al. catalogues. After re-creating the new photometry using the mentioned technique, we obtained that the photometric redshift accuracy exactly matched that obtained from real data (Ascaso et al., in preparation).

4 Results

We have studied the performance of the photometric redshift for each of the surveys considered as a function of magnitude and redshift. Also, we have considered making different quality cuts with the purpose of selecting a best quality subsample that can result into a best measurement for different scientific purposes.

We have disentangled some of the advantages of using each of these different datasets in terms of photometric redshift resolution. First, the advantage of using multi band narrow-band surveys is directly related to the level of photometric redshift accuracy and photometric redshift bias expected for the survey down to moderate magnitudes ($m < 23$) and redshift ranges ($z < 0.8$) . On the other hand, deep broad-band optical surveys allow to explore the luminosity function in the optical range even if with worse photometric redshift resolution. They are also an excellent complement for deep infrared surveys, particularly to dramatically decrease the rate of outliers and improve the photometric redshift accuracy. Finally, the deep infrared surveys provide an excellent photometric redshift accuracy in a wide range of redshift ($z < 3$) with a moderate rate of catastrophic outliers.

We have been detecting galaxy clusters in the mock catalogues and we have computed the completeness and purity of the results as a function of redshift and richness as shown in Fig.1 for the case of J-PAS. Based on these results, we expect to detect galaxy clusters and groups with completeness rates $> 80\%$ and purity rates $> 70\%$ for clusters and groups down to $M > 3 \times 10^{13} M_{\odot}$ up to redshift 0.8. At higher redshifts, the completeness rates decays. Let's note that the extremely good quality of the photometric redshifts in the J-PAS survey make these results comparable to what we would expect for a low-resolution spectroscopic survey, in agreement to our results found with present cluster samples (section 2.2).

We have finally created a cosmological pipeline that, based on the selection function provided by different survey, computes the Fisher Matrix of the cluster counts and provides different constraints for different cosmological parameters.

A way more extended and detailed version of these results will come up soon in a series of papers (Ascaso et al. in prep).

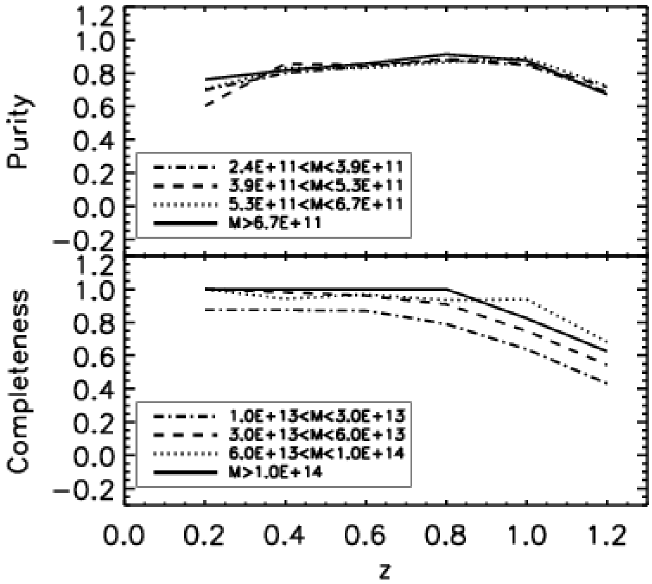

Fig. 1. Purity (top plot) and completeness (bottom plot) rates as a function of redshift for different dark matter halo and total stellar mass bins. While purity remains almost constant (~ 0.7) as a function of redshift, being lower for lower masses, we find a decreasing in the completeness rate with both redshift and mass.

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