SF2A 2013
L. Cambrésy, F. Martins, E. Nuss and A. Palacios (eds)

OPTICAL STUDY OF THE DAFT/FADA GALAXY CLUSTER SURVEY

N. Martinet[1], F. Durret[1], D. Clowe[2], C. Adami[3] and the DAFT/FADA team

Abstract. DAFT/FADA (Dark energy American French Team) is a large survey of ∼90 high redshift ($0.4 < z < 0.9$) massive (M$> 2 \times 10^{14}$ M$_\odot$) clusters with HST weak lensing oriented data, plus BVRIZJ 4m ground based follow up to compute photometric redshifts. The main goals of this survey are to constrain dark energy parameters using weak lensing tomography and to study a large homogeneous sample of high redshift massive clusters. We will briefly review the latest results of this optical survey, focusing on two ongoing works: the calculation of galaxy luminosity functions from photometric redshift catalogs and the weak lensing analysis of ground based data.

Keywords: Galaxies: clusters, luminosity function - Lensing: weak lensing

1 Introduction

The DAFT/FADA (Dark energy American French Team) project (`http://cencos.oamp.fr/DAFT/`) has been undertaken to tackle some questions of modern cosmology, such as the acceleration of the expansion of the Universe, the large scale structure formation and the Universe content. Galaxy clusters are particularly important in this context (e.g. Nichol (2007)). The two main goals of this large cluster survey are to build a large cluster database to mine for years, and to apply weak lensing tomography on a test sample to constrain dark energy and prepare future very large tomography surveys.

DAFT/FADA is a large survey of ∼90 high redshift ($0.4 < z < 0.9$) massive ($M > 2\times10^{14}M_\odot$) clusters. All of them have HST data (ACS or WPC2) allowing a weak lensing analysis. Thanks to archive data and about 70 nights granted to the survey on 4m class telescopes, we built a ground based follow up in the BVRIZ optical bands and in the J near infrared band (see `http://cencos.oamp.fr/cgi-bin/DAFT/daft_status.pl` for the detailed status of the survey). This multi-band database enables us to measure reliable photometric redshifts (see Guennou et al. (2010)). This exceptional data set will be used to perform weak lensing tomography with clusters (WLTC). This technique is based on the idea that every background galaxy around the cluster is weakly lensed, so the signal from the combination of all the background galaxies around the cluster can be measured at high signal-to-noise levels, over a large range of radii (see e.g. Jain & Taylor (2003)). This shear signal combined with the photometric redshifts of the background galaxies provide a purely geometrical method for determining w (the parameter in the dark energy equation of state). We already performed the weak lensing analysis of a subsample of about 10 ACS clusters (Murphy et al. (2013)) but need more clusters to get an estimation of w.

The ground based data have also been used to investigate some cluster properties such as the intra cluster light in distant clusters (Guennou et al. (2012)). Combining those with X-ray archive data (when available) and spectroscopic data, we investigated the evolution of substructures within clusters (Guennou et al. (2013a)) and conducted a joint strong lensing and dynamic study for the very massive cluster LCDCS0504 (Guennou et al. (2013b)).

Here we present two ongoing works: the calculation of galaxy luminosity functions from photometric redshift catalogs and the weak lensing analysis of ground based data. The first one will allow us to better understand

[1] UPMC Université Paris 06, UMR 7095, Institut d'Astrophysique de Paris, 98bis Bd Arago, F-75014, Paris, France, email: martinet@iap.fr
[2] Department of Physics and Astronomy, Ohio University, 251B Clippinger Labs, Athens, OH 45701
[3] LAM, OAMP, Université Aix-Marseille & CNRS, Pôle de l'Etoile, Site de Château Gombert, 38 rue Frédéric Joliot-Curie, 13388 Marseille 13 Cedex, France

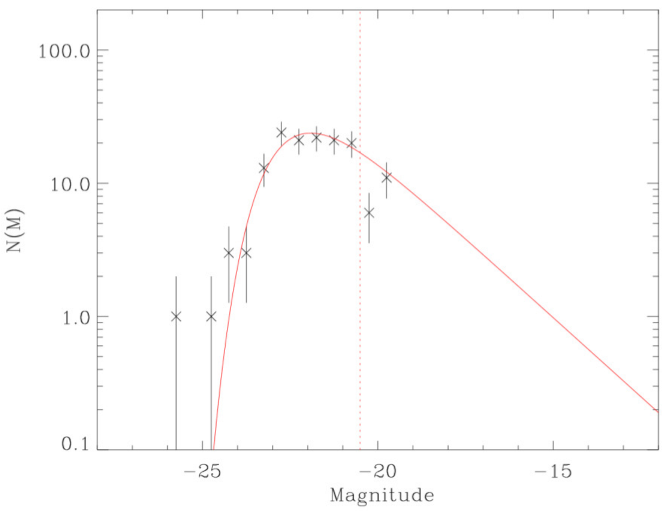
the optical behavior of clusters and their evolution with redshift. The second one will come as a complement to the substructure study already done with X-rays and spectroscopic data (Guennou et al. (2013a)) and will provide us with a shear catalog both deep and large, when combined with the HST imaging shear catalog.

2 Galaxy Luminosity Function

The current model of the Universe starts with the Big Bang and predicts the evolution of the density and density perturbation growth leading to the formation of large scale structures. In this framework, building a detailed picture of galaxy and large-scale structure growth is necessary to understand the Universe evolution. To achieve these goals we propose to analyse the evolution of the galaxy luminosity function (GLF) of clusters with both redshift and mass. There are contradictory results concerning the evolution of the faint end of the GLF which is said to decrease (Rudnick et al. (2009)) or to be constant (De Propris et al. (2013)) with redshift. Our sample presents a good redshift coverage and we should be able to discriminate between the two observed behaviours when the analysis is complete (Martinet et al. 2014, in preparation).

Magnitudes are extracted via the MAG_AUTO keyword of SExtractor (Bertin & Arnouts (1996)) on BVRIZ and J band images. We then cross-correlate our catalogs with a 2 arcsec matching radius. We compute our final photometric redshift (photo-z) catalog by applying the LePhare software (Arnouts et al. (1999), Ilbert et al. (2006)). LePhare compares the sampling of the spectrum with several theoretical spectral energy distributions and comes up with the best theoretical set of properties corresponding to the galaxy under study (photo-z, type, k-correction, color...). As we are using data from various telescopes we ask LePhare to model all the magnitudes as if the images had been taken at the VLT. Finally we correct for galactic extinction using the cirrus maps of Schlegel et al. (1998).

Cluster members are determined in a semi-statistical way, selecting galaxies with photometric redshifts in a $\pm$ 0.2 range from the cluster redshift. We then calculate a luminosity function in bins of 0.5 magnitude and retrieve field galaxy counts calculated in the same redshift and magnitude intervals by Ilbert et al. (2005). To be able to fit a Schechter function (Schechter (1976)) we then need to estimate the completeness of our sample. To do this we model a gaussian point spread function (PSF), include it in the image with a given magnitude and redetect it. The PSF is first estimated from the image stars using PSFEx (Bertin (2011)). We model a hundred stars for each bin of 0.5 magnitudes and try to redetect them. When the redetection rate is inferior to 90% we consider that we have reached the acceptable star completeness. The 90% completeness on galaxies is estimated to be lower than that of stars by $\sim$0.5 magnitude (e.g. Adami et al. (2006)), depending also on the galaxy type. As an example, the GLF of MS 1054-03 (hereafter MS 1054) in the R band is shown in Fig. 1 along with its best fit Schechter parameters. The fit is shown in red and only galaxies brighter than the 90% completeness limit (red vertical line) are taken into account.



	Schechter parameters
α	-0.41 $\pm$ 0.32
M*	-22.48 $\pm$ 0.34
ϕ*	63.7 $\pm$ 15.8

Fig. 1. MS 1054-03 (z=0.8231) R band galaxy luminosity function and parameters corresponding to the best fit by a Schechter function (red curve). The vertical red line shows the 90% completeness. Only galaxies brighter than this limit are taken into account when performing the fit.

The faint end slope of the Schechter fit to the GLF of MS 1054 is $\alpha = -0.41$. This is far from the usual slope of about -1 found for low redshift clusters (e.g. De Propris et al. (2013)). However, MS 1054 is at a redshift $z = 0.8231$ and this decrease of the faint end of the GLF could be in agreement with the behaviour of high redshift clusters observed by Rudnick et al. (2009). Of course, these are only preliminary results and we still have to check all the possible systematics in our analysis. For example, when combining our photometric catalogs we lose all the objects that are not detected in all 6 bands. This will be addressed soon by applying a completeness correction using single band catalogs.

3 Ground Based Weak Lensing

Since HST data are available for all the DAFT/FADA clusters, one could ask why bother making a weak lensing (WL) analysis on ground based data. Indeed, data from space are not contaminated by our atmosphere and therefore reach a much better seeing and completeness. However, even if ground based data are of lower quality, they are very useful because they cover a field of view much larger than that of the HST (3.4'×3.4' for ACS). With wider ground based images we will better sample the cluster to its outskirts, while the HST data only give access to the cluster core. In particular, WL on large fields will allow to study the substructures of clusters and to compare them with those detected from optical spectroscopy and from X-rays by Guennou et al. (2013a) and will help to break the mass sheet degeneracy to increase the accuracy of the WLTC. The final objective is to combine shear catalogs from HST and ground based images to obtain a shear catalog which is both large and deep in the cluster center.

The principle of lensing studies is to connect the distortion of light on background galaxies due to a foreground object called the lens. This distortion results in a size and shape modification (respectively the convergence and shear) of the lensed background galaxy images which are proportional to a linear combination of the second derivatives of the lens potential and to the ratio of the source and lens distances to the observer. In our case the measurement of the ellipticity of background galaxies lensed by a cluster gives access to the mass distribution of the cluster, knowing all distances through the calculated photometric redshifts. Our WL reduction follows the usual KSB method (Kaiser et al. (1995)). The main point is to measure the anisotropy of the instrument PSF on the stars found in the image and then to correct the galaxy shapes from this instrumental bias using some mathematical recipes. This method relies on the gaussianity of the PSF which can be a strong approximation for some instruments. Once we obtain corrected galaxy shapes, we reduce the noise by fitting the shear sample with polynoms and regenerating less noisy shear values. We also applied our programs to the simulated fields of STEP2 (Massey et al. (2007)) with constant shear in order to measure the bias of our technique. We found a 13% bias that we corrected for in our analysis. Object positions and magnitudes are extracted with SExtractor (Bertin & Arnouts (1996)) while ellipticities are measured with the IMCAT software (`http://www.ifa.hawaii.edu/~kaiser/imcat`).

The final step is to separate the background galaxies from the cluster members and the foreground galaxies. This is necessary to avoid diluting the shear signal when taking into account the ellipticities of galaxies which are not lensed by the cluster, and is usually done through a color color cut. As colors of galaxies reflect their components, they are linked to the galaxy formation history. Hence, using Bruzual & Charlot (2003) we can compute the theoretical color a galaxy should have according to its type and redshift. Fig. 2 shows a (B-V) versus (V-I) color–color cut diagram for LCDCS0541. The dashed region is the region removed from our catalog as corresponding to cluster members and foreground galaxies. Note that after we have all the photo-zs in hand we will perform a more acccurate cut, identifying the galaxies for which we are able to calculate the redshift.

A detection significance is obtained by fitting a singular isothermal sphere (SIS) profile centered on the optical center of the cluster (i.e. the BCG). The shear is then averaged in boxes and smoothed with FFT to draw contours of iso-mass on the original image. A comparison between the results obtained from the space analysis (Murphy et al. (2013)) and from the ground is given in Fig. 3 in the case of LCDCS0541. Both contour maps encircle the optical center and the detection significance is very similar: 7.9σ with VLT/FORS2 and 7.8σ with HST/ACS.

4 Conclusions

DAFT/FADA is a promising survey especially in terms of both cluster properties and lensing studies. As explained in the introduction we have already obtained some nice results using the optical data we have in hand: a large photometric redshift sample (Guennou et al. (2010)), an analysis of the intra cluster light of

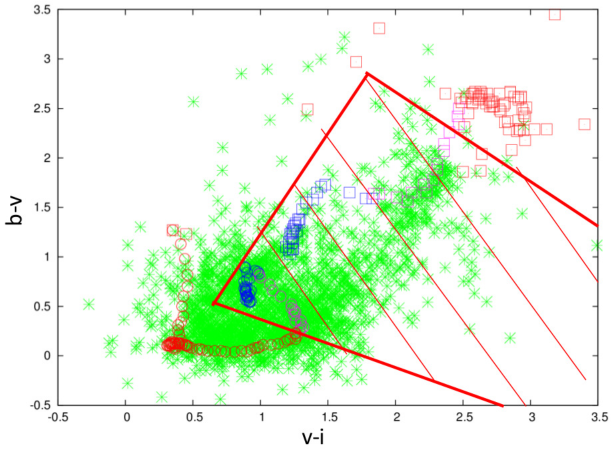


Fig. 2. B-V versus V-I color color diagram for LCDCS0541. Green crosses correspond to all observed galaxies. Blue, purple and red circles respectively correspond to theoretical spiral galaxies lower, in and higher than the interval of ± 0.2 around the redshift of the cluster. Blue, purple and red squares respectively correspond to theoretical elliptical galaxies lower, in and higher than the interval of ± 0.2 around the redshift of the cluster. The dashed region is the region removed from our catalog as corresponding to cluster members and foreground galaxies.

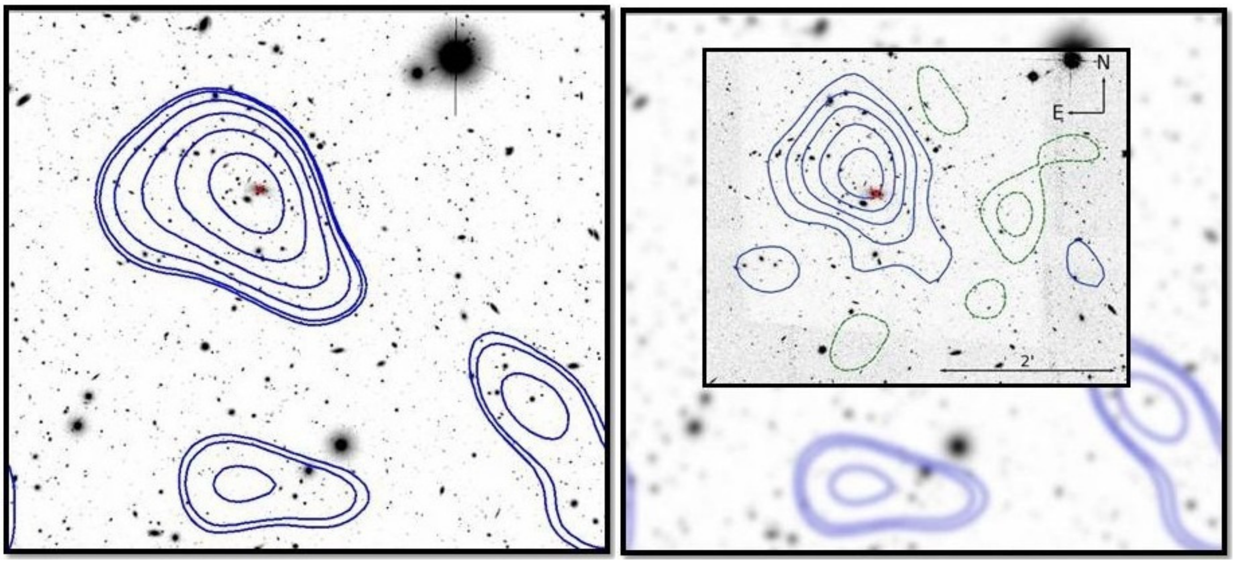


Fig. 3. Left: mass contour map of LCDCS0541 based on VLT/FORS2 data. The level of the weak lensing detection is 7.9σ. **Right:** mass contour maps of LCDCS0541 computed from 5 HST/ACS fields superposed to the ground based map. The level of the weak lensing detection is 7.8σ. Red crosses correspond to the optical cluster center.

distant clusters (Guennou et al. (2012)), an HST/ACS weak lensing reduction pipeline (Murphy et al. (2013)), a detailed picture of cluster substructures based on X-rays and optical spectroscopy (Guennou et al. (2013a)), and the detailed study of one cluster core with strong lensing and dynamics (Guennou et al. (2013b)).

We presented here two ongoing works with some nice prospects. First we showed how we computed the luminosity function of clusters using photometric redshifts. Note that the redshift coverage of our sample should allow us to discriminate between the two current behaviors of the faint ends of the GLF observed in the literature. Then we depicted how we conducted the weak lensing analysis on ground based images. We showed that even if ground based data are less deep than HST data, they allow to achieve comparable results thanks to their larger field of view. Our ultimate goal is therefore to merge both space and ground based catalogs to get a shear catalog which is deep in the cluster core and reaches the cluster outskirts with a lower galaxy density.

Acknowledgements: We acknowledge long term financial support from CNES.

References

Adami et al. 2006, A&A 451, 1159
Arnouts et al. 1999 MNRAS, 310, 540
Bertin, E. & Arnouts, S. 1996, A&AS 317, 393
Bertin 2011, ASPC 442, 435
Bruzual & Charlot 2003, MNRAS 344, 1000
De Propris et al. 2013, arXiv:1307.1592
Guennou et al. 2010, A&A 523, 21
Guennou et al. 2012, A&A 537, 64
Guennou et al. 2013a, A&A submitted
Guennou et al. 2013b, A&A submitted
Ilbert et al. 2005, A&A 439, 863
Ilbert et al. 2006, A&A, 457, 841
Jain & Taylor 2003, PhRvL, 91, 1302
Kaiser et al. 1995, ApJ 449, 460
Massey et al. 2007, MNRAS 376, 13
Murphy et al. 2013, ApJ submitted
Nichol 2007, ASPC, 379, 89
Rudnick et al. 2009, ApJ 700, 1559
Schechter 1976, ApJ 203, 297S
Schlegel et al. 1998, ApJ, 500, 525