

Galaxy Clusters activity within Euclid

S. Maurogordato

Laboratoire J.L. Lagrange, OCA, Nice

On behalf of the Euclid SGS/OU-LE3 WPs and SWG
Galaxy Clusters



Galaxy clusters as probes of dark energy

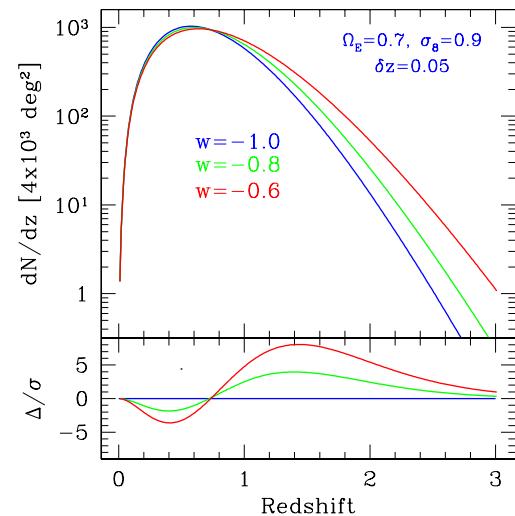
Distribution of cluster counts as a function of redshift and mass:

$$\frac{dN}{dz} = \Delta\Omega \frac{dV}{dzd\Omega}(z) \int_0^\infty f(M, z) \frac{dn(M, z)}{dM} dM$$

comoving volume element selection function halo mass function

Sensitive to DE:

- Growth rate of density perturbation
 - Volume element
-
- Different systematics than other probes
 - Combined with geometrical probes:
enable to discriminate DE/ modified gravitation



Mohr et al. 2002

Main challenges

- Mass is not a direct observable: assume proxies of mass
 - Scaling relation: Mass/observable
- One has in general to deal with a redshift estimate
 - improved photometric redshifts
- Control systematics in detection: purity/completeness
 - well controlled selection function

Cosmology with Clusters in Euclid

- Large sky coverage, Strong statistics, sampling the high z tail

Analytical estimated selection function of the photometric catalog nearly flat:
All Λ CDM clusters with $M > 2 \cdot 10^{14} M_{\odot}$ detected at 3σ up to $z=2$:
60000 clusters of which 18000 with $z > 1$

- Calibration of the mass-observable relation and scatter:
 - State of the art WL mass estimates
 - Multiwavelength Synergy for scaling relations: e-Rosita, Athena+, Planck,...

Cluster activity in Euclid

Science Working Group Clusters of Galaxies ~ 120 members (2014)

Leads: L. Moscardini , J. Weller , J. Bartlett 

Fix the science objectives

Requirements: pipeline products and performances

Final science analyses

Workpackages: <http://euclid.roe.ac.uk/projects/cgswg/wiki/>

- ◆ Sample Selection (A. Gonzalez, A. Iovino, L. Moscardini)
- ◆ Mass Modelling (A. von der Linden, M. Meneghetti, H. Hoekstra)
- ◆ Likelihood (S. Borgani, J. Weller)
- ◆ Statistics on Cluster Samples (J. Weller, J. Bartlett, L. Moscardini)
- ◆ Mass-Observable Relation (J. Bartlett, A. Biviano, S. Maurogordato)
- ◆ Validation (S. Bardelli, A. Stanford/M. Brodwin)
- ◆ Astrophysics of galaxy clusters (S. Mei, G. de Lucia)
- ◆ External Data (T. Reiprich, P. Rosati, J.B. Melin)

Requirements Task force

Cluster activity in Euclid

SGS: OU-LE3 WP Clusters of Galaxies

Implementation: Leads: A. Biviano , S. Maurogordato  ~ 65 members (2014)
Validation: Leads.: R. Pello , T. Giannantonio  ~ 25 members (2014)

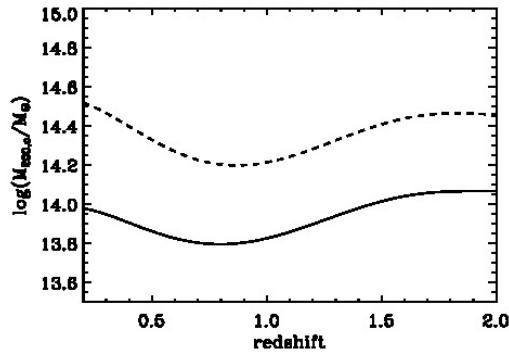
Tasks: Implement/validate algorithms

- Cluster detection & Selection Function
- Mass proxy estimates: richness – velocity dispersion – WL aperture masses
- Cluster Clustering

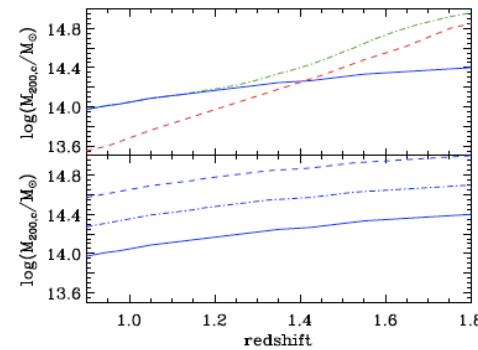
More on: <http://euclid.roe.ac.uk/projects/oule3-clus-impl/wiki>

I- Cluster detection and selection function

Photometric catalog

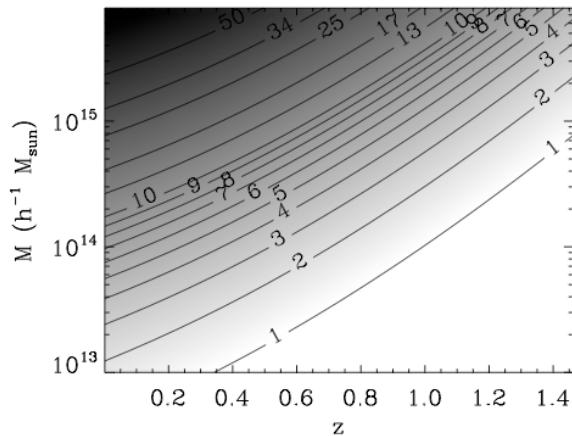


Spectroscopic catalog



Sartoris et al. 2015

Weak lensing



Bergé et al. 2010

The Euclid Cluster Finder Challenge

OU-LE3 CG WP

Objective:

to set in place a procedure to compare different cluster finder algorithms developed in the context of the Euclid mission

NOT to select one algorithm among the others (at this stage)

Participants:

S. Farrens, A. Iovino, A. Biviano, S. Maurogordato, C. Adami, F. Bellagamba, C. Benoist, A. Cappi, O. Cucciati, F. Durret, S. Farrens, A. Gonzalez, A. Iovino, R. Licitra, S. Mei, M. Roncarelli, S. Bardelli, J.G. Bartlett, C. Baugh, S. Borgani, A. Merson, L. Moscardini, M. Vannier

The Euclid Cluster Finder Challenge

Main steps (2013-2014)

- Definition of a protocol for comparing the cluster finders (WG led by A. Iovino)
- Test of the properties of mocks (WG led by A. Cappi)
- Preparation of the mocks for the challenge (A. Cappi)
- Set up of a secured platform in Nice to exchange the data
- Cluster finder algorithms are run on the mocks
- First results presented at Nice SWG/OULE3 meeting, 17/12/2013
- Analysis of the results by the TAG, document issued April 10th 2014
- Results presented at the Marseille Euclid consortium meeting May 5th 2014
- Second Cluster Finder Challenge ongoing
- Analysis of Second CFC at the Sesto Euclid meeting July 5-10, 2014
- EC document « Results from the analysis of the 1st round of the Cluster Finder Challenge »

The algorithms

Need to cover a wide variety of methods, density-based and using the properties of galaxies in clusters.

7 codes challenging:

- Optimal filtering – F. Bellagamba & M. Roncarelli  (CFC 1&2)
- Wavelet Z-Phot Cluster Finder – C. Benoist  (CFC 1&2)
- Friends of Friends – S. Farrens  (CFC 1&2)
- Wavelet adaptive – A. Gonzalez  (CFC 1&2)
- Voronoi-Delaunay tessellation – A. Iovino- O. Cucciati  (CFC 1)
- Galaxy overdensities + Red Sequence – R. Licitra & S. Mei  (CFC 1&2)
- Z-phot Tomography – C. Adami & F. Durret  (CFC 2)

The mocks

Parent catalog: Euclid 500 \square^2 light cone limited to $H \leq 24.1$ provided by the Durham group (C. Baugh & A. Merson) Millenium + SAM (Merson et al. 2013)

4 subsets 100 \square^2 (prepared by A. Cappi):

2 'blind' test catalogs: no information on real halos

2 calibration catalog: contains information about real halos

'good': $\sigma(z_{\text{phot}}) = 0.03 (1+z)$, 5% catastrophic

'bad': $\sigma(z_{\text{phot}}) = 0.05 (1+z)$, 10% catastrophic

No spectroscopic information is used at the moment

The challenge

Each cluster finder developper is asked to run his/her algorithm in a limited timescale on the test catalogs (taking advantage of the calibration catalog) and to provide his/her catalog of detected halos providing:

- Observed cluster centre (RA_{obs} , Dec_{obs} , z_{obs})
- S/N of detection
- Numerosity
- Estimate of an internal mass proxy

A Testing Algorithm Group is then charged of the comparison of different algorithms (J. Bartlett, C. Benoist, A. Biviano, S. Borgani, A. Cappi, S. Farrens, A. Iovino, S. Maurogordato, L. Moscardini) in close connection with the cluster finder developpers.

Selection Function: Purity and Completeness

When matching the observed halos catalog with the parent real halo catalog (with a mass cut above some threshold) , one can define:

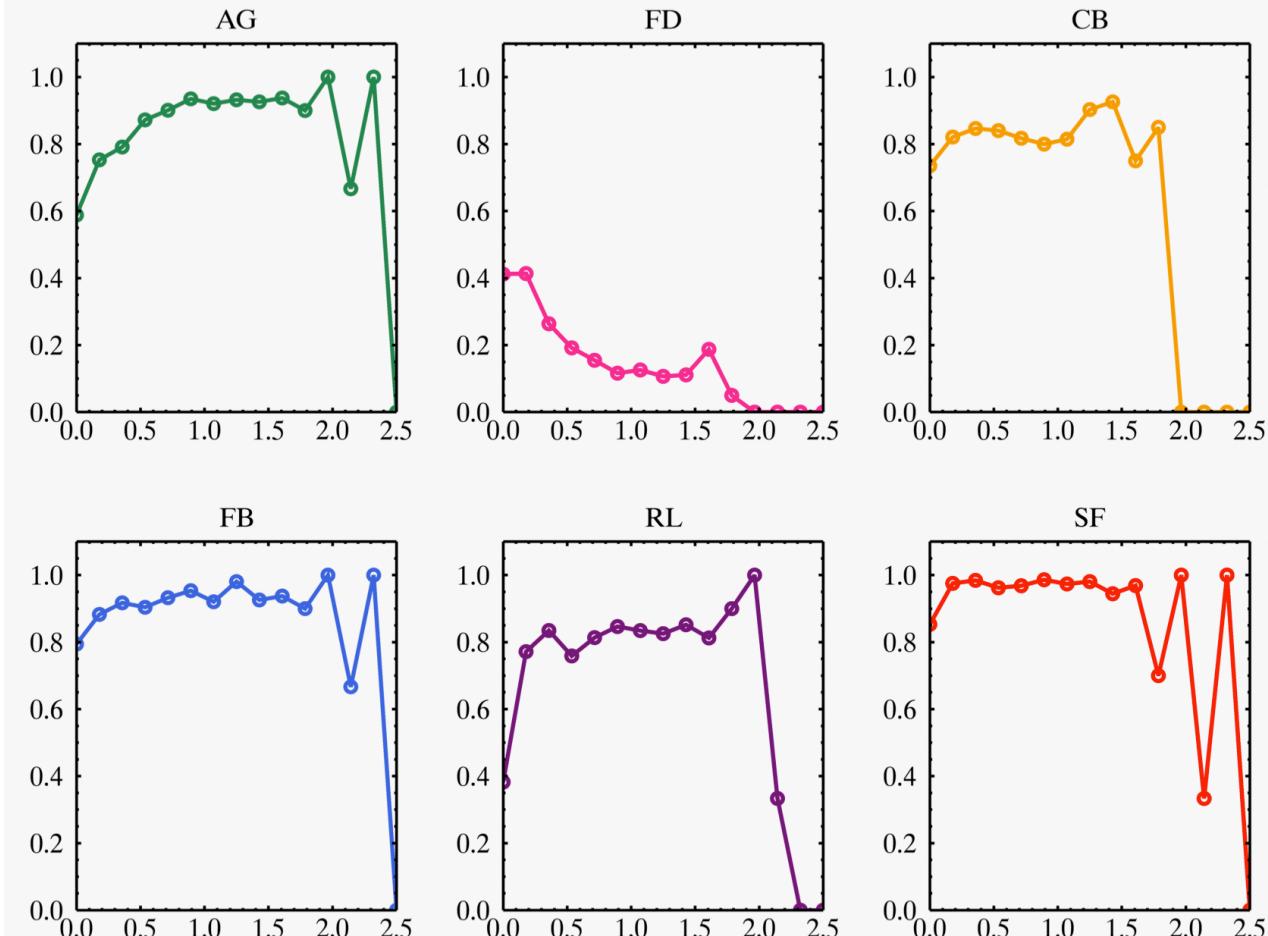
$$\text{Purity} \quad P = N_{\text{match}} / N_{\text{obs}}$$

$$\text{Completeness} \quad C = N_{\text{match}} / N_{\text{real}}$$

- Completeness is mass dependent (should specify the mass threshold for matching)
- Purity is very challenging to estimate as it depends of the mass threshold of the observed sample, not known a priori – Requires the use of a mass proxy

Here, the minimum mass threshold investigated is $M > 10^{13}$ Msol and only halos with ≥ 5 members are considered.

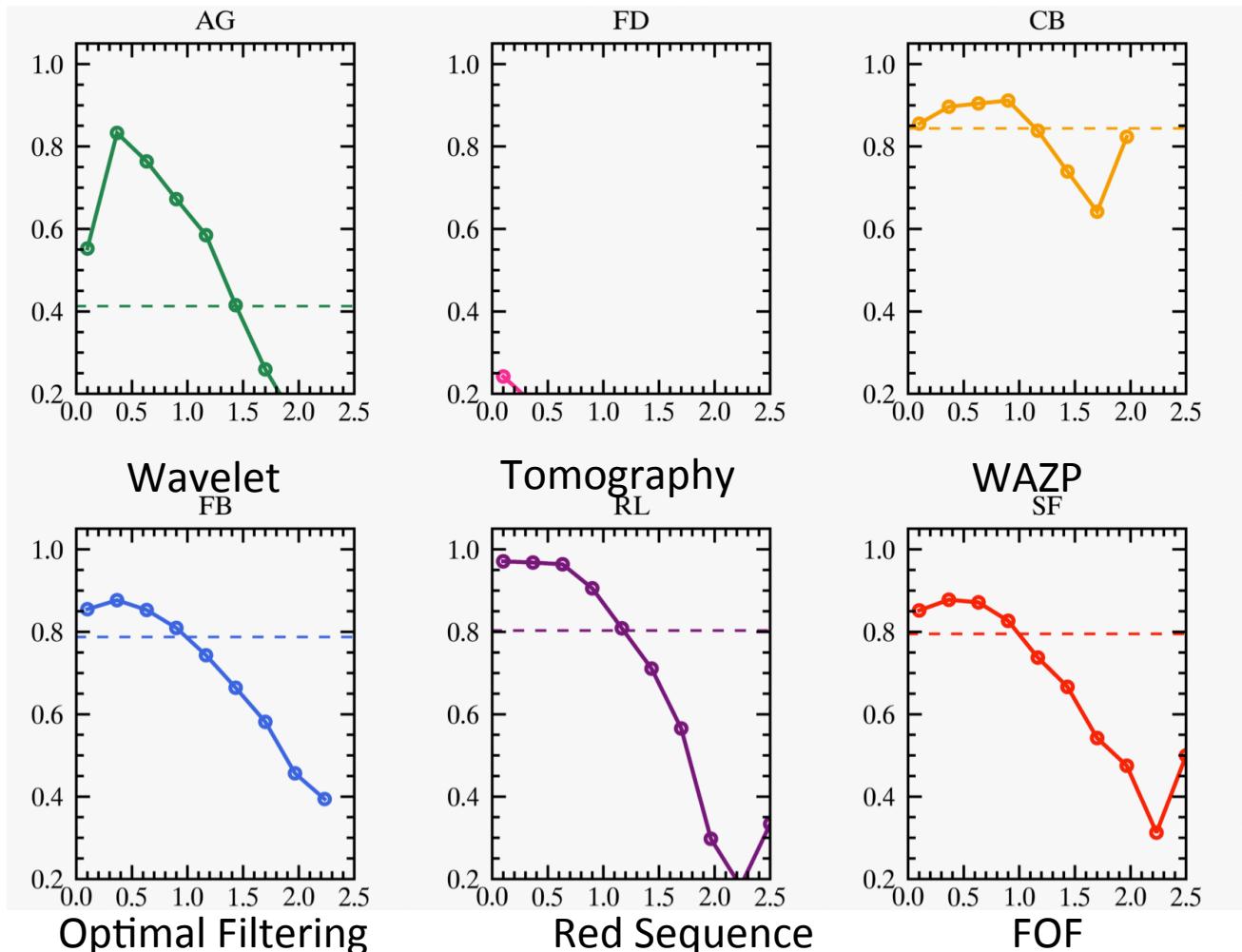
Completeness as a function of redshift



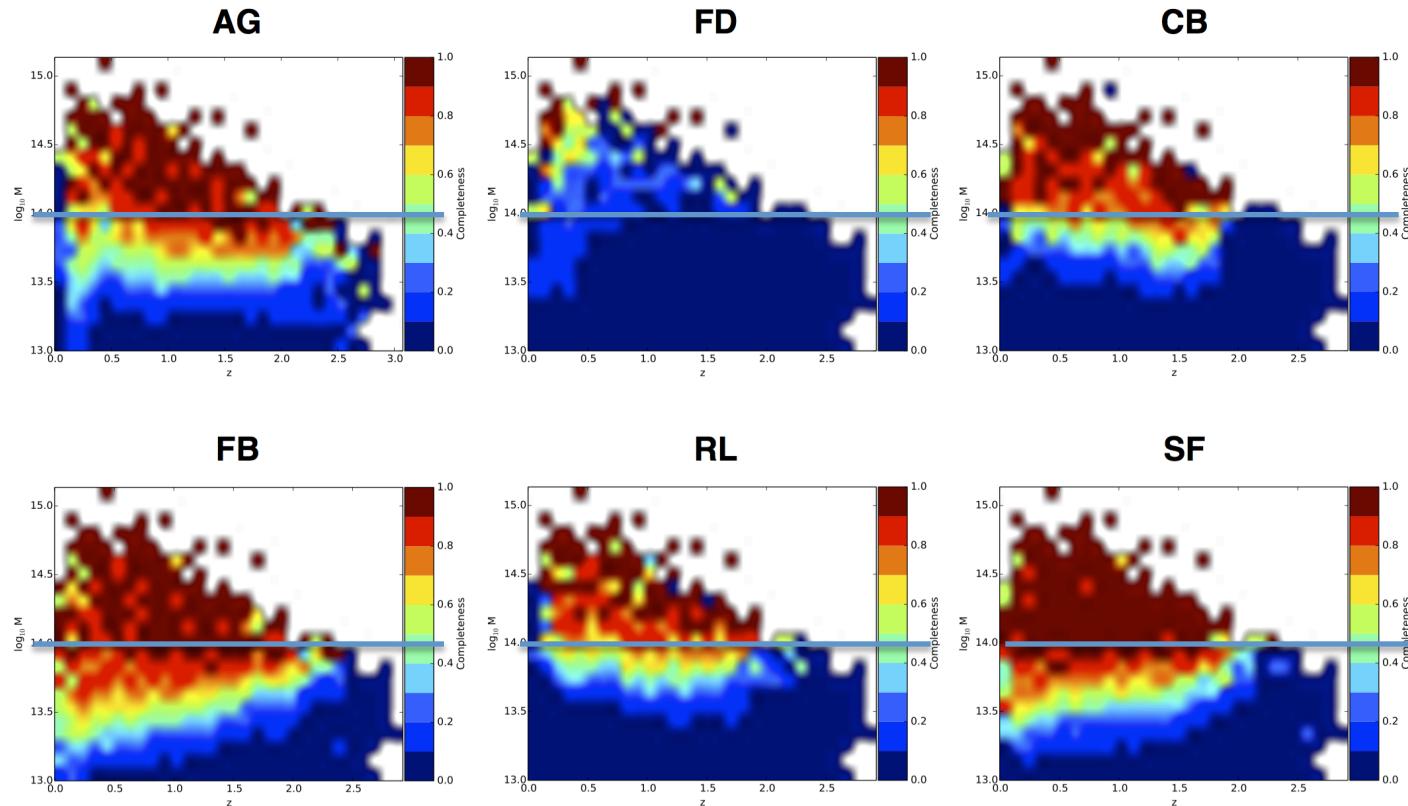
Matched with halos $M > 10^{14} \text{ Msol}$

Farrens, Iovino, Biviano, Maurogordato et al., 2014, Results of Cluster Challenge 2

Purity as a function of redshift



Completeness (Mass-redshift plane)



Optimal Filtering

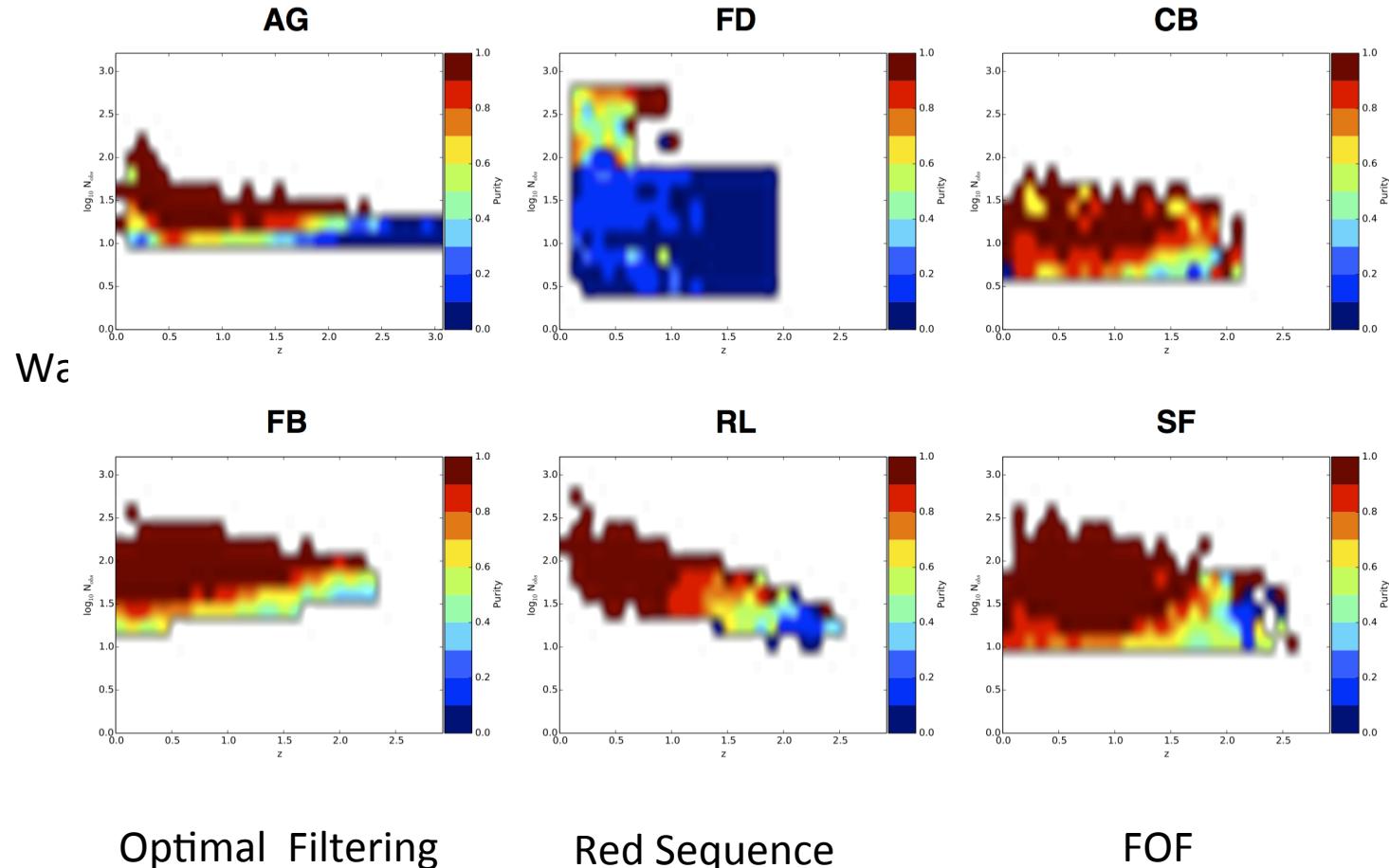
Red Sequence

FOF

Matched with halos $M > 10^{14}$ Msol

Farrens, Iovino, Biviano, Maurogordato et al., 2014, Results of Cluster Challenge 2

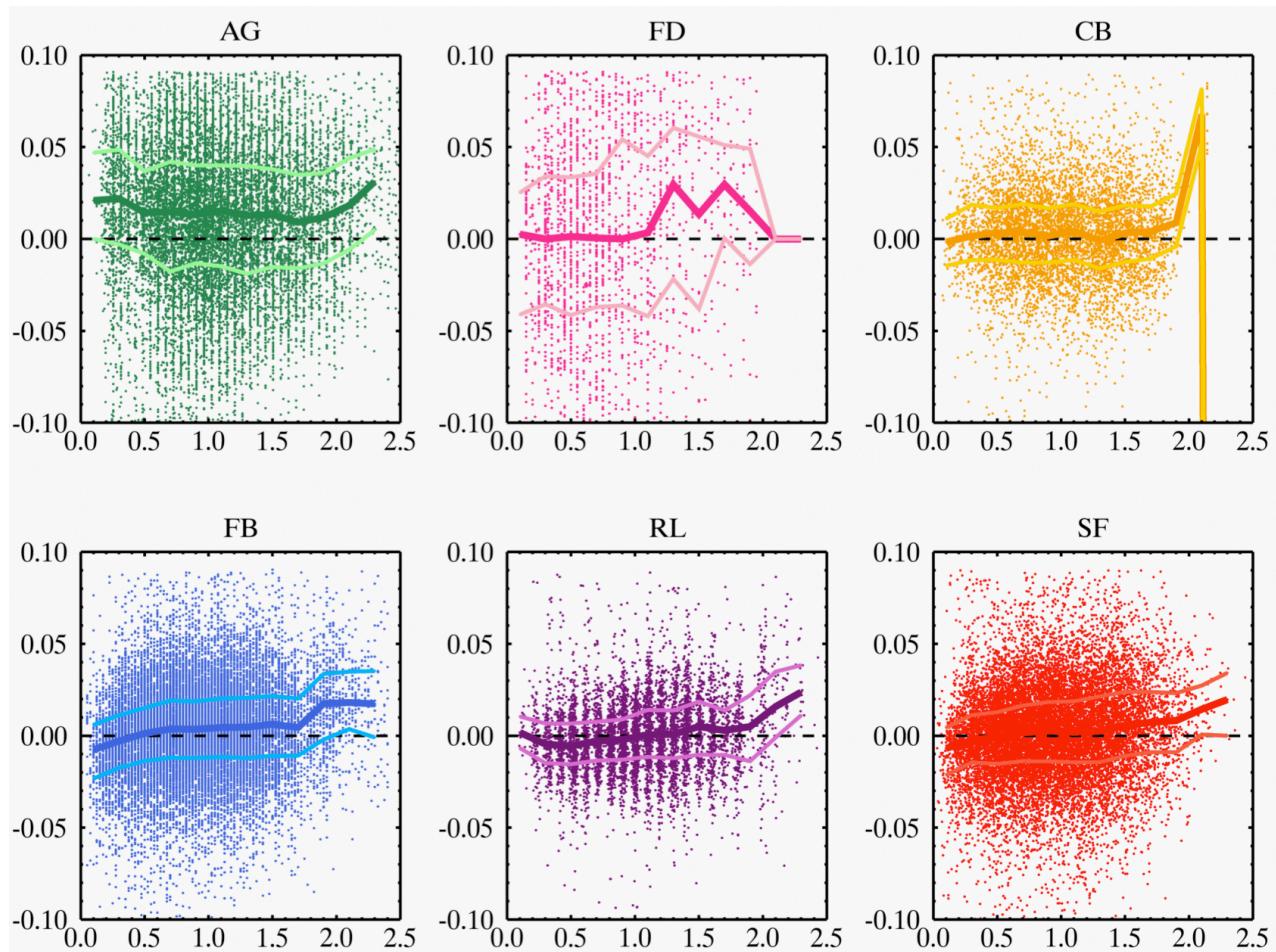
Purity (Nobs-redshift plane)



Matched with halos $M > 10^{13} \text{ Msol}$

Farrens, Iovino, Biviano, Maurogordato et al.,
2014, Results of Cluster Challenge 2

Accuracy on redshift



Farrens, Iovino, Biviano, Maurogordato et al.,
2014, Results of Cluster Challenge 2

Detection: Next future

- Set-up of the procedure to compare the performances of cluster detection from photometric samples is done
- Several runs of CFC are scheduled in future (March 2015 – End 2015, algorithms to be given for validation in 2016)
 - Refined matching using memberships
 - Fully automated analysis (ongoing at Lagrange, M. Vannier & P.F. Rocci)
 - Extended to use the spectroscopic information
 - Common challenge with cluster finders from Weak Lensing
 - Realistic zphot errors
 - Introduce masking

URGENT NEED for wide-angle mocks ($> 5000 \text{ deg}^2$) reproducing the properties of galaxies in clusters (counts, luminosity functions, density, velocity distribution and colors) up to $z=2$



Strong impact on the selection of the cluster finder
and on the resulting cluster catalog

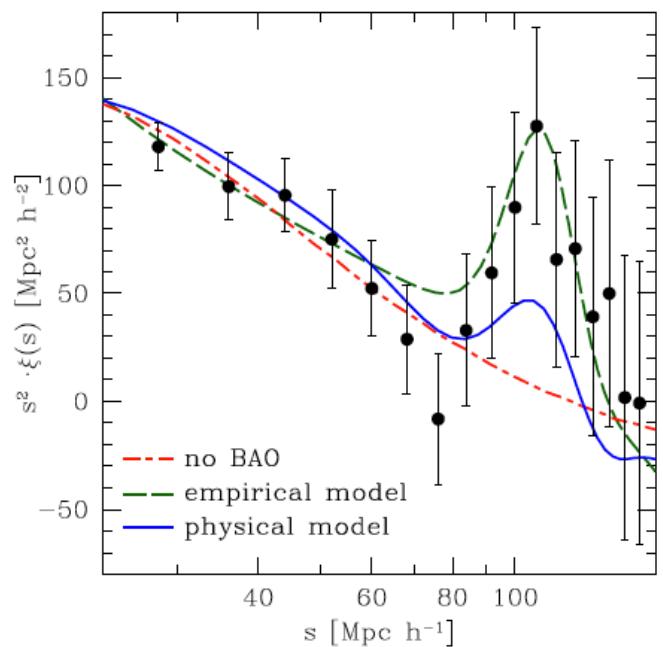
II – Mass proxies

- Determine the mass-observable relation and its uncertainties for various observables
- Need to minimize statistical and systematic errors: direct impact on the cosmological constraints
- Richness, from cluster finders or external (C. Benoist, F)
- Luminosities in NIR bands
- Stellar Masses
- Velocity dispersion
- Reconstructed Masses from weak lensing (A. Leonard, UK)
Joint WP with WL

III- Cluster Clustering

Joint WP with Galaxy Clustering led by F. Marulli (I)

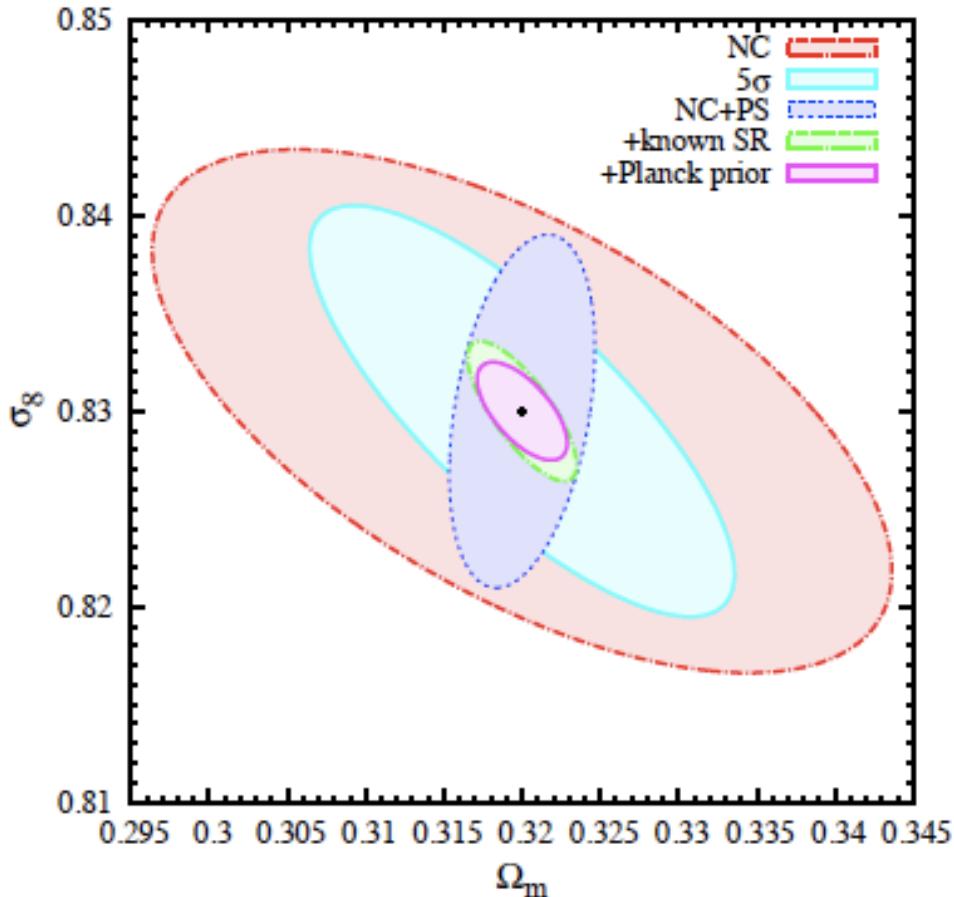
- Cluster Clustering used together with number counts to constrain cosmology
- 2-pt and 3-pt cluster correlation function
- Cluster power spectrum and bi-spectrum
- Covariances matrices



Detection of BAOs in clusters in SDSS
Veropalumbo, Marulli, Moscardini et al. 2014

SWG: Cosmological constraints:

$\sigma_8 - \Omega_{\text{matter}}$



68 per cent contour levels

From counts only:

$$\Delta\Omega_m = 0.016 \text{ and } \Delta\sigma_8 = 0.009$$

Adding power spectrum:

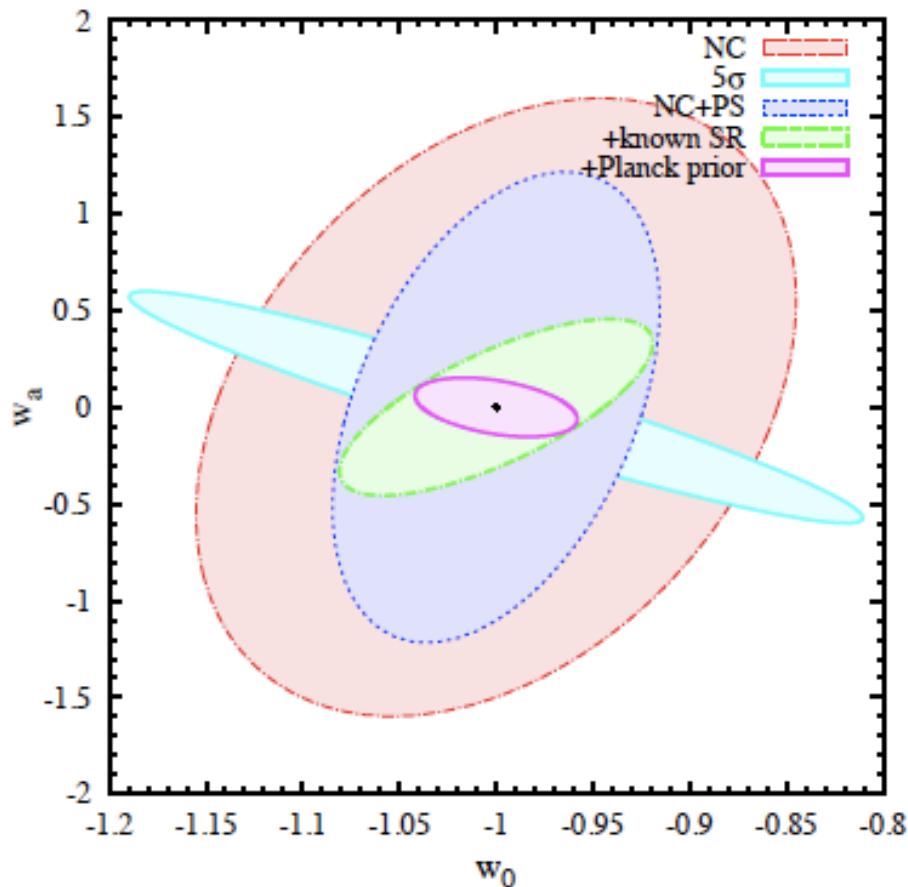
$$\Delta\Omega_m = 0.003 \text{ and } \Delta\sigma_8 = 0.006$$

A further **large improvement** assuming to know the scaling relation.

Planck priors not important

Sartoris et al. 2015 (SWG)

SWG: Cosmological constraints: dark energy equation of state



$$w(a)=w_0+w_a(1-a)$$

$$FoM = \frac{1}{\sqrt{\det[Cov(p_i, p_j)]}}$$

$N_{200}/\sigma_{\text{field}} \geq 3$ Euclid photometric cluster selection

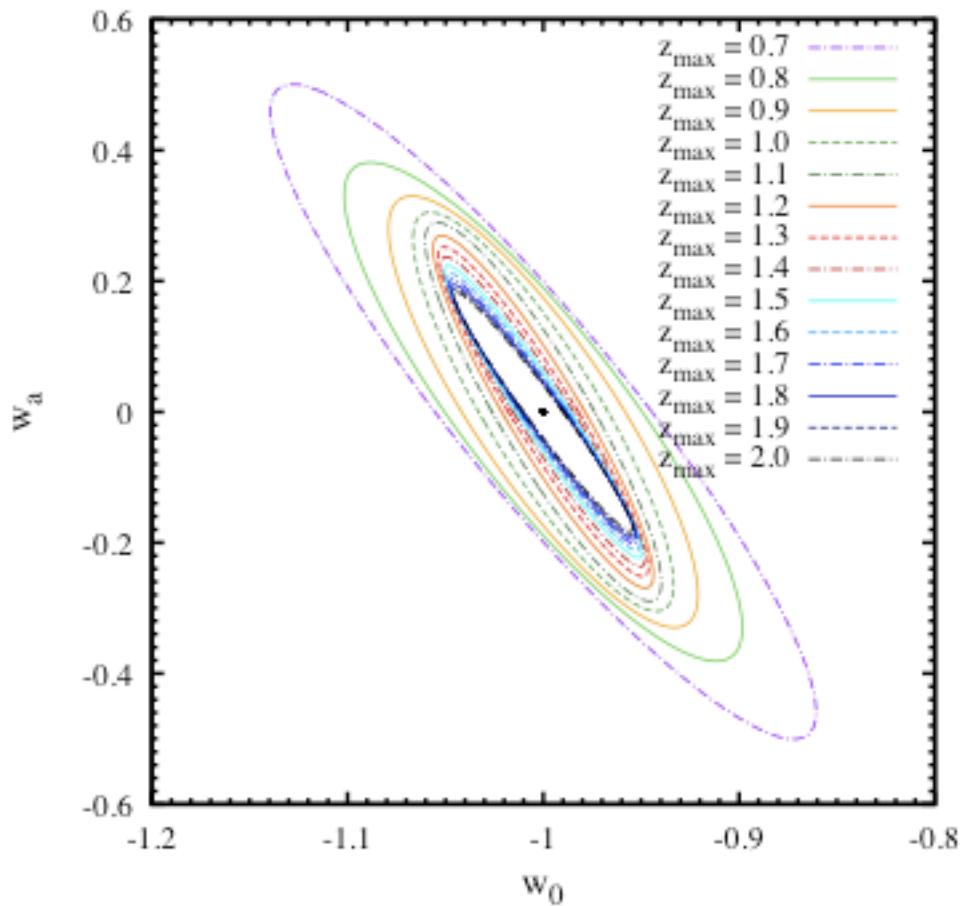
	FoM	Δw_0	Δw_a
NC	9.9	0.102	1.05
NC+PS	24.7	0.056	0.80
NC+PS+known SR	90.4	0.053	0.30
NC+PS+known SR+Planck	391.9	0.028	0.10

$N_{200}/\sigma_{\text{field}} \geq 5$ Euclid photometric cluster selection

NC+PS+known SR+Planck	68.0	0.125047	0.395269
-----------------------	------	----------	----------

Sartoris et al. 2015 (SWG)

SWG: Cosmological constraints: dark energy equation of state



$$w(a) = w_0 + w_a(1-a)$$

$$FoM = \frac{1}{\sqrt{\det[Cov(p_i, p_j)]}}$$

The importance of Euclid
high-z clusters:

only 20% of the total FoM is from
 $z < 1$, 50% is reached @ $z=1.4$.

Sartoris et al. 2015 (SWG)

Courtesy Lauro Moscardini

Conclusions

- Cosmology with clusters: strongly evolving field in the era of large galaxy surveys
 - Euclid strengths
 - Depth: high z range essential for constraining cosmology
 - Large statistics: both number counts and clustering
 - Calibration of the mass-observable relation by Weak Lensing (+ stacked velocity dispersions)
- Most current works \approx 10-15 % uncertainty, Weighing the Giants \approx 8%, Euclid aims a few % !
key: control of systematic uncertainties

- Activities
 - SWG: First Forecasts for Euclid, other WP activities in development
 - Task force on Requirements
 - OU-LE3:
 - Implementation: Detection: CFC 1 and 2 have shown that several codes have good performances (completeness, purity) - Other WPs in progress
 - Validation: Methodology in dev (Simulations and real data)

Conclusions

URGENT NEED NEW MOCKS with representative properties of galaxies in clusters up to $z=2$!

Durham 500deg2: Problems with velocity distributions and with colors impact Red Sequence based cluster finders

MICE 500 deg2: Problems with depth (limited at $H < 22$ and $z = 1.4$)
Absolute magnitude cut: $Mr = -18.9$ (lack of faint galaxies in low z clusters)

Need also Wide Angle (> 5000 deg2) : cluster clustering & uncertainties on purity and completeness