CLUSTER COSMOLOGY WITH LSST, EUCLID AND J-PAS

Begoña Ascaso

Marie Curie Fellow at the
Astroparticle et Cosmologie (APC) Laboratoire /CNRS

OUTLINE

① Galaxy clusters

② Next-generation surveys.

③ Creation of realistic mock catalogues

④ Detection of galaxy clusters in the optical

⑤ Cosmology with cluster counts

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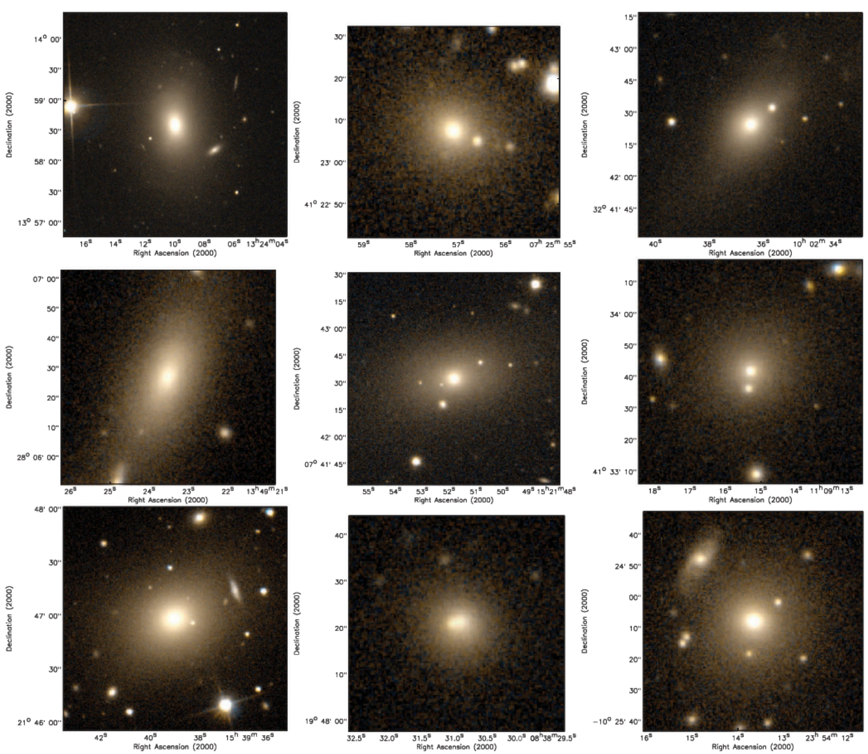
A1689 (ACS/HST)

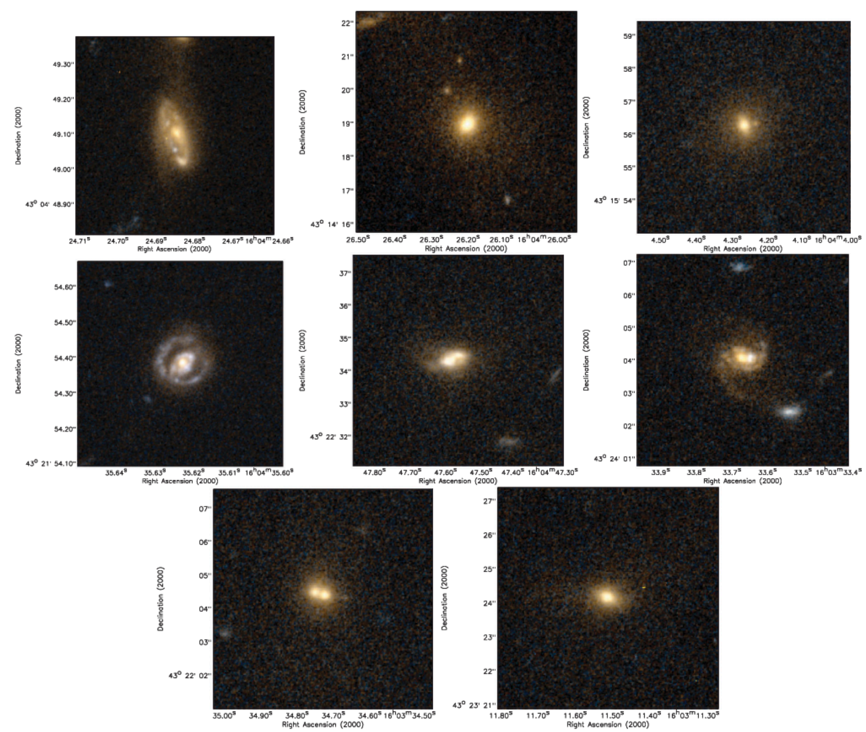
GALAXIES IN CLUSTERS

Brightest Cluster Galaxies (BCGs)

z~0



z~0.9



Ascaso et al. 2014b

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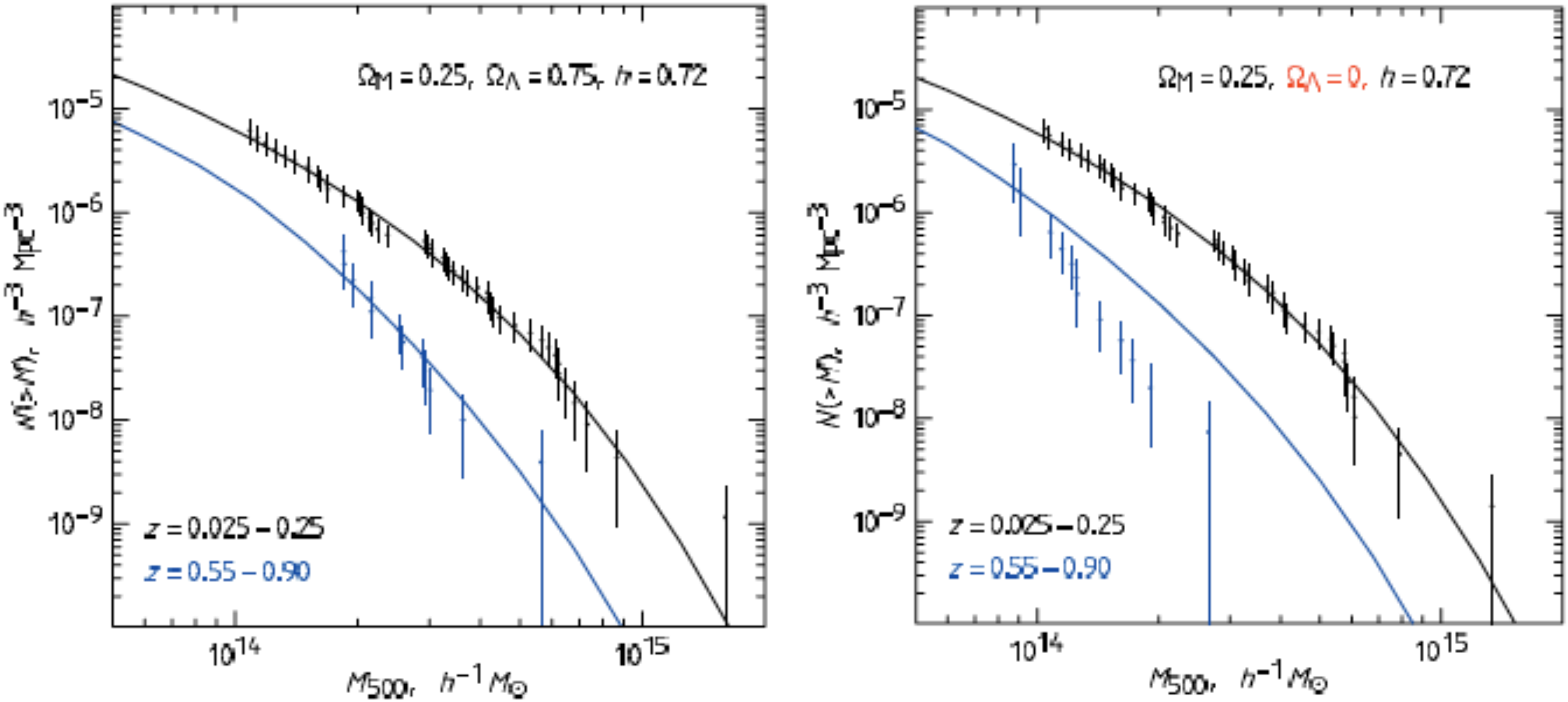
CLUSTERS IN COSMOLOGY

Vikhlinin et al. 2009



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COSMOLOGY WITH CLUSTER COUNTS

$$\frac{dN}{dM_{obs}dz} = \underbrace{\Phi(M_{obs}, z, \Omega)}_{\text{Selection function}} \int dM \, \underbrace{P(M_{obs}|M, z)}_{\text{Mass-Observable relation}} \frac{dN}{dV\,dM} \frac{dV}{dz\,dM_{obs}}$$

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“ClOThIlde”

The Cluster Observations and Theory Intersection

H2020-MSCA-IF-2014
P.I: B. Ascaso

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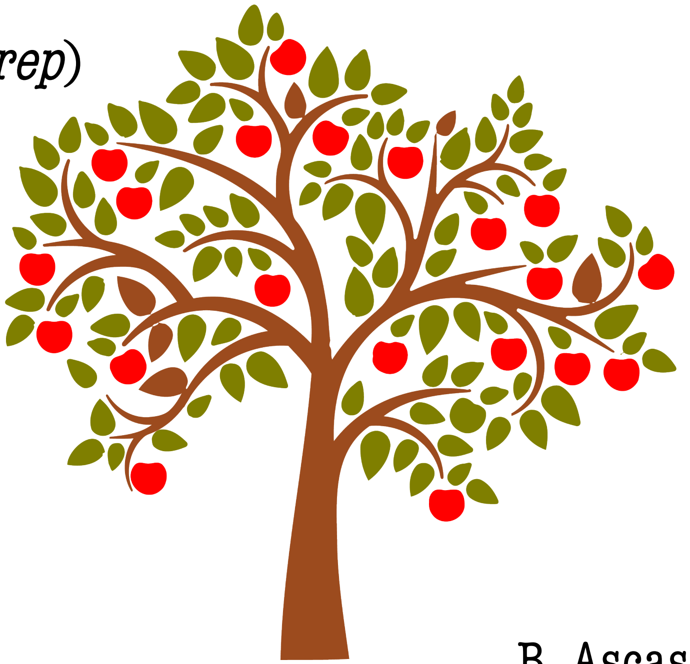
APPLES TO APPLES: A^2

Cluster-related project to

1. Use the same mock catalogues to compare photometry and photo-z properties (*Ascaso et al. 2015b*)
2. Obtain cluster Selection Functions and Mass-Observable relations (*Ascaso et al 2016a,b*)
3. Forecast cosmological constraints (*in prep*)

Stage IV Optical Surveys considered:

- LSST
- Euclid
- J-PAS



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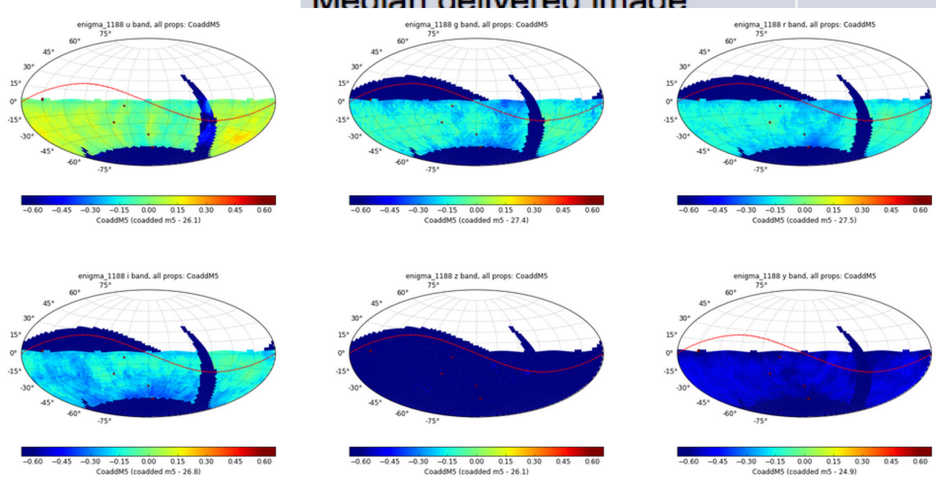
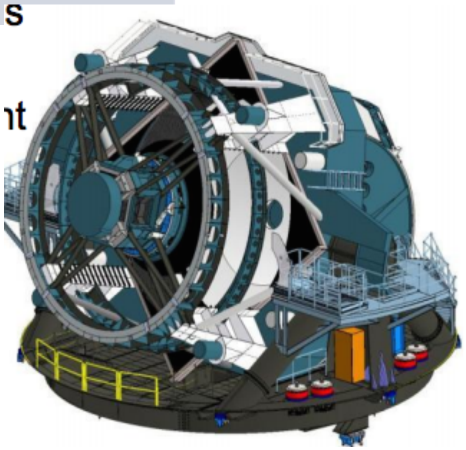
LSST IN A NUTSHELL

http://www.lsst.org/

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image	~ 0.7 arcsec. FWHM

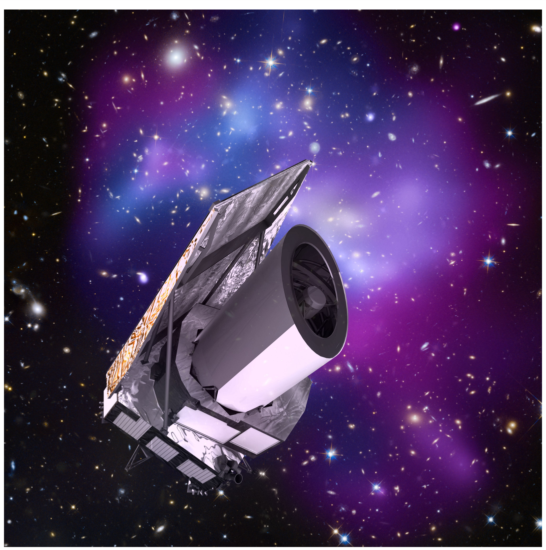


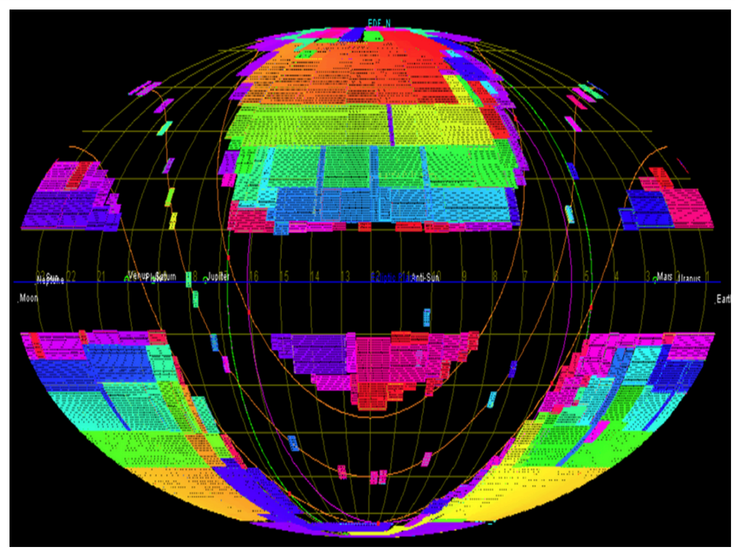


EUCLID IN A NUTSHELL

http://www.euclid-ec.org/

SURVEYS					
	Area (deg2)	Description			
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.			
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey			
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of $n = 1.5\times10^9$ galaxies			z of $n=5\times10^7$ galaxies	





J-PAS IN A NUTSHELL

http://j-pas.org

8600 sq. deg. survey with 56 filters with 136A width, 100A spacing I~22
2.5m tel. + 5sq. Deg. Cam, 1.2Gpix, etendue=1.5xPS2
First light in Mid 2017.

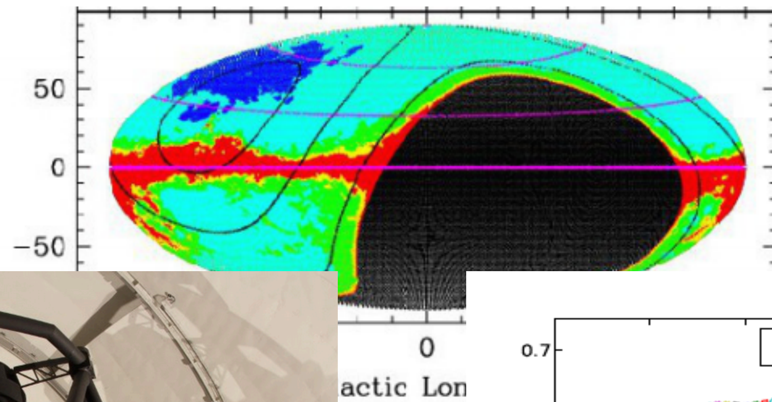
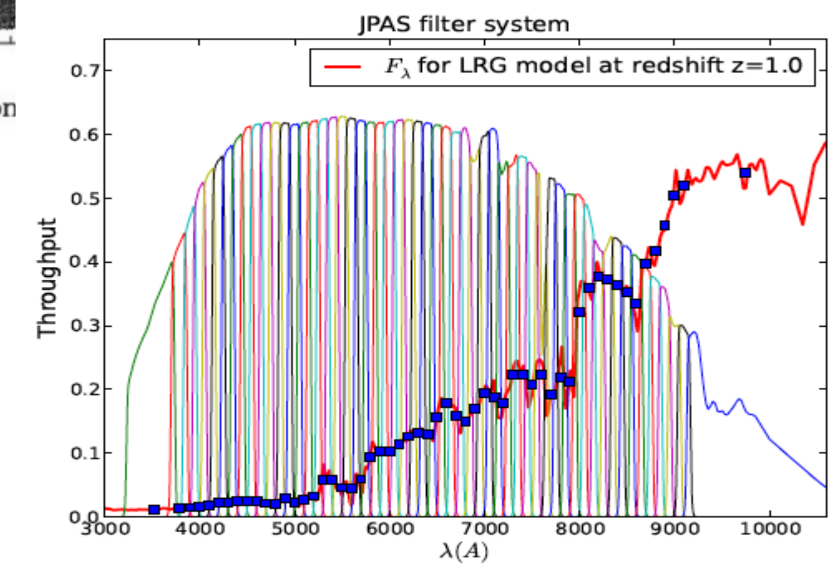


Photo-z precision: 0.003(1+z)



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REALISTIC COSMOLOGICAL SIMULATIONS

Starting from the 500 deg^2 EUCLID public lightcone mock catalogue *(Merson et al. 2013*) down to H=24 AB

- N-body simulation from the Millennium Run
- Semi-analytic models of galaxy formation (Galform)

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Starting from the 500 deg^2 EUCLID public lightcone mock catalogue *(Merson et al. 2013*) down to H=24 AB

- N-body simulation from the Millennium Run
- Semi-analytic models of galaxy formation (Galform)

We used **PhotReal** (*Ascaso et al. 2015b)* to create four new mock catalogues:

- LSST
- Euclid-Pessimistic (using an optical counterpart just from DES)
- Euclid-Optimistic (using an optical counterpart from DES+LSST)
- J-PAS

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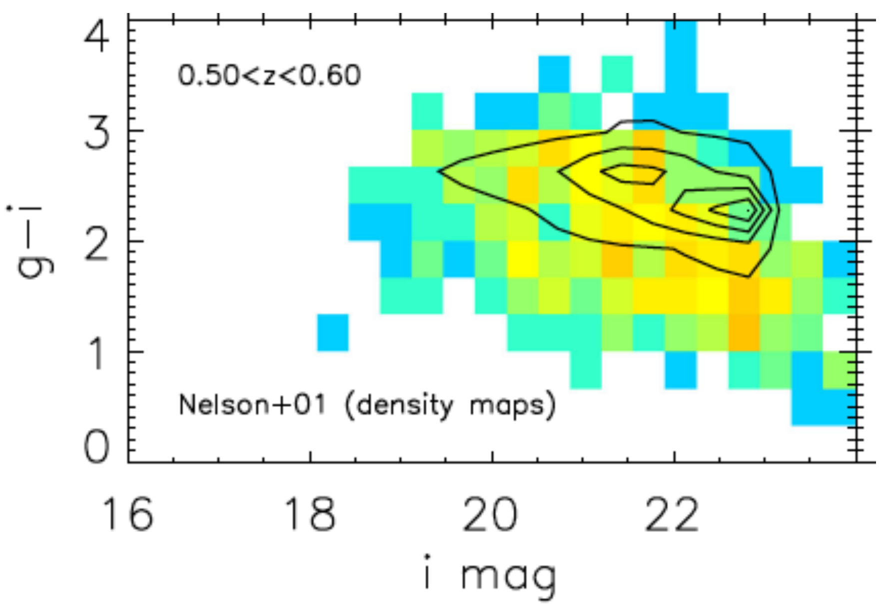
PHOTREAL

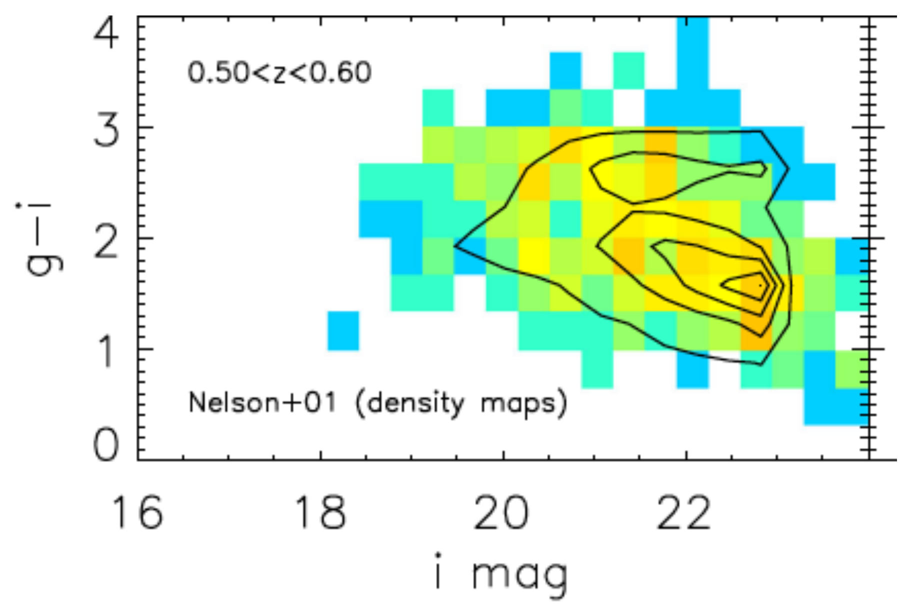
Use PhotReal to add parameters to existing mock catalogues:

- Realistic photometry, colors and photometric errors

Before PhotReal



After PhotReal



Ascaso et al. 2015b

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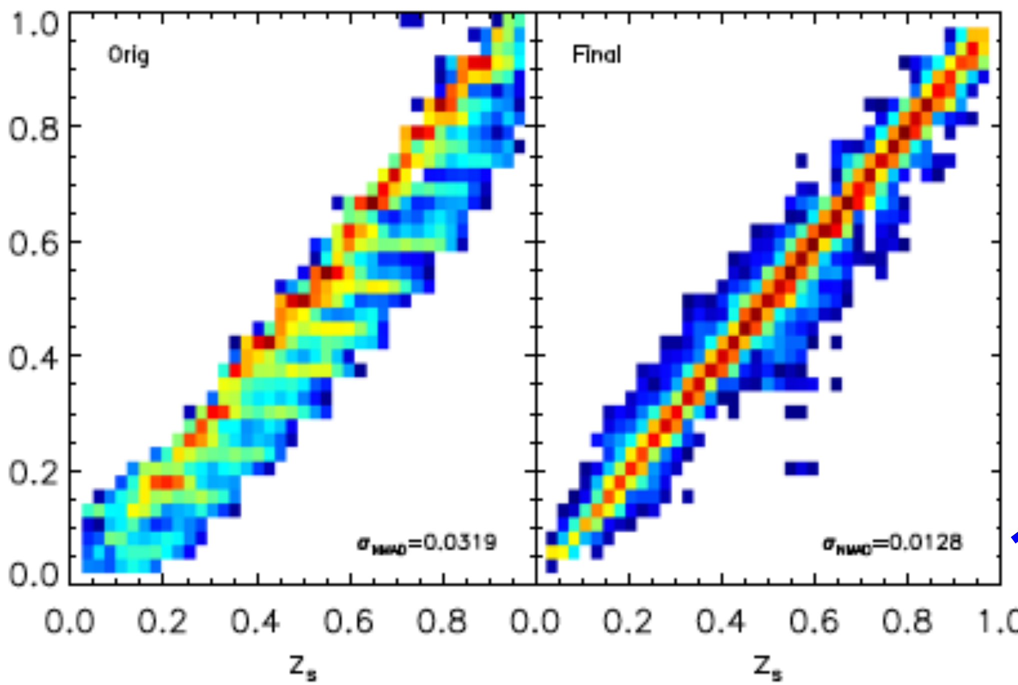
PHOTREAL

Use PhotReal to add parameters to existing mock catalogues:

- Realistic photometry, colors and photometric errors
- Realistic photometric redshifts and derived parameters

Before PhotReal   After PhotReal

ALHAMBRA mock catalogue



=ALHAMBRA data

σ_{NMAD}= 0.0125

Ascaso et al. 2015a

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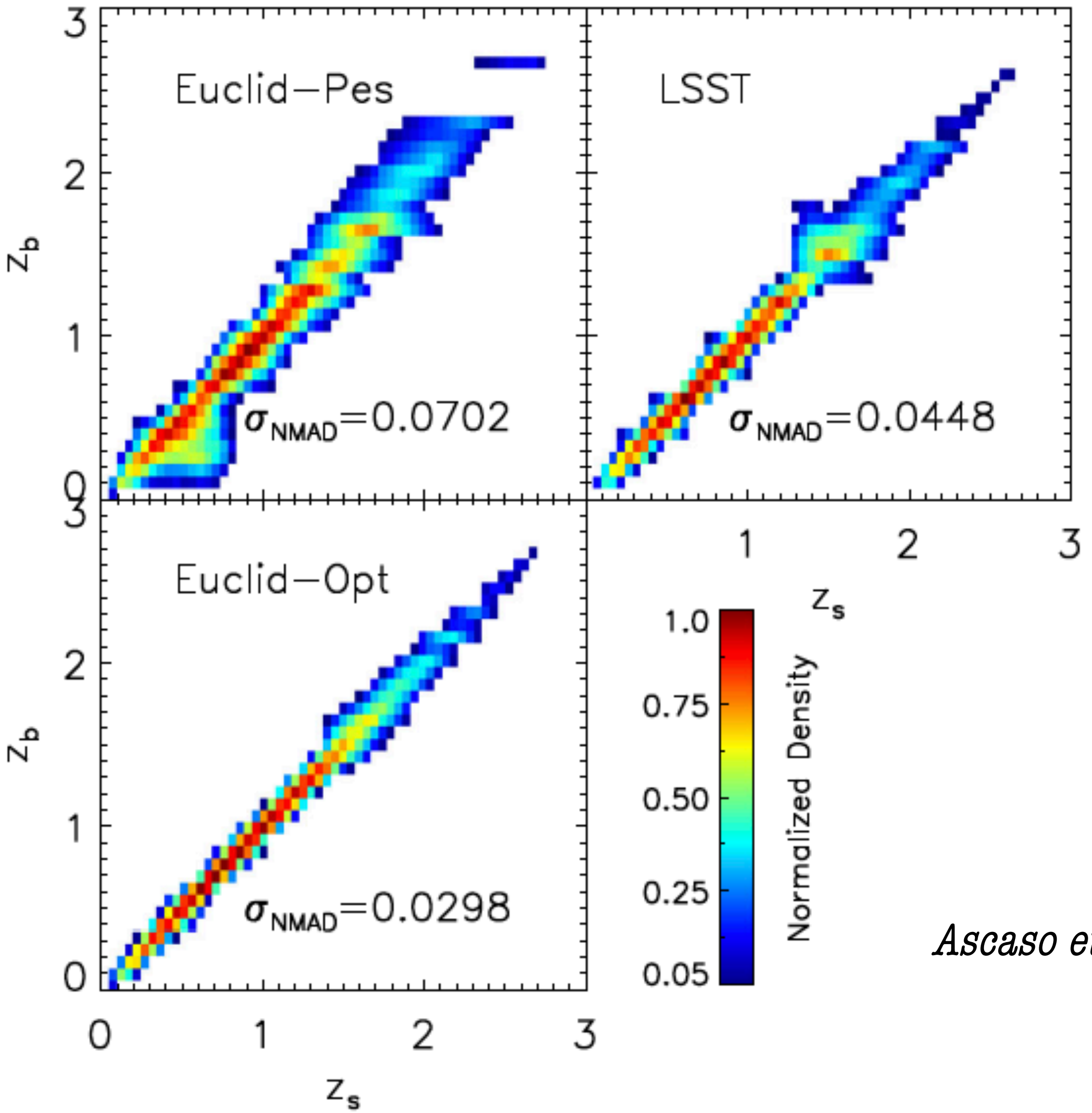
PHOTREAL

Use Phot

- Real
- Real



Ascaso et al. 2015b

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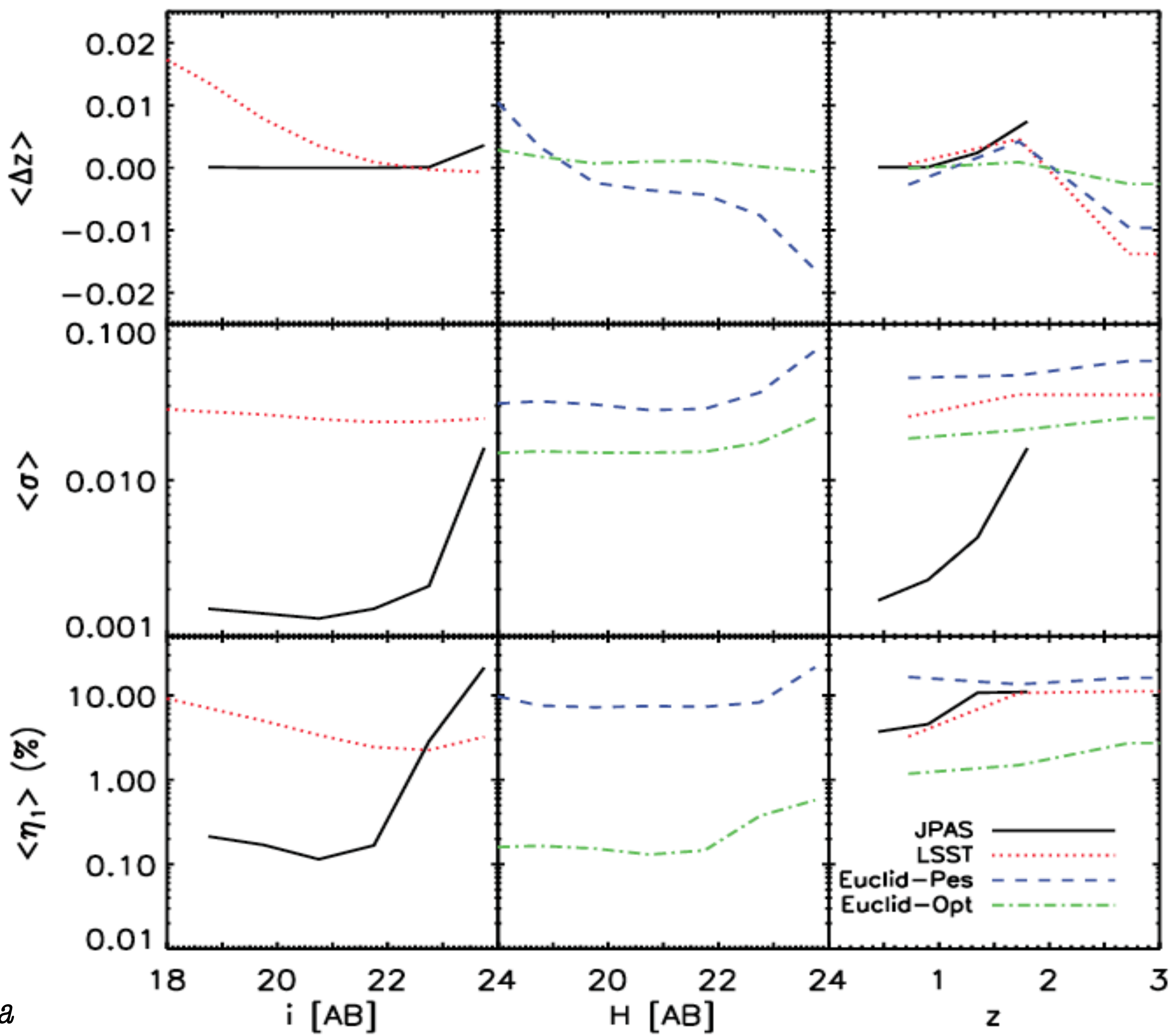
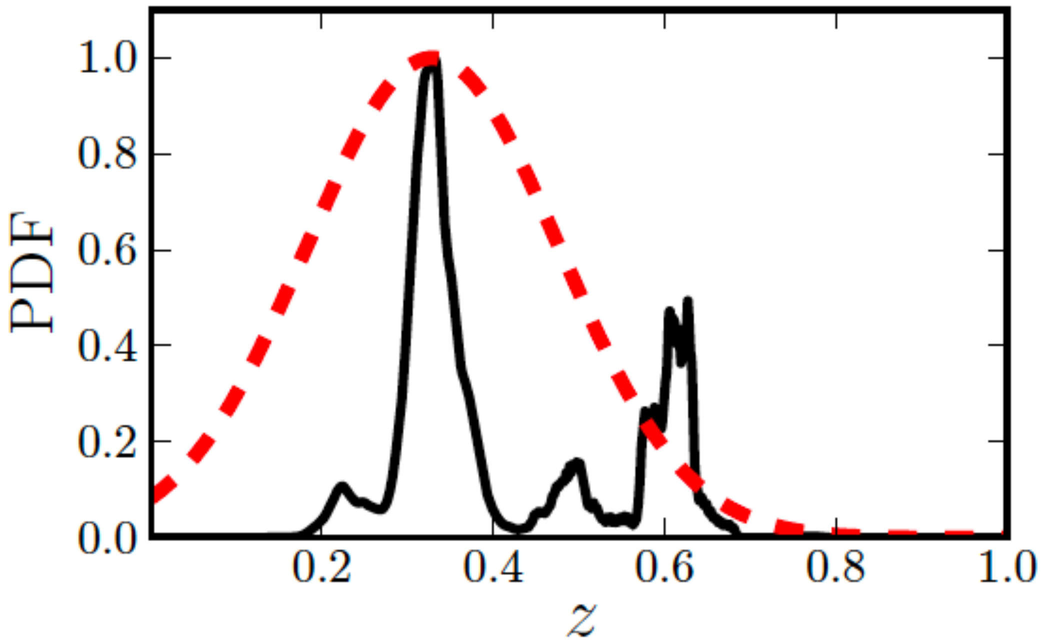


Ascaso et al. 2016a

PHOTREAL

Use PhotReal to add parameters to existing mock catalogues:

- Realistic photometry, colors and photometric errors
- Realistic photometric redshifts and derived parameters
- Realistic P(z)



López-Sanjuan et al. 2015

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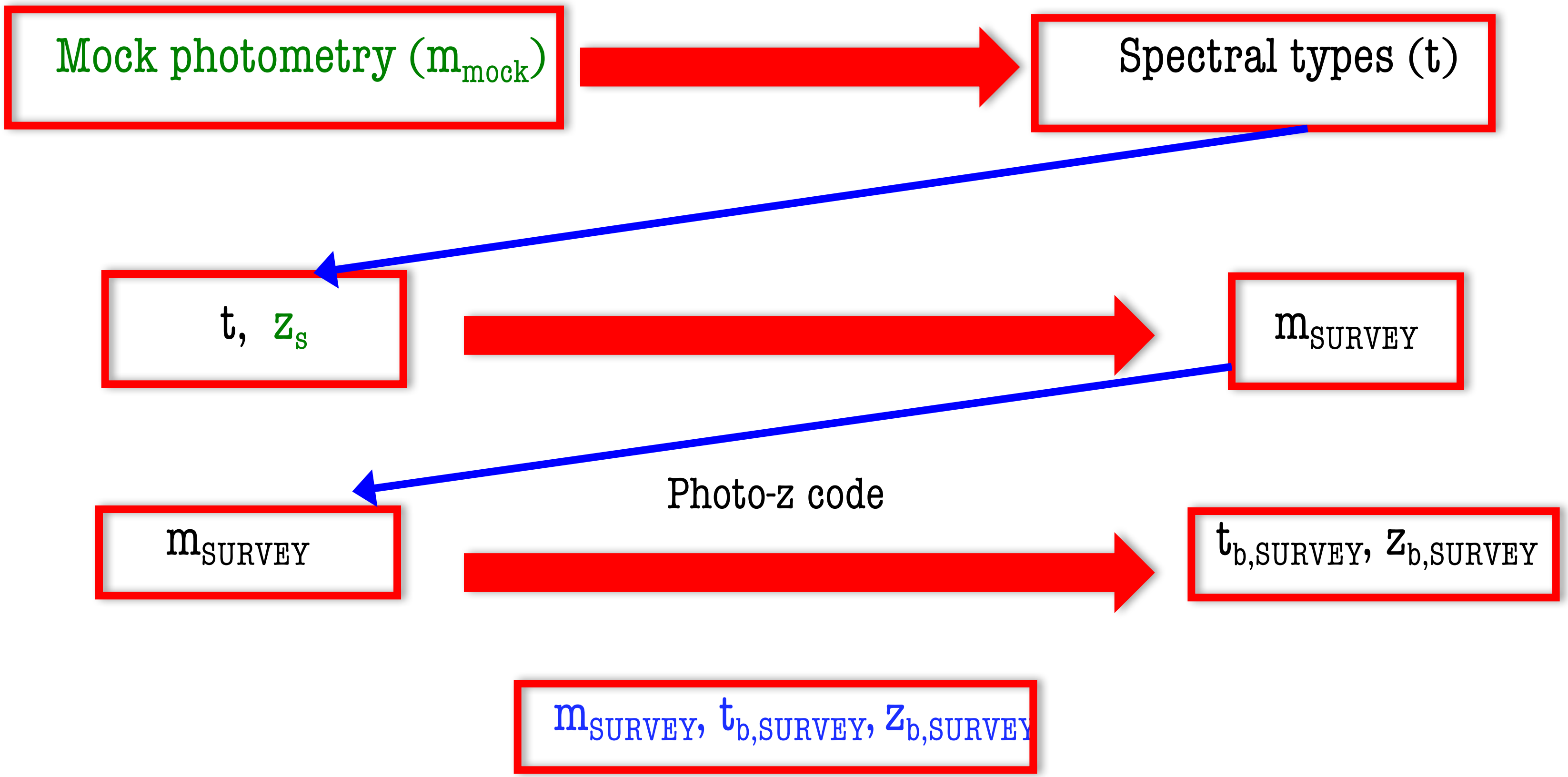
PHOTREAL

(Ascaso et al 2015b; Benítez et al. in prep)



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AVAILABLE PHOTREAL MOCKS

ALHAMBRA	J-PAS	J-PAS	LSST*	EUCLID-W*	EUCLID-D
Merson+13	*Zandivarez+14*	*Merson+13*	*Merson+13*	*Merson+13*	*Merson et al. in prep*
N-body simulation (Millenium)+SAM (Galform)	N-body simulation (Millenium)+SAM (*Guo+11*)	N-body simulation (Millenium)+SAM (Galform)	N-body simulation (Millenium)+SAM (Galform)	N-body simulation (Millenium)+SAM (Galform)	N-body simulation (Millenium)+SAM (Galform)
200 deg^2	17.6 deg^2	500 deg^2	500 deg^2	500 deg^2	20 deg^2
F814W<24.5	i<22.5	H<24.0	H<24.0	H<24.0	H<27.0
0<z<2	0<z<2	0<z<3	0<z<3	0<z<3	0<z<6
$M_h>10^{10}M_\odot$	$M_h>10^{8}M_\odot$	$M_h>10^{10}M_\odot$	$M_h>10^{10}M_\odot$	$M_h>10^{10}M_\odot$	$M_h>10^{10}M_\odot$
Ascaso et al. 2015a, MNRAS, 452, 549	*Zandivarez et al. 2014, A&A, 561, 71*	*Ascaso et al. 2016a, MNRAS, 456, 4291*	*Ascaso et al. 2015b, MNRAS, 453, 2515*	*Ascaso et al. 2015b, MNRAS, 453, 2515*	Euclid consortium

* Publicly available at http://photmocks.obspm.fr

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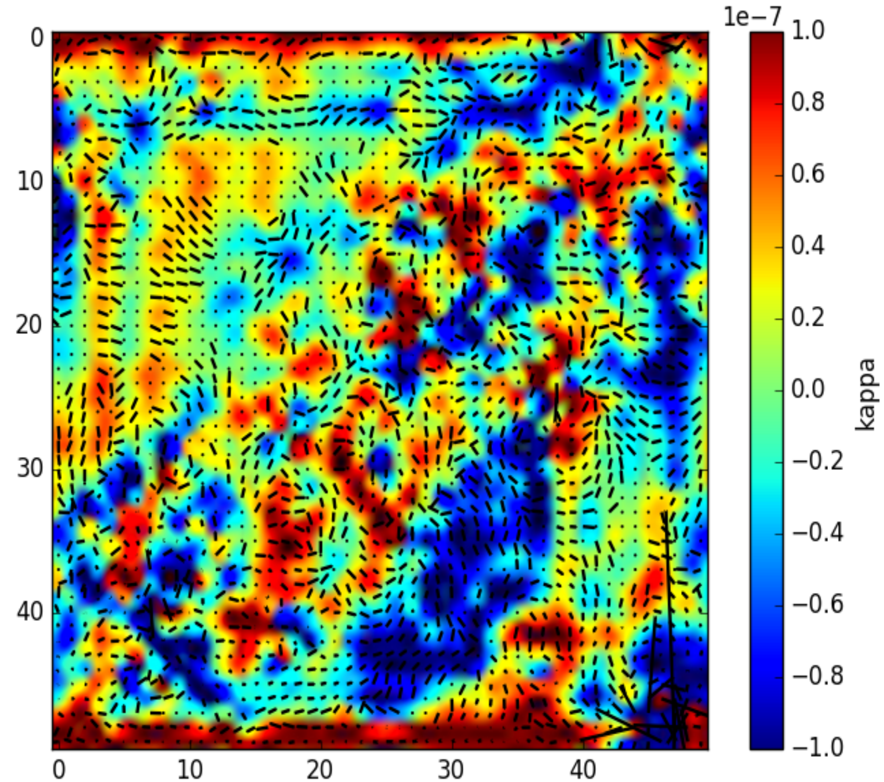
GALAXY SHEAR INTRODUCTION

In preparation

Technique to introduce the shear and the convergence for all the galaxies in the catalogues

Ideal for testing and calibrating the scatter in the measurement of the weak lensing mass of clusters.



LSST convergence simulated map

Work in progress with the APC – LSST group
(with C. Roucelle, E. Aubourg, T. Montandon, C. Doux)

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CLUSTER OPTICAL DETECTORS

MATCHED FILTER TECHNIQUES

Matched Filter *(Postman et al. 1996, 2002)*

Adaptative Kernel Filter *(Kepner et al. 1999, Gal et al. 2006)*

Photo-z Cluster Detector *(Pello et al. 1998)*

Adaptative Matched Filter *(Kim et al. 2002)*

3D-Matched Filter *(Milkeraitis et al. 2010)*

Adami & MAzure Cluster Finder *(Durret et al. 2011, 2015)*

Bayesian Cluster Finder *(Ascaso et al. 2012, 2014a, 2015a)*

GEOMETRICAL TECHNIQUES

Voronoi Tessellation *(Kim et al. 2002, Ramella et al. 2001, Lopes et al. 2004),*

Counts in cells *(Couch et al. 1991, Lidman & Peterson 1996),*

Percolation FoF Algorithm *(Dalton et al. 1997)*

RED SEQUENCE METHODS

MaxBCG *(Koester et al. 2007)*

The Cluster Red Sequence Method *(Gladders & Yee 2000, 2005)*

Cut-and-enhance *(Goto et al. 2002)*

C4 clustering algorithm *(Miller et al. 2005)*

RedMaPPer *(Rykoff et al. 2014)*

RedGold *(Licitra et al. 2016)*

CLUSTER OPTICAL DETECTORS

MATCHED FILTER TECHNIQUES

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Ada

Pho

al. 1998)

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GEOMETRICAL TECHNIQUES

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RED SEQUENCE METHODS

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Cut-and-enhance *(Goto et al. 2002)*

C4 clustering algorithm *(Miller et al. 2005)*

RedMaPPer *(Rykoff et al. 2014)*

RedGold *(Licitra et al. 2016)*

Bayesian Cluster Finder (BCF)

Ascaso et al, 2012, 2014a, 2015a

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THE BAYESIAN CLUSTER FINDER

(Ascaso et al. 2012, 2014a, 2015a, 2016a,b)

$$\ln L(X,Y,N_g,R_c,z_c) = \sum_i P(r(x_i,y_i|X,Y,z_c))L(m_i,z_i|z_c)p(z_i|z_c)$$

Cluster Spatial Prof — Cluster Lum Prof — Redshift prob distrib

The prior (introduction of a CMR, BCG prior)

$$p(X,Y,N_g,R_c,z_c|I) = p(col_i)p(m_{BCG}(z))$$

Expected cluster colors — Expected BCG mag

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THE BAYESIAN CLUSTER FINDER

1. Redshift slices (z_s) from $0.1 \leq z_s \leq 1.2$ in steps of 0.1
2. Each galaxy (α_i, δ_i, $z_{s,i}$) -> prob
3. Each z_s -> background and σ probability. Only select 3σ detections.
4. Center: maximum peak of the probability
5. Output:
   - Richness:
     - Λ_{cl}; effective number of L^* galaxies in the cluster.
     - N_{200}: Number of galaxies lying on the red sequence down to M*+1
     - M*: Total stellar mass of the galaxies 'belonging' to the cluster
   - Position (α_c, δ_c)
   - Maximum probability redshift z_s
   - Mean redshift (z_m) from the photo-z's galaxy distribution

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1. Redshift slices (z_s) from $0.1 \leq z_s \leq 1.2$ in steps of 0.1
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4. Center: maximum
5. Output:
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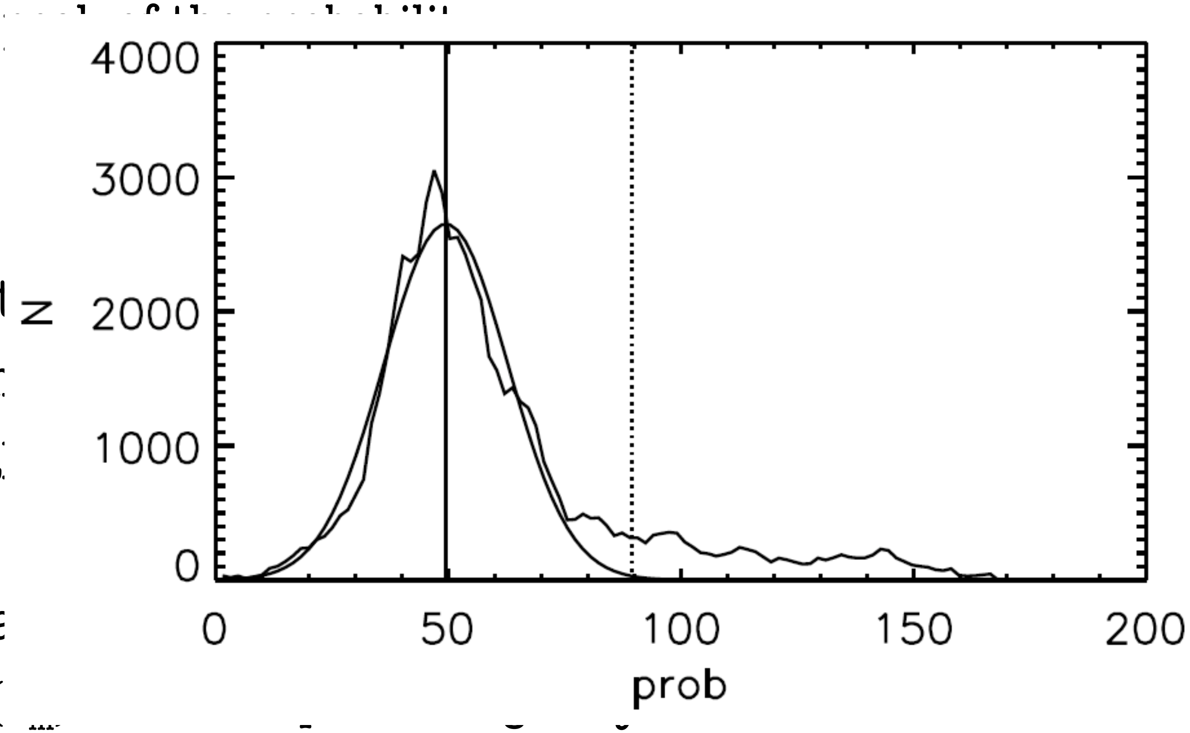
     - Λ_{cl}; effec
     - N_{200}: Nur
     - M*: Tota
   - Position (α_c, δ_c)
   - Maximum proba
   - Mean redshift (



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APPLICATIONS TO REAL SURVEYS

CFHTLS	DLS	ALHAMBRA
Erben et al. 2009 (CARS) + Others	*Wittman et al. 2002* + Others	*Moles et al. 2008* + Others
37 □^{2}	20 □^{2}	4 □^{2} (8 x 0.5 □^{2})
6 optical broad bands	5 optical broad bands	20 optical narrow bands + JHK
Complete down to I~25.5 mag/arcsec^2	Complete down to R~26.5 mag/arcsec^2	Complete down to F814~24.5 mag/arcsec^2
$\Delta z/1+z \sim 0.06$	$\Delta z/1+z \sim 0.08$	$\Delta z/1+z \sim 0.01$

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APPLICATIONS TO REAL SURVEYS

CFHTLS	DLS	ALHAMBRA
Ascaso et al. 2012, MNRAS, 420, 1167	*Ascaso et al. 2014a, MNRAS, 439, 1980*	*Ascaso et al. 2015a, MNRAS, 549, 65*
1246 structures ~ 33.7 /deg^2	882 structures ~ 44.1 /deg^2	348 structures ~125.18 /deg^2
$0.1<z<1.2$	$0.25<z<1.2$	$0.2<z<1.2$
$M>10^{14.2}M_\odot$	$M>10^{14}M_\odot$	$M>10^{13.6}M_\odot$
Good match with optical surveys: *Adami et al. 2010, Olsen et al. 2008*; and X-ray: *Pacaud et al. 2009*	Good agreement with spectroscopy, WL, X-rays and optical detections. Allow the study of systematic.	Good agreement with COSMOS (+ pretty unknown fields)

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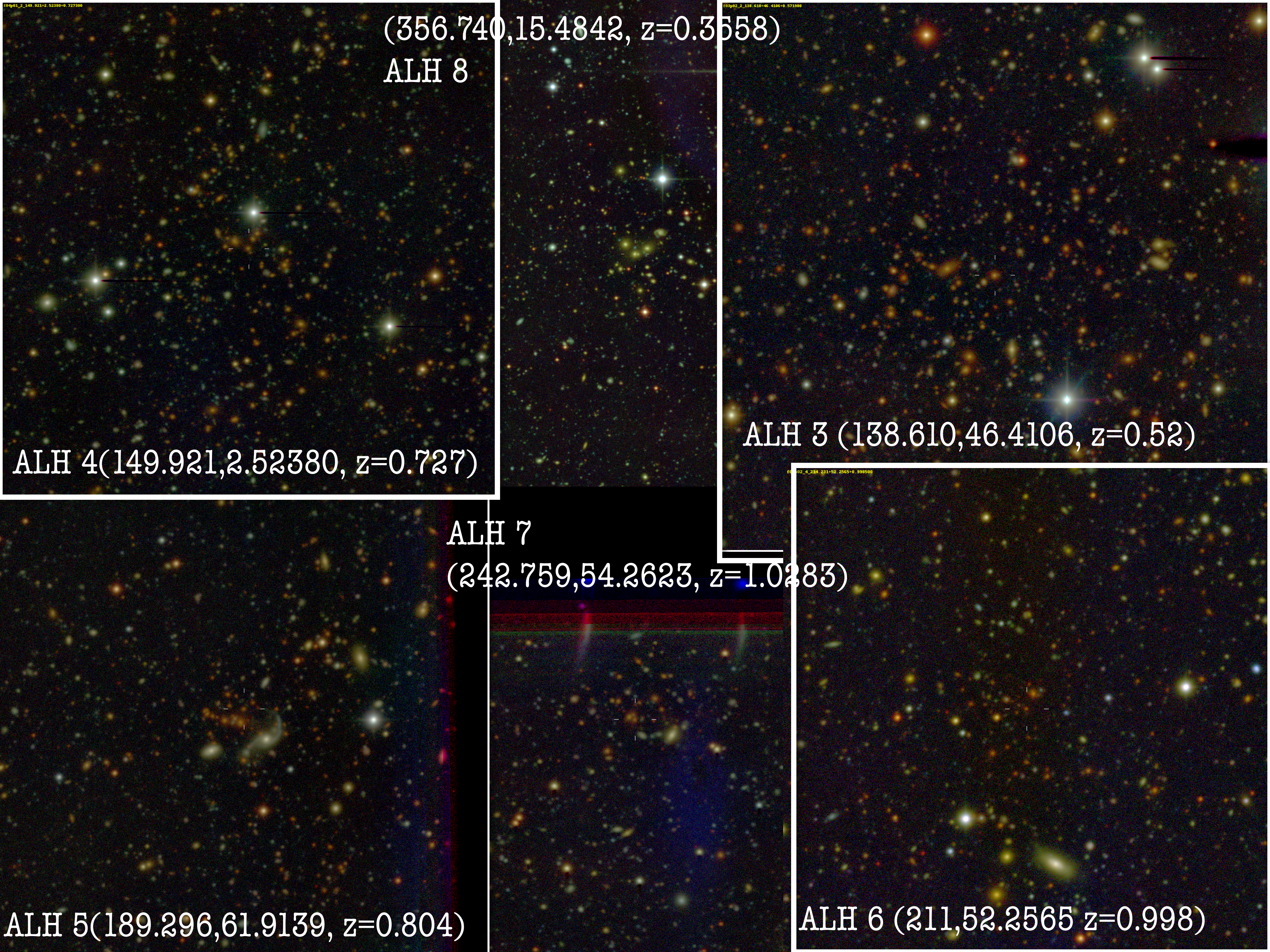
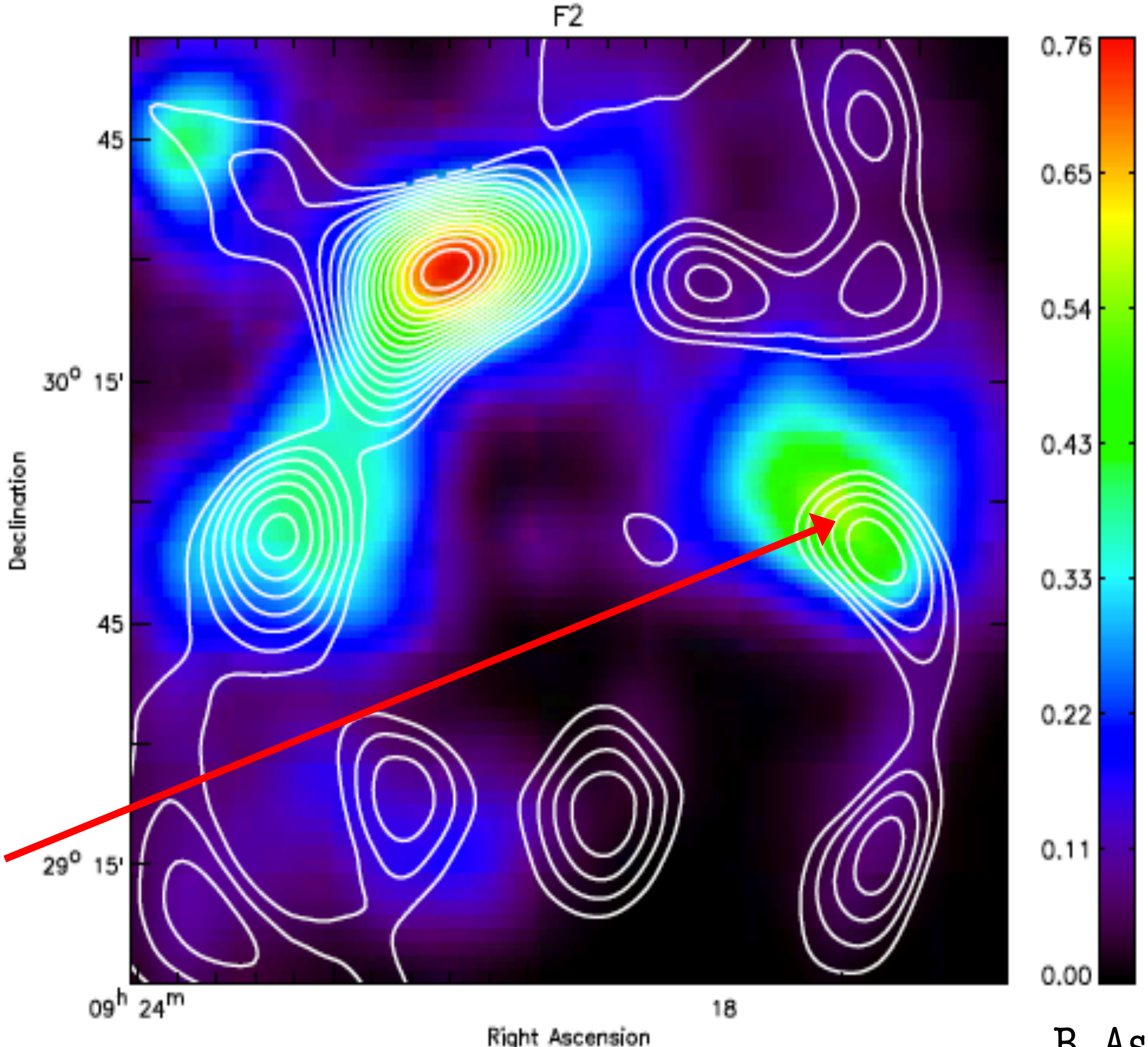

(356.740,15.4842, z=0.3558)
ALH 8
ALH 4(149.921,2.52380, z=0.727)
ALH 3 (138.610,46.4106, z=0.52)
ALH 7
(242.759,54.2623, z=1.0283)
ALH 5(189.296,61.9139, z=0.804)
ALH 6 (211,52.2565 z=0.998)

Deep Lens Survey (DLS)

Ascaso et al. 2014a



Musket Ball Cluster
(*Dawson et al. 2012*)

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MASS-OBSERVABLE RELATIONS

Ascaso et al. 2016 a,b

J-PAS

J-PAS

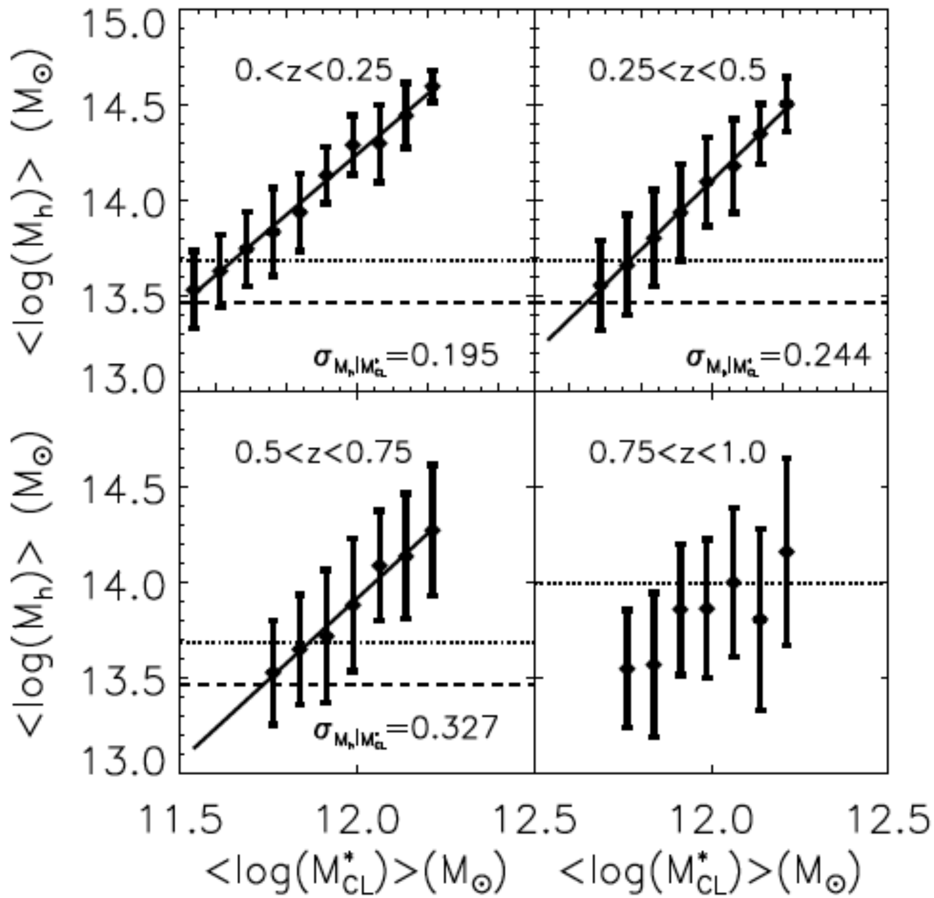
$\sigma_{Mh|M^*CL}$~0.24 dex to M~3x10^{13}M$_{\odot}$

Euclid

$\sigma_{Mh|M^*CL}$~0.20-0.25 dex to M~5x10^{13}M$_{\odot}$

LSST

$\sigma_{Mh|M^*CL}$~0.22 dex to M~5x10^{13}M$_{\odot}$



Observable: M$^*_{CL}$= total stellar mass in the cluster

Mass: Halo mass of the mock catalogue

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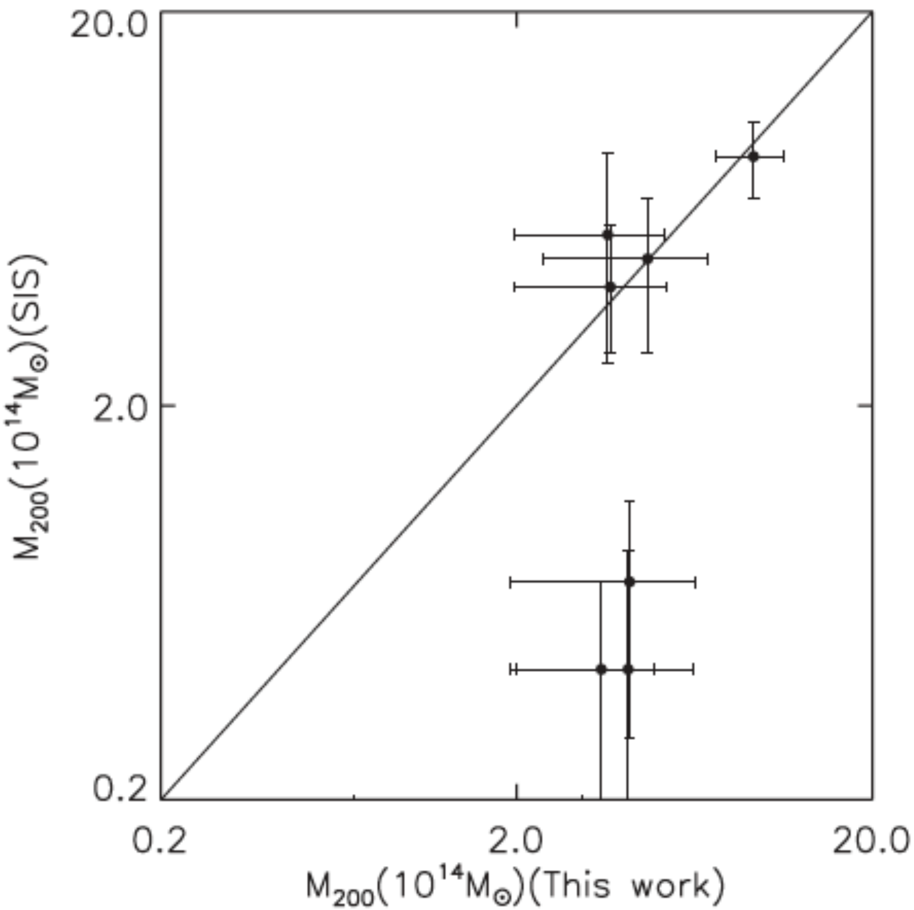
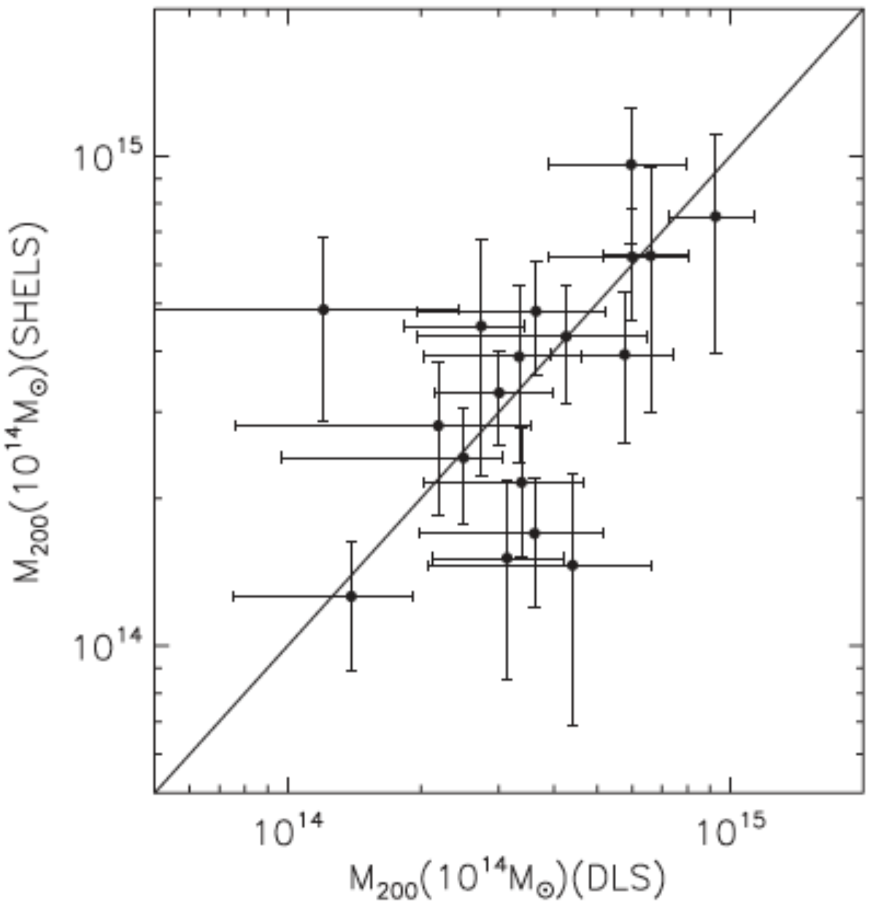
MASS-OBSERVABLE RELATION

Deep Lens Survey (DLS)





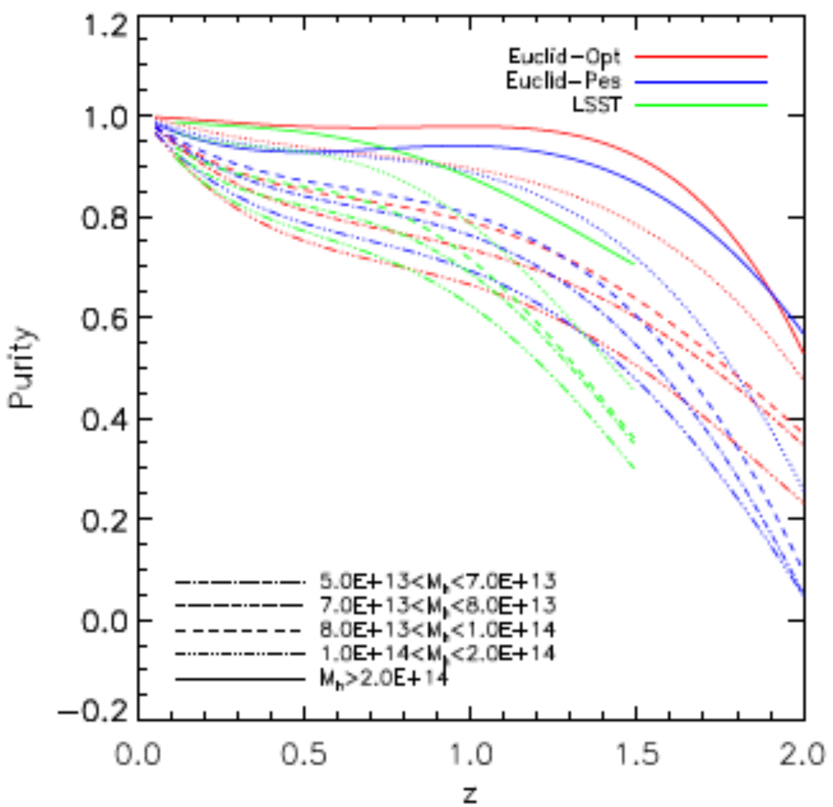
Ascaso et al. 2014a

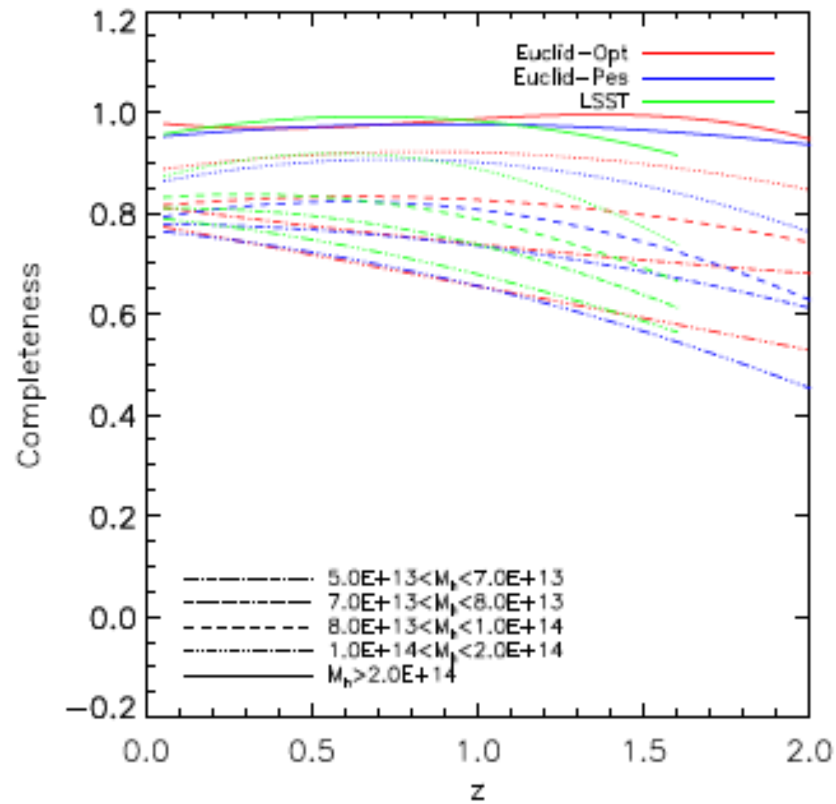
See also *Foëx et al. 2012, Andreon et al. 2012, etc*

SELECTION FUNCTIONS

COMPLETENESS-PURITY RATES

Euclid and LSST





Ascaso et al. 2016b, MNRAS, in press

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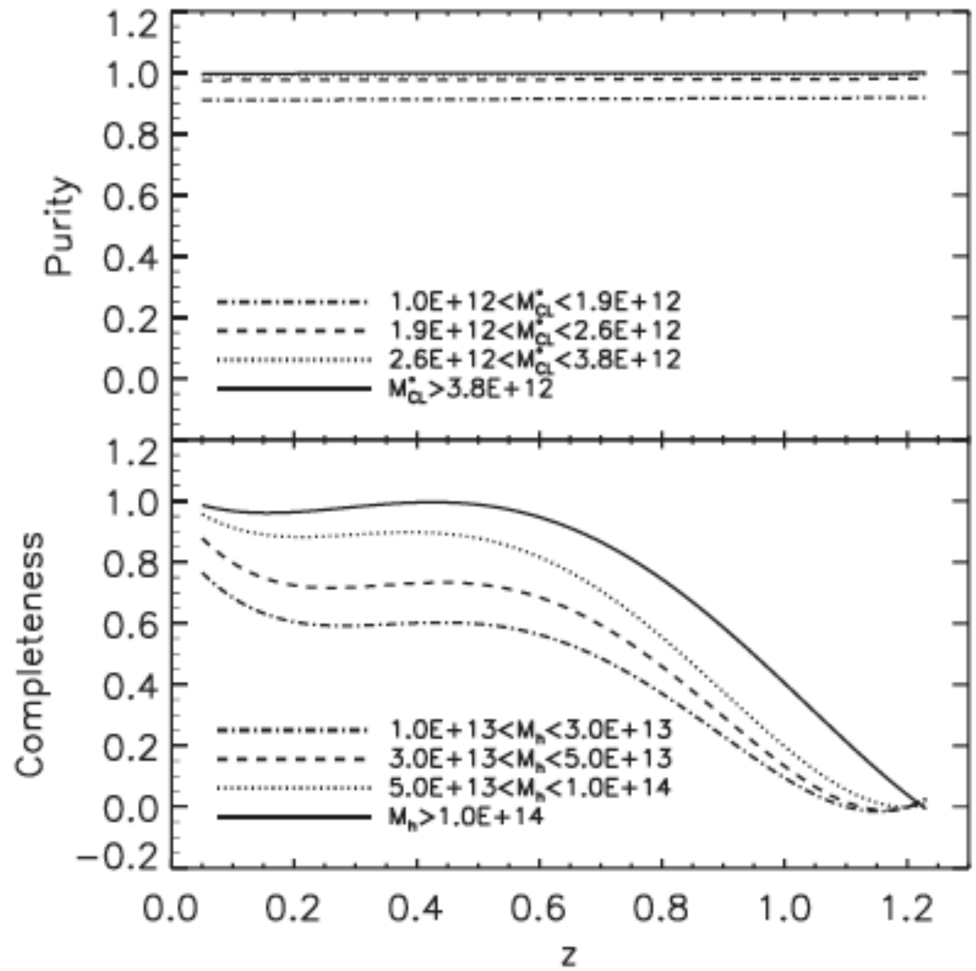
COMPLETENESS-PURITY RATES



J-PAS

Ascaso et al. 2016a

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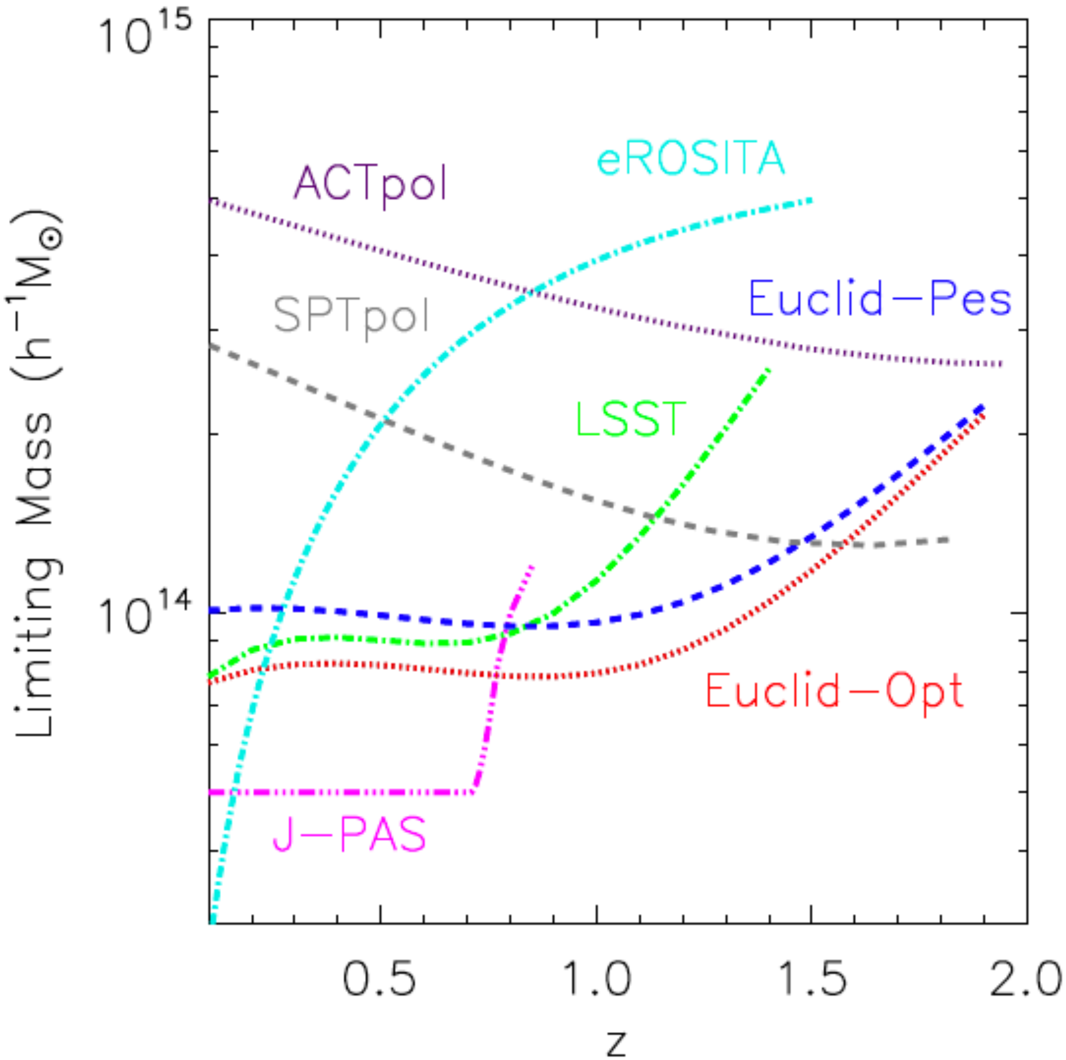
SELECTION FUNCTIONS



Ascaso et al. 2016b, MNRAS, in press

- ACTpol and SPTpol: Weinberg et al. 2013
- eROSITA: Pillepich et al. 2012
- J-PAS: Ascaso et al. 2016a
- Euclid, LSST: Ascaso et al. 2016b

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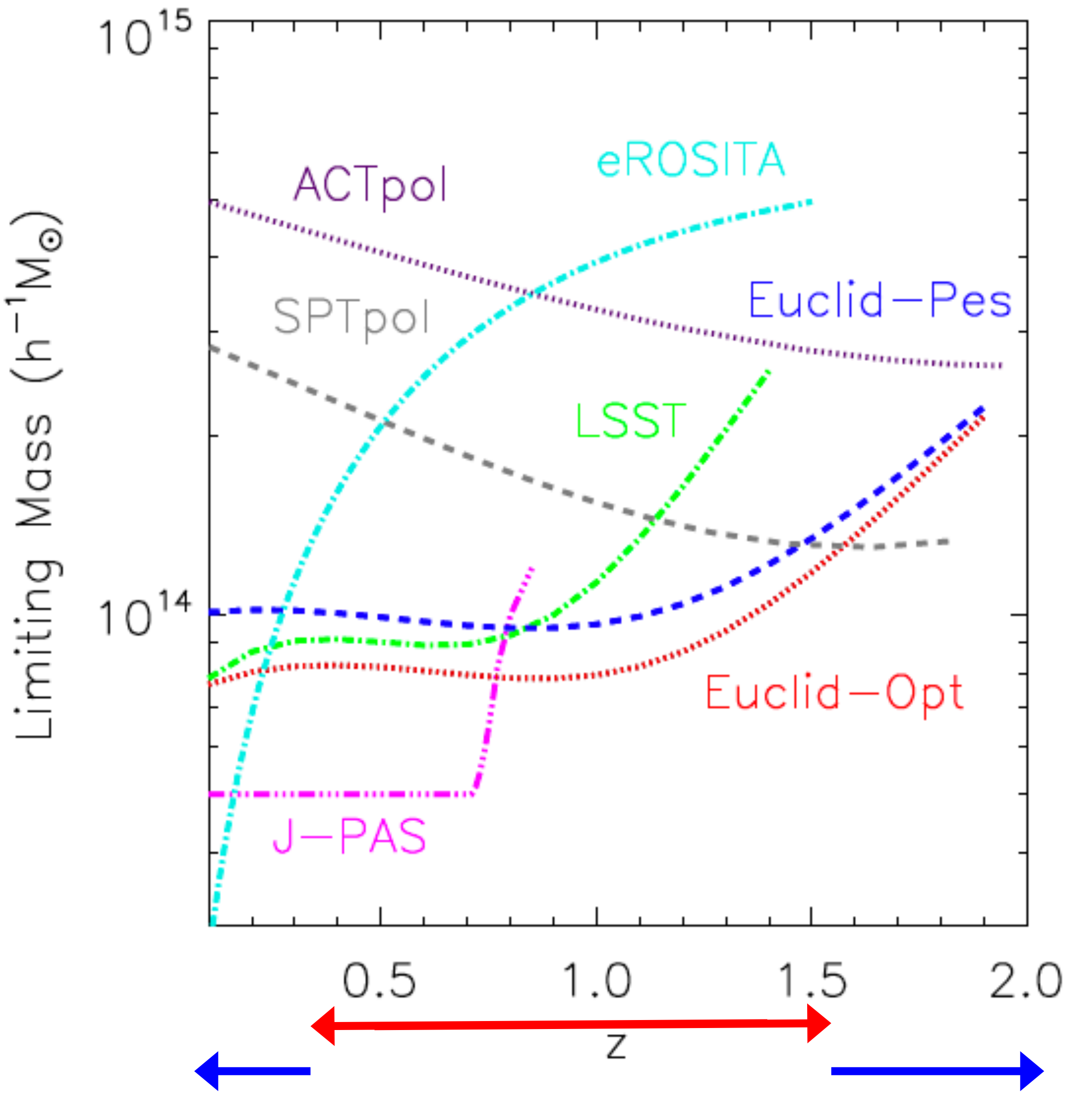
SELECTION FUNCTIONS



Ascaso et al. 2016b, MNRAS, in press

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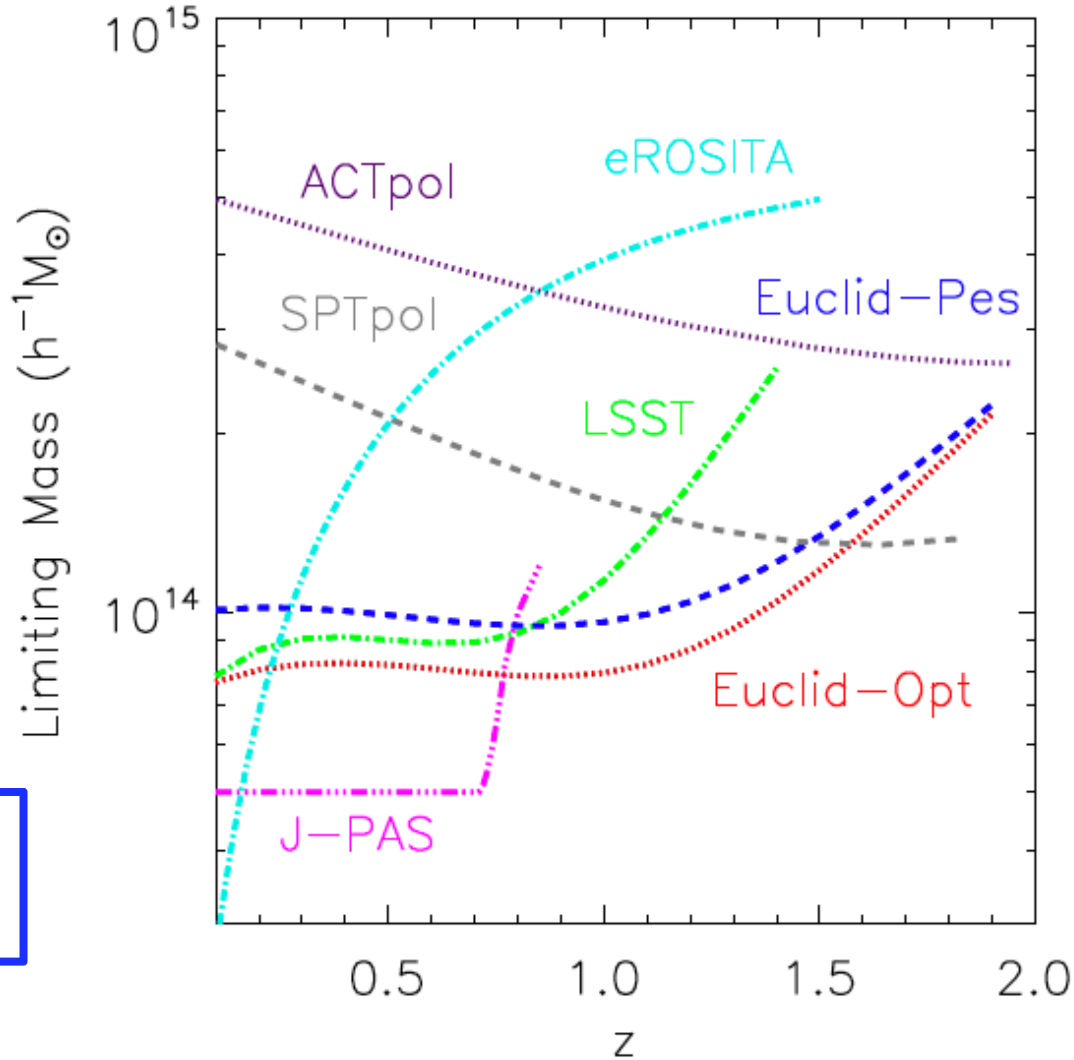
SELECTION FUNCTIONS

In preparation

-Selection function of SKA (radio)

-Mass-Observable relation for SKA



work in progress with
D. Herranz, F. Combes

Ascaso et al. 2016b, MNRAS, in press

B. Ascaso

DIFFERENT SOURCES OF ERROR

(OPTICAL CLUSTERS ARE COMPLICATED)

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(OPTICAL CLUSTERS ARE COMPLICATED)

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DIFFERENT SOURCES OF ERROR

(OPTICAL CLUSTERS ARE COMPLICATED)

- Definition of a cluster / halo
- Best observable to use
- Matching procedures
- Completeness / Purity computation
- Signal-to-noise cuts imposed in cluster / halo catalogues

Effort done in *Ascaso et al. 2015b, 2016a, 2016b*

+ work in progress together with the Euclid Cluster Science Group

B. Ascaso

COSMOLOGY WITH CLUSTER COUNTS

$$\frac{dN}{dM_{obs}dz} = \underbrace{\Phi(M_{obs}, z, \Omega)}_{\text{Selection function}} \int dM \, \underbrace{P(M_{obs}|M, z)}_{\text{Mass-Observable relation}} \frac{dN}{dV\,dM} \frac{dV}{dz\,dM_{obs}}$$

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COSMOLOGY WITH CLUSTER COUNTS

In preparation

Goal: Obtain constraints using galaxy clusters for two main models mainly

- Dark Energy Equation of State (EoS)
- Modified Gravity (MG)

For LSST, Euclid and J-PAS (at least)

Work in progress with the J. Bartlett & M. Penna-Lima

COSMOLOGY WITH CLUSTER COUNTS

In preparation

1st approach: Fisher Matrix

The Fisher Matrix of the number counts

$$F_{\mu\nu} = \sum_{ij} \frac{\partial \overline{m}_i}{\partial p_\mu} (C^{-1})_{ij} \frac{\partial \overline{m}_j}{\partial p_\nu}$$

C= Covariance matrix of the cluster counts

Implemented by creating a new library in iCosmo (*Refregier et al. 2008*) for galaxy clusters counting

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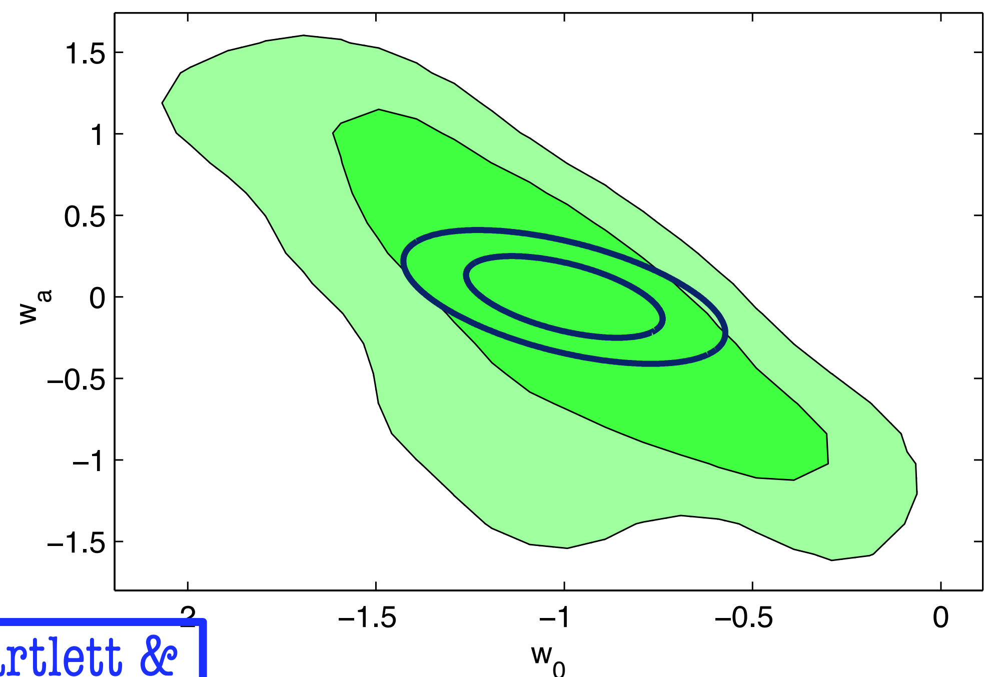
COSMOLOGY WITH CLUSTER COUNTS

In preparation

2^{nd} approach: sample the cosmological parameter space with Markov Chain Monte Carlo (MCMC)

Implemented with NumCosmo
(*Vitenti & Penna-Lima 2012*)

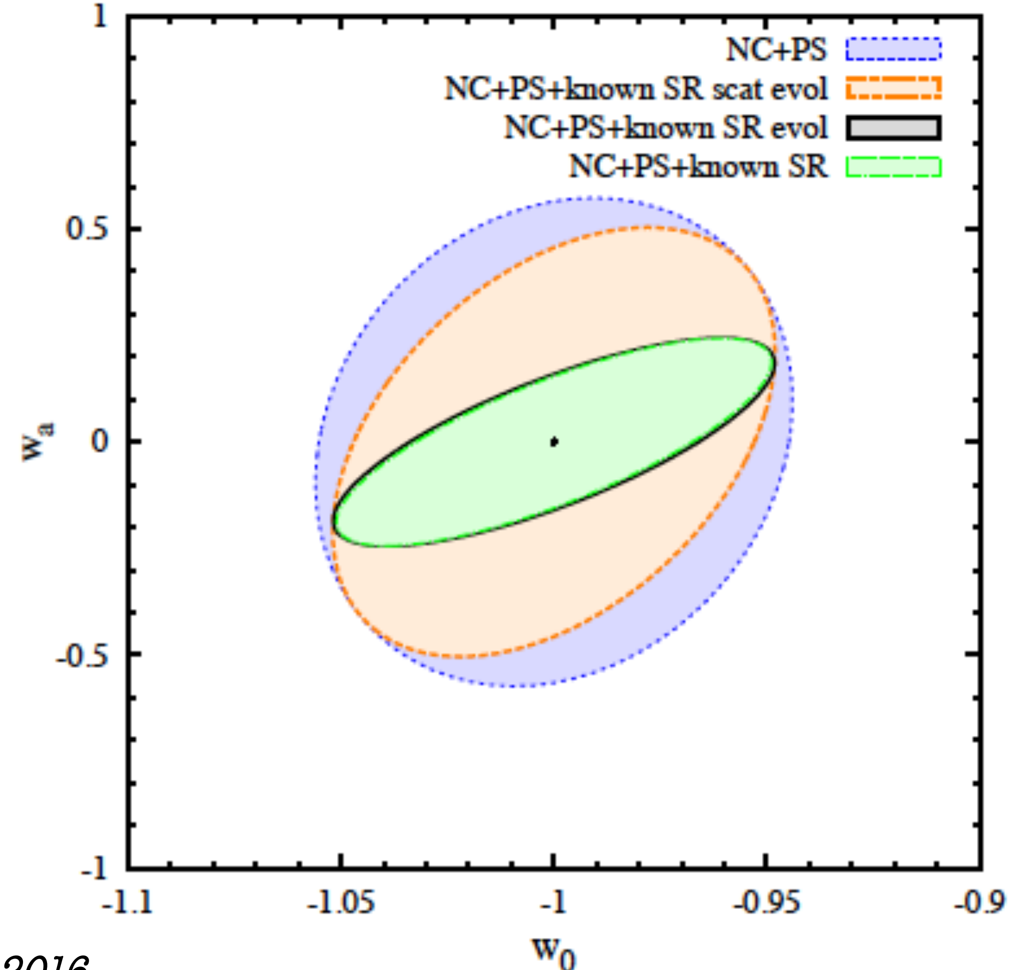


Constraints for eROSITA
Khedekar & Majumdar 2013

Work in progress with the J. Bartlett & M. Penna-Lima

CLUSTER COUNTS FORECAST

Euclid



Sartoris et al. 2016

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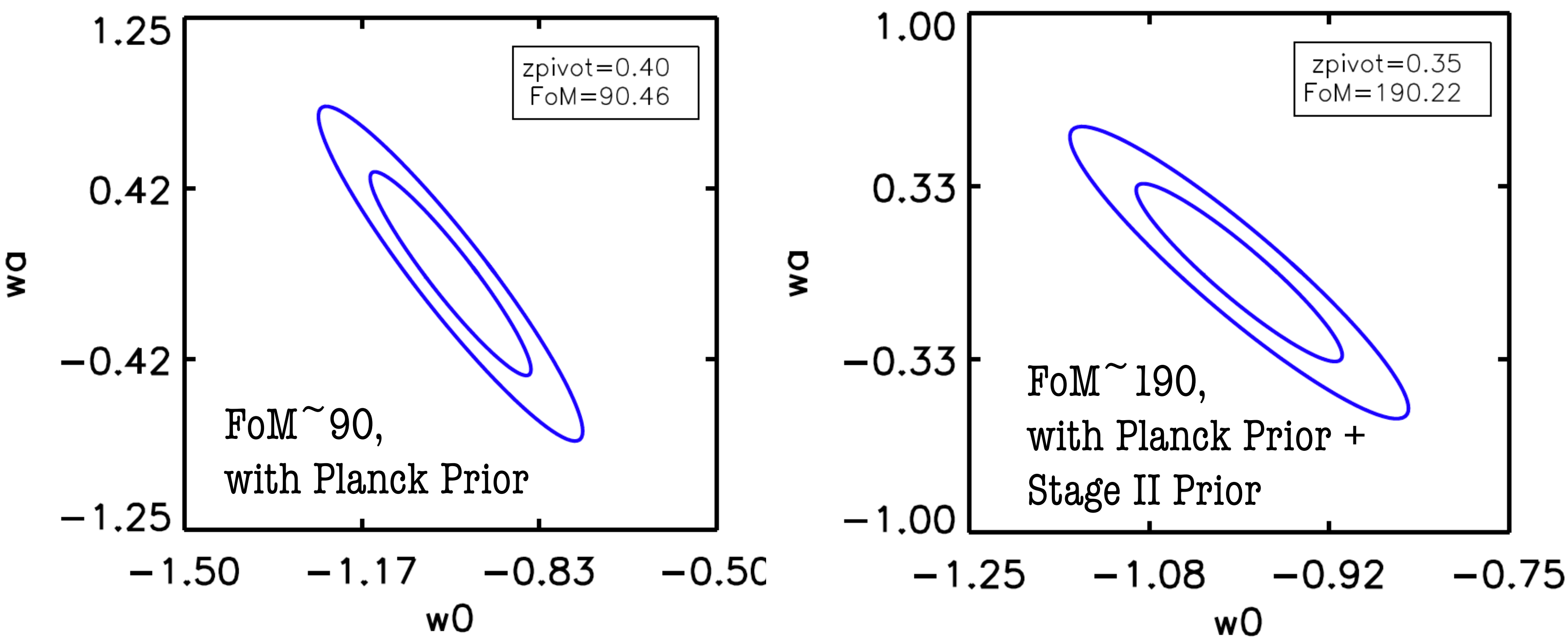
CLUSTER COUNTS FORECAST

In preparation

J-PAS $z=[0,1.2], \Delta\Omega = 8000 deg^2, M_{th} = 5\times 10^{13}, \sigma_{\ln M} = 0.25$

$$\mathrm{FoM} = [\sigma(w_p)\sigma(w_a)]^{-1}$$



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CONCLUSIONS

- Consistent comparison between three next-generation stage IV optical surveys: LSST / Euclid / J-PAS

- Mock catalogues mimicking realistically the surveys with PhotReal

- Mass-Observable calibrated relation and estimated selection functions for the three surveys. Needed “better” masses.

- Obtained cosmological constraints with cluster counts and derived Figure of Merit for the dark energy EoS.

- Optical clusters are crucial to sample correctly the mass function. Synergies with X-rays and SZ. Future constraints from radio clusters.

B. Ascaso

Merci!

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