

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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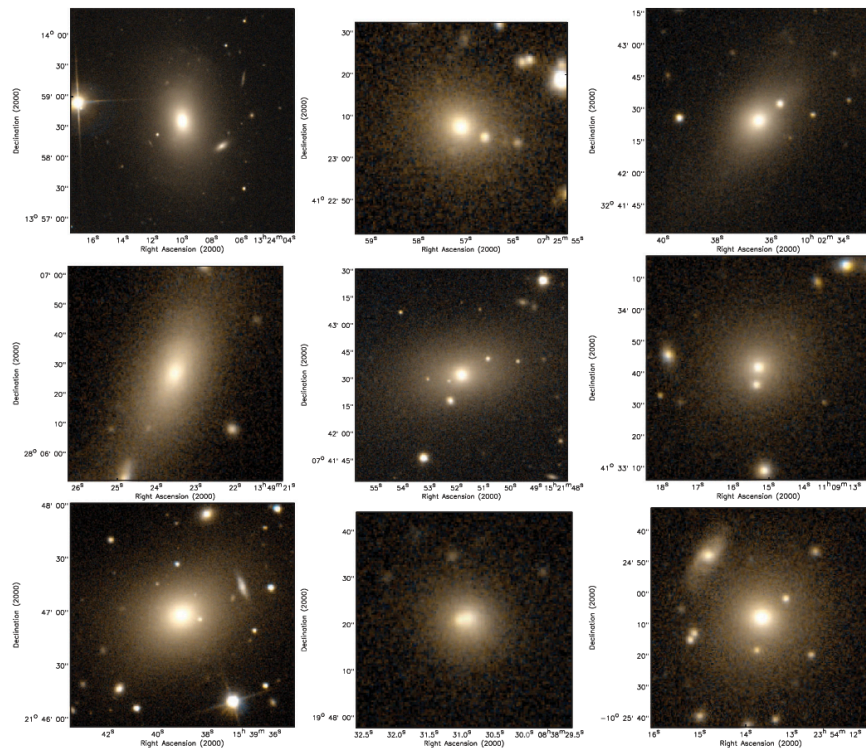


A1689 (ACS/HST)

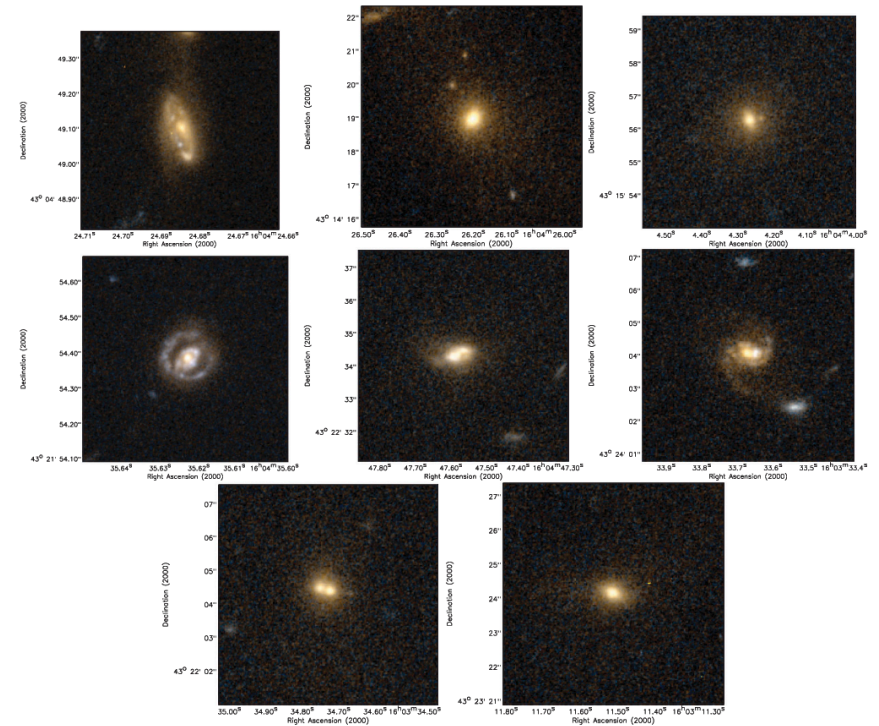
GALAXIES IN CLUSTERS

Brightest Cluster Galaxies (BCGs)

$z \sim 0$



$z \sim 0.9$

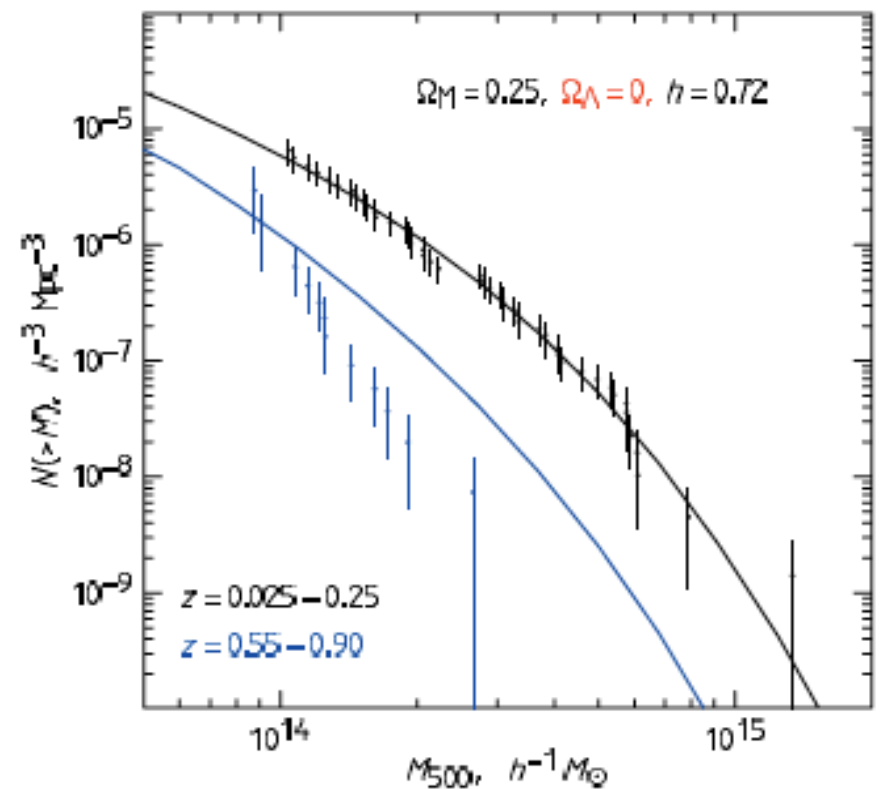
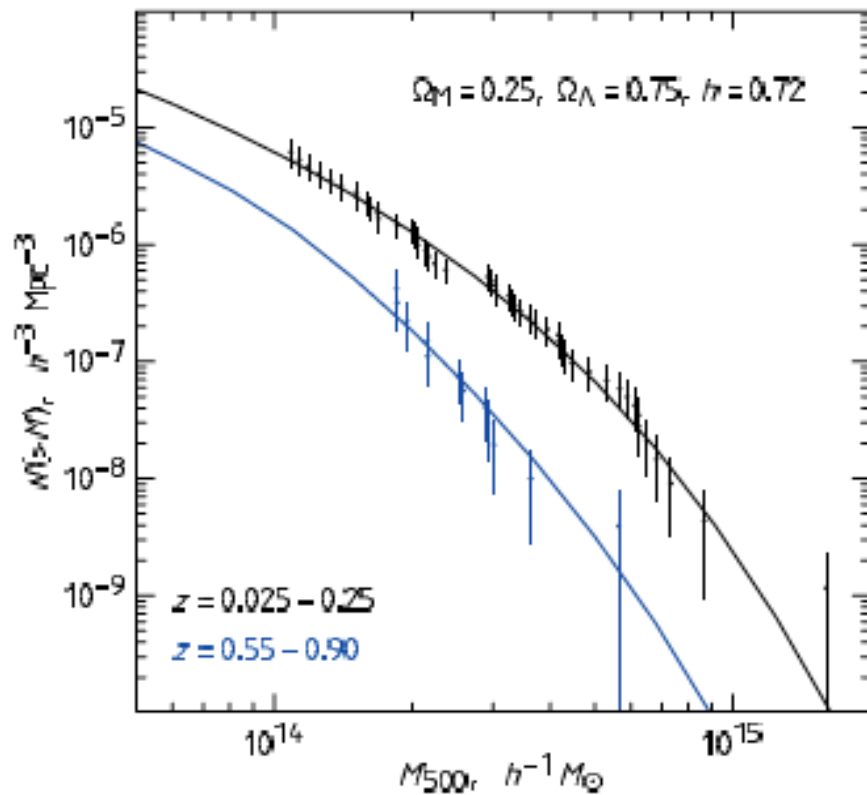


Ascaso et al. 2014b

B. Ascaso

CLUSTERS IN COSMOLOGY

Vikhlinin et al. 2009



COSMOLOGY WITH CLUSTER COUNTS

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

Selection function

Mass-Observable relation

COSMOLOGY WITH CLUSTER COUNTS

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

Selection function

Mass-Observable relation

“CLOThIde”

The Cluster Observations and Theory Intersection

H2020-MSCA-IF-2014

P.I: B. Ascaso

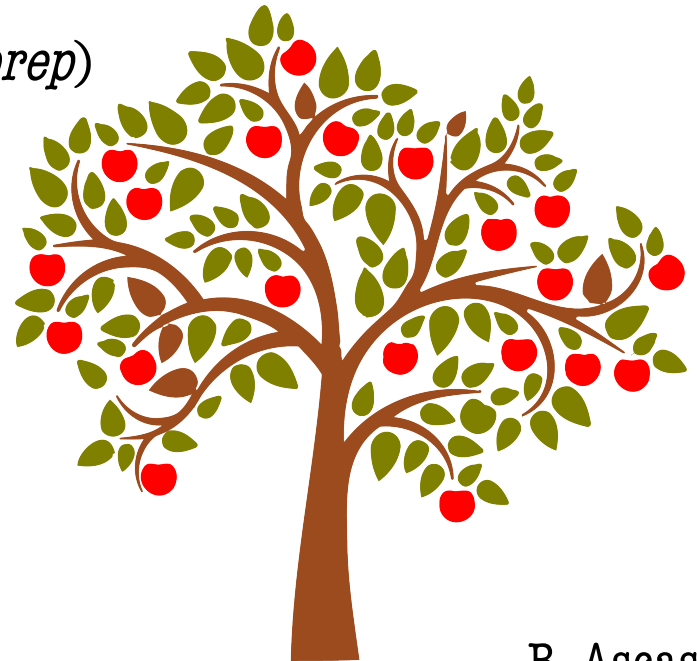
APPLES TO APPLES: A²

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



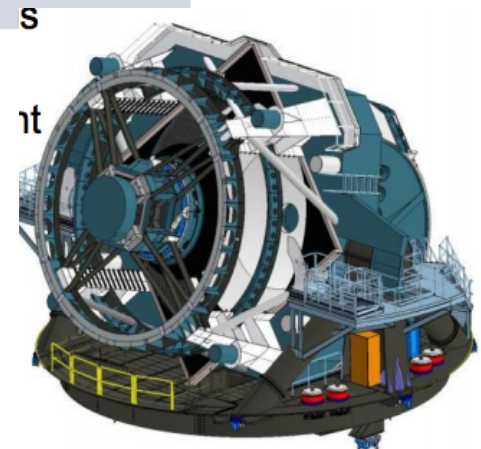
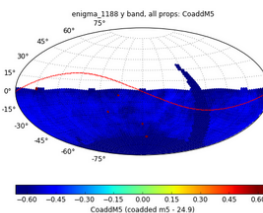
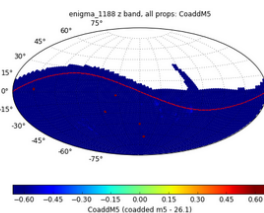
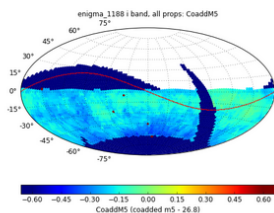
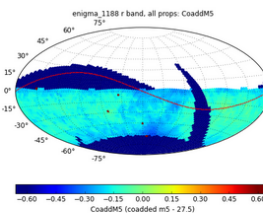
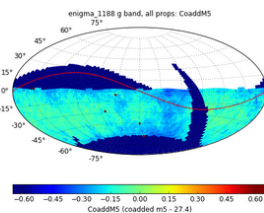
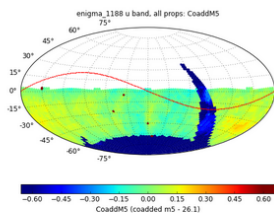
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LSST IN A NUTSHELL

<http://www.lsst.org/>

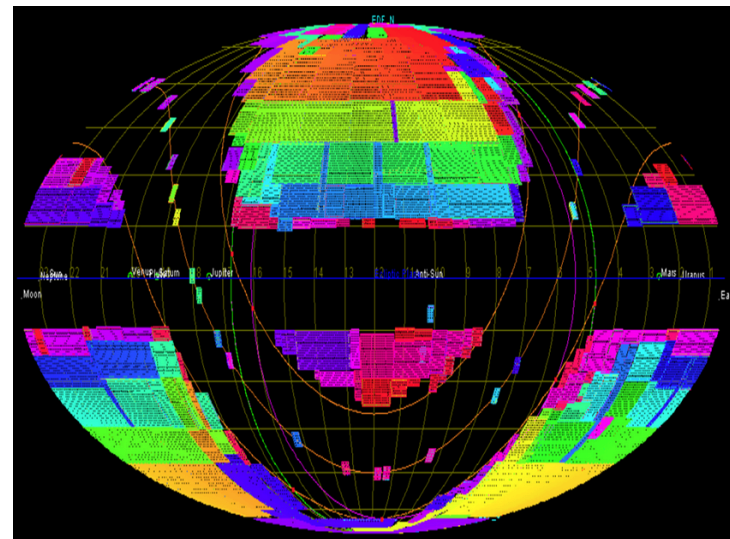
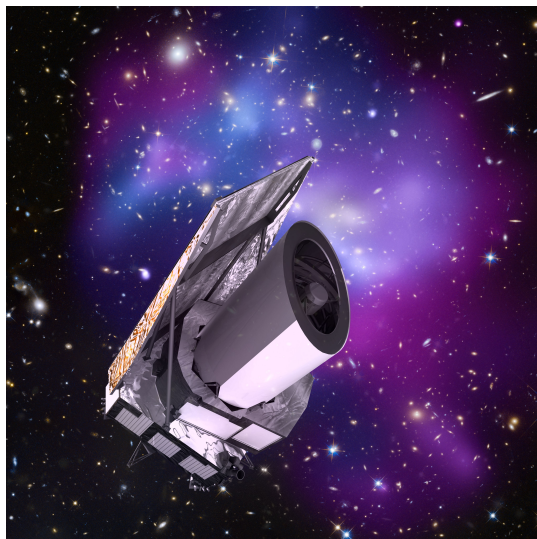
Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute,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



EUCLID IN A NUTSHELL

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

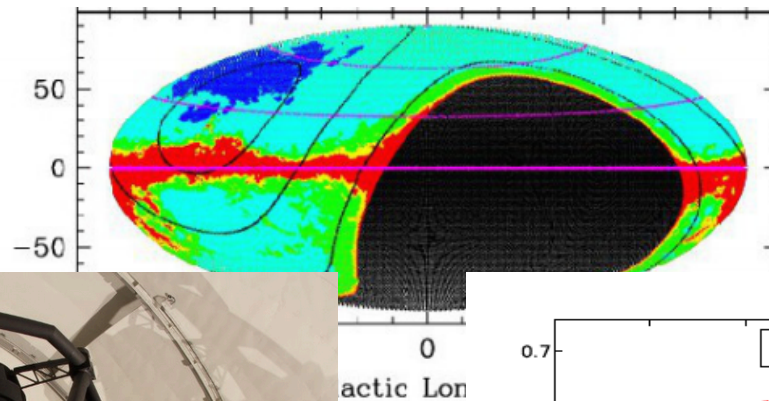
SURVEYS					
	Area (deg ²)	Description			
Wide Survey	15,000 deg²	Step and stare with 4 dither pointings per step.			
Deep Survey	40 deg²	In at least 2 patches of $> 10 \text{ deg}^2$ 2 magnitudes deeper than wide survey			
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)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



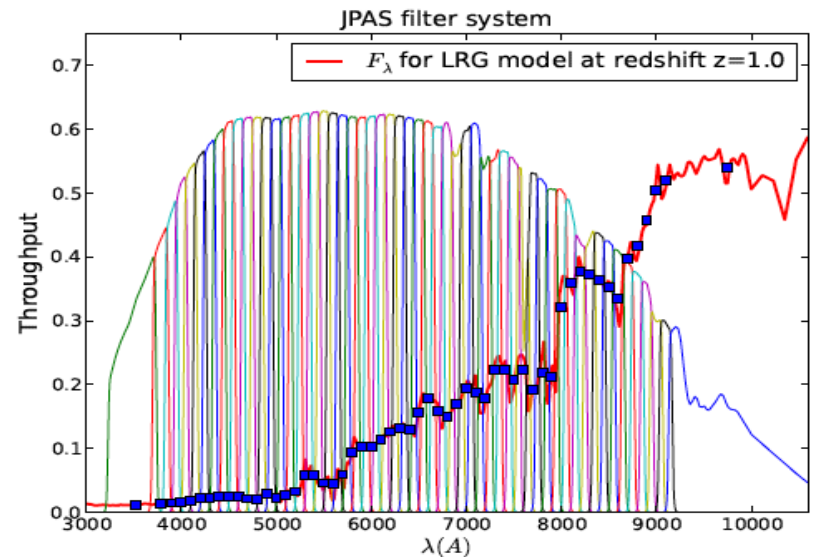
J-PAS IN A NUTSHELL

<http://j-pas.org>

8600 sq. deg. survey with 56 filters with 136Å width, 100Å spacing $I \sim 22$
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 deg² 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)

REALISTIC COSMOLOGICAL SIMULATIONS

Starting from the 500 deg² 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:

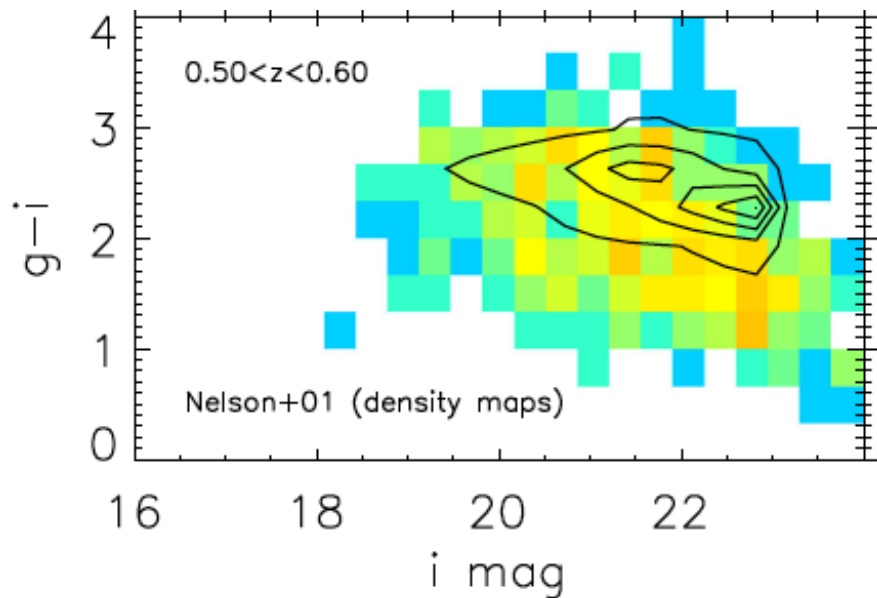
- LSST
- Euclid-Pessimistic (using an optical counterpart just from DES)
- Euclid-Optimistic (using an optical counterpart from DES+LSST)
- J-PAS

PHOTREAL

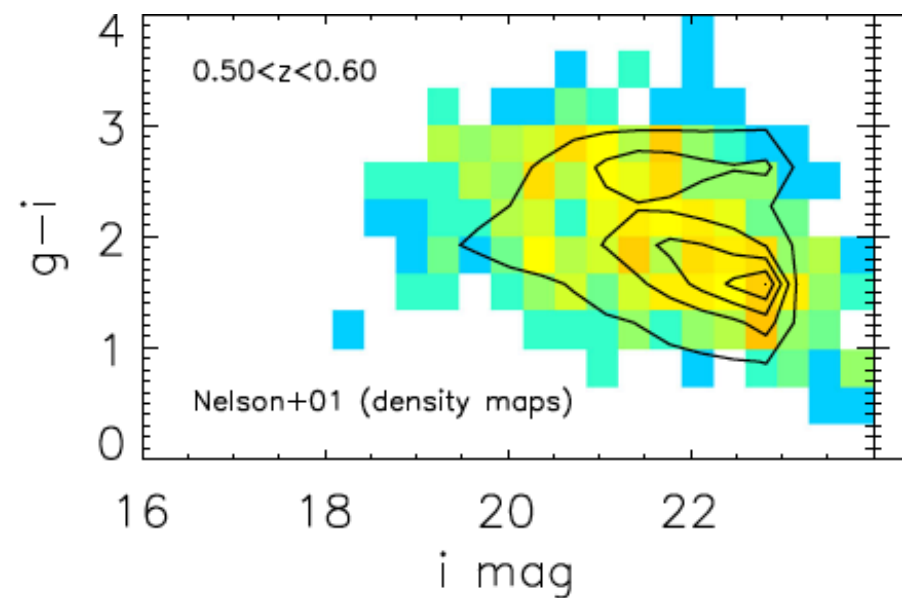
Use [PhotReal](#) to add parameters to existing mock catalogues:

- Realistic photometry, colors and photometric errors

Before PhotReal



After PhotReal



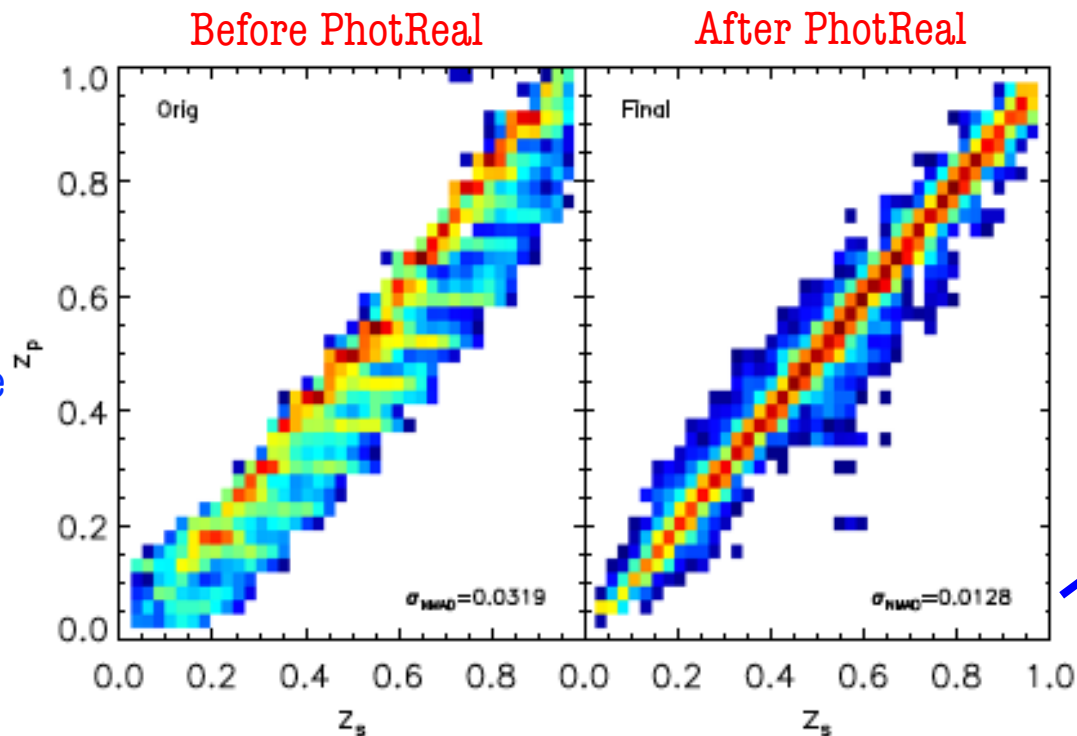
Ascaso et al. 2015b

PHOTREAL

Use **PhotReal** to add parameters to existing mock catalogues:

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

ALHAMBRA
mock catalogue

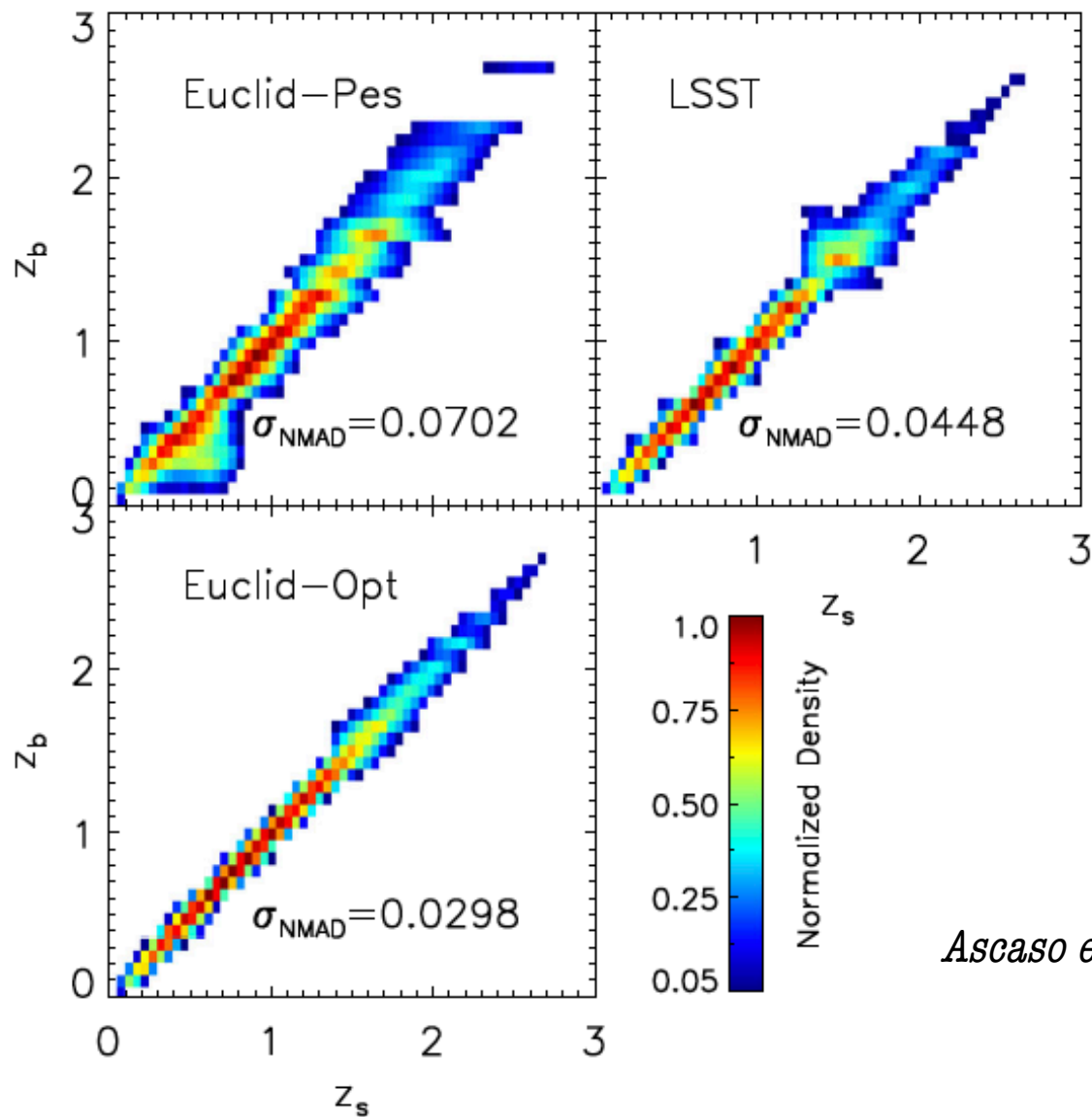


=ALHAMBRA data
 $\sigma_{\text{NMAD}}=0.0125$

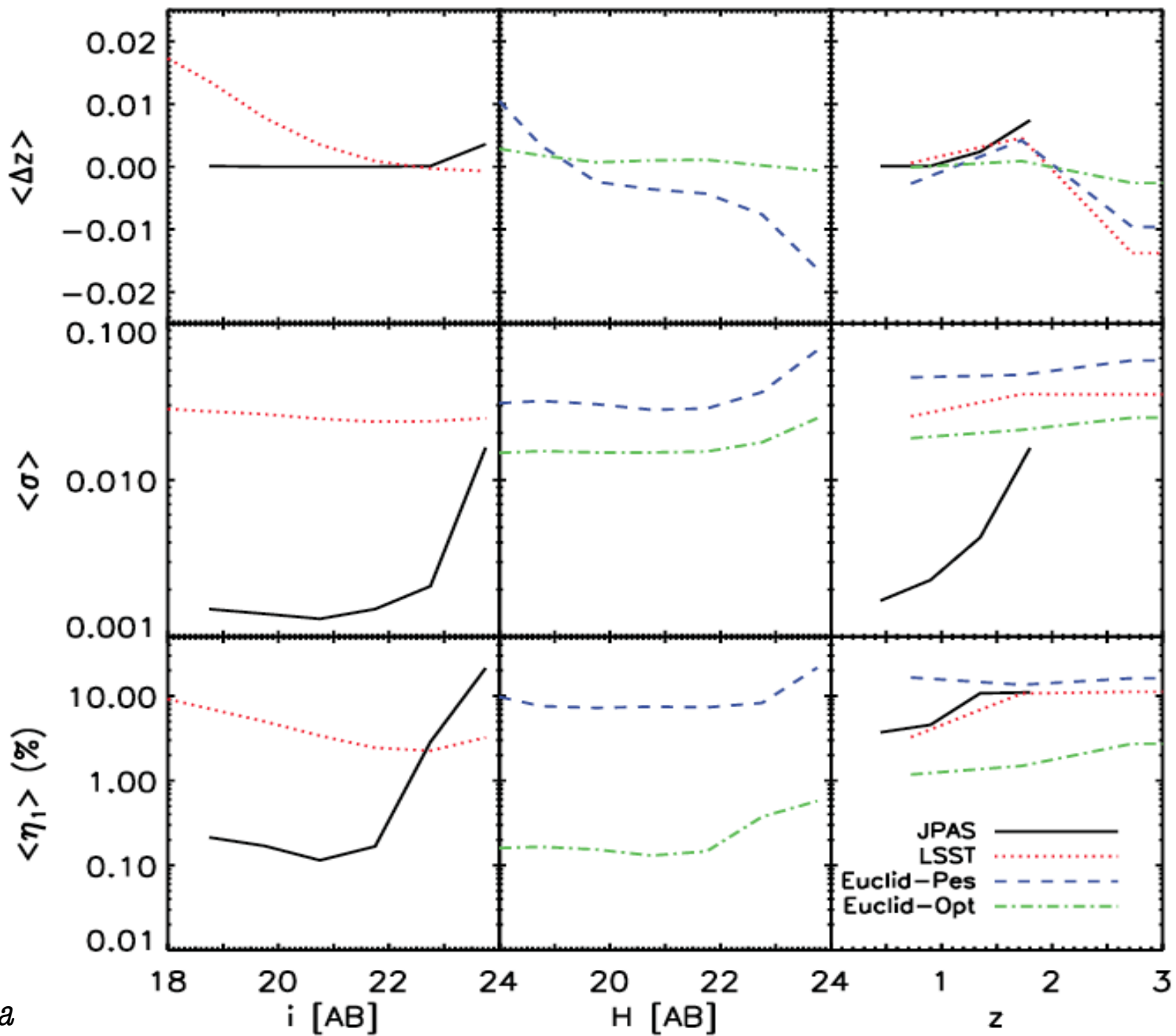
PHOTREAL

Use Phot.

- Real
- Real



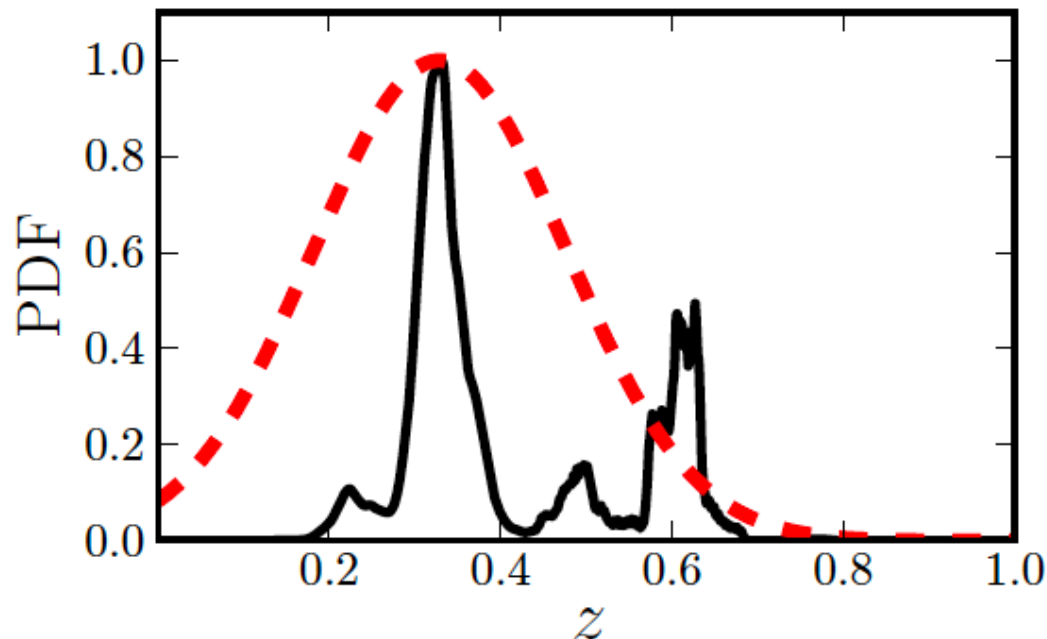
Ascaso et al. 2015b



PHOTREAL

Use [PhotReal](#) to add parameters to existing mock catalogues:

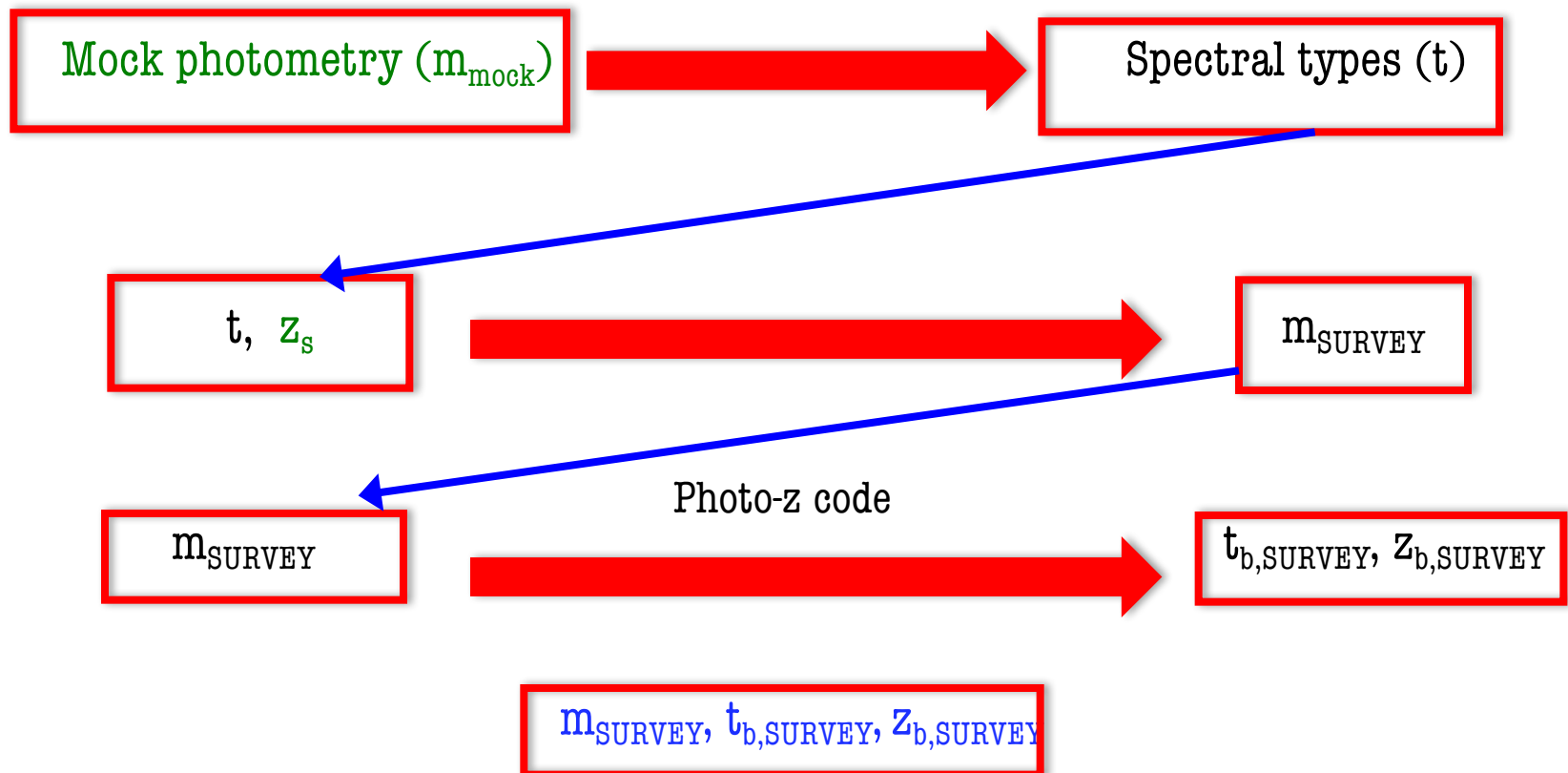
- Realistic photometry, colors and photometric errors
- Realistic photometric redshifts and derived parameters
- Realistic $P(z)$



López-Sanjuan et al. 2015

PHOTREAL

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



AVAILABLE PHOTREAL MOCKS

ALHAMBRA	J-PAS	J-PAS	LSST*	EUCLID-W*	EUCLID-D
<i>Merson+13</i>	<i>Zandivarez+14</i>	<i>Merson+13</i>	<i>Merson+13</i>	<i>Merson+13</i>	<i>Merson et al. in prep</i>
N-body simulation (Millenium)+SA M (Galform)	N-body simulation (Millenium)+SA M (<i>Guo+11</i>)	N-body simulation (Millenium)+SA M (Galform)	N-body simulation (Millenium)+SA M (Galform)	N-body simulation (Millenium)+SA M (Galform)	N-body simulation (Millenium)+SA M (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 _⊙	M _h >10 ⁸ M _⊙	M _h >10 ¹⁰ M _⊙	M _h >10 ¹⁰ M _⊙	M _h >10 ¹⁰ M _⊙	M _h >10 ¹⁰ M _⊙
<i>Ascaso et al. 2015a, MNRAS, 452, 549</i>	<i>Zandivarez et al. 2014, A&A, 561, 71</i>	<i>Ascaso et al. 2016a, MNRAS, 456, 4291</i>	<i>Ascaso et al. 2015b, MNRAS, 453, 2515</i>	<i>Ascaso et al. 2015b, MNRAS, 453, 2515</i>	Euclid consortium

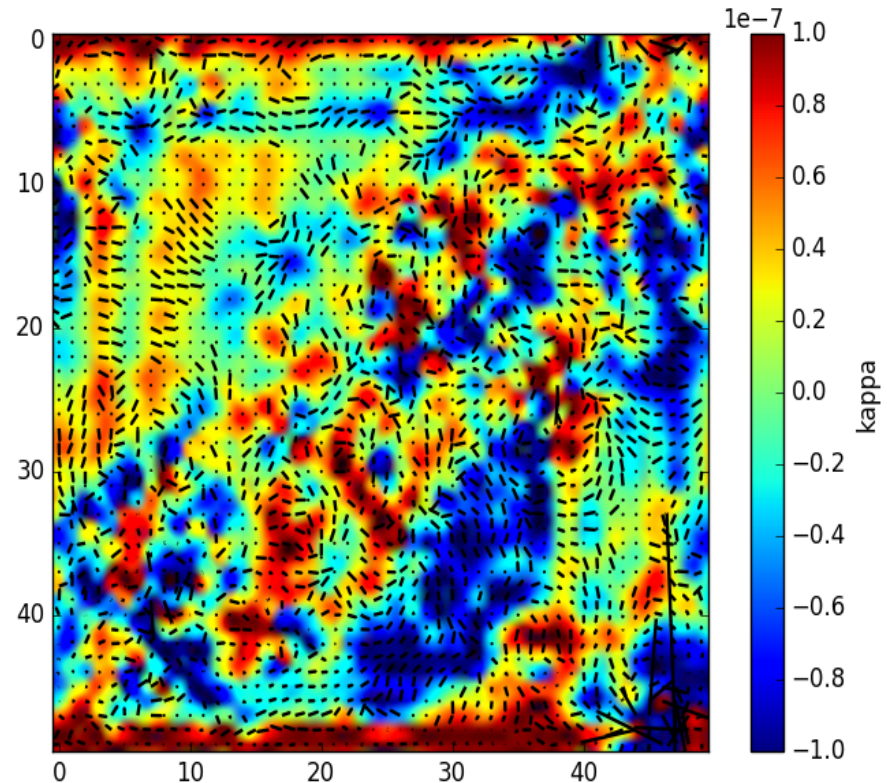
* Publicly available at <http://photmocks.obspm.fr>

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. Rouelle, 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

GEOMETRICAL TECHNIQUES

Bayesian Cluster Finder (BCF)

Ascaso et al, 2012, 2014a, 2015a

Mat

Ada

Pho

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*)

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RedGold (*Licitra et al. 2016*)

THE BAYESIAN CLUSTER FINDER

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

$$\ln L(X, Y, N_g, R_c, z_c) = \sum_i \underbrace{P(r(x_i, y_i|X, Y, z_c))}_{\text{Cluster Spatial Prof}} \underbrace{L(m_i, z_i|z_c)}_{\text{Cluster Lum Prof}} \underbrace{p(z_i|z_c)}_{\text{Redshift prob distrib}}$$

The prior (introduction of a CMR, BCG prior)

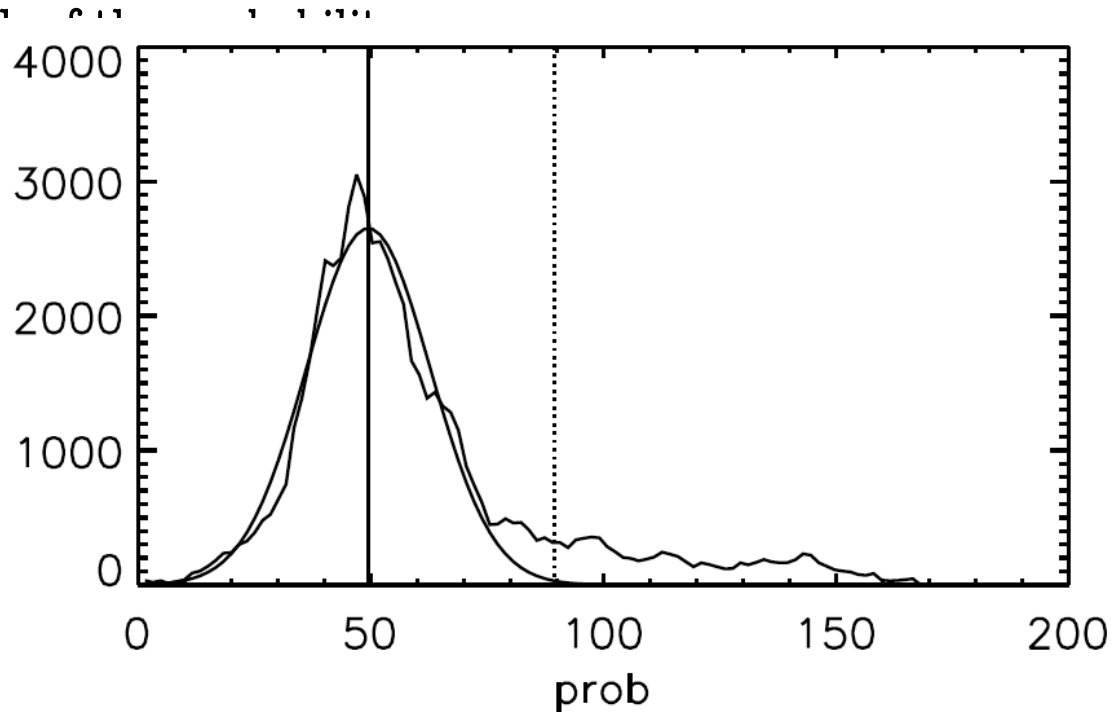
$$p(X, Y, N_g, R_c, z_c|I) = \underbrace{p(col_i)}_{\text{Expected cluster colors}} \underbrace{p(m_{\text{BCG}}(z))}_{\text{Expected BCG mag}}$$

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 ($\alpha_i, \delta_i, z_{s,i}$) $\rightarrow$ prob
3. Each $z_s \rightarrow$ 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

THE BAYESIAN CLUSTER FINDER

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3. Each $z_s \rightarrow$ background and σ probability. Only select 3σ detections.
4. Center: maximum
5. Output:
 - Richness:
 - Λ_{cl} ; effective
 - N_{200} : Number
 - M^* : Total
 - Position (α_c, δ_c)
 - Maximum prob
 - Mean redshift (



THE BAYESIAN CLUSTER FINDER

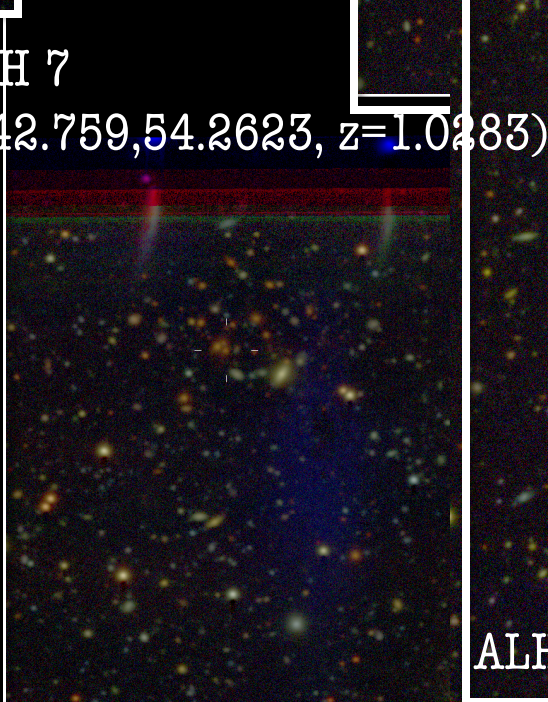
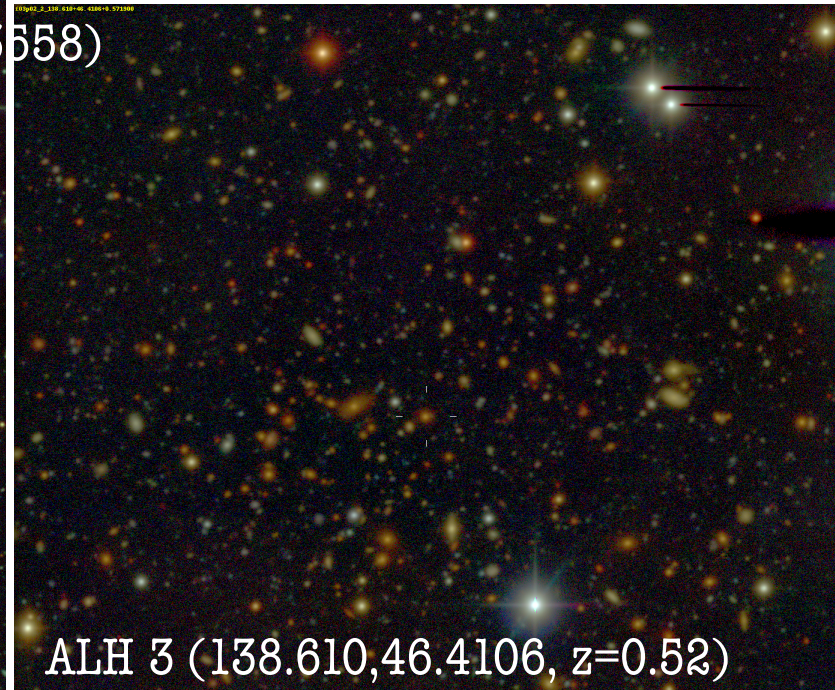
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APPLICATIONS TO REAL SURVEYS

CFHTLS	DLS	ALHAMBRA
<i>Erben et al. 2009</i> (CARS) + Others	<i>Wittman et al. 2002</i> + Others	<i>Moles et al. 2008</i> + Others
37 $\square^2$	20 $\square^2$	4 $\square^2$ (8 x 0.5 $\square^2$)
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
$\Delta z/1+z \sim 0.06$	$\Delta z/1+z \sim 0.08$	$\Delta z/1+z \sim 0.01$

APPLICATIONS TO REAL SURVEYS

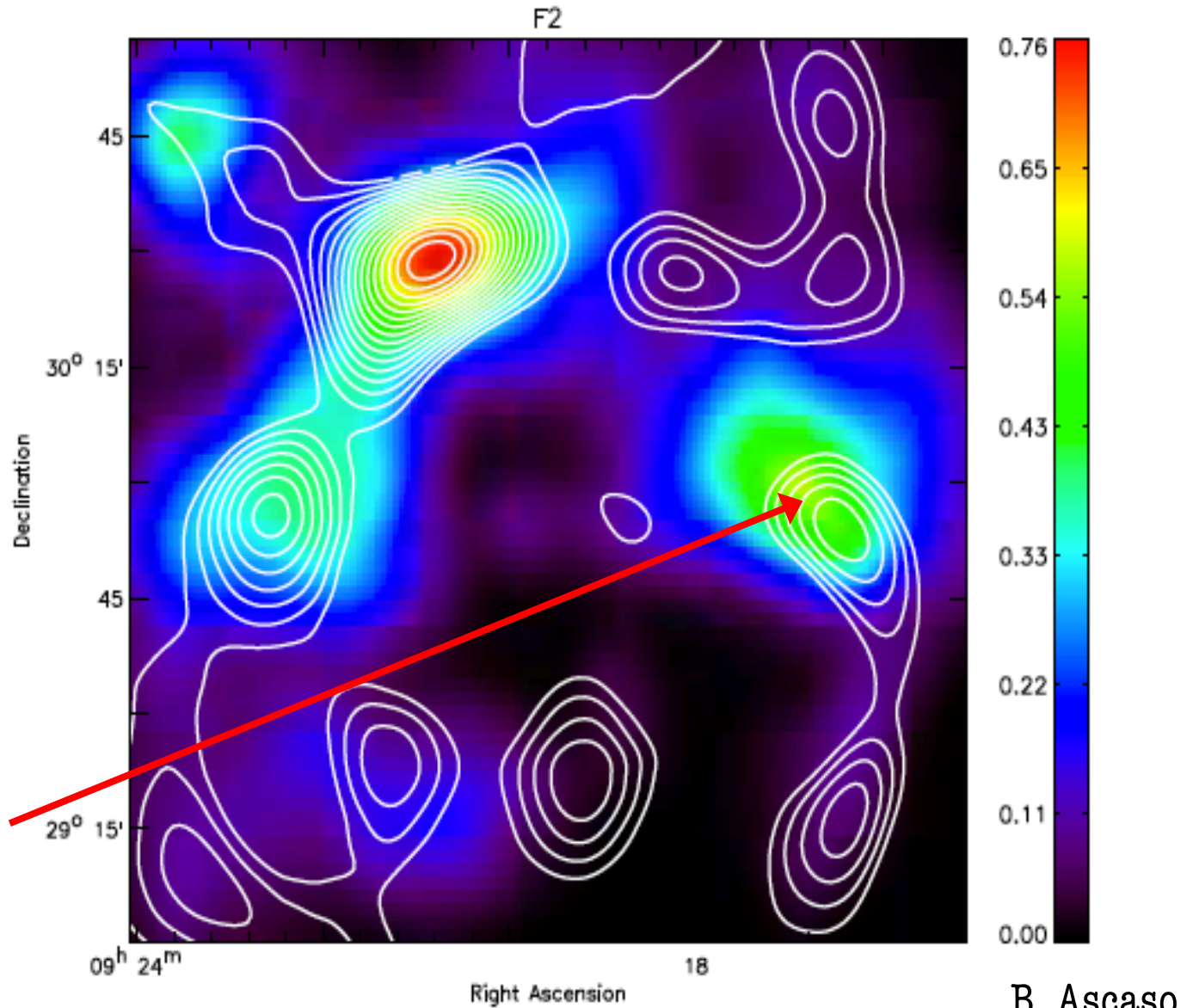
CFHTLS	DLS	ALHAMBRA
<i>Ascaso et al. 2012, MNRAS, 420, 1167</i>	<i>Ascaso et al. 2014a, MNRAS, 439, 1980</i>	<i>Ascaso et al. 2015a, MNRAS, 549, 65</i>
1246 structures ~ 33.7 /deg ²	882 structures ~ 44.1 /deg ²	348 structures ~ 125.18 /deg ²
0.1 < z < 1.2	0.25 < z < 1.2	0.2 < z < 1.2
$M > 10^{14.2} M_{\odot}$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



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

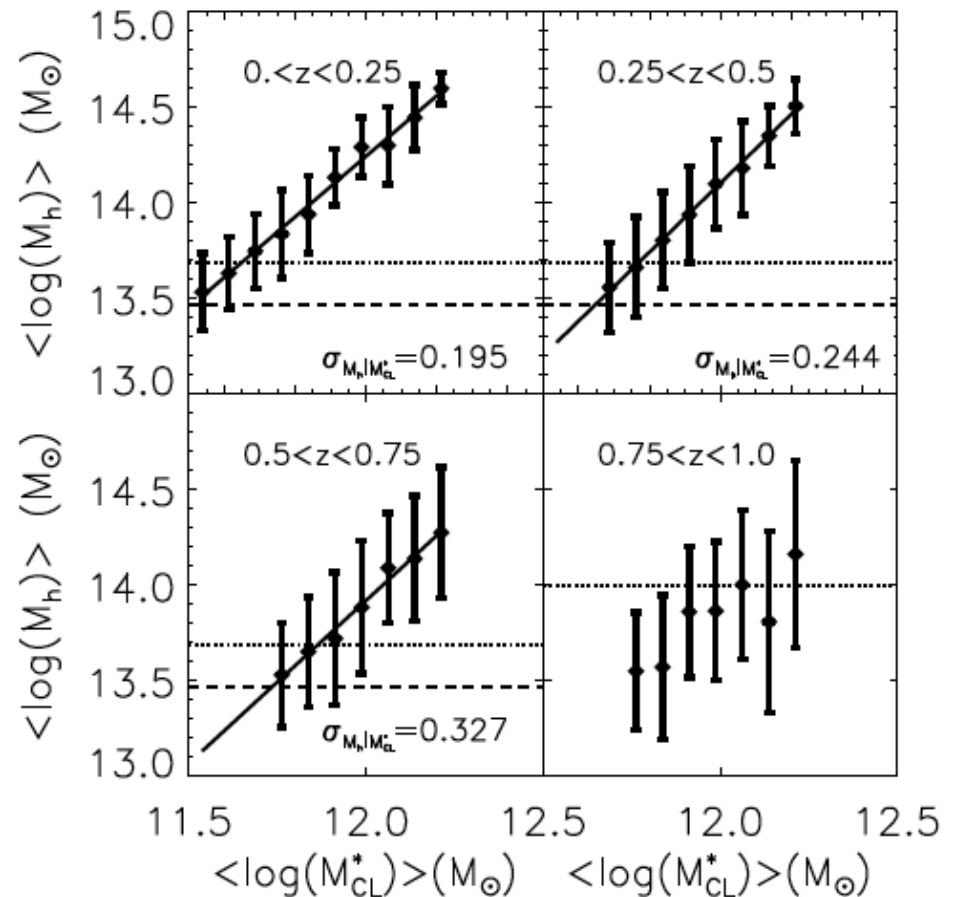
$$\sigma_{M_h|M^*_{CL}} \sim 0.24 \text{ dex to } M \sim 3 \times 10^{13} M_{\odot}$$

Euclid

$$\sigma_{M_h|M^*_{CL}} \sim 0.20\text{--}0.25 \text{ dex to } M \sim 5 \times 10^{13} M_{\odot}$$

LSST

$$\sigma_{M_h|M^*_{CL}} \sim 0.22 \text{ dex to } M \sim 5 \times 10^{13} M_{\odot}$$



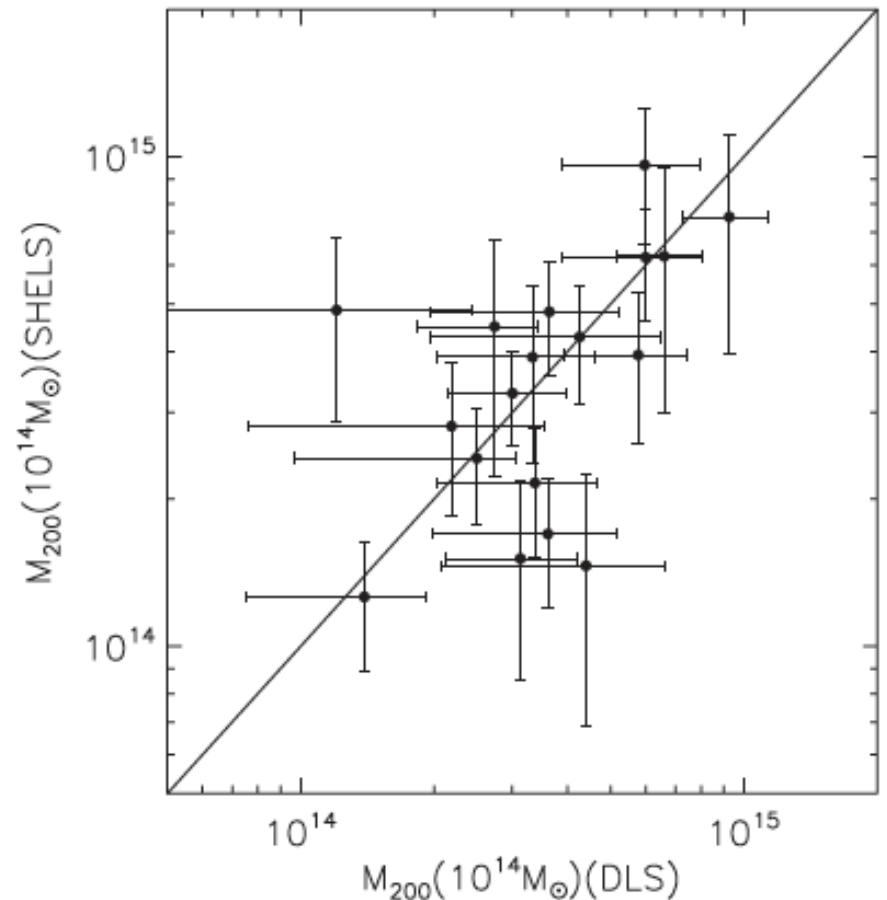
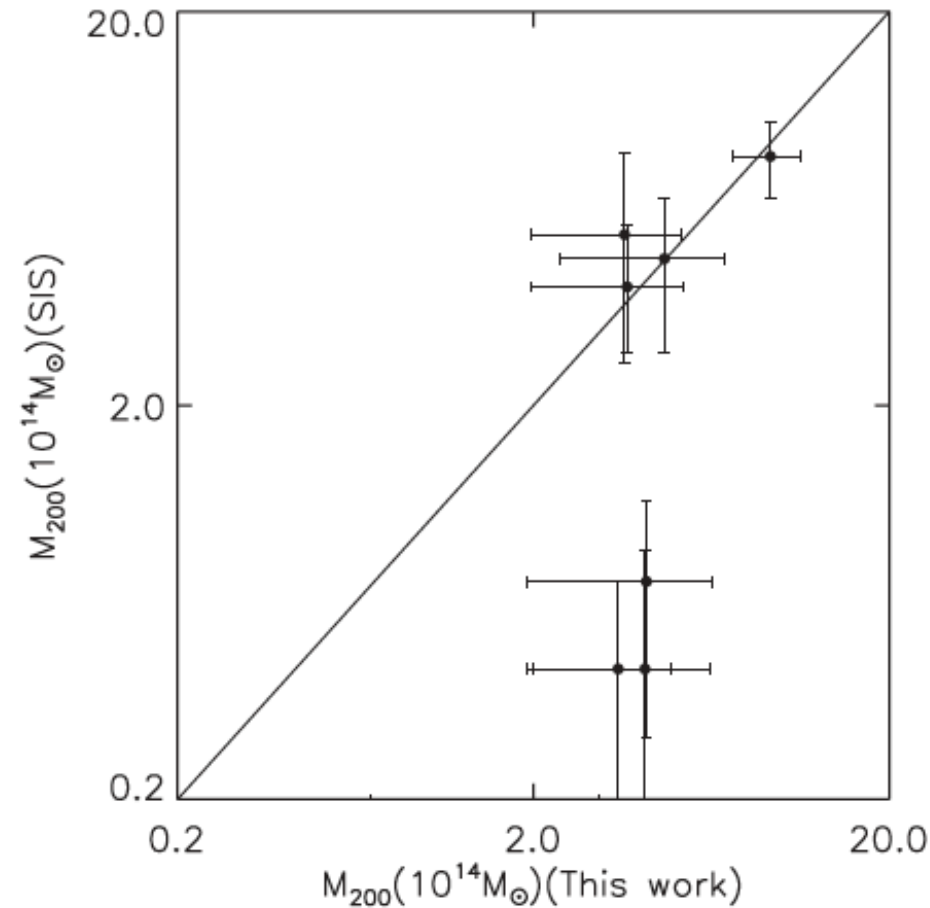
Observable: M^*_{CL} = total stellar mass in the cluster

Mass: Halo mass of the mock catalogue

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MASS-OBSERVABLE RELATION

Deep Lens Survey (DLS)



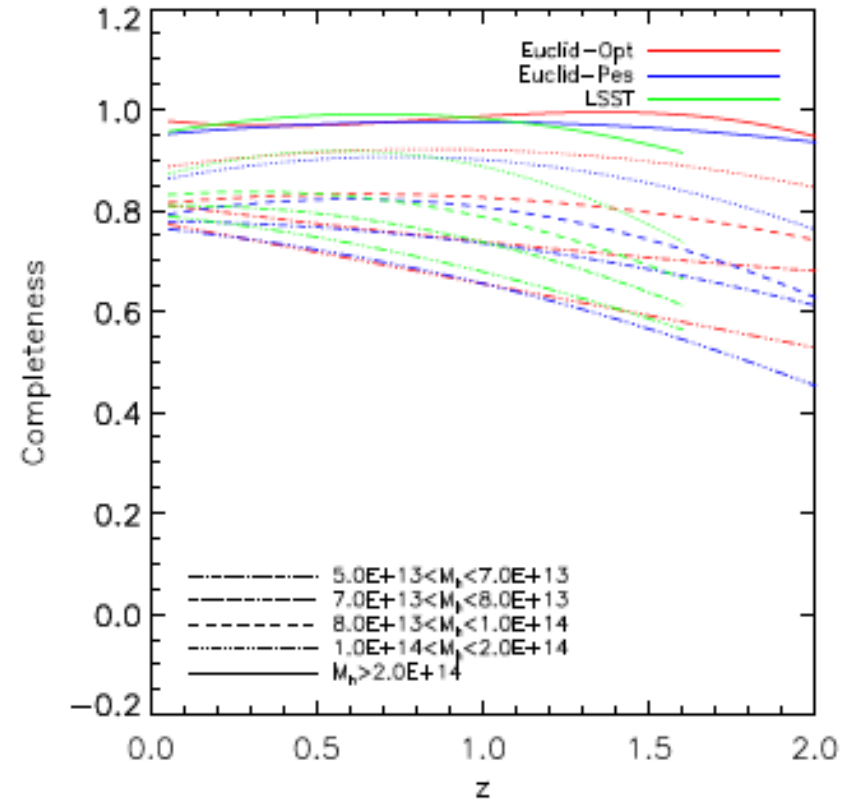
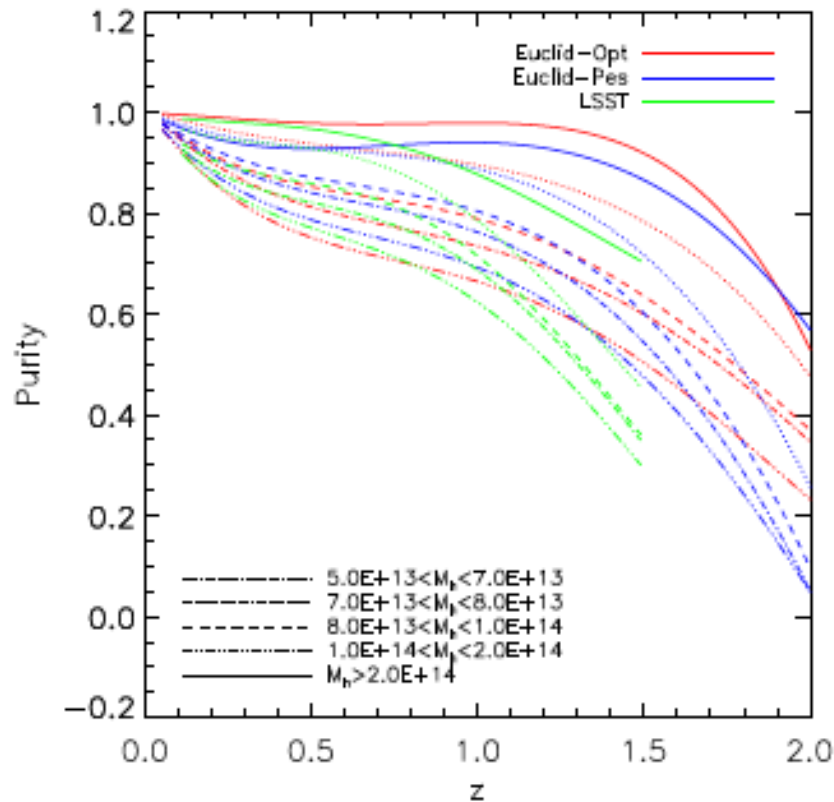
Ascaso et al. 2014a

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

SELECTION FUNCTIONS

COMPLETENESS-PURITY RATES

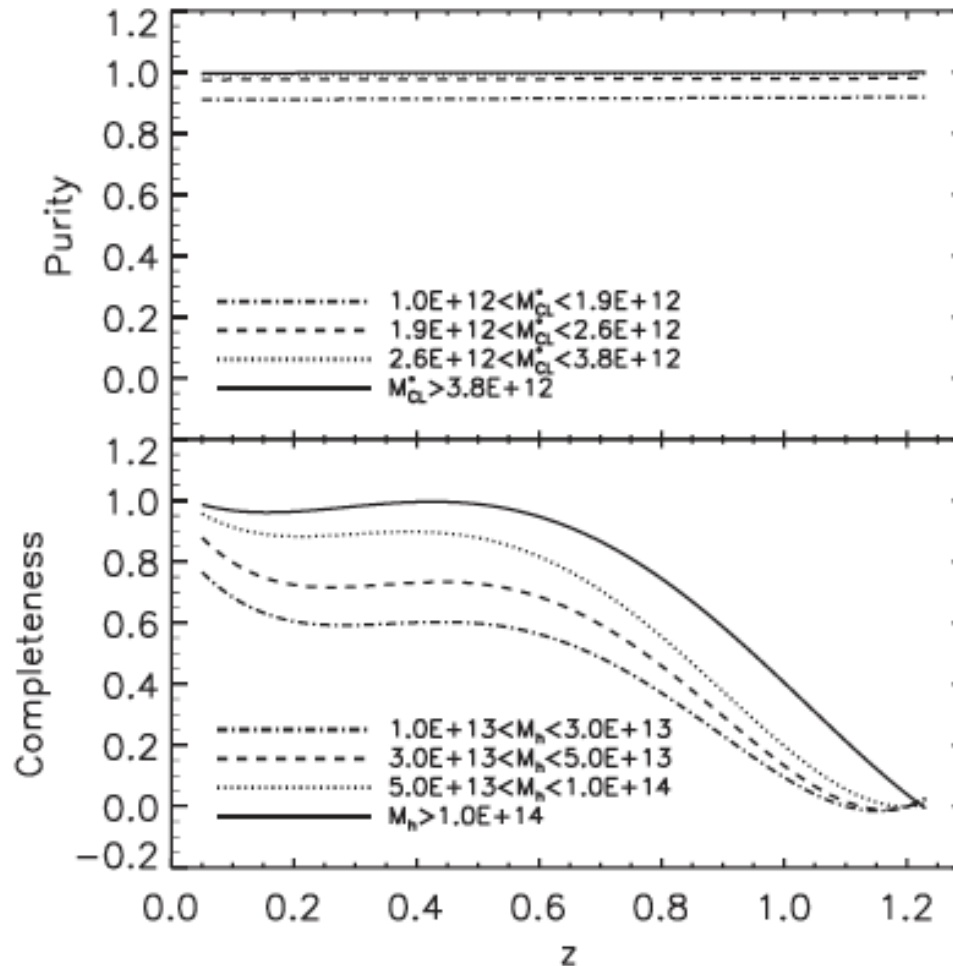
Euclid and LSST



Ascaso et al. 2016b, MNRAS, in press

SELECTION FUNCTIONS

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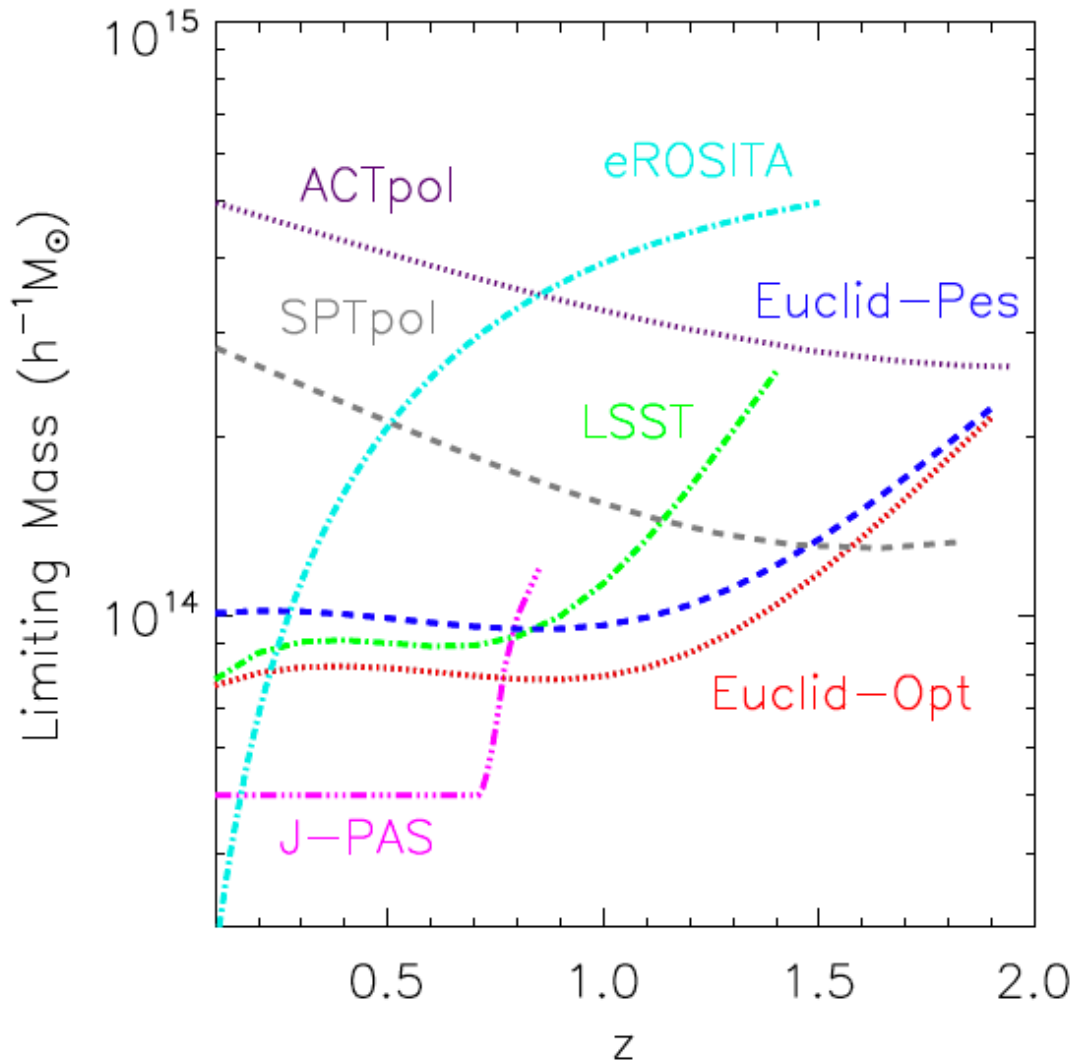


J-PAS

Ascaso et al. 2016a

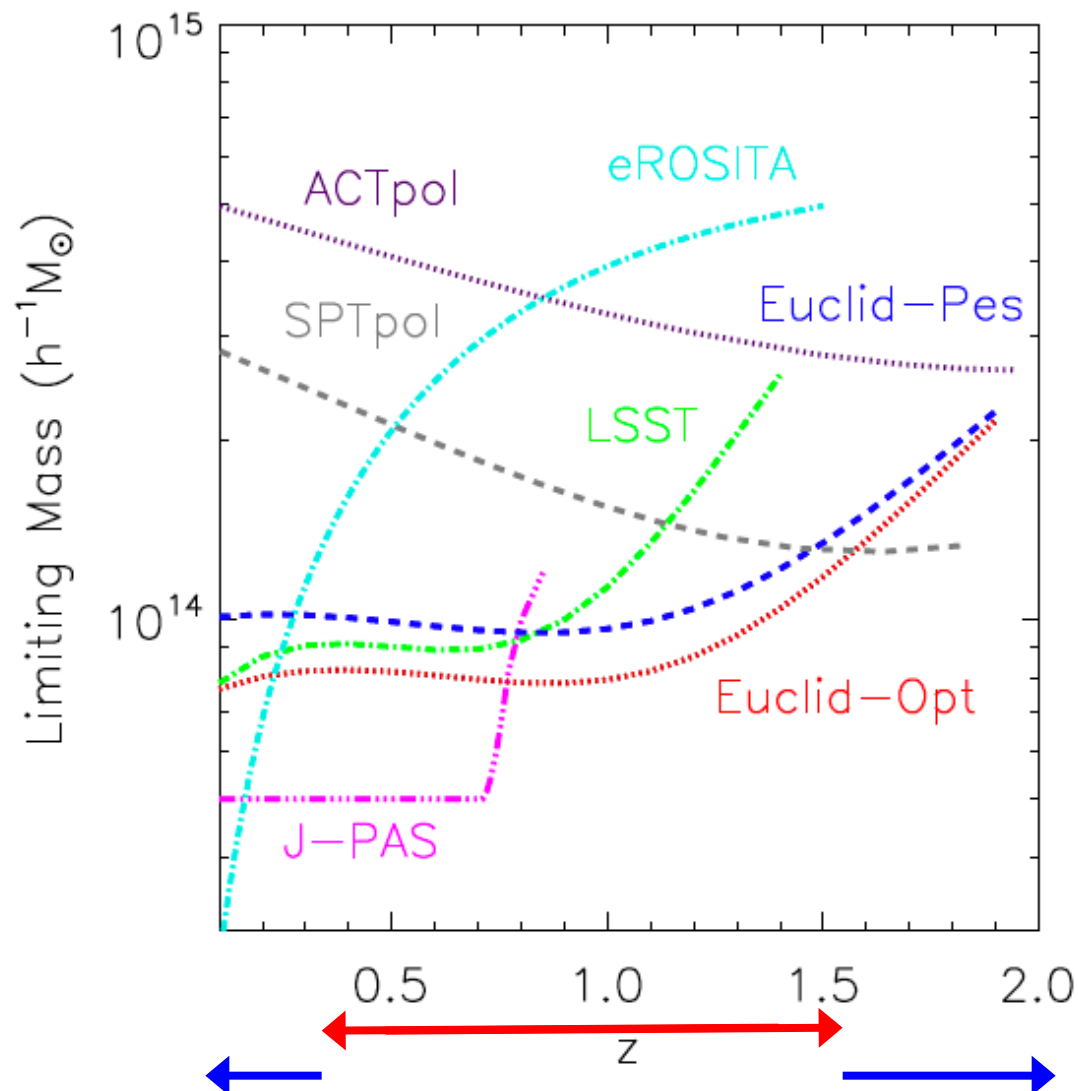
B. Ascaso

SELECTION FUNCTIONS



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

SELECTION FUNCTIONS



Ascaso et al. 2016b, MNRAS, in press

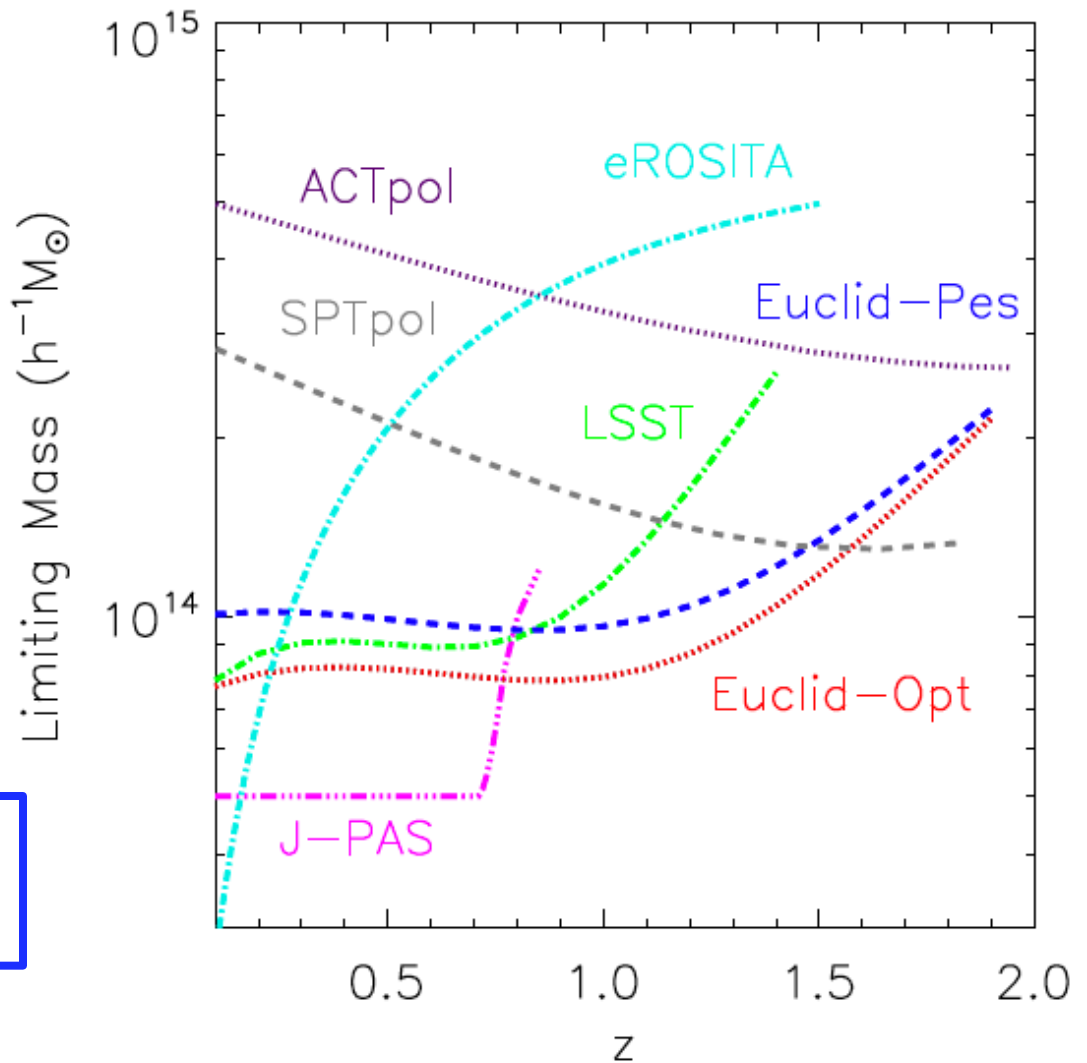
B. Ascaso

SELECTION FUNCTIONS

In preparation

- Selection function of SKA (radio)
- Mass-Observable relation for SKA

work in progress with
D. Herranz, F. Combes



DIFFERENT SOURCES OF ERROR

(OPTICAL CLUSTERS ARE COMPLICATED)

DIFFERENT SOURCES OF ERROR

(OPTICAL CLUSTERS ARE COMPLICATED)



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

COSMOLOGY WITH CLUSTER COUNTS

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

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

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

C= Covariance matrix of the cluster counts

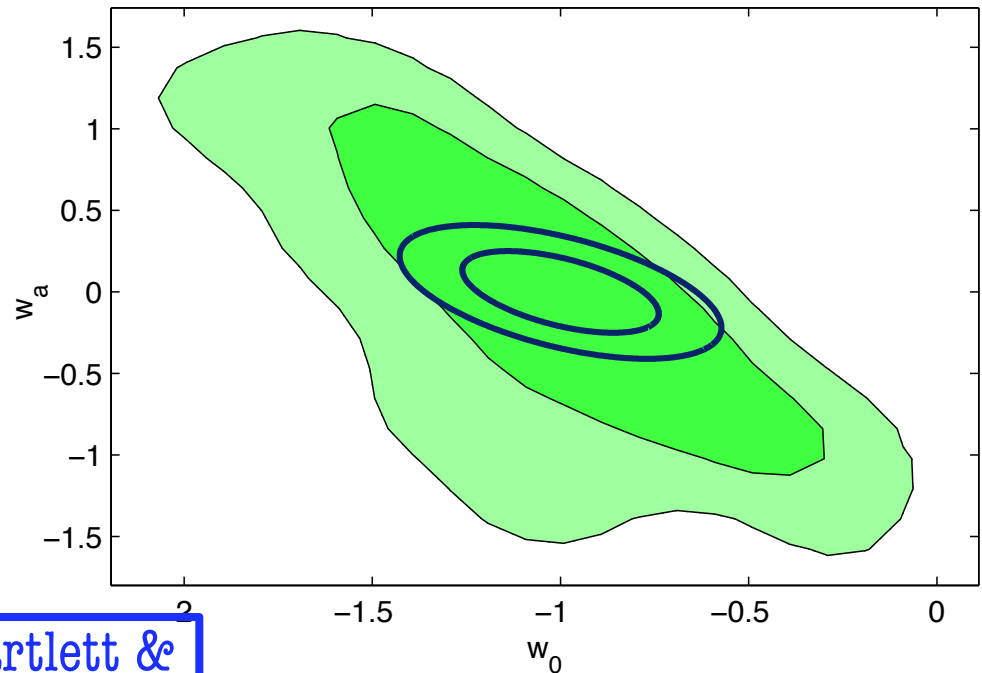
Implemented by creating a [new library in iCosmo](#) (*Refregier et al. 2008*) for galaxy clusters counting

COSMOLOGY WITH CLUSTER COUNTS

In preparation

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

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

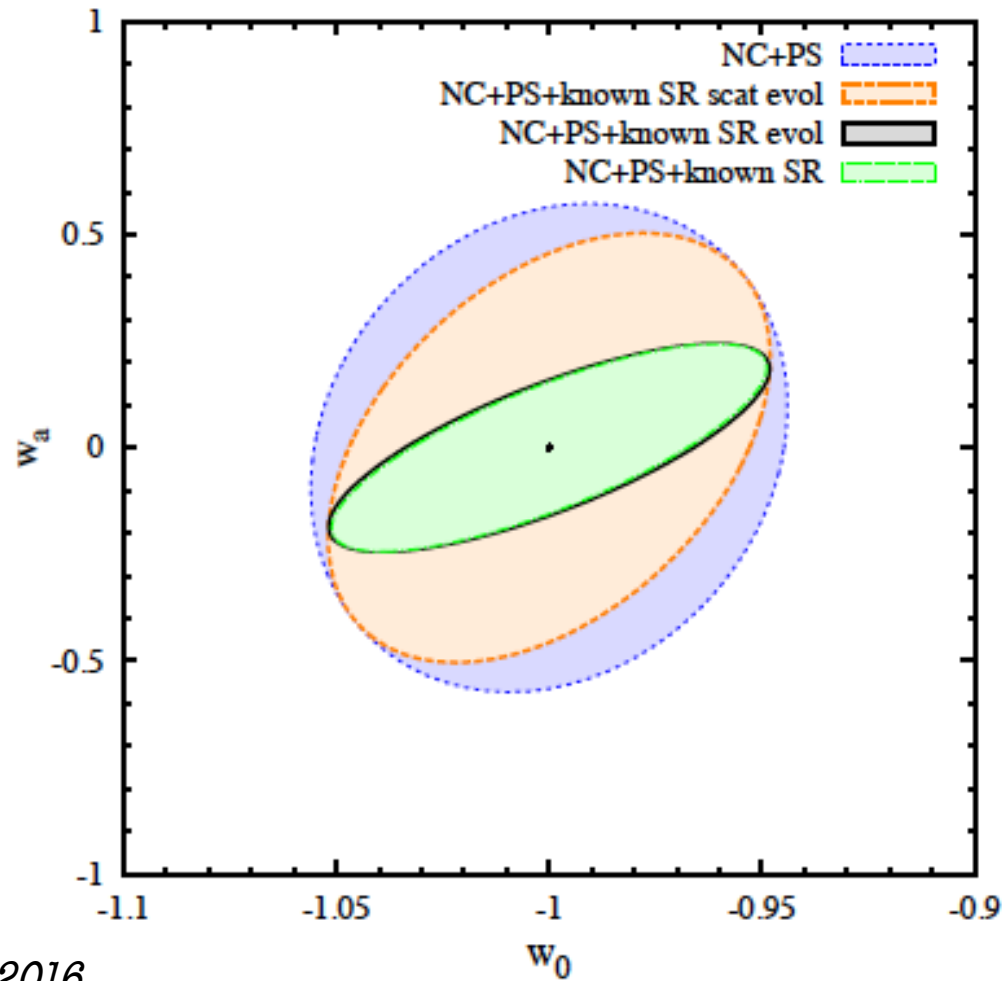


Work in progress with the J. Bartlett & M. Penna-Lima

Constraints for eROSITA
Khedekar & Majumdar 2013

CLUSTER COUNTS FORECAST

Euclid



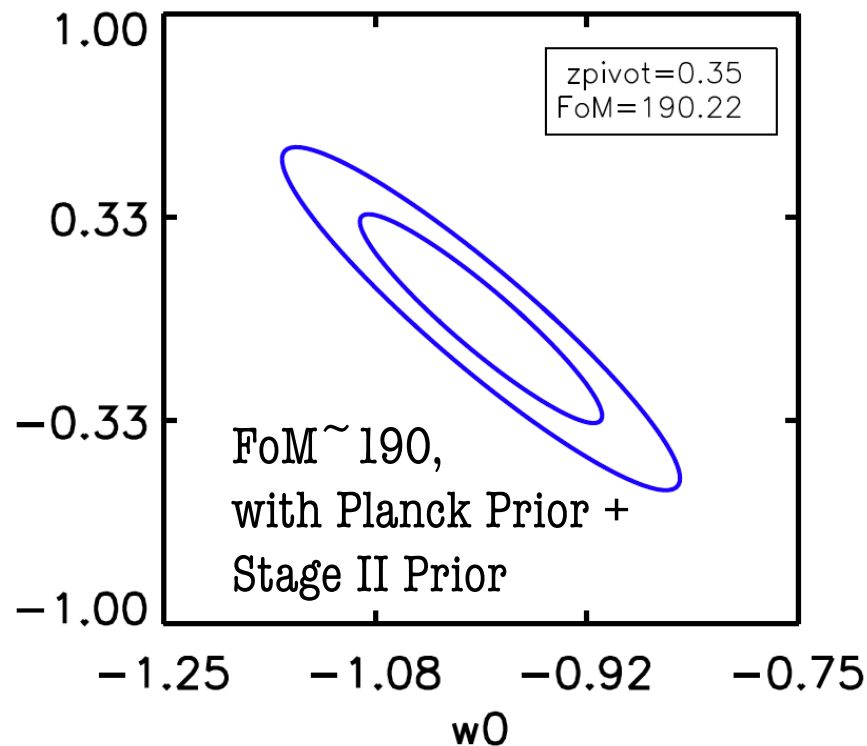
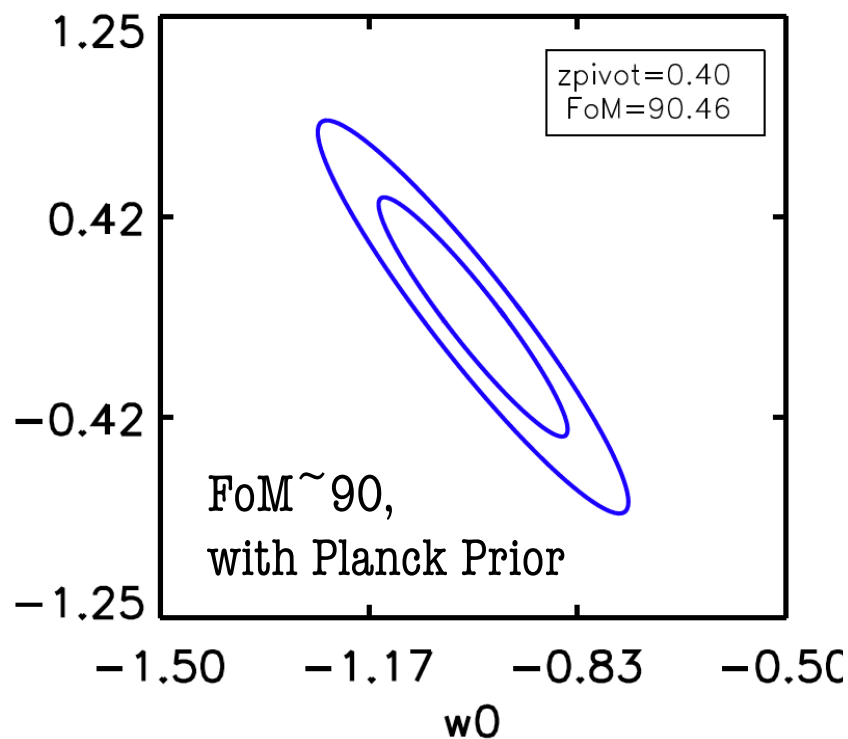
CLUSTER COUNTS FORECAST

In preparation

J-PAS

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

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



B. Ascaso

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.

Merci!

bego.ascaso.work@gmail.com