AMICO:
Adaptive Matched Identifier of Clustered Objects

ArXiv:1705.03029

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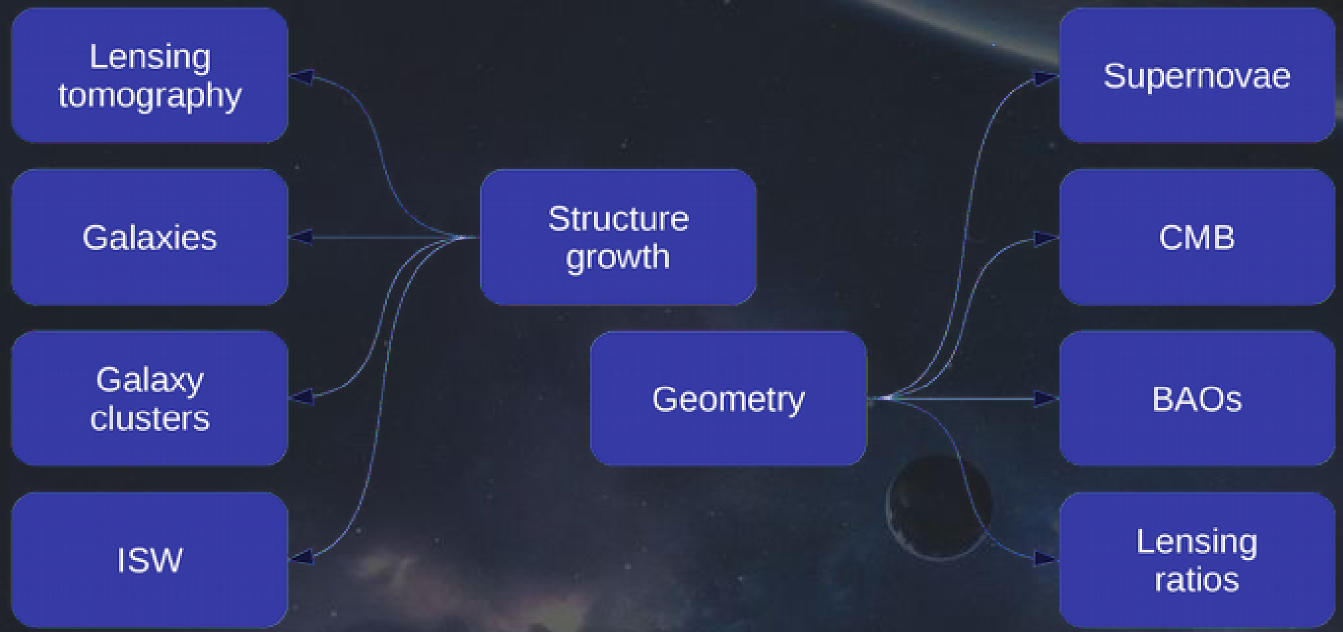
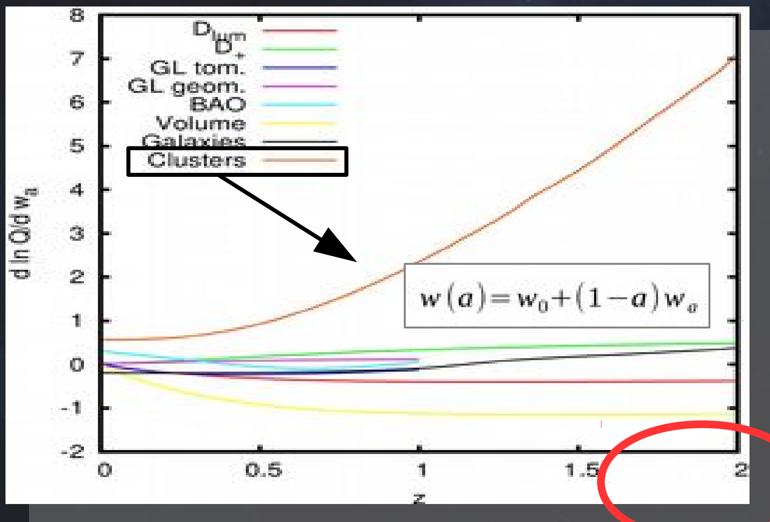
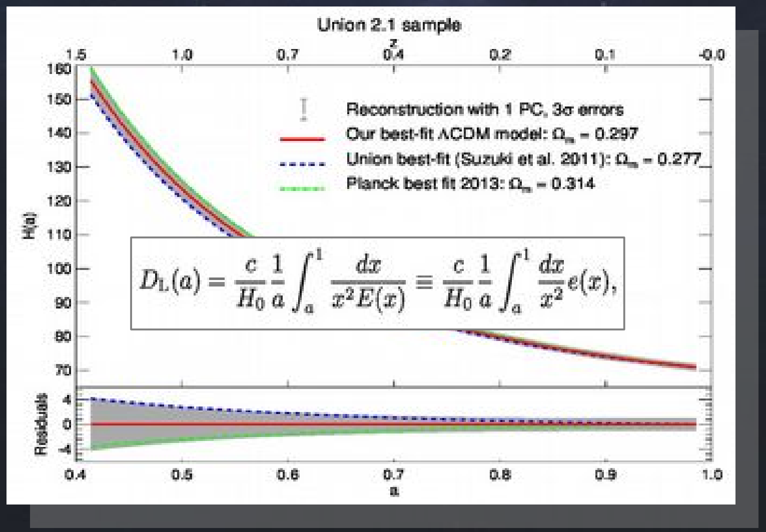
The manifestations of cosmology







Nice but....

...first you need to find them:

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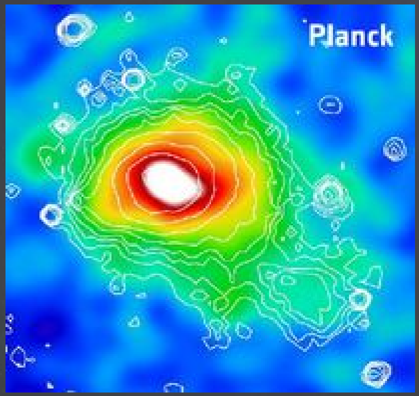
Use all what we know about them

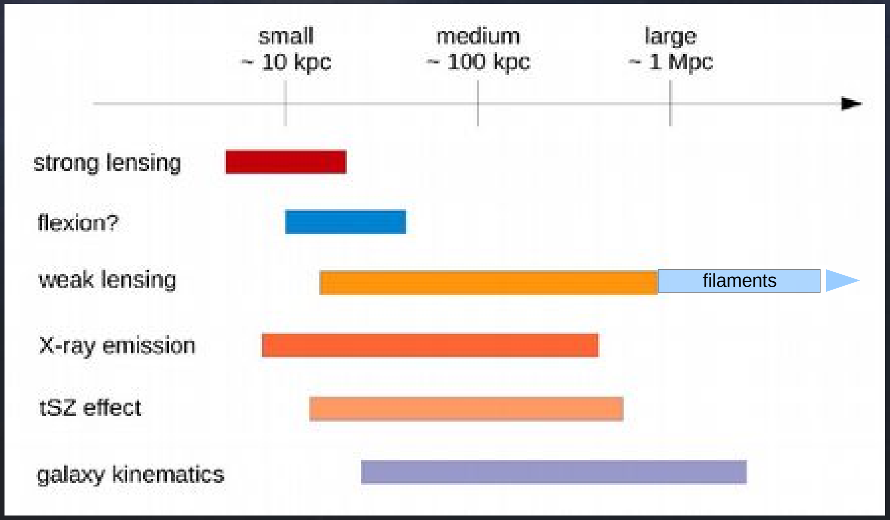
N-Body simulations

Gravitational lensing(s)

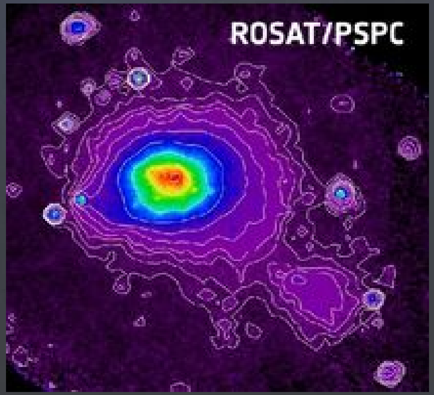
Galaxy overdensity

SZ



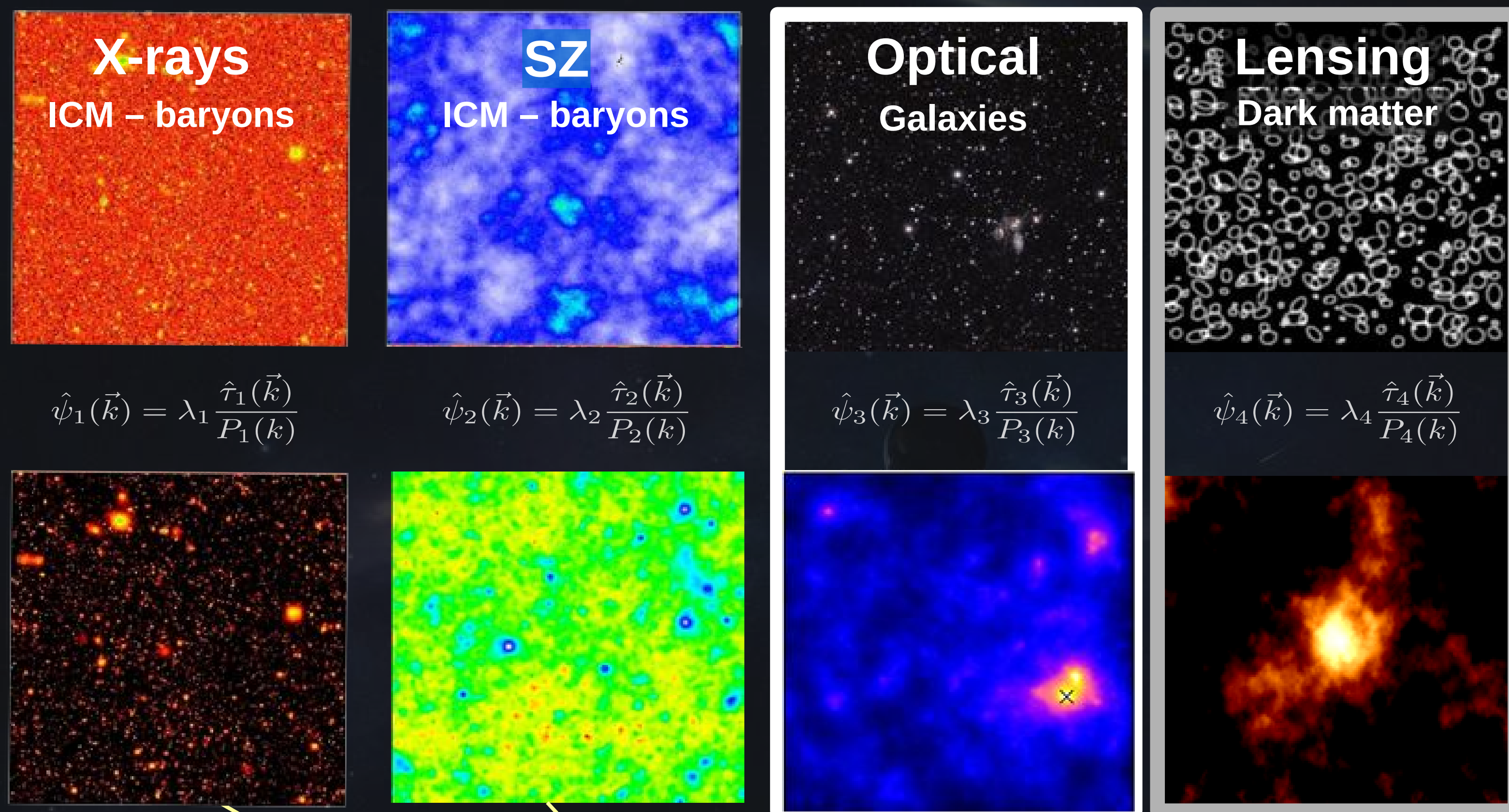


X-ray emission



The Idea?

Multi-band Optimal Matched Filter



Data

Filter(s) ->

$$\hat{\psi}_1(\vec{k}) = \lambda_1 \frac{\hat{\tau}_1(\vec{k})}{P_1(k)} \qquad \hat{\psi}_2(\vec{k}) = \lambda_2 \frac{\hat{\tau}_2(\vec{k})}{P_2(k)} \qquad \hat{\psi}_3(\vec{k}) = \lambda_3 \frac{\hat{\tau}_3(\vec{k})}{P_3(k)} \qquad \hat{\psi}_4(\vec{k}) = \lambda_4 \frac{\hat{\tau}_4(\vec{k})}{P_4(k)}$$

Intermediate maps

Estimator ->

$$\hat{\mathrm{A}}(\tilde{\mathrm{k}}) = \sum_{\mathrm{i}=0}^{\mathrm{bands}} \hat{\mathrm{D}}(\tilde{\mathrm{k}}) \hat{\Psi}_{\mathrm{i}}^{*}(\tilde{\mathrm{k}})$$

Multi-band Optimal filtering

Weak lensing: Maturi et al. (2005)
SZ, X-ray: Pace et al. (2007)
Optical: Bellagamba et al. (2011), Radovich et al. (2016)

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Adaptive Matched Identifier of Clustered Objects

Data Model

$$\mathbf{D}_\nu(\tilde{\theta}) = \mathbf{S}_\nu(\tilde{\theta}) + \mathbf{N}_\nu(\tilde{\theta}) \qquad \mathbf{S}_\nu(\tilde{\theta}) = \mathbf{A}\mathbf{f}_\nu \tau_\nu(\tilde{\theta})$$

← **We assume a template for each band**

Noise covariance

$$\mathbf{C}_{\nu\mu} = \left\langle \hat{\mathbf{N}}_\nu(\tilde{\mathbf{k}}) \hat{\mathbf{N}}^*_\mu(\tilde{\mathbf{k}}) \right\rangle = (\mathbf{2}\pi)^{\mathbf{2}} \delta(\tilde{\mathbf{k}} - \tilde{\mathbf{k}}') \mathbf{P}_{\mu\nu}(\mathbf{k})$$

← **Derive statistics from data**

Filter

$$\mathbf{\Psi} = \alpha \mathbf{C}^{-1} \tilde{\mathbf{F}} \qquad \mathbf{\Psi} = [\mathbf{\Psi}_\nu] \quad \mathbf{C} = [\mathbf{C}_{\nu\mu}] \quad \mathbf{F} = [\mathbf{f}_\nu]$$

← **Derive the filter constrain minimization**
1- minimum variance
2- unbiased estimator

Estimator

$$\mathbf{A}_{\mathbf{est}}(\tilde{\mathbf{k}}) = \sum_{\nu=\mathbf{1}}^{\mathbf{M}} \hat{\mathbf{D}}_\nu(\tilde{\mathbf{k}}) \hat{\mathbf{\Psi}}^*_\nu(\tilde{\mathbf{k}})$$

← **Apply the filter (filtered map)**

+ ...

When using galaxies only...

(Ra,Dec) (m$_1$, m$_2$,..., c$_1$, c$_2$, ...) (z)

$$A(\boldsymbol{\theta}_c, z_c) = \alpha^{-1}(z_c) \int \Psi_c(\boldsymbol{\theta}-\boldsymbol{\theta}_c, \boldsymbol{m}, z) D(\boldsymbol{\theta}, \boldsymbol{m}, z)\, d^2\theta\, d^n m\, dz - B(z_c),$$

← **The n-dimensional space in which we work**

$$A(\boldsymbol{\theta}_c, z_c) = \alpha^{-1}(z_c)\; S(\boldsymbol{\theta}_c, z_c) \quad S(\boldsymbol{\theta}_c, z_c) = \sum_{i=1}^{N_{gal}} \frac{M_c(\boldsymbol{\theta}_i - \boldsymbol{\theta}_c, \boldsymbol{m}_i)\; p_i(z_c)}{N(\boldsymbol{m}_i, z_c)},$$

← **We have discrete data**

$$\sigma_A^2(\boldsymbol{\theta}_c, z_c) = \alpha^{-1}(z_c) + A(\boldsymbol{\theta}_c, z_c)\; \frac{\gamma(z_c)}{\alpha^2(z_c)},$$

← **The variance of the estimate**

- minimum variance
- unbiased estimator

$$\mathcal{L}(\boldsymbol{\theta}_c, z_c) = -\int \frac{\{D - [A M_c(\boldsymbol{\theta} - \boldsymbol{\theta}_c, \boldsymbol{m}) + N(\boldsymbol{m}, z_c)]\}^2}{N(\boldsymbol{m}, z_c)} d^2\theta\, d^n m\, dz.$$

$$\mathcal{L}(\boldsymbol{\theta}_c, z_c) = \mathcal{L}_0 + A^2(\boldsymbol{\theta}_c, z_c)\; \alpha(z_c),$$

← **Likelihood of a galaxy to be a cluster**

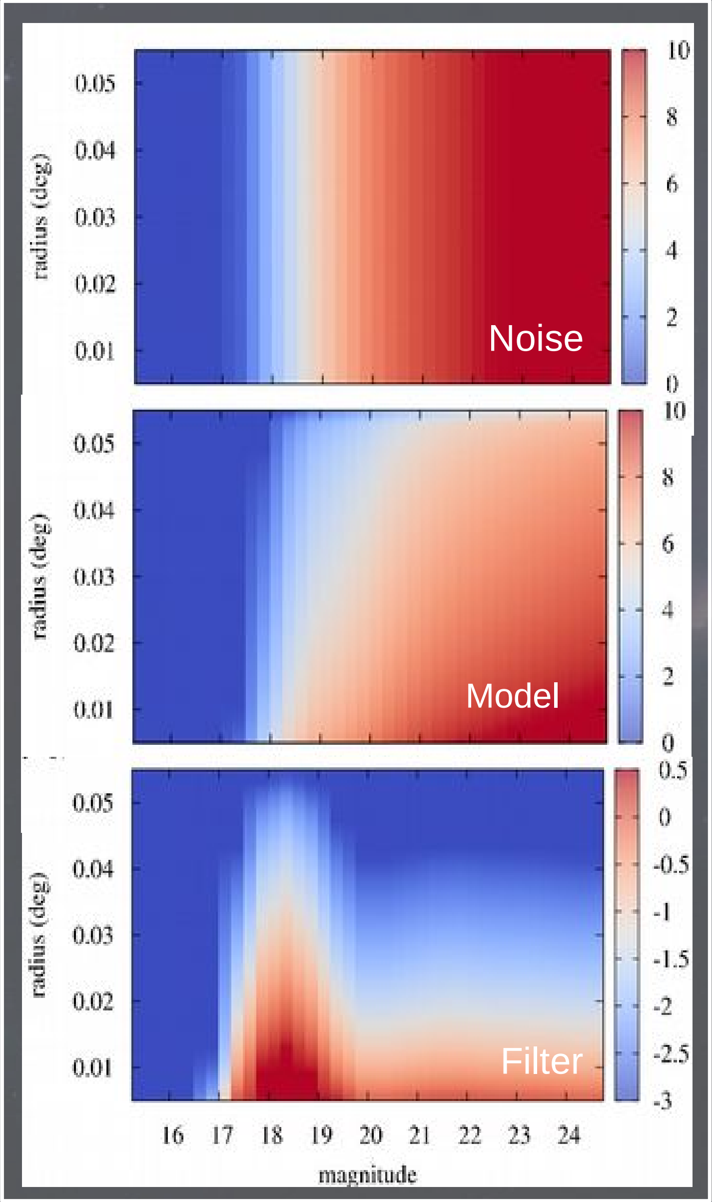
$$P(i \in j) \equiv \frac{A_j M_j(\boldsymbol{\theta}_i - \boldsymbol{\theta}_j, \boldsymbol{m}_i) p_i(z_j)}{A_j M_j(\boldsymbol{\theta}_i - \boldsymbol{\theta}_j, \boldsymbol{m}_i) p_i(z_j) + N(\boldsymbol{m}_i, z_j)},$$

← **Galaxy-Clusters probability association**

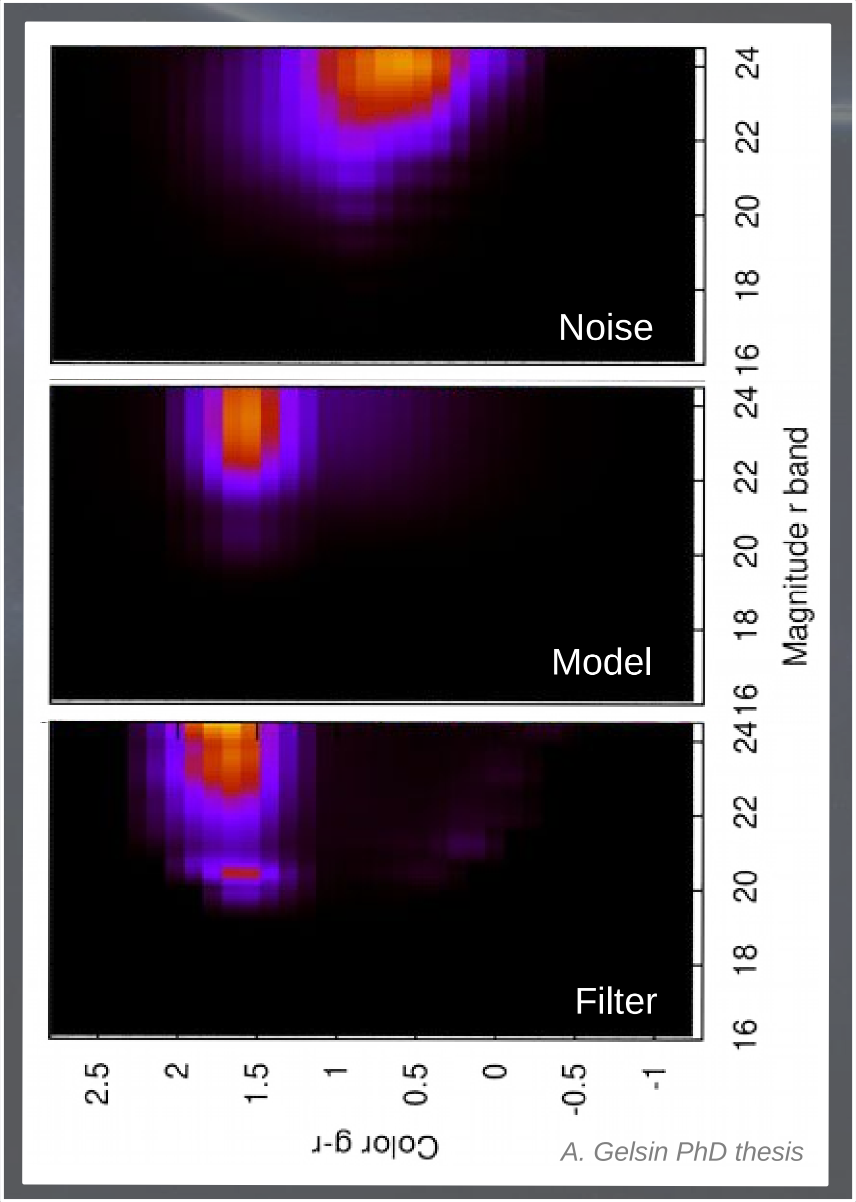
A closer look

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

mag – rad



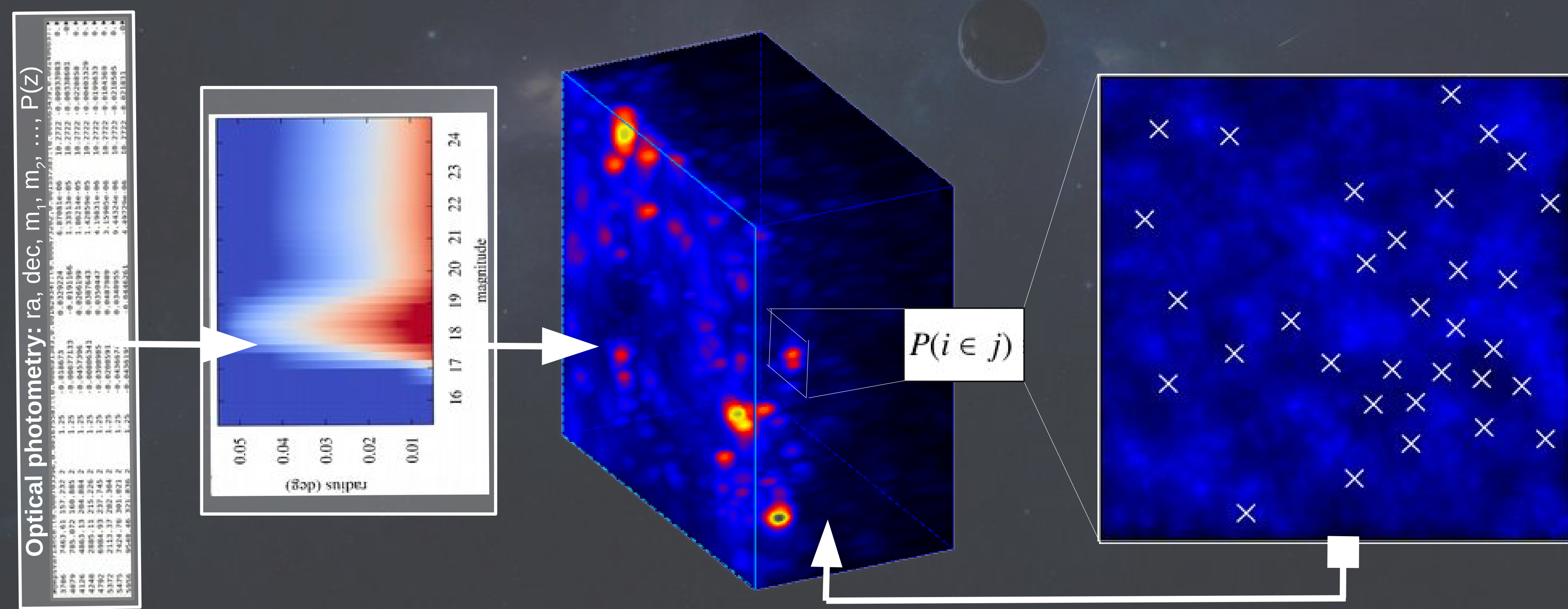
mag – col



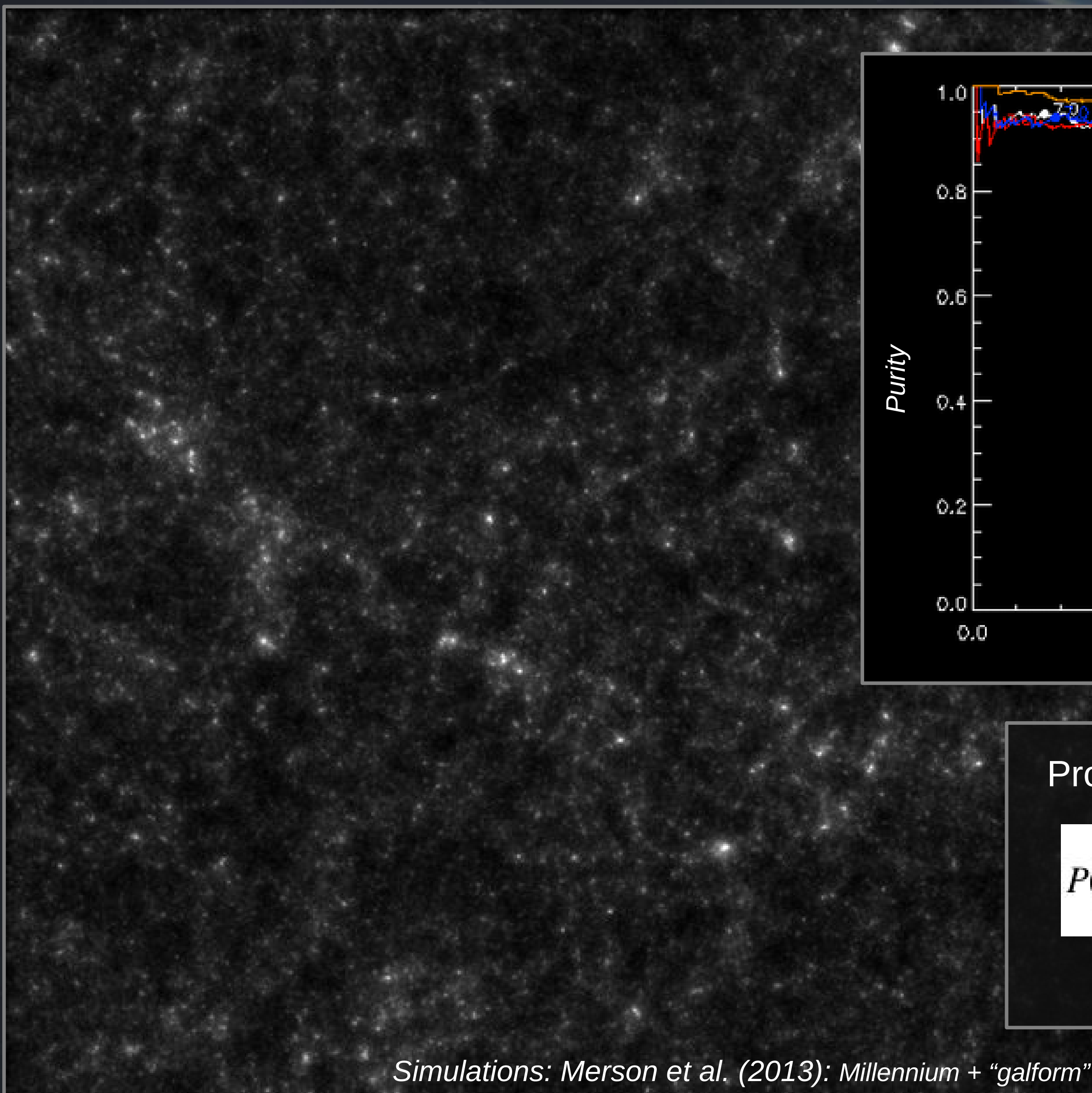
All steps

1. Decide what you are searching for: cluster model and background as a function of z
2. Make amplitude 3D map creation with its uncertainty and likelihood
3. Select the most-likely detection among pixels with S/N above threshold
4. Attribute membership probability to galaxies
5. Cleaning map from detection by removing contribution of member galaxies

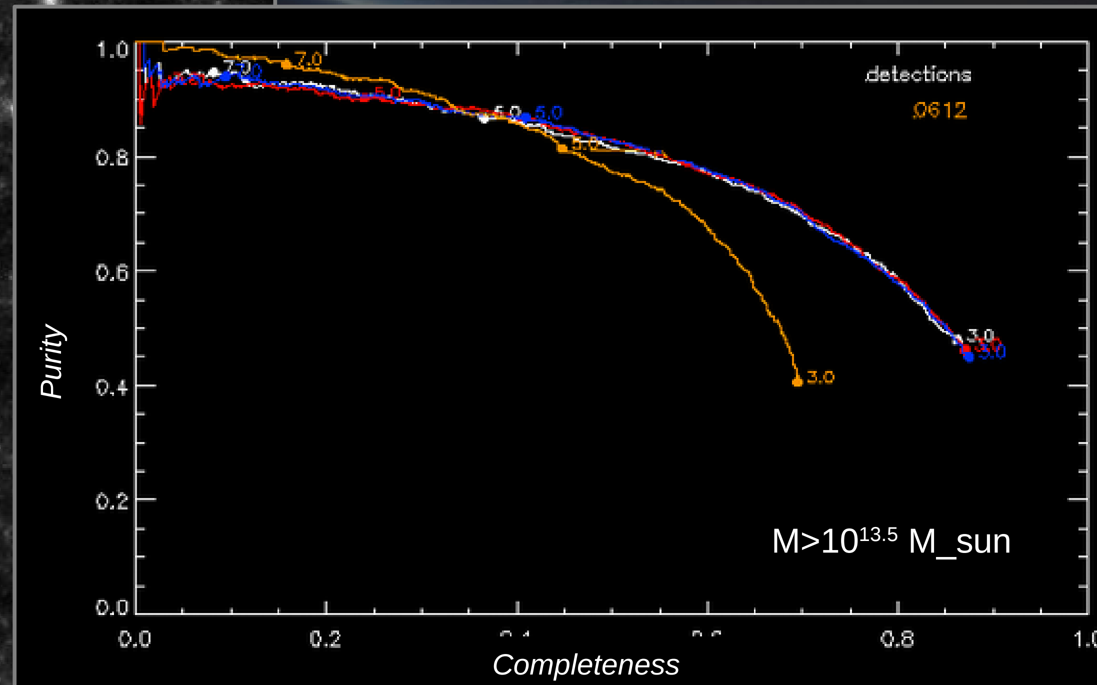
Repeat down to SN_{min}



A closer look: cleaning



Simulations: Merson et al. (2013): Millennium + “galform”



Probability association of galaxies to clusters

$$P(i \in j) \equiv \frac{A_j M_j(\boldsymbol{\theta}_i - \boldsymbol{\theta}_j, \boldsymbol{m}_i) p_i(z_j)}{A_j M_j(\boldsymbol{\theta}_i - \boldsymbol{\theta}_j, \boldsymbol{m}_i) p_i(z_j) + N(\boldsymbol{m}_i, z_j)},$$

Iterative removal of clusters

Output

Maps: amplitude, likelihood, variance, …

Catalogue of detections

ID	R.A.	Dec	z	S/N	Amp	N_{gal}	f_{mask}
1	52.125	-6.545	0.53	14.604	4.621	560.492	0
2	52.245	-5.805	0.50	11.468	2.814	351.540	0
3	51.995	-6.145	0.26	12.199	2.377	441.394	0

Galaxy catalog with probabilistic association

ID	R.A.	Dec	mag	P_{field}	N_{assoc}	ID_{assoc}	$P_{i\in j}$
0	50.5949	-4.8657	21.59	1	0		
1	50.5934	-4.8518	22.1	0.8558	1	17	0.1442
2	52.0427	-6.0891	23.68	0.6124	2	{3,4}	{0.3515,0.0361}

Moreover...

- it deals with missing data (masks, holes, survey boundaries, …)
- it deals with non uniform local background
- It can be iterated to cope with unexpected features

Testing the code

Model

- Optimized from objects with mass ~ 10^{14} M
- NFW profile + Schechter distribution + BCG component

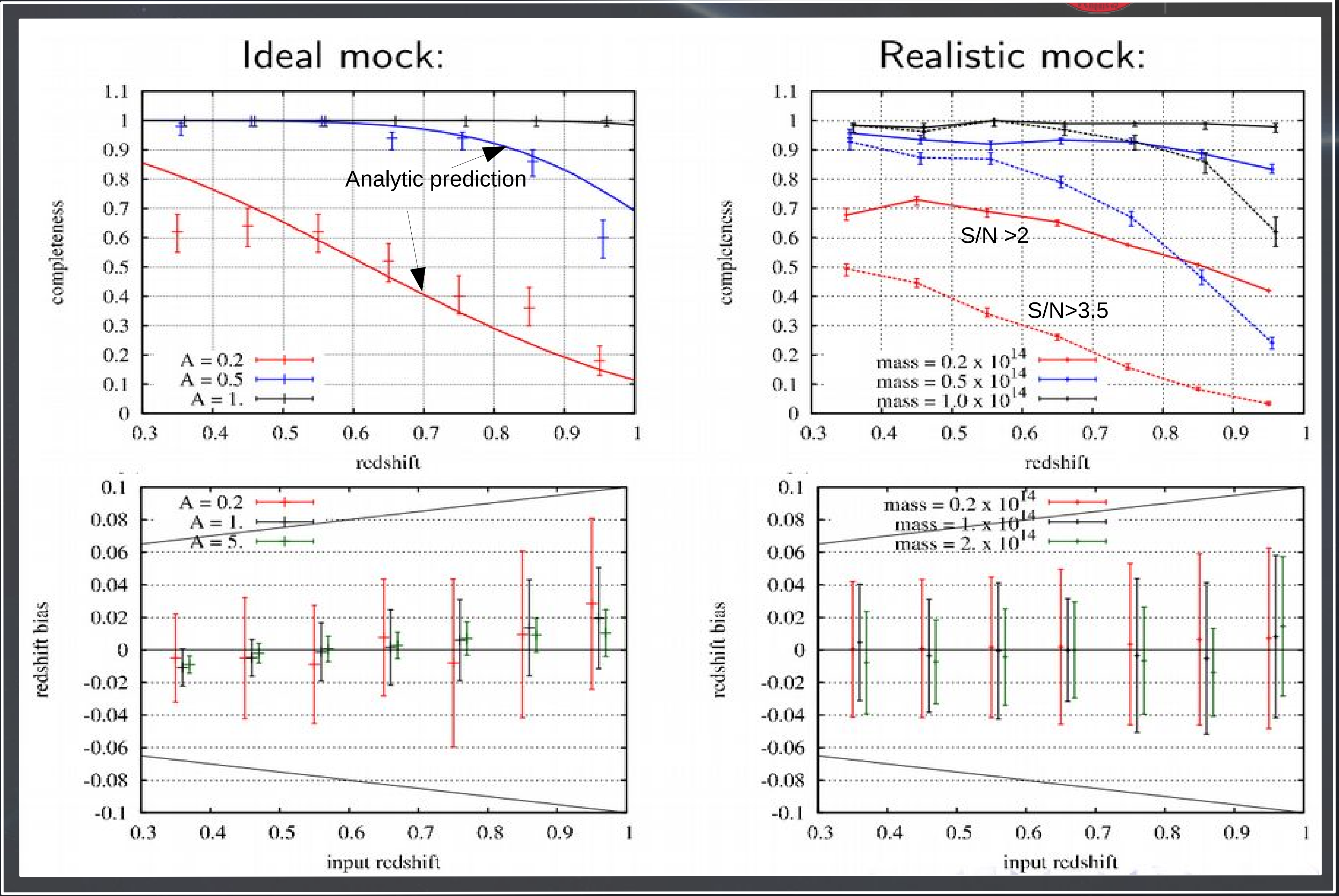
Two sets of tests:

1) *Ideal catalogue*, with clusters from MonteCarlo realisations of the model M and a uniform background

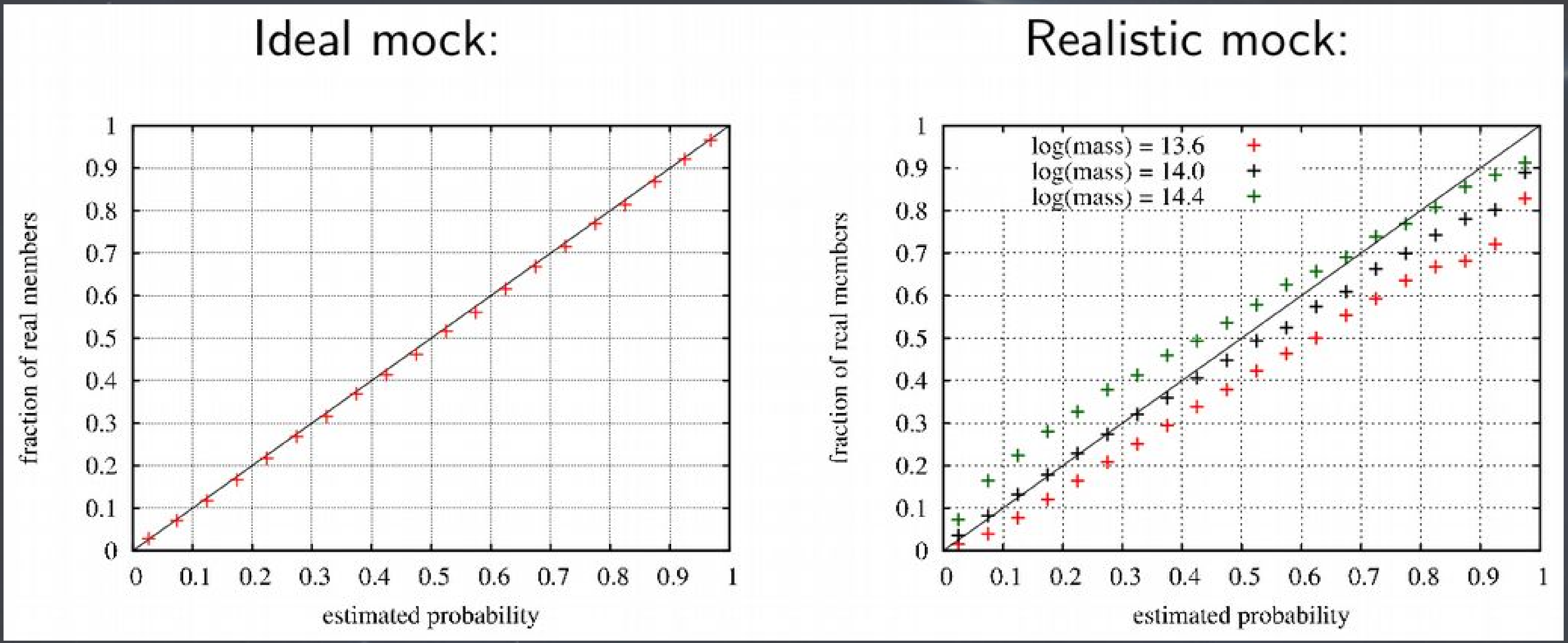
2) *Realistic catalogue*, with diverse clusters embedded in the large-scale structure

- Millennium simulation + De Lucia & Blaizot (2007) [$10^{13.5}M_{sun}$]
- 200 deg^2
- limited to I < 25
- $0.3 < z < 1$
- $\sigma_z = 0.05\,(1+z)$

Completeness and redshift



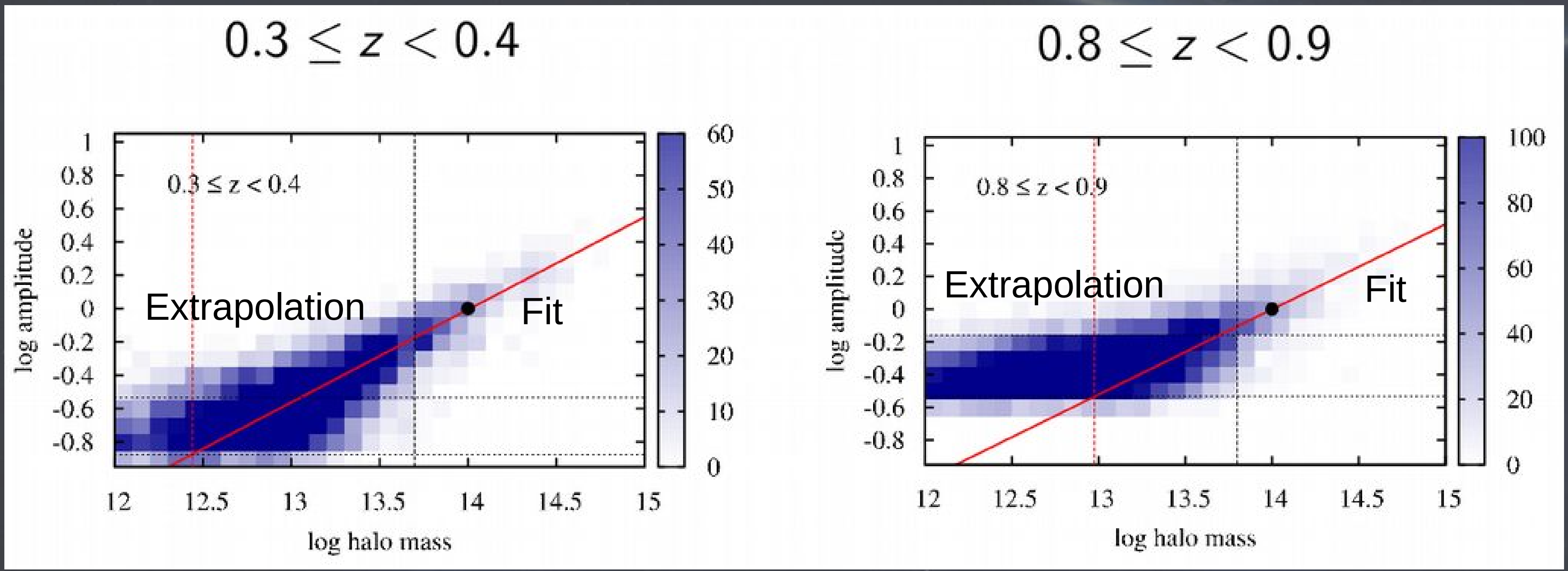
Membership



- <u>Ideal mock: almost perfect agreement</u>
- <u>Realistic mock</u>: reliable through about an order of magnitude in mass.

∼10^{14} M/h the relation is well calibrated with differences lower than 0.1.

Mass-observable relation (realistic mock)

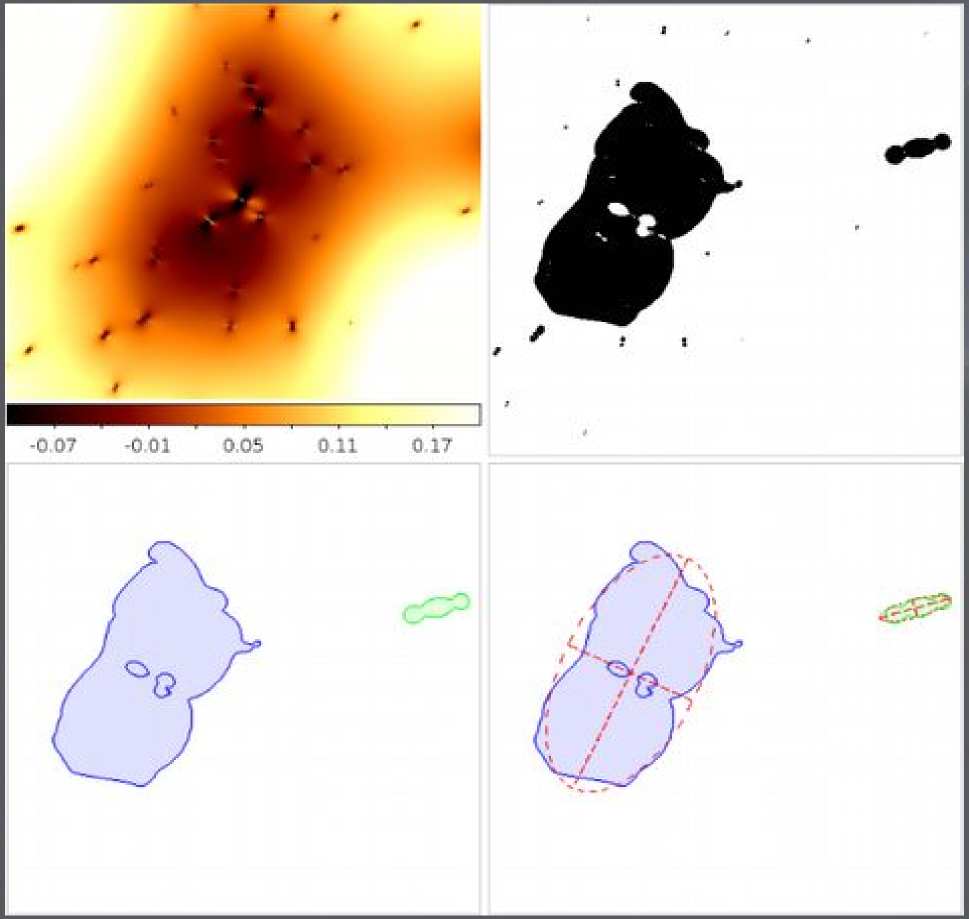


- Slope of the relation ~ 0.55 at any redshift.
- Very precise estimate of the amplitude for objects with mass ~ 10^{14} M_{sun}/h
- Unbiased redshift-independent mass proxy for haloes of similar model mass.

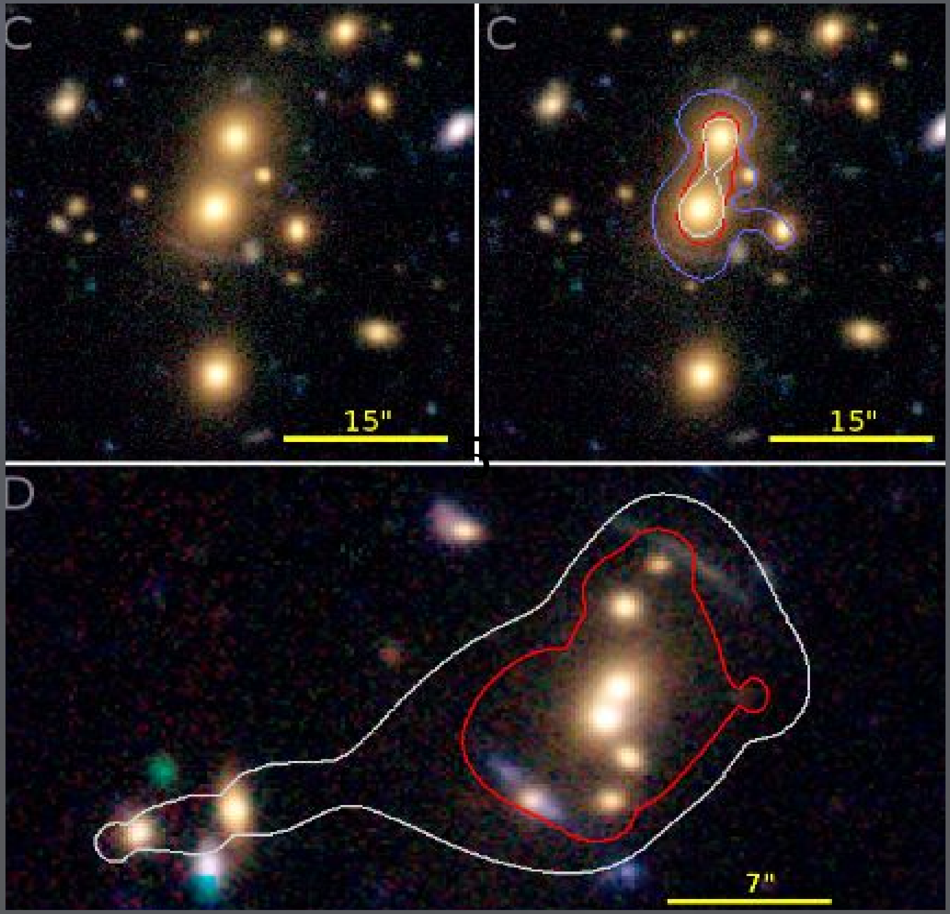
Additional information

EasyCritics: strong lensing indication

Einstein radious



Examples



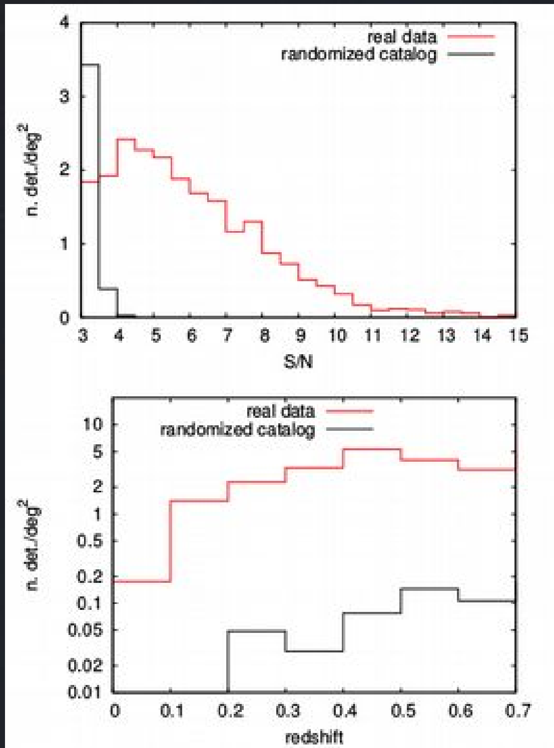
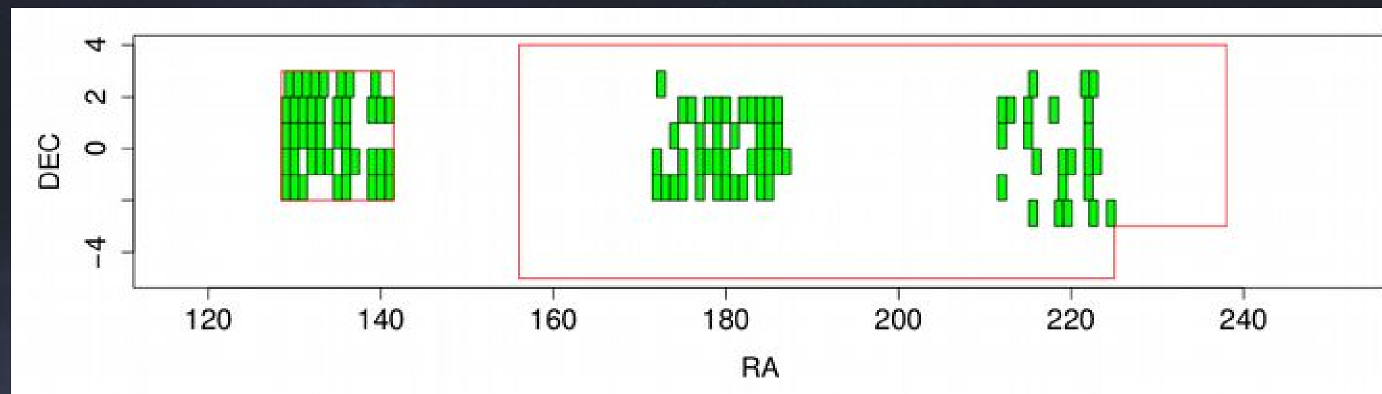
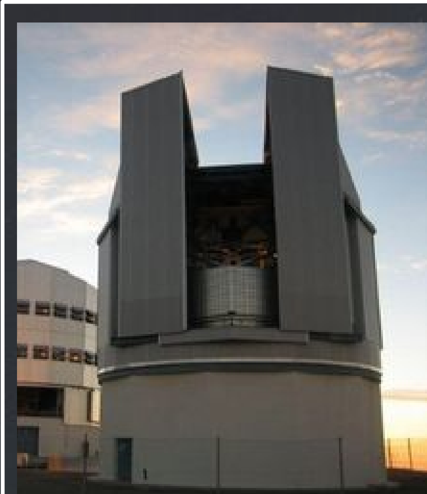
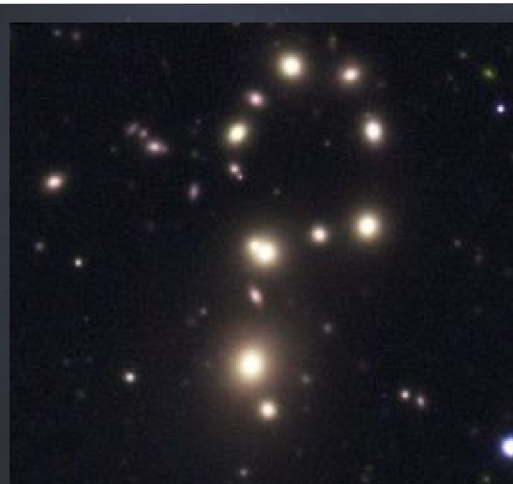


Fig. 2. Number of detections on real data and on randomized catalogs as a function of signal-to-noise ratio (top panel) and redshift (bottom panel). In the bottom panel, only detections with S/N > 3.5 are shown, as this is the limit applied in the final analysis.

KiDS
Kilo Degree Survey







VST (VLT Survey Telescope)

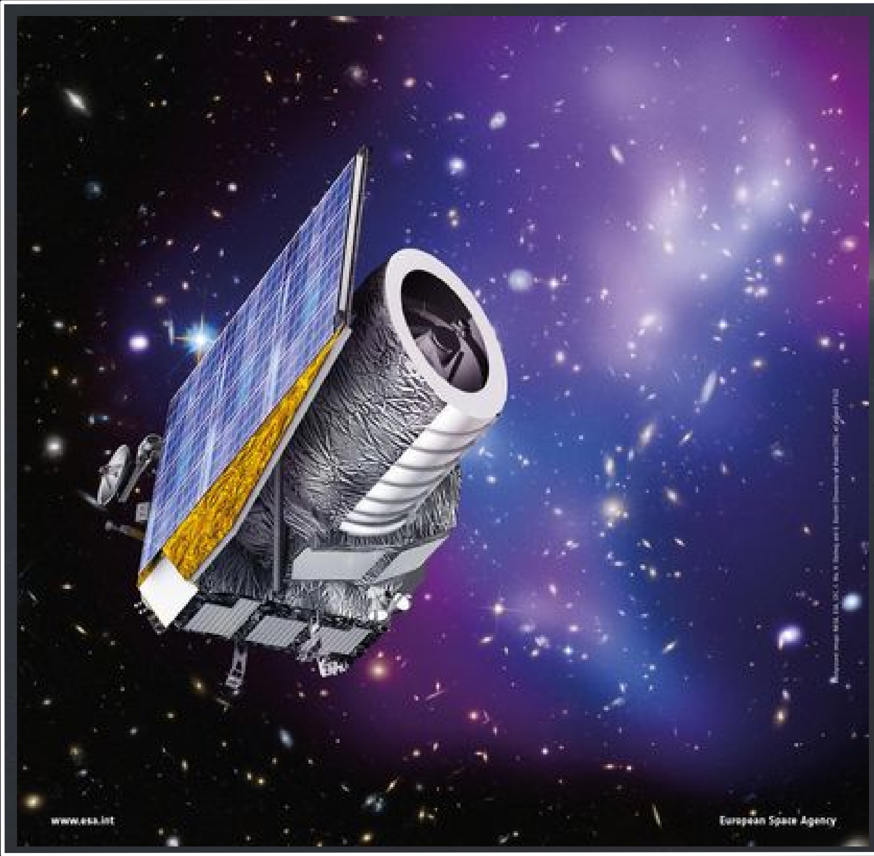
u,g,r,i <u>We used r-band only, old version!</u>

DR2: 114 Deg^2 (1.400 to come)

1.800 detections z<0.75, S/N>3.5
M> $10^{13.5}$$M_{sun}$ ~80% complete

Radovich et al. 2017, A&A, 598, A107

Euclid:
implementation in the pipeline



Space mission in L2, 6 years

Instrumnt:
- 1.2m
- optical g,r,i,z
- infrared Y,J,H

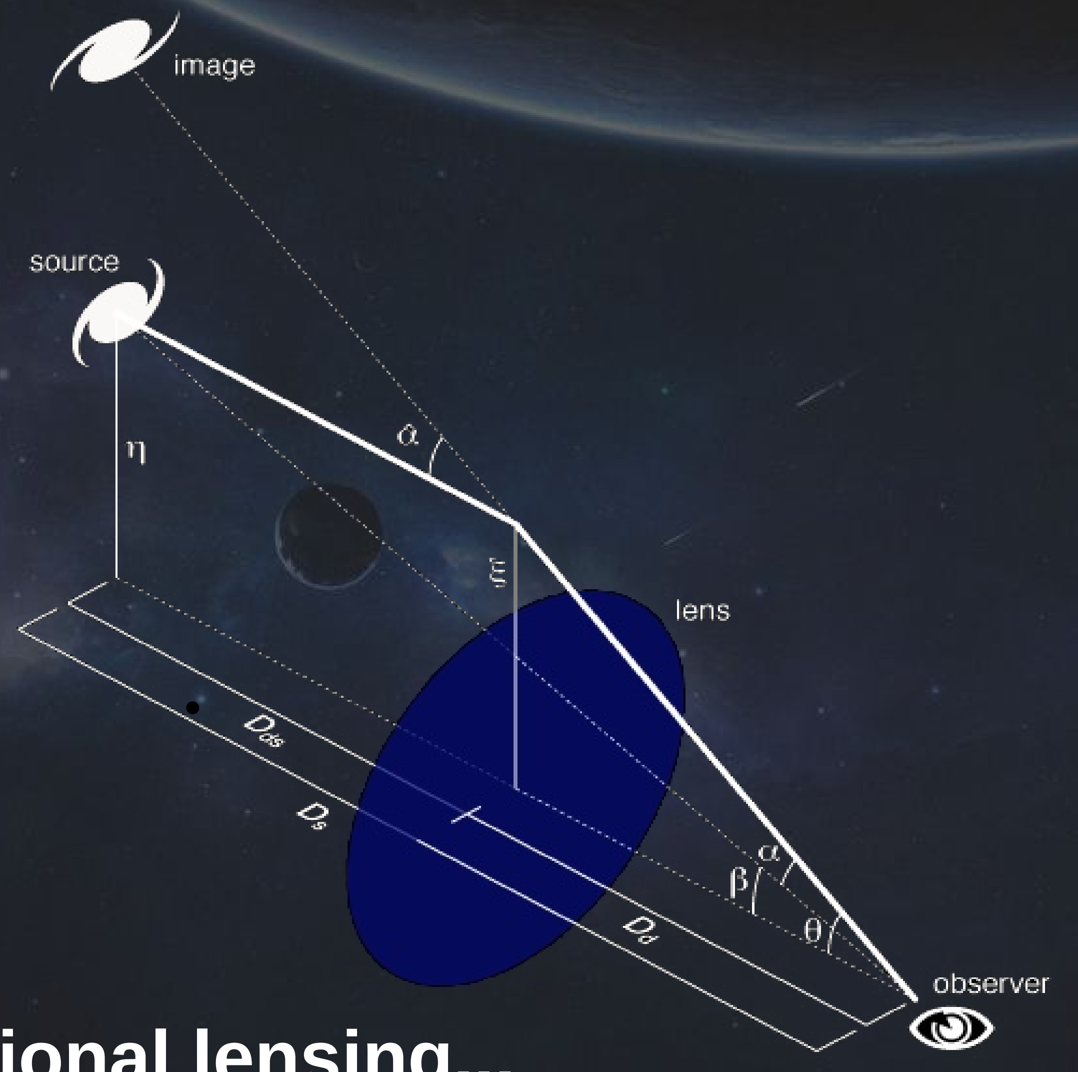
Wide field: 15.000 Deg^2 (mag 24 at 10 sigma)

Deep field: 40 Deg^2 (2 mag deeper)

10 billions galaxies (1 billions for lensing)

We expect 300.000+ clusters (assuming KiDS quality...)

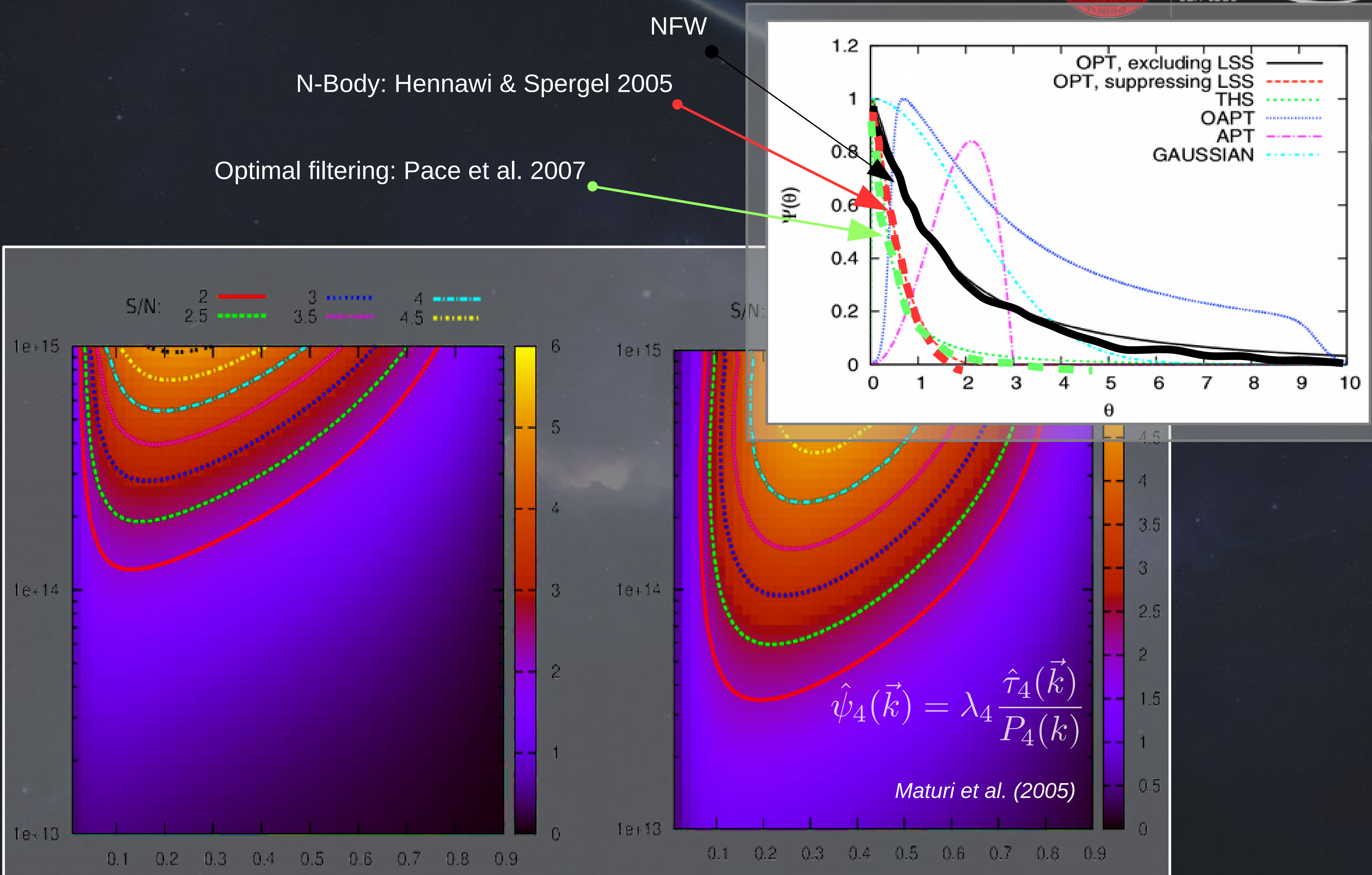
Recently plugged in Euclid Pipeline (STC: Emiliano Munari)



Next:

include weak gravitational lensing...

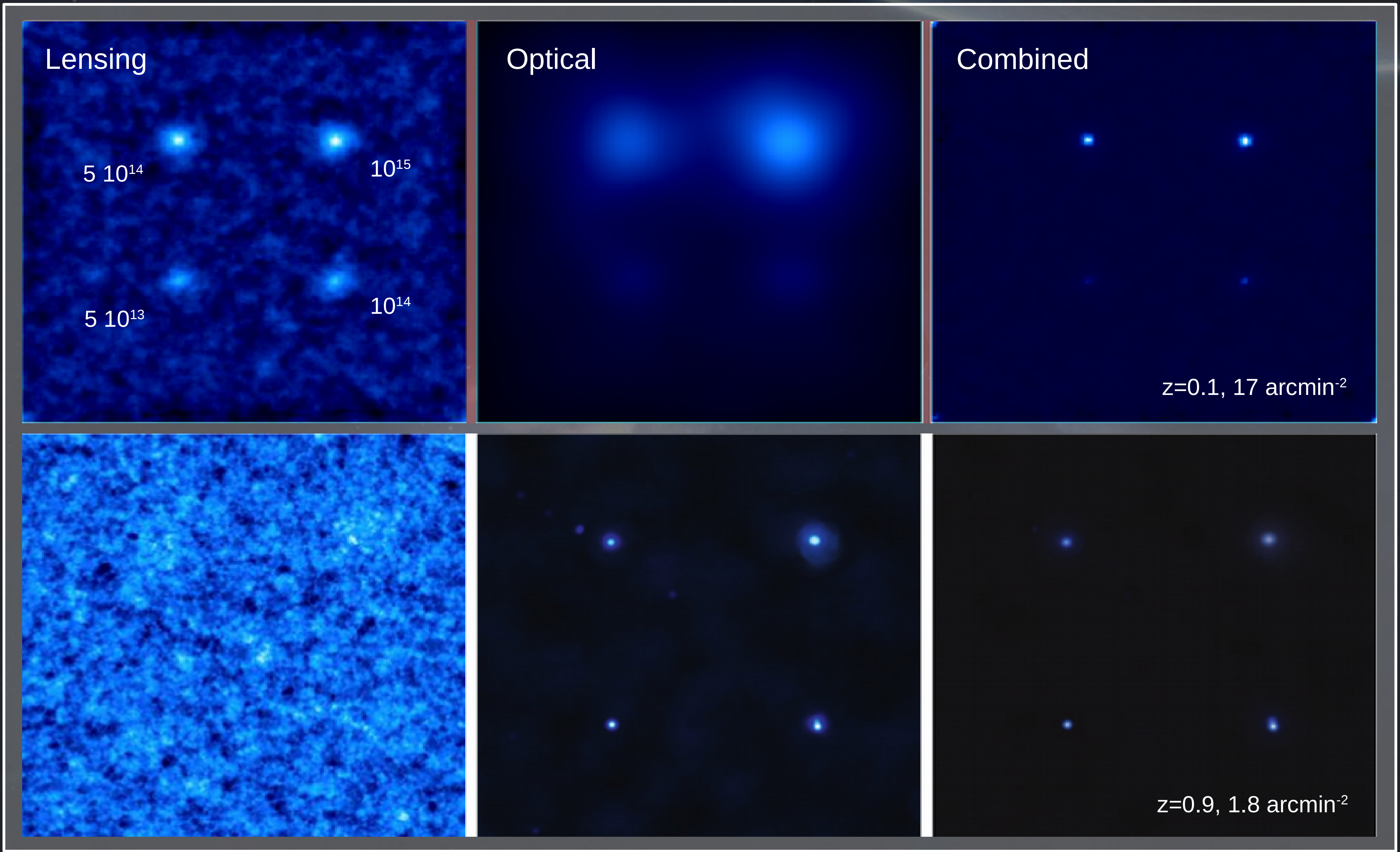
Weak gravitational lensing alone



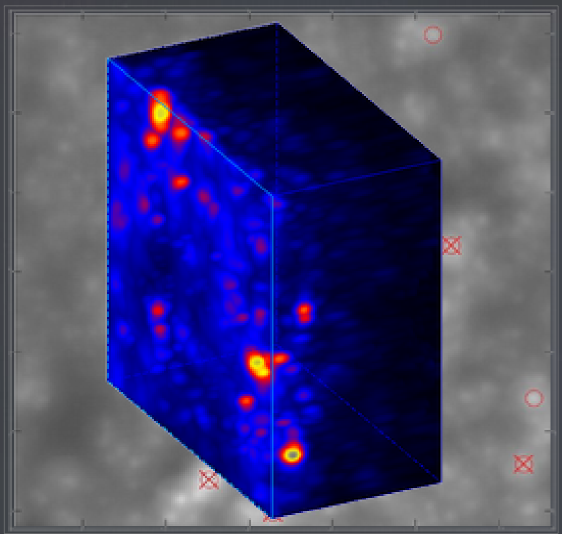
Photometry + weak lensing (pre-preliminary)

Laila Linke

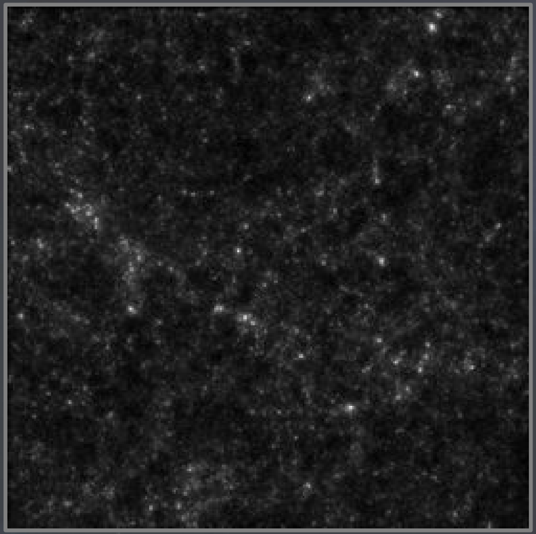
- larger S/N
- less blending (angular)

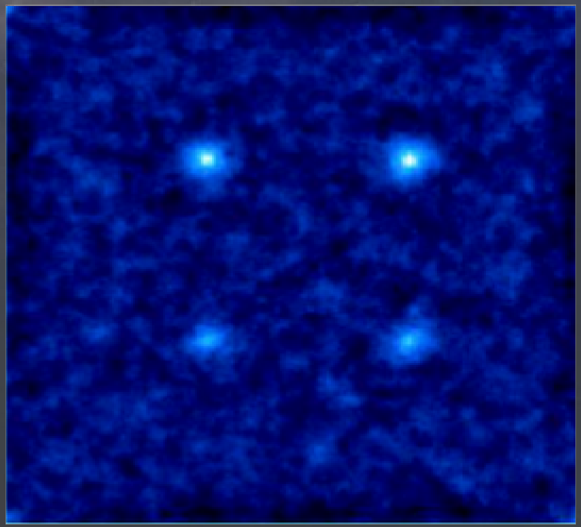


Conclusions



Cluster finding (AMICO)
ArXiv:1705.03029





Cluster finding (lensing)
Maturi et al (2007)

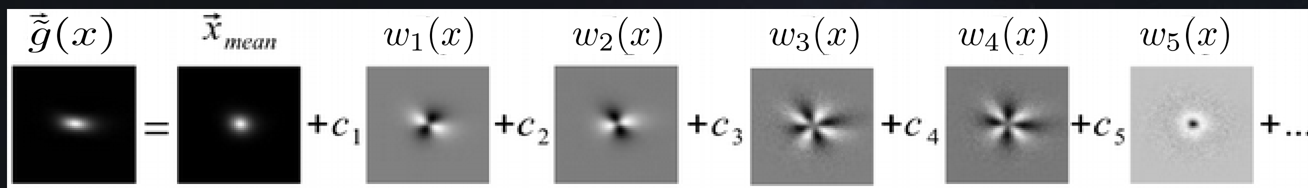
Optical + lensing
Maturi and Linke in pre-prep.

Image denoising with EMPCA

Split signal and noise

$$d(x) = \sum_{k=1}^{M} a_k w_k(x) + \sum_{k=1}^{n-M} a_k w_k(x) = \tilde{g}(x) + \tilde{n}(x) \,,$$

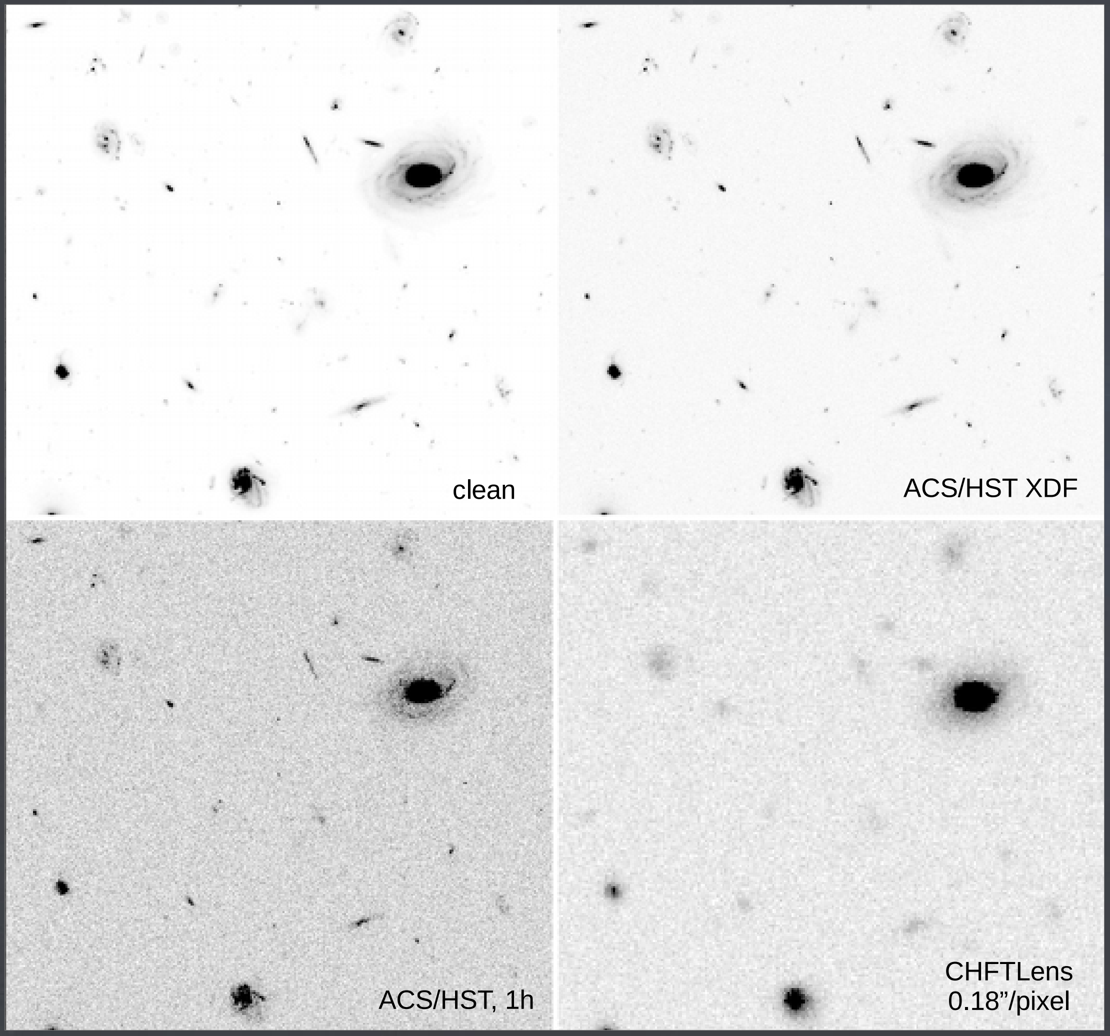
$$a_k = < d(\mathbf{x}) w_k(\mathbf{x}) > = \sum_{i=1}^{n} d_i w_{ki} \,,$$

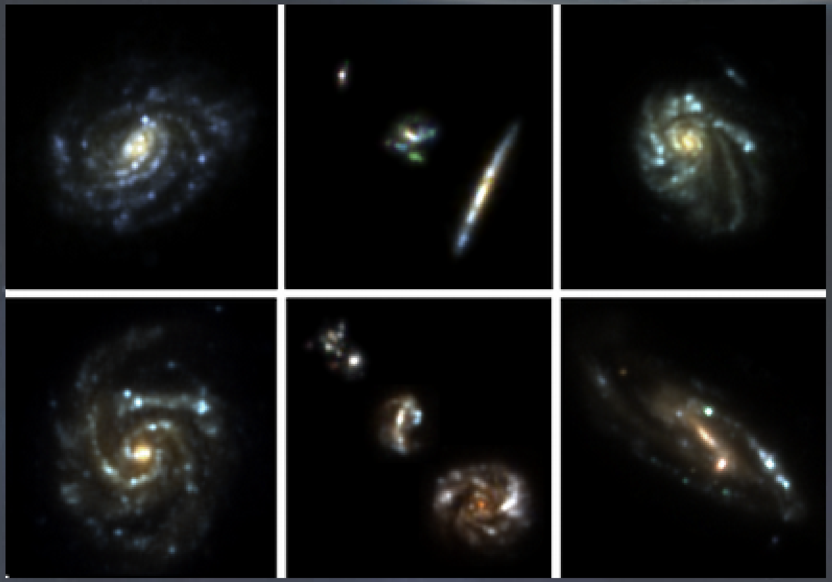


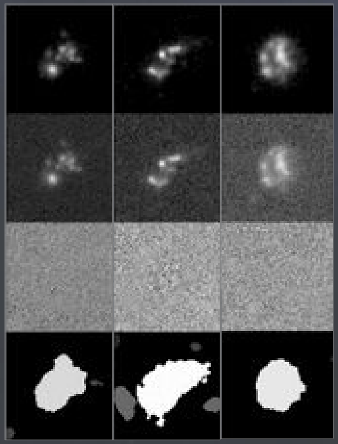
Maturi (2016)

Simulations for strong/weak lensing

M. Maturi 2016



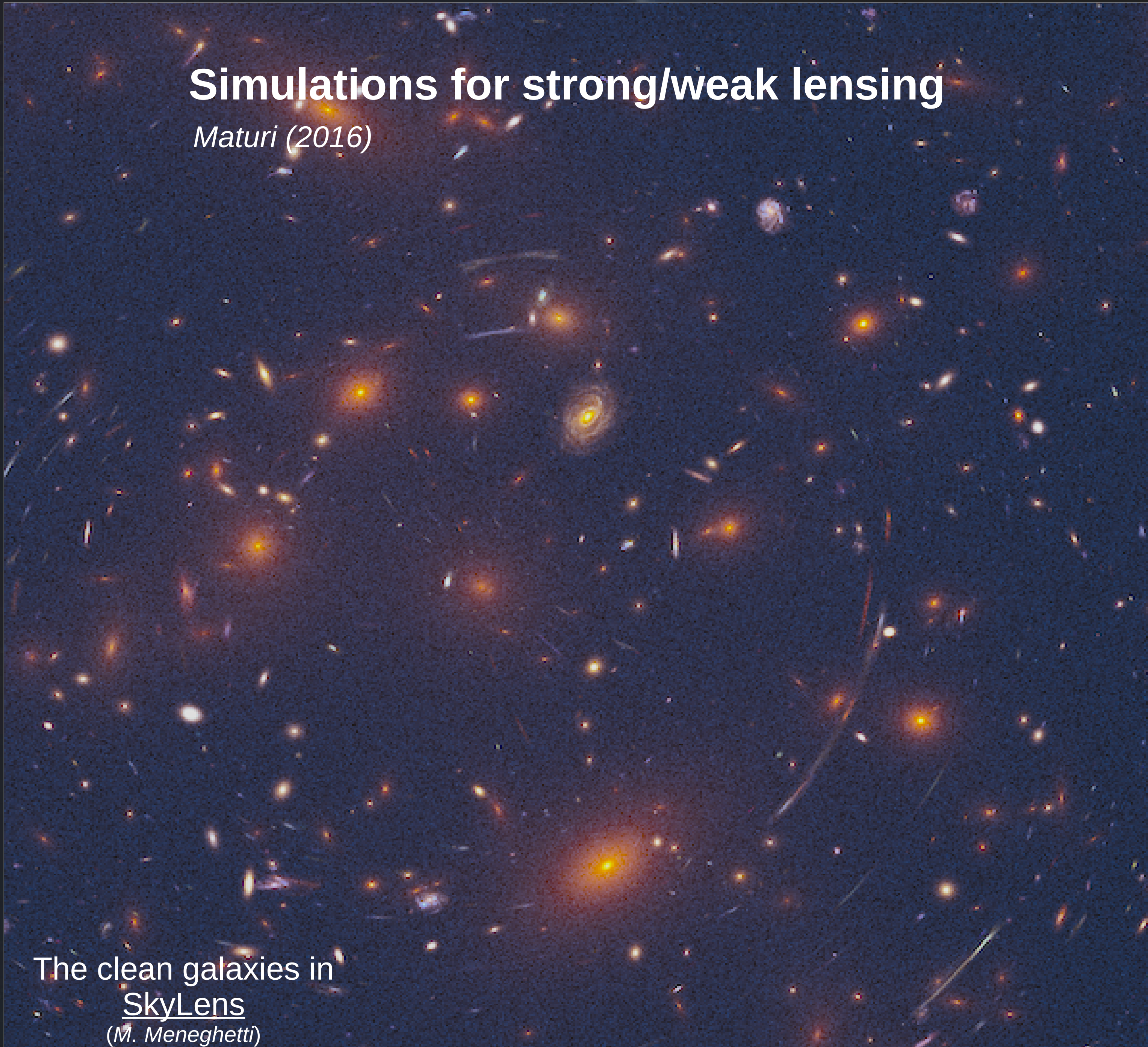




Biased simulations
=
biased lensing

Simulations for strong/weak lensing

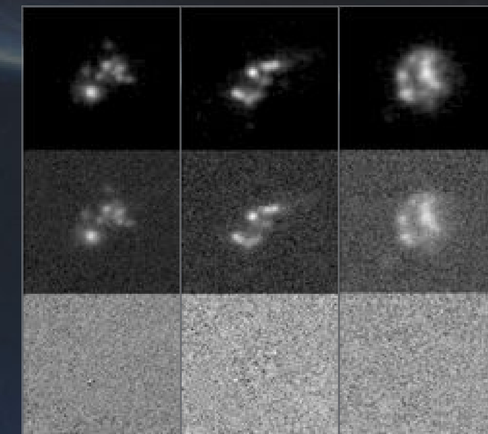
Maturi (2016)

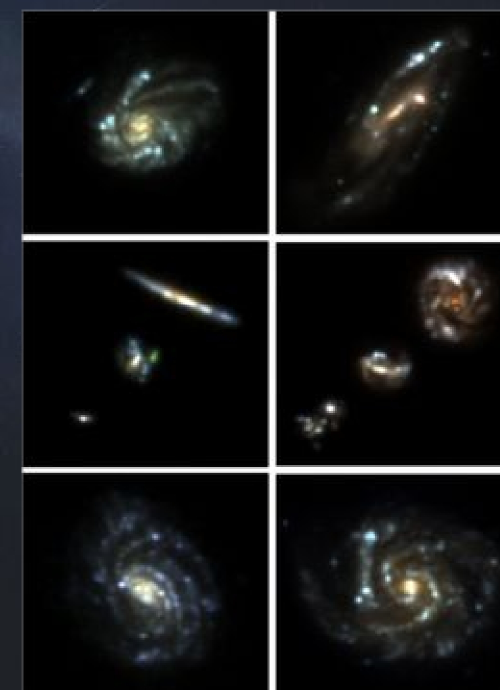


The clean galaxies in [SkyLens]

(*M. Meneghetti*)

XDF galaxies





Including weak gravitational lensing...

All lensing effects given by effective lensing potential:

$$\psi = \frac{2}{c^2} \frac{D_{\rm ds}}{D_{\rm d} D_{\rm s}} \int \Phi \mathrm{d}z$$

(Potential) observables:

- Surface-mass density: $\kappa = \partial^\dagger \partial \psi$
- Shear: $\gamma = \partial^2 \psi$
- Critical curves: $\det(\delta_{ij} - \partial_i \partial_j \psi) = 0$
- Flexion: $\mathcal{F} = \partial \kappa$, $\mathcal{G} = \partial \gamma$