Cluster mass calibration and cosmology

Analysis of KiDS-1000 and prospects for *Euclid*

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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

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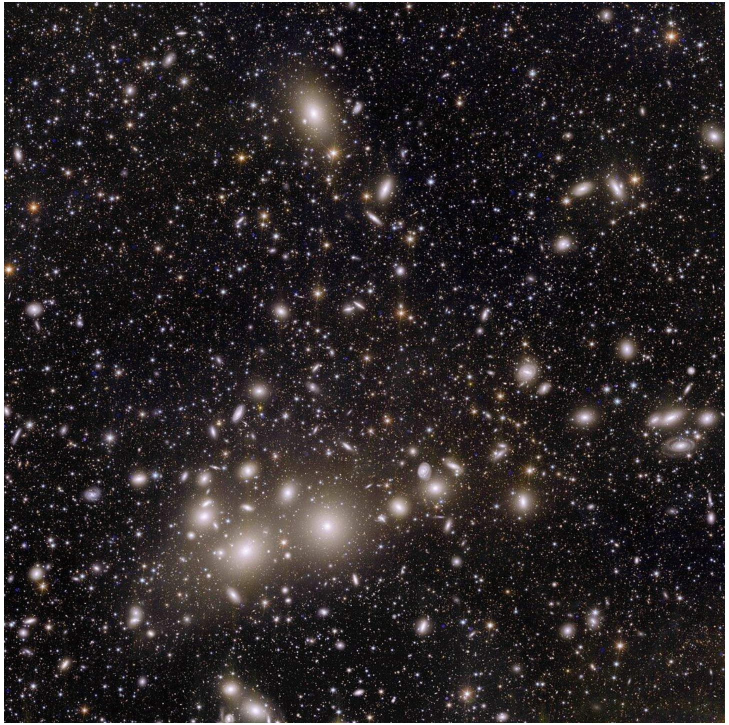
Cosmology with photometric galaxy clusters



Euclid's view of the Perseus cluster of galaxies, ESA

Cluster detection and selection function

↓

Definition of a cluster mass proxy
(e.g. richness)

↓

Cluster weak-lensing profiles
-> mass-observable relation

↓

Joint analysis of cosmological (counts, clustering) and mass (weak lensing) probes

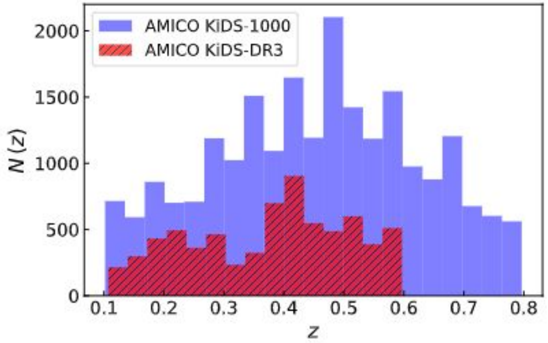
AMICO clusters in KiDS-1000

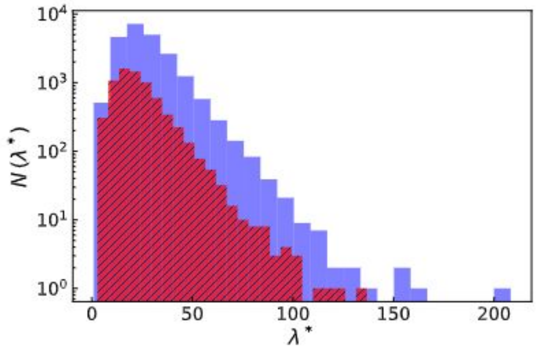
Catalogue (Maturi+ submitted)

Effective area: **840 deg^2**.

~ 8000 clusters in the cosmological sample.

Reliable cluster statistics **up to *z* = 0.8**.





AMICO clusters in KiDS-1000

Weak-lensing measurements (Lesci+ submitted)

Stacked reduced shear in bins of richness and redshift.

Shear catalogue: 6.17 galaxies per square arcmin.

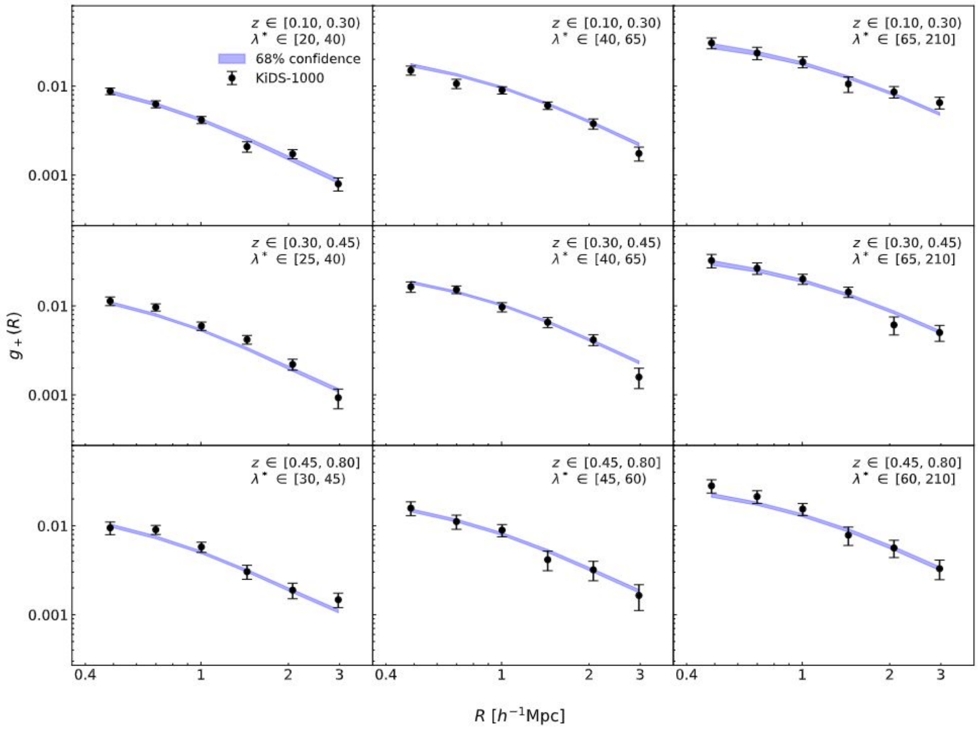
Background selection:

$$(\text{photo-}z\text{ selection}) \vee (\text{colour selection})$$

$$z_{\mathrm{g,min}} > z + 0.05$$

minimum of the interval containing 95% of the probability around the first mode of $p(z_g)$

griz by Euclid Collab.: Lesci+24



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AMICO clusters in KiDS-1000

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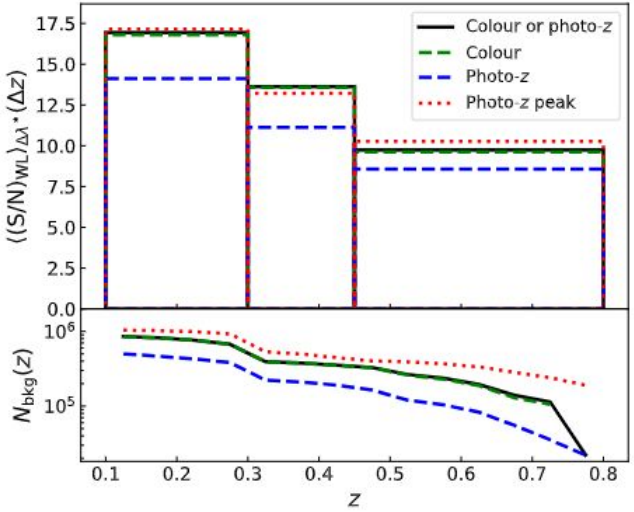


S/N of the stacks averaged over radial and richness bins. The photo-*z* selection is more conservative than the colour selection.

Enhancing the background completeness at the expense of the purity is not convenient: the S/N does not improve.

AMICO clusters in KiDS-1000

Weak-lensing measurements (Lesci+ submitted)

Reference to the colour selection paper:

***Euclid* preparation. XXXVII.**

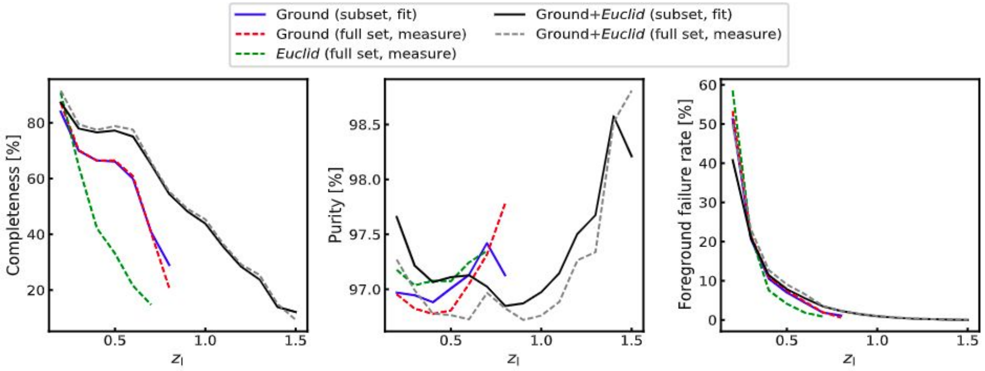
Galaxy colour selections with *Euclid* and ground photometry for cluster weak-lensing analyses

Euclid Collaboration: G. F. Lesci[1,2★], M. Sereno[2,3], M. Radovich[4], G. Castignani[1,2], L. Bisigello[5,4], F. Marulli[1,2,3], L. Moscardini[1,2,3], L. Baumont[6], G. Covone[7,8,9], S. Farrens[6], C. Giocoli[2,10], L. Ingoglia[1],

DOI

We derived:
ground-only (***griz***, up to z_l=0.8) and
ground + *Euclid* (***grizY***$_E$***J***$_E$***H***$_E$, up to z_l=1.5)
colour selections.

As a continuous function of lens redshift



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AMICO clusters in KiDS-1000

Weak-lensing measurements (Lesci+ submitted)

But…

Shear calibration is statistically derived, based on observed and simulated galaxy samples.

Through galaxy cluster background selections, some galaxy populations may be systematically excluded.
This may invalidate the statistical estimate of the shape multiplicative bias, m.

In Euclid Collab.: Lesci et al. 2024 we showed that, in Stage-III surveys, colour + photo-z selections do not yield systematics on m.

Based on simulations, colour + photo-z selections yield ~90% completeness in *Euclid*, up to z_l~1.5.
This is promising, but let's see what the data will say.

If background selections introduce biases, we need to perform our own shear calibration.

Safe, fast, but suboptimal choice: same tomographic selections used for cosmic shear.

AMICO clusters in KiDS-1000

Weak-lensing modelling (Lesci+ submitted)

Expected value for the stacked reduced shear:

$$\langle g_+(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle = (1 - \boxed{f_{\rm off}})\langle g_{+,{\rm cen}}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle + \\ + f_{\rm off}\langle g_{+,{\rm off}}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle$$

Fraction of miscentred clusters
(the miscentring follows a Rayleigh distribution)

AMICO clusters in KiDS-1000

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where

$$\langle g_{+,{\rm cen}}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle = \frac{\mathcal{P}_{\rm clu}(\Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\,\langle\mathcal{P}_{\rm bkg}(\Delta z_{\rm ob})\rangle}{\boxed{\langle N(\Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle}} \times \\ \times \int_0^\infty {\rm d}z_{\rm tr}\,\frac{{\rm d}^2 V}{{\rm d}z_{\rm tr}{\rm d}\Omega}\int_0^\infty {\rm d}M\,\frac{{\rm d}n(M, z_{\rm tr})}{{\rm d}M}\,\mathcal{B}_{\rm HMF}(M)\times \\ \times\, g_{+,{\rm cen}}(R^{\rm test}, M, z_{\rm tr})\int_0^\infty {\rm d}\lambda^*_{\rm tr}\,C_{\rm clu}(\lambda^*_{\rm tr}, z_{\rm tr})\,P(\lambda^*_{\rm tr}|M, z_{\rm tr})\times \\ \times \int_{\Delta\lambda^*_{\rm ob}} {\rm d}\lambda^*_{\rm ob}\;P(\lambda^*_{\rm ob}|\lambda^*_{\rm tr}, z_{\rm tr})\int_{\Delta z_{\rm ob}} {\rm d}z_{\rm ob}\;P(z_{\rm ob}|z_{\rm tr})$$

Expected number of clusters in the bin of richness and redshift

AMICO clusters in KiDS-1000

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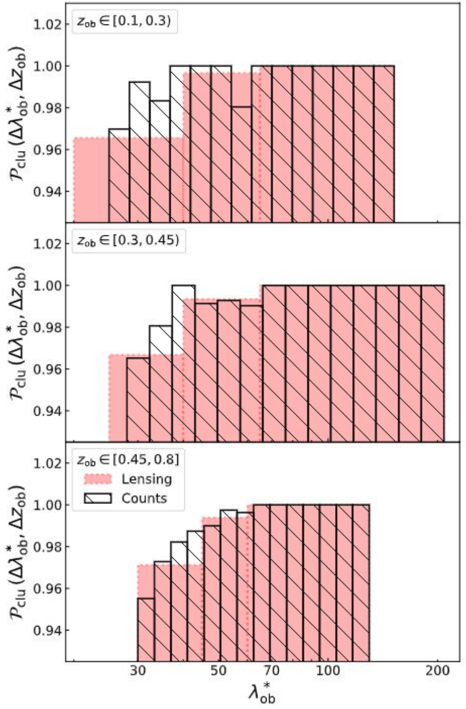
Purity of the cluster sample, based on SinFoniA



AMICO clusters in KiDS-1000

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where

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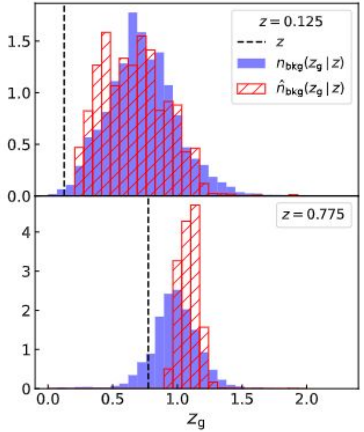
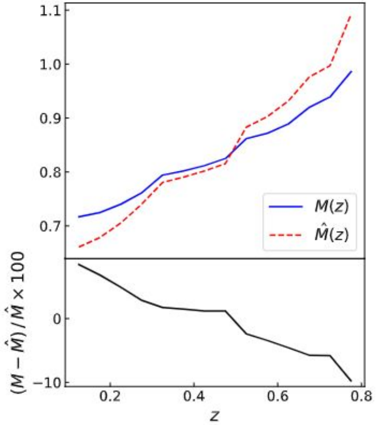
Purity of the background sample, derived by reconstructing the true $n(z_g)$ via self-organising maps (SOM).



Examples of rough (hatched) and reconstructed (blue) background redshift distributions, given two lens redshift values.



Median values of rough and reconstructed background redshift distributions, as a function of lens redshift.

AMICO clusters in KiDS-1000

Weak-lensing modelling (Lesci+ submitted)

Expected value for the stacked reduced shear:

$$\langle g_+(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle = (1 - f_{\rm off})\langle g_{+,\rm cen}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle + \\ + f_{\rm off}\langle g_{+,\rm off}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle$$

where

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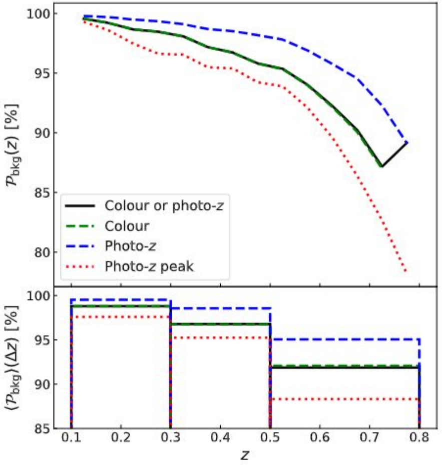

Purity of the background selections derived from the self-organising map analysis, as a function of lens redshift

AMICO clusters in KiDS-1000

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BMO profile (Baltz+09) including a 2-halo term

$$g_{+,\rm cen}(R, M, z) = \frac{\Delta\Sigma_{+,\rm cen}(R, M, z)\,\langle\Sigma^{-1}_{\rm crit}(z)\rangle}{1 - \Sigma_{\rm cen}(R, M, z)\,\langle\Sigma^{-1}_{\rm crit}(z)\rangle^{-1}\,\langle\Sigma^{-2}_{\rm crit}(z)\rangle}$$

The SOM-reconstructed background redshift distribution appears within the critical surface density:

$$\langle\Sigma^{-\eta}_{\rm crit}(z)\rangle = \frac{\int_{z_{\rm g}>z} {\rm d}z_{\rm g}\,\Sigma^{-\eta}_{\rm crit}(z_{\rm g}, z)\,n(z_{\rm g}\,|\,z)}{\int_{z_{\rm g}>z} {\rm d}z_{\rm g}\,n(z_{\rm g}\,|\,z)}$$

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AMICO clusters in KiDS-1000

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Geometric distortions are accounted for

$$R^{\rm test} = \theta D_{\rm l}^{\rm test} = R^{\rm fid}\,\frac{D_{\rm l}^{\rm test}}{D_{\rm l}^{\rm fid}}$$

$D_{\rm l}$ is the diameter angular distance of the lens

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Halo mass function

Bias on the halo mass function (from Costanzi+19). Statistical uncertainties are propagated into the final posteriors.

AMICO clusters in KiDS-1000

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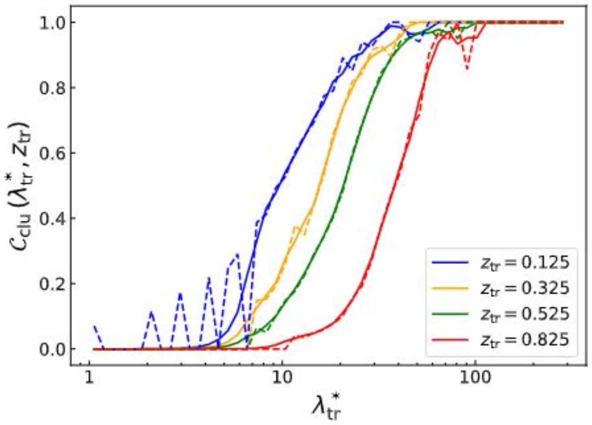
Cluster sample completeness from mocks



The **blinding** strategy involved biasing the completeness estimates.

AMICO clusters in KiDS-1000

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Uncertainty on the mass proxy

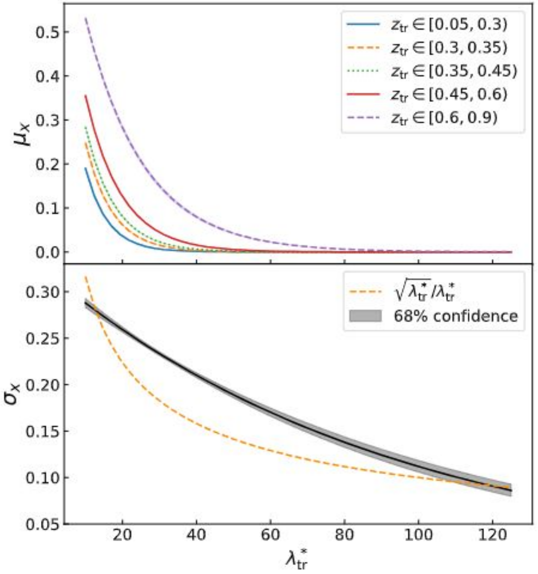
mean, μ_x, rms, σ_x, of

$$P(\Delta x\,|\,\Delta\lambda^*_{\rm tr}, \Delta z_{\rm tr})$$

where

$$x = (\lambda^*_{\rm ob} - \lambda^*_{\rm tr})/\lambda^*_{\rm tr}$$

Contribution by masking, projection effects, and blending.



AMICO clusters in KiDS-1000

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Uncertainty on cluster redshifts from GAMA spectroscopy

AMICO clusters in KiDS-1000

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$$\langle g_+(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle = (1 - f_{\rm off})\langle g_{+,\rm cen}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle + \\ + f_{\rm off}\langle g_{+,\rm off}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle$$

where

$$\langle g_{+,\rm cen}(R, \Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle = \frac{\mathcal{P}_{\rm clu}(\Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\,\langle \mathcal{P}_{\rm bkg}(\Delta z_{\rm ob})\rangle}{\langle N(\Delta\lambda^*_{\rm ob}, \Delta z_{\rm ob})\rangle} \times \\ \times \int_0^\infty {\rm d}z_{\rm tr} \frac{{\rm d}^2 V}{{\rm d}z_{\rm tr}{\rm d}\Omega} \int_0^\infty {\rm d}M \frac{{\rm d}n(M, z_{\rm tr})}{{\rm d}M} \mathcal{B}_{\rm HMF}(M) \times \\ \times\, g_{+,\rm cen}(R^{\rm test}, M, z_{\rm tr}) \int_0^\infty {\rm d}\lambda^*_{\rm tr}\, C_{\rm clu}(\lambda^*_{\rm tr}, z_{\rm tr}) \boxed{P(\lambda^*_{\rm tr}|M, z_{\rm tr})} \times \\ \times \int_{\Delta\lambda^*_{\rm ob}} {\rm d}\lambda^*_{\rm ob}\; P(\lambda^*_{\rm ob}|\lambda^*_{\rm tr}, z_{\rm tr}) \int_{\Delta z_{\rm ob}} {\rm d}z_{\rm ob}\; P(z_{\rm ob}|z_{\rm tr})$$

Proxy-mass relation PDF

$$P(\lambda^*_{\rm tr}|M, z_{\rm tr}) = \frac{1}{\ln(10)\lambda^*_{\rm tr}\sqrt{2\pi}\sigma_{\rm intr}} \exp\left(-\frac{[\log\lambda^*_{\rm tr} - \mu(M, z_{\rm tr})]^2}{2\sigma^2_{\rm intr}}\right)$$

where

$$\mu(M, z_{\rm tr}) = \alpha + \beta \log\frac{M}{M_{\rm piv}} + \gamma\log\frac{H(z_{\rm tr})}{H(z_{\rm piv})} + \log\lambda^*_{\rm piv}$$

AMICO clusters in KiDS-1000

Weak-lensing modelling (Lesci+ submitted)

Other uncertainties entering the modelling

Concentration - mass relation:

$$\log c_{200} = \log c_0 + c_M \log\left(\frac{M_{\rm tr}}{10^{14}h^{-1}M_\odot}\right) + c_z \log\left(\frac{1+z_{\rm tr}}{1+z_{\rm piv}}\right)$$

uniform priors on $\log c_0$ and $\sigma_{\rm intr}$ to account for baryons.
c_M and c_z are fixed to the values by Duffy+08.

Parameter	Description	Prior
$\Omega_{\rm CDM}$	Cold dark matter density parameter at $z = 0$	[0.1, 0.4]
$10^9 A_{\rm s}$	Amplitude of the primordial matter power spectrum	[0.8, 8]
$\Omega_{\rm m}$	Total matter density parameter at $z = 0$	—
σ_8	Amplitude of the matter power spectrum at $z = 0$	—
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$	Cluster normalisation parameter	—
$\Omega_{\rm b}$	Baryon density parameter at $z = 0$	$\mathcal{N}(0.0493, 0.0016)$
$n_{\rm s}$	Primordial power spectrum spectral index	$\mathcal{N}(0.9649, 0.0210)$
$h \equiv H_0/(100$ km/s/Mpc$)$	Normalised Hubble constant	$\mathcal{N}(0.7, 0.03)$
α	Amplitude of the $\log \lambda^* - \log M_{200}$ relation	[-2, 2]
β	Slope of the $\log \lambda^* - \log M_{200}$ relation	[0, 3]
γ	Redshift evolution of the $\log \lambda^* - \log M_{200}$ relation	[-3, 3]
$\sigma_{\rm intr}$	Intrinsic scatter of the $\log \lambda^* - \log M_{200}$ relation	[0.01, 0.5]
$\log c_0$	Amplitude of the $\log c_{200} - \log M_{200}$ relation	[0, 1.3]
$f_{\rm off}$	Fraction of miscentred clusters	$\mathcal{N}(0.3, 0.1)$
$\sigma_{\rm off}$	Miscentring scale (in h^{-1}Mpc)	[0, 0.5]
$F_{\rm t}$	Truncation factor of the BMO density profile	$\mathcal{N}(3, 0.5)$
(s, q)	Parameters entering the mass function correction factor	$\mathcal{N}(\mu_{\rm HMF}, C_{\rm HMF})$

Covariance matrix:

$$C_{kl} = C_{kl}^{\rm BT} + C_{kl}^{\rm sys}, \quad \text{where} \quad C_{kl}^{\rm sys} = (\sigma_m^2 + \sigma_{\rm SOM}^2 + \sigma_{\rm OP}^2)\, g_{+,k}^{\rm ob}\, g_{+,l}^{\rm ob}$$

stat. err. on multiplicative shear bias (2%)

residual uncertainty on orientation and projections (3%)

uncertainty on the SOM-reconstructed $n(z_g)$ (1-4%)

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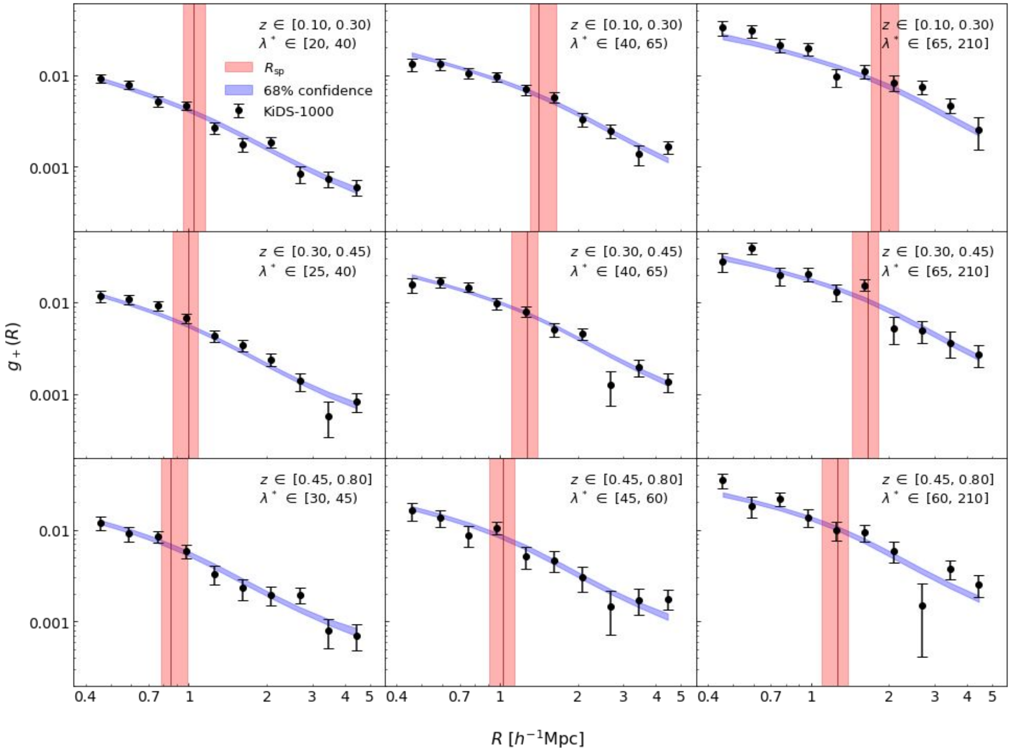
AMICO clusters in KiDS-1000

Splashback radius modelling (Lesci+ in prep.)



AMICO clusters in KiDS-1000

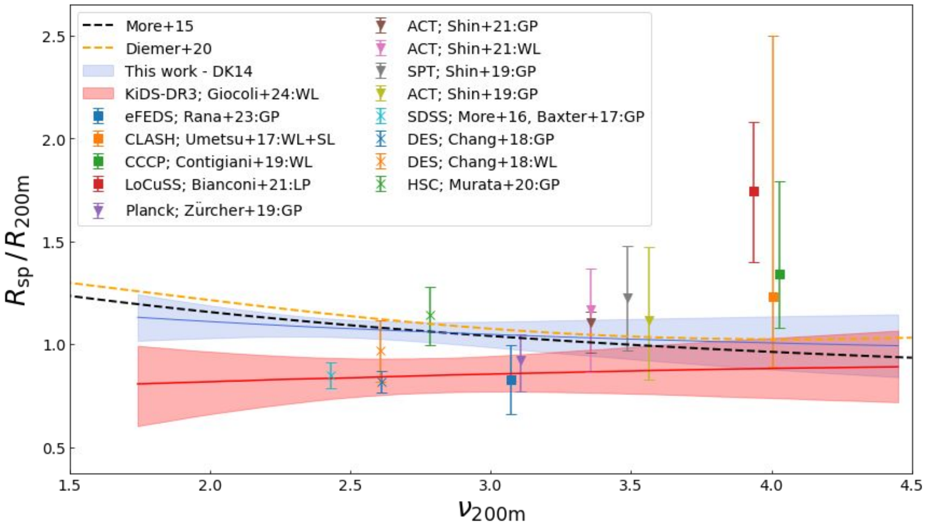
Splashback radius modelling (Lesci+ in prep.)

$R_{\rm sp}$ defined as the minimum of d logρ / d logR.

$$\boxed{\langle R_{\rm sp}(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle = \frac{1}{\langle N(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle}\int_0^\infty {\rm d}z_{\rm tr}\,\frac{{\rm d}^2V}{{\rm d}z_{\rm tr}{\rm d}\Omega}\int_0^\infty {\rm d}M\, R_{\rm sp}(M,z_{\rm tr})\,\frac{{\rm d}n(M,z_{\rm tr},\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})}{{\rm d}M}}$$

$$\langle R_{\rm 200m}(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle = \frac{1}{\langle N(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle}\int_0^\infty {\rm d}z_{\rm tr}\,\frac{{\rm d}^2V}{{\rm d}z_{\rm tr}{\rm d}\Omega}\int_0^\infty {\rm d}M\, R_{\rm 200m}(M,z_{\rm tr})\,\frac{{\rm d}n(M,z_{\rm tr},\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})}{{\rm d}M}$$

$$\langle \nu_{\rm 200m}(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle = \frac{1}{\langle N(\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})\rangle}\int_0^\infty {\rm d}z_{\rm tr}\,\frac{{\rm d}^2V}{{\rm d}z_{\rm tr}{\rm d}\Omega}\int_0^\infty {\rm d}M\, \nu_{\rm 200m}(M,z_{\rm tr})\,\frac{{\rm d}n(M,z_{\rm tr},\Delta\lambda^*_{\rm ob},\Delta z_{\rm ob})}{{\rm d}M}$$



Next: adding the cluster-galaxy 2PCF

Summary

- Need to extend the cluster pipeline down to shear calibration;
- Compromise between background selection purity and completeness, in order to maximise the weak-lensing S/N;
- Impact of selection effects on cluster statistics in *Euclid* (ongoing work in the Clusters of Galaxies SWG, FornaX Collaboration);
- The mass calibration pipeline for cosmology enables additional analyses, e.g. splashback radius -> “easy” additions to CLOE.