Euclid Preparation XYZ: Forecasts for 10 different Higher Order Weak Lensing Statistics[*]

Euclid Collaboration[**]: Virginia Ajani[11,14], Marco Baldi[3,6,20], Alexandre Barthelemy[1], Aoife Boyle[2], Vincenzo Cardone[4], Sihao Cheng[5], Sandrine Codis[2], Carlo Giocoli[6,20], Joachim Harnois-Déraps[7], Sven Heydenreich[9], Martin Kilbinger[15], Francois Lanusse[16], Laila Linke[9], Claudio Llinares[12,13], Nicolas Martinet[10], Carolina Parroni[17], Austin Peel[18], Sandrine Pires[11], Lucas Porth[9], Ismael Tereno[12,13], Cora Uhlemann[7], Martina Vicinanza[19], Simone Vinciguerra[4], et al.
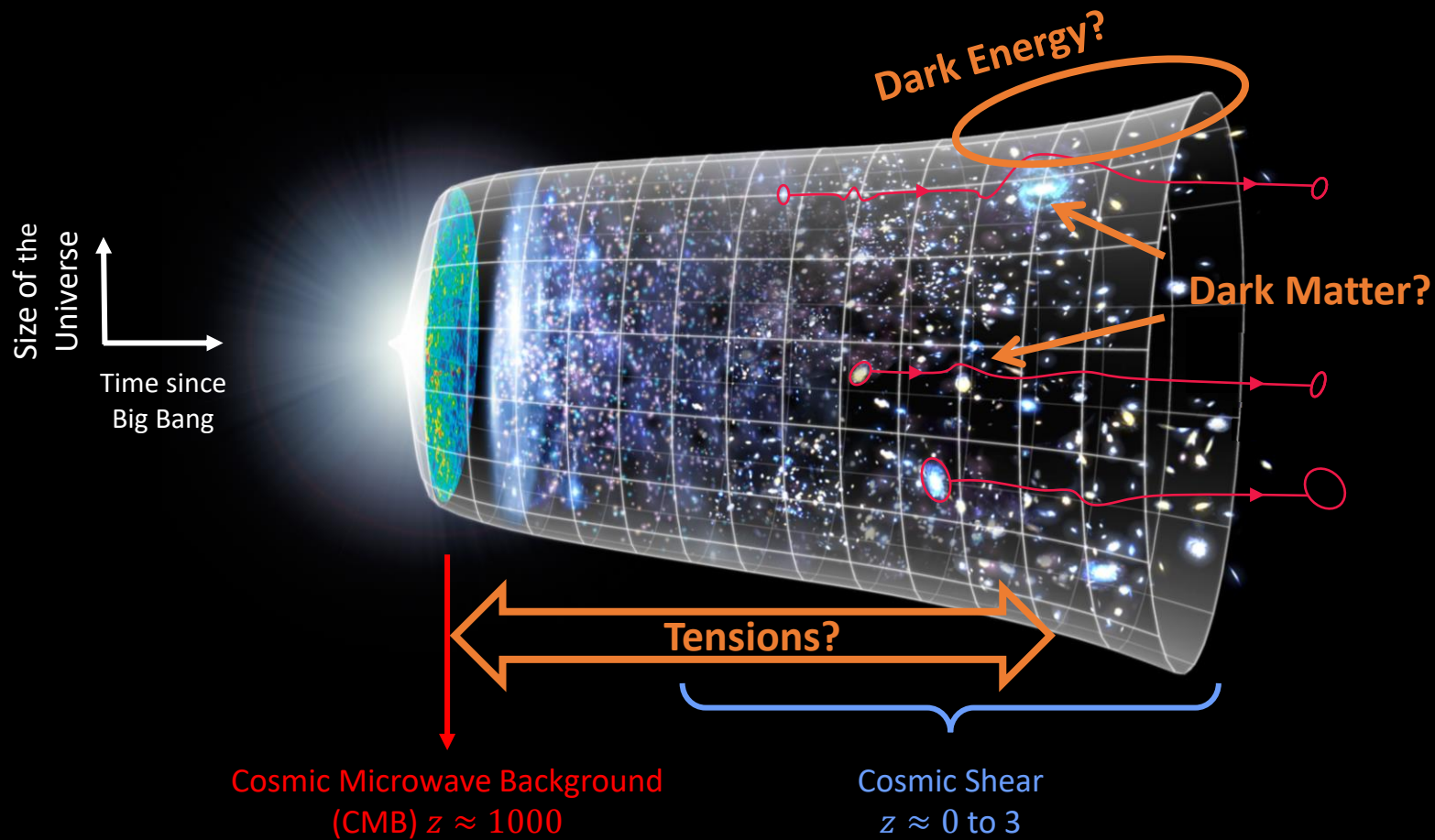
Size of the Universe

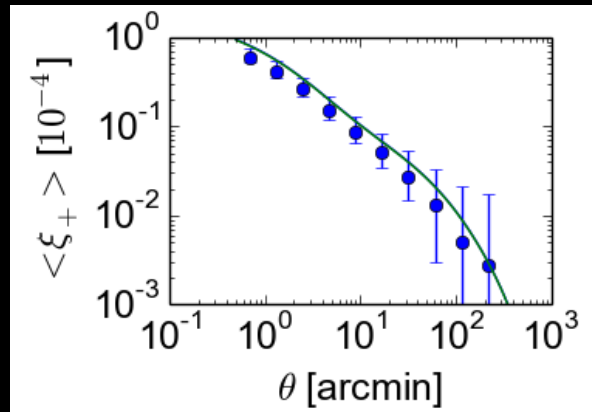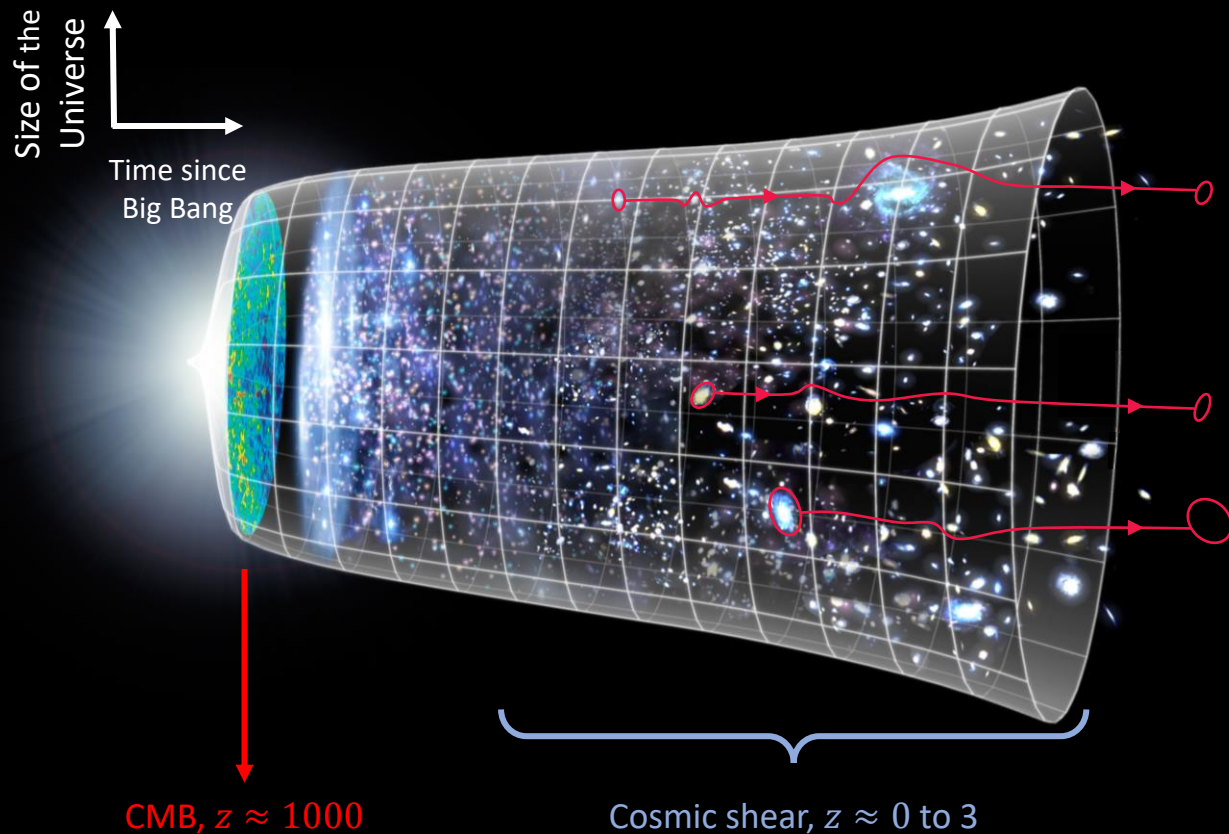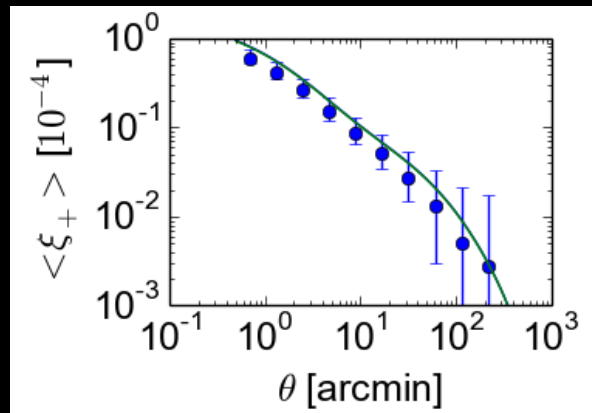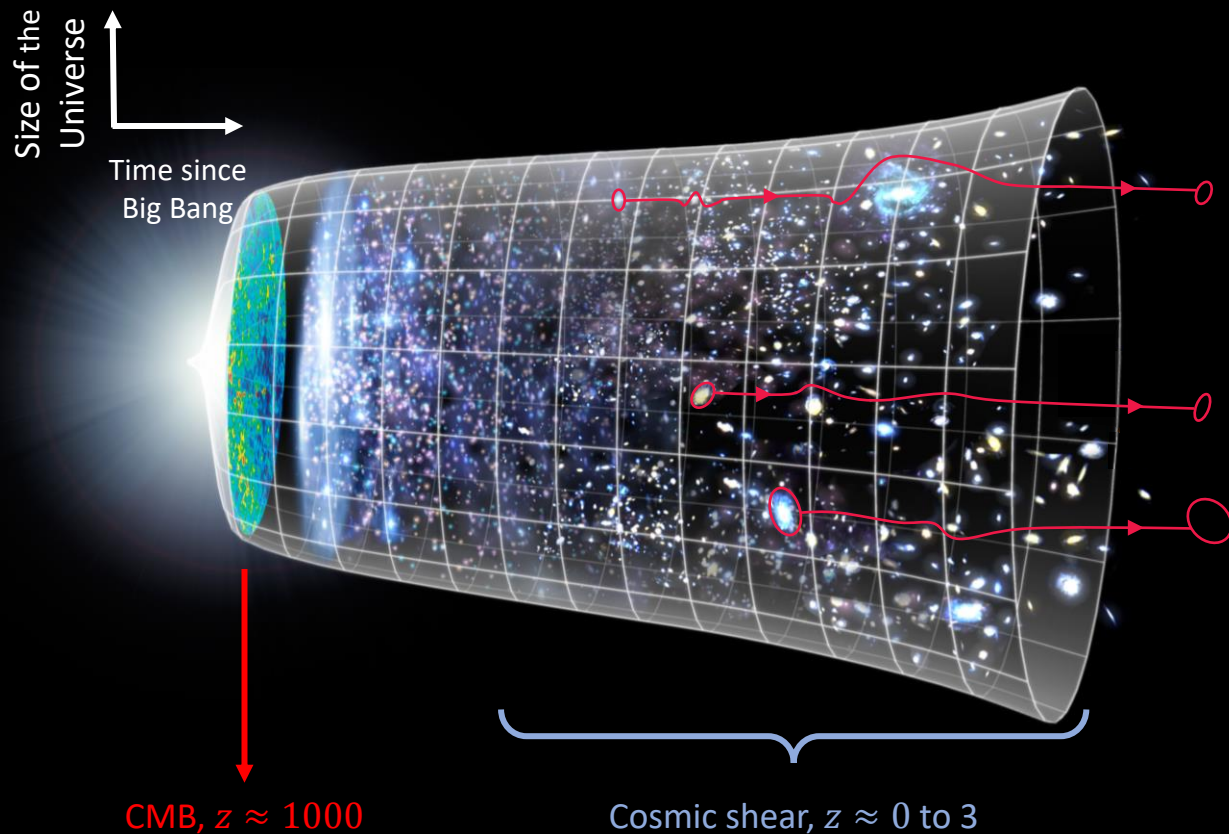Time since Big Bang

Cosmic Shear
$z \approx 0$ to 3

2

Size of the Universe

Time since Big Bang

Dark Energy?

Dark Matter?

Tensions?

Cosmic Microwave Background (CMB) $z \approx 1000$

Cosmic Shear $z \approx 0$ to 3

3

Shear two-point correlation function
(shear-2PCF)

Size of the Universe

Time since Big Bang

CMB, $z \approx 1000$

Cosmic shear, $z \approx 0$ to 3

Size of the Universe

Time since Big Bang

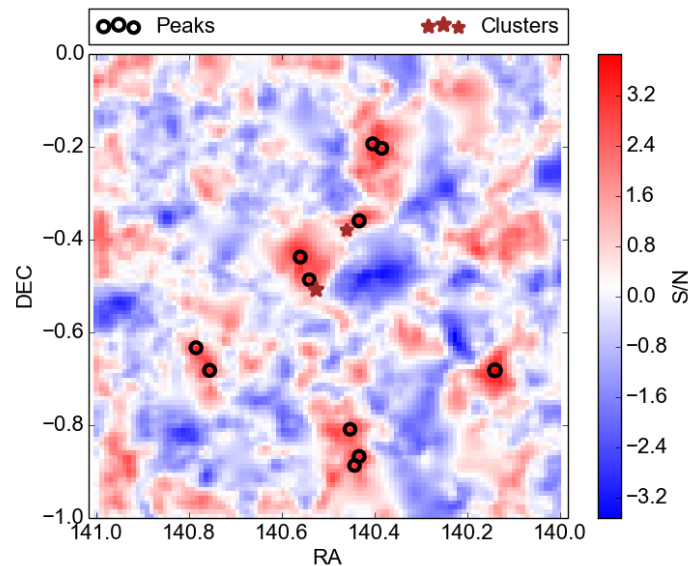CMB, $z \approx 1000$

Cosmic shear, $z \approx 0$ to 3

Shear two-point correlation function
(shear-2PCF)
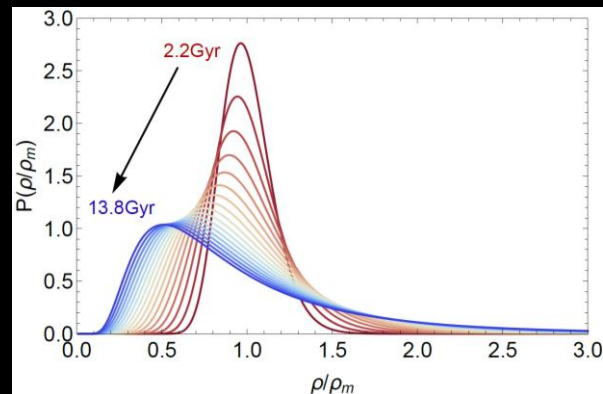
Evolution of the matter distribution
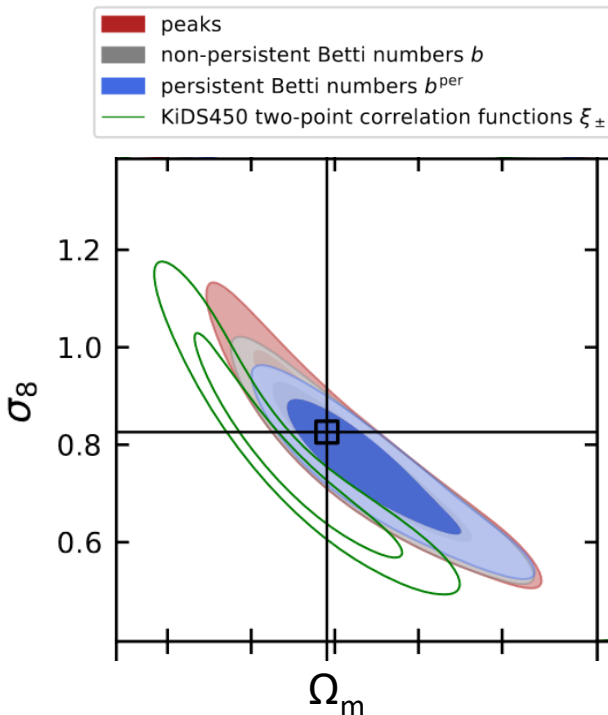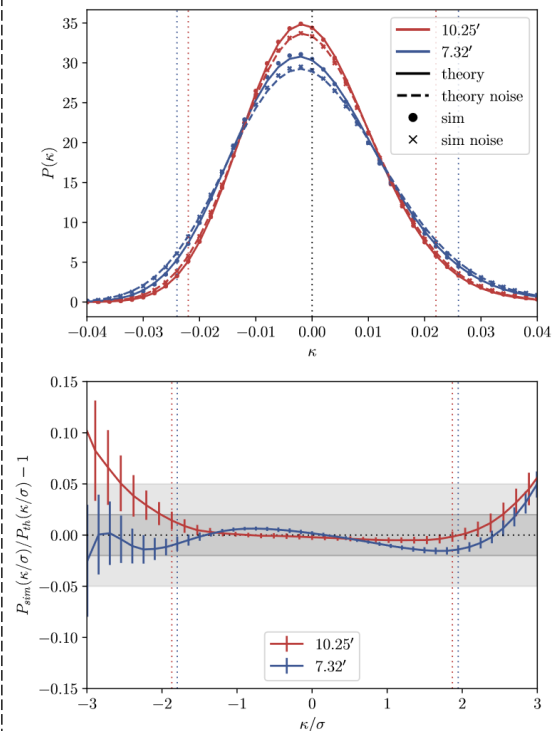with redshift - Courtesy Sandrine Codis

Peak counts (e.g. Martinet+18)

KiDS-450 mass map

Persistent homology (e.g. Heydenreich+21)
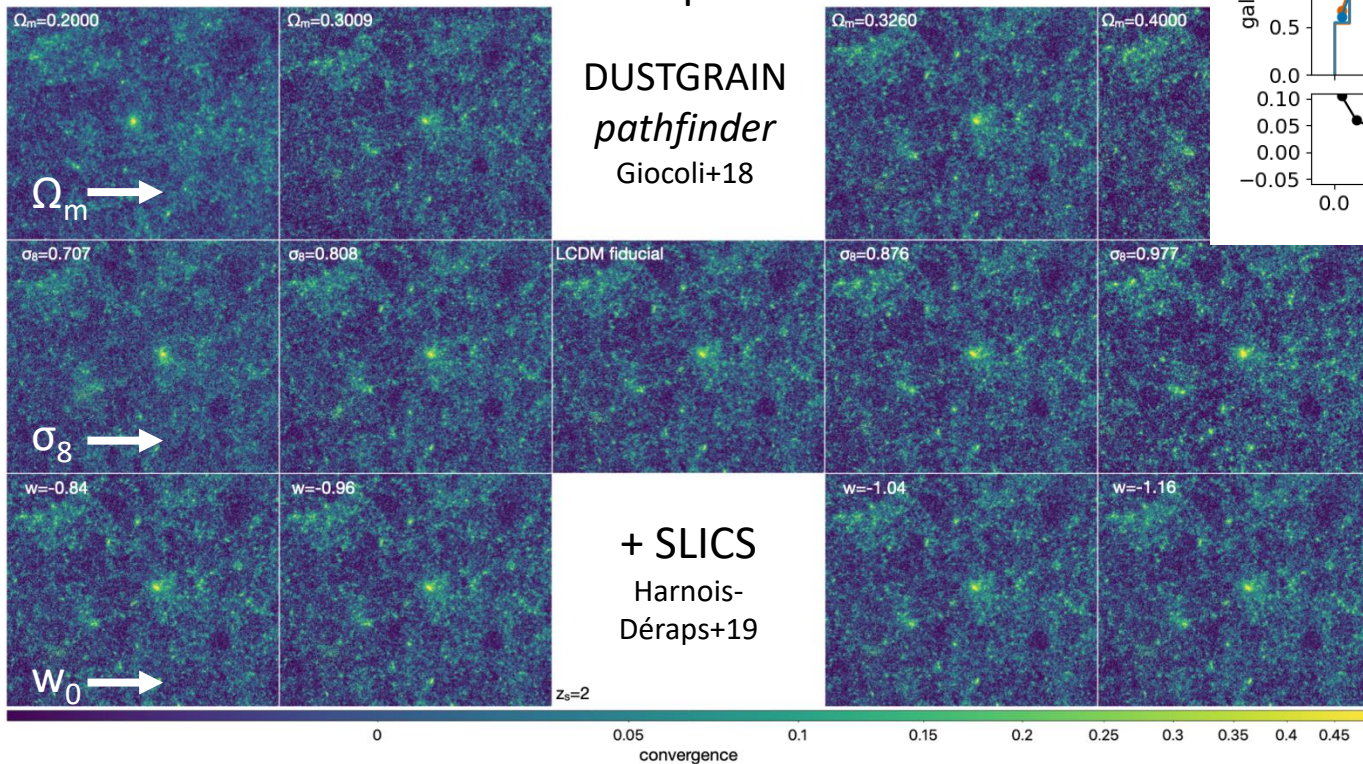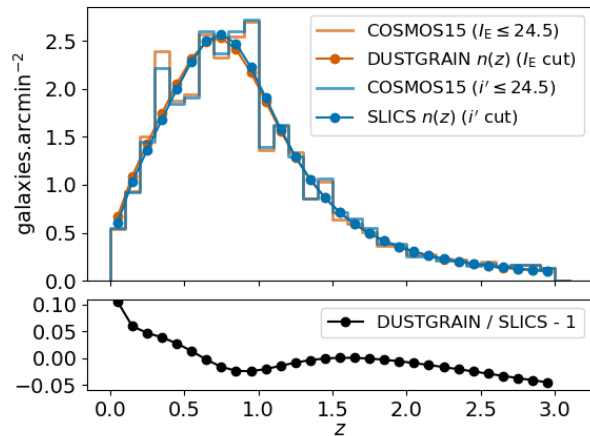
Forecasts for KiDS-450

PDF (e.g. Boyle+21)

Simulated vs. theoretical data

HOWLS data set

Set of HOWLS simulated mass maps

DUSTGRAIN
pathfinder
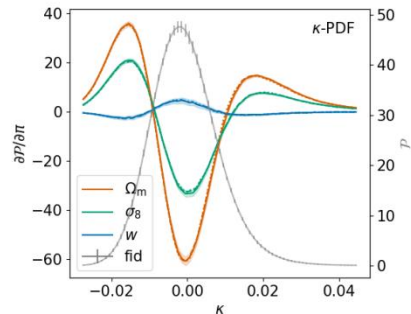Giocoli+18

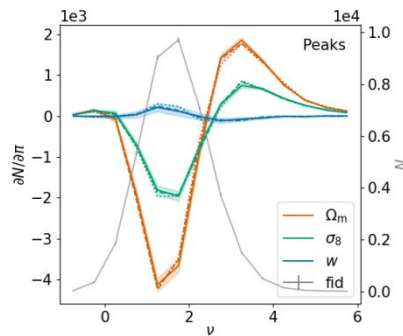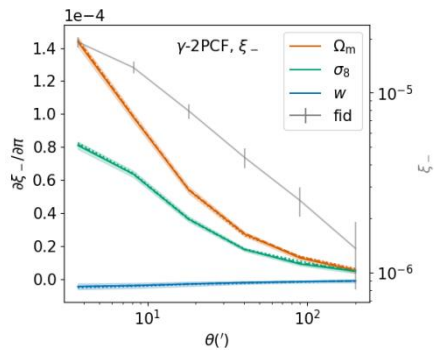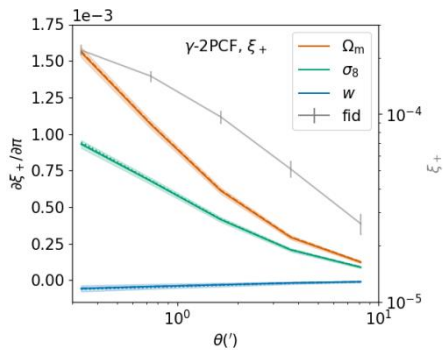Ω_m ➡

σ_8 ➡

+ SLICS
Harnois-
Déraps+19

w_0 ➡

- 12 cosmologies + SLICS covariance

- Realistic Euclid mocks (n(z), shape noise)

- Kaiser&Squires93 mass maps

- Fisher forecasts
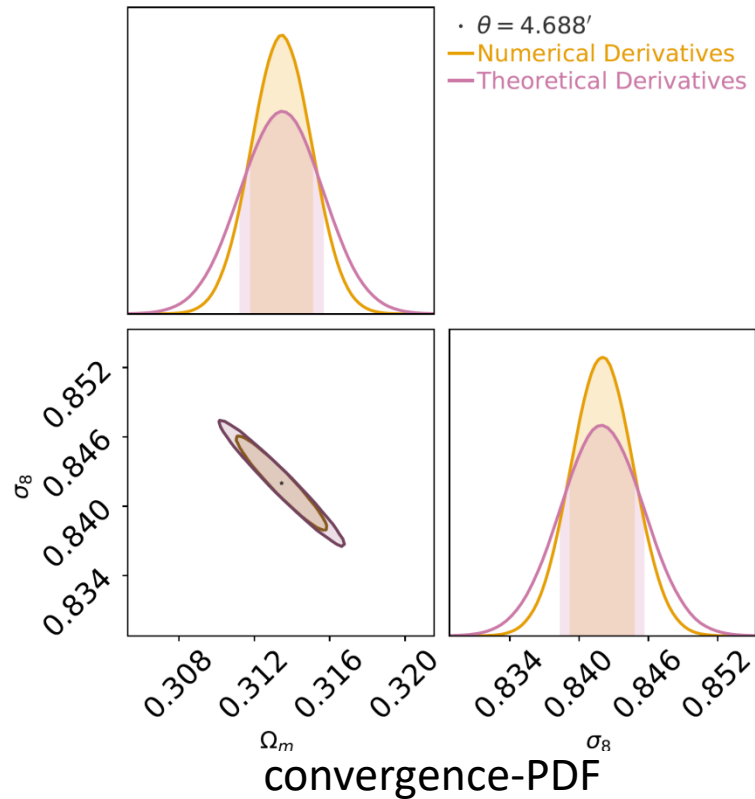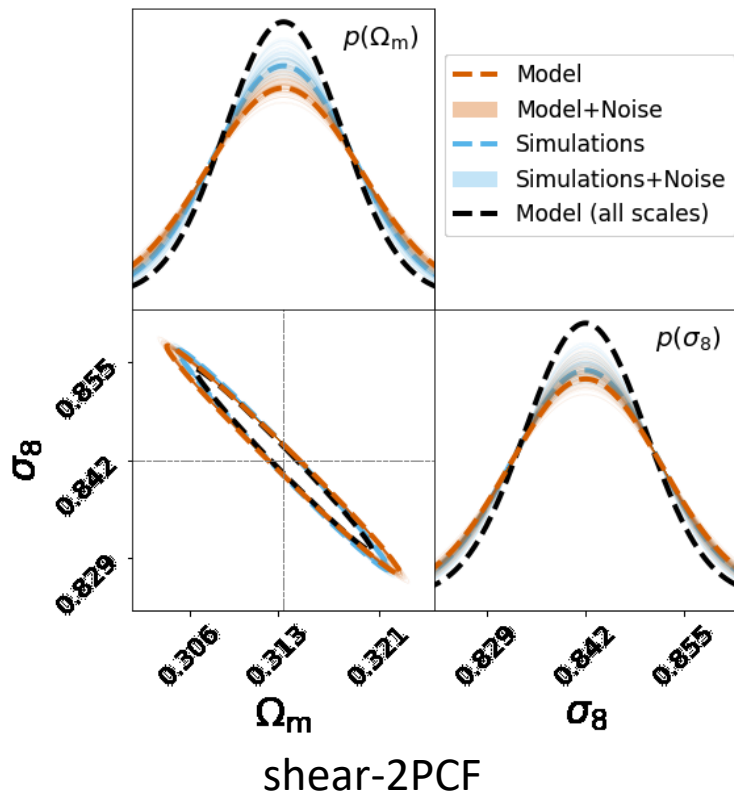
- Data set released with the paper

Summary statistics

Field	Statistics	Abbreviation	Teams
γ	two-point correlation functions	γ-2PCF (ξ_+/ξ_-)	1 (+1)
κ	two-point correlation function	κ-2PCF (ξ_κ)	1 (+2)
κ	one-point probability distribution function	κ-PDF ($\mathcal{P}$)	1
κ	higher order moments	HOM ($\mathcal{M}$)	2 (+2)
$M_{ap}(\gamma)$	third order moments	$\langle M_{ap}^3 \rangle$	1
$M_{ap}(\gamma)$	n-th order moments	$\langle M_{ap}^n \rangle$	1
$M_{ap}(\kappa)$	peak counts	peaks (N)	1 (+2)
κ	Minkowski functionals	MFs (V_0, V_1, V_2)	1 (+2)
κ	Betti numbers	BNs (β_0, β_1)	1 (+2)
$M_{ap}(\gamma)$	persistent homology Betti numbers	pers. BNs (β)	1
$M_{ap}(\gamma)$	persistent homology heatmap	pers. heat. (h)	1
κ	scattering transform coefficients	s_1, s_2	1

- 12 different statistics
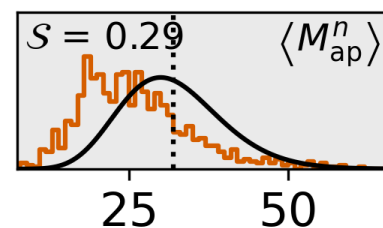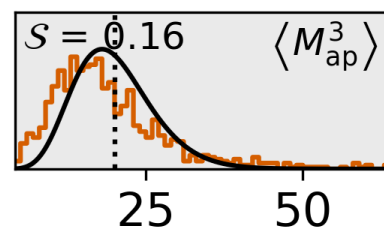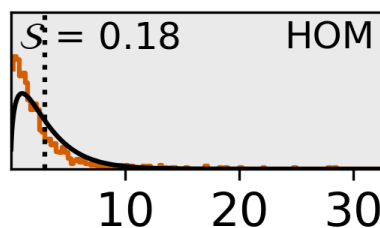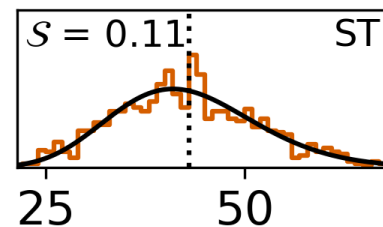- 12 independent teams
- 24 data vectors
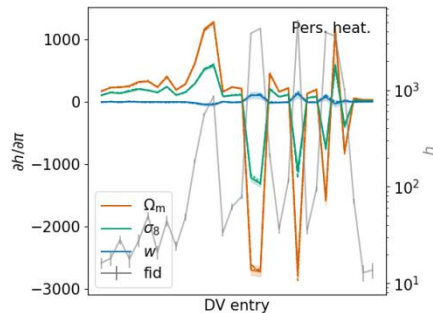
Theoretical validation

shear-2PCF

convergence-PDF

Gaussian likelihood

$\mathcal{S} = 0.08$ γ-2PCF
$\mathcal{S} = 0.06$ κ-2PCF
$\mathcal{S} = 0.12$ κ-PDF
$\mathcal{S} = 0.07$ Peaks
$\mathcal{S} = 0.15$ MFs
$\mathcal{S} = 0.13$ BNs
$\mathcal{S} = 0.1$ Pers. BNs
$\mathcal{S} = 0.06$ Pers. heat.
$\mathcal{S} = 0.11$ ST
$\mathcal{S} = 0.18$ HOM
$\mathcal{S} = 0.16$ $\langle M_{\mathrm{ap}}^3 \rangle$
$\mathcal{S} = 0.29$ $\langle M_{\mathrm{ap}}^n \rangle$
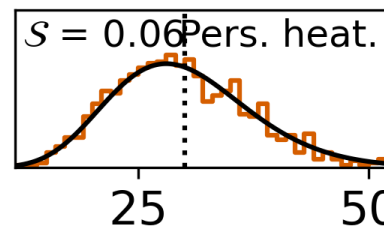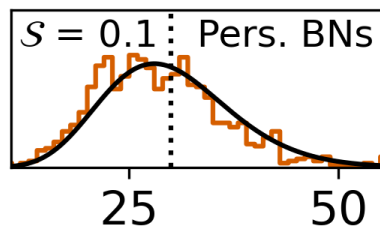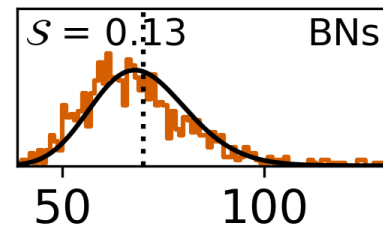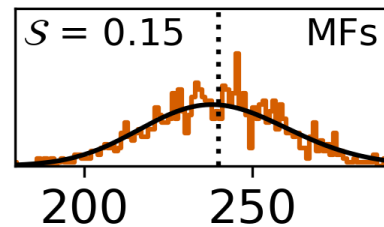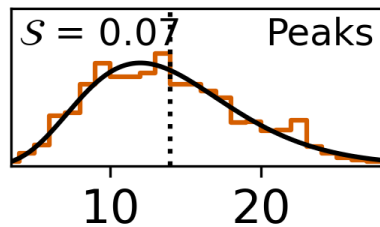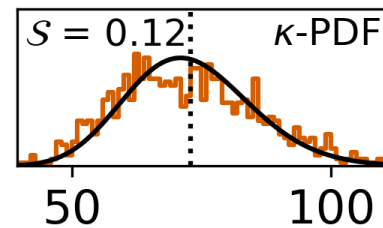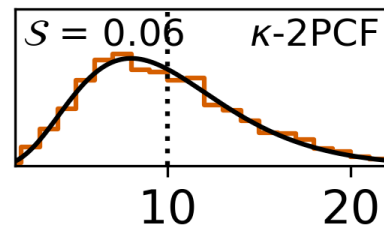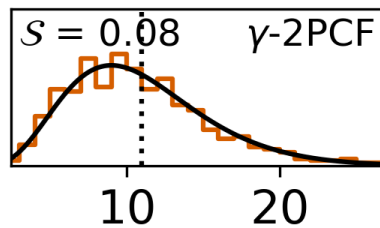
χ^2 χ^2 χ^2

Fisher forecasts

- Every higher order statistic outperforms the shear-2PCF
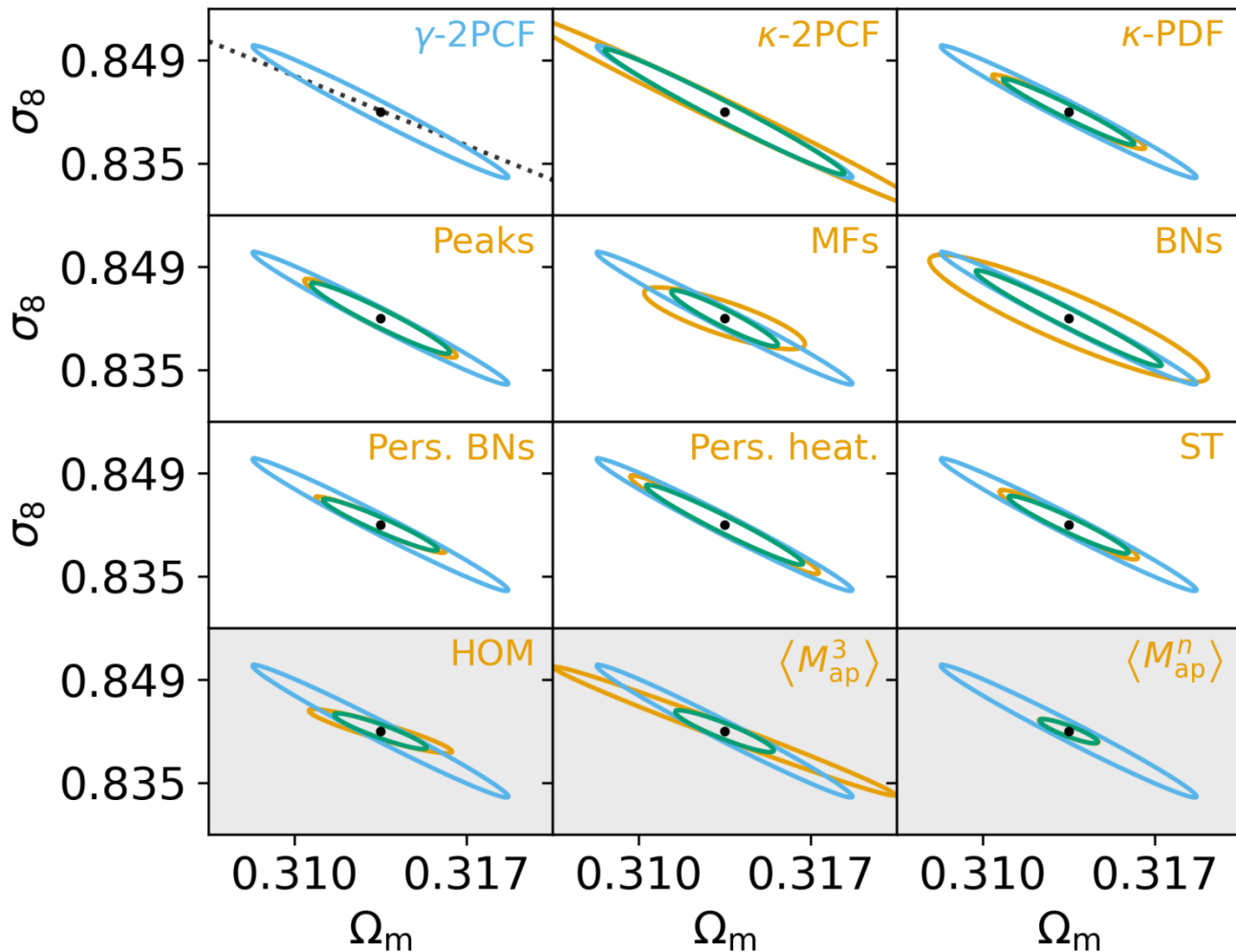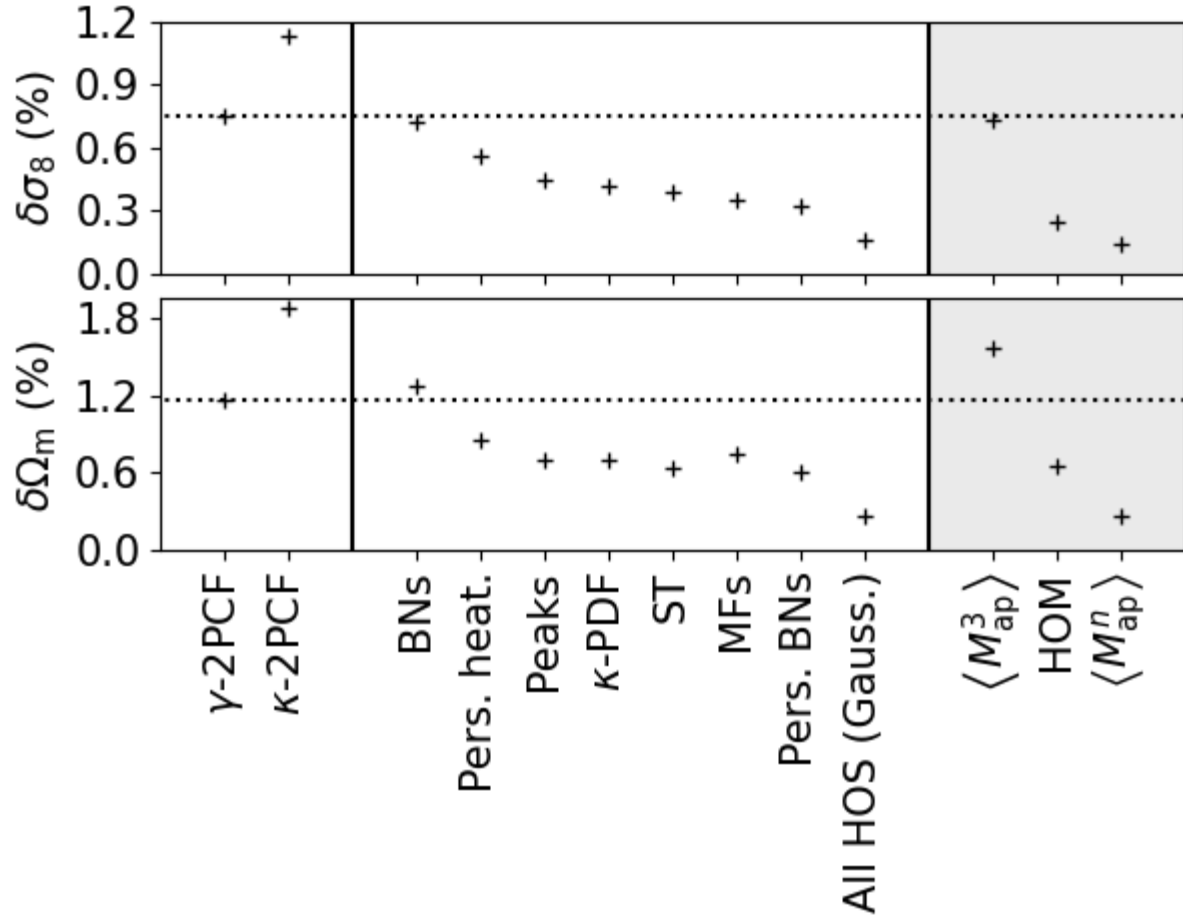
Ranking

- x2 improvement over shear-2PCF
- No obvious winner

Towards a combination

Correlation matrix

Joint forecasts
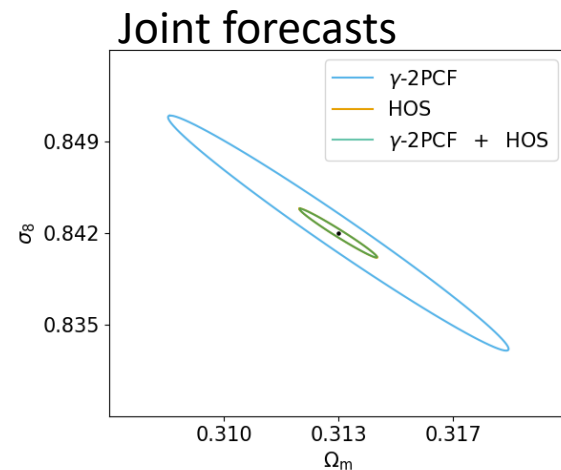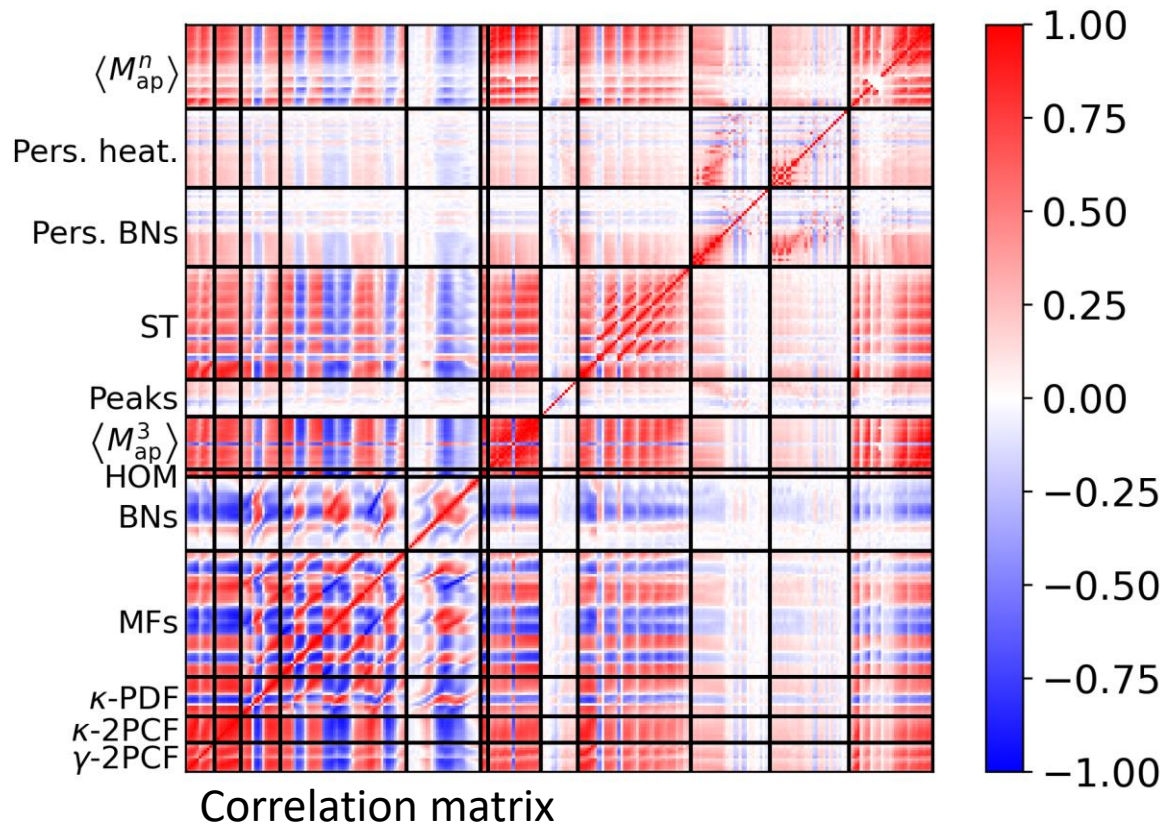
- High correlations between statistics
- x5 improvement over shear-2PCF

Perspectives

- HOS significantly improve cosmological constraints
- Most HOS perform similar, but combining them can be beneficial
- Fisher analyses require assumptions not fulfilled by all probes

HOWLS series of papers:

- **Paper I**: presentation of the data set + first results
  (*leads: Martinet, Cardone*)
- **Paper II**: + tomography & systematics
  (*leads: Pires, Tereno*)
- **Paper III**: + emulator & non-Gaussian likelihood
  (*leads: Harnois-Déraps, Codis*)

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PhD: https://jobregister.aas.org/ad/3e4c122d
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