Higher-oder statistics in cosmic shear...

... improved confidence for cosmological parameters!


credit: datanami

PRESENTED BY:
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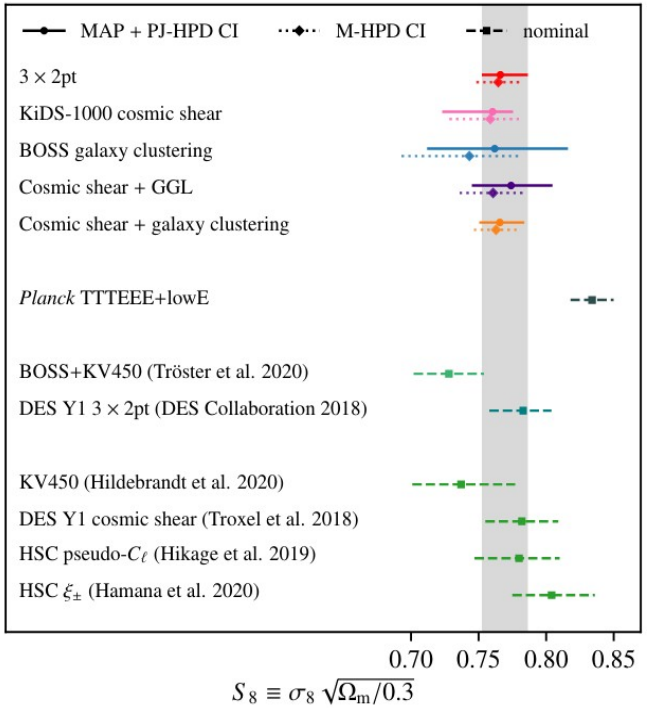
at the IFPU focus week

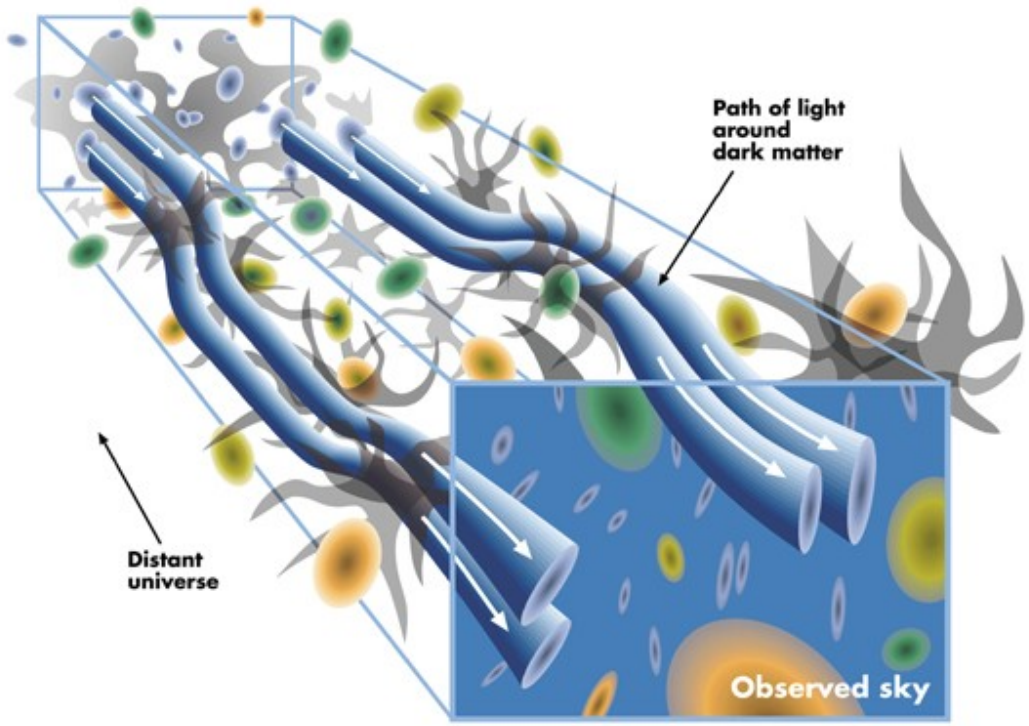
in collaboration with ***Peter Schneider, Laila Linke, Benjamin Brück***, Pierre Burger, Joachim Harnois-Déraps, Sandra Unruh, Tiago Castro, Klaus Dolag and Nicolas Martinet

Why care about cosmological parameters?



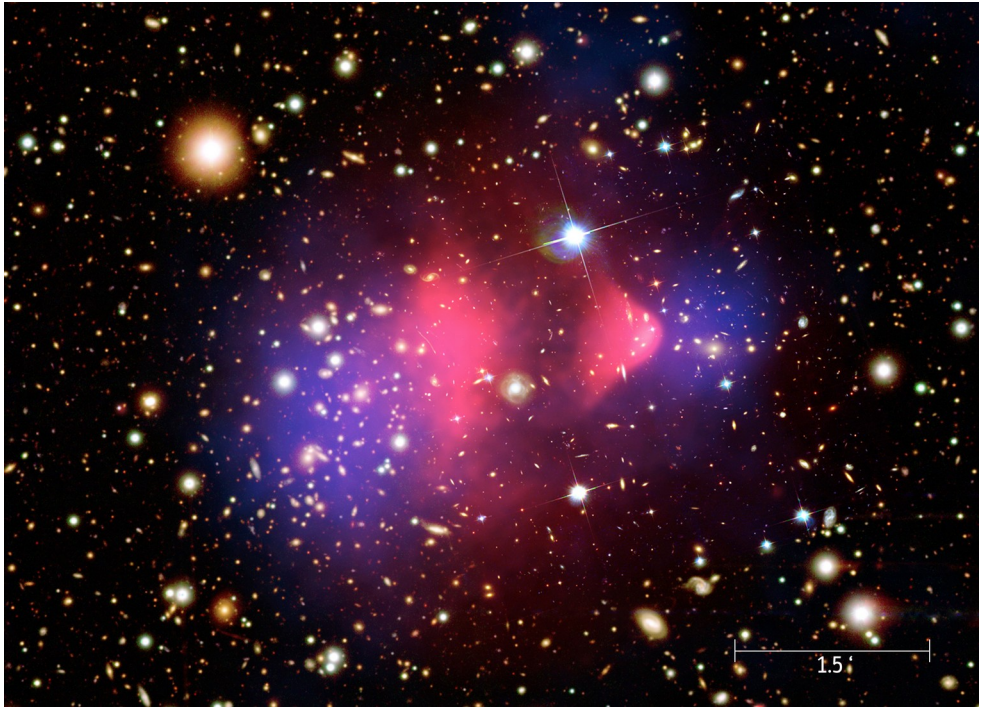
Heymans et al. (2021)

What is cosmic shear?



Bell Labs/Lucent

Why use cosmic shear?



NASA/CXC/M. Weiss

Why do we need higher-oder statistics?

- Non-Gaussianities in LSS

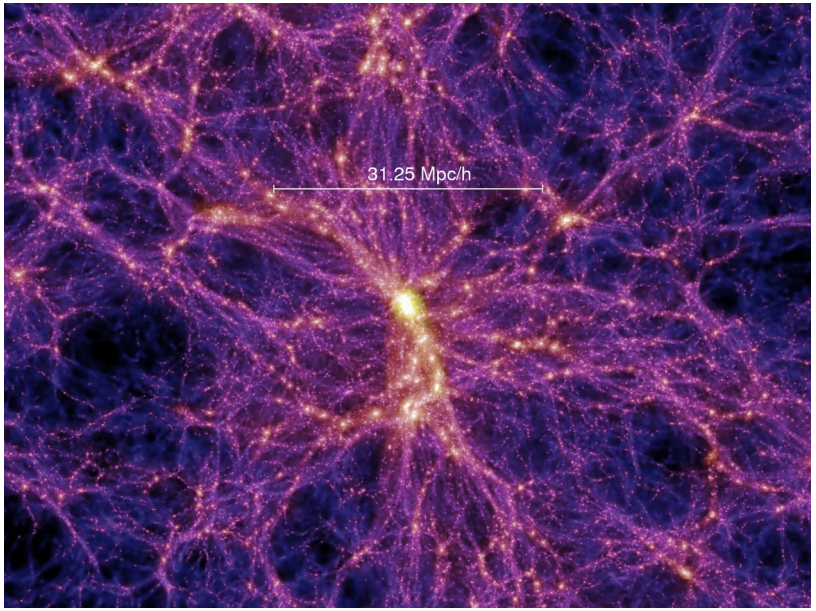
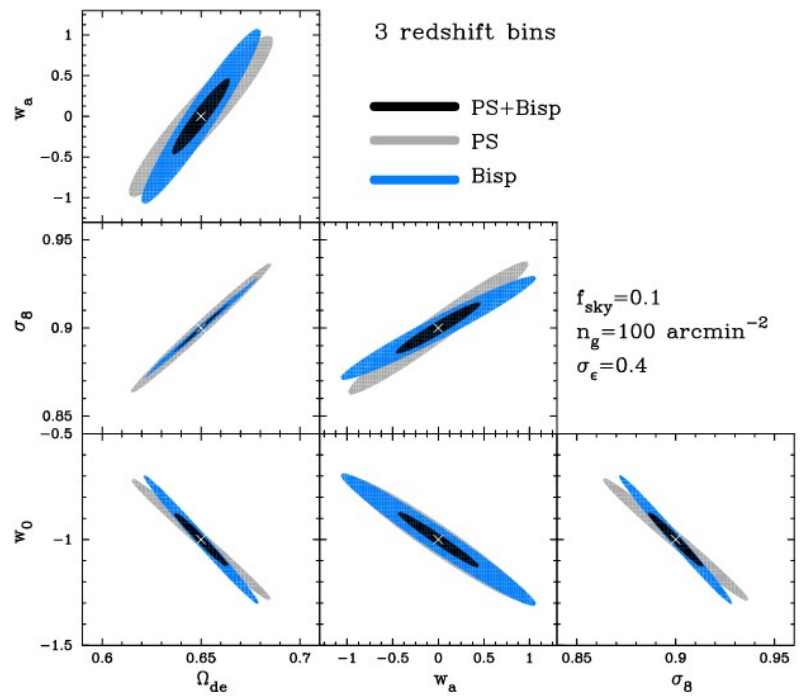


Image credit: https://wwwmpa.mpa-garching.mpg.de/galform/virgo/millennium/

Why do we need higher-oder statistics?

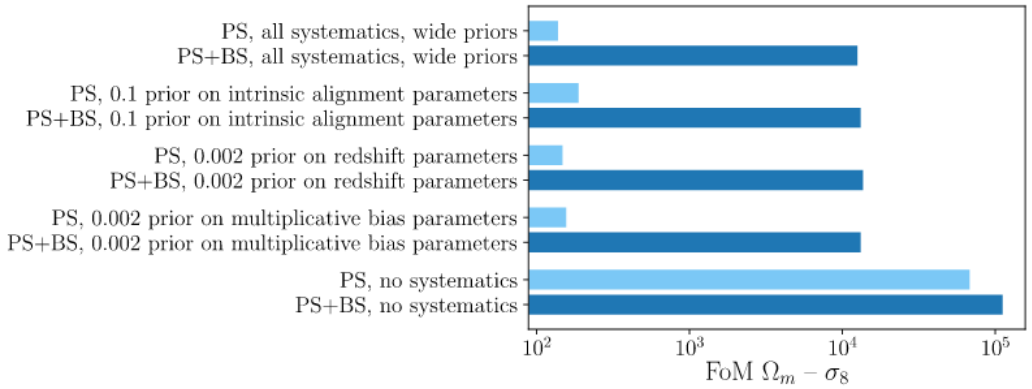
- Non-Gaussianities in LSS
- Break degeneracies



Takada & Jain (2004)

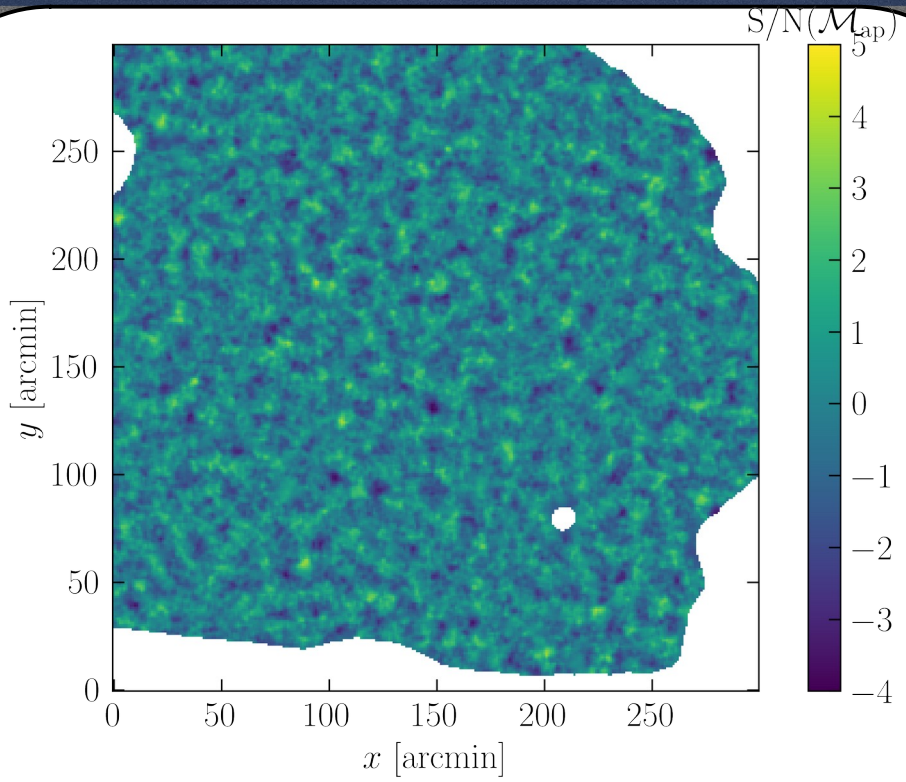
Why do we need higher-oder statistics?

- Non-Gaussianities in LSS
- Break degeneracies
- Control nuisance parameters



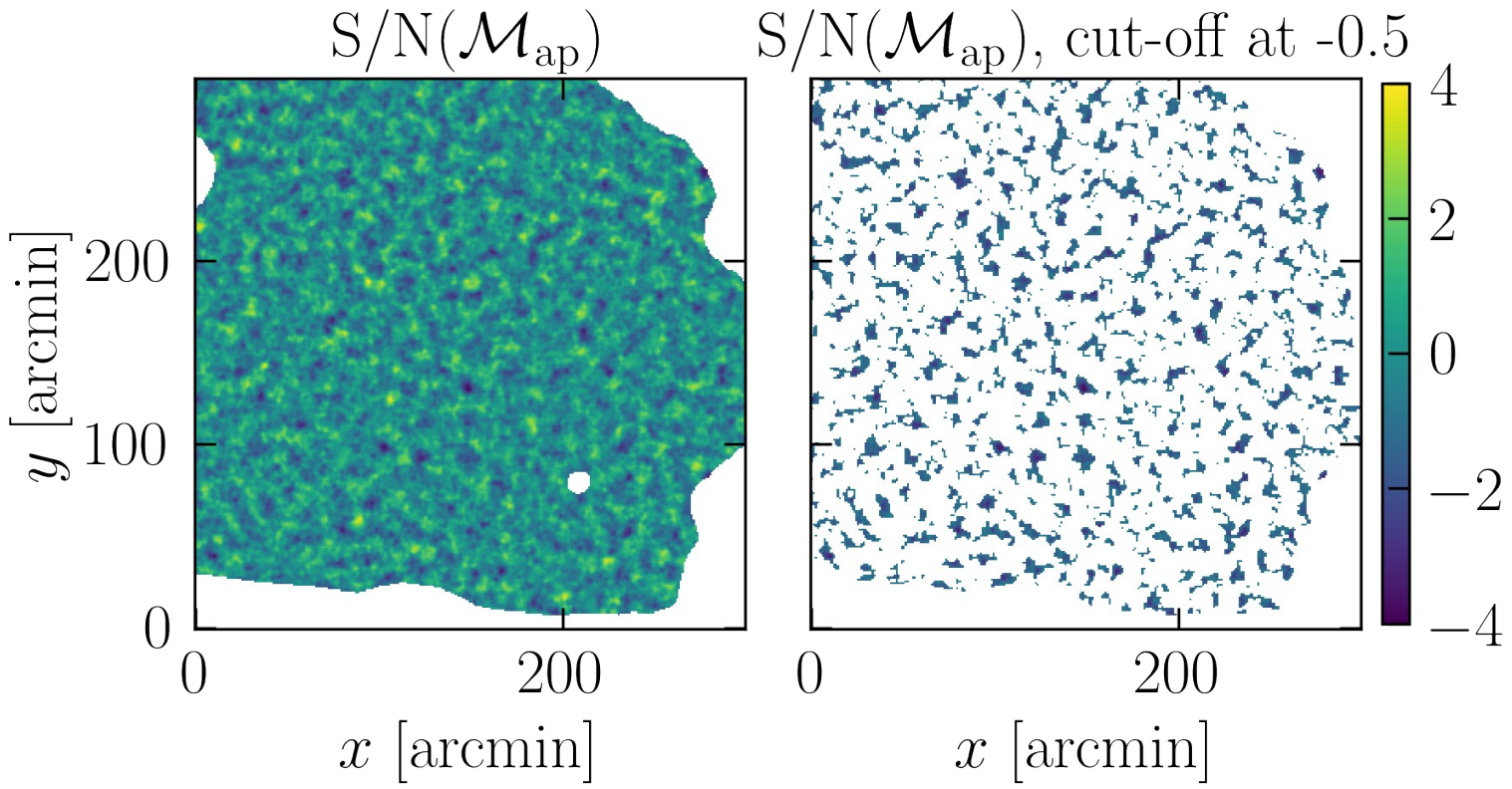
Pyne & Joachimi (2021)

Persistent homology of aperture masses



Signal-to-noise map of Aperture masses

Persistent homology of aperture masses



Signal-to-noise map of Aperture masses

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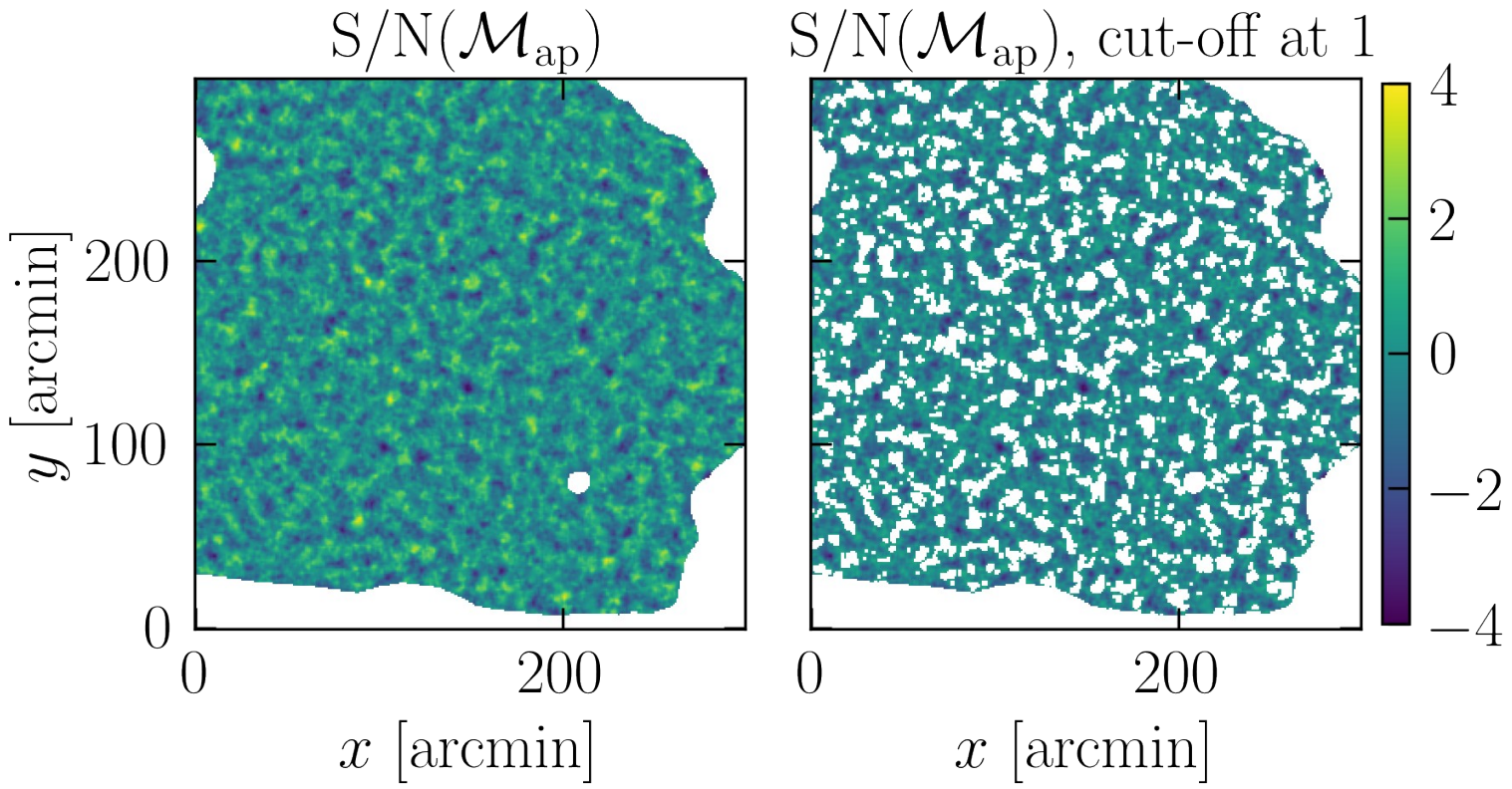
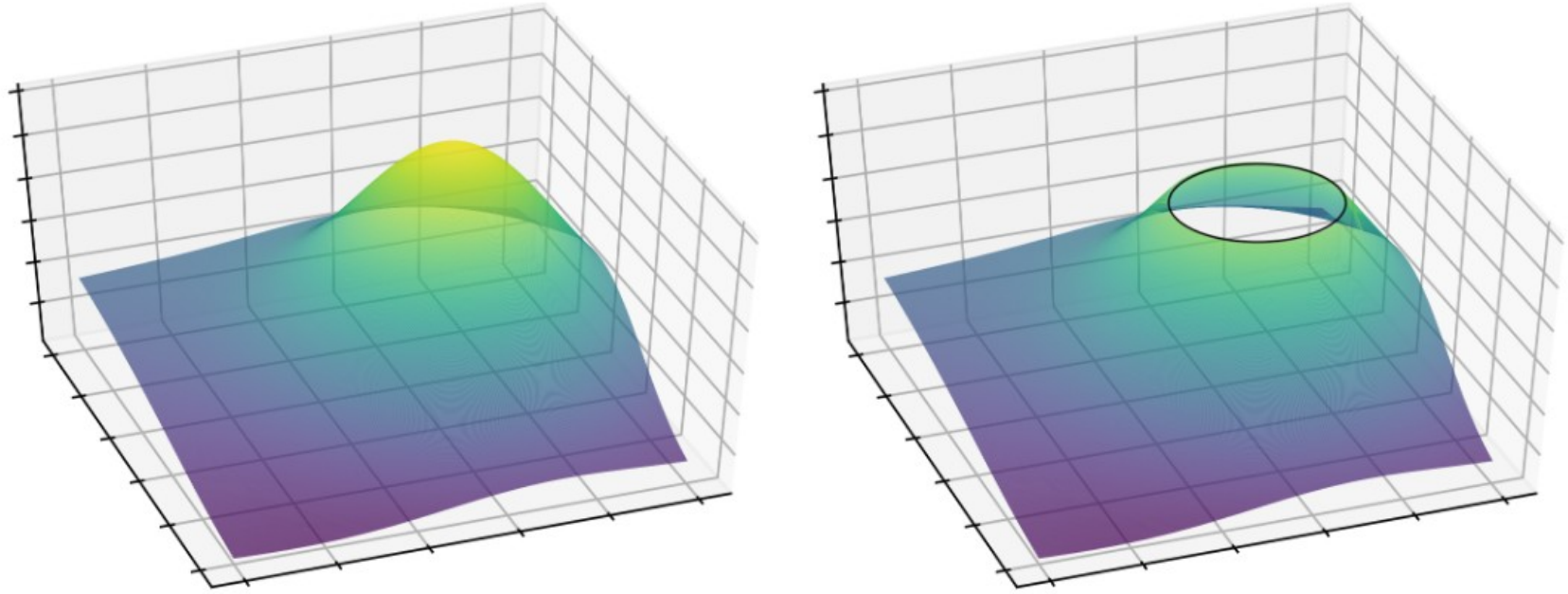


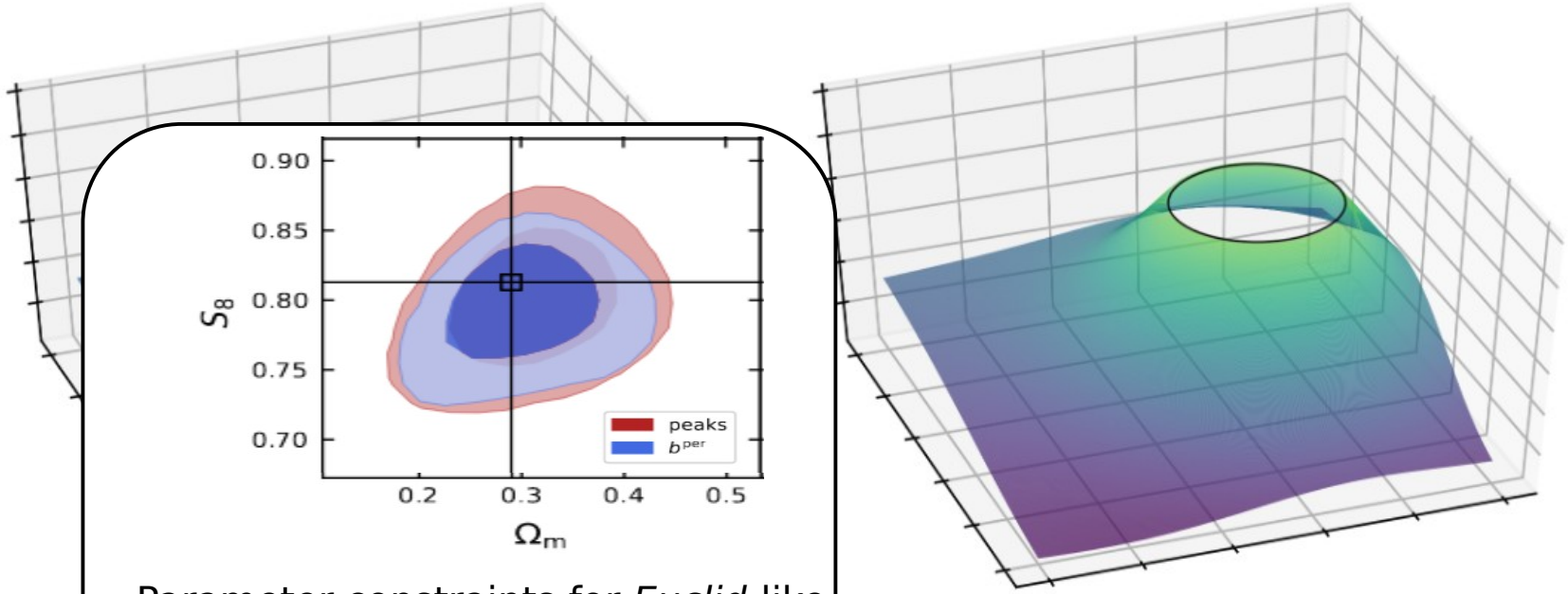
Signal-to-noise map of Aperture masses

Persistent homology vs peak statistics



A peak in a sublevel filtration. Adapted from Heydenreich et al. (2021)

Persistent homology vs peak statistics



Parameter constraints for *Euclid*-like mock data. Adapted from Heydenreich et al. (2021)

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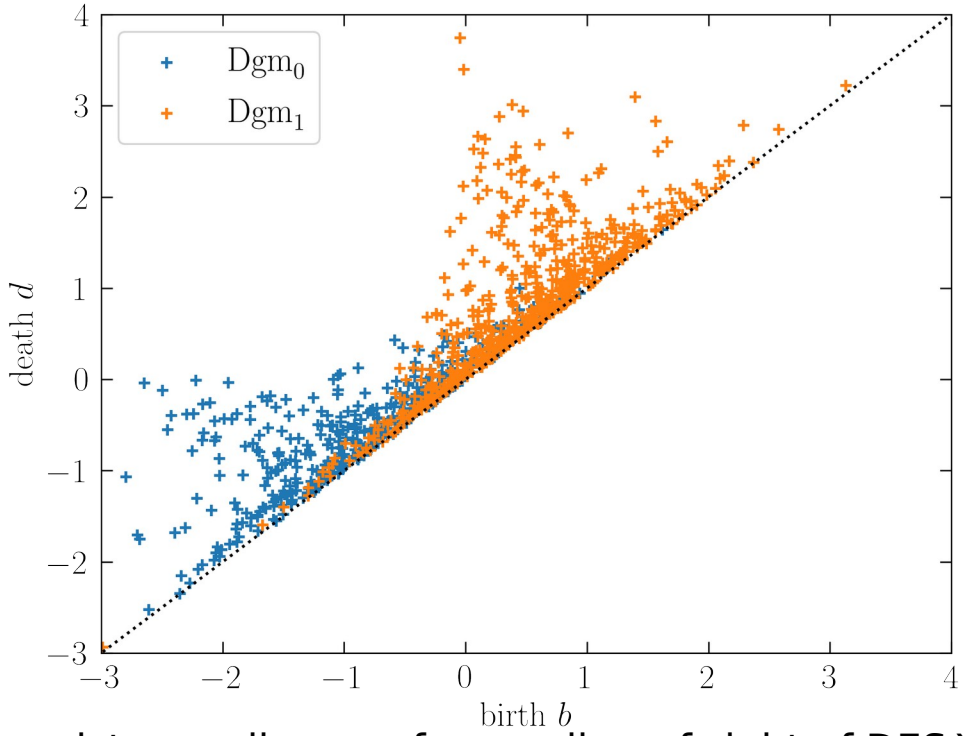
Visualising persistent homology: the persistence diagram



A persistence diagram for one line-of-sight of DES-Y1-like Mock data. Adapted from Heydenreich et al. (2022)

Statistics on persistence diagrams: the persistence heatmap

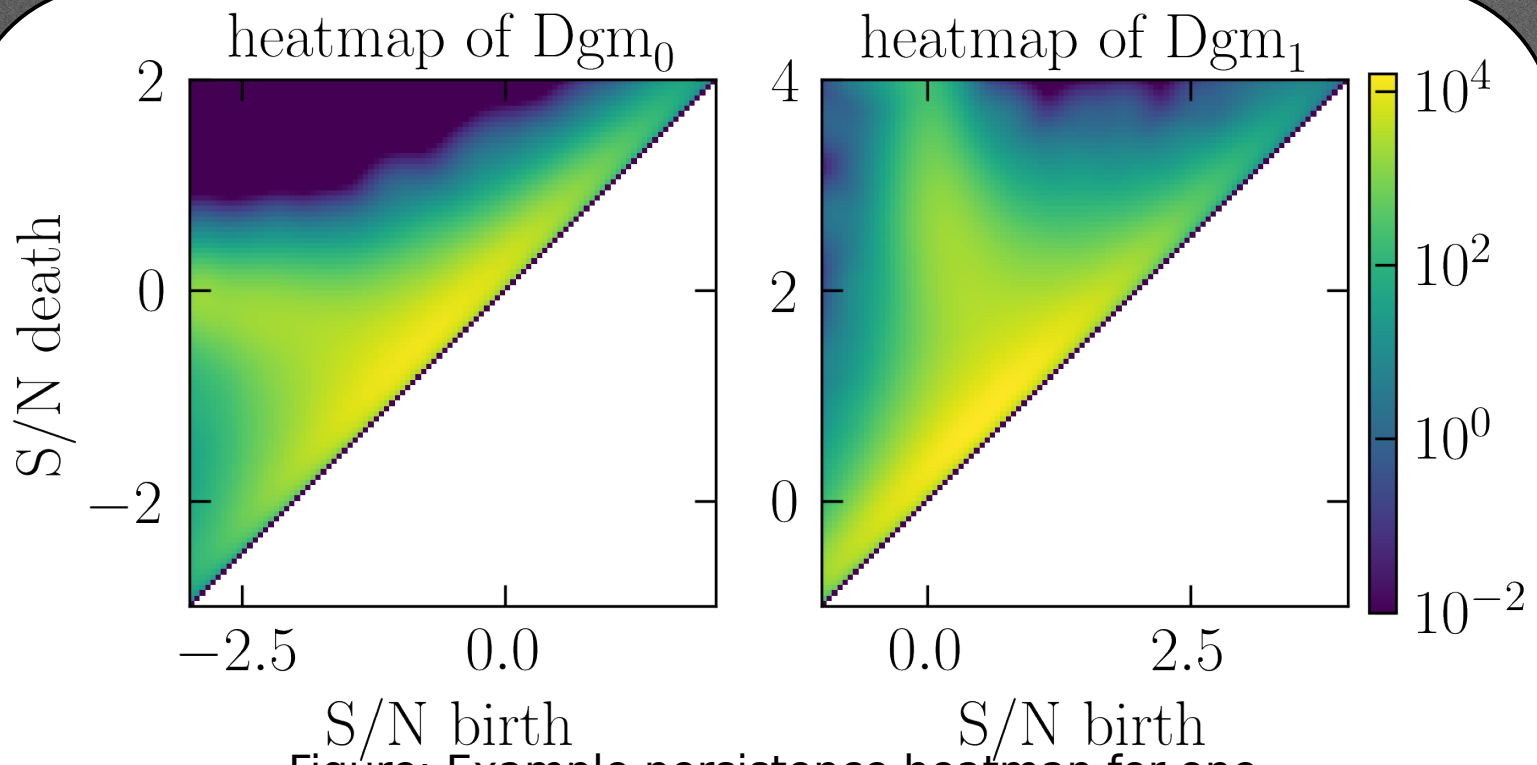
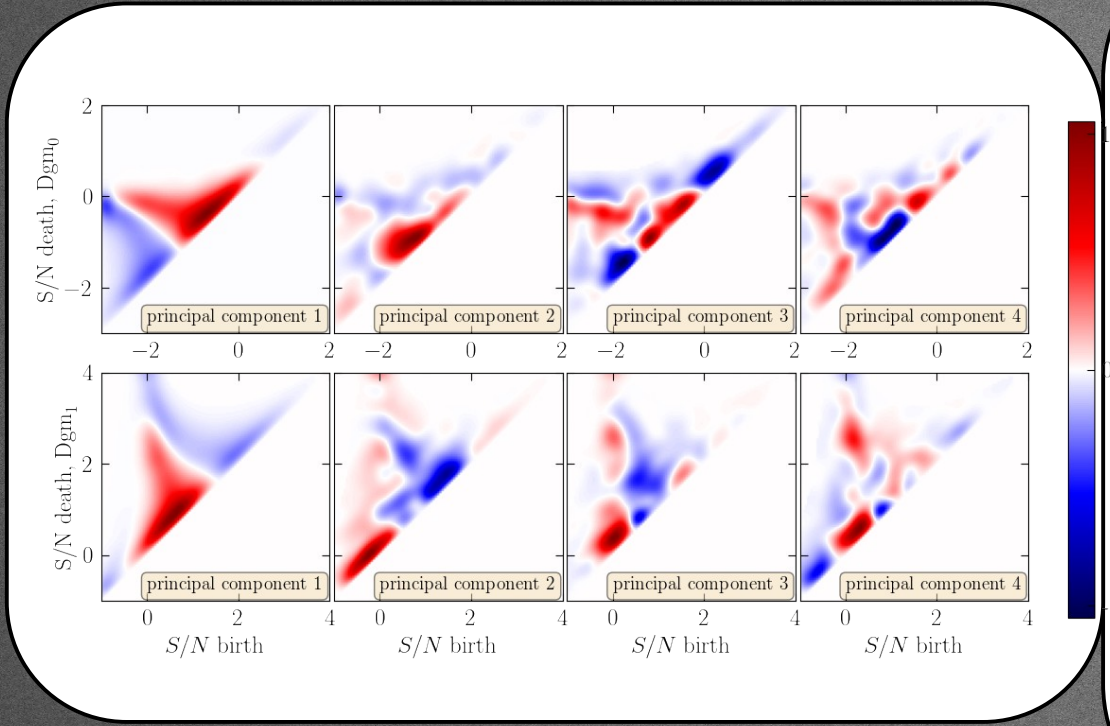
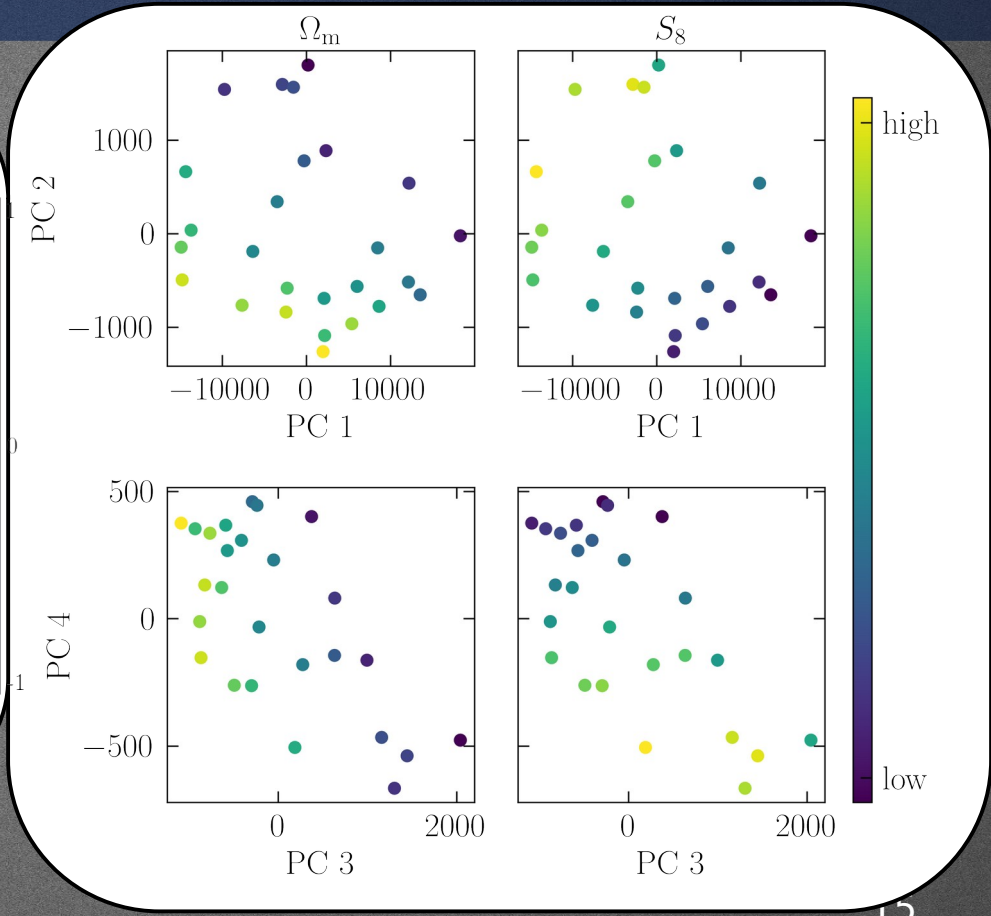


Figure: Example persistence heatmap for one line-of-sight of DES-Y1-like mock data

Interpreting the data with PCA





Statistics on persistence diagrams: the persistence heatmap

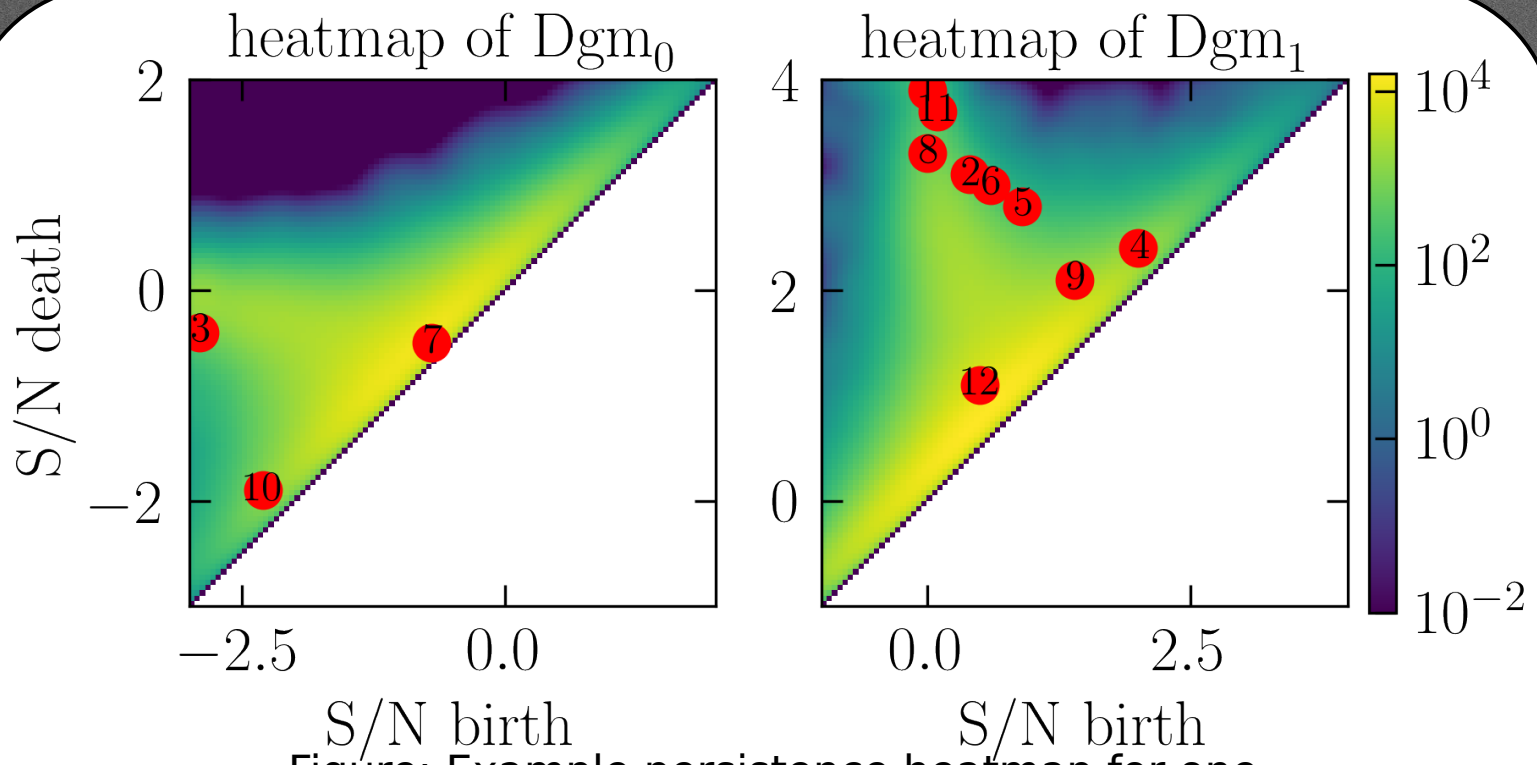
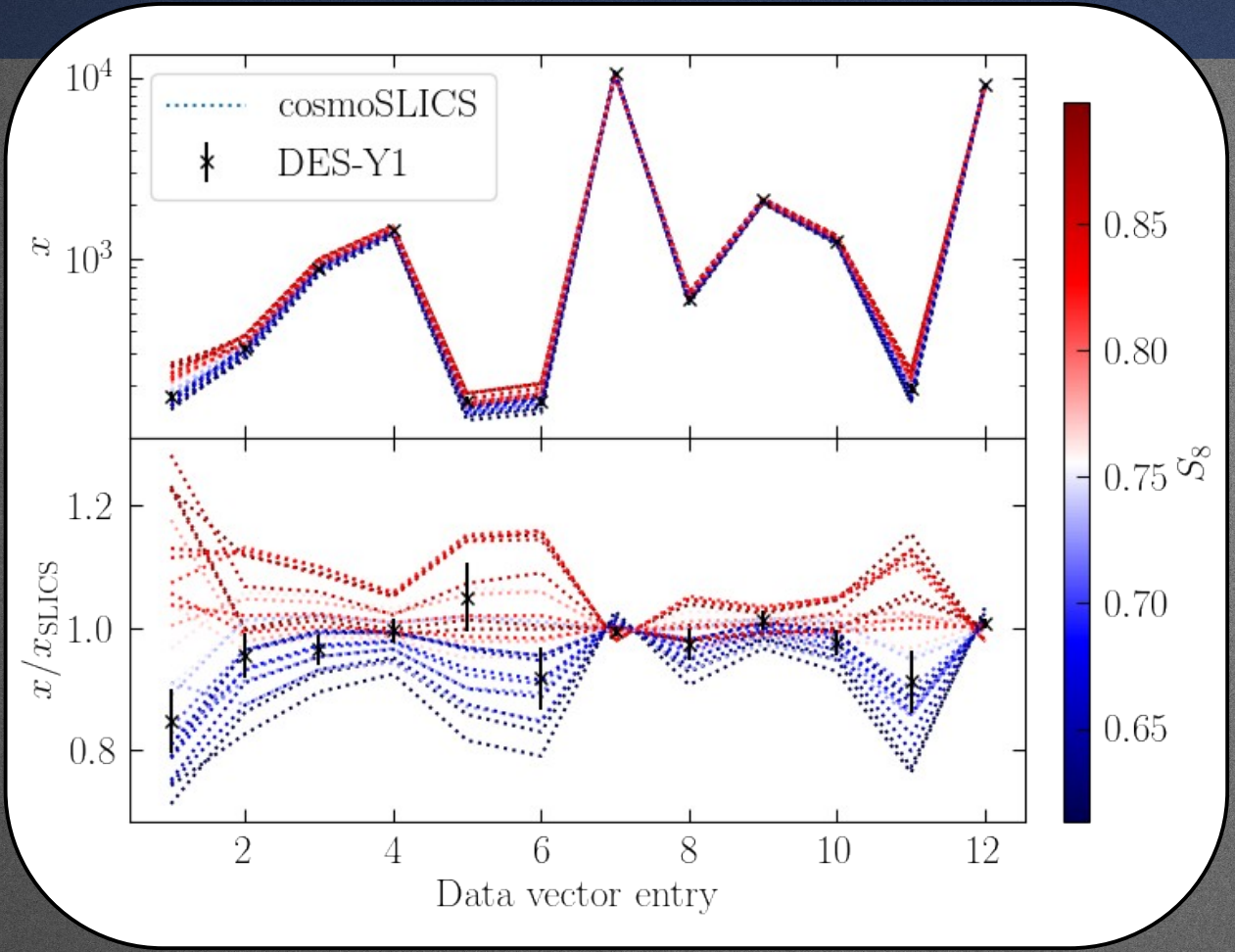


Figure: Example persistence heatmap for one line-of-sight of DES-Y1-like mock data

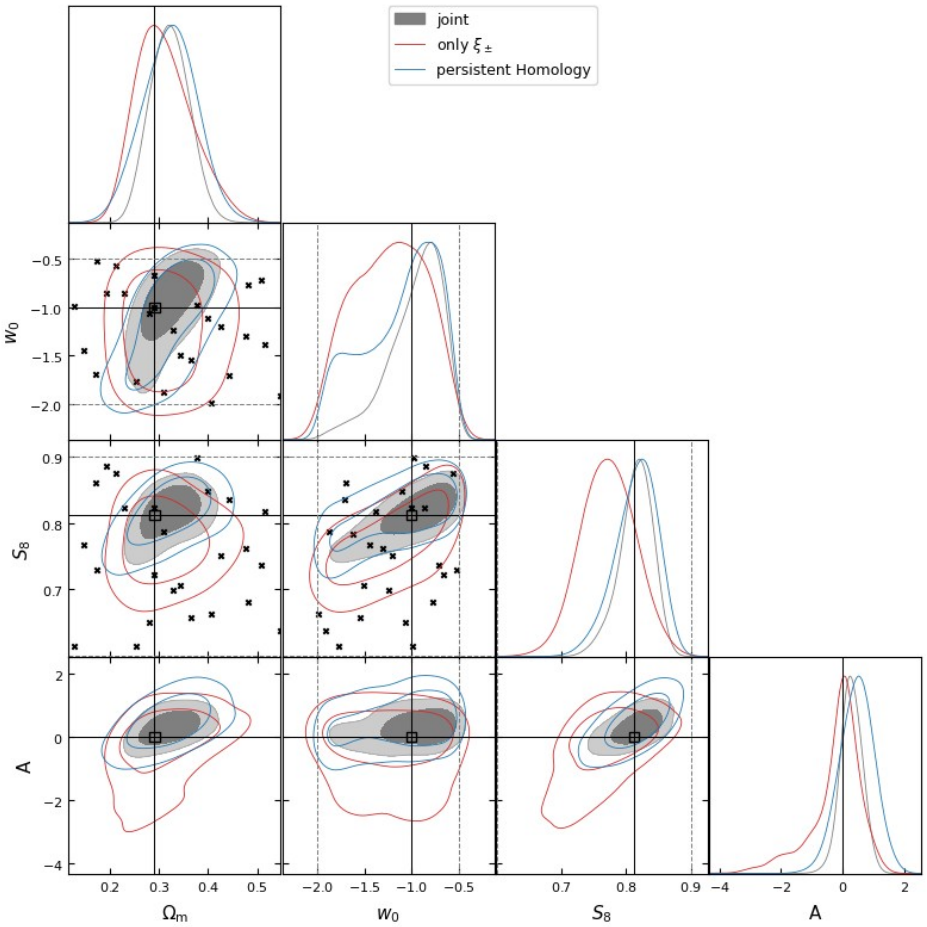
Shape of the data vector



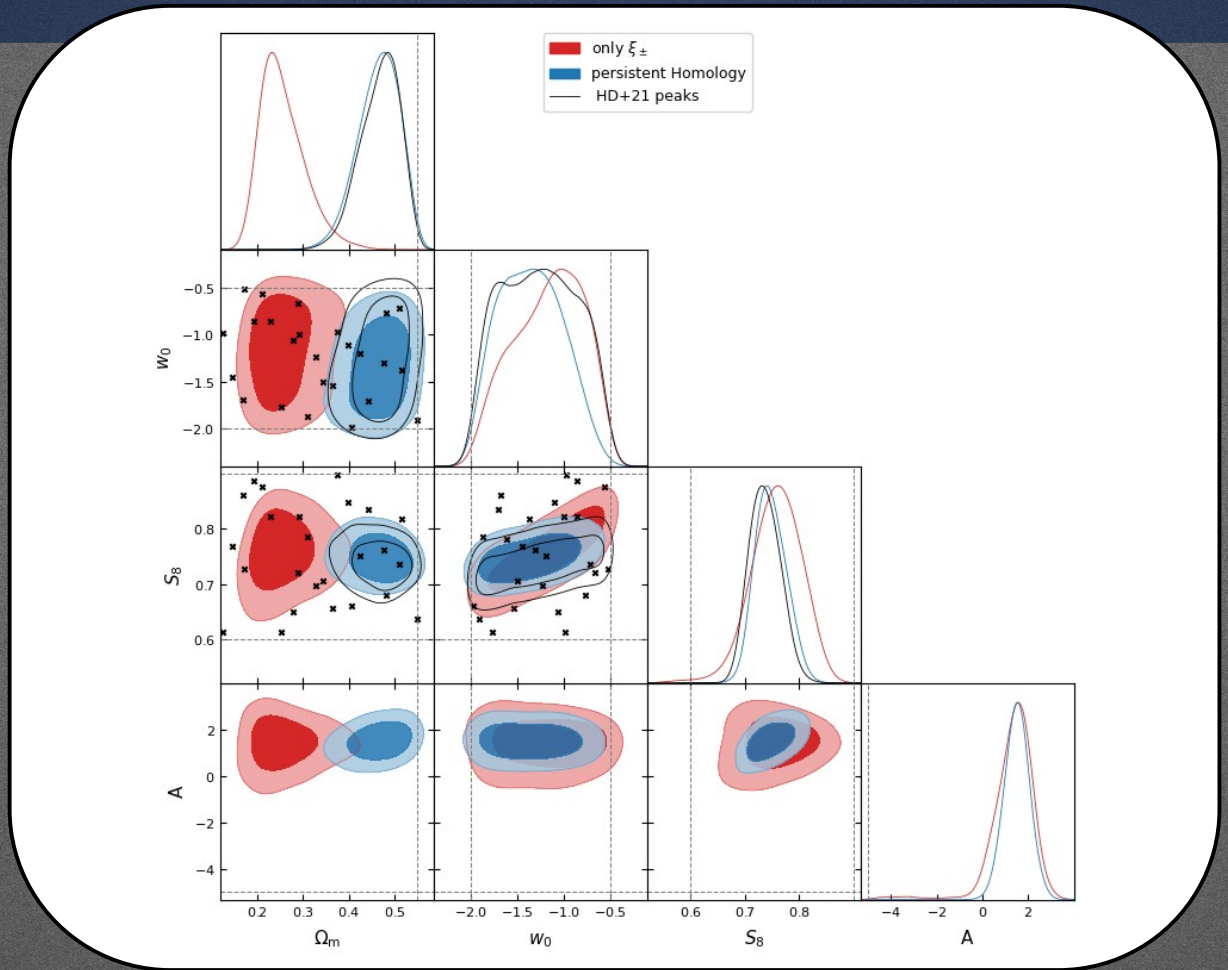
Top: extracted data vector of the heatmaps

Bottom: extracted data vector normalised by the mean of the SLICS

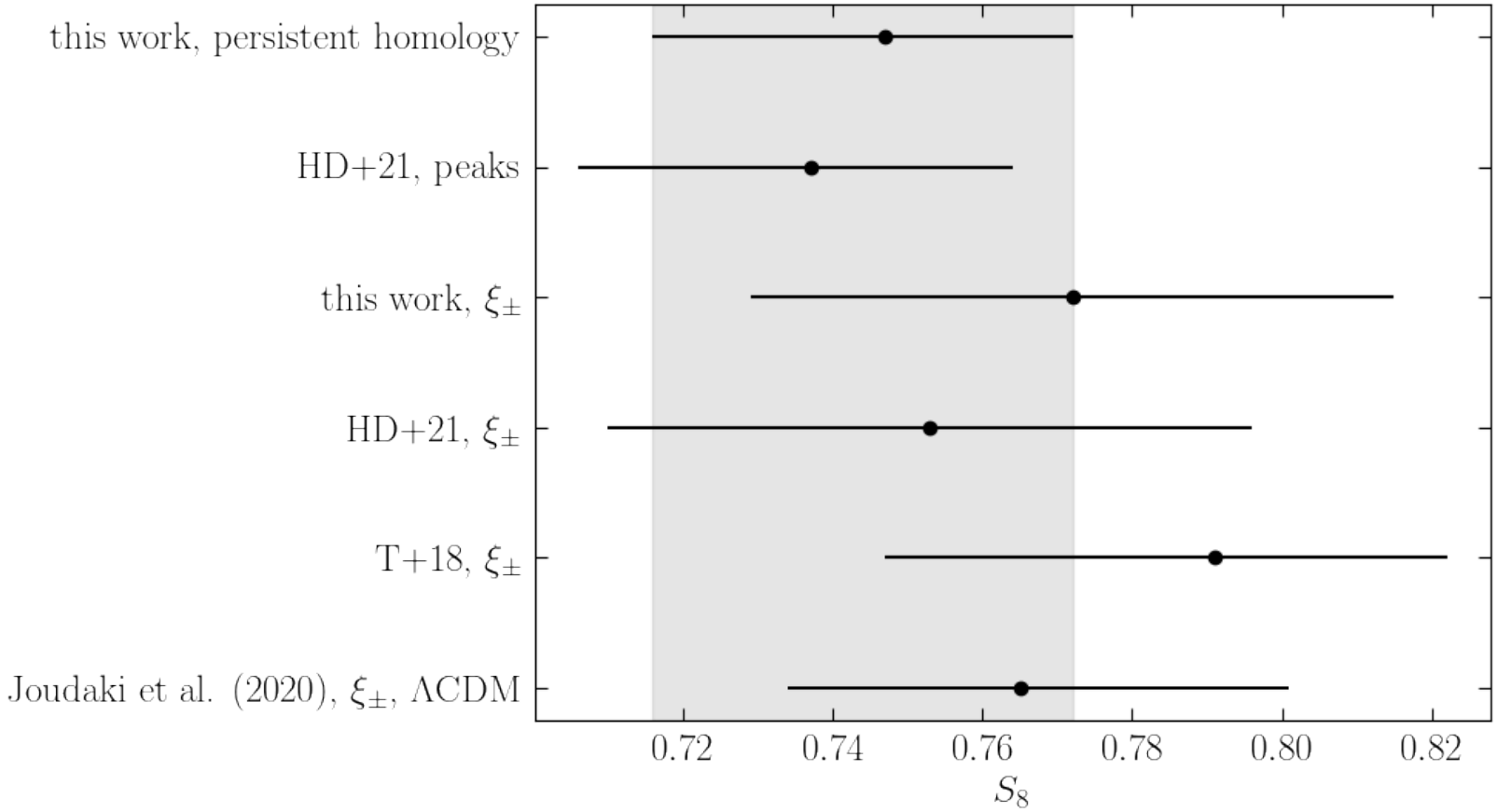
Validating on mock data



Analysis of DES-Y1



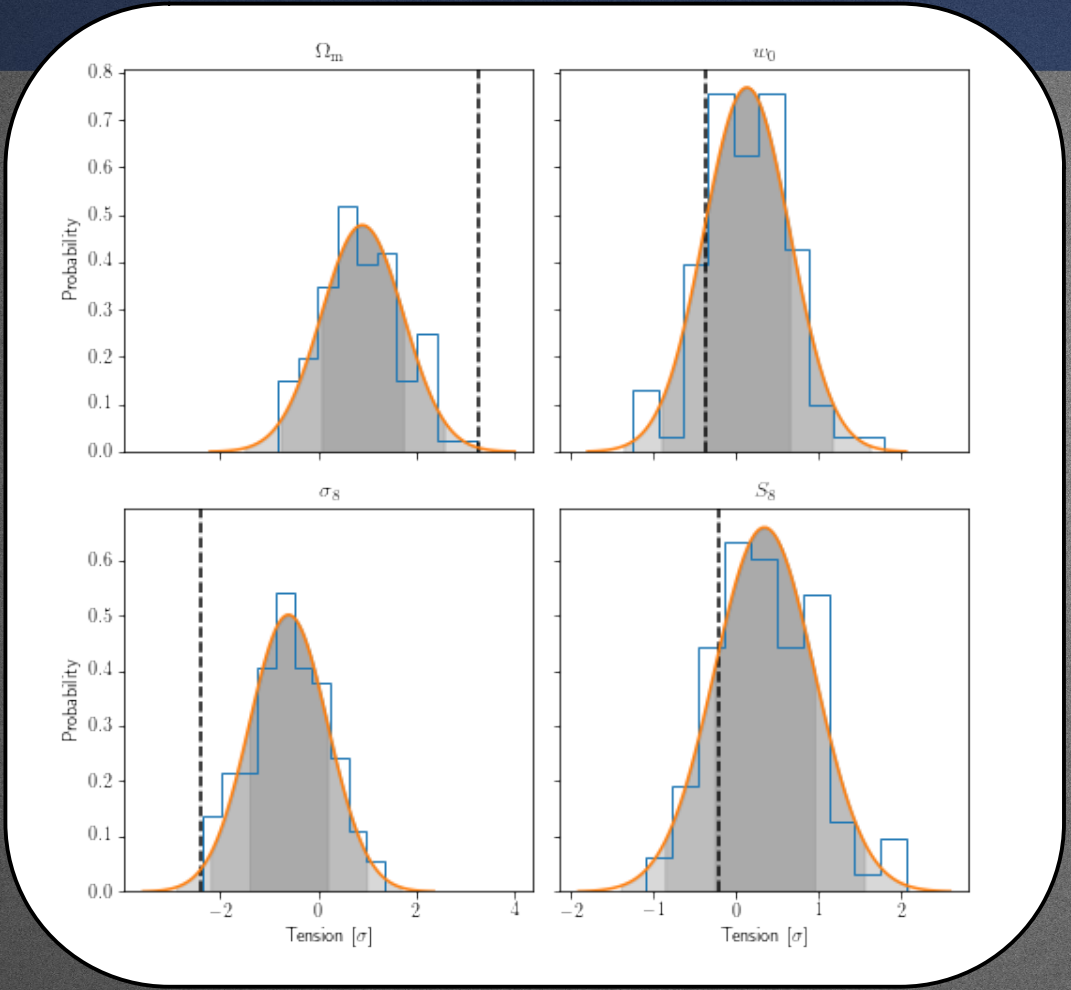
Consistency of S_8 measured in DES-Y1



Regarding the Tension in Ω_m

- Stable to all tested analysis choices
  - Training Set
  - Scale cut-offs
  - Emulator vs Theory
  - Systematics marginalisation
- Confirmed by independent analysis from Harnois-Deraps et al. (2021)

Assessing the tension



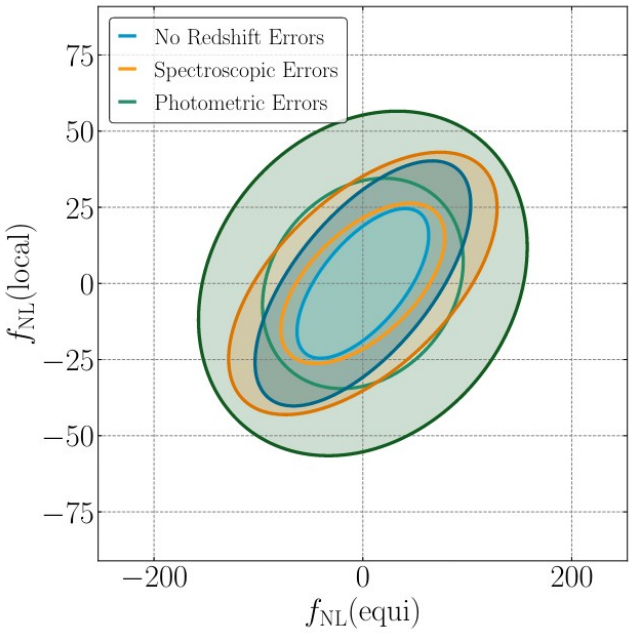
Blue: Histogram of measured tension between persistent homology and 2pcf in mock simulations

Orange: Gaussian fit

Black dashed: Tension measured in DES-Y1

Regarding the Tension in Ω_m

- Persistent Homology is sensitive to non-Gaussian information
  - Pranav (2021): Anomalies in the CMB at super-horizon scales
  - Biagetti et al. (2022): PH is sensitive to primordial non-Gaussianities

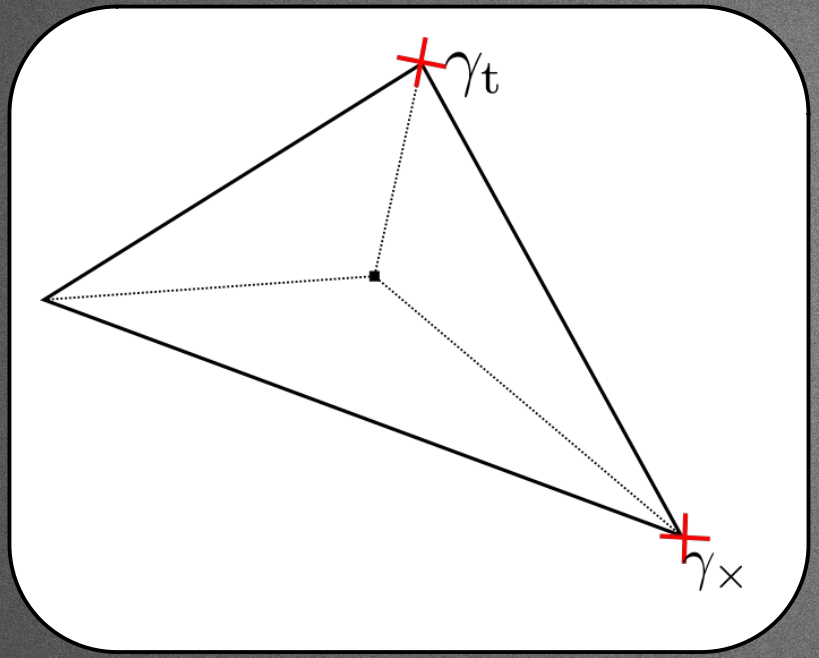


Fisher-forecast for primordial NG in PH. Taken from Biagetti et al. (2022)

Regarding the Tension in Ω_m

- We measure a tension in Ω_m, but ***can we trust it?***
- Improved confidence intervals are only as good as our confidence in the method

Work in progress – third order lensing statistics



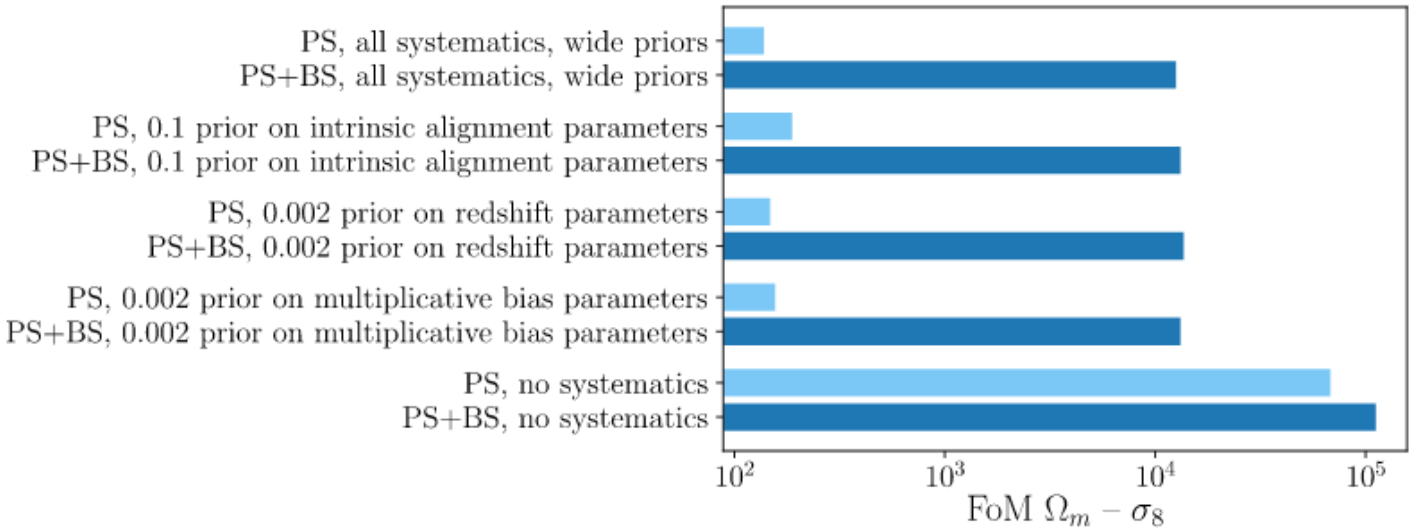
$$\Gamma^{(0)} = \gamma_{ttt} - \gamma_{t\times\times} - \gamma_{\times t\times} - \gamma_{\times\times t} + i\gamma_{tt\times} + \gamma_{t\times t} + \gamma_{\times tt} - \gamma_{\times\times\times}$$

$$\Gamma^{(1)} = \gamma_{ttt} - \gamma_{t\times\times} + \gamma_{\times t\times} + \gamma_{\times\times t} + i\gamma_{tt\times} + \gamma_{t\times t} - \gamma_{\times tt} + \gamma_{\times\times\times}$$

$$\Gamma^{(2)} = \gamma_{ttt} + \gamma_{t\times\times} - \gamma_{\times t\times} + \gamma_{\times\times t} + i\gamma_{tt\times} - \gamma_{t\times t} + \gamma_{\times tt} + \gamma_{\times\times\times}$$

$$\Gamma^{(3)} = \gamma_{ttt} + \gamma_{t\times\times} + \gamma_{\times t\times} - \gamma_{\times\times t} + i-\gamma_{tt\times} + \gamma_{t\times t} + \gamma_{\times tt} + \gamma_{\times\times\times}$$

Work in progress – third order lensing statistics



Pyne & Joachimi (2021)

- Main advantage: direct modelling possible

Direct modelling allows for consistency checks

$$
\begin{tikzcd}
 & \Gamma^{(i)} \arrow[d, dashed, "\textsc{TreeCorr}"] & \\
\Omega_{\mathrm{m}}, \sigma_8, \ldots \arrow[r, two heads, "\textsc{BiHalofit}"] & B_\kappa \arrow[ur] \arrow[dr] & \\
 & \langle \mathcal{M}_{\mathrm{ap}}^3 \rangle & \text{Simulations} \arrow[ul, dashed, "\textsc{TreeCorr}"'] \arrow[dl]
\end{tikzcd}
$$

Tests for the 3pcf...

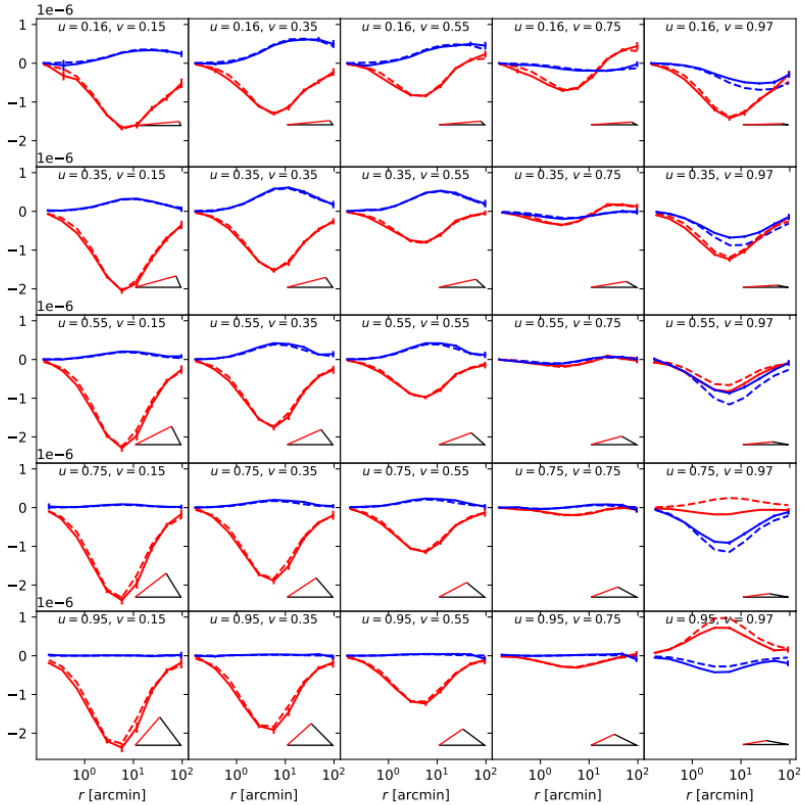
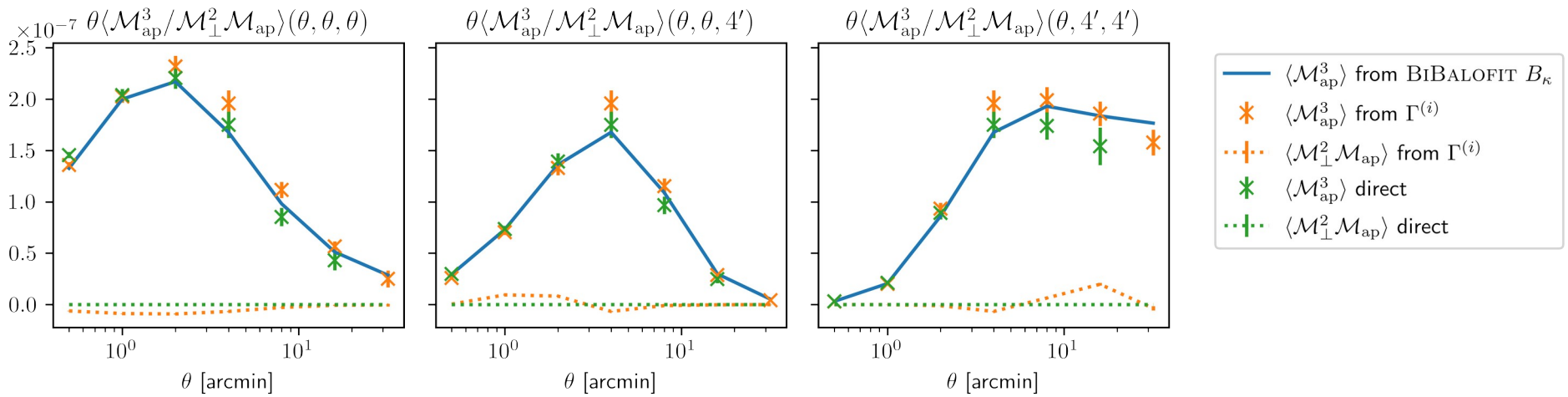


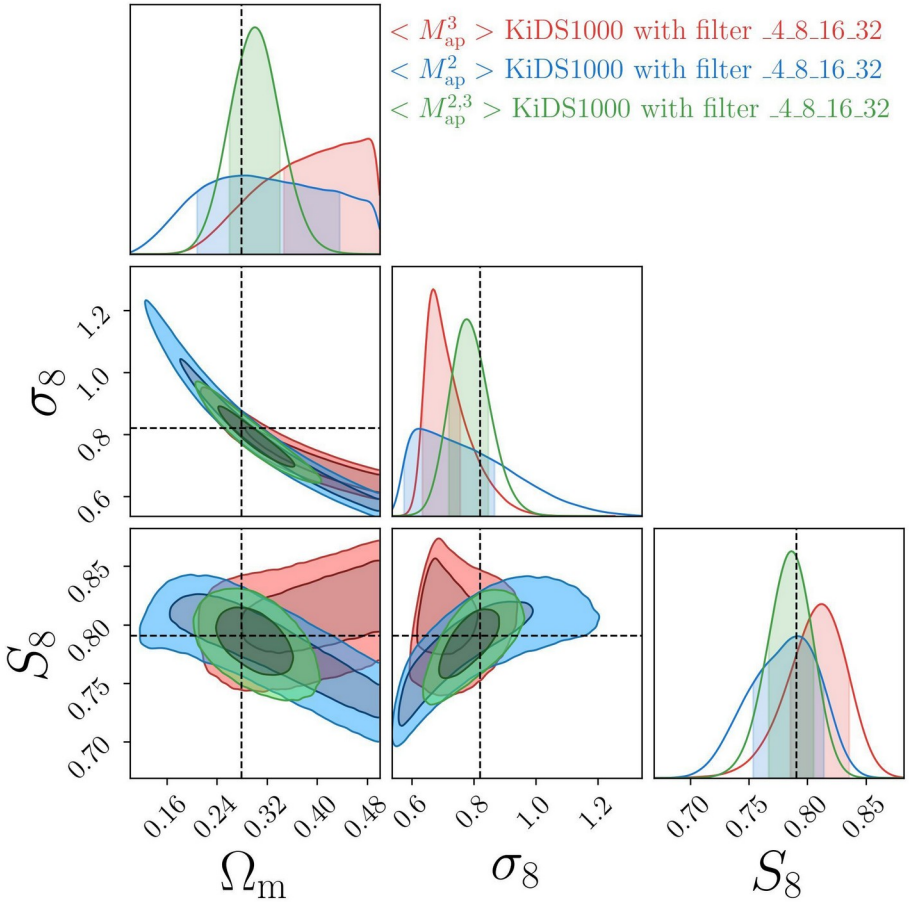
Figure: Three-point correlation functions from the BiHalofit bispectrum compared to Simulations

… and third-order aperture masses



Third-order aperture mass statistics from a cosmological model compared to results from N-body simulations

Combined analysis improves constraints



Summary

persistent Homology

- Very powerful on its own
- Interpretable datavector
- Highly sensitive to non-Gaussian effects
- Applicable to all kinds of data

Third-order statistics

- Most powerful in combination with 2nd-order statistics
- Direct modelling allows for more consistency checks and better nuisance parameter constraints
- E-/B-mode decomposition yields more robustness

References I

- Biagetti, M., Calles, J., Castiblanco, L., Cole, A., Noreña, J.: *Fisher Forecasts for Primordial non-Gaussianity from Persistent Homology,* **2022,** arXiv:2203.08262
- Harnois-Déraps, J., Martinet, N., Castro, T., Dolag, K. ; Giblin, B. et al.: *Cosmic shear cosmology beyond two-point statistics: a combined peak count and correlation function analysis of DES-Y1,* ***2021,*** *MNRAS, 506, 1623*
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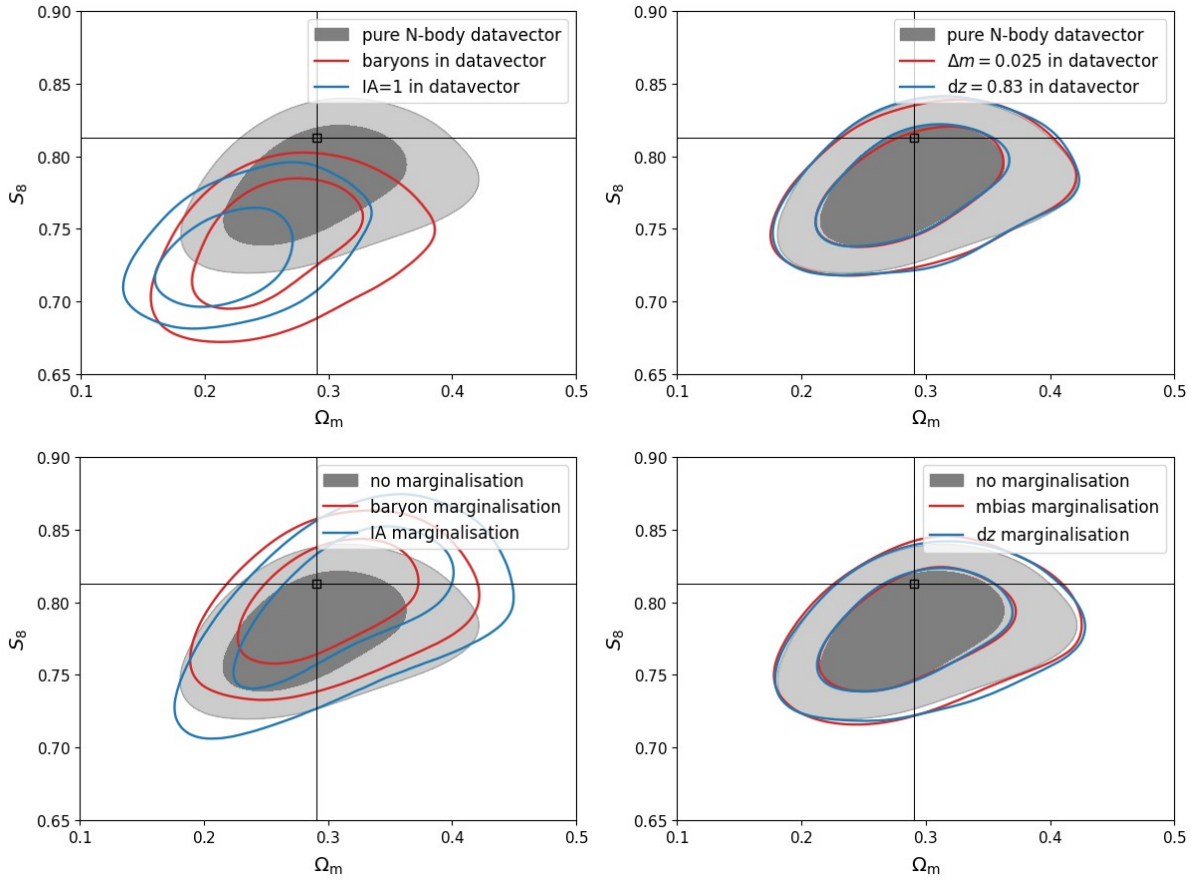
- Heymans, C., Troester, T., Asgari, M., Blake, C., Hildebrandt, H. et al.: *KiDS-1000 Cosmology: Multi-probe weak gravitational lensing and spectroscopic galaxy clustering constraints*, **2021,** A&A, 646, 140

References II

- Heydenreich, S., Brück, B., Burger, P., Harnois-Déraps, J., Unruh, S. et al.: *Persistent homology in cosmic shear II: A tomographic analysis of DES-Y1,* **2022,** arXiv:2204.11831
- Pranav, P.: *Anomalies in the topology of the temperature fluctuations in the cosmic microwave background: An analysis of the NPIPE and FFP10 data releases,* **2022,** A&A, 659, 115
- Pyne, S., Joachimi, B.: *Self-calibration of weak lensing systematic effects using combined two- and three-point statistics,* **2022,** MNRAS, 503, 2300
- Takada, M., Jain, B.: *Cosmological parameters from lensing power spectrum and bispectrum tomography,* **2004,** MNRAS, 348, 897

Impact of systematics



Top: Impact of un-marginalised systematics

Bottom: Impact of marginalisation over systematics

Combined analysis of full-scale map