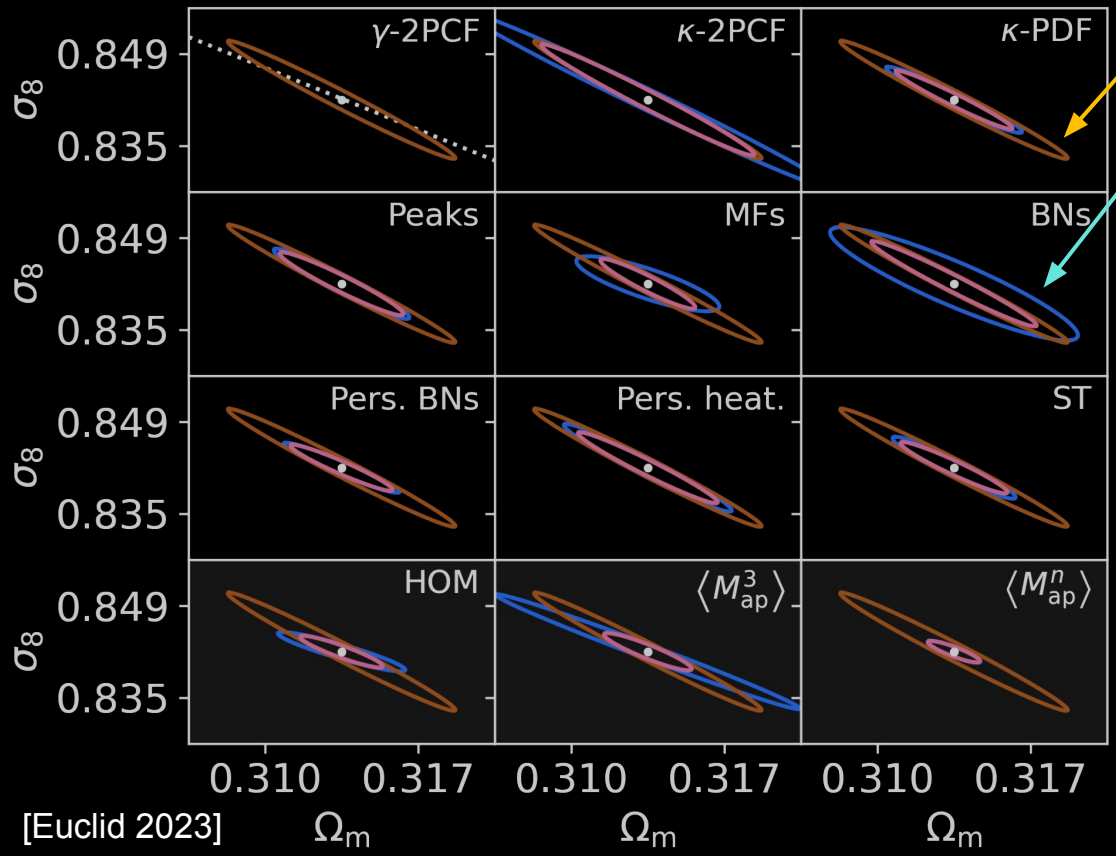
Higher-order statistics in Subaru Hyper Suprime-Cam Year-1 weak lensing data

Joaquin Armijo, Jessica Cowell, Camila Novaes, Leander Thiele

(in collaboration with Gabriela Marques, Sihao Cheng, Jia Liu, Masato Shirasaki)

Why analyze higher-order statistics in HSC now?

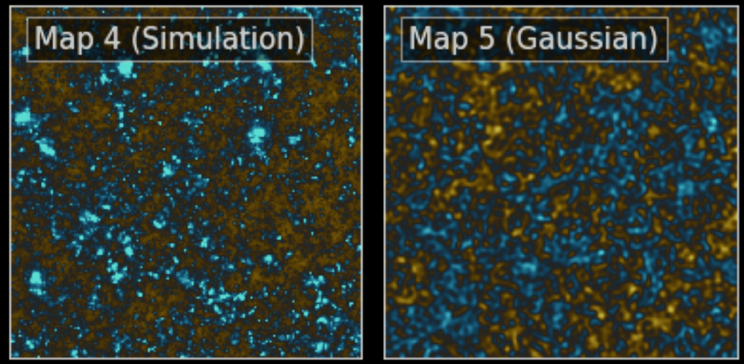


[Euclid 2023]

2pt correlation function

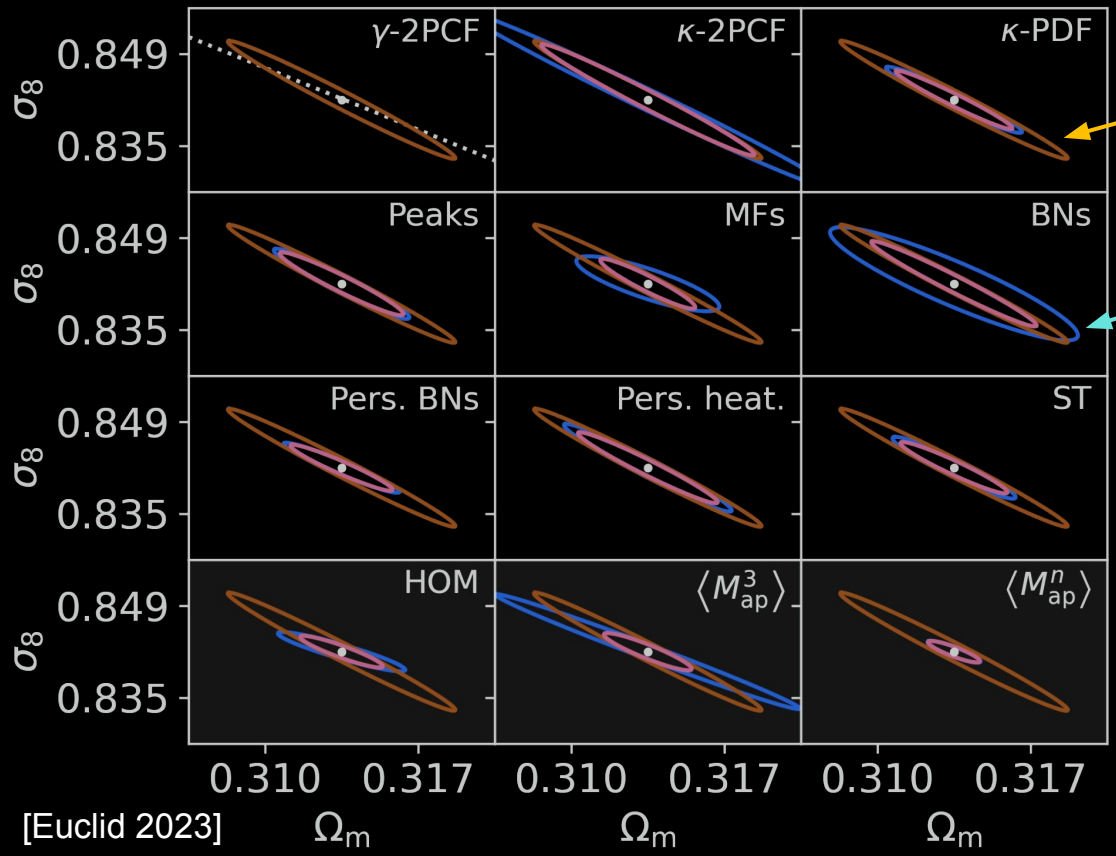
higher-order stats

[J. Liu]



Gravity leaks information into higher-order moments

Why analyze higher-order statistics in HSC now?



[Euclid 2023]

2pt correlation function

higher-order stats

This is Fisher under simple assumptions…

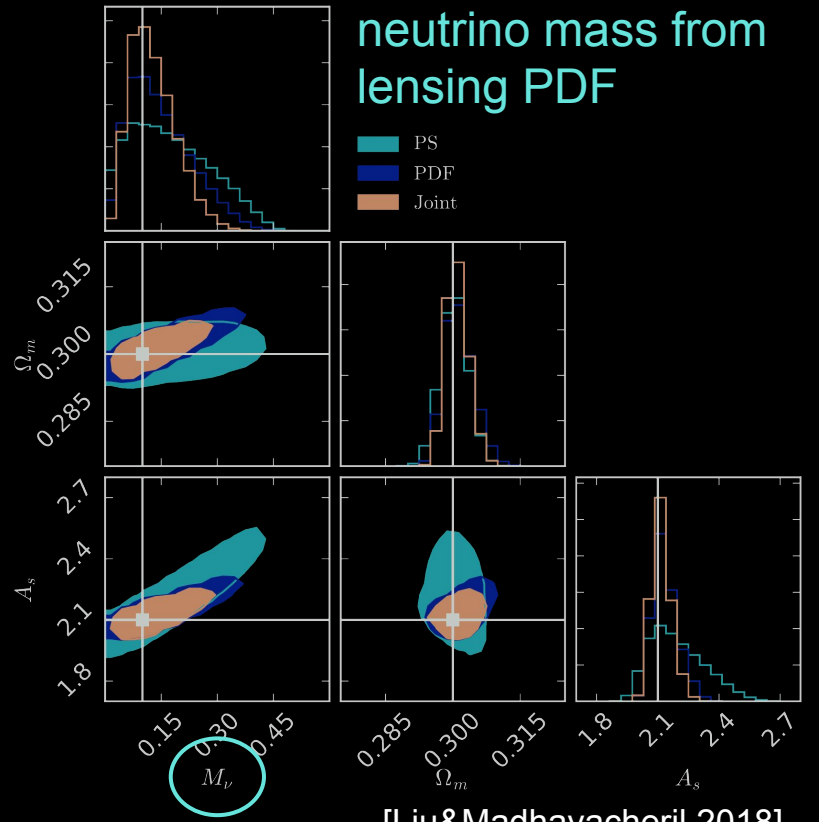
How does it hold up in an actual analysis?

Why analyze higher-order statistics in HSC now?

Beyond ΛCDM will be a main target for Stage-IV (Rubin/LSST, Euclid for lensing).

Higher-order statistics will be instrumental.

But we'll need to get it right – how will particle physicists believe our neutrino mass measurement?



[Liu&Madhavacheril 2018]

Why analyze higher-order statistics in HSC now?

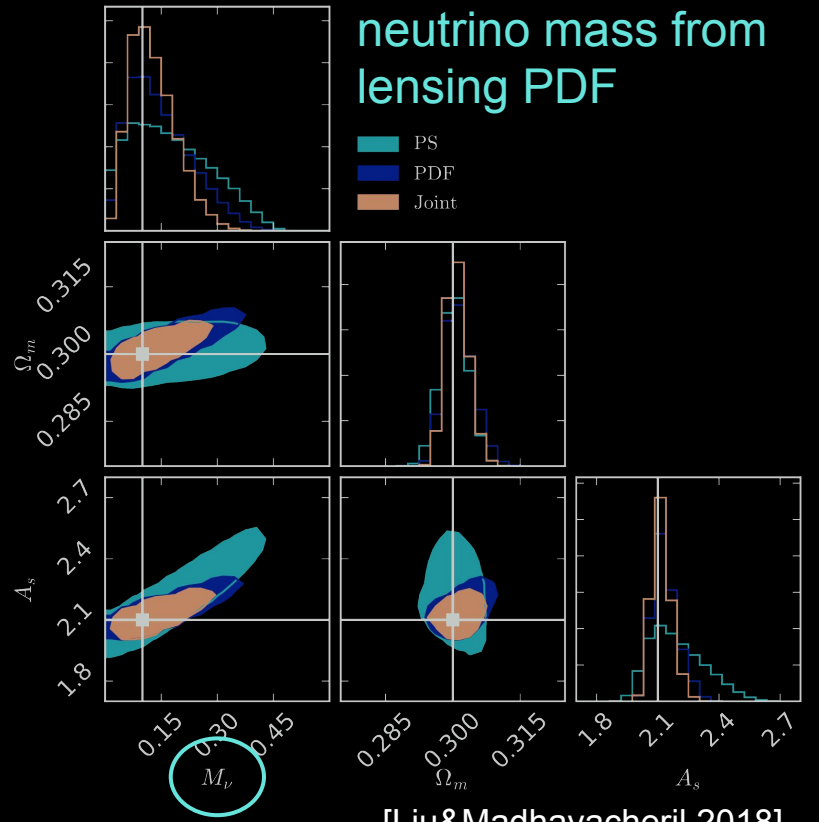
Beyond ΛCDM will be a main target for Stage-IV (Rubin/LSST, Euclid for lensing).

Higher-order statistics will be instrumental.

But we'll need to get it right – how will particle physicists believe our neutrino mass measurement?

Timely to do exercises with existing data and ΛCDM parameters (Ω_m, S_8).

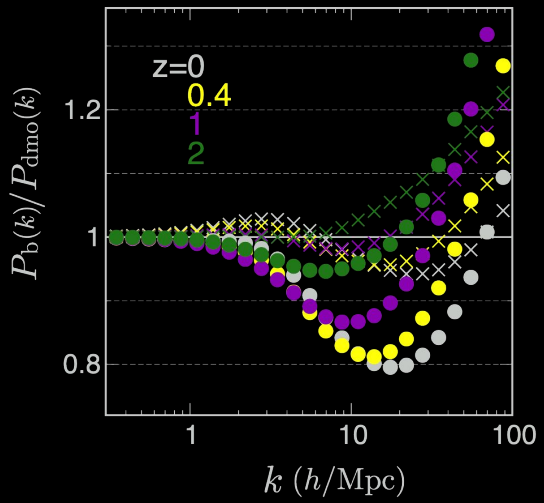
HSC pathfinder for Stage-IV.



[Liu&Madhavacheril 2018]

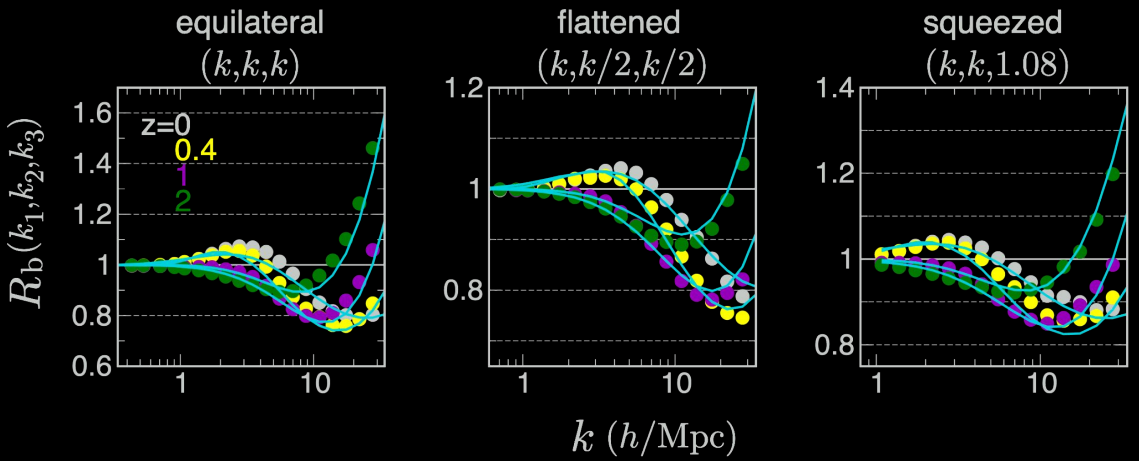
Why use higher-order statistics?

respond non-trivially to systematic errors



baryonic powerspectrum change

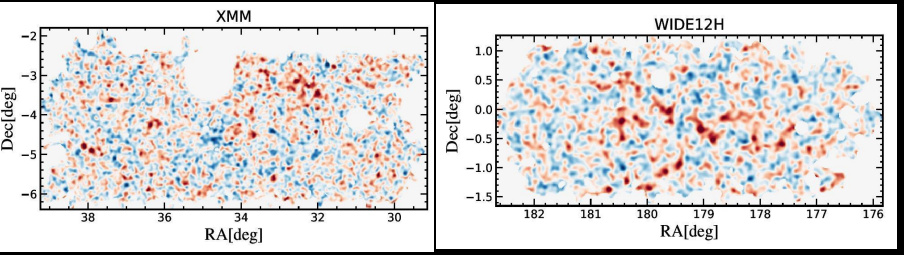
[Takahashi+2020]

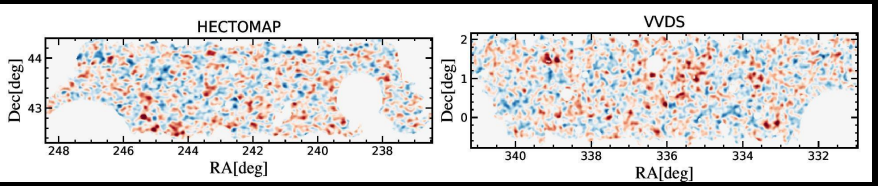


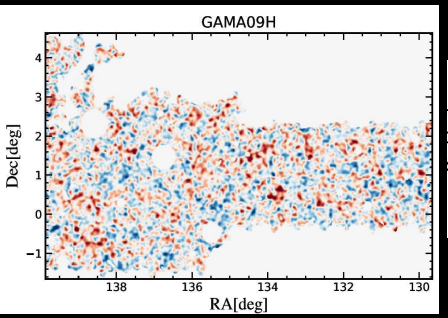
baryonic bispectrum change

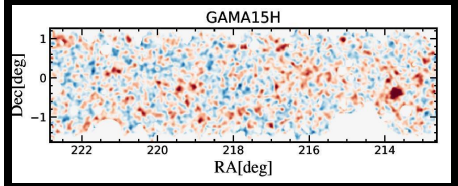
(see also Grandon+2024 for baryonic effects in HSC higher-order stats)

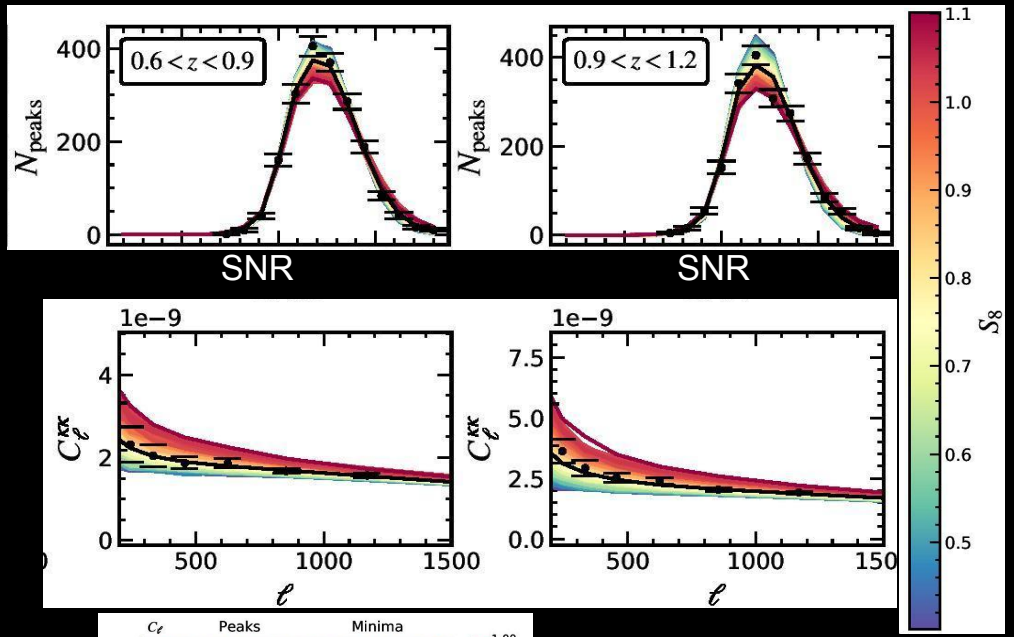
HSC-Y1 Convergence maps





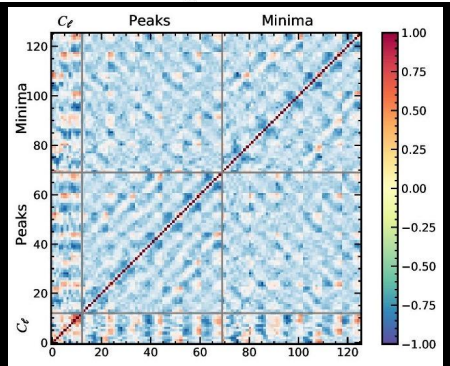






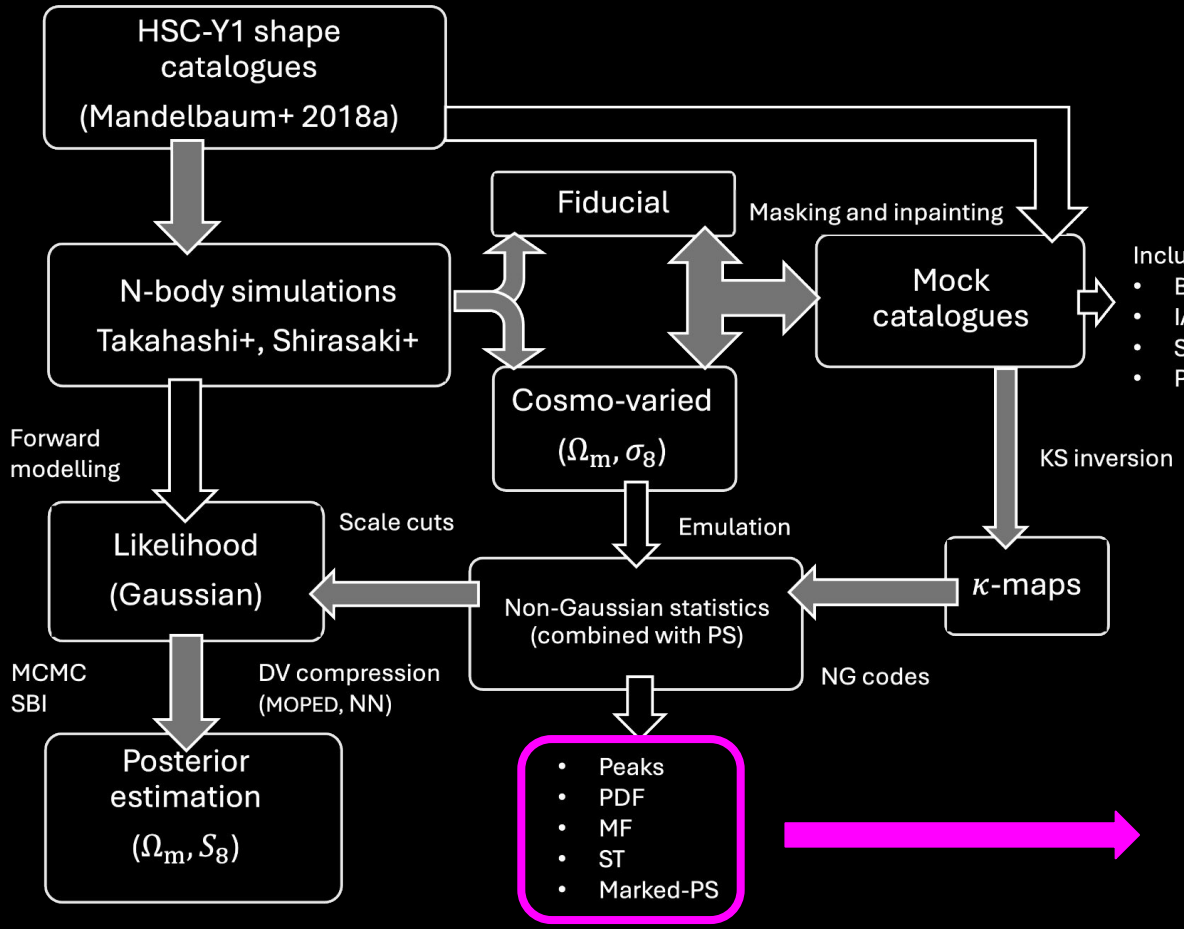
MOPED

$$D^{\rm compr} = \frac{\partial D^{\rm T}}{\partial p_m} C^{-1} D\,,$$



Marques+2024

HSC-Y1: NG statistics pipeline



NG stats list:

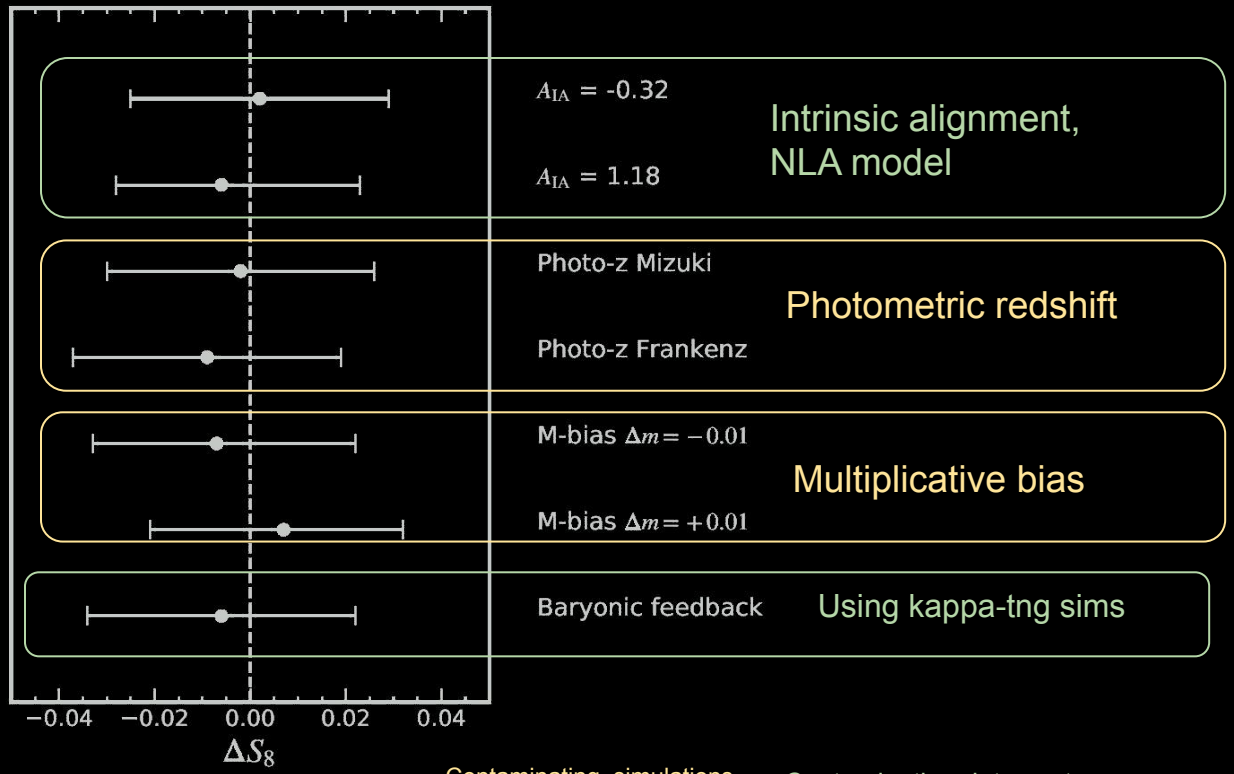
- Peak counts
- PDF
- Minkowski functionals
- Scattering transform
- Marked power spectrum

More stats upcoming…

HSC-Y1:Robustness against systematics

Example from peaks-minima data vector.

For all statistics, we choose scale-cuts, to limit effects from systematics to $\Delta S8 < 0.3\sigma(S8)$



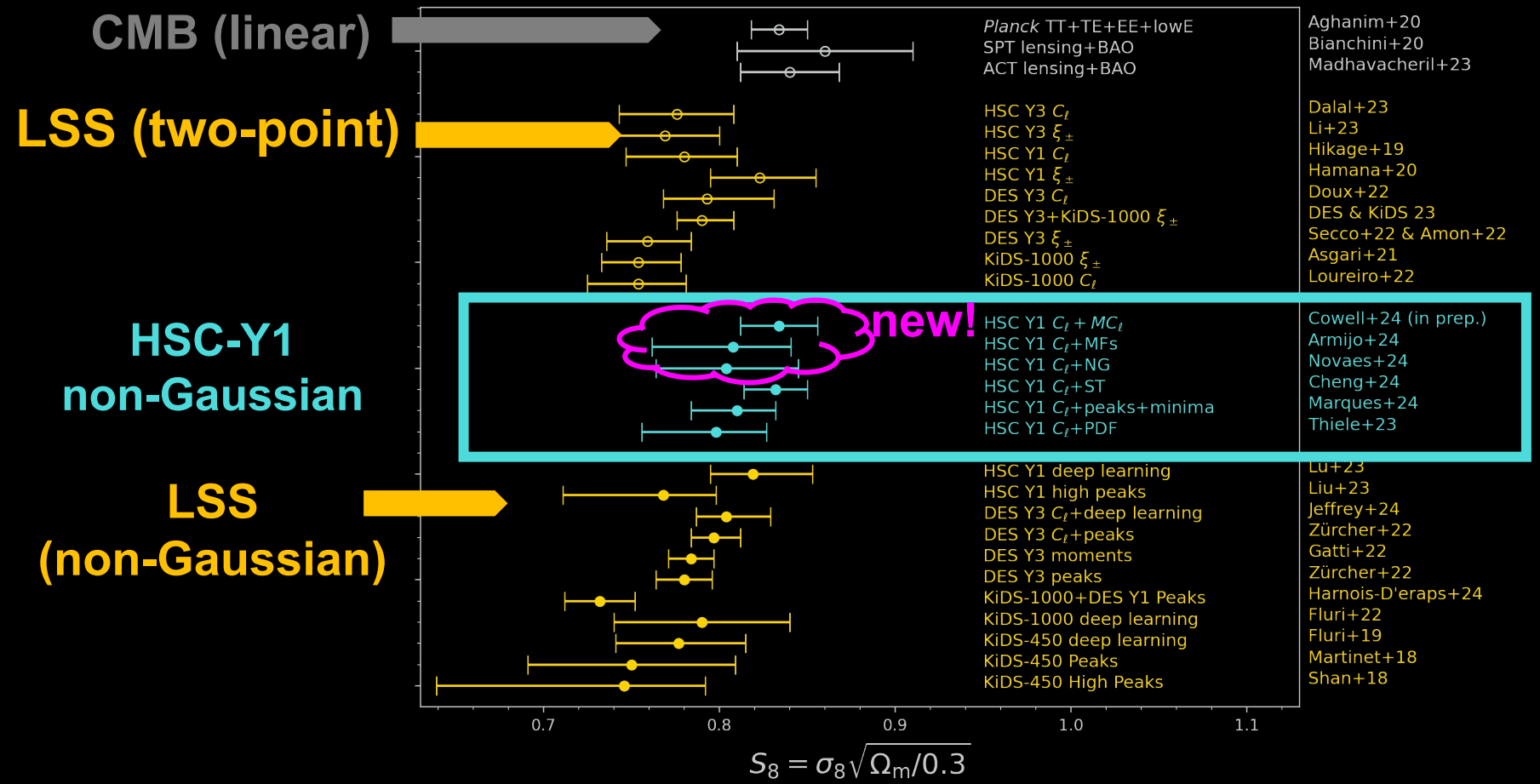
Contaminating simulations

Contaminating data vector

Other checks:

- Redshift bin choices
- Emulator accuracy of data vector
- Emulator accuracy: shifts in posterior values

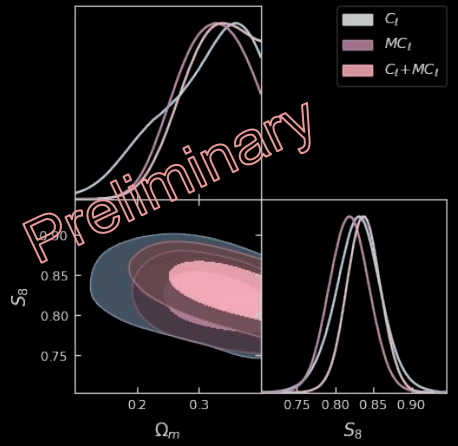
HSC-Y1 non-Gaussian results



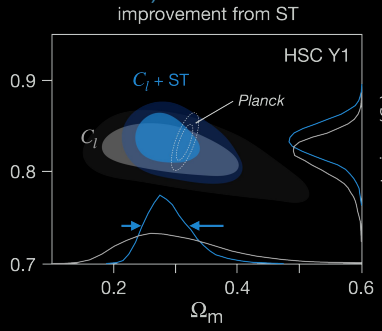
HSC-Y1 non-Gaussian results:S8 improvements

(Improvements over angular power spectrum)

Marked Power Spectra 36%

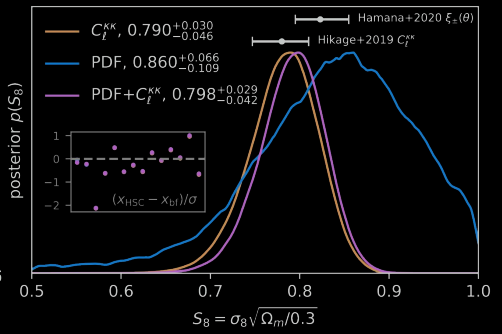


Scattering Transforms .(c.f. Sihaos talk)



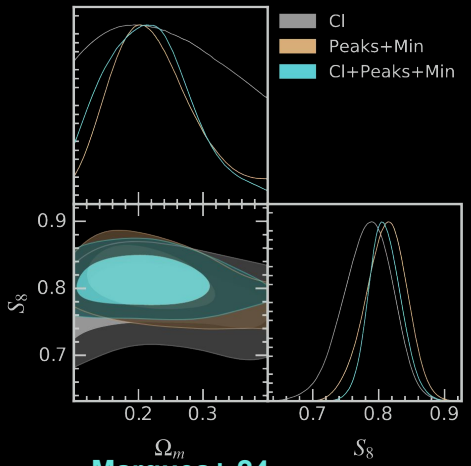
Cheng+ 24

PDF 10%



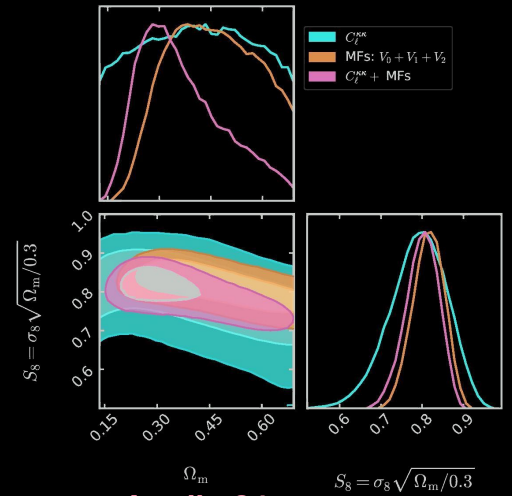
Thiele+ 23

Peaks and Minima- 35%



Marques+ 24

Minkowski functionals 38%



Armijo 24

Marked Power Spectra: First application to 2D fields!

Jessica A. Cowell
jessica.cowell@physics.ox.ac.uk

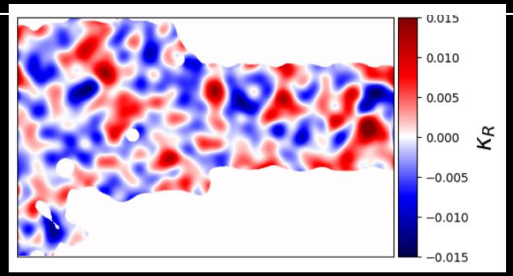
36% tighter S8 than C_ℓ alone

Using new type of mark function from (Cowell+ 24)

arXiv: 2409.05695

$$S8 = 0.838 \pm 0.022$$

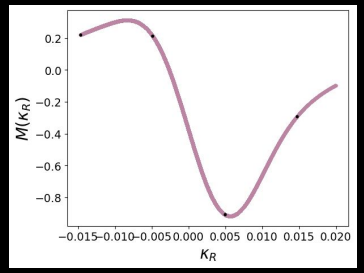
preliminary



$\kappa_{R=10}(\vec{x})$

$m(\kappa_R(x))$

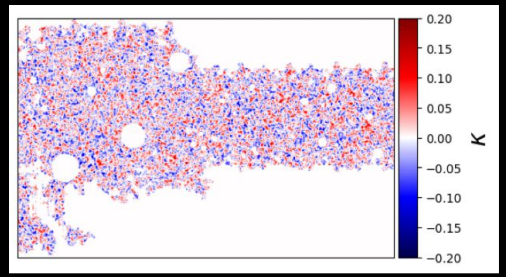
Mark function



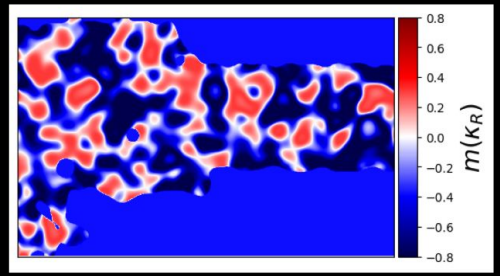
Calculate mark field

Smooth

$\kappa(\vec{x})$



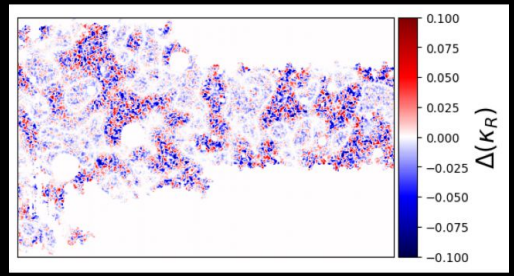
$m(\kappa_R(\vec{x}))$



$\Delta(\vec{x})$

Marked field!

$$\Delta(\vec{x}) = \kappa(\vec{x})\, m(\kappa_R(\vec{x}))$$



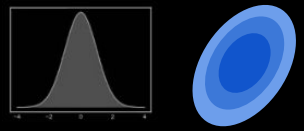
Cowell+2024 (in prep.)

Likelihood-free inference with HSC Y1 Weak Lensing Higher-Order Statistics

Camila Paiva Novaes

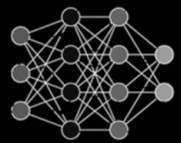
National Institute for Space Research - INPE

(Learned) Posterior



HSC data

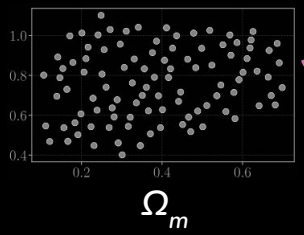
Neural density estimator (NDE)

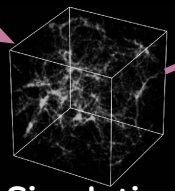


Simulation-based Inference

SBI

Prior





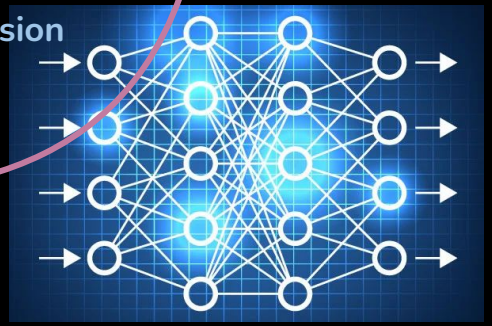
Simulation (forward model)

PS, MFs, peaks, minima, PDF

(S_8, Ω_m)

+ True (S_8, Ω_m)

Neural compression

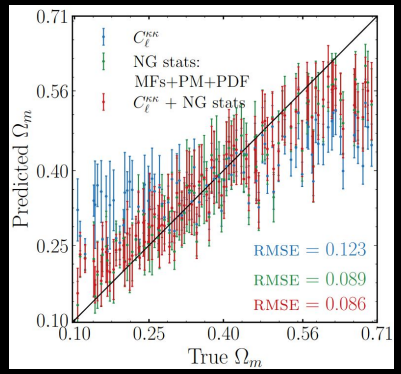


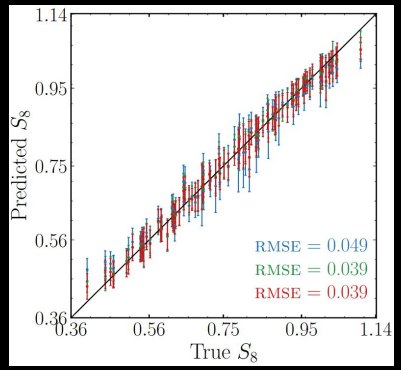
[camila.novaes@inpe.br]

HSC Y1: cosmological constraints

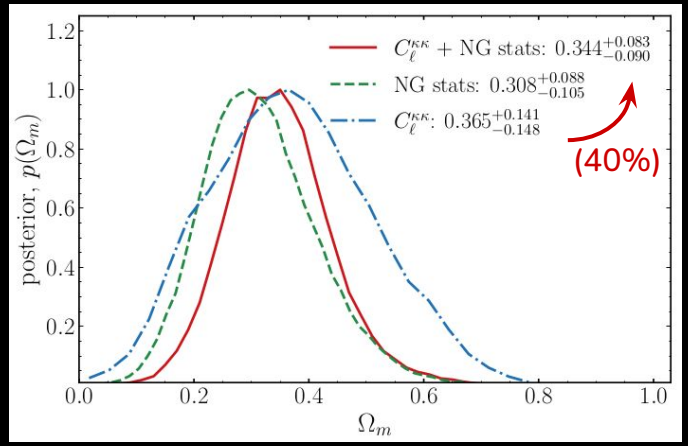
SBI

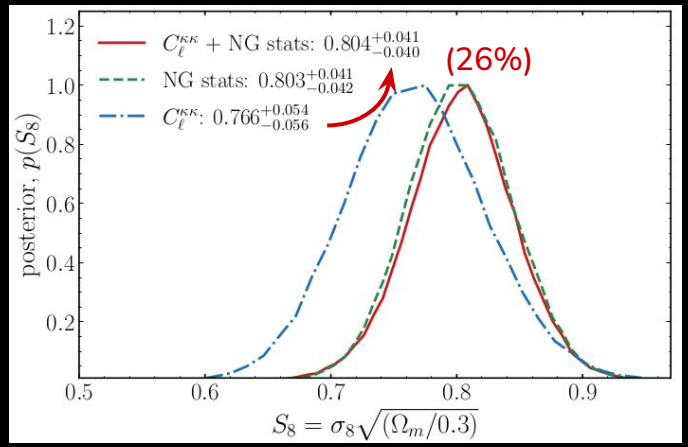
Neural compression



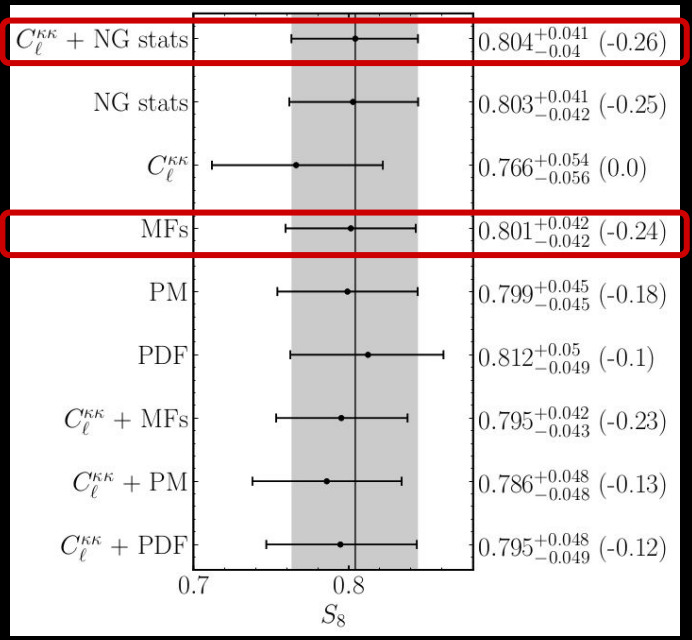


Learned posterior





Gauss X NG stats

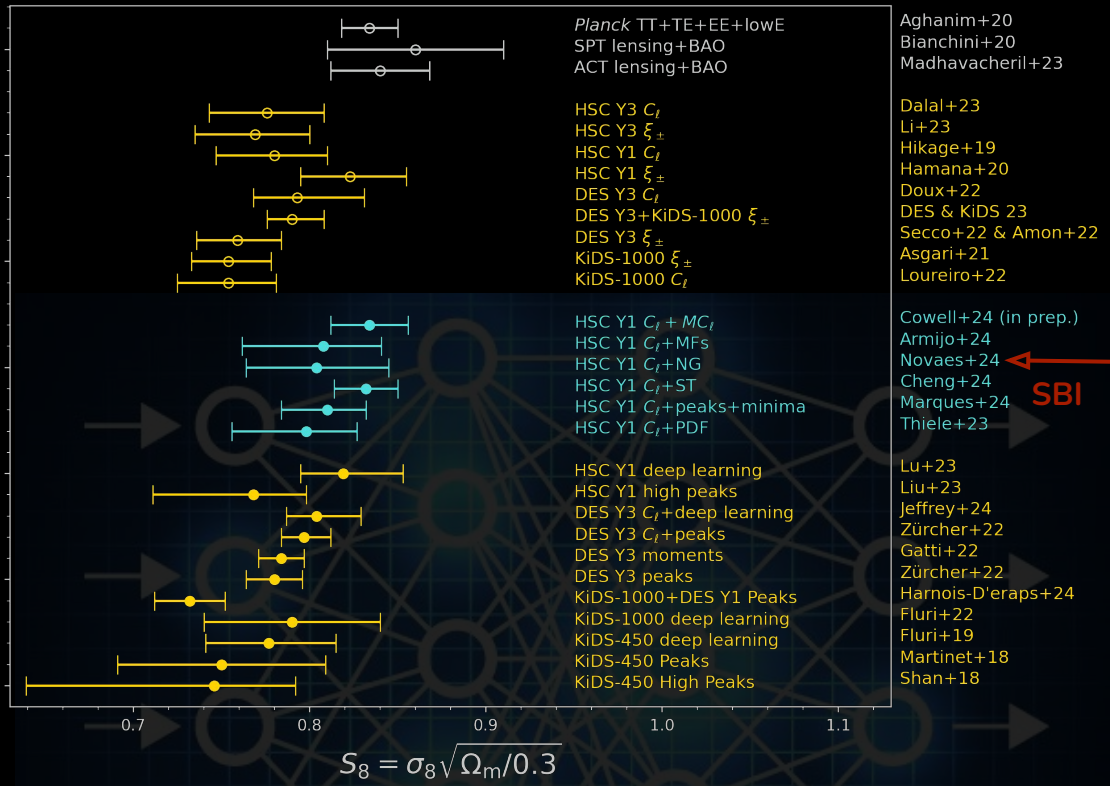


[Novaes+ 2024]

[camila.novaes@inpe.br]

HSC Y1 - SBI

- Confirm high **constraining power** of NG statistics compared to C_l only,
- Easy combination of stats - **with no approximations**,
- SBI competitive and feasible even with **a limited number of simulations** (challenge in weak lensing analyses),
- Future: particularly promising in the context of **next generation of surveys** (Euclid, LSST, ...).



[camila.novaes@inpe.br]


Thank you!

Presentation Cosmo2024 京都

Leander, Joaquin, Jess, Camila

PLAN

1) Intro – why higher order stats, why HSC – Leander, 2 slides
2) Sims, forward modeling, mention stats – Joaquin, 2 slides
3) Results (probably include tests for systematics & scale cuts?) – Jess, 3 slides
4) Implicit likelihood inference (the future…) – Camila, 3 slides

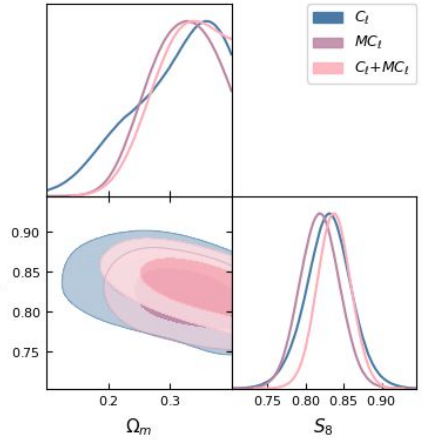
10 mins: Summarize non-Gaussian, talk about HSC-Y1and present results, extended approach (ML+SBI), conclusions (scale cuts), systematic mitigation

Joaquin: I would prefer to divide the work and maybe have just one(or two) of us presenting (but I understand if that’s not fair). If not we can always divide the time equally (2.5 mins each).

HSC-Y1 non-Gaussian results:S8 improvements

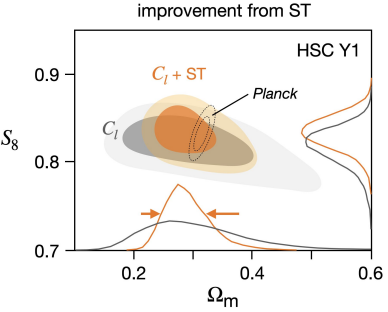
No significant deviations from Planck results are found.

Marked Power Spectra 36%



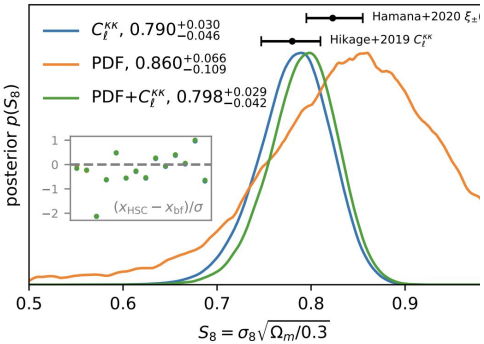
Scattering Transforms

(c.f. Sihaos talk)



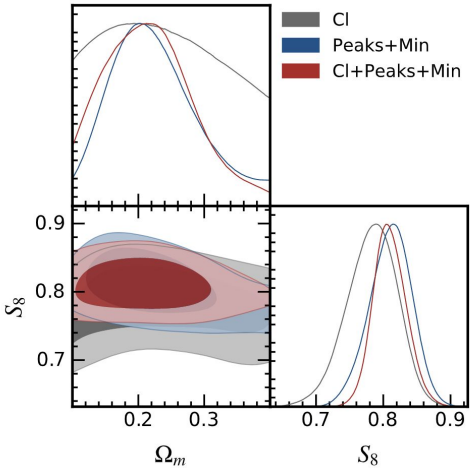
Cheng+ 24

PDF 10%



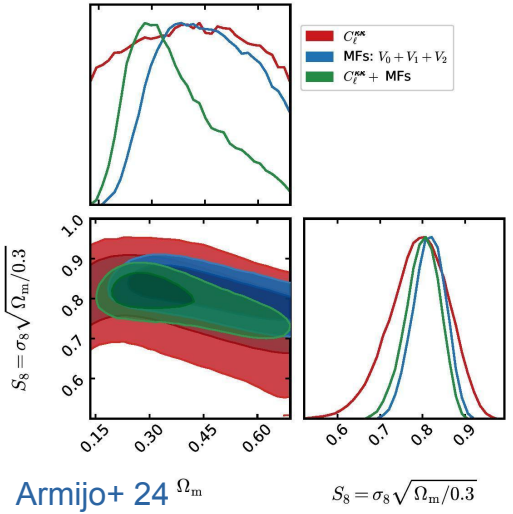
Thiele+ 23

Peaks and Minima- 35%



Marques+ 24

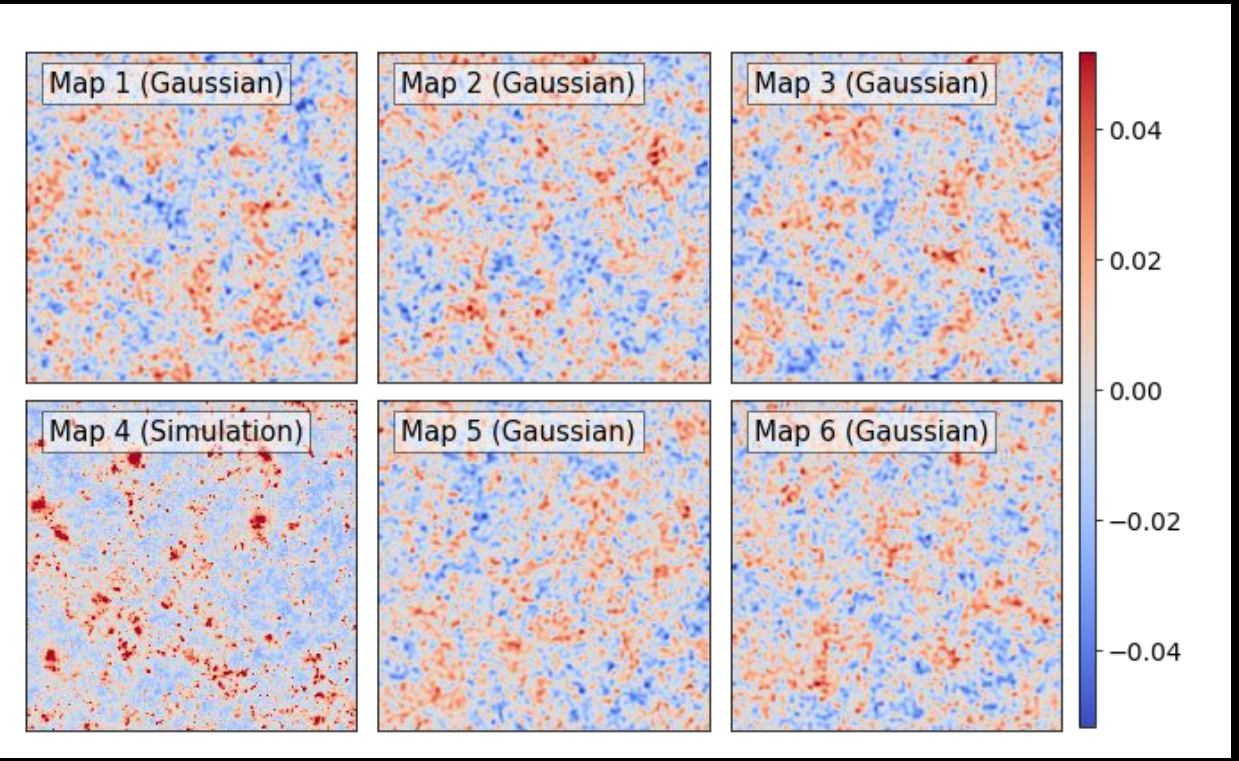
Minkowski functionals 38%

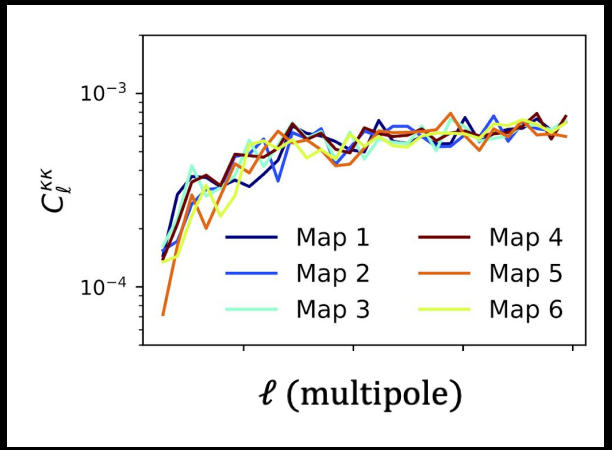


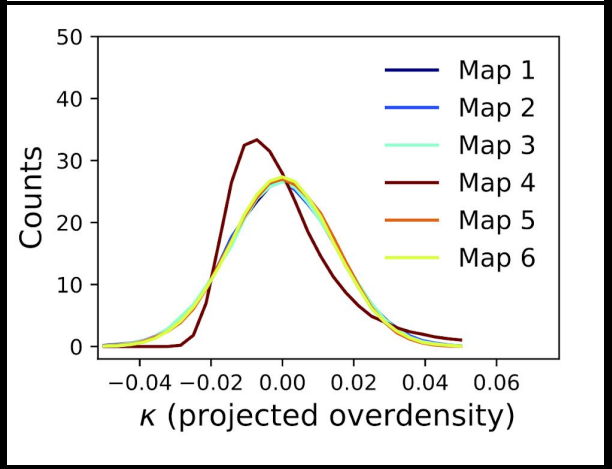
Armijo+ 24

Missing information in two-point statistics

indistinguishable at power spectrum level ⇒ new statistics to capture all information.







Credits: Jia Liu