Bispectrum & finite-volume effects

in collaboration with:

F.Rizzo, C.Moretti, M.Biagetti, E. Di Dio, E. Castorina, E. Sefusatti, P. Monaco, …

New Physics from Galaxy Clustering II

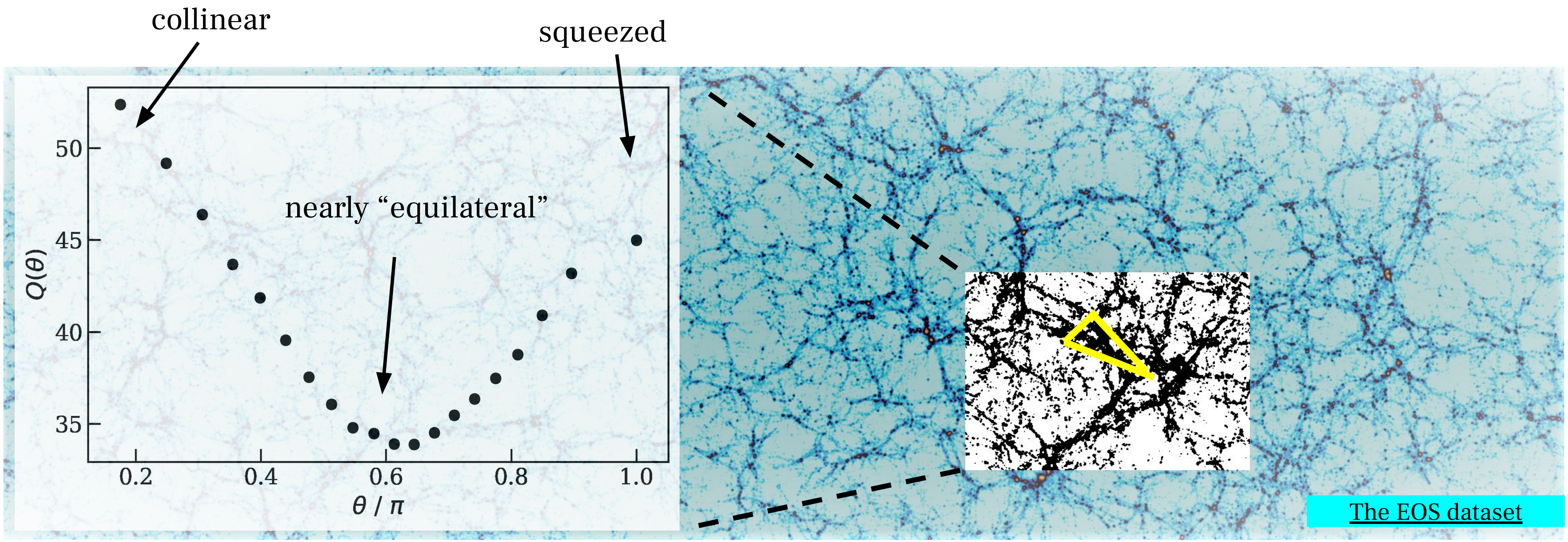
6 Nov, IFPU (Trieste)

Kevin Pardede

INFN Parma

INFN

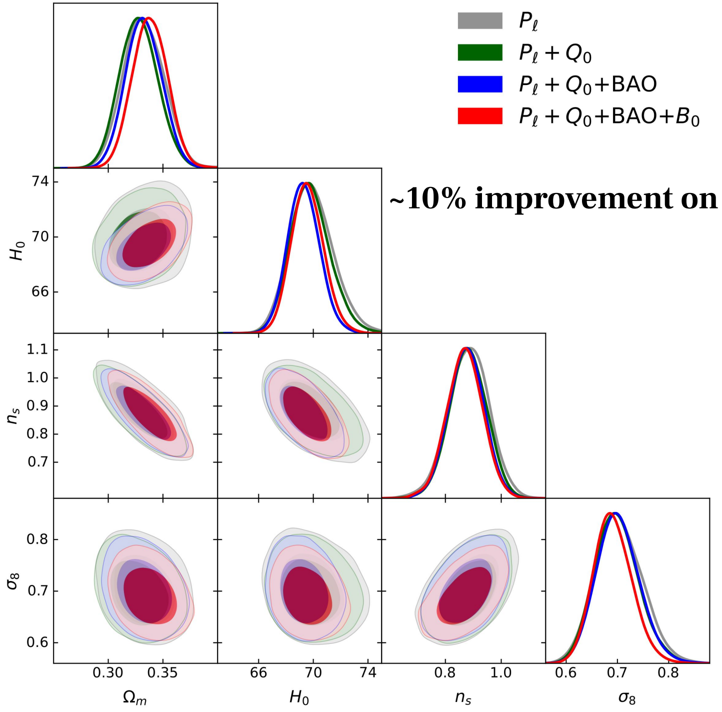
Bispectrum and the filamentary structure



$$Q(k_1, k_2, k_3) \equiv \frac{B(k_1, k_2, k_3)}{P(k_1)P(k_2) + P(k_2)P(k_3) + P(k_3)P(k_1)}$$

Bispectrum analyses

Constraint on cosmological params:

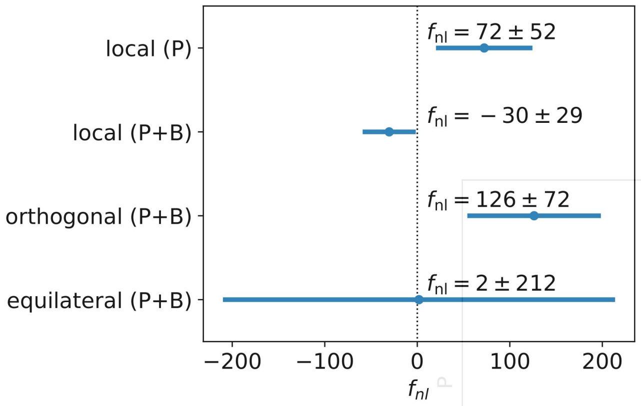


~10% improvement on σ_8

[Philcox&Ivanov21, D'Amico+19]

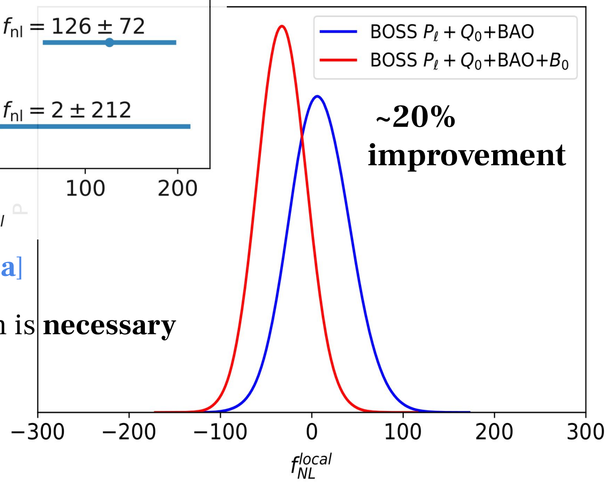
also **one-loop bispectrum**: [Philcox+22, D'Amico+22b]
also including **bispectrum multipoles**: [D'Amico+22b, Ivanov+23]

Constraint on primordial non-Gaussianity:



[Cabass+22a,b, D'Amico+22a]

For **non-local PNG**: bispectrum is **necessary**



~20% improvement

also recently: **interacting DE** [Tsedrik+22], w/ **bootstrap** [Amendola+23], w/ **SBI** [Tucci+23], **nonlinear** galaxy bispectrum [Hahn+23], ...

The bispectrum estimator

The Scoccimarro estimator [Scoccimarro15]

FFT-based

$$\hat{B}_L(k_1,k_2,k_3) = \frac{2L+1}{V_B V}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i \int_V d^3x_i e^{-i\mathbf{q}_i\cdot\mathbf{x}_i}\right] \delta_D(\mathbf{q}_{123})\tilde{\delta}(\mathbf{x}_1)\tilde{\delta}(\mathbf{x}_2)\tilde{\delta}(\mathbf{x}_3)\mathcal{L}_L(\hat{\mathbf{q}}_1\cdot\hat{\mathbf{x}}_3)$$

$$\int_{k_1} d^3q_1 \equiv \int_{|k_1-\Delta k/2|\leq k_1\leq|k_1+\Delta k/2|} d^3q_1 \qquad V_B \equiv \int_{k_1} d^3q_1 \int_{k_2} d^3q_2 \int_{k_3} d^3q_3 \delta_D(\mathbf{q}_{123})$$

Measurement vs. theory: the finite-volume effects

$$\hat{B}_L(k_1,k_2,k_3) = \frac{2L+1}{V_B V}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i \int_V d^3x_i e^{-i\mathbf{q}_i\cdot\mathbf{x}_i}\right] \delta_D(\mathbf{q}_{123})\tilde{\delta}(\mathbf{x}_1)\tilde{\delta}(\mathbf{x}_2)\tilde{\delta}(\mathbf{x}_3)\mathcal{L}_L(\hat{\mathbf{q}}_1\cdot\hat{\mathbf{x}}_3)$$

1. binning effects $\frac{1}{V_B}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i\right] \delta_D(\mathbf{q}_{123})$

2. window function $\tilde{\delta}(\mathbf{x}) = W(\mathbf{x})\delta(\mathbf{x})$

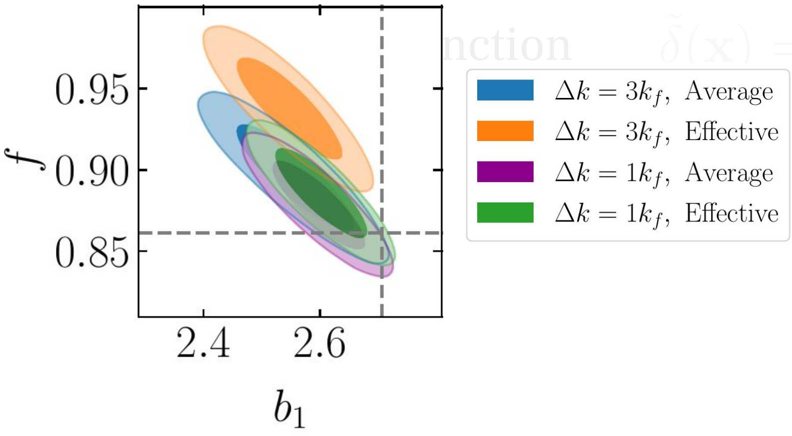
3. LOS choice $\tilde{\delta}_L(\mathbf{q}) \equiv \int d^3x\ \tilde{\delta}(\mathbf{x})\mathcal{L}_L(\mathbf{q}\cdot\mathbf{x})e^{-i\mathbf{q}\cdot\mathbf{x}}$

… but, the estimator is biased on large scale

The binning effects

$$\hat{B}_L(k_1,k_2,k_3) = \frac{2L+1}{V_B V}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i \int_V d^3x_i e^{-i\mathbf{q}_i\cdot\mathbf{x}_i}\right] \delta_D(\mathbf{q}_{123})\tilde{\delta}(\mathbf{x}_1)\tilde{\delta}(\mathbf{x}_2)\tilde{\delta}(\mathbf{x}_3)\mathcal{L}_L(\hat{\mathbf{q}}_1\cdot\hat{\mathbf{x}}_3)$$

1. binning effects $\frac{1}{V_B}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i\right] \delta_D(\mathbf{q}_{123})$ **on simulation boxes …**



[Rizzo, Moretti, Pardede+22]

The window function

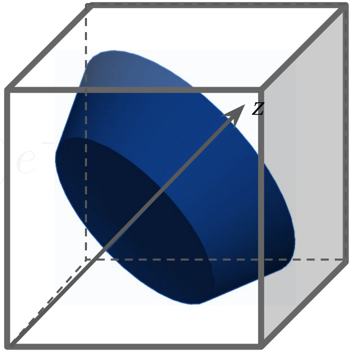
$$\hat{B}_L(k_1,k_2,k_3) = \frac{2L+1}{V_B V}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i \int_V d^3x_i e^{-i\mathbf{q}_i\cdot\mathbf{x}_i}\right]\delta_D(\mathbf{q}_{123})\tilde{\delta}(\mathbf{x}_1)\tilde{\delta}(\mathbf{x}_2)\tilde{\delta}(\mathbf{x}_3)\mathcal{L}_L(\hat{\mathbf{q}}_1\cdot\hat{\mathbf{x}}_3)$$

on real surveys …

1. binning effects $\frac{1}{V_B}\prod_{i=1}^{3}\left[\int_{k_i} d^3q_i\right]\delta_D(\mathbf{q}_{123})$

2. window function* $\tilde{\delta}(\mathbf{x}) = W(\mathbf{x})\delta(\mathbf{x})$

$$\Rightarrow \tilde{B}(\vec{k}_1,\vec{k}_2) = \int\frac{d^3p_1}{(2\pi)^3}\int\frac{d^3p_2}{(2\pi)^3}B_W(\vec{k}_1-\vec{p}_1,\vec{k}_2-\vec{p}_2)B(\vec{p}_1,\vec{p}_2)$$



[Baumgart, Fry 1991]

*window-free estimator [Philcox20, Philcox21, Ivanov+23]
see also Tri-poSH based bispectrum estimator [Sugiyama+18]
see also [Alkhanishvili+23] for NN-based approach

Survey window effects in the bispectrum

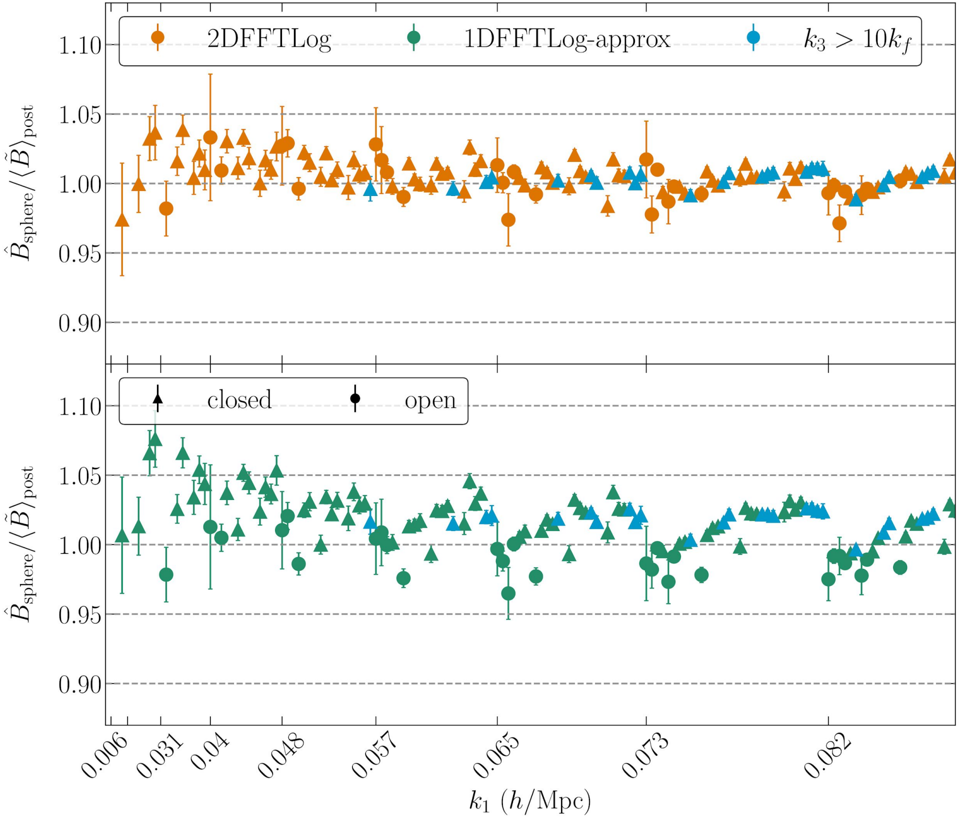
K. Pardede, F. Rizzo, M. Biagetti, E. Castorina, E. Sefusatti and P. Monaco, JCAP 10 (2022) 066 [2203.04174]

“**Mixing matrix** via (2D) FFTLog of the window 3PCF”

$$\tilde{B}_\ell[T_i] = \sum_{j,\ell'} \mathcal{M}_{\ell\ell'}[T_i, T'_j] B_{\ell'}[T'_j]$$

Real-space spherical window tests

- Pinocchio mocks [Monaco+02]
- Total volume ≈ 3500 [Gpc/h]^3
- Monopole-monopole computation takes ~ 2 seconds



The wide-angle effects

$$\hat{B}_L(k_1,k_2,k_3) = \frac{2L+1}{V_B V} \prod_{i=1}^{3} \left[\int_{k_i} d^3 q_i \int_V d^3 x_i e^{-i\mathbf{q}_i\cdot\mathbf{x}_i} \right] \delta_D(\mathbf{q}_{123}) \tilde{\delta}(\mathbf{x}_1)\tilde{\delta}(\mathbf{x}_2)\tilde{\delta}(\mathbf{x}_3) \mathcal{L}_L(\hat{\mathbf{q}}_1 \cdot \hat{\mathbf{x}}_3)$$

not plane parallel …

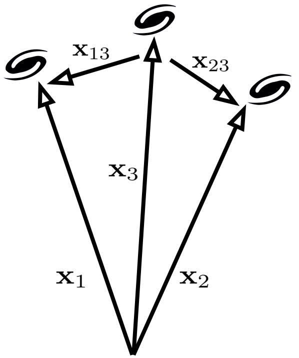
1. binning effects $\frac{1}{V_B} \prod_{i=1}^{3} \left[\int_{k_i} d^3 q_i \right] \delta_D(\mathbf{q}_{123})$

2. window function $\tilde{\delta}(\mathbf{x}) = W(\mathbf{x})\delta(\mathbf{x})$

$$B(\mathbf{k}_1, \mathbf{k}_2, \mathbf{d}) = \sum_{n, i+j=n} B^{(i+j)}(\mathbf{k}_1, \mathbf{k}_2, \hat{\mathbf{d}})(k_1 d)^{-i}(k_2 d)^{-j}$$

3. LOS choice*

$$\tilde{\delta}_L(\mathbf{q}) \equiv \int d^3x \; \tilde{\delta}(\mathbf{x}) \mathcal{L}_L(\mathbf{q}\cdot\mathbf{x}) e^{-i\mathbf{q}\cdot\mathbf{x}}$$

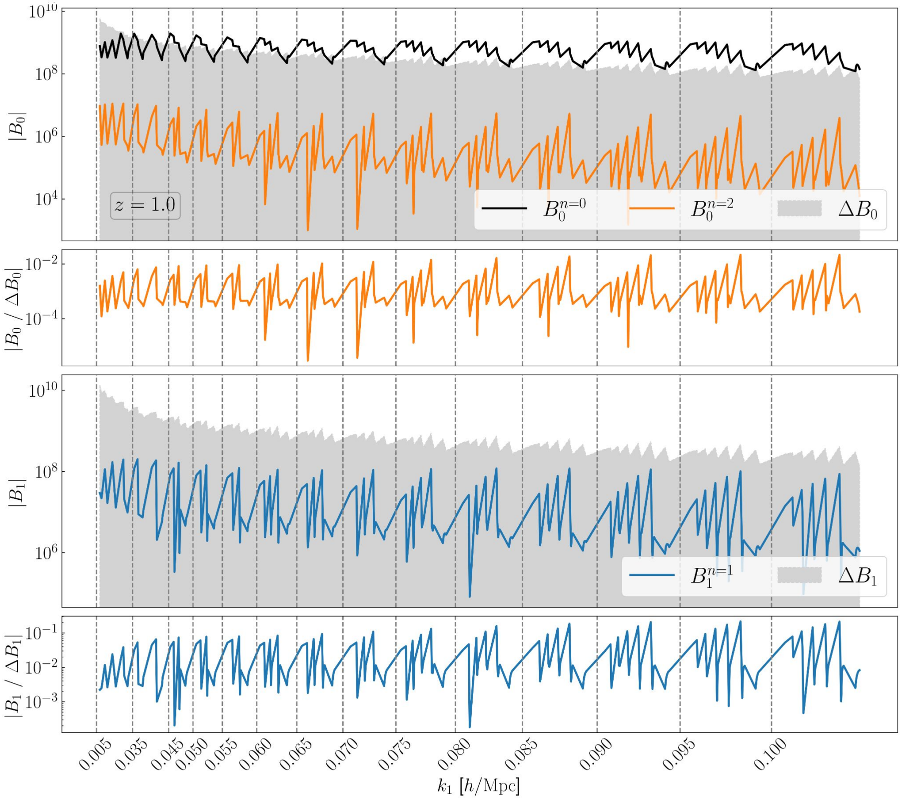


*see also [Milad Noorikuhani & Scoccimarro 2022]

The wide-angle effects in the bispectrum

K. Pardede, E. Di Dio, E. Castorina, **JCAP 09 (2023) 030, [2302.12789]**

- Monopole correction only generated at second order ~ 0.1%
- Dipole correction ~ 1% of the flat-sky monopole
- S/N of dipole ~ $[V/(8\ \mathrm{Gpc}^3\ h^{-3})]^{1/2}$

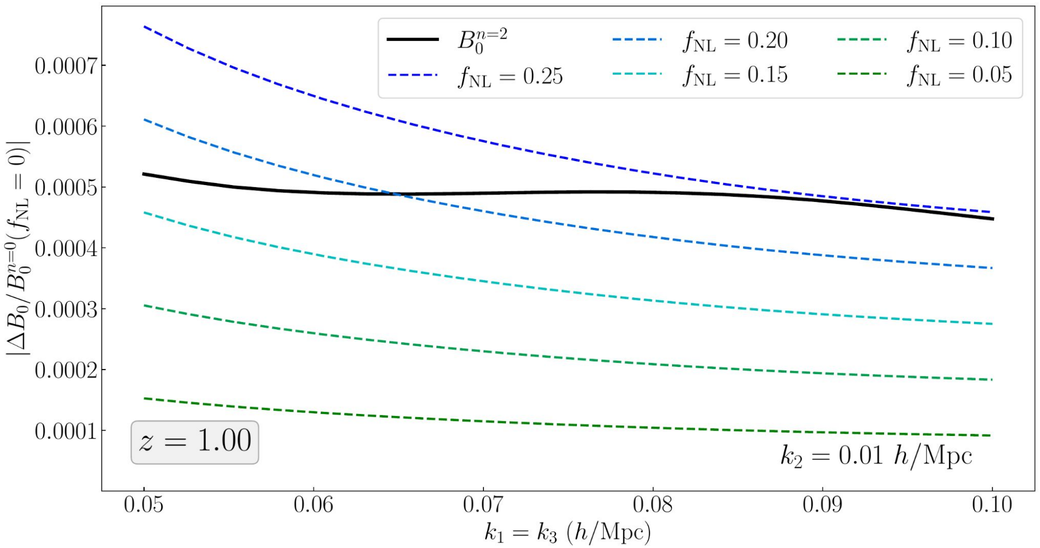


comparison with a Gaussian variance with $V = 8\ (\mathrm{Gpc}/h)^3$, $n_g \sim 6.10^{-4}\ (h/\mathrm{Mpc})^3$ @ $z = 1$

Monopole correction ~ small local f_{NL}

K. Pardede, E. Di Dio, E. Castorina, JCAP 09 (2023) 030, [2302.12789]

- Monopole correction scales as k^{-2}
- Can mimic a local PNG signal



Conclusions & Outlook

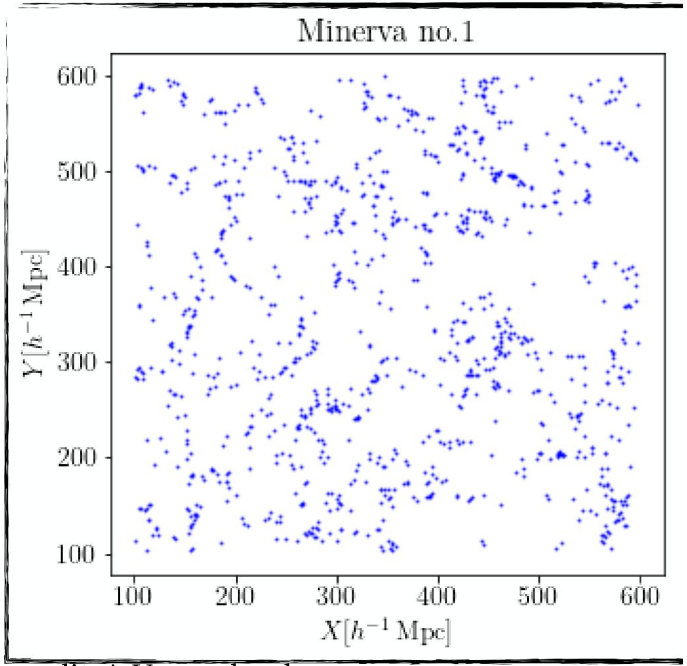
- Finite-volume effects affect the bispectrum on large-scales
- We gave a formulation for bispectrum-window convolution and bispectrum beyond plane-parallel approximation
- **Next**: application on real data, + GR effects, signal in bispectrum dipole, squeezed bispectrum, …

THANK YOU!

Extras

Dark matter halo catalogs

1. 298 **Minerva** (N-body) **Grieb+16**
2. 10000 **Pinocchio** (3LPT) Monaco+02



credit: A.Veropalumbo

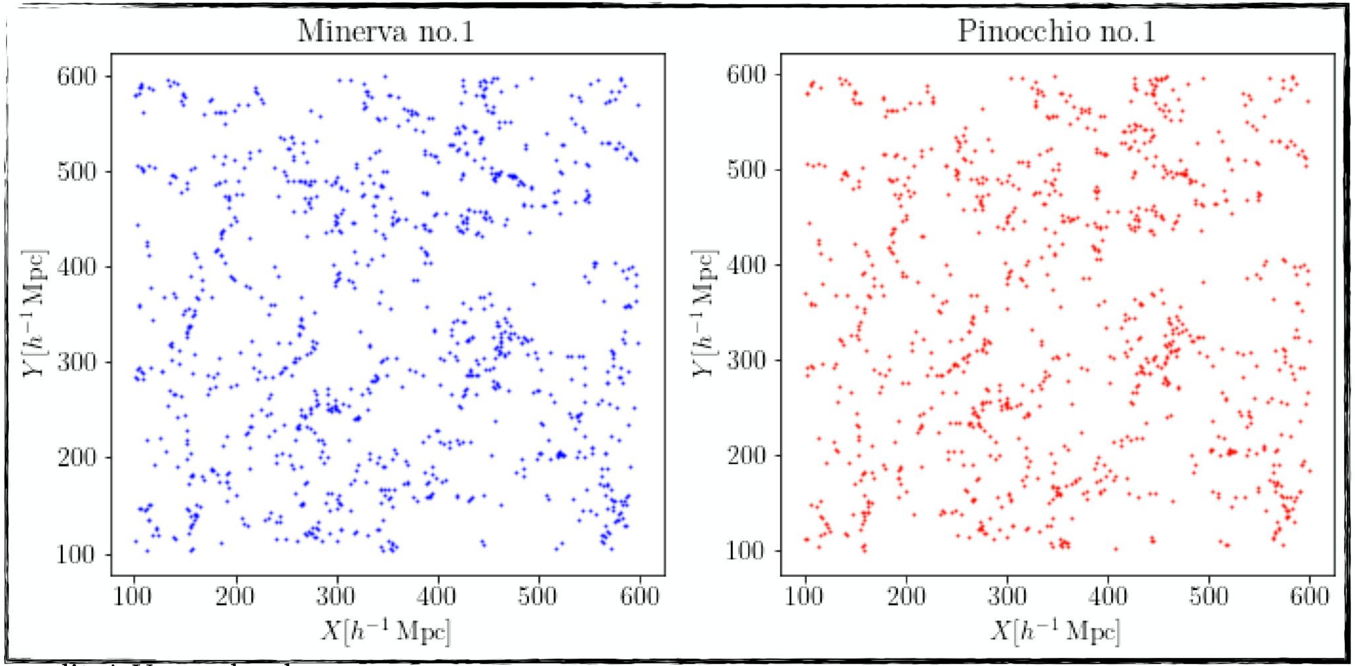
@$z = 1$
ΛCDM cosmology
$L_{box} = 1500\ \mathrm{Mpc}/h$
$V_{eff} \simeq 1000\ (\mathrm{Gpc}/h)^3$
$\simeq$ 2x volume in **Nishimichi+20**

Dark matter halo catalogs + numerical covariance

1. 298 **Minerva** (N-body) Grieb+16
2. 10000 **Pinocchio** (3LPT) **Monaco+02**

- approx. based on Lagrangian perturbation theory
- relatively fast and accurate

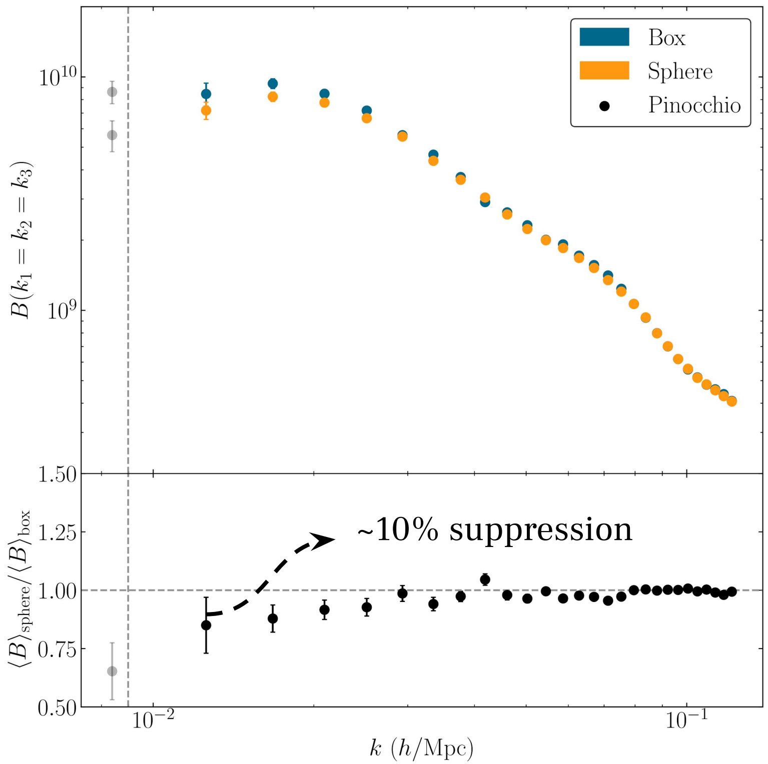
provide a robust estimate of the covariance



credit: A.Veropalumbo

Window effects in the equilateral bispectrum

Equilateral configurations



window convolution will mix modes

10000 Pinocchio sphere catalogue

Note: this is a huge volume ≈ 3500 [Gpc/h]^3

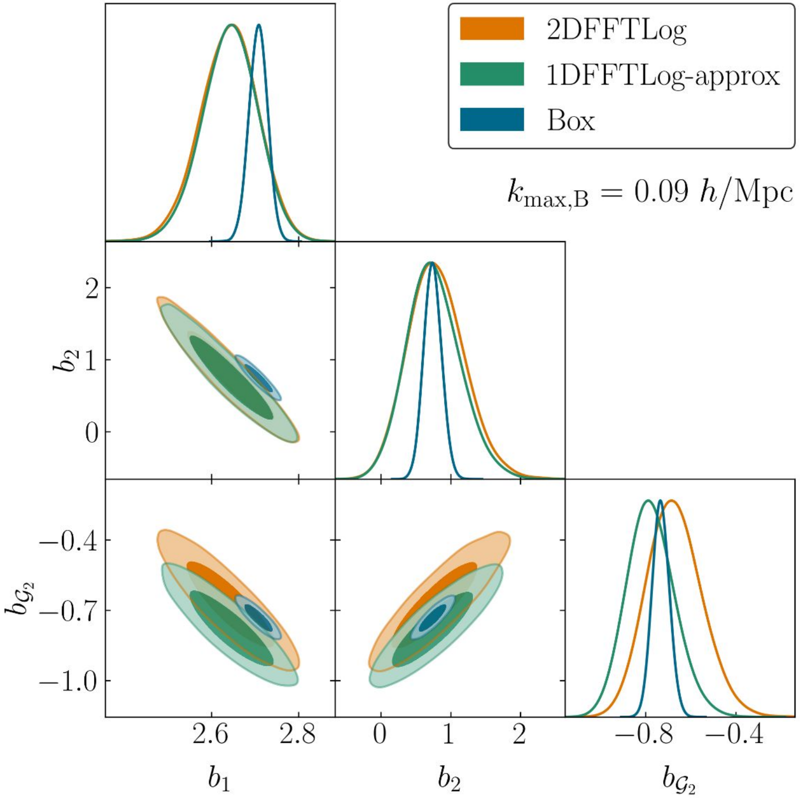
… main effect is on the large scale

Recovering bias parameters

K. Pardede, F. Rizzo, M. Biagetti, E. Castorina, E. Sefusatti and P. Monaco, JCAP 10 (2022) 066 [2203.04174]

Analysis on **Minerva** data
[Grieb+16]

$\approx$ 1/6 times volume in [Nishimichi+20]
$\approx$ 6 times $z \in [1.5, 1.8]$ *Euclid* volume



Wide-angle effects in the bispectrum

K. Pardede, E. Di Dio, E. Castorina, JCAP 09 (2023) 030, [2302.12789]

$$B_L(k_1,k_2,k_3) = \sum_{i+j\leq n,\ell_1,\ell_2,\cdots} B^{(n)}_{L,\ell_1,\ell_2,\cdots}(\mathbf{k}_1,\mathbf{k}_2)\mathcal{M}^{(n)}_{L,\ell_1,\ell_2,\cdots}(\mathbf{k}_1,\mathbf{k}_2)\left(\frac{1}{k_1x_3}\right)^i\left(\frac{1}{k_2x_3}\right)^j$$

- The “mixing-matrix” and the ($n > 0$) “bispectrum” has a high dimensionality (#ℓ’s ~10)
- Evaluating the ($n > 0$) “bispectrum” terms takes ~10 minutes
- The “multiplication” can be done analytically in the case of no window