PRIMORDIAL NON-GAUSSIANITIES AND THEIR IMPRINTS IN THE LARGE SCALE STRUCTURE

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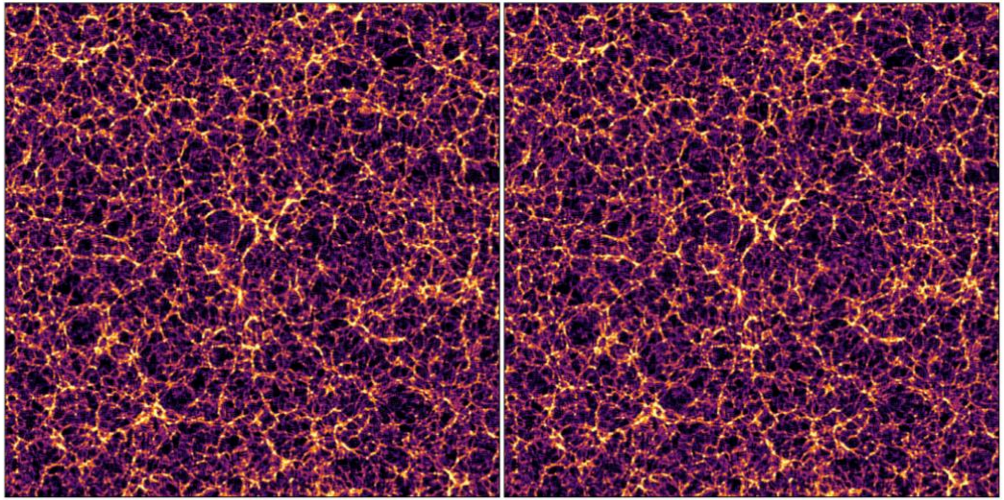
WHAT ARE PRIMORDIAL NON-GAUSSIANITIES?

- Initial Conditions seeded by Inflation.
- Single-field, slow roll inflation predicts a nearly gaussian spectrum of perturbations.
- Any violation of one of these two conditions leads to some degree of Primordial Non-Gaussianities (PNGs) $(f_{\rm NL}^{local} > 1)$



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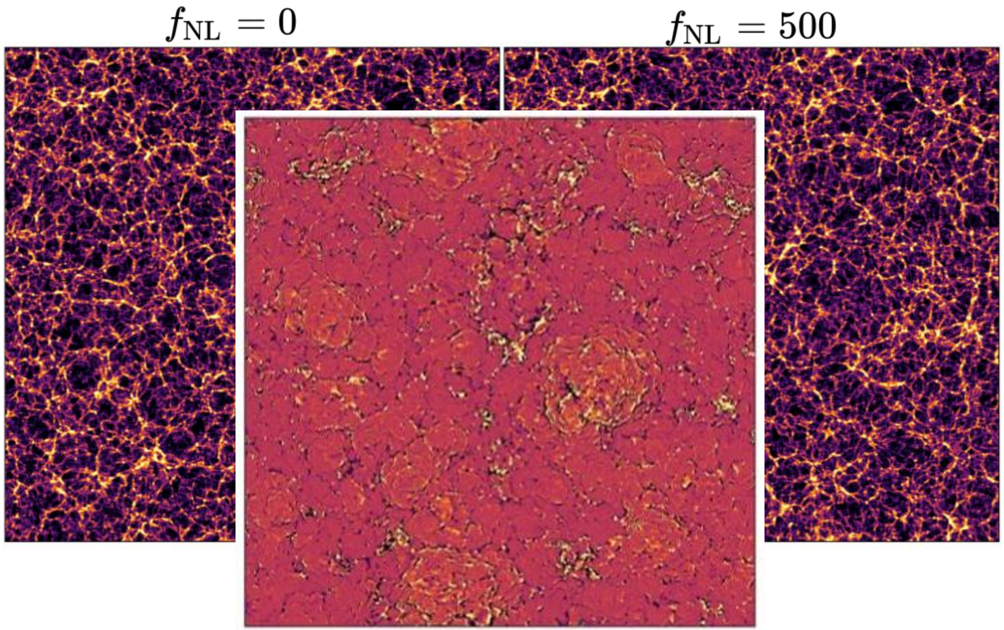


WHAT ARE PRIMORDIAL NON-GAUSSIANITIES?

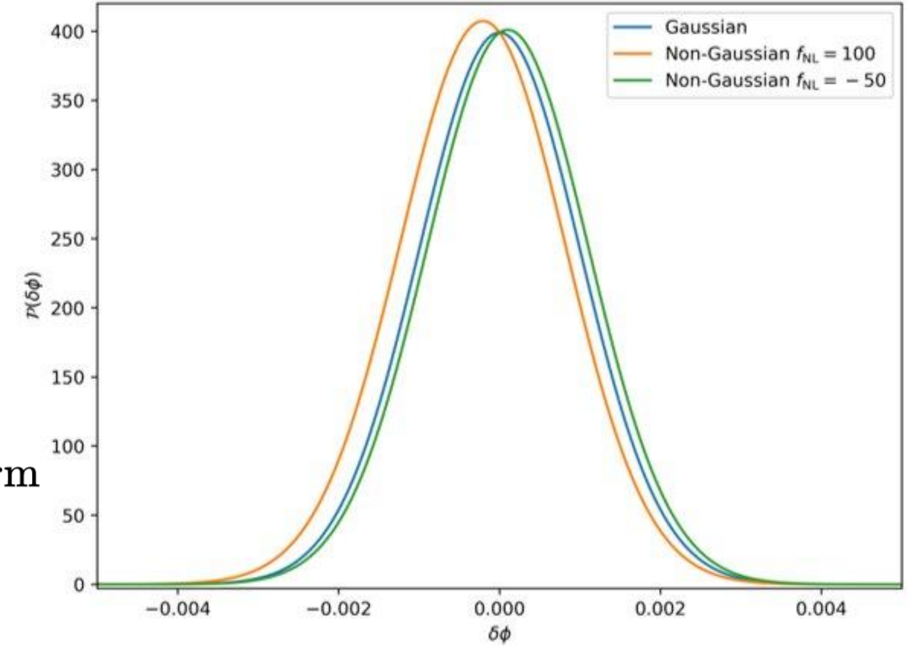
- *local*-PNGs parametrized at first order as:

$$\Phi = \phi_G + f_{\rm NL}^{local}(\phi_G^2 - \langle\phi_G\rangle^2)$$

- Modification of the PDF: Enhancement/Suppression of structure formation (HMF)
- Non-vanishing bispectrum.

$$B(k_1, k_2, k_3) = 2f_{\rm NL}P(k_1)P(k_2) + 2\text{perm}$$

- They induce a scale-dependece in the galaxy bias



CONSTRAINTS ON PNGS

Planck Collaboration (2020)

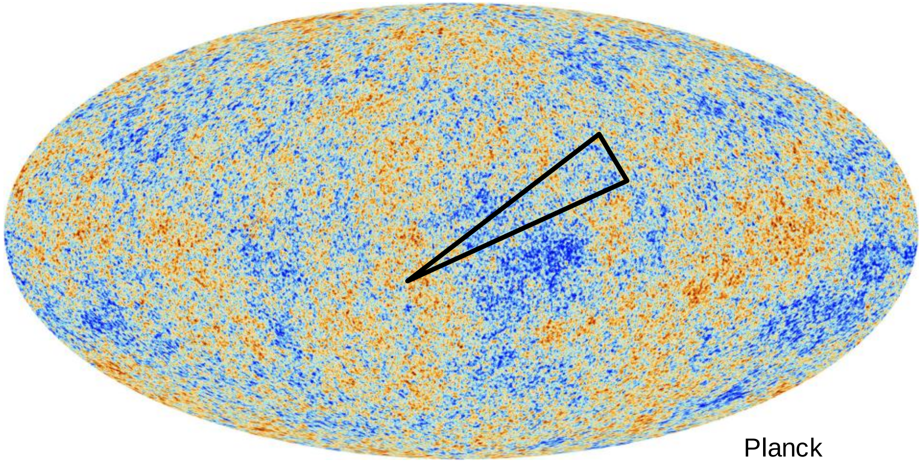
$$f_{\rm NL}^{local} = -0.9 \pm 5.1(1\sigma)$$

[CMB]

Mueller et al. (2021) [eBOSS]

$$f_{\rm NL}^{local} = -12 \pm 21(1\sigma)$$

[LSS]



Planck Collaboration

HALO MASS FUNCTION

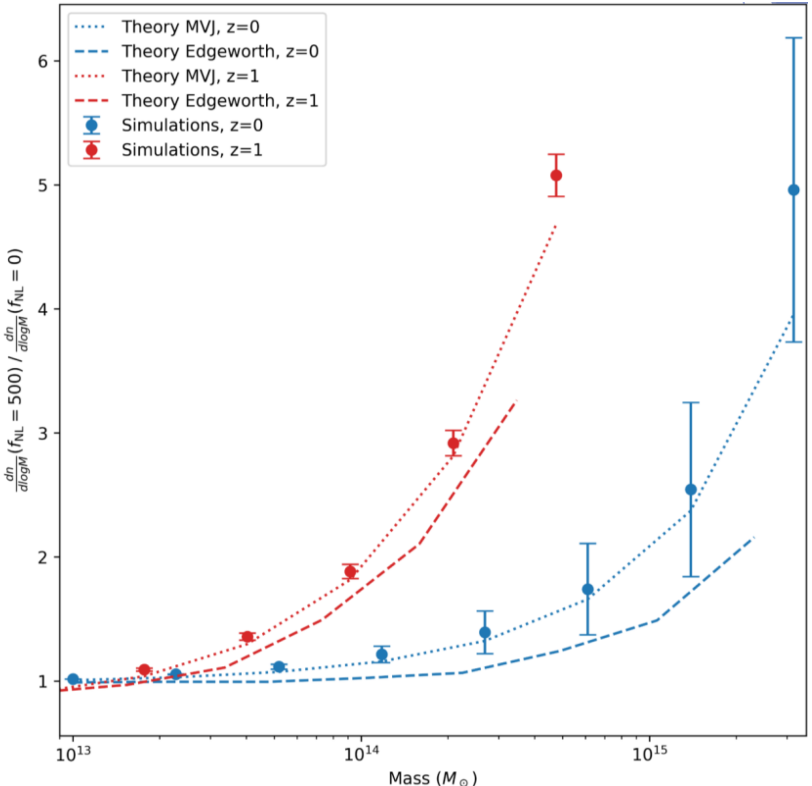
- Following the Press-Schechter formalism:
  [Press & Schechter(1974)]

$$\frac{dn}{dM}(M,z) = -2\frac{\bar{\rho}}{M}\frac{d}{dM}\left[\int_{\delta_c/\sigma(M)}^{\infty} d\nu P(\nu,M)\right]$$

- The PDF of the perturbations for the non-gaussian case is then given by [Materrese et al.(2000), LoVerde et al. (2007)]:

$$P(\nu)d\nu = \frac{d\nu}{\sqrt{2\pi}}e^{-\nu^2/2}\left[1+\sigma_R\frac{S_3(R)}{6}H_3(\nu)+\mathcal{O}(S_3(R)^2)\right]$$

$$S_3(R) = \frac{\langle\delta_R^3\rangle}{\langle\delta_R^2\rangle^2} \propto f_{\rm NL}$$



THE SCALE-DEPENDENT BIAS

- Galaxies are a "biased tracers" of the underlying matter distribution.

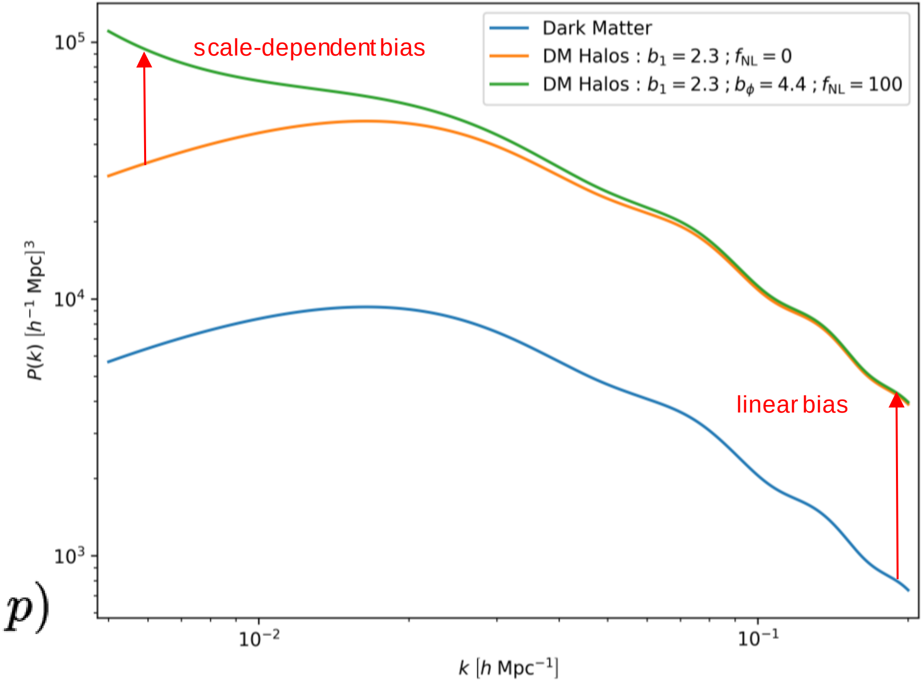
$$\delta_g = \frac{n_g(\mathbf{x}) - \bar{n}_g}{\bar{n}_g} \qquad \delta_g = \sum_i b_i \delta_m^i$$

- *Local*-PNGs induce a scale-dependence in this bias [Dalal et al. (2008)]

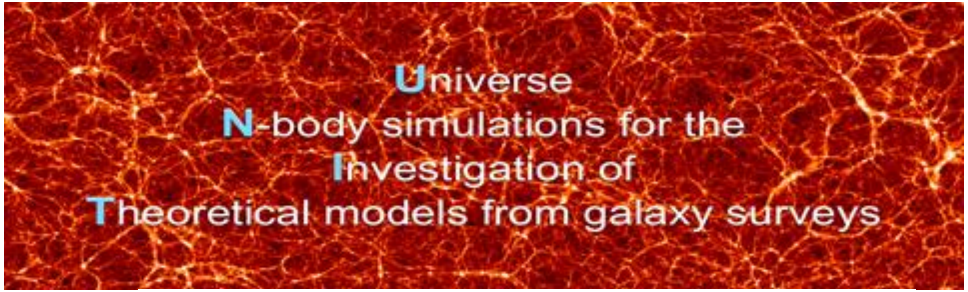
$$\delta_g = (b_1 + b_\phi f_{\rm NL} \frac{1}{\alpha(k)})\delta_m = b \cdot \delta_m$$

- $f_{\rm NL}$ and b_ϕ are degenerated: We need to put strong priors on b_ϕ for measuring $f_{\rm NL}$

$$b_\phi = 2\delta_c(b_1 - 1) \rightarrow b_\phi = 2\delta_c(b_1 - p)$$



PNG-UNIT SIMULATIONS



- 2 DM-only simulations:

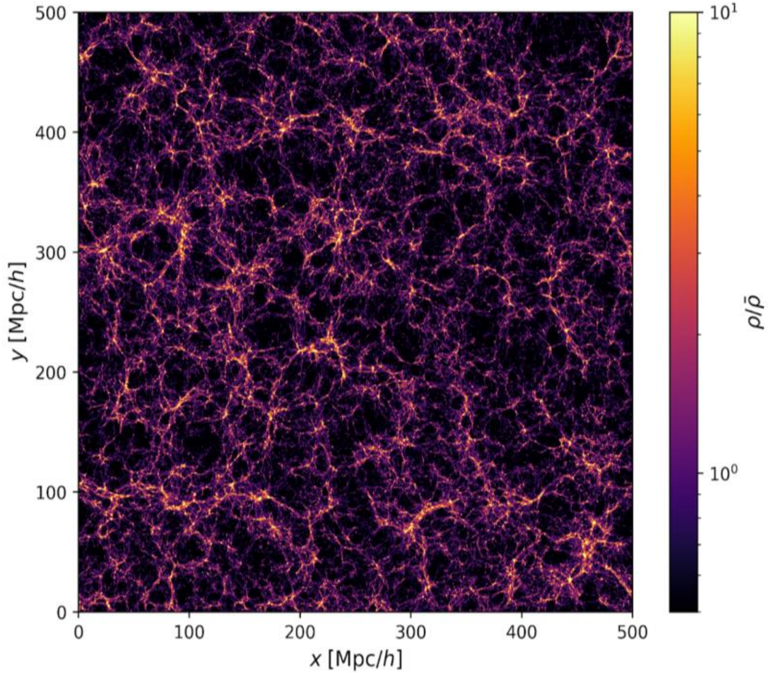
$$L = 1\ h^{-1}\mathrm{Gpc}\ ;\ N_{part} = 4096^3$$
$$M_{part} = 1.25 \times 10^9 h^{-1} M_\odot$$

- Gaussian $f_{\rm NL} = 0$ and Non-Gaussian $f_{\rm NL} = 100$ realizations [Chuang, Yepes et al. (2019); Adame, Ávila, Yepes et al. (in prep)]

- Fixed initial conditions [Angulo & Pozten (2016)]
- Matched initial conditions [Ávila & Adame (2022)]

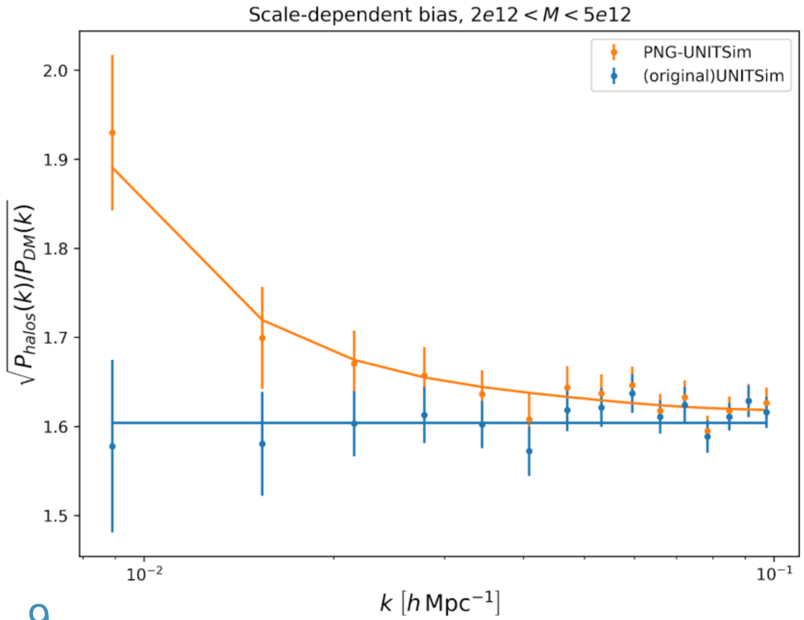
$$V_{eff} \sim 70\ h^{-3}\mathrm{Gpc}^3$$

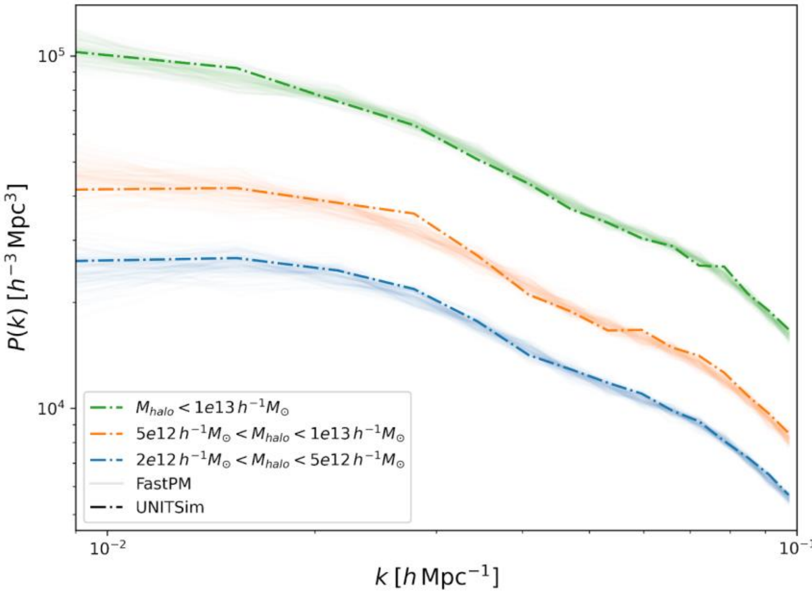
- 200 FastPM realizations (100 with $f_{\rm NL} = 0$ and 100 with $f_{\rm NL} = 100$)



PNG-UNIT: SCALE DEPENDENT BIAS

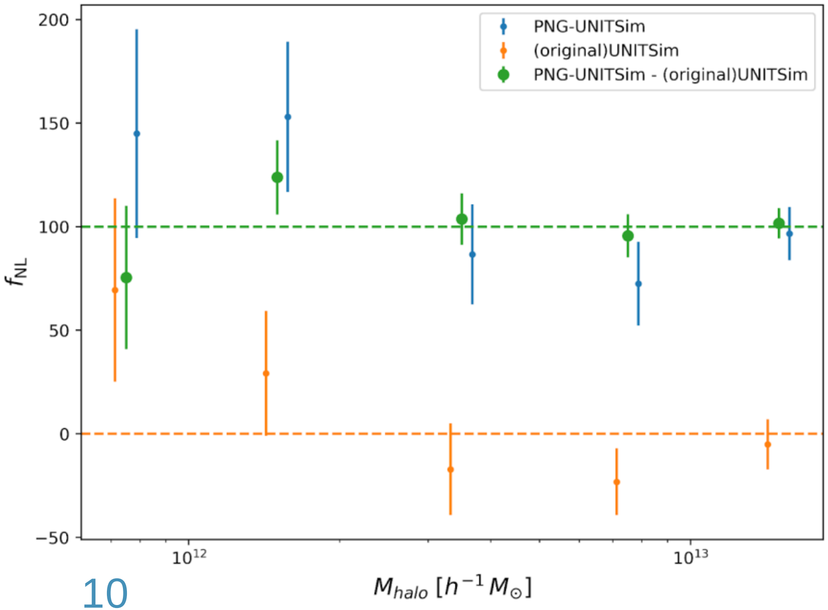
- Fixed $f_{\rm NL}$, fitting for both b_1 and p
- Using FastPM for estimating variances.
- Matching $f_{\rm NL} = 0$ and $f_{\rm NL} = 100$ sims. [Ávila & Adame (2022)]

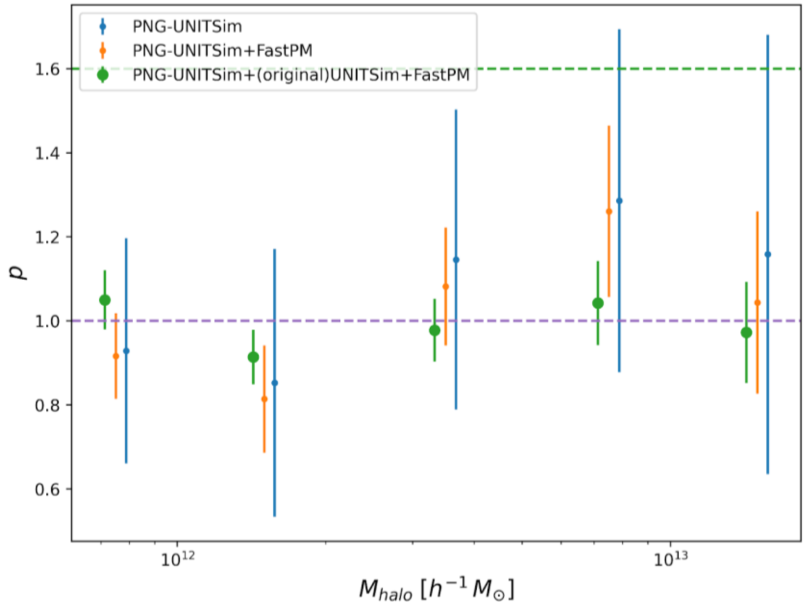




PNG-UNIT: CONSTRAINTS ON P

- Preliminary results: For DM halos Universality relation holds (p=1).
- Next step: Other tracers. (QSO, LRGs...)





CONCLUSIONS

- Putting strong priors in p will be key for obtaining an unbiased value of f_{NL}
- Numerical simulations will play a central role in this task.
- Fixing, pairing and matching the ICs provide a huge suppression in the variance of the simulations.
- This can be applied when there are PNGs.
- The PNG-UNITSim would be sufficient for validating the analysis pipelines for the next generation galaxy surveys.

BACKUP SLIDES

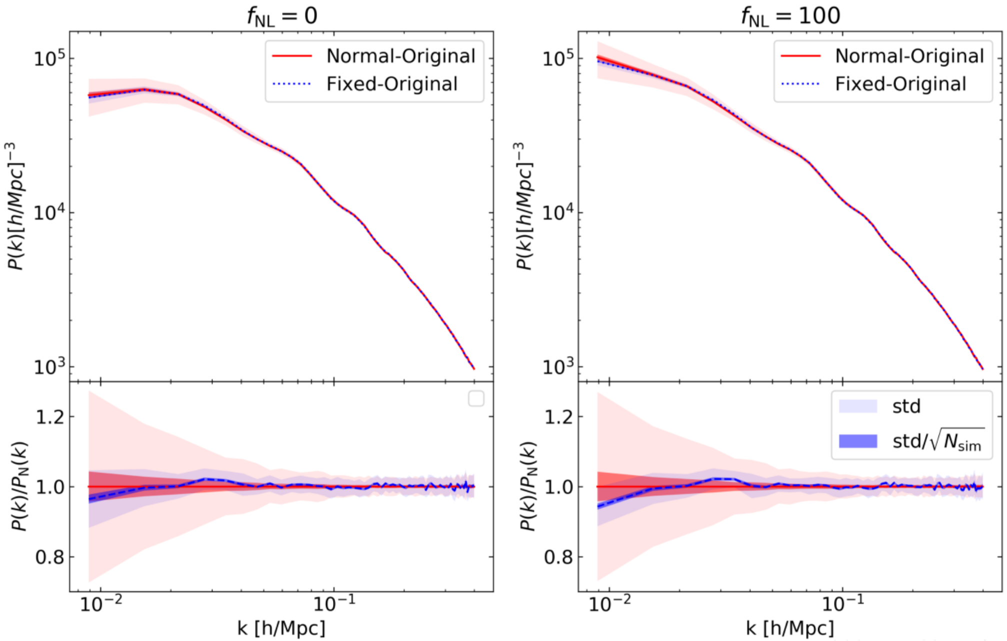
SUPPRESSING COSMIC VARIANCE IN NON-GAUSSIAN SIMULATIONS.

- Fixed and Paired ICs also valid for $f_{\rm NL}^{local} \neq 0$ [Ávila & Adame (2022)]

- "Matching" 2 simulations with different cosmology but same stochastic part of the ICs => **Huge variance suppression.**

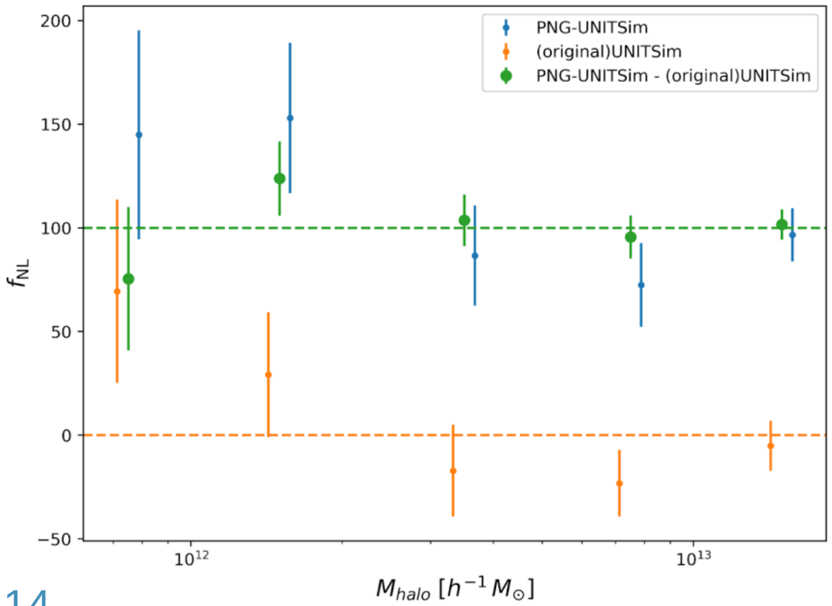
$$\sigma^2(\Delta \hat{f}_{\rm NL}) = \sigma^2(\hat{f}^{100}_{\rm NL}) + \sigma^2(\hat{f}^{0}_{\rm NL}) - 2\rho\sigma(\hat{f}^{100}_{\rm NL})\sigma(\hat{f}^{0}_{\rm NL})$$

- With **just 2 Fixed, Paired and Matched** simulations we expect to get $\sigma(f_{\rm NL}) \sim 5$



Equivalent to running 140 normal sims.

MATCHING FNL 0 AND FNL 100



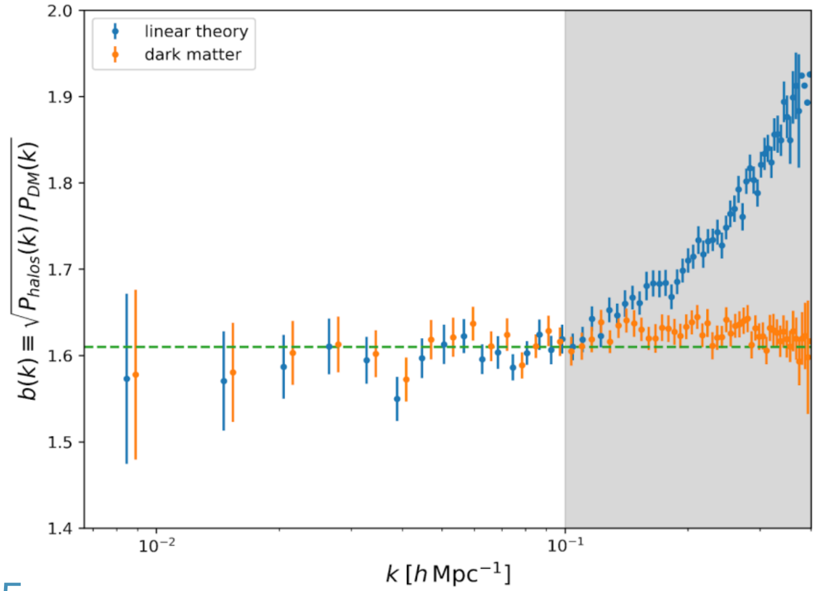
- The original UNITSim have matched ICs. Measurements are correlated [Ávila and Adame (2022)].

$$\sigma^2(\Delta \hat{f}_{\rm NL}) = \sigma^2(\hat{f}^{100}_{\rm NL}) + \sigma^2(\hat{f}^{0}_{\rm NL}) - 2\rho\sigma(\hat{f}^{100}_{\rm NL})\sigma(\hat{f}^{0}_{\rm NL})$$

- Obtain ρ from FastPMs.
- Assuming p=1, we get an offset in measurements of $f_{\rm NL}$
- From $\Delta f_{\rm NL}$, we derive the expected p:

$$\hat{p} = \hat{b}_1 - (\hat{b}_1 - 1)\frac{\hat{f}_{\rm NL}}{f^{true}_{\rm NL}}$$

SCALE CUTS

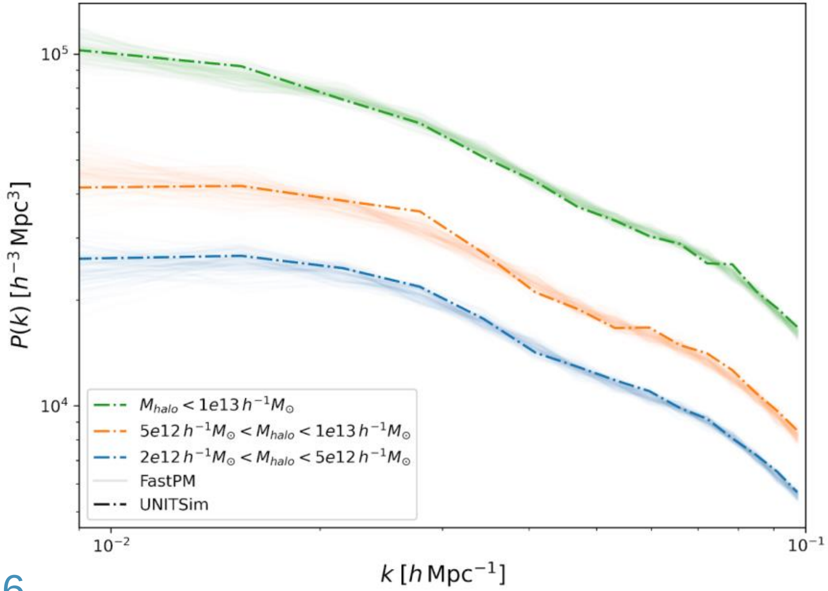


- We model the bias as:

$$\delta_{halos} = b(k, f_{\mathrm{NL}}) \cdot \delta_m$$

- Linear theory describes accurately the $P_{halos}(k)$ for $k_{max} < 0.1 h\,\mathrm{Mpc}^{-1}$ up to the fundamental mode of the box: $k_f = 0.00628 h^{-1}\mathrm{Mpc}$
- We can get a bit into the non-linear regime by using $P_{DM}(k)$
- Conservative approach: only the purely linear part.

FASTPM CLUSTERING MATCHING



- Approximated N-body realizations (FastPM)
- Used for estimating the variance of $b(k)$ and correlation coefficients.
- Different mass definitions w.r.t. full N-body.
- For selecting the "equivalent" halos we have applied a clustering matching.
- Comparable results on p(M) for
  - Abundance matching.
  - Mass bins "as-given".

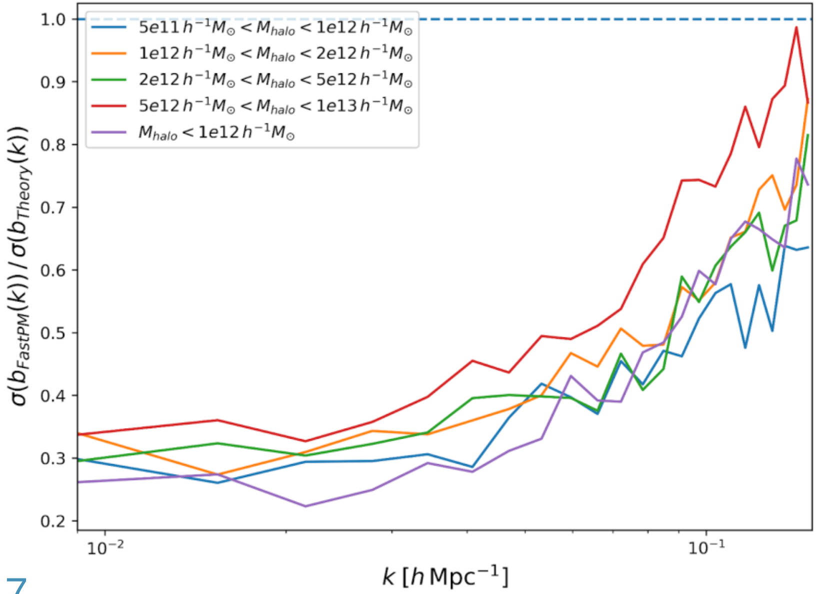
FASTPM CLUSTERING MATCHING

- Fixing ICs [Angulo & Pozten (2016)] reduces the variance w.r.t. theoretical expectation for a Gaussian field [Feldman et al. (1994)].

$$\sigma^2(P(k)) = (P(k) + \frac{1}{n})\frac{4\pi^2}{Vk^2\Delta k}$$

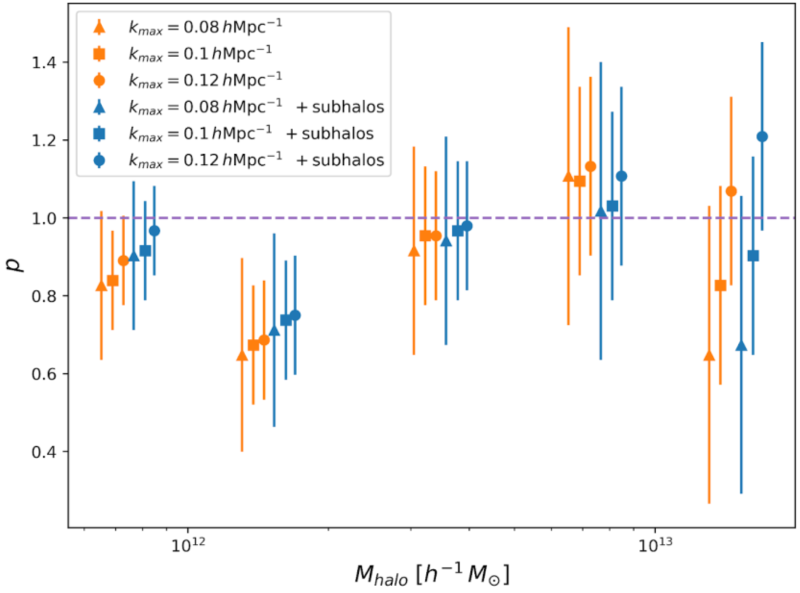
- The decrease in $\sigma(b(k))$ affects the constraint on p as:

$$\sigma_{fix}(p) \simeq \frac{1}{2}\sigma_{normal}(p)$$

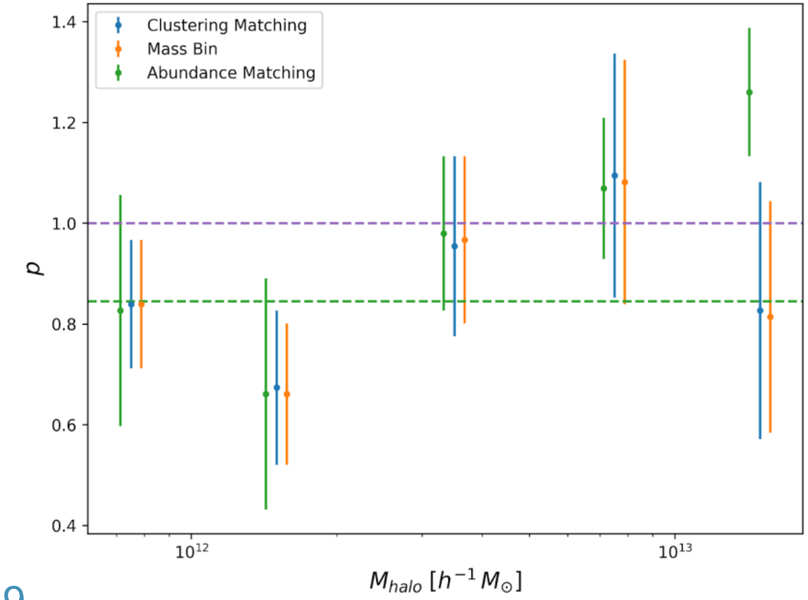


ROBUSTNESS TESTS

- Our methodology does not bias the final results:
  - Varying k_{max} does not shift the central value more than 1σ w.r.t. the reference $k_{max} = 0.1 h\,\mathrm{Mpc}^{-1}$
  - Including the subhalos does not affect the fits on p.
  - Our variance reduction techniques does not bias the results



FASTPM: MATCHING TO UNITSIMS



- Comparable results on p(M) for
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  - Mass bins "as-given".

- Abundance Matching and Mass bins: Different clustering w.r.t. UNITSim.

- $M_{halos} > 10^{13} h^{-1} M_\odot$
  - Abundance-Matching: ~20% more halos than clustering matching bins.