THE PNG-UNIT SIMULATIONS: CONSTRAINING THE PNG-RESPONSE PARAMETER

ADRIÁN GUTIÉRREZ ADAME

In collaboration with:
S.Ávila, G.Yepes, V. González-Pérez, J.García-Bellido, M.Pellejero et al.

A Cosmic Window to Fundamental Physics: Primordial Non-Gaussianity and Beyond
Madrid, 19th September, 2022

Instituto de Física Teórica UAM-CSIC

RED ESPAÑOLA DE SUPERCOMPUTACIÓN

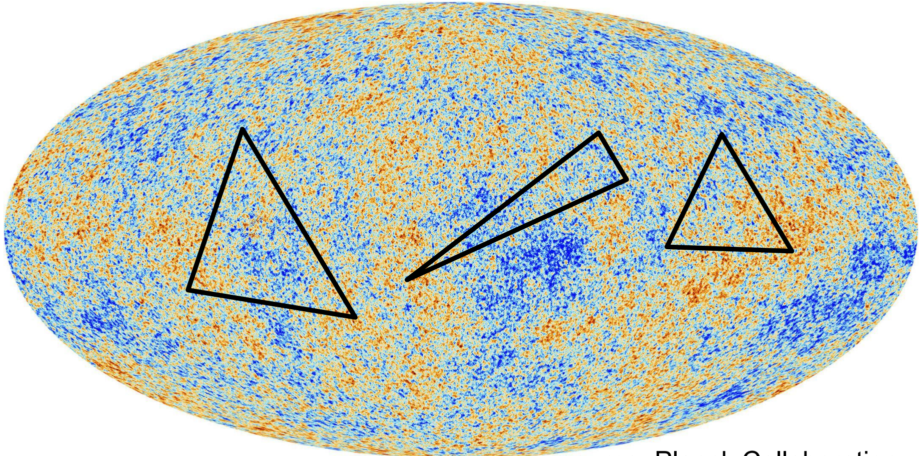
Universidad Autónoma de Madrid

CURRENT CONSTRAINTS ON PNG

Planck Collaboration (2020)

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

[CMB]



source: Planck Collaboration

Mueller et al. (2021) [eBOSS]

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

[LSS]

THE SCALE-DEPENDENT BIAS

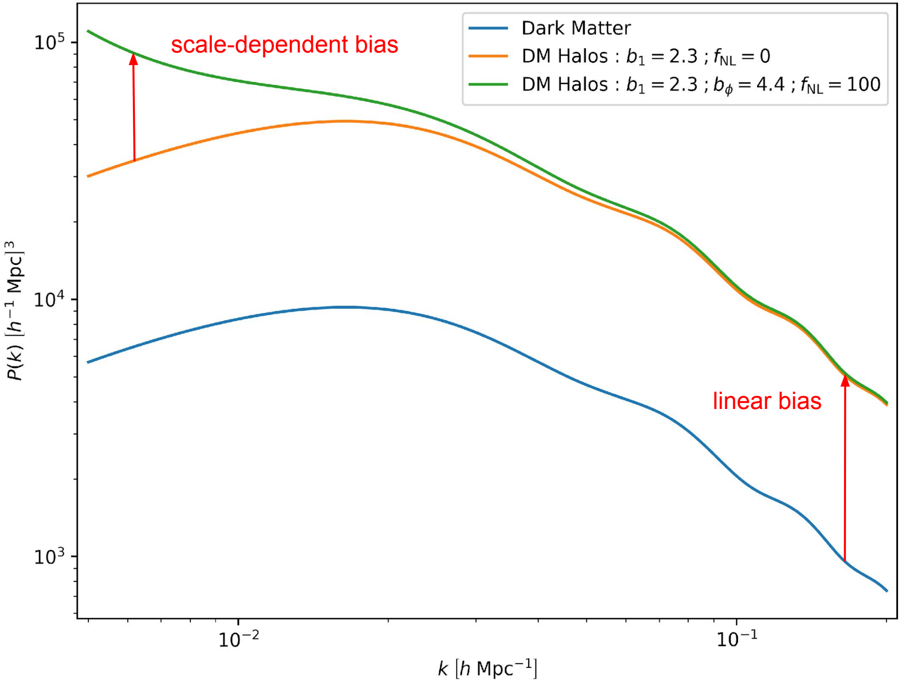
- Galaxies are a "biased" tracers of matter.

$$\delta_g = \frac{n_g(\mathbf{x}) - \bar{n}_g}{\bar{n}_g} = b \cdot \delta_m$$

- *Local*-PNGs induce a scale-dependence
[Dalal et al. (2008), Slosar et al. (2008)]

$$\delta_g = (b_1 + b_\phi f_{\rm NL} \frac{1}{\alpha(k)})\delta_m \; ; \; \alpha(k) \propto k^2$$
$$b_\phi = 2\delta_c(b_1 - p)$$

- p and $f_{\rm NL}$ are completely degenerated.
- **GOAL:** put priors on $p(M_{halo})$



PNG-UNIT SIMULATIONS

- 2 DM-only simulations:

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

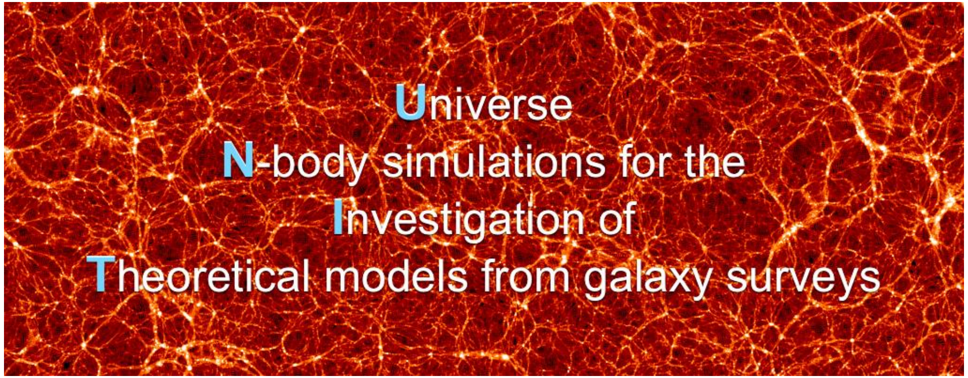
- Original UNITSim: $f_{\rm NL} = 0$ [Chuang, Yepes et al. (2019)]
- **New:** Simulation with $f_{\rm NL} = 100$ [Adame, Ávila, Yepes et al. (in prep)]

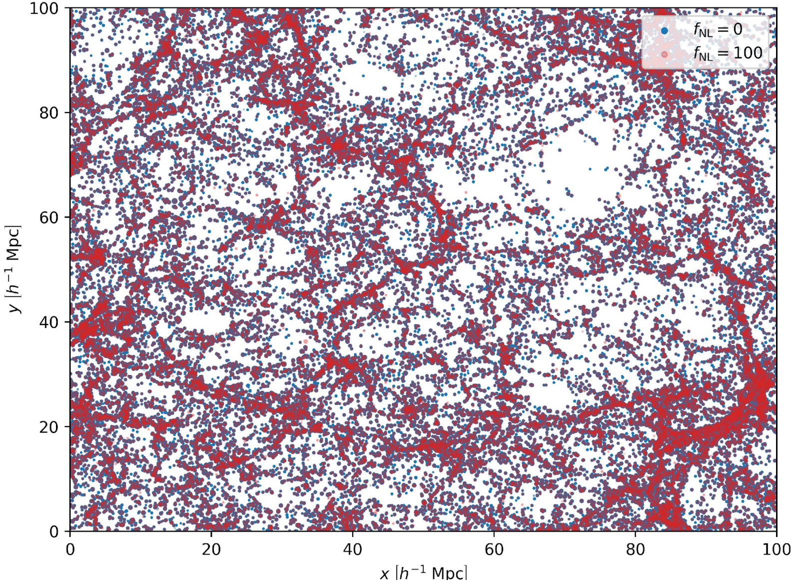
- Fixed ICs [Angulo & Pozten (2016)]
- Matched ICs [Ávila & Adame (2022)]

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

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

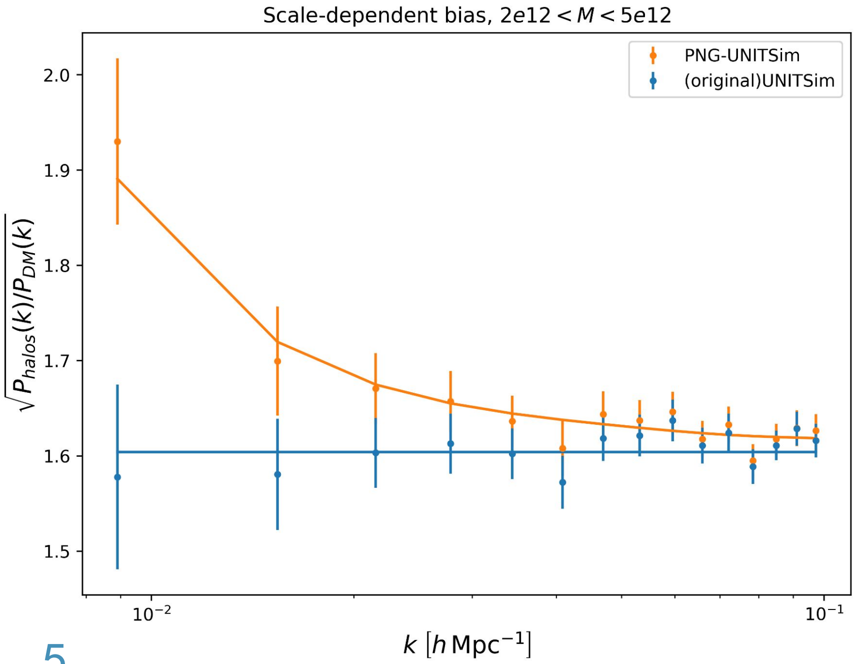
$$M_{part,fastPM} = 9.97 \times 10^9 h^{-1} M_\odot$$

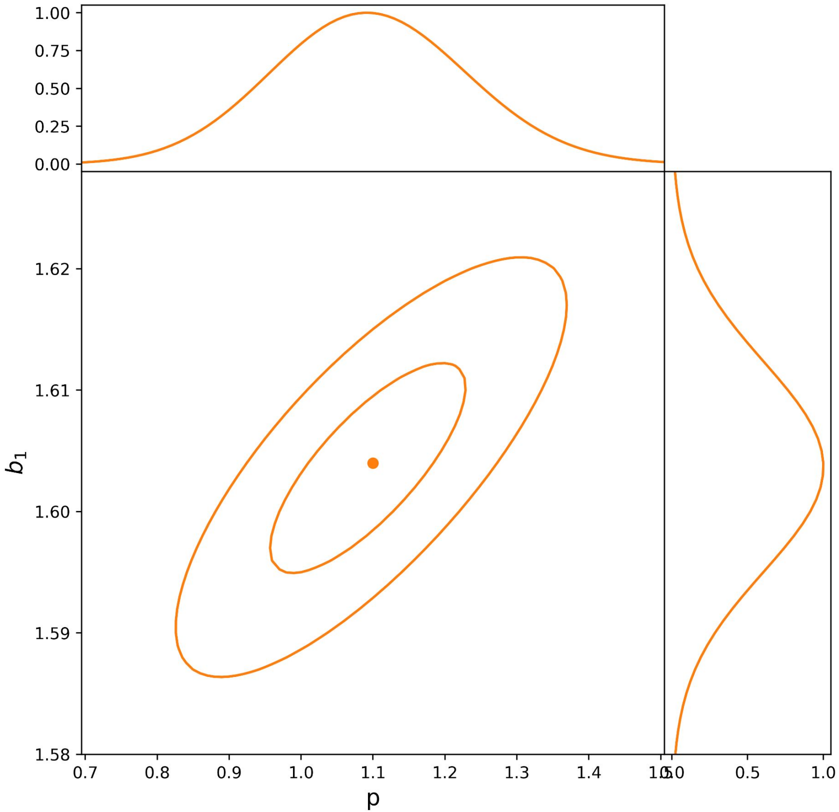




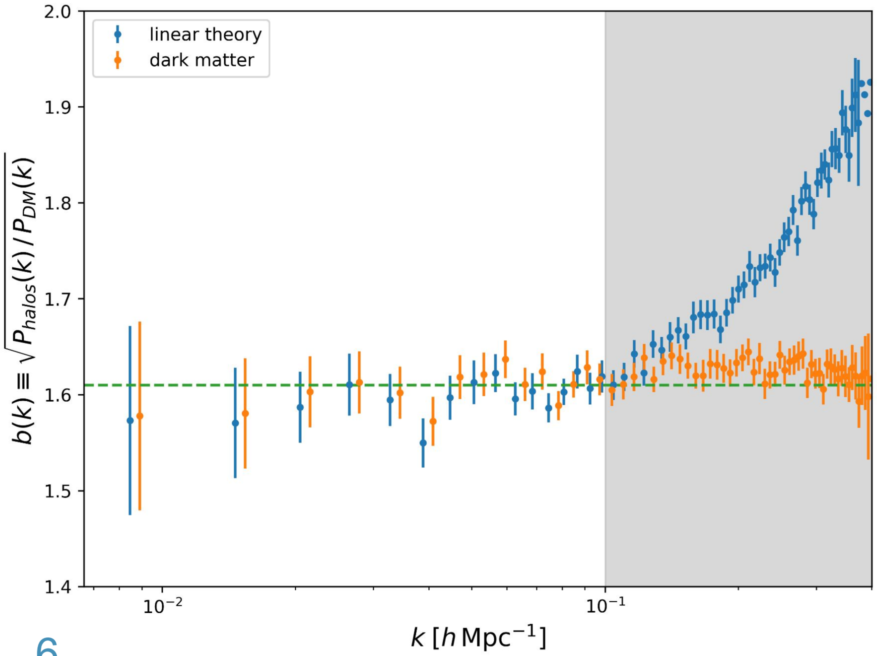
METHODOLOGY

- Fix $f_{\rm NL}$. We explore the parameter space (b_1, p)





SCALE CUTS



- We model the bias as:

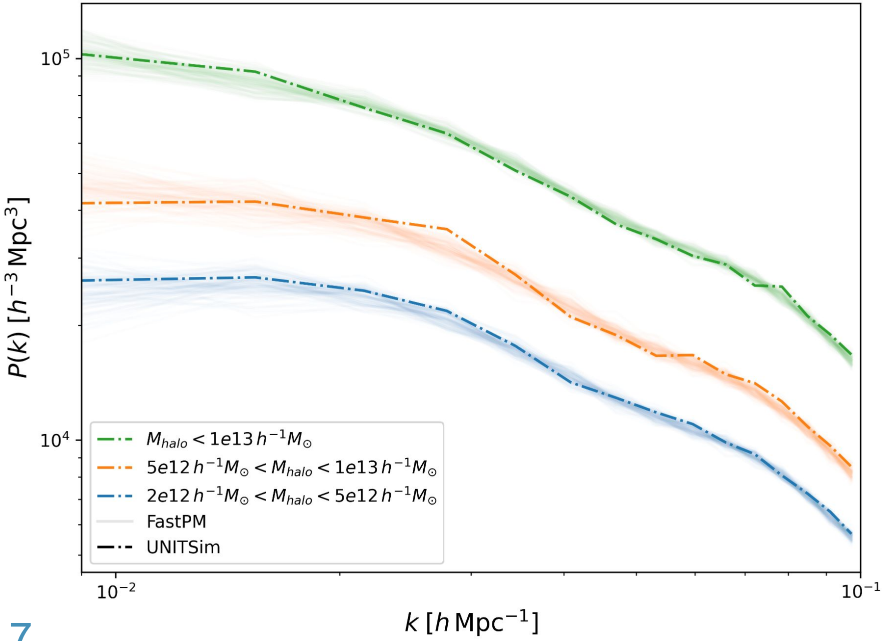
$$\delta_{halos} = b(k, f_{\mathrm{NL}}) \cdot \delta_m$$

- Linear theory describes accurately the $P_{halos}(k)$ for $k_{max} < 0.1h\,\mathrm{Mpc}^{-1}$ up to the fundamental mode of the box: $k_f = 0.00628h^{-1}\mathrm{Mpc}$

- We can get a bit into the non-linear regime by using $P_{DM}(k)$

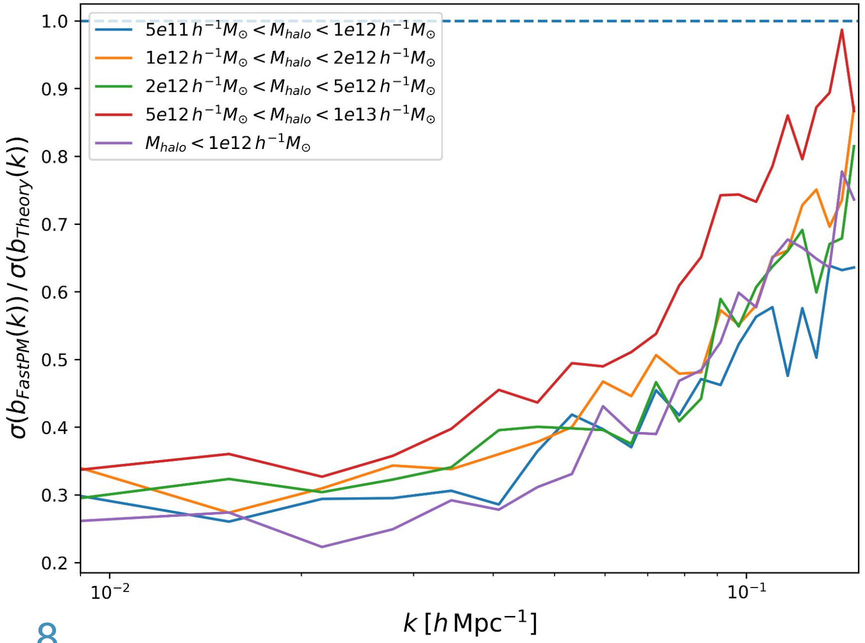
- Conservative approach: only the purely linear part.

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
VARIANCE SUPPRESSION



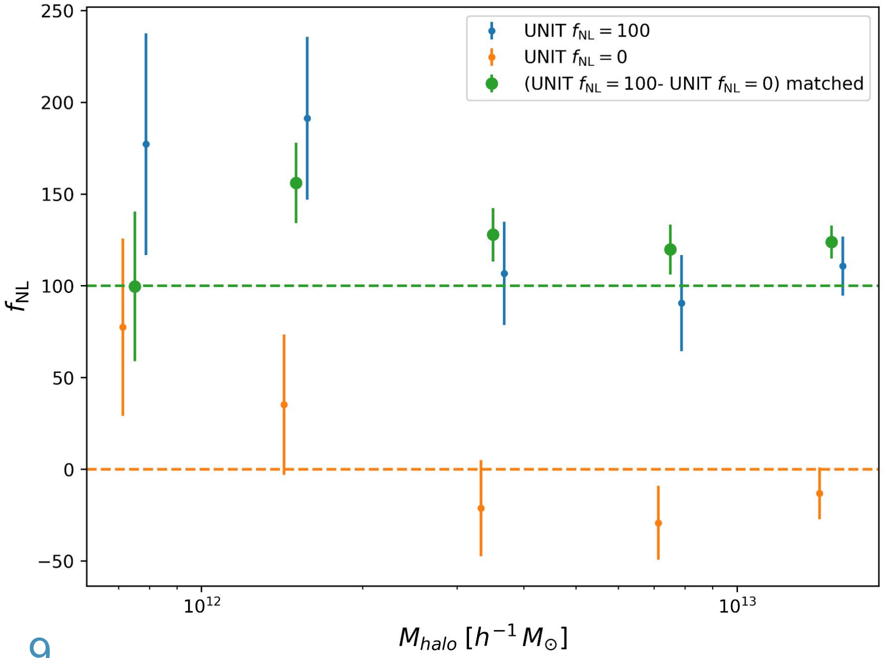
- Fixing ICs [Angulo & Pozten (2016)] reduces the variance w.r.t. theoretical expectation for a Gaussian field [Feldman et al. (1994)].

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

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

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

MATCHING FNL 0 AND FNL 100



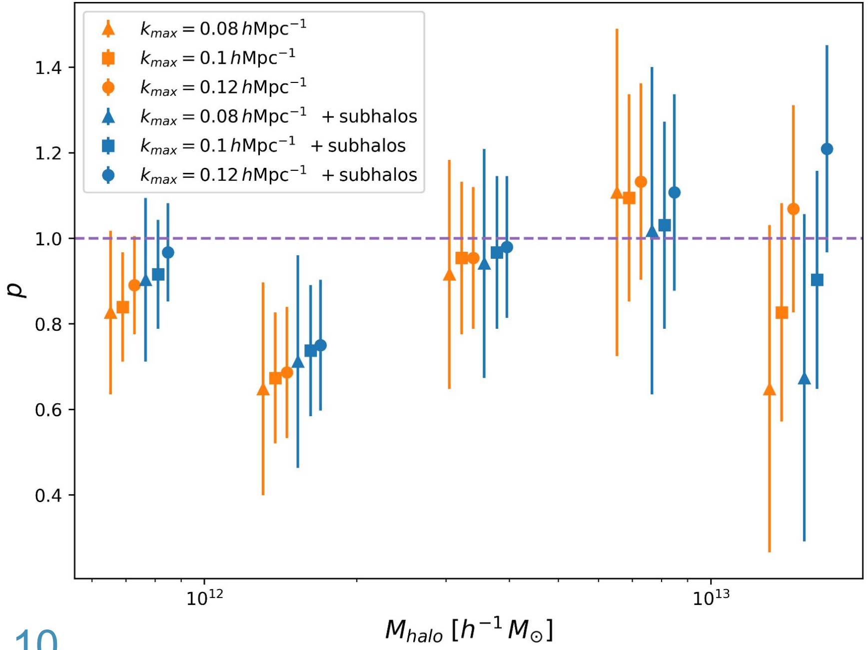
- The original UNITSim have matched ICs. Measurements are correlated [Ávila and Adame (2022)].

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

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

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

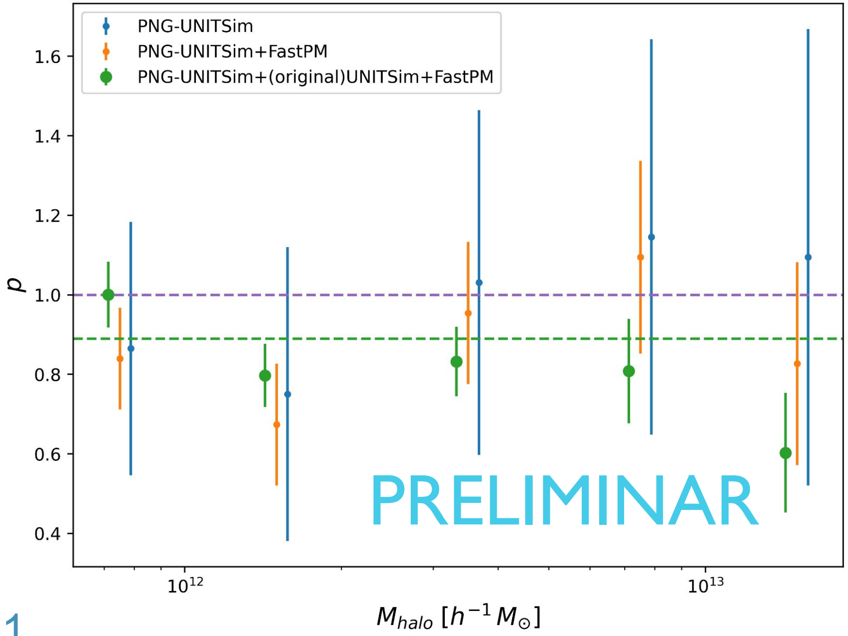
ROBUSTNESS TESTS



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 $k_{max} = 0.1h\,\mathrm{Mpc}^{-1}$
- Including the subhalos does not affect the fits on p.
- Our variance reduction techniques does not bias the results

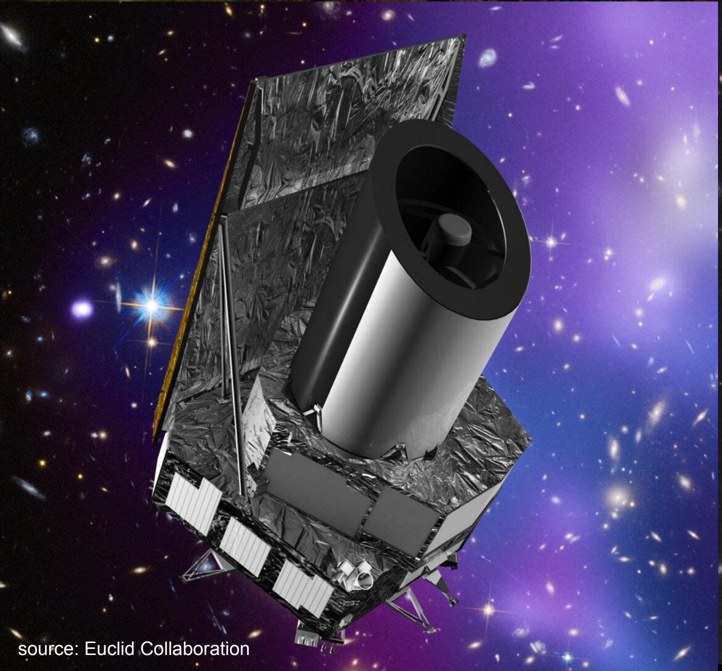
CONSTRAINTS ON P



- The preliminary results indicate that for DM halos:
  - p(M)< 1 preferred at $> 1\sigma$
  - No significant variation of p with mass $(< 2\sigma)$
  - "Fixed and matched" ICs + FastPM realizations: improve constraints on p by a factor of ~4
  - Using all these halos in at the time, we get:

$$p = 0.89 \pm 0.07$$

source :DESI Collaboration



source: Euclid Collaboration

PROSPECTS

- Extend our analysis to lower halo masses
- Check the convergence with other box sizes/resolutions.
- Using SAM to populate the PNG-UNITSim with:
  - LRGs and ELGs, (e. g. SAGE as in Knebe et al. (2022)
  - HI (as in Ávila, Vos-Ginés et al. (2022)) .
- With one pair of sims, we expect to be able to put priors on p, that will derive in uncertainties of $\sigma(f_{\rm NL}) < 5$ (comparable to DESI or EUCLID forecasts).

source: NASA/JWST

CONCLUSIONS

- Combining the PNG-UNITSim with the original one, we get strong constraints on p.
- Using FastPM mocks we get a reduction in the errors by a factor ~2 at low computational cost.
- The measurement is robust against changes in:
  - Scale cuts
  - Halos/subhalos
  - FastPM variances
  - Matching the simulations
- Preliminary results suggest that p may not vary with mass.
- Combining all the mass bins, $p<1$ is preferred at 1.6-sigmas

source: NASA/APOD 2010/11/18: John Davis

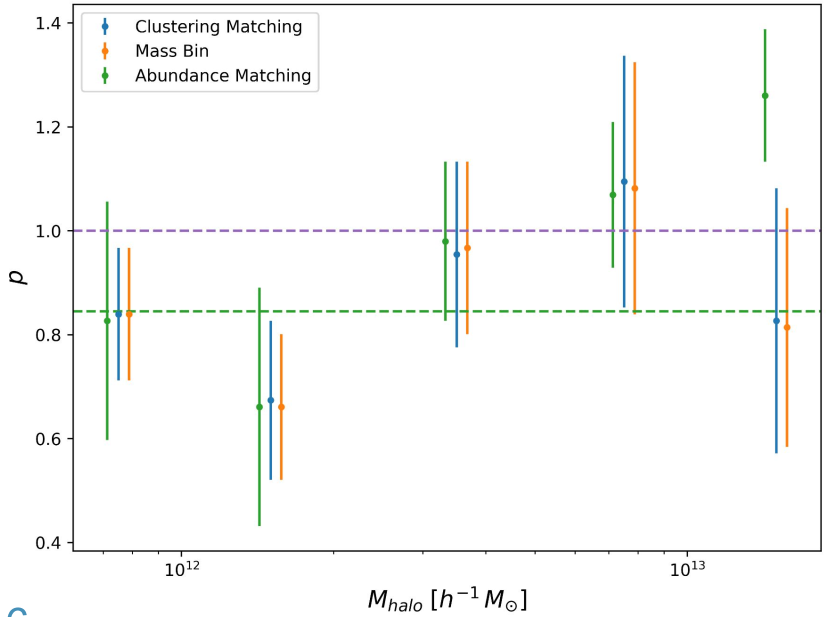
Backup slides

MASS BINS

$M_{min}\,[h^{-1} M_{\odot}]$	$M_{max}\,[h^{-1} M_{\odot}]$
5e11	1e12
1e12	2e12
2e12	5e12
5e12	1e13
1e13	–

- We defined 5 mass bins separated in a logarithmic scale.
- The minimum mass is given by the resolution of the FastPM realizations:
  - $M_{halo,min} \sim 50\, M_{part,FastPM}$
- The last bin is "special". We take all the halos heavier than the lower limit.
- We have more than 200.000 halos in each bin.

FASTPM: MATCHING TO UNITSIMS



- Comparable results on p(M) for
  - Abundance matching.
  - 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.