Cosmic Structure Evolving from Primordial non-Gaussianities

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Abstract

Cosmic structure is seeded by highly Gaussian quantum fluctuations that freeze out as the horizon shrinks (k_{horizon} increases) during inflation. Primordial non-Gaussianity (PNG) sheds light on the physics of inflation. We demonstrate new constraints on inflation using an intermittent form of PNG (PING) generic to any inflation model with an additional field χ [1,2]. Using Large-scale structure simulations, we show that PING can give rise to measurable effects on the sky, and contrast them with recently observed anomalous phenomena like JWST high-z galaxies [3].

Theory: Primordial Non-Gaussianity

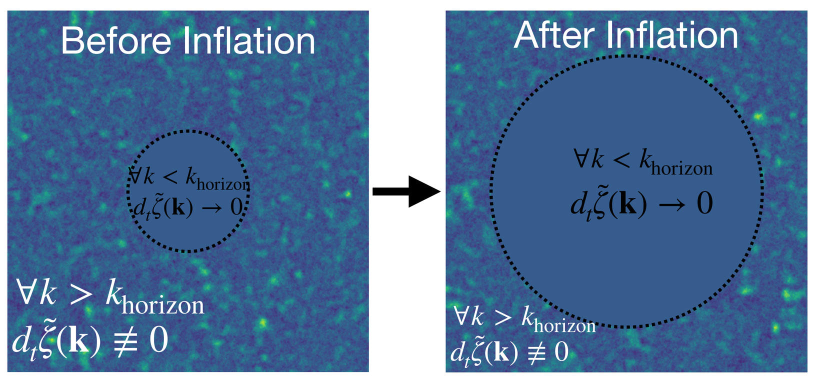

Figure 1: cartoon illustrating that as modes $\tilde{\zeta}(\mathbf{k})$ cross outside the horizon (dotted line) and stop evolving $d_t\tilde{\zeta}(\mathbf{k}) \to 0$ (blue). Inside the horizon they fluctuate freely between positive (yellow) and negative (violet).

In multi-field inflation[1], instabilities in the potential $V(\phi, \chi)$ generate **PING related by a functional to the second inflationary field** χ.

Instabilities grow a non-Gaussian perturbation to the inflaton

$$\Delta\phi(\mathbf{x}, H_e) \propto \chi_g^2(\mathbf{x}, H_e)$$

The non-Gaussian response is preserved in the ζ field mode-by-mode as it freezes out, this can be expressed as a convolution with a transfer function[2]

$$\Delta\tilde{\zeta}_{ng}(\mathbf{k}, H_f) = T_{\Delta\phi(H_e)\to\Delta\zeta_{ng}(H_f)}(k)\Delta\tilde{\phi}(\mathbf{k}, H_e)$$

After inflation, $\dot{k}_{\text{horizon}} < 0$ and ζ modes re-enter the horizon, coupling to observable fields like density contrast $\tilde{\delta}(\mathbf{k}) = T_{\zeta\to\delta}(k)\tilde{\zeta}(\mathbf{k})$ [5].

Cosmological Simulations

We model the effects of PING on cosmic structure across a range of scales using simulations of the Cosmic Web.

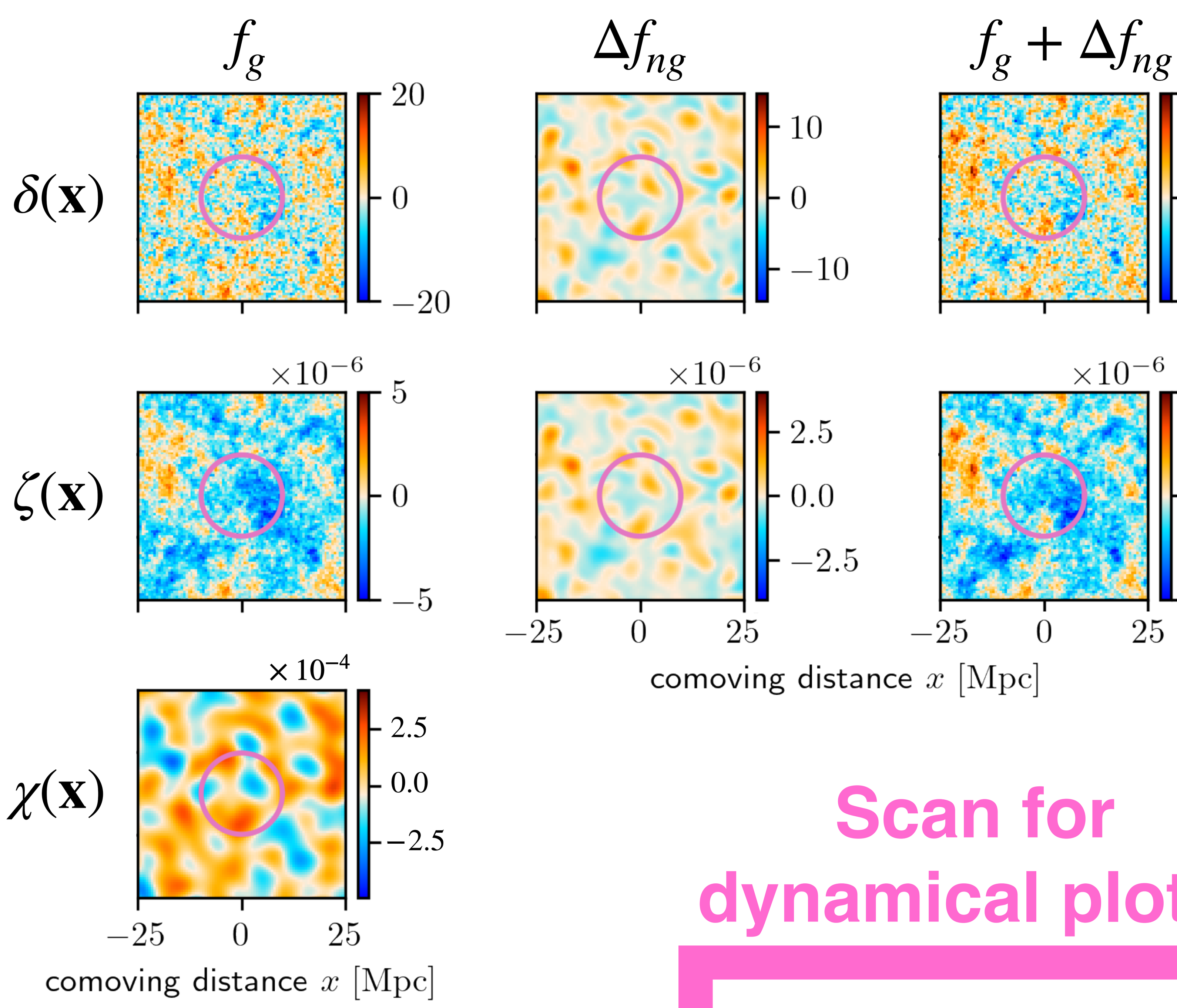

Figure 2: slices of cubic realizations of cosmic fields. Pink circles show the characteristic scale of the PINGs.

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[1] For the lowest-order PNG in single-field inflation models, $\zeta(\mathbf{x}) = \zeta_g(\mathbf{x}) + f_{\text{NL}}[\zeta_g^2(\mathbf{x}) - \langle\zeta_g^2(\mathbf{x})\rangle]$, f_{NL} is constrained to order 1 by bispectrum measurements [4]. Such constraints aren't expected for PING.

[2] The transfer function relates the inflaton perturbation when the instability is extremized at H_e, to the ζ response sufficiently long after the end of the instability for $\Delta\zeta_{ng}$ to have stopped fluctuating at H_f.

References

[1] Morrison, T., Braden, J., and Bond, J. R. (in prep.)

[2] Morrison, T., *et al.* II. (in prep.)

[3] Cariani, S., et al. (2024) arXiv:2405.18485.

[4] Planck Collaboration (2020) *A&A* **641**(A9), arXiv:1905.05697.

[5] Bardeen, J. M., Bond, J., R., Kaiser, N., Szalay, A. S. (1986) *ApJ* **304**(15), doi: 10.1086/164143.

Scan for dynamical plots!

Peak Patch Dark Matter Halo Catalogues

We use the ***Peak Patch*** code to simulate the distribution of dark matter (DM) halos that will form from the primordial overdensity $\delta(\mathbf{x})$.

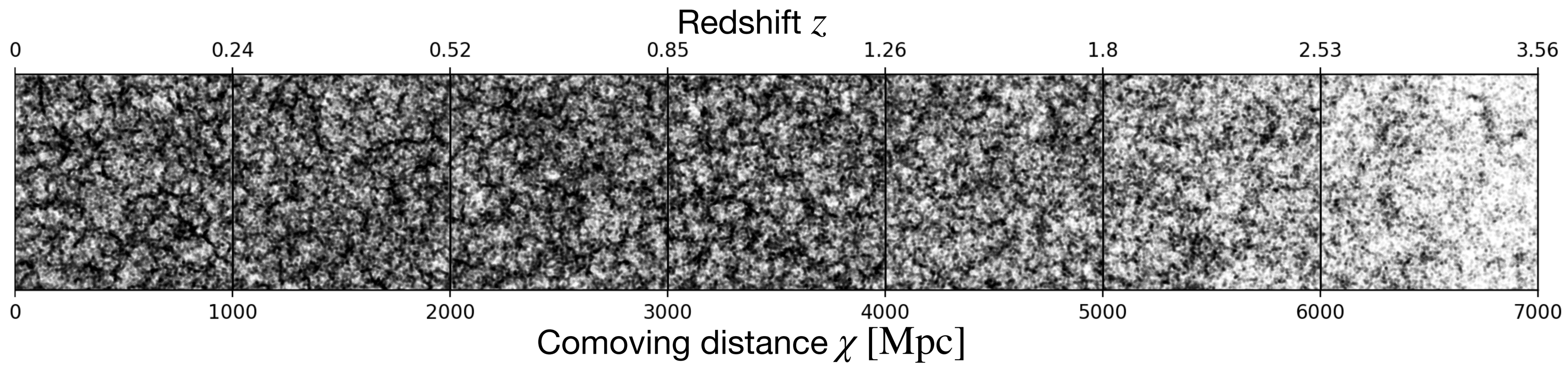

Figure 3: a number density plot of *Peak Patch* DM halos. The redshift evolution of structure is visible with fewer halos at high redshift and more filamentary structure of the Cosmic Web visible at low redshift.

WebSky2.0 Mock Maps of the Sky

We use the ***WebSky*** code to generate **mock maps** in a wide suite of cosmological observables. The PING model can produce structures at almost any scale. The breadth of observables allow us test vast swathes of the PING parameter space.

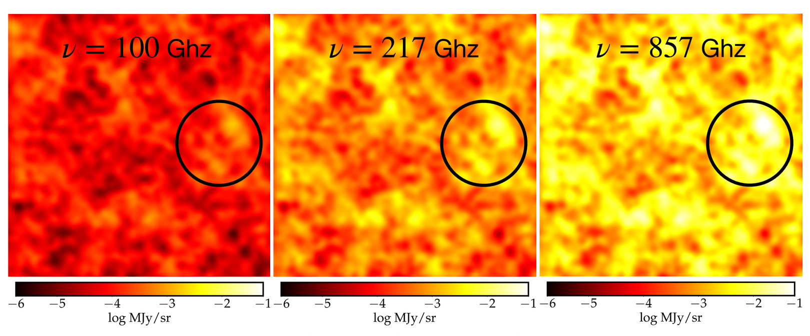

Figure 4: *WebSky* CIB, tSZ and lensing mock maps.

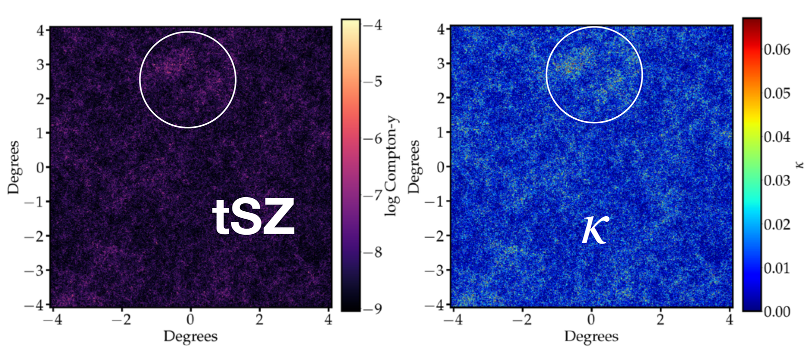

Figure 5: *WebSky* tSZ and lensing mock maps, highlighting a prominent PING signal augmentation.

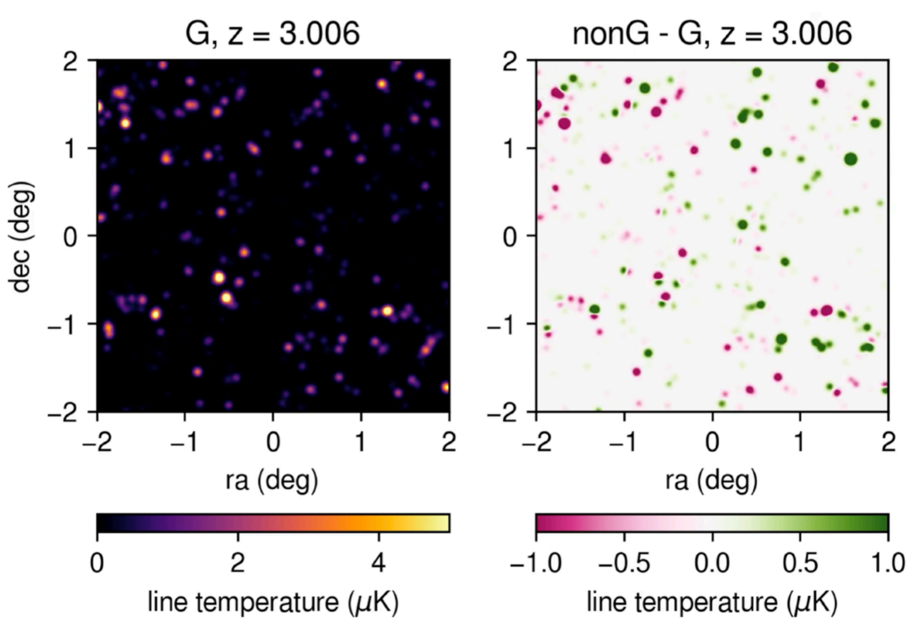

Figure 6: *WebSky* CII Line intensity mock map. Left panel: CII map with Gaussian initial conditions; right panel: difference map showing the excess CII emission signal due to PINGs.

Statistical Analysis

Together, halo catalogues and mock sky maps provide a wealth of information for statistical analyses. **We use relative entropy (K-L divergence) to measure statistical difference between Gaussian and PING cases**.

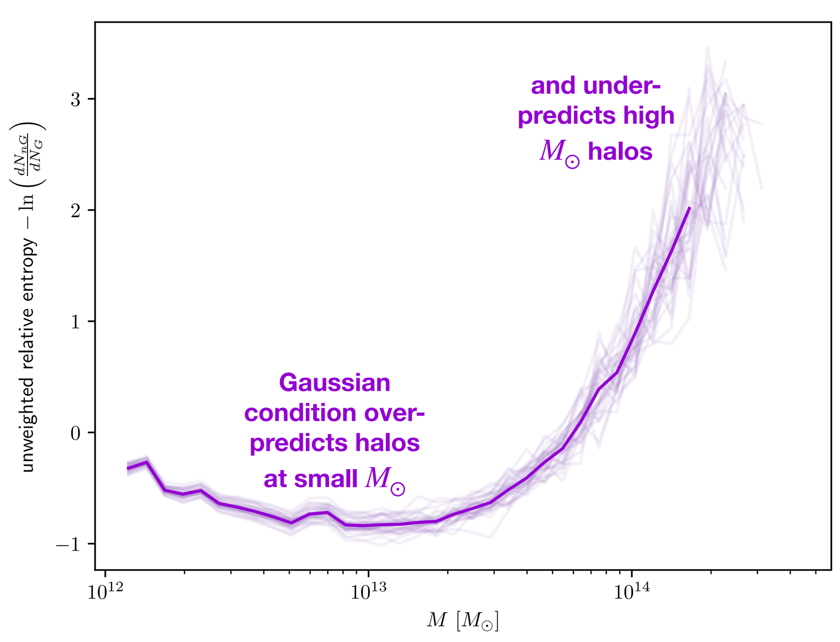

Figure 7: Relative entropy showing statistical difference between the two halo catalogues.

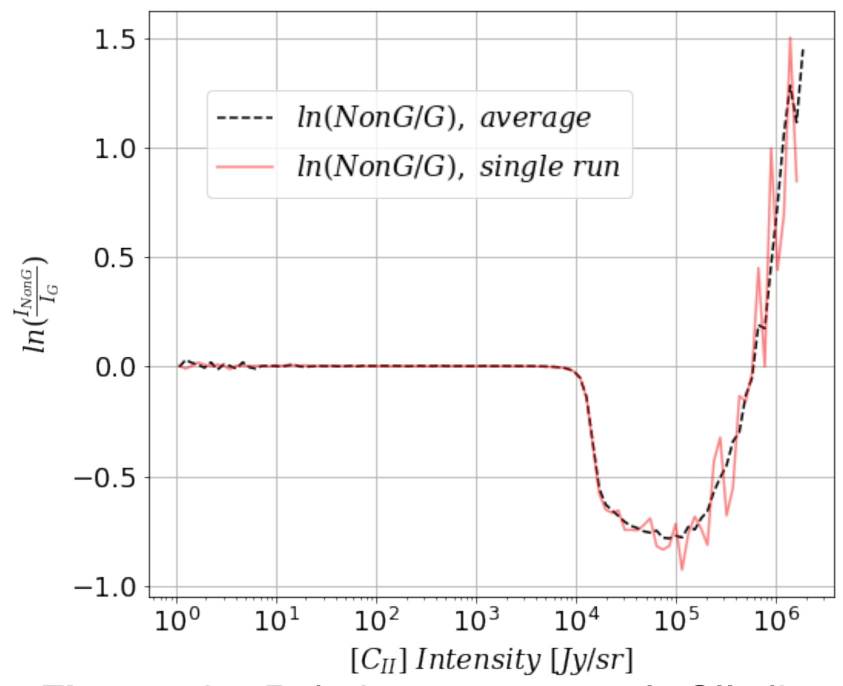

Figure 9: Relative entropy of CII line intensity map.

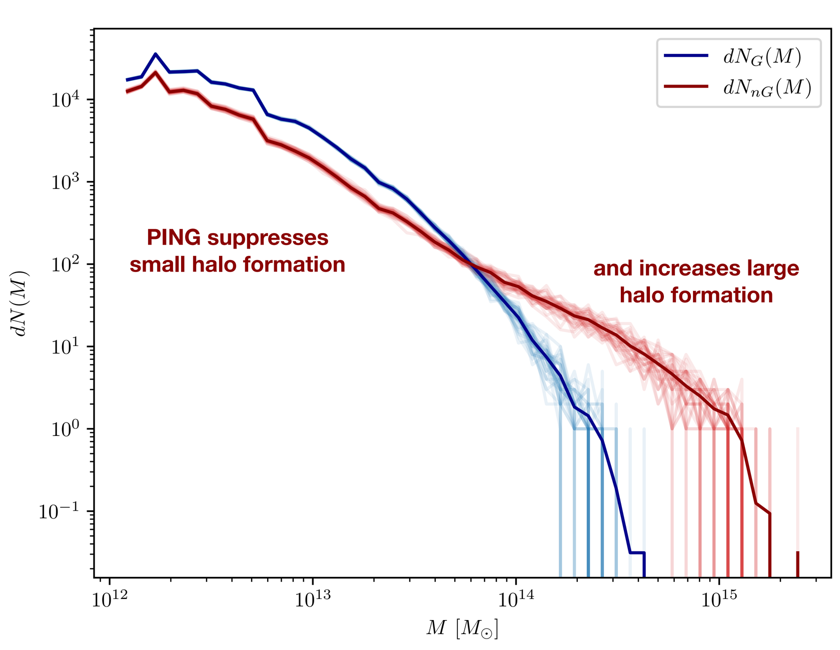

Figure 8: *Peak Patch* halo mass functions for Gaussian and PING cases.

Conclusions

- We can put constraints on the parameter space of ***all*** multi-field inflation models.
- Constraints span many orders of magnitude in scale, affecting physics of star formation to reionization to the Cosmic Web and could explain anomalous high-z galaxies.