

Effect of Trans-Planckian Environment on Primordial Spectra and Non-Gaussianity

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A close look to vacuum fluctuations

$$h_k'' + 2\mathcal{H}h_k' + k^2h_k = 0$$

Homogeneous differential equation

$$h_k(\tau) = A_k\sqrt{-k\tau}H_\nu^{(1)}(-k\tau) + B_k\sqrt{-k\tau}H_\nu^{(2)}(-k\tau)$$

General solution

$$\bar{\tau}(k) = -\frac{\Lambda}{kH}$$

$$A_k = 1 \quad B_k = 0$$

Bunch-Davies choice

$$B_k = \frac{\Lambda}{2H} \quad A_k = \sqrt{1 + B_k^2}$$

Cut-off energy scale

$$P_{BD}^t = \frac{2H^2}{\pi^2 M_{Pl}^2}$$

Nearly scale invariant

$$P_{\alpha-vacua}^t = \frac{2H^2}{M_{Pl}^2 \pi^2} \left[1 + \frac{H}{\Lambda} \sin\left(\frac{2\Lambda}{H}\right) + \dots \right]$$

Alpha-vacua

Danielsson: arxiv 0203198

Broy: arxiv 1609.03570

For recent developments see: Kanno, Sasaki arxiv 2206.03667

Induced degeneracy by a stochastic source

Our set-up

$$\begin{aligned}
 h_k'' + 2\mathcal{H}h_k' + k^2h_k &= 16\pi G \Pi_k & \tau \leq \bar{\tau}(k) \\
 h_k'' + 2\mathcal{H}h_k' + k^2h_k &= 0 & \tau > \bar{\tau}(k)
 \end{aligned}
 \quad \bar{\tau}(k) = -\frac{\Lambda}{kH}$$

THE SOURCE

$$\hat{\Pi}_k^r(\tau) = \Pi_k(\tau)\hat{a}_k^r + \Pi_k^*(\tau)\hat{a}_{-k}^{r\dagger}, \quad \langle \Pi_k(\tau) \rangle = 0$$

$$\langle \Pi_k(\tau)\Pi_k^*(\tau') \rangle = \mathcal{N}\delta(\tau - \tau')F(k)$$

THE MATCHING

$$\begin{aligned}
 \tilde{h}_k(\bar{\tau}_-) &= h_k(\bar{\tau}_+) & A_k &= \frac{e^{ik\bar{\tau}}[\tilde{h}(\bar{\tau})(-1 + ik\bar{\tau} + k^2\bar{\tau}^2) - \tilde{h}'_k(\bar{\tau})(\bar{\tau} - ik\bar{\tau}^2)]}{\sqrt{2}k^{3/2}\bar{\tau}^2} \\
 \tilde{h}'_k(\bar{\tau}_-) &= h'_k(\bar{\tau}_+) & B_k &= \frac{e^{-ik\bar{\tau}}[\tilde{h}(\bar{\tau})(-1 - ik\bar{\tau} + k^2\bar{\tau}^2) - \tilde{h}'_k(\bar{\tau})(\bar{\tau} + ik\bar{\tau}^2)]}{\sqrt{2}k^{3/2}\bar{\tau}^2}
 \end{aligned}$$

Phenomenological model for $F(k)$

Black Hole gas model

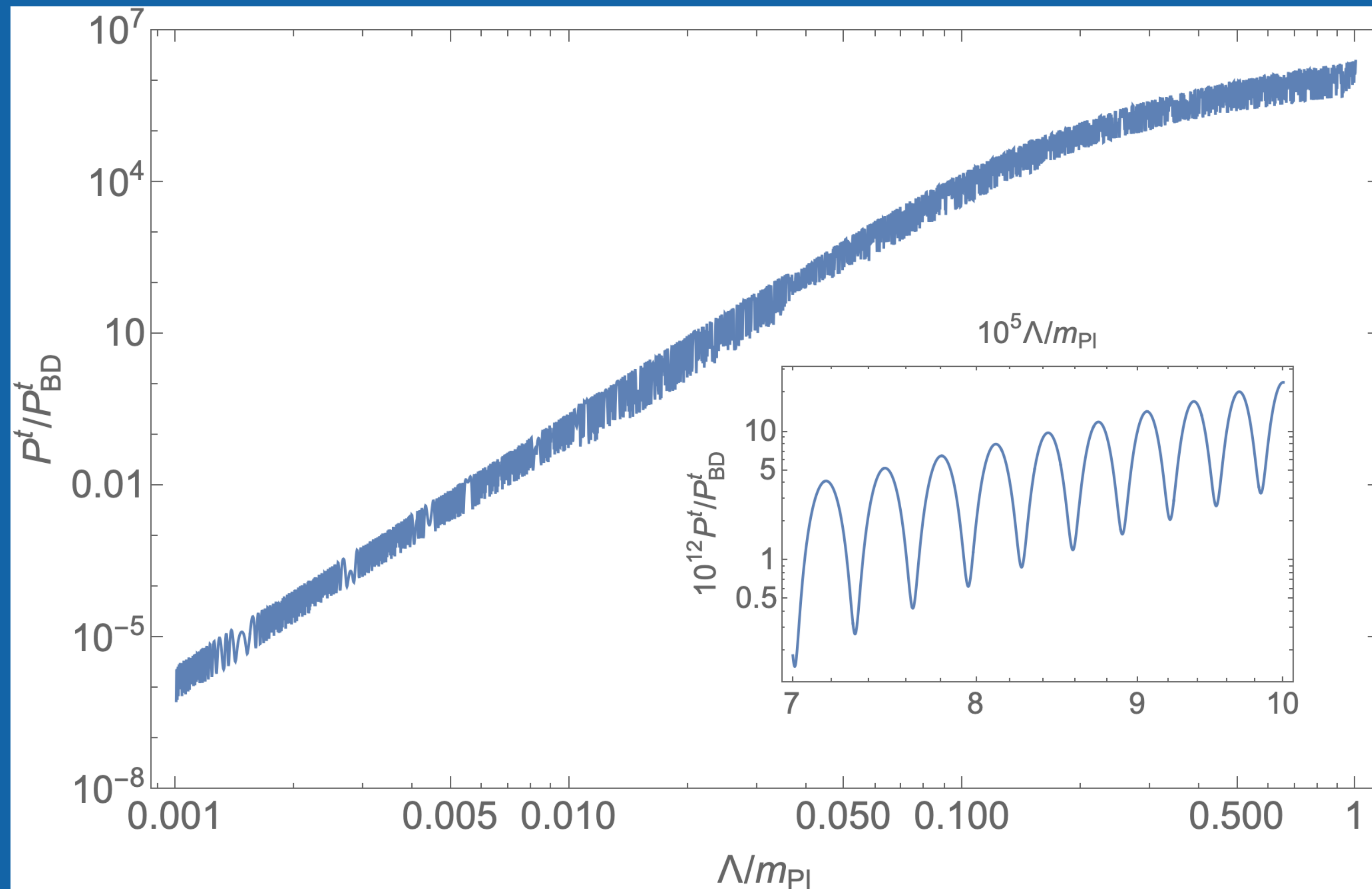
- For $\Lambda \geq m_{pl}$ linear perturbation theory is not reliable
- Trapped surfaces form due to the collapse of trans-Planckian modes
- We can model the $F(k)$ function to model the environment as follow:

$$F(k) = \int_0^{\infty} \underbrace{\xi(M)dM}_{\text{M-B distribution for Hawing radiation}} \underbrace{e^{-\frac{k_{phys}}{T_H}}}_{\text{M-B distribution for Hawing radiation}}$$

M-B distribution for Hawing radiation

$$\xi(M)dM = \frac{e^{-M/\Lambda}}{\Lambda} dM$$

A scale-invariant result from BH-gas model



Looking for degeneracies into CMB data (Planck18)

$$P_{scalar} = \frac{H^2}{m_{Pl}^2 \times \epsilon_{inflation}} \times S(\Lambda/m_{Pl}) \times \left(\frac{k}{k_*}\right)^{n_s-1}$$

More freedom for ϵ !

$$A_S = \frac{H^2}{m_{Pl}^2}$$

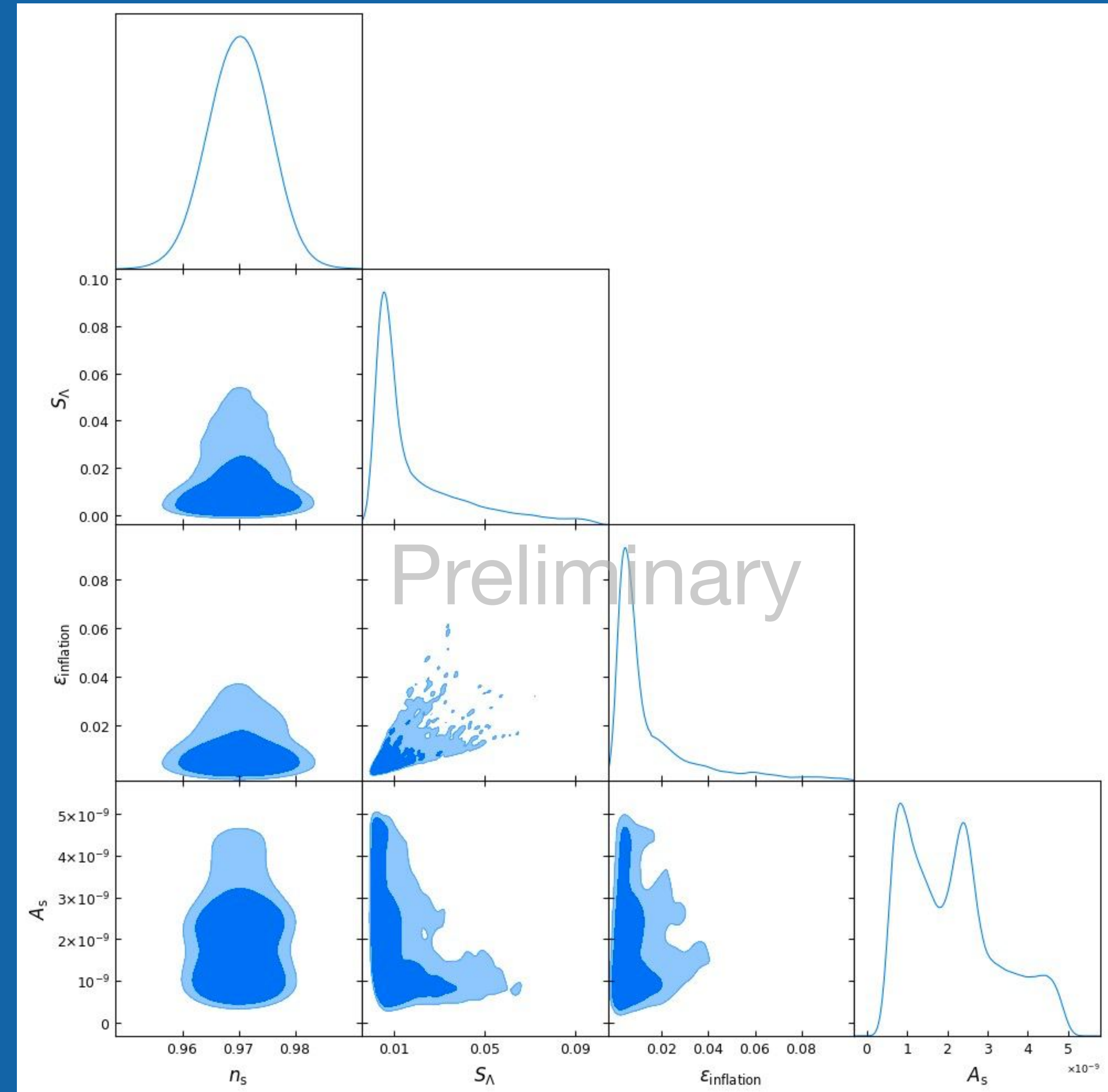
Current values

$$n_s = 0.9649 \pm 0.044$$

$$\ln(10^{10} A_S) = 3.044 \pm 0.016$$

$$H_* \leq 8 \times 10^{13} GeV$$

MC, Mangano, Pisanti. arxiv:23XX.XXXX



The Smoking Gun: Non-Gaussianity

Gravitational Wave non-Gaussianity from trans-Planckian Quantum Noise

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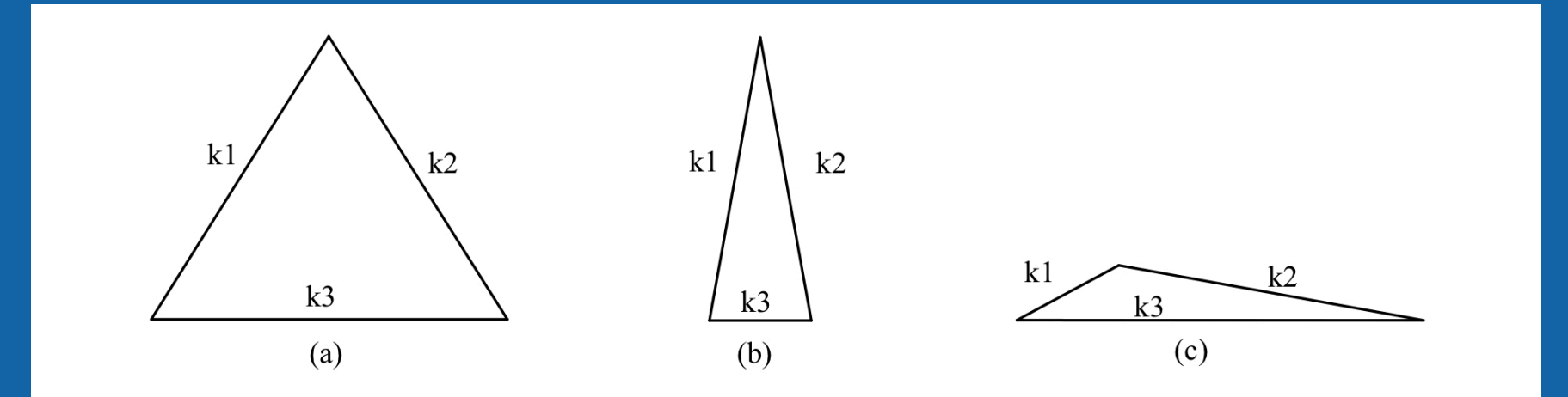
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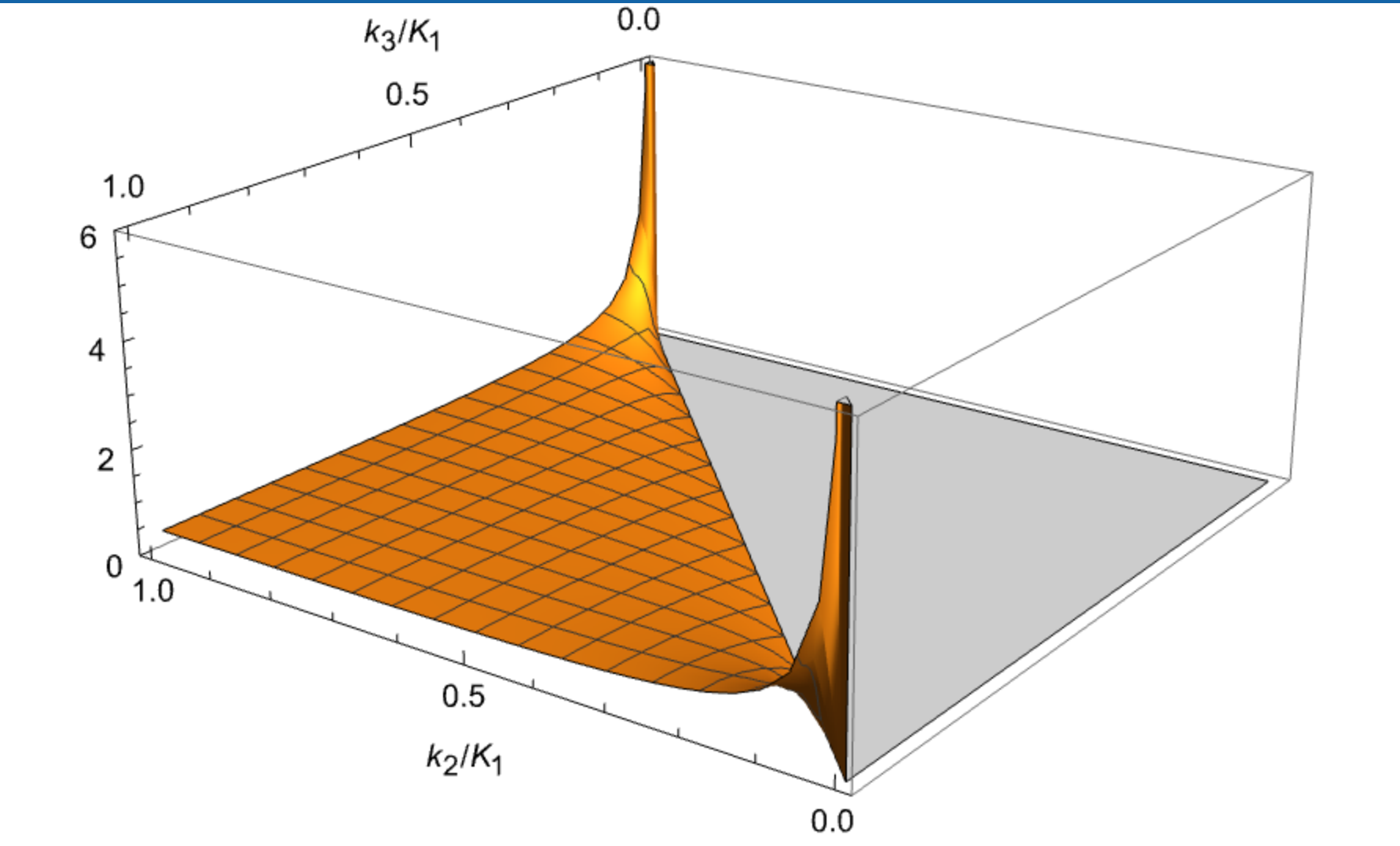
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arxiv:2309.XXXX

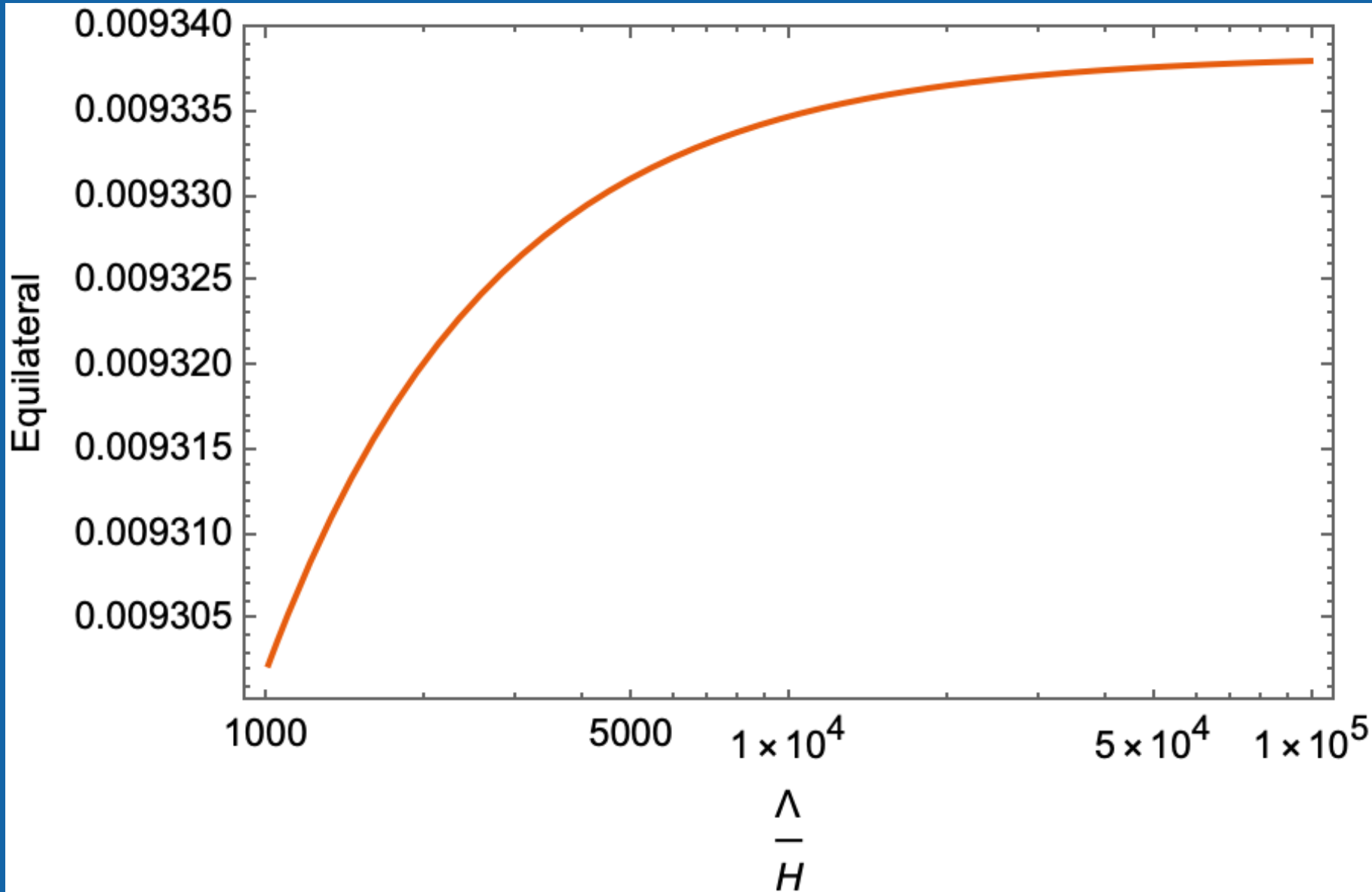
$$F(k) = 1$$

BD Vacuum

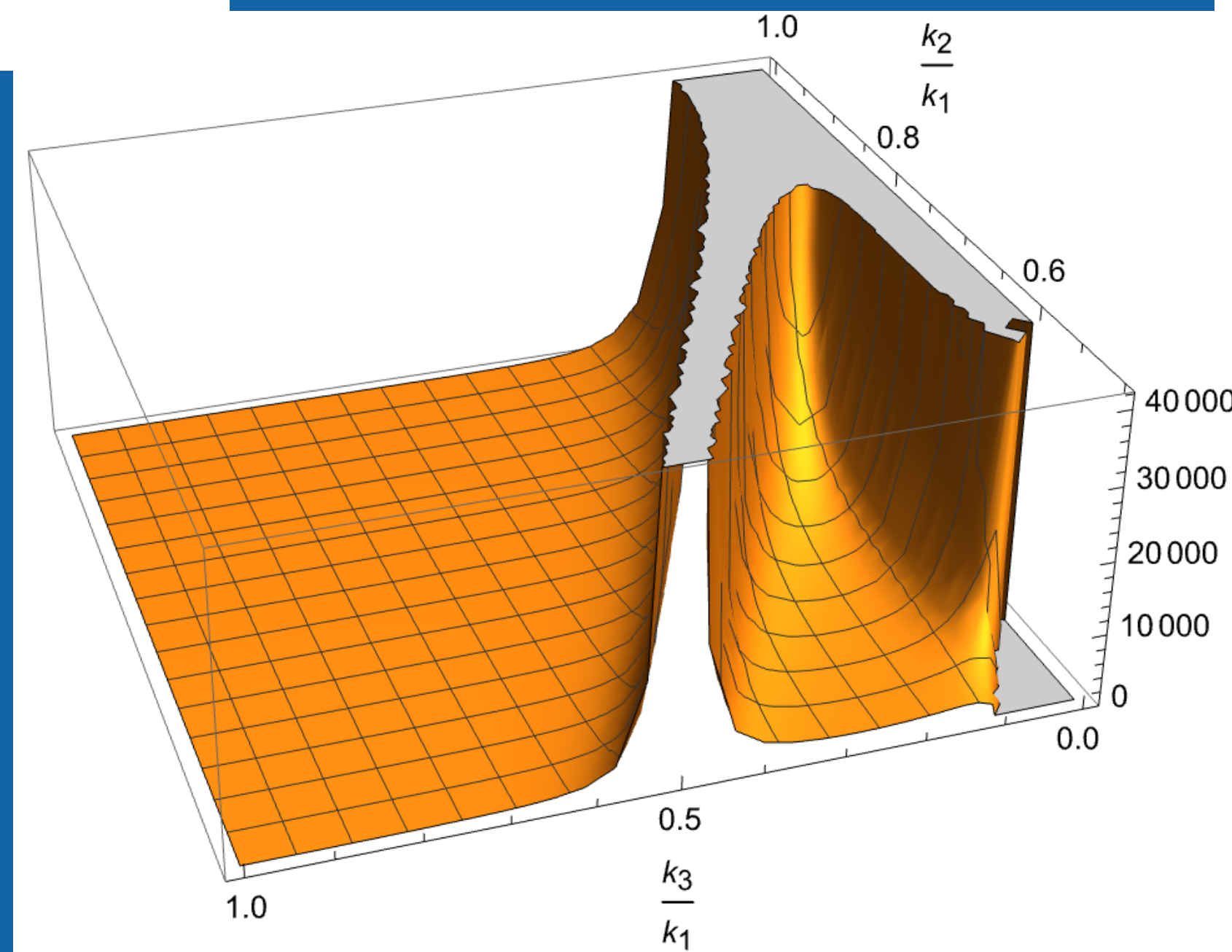
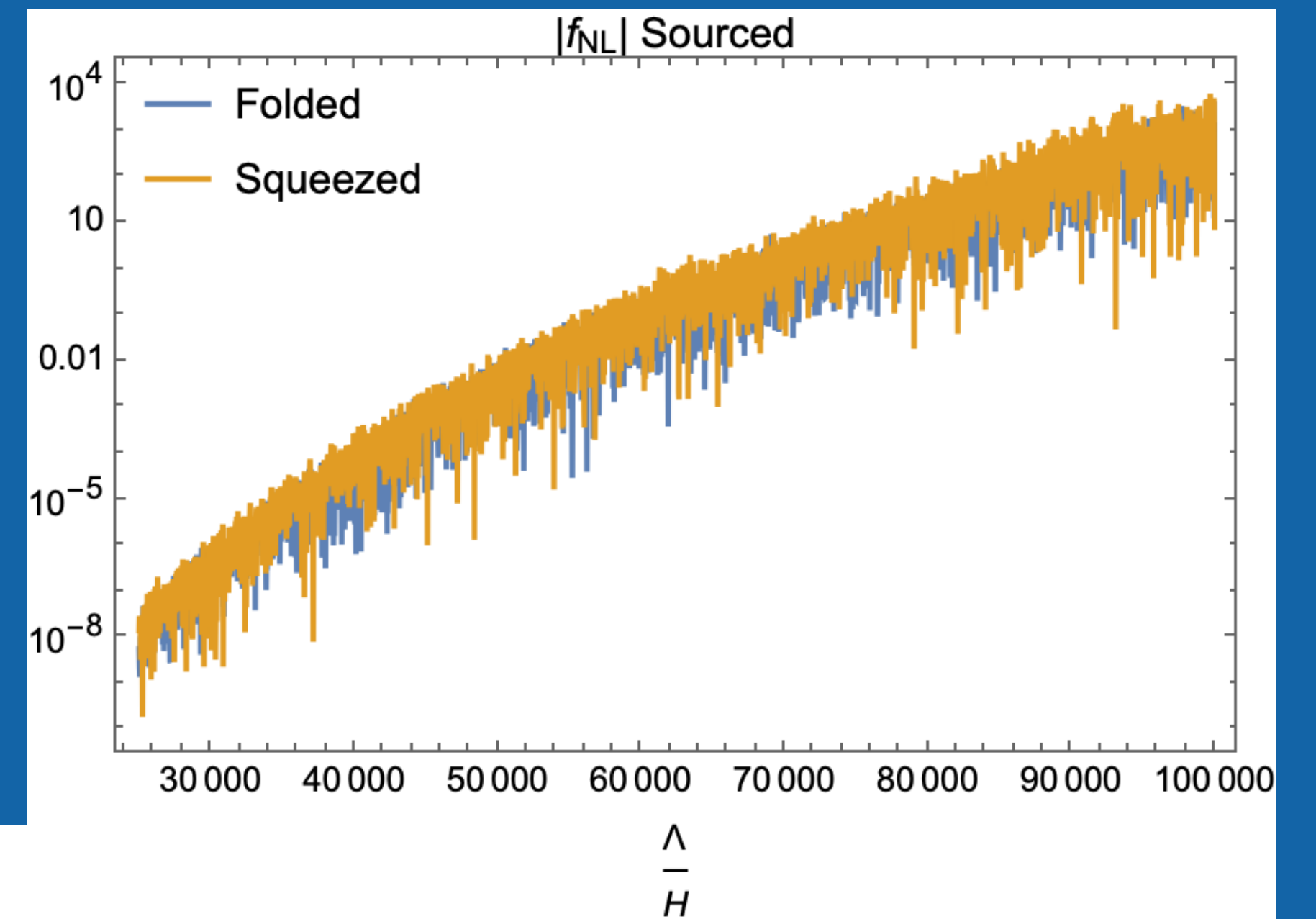
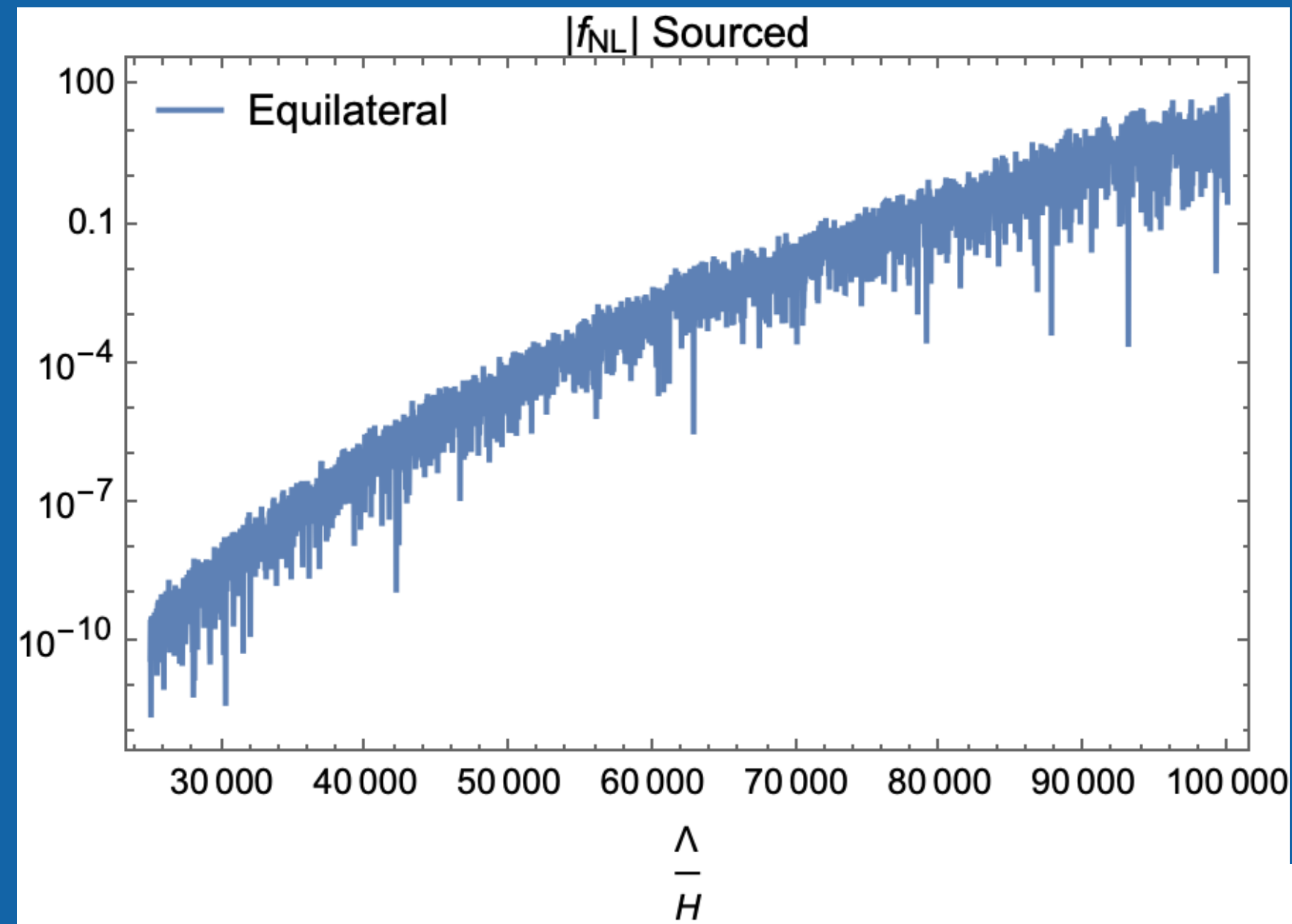


f_{NL} parameter for BD vacuum		
Equilateral	Squeezed	Folded
0.00933	0.00293	0

Fixed Time selection from alpha-vacua



SWITCHING ON THE SOURCE



Take Home Message

Trans-Planckian environments can play active roles and open windows to yet not well-explored physics sectors

Future Prospects:

- Deeper characterization of the PGWB
- Shedding light on quantum phenomena during Inflation
- Opening a window on stochastic effects on PGWB

Thank you for your attention!

