# Effect of Trans-Planckian Black Holes on primordial spectra

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NEHOP - NEW HORIZONS IN PRIMORDIAL BLACK HOLES
NAPLES

In collaboration with: Matteo Fasiello, Gianpiero Mangano and Ofelia Pisanti

# A close look to vacuum fluctuations

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

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

$$A_k = 1 \qquad B_k = 0$$

Bunch-Davies choice

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

Nearly scale invariant

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

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

Cut-off energy scale

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

Alpha-vacua

Danielsson: arxiv 0203198
Broy: arxiv1609.03570

For recent developments see: Kanno, Sasaki arxiv 2206.03667

# Induced degeneracy by a stochastic source

Our set-up

$$h_k'' + 2\mathscr{H} h_k' + k^2 h_k = 16\pi G\, \Pi_k \qquad \tau \leq \bar{\tau}(k)$$
$$h_k'' + 2\mathscr{H} h_k' + k^2 h_k = 0 \qquad \tau > \bar{\tau}(k)$$
$$\bar{\tau}(k) = -\frac{\Lambda}{kH}$$

THE SOURCE

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

THE MATCHING

$$\tilde{h}_k(\bar{\tau}_-) = h_k(\bar{\tau}_+)$$
$$\tilde{h}_k'(\bar{\tau}_-) = h_k'(\bar{\tau}_+)$$

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

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

MC, Mangano, Pisanti. arXiv:2211.04316 (PRD)

# Phenomenological model for F(k)

## Black Hole gas model

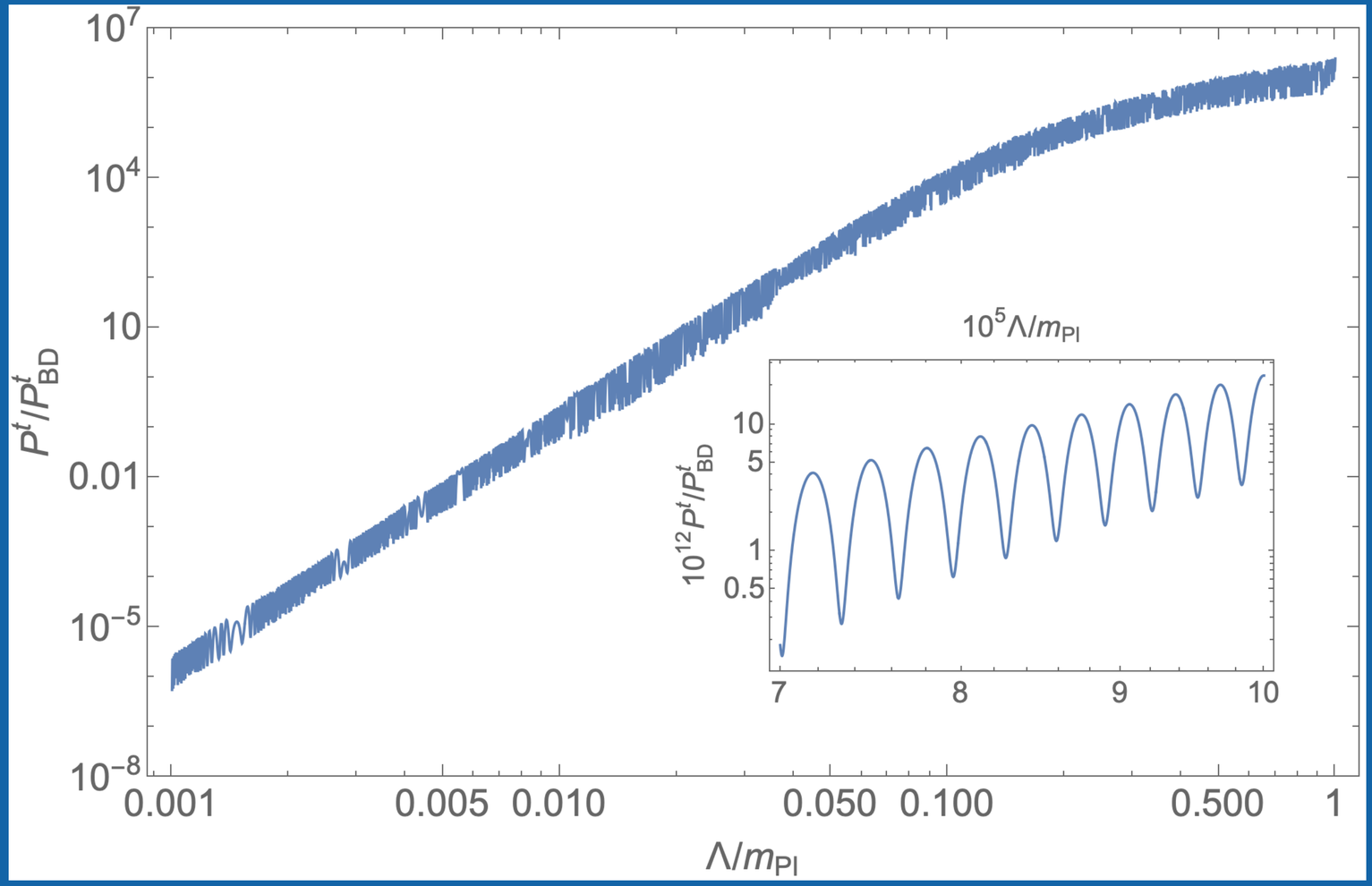
- For $\Lambda \geq m_{Pl}$ linear perturbation theory is not reliable
- Trapped surfaces form due to the collapse of trans-Planckian modes
- We can model the F(k) function to model the environment as follow:

$$F(k) = \int_0^\infty \underbrace{\xi(M)dM}\ \underbrace{e^{-\frac{k_{phys}}{T_H}}}$$

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

M-B distribution for Hawing radiation

# 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 $\epsilon$!

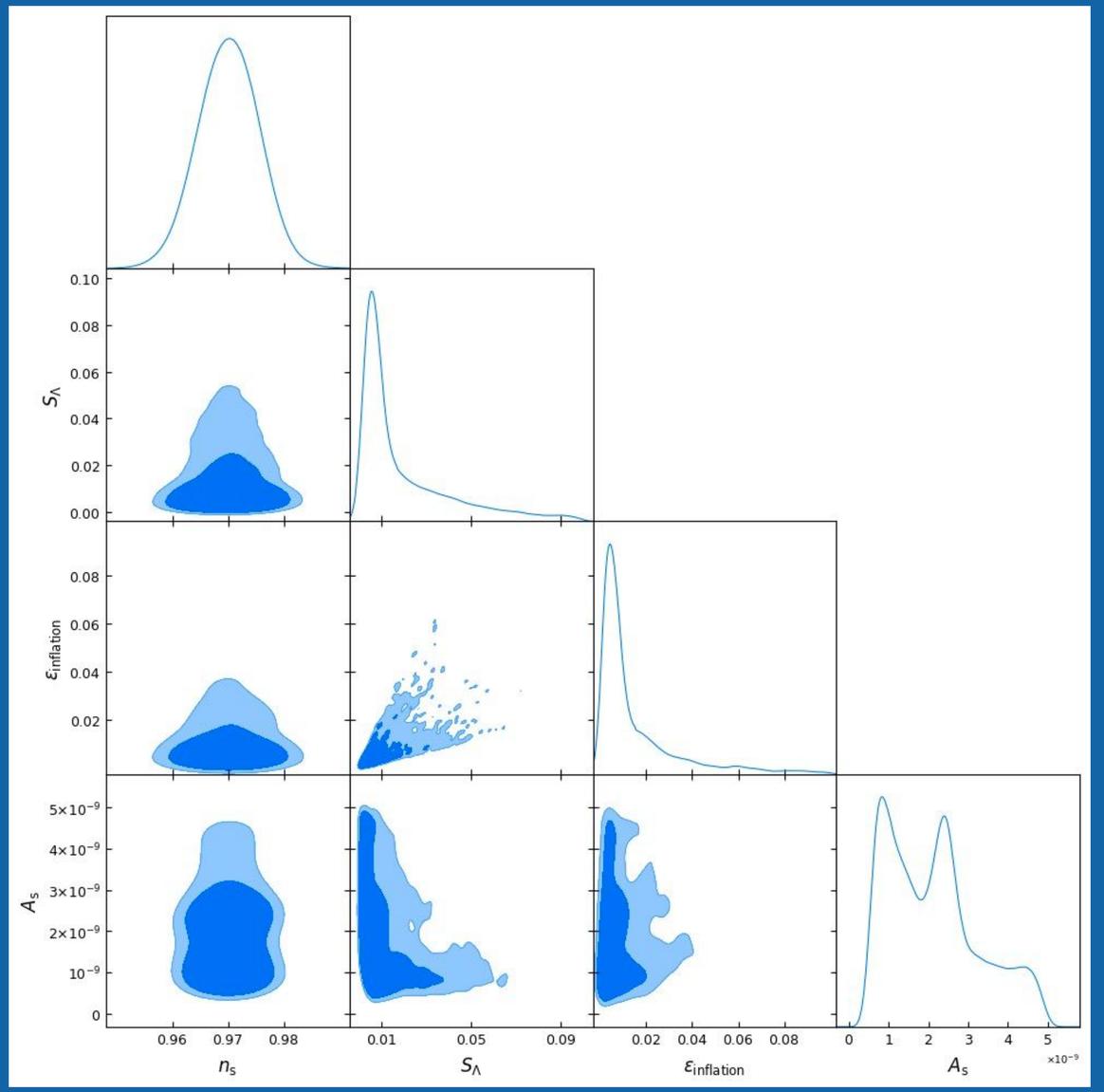
$$A_S = \frac{H^2}{m_{Pl}^2}$$

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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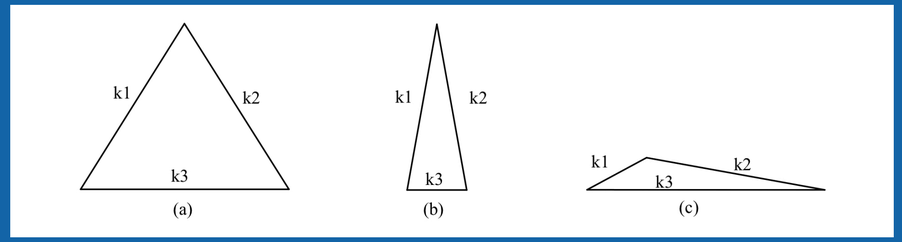
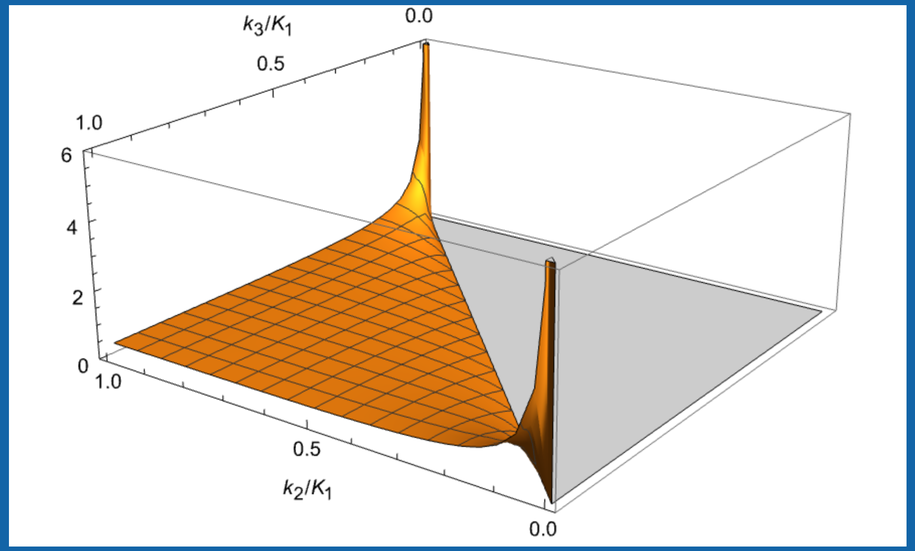



arxiv:2306.XXXX

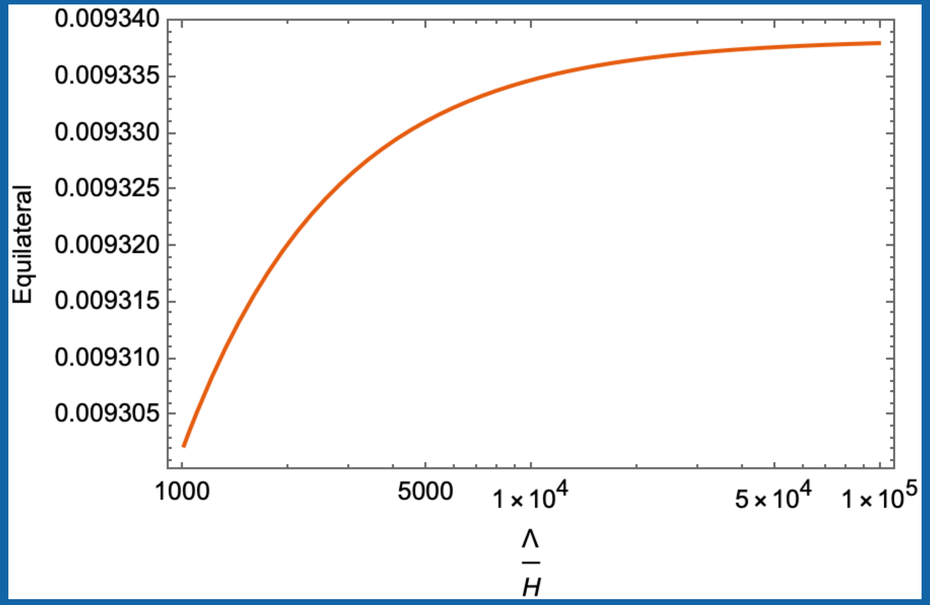
$$F(k) = 1$$

# BD Vacuum

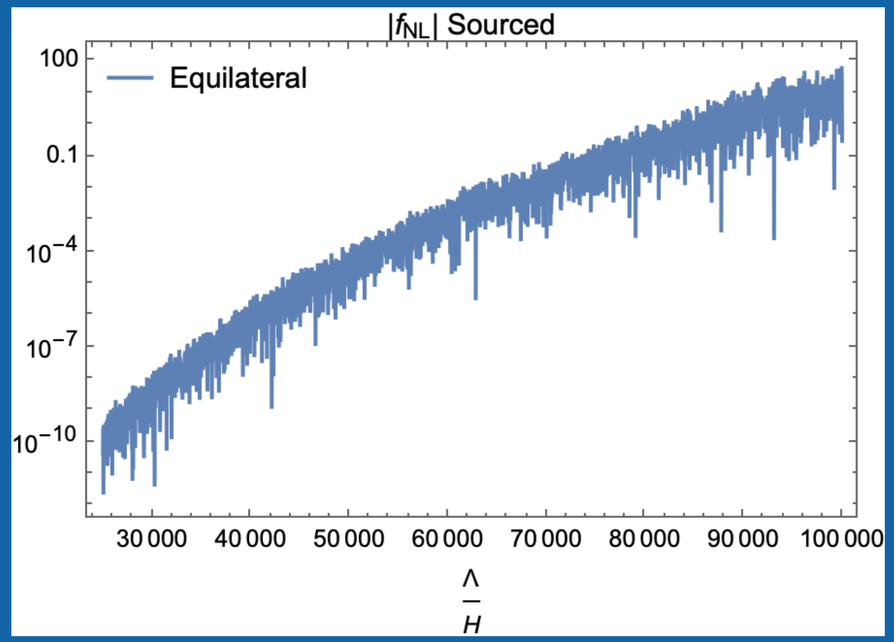


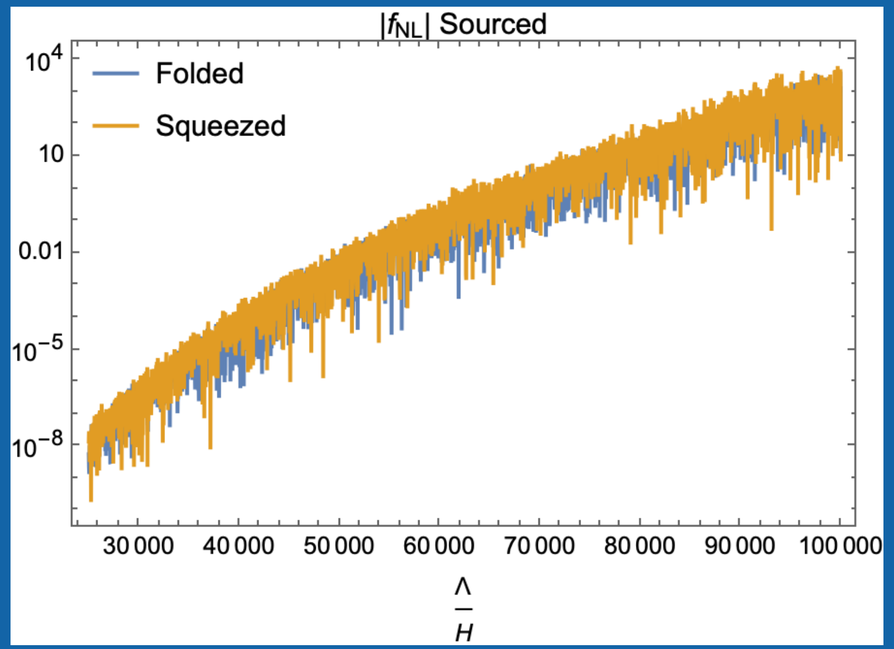

| $f_{NL}$ parameter for BD vacuum | | |
|---|---|---|
| Equilateral | Squeezed | Folded |
| 0.00933 | 0.00293 | 0 |

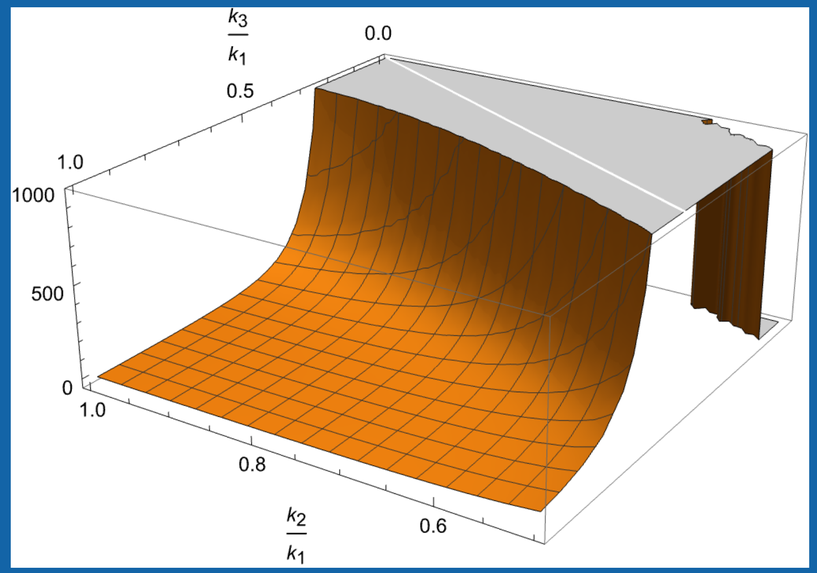
# Fixed Time selection from alpha-vacua



# SWITCHING ON THE SOURCE



## Take Home Message

Black Holes environment can play active roles and open windows to yet not well-explored physics sectors

# Thank you!