Impact of Trans-Planckian noise on primordial gravitational wave spectra

Mattia Cielo , PhD student

mattia.cielo@unina.it

Università degli Studi di Napoli Federico II & INFN Sezione di Napoli, Italy

Member of the LISA Cosmology Working Group

PhD Supervisor: Gianpiero Mangano

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

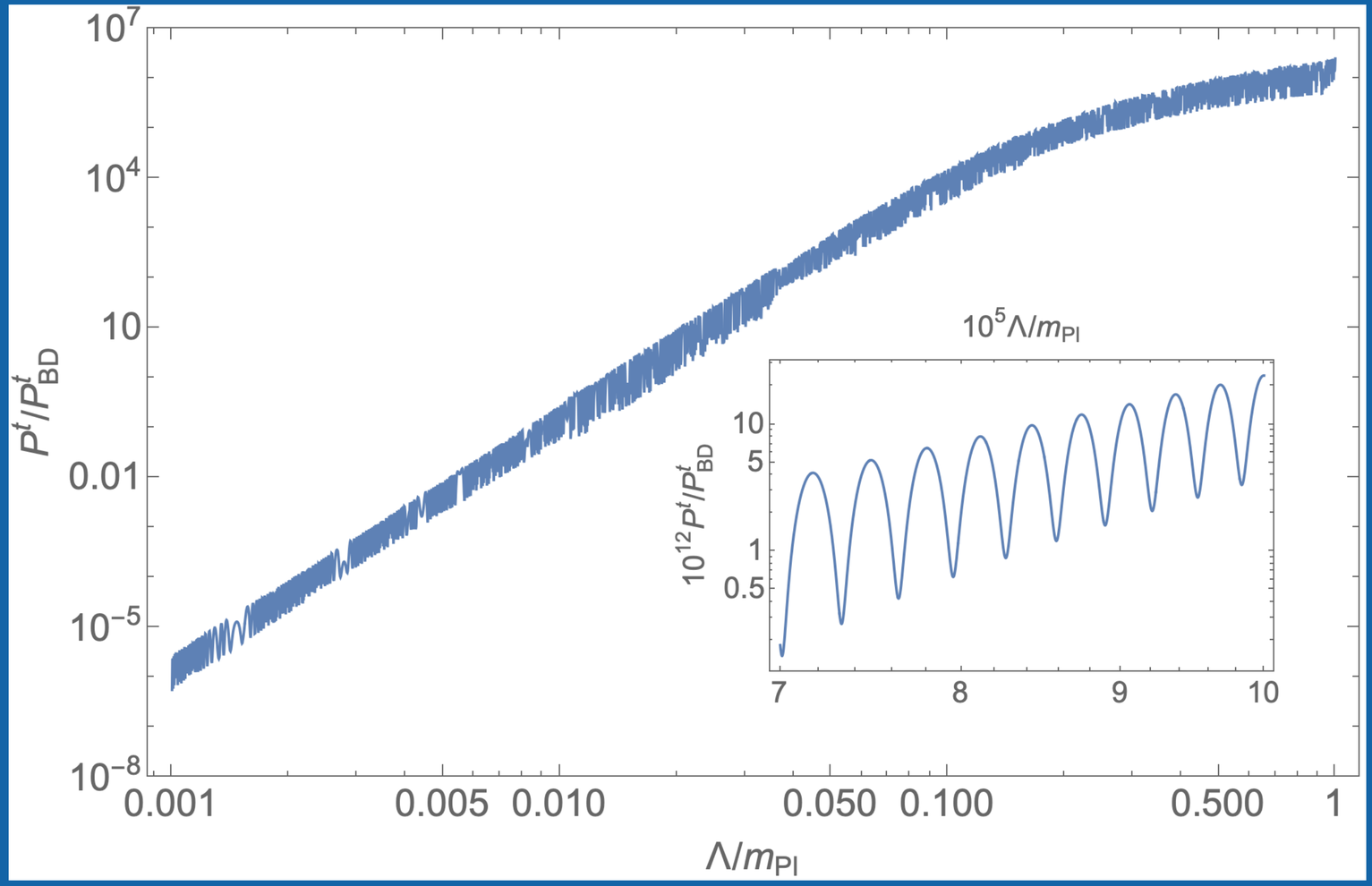
- For $\Lambda \geq m_{Pl}$ linear perturbation theory is not reliable
- Trapped surfaces form due to the collapse of trans-Planckian modes
- We can model the F(k) function to model the environment as follow:

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

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

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 ϵ!

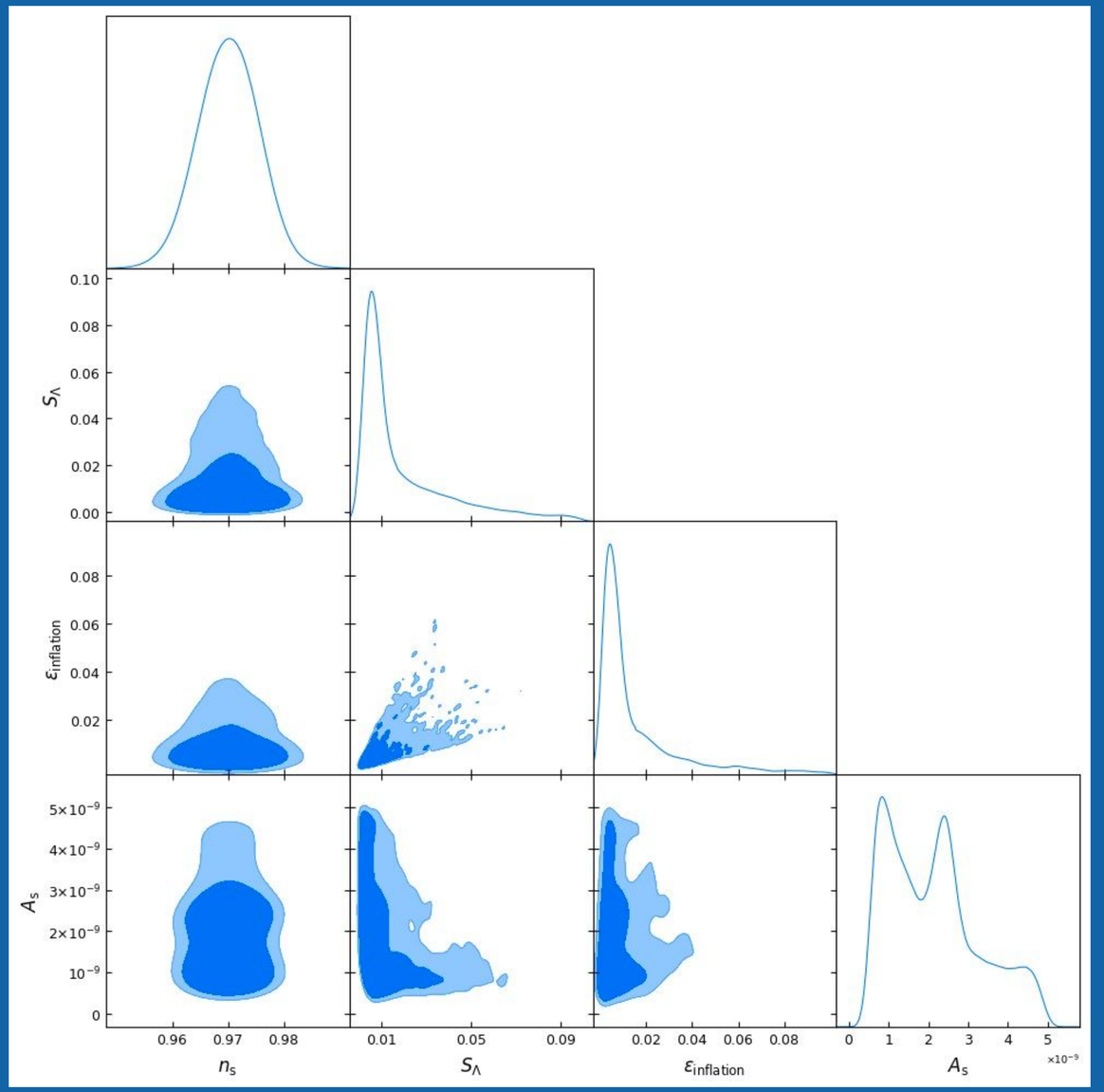
$$A_S = \frac{H^2}{m_{Pl}^2}$$

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

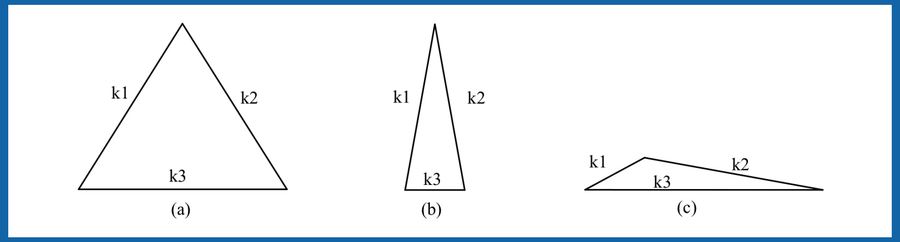
The Smoking Gun: Non-Gaussianity

Gravitational Wave non-Gaussianity from trans-Planckian Quantum Noise

Mattia Cielo,[a,b] **Matteo Fasiello,**[c,d] **Gianpiero Mangano,**[a,b] **Ofelia Pisanti**[a,b]

[a]INFN - Sezione di Napoli, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy
[b]Dipartimento di Fisica "Ettore Pancini", Università degli studi di Napoli "Federico II", Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy
[c]Instituto de Física Téorica UAM/CSIC, calle Nicolás Cabrera 13-15, Cantoblanco, 28049, Madrid, Spain
[d]Institute of Cosmology & Gravitation, University of Portsmouth, PO1 3FX, UK

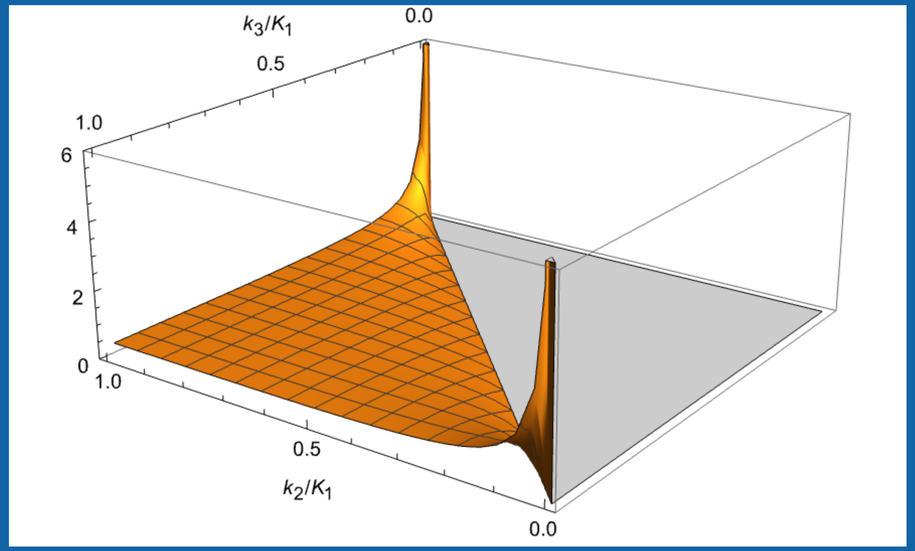
E-mail: mattia.cielo@na.infn.it, matteo.fasiello@csic.es, gmangano@na.infn.it, pisanti@na.infn.it



arxiv:2307.XXXX

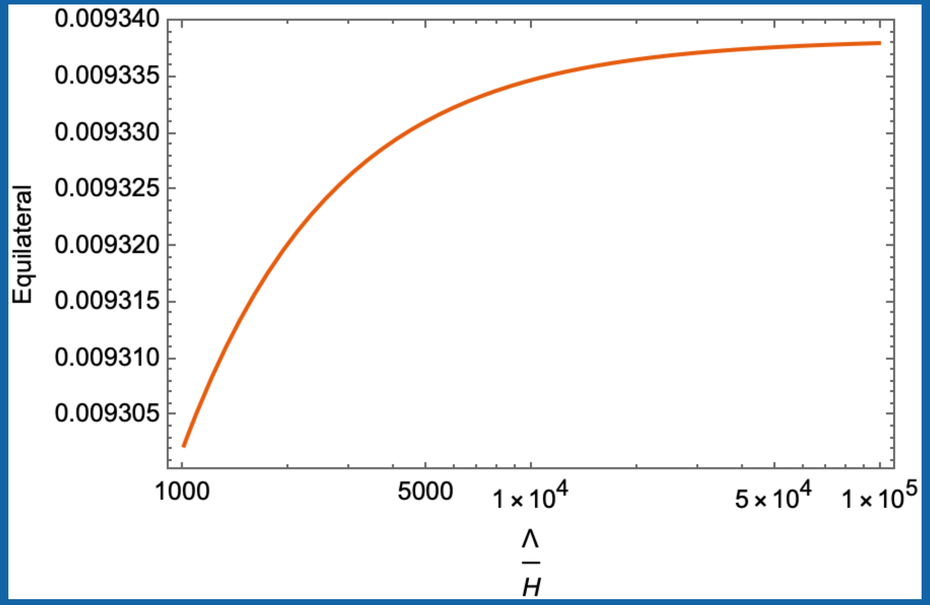
$$F(k) = 1$$

BD Vacuum

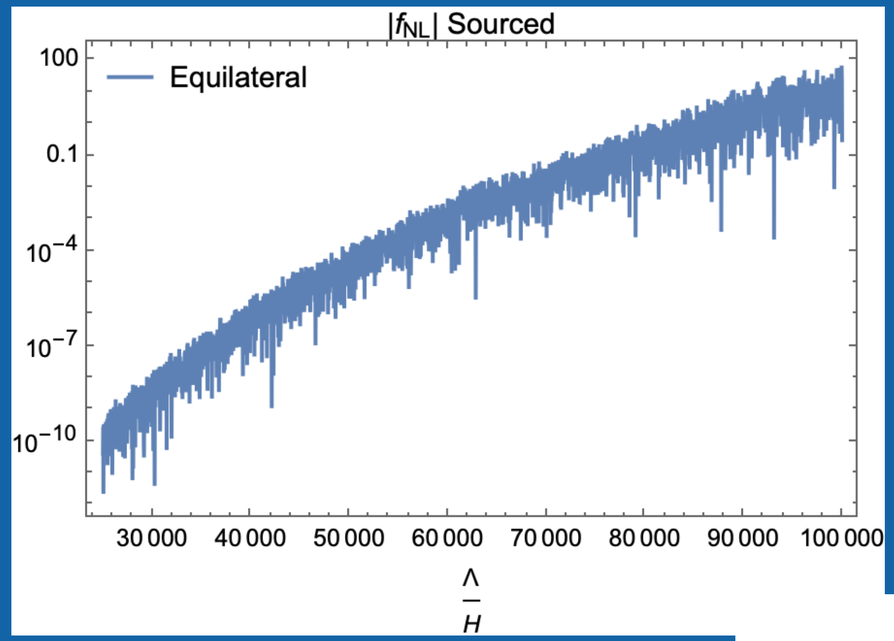


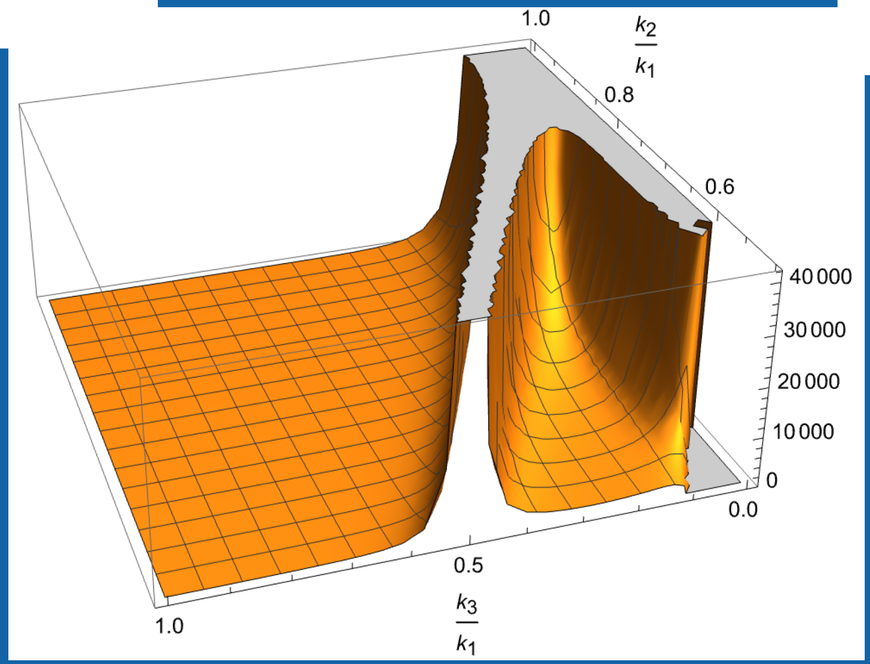
f_{NL} parameter for BD vacuum		
Equilateral	Squeezed	Folded
0.00933	0.00293	0

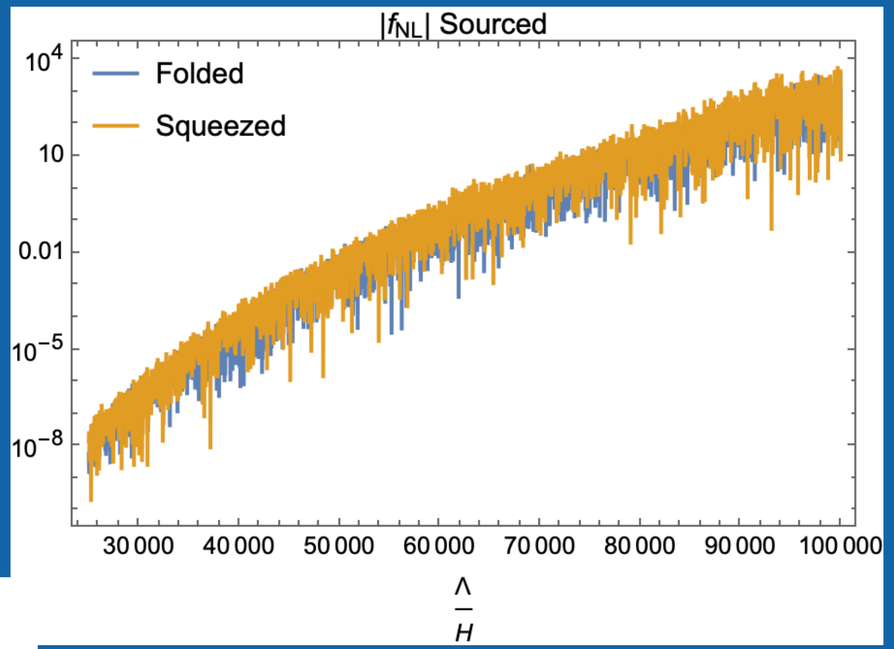
Fixed Time selection from alpha-vacua



SWITCHING ON THE SOURCE







Take Home Message

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

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!

(And for the nice food)

Glad to have met you all :)