Perturbative unitarity bounds on field-space curvature in de Sitter spacetime

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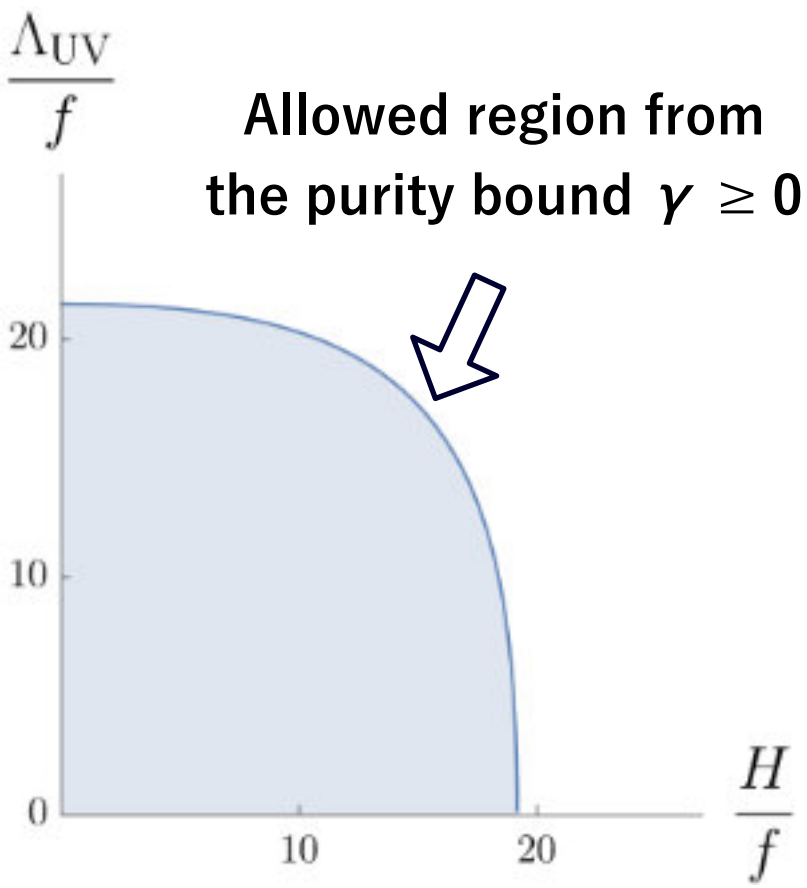
Perturbative Unitarity Bounds

Theoretical constraints on EFT parameters from **unitarity** as a consistency condition

We investigate unitarity bounds for a field-space curvature model

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}(\partial\sigma)^2 - H^2\sigma^2 + \frac{1}{4f^2}\sigma^2(\partial\phi)^2$$

in **de Sitter spacetime**.

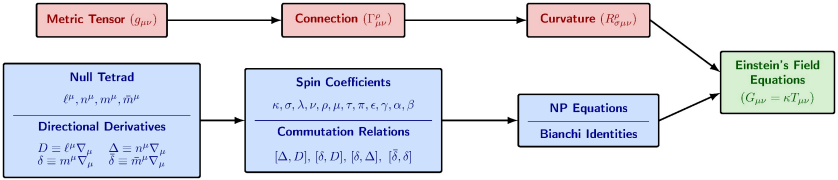


We derive the bounds using **momentum-space purity γ** rather than scattering amplitudes.

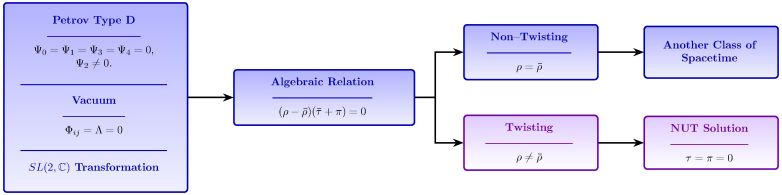
(following an approach developed at Cambridge!)

The Path to the NUT Solution: A Coordinate-Free Approach

1 Newman–Penrose (NP) Formalism



2 Newman–Unti–Tamburino (NUT) Solution



HOW CAN GRAVITON FLUCTUATIONS INDUCE A SPREAD OF THE LIGHTCONE?

Samuel Ramos

arXiv:2606.02729

Scalar field Φ coupled to thermal gravitons ⇒ corrections to scalar field commutator

$$P\Big([\phi(x),\phi(0)]\neq 0\Big)\propto \exp\frac{-(\vec{x}^2-t^2)^2}{2\mathrm{Var}(\vec{x}^2)}$$

Thermal contribution

$$\mathrm{Var}(\vec{x}^2)=\frac{16\,G_N T t^3}{3}$$

Vacuum contribution

$$\mathrm{Var}(\vec{x}^2)\sim t^2\log\left(\frac{t}{R}\right)$$

$$\frac{\mathrm{Var}(\vec{x}^{\,2})}{\langle\vec{x}^{\,2}\rangle^2}\sim\frac{1}{t}$$

Still a perturbative effect

At T=300 K,
wait 10^4 yrs for the lightcone spread to reach a meter

Black Hole application

$$t\sim t_P\left(\frac{M}{M_P}\right)^{5/3}$$

Time duration for the lightcone spread to reach the BH size

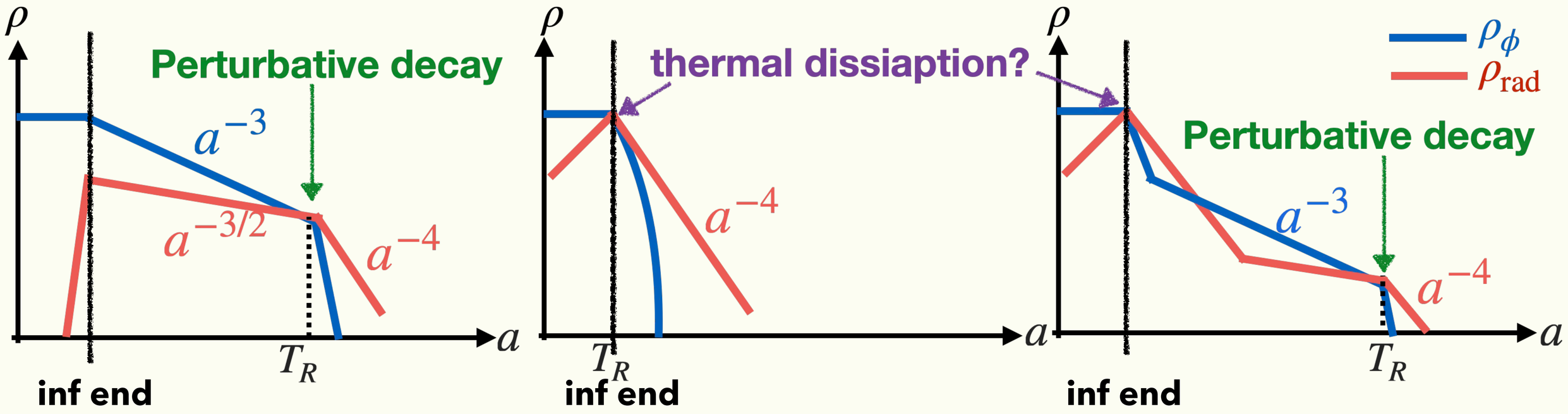
Reheating after axion inflation

Tenta Tsuji
KEK Theory Center

$$\ddot{\phi} + 3H\dot{\phi} + \underline{\Gamma_\phi \dot{\phi}} + V'(\phi) = 0$$

thermal friction from thermal bath

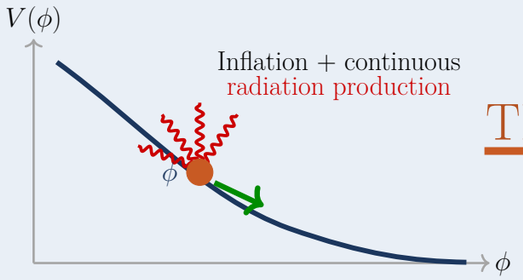
- **The completion of Reheating?** [2503.01228, JCAP07(2025)002]



We study this question in axion inflation set up

Thermal Equilibrium Open EFT of de Sitter and Warm Inflation

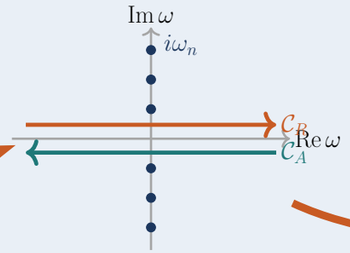
Wenqi Yu (HKUST)



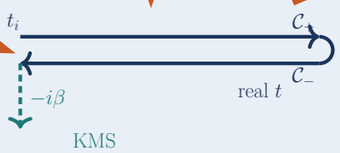
warm inflation

TFT

Matsubara



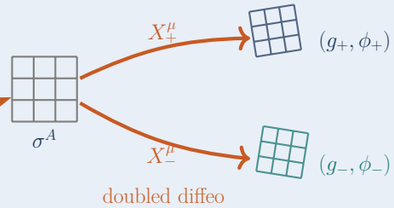
continuation
noise
initial transient



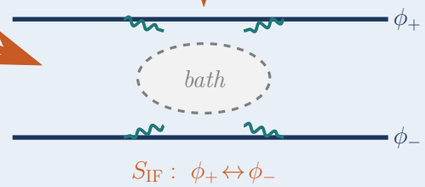
real time:
Schwinger-Keldysh

Thermal equilibrium in de Sitter

dynamical gravity



decoupled
limit



DKMS symmetry

$$\Theta : \phi_\pm(t) \to \phi_\pm\left(-t \pm \frac{i\beta}{2}\right)$$

Goldstone EFT
$\phi \to t + \pi$
tadpole
hierarchies

Phenomenology:
cubic combinations
Lorentz-violation
bispectrum

How many Nambu–Goldstone modes?

Goldstone theorem

$$\text{SSB} \quad \Longrightarrow \quad \text{gapless Nambu–Goldstone modes (NGMs)}$$

But in general $N_{\mathrm{NGM}} \leq N_{\mathrm{BG}}$.

Known reduction mechanisms

Two reduction mechanisms are known:

$$\langle [Q, Q'] \rangle \neq 0 \quad \Longrightarrow \quad \mathcal{L}_{\mathrm{eff}} \supset \pi \dot{\pi}' \qquad \text{(BWM pairing)}$$

$$[P, Q] \sim Q' \quad \Longrightarrow \quad \pi' \sim \partial \pi \qquad \text{(inverse Higgs)}$$

New mechanism: **geometric pairing**

$$[P, Q] \sim P \quad \Longrightarrow \quad \mathcal{L}_{\mathrm{eff}} \supset \pi \dot{\pi}'$$

A general counting formula for NGMs in many-body systems follows.