The trans-Planckian problem in loop quantum cosmology

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University of Sheffield

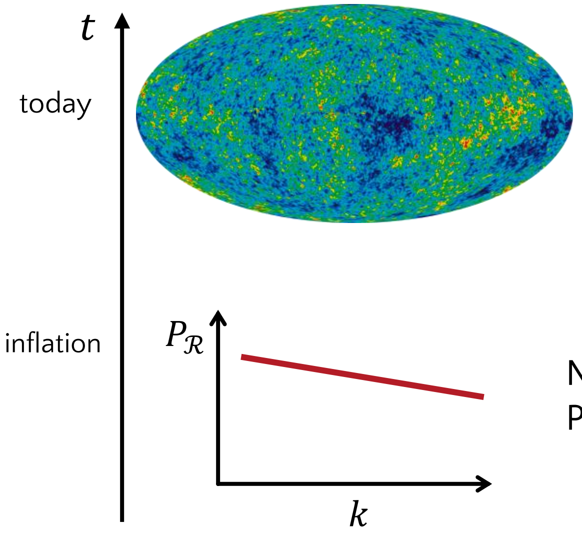
1

The trans-Planckian problem

Standard cosmology

Overview

Inflation + perturbations:

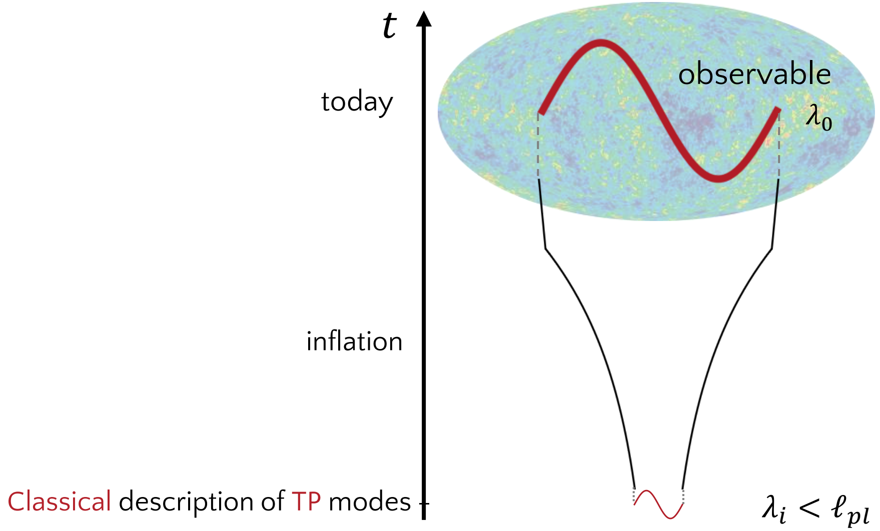


✓

Near-scale-invariant
Primordial power spectrum

Overview

Inflation + perturbations:



Scales that are observable today may have been trans-Planckian at the onset of inflation

The problem

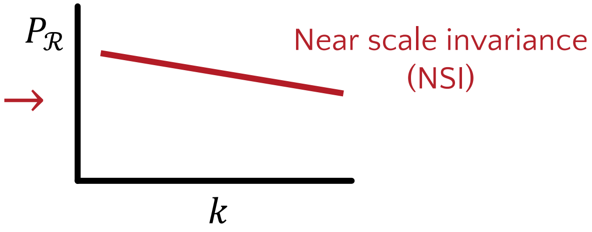
Initial conditions based on classical dynamics applied to trans-Planckian modes

- Fourier components of scalar perturbations

$$v_k'' + \omega_k^2(\eta) v_k = 0 \qquad \omega_k^2(\eta) = k^2 + s(\eta)$$

[QFT on classical background]

$k^2 \gg s(\eta)$ → free waves → BD vacuum →



The problem

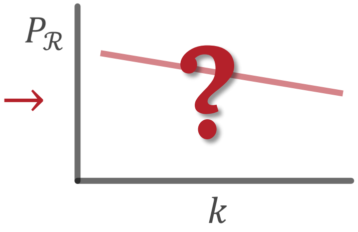
Initial conditions based on classical dynamics applied to trans-Planckian modes

- Fourier components of scalar perturbations

trans-Planckian corrections

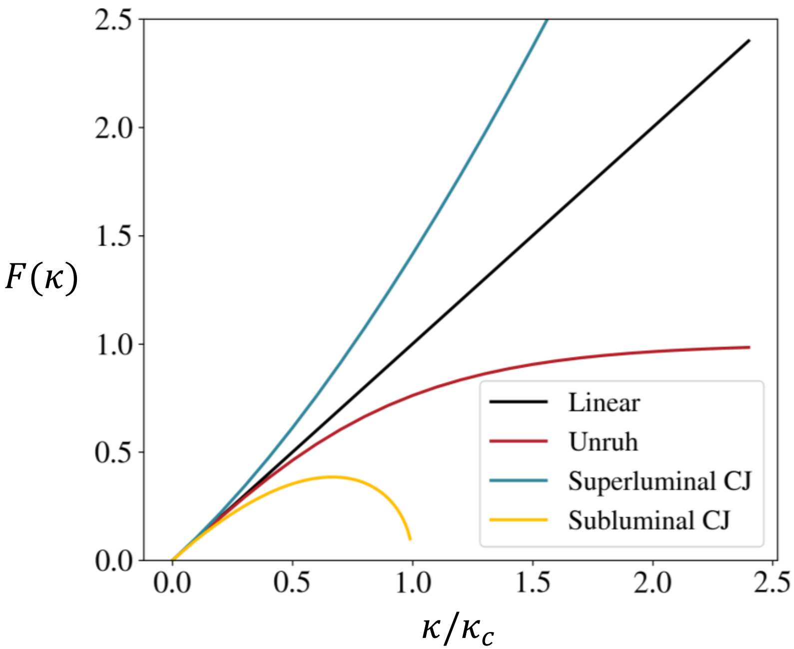
$$v_k'' + \omega_k^2(\eta) v_k = 0 \qquad \omega_k^2(\eta) = [a(\eta)F(\kappa)]^2 + s(\eta) \qquad \kappa = k/a$$

$k^2 \gg s(\eta)$ → free waves → BD vacuum →



Modified dispersion relations

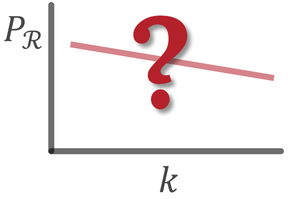
$$\omega_k^2(\eta) = [a(\eta)F(\kappa)]^2 + s(\eta)$$



1. Brute force

For each $F(\kappa)$ compute $P_\mathcal{R}$

Check if NSI is lost



2. Adiabaticity analysis [1]

$$\epsilon(k,\eta) = \left|\frac{\omega_k'}{\omega_k^2}\right|$$

$\epsilon \ll 1 \rightarrow$ power spectrum ~ NSI ✓

$\epsilon \gtrsim 1 \rightarrow$ departure from NSI X

[1] Niemeyer, Parentani, astro-ph/0101451

2

Loop quantum Cosmology

(LQC)

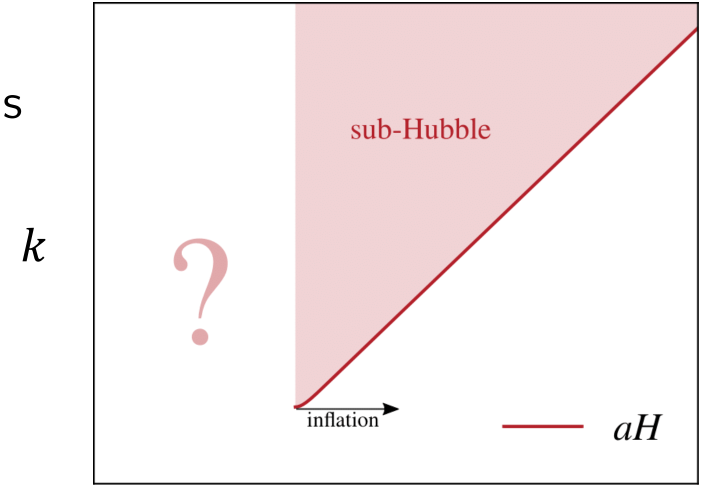
Pre-inflationary dynamics

- LQC: big-bang → bounce

  ⇒ well-defined pre-inflationary dynamics

- Background

$$H^2 = \frac{8\pi G}{3}\rho\left(1 - \frac{\rho}{\rho_c}\right)$$



Pre-inflationary dynamics

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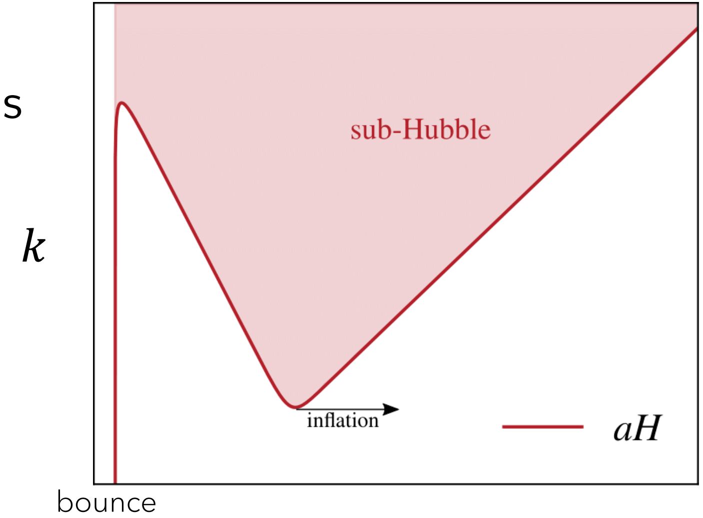


➢ No longer start description at onset of inflation

Perturbations

- Different approaches:
  - Both take background + perturbations

quantisation Loops QFT

- Corrected equations of motion:

$$v_k'' + \omega_k^2(\eta) v_k = 0 \qquad \omega_k^2(\eta) = k^2 + s(\eta)$$

NOT the TP corrections!

Perturbations

- Different approaches:
  - Both take background + perturbations

quantisation Loops Loops

- Corrected equations of motion:

$$v_k'' + \omega_k^2(\eta) v_k = 0 \qquad \omega_k^2(\eta) = k^2 + s(\eta, k)$$

Would be TP corrections!

Perturbations

- Different approaches:
  - Both take background + perturbations

quantisation Loops QFT

- Corrected equations of motion:

$$v_k'' + \omega_k^2(\eta) v_k = 0 \qquad \omega_k^2(\eta) = k^2 + s(\eta)$$

Trans-Planckian problem?

NOT the TP corrections!

Primordial power spectrum

- Concrete shape depends on initial conditions

Of perturbations:

Corrections to IR modes

Primordial power spectrum

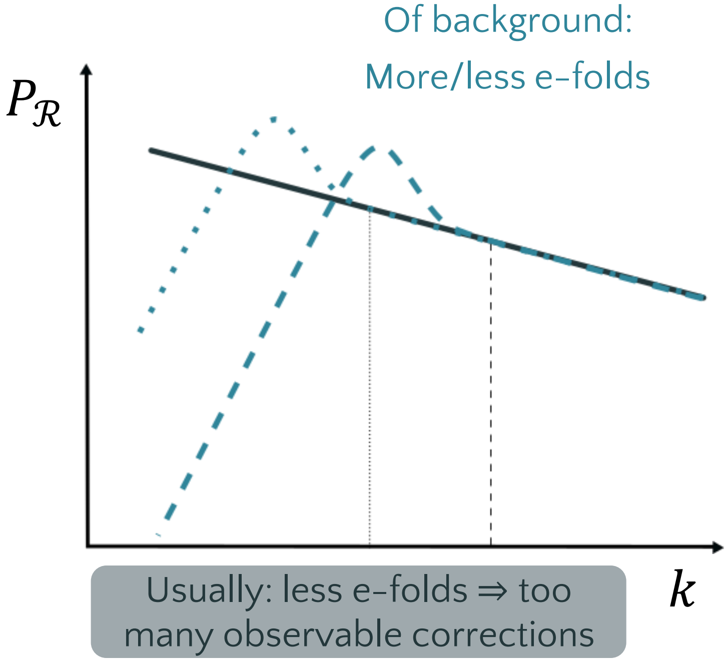
- Concrete shape depends on initial conditions

Model	Number of e-folds	
	Pre-inflation	Inflation
A	4.9	72
B	4.9	61

Both compatible with observations

A: Ashtekar, Gupt, 1608.04228

B: Martín-Benito, RN, Olmedo, 2305.09599

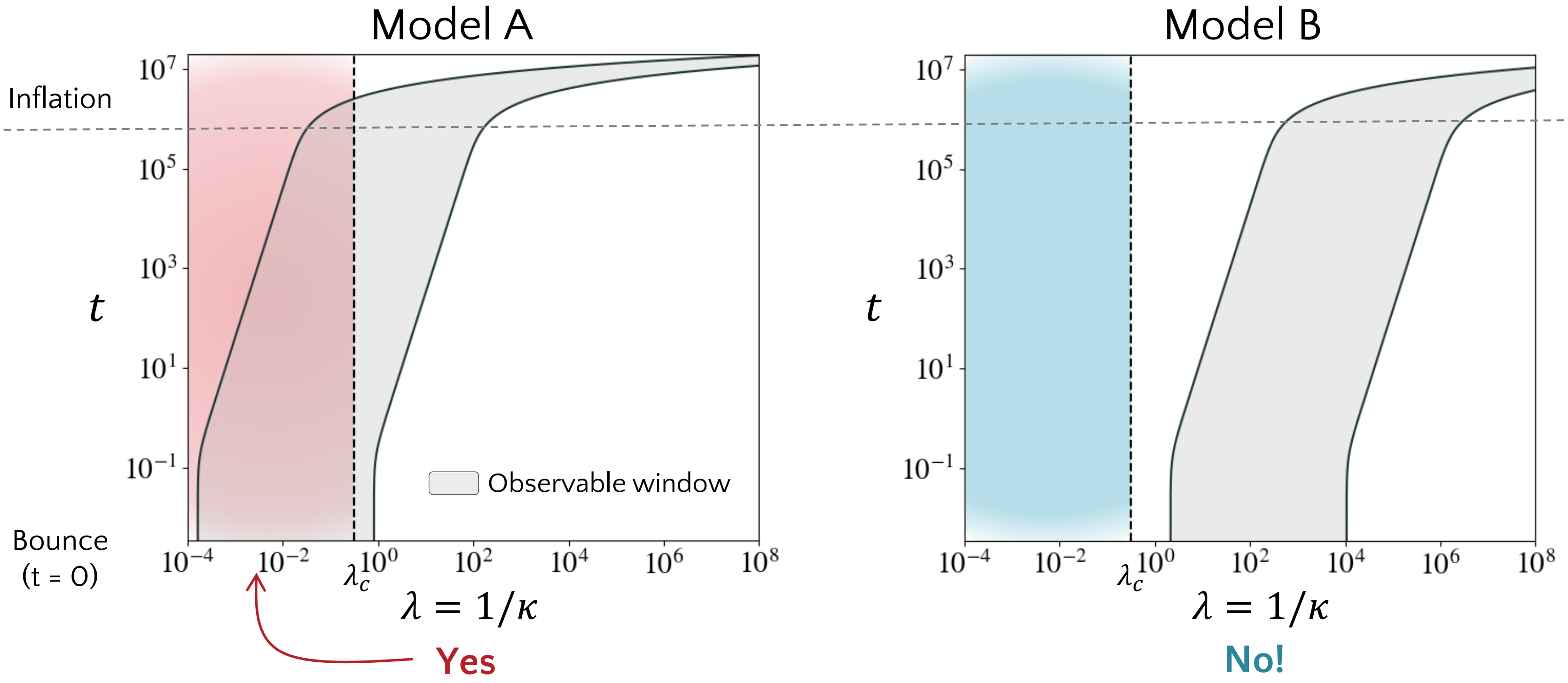


3

The trans-Planckian problem

in LQC

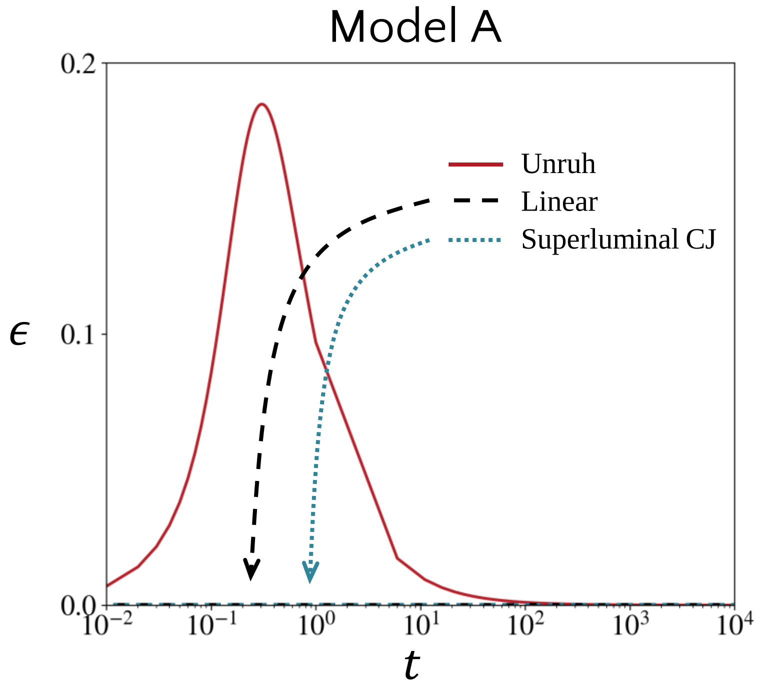
1 Are observable modes trans-Planckian?



more e-folds of inflation

less e-folds of inflation

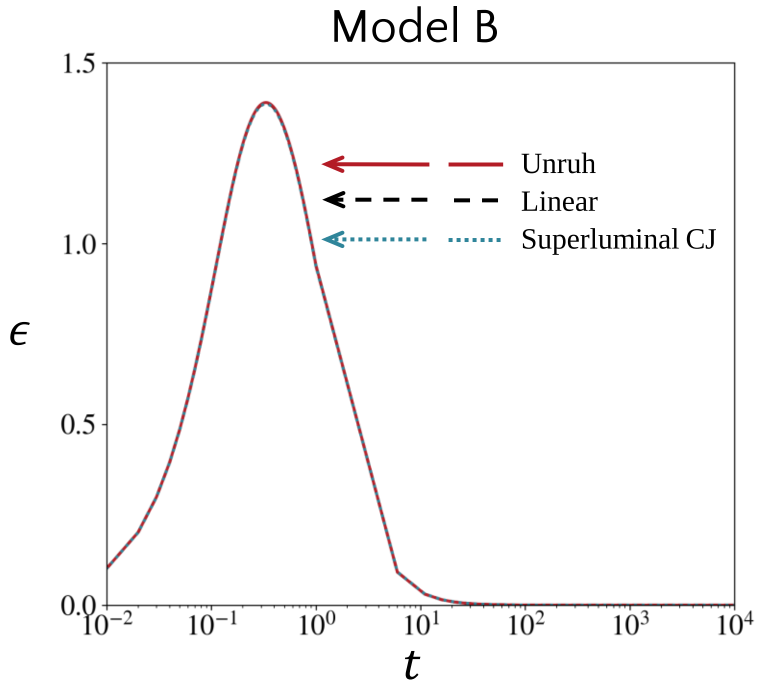
2 Are they adiabatic?



- No: $\epsilon \sim 0.2 \rightarrow$ non negligible
- Depends heavily on $F(\kappa)$
- While modes are TP

$\Rightarrow$ (soft?) Trans-Planckian problem

2 Are they adiabatic?



- Definitely not: $\epsilon > 1$
- But not trans-Planckian!

[that is why there is no dependence on $F(\kappa)$

$\Rightarrow$ no effect on observable power spectrum]

$\Rightarrow$ Avoids the trans-Planckian problem

4 Conclusions

Conclusions

- LQC models do not ***necessarily*** present a trans-Planckian problem.
  - Model A: more e-folds lead to modes that are trans-Planckian and (slightly) non-adiabatic,
  - Model B: less e-folds, avoids the issue.

- Caveat: Model B is "fine-tuned":
  - less e-folds → too many corrections from LQC observable window
  - Vacuum chosen such that part of those corrections is suppressed
  - General scenario would be somewhere in between A and B.

Thank you for your attention!