Quantum Nature of Big Bang with Polymer Matter

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Based on upcoming works with Bao-Fei Li and Sahil Saini

Outline

- Motivation and a brief overview of standard loop quantum cosmology (LQC)
- Polymer matter with polymer gravity
- From Big Bounce to the Loitering Bounce
- Polymer matter and constraints on inflation and signatures in CMB
- Summary

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Quantum geometry dictates Planck scale physics. Matter does not matter! No potential favored/disfavored.

LQC: key features

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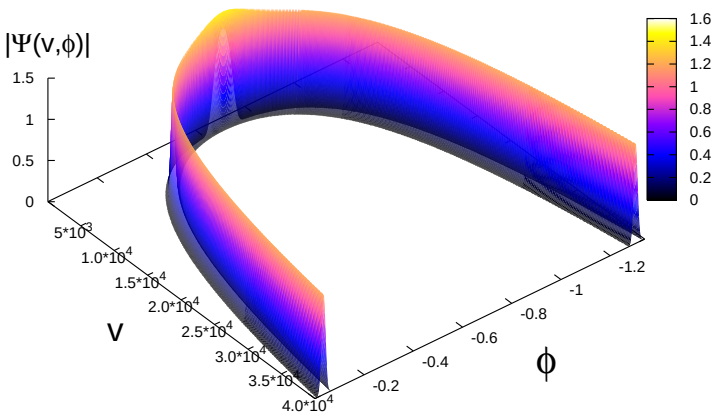
Hamiltonian is a non-singular difference equation

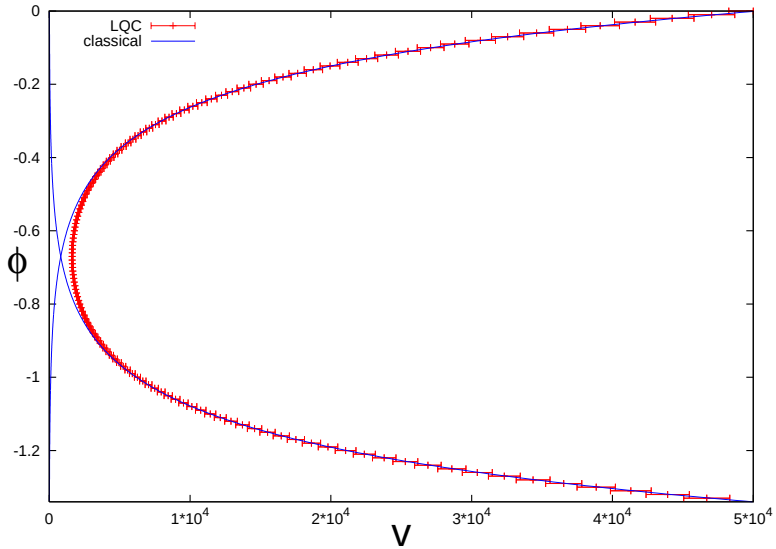
(Ashtekar, Bojowald, Corichi, Kaminski, Lewandowski, Pawlowski, PS, Vandersloot (2001-2008))

$$\mathcal{C}^+(v)\Psi(v+4,\phi)+\mathcal{C}^0(v)\Psi(v,\phi)+\mathcal{C}^-(v)\Psi(v-4,\phi)=\hat{\mathcal{H}}_\phi\Psi(v,\phi)$$

At volumes much greater than the Planck volume, Wheeler-DeWitt differential equation recovered. Implies an agreement with Einstein's theory when gravity is weak.

Big Bounce





For a large class of states, big bang is replaced by a sharp swift big bounce at a maximum of energy density

$\rho_{\max} = 3/8\pi G\lambda^2 \approx 0.41\rho_{\mathrm{Planck}}$

For sharply peaked states, peaked at late times in a macroscopic universe, bounce captured extremely well by an effective Hamiltonian leading to modified Friedmann equation:

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

(Ashtekar, Pawlowski, PS (06); Diener, Gupt, PS (14))

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Assuming the validity of effective dynamics:

Nature of bounce unaffected for different choices of matter. There is no violation of any energy condition. Generic resolution of all strong singularities in isotropic and anisotropic spacetimes. **(PS (09-11); Saini, PS (14-18))**

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Quantum geometric modifications to Mukhanov-Sasaki equation result in potential signatures in the CMB **(Agullo, Ashtekar, Barrau, Bojowald, Grain, Maartens, Motaharfar, Li, Mena Marugan, Mielczarek, Olmedo, PS, Tsujikawa, Wang,... (2004-..))**

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Does polymer matter leave distinct signatures in CMB?

Which matter variable to polymerize?

Consider a spatially-flat homogeneous FLRW spacetime sourced with a scalar field in potential $U(\phi)$. The classical Hamiltonian constraint is:

$$\mathcal{H} = -\frac{3|p|^{1/2}c^2}{8\pi G\gamma^2} + \frac{p_\phi^2}{2|p|^{3/2}} + |p|^{3/2}U(\phi) \approx 0$$

Following polymerization procedure in LQC, the polymerized variable must satisfy invariance under choice of fiducial cell and recovery of classical limit at small spacetime curvatures.

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LQC (improved dynamics) based on polymerizing $b := c/|p|^{1/2}$, leading to

$$\mathcal{H} = -\frac{3v\sin^2(\lambda b)}{8\pi G\gamma^2\lambda^2} + \frac{p_\phi^2}{2|p|^{3/2}} + |p|^{3/2}U(\phi) \approx 0, \quad \lambda^2 = 4\sqrt{3}\pi\gamma l_{\rm Pl}^2$$

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Contrary to previous works, polymer matter successfully resolves singularities even with unpolymerized gravity.

Interplay of polymer matter and polymer gravity

For simplicity let us consider $\lambda = \lambda_\phi$. The modified Friedmann equation is

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

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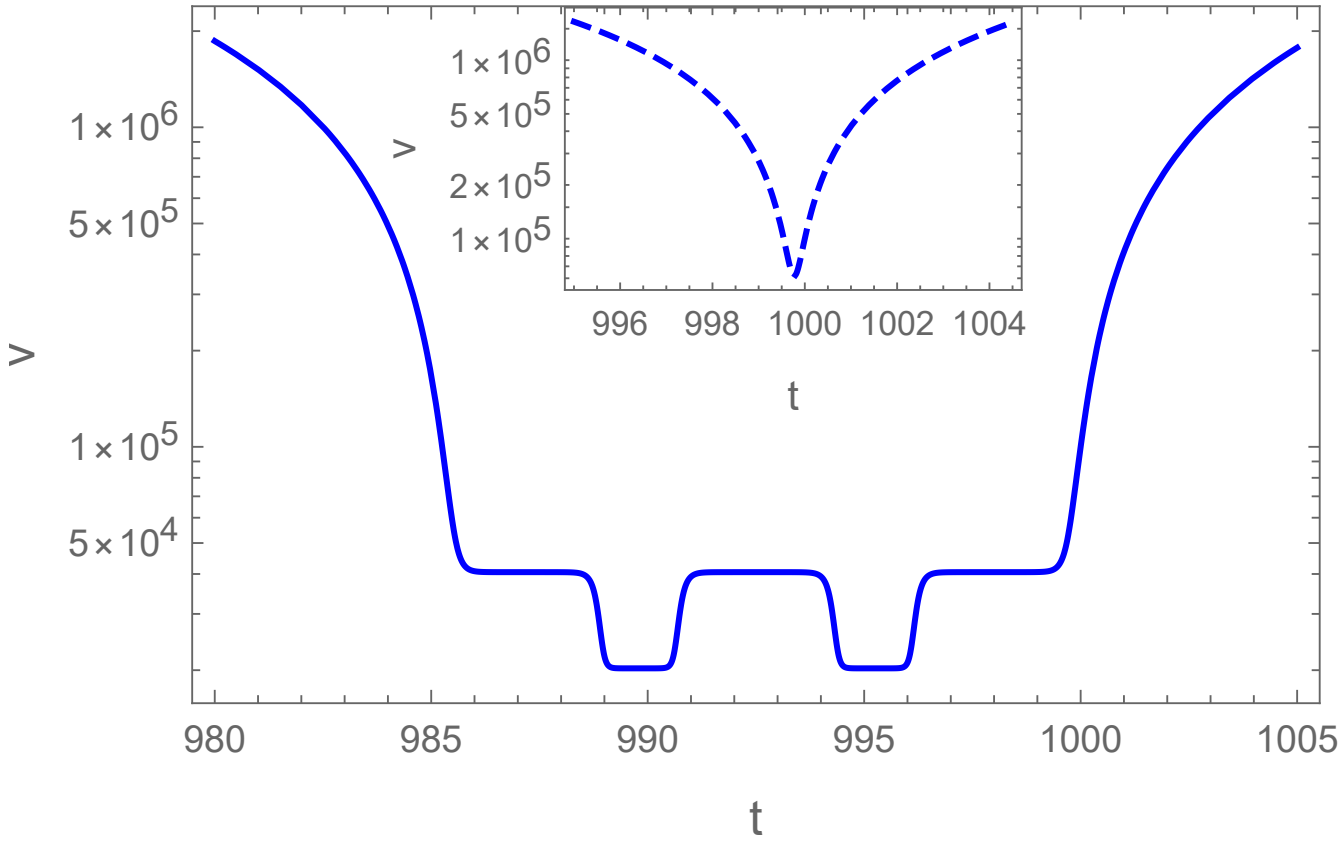
If the big bounce does occur, it must be potential dominated! Significant changes from standard LQC.

For $\lambda_\phi \gtrsim 0.5\lambda$, polymer matter dictates singularity resolution.

The loitering bounce



Big bounce of LQC is replaced by a loitering bounce – a phase of unstable static states which join two macroscopic regimes of our universe.

Instead of a sharp and swift bounce, the Universe can potentially loiter for a long time in the "bounce regime."

The loitering bounce and inflation

Loitering bounce is incompatible with various models of inflation.
Conventional potentials such as chaotic or Starobinsky potentials which satisfy $U(\phi) = U'(\phi) = 0$ only at a few isolated points require a lot of fine-tuning to permit loitering bounce.

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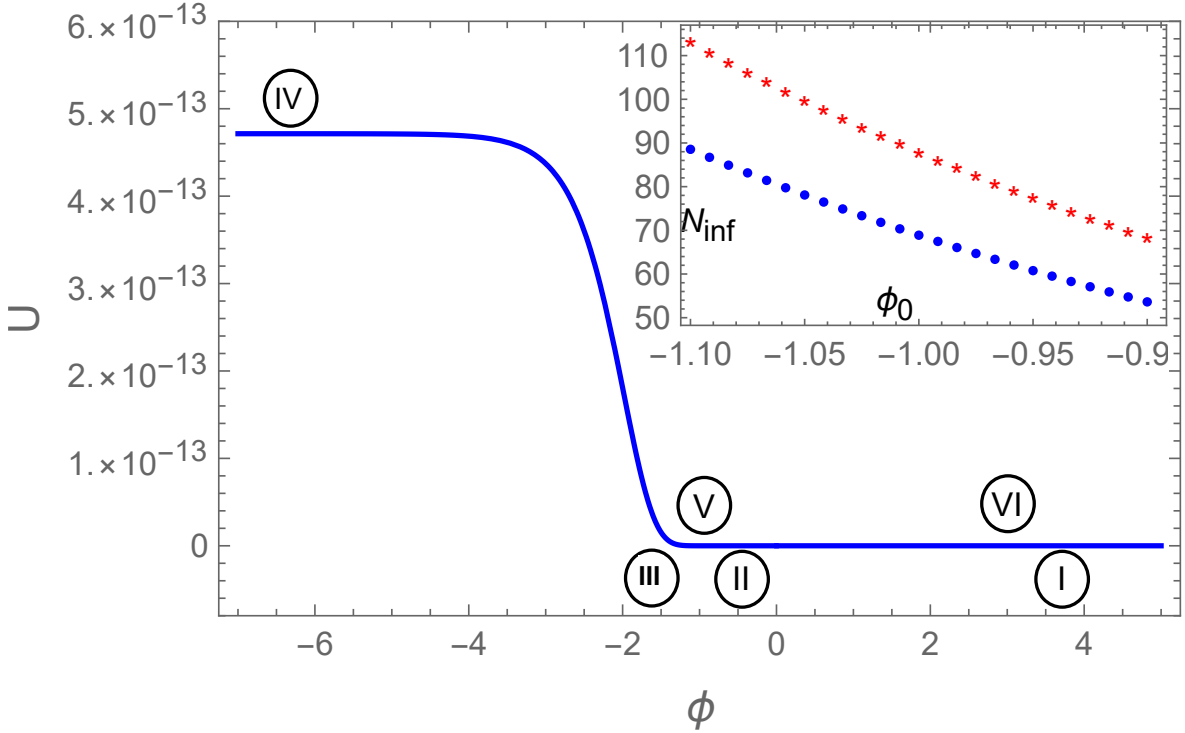

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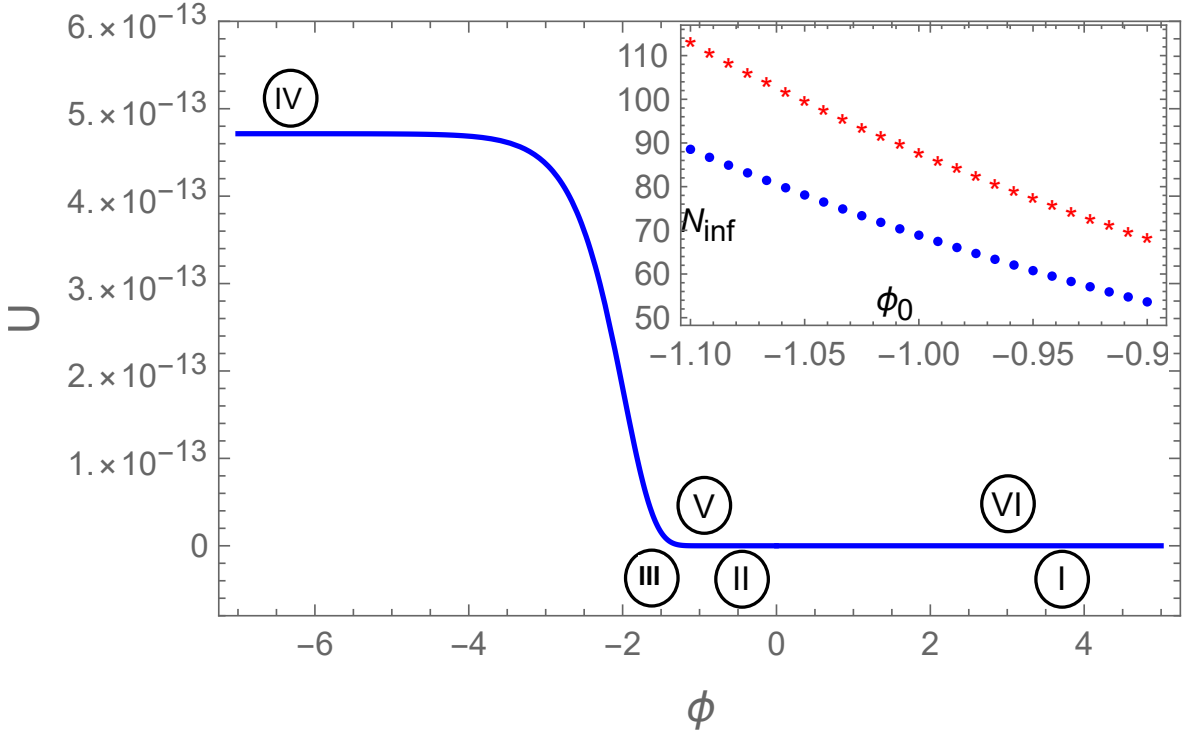
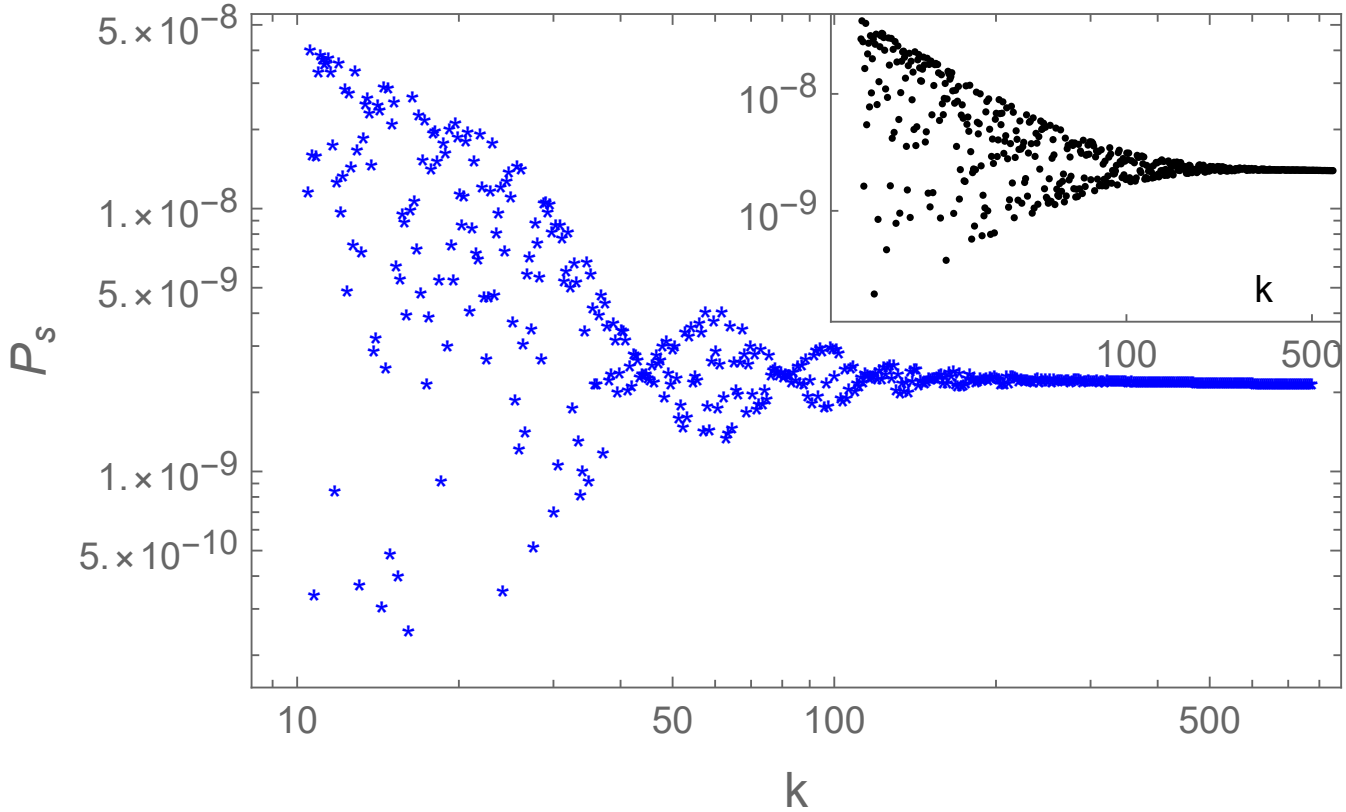


Loitering bounce selects quintessential inflation as well as models inspired from SUGRA as natural compatible models.

The loitering bounce and CMB



Following the strategy used in LQC with cosmological perturbations (dress/hybrid), the polymerized scalar field and the resulting loitering bounce also leave distinct signatures on the primordial power spectrum.

Potentially distinct signatures in CMB from standard LQC.

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