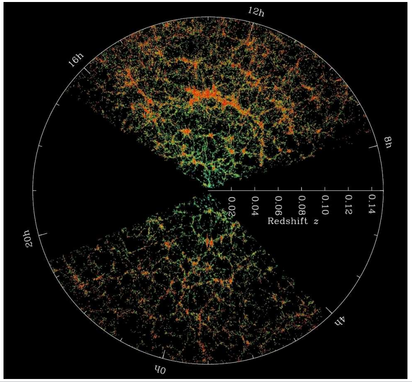

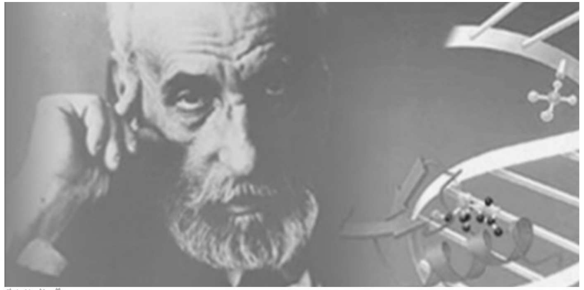

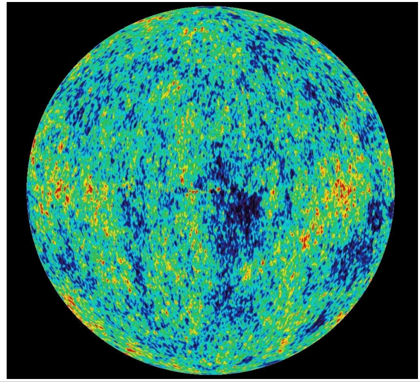

IEM INSTITUTO DE ESTRUCTURA DE LA MATERIA
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
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Covariant Effective Action for LQC à la Palatini

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G.O. and P.Singh, JCAP (2009)

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- Structure of the talk:
  - Introduction to LQG, LQC, and the Big Bounce.
  - Advantages of a covariant action for LQC.
  - Finding a covariant action for LQC: do it yourself.

LQG,LQC and Palatini $f(R)$ gravity

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- LQC is a symmetry-reduced homogeneous and isotropic model based on LQG in which the Big Bang singularity is replaced by a quantum bounce.

  - The fundamental description in LQC is discrete.
  - It admits an effective continuum spacetime description which successfully captures the quantum gravity effects at high energies and becomes classical at low energies.

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- This problem will also force us to use our knowledge on modified theories of gravity to reproduce an explicitly given set of dynamical equations.
  - Is the LQC dynamics of scalar-tensor type?
  - Can it be written as an $f(R)$ theory?
  - Is it something more complicated than these candidates?

Effective LQC Dynamics

- Using coherent state techniques, from the fundamental difference equations one can find the following effective o.d.e. :

$$H^2 = \frac{8\pi G}{3}\rho\left(1-\frac{\rho}{\rho_{crit}}\right)$$, with $\rho_{crit} = 0.41\rho_{Planck}$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho\left(1-4\frac{\rho}{\rho_{crit}}\right) - 4\pi GP\left(1-2\frac{\rho}{\rho_{crit}}\right)$$

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- Any $f(R, R_{\mu\nu}R^{\mu\nu}, \ldots)$ action in metric formalism and any scalar-tensor theory introduce additional degrees of freedom, not present in LQC.
- Palatini $f(R)$ theories have the same number of d.o.f. as GR and LQC: they seem a natural candidate to produce an effective action.

Palatini $f(R)$ theories

- Action and field equations of Palatini $f(R)$ theories:

  $S=\frac{1}{2\kappa^2}\int d^4x\sqrt{-g}f(R)+S_m(g_{\mu\nu},\psi)$, where $(g_{\mu\nu},\Gamma^{\alpha}_{\beta\gamma})$ are independent.

  $f_R R_{\mu\nu}(\Gamma)-\frac{1}{2}g_{\mu\nu}f(R)=\kappa^2 T_{\mu\nu}$, where $f_R\equiv df/dR$.

  $\nabla_\alpha\left(\sqrt{-g}f_R g^{\beta\gamma}\right)=0 \;\Rightarrow\; \Gamma^{\alpha}_{\beta\gamma}=\frac{t^{\alpha\rho}}{2}\left[\partial_\beta t_{\rho\gamma}+\partial_\gamma t_{\rho\beta}-\partial_\rho t_{\beta\gamma}\right]$, where

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- Resulting equations for the metric $g_{\mu\nu}$:

$$G_{\mu\nu}(g) = \frac{\kappa^2}{f_R}T_{\mu\nu} - \frac{\mathcal{R}f_R - f}{2f_R}g_{\mu\nu} - \frac{3}{2f_R^2}\left(\partial_\mu f_R\partial_\nu f_R - \frac{1}{2}g_{\mu\nu}(\partial f_R)^2\right) + \frac{1}{f_R}\left(\nabla_\mu\nabla_\nu f_R - g_{\mu\nu}\Box f_R\right)$$

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- Palatini $f(R)$ looks like GR with a modified source !!!

Finding the CEA

- For a massless scalar, the Hubble function is given by
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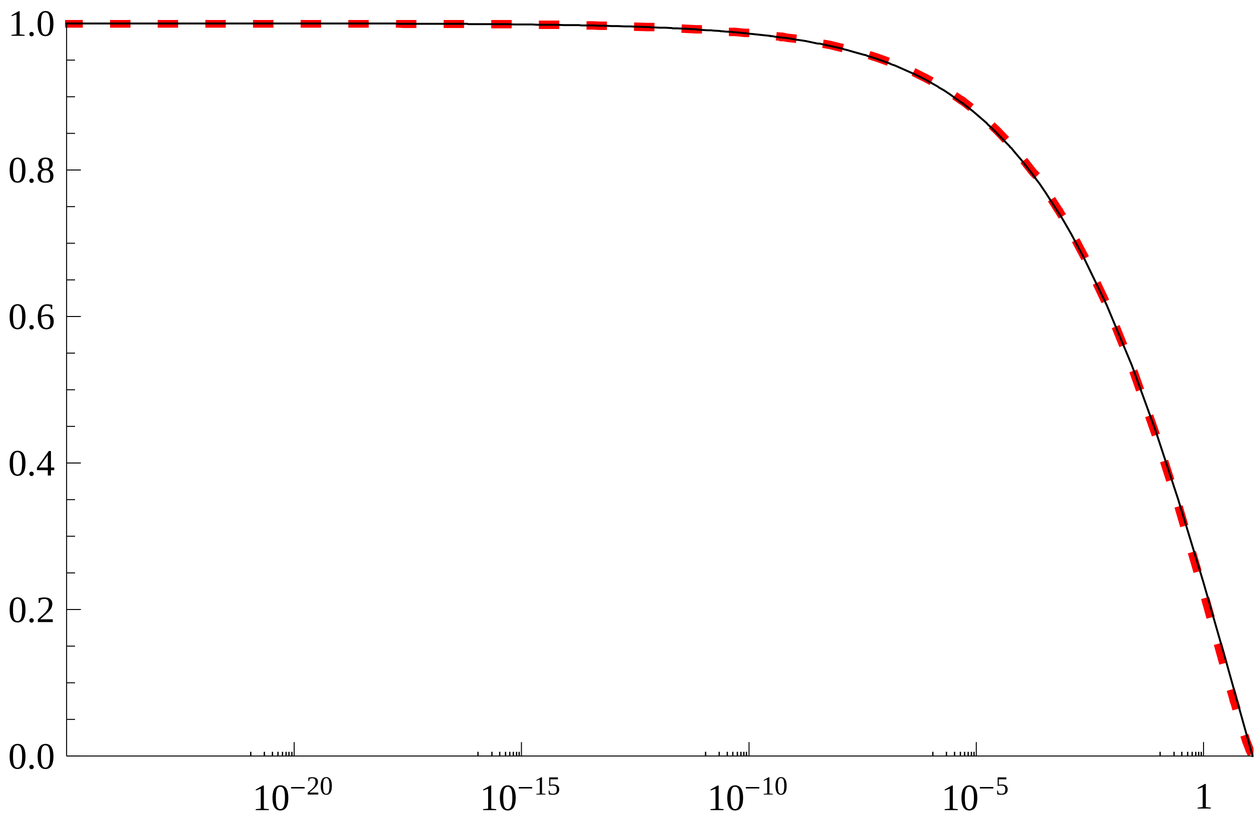
  $B=2\sqrt{\mathcal{R}_c f_R(2\mathcal{R}_c f_R-3f)}$, and $\mathcal{R}_c\equiv\kappa^2\rho_c$.
- There is a unique solution with $f_R\to 1$ when $R\to 0$ satisfying $\ddot{a}_{LQC}=\ddot{a}_{Pal}$ at $\rho=\rho_c$.

Numerics and Functional Fits

- Dashed red line: Numerical Curve.
- Solid line: $\frac{df}{dR} = -\tanh\left(\frac{5}{103}\ln\left[\left(\frac{R}{12\mathcal{R}_c}\right)^2\right]\right)$



Vertical axis: df/dR ; Horizontal axis: R/R_c

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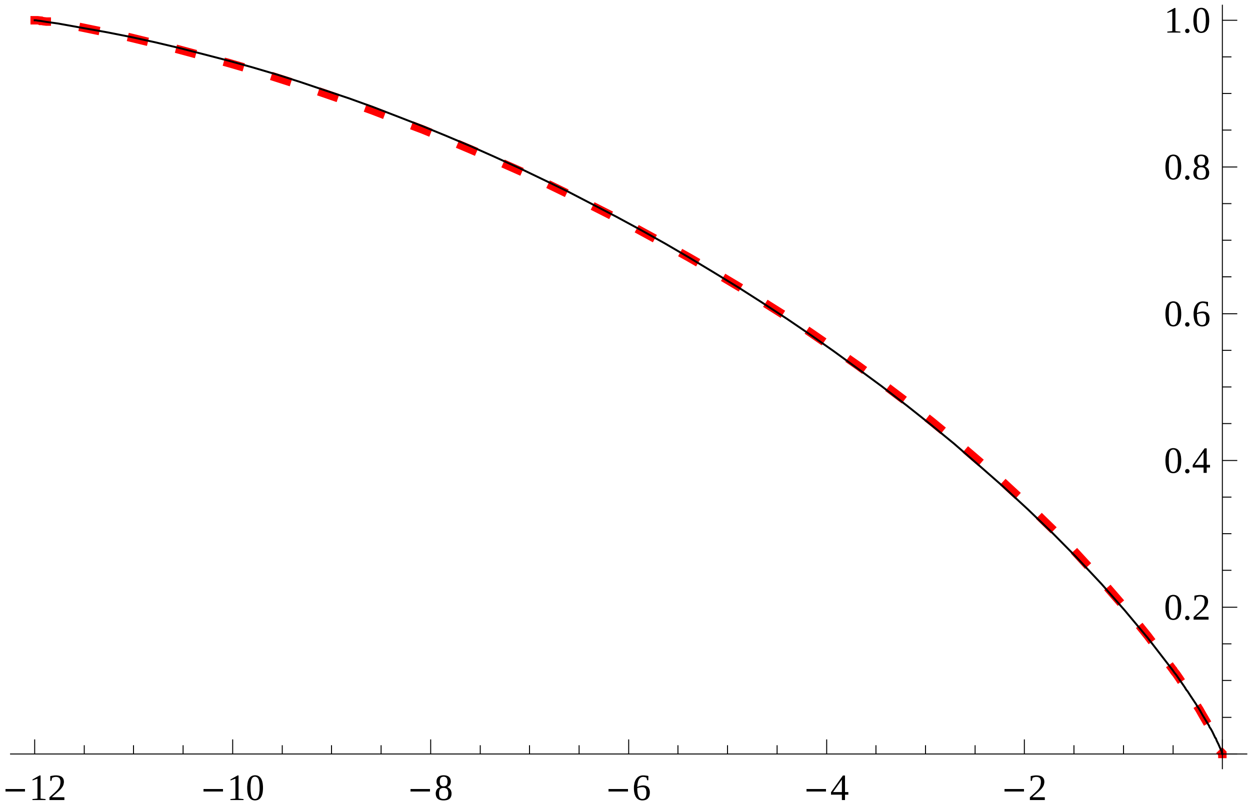

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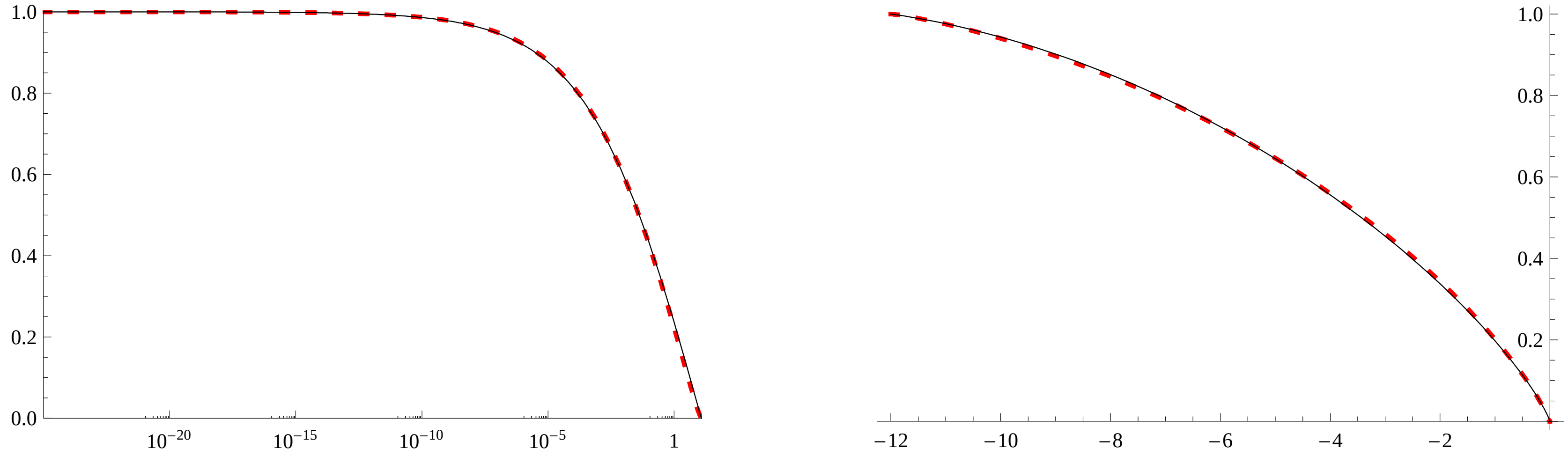

- This $f(R)$ lagrangian exactly reproduces the dynamics of isotropic LQC.
- The cosmic bounce occurs at $R = -12R_c$, where $f_R \to 0$.

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requires an infinite series in R to capture the full non-perturbative dynamics.

- Our results provide new insights on the kind of fields that an action must contain to capture non-perturbative quantum gravity effects:

> *Unlike in the classical spacetime of GR, the metric might not be the sole fundamental geometric entity, which shares similarities with the effective continuum geometry of crystals.*

Thanks !!!