Emergent Late- and Early-Times Acceleration from Quantum Gravity

In collaboration with: T. Ladstätter and D. Oriti
(but also review of results from M. De Cesare, A. Pithis, X. Pang, M. Sakellariadou. . .)

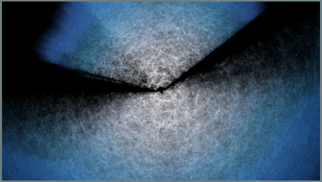
Luca Marchetti

FAU^2 Workshop on Quantum Gravity Across Scaless

FAU Erlangen-Nürnberg

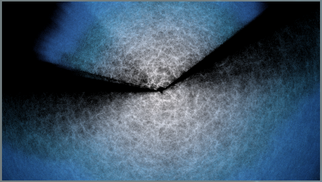
21 May 2025

OIST
Kavli IPMU



The DESI galaxy survey

- BAOs create features in galaxy clusters of the size of the sound horizon at recombination.
- This is used as a ruler to determine the distance to different galaxies.
- In turn, this determines the Universe's evolution.



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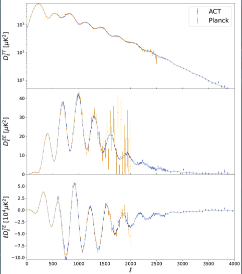
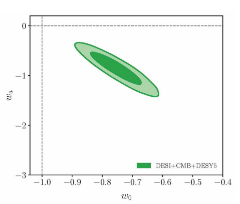
The ACT power spectra

- Ground based CMB observations.
- Higher angular resolution and targeted observation when compared to Planck.
- In practice: much smaller noise levels at small scales and extension to larger multipoles.





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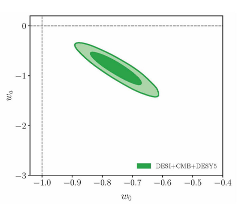

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Restriction of the parameter space for inflationary models. In particular, Starobinsky inflation disfavored at $\gtrsim 2\sigma$ for $50 < N < 60$.

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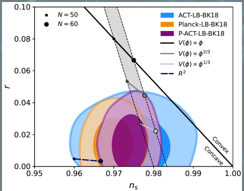

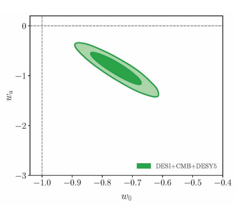

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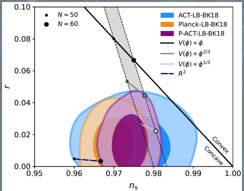

Need for a paradigm shift?

GFT cosmology

Collective states

GFT coherent states

- Collectivity: States should accommodate an infinite number of quanta. E.g.: coherent states $|\sigma\rangle$.
- Homogeneity: Wavefunction σ depends only on geometry and on a clock field χ, $\sigma = \sigma(g_a, \chi)$.
- Isotropy: Wavefunction σ depends only on a single spin label, $\sigma \equiv \sigma_j(\chi)$.
- Relationality: σ is localized in relational time (can alternatively be implemented on observables).

LM, Oriti, Pithis, Thürigen 2211.12768; LM, Oriti 2008.02774-2112.12677; Oriti, Sindoni, Wilson-Ewing 1602.05881; LM, Wilson-Ewing 2412.14622. . .

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Coarse-graining

Macroscopic dynamics = mean-field approximation

- Take simplest SD equations, i.e., the averaged quantum equations of motion: $\langle \delta S_{\mathrm{GFT}}/\delta\hat{\varphi}^\dagger\rangle_\sigma = 0$.

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Macroscopic quantities = Averaged one-body operators

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- Only need volume $V \equiv \langle \hat{V}\rangle_\sigma = \sum_j V_j \rho_j^2$, with $\sigma_j \equiv \rho_j e^{i\theta_j}$, to describe cosmological quantities:

$$\bar{V} a^3 = V = \sum_j V_j \rho_j^2\,, \qquad H^2 = \frac{\pi_\chi^2}{9V^2}\left(\frac{V'}{V}\right)^2, \qquad w = 3 - 2\frac{VV''}{(V')^2}$$

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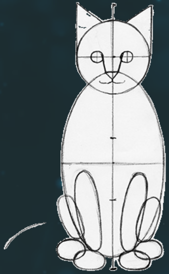
The spherical cat model



(Pseudo)-Tensorial interactions and single-mode system

$$\mathcal{V}[\sigma, \sigma^*] = -\sum_j \left(m_j^2 |\sigma_j|^2 + 2\frac{\lambda_j}{n_j} |\sigma_j|^{n_j} \right)$$

De Cesare, Pithis, Sakellariadou 1606.00352; De Sousa, Barrau, Martineau 2305.05438.

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Model and assumptions

- (Pseudo-)Tensorial interactions: Chosen phenomenologically to depend only on $|\sigma_j| \equiv \rho_j$.
- Truncation: Only one interaction is considered, with $2 < n_j$.
- Single spin: One mode σ_{j_o} dominates the universe's evolution: $V = V_{j_o}\rho_{j_o}^2 \equiv V_{j_o}\rho^2$.

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Results

$$H^2 \xrightarrow[\text{late times}]{} \frac{8\pi_\phi^2}{9} \left(\Lambda_\lambda V^{-(3-n/2)} \right)$$

- Late times dynamics: As the volume grows, ρ grows and high-order interactions dominate.
- Emergent acceleration: If $n=6$, emergence of a cosmological const., $\Lambda_\lambda = -\lambda V_{j_o}^{-2}/6$.

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- Inflation? If $\mu > 0$ ($\Lambda_\mu < 0$), acceleration ends after $N(\mu)$ e-folds.

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Bad news

Limitations

- No QG inflation: μ-interactions dominate and generate a recollapse: cyclic universe.
- No radiation phase (minor): For the above interactions, $H^2 \propto a^{-\alpha}$, with $\alpha < 3/2 < 4$.

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Adding details (and modes)

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Oriti, Pang 2105.03751 and 2502.12419.

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A more realistic model

Model and assumptions

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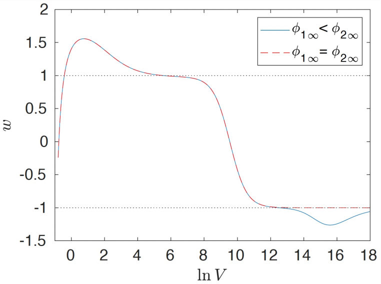
Phantom dark energy

$$w \underset{\text{late times}}{\longrightarrow} -1 - \frac{b}{V}$$

- Emergent phantom dark energy with no field theoretical issue.
- Fast transition: End of Friedmann phase, phantom crossing, and minimal value of w are close to each other.
- Recent crossing: If we are in a phantom phase, the crossing must have happened recently.
- Increased H_0 with respect to single-mode.



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Emergent dynamical dark energy

$$\mathcal{V}[\sigma, \sigma^*] = -\sum_j \left(m_j^2 |\sigma_j|^2 + \lambda_j e^{i\vartheta} \sigma_j^l + \text{ c.c} \right)$$

Ladstätter, LM, Oriti (to appear).

Emergent dynamical dark energy

$$\rho_j'' - [(\theta_j')^2 + m_j^2]\rho_j - \lambda_j \cos\varphi_j \rho_j^l = 0 \qquad \rho_j\theta_j'' + 2\rho_j'\theta_j' - \lambda_j \sin\varphi_j \rho_j^l = 0$$

Pseudosimplicial: Good News

Model and Assumptions

- (Pseudo-)Simplicial interactions: Less symmetric, but more easily connected to simplicial gravity.
- Phase dependence: Equations depend on ρ_j and θ_j (also in $\varphi_j \equiv \vartheta_j - n\theta_j$, $n = l + 1$).
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Evolving Dark Energy

- Asymptotically autonomous system: standard stability analysis possible.

$$x = \theta\,, \quad y = \rho'/\rho^3\,, \quad z = \theta'\,.$$

$$\begin{aligned} x' &= z\,, \\ y' &= -3\rho^2 y^2 + (z^2 + m^2)/\rho^2 + \lambda\rho^{l-3}\cos\varphi(x)\,, \\ z' &= -2\rho^2 yz + \lambda\rho^{l-1}\sin\varphi(x)\,. \end{aligned}$$

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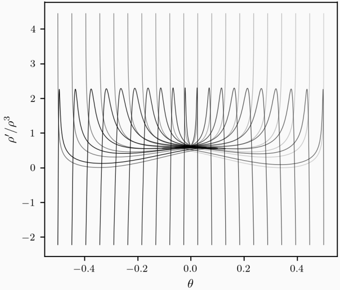

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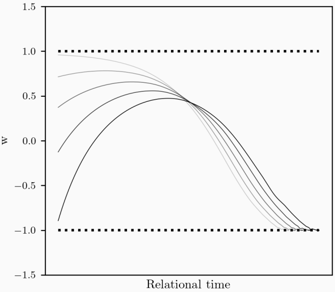

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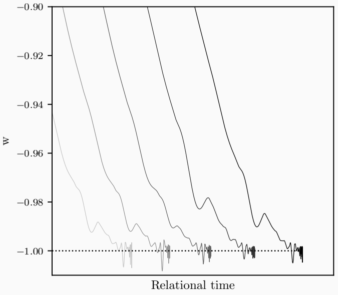

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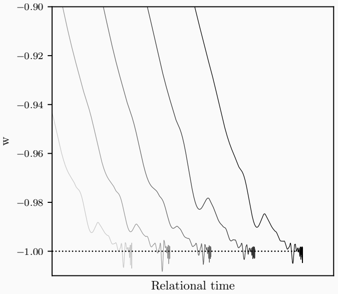

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Pseudosimplicial: Even Better News

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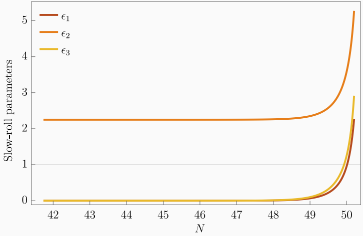
Emergent inflation!

- Persistent acceleration: $N_{\mathrm{end}} \gg 1$ if $\varphi_{\mathrm{in}} \simeq 0$.
- Almost slow-roll: $\epsilon_{1,3} \ll 1$ during inflation.



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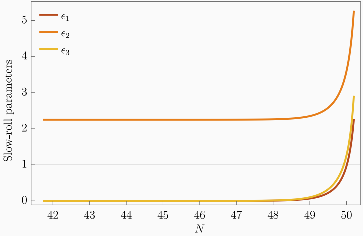
- Persistent acceleration: $N_{\text{end}} \gg 1$ if $\varphi_{\text{in}} \simeq 0$.
- Almost slow-roll: $\epsilon_{1,3} \ll 1$ during inflation.
- Preliminary: Post-inflation $\langle w \rangle_{\text{osc}} = 1$.



Ladstätter, LM, Oriti (to appear); Mukhanov 1409.2335.

Emergent inflation

$$\rho_j'' - [(\theta_j')^2 + m_j^2]\rho_j - \lambda_j \cos\varphi_j \rho_j^l = 0 \qquad \rho_j\theta_j'' + 2\rho_j'\theta_j' - \lambda_j \sin\varphi_j \rho_j^l = 0 \qquad \varphi_j = \vartheta_j + (l+1)\theta_j$$

Pseudosimplicial: Even Better News

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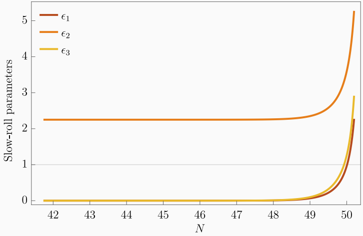
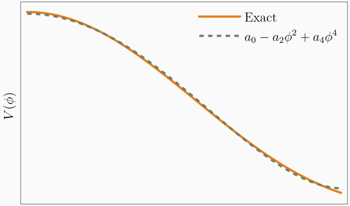


Inflaton description

- One can construct a ϕ with potential $V(\phi)$ driving the inflationary dynamics $\epsilon_1(N)$.

GFT inflation as emergent SFI!

- No analytic form for $V(\phi)$, but numerically well approximated by a Mexican-hat potential.



Ladstätter, LM, Oriti (to appear); Mukhanov 1409.2335.

Dynamical Dark Energy

- Order 6 GFT interactions generate acceleration, both in pseudo-tensorial/-simplicial models.
- Asymptotically de Sitter is an attractor, with Λ depending on GFT parameters.
- Emergent description is that of a dynamical dark energy, with $w = w(a)$ depending on the microscopic dynamics.

Late Times

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Paper out soon, stay tuned!

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Outlook

Model Building and Phenomenology

- What is the simplicial gravity interpretation of the emergent inflationary models?
- Impact of additional modes in pseudo-tensorial/-simplicial models?
- Evolving dark energy affects H_0. Can QG alleviate cosmological tensions?
- How do primordial cosmological perturbations emerge from QG? (No inflaton in this picture!)
- In this scenario, what can cosmological power spectra tell us about QG?
- Can a similar mechanism also produce a dark matter component? Emergent tracking solutions?
- ...