Emergent Acceleration from Quantum Gravity: Dynamical Dark Energy and Inflation

In collaboration with: T. Ladstätter and D. Oriti (2512.11712)

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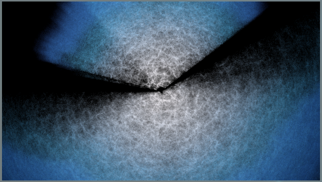
Concepts of Quantum and Spacetime

KEK, Tsukuba

Mar 11, 2026

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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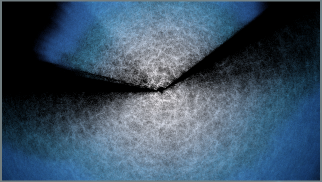

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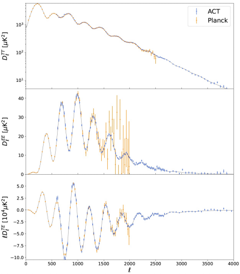
The ACT power spectra

- 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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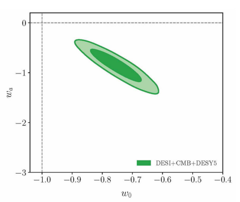

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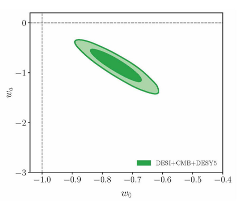

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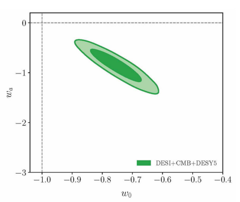

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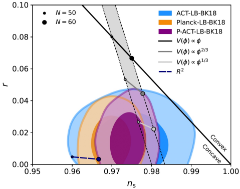

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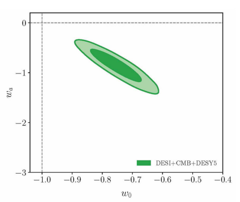

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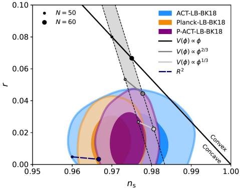

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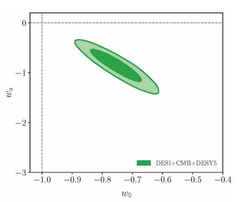

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- Fluid: violates NEC: which "matter"?
- Fundamental (k-essence): classical (gradient) & quantum instability (vacuum decay, ghosts).

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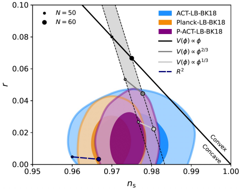

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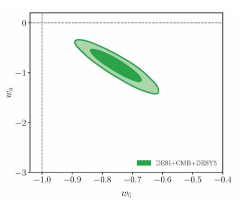

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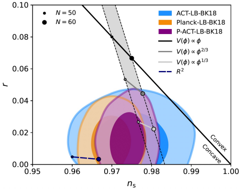

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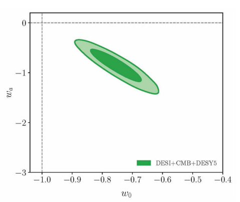

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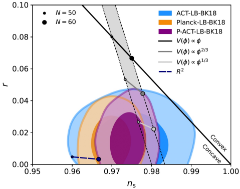

Need for a paradigm shift?

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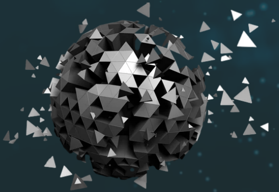

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- GFT field $\phi : \mathcal{G} \to \mathbb{C}$; $\mathcal{G}$ field space group, not spacetime!
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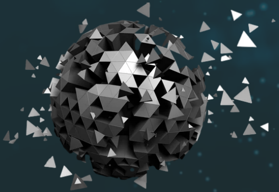
Freidel 0505016; Oriti 1408.7112; Oriti, Ryan, Thürigen 1409.3150; Oriti, Sindoni, Wilson-Ewing 1602.05881; LM, Oriti 2008.02774; . . .



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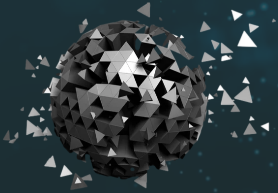

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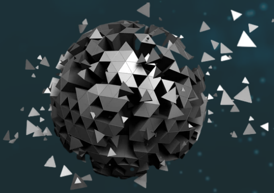

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Relational 2nd order differential operator

Non-local and non-linear.

- Macroscopic states: Derived from $\langle \delta S_{\mathrm{GFT}}/\delta\hat{\varphi}^\dagger\rangle_\sigma = 0$ where $|\sigma\rangle$ are frame-localized coherent states.
- Cosmology: typically evolution wrt. MCMF scalar field clock; non-linear and non-local extension of QC.

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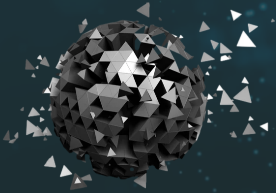

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Macroscopic Observables: Hydrodynamic Averages

- Hydrodynamic: Macroscopic quantities $\sim O_\sigma \sim \sigma$-"hydrodynamic" averages of collective observables.

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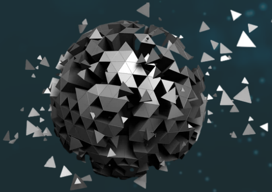

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Clock time derivative

$$\bar{V}a^3 = V = \sum_\upsilon \mathfrak{v}_\upsilon \rho_\upsilon^2\,, \qquad H^2 = \frac{\pi_\chi^2}{9V^2}\left(\frac{V'}{V}\right)^2, \qquad w = 3 - 2\frac{VV''}{(V')^2}$$

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Emergent acceleration I: Stability

Mean-field model

Model and Assumptions

$$\overset{\text{kinetic kernel}}{\mathcal{K}_\upsilon[\sigma_\upsilon]} + \underset{\text{interaction kernel}}{\mathcal{V}_\upsilon[\sigma_\upsilon,\sigma^*_\upsilon]} = 0\,, \qquad \mathcal{K}_\upsilon = \partial^2_\chi - E^2_\chi\,, \qquad \mathcal{V}_\upsilon[\sigma_\upsilon,\sigma^*_\upsilon] = -\underset{\in\mathbb{R}}{\lambda_\upsilon}\,\rho_\upsilon^{\overset{\text{int. order }\in\,\mathbb{N}^+}{l}} e^{i((m+1)\theta_\upsilon+\vartheta_\upsilon)}\,,$$

- **Generalized mean-field:** Reduces to pseudo-tensorial/simplicial for $m = 0$ and $m = -(l+1)$, resp.
- **Assumptions:** Homogeneity, isotropy, single-mode, late times. Interactions are non-perturbative.

LM, Ladstätter, Oriti 2512.11712; Ladstätter, LM 2508.16194; Oriti, Pang 2105.03751-2502.12419; De Cesare, Pithis, Sakellariadou 1606.00352...

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Dynamical system

Fixed points and dynamical stability

- First order for $x = \theta$, $y = \rho'/\rho^3$, $z = \theta'$.
- FP_∞: $l=5$, $\bar{y}^2 = |\lambda|/3$, $\bar{x} = (n\pi - \vartheta)/m$, $z = 0$.
- FP_∞ dynam. (weak) attractor iff $1+3m/4<0$.

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$$H^2 \propto y^2\,, \qquad w = -[(1 + y'/(\rho^2 y^2)]$$

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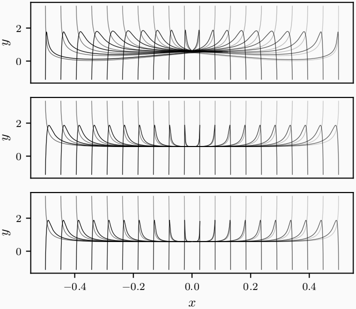
Emergent dS cosmological attractor for $m \leq 0$.



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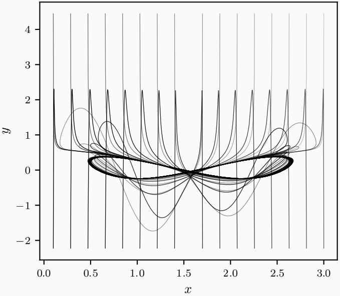
Emergent dS cosmologically unstable for $m > 0$.



LM, Ladstätter, Oriti 2512.11712; Ladstätter, LM 2508.16194; Oriti, Pang 2105.03751-2502.12419; De Cesare, Pithis, Sakellariadou 1606.00352...

Emergent acceleration II: Dynamical Dark Energy

Asymptotics

Asymptotic Λ

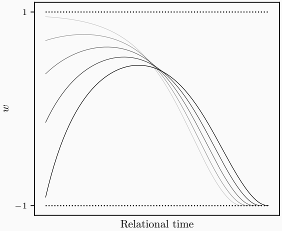
- Emergent DE: For $m \leq 0$ asymptotic dS attractor.

GFT coupling

Clock momentum

$$\bar{w} = -1, \qquad \bar{\Lambda} = |\lambda| \frac{4\pi_{\chi}^{2}}{9\mathfrak{v}^2}$$

Volume eigenvalue



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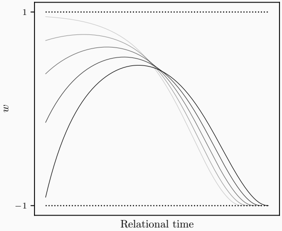

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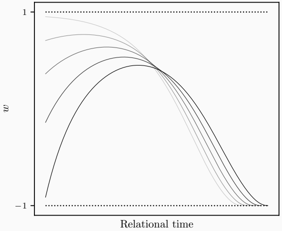


Dynamical behavior

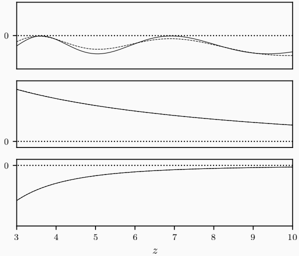
EoS dynamics

$(1 + z_q)/(1 + z)$ $\propto \log \mathcal{T}(z)$

$$\delta w(z) = \begin{cases} [\mathcal{T}(z)]^{-6}(\delta w_0 + \delta w_1 \cos 2\Phi(z) + \delta w_2 \sin 2\Phi(z)) \\ \delta w_0 [\mathcal{T}(z)]^{6(\sqrt{1+3m/4}-1)} \\ \delta w_0 [\mathcal{T}(z)]^{-6} \log^2[\mathcal{T}(z)] \end{cases}$$

Solutions depend on $\mathrm{sgn}(1+3m/4)$.

- Quantum features: $z_q \sim \#$ of QG atoms today.



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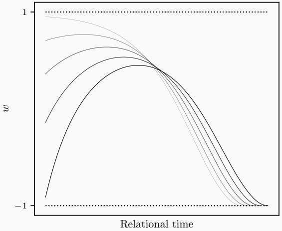

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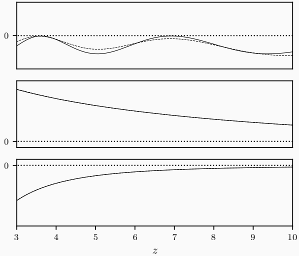

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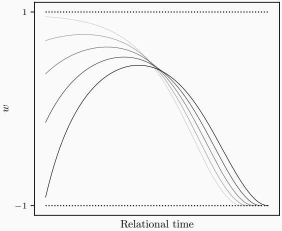

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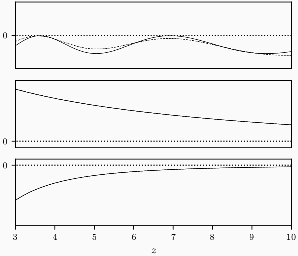
Emergent dynamical (typically phantom) dark energy!



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Emergent acceleration III: Emergent Inflation

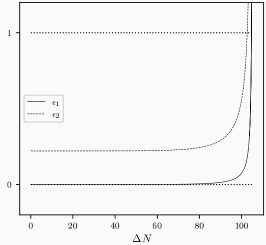
Quasi dS phase

Slow-Roll Inflation

- Quasi dS: For $m > 0$ FP_∞ repulsive; acceleration ends.

$$\epsilon_1(N) = \exp[-\epsilon_2(N_{\text{end}} - N)]$$

$$\epsilon_2(N) = 6(\underbrace{\mu}_{\uparrow (1+3m/4)^{1/2}} - 1)$$



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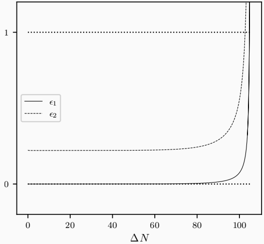

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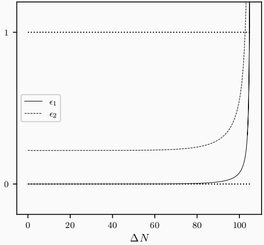


Single-field description

Emergent Inflaton

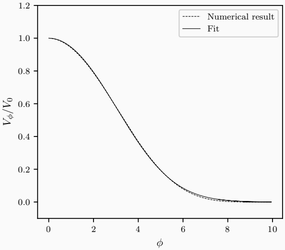
- SFI: GFT inflation can be described by emergent ϕ:

$$\delta\theta(\phi) \propto \phi - \phi_0$$

GFT phase

$\in [\phi_0, \phi_0 + 1]$

$$V(\phi) = V_0 \left(1 - \frac{(\phi - \phi_0)^2}{3}\right) e^{-2(\phi-\phi_0)^2/\epsilon_2} \,,$$



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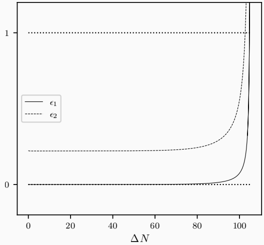

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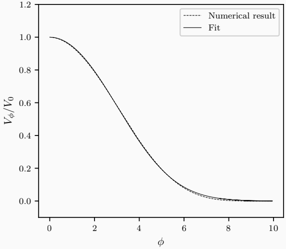
Emergent slow-roll single-field inflation!



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Dynamical Dark Energy

- Order 6 GFT interactions generate acceleration, both in pseudo-tensorial/-simplicial models.
- For $m \leq 0$ de Sitter is an asymptotic attractor, with Λ depending on GFT parameters.
- Emergent dynamical dark energy, with $w = w(z)$ depending on the microscopic parameters.
- Dark energy is phantom for a large set of models (including pseudo-simplicial)!

Late Times

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- Inflaton potential: in this description, the emergent inflaton potential is a polynomial-Gaussian..
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QG as the mechanism underlying cosmic acceleration, not just a correction!

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Outlook

Model Building and Phenomenology

- ⚠ How do predictions on $w(z)$ compare with data?
- 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?
- Constraining effective theory space: map between SFI models and GFT mean-field theory models?
- Impact of additional modes on emergent dynamical dark energy behavior?
- ...