Late time cosmological acceleration from group field theory

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- Characterizing acceleration: equation of state w; $w \simeq -1$, or even $w < -1 \rightarrow$ phantom energy;
- Two points of view regarding to the acceleration:
  - From particle physics: dark energy models;
  - From gravitational physics: modified gravity theories;

Is it possible that the accelerating has some quantum gravity origin?

Group Field Theory

Acceleration emerges from interaction couplings.

Bamba et al. 2008; Nojiri and Odintsov 2006; Saitou and Nojiri 2012; Zhao et al. 2017

Accelerating Universe

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Group field theory

- Group field: functions $\varphi : SU(2)^{\times 4} \times \mathcal{R} \to \mathcal{C}$, whose excitations are represented by tetrahedrons, building blocks of the spacetime;
- Condensate states: $|\sigma_\varepsilon; \phi, \pi\rangle$, can be labelled by $\sigma_j(\phi)$, peaked on given relational time ϕ; j labels different modes;
- Effective action:
  $S(\bar{\sigma}, \sigma) = \int \mathrm{d}\phi \left\{ \sum_j \left[\bar{\sigma}_j(\phi) \tilde{\sigma}_j''(\phi) - m_j^2 \bar{\sigma}_j(\phi) \sigma_j(\phi) \right] + U(\bar{\sigma}, \sigma) \right\}$,
  with

$$U(\bar{\sigma}, \sigma) = \sum_j \frac{2\lambda_j}{n_j} |\sigma_j(\phi)|^{n_j}, \tag{1}$$

- Total volume:

$$V(\phi) = \langle \sigma_\varepsilon; \phi, \pi | \hat{V} | \sigma_\varepsilon; \phi, \pi \rangle = \sum_j V_j |\sigma_j|^2 = \sum_j V_j \rho_j^2. \tag{2}$$

Gielen 2016; Gielen and Sindoni 2016; Krajewski 2013; Marchetti and Oriti 2020; Oriti 2011; Oriti, Sindoni, and Wilson-Ewing 2016

- Equation of motion:

$$\rho_j'' - \frac{Q_j^2}{\rho_j^3} - m_j^2\rho_j + \lambda_j\rho_j^{n_j-1} = 0, \tag{3}$$

- Approximated solution at large volume:

$$\rho_j(\phi) = \left(\frac{2}{n_j-2}\sqrt{\frac{-2\lambda_j}{n_j}}\right)^{-\frac{2}{n_j-2}} \frac{1}{(\phi_{j\infty}-\phi)^{\frac{2}{n_j-2}}} \quad , \tag{4}$$

- The quantity $\phi_{j\infty}$ is determined by several parameters of the theory

$$\phi_{j\infty} = -\frac{\ln[-\lambda_j/(2m_j^2)]}{(n_j-2)m_j} + \frac{1}{2m_j}\ln\left[\frac{n_j^{\frac{2}{n_j-2}}(2m_j^2)}{\sqrt{E_j^2+m_j^2Q_j^2}}\right].$$

Oriti and Pang 2021

Phantom crossing with two-modes

Consider the case with two modes, at large volume setting $n_1 = n_2 = n$ leads to

$$w = 2 - \frac{n}{2} - \left(\frac{n}{2} + 1\right) \frac{V_1 V_2 r^2 \left(r^{n/2-1} - \sqrt{\lambda_1/\lambda_2}\right)^2}{\left(\sqrt{\lambda_1/\lambda_2} V_1 + V_2 r^{n/2+1}\right)^2} \quad . \qquad (5)$$

where $r = \rho_2/\rho_1$, i.e., w only depends on this ratio in this approximation.

- Special case: $r = \left(\frac{\lambda_1}{\lambda_2}\right)^{\frac{n}{4}-\frac{1}{2}}$, $\Rightarrow w = 2 - \frac{n}{2}$ is a constant. Happens when $\phi_{1\infty} = \phi_{2\infty}$.
- Further approximation: Setting $n = 6$, for $\phi_{1\infty} < \phi_{2\infty}$, at large volume ρ_1 dominates hence $r \to 0$, we get a simple behaviour

$$w \approx -1 - \frac{4V_2}{V_1} r^2 = -1 - \frac{4V_2}{V_1} \frac{\rho_2(\phi)^2}{\rho_1(\phi)^2} \approx -1 - \frac{b}{V}. \qquad (6)$$

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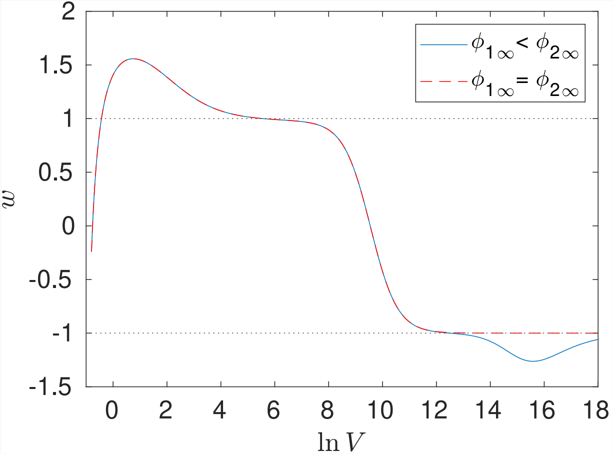

The behaviour of w in the two modes case, where both modes have only one interaction term.

Fictitious field ψ: conservation equation $\dot{\rho}_\psi + 3H(1+w_\psi)\rho_\psi = 0$ with $w_\psi \equiv p_\psi/\rho_\psi = w$.

Evolution of fictitious field ψ

Conservation equation can be rewritten as $\frac{\mathrm{d}\rho_\psi}{\mathrm{d}V} + \frac{1+w}{V}\rho_\psi = 0$, substituting equation of state (6), we get

$$\frac{\mathrm{d}\rho_\psi}{\mathrm{d}V} - \frac{b}{V^2}\rho_\psi = 0 \quad ,$$

whose solution is

$$\rho_\psi = \rho_{\psi 0}\mathrm{e}^{-\frac{b}{V}} \approx \rho_{\psi 0} - \frac{\rho_{\psi 0} b}{V} \quad . \tag{7}$$

McInnes 2001; Oriti and Pang 2021

Summary

- As a quantum theory of gravity, GFT can be used to extract the cosmological evolution, and the late time acceleration emerges as a reault of the GFT interactions;
- The phantom-like behaviour can be recovered from condensate with two-modes, where the effective equation of state approaches to -1 from below, resulting an energy density increases as the volume of universe grows;
- Although the evolution is phantom-like, we won't encounter future singularities, instead, the de Sitter spacetime will show up asymptotically.

Thank you!