Stability of de Sitter spacetime against the backreaction of the infrared modes of scalar fields

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Quantum field theory in de Sitter spacetime

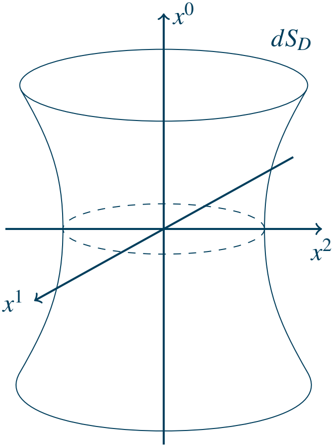
We do a semi-classical treatment with

- a classical background metric
- quantum fields as a content

It is **maximally symmetric**

We will consider the **Expanding Poincaré patch** $\rightarrow$ FLRW with constant Hubble rate H

- $\mathrm{d}s^2 = -\mathrm{d}t^2 + a^2(t)\mathrm{d}\vec{X}^2$, $a(t) = e^{Ht}$
- Conformal time, $\mathrm{d}\eta = \frac{\mathrm{d}t}{a(t)}$,
  $\mathrm{d}s^2 = a^2(\eta)\left(-\mathrm{d}\eta^2 + \mathrm{d}\vec{X}^2\right)$.



Particle creation and backreaction

Gravitational effects in de Sitter : **particle creation**

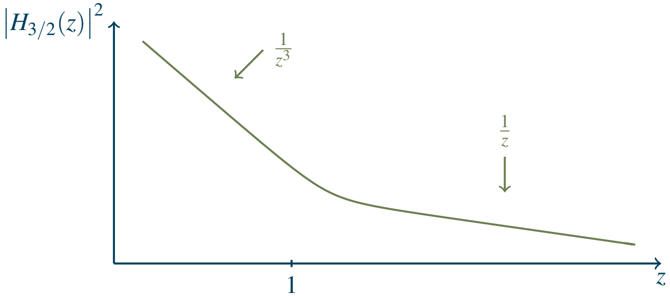
Similar effects when one puts a quantum field with a constant background field

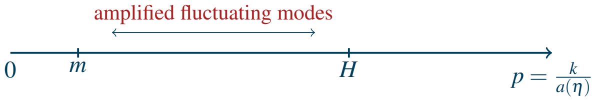
- Schwinger effect : pair creation in the presence of an electric field $\vec{E}$
- Unruh-Hawking radiation : pair creation in the presence of a black hole

In both cases : the creation of pairs **has potentially nontrivial backreaction on the background source**

Free scalar field

The mode function of light scalar fields $m \ll H$ in Bunch-Davies vacuum is $\varphi_k(\eta) \sim H_{3/2}\left(\frac{k}{a(\eta)}\right)$





Stability of de Sitter

For scalar field in dS,

- Large gravitational effects in the infrared (superhorizon scales)
- Infrared modes are amplified
- Interactions cannot be treated perturbatively

A. A. Starobinsky, J. Yokoyama ’94 ; N. C. Tsamis, R. P. Woodard ’05 ;
C. P. Burgess et al. ’10

It is interesting to study the **backreaction** of these infrared modes fluctuations to test whether de Sitter space is stable under their amplification and interactions.

E. Mottola ’85 ; I. Antoniadis et al. ’86 ; R. H. Brandenberger et al. ’96 ; Unruh ’98 ;
A. M. Polyakov ’10, ’12

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Non perturbative renormalization group

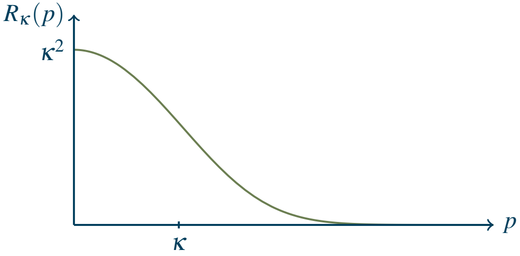
J. Serreau '13 ; A. Kaya '13 ; M. Guilleux, J. Serreau '15

Formulation of NPRG is done in term of the effective action

$$e^{-i\mathscr{W}_\kappa[j,g]} = \int \mathscr{D}\hat{\varphi} e^{iS[\hat{\varphi},g]+i\Delta S_\kappa[\hat{\varphi},g]+i\int j\hat{\varphi}}$$

$g_{\mu\nu}$ background metric, S action of an $O(N)$ scalar theory.

$$\Gamma_\kappa[\varphi,g]+\Delta S_\kappa[\varphi,g] = -\mathscr{W}_\kappa[j,g]+j\cdot\varphi, \quad \varphi = \langle\hat{\varphi}\rangle$$



$$\Gamma_{\kappa\to\infty} = S$$

$$\Gamma_{\kappa\to 0} = \Gamma$$

Non perturbative renormalization group 2

We want to solve the flow of Γ_κ : it obeys the **Wetterich equation**, which is IR and UV finite

$$\dot{\Gamma}_\kappa = \frac{1}{2}\operatorname{tr}\dot{R}_\kappa(\Gamma_\kappa^{(2)} + R_\kappa)^{-1}.$$

C. Wetterich '93

The **physical values** for g and φ are simultaneously determined at each scale κ through

$$\frac{\delta\Gamma_\kappa}{\delta\varphi} = 0, \quad \frac{\delta\Gamma_\kappa}{\delta g^{\mu\nu}} = 0 \quad \text{or} \quad G^\kappa_{\mu\nu} = \langle T^\kappa_{\mu\nu}\rangle$$

We take constant values of φ and de Sitter spacetime : it gives the **flow of the Hubble constant**

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Zero dimensional theory

The theory flows towards a zero dimensional theory

J. Serreau ’14 ; M. Guilleux, J.Serreau ’15

$$e^{H^{-4}\Omega \mathscr{W}_\kappa(j,h)} = \int \mathrm{d}^N \hat{\varphi}\, e^{-H^{-4}\Omega\left(U_{in}(\hat{\varphi},h)+\frac{\kappa^2}{2}\hat{\varphi}^2 - j\cdot\hat{\varphi}\right)}$$

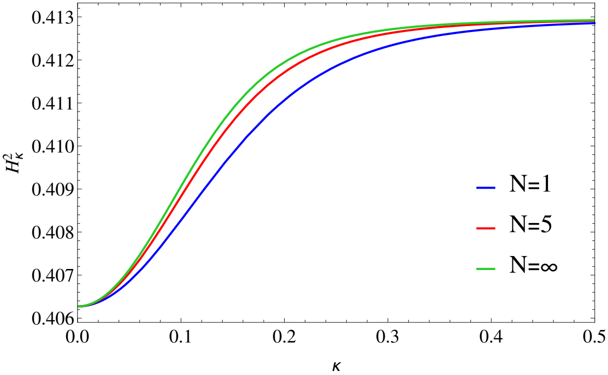
- It coincides with the equilibrium probability distribution in the stochastic formalism

  A. A. Starobinsky, J. Yokoyama ’94
- It is the **effective theory for the scalar field averaged over a Hubble patch** at constant values of the field

With $U_{in}(\hat{\varphi},h) = \alpha - \frac{\beta}{2}H^2 + \frac{\lambda}{8}\hat{\varphi}^4, \quad \alpha \propto \Lambda, \quad \beta H^2 \propto R$

$$H_\kappa^2 = \frac{4\alpha}{\beta} + \frac{2\kappa^2}{\beta}\left\langle \hat{\varphi}^2 \right\rangle + \frac{\lambda}{2\beta}\left\langle \hat{\varphi}^4 \right\rangle$$

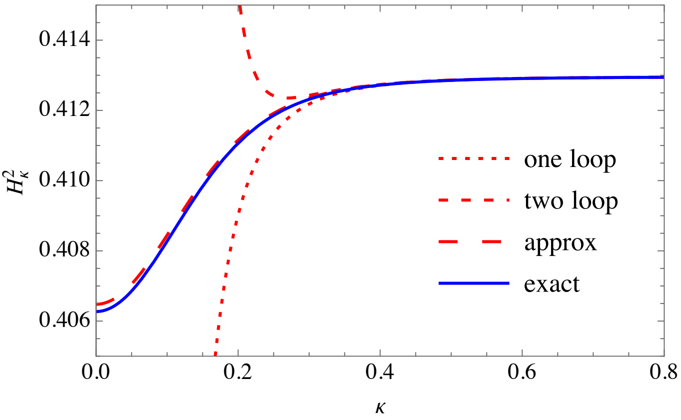
Result for a massless self-interacting field



- Enhanced superhorizon modes draw energy from the gravitational field
- The dynamical generation of a mass screens this effect
- Finite renormalization of H^2 : $H_\infty^2 \approx H_{cl}^2 + \frac{2H_{cl}^4}{\beta\Omega}$, $\quad H_0^2 \approx H_{cl}^2 + \frac{H_{cl}^4}{\beta\Omega}$

Perturbation theory

Expansion parameter is $\frac{\lambda H^4}{\kappa^4}$: perturbation theory breaks down when κ decreases



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Conclusion

- The gravitational mass generation screens the renormalization of the Hubble parameter
- Non minimal coupling between the scalar fields and gravitational field has a non trivial effect on the flow
- Goldstone modes do not contribute
- A full non perturbative treatment is needed as the perturbative approach breaks down

Perspectives :

- Generalize to FLRW metric
- apply the same treatment directly to the effective stochastic theory, using QFT formulation of Langevin equation