Higgs-Starobinsky Inflation[1]

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[1] based on X. Calmet, I. K. [arXiv:1605.02236]

Seminar structure

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1. Inflation
2. Examples
3. Higgs-Starobinsky inflation
4. Conclusions

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Seminar structure

- Conditions for inflation; violation of SEC.

$$\frac{\mathrm{d}^2 a}{\mathrm{d}t^2} > 0 \iff \omega = \frac{p}{\rho} < -\frac{1}{3}$$

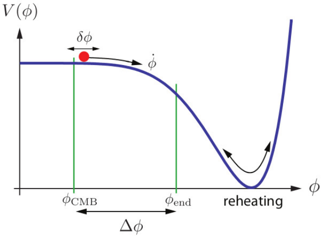
- What kind of matter can satisfy this condition?
- Simplest model: scalar field (inflaton).

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{M_p^2}{2}R + \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right]$$

$$T_{\mu\nu}^{(\phi)} = -\frac{2}{\sqrt{-g}}\frac{\delta S_\phi}{\delta g^{\mu\nu}} \implies \begin{cases} p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) \\ \rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) \end{cases}$$

- If the potential is much greater than the kinectic term we have slow roll inflation.

$$\omega_\phi = \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)} \approx -1$$



Seminar structure

- Higgs inflation: $H = \frac{1}{\sqrt{2}}(0, h)^T$ non-minimally coupled to gravity and $M_p^2 = (M^2 + \xi v^2)$.

$$S_J = \int \mathrm{d}^4 x \sqrt{-g} \left[\frac{M^2}{2} R + \xi H^\dagger H R + \mathcal{L}_H \right] \quad \text{(Jordan frame)}$$

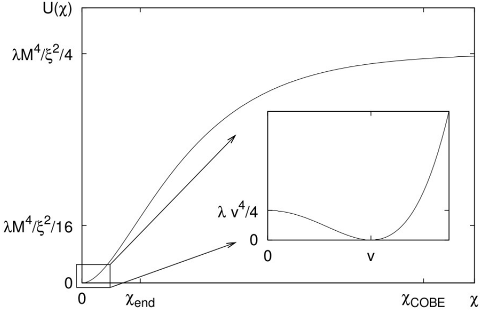
- Conformal transformation $\tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$ with $\Omega^2 = 1 + \frac{\xi h^2}{M_p^2}$.

$$S_E = \int \mathrm{d}^4 x \sqrt{-\tilde{g}} \left[\frac{M_p^2}{2} \tilde{R} + \frac{1}{2} \tilde{g}^{\mu\nu} \partial_\mu \chi \partial_\nu \chi - U(\chi) \right] \quad \text{(Einstein frame)}$$

$$\frac{\mathrm{d}\chi}{\mathrm{d}h} = \sqrt{\frac{\Omega^2 + 6\xi^2 h^2 / M_p^2}{\Omega^4}}$$

$$U(\chi) = \frac{1}{\Omega(\chi)^4} \frac{\lambda}{4} \left[h(\chi)^2 - v^2 \right]^2$$

- Potential is good for inflation.



- Instability: the universe is metastable and ends up in the true vacuum [arXiv:1112.5430].

- Starobinsky model:

$$S_J = \frac{M_p^2}{2}\int \mathrm{d}^4x\sqrt{-g}\,\overbrace{\left(R + \frac{c_s}{M_p^2}R^2\right)}^{f(R)} \quad \text{(Jordan frame)}$$

$$c_s = 0.97 \times 10^9$$

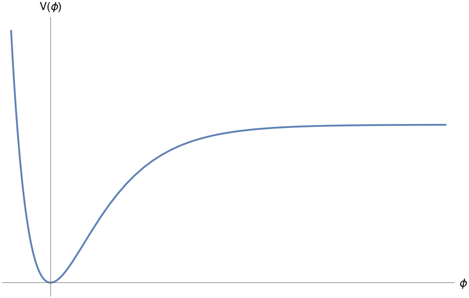
- Conformal transformation $\tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}$ with $\Omega^2 = f'(R)$.

$$S_E = \int \mathrm{d}^4x \left(\frac{M_p^2}{2}\tilde{R} + \frac{1}{2}\tilde{g}^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right) \quad \text{(Einstein frame)}$$

$$\phi = M_p\sqrt{\frac{3}{2}}\log f'(R)$$

$$V(\phi) = \frac{M_p^4}{c_s}\left[1 - \exp\left(-\sqrt{\frac{2}{3}}\frac{\phi}{M_p}\right)\right]^2$$

- Also good!



- Starobinsky model has no obvious problems.

Seminar structure

- Both terms $\xi H^\dagger H R$ and $c_1 R^2$ are expected to appear in high energies below M_*; diffeomorphism invariance.

$$S = \int \mathrm{d}^4 x \sqrt{-g} \Big[\left(\frac{M^2}{2} + \xi H^\dagger H \right) R + c_1 R^2 + c_2 C^2 + c_3 E + c_4 \Box R - \Lambda^4 + \mathcal{L}_{SM} + \mathcal{L}_{DM} + O(M_*^{-2}) \Big]$$

$$E = R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} - 4 R_{\mu\nu} R^{\mu\nu} + R^2$$

$$C^2 = E + 2 R_{\mu\nu} R^{\mu\nu} - \frac{2}{3} R^2$$

- Running of c_1 due to one loop diagrams of scalar fields [arXiv:1507.06308]:

$$\mu\partial_\mu c_1(\mu) = \frac{(1-12\xi)^2}{1152\pi^2} N_s.$$

- Fermions and vector fields don't contribute and the contribution from gravitons is negligible.

- The RGE can be easily integrated:

$$c_1(\mu_2) = c_1(\mu_1) + \frac{(1-12\xi)^2 N_s}{1152\pi^2} \log \frac{\mu_2}{\mu_1}. \tag{1}$$

- $c_1(\mu_{\text{inf}} = 10^{15}\text{GeV}) = 0.97 \times 10^9$ and $c_1(\text{today}) = 1$:

$$\xi = 1.8 \times 10^4.$$

- Does it satisfy the bounds? $|\xi| < 2.6 \times 10^{15}$.
- Higgs triggers Starobinsky inflation.

- What about the other higher order terms? Don't they destabilize the potential?
- Effective action Γ_{EFT}:

$$e^{-M^2 \Gamma_{EFT}[g]} = \int_{1PI} \mathcal{D}h_{\mu\nu}\, e^{-S[g+\frac{1}{M^2}h]}$$

$$\Longrightarrow \Gamma_{EFT} = \frac{1}{16\pi G} \int \mathrm{d}^4x \sqrt{-g} \left(R + \alpha R^2 + \beta R \log \frac{\Box}{\mu^2} R + \cdots \right)$$

- In the Einstein frame:

$$V(\phi) = V_{\text{Starobinsky}} + O(V_{\text{Starobinsky}} \times 10^{-3}).$$

- So the quantum corrections do not affect the flatness of $V(\phi)$.

Seminar structure

- It's still Starobinsky inflation!
- We found a new connection between the Higgs boson and inflation.
- Although this corresponds to Starobinsky model, the Higgs field plays a fundamental role.
- We don't have stability problems since the Higgs doesn't take large values.