Conformal Standard Model and Inflation

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Inflation - problems of Λ-CDM model

- Horizon problem
- Flatness problem
- Nonhomogenous CMB radiation

Introducing inflation era resolves these problems! However poses a question on a mechanism which drives it.

Experimental tests - Planck data

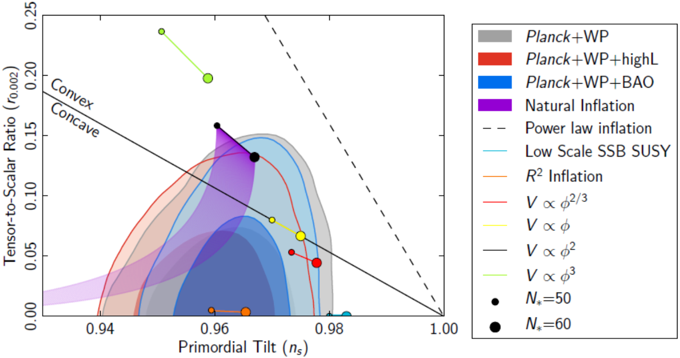

Figure: Bounds on n_s and r, credits: PLANCK satellite data

Non-minimally coupled Higgs inflation: Bezrukov-Shaposhnikov model.

Action:

$$S_H = \int d^4x\sqrt{|g|}\left[-\frac{M_P^2+\xi h^2}{2}R+ \right. \tag{1}$$

$$\left. \frac{\partial_\mu h \partial^\mu h}{2} + \frac{h^2\partial_\mu\theta\partial^\mu\theta}{2} - \frac{\lambda}{4}\left(h^2-v^2\right)^2\right], \tag{2}$$

This model model gives correct values of n_s and r for $N \approx 60$, e-folds.

$$n \simeq 1 - 2/N \simeq 0.97, \tag{3}$$

$$r \simeq 12/N^2 \simeq 0.0033, \tag{4}$$

Unitary issue. Value of parameter ξ.

Conformal Standard Model

- Only slight extension
- Relies on Softly Broken Conformal Symmetry Mechanism (SBCS)
- Right handed neutrinos
- Introduction of sterile complex scalar (coupled only to right handed neutrinos and Higgs).
- Higgs particle combined from two mass states
- Dark matter candidates
- Baryogengesis via leptogenesis

Inflation in Conformal Standard Model

Lagrangian in the Jordan frame:

$$\mathcal{L} = \frac{1}{2}\partial_\mu h \partial^\mu h + \frac{1}{2}\partial_\mu s \partial^\mu s - \frac{\left(M_P^2 + \xi_1 h^2 + \xi_2 s^2\right)}{2} R - V_J(h,s), \quad (5)$$

with $\xi_i > 0$. With the potential:

$$V_J(h,s) = \frac{1}{4}\lambda_1 (h^2 - v_H^2)^2 + \frac{1}{4}\lambda_p (s^2 - v_\phi^2)^2 + \frac{1}{2}\lambda_3 \left(h^2 - v_H^2\right)\left(s^2 - v_\phi^2\right), \quad (6)$$

Einstein frame transformation:

$$\tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}, \qquad \Omega^2 = 1 + \frac{\xi_1 h^2 + \xi_2 s^2}{M_P^2}, \quad (7)$$

Inflation in Conformal Standard Model (2)

We assume that:

$$\xi_1 h^2 + \xi_2 s^2 \gg M_P^2 \gg v_i^2, \tag{8}$$

And define new fields:

$$\chi = \sqrt{\frac{3}{2}} \log(\xi_1 h^2 + \xi_2 s^2), \tag{9}$$

$$\tau = \frac{h}{s}, \tag{10}$$

Behaviour of τ and χ

$$\mathcal{L}_{\text{kin}} \simeq \frac{1}{2}(\partial_\mu \chi)^2 + \frac{1}{2}\frac{\xi_1^2\tau^2 + \xi_2^2}{(\xi_1\tau^2 + \xi_2)^3}(\partial_\mu \tau)^2, \tag{11}$$

and the potential in new variables reads:

$$V_E(\tau, \chi) = U(\tau)W(\chi) = \frac{\lambda_1\tau^4 + \lambda_p + 2\lambda_3\tau^2}{4(\xi_1\tau^2 + \xi_2)^2}\left(1 + e^{-2\chi/\sqrt{6}}\right)^{-2}. \tag{12}$$

Then τ drops to minimum. Since the heavy state decouples we are left with Bezrukov-Shaposhnikov like evolution:

$$V(\chi) = \frac{\lambda_{eff}}{4\xi^2}W(\chi), \tag{13}$$

Since inflation parameters n_s, r depends only on shape of the potential, so they fit data.

Further work

- Does this model posses a UV completion? Supergravity, string theory?
- Can SBCS mechanism still hold and up to which scale, when considering the inflation model?

Thank you for your attention

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Source material

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- A. Lewandowski, K. A. Meissner, and H. Nicolai, *Conformal Standard Model, Leptogenesis and Dark Matter*, arXiv:1710.06149[hep-th].

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- A. Starobinsky, *A new type of isotropic cosmological models without singularity*, Phys.Lett. **B91** (1980) 99.
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- P. H. Chankowski, A. Lewandowski, K. A. Meissner, and H. Nicolai, *Softly broken conformal symmetry and the stability of the electroweak scale*, Mod. Phys. Lett. **A30** (2015) 1550006.

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- O. Lebedev and H. M. Lee, *Higgs Portal Inflation*, Eur. Phys. J., **C71** (2011) 1821.
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Softly borken conformal symmetry mechanism

There exist a cutoff scale Λ, determined by a UV complete fundamental theory.

Two mechanisms:

- Quadratic divergences cancels out by some symmetry
- The putative fundamental theory singles out a particular scale Λ, the physical cutoff, at which $m_B^2(\Lambda) \ll \Lambda^2$ and at which the $\propto \Lambda^2$ corrections to the physical spin-zero boson(s) (and thus to the ratio M_{EW}^2/M_P^2) vanish. The crucial fact, which is at the heart of this proposal is that the coefficient in front of Λ^2 can be written as a function of the bare coupling(s) only:

Second one: SBCS.

CSM with extended scalar sector

The complex scalar sterile sextet $\phi_{ij} = \phi_{ji}$ is introduced:

$$\mathcal{L}_{scalar} = (D_\mu H)^\dagger (D^\mu H) + \mathrm{Tr}(\partial_\mu \phi^* \partial^\mu \phi) - V(H,\phi), \tag{14}$$

and the potential is given by a formula:

$$V(H,\phi) = m_1^2 H^\dagger H + m_2^2 \mathrm{Tr}(\phi\phi^*) + \lambda_1 (H^\dagger H)^2 \\ + \lambda_2 [\mathrm{Tr}(\phi\phi^*)]^2 + 2\lambda_3 (H^\dagger H)\mathrm{Tr}(\phi\phi^*) + \lambda_4 \mathrm{Tr}(\phi\phi^*\phi\phi^*), \tag{15}$$

The potential is invariant under $U(3)$ transformations.

τ behaviour

Table: Minimal values of the radial part of inflation potential

τ_0 values	stable minimum condition	U_0
$\tau_0 = 0$	$a > 0$ and $b < 0$	$\frac{\lambda_1}{4\xi_1^2}$,
$\tau_0 = +\infty$	$a < 0$ and $b > 0$	$\frac{\lambda_p}{4\xi_2^2}$,
$\tau_0 = \pm\sqrt{\frac{b}{a}}$	$a > 0$ and $b > 0$	$\frac{\lambda_1\lambda_p - \lambda_3^2}{4(\lambda_1\xi_2^2 + \lambda_p\xi_1^2 - 2\lambda_3\xi_1\xi_2)}$,
$\tau = 0$ or $\tau_0 = +\infty$	$a < 0$ and $b < 0$	$\frac{\lambda_1}{4\xi_1^2}$ or $\frac{\lambda_p}{4\xi_2^2}$.

Then we have two types of scenarios. Either we have single Inflaton case: Higgs or single “shadow” Higgs inflation, when τ_0 obtains zero or infinity value. Slow - roll such behaviour can be showed explicitely.