Semi-Periodic Higgs Inflation

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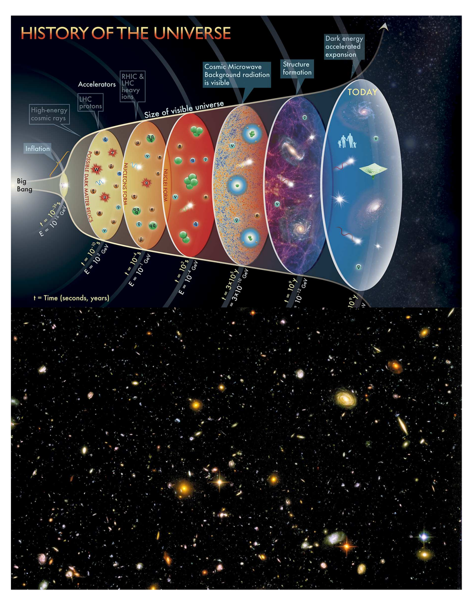
Abstract

Inflationary cosmology represents a well-studied framework to describe the expansion of space in the early universe, explaining the origin of the large-scale structure of cosmos and the isotropy of the cosmic microwave background radiation. The recent detection of the Higgs boson renewed research activity where the inflaton is identified with the Higgs field. At the same time, the issues whether the inflationary potential can be extended to the electroweak scale and whether it should be necessarily chosen ad hoc in order to be physically acceptable are at the center of an intense debate. Here we introduce single-field two-parameters scalar (Higgs) inflationary model the Massive sine-Gordon (MSG) theory and we perform it's standard slow-roll analysis We show that, using PLANCK data one can fix the parameters of the model and argue it serves as a possible UV completion of the SM Higgs potential. We also demonstrate that the value for the parameters chosen at cosmological scale does not influence the results at electroweak scale. We argue that other models can have similar properties both at cosmological and electroweak scales, but with the MSG model one can complete the theory towards low energies and – unlike many other models one can think of – perform explicitly in an easy way the integration of modes up to the electroweak scale producing the correct order of magnitude for the Higgs mass.

Cosmic Inflation

What caused the inflation?



- Starting from the Einstein equation

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

- Substituting
  - $g_{\mu\nu} = \mathrm{diag}(-1, a^2, a^2, a^2)$
  - $T^{\mu}{}_{\nu} = \mathrm{diag}(-\rho, p, p, p)$
- Friedmann equations, which describe the evolution of the universe

$$\left(\frac{\dot a}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2} \qquad \frac{\ddot a}{a} = -\frac{8\pi G}{6}(\rho + 3p)$$

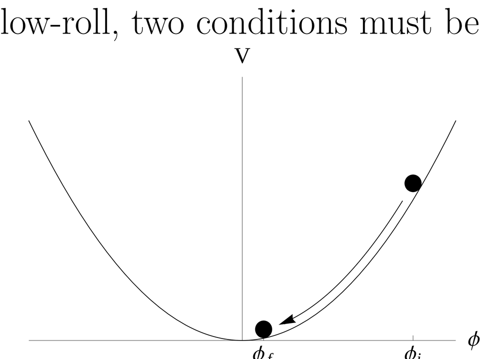
Solution: if $\boxed{\rho = -p} \implies \boxed{a \sim e^{Ct}}$ Inflation!

Slow-roll and CMBR

To have a prolonged exponential inflation with slow-roll, two conditions must be satisfied ($m_p = 1$)

$$\epsilon \ll 1 \quad \epsilon \equiv \frac{1}{2}\frac{V'^2}{V^2}$$

$$\eta \ll 1 \quad \eta \equiv \frac{V''}{V}$$



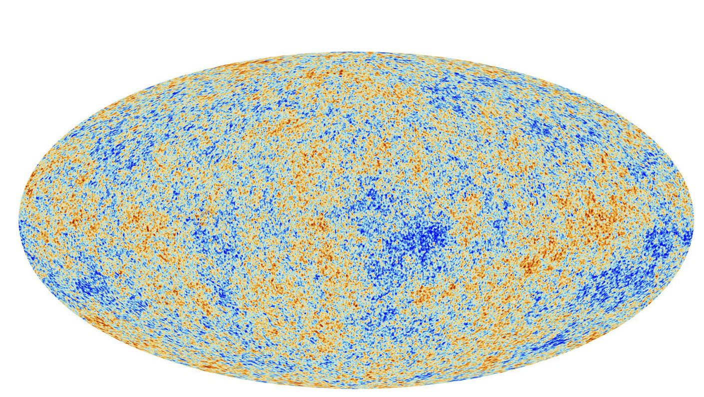
The e-fold number express that the universe got $e^{50} - e^{60}$ times larger

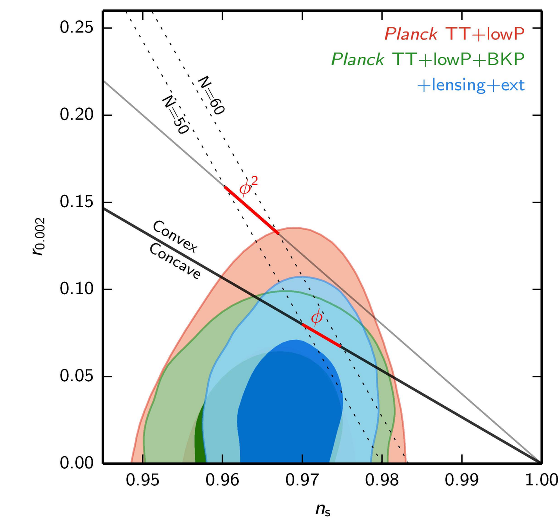
$$N = 50 - 60 \qquad N \equiv -\int_{\phi_i}^{\phi_f} d\phi \frac{V}{V'}$$

Parameters of the fluctuations can be expressed by ϵ and η

$$n_s - 1 \approx 2\eta - 6\epsilon \qquad r \approx 16\epsilon$$

N, n_s, r are measurable quantities from the background radiation



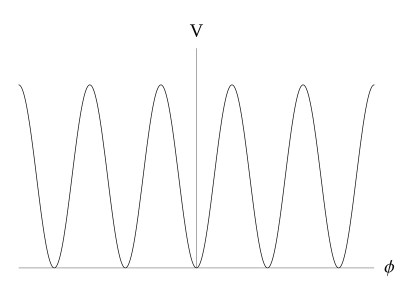


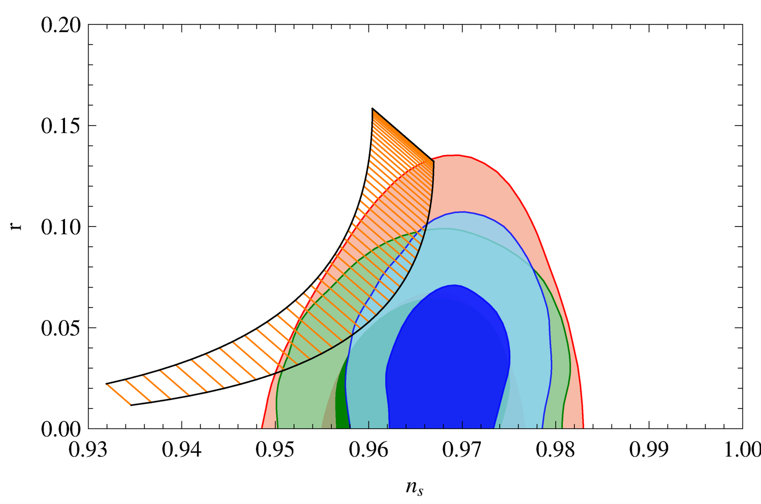
~~$V \sim \phi^2$~~ $V \sim \phi$

Periodic Inflation

Sine-Gordon model

$$V_{\rm SG} = u[1 - \cos(\beta\phi)]$$

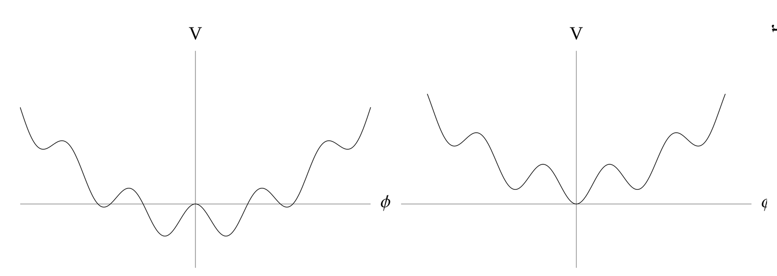


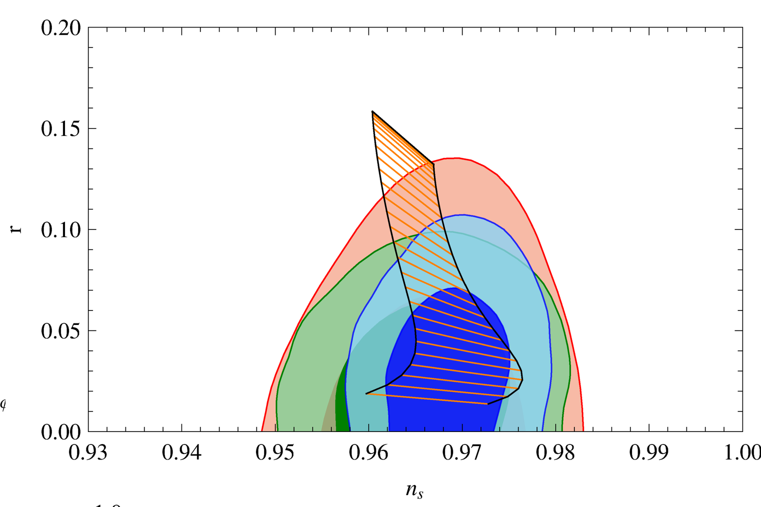


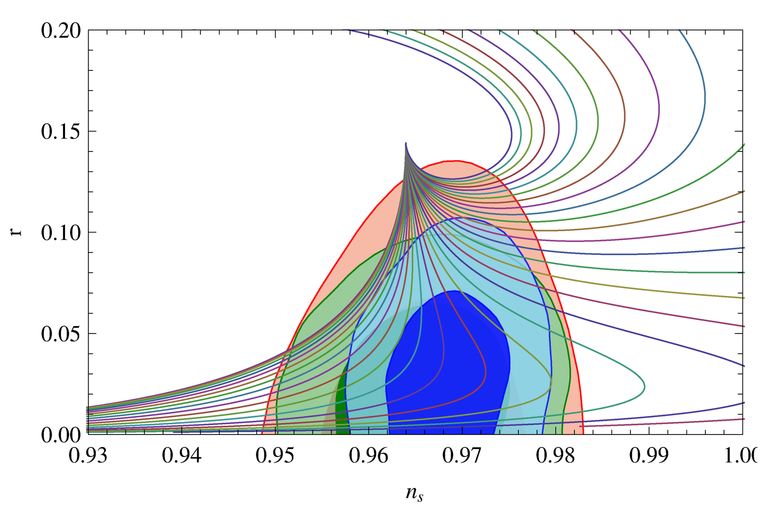
Semi-Periodic Inflation

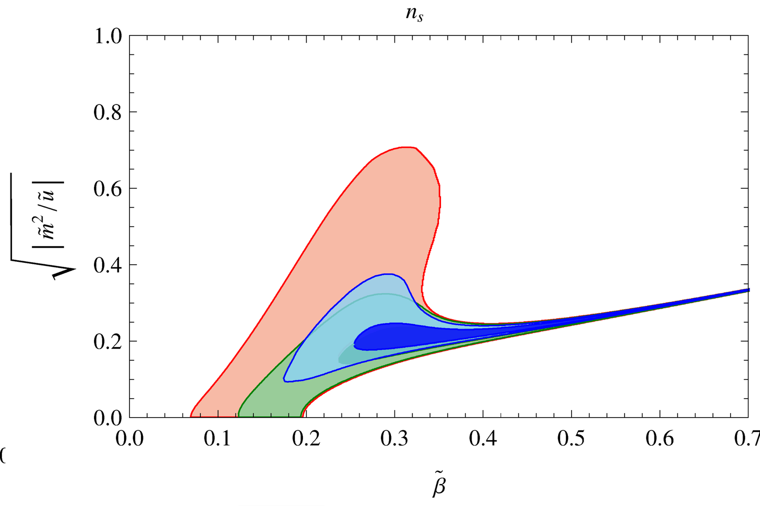
Massive Sine-Gordon model

$$V_{\rm MSG} = \frac{1}{2}m^2\phi^2 + u[1 - \cos(\beta\phi)]$$









Best fitting parameters: $\tilde\beta \approx 0.3 \quad \sqrt{\tilde m^2/\tilde u} \approx 0.2$

Higgs Inflation

Lagrangian for the Higgs sector of the SM with the single real scalar field h reads

$$\mathcal{L} = \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{1}{2}M_h^2 h^2 - \frac{M_h^2}{2v}h^3 - \frac{M_h^2}{8v^2}h^4 + \left(M_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2}M_Z^2 Z_\mu Z^\mu\right)\left(1 + 2\frac{h}{v} + \frac{h^2}{v^2}\right)$$

Extrapolating the SM up to very high energies lead to interpret the Higgs boson as the inflaton. Large non-minimal coupling to gravity results in the following action

$$S = \int d^4x\sqrt{-\tilde g}\frac{m_p^2}{2}\left[F(\tilde h)\tilde R - \tilde g^{\mu\nu}\partial_\mu\tilde h\partial_\nu\tilde h - 2U(\tilde h)\right]$$

$$\text{with } F(h) = 1 + \xi\tilde h^2, \quad U(\tilde h) = m_p^2\frac{\lambda}{4}\left(\tilde h^2 - \frac{v^2}{m_p^2}\right)^2$$

where $U(\tilde h)$ is the SM Higgs potential.

To perform the slow-roll study, the action is usually rewritten and takes the form

$$V \equiv m_p^2 U/F^2, \qquad \frac{d\phi}{d\tilde h} = m_p\frac{\sqrt{1 + \xi(1 + 6\xi)\tilde h^2}}{1 + \xi\tilde h^2}$$

For $\xi \neq 0$, the SM Higgs inflaton potential reads

$$V(\phi) = \frac{m_p^4\lambda}{4\xi^2}\left(1 - e^{-\sqrt{2/3}\phi/m_p}\right)^2$$

For $\xi = 0$, $V \equiv m_p^2 U$ and the MSG is a possible UV completion

$$V_{\rm MSG} \approx \frac{1}{2}(m^2 - u\beta^2)\phi^2 + \frac{1}{24}u\beta^4\phi^4 + \ldots$$

$$\implies \lambda v^2 \equiv (u\beta^2 - m^2), \quad \lambda \equiv \frac{1}{6}u\beta^4$$

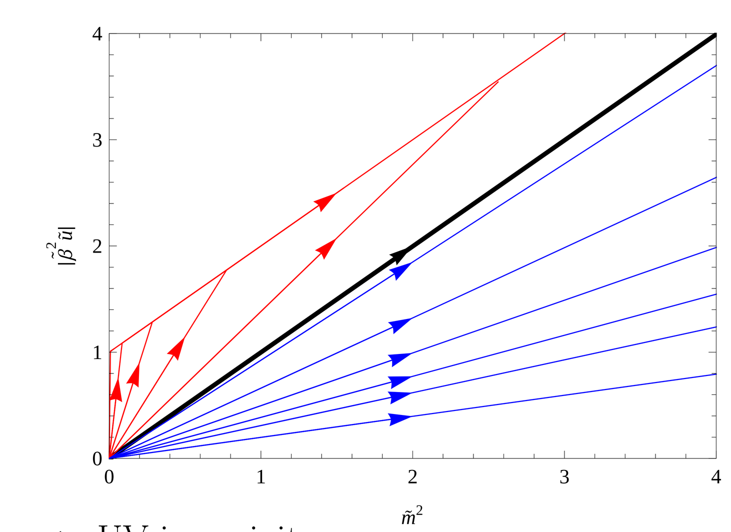
$$M_h \equiv m\sqrt{2\left(\frac{u\beta^2}{m^2} - 1\right)}, \qquad v \equiv \frac{1}{\beta}\sqrt{\frac{6(u\beta^2/m^2 - 1)}{u\beta^2/m^2}}$$

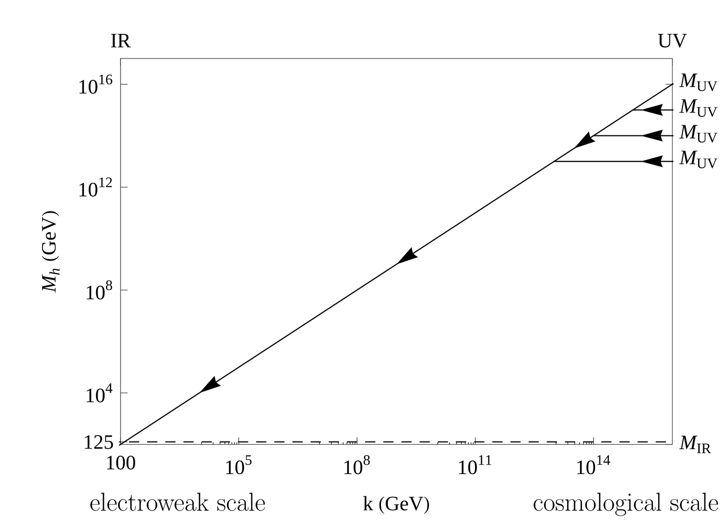
RG scaling

$$M_{h,\rm IR} = 125\text{GeV}, \quad v_{\rm IR} = 245\text{GeV at } k_{\rm IR} \sim 250\text{GeV} \quad \text{electroweak scale}$$

$$M_{h,\rm UV} \sim v_{\rm UV} \sim 10^{15}\text{GeV at } k_{\rm UV} \sim 10^{15}\text{GeV} \quad \text{cosmological scale}$$

Can the RG running connect the two distant scales? $k_{\rm cosmo} \to k_{\rm electroweak}$?





$\implies$ UV-insensitivity

Summary:

We conclude that the MSG model is valid both at cosmological and electroweak scales. RG running connects the cosmological and electroweak scales. High-energy properties do not effect the low-energy ones: *UV-insensitivity*.

References

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