Title: Inflation scenario via the Standard Model Higgs boson and LHC

Date: Jun 03, 2008 04:45 PM

URL: http://pirsa.org/08060065

Abstract: We discuss a quantum corrected inflation scenario driven by a generic GUT or Standard Model type particle model, whose scalar field playing the role of an inflaton has a strong non-minimal curvature coupling. We show that currently widely accepted bounds on the Higgs mass falsify the suggestion of [arXiv:0710.3755] (the work underestimating the role of radiative corrections) that the Standard Model Higgs boson can serve as the inflaton. However, if the Higgs mass could be raised to 216 GeV, then the Standard Model could generate the inflationary scenario matching the CMB data with $n_ssimeq 0.93$ and a very low tensor to scalar perturbation ratio $rsimeq 0.0005$.

Inflation scenario via the Standard Model Higgs boson and LHC

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Introduction

inflaton

$$L(g_{\mu\nu}, \varphi, \ldots) \Rightarrow \delta^2_\Phi(k),\ n_s,\ T/S,\ \Delta T/T$$

GUT theory boson as an inflaton:

$$\frac{\lambda\varphi^4}{4},\ \ \frac{\Delta T}{T} \sim \sqrt{\lambda},\ \ \lambda \sim 10^{-13},$$ now ruled out by WMAP

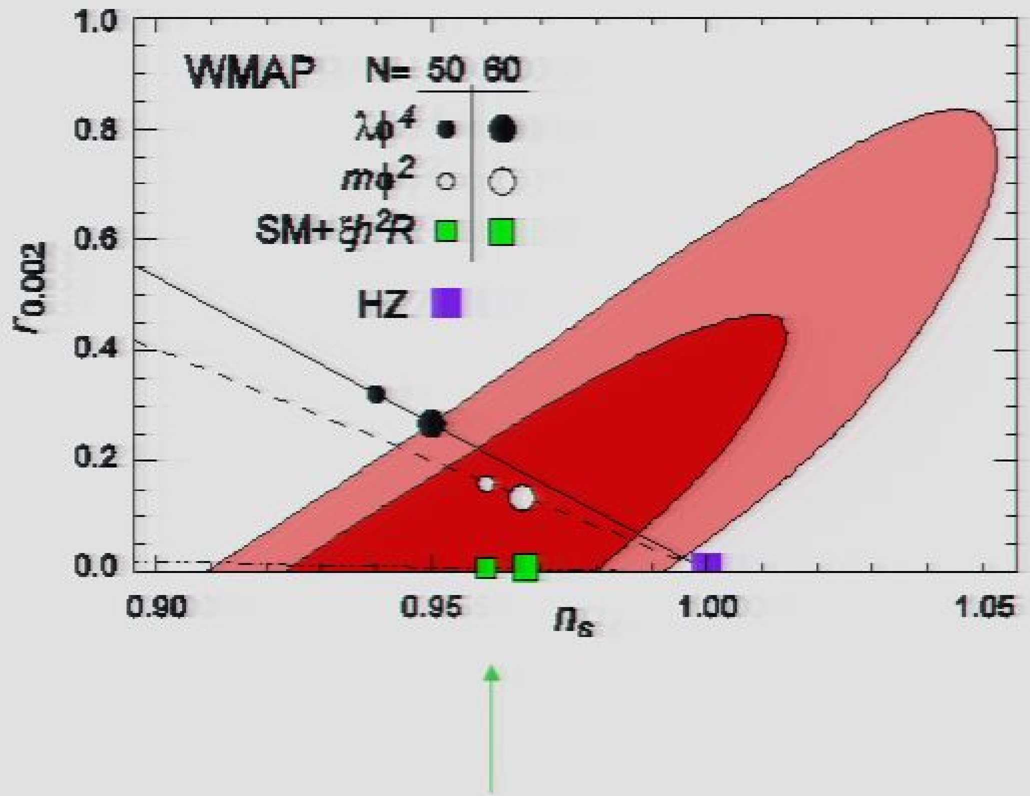
Non-minimal curvature coupling:

$$\frac{1}{2}\xi\varphi^2 R,\ \ \frac{\Delta T}{T} \sim \frac{\sqrt{\lambda}}{\xi},\ \ \xi \gg 1$$

B. Spokoiny (1984),
D.Salopek, J.Bond & J. Bardeen (1989),
R. Fakir& W. Unruh (1990),
A.Barvinsky & A. Kamenshchik (1994, 1998)

F.Bezrukov & M.Shaposhnikov, Phys.Lett. 659B (2008) 703:

Standard Model Higgs boson as an inflaton – tree-level approximation, smallness of radiative corrections due to ξÀ 1



Radiative corrections are enhanced by a large ξ and can be probed by current and future CMB observations and LHC experiments. With an upper bound on the Higgs mass, m_H<180 GeV, this model is falsified, but with $m_{H›}$ 216 GeV the SM Higgs can drive inflation with a low spectral index $n_{s›}$ 0.93 and a very low tensor to scalar perturbation ratio r' 0.0004.

Model

inflaton

non-minimal curvature coupling

$$L(g_{\mu\nu}, \varphi, \chi, A_\mu, \psi) =$$

$$g^{1/2}\left\{\frac{1}{2}(M_P^2 + \xi\varphi^2)R - \frac{1}{2}(\nabla\varphi)^2 - \frac{\lambda}{4}(\varphi^2 - \nu^2)^2\right\}$$ inflaton-graviton sector

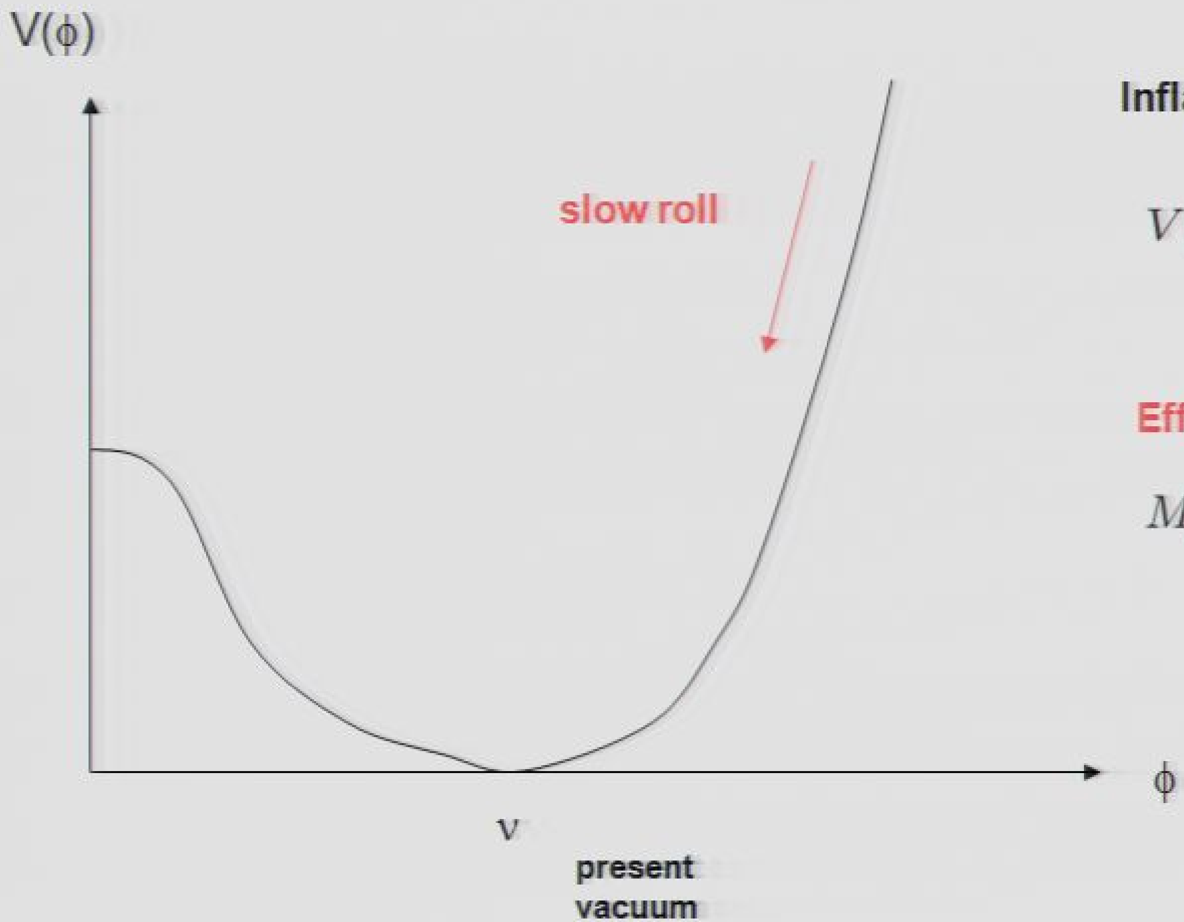
$$+g^{1/2}\left\{-\frac{1}{2}\sum_\chi(\nabla\chi)^2 - \frac{1}{4}\sum_A F_{\mu\nu}^2(A) - \sum_\psi \bar\psi\hat\nabla\psi\right\}$$ SM sector

$$+L_{\rm int}(\varphi, \chi, A_\mu, \psi)$$ inflaton-SM coupling sector

$$L_{\rm int} = \sum_\chi \frac{\lambda_\chi}{2}\chi^2\varphi^2 + \sum_A \frac{1}{2}g_A^2 A_\mu^2\varphi^2 + \sum_\psi f_\psi \varphi\bar\psi\psi + \text{derivative coupling}$$

Coupling constants $\lambda_\chi,\ g_A,\ f_\psi$

Non-minimal coupling constant $\xi \gg 1$



Inflaton potential:

$$V(\phi) = \frac{\lambda}{4}(\phi^2 - \nu^2)^2$$

Effective Planck mass:

$$M_P^2 \to M_{\rm eff}^2(\phi) = M_P^2 + \xi\phi^2$$

Compatibility with solar system tests

$$M_{\rm eff}^2(\nu) = M_P^2 + \xi\nu^2 \simeq M_P^2$$

$$m_\phi^2 = 2\lambda\nu^2 \neq 0$$

Effective action

- Higgs effect due to big slowly varying inflaton:

$$\varphi \neq 0 \to m(\varphi) = \{m_\chi, m_A, m_\psi\}, \quad m_\chi^2 = \lambda_\chi \varphi^2, \; m_A^2 = g_A^2 \varphi^2, \; m_\psi^2 = f_\psi^2 \varphi^2$$

- 1/m gradient and curvature expansion: $\frac{R}{m^2} \sim \frac{R}{\varphi^2} \sim \frac{\lambda\varphi^4}{3M_{\rm eff}^2\varphi^2} \simeq \frac{\lambda}{\xi} \ll 1$
- suppression of graviton-inflaton loops by $\frac{M_P^2}{M_{\rm eff}^2(\varphi)} \sim \frac{M_P^2}{\xi\varphi^2} \ll 1$

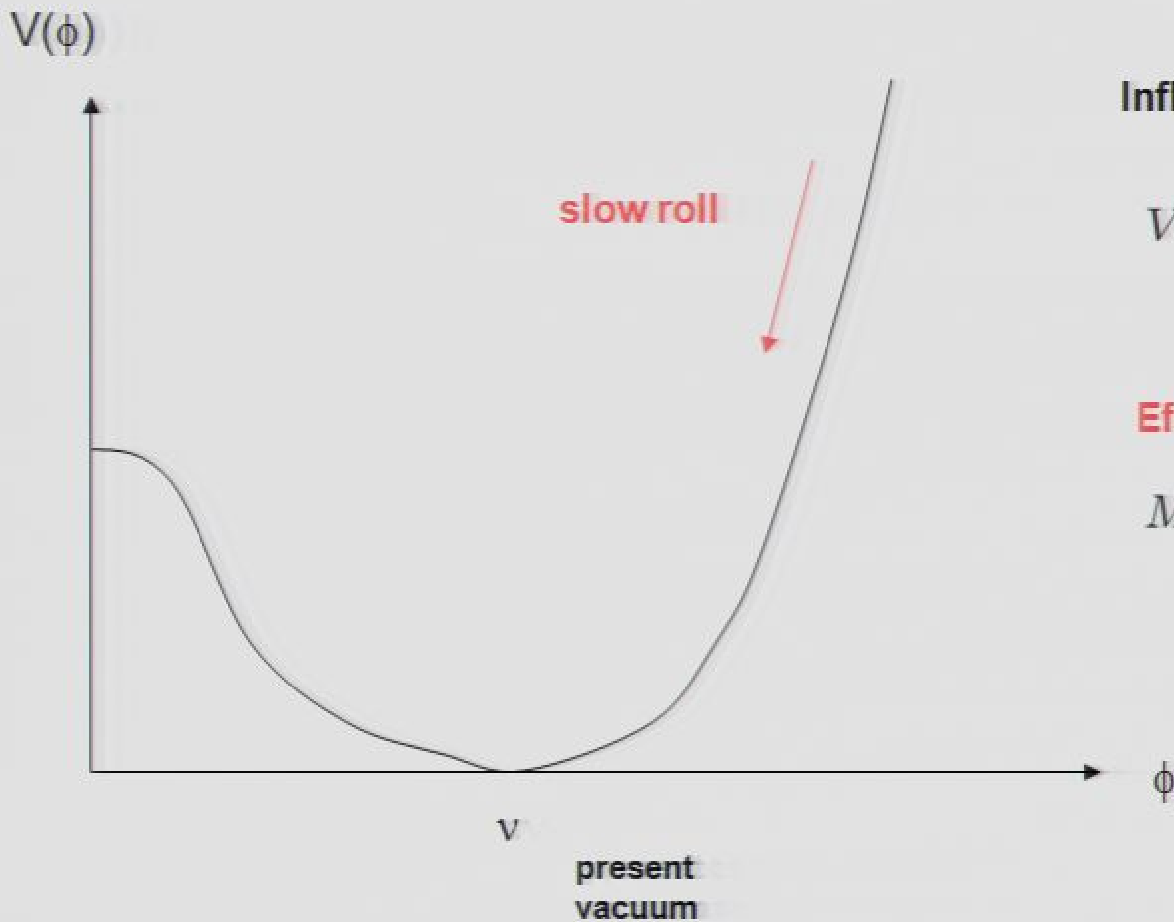
$$\Downarrow$$

$$S[g_{\mu\nu}, \varphi] = \int d^4x\, g^{1/2} \left(-V(\varphi) + U(\varphi)\, R(g_{\mu\nu}) - \frac{1}{2} G(\varphi)\, (\nabla\varphi)^2 \right)$$

$$V(\varphi) = \frac{\lambda}{4}(\varphi^2 - \nu^2)^2 + \frac{\lambda\varphi^4}{128\pi^2}\left(\boldsymbol{A} \ln\frac{\varphi^2}{\mu^2} - \boldsymbol{B} \right),$$

$$U(\varphi) = \frac{1}{2}(M_P^2 + \xi\varphi^2) + \frac{\varphi^2}{384\pi^2}\left(\boldsymbol{C} \ln\frac{\varphi^2}{\mu^2} - \boldsymbol{D} \right) \simeq \frac{1}{2}(M_P^2 + \xi\varphi^2),$$

$$G(\varphi) = 1 + \frac{1}{192\pi^2}\left(\boldsymbol{G} \ln\frac{\varphi^2}{\mu^2} + \boldsymbol{E} \right) \simeq 1.$$



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⇓

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$$G(\varphi) = 1 + \frac{1}{192\pi^2} \left(\boldsymbol{G} \ln \frac{\varphi^2}{\mu^2} + \boldsymbol{E} \right) \simeq 1.$$

Anomalous scaling behavior constant A

$$\frac{1}{64\pi^2}\,\mathrm{tr}\sum_{\text{particles}}\Big(\pm m^4(\varphi)\Big) = \frac{\lambda\varphi^4}{128\pi^2}A$$

Overall Coleman-Weinberg potential

$$\mathrm{tr}\sum_{\text{particles}}\frac{\pm m^4(\varphi)}{64\pi^2}\ln\frac{m^2(\varphi)}{\mu^2} = \frac{\lambda A}{128\pi^2}\varphi^4\ln\frac{\varphi^2}{\mu^2} + \ldots$$

sum over polarizations

$$A = \frac{2}{\lambda}\left(\sum_\chi \lambda_\chi^2 + 3\sum_A g_A^4 - 4\sum_\psi f_\psi^4\right)$$

# of polarizations of vector bosons and Dirac spinors

Conformal frame dependence of quantum corrections

(comparizon with F.Bezrukov and M.Shaposhnikov, Phys.Lett. 659B (2008) 703)

Transition to the Einstein frame --- conformal transformation and canonical normalization of the inflaton:

$$\varphi \to \hat{\varphi},\ g_{\mu\nu} \to \hat{g}_{\mu\nu},\ \hat{g}_{\mu\nu} = \Omega^2(\varphi) g_{\mu\nu},\ \Omega^2(\varphi) = 1 + \xi\varphi^2/M_P^2$$

Particle masses in the Einstein frame:

$$m(\varphi) \to \hat{m}(\varphi) = \frac{m(\varphi)}{\Omega(\varphi)} \sim \frac{M_P}{\sqrt{\xi}}$$

small and field-independent, flat CW potential

However, the factor of $\hat{g}^{1/2} = \Omega^4(\varphi)\, g^{1/2}$ in the effective Lagrangian

$$\hat{g}^{1/2}\, \hat{m}^4(\varphi) \ln \frac{\hat{m}^2(\varphi)}{\mu^2} \simeq \mathrm{const}\, g^{1/2}\, m^4(\varphi)$$

only log disappears: weak logarithmic frame dependence due to conformal anomaly

Tree-level potential is very flat, and logs are important below, so which frame is correct?

The original – Jordan one – because it determines physical distances!

Inflation

Range of the field at the inflation stage $\varphi^2 \gg M_P^2/\xi \gg \nu^2$

Smallness parameters $\dfrac{M_P^2}{\xi\varphi^2} \ll 1, \quad \dfrac{\boldsymbol{A}}{32\pi^2} \ll 1$

Along with

$$\frac{1}{32\pi^2}(\boldsymbol{B}, \boldsymbol{C}, \boldsymbol{D}, \boldsymbol{G}, \boldsymbol{E}) \ll 1$$

smallness of radiative corrections

Equations of motion in the slow-roll regime

$$\ddot{\varphi} + 3H\dot{\varphi} - F = 0$$

$$H^2 = \frac{V}{6U}$$

$$F(\varphi) = \frac{2VU' - V'U}{GU + 3U'^2} \simeq -\frac{\lambda M_P^2}{6\,\xi^2}\varphi\left(1 + \frac{\varphi^2}{\varphi_I^2}\right) \qquad \varphi_I^2 = \frac{64\pi^2 M_P^2}{\xi \boldsymbol{A}}$$

tree-level (1) quantum (φ^2/φ_I^2)

Quantum scale of inflation from quantum cosmology of the tunneling state (A.B. & A.Kamenshchik, Phys.Lett. B332 (1994) 270)

Einstein frame: $g_{\mu\nu} \to \hat{g}_{\mu\nu},\ \varphi \to \hat{\varphi},\ \ \hat{U} = M_P^2/2,\ \hat{G} = 1$

$$\hat{V}(\hat{\varphi}) = \left(\frac{M_P^2}{2}\right)^2 \frac{V(\varphi)}{U^2(\varphi)}\bigg|_{\varphi=\varphi(\hat{\varphi})}$$

Slow-roll smallness parameters

$$\hat{\varepsilon} \equiv \frac{M_P^2}{2}\left(\frac{1}{\hat{V}}\frac{d\hat{V}}{d\hat{\varphi}}\right)^2 = \frac{4M_P^4}{3\xi^2\varphi^4}\left(1+\frac{\varphi^2}{\varphi_I^2}\right)^2$$

$$\hat{\eta} \equiv \frac{M_P^2}{\hat{V}}\frac{d^2\hat{V}}{d\hat{\varphi}^2} = -\frac{4M_P^2}{3\xi\varphi^2}$$

$\hat{\varepsilon}, \hat{\eta} \ll 1$

is guaranteed by

$\frac{M_P^2}{\xi\varphi^2} \ll 1, \ \ \frac{\boldsymbol{A}}{32\pi^2} \ll 1$

end of inflation, $\hat{\varepsilon}_{\text{end}} \sim 1,\ \varphi_{\text{end}}^2/\varphi_I^2 \ll 1$

e-folding # $$N(\varphi) = \int_{\varphi}^{\varphi_{\text{end}}} d\varphi' \frac{3H^2(\varphi')}{F(\varphi')} \simeq \frac{48\pi^2}{\boldsymbol{A}} \ln\left(1+\frac{\varphi^2}{\varphi_I^2}\right)$$

Inflation

Range of the field at the inflation stage $\varphi^2 \gg M_P^2/\xi \gg \nu^2$

Smallness parameters $\frac{M_P^2}{\xi\varphi^2} \ll 1, \quad \frac{\boldsymbol{A}}{32\pi^2} \ll 1$

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tree-level (1) — quantum (φ^2/φ_I^2)

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$$\frac{\varphi^2}{\varphi_I^2} = e^x - 1$$

$$x \equiv \frac{N\boldsymbol{A}}{48\pi^2}$$

This parameter relates the initial value of the inflaton to the quantum cosmological scale φ_I^2. In quantum cosmology the normalizability of the cosmological quantum state requires $\boldsymbol{A}$ to be positive [A.O.B. & A.Kamenshchik, Phys. Lett. **B332** (1994) 270; Nucl. Phys. **B532** (1998) 339], so that $\varphi_I^2 > 0$, and $\varphi = \varphi_I$ corresponding to $x = x_I \equiv \ln 2 \simeq 0.69$. Here we adopt an alternative approach and deduce the value of x from the spectral properties of CMB. In particular, we relax the requirement of positivity for $\boldsymbol{A}$ and admit also negative values when the parameter x is negative and $\varphi^2 < |\varphi_I^2|$.

CMB bounds

WMAP normalization:

$k \simeq (2000\,\mathrm{Mpc})^{-1}$

$N \simeq 60$

CMB power spectrum

$$\delta_\Phi^2(k) = \frac{1}{54\pi^2 \hat{\varepsilon}} \frac{\hat{V}}{M_P^4}\Big|_{\text{horizon crossing}} \simeq 3 \times 10^{-9}$$

$$\frac{\lambda}{\xi^2} \sim 10^{-9} \left(\frac{x\, e^x}{e^x - 1}\right)^2$$

quantum factor

B. Spokoiny (1984),
D.Salopek, J.Bond & J. Bardeen (1989),
R. Fakir& W. Unruh (1990),
A.Barvinsky & A. Kamenshchik (1994, 1998),
F.Bezrukov & M.Shaposhnikov (2008)

Spectral index and tensor to scalar ratio:

WMAP at 95%

spectral index $n_s = 1 - 6\hat{\varepsilon} + 2\hat{\eta} \simeq 0.96 \pm 0.03$

T/S ratio $r = 16\,\hat{\varepsilon}$

$$\hat{\varepsilon} = \frac{3}{4N^2}\left(\frac{xe^x}{e^x-1}\right)^2, \quad \hat{\eta} = -\frac{1}{N}\frac{x}{e^x-1}, \quad \hat{\varepsilon} \ll |\hat{\eta}|$$

$$r = 16\hat{\varepsilon} = \frac{12}{N^2}\left(\frac{xe^x}{e^x-1}\right)^2$$

⇓

$$0.93 < n_s < 0.99$$

$$-1.73 < x < 2.07$$

$$-13.7 < A < 16.4$$

$$0.0004 < r < 0.02$$

Very small!

Standard Model bounds

Standard model, φ **-- Higgs field,** $\varphi = \nu$ **-- symmetry breaking scale**

$$m(\nu) = \left\{ m_Z, m_{W_\pm}, m_t, \text{lighter masses} \right\}$$

Higgss mass $m_H^2 = 2\lambda\nu^2$

$$\boldsymbol{A} = \frac{2}{\lambda\varphi^4} \mathrm{tr} \sum_{\text{particles}} \Big(\pm m^4(\varphi) \Big)_{\varphi=\nu} \simeq \frac{12}{m_H^2 \nu^2} \left(m_Z^4 + 2m_W^4 - 4m_t^4 \right)$$

$$m_Z = 91 \text{ GeV}, m_W = 80 \text{ GeV}, m_t = 171 \text{ GeV}, \nu = 247 \text{ GeV},$$

$$115\,\text{GeV} < m_H < 180\,\text{GeV}$$

Particle Data Group,
W.-M.Yao et al (2006)

$$-48 < \boldsymbol{A} < -20$$

vs CMB window

$$-13.7 < \boldsymbol{A} < 16.4$$

Conclusions

If future LHC experiments on SM could raise the Higgs mass up to 216 GeV then the SM Higgs boson could serve as the inflaton for a scenario with n_s» 0.93 and T/S» 0.0004

The mechanism is very different from F.Bezrukov and M.Shaposhnikov, Phys.Lett. 659B (2008) 703 because it is dominated by the quantum effects: CMB data probe quantum anomalous scaling induced by all heavy massive particles rather than only the graviton-inflaton sector. The deviation of n_s from unity --- the ``deSitter" anomaly --- is determined by the quantum conformal anomaly:

$$n_s(N) = 1 - \frac{2a}{e^{Na} - 1}, \quad a \equiv \frac{\boldsymbol{A}}{48\pi^2}$$

SM Higgs driven inflation is falsified for m_H· 180 GeV, but precision tests of EW theory give a weaker bound m_H· 285 GeV at 95% confidence level [ALEPH, Phys. Rept. 427(2006)257]. This gives an overlap of CMB and SM windows

$$-13.7 < \boldsymbol{A} < -8.0$$

$$0.93 < n_s < 0.95$$

$$0.0004 < r < 0.001$$

Looking forward to LHC Higgs discovery! Big reserve for possible smallness of T/S-ratio in future CMB tests without appealing to exotic models like k-inflation.