Modified Higgs Inflation

(In Progress · · ·)

Aditya Aravind
In collaboration with Minglei Xiao and Jiang-Hao Yu

Weinberg Theory Group
Department of Physics
The University of Texas at Austin

July 29, 2015

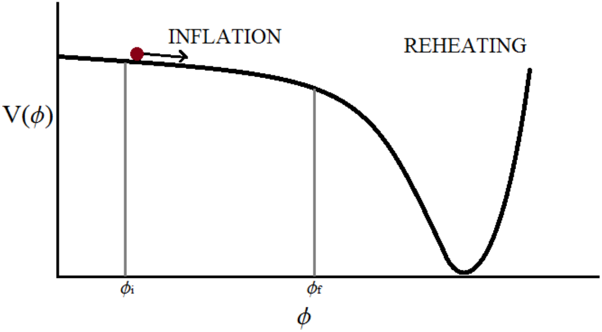
Why Inflation?

- The universe, as "photographed" in the CMB is very uniform.
- It is spatially flat according to current measurements.
- A period of accelerated expansion can naturally explain these (and other) observations.
- Inflation: Typically involves quasi de-Sitter expansion.

Single Field Slow-Roll

Simple Mechanism: Driving inflation using potential energy of a single scalar field.

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



"Slow-Roll"

Friedmann Equations:

$$H^2 = \frac{1}{3M_P^2}\rho \approx \frac{1}{3M_P^2}V(\phi)$$

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

Slow Roll Parameters:

$$\epsilon_V = \frac{1}{2M_P^2}\left(\frac{V'}{V}\right)^2 \qquad \eta_V = M_P^2\frac{V''}{V}$$

When $\epsilon, \eta \ll 1$, we have

$$\epsilon_V \approx \epsilon_\phi = \frac{1}{2}\frac{\dot{\phi}^2}{H^2 M_P^2}$$

Inflation using Higgs?

- It is natural to try to do this using the one scalar field we know exists.
- Higgs potential: Quartic for large field values

$$V(h) = \lambda_h (h^2 - v^2)^2 \approx \lambda_h h^4$$

- Large-field chaotic inflation?
- $\lambda_h \sim 0.13$ gives fluctuations that are too large.

Higgs-ξ Inflation

- Bezrukov and Shaposhnikov (2007): Nonminimal coupling of Higgs to gravity works.
- Jordan frame action:

$$S_J = \int d^4x\sqrt{-g}\left[-\frac{M^2+\xi h^2}{2}R + \frac{\partial_\mu h\partial^\mu h}{2} - \frac{\lambda}{4}(h^2-v^2)^2\right]$$

- Einstein frame action:

$$S_E = \int d^4x\sqrt{-\hat{g}}\left[-\frac{M_P^2}{2}\hat{R} + \frac{\partial_\mu \chi\partial^\mu \chi}{2} - \frac{1}{\Omega(\chi)^4}\frac{\lambda}{4}(h(\chi)^2-v^2)^2\right]$$

- χ is defined using $\frac{d\chi}{dh} = \sqrt{\frac{\Omega^2+6\xi^2h^2/M_P^2}{\Omega^4}}$ with $\Omega^2 = 1+\frac{\xi h^2}{M_P^2}$

Higgs-ξ Inflation - Continued

- $V_E(\chi)$ flattens out at large $\chi \sim \mathcal{O}\left(\frac{M_P}{\sqrt{\xi}}\right)$: Typical Slow-Roll Potential
- ξ adjusted to give correct normalization of fluctuations.
- Number of e-foldings $N \approx 60$ - Mildly depends on reheating details.
- Observables: $n_s = 1 - 6\epsilon + 2\eta \sim 0.967$ and $r = 16\epsilon \sim 0.003$.
- Squarely within the allowable region of $n_s - r$ plot (even now).
- Interestingly, λ doesn't affect n_s and r.
- Universal Attractors: Classes of Models that flow towards same fixed point. (Kallosh, Linde, Roest '13)

Radiative Corrections

- Radiative corrections from quantum gravity and standard model fields assumed/argued to have small effect.
- Radiative corrections discussed in Barvinsky et al. [0809.2104], Simone et al. (0812.4946), Bezrukov et al., etc.
- Graviton and inflaton loops are suppressed by $M^2_{P,eff} = M^2_P + \xi h^2 \approx \xi h^2$.
- The basic picture worked, but accurate computation required: n_s and r depend sensitively on shape of the potential.

Unitarization

- Detailed discussion of effective field theory cutoffs in both frames using tree-level unitarity arguments: Bezrukov et al. (1008.5157).

$$\Lambda = \begin{cases} \frac{M_P}{\xi}, & h \ll \frac{M_P}{\xi} \\ \frac{\xi h^2}{M_P}, & \frac{M_P}{\xi} \ll h \ll \frac{M_P}{\sqrt{\xi}} \\ M_P, & h \gg \frac{M_P}{\sqrt{\xi}}. \end{cases}$$

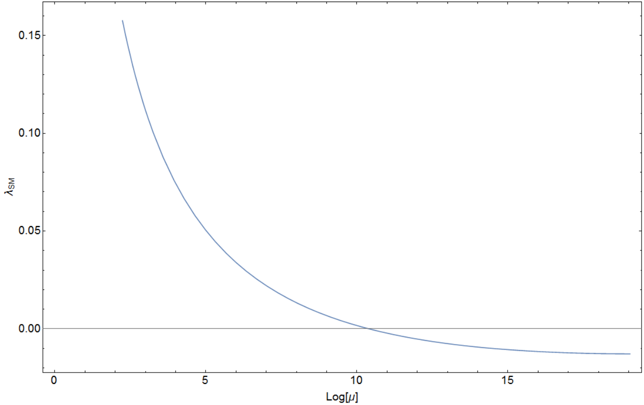
- For large background field value, the cutoff also increases thus making the theory consistent.
- Shift symmetry ensures that any corrections from UV physics can be kept in control.
- Prokopec et al. (1403.3219) computed the cutoff using gauge invariant variables in an explicitly frame-independent way.

Extensions to Higgs inflation

- Scalar Field coupled to Higgs (Lebedev et al., '11): "Higgs Portal Inflation"
- More particle species coupled to the Higgs.
- Supersymmetry-motivated extensions.
- String-theory motivated extensions.

Why are we considering another extension to Higgs Inflation?

- Based on the measured central values of $m_t = 173.34\text{GeV}$ and $m_h = 125.1\text{GeV}$, the Higgs self-coupling runs as:



Model Details

Jordan frame Lagrangian:

$$\mathcal{L} = \frac{1}{2}\sqrt{-g}\Big[-\left(M_{\rm pl}^2 + \xi_h H^\dagger H + \xi_s S^2\right) R + 2\partial_\mu H^\dagger \partial^\mu H + (\partial_\mu S)^2 + 2V(H,S)\Big],$$

with $H = \begin{pmatrix} \pi^+ \\ \frac{1}{\sqrt{2}}\left(\phi + i\pi^0\right) \end{pmatrix}$,

$$V(H,S) = -\mu_h^2 H^\dagger H + \lambda_h (H^\dagger H)^2 - \mu_s^2 S^2 + \mu_1^3 S + \frac{1}{3}\mu_3 S^3 + \frac{1}{4}\lambda_s S^4 + \frac{1}{2}\mu_{sh} H^\dagger H S + \frac{1}{4}\lambda_{sh} H^\dagger H S^2.$$

Model Summary

- For the purposes of inflation, we can treat the potential to be

$$V_J(\phi, s) = \lambda_h \phi^4 + \lambda_s s^4 + \lambda_{sh}\phi^2 s^2$$

- The Fermion χ coupled to the scalar s through the Yukawa coupling y_χ

$$\mathcal{L}_{\rm DM} = \bar{\chi}\gamma^\mu \partial_\mu \chi - m' \bar{\chi}\chi - y_\chi S \bar{\chi}\chi.$$

- What role do these fields play during inflation?

$$\begin{aligned}
\beta_{\lambda_h} &= \frac{1}{(4\pi)^2}\Big[6(1+3s^2)\lambda_h^2 - 6y_t^4 + \frac{3}{8}(2g^4 + (g^2 + g'^2)^2) \\
&\quad + \lambda_h(-9g^2 - 3g'^2 + 12y_t^2) + \frac{1}{2}\lambda_{sh}^2\Big] \\
\beta_{\lambda_s} &= \frac{1}{(4\pi)^2}\Big[18\lambda_s^2 + 4\lambda_s y_\chi^2 + 2s^2\lambda_{sh}^2 - 2y_\chi^4\Big]
\end{aligned}$$

Parameter Region

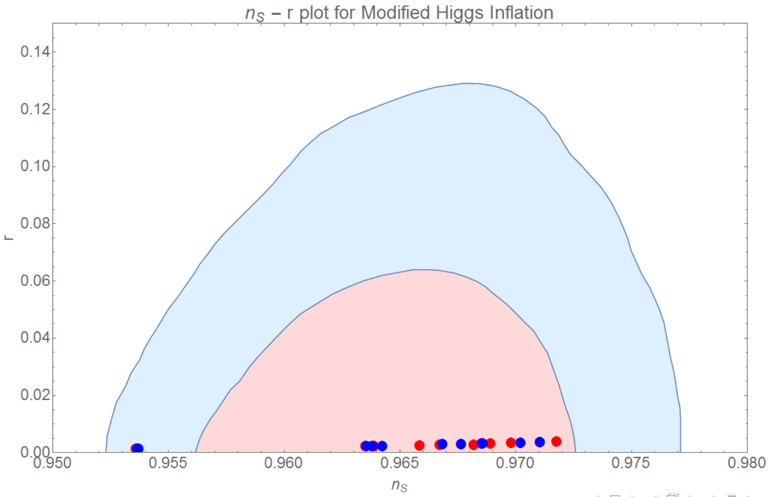
- Input parameters: λ_s, λ_{sh} and y_χ
- Parameter ranges that work:

$$
\begin{aligned}
0.05 &< \lambda_{sh} < 0.2 \\
0.02 &< \lambda_s < 0.2 \\
0 &< y_\chi < 0.6
\end{aligned}
$$

- We can do without the fermion, but the scalar self-coupling and cross coupling are necessary.

Preliminary Results

$y_\chi = 0.1$ (Red), $y_\chi = 0.4$ (Blue)



Conclusions

- Higgs potential has instabilities below Planck scale for measured SM parameters.
- Quartic coupling to an additional scalar field can help stabilize the Higgs potential.
- It is easy to find a range of parameter values that provides n_s and r values that agree with current observations.
- Parameter range should be further constrained with better data.

Further Work

- Constraining dark matter (χ) parameters using LHC data (in progress).
- Consider inflation in the *s*-direction rather than the Higgs direction (in progress).

References

[1] F. Bezrukov, M. Shaposhnikov, *The Standard Model Higgs boson as the inflaton*, [arXiv:0710.3755]
[2] R. Kallosh, A. Linde, D. Roest, *A Universal Attractor for Inflation at Strong Coupling*, [arXiv:1310.3950]
[3] A. Barvinsky, A. Kamenshchik, A. Starobinsky, *Inflation scenario via the Standard Model Higgs Boson and LHC*, [arXiv: 0809.2104]
[4] A. Simone, M. Hertzberg, F. Wilczek, *Running Inflation in the Standard Model*, [arXiv: 0812.4946]
[5] F. Bezrukov, A. Magnin, M. Shaposhnikov, S. Sibiryakov, *Higgs inflation: consistency and generalisations*, [arXiv: 1008.5157]
[6] T. Prokopec, J. Weenink, *Naturalness in Higgs inflation in a frame independent formalism*, [arXiv: 1403.3219]
[7] X. Calmet, R. Casadio, *Self-healing of unitarity in Higgs inflation*, [arXiv: 1310.7410]
[8] O. Lebedev, H. Lee, *Higgs Portal Inflation*, [arXiv: 1105.2284]
[9] J. Gong, H. Lee, S. Kang, *Inflation and dark matter in two Higgs doublet models*, [arXiv: 1202.0288]
[10] M. Xiao, J. Yu, *Stabilizing Electroweak Vacuum in a Vector-like Fermion Model*, [arXiv: 1404.0681]