Single field inflationary models and UV sensitivity

Jacopo Fumagalli

Nikhef

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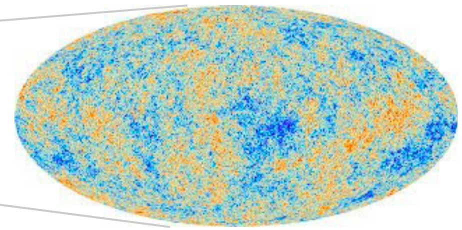
Based on
J.F. and M. Postma. 1602.07234, JHEP 1605 (049) (2016)
J.F. 1611.04997, Phys Lett B 769 (2017)
J.F., S. Mooij and M. Postma. 1709.xxxx.

Motivation

- Inflation $\ddot{a}(t) > 0$



- Inflationary model:
  - Consistent
  - Predictive (in agreement with data if possible)

- Quantum corrections can affect the predictiveness?

$$n_s - 1 = -\frac{2}{N} + f(\beta, \lambda_i, \lambda_j) + O(N^{-2})$$

  - Light on UV dependence
  - NB: No Planck scale physics or eta-problem

Simple renormalizable example

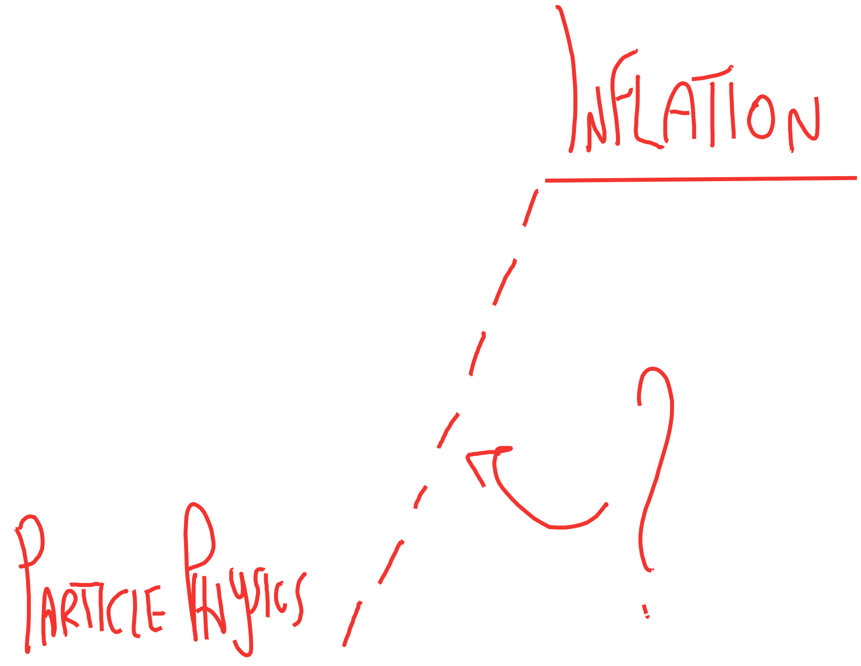
$$\mathcal{L} = -\tfrac{1}{2}(\partial\phi)^2 - \tfrac{\lambda}{4}\phi^4$$

RG improved potential

$$V(\phi) = \tfrac{1}{4}\lambda(\phi)\phi^4 \quad \Longrightarrow \quad n_s = n_s^{\mathrm{cl}}\left(1 + \frac{\beta_\lambda}{\lambda}\right)$$

$$\frac{\beta_\lambda}{\lambda} \propto \lambda \ll 1$$

$$\frac{\beta_\lambda}{\lambda} \propto O\left(\frac{g^4}{\lambda}\right) \not\ll 1$$



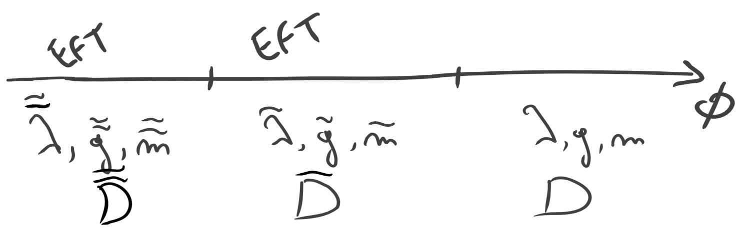
Overview

- Main Idea
- Cosmological Attractors
- New Higgs Inflation
- Conclusion

Idea

- (n_s, r) from $\dfrac{\mathcal{L}_{\rm eff}[\phi_{cl}]}{\sqrt{-g}} = \frac{1}{2} Z(\phi_{cl}) \partial_\mu \phi_{cl} \partial^\mu \phi_{cl} + (\text{h.d.o.}) + \text{V}[\phi_{\rm cl}]$

$$V^0 + V^1 + \ldots V^{(L)} = V^{(L)}(s_1, s_2, ..)$$



$$s_i = \hbar \ln \frac{M_i^2(\phi)}{\mu^2}$$

$$\mathcal{D} V \equiv \left(\mu \frac{\partial}{\partial \mu} + \lambda_i \frac{\partial}{\partial \lambda_i} - \gamma \phi \frac{\partial}{\partial \phi} \right) V = 0$$

B.Kastening '92
M. Masako, T. Kugo, N. Maekewa,
H. Nakano '92 '93

Idea

- Solution of the RGE in the inflationary regime

$$V(\phi, \lambda_i, \mu) = V(\bar{\phi}(t), \bar{\lambda}_i(t), \bar{\mu}(t)) \equiv V(t)$$

$$\begin{cases} \dfrac{d\bar{\phi}(t)}{dt} = -\gamma_\phi(\bar{\lambda}_i(t))\bar{\phi}(t) \\ \dfrac{d\bar{\lambda}_i(t)}{dt} = \beta_i(\bar{\lambda}_j(t)) \\ \bar{\mu}(t) = \mu e^t \end{cases}$$

$$\bar{s}(\tilde{t}) \equiv \ln \frac{\bar{M}^2(\tilde{t})}{\bar{\mu}^2(\tilde{t})} = 0 \implies \tilde{t}(\phi, \bar{\lambda}_i(\tilde{t}))$$

- Inflation $\rho \ll 1 \longleftrightarrow \phi \longrightarrow \tilde{t}(\rho)$

$$V = V(\bar{\lambda}_i(\tilde{t}(\rho)), \rho) \longrightarrow n_s = n_s(\beta_{\lambda_i}, \bar{\lambda}_j), \quad r = r(\beta_{\lambda_i}, \bar{\lambda}_j)$$

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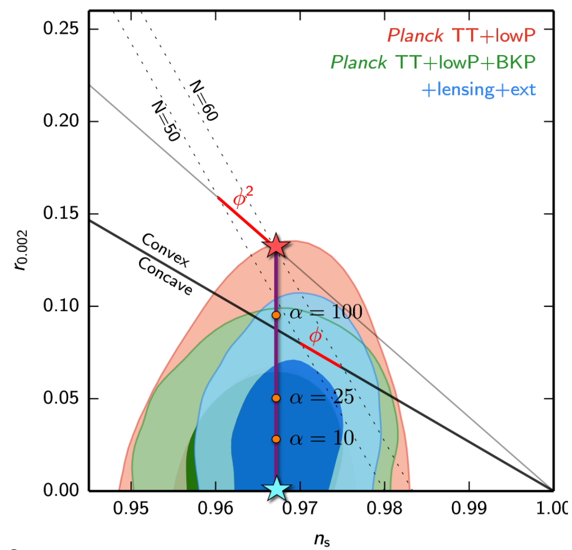
Cosmological attractors

Higgs inflation, Starobinsky , .. $n_s = 1 - \frac{2}{N}, \qquad r = \frac{12}{N^2}$

- **α-attractors** S.Ferrara, R.Kallosh, A. Linde, M.Porrati '13; R. Kallosh, A. Linde, D. Roest '13

$$\mathcal{L}_\alpha = \sqrt{-g}\left[\frac{1}{2}R - \frac{\alpha}{(1-\phi^2/6)^2}\frac{(\partial\phi)^2}{2} - \alpha f^2(\phi/\sqrt{6})\right]$$

$$n_s = 1 - \frac{2}{N}, \qquad r = \frac{12\alpha}{N^2}$$



R. Kallosh, A. Linde '15

- **ξ-attractors** G. Giudice, H. Lee '14; R. Kallosh, A. Linde, D. Roest '14; C. Pallis '14

$$\mathcal{L}_\xi = \sqrt{-g}\left[\frac{1}{2}\Omega(\phi)R - K_J(\phi)\frac{(\partial\phi)^2}{2} - V_J(\phi)\right] \qquad \frac{\lambda}{\xi^2}(\Omega-1)^2$$

  - Universal attractors $K_J = 1\,,\ \Omega = 1 + \xi f(\phi)$
  - Induced inflation $K_J = 1\,,\ \Omega = \xi f(\phi)$

$\xi \gg 1$ SAME PREDICTIONS AS $\alpha \to 1$

Unity of Cosmological Attractors

M. Galante, R. Kallosh,
A. Linde, D. Roest '14

$$\mathcal{L} = \sqrt{-g}\left[\frac{1}{2}R - \frac{1}{2}K_E(\rho)(\partial\rho)^2 - V_E(\rho)\right]$$

$$\rho \to 0$$

$$K_E = \frac{a_p}{\rho^p} + \frac{a_{p-1}}{\rho^{p-1}} + \ldots$$

$p = 2$

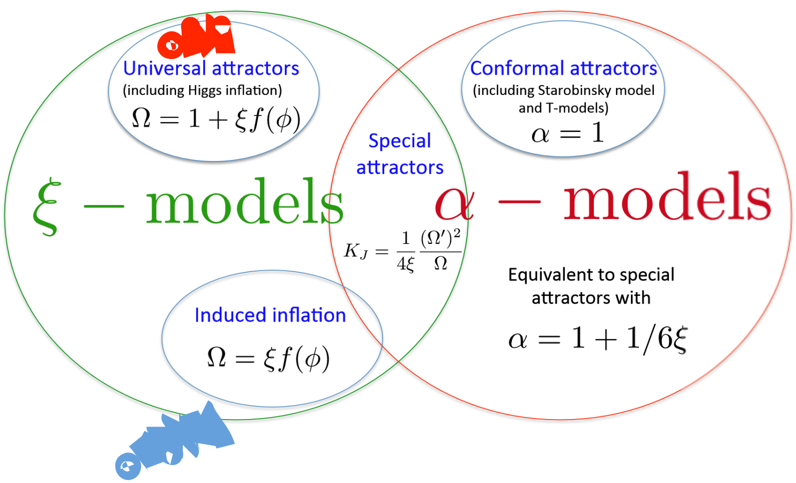
$$V_E = V_0(1 + c\rho + ..)$$

$$n_s = 1 + \frac{p}{2(1-p)}\frac{1}{N}$$

$$r = 8c^{\frac{p-2}{p-1}} a_p^{\frac{1}{p-1}}\left(\frac{1}{(1-p)N}\right)^{\frac{p}{p-1}}$$

$$n_s = 1 - \frac{2}{N}\,, \qquad r = \frac{8a_2}{N^2}$$

$\frac{3}{2}\left(1+\frac{1}{6\xi}\right)$ $\qquad \frac{3}{2}\alpha$



M. Galante, R. Kallosh,
A. Linde, D. Roest '14

RG independence of Cosmological attractors

$$\frac{\mathcal{L}_{\text{eff}}}{\sqrt{-g}} \simeq -\frac{1}{2}K(\rho, \lambda_i(\tilde{t}(\rho)))(\partial\rho)^2 - V(\rho, \lambda_i(\tilde{t}(\rho)))$$

$$(n_s, r) \longleftarrow \eta, \epsilon \qquad \rho_\star = \rho_\star(N)$$

Assumption
$$\frac{d\tilde{t}}{d\rho} = \Sigma_{k=0}^{\infty} c_k \rho^k$$

$F_\star$

$$\epsilon = \frac{1}{2}\frac{\rho^2}{a_p}c^2 + O(\rho^3) \qquad \eta = \frac{\rho}{a_p}c + O(\rho^2)$$

$$c \to c\left(1 + \frac{\beta_{V_0}}{V_0}\frac{c_0}{c}\right) \equiv c'$$

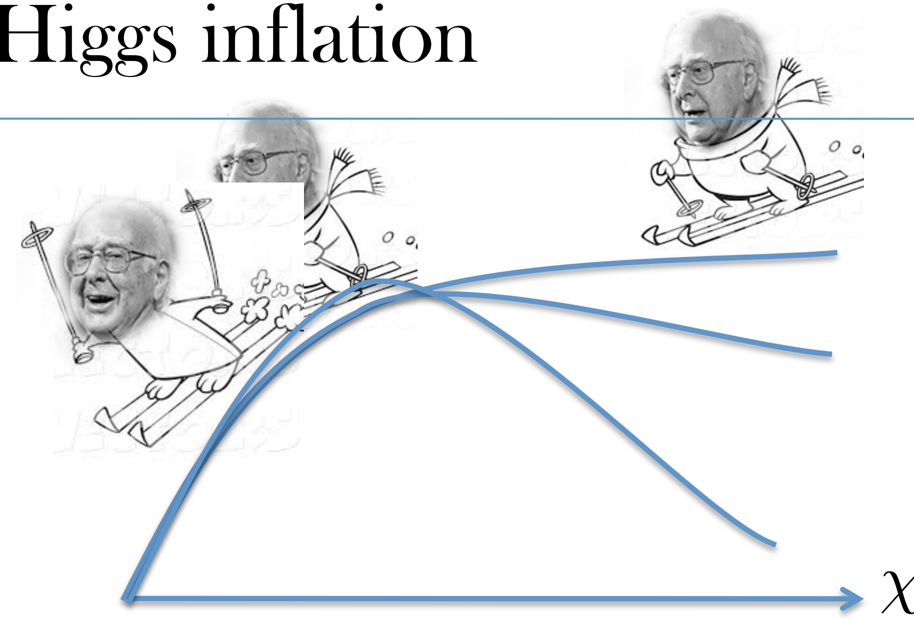
$$n_s = 1 - \frac{2}{N} \quad , \quad r = \frac{8a_2}{N^2}$$

Same as tree level results!

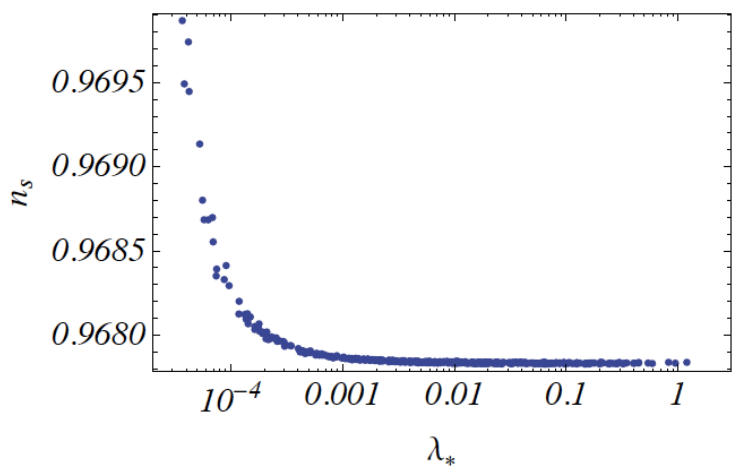
J.F. Phys LettB 769 (2017)

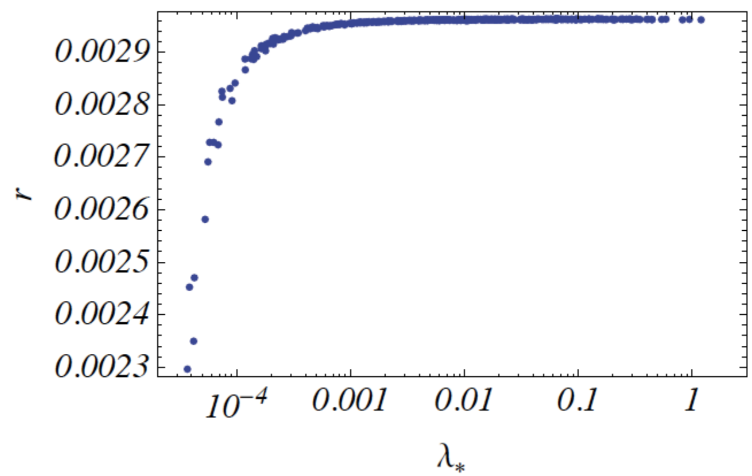
UV (in)sensitivity of Higgs inflation

$$F_* \ll \rho_*$$



J.F., Postma, JHEP 1605 (049)





RG independence of Cosmological attractors

$$\frac{d\tilde{t}}{d\rho} = \Sigma_{k=0}^{\infty} c_k \rho^k \qquad ?$$

Ensured by renormalizability in the EFT sense in the low/ high EFT!

J.F. Phys Lett B 769 (2017)

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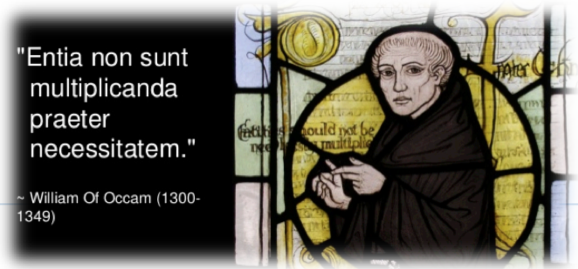
New Higgs Inflation



$$S = \int d^4x\sqrt{-g}\left(\frac{1}{2}m_{pl}^2 R + \mathcal{L}_{\rm SM} + \frac{G^{\mu\nu}}{M^2}D_\mu\Phi^\dagger D_\nu\Phi\right)$$

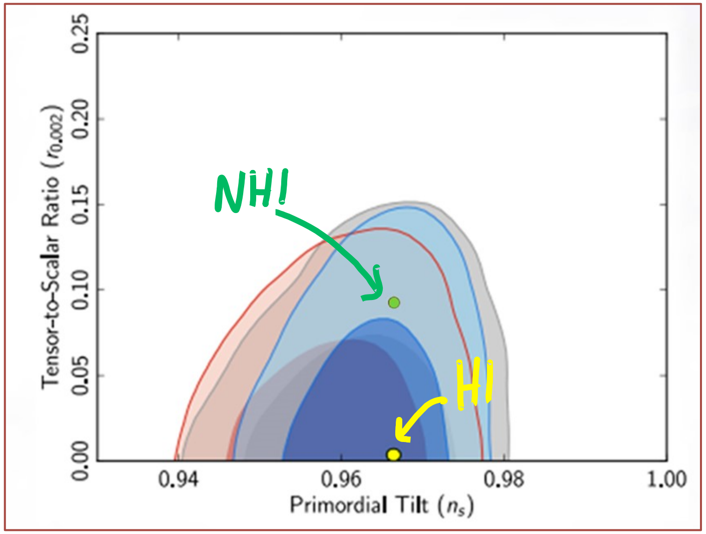
C. Germani, A. Kehagias '10

Disformal Transformation C. Germani, S.Di Vita '16

$$g_{\alpha\beta} \to g_{\alpha\beta} + 2\frac{D_\alpha\Phi^\dagger D_\beta\Phi}{\mathcal{M}^4} \qquad \mathcal{M}^4 = M^2 m_{\rm pl}^2$$

$$S = S_{EH} - \int d^4x\sqrt{-g}\left(1 + \frac{V}{\mathcal{M}^4}\right) D^\mu\Phi^\dagger D_\mu\Phi + V + O(\varepsilon^2)$$

$$\varepsilon = \frac{\dot\phi^2}{M^4}$$

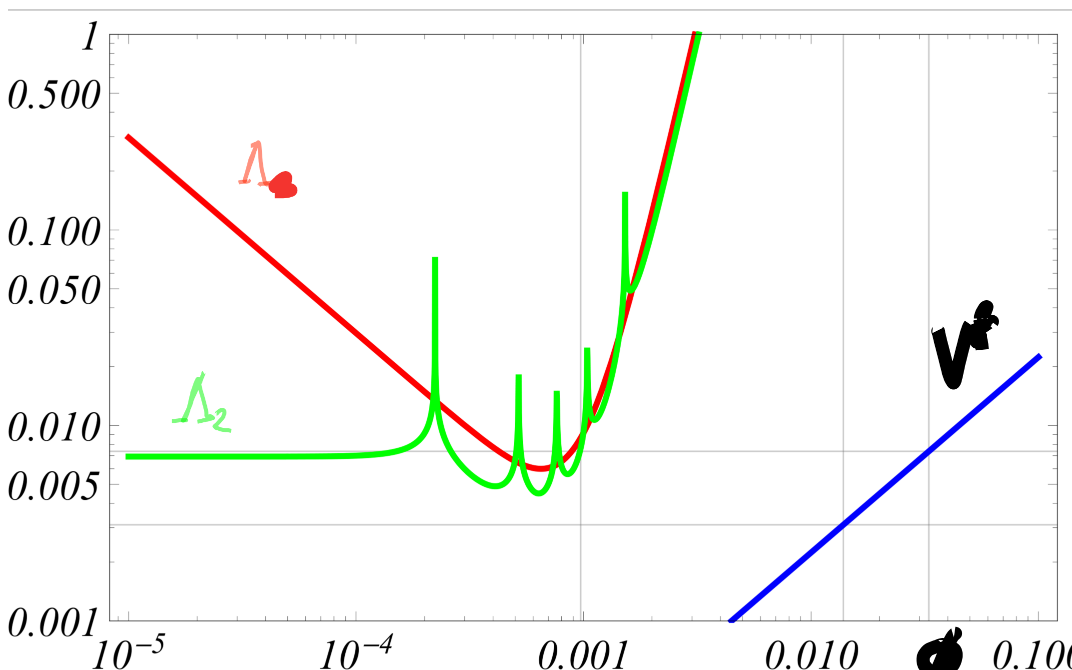


Unitarity Cutoff

Chiral Lagrangian $\Sigma = e^{i\vec{\pi}\cdot\vec{\sigma}/\bar{F}}$ $\quad \Phi = \Sigma \begin{pmatrix} 0 \\ \phi \end{pmatrix}$

$$\mathcal{L}_{NHI} = -\frac{1}{2}(\partial h)^2 - \frac{\bar{F}^2}{4}\left(1 + 2a\frac{h}{\bar{F}} + b\frac{h}{\bar{F}^2} + \ldots\right) \mathrm{Tr}[(D^{\mu}\Sigma)^{\dagger} D_{\mu}\Sigma]$$

- $\mathcal{A}(\pi^+\pi^- \to hh) > 1$
- $\mathcal{A}(2h \to nh) > 1$



Escrivà and Germani '16
J.F, Mooij, Postma *in prep.*

Non renormalizability/EFT

$$\mathcal{L} \supset \mathcal{L}_K - \lambda U(h) - gF^2(h) A_\mu A^\mu + \frac{y_t}{\sqrt{2}} Y(h) \bar{\psi}\psi$$

Loop corrections $\quad h \rightarrow h + \delta h$

Bezrukov, Magnin,
Shaposhnikov, Sibiryakov '11,

$$\Gamma^{1-\text{loop}} \supset \frac{1}{\epsilon} \frac{\lambda^2}{32\pi^2} (U''(h))^2$$

$$\mathcal{L}^{(1)}_{\text{h.o.}} = \lambda^2 C_1 U_1 + \lambda^3 C_2 U_2 + \ldots$$

$$\delta = \frac{V}{\mathcal{M}^4} \ll 1 \longleftrightarrow \phi/\Lambda \ll 1$$

$$\delta \gg 1 \longleftrightarrow w = 1/\delta \rightarrow 0$$

$$\mathcal{L}^{(1)}_{\text{h.o.}} = \lambda^2 C_1 U(h) \sum_{n=1}^{\infty} c_n \left(\frac{\phi(h)}{\Lambda}\right)^{4n}$$

$$-\#\lambda^2 C_1 U(h) + \lambda^2 C_1 \sum_{n=1}^{\infty} d_n w^n$$

$$\lambda \rightarrow \tilde{\lambda} = \lambda - \#\lambda^2 C_1$$

uncertainty on UV breaks the connection!

New Higgs Inflation – Sensitivity of the predictions

Inflationary parameters beyond tree level   J.F, Mooij, Postma *in prep.*

$$n_s - 1 = -\frac{5}{3N_\star}\left(1 - \frac{4\beta_\lambda}{5\lambda} + \frac{9\beta_{\mathcal{M}^4}}{10\mathcal{M}^4}\right),$$

$$r = \frac{16}{3N_\star}\left(1 - \frac{3\beta_\lambda}{4\lambda} + \frac{\beta_{\mathcal{M}^4}}{\mathcal{M}^4}\right)$$

- Minimally coupled set up:

$$V_{\text{eff}}|_{\delta \gg 1} = \frac{\phi}{4}\left[\lambda + \delta\lambda - \frac{1}{8\pi^2\epsilon}\cdot(-3y_t^4)\right].$$

$\Longrightarrow$ NHI UV sensitive

Conclusions

- UV sensitivity that might affect non renormalizable models
- Class of models (almost) insensitive to these corrections (Universal regime)
- It remains to be proven that an UV completion of this kind does exist
- Sensitivity in New Higgs inflation scenario
- Problem of predictivity vs virtue