NEW HIGGS INFLATION

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Based on: C. G. and Alex Kehagias PRL 105:011302 [1003.2635]; JCAP 1005:019,2010 [1003.4285] Lowering the curvature during Inflation

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In Standard GR Higgs inflation fails because of Quantum Gravity:

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$$R\sim H^2\propto V(\Phi)\propto \Phi^4$$

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$$\dot{\Phi} \simeq -M_{p} \Phi$$

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$$\dot{\Phi} \simeq -M_{p}\Phi$$
$$\epsilon = -\frac{\dot{H}}{H^{2}} \propto \frac{\dot{\Phi}^{2}}{H^{2}M_{p}^{2}} \sim \frac{M_{p}^{2}}{\Phi^{2}} \ll 1$$
$$\Downarrow$$
$$R \gg M_{p}^{2}$$

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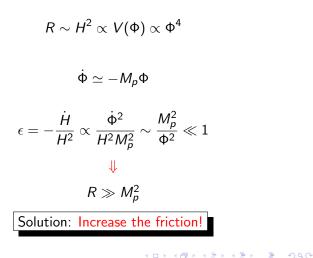
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How to increase the friction:

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How to increase the friction:

if $\dot{\Phi} \rightarrow \Omega^2 \dot{\Phi}$ with $\Omega \gg 1$

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$$\epsilon \propto rac{\dot{\Phi}^2}{H^2 M_p^2} \sim rac{M_p^2}{\Phi^2 \Omega^2} \ll 1 \rightarrow M_p^2 \gg R \gg rac{M_p^2}{\Omega^8} \; \text{(for large enough } \Omega)$$

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Quantum Gravity regime is avoided during Inflation!

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During Inflation H is "large" so we may construct

$$\Omega^2 = \omega^2 H^2 \sim \omega^2 G^{tt}$$

(where $G^{\alpha\beta}$ is the Einstein tensor)

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During Inflation H is "large" so we may construct $\Omega^2 = \omega^2 H^2 \sim \omega^2 G^{tt}$

(where $G^{lphaeta}$ is the Einstein tensor)

This is achieved by the following replacement of the Kinetic lagrangian of $\boldsymbol{\Phi}$

$$g^{lphaeta}\partial_{lpha}\Phi\partial_{eta}\Phi
ightarrow \left(g^{lphaeta}-\omega^2G^{lphaeta}
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This defines the "New Higgs Inflation" Lagrangian:

$$S = \int d^4x \sqrt{-g} \left[rac{R}{2\kappa^2} - rac{1}{2} \left(g^{lphaeta} - \omega^2 G^{lphaeta}
ight) \partial_lpha \Phi \partial_eta \Phi - rac{\lambda}{4} \Phi^4
ight]$$

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We found a realization of the "New Higgs Inflation" idea Is this unique?

 Require only a spin-2 and a spin-0 degrees of freedom to propagate (in general background)

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We found a realization of the "New Higgs Inflation" idea Is this unique?

- Require only a spin-2 and a spin-0 degrees of freedom to propagate (in general background)
- Modify only the kinetic term

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The unique action is the New Higgs Inflation action!!!

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Does the non-renormalizable operator

 $I = \omega^2 G^{\alpha\beta} \partial_\alpha \Phi \partial_\beta \Phi$

violates unitarity during Inflation since $\omega^2 H^2 \gg 1$?

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Expand the fields at linear level

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- Expand the fields at linear level
- Canonically normalize the Higgs: $\Phi = \Phi_0 + \frac{1}{\sqrt{3}\omega H}\phi$

(the non-standard normalization comes from $\omega^2 G^{tt} \dot{\phi}^2$)

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Canonically Normalize the metric: $g_{\mu\nu} = g^0_{\mu\nu} + \frac{1}{M_p} h_{\mu\nu}$

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■ Read out the scale (Λ) in which $I \sim O(1)$: $\Lambda(H) \sim (M_p H^2)^{1/3} \gg R \sim H^2$ because $H \ll M_p$ Lowering the curvature during Inflation

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Unitarity *is not* violated up to the Quantum Gravity scales!!!!

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- In large field Inflation $\Phi \gg M_p \Rightarrow$ we cannot trust the tree-level potential
- Suppose some global symmetry is broken at energies
 f >TeV (like in the QCD axion case)

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- In large field Inflation $\Phi \gg M_p \Rightarrow$ we cannot trust the tree-level potential
- Suppose some global symmetry is broken at energies
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- a Pseudo Nambu-Goldston Boson Φ is produced

$$V(\Phi) = 2\Lambda^4 \sin^2(\frac{\Phi}{f}) \simeq 2\Lambda^4 \left(1 - \frac{\Phi^2}{4f^2}\right)$$

protected by global shift symmetry $\Phi \to \Phi + c$ at $\Lambda \to 0$

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$$n_s - 1 \propto \epsilon \simeq - rac{M_p^2}{8\pi f^2}$$

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• so $n_s \leq 1 \rightarrow f > M_p \Rightarrow$ the model cannot be trusted!

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Once again we can increase the friction so that

$$\epsilon \rightarrow \frac{\epsilon_{old}}{\Omega^2} \Rightarrow n_s - 1 \sim -\frac{M_p^2}{8\pi f \Omega^2}$$

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Then for large enough Ω , $f \ll M_p$!!!!

The model is Natural!!! (i.e. no UV modifications of the potential)

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This is due to the fact that the new coupling $G^{\alpha\beta}\partial_{\alpha}\Phi\partial_{\beta}\Phi$ is the unique that

- Does not introduce new degrees of freedom
- *Is invariant* under the global unbroken symmetry $\Phi \rightarrow \Phi + c$

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 By increasing the friction Inflation can be obtained with the Standard Model Higgs Boson without unitarity violation Lowering the curvature during Inflation

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- By increasing the friction Inflation can be obtained with the Standard Model Higgs Boson without unitarity violation
- The friction can be increased by non minimally coupling the Einstein tensor to the Kinetic term of the Higgs Boson

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- New proposal: small field inflation with Nambu-Goldston Boson → New Natural Inflation

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