Sneutrino Inflation in GUTs

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Outline

- Motivation
- $U(1)$ Toy Model
- Sneutrino Inflation in Pati-Salam
- Road to $SO(10)$
- Summary

Motivation

Inflation is very sucessful in explaining

- ... why the Universe is homogeneous and isotropic on large scales
- ... why the Universe is almost perfectly spatially flat
- ... the possible origin of the small-scale fluctuations

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Inflation typically involves energy scales around the GUT scale $\Lambda \sim 10^{15}\mathrm{GeV}$

Particle physics only explored experimentally up to the TeV scale $E \lesssim \mathrm{TeV}$

The connection between Inflation and Particle Physics remains unclear !

Motivation

To make this connection, our strategy will be the following:

> Assuming a supersymmetric GUT at the energy scale relevant for inflation we want to identify the inflaton with the scalar superpartner of some “matter field”.

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To make this connection, our strategy will be the following:

Assuming a supersymmetric GUT at the energy scale relevant for inflation we want to identify the inflaton with the scalar super-partner of some “matter field”.

However, this is not without problems

In general, the inflaton is now a gauge non-singlet !

The inflaton potential might recieve large D-term contributions.
$\Rightarrow$ violates slow-roll

Two loop mass corrections might drive the inflaton mass above the Hubble scale.
$\Rightarrow m^2 > H$, $|\eta| > 1$

The production of stable topological defects has to be avoided.

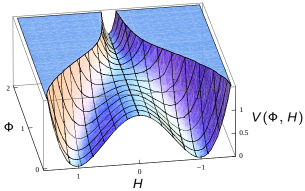
$U(1)$ Toy Model

To illustrate our approch, let's first consider the most simple case, an inflaton charged under $G = U(1)$.

$$\boxed{W = \kappa\, S\,(H\,\bar{H} - M^2) + \frac{\zeta}{\Lambda}(H\,\bar{H})(\Phi\,\bar{\Phi}) + \ldots}$$

- S is kept at 0 during and after inflation and provides the vacuum energy by its F-term.
- The waterfall fields $\bar{H}$ and H remain at 0 during inflation and end inflation by acquiring a vev.
- $\bar{\Phi}$ and Φ act as inflatons.

For $\langle\bar{\Phi}\rangle^* = \langle\Phi\rangle$ and $\langle\bar{H}\rangle = \langle H\rangle = \langle S\rangle = 0$ inflation proceeds along a D-flat valley. On this trajectory the inflaton potential is tree-level flat!



Tree level potential in the D-flat valley

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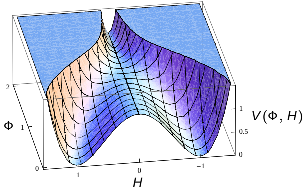
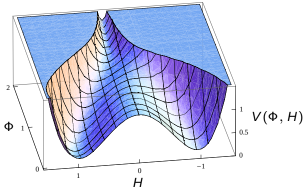
Higher dimensional operators can lead to effective superpotential terms like $\delta(H\bar{\Phi})$, leading to a deformed potential with a preferred vacuum.



Tree level potential in the D-flat valley



Deformed potential yielding a preferred vacuum

Inflation in Pati-Salam

A more realistic example: Sneutrino inflation in Pati-Salam
$G_{PS} = SU(4)_C \times SU(2)_L \times SU(2)_R$

Minimalistic field content:

$$R_i^c = (\bar{\mathbf{4}}, \mathbf{1}, \bar{\mathbf{2}}) = \begin{pmatrix} u_i^c & u_i^c & u_i^c & \nu_i^c \\ d_i^c & d_i^c & d_i^c & e_i^c \end{pmatrix} \qquad \bar{R}^c = (\mathbf{4}, \mathbf{1}, \mathbf{2}) = \begin{pmatrix} \bar{u}^c & \bar{u}^c & \bar{u}^c & \bar{\nu}^c \\ \bar{d}^c & \bar{d}^c & \bar{d}^c & \bar{e}^c \end{pmatrix}$$

$$H^c = (\bar{\mathbf{4}}, \mathbf{1}, \bar{\mathbf{2}}) = \begin{pmatrix} u_H^c & u_H^c & u_H^c & \nu_H^c \\ d_H^c & d_H^c & d_H^c & e_H^c \end{pmatrix} \qquad \bar{H}^c = (\mathbf{4}, \mathbf{1}, \mathbf{2}) = \begin{pmatrix} \bar{u}_H^c & \bar{u}_H^c & \bar{u}_H^c & \bar{\nu}_H^c \\ \bar{d}_H^c & \bar{d}_H^c & \bar{d}_H^c & \bar{e}_H^c \end{pmatrix}$$

$$S, X = (\mathbf{1}, \mathbf{1}, \mathbf{1})$$

$i = 4$ (four generations) $\longrightarrow$ 3 light generations after inflation !

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Superpotential:

$$\begin{aligned} W &= \kappa\, S \left(\frac{\langle X \rangle}{\Lambda} H^c \bar{H}^c - M^2 \right) \\ &+ \frac{\lambda_{ij}}{\Lambda} (R_i^c \bar{H}^c)(R_j^c \bar{H}^c) + \frac{\gamma}{\Lambda} (\bar{R}^c H^c)(\bar{R}^c H^c) + \frac{\zeta_i}{\Lambda} (R_i^c \bar{R}^c)(H^c \bar{H}^c) + \frac{\xi_i}{\Lambda} (R_i^c \bar{H}^c)(\bar{R}^c H^c) \\ &+ \ldots \end{aligned}$$

Sneutrino Trajectory

Special trajectory : Sneutrino inflation !

$$\langle R_1^c \rangle = \begin{pmatrix} 0 & 0 & 0 & \langle \nu^c \rangle \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad \langle \bar{R}^c \rangle = \begin{pmatrix} 0 & 0 & 0 & \langle \bar{\nu}^c \rangle \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad \langle R_{i \neq 1}^c \rangle = 0$$

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- D-flatness $\Rightarrow V_D = \frac{g^2}{2} \sum_{a=1}^{18} \sum_i \left(-R_i^{c\dagger} \mathcal{T}^{a*} R_i^c + \bar{R}^{c\dagger}\, \mathcal{T}^a\, \bar{R}^c \right)^2 \equiv 0$
  $\Rightarrow |\langle \nu^c \rangle| = |\langle \bar{\nu}^c \rangle| \equiv \nu/\sqrt{2} \in \mathbb{R}$
- $\langle H^c \rangle = \langle \bar{H}^c \rangle = 0$ during inflation due to large masses from the F-term potential.
- At some critical value ν_{crit} one or more component fields of $H^c, \bar{H}^c$ become tachyonic and end inflation by acquiring a vev (“waterfall”).

$$\nu_{\text{crit}} = \sqrt{\frac{2|\kappa|M}{|\zeta|}} \quad \text{for} \quad u_H^c, d_H^c, e_H^c, \ldots$$

$$\nu_{\text{crit}} = \sqrt{\frac{2|\kappa|M}{|\zeta+\xi\pm 2\gamma|}} \quad \text{for} \quad \Re(\bar{\nu}_H^c - \nu_H^c), \Im(\bar{\nu}_H^c - \nu_H^c)$$

Preferred direction
$\Rightarrow$ No monopoles !

Non-Singelt Inflaton ?

What about the problems mentioned in the introduction?

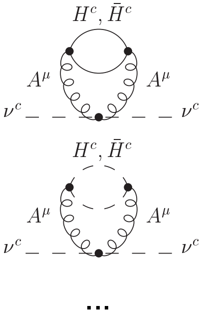
- D-term contributions $\longrightarrow$ D flat valley $\surd$
- Monopoles $\longrightarrow$ Preferred direction $\surd$
- Domain walls $\longrightarrow$ Higher dim. operators, tilt of potential $\surd$

Non-Singelt Inflaton ?

What about the problems mentioned in the introduction?

- D-term contributions → D flat valley ✓
- Monopoles → Preferred direction ✓
- Domain walls → Higher dim. operators, tilt of potential ✓

- Two loop contributions to the inflaton mass



- Typical problem: 2-loop mass contribution for non-singelts

$$\delta m^2 \sim \frac{g^4}{(4\pi)^2} \frac{|W_S|^2}{m_F^2} > H^2 \quad \text{[Dvali '95]}$$

- However in our class of models: Gauge symmetry broken in the inflaton direction

$$\delta m^2 \sim \frac{g^4}{(4\pi)^2} \frac{\mu^4}{M_g^2} \ll H^2 \qquad \checkmark$$

Road to $SO(10)$

- Make the model left-right symmetric
  - Add $L_i = (\mathbf{4}, \mathbf{2}, \mathbf{1}), \bar{L} = (\overline{\mathbf{4}}, \overline{\mathbf{2}}, \mathbf{1}), H = (\mathbf{4}, \mathbf{2}, \mathbf{1})$ and $\bar{H} = (\overline{\mathbf{4}}, \overline{\mathbf{2}}, \mathbf{1})$ to the field content
  - Two sectors of inflation, "inflaton race"
- Unify left- and right-charged leptoquark superfields

$$
\begin{aligned}
\mathbf{16} = (\mathbf{4}, \mathbf{2}, \mathbf{1}) \oplus (\overline{\mathbf{4}}, \mathbf{1}, \overline{\mathbf{2}}) \quad &\rightarrow \quad \boldsymbol{F_i} = L_i \oplus R_i^c \ , \ \boldsymbol{H} = H \oplus H^c \\
\overline{\mathbf{16}} = (\overline{\mathbf{4}}, \overline{\mathbf{2}}, \mathbf{1}) \oplus (\mathbf{4}, \mathbf{1}, \mathbf{2}) \quad &\rightarrow \quad \bar{\boldsymbol{F}} = \bar{L} \oplus \bar{R}^c \ , \ \bar{\boldsymbol{H}} = \bar{H} \oplus \bar{H}^c
\end{aligned}
$$

- $SO(10)$ superpotential

$$
\boxed{
\begin{aligned}
W = \kappa\, S \left(\frac{\langle X \rangle}{\Lambda} H\bar{H} - M^2 \right) \\
+ \frac{\lambda_{ij}}{\Lambda}(F_i F_j \bar{H}\bar{H}) + \frac{\gamma}{\Lambda}(\bar{F}\bar{F}HH) + \frac{\zeta_i}{\Lambda}(F_i \bar{F} H \bar{H}) + ...
\end{aligned}
}
$$

Summary

- Connection between inflation and particle physics still unclear: inflaton often postulated ad-hoc.
- Embedding of inflation into SUSY GUTs $\rightarrow$ inflaton a gauge non-singlet ?
- New class of models: Gauge Non-Singlet (GNS) Inflation in SUSY GUTs
- Inflaton gauge interactions and D-term contributions to the inflaton potential entail certain problems for the realization of slow-roll ...
- ... we provided a proof of existence: Sneutrino trajectory is a viable trajectory for inflation in PS or $SO(10)$ that solves these problems.