Higgs-Matter Tribrid Inflation

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Outline

- Susy Hybrid Inflation
- Smooth Hybrid Inflation
- Tribrid Inflation
- Higgs-Matter (Pseudosmooth) Tribrid Inflation
- Summary and Conclusions

Susy Hybrid Inflation

[Copeland, Liddle, Lyth, Stewart, Wands; Dvali, Shafi, Schaefer '94]

[V. N. Senoguz, Q. Shafi '04; A. D. Linde, A. Riotto '97]

- Attractive scenario in which inflation can be associated with symmetry breaking $G \longrightarrow G'$
- Susy hybrid inflation is defined by the superpotential

$$W = \kappa\, S\, (H\, \overline{H} - M^2)$$

S = gauge singlet inflaton, waterfall field = $(H\,, \overline{H}) \in G$

- R-symmetry

$$H\, \overline{H} \to H\, \overline{H},\;\; S \to e^{i\alpha}\, S,\;\; W \to e^{i\alpha}\, W$$

$\Rightarrow$ W is unique renormalizable superpotential

Susy Hybrid Inflation

- Some examples of gauge groups:

$G = U(1)_{B-L}$, (Supersymmetric superconductor)

$G = SU(5) \times U(1)$, $(H = 10)$, (Flipped $SU(5)$)

$G = 3_c \times 2_L \times 2_R \times 1_{B-L}$, $(H = (1, 1, 2, +1))$

$G = 4_c \times 2_L \times 2_R$, $(H = (\overline{4}, 1, 2))$, $G = SO(10)$, $(H = 16)$

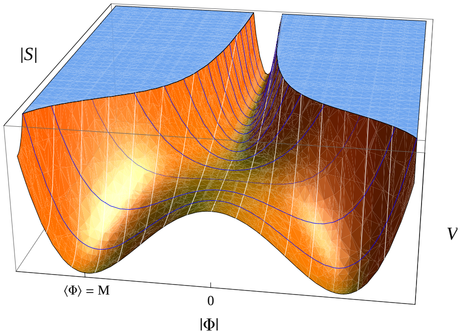
Susy Hybrid Inflation

- Tree level potential (with $|\overline{H}| = |H|$)

$$V_F = \left|\frac{\partial W}{\partial z_i}\right|^2 = \kappa^2\left(M^2 - |H^2|\right)^2 + 2\kappa^2|S|^2|H|^2$$

- Higgs mass-squared (with $H = 0$)

$$m_H^2 = 4\kappa^2\left[(|S|^2 - M^2)\right] \qquad \text{(waterfall)}$$



Susy Hybrid Inflation

Take into account radiative corrections

- Mass splitting in $H - \overline{H}$ supermultiplets

$$m_{\pm}^2 = \kappa^2 S^2 \pm \kappa^2 M^2, \quad m_F^2 = \kappa^2 S^2$$

- One-loop radiative corrections

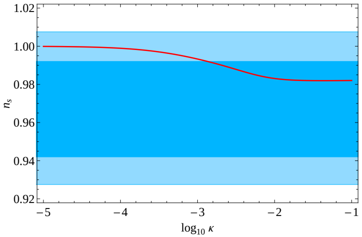
$$\Delta V_{\text{1loop}} = \frac{1}{64\pi^2}\text{Str}[\mathcal{M}^4(S)(\ln\frac{\mathcal{M}^2(S)}{Q^2} - \frac{3}{2})]$$

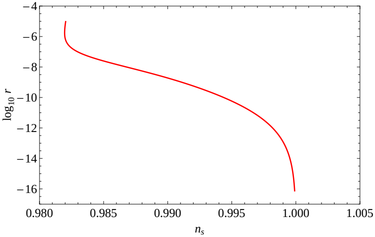
- In the inflationary valley $(H = 0, |S| \gg M)$

$$V \simeq \kappa^2 M^4 \left(1 + \frac{\kappa^2 \mathcal{N}}{8\pi^2} \ln(|S|/M)\right)$$

Susy Hybrid Inflation

Tree level plus radiative corrections:





$$n_s \approx 1 - \frac{1}{N_0} \approx 0.98$$

$\delta T/T \propto (M/M_P)^2 \sim 10^{-5} \longrightarrow$ attractive scenario

Sugra Hybrid Inflation

Also include supergravity corrections

- The Kähler potential can be expanded as

$$K = |S|^2 + |H|^2 + \left|\overline{H}\right|^2 + \kappa_S \frac{|S|^4}{4\, m_P^2} + \kappa_{SS} \frac{|S|^6}{6\, m_P^4} + \cdots$$

- The Sugra scalar potential is given by

$$V_F = e^{K/m_p^2} \left[\left(W_i + m_P^{-2} K_i\right) K_{ij}^{-1} \left(W_j + m_P^{-2} K_j\right)^* - 3 m_p^{-2} |W|^2 \right]$$

- Take into account sugra corrections, and radiative corrections, the potential is given by

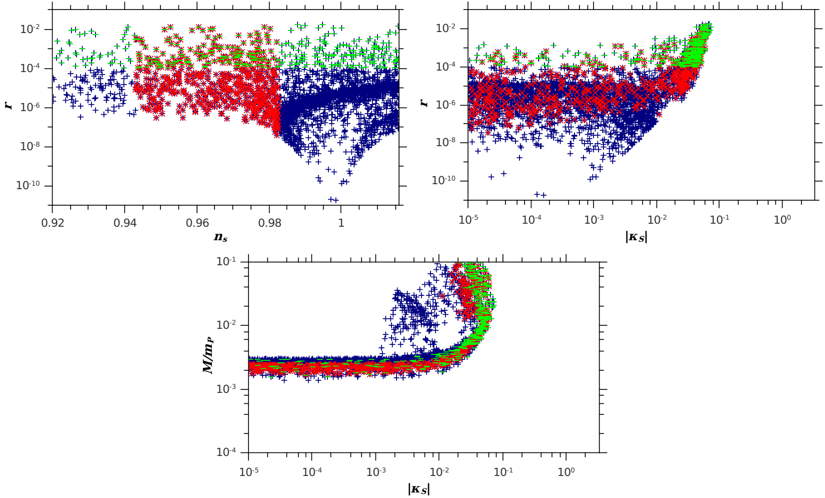
$$V \simeq \kappa^2 M^4 \left(1 - \kappa_S \left(\frac{S}{m_P} \right)^2 + \frac{\gamma_S}{2} \left(\frac{S}{m_P} \right)^4 + \frac{\kappa^2 \mathcal{N}}{8\pi^2} \ln\left(\frac{S}{M}\right) \right)$$

where, $\gamma_S = 1 - \frac{7\kappa_S}{2} - 2\kappa_S^2 - 3\kappa_{SS}$.

Note: No 'η problem' with minimal Kähler potential

Sugra Hybrid Inflation

[M. R, Q. Shafi, J. Wickman, 2011]



Smooth Hybrid Inflation

[G. Lazarides, C. Panagiotakopoulos '1995]

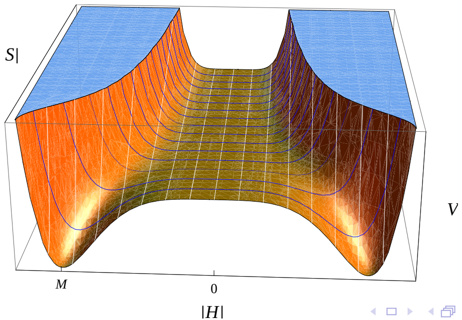
- Smooth hybrid inflation is defined by the superpotential

$$W = S\left(\mu^2 - \frac{(H\,\overline{H})^2}{m_P^2}\right)$$

- Scalar potential (with $|\overline{H}| = |H|$)

$$V_F = \mu^4\left[\left(1 - \frac{|H|^4}{M^4}\right)^2 + 8\frac{|S|^2}{M^2}\frac{|H|^6}{M^6}\right],$$

where, $M = \sqrt{\mu\, m_P}$.



Smooth Hybrid Inflation

Here, we use $M = 1$ units.

- Minimize the potential w.r.t H,

$$H = 0, \quad 6\, S^2 H^2 + H^4 - 1 = 0$$

- Inflationary track ($|H| \ll 1$)

$$H^2 \simeq \tfrac{1}{6\, S^2}$$

- Higgs mass-squared

$$m_H^2 = 24\, \mu^4\, H^2 \left[10\, S^2\, H^2 + \tfrac{7}{3}\, H^4 - 1\right]$$

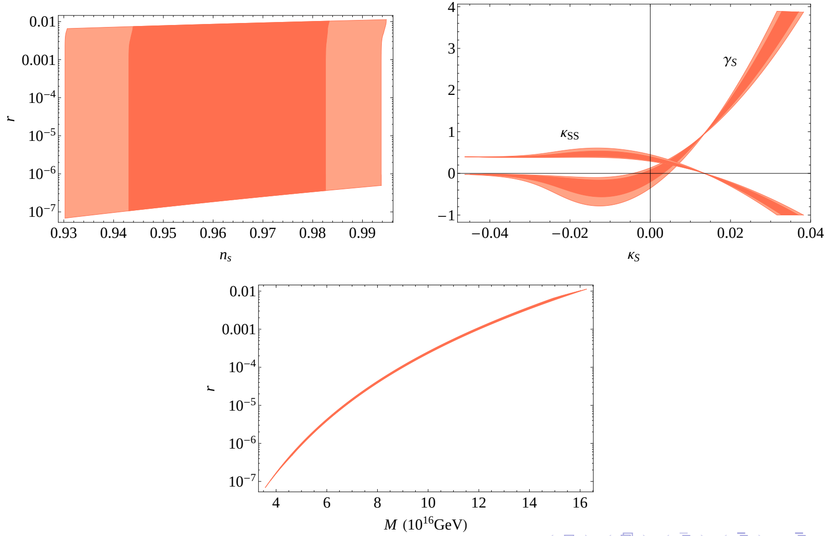
- Scalar potential during inflation

$$V_F \simeq \mu^4 \left(1 - \tfrac{1}{54\, S^4} - \kappa_S \left(\tfrac{S}{m_P}\right)^2 - \tfrac{\gamma_S}{2} \left(\tfrac{S}{m_P}\right)^4\right)$$

where, $\gamma_S = 1 - \frac{7\kappa_S}{2} - 2\kappa_S^2 - 3\kappa_{SS}$.

Results

[M. R, Q. Shafi, 2012]



Tribrid (Matter) Inflation

[Antusch, Bastero-Gil, King, Shafi '04, Antusch, Dutta, Kostka '09]

- Consider a simple example of tribrid inflation

$$W = \kappa\{S\left(M^2 - H^2\right) + \lambda \frac{H^2\,\phi^2}{m_P}\}$$

- Susy vacuum

$$\langle S\rangle = 0,\ \langle H\rangle = M \text{ and } \langle\phi\rangle = 0$$

- An attractive candidate for the inflaton ϕ is the RH sneutrino
- The inflaton ϕ can be a gauge non-singlet matter field
- Scalar potential

$$V_F = \kappa^2\left[\left(M^2 - H^2\right)^2 + 4H^2\left(\lambda\frac{\phi^2}{m_P} - S\right)^2 + 4\lambda^2\frac{\phi^2}{m_P^2}H^4\right],$$

- Flat direction $(H = 0)$

$$V_F = |F_S|^2 = \kappa^2 M^4$$

Tribrid (Matter) Inflation

- Sugra corrections from the Kähler potential, $\delta K = \kappa_S \frac{|S|^4}{4\, m_P^2}$, induce a Hubble mass-squared $m_S^2 \gtrsim \frac{\kappa^2 M^4}{3\, m_P^2}$ for the driving field S, with $|\kappa_S| \gtrsim 1/3$.

$$\Longrightarrow \quad S = 0 \quad \text{during inflation}$$

- Higgs mass-squared with $(S = 0,\ H = 0)$

$$m_H^2 = 4\,\kappa^2 \left[-M^2 + 2\,\lambda^2 \frac{\phi^4}{m_P^2} \right] \quad \text{(waterfall)}$$

- S provides $V_0 = \kappa^2 M^4$, H ends inflation, $\phi =$ inflaton
- Scalar potential during inflation $(S = 0,\ H = 0)$

$$V \simeq \kappa^2 M^4 \left[1 + \gamma \left(\frac{\phi}{m_P} \right)^2 + \frac{\delta}{2} \left(\frac{\phi}{m_P} \right)^4 \right] + \delta V_{1-loop},$$

- Essentially same results/predictions are obtained as that of 'standard' Susy hybrid inflation.

Higgs-Matter (Pseudosmooth) Tribrid Inflation

[S. Antusch, D. Nolde, M. R '2012]

- Consider a superpotential with generalized tribrid structure:

$$W = \kappa \left\{ S(M^2 - H^l) + \lambda H^m \phi^n \right\} .$$

Here and below we use Planck units $m_P = 1$.

- Susy vacuum

$$\langle S \rangle = 0,\ \langle H \rangle = M \text{ and } \langle \phi \rangle = 0$$

- The Susy F-term potential then is

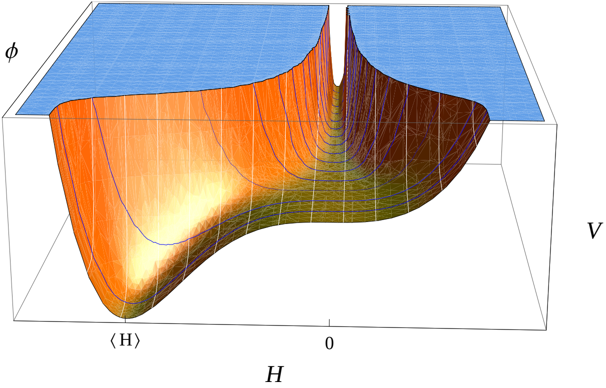
$$V_F = \kappa^2 \left[\left| H^l - M^2 \right|^2 + \left| l S H^{l-1} - m \lambda H^{m-1} \phi^n \right|^2 + \left| n \lambda H^m \phi^{n-1} \right|^2 \right]$$

- The inflationary track with $H \neq 0$ in general implies $S \neq 0$
- However, a large Sugra mass term $\kappa_S \frac{\kappa^2 M^4}{m_P^2} |S|^2$ can suppress S during inflation with $\kappa_S \gtrsim \mathcal{O}(1)$

Higgs-Matter (Pseudosmooth) Tribrid Inflation

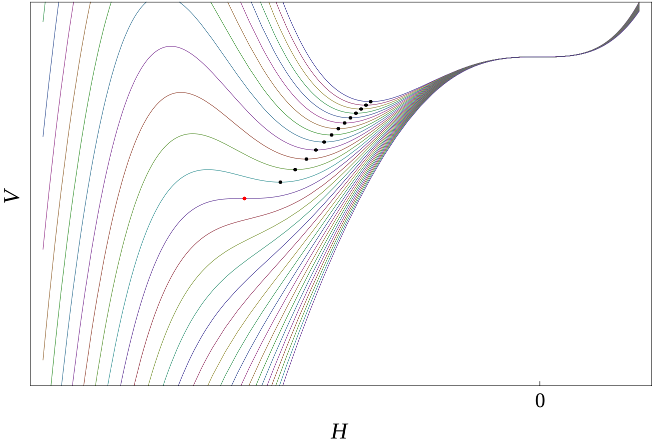
- The Susy potential now becomes

$$V = \left|H^l - M^2\right|^2 + \left|lSH^{l-1} - m\lambda^2 H^{m-1}\phi^n\right|^2 + \left|n\lambda^2 H^m \phi^{n-1}\right|^2 + \kappa_S M^4 \left|S\right|^2$$



The scalar potential V as a function of H and ϕ with $S = S_{\text{min}}$ and $l = m = 3$, $n = 2$.

Pseudosmooth Tribrid Inflation



The scalar potential V as a function of H with $l = m = 3$ and $n = 2$, for various values of ϕ near the waterfall which starts at the red dot. The small black dots represent minima of the potential along the inflationary track.

Allowed superpotential parameters l and m

For integer values of l and m, the combined constraints are

$$l \geq m > 1 + \frac{l}{2} \qquad \text{(without } m_{H,SUGRA}\text{)}$$

$$l \geq m > 2 \qquad \text{(with } m_{H,SUGRA}\text{).}$$

In both cases the constraints imply that $l, m > 2$.

	$m = 2$	$m = 3$	$m = 4$	$m = 5$
$l = 2$	$m \leq 2$	$m > l$	$m > l$	$m > l$
$l = 3$	$m \leq 2$	possible	$m > l$	$m > l$
$l = 4$	$m \leq 2$	with $m_{H,SUGRA}$	possible	$m > l$
$l = 5$	$m \leq 2$	with $m_{H,SUGRA}$	possible	possible

Viable (green) and dysfunctional (red) superpotential choices for the proposed model class. The red text indicates why above condition is violated. The orange entries satisfy the necessary condition and may be smooth or pseudosmooth. Some of these models can only work with additional SUGRA contributions to m_H^2. Larger l, m are possible, but increasingly Planck-suppressed. Superpotentials which do not work for this model class can still provide inflation by other mechanisms (e.g. $l \geq m = 2$ for 'standard' tribrid inflation).

Approximate analytical treatment for $l = m$

- Minimizing the potential $V(\phi, H, S)$ w.r.t S

$$S_{\text{min}} = \frac{l^2 \lambda \phi^n H^{2l-2}}{\kappa_S M^4 + l^2 H^{2l-2}}$$

- The effective 2-field potential then is

$$V_2 = V(\phi, H, S_{\text{min}}(\phi, H)) \simeq M^4 - 2M^2 H^l + l^2 \lambda^2 H^{2l-2} \phi^{2n} - \frac{l^4 \lambda^2 \phi^{2n} H^{4l-4}}{\kappa_S M^4 + l^2 H^{2l-2}}$$

- Waterfall at ϕ_c:

$$\partial_H V_2(H_c, \phi_c) = \partial_H^2 V_2(H_c, \phi_c) = 0$$

This implies,

$$\phi_c^{2n} = \frac{16(l-1)}{l(3l-2)^2} \frac{M^2}{\lambda^2} \left(\frac{3l-2}{l-2} \frac{l^2}{\kappa_S M^4} \right)^{\frac{l-2}{2l-2}}$$

$$H_c^{2l-2} = \left(\frac{l-2}{3l-2} \frac{\kappa_S M^4}{l^2} \right)$$

Approximate analytical treatment for $l = m$

- The effective single-field potential is obtained with $H = H_{\mathsf{min}}(\phi)$

$$V_1 = V_2(\phi, H_{\mathsf{min}}(\phi)) = M^4 - M^2 \frac{l-2}{l-1} \left(\frac{1}{l(l-1)} \frac{M^2}{\lambda^2} \right)^{\frac{l}{l-2}} \left(\frac{1}{\phi} \right)^{\frac{2nl}{l-2}}$$

- The scalar spectral index n_s is given by

$$n_s = 1 - 2 \left(\frac{1+\frac{2nl}{l-2}}{2+\frac{2nl}{l-2}} \right) \frac{1}{N_0 + c_{ln} \left(\frac{1}{M}\right)^{\frac{2}{l-1}(1-\frac{1}{n})} \left(\frac{1}{\kappa_S}\right)^{\frac{l}{2l-2}(1+\frac{l-2}{nl})} \left(\frac{1}{\lambda}\right)^{\frac{2}{n}}}$$

with $c_{ln} = \mathcal{O}(1)$, e.g. $c_{32} = 0.92$, or more detailed

$$c_{ln} = \frac{l-1}{nl\left(2+\frac{2nl}{l-2}\right)} \left[l(l-1)\right]^{\frac{l}{l-2}} \left[\frac{16(l-1)}{l(3l-2)^2}\right]^{\frac{l}{l-2}+\frac{1}{n}} \left[\frac{l^2(3l-2)}{l-2}\right]^{\frac{l}{2l-2}+\frac{l-2}{n(2l-2)}}$$

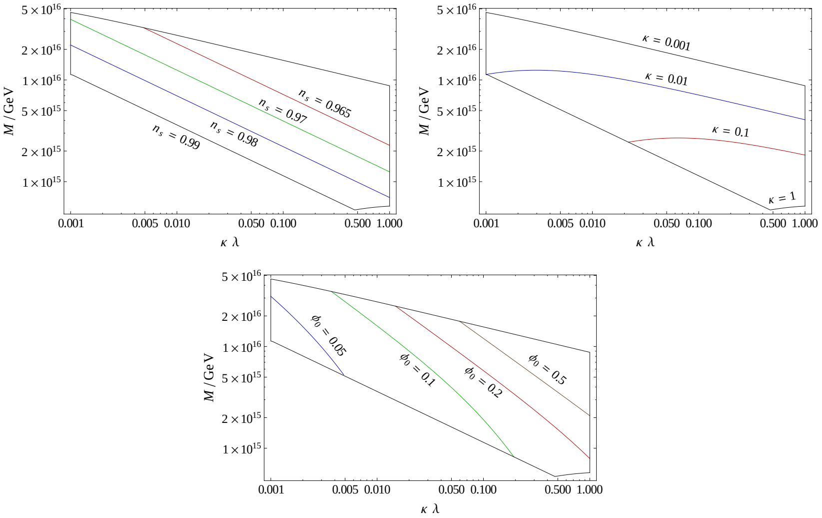
- With $N_0 \geq 50$

$$0.96 < n_s < 1$$

$$r < 4 \times 10^{-5}$$

$$-10^{-3} < dn_s/d\ln k < 0$$

Numerical results for the $(l = m = 3,\ n = 2)$ case



Summary/Conclusions

- One of the most important challenges is to find a "Standard Model of Inflationary Cosmology".
- Susy hybrid inflation models provide an attractive framework for realising inflation in close contact with particle physics.
- Tribrid inflation models further open up new possibility of realising inflation with a gauge non-singlet inflaton.
- In pseudosmooth tribrid inflation, the inflaton field is a combination of Higgs and matter fields.
- Due to preselection of the vacuum the monopole problem is avoided in pseudosmooth tribrid inflation.
- The predictions for various CMB observables are in good agreement with WMAP current observations and will be tested by the forthcoming data from the Planck satellite.

Thanks for your attention