Inflation in an extended SUSY Pati-Salam model

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The model

- It is an extension[a] of the SUSY Pati-Salam model.
- SUSY models with exact Yukawa unification and universal boundary conditions predict an unacceptably large b-quark mass for $\mu > 0$.
- The SUSY PS model was extended in order to incorporate a moderate violation of exact Yukawa unification and, thus, allow for an acceptable b-quark mass, even with universal boundary conditions, in the case $\mu > 0$.

Gauge group: $G_{\rm PS} = {\rm SU(4)_c} \times {\rm SU(2)_L} \times {\rm SU(2)_R}$

Field content:

$F_i(4,2,1)$, $F_i^c(\bar{4},1,2)$	(quarks and leptons)
$h(1,2,2)$	(electroweak Higgs)
$\bar{H}^c(4,2,1)$, $H^c(\bar{4},2,1)$, S(1,1,1)	(SSB fields)
h', $\bar{h}'(15,2,2)$ and ϕ, $\bar{\phi}(15,1,3)$	(Yukawa quasi-unification)
$G(6,1,1)$, $\bar{N}$, $N(1,1,1)$	(other fields)

[a] M. E. Gomez, G. Lazarides and C. Pallis, Nucl. Phys. B **638**, 165 (2002)

New smooth hybrid inflation

Superpotential: $W = \kappa S(M^2 - \phi^2) - \gamma S H^c \bar{H}^c + m\phi\bar{\phi} - \lambda\bar{\phi} H^c \bar{H}^c$

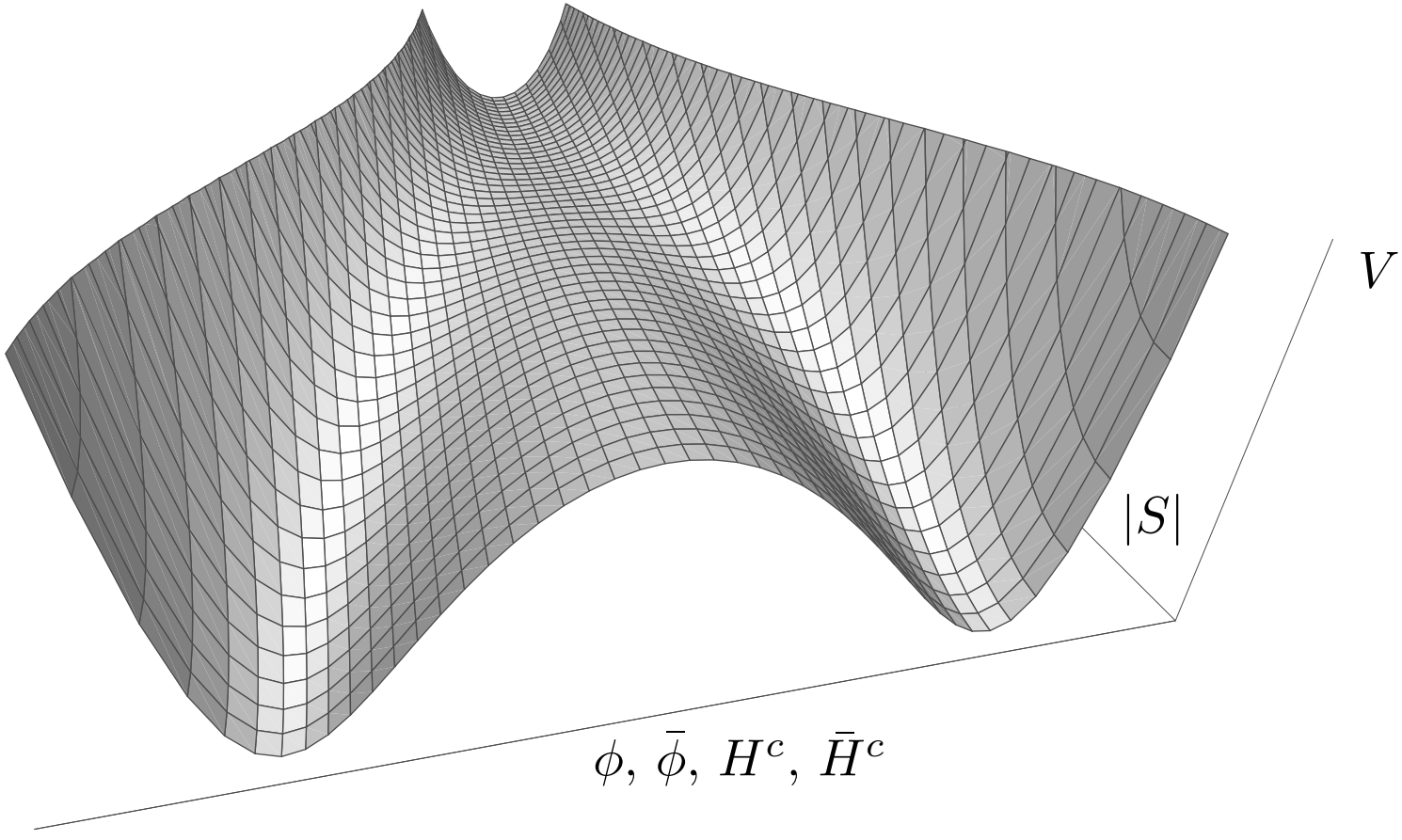
ScalarPotential: $V = |\kappa\,(M^2 - \phi^2) - \gamma H^c \bar{H}^c|^2 + |m\bar{\phi} - 2\kappa S\phi|^2$
$+|m\phi - \lambda H^c \bar{H}^c|^2 + |\gamma S + \lambda\bar{\phi}\,|^2 \left(|H^c|^2 + |\bar{H}^c|^2\right)$

- The model can accommodate conventional hybrid inflation along the flat direction $\phi = \bar{\phi} = H^c = \bar{H}^c = 0$ (trivial direction).
- It was later realized that the model also possesses 3 extra inflationary paths. A 'shifted' one, a 'semi-shifted' one and a 'new smooth' one.
- The 'new smooth' path leads to 'new smooth' hybrid inflation[a]. It is a path with an inclination at the classical level along which $G_{\rm PS}$ is broken to $G_{\rm SM}$.
- The motivation comes from WMAP3: spectral index too low for conventional models of hybrid inflation to be viable.

[a] G. Lazarides and A. Vamvasakis, arXiv:0705.3786 [hep-ph]

New smooth hybrid inflation-Global SUSY

- The trivial flat direction is stable for $|S| > S_c \equiv \sqrt{\kappa/\gamma}\, M$ and unstable for $|S| < S_c$. The new smooth path appears right after the destabilization of the trivial direction.

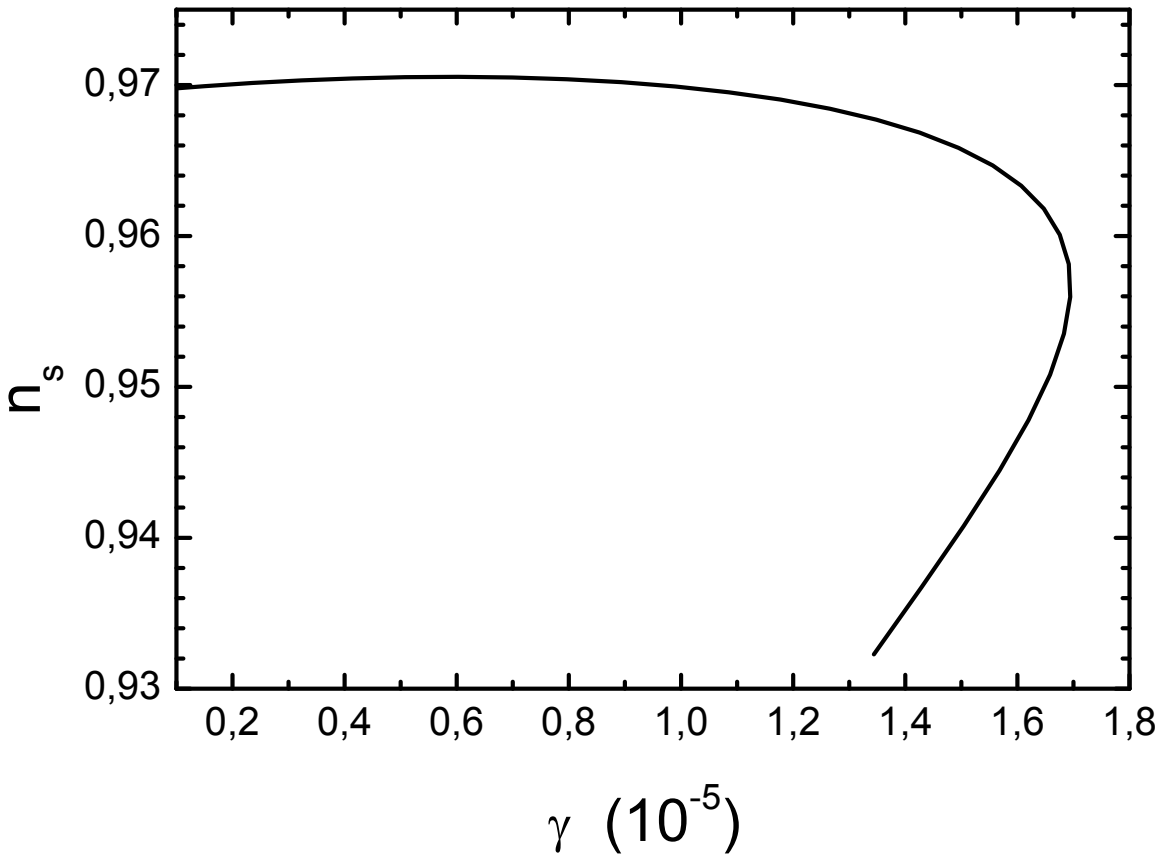


New smooth hybrid inflation-Global SUSY

- The trivial flat direction is stable for $|S| > S_c \equiv \sqrt{\kappa/\gamma}\, M$ and unstable for $|S| < S_c$. The new smooth path appears right after the destabilization of the trivial direction.
- In the limit $\gamma \to 0$, the effective potential on the new smooth path closely resembles the effective potential of conventional smooth hybrid inflation[a].
- For γ adequately small, S_c is adequately large and the system can inflate with the required number of e-foldings along the new smooth path.
- Because of the presence of the critical point, above which the new smooth path does not exist, the spectral index can be reduced.
- The model contains 5 free parameters, m, M, κ, λ and γ. The first 4 of them can be fixed from phenomenological and cosmological constraints (e.g. $P_{\mathcal{R}}$). We plot the results with respect to γ.

[a] G. Lazarides and C. Panagiotakopoulos, Phys. Rev. D **52**, 559 (1995)

New smooth hybrid inflation-Global SUSY



- Contrary to conventional smooth hybrid inflation ($n_{\rm s} \simeq 0.97$), we obtain spectral indices significantly lower, lying within the $1-\sigma$ range of WMAP3: $n_{\rm s} = 0.958 \pm 0.016 \;\Rightarrow\; 0.942 \lesssim n_{\rm s} \lesssim 0.974$.

SUGRA corrections

- Inclusion of minimal SUGRA corrections increases the spectral index above the 95% confidence level of the range of WMAP3.
- One can consider the effect of non-minimal terms in the Kähler potential,

$$K = K_{\min} + \frac{k_S}{4}\frac{|S|^4}{m_{\rm P}^2} + \frac{k_{SS}}{6}\frac{|S|^6}{m_{\rm P}^4}.$$

- The effect of these terms in the case of standard[a] and smooth[b] hybrid inflation has already been investigated.
- For large k_S, the potential acquires a local minimum and maximum which can spoil inflation by trapping the system in the minimum.
- In smooth and new smooth hybrid inflation a significant decrease in the spectral index can be achieved with values of k_S that are low enough.

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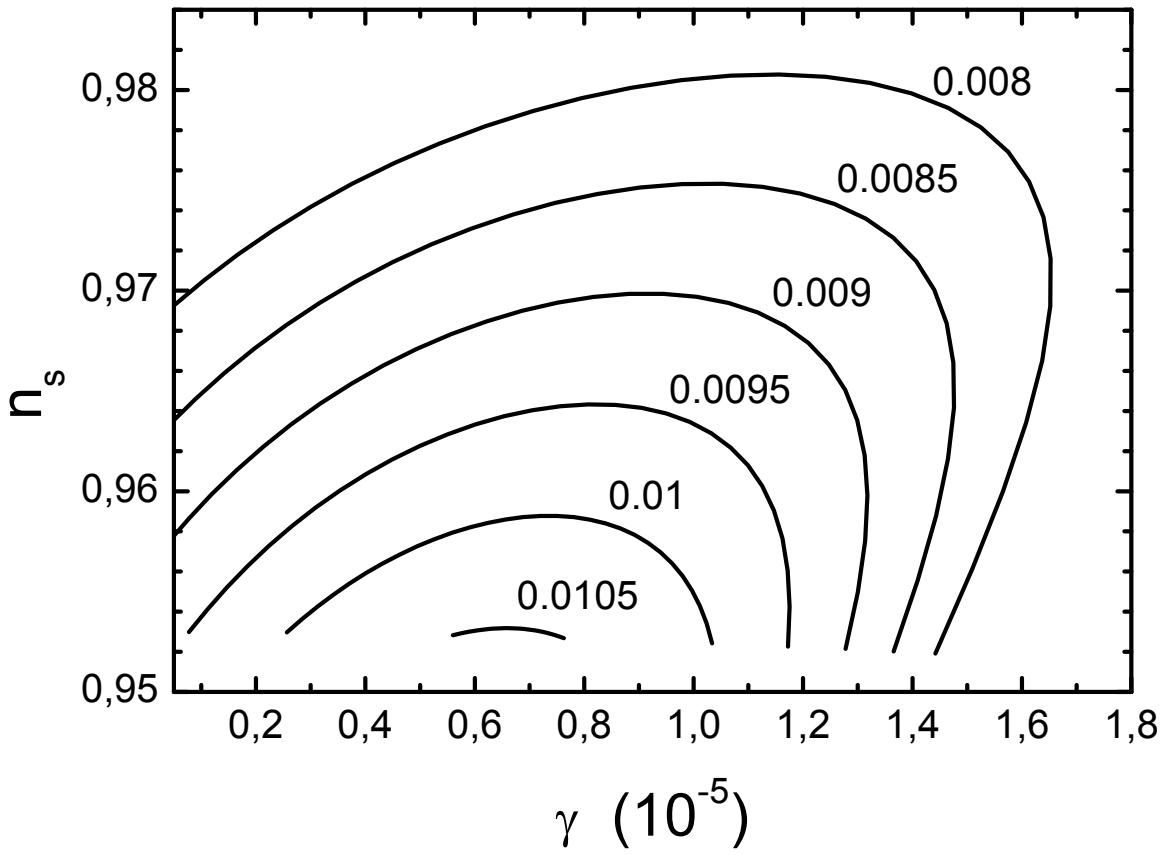
[a] M. Bastero-Gil, S. F. King and Q. Shafi, Phys. Lett. B **651**,345 (2007)

[b] M. ur Rehman, V. N. Senoguz and Q. Shafi, Phys. Rev. D **75**,043522 (2007)

SUGRA corrections



- $n_{\rm s}$ is plotted for various values of k_S shown in the figure.
- We end the curves when the local min-max on the path appear.
- The central value for the spectral index, $n_{\rm s} = 0.958$, is achievable.

Conclusions

- A model that has been introduced for very different reasons than inflation is shown to posses an in built inflationary path with the properties of smooth hybrid inflation, using only renormalizable superpotential terms.
- Contrary to standard smooth hybrid inflation, where the predicted spectral index in the global SUSY case is $n_{\rm s} \simeq 0.97$, new smooth hybrid inflation accommodates also lower values for the spectral index, comfortably within the $1-\sigma$ range of WMAP3.
- Inclusion of minimal SUGRA corrections increases the spectral index to unacceptable values. Though, the presence of non-minimal terms in the Kähler potential can lower the spectral index to values that are consistent with WMAP3.
- This can be done without the appearance of a local minimum and maximum on the inflationary path, which can invalidate inflation. Furthermore, topological defects are not produced at the end of inflation since the GUT gauge group is already broken during it.

Future work

Two stage standard-smooth hybrid inflation

- In this case, the system, before entering the new smooth path, experiences a stage of hybrid inflation on the trivial flat direction.
- A completely different, two stage inflationary scenario occurs where one can lower the spectral index to acceptable values, even with minimal SUGRA, by limiting the number of e-foldings in the first inflationary stage.

Semi-shifted hybrid inflation

- The same model, for different parameter values, possesses a classically flat inflationary path, on which $G_{\rm PS}$ is broken to $G_{\rm SM} \times {\rm U}(1)_{\rm B-L}$.
- Cosmic strings are formed at the end of inflation. It has been shown that this can increase the preferred value for the spectral index to about 0.985. This is very close to the prediction of the model, even in minimal SUGRA.

  Final remark: A specific SUSY model, that was constructed for a very different reason than inflation, is shown to possess a very rich inflationary phenomenology and leads to predictions consistent with WMAP3.