SQCD Inflation and SUSY Breaking

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Based on the works,

P. Brax, C.A. Savoy, A.S, JHEP 0904 (2009) 092;

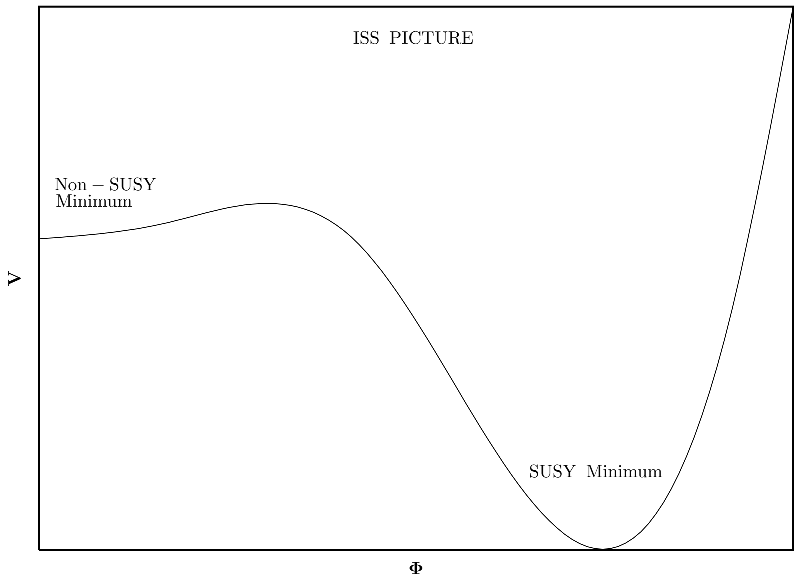
C.A. Savoy and A.S, PLB660 (2008) 236

Outline

- Introduction and motivation
- A brief description of Intriligator-Seiberg-Shih (ISS) model of *metastable supersymmetry breaking*
- Our scenario: *describing a possible connection between Supersymmetry Breaking (in* ISS Model*) and supersymmetric hybrid Inflation based on the work,* C.A. Savoy, A.S. PLB660 (2008) 236*.*
- Few shortcomings of the Set-up
- Revisiting the model with *deformed* ISS sector and SQCD Inflation: based on the work P. Brax, C.A. Savoy, A.S, JHEP0904 (2009) 092.
- Conclusions

ISS Picture of Metastable Supersymmetry Breaking

K. Intriligator, N. Seiberg and D. Shih, JHEP 0604 (2006) 021



It permits a SUSY vacuum along with the existence of a long-lived (metastable) supersymmetry breaking vacuum, $V_+ \sim \mu^4$;

we are in this non-SUSY minimum.

Motivation

- Note two points:

  a) μ is set by hand.

  b) why the universe should be in the non-SUSY minimum?

- We want to answer both these questions in a single framework.
- Our answer: Inflation can put the universe to the metastable minimum, not to the SUSY one. The scale of SUSY breaking is also generated from the scale of inflation.

ISS Model

Framework: N=1 SU(N_c) SQCD with N_f flavors,

$$N_c + 1 < N_f < \frac{3}{2} N_c$$

Microscopic Description (Electric):
when all quarks are massive, $W_{ISS} = \mathrm{Tr} m Q \tilde{Q}$

	$SU(N_c)$	$SU(N_f)$	$SU(N_f)$
Q	N_c	N_f	1
$\tilde{Q}$	$\bar{N}_c$	1	N_f

To study the low energy limit with $m \ll \Lambda$, we should use the ..

Macroscopic Description (Magnetic)

$SU(N)$ gauge theory with $N = N_f - N_c$ (using Seiberg duality)

$$W_{ISS} = \mathrm{Tr} q \Phi \tilde{q} - \mu^2 \mathrm{Tr} \Phi, \quad \mu^2 = \Lambda m$$

(The magnetic description would be IR free)

$q, \tilde{q} \rightarrow$ magnetic quarks;

$\Phi = \frac{Q\tilde{Q}}{\Lambda} \rightarrow$ Singlet made of mesons.

	$SU(N)$	$SU(N_f)$	$SU(N_f)$
q	N	$\bar{N}_f$	1
$\tilde{q}$	$\bar{N}$	1	N_f
Φ	1	N_f	$\bar{N}_f$

$U(1)_R$ charge: $[\Phi]$ = 2, $[q\tilde{q}]$ = 0

Supersymmetry Breaking via rank condition

$W_{ISS} = \mathrm{Tr} q\Phi\tilde{q} - \mu^2 \mathrm{Tr}\Phi$

• The Kahler potential for the IR free fields is smooth near the origin and can be taken to be canonical,

$$K = Tr\Phi^\dagger\Phi + q^\dagger q + \tilde{q}^\dagger\tilde{q}$$

• The local Non-SUSY Vacuum is therefore:

$$\Phi = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, q = \tilde{q}^T = \begin{pmatrix} \mu I_N \\ 0 \end{pmatrix}.$$

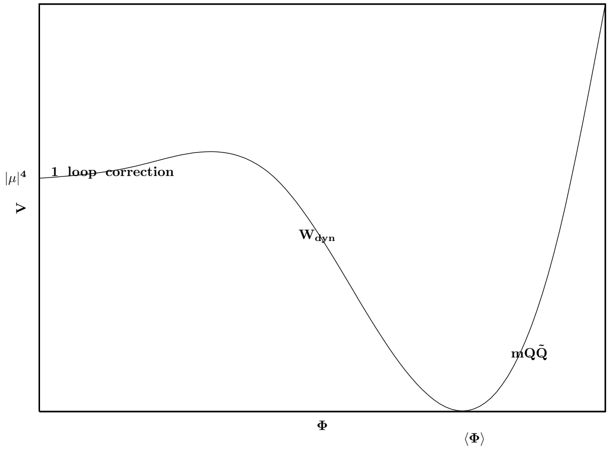
• So Supersymmetry is broken by rank condition with Vacuum energy $V_+ \simeq N_c|\mu|^4$.

• The SUSY minimum is obtained while incorporating the non-perturbative term,

$$W_{dyn} = N\left(\frac{\det\Phi}{\Lambda^{N_f-3N}}\right)^{\frac{1}{N}},$$

The Susy Minimum is given by:

$$\Phi_0 = \langle\Phi\rangle = \mu\left[\frac{\Lambda}{\mu}\right]^{\frac{N_f-3N}{N_c}}, \ \ \langle q\rangle = \langle\tilde{q}\rangle = 0.$$



Metastability

- Lifetime of metastable vacuum

(1) $$\Gamma \sim e^{-S_{bounce}}, \text{ where } S_{bounce} \simeq \frac{\langle \Delta\Phi \rangle^4}{V_+} \gg 1$$

- By choosing $\mu \ll \Phi_0 < \Lambda$, it is possible to ensure the metastability of the non-susy minimum.

To make this ISS model more natural we are now going to discuss how μ could be generated dynamically.

Set Up

- Assume two separate sectors:
  (a) Inflationary sector :
  (described by Supersymmetric Hybrid Inflation)

$$W_{\rm Inf} = kS(\chi^2 - M_{\rm Inf}^2),$$

[C.A. Savoy, A.S. PLB 660 (2008) 236)]

  (b) ISS sector with massless electric quarks.

- These two sectors are connected only through gravity,

$$W_{int} = \frac{g}{M_P}\chi^2 {\rm Tr} Q\tilde{Q},$$

(*Note that the interaction term respects R-symmetry.)*

- At the end of inflation, the waterfall field χ gets a vev $\sim M_{\text{Inf}}$, that develops the mass term for quarks, producing

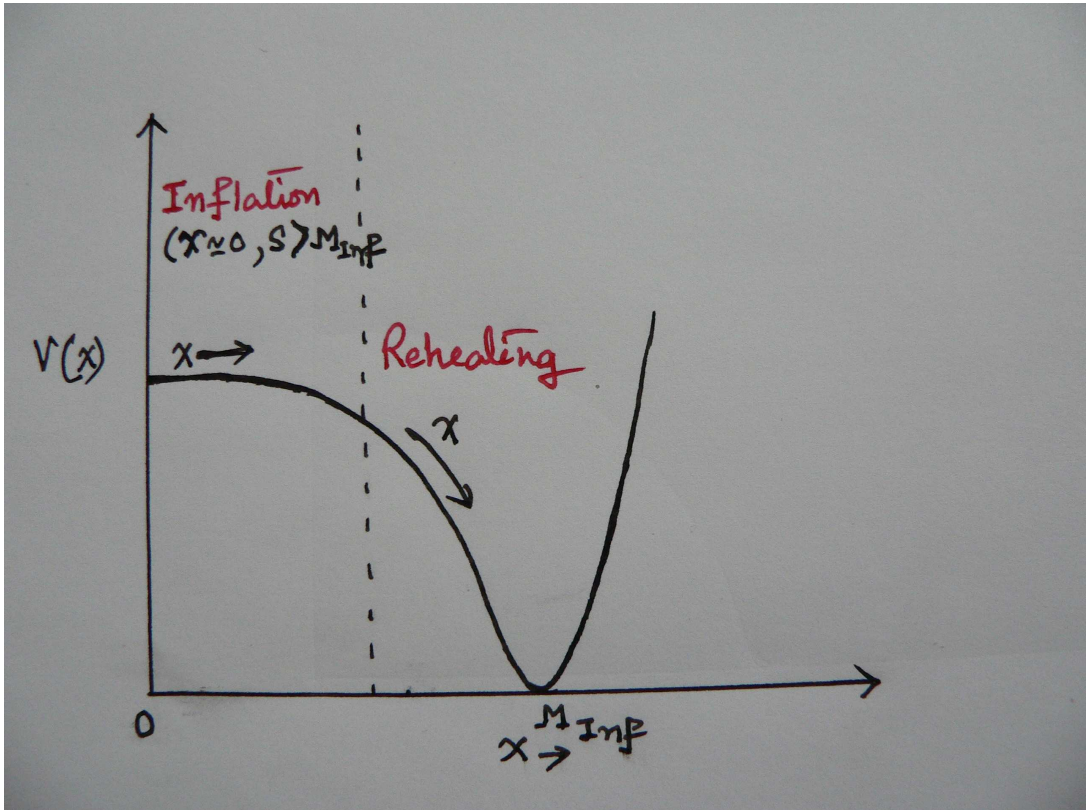
$$\mu^2 = \frac{\Lambda}{M_P} M_{\text{Inf}}^2.$$

- To discuss (b) we need to understand the inflationary dynamics in brief.

Inflation

$$V = k^2|\chi^2 - M_{\rm Inf}^2|^2 + 4|\chi|^2(k^2|S|^2 + |Q\tilde{Q}|^2/M_P^2)$$

- $S > M_{\rm Inf}$, and $\chi = 0 \rightarrow$
  Inflation with Vac. Energy $\sim k^2 M_{\rm Inf}^4$
- SUSY Minimum: $\langle S \rangle = 0$; $\langle \chi \rangle = M_{\rm Inf}$



- Slow roll :

  The inclination over the inflationary valley is provided by the Coleman-Weinberg correction to the scalar potential

- Estimate of $\frac{\delta T}{T} \sim 10^{-5}$, spectral index n_s in the right range:
  set $\sqrt{k} M_{Inf} \simeq (10^{13} - 10^{15})$ GeV

- End of Inflation:

  when $S_c > M_{\rm Inf}$, the mass term of χ becomes negative, and the system ends up in the supersymmetric minimum.

Why we should be at the metastable vacuum?

- During Inflation:
  $Q, \tilde{Q}$ acquire positive mass square terms $\sim H^2$
  ($H^2 = k^2 M_{\rm Inf}^4 / 3M_P^2$) from supergravity corrections,
  and thereby they settle at the origin.

  (assuming canonical Kahler potential)

- After Inflation:
  As $Q = \tilde{Q} = 0$ happens to coincide with the location
  of the false minimum ($\Phi = 0$), it is possible that the field
  remains stranded there even after inflation is over. Thus provides a
  natural solution to (b).

- Ensure Metastability:
  $S_{bounce} = \frac{2\pi^2}{3} \frac{N^3}{N_f^2} \left(\frac{\langle\Phi\rangle}{\mu}\right)^4 \simeq \frac{1}{(\frac{\mu}{\Lambda})^{4(N_f - 3N)/(N_f - N)}} \gg 1,$
  $\text{for} \mu \ll \Lambda.$

- Possible constraints over mass scales μ, Λ:

  (1) metastability condition:

  $\mu \ll \Lambda$ to preserve the ISS vacuum,

  (2) supersymmetry mediation condition:

  $m_{\rm susy} M_P \simeq F_{sugra} \geq F_{ISS} = \mu^2$.

- $k = O(10^{-2}), g = O(10^{-1} - 10^{-2}), \mu = O(10^{12}\ {\rm GeV})$ and $\Lambda = O(10^{14}\ {\rm GeV})$.

Further Developments

- In the original version of the ISS model, R-symmetry breaking needs to be included – so the model has to be modified.
- Whether combination of Inflation and susy breaking can accommodate the gauge mediation.

Following S. Abel *et al.* PLB 661, 201 (2008); the deformed ISS superpotential (in the dual magnetic description) is described by,

$$W_{dISS} = q_i \Phi_{ij} \tilde{q}_j - \mu_{ij}^2 \Phi_{ji} + W_{dyn} + m\epsilon_{ab}\epsilon_{rs} q_r^a q_s^b$$

with $N_f = 7$ and $N_c = 5$, where $i, j = 1, ..7, r, s = 1, 2$ are flavor indices; and $a, b = 1, 2$ are magnetic color indices.

- The flavor group $SU_f(7) \to SU_f(2) \times SU_f(5)$;
  $SU_f(5)$ can be gauged and identified with the $SU(5)$ GUT of the MSSM.
- Quarks charged under $SU_f(5)$ will act as messengers.
- μ^2 can be brought into diagonal form, $\mu^2 = \mathrm{diag}(\mu_2^2 \mathrm{I}_2, \mu_5^2 \mathrm{I}_5)$;
  $m \sim \Lambda^3 / M_{PL}^2$ (from $W_{el} = \frac{1}{M_{PL}^2} QQQQQ$).

  Then minimization of the potential shows:

- $\langle\Phi\rangle \neq 0$, R-sym is broken, giving mass to gauginos
- $\mu_2 \sim \mu_5 \simeq m \sim 10^{7-8}$ GeV (Gauge mediation)

Our goal is to provide a mechanism to generate these parameters.

Inflation Sector: SQCD Model

Represented by a strongly coupled supersymmetric $SU(\mathcal{N})$ gauge group with $\mathcal{N}_f = \mathcal{N}$ flavors of quark superfields $\mathcal{Q}_i$ and $\bar{\mathcal{Q}}_i$ $(i = 1, \ldots \mathcal{N}_f)$ in the $\mathcal{N}$ and $\bar{\mathcal{N}}$ representations of the gauge group.

Below the scale Λ_0, the theory (with $\mathcal{N}_f = \mathcal{N} = 4$) is described by an effective theory of composite mesons, baryon and anti-baryon

$T_{ij} = \frac{1}{2}\Lambda_0^{-1}\mathcal{Q}_i^a\bar{\mathcal{Q}}_i^a$, $B = \frac{1}{3}\Lambda_0^{-3}\epsilon_{ijkl}\mathcal{Q}_i^1\mathcal{Q}_j^2\mathcal{Q}_k^3\mathcal{Q}_\ell^4;\ \ \bar{B} = \frac{1}{3}\Lambda_0^{-3}\epsilon_{1234}\bar{\mathcal{Q}}_i^1\bar{\mathcal{Q}}_j^2\bar{\mathcal{Q}}_k^3\bar{\mathcal{Q}}_l^4$

respectively, with the superpotential

$$W = S\left(\frac{\det T}{\Lambda_0^2} - B\bar{B} - \Lambda_{eff}^2\right).$$

In the so-called meson branch of the theory (i.e. with $B=\bar{B}=0$), the superpotential can be redefined as

$W_{Infl} = S\left(\frac{\chi^4}{\Lambda_0^2} - \Lambda_{eff}^2\right)$, (replacing $\det T = \chi^4$)

which has a supersymmetric vacuum at $\langle\chi\rangle = (\Lambda_{eff}\Lambda_0)^{1/2}, \;\; S=0.$

(Identical with the supersymmetric smooth hybrid inflationary potential)

[earlier ref. for SQCD inflation, Dimopoulos, Dvali, Rattazzi, PLB410 (1997) 119]

The above potential can be obtained also by considering $\mathcal{N}_f = \mathcal{N}+1$ SQCD and with an additional quark mass term

$W = \mathrm{Tr}\hat{m}\mathcal{Q}\bar{\mathcal{Q}} \qquad (\hat{m} = \mathrm{diag}(0,0,0,0,m_Q))$

so that $\Lambda_{eff}^2 = m_Q\Lambda_0$.

The generation of the DSSB scale from its gravitational coupling to the inflation sector:

- The lowest dimensional UV term which respects $U(1)_R$ and the other chiral $SU(4)\otimes SU(4)$ flavor symmetries in the inflation sector is given by

  $W_{int} = \frac{\det \mathcal{Q}\bar{\mathcal{Q}}}{M_P^7}\mathrm{Tr} fQ\tilde{Q} \quad \longrightarrow \quad \frac{\Lambda_0^4\Lambda}{M_{PL}^7}\det\mathrm{T}\,\mathrm{Tr}\Phi = \mu^2\mathrm{Tr}\Phi.$

Phenomenological aspects of the scenario

- Right amount of gauge mediation and inflationary requirements (consistent with WMAP5 data) indicate:
  $\mu \sim 10^8$ GeV, $\Lambda_0 \sim 7 \times 10^{16}$ GeV, $m_Q \sim 4 \times 10^{12}$ GeV, $\Lambda \sim 10^{15}$ GeV.
- Reheating via ISS mediation: we see that the inflaton can decay into the magnetic quarks $q, \tilde{q}$ of the dISS sector,
  $V \supset |\frac{\partial W}{\partial \Phi}|^2 = |q\tilde{q} + f_{2,5}\frac{\chi^4 \Lambda_0^4}{M_P^7}\Lambda|^2$.
  Since part of these $q, \tilde{q}$ are charged under $SU(5)$ of MSSM after gauging, the particular decay mode $\chi \to q\tilde{q}$ is instrumental for the production of MSSM particles.
  Reheat Temperature: $T_R \simeq$ 100 GeV - 1 TeV.
- Problem with pseudo-NGB: can be cured by adding explicit mass terms ($m_{\rm x} \ll m_Q$) breaking chiral symmetry explicitly.

Conclusions

- Natural solution to (a) and (b).
- The susy breaking scale is related to the inflationary scale and it is in the range of gravity/gauge mediation depending upon the type of inflations.
- We have introduced a new SQCD model of inflation.
- This setup contains a single dimensionful parameter in the form of a quark mass term in the inflationary sector, i.e. all other scales involved are either related to this single mass parameter or dynamically generated.
- R-symmetry breaking is introduced.