# Cosmological Vacuum Selection and Metastable Supersymmetry Breaking

Based on the **arXiv:1001.4106**
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- Gauge Mediation models are considered compelling candidates for the UV completion of the MSSM. So we consider:

  *Hidden Sector + Messengers +Visible Sector*

- According to *Nelson and Seiberg* the theory should possess an R-symmetry in order to obtain supersymmetry breaking:

  *+ $U(1)_R$ symmetry*

- The gauge mediated susy breaking vacuum is likely to be metastable -usually because of the messenger structure. According to *Intriligator, Shih and Seiberg R-symmetry* arguments also support metastability (in the IR) in model building. In *ISS* model it was shown that metastable susy minima are indeed generic:

  *+ metastability*

- Considering a theory of low scale susy breaking it is natural to expect corrections to the Kahler potential originating from the UV theory:

  *+ general Kahler potential*

**Therefore, the theory considered is the following**:

$$W = \mu^2 S + (\lambda_{ij} S + m_{ij}) q_i \bar{q}_j \equiv \mu^2 S + \mathcal{M}_{ij} q_i \bar{q}_j$$

$$K = |S|^2 \mp \frac{|S|^4}{\Lambda_1^2} - \frac{|S|^6}{\Lambda_2^4} + \sum_i \left(|q_i|^2 + |\bar{q}_i|^2\right)$$

Where $S = \langle S \rangle + \theta^2 F$

According to *Cheung, Fitzpatrick and Shih* we can make the classification

1. $\det m \neq 0$ and $\det \lambda = 0$ Type I

2. $\det m = 0$ and $\det \lambda \neq 0$ Type II

The fact that the leading order gaugino masses are proportional to

$$m_{1/2} \propto \partial_S \ln \det \mathcal{M}$$

If matrix ***m*** is full rank then *R-symmetry* renders the matrix ***M*** to be ***S***-independent.

• This makes the *type II* models of special phenomenological interest.

**<u>We consider type II models that seem to be thermally disfavored and examine their possible evolution in the early universe.</u>**

- The simplest case is

$$W = \mu^2 S - \lambda S q\bar{q} + c$$

$$K = |S|^2 \mp \frac{|S|^4}{\Lambda_1^2} - \frac{|S|^6}{\Lambda_2^4} + |q|^2 + |\bar{q}|^2$$

- The *susy breaking metastable vacuum is created by gravity and/or quantum corrections.*

- Firstly, we examine the *thermal evolution* of this model:

$$\bar{V}_1^T(\phi_c) = \frac{T^4}{2\pi^2}\int_0^\infty dy y^2 \left\{ \sum_i \ln\left[1 - \exp\left(-\sqrt{y^2 + (M_S^2)_i/T^2}\right)\right] + \dots\right.$$

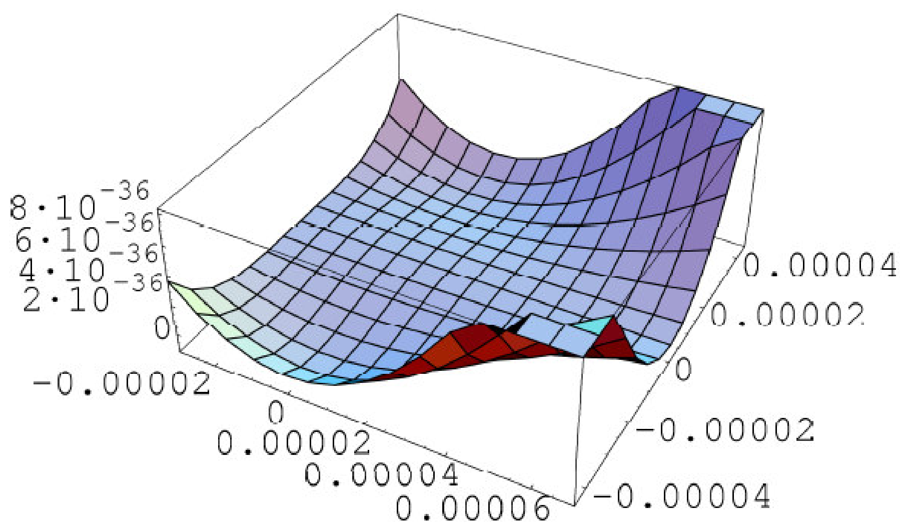
We find a 2nd order phase transition to susy vacua at $T_{cr} \cong 2\frac{\mu}{\sqrt{\lambda}}$

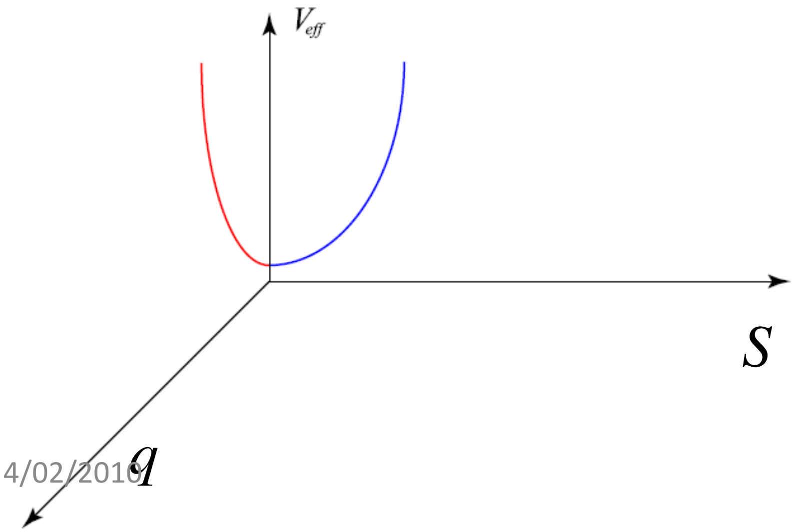
but *also* $T_S^2 \sim \frac{c\mu}{\sqrt{\lambda^3}}$ when the susy breaking vacuum becomes *(meta)stable.*

| $K = \lvert S\rvert^2 \mp \frac{\lvert S\rvert^4}{\Lambda_1^2} - \frac{\lvert S\rvert^6}{\Lambda_2^4}$ | Metastable Vacuum $\langle S \rangle$ | $\Lambda_1$ | $\Lambda_2$ | $\lambda$ |
|---|---|---|---|---|
| 1. $(-)$, $\Lambda_2 = \Lambda_1 \equiv \Lambda$ | $S \sim \Lambda^2$ | $\Lambda > 10^{-14/3}$ | - | $\lambda < \Lambda$ |
| 2. $(+)$, $\Lambda_1^{3/2} < \Lambda_2$ | $S \sim \pm \frac{\Lambda_2^2}{\Lambda_1}$ | $\Lambda_1 > \Lambda_2$ | $\Lambda_2 > 10^{-7} \left( \frac{\Lambda_1^{3/2}}{\Lambda_2} \right)$ | $\lambda < \left( \frac{\Lambda_2}{\Lambda_1} \right)^2$ |
| 3. $(+)$, $\Lambda_1^{3/2} > \Lambda_2$ | $S \sim \Lambda_2^{4/3}$ | $\Lambda_1 > \Lambda_2$ | $\Lambda_2 > 10^{-7}$ | $\lambda < \Lambda_2^{2/3}$ |

Table 1: *Zero temperature vacuum stability constraints*

$$\mu^2 = \left( \frac{\alpha}{4\pi} \right)^{-1} m_{\text{gaugino}} \langle S \rangle \simeq 10^{-14} \Lambda^2$$



## Initial Conditions?

- Gravitational particle production during an inflationary phase for 'light' scalar fields

$$Q_I = S_0 \sim H_I$$

- There may be a coupling to the inflaton in the superpotential:

$$W = W_I\left(1 - \xi Q_I S + \ldots\right)$$

or to the Kahler potential: $\delta K = -q^\dagger q I^\dagger I$

*It is natural to expect that the fields are displaced from the zero temperature minmum.*

## Thermalization?

- We expect messengers to be in thermal equilibrium until temperatures $T_q \sim m_q/20$
- Hence there is a *thermal induced mass* on the spurion: $\lambda^2|S|^2\langle|q|^2\rangle_T \sim \lambda^2|S|^2T^2$
- The spurion is out of equilibrium:

$$\Gamma_{int} =< \sigma v n >_T \sim \frac{\lambda^4\alpha^2}{16\pi^2}T$$ cannot 'catch' the Hubble rate.

**When the Susy breaking Metastable Vacuum can be realized?**

1) $\Lambda^2 \leq S_{initial} < \Lambda$

2) *The spurion must not be driven to the origin by thermal corrections.*

- It is believed that the only way out is to allow a reheating temperature lower than the mass of messengers: $T_{rh} < m_q \approx \lambda \langle S \rangle$

- However this requirement cannot justify localization of messengers to the origin.

- A way out is to require $m_q < T_{rh} < T_S$

Thus, the susy breaking vacuum *has formed* and the *messengers are thermalized*.

- Also, if $\lambda < T_S$ then the reheating temperature can be arbitrary large. This comes from the observation that the spurion rolls down only when $H \sim m_S(T)$ This can be seen from the e.o.m.:

$$\ddot{S} + 3\sqrt{g_*}T^2(t)\dot{S} + \lambda^2 T^2(t) S \approx 0$$

- We require: $$\frac{m_{3/2}}{m_{\text{gaugino}}} = \frac{4\pi}{\alpha\sqrt{3}}\frac{\langle S\rangle}{M_{Pl}} < \mathcal{O}(10\%)$$

| $K = \lvert S\rvert^2 \mp \frac{\lvert S\rvert^4}{\Lambda_1^2} - \frac{\lvert S\rvert^6}{\Lambda_2^4}$ | $\Lambda_1$ | $\Lambda_2$ | $\lambda$ |
|---|---|---|---|
| 1. $(-)$, $\Lambda_2 = \Lambda_1 \equiv \Lambda$ | $Q_I < \Lambda \leq 10^{-2}$ | $-$ | $\lambda < \Lambda$ |
| 2. $(+)$, $\Lambda_1^{3/2} < \Lambda_2$ | $\Lambda_1 > \Lambda_2$ | $Q_I < \Lambda_2 \leq \left(10^{-4}\Lambda_1\right)^{1/2}$ | $\lambda < \left(\frac{\Lambda_2}{\Lambda_1}\right)^2$ |
| 3. $(+)$, $\Lambda_1^{3/2} > \Lambda_2$ | $\Lambda_1 > \Lambda_2$ | $Q_I < \Lambda_2 \leq 10^{-3}$ | $\lambda < \Lambda_2^{2/3}$ |

Table 2: *Combined constraints coming from zero temperature vacuum stability, cosmological considerations and gauge domination over gravity.*

| $(\Lambda, \lambda)$ | $m_q$ | $T_S$ | $T_{rh}$ |
|---|---|---|---|
| $(10^{-2}, 10^{-7})$ | $10^{-9}$ | $10^{-8.25}$ | $10^{-9} < T_{rh} < 10^{-8.25}$ |
| $(10^{-2}, 10^{-8})$ | $10^{-10}$ | $10^{-7.5}$ | $10^{-10} < T_{rh}$ |
| $(10^{-2}, 10^{-9})$ | $10^{-11}$ | $10^{-6.75}$ | $10^{-11} < T_{rh}$ |
| $(10^{-2}, 10^{-10})$ | $10^{-12}$ | $10^{-6}$ | $10^{-12} < T_{rh}$ |
| $(10^{-3}, 10^{-7})$ | $10^{-10}$ | $10^{-9.75}$ | $10^{-10} < T_{rh} < 10^{-9.75}$ |
| $(10^{-3}, 10^{-8})$ | $10^{-11}$ | $10^{-9}$ | $10^{-11} < T_{rh} < 10^{-9}$ |

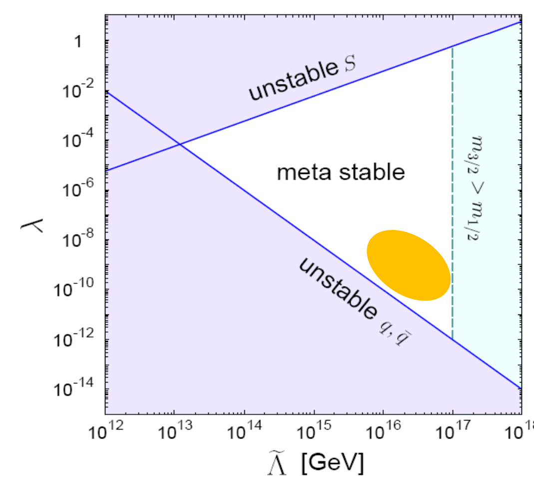



Table 3: *The (conservative) range of values of the reheating temperature that could result in the selection of the susy breaking vacuum by the system of fields.*

## Breaking R-symmetry

- It is unlikely that any fundamental theory exhibits continuous symmetries. The *R-symmetry* of the O'R models should be approximate. The continuous *R-symmetry* might be a consequence of a discrete *R-symmetry*.

- We include explicit *mass term* *M for messengers*:

$$W = \mu^2 S - \lambda S q\bar{q} \pm M q\bar{q} + c$$

- In the global susy the theory has a global minimum at

$$S = \mp\frac{M}{\lambda}, \quad q\bar{q} = \frac{\mu^2}{\lambda}$$

- And a susy breaking minimum $S = q = \bar{q} = 0$

- But *including gravity* the metastable minimum is shifted to $S \approx c\Lambda^2/(2\mu^2)$

- Moreover the thermal evolution of the models is similar: The susy breaking vacuum seems to be disfavored.

## Including the MSSM sector

• The next step is to consider the other sectors: Low energy Visible Sector and other fields (moduli,…) of the non-susy breaking Hidden Sector.

• Including the MSSM the superpotential reads

***W= W(Hidden sector + messenger sector) + MSSM(GUT)superpotential.***

• The MSSM fields *enhance the thermal induced mass on the messenger fields*. This fact reduces the critical temperature of the second order phase transition.

$$T_{cr} = \frac{\mu}{\sqrt{\lambda}} \quad \rightarrow \quad T_{cr} = \frac{\mu}{\sqrt{\lambda}} \frac{\lambda}{\tilde{\lambda}}$$

•It is possible then the system of the fields to evolve to the susy breaking vacuum even in the case that the fields are localized in the origin. This would result in a natural solution to the problem of the selection of the phenomenological favorable vacuum.

## Conclusions

- The phenomenologically favorable models of O'R type metastable susy breaking vacua were generally considered cosmologically disfavored. It was believed that the only way out was to consider a non thermal evolution of the fields with unjustified assumptions about the initial VEVs of messenger fields.

- We presented that for a specific range of parameters the susy breaking vacua can be cosmological favorable even in the case of a thermalized susy breaking/mediation sector.