Moduli stabilization, uplifting and low-energy physics

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work with

S. Vempati, Nucl.Phys.B727:139-162,2005 , Y. Mambrini, JHEP 0610:044,2006

C. Papineau and S. Pokorski, JHEP 0702:028,2007

and

Y. Mambrini,S. Pokorski and A. Romagnoni (in progress)

Outline

- Moduli stabilization and uplifting
- Gauge ("D- term") uplifting
- Dynamical F-term SUSY breaking and uplifting
- Phenomenological consequences
- Generalized case : New SUSY spectra ?
- Conclusions and Perspectives

1. Moduli stabilization and uplifing

KKLT ideology :

- add all possible 3-form fluxes : stabilize all but the volume (Kahler) T_i moduli in type IIB strings
- add non-perturbative effects to stabilize T_i

$$W = W_0 + a\, e^{-bT}$$

$\rightarrow$ end up in anti-de Sitter SUSY space

- " Uplift " vacuum energy to zero by an explicit (non-linear susy) source of SUSY breaking (antibranes)

A manifestly (linear) SUSY formulation is preferable. There are two generic possibilities : gauge ($U(1)$ or "D-term") and matter (F-term)

2. Gauge ("D- term") uplifting

(see also Villadoro-Zwirner, Casas et coll, Choi et coll.)
Add a magnetic flux on a D7 brane which wraps an internal 4-space of volume $\mathcal{V} = T + \bar{T}$ (Burgess,Kallosh,Quevedo)

$$\int d^8x \sqrt{g_8} F_{ij} F^{ij} \rightarrow \frac{c}{(T+\bar{T})^3} \quad = \quad V_{uplift}$$

By doing this, the axionic partner of $\mathcal{V}$, $T = \mathcal{V} + ia$, becomes charged under gauge transformations of the " magnetized"' brane

$$V_X \rightarrow V_X + \Lambda + \bar{\Lambda} \quad , \quad T \rightarrow T + \delta_{GS} \Lambda \ .$$

But... in this case the gaugino condensation term e^{-bT} is not gauge-invariant $\leftrightarrow$ hidden sector must contain charged matter fields $Q, \bar{Q}$, which condense into "mesons" $M = Q\bar{Q}$

Gauge ("D- term") uplifting :cont.

$$W = W_0 + a\left(\frac{e^{-bT}}{detM}\right)^{\frac{1}{N_c - N_f}} + (\frac{\Phi}{M_P})^{q+\tilde{q}}M$$

An anomaly analysis shows that the nonperturbative term is precisely gauge invariant. The gauge (D-term) vacuum energy is now

$$V_D \sim \frac{1}{T+\bar{T}}\left(-|\Phi|^2 + Tr(\bar{M}M)^{1/2} + \frac{3\delta_{GS}}{2(T+\bar{T})}\right)^2$$

The total vacuum energy is

$$V = |F|^2 + \frac{1}{2}D^2 - 3m_{3/2}^2 M_P^2$$

Gauge ("D- term") uplifting :cont.

For $\delta_{GS} > 0 \longrightarrow$ the field Φ gets a vev and compensate (rather) efficiently the "magnetic" vacuum energy. We get :

$$F \sim m_{3/2} M_P \quad , \quad D \sim m_{3/2}^2$$

$$V_0 \sim -m_{3/2}^2 \delta_{GS} + m_{3/2}^4$$

Uplifting works only for $m_{3/2}^2 \sim \delta_{GS}$. Natural values of $\delta_{GS} \sim (10^{-2} - 10^{-3}) M_P^2$ imply high-scale SUSY.

3. F-term breaking and uplifting

(Gomez-Reino-Scrucca, Lebedev-Nilles-Ratz, DPR, Abe et al., Kallosh-Linde)
Main problem with D-term uplifting and TeV gravitino mass is a natural way to get

$$D \sim m_{3/2} M_P \sim (10^{11} GeV)^2$$

A (maybe) simpler possibility is to use a sector, coupling only gravitationally to the KKLT sector, which dynamically breaks SUSY by F-terms in the global limit. Then

$$V_{uplift} \sim \Lambda_{dyn}^4 \sim 3 m_{3/2}^2 M_P^2$$

could lead to a TeV gravitino mass.
One example we studied is ISS-KKLT

F-term breaking and uplifting : cont.

$$W = W_0 + ae^{-bT} + W_{ISS} \ ,$$
$$K = -3\ln(T+\bar{T}) + K_{ISS}$$

We find that :

• F^T contribution to SUSY breaking is small.

• cosmological constant uplift is realized by "mesons" N of the dynamical sector $|F^N|^2 \simeq 3m_{3/2}^2 M_P^2$.

• Up to now, all minima of this type we found are metastable, but the lifetime can be made very large.

• String realization ? Not known. Plausible starting point:

- D7 branes : nonperturbative KKLT superpot. Some D7 brane positions are the mesons of the ISS model
- D3 branes : ISS gauge group. (Anti)quarks from the D7-D3 strings (Uranga and coll.).

4. Phenomenological remarks

(see also Lebedev,Mambrini,Nilles,Ratz)
In previous studied with explicit SUSY breaking (non-linear SUSY) by Choi, Nilles et coll, it was found a (moderate) hierarchy

$$m_T \sim 4\pi^2 m_{3/2} \sim (4\pi^2)^2 m_{soft}$$

where m_{soft} are soft terms in the observable sector.
In our dynamical F-term examples we find situations closer to Gravity Mediated SUSY breaking $\rightarrow$
Soft masses in the observable (MSSM) sector depend on the strength of the couplings of SM fields to the hidden mesons N :

Phenomenological remarks :cont

i) small couplings to hidden mesons :

$$\begin{aligned} \text{scalars} \ &: m_{0,soft} \ = \ m_{3/2} \ (\text{universal}) \\ \text{gauginos} \ &: m_{1/2} \ \sim (\frac{1}{T+\bar{T}}) m_{0,soft} \ll m_{3/2} \\ \text{A}-\text{terms} &: A_{ijk} \ = \ 3 m_{3/2} \lambda_{ijk} \end{aligned}$$

The FCNC effects are highly suppressed, light gauginos.
ii) large and flavor-violating couplings to hidden mesons :

$$\begin{aligned} \text{scalars} \ &: m_{0,soft} \ \sim m_{3/2} (\text{non}-\text{universal}) \\ \text{gauginos} \ &: m_{1/2} \ \ll m_{3/2} \ \text{or} \ m_{1/2} \ \sim m_{3/2} \\ \text{A}-\text{terms} &: A_{ijk} \ \sim \ m_{3/2} \end{aligned}$$

A-terms not proportional to Yukawas, large FCNC effects.

5. New SUSY spectra ?(DMPR,in progress)

It is expected to be possible to have Hybrid models with D and F-terms, of Fayet-Iliopoulos type, with modulus-dependent FI term.

$$F_\chi \sim m_{3/2} M_P \quad , \quad m_{3/2}^2 \ll D \ll m_{3/2} M_P$$

F-terms provide uplifting with $m_{3/2} \sim TeV$. Assume SM fields are neutral wrt $U(1)_X$ (otherwise $\rightarrow$ large soft masses). Mixed anomalies suggest additional fields charged under $U(1)_X$ and SM (say $5 + \bar{5}$) $M, \tilde{M}$, with $X_M = X_{\tilde{M}} = 1/2$ and $W = \Phi M \tilde{M} + \cdots$

In the "messenger" sector $Str M^2 > 0$.

Then there are 2-loop negative "gauge" contributions to the SM soft terms (Poppitz-Trivedi, 97).

New SUSY spectra ? cont.

Adding the supergravity F-term contributions

$$m_0^2 \;\sim\; m_{3/2}^2 - (\frac{g^2}{16\pi})^2 \ln(\Lambda/\langle\Phi\rangle) D$$

For gauginos, generically $M_{1/2} \sim F_T \ll m_{3/2}$.
At high-energy therefore

$$m_{\tilde{l}}^2 \;>\; m_{\tilde{q}} \;\gg\; M_{1/2}$$

At low energy it is possible in principle to get

$$m_{\tilde{l}}^2 \;\sim\; m_{\tilde{q}} \;\gg\; M_{1/2}$$

very different from mSUGRA or gauge mediation.

Conclusions and Perspectives

- D-term uplifting with $D \sim m_{3/2} M_P$ is hard to realize
- For F-uplifting, the flavor problem could be less severe than generic gravity mediation
- Mixed D and F-term scenario could be important to obtain a compressed spectrum of sparticles at low energy
- The important feature is not metastability, but the presence of a positive vacuum energy (SUSY breaking) in the $M_P \to \infty$ limit.