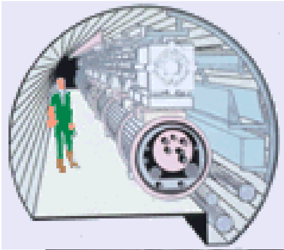

GAUGE MEDIATION AND STABILIZED MODULI

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LIVERPOOL '08

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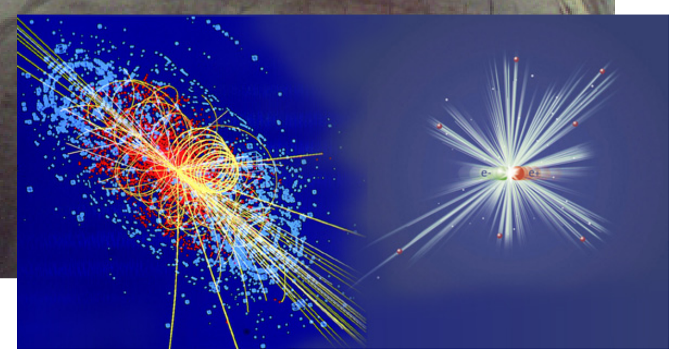


$$V = (K^{-1})^{i\bar{j}} F_i F_{\bar{j}} + \frac{1}{2} g^2 D^2$$

$$F_i = \frac{\partial W}{\partial \phi^i}, \; D = K'_j Q^j_k \phi^k$$

$$W = \mu^2 \phi + c \quad \rightarrow \quad F = \mu^2 \neq 0$$

$$V = e^K \left((K^{-1})^{i\bar{j}} F_i F_{\bar{j}} - 3|M|^2 \right) + \frac{1}{2} g^2 D^2$$

$$F_i = \frac{\partial W}{\partial \phi^i} + K'_i W, \; M = W$$

$$|c|^2 = \frac{\mu^4}{3} \quad \rightarrow \quad V_{min} = c.c. = 0$$

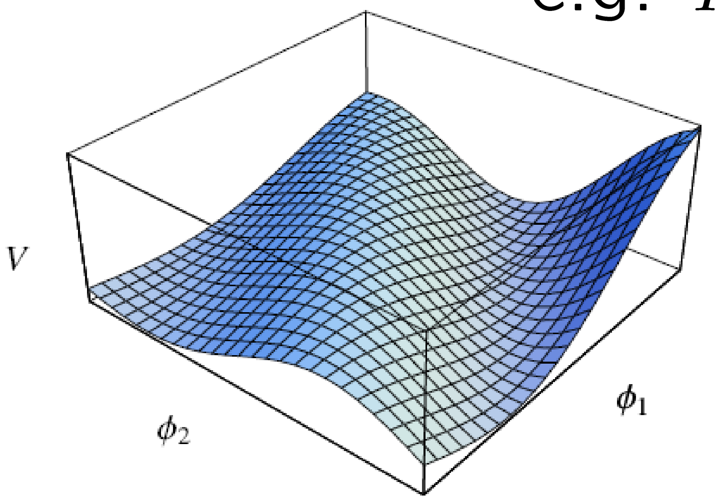
Spectrum of the model

- Chiral superfields, charged under the gauge group

$$\Phi = (\phi, \psi, F)$$

couplings ⟷ **expectation values of gauge-singlet fields**

e.g. $Re(S)F^2$



- Some of these fields have flat (or trivial) potentials at classical/perturbative level
- These flat directions are called **moduli**
- Examples: dilaton *S*: $< \mathrm{Re}(S) >= e^{\varphi}$

  volume modulus *T:* $< \mathrm{Re}(T) - |\Phi|^2 >= R^2$

- Many D-flat and F-flat directions in the space of charged fields, eg *LLe, udd* condensation + retrofitting

$$W_{LE} = W(T) + \mu^2(\Lambda_{dyn})X + \frac{1}{2}m(\Lambda_{dyn})X^2$$
$$+\lambda Qq + ...$$

supersymetry breakdown + inflation

$$m_{3/2} = \frac{F^X}{\sqrt{3}M_P}$$

$$m_{gaugino} = \frac{\alpha(m)}{4\pi}\frac{F^X}{<X>}$$

$$m_{scalar} = \frac{\alpha(m)}{4\pi}\boxed{\frac{\sqrt{3}M_P}{<X>}}m_{3/2}$$

$$\Rightarrow \quad m_{3/2,moduli} \ll m_{g,s}$$

- gauge mediation: suppression of flavour changing neutral currents
- but: light gravitino, problematic cc cancellation
- introduce moduli - can they play a similar role as in gravity mediation?
- gauge and gravity mediation - can one mix them in an arbitrary manner?
- or: to what extent the hidden sector actually needs to be separated from the observable sector?
- are messengers consistent with gravity mediation?

Kitano:

$$W = \mu^2 X - \lambda X Q q + c$$

$$K = \bar{X} X - \frac{(\bar{X} X)^2}{\tilde{\Lambda}^2} + \bar{q} q + \bar{Q} Q$$

$$\boxed{F^X = e^{K/2} \mu^2, \qquad \mu^2 = c/\sqrt{3}}$$

$$< X >= \frac{\sqrt{3}\tilde{\Lambda}^2}{6 M_P}, \;\; < Q >=< q >= 0$$

Polonyi:

$$< X >= \sqrt{3} - 1, \;\; < Q >=< q >= 0$$

$$\mu^2 = -(2 + \sqrt{3})\, c$$

Stability in the messenger sector

Kitano:

$$\frac{12\mu^2 M_P^2}{\tilde{\Lambda}^4} < \lambda < \frac{8\pi}{\sqrt{6N_q}}\frac{\tilde{\Lambda}^2}{M_P^2}$$

Polonyi:

$$\left|\frac{\lambda}{c}\right| > \frac{-2-3\sqrt{3}-\sqrt{15+4\sqrt{3}}}{4\left(-2+\sqrt{3}\right)} \approx 11.08$$

Vacua of microscopic O'R models

$$W_1 = \frac{\lambda}{\sqrt{2}} X \phi_1 \phi_2 + \frac{m}{\sqrt{2}} \phi_1 \phi_3 + \frac{1}{2\sqrt{2}} m_2 \phi_2^2 + f X + c$$

$$K_{\text{eff}} = \frac{m^2}{128\pi^2} \left[f_0(R, m^2/\Lambda^2) + f_2(R, m^2/\Lambda^2) a^2 + f_4(R) a^4 + f_6(R) a^6 + \mathcal{O}(a^8) \right]$$

$$a \equiv \lambda X/m \ \text{ and } \ R \equiv m_2/m$$

$$\begin{aligned}
f_0(R, m^2/\Lambda^2) &= (2 + R^2) \ln\left(\frac{m^2}{4\Lambda^2}\right) + R^2 \ln R^2 \\
f_2(R, m^2/\Lambda^2) &= -2 - 2\ln\left(\frac{m^2}{4\Lambda^2}\right) + \frac{2R^2}{R^2 - 1} \ln R^2 \\
f_4(R) &= \frac{1 + 2R^2 - 3R^4 + R^2(R^2 + 3) \ln R^2}{(R^2 - 1)^3} \\
f_6(R) &= -\frac{1 + 27R^2 - 9R^4 - 19R^6 + 6R^2(R^4 + 5R^2 + 2) \ln R^2}{3(R^2 - 1)^5}
\end{aligned}$$

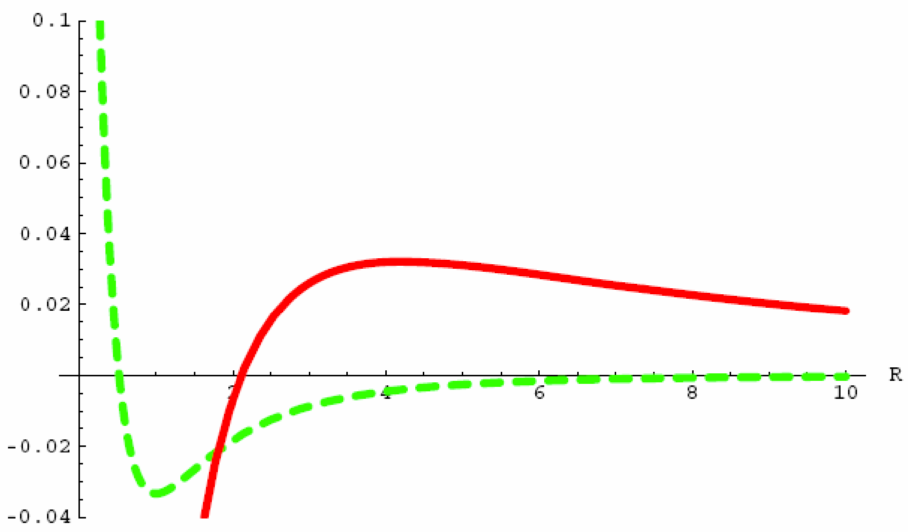


Figure 3: *Values of the coefficients f_4 and f_6 in the Kähler potential (67), solid and dashed lines, respectively.*

$$\tilde{\Lambda}^{-2} \equiv \lambda^4/(128\pi^2 m^2)\,|f_4(R)|$$

$R < 2.11$

$$X \approx \tilde{\Lambda}^2/\sqrt{12}$$

this assumes sugra

corrections null

$R > 2.11$

$$X^2 = -\frac{2f_4(R)}{9f_6(R)}\frac{m^2}{\lambda^2}$$

if: $$\tilde{\Lambda}^2 > (\lambda^2/48\sqrt{3}\pi^2)(f_4^2/|f_6|)$$

the term linear in X, sourced by sugra, becomes important, and :

$$X^3 = -\frac{V_1}{4V_4} = -\frac{128\pi^2}{9\sqrt{3}f_6(R)}\frac{m^4}{\lambda^6}$$

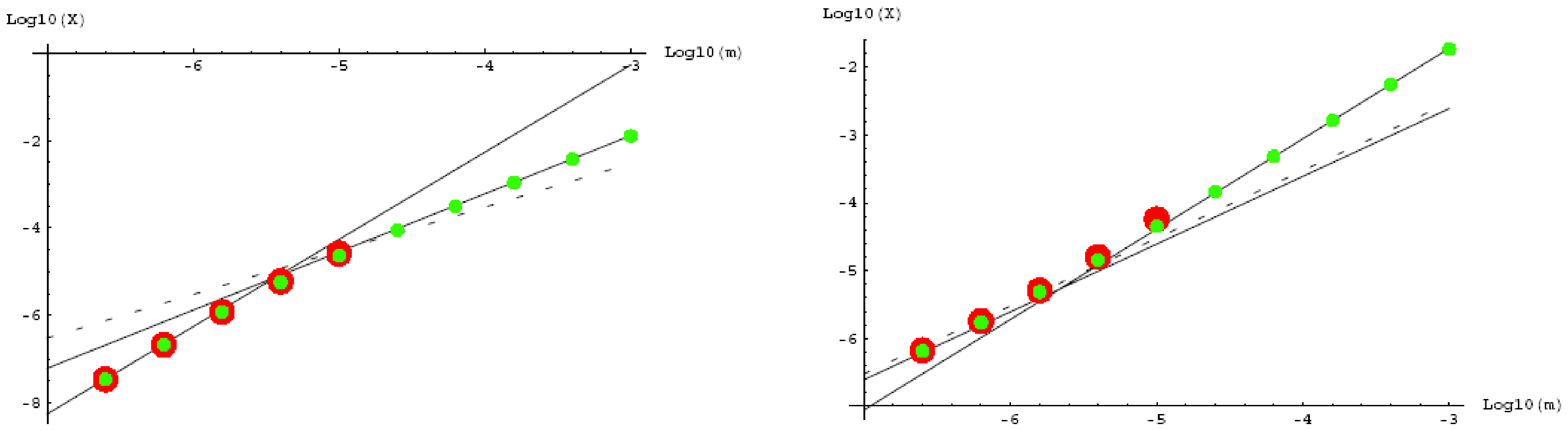


Figure 4: *Position of the minimum of the full supergravity potential for* $R = 1.5$ *(left panel) and* $R = 3$ *(right panel) shown as large red dots. Small green dots represent the results obtained with the use of the expansion (67). In the left panel, the approximate result (82) is shown as the steeper solid line and the the approximate result (85) as the less steep one. In the right panel, the approximate solutions (84) and (85) are shown as less and more steep solid lines, respectively. In both cases, the minimum with* $X \neq 0$ *does not exist if* m *is too large.*

Adding moduli

$$W = \mu^2 X - \lambda X Q q + A e^{-aT} + B$$

$x = aT$

$$m_{soft} = \frac{g^2}{16\pi^2}\frac{\mu^2}{\tilde{\Lambda}^2}\frac{a^{3/2}}{x^{3/2}} = \frac{g^2}{16\pi^2}\frac{\mu^2}{\tilde{\Lambda}^2}\frac{1}{(Nx)^{3/2}}$$

$N = 10,\ g^2 = 0.01$

request that $m_{soft} = \gamma\,\mathrm{TeV} = \gamma\,10^{-15}$

cc=0: $\frac{2}{\sqrt{3}}|A| x e^{-x} = \mu^2$

$$\tilde{\Lambda}^2 = 2 \times 10^9 \gamma^{-1} x^{-1/2} e^{-x}$$

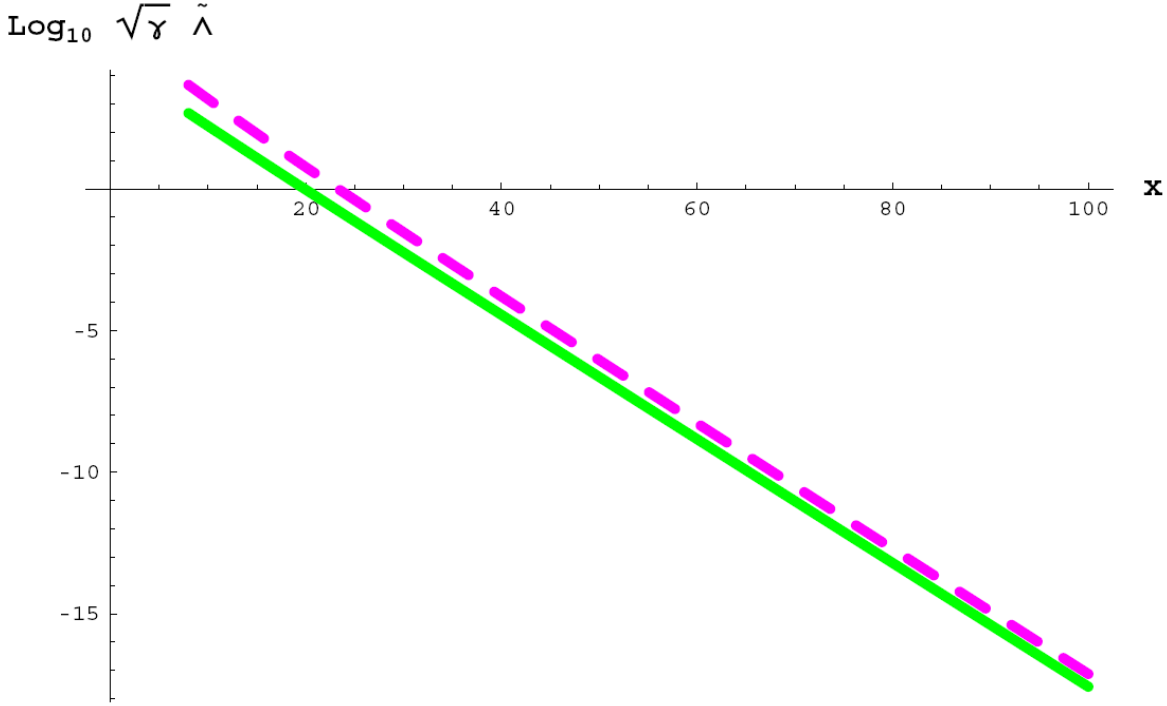


Figure 1: *Plot of* $\log_{10}(\sqrt{\gamma}\tilde{\Lambda})$ *as the function of* $x = T/N$. *The lower curve corresponds to a fixed value of* g^2, *and the upper (dashed) to* $g^2 = 8\pi^2 a/x$

gravitational contribution to scalar masses amounts to 10% and 30% of the gauge mediated contribution, one obtains
$\tilde{\Lambda} = 6\,10^{-3}\,M_P$ and $\tilde{\Lambda} = 10^{-2}\,M_P$ respectively

generic X

$$x = aT$$

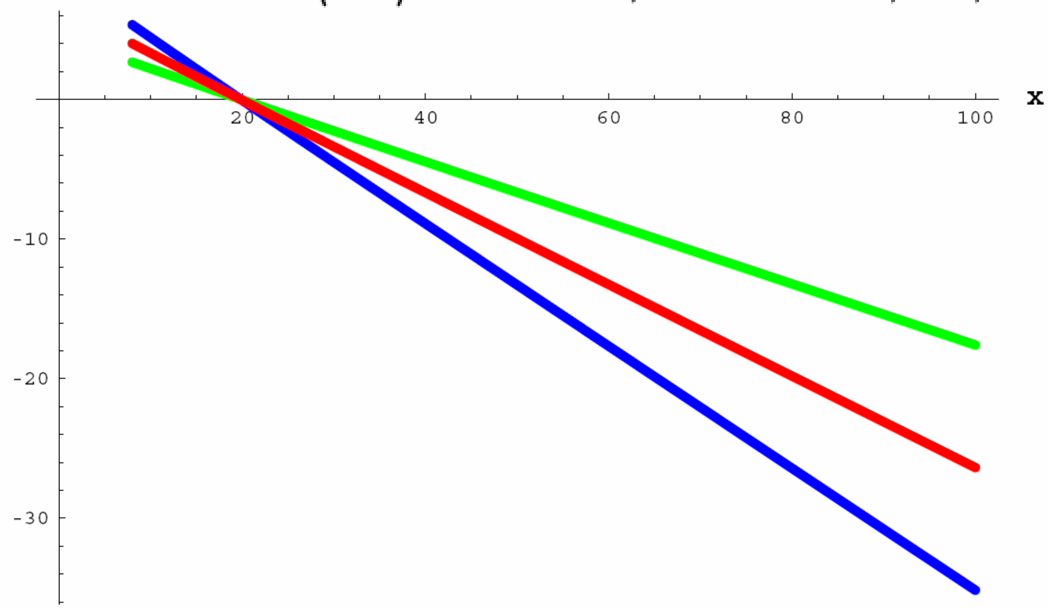
$$m_{soft} = \frac{g^2}{16\pi^2}\frac{\mu^2}{\langle X\rangle}\frac{a^{3/2}}{x^{3/2}} = \frac{g^2}{16\pi^2}\frac{\mu^2}{\langle X\rangle}\frac{1}{(Nx)^{3/2}}$$

request that $m_{soft} = 1\,\text{TeV} = 10^{-15}$

$$\langle X\rangle = 2\times 10^9 x^{-1/2} e^{-x}$$

$$\langle X\rangle = m^{\alpha},\ \ \alpha = 2,\, 1,\, 4/3$$

Log$_{10}$m



$\alpha = 2$

$\alpha = 4/3$

$\alpha = 1$

$$|F_X|/|F_T| \sim aT^2$$

$$m_T^2 \sim (4/3T^3)A^2a^4T^4e^{-2aT}$$

$$m_{\rm soft}^2/m_T^2 \sim 10^{-4}/(\tilde{\Lambda}^4(aT)^2)$$

A way out:

$$W_{npert} = ANe^{-T/N} - B(N+1)e^{-T/(N+1)} + \tilde{c}$$

$$W_{eff}(T) = \frac{\Delta}{2}(T - T_0)^2 + C$$

$$t_0 = N(N+1)\log\left(\frac{A}{B}\right), \ \Delta = \frac{A}{N}e^{-t_0/N}(1 - e^{-t_0/N^2})$$

no relation between t_0 and $\tilde{\lambda}$

but $t_0 \gg 1$ and cc cancellation $\rightarrow$ $F^T/F^X \ll 1$

$$m_T = \frac{\Delta}{2\sqrt{3t_0}}$$

cosmology:

$$m_T > 10\,\text{TeV} \rightarrow \Delta > 20\sqrt{3}\,\sqrt{t_0}\;\text{TeV}$$

Assuming $\Delta \gg \mu^2$ one obtains in the leading order a vanishing vacuum energy for $c \approx \mu^2/\sqrt{3}$ at $< z >= \frac{\sqrt{3}}{2}\mu^2/(T_0^2\Delta)$ and $< X >= \sqrt{3}/3M_P$.

The limit $\Delta \gg \mu^2$ can easily be fullfilled together with the requirement that the physical mass of the modulus should be cosmologically safe!

Messengers coupled to the modulus

$$\delta W = \lambda_T e^{-bT} Q q$$

$$T = \tilde{M} + \theta^2 F^T \quad \Longrightarrow \quad e^{-T} = e^{-\tilde{M}} \left(1 - \theta^2 F^T\right)$$

$$m_{g,s} = \frac{\alpha}{4\pi} \frac{(e^{-bT})_F}{(e^{-bT})_A} = \frac{\alpha}{4\pi}(-b) F^T$$

$$\boxed{m_{g,s} = \frac{\alpha}{4\pi} |bF^T| \ll \frac{F^X}{M_P} = m_{3/2}}$$

stability: $$\lambda_T > \frac{\left|\frac{\partial W}{\partial T}\right| b^2}{\left|e^{-bT}\right|}$$

single cond: $$\lambda_T > 10^{-2}|e^{(a-b)T}|$$

racetrack: $$\lambda_T > \frac{\Delta}{M_P^2}|\delta T|be^{bT}$$

Polonyi: $$\lambda_T > \frac{\mu^2}{M_P^2}b\frac{\sqrt{3}}{2}\frac{e^{bT_0}}{T_0}$$

$$T_0 b = 10: \ \mu/M_P < 10^{-5} \rightarrow m_{3/2} < 10^{-10}\,M_P$$

Multi-scale O'R

$$W = \mu^2 X - \lambda X Q q + \mu'^2 P + C(T)$$

$$K = \bar{X} X - \frac{(\bar{X} X)^2}{\tilde{\Lambda}^2} + \bar{P} P - \frac{(\bar{P} P)^2}{\tilde{\Lambda}'^2}$$

$\mu' > \mu$

$$s \approx \frac{1}{2\sqrt{3}} \frac{\mu'^2}{\mu^2} \tilde{\Lambda}^2, \quad C \approx \mu'^2 / \sqrt{3}$$

$$p \approx \frac{1}{2\sqrt{3}} \tilde{\Lambda}'^2$$

$$m_{grav} = \mu'^2$$

$$m_{soft} = \frac{g^2}{16\pi^2} \frac{m_{grav}}{\tilde{\Lambda}^2} \left(\frac{\mu}{\mu'} \right)^4$$

$K_{X\bar{X}} > 0 \rightarrow \frac{\mu'^2}{\mu^2} < \frac{\sqrt{3}}{\tilde{\Lambda}}$ ➡ any hierarchy for small $\tilde{\Lambda}$

SUMMARY

- Moduli decouple from O'Raifeartaigh susy breaking and the moduli sector serves as the cc cancellation mechanism.

- In the O'R models with gauge mediation it is very difficult to rise naturally and smoothly the gravitational contribution to the level of the gauge contribution

- With large raferton masses, one needs to include gravity effects in the O'R sector as gravitational terms linear in X become important

- The reason for F^X dominance is that due to CW in the leading order $F^X \neq 0$ while $F^T \approx 0$ due to the nature of the racetrack

- One can consider the scenario where it is the modular sector which is responsible for feeding supersymmetry breaking into the visible sector via the direct coupling to messengers. This solves the problem of light gravitini and light moduli even in the simple scheme with a single condensate