Moduli stabilization and mixed gauge-gravity mediation

Alberto Romagnoni

Laboratoire de Physique Théorique, Université Orsay-Paris Sud
Centre de Physique Théorique, École Polytechnique

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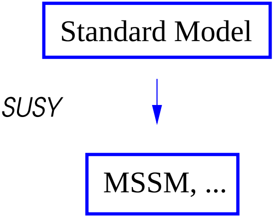
E. Dudas, Y. Mambrini, S. Pokorski, A.R.
JHEP 04 (2008) 015 [arXiv:0711.4934]

E. Dudas, Y. Mambrini, S. Pokorski, A.R. *work in progress*

Motivations and Ingredients

Standard Model

Motivations and Ingredients



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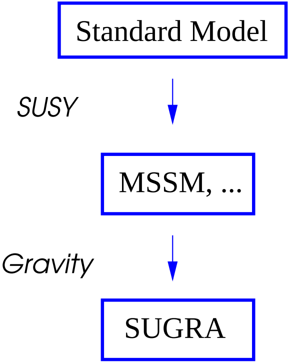

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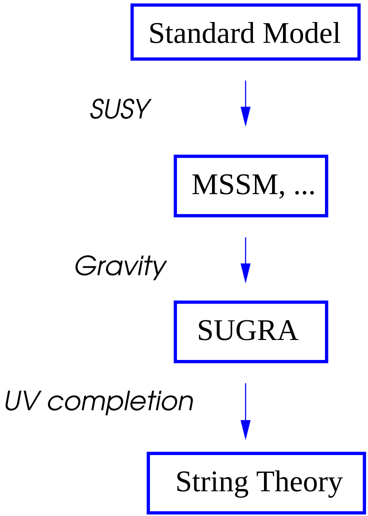

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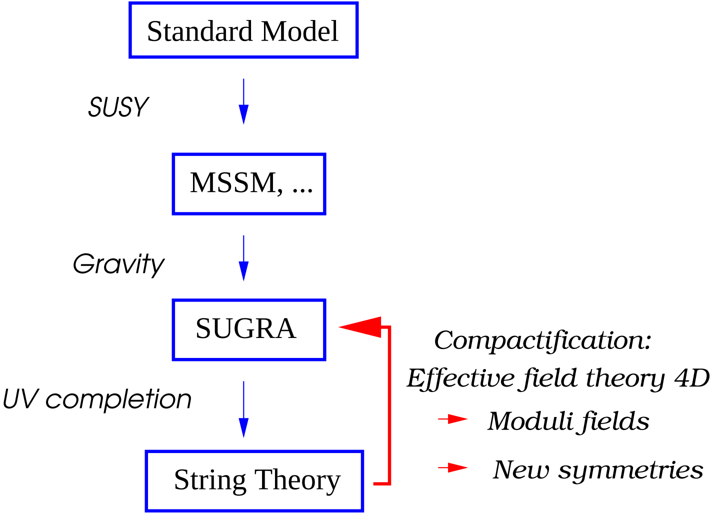

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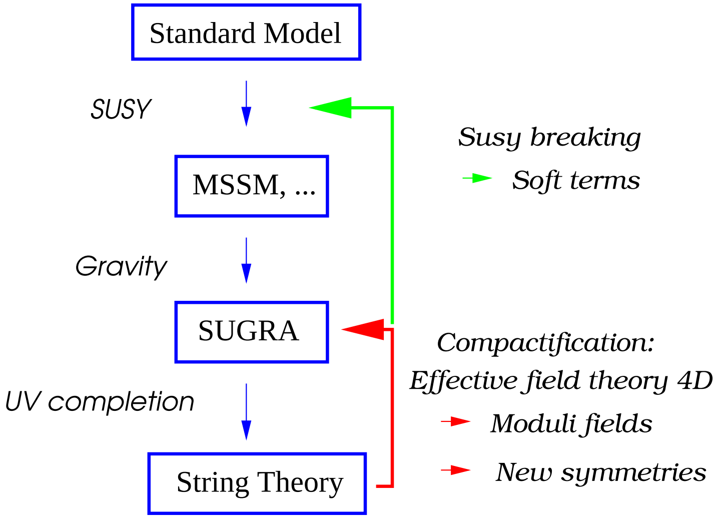

Motivations and Ingredients

Moduli

- Fields parametrizing "flat directions": there's no potential for them
- Their vev's are related to physical parameters
  $\longrightarrow$ they have to be taken into account and **stabilized**

New Symmetries

- New $U(1)_X$ gauge symmetries appear very naturally
- New charged fields Φ_i in the spectrum $\longrightarrow$ interplay in the game

Moduli problem: Main Ideas of KKLT model

Kachru, Kallosh, Linde, Trivedi, hep-th/0301240

General Framework

Type IIB 10D compactified on orientifold $\longrightarrow$ SUGRA in 4D

Three logical "steps"

1- Turn on magnetic fields **Giddings, Kachru, Polchinski, hep-th/0301240**
$\hookrightarrow$ All moduli stabilized, except "T" (overall volume)

2- Provide nonperturbative potential for T
$\hookrightarrow$ AdS vacuum ($\Lambda_c < 0$)

3- Uplift the vacuum energy adding $\overline{D3}-$branes **[KKLT]**
$\hookrightarrow$ Susy explicitely broken, not standard SUGRA

From the MSSM point of view

SUSY breaking in a new hidden sector
$\hookrightarrow$ soft terms for the MSSM masses & couplings

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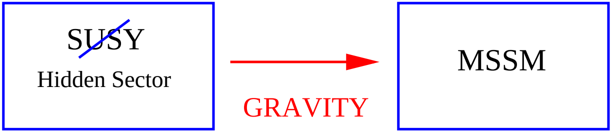

Other possibilities: stay in SUGRA & change step 3

Main ingredients for SUSY theories

- real Kahler potential: K $\longrightarrow$ kinetic terms
- holomorphic superpotential: W $\longrightarrow$ interaction terms

Auxiliary fields

- Scalar multiplets $\longrightarrow$ F
- Vector multiplets $\longrightarrow$ D

E.O.M.: F, D functions of the scalar fields depending on K & W

Scalar potential in SUGRA

$V \sim \Sigma \left(|F - terms|^2 + |D - terms|^2 \right) - 3|W|^2$

SUSY preserved if $F_i = D_i = 0 \; \longrightarrow \; \Lambda_c \sim -3|W|^2$

Other possibilities: stay in SUGRA & change step 3

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Scalar potential in SUGRA

$V \sim \Sigma \left(|F - terms|^2 + |D - terms|^2 \right) - 3|W|^2$

Idea: F_i and/or $D_i \neq 0$ $\longrightarrow$ uplift and spontaneous SUSY breaking

Adding an extra anomalous $\mathrm{U}(1)_X$

T charged under $\mathrm{U}(1)_X$

- it transforms as a Goldstone boson
- mass to $\mathrm{U}(1)_X$ gauge boson
- coupling depends on T $\rightarrow$ anomalies $\rightarrow$ G.-S. mechanism
- gauge invariance + SUSY + other fields
  - $\hookrightarrow$ Fayet-Iliopoulos term depending on T
  - $\hookrightarrow$ constraints for terms in the superpotential

More in details

$$K = -3\ln(T+\overline{T}) + |\Phi_+|^2 + |\Phi_-|^2 + K_{MSSM}$$
$$W = W_0 + e^{-bT}\Phi_-^q + m\,\Phi_+\Phi_-$$

$\hookrightarrow$ $V = e^K(|F_T|^2 + |F_+|^2 + |F_-|^2 - 3|W|^2) + g_T^2\,D^2$

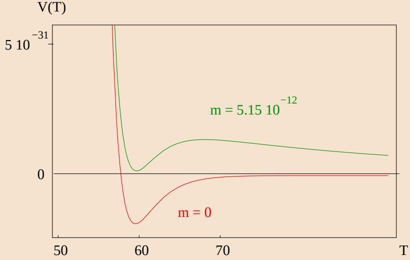
FI mechanism $\rightarrow$ spontaneous SUSY Breaking: $D, F_i \neq 0$

First Phenomenological Results

Uplift

Parameters in the superpotential fixed by some phenomenological requirements:

- $m_{3/2} \sim \frac{W}{M_P^2} \Rightarrow$ fix W_0
- Imposing $\Lambda_{cosm} = 0$ $\Rightarrow$ fix m



Soft terms by gravitational effects:

$m_{1/2} \sim \frac{F_T}{T}$ (if T couples to SM vector fields)

$m_0 \sim m_{3/2}$

Usually F_T is small.....here:

$m_{1/2} \lesssim m_0 \sim m_{3/2} \sim \text{TeV}$ $\quad D \sim (100\ \text{TeV})^2$

Anomalies & Gauge Messengers

If T couples to the SM gauge fields, since it is charged under $\mathrm{U}(1)_X$, its shift generates mixed $\mathrm{U}(1)_X - G_a^2$ anomalies

(G_a =SU(3), SU$(2)_L$, U$(1)_Y$)

$$\int d^2\theta \, T \, W_a^\alpha \, W_{\alpha\ a} \ \rightarrow \ Re[T] \, F_a^{\mu\nu} F_{\mu\nu\ a} + i \, Im[T] \, F_a^{\mu\nu} \, \widetilde{F}_{\mu\nu\ a}$$

Possibilities :

- MSSM fields charged under $\mathrm{U}(1)_X \Rightarrow$
  problems: large masses for squarks and sleptons $\sim \sqrt{D}$, tachyonic directions,...
- MSSM fields uncharged but additional fields $M, \widetilde{M}$

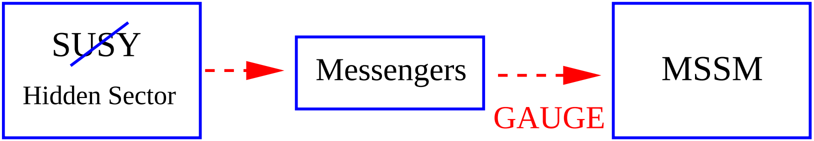
$M, \widetilde{M}$ "Messengers" fields introduced in Gauge Mediated Supersymmetry Breaking

Gauge Mediation & Soft masses

Giudice,Rattazzi hep-ph/9801271

GMSB: Messengers $M, \widetilde{M}$ couple to Susy Breaking hidden sector (superfield S)

$$\lambda \int d^4\theta \, S \, M \, \widetilde{M}$$



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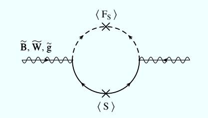
$\hookrightarrow$ mediation of Susy Breaking at perturbative level

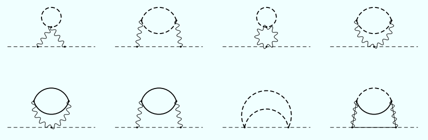
Gaugino masses

$$m_{1/2}^{GMSB} \sim \frac{g_a^2}{8\pi^2} \frac{F_S}{S}$$



Scalar masses

$$(m_0^{GMSB})^2 \sim \frac{g_a^4}{128\pi^4} \left(\frac{F_S}{S}\right)^2$$



Gauge Mediation & Uplift + D-term

Scalar soft masses

Poppitz, Trivedi, hep-ph/9703246

$$\mathrm{STr}\, \mathcal{M}^2_{Mess} = \mathrm{Tr}\, m^{mess\ 2}_{scal} - \mathrm{Tr}\, m^{mess\ 2}_{ferm} \neq 0$$

$\Rightarrow$ different GMSB result for scalars

In this model...

- Anomalies argument: $M, \widetilde{M}$ charged "+" under $\mathrm{U}(1)_X$

$\hookrightarrow$ $\mathrm{STr}\, \mathcal{M}^2_{Mess} \sim D$ (D-term)

$\hookrightarrow$ Coupling with SUSY breaking sector: $\lambda \int d^4\theta\, \Phi_-\, M\, \widetilde{M}$

True GMSB contribution for scalar soft masses

$$(m_0^{GMSB})^2 = \frac{g_a^4}{128\pi^4} \left\{ \left(\frac{F_-}{\Phi_-} \right)^2 + D \left[2 - \ln \left(\frac{\Lambda^2_{UV}}{m^2_{Mess}} \right) \right] \right\}$$

Mixed Mediation

$$(m_0^{GMSB})^2 = \frac{g_a^4}{128\pi^4}\left\{ \left(\frac{F_-}{\Phi_-}\right)^2 + D\left[2 - \ln\left(\frac{\Lambda_{UV}^2}{m_{Mess}^2}\right)\right] \right\}$$

Nontrivial interplay between $(m_0^2)_{\text{grav.}}$ and $(m_0^{GMSB})^2$:

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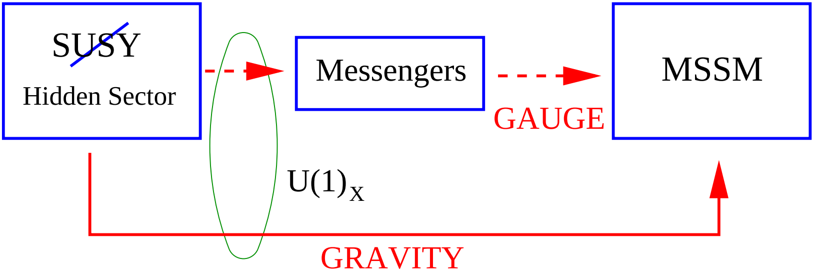

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- $(m_0^{GMSB})^2$ depends on couplings between scalars and gauge vectors

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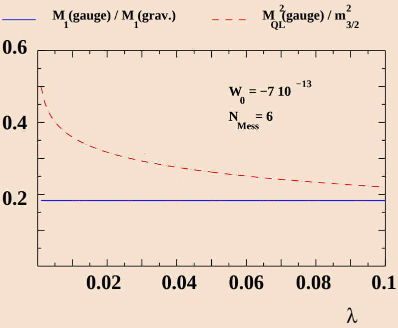
- $(m_0^2)_{\text{grav.}}$ is "universal" and of the same order
- $(m_0^{GMSB})^2$ depends on couplings between scalars and gauge vectors

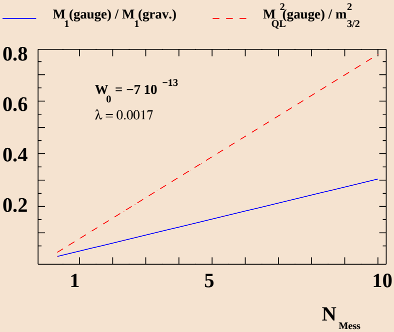
$\Rightarrow$ Squarks can be lighter than sleptons at high energy
$\hookrightarrow$ measurable effects at low energy after RG flow

Gravity vs. Gauge

Playing with λ and $N_{\rm Mess}$

$$
\begin{aligned}
(m_0^2) &= (m_0^2)_{\rm grav.} + N_{\rm Mess}(m_0^{GMSB})^2 \\
m_{1/2} &= (m_{1/2})_{\rm grav.} + N_{\rm Mess}(m_{1/2}^{GMSB})
\end{aligned}
$$





Some numbers

	A	B
W_0	$-7\ 10^{-13}$	$-4.3\ 10^{-13}$
m	$7.3\ 10^{-12}$	$4.5\ 10^{-12}$
a	1	1
b	0.3	0.5
q	1	1
$\tan\beta$	30	15
t	98.3	59.4
μ (GeV)	810	1070
$B\mu\ (GeV)^2$	$(400)^2$	$(870)^2$
$m_{\chi_1^0}$	110	140
$m_{\chi_1^+}$	220	290
$m_{\tilde{g}}$	760	950
m_h	120	120
m_A	2220	3290
$m_{\tilde{t}_1}$	1380	1770
$m_{\tilde{t}_2}$	1920	2610
$m_{\tilde{c}_1}, m_{\tilde{u}_1}$	2580	3300
$m_{\tilde{b}_1}$	1910	2610
$m_{\tilde{b}_2}$	2310	3230
$m_{\tilde{s}_1}, m_{\tilde{d}_1}$	2580	3300
$m_{\tilde{\tau}_1}$	2290	3200
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$m_{\tilde{\mu}_1}, m_{\tilde{e}_1}$	2550	3270

$\Rightarrow$

	A+GMSB	B+GMSB
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a	1	1
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$\tan\beta$	30	15
t	97.3	59.4
λ	$1.7\ 10^{-3}$	$1.1\ 10^{-3}$
N_{Mess}	6	6
μ (GeV)	186	216
$B\mu\ (GeV)^2$	$(330)^2$	$(730)^2$
$m_{\chi_1^0}$	120	150
$m_{\chi_1^+}$	160	200
$m_{\tilde{g}}$	850	1060
m_h	120	120
m_A	1740	2770
$m_{\tilde{t}_1}$	990	1220
$m_{\tilde{t}_2}$	1280	1710
$m_{\tilde{c}_1}, m_{\tilde{u}_1}$	1950	2420
$m_{\tilde{b}_1}$	1250	1700
$m_{\tilde{b}_2}$	1930	2690
$m_{\tilde{s}_1}, m_{\tilde{d}_1}$	1950	2420
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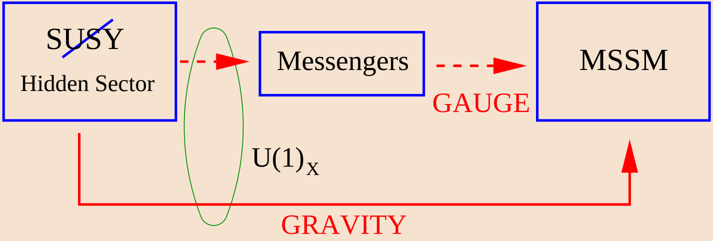
Hybrid Model

Gauge - Gravity mixed mediation

Idea: Generalize the previous stringy motivated example



Generic scenario with both gauge and gravity contributions to the soft terms at the GUT scale

$\hookrightarrow$ Suitable parametrization and scan on the parameters space

Parametrization

Soft terms for the masses

$$\left(m_0^2\right)_i = M_S^2 \left[\, 1 + \, \mathrm{N}_{\text{mess}}\, \tilde{\alpha}_i \,(1 - \tilde{\beta})\right]$$

$$\left(m_{1/2}\right)_a = f\, M_S$$

Parametrization

Soft terms for the masses

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- M_S $\longrightarrow$ scale of the gravity mediation

Parametrization

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- M_S $\rightarrow$ scale of the gravity mediation
- $\mathrm{N}_{\mathrm{mess}}$ $\rightarrow$ number of messengers

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- $\tilde{\alpha}_i$ → relative contribution of GMSB (field-dependent)
- $\tilde{\beta}$ → effects of $\mathrm{STr}\, \mathcal{M}^2_{Mess} \neq 0$
- f → both gravity & gauge contributions universal

Parametrization...$\tilde{\alpha}_i$

$$
\begin{aligned}
m^2_{Q_L} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{4}{3}n_q\alpha_3^2 + \frac{3}{4}n_l\alpha_2^2 + \frac{3}{5}\left(\frac{1}{6}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{U_R} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{4}{3}n_q\alpha_3^2 + \frac{3}{5}\left(\frac{-2}{3}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{D_R} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{4}{3}n_q\alpha_3^2 + \frac{3}{5}\left(\frac{1}{3}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{E_L} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[+\frac{3}{4}n_l\alpha_2^2 + \frac{3}{5}\left(\frac{-1}{2}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{E_R} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{3}{5}(1)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{H_u} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{3}{4}n_l\alpha_2^2 + \frac{3}{5}\left(\frac{1}{2}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
m^2_{H_d} &= M_S^2 + (1-\tilde{\beta})\tilde{\alpha}\left[\frac{3}{4}n_l\alpha_2^2 + \frac{3}{5}\left(\frac{-1}{2}\right)^2\frac{2n_q+3n_l}{5}\alpha_1^2\right] M_S^2,\\
(m_{1/2})_a &= M_S f = M_{1/2}
\end{aligned}
$$

Sample spectra

SUSPECT + micrOMEGAs2.0

	A	B	C
M_S	1.3 TeV	1.3 TeV	1.3 TeV
$M_{1/2}$	500	500	500
$\tilde{\alpha}$	0	1	1
$\tilde{\beta}$	0	0	1.85
$\tan\beta$	5	5	5
μ	750	1070	258
M_1	212	213	209
$m_{\chi_1^0}$	211	211	186
$m_{\chi_1^+}$	400	408	430
$m_{\tilde{g}}$	1222	1251	1175
m_h	113.2	114.1	112.4
m_A	1530	1920	1095
$m_{\tilde{t}_1}$	1066	1260	844
$m_{\tilde{t}_2}$	1403	1780	1008
$m_{\tilde{c}_1}$, $m_{\tilde{u}_1}$	1612	2052	1119
$m_{\tilde{b}_1}$	1388	1771	954
$m_{\tilde{b}_2}$	1588	1891	1282
$m_{\tilde{s}_1}$, $m_{\tilde{d}_1}$	1613	2053	1122
$m_{\tilde{\tau}_1}$	1275	1448	1046
$m_{\tilde{\tau}_2}$	1302	1550	1106
$m_{\tilde{\mu}_1}$, $m_{\tilde{e}_1}$	1303	1551	1047
Ωh^2	15.1	29.4	0.105

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- Squarks more sensitive than sleptons to GMSB negative contribution

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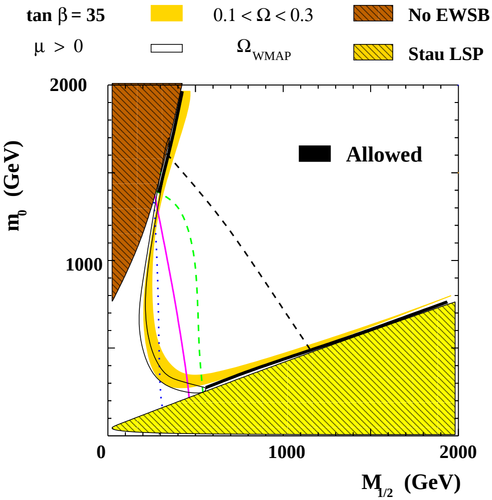
$$\mu^2 \approx -m_{H_2}^2 - \frac{1}{2}M_Z^2$$

$$\frac{\partial m_{H_2}^2}{\partial \log \mu} \approx 6y_t^2(m_{H_2}^2 + m_{U_3}^2 + m_{Q_3}^2 + A_t^2)$$

Initial conditions + RG flow effects:

- Lighter squarks
- $\hookrightarrow$ lower $|m_{H_2}^2|$ value
- $\hookrightarrow$ lower μ value
- $\hookrightarrow$ Lightest neutralino is generally a mixed bino-higgsino state
- $\hookrightarrow$ Suitable dark matter relic density value allowed

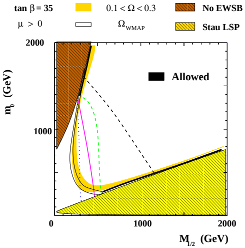
Examples of scan $N_{mess} = 5 \quad \tilde{\beta} = 5$

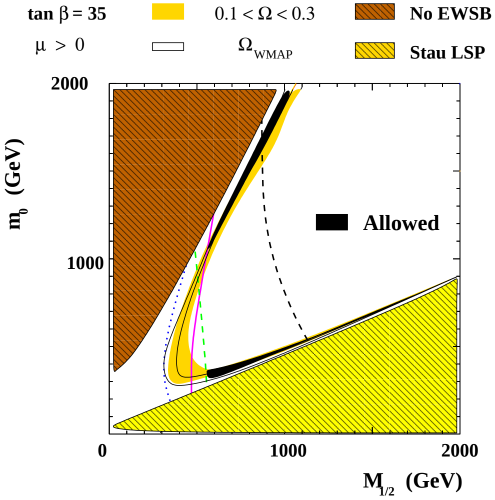


$\tilde{\alpha} = 0$ (mSUGRA)

Examples of scan

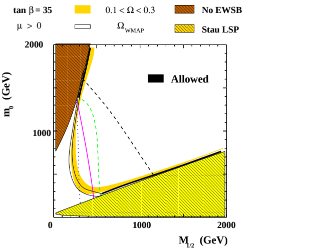
$N_{mess} = 5 \quad \tilde{\beta} = 5$

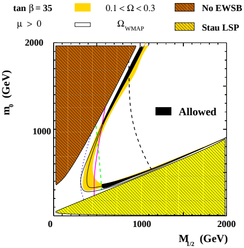


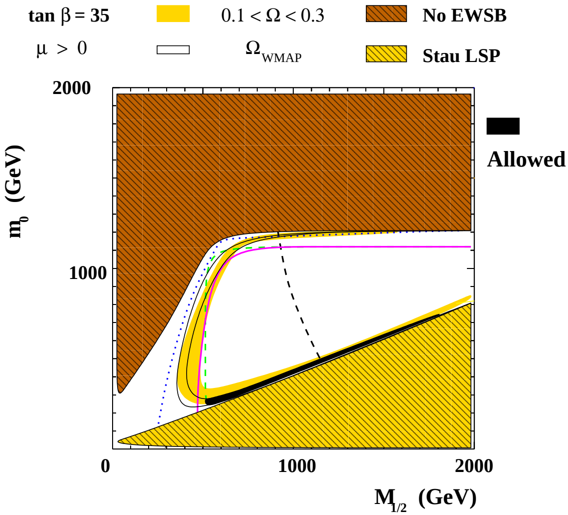


$\tilde{\alpha} = 1$

Examples of scan $N_{mess} = 5 \quad \tilde{\beta} = 5$







$\tilde{\alpha} = 1.1$

Conclusions & Outlook

Results

- High energy:
  - Example of a **non-decoupled** uplift: modulus contribution F_T to SUSY Breaking is not negligible
  - Natural mixing between **gauge** & **gravity** mediation mechanisms
- Low energy:
  - Gaugino masses **comparable** to the scalars and gravitino masses
  - **Spectrum "compressed"**: squarks more sensitive to GMSB

Work in progress

- Top-down: Can F_T be increased?
- Bottom-up: Systematic study of the phenomenology of the **hybrid** model