Tree Level
Gauge Mediation

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SISSA

with Nardecchia, Ziegler
arXiv:0909.3058 (JHEP)
arXiv:0912.5482 (JHEP)
and Monaco (in progress)

A wide class of models of supersymmetry breaking

[Polchinski Susskind,
Dine Fischler,
Dimopoulos Raby,
Barbieri Ferrara Nanopoulos]

SUSY breaking

Hidden sector

MSSM

Observable sector

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$\langle Z \rangle = F\theta^2$
$F \gg (M_Z)^2$
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SUSY breaking

bulk
mediation

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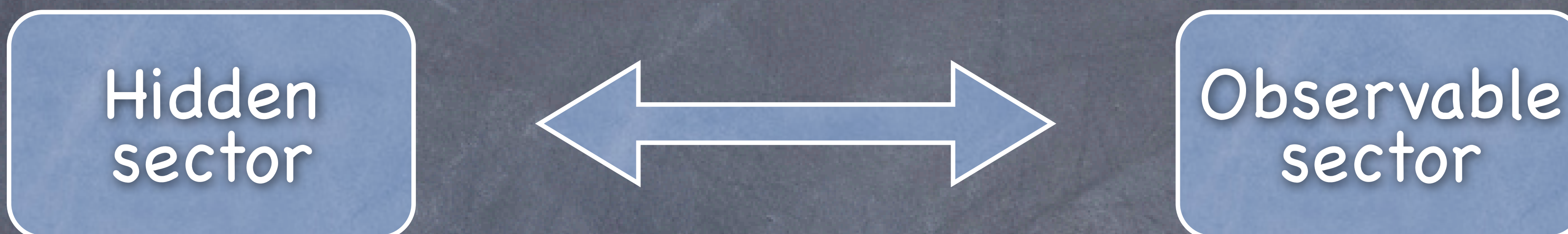
SUSY breaking

tree-level gauge mediation

MSSM



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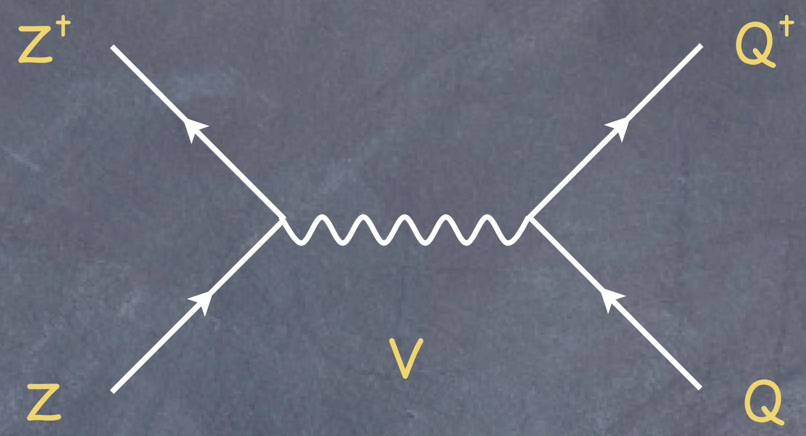

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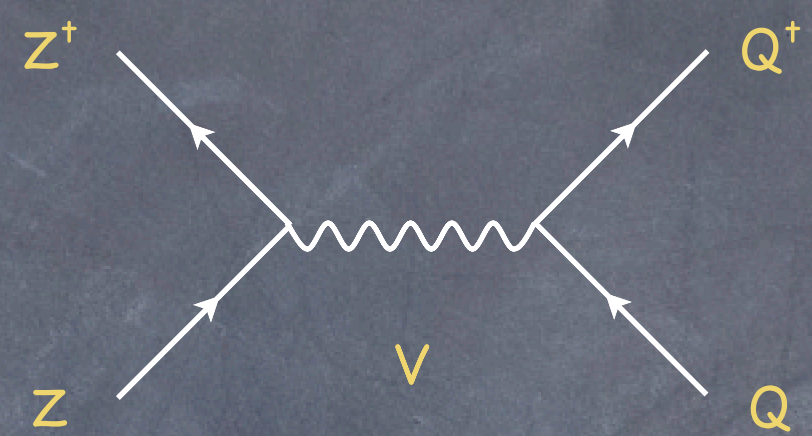

↑

heavy vector superfield
SM singlet
non-anomalous
assumed to part of a GUT

???

???

- Supersymmetry breaking masses (Z*ZQ*Q) are obtained at the tree level from spontaneous SUSY breaking in a renormalizable theory

- Two arguments seem to prevent this possibility

1. the supertrace formula

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$$\left(\tilde{m}^2_{\text{lightest ``squark''}} \leq m_d^2 \text{ or } m_u^2 \quad \text{if no additional U(1)'s}\right)$$

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2. small gaugino masses [Arkani-Hamed Dimopoulos Giudice R]

$$\tilde{m}_f \sim 100\, M_2 \gtrsim 10\,\mathrm{TeV} \Rightarrow \tilde{m}_f \sim 10\, M_2 \cdot \eta \gtrsim 1\,\mathrm{TeV} \cdot \eta$$

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- Peculiar, testable prediction of minimal models: $\tilde{m}^2_{q,u^c,e^c} = \frac{1}{2}\tilde{m}^2_{l,d^c}$

A concrete example

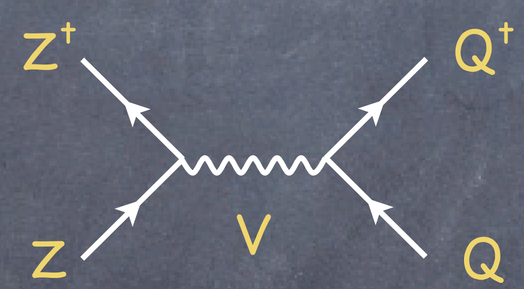
- G = SO(10) "minimal" GUT (V heavy SM singlet means rank ≥ 5)

- V associated to the SU(5)-invariant generator "X"

-

SO(10)		SU(5)				
16	=	$\bar{5}$	+	10	+	1
X		−3		1		5

SO(10)		SU(5)		
10	=	$\bar{5}$	+	5
X		2		−2

- 

gives $\tilde{m}_Q^2 \propto X_Q X_Z$

- The (usual) embedding of a MSSM family in a single 16 does not work (whatever the sign of X_Z)

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- The three MSSM families are embedded in $16_i + 10_i$, i=1,2,3 (needs $X_Z > 0$)

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- Does not require any effort! (SO(10) reps with $d < 120$)

SO(10) breaking needs $16 + \overline{16}$ with $\langle 16 \rangle = \langle \overline{16} \rangle = \textcircled{M} \approx M_{GUT}$

$h_{ij}\, 16_i\, 10_j\, 16 \to M_{ij}\, 5_i\, \bar{5}_j$ when $16 \to \langle 16 \rangle$

(Reinforces the theoretical consistency)

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$$\tilde{m}_Q^2 = \frac{X_Q}{2X_Z}\frac{F^2}{M^2}$$

- Then $\tilde{m}^2_q = \tilde{m}^2_{u^c} = \tilde{m}^2_{e^c} = \tilde{m}^2_{10} = \frac{1}{10}m^2, \quad \tilde{m}^2_l = \tilde{m}^2_{d^c} = \tilde{m}^2_{\bar{5}} = \frac{1}{5}m^2, \quad m = \frac{F}{M}$
- In particular
  - all sfermion masses are positive
  - sfermion masses are flavour universal, thus solving the supersymmetric flavour problem, and determined by a single parameter
  - $\tilde{m}^2_{q,u^c,e^c} = \frac{1}{2}\tilde{m}^2_{l,d^c}$ (at M)

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How general are the predictions?

- They assume:
  - Minimal GUT implementation (SO(10))
  - Only SO(10) reps with d < 120
  - Pure embeddings of SM multiplets in 1 type of SO(10) reps (guarantees the solution of the SUSY flavour problem), or no matter mass terms
- Non minimal GUTs?
  - A natural option is E_6
  - $27_i = 16_i + 10_i + 1_i$ under SO(10)

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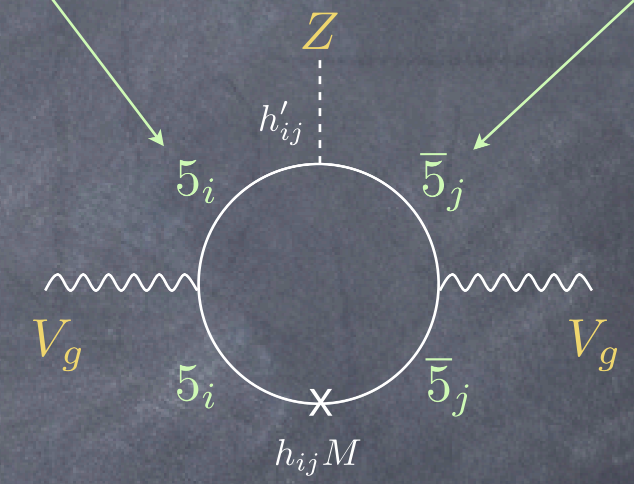

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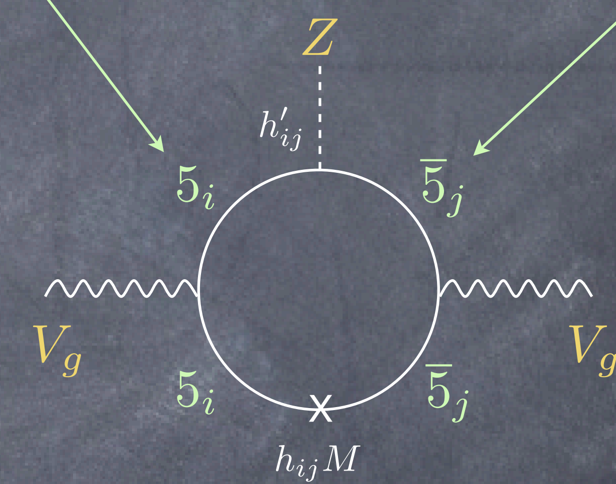
- ($W = h_{ij}\, 16_i\, 10_j\, 16 + h'_{ij}\, 16_i\, 10_j\, 16'$)



- $$\left.\frac{M_2}{\tilde{m}_t}\right|_{M_{\rm GUT}} = \frac{3\sqrt{10}}{(4\pi)^2}\,\lambda, \quad \lambda = \frac{g^2\,\mathrm{Tr}(h' h^{-1})}{3}$$

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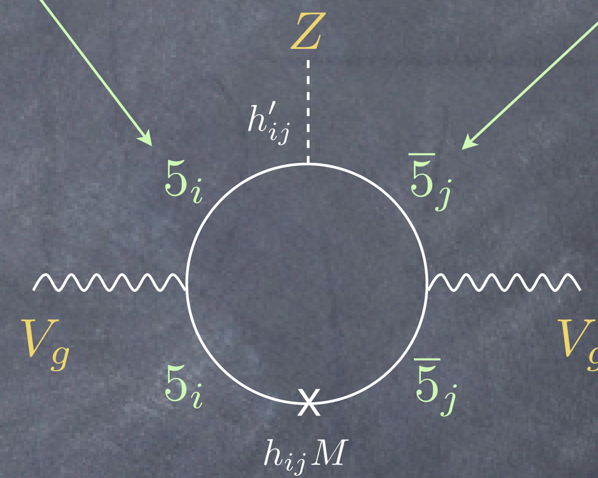

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- O(100) hierarchy → O(10): $\tilde{m}_t$ > O(1 TeV) x model dep factor λ

Miscellaneous

- A new D=3 solution of the μ problem
  D=4 (NMSSM) and D=5 (Giudice-Masiero) can also work
- Sugra contamination smaller than in loop gauge mediation (M_{GUT} OK)
- LSP is the gravitino
- Higgs soft terms bounded in predicted interval
- Up and down Yukawas decoupled despite SO(10)
- Neutrino masses through type-I, type-II, or hard susy breaking operators
- Type-II leptogenesis possible

Conclusions

- Simple (st)
- Sfermion masses are flavour universal, thus solving the supersymmetric flavour problem
- Sfermion masses determined in terms of a single parameter (as in the CMSSM, but for a reason)
- Peculiar, testable prediction of minimal models: $\tilde{m}^2_{q,u^c,e^c} = \frac{1}{2}\tilde{m}^2_{l,d^c}$

Spare

- Higgs doublets: only possible embeddings are into 16, 10 (h_d), $\overline{16}$, 10 (h_u)

- Let $\cos^2\theta_{u,d}$ be the size of the components of $h_{u,d}$ in 10's

- Then $$m_{h_u}^2 = \frac{-2c_u^2 + 3s_u^2}{5} m^2 \qquad m_{h_d}^2 = \frac{2c_d^2 - 3s_d^2}{5} m^2$$
$$-\frac{2}{5}m^2 < m_{h_u}^2 < \frac{3}{5}m^2 \qquad -\frac{3}{5}m^2 < m_{h_d}^2 < \frac{2}{5}m^2$$

SM Yukawas

- Down quark and charged lepton Yukawas:
  - $10_i\ \bar{5}_j\ \bar{5}_H$ (in SU(5) language) → $h_{ij}\ 16_i\ 10_j\ 16_H$ (where possibly $16_H = 16$)
- Up quarks:
  - $10_i\ 10_j\ 5_H$ (in SU(5) language) → $y_{ij}\ 16_i\ 16_j\ 10_H$
- Note: down and up quarks described by two independent Yukawa matrices (room to explain their different structure despite the SO(10) constraints)

Sugra contributions to sfermion masses

- Add to the tree level gauge mediated contribution and may induce FCNCs

- Their size is less important than in loop gauge mediation (because no loop suppression here). As a consequence, a messenger scale as large as M_{GUT} does not represent a potential problem for FCNCs

- Assuming the gravity contribution to a generic entry of the sfermion mass matrix is $(m^2)_{sugra} = (F/M_{Pl})^2$ ($M_{Pl} = 2.4\ 10^{18}$ GeV) we obtain

- $(m^2)_{sugra} < 2\ 10^{-3}\ (m^2)_{stop}$ iff $M < 3\ 10^{16}$ GeV (guarantees FCNC effects from flavour-anarchical sugra contribution are under control)

A new solution to the μ-problem

- μ is a supersymmetric mass parameter that accounts for Higgsino masses
- Its phenomenological window O(100 GeV) < μ < O(1 TeV) turns out to coincide with the window of supersymmetry breaking sfermion masses m̃: is it an accident or is there a connection between μ and m̃?
- In the absence of a connection, there would be no reason why μ should not be of the order of a much larger, susy-conserving mass scale, such as M_{GUT} or M_{Pl}. Or, if μ is suppressed by a symmetry, there would be no reason why it should not be much smaller or vanish
- Well known, appealing solutions of the μ-problem can be implemented
  - D=5: Giudice-Masiero $\int d^4\theta\, a \frac{Z^\dagger}{M} h_u h_d \to \mu = a \frac{F}{M}$ can arise at loop-level; μ ≈ M_g ≈ 100 GeV, Bμ ≈ m ≈ TeV (because of μ/Bμ connection)
  - D=4: NMSSM $\int d^2\theta\, \lambda S h_u h_d \to \mu = \lambda \langle S \rangle \sim \lambda \tilde{m}$ S can have negative soft mass (unlike in ordinary gauge mediation) but should take care of quartic coupling
  - D=3: an intrinsic TGM solution

- The D=3 solution of the μ-problem in TGM: μ and $\tilde{m}$ arise from the same mass term in the superpotential
- Reminder: we need
  - $16 = \bar{5} + 10 + 1 \quad \overline{16} = 5 + \overline{10} + \bar{1} \quad \langle 1 \rangle = \langle \bar{1} \rangle = M \approx M_{GUT}$
  - $16' = \bar{5}' + 10' + Z \quad \overline{16}' = 5' + \overline{10}' + \bar{Z} \quad \langle Z \rangle = F\,\theta^2$
- The easiest way to get a susy-breaking <16'> is through
  $W = m\, 16'\, \overline{16} \quad [+ Y\, (16\, \overline{16} - M^2) + X\, \overline{16}'\, 16]$
  then $F = m\, M$ (so that $m = F/M$)
- Because of SO(10), m is also the mass term of the doublet components of $16'\, \overline{16}$, which can contain a Higgs component: $16' = \alpha'\, h_d + \ldots$, $\overline{16} = \alpha\, h_u + \ldots$ so that $\mu = \alpha\, \alpha'\, m = \alpha\, \alpha'\, (F/M)$

Cosmology

- LSP is the gravitino (in the regime in which sugra FCNC effects are under control), as in loop gauge mediation

$$m_{3/2} = \frac{F}{\sqrt{3} M_{\mathrm{P}}} \approx 15\,\mathrm{GeV} \left(\frac{\tilde{m}_{10}}{\mathrm{TeV}} \frac{M}{2 \cdot 10^{16}\,\mathrm{GeV}} \right)$$

- Stable gravitino: a dilution mechanism is necessary not to overclose the universe, $T_R < 2\ 10^9$ GeV
- NLSP decay can spoil BBN
  - If the NLSP is a neutralino (typical case) a decay channel much faster than the Goldstino one is needed in order not to spoil BBN (e.g. a tiny amount of R_P-violation; consistent with thermal leptogenesis and gravitino DM)

    [Buchmuller, Covi, Hamaguchi, Ibarra, Yanagida, arXiv:hep-ph/0702184 (JHEP)]
  - If the NLSP is a stau (the other possibility) BBN not a problem but the peculiar predictions of TGM are hidden by large loop gauge mediation contributions
  - (work in progress)

An example of spectrum

Higgs:	m_{h^0}	114
	m_{H^0}	1543
	m_A	1543
	$m_{H^\pm}$	1545
Gluinos:	$M_{\tilde{g}}$	448
Neutralinos:	$m_{\chi_1^0}$	62
	$m_{\chi_2^0}$	124
	$m_{\chi_3^0}$	1414
	$m_{\chi_4^0}$	1415
Charginos:	$m_{\chi_1^\pm}$	124
	$m_{\chi_2^\pm}$	1416
Squarks:	$m_{\tilde{u}_L}$	1092
	$m_{\tilde{u}_R}$	1027
	$m_{\tilde{d}_L}$	1095
	$m_{\tilde{d}_R}$	1494
	$m_{\tilde{t}_1}$	1007
	$m_{\tilde{t}_2}$	1038
	$m_{\tilde{b}_1}$	1069
	$m_{\tilde{b}_2}$	1435
Sleptons:	$m_{\tilde{e}_L}$	1420
	$m_{\tilde{e}_R}$	1091
	$m_{\tilde{\tau}_1}$	992
	$m_{\tilde{\tau}_2}$	1387
	$m_{\tilde{\nu}_e}$	1418
	$m_{\tilde{\nu}_\tau}$	1382

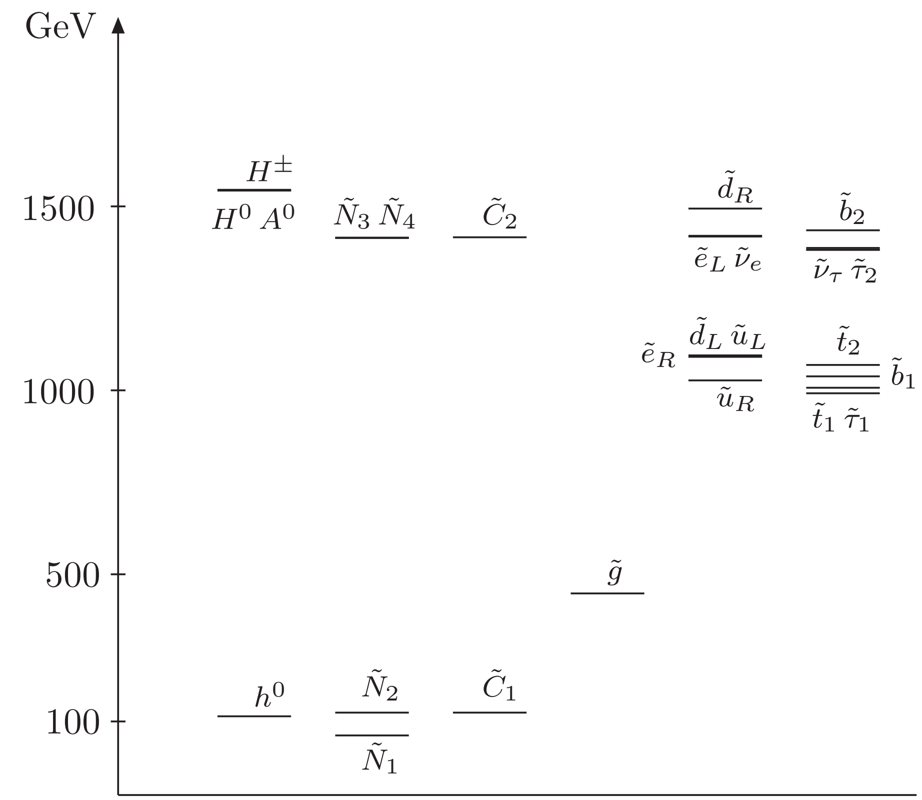

Figure 2: An example of spectrum, corresponding to $m = 3.2\,\text{TeV}$, $M_{1/2} = 150\,\text{GeV}$, $\theta_d = \pi/6$, $\tan\beta = 30$ and $\text{sign}(\mu) = +$, $A = 0$, $\eta = 1$. All the masses are in GeV, the first two families have an approximately equal mass.