Dirac Gauginos

(A Quick Survey)

Karim BENAKLI
(LPTHE, Paris)

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Introduction

Dirac or Majorana ?

Fermion masses of two kinds: Dirac or Majorana

- **Dirac**: 4 components fermions ⇨ *Preserve U(1) symmetries (ex: Lepton number, R-symmetry)*

- **Majorana**: 2 components ⇨ *Break U(1) symmetries (ex: Lepton number, R-symmetry)*

The MSSM gauginos

Gauge bosons: 2 d.o.f. ➪ Gauginos: 2 d.o.f.

➪ Masses have be of Majorana type *(often predicted too small !)*

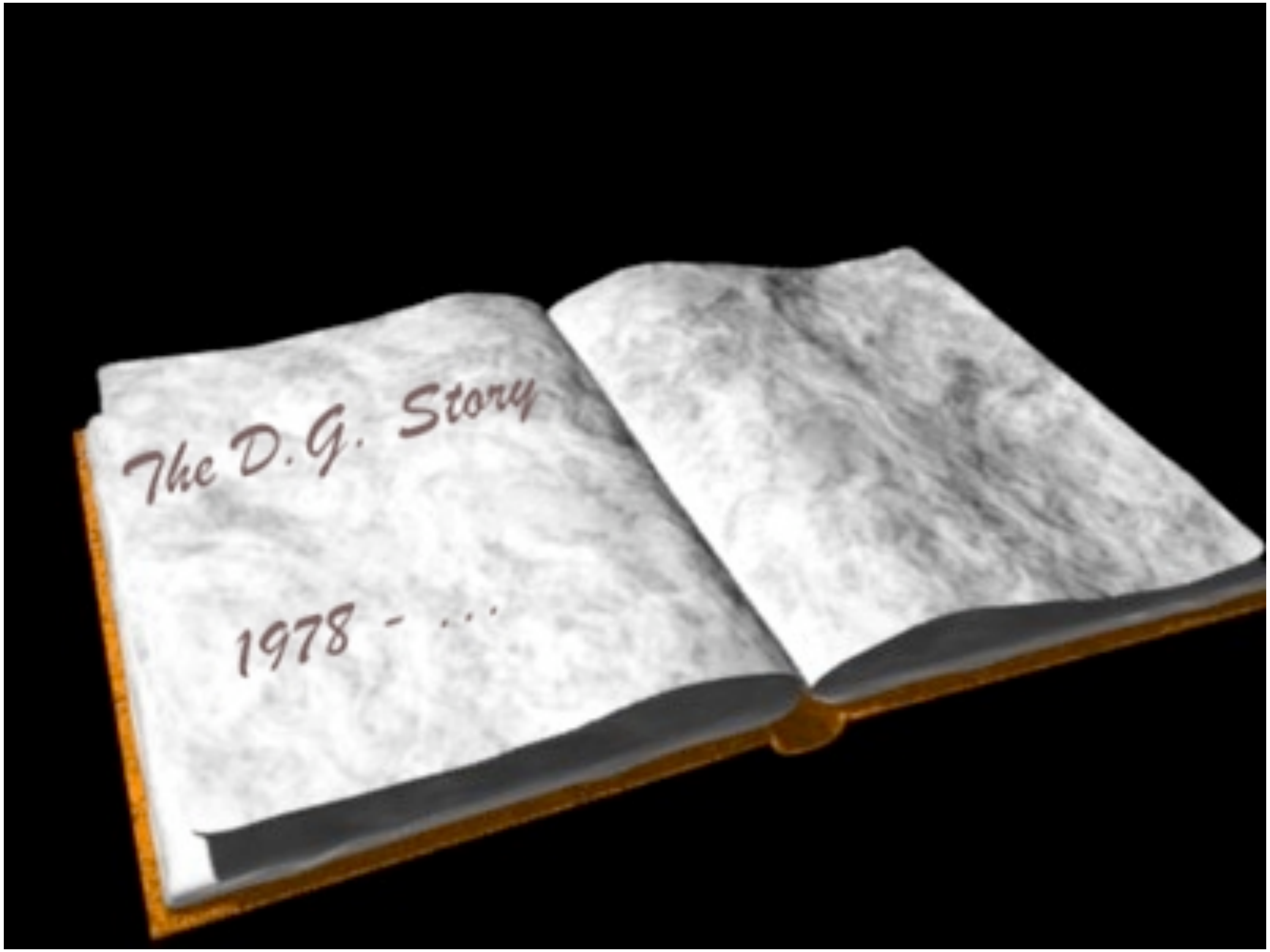
How does the theory look like with Dirac masses?

Dirac masses require *extra fermions* in adjoint representations: **DG-adjoints.**

DG-SSM Field Content

Names		Spin 0	Spin 1/2	Spin 1	$SU(3)$, $SU(2)$, $U(1)_Y$
Quarks	$\mathbf{Q}$	$\tilde{Q} = (\tilde{u}_L, \tilde{d}_L)$	(u_L, d_L)		$(\mathbf{3},\ \mathbf{2},\ 1/6)$
	$\mathbf{u^c}$	$\tilde{u}^c_L$	u^c_L		$(\overline{\mathbf{3}},\ \mathbf{1},\ \text{-}2/3)$
(×3 families)	$\mathbf{d^c}$	$\tilde{d}^c_L$	u^c_L		$(\overline{\mathbf{3}},\ \mathbf{1},\ 1/3)$
Leptons	$\mathbf{L}$	$(\tilde{\nu}_{eL},\tilde{e}_L)$	(ν_{eL}, e_L)		$(\mathbf{1},\ \mathbf{2},\ \text{-}1/2)$
(×3 families)	$\mathbf{e^c}$	$\tilde{e}^c_L$	e^c_L		$(\mathbf{1},\ \mathbf{1},\ 1)$
Higgs	$\mathbf{H_u}$	(H^+_u, H^0_u)	$(\tilde{H}^+_u, \tilde{H}^0_u)$		$(\mathbf{1},\ \mathbf{2},\ 1/2)$
	$\mathbf{H_d}$	(H^0_d, H^-_d)	$(\tilde{H}^0_d, \tilde{H}^-_d)$		$(\mathbf{1},\ \mathbf{2},\ \text{-}1/2)$
Gluons	$\mathbf{W_{3\alpha}}$		$\lambda_{3\alpha}$ $[\equiv \tilde{g}_\alpha]$	g	$(\mathbf{8},\ \mathbf{1},\ 0)$
W	$\mathbf{W_{2\alpha}}$		$\lambda_{2\alpha}$ $[\equiv \tilde{W}^\pm, \tilde{W}^0]$	$W^\pm, W^0$	$(\mathbf{1},\ \mathbf{3},\ 0)$
B	$\mathbf{W_{1\alpha}}$		$\lambda_{1\alpha}$ $[\equiv \tilde{B}]$	B	$(\mathbf{1},\ \mathbf{1},\ 0\ )$
DG-octet	$\mathbf{O_g}$	O_g $[\equiv \Sigma_g]$	χ_g $[\equiv \tilde{g}']$		$(\mathbf{8},\ \mathbf{1},\ 0)$
DG-triplet	$\mathbf{T}$	$\{T^0, T^\pm\}$ $[\equiv \{\Sigma^W_0, \Sigma^\pm_W\}]$	$\{\chi^0_T, \chi^\pm_T\}$ $[\equiv \{\tilde{W}'^\pm, \tilde{W}'^0\}]$		$(\mathbf{1},\mathbf{3},\ 0\ )$
DG-singlet	$\mathbf{S}$	S $[\equiv \Sigma_B]$	χ_S $[\equiv \tilde{B}']$		$(\mathbf{1},\ \mathbf{1},\ 0\ )$

D.G. Hard Life



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We will try to identify (some of) the problems.

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2. Give examples for the spectrum hierarchies.

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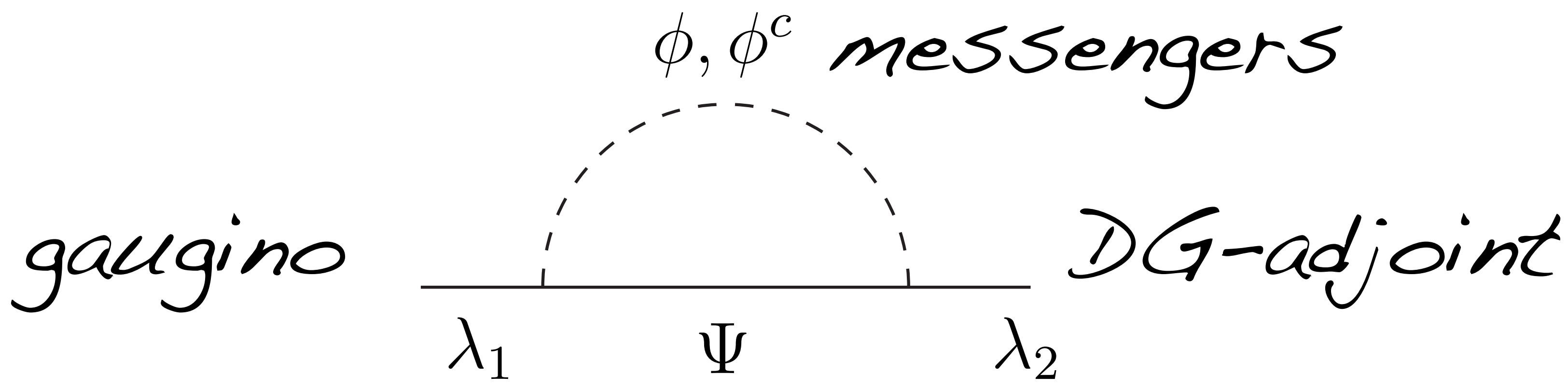
⇨ Other operators will be generated at the same order. See earlier history

Back To 1978

"Fayet 78": Dirac gaugino to preserve R-symmetry.

Dirac gaugino generated by loop of messengers:



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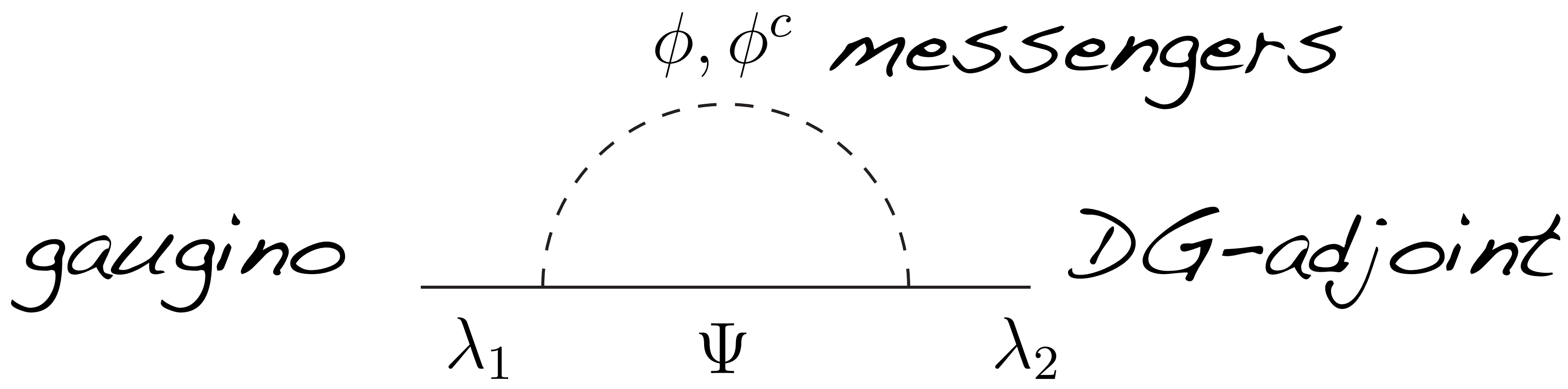

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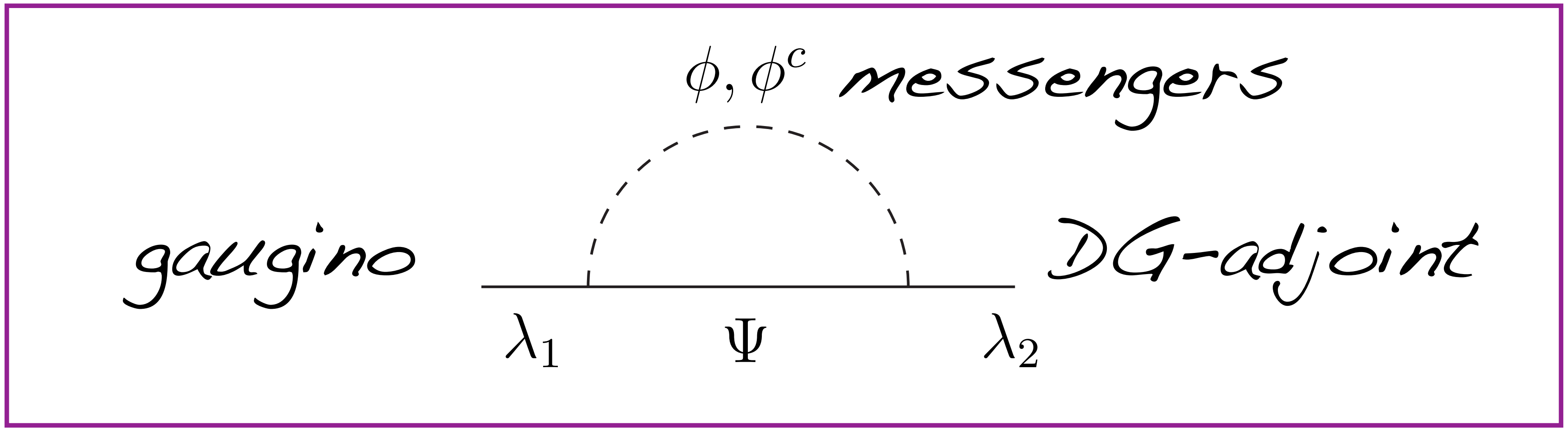

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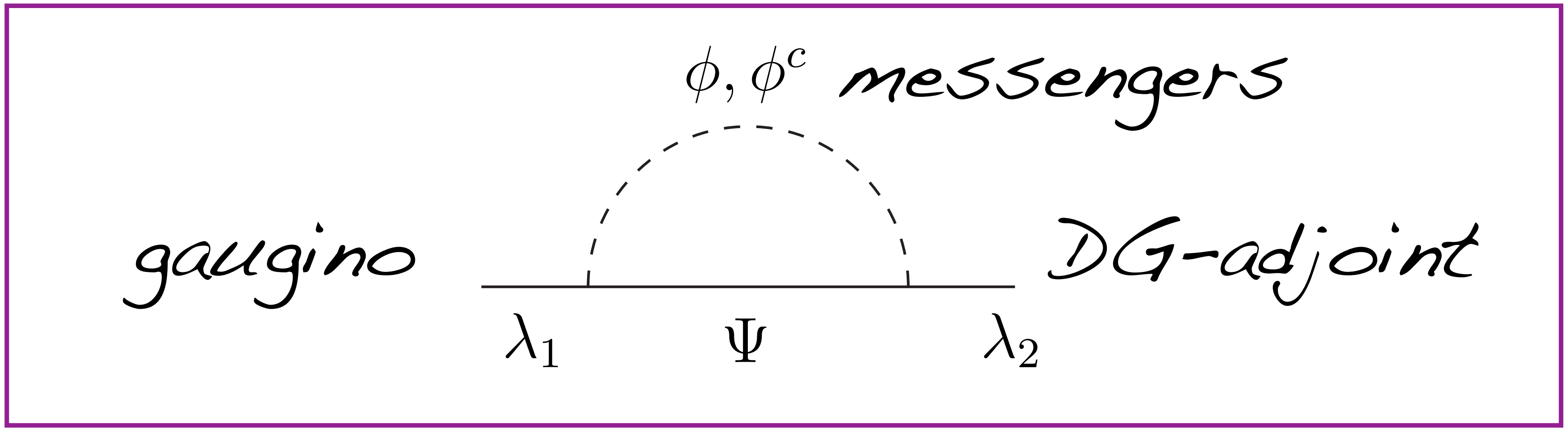

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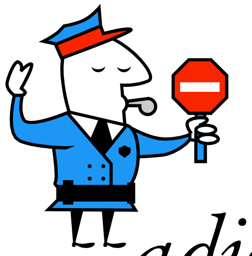

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Solved by giving *by hand* the adjoint a large susy mass: ⇨... Majorana gaugino masses.

Toward Model Building

A Model Builder's Wish List

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1. Dirac gaugino masses *dominate* Majorana ones
2. Messenger masses and quantum numbers such that the model is perturbative up to very high scale (GUT or Planck).
3. At this scale, unification of gauge couplings
4. Realistic and "*interesting*" hierarchy of soft terms

All together, this is hard to achieve

Small Majorana Masses?

- R-symmetry is the only known protection against Majorana masses.
- R-symmetry is **NOT** a symmetry of the Higgs sector, broken either by μ or the Higgs vevs.
- Majorana gaugino masses *non-vanishing*, but often "too small". Then, the Dirac masses can be important.

The "D-term way"

- Susy is broken by an anomalous U(1)
- **To avoid the tachyon:** the messenger Yukawa couplings to the DG-adjoints have to be off-diagonal and charged under the anomalous U(1) (K.B. and M. Goodsell, 2008)
- Strong hierarchy of the resulting soft masses:

  Sfermions < Gauginos < Adjoint scalars

- small Majorana masses induced by Higgs couplings

The "F-term way"

- Susy is broken by a (possibly R-symmetric) F-term
- **To avoid the tachyon:** the messengers Yukawa couplings to the DG-adjoints have to be off-diagonal.
- Stronger hierarchy of the resulting soft masses, split-Susy, unless F-term and messenger masses of the same order ⇨ Very light messengers ⇨ Landau pole below GUT scale.
- (Ex: **Amigo, Blechman, Fox, Poppitz; 2008**)

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- D < F

HIERARCHY EXAMPLE (K.B. and M. Goodsell, in progress)

Messengers:

$$4 \times [(1,1)_1 + (1,1)_{-1}] \quad \text{at} \quad m_1 = 3\ 10^{12}\text{GeV}$$

$$4 \times [(1,2)_{1/2} + (1,1)_{-1/2}] \quad \text{at} \quad m_2 = 1.3\ 10^{13}\text{GeV}$$

$$2 \times [(3,1)_{1/3} + (3,1)_{-1/3}] \quad \text{at} \quad m_3 = 10^{13}\text{GeV}$$

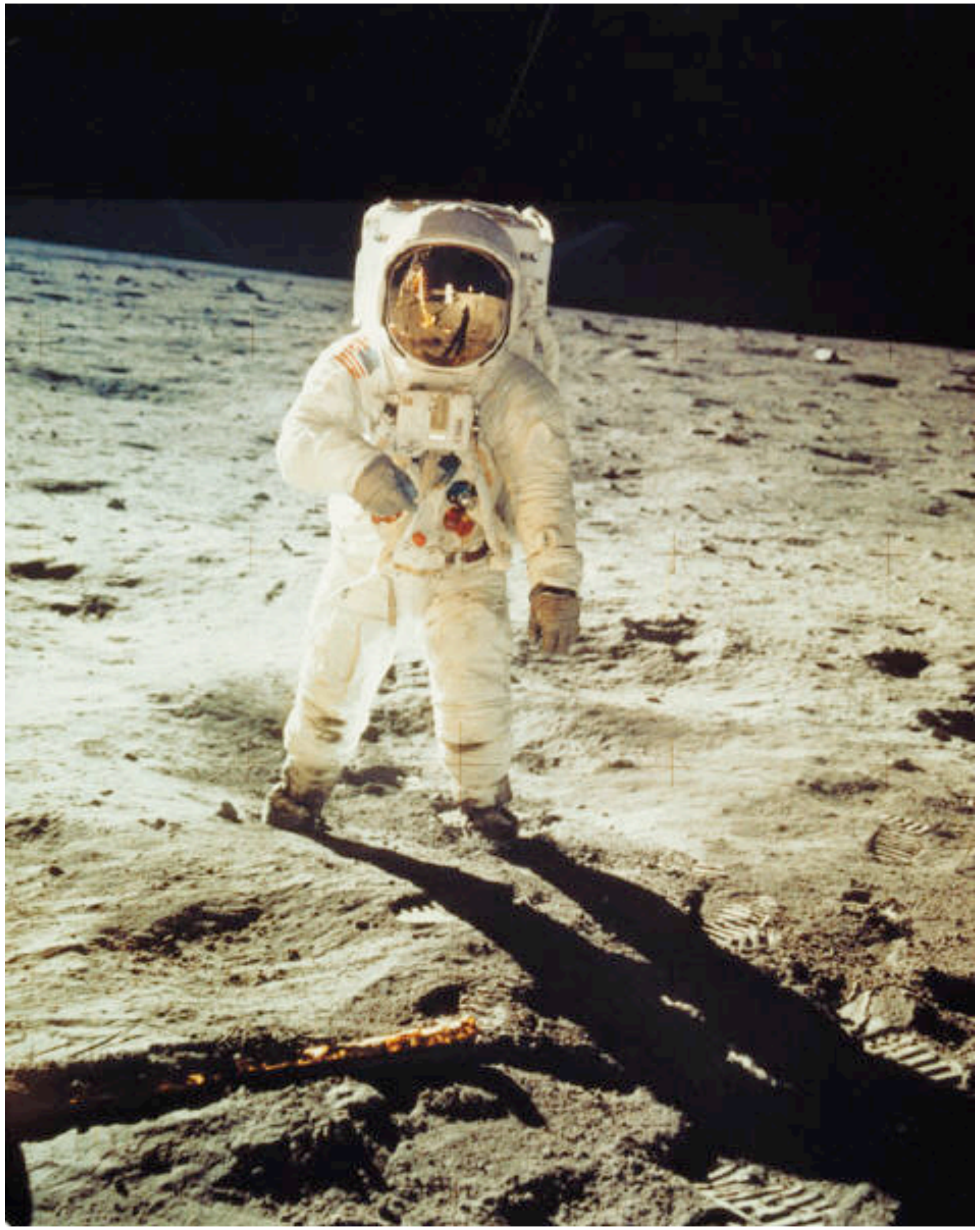
Unification: $M_U \sim 9.9 \cdot 10^{17}\text{GeV}$ $\qquad \alpha_U^{-1} \sim 4.77$

Sparticle spectrum:

Field	Mass (GeV)
m_{1D}	123
m_{2D}	127
m_{3D}	340
S_R	1595
T_R	1941
O_R	638
S_I	9690
T_I	5042
O_I	7089
Q	748
U	759
D	709
L	362
E	471

$M_{3/2} \sim 500$ MeV

Up There!



Next ...

Back To Earth
Confront Experiments

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Confront Experiments

(K.B., C. Moura), (G. Belanger, K.B., C. Moura, M. Goodsell, A. Pukhov)

- Go beyond just the microscopic model predictions
- Lagrangian contains: N=2 structure of gauge -Higgs sector and couple to N=1 matter *(breaking R-symmetry)*.
- Soft-terms allowed with arbitrary hierarchy
- Look for interesting scenarios as having well-defined experimental signatures.
- Later, search for microscopic realization

Gaugino Mass Terms

$$\mathcal{L}_{gauge} = \int d^4x d^2\theta \, [\, \frac{1}{4}\mathbf{M}_1 \mathbf{W}_1^\alpha \mathbf{W}_{1\alpha} + \frac{1}{2}\mathbf{M}_2 \mathrm{tr}(\mathbf{W}_2^\alpha \mathbf{W}_{2\alpha}) + \frac{1}{2}\mathbf{M}_3 \mathrm{tr}(\mathbf{W}_3^\alpha \mathbf{W}_{3\alpha})$$

$$+\sqrt{2}\mathbf{m}_{1D}^\alpha \mathbf{W}_{1\alpha}\mathbf{S} + 2\sqrt{2}\mathbf{m}_{2D}^\alpha \mathrm{tr}(\mathbf{W}_{2\alpha}\mathbf{T}) + 2\sqrt{2}\mathbf{m}_{3D}^\alpha \mathrm{tr}(\mathbf{W}_{3\alpha}\mathbf{O_g}) \,]$$

$$+ \int d^4x d^2\theta d^2\bar{\theta} \quad (\sum_{ij} \mathbf{\Phi}_i^\dagger e^{g_j \mathbf{V_j}} \mathbf{\Phi}_i + h.c.)$$

$$\mathbf{M}_i = 1 + 2\theta\theta M_i$$

$$\mathbf{m}_{\alpha i D} = \theta_\alpha m_{iD}$$

Higgs Couplings

The superpotentiel :

$$\int d^4x d^2\theta \left[\mu \mathbf{H_u} \cdot \mathbf{H_d} + \frac{M_S}{2}\mathbf{S}^2 + \lambda_S \mathbf{S}\mathbf{H_d} \cdot \mathbf{H_u} + M_T \mathrm{tr}(\mathbf{T}\mathbf{T}) + 2\lambda_T \mathbf{H_d} \cdot \mathbf{T}\mathbf{H_u} \right]$$

Soft breaking terms :

$$\begin{aligned} -\Delta\mathcal{L}_{soft} \;\; = \;\; & m^2_{H_u}|H_u|^2 + m^2_{H_d}|H_d|^2 + B_\mu(H_u \cdot H_d + h.c.) \\ & + m_S^2|S|^2 + \frac{B_S}{2}(S^2 + h.c.) + 2m_T^2 \mathrm{tr}(T^\dagger T) + B_T(\mathrm{tr}(TT) + h.c.) \\ & + A_S\lambda_S(SH_d \cdot H_u + h.c.) + 2A_T\lambda_T(H_d \cdot TH_u + h.c.) \end{aligned}$$

Higgs doublets form an N=2 hypermultiplet, @ the N=2 scale :

$$\lambda_S = \sqrt{2}g'\frac{1}{2}, \qquad \lambda_T = \sqrt{2}g\frac{1}{2},$$

Antoniadis, K.B., Quiros

Signatures

- **Collider signals, examples:**

  S. Y. Choi, M. Drees, A. Freitas and P. M. Zerwas, (2008)

  T. Plehn and T. M. P. Tait, (2009)

  S. Y. Choi, M. Drees, J. Kalinowski, J. M. Kim, E. Popenda and P. M. Zerwas, (2009)

  M. M. No jiri and M. Takeuchi, (2007)

- **Dark matter, examples:**

  G. Belanger, K. Benakli, M. Goodsell, C. Moura and A. Pukhov, (2009)

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This allows to take the road in the reverse way: look for LHC possible signals and turn the challenge to the side of the microscopic models with the desired spectrum.

THE END