SUPERSYMMETRY BREAKING

BORUT BAJC

JSI, LJUBLJANA

BW 2007

WORK DONE WITH

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(ALEJANDRA MELFO)

OUTLINE

1. INTRODUCTION
2. THE PHILOSOPHY
3. AN EXPLICIT EXAMPLE
   - SUSY BREAKING
   - MEDIATION
4. CONCLUSIONS

SUPERSYMMETRY:

FERMIONS $\Longleftrightarrow$ BOSONS

$$e \longrightarrow E = \tilde{e} + \theta e + \theta\theta F$$

FERMION $s = 1/2$

SUPERFIELD

BOSON $s = 0$

FERMION $s = 1/2$

AUXILIARY FIELD

θ ... GRASSMAN VARIABLE

$F \neq 0 \Longleftrightarrow$ ~~SUSY~~

SUPERSYMMETRY (SUSY)

MOTIVATED BY ([redacted])

- GAUGE COUPLING UNIFICATION
- HIERARCHY PROBLEM
- DYNAMICAL ELECTROWEAK SYMMETRY BREAKING
- DARK MATTER

SUPER POTENTIAL

SUSY PART OF MSSM (W) KNOWN

~~SUSY~~ PART OF MSSM UNKNOWN

PHENOMENOLOGICAL CONSTRAINTS:

DIRECT SEARCHES $\Rightarrow \tilde{m} \gtrsim 100$ GeV

FCNC $\Rightarrow$ FLAVOUR STRUCTURE OF SFERMIONS SIMILAR TO FERMIONS (V_{CKM})

CAN WE BREAK SUSY IN MSSM?

$F_{H,\bar{H}} \neq 0$ (THE ONLY POSSIBILITY)

$$\int d^2\theta \, y_e H L e^c \longrightarrow y_e F_H \tilde{e} \tilde{e}^c$$

$$V = \sum_i \left| \frac{\partial W}{\partial \varphi_i} \right|^2 = y_e^2 |H|^2 \left(|\tilde{e}|^2 + |\tilde{e}^c|^2 \right) + \dots$$

$$(\tilde{e}^*, \tilde{e}^c) \begin{pmatrix} y_e^2 v^2 & y_e^2 F \\ y_e^2 F & y_e^2 v^2 \end{pmatrix} \begin{pmatrix} \tilde{e} \\ \tilde{e}^{c*} \end{pmatrix}$$

$$m_{1,2}^2 = y_e^2 (v^2 \pm F)$$

$$\Downarrow$$

$$m_1^2 + m_2^2 = 2 m_e^2$$

IMPOSSIBLE!

SUCH ~~[illegible]~~
MASS SUM RULE
ALWAYS IN SUSY
AT TREE ORDER.

WAYS OUT:

a) USE OF LOCAL SUSY (SUGRA)

b) SUSY BREAKING (MEDIATION) BY LOOPS

IN BOTH CASES HIGHER DIMENSIONAL
~~NONRENORMALIZABLE~~ OPERATORS
(BUT IN b) CALCULABLE)

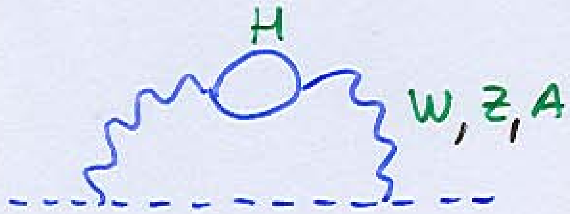
② CAN ONE ADD JUST ONE EXTRA FIELD X WITH $F \neq 0$? NO!

$$\int d^2\theta \, H\bar{H}(\mu + X) \Rightarrow m_{\tilde{H}} = \mu \quad \text{(HIGGSINO)}$$

$$m^2_{H_1} = \mu^2 - F \quad \text{(SM HIGGS)}$$

$$m^2_{H_2} = \mu^2 + F$$

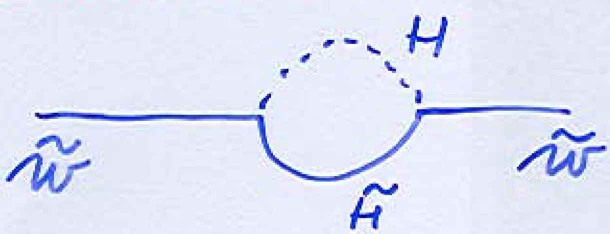
OTHER SFERMIONS:



$$\tilde{m}^2 \sim \left(\frac{\alpha}{4\pi}\right)^2 \left(\frac{F}{\mu}\right)^2 \ll F$$

$F \sim \mu^2$ LARGE $\quad (m^2_{H_1} \sim m^2_W)$

GAUGINO:

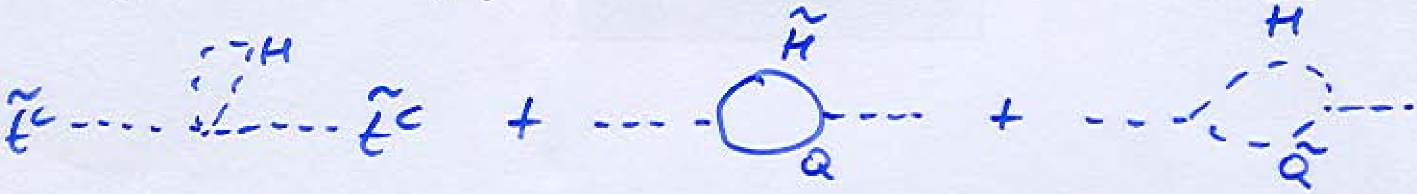


→ BUT NO 1-LOOP MASS FOR GLUINO!

[redacted]

$\boxed{\text{1}^{\text{ST}}\text{ PROBLEM}}$

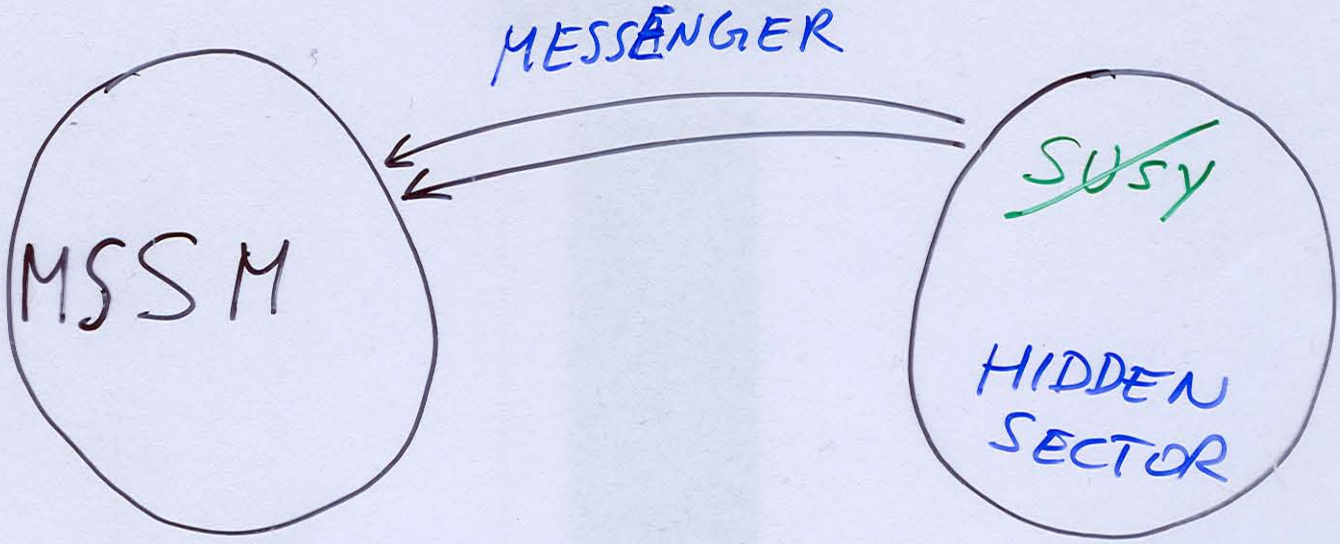
→ BUT $y_t \sim 1$:



$$\Rightarrow m^2_{\tilde{t}^c} \simeq -y_t^2 F$$

LARGE AND NEGATIVE!

$\boxed{\text{2}^{\text{ND}}\text{ PROBLEM}}$


MESSENGER
MSSM
SUSY
HIDDEN SECTOR

(3) FEW SHORT COMMENTS ON KNOWN MODELS OF ~~SUSY~~:

(A) GRAVITY MEDIATION

MESSENGER $\Longrightarrow$ GRAVITY

- GRAVITY ALREADY THERE
- JUST A PARAMETRIZATION, SOFT TERMS DEPEND ON ASSUMPTIONS ON KÄHLER

CMSSM:

EVERYTHING CALCULABLE IN TERMS OF FEW PARAMETERS (m_0, $m_{1/2}$, A, B, ...), BUT THEORETICALLY NOT MOTIVATED!

WHY SHOULD KÄHLER BE CANONICAL?

(B) ANOMALY MEDIATION

AGAIN CONNECTED WITH GRAVITY, ALWAYS THERE

VERY PREDICTIVE $\Rightarrow$ WRONG

[redacted]

$m^2 \sim \beta_g$ (RG INVARIANT)

$\Rightarrow$ SLEPTONS GET $m^2 < 0$

NEED TO COMBINE WITH OTHER SOURCES OF ~~SUSY~~:

BACK TO OLD UNCERTAINTIES

(C) GAUGE MEDIATION

ALREADY SEEN AN UNSUCCESSFUL EXAMPLE WITH

- $F_X \neq 0$
- X COUPLED TO $H, \bar{H}$

$\boxed{F_X \neq 0}$ $\xRightarrow[\text{SM GAUGE BOSONS}]{}$ $\boxed{\text{MSSM}}$

EXTRA $q, \bar{q}, \ell, \bar{\ell}$ GETS MSSM MASSES

$$W = \lambda_q X \bar{q} q + \lambda_e X \bar{e} e + W_{MSSM}$$

APPARENTLY FLAVOUR CONSERVING
(GAUGE INTERACTIONS FLAVOUR BLIND)

BUT TO SAVE GAUGE COUPLING UNIFICATION

$5 \sim (q, \ell)$ $\qquad \bar{5} \sim (\bar{q}, \bar{\ell})$

"d^c" "L"

$\Rightarrow \tilde{Y} H \ell e^c$ POSSIBLE
(EXTRA FLAVOUR MIXING!)

$\Rightarrow \tilde{Y} \ll 1$

NOT MUCH BETTER THAN SUGRA!

(C) GAUGE MEDIATION

ALREADY SEEN AN UNSUCCESSFUL EXAMPLE WITH
- $F_X \neq 0$
- X COUPLED TO $H\,\bar{H}$

$F_X \neq 0$ $\overset{\text{SM GAUGE BOSONS}}{\Longrightarrow}$ MSSM

EXTRA $q, \bar{q}, \ell, \bar{\ell}$

GETS ~~MSSM~~ MASSES

$$W = \lambda_q X \bar{q} q + \lambda_\ell X \bar{\ell} \ell + W_{MSSM}$$

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$\Rightarrow \tilde{Y} \ll 1$

NOT ~~[struck]~~ MUCH BETTER THAN SUGRA!

(4) SUSY NATURALLY TIED WITH GUTS

(GAUGE COUPLING UNIFICATION)

CAN WE GET ANY INSIGHT IF WE CONNECT THE FIELD X THAT BREAKS SUSY ($F_X \neq 0$) WITH A GUT MULTIPLET?

④ SUSY NATURALLY TIED WITH GUTS

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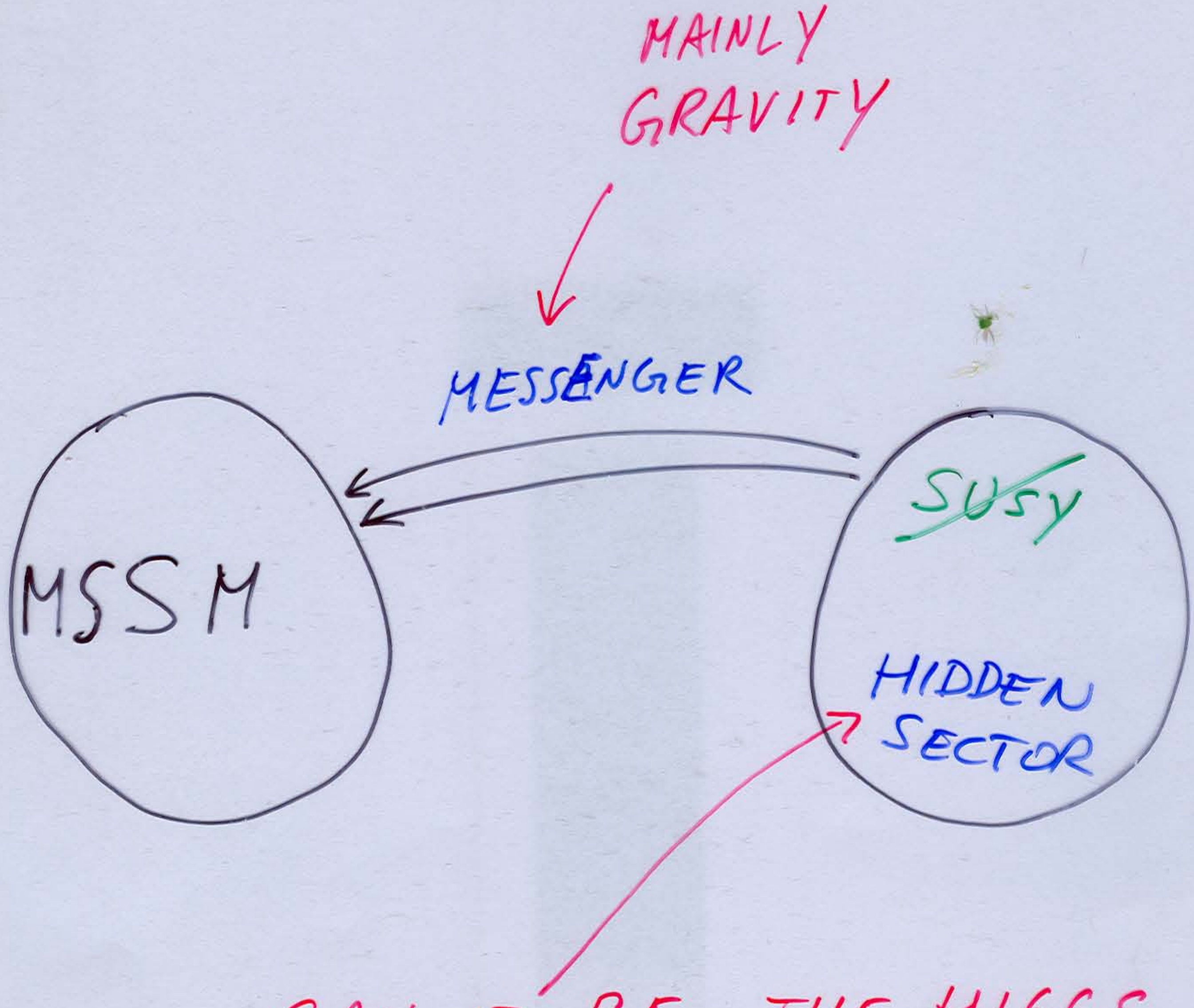


CAN IT BE THE HIGGS SECTOR IN A GUT?

(FOR EX. 24_H IN $SU(5)$)

RULES OF THE GAME :

1. NO EXTRA INTERACTIONS EXCEPT GUT
   (NO ROOM FOR DYNAMICAL SUPERSYMMETRY BREAKING OR FAYET_ILIOPOULOS)
   AND GRAVITY
   (= MESSENGER)
2. NO SINGLETS
   (NO ROOM FOR O'RAIFEARTAIGH)

CAN THE SAME FIELD BREAK BOTH GUT AND SUSY ?

TYPICALLY CONSIDERED DIFFICULT, DIFFERENT ARGUMENTS AGAINST IT

PROBLEM

LOCAL SUSY (SUGRA)

$$=$$

GLOBAL SUSY $+ \dfrac{1}{M_{Pl}}$ CORRECTIONS
(TYPICALLY SMALL)

$$\Downarrow$$

$\not{\text{SUSY}}$ IN LOCAL SUSY
JUST GENERALIZATION OF
$\not{\text{SUSY}}$ IN GLOBAL SUSY
(O'RAIFEARTAIGH OR FAYET-ILIOPOULOS)

PROBLEM

~~SUSY~~

$\Downarrow$

GOLDSTINO MASSLESS

$\Downarrow$

PARTNERS IN GUT & SUSY MULTIPLET EASILY LIGHT

$\Downarrow$

SPOILS GAUGE COUPLING UNIFICATION

$$\Sigma = \sigma \begin{pmatrix} 2 & & & & \\ & 2 & & 0 & \\ & & 2 & & \\ & 0 & & -3 & \\ & & & & -3 \end{pmatrix} + \left(\begin{array}{c:c} \Sigma_8 & \\ \hdashline & \Sigma_3 \end{array}\right)$$

SIMILAR TO X BEFORE

$F_\sigma \neq 0$

$\langle \sigma \rangle = M_{GUT}$

Σ_8 ... COLOR OCTET

Σ_3 ... WEAK TRIPLET

USUALLY $m_{3,8} \sim M_{GUT}$

WE WILL SEE THAT MINIMALITY IMPLIES

$F_\sigma \neq 0 \iff m_{3,8} \ll M_{GUT}$

- ONE FIELD σ
- KÄHLER CANONICAL

$$V = e^{\frac{|\sigma|^2}{M_{pe}^2}} \left(\left| W' + \sigma^* \frac{W}{M_{pe}^2} \right|^2 - 3 \frac{|W|^2}{M_{pe}^2} \right)$$

CONSTRAINTS ON $W(\sigma)$

$$\langle W \rangle = m_{3/2} M_{pe}^2$$

$$\langle V \rangle = 0 \iff \langle W' \rangle = \sqrt{3}\, m_{3/2} M_{pe} \left(1 + O\left(\frac{\langle \sigma \rangle}{M_{pe}} \right) \right)$$

$$\left\langle \frac{\partial V}{\partial \sigma} \right\rangle = 0 \iff \langle W'' \rangle = 2\, m_{3/2} \left(1 + O\left(\frac{\langle \sigma \rangle}{M_{pe}} \right) \right)$$

MINIMUM (NOT MAXIMUM) AT $\langle \sigma \rangle = M_{GUT}$ $\iff$ $$\left| \langle W''' \rangle \right| \le \frac{2\, m_{3/2}}{\sqrt{3} M_{pe}} \left(1 + O\left(\frac{\langle \sigma \rangle}{M_{pe}} \right) \right)$$

WE NEED $W(\sigma)$ WITH THESE 4 CONSTRAINTS $\Rightarrow$ 4 FREE PARAMETERS

$$W = m\sigma^2 + \lambda\sigma^3 + \frac{c_1}{M_{Pl}}\sigma^4 + \frac{c_2}{M_{Pl}^2}\sigma^5$$

$$\Big\Downarrow \text{ PARAMETRIZE}$$

$$W = \frac{1}{M_{Pl}^2}\Big(a_1 M_{GUT}^3\sigma^2 + a_2 M_{GUT}^2\sigma^3 + a_3 M_{GUT}\sigma^4 + a_4\sigma^5\Big)$$

CLOSE TO $\sigma = M_{GUT}$ ALL

4 TERMS COMPARABLE

OVRUT, RABY, 83

INTERESTED IN LOW-ENERGY SUSY

$$m_{3/2} \simeq \mathcal{O}(\text{TeV}) \ll M_{GUT}$$

TYPICAL

$$\frac{d^m W}{d\pi^m} \approx a\, M_{GUT}^{3-m} \approx m_{3/2} M_{Pl}^{2-m}$$

$m = 0, 1, 2, 3$

IT FOLLOWS:

1. AT LEAST 4 COEFFICIENTS a's OF COMPARABLE ORDER

2. $a \ll 1$

DETERMINE a_1, a_2, a_3, a_4

TO GET THE MINIMUM OF V

AT $\sigma = M_{GUT}$ WITH

$$\langle V \rangle = 0$$

$$\langle W \rangle = m_{3/2} M_{Pl}^2$$

$$\Downarrow$$

$$\begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = M_{Pl}^2 \begin{pmatrix} 10 & -6 & \frac{3}{2} & -1/6 \\ -20 & 14 & -4 & 1/2 \\ 15 & -11 & 7/2 & -1/2 \\ -4 & 3 & -1 & 1/6 \end{pmatrix} \begin{pmatrix} \langle W \rangle / M_{GUT}^5 \\ \langle W' \rangle / M_{GUT}^4 \\ \langle W'' \rangle / M_{GUT}^3 \\ \langle W''' \rangle / M_{GUT}^2 \end{pmatrix}$$

$$a_i \approx \frac{m_{3/2} M_{Pl}^4}{M_{GUT}^5} \ll 1$$

SM SINGLET σ CAN COME

FROM $\Sigma = 24_H$ IN $SU(5)$

$$W = m \,\mathrm{Tr}\,\Sigma^2 + \lambda \,\mathrm{Tr}\,\Sigma^3 +$$

$$+ \frac{b_1^{(1)}}{M_{pe}} \mathrm{Tr}\,\Sigma^4 + \frac{b_1^{(2)}}{M_{pe}} \left(\mathrm{Tr}\,\Sigma^2\right)^2 +$$

$$+ \frac{b_2^{(1)}}{M_{pe}^2} \mathrm{Tr}\,\Sigma^5 + \frac{b_2^{(2)}}{M_{pe}^2} \left(\mathrm{Tr}\,\Sigma^3\right)\left(\mathrm{Tr}\,\Sigma^2\right)$$

$$\Sigma = \frac{\sigma}{\sqrt{30}} \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix} + \left(\begin{array}{c|c} \Sigma_8 & \\ \hline & \Sigma_3 \end{array}\right)$$

$$b_i = f_i\left(m, \lambda, b_\alpha^{(\beta)}\right)$$

4 PARAMETERS (DETERMINED!) SMALL

6 PARAMETERS (2 LEFT) CAN BE $\mathcal{O}(1)$

MORE PRECISELY

$$a_1 \frac{M_{GUT}^3}{M_{pe}^2} = m$$

$$a_i \ll 1$$

$$a_2 \frac{M_{GUT}^2}{M_{pe}^2} = - \frac{\lambda}{\sqrt{30}}$$

$$a_3 \frac{M_{GUT}}{M_{pe}^2} = \frac{1}{M_{pe}} \left(\frac{7}{30} b_1^{(1)} + b_1^{(2)} \right)$$

$$a_4 \frac{1}{M_{pe}^2} = \frac{1}{M_{pe}^2} \left(- \frac{13}{30\sqrt{30}} b_2^{(1)} - \frac{1}{\sqrt{30}} b_2^{(2)} \right)$$

$$\Downarrow$$

→ $m \ll M_{GUT}$

→ $\lambda \ll 1$

→ $b_i^{(\alpha)}$ COULD BE EVEN $O(1)$

PROVIDED THE ABOVE COMBINATIONS $\ll 1$

BOTTOM LINE : INTERMEDIATE STATES

$$m_3 \simeq \frac{8}{3} b_1^{(1)} \frac{M_{GUT}^3}{M_{pe}^2} - \frac{28}{3\sqrt{30}} b_2^{(1)} \frac{M_{GUT}^3}{M_{pe}^2}$$

$$m_8 \simeq \frac{2}{3} b_1^{(1)} \frac{M_{GUT}^3}{M_{pe}^2} + \frac{1}{\sqrt{30}} b_2^{(1)} \frac{M_{GUT}^3}{M_{pe}^2}$$

RGE :

$M_{GUT}^0 = 10^{16}$ GeV

$$M_{GUT} = M_{GUT}^0 \left(\frac{M_{GUT}^0}{(m_3 \, m_8)^{1/2}} \right)^{1/2}$$

M_{GUT} INCREASES $\left(\simeq 10^{17} - 10^{18} \text{ GeV} \right)$

$d=6$ PROTON DECAY SUPPRESSED

$$\tau_p(d=6) = \tau_p^0(d=6) \left(\frac{M_{GUT}}{M_{GUT}^0} \right)^4$$

RGE :

$$5_H = \begin{pmatrix} T \\ D \end{pmatrix}$$

$$m_T = m_T^0 \left(\frac{m_3}{m_8} \right)^{5/2}$$

EASILY MAKE m_T INCREASE

$d=5$ PROTON DECAY EASILY SUPPRESSED

FOR EXAMPLE :

$$b_2^{(i)} \simeq 0 \implies m_3 = 4\, m_8$$

$$\Downarrow$$

$$\tau_p(d=5) = \tau_p^0(d=5) \left(\frac{m_T}{m_T^0} \right)^2 \qquad m_T = 32\, m_T^0$$

$$\Downarrow$$

$$\tau_p \simeq 10^3\, \tau_p^0$$

PRICE TO PAY : FINE-TUNING

$$m_\sigma \simeq m_{3/2}$$

$$m_{3,8} \gg m_{3/2}$$

UNAVOIDABLE WITH ONLY 24_H

UNLESS FINE-TUNING:

$$W = m_\sigma \sigma^2 + m_3 \sigma_3^2 + m_8 \sigma_8^2 + \ldots$$

$m_\sigma \ll m_{3,8}$

(TRIPLET + OCTET) VS. SINGLET SPLITTING

UNLESS TERMS IN W VERY SMALL

$\Downarrow$

$\frac{1}{M_{pe}}$ CORRECTIONS RELEVANT!

MEDIATION OF SUSY

1. GRAVITY
2. X, Y GAUGE BOSONS
3. σ_3, σ_8
4. LIGHT HIGGSES

① GRAVITY

$$m_{\tilde f} \simeq \frac{F}{M_{Pl}} \simeq m_{3/2}$$

GAUGINO :

$$\delta \mathcal{L} \sim \int d^2\theta \, \frac{c}{M_{Pl}} \, \mathrm{Tr}\left(\Sigma W^\alpha W_\alpha\right) + \text{h.c.}$$

$$\Longrightarrow \underbrace{\frac{c}{M_{Pl}} F \,\mathrm{Tr}\left(Y \lambda \lambda\right)}_{\text{gaugino mass}} + \underbrace{\frac{c \, M_{GUT}}{M_{Pl}} \mathrm{Tr}\left(Y F^{\mu\nu} F_{\mu\nu}\right)}_{\Delta\left(\frac{1}{g^2}\right)}$$

$c \ll 1 \Longrightarrow$ SAME RESULTS APPLY

$$m_\lambda \ll m_{\tilde f}$$

WHAT IF $c \approx \mathcal{O}(1)$?

RGE CHANGED

$$M_{GUT} = M^{\circ}_{GUT} \left(\frac{M^{\circ}_{GUT}}{(m_3 m_8)^{1/2}} \right)^{1/2} \underbrace{e^{-\left[\frac{5}{24} \frac{(4\pi)^2}{\sqrt{30}} \frac{M_{GUT}}{M_{Pe}} \cdot c\right]}}_{\mathcal{O}(1)}$$

$\mathcal{O}(1)$ FOR $c=1$

M_{GUT} DOES NOT CHANGE MUCH

$$m_T = m^{\circ}_T \left(\frac{m_3}{m_8} \right)^{5/2} \underbrace{e^{+26\left[\frac{5}{24} \frac{(4\pi)^2}{\sqrt{30}} \frac{M_{GUT}}{M_{Pe}} c\right]}}_{\mathcal{O}(10^{\pm 7})}$$

$\mathcal{O}(10^{\pm 7})$ FOR $c=\pm 1$

m_T VERY DEPENDENT ON c

$\frac{m_3}{m_8}$ AND c CONSTRAINED

② X, Y GAUGE BOSONS

$$m_{\tilde{f}} \sim \frac{F}{M_{GUT}} \cdot \frac{\alpha_{GUT}}{4\pi}$$

BUT IN OUR CASE

$$\underbrace{\frac{\alpha_{GUT}}{4\pi} \cdot \frac{1}{M_{GUT}}}_{\text{X,Y GAUGE MEDIATED}} \ll \underbrace{\frac{1}{M_{pe}}}_{\text{GRAVITY MEDIATED}}$$

NEGLIGIBLE

[redacted]

$$\frac{\alpha_{GUT}}{4\pi} \cdot \frac{1}{M_{GUT}} \simeq \frac{1}{10} \frac{1}{M_{pe}}$$

$$\frac{\alpha_{GUT}}{4\pi} \to \lesssim 10^{-2} \qquad \frac{1}{M_{GUT}} \to 10/M_{pe}$$

(3) σ_3, σ_8 FROM 24_H

$$m_{\tilde{f}} \simeq \frac{\alpha}{4\pi} \frac{F}{m_i(\sigma)} \frac{\partial m_i(\sigma)}{\partial \sigma} \qquad i = 3, 8$$

IN PRINCIPLE POSSIBLE:

$m_i(\sigma)$ POLINOMIAL IN σ

$\longrightarrow$ MAKE $m_i(\sigma)$ SMALL

KEEPING $\frac{\partial m_i}{\partial \sigma}(\sigma)$ LARGE

EXAMPLE: $m(\sigma) = a\sigma^2 + b\sigma$

$$\Rightarrow a\langle\sigma\rangle^2 + b\langle\sigma\rangle \longrightarrow 0$$

$\uparrow$ FINE-TUNE a, b

$$\Rightarrow 2a\langle\sigma\rangle + b \neq 0$$

LOWER LIMIT FROM $M_{GUT} < M_{Pl}$

TYPICALLY SUBDOMINANT, MAYBE BORDERLINE

COMMENT:

WE ASSUMED LOW-ENERGY SUSY

$$\Lambda_{MSSM} \simeq m_Z$$

IF NOT

$$M_{GUT} = M^{0}_{GUT} \quad (\simeq 10^{16}\ GeV)$$

$$m_T = m^{0}_{T} \quad (\simeq 10^{16}\ GeV)$$

EVEN WITH

$$\frac{m_3}{M_{GUT}} = \left(\frac{m_Z}{\Lambda_{MSSM}}\right)^{5/6} \qquad m_3 \downarrow \quad \Lambda_{MSSM} \uparrow$$

$$\frac{m_8}{M_{GUT}} = \left(\frac{m_Z}{\Lambda_{MSSM}}\right)^{1/2} \qquad m_8 \downarrow \quad \Lambda_{MSSM} \uparrow$$

(BUT LESS)

(GORAN SENJANOVIĆ TALK [redacted])

$\Lambda_{MSSM} \to M_{GUT}$

$m_3 \to m_Z$

$m_8 \to 10^{8}\ GeV$ (HALF WAY)

4 HIGGS DOUBLETS

$$\int d^2\theta \; m_H(\sigma)\,\bar{H}H + h.c. \quad \swarrow \text{ FROM } \bar{H}\left(m + \lambda\Sigma + \frac{\Sigma^2}{M_{Pl}} + \dots\right)H$$

$$m_H(\langle\sigma\rangle) = \mu$$

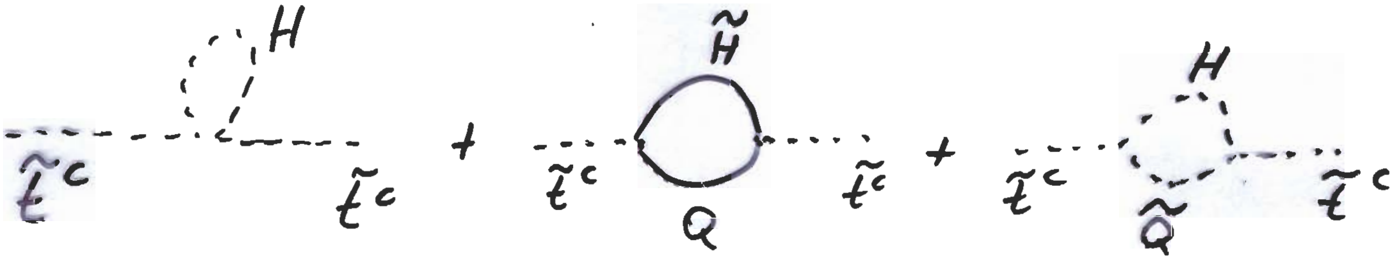
FINE-TUNING (DT SPLITTING)

$$F\,\frac{\partial m_H}{\partial\sigma}(\langle\sigma\rangle) = B$$

EXTRA FINE-TUNING

$(B \le \mu^2)$

1-LOOP



$$m^2_{\tilde{t}^c} \simeq -\frac{y_t^2}{(4\pi)^2}\,B \qquad \text{NEGATIVE!}$$

$H, \bar{H}$ CONTRIBUTION CANNOT DOMINATE

(BUT NOT NECESSARILY NEGLIGIBLE)

MESSAGE OF THIS TALK

(1) TAKE YOUR FAVOURITE THEORY BEYOND THE STANDARD MODEL

- MINIMAL
- REALISTIC (G_{321} at low E, correct spectrum, m_f, V_{CKM}, V_{PMNS})

(2) BREAK SUSY IN THIS MODEL (IF POSSIBLE)

(3) FIND OUT THE MEDIATION

(4) ANY PREDICTION ?

($m_{3,8}$ LIGHT)

ANOTHER EXERCIZE

(1) RENORMALIZABLE SU(5)
(NO GRAVITY!)

(2) $W = \xi X$; $F_X = \xi$

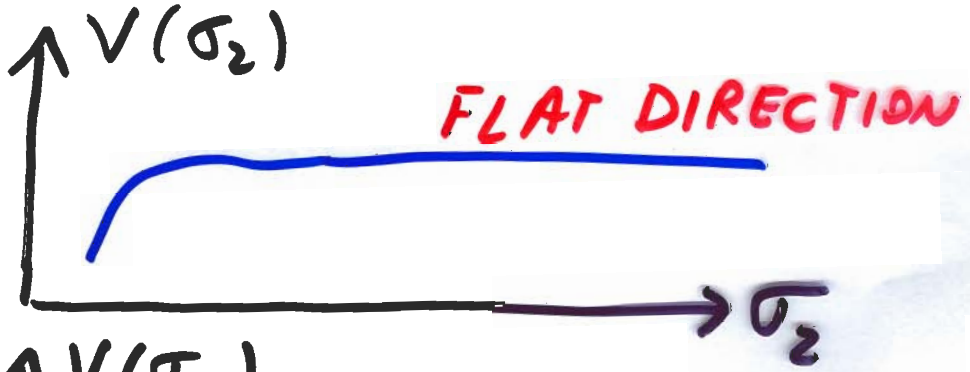
IN SU(5) $\Sigma_i \ldots 24_i$

$$W = \mathrm{Tr}\left(\Sigma_1^2 \Sigma_2\right)$$

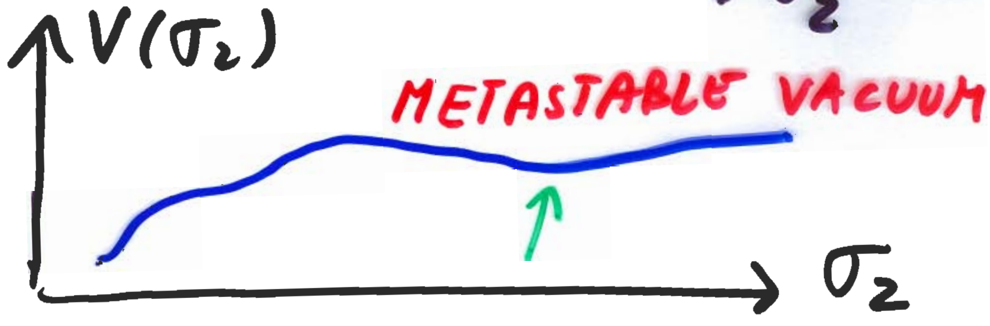
$$\langle \Sigma_1 \rangle = v_1 \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix}$$

$\Rightarrow$ $W \simeq v_1^2 \sigma_2$; $F_2 \simeq v_1^2$

TREE LEVEL $\rightarrow$



LOOPS $\rightarrow$



USE OF METASTABLE VACUA

FOR SUSY BREAKING

KNOWN LONG AGO

DIMOPOULOS, DVALI, GIUDICE, RATTAZZI, 97

- REALISTIC EXAMPLES
- DECAY RATES

REVIVAL:

INTRILIGATOR, SHIH, SEIBERG, 06

SU(5) WITH TWO 24

AND RENORMALIZABLE W

CAN SPONTANEOUSLY
BREAK SUSY

– PROBLEMS

(1) 3_W + 8_C LIGHT

GAUGE COUPLING UNIFICATION?

(2) DIFFICULT TO SPLIT DT

- EITHER FAST PROTON DECAY
- OR DESTABILIZE
SU(2) BREAKING

CONCLUSIONS

1. POSSIBLE TO USE MINIMAL (NON RENORMALIZABLE) SU(5) TO BREAK BOTH GUT AND SUSY

2. PRICE TO PAY: FINE-TUNINGS

   → $m_\sigma \ll M_{GUT}$ (NEW)

   → $\mu \ll M_{GUT}$

   → $B \ll M_{GUT}^2$

3. PREDICTIONS:

   → M_{GUT} LARGE (d=6 p DECAY NEGLIGIBLE)

   (d=5 ALSO EASILY SAVED)

   → GRAVITY MEDIATION DOMINATES