SEE-SAW

and

GRAND UNIFICATION

Paris, June 2004

SEE SAW MOST COMMONLY DEFINED AS

(IN THE SM)

Gell-Mann, Ramond, Slansky

Yanagida

Mohapatra, G.S.

Glashow (79)

add ν_R $\therefore$

$$\mathcal{L}_Y(\nu) = Y_D \, \bar{\nu}_L \, \phi \, \nu_R + M_R \, \nu_R^T C \nu_R + h.c.$$

$$\begin{array}{c} \nu_L \\ \nu_R \end{array} \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} \qquad m_D = Y_D \langle \phi \rangle \lesssim M_W$$

a mess, unless $M_R \gg M_W$

NATURAL : M_R a gauge invariant quantity

(minimal fine tuning)

$$m_\nu^I \simeq m_D^T M_R^{-1} m_D \ll M_W, m_f \quad \text{(type I see-saw)}$$

NEUTRINOS EXPECTED TO BE LIGHT

10^{10} GeV $< M_R < 10^{15}$ GeV

ALTERNATIVELY

Add $SU(2)_L$, $B-L=2$ triplet Δ

$$\Delta \mathcal{L}_Y = Y_\nu \, \ell_L^T C \, \ell_L \, \Delta \qquad \ell = \begin{pmatrix} \nu \\ e \end{pmatrix}$$

$$\Delta V = M \, \Phi^T \Delta \Phi + M_\Delta \, \Delta^+ \Delta + \cdots \text{ O.T.}$$

Magg, Wetterich '80

$$\langle \Delta \rangle \simeq \frac{M_W^2 M}{M_\Delta^2} \simeq \frac{M_W^2}{M_\Delta}$$

Lazarides, Shafi, Wetterich

Mohapatra, G.S. '81

FOR $M \sim M_\Delta \gg M_W$ (same principle as before)

$$\Downarrow$$

$$m_\nu^{II} \simeq Y_\nu \frac{M_W^2}{M_\Delta} \ll M_W, \, m_f \quad \text{NATURAL}$$

Type II see-saw

~~SM : no difference ; an effective operator~~

~~$$\frac{\ell_L^T C \, \Phi^* \, \Phi^+ \, \ell_L}{M_\nu}$$~~

~~Weinberg~~

~~Need Y_D, M_R, Y_ν ....~~

~~$\boxed{M_\nu \ll M_{pe} \;??}$~~

SM : NO DIFFERENCE

Needs a theory of mass scales ;

(restrictions on) Y_D, Y_ν, ...

e.g. $Y_D \propto Y_\nu \propto M_R$ ⇒ same (I = II)

SM – $\boxed{\text{effective operator}}$

$$\Delta L_Y = \frac{(\ell_i^T \sigma_2 C \Phi^*)(\Phi^\dagger \sigma_2 \ell_j)}{M_\nu} c_{ij}$$

Weinberg '79

$m_\nu < 1$ eV $M_\nu : 10^{10} - 10^{15}$ GeV

$M_\nu \ll M_{Pl}$ ($M_{Pl} \Rightarrow m_\nu \simeq 10^{-5} - 10^{-6}$ eV)

WHY?

⇓

GRAND UNIFICATION : a theory of mass scales (large)

+ restriction on Yukawa

How to incorporate see-saw

in GUTS ?

⇕

WHAT IS 'THE' GUT ?

Minimal consistent theory

NO D-T. . .   (CORRECT LOW ENERGY THEORY)

[illegible] DARK

Old days : $m_\nu = 0$ prejudice !

↓

minimal SU(5) + supersymmetry

←

unification

(hierarchy)

Mostly SUSY GUTS ;

(ordinary at the end)

'PURE' GUTS (no additional symmetries)

SYMMETRY REASONING

Minimal SM ⇒

accidental global B−L

↑ ANOMALY FREE

broken by M_R (M)

- MAYBE ACCIDENT ⇒

SU(5) DIRECTION

- GAUGE B−L ⇒ $(B-L)^3$ anomaly

⇒ ∃ ν_R (simplest)

⇓

$SU(5)\times U(1) \subset$ SO(10) DIRECTION

$\cup$

$SU(2)_L \times SU(2)_R \times SU(4)_c$ (L−R ; Pati-Salam)

$\cup$

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

$$Q = T_{3L} + T_{3R} + \frac{B-L}{2}$$

Mohapatra, G.S.

GRAND UNIFICATION

- SU(5) THEORY

give up gauging B−L

$\nearrow$ accidental global symmetry

neutrino mass:

(i) $\exists\ \nu_R$ − singlets of SU(5)

Minimal fine-tuning:

M_R gauge invariant $\Rightarrow M_R \gg M_{GUT} \simeq 10^{16}$ GeV

(SUSY)

$$\Rightarrow m_\nu \ll \frac{M_W^2}{M_{GUT}} \simeq 10^{-3} \text{eV}$$

↑ SMALL

(ii) add $\Delta \leq 15$ (symmetric 5×5)

same principle $M_\Delta \gg M_{GUT}$

NOT RIGOROUS − but in the spirit of see-saw

SU(5) not such a good theory of fermion masses

minimal $\Rightarrow m_d = m_e$ at M_{GUT}

$m_b \simeq m_\tau$ at M_{GUT}

$$\left.\begin{array}{l} m_s \simeq 1/3\, m_\mu \\ \\ m_d \simeq 3\, m_e \end{array}\right\} \text{large deviations}$$

(45) - Georgi-Jarlskog

Needs new Higgs or / and

Barbieri et al

non-renormalizable interactions ($1/M_{pl}$)

$\Downarrow$

NOT PREDICTIVE

POSSIBILITY: add extra (flavor) symmetries

- $d = 5$ proton decay ?

ruled out : Murayama, Pierce ('01)

no ! Bajc, Fileviez Perez, G.S. ('02)

● SO(10) : MINIMAL GUT OF MATTER AND INTERACTIONS

ideal framework for ν masses and mixings (other fermions)

- a family of fermions = 16 (spinor)

$$16 = \begin{pmatrix} f \\ f^c \end{pmatrix}_L \qquad (f^c)_L \equiv C \bar{f}_R^{\,T}$$

- L-R a gauge symmetry : C

- supersymmetry R-parity (matter parity) a gauge symmetry

Mohapatra '86

$$R: \; p \to p, \; \tilde{p} \to -\tilde{p} \qquad R = (-1)^{2S} M \equiv (-1)^{3(B-L)}$$

$$M: \; f \to -f, \; f^c \to -f^c; \; \Phi \to \Phi$$

$$16 \to -16, \quad 10 \to 10$$

$\hookrightarrow \subseteq Z_4$ center of SO(10)

$(16 \to i16, \; 10 \to -10)$

Yukawa sector in SO(10)

$$16_F \times 16_F = 10_H + 120_H + 126_H$$

$16_F\, C\, \Gamma_i\, 16_F\, 10_i$ symmetric

$16_F\, C\, \Gamma_i \Gamma_j \Gamma_k\, 16_F\, 120_{[ijk]}$ anti

$16_F\, C\, \Gamma_i \Gamma_j \Gamma_k \Gamma_l \Gamma_m\, 16_F\, \overline{126}_{[ijklm]}$ symmetric

which is correct ?

What is the minimal Higgs ?

Natural : ONLY 10_H ~ generates M_W and m_f (SM)

see-saw ⇒ more Higgs : $\overline{126}$

STRONGER : $\overline{126}$ (direct or effective) needed for charged fermion masses

(10 NOT ENOUGH)

Pati - Salam decomposition : $SU(2)_L \times SU(2)_R \times SU(4)_c$

$$\begin{pmatrix} u & u & u & \nu \\ d & d & d & e \end{pmatrix}_{L,R}$$

useful language!

$$16 = \underset{q,\, l}{(2,1,4)} + \underset{q^c,\, l^c}{(1,2,\bar{4})}$$

$$10 = \underset{\uparrow \text{ LIGHT HIGGS}}{(2,2,1)} + (1,1,6)$$

$$\overline{126} = \underset{\text{see saw II?}}{\underline{(3,1,10)}} + \underset{\text{mass for } \nu_R}{\underline{(1,3,\overline{10})}} + \underset{\text{LIGHT HIGGS?}}{\underline{(2,2,15)}} + (1,1,6)$$

NOTICE: $\langle 10 \rangle = \langle 2,2,1 \rangle$ ~ PS singlet

⇓

$m_q = m_l$ at M_{GUT}

(even if more 10's)

$\theta_q = 0$

Fails badly for 2nd and 1st generation

⇒ $\overline{126}$ A MUST !!

$\langle 2,2,15 \rangle$:

$3\, m_q = -\, m_l$

(2nd gen.)

(tree level; loop;

renormalizable; non-renorm. ?)

Georgi - Glashow decomposition   SU(5)

$$16 = 10 + \bar{5} + 1 \sim \nu^c$$

$$10 = 5 + \bar{5} \leftarrow \text{light Higgs}$$

$$\overline{126} = \underset{\substack{\uparrow \\ \text{mass to } \nu^c}}{1} + 5 + \underset{\substack{\uparrow \\ \text{type II?}}}{15} + \underset{\substack{\uparrow \\ \text{light Higgs}}}{\overline{45}} + 50$$

(Georgi - Jarlskog)

- effective $\overline{126}$

$$\frac{1}{M_{pl}} \overline{16}_H \, C\Gamma\Gamma\Gamma\Gamma\Gamma \, \overline{16}_H \sim \overline{126}_H$$

NON-RENORMALIZABLE

COUPLINGS

MINIMAL SO(10) ?

MINIMAL GUT ?

- SMALL [redacted] REPRESENTATIONS

$(\varphi, \bar\varphi)$ 16_H (+ $\overline{16}_H$ in SUSY)

(A) 45_H – adjoint

$\Big\}$ M_{GUT}

M_I ?

(H) 10_H – low scale (M_W)

small # fields ⇒ • AF above M_{GUT}

• high precision(?)

$\boxed{SUSY}$ • COMPLICATED HIGGS SECTOR

$$W_H = m_A^2 A^2 + \frac{(A^2)^2 + A^4}{M_{p\ell}}$$

$$+ m_\varphi \varphi\bar\varphi + \frac{(\varphi\bar\varphi)^2 + (\varphi\Gamma\Gamma\bar\varphi)^2 + (\varphi(\Gamma\Gamma\Gamma\Gamma)\bar\varphi)^2}{M_{p\ell}}$$

$$+ \frac{(\varphi\Gamma\varphi)^2 + (\varphi\Gamma^5\bar\varphi)^2 + \varphi\to\bar\varphi}{M_{p\ell}}$$

$$+ \varphi\Gamma\Gamma\varphi A + \bar\varphi\Gamma\Gamma\bar\varphi A + \frac{(\varphi\Gamma^4\varphi A^2 + \varphi\to\bar\varphi)}{M_{p\ell}}$$

$$+ m_H H^2 + \varphi\Gamma\varphi H + \bar\varphi\Gamma\bar\varphi H + \frac{\varphi\Gamma^3\varphi A H}{M_{p\ell}} + \varphi\to\bar\varphi$$

● MORE PROBLEMATIC : PROTON DECAY ISSUE

$\langle 16_H \rangle \neq 0 \neq \langle \overline{16}_H \rangle$

BREAKS MATTER (R) PARITY at M_{GUT}

DISASTER

$16_F \, \Gamma \, 16_H \, 10_H \Rightarrow M_{GUT} \, L \bar{H}$

$$\frac{(16_F \, \Gamma \, 16_F)(16_F \, \Gamma \, 16_H)}{M_{pl}} \to \frac{M_{GUT}}{M_{pl}} \left(U^c D^c D^c + Q L D^c \right)$$

10^{-3}

$d=4$ p decay

$(m_{\tilde{d}^c} \simeq \text{TeV})$

NEED $\leq 10^{-12}$

$\Downarrow$

Ad-hoc new 'matter' parity

$16_H \to -16_H, \quad \overline{16}_H \to -\overline{16}_H$

UGLY !

Matter parity - gauge symmetry in SO(10)

- Yukawa sector messy

$$W_Y = 16_F \Gamma 16_F H_{(10)} \leftarrow \text{top (b) quark mass}$$

$$+ \frac{16_F \Gamma 16_F \varphi \Gamma \varphi}{M_{pl}} + \frac{16_F \Gamma 16_F \bar{\varphi} \Gamma \bar{\varphi}}{M_{pl}} \quad (10)$$

$$+ \frac{16_F \Gamma\Gamma\Gamma 16_F A H}{M_{pl}} \quad (120) \leftarrow \text{mass corrections } (2,2,15) - GJ$$

$$+ \frac{16_F \Gamma^5 16_F \bar{\varphi} \Gamma^5 \bar{\varphi}}{M_{pl}} \quad (\overline{126})$$

ν^c mass

(2,2,15)
(mass corrections - GJ) - automatically small
(keeps b-τ unification)

5 SETS OF YUKAWAS

- Add flavor symmetries (textures) Albright Babu, Barr Raby ...
  - $M_R = \frac{M_{GUT}^2}{M_{pl}} \simeq 10^{13}$ GeV <- nice
  - type II suppressed $(1/M_{pl})$

BUT PROTON DECAY STRIKES AGAIN

$$\frac{1}{M_{Pl}} (16_F \Gamma 16_F)(16_F \Gamma 16_F)$$

$$\downarrow$$

$$\frac{QQQL}{M_{Pl}}$$

TOO FAST $\boxed{\tau_p \simeq 10^{23} yr}$

Needs a large suppression:

$C_{pl} \leq 10^{-6}$ (why others O(1)?)

Could it be that $1/M_{Pl}$ suppressed ???

... Maybe a renormalizable theory only ??? !!!

elementary $\overline{126}_H$: GRS Glashow

AN INSTRUCTIVE

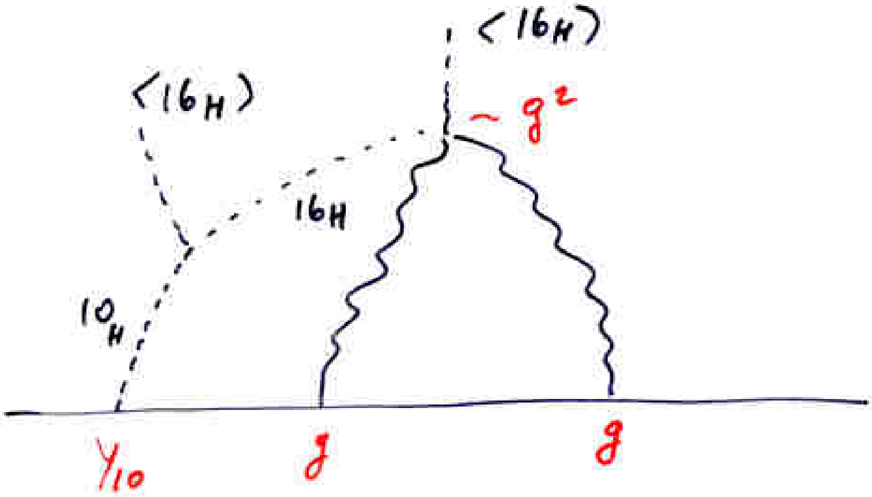
• (ILLUSTRATIVE) FAILURE

Witten '80

ORDINARY SO(10)

$10_H,\ 16_H,\ 45_H$

$\overline{126}$ – EFFECTIVE TWO-LOOP



$$M_{GUT}\ 16_H \Gamma 16_H 10_H$$

$$M_{\nu_R} \simeq Y_{10}\left(\frac{\alpha}{4\pi}\right)^2 M_{GUT}$$

$\sim Y_{up}$ ← Pati-Salam $\langle (2,2,1) \rangle$

10_H: $Y_D = Y_{up}$, $M_{\nu_R} \propto Y_{up}$

$m_\nu \propto m_{up}$

$m_e = m_{down}$ ⇒ $\theta_{lept} = \theta_{quark}$

$(=0)$

MORE 10_H ⇒ $\theta_q \neq 0$, $\theta_{lep} \neq 0$

(arbitrary) $M_{\nu_R} \not\propto M_{up}$ $\boxed{m_e = m_d}\left(1+\left(\frac{\alpha}{4\pi}\right)^2\right)$

Message?

- SUSY LOVERS :

$16_H \, 16_H \, 10_H$ $\quad M_{GUT} \to m_{3/2}$ (SOFT)

$\Rightarrow m_{\nu_R} \propto m_{3/2}$ too small

- FERMION (CHARGED) MASSES

$\left(1+\left(\frac{\alpha}{4\pi}\right)^2\right) m_d = m_e$ at M_{GUT}

cannot be corrected in Witten

– only Y_{10} flavor structure
(mostly)

$\overline{126}$ – a must for charged fermions too

([redacted]

BIG IS BETTER

- RENORMALIZABLE INT.

Clark, Kuo, Nakagawa '82
Aulakh, Mohapatra '82

Aulakh, Bajc, Melfo, Vissani, G.S. (2003)

$126_H + \overline{126}_H$

210_H (4 index antisym.)

10_H

(OR $54_H + 45_H$)

$$W_H = m_{210}\,(210)^2 + M_{126}\; 126\cdot\overline{126}$$

$$+\ \lambda\,(210)^3 + \eta\; 210\cdot 126\cdot\overline{126}$$

$$+\ \alpha\; 210\cdot 126\cdot 10 + \bar{\alpha}\; 210\cdot\overline{126}\cdot 10$$

$$W_Y = Y_{10}\, 16_F\, \Gamma\, 16_F\, 10_H + Y_{126}\, 16_F\, \Gamma^5\, 16_F\, \overline{126}_H$$

ONLY TWO SETS OF SYMMETRIC (generation space) YUKAWAS

$$\Downarrow$$

$3 + 6 \cdot 2 = 15$ real parameters (only)

Pati - Salam decomposition

$i = 1, \dots, 10$

$a = 1, \dots, 4$ $SO(4) = SU(2)_L \times SU(2)_R$

$\alpha = 5, \dots, 10$ $SO(6) = SU(4)_C$

- 10_H :

$$\utilde{10_a \ (2,2,1)}$$

$$10_\alpha \ (1,1,\alpha)$$

- 210_H :

$$[abcd] = \underline{(1,1,1)}$$

$$[abc]\alpha = (2,2,6)$$

$$[ab][\alpha\beta] = \underline{(1,3,15)} + (3,1,15)$$

$$a\,[\alpha\beta\gamma\delta] = \utilde{(2,2,10)} + \utilde{(2,2,\overline{10})}$$

$$[\alpha\beta\gamma\delta] = \underline{(1,1,15)}$$

— = GUT vev fields

- $126_H, \overline{126_H}$:

$$[abcd]\alpha = (1,1,6)$$

$$[abc][\alpha\beta] = \utilde{(2,2,15)}$$

$$[ab][\alpha\beta\gamma] = \underline{(1,3,10)} + (3,1,10)$$

↑ type II

∼∼ = light Higgs candidates

Pati - Salam decomposition

$i = 1, \ldots, 10$

$a = 1, \ldots, 4$ $SO(4) = SU(2)_L \times SU(2)_R$

$\alpha = 5, \ldots, 10$ $SO(6) = SU(4)_C$

- 10_H :

$$\utilde{10_a \; (2,2,1)}$$

$$10_\alpha \; (1,1,\alpha)$$

- 210_H :

$$[abcd] = \underline{(1,1,1)}$$

$$[abc]\alpha = (2,2,6)$$

$$[ab][\alpha\beta] = \underline{(1,3,15)} + (3,1,15)$$

$$a\,[\alpha\beta\gamma\delta] = \utilde{(2,2,10\;)} + \utilde{(2,2,\overline{10})}$$

$$[\alpha\beta\gamma\delta] = \underline{(1,1,15)}$$

— = GUT vev fields

- $126_H, \overline{126_H}$:

$$[abcd]\alpha = (1,1,6)$$

$$[abc][\alpha\beta] = \utilde{(2,2,15)}$$

$$[ab][\alpha\beta\gamma] = \underline{(1,3,10)} + \underset{\substack{\uparrow \\ \text{type II}}}{(3,1,10)}$$

∼∼ = light Higgs candidates

LIGHT HIGGS ?

$$\boxed{\begin{array}{l}(\Phi) \equiv 210, \\ \Sigma, \bar{\Sigma} \equiv 126, \overline{126} \\ H \equiv 10\end{array}}$$

$$\Delta W_H = \alpha \underset{\substack{\uparrow \\ 210}}{\Phi} \underset{\substack{\uparrow \\ 126}}{\Sigma} \underset{\substack{\uparrow \\ 10}}{H} + \bar{\alpha} \, \Phi \bar{\Sigma} H$$

$$\downarrow \qquad\qquad\qquad\qquad \searrow$$

$$\begin{array}{ccc} (2,2,10) & (2,2,1) & \langle(1,3,\overline{10})\rangle \\ \Phi & H & \langle \Sigma \rangle \\ (210) & (10) & (126) \end{array} \qquad \begin{array}{ccc} (2,2,1) & (2,2,15) & \langle(1,1,15)\rangle \\ H & \Sigma & \langle \Phi \rangle \end{array}$$

$$\Downarrow$$

$$\text{LIGHT Higgs} = \underset{H(10)}{(2,2,1)} + \underset{\substack{\uparrow \\ \bar{\Sigma}\,(\overline{126})}}{(2,2,15)} + \cdots$$

$$\Downarrow$$

$\bar{\Sigma}\,(\overline{126}_H)$ at the same time

gives a mass to ν_R: $\langle(1\,3\,10)\rangle$

and charged fermions: $\langle(2,2,15)\rangle$

Lazarides, Shafi, Wetterich '81

↑

Georgi - Jarlskog

Babu, Mohapatra '92

see - saw : I or II (or both) ?

INEQUIVALENT

Bajc, Vissani, G.S
'2004

II : $m_\nu^{II} \propto M_e - M_d$

2 - 3 gen.

$$\overset{\parallel}{\begin{pmatrix} m_\mu & 0 \\ 0 & m_\tau \end{pmatrix}}$$

θ_q small $\Rightarrow$ $m_\nu^{II} \propto \begin{pmatrix} m_\mu - m_s & \epsilon \\ \epsilon & m_\tau - m_b \end{pmatrix}$

$$\boxed{\text{Large } \theta_{atm} \Leftrightarrow m_b = m_\tau}$$

Bajc, Vissani, G.S.
PRL '2003

3 generations : numerical studies

Goh, Mohapatra, Ng
'2003

large 1-3 mixing : $|U_{13}| \simeq .15$

R - PARITY

Aulakh, Melfo, G.S.
+ Rasin

better $M = (-1)^{3(B-L)} \equiv (-1)^{2S} R$

- $M \ \overline{126} = \overline{126}$

- $\langle \tilde{\nu}_R \rangle = 0$ (in 16_F)

  $M_{\tilde{\nu}_R} = M_R \gg m_{3/2}$ – does not destabilized

- $\langle \tilde{\nu}_L \rangle = ?$ Aulakh, Mohapatra ('82)

  IN MSSM ⇒ MAJORON COUPLED TO Z – ruled out!

integrate out N (ν^c) superfield

$$W_{eff} \simeq Y_D^2 \frac{(LH)^2}{m_N} \Rightarrow V \simeq m_{3/2} Y_D^2 \frac{(\tilde{L}H)^2}{m_N}$$

$$\langle \tilde{\nu}_L \rangle = \langle \tilde{L} \rangle \neq 0 \Rightarrow m^2_{Im\,\tilde{\nu}_L} = Y_D^2 \frac{m_{3/2}\, m_W^2}{m_N} \ll m_W$$

$$\Downarrow$$

Z decay ⇒ ruled out

$\boxed{\text{R-parity exact}}$ STABLE LSP (DARK MATTER)

OBJECTIONS

- NOT asymptotically free

  $\Lambda_F \lesssim 10 M_{GUT}$ (strong coupling)

- WHY NO $1/M_{pe}$ TERMS $(1/\Lambda_F)$?

  $\uparrow$

  Hint: $c_{pe} \dfrac{QQQL}{M_{pe}} \Rightarrow c_{pe} \leq 10^{-6}$

  $c_F \dfrac{QQQL}{\Lambda_F} \Rightarrow c_F \leq 10^{-8}$

  All small ? OR hierarchy large to small ?

- computations involved (C-G), but under control

Bajc, Melfo, Vissani, G.S.

Fukuyama, Ilakovac, Kikuchi, Meljanac, Okada

treshold effects small ? $\Leftarrow$ Aulakh, Girdhar (2004)

CONCLUSIONS

?

QUEST GOES

ON

LEPTO GENESIS

Rather involved; not clear who is the culprit

most natural:

ν_R ($\tilde{\nu}_R$) decay ↖

but Δ could naturally dominate the process (II type)

Hambye, G.S. '03

Antusch, King '04

needs detailed study

(planned)

Large M_R a problem in SUGRA

(gravitino abundance)

PROTON DECAY

SUSY:

- $d=4$ absent with $\overline{126}$

  and 16 if more symmetry postulated

- $d=6$ somewhat slow

  $M_{GUT} \simeq 10^{16}$ GeV $\Rightarrow$ $\tau_p \simeq 10^{36}$ yr

- $d=5$ somewhat fast ($\overline{126}$)

  needs a detailed study

Mohapatra et al
(2003)

Aulakh, Bajc, Melfo,
Vissani, G.S.
(in progress)

ORDINARY:

$d=6$ possibly observable

Fukuyama et al
(OK)
(fine-tuning)
8/6/2004

- d=5 proton decay: uncertainties

$16_H + \overline{16}_H, \quad 45_H$

$$45 = \underset{SU(5)}{24} + \underset{SU(5)}{1} + \underset{SU(5)}{10} + \underset{SU(5)}{\overline{10}}$$

$24 = 8_c + 3_w +$ "goldstones"

<u>NO</u> CUBIC TERM $(24)^3 \Rightarrow$

FROM $(24)^4$: $m_3 = 4\, m_8$

$\Downarrow$

$$M_{GUT} = \overset{\circ}{M}_{GUT} \left(\frac{\overset{\circ}{M}_{GUT}}{2\, m_8} \right)^{1/2} \qquad (\circ \Leftrightarrow m_3 = m_8)$$

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

—

$m_8 \simeq \overset{\circ}{M}_{GUT}^{2} / M_{pe} \Rightarrow M_{GUT} \simeq 10\, \overset{\circ}{M}_{GUT}$

Bachas, Fabre, Yanagida (96)

$m_T \simeq 30\, M_T$

$d=5 \propto m_T^2 \simeq 1000!$

Bajc, Fileviez Perez, G.S. (2002)

GIVE UP ON SUSY:

ORDINARY SO(10)

UNIFICATION : $M_{SU(2)_R} \simeq 10^{10} - 10^{13}$ GeV

- $16_H, 45_H \Rightarrow M_R = \frac{M^2_{SU(2)_R}}{M_{pe}} \simeq 10 - 10^7$ GeV

NOT GOOD

- $\overline{126}_H, 210_H$: $M_R = 10^{10} - 10^{13}$ GeV

GOOD

AF OK

In this case no problem with large representations

# of fields <u>not</u> an issue –

calculability

Bacella et al
(2000 - 2004)

Bajc, Melfo, Vissani,
G.S.
(in preparation)