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MSGUTs at 25: back to Limbo?

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MSGUTs at 25 : back to Limbo ?

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- MSGUTs : A brief bi(bli)o-graphy
- SO(10) Fermion Fitting Frenzy
- Bloom to Doom : MSGUT Seesaw failure
- Saving the MSGUT
- New Minimal Susy GUT : Back to Limbo ?
- RG Thresholds : Generic $\tau_P^{d=5} >> 10^{33yrs}$ yrs
- Pleromal Condensation : Liberation from Limbo ?

MSGUTs : A brief bi(bli)o-graphy -I

Structural Aspects : SSB,Spectra,RG Flow

- BIRTH (1982) : $\mathbf{210 + 10 + 126 + \overline{126}}$ **SO(10) Susy GUT** CSA,Mohapatra ; Clark, Kuo, Nakagawa.
- BAPTISM 1993 : D.G. Lee : Symmetry Breaking and Mass Spectra in Minimal Susy SO(10) Unified Theory
- BAR-MITZVAH 2003 : Parameter Counting, Analytic SSB CSA, Bajc, Melfo, Senjanovic,Vissani(BMSV) (2003,2004); Spectra CSA Girdhar (2003,2004); BMSV (2004) ; Fukuyama, Ilakovac, Kikuchi, Meljanac, Okada(2004).
- YOUTH : Threshold Effects Meaningful : CSA,Girdhar(2004); Apposite (High M_X, M_t..) : CSA, Garg(2005,2006) *The New MSGUT*.

MSGUTs : A brief bi(bli)o-graphy -II

Angst and Bloom : Fermion Spectra and Predictivity

- Seminal idea for SO(10) Fermion Masses : $\mathbf{10} + \overline{\mathbf{126}} \Rightarrow$ **predictive for** M_ν **? !** Babu, Mohapatra(1992)
- Angst : Large θ_{PMNS} failures : **First Type I fit : Complex!** Matsuda,Koide, Fukuyama,Nishiura (2002) BLOOM Bajc, Senjanovic, Vissani(2003) : **Type II** $\Rightarrow m_b - m_\tau \Leftrightarrow$ *large* θ_{PMNS} **: FFF** ; 3 Generation. Goh Mohapatra Ng + Nasri (2003,4).
- Bertolini,Frigiero, Malinsky(2004,2005)Realistic Type II +/− **120**; Babu,Macesanu(2005) (Almost) Realistic Type I, II.
- Datta,Mimura, Mohapatra(04/05): $\mathbf{120} + < \mathbf{CP} > +$ **Type II** optimal

MSGUTs : A brief bi(bli)o-graphy -III

Doom and Rebirth : Falsification and reinvention

- Intimations of Mortality : M_ν always too small hep-ph/0506291 **C.S.A** *MSGUTs From germ to bloom : Towards Falsifiability and beyond* ; BMSV (hep-ph/0511352):'x' best scan parameter .
- hep-ph/0512224 Global Proof **C.S.A, S.K. Garg** *MSGUT : From Bloom to Doom.*
- Confirmed Heartbreak ph-0605006, **Bertolini,Schwetz, Malinsky**
- $\mathbf{10}, \mathbf{120} >> \overline{126}$ Type I evades no-go CSA hep-ph/0602132, hep-ph/0607252 .
- Accurate Type I $10, 120 >> \overline{126}$ Realistic Fits : W. Grimus and H. Kühbock hep-ph/0607197, hep-ph/0612132. Non predictive !

VIRTUES OF SO(10) UNIFICATION

- $\{Q_L, L_L, u_L^c, d_L^c, l_L^c \oplus \nu_{\mathbf{L}}^{\mathbf{c}}\} \equiv 16$: Tight and complete !
- NATURAL HOME TO BOTH SEESAWS
  $\vec{\Delta}_R(1,3,-2), \vec{\Delta}_L(3,1,2) \subset \overline{126}$:

$$M_{B-L} \sim < \vec{\Delta}_R >_{SM=0} \Rightarrow M_{\nu^c} \Rightarrow M_\nu^I$$
$$\frac{v_W^2 M'_{B-L}}{M_{B-L}^2} \sim < \vec{\Delta}_L >_{Y=2, T_{3L}=-1} \Rightarrow \quad M_\nu^{II}$$

- SO(10) FM Higgs

$$16 \otimes 16 \quad = \quad 10 \oplus 120 \oplus 126 \Rightarrow 16 \cdot 16 \cdot (10 + 120 + \overline{126})$$

- SO(10) AM Higgs (R-PARITY PROTECTED! LSP STABLE):
  $\mathbf{45} \oplus \mathbf{54} \oplus \mathbf{126} \oplus \overline{\mathbf{126}}$ OR $\mathbf{210} \oplus \mathbf{126} \oplus \overline{\mathbf{126}} \Rightarrow MSGUT$

Guts OF MSGUT

- **AM Higgs** : $< \mathbf{210}(\Phi_{ijkl}), \ \ \overline{\mathbf{126}}(\overline{\mathbf{\Sigma}}_{ijklm}) \ \ \mathbf{126} > \Rightarrow$
  $Susy\ SO(10) \longrightarrow MSSM$
- **FM Higgs** : $\mathbf{10}$-plet($\mathbf{H}_i$) $\ \overline{\mathbf{126}}$ dual (AM-FM) : $v_{EW}, M_\nu^{I,II}$
- $3 \times \mathbf{16} : \mathbf{\Psi_A}(A = 1,2,3)$ **MATTER** (including $\bar{\nu}_L^A$).
  $\mathbf{16} = (4,2,1) + (\bar{4},1,2) \quad ; \quad \mathbf{4} = [3,1,\frac{1}{3}] + [1,1,-1]$
  $(4,2,1) = (Q_\alpha, L_\alpha) \qquad\qquad (\overline{4},1,2) = (\overline{Q}_{\dot\alpha}, \overline{L}_{\dot\alpha})$
-

  $$SU(3) \times U(1)_{B-L} \times SU(2)_R \times SU(2)_L \subset SU(4) \times SU(2)_R \times SU(2)_L \subset SO(10)$$

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

MSGUT SSB-I : VEVS

- **Superpotential**

$$\begin{aligned} W &= m\ 210^2 + \lambda\ 210^3 + M\ 126\cdot\overline{126} + \eta\ 210\cdot 126\cdot\overline{126} \\ &+ 10\cdot 210(\gamma\ 126 + \bar{\gamma}\ \overline{126}) \\ &+ M_H\ 10^2 + h_{AB}\ 16_A\cdot 16_B + f'_{AB}\ 16_A 16_B \end{aligned}$$

Superpotential Parameters : (**25**) **Minimal** !! ABMSV(2003)

- **GUT scale VEVS** : $SO(10) \rightarrow MSSM$

$$\langle(15,1,1)\rangle_{210} \quad : \quad \langle\phi_{abcd}\rangle = \frac{a}{2}\epsilon_{abcdef}\epsilon_{ef}$$

$$\langle(15,1,3)\rangle_{210} \quad : \quad \langle\phi_{ab\tilde{\alpha}\tilde{\beta}}\rangle = \omega\epsilon_{ab}\epsilon_{\tilde{\alpha}\tilde{\beta}}$$

$$\langle(1,1,1)\rangle_{210} \quad : \quad \langle\phi_{\tilde{\alpha}\tilde{\beta}\tilde{\gamma}\tilde{\delta}}\rangle = p\epsilon_{\tilde{\alpha}\tilde{\beta}\tilde{\gamma}\tilde{\delta}}$$

$$\langle(10,1,3)\rangle_{\overline{126}} \quad : \quad \langle\overline{\Sigma}_{\hat{1}\hat{3}\hat{5}\hat{8}\hat{0}}\rangle = \bar{\sigma} \quad ; \quad \langle(\overline{10},1,3)\rangle_{126} \ : \langle\Sigma_{\hat{2}\hat{4}\hat{6}\hat{7}\hat{9}}\rangle = \sigma$$

MSGUT SSB-III : Analytic Solution : 1 Complex Modulus

- D Terms : $|\sigma| = |\overline{\sigma}|$

- F Terms :SSB completely analyzable !!4 eqns $\Rightarrow$ **Cubic in** $x = -\lambda\omega/m$: $\xi = \frac{\lambda M}{\eta m}$. (ABMSV 2003)
  $8x^3 - 15x^2 + 14x - 3 = -\xi(1-x)^2$

- Units : $\frac{m}{\lambda}$
  $\tilde{a} = \frac{(x^2+2x-1)}{(1-x)}$; $\tilde{p} = \frac{x(5x^2-1)}{(1-x)^2}$; $\tilde{\sigma}\tilde{\overline{\sigma}} = \frac{2}{\eta}\frac{\lambda x(1-3x)(1+x^2)}{(1-x)^2}$

- At Special Points : Quadratic/Linear e.g :

* $SU(5) \times U(1)$: $p = a = -\omega = -m_\Phi/3\lambda$; $\sigma = 0$

* $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$: $p = \omega = \sigma = 0$; $a = -m_\Phi/\lambda$

Spectra and Control Parameter x

- ξ/x **Crucial Control Parameter**

  $x \to \xi$ **1 to 1**!! Trade ξ for x : : **3 FOLD GAIN !!**

  :SCAN OVER x-plane for fixed values of slow parameters.

- Chiral GUT scale spectra : 52 MSSM multiplet sets,

  26 MSSM types : 18 unmixed , 8 mixed : 504 Fields

  CSA, Girdhar(2003) ; Fukuyama, Ilakovac, Kikuchi, Mejanac, Okada (2004), BMSV (2004), CSA Girdhar(2004)

  Complete gauge, spinor couplings , Clebsches : CSA Girdhar (2002) (2004)

- Spectra⇒ RG including Threshold effects etc.CSA, Girdhar (2004), CSA, Garg(2005/6)

Light Doublets and $m_{q,l}$

- Doublet Masses CSA, Girdhar (2003) : $\mathbf{10}, \overline{\mathbf{126}}, \mathbf{126}, \mathbf{210}$

$$\mathcal{H} = \begin{pmatrix} -M_H & +\bar\gamma\sqrt{3}(\omega - a) & -\gamma\sqrt{3}(\omega + a) & -\bar\gamma\bar\sigma \\ -\bar\gamma\sqrt{3}(\omega + a) & 0 & -(2M + 4\eta(a + \omega)) & 0 \\ \gamma\sqrt{3}(\omega - a) & -(2M + 4\eta(a - \omega)) & 0 & -2\eta\bar\sigma\sqrt{3} \\ -\sigma\gamma & -2\eta\sigma\sqrt{3} & 0 & -2m + 6\lambda(\omega - a) \end{pmatrix}$$

- $\overline{U}^T \mathcal{H} U = Dg(m_H^{(1)}, m_H^{(2)}, ..);\ h^{(i)} = U_{ij} H^{(j)} \quad ; \quad \bar h^{(i)} = \bar U_{ij} \bar H^{(j)}$
- Fine Tune $M_H \Leftarrow Det\mathcal{H} = 0 \Rightarrow$ Light Doublets $H^{(1)}, \overline{H}^{(1)}$

$$E << M_X \quad : \quad \begin{array}{cccccc} h^{(i)} & \rightarrow & \alpha_i H^{(1)} & ; & \alpha_i = U_{i1} \\ \bar h^{(i)} & \rightarrow & \bar\alpha_i \bar H^{(1)} & ; & \bar\alpha_i = \bar U_{i1} \end{array}$$

- $\mathcal{H}\alpha = 0 \quad ; \quad \bar\alpha^T \mathcal{H} = 0 \quad \Rightarrow \alpha, \overline{\alpha}.$
(ABMSV(2003), BMSV(2004),CSA,Garg(2006))

FERMION MASSES IN SO(10)

- Data for GUT To Explain :
  Measured(17) : $m_{q,l}, \theta_i^{CKM}, \delta^{CKM}, \Delta m_\nu^2, \theta_{12,23}^{PMNS}$
  Bounded: $\theta_{13}^{PMNS} < .15$
- **Awaited (4) :** $M_\nu, \delta^{PMNS}, \alpha_{1,2}^{PMNS}$
- Yukawa couplings : $h = h^T, f = f^T, g = -g^T$
  $W = \mathbf{16}_A \times \mathbf{16}_B \cdot (h_{AB}\mathbf{10} + f_{AB}\overline{\mathbf{126}} + g_{AB}\mathbf{120})$
- MSGUT : only $\mathbf{10} + \overline{\mathbf{126}}$ Dirac masses at M_X

$$\begin{aligned} m^u &= v(\hat{h} + \hat{f}) \\ m^\nu &= v(\hat{h} - 3\hat{f}) \\ m^d &= v(r_1\hat{h} + r_2\hat{f}) \\ m^l &= v(r_1\hat{h} - 3r_2\hat{f}) \end{aligned}$$

- Seesaw masses :

$$
\begin{aligned}
M_\nu^I &= v r_4 \hat{n} \\
M_\nu^{II} &= 2 v r_3 \hat{f} \\
\hat{n} &= (\hat{h} - 3\hat{f}) \hat{f}^{-1} (\hat{h} - 3\hat{f})
\end{aligned}
$$

- Babu and Mohapatra (1992): $\mathbf{10} \oplus \overline{\mathbf{126}} \Leftrightarrow \quad m_{q,l} \Rightarrow$ Predictive in the Neutrino Sector ?! : failure (1992,93,94..)

- Matsuda, Koide , Fukuyama, Nishiura (2002): Successful Type I , large θ^{PMNS} fit. Requires CP violation!

Type II: BM -BSV FITTING FRENZY

- Bajc, Senjanovic, Vissani (2003) Large PMNS mixing angle $b-\tau$ unification connection

  $$M_\nu^{II} \sim f < \Delta_L > \sim (M_d - M_l) \sim m_\tau \begin{pmatrix} & \epsilon^2 & \epsilon^2 \\ \epsilon^2 & & \frac{(m_b - m_\tau)}{m_\tau} \end{pmatrix} \Rightarrow$$

  MSSM : $m_b \simeq m_\tau(M_X) \quad \Rightarrow \theta_{23}^{PMNS} \simeq 1$

- Goh Mohapatra Ng : Type II : 3 generations , Real/Complex : Good Fits except $\delta^{CKM} > \frac{\Pi}{2}$.

- Bertolini, Malinsky (2004)(Type II, $\oplus$120) ; Babu Macesanu (2005)(Type I and II) **Good Angle and Ratio Fits. !!**

- Datta Mimura, Mohapatra(2004/5) **120**,$< CP >$,Type II: parameters reduced and generic fits excellent. $d = 5$ proton decay controllable by cancellations

MSGUT DOOM

- Type I ,Type II generic fits : freedom to choose r_1, r_2, r_3, r_4 *assumed.* M_ν scale, Relative strength of Type I / Type II *assumed.* NOT JUSTIFIED IN MSGUT !
- In MSGUT magnitude and relative strength of seesaw masses fixed !! Fit fully specified : is it viable ??
- NO !! CSA (2005),CSA,Garg (2005)

  Seesaw masses $(v^2/M_X^0 = (1.7 \times 10^{-3} eV)\ )$

$$M_\nu^I = (1.7 \times 10^{-3} eV) \sin\beta \ F_I \ \hat{n}$$
$$M_\nu^{II} = (1.7 \times 10^{-3} eV) \sin\beta \ F_{II} \ \hat{f}$$

- $F_{I,II}$ known and bounded by $10^{\sim 1}$ so M_ν too small.

$$F_I = \frac{10^{-\Delta_X}}{2\sqrt{2}} \frac{\gamma g}{\sqrt{\eta\lambda}} |p_2 p_3 p_5| \sqrt{\frac{z_2}{z_{16}}} \sqrt{\frac{(1-3x)}{x(1+x^2)} \frac{q_3'}{p_5}}$$

$$F_{II} = 10^{-\Delta_X} \frac{2\sqrt{2}\gamma g}{\sqrt{\eta\lambda}} \frac{|p_2 p_3 p_5|}{(x-1)} \sqrt{\frac{z_2}{z_{16}}} \sqrt{\frac{(x^2+1)}{x(1-3x)}} \frac{(4x-1)q_3^2}{q_3' q_2 p_5}$$

- **Demo (real ξ)** : CSA(2005-May)
- **Proof using x** : CSA,Garg (2005-December)
- **Checked**, Bertolini, Schwetz, Malinski(2006-April)
- Type II fit $\Rightarrow \hat{f}_{II} << \hat{n} = (\hat{h}(\hat{f})^{-1}\hat{h})_{II} \Rightarrow$ Type II << Type I : Compensation impossible !:
- Typical Type I fits $\Rightarrow \hat{n} \sim .5 \Rightarrow (M_\nu^I)_{max} < 10^{-3} eV$ (Including all viable singular points) $\Leftarrow F_I < 1$

Saving MSGUTs

- $\mathbf{10} \oplus \overline{\mathbf{126}}$ FM Higgs irreps $\Rightarrow$ Type I , Type II Seesaw failure : $\oplus$**120**-plet $\Rightarrow$???
- $\oplus$**120** perturbation : Bertolini Malinsky, Datta Mimura Mohapatra (Spontaneous CP and Type II) ; $g_{AB} = -g_{BA}$:
- NEW SCENARIO : $h \oplus g >> f \quad \Rightarrow (m_{q,l}, \theta^i_q, \delta_c)$. **120** not a perturbation but zeroth order contribution.

$\mathbf{120} \supset (\mathbf{15}, \mathbf{2}, \mathbf{2}) \oplus (\mathbf{1}, \mathbf{2}, \mathbf{2}) \Rightarrow$ Novel Georgi-Jarlskog$(m_\mu(M_X) \approx 3m_s(M_X))$.

- $f << h, g \Rightarrow$ Type I boosted !! $(\hat{n} \sim \hat{f}^{-1})$!
- $h, g \sim 1 >> f \Rightarrow M_{\nu^c} << M_X$: Characteristic feature!!
- Viable m_f , CKM , Δm^2_ν, PMNS ?? : Yes!

Guts of NMSGUT

- Decomposition **120**-plet w.r.t $SU(4) \times SU(2)_L \times SU(2)_R$

$$O_{ijk}(120) = O^{(s)}_{\mu\nu}(10,1,1) + \overline{O}^{\mu\nu}_{(s)}(\overline{10},1,1) + O_{\nu\alpha\dot{\alpha}}{}^{\mu}(15,2,2) + O^{(a)}_{\mu\nu\dot{\alpha}\dot{\beta}}(6,1,3) + O^{(a)}_{\mu\nu\ \alpha\beta}(6,3,1) + O_{\alpha\dot{\alpha}}(1,2,2)$$

- AM SSB unmodified, 26 MSSM multiplet types same.

$$W_{120} = M_O\ 120 \cdot 120 + k\ 10 \cdot 120 \cdot 210 + \rho\ 120 \cdot 120 \cdot 210 + \zeta\ 120 \cdot 126 \cdot 210 + \bar{\zeta}\ 120 \cdot \overline{126} \cdot 210 + g_{[AB]} 16_A \cdot 16_B \cdot 120$$

- Parameter Counting : Complex Case

$M_O, k, \rho, \zeta, \bar{\zeta}, g_{AB} : (1+1+1+2+3) \times 2 - 1 = 15 \oplus 25\ \ (old) = 40$

(Minimal No Longer ?)

- Too Hasty : Spontaneous CP violation only ? $\Rightarrow$ All Superpot couplings Real, phases from vevs ($\Rightarrow$ *Complex x!!*)

$$
\begin{aligned}
OLD &: \quad g, m, M, M_H, \lambda, \eta, \gamma, \bar{\gamma}, h_{AB}, f_{AB} : 8+3+6=17 \\
NEW &: \quad M_O, k, \rho, \zeta, \bar{\zeta}, g_{AB} : 5+3=8 \\
TOTAL &: \quad 25 \;\; I.E \;\; one\ less\ than\ MSGUT
\end{aligned}
$$

- Yukawa couplings to MSSM fermions :

$$
\begin{aligned}
m^u &= v(\hat{h} + \hat{f} + \hat{g}) \\
m_\nu &= v(\hat{h} - 3\hat{f}) + (r_5 - 3)\hat{g}) \\
m^d &= v(r_1\hat{h} + r_2\hat{f} + r_6\hat{g}) \\
m^l &= v(r_1\hat{h} - 3r_2\hat{f} + (\bar{r}_5 - 3r_6)\hat{g}) \\
\hat{g} &= 2ig\sqrt{\frac{2}{3}}(\alpha_6 + i\sqrt{3}\alpha_5)\sin\beta \quad ; \quad \hat{h} = 2\sqrt{2}h\alpha_1\sin\beta
\end{aligned}
$$

- New Baryon Decay Channels : P$[3,3,\pm\frac{2}{3}]$, K$([3,1,\pm\frac{8}{3}] \subset 120$

Can the $\overline{126}$ sub dominant scenario work in the NMSGUT ?

YES !

REAL CORE SCENARIO C.S.A (2006)

- Semi-Realistic 3 Generation Model C.S.A(June 2006) : Perturb around 23 sector Core : Good Charged Fermion fit $\oplus$ One Large PMNS $\oplus$ large $\hat{n}$

  The eigenvalues of $\hat{h}, \hat{f}, \hat{g}, \hat{n}$ are (note highly boosted $\hat{n}$)

$$\begin{aligned}
\hat{h} &: .518 \quad ; \quad .0277 \quad ; \quad 1.92\times 10^{-5} \\
\hat{f} &: 1.33\times 10^{-4} \quad ; \quad 1.11\times 10^{-4} \quad ; \quad 0.171\times 10^{-4} \\
r_5'\hat{g} &: \pm 0.122 \quad ; \quad 0 \\
\hat{n} &: 113.8 \quad ; \quad 20.045 \quad ; \quad 1.97\times 10^{-5}
\end{aligned}$$

$\Leftrightarrow$ Complex necessary ! But Phases not perturbative :

REALISTIC SPONTANEOUS CP VIOLATION FITS

- Grimus Kühbeck (July 2006) :Spontaneous CP violation : All Superpot couplings Real. Downhill Simplex Method : Accurate fit.
- Fit I ; Ad-hoc $Z_2 \Rightarrow \quad f_{12} = f_{23} = g_{13} = 0$, 21 free parameters fit 18 observables

$$
\begin{aligned}
\hat{h} \quad &: \quad 0.58 \quad ; \quad -0.0213 \quad ; \quad 0.000375 \\
\hat{f} \quad &: \quad 0.105 \quad ; \quad 0.021 \quad ; \quad 0.00033 \\
r_5'\hat{g} \quad &: \quad \pm 0.65 \quad ; \quad 0 \\
\hat{n} \quad &: \quad 31.19 \quad ; \quad 5.996 \quad ; \quad 1.045 \\
\delta^P \quad &= \quad .21 \quad ; \quad \alpha_1^P = 3.174 \quad ; \quad \alpha_2^P = 0.0023
\end{aligned}
$$

- Grimus Kühbeck Fit II, December 2006 Even better fit with only 18 parameters (No Z_2 symmetry but 6 phases fixed in maximally CP violating way in 120 sector vevs only)

$$\begin{aligned} \hat{h} &: .473 \;;\; .00037 \;;\; 8.15\times 10^{-5} \\ \hat{f} &: 2.45\times 10^{-3} \;;\; 1.49\times 10^{-3} \;;\; 5.8\times 10^{-5} \\ r_5'\hat{g} &: \pm.108 \;;\; 0 \\ \hat{n} &: 220.035, 39.867, 7.974 \\ \delta^P &= .0347 \;;\; \alpha_1^P = .0111 \;;\; \alpha_2^P = .0034 \end{aligned}$$

- Z_2 and Phase fixing are ad hoc : 4 parameter freedom remains in reserve to fit measured $\delta^{PMNS}, \alpha_{1,2}^{PMNS}, M_\nu$.
- Similar Inverted Hierarchy fit with even larger $\hat{n}$
- Clearly of the $\overline{126}$ subdominant type : $\hat{h} > \hat{r}_5'\hat{g} >> \hat{f} \sim$ and $\hat{n}$ larger by a factor $> 20 - 400$! So little constraint from GUT coefficients.

MSGUT RG Analysis

CSA Girdhar (2004), CSA (2005), CSA Garg (2005,2006)

- *Are the one loop values of* $\alpha_G(M_X), Sin^2\theta_W$ *and* M_X *generically stable against superheavy threshold corrections ?.*

- Hall(Weinberg) : MSSM / Broken SO(10) matching:

$$\frac{1}{\alpha_i(M_S)} = \frac{1}{\alpha_G(M_X)} + 8\pi b_i ln\frac{M_X}{M_S} + 4\pi\sum_j \frac{b_{ij}}{b_j} lnX_j - 4\pi\lambda_i(M_X)$$

Match Point : $M_i = M_V = M_X$ Mass of lightest $\Delta B \neq 0$ mediating $[3, 2, \pm\frac{5}{3}]$(X-type) gauge bosons

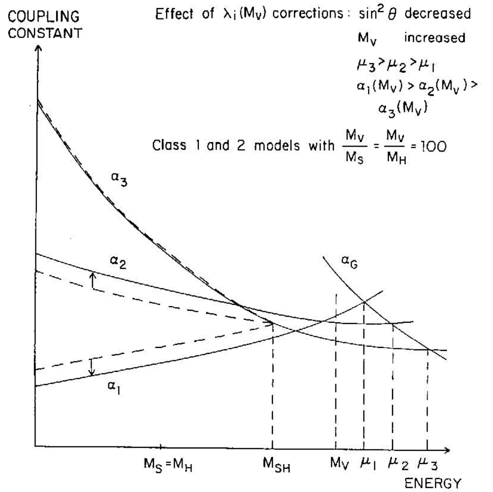

Fig. 3. Unification plot for class 1 and 2 models: $M_V > M_H = M_S$. The dashed lines show the evolution of the two-loop coupling constants $\alpha_i(\mu)$ when $\lambda_i(\mu)$ is neglected, that is with a boundary condition $\alpha_i(M_{SH}) = \alpha_G(M_{SH})$. The full curves show the evolution of $\alpha_i(\mu)$ when all second-order corrections are included. The arrows show the displacement of α_1 and α_2 due to the contributions of $\lambda_i(M_V)$ to $\sin^2\theta$. The curves are drawn for a fixed α_{QED} and α_s input at $\bar{\mu}$, but are not drawn to scale. The position of the unification points at μ_i (although not their orderings) depends on the details of the model.

Figure 1:

Unification Stability : $\Delta\{(\log_{10} M_X,\ \sin^2\theta_W(M_S)\ ,\ \alpha_G^{-1}(M_X))\}$

- SO(10) perturbative $\oplus\lambda,\eta,\gamma,\bar{\gamma},G_N$ loop neglect $\oplus$ data accuracy :

$$
\begin{aligned}
|\Delta_G| &= |\Delta(\alpha_G^{-1}(M_X))| \leq 10 \\
2 > \Delta_X &= \Delta(Log_{10}M_X) \geq -1 \\
|\Delta_W| &= |\Delta(sin^2\theta_W(M_S))| < .02
\end{aligned}
$$

- Threshold + 2 Loop (-.08,.0026,-.546) Corrections :

$$
\begin{aligned}
\Delta_X &= -.0583 + .0167\sum_{M'}(5\bar{b}_1' + 3\bar{b}_2' - 8\sum_{M'}\bar{b}_3')Log_{10}\frac{M'}{M_X} \\
\Delta_W &= .00264 - .00024\sum_{M'}(4\bar{b}_1' - 9.6\bar{b}_2' + 5.6\bar{b}_3')Log_{10}\frac{M'}{M_X} \\
\Delta_G &= -.3895 + .01832\sum_{M'}(5\bar{b}_1' + 3\bar{b}_2' + 12\bar{b}_3')Log_{10}\frac{M'}{M_X}
\end{aligned}
$$

- MSGUT 504 heavy Fields (NMSGUT 624 heavy fields)
  $\sum_{M'} \Rightarrow$ Large threshold effects ?? Dixit, Sher(1989) : *Futility of High Precision SO(10) Calculations* .
  CSA,Girdhar (2004)Calculated spectra $\Rightarrow$ well defined, consistent perturbative fine structure at M_X to 1-loop architecture.

- $\xi = \lambda M/\eta m \leftrightarrow x$ only "fast " spectral control parameter.

- $\Delta^{th} \sim \log(\lambda, \eta, \gamma, \bar{\gamma})$

* $\lambda, \eta << 1 \Rightarrow \Delta_G << 0 \Rightarrow \alpha_G$ explosion !! $\Rightarrow \lambda, \eta \sim 1$ (exact unimportant).

- Mass parameters : Overall scale : $m_{210} \sim M_X$; M_H tuned , M_{126} in ξ.

$$|m| = 10^{16.25+\Delta_X} \frac{|\lambda|}{g\sqrt{4|\tilde{a}+\tilde{w}|^2 + 2|\tilde{p}+\tilde{\omega}|^2}} GeV$$

Large M_X Natural ?

- Generic problem of Susy GUTs : $\tau_P^{d=5,\ \Delta B \neq 0} < 10^{33}$ yrs already near conflict with $M_X \sim 10^{16.25}$ GeV.
- Raising M_X with threshold corrections....... Bajc, Senjanovic (2006)

(a) Artificial cancellations to raise $\tau_P^{d=5,\ \Delta B \neq 0}$ unnatural. Radical solution: Raise M_X by threshold effects to $>\sim 10^{18} GeV$!! Shown possible in toy model with M_3, M_8 free (rest neglected)

(b) $M_X \sim M_P \Rightarrow$(Ovrut,Raby .....)dispense with extra GUT singlet sector, use GUT MSSM singlets for Susy breaking. !!

- NMSGUT : All thresholds calculated : $M_X > 10^{17.25}$ GeV generic in MSGUTs !!

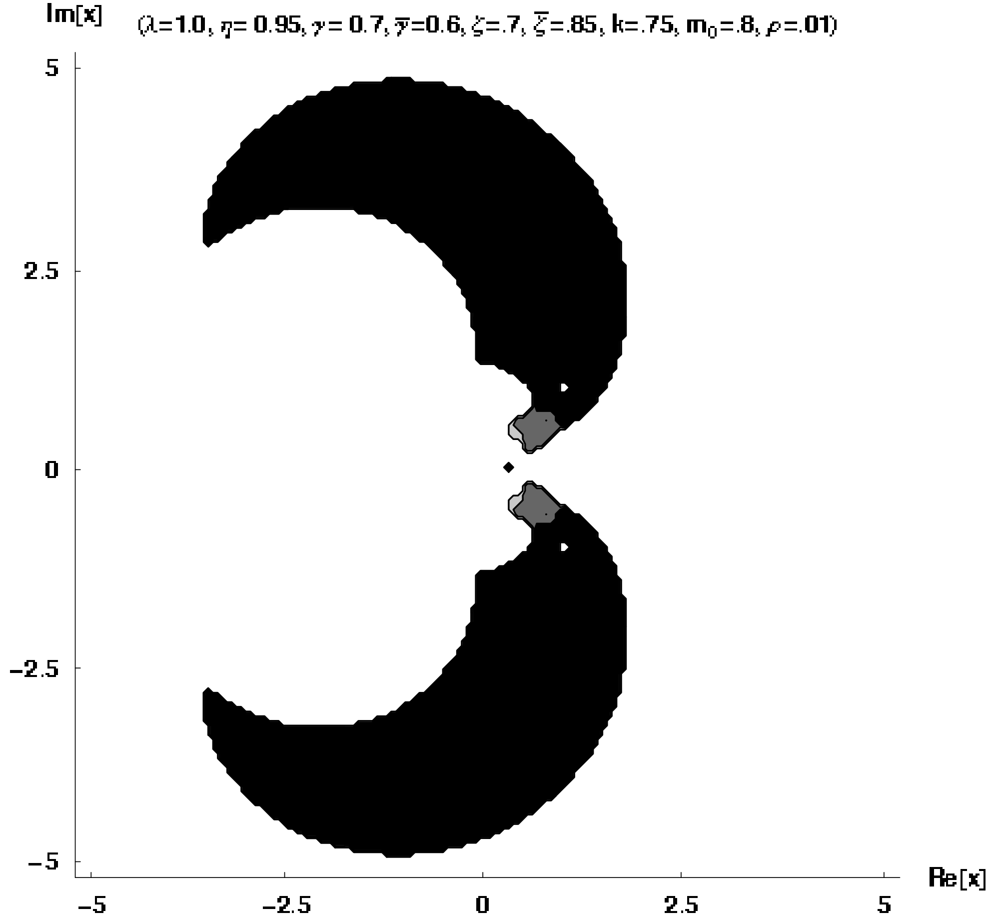

Figure 2: Typical NMSGUT : Regions of the x-plane compatible with the unification constraints : darkest regions have $2 \geq \Delta_X > 1$ (corresponding to $10^{18.25} > M_X > 10^{17.25} GeV$), the next darkest $1 \geq \Delta_X > 0$ the lightest shade $0 \geq \Delta_X > -1$ and the white regions are disallowed.

NMSGUT RG Features

- Spont CP violation requires complex branch $x_+(\xi)$
- On Spontaneous CP solution line, $\Delta_X > 0.2 \quad : M_X$ always raised !
- $x_+(\xi) \quad : \quad M_X < 10^{17.25}$ exceptionally near $\xi \sim 4$ only !
- All masses follow M_X through $m \sim M_X$: Lightest Baryon violating triplets in all sectors $t[3,1,\pm\frac{2}{3}], P[3,1,\pm\frac{2}{3}], K[3,1,\pm\frac{8}{3}]$ raised above $10^{16.5} GeV \quad \Rightarrow \quad d = 5$ decay operators innocuous.
- $\overline{\mathbf{126}}$ vev also raised above $10^{16} GeV$! Very Small $\overline{\mathbf{126}}$ Yukawa couplings necessary!! Another seesaw scissor between m_ν *and* M_X !
- Landau Pole of MSGUTs : Huge SO(10) beta Fns $\bar{b} > 137$!! $\Rightarrow \quad \Lambda \sim M_X$! Gauge/Planck strong coupling. SQUEEZE HERE !!

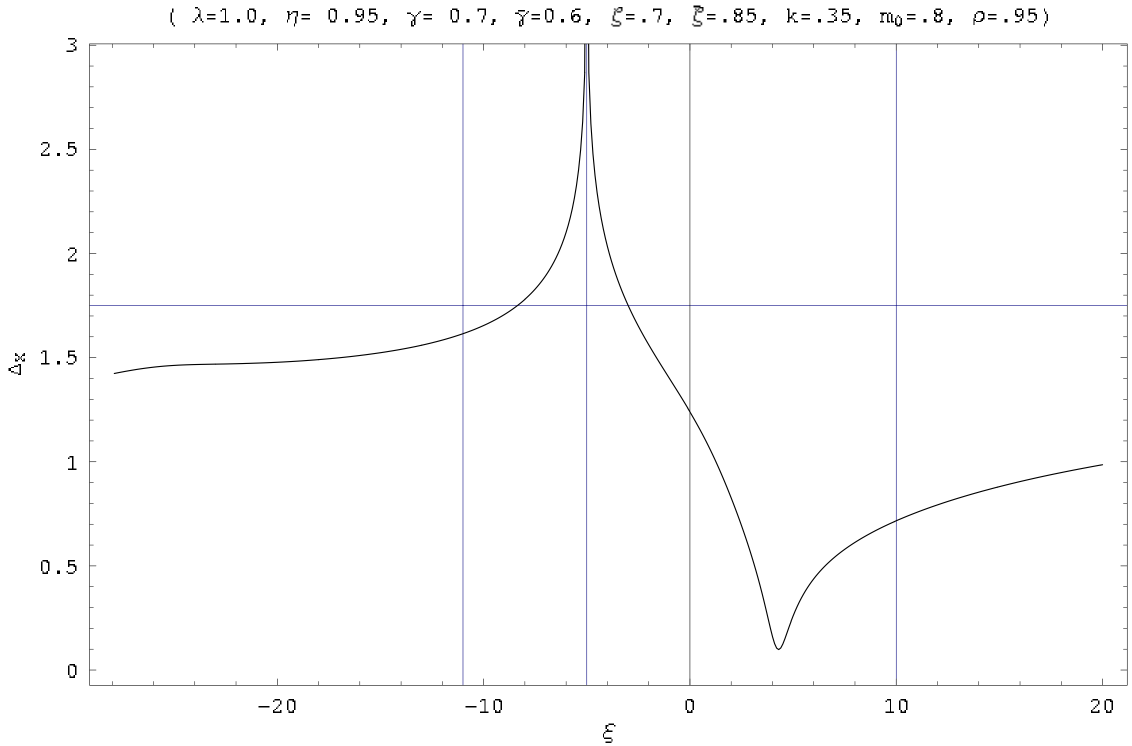

Figure 3: Plot of Δ_X against ξ on the CP violating solution branch $x_+(\xi)$ at representative allowed values of the diagonal parameters. Spike due to $C[8,2,\pm1]$ massless exactly at $\xi=-5$

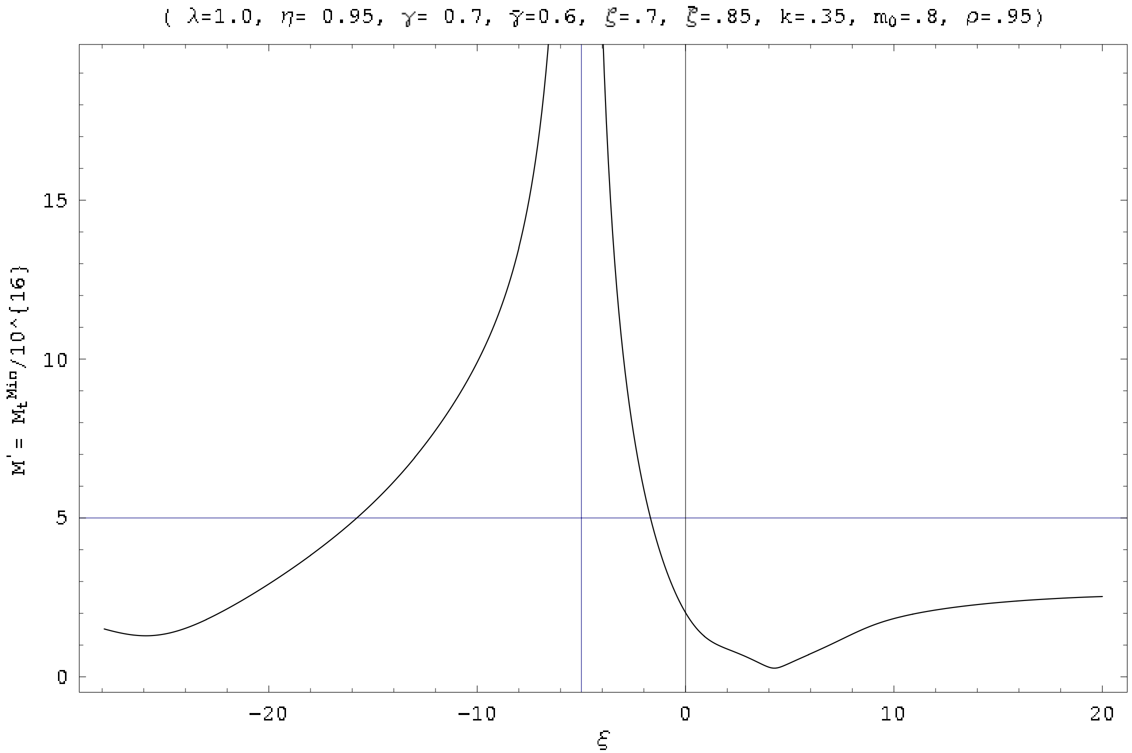

Figure 4: Plot of M_t^{min}, the lightest triplet of MSSM type $[3, 1, \pm\frac{2}{3}]$, against ξ on the CP violating solution branch $x_+(\xi)$ at representative allowed values of the diagonal parameters. Units of $10^{16} GeV$.

Taming Asymptotic Strength

- SU(2) Toy model CSA(2002): **5** plet $b_0 = 10 - 6 = 4 \Rightarrow$ Asymptotically Strong : Landau pole at $\mu = \Lambda \sim m e^{\frac{2\pi^2}{g^2(m)}}$
- Supersymmetry in UV $\Rightarrow$ Apply Holomorphy techniques !
- UV Dynamical symmetry breaking $SU(2) \to U(1)$ due to condensation of Coset gauginos and Φ in ULTRAVIOLET

$$< \lambda^+ \lambda^- > \quad \sim \quad < S = W^2/32\pi^2 >= (\sqrt{\frac{3}{10}\frac{1}{\lambda}})^5 \Lambda^3$$

$$\Phi \quad = \quad \sqrt{\frac{3}{10}\frac{\Lambda}{\lambda^2}} Diag(1, 1, -2)$$

- Vev Independent of Superpotential mass parameter !

Dynamically Breaking out of Limbo ? : Speculative Wish list

- Coset Gaugino CondensateCalculable GUT dynamical ssb by UV Susy SO(10) gaugino/chiral condensation. Gauginos in coset G/H condense preserving H, Chiral multiplet vevs break $G \to H$. Condensates related via Konishi anomaly and calculable using Seibergistics
- Konishi problem for **10,16,120** Susy breaking and/or quantum condensates of composite operators $\mathbf{16}, \mathbf{10}, \mathbf{120}$ may be required to satisfy Konishi Anomaly constraints.
- Dynamical Scale generationDSB scale arises from RG flow as UV cutoff of flow. No need for mass scales in Superpot ?
- **Susy Breaking :** Could MSSM singlets in GUT allow metastable susy breaking with $\sqrt{F} \preceq 10^{12}$ GeV ?

- Doublet masses : In absence of Superpotential mass parameters light doublet pair with masses M_I^2/M_X may arise naturally and get vevs by RSB.
- **Induced Gravity** Λ_X Supersymmetric Physical Cutoff set by Landau pole : evades no go arguments against Induced Gravity due to CC (Λ^4) and Newton's constant(Λ^2) ambiguities.
- Dual Unification Quarks with hearts(G-GUT UV tangles) dual to monopoles of $\tilde{G}$: asymptotically strong FM yukawas dual to asymptotically weak $\tilde{G}$??

Conclusions

- SO(10) NMSGUT is fully compatible with all known FM data and also probably with remaining FM data when available.
- Proton Decay scales are naturally raised
- Falsifiability problematic ! But early days yet !
- Manic/genial UV behaviour : Killer Pandora or Cornucopia ?