Spontaneous SUSY breaking in natural SO(10) GUT

Nobuhiro Maekawa (KMI, Nagoya Univ.)
with Y. Omura, Y. Shigekami, M. Yoshida

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1. Natural (anomalous U(1)) GUT
2. Sp. SUSY breaking in natural GUT
3. SUGRA effects induce gaugino masses
4. Predictions
5. Summary and discussion

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Natural GUT (Anomalous U(1) GUT)

N.M.01
N.M.&Yamashita,02

1. **Doublet-triplet splitting and realistic quark and lepton masses and mixings are realized under natural assumption.**
   Geneneric interactions (incl. higher dim. Interactions) are introduced with O(1) coefficients. (No $U(1)_R$.)
   Once we fix the symmetry of the model, we can predict everything except O(1) coefficients.

2. **Natural gauge coupling unification.**
   Natural GUT gives a new explanation for the success of gauge coupling unification in MSSM.
   The cutoff scale should be taken to be the usual GUT scale.

$$\Lambda \sim \Lambda_{GUT}$$

VEVs in natural GUT?

- VEVs are determined by the symmetry as

$$\langle Z_+^i \rangle = 0 \qquad z_+^i > 0 \quad (i = 1,2,\cdots,N_+)$$

$$\langle Z_-^i \rangle \sim \lambda^{-z_-} \quad z_-^i \leq 0 \quad (i = 1,2,\cdots,N_-)$$

$\lambda = \xi \sim 0.22 \qquad \Lambda = 1 \qquad \xi$: FI parameter

$F_{Z_-} = 0$ is automatically satisfied.

- $F_{Z_+} = 0,\ D_A = 0$ determine the VEVs of Z_-

Kim-N.M.-Nishino-Sakurai08

$N_+ + 1 > N_-$ Overdetermined meta-stable SUSY breaking

Natural GUT with sp. SUSY breaking

$N_+ + 1 = N_-$ Generically no flat direction (all massive)

Natural GUT

$N_+ + 1 < N_-$ Flat direction (massless modes appear)

Natural SO(10) GUT

- Natural SO(10) GUT

$SO(10)$	$negative$
45	$A(a=-1,-)$
16	$C(c=-4,+)$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$
10	$H(h=-3,+)$

The minimal Higgs content to break SO(10) into G_{SM}.

Natural SO(10) GUT

- Natural SO(10) GUT

$SO(10)$	$negative$	$positive$
45	$A(a=-1,-)$	$A'(a'=3,-)$
16	$C(c=-4,+)$	$C'(c'=3,-)$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$	$\bar{C}'(\bar{c}'=6,-)$
10	$H(h=-3,+)$	$H'(h'=4,-)$

The minimal Higgs sector in anomalous U(1) (natural) GUT.

Natural SO(10) GUT

- Natural SO(10) GUT

$SO(10)$	$negative$	$positive$
45	$A(a=-1,-)$	$A'(a'=3,-)$
16	$C(c=-4,+)$	$C'(c'=3,-)$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$	$\bar{C}'(\bar{c}'=6,-)$
10	$H(h=-3,+)$	$H'(h'=4,-)$
1	$Z,\bar{Z}(Z=\bar{z}=-2,-),$	$Z'(z'=5,+)$

The doublet triplet splitting problem can be solved in the almost minimal Higgs content.

Natural SO(10) GUT

- Natural SO(10) GUT

$SO(10)$	$negative$	$positive$	$matter$
45	$A(a=-1,-)$	$A'(a'=3,-)$	
16	$C(c=-4,+)$	$C'(c'=3,-)$	$\Psi_a(\psi_1=\frac{9}{2},\psi_2=\frac{7}{2},\psi_3=\frac{3}{2},+)$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$	$\bar{C}'(\bar{c}'=6,-)$	
10	$H(h=-3,+)$	$H'(h'=4,-)$	$T(t=\frac{5}{2},+)$
1	$Z,\bar{Z}(Z=\bar{z}=-2,-),$	$Z'(z'=5,+)$	

The doublet triplet splitting problem can be solved.
Realistic quark and lepton masses and mixings are obtained just by introducing all terms which are allowed by symmetry with O(1) coefficients.

Sp. SUSY breaking in natural GUT

- Natural SO(10) GUT

$SO(10)$	$negative$	$positive$	$matter$
45	$A(a=-1,-)$	$A'(a'=3,-)$	
16	$C(c=-4,+)$	$C'(c'=3,-)$	$\Psi_a(\psi_1=\frac{9}{2},\psi_2=\frac{7}{2},\psi_3=\frac{3}{2},+)$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$	$\bar{C}'(\bar{c}'=6,-)$	
10	$H(h=-3,+)$	$H'(h'=4,-)$	$T(t=\frac{5}{2},+)$
1	$Z,\bar{Z}(Z=\bar{z}=-2,-),$	$Z'(z'=5,+)$	

- Let us decrease one negatively charged field.
- One F of $W_{C'}=\bar{C}(A+Z)C',\ \ W_{\bar{C}'}=\bar{C}'(A+Z)C$ is not vanishing.

Barr-Raby 97

For alignment by Barr-Raby mechanism is sufficient if $F_{C'}=0$.

$$\frac{\partial W_{\bar{C}'}}{\partial \bar{C}'}=(A+Z)C\sim\lambda^{\bar{c}'+\frac{1}{2}(c-\overline{c})}=\lambda^{\frac{9}{2}}\sim(2\times10^{13}\mathrm{GeV})$$ too large

- SUSY breaking scale can be smaller by choosing larger $\bar{c}'$.

Gauge messenger gives sizable gaugino mass?

- Massive vector multiplets do not respect SUSY $(F_{\bar{C}'} \neq 0)$

  Generically they induce $m_{1/2} \sim c_i \frac{\alpha_i}{4\pi}\frac{F_{\bar{C}'}}{\Lambda} \sim 10^{-2} m_0$(gauge messenger)

- Unfortunately, induced gaugino masses are quite small.

  because of approximate $U(1)_R$ symmetry.

$SO(10)$	$negative$	$positive$	
45	$A(a=-1,-)$	$A'(a'=3,-)$	$\langle A\rangle \neq 0$
16	$C(c=-4,+)$	$C'(c'=3,-)$	$\langle F_{C'}\rangle \neq 0$
$\overline{16}$	$\bar{C}(\bar{c}=-1,+)$	$\bar{C}'(\bar{c}'=6,-)$	
10	$H(h=-3,+)$	$H'(h'=4,-)$	massive chiral multiplets do not
1	$Z(Z=-2,-)$,	$Z'(z'=5,+)$	respect SUSY but $m_{1/2} \sim \mathrm{m}_0^2/\Lambda$
$U(1)_R$	0	$2(F_{C'}:0)$	Very small $\langle Z'\rangle, \langle F_Z\rangle$

Very small $U(1)_R$ breaking like $\lambda^{c'+\bar{c}'}\bar{C}'C'$ must be picked up for gaugino mass.

Anomaly mediation gives $m_{1/2} \sim 10^{-2} m_{3/2} \sim 10^{-5} m_0 . (m_{3/2} \sim F_{\bar{C}'}/M_{Pl} \sim 10^{-3} m_0$

Ten years ago, we gave up to build model because of too small gaugino mass.

SUGRA effects induce $m_{1/2} \sim m_{3/2}$

N.M.-Omura-Shigekami-Yoshida17, talk by Omura

- R symmetry breaking $\langle W \rangle$ gives larger contribution to gaugino masses
- SUSY breaking spectrum becomes

$\bar{c}'$	$F_{\bar{c}'}/\Lambda$	$m_{1/2} \sim m_{3/2}$	$m_0 \sim \sqrt{D_A}$	
18	200 TeV	2TeV	2000TeV	
19	40 TeV	400 GeV	400TeV	

- High scale SUSY is predicted. (D_A dominates)

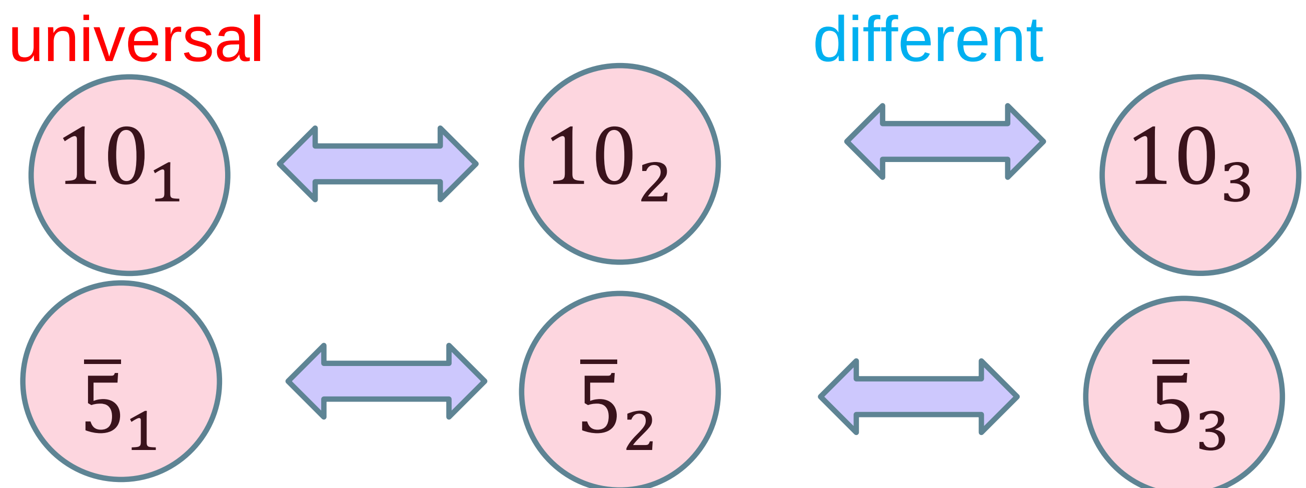
  Roughly $m_{1/2} \sim 1$ TeV, $m_0 \sim (100-)1000$ TeV
- No SUSY flavor and CP problem.

"Direct" signature for GUT

- D term dominates sfermion masses.

$$\tilde{m}^2_{10} \sim \left(\frac{9}{2},\frac{7}{2},\frac{3}{2}\right) D_A + D_V \qquad SO(10) \supset SU(5)\times U(1)_V$$

$$\tilde{m}^2_{\bar{5}} \sim \left(\frac{9}{2},\frac{5}{2},\frac{7}{2}\right) D_A + (-3,2,-3) D_V$$



- Sfermion masses respect SU(5) unification!

They can be a direct signature of unification of matter in SU(5) GUT.

- Sfermion masses are fixed by D_A and D_V.

Predictions from E_6 GUT

- $E_6 \supset SO(10) \times U(1)_{V'}$ has 3 D terms

Bando-N.M.01
N.M.-Yamashita 02

$$\tilde{m}^2_{10} \sim \left(\frac{9}{2}, \frac{7}{2}, \frac{3}{2}\right) D_A + D_{V'} + D_V$$

$$\tilde{m}^2_{\bar{5}} \sim \left(\frac{9}{2}, \frac{9}{2}, \frac{7}{2}\right) D_A + (1, -2, 1) D_{V'} + (-3, 2, -3) D_V$$

- $E_6 \times SU(2)_F$ has 4 D terms

N.M.02
Ishiduki-Kim-N.M.-Sakurai 09
N.M.-Muramatsu-Shigekami 14

$$\tilde{m}^2_{10} \sim \left(4, 4, \frac{3}{2}\right) D_A + D_{V'} + D_V + \frac{1}{2}(1, -1, 0) D_F$$

$$\tilde{m}^2_{\bar{5}} \sim (4, 4, 4) D_A + (1, -2, 1) D_{V'} + (-3, 2, -3) D_V + \frac{1}{2}(1, 1, -1) D_F$$

- The sfermion mass scale is much smaller than the GUT scale, although it is too large to reach by experiments in near future.
- Various GUT can be tested.

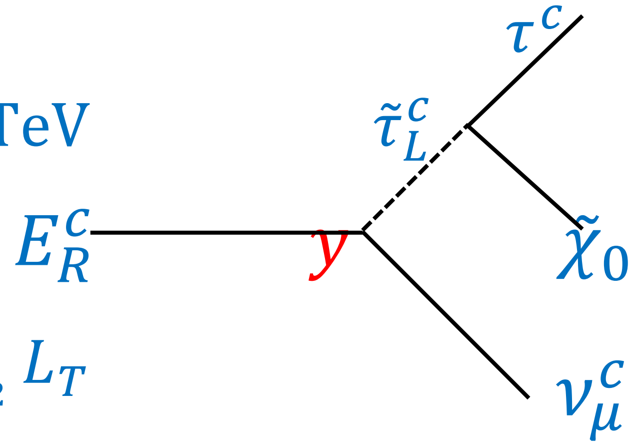
An interesting prediction(preliminary)

- Long-lived heavy electron(R-parity odd)

Lightest particle in Higgs sector is $E_R^c + \overline{E_R^c}$ in $16_{C'} + \overline{16}_{\bar{C}'}$

Roughly we take

$m_0 \sim 1000\text{TeV}, m_{1/2} \sim 1\text{TeV}, \ m_{E_R^c} \sim 1\text{TeV}$



- Decay mode is $\tau^c \nu_\mu^c \tilde{\chi}_0$ or $\mu^c \nu_\tau^c \tilde{\chi}_0$

$y = \lambda^{c'+\psi_2+t}$, $\quad 16_{C'} 16_{\psi_2} 10_T \to E_R^c L_{\psi_2} L_T$

- $\tau_{E_R^c} \sim O(1)\sec \left(\frac{10^{-6}}{y}\right)^2 \left(\frac{m_0}{1000\text{TeV}}\right)^4 \left(\frac{1\text{TeV}}{m_{E_R^c}}\right)^5$ sec

$\tau < 1$ is needed for BBN.

- LHC gives a constraint for long-lived charged particle.

$m_{E_R^c} > 574$ GeV (CMS 1305)

- LHC may find this particle.

Summary and discussions

Good points

- SUSY and GUT breaking in a model (just by decreasing a singlet).
- No R-axion. Constant superpotential is allowed by symmetry. (No $U(1)_R$.)
- It produces gaugino mass by gravity mediation. High scale SUSY!

  $m_{1/2} \sim m_{3/2} \sim$ 1TeV, $m_0 \sim$ 1000TeV.
- Interesting phenomenology.

  Long lived charged lepton appears.

$$\tau_{E_R^c} \sim O(10^{-2})\ \mathrm{sec}\left(\frac{m_0}{1000\mathrm{TeV}}\right)^4\left(\frac{1\mathrm{TeV}}{m_{E_R^c}}\right)^5$$

  LHC may discover it.
- "Direct" signatures of GUT in sfermion mass spectrum

Bad points

- High scale SUSY needs finetuning. It is caused by $\Lambda \sim \Lambda_G \ll M_{Pl}$, which is required to explain the success of RGE gauge couplings.
- Artificial discrete symmetry and singlets are introduced to obtain lower SUSY scale. (E6 GUT may avoid this issue.) Artificially large $U(1)_A$ charge.
- Gravitino problem
- Bino DM (overproduction?)

The upper 2 bad points are based on the assumption of O(1) coefficients. Suppression factors from extra dimension may avoid these.

Bino overproduction problem

Why is bino LSP?

- D term dominates $\frac{F_{\bar{C}'}}{\Lambda}$ contribution.
- μ must be large to cancel the D term contribution to Higgs.
- $m_{1/2} \sim m_{3/2} \sim 1\text{TeV},\ m_0 \sim 1000\text{TeV}$.
- Interesting phenomenology.

  Long lived charged lepton appears.

  $$\tau_{E_R^c} \sim O(1)\ \text{sec} \left(\frac{m_0}{1000\text{TeV}}\right)^4 \left(\frac{1\text{TeV}}{m_{E_R^c}}\right)^5$$

  LHC may discover it.
- "Direct" signatures of GUT in sfermion mass spectrum.
- D term domination is a result of a simple model. This may change in more realistic and complex model.)

Higgsino LSP(DM)

- $\sqrt{D} \sim \frac{F_{\bar{C}'}}{\Lambda}$.
- μ can be small since D can be cancelled by $\frac{F_{\bar{C}'}}{\Lambda}$.
- $m_{1/2} \sim m_{3/2} \sim 1\text{TeV},\ m_0 \sim 100\text{TeV}$.

  Finetuning is improved!
- Interesting phenomenology.

  Long lived charged lepton appears.

  $$\tau_{E_R^c} \sim O(0.1)\ \text{sec} \left(\frac{m_0}{100\text{TeV}}\right)^4 \left(\frac{1\text{TeV}}{m_{E_R^c}}\right)^5$$

  Yukawa suppression is compensated by smaller m_0.

  LHC may discover it.
- "Direct" signatures of GUT in sfermion mass spectrum. D-term observation becomes indirect.