No-go theorem in SUSY GUT and its implication

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Beyond Standard Model

- Standard Model Confirmed!!

  Gauge bosons, Matters, Higgs(2012)
  SU(3)×SU(2)×U(1)

- Many unsolved problems on SM

  The hierarchy between Planck and electroweak scale

  The origin of SM gauge bosons and matters

  The origin of dark matters

  Strong CP Problem …

Beyond Standard Model !!

MSSM beyond Standard Model

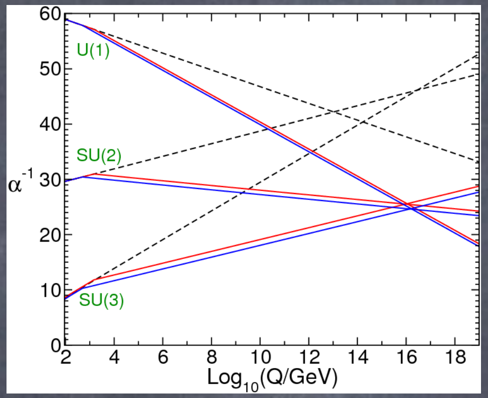
- Minimal supersymmetry standard model(MSSM)

  The hierarchy between Planck and electroweak scale

  The origin of dark matters

  <u>Gauge coupling Unification</u>

  GUT



S. Martin (1997)

- mu-Problem

  At Planck scale

  SM Higgs

  $$W_{MSSM} \ni \mu H_u H_d \qquad \underline{\mu \ll \text{Planck scale}}$$

  Planck scale?

  hierarchy problem

- Solving mu-Problem by global symmetry

  eg. R-symmetry Casas and Munoz (1993)

  $$\underset{R=+2}{W_{MSSM}} \ni \mu \underset{R=0}{\cancel{H_u} H_d} \longrightarrow m_{3/2} H_d H_d$$

  gravitino mass

GUT beyond Standard Model

- **Grand Unified Theory(GUT)**

  The origin of standard model gauge group

  eg. SU(5)⊃SU(3)×SU(2)×U(1)

  Charge quantization

  Q(proton)=-Q(electron)

- **Doublet-Triplet Splitting Problem(DTS Problem)**

$$\underset{\text{Higgs}}{H} = \underset{\text{SM}}{\begin{pmatrix} (\mathbf{3},\mathbf{1}) \\ (\mathbf{1},\mathbf{2}) \end{pmatrix}} \begin{matrix}\text{heavy}\\ \text{light}\end{matrix}, \bar{H} = \underset{\text{SM}}{\begin{pmatrix} (\bar{\mathbf{3}},\mathbf{1}) \\ (\mathbf{1},\bar{\mathbf{2}}) \end{pmatrix}} \begin{matrix}\text{heavy}\\ \text{light}\end{matrix}$$

$$\underset{\text{GUT scale}}{(\mathbf{3},\mathbf{1})} \underset{\text{mass}}{\gg} \underset{\text{SM scale}}{(\mathbf{1},\mathbf{2})}$$

Colored Higgs should be heavy

Early proton decay

- **Solving DTS Problem**

  Missing Partner, Missing VEV ....

  H. Georgi (1982) et al. S. Dimopoulous and F. Wilczek (1981)

Out Line

1. Introduction

MSSM and mu-Problem
solved by global symmetry

GUT and DTS-Problem
solved by some mechanisms

2. Our Work on SUSY GUT

2-1. No-go theorems in SUSY GUT

⇩ Compromise idea

2-2. SUGRA with gauged R-symmetry
SUSY-ZERO

No-go theorem on SUSY GUT

On SUSY GUT, can we solve mu-Problem by symmetry?

$W \ni \mu \cancel{H_u} H_d$ suppressed by symmetry

$\xrightarrow{\text{No}}$ symmetry broken at GUT scale!!

$\boxed{\text{Proof: anomaly matching}}$

Assumption: achieving DTS Problem, automatically unification

Below the GUT scale (DTS assumption)

$$H_u H_d = 2q$$

$$A^{Higgs}_{D-SU(3)_c-SU(3)_c} = 0, A^{Higgs}_{D-SU(2)_L-SU(2)_L} = 2q$$

At GUT scale (automatical unification)

$$A^{Higgs}_{D-SU(3)_c-SU(3)_c} = A^{Higgs}_{D-SU(2)_L-SU(2)_L} = A^{Higgs}_{D-SU(5)-SU(5)}$$

$$\xrightarrow[\text{Anomaly matching}]{} \underline{2q = 0!!}$$

No-go theorem on SUSY GUT

SUSY GUT cannot simply solve mu-Problem by symmetry

DTS solution   mu solution by symmetry

Remaining Hierarchy Problem !!!

K. Harigaya, M. Ibe and M. S., JHEP 1509, 155 (2015)

(For simple group GUTs by Witten et.al.)

M. Goodman, E. Witten (1986)

E. Witten (2001)

SUSY ZERO for DTS (mu) Problem

No-go theorem....

Solution: missing VEV + SUSY ZERO

- Missing VEV → massive triplet Higgs

S. Dimopoulous and F. Wilczek (1981)

$$W_{DTmass} = \mathbf{10}_1.A_1.\mathbf{10}_2 + m\mathbf{10}_2.\mathbf{10}_2$$

SO(10) GUT

SM Higgs $< A_1 >= i\sigma_2 \otimes \text{Diagonal}(a, a, a, 0, 0)$

10_i : $SO(10)$ fundamental representation

A_1 : $SO(10)$ adjoint representation

$$\longrightarrow \mathbf{10}_1.A_1.A_1.\mathbf{10}_1$$

$$\longrightarrow (\mathbf{10}_1.\mathbf{10}_{\cancel{1})}(A_1.A_1)$$ Heavy SM Higgs!!

- SUSY ZERO mechanism (holomorphy)

$\xi : U(1)_R$ order parameter

$\mathbf{10_1} = 1, A_1 = 1, \mathbf{10_2} = -3, \xi = 1$

$$W_{DTmass} = \xi^3\mathbf{10}_1 A_1.\mathbf{10}_2 + m\xi^6\mathbf{10}_2.\mathbf{10}_2$$

Q($10_1.A_1\cancel{.}A_1.10_1$) > +2

forbidden

SUSY ZERO induced by gauged-R SUGRA

Gauged R-symmetry SUGRA ⟶ SUSY ZERO

1.Supercomformal SUGRA for gauged U(1)R

SUGRA $\underset{\text{Compensator}}{\rightleftarrows}$ Supercomformal SUGRA

2.Gauged U(1)R SUGRA

SUGRA $\underset{\text{Compensator}}{\rightleftarrows}$ Supercomformal SUGRA

+U(1)R

U(1)A+U(1)X

3.U(1)R Fayet Illiopoulos term

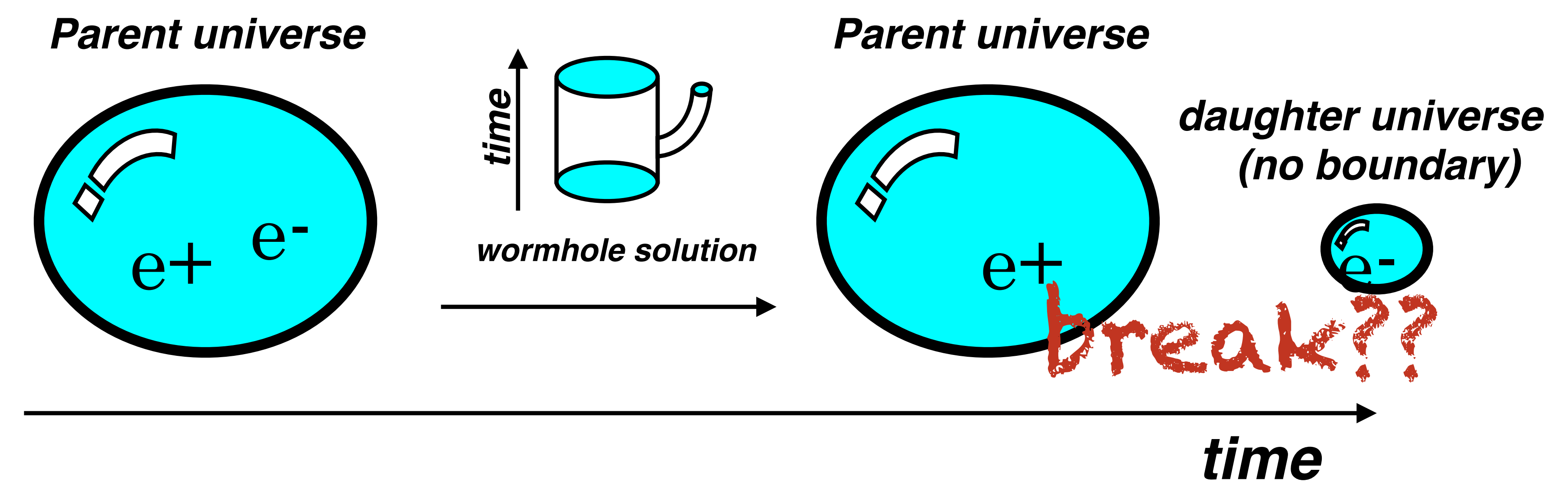
@SUGRA $$D_R^2 \sim (|\underset{\text{matter chiral field}}{\overset{+1}{\phi}}|^2 - \underset{\text{Compensator VEV}}{\overset{-1}{\xi}})^2 \longrightarrow \underset{R=+1}{<\phi>} = \xi = +2/3$$

SUSY ZERO!!

Gauge Symmetry @ Planck scale

Gauge symmetry is broken by warm fall?? → No!!

J. Preskill and L. Krauss (1990)



1. Consider Gauss Law at daughter universe

J. Preskill and L. Krauss (1990)

$$\int_{\Sigma} E \cdot dS = 0!!$$

No boundary!!

2. Gauge symmetry is just a redundancy.

L. Krauss and F. Wilczek (1989)

Conclusion

- SUSY GUT is the most attractive beyond SM
- We found "No-go theorem" for mu-Problem in SUSY GUT
- Compromise idea: gauged R-symmetry SUGRA

SUSY ZERO induced by gauged-R SUGRA

Gauged R-symmetry SUGRA

$\longrightarrow$ SUSY ZERO

SUGRA action

$$\begin{aligned} S &= \int d^4x(d^4\theta E[(-3/\kappa^2)S_0^\dagger e^{2(\xi/3)V_R}S_0 e^{-\kappa^2 K_0/3}] + [\int d^2\theta\epsilon S_0^3 W(\Phi^i) + h.c.]) \\ \kappa^2 K &\equiv \kappa^2 K_0 - 2\xi V_R \end{aligned}$$

$$S_0 : compensator, \quad \xi : Fayet - Illiopoulos\ term$$

SuperWeyl transformation + U(1)R $\longrightarrow$ "U(1)R"

SW
$$\begin{aligned} \lambda &\to e^{-3\tau}\lambda, \quad E \to e^{2\tau+2\bar{\tau}}E, \quad \epsilon \to e^{6\tau}\epsilon, \quad \mathcal{W}_\alpha \to e^{-3\tau}\mathcal{W}_\alpha, \\ V^{(a)} &\to V^{(a)}, \quad S_0 \to e^{-2\tau}S_0, \quad W \to W, \quad \bar{\mathcal{W}}^{\dot{\alpha}} \to e^{-3\bar{\tau}}\bar{\mathcal{W}}^{\dot{\alpha}} \end{aligned}$$

U(1)R
$$\begin{aligned} VR &\to V_R + \frac{i}{2}(\Lambda - \Lambda^\dagger), \quad \bar{D}\Lambda = 0, \\ \kappa^2 K &\to \kappa^2 K - i\xi(\Lambda - \Lambda^\dagger), \\ S_0 &\to e^{-i\xi/3\Lambda}S_0, \; W \to e^{+i\xi\Lambda}W \end{aligned}$$