3. Soft Masses からわかること.

① SUSYの Mediation Mechanism の選別

② 対称性 (SUGRA)

③ SUSY scale (gauge mediation)

① Mediation Mechanism

← SUSY FCNCの解決.

- "degenerate"? "decoupling"? …
- mSUGRA?

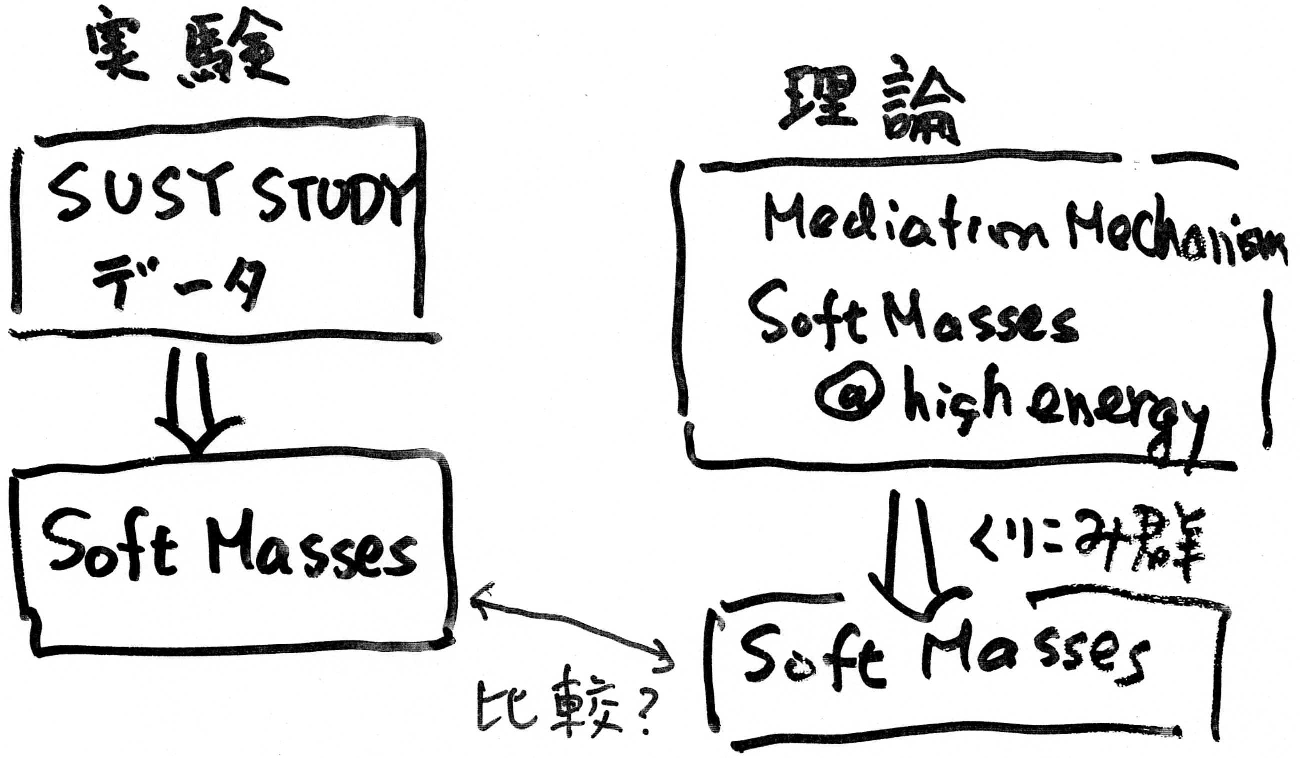
  gauge mediation?

  gaugino mediation?

  anomaly mediation?

  あるいは、今までに知られていないパターン?

(概念図)



Sparticle Masses と Soft Masses.

1. Squark, slepton (1, 2世代)

$$\begin{pmatrix}\text{physical}\\ \text{mass}\end{pmatrix}^2 = \begin{pmatrix}\text{Soft}\\ \text{mass}\end{pmatrix}^2 + (\text{D term}) \leftarrow O(m_Z^2)$$

2. Squark, slepton (3世代)

LR 混合 (← 後述)

3. Gluino

(physical mass) = (soft mass)

4. Neutralinos & Charginos

mixing.

Neutralinos & Charginos.

・Neutralino Mass Matrix $(\tilde{B}, \tilde{W}^0, \tilde{H}_1^0 \tilde{H}_2^0)$

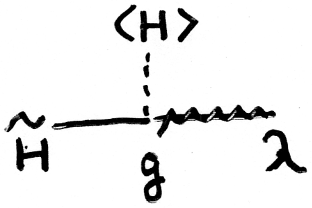
$\xrightarrow{\text{mass 対角化}}$ $\chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0$

$$\begin{bmatrix} M_1 & & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & & -\mu \\ m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & \end{bmatrix}$$

M_1, M_2 : gaugino masses for $\tilde{B}, \tilde{W}^0$

μ : higgsino mass parameter

$\tan\beta = v_2/v_1$.

[黒い部分  から来ている]

mSUGRA case

・$M_{1/2} \xrightarrow[RG]{} M_1 : M_2 = 1:2$

・μ large.

$\Rightarrow$ lightest neutralino $\chi_1^0 \simeq \tilde{B}$

・mSUGRAでないと異なるときがある.

Chargino Mass Matrix $(\tilde{W}^{\pm}, \tilde{H}^{\pm})$

$\rightarrow \chi_1^{\pm}, \chi_2^{\pm}$

$$\begin{bmatrix} M_2 & \sqrt{2}\, m_W\, c_\beta \\ \sqrt{2}\, m_W\, s_\beta & \mu \end{bmatrix}$$

くりこみ群 @ 1-loop.

・ゲージーノ

$$E\frac{d}{dE}\left(\frac{M_i}{g_i^2}\right)=0$$

もし，$M_1=M_2=M_3(=M_{1/2})$ @ GUT scale

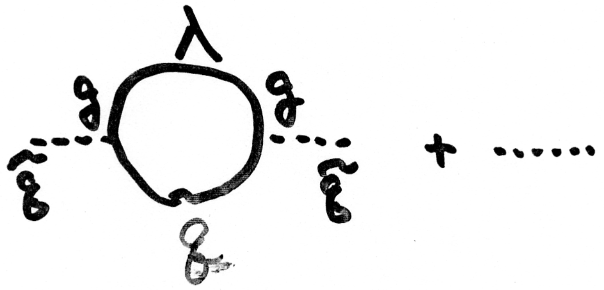
$\Rightarrow M_1:M_2:M_3\simeq 1:2:7$

@ weak scale

・スクォーク，スレプトン（1，2世代）

. Yukawa coupling 小 → 無視

・ゲージ相互作用からの寄与のみ

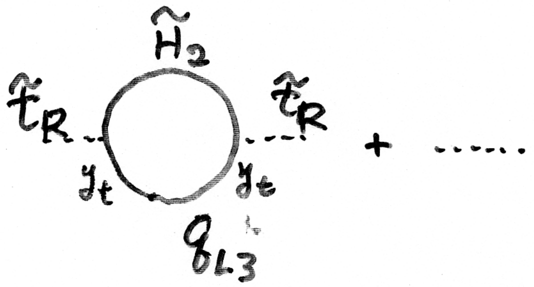


第3世代は複雑.

① くりこみ群.

Yukawa coupling が入ってくる.

$$y_t \propto \frac{m_t}{\sin\beta}, \quad y_b \propto \frac{m_b}{\cos\beta}, \quad y_\tau \propto \frac{m_\tau}{\cos\beta}.$$



② LR混合.

例) $\tilde{\tau}$ (スタウ)

$$(\tilde{\tau}_L^* \ \tilde{\tau}_R^*)\begin{pmatrix} m_{\tilde{\tau}_L}^2 & m_\tau(A_\tau+\mu\tan\beta) \\ m_\tau(A_\tau+\mu\tan\beta) & m_{\tilde{\tau}_R}^2 \end{pmatrix}\begin{pmatrix} \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix}$$

⇒ 対角化. $\tilde{\tau}_1, \tilde{\tau}_2$

② 対称性 (SUGRA scenario)

くりこみ群の出発点: GUT ~ Planck scale

高いエネルギースケールでの対称性をプローブできる.

例.)

- gaugino masses

GUT:

$M_1 = M_2 = M_3 (\equiv M_{1/2})$ @ GUT scale

と期待

$\Rightarrow M_1 : M_2 : M_3 \simeq 1 : 2 : 7$ @ weak scale

これが成り立っているか?

- Scalar Masses.

SU(5) GUT

$$10 = (q_L, u_R^c, e_R^c)$$

$$5^* = (d_R^c, l_L)$$

$$\Rightarrow \quad m_{\tilde{q}_L} = m_{\tilde{u}_R} = m_{\tilde{e}_R} = m_{10}$$

$$m_{\tilde{d}_R} = m_{\tilde{l}_L} = m_{5^*} \qquad @\,\mathrm{GUT}$$

これが成り立っているか？

SO(10) GUT. (SO(10) ⊃ SU(5) × U(1))

$$m_{\tilde{q}_L}^2 = m_{16}^2 + g^2 D$$

$$m_{\tilde{u}_R}^2 = m_{16}^2 + g^2 D$$

$$m_{\tilde{e}_R}^2 = m_{16}^2 + g^2 D$$

$$m_{\tilde{d}_R}^2 = m_{16}^2 - 3 g^2 D$$

$$m_{\tilde{l}_L}^2 = m_{16}^2 - 3 g^2 D.$$

∴ SU(5)のときと同じパターン.

SO(10) → SM : D-term contribution

Kawamura
Murayama
+ M.Y.

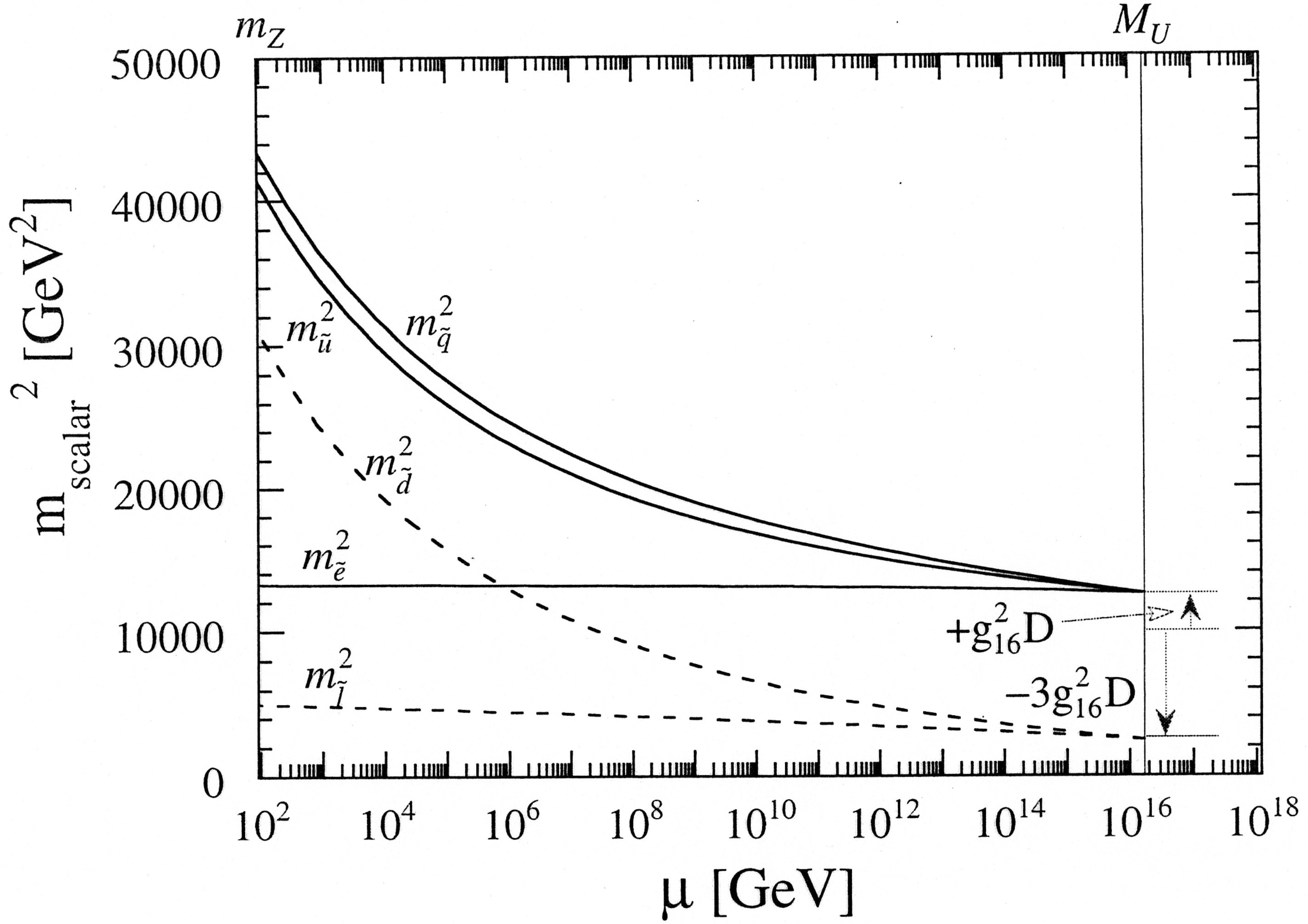
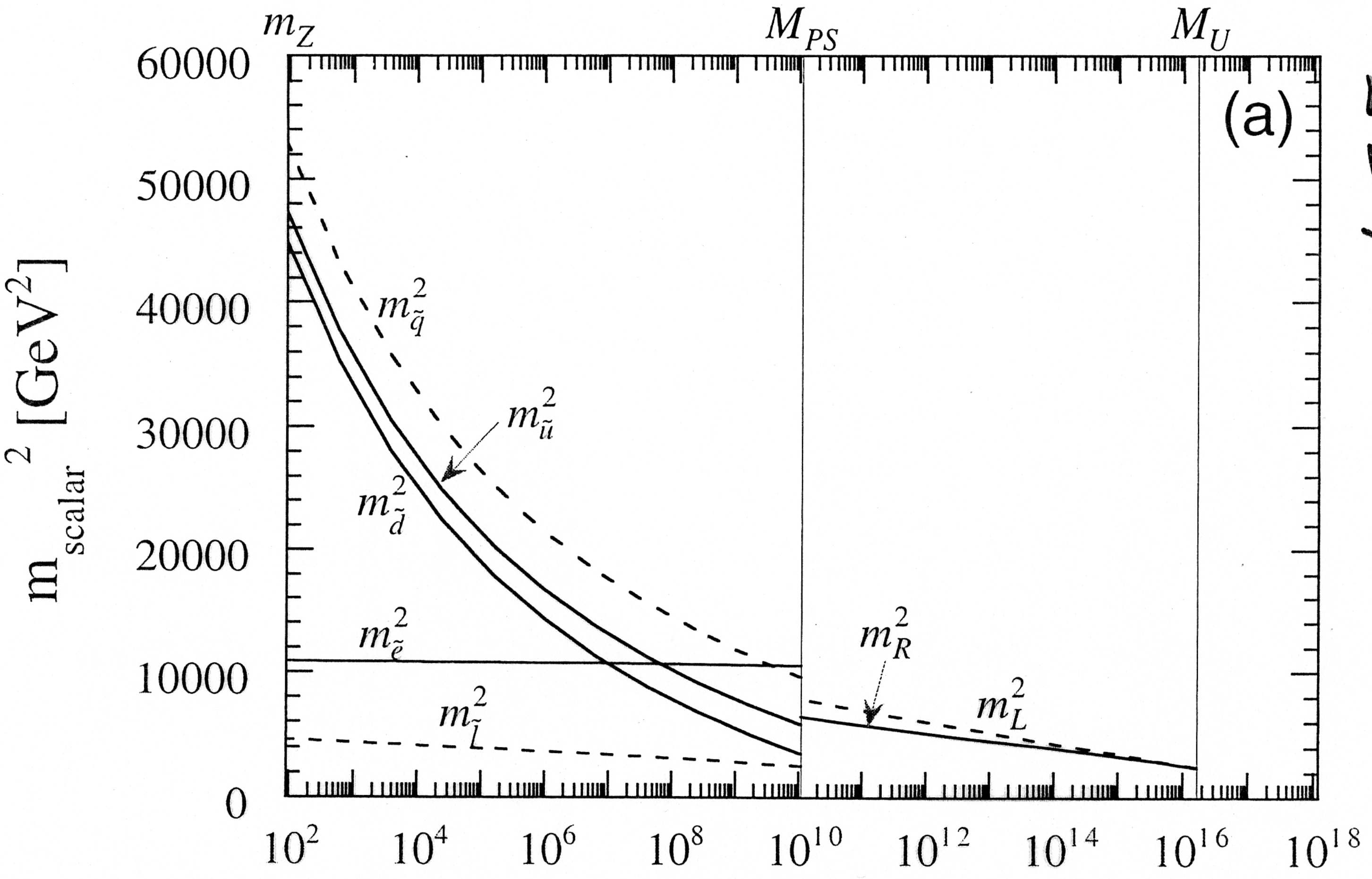


Fig. 1

p10

SO(10) → SU(4) × SU(2) × SU(2) → SM



Kawamura
Murayama
+ M.Y.

Fig. 2(a)

An Exceptional Case : Anomaly Mediation

Conformal Anomaly (スケール変換)によって、

Soft Mass が生成.

$$M_i \sim b_i \frac{\alpha_i}{4\pi} m_{3/2}$$

(b_i = β-関数の係数)

$\Rightarrow$ $M_1 : M_2 : M_3 = 3.3 : 1 : -10$

$\Rightarrow$ "Wino LSP"

何故 GUT relation が成り立たないか？

Gauge kinetic function

$$f(z) = f_0(z) + f_1(z)$$

$f_0(z)$: universal, GUT inv. part

$f_1(z)$: non-universal,
GUT breaking を感じる part.

$\langle f(z) \rangle = \frac{1}{g^2}$: ゲージ結合定数

$\langle f'(z) F_z \rangle = M$: ゲージーノ質量.

- **Coupling unification**

  $\langle f_0(z) \rangle : \langle f_1(z) \rangle = 100 : 1$

- **Gaugino mass.**

  $\langle f_0'(z) \rangle : \langle f_1'(z) \rangle$???

  $\langle f_0'(z) \rangle$ dominant → GUT relation (universal)

  $\langle f_1'(z) \rangle$ dominant → non-universal gaugino mass.

Gauge Mediation

- LSP $= \tilde{G}_{3/2}$: gravitino

$$m_{3/2} = \frac{F}{\sqrt{3} M_{pl}} \simeq 1\,\mathrm{keV} \left(\frac{\sqrt{F}}{2\times 10^6\,\mathrm{GeV}} \right)^2$$

[$m_{3/2} \sim 10\,\mathrm{eV} - 1\,\mathrm{GeV}$: model dependent]

- NLSP ? $\chi_1^0 (\simeq \tilde{B})$ or $\tilde{\tau}_R$

Longitudinal mode of gravitino
= Goldstino.
重力相互作用より強く相互作用する.

$$\Gamma(\chi_1^0 \to \gamma \tilde{G}_{3/2}) = m_\chi^5 \cos^2\theta_W / 16\pi F^2 \quad (\chi_1^0 = \tilde{B})$$

$$\to (c\tau)_{\chi_1^0} \simeq 24\,\mathrm{m} \left(\frac{100\,\mathrm{GeV}}{m_{\chi_1^0}} \right)^5 \cdot \left(\frac{m_{3/2}}{1\,\mathrm{keV}} \right)^2$$

decay length は $m_{3/2}$, NLSP mass に強く依る.

場合分け.

a) NLSP = χ_1^0, long decay length

χ_1^0 :- detector の外で decay

→ signal は SUGRA に近い.

missing energy (carried by χ_1^0)

b) NLSP = χ_1^0, short decay length.

$\chi_1^0 \to \gamma + \tilde{G}_{3/2}$

⇒ · photon + missing energy ($\tilde{G}_{3/2}$)

· decay vertex

c) NLSP = $\tilde{\tau}$ long decay width

$\tilde{\tau}$ は detector の外で decay

→ charged track.

d) NLSP = $\tilde{\tau}$ short decay width

$\tilde{\tau} \longrightarrow \tau + \tilde{G}_{3/2}$

→ · missing energy ($\tilde{G}_{3/2}$)

· decay vertex.

$m_{3/2}$ に対するヒント？

Warm Dark Matter

従来の CDM： 小さな scale での密度ゆらぎが大きすぎる

⇒ · cusp in galactic center

· power spectrum が合わない.

A Resolution

Warm Dark Matter

free streaming length ~ O(0.1–1)Mpc

1つの候補

Gravitino $m_{3/2} \sim 1\,\mathrm{keV}$.