Meaning of the Seesaw

T. Yanagida.

(Jun 1998)

Some New Physics after the Weinberg-Salam model ~ late 70's.

"Two classes of the Extensions."

(i) Horizontal Direction

$$\begin{pmatrix} \nu_e & \nu_\mu & \nu_\tau \\ e & \mu & \tau \end{pmatrix}_L \qquad (e, \mu, \tau)_R$$

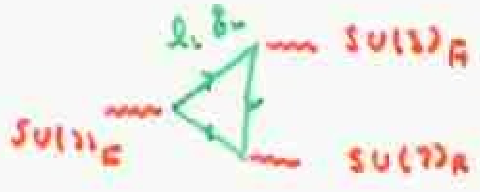
$$\begin{pmatrix} u & c & t \\ d & s & b \end{pmatrix}_L \qquad \begin{matrix} (u, c, t)_R \\ (d\ s\ b)_R \end{matrix}$$

← Horizontal SU(3) → ⟷

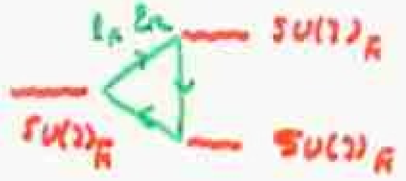
Gauging Family

$$\{ SU(3)_c \times SU(2) \times U(1) \} \times SU(3)_H$$

But this model has Gauge Anomaly.



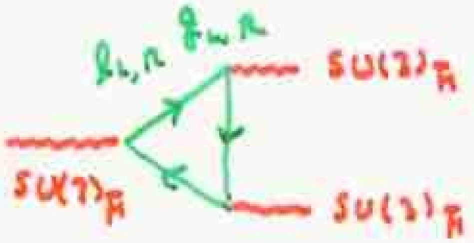
$+$



$\neq 0$

The Right-handed Neutrinos are required to cancell the anomaly !!

$$(\nu_e\ \ \nu_\mu\ \ \nu_\tau)_R$$



$= 0$!!

But the Neutrinos have Large masses as Quarks and Leptons.

$$\mathcal{L} = m_{ij}\ \bar{\nu}_R^i\, \nu_L^j\, \langle H \rangle$$

$$m_{ij} \sim m_q \sim m_\ell$$

(ii) Vertical Direction

One family : $\begin{pmatrix} u \\ d \end{pmatrix}_L \quad u_R \quad d_R$

$\begin{pmatrix} \nu \\ e \end{pmatrix}_L \quad e_R \qquad 15$

Unify all quarks and leptons

$SU(5)_{GUT}$

$$10 = \left(\begin{pmatrix} u \\ d \end{pmatrix}_L , \bar{u}_L \quad \bar{e}_L \right)$$

$$5^* = \left(\bar{d}_L \quad \begin{pmatrix} \nu \\ e \end{pmatrix}_L \right)$$

unification of $SU(3)_c \times SU(2)_L \times U(1)$

Georgi, Glashow (1972)

But this is incomplete for matter unification.

$SO(10)_{GUT}$

$$16 = \left(\begin{pmatrix} u \\ d \end{pmatrix} , \bar{u}, \bar{e} ; \bar{d} , \begin{pmatrix} \nu \\ e \end{pmatrix} : \bar{\nu} \right)$$

Right-handed Neutrino

Both extensions of the standard model contain the right-handed neutrinos.

The ν_R is a key point of new physics.

$\boxed{\text{Why they are light ???}}$

Without finding a natural explanation we could not believe them.

Beyond $\xrightarrow[\text{S.B.}]{}$ standard

ν_R get masses.

(i) $\langle \chi(\underline{\bar{5}}) \rangle = V$: $SU(3)_R \to$ nothing

$$\mathcal{L} = g \cdot \langle \bar{5} \rangle \nu_R \nu_R$$

(ii) $\langle \chi(126) \rangle = V$: $SO(10) \to SU(5)$

$$\mathcal{L} = \frac{g}{2} \langle 126 \rangle \nu_R \nu_R$$

Neutrino mass matrix

$$\mathcal{L}_{mass} = f_1 \bar{\nu}_R \nu_L \langle H \rangle + \frac{g}{2} V \nu_R \nu_R + h.c.$$

what meaning ?

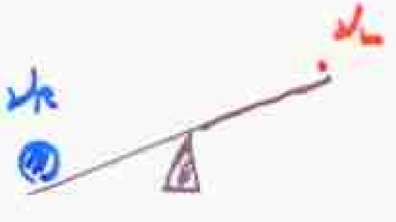
Pauli - Gürsey Transformation :

$$\begin{cases} \chi \equiv \psi_L + \psi_L^c \\ \omega \equiv \psi_R - \psi_R^c \end{cases}$$

$$\mathcal{L} = \frac{1}{2}\left(\bar{\chi}\,\gamma\,\chi + \bar{\omega}\,\gamma\,\omega\right)$$

$$+ \frac{1}{2}\left(\bar{\chi}, \bar{\omega}\right) \begin{pmatrix} 0 & f\langle H\rangle \\ f\langle H\rangle, & gV \end{pmatrix} \begin{pmatrix} \chi \\ \omega \end{pmatrix}$$

$$\begin{cases} m_\chi \simeq (f\langle H\rangle)^2/gV \\ m_\omega \simeq gV \end{cases}$$ ← Very small ν mass



See saw

「The small ν mass is an indication of a new physics at very high-energy scale.」

Generic Predictions of the Seesaw Model

G.M. R. S.
Y. (1979)

Besides the Small Neutrino Masses

$$m_{\nu_i} \simeq \frac{m_{D_i}^2}{M_i}$$

Super K

[I]

$$\begin{cases} \text{Large Mixing } \theta_{\nu_\mu - \nu_\tau} \sim O(1) \\[2ex] \text{Small Mixing } \theta_{\nu_e - \nu_\mu} \ll O(1) \end{cases}$$

MSW

⇒ A Natural Prediction of the Seesaw in the $SU(5)_{GUT}$.

P. Ramond
T. Y. (1998)

$SO(10)_{GUT}$

E_6

$SU(5)_{GUT}$:

$$10_i = \left(\begin{pmatrix} u \\ d \end{pmatrix}_L , \bar{u} , \bar{e} \right)_i$$

$$5^*_i = \left(\bar{d} \, , \, \ell = \begin{pmatrix} \nu \\ e \end{pmatrix}_L \right)_i$$

Mass Spectrum

$$\begin{array}{c|ccc} & 10_3 & 10_2 & 10_1 \\ \hline 10_3 & 1 & & * \\ 10_2 & & \sim \epsilon^2 & \\ 10_1 & * & & \sim \epsilon^4 \end{array}$$

$$\epsilon^2 \simeq \frac{m_c}{m_t} \simeq \frac{m_u}{m_c}$$

$(\epsilon \sim 0.1)$

↑ UP-type Quarks

$$\begin{array}{c|ccc} & 5^*_3 & 5^*_2 & 5^*_1 \\ \hline 10_3 & 1 & & * \\ 10_2 & & \sim \epsilon & \\ 10_1 & * & & \sim \epsilon^3 \end{array}$$

$$\epsilon \simeq \frac{m_\mu}{m_\tau}$$

$$\epsilon^2 \simeq \frac{m_e}{m_\mu}$$

↑ DOWN-type Quarks or Leptons

Broken $U(1)$:

$$W = \epsilon^{(Q_i+Q_j)}\, 10_i\, 10_j\, H$$
$$+\, \epsilon^{(Q_i+Q'_j)}\, 10_i\, 5^*_j\, \bar{H}$$

$$Q(10_i) = Q_i \qquad Q(5^*_i) = Q'_i$$

$$Q(\epsilon) = -1 \qquad \langle\epsilon\rangle \sim 0.1$$

$$\Downarrow$$

Suppose $\begin{cases} Q_3 = 0 \\ Q'_3 = 0 \end{cases} \Rightarrow \begin{cases} Q_2 = 1,\ Q_1 = 2 \\ \underline{Q'_2 = 0},\ \underline{Q'_1 = 1} \end{cases}$

★ 5^*_3 and 5^*_2 have the same $U(1)$ charge !!

ν Masses $\quad W_{eff} \simeq \dfrac{1}{\cancel{M}_i}\, \epsilon^{(Q'_i+Q'_j)}\, 5^*_i\, 5^*_j\, HH$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \ni l_i\, l_j\, \langle H\rangle^2$

Seesaw

$$\begin{array}{cc|ccc} & & (0) & (0) & (1) \\ & & l_3 & l_2 & l_1 \\ \hline (0) & l_3 & \sim 1 & \sim 1 & \sim\epsilon \\ (0) & l_2 & \sim 1 & \sim 1 & \sim\epsilon \\ (1) & l_1 & \sim\epsilon & \sim\epsilon & \sim\epsilon^2 \end{array} \Longrightarrow \begin{cases} \theta_{\nu_\mu-\nu_\tau} \sim O(1) \\ \theta_{\nu_e-\nu_\mu} \sim O(0.1) \end{cases}$$

Naturally Obtained

Unparallel Family Structure

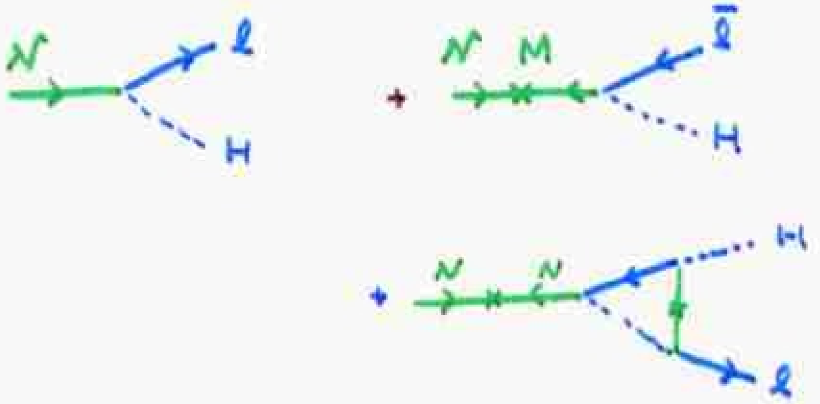
$$\left\{ \begin{array}{l} 10_3 \; , \; 5^*_{\underline{3}} \; , \; 5^*_{\underline{2}} \\ \\ 10_2 \; , \; 5^*_1 \\ \\ 10_1 \end{array} \right.$$

WHY ?

[II] Cosmological Baryon Asymmetry is Naturally Explained in the Seesaw Model

F. T.

N_R decays produce Lepton Asymmetry in the early universe. $M_{N_R} \simeq (10^{10} - 10^{15})$ GeV



$\boxed{\Delta L \neq 0}$

But $\Delta L \longrightarrow \Delta B$

Sphaleron Effects K.R.S.

$\Delta B \neq 0$ is OBTAINED.

H. Murayama

Family Unification (late 70')

$$\begin{cases} SU(5)_{GUT} \rightarrow SU(5+n) \\ SO(10)_{GUT} \rightarrow SO(10+2m) \end{cases}$$

The number of family is not fixed.

But Exceptional Group does it.

E_6, E_7, E_8 Gürsey.

$$E_8 \supset SU(8) = SU(5)_{GUT} \times \underbrace{SU(3)_F}_{\text{3 family}} \times U(1)$$

But. E_7, E_8 do not have complex representations.

All multiplets are real.

(family) + (anti-family)

Non-linear Realization of G.

$G \to H$.

We have Nambu-Goldstone bosons π_i associated to the broken generator X_i.

For example, in QCD

$$SU(3)_L \times SU(3)_R \longrightarrow SU(3)_V$$

we have $\pi_i(8)$.

But π_i are Real.

Namely if we have a broken generator X_i we always have a broken generator X^i. Thus, N-G bosons are always real ($\pi_i + \pi^i$).

$$\Downarrow \text{SUSY}$$

$$\begin{cases} \phi_i = (i\pi_i + \varphi_i) + \theta\psi_i \\ \phi^i = (i\pi^i + \varphi^i) + \theta\psi^i \end{cases}$$

$\psi^i + \psi_i$ are real.

But in SUSY theory

$$\Phi_i = \underbrace{\varphi_i}_{\text{complex boson}} + \theta\psi_i$$

Then we identify

$$\varphi_i = \pi_i + i(\pi^i)^*$$

N-G chiral multiplets are only

$$\Phi_i = \varphi_i + \theta\psi_i .$$

contain both of π_i and $(\pi^i)^*$

NG multiplets are Complex.

$$\boxed{E_7 / SU(5) \times U(1)^3}$$

$\boxed{\text{Complex}}$

G 2

Large Lepton-Mixing

in a Coset-space Family Unification

T. Yanagida

"Large ν_i Mixing Observed at Super Kamiokande

is Naturally Explained in CSFU."

I. What and Why ? Motivations

II. Generic Predictions

3 Families and Massive Neutrinos

III. Mass Matrices for Quarks and Leptons

- Natural Explanation for the Mass Hierarchy
- Large $\nu_\mu - \nu_\tau$ ← SuperK Atmospheric ν
  Small $\nu_e - \nu_\mu$ ← Solar ν
  Mixings

IV. More Speculations

I. Coset - space Family Unification (CFU)

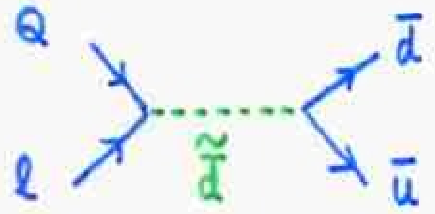
Buchmuller, Peccei, Love, T. Y.
('83)

✱ Generic Problems in SUSY standard Model

(i) Proton - decay Problem

Low - Dimensin Operators for B- Violation

· D=4 ; $W = \lambda\, \bar{d} Q \ell + \lambda' \bar{d} \bar{d} \bar{u}$



$$\sim \lambda \cdot \lambda' \frac{1}{m_{SUSY}^2}$$

$$\lambda \cdot \lambda' < 10^{-26} \; !!$$

for $m_{SUSY} < 1$ TeV.

We impose R- parity invariance.

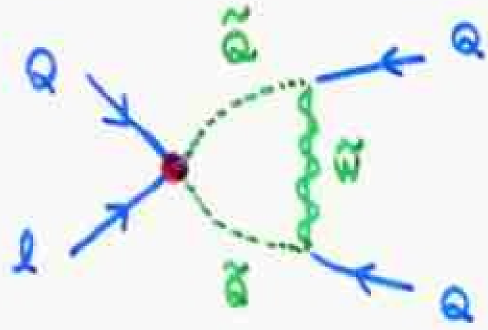
$$R : \{ Q, \bar{u}, \bar{d}, \ell, \bar{e} \}$$
$$\longrightarrow - \{ Q, \bar{u}, \bar{d}, \ell, \bar{e} \}$$

The R- parity forbids the D=4 operators.

However, we have $D=5$ operators.

$$W = \frac{\lambda}{M_{Pl}} QQQ\ell$$

Sakai, T.Y.
Weinberg
('81)



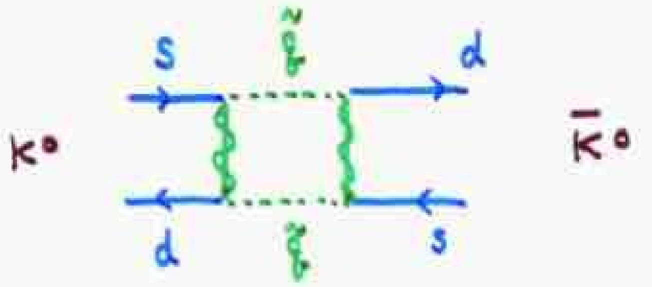
$$\sim \alpha \cdot \frac{\lambda}{M_{Pl}} \frac{1}{m_{SUSY}} \ell QQQ$$

$\lambda < 10^{-6}$ for $m_{SUSY} < 1\,\mathrm{TeV}$

➡ Why the $D=5$ operators are suppressed?

(The $D=5$ operators are allowed by R-parity invariance.)

(ii) FCNC Problem



SUSY-particle exchange diagrams cause K^0-$\bar{K}^0$ mixing.

$$\frac{\delta m^2_{\tilde{q}}}{m^2_{\tilde{q}}} < 10^{-2} - 10^{-3}$$

$$\delta m^2_{\tilde{q}} = m^2_{\tilde{s}} - m^2_{\tilde{d}}$$

A similar bounds are given for sleptons.

➡ Why squarks and sleptons in diferent families degenerate in mass ?

Hypothesis !!

B. P. L. Y.

Squarks and Sleptons are Nambu-Goldstone bosons.

Quark } supermultiplets are
Lepton }

NG supermultiplets.

$$\begin{cases} Q = \tilde{q} + \theta q \\ L = \tilde{l} + \theta l \end{cases}$$

NG bosons

quasi NG fermions.

Quarks and Leptons are superpartners of NG bosons.

They live in a Coset Space G/H.

(1) D=5 operators are Absent.

$$\left(\frac{1}{M_{Pl}}\right)^3 \partial_\mu \tilde{q}\, \partial^\mu \tilde{q}\; q \cdot l \quad \sim \left(\frac{m_E}{M_{Pl}}\right)^2 \frac{1}{M_{Pl}} \tilde{q}\tilde{q}\; q \cdot l$$

Strongly Suppressed.

Low-energy theorem
(Adler zero)

(2) Mass degeneracy for squarks and sleptons.

In supergravity, the soft-SUSY breaking masses for sfermions depend on the Kähler potential.

The Kähler potential for NG multiplets is fixed by G/H.

$\Downarrow$

the same mass to all NG bosons.

$$m_{\tilde{q}_i} = m_{\tilde{l}_i} = m_0$$

The two generic problems in SUSY SM are solved in CFU.

Suppose $G \longrightarrow H$, then we have

Global symmetry

massless NG supermulitiplets at low energies.

The NG multiplets live on a coset space G/H.

In SUSY theories

G/H must be Kähler manifolds.

$\boxed{\text{What } G/H \text{ accommodates quarks and leptons?}}$

For search we assume

$H \supset SU(5)_{GUT}$.

II. Generic Predictions

Search for G/H.

- We choose $H \supset SU(5)_{GUT}$ or $H \supset SO(10)_{GUT}$.

Quarks and Leptons: $\begin{cases} 5^* + 10 & \leftarrow SU(5) \\ 16 & \leftarrow SO(10) \end{cases}$

WHAT IS G/H ?

- Consider $SU(6) \rightarrow SU(5) \times U(1)$ Kähler manifold

  A NG multiplet is 5^*.

- Consider $SO(10) \rightarrow SU(5) \times U(1)$ Kähler manifold

  A NG multiplet is 10.

$$\Downarrow$$

$$G \simeq SU(6) \,\hat{\cup}\, SO(10)$$

E_7 algebra.

$$\mathcal{J} = E_{\alpha\beta\gamma\delta} + T^{\alpha}{}_{\beta} \qquad (\alpha, \beta = 1-8)$$

SU(8) adjoint **63**

70 $\boxed{}$ of SU(8)

$70 + 63 = \underline{133}$

- $E_7 \to SU(8)$ $\quad$ $\boxed{}$ are NG.

$\left.\begin{array}{l}(10, 3^*) + (\bar{5}, 1) \\ (10^*, 3) + (5, 1)\end{array}\right\}$

$\phi(10)$, $\phi(5)$ are NG.

- $SU(8) \to SU(5) \times SU(3) \times U(1)$

$T^a{}_i$, $T^i{}_a$ are broken generators

$(5^*, 3)$ $\quad$ $(5, 3^*)$

$\phi^a{}_i$: NG multiplets

- $SU(3) \to U(1)^2$

$8 - 2 = 6$ NG bosons

<u>three</u> triplets <u>N</u> are <u>NG</u>.

Exceptional Groups DO This Job !!!

$E_6 / SO(10) \times U(1)$

NG : 16 one family

$E_7 / SU(5) \times U(1)^3$

NG : $3 \times (5^* + 10 + 1)$

$+ 5$ three families

$E_8 / SO(10) \times U(1)^3$

NG : $3 \times (16)$

$+ 1 \times (16^*)$ two families

Since E_8 is the maximum exceptional group,

Three-Family is A Generic Prediction of Our Approach.

Kugo. T.Y. ('83)

$E_7/SU(5)_{GUT} \times U(1)^3$

NG multiplets : $3 \times (5^* + 10 + 1) + 5$

right-handed neutrino N_R

Neutrinos have masses.

$$W \simeq f_{ij} N_i \nu_{L j} \langle H \rangle + M_{ij} N_i N_j$$

$$\hookrightarrow \begin{pmatrix} \nu & N \end{pmatrix} \begin{pmatrix} 0 & f\langle H \rangle \\ f\langle H \rangle & M \end{pmatrix} \begin{pmatrix} \nu \\ N \end{pmatrix}$$

$$m_\nu \simeq f\langle H \rangle \frac{1}{M} f\langle H \rangle \ll m_{q,l}$$

Seesaw Mechanism

G.M.R.S.

T.Y. ('79)

Small Neutrino Mass is A Generic Prediction.

III. Mass Matrices for Quarks and Leptons

$E_7 / SU(5)_{GUT} \times U(1)^3$

$$\text{NG multiplets} = \left\{ \begin{array}{l} 3 \times (5^* + 10 + N_R) \\ \quad + 5 \end{array} \right\}$$

$$+ 5^* \, (\text{'t Hooft})$$

massless 't Hoofton

In the limit of E_7 being Exact, all quarks and leptons are massless.

The mass hierarchy for quarks and leptons can be understood in terms of a hierarchy in some E_7 - explicit breaking parameters.

In QCD

$$m_{K, \eta^0} \gg m_\pi \quad \Leftarrow \quad m_s \gg m_{d,u}.$$

NG bosons on $SU(3)_L \times SU(3)_R / SU(3)_V$

explained.

$\sim (3^*, 3)$ of $SU(3)_L \times SU(3)_R$

$E_7 / SU(5) \times U(1)^3$ is composed of three sub-spaces.

- $E_7 / E_6 \times U(1)$: $\underline{10} + \underline{5}^* + \underline{5}^* + 1 + 1 + 5$

- $E_6 / SO(10) \times U(1)$: $\underline{10} + \underline{5}^* + 1$

- $SO(10) / SU(5) \times U(1)$: $\underline{10}$

Un-parallel Family Structure

Explicit Breaking :

(1) $E_7 \rightarrow E_6$: t, b become massive.
ε_0 τ

(2) $E_6 \longrightarrow SO(10)$: c, s become massive.
ε_1 μ

(3) $SO(10) \longrightarrow SU(5)$: u, d become massive.
ε_2 e

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ε_2 e

The mass hierarchy :

$$m_t, m_b \gg m_c, m_s \gg m_u, m_d$$

is explained by $\varepsilon_0 \gg \varepsilon_1 \gg \varepsilon_2$.

The explicit breaking parameters ?

$\varepsilon_i \in \underline{56}$ of E_7

J. Sato , T.Y. ('99)

$$56 \ni \left.\begin{matrix} \varepsilon_0 + \bar{\varepsilon}_0 \\ \varepsilon_1 + \bar{\varepsilon}_1 \\ \varepsilon_2 + \bar{\varepsilon}_2 \end{matrix}\right\} \text{6 singlets of } SU(5)$$

Mass Matrices :

Up-type Quarks

$$\begin{array}{cccc} & 10_3 & 10_2 & 10_1 \\ 10_3 & \underline{\varepsilon_0^2} & \varepsilon_0\varepsilon_1 & \varepsilon_0\varepsilon_2 \\ 10_2 & \varepsilon_0\varepsilon_1 & \underline{\varepsilon_1^2} & \varepsilon_1\varepsilon_2 \\ 10_1 & \varepsilon_0\varepsilon_2 & \varepsilon_1\varepsilon_2 & \underline{\varepsilon_2^2} \end{array} \times \langle H \rangle$$

$\varepsilon_0 \sim 1$, $\varepsilon_1 \sim 0.1$, $\varepsilon_2 \sim 0.01$

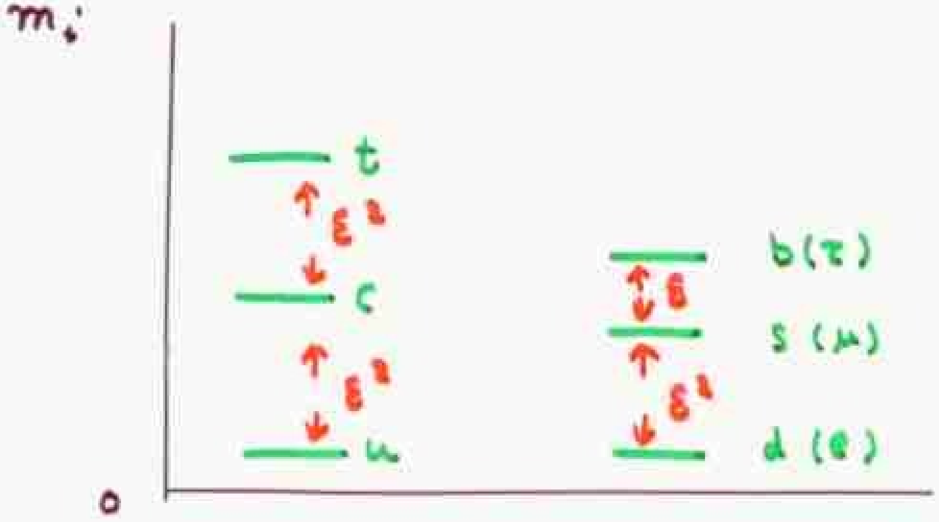
Down-Type Quarks
Leptons

	5^*_3	5^*_2	5^*_1
10_3	ε_0^2	ε_0^2	$\varepsilon_0\varepsilon_1$
10_2	$\varepsilon_0\varepsilon_1$	$\varepsilon_0\varepsilon_1$	ε_1^2
10_1	$\varepsilon_0\varepsilon_2$	$\varepsilon_0\varepsilon_2$	$\varepsilon_1\varepsilon_2$

$\times \langle \bar{H} \rangle$

$$\frac{m_t}{m_b} = \frac{\langle H \rangle}{\langle \bar{H} \rangle} \equiv \tan\beta \sim 50$$

Large $\tan\beta$



$\left\{ \begin{array}{l} \varepsilon_1 \sim \varepsilon \sim 0.1 \\ \varepsilon_2 \sim \varepsilon^2 \sim 0.01 \end{array} \right.$

$$\frac{m_c}{m_t} \propto \left(\frac{\varepsilon_1}{\varepsilon_0}\right)^{2} \sim 0.01 \qquad \left(\frac{m_\mu}{m_\tau}\right) \simeq \left(\frac{\varepsilon_1}{\varepsilon_0}\right) \sim 0.1$$

This model explains the larger hierarchy in t and c.

Mixings in Quarks and Leptons

$$10 = \left\{ \begin{pmatrix} u \\ d \end{pmatrix}, \bar{u}, \bar{e} \right\}$$

CKM mixing

$$5^* = \left\{ \bar{d}, \begin{pmatrix} \nu \\ e \end{pmatrix} \right\}$$

ν oscillation mixing (M.N.S)

- CKM mixing $\leftrightarrow$ mixing in 10's.
- ν mixing (MNS) $\leftrightarrow$ mixing in 5^*'s.

* Mixings in 10's are small, since each 10 belongs to the different sub-space.

$$\theta_{ij} \sim \frac{\varepsilon_i}{\varepsilon_j}$$

* Mixing between 5^*_3 and 5^*_2 is Large $O(1)$, since they belong to the <u>same</u> coset-sub-space.

* But mixing between $5^*_{3,2}$ and 5^*_1 is small.

This model predicts

A Large $\nu_\mu - \nu_\tau$ Mixing,

but A Small $\nu_\mu - \nu_e$ Mixing.

→ Atmospheric ν anomaly observed by Superkamiokande.

→ Solar ν problem. (MSW solution)

⊙ Difficulty for obtaining a large ν mixing.

In SO(10)

$$16_i = 5^*_i + 10_i + 1_i$$

$$16_3 \supset 10_3 \, , \quad 5^*_3$$

small mixing

$$16_2 \supset 10_2 \, , \quad 5^*_2$$

small mixing

$$16_1 \supset 10_1 \, , \quad 5^*_1$$

Parallel Family Structure

In Our model.

$$10_3 \qquad 5^*_3 \, , \; 5^*_2$$

$$10_2 \qquad 5^*_1$$

$$10_1$$

$$\boxed{\text{Unparallel Family Structure}}\,.$$

m_{ν_τ}

$$W = \varepsilon^2 \bar{\varepsilon}^2 \, N \cdot N \times M_G$$

$$\begin{array}{r|l} 1 & \varepsilon_0 \\ 0.1 & \varepsilon_1 \\ 0.01 & \varepsilon_2 \; \cdots \bar{\varepsilon}_0 \; \bar{\varepsilon}_1 \; \bar{\varepsilon}_2 \end{array}$$

Hierarchy in Breaking Parameters

Masses for Right-handed Neutrinos M_R

$$\approx 10^{14} \text{ GeV}.$$

Seesaw $\Rightarrow$ $m_{\nu_i} \simeq \dfrac{m_{D_i}^2}{M_R}$

Heaviest ν_τ $\quad m_{\nu_\tau} \simeq O(0.1)$ eV

$$m_{\nu_\tau}^2 \simeq O(10^{-2}) \text{ eV}$$

Consistent with the report by Super-Kamiokande on Atmospheric ν oscillation.

$\rightarrow$ Fig.

5. Unparalled Family structure.

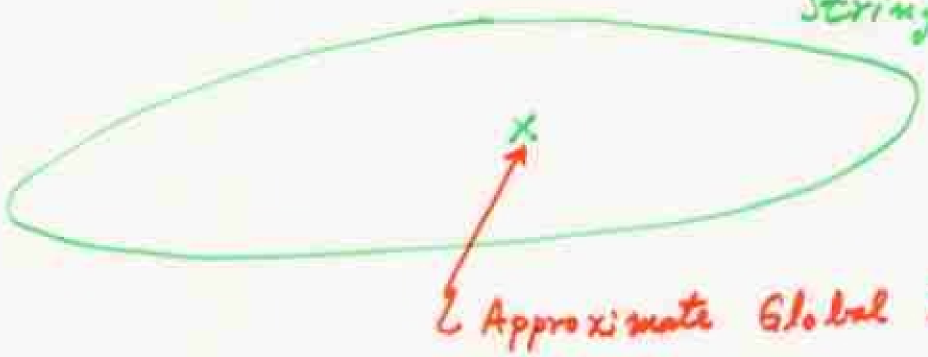
→ Large Lepton Violation.

$$\begin{cases} Br(\tau \to \mu \gamma) \gtrsim 10^{-8} \\ Br(\mu \to e \gamma) \gtrsim 10^{-13} \end{cases}$$

Hisano, Nomura, T.Y.

See Figs.

$$\begin{cases} \text{WHY } E_7 \text{ EXISTS ?} \\ \text{WHERE THE EXPLICIT BREAKINGS COME ?} \end{cases}$$



String Moduli Space

Approximate Global E_7 Appears?

An Example is $E_{7,7}$ (Global) in $N=8$ Supergravity.

Cremmer, Julia ('79)

hep-ph/9711348 17 Nov 1997

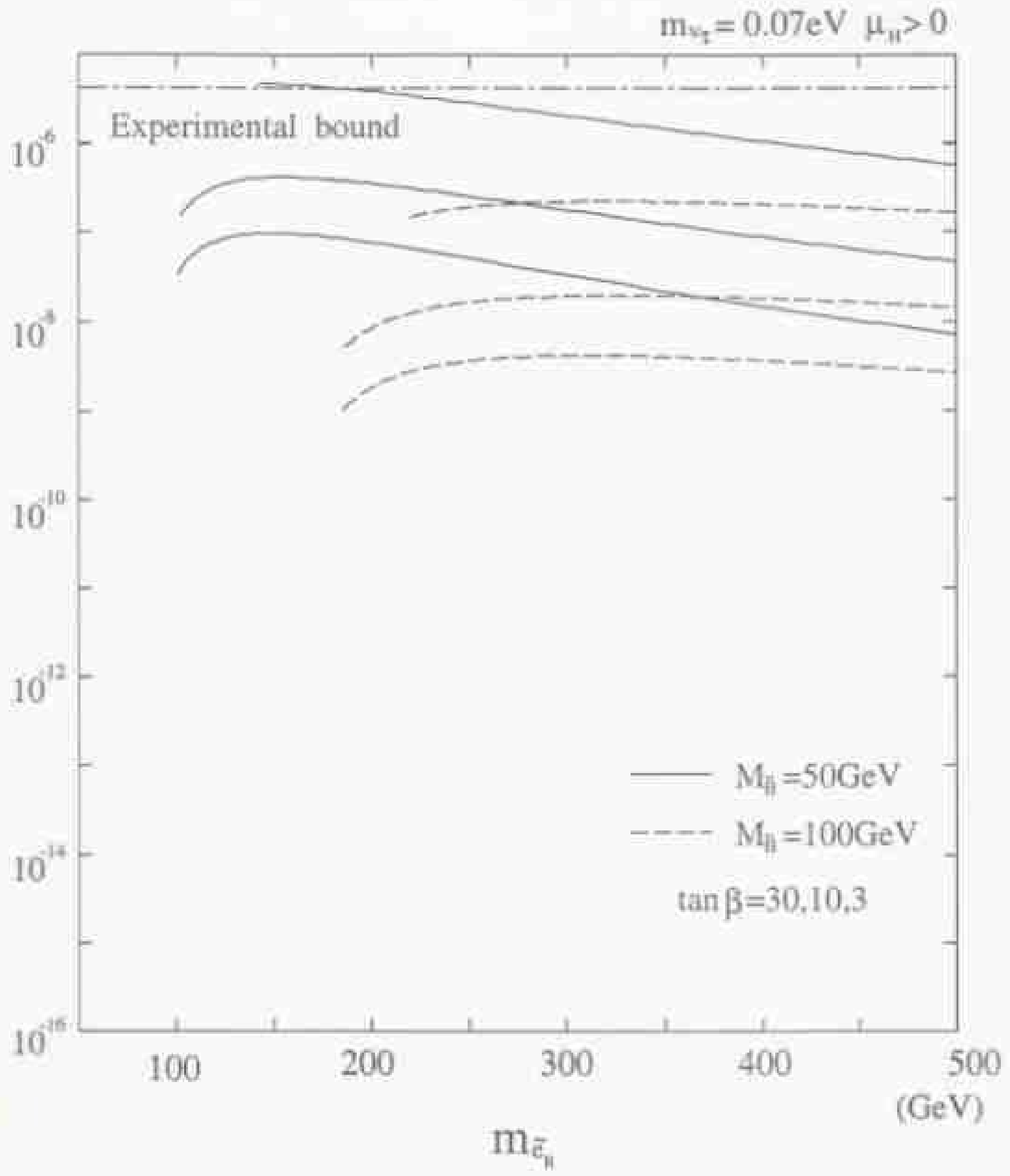


Fig. 4

J. Hisano . D. Nomura

hep-ph/9711348 17 Nov 1997

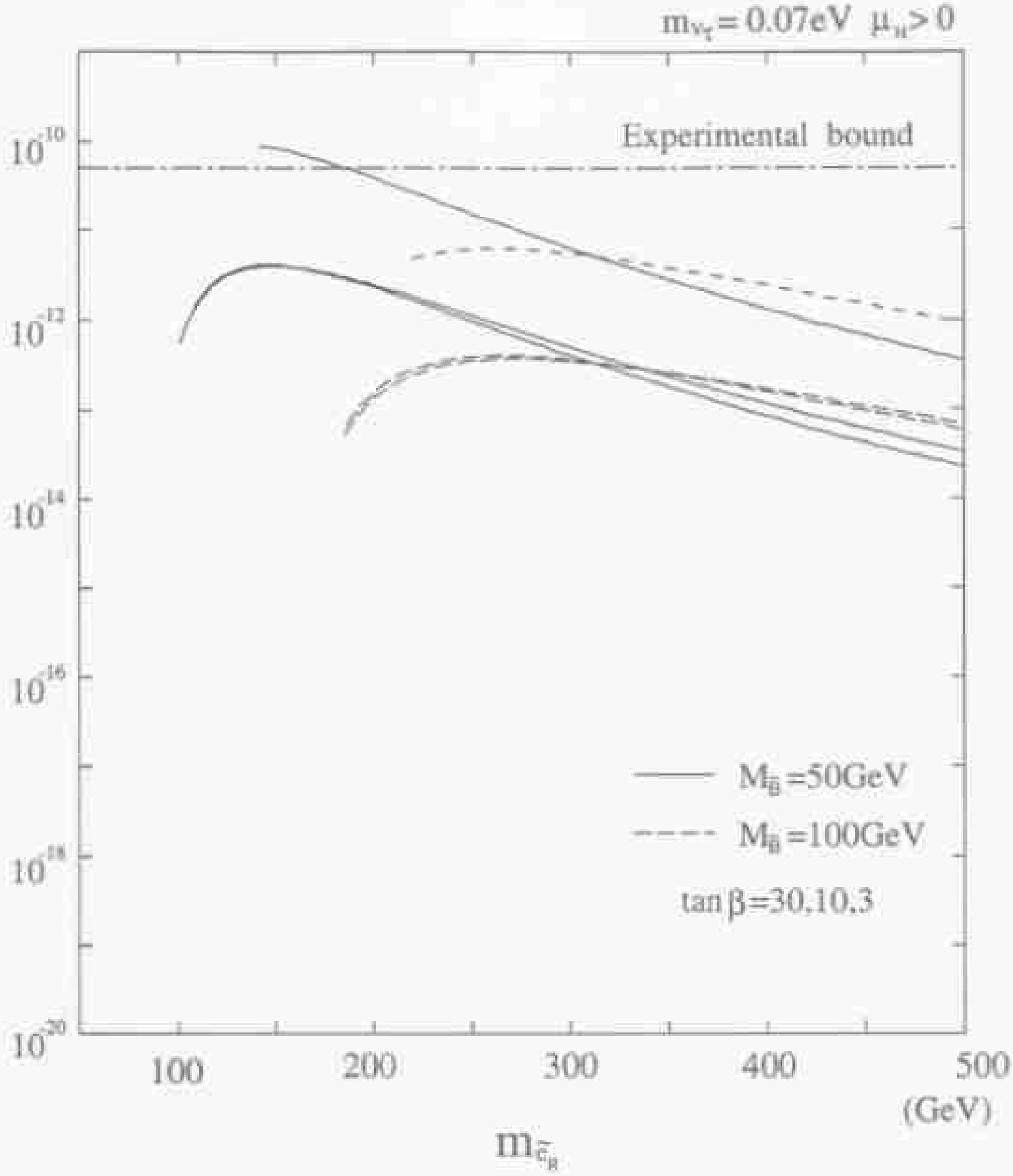


Fig. 3

J. Hisano . D. Nomura

IV More Speculations

Why Global E_7 ?

Compactification of the M theory on a singular Calabi-Yau manifold.

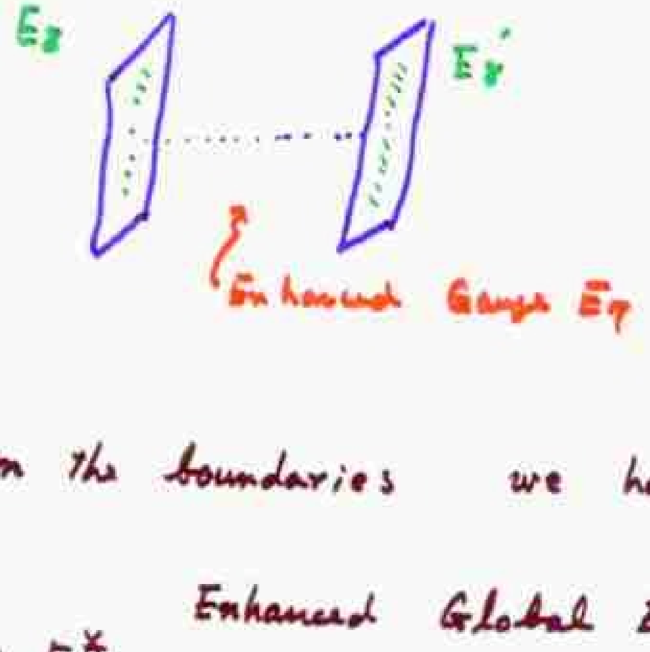
Sharpe
:

Enhanced Gauge Symmetry

Could be E_7.

Consider 11 d theory on $CY \times R^4 \times S^1/Z_2$

Horava, Witten (1995)



On the boundaries we have an

Enhanced Global E_7.

$\frac{1}{M}\, 10.10.10.5^*$

$10 \to e^{i\delta}10$

$5^* \to e^{i\delta}5^*$

V. Conclusions

The observed mass hierarchies

$$m_c/m_t \simeq \underline{\epsilon}^2, \quad m_u/m_c \simeq \epsilon^2$$

$$m_\mu/m_\tau \simeq \underline{\epsilon} \quad m_e/m_\mu \simeq \epsilon^2$$

suggest <u>unparallel</u> family structure.

$$\begin{array}{lll} 10_3 & 5^*_3 & 5^*_2 \\ 10_2 & 5^*_1 & \\ 10_1 & & \end{array}$$

This naturally predicts

$$\begin{cases} \text{Large Mixing} & \theta_{\nu_\mu - \nu_\tau} \sim O(1) \\ \text{Small Mixing} & \theta_{\nu_e - \nu_\mu} \ll 1 \end{cases}.$$

The Seesaw is consistent with

- ⊙ Atmospheric ν oscillation OBSERVED at Super K.
- ⊙ Small-angle MSW solution to the Solar ν problem.