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# ユカワオンモデルの 最近の進展

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Based on YK, Phys.Lett. B665 (2008), 227;  
Phys.Rev. D78 (2008), 093006 ; D79 (2009), 03702;  
arXiv:0902.4501 [hep-ph].

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**Sec. 1**

**New approach to the  
masses and mixings**

**--- Yukawaon model ---**

# 「ユカワオン」とは何か？

去年の秋に創り出された新語

質量の起源

質量スペクトルの起源

標準模型： Higgs scalars

Yukawa c.c.

ユカワオン模型： Higgs scalars

VEV of Yuawaon

標準模型:  $H_Y = \sum_{i,j} \bar{q}_L^i (Y_u)^j_i u_{Rj} H_u + \dots$

$Y_f$  are numerical coefficients

ユカワオン模型:  $H_Y = \sum_{i,j} \frac{y_u}{\Lambda} \bar{q}_L^i (Y_u)^j_i u_{Rj} H_u + \dots$

$Y_f$  are gauge-singlet scalar fields

$$Y_f^{eff} = \frac{y_f}{\Lambda} \langle Y_f \rangle$$

For example: We assume an O(3)-flavor symmetry

$$\begin{aligned}
 W_Y = & \sum_{i,j} \frac{y_u}{\Lambda} u_i^c (Y_u)_{ij} q_j H_u + \sum_{i,j} \frac{y_d}{\Lambda} d_i^c (Y_d)_{ij} q_j H_d \\
 & + \sum_{i,j} \frac{y_\nu}{\Lambda} l_i (Y_\nu)_{ij} \nu_j^c H_u + \sum_{i,j} \frac{y_e}{\Lambda} l_i (Y_e)_{ij} e_j^c H_d + h.c. \\
 & + \sum_{i,j} y_R \nu_i^c (Y_R)_{ij} \nu_j^c
 \end{aligned}$$

In the O(3) model,  $Y_f$  are symmetric fields, so that the VEVs of Yukawaons are diagonalized as

$$U_f^T \langle Y_f \rangle U_f = D_f, \quad (f = u, d, e, \nu, R)$$

In order to distinguish each  $Y_f$  from others, we assign  $U(1)_X$  charges as  $Q_X(f^c) = -x_f$ ,  $Q_X(Y_f) = +x_f$  and

$$Q_X(Y_R) = 2x_\nu$$

# 計算処方

Example in the lepton sector:

(1)  $O(3)$  flavor symmetry および  $U(1)$  sector charge  
これら対称性のもとで、スーパーポテンシャルを書き下す

We introduce a field  $\Phi_e$  which we refer as  
“ur-Yukawaon” hereafter, and we assume the following  
superpotential

$$W_e = \lambda_e [\Phi_e \Phi_e X_e] + \mu_e [Y_e X_e] + W_\Phi$$

where  $Q_X(\Phi) = +\frac{1}{2}x_e$ ,  $Q_X(Y_e) = +x_e$ ,  $Q_X(X_e) = -x_e$

Here, for simplify, we have denote  $\text{Tr}[\dots]$  as  $[\dots]$ .

(2) SUSY vacuum conditions からユカワオンのVEVを  
求める

Then, the SUSY vacuum condition

$$\frac{\partial W}{\partial X_e} = 0 = \lambda_e \Phi_e \Phi_e + \mu_e Y_e$$

leads to

$$\langle Y_e \rangle = -\frac{\lambda_e}{\mu_e} \langle \Phi_e \rangle \langle \Phi_e \rangle$$

so that VEV of Yukawaon  $Y_e$  is given  
by a bilinear form of VEV of  $\Phi_e$

(3) Also, the remaining SUSY vacuum conditions  
leads to the VEV relation

$$c_3 \Phi_e^3 + c_2 \Phi_e^2 + c_1 \Phi_e + c_0 \mathbf{1} = 0$$

Recall that in a cubic equation, generally,

$$A^3 + c_2 A^2 + c_1 A + c_0 1 = 0$$

the coefficients have the following relations for the eigenvalues

$$c_2 = -[A], \quad c_1 = \frac{1}{2}([A]^2 - [AA]), \quad c_0 = -\det A$$

(4) we obtain

$$K_e \equiv \frac{m_e + m_\mu + m_\tau}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2} = \frac{[\Phi_e \Phi_e]}{[\Phi_e]^2} = 1 + 2 \frac{c_1}{c_2} \frac{1}{[\Phi_e]}$$

$$\kappa_e \equiv \frac{\sqrt{m_e m_\mu m_\tau}}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^3} = \frac{\det \Phi_e}{[\Phi_e]^3} = \frac{c_0}{c_2} \frac{1}{[\Phi_e]^2}$$

where we have used  $c_2 = -[\Phi_e] c_3$

このように、 $W_\Phi$  を適当に与えることによって、

クォーク・レプトンの質量スペクトルは完全に決定される





## **Sec. 2**

# **Recent Developments**

**2.1 Charged lepton mass relation**

**2.2 Neutrino mass matrix related to up-quark masses**

**2.3 Massless Yukawaons**

## 2.1 Charged lepton mass relation

$K_e = \frac{2}{3}$  を与える  $W_\Phi$  の例

- Unbroken  $U(1)_X$  model: [PRD79 \(2009\), 03702](#)

$$\begin{aligned} W_e = & \lambda_A [\Phi_e \Phi_e A_e] + \mu_A [Y_e A_e] \\ & + \lambda'_A [\Phi_e \Phi_e A'_e] + \mu'_A [Y_e A'_e] \\ & + \lambda''_A [\hat{\Phi}_e \hat{\Phi}_e A'_e] + \mu''_A [Y'_e A'_e] \\ & + \lambda_B \left( [\Phi_e Y'_e B_e] + \varepsilon [\Phi_e] [Y'_e] [B_e] \right) \end{aligned}$$

where  $\hat{\Phi}_e = \Phi_e - \frac{1}{3}[\Phi_e]$ .

- Broken  $U(1)_X$  model: [arXiv:0902.4501 \[hep-ph\]](#)

$$\begin{aligned} W_e = & \lambda [\Phi_e \Phi_e X_e] + \mu [Y_e X_e] \\ & + \varepsilon \left\{ \lambda' [\hat{\Phi}_e \Phi_e \Phi_e] + \lambda'' [\hat{\Phi}_e \Phi_e Y_e] \right\} \end{aligned}$$

## 2.2 Neutrino mass matrix related to up-quark

- YK, JPG 35 12500 (2008); PLB 665, 227 (2008)

We assume

$$W_R = \lambda_R[(Y_e \Phi_u + \Phi_u Y_e) X_R] + \mu_R[Y_R X_R]$$

which leads to a seesaw type neutrino mass matrix

$$M_\nu \propto \langle Y_e \rangle (\langle Y_e \rangle \langle \Phi_u \rangle + \langle \Phi_u \rangle \langle Y_e \rangle)^{-1} \langle Y_e \rangle$$

This mass matrix can lead to a nearly tribimaximal mixing by using the observed values at the quark sector, but without assuming any discrete symmetry.

$$\sin^2 2\theta_{23} = 0.995 \quad \tan^2 \theta_{12} = 0.553 \quad |U_{13}| = 0.0009$$

このように、ユカワオンは互いに関連し合ってスーパーポテンシャルに登場する。その関係を見つけ出すことがユカワオン模型構築の課題

## 2.3 Massless Yukawaons

Y.K., arXiv:0902.4501 [hep-ph]

Broken  $U(1)_X$  model について結論のみを紹介する

$$\begin{pmatrix} Y \\ \Phi \\ X \end{pmatrix} = U \begin{pmatrix} Y' \\ \Phi' \\ X' \end{pmatrix} \quad U \simeq \begin{pmatrix} c & \frac{1}{\sqrt{2}}s & \frac{1}{\sqrt{2}}s \\ -s & \frac{1}{\sqrt{2}}c & \frac{1}{\sqrt{2}}c \\ 0 & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$
$$s = \frac{a}{\sqrt{a^2 + b^2}}, \quad c = \frac{b}{\sqrt{a^2 + b^2}} \quad a = \mu, \quad b = \lambda(v_i + v_j)$$

$m(Y') = 0, \quad m(\Phi') \simeq -\sqrt{a^2 + b^2}, \quad m(X') \simeq \sqrt{a^2 + b^2}$   
すなわち, massless Yukawaons は

$(Y'_{12}, Y'_{23}, Y'_{31})$  の3つのみ

荷電レプトンとの effective coupling は invisibly small

$$\langle H_d \rangle / \Lambda \sim 10^2 \text{ GeV} / 10^{15} \text{ GeV} \sim 10^{-13}$$

もう少し詳しく言うと

|                               | mass               | c.c.                               |
|-------------------------------|--------------------|------------------------------------|
| $(Y'_{12}, Y'_{23}, Y'_{31})$ | 0                  | $10^{-13} e_i e_j^c Y'_{ij}$       |
| $(Y'_{11}, Y'_{22}, Y'_{33})$ | $\epsilon \Lambda$ | $\epsilon Y'_{11} Y'_{12} Y'_{21}$ |
| $\Phi', X'$                   | $\Lambda$          |                                    |

残念ながら、地上での実験では、検出できそうにもない  
Cold dark mater の説明にも使えそうにもない



A high-altitude mountain range with snow-capped peaks and a clear blue sky. The mountains are rugged and rocky, with patches of snow and ice. The sky is a clear, deep blue. The overall scene is a vast, open landscape.

**Sec. 3**

**Concluding remarks**

# Our Goal

(1) すべての Yukawaons の VEV を単一の ur-Yukawaon  $\Phi_e$  (あるいはせめて2つの ur-Yukawaons  $\Phi_e$  and  $\Phi_u$ ) によって統一的に記述したい.

(2) massless (and tiny) Yukawaons の現象論 harmless に!

しかしできれば積極的に TeV region physics に寄与させたい.



# やり残しの仕事

(1) まだ radiative correction for  $W$  は手をつけていない. 特に  $K=2/3$  はどうずれるか?

See Y. Sumino, PLB671, 477 (2009)

(2) Yukawaons の節約

(3)  $O(3)$  or  $U(3)$ ?

(4) Quark & lepton masses and mixings の  
統一的記述





**Thank you**

