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ユカワオン模型の最近の進展

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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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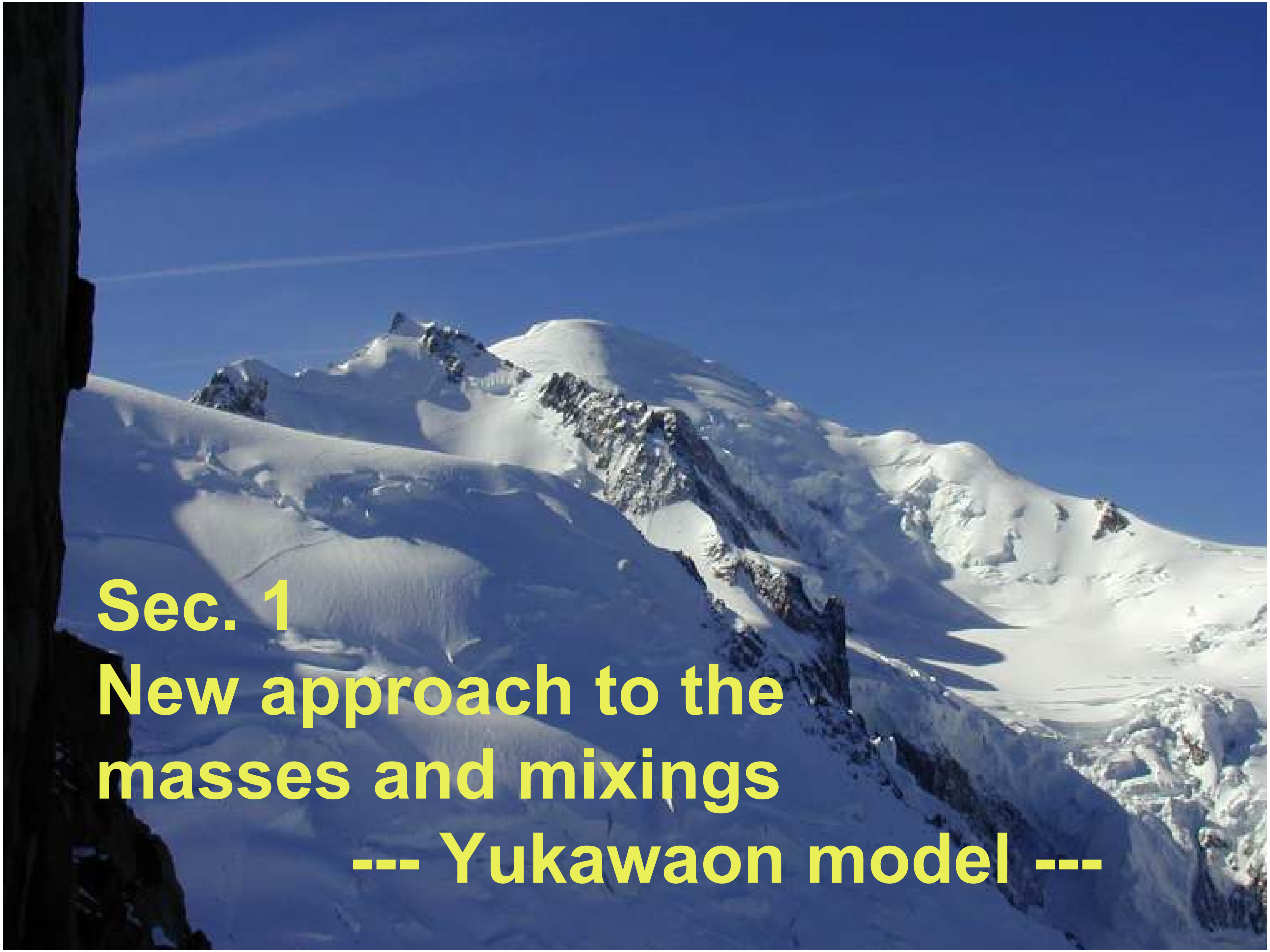

Sec. 1
New approach to the masses and mixings
--- Yukawaon model ---

「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: $H_Y = \sum_{i,j} \overline{q}_L^i (Y_u)_i^j u_{Rj} H_u + \cdots$

Y_f are numerical coefficients

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

Y_f are gauge-singlet scalar fields $\quad Y_f^{eff} = \frac{y_f}{\Lambda} \langle Y_f \rangle$

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

$$W_Y = \sum_{i,j} \frac{y_u}{\Lambda} u_i^c (Y_u)_{ij} q_j H_u + \sum_{i,j} \frac{y_d}{\Lambda} d_i^c (Y_d)_{ij} q_j H_d$$

$$+ \sum_{i,j} \frac{y_\nu}{\Lambda} \ell_i (Y_\nu)_{ij} \nu_j^c H_u + \sum_{i,j} \frac{y_e}{\Lambda} \ell_i (Y_e)_{ij} e_j^c H_d + h.c.$$

$$+ \sum_{i,j} y_R \nu_i^c (Y_R)_{ij} \nu_j^c$$

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

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

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

Here, for simplify, we have denote Tr[...] as [...].

(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 Φ_e

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

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

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_Φ 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_Φ 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]**

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

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

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

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

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

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

$$\begin{pmatrix} Y \\ \Phi \\ X \end{pmatrix} = U \begin{pmatrix} Y' \\ \Phi' \\ X' \end{pmatrix} \qquad U \simeq \begin{pmatrix} c & \frac{1}{\sqrt{2}}s & \frac{1}{\sqrt{2}}s \\ -s & \frac{1}{\sqrt{2}}c & \frac{1}{\sqrt{2}}c \\ 0 & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

$$s = \frac{a}{\sqrt{a^2+b^2}}, \quad c = \frac{b}{\sqrt{a^2+b^2}} \qquad a = \mu, \quad b = \lambda(v_i + v_j)$$

$$m(Y') = 0, \quad m(\Phi') \simeq -\sqrt{a^2+b^2}, \quad m(X') \simeq \sqrt{a^2+b^2}$$

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**

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

もう少し詳しく言うと

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

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

Sec. 3

Concluding remarks

Our Goal

(1) すべての Yukawaonsの VEVを単一の ur-Yukawaon Φ_e (あるいはせめて2つの ur-Yukawaons Φ_e and Φ_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