Strong coupling, discrete symmetry and flavour

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based on S.Abel, JB - arXiv:1005.1668 [hep-ph]

Some observations

Several open questions in SM flavour structure:

- Origin of large hierarchies in masses and quark mixing.
- Origin of tribimaximal mixing in neutrino sector.
- Grand unification?

Attempt to address these problems using two observations:

Observation

Neutrino mixing matrix suggests a **discrete flavour symmetry**.

Observation

Large hierarchies arise naturally in theories with **strong coupling**.

Mixing patterns from discrete symmetry

Observation

Neutrino mixing matrix suggests a **discrete flavour symmetry**.

- Highly symmetrical – **tribimaximal mixing**.
- Many successful models[1] apply a discrete flavour symmetry.
- Examples of groups: A_4, S_4, $PSL_2(7)$, $\Delta(27)\dots$

But

- Need extended Higgs sector with particular **vacuum alignment** to break flavour symmetry.
- Hard to apply to quark sector $\implies$ **difficulties with GUTs**.

[1] G.Altarelli, F.Feruglio - arXiv:1002.0211 [hep-ph]

Hierarchies from dynamical scales

Observation

Large hierarchies arise naturally in theories with **strong coupling**.

- Dynamical scales generated by renormalisation group flow:

$$\Lambda \sim E e^{-8b\pi^2/g^2(E)}$$

- Λ is dynamical **strong coupling** scale where $g \to \infty$.
- Exponential dependence $\implies$ naturally large hierarchies.
- Readily applicable to SM mass hierarchies[2].

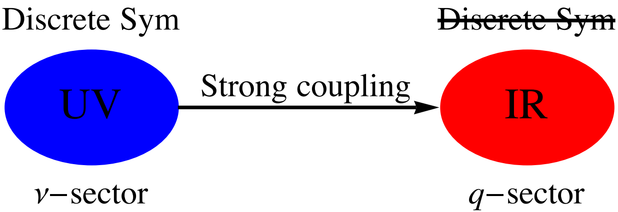
[2] A.E.Nelson, M.J.Strassler - hep-ph/9607362, hep-ph/0006251

Addressing the flavour problem

Postulate

The flavour problem can be solved using two principles:

1. **Discrete flavour symmetry** for mixing.
2. **Strong coupling** for **all hierarchies** and flavour symmetry breaking.



(C.F. A.E.Nelson, M.J.Strassler - hep-ph/0006251 with discrete flavour symmetry in UV rather than anarchy)

Comments

- **Multiple** strongly coupled sectors for hierarchies – one per generation.
- Should be a generic feature of strong coupling.

Note:

- Strongly coupled $\equiv$ asymptotically free.
- Will use $\mathcal{N} = 1$ SUSY but ideas should apply to non-SUSY theories.

Yukawa couplings

How does it work?

- Suppose SU(5) $\mathbf{10}_j$ is actually a **bound state** of the strongly coupled gauge group G_j

$$\Lambda_j \mathbf{10}_j = Y_j Y_j$$

- **Elementary** 'Yukawa' couplings are e.g.

$$W_{\mathrm{UV}} \supset \frac{\xi_{ij}}{M_X} \bar{\mathbf{5}}_i (Y_j Y_j) \bar{\mathbf{5}}_H$$

G_j s-confines[3], match to low energy couplings

$$\frac{\xi_{ij}}{M_X} \bar{\mathbf{5}}_i (Y_j Y_j) \bar{\mathbf{5}}_H = \lambda_{ij} \bar{\mathbf{5}}_i \mathbf{10}_j \bar{\mathbf{5}}_H \quad \Longrightarrow \quad \lambda_{ij} = \frac{\Lambda_j}{M_X} \xi_{ij}$$

[3] K.A.Intriligator, N.Seiberg - hep-th/9509066

Yukawa couplings

Ten centred model with Z_3 permutation symmetry yields

$$\lambda_{ij} = \frac{\Lambda_j}{M_X}\xi_{ij} = \frac{\Lambda_3}{M_X}\begin{pmatrix} a\varepsilon\eta & b\varepsilon & c \\ c\varepsilon\eta & a\varepsilon & b \\ b\varepsilon\eta & c\varepsilon & a \end{pmatrix} \quad \text{where} \quad \varepsilon\,,\eta \ll 1$$

- a, b, c are complex, order unity parameters (from Z_3).
- Λ_j are dynamical scales, $\varepsilon = \Lambda_2/\Lambda_3$ and $\eta = \Lambda_1/\Lambda_2$.
- $\Lambda_1 \ll \Lambda_2 \ll \Lambda_3$ natural.
- Dynamical scales produce **hierarchies in quark Yukawas** and **break flavour symmetry**.

Mass and mixing hierarchies

$\mathbf{10} \ni Q, u^c, e^c$ and $\bar{\mathbf{5}} \ni L, d^c$ hence

- $\lambda^e_{ij} \sim \Lambda_j$ for charged lepton mass hierarchy.
- $\lambda^u_{ij} \sim \Lambda_i \Lambda_j$ (from $\mathbf{10}_i \mathbf{10}_j \mathbf{5}_H$ term) for **squared** up quark mass hierarchy.

Result – mass hierarchies

$$\frac{m_e}{m_\mu} \sim \frac{m_d}{m_s} \sim \sqrt{\frac{m_u}{m_c}} \sim \eta \quad \text{and} \quad \frac{m_\mu}{m_\tau} \sim \frac{m_s}{m_b} \sim \sqrt{\frac{m_c}{m_t}} \sim \varepsilon$$

Diagonalise to find CKM matrix:

Result – hierarchies in quark mixing

$$V_{\rm CKM} \sim \begin{pmatrix} 1 & \eta & \varepsilon\eta \\ \eta & 1 & \varepsilon \\ \varepsilon\eta & \varepsilon & 1 \end{pmatrix}$$

Mass and mixing hierarchies

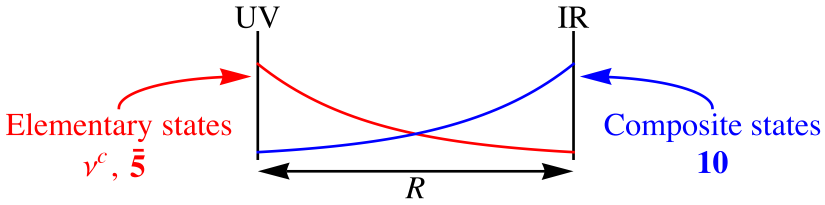
Different story in neutrino[4] sector:

- Assume **elementary** neutrinos $\implies$ no dynamical scales in Yukawa couplings.
- Neutrinos **do not** see effects of strong coupling.
- Mixing determined **only** by elementary coupling constants.
- Flavour symmetry preserved $\implies$ **tribimaximal mixing**.
- Absence of mass hierarchies in neutrino sector.

[4] C.F. N.Haba - arXiv:hep-ph/9807552

Geometric interpretation

Use AdS/CFT to gain **equivalent** geometrical description. Picture is dual to **5D gravity theory**:



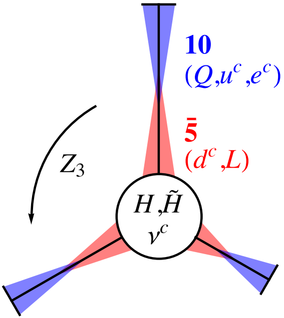
strongly coupled sector $\leftrightarrow$ warped extra dimension

dynamical scale $\leftrightarrow$ warp factor $M_X e^{-kR}$

Geometric interpretation

Three strongly coupled sectors $\implies$ multithroat background[5].

- Central UV brane with rotational Z_3 flavour symmetry.
- Strongly coupled sectors in 3 throats.
- Throat lengths generate hierarchies, break flavour symmetry.
- Quarks (in throats) feel hierarchies and flavour symmetry breaking.
- Neutrinos (on UV brane) do not.
- **All mixing** occurs on UV brane.
- **GUT compatible**.

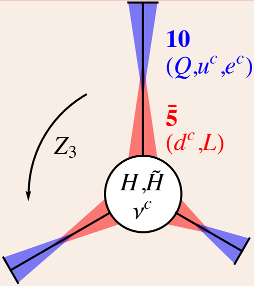


[5] G.Cacciapaglia, C.Csaki, C.Grojean, J.Terning - hep-ph/0604218

Summary

The flavour problem can be addressed using two principles:

- Discrete flavour symmetry for mixing.
- Strong coupling for hierarchies and flavour symmetry breaking.
- Quarks see strong coupling effects, neutrinos do not.
- Approach is GUT compatible.



Simplest examples[6] use Z_3 permutation symmetry with strong coupling described by:

- s-confinement
- AdS/CFT correspondence

with same results.

[6] S.Abel, JB - arXiv:1005.1668 [hep-ph]