Flavor symmetries in the lepton sector

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What we know

$$U_{PMNS} = R_{23}\, R_{13}\, R_{12}\, P_M$$

Atmospheric

$$\theta_{23} \simeq 45^\circ$$

Reactor

$$\theta_{13} < 10^\circ$$

Solar

$$\theta_{12} \simeq 35^\circ$$

$$\Delta m_{12}^2 \simeq 7.6 \times 10^{-5}\, eV^2$$

$$\left|\Delta m_{23}^2\right| \simeq 2.4 \times 10^{-3}\, eV^2$$

...and what we don't know

$$U_{PMNS} = R_{23}\, R_{13}\, R_{12}\, P_M$$

$R_{13} \rightarrow \delta = ?$

$P_M \rightarrow$ Majorana phases

* Absolute neutrino mass scale

* Normal or Inverted hierarchy?

* Majorana or Dirac?

Is what we know enough to infer a fundamental theory?

A general observation

In the diagonal charged lepton basis:

* $Z_2 \times Z_2$ symmetry in ν sector
* Z_n symmetry in charged lepton sector

→ We want a larger symmetry broken down to these residual symmetries

The flavor symmetry program

- choose a PMSN matrix (compatible with data)
- infer Z_2 x Z_2 generators (S, U), choose ”n” of Z_n, infer its generator T
- construct the irreps of the group generated by <S, U, T>
- choose representations for matter fields (usually L ~ 3)

The flavor symmetry program

- Flavor symmetry breaking sector:

$$G \stackrel{\phi_{S,U}}{\longrightarrow} G_{S,U}$$

$$G \stackrel{\phi_{T}}{\longrightarrow} G_{T}$$

- Make sure that the vacuum alignment can be obtained in a reasonable way by minimizing a suitable potential for the flavons

Issues

- Usually masses fitted, not predicted
- Usually, additional symmetries needed to keep lepton and neutrino sectors separated
- Effective theory

$\rightarrow$ next-order terms play an important role, but <u>much more</u> parameters introduced in the theory

$\rightarrow$ loss of the (already partial) predictivity

A well known example

TBM ansatz

$$s_{12}=\frac{1}{\sqrt{3}} \qquad \theta_{13}=0 \qquad s_{23}=\frac{1}{\sqrt{2}}$$

$$U_{TBM}=\begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ \frac{-1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & \frac{-1}{\sqrt{3}} & \frac{-1}{\sqrt{2}} \end{pmatrix}$$

Harrison, Perkins, Scott, 2002

Which symmetry group?

A (partial) list:

A_4, S_4, $Z_7 \ltimes Z_3$, $\Delta(27)$, $\Delta(96)$, $PSL_2(7)$...

Common features:

- At leading order, exact TBM
- At next-order, deviations from TBM

Example

A_4 x Z_3 model by Altarelli-Feruglio

[hep-ph/0504165, hep-ph/0512103,...]

$\theta_{13} = 0$ at leading order,

$\theta_{13} \neq 0$ at next-to-leading order, dependence on

- Neutrino masses
- 4 additional parameters coming from corrections to neutrino mass matrix and vacuum alignment

(No) Conclusions

- The quest for a theory of flavor is far from being at the end
- Many groups lead to similar conclusions: these symmetries may have something to say about the fundamental theory of nature
- But very difficult to draw any firm conclusion, since essentially all proposed groups are still not ruled out
- Non zero reactor angle does not change much the above situation