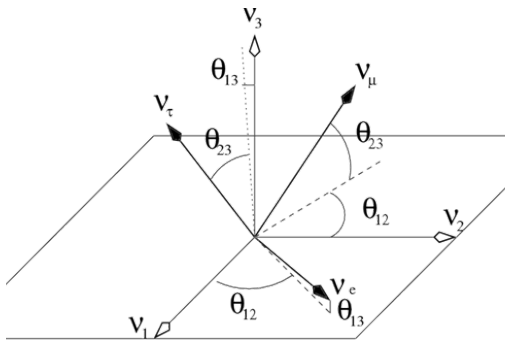
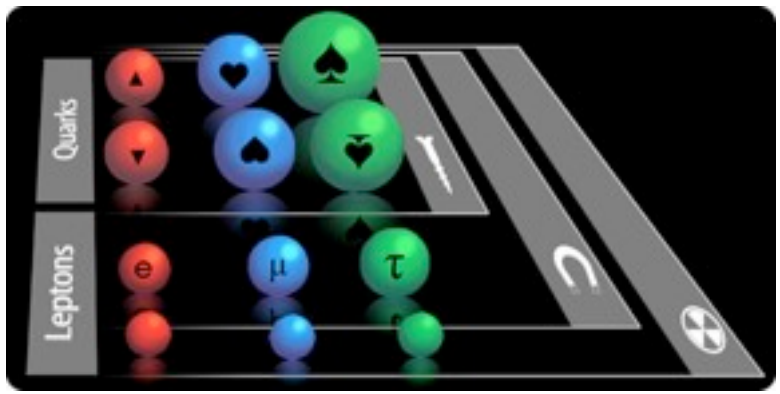
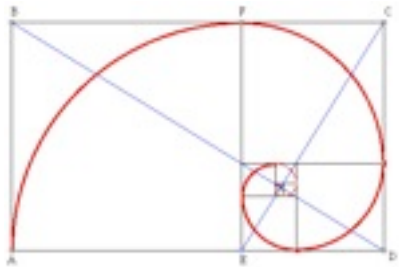
Perspectives on Neutrino Mass Models







Lisa L. Everett

Snowmass on the Pacific, KITP

May 30, 2013

The Big Picture -- Many Questions Remain

- How many light neutrinos?

  Anomalies: LSND, MiniBooNE, Gallium, Reactor

  eV-scale sterile neutrinos? But tension still with all oscillation data

  see e.g. Kopp et al., 1303.3011, Abazajian et al. 1204.5379 (white paper),...

Thus: restrict here to 3-family neutrino models only

$$\text{SM} \longrightarrow \nu\text{SM}$$

- Still, many questions:

  Nature of neutrino mass suppression? Majorana? Dirac?

  Mass hierarchy? Lepton mixing angle pattern? CP violation?

  Implications for BSM paradigms? Connections to other NP?

The Flavor Puzzle, Rejuvenated

Flavor puzzle of SM is notoriously difficult...

Still difficult in νSM, but more interesting --

One primary reason: two large mixing angles!

$$\theta_{23} \simeq 45^\circ \pm 5^\circ \qquad \theta_{12} \simeq 34^\circ \pm 1^\circ$$

3-family models: handwave a bit (in diagonal charged lepton basis)

3	small angles	$\longrightarrow$	$\sim$ diagonal $\mathcal{M}_\nu$	("easy")
1	large, 2 small	$\longrightarrow$	$\sim \mathrm{Rank}\mathcal{M}_\nu < 3$	
3	large angles	$\longrightarrow$	anarchical $\mathcal{M}_\nu$	("harder")
2	large, 1 small	$\longrightarrow$	fine-tuning, non-Abelian	

Anarchy vs. Structure

⟶ The question: is θ_{13} large or small?

$$\theta_{13} \simeq 9^\circ \pm 1^\circ$$

Post-March 2012 case for anarchy: de Gouvea and Murayama, 1204.1249

some recent explicit realizations: Bai and Torroba, 1210.2394
Altarelli et al., 1207.0587,...

Focus here on structure (symmetry):

Paradigm: discrete non-Abelian family symmetry

(subgroup of SO(3) or SU(3), broken to some appropriate coset space)

Main issue/challenge: many theoretical starting points

Role of Small (Cabibbo-sized?) Corrections

Quark sector:

$$\mathcal{U}_{\rm CKM} \sim 1 + O(\lambda_C)$$

Cabibbo angle λ_C (or some power) as a flavor expansion parameter

Lepton sector:

$$\mathcal{U}_{\rm MNSP} \sim \mathcal{W} + O(\lambda')$$

"bare" mixing angles $(\theta^0_{12}, \theta^0_{13}, \theta^0_{23})$ perturbations

choice of bare mixing angles? depends on perturbations

Unification paradigm (broad sense): useful to take

$$\lambda' = \lambda_C$$

ideas of quark-lepton complementarity and "Cabibbo haze"

Raidal '04, Minakata+Smirnov, '04, many others...

Ramond and collaborators (including yours truly...)

Long before 2012, it was conjectured that θ_{13} is a Cabibbo effect

$$\theta_{13} \sim \frac{\lambda_C}{\sqrt{2}} \sim \lambda_C \cos\theta_{23}^0$$

Ramond '03, '04,...

(general idea often called "charged lepton corrections") $\mathcal{U}_{\rm MNSP} \sim \mathcal{U}_{\rm CKM}^\dagger \mathcal{W}$

good fit to data! but nontrivial to implement...

one reason: now $\sim \lambda_C$ corrections floating around

Family Symmetry Model (Broad) Taxonomy

Pre-March 2012 most models: $\theta_{23}^0 = 45^\circ \quad \theta_{13}^0 = 0^\circ$

Choices for "bare" solar angle θ_{12}^0:

(1) within $\sim \lambda_C^2$ of exp:

tri-bimaximal mixing $\tan\theta_{12}^0 = \frac{1}{\sqrt{2}} \quad \theta_{12}^0 = 35.26^\circ$

Harrison, Perkins, Scott '02

"the beautiful matrix with the ugly name"

(100s of papers. Key players include Ma, Chen et al., Altarelli et al.,...)

others, such as golden ratio mixing $\phi = (1+\sqrt{5})/2$

$\tan\theta_{12} = \phi^{-1} \quad \theta_{12} = 31.72^\circ$ or $\cos\theta_{12} = \frac{\phi}{2} \quad \theta_{12} = 36^\circ$

Ramond, Kajiyama et al., LE+Stuart (+Ding), Feruglio et al.,...

Rodejohann et al.,...

(2) within $\sim \lambda_C$ of exp:

bimaximal mixing $\tan\theta_{12}^0 = 1$ (quark-lepton complementarity)

Post-March 2012

- Keep $\theta_{23}^0 = 45^\circ \quad \theta_{13}^0 = 0^\circ$

  (1) within $\sim \lambda_C^2$ of exp:

  need to control corrections to ensure other angles not shifted out of experimentally allowed ranges

  TBM (or other mixing scenarios) as leading order framework

  original scenarios need modifying; this however is doable

  (CP phases often play a significant role)

  Lin 0905.3534 -- anticipated issue and proposed a solution

  See also e.g. Ma '12, King+Stuart et al. '12, other talks here,...

  (2) within $\sim \lambda_C$ of exp: resurgence?

- Modify $\theta_{23}^0 = 45^\circ \quad \theta_{13}^0 = 0^\circ$

  θ_{13} numerology

  drop maximal θ_{23} (some hints in data)?

Some final thoughts...

- Exciting times! Lots of ideas, lots of room for more
- issue of connection to observations and testability

  ⟶ requires NP!

  but NP generically comes with its own flavor puzzle
  how to disentangle?

- role of CP phases -- new focus

  connection to leptogenesis highly model dependent

  better soundbite/motivation for exp program??