CSD(n) vacuum alignments in models of flavour

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Outline

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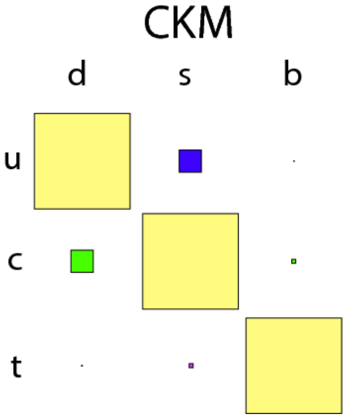
The flavour puzzle

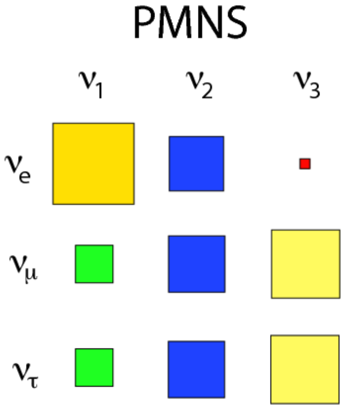
Yukawa and mixing matrices: quarks

- Yukawa matrices Y_u, Y_d
- Diagonalise by V_u, V_d
- $U_{\mathrm{CKM}} = V_u^\dagger V_d$

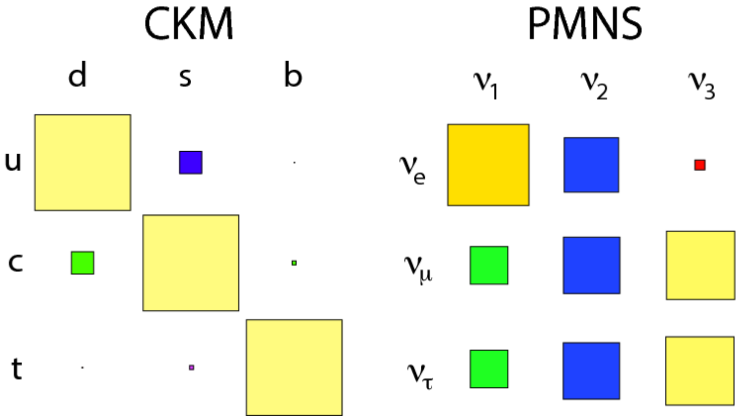


Yukawa and mixing matrices: leptons

- Yukawa matrices Y_ν, Y_e
- Add Majorana mass matrix M_R
- See-saw: $m_\nu = -v_{Higgs}^2 Y_\nu M_R^{-1} Y_\nu^{\mathrm{T}}$
- $U_{\mathrm{PMNS}} = V_\nu^\dagger V_e$



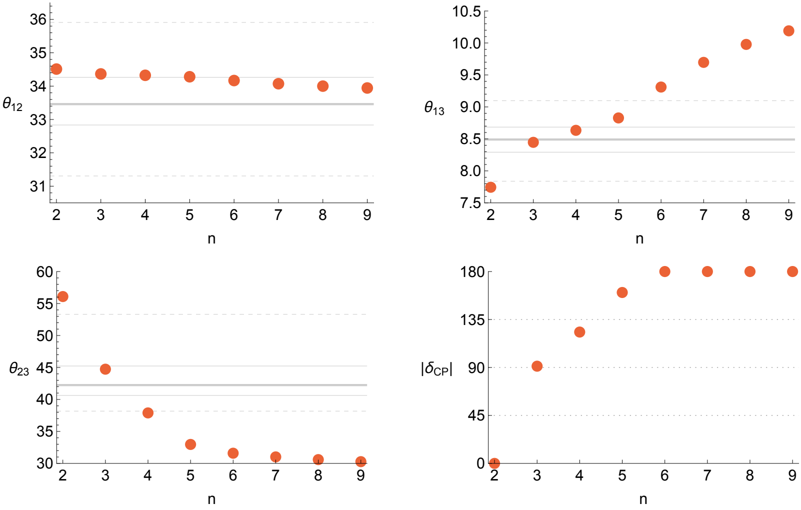
Yukawa and mixing matrices



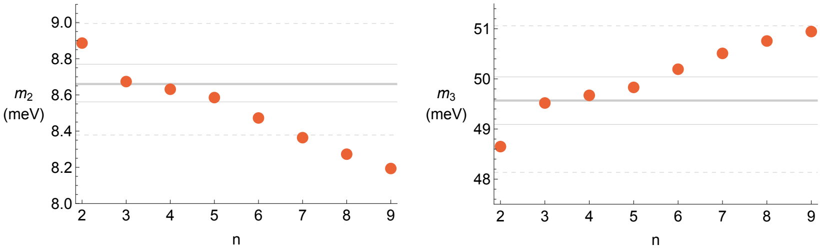
[Stone, arXiv:1212.6374]

Results

PMNS parameters



PMNS parameters



Note: when $m_1 \ll m_2, m_3$, $\Delta m^2_{21} \simeq m^2_2$, $\Delta m^2_{31} \simeq m^2_3$

- These plots assume only 2 RH neutrinos - generalisation to 3RHν is slightly messier but yields similar results. (Why?)

Questions

- What is the model, and what is *n*?
- What assumptions are being made?
- Is this predictive?
- How are results fitted to data?

Flavour model building

Basics of flavour modelling

- Assume discrete flavour symmetry – such as A_4 – in (at least) the lepton sector
- Break symmetry using flavons ϕ_i that gain VEVs
  - Couple to fermions and Higgs like

$$\frac{1}{\Lambda} HLE^c\phi \quad or \quad \frac{1}{\Lambda} HLN^c\phi$$

  - Vacuum alignment of ϕ_i dictate Yukawa structure

Features of CSD(n)

- Constrained Sequential Dominance (CSD):

$$\langle\phi_e\rangle \propto \begin{pmatrix}1\\0\\0\end{pmatrix} \qquad \langle\phi_\mu\rangle \propto \begin{pmatrix}0\\1\\0\end{pmatrix} \qquad \langle\phi_\tau\rangle \propto \begin{pmatrix}0\\0\\1\end{pmatrix}$$

$$\langle\phi_{\rm atm}\rangle \propto \begin{pmatrix}0\\1\\1\end{pmatrix} \quad \langle\phi_{\rm sol}\rangle \propto \begin{pmatrix}1\\n\\n-2\end{pmatrix} \quad \langle\phi_{\rm dec}\rangle \propto \begin{pmatrix}0\\0\\1\end{pmatrix},$$

  - CSD(n) is an evolution of tri-bimaximal mixing [CSD(1)]
  - Preserves TBM(ish), but switches on θ_{13}
  - Asserts normal ordering

Features of CSD(n)

$$m_\nu = m_a \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} + m_b e^{i\eta} \begin{pmatrix} 1 & n & n-2 \\ n & n^2 & n(n-2) \\ n-2 & n(n-2) & (n-2)^2 \end{pmatrix}$$
$$\left[+ m_c e^{i\xi} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right]$$

- Once flavon VEVs are fixed, only 3-5 free parameters
  - m_a, m_b, η [2RHν]
  - $+m_c$, ξ [3RHν]

Assumptions

- No charged lepton corrections
- Strong RH neutrino hierarchy (+ diagonal M_R)

Is it predictive?

- Input: n, m_a, m_b, η (and m_c, ξ)
  - 4-6 parameters
- Output: θ_{12}, θ_{13}, θ_{23}, δ_{CP}, m_1, m_2, m_3, α_{21}, α_{31}
  - 9 parameters
- Testable parameters: θ_{12}, θ_{13}, θ_{23}, δ_{CP}, Δm^2_{21}, Δm^2_{31}

Summary & outlook

Summary & outlook

- CSD(3) provides an excellent fit to current PMNS data
  - Distinct prediction for δ_{CP} which may be testable in near future
  - Predicts normal ordering
- CSD(n) reduces parameter count in neutrino sector, but remains flexible
- Can be incorporated into GUTs
  - Adds structure to Yukawa matrices, constraints on parameters

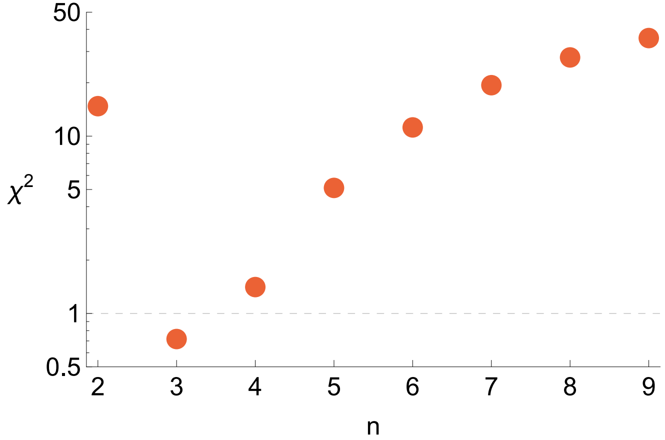
Backup slides

Fitting methodology

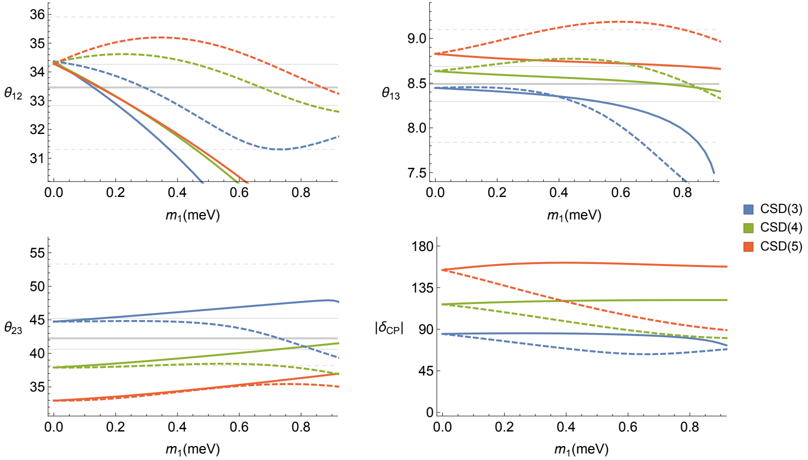
$$\chi^2 = \sum_{i=1}^{5} \left(\frac{P_i(x) - \mu_i}{\sigma_i} \right)^2$$

- i: physical observable (mixing angles, masses)
- x: input parameters (masses, phases)
- P_i: calculated value of observable
- μ_i: best-fit data value
- σ_i: 1σ data spread

Variation with n



Variation with m_1



Variation with m_1