UNIVERSITY OF CALIFORNIA
SANTA CRUZ

A Supersymmetric Flavor Clockwork

W. Altmannshofer, S. A. Gadam arXiv:2106.09869

S. Aditya Gadam

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Santa Cruz Institute for Particle Physics

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Introduction to Clockwork

A Burst of Flavor

Flavor Physics in the quark sector is heavily guided by the Yukawa interactions of the Standard Model (SM),

$$\mathcal{L}_{Yukawa} \supset Y^d_{ij}\overline{q}^i_L H d^j_R + Y^u_{ij}\overline{q}^i_L \tilde{H} u^j_R. \tag{1}$$

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- Why? $\in$ SM Flavor Puzzle

Fermion Mass Hierarchy

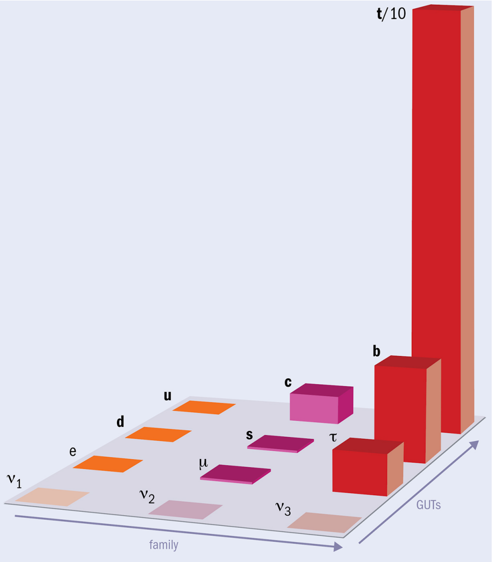

Figure 1: https://cerncourier.com/a/who-ordered-all-of-that/

Clockwork: The Setup

The Clockwork mechanism [Giudice et. al 1610.07962] can generate small (or large) scales from $\mathcal{O}(1)$ numbers. As a quick introduction, let us consider the simplest SM Clockwork, for the RH up quark $u_R \sim (3, 1, \frac{2}{3})$:

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$$\mathcal{L}_{breaking} = -m \sum_{A=1}^{N} \left(\overline{\psi}_L^{(A)} \psi_R^{(A)} - \chi \overline{\psi}_L^{(A)} \psi_R^{(A+1)} + \text{h.c.} \right) . \qquad (2)$$

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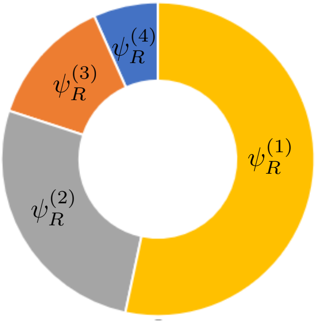

$$\xi_R^{(N+1)} = \mathcal{N} \sum_{A=1}^{N+1} \frac{\psi_R^{(A)}}{\chi^{A-1}}$$
$$\mathcal{N} \simeq 1$$

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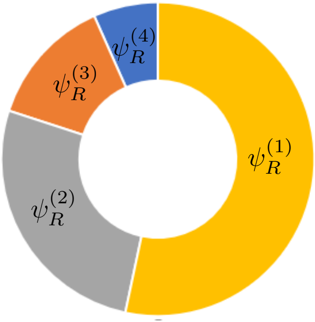

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$$\mathcal{L} \supset -\tilde{Y}^u \, \overline{q}_L \tilde{H} \, \psi_R^{(N+1)} \supset -\frac{1}{\chi^N} \tilde{Y}^u \, \overline{q}_L \tilde{H} \, u_R \tag{3}$$

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$$Y_x^{ik} \simeq \tilde{Y}_x^{ik} \chi^{-N_q^i - N_x^k}, \qquad x \in \{u, d\} \tag{4}$$

$$N_q = \begin{pmatrix} 3 \\ 2 \\ 0 \end{pmatrix}, \quad N_u = \begin{pmatrix} 5 \\ 2 \\ 0 \end{pmatrix}, \quad N_d = \begin{pmatrix} 4 \\ 3 \\ 3 \end{pmatrix} \tag{5}$$

SUSY

https://www.symmetrymagazine.org/article/the-status-of-supersymmetry

Fixing A *Massive* Problem

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$$W \supset \mathbf{\Phi}_{Q_i} \boldsymbol{m}_{Q_i} \mathbf{\Phi}_{Q_i^c} + \mathbf{\Phi}_{U_i} \boldsymbol{m}_{U_i} \mathbf{\Phi}_{U_i^c} + \mathbf{\Phi}_{D_i} \boldsymbol{m}_{D_i} \mathbf{\Phi}_{D_i^c} + \tilde{Y}_u^{ij} H_u \mathbf{\Phi}_{Q_i} \mathbf{\Delta}_u^{ij} \mathbf{\Phi}_{U_j^c} + \tilde{Y}_d^{ij} H_d \mathbf{\Phi}_{Q_i} \mathbf{\Delta}_d^{ij} \mathbf{\Phi}_{D_j^c} \,, \tag{6}$$

where $\mathbf{\Phi}_{\psi_i}$, the chiral super-field corresponding to the SM ψ_i, is a vector in Clockwork space, while $\mathbf{\Delta}_x^{ij}$ is a projection operator, selecting the $(N_q^i + 1, N_x^j + 1)$ gear fields.

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$$\begin{aligned}\mathcal{L}_{soft} \supset\ & \tilde{\mathbf{Q}}_i^\dagger \boldsymbol{\mu}^2_{Q_i} \tilde{\mathbf{Q}}_i + \tilde{\mathbf{Q}}_i^{c\,\dagger} \boldsymbol{\mu}^2_{Q_i^c} \tilde{\mathbf{Q}}_i^c + (M_Q^2)_{ij} \tilde{\mathbf{Q}}_i^\dagger \boldsymbol{\Delta}_Q^{ij} \tilde{\mathbf{Q}}_j \\ & + \tilde{\mathbf{U}}_i^\dagger \boldsymbol{\mu}^2_{U_i} \tilde{\mathbf{U}}_i + \tilde{\mathbf{U}}_i^{c\,\dagger} \boldsymbol{\mu}^2_{U_i^c} \tilde{\mathbf{U}}_i^c + (M_U^2)_{ij} \tilde{\mathbf{U}}_i^{c\,\dagger} \boldsymbol{\Delta}_U^{ij} \tilde{\mathbf{U}}_j^c \\ & + \tilde{\mathbf{D}}_i^\dagger \boldsymbol{\mu}^2_{D_i} \tilde{\mathbf{D}}_i + \tilde{\mathbf{D}}_i^{c\,\dagger} \boldsymbol{\mu}^2_{D_i^c} \tilde{\mathbf{D}}_i^c + (M_D^2)_{ij} \tilde{\mathbf{D}}_i^{c\,\dagger} \boldsymbol{\Delta}_D^{ij} \tilde{\mathbf{D}}_j^c\ ,\end{aligned}$$

Squark Mixing

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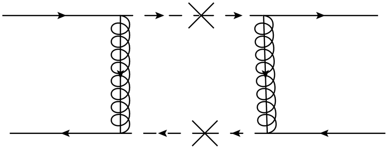
$$m_{\tilde{q}}^2 \simeq m_S^2 \begin{pmatrix} 1 & \chi^{-1} & \chi^{-3} \\ \chi^{-1} & 1 & \chi^{-2} \\ \chi^{-3} & \chi^{-2} & 1 \end{pmatrix}, \tag{7}$$

$$m_{\tilde{u}}^2 \simeq m_S^2 \begin{pmatrix} 1 & \chi^{-1} & \chi^{-3} \\ \chi^{-1} & 1 & \chi^{-2} \\ \chi^{-3} & \chi^{-2} & 1 \end{pmatrix}, \quad m_{\tilde{d}}^2 \simeq m_S^2 \begin{pmatrix} 1 & \chi^{-1} & \chi^{-1} \\ \chi^{-1} & 1 & 1 \\ \chi^{-1} & 1 & 1 \end{pmatrix} \tag{8}$$

Validity



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Valid Parameter Space

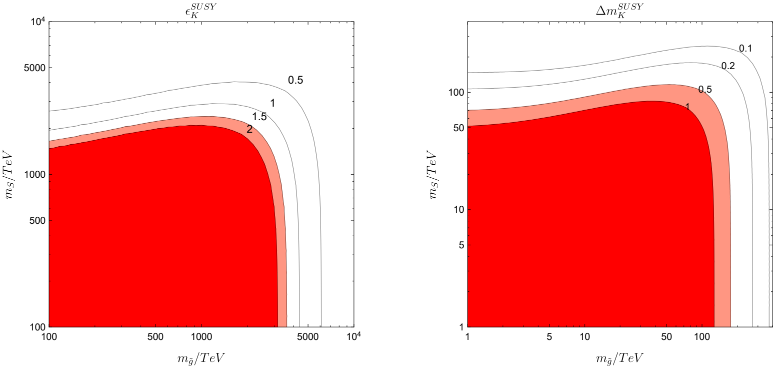

Figure 2: The ϵ_K plot indicates some contours labelling the ratio of the Clockwork SUSY contribution to ϵ_K to the theoretical uncertainty of the SM ϵ_K prediction in [Brod et. al, 1911.06822]. The Δm_K plot tracks the ratio of the Clockwork SUSY contribution to Δm_K to the Standard Model experimental value found in the PDG review.

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- Further flavor mixing and fine-tuning can be incorporated and tweaked by having non-universal masses and gear ratios

Questions?