A Model of Lepton-Flavor-Nonuniversal Dark Gauge Bosons

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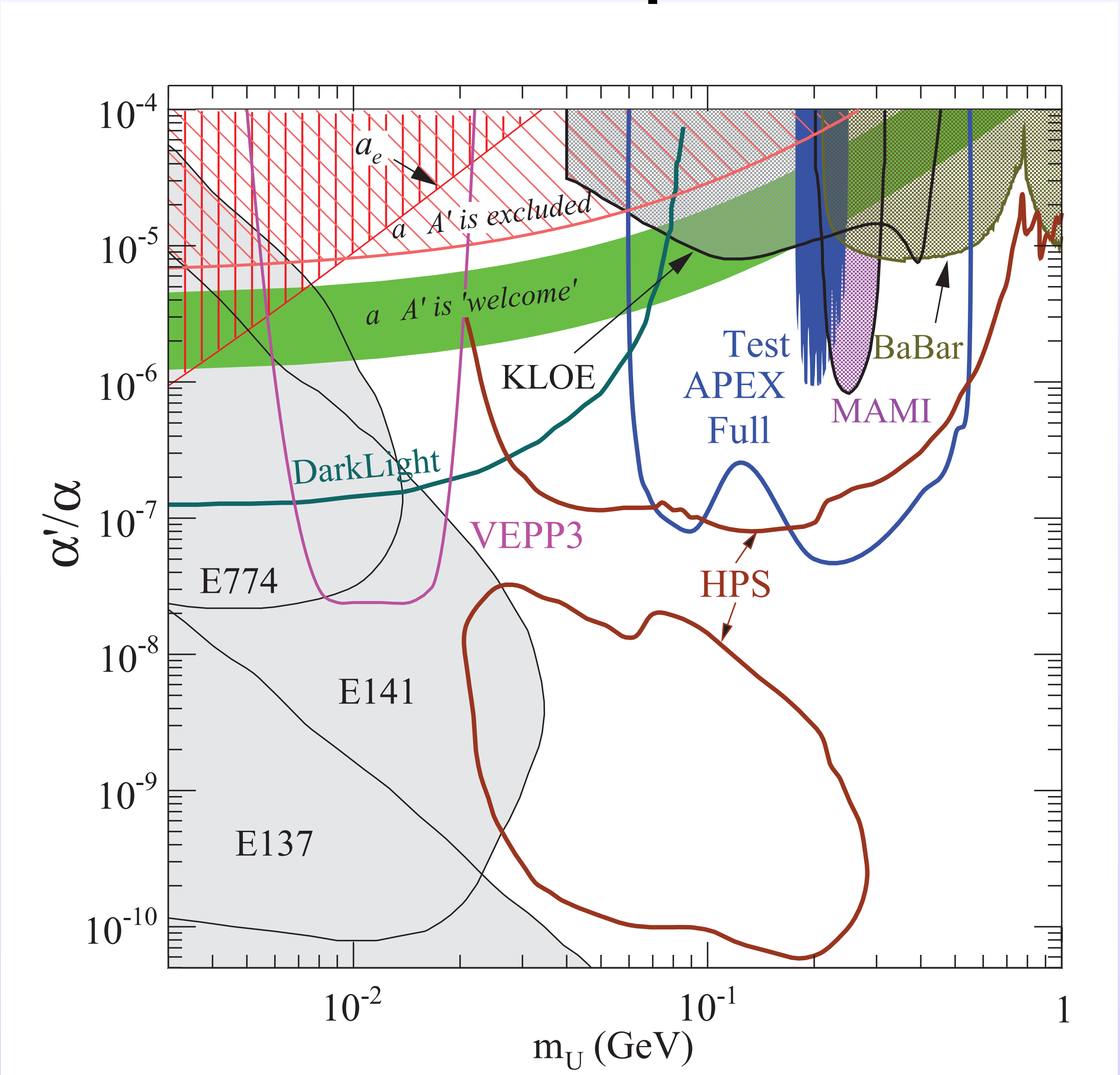
Light U(1) boson, kinetically mixed with hypercharge

Well motived (e.g., PAMELA, Fermi-LAT data)

A target of numerous experimental searches:



These dark photons / Z's couple flavor-universally.
However, there are other possibilities.

Dark SU(2)

Vector-like doublet under $SU(2)_D$:   (A different portal.)

$$E^a_L\,, \quad E^a_R$$

Same electroweak quantum numbers as e_R

Complex scalar doublet $\phi^a \sim \mathbf{2}\,,\ \langle\phi\rangle = \begin{pmatrix} 0 \\ v_D/\sqrt{2} \end{pmatrix}.$

Allows for mixing. For example

$$\mathcal{L} \supset h\,\overline{\mu}_R \phi^*_a E^a_L + h'\,\epsilon_{ab}\,\overline{\mu}_R \phi^a E^b_L + \text{ h.c.}$$

SM leptons couple primarily to dark gauge bosons via mass mixing.

Simplified case: $h' = 0$ **Let** $\Psi = (\mu\,,\; E^{(2)})^T$

$$\mathcal{L} \supset \overline{\Psi}_L \begin{pmatrix} m_\mu & 0 \\ \delta m & M \end{pmatrix} \Psi_R + \text{h.c.}\,,$$

where $\delta m = h\, v_d/\sqrt{2}$

$$\Psi_j = \begin{pmatrix} c_j & s_j \\ -s_j & c_j \end{pmatrix} \Psi_j{}^{\text{mass}}$$

$$s_j = \sin\theta_j\,, \quad c_j = \cos\theta_j \quad (j = L, R)$$

$$\theta_R \approx \delta m/M \qquad\qquad \theta_L \approx (m_\mu/M)(\delta m/M)$$

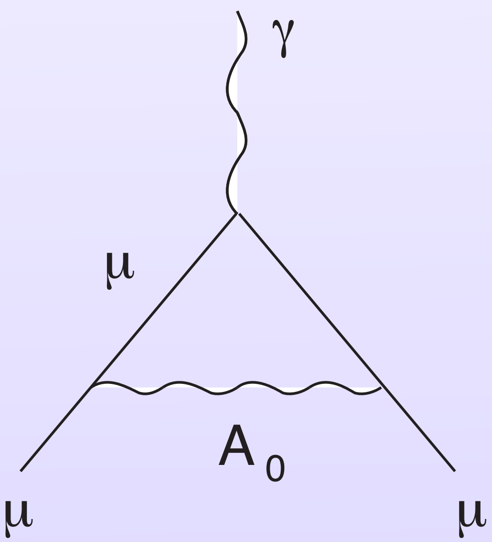
Also define

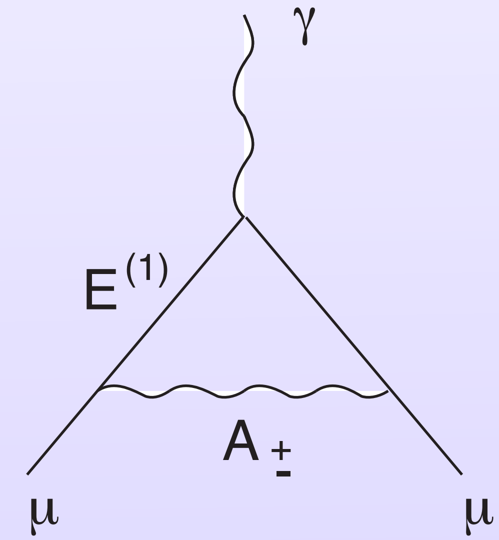
$$A_D^a T^a = \begin{pmatrix} A_0/2 & A_+/\sqrt{2} \\ A_-/\sqrt{2} & -A_0/2\,, \end{pmatrix}$$

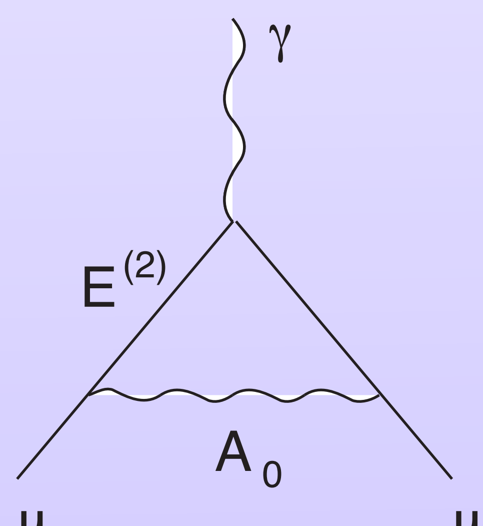
Then one finds:

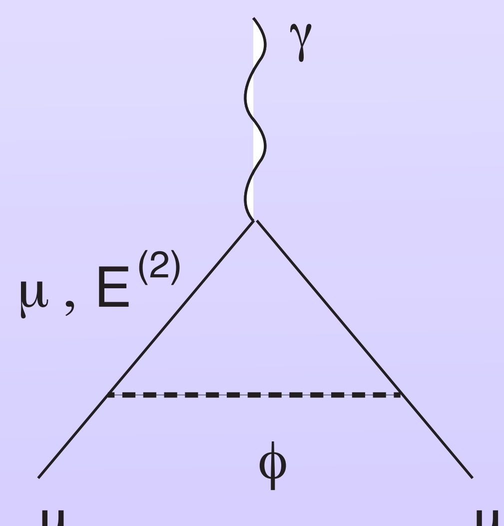
$$\begin{aligned}\mathcal{L} \;\supset\; & [-\frac{1}{2}s_R^2\, g_D\, (\overline{\mu}_R \not{A}_0 \mu_R) - \frac{1}{\sqrt{2}} s_R\, g_D\, (\overline{\mu}_R \not{A}_- E_R^{(1)} + \mathrm{h.c.}) \\ + \;& \frac{1}{2} s_R c_R\, g_D\, (\overline{\mu}_R \not{A}_0 E_R^{(2)} + \mathrm{h.c.})] + [\mathrm{R} \to \mathrm{L}]\end{aligned}$$

These vertices lead to new contributions to muon g-2

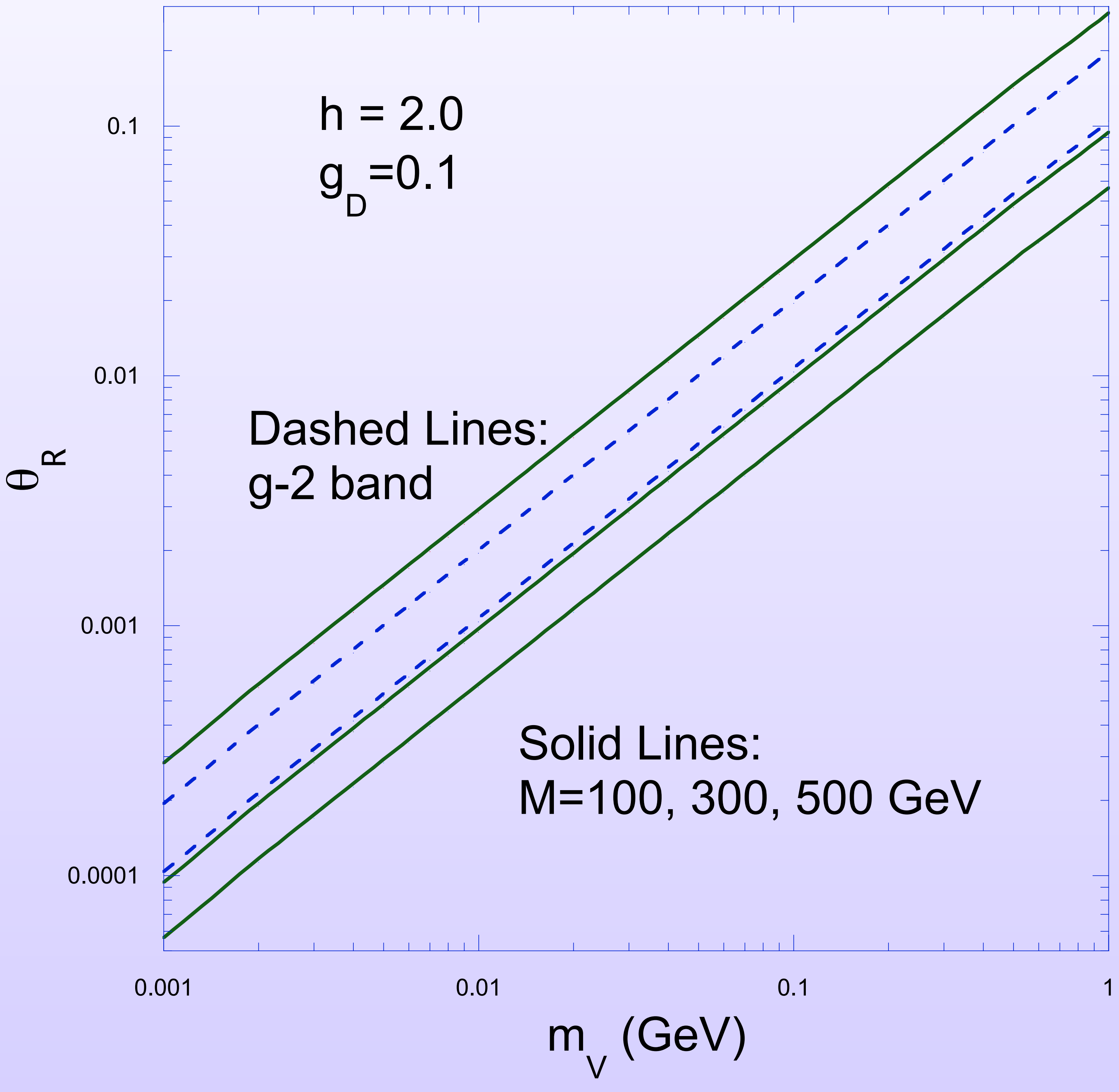








$$\Delta a_\mu = a_\mu^{\exp} - a_\mu^{\rm SM} = 287 \pm 80 \times 10^{-11}$$



Symmetry Structure

Non-generic flavor structure from a discrete symmetry:

$$G_F = A_4$$

Irreducible representations: $\mathbf{3}$, $\mathbf{1}^0$, $\mathbf{1}^+$, and $\mathbf{1}^-$.

Usual assignments for tribimaximal neutrino mixing:

$$L_L \sim \mathbf{3}\,, e_R \sim \mathbf{1}^0\,, \mu_R \sim \mathbf{1}^+\,, \tau_R \sim \mathbf{1}^-$$

Flavon fields:

$$\langle \varphi_S \rangle = \begin{pmatrix} v_S \\ v_S \\ v_S \end{pmatrix} , \qquad \langle \varphi_T \rangle = \begin{pmatrix} v_T \\ 0 \\ 0 \end{pmatrix}$$

Symmetry breaking:

Charged lepton sector: $\langle \varphi_T \rangle$ breaks $A_4 \to Z_3$

Neutrino sector: $\langle \varphi_S \rangle$ breaks $A_4 \to Z_2$

e.g., under the unbroken Z_3 elements of Y_L transform by

the phases $\begin{pmatrix} 1 & \eta & \eta^2 \\ \eta^2 & 1 & \eta \\ \eta & \eta^2 & 1 \end{pmatrix}$ where $\eta^3 = 1$

Guarantees diagonal form (up to small corrections):

$$Y_L = \frac{v_T}{\Lambda_F} \begin{pmatrix} y_e & 0 & 0 \\ 0 & y_\mu & 0 \\ 0 & 0 & y_\tau \end{pmatrix}$$

Assign flavor quantum numbers to vector-like states:

$$E_L^a \sim E_R^a \sim \mathbf{1}^+$$

Original mixing terms are allowed, but these aren't:

$$\overline{e}_R \phi_a^* E_L^a \sim \mathbf{1}^+ \,, \qquad \overline{\tau}_R \phi_a^* E_L^a \sim \mathbf{1}^- \,.$$

Same residual symmetry that keeps Y_L diagonal assures that the E states only mix with muons.

LFV effects are entirely controlled by Z_3 breaking...

Make the conventional choice: $\nu_R^c \sim \mathbf{3}$

$$\mathcal{L}_\nu = \frac{1}{2} m_R \, \overline{\nu_R^c} \, \nu_R + \frac{1}{2} x \, \overline{\nu_R^c} \, \varphi_S \, \nu_R + [y \, \overline{L}_L H \nu_R + \mathrm{h.c.}]$$

Leads to tribimaximal form:

$$m_{LR} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} y\, v$$

$$m_{RR} = \begin{pmatrix} A + 2B/3 & -B/3 & -B/3 \\ -B/3 & 2B/3 & A - B/3 \\ -B/3 & A - B/3 & 2B/3 \end{pmatrix} m_R$$

where $A = 1$, $B = x v_S / m_R$, and $v \approx 246$ GeV

Z_3 breaking parameter: v_S/Λ_F

Observed neutrino masses are consistent with

$$v_S \sim m_R \ll \Lambda_F \quad \text{if} \quad y \ll 1$$

For example, if $y \approx y_e$ (easily arranged with an additional Z_N)

$m_R \sim v_S \sim 20$ TeV then $v_S/M_* \approx 10^{-14}$

LFV bounds easily satisfied.

For example, effective operator: $\ell_i \to \ell_j \, \gamma$

$$\frac{1}{\Lambda_{\rm NP}^2} \overline{L}_{L\,i} \, H \sigma^{\mu\nu} F_{\mu\nu} Z_{ij} e_{Rj}$$

$$\Lambda_{\rm NP} \approx 4\pi M / g_D \qquad\qquad Z_{ij} \sim \mathcal{O}(v_T v_S / \Lambda_F^2) \;\; , \quad (i \neq j)$$

For $v_T/\Lambda_F \sim 0.01$, $\Lambda_F = M_*$, $M_R \approx 20$ TeV: $Z_{ij} \sim \mathcal{O}(10^{-16})$

For $g_D = 0.1$ and $M = 100$ GeV, **Bound:** $Z_{\mu e} < 7.1 \times 10^{-7}$

Conclusions

Dark photon/Z's with non-universal couplings to leptons can be viable due to discrete symmetries. This motivates further phenomenological study.