Anomaly-free leptophilic ALP and its LFV tests

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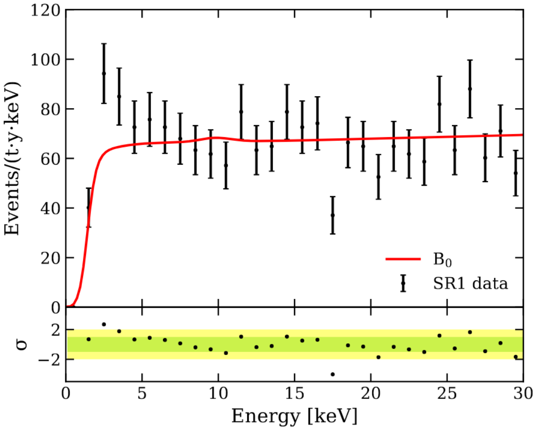
C. Han, M. L. López-Ibáñez, A. Melis, O. Vives and J. M. Yang, Phys. Rev. D 103 (2021) no.3, 035028

Sizeable discrepancy at Xenon1T



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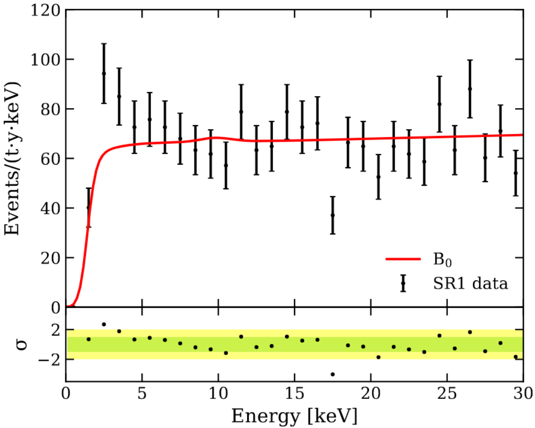

Excess in e^- recoil energy between 2 and 3 keV.

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ALPs

Pseudo-Goldstone bosons from broken global symmetries with $m_a \simeq \mathcal{O}(\mathrm{keV})$ and a weak coupling to e^-, could explain this excess

However, X-ray observations forbid anomalous coupling to photons for $m_a \gtrsim 0.1$ keV

$\Longrightarrow$ $\boxed{U(1)_{\mathrm{em}}\ \textbf{anomaly-free ALP}}$

SM particle content, only $B - L$ and L are $U(1)_{\mathrm{em}}$ anomaly-free with family universal charges.

But ... breaking associated to N_R masses, too high in Seesaw models.

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- Global flavor-dependent $U(1)_\phi$ symmetry spontaneously broken

$\Rightarrow$ Axion Like Particle

Model I: $U(1)$ flavor symmetry

Scalar flavon field, ϕ, generates Yukawa couplings as function of small vevs, $Y_{ij} = \left(\left(\frac{\langle\phi\rangle}{M}\right) \ll 1\right)^n$. with n function of charges.

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- Anomaly-free $U(1)_\phi$: $\sum_i Q_{L_i} = 0$ and $\sum_i Q_{e_i} = 0$.

Field	τ_L	μ_L	e_L	τ_R	μ_R	e_R	$N_{R,i}$	ϕ	H_1	H_2
$U(1)_\phi$	-1	0	1	1	0	-1	0	0	2	1
Z_2	$+$	$+$	$+$	$-$	$-$	$-$	$-$	$+$	$-$	$+$

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Soft-breaking of $U(1)_\phi \times Z_2$: $m^2 H_1 H_2$, with $m \sim \mathcal{O}(\mathrm{EW})$.

$$\longrightarrow m_a \simeq m^2/v_\phi$$

Yukawa coouplngs:

$$\mathcal{L}_Y \supset c^e_{ij}\,\epsilon^{n^e_{ij}}\,\bar{L}_i\,\widetilde{H}_2\,e_j + \; c^\nu_{ij}\,\epsilon^{n^\nu_{ij}}\,\bar{L}_i\,H_2\,N_j \; + \; (M_R)_{ij}\; N_{R_i}\,N^c_{R_j},$$

with $\epsilon \simeq 0.1$ and $n^e_{ij} = q_{L_i} - q_{e_j} + q_{H_2},\, n^\nu_{ij} = q_{L_i} - q_{N_{R,j}} - q_{H_2},$

$$n^e_{ij} \; = \; \begin{pmatrix} 4 & 3 & 2 \\ 3 & 2 & 1 \\ 2 & 1 & 0 \end{pmatrix}, \qquad n^\nu_{ij} \; = \; \begin{pmatrix} 1 & 1 & 1 \\ 2 & 2 & 2 \\ 3 & 3 & 3 \end{pmatrix}.$$

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- After symmetry breaking: $\phi(x) \;=\; \frac{1}{\sqrt{2}}\,(v_\phi + s(x))\,e^{i\,a(x)/v_\phi}$
- With couplings to charged leptons,

$$-\mathcal{L}_{ae} \;=\; i\frac{\partial_\mu a}{2f_a}\,\overline{e}_i\,\gamma^\mu\,(V^e_{ij} + \gamma^5 A^e_{ij})\,e_j.$$

$$V^e_{ij} = \frac{1}{2}\left(U^{e\,\dagger}_R Q_e U^e_R \;+\; U^{e\,\dagger}_L Q_L U^e_L\right), \qquad A^e_{ij} = \frac{1}{2}\left(U^{e\,\dagger}_R Q_e U^e_R \;-\; U^{e\,\dagger}_L Q_L U^e_L\right)$$

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Generalize the previous structure to allow for larger mixings determined by a larger symmetry $\mathcal{F}$, with global $U(1)_\phi$ part of $\mathcal{F}$

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- PMNS-like mixing in charged-leptons. Then:

$$V^e_{ij},\, A^e_{ij} = \frac{1}{2}\, U^{e\,\dagger}_{\rm PMNS} \left(Q_e \,\pm\, Q_L \right) U^e_{\rm PMNS}$$

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$\Longrightarrow$ **Too large LFV ???**

LFV and Astrophysics Constraints

$$\mathrm{BR}(e_i \to e_j a) = \frac{m_{e_i}^3}{16\pi\Gamma(e_j)} \frac{\left|C_{ij}^e\right|^2}{4 f_a^2} \left(1 - \frac{m_a^2}{m_{e_i}^2}\right)^2 .$$

with $\left|C_{ij}^e\right|^2 = \left|V_{ij}^e\right|^2 + \left|A_{ij}^e\right|^2$

Lepton decay	**BR limit**		**Projection**	
$\mathrm{BR}(\mu \to e\,a)$	$< 2.6 \cdot 10^{-6}$	`Jodidio et al.`	$< 1.3 \cdot 10^{-7}$	MEGII-fwd
$\mathrm{BR}(\mu \to e\,a)$	$< 2.1 \cdot 10^{-5}$	`TWIST`	$< 7.3 \cdot 10^{-8}$	`Mu3e`
$\mathrm{BR}(\mu \to e\,a\,\gamma)$	$< 1.1 \cdot 10^{-9}$	`Crystal Box`		
$\mathrm{BR}(\tau \to e\,a)$	$< 2.7 \cdot 10^{-3}$	`ARGUS`	$< 8.4 \cdot 10^{-6}$	`Belle-II`
$\mathrm{BR}(\tau \to \mu\,a)$	$< 4.5 \cdot 10^{-3}$	`ARGUS`	$< 1.6 \cdot 10^{-5}$	`Belle-II`

Coling of white dwarfs and red giants:

$f_a \gtrsim 2.3 \times 10^9 |C_{11}^e|$ GeV, $\qquad f_a \gtrsim 1.2 \times 10^9 |C_{11}^e|$ GeV.

Results

Analysis of *Takahashi-Yamada-Yin*, Xenon1T explained by ALP with $A^e_{11} \simeq 10^{-13} \frac{f_a}{m_e}$ for $m_a \in [2,3]$ keV.

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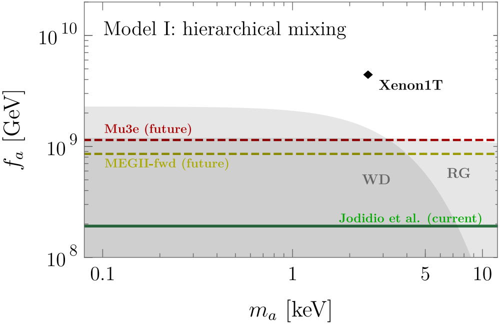

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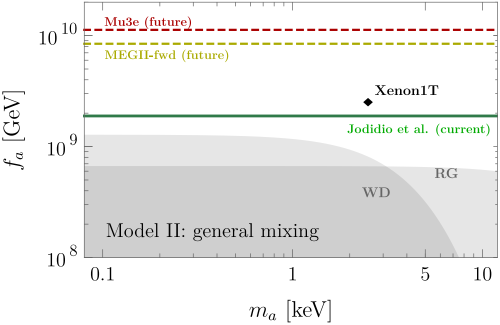

Conclusions

- Xenon1T excess can by explained by flavored ALP with minimal particle content.
- Simultaneously, LFV ALP interactions could be detected at low-energy experiments.
- ALP flavor couplings depend on charged-lepton mixings and charges.
- Flavor models of small mixings (CKM-like) produce too small effects for proposed experiments.
- Models of PMNS-like charged-lepton mixings explaining Xenon1T could be detectable in LFV experiments.