1508±1.xxxx @ 1σ

Non-standard neutrino interactions with light mediators

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in collaboration with
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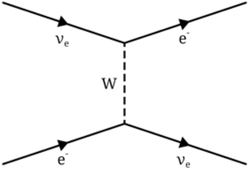
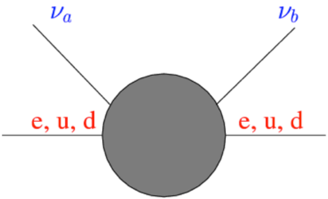
Neutrino matter effects and NSIs



$$\mathcal{H} = \frac{1}{2E} U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} U^\dagger + \frac{1}{2E} \begin{pmatrix} V & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

New physics could induce new matter effects



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Neutrino NSIs

Typically effective operators can be used
to parametrize such interactions

Dimension 6 operators are expected to be dominant, for instance

$$\frac{1}{\Lambda^2}(\bar{L}_\alpha \gamma^\rho L_\beta)\,(\bar{L}_\gamma \gamma_\rho L_\delta\,)$$

SU(2) invariance ensures that the same FCNCs in the neutrino sector are present in the charged lepton sector

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Neutrino NSIs

Now compare neutrino oscillation precision with rare decays

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Neutrino NSIs

Now compare neutrino oscillation precision with rare decays

BR(μ to 3e) < 10^{-12}
BR(τ to 3μ) < 2 10^{-8}
BR(τ to 3e) < 3 10^{-8}
Oscillation errors: 1~10%

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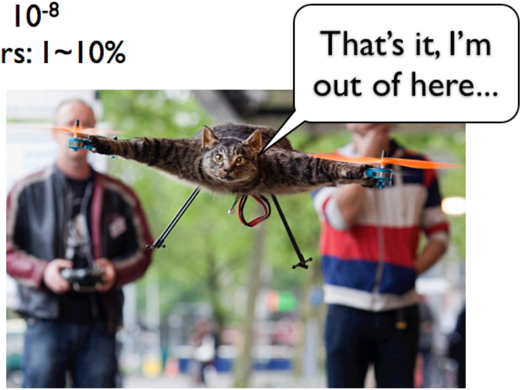

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Neutrino NSIs

Is it possible to have large neutrino NSIs while respecting SU(2) invariance and still being consistent with all flavor data?

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Neutrino NSIs

One could try specific models, for instance:

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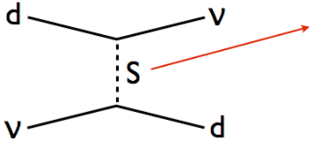

This would be a leptoquark scalar triplet with coupling Q.S.L

Different triplet components would induce FCNC for neutrinos and charged leptons

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Neutrino NSIs

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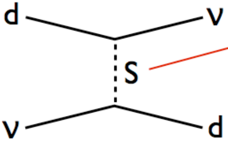

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Different triplet components would induce FCNC for neutrinos and charged leptons

Different masses → Different FCNC effects

Different masses → T parameter...

Bergmann et al 1999

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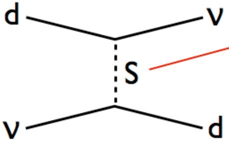

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Bergmann et al 1999

This argument used to work on the last century, but now with more data (h, B factories) it is not valid anymore

Friedland et al 2012

Neutrino NSIs

Is it possible to have large neutrino NSIs while respecting SU(2) invariance and still being consistent with all flavor data?

D=6 operators induce too large FCNC for charged sector

Fine tuning would be needed to suppress D=6 while maintaining D=8 operators dominant

Gavela et al 2009

Even D=8 operators would be severely constrained

Antusch et al 2008

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Neutrino NSIs and light mediators

There is another possibility: a weakly coupled light messenger

EFT would not apply

Generically, an experiment probes a mediator which mass is close to the experiment energy scale

$$A \propto \frac{1}{q^2 - m^2}$$

Neutrino matter effect is a *zero* momentum phenomenum

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Neutrino NSIs and light mediators

We need flavor changing and well behaved interactions
We gauge B – L number of the third family (call it X)

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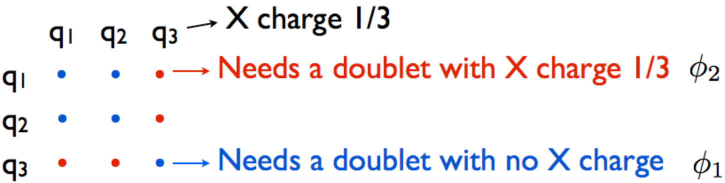

q_1 q_2 q_3 → X charge 1/3

q_1 → Needs a doublet with X charge 1/3 ϕ_2

q_2

q_3 → Needs a doublet with no X charge ϕ_1

Due to details on the scalar potential and neutrino masses we also need a scalar singlet s with X charge 1/3

Neutrino NSIs and light mediators

Due to the presence of a doublet that also has X charge, there is a mass mixing in the gauge boson sector

$$M_{\rm gauge} = \frac{1}{4}\begin{pmatrix} g'^2 v^2 & -gg' v^2 & -g' g_X v_2^2/3 \\ -gg' v^2 & g^2 v^2 & g g_X v_2^2/3 \\ -g' g_X v_2^2/3 & g g_X v_2^2/3 & g_X^2 (v_2^2 + v_s^2)/9 \end{pmatrix}$$

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Usual B-W^3 mass matrix

$$M_{\rm gauge} = \frac{1}{4}\begin{pmatrix} g'^2 v^2 & -gg'v^2 & -g' g_X v_2^2/3 \\ -gg'v^2 & g^2v^2 & g g_X v_2^2/3 \\ -g' g_X v_2^2/3 & g g_X v_2^2/3 & g_X^2(v_2^2+v_s^2)/9 \end{pmatrix}$$

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linear combination: massless state

$$M_{\text{gauge}} = \frac{1}{4}\begin{pmatrix} g'^2v^2 & -gg'v^2 & -g'g_Xv_2^2/3 \\ -gg'v^2 & g^2v^2 & gg_Xv_2^2/3 \\ -g'g_Xv_2^2/3 & gg_Xv_2^2/3 & g_X^2(v_2^2+v_s^2)/9 \end{pmatrix}$$

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Mixing between X and Z

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$$Z_\mu \approx -s_w B_\mu + c_w W_\mu^3 + s_X X_\mu^0 \qquad M_X^2 = \frac{1}{36} g_X^2 \left(\frac{v_1^2 v_2^2}{v^2} + v_s^2\right)$$

$$X_\mu \approx -s_X(-s_w B_\mu + c_w W_\mu^3) + X_\mu^0$$

$$s_X \equiv \frac{1}{3}\frac{g_X}{\sqrt{g^2 + g'^2}}\frac{v_2^2}{v^2}$$

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We could also have kinetic mixing

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Neutrino NSIs and light mediators

$$\mathcal{L}^{q}_{yuk} = \overline{\mathbf{Q}}_L \begin{pmatrix} y^u_{11}\widetilde{\phi}_1 & y^u_{12}\widetilde{\phi}_1 & y^u_{13}\widetilde{\phi}_2 \\ y^u_{21}\widetilde{\phi}_1 & y^u_{22}\widetilde{\phi}_1 & y^u_{23}\widetilde{\phi}_2 \\ 0 & 0 & y^u_{33}\widetilde{\phi}_1 \end{pmatrix} \mathbf{u}_R + \overline{\mathbf{Q}}_L \begin{pmatrix} y^d_{11}\phi_1 & y^d_{12}\phi_1 & 0 \\ y^d_{21}\phi_1 & y^d_{22}\phi_1 & 0 \\ y^d_{31}\phi_2 & y^d_{32}\phi_2 & y^d_{33}\phi_1 \end{pmatrix} \mathbf{d}_R + \mathrm{h.c.}$$

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We choose to generate the CKM mixing on the up sector

$$R^{uL}_{12}.M_u.R^{uR\dagger}_{12} \approx \begin{pmatrix} m_u & 0 & V^0_{ub}m_t \\ 0 & m_c & V^0_{cb}m_t \\ 0 & 0 & m_t \end{pmatrix} \quad \text{and} \quad R^{dL}_{12}.M_d.R^{dR\dagger}_{12} \approx \begin{pmatrix} m^0_d & 0 & 0 \\ 0 & m^0_s & 0 \\ 0 & 0 & m^0_b \end{pmatrix}$$

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$$\mathcal{L}_{\text{X}-\text{FCNC}} = \frac{g_X}{3} \overline{\mathbf{Q}}_L \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} \gamma^\mu X_\mu \mathbf{Q}_L$$

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Neutrino NSIs and light mediators

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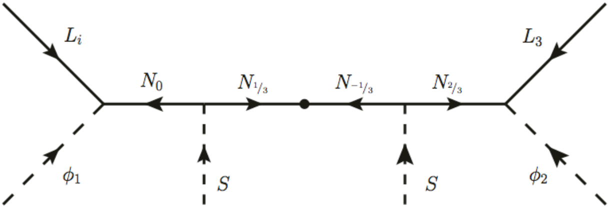
Neutrino NSIs and light mediators

PMNS mixing cannot be generated in the charged fermion sector: tree level FCNC free!

Neutrino masses and mixing: Froggatt-Nielsen mechanism



Presence of TeV-ish fermion singlets

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Phenomenology

Eletron and muon anomalous magnetic moment

Fixed target experiments

Upsilon and kaon decays

B meson and kaon oscillations

LSND

NUTEV

Borexino and GEMMA

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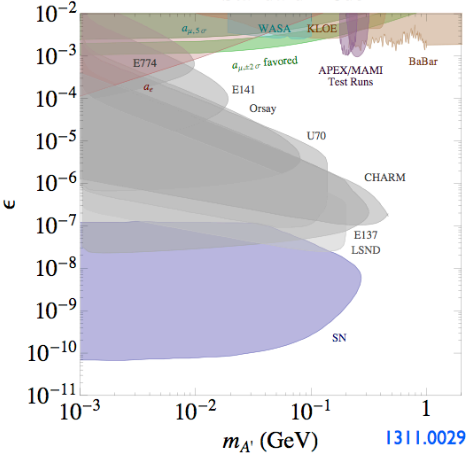

A' → Standard Model

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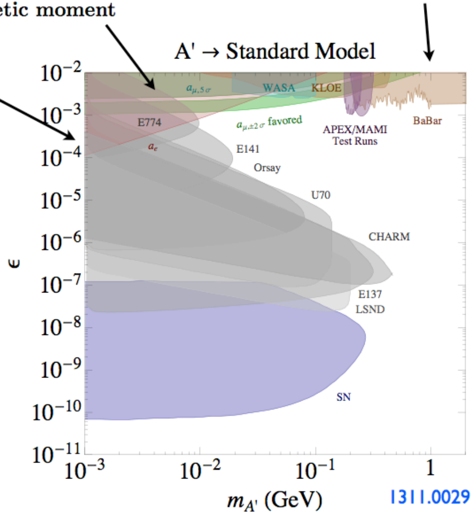

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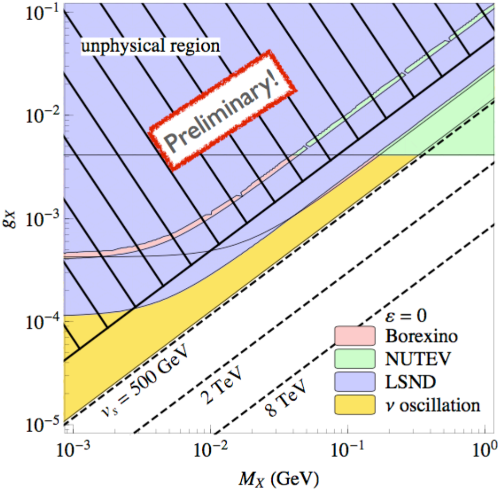

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Upsilon and kaon decays $\boxed{g_X \lesssim 0.018}$

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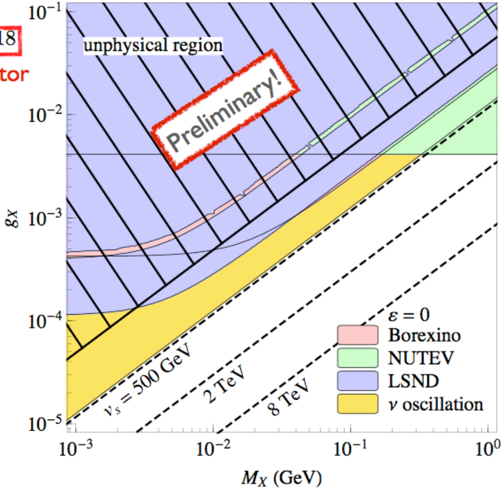

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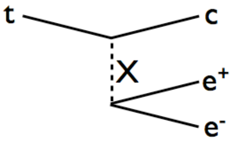

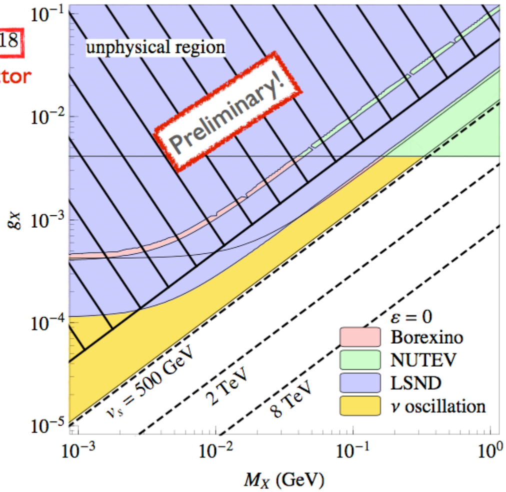

Conclusions

We elaborated a *renormalizable, UV complete* model which can provide large NSI in the neutrino sector and pass all flavor bounds

This simple realization may indicate a whole class of flavorful light mediator models which may have an interesting phenomenology

We found that the strongest bound comes from neutrino oscillation experiments

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