Sterile Neutrinos from Flavor Gauge Dynamics

Adam Smetana
adamsmetana@seznam.cz

Nuclear Physics Institute, Řež, Czech Republic

collaboration with Petr Beneš, and Jiří Hošek

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- there are many models aspiring to solve **the electro-weak symmetry breaking problem**
- some of them introduce a new **gauge dynamics** (TC-like models)
- not a new idea is to gauge **flavor** (family, horizontal) symmetry $\mathrm{SU}(3)_F$
- but its particular implementation in **the recent model** can bring new inspiration
- here we present consequences of the recent model
  - rich sector of **sterile neutrinos**
  - rich spectrum of neutrino spin-0 composites - **majorons**

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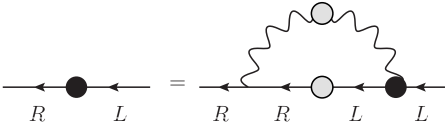
The model - strong flavor dynamics



- at the scale $\Lambda_F \gg M_W$ the flavor symmetry is broken by its own dynamics providing
  - mass matrices for fermions $m(p)$

$$\mathrm{SU}(3)_c \times \underbrace{\mathrm{SU}(3)_F}_{8\times M_F} \times \underbrace{\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y}_{3\times M_{W,Z}} \xrightarrow{\Lambda_F} \mathrm{SU}(3)_c \times \mathrm{U}(1)_{em}$$

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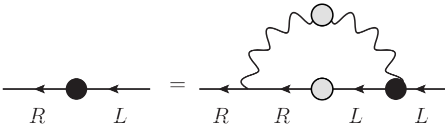

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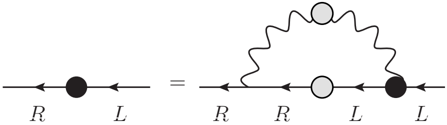

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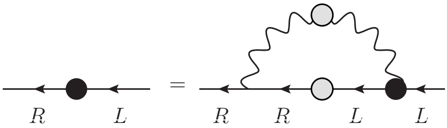

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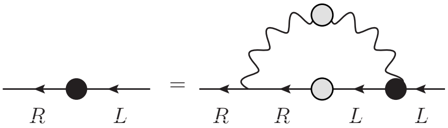

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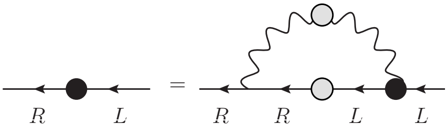

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The model - hierarchies

- strong dynamics is promising in generating large hierarchies

$$\frac{M_W}{M_F} \ll 1, \quad \frac{m}{M_F} \ll 1, \quad \frac{m_1}{m_2} \ll 1$$

The model - requirements

The model requires

- to be **strongly coupled** and **asymptotically free**
  - to have the theory under control in UV
  - to create a scale Λ_F ($\gtrsim 10^{-6}$ TeV $\Leftarrow$ FCNC),
- to have a **non-vector-like** gauge boson–fermion coupling
  - not to be QCD-like,
- **not** to have **confinement** of the flavor.

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Main concept is

- to put left and right u, d, and e fermions into distinct combinations of flavor representations

	q_l	u_R	d_R	l_L	e_R
case I	$\mathbf{3}$	$\mathbf{3}$	$\overline{\mathbf{3}}$	$\overline{\mathbf{3}}$	$\mathbf{3}$
case II					$\overline{\mathbf{3}}$

  - to distinguish their mass matrices

$$m_{\mathbf{3}\times\mathbf{3}} \neq m_{\overline{\mathbf{3}}\times\mathbf{3}} \neq m_{\mathbf{3}\times\overline{\mathbf{3}}} \neq m_{\overline{\mathbf{3}}\times\overline{\mathbf{3}}}$$

- as a result the model is non-vector-like!

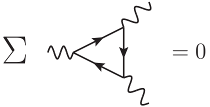
The model predicts sterile neutrinos

From

- gauge anomaly freedom
- asymptotic freedom

a limited number of sterile neutrinos arise

Flavor gauge anomaly freedom



- sterile neutrinos ν_R has to be added
  - they are **electro-weak** and **color** singlets
  - they are in balanced combination of **flavor** representations

$$\mathbf{3}, \overline{\mathbf{3}}, \mathbf{6}, \overline{\mathbf{6}}, \mathbf{8}, \mathbf{10}, \overline{\mathbf{10}}, \ldots$$

that compensates the non-vanishing anomaly contribution of electro-weakly charged fermions

Asymptotic freedom

- not to disturb flavor asymptotic freedom the number of sterile neutrinos ν_R is limited

$$\beta(h) = -\frac{h^3}{(4\pi)^2}\left[11 - 5 - \frac{2}{3}\eta_{AF}\right]$$

$$\Rightarrow \quad 1/2N_3 + 5/2N_6 + 3N_8 + 15/2N_{10} + ... \equiv \eta_{AF} < 9$$

Main result - all possible settings of sterile neutrinos

	setting	$\frac{(4\pi)^2}{h^3}\beta$	# of ν_R
case I	$3 \times \mathbf{3}$	-5	9
case II	$5 \times \mathbf{3}$	$-13/3$	15
case II	$1 \times \mathbf{6} + 2 \times \overline{\mathbf{3}}$	$-11/3$	11
case I	$1 \times \mathbf{6} + 4 \times \overline{\mathbf{3}}$	-3	13
case I	$1 \times \overline{\mathbf{6}} + 10 \times \mathbf{3}$	-1	36
case II	$1 \times \overline{\mathbf{6}} + 12 \times \mathbf{3}$	-1	39
	$+n \times (\mathbf{3} + \overline{\mathbf{3}})$ $+m \times \mathbf{8}$ $+k \times (\mathbf{6} + \overline{\mathbf{6}})$		

Global symmetry among sterile neutrinos

- copies of sterile ν_R flavor multiplets has to be introduced

$$\Longrightarrow \text{ global sterile symmetry } G_S$$

- for the simplest case $3 \times \mathbf{3}$ the global sterile symmetry is

$$G_S = \mathrm{U}(1) \times \mathrm{SU}(3)$$

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Note - Global sterile symmetry can be reduced

- *in cases where*
  - *some* ν_R*'s are in* $\mathbf{r}$
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the global sterile symmetry G_S *is explicitly broken by hard Majorana masses*

$$\overline{(\nu_{R\overline{\mathbf{r}}})^c} M \nu_{R\mathbf{r}} + \text{h.c.}$$

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Majorons from spontaneous global sterile symmetry breaking

- mass matrix for neutrinos (generated by the flavor gauge dynamics) breaks the global sterile symmetry G_S

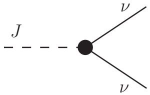
$$\Rightarrow \text{ Nambu–Goldstone bosons} = \textbf{majorons } J$$

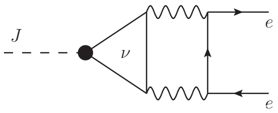
- there are two types of majorons
  - heavy majorons
  - light majorons

Heavy majorons

- some $\mathrm{U}(1)$ subgroups of the global sterile symmetry G_S have anomaly
- corresponding majorons are **heavy**, they acquire large mass by instanton effect
$$M \sim \Lambda_F$$
- the *heavy majorons* couple predominantly to sterile neutrinos and flavor gauge bosons

- anomaly free subgroup of the global sterile symmetry G_S provides majorons that are **light**,
  they could acquire a tiny gravitationally generated mass ($\sim$ eV)
- they can possibly account for the observed dark matter component of the Universe
- the *light majorons* have a coupling to fermions





Conclusions

- The model of EWSB due to strong flavor gauge dynamics has been presented.
- The model has one parameter h and one scale Λ_F responsible for EWSB.
- The model is based on **assumption** that
  - the flavor gauge dynamics **breaks its own gauge symmetry**
  - the flavor does **not confine**
  - the solution of S.–D. equations exists and is **hierarchical**.
- We study the consequences of the model:
  - sterile neutrinos
  - majorons
  - other spin-0 composites: axions, etc. (not discussed here)
  - possible dark matter components
  - physics of low-energy frontier.

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Reference:

J. Hošek: arXiv:0909.0629

Appendix I: The non-vector-like model

The model is built as non-vector-like but around the energy scale $\gtrsim \Lambda_F$

- case $3 \times \mathbf{3}$

$$\Psi_L = \begin{pmatrix} u_L^1 \\ u_L^2 \\ u_L^3 \\ d_L^1 \\ d_L^2 \\ d_L^3 \\ (d_R^1)^c \\ (d_R^2)^c \\ (d_R^3)^c \end{pmatrix}, \quad \Psi_R = \begin{pmatrix} u_R^1 \\ u_R^2 \\ u_R^3 \\ (\nu_L)^c \\ (e_L)^c \\ e_R \\ \nu_R^i \\ \nu_R^{ii} \\ \nu_R^{iii} \end{pmatrix}$$

$$G_{chiral} = \mathrm{U}(9)_R \times \mathrm{U}(9)_L$$

$$\mathcal{L}_F = \overline{\Psi_R} \mathrm{i}\not{D}\, \Psi_R + \overline{\Psi_L} \mathrm{i}\not{D}\, \Psi_L \qquad \text{QCD-like theory}$$

- case $1 \times \mathbf{6} + 4 \times \overline{\mathbf{3}}$ – non-minimal ν_R-setting

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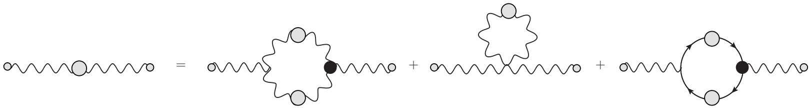
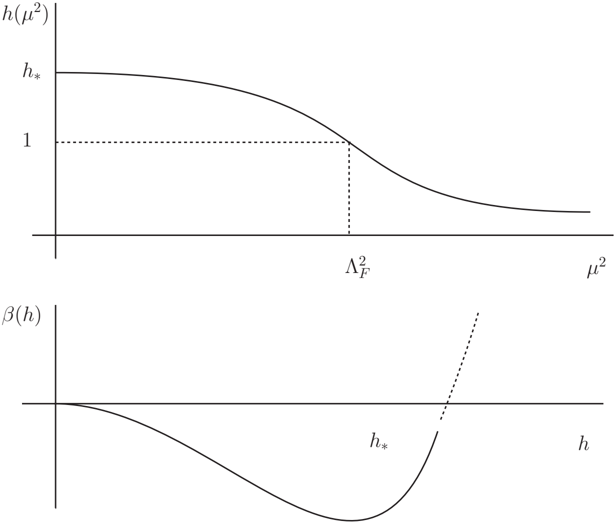
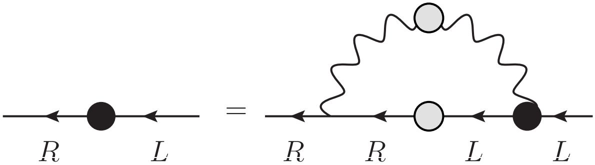
Gauge boson SDE




$h(\mu^2)$
h_*
1
Λ_F^2
μ^2
$\beta(h)$
h_*
h

Appendix IV



$$m(p) = \int \frac{\mathrm{d}^4 k}{(2\pi)^4} D_{ab}(k+p) T_a m(k) [k^2 - m^*(k) m(k)]^{-1} T_b$$