Flavored Dark Matter: Scotogenic Dark Symmetry from Flavor symmetry

Newton Nath

INFN Bari, Italy

In collaboration with: Ranjeet Kumar,
Rahul Srivastava,
arXiv: 2207.0xxxx (in preparation)

FLASY 2022
30/06/2022

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Motivation:

Origin of *dark* symmetry from flavor symmetry

Outcomes:

Neutrino masses and mixings and fermonic DM

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Talks:
E. Ma,
P. Escribano, O. Median,
H. B. Câmara, S. Chuliá

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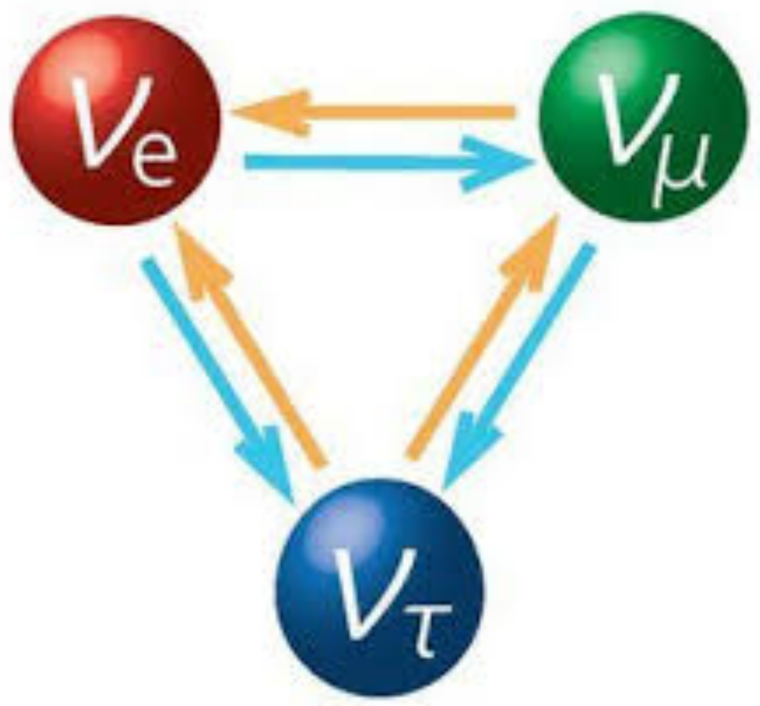
Neutrino Mass:

- Neutrinos are massless in the Standard Model

Neutrino oscillation => Transition from one flavour to another

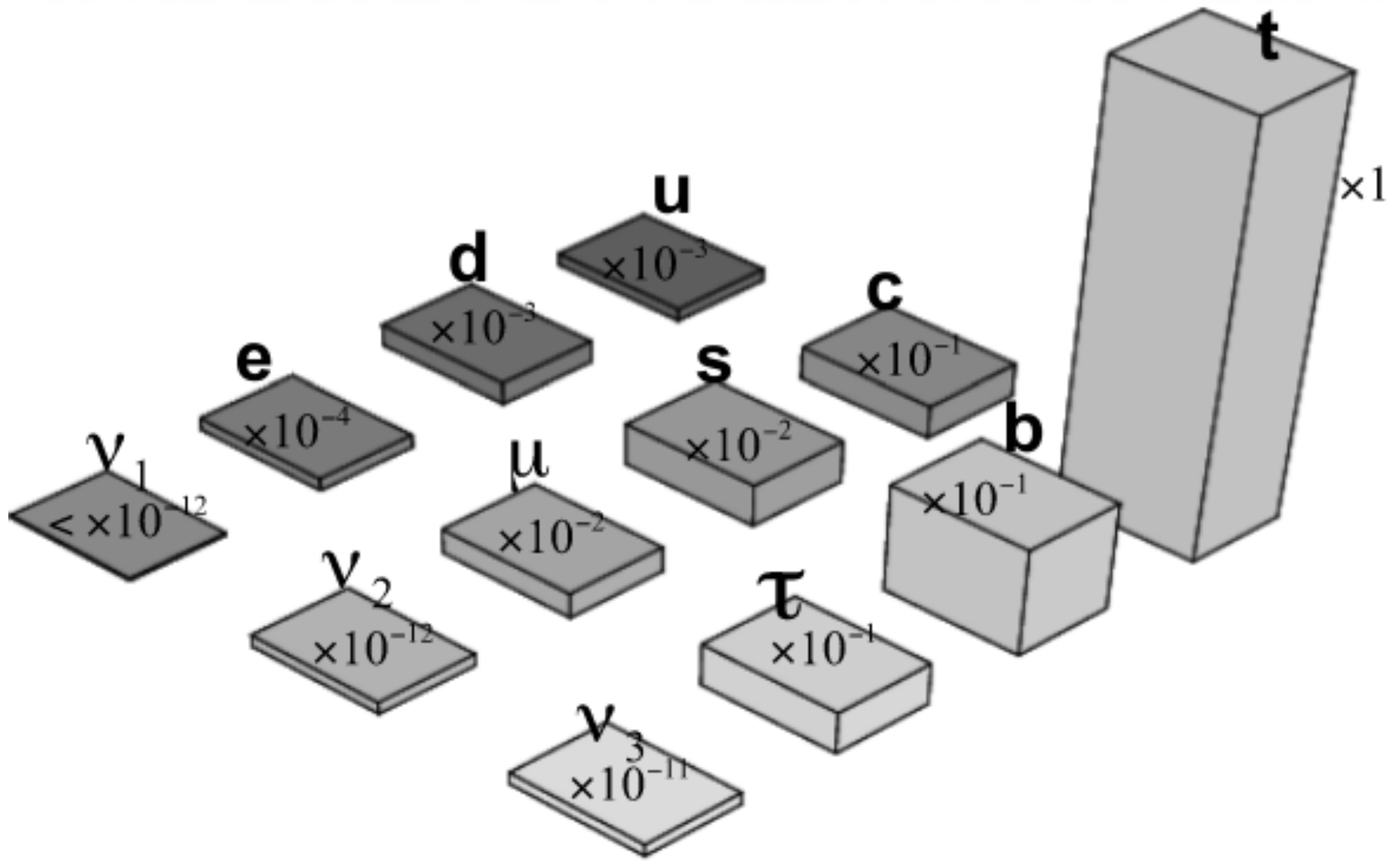
time = 0; time = t;

ν_e; $\longrightarrow$ distance = L; $\longrightarrow$ ν_e, ν_μ, ν_τ;



Nobel Prize 2015:
T. Kajita and A. B. McDonald

- Tiny Neutrino Mass: a long standing issue



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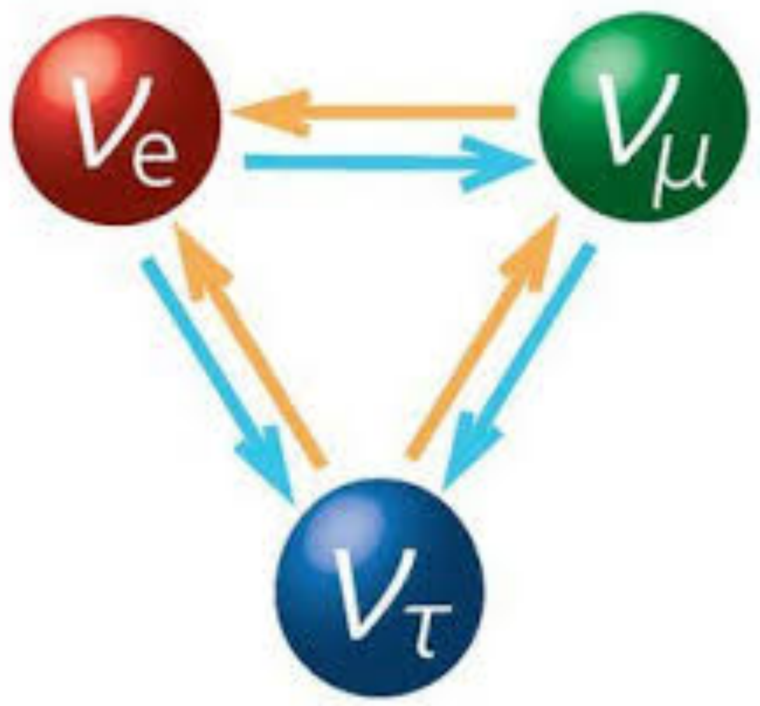

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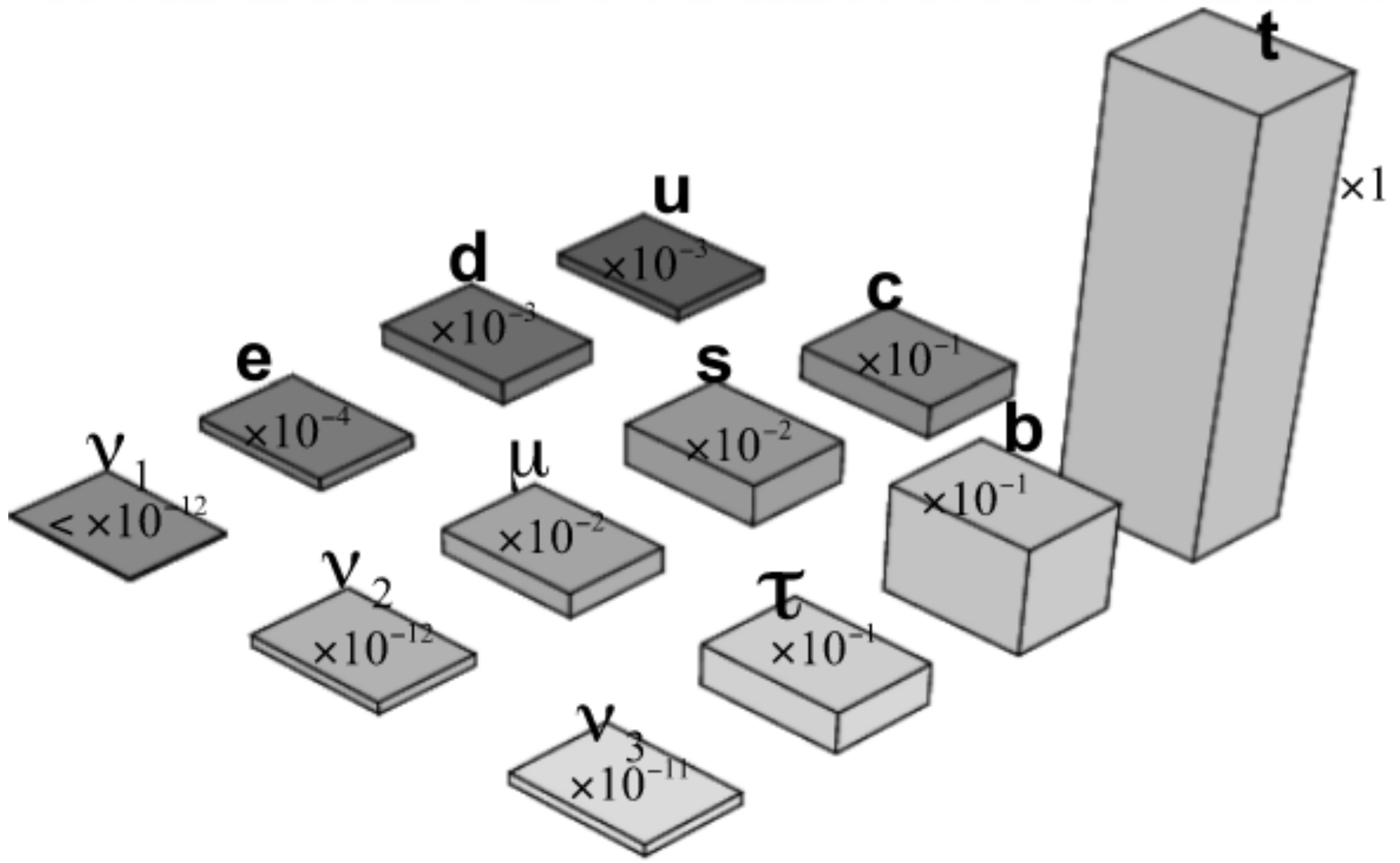
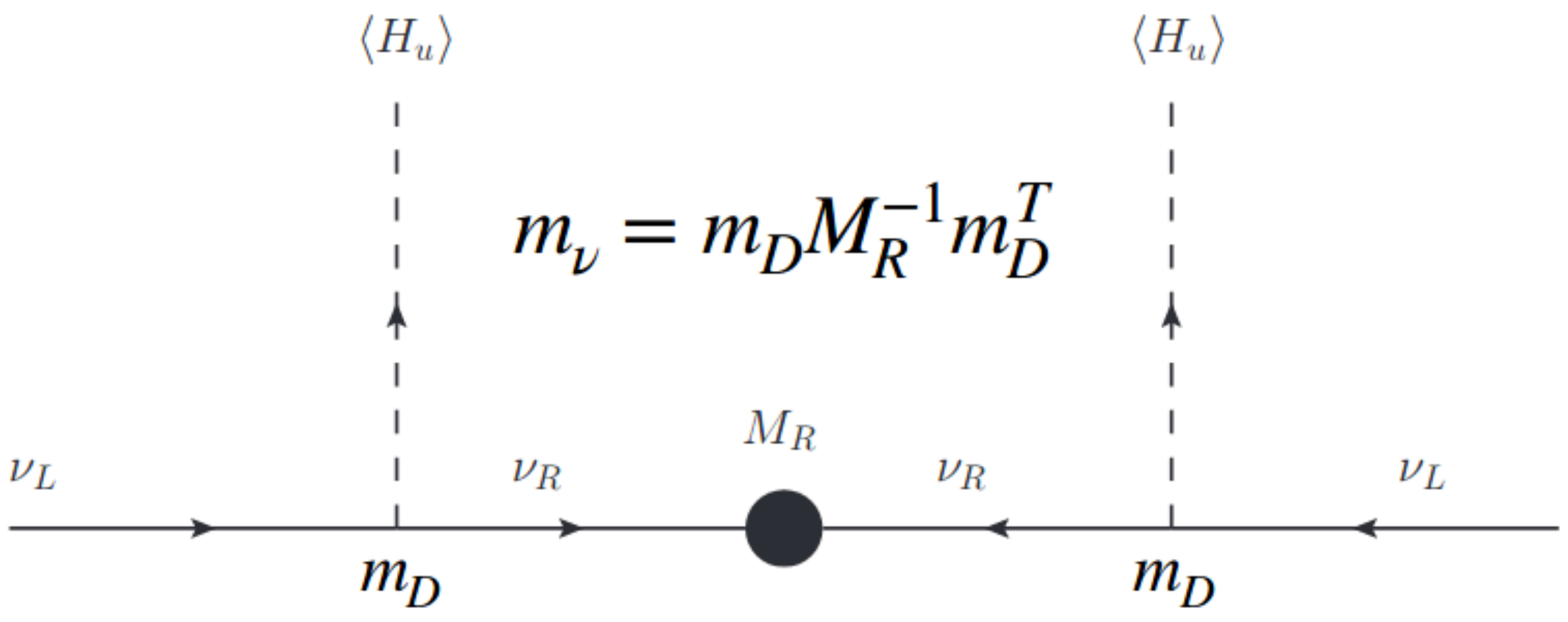


type-I seesaw



[Minkowski'77, Yanagida'79, Gell-Mann/Slansky/Ramond'79, Mohapatra/Senjanovic'80, Schecter/Valle'80]

Neutrino Mixing: Three-flavor

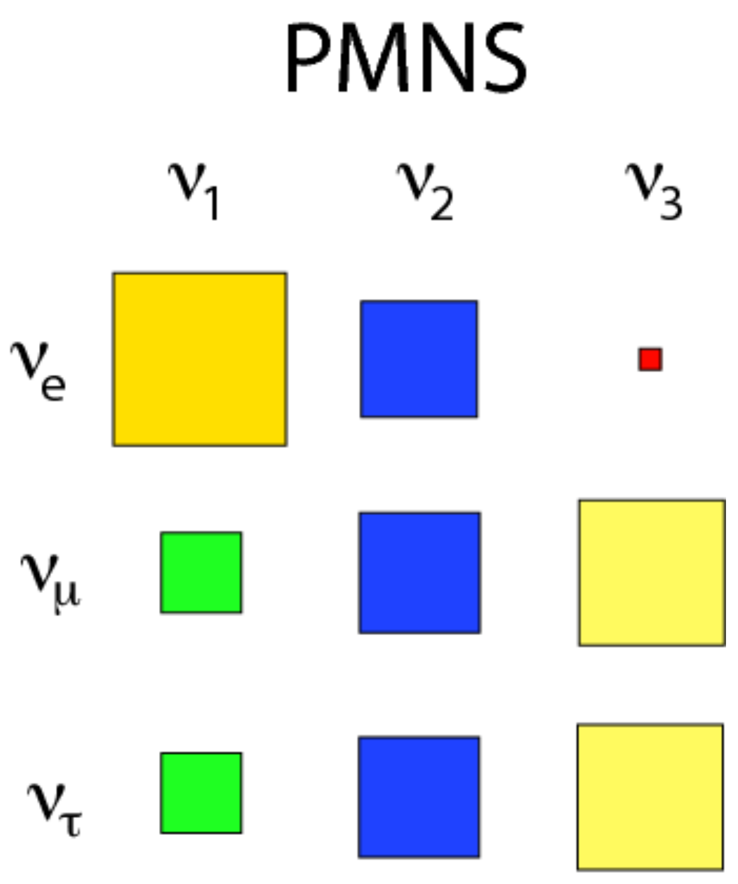
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\mathrm{CP}}} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

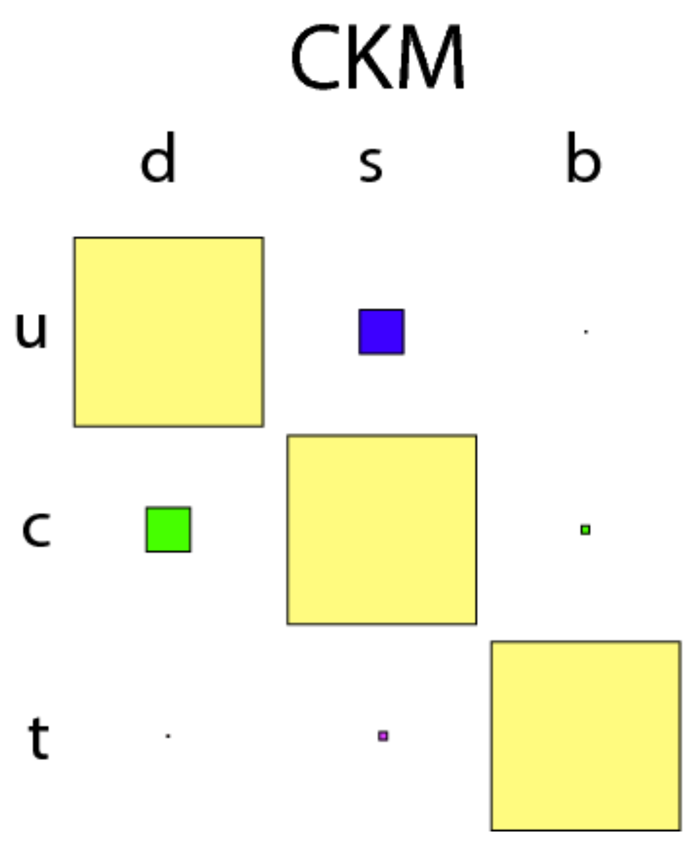
Atmospheric,
K2K, MINOS, T2K, etc.,
$\theta_{23} \sim 45^0$

Reactor,
Accelerator,
$\theta_{13} < 10^0$

Solar,
KamLAND,
$\theta_{12} \sim 33^0$

- 3-mixing angles, 1 CP-phase. (Dirac neutrinos)
- 2-additional Majorana phases. (Majorana neutrino)





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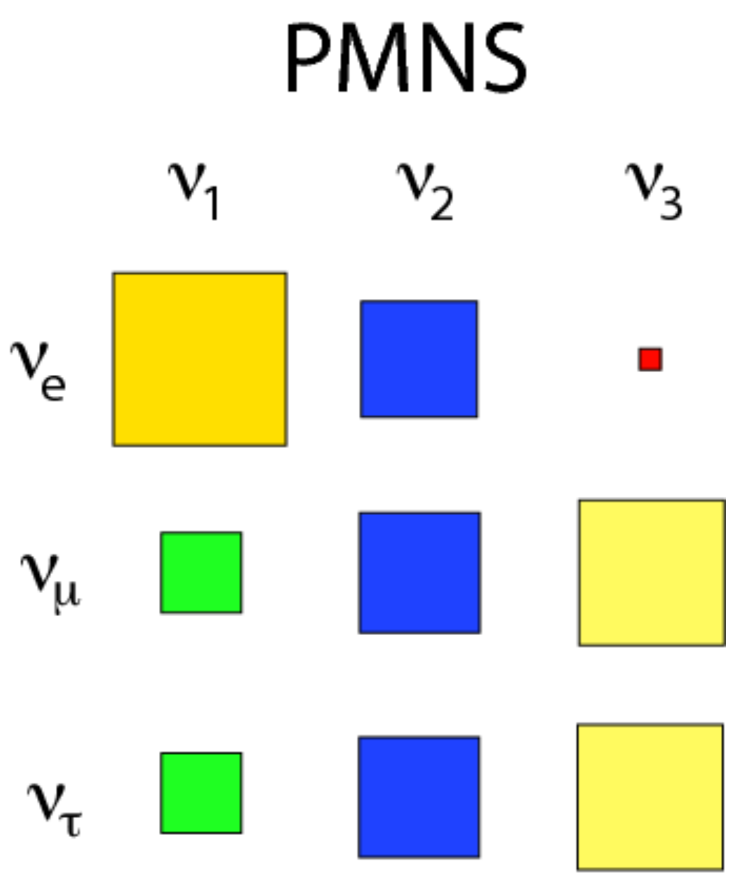
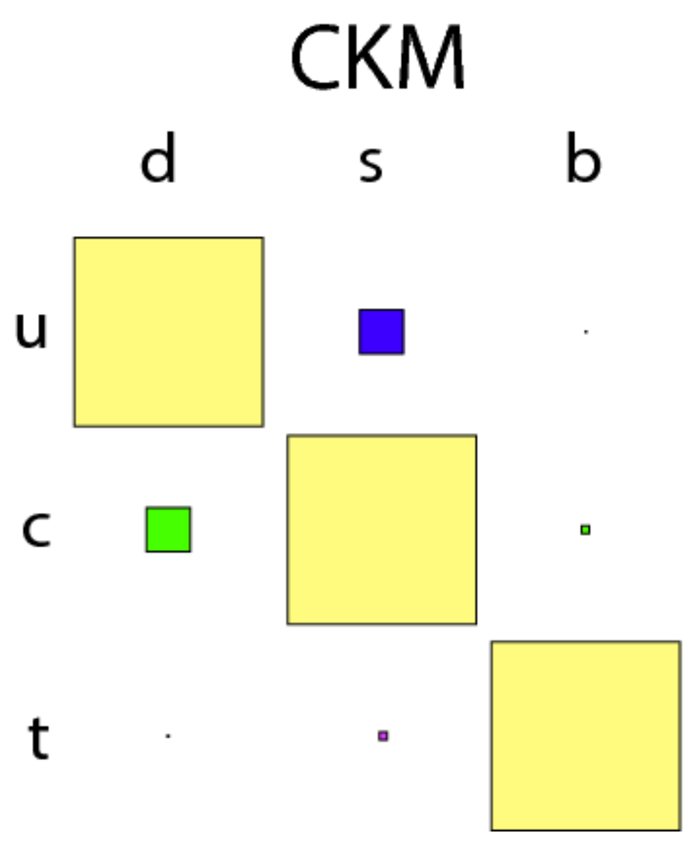




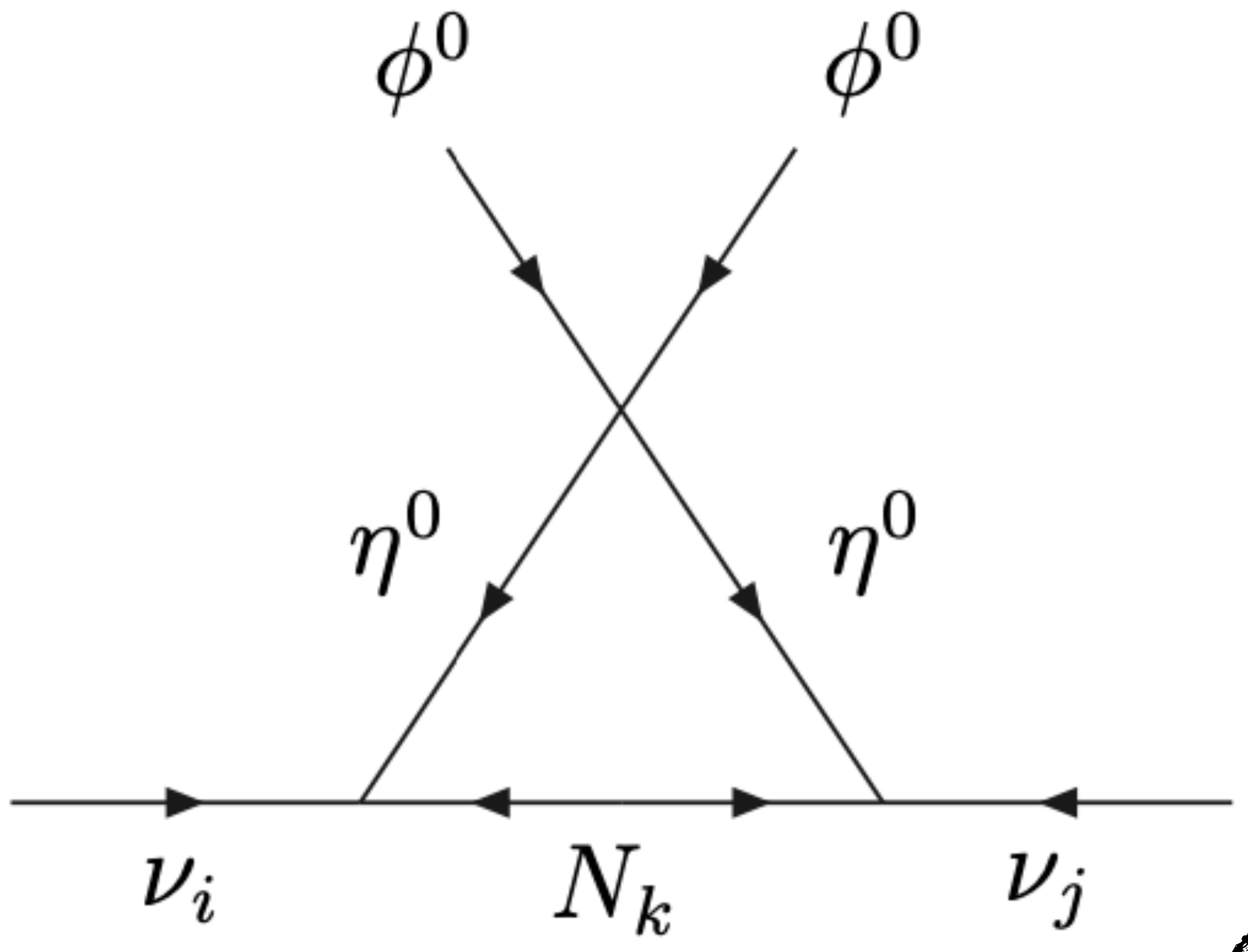
[Why this form ?]

Interplay between Dark Matter & Neutrino:

- The scotogenic model: a minimal extension of the SM has been considered

$$(\nu_i, l_i) \sim (2, -1/2; +), \quad l_i^c \sim (1, 1; +), \quad N_i \sim (1, 0; -),$$
$$(\phi^+, \phi^0) \sim (2, 1/2; +), \quad (\eta^+, \eta^0) \sim (2, 1/2; -).$$

The symmetry $SU(2)_L \times U(1)_Y \times Z_2$



Originally proposed by Ma, PRD 73 (2006) 077301

- $Z_2 \Rightarrow$ the lightest stable particle

- Two possible DM candidates: the lightest neutral dark scalar or the lightest dark fermion

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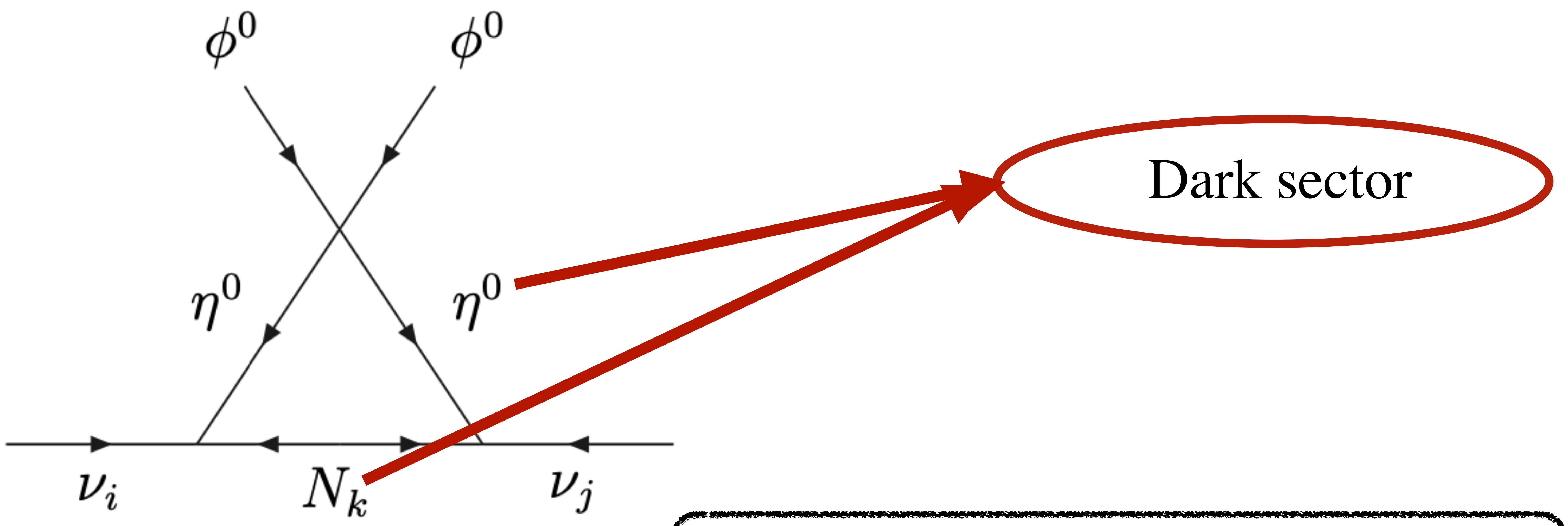

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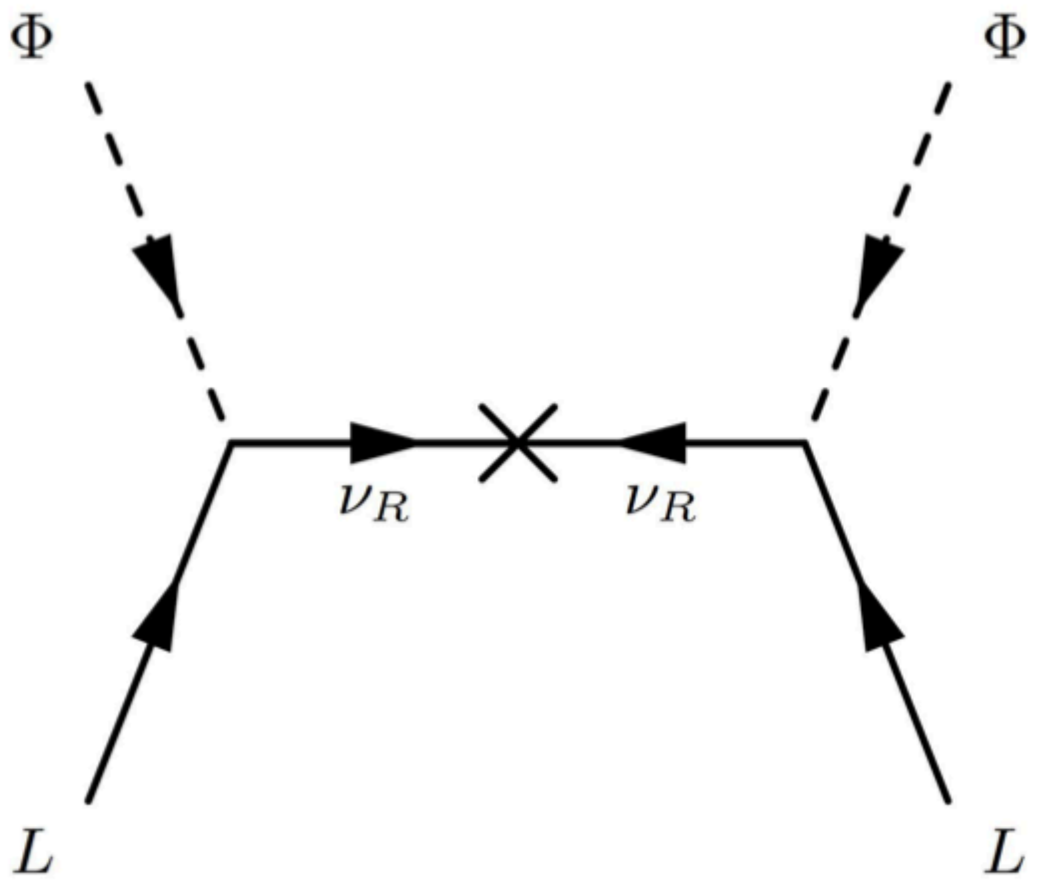
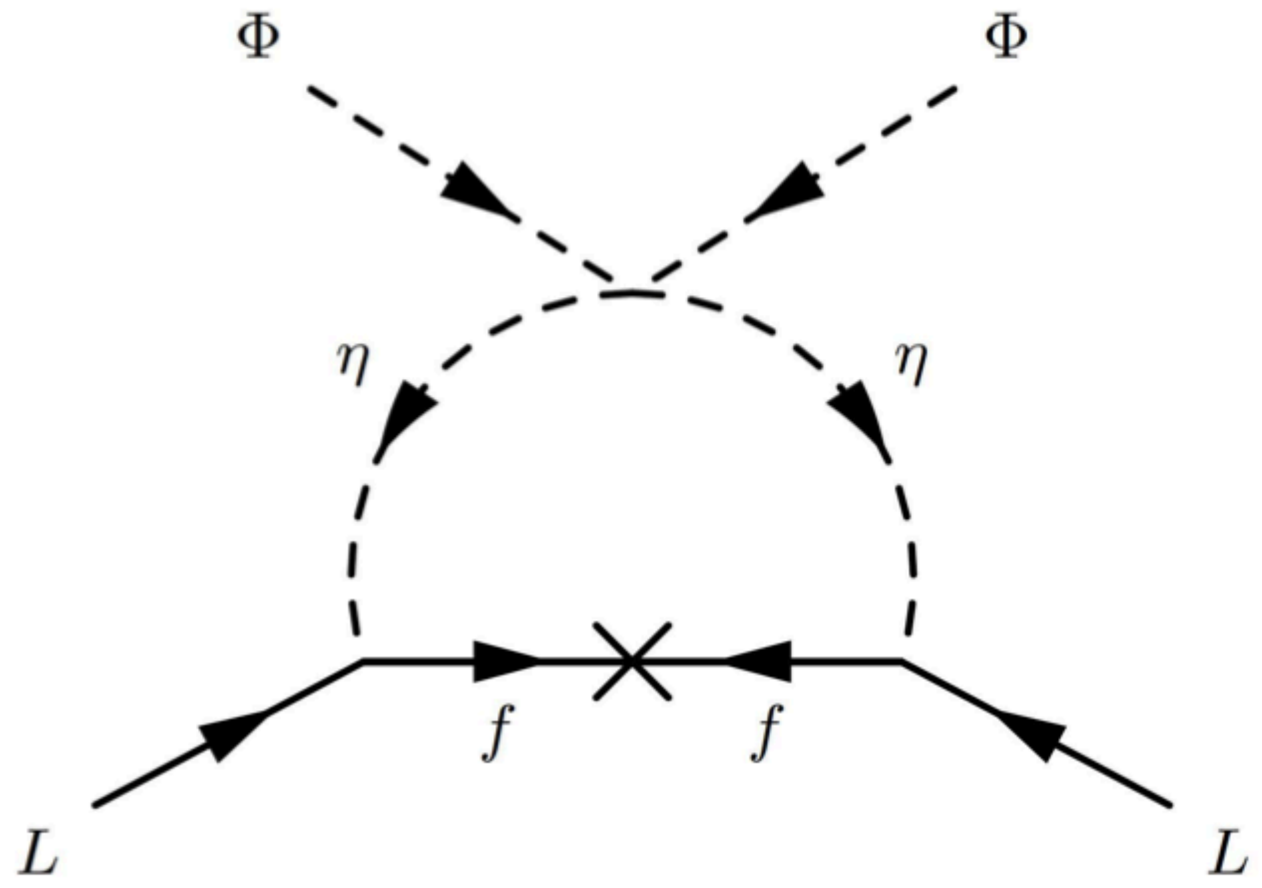
The scoto-seesaw model:

Rojas, Srivastava, Valle, PLB789 (2019) 132–136

- Idea was to explain the two observed neutrino oscillation scales





$$\Delta m^2_{\rm ATM} \sim \left(\frac{v^2}{M_N} \mathbb{Y}^2_{(N)} \right)^2$$

$$\Delta m^2_{\rm SOL} \sim \left(\frac{1}{32\pi^2} \right)^2 \left(\frac{\lambda_5 v^2}{M_f^2 - m_\eta^{(R)2}} M_f \mathbb{Y}^2_{(f)} \right)^2 .$$

- Flavor structure in scoto-seesaw model using Z_8 symmetry

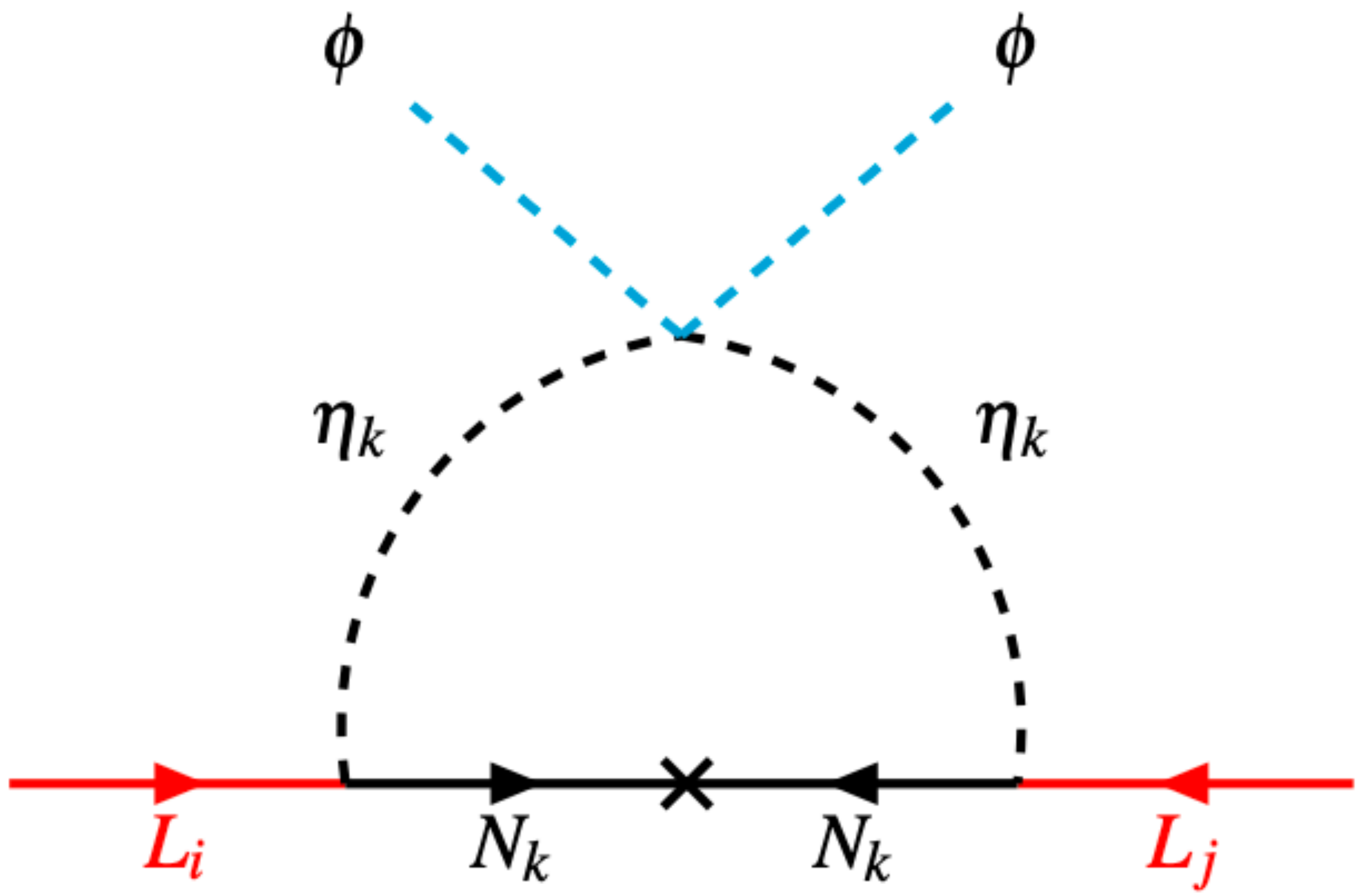
Barreiros, Joaquim, Srivastava, and Valle, 2012.05189
Barreiros, H. B. Camara, and F. R. Joaquim, 2204.13605.

Our set-up

- Started with scotogenic model with the help of A_4

Fields and their quantum numbers

Fields	$SU(2)_L \otimes U(1)_Y$	A_4	Z_2 (After symmetry breaking)
L_{iL}	(2, -1)	$1, 1', 1''$	+, +, +
e_{iR}	(1, -2)	$1, 1', 1''$	+, +, +
ϕ	(2, 1)	1	+
η	(2, 1)	3	(+, −, −)
N	(1, 0)	3	(+, −, −)

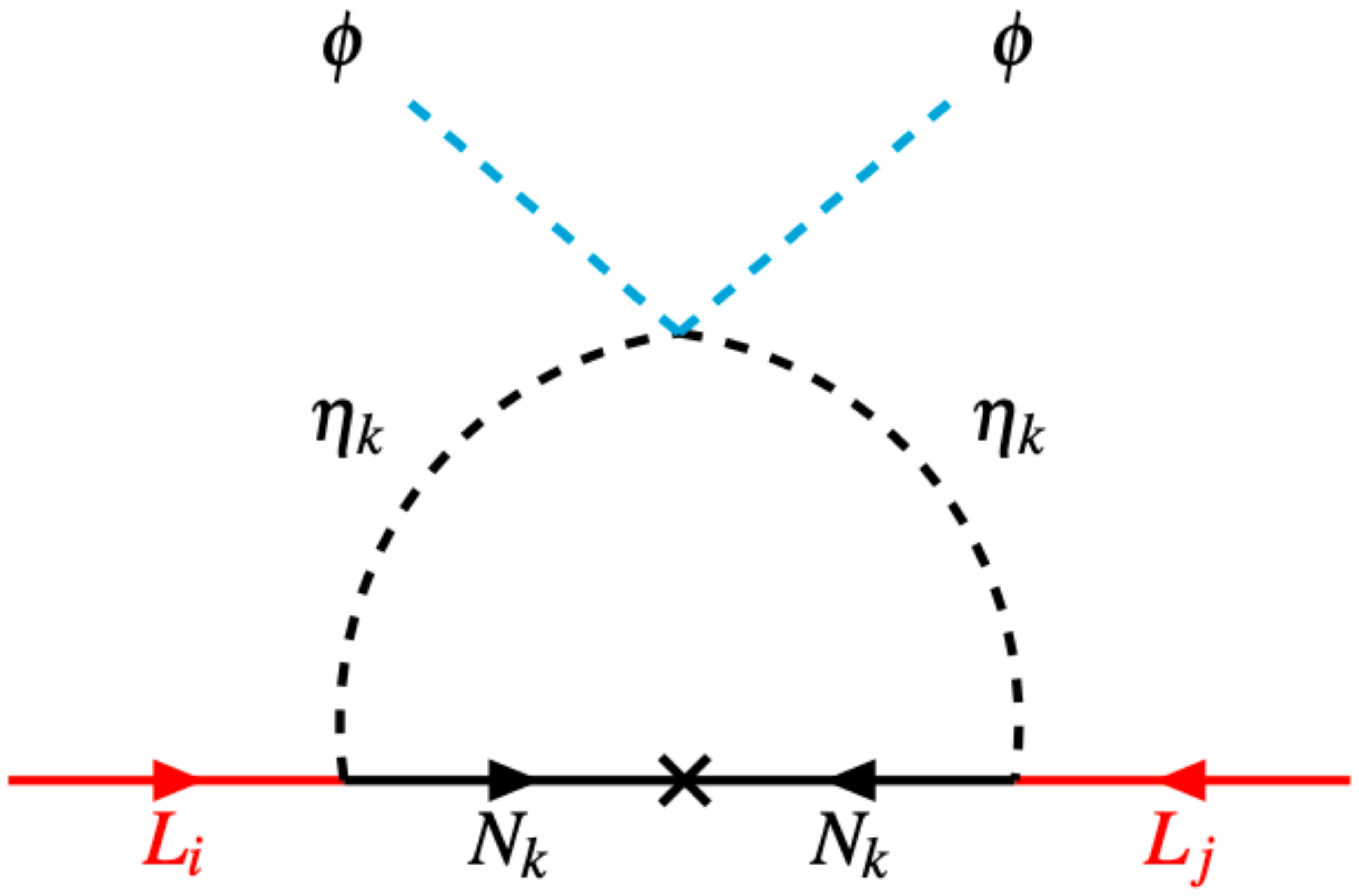


The scoto-seesaw scenario

- The leptonic Yukawa Lagrangian is: $$-\mathcal{L}_y = y_{11}(\overline{L_1})_1\phi(e_{1R})_1 + y_{22}(\overline{L_2})_{1''}\phi(e_{2R})_{1'} + y_{33}(\overline{L_3})_{1'}\phi(e_{2R})_{1''}$$ $$+ y_1(\overline{L_1})_1(\eta N)_1 + y_2(\overline{L_2})_{1''}(\eta N)_{1'} + y_3(\overline{L_3})_{1'}(\eta N)_{1''}$$ $$+ M(\overline{N^c}N)_1 + h.c. \,,$$
- The adopted "VEV" alignment $\langle \eta_1 \rangle = v_2, \langle \eta_2 \rangle = 0 = \langle \eta_3 \rangle$ **and** $\langle \phi \rangle = v_1$.

Boucenna, Hirsch, Morisi, Peinado, Taoso, Valle , JHEP 05 (2011) 037

- VEV alignment breaks $A_4 \to Z_2$ subgroup, and it's responsible for the DM stability
- Scoto-seesaw



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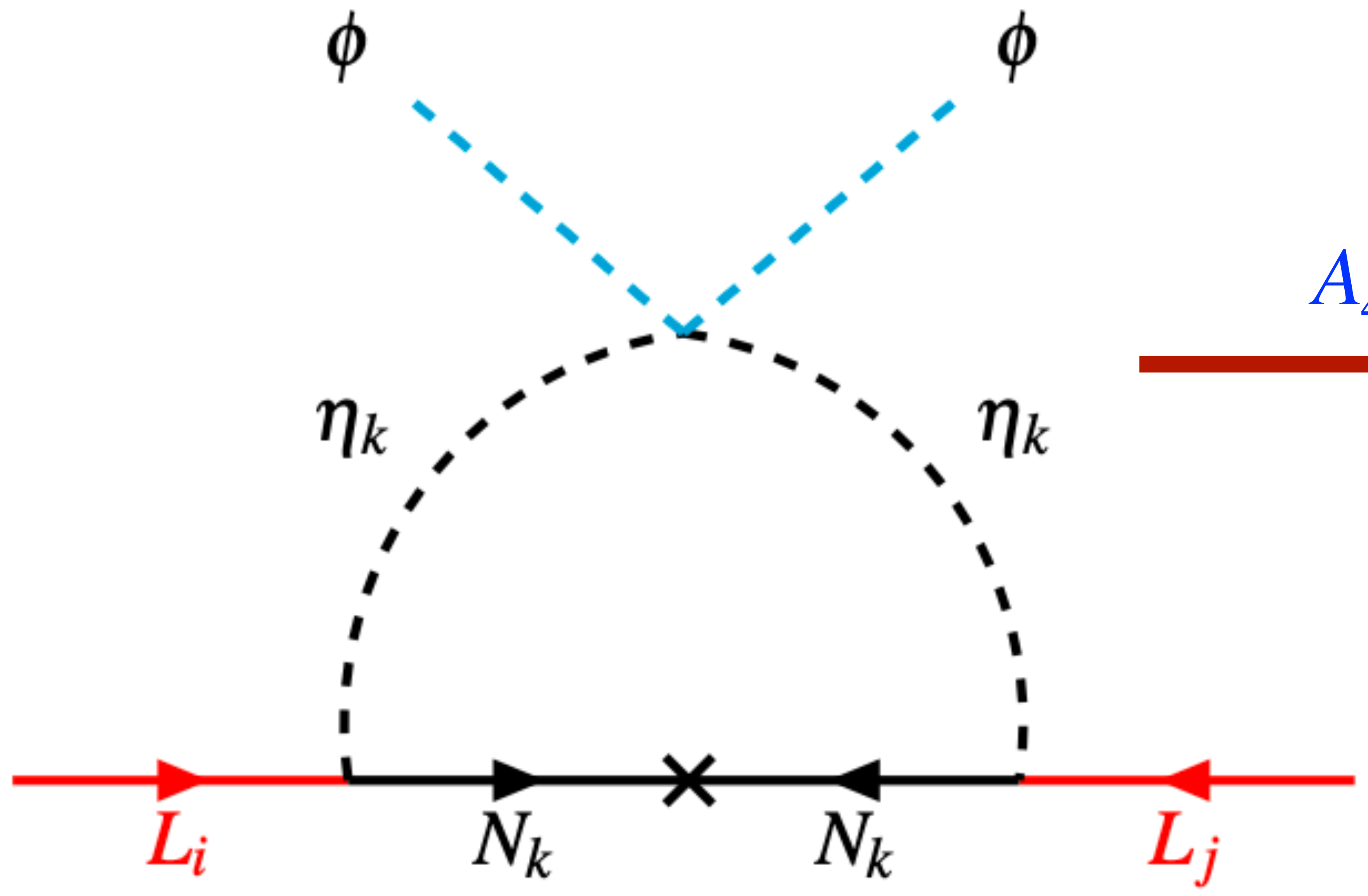
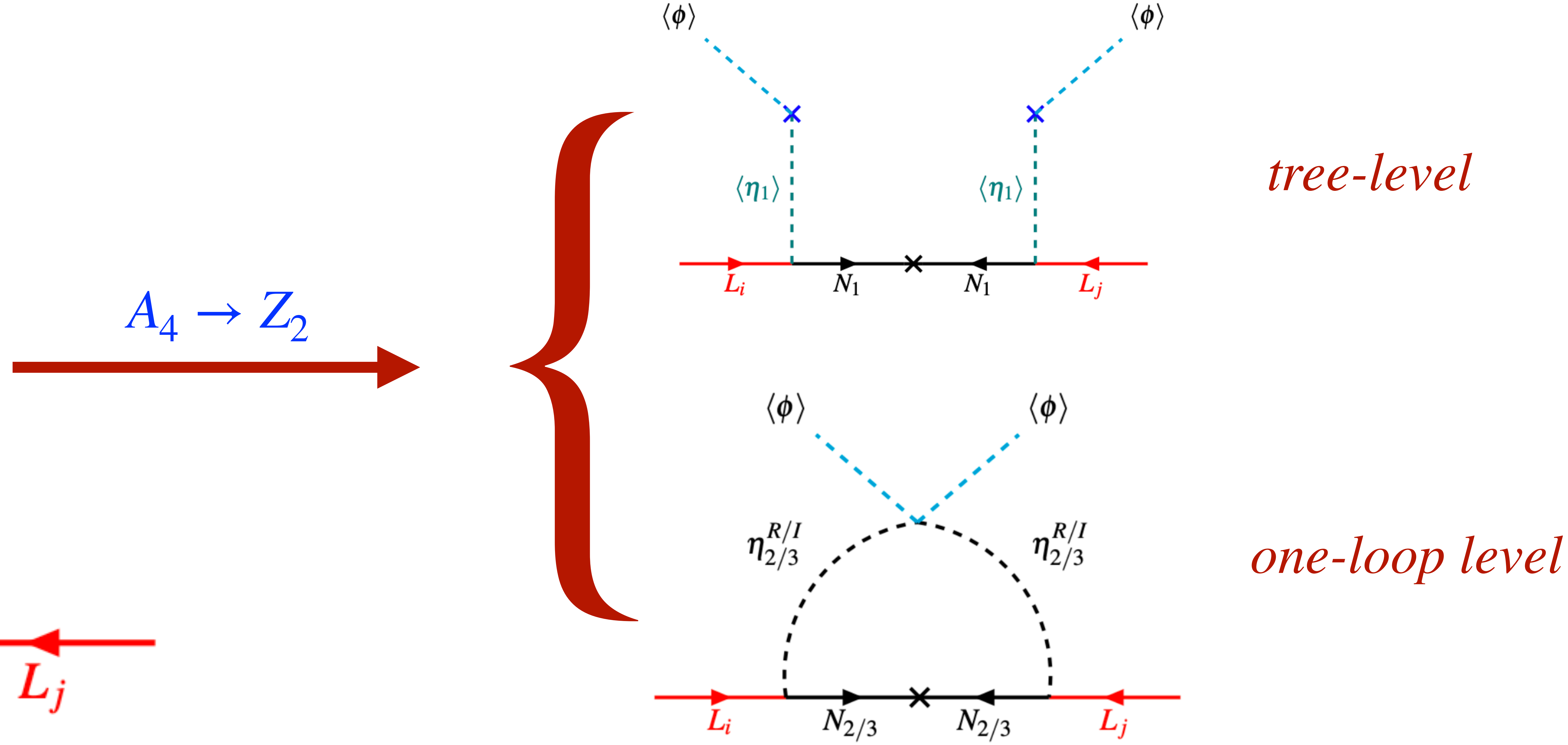




Neutrino sector:

- Neutrino mass in type-I seesaw

$$m_D = \begin{pmatrix} y_1 v_2 & 0 & 0 \\ y_2 v_2 & 0 & 0 \\ y_3 v_2 & 0 & 0 \end{pmatrix}, \ \mathcal{M} = \begin{pmatrix} M & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix} \Rightarrow \quad m_\nu^{(1)} = -\frac{1}{M} \begin{pmatrix} y_1^2 v_2^2 & y_1 y_2 v_2^2 & y_1 y_3 v_2^2 \\ * & y_2^2 v_2^2 & y_2 y_3 v_2^2 \\ * & * & y_3^2 v_2^2 \end{pmatrix}$$

- Rank of $m_\nu^{(1)}$ is 1 $\Rightarrow$ only one massive neutrino

- Neutrino mass at one-loop level

$$m_\nu^{(2)} = \begin{pmatrix} y_1^2 d_1 & y_1 y_2 d_2 & y_1 y_3 d_3 \\ * & y_2^2 d_3 & y_2 y_3 d_1 \\ * & * & y_3^2 d_2 \end{pmatrix}$$

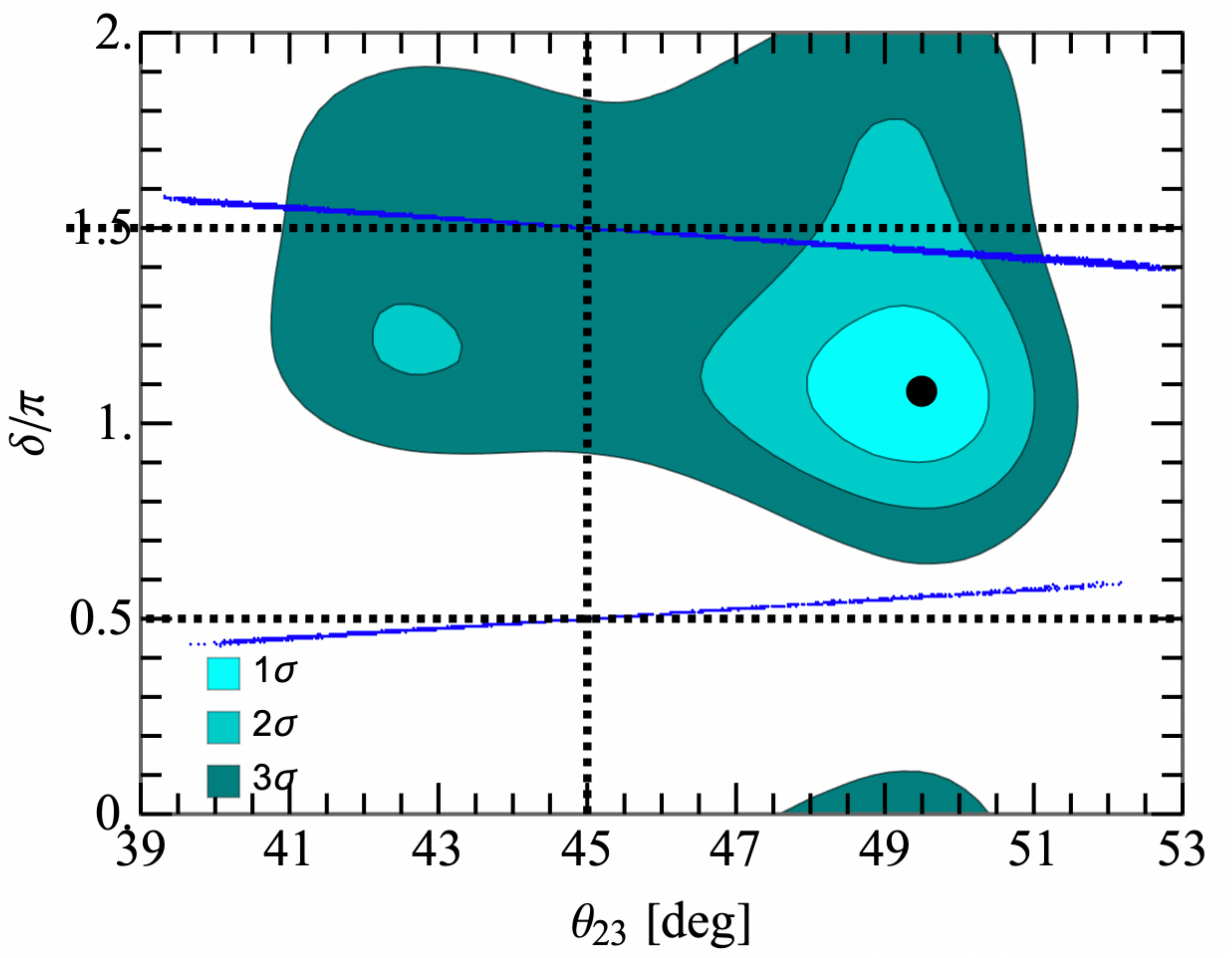
d_2, d_3 **are complex and responsible for CP violation**

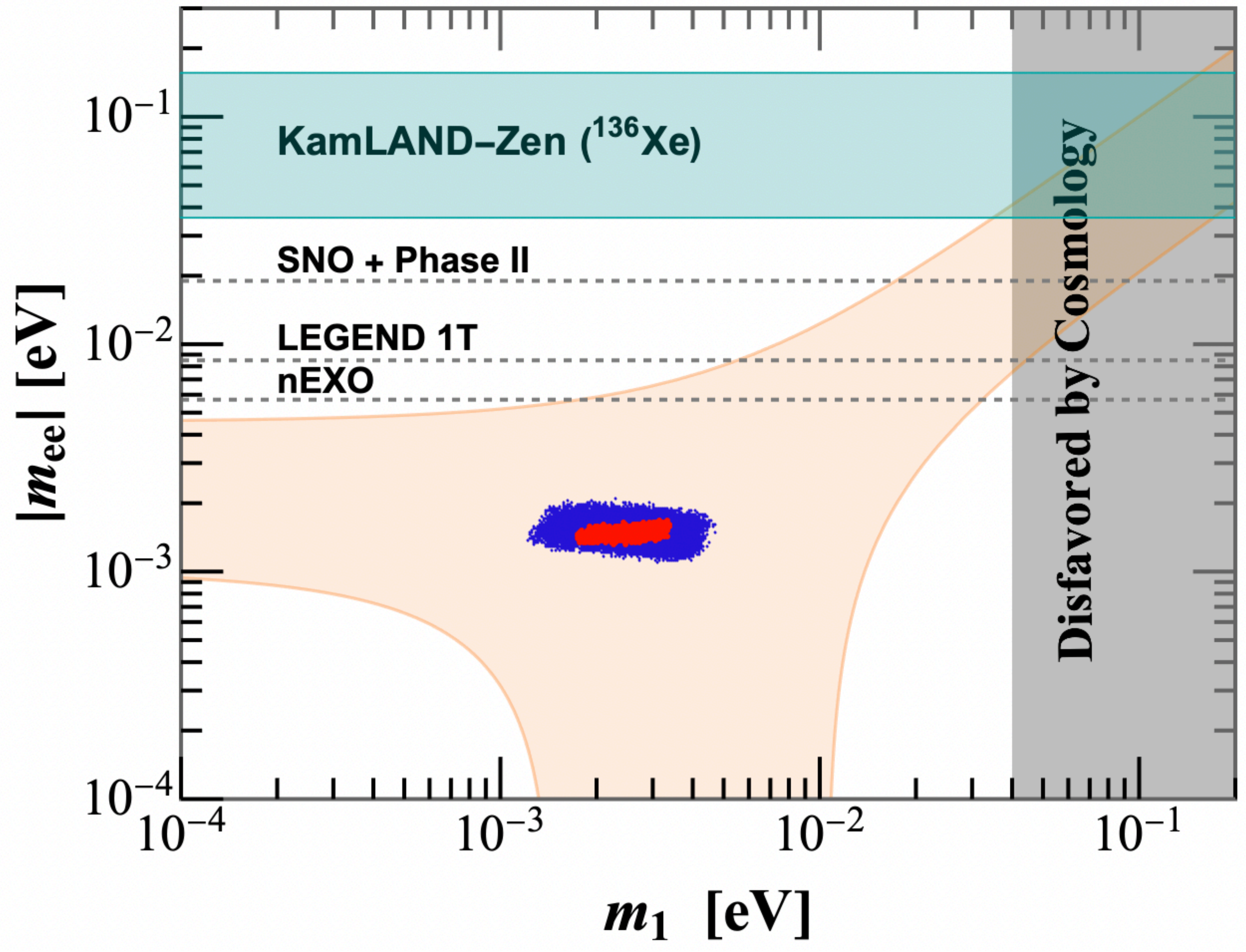
Cont…

- Neutrino mass in "scoto-seesaw" scenario

$$m_\nu^{(TOT)} = \begin{pmatrix} A & C & \tilde{C}^* \\ C & B & D \\ \tilde{C}^* & D & \tilde{B}^* \end{pmatrix}$$

"Generalised $\mu - \tau$ reflection symmetry"





Dark Matter

Two scenarios

Heavy N: Scalar DM

Light N: Scalar/Fermionic DM

Dark Matter

Two scenarios

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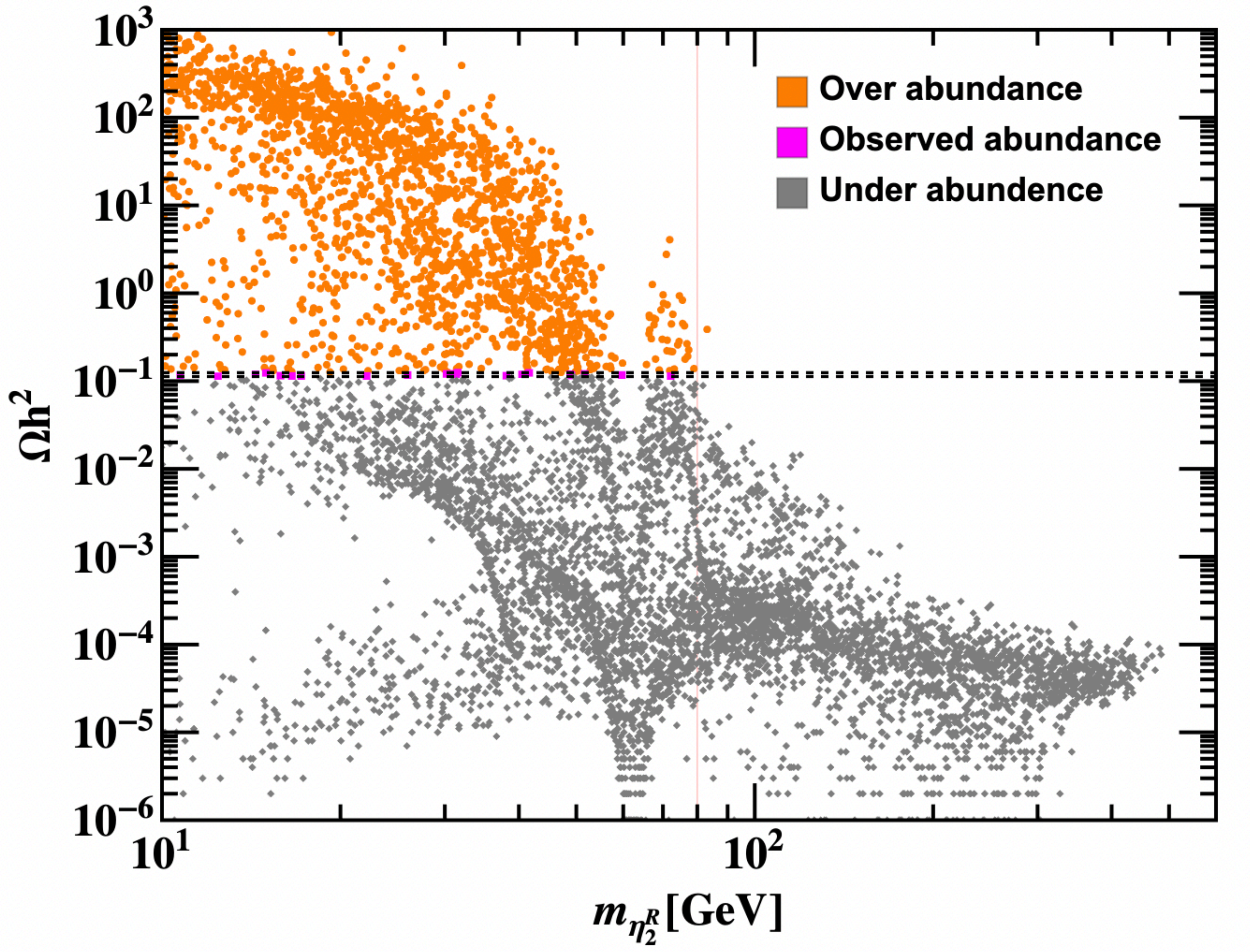
Scalar DM



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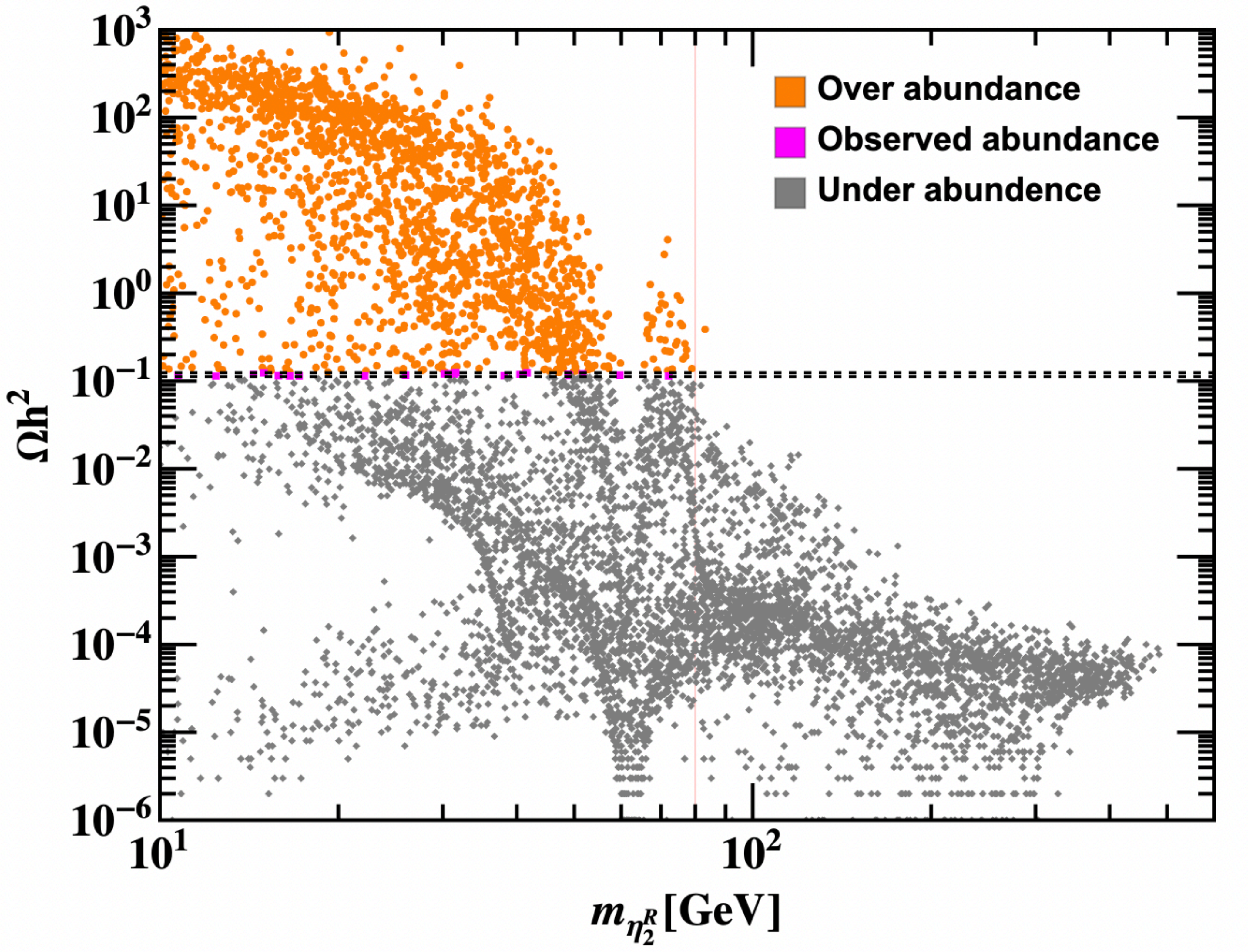
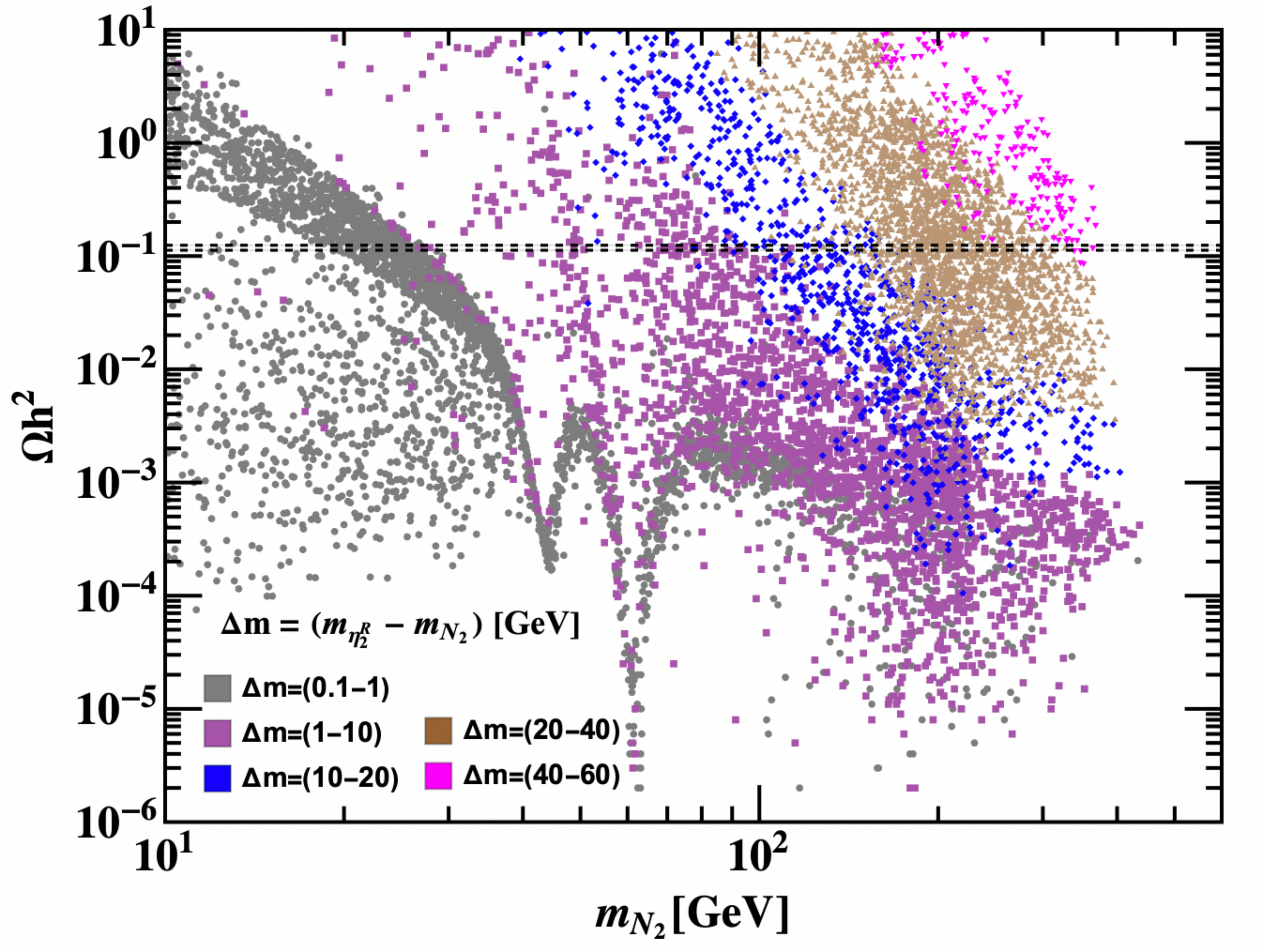


Fermionic DM



Final remarks:

- Described a set up to explain the origin of "dark symmetry" from flavor symmetry.

- The 'scotogenic' mechanism has been exploited in the presence of A_4 symmetry.

- Breaking of A_4 leads to 'scoto-seesaw' scenario and the residual Z_2 plays the role of '*dark symmetry*'

- Neutrino mass has been generated from the combination of tree and loop-level seesaw mechanism.

- Neutrino flavor structure, as well as relic density for the fermionic DM, are explained.


grazie
谢谢
ขอบคุณ
merci
Σας ευχαριστ
takk
bedankt
Спасибо
धन्यवाद
ありがとう
tack
thank you
terima kasih
gracias
obrigado
teşekkür ederim
شكرا
고마워요
danke
kiitos
köszönjük