Discrete Dark Matter

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Plan of the Talk

1. Introduction
2. Stability Mechanism
3. The Model
4. Phenomenology
5. Conclusions

Flavor and Flavor models

Horizontal flavor symmetries used to:

Predict relations beween quark masses and mixings

Wilczek and Zee Phys.Lett. B70 (1977) 418

Pakvasa and Sugawara Phys.Lett. B73 (1978) 61

Sartori Phys.Lett. B82 (1979) 255

Wyler Phys.Rev. D19 (1979) 3369

⋮

$$\Theta_C \simeq \sqrt{m_d/m_s}$$

Gatto Satori, Tonin Phys.Lett. B28 (1968) 128-130

Mixing

Small mixing angles

$$U_{CKM} \sim \begin{bmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 & -\lambda^2 & 1 \end{bmatrix}$$

$$\lambda = \sin\theta_C = 0.23$$

Neutrino masses

There is evidence of solar, atmospheric and reactor neutrino oscillation

Difference mass squared

$\Delta m^2_{atm} \sim 2.5\ 10^{-3}\ eV^2$,
$\Delta m^2_{sol} \sim 8\ 10^{-5}\ eV^2$

Mixing angles

θ_{12} (solar) large
θ_{23} (atm) large,~ maximal
θ_{13} (T2K, Double Chooz, Daya Bay) small

Forero, Tortola and Valle arXiv:1205.4018v2 [hep-ph]

3-Neutrino oscillation parameters

parameter	best fit $\pm 1\sigma$	2σ	3σ
$\Delta m^2_{21}\ [10^{-5}\text{eV}^2]$	$7.59^{+0.20}_{-0.18}$	7.24–7.99	7.09–8.19
$\Delta m^2_{31}\ [10^{-3}\text{eV}^2]$	$2.50^{+0.09}_{-0.16}$ $-(2.40^{+0.08}_{-0.09})$	$2.25 - 2.68$ $-(2.23 - 2.58)$	$2.14 - 2.76$ $-(2.13 - 2.67)$
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$	0.28–0.35	0.27–0.36
$\sin^2\theta_{23}$	$0.52^{+0.06}_{-0.07}$ 0.52 ± 0.06	0.41–0.61 0.42–0.61	0.39–0.64
$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$ $0.016^{+0.008}_{-0.006}$	0.004–0.028 0.005–0.031	0.001–0.035 0.001–0.039
δ	$\left(-0.61^{+0.75}_{-0.65}\right)\pi$ $\left(-0.41^{+0.65}_{-0.70}\right)\pi$	$0 - 2\pi$	$0 - 2\pi$

Double CHOOZ experiment, talk by H.De. Kerrect at LowNu2011, http://workshop.kias.re.kr/lownu11/

Best measured

Daya Bay: $\sin^2\theta_{13} \sim 0.0235$

CP mesurable??

DM Stability

DM is stable

$$\tau_{DM} > \tau_U \sim 10^{18}\,\mathrm{sec}$$

$$\tau_{DM} \gtrsim 10^{26}\,\mathrm{sec}$$ $\Leftarrow$ in most models not to produce e^+, $\bar{p}$, γ, ... fluxes larger than observed

In many models Stability

DM Stability

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$$\tau_{DM} \gtrsim 10^{26}\,\mathrm{sec}$$ $\Leftarrow$ in most models not to produce e^+, $\bar{p}$, γ, ... fluxes larger than observed

In many models Stability **assumed by hand**

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In many models Stability **assumed by hand**

↓

ad hoc global symmetry assumed, e.g. a Z_2

DM Stability

DM is stable

$$\tau_{DM} > \tau_U \sim 10^{18}\,\mathrm{sec}$$

$$\tau_{DM} \gtrsim 10^{26}\,\mathrm{sec}$$ ⇐ in most models not to produce $e^+,\ \bar{p},\ \gamma,\ \ldots$ fluxes larger than observed

In many models Stability **assumed by hand**

ad hoc global symmetry assumed, e.g. a Z_2

Some fundamental expanations e.g. GUTS and SUSY GUTS

Neutrino masses

3-Neutrino oscillation parameters

parameter	best fit $\pm 1\sigma$	2σ	3σ
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	7.62 ± 0.19	7.27–8.01	7.12–8.20
Δm^2_{31} $[10^{-3}\mathrm{eV}^2]$	$2.53^{+0.08}_{-0.10}$ $-(2.40^{+0.10}_{-0.07})$	$2.34 - 2.69$ $-(2.25 - 2.59)$	$2.26 - 2.77$ $-(2.15 - 2.68)$
$\sin^2\theta_{12}$	$0.320^{+0.015}_{-0.017}$	0.29–0.35	0.27–0.37
$\sin^2\theta_{23}$	$0.49^{+0.08}_{-0.05}$ $0.53^{+0.05}_{-0.07}$	0.41–0.62 0.42–0.62	0.39–0.64
$\sin^2\theta_{13}$	$0.026^{+0.003}_{-0.004}$ $0.027^{+0.003}_{-0.004}$	0.019–0.033 0.020–0.034	0.015–0.036 0.016–0.037
δ	$(0.83^{+0.54}_{-0.64})\,\pi$ 0.07π [a]	$0 - 2\pi$	$0 - 2\pi$

Double CHOOZ experiment
Daya Bay, RENO

Best measured

Daya Bay: $\sin^2\theta_{13}$ 0.026 / 0.027

CP mesurable??

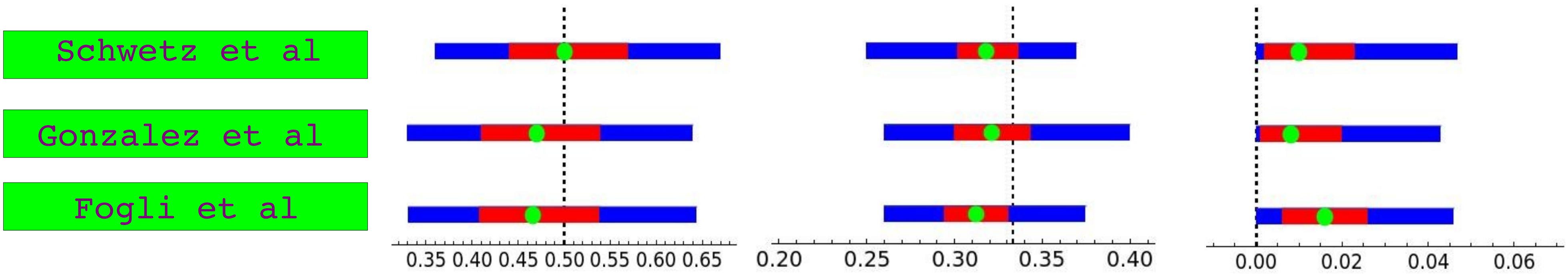
Forero, Tortola and Valle
arXiv:1205.4018v2 [hep-ph]

TBM mixing

$$U_{HPS} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$

Harrison, Perkins & Scott

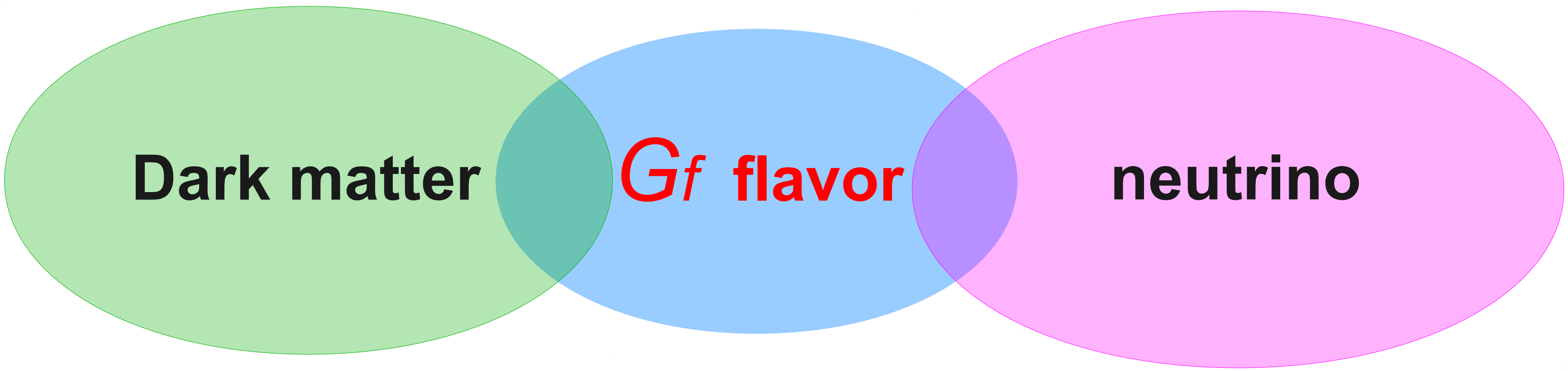
$\sin^2\theta_{23} = 0.5$ $\sin^2\theta_{12} = 1/3$ $\sin^2\theta_{13} = 0$



Different ansatz has been studied: mu-tau, trimaximal, tetramaximal, symmetric mixing, hexagon mixing, bimaximal, golden, quark-lepton complementarity...

Albright,Dueck,Rodejohann 1004.2798

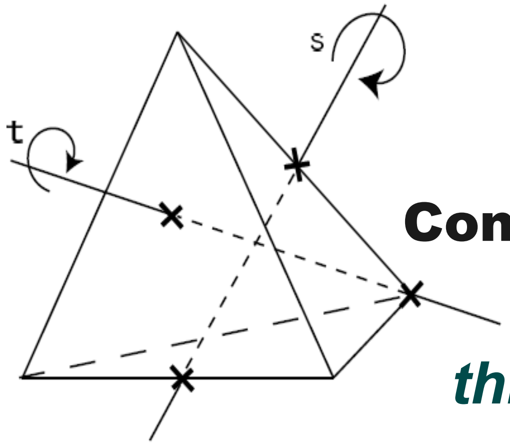
DM - neutrino



Talk by M. lindner

A4 Symmetry

the discrete group even permutations four objects



$$S^2 = T^3 = (ST)^3 = 1$$

Contains 4 Irreducible representations

three singlets 1, 1', 1"

one triplet 3

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \qquad T = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

A4 Symmetry

The generators are :

S and T $\qquad S^2 = T^3 = (ST)^3 = \mathcal{I}.$

$1,\ 1',\ 1''$ and 3

1	$S = 1$	$T = 1$
$1'$	$S = 1$	$T = e^{i4\pi/3} \equiv \omega^2$
$1''$	$S = 1$	$T = e^{i2\pi/3} \equiv \omega$

S diagonal basis

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad T = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

A4 spontaneously broken

Z3 in the charged sector

Z2 in the neutrino sector

TBM

A4 spontaneously broken

Z3 in the charged sector X

Z2 in the neutrino sector

stabilize the DM

TBM X

A4 spontaneously broken

Z2 in the charged sector

Z2 in the neutrino sector

stabilize the DM

↓ ↓

Hirch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

1, 1', 1''

3

The mechanism

SM + 3 Higgs SU(2) doublets , 4 right handed neutrinos

Hirch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	H	η
$SU(2)$	2	2	2	1	1	1	1	1	2	2
A_4	1	$1'$	$1''$	1	$1''$	$1'$	3	1	1	3

The alignment

$$\langle \eta \rangle \sim (1,0,0)$$

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$A_4 \to Z_2$

Z_2

$$\begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{pmatrix} \longrightarrow \begin{pmatrix} \eta_1 \\ -\eta_2 \\ -\eta_3 \end{pmatrix}$$

Z_2 residual symmetry

$$\langle \eta \rangle \sim (1, 0, 0)$$

$$H = \begin{pmatrix} \tilde{H}_0^+ \\ (v_h + \tilde{H}_0 + i\tilde{A}_0)/\sqrt{2} \end{pmatrix}, \quad \eta_1 = \begin{pmatrix} \tilde{H}_1^+ \\ (v_\eta + \tilde{H}_1 + i\tilde{A}_1)/\sqrt{2} \end{pmatrix}$$

→ Z_2 even

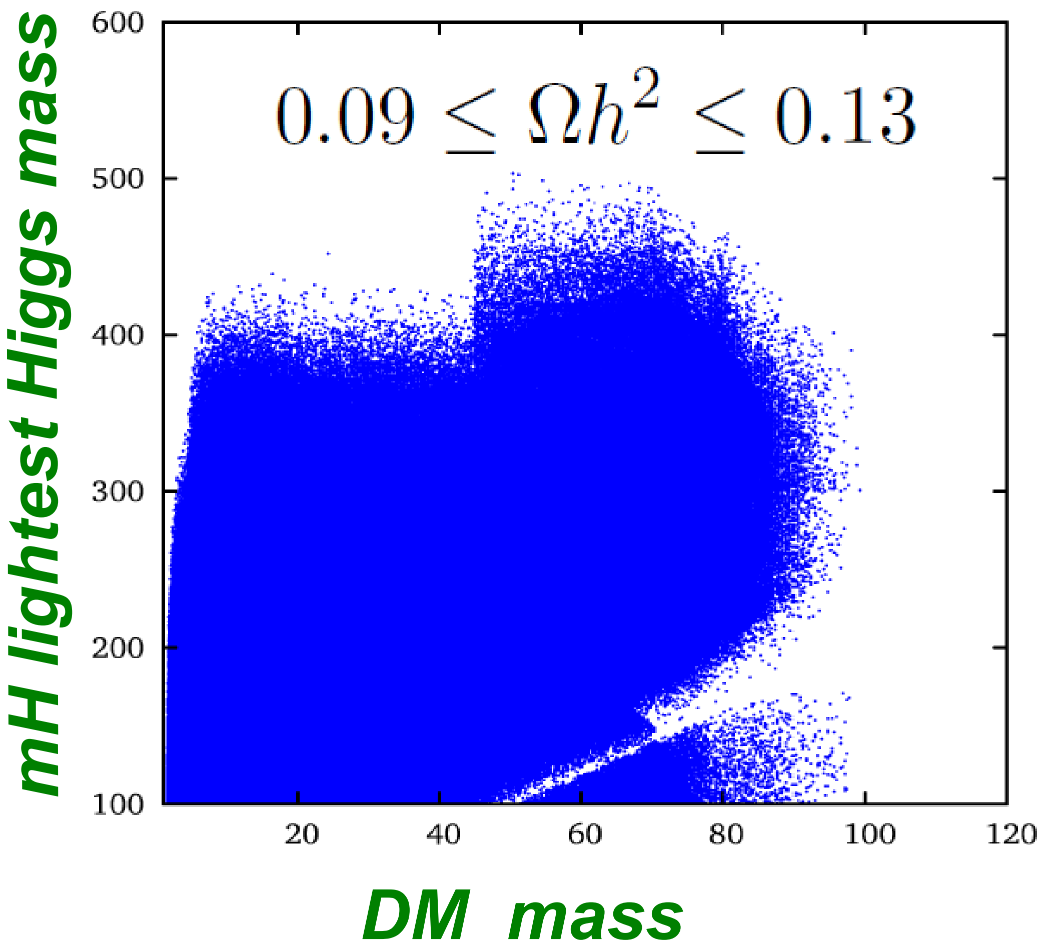
$$\eta_2 = \begin{pmatrix} \tilde{H}_2^+ \\ (\tilde{H}_2 + i\tilde{A}_2)/\sqrt{2} \end{pmatrix}, \quad \eta_3 = \begin{pmatrix} \tilde{H}_3^+ \\ (\tilde{H}_3 + i\tilde{A}_3)/\sqrt{2} \end{pmatrix}$$

→ Z_2 odd

→ **Dark Matter Stability**

The mechanism

Hirch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)



IH : $m_3 = 0$

0.03 eV< 0nubb <0.05 eV

$\theta_{13} = 0$

Constraints

- Relic Density
- Collider bounds
- EW precision
- Vacuum stability
- ...

M. S. Boucenna, M. Hirsch, S. Morisi, E. Peinado, M. Taoso and J. W. F. Valle, JHEP 1105 (2011) 037

The Model

Is it possible to have non trivial rep for charged leptons (and quarks)?

G: r_a and r_b with $\dim(r_{a,b}) > 1$

$G \supset Z_N$ **DM stability**

$$\Delta(54) \sim (Z_3 \times Z_3) \rtimes S_3$$

triplets Four $\mathbf{2}_{1,2,3,4}$ Two singlets $\mathbf{1}_{\pm}$

$$\mathbf{2}_{\mathrm{k}} \times \mathbf{2}_{\mathrm{k}} = \mathbf{1}_{+} + \mathbf{1}_{-} + \mathbf{2}_{\mathrm{k}}$$

$$P \equiv (Z_3 \times Z_3)$$

$$\mathbf{2}_1 \times \mathbf{2}_2 = \mathbf{2}_3 + \mathbf{2}_4$$

$$\mathbf{2}_3 \sim (\chi_1, \chi_2)$$

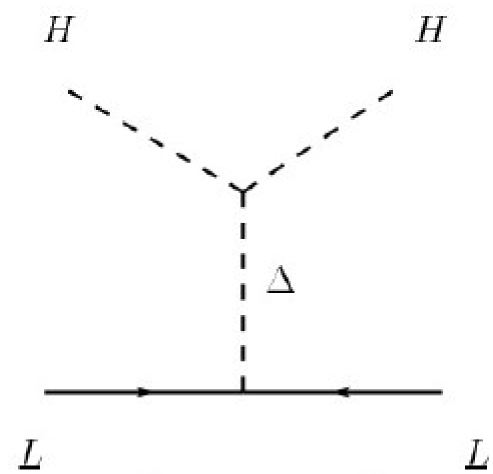
$\chi_1 \; (\omega^2, \omega)$

$\chi_2 \; (\omega, \omega^2)$

The Model

S. Boucenna, S. Morisi, E. Peinado, Yusuke Shimizu and J. W. F. Valle
arXiv:1204.4733 [hep-ph]

	$\overline{L}_e$	$\overline{L}_D$	e_R	l_D	H	χ	η	Δ
$SU(2)$	2	2	1	1	2	2	2	3
$\Delta(54)$	$\mathbf{1}_+$	$\mathbf{2}_1$	$\mathbf{1}_+$	$\mathbf{2}_1$	$\mathbf{1}_+$	$\mathbf{2}_1$	$\mathbf{2}_3$	$\mathbf{2}_1$



$$\langle\Delta\rangle \sim (1,1) \text{ and } \langle\chi_1\rangle \neq \langle\chi_2\rangle$$

$$r = \langle\chi_2\rangle / \langle\chi_1\rangle$$

Mass sum rule

$$m_1^\nu + m_2^\nu = m_3^\nu$$

$$M_\ell = \begin{pmatrix} a & br & b \\ cr & d & e \\ c & e & dr \end{pmatrix} \qquad M_\nu \propto \begin{pmatrix} 0 & \delta & \delta \\ \delta & \alpha & 0 \\ \delta & 0 & \alpha \end{pmatrix}$$

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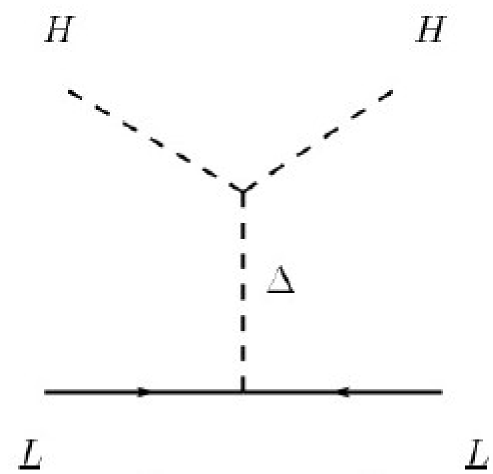

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Mass sum rule

L. Dorame, D. Meloni, S. Morisi, EP and J. Valle, 1111.5614
J. Barry and W. Rodejohann, Nucl.Phys. B842, 33 (2011), 1007.5217

The Model

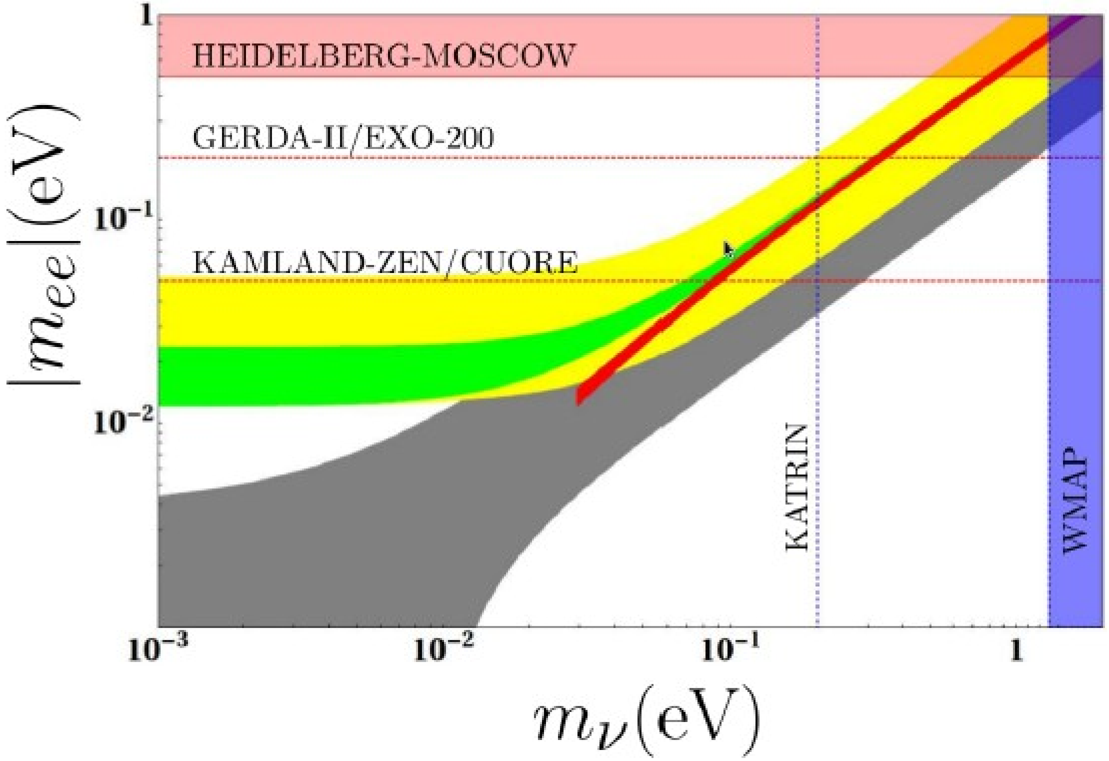
	$Q_{1,2}$	Q_3	(u_R, c_R)	t_R	d_R	s_R	b_R
$SU(2)$	2	2	1	1	1	1	1
$\Delta(54)$	$\mathbf{2}_1$	$\mathbf{1}_+$	$\mathbf{2}_1$	$\mathbf{1}_+$	$\mathbf{1}_-$	$\mathbf{1}_+$	$\mathbf{1}_+$

$$M_d = \begin{pmatrix} r a_d & r b_d & r d_d \\ -a_d & b_d & d_d \\ 0 & c_d & e_d \end{pmatrix}, \quad M_u = \begin{pmatrix} r a_u & b_u & d_u \\ b_u & a_u & r d_u \\ c_u & r c_u & e_u \end{pmatrix}$$

$$0.1 < r < 0.2$$

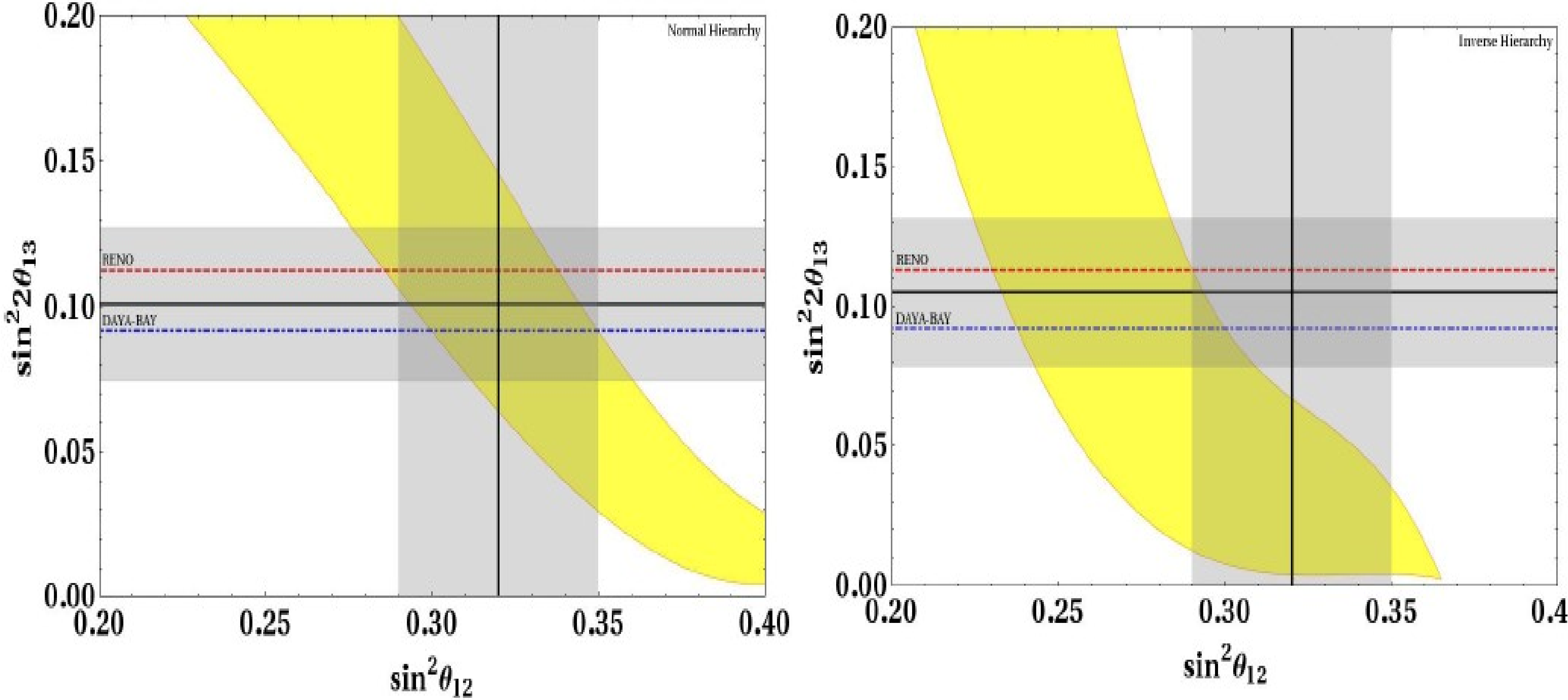
Correlations

$$m_1^\nu + m_2^\nu = m_3^\nu$$



Correlations

NI **IH**

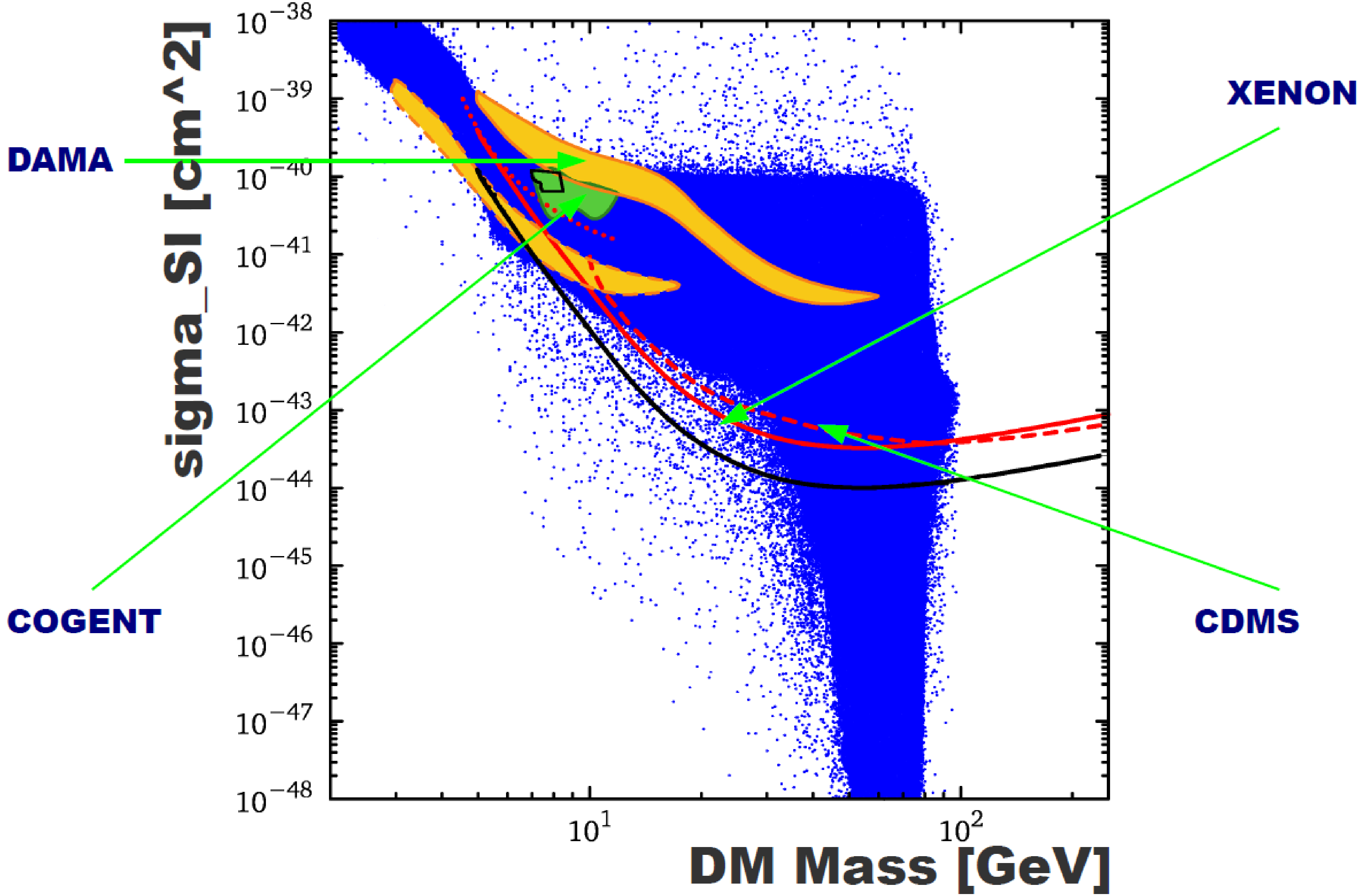


Conclusions

Non-Abelian Flavor Symmetries are useful to explain the patterns of masses and mixings of neutrinos: Reduce the number of free parameters in the SM

{ **Predictive** }

We show that are also useful to explain the **DM** in the Universe:
Also with a rich phenomenology



... Direct Detection