Simple A_4 models for dark matter stability with texture zeros

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In a simple framework which naturally incorporates dark matter stability and neutrino phenomenology, we compute all the possible texture zeros which arise when the non-Abelian flavor symmetry A_4 is spontaneously broken to Z_2 . As a result, we obtain four textures with two vanishing matrix elements. Two of such textures predict a zero contribution to the neutrinoless double beta decay effective mass parameter at tree level, and as a one loop bound we get $m_{ee} < 8 \times 10^{-2}$ meV. These are compatible with the normal ordering for the neutrino masses and the allowed range for the lightest neutrino mass is between $m_{\nu_{\min}} \sim 3$ meV and $m_{\nu_{\max}} \sim 8$ meV. Additionally we obtain dark matter stability linked to the way the flavor symmetry is broken, leaving a residual Z_2 symmetry.

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I. INTRODUCTION

The pattern of neutrino masses and mixing, which is very different from the quarks pattern, has been extensively studied. Two main approaches for correlating neutrino oscillation observables have been used, one based on non-Abelian flavor symmetries, very useful to explain certain patterns in the mixing parameters such as the tribimaximal mixing [1], bimaximal mixing [2], or the golden ratio mixing [3,4], and one based on the assumption of zeros in the neutrino mass matrix and diagonal charged-lepton mass matrix. The Glashow-Frampton-Marfatia classification for the two-zero texture Majorana neutrino mass matrices is given in Table I [5]. In this paper, we demonstrate how some of the two-zero textures in the neutrino mass matrix can be obtained in a framework of the non-Abelian¹ flavor symmetry A_4 . In this framework, the dark matter (DM) stability is due to a residual Z_2 symmetry of A_4 . For a model based on A_4 where the Majorana neutrinos acquire masses through type I and type II seesaw mechanisms giving rise to texture zeros

see [8].² In a recent work [9], texture zeros were obtained corresponding to the B_3 and B_4 in Table I. In this model, the texture zeros are related with the flavor symmetry breaking, the same that is responsible for the stability of DM. Following this approach, we obtain the two textures predicting a vanishing neutrinoless double beta decay at tree level, namely A_1 and A_2 .

II. THE FRAMEWORK

A_4 is the alternating group of four objects. It is formed by the even permutations of the larger permutation group S_4 . A_4 is generated by S and T where $S^2 = T^3 = (ST)^3 = I$. The dimensionality of A_4 is 12 and the number of conjugacy classes is 4. Then we have four irreducible representations (irreps), three of them are one-dimensional, $\mathbf{1}$, $\mathbf{1}'$, $\mathbf{1}''$, and one three-dimensional, $\mathbf{3}$. Actually it is the smallest discrete group which contains a triplet irreducible representation, this has been extensively used by model builders because it is possible to accommodate the families in a triplet representation [11–13]. The generators S and T in the S -diagonal basis are given in Table II.

To obtain singlets under the A_4 symmetry, it will be necessary to compute direct products of irreps. In particular, the product rule for two triplet representations [11] is

$$\mathbf{3} \otimes \mathbf{3} = \mathbf{1} \oplus \mathbf{1}' \oplus \mathbf{1}'' \oplus \mathbf{3} \oplus \mathbf{3}, \quad (1)$$

where the representations $\mathbf{1}'$ and $\mathbf{1}''$ are complex conjugate to each other. The model we considered here contains an

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¹It is also possible to obtain texture zeros using Abelian symmetries, see e.g., [6], where several scalar fields are needed or [7], where the symmetry group used is $Z_2 \times Z_8$ in a left-right symmetric model.

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²In the model by Hirsch *et al.* [8], the texture zeros correspond to B_1 and B_2 in the classification of [5].

TABLE I. Viable cases in the framework of texture zeros in the Majorana neutrino mass matrix m_ν with two vanishing elements and a diagonal charged-lepton mass matrix $\mathcal{M}_\ell$ [5]. It has been pointed out that the C case for the normal hierarchy is excluded [10]. The notation $((a, b), (c, d))$ refers to the vanishing matrix elements. For instance, if $a = 1$, $b = 1$ and $c = 1$, $d = 2$ means that the $(1,1)$ and $(1,2)$ components of the matrix are zero.

Case	Texture zeros	$((a,b),(c,d))$
A_1	$(m_\nu)_{ee} = (m_\nu)_{e\mu} = 0$	$((1,1),(1,2))$
A_2	$(m_\nu)_{ee} = (m_\nu)_{e\tau} = 0$	$((1,1),(1,3))$
B_1	$(m_\nu)_{\mu\mu} = (m_\nu)_{e\tau} = 0$	$((2,2),(1,3))$
B_2	$(m_\nu)_{\tau\tau} = (m_\nu)_{e\mu} = 0$	$((3,3),(1,2))$
B_3	$(m_\nu)_{\mu\mu} = (m_\nu)_{e\mu} = 0$	$((2,2),(1,2))$
B_4	$(m_\nu)_{\tau\tau} = (m_\nu)_{e\tau} = 0$	$((3,3),(1,3))$
C	$(m_\nu)_{\mu\mu} = (m_\nu)_{\tau\tau} = 0$	$((2,2),(3,3))$

extended Higgs sector with the standard model (SM) Higgs H transforming as a singlet $\mathbf{1}$, three copies of Higgses in a triplet representation of A_4 , $\eta = (\eta_1, \eta_2, \eta_3)^T$, and three

TABLE II. A_4 generators for the irreducible representations in the S -diagonal basis, $\omega = e^{i2/3\pi}$ is the cubic root of 1.

Irrep	S	T
$\mathbf{1}$	1	1
$\mathbf{1}'$	1	ω
$\mathbf{1}''$	1	ω^2
$\mathbf{3}$	$\begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$

scalar singlets of the SM also in a triplet of A_4 , $\phi = (\phi_1, \phi_2, \phi_3)^T$. We also considered five right-handed (RH) neutrinos, three of them in the triplet representation of A_4 , $N_T = (N_1, N_2, N_3)^T$ and two singlets N_4 and N_5 . The complete assignment of the matter fields to irreps of A_4 is shown in Table III.

The most general Lagrangian consistent with the symmetries of our theory is

$$\begin{aligned}
\mathcal{L}_Y = & y_e \bar{L}_e l_e H + y_\mu \bar{L}_\mu l_\mu H + y_\tau \bar{L}_\tau l_\tau H + y_1^e \bar{L}_e [N_T \eta]_\alpha + y_2^e \bar{L}_\mu [N_T \eta]_\beta + y_3^e \bar{L}_\tau [N_T \eta]_\gamma \\
& + y_4^e \delta_{\alpha\delta} \bar{L}_e N_4 H + y_4^{\nu 2} \delta_{\beta\delta} \bar{L}_\mu N_4 H + y_4^{\nu 3} \delta_{\gamma\delta} \bar{L}_\tau N_4 H + y_5^e \delta_{\alpha\epsilon} \bar{L}_e N_5 H + y_5^{\nu 2} \delta_{\beta\epsilon} \bar{L}_\mu N_5 H + y_5^{\nu 3} \delta_{\gamma\epsilon} \bar{L}_\tau N_5 H \\
& + M \bar{N}_T^c N_T + M_4 \delta_{\delta 1} \bar{N}_4^c N_4 + M_5 \delta_{\epsilon 1} \bar{N}_5^c N_5 + y_2^{N_1} \delta_{1\delta} [\bar{N}_T^c \phi]_1 N_4 + y_2^{N_{1''}} \delta_{1''\delta} [\bar{N}_T^c \phi]_{1'} N_4 \\
& + y_2^{N_{1'}} \delta_{1'\delta} [\bar{N}_T^c \phi]_{1''} N_4 + y_3^{N_1} \delta_{1\epsilon} [\bar{N}_T^c \phi]_1 N_5 + y_3^{N_{1''}} \delta_{1''\epsilon} [\bar{N}_T^c \phi]_{1'} N_5 + y_3^{N_{1'}} \delta_{1'\epsilon} [\bar{N}_T^c \phi]_{1''} N_5 \\
& + y_1^N [\bar{N}_T^c \phi]_{3_1} N_T + (y_1^N)' [\bar{N}_T^c \phi]_{3_2} N_T + M_{45} \delta_{\delta\epsilon^*} \bar{N}_4^c N_5 + \text{H.c.},
\end{aligned} \tag{2}$$

where $\alpha, \beta, \gamma, \delta$, and ϵ can be any of the three singlet representations of A_4 . Notice that charged leptons are diagonal since $\mathbf{1}^* = \mathbf{1}''$ and $\mathbf{1}' \otimes \mathbf{1}'' = \mathbf{1}$. The scalar fields η, H , and ϕ get a vacuum expectation value (vev). There are two possible configurations of the vev to get a minimum of the potential, these are $\langle \phi \rangle_{Z_2} = (v_\phi, 0, 0)^T$ (S invariant) and $\langle \phi \rangle_{Z_3} = (v_\phi, v_\phi, v_\phi)^T$ (T invariant). The first one leaves a Z_2 symmetry after the breaking and the other one will leave a Z_3 symmetry, which can be easily seen from the generators in Table II. The same arguments apply for the vev of η .

III. RESULTS

With the matter content of our model, we were able to get the type A_1, A_2, B_3 , and B_4 texture zeros. These textures are

TABLE III. Summary of the particle content and quantum numbers. $\alpha, \beta, \gamma, \delta$, and ϵ can be any of the singlet representations $\mathbf{1}, \mathbf{1}', \mathbf{1}''$.

	L_e	L_μ	L_τ	l_e	l_μ	l_τ	N_T	N_4	N_5	H	η	ϕ
SU(2)	2	2	2	1	1	1	1	1	1	2	2	1
A_4	α	β	γ	α	β	γ	3	δ	ϵ	1	3	3

only obtained when the flavor symmetry is broken into the Z_2 subgroup. The residual Z_2 symmetry is defined as

$$\begin{aligned}
\eta_1 &\rightarrow \eta_1, & \eta_2 &\rightarrow -\eta_2, & \eta_3 &\rightarrow -\eta_3, \\
\phi_1 &\rightarrow \phi_1, & \phi_2 &\rightarrow -\phi_2, & \phi_3 &\rightarrow -\phi_3, \\
N_1 &\rightarrow N_1, & N_2 &\rightarrow -N_2, & N_3 &\rightarrow -N_3.
\end{aligned} \tag{3}$$

The lightest and Z_2 odd (and neutral) particle would play the role of DM since it will be stable [9,14]. In the active sector beside the SM fields, we have two scalars (η_1, ϕ_1) and three right-handed neutrinos (N_1, N_4, N_5), while in the dark sector we have all the Z_2 odd fields in Eq. (3).

The models resulting from fixing the irreducible representations for the left-handed fields and the (RH) neutrinos in Eq. (2) are summarized in Table IV. Textures B_3 and B_4 were already reported in [9]. The type A_1 and A_2 matrices have a zero tree level contribution to the neutrinoless double beta decay effective mass parameter, m_{ee} ,³ and also zero $m_{e\mu}$ and $m_{e\tau}$ components, respectively. These zeros are extremely powerful and predictive. To see this, let us remark that, in general, neutrino oscillation experiments

³A direct consequence of a vanishing m_{ee} is that these textures are only compatible with normal hierarchy.

TABLE IV. Particle transformation under A_4 that gives rise to texture zeros in the neutrino mass matrices. We get the same texture matrix if we exchange $\mathbf{1}' \leftrightarrow \mathbf{1}''$ in each line. In the same way, we get the same texture if we exchange the representations of N_4 and N_5 . The last column gives the matrix type according to [5].

L_e	L_μ	L_τ	N_4	N_5	Neutrino matrix	Type
$\mathbf{1}$	$\mathbf{1}''$	$\mathbf{1}'$	$\mathbf{1}$	$\mathbf{1}'$	$\begin{pmatrix} X & 0 & X \\ 0 & 0 & X \\ X & X & X \end{pmatrix}$	B_3
$\mathbf{1}$	$\mathbf{1}''$	$\mathbf{1}'$	$\mathbf{1}$	$\mathbf{1}''$	$\begin{pmatrix} X & X & 0 \\ X & X & X \\ 0 & X & 0 \end{pmatrix}$	B_4
$\mathbf{1}''$	$\mathbf{1}$	$\mathbf{1}'$	$\mathbf{1}$	$\mathbf{1}'$	$\begin{pmatrix} 0 & 0 & X \\ 0 & X & X \\ X & X & X \end{pmatrix}$	A_1
$\mathbf{1}''$	$\mathbf{1}'$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}'$	$\begin{pmatrix} 0 & X & 0 \\ X & X & X \\ 0 & X & X \end{pmatrix}$	A_2

can only access to two neutrino mass differences, three mixing angles and one CP violating phase, i.e., to six parameters of the theory. On the other hand, the theory has three masses, three mixing angles, and three CP violating phases. This is where the zeros play an important role, they give four constraints (because the elements are in general complex) which give correlations between the six parameters to which the experiments have access. We will see explicitly the Lagrangians for models A_1 and A_2 by fixing the field irreps in Eq. (2).

A. Model for A_1

In this case, the irreps for the lepton fields are as follows: L_e, L_μ , and L_τ transform as $\mathbf{1}'', \mathbf{1}$, and $\mathbf{1}'$, respectively, while N_4 and N_5 are in $\mathbf{1}$ and $\mathbf{1}'$, or in the notation of Table III $\alpha = \mathbf{1}'', \beta = \mathbf{1}, \gamma = \mathbf{1}', \delta = \mathbf{1}$, and $\epsilon = \mathbf{1}'$. The Lagrangian in Eq. (2) is reduced to

$$\begin{aligned} \mathcal{L}_Y = & y_e \bar{L}_e l_e H + y_\mu \bar{L}_\mu l_\mu H + y_\tau \bar{L}_\tau l_\tau H \\ & + y_1^\nu \bar{L}_e [N_T \eta]_{1''} + y_2^\nu \bar{L}_\mu [N_T \eta]_1 + y_3^\nu \bar{L}_\tau [N_T \eta]_{1'} \\ & + y_4^{\nu 2} \bar{L}_\mu N_4 H + y_5^{\nu 3} \bar{L}_\tau N_5 H + M \bar{N}_T^c N_T \\ & + M_4 \bar{N}_4^c N_4 + y_2^{N_1} [\bar{N}_T^c \phi]_1 N_4 + y_3^{N_{1'}} [\bar{N}_T^c \phi]_{1'} N_5 \\ & + y_1^N [\bar{N}_T^c \phi]_3 N_T + (y_1^N)' [\bar{N}_T^c \phi]_{3_2} N_T + \text{H.c.} \end{aligned} \quad (4)$$

Once the flavor symmetry is broken by the scalar field ϕ , the mass matrix for the RH neutrino fields takes the form [9]⁴

$$M_R = \begin{pmatrix} M & 0 & 0 & v_\phi y_2^{N_1} & v_\phi y_3^{N_{1'}} \\ 0 & M & M_\phi & 0 & 0 \\ 0 & M_\phi & M & 0 & 0 \\ v_\phi y_2^{N_1} & 0 & 0 & M_4 & 0 \\ v_\phi y_3^{N_{1'}} & 0 & 0 & 0 & 0 \end{pmatrix}, \quad (5)$$

where $M_\phi = v_\phi (y_1^N + (y_1^N)')$, while the Dirac neutrino mass matrix is given by

$$m_D = \begin{pmatrix} v_\eta y_1^\nu & 0 & 0 & 0 & 0 \\ v_\eta y_2^\nu & 0 & 0 & v_H y_4^{\nu 2} & 0 \\ v_\eta y_3^\nu & 0 & 0 & 0 & v_H y_5^{\nu 3} \end{pmatrix}. \quad (6)$$

Using the type I seesaw formula for light neutrino masses $m_\nu = -m_D M_R^{-1} m_D^T$, the light left-handed neutrino mass matrix takes the form

$$m_\nu = \begin{pmatrix} 0 & 0 & w \\ 0 & x & y \\ w & y & z \end{pmatrix}, \quad (7)$$

which corresponds to the A_1 texture, where

$$\begin{aligned} w &= \frac{-v_H v_\eta y_1^\nu y_5^{\nu 3}}{(v_\phi y_3^{N_{1'}})}, \\ x &= \frac{-v_H^2 (y_4^{\nu 2})^2}{M_4}, \\ y &= \frac{y_3^{N_{1'}} v_H (v_H v_\phi y_4^{\nu 2} y_2^{N_1} - v_\eta M_4 y_2^\nu)}{M_4 v_\phi y_3^{N_{1'}}}, \\ z &= \frac{y_3^{N_{1'}} v_H (M M_4 y_3^{N_{1'}} v_H - 2 M_4 y_3^\nu y_3^{N_{1'}} v_\phi v_\eta - v_H v_\phi^2 (y_2^{N_1})^2 y_3^{N_{1'}})}{M_4 v_\phi^2 (y_3^{N_{1'}})^2}. \end{aligned} \quad (8)$$

⁴Note that the RH neutrino mass matrix is the same for case A_2 .

B. Model for A_2

In this case, the irreps for the lepton fields are as follows: L_e, L_μ , and L_τ transform as $\mathbf{1}'', \mathbf{1}'$, and $\mathbf{1}$, respectively, while N_4 and N_5 are in $\mathbf{1}$ and $\mathbf{1}'$, or in the notation of Table III $\alpha = \mathbf{1}'', \beta = \mathbf{1}', \gamma = \mathbf{1}, \delta = \mathbf{1}$, and $\epsilon = \mathbf{1}'$. The resulting Lagrangian is

$$\begin{aligned} \mathcal{L}_Y = & y_e \bar{L}_e l_e H + y_\mu \bar{L}_\mu l_\mu H + y_\tau \bar{L}_\tau l_\tau H \\ & + y_1^\nu \bar{L}_e [N_T \eta]_{1''} + y_2^\nu \bar{L}_\mu [N_T \eta]_{1'} + y_3^\nu \bar{L}_\tau [N_T \eta]_1 \\ & + y_4^{\nu 3} \bar{L}_\tau N_4 H + y_5^{\nu 2} \bar{L}_\mu N_5 H + M \bar{N}_T^c N_T \\ & + M_4 \bar{N}_4^c N_4 + y_2^{N_1} [\bar{N}_T^c \phi]_1 N_4 + y_3^{N_{1'}} [\bar{N}_T^c \phi]_{1''} N_5 \\ & + y_1^N [\bar{N}_T^c \phi]_{3_1} N_T + (y_1^N)' [\bar{N}_T^c \phi]_{3_2} N_T + \text{H.c.} \end{aligned} \quad (9)$$

After the breaking of the flavor and electroweak symmetries, the Dirac neutrino mass matrix is

$$m_D = \begin{pmatrix} v_\eta y_1^\nu & 0 & 0 & 0 & 0 \\ v_\eta y_2^\nu & 0 & 0 & 0 & v_H y_5^{\nu 2} \\ v_\eta y_3^\nu & 0 & 0 & v_H y_4^{\nu 3} & 0 \end{pmatrix}, \quad (10)$$

and the light left-handed neutrino mass matrix takes the form

$$m_\nu = \begin{pmatrix} 0 & w' & 0 \\ w' & x' & y' \\ 0 & y' & z' \end{pmatrix}, \quad (11)$$

which corresponds to the A_2 texture, where

$$\begin{aligned} w' &= \frac{-v_H v_\eta y_5^{\nu 2} y_1^\nu}{v_\phi y_3^{N_{1'}}}, \\ x' &= \frac{v_H y_5^{\nu 2} (-2M_4 v_\eta v_\phi y_2^\nu y_3^{N_{1'}} + M M_4 v_H y_5^{\nu 2} - v_H v_\phi^2 (y_2^{N_1})^2 y_5^{\nu 2})}{M_4 v_\phi^2 (y_3^{N_{1'}})^2}, \\ y' &= \frac{v_H (-M_4 v_\eta y_3^\nu + v_H v_\phi y_2^{N_1} y_4^{\nu 3}) y_5^{\nu 2}}{M_4 v_\phi y_3^{N_{1'}}}, \\ z' &= \frac{-v_H^2 (y_4^{\nu 3})^2}{M_4}. \end{aligned} \quad (12)$$

C. Phenomenology

These textures have been extensively studied [5,10,15–29]. Here for completeness, we present some results and give an estimate of the radiative correction for the neutrinoless double beta decay effective mass parameter. In order to do this, the first step is to notice that the neutrino mass in the

flavor basis is related to the mass matrix in the mass basis by a unitary transformation U , i.e., $m_\nu = U D U^T$, where $D = \text{diag}(m_1, m_2, m_3)$ is the diagonal neutrino mass matrix. The matrix U in the PDG parametrization [30] is given in terms of three mixing angles, one Dirac CP violating phase (δ) and two Majorana phases (α_{21}, α_{31}),

$$U = \begin{pmatrix} s_{12} c_{13} & c_{13} s_{12} & e^{-i\delta} s_{13} \\ -c_{23} s_{12} - e^{i\delta} c_{12} s_{13} s_{23} & c_{12} c_{23} - e^{i\delta} s_{12} s_{13} s_{23} & c_{13} s_{23} \\ s_{12} s_{23} - e^{i\delta} c_{12} c_{23} s_{13} & -e^{i\delta} c_{23} s_{12} s_{13} - c_{12} s_{23} & c_{13} c_{23} \end{pmatrix} \text{diag}(1, e^{i\frac{\alpha_{21}}{2}}, e^{i\frac{\alpha_{31}}{2}}), \quad (13)$$

where $c_{ij} = \cos \theta_{ij}$ and $s_{ij} = \sin \theta_{ij}$. We define the masses including the corresponding Majorana phases as $\mu_1 \equiv m_1$, $\mu_2 \equiv e^{i\alpha_{21}} m_2$, $\mu_3 \equiv e^{i\alpha_{31}} m_3$. Using the texture zeros we solve for the masses μ_2 and μ_3 in terms of $(\mu_1, \sin^2 \theta_{12}, \sin^2 \theta_{23}, \sin^2 \theta_{13}, \delta)$, see for instance [10,15]. Then we compute the differences Δm_{12}^2 and Δm_{23}^2 , both will be proportional to μ_1 . Taking the ratio will give us something that is independent of μ_1 and is only a function of the parameters measured by experiments. The next step is to draw random points for

$(\sin^2 \theta_{12}, \sin^2 \theta_{23}, \sin^2 \theta_{13})$ and predict the CP oscillation phase at each draw. Once we get the CP violating phase we can substitute its value in the functions Δm_{12}^2 or Δm_{23}^2 and solve for the mass μ_1 . Finally, we check if our predictions are consistent with the neutrino allowed regions given by global neutrino oscillation fits [31,32]. For the types A_1 and A_2 , the lightest neutrino mass we get is between $m_1 = [0.004, 0.008]$ eV and $m_1 = [0.003, 0.008]$ eV, respectively. At leading order in θ_{13} one can easily extract the Majorana phases

FIG. 1. Loop diagram which generates a nonzero m_{ee} and consequently a small double beta decay rate.

$$\begin{aligned}\mu_2 &\simeq -\mu_1 \cot^2 \theta_{12}, \\ \mu_3 &\simeq \pm \mu_1 e^{i\delta} \frac{\cot \theta_{12} \cot \theta_{23}}{\sin \theta_{13}},\end{aligned}\quad (14)$$

where the “+” is for A_1 and the “−” for A_2 , then the Majorana phases are simply $\alpha_{21} = \pi$ and $\alpha_{31} = \delta$ ($\alpha_{31} = \delta + \pi$). An interesting property of the A_1 and A_2 matrices obtained here is that the neutrinoless double beta decay effective mass parameter is predicted to be zero at tree level. In any case, it should be pointed out that loop corrections like the one shown in Fig. 1 give a nonzero (but small) contribution to m_{ee} . The one loop contribution is not computed exactly, instead of it, we estimate the bound with a few assumptions. We assume that the Yukawa couplings in the theory are of the same order of magnitude. The one loop diagram that contributes to m_{ee} is just the one shown in Fig. 1 (which depends on the coupling y_1^ν). Other possible diagrams such as one with external Higgs singlet of A_4 are forbidden by the flavor symmetry. Thus to estimate it, we use the neutrino matrix element⁵ which has vev’s and Yukawas similar to the ones that appear in the one loop contribution in Fig. 1. We have performed the scan in our parameter space, and taken the maximal value for the neutrino matrix element in the three sigma scan and this value is divided by the usual one loop suppression factor $(4\pi)^2$. For A_1 , we have $m_{e\tau} < 0.012$ eV, thus we get $m_{ee} \lesssim (0.012 \times (\frac{1}{4\pi})^2 = 8 \times 10^{-5})$ eV, which is well

⁵ $m_{e\tau}$ ($m_{e\mu}$) for A_1 (A_2) texture.

below current experimental limits [33]. For A_2 , we get exactly the same constraint.

D. Other textures: B_1 and B_2

Finally, it is important to mention that if we break A_4 to Z_3 , in many cases the RH neutrino mass matrices are noninvertible while some of them give only two non-vanishing light neutrino mass elements and therefore the phenomenology for masses and mixings are trivial and noncompatible with the observations. Nevertheless, if we include another scalar field Δ which is triplet under $SU(2)_L$ and a singlet under A_4 , just as in [8] we are able to obtain two more texture zeros, namely B_1 and B_2 . For example, B_2 can be obtained if we use the irrep assignment $L_e = \mathbf{1}$, $L_\mu = \mathbf{1}''$, $L_\tau = \mathbf{1}'$, $N_4 = \mathbf{1}'$, $N_5 = \mathbf{1}''$, and $\Delta = \mathbf{1}'$. Thus a simple extension of our model allows us to obtain six of the seven texture zeros. In these scenarios, the DM stability is lost since the charged leptons transform also nontrivially under the residual Z_3 symmetry.

IV. CONCLUSIONS

We extended the model presented in [9] to other representations of the alternating symmetry group of four elements A_4 getting two more texture zeros, A_1 and A_2 . We computed the experimental constraints that these matrices induce to the neutrino masses, mixings, and the CP phases (Dirac and Majorana). Due to the residual Z_2 symmetry, this framework relates the neutrino phenomenology and dark matter stability in a nontrivial way. Thus we have a solid theoretical framework to justify this texture zeros. Furthermore, breaking to Z_3 and including an scalar $SU(2)_L$ triplet we were able to obtain two more texture zeros B_1 and B_2 .

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