Chapter 16
Impact of Texture Zeros of Neutrino Mass Matrix on Dark Matter Phenomenology

Nayana Gautam and Mrinal Kumar Das

Abstract We study an inverse seesaw ISS (2,3) framework to explain neutrino phenomenology and dark matter simultaneously with one zero textures of neutrino mass matrix. ISS (2,3) is obtained by the addition of two right-handed neutrinos and three gauge singlets sterile fermions to the standard model. The model is more predictive because of presence of less number of right-handed neutrinos than the conventional inverse seesaw. Moreover, texture zeros in the structures of the mass matrices reduce the free parameters. We extensively study the effect of different textures of neutrino mass matrix on sterile neutrino dark matter phenomenology. Based on different properties of the dark matter, we verify the viability of different one zero textures of the light neutrino mass matrix.

16.1 Introduction

Neutrino mass and mixing, ordering of the neutrino mass, Dirac CP phase, dark matter and baryon asymmetry of universe (BAU) are major reasons to expect physics beyond standard model (BSM). Different BSM frameworks are available in literature which can account for such issues. Inverse seesaw is one of the most promising mechanisms as the neutrino mass generation takes place at lower scale than the conventional seesaw. Here, we study an inverse seesaw framework where two right-handed neutrinos and three sterile fermions are added to the standard model particle content. The most attractive feature of the model lies in the fact that besides explaining neutrino mass, it can lead to a sterile neutrino in keV scale which can account for a viable dark matter candidate. We consider the possibility of one zero at certain position of the neutrino mass matrix. In the framework of ISS (2,3), there are three phenomenologically viable one zero textures of neutrino mass matrix. We have stud-

N. Gautam (✉) · M. K. Das
Department of Physics, Tezpur University, Tezpur 784028, India
e-mail: nayana@tezu.ernet.in

M. K. Das
e-mail: mkdas@tezu.ernet.in

S. Sengupta et al. (eds.), *Selected Progresses in Modern Physics*, Springer Proceedings in Physics 265, https://doi.org/10.1007/978-981-16-5141-0_16

ied dark matter phenomenology in all the three textures. Then we have implemented cosmological bounds on the parameters and have confirmed the viability of different textures.

The paper is planned as follows. In Sect. 16.2, we describe the neutrino mass and dark matter production within the framework of ISS (2,3). Section 16.3 is the brief discussion on different one zero textures of neutrino mass matrix. We discuss the results of the numerical analysis in Sect. 16.4. Finally, we conclude in Sect. 16.5.

16.2 Neutrino Mass and Dark Matter Production

In ISS(2,3), the standard model is extended by the sequential addition of RH neutrinos and SM singlet fermions s_i [1, 2]

$$L = -\frac{1}{2} n_L^T C M n_L + h.c \tag{16.1}$$

The mass matrix in the basis $n_L = (\nu_L, N_R, s)$ can be written as,

$$M = \begin{pmatrix} 0 & M_d & 0 \\ M_d^T & 0 & M_N \\ 0 & M_N^T & \mu \end{pmatrix} \tag{16.2}$$

We obtain the light active neutrino mass in this framework as

$$m_\nu \approx M_d d M_d^T \tag{16.3}$$

where d is a 2×2 matrix given by

$$M_H^{-1} = \begin{pmatrix} d_{2\times2} & \cdots \\ .... & .... \end{pmatrix} with\ M_H = \begin{pmatrix} 0 & M_N \\ M_N^T & \mu \end{pmatrix} \tag{16.4}$$

Apart from the light active neutrinos, the model naturally leads to a sterile neutrino dark matter (DM). To study DM phenomenology, one needs to consider three main aspects: relic abundance, stability and structure formation. The relic abundance of the proposed dark matter can be expressed as [1]

$$\Omega_{DM} h^2 = 1.1 \times 10^7 \sum C_\alpha(m_s) |\mathcal{U}_{\alpha s}|^2 \left(\frac{m_s}{keV}\right)^2, \alpha = e, \mu, \tau \tag{16.5}$$

$C_\alpha(m_s)$can be determined numerically and are found to be of order 0.5.

To ensure the stability of dark matter, we calculate the decay rate of the lightest sterile neutrino in the process $N \longrightarrow \nu + \gamma$ which is given by [4],

$$\Gamma = 1.38 \times 10^{-32}\left(\frac{sin^2 2\theta}{10^{-10}}\right)\left(\frac{m_s}{keV}\right)^5 s^{-1}. \tag{16.6}$$

where $sin^2 2\theta = 4\sum_\alpha |\mathcal{U}_{\alpha s}|^2$ with $\alpha = e, \mu, \tau$.

16.3 Different One Zero Textures of Neutrino Mass Matrix in ISS(2,3)

The one zero textures of the neutrino mass matrix allowed in the framework of ISS (2, 3) are

$$a = \begin{pmatrix} \times & 0 & \times \\ 0 & \times & \times \\ \times & \times & \times \end{pmatrix},\ b = \begin{pmatrix} \times & \times & \times \\ \times & \times & 0 \\ \times & 0 & \times \end{pmatrix},\ c = \begin{pmatrix} \times & \times & 0 \\ \times & \times & \times \\ 0 & \times & \times \end{pmatrix}. \tag{16.7}$$

For class a ,

$$M_D = \begin{pmatrix} 0 & b \\ c & 0 \\ e & h \end{pmatrix},\ \mu = \begin{pmatrix} p & 0 & 0 \\ 0 & p & 0 \\ 0 & 0 & p \end{pmatrix},\ M_N = \begin{pmatrix} f & 0 & 0 \\ 0 & g & 0 \end{pmatrix}. \tag{16.8}$$

For class b ,

$$M_D = \begin{pmatrix} a & b \\ c & 0 \\ 0 & h \end{pmatrix},\ \mu = \begin{pmatrix} p & 0 & 0 \\ 0 & p & 0 \\ 0 & 0 & p \end{pmatrix},\ M_N = \begin{pmatrix} f & 0 & 0 \\ 0 & g & 0 \end{pmatrix}. \tag{16.9}$$

For class c ,

$$M_D = \begin{pmatrix} 0 & b \\ c & d \\ e & 0 \end{pmatrix},\ \mu = \begin{pmatrix} p & 0 & 0 \\ 0 & p & 0 \\ 0 & 0 & p \end{pmatrix},\ M_N = \begin{pmatrix} f & 0 & 0 \\ 0 & g & 0 \end{pmatrix}. \tag{16.10}$$

In all the cases, we have considered maximal possible zeros in M and μ. Different zero textures of M_D are taken to get the one zero textures of the neutrino mass matrix.

16.4 Numerical Analysis and Results

The light neutrino mass matrix can be diagonalised with the unitary PMNS matrix [5] as follows:

$$m_\nu = U_{PMNS} m_\nu^{diag} U_{PMNS}^T \tag{16.11}$$

Again, the active-sterile mixing can be obtained by the numerical diagonalisation of the full 8×8 mass matrix using $\mathcal{U}$

$$\mathcal{U}^T M \mathcal{U} = M^{diag} = diag(m_1, m_2....m_8) \tag{16.12}$$

In the framework of ISS (2, 3), the lightest neutrino mass is found to be zero. We evaluate the model parameters in all the textures by comparing the neutrino mass matrix arising from the model with the one which is parametrised by the available 3σ global fit data [3]. After evaluating the model parameters, we calculate the mass of the sterile neutrino dark matter m_{DM} as well as DM-active mixing using Eq. 16.12 and the parameter space for all the categories are shown in Fig. 16.1. Again, with the mass and mixing of the dark matter, we evaluate the decay rates of the sterile DM and relic abundance in the above categories which are represented in Figs. 16.2 and 16.3, respectively. We have also implemented the cosmological X-ray bound [4] and XQ-100 Lyman-α which is also compatible with SDSS-I + UVES data [6] bound on sterile neutrino dark matter.

From Figs. 16.1 and 16.2, it is evident that a wide range of parameter space is allowed by cosmology data. However, the texture A2 can account for only 15% of the total DM abundance for the allowed mass region as can be seen from Fig. 16.3.

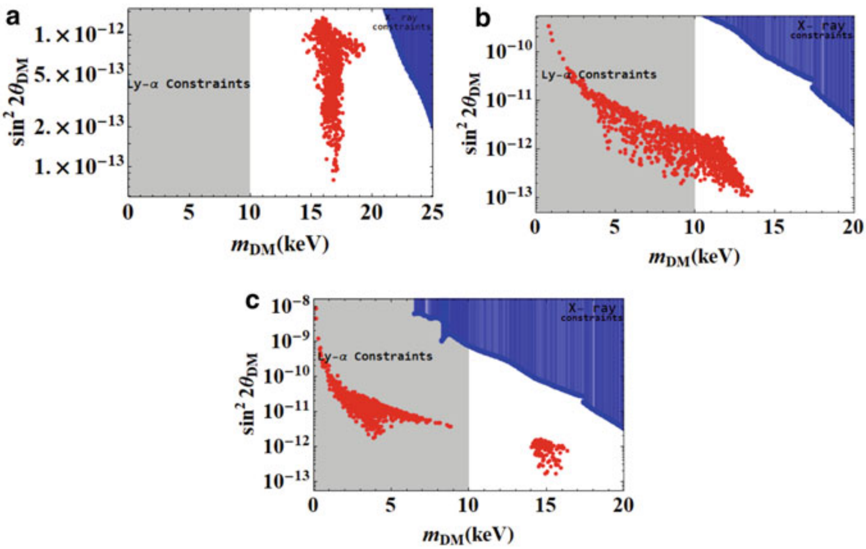

Fig. 16.1 DM-active mixing as a function of the mass of the DM in different textures

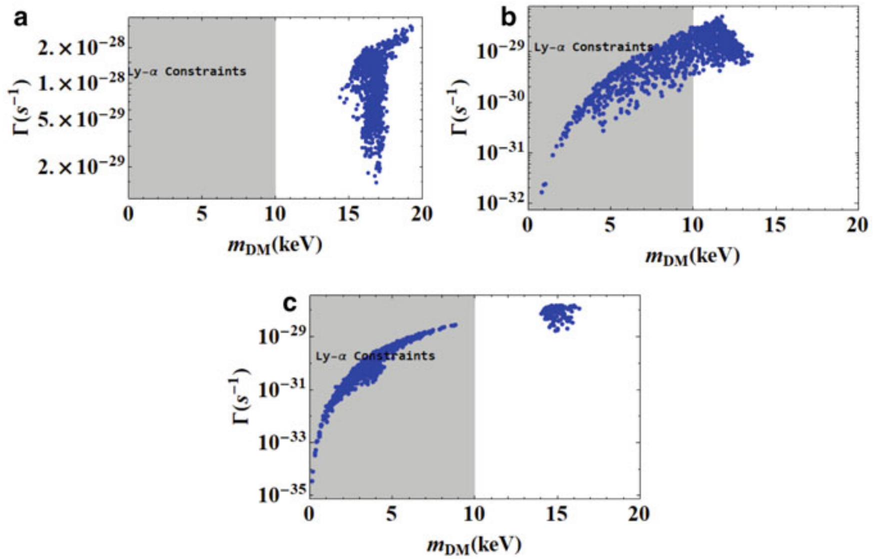

Fig. 16.2 Decay rate (in s^{-1})of the lightest sterile neutrino as a function of DM mass in different textures

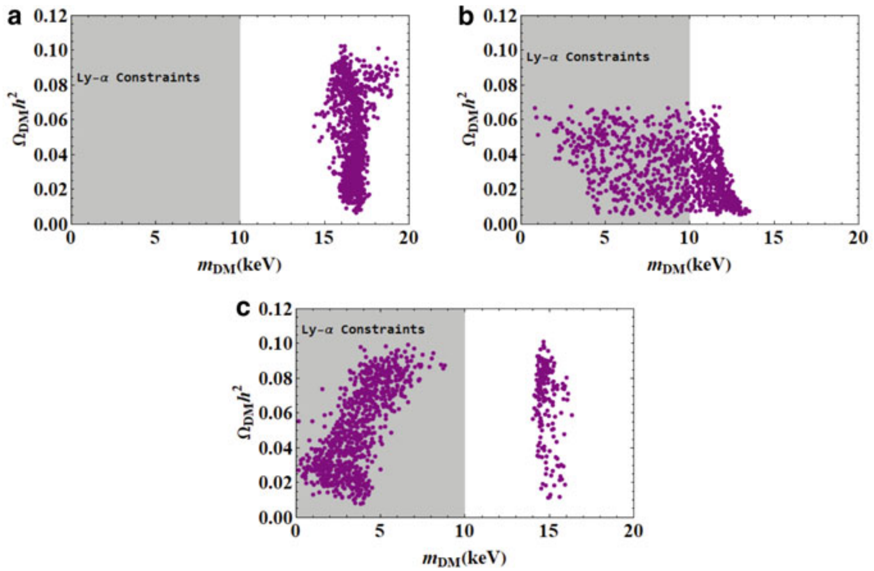

Fig. 16.3 Predictions of different textures on relic abundance of sterile neutrino dark matter

16.5 Summary and Conclusion

We have conducted our study in the framework of ISS(2,3) which leads to three light active neutrino states, two pseudo-Dirac states and an additional sterile state in keV range. We have explored the scenario with only two right-handed neutrinos and one texture zero of neutrino mass matrix and their impacts on sterile neutrino dark matter phenomenology. We have calculated dark matter mass, DM-active mixing and decay rate of the proposed particle and have obtained the mass-mixing parameter space within the range predicted by cosmology for the three textures. However, it has been observed that one particular texture leads to a very small relic abundance of dark matter. Thus, we may conclude that only two $1-0$ textures in the framework of ISS $(2, 3)$ are suitable for explaining dark matter as well as neutrino phenomenology.

Acknowledgements NG would like to acknowledge Department of Science and Technology (DST),India(grant DST/INSPIRE Fellowship/2016/IF160994) for the financial assistantship.

References

1. A. Abada, G. Arcadi, M. Lucente, Dark matter in the minimal Inverse Seesaw mechanism. J. Cosmol. Astropart. Phys. **2014**(10), 001 (2014). https://doi.org/10.1088/1475-7516/2014/10/001
2. N. Gautam, M.K. Das, Phenomenology of keV scale sterile neutrino dark matter with S4 flavor symmetry. JHEP **01**, 098 (2020). https://doi.org/10.1007/JHEP01(2020)098
3. I. Esteban, M. Gonzalez-Garcia, M. Maltoni et al., The fate of hints: updated global analysis of three-flavor neutrino oscillations. J. High Energy Phys. **2020**, 178 (2020). https://doi.org/10.1007/JHEP09(2020)178
4. K.C.Y. Ng et al., New constraints on sterile neutrino dark matter from NuSTAR M31 observations. Phys. Rev. D **99**, 083005 (2019). https://doi.org/10.1103/PhysRevD.99.083005
5. C. Giganti, S. Lavignac, M. Zito, Neutrino oscillations: the rise of the PMNS paradigm. Prog. Part Nucl. Phys. 98 (2018). https://doi.org/10.1016/j.ppnp.2017.10.001
6. J. Baur, N. Palanque-Delabrouille, C. Yeche, A. Boyarsky, O. Ruchayskiy, É. Armengaud, J. Lesgourgues, Constraints from Ly-α forests on non-thermal dark matter including resonantly-produced sterile neutrinos. JCAP **12**, 013 (2017). https://doi.org/10.1088/1475-7516/2017/12/013