No-go for freeze-in DM in right-handed neutrino extended MSSM

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Summary

We investigate the possibility of saturating the relic density bound with light higgsinos. When the minimal supersymmetric Standard Model is extended with right-handed neutrino superfields and the seesaw scale is very low, right sneutrinos can be produced via the freeze-in mechanism. In such a case we can have essentially two independent sources for dark matter, the traditional freeze-out of higgsinos and the freeze-in of right-handed sneutrinos. The heavier of these two will decay to the lighter species with a delay. We have ruled out such a scenario for all seesaw models as the lifetime of sterile neutrino, produced via Dodelson-Widrow mechanism, exceeds the age of the universe and will contribute to the relic density.

Fix

Freeze-in mechanism comes to the rescue. But it requires coupling between DM and thermal bath to be below 10^{-7} or so. Such couplings exist naturally in electroweak scale seesaw models if the MSSM is extended with sterile neutrino superfields.

Properties

- ✔ Will have both independent freeze-in and freeze-out contribution.
- ✔ Heavier species will eventually decay into lighter species.
- ✔ A sterile sneutrino would evade all direct detection constraints.

Why

Natural supersymmetry prefers a light higgsino while other superpartners can be heavier. This motivates us to explore other weakly interacting massive particle (WIMP) alternatives.

Freeze-out component

We get a Higgsino-like neutralino which can either be stable or decays to RH neutrinos. Large part of parameter space has already been excluded by experiments. However, constraints can be evaded if sneutrino is our DM.

$$W_{\text{Dirac}} = y^u Q H_u U^c + y^d Q H_d D^c + y^\ell L H_d E^c + \mu H_u H_d + y^\nu L H_u N^c$$

$$M^2_{\nu,N} = \begin{pmatrix} 0 & m^2_{\tilde{\ell}} + \frac{1}{8}(g^2+g'^2)v^2\cos 2\beta & 0 & A_\nu v_u - y^\nu \mu v_d \\ m^2_{\tilde{\ell}} + \frac{1}{8}(g^2+g'^2)v^2\cos 2\beta & 0 & A_\nu v_u - y^\nu \mu v_d & 0 \\ 0 & A_\nu v_u - y^\nu \mu v_d & M^2 & m^2_{\tilde{N}} \\ A_\nu v_u - y^\nu \mu v_d & 0 & m^2_{\tilde{N}} & M^2 \end{pmatrix}$$

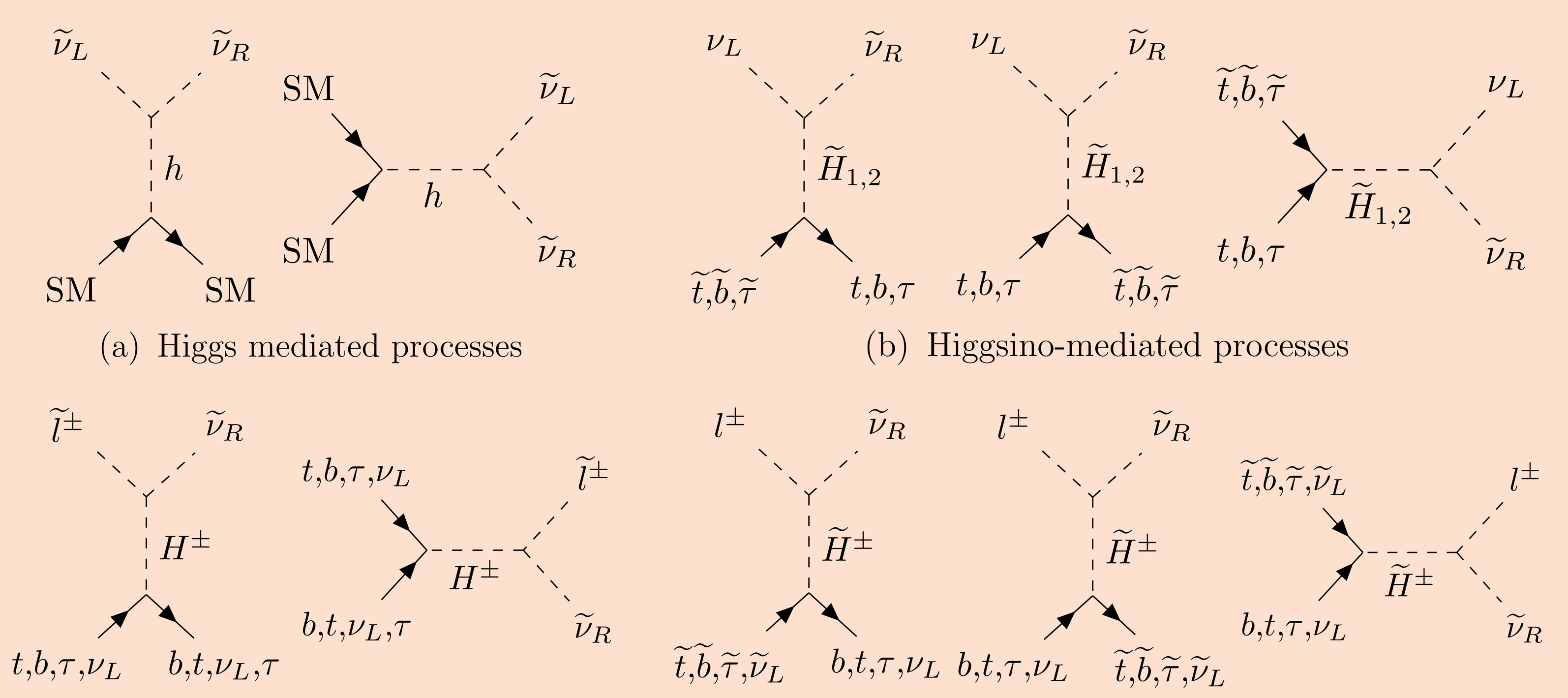
Four possible models!

Dirac neutrino: One can add right-handed neutrino superfields and corresponsing Yukawa coupling.	W_{Dirac}	$m_{\nu,ij} = y^\nu_{ij} v \sin\beta$	$M^2 = 0$
Type-I seesaw[1,2]: One can add the Majorana mass term for the right-handed neutrino	$W = W_{\text{Dirac}} + \frac{1}{2} M_{Ni} N^c_i N^c_i$	$m_\nu \simeq \frac{(y^\nu v \sin\beta)^2}{2M}, \quad m_N \simeq M$	Lepton number violating mass term M^2
Linear[3]: One can have two sets of sterile neutrinos.	$W_{\text{LS}} = W_{\text{Dirac}} + M_N N^c S + y^{LS} L \cdot H_u S$	$m_\nu \simeq \frac{y^\nu y^{LS} v^2 \sin^2\beta}{2M_N}$	
Inverse seesaw[4]: One can also have two sets of sterile neutrinos.	$W_{\text{IS}} = W_{\text{Dirac}} + M_N N^c S + \frac{1}{2}\mu_S S^2$	$m_\nu \simeq \left(\frac{y^\nu v \sin\beta}{\sqrt{2} M_N}\right)^2 \mu_S$	

- There is extremely small mass splitting between the CP-even and CP-odd states generated by M^2 term.
- Hence, the particle created as a (anti)sneutrino will remain nearly as a (anti)sneutrino for a long period.
- $A_\nu v_u - y^\nu \mu v_d$ term mix left- and right-handed sneutrinos.
- A_ν is vanishingly small which leads to negligible mixing between left- and right-handed neutrinos.

So far work on Dirac neutrinos with FIMPs!![5]

Freeze-in component

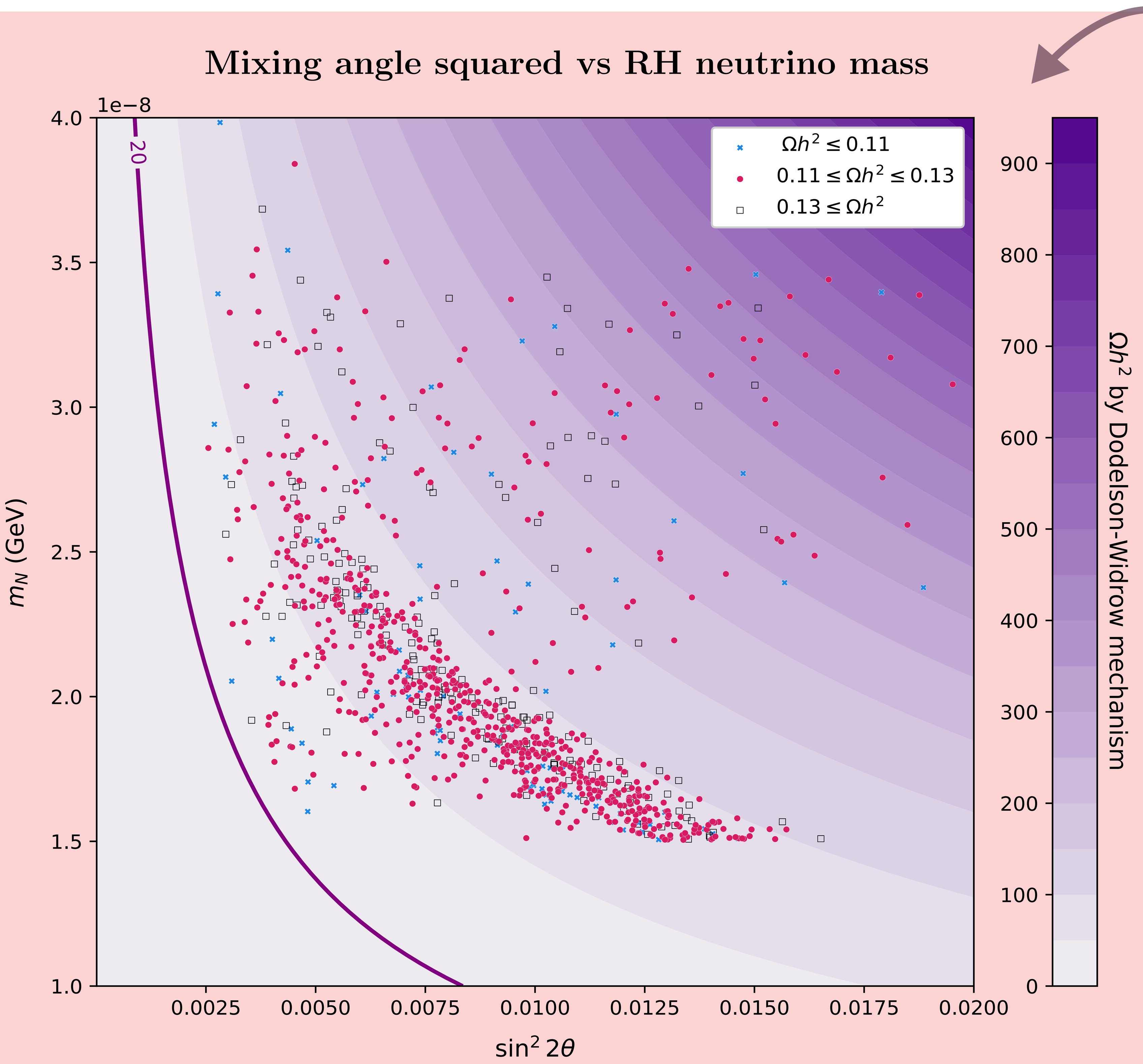


(a) Higgs mediated processes (b) Higgsino-mediated processes (c) Charged Higgs mediated processes (d) Charged Higgsino mediated processes

Dodelson-Widrow mechanism

The dominant mechanism for sterile neutrino dark matter generation is oscillations between active and sterile neutrinos known as the Dodelson-Widrow mechanism [6].

$$\Omega h^2 \simeq 0.12 \left(\frac{m_N}{1\,\text{keV}}\right)^2 \left(\frac{\sin^2 2\theta}{7.3\times 10^{-8}}\right)^{1.23}$$



Results

We have shown that irrespective of sterile neutrino mass or choice of Yukawa coupling, there is always overproduction in the otherwise viable parameter space.

Tools

The model files were generated with SARAH v4.14.5 and the particle spectrum was generated with SPHENO v4.0.5. We used MICROMEGAS v5.3.41 for relic density calculations.

Conclusion

- In **type-I seesaw**, it is impossible to suppress mixing (θ) while keeping the neutrino mass spectrum viable.
- In **linear seesaw**, we can supress this mixing by making sterile neutrino more massive. But it leads to high freeze-in contribution.
- In **inverse seesaw**, we see that it is essentially a type-I seesaw once we integrate out sneutrinos and singlet neutrinos.

References

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