Anatomy of RHN-portal DM

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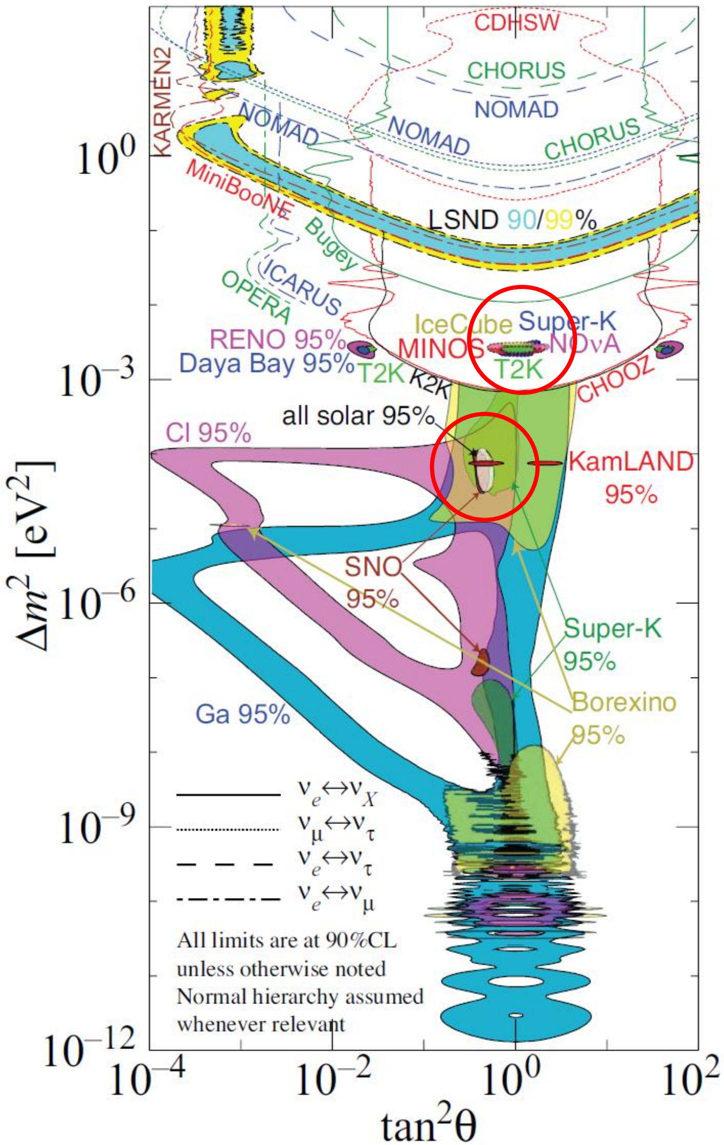
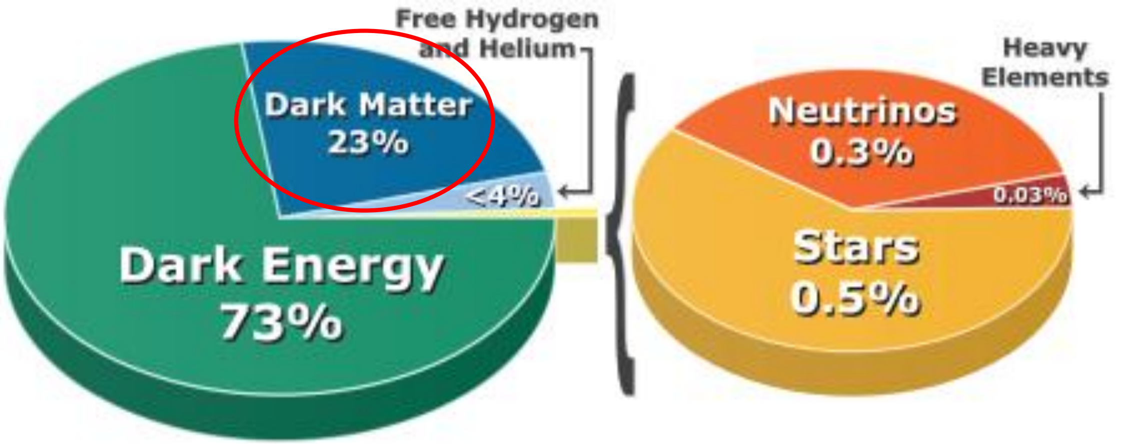
Neutrino mass & dark matter





Seesaw mechanism

- Appealing explanation for $m_\nu/m_t \sim 10^{-13}$:

$$\mathcal{L}_{seesaw} = y_N\, LHN + \frac{1}{2} M\, NN + h.c.$$

$$\mathcal{L}_{mass} = m_D \nu N + \frac{1}{2} MNN \rightarrow \frac{1}{2} m_\nu \nu\nu + \frac{1}{2} m_N NN$$

$$\begin{pmatrix} 0 & m_D \\ m_D & M \end{pmatrix} \rightarrow \begin{pmatrix} -\frac{m_D^2}{M} & 0 \\ 0 & M + \frac{m_D^2}{M} \end{pmatrix}$$

- Seesaw at TeV scale:

$$M \sim 100\ GeV,\ m_\nu \lesssim 0.1 eV \ \rightarrow\ m_D = \sqrt{m_\nu M} \lesssim 0.1\mathrm{MeV}$$

$$\Rightarrow y_N \lesssim 10^{-6}$$

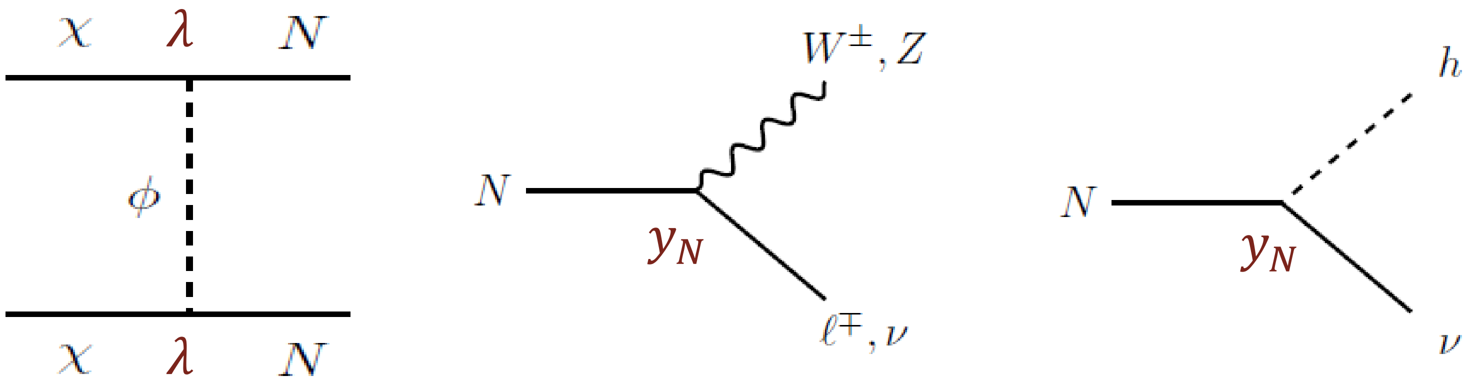
RHN-portal DM

- RHN couples to a dark sector fermion and boson:

$$\lambda N \chi \phi$$

Pospelov-Ritz-Voloshin, 0711.4866

- Consider a fermion DM which annihilates to RHN:



- RHN has a small Yukawa coupling to SM particles → It's size c ontrols how efficiently a RHN is in thermal equilibrium.

Specific realization in B-L Seesaw

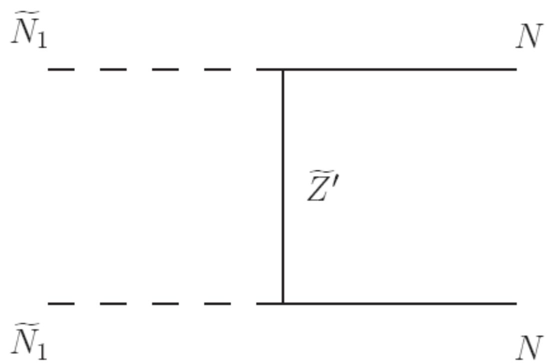
- Seesaw from gauged $U(1)_{B-L}$ breaking:

$$\mathcal{L}_{B-L} = y_N\, LHN + \frac{1}{2}\lambda_S\, SNN + h.c.$$

  - $Q_{B-L}(L, N, S) = (-1, +1, -2)$

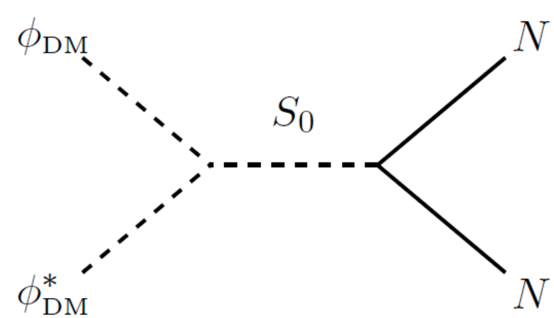
- Neutrino Yukawa effects are studied for

Sneutrino DM



Bandyopadhyay-EJC-Park, 1105.1651

B-L Higgs DM



Bandyopadhyay-EJC-Mandal, 1707.00874

Yukawa effect in DM freeze-out

- Coupled Boltzmann equation for DM & RHN:

$$\frac{dY_\chi}{dx} = -\frac{1}{x^2}\frac{s(m_\chi)}{H(m_\chi)}\langle\sigma v\rangle_{\chi\chi\to NN}\left(Y_\chi^2 - Y_N^2\right),$$

$$\frac{dY_N}{dx} = \frac{1}{x^2}\frac{s(m_\chi)}{H(m_\chi)}\langle\sigma v\rangle_{\chi\chi\to NN}\left(Y_\chi^2 - Y_N^2\right) - \frac{\Gamma}{H(m_\chi)}x\left(Y_N - Y_N^{\rm eq}\right)$$

$$\langle\sigma v\rangle = \frac{\lambda^4\left(m_\chi + m_N\right)^2}{16\pi\left(m_\chi^2 + m_\phi^2 - m_N^2\right)^2}\left(1 - \frac{m_N^2}{m_\chi^2}\right)^{1/2}$$

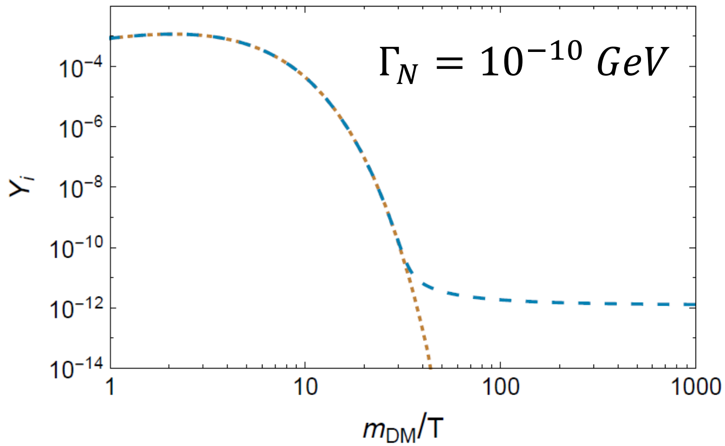
$$\Gamma(N\to h\nu) = \Gamma(N\to h\bar\nu) = \frac{y_N^2 m_N}{64\pi}\left(1 - \frac{m_h^2}{m_N^2}\right)^2,$$

$$\Gamma(N\to \ell^- W^+) = \Gamma(N\to \ell^+ W^-) = \frac{y_N^2 m_N}{32\pi}\left(1 - \frac{m_W^2}{m_N^2}\right)^2\left(1 + 2\frac{m_W^2}{m_N^2}\right),$$

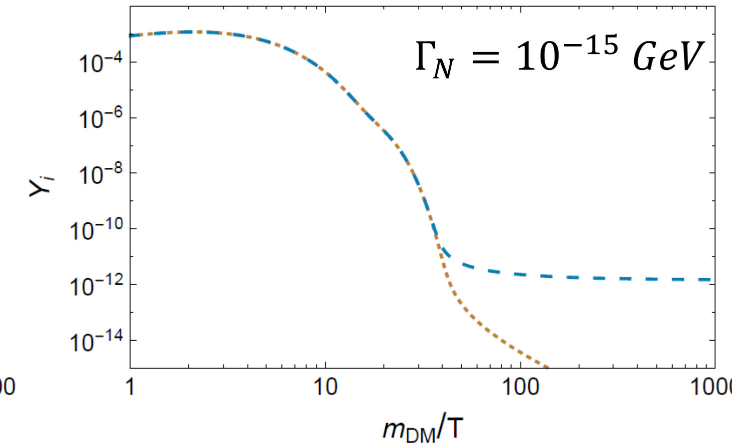
$$\Gamma(N\to Z\nu) = \Gamma(N\to Z\bar\nu) = \frac{y_N^2 m_N}{64\pi}\left(1 - \frac{m_Z^2}{m_N^2}\right)^2\left(1 + 2\frac{m_Z^2}{m_N^2}\right).$$

- Smaller Yukawa → later thermal equilibrium → larger DM relic density → requires larger annihilation rate.

Evolution of DM & N densities



(a)



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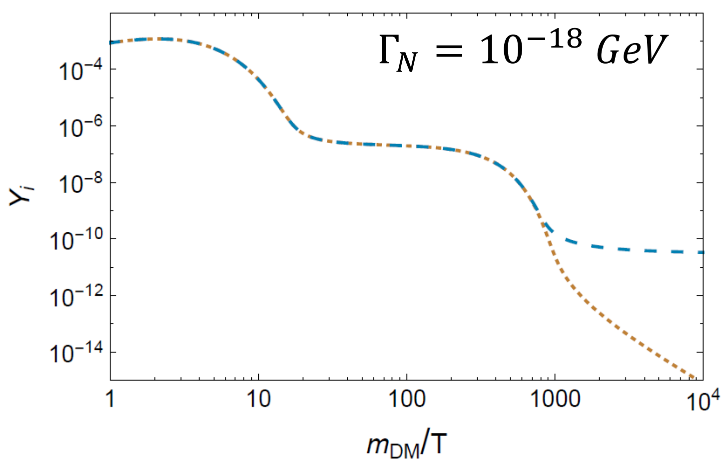

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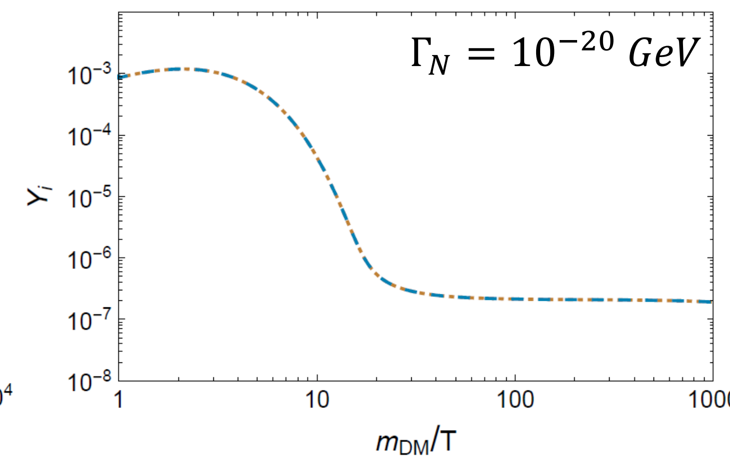
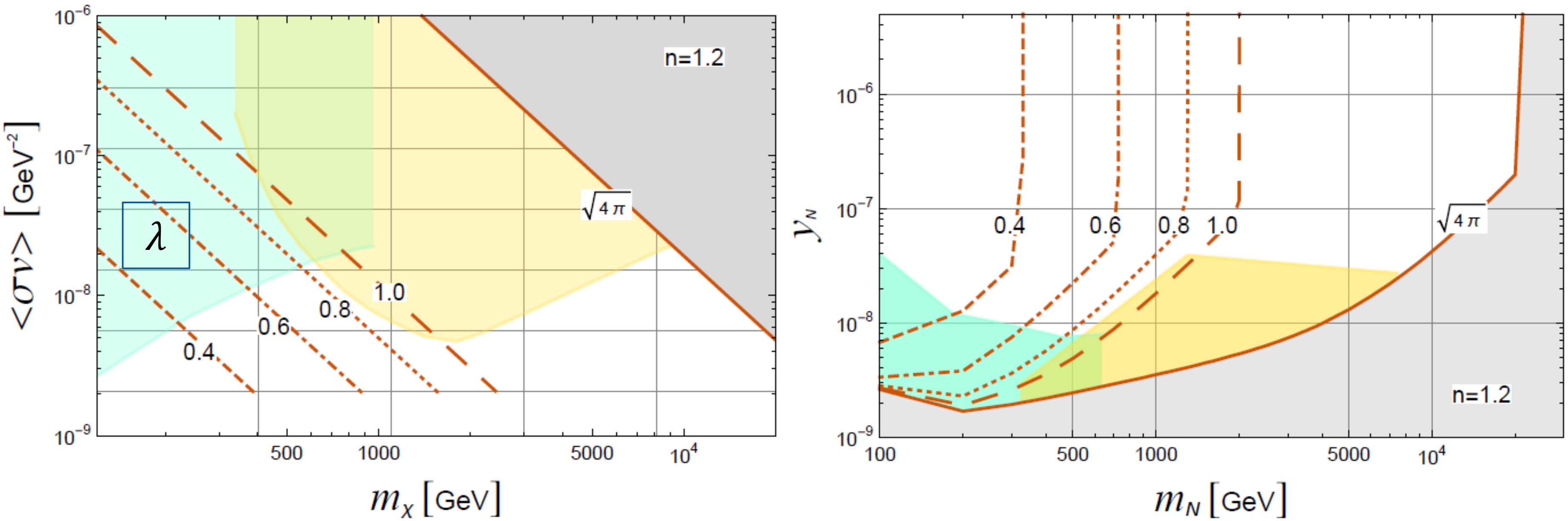


(d)

Gamma ray signals

- Larger annihilation rate excluded by FermiLAT & HESS

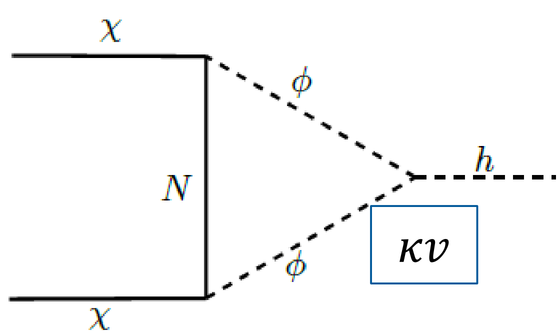


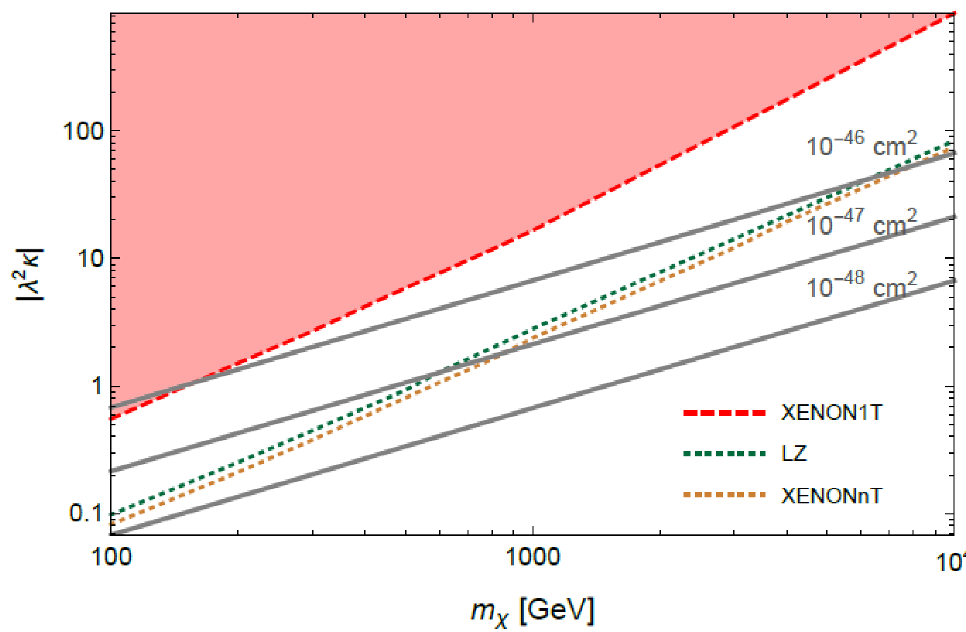
$$m_\chi = n\, m_N = 1/n\, m_\phi$$

Direct detection

- DM-DM-Higgs coupling at one-loop:

$$-\mathcal{L}_{h\chi\chi} = \kappa' h \bar{\chi}\chi \quad \text{where} \quad \kappa' \equiv \frac{\lambda^2 \kappa v}{16\pi^2} \frac{m_\chi c_1(x) - m_N c_0(x)}{m_\phi^2},$$





Summary

- A RHN, required to explain tiny neutrino masses, may be a portal to the dark sector.
- Thermal freeze-out density of DM depends on the tiny ne utrino Yukawa coupling.
- Its effect (for a fermionic DM) is analyzed to study gamma ray signals from DM annihilation searched by Fermi-LAT a nd HESS.
- Direct detection process arises at one-loop involving an i ndependent input parameter for a scalar in the dark secto r.