A Leptophilic Model Explaining Dark Matter and Neutrino Masses at Low Energies

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based on:
Y. Farzan, S. Pascoli, MS [1005.5323] and [1006.xxxx]

Outline

1. Model
2. Lepton Sector
3. Dark Matter
   - Dark Matter Annihilation
   - Dark Matter Direct Detection
   - DAMA/CoGeNT/CDMS-II?
   - Indirect Detection
4. More Phenomenology
5. Comments on Alternatives
6. Conclusions

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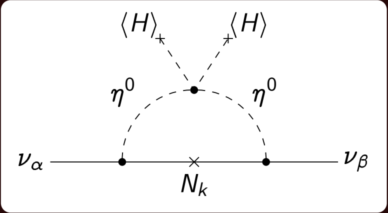
Radiative Mass Generation

Ma Model[Ma (2006)]



$$(m_\nu)_{\alpha\beta} = \sum_k \frac{Y_{\alpha k} Y_{\beta k} M_k}{16\pi^2} \left[\frac{m_R^2}{m_R^2 - M_k^2} \ln \frac{m_R^2}{M_k^2} - \frac{m_I^2}{m_I^2 - M_k^2} \ln \frac{m_I^2}{M_k^2} \right]$$

Conditions for Majorana Neutrino Mass Term

- Particle in loop have to couple to $SU(2)_L$ doublet

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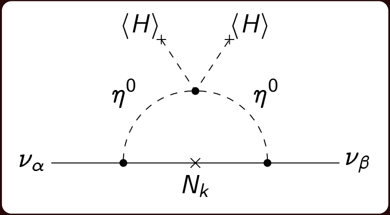

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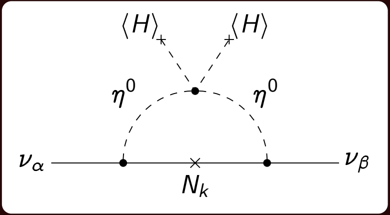

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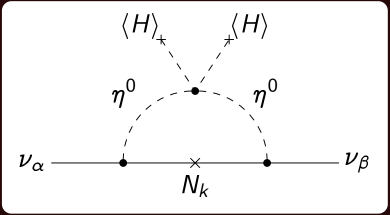

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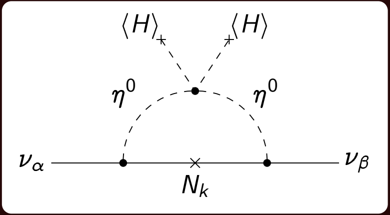

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  $\Rightarrow \eta^0$ stable particle $\Rightarrow$ DM candidate

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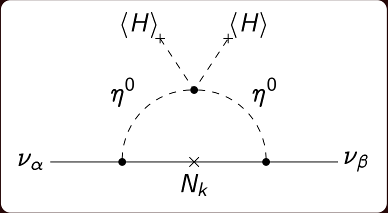

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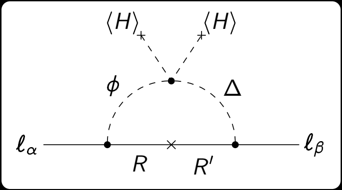
- But no symmetry explanation for smallness of couplings

Model

Particle Content

	SU(2)	U(1)	U(1)$_X$	$\mathbb{Z}_2$
$\ell_L^{(i)}$	2	-1/2	0	+
R_R	2	-1/2	1	-
R'_R	2	1/2	-1	-
Δ	3	1	1	-
ϕ	1	0	-1	-



- Symmetry explanation for smallness of couplings U(1)$\rightarrow \mathbb{Z}_2$
- $\Rightarrow$ here explicit, later spontaneous
- Symmetry protects smallness from large quantum corrections

Fermion Sector

$$-\boxed{m_{RR}(R'^C)^\dagger \cdot R} - \boxed{g_\alpha \phi^\dagger R^\dagger \ell_{L\alpha}} - \boxed{\tilde{g}_\alpha \phi R^\dagger \ell_{L\alpha}} - \boxed{(\tilde{g}_\Delta)_\alpha R'^\dagger \cdot \Delta \cdot \ell_{L\alpha}} + \text{h. c.}$$

skip technical details

Particle Content and Symmetries

	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathrm{U}(1)_X[\mathbb{Z}_2]$	$\mathrm{U}(1)_{L1}$	$\mathrm{U}(1)_{L2}$	$\mathrm{U}(1)_{L3}$
$Q_L^{(i)}$	3	2	1/6				
$u_R^{(i)}$	3	1	2/3				
$d_R^{(i)}$	3	1	-1/3				
$\ell_L^{(i)}$	1	2	-1/2	0[+]	+1	-1	+1
$e_R^{(i)}$	1	1	-1	0[+]	-1	+1	-1
H	1	2	1/2				
R_R	1	2	-1/2	1[-]	+1	+1	+1
R'_R	1	2	1/2	-1[-]	-1	-1	-1
Δ	1	3	1	1[-]	0	0	-2
ϕ	1	1	0	-1[-]	0	0	0

Yukawa Couplings

Particle Content

	$\mathrm{U}(1)_X$	$\mathbb{Z}_2$	$\mathrm{U}(1)_{L1}$	$\mathrm{U}(1)_{L2}$	$\mathrm{U}(1)_{L3}$
$\ell_L^{(i)}$	0	+	+1	-1	+1
R_R	1	-	+1	+1	+1
R'_R	-1	-	-1	-1	-1
Δ	1	-	0	0	-2
ϕ	-1	-	0	0	0

- Dirac mass $m_{RR} \gtrsim 100\,\mathrm{GeV}$

$$-\boxed{m_{RR}(R'^C)^\dagger \cdot R} - \boxed{g_\alpha \phi^\dagger R^\dagger \ell_{L\alpha}} - \boxed{\tilde{g}_\alpha \phi R^\dagger \ell_{L\alpha}} - \boxed{(\tilde{g}_\Delta)_\alpha R'^\dagger \cdot \Delta \cdot \ell_{L\alpha}} + \mathrm{h.\,c.}$$

- $\cancel{L}_2$
- $\cancel{L}_2$, $U(1)_X$ breaking
- $\cancel{L}_1$, $U(1)_X$ breaking

Higgs Potential

Particle Content

	$\mathrm{U}(1)_X$	$\mathbb{Z}_2$	$\mathrm{U}(1)_{L1}$	$\mathrm{U}(1)_{L2}$	$\mathrm{U}(1)_{L3}$
Δ	1	-	0	0	-2
ϕ	-1	-	0	0	0

- DM coannihilation into SM Higgs boson h
- Direct mass terms

$$\mathscr{V} \supset \boxed{m_\Delta^2 \operatorname{Tr} \Delta^\dagger \Delta + m_\phi^2 \phi^\dagger \phi} + \boxed{\lambda_L \frac{v_H}{\sqrt{2}} h \left(\delta_1^2 + \delta_2^2\right)}$$

$$+ \boxed{\frac{2 m_{\phi\Delta}^2}{v_H^2} H^T \,\mathrm{i}\, \sigma_2 \Delta^\dagger H \phi^\dagger} + \boxed{\frac{2 \tilde{m}_{\phi\Delta}^2}{v_H^2} H^T \,\mathrm{i}\, \sigma_2 \Delta^\dagger H \phi} + \boxed{\tilde{m}_\phi^2 \phi^2} + \mathrm{h.\,c.}$$

- $\cancel{L_3}$, $U(1)_\phi \times U(1)_\Delta \to U(1)_X$
- $\cancel{L_3}$, $U(1)_X \to \mathbb{Z}_2$, mixing ϕ and Δ
- $U(1)_X \to \mathbb{Z}_2$, mass splitting of $\mathrm{Re}(\phi)$ and $\mathrm{Im}(\phi)$

Neutral Scalar Masses

$$\phi = (\phi_1 + \mathrm{i}\ \phi_2)/\sqrt{2} \qquad\qquad \Delta^0 = (\Delta_1 + \mathrm{i}\ \Delta_2)/\sqrt{2}$$

$$\begin{pmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{pmatrix} = \begin{pmatrix} \cos\alpha_1 & 0 & \sin\alpha_1 & 0 \\ 0 & \cos\alpha_2 & 0 & \sin\alpha_2 \\ -\sin\alpha_1 & 0 & \cos\alpha_1 & 0 \\ 0 & -\sin\alpha_2 & 0 & \cos\alpha_2 \end{pmatrix} \begin{pmatrix} \phi_1 \\ \phi_2 \\ \Delta_1 \\ \Delta_2 \end{pmatrix}$$

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$$M_1^2 \simeq m_\phi^2 - \frac{m_{\phi\Delta}^4}{m_\Delta^2 - m_\phi^2} - \tilde{m}_\phi^2 - 2\frac{m_{\phi\Delta}^2}{m_\Delta^2 - m_\phi^2}\tilde{m}_{\phi\Delta}^2$$

$$M_2^2 \simeq m_\phi^2 - \frac{m_{\phi\Delta}^4}{m_\Delta^2 - m_\phi^2} + \tilde{m}_\phi^2 + 2\frac{m_{\phi\Delta}^2}{m_\Delta^2 - m_\phi^2}\tilde{m}_{\phi\Delta}^2$$

$$M_3^2 \simeq m_\Delta^2 + 2\frac{m_{\phi\Delta}^2}{m_\Delta^2 - m_\phi^2}\tilde{m}_{\phi\Delta}^2$$

$$M_4^2 \simeq m_\Delta^2 - 2\frac{m_{\phi\Delta}^2}{m_\Delta^2 - m_\phi^2}\tilde{m}_{\phi\Delta}^2$$

mixing angles: $|\tan 2\alpha_1| \simeq |\tan 2\alpha_2| \simeq 2m_{\phi\Delta}^2/(m_\Delta^2 - m_\phi^2)$

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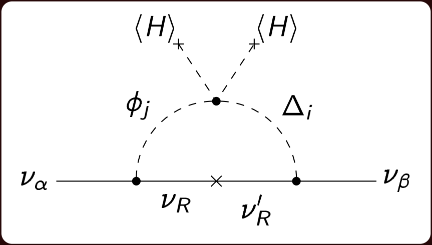
Neutrino Masses

One Loop Diagram Generating Neutrino Masses



- neutral scalar mass eigenstates δ_i
- with scalar masses M_i
- α_1 mixing between $\delta_{1,3}$
- α_2 mixing between $\delta_{2,4}$

$$(m_\nu)_{\alpha\beta} = [g_\alpha(\tilde{g}_\Delta)_\beta + g_\beta(\tilde{g}_\Delta)_\alpha]\tilde{\eta} + [\tilde{g}_\alpha(\tilde{g}_\Delta)_\beta + \tilde{g}_\beta(\tilde{g}_\Delta)_\alpha]\eta$$

$$\tilde{\eta} = \frac{m_{RR}}{64\pi^2}\left(\frac{M_3^2}{m_{RR}^2 - M_3^2}\ln\frac{m_{RR}^2}{M_3^2} - \frac{M_1^2}{m_{RR}^2 - M_1^2}\ln\frac{m_{RR}^2}{M_1^2}\right)\sin 2\alpha_1 + [(1,3)\to(2,4)]$$

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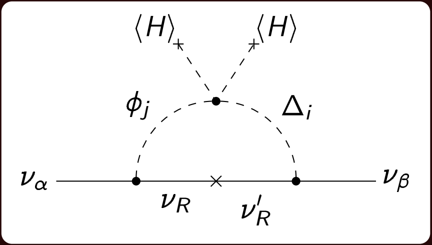

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$$\tilde{\eta} \simeq \frac{m_{RR}}{16\pi^2}\left(\frac{\tilde{m}_\phi^2 m_{\phi\Delta}^2}{m_{RR}^2 m_\Delta^2}\left(\frac{m_{RR}^2}{m_{RR}^2 - m_\Delta^2}\ln\frac{m_{RR}^2}{m_\Delta^2} + 1 - \ln\frac{m_{RR}^2}{M_1^2}\right) - \frac{\tilde{m}_{\phi\Delta}^2}{m_{RR}^2 - m_\Delta^2}\ln\frac{m_{RR}^2}{m_\Delta^2}\right)$$

$$\eta \simeq -\frac{m_{RR}}{16\pi^2}\frac{m_{\phi\Delta}^2}{m_{RR}^2 - m_\Delta^2}\ln\frac{m_{RR}^2}{m_\Delta^2}$$

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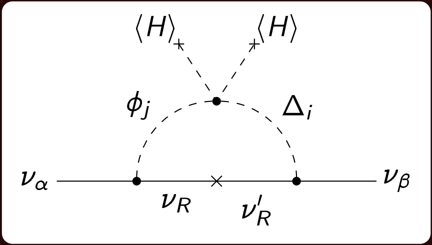

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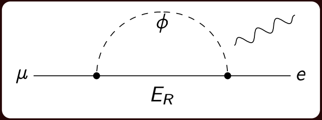
$$g\tilde{g}_\Delta \simeq 4.0 \times 10^{-6} \frac{m_\nu}{0.05\text{ eV}} \frac{70\text{ GeV}}{M_1} \frac{50\text{ MeV}}{\delta} \frac{m_{RR}}{300\text{ GeV}} \frac{0.1}{|\sin\alpha_1|} \left(\frac{m_{RR}^2}{m_{RR}^2 - m_\Delta^2} \cdots \right)^{-1}$$

$$g\tilde{g}_\Delta \simeq 4.5 \times 10^{-6} \frac{m_\nu}{0.05\text{ eV}} \frac{300\text{ GeV}}{m_{RR}} \frac{1\text{ GeV}^2}{\tilde{m}_{\phi\Delta}^2} \left(\frac{m_\Delta}{500\text{ GeV}} \right)^2 \frac{m_{RR}^2 - m_\Delta^2}{m_\Delta^2} \left(\log \frac{m_{RR}^2}{m_\Delta^2} \right)^{-1}$$

$$\tilde{g}\tilde{g}_\Delta \simeq 1.8 \times 10^{-10} \frac{m_\nu}{0.05\text{ eV}} \frac{300\text{ GeV}}{m_{RR}} \frac{0.1}{\sin\alpha_1} \frac{m_{RR}^2 - m_\Delta^2}{m_\Delta^2} \left(\log \frac{m_{RR}^2}{m_\Delta^2} \right)^{-1}$$

Lepton Flavour Violation and $(g\text{-}2)_\mu$

Lepton Flavour Violation



$$\mathrm{Br}(\mu \to e\gamma) = 2.5 \cdot 10^{-9} \left(\frac{300\ \mathrm{GeV}}{m_{RR}}\right)^4 \left|\frac{g_\mu^*}{0.1}\frac{g_e}{0.1}\right|^2$$

$$\mathrm{Br}(\tau \to \alpha\gamma) = 4.5 \cdot 10^{-10} \left(\frac{300\ \mathrm{GeV}}{m_{RR}}\right)^4 \left|\frac{g_\tau^*}{0.1}\frac{g_\alpha}{0.1}\right|^2$$

Experimental Limits[PDG 2009 (90% CL)]

$$\mathrm{Br}(\mu \to e\gamma) < 1.2 \cdot 10^{-11}$$

$$\mathrm{Br}(\tau \to e\gamma) < 1.1 \cdot 10^{-7}$$

$$\mathrm{Br}(\tau \to \mu\gamma) < 4.5 \cdot 10^{-8}$$

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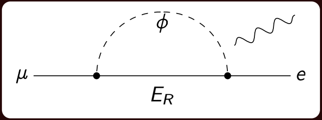

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Solutions

- $m_{RR}/g > 6$ TeV
- $g_e \ll g_\mu$ or $g_\mu \ll g_e$ (allowed by flavour structure)

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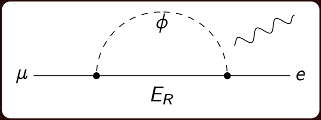

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Anomalous Magnetic Moment of Muon

$$\delta(g-2)_\mu/2 \sim 10^{-11} \left(\frac{300\ \ \mathrm{GeV}}{m_{RR}}\right)^4 |g_\mu|^2 \lesssim \text{exp. uncertainty}$$

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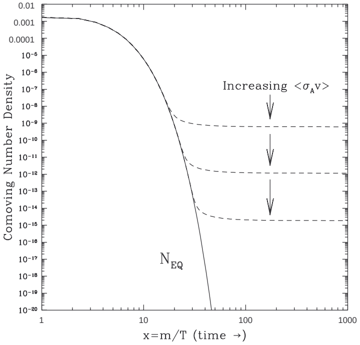
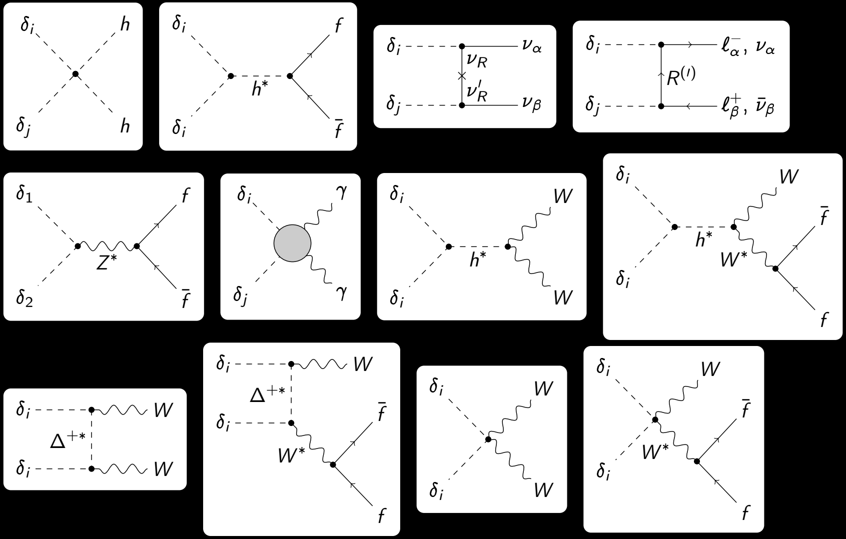
Dark Matter Freeze Out

- Assumption: thermal production after inflation
- Annihilation rate related to production rate
- Quasi-degenerate scalar masses
  $\Rightarrow$ both species have to be considered
- $\sigma_{12} \ll \sigma_{11}, \sigma_{22} \Rightarrow \delta_1$ and δ_2 produced and later $\delta_2 \to \delta_1 \nu \bar{\nu}$
- $\Gamma(\delta_2 \xrightarrow{Z} \delta_1 \nu \bar{\nu}) \approx$
  $$14 \left(\frac{\delta}{50\,\mathrm{MeV}} \right)^5 \left(\frac{\sin \alpha_1}{0.1} \right)^4 \mathrm{sec}^{-1}$$
- $$\sum_{i=1}^{2} \langle \sigma(\delta_i \delta_i \to \dots) v \rangle = 3 \cdot 10^{-26} \, \frac{\mathrm{cm}^3}{\mathrm{sec}}$$

Thermal freezeout one species



Dark Matter Annihilation Channels



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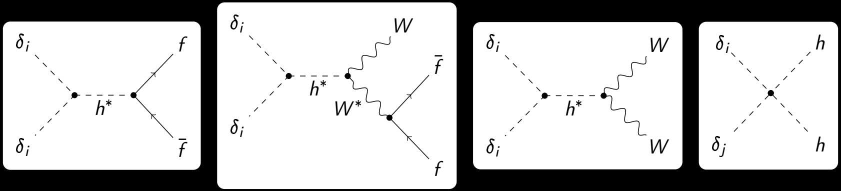

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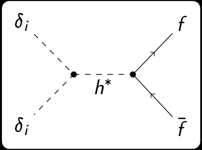
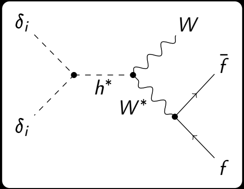
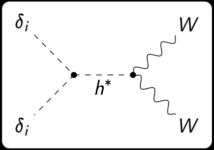
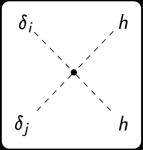
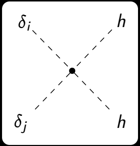


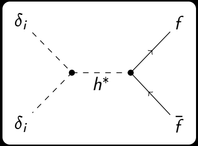






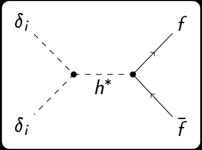


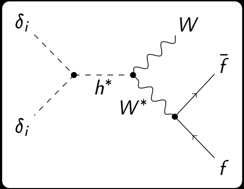
$$\Rightarrow \left\langle \sigma^H_{hh} v \right\rangle \simeq \frac{|\lambda_L|^2 (M_1^2 - m_h^2)^{1/2}}{16\pi M_1^3}$$

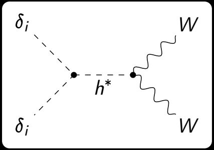


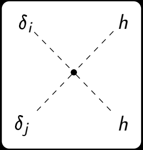
$$\Rightarrow \left\langle \sigma^H_{f\bar{f}} v \right\rangle \simeq N_c \frac{|\lambda_L|^2}{\pi} \frac{m_f^2}{(4\,M_1^2 - m_h^2)^2} \frac{(M_1^2 - m_f^2)^{3/2}}{M_1^3}$$

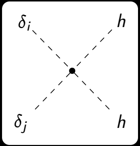
Dark Matter Annihilation











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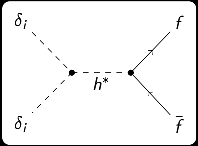

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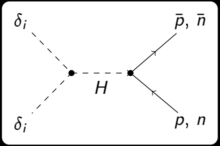
In general for Higgs mediated annihilation:

$$\langle \sigma(\delta_1 \delta_1 \to h^* \to \ldots)_H v \rangle = (2 m_h \Gamma(h \to \ldots))|_{m_h \to 2M_1} \frac{1}{4M_1^2} \frac{4|\lambda_L|^2 v_H^2}{(4M_1^2 - m_h^2)^2}$$

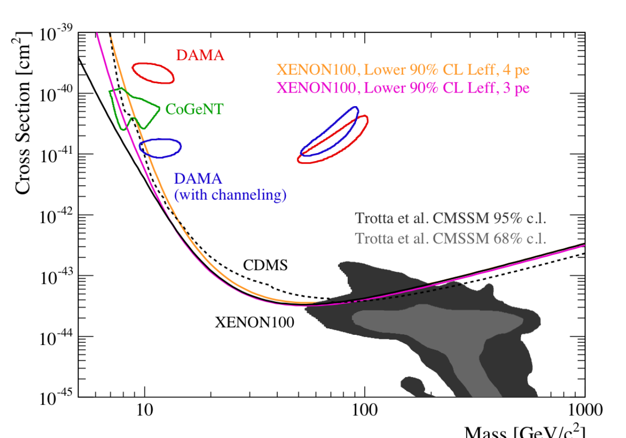
Using HDecay: $\Gamma|_{2\times 70\,\mathrm{GeV}} = 8.3\ \mathrm{MeV} \Rightarrow \lambda_L \approx 0.07$

Direct DM Detection



$$\sigma_n = \frac{|\lambda_L|^2}{\pi} \frac{\mu_{\delta_1 n}^2 m_p^2}{M_1^2 m_h^4} f^2$$

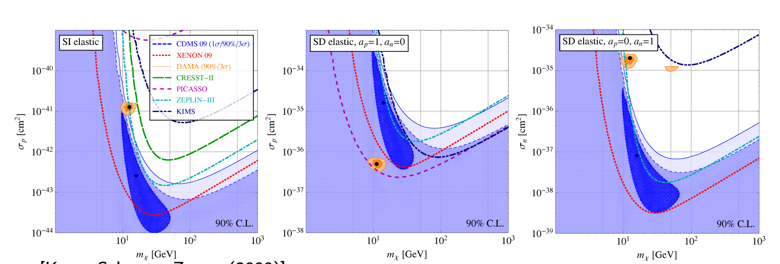
$$\approx 5.2\times 10^{-44} \left(\frac{\lambda_L}{0.07}\right)^2 \left(\frac{70\ \text{GeV}}{M_1}\right)^2 \left(\frac{120\ \text{GeV}}{m_h}\right)^4 \left(\frac{f}{0.3}\right)^2 \text{cm}^2$$



[XENON100 collaboration]

Elastic SI Scattering

CDMS-II



[Kopp, Schwetz, Zupan (2009)]

- $M_1 \sim 20$–50 GeV and $\sigma_n \sim 10^{-44}$ cm^2–10^{-43} cm^2
- for $M_1 = 50\,\text{GeV},\ m_h = 120\,\text{GeV} \Rightarrow \sigma_n \simeq 5.4 \times 10^{-44} \left(\dfrac{f}{0.14}\right)^2 \text{cm}^2$

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CoGeNT/DAMA

- $7\,\mathrm{GeV} \lesssim M_1 \lesssim 11\,\mathrm{GeV}$ with $\sigma_n \sim 10^{-41}\ \mathrm{cm}^2$–$10^{-40}\ \mathrm{cm}^2$

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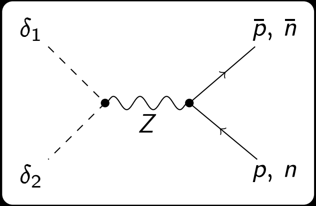
However, a proper analysis is required to make definite statements, whether it is possible at all!

Inelastic SI Scattering

Best fit in [Schwetz, Kopp, Zupan (2009)]: $M_1 = 10\,\mathrm{GeV}$ with $\sigma_p \sim 1 \times 10^{-40}$ cm^2 which corresponds to $\sigma_n = 3.3 \times 10^{-40}\mathrm{cm}^2$



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$$\sigma_n = \frac{8}{\pi}\sin^2\alpha_1 \sin^2\alpha_2 G_F^2 \mu_{\delta_1 n}^2$$

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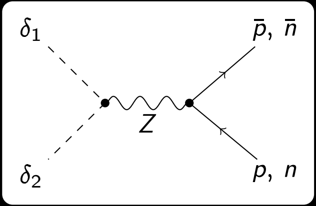

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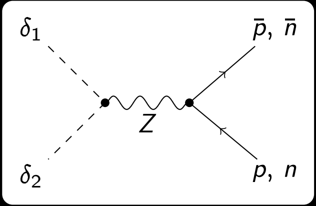

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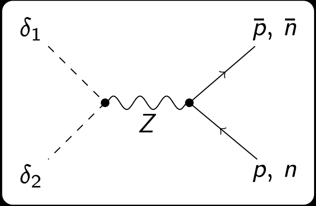

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- Increase of energy density for neutrinos

$$\frac{\Delta\rho_\nu}{\rho_\nu} \equiv \frac{\rho_\nu^f - \rho_\nu^i}{\rho_\nu} = \frac{\Omega_2 - \Omega_1}{\Omega_\nu} \approx \frac{\delta}{2M_1}\frac{\Omega_{\rm DM}}{\Omega_\nu} \lesssim 1.2 \times 10^{-4}\,,$$

Neutrinos From Sun

- Number of WIMPs: $\dot{N} = C - AN^2 - EN$
- Capture rate
  $C(\rho_{DM}, \bar{v}, m_{DM}, \sigma) \simeq 1.3 \cdot 10^{25}\mathrm{sec}^{-1}$" $\propto \rho_{DM}\sigma\,\bar{v}^{-1}\,m_{DM}^{-1}$"
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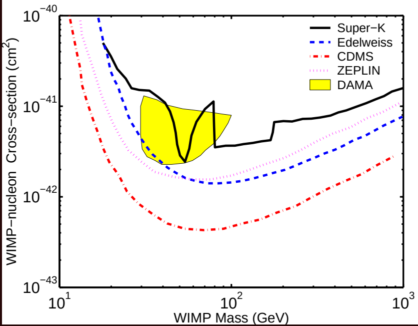
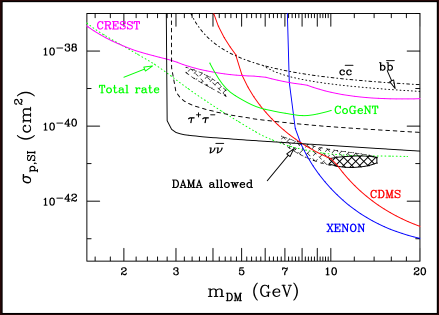
Bounds[Hooper,Petriello, Zurek, Kamionkowski (2008)]





[SuperKamiokande (2004)]

Indirect Detection

- Possible DM signals in γ-rays (e.g. EGRET, Fermi-LAT), neutrinos (e.g. IceCube), positrons (e.g. PAMELA), anti-protons (e.g. PAMELA), anti-deuterons (e.g. AMS-02, GAPS)

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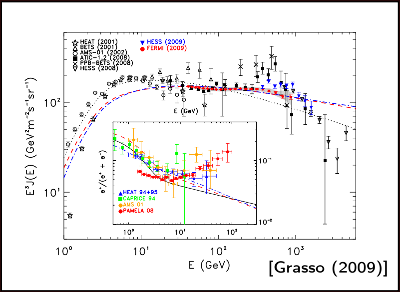
Signals from PAMELA, Fermi-LAT,...



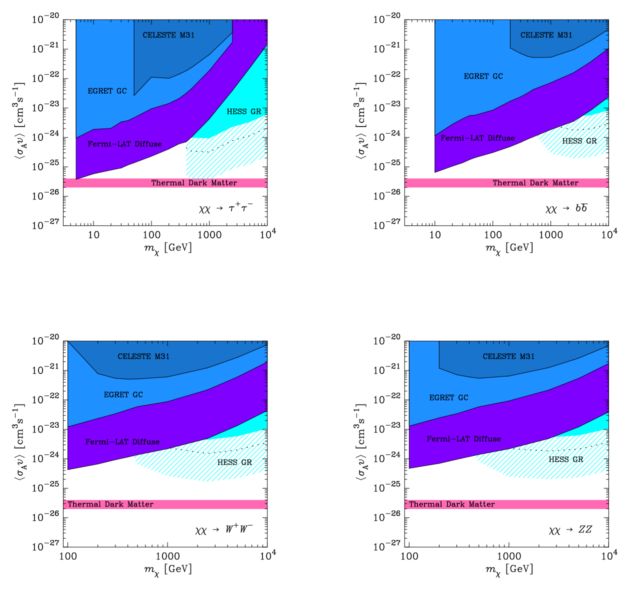
[Grasso (2009)]

- Positron excess in PAMELA
- Bump in charged lepton flux in ATIC/BESS, FERMI/HESS
- $\Rightarrow$ can be explained by acceleration of secondaries

  [Blasi,Serpico (2009); Ahlers, Mertsch, Sarkar (2009)]

  as well as pulsars
- Study of nuclei in cosmic rays can refute or confirm explanations

Constraints from Isotropic Diffuse γ-ray Background[Abazajian, Agrawal, Chacko, Kilic (2010)]



Outline

1. Model
2. Lepton Sector
3. Dark Matter
   - Dark Matter Annihilation
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Constraints

Electroweak Precision Tests: Higgs Triplet

$$\hat{S} = \frac{g^2_{\mathrm{SU(2)}}}{24\pi^2}\xi \qquad \hat{T} = \frac{25 g^2_{\mathrm{SU(2)}}}{576\pi^2}\frac{m^2_\Delta}{m^2_W}\xi^2$$

with $\xi := (m^2_{\Delta^{++}} - m^2_\Delta)/m^2_\Delta$ and $m^2_{\Delta^{++}} = m^2_\Delta + 2m^2_{\Delta^+}$

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Invisible Z-Decay Width

- DM particle δ_1 couples to Z-boson via mixing of Δ^0
- If $M_1 + M_2 < m_Z$, the corresponding Z-decay width is

$$\Gamma(Z \to \delta_1\delta_2) = \frac{G_F \sin^2\alpha_1 \sin^2\alpha_2}{6\sqrt{2}\pi} m_Z^3$$

- Bound on mixing angle in scalar sector: $\sin\alpha_1 \sin\alpha_2 < 0.07$, i.e. $m_{\phi\Delta}^2 \ll m_\Delta^2$ (protected by $U(1)_\phi \times U(1)_\Delta$)

Collider Physics

Higgs Search

- Higgs might dominantly decay invisibly if $2\,M_1 < m_h$

$$H \to \delta_1\delta_1\,, \quad H \to \delta_2\delta_2 \to (\delta_1\nu\bar{\nu})(\delta_1\nu\bar{\nu})$$

- Displaced vertex if mass splitting large $\delta_2 \to \delta_1\mu^+\mu^-$

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New Particles

- New particles accessible at LHC
- ...decay into the SM particles and DM $\Rightarrow$ missing energy
- Mass relation of triplet $2 m_{\Delta^+}^2 = m_{\Delta^{++}}^2 + m_{\Delta}^2$
- Expect small mass splitting $m_{\Delta^{++}}^2 - m_{\Delta^+}^2$
- Determination of g_α: $\mathrm{Br}(E_R^- \to \ell_\alpha^- \delta_{1,2}) \propto |g_\alpha|^2$
- Determination of $\tilde{g}_\Delta$: decay modes of Δ^+ and Δ^{++}, especially $\Gamma(\Delta^{++} \to \ell_\alpha^+ \ell_\beta^+ \delta_{1,2}) \propto |(\tilde{g}_\Delta)_\alpha g_\beta + (\tilde{g}_\Delta)_\beta g_\alpha|^2$

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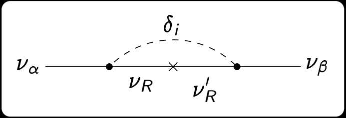
- 

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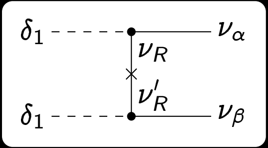

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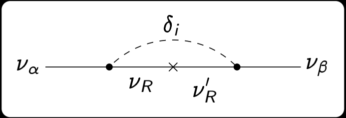
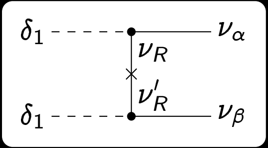
- 



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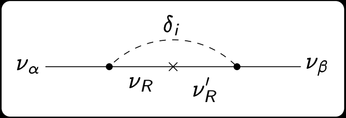
- 

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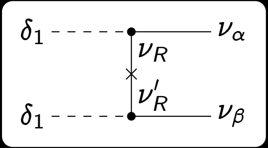
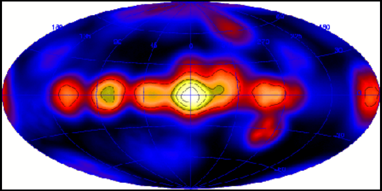
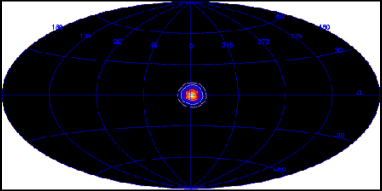


- Direct relation between neutrino mass and DM annihilation $\Rightarrow$ light dark matter $M_1 \sim \mathcal{O}\,(\mathrm{MeV})$
- MeV scale dark matter might explain the 511 keV γ line measured by SPI/INTEGRAL [Weidenspointner (2007)]





A Gauged Model

Particle Content

	SU(2)	U(1)	$U(1)_X$	$\mathbb{Z}_2$
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N_L	1	0	1	-
η	2	-1	-1	-
ξ	1	0	-1	-
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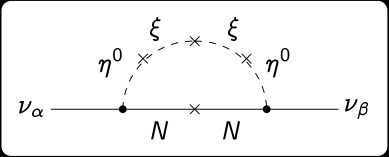

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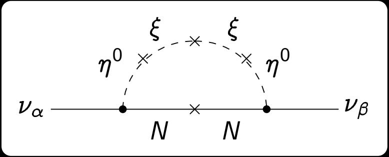


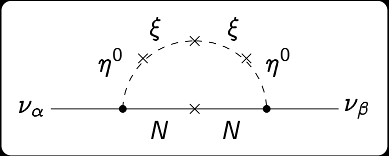
- Neutrino masses from pseudo Dirac neutrinos N

$$m_{\alpha\beta} \simeq \frac{\kappa_{\xi\phi}\,\lambda^2_{H\eta\xi\phi}}{16\pi^2}\frac{\langle\phi\rangle^2\,\kappa^2_{H\eta\xi}}{m_\eta^4}\frac{\langle H\rangle^2}{m_N^2}\sum_{i,j}(Y_N)_{i\alpha}(Y_N)_{j\beta}\,f_{ij}(m_N, Y_{LL}, Y_{RR}, m_\xi)$$

A Gauged Model

Particle Content

	SU(2)	U(1)	$U(1)_X$	$\mathbb{Z}_2$
$\ell_L^{(i)}$	2	-1	0	+
N_R	1	0	1	-
N_L	1	0	1	-
η	2	-1	-1	-
ξ	1	0	-1	-
ϕ	1	0	-2	+



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- LFV similar: $(m_N,\, m_{\eta^-})/Y_N \gtrsim 6\,\text{TeV}$ (unless special flavour structure)

More Phenomenology

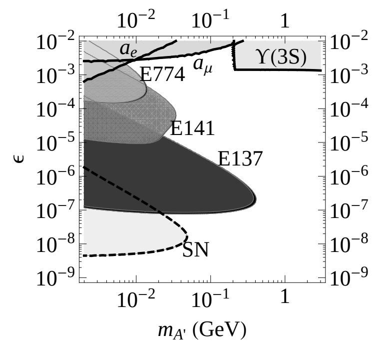
Z'

Gauge kinetic Lagrangian

$$\mathcal{L}_{\mathrm{U}(1)} = \frac{1}{4}F_Y^2 + \frac{1}{4}F_X^2 + \frac{\epsilon}{2}F_X F_Y$$

η in loop induces

$$\epsilon \simeq \frac{g_X g_Y}{16\pi^2} \ln \frac{\Lambda^2}{\mu_\eta^2}$$



[Bjorken,Essig,Schuster,Toro (2009)]

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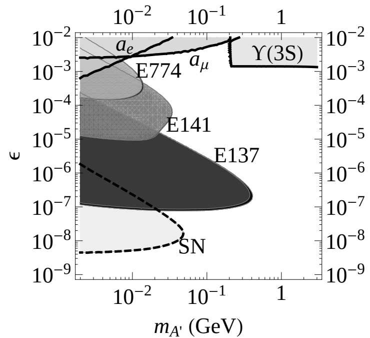

[Bjorken,Essig,Schuster,Toro (2009)]

Collider

- SM Higgs mixes with $\mathrm{U}(1)_X$-Higgs $\Rightarrow$ Higgs mass bounds weakened
- Invisible Higgs decay like in all DM models in which Higgs exchange dominates

Outline

1 Model

2 Lepton Sector

3 Dark Matter
- Dark Matter Annihilation
- Dark Matter Direct Detection
- DAMA/CoGeNT/CDMS-II?
- Indirect Detection

4 More Phenomenology

5 Comments on Alternatives

6 Conclusions

Conclusions and Outlook

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- Neutrino mass can be generated radiatively at the TeV scale and linked to dark matter

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Outlook

- Study of a gauged model
- Leptogenesis in models of radiative neutrino mass generation

Thank you very much for your attention.