Sneutrino Dark Matter in the BLSSM

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Outline

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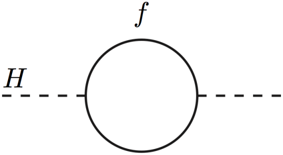
Motivations

- Hierarchy Problem



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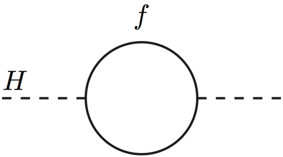
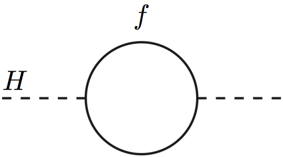


- Dark Matter

Figure: Chandra X-ray Observatory

Motivations

- Hierarchy Problem



- Dark Matter

- Non-vanishing Neutrino Masses

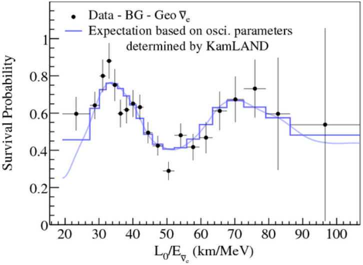
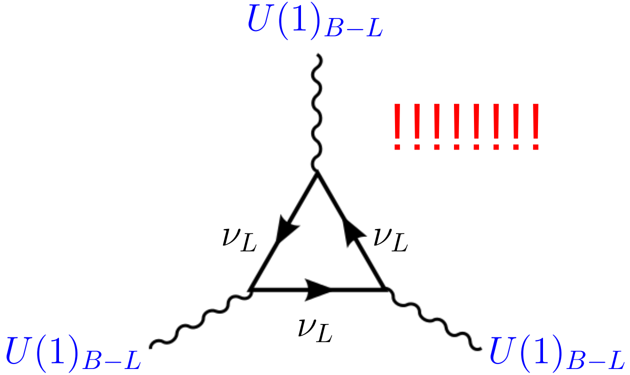


Figure: Chandra X-ray Observatory // KamLAND experiment, 0801.4589

Explaining the BLSSM – "B-L"

- SM has exact B-L conservation
- Promote accidental, global symmetry to local. SM gauge group now extended to: $G_{B-L} = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$
- anomaly cancellation - require SM singlet fermion (right-handed neutrinos)



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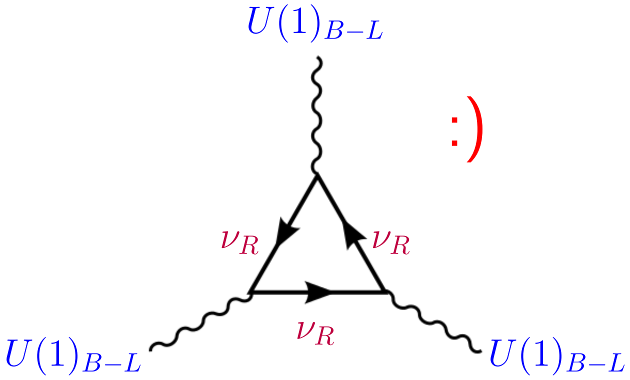


Explaining the BLSSM – "SSM"

Chiral Superfield		Spin 0	Spin 1/2	G_{B-L}
Quarks/Squarks, (x3 generations)	$\hat{Q}$	$(\tilde{u}_L \tilde{d}_L) \equiv \tilde{Q}_L$	$(u_L d_L)$	$(\mathbf{3},\ \mathbf{2},\ \frac{1}{6},\ \frac{1}{6})$
	$\hat{U}$	$\tilde{u}_R^*$	$\bar{u_R}$	$(\bar{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3},\ -\frac{1}{6})$
	$\hat{D}$	$\tilde{d}_R^*$	$\bar{d_R}$	$(\bar{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3},\ -\frac{1}{6})$
Leptons/Sleptons, (x3 generations)	$\hat{L}$	$(\tilde{\nu}_L \tilde{e}_L) \equiv \tilde{L}_L$	$(\nu_L e_L)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ -\frac{1}{2})$
	$\hat{E}$	$\tilde{e}_R^*$	$\bar{e_R}$	$(\mathbf{1},\ \mathbf{1},\ 1,\ \frac{1}{2})$
Higgs/Higgsinos	$\hat{H}_u$	$(H_u^+ H_u^0)$	$(\tilde{H}_u^+ \tilde{H}_u^0) \equiv \tilde{H}_u$	$(\mathbf{1},\ \mathbf{2},\ \frac{1}{2},\ 0)$
	$\hat{H}_d$	$(H_d^0 H_d^-)$	$(\tilde{H}_d^0 \tilde{H}_d^-) \equiv \tilde{H}_d$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ 0)$

Vector Superfields	Spin 1/2	Spin 1	G_{B-L}
Gluino, gluon	$\tilde{g}$	g	(**8**, **1**, 0,0)
Wino/W bosons	$\tilde{W}^{\pm}\ \tilde{W}^0$	$W^{\pm} W^0$	(**1**, **3**, 0, 0)
Bino / B boson	$\tilde{B}^0$	B^0	(**1** **1**, 0, 0)

Explaining the BLSSM – "SSM"

- Content in addition to MSSM:

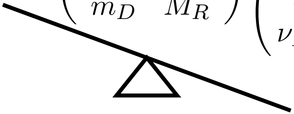
Chiral Superfield		Spin 0	Spin 1/2	G_{B-L}
RH Sneutrinos / Neutrinos (x3)	$\hat{\nu}$	$\tilde{\nu}_R^*$	$\bar{\nu_R}$	$(\mathbf{1}, \mathbf{1}, 0, \frac{1}{2})$
Bileptons/Bileptinos	$\hat{\eta}$	η	$\tilde{\eta}$	$(\mathbf{1}, \mathbf{1}, 0, -1)$
	$\hat{\bar{\eta}}$	$\bar{\eta}$	$\tilde{\bar{\eta}}$	$(\mathbf{1}, \mathbf{1}, 0, 1)$
Vector Superfields		**Spin 1/2**	**Spin 1**	G_{B-L}
BLino / B' boson		$\tilde{B}'^0$	B'^0	$(\mathbf{1}\ \mathbf{1}, 0, 0)$

- Three extra RH neutrinos + SUSY partner (from anomaly cancellation condition)
- Two extra Higgs (for breaking gauged $U(1)_{B-L}$)
- One B' + SUSY partners (from broken $U(1)_{B-L}$)

Non-vanishing Neutrino Masses I

- ν_L have mass!
- Introducing RH neutrinos can explain mass for ν_L

$$(\bar{\nu_L} \bar{\nu_R^c}) \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} \begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix}$$



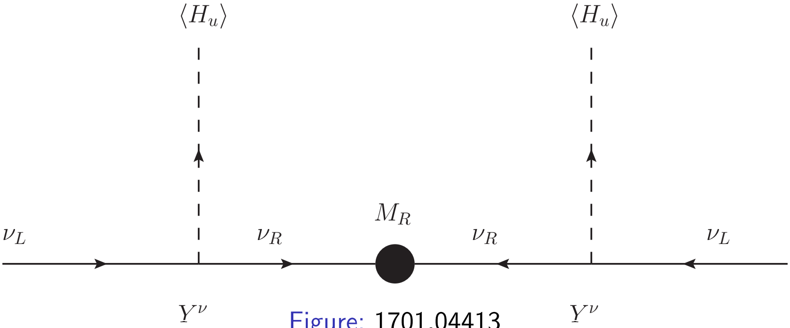
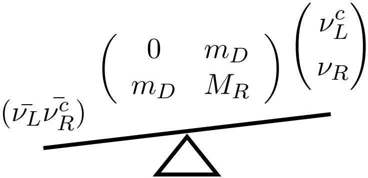


Figure: 1701.04413

Non-vanishing Neutrino Masses I

- ν_L have mass!
- Introducing RH neutrinos can explain mass for ν_L
- Large RH mass can explain small LH mass in a see-saw mechanism



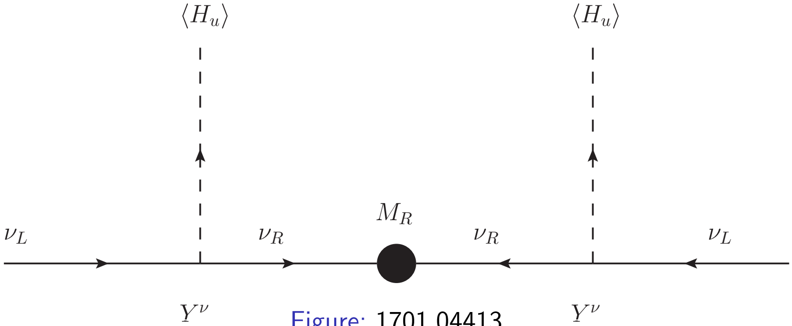


Figure: 1701.04413

Non-vanishing Neutrino Masses II

- ...However, this leads to $B - L$ violation, as in $0\nu 2\beta$-decay

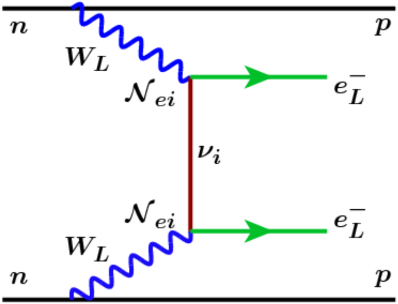


Figure: 1301.4784

- In BLSSM, gauge symmetry is broken with a Higgs mechanism

BLSSM Review

- Superpotential:

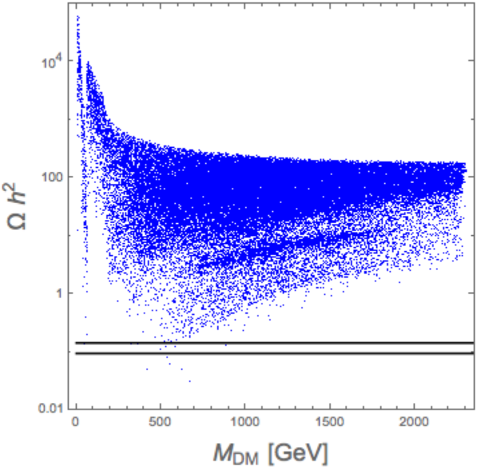
$$\begin{aligned} W &= \mu H_u H_d + Y_u^{ij} Q_i H_u u_j^c + Y_d^{ij} Q_i H_d d_j^c + Y_e^{ij} L_i H_d e_j^c \\ &+ Y_\nu^{ij} L_i H_u N_i^c + Y_N^{ij} N_i^c N_j^c \eta_1 + \mu' \eta_1 \eta_2 \end{aligned}$$

- Type-I see-saw mechanism, RH neutrinos have $\lesssim$ TeV mass
- $M_{Z'}$ fixed at 4 TeV, from LEP-II EWPOs and LHC di-lepton searches
- Complete universality at GUT scale, $g_{bl} = g_1 = g_2 = g_3,\ \tilde{g} = 0.$ From RGE evolution, at EW scale, $\tilde{g} \simeq -0.1$ and $g_{bl} \simeq 0.5$

DM Review in MSSM

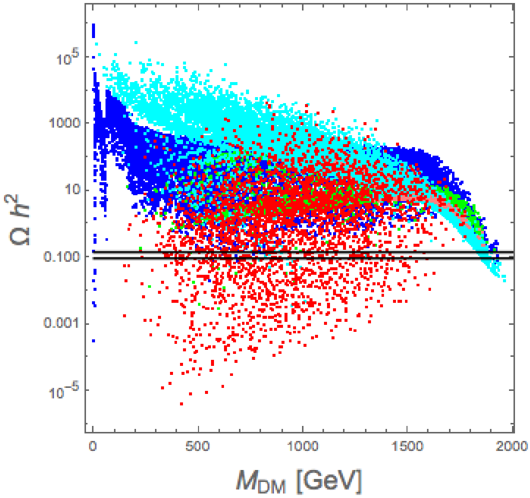
- LSP stable from R-parity (ad-hoc)

- Allowed Candidates:
- Bino ($\tilde{B}^0$)
- ~~LH Sneutrino ($\tilde{\nu}_L$)~~
  (Z interactions LEP)
- ~~Higgsino / Wino~~
  (Direct Detection LUX)



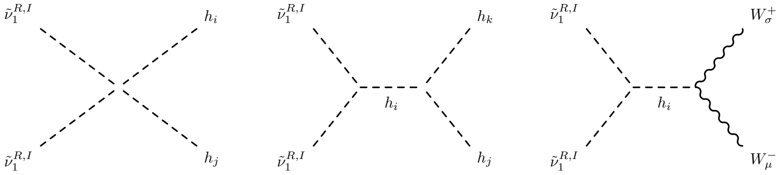
DM Review in BLSSM

- Natural R-parity: $R = (-1)^{3(B-L)+2S}$. If $B - L$ broken by Higgs with even $B - L$ charge, then Z_2 remains unbroken
- Allowed candidates:
- Bino ($\tilde{B}^0$)
- Sneutrino ($\tilde{\nu}_R^*$)
- Bileptino ($\tilde{\eta}$, $\tilde{\bar{\eta}}$)
- BLino ($\tilde{B}'^0$)



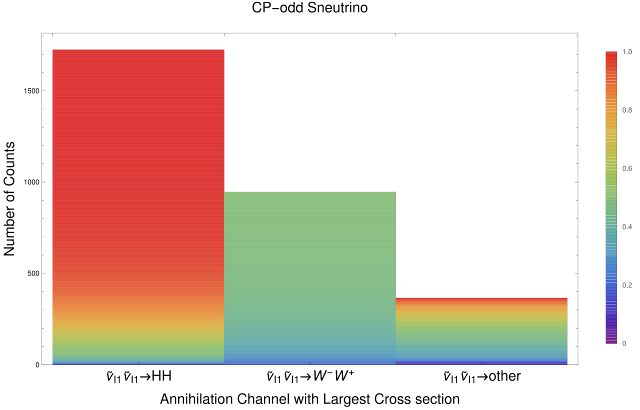
RH Sneutrino Interactions

- RH sneutrinos and RH anti-sneutrinos mix, $\tilde{\nu}_R$ and $\tilde{\nu}_R^*$ no longer mass eigenstates due to $\Delta L = 2$ operator, in $M_N N^c N^c$ mass term
- Physical mass states are either CP-even or CP-odd. Either can be lightest, so both are valid LSP candidates



Sneutrino Interactions - Continued

- Mostly annihilate to heavy CP-even Higgs
- Otherwise annihilate to W^+W^- pair if HH disallowed by mass

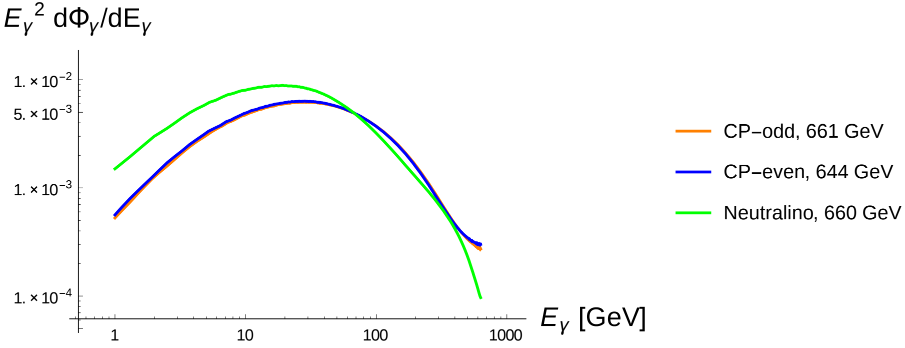


Fermi-LAT

- Indirect detection: annihilation of sneutrino DM in centre of galaxy producing charged products, which radiate photons
- $\tilde{\nu}_R \tilde{\nu}_R \rightarrow W^+ W^-$

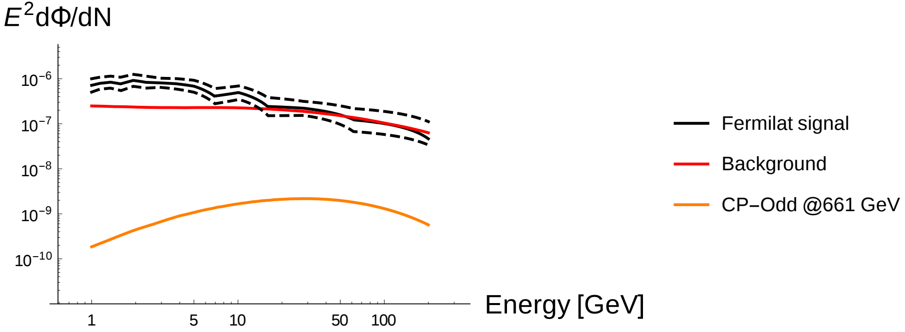
Photon Flux Distribution: Scalar vs Fermionic

- Shape of observed spectrum can differentiate DM candidates depending on spin



Fermi-LAT: Background

- Limiting factor is energy cut-off



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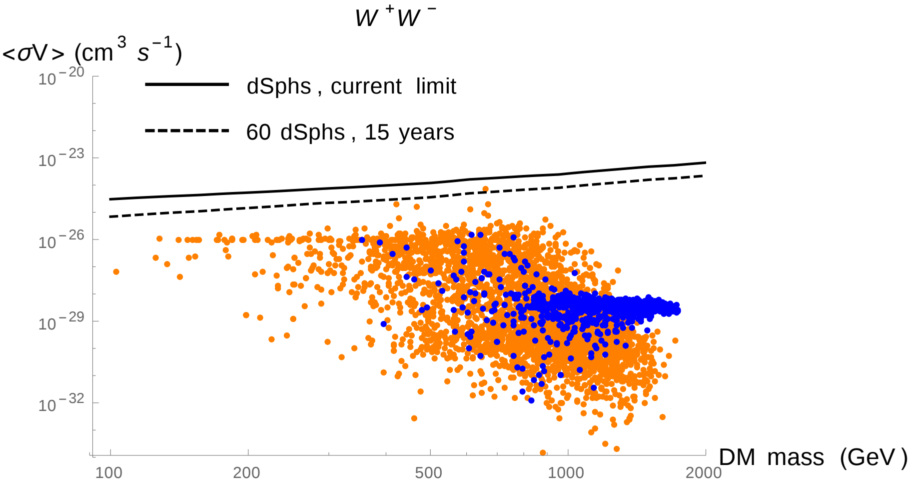
Fermi-LAT: Current Status & Future Prospects

- Future indirect-detection experiments can detect sneutrino DM!
- Integrated flux over all energy range CP-odd CP-even



Conclusions

- The BLSSM . . .
  - Solves the hierarchy problem
  - predicts light, non-vanishing left-handed neutrino masses
  - offers much larger parameter space than the MSSM
- Future indirect-detection experiments will probe sneutrino DM