Decaying LSP in the Minimal SO(10) and PAMELA's cosmic positron

Bumseok Kyae
(SNU)

arXiv:0809.2601 (J.-H. Huh, J.E. Kim, BK),
arXiv:0812.3511 (K. Bae, J.-H. Huh, J.E. Kim, BK, R.Viollier)
arXiv:0902.0071 (BK)
arXiv:0902.3578 (K. Bae, BK)
arXiv:0909.xxxx (BK)

WIMP and LSP

- WIMPs have been long believed to be a promising CDM candidate.

- LSP is a good example of WIMP,

well motivated from the promising particle physics model   (i.e. MSSM).

Recently PAMELA/Fermi reported very challenging observational results.

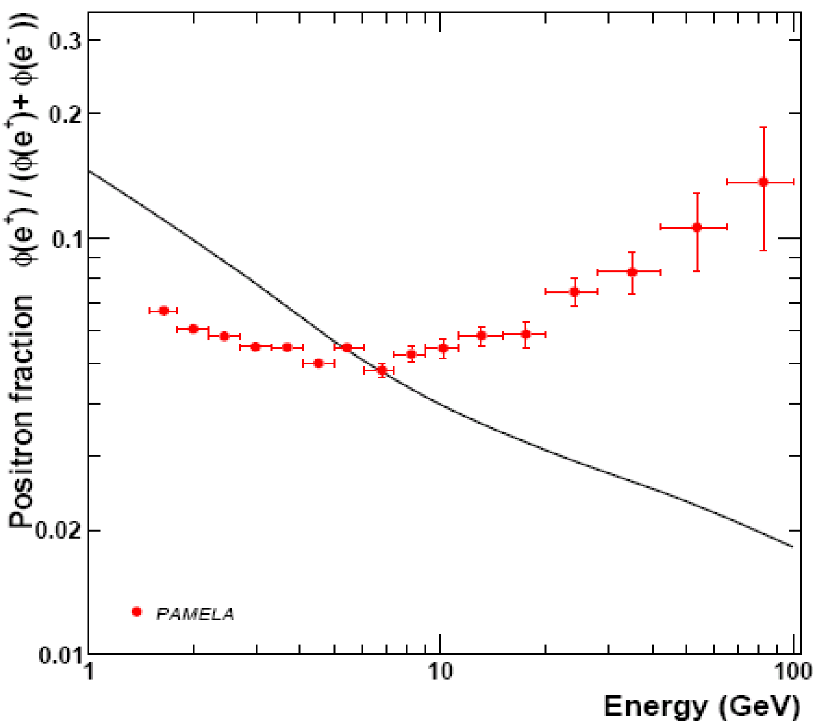
PRL **102**,051101(2009); Nature **458**, 607 (2009)
arXiv:0905.0025(astro-ph HE)

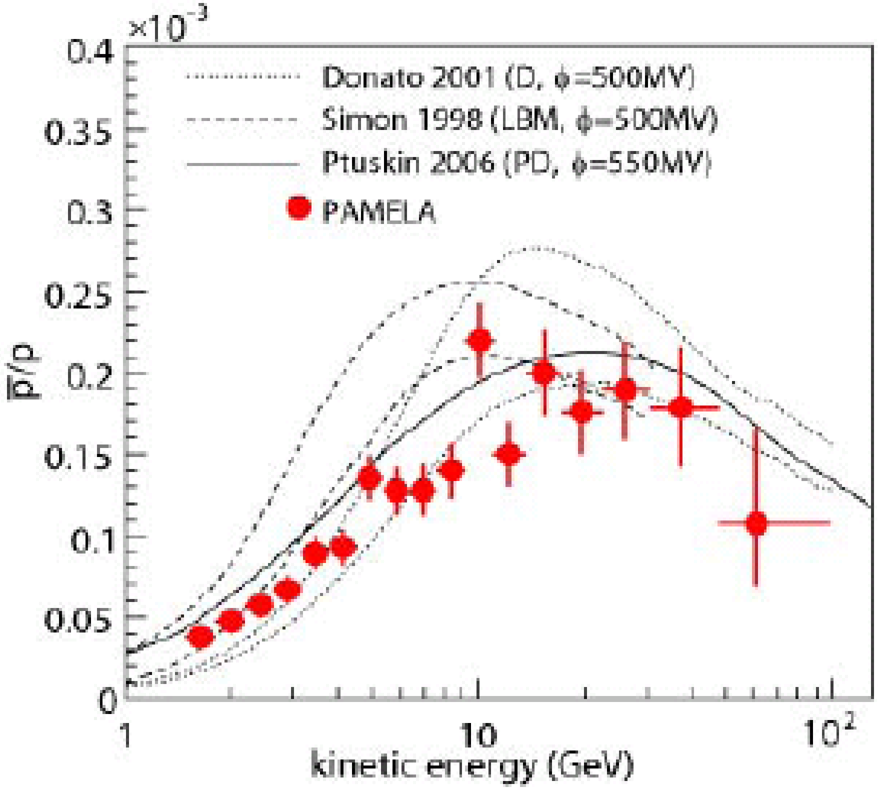
- PAMELA (Payload for Anti Matter Exploration and Light nuclei Astrophysics)
  [exp. by a SATELLITE] measures
  particles & nuclei fluxes in cosmic ray.

- Fermi [exp. by a SATELLITE] released data on electrons & positrons fluxes in cosmic ray.

What are surprising?

PAMELA [arXiv.0810.4994,4995]





PAMELA positron fraction
v.s. theoretical models
(by Moskalenko & Strong '98)

PAMELA anti-proton/proton flux ratio
v.s. theoretical calculation

What are surprising?

(PAMELA)

Significant energetic positron excesses

(10 GeV – 100 GeV) are observed with small error bar.

The deviation at low energy can be explained by the solar modulation effect [arXiv:0810.4994, 4995].

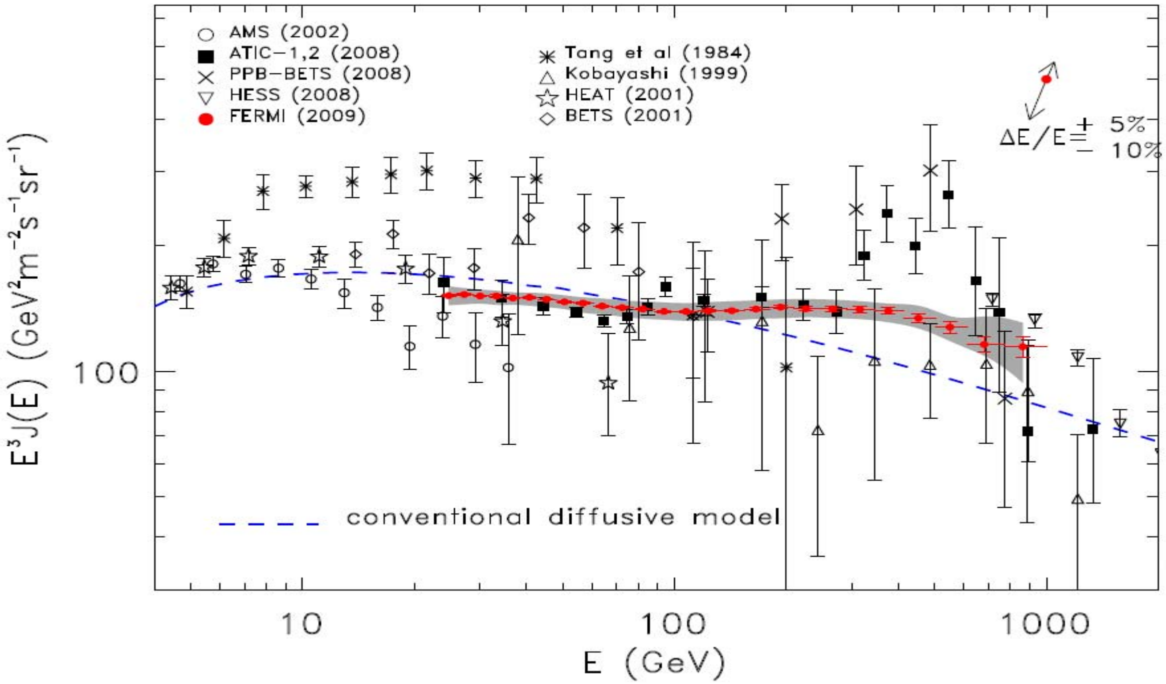
However,

No anti-proton excesses are observed.

What are surprising?

Fermi-LAT

[arXiv:0905.0025(astro-ph HE)]



$(e^+ + e^-)$ excesses of cosmic ray are observed.

[100 GeV – 1000 GeV]

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(Fermi-LAT)

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mildly upto 1 TeV.

As a strong possibility, it can be interpreted as a result from TeV scale DM annihil. or decay.

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Therefore,
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- DM is predominantly annihilated to e^+e^-.

- DM has a small branching ratio to proton–antiproton.

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To explain the e^+ excess with annihilation,

- Should overcome "helicity suppression," to enhance DM annihl. to e^+e^- .

- Should suppress the hadronic modes.

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Berstone etal. [arXiv:0811.3744]

DM annihl. seems to be disfavored by
Gamma ray constraint,

if $m_{DM} \sim$ TeV (for explaining Fermi),
[$\Phi_{e+} \propto (\rho/m_{DM})^2$] and
if accept
the galactic profile of NFW or Einasto,

because of
Bremsstrahlung at the galactic center.

DM DECAY for e^+ flux

($DM \rightarrow e^+ e^-, \mu^+ \mu^-, \tau^+ \tau^-$ + neutral ptl.)

- We DON'T have to consider "helicity suppression."

- Gamma ray constraint is NOT serious.
  [$\Phi_{e+} \propto (\rho/m_{DM})^1$]
- Hadronic decay should not exceed 10 %.
  i.e. should be "Leptophilc Decay"
- $\Gamma_{DM} \sim 10^{-26}$ sec^{-1} for need e^+ flux
- $m_{DM} \sim 2$ TeV for explaining Fermi
- Various and/or many body leptonic decays are needed for mild positron excess. [Bergtrom etal '09]

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PAMELA/Fermi's observ. might be a signal of GUT.

For a promising DM Decay model,

- Introduce Leptophilic int. between superheavy fields and DM.

- Introduce other (global) symmetries to completely kill the dim. 5 operators.

- Introduce an extra DM component with a TeV scale mass for light enough Higgs mass.

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Two DM Model (I)

K. Bae, BK [arXiv:0902.3578]

Superfields	e^c	N	E	E^c	X	X^c	O	O^c
$\mathrm{U(1)_Y}$	1	0	q	$-q$	$-q$	q	$q-1$	$-q+1$
$\mathrm{U(1)_R}$	1	$2/3$	$1/3$	$5/3$	1	1	0	2
$(\ \mathcal{G}\ )$	$\mathbf{1}$	$\mathbf{1}$	$(\ \mathcal{R}\ )$	$(\ \mathcal{R}^*\ )$	$(\ \mathcal{R}^*\ )$	$(\ \mathcal{R}\ )$	$(\ \mathcal{R}\ )$	$(\ \mathcal{R}^*\ )$

(N,χ) : two DM components,

(E,E^c), (X,X^c), (O,O^c) : (exotically charged) vec.–like superheavy ptl.

Superpotl.

$$W_{\rm tri} = \mathbf{N}EX + XO\mathbf{e^c} + \mathbf{N^3},$$
$$W_{\rm bi} = M_E E E^c + M_X X X^c + M_O O O^c.$$

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Due to the A-term of N^3,

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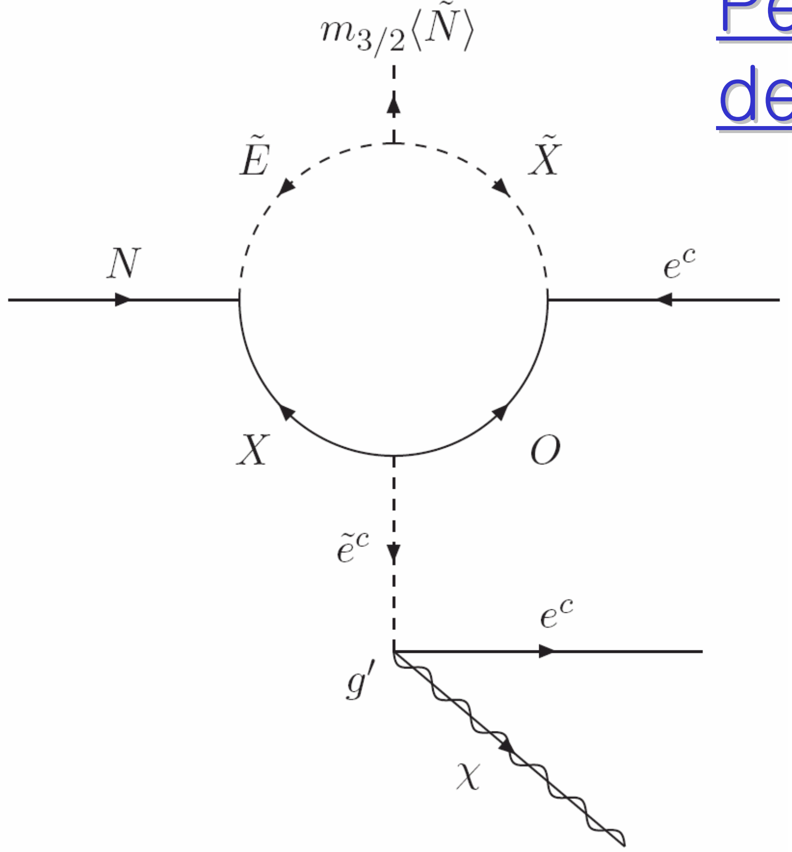
So, $m_{DM} = m_N \sim$ 2 TeV , and N can decay

$$N \longrightarrow \chi + e^- + e^+$$

Penguin-type one loop decay diagram of N



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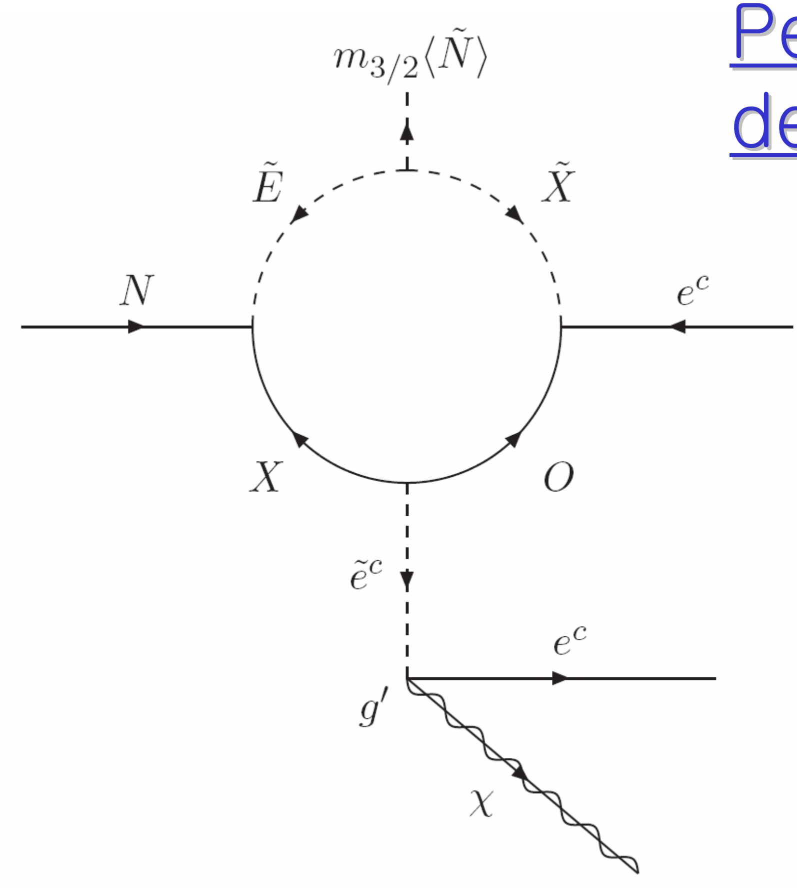
The light External particles carry the INTEGER charges.

The heavy Exotics must be co-created and co-annihilated between the initial and final states.



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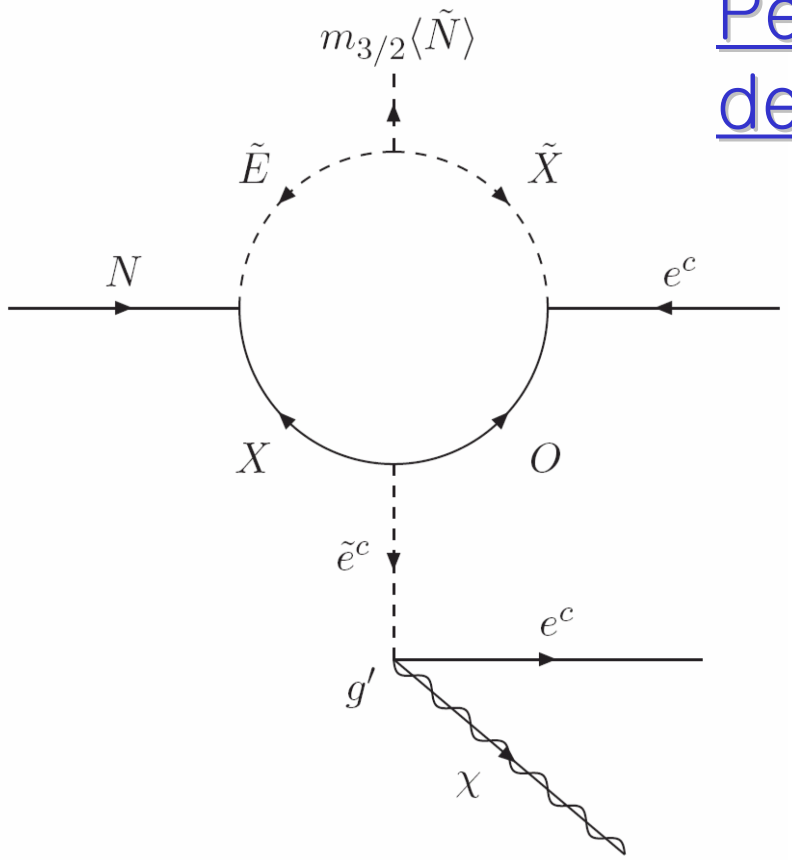

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$$\Gamma_N \approx \frac{m_{\rm DM}^5}{192\pi^3} \times \left[\frac{\sqrt{2}g'}{2^{3/2}m^2_{\tilde{e}^c}}\right]^2 \times \left[\frac{m_{3/2}\langle\tilde{N}\rangle}{48\pi^2 M_*^2} \times \mathcal{O}(y^4) \times \mathcal{N}\right]^2$$

$\Gamma_{DM} \sim 10^{-26}$ sec^{-1},

for $m_{DM} \sim$ 2 TeV, $m_{3/2} \sim \langle\check{N}\rangle \sim O(10^2\text{–}10^3)$ GeV.

For simplicity, we set

$M_E = M_X = M_O = M_* = 10^{15-16}$ GeV.

The Exotics superheavy masses are responsible for the extremely small DM decay rate.

This model can be easily extended such that

$N \to \chi e^+e^-$, $\chi\mu^+\mu^-$, $\chi\tau^+\tau^-$, and/or $N \to \nu_\mu 2e^+2e^-$, etc.

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PAMELA/Fermi anomaly

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PAMELA/Fermi anomaly is NOTHING in 2-DM decay model !!

$$\Phi_{e^+}(E) = \left(\frac{\rho}{m_{\rm DM}}\right) \cdot \Gamma_{\rm DM} \times \frac{1}{4b(E)} \int_E^{m_{\rm DM}} dE' \, \frac{dN_{e^+}}{dE'} \, I(\lambda_D),$$

In 2-DM model, (ρ/m_{DM}) can be smaller,
only if Γ_{DM} is larger,
[but $\Gamma_{\mathbf{DM}} < 10^{-17}$ sec^{-1}, (age of univ.)$^{-1}$],

because the needed **$\rho_{\mathbf{DM}} \sim 10^{-6}$ GeV cm^{-3} can be supported by χ.**

Even extremely small amount of N

$$[\ O(10^{-10}) < (n_N / n_\chi)\ ]$$

can produce the positron flux needed to account for PAMELA/Fermi data,

only if the decay rate is enhanced by relatively lighter M_* ,

$$[10^{12}\ \mathrm{GeV} < M_* < 10^{16}\ \mathrm{GeV}].$$

Two DM Model (II)

BK [arXiv:0902.0071]

- Introduce one more DM component N.
- Consider leptophilic couplings of N with the superheavy vec.-like SU(2) lepton doublets (L,L^c), and lepton singlets (E,E^c) :

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$$W_{N\mathrm{decay}} = N e^c E + L h_d E^c + N^3 + m_{3/2} l_1 L^c,$$

$$W_{\mathrm{mass}} = M_L L L^c + M_E E E^c + m_N N N^c + m'_{3/2} h_u h_d,$$

Using the equations of motion,

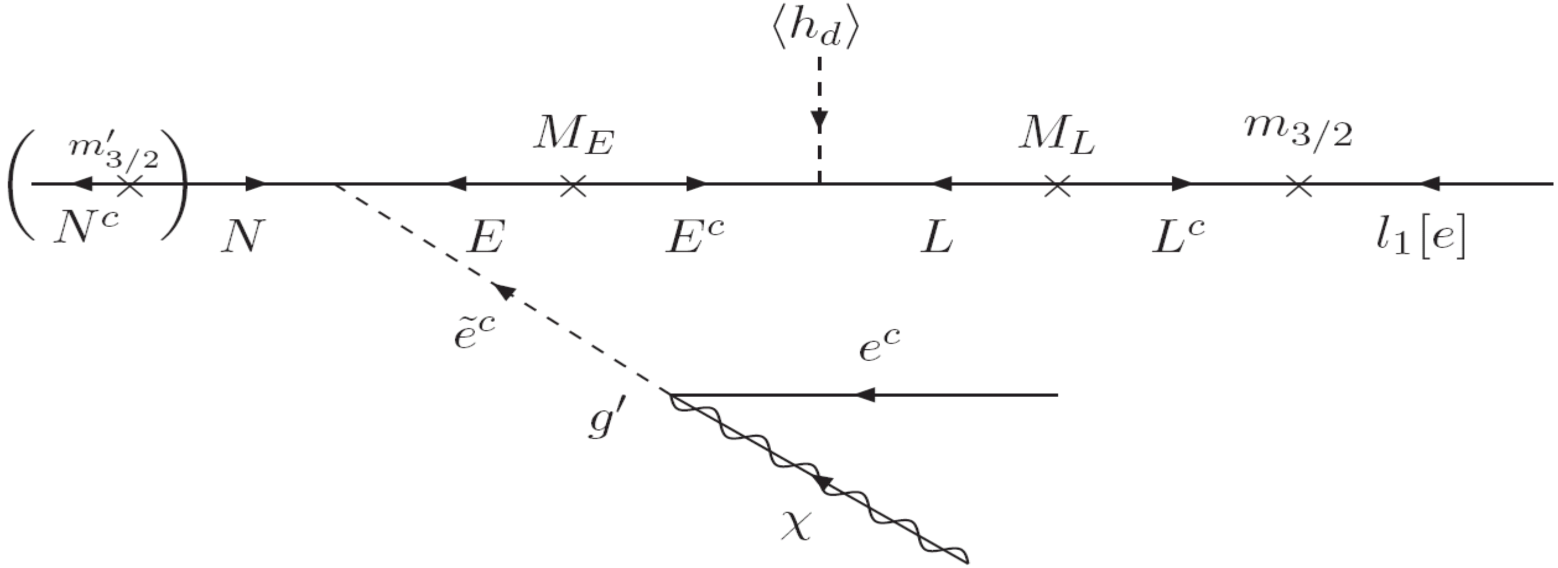
$$\partial\mathcal{L}/\partial E = \partial\mathcal{L}/\partial E^c = \partial\mathcal{L}/\partial L = \partial\mathcal{L}/\partial L^c = 0$$

or

$$E^c = -\tilde{e}^c N/M_E,\ E = -\langle h_d\rangle L/M_E,\ L^c = -\langle h_d\rangle E^c/M_L, \text{ and } L = -m_{3/2} l_1/M_L$$

One can integrate out the heavy fermions, and obtain the effective Lagrangian or effective Kahler potential:

$$\mathcal{L}_{\text{eff.}} = \frac{m_{3/2}}{M_E M_L} h_d \tilde{e}^c l_1 N \quad \subset \quad \int d^2\theta d^2\bar{\theta}\left[\frac{\Sigma^\dagger}{M_P M_E M_L} h_d e^c l_1 N + \text{h.c.}\right]$$



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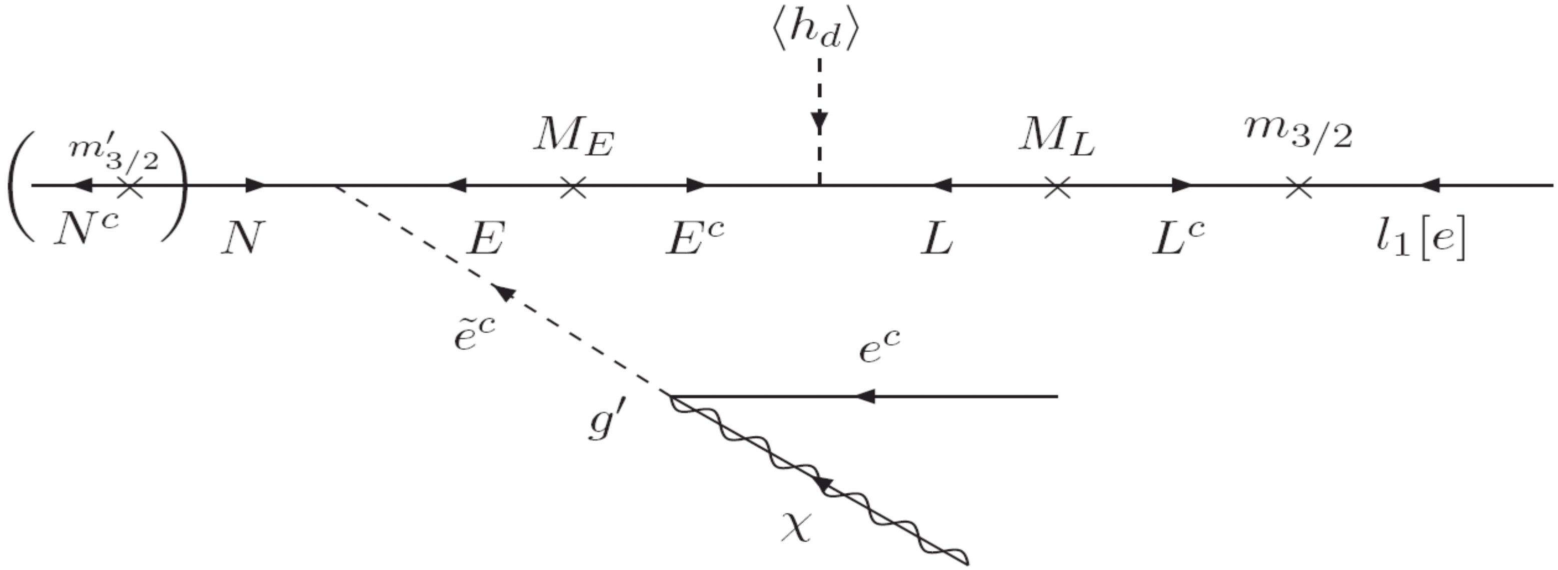

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$\Gamma_N \sim$ **$m_N^5/[192\pi^3(M_E M_L)^2] \sim 10^{-26}$ sec^{-1}**,

for $m_{DM} \sim 2$ TeV, $M_E \sim M_L \sim 10^{16}$ GeV

In the both Models,

- The low energy field spectrum is exactly the same as that of the MSSM except for a neutral singlet N.
  → gauge coupling unif. at 10^{16} GeV

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- For lighter M_* ($\sim 10^{12}$ GeV), one can rescue the MSSM CDM scenario.

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For explainig PAMELA/Fermi data, we need a DM decay model having

- Leptophilic YUKAWA int. between superheavy fields and DM,
- Other (global) symmetry for dim. 6 decay dominance,
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- Even extremely small amount of N can explain the PAMELA/Fermi data.
- The nobleness of the MSSM (SUSY at 10^2 GeV, gauge coupling unif., χCDM) can be maintained.
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Problems in DM annihilation

- Should overcome the helicity suppr.
- Serious gamma ray constraint (TeV DM)
- Introduction of a new TeV DM and new interactions are Ad hoc.

Problems in DM decay

- Desired relic density is not automatic.
- Need a natural explanation for 10^{-26} sec.$^{-1}$ decay rate.
- Need an elaborate decay process for Fermi.
- Introduction of a new TeV DM and new interactions are Ad-hoc.

From now on, I will try to explain PAMELA only within the framework of a well-known Particle physics model, SO(10) without introducing any new DM and new special interactions.

I suppose that DM is the bino-like LSP.

SO(10)

45_G = SM + {E,E^c} + N
+ {Q',Q'^{c}} + {Q,Q^c; U,U^c}

SO(10) → $SU(3)_c$x$SU(2)_L$x$SU(2)_R$x$U(1)_{B-L}$=LR
by <45_H> , {Q',Q'^{c}}, {Q,Q^c; U,U^c} massive

SO(10) → SU(5) by <16_H>, <16^*_H>
{E,E^c}, N, {Q,Q^c; U,U^c} massive

$\langle 45_H \rangle$ is 10^{16} GeV from RG eff.of the MSSM gauge couplings, but

$\langle 16_H \rangle$ is not pinned down yet.

If $\langle 45_H \rangle > \langle 16_H \rangle = \langle 16^*_H \rangle$,

masses of $\{Q', Q'^c\}$, $\{Q, Q^c; U, U^c\} > \{E, E^c\}$, N

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masses of $\{E, E^c\}$, N, $\{Q, Q^c; U, U^c\} > \{Q', Q'^c\}$

So $\{Q, Q^c; U, U^c\}$ are always heavier.

Superheavy fields in SO(10)

- Gauge boson/Gauginos of SO(10)/SM
- Triplets in 10_h (={D^c,h_d}+{D,h_u})

  e.g. by 10_h <45_H> 10_h
- GUT breaking Higgs

  due to its VEV, they couple to MSSM fields only via non-renormalizable terms. They weakly coupled to SM

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LSP decay due to sRH ν

- If (1) R-parity is absolutely preserved, and (2) χ is the LSP, χ can not decay.
- BUT if sRH ν develops a VEV (R viol.), or sRH ν is lighter than χ (sRH ν LSP), χ could decay.
- RH ν and sRH ν are neutral singlets under SM. Were it not for $W=lh_u\nu^c$, it extremely weakly interacting with SM.

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Interactions of the MSSM fields and heavy gauginos			
$\tilde{e}_i^{c*}\nu_i^c\tilde{E}^c$,	$\tilde{d}_i^{c*}u_i^c\tilde{E}^c$,	$h_u^{+*}\tilde{h}_d^0\tilde{E}^c$,	$h_u^{0*}\tilde{h}_d^-\tilde{E}^c$
$\tilde{\nu}_i^{c*}e_i^c\tilde{E}$,	$\tilde{u}_i^{c*}d_i^c\tilde{E}$,	$h_d^{0*}\tilde{h}_u^+\tilde{E}$,	$h_d^{-*}\tilde{h}_u^0\tilde{E}$
$\tilde{\nu}_i^{c*}\nu_i^c\tilde{N}$,	$\tilde{e}_i^{c*}e_i^c\tilde{N}$,	$\tilde{u}_i^{c*}u_i^c\tilde{N}$,	$\tilde{d}_i^{c*}d_i^c\tilde{N}$
$h_u^{+*}\tilde{h}_u^+\tilde{N}$,	$h_d^{0*}\tilde{h}_d^0\tilde{N}$,	$h_u^{0*}\tilde{h}_u^0\tilde{N}$,	$h_d^{-*}\tilde{h}_d^-\tilde{N}$
$\tilde{e}_i^{c*}q_i\tilde{Q}'^c$,	$\tilde{d}_i^{c*}l_i\tilde{Q}'^c$,	$\tilde{q}_i^*u_i^c\tilde{Q}'^c$	
$\tilde{q}_i^*e_i^c\tilde{Q}'$,	$\tilde{l}_i^*d_i^c\tilde{Q}'$,	$\tilde{u}_i^{c*}q_i\tilde{Q}'$	
$\tilde{\nu}_i^{c*}q_i\tilde{Q}^c$,	$\tilde{u}_i^{c*}l_i\tilde{Q}^c$,	$\tilde{q}_i^*d_i^c\tilde{Q}^c$	
$\tilde{q}_i^*\nu_i^c\tilde{Q}$,	$\tilde{l}_i^*u_i^c\tilde{Q}$,	$\tilde{d}_i^{c*}q_i\tilde{Q}$	
$\tilde{u}_i^{c*}\nu_i^c\tilde{U}^c$,	$\tilde{l}_i^*q_i\tilde{U}^c$,	$\tilde{d}_i^{c*}e_i^c\tilde{U}^c$	
$\tilde{\nu}_i^{c*}u_i^c\tilde{U}$,	$\tilde{q}_i^*l_i\tilde{U}$,	$\tilde{e}_i^{c*}d_i^c\tilde{U}$	

For leptophilic χ decay,

- $\langle 16_H \rangle \ll \langle 45_H \rangle$, effectively LR model
- If $s\nu^c$ is heavier than χ,
  a non-zero VEV $\langle s\nu^c \rangle$ must be assumed.
- Squarks, charged Higgs, and soft para.
  are much heavier (1 TeV) than a slepton.
- For PAMELA, $m_\chi \sim 200 - 300$ GeV,

Fermi is explained with astrophys. source.

- One RH ν is lighter than χ.

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Even with 2 RH ν, seesaw mech. is still O.K.

$$W_\nu = y_{ij}^{(\nu)}\ l_i h_u \nu_j^c (j \neq 1) + \frac{1}{2} M_{i,j}\ \nu_i^c \nu_j^c (i, j \neq 1),$$

$$m_\nu = m_\nu^T = - \begin{pmatrix} 0 & v_{12} & v_{13} \\ 0 & v_{22} & v_{23} \\ 0 & v_{32} & v_{33} \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ 0 & M_{22}^{-1} & M_{23}^{-1} \\ 0 & M_{23}^{-1} & M_{33}^{-1} \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ v_{12} & v_{22} & v_{32} \\ v_{13} & v_{23} & v_{33} \end{pmatrix}$$

Still 3 LH ν can be maximally mixed.

[Frampton, Glashow, Yanagida (2002)]

If sRHν is lighter than χ, a VEV of sRHν is not essential. → 4 bdy decay !!

Just for simplicity, assume a VEV of sRHν. (→ 3 bdy decay) e.g. by

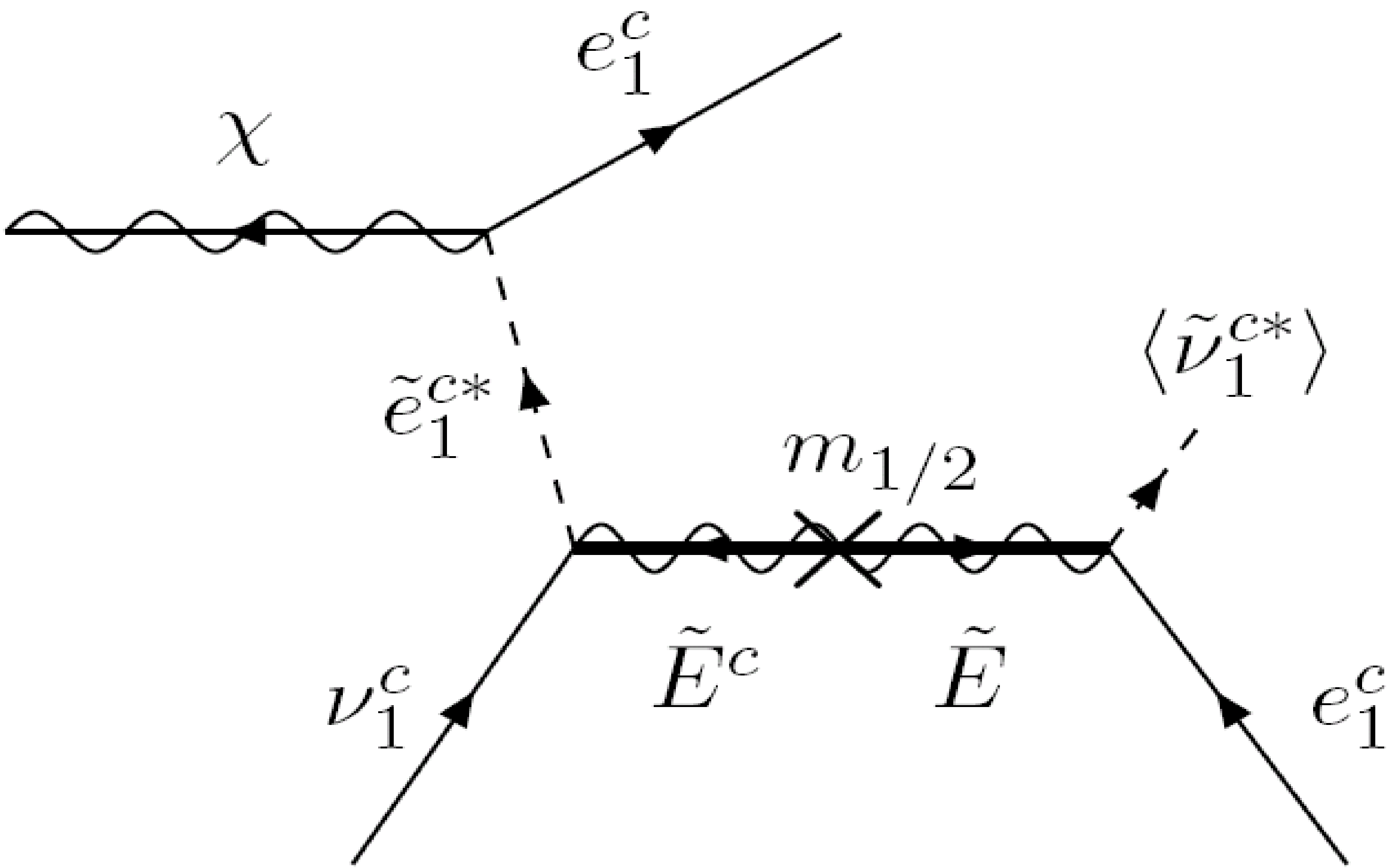
$$W \supset \frac{1}{M_P} \langle \overline{\mathbf{16}}_H \rangle \mathbf{16}_1 S^2 + S^3$$

$R(16_1) = R(S) = 2/3$

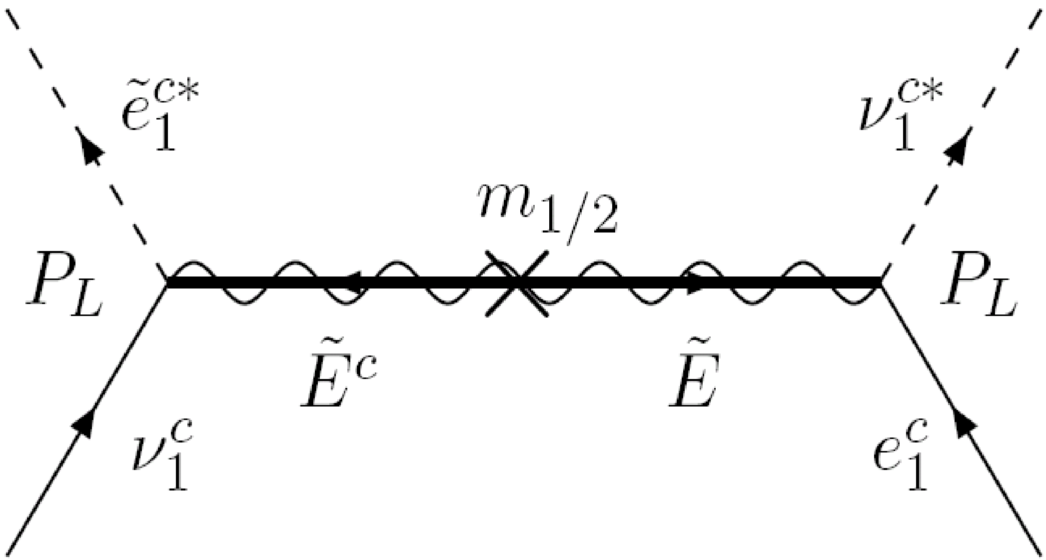
$R(16^*_H) = 0$

including soft terms in V, $\langle \tilde{\nu}_1^c \rangle \sim m_{3/2} \times \frac{M_E}{M_P}$

LSP decay diagram



Charged gaugino mediation

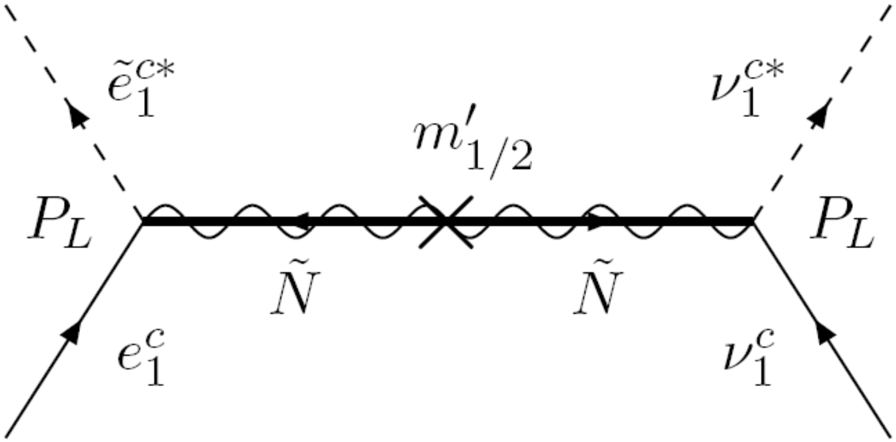


Dirac mass M_E by Gauge sym. breaking >> Majorana mass $m_{1/2}$ by SUSY breaking

This diagram is suppressed by

$$m_{1/2}/ M_E^2$$

Neutral gaugino mediation



$g_{LR} = (2/3)^{1/2}\, g_{B-L} = g_{10}$

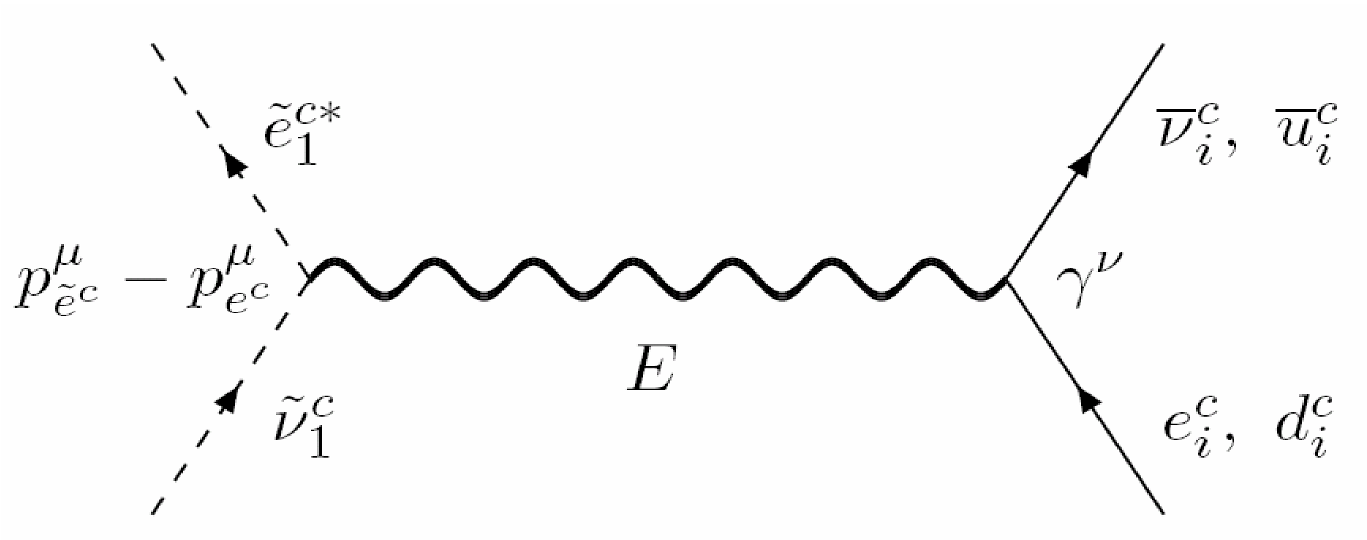
$M_N = M_E \times (5/2)^{1/2}$

Eff. coupling is ¼ of the C.C. case.

Suppressed by $2/5 \times 1/4 = 1/10$

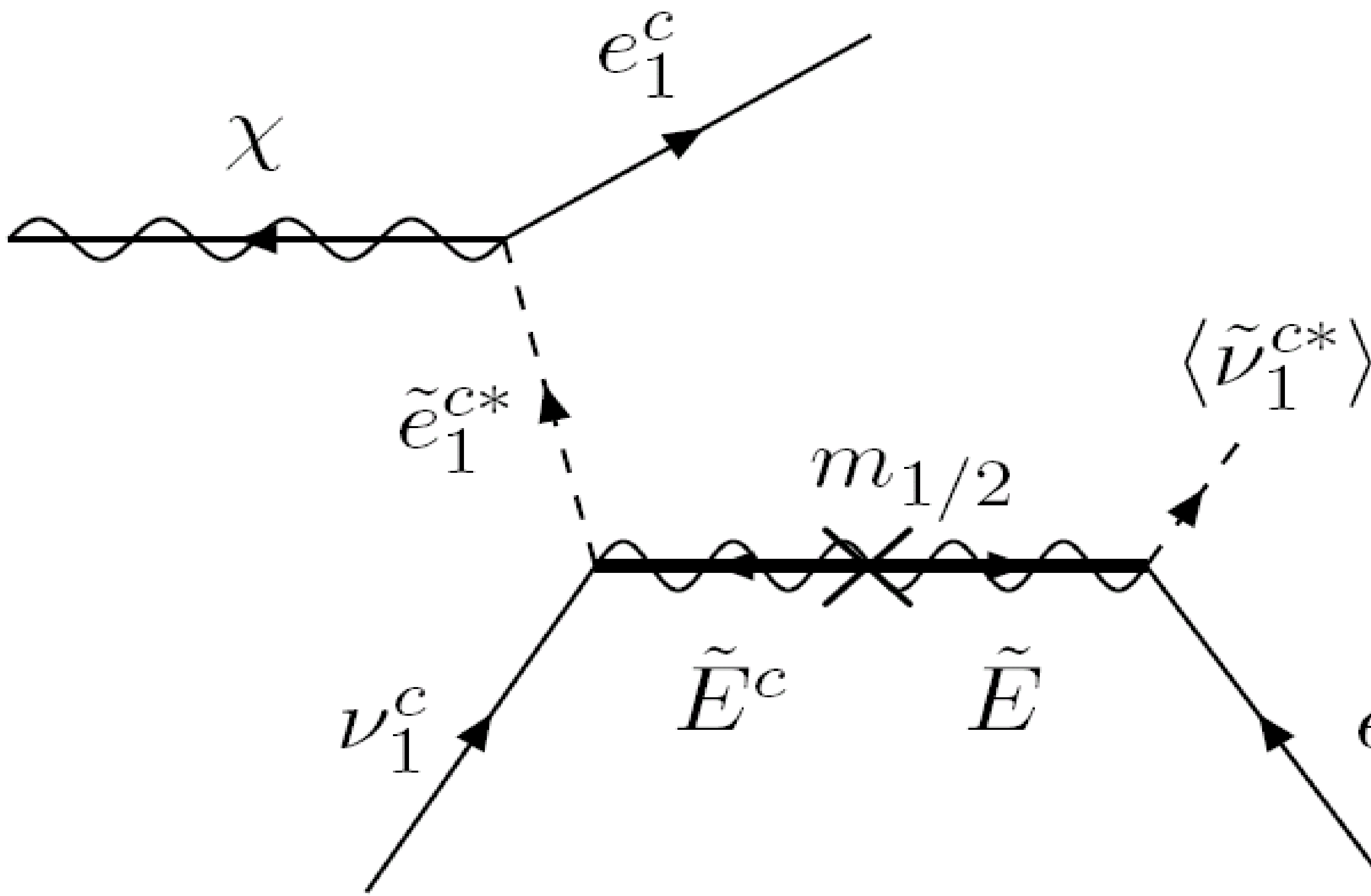
Compared to the C.C. case

Charged gauge field mediation



A derivative coupling is involved.

Since $m_{1/2} >> m_\chi$, this diagram is suppressed.



The 1st realization of $\Gamma_\chi \sim 1/M_{GUT}^4$ from the gauge interaction

The decay rate of χ is

$$\Gamma_\chi = \frac{\alpha_{10}^2 \alpha' m_\chi^5}{96 M_E^4} \left(\frac{m_{1/2} \langle \tilde{\nu}_1^c \rangle}{m_{\tilde{e}_1^c}^2} \right)^2 \sim \frac{\alpha_{10}^2 \alpha' m_\chi^5}{96 M_E^2 M_P^2} \left(\frac{m_{1/2}\ m_{3/2}}{m_{\tilde{e}_1^c}^2} \right)^2 \sim 10^{-26}\ \mathrm{sec.}^{-1}$$

To be consistent with the PAMELA's data,

$M_E \sim \langle 16_H \rangle \sim 10^{14}$ GeV

2 RH ν masses $\sim 10^{10}$ GeV

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from $$W \supset \frac{1}{M_P} \langle \overline{\mathbf{16}}_H \rangle \langle \overline{\mathbf{16}}_H \rangle \mathbf{16}_i \mathbf{16}_j (i, j \neq 1) \supset (10^{10}\ \text{GeV}) \times \nu_i^c \nu_j^c (i, j \neq 1)$$

Conclusions II

- Still the bino-like LSP DM scenario is consistent with PAMELA,

  if sRH ν develops a VEV or is lighter than bino, and a RH ν is light enough.
- SO(10) provides a relatively predictable explanation.
- In the specific case, LR breaking scale is 10^{14} GeV, and the seesaw scale is 10^{10} GeV.

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