Positron Excess from PAMELA/Fermi and Leptophilic GUT

Bumseok Kyae
(SNU)

Based on
arXiv:0809.2601 (J.-H. Huh, J.E. Kim, <u>BK</u>),
arXiv:0812.3511 (K. Bae, J.-H. Huh, J.E. Kim, <u>BK</u>, R.Viollier)
arXiv:0902.0071 (<u>BK</u>)
arXiv:0902.3578 (K. Bae, <u>BK</u>)

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)

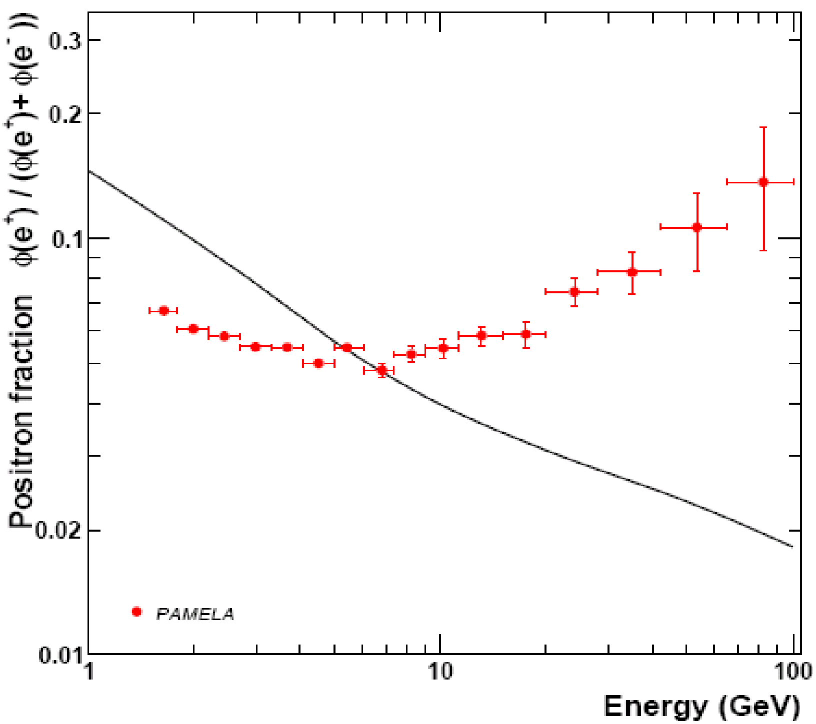
- PAMELA (Payload for Anti Matter Exploration and Light nuclei Astrophysics)

  [exp. by a SATELLITE] measures particles & nuclei fluxes in cosmic ray.

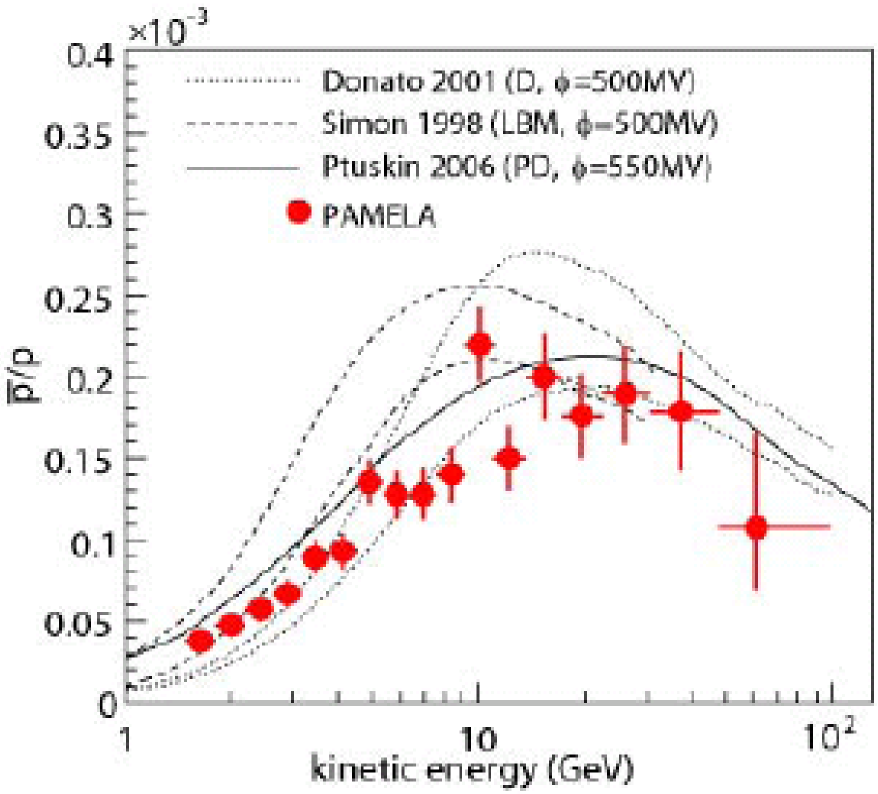
- Fermi [exp. by a SATELLITE] released data on electrons & positrons fluxes in cosmic ray.

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].

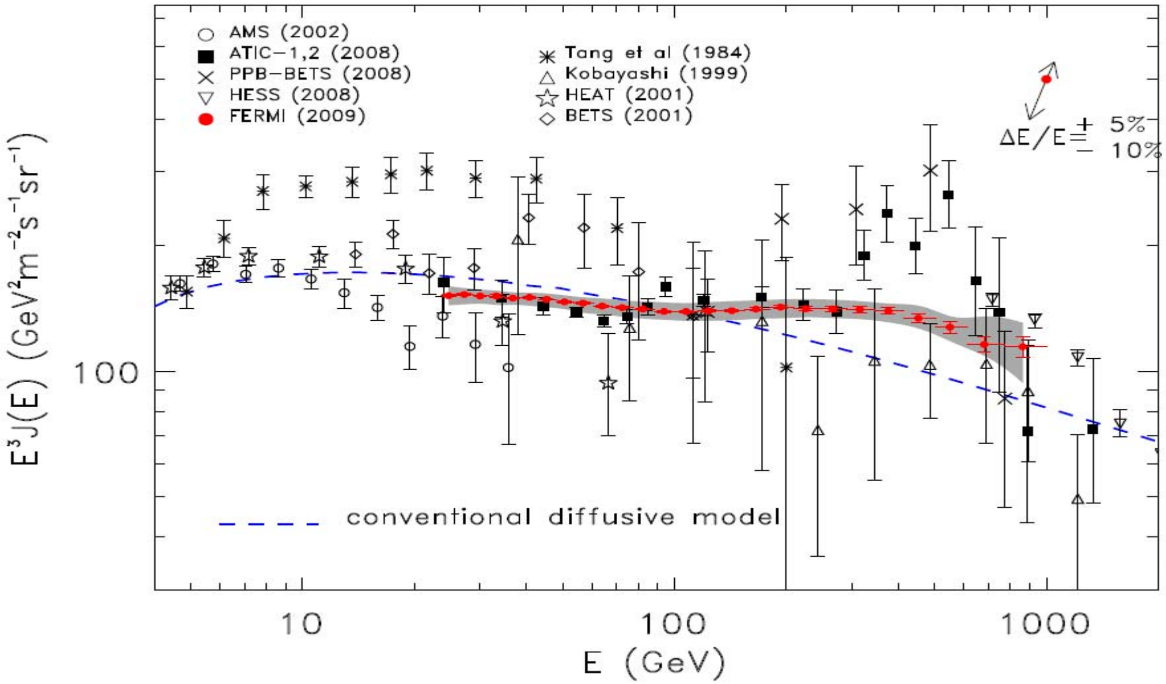
However,

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.

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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 → $e^+ e^-$, $\mu^+ \mu^-$, $\tau^+ \tau^-$ + 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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Fermi's observ. might be **a signal of GUT.**

However,

- In GUTs, the GAUGE int. by heavy gauge boson ($\sim 10^{16}$ GeV) exchange

can provide the eff. Dim. 6 operator (or 4 fermi. Interaction).

- NO GUT embedding the SM gives the leptonphilic GAUGE int.

For a promising DM Decay model,

- Introduce Leptophilic YUKAWA 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.

$$W_{\rm tri} = \mathbf{N}EX + XO\mathbf{e^c} + \mathbf{N^3},$$

$$W_{\rm bi} = M_E EE^c + M_X XX^c + M_O OO^c.$$

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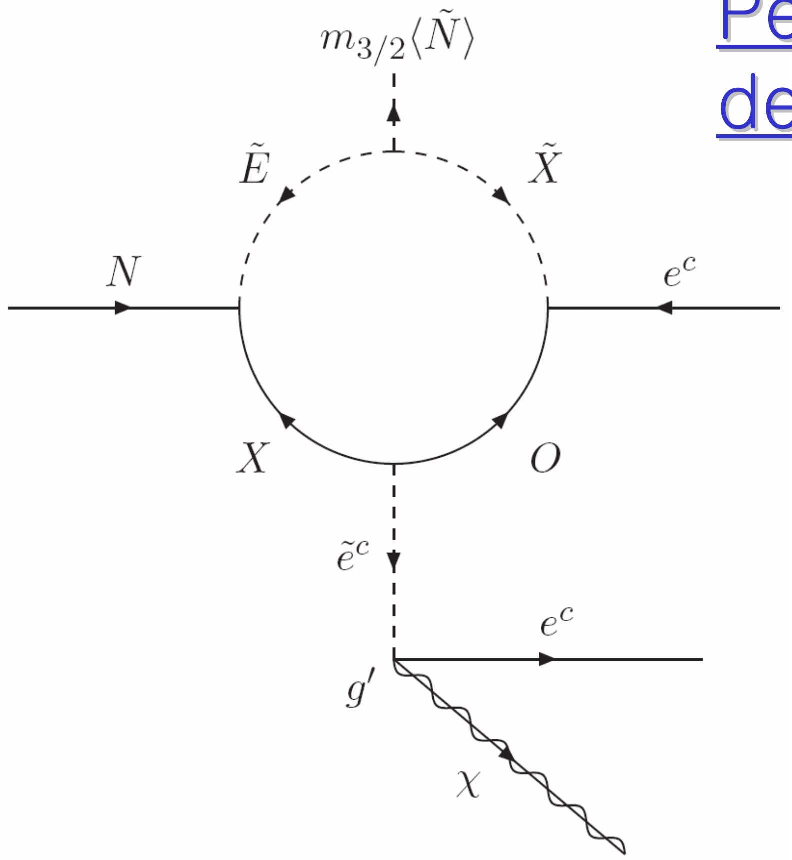
So, $m_{DM} = m_N \sim 2$ TeV , and N can decay

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

Penguin-type one loop decay diagram of N



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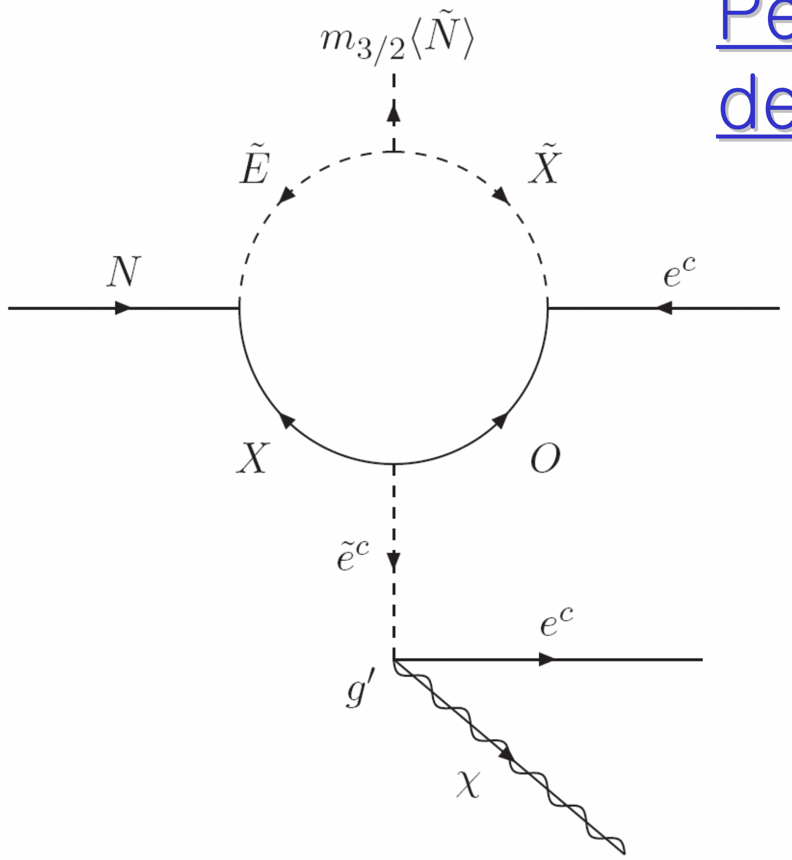
The light External particles carry the INTEGER charges.

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



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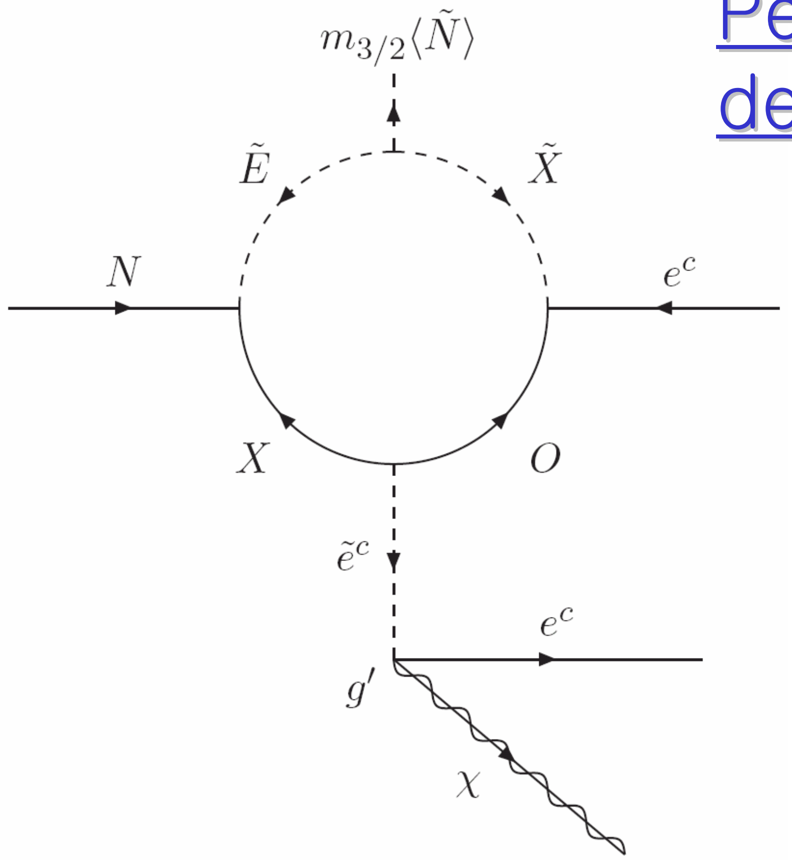

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$$\Gamma_N \approx \frac{m_{\rm DM}^5}{192\pi^3} \times \left[\frac{\sqrt{2}g'}{2^{3/2}m_{\tilde{e}^c}^2}\right]^2 \times \left[\frac{m_{3/2}\langle\tilde{N}\rangle}{48\pi^2 M_*^2} \times \mathcal{O}(y^4) \times \mathcal{N}\right]^2$$

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

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

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

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

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

because the needed **$\rho_{DM} \sim 10^{-6}$ 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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$$W_{N\mathrm{decay}} = Ne^cE + Lh_dE^c + N^3 + m_{3/2}l_1L^c,$$

$$W_{\mathrm{mass}} = M_LLL^c + M_EEE^c + m_NNN^c + m'_{3/2}h_uh_d,$$

Using the equations of motion,

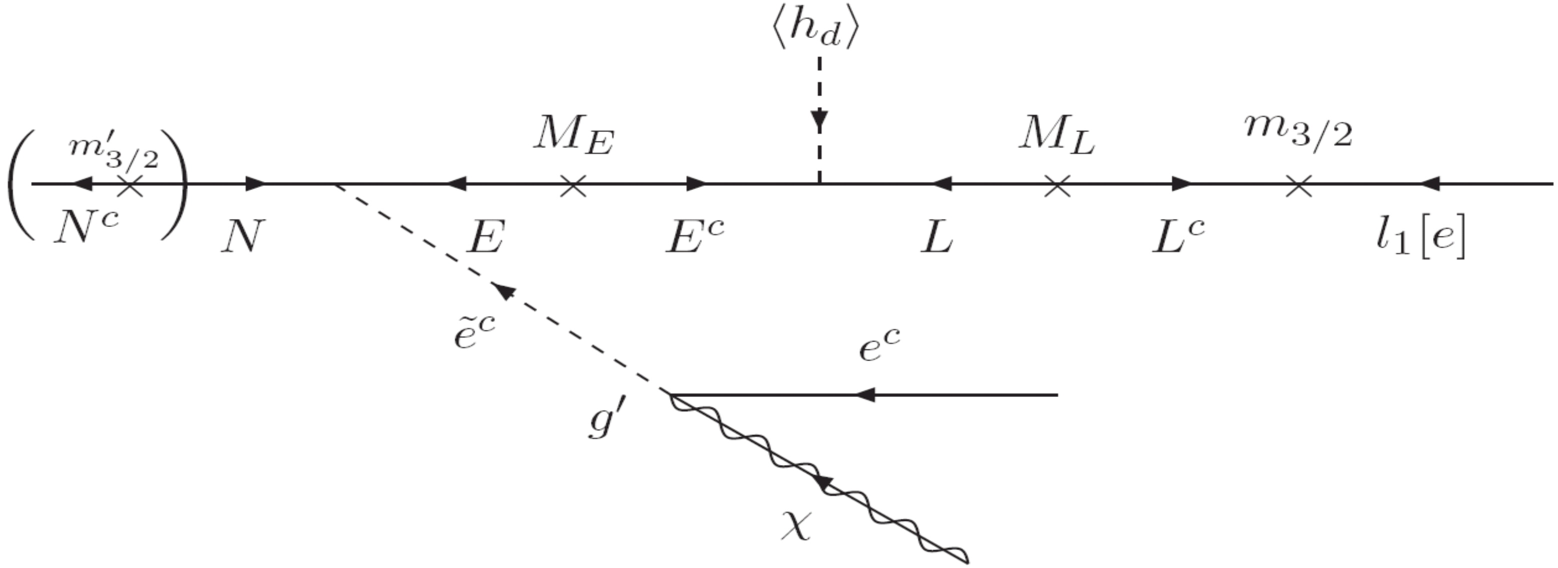
$$\partial\mathcal{L}/\partial E = \partial\mathcal{L}/\partial E^c = \partial\mathcal{L}/\partial L = \partial\mathcal{L}/\partial L^c = 0$$

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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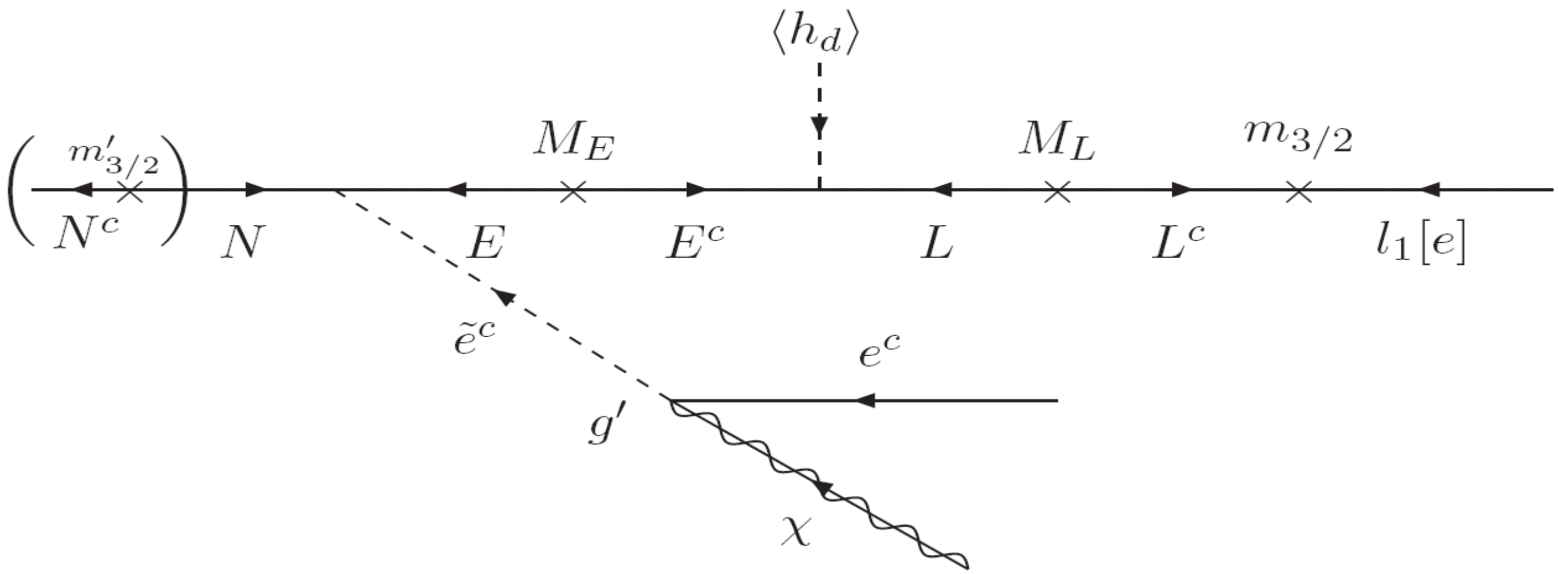

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$\Gamma_N \sim$ **$m_N^5/[192\pi^3(M_E M_L)^2]$** $\sim$ **10^{-26} sec^{-1}**,

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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How can the Model compromise with GUT?

- GUTs combine Quark and Lepton degrees in an irreducible Rep.
- e^C are embedded e.g.

  in 10 (={u^c,Q,e^c}) in G-G SU(5).
- It would lead to p-p* excess, which was NOT observed in PAMELA.

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$$\frac{1}{2}Y = -\frac{1}{5}Z + \frac{1}{5}X \ ,$$

where $$Z = \text{diag.}\left(\frac{-1}{3} \ \frac{-1}{3} \ \frac{-1}{3} \ \frac{1}{2} \ \frac{1}{2}\right)$$

$$\mathbf{10}_1 = \begin{pmatrix} d^c & Q \\ & \nu^c \end{pmatrix}, \quad \overline{\mathbf{5}}_{-3} = \begin{pmatrix} u^c \\ L \end{pmatrix}, \quad \mathbf{1}_5 = e^c$$

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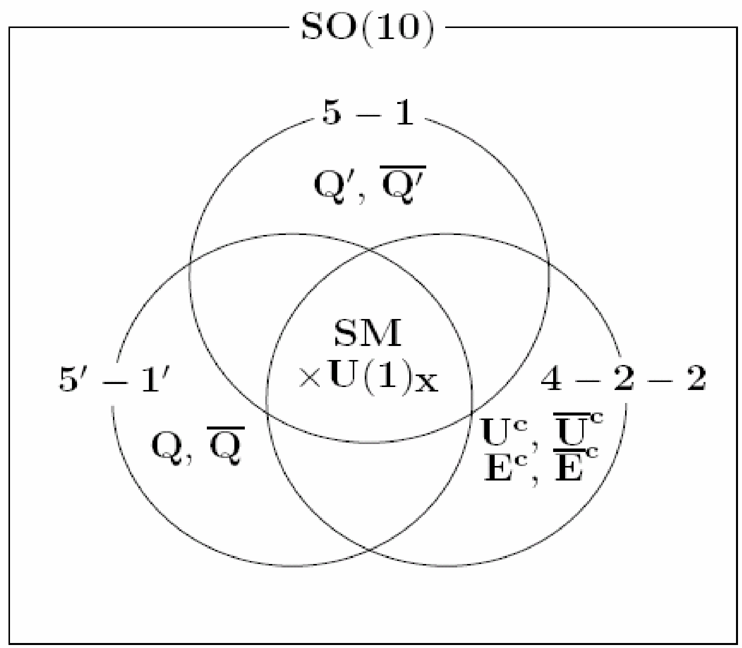
$$\mathbf{5}_{-2} = \begin{pmatrix} \overline{d}^c \\ H_d \end{pmatrix}, \qquad \overline{\mathbf{5}}_2 = \begin{pmatrix} d^c \\ H_u \end{pmatrix}$$

$$H_u \longleftrightarrow H_d$$

Flipped SU(5) is broken to G_{SM} by $\langle \mathbf{10}_H \rangle, \langle \overline{\mathbf{10}}_H \rangle \neq 0$



$$\mathbf{10}_H = \begin{pmatrix} d^c_H & Q_H \\ & \langle \nu^c{}_H \rangle \end{pmatrix}, \quad \overline{\mathbf{10}}_H = \begin{pmatrix} \overline{d}^c_H & \overline{Q}_H \\ & \langle \overline{\nu}^c{}_H \rangle \end{pmatrix}$$

$\{Q_H, \overline{Q}_H\}$ are eaten.

Doublet/Triplet Splitting:

(Missing Partner Mechanism)

$$\mathbf{5}_h = \begin{pmatrix} \overline{d}_h^c \\ H_d \end{pmatrix}, \qquad \overline{\mathbf{5}}_h = \begin{pmatrix} d_h^c \\ H_u \end{pmatrix}$$

$$W \supset \mathbf{10}_H \mathbf{10}_H \mathbf{5}_h + \overline{\mathbf{10}}_H \overline{\mathbf{10}}_H \overline{\mathbf{5}}_h$$

$$= \langle \nu_H^c \rangle d_H^c \overline{d}_h^c + \langle \overline{\nu}_H^c \rangle \overline{d}_H^c d_h^c$$

MSSM Yukawa couplings

$$W \supset y^{ij}_{(d)} 10_i 10_j 5_h + y^{ij}_{(u,\nu)} 10_i \bar{5}_j \bar{5}_h + y^{ij}_{(e)} 1_i \bar{5}_j 5_h + \frac{y^{ij}_{(M)}}{M_P} \overline{10}_H \overline{10}_H 10_i 10_j$$

d-type quarks	u-type quarks/ Dirac neutrinos	charged leptons	Majorana neutrinos

Not $M_d^{ij} = M_e^{ji}$ but $M_u^{ij} = M_{D\nu}^{ji}$

$\frac{\langle \overline{\mathbf{10}}_H \rangle^2}{M_P} \sim 10^{14}$ GeV so $m_\nu \sim \frac{m_{\rm top}^2}{10^{14}{\rm GeV}} \sim 0.1$ eV

In Model (I), NEX + XOe^c + N^3 was introduced.

$$N = 1_0 , \quad e^c = 1_5$$

remain SU(5) singlets in flipped SU(5),

without being accompanied with quarks.

$$E = R_x, \quad X = R^*_{-x}, \quad O = R_{-x-5}$$

$$\text{(and } E^c = R^*_{-x}, \quad X^c = R_x, \quad O^c = R^*_{x+5} \text{)}$$

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Conclusions

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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