Minimal extension of MSSM for Fermi-LAT/PAMELA CR data

(Based on Jihn E. Kim and JH, arXiv:0908.0152)

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2009 LHC Workshop Korea,Konkuk Univ.
and
KIAS-KAIST-YITP Workshop on DM, LHC and Cosmology

Outline

DM

Nowadays, there is no doubt in existence of Dark Matter(DM).

- Rotation curves of galaxies
- Multi-disciplinary study on galaxy clusters (Bullet cluster)
- Cosmic Microwave Background (WMAP)

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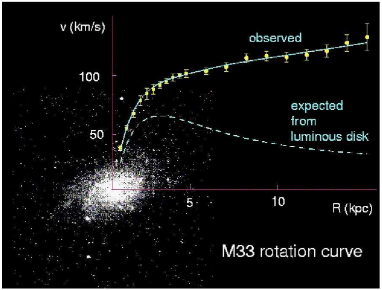

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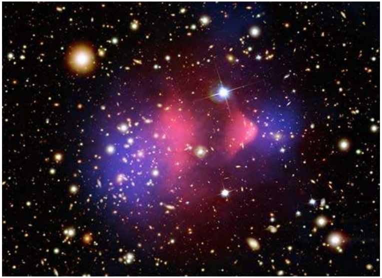

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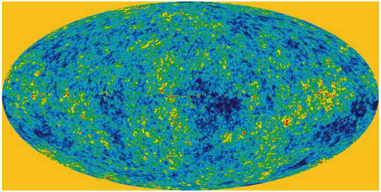

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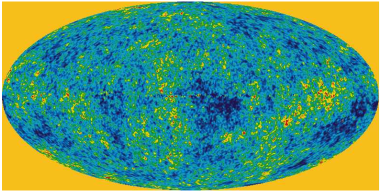

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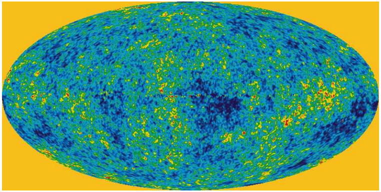

- But nobody knows non-gravitatinal nature of DM at all.
- Recently, however, charged Cosmic-Ray(CR) excesses are reported. It's a candidate of firstly-observed, non-gravitational DM signal.

CR

- Victor Hess(Aug.7, 1912) discovered CR.
- In 1948, it was found that CR contains various nuclei.
- Their relative abundances give us hints about their origin and propagation mechanism.
- Primary source is SNR. Secondary CR are from ISM spallation process.
- CR propagation is governed by diffusion-loss equation(IC, Synchrotron, ..)
  - stable nucle
    —> diffusion coefficient
  - radioactive nuclei(beta decay or K-capture)
    —> propagation time scale and injection energy spectrum
- Nowadays, there is numerical model for CR propagation ,*Galprop* code(Strong and Moskalenko)

CR experiments

- These days, there are lot of CR experiments.
- AMS, ACE, HESS, Fermi-LAT(a.k.a GLAST), ATIC, BESS, PPB-BETS, CAPRICE, CREAM, HEAT, PAMELA

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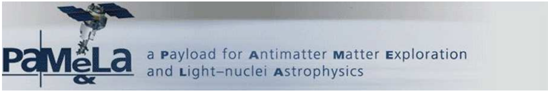
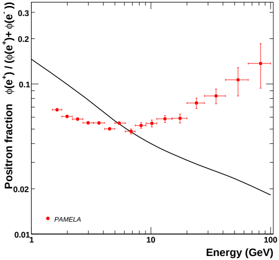
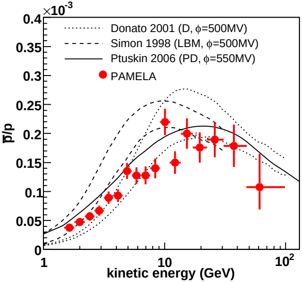
- AMS, ACE, HESS, Fermi-LAT(a.k.a GLAST), ATIC, BESS, PPB-BETS, CAPRICE, CREAM, HEAT, PAMELA
- Some of them reported excess of CR. Moreover, recently, two experiments confirms these excesses with better statistics.

PAMELA

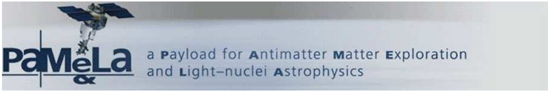


- positron fraction $e^+/(e^+ + e^-)$
- anti-proton/proton ratio $\bar{p}/p$

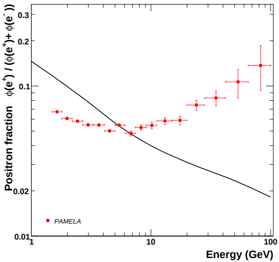


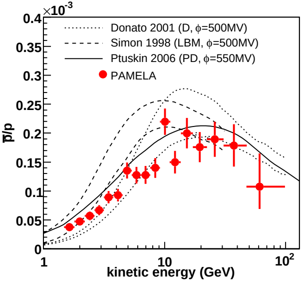


PAMELA

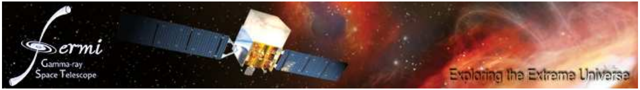


- positron fraction $e^+/(e^+ + e^-)$
  rising from 20 GeV –> primary positron source
- anti-proton/proton ratio $\bar{p}/p$
  no observed anti-proton excess –> leptophilic source

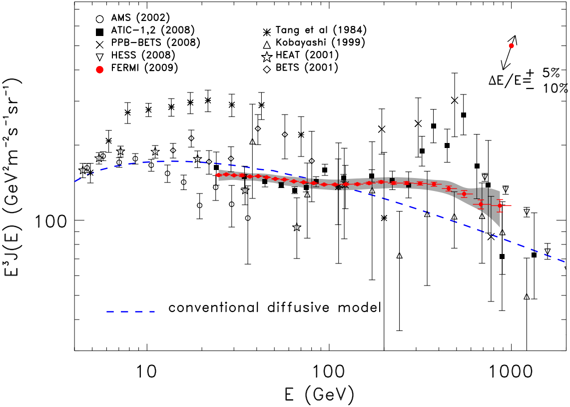




Fermi-LAT



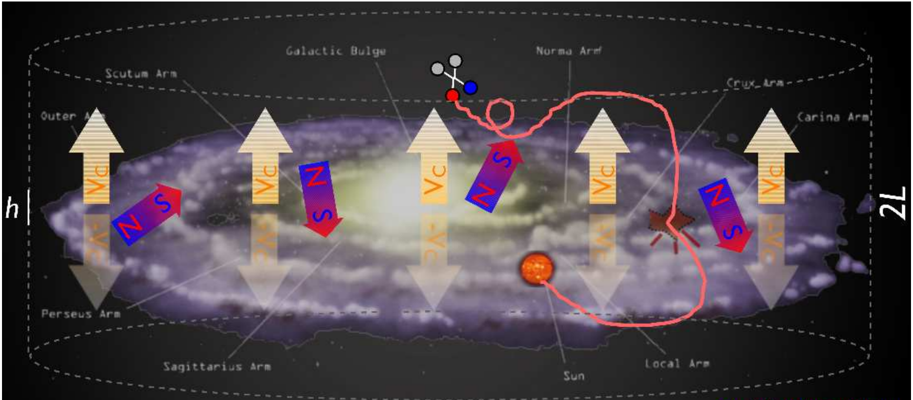
- electron(+positron) flux $e^+ + e^-$



DM vs Pulsar

- Primary positrons from nearby pulsar
- Primary positrons from DM (annihilating or decaying)

CR propagation model



Salati, Chardonnay, Barrau, Donato, Taillet, Fornengo, Maurin, Brun... '90s, '00s

spectrum

$$\frac{\partial f}{\partial t} - K(E)\cdot\nabla^2 f - \frac{\partial}{\partial E}(b(E)f) + \frac{\partial}{\partial z}(V_c f) = Q_{\rm inj} - 2h\delta(z)\Gamma_{\rm spall} f$$

diffusion energy loss convective wind source spallations

Cirelli's talk in SUSY '09

diffusion and propagation

- Diffusion-loss equation

$$\frac{\partial f}{\partial t} - K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E}(b(E)f) + \frac{\partial}{\partial z}(V_c f) = q$$

- diffusion coefficient $K(E) = K_0(E/\mathrm{GeV})^{\delta}$ (turbulent magnetic fields)
- energy loss coefficient $b(E) = E^2/(\mathrm{GeV}\tau_E)$ with $\tau_E = 10^{16}$s (synchrotron radation and inverse Compton scattering)
- convecting wind $V_c = V_c(z)$ (To explain observed galatic wind of ext-galaxies and isotope ratio spectrum.)

Decaying dark matter

- CR can be from decaying of DM with few TeV mass.
- To make sufficient postiron flux, decay rate should be $\Gamma \sim 10^{-26} s^{-1} \sim \text{(phase factor)} \times m_{\rm DM}^5 / M_{\rm GUT}^4$
- Dimension 6 operator with GUT scale suppression. And all dimension-5 operator which allows DM decay must be killed.

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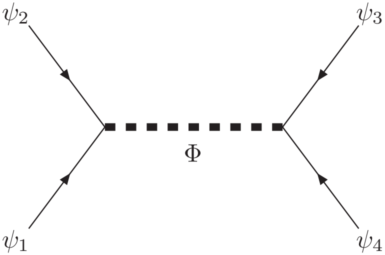
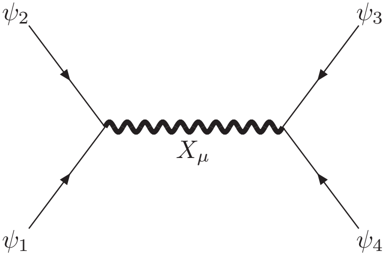
Question?
Grand Unified Theory is something to do with decaying DM?
If so, what is the origin of that interaction?

dim-6 in SUSY GUT (1)

- If we assume SUSY, however, it's not the simple task to achive it by integrating super heavy particle with GUT scale mass.



$\sim (1/M^2)\psi_1\psi_2\psi_3\psi_4$



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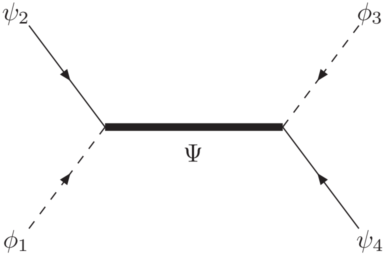

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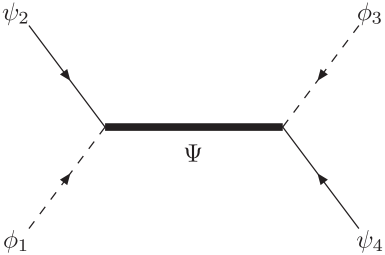

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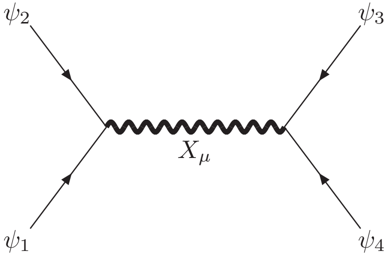

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GUT group must be enlarged significantly!!

dim-6 in SUSY GUT (2)

- 1. If one consider super heavy scalar exchange diagram to make dimension-6 operator, there's heavy fermion exchange diagram as SUSY counter part. Then there's dimension-5 operator
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Yes!

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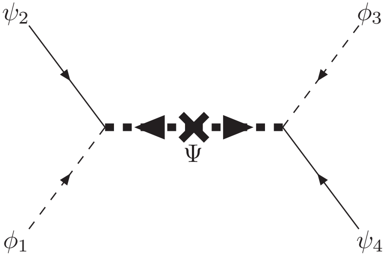

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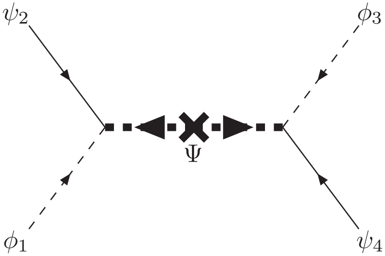

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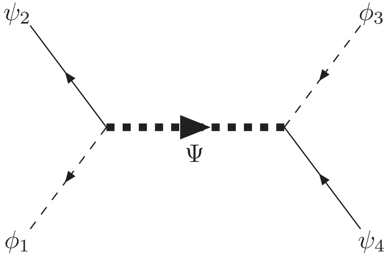

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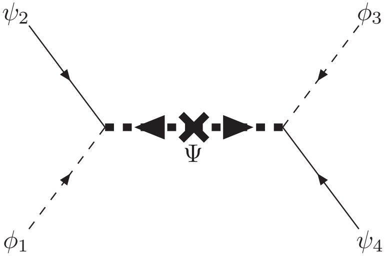

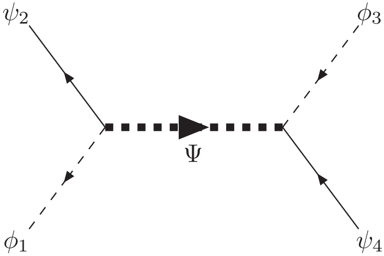

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Thanks to Prof.Kyae for pointing it out.

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Barr(1982), Derendinger,J.E.Kim&Nanopoulos(1984)

SU(5) vs. flipped-SU(5)

- $G_{\rm GG}$=SU(5)
  Y=Y_5 $\equiv$(-1/3,-1/3,-1/3,1/2,1/2)
  (MSSM) = 10+$\bar{5}$+(1)
- $G_{\rm flip}$=U(1)$_X \times$SU(5)
  Y=(X-Y_5)/5
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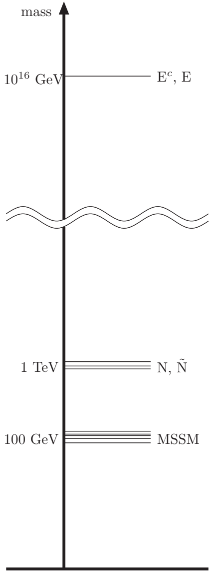
- In flipped-SU(5), We are free to add charged lepton singlet pair E, E^c in GUT scale, because they're appeared as GUT singlet.

Minimal extension

- Keep SUSY 100 GeV to be a solution of *gauge hierarchy problem*, i.e. LSP mass $\sim$ 100 GeV
- Introduce neutral singlet N with mass TeV order to explain Fermi-LAT
- Introduce E and E^c pair with GUT scale mass and interaction $W \sim Ne^c E$ to make N decay into lepton and slepton by dim-6 operator.
- $W \sim Ne^c E + m_{\rm TeV} N^2 + M_{\rm GUT} E^c E$



PQ symmetry and singlets

	N	Σ	E	E^c	ℓ_l	e_l^c	ϕ_u	ϕ_d
R	$+$	$+$	$-$	$-$	$-$	$-$	$+$	$+$
Y	0	0	-1	$+1$	$-\frac{1}{2}$	$+1$	$+\frac{1}{2}$	$-\frac{1}{2}$
Γ	$+1$	$+2$	0	0	-1	1	$+2$	0

Table: Color singlet chiral fields and their quantum numbers.

- Using Giudice-Masiero mechanism, N gets supersymmetric mass at TeV
  $\int d^4\theta \, \frac{\Sigma^\dagger}{M_{pl}} N^2 \sim \int d^2\theta \, \frac{F_\Sigma^\dagger}{M_{pl}} N^2 \sim \int d^2\theta \, m_{\mathrm{TeV}} N^2$
- PQ-symmetry forbids un-wanted terms and makes accidental parity symmetry which assigns odd only to N, E and E^c.
  N becomes stable.

3 scenario

There are 3 possible scenario which depends on spectrum of N multiplet and whether $\tilde{N}$ developes VEV or not

- case (a)
  $m_N > m_{\tilde{N}}$ and $\langle \tilde{N} \rangle = 0$
  $N \to \tilde{N} + e + \tilde{e}$
- case (b)
  $m_N < m_{\tilde{N}}$ and $\langle \tilde{N} \rangle = 0$
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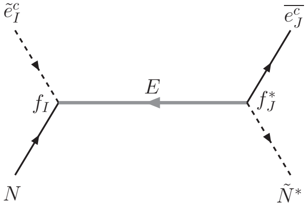

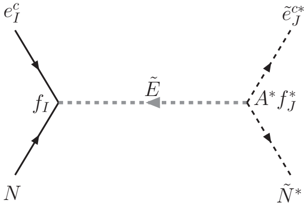

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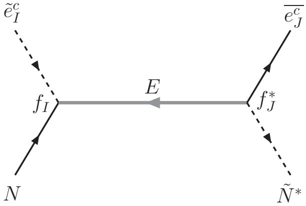
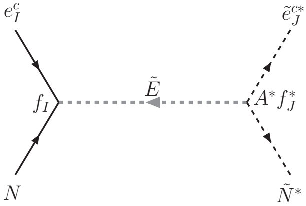
- case (c)
  $m_N < m_{\tilde{N}}$ and $\langle \tilde{N} \rangle \neq 0$
  $\tilde{N} \to e + \tilde{e}$
  Relatively harder spectrum than case (a) and (b)

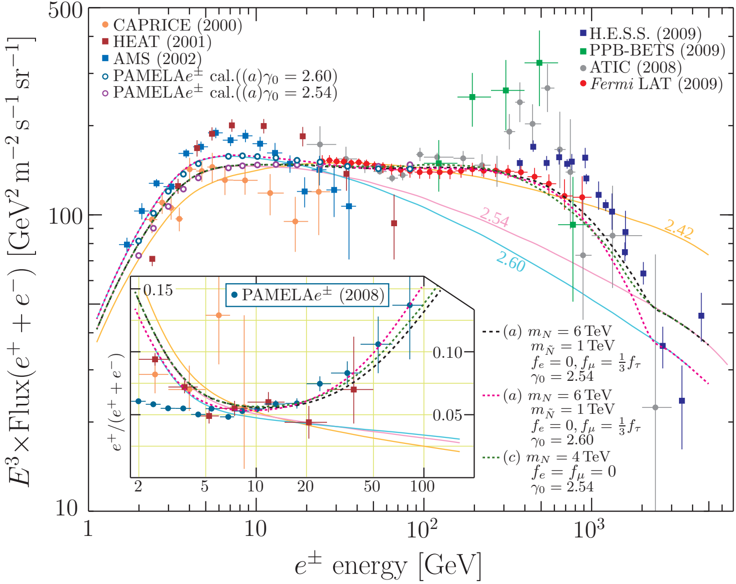




PYTHIA and Galprop

- PYTHIA
  - We used PYTHIA to calculate $e^{\pm}$ energy spectrum of slepton subsequent decay.
  - We also tested $\bar{p}$ spectrum. In certain MSSM parameters region, $\bar{p}$ production is small enough or even almost anti-proton free. But it may depend on detailed spectrum of right-handed sleptons and neutralinos.
- Galprop
  - Current public release version(v50) of Galprop has the routine for DM primary source.
  - But it's only for annihilating DM models and only specific form of CR injection spectrum (gaussian type) can be used.
  - Therefore, we partially re-write and add the module for Galprop to be used with decaying dark matter with arbitrary CR injection spectrum.

Results


CAPRICE (2000)
HEAT (2001)
AMS (2002)
PAMELA $e^\pm$ cal.((a) $\gamma_0 = 2.60$)
PAMELA $e^\pm$ cal.((a) $\gamma_0 = 2.54$)
H.E.S.S. (2009)
PPB-BETS (2009)
ATIC (2008)
Fermi LAT (2009)
PAMELA $e^\pm$ (2008)
(a) $m_N = 6$ TeV, $m_{\tilde{N}} = 1$ TeV, $f_e = 0$, $f_\mu = \frac{1}{3} f_\tau$, $\gamma_0 = 2.54$
(a) $m_N = 6$ TeV, $m_{\tilde{N}} = 1$ TeV, $f_e = 0$, $f_\mu = \frac{1}{3} f_\tau$, $\gamma_0 = 2.60$
(c) $m_N = 4$ TeV, $f_e = f_\mu = 0$, $\gamma_0 = 2.54$
2.54
2.60
2.42
$E^3 \times \mathrm{Flux}(e^+ + e^-)$ [GeV^2 m^{-2} s^{-1} sr^{-1}]
$e^\pm$ energy [GeV]
$e^+/(e^+ + e^-)$

Conclusion

- We interpret Fermi-LAT/PAMELA CR data in the context of decaying DM scenario.
- We find the model with only one additional chiral field N in the low energy.
- It can be easily embedded in flipped-SU(5) model.
- It fits Fermi-LAT/PAMELA well, because subsequent decays make primary $e^{\pm}$ spectrum soft enough.
- Doing so, PQ symmetry is crucially used.
  - Forbids un-wanted term while giving TeV mass to N and allowing Ne^cE coupling
  - Make accidental parity
  - Make model can be embedded in heavy axino decay scenario, so becomes more predictable. (I didn't mention here.)

Thank you !