# “White Dwarf Axions with SUSY Flipped SU(5)”

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# 1. Introduction

The most awaited information in the universe now is what is the DM of the universe. One plausible candidate is the WIMP (eWIMP) and the other attractive candidate is a very light axion. We try to discuss these aspects from scarce experimental hints and comment a viable model in a SUSY framework.

Axion is a Goldstone boson arising when the PQ global symmetry is spontaneously broken. The simple form dictates that its interaction is only through the anomaly term. A more detailed theory may have Yukawa couplings which are destined to contribute negligibly to the energy compared to the anomaly term. The axion models have the spontaneous symmetry breaking scale $F$ and the axion decay constant $F_a$ which are related by $F=N_{DW}\, F_a$.

Reviews: Kim (Prep., 87), Cheng (Prep., 88), Peccei(89),
Recently, taking the researches of last 20 years,
Kim-Carosi (RMP, 09)

$10^9$ GeV < $F_a$ < $10^{12}$ GeV

Turner (86), Grin et al (07),
Giudice-Kolb-Riotto (08),

Bae-Huh-K (08): recalculated including the anharmonic term carefully.

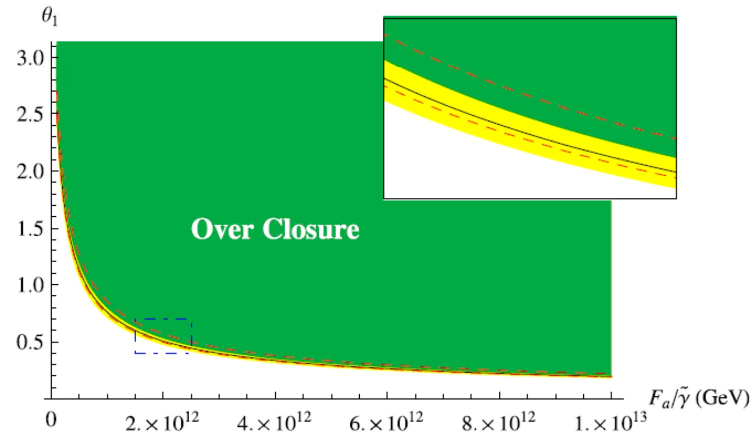



**Figure 9.** The bound from overclosure of the universe. The yellow band shows the error bars of $\Lambda$ and two red dashed lines are the limits of the allowed current quark masses. The anharmonic effect is taken into account, including the initial correction factor of equation (15). Here, the entropy production ratio $\gamma$ is absorbed into the bracket of $F_a$: $\tilde{\gamma} = \gamma^{(n+4)/(n+6)} \simeq \gamma^{0.84}$.

The axion model got a boost from the study of white dwarf evolution history [Isern et al., 2008]. Here, the axion-electron coupling turns out to be quite large. In fact, it points to the center of the allowed axion window. This region may be reached by Melissino's side band technique [2009].

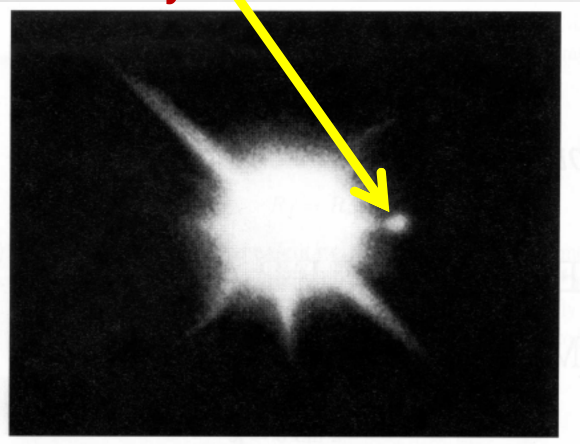
In the summer of 2008, the PAMELA group reported a spectacular excess of the positron/electron ratio in our vicinity. In the standard SUSY framework, this may lead to a two-component DM scenario [Huh-Kim-Kyae, PRD79 (2009) 063529, arXiv:0809.2601].

In this talk, I try to relate all these observations. When we try to interpret most data, we must resort to a specific model, for which we take the flipped SU(5). Note, in general, a general argument can fail in the detail description.

# 2. White dwarf axion possibility

White dwarfs can give us useful information about their last stage evolution. Main sequence stars will evolve after consuming all their nuclear fuel to WDs if their mass is less than 1.08 $M_{\odot}$. WDs of Sun's mass have the size of Earth, and DA WDs are studied most.

Sirius B, 1.05$M_{\odot}$
8.65 ly



The exceptionally strong pull of WD's gravity is the reason for the thin hydrogen surface of DA white dwarfs. In fact, the core of WDs follows simple physics, the degenerate fermion gas.

The Fermi energy at T=0 K is

$$\varepsilon_F = \frac{\hbar^2}{2m}(3\pi^2 n)^{2/3}$$
$$= \frac{\hbar^2}{2m}\left(3\pi^2 \frac{Z}{A}\frac{\rho}{m_H}\right)^{2/3}$$

The condition for a degenerate electron gas is

$$\frac{T}{\rho^{2/3}} < 1.3\times10^5\, K cm^2 gr^{-2/3}$$

Sirius B: $3.6\text{x}10^3$

The pressure of the degenerate electron gas is

$$\boxed{P = \frac{(3\pi^2)^{2/3}}{5}\frac{\hbar^2}{m_e}\left[\left(\frac{Z}{A}\right)\frac{\rho}{m_H}\right]^{5/3}}$$

The Chandrasekhar limit

$$M_{Ch} = 1.44 M_{Sun}$$

The astronomers are able to recover the history of star formation in our Galaxy by studying the statistics of WD temperatures.

For this, the energy transport mechanism from the core is essential. Unlike in Sun, it is transported by neutrinos at high T since most electron are filling the Degenerate energy levels. So, the transport mechanism is very simple. And the resulting luminosity at the surface is calculable and reliable.

$$L_{wd} = CT^{7/2}$$

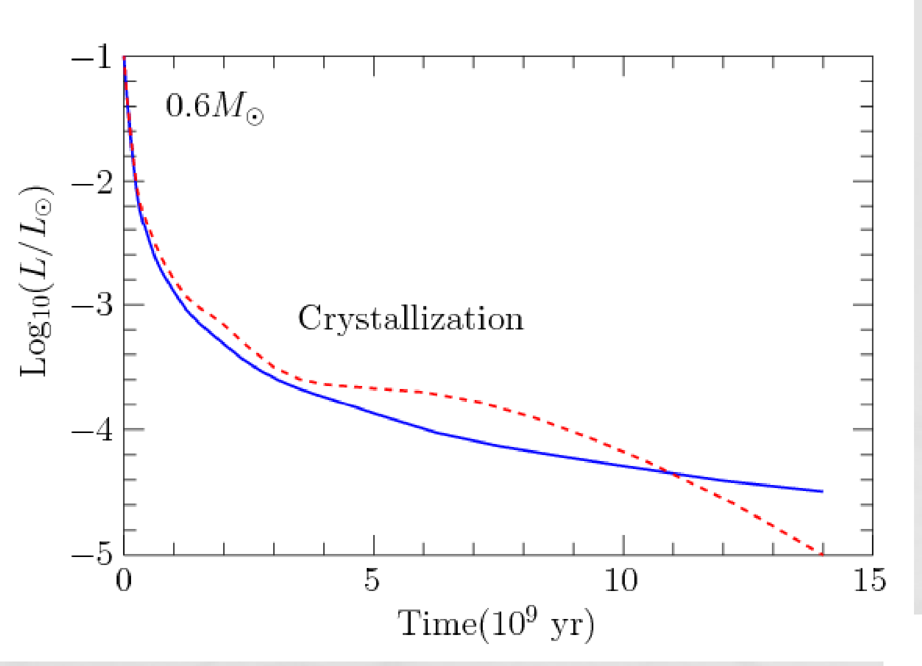
$$C = 7.3\times 10^5 \left(\frac{M_{wd}}{M_{Sun}}\right)\frac{\mu}{Z(1+X)}, \qquad \mu = av. \sim molar \sim wt$$

The later stage of evolution is cristalization from the core. As time goes on, the luminosity drops. In terms of t,

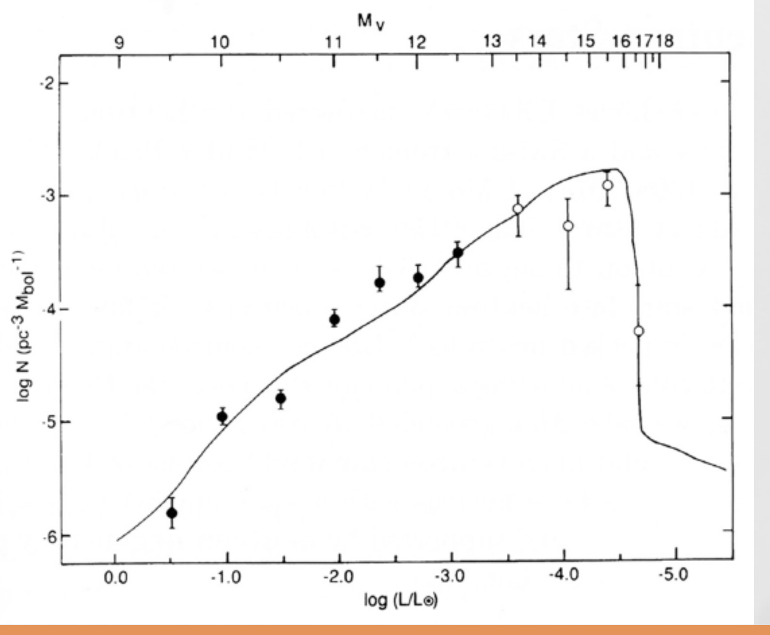
$$L_{wd} = L_0\left(1+\frac{5}{2}\frac{t}{\tau_0}\right)^{-7/5}, \qquad \tau_0 \cong 2.16\times 10^7\, yr$$

charateristic time of WD

A more complete treatment changes this simple behavior little bit (red dash line). With more data, Isern et al. gives a very impressive figure.




Winget et al., Ap. J. Lett. 315 (1987) L77.

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The energy loss in the early stage is through the photon conversion to neutrino pairs in the electron plasma.
This calculation of the photon decay was initiated in 1960s, but the accurate number was available after 1972 when the NC interaction was taken into account.

D. A. Dicus, PRD6 (1972) 941;
E. Braaten, PRL66 (1991) 1655;
N. Itoh et al., Ap. J. 395 (1992) 622;
Braaten-Segel, PRD48 (1993)1478;
Y. Kohyama et al., Ap. J. 431 (1994) 761

Isern et al., [Ap. J. Lett. 682 (2008) 109]
gives a very impressive figure on the most recent calculation of these pioneering works, including this early stage and the crystalization period.

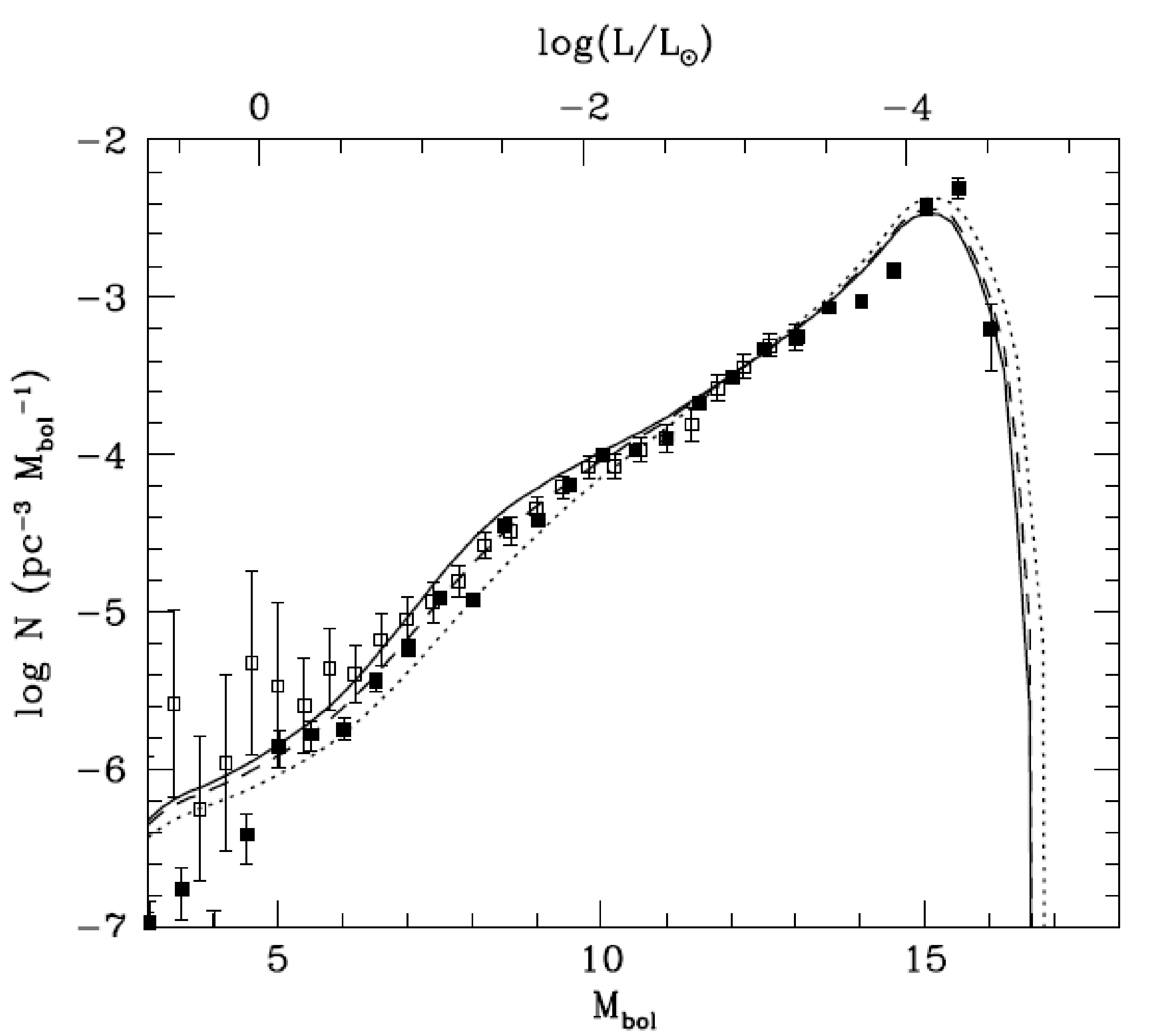



FIG. 3.— White dwarf luminosity functions for different values of the axion mass. The luminosity functions have been computed assuming $m_a \cos^2\beta = 0$ (solid line), 5 (dashed line) and 10 (dotted line) meV.

Isern et al., Ap. J. Lett. 682 (2008) 109

Here, the luminocity is smaller than the above calculation.

One obvious possibility is the contribution from neutrino transition magnetic moments, and their plasmon decay leads to:

$$\frac{1}{2}\mu_{ij}\nu^{iT}C\gamma^{\mu\nu}\nu^{j}F_{\mu\nu} \to \quad \Gamma = \frac{|\mu|^2}{24\pi} Z_{T,L} \frac{\left(\omega_{T,L}^2 - \vec{p}^{\,2}_{plasmon}\right)^2}{\omega_{T,L}}$$

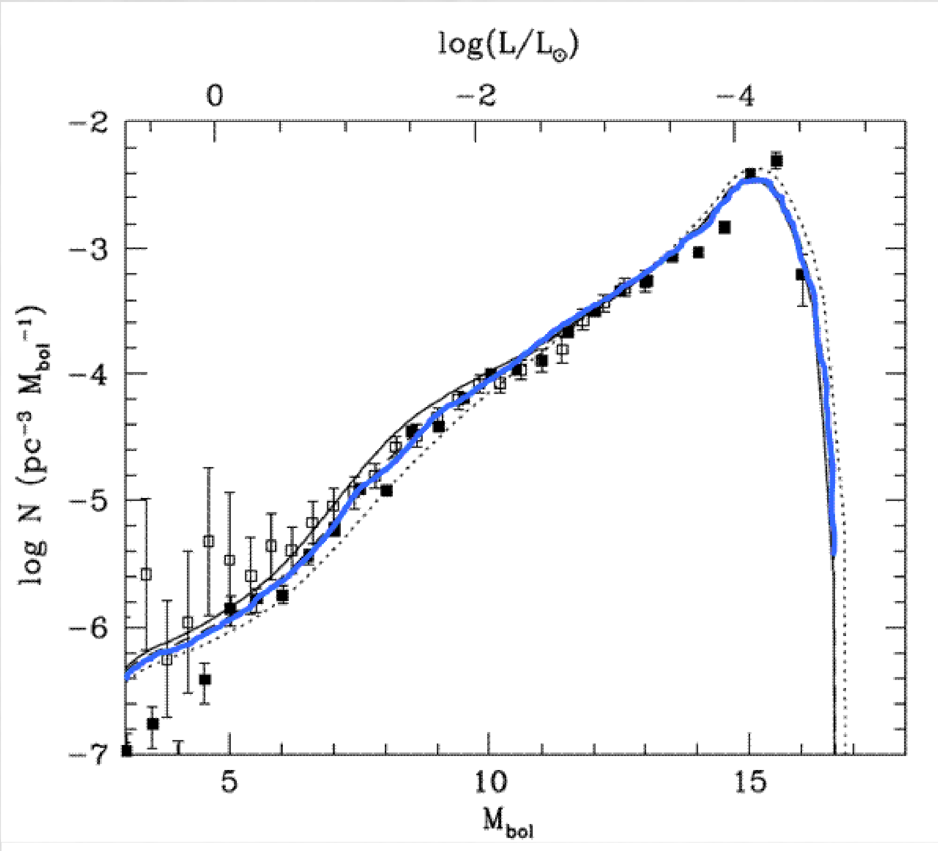
which can be compared to the SM decay to neutrinos in the plasma,

$$C_V = (e\,\nu)\ vector\ \ NC\ \ coupling \to \quad \Gamma = \frac{G_F^2\ C_V^2}{48\pi^2\alpha_{em}} Z_{T,L} \frac{\left(\omega_{T,L}^2 - \vec{p}^{\,2}_{plasmon}\right)^3}{\omega_{T,L}}$$

So, the radiation rate ratio is [Raffelt's book]

$$\boxed{\frac{Q_{mag.\ mom.}}{Q_{SM}} = \ 6.01\left(\frac{\mu}{10^{-11}\mu_{Bohr}}\right)^2\left(\frac{23\ keV}{\omega_P}\right)^2\frac{Q_3}{Q_2}, \quad \frac{Q_3}{Q_2} = O(1)}$$

They varied the star burst rates which is the only important uncertainty, and found that in the middle the predicted WD number stays almost the same. So, they used this almost burst rate independent region to estimate the WD luminocity.




The neutrino magnetic moment possibility is out in the SM.
So, they conclude that there must be another mechanism for the energy loss, and considered the axion possibility.

We translate their number to the axion-electron coupling

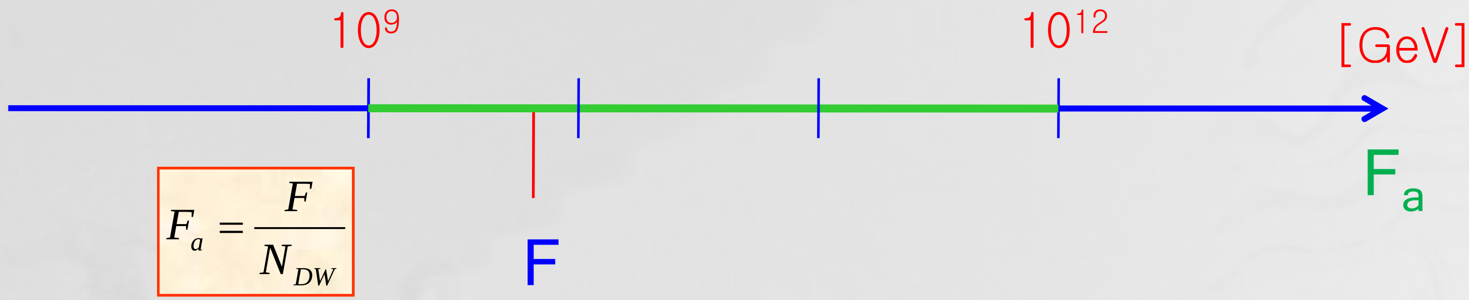
$$\left|\frac{m_e\Gamma(e)}{F}\right| = \frac{m_e}{0.72\times 10^{10}\,GeV} \simeq 0.7\times 10^{-13} : any \quad axion \quad model$$

$$axion-electron \quad coupling: \quad \frac{m_e\Gamma(e)}{F}\bar{e}i\gamma_5 ea, \quad F = N_{DW}F_a$$

So, the axion-electron coupling has the form,

$$\frac{m_e\Gamma(e)/N_{DW}}{F_a}\bar{e}i\gamma_5 ea, \qquad F = N_{DW}F_a, \qquad \Gamma(e) = PQ \quad charge$$

To have a QCD axion at the intermediate scale, $10^9$ - $10^{12}$ GeV, we need some PQ charge carrying scalar develop VEV(s) at that scale. But the domain wall number relates $F=N_{DW}F_a$ with $N_{DW}=1/2$.




$$F_a = \frac{F}{N_{DW}}$$

If we anticipate the axion decay constant at the middle of the axion window, $N_{DW}$ must be smaller than 1 since the needed axion-electron coupling is quite large.

If it is done by the phase of a singlet scalar S, presumably the PQ charges of the SM quark fields must be odd such that sum of the PQ charges of all the quarks(including heavy ones) be 1. But sum of the PQ charges of $e_{2L}$ and $e_R$ is 2. Then we obtain $N_{DW}$ =1/2. Because our objective is the quark-lepton unification, this choice is the simplest.

An enhanced electron coupling compared to the axion lower bound is possible by,

(i) Assign a large PQ charge to e.
The quark-lepton unification makes this idea not very promising, especially in GUTs.

(ii) Assign 1 PQ charge to e, but let the DW number be fractional. In this case, only ½ is possible.
For the quark sector, effectively only one chirality of one quark carries PQ charge, but both $e_L$ and $e_R$ carries PQ charges.

Bae-Huh-Kim-Kyae-Viollier, NPB817 (2009) 58
used only $u_R$ for an effective PQ charged quark. It is Possible in the flipped SU(5) since (u, nu, e)L appear and $e_R$ can be a singlet.

# 3. Two DM components

Huh-Kim-Kyae, PRD79 (2009) 063529

arXiv: 0809.2601.

The PAMELA group observed the excess of positrons.

O. Adriani et al., Nature 458 (2009) 607

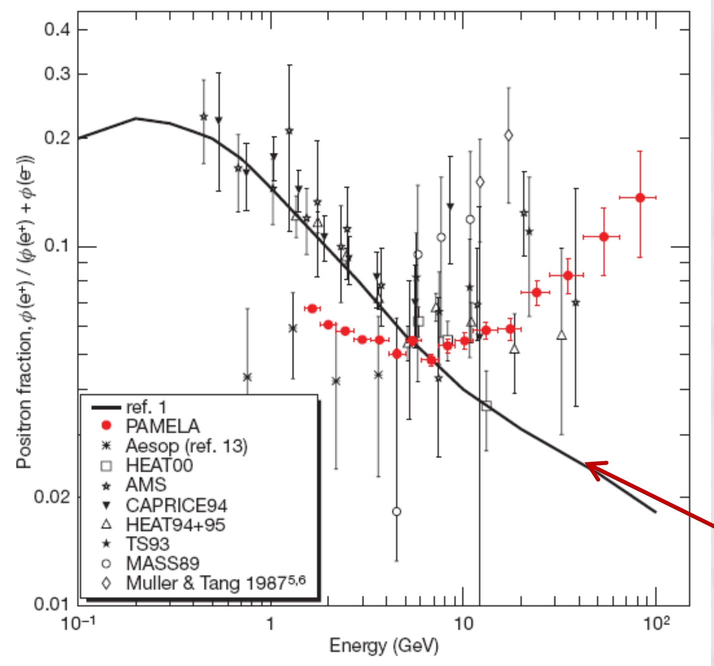



**Figure 2 | PAMELA positron fraction with other experimental data and**

HEAT showed the trend but the PAMELA data indicates the rise above 10 GeV with smaller error bars.

I.V. Moskalenko & A. W. Strong, Ap. J. 493 (1998) 694: Production and propagation of cosmic ray positrons and electrons.

If there is only one Majorana fermion DM (here called LNX), the Fermi-Dirac statistics implies that s-wave amplitude needs anti-parallel helicities of two incoming LNX, i.e. J=0. Since we have v is of order $10^{-3}$, J=0 initially.

If the final state is f f-bar, where f is much lighter than LNX, it must have J=0. If electron-positron pair is directly produced (not by decays of heavy particles), it is suppressed. One may consider the unsuppressed diagram (a), but it is Yukawa suppressed, or (b) at higher order of the e.m. coupling.

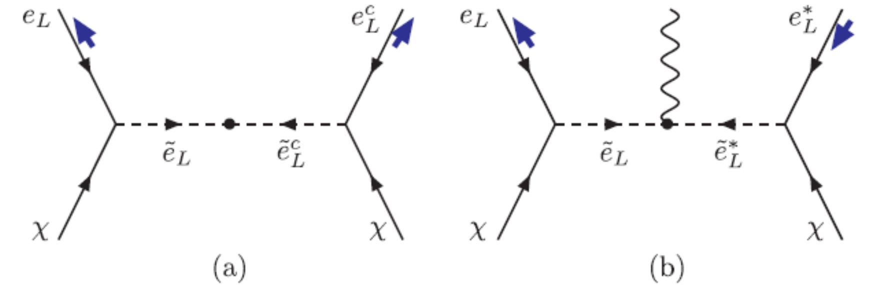



FIG. 1 (color online). The binolike neutralino annihilation. (a) The bullet carries an $SU(2)_W$ quantum number. (b) Here, the bullet can carry angular momentum 1. The helicities of electrons and positrons are shown by thick arrow lines.

So we need at least two components for WIMP DMs.

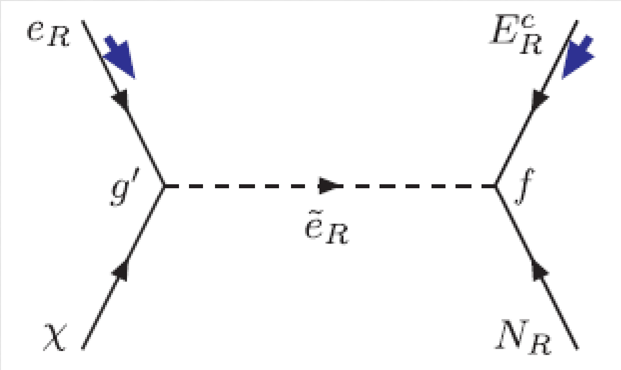
Now our simplest extension of the MSSM will be

(i) Keep the most features of the MSSM.

(ii) Add one more two component neutral DM N.

(iii) Include extra particles such that N-LNX does not have the Fermi-Dirac suppression for $e^+e^-$ production. One must include additional particles such that the needed interaction is present.

The simplest extension is, Introducing N(neutral)and E(charged). The production diagram is

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Here we need both LNX and N to be stable. But,
The MSSM has only one parity for this:

R-parity.

| | $e_R$ | $N_R$ | $N_R^c$ | $E_R$ | $E_R^c$ |
|---|---|---|---|---|---|
| Y= | -1 | 0 | 0 | -1 | +1 |
| R= | +1 | 2/3 | -2/3 | -1/3 | +1/3 |

We try to make our two DM components work even with one parity, R-parity, by some kinematic constraints. The needed couplings are

$$
\boxed{\begin{aligned} &W = f e_R E_R^c N_R + h N_R{}^3 \qquad with \\ &\int d^4\vartheta \left[ \frac{S^*}{M_P} (\lambda E_R E_R^c + \lambda' N_R N_R^c + h.c.) \right] \end{aligned}}
$$

Giudice-Masiero mechanism for E, N mass by $S_F$

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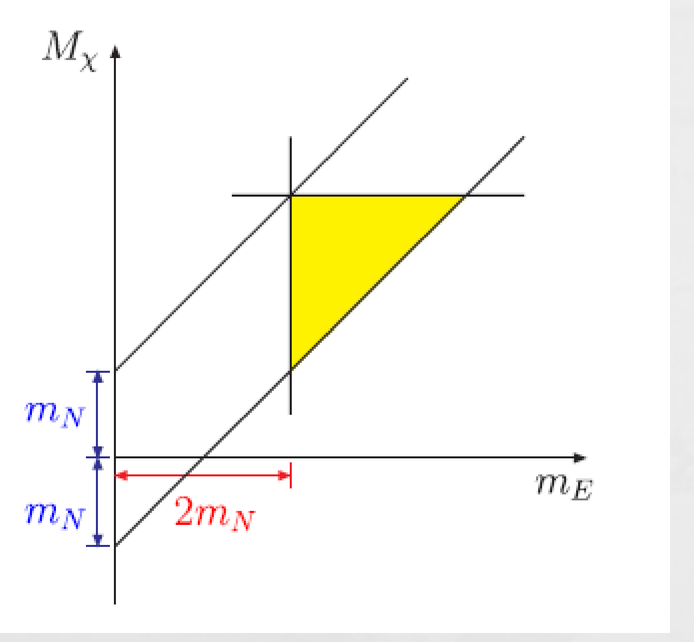
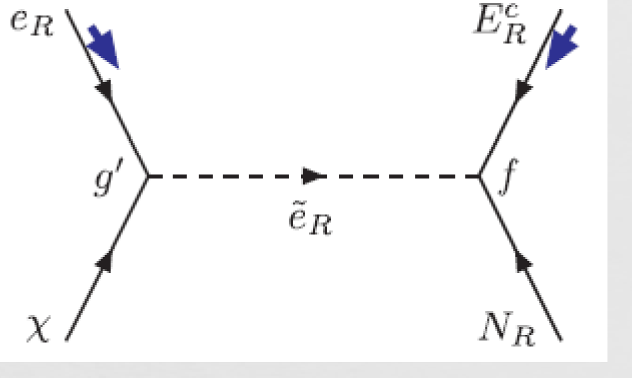
There exists a finite region where N is stable.
In this case we have two DMs even with one parity.
(i) LNX+N→ $E_R$+ $e_R^c$ possible
(ii) LNX should not decay to
$NE_Re_R^c$
(iii) E decay is allowed
(iv) LNX decay is forbidden,
MX< $3m_N$ +$2m_e$




Then, the process produces positrons and electrons after E decay. We use the flux estimation of Delahaye et al. PRD77 (2008) 063527
Cirelli et al, NPB800 (2008) 204



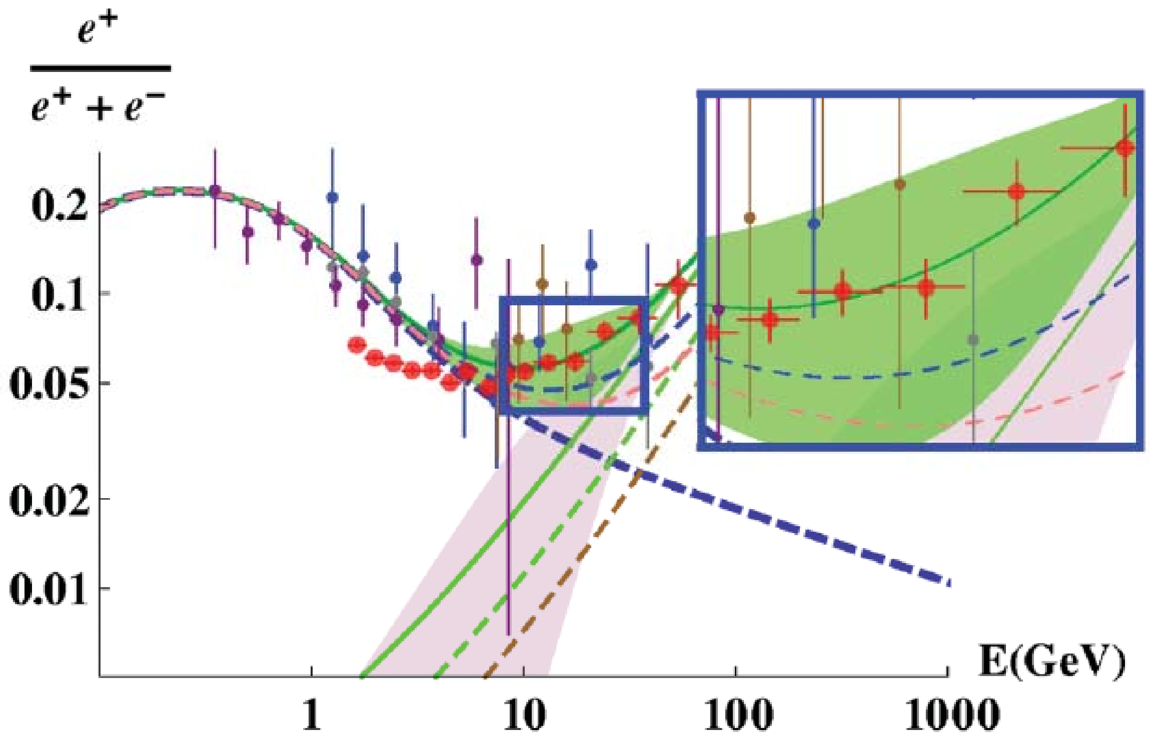
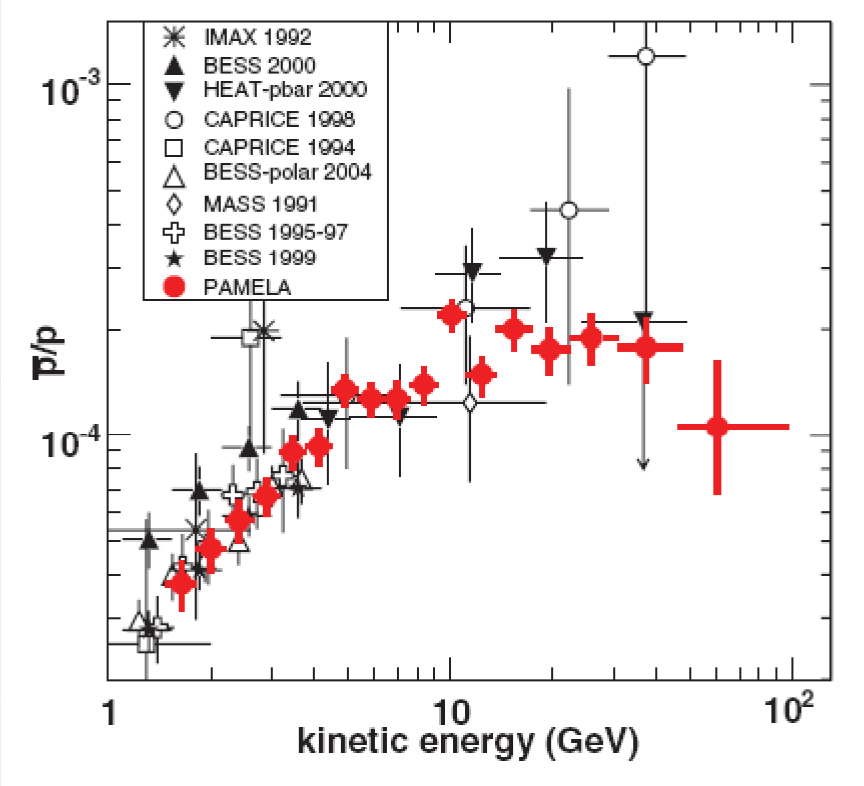



FIG. 4 (color). The positron fraction from our model with $M_\chi = 200$ GeV, $m_N = 80$ GeV, $m_E = 200$ GeV, $M_{\tilde{E}} = 400$ GeV, $M_{\tilde{e}} = 220$ GeV (thick green line), and $B = 7$. $M_{\tilde{e}}$ for 250 GeV (blue dashed line) and 280 GeV (brown dashed line) are also shown. The pink band is the primary positron fraction ($e^+_{\rm primary}/(e^+ + e^-)_{\rm total}$) coming from $\chi N$ and $NN$ annihilations and the green band is this positron excess on top of the astrophysical background (the thick dark-blue dashed line)

Huh-Kim-Kyae,
PRD79 (2009) 063529
arXiv: 0809.2601.

So, neutralino of a few hundred GeV And N of order 100 GeV can have rising positron spectrum for the PAMELA data.




O. Adriani et al., PRL 102 (2009) 051101

The PAMELA group reports no particular increase of antiprotons above 10 GeV. So we have no $u_R U_R^c N_R$ and $d_R D_R^c N_R$ . But we allow $e_R E_R^c N_R$ .

# 4. Flipped SU(5)

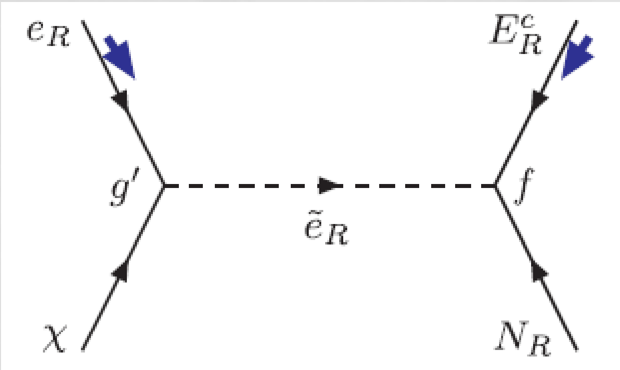
The coupling constant unification implies SUSY GUT models or string compactified models. For the recent observation of PAMELA positrons,

(0) There may be astrophysical sources from pulsars.

Now, we require an interpretation from particle origin:

(i) PAMELA: positrons but no anti-protons
(ii) Introduce minimum needed particles:
two DMs, plus more charged particles
for the idea to make sense
(iii) Try to understand the WD energy loss
mechanism also

To have the following diagram, we need SU(5) singlet charged leptons. We also introduce a neutral singlet N for a DM component.




$$W_{DM} = f e_R E^c_R N_R + N^3_R$$

If we use, e in 10 or 5* of GG model, there must be accompanying quark interactions of the form, $d_R D^c_R N_R$ with a TeV scale D since a TeV scale E must be in 5* or 10. This leads to an antiproton excess by N decay. So, for this N dark matter to work we need E in SU(5) singlets and the flipped SU(5) is a GUT toward this purpose.

The Georgi-Glashow SU(5) turned out to be a good classification scheme of the known fermions.

Rank of SU(5) = 4

Rank of SU(3)xSU(2)xU(1) = 4

So, to break SU(5) down to the SM, we need a Higgs field which contains one of its members sits at the origin of the weight diagram. Then, the rank is not reduced.

It is achieved by the adjoint representation

24 [in general RxR* form]

Namely, many fields are introduced. Another difficulty from string compactification is the difficulty of obtaining such an adjoint representation at level 1. Then the Georgi-Glashow SU(5) is out for a GUT.

All the fundamentals of SU(N) do not have their members at the origin of the weight diagram.
So, a VEV of such Higgs fields break one rank.
The minimal rank containing the SM (as 4+n) is 5.

Rank of SU(5)xU(1) = 5, Rank of SO(10)=5

Rank of SU(3)xSU(2)xU(1) = 4

SUSY GUT models or string compactified models are needed to achieve the coupling constant unification.
This is the reason we consider the flipped-SU(5) as a SUSY or a string generated GUT.

Then,

$$SU(5)_{flip}=SU(5)xU(1)_X$$

can be broken by representation $<10_1>$ as commented above.

$SU(5)_{flip}=SU(5)xU(1)_X$ :

non-SUSY: Barr

SUSY: with a rank reducing symmetry breaking

Derendinger-Kim-Nanopoulos

string construction: with $10_1$

Antoniadis-Ellis-Hagelin-Nanopoulos fermionic string

Kim-Kyae $Z_{12-I}$ orbifold

$$SU(5)\times U(1)_X : \qquad Y=\frac{1}{5}Y_5-\frac{1}{5}X$$

$$Y_5=diag.\left(\frac{-1}{3},\frac{-1}{3},\frac{-1}{3},\frac{1}{2},\frac{1}{2}\right)$$

$$10_1=\begin{pmatrix} d & \boxed{\begin{matrix} u^c \\ d^c \end{matrix}} & \mathrm{N}^c{}_{seesaw} \end{pmatrix}_R, \qquad \overline{5}_{-3}=\begin{pmatrix} u & \boxed{\begin{matrix} \nu_e{}^c \\ e^c \end{matrix}} \end{pmatrix}_R, \qquad 1_5=\boxed{e_R}$$

So a charge q singlet has the X quantum number X=-5q. The flipped-SU(5) can have charged singlets, which was needed from our two DM scenario.

WD axion interpretation needs family difference of PQ charges. Then, it is a natural place to introduce a mass hierarchy.

We tried to understand the family hierarchy problem also. But these contain too much details and discussed extensively in

Bae-Huh-Kim-Kyae-Viollier, NPB817, (2009) 58-75 [arXiv:0812.3511]

The point is that it is indeed possible to construct such SUGRA models with a spontaneously broken PQ symmetry with $N_{DW}$=1/2.

# Conclusion

I talked on SU(5)s in the visible and hidden sectors. The chief reason is that SU(5) is the simplest simple group having chiral representations with fundamentals.

1. GUT motivation. Of course, the SM is chiral but it is not a unification group.
2. In fact, the visible sector better to be a flipped SU(5), from WD axions, PAMELA data. But, this is just an example.
3. The hidden sector is better to be chiral. So, among simple groups we choose SU(5)' as the simplest possibility of the hidden sector. A bigger group will be more difficult to be realized from string compactification.