Asymmetric Sneutrino Dark Matter

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- *Asymmetric Sneutrino Dark Matter and the Ω_b/Ω_{dm} Puzzle*;
  hep-ph/0410114, PLB, Dan Hooper, John March-Russell, and SW

from earlier work,

- hep-ph/0403067, PLB, John March-Russell and SW
- hep-ph/0403183, JHEP, Thomas Hambye, John March-Russell, and SW
- hep-ph/0408318, PRD, SW

Brief Introduction

- Inferred values of the cosmological baryon and dark matter densities are strikingly similar. WMAP determined range for dark matter density,

  $$0.129 > \Omega_{\rm dm} h^2 > 0.095$$

  Combined WMAP and big-bang nucleosynthesis determined value of the baryon density,

  $$0.025 > \Omega_{\rm b} h^2 > 0.012$$

- In most theories of the early Universe, these densities are determined by separate dynamics

- Baryon density set by a baryon asymmetry
  $\Rightarrow$ Depends on unknown baryon-number violating dynamics and unknown CP-violating phases

- Dark matter density is set by the 'freeze-out' of the interactions that keep the dark matter in equilibrium, and is independent of the dynamics of baryogenesis
  $\Rightarrow$ No reason why we should expect $\Omega_{\rm b}$ and $\Omega_{\rm dm}$ to coincide

Sharing a quantum number

- Possible solution is to link the dynamics of the two sectors
- Natural to consider models where the dark matter and baryon sectors share a quantum number
- Provides a relation between surviving number densities and thus energy densities
- First consider a simple example...

⇒ Simple case where dark matter and baryon sectors cannot exchange their quantum numbers after production.
⇒ Let SM Baryon state have global charge q and lightest dark matter state (with mass m_{dm}) have global charge Q.

Conservation of global charge means,

$$q\,(n_{\rm b} - n_{\bar{\rm b}}) = -Q\,(n_{\rm dm} - n_{\bar{\rm dm}})$$

$\rightarrow$ Assume further that interactions in each sector are strong enough so that anti-particles are eliminated by annihilations with particles (and $Q/q < 0$ for simplicity). This implies,

$$n_{\rm b} = c n_{\rm dm} \quad \text{with} \quad c = |Q/q|$$

and moreover,

$$\frac{\Omega_{\rm b}}{\Omega_{\rm dm}} = \frac{m_{\rm b}}{m_{\rm dm}} \frac{n_{\rm b}}{n_{\rm dm}} = c \frac{m_{\rm b}}{m_{\rm dm}}$$

- Energy densities are related, but the ratio is only naturally $\mathcal{O}(1)$ if the ratio of the baryon to dark matter masses is not too small.

- Disfavours models of the above type where DM is from a "hidden sector" and favours DM with masses generated from e-weak physics, such as softly broken susy at weak scale

- Realistic models will have exchange of shared quantum numbers between two sectors

- Ratio of conserved quantum number, c, determined by "chemical" equilibrium conditions just before freeze out.

Example Model

- Propose a model where dark matter has a particle-antiparticle asymmetry

- Via shared quantum number, asymmetry could determine both the baryon asymmetry and the dark matter density, thus naturally linking $\Omega_{\rm b}$ and $\Omega_{\rm dm}$

- Simple relation, $\Omega_{\rm b} = c\Omega_{\rm dm} m_{\rm b}/m_{\rm dm}$, needs to be modified, assuming the particle-particle annihilation cross section is negligible,

$$\Omega_{\rm dm} h^2 = \Omega_{\rm b} h^2 \frac{A}{A_{\rm bary}} \frac{m}{m_{\rm bary}},$$

  where A and $A_{\rm bary}$ are the particle-antiparticle asymmetries of the dark matter relic and of baryons, defined by $A = (n - \bar{n})/n$. Here m and $m_{\rm bary}$ are the masses of our dark matter relic and of baryons ($i.e.$ the proton mass)

Dark Matter Candidate

- Such a model is not possible with neutralino.
- Can a sneutrino be the DM in this case?
- Within MSSM, sneutrinos make a poor dark matter candidate. They annihilate efficiently $\Rightarrow \Omega_{\tilde{\nu}} h^2 \ll 0.1$ for $m_{\tilde{\nu}} < 500$ GeV. Also, elastic σ is sufficiently large and so would be easily observed by DM experiments as well as invisible width of Z.
- However, in a particular class of models, where the RH neutrino has TeV scale mass, the LHD and RHD sneutrino states can have large mixing via large trilinear A-terms
- Mixing between the lhd 'active' sneutrino, $\tilde{\nu}$, and rhd 'sterile' sneutrino, $\tilde{n}$: Lightest mass eigenstate

$$\tilde{\nu}_1 = -\tilde{\nu} \sin\theta + \tilde{n}^* \cos\theta$$

- Since $Z \to \tilde{\nu}_1 \tilde{\nu}_1$ decay is suppressed by $\sin^4\theta$, the LEP constraints are greatly weakened.
  $\Rightarrow$ LSP can be $\tilde{\nu}_1$

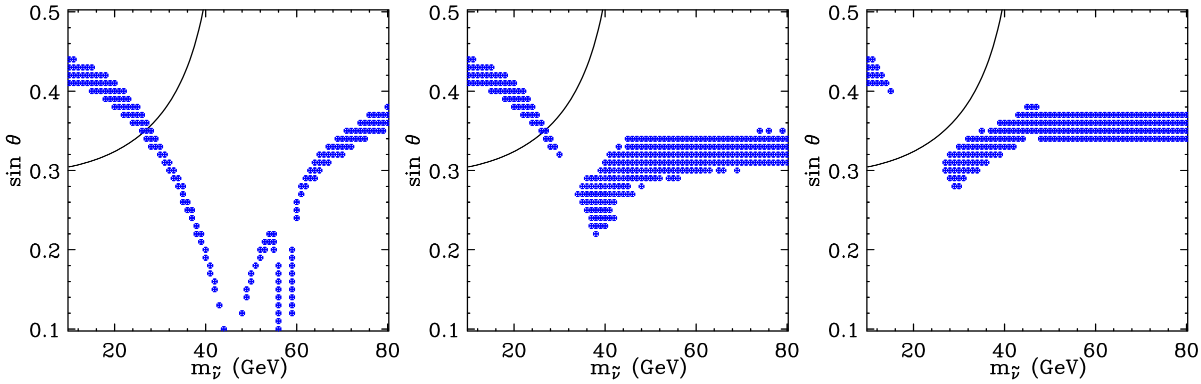
In addition...

- Annihilation cross section is also suppressed by $\sin^4\theta$ $\Rightarrow$ sneutrino thermal relic abundances increased to relevant values

- If sneutrino $\tilde{\nu}_1$ is LSP and DM then asymmetry in sneutrino number can result from leptogenesis, giving Ω_{dm}, which automatically implies non-zero Ω_b through the electroweak (EW) anomaly

- Consequently, in this model, the shared quantum number is B-L.

Results



- The regions of parameter space which provide the quantity of mixed sneutrino cold dark matter measured by WMAP, $0.129 > \Omega_{\rm dm}h^2 > 0.095$

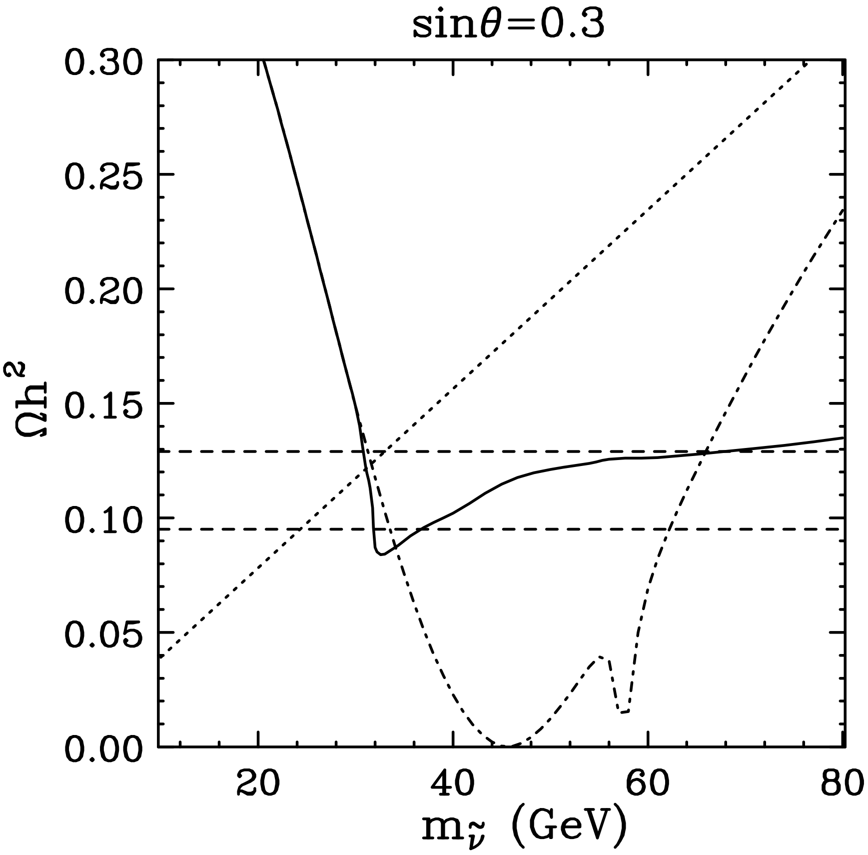
- In the left frame, standard calculation with no matter-antimatter asymmetry is used

- Approaching Z-mass, need smaller $\sin[\theta]$ to have correct relic density

- Center frame effect of an asymmetry with $A/A_{\rm bary} \simeq 1/6$ is included, while in the right frame an asymmetry $A/A_{\rm bary} \simeq 1/3$ is used. (Ratio values dependent on no. RH (s)neutrinos have masses below T_c)

- Region above solid line excluded by invisible Z width

More...



- Thermal relic density as a function of mass for sneutrinos+antisneutrinos with no asymmetry (dot-dash), with a matter-antimatter asymmetry of $A/A_{\rm bary} \simeq 1/6$ (solid) and the simplified estimate (dots).

- The relic density range favored by WMAP is bound by dashed lines ($0.129 > \Omega_{\rm dm}h^2 > 0.095$).

- Parameters, $\sin\theta$=0.3, M_1=300 GeV, M_2=300 GeV, μ=600 GeV, $\tan\beta = 50$ and m_h=115 GeV have been used.

Comments and Conclusions

- Using a shared quantum number, one can relate the dark matter energy density to the baryon energy density

- Sneutrino can be an example of such dark matter

- Sneutrino is usually a bad dark matter candidate but can be viable dark matter if LHD and RHD states have large mixing

- In addition, if there exists a sneutrino-antisneutrino asymmetry, the acceptable parameter space for producing the correct size for $\Omega_{\rm dm}h^2$ is greatly increased