Common Origin of Asymmetric Inert Doublet DM and Leptogenesis

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Observations from Cosmology

- Baryon Asymmetry of the Universe:

$$\left.\frac{n_B}{n_\gamma}\right|_0 = (6.15 \pm 0.25) \times 10^{-10}$$

- Contribution of baryon to Critical density:

$$\Omega_B = 0.0456 \pm 0.0016$$

- Relic Abundance of Dark Matter:

$$\left.\frac{n_{DM}}{n_\gamma}\right|_0 \approx 2.8 \times 10^{-10} \left(\frac{10GeV}{M_{DM}}\right)\left(\frac{\Omega_{DM} h^2}{0.11}\right)$$

- Contribution of DM to critical density:

$$\Omega_{DM} = 0.227 \pm 0.014$$

Implication for DM and BAU

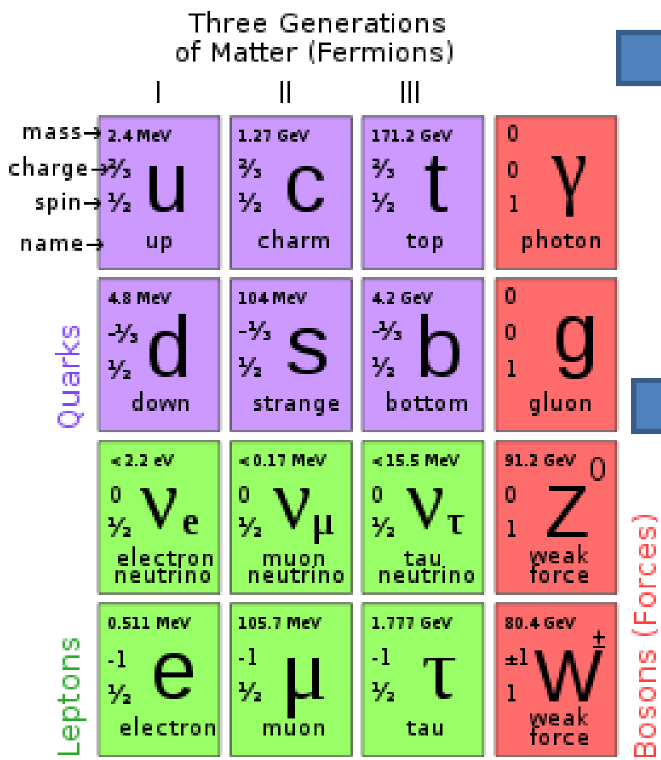
- Relic abundance of DM could be an asymmetric component like baryon asymmetry of the Universe.

- The two asymmetries could share a common origin and therefore they can easily explain:

$$\frac{\Omega_{DM}}{\Omega_B} = 4.978 \pm 0.350$$

(Ratio of two Gaussian distributions)

Quick look on SM of Particle Physics

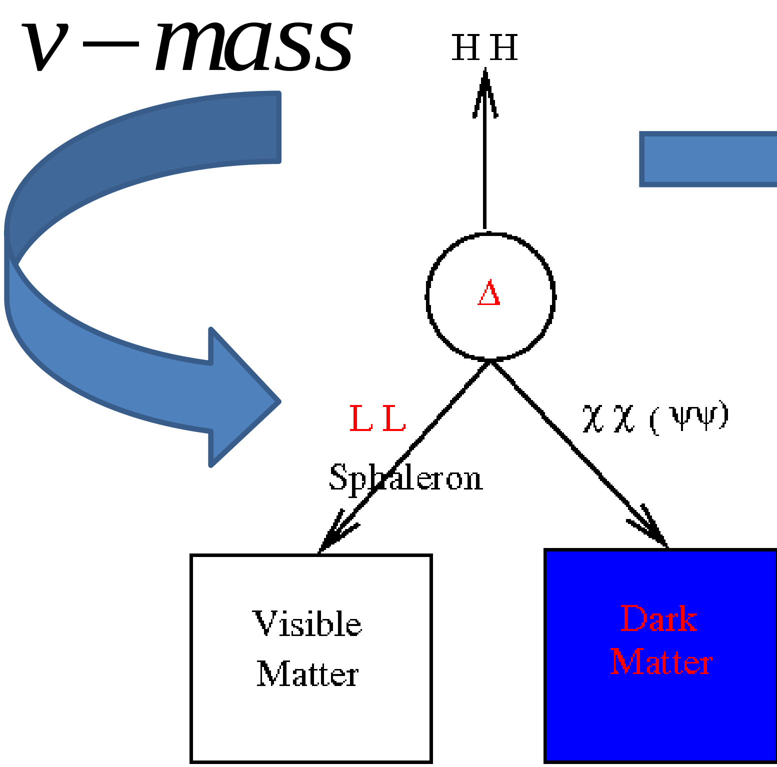


A candidate of DM is required to be introduced

An explanation of baryon asymmetry of the Universe is to be added.

Sub-eV neutrino masses should be explained.

Model for Asymmetric DM, BAU and ν-masses



$$\varepsilon_L \neq \varepsilon_{DM}$$

Large DM masses up to O(TeV) is allowed to satisfy: $\dfrac{\Omega_{DM}}{\Omega_B} = 4.978 \pm 0.350$

Technical description of the Model

For inert (Z_2 symmetry odd) scalar doublet DM :

$$-\mathcal{L} = M_\Delta{}^2 \Delta^+ \Delta + f_L \Delta LL + f_H M_\Delta \Delta^+ HH + f_\chi M_\Delta \Delta^+ \chi\chi + h.c.$$

For inert (Z_2 symmetry odd) fermion doublet DM:

$$-\mathcal{L} = M_\Delta{}^2 \Delta^+ \Delta + M_D \overline{\psi}\psi + f_L \Delta LL$$
$$+ f_H M_\Delta \Delta^+ HH + f_\psi M_\Delta \Delta \psi\psi + h.c.$$

In either model Neutrino mass: $M_\nu = f_L f_H \dfrac{v^2}{M_\Delta}$

- The partial decay: $\Delta \to LL$ and $\Delta \to \chi\chi(\psi\psi)$ gives rise to a common origin of asymmetric inert doublet (scalar or fermion) DM and successful lepton asymmetry.

Elastic versus Inelastic Doublet DM

- Elastic doublet DM is strongly ruled-out by the direct DM search experiments as Z-boson mediated process (DM N → DM N) gives large cross-section.

- Any valid doublet DM (non-zero hyper charge) should be inelastic type. Namely the valid process at direct DM search experiments should be

$$DM_1 N \rightarrow DM_2 N$$

with mass splitting $\delta = DM_2 - DM_1$

Inelastic Scalar doublet DM (SDDM)

Due to the $SM \times Z_2$ symmetry, the scalar potential involving the scalar triplet Δ, the inert scalar doublet χ and the SM Higgs H permits a term:

$$\frac{\lambda_5}{2}[(H^+\chi)^2 + h.c.]$$

When H acquires a vev, it gives a mass splitting between the real (S) and imaginary (A) part of the neutral component of the inert SDDM

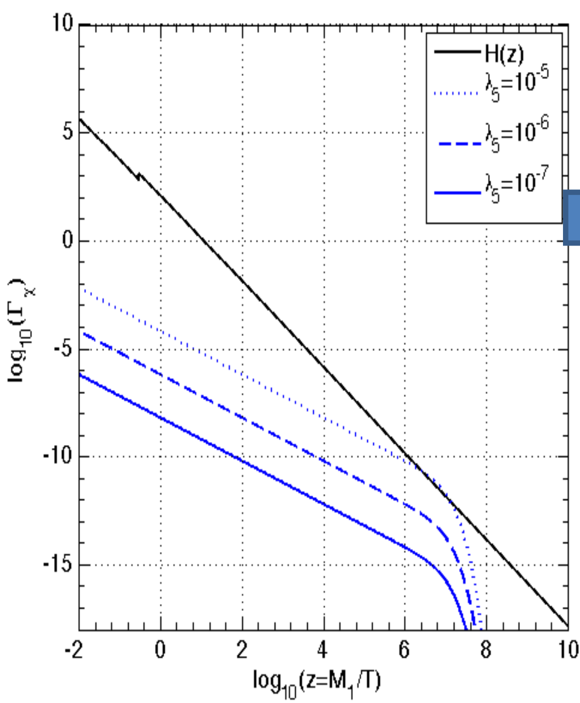
$$\chi^T = (\chi^+, \chi^0) = (\chi^+, S + iA)/\sqrt{2})$$

to be $\Delta M^2 \equiv M_S{}^2 - M_A{}^2 = \lambda_5 \langle H \rangle^2 \Rightarrow \lambda_5 = \dfrac{2M_S\delta}{\langle H \rangle^2}$

Inelastic SDDM and Constraints

Reconciling annual modulation at DAMA with null results at other experiments demands

$$\delta = M_S - M_A = O(100)keV \Rightarrow \lambda_5 \approx 10^{-7}$$



Contact annihilation $\chi\chi \to HH$ via λ_5 is out of danger, otherwise strongly depletes DM asymmetry

$$M_\chi = 2TeV, M_1 = 10^{10} GeV$$

$$\frac{M_\chi}{T} = \frac{M_\chi}{M_1} z = 0(1)$$

Inelastic SDDM and Constraints

Below EW phase transition λ_5 introduces a mass splitting between real (S) and imaginary (A) part of χ^0. Therefore there is a fast oscillation between the two states:

$$\left|\chi^0\right\rangle = \frac{1}{\sqrt{2}}(S+iA) \Leftrightarrow \left|\overline{\chi^0}\right\rangle = \frac{1}{\sqrt{2}}(S-iA)$$

With probability $P_{\left|\chi^0\right\rangle \to \left|\overline{\chi^0}\right\rangle} \approx \frac{1}{2}[1-\cos(\frac{\Delta M^2(t-t_{EW})}{2E})]$

$M_\chi > 2TeV$

Asymmetry in DM survives

Inelastic Fermion Doublet DM (FDDM)

The $SM \times Z_2$ symmetry also allows a vector like fermion doublet DM $\psi \equiv (\psi_{DM}, \psi_-)$,whose mass is given by:

$$-\mathcal{L} = M_D \overline{\psi_{DM}} \psi_{DM} + \frac{1}{\sqrt{2}} g \overline{\psi^c{}_{DM}} \psi_{DM} \langle \Delta^0 \rangle$$

If we write $\psi_{DM} = (\psi_{DM})_L + (\psi_{DM})_R$, then their mass can be given by the 2×2 mass term

$$\begin{pmatrix} M_D & m \\ m & M_D \end{pmatrix}$$

Diagonalising we get two mass eigen states $(\psi_{DM})_1$ and $(\psi_{DM})_2$ with masses $M_D - m$ and $M_D + m$

Inelastic FDDM and Constraints

- Reconciling DAMA annual modulation with the null results from other experiments demands the mass splitting between the two states :

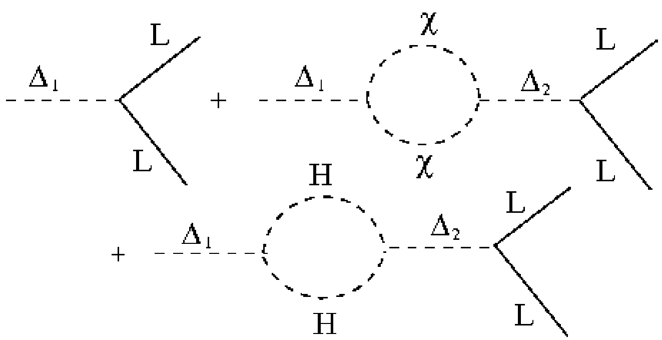
$$\delta = 2m = O(100)keV$$

- Invisible Z-decay width demands the mass of FDDM:

$$m_{DM} > \frac{M_Z}{2}$$

Asymmetries in Lepton and DM sectors

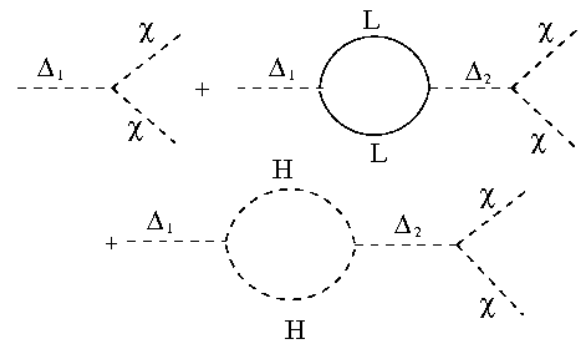
- CP asymmetry in lepton sector:



- Yield for leptons

$$Y_L = \varepsilon_L \eta_L X_\Delta$$

- CP asymmetry in DM sector:



- Yield for Dark Matter

$$Y_{DM} = \varepsilon_{DM} \eta_{DM} X_\Delta$$

$$\frac{\Omega_{DM}}{\Omega_B} = \frac{1}{S_{DM}} \frac{m_{DM}}{m_p} \frac{\varepsilon_{DM}}{\varepsilon_L} \frac{\eta_{DM}}{\eta_B}$$

Boltzmann equations for asymmetries

$$\frac{dX_\Delta}{dz} = -\frac{\Gamma_D}{zH(z)}(X_\Delta - X_\Delta^{eq}) - \frac{\Gamma_A}{zH(z)}\left(\frac{X_\Delta^2 - X_\Delta^{eq\,2}}{X_\Delta^{eq\,2}}\right)$$

$$\frac{dY_\Delta}{dz} = -\frac{\Gamma_D}{zH(z)}Y_\Delta + \sum_j \frac{\Gamma_{ID}^j}{zH(z)} 2B_j Y_j \qquad j = L, H, \chi(\psi)$$

$$\frac{dY_j}{dz} = 2\left[\frac{\Gamma_D}{zH(z)}\left(\varepsilon_j (X_\Delta - X_\Delta^{eq})\right) + B_j\left(\frac{\Gamma_D}{zH(z)}Y_\Delta - \frac{\Gamma_{ID}^j}{zH(z)}2Y_j\right) - \sum_k \frac{\Gamma_S^k}{zH(z)}\frac{X_\Delta^{eq}}{X_k^{eq}}2Y_k\right]$$

$$2Y_\Delta + \sum_j Y_j = 0 \qquad \Gamma_D = \frac{1}{8\pi}\frac{m_\nu M_1^2}{\langle H\rangle^2\sqrt{B_L B_H}}\frac{K_1(z)}{K_2(z)} \qquad z = \frac{M_1}{T}$$

Input parameters and Constraints

- We set the triplet mass $M_1 = 10^{10} GeV$. Therefore the scatterings are not important.

- The dominant factors that drives the yields are the branching fractions: B_L, B_{DM}, B_H. They satisfy the constraint: $B_L + B_{DM} + B_H = 1$

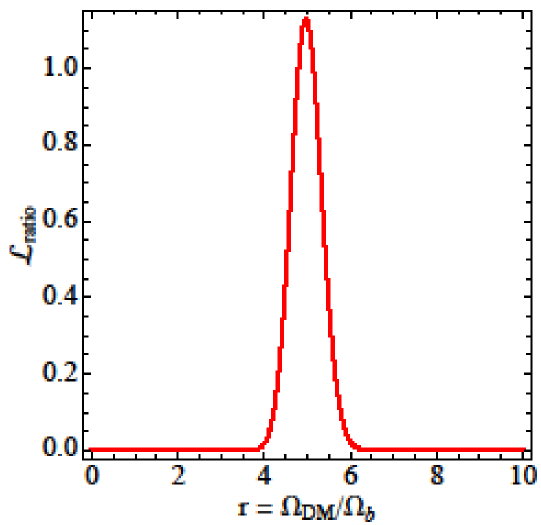
- The CP asymmetries follow the relation:

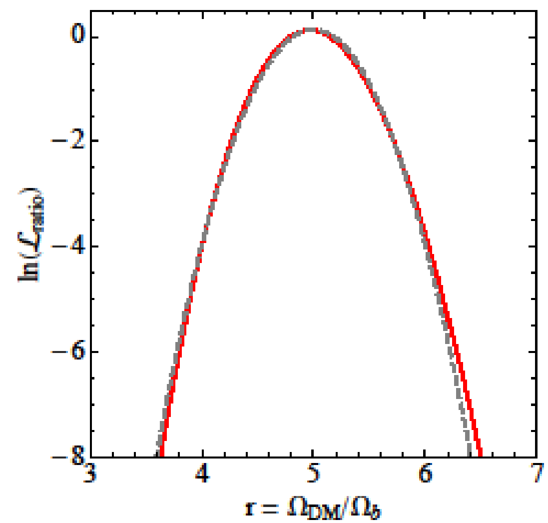
$\varepsilon_L + \varepsilon_{DM} + \varepsilon_H = 0$ and $|\varepsilon_j| \leq 2B_j$

- Thus we have five independent parameters $B_L, B_{DM}, \varepsilon_L, \varepsilon_{DM}, m_{DM}$ for the ratio: Ω_{DM}/Ω_B

Bayesian inference and MCMC Techniques

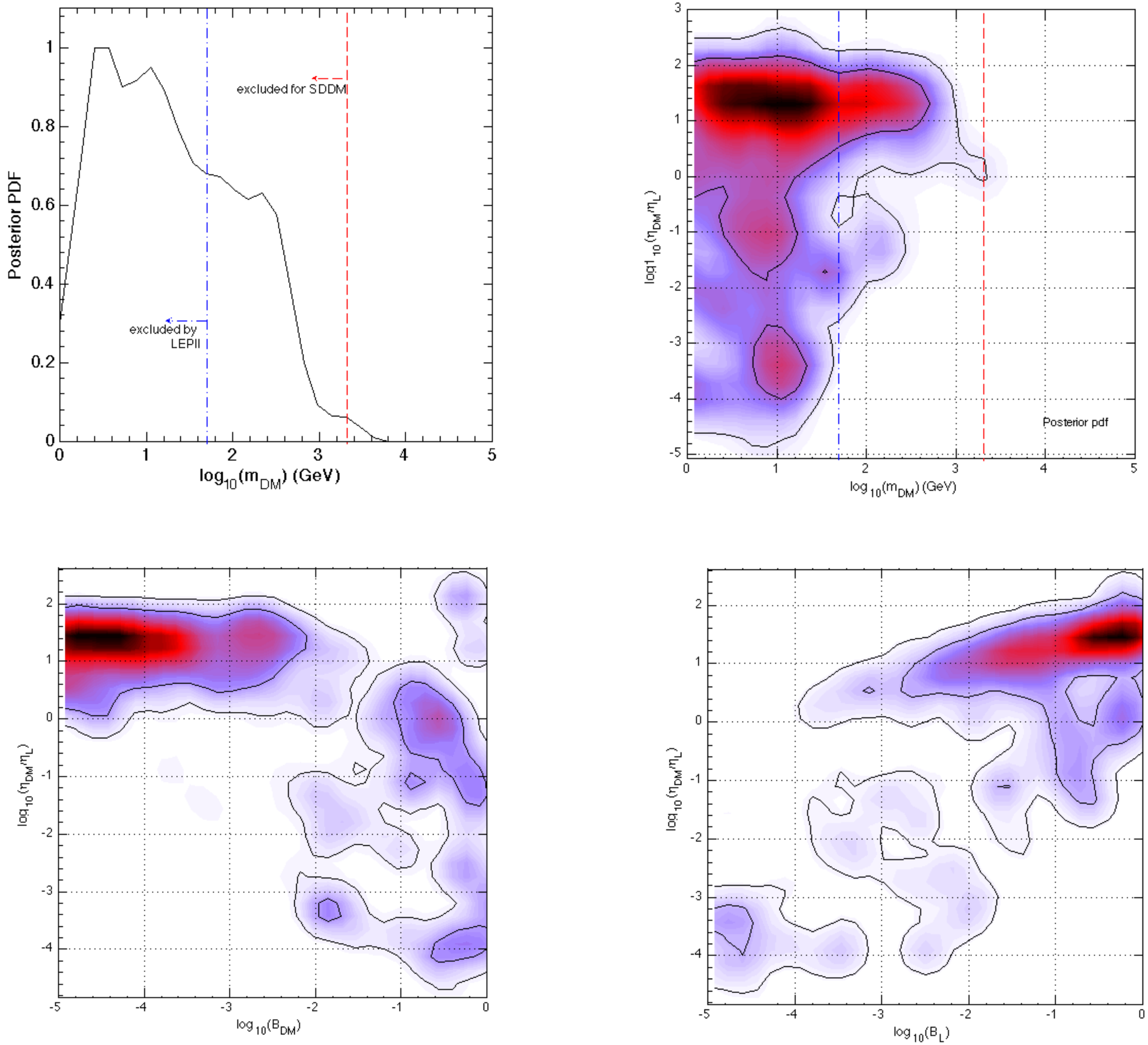
The important point for this analysis is the Bayes theorem: $p(\theta | X) d\theta = L(X | \theta) \pi(\theta) d\theta$



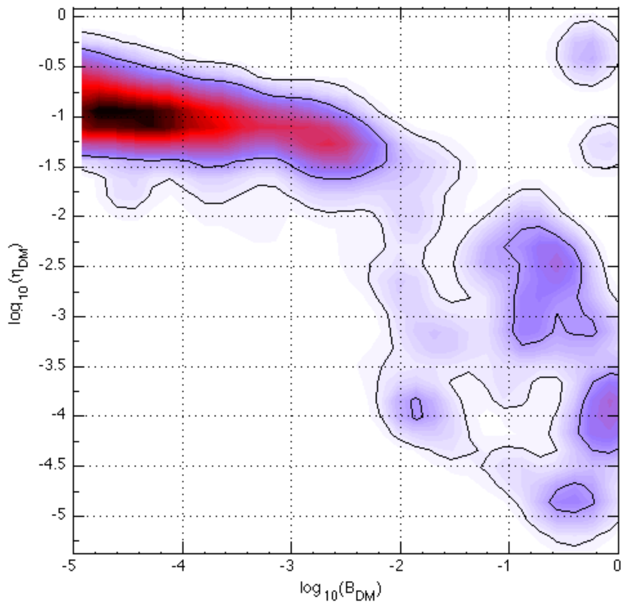


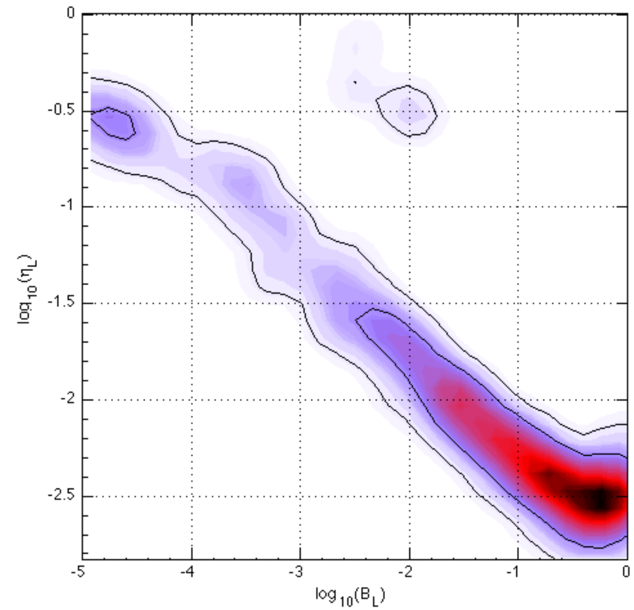
The likelihood of the ratio is almost a Gaussian

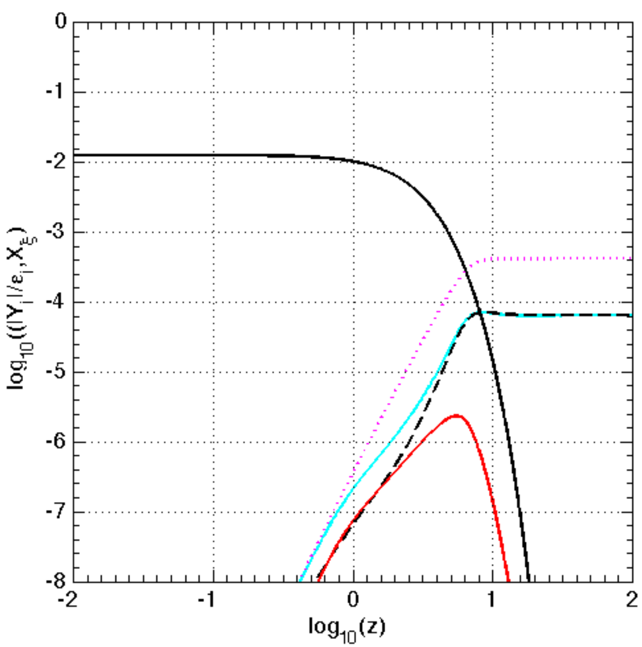
$$\frac{\Omega_{DM}}{\Omega_B} = 4.978 \pm 0.350$$

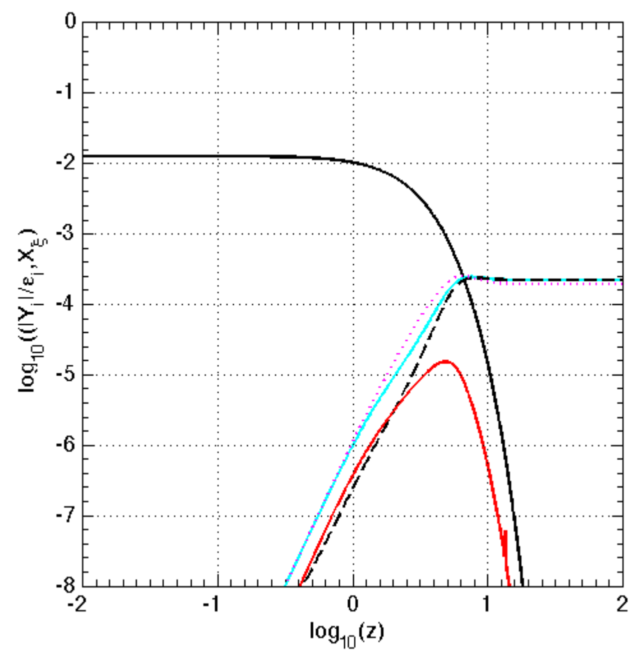


Posterior PDF
log10(mDM) (GeV)
excluded for SDDM
excluded by
LEPII
log1 10(ηDM/ηL)
Posterior pdf
log 10(mDM) (GeV)
log10(ηDM/ηL)
log 10(BDM)
log10(ηDM/ηL)
log 10(BL)

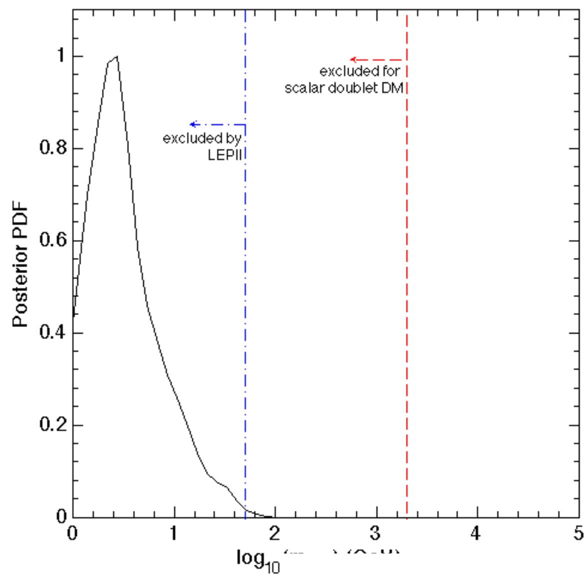

log10(ηDM)
log10(BDM)

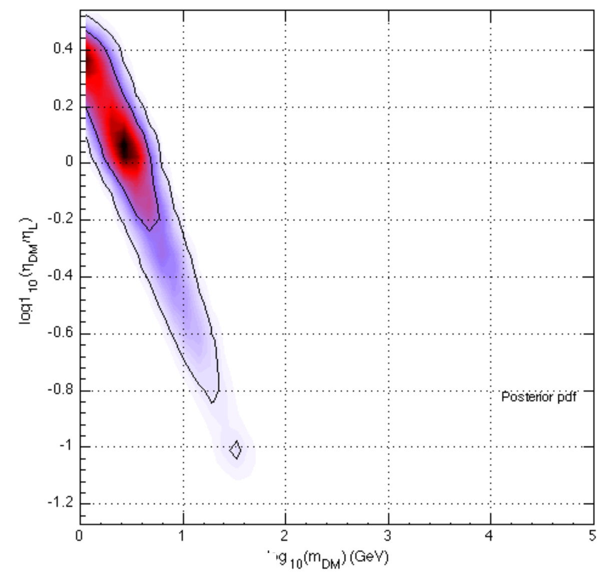

log10(ηL)
log10(BL)

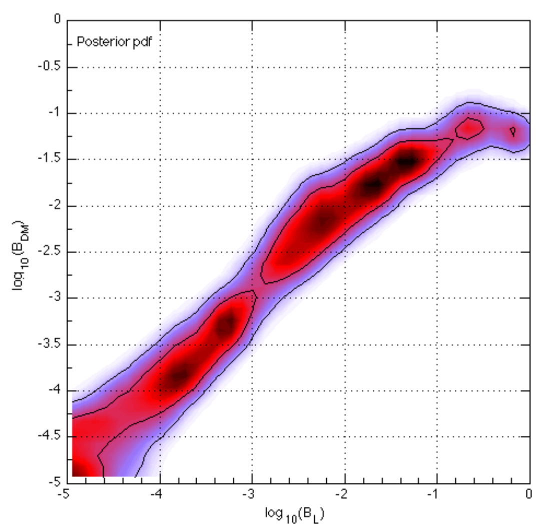

log10((|Yi|/εi, Xξ)
log10(z)


log10((|Yi|/εi, Xξ)
log10(z)

PDF with equal CP Asymmetries







Conclusions

1. We proposed a triplet seesaw model to explain the common origin of asymmetric DM, baryon asymmetry and the sub-eV neutrino masses

2. The asymmetric scalar doublet DM is required to be order of TeV scale in order to surive from catastrophic oscillation below EW scale, while a vector like fermion doublet DM of 100 GeV is perfect from all respective (including direct search)

3. The observed baryon asymmetry of the Universe and asymmetric DM requires large branching ratio towards lepton and small branching ratio towards DM for which the ratio of efficiency factors maximises.