WIMPy Baryogenesis/Leptogenesis Miracle

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Arnab, Chandan, SP, Utpal, [arXiv:1605.01292] Appeared Today !!

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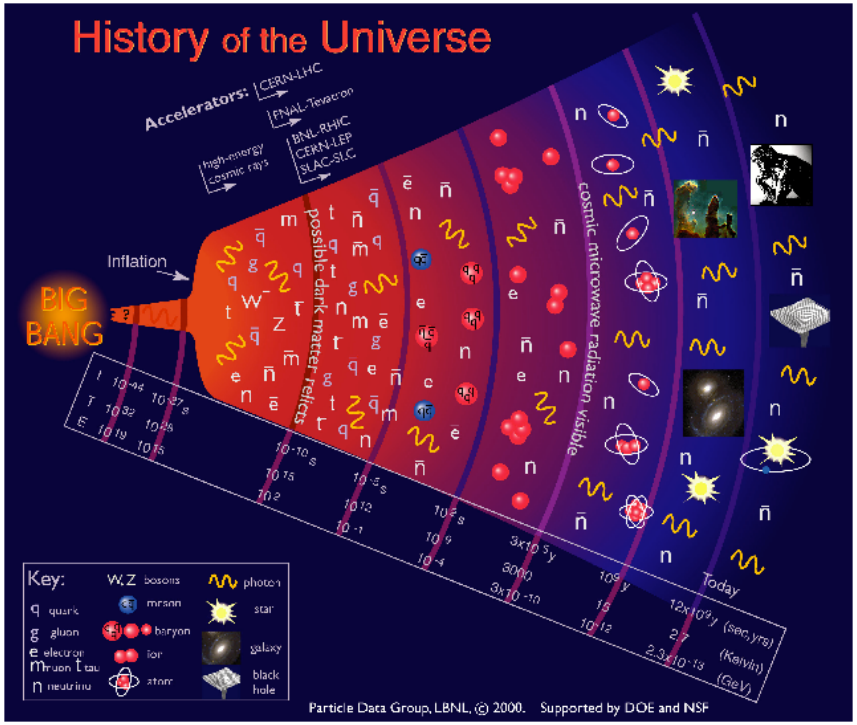
Workshop on perspectives on the Extragalactic origin: Astrophysics to Fundamental Physics

Plan

- ★ A cosmic puzzle: Link between Baryon asymmetry and Dark Matter of the Universe
- ★ WIMPy Baryogenesis
- ★ WIMPy Leptogenesis: a TeV scale Miracle.
  - Basic Picture
  - CP-asymmetry
  - Boltzmann Equation
- ★ Summary

Unsolved Problems in Astro-Particle Physics

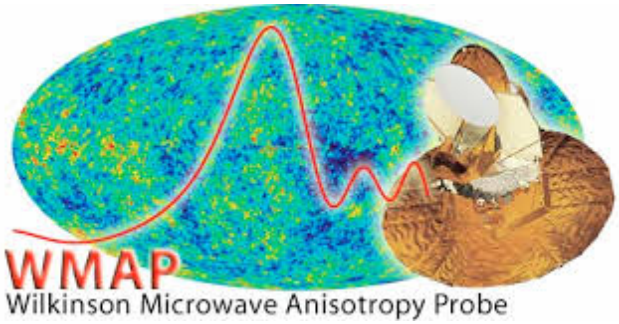


★ **Baryon Asymmetry:** Why our present Universe is matter dominated ?

★ **Dark Matter:** Constituting 25% energy density of Universe ?

★ Theoretical origin of non-zero Neutrino masses ?

Observational Facts



★ **Cosmic microwave background (CMB) anisotropy observations by the Wilkinson Microwave Anisotropy Probe (WMAP):**
Baryon to Photon ratio as

$$\eta_B^{\rm CMB} \equiv \frac{n_B - n_{\overline{B}}}{n_\gamma} = (6.3 \pm 0.3) \times 10^{-10}$$ **[From Planck 2015 also]**

★ **Dark Matter (DM) relic abundance:** $\Omega_{DM} h^2 \simeq 0.1123$
★ **Baryonic Mater abundance:** $\Omega_B h^2 \simeq 0.0.02$

Can DM and Baryon asymmetry connected ...?

- ★ **Coincidences: $\Omega_{DM}/\Omega_B \simeq 5$ related to Asymmetric Dark Matter**
- ★ **WIMP Miracle: $\Omega_{DM} \simeq 0.1123$ Weak scale mass and coupling, thermal freeze-out**
- ★ **Generally, baryogenesis and the establishment of the dark matter number density are treated as independent processes.**
- ★ **Can weakly interacting massive particle (WIMP) dark matter connected dark matter physics with baryogenesis ?**
  - ★ **WIMPy Baryogenesis:-** Cui, Randall, Shuve, JHEP 1204 (2012) 075

    Different from Asymmetric Dark Matter: Not discussed here !

Motivation

Keep the WIMP miracle and ask the question

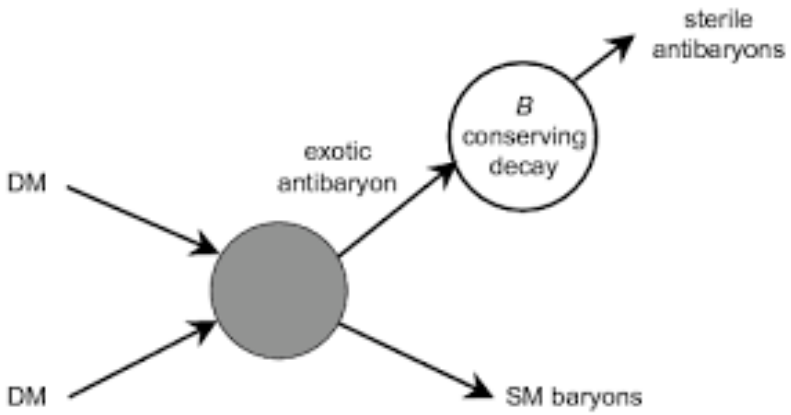
can we have a framework where the baryon asymmetry can be related to the thermal WIMP relic abundance?

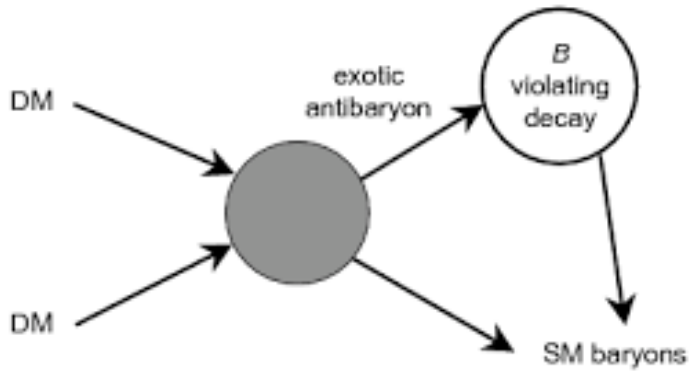
WIMPy Baryogenesis:Miracle and Miracle !!

Cui, Randall, Shuve, JHEP 1204 (2012) 075

★ **Two miracle happen in one framework**

- **WIMP Miracle:**
  weak-scale DM, thermal relic abundance
- **WIMPy baryogenesis miracle:**
  Weakly Interacting Massive Particle (WIMP) Dark Matter annihilation is directly responsible for Baryon asymmetry





Sakharov conditions for WIMPy Baryogenesis

- ★ **Baryon number violation:**
  - **WIMP annihilations violate baryon or lepton number. We propose a minimal $U(1)_{B-L}$ gauge model to realize.**
- ★ **CP violation:**
  - **WIMP couplings to Standard Model fields violate CP**
- ★ **Departure from thermal equilibrium:**
  - **the cooling of the universe provides the nec- essary departure from thermal equilibrium.**

A TeV scale model for WIMPy Leptogenesis
Arnab, Chandan, SP, Utpal [arXiv:1605.01292]

- ★ **propose a novel framework to explain dark matter abundance and matter-antimatter asymmetry simultaneously via WIMPy leptogenesis.**
- ★ **SM + DM fermions (N's)+ Extra scalars (η, ζ)**
- ★ **The role of $N's$ are two fold:-**
  - To cancel the gauge triangle anomalies indued by $U(1)_{B-L}$ gauge model:

$$\mathcal{A}\left[(U(1)_{B-L})^3\right], \qquad \mathcal{A}\left[U(1)_{B-L}(U(1)_Y)^2\right]$$
$$\mathcal{A}\left[U(1)_{B-L}(SU(2)_L)^2\right] \qquad \mathcal{A}\left[\text{gravity}^2 \times U(1)_{B-L}\right]$$

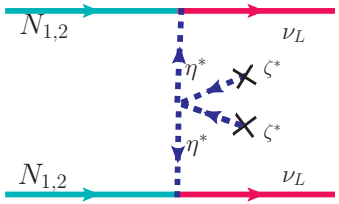
  - excellent WIMP Dark Matter while their annihilation can provide DM abundances as well as correct Baryon asymmetry of the Universe.

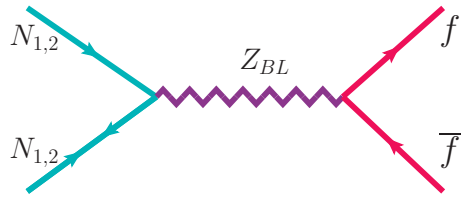
Basic Ingredients of WIMPy Leptogenesis

$$\mathcal{L} \supset y_u\,\overline{q_L}\widetilde{H}u_R + y_d\overline{q_L}H\,d_R + y_e\,\overline{\ell_L}He_R + y_\nu\overline{\ell_L}\widetilde{\eta}\,N_{1,2} + \sum_{\alpha,\beta=1,2} h_{\alpha\beta}\overline{N^c_\alpha}\chi N_\beta + \sum_{\alpha,\beta=1,2} h_{3\alpha}\xi\overline{N^c_\alpha}N_3. \quad (1)$$

★ **Sakharov Conditions Revisited:**

- **Baryon Number Violation**
  WIMP annihilations violate L number via $\lambda''(\zeta^\dagger\eta)^2$





- **CP violation**
  WIMP couplings to SM fields violate CP $y_\nu\overline{\ell_L}\widetilde{\eta}\,N_{1,2}$
- **Departure from thermal Equilibrium**
  The coolong/Expansion of the Universe provides the necessary deparure from thermal equilibrium

CP-asymmetry

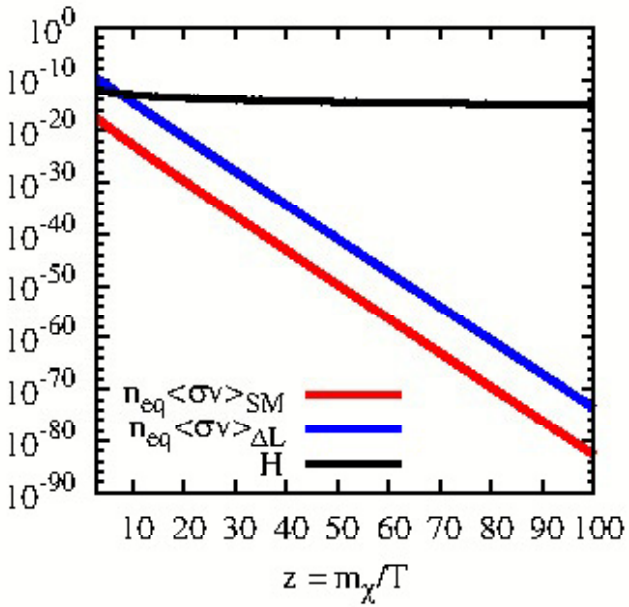
★ **CP-violation comes through the interference with the tree and loop diagrams:**

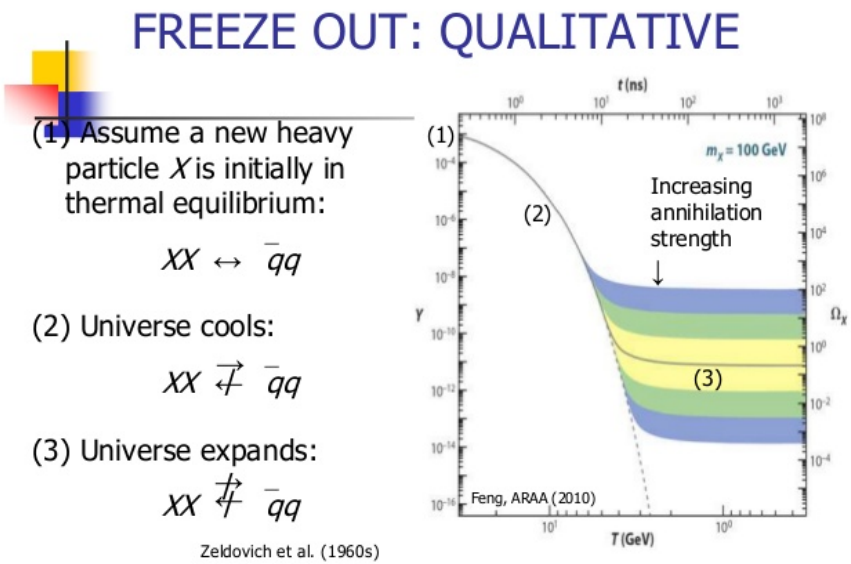
★ **CP asymmetry parameter for Lepton asymmetry**

$$\epsilon = \frac{\sigma_{N_1 N_1 \to \nu\nu} + \sigma_{\overline{N_1 N_1} \to \nu\nu} - \sigma_{\overline{N_1 N_1} \to \overline{\nu\nu}} - \sigma_{N_1 N_1 \to \overline{\nu\nu}}}{\sigma_{N_1 N_1 \to \nu\nu} + \sigma_{\overline{N_1 N_1} \to \nu\nu} + \sigma_{\overline{N_1 N_1} \to \overline{\nu\nu}} + \sigma_{N_1 N_1 \to \overline{\nu\nu}}}. \tag{2}$$

Cross-check for WIMPy Leptogenesis !! [arXiv:1605.01292]

- **Successful generation of lepton asymmetry through WIMPy leptogenesis requires:**
  - **Strength of CP-violating DM annihilation cross-section should be larger than CP-conserving ones** $\frac{\langle \sigma_{N_{1,2}N_{1,2}\to\nu\nu} v\rangle}{\langle \sigma_{N_{1,2}N_{1,2}\to f\bar{f}} v\rangle} > 1$

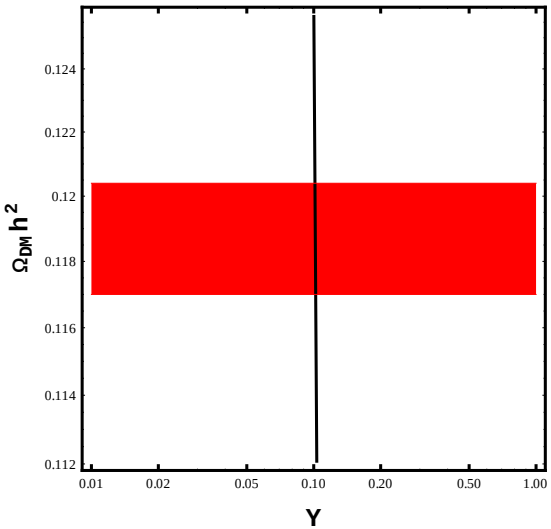


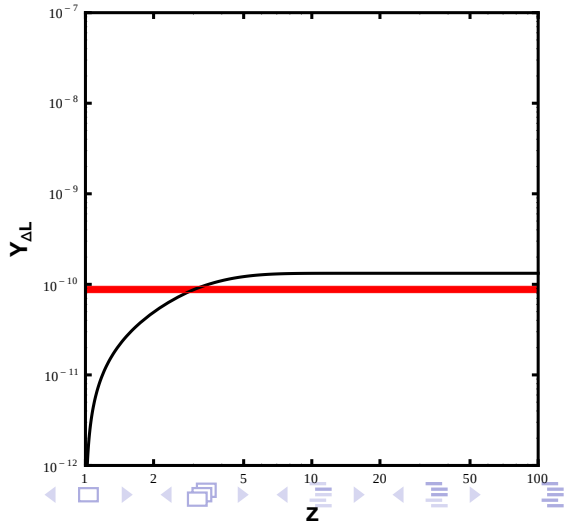


  - **Out-of-equilibrium condition:-** $\frac{n_{eq}^{N_{1,2}} \langle \sigma_{N_{1,2}N_{1,2}\to\nu\nu} | v\rangle}{H} < 1$

Effect of Wash-out processes: Central Result [arXiv:1605.01292]

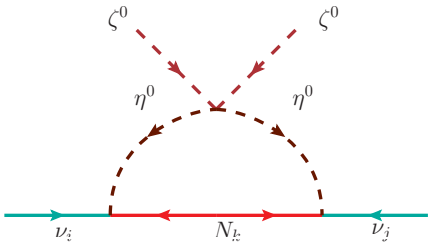
- ★ **WIMP annihilation can generate a baryon asymmetry, there are other processes that have the potential to wash out the asymmetry, and their freeze-out is crucial to create the observed baryon asymmetry.**
  - **If washout processes freeze out before WIMP freeze-out, then a large baryon asymmetry may accumulate**
  - **Its final value is proportional to the WIMP abundance at the time that washout becomes inefficient.**



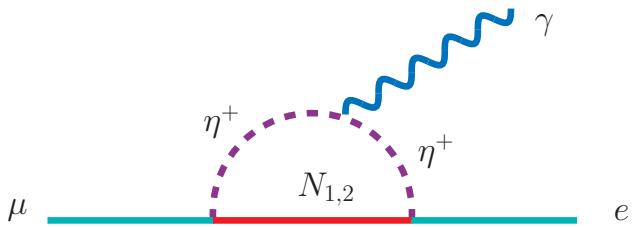


Other Phenomenology

★ **Neutrino Mass via Radiative Mechanism**



★ **Lepton Flavour Violation** $\mu \to e\gamma$



Potential LHC prospects with TeV scale spectrum and hence, can easily be probed by upcoming search experiments

Summary

★ **WIMPy Baryogenesis/Leptogenesis Miracle New !!**

- **A miracle by generating the observed baryon asymmetry through annihilations of weak-scale dark matter**
- **provides a dynamical connection between the dark matter and baryon abundances**
- **Viable Window for new Physics searches at TeV scale: LHC !**