# Charge asymmetry of new stable quarks in baryon asymmetrical Universe

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# STANDARD MODEL AND EXTENSIONS….

- Standard Model of Particle Physics: Describes 3 of the 4 fundamental forces and classifies the fundamental particles.

- Predicts various properties of weak neutral currents and W & Z bosons successfully.

# STANDARD MODEL AND EXTENSIONS….

## SHORTCOMINGS:

- Incomplete theory for describing fundamental interactions.
- Baryon asymmetry not explained fully.
- No viable candidates for dark matter….

# STANDARD MODEL AND EXTENSIONS….

- And hence extensions to SM were made to fulfil the shortcomings.

- Multi-Higgs extensions includes 2HDM, Supersymmetry, etc.

- Multi-charged extensions include Walking technicolor models (WTC), $4^{th}$ generation particles, etc.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

Electroweak phase transition can link the baryon excess to the excess stable quarks of $4^{th}$ generation. A proper relationship between them can be phenomenologically derived considering the conservation of all quantum number and charges.

In the case of pre-existing dark matter, EWPT can dilute it. It can dilute the pre-existing baryon asymmetry as well.

**This presentation is based on the paper: arXiv: 2106.11646**

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The origin of baryon asymmetry of the universe has been dealt with great interest and passion throughout the last few decades.

Results: Numerous models on baryogengesis ranging from GUT to EWPT.

Irrespective of the the mechanisms, the preexisting asymmetry is diluted by baryon number violating mechanisms in the electroweak theory.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

In electroweak theory, it is possible for a sphaleron to convert baryons into anti-leptons and vice versa, thus violating the baryon (lepton) number.

And in this process the difference between the baryon and lepton numbers $B - L$ is conserved, even though individually the quantum numbers are violated.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

In this work we consider $4^{th}$ generation family as an extension to the Standard Model (SM) and proceed to study the electroweak phase transition (EWPT).

The simplest charge-neutral model is considered here and also we've considered that EWPT is of second order.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The fourth generation is of theoretical interest in the context of sphaleron transition, electroweak symmetry breaking and large CP violating processes which might play a crucial role in understanding the baryon asymmetry in the Universe.

Due to the excess of $\bar{U}$, only $-2$ charge or neutral hadrons are present in the universe.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

$^4He$ formed during Big Bang nucleosynthesis completely screens $Q^{--}$ charged hadrons in composite $[^4HeQ^{--}]$ “atoms".

If this $4^{th}$ family follows from string phenomenology, we have new charge associated ($F$) with $4^{th}$family fermions.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

To keep matter simple, an analogy with $WTC^1$ model is made and assume two numbers $FB$ (for 4th quark) and $L'$ for ($4^{th}$neutrino).

As universe expanded and the temperature fell down and the quantum number violating processes ceases to exists, the relation among the particles emerging from the process ($SM + 4^{th}$generation) follows the expression:

$$3(\mu_{u_L} + \mu_{d_L}) + \mu + \mu_{U_L} + \mu_{D_L} + \mu_{L'} = 0.$$

Here $\mu$ is the chemical potential of all the SM particles, $\mu_{L'}$ is the chemical potential of the new species leptons and $\mu_{U_L}$ and $\mu_{D_L}$ are that of the $4^{th}$ generation quarks.

**1. 10.1103/PhysRevD.74.095008**

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The number densities follows, respectively for fermions and bosons:

$$n = g_* T^3 \frac{\mu}{T} f(\frac{m}{T})$$

and

$$n = g_* T^3 \frac{\mu}{T} g(\frac{m}{T})$$

where $f$ and $g$ are hyperbolic mathematical functions and $g_*$ is the effective degrees of freedom.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The hyperbolic functions are given by:

$$f(z) = \frac{1}{4\pi^2}\int_0^\infty x^2 cosh^{-2}\left(\frac{1}{2}\sqrt{z^2+x^2}\right) dx$$

and

$$g(z) = \frac{1}{4\pi^2}\int_0^\infty x^2 sinh^{-2}\left(\frac{1}{2}\sqrt{z^2+x^2}\right) dx$$

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The number density of baryons follows the expression:

$$B = \frac{n_B - n_{\bar{B}}}{gT^2/6}$$

As the main point of interest is the ratio of baryon excess to to excess of stable $4^{th}$ generation, the normalization cancels out without without loss of generality.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

Defining a parameter $\sigma$ for fermions and bosons respectively:

$$\sigma_f = 6f\frac{m}{T_c} \text{ and } \sigma_g = 6g\frac{m}{T_c}$$, where $Tc$ is the transition temperature.

The new generation charge is calculated to be:

$$FB = \frac{2}{3}(\sigma_{U_L}\mu_{U_L} + \sigma_{U_L}\mu_{D_L} + \sigma_{D_L}\mu_{D_L})$$

where $FB$ corresponds to the anti-U ($\bar{U}$) excess.

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The SM baryonic and leptonic quantum numbers are expressed as:

$$B = \left[(2+\sigma_t)(\mu_{uL}+\mu_{uR}) + 3(\mu_{dL}+\mu_{dR})\right]$$

and

$$L = 4\mu + 6\mu_W$$

For the $4^{th}$ generation lepton family, quantum number is given by:

$$L' = 2(\sigma_{\nu'}+\sigma_{U_L})\mu_{\nu' L} + 2\sigma_{U_L}\mu_W + (\sigma_{\nu'}-\sigma_{U_L})\mu_0$$

# BALANCING ASYMMETRIC DARK MATTER WITH BARYON ASYMMETRY

The ratio of the number density of number density of the $4^{th}$ generation to the baryon number density can be expressed as a function of the ratio of original and new quantum numbers. In the limiting case of second order EWPT, we get:

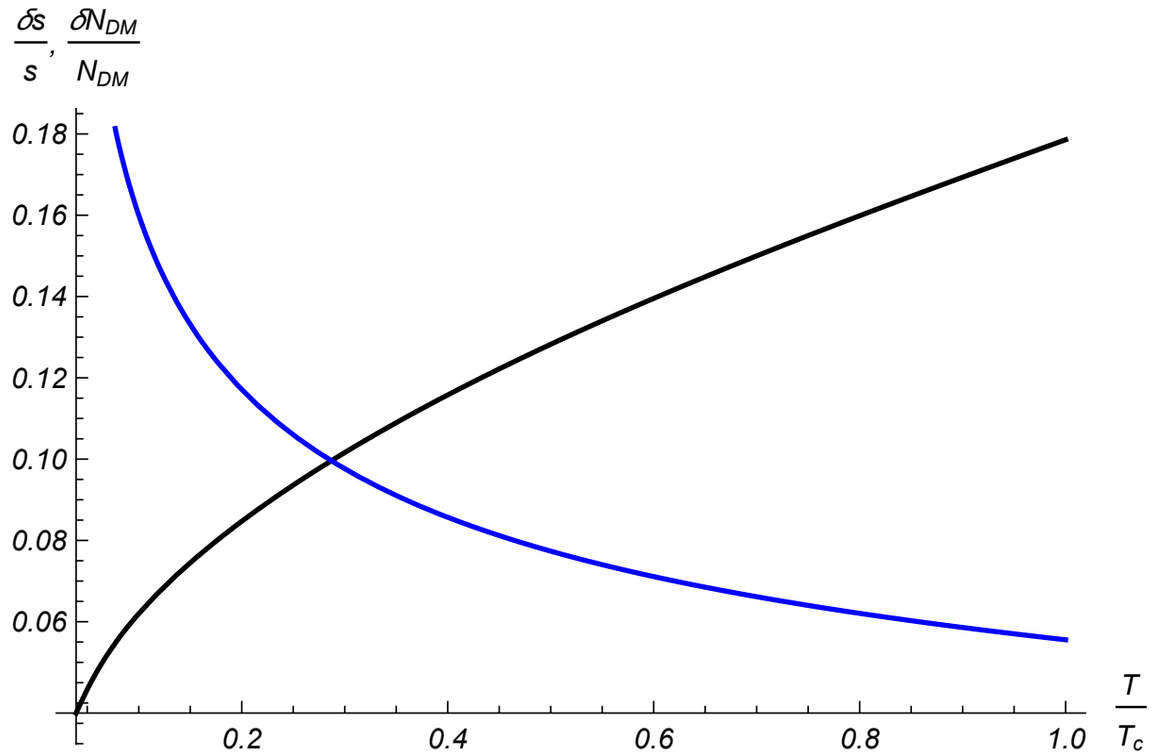
$$-\frac{FB}{B} = \frac{\sigma_{U_L}}{3(18+\sigma_{\nu'})}\left[(17+\sigma_{\nu'}) + \frac{(21+\sigma_{\nu'})}{3}\frac{L}{B} + \frac{2}{3}\frac{9+5\sigma_{\nu'}}{\sigma_{\nu'}}\frac{L'}{B}\right].$$

Hence we establish a relationship between the baryon excess and the excess of $\bar{U}$ for second order EWPT.

# DILUTION OF PRE-EXISTING DARK MATTER DENSITY

- This resulting phase transition can dilute the pre-existing dark matter density through the process of entropy production and influx into the plasma. Details about entropy production has already been explained by my colleague Shiladitya.

# DILUTION OF PRE-EXISTING DARK MATTER DENSITY




Entropy production (black line) and the dilution of pre-existing dark matter (blue line) in the presence of $4^{th}$ generation fermions are presented.

# CONCLUDING REMARKS

1. A definite relationship between the value and sign of $4^{th}$ generation family excess relative to the baryon asymmetry due to electroweak phase transition and possible sphaleron production can been established.

2. Dilution of pre-existing dark matter density is calculated and in the present scenarios the dark matter density is reduced by $\sim 18\,\%$.

*THANK*

*YOU*

*FOR*

*YOUR*

*ATTENTION*