Colour Breaking Baryogenesis

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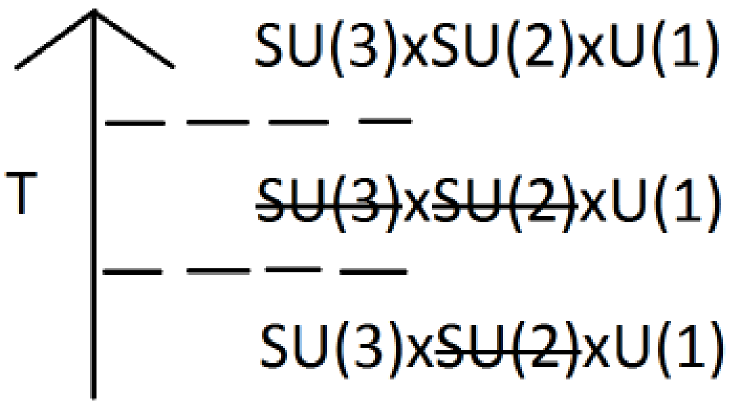
Outline

- Baryon Asymmetry of the Universe
- Colour Breaking Baryogenesis
- Why Colour Breaking
- Dynamics of Colour Breaking
  - Symmetry Breaking
  - Goldstone Modes
  - Conservation Laws
- Transport equations
- Baryon Asymmetry

Baryon Asymmetry

- There are more particles than anti-particles in the Universe
- Inflation washes out any initial baryon asymmetry
  - Cannot just have the Baryon asymmetry as an initial condition
- Requires BSM physics!
- Often testable in the near future
  - EDMs
  - New weak scale scalar fields
  - (sometimes) new sources of B violation

Colour Breaking Baryogenesis



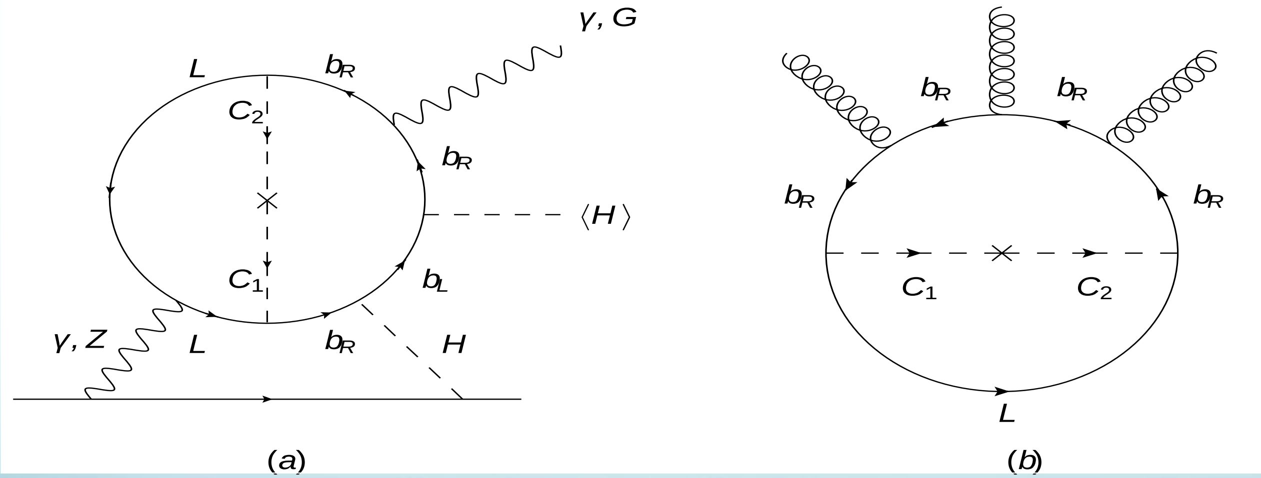
- Add Leptoquark interactions to Legrangian

$$\begin{aligned} L &= L_{SM} + \lambda_1 C_1 \bar{b}_r \epsilon L_3 \\ &\quad + \lambda_2 C_2 \bar{b}_r \epsilon L_3 + \Delta V \quad (5) \end{aligned}$$

- Sakarov Conditions
  - $\lambda_i \mapsto$ CP violation
  - $\Delta V \mapsto$ 1st order PT
  - B violated sponaneously
- consistent with $0T$ pheno

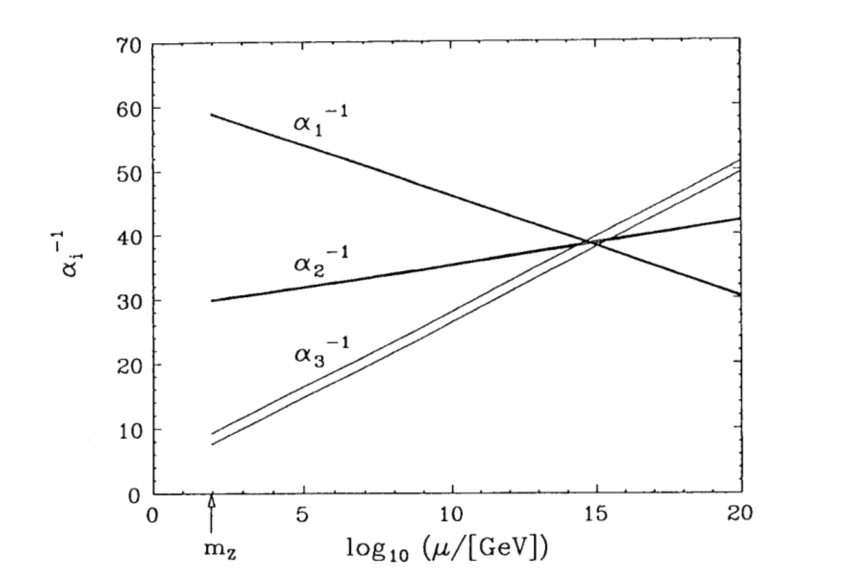
Why Colour Breaking

- Multistep Phase transitions are ubiquitous in condensed matter
- New paradigm on how to produce the BAU!
- Do not have to have a SFO EWPT
- Easily avoid EDM constraints



Why Colour Breaking

- The type of leptoquark we chose when added to the standard model gives gauge coupling unification



Why Colour Breaking

- This type of Leptoquark avoids problems with proton decay
- Testable (simple models requires leptoquarks to not be a few TEV at most)

Dynamics of Colour Breaking

- Spontaneous colour breaking

$$(C_{1,2})_i = \begin{pmatrix} (\chi^{2/3}_{1,2})_i \\ v_{1,2}\,\delta_{i3} + (\chi^{-1/3}_{1,2})_i \end{pmatrix}$$

- Gluons get mass

$$D_\mu = \partial_\mu - ig_s G^i_\mu T^i - ie_S\Big(G^{+,45}_\mu T^{+,45} + G^{-,45}_\mu T^{-,45} + G^{+,67}_\mu T^{+,67} + G^{-,67}_\mu T^{-,67}\Big) - ie_W\Big(W^+_\mu \tau^+ + W^-_\mu \tau^-\Big) - ie_{X_1} Q_{X_1} X_{1\mu} - ie_{X_2} Q_{X_2} X_{2\mu} - ie_{X_3} Q_{X_3} X_{3\mu} \qquad (13)$$

- New conservation laws

$$Q_{X_1} = T^8 - \frac{2}{\sqrt{3}}\tau^3,$$

$$Q_{X_2} = \tau^3 + 3Y,$$

Transport Equations

- Transport coefficients and CP violating source terms are derived in the CTP formalism
- Even if we ignore 1st and 2nd generation particles the number of particle species/transport equations is
  - 2 for the left handed lepton doublet
  - +2x3x2=12 for the coloured scalars
  - +2x3=6 for the left handed quark doublet
  - +3 for the right handed top quark
  - +3 for the right handed bottom quark
  - +2 for the Higgs doublet
  - +1 for massive W Bosons
  - +2 for massive gluons
  - =29!

Transport Equations

- Can reduce transport equations using conservation laws
- SU(2)_C subgroup means the number densities for first two colours will be equal.
- Can then write all coloured particles in terms of colour singlets and octets

$$m_1 + m_2 + m_3 = m$$

$$\frac{1}{2\sqrt{3}}(m_1 + m_2 - 2m_3) = m_8$$

- Assume guage interactions are very fast

$$m_- - m_+ = m_3 = m_W$$

$$m_1 - m_3 = \sqrt{3}m_8 = m_G$$

- All SU(2) triplets are in local equilibrium
- All SU(3) octets are in equilibrium

Transport equations

- Can reduce transport equations using conservation laws
- QX1 gives relation $m_G = m_W$
- We also get a "free" relation for C $m_C = -7 m_W$
- QX2 gives relation

$$m_C = -\frac{7}{60}\left(\frac{Q_L}{k_Q} + 2\frac{t_R}{k_t} - \frac{b_R}{k_b} - \frac{L}{k_L} + 2\frac{H}{k_H}\right)$$

- Can use the above to write all colour octets and SU(2) triplets in terms of gauge singlets!
- There are now only 5 transport equations!

Transport equations

$$\P_m t_R^m = G_{SS}(2\frac{Q}{k_Q} - \frac{t_R}{k_t} - \frac{b_R}{k_b} - 8\frac{c_R}{k_{C_R}}) - G_H(\frac{t_R}{k_t} - \frac{Q}{k_Q} - \frac{H}{k_H})$$

$$\P_m Q_L^m = -2G_{SS}(2\frac{Q}{k_Q} - \frac{t_R}{k_t} - \frac{b_R}{k_b} - 8\frac{c_R}{k_{C_R}}) + G_H(\frac{t_R}{k_t} - \frac{Q}{k_Q} - \frac{H}{k_H})$$

$$\P_m H^m = G_H(\frac{t_R}{k_t} - \frac{Q_L}{k_Q} - \frac{H}{k_H})$$

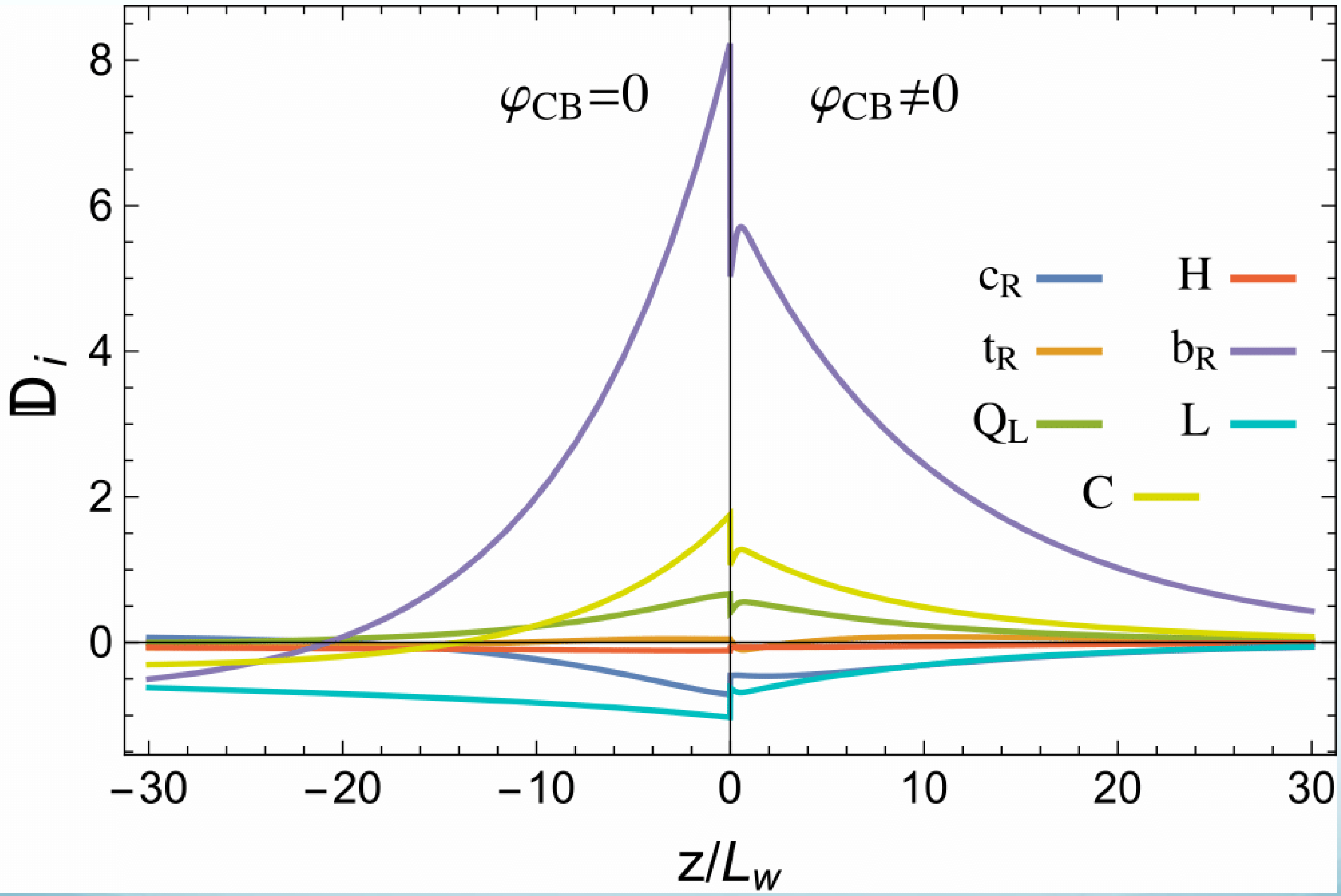
$$\P_m b_R^m = G_{SS}(2\frac{Q}{k_Q} - \frac{t_R}{k_t} - \frac{b_R}{k_b} - 8\frac{c_R}{k_{C_R}}) - (G_C + G_M)(\frac{b_R}{k_b} - \frac{C}{k_C} - \frac{L}{k_L}) + S^{CPV}$$

$$\P_m L^m = (G_C + G_M)(\frac{b_R}{k_b} - \frac{C}{k_C} - \frac{L}{k_L}) - S^{CPV}$$

Transport Equations

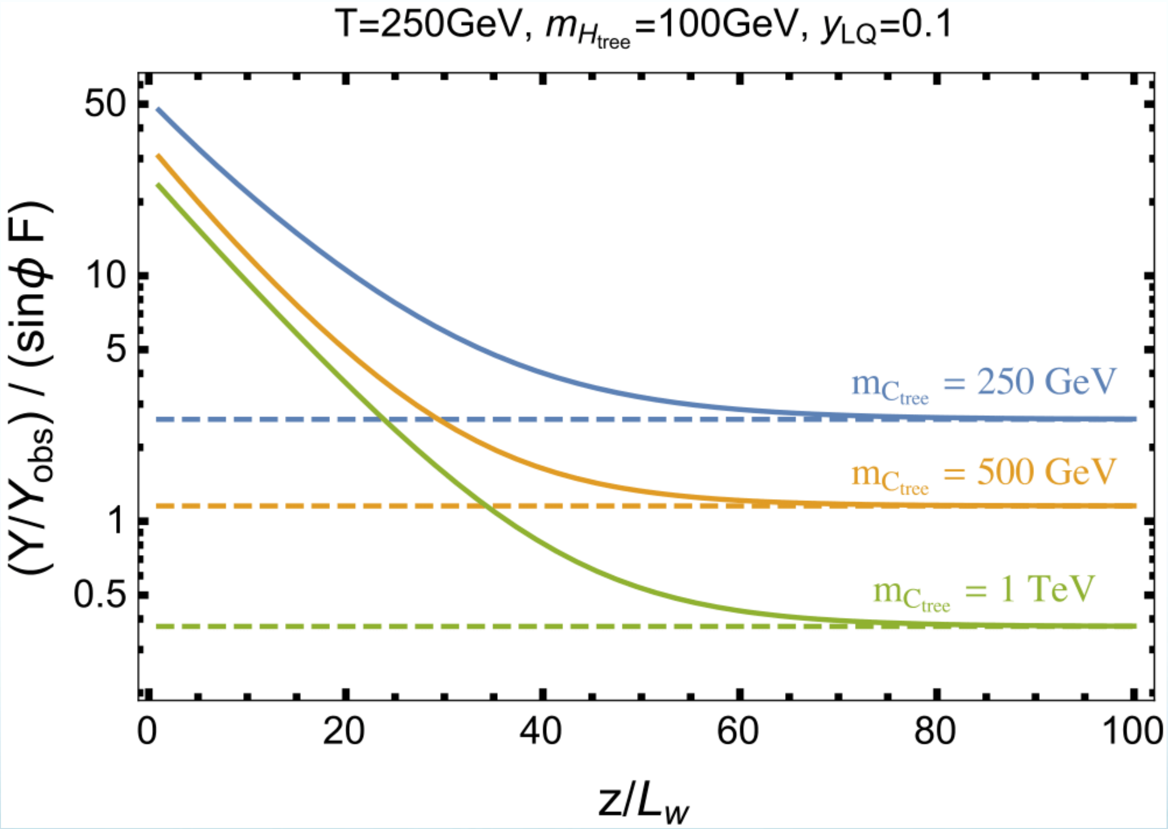
- Can now solve the transport equations using techniques in G. A. White arXiv:1510.03901
- Baryon asymmetry has two components
  - Colour breaking component where ρ_B is a function of z. This will be frozen in when the SM PT occurs
    - Want $\rho_B \sim 0$ so EM charge is also 0!
  - Standard EWBG where n_L seeds production via weak sphaleron processes

Results



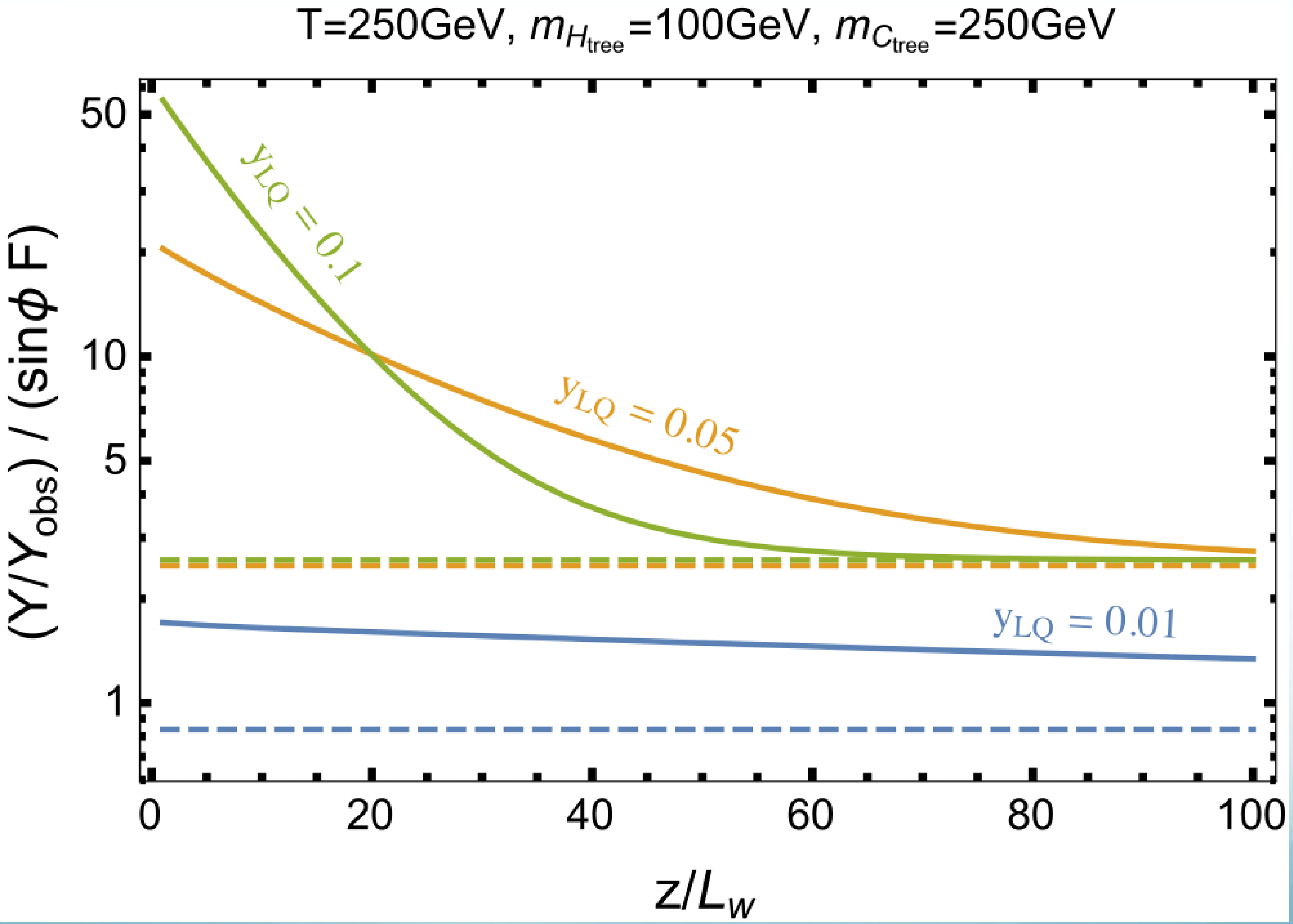
$\varphi_{CB}=0$
$\varphi_{CB}\neq0$
c_R
H
t_R
b_R
Q_L
L
C
$\mathbb{D}_i$
z/L_w
8
6
4
2
0
−30
−20
−10
0
10
20
30

Results



T=250GeV, $m_{H_{tree}}$=100GeV, y_{LQ}=0.1
$m_{C_{tree}}$ = 250 GeV
$m_{C_{tree}}$ = 500 GeV
$m_{C_{tree}}$ = 1 TeV
(Y/Y$_{obs}$) / (sinϕ F)
50
10
5
1
0.5
0
20
40
60
80
100
z/L_w

Results


T=250GeV, $m_{H_{tree}}$=100GeV, $m_{C_{tree}}$=250GeV
$y_{LQ} = 0.1$
$y_{LQ} = 0.05$
$y_{LQ} = 0.01$
(Y/Y_{obs}) / (sinϕ F)
50
10
5
1
0
20
40
60
80
100
z/L_w

Summary and Conclusion

- New Paradigm for producing the BAU
- Can reproduce 0T Phenomenology
- Can easily produce the BAU