TRIUMF

Color Breaking Baryogenesis (arXiv:1708.07511)

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Logic for suspecting phase transition

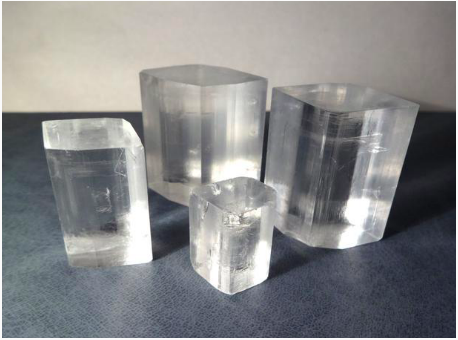
- Low temperature symmetry breaking
- Generically high enough reheating temperature
- Study of SM at high temperature

QCD, EW....

Other candidates: GUT, Dark phase transitions...

Rochelle Salt as a caution to intuition

- Heat up Rochelle salt and crysalization *increases*
- Heat further again and the salt will melt



Cosmological symmetry breaking and restoration

Could a zero temperature symmetry be broken at high temperature and restored as the Universe cools?

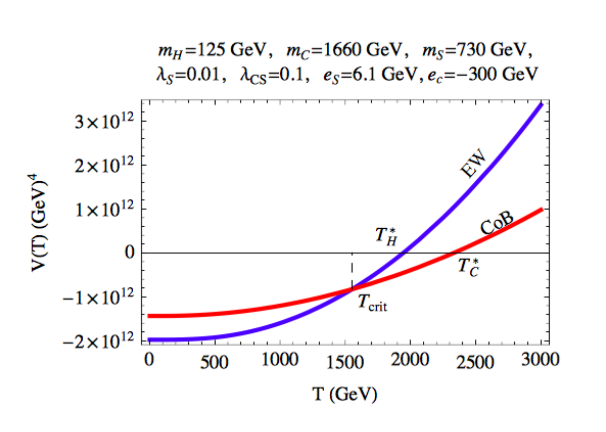
Two options

- Change the Macrophysics (some large number density in early Universe)
- Change the Microphysics (Deepest minimum breaks different symmetries at different temperatures)

Intermediate color breaking

$$V = V_{SM}(H) + \lambda_{HC} H^\dagger H C^\dagger C + V(C) \quad (1)$$

Add a gauge singlet to boost the colored scalar mass



Colored scalar candidates

Choose scalar leptoquarks Want to quench EW sphalerons $\rightarrow$ must have nontrivial isospin
Leptoquark candidates

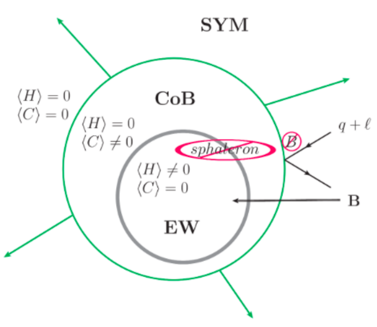
- (3,3,-1/3)
- (3,2,7/6)
- (3,2,1/6)

Third option avoids proton decay, has weak bounds on 3rd generation mass and and can lead to GCU

CoB and Sakharov

$$L = L_{\text{SM}} + \lambda_i C_i \bar{b}_R L + \Delta V$$

- $\langle \not{B} \rangle \rightarrow$ Spontaneous. Also have EW sphalerons
- $\lambda_i \rightarrow$ CPV phase
- $\Delta V \rightarrow$ Departure from equilibrium

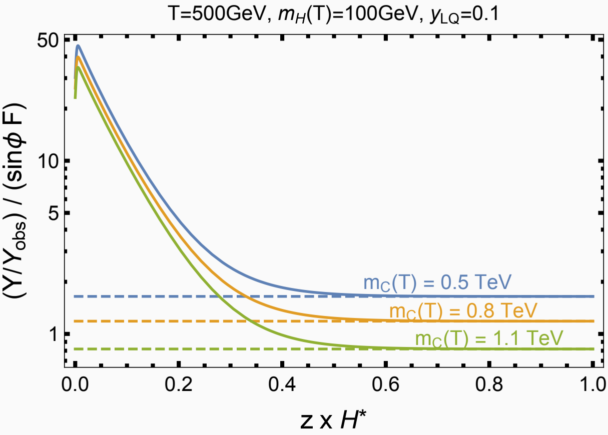


Charge non-conservation

Will also violate SM charges

- Color Octet charge T_8
- Electromagnetic charge Q_{EM}

Results



T=500GeV, m_H(T)=100GeV, y_{LQ}=0.1
50
10
5
1
(Y/Y_{obs}) / (sinϕ F)
0.0
0.2
0.4
0.6
0.8
1.0
z x H^*
m_C(T) = 0.5 TeV
m_C(T) = 0.8 TeV
m_C(T) = 1.1 TeV

Relic Charge Asymmetry

- Assume EWPT occurs after a color breaking bubble has a radius of H^{-1}.
- The charge asymmetry barely penetrates the bubble wall compared to H^{-1}
- Eventually the bubble wall becomes ultrarelativistic and some charge asymmetry is frozen inside the bubble
- An order of magnitude estimate yields for our case

$$Y_{Q_{EM}} \sim O(10^{-45}) - O(10^{-47}) << 10^{-37} \tag{2}$$

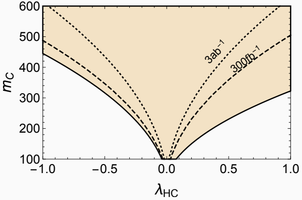
- downside is a similar argument holds for spontaneous baryon number production.
- almost all baryon production is due to EW sphalerons

Constraints on 3rd Generation LQs

- Pair production through gluon-gluon fusion and quark-antiquark annhilation cross sections depend only the mass.
- Assuming unit branching ratio $m_{C^{2/3}} \geq 850GeV$
- Leptoquarks decaying to $b_R\bar{\nu}_\tau$ agian with unit branching ratios give $m_{C^{-1/3}} \geq 640$

Constraints from Higgs decays

- Modifies Higgs signal strengths
  - Interferes in top quark loop in gluon-gluon fusion Higgs production
  - Interferes with top and W loops in Higgs to diphoton

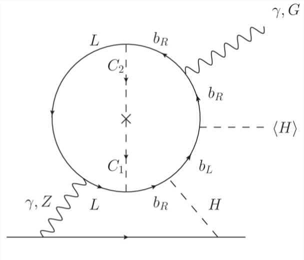


Naive dimensional analysis

$$d_e \sim e\frac{\alpha_{\mathrm{EM}}}{4\pi}\frac{\mathrm{Im}y_1y_2}{(4\pi)^4}\frac{m_e m_b^2}{m_{\mathrm{C}}^4} \quad (3)$$

For $m_C \sim 500$ GeV

$$\begin{aligned} d_e &\sim 10^{-34}\mathrm{Im}[y_1y_2]\mathrm{e}\cdot\mathrm{cm} \\ &<< 8.7\times 10^{-29} \end{aligned}$$



Nuetron EDMs and isoscalar pion nucleon coupling

For $m_C \sim 500$ we have

$$
\begin{aligned}
d_N &\sim 10^{-28}\mathrm{Im}(y_1 y_2) << [2.9 - 3.0] \times 10^{-26}\mathrm{e}\cdot\mathrm{cm} \\
\bar{g}_\pi^0 &\sim 10^{-14}\mathrm{Im}(y_1 y_2) << 3.8 \times 10^{-12}
\end{aligned}
$$

Future pheno work

Recent flavour anomaly

$$R_{K^*} = \frac{\Gamma\left(\bar{B} \to K^* \mu^+ \mu^-\right)}{\Gamma\left(\bar{B} \to K^* e^+ e^-\right)}$$

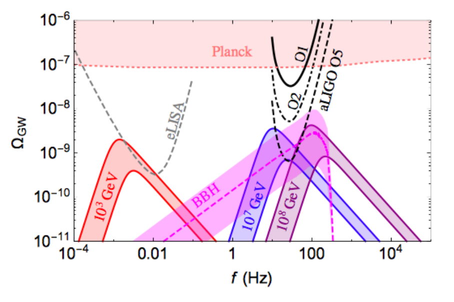
Current measurement (SM ~ 1)

$$R_{K^*} = 0.66^{+0.11}_{-0.07} \pm 0.024 \tag{4}$$

- Can be explained through 2nd generation LQ (3,2,1/6)
- Can baryogenesis, EDMs etc work and explain R_{K^*}?
- This LQ can also be resposible for GCU

Future pheno work

Rough estimates of relic gravitational wave peak frequency and amplitude.



A multi-step phase transition of $T_N \sim O(\text{TeV})$ is ideal for detection at LISA

Future Model building work

This is just one implementation of this paradigm

- Other microphysics options: other colored scalars (diquarks, other LQs)
- is a macrophysics implementation possible?