Big Bounce Baryogenesis

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Matter-antimatter Asymmetry

The asymmetry is described quantitatively by,

$$\eta = \frac{n_b - n_{\bar{b}}}{s} \simeq 8.5 \times 10^{-11}$$

The Sakharov Conditions

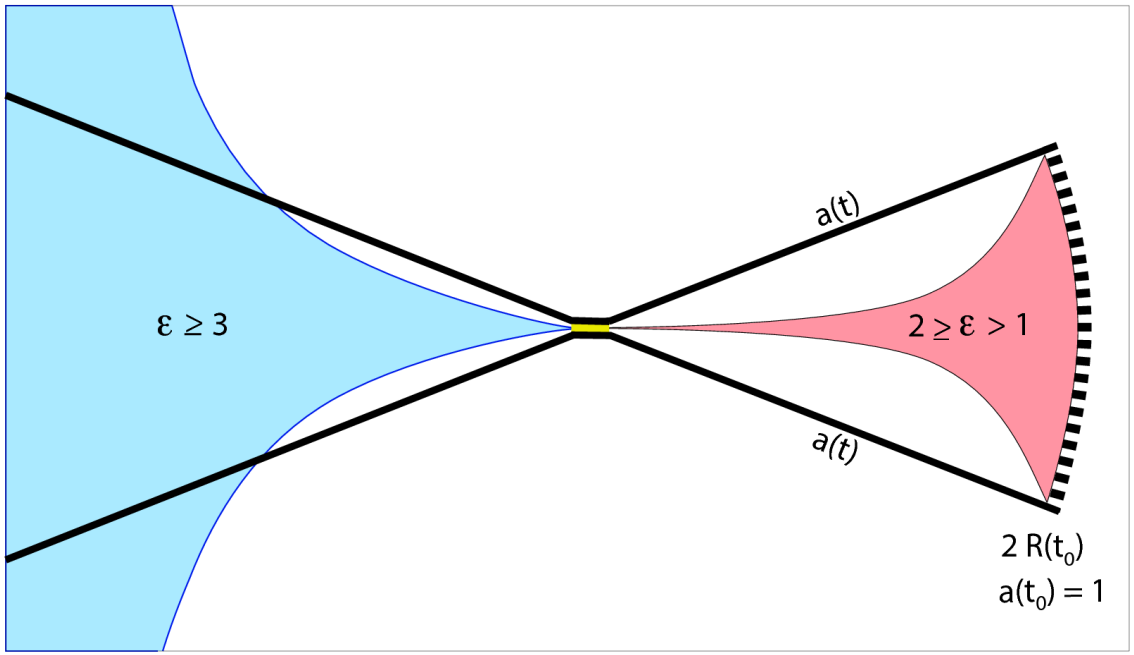
1. Baryon number violation
2. $\mathcal{C}$ and $\mathcal{CP}$ violation
3. Period of non-equilibrium

Standard Model $\rightarrow \eta_{sm} \sim 10^{-18}$.

Inflationary dilution $\Rightarrow$ Typically generated during or after reheating.

Bounce Cosmology

- Alternative Cosmology to usual inflation paradigm,
- Can solve cosmological issues and source perturbations, like inflation,
- But requires violation of NEC.
- Ekpyrotic Contraction: $a \propto t^{\frac{1}{q}} \propto \tau^{\frac{q}{1-q}}$.



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The Model

- New gauge group: $SU(3) \times SU(2) \times U(1)_Y \times U(1)_B$

New Lagrangian terms:

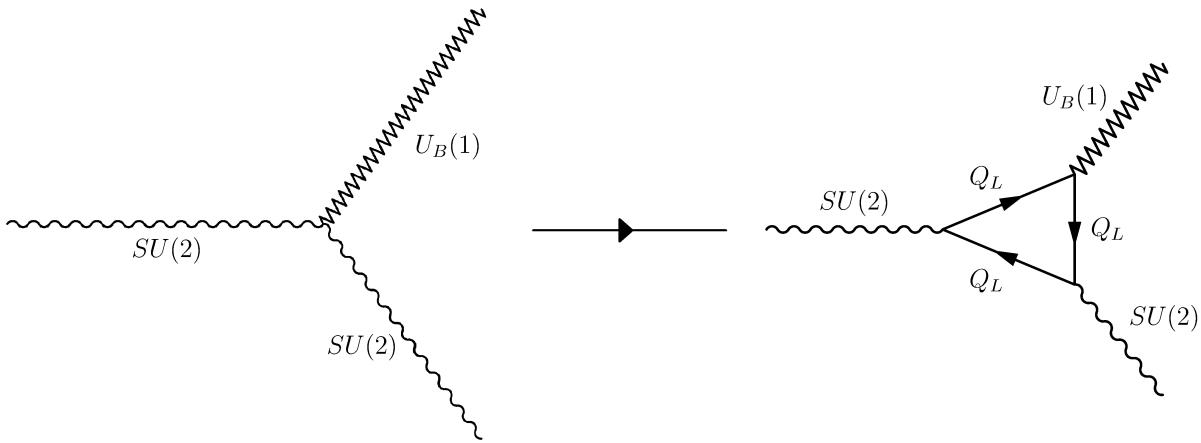
$$\frac{1}{\sqrt{-g}}\mathcal{L}_B = -\frac{1}{4}g^{\mu\alpha}g^{\nu\beta}B_{\mu\nu}B_{\alpha\beta} + \frac{1}{2}f_B^2 g^{\mu\nu}\left(g_B B_\mu - \partial_\mu\theta\right)\left(g_B B_\nu - \partial_\nu\theta\right)$$
$$+ \frac{3g_1^2}{32\pi^2}\theta(x)Y^a_{\mu\nu}\tilde{Y}^{a\mu\nu} - \frac{3g_2^2}{32\pi^2}\theta(x)W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$$

Satisfying the Sakharov Conditions

1. Anomalous currents,
2. Counter terms in the cosmological setting,
3. Contracting phase

Will consider $q = \frac{1}{3}$, Kinetic energy domination.

Anomalies and the Green-Schwarz mechanism



- Current corrections:

$$\partial_\mu j^\mu = \mathcal{A}\frac{g_F^2}{16\pi^2}F_{\mu\nu}\tilde{F}^{\mu\nu}$$

- Gauge anomalies $\rightarrow$ breakdown in gauge invariance,
- Non-invariance of the effective action matched by counter terms,
- Introduce ($\mathcal{CP}$ invariant) counter terms of the form:

$$\mathcal{L} = -\frac{g^2}{16\pi^2}\mathcal{A}\theta(x)F_{\mu\nu}\tilde{F}^{\mu\nu} \ .$$

$\mathcal{CP}$ Violation and Particle Production

- Considering a FRW universe $\Rightarrow f_B\theta(x) \rightarrow f_B\theta(t) = \phi(t)$.
- $\mathcal{CP}$ violation: $\mathcal{CP}(\phi(t)F_{\mu\nu}\tilde{F}^{\mu\nu}) = -\phi(t)F_{\mu\nu}\tilde{F}^{\mu\nu}$.

- Expanding spacetime $\rightarrow$ time dependent vacuum state,
- Bogoliubov transformation $\rightarrow$ accumulated particle number,
- Anomalous currents lead to the generation of B charge.

The Chern-Simons number density,

$$n_{CS} = n_g \frac{g_2^2}{32\pi^2} \int d^3x \epsilon^{ijk} Tr(W_i \partial_j W_k + \frac{2ig_2}{3} W_i W_j W_k) \ .$$

Field Quantisation and Mode Functions

- Derive equations of motion in FRW background,
- Solving for circularly polarised wave modes ($\alpha = +, -$),

$$W_i = \int \frac{d^3\vec{k}}{(2\pi)^{3/2}} \sum_\alpha \left[F_\alpha(\tau, k)\epsilon_{i\alpha}\hat{a}_\alpha e^{i\vec{k}\cdot\vec{x}} + F^*_\alpha(\tau, k)\epsilon^*_{i\alpha}\hat{a}^\dagger_\alpha e^{-i\vec{k}\cdot\vec{x}} \right] .$$

- Thus, where $\kappa_B = \frac{g_2^2\phi_0'}{8\pi^2 f_B H_b}$ and $\phi' = \frac{\phi_0'}{a(\tau)^2}$,

$$F''_\pm + \left(k^2 \mp \frac{\kappa_B k}{\tau} \right) F_\pm = 0 .$$

- To avoid instabilities we will impose the cut-off $k\tau > \kappa_B$.

Wave Mode Functions

- The wave mode functions are,

$$F_{\pm} = \frac{-i}{\sqrt{2k}} e^{-ik\tau} e^{\pm\pi\kappa/4} U\left(\pm i\kappa/2, 0, 2ik\tau\right) \ .$$

  Matched to planewave modes at $\tau \to -\infty$.

- Calculate accumulated n_{CS} at the bounce $\tau_b \to -\frac{1}{3H_b}$, by a Bogoluibov transformation.

- Related to the baryon number,

$$\partial_\mu \left(\sqrt{-g} j^\mu_B\right) = \frac{3g_2^2}{32\pi^2} \epsilon^{\mu\nu\rho\sigma} W^a_{\mu\nu} W^a_{\rho\sigma} = \frac{3g_2^2}{16\pi^2} \partial_\mu \left(\sqrt{-g} K^\mu\right) \ .$$

Calculating the Generated Baryon Asymmetry

- No significant entropy production after reheating ($s \simeq \frac{2\pi^2}{45} g^* T_{\rm rh}^3$),
- Evaluating near the bounce,

$$\eta_B = \frac{n_B}{s} \approx 10^{-5} \kappa_B \left(\frac{H_b}{T_{\rm rh}}\right)^3 \left(\frac{a_b}{a_{\rm rh}}\right)^3 ,$$

for $\kappa_B \sim 1$ and assuming instantaneous reheating,

$$\frac{\eta_B}{\eta_B^{obs}} \approx \left(\frac{T_{\rm rh}}{3 \cdot 10^{15}\ {\rm GeV}}\right)^3 \approx \left(\frac{H_b}{2 \cdot 10^{13}\ {\rm GeV}}\right)^{\frac{3}{2}} .$$

Conclusion and Future Work

- Gauge boson which couples to B charge,
- Utilise dynamics of ekpyrotic contraction before, bounce.
- Can successfully produce the η_B^{obs} with a big bounce.

Future Investigations

- Detail the bounce dynamics,
- Magnetogenesis from hypercharge anomaly,
- Possible LHC Phenomenology.