Source terms in EWBG

2206.01120 w/ Graham White
Jorinde v/d Vis

2107.05571

$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} = 6 \cdot 10^{-10}$$

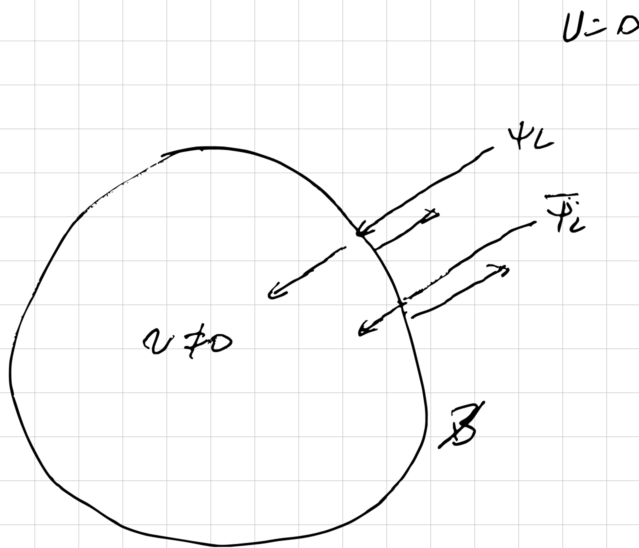
Sakharov conditions

1) $\cancel{B}$ — SM
2) $\cancel{C}$ & $\cancel{CP}$ — new physics
3) 1st order EW PT — new physics

↙

- can be tested by LHC, EDMs
- need precise theoretical predictions

EWBG



$$\mathcal{L} \supset \underbrace{-y_{\psi_L}\, v\left(1 + c\frac{v^2}{\Lambda^2}\right)}_{m_{eff}\ \text{complex}} \bar{\psi}_L \psi_R + h.c.$$

$\not{CP}$ $\Rightarrow$ chiral asymm $n_L - n_{\bar{L}} \neq 0$

$\Rightarrow$ bias sphaleron transitions
$\not{B}$

Boltzmann typ eqs for phase space densities

$$f_i(k,x) = f_i^{eq}(k) + \delta f(k,x)$$

f_i^{eq}: Fermi dirac

δf: $m(x)$

Source terms

* semi-classical / WKB source

$$\frac{\partial m}{\partial z} \neq 0$$

* flavor dynamics $U(x)$ mixing matrix

source $\propto$ U)

* VIA approx : perturb. in $\delta m(x)$

→ divergence in $\Gamma_{th} \to 0$ limit (pinch singularity?)

→ no clear physical interpretation

→ mixing important $\delta_L = -\delta_R$

→ thermal corrections important

→ at lower order in derivative expansion ⇒ larger yield

→ can be compatible w/ EOM

refs

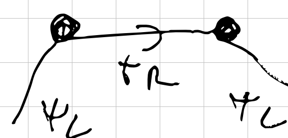
- semi-classical
  Cohen & Kaplan
  Kainulainen, Prokopec, Cline, Joyce
  Schmidt, Tarok, Weinstocke
- flavor
  Konstandin, Prokopec, Schmidt
  Cirigliano, Lee, Tulin
- VIA
  Riotto
  Cirigliano, Lee, Ramsey-Musolf, Tulin

VIA literature

- $\mathcal{L} = \mathcal{L}_{free} + \mathcal{L}_{int}$

  δm

  not 1PI



- 2-step
  - include thermal corrections in G
  - use correct G and include δm correction

Our approach

- $\mathcal{L} = \mathcal{L}_{free} + \mathcal{L}_{int}$

  δm

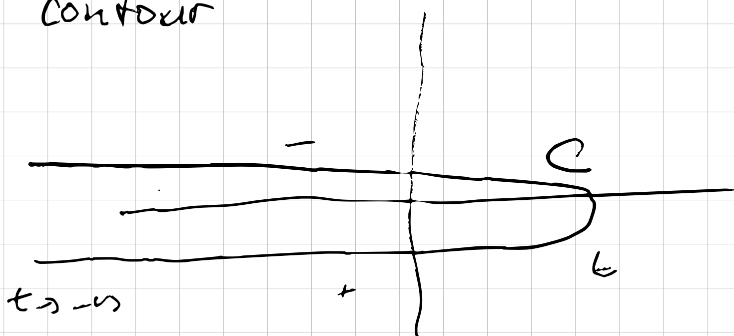
  $\Rightarrow$ calculate resummed G

  $\Rightarrow$ one-step: solve eq w/ T & δm correction

QFT derivation of transport eqs

* CPT – formalism for $\langle in | in \rangle$ expectation values

trick:
contour



- time ordering → contour ordering

- $G^{\pm\pm} \sim \langle \psi^{\pm} \bar{\psi}^{\pm} \rangle$

* G thermal correltation functions 7)

$$\int dk^0 \, k^0 \, G^{>} \sim f$$

* Schwinger-Dyson eqs

$$G = G_0 + G_0 \otimes \Pi \otimes G$$

$$G = G_0 + G \otimes \Pi \otimes G_0$$

* Wigner transform

$$G(k,x) = \int dr\, G(x+r,\, x-r)\, e^{-ikr}$$

Fourier trafo wrt relative coördinate

derivative expansion in powers ∂_x^4

slowly varying
bubble wall background

$$x = \tfrac{1}{2}(u+v)$$

$$r = u - v$$

- Add & subtract Schwinger - Dyson eq (massage results)

- constraint eq : spectrum
  solve to find G

- kinetic eq : dynamics
  gives $\partial_x G$

kinetic eq

$$\frac{i}{2}\{\not{\partial}_x , G^> + G^<\} + [\not{k}, G^> + G^<]$$

$$= e^{-i\Diamond}\Big([m_0 + \pi^h, G^> + G^<] + [\pi^> + \pi^<, G^h] + \{\pi^>, G^<\} - \{\pi^<, G^>\} \Big)$$

$$\Diamond (A B) = \frac{1}{2}\left(\partial_x A \, \partial_k B - \partial_k A \, \partial_x B\right)$$

- matrices $\quad G = \begin{pmatrix} G_{LR} & G_{LL} \\ G_{RR} & G_{RL} \end{pmatrix}$

$$m_0 + \pi^h = \begin{pmatrix} m_{RL} & \pi_L \\ \pi_R & m_{LR} \end{pmatrix}$$

* lhs $\quad \int d^4k \, \mathrm{Tr}\left(P_L \, \mathrm{lhs}\right) = \partial_\mu J^\mu_L$

* rhs $\quad \int d^4k \, \mathrm{Tr}\left(P_L \, \mathrm{rhs}\right) = \mathrm{source}$

$e^{i\diamond} = 1 + i\diamond + \dots$

↳ semi classical source $\{\partial_x m, \partial_k G\}$

↳ flavor source

VIA

Literature VIA

- 1 contribution from collission term

Our approach

- collission term
  w/ $\Pi = \Pi_{thermal}$
  $G = G(\delta m)$

- mass commutator

they cancel!

Conclusion

- We did systematic calculation VIA source

- VIA source cancels in LO derivative expansion

- in hindsight expected:

  $G(x) = G$ calculated for constant background

  kinetic eq in constant background should vanish
  $\Leftrightarrow$ same limit as VIA

- source term may still arise at NLO in VIA

  - thermal corrections give misalignment flavor & mass eigenstates for the two chiralities

  - need chiral theory for this

  (can also be seen as individual LO terms $\propto (n_L - n_R)$)