An Effective Sphaleron Awakens

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Xu-Xiang Li, Michael J. Ramsey-Musolf, Tuomas V. I. Tenkanen, **Yanda Wu**

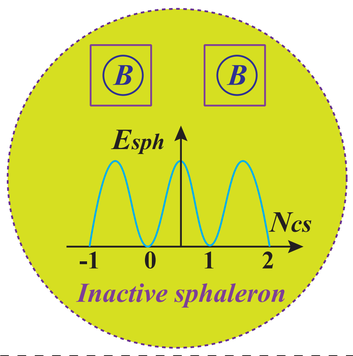
李政道研究所 TSUNG-DAO LEE INSTITUTE

★ Can the baryon asymmetry survive the sphaleron?

- Electroweak baryogengesis in the broken phase: to what extent can sphaleron processes erase the generated baryon asymmetry?

  This requires a robust computation of sphaleron rate.

$$\frac{\partial}{\partial t} n_B \propto -\frac{\Gamma_{sph}}{T^3} n_B$$



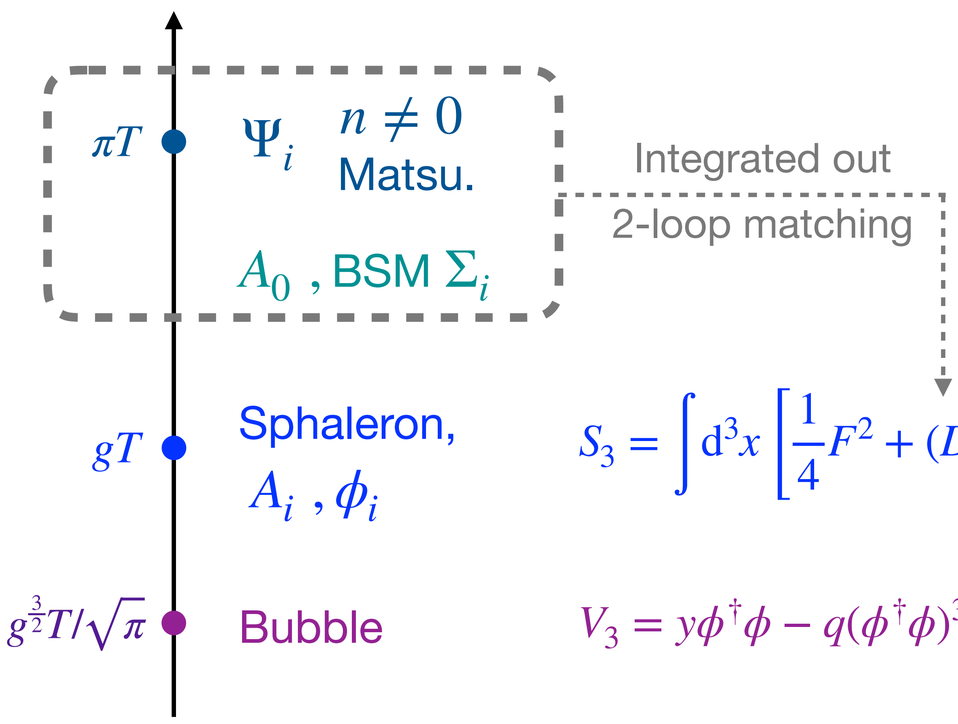
★ Sphaleron washout governs the viability of CPV for EW baryogenesis

- Sphaleron-induced washout is critical for electroweak baryogenesis, demanding stronger CPV sources to compensate the washout, thereby constraining models like xSM, TSM, 2HDM, MSSM, etc.
- The traditional washout-avoidance criterion, $v_c/T_c \gtrsim 1$, suffers from

  (1) v_c is gauge-dependent in general; (2) the absence of a consistent two-loop thermal corrections.

★ Build sphaleron EFT: gauge invariant assessment of sphaleron/bubble nucleation interplay

(i) First, we build a two-loop–resummed, SM-like 3D EFT by integrating out the heavy degrees of freedom and new particles.

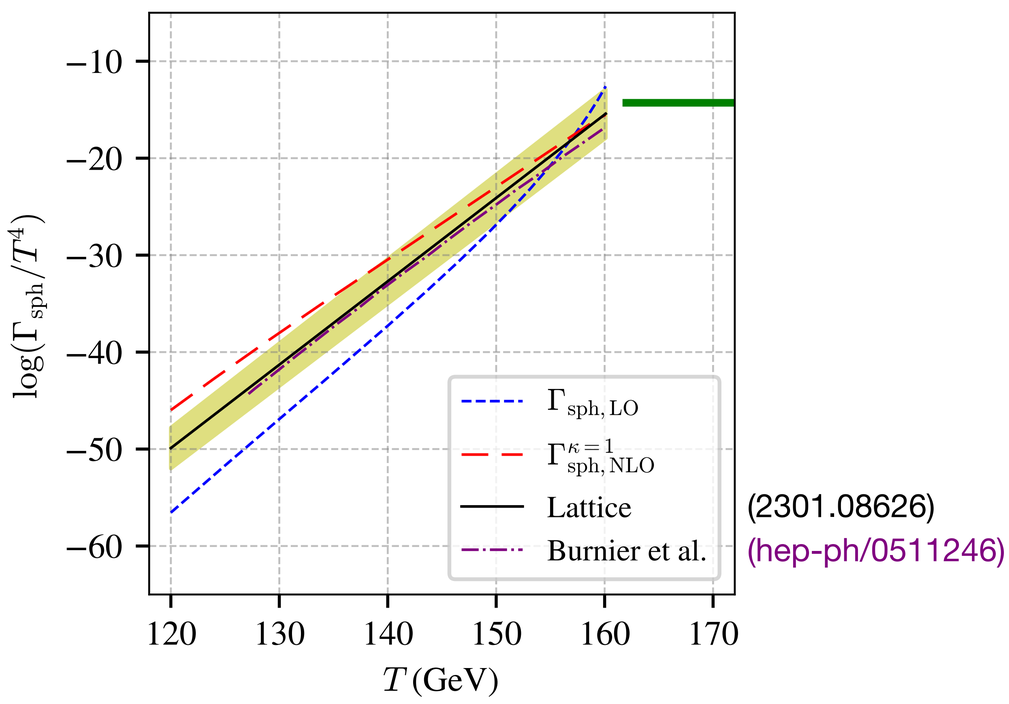


$$S_3 = \int \mathrm{d}^3x \left[\frac{1}{4}F^2 + (D_i\phi)^2 + V_3\right] ,$$

$$V_3 = y\phi^\dagger\phi - q(\phi^\dagger\phi)^{3/2} + x(\phi^\dagger\phi)^2 .$$

(ii) Next, using the LO gauge-invariant potential, we compute the sphaleron rate for SM crossover, in agreement with existing SM lattice results.

$$\Gamma_{sph,LO}(x,y) = T^4 e^{-S_3} , \quad \Gamma_{sph,NLO}(x,y) = T[det]_0 e^{-S_3} .$$

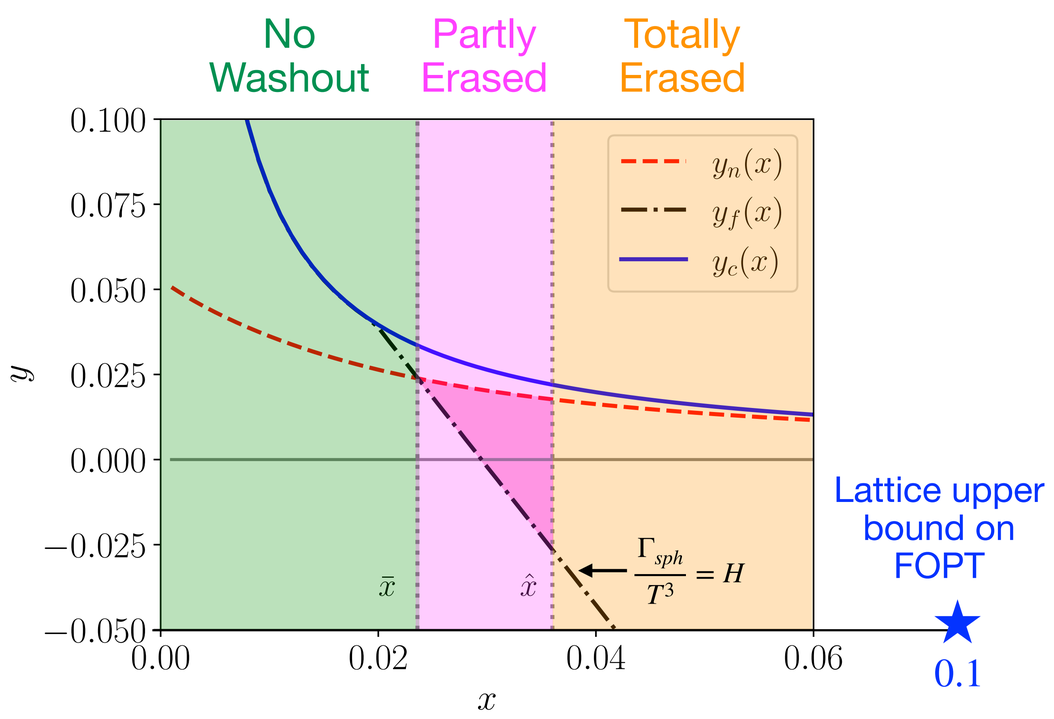


(iii) Finally, we apply the above formalism to compute the gauge-invariant sphaleron rate and baryon washout during a first-order phase transition, revealing three possible washout scenarios depending on the value of x.

- The washout criterion in gauge-invariant quantities:

$$y = \frac{\mu_3^2}{g_3^4} , \quad x = \frac{\lambda_3}{g_3^2} .$$

- As T decreases, y transitions from positive to negative, while x remains ~constant.
- BSM parameters map to a vertical line in the $x-y$ plot, determining the amount of baryon asymmetry washed out.



★ Potential Implications:

- We present a gauge-invariant, perturbatively consistent criterion for baryon-number preservation applicable to any BSM with heavy new particles integrated out in a 3D EFT;
- Our framework facilitates future lattice sphaleron studies and provides additional information for BSM collider searches (in HL-LHC and future CEPC, ILC, CLIC, FCC).

: yanda.wu7@sjtu.edu.cn : Shanghai, China