第十七届粒子物理、核物理和宇宙学交叉学科前沿问题研讨会（2024.07.12-2024.07.17，贵州省、贵阳市、贵州财经大学）

Axion-like particle triggered baryogenesis

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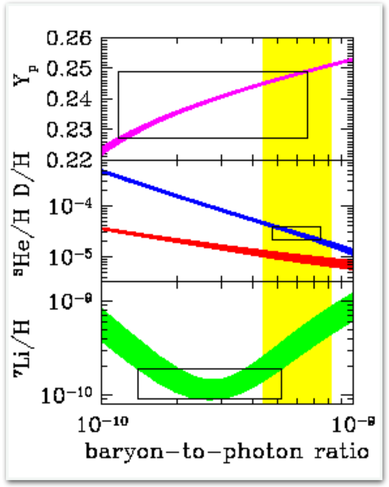
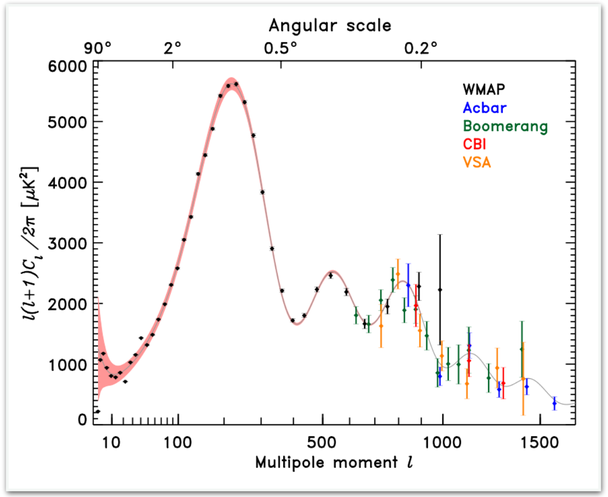
New physics—The Baryon asymmetry

Matter-antimatter asymmetry

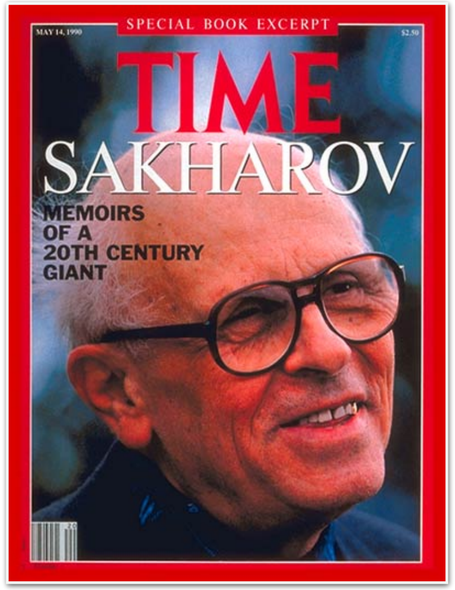
- 没有观测到反物质星系，否则光学望远镜会观测到星系湮灭的射线
- 元素的原初丰度以及CMB功率谱的形状都依赖于重子数与光子数之比

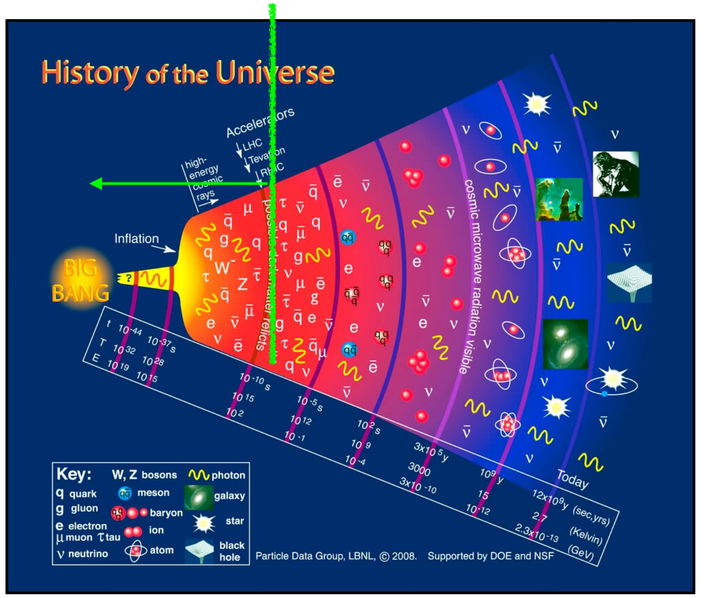




Baryon asymmetry: $Y_B = \frac{\rho_B}{s} = (8.59 \pm 0.11) \times 10^{-11}$ **Planck**

Baryogenesis





- ★Baryon number violating
- ★C&CP violation
- ★Departure from equilibrium

- Leptogenesis
- Electroweak Baryogenesis
- GUT Baryogenesis
- Afleck-Dine Baryogenesis
- Post-sphleron baryogenesis

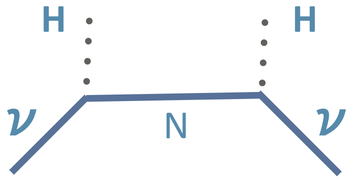
History and development: Leptogenesis

轻子数破坏与 Leptogenesis (type-I seesaw case)

Lagrangian:

$$-\mathcal{L} = Y_\nu \overline{\ell_L} \tilde{H} N_R + \frac{1}{2} \overline{N_R^C} M_R N_R + \text{h.c.}$$

Seesaw Mechanism



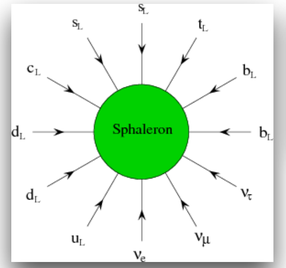
Neutrino mass:

$$M_\nu = -M_D M_R^{-1} M_D^T$$

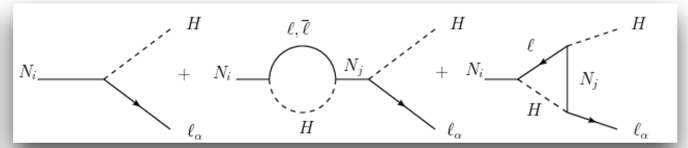
Elegant but losing testability at colliders!

物理图像

BV



CPV



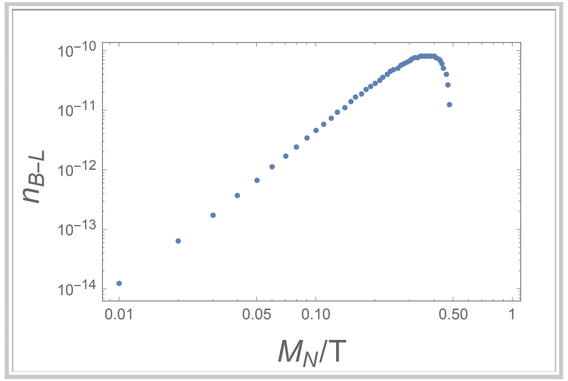
Out of EQ

Heavy neutrinos decouple

Boltzmann EQ

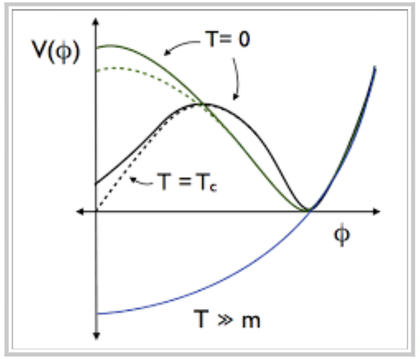
$$\frac{dN}{dz} = -D(N - N^{\text{eq}})$$

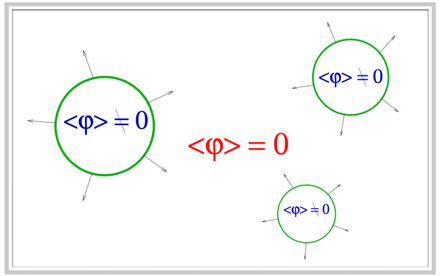
$$\frac{dN_{\text{B-L}}}{dz} = -\varepsilon D(N - N^{\text{eq}}) + W_{\text{ID}} N_{\text{B-L}}$$



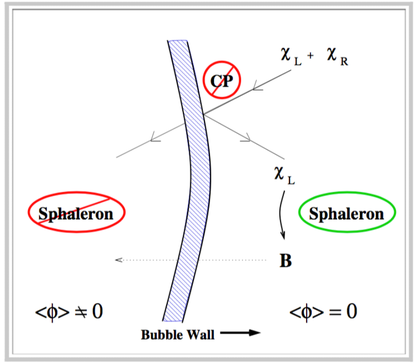
History and development: EW Baryogenesis

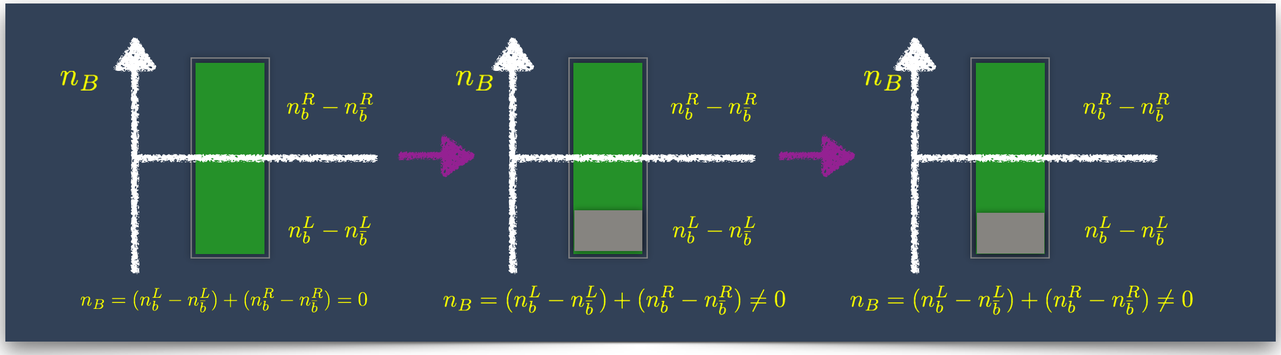
EWBG





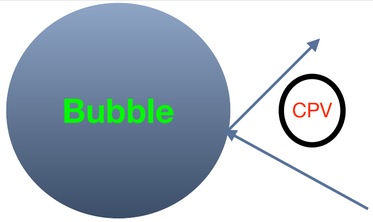
Basic description





输运方程

$$\frac{\partial n}{\partial t} + \nabla \cdot j(x) = -\int d^3z \int_{-\infty}^{x_0} dz^0 \mathrm{Tr}[\Sigma^>(x,z)S^<(z,x) - S^>(x,z)\Sigma^<(z,x) + S^<(x,z)\Sigma^>(z,x) - \Sigma^<(x,z)S^>(z,x)]$$



$$n_H \longleftrightarrow n_L$$

Yukawa

$$\partial_\mu \psi_\mu = +\Gamma_\psi^+ \left(\frac{\chi}{k_\chi} + \frac{\psi}{k_\psi}\right) + \Gamma_\psi^- \left(\frac{\chi}{k_\chi} - \frac{\psi}{k_\psi}\right) + \left(\sum_i \Gamma_{y_i}\right)\left(\frac{\chi}{k_\chi} - \frac{H}{k_H} - \frac{\psi}{k_\psi}\right) + S_{\mathrm{CP}}^\psi$$

$$\partial_\mu \chi_\mu = -\Gamma_\psi^+ \left(\frac{\chi}{k_\chi} + \frac{\psi}{k_\psi}\right) - \Gamma_\psi^- \left(\frac{\chi}{k_\chi} - \frac{\psi}{k_\psi}\right) - \left(\sum_i \Gamma_{y_i}\right)\left(\frac{\chi}{k_\chi} - \frac{H}{k_H} - \frac{\psi}{k_\psi}\right) - S_{\mathrm{CP}}^\psi$$

$$\partial_\mu H_\mu = \Gamma_{Y_t}\left(\frac{T}{k_T} - \frac{H}{k_H} - \frac{Q}{k_Q}\right) + \left(\sum_i \Gamma_{y_i}\right)\left(\frac{\chi}{k_\chi} - \frac{H}{k_H} - \frac{\psi}{k_\psi}\right) - \Gamma_h \frac{H}{k_H},$$

History and development: Afleck-Dine

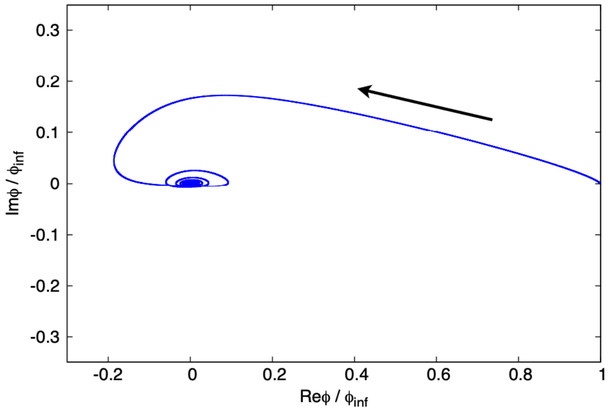
Afleck-Dine Mechanism

Scalars carrying non-zero U(1) charges

Flat directions (AD fields)

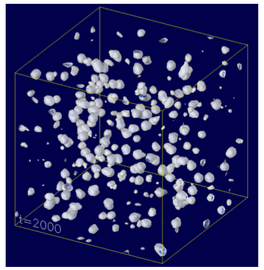
Lifting the potential via B/L violation operators

$$V = (m^2 - cH^2)|\phi|^2 + \lambda|\phi|^4 + \left(\frac{\phi^n}{M^{n-4}} + \mathrm{h.c.}\right)$$



$$\dot{n}_{B,L} + 3Hn_{B,L} = 2\beta \mathrm{Im}\left[\frac{\partial V}{\partial \phi}\phi\right]$$

Q-ball formation (Non-topological soliton in scalar field theory)



Oscillation of AD field

↓

Q-ball formation

↓

Long lived Q-ball

↓

DM candidate

Evaporation

↓

BAU when sphaleron erase is irrelevant

History and development: Axiogenesis

QCD Axion

Strong CP problem → **Peccei-Quinn mechanism** → **Axion**

$$d_n = 5.2 \times 10^{-16} \bar{\theta} \mathrm{e} \cdot \mathrm{cm}$$

$$d_n \leq 10^{-26} \mathrm{e} \cdot \mathrm{cm}$$

Pseudo-scalar particle

[Preskill, Wise, Wilczek (1983)]
[Abbott, Sikivie (1983)]
[Dine, Fischler (1983)]

Misalignment mechanism : $\phi_0 \neq 0, \quad \dot{\phi} = 0$

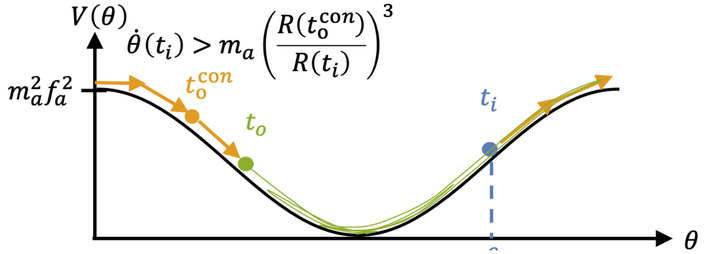
$$\ddot{\phi} + 3H\dot{\phi} + \frac{\Lambda^4(T)}{f^2}\phi = 0$$

$$\rho_{\mathrm{DM}} \sim m_\phi \left[\frac{a(T_{osc})}{a_0}\right]^3 \left[\frac{\Lambda(T_{osc})^4 \theta_i^2}{m_\phi(T_{osc})}\right]$$

Axiogenesis

Kinetic Misalignment mechanism : $\phi_0 \neq 0, \quad \dot{\phi} \neq 0$

[Co, Hall, Harigaya (2019)]
[Chang, Cui (2019)]



Non-zero Peccei-Quinn number→Axiogenesis!

Strong sphaleron → **Quake chiral asymmetry**

$$n_{PQ} = S^2 \dot{\phi}$$

EWsphaleron

PRL, 124, 111602

EWsphaleron → **Baryon asymmetry**

Two little works based on previous developments

- Axion-inflaton triggered baryogenesis

✓

Axion-inflation triggered baryogenesis, Wei Chao, Y.H. Wang, C.H. Xie, in submission

- Majoron dark matter triggered baryogenesis

Axion-like dark matter from the type-II seesaw mechanism, Wei Chao, M.J. Jin, H.J. Li Y.Q. Peng, PRD

Majorana Majoron and the baryon asymmetry of the Universe, Wei Chao,Y.Q. Peng, in submission

Axion-inflation triggered baryogensis

- Original idea : Alexander, Peskin, Sheikh-Jabbari, PRL 2004

$$S = \int \sqrt{-g}\left[\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - F(\phi)R\tilde{R}\right]$$

➡ **$R\tilde{R}$ production during axion inflation**

$$\partial_\mu J^\mu_l = \frac{3}{16\pi^2}R\tilde{R}$$

➡ **Net lepton number density after inflation!**

- Net number densities of SM particles can be produced via the axion-inflaton that couples to the Hyper U(1) gauge field via the Chern-Simons interaction, $g(\phi)F\tilde{F}$.
- Hyper-magnetic field may survive to the EWPT, resulting in net BAU (JHEP12(2017)011)

Axion-inflation triggered baryogensis

- **Axion inflation with interactions**

$$\mathscr{L}_{\rm int} = \frac{\alpha}{4\pi}\frac{\phi}{f_a}F_{\mu\nu}\widetilde{F}^{\mu\nu}$$

- **Production of gauge fields during inflation:** $\left(\Box\eta^{\mu\nu} - a\frac{\alpha\dot{\phi}}{\pi f_a}\varepsilon^{0\mu\sigma\nu}\partial_\sigma\right)A_\nu = 0$

$$A(\tau,x) = \sum_{\lambda=\pm}\int\frac{d^3k}{(2\pi)^3}\left[A_\lambda(\eta,k)\varepsilon_\lambda(k)a_\lambda(k)e^{ik\cdot x} + \mathrm{h.c.}\right]$$

$$\Rightarrow \left[\frac{\partial^2}{\partial\eta^2} + k(k+2\lambda\xi aH)\right]A_\lambda(\eta,k) = 0 \Rightarrow$$

$$A_\lambda^k(\tau) = \frac{e^{\lambda\pi\xi/2}}{\sqrt{2k}}W_{-i\lambda\xi,1/2}(2ik\tau)$$

Axion-inflation triggered baryogensis

- **Triangle anomalies for various U(1) gauge fields**

scenario	symmetries	Q_L	ℓ_L	U_R	D_R	E_R	N_R	H	ψ_L	ψ_R	χ_L	χ_R	η_L	η_R
(i)	$U(1)_{\mathbf{B-L}}$	$+\frac{1}{3}$	-1	$+\frac{1}{3}$	$+\frac{1}{3}$	-1	-1	0	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$
(ii)	$U(1)_{\mathbf{R}}$	0	0	-1	$+1$	-1	$+1$	1	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$
(iii)	$U(1)_{\mathbf{B}}$	$+\frac{1}{3}$	0	$+\frac{1}{3}$	$+\frac{1}{3}$	0	0	0	-1	$+2$	$+2$	-1	$+2$	-1
(iv)	$U(1)_{\mathbf{L}}$	0	$+1$	0	0	$+1$	$+1$	0	-1	$+2$	$+2$	-1	$+2$	-1

Axion-inflation triggered baryogensis

- **U(1)$_{B-L}$**

$$\partial_\mu\left(j^\mu_{B,Q}\right)=\frac{1}{32\pi^2}\left(g^2W\widetilde{W}+\frac{1}{9}g'^2F\widetilde{F}+\frac{4}{9}g^2_{B-L}F'\widetilde{F}'\right)$$

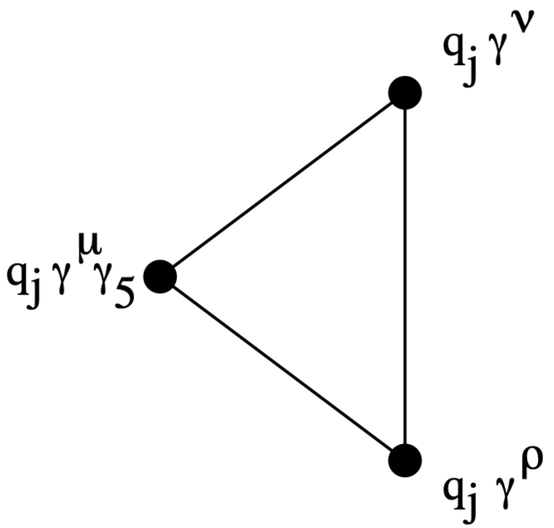
$$\partial_\mu\left(j^\mu_{B,u}\right)=\frac{1}{16\pi^2}\left(-\frac{4}{9}g'^2F\widetilde{F}-\frac{1}{9}g^2_{B-L}F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{B,d}\right)=\frac{1}{16\pi^2}\left(-\frac{1}{9}g'^2F\widetilde{F}-\frac{1}{9}g^2_{B-L}F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{L,\ell}\right)=\frac{1}{32\pi^2}\left(g^2W\widetilde{W}+g'^2F\widetilde{F}+4g^2_{B-L}F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{L,E}\right)=\frac{1}{16\pi^2}\left(-g'^2F\widetilde{F}-g^2_{B-L}F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{L,N}\right)=\frac{1}{16\pi^2}\left(-g^2_{B-L}F'\widetilde{F}'\right)$$



$$\partial_\mu\left(j^\mu_B-j^\mu_L\right)=\partial_\mu j^\mu_N=\frac{-g^2_{B-L}}{16\pi^2}F'\widetilde{F}'$$

Key-point of this study!

Axion-inflation triggered baryogensis

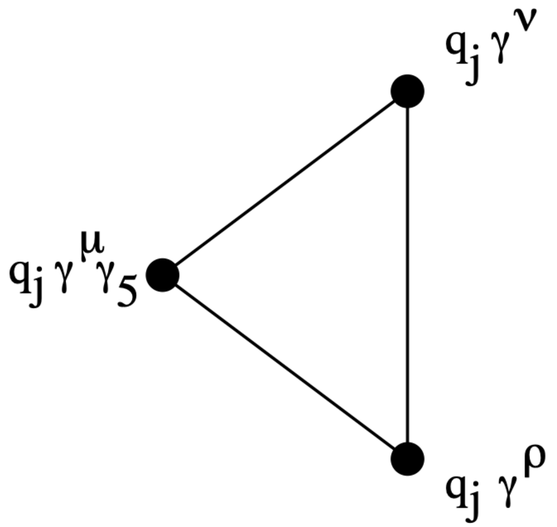
- **U(1)$_R$**

$$\partial_\mu\left(j^\mu_{B,u}\right)=\frac{1}{16\pi^2}\left(-\frac{4}{9}g'^2F\widetilde{F}-g_R^2F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{B,d}\right)=\frac{1}{16\pi^2}\left(-\frac{1}{9}g'^2F\widetilde{F}-g_R^2F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{L,E}\right)=\frac{1}{16\pi^2}\left(-g'^2F\widetilde{F}-g_R^2F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{L,N}\right)=\frac{1}{16\pi^2}\left(-g_R^2F'\widetilde{F}'\right)$$



$$\partial_\mu\left(j^\mu_B-j^\mu_L\right)=\partial_\mu j^\mu_N=\frac{-g^2_{B-L}}{16\pi^2}F'\widetilde{F}'$$

Axion-inflation triggered baryogensis

- **$U(1)_B$:**

- **current equations for quarks are the same as these in the $U(1)_{B-L}$**
- **current equations for leptons are the same as these in the SM**

$$\partial_\mu\left(j^\mu_{\psi_L}\right) = +\frac{1}{32\pi^2}\left(g^2 W\widetilde{W} + g'^2 F\widetilde{F} + 4g_B^2 F'\widetilde{F}'\right) \qquad \partial_\mu\left(j^\mu_{\psi_R}\right) = -\frac{1}{32\pi^2}\left(g^2 W\widetilde{W} + g'^2 F\widetilde{F} + 16g_B^2 F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{\chi_L}\right) = +\frac{1}{16\pi^2}\left(g'^2 F\widetilde{F} + 4g_B^2 F'\widetilde{F}'\right) \qquad \partial_\mu\left(j^\mu_{\chi_R}\right) = -\frac{1}{16\pi^2}\left(g'^2 F\widetilde{F} + g_B^2 F'\widetilde{F}'\right)$$

$$\partial_\mu\left(j^\mu_{\eta_L}\right) = +\frac{1}{4\pi^2}\left(g_B^2 F'\widetilde{F}'\right) \qquad \partial_\mu\left(j^\mu_{\eta_R}\right) = -\frac{1}{16\pi^2}\left(g_B^2 F'\widetilde{F}'\right)$$

$$\Rightarrow \quad \partial_\mu\left(j^\mu_{\psi_L} + j^\mu_{\psi_R} + j^\mu_{\chi_L} + j^\mu_{\chi_R} + j^\mu_{\eta_L} + j^\mu_{\eta_R}\right) = 0$$

$$\partial_\mu\left(j^\mu_B - j^\mu_L\right) = 0\,!$$

Axion-inflation triggered baryogensis

- **$U(1)_L$:**

- **current equations for quarks are the same as these in the SM**
- **current equations for leptons are the same as these in the $U(1)_{B-L}$**
- **current equations for new fermions are the same as these in the $U(1)_B$**

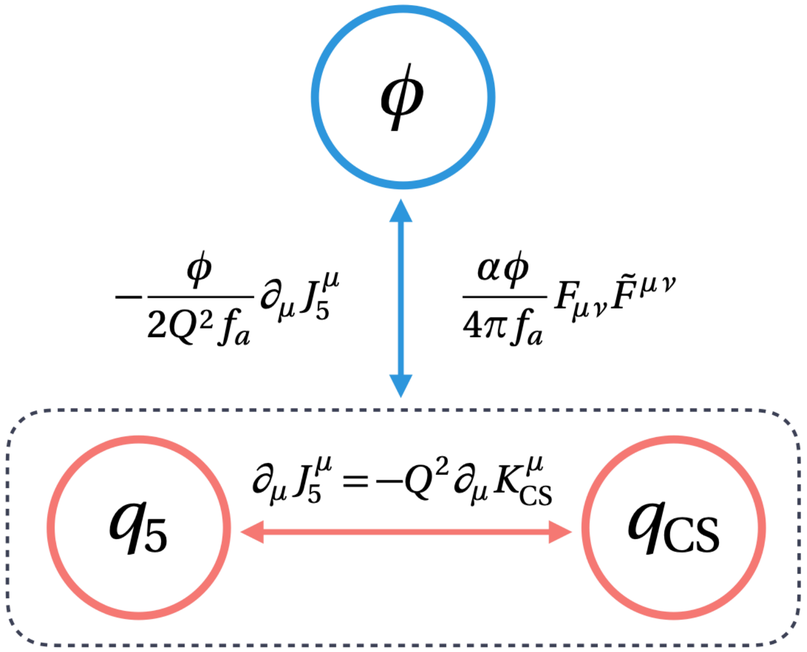
$$\partial_\mu \left(j^\mu_{\psi_L} + j^\mu_{\psi_R} + j^\mu_{\chi_L} + j^\mu_{\chi_R} + j^\mu_{\eta_L} + j^\mu_{\eta_R} \right) = 0$$

$$\partial_\mu \left(j^\mu_B - j^\mu_L \right) = \partial_\mu j^\mu_N \neq 0 !$$

If neutrinos are Dirac particles which means that its Yukawa interaction never reach equilibrium, then we have the source of the BAU for the $U(1)_{B-L}$, $U(1)_R$ and $U(1)_L$ cases!

Axion-inflation triggered baryogensis

- **Axion inflation** $\rightarrow q_{CS} \rightarrow q_5$



- **Chern Simons number:**

$$n_{CS} \equiv \frac{1}{(2\pi)^2}\mathcal{K}(\xi)a^3H^3$$

$$= \frac{1}{(2\pi)^2}\sum_{\lambda=\pm}\lambda e^{i\kappa_\lambda \pi}\int \tilde{\tau}^3 d\ln\tilde{\tau} W^*_{\kappa_\lambda,\mu}(-2i\tilde{\tau})W_{\lambda_\sigma,\mu}(-2i\tilde{\tau})a^3H^3$$

- **Chiral fermion asymmetry during reheating**

$$n_{f,\sigma} = -\epsilon_\sigma N_{f,\sigma}\frac{g_X^2}{8\pi^2 a^3}n_{CS} = -\epsilon_i N_i \frac{g_X^2}{2(2\pi)^4}H^3\mathcal{K}(\xi)$$

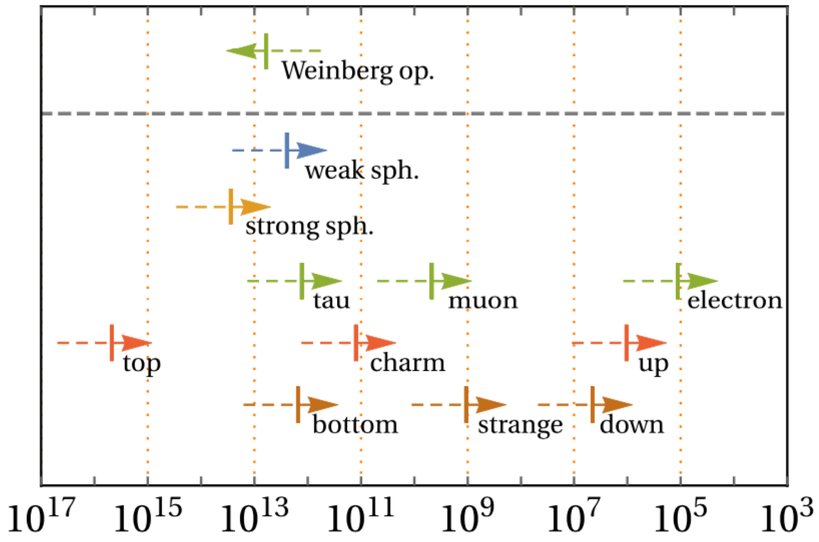
Axion-inflation triggered baryogensis

- **From chiral fermion asymmetries to the BAU**

Transport equations:

$$-\frac{d}{d\ln T}\left(\frac{\mu_i}{T}\right) = -\frac{1}{g_i}\sum_\alpha n_i^\alpha \frac{\gamma_\alpha}{H}\left[\sum_j n_j^\alpha \left(\frac{\mu_j}{T}\right)\right],$$

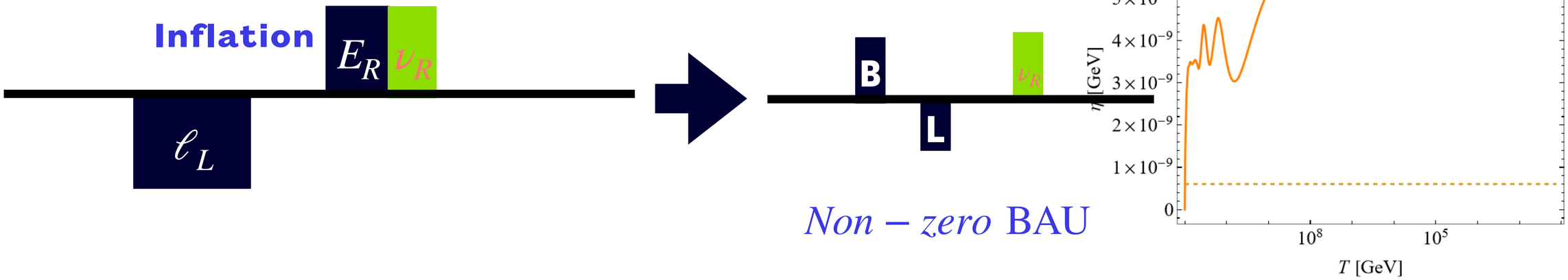
Interaction		WS	SS	Y_e	Y_μ	Y_τ
Γ_α/T^4		$\frac{1}{2}\kappa_{\rm WS}\alpha_2^5$	$\frac{1}{2}\kappa_{\rm SS}\alpha_3^5$	$\kappa_{Y_e}\, y_e^2$	$\kappa_{Y_e}\, y_\mu^2$	$\kappa_{Y_e}\, y_\tau^2$
T_α [GeV]	6.0×10^{12}	2.5×10^{12}	2.8×10^{13}	1.1×10^{5}	4.7×10^{9}	1.3×10^{12}
Interaction	Y_u	Y_c	Y_t	Y_d	Y_s	Y_b
Γ_α/T^4	$\kappa_{Y_u}\, y_u^2$	$\kappa_{Y_u}\, y_c^2$	$\kappa_{Y_t}\, y_t^2$	$\kappa_{Y_d}\, y_d^2$	$\kappa_{Y_d}\, y_s^2$	$\kappa_{Y_d}\, y_b^2$
T_α [GeV]	1.0×10^{6}	1.2×10^{11}	4.7×10^{15}	4.5×10^{6}	1.1×10^{9}	1.5×10^{12}



Axion-inflation triggered baryogensis

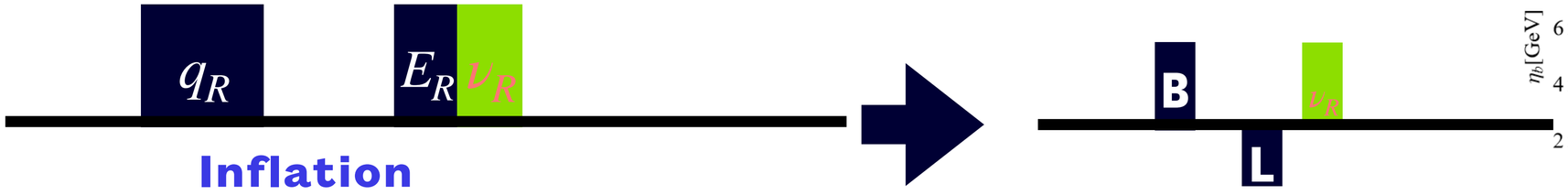
- $F\tilde{F}$: $U(1)_B$ gauge field ✗ (or require exotic mechanism!)

- $F\tilde{F}$: $U(1)_L$ gauge field ✓

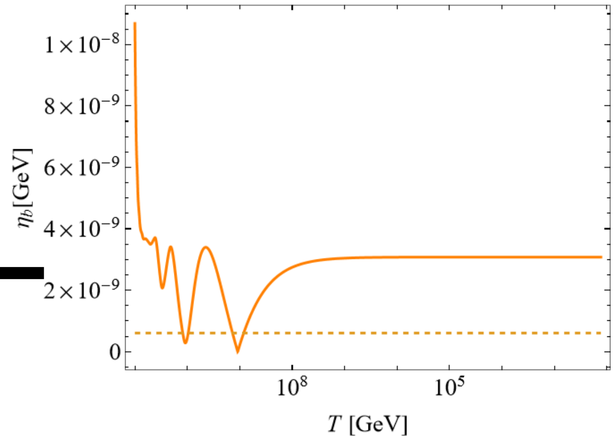


Axion-inflation triggered baryogensis

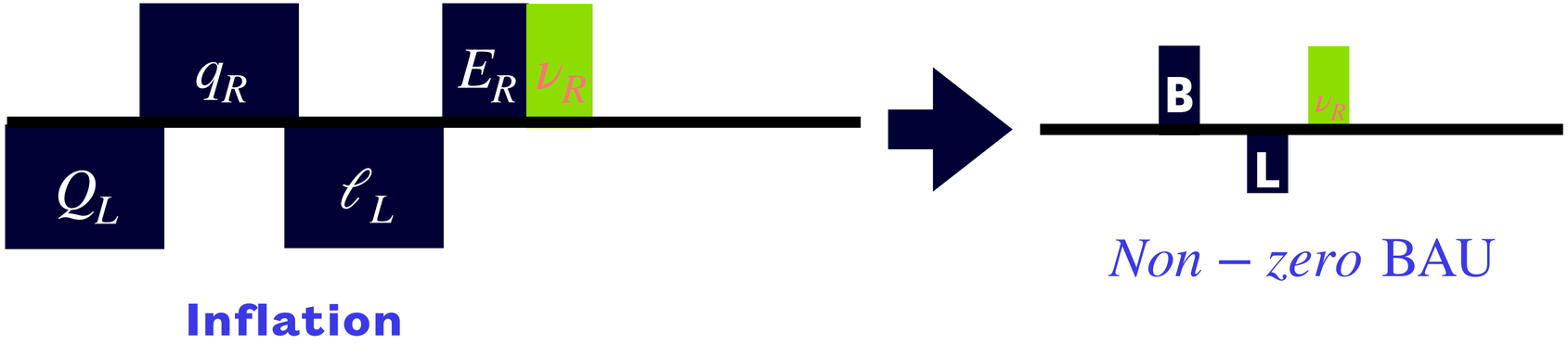
- $F\tilde{F}$: **U(1)$_R$ gauge field** ✓



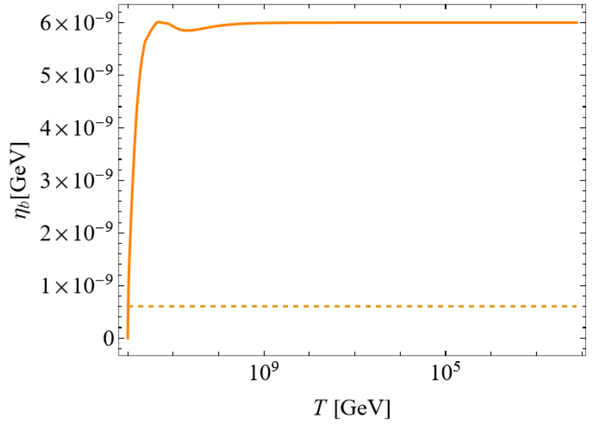
Non – zero BAU



- $F\tilde{F}$: **U(1)$_{B\text{-}L}$ gauge field** ✓



Non – zero BAU



Two little works based on previous developments

- Axion-inflaton triggered baryogenesis

Axion-inflation triggered baryogenesis, Wei Chao, Y.H. Wang, C.H. Xie, in submission

- Majoron dark matter triggered baryogenesis ✓

Axion-like dark matter from the type-II seesaw mechanism, Wei Chao, M.J. Jin, H.J. Li Y.Q. Peng, PRD

Majorana Majoron and the baryon asymmetry of the Universe, Wei Chao,Y.Q. Peng, in submission

Majoron & neutrino mass via type-I seesaw

Type-I seesaw + spontaneous breaking $U(1)_L$ symmetry

$$\mathscr{L}_{\rm BSM} = \left(\partial_\mu \Phi\right)^\dagger (\partial^\mu \Phi) + \mu_\Phi^2 \Phi^\dagger \Phi - \lambda_1 (\Phi^\dagger \Phi)^2 - \lambda_2 (\Phi^\dagger \Phi)(H^\dagger H) - \left[Y_{\rm N} \overline{\ell}_L \tilde{H} N_R + \frac{1}{2} \overline{N_R^C} \left(Y_{\rm M} \Phi + m \right) N_R + {\rm h.c.} \right]$$

LNV term!

$$H = \begin{pmatrix} \phi^+ \\ \dfrac{v_\phi + \phi + i\chi}{\sqrt{2}} \end{pmatrix} \qquad \Phi = \frac{v_s + \tilde{s} + i\tilde{a}}{\sqrt{2}}$$

$\tilde{a}$: **Majoron**

Yukawa Interaction $\quad -Y_{\rm N} \overline{\ell}_L \tilde{H} N_R \to M_D = Y_N v/\sqrt{2}$

Key term: $\quad m\overline{N_R^C} N_R + h.c.$

Quantum Gravity effect!

Majoron interactions and Majoron mass

Field-dependent phase transformation

$$\left.\begin{aligned} \ell_L &\to e^{-\frac{ia}{2f}}\ell_L \qquad S \to e^{+\frac{ia}{f}}S \\ E_R &\to e^{-\frac{ia}{2f}}E_R \qquad H \to H \end{aligned}\right\}$$

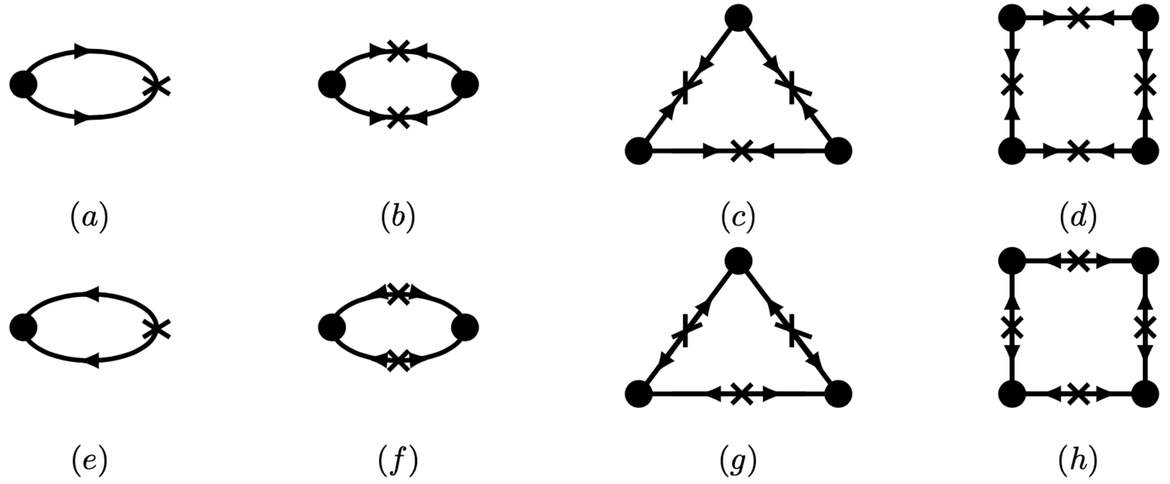
$$\begin{aligned} \mathscr{L} &\to \mathscr{L} - \frac{a}{2f}\partial_\mu\left(\overline{\ell_L}\gamma^\mu\ell_L + \overline{E_R}\gamma^\mu E_R\right) \\ &= \mathscr{L} - \frac{a}{2f}\partial_\mu J^L_\mu \\ &= \mathscr{L} + \frac{a}{2f}\frac{N_f}{32\pi^2}\left(g^2 W^a_{\mu\nu}\widetilde{W}^{\mu\nu,a} - g'^2 B_{\mu\nu}\widetilde{B}^{\mu\nu}\right) \end{aligned}$$

$$N_R \to e^{-\frac{ia}{2f}}N_R \quad \longrightarrow \quad \frac{1}{2}e^{-i\theta}\overline{N_R^C}mN_R + h.c.$$

Majoron interactions and Majoron mass

$$\frac{1}{2}e^{-i\theta}\overline{N_R^C}mN_R + h.c. \longrightarrow$$

Mass insertion of right-handed neutrino masses:



Before symmetry breaking: $M = m$

After symmetry breaking: $M = f_a Y_M/\sqrt{2} + m$

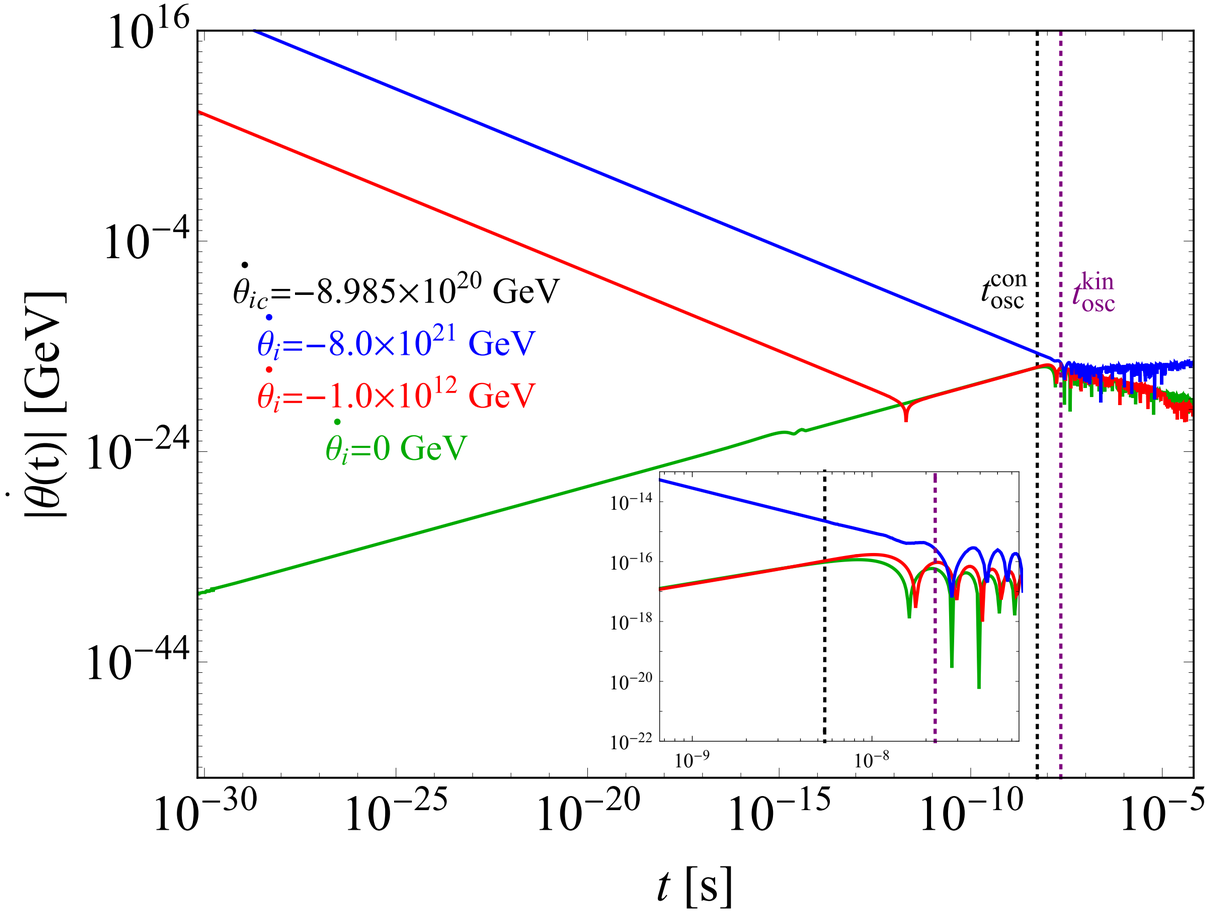
$$V_a \sim -\frac{1}{16\pi^2}\sum_{n=1}^{4} a_n \cos n\theta .$$

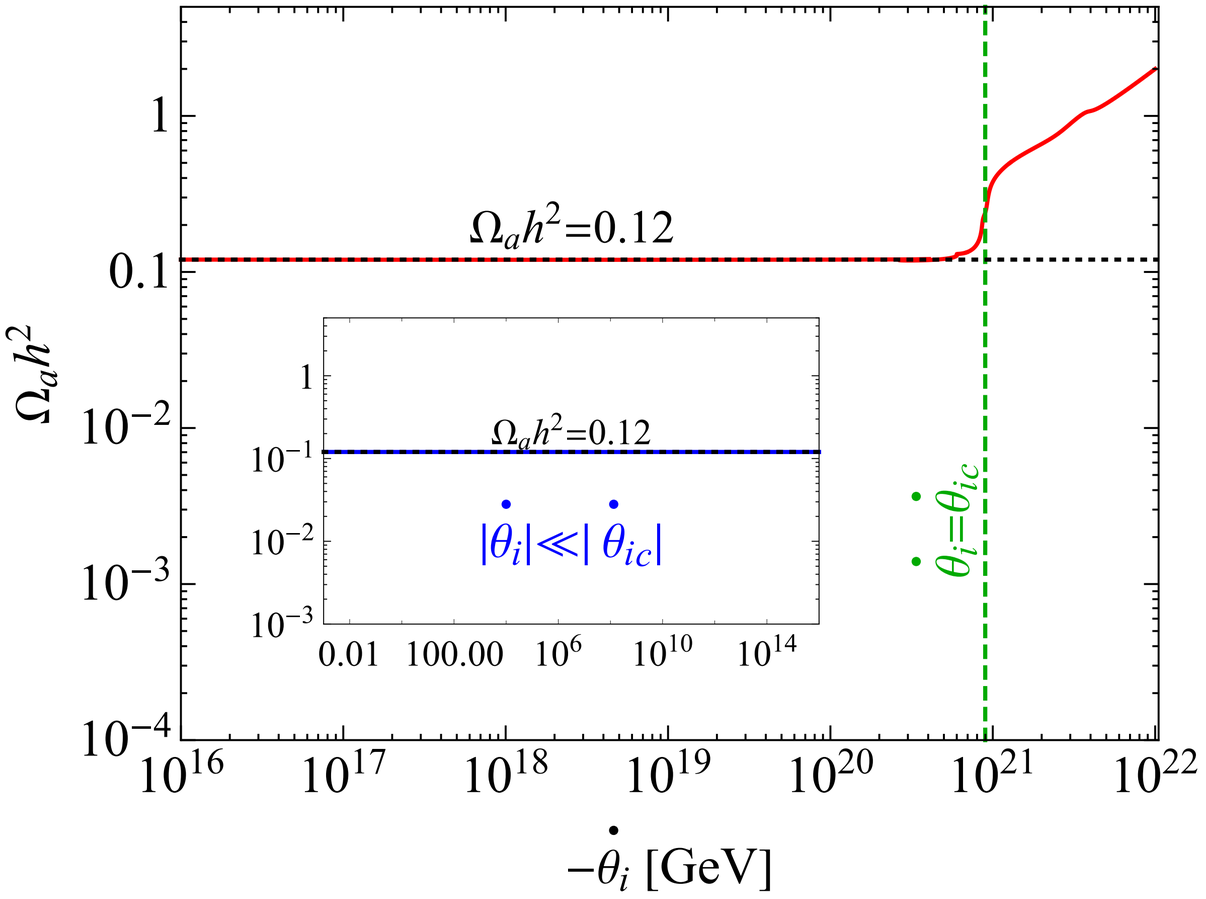
a_1	a_2	a_3	a_4
$mM^3\left(1-\log\frac{M^2}{M_{pl}^2}\right)$	$2m^2M^2\log\frac{M^2}{M_{pl}^2}$	$-m^3M$	$m^4/3$

Majoron mass and its relic density

Majoron mass:	$m_a^2 = \frac{1}{f_a^2}\frac{d^2V}{d\theta^2} = \frac{1}{16\pi^2 f_a^2}\left\lvert a_1 + 4a_2 + 9a_3 + 16a_4 \right\rvert .$	
Initial velocity: **(From Noether theorem)**	$\partial_\mu j^\mu = \left(\frac{\partial V}{\partial \phi}\right)\phi - \phi^\dagger\left(\frac{\partial V}{\partial \phi^\dagger}\right)$	**In the traditional misalignment mechanism** $\dot{\theta}_i = 0$
EOM	$\ddot{\theta} + 3H\dot{\theta} + \frac{1}{f_a^2}\frac{dV_a}{d\theta} = 0,$	**Different oscillation temperature**

Majoron mass and its relic density





Baryon asymmetry of the universe

$m\overline{N_R^C}N_R + h.c.$ → **LNV carried by** $\dot{\theta}$ → **Non-zero B-L**

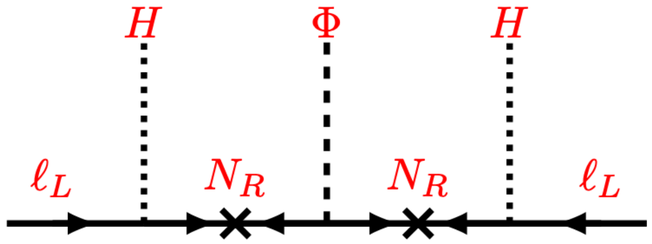
Weinberg operator

Chern-Simons operator

Non-zero B-L → **BAU**

Sehemas

Key:



$$\mathscr{L}_{\rm int} \supset \frac{1}{2M}\frac{a}{f_a}\ell\ell HH, \qquad \mathscr{L}_{\rm int} \supset \frac{3g^2}{64\pi^2}\frac{a}{f_a}W\widetilde{W}$$

Baryon asymmetry of the universe

Transport equations:

$$-\frac{d}{d\ln T}\left(\frac{\mu_i}{T}\right) = -\frac{1}{g_i}\sum_\alpha n_i^\alpha \frac{\gamma_\alpha}{H}\left[\sum_j n_j^\alpha\left(\frac{\mu_j}{T}\right) - n_S^\alpha \frac{\dot{\theta}(T)}{T}\right],$$

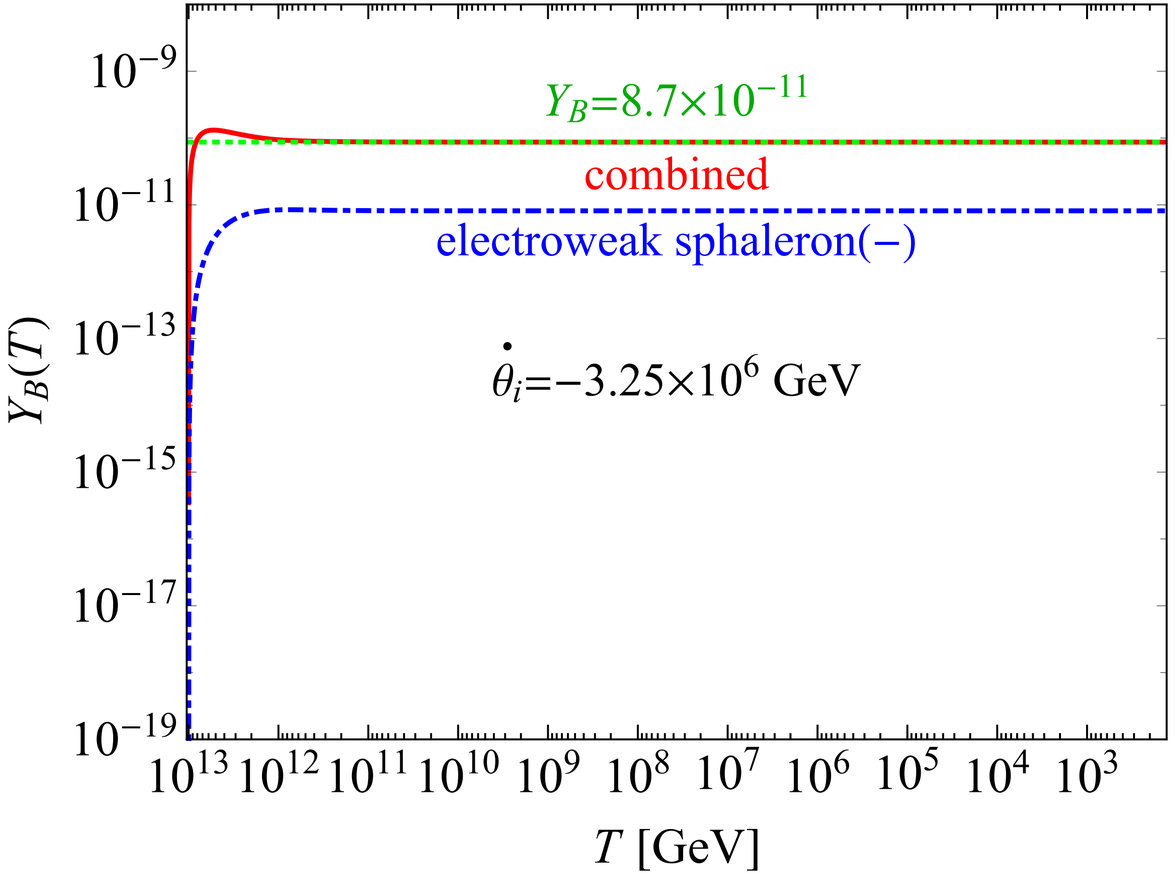
Source term:

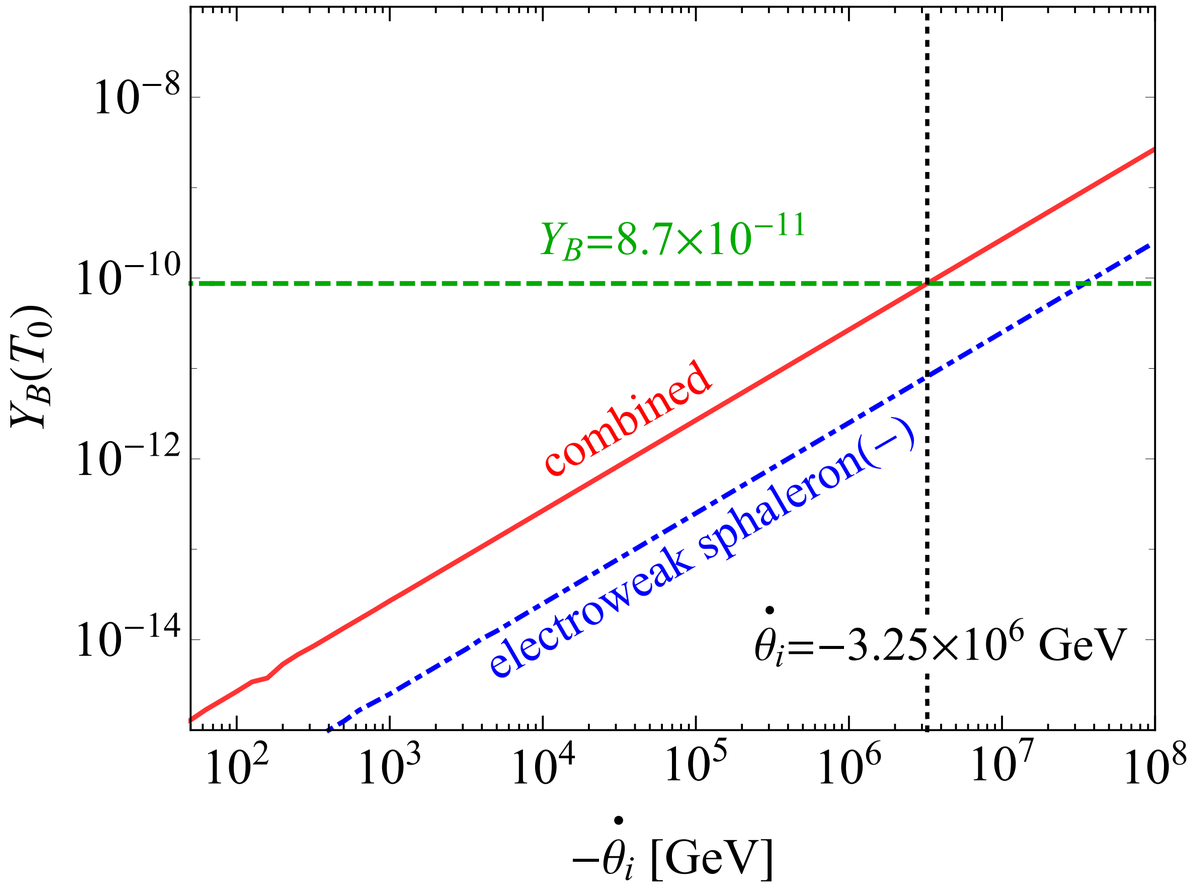
$$\left(n_S^{WS}, n_S^{W_{12}}, n_S^{W_3}, n_S^{SS}, n_S^{Y_\tau}, n_S^{Y_t}, n_S^{Y_b}\right) = \left(\frac{3}{2}, 1, 1, 0, 0, 0, 0\right).$$

Weinberg operator decoupling temperature:

$$T_{\rm W} \simeq 6\times 10^{12}\,{\rm GeV}\times\left(\frac{0.05\,{\rm eV}}{m_\nu}\right)^2.$$

Baryon asymmetry of the universe





Summary

Dark matter and the baryon asymmetry of the universe are two solid hints of new physics beyond the SM.

They can be explained simultaneously in a simple theory.

We have proposed two possible solutions to the baryon asymmetry based on axion-like dark matter or inflation theories.

Thank you for your attention!