COGENESIS BY QCD AXION

EJC, Jung, 2311.09005

EJC, Das, He, Jung, Sun, 2406.04180

Work in preparation

Eung Jin Chun

KIAS
KOREA INSTITUTE FOR ADVANCED STUDY

DARK MATTER 2025
FROM THE SMALLEST TO THE LARGEST SCALES
JUNE 2-6, 2025 | SANTANDER

PNGB FOR CDM & BAU

Spontaenous $U(1)$ breaking: $\Phi = \frac{f_a}{\sqrt{2}} e^{i\theta}, \theta \equiv \frac{a}{f_a}$

Kinetic motion as a source of baryogenesis

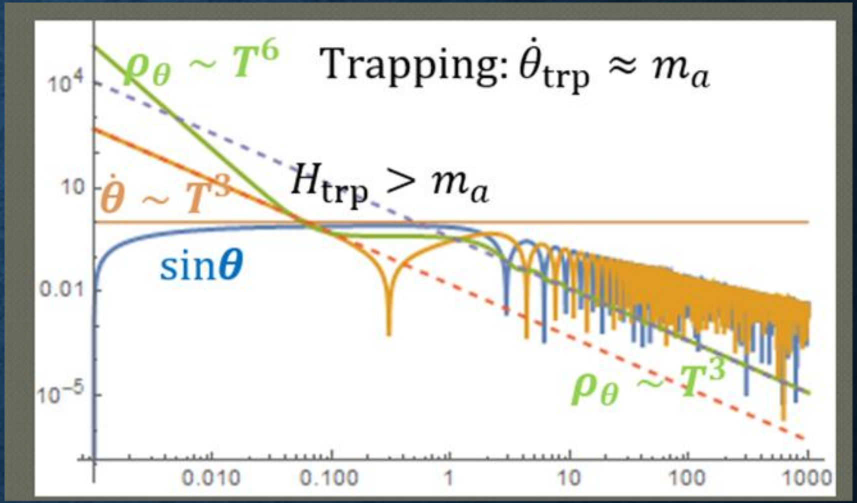
- In the background of $\dot{\theta} \neq 0$ violating C & CPT, $\psi/\bar{\psi}$ get a potential $\pm x_\psi \dot{\theta}$.
- When B(L)NV interactions are in equilibrium, it is fed into $\mu_\psi = c_\psi \dot{\theta}$ generating BAU $\mu_B = c_B \dot{\theta}$.
- QCD axion from $U(1)_{\rm PQ}$ breaking: weak spharelon in equilibrium till $T_B = T_{EW}$.

$$\sum_{\psi \in A} \mu_\psi = c_A \dot{\theta}$$

- Majoron from $U(1)_{B-L}$ breaking: $N \leftrightarrow lH$ in equilibrium around $T_B \sim M_N$.

$$\mu_l + \mu_H = x_N \dot{\theta}$$

Coherent oscillation as CDM



$$Y_\theta \equiv \frac{n_\theta}{s} = \frac{\dot{\theta} f_a^2}{s} = \text{conserved}$$

$$\frac{\rho_{\rm DM}}{s} = 2 m_a Y_\theta \approx 0.44 \text{ eV}$$

$$Y_B = \frac{1}{6} \mu_B T^2 \approx 10^{-10}$$

COGENESIS BY QCD AXION=MAJORON

- KSVZ+Seesaw :

$$\mathcal{L}_{\rm PQ} = y_Q \Phi Q Q^c + \frac{1}{2} y_N \Phi N N + h.c.$$

(PQ charges: $x_{Q,Q^c} = x_N = -x_l = x_{e^c} = -\frac{1}{2}$)

- After the PQ breaking:

$$\mathcal{L} = y_{u_i} q_i u_i^c H + y_{d_i} q_i d_i^c \widetilde{H} + y_{e_i} l_i e_i^c \widetilde{H} + y_{\nu_i} l_i N_i H$$

$$+ M_Q Q Q^c + \frac{1}{2} M_N N N + \frac{c_S \theta}{32\pi^2} G\widetilde{G} + \frac{c_W \theta}{32\pi^2} W\widetilde{W}$$

- Equilibrium conditions; $\dot{n}_{q_i} = \dot{n}_{u_i^c} = \dot{n}_{d_i^c} = \dot{n}_{l_i} = \dot{n}_{e_i^c} = 0$ (Yukawas+SS+WS) & charge neutrality, can be solved to find

$$\mu_B = \frac{28}{79}\frac{1}{33}\left(28\, c_W - \frac{57\, m_u^2 - 15 m_d^2}{m_u^2 + m_d^2} c_S - 153 x_l\right)\dot{\theta} = c_B \dot{\theta} \;\; \text{at} \;\; T_B \sim M_N$$

$c_B = -2.2$ for $c_W = 0$ & $c_S = N_Q = 1$

Cogenesis requires $Y_B = c_B \left(\frac{0.22\text{eV}}{m_a}\right)\left(\frac{T_B}{f_a}\right)^2 \Rightarrow M_N \sim 30\text{TeV}\sqrt{\frac{f_a}{10^{10}\text{GeV}}}$

(Origin of large $\dot{\theta}$: time/temperature dependent mass correction with explicit PQ breaking of good quality)

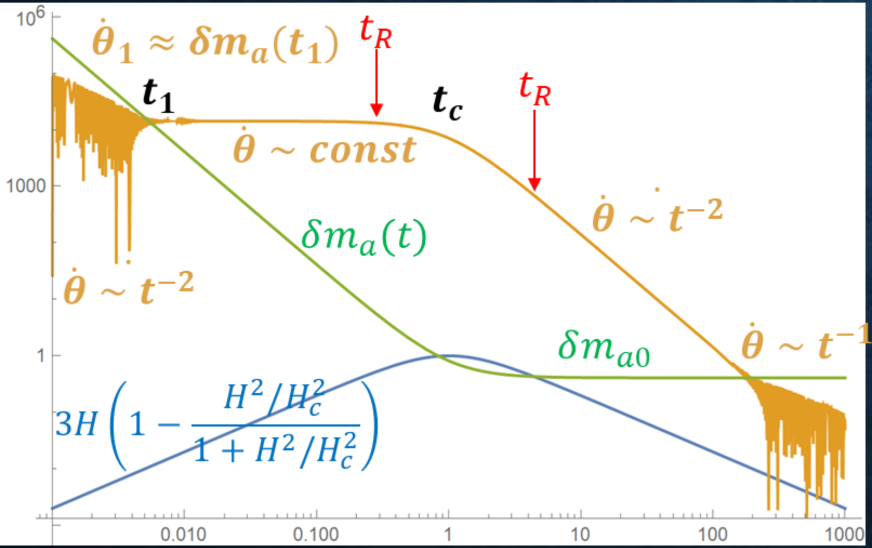
LARGE $\dot{\theta}$ VIA AD MECHANISM

- PQV operator of good quality to generate $Y_\theta = \frac{0.22\text{eV}}{m_a} \approx 400 \left(\frac{f_a}{10^{10}\text{GeV}}\right)$

$$V = -\frac{1}{2}(\mu_0^2 + c_H H^2)\phi^2 + \frac{\lambda_0}{4}\phi^4 - \frac{\lambda_n}{\sqrt{2^n}}\frac{\phi^n}{M_P^{n-4}} 2\cos(n\theta) \qquad \Phi = \frac{\phi}{\sqrt{2}}e^{i\theta}$$

$$\phi = \sqrt{\frac{\mu_0^2 + c_H H^2}{\lambda_0}} \equiv f_a \sqrt{1 + \frac{H^2}{H_c^2}} \text{ with } H_c \equiv \frac{\mu_0}{\sqrt{c_H}} \qquad \delta m_{a0}^2 = 2n^2 \frac{\lambda_n}{\sqrt{2^n}}\frac{f_a^n}{M_P^{n-4}} \ll m_a^2$$

During inflation ($H = H_I$) & matter domination ($H = \frac{2}{3t}$)



$$Y_{\max} \approx 30 \left(\frac{\delta m_{a0}}{\mu\text{eV}}\right)\left(\frac{H_1}{10^{13}\text{GeV}}\right)^4 \left(\frac{10^5\text{GeV}}{H_c}\right)^{\frac{11}{2}}$$

at $t_c = t_R$ for $n = 10$ & $f_a = 10^{10}$GeV.