Dulition of axion dark radiation

Osamu Seto (Hokkai-Gakuen Univ.)

With Hironori Hattori, Tatsuo Kobayashi and
Naoya Omoto (Hokkaido Univ.)

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§ Introduction

§ § SM of particle physics

Success of the standard model of particle physics

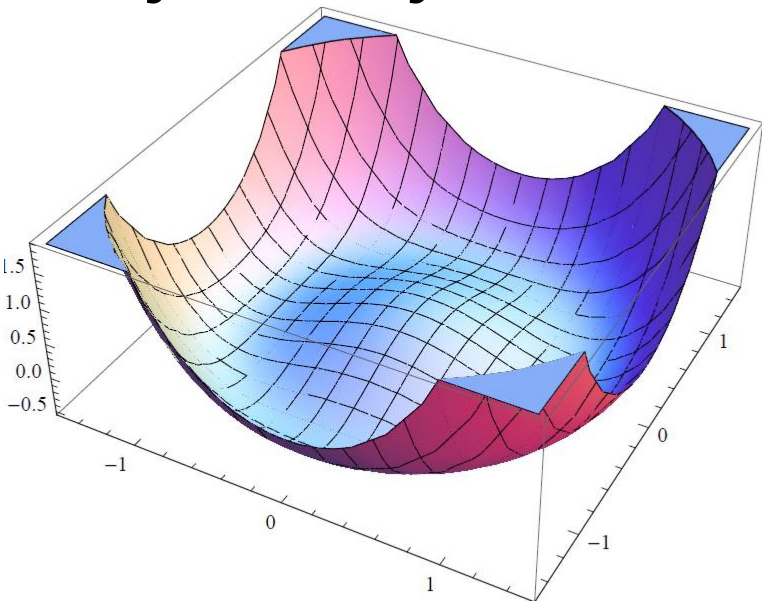
- It well explain almost all phenomena occurred at accelerator experiments.

Problems of the SM

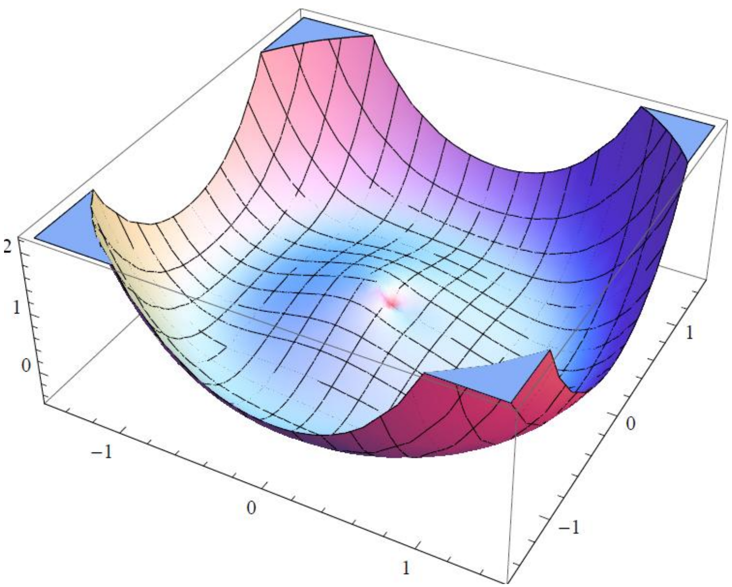
- Nonvanishing neutrino mass
- Strong CP problem → **axion in PQ mechanism**
- Gauge hierarchy problem
- …

§ § Axion

- Axion is a NG boson of broken global $U(1)_{PQ}$ symmetry



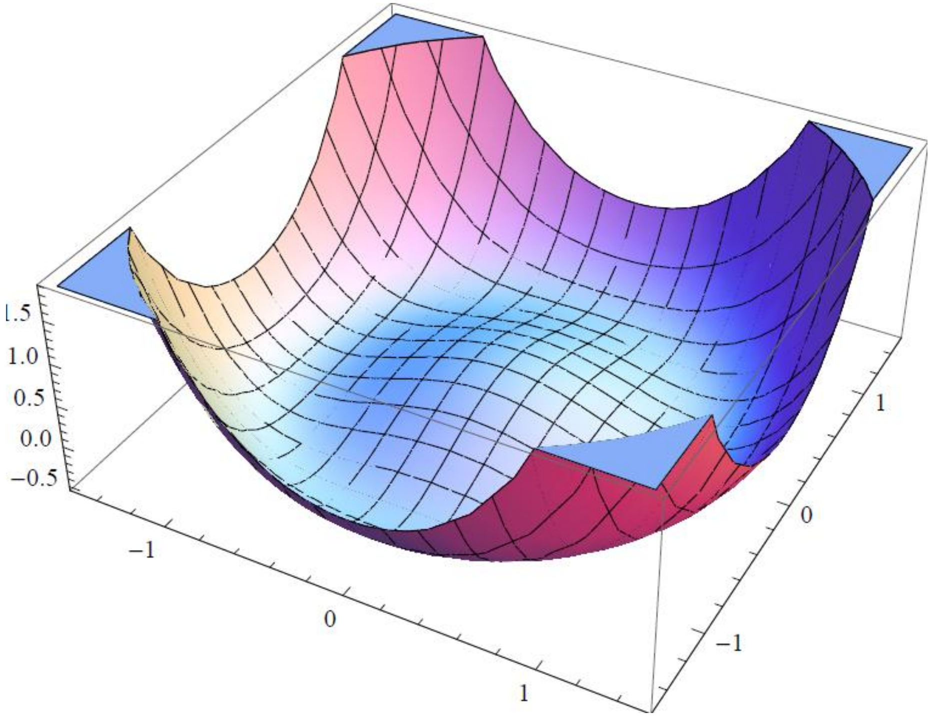
QCD⟹



- Tiny mass below QH transition.

§ § Axion

- Radial direction of the field also evolves in the early Universe.



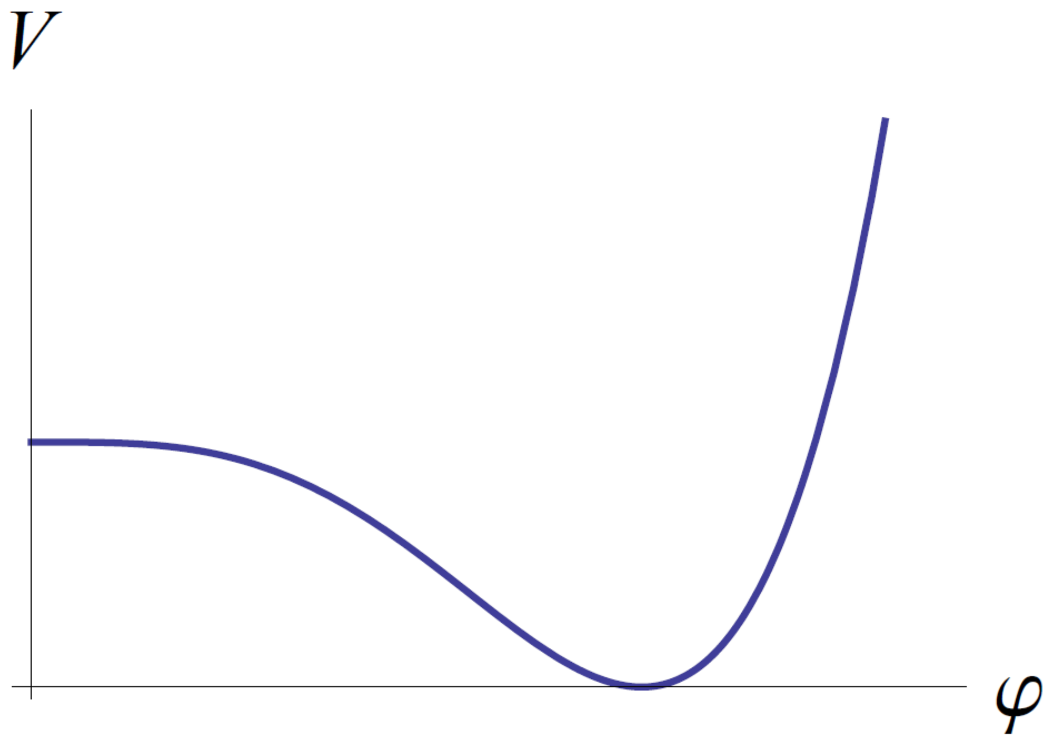
- The radial field (PQ field) would decay into 2axions.

§ Assumed cosmic history

- Primordial inflation
- Reheating by the primordial inflation
- PQ scalar domination
- PQ scalar decay into axions, relativistic axion dominated Universe
- Thermal inflation
- Reheating after thermal inflation
- Baryogenesis, dark matter production, etc
- Big bang nucleosynthesis

§ Thermal inflation

- A promising mechanism to dilute unwanted relics



§ Thermal inflation

- Potential: Higgs for gauged U(1)

$$V(\varphi) = V_0 - m^2|\varphi|^2 + \frac{|\varphi|^{2n}}{\Lambda^{2(n-2)}} + \boxed{\frac{g_\varphi}{24}T^2|\varphi|^2}$$

- Number of e-fold

$$N_{2n} = N_4 - \frac{1}{4}\ln\frac{n^2}{4(n-1)} + \frac{1}{2}(n-2)\ln\left(\frac{M_P}{v}\right),$$

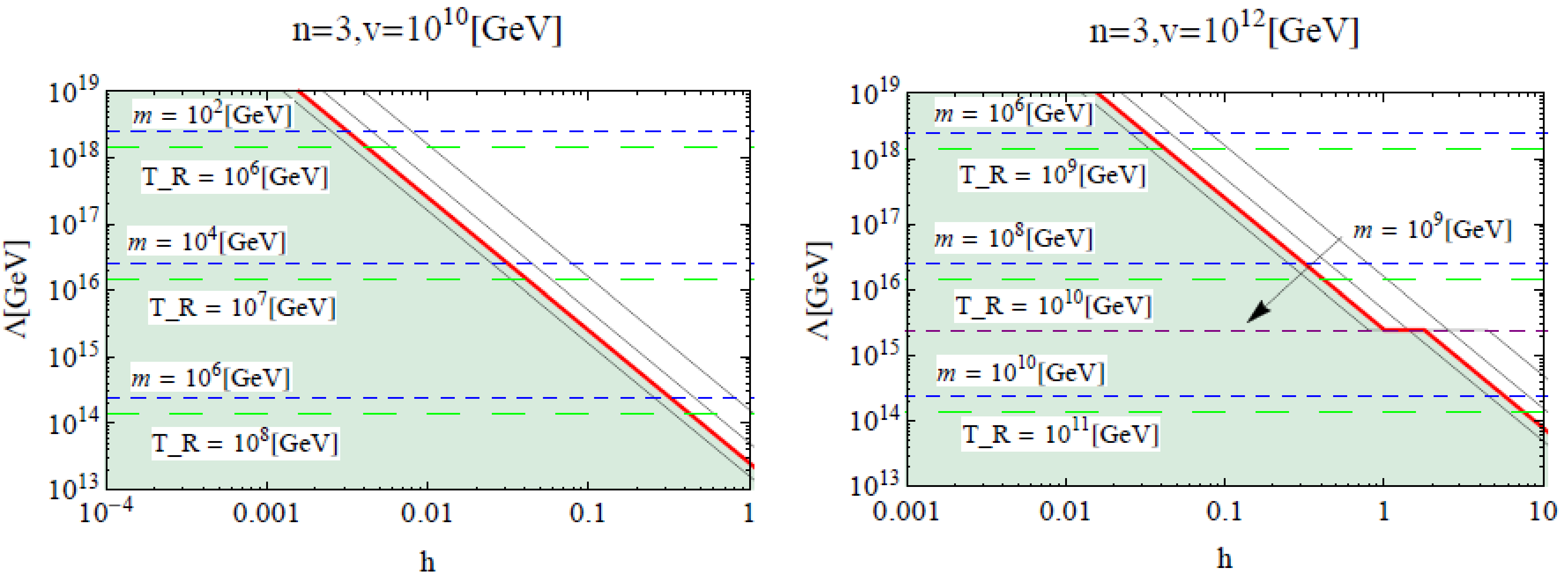
$$N_4 = -\ln 4\sqrt{3} - \frac{1}{4}\ln\left(\frac{\pi^2}{30}g_*\right) + \frac{1}{2}\ln\frac{\Lambda}{M_P}h,$$

- Results for n=3

TABLE II: Quantities in thermal inflation by the potential (19)

Λ(GeV)	h	v(GeV)	T_i(GeV)	T_f(GeV)	N	ΔN_{eff}	T_R(GeV)
10^{16}	8.27×10^{-3}	10^8	2.79×10^3	1.03×10^3	1.00	0.05	5.9×10^3
10^{16}	8.27×10^{-2}	10^{10}	2.79×10^6	1.03×10^6	1.00	0.05	5.9×10^6
10^{16}	8.27×10^{-1}	10^{12}	2.87×10^9	1.03×10^9	1.00	0.05	5.9×10^9

§ Relic abundance and viable baryogenesis



Compatible baryogeneis

Low scale thermal leptogenesis

High scale thermal leptogenesis

§ Summary

- PQ scalar might dominate the energy density of the early Universe and decay mostly into relativistic axion.
- Thermal inflation by a Higgs field for a gauged U(1) can dilute them.
- Promising viable baryogenesis: High or low scale thermal leptogenesis