Constraints on the Abundances of Relics in an Axion-Gauge Fields Model

Paper in preparation

Masahito Ogata (U. Of Toyama)
Collaborator : Mitsuru Kakizaki (U. Of Toyama), Osamu Seto (Hokkaido Univ.)

✓ Sorting Inflation Models

Observation of tensor fluctuations $\mathcal{P}_h^{\rm obs}$ is expected to determine the energy scale of inflation $H_{\rm inf}$.

$\varepsilon_B \equiv g^2 A_{\rm BG}^4/(M_{\rm pl}H)^2$

$m_Q \equiv g A_{\rm BG}/H$

- Usually expected
- There is another source

Vacuum

$$\mathcal{P}_h^{\rm vac} = \frac{2H_{\rm inf}^2}{\pi^2 M_{\rm pl}^2}$$

Axion-Gauge Field

$$\mathcal{P}_h^{A} \approx \frac{2\varepsilon_B H_{\rm inf}^2}{\pi^2 M_{\rm pl}^2} e^{3.6 m_Q}$$

✓ Uncertainty of the Inflation Scale

The inflation scale corresponding to $\mathcal{P}_h \sim 10^{-12}$ is

- $H_{\rm inf} \sim \mathcal{O}(10^{12}{\rm GeV})$ if $\mathcal{P}_h^{\rm vac}$ is dominant.
- $H_{\rm inf} \gtrsim \mathcal{O}(10^{-22}{\rm GeV})$ if $\mathcal{P}_h^{A}$ is dominant.

➡ **Is the scenario in which $\mathcal{P}_h^{A}$ is dominant consistent with current observations?**

✓ SU(2) axion-gauge fields model

Fujita, Namba, Tada, (2017)

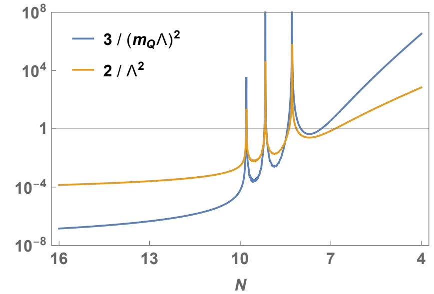
$$\mathcal{L} = \mathcal{L}_\phi + \frac{1}{2} g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi - V(\chi) - \frac{1}{2}{\rm Tr}[F_{\mu\nu}F^{\mu\nu}] + \frac{\lambda}{2f}\chi\,{\rm Tr}\left[F_{\mu\nu}\tilde{F}^{\mu\nu}\right]$$

✓ Stability Conditions

$\Lambda \equiv \lambda A_{\rm BG}/f$

$$3/(m_Q\Lambda)^2 \ll 1 \ , \quad 2/\Lambda^2 \ll 1$$

Energy density is stable in order to generate fluctuations.

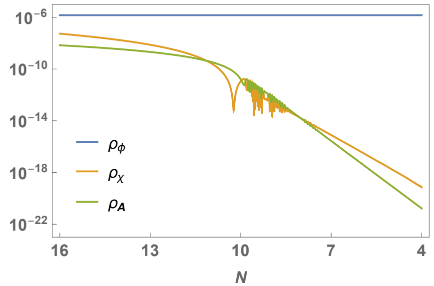


➡ **Relic density can be large**

✓ Axion Dark Matter

After the conditions are broken, energy density of axion ρ_χ decreases like matter.

$$\rho_\chi \propto a^{-3}$$



When $H_{\rm inf} \sim 10^{-22}{\rm GeV}$, we found a parameter region where

$$\Omega_\chi \gtrsim \Omega_{\rm DM} \ .$$

✓ Conclusion

- We find the axion abundance consistent region for a low $H_{\rm inf}$
- However, such a region is not compatible with the constraints by over-enhancement of the scalar density perturbation

✓ Components and Roles

$$\mathcal{L} = \mathcal{L}_\phi + \frac{1}{2} g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi - V(\chi) - \frac{1}{2}\mathrm{Tr}[F_{\mu\nu}F^{\mu\nu}] + \frac{\lambda}{2f}\chi\,\mathrm{Tr}\left[F_{\mu\nu}\widetilde{F}^{\mu\nu}\right]$$

- **Inflaton(ϕ)**

  …cause inflation

$$3(M_{\rm pl}H)^2 \approx \rho_\phi$$

- **Hidden SU(2) Gauge Fields(A_μ)**

  …generate tensor fluctuations

$$\overline{A}_i\delta A_j \;\rightarrow\; h_{ij} \qquad \overline{A}_i^a = aQ\delta_i^a$$

- **Axion(χ)**

  … excite the gauge fields

$$H\dot{Q} \approx -\frac{\delta V_{\rm eff}(Q,\chi)}{\delta Q}$$

✓ Sources of Tensor Fluctuations

$$\mathcal{P}_h^{\rm obs} = \mathcal{P}_h^{\rm vac} + \mathcal{P}_h^{A}$$

$$\mathcal{P}_h^{\rm vac} = \frac{2H_{\rm inf}^2}{\pi^2 M_{\rm pl}^2} \qquad \mathcal{P}_h^{A} \approx \frac{2\varepsilon_B H_{\rm inf}^2}{\pi^2 M_{\rm pl}^2} e^{3.6m_Q}$$

Cannot distinguish between sources of fluctuations.

✓ Tensor to Scalar Ratio

$$H_* = 3.1\times10^{-22}\ \mathrm{GeV}\ ,\quad \lambda = 2800\ ,\quad g = 2.4\times10^{-36}$$

$$\mu = 0.040\ \mathrm{GeV}\ ,\quad f = 2.2\times10^{18}\ \mathrm{GeV}$$

$$r \approx \frac{2\varepsilon_B H_{\rm inf}^2}{\mathcal{P}_\zeta(\pi M_{\rm pl})^2} e^{3.6m_Q}$$

Observable tensor fluctuations are generated.