Particle Dark Matter Lecture 5

Axion potential:

N = # fields charged under PQ

$$V(\varphi) = \Lambda_{QCD}^4 \left[1 - \cos\left(\frac{\varphi}{f_a}\right)\right]$$

$$= m_a^2 f_a^2 \left[1 - \cos\left(\varphi/f_a\right)\right]$$

Generalize to ALPs where $m_a \neq \frac{\Lambda_{QCD}^2}{f_a}$

$$V_{ALPS} = m_\varphi^2 f_\varphi^2 \left[1 - \cos\left(\varphi/f_\varphi\right)\right]$$

Extend misalignment mechanism to any ALPs

$$\Omega_{\tilde\varphi} h^2 \propto \frac{1}{2} m_\varphi(t_H)\, m_\varphi(t_{today})\, f_\varphi^2\, \theta_\varphi^2$$

$$m_\varphi(t_H) = H$$

for constant mass $\Rightarrow$ band in plane $1/f_\varphi$ vs m_φ

What should we take for θ_i ?

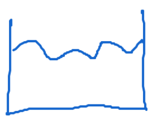
PQ symmetry broken before inflation	PQ symmetry broken after inflation
$\Rightarrow$ single value of θ_i $\forall$ universe	$\Rightarrow$ different domains take $\langle \theta_i^2 \rangle$
$\Rightarrow$ axion massless during inflation	$\Rightarrow$ defects $\Rightarrow$ axion miniclusters

Scenario 1: PQ broken before inflation

axion is massless $\Rightarrow$ isocurvature perturbations

curvature

single fluid



isocurvature

two fluids

Fluctuation during inflation $\delta\varphi \sim \frac{H}{2\pi}$

Limits from CMB on isocurvature

$$\frac{P_{ISO}}{P_{TOT}} < 0.01 \quad \text{from Planck 2018}$$

$$P_{ISO} \sim \left(\frac{\delta\varphi}{\varphi}\right)^2 \simeq \frac{H_I^2}{4\pi^2 f_a^2} \qquad P_{TOT} \sim 0.2 \cdot 10^{-8}$$

$$\Rightarrow H_I \leq 0.5 \cdot 10^{-5} (2\pi) f_a$$

Scenario 2: PQ symmetry broken after inflation

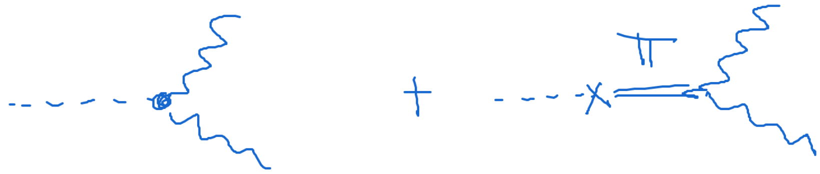
$$\theta_i \sim \sqrt{\langle \theta_i^2 \rangle} = \frac{\pi}{\sqrt{3}}$$

→ in general no isocurvature perturbation

→ defects are formed: → strings
→ domain walls $N > 1$

strings can give more axions
even a factor 10 more!

Axion decay: axion DM is very light & can decay only in $\gamma\gamma$



$$\sim \frac{C_{a\gamma\gamma}\,\alpha_{QED}}{\pi f_a}$$

$$\Gamma(a\to 2\gamma) = \frac{C_{a\gamma\gamma}^2\,\alpha_{QED}^2}{2^8\pi^3 f_a^2}\, m_a^3 \sim m_a^5$$

$$\tau(a\to 2\gamma) = 3.65\cdot 10^{24}\,\mathrm{s}\ \frac{1}{C_{a\gamma\gamma}^2}\left(\frac{m_a}{\mathrm{eV}}\right)^{-5}$$

$$= 0.8\cdot 10^{7}\,\tau_{univ}\ \frac{1}{C_{a\gamma\gamma}^2}\left(\frac{m_a}{\mathrm{eV}}\right)^{-5}$$

For axion DM $m_a \simeq 10^{-5} - 10^{-6}\,\mathrm{eV}$

therefore lifetime too long to see the decay!

Axion oscillation frequency

$$\frac{\omega_a}{2\pi} = 2.4 \text{ GHz} \left(\frac{10^{-6} \text{eV}}{m_a}\right)$$

De Broglie wavelength

$v \sim 270 \text{ km/s}$

$$\lambda_a = \frac{h}{m_a v} \sim 10^8 \text{ m} \left(\frac{\text{eV}}{m_a}\right)$$