Domain walls of string theory axions

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Introduction

Axions domain walls are created after QCD phase transition.

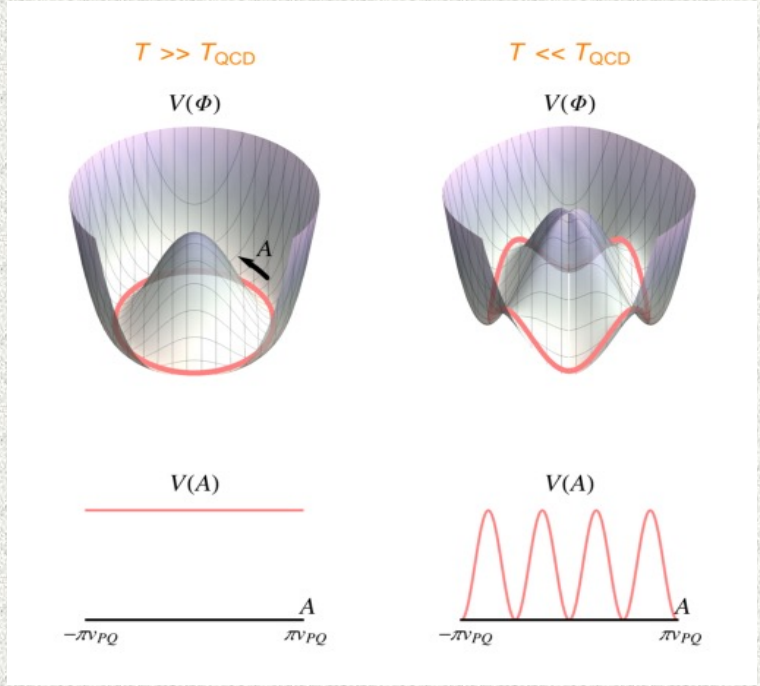
If the QCD axions have multiple degenerate minima, the string domain wall network is stable.

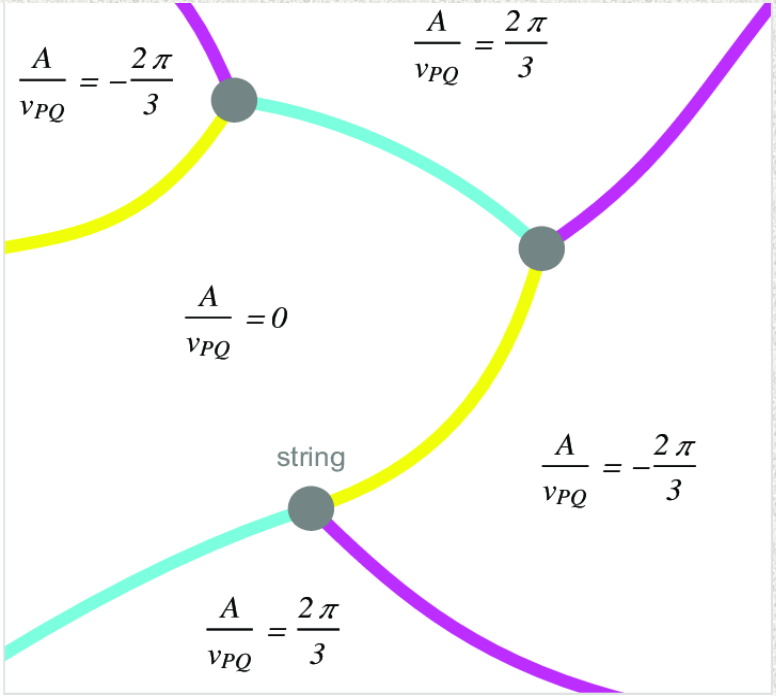
Domain walls quickly dominate the energy density of the universe, unless they decay.

The collapse of domain walls can create axion DM, GWs.

Sanghyeon Chang, Christian A. Hagmann, Pierre Sikivie, PhysRevD.59.023505
Takashi Hiramatsu, Masahiro Kawasaki and Ken'ichi Saikawa, JCAP08(2011)030
Takashi Hiramatsu, Masahiro Kawasaki, Ken'ichi Saikawa and Toyokazu Sekiguchi, JCAP01(2013)001

Introduction





Eric Armengaud et al, arXiv:1904.09155

Multiple axions

In general, it is imperative to consider multiple axion scenario

The axions are generally coupled

$$\mathcal{L} \subset -\frac{K_{ij}}{2}\partial_\mu a_i \partial^\mu a_j - \Lambda_n^4 \left[1 - \cos\left(Q_{ni}\frac{a_i}{f_i} + \delta_n\right)\right]$$

K_{ij} is the kinetic mixing matrix which we assume to be diagonal

Q_{ni} are the integer instanton charges

$$\Lambda_n \sim \Lambda_{string} \exp(-S_n)$$

Mehmet Demirtas, Naomi Gendler, Cody Long, Liam McAllister and Jakob Moritz, JHEP06(2023)092
David Cyncynates, Tudor Giurgica-Tiron, Olivier Simon , and Jedidiah O. Thompson, PhysRevD 105, 055005 (2022)
Joshua N. Benabou, Quentin Bonnefoy, Malte Buschmann, Soubhik Kumar and Benjamin R. Safdi, arXiv:2312.08425

Unstable domain walls

String theory axions strings are different than field theory axion strings.

If the string domain wall network is unstable, the strings overproduce QCD axion DM.

In the case of multiple axion, it is possible to populate the observed abundance of DM.

What happens if the string domain wall network is stable for a long time?

Joshua N. Benabou, Quentin Bonnefoy, Malte Buschmann, Soubhik Kumar and Benjamin R. Safdi, arXiv:2312.08425

Domain wall decay

$$V_1(a_1, a_2) = \Lambda_1^4 \left[1 - \cos\left(N_{11}\frac{a_1}{f_1} + N_{12}\frac{a_2}{f_2} + \delta_1\right)\right]$$

If the strings source a_1, the domain walls are 'formed' when Hubble crosses wall thickness.

$N_{11} = 1$ The string domain wall network is unstable and decays quickly.

$N_{11} \neq 1$ The network is stable for a long time.

Joshua N. Benabou, Quentin Bonnefoy, Malte Buschmann, Soubhik Kumar and Benjamin R. Safdi, arXiv:2312.08425

Domain wall decay

$$V_2(a_1, a_2) = \Lambda_2^4 \left[1 - \cos\left(N_{21}\frac{a_1}{f_1} + N_{22}\frac{a_2}{f_2} + \delta_2\right)\right]$$

$$\Lambda_1 > \Lambda_2 > \Lambda_b$$

V_1 and V_2 fixes the classical minima for the axions.

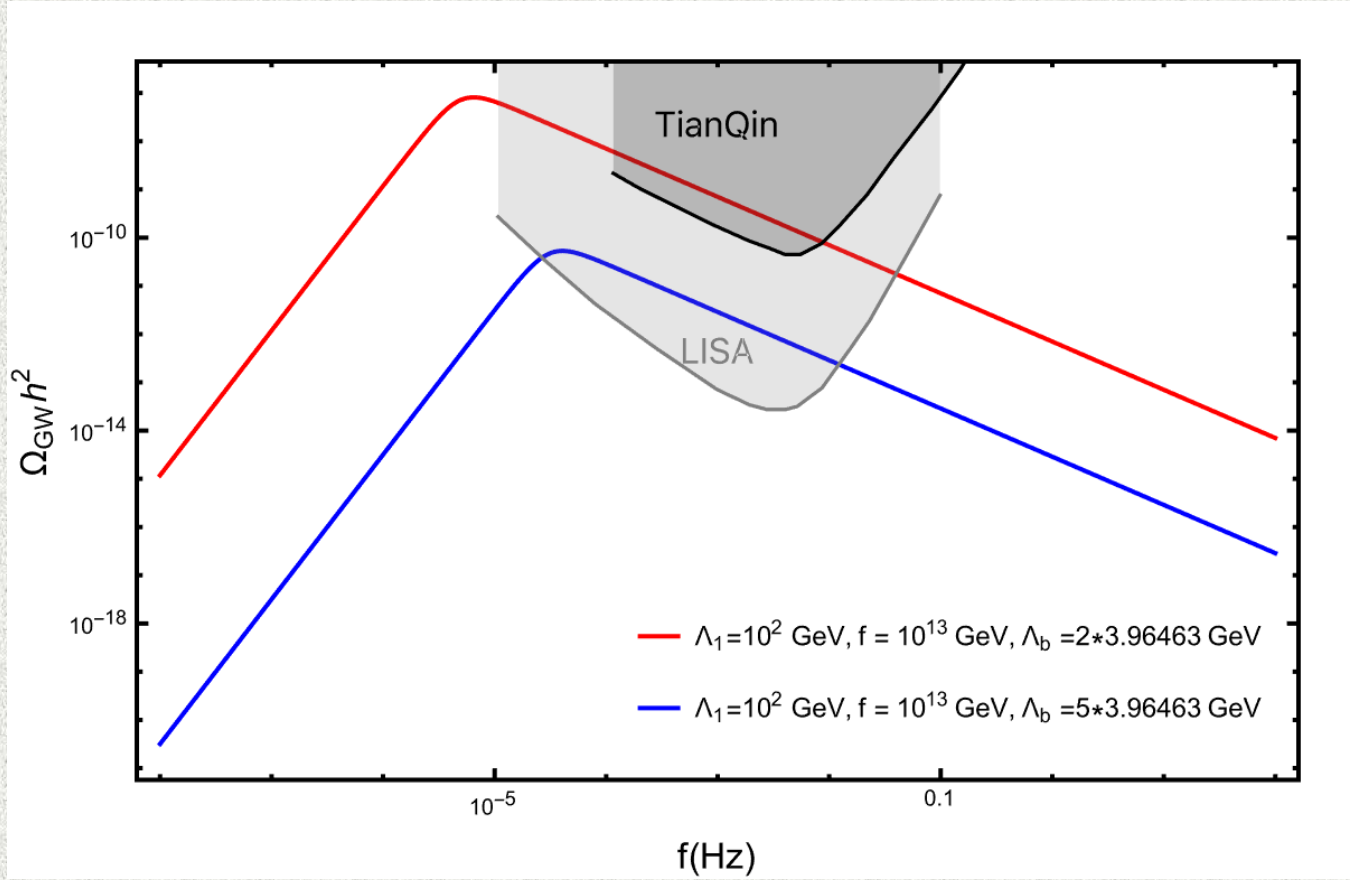
$$V_b(a_1, a_2) = \Lambda_b^4 \left[1 - \cos\left(N_{b1}\frac{a_1}{f_1} + N_{b2}\frac{a_2}{f_2} + \delta_b\right)\right]$$

To avoid domain wall domination

$$\Lambda_b > \Lambda_1\sqrt{\frac{f_1}{M_{pl}}}$$

$$N_{12} = N_{21} = N_{22} = N_{b1} = N_{b2} = 1 \qquad f_1 = f_2 = f$$

Emission of Gravitational waves



Axion dark matter

The mass eigenstates are related to the flavor states.

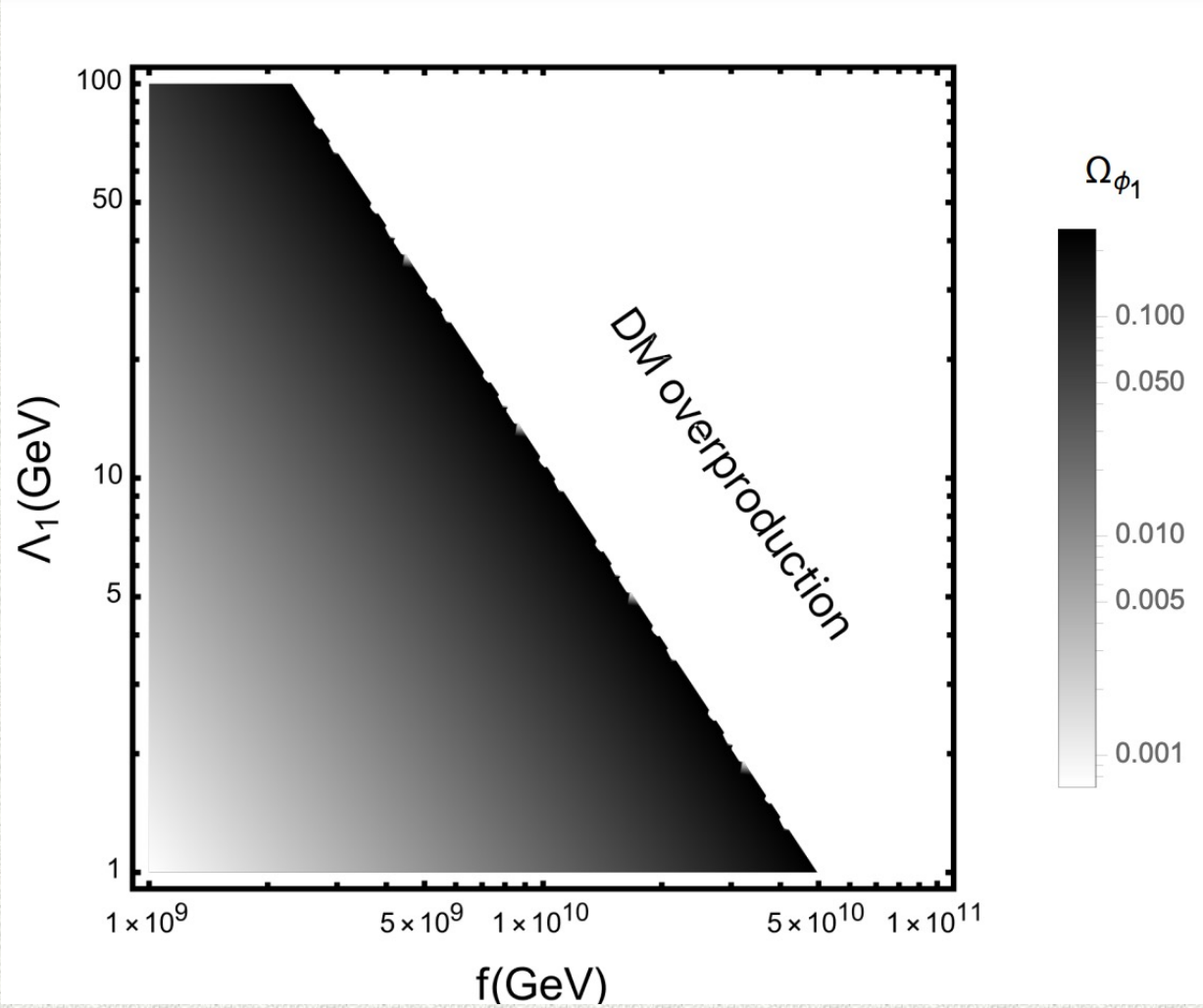
$$\begin{pmatrix}\phi_1\\ \phi_2\end{pmatrix} = R(\theta)\begin{pmatrix}a_1\\ a_2\end{pmatrix} \qquad R(\theta) = \begin{pmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{pmatrix} \qquad m_{\phi_1} > m_{\phi_2}$$

The wall emits the flavor state it couples to.

The collapse can thus produce more than one type of relic axion abundance. However, the DM abundance is dominated by misalignment contribution.

For a large part of parameter space, the heavier axion creates EMD era and decays subsequently.

Axion dark matter



Summary

Stable axion string domain wall network can be produced before QCD phase transition.

Collapse of the same can leave observable imprints.

Domain wall domination is an interesting possibility!

Thank you