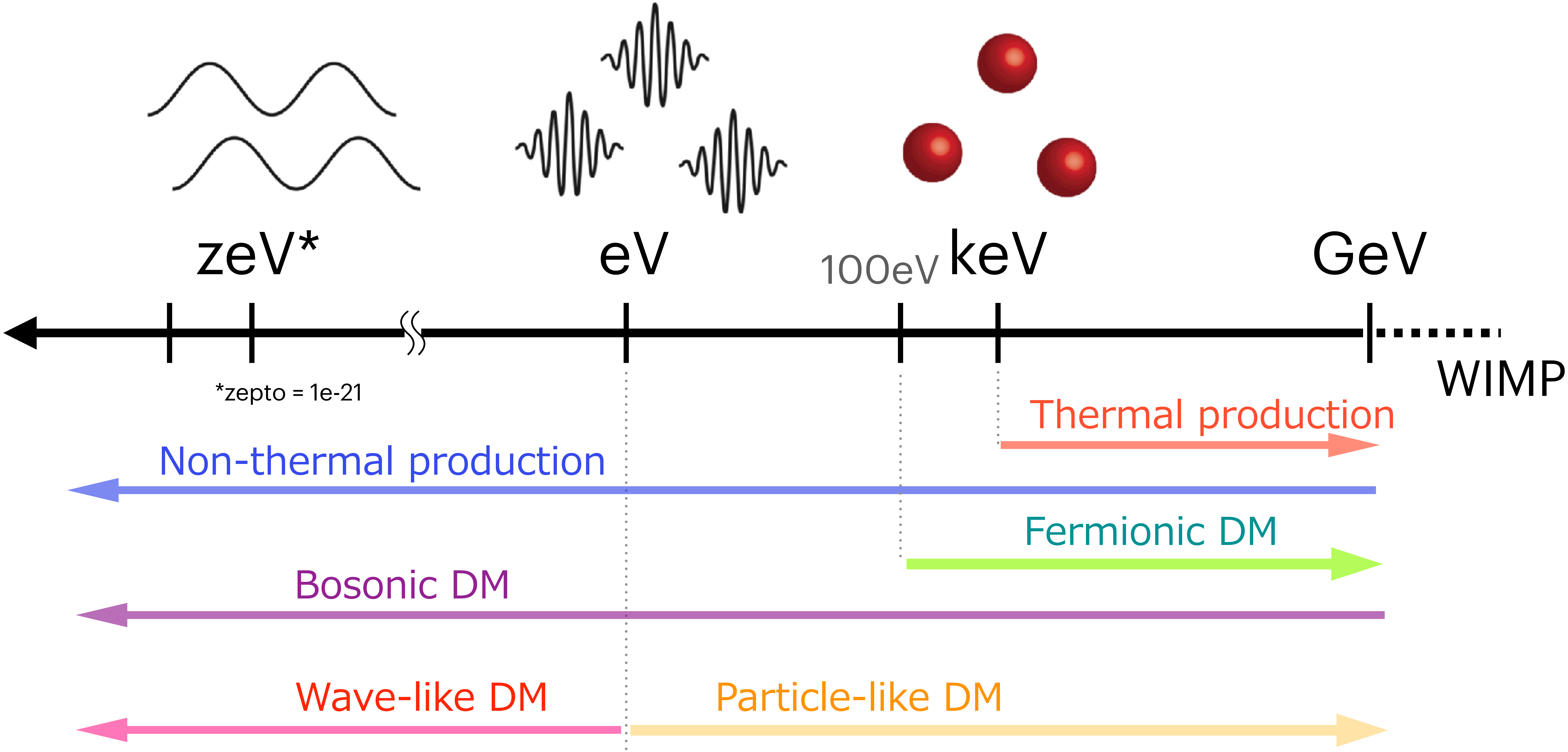
TOHOKU
UNIVERSITY

A01: Light dark matter

Mar. 29. 2022 @
“What is dark matter? - Comprehensive study of the huge discovery space in dark matter”
Annual Symposium

Fuminobu Takahashi (Tohoku)

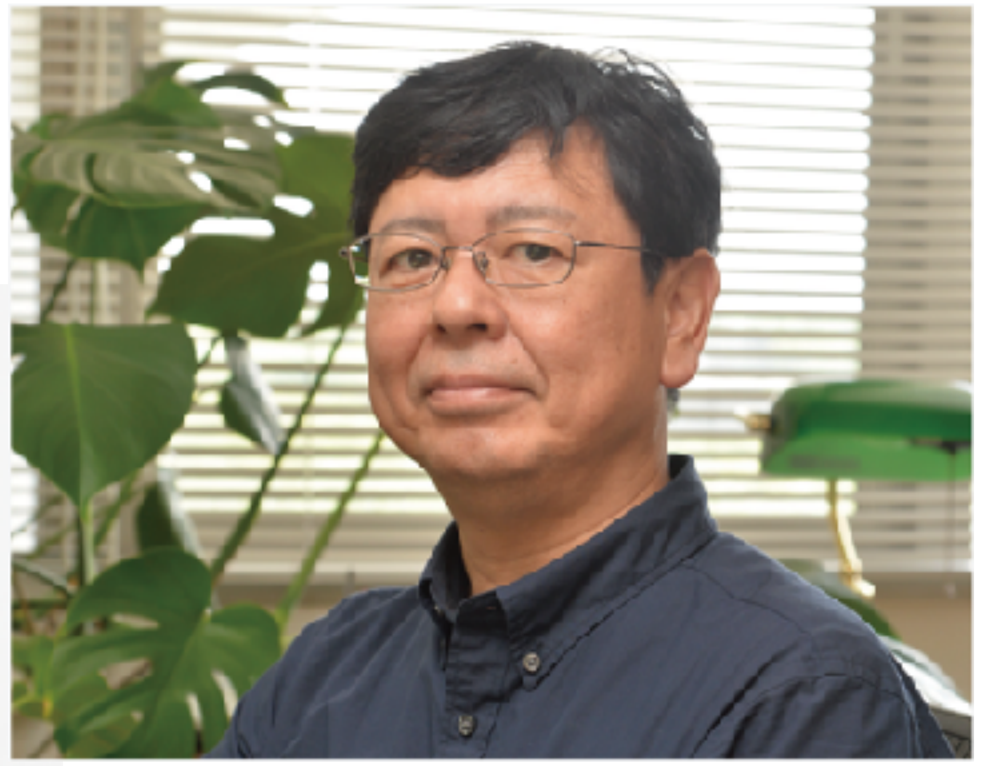
Mass scale of light dark matter

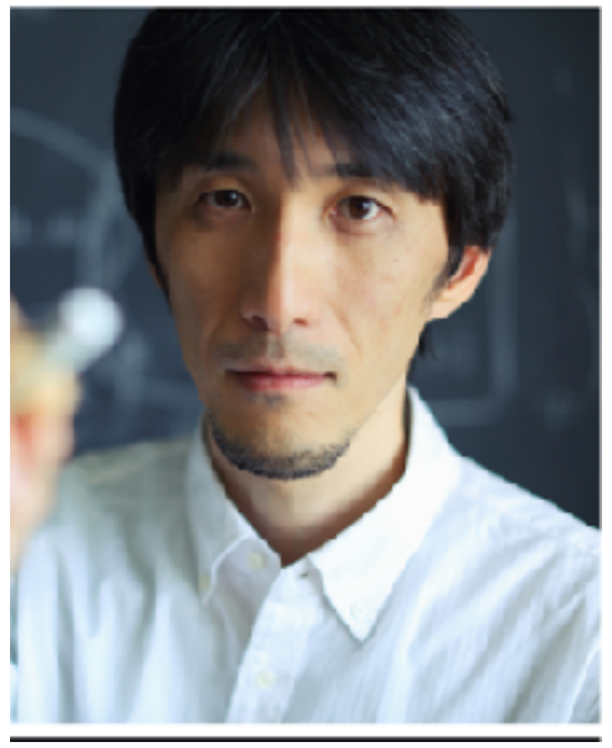
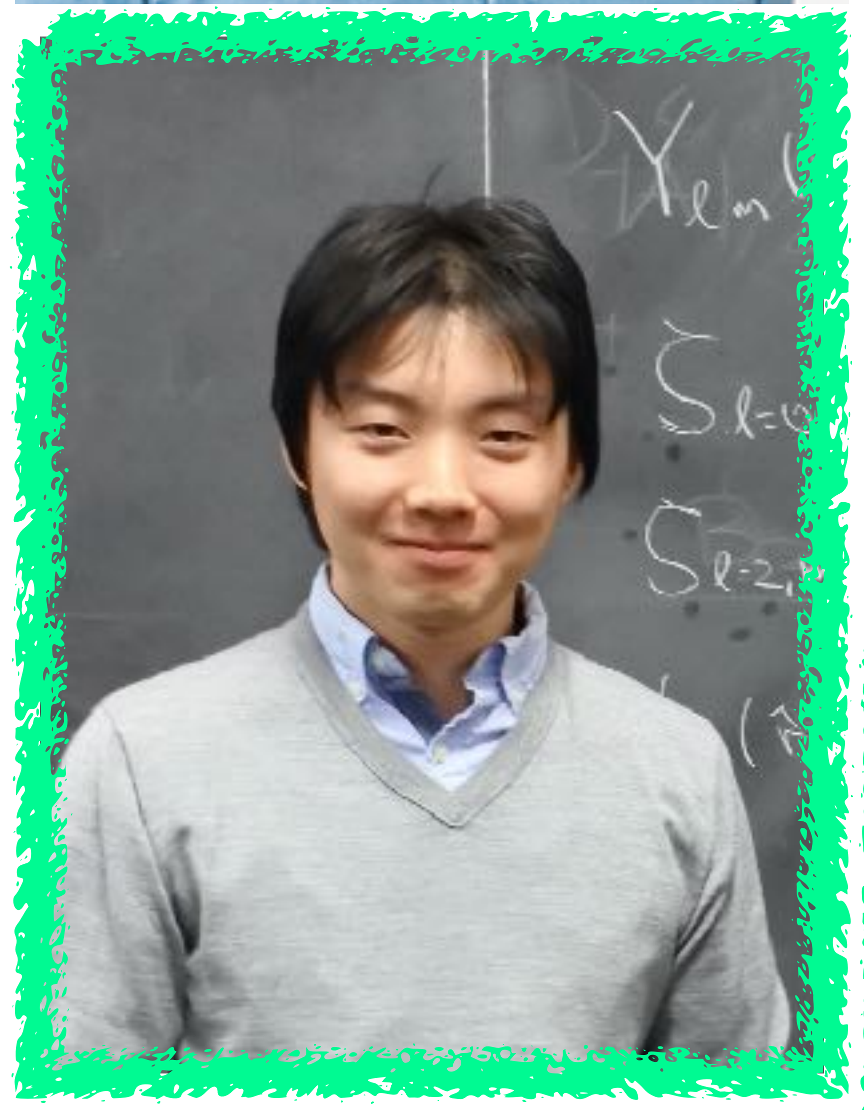


Mass scale of light dark matter

Members

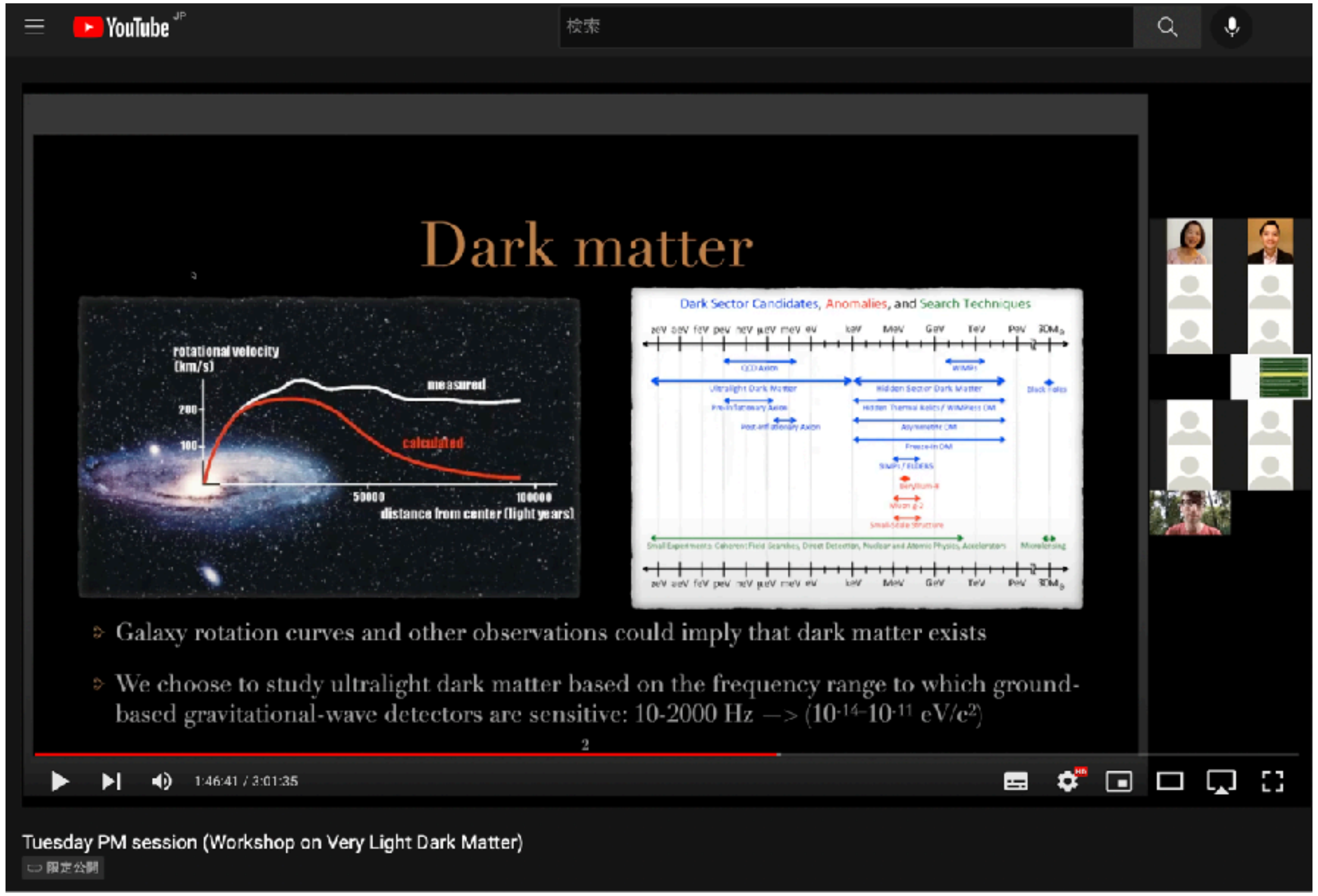
- Masahiro Kawasaki
- Naoya Kitajima
- Fuminobu Takahashi
- Masaki Yamada
- Wen Yin



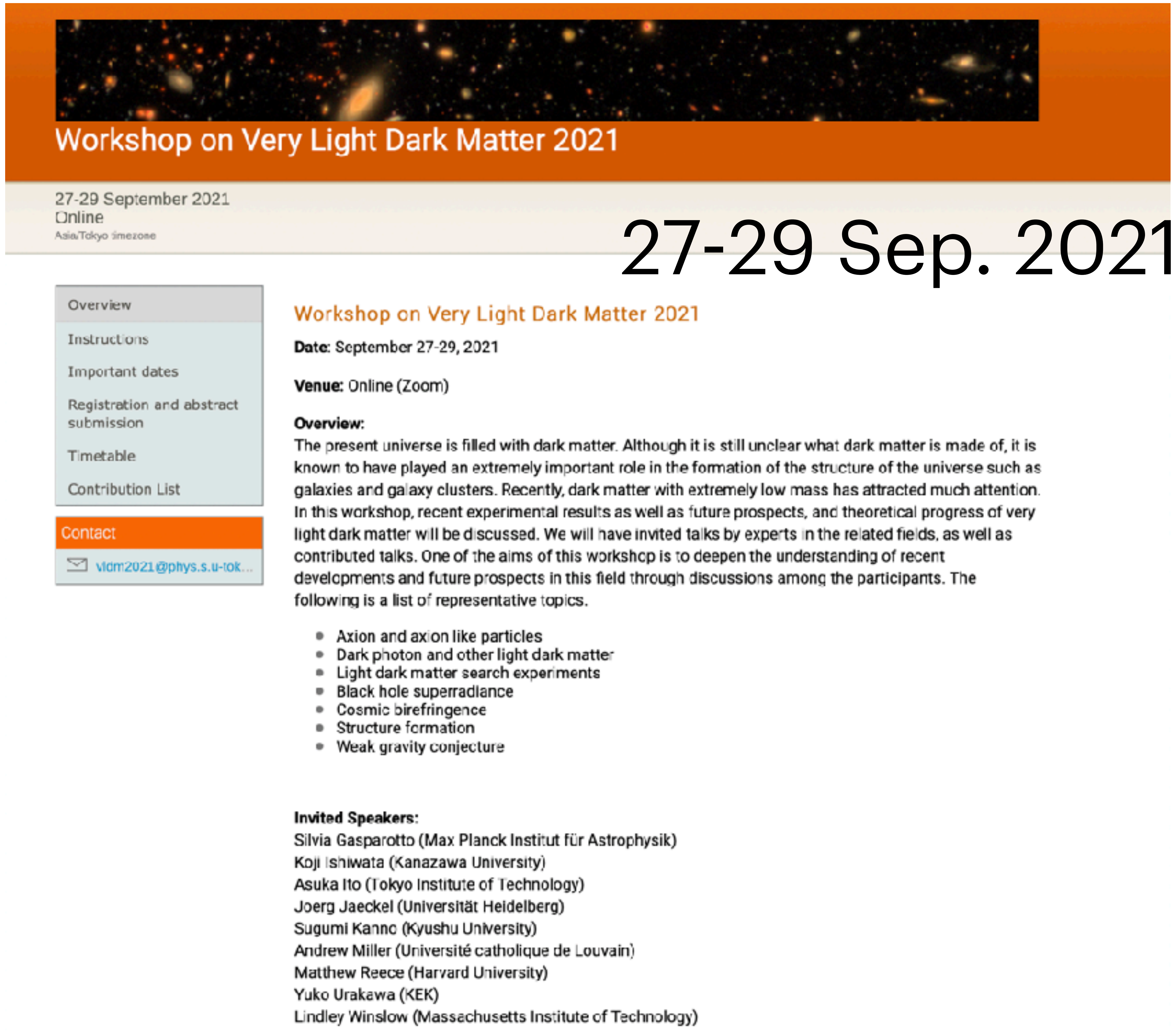




Workshop

Workshop on Very Light Dark Matter 2021 was organized by A01+B01 groups



27-29 Sep. 2021



Workshop on Very Light Dark Matter 2021

27-29 September 2021
Online
Asia/Tokyo timezone

- Overview
- Instructions
- Important dates
- Registration and abstract submission
- Timetable
- Contribution List

Contact
vldm2021@phys.s.u-tok...

Workshop on Very Light Dark Matter 2021

Date: September 27-29, 2021

Venue: Online (Zoom)

Overview:
The present universe is filled with dark matter. Although it is still unclear what dark matter is made of, it is known to have played an extremely important role in the formation of the structure of the universe such as galaxies and galaxy clusters. Recently, dark matter with extremely low mass has attracted much attention. In this workshop, recent experimental results as well as future prospects, and theoretical progress of very light dark matter will be discussed. We will have invited talks by experts in the related fields, as well as contributed talks. One of the aims of this workshop is to deepen the understanding of recent developments and future prospects in this field through discussions among the participants. The following is a list of representative topics.

- Axion and axion like particles
- Dark photon and other light dark matter
- Light dark matter search experiments
- Black hole superradiance
- Cosmic birefringence
- Structure formation
- Weak gravity conjecture

Invited Speakers:
Silvia Gasparotto (Max Planck Institut für Astrophysik)
Koji Ishiwata (Kanazawa University)
Asuka Ito (Tokyo Institute of Technology)
Joerg Jaeckel (Universität Heidelberg)
Sugumi Kanno (Kyushu University)
Andrew Miller (Université catholique de Louvain)
Matthew Reece (Harvard University)
Yuko Urakawa (KEK)
Lindley Winslow (Massachusetts Institute of Technology)

There were 184 participants.

Publications

35 papers from A01 group (as of Mar.29)

Highlights

- Cosmic birefringence triggered by dark matter — See talk by Masaki Yamada
- Cosmic birefringence and ALP domain walls — See talk by Wen Yin
- PQ breaking and the QCD axion dark matter
- Oscillon/I-ball formation from axion
- CMB constraints on dark matter annihilation
- Enhancement of QCD axion fluctuation
- Non-thermally trapped inflation
- Hubble tension and curvaton

Highlights

- Cosmic birefringence triggered by dark matter **See talk by Masaki Yamada**
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- PQ breaking anc
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東北大、宇宙背景放射の偏光面の回転を説明するアクシオンの運動機構を提唱

2021年10月29日 15:41

発表日:2021年10月29日

宇宙背景放射の偏光面の回転を説明するアクシオンの運動機構の提唱

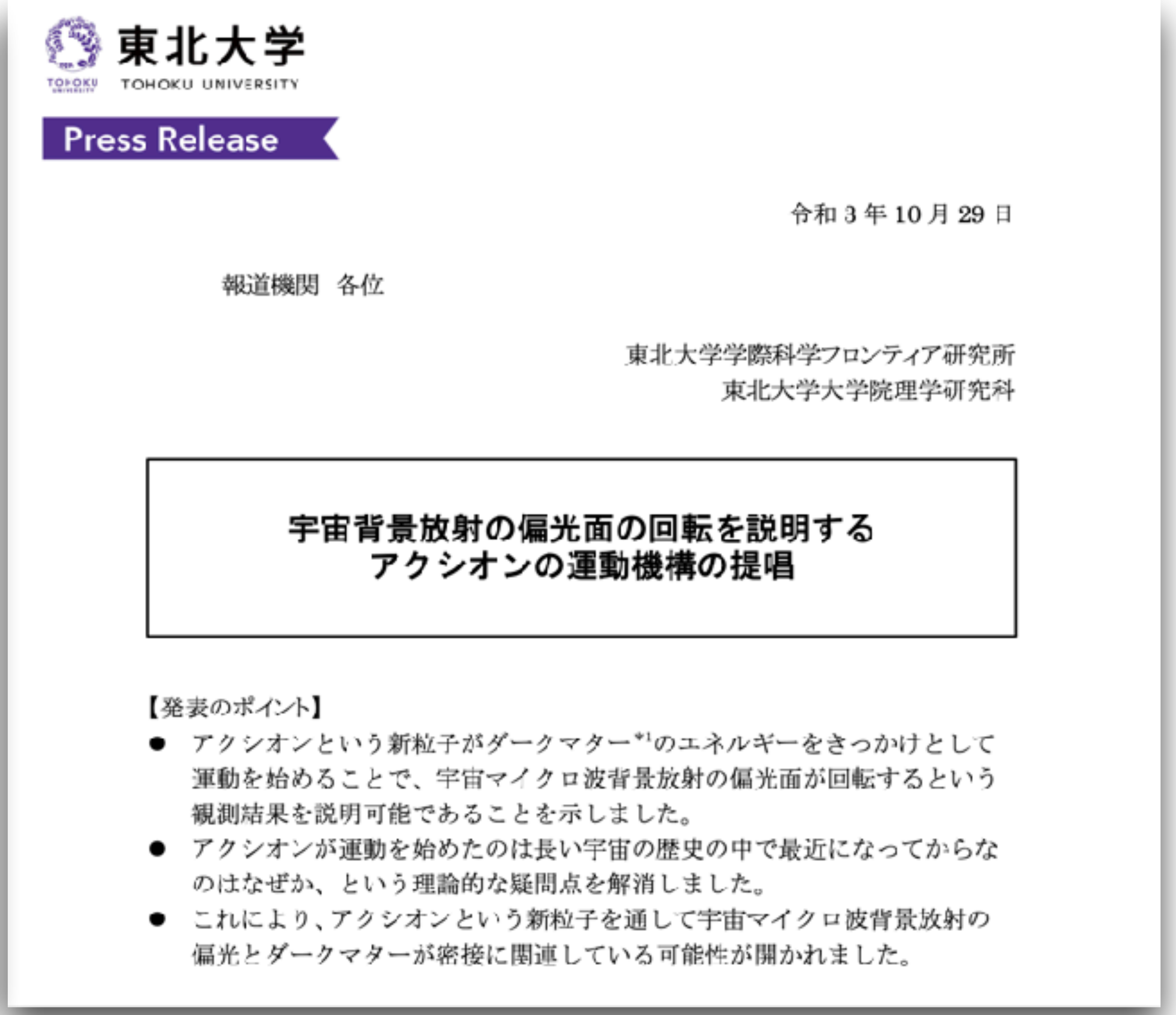
【発表のポイント】

●アクシオンという新粒子がダークマター（＊1）のエネルギーをきっかけとして運動を始めることで、宇宙マイクロ波背景放射の偏光面が回転するという観測結果を説明可能であることを示しました。

●アクシオンが運動を始めたのは長い宇宙の歴史の中で最近になってからなのはなぜか、という理論的な疑問点を解消しました。

●これにより、アクシオンという新粒子を通して宇宙マイクロ波背景放射の偏光とダークマターが密接に関連している可能性が開かれました。

【概要】


東北大学 TOHOKU UNIVERSITY

Press Release

令和 3 年 10 月 29 日

報道機関 各位

東北大学学際科学フロンティア研究所
東北大学大学院理学研究科

宇宙背景放射の偏光面の回転を説明する
アクシオンの運動機構の提唱

【発表のポイント】

- アクシオンという新粒子がダークマター*1のエネルギーをきっかけとして運動を始めることで、宇宙マイクロ波背景放射の偏光面が回転するという観測結果を説明可能であることを示しました。
- アクシオンが運動を始めたのは長い宇宙の歴史の中で最近になってからなのはなぜか、という理論的な疑問点を解消しました。
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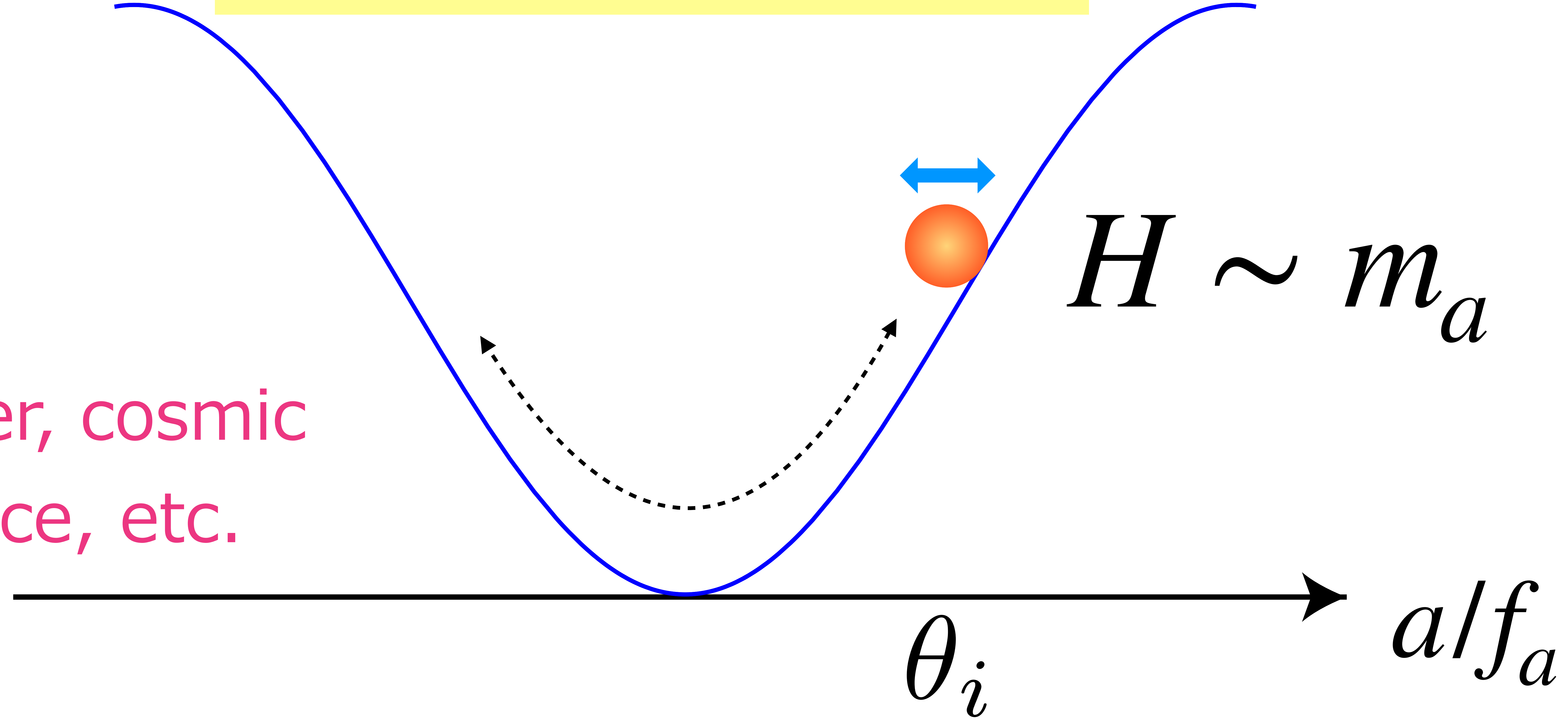
Axion moves.

Misalignment mechanism

Preskill, Wise, Wilczek `83, Abbott, Sikivie `83, Dine, Fischler `83 Mayle et al `88, Raffelt and Seckel `88, Turner 88.

Axion begins to oscillate when mass and Hubble parameter become comparable.

$$a_i \neq a_{\rm now}$$

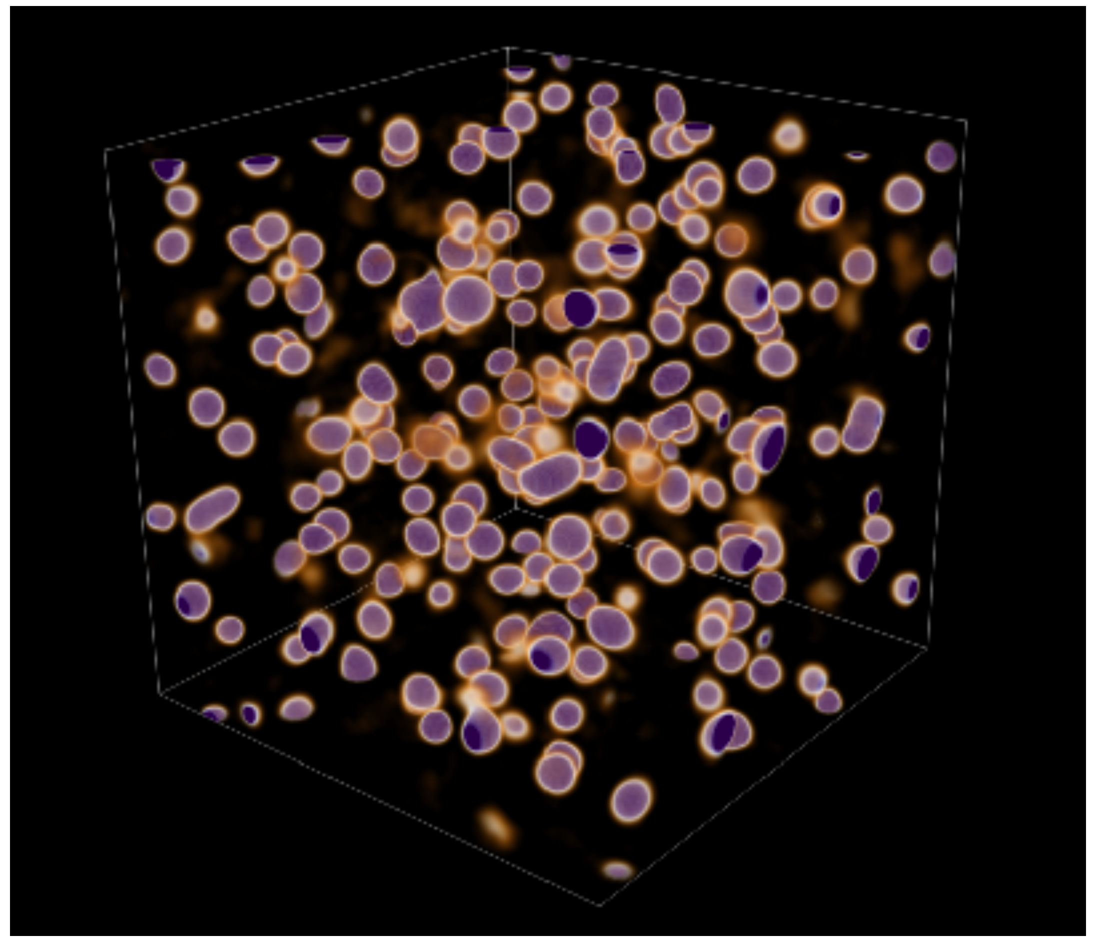


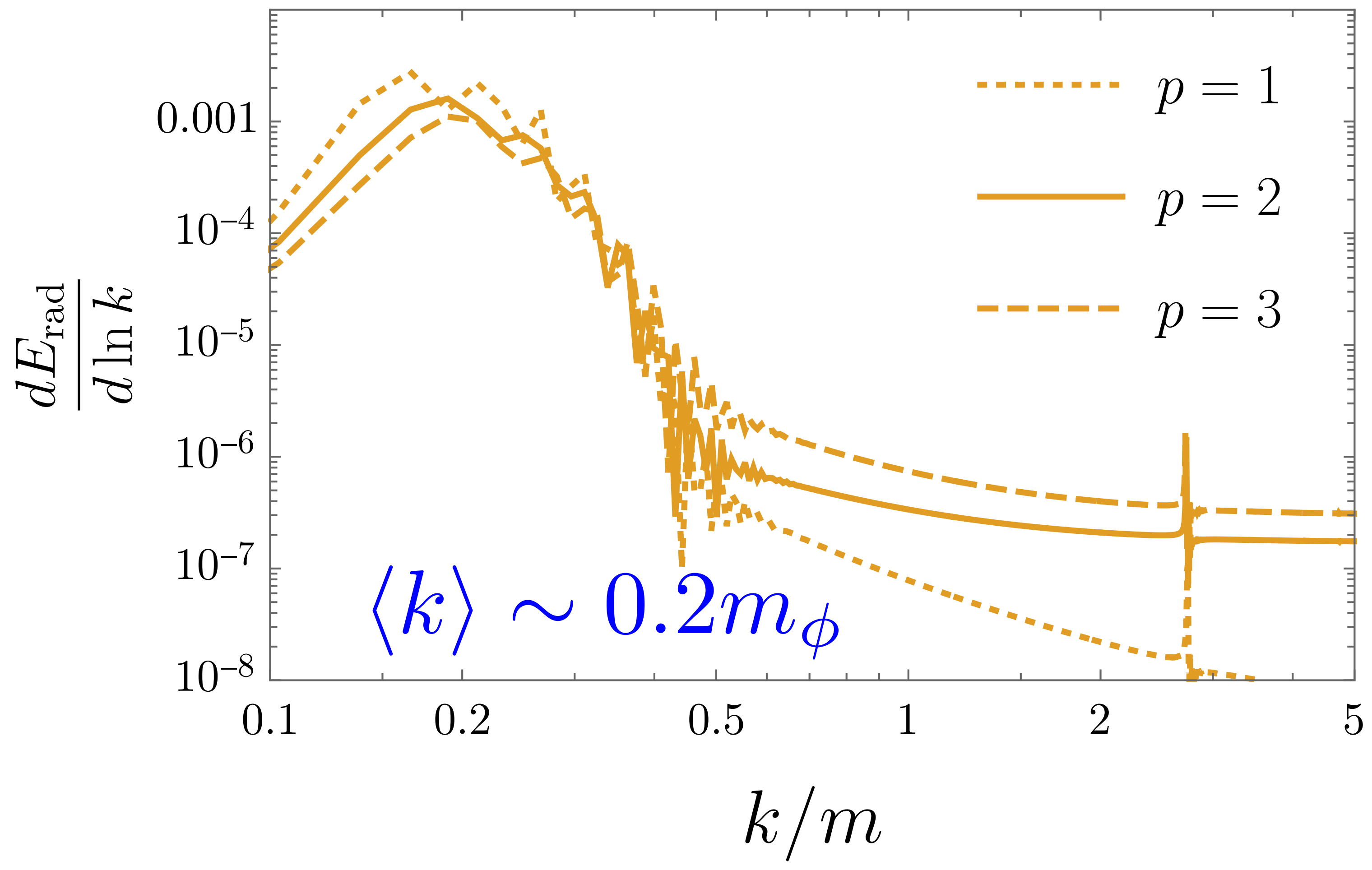
Dark matter, cosmic birefringence, etc.

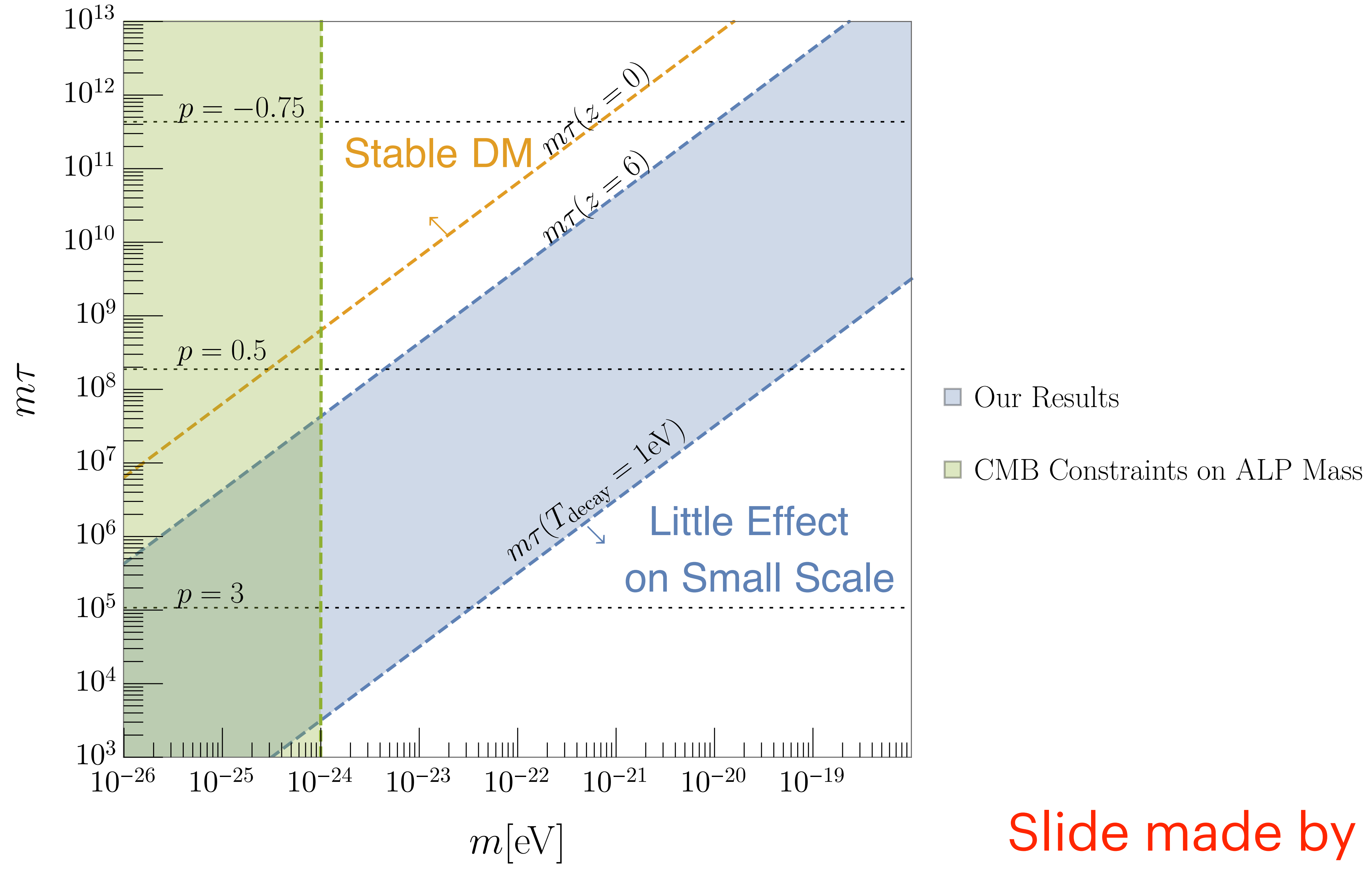
Oscillon/I-ball of Axion-like particles (ALPs)

Imagawa et al (2021) arXiv:2110.05790

- Oscillons/I-balls can be formed for some ALP potential
  - Pure natural type $V(\phi) = \frac{m^2 M^2}{2p}\left[1 - \left(1 + \frac{\phi^2}{M^2}\right)^{-p}\right]$
    Nomura Watari Yamazaki (2017)
  - Long-lived for $m_\phi \lesssim 10^{-20}$ eV
  - Simulation: ~60% of ALPs form oscillons
    Kawasaki Nakano Sonomoto (2019)
- Oscillon decay emits ALPs with high velocity
  - Free streaming of ALPs erases small scale perturbations
  - Constraints on mass and lifetime







Slide made by Kawasaki

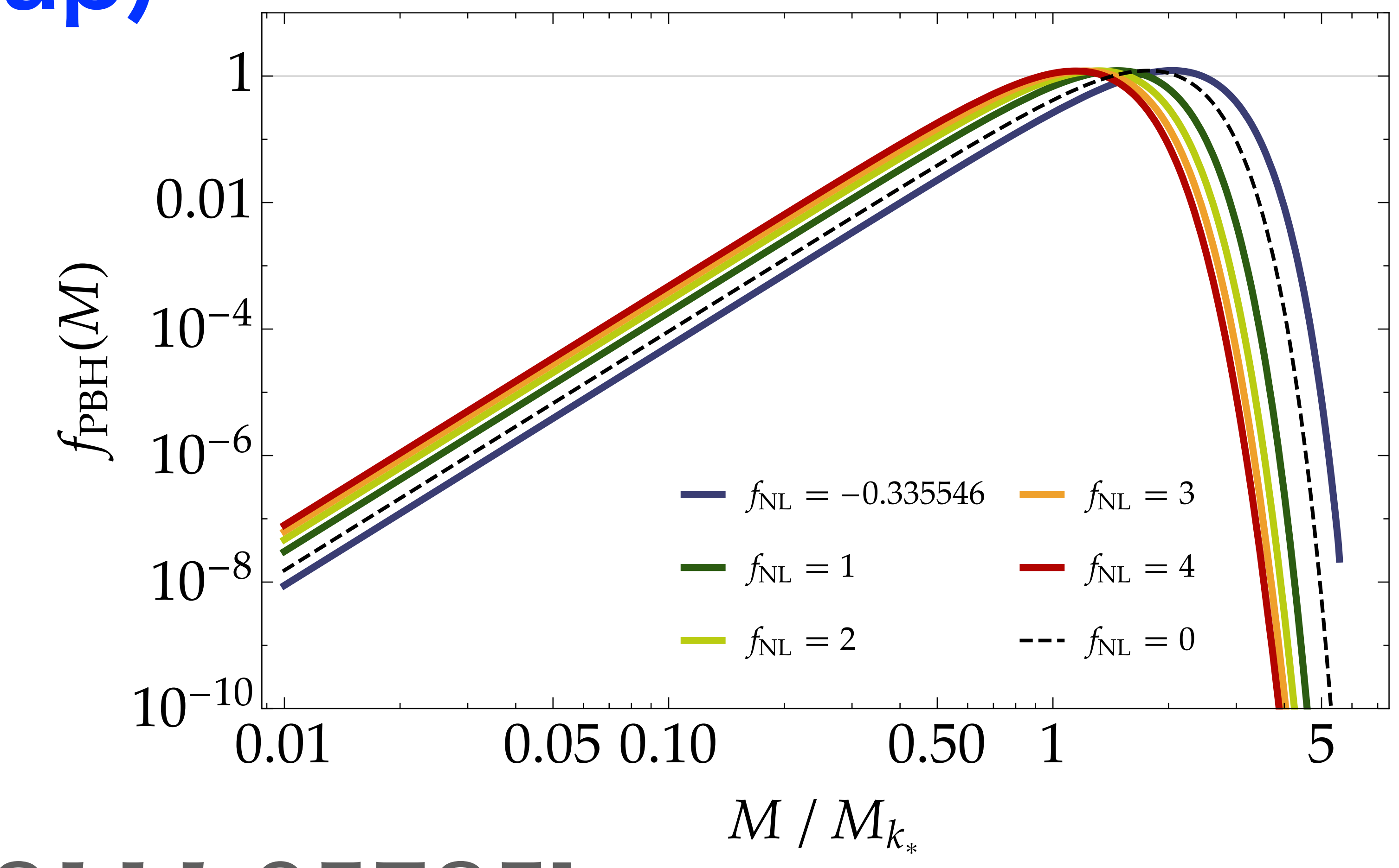
- PBH formation with non-Gaussianity/exponential tail

NK, Y. Tada, S. Yokoyama, C. M. Yoo, JCAP 10 (2021) 053 [2109.00791]

(collaboration with A03 group)

Modification of PBH abundance
by non-Gaussian primordial fluctuations:

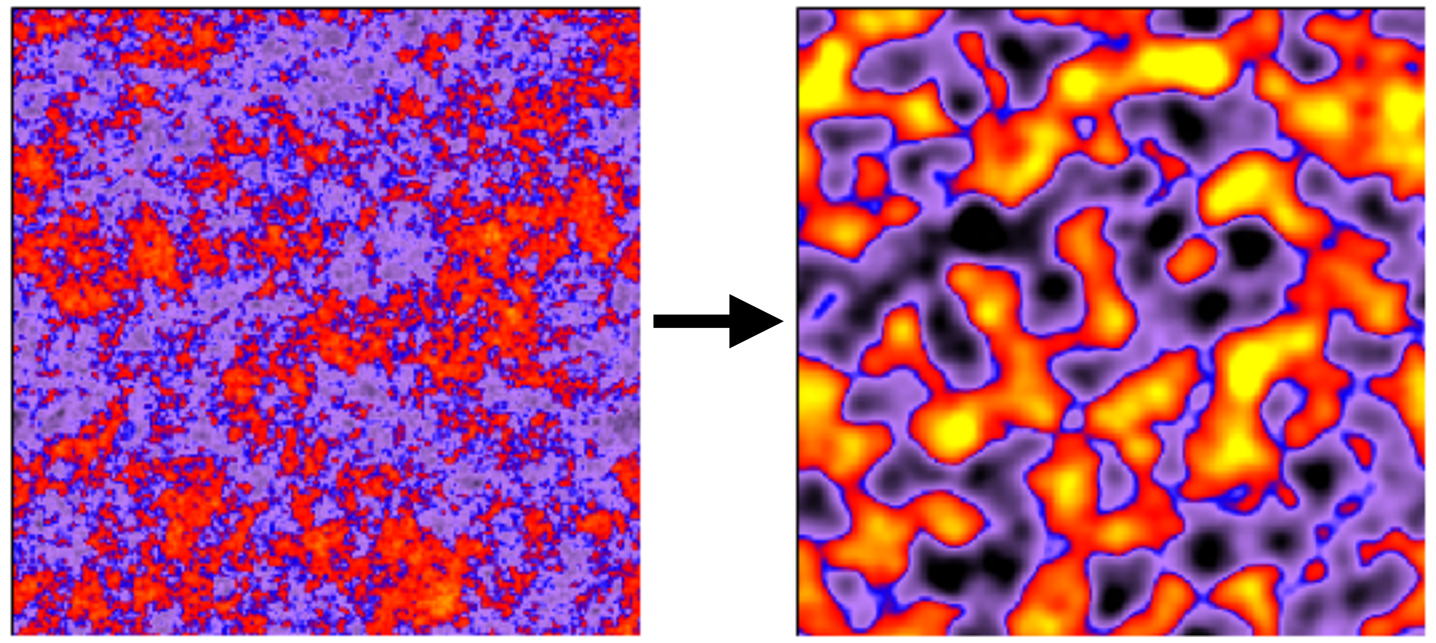
See C.M. Yoo & Y. Tada's talk (A03)



- Enhancement of QCD axion fluctuation

NK, K. Kogai, Y. Urakawa, JCAP 03 (2022) 039 [2111.05785]

We have found T-dependent mass
leads to axion clustering:



- Non-thermally trapped inflation

NK, S. Nakagawa, F. Takahashi [2111.06696]

Tachyonic production of gauge field from axion oscillation
—> dark higgs stabilization & secondary inflation

Slide made by Kitajima

PQ symmetry breaking and QCD axion DM

Jeong, Matsukawa, Nakagawa, FT, 2201.00681

Misalignment mechanism

Preskill, Wise, Wilczek `83, Abbott, Sikivie `83, Dine, Fischler `83 Mayle et al `88, Raffelt and Seckel `88, Turner 88.

Axion begins to oscillate when mass and Hubble parameter become comparable.

Abundance of QCD axion:

$$\Omega_a h^2 \simeq 0.14\, \theta_{\rm ini}^2 F(\theta_{\rm ini}) \left(\frac{f_a}{10^{12}{\rm GeV}} \right)^{1.17}$$

Ballesteros et al, 1610.01639

(Classical) axion window:

$$10^8\,{\rm GeV} \lesssim f_a \lesssim 10^{12}\,{\rm GeV}$$

$$m_{a,0} \simeq 6\,\mu{\rm eV} \left(\frac{f_a}{10^{12}{\rm GeV}} \right)^{-1}$$

i.e. $\mathcal{O}(1)\mu{\rm eV} \lesssim m_a \lesssim \mathcal{O}(10)\,{\rm meV}$

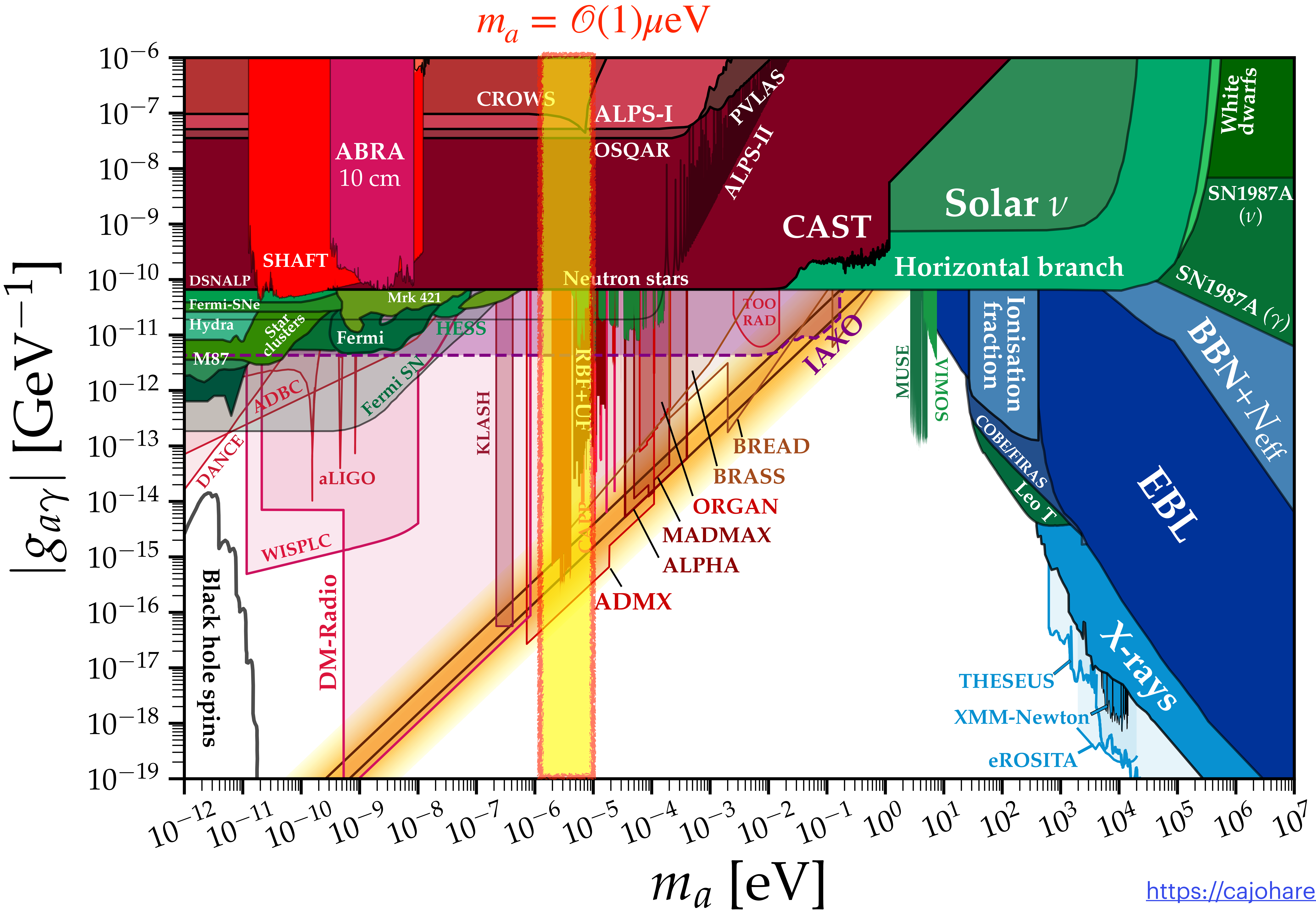
The upper limits assumes $\theta_{\rm ini} = \mathcal{O}(1)$.

See however FT, Wen Yin, Alan H. Guth, 1805.08763
Peter W. Graham, Adam Scherlis, 1805.07362

The lower limits from stellar cooling.

e.g. Leinson 1405.6873, 1909.03941, Hamaguchi et al 1806.07151, Bushmann et al 2111.09892.

Searching for (QCD)axion dark matter

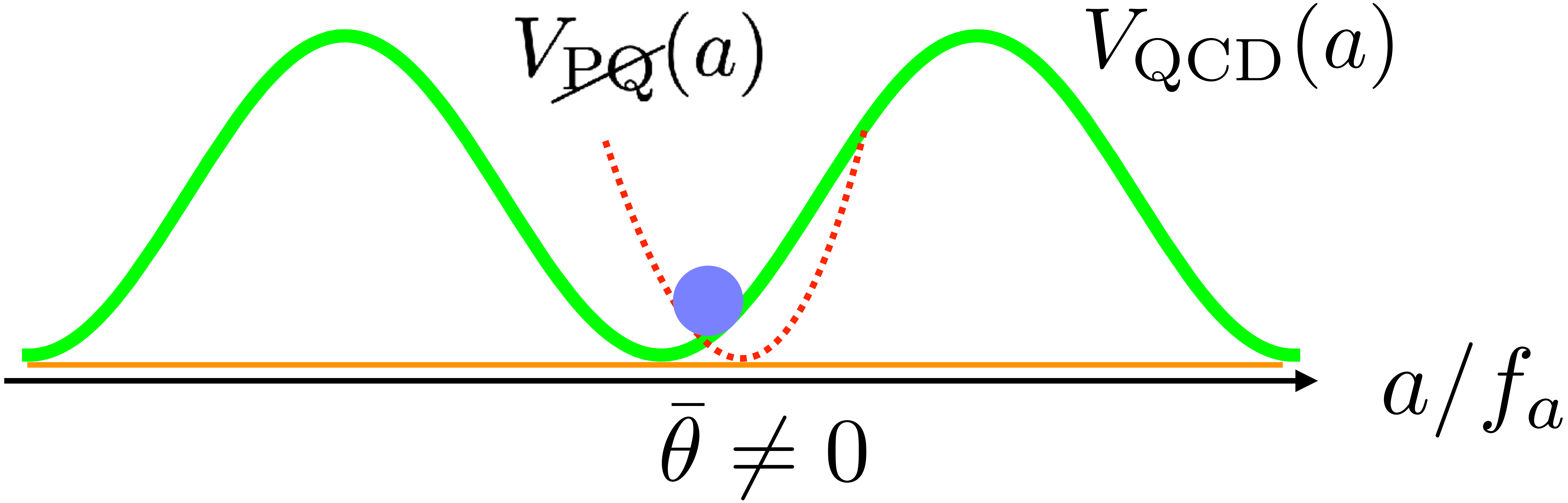


https://cajohare.github.io/AxionLimits/

Quality of PQ symmetry

To solve the strong CP problem, PQ symmetry breaking other than QCD must be very small.

“PQ quality problem”



If it's that small, it wouldn’t change the axion dynamics?

In fact, even a slight PQ breaking can be relevant since QCD is asymptotic free.

PQ symmetry breaking and QCD axion DM

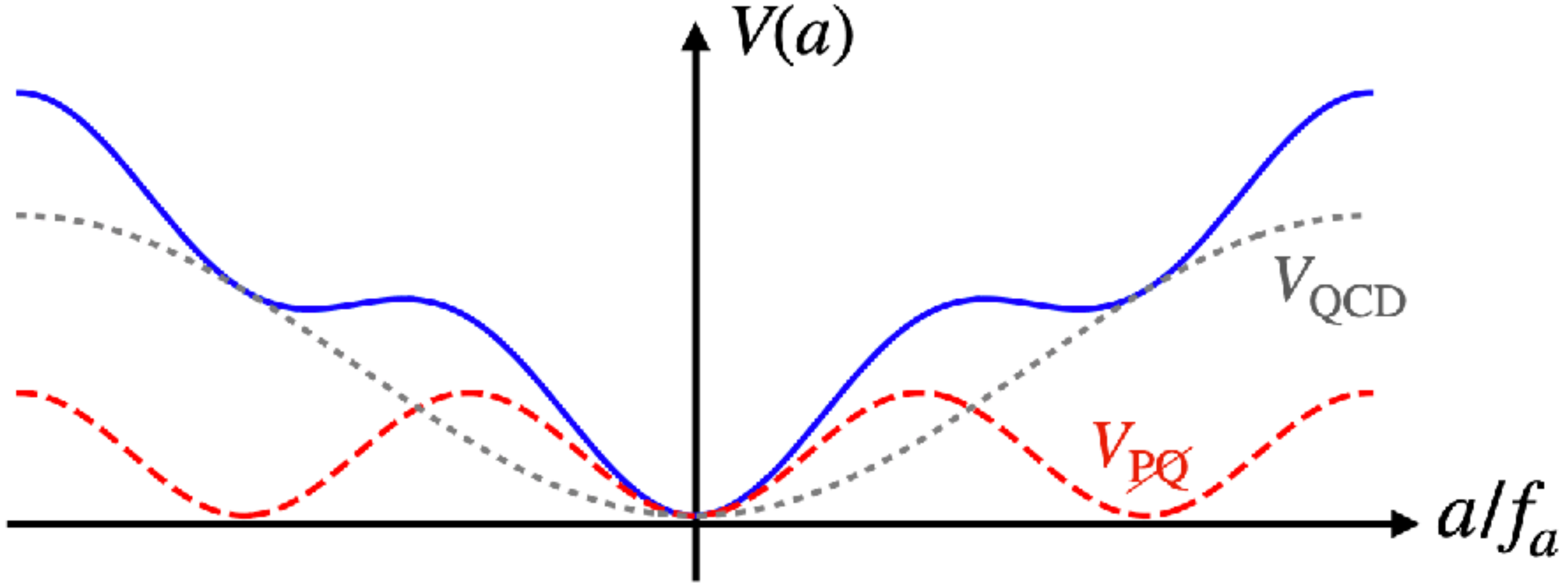
Jeong, Matsukawa, Nakagawa, FT, 2201.00681
Higaki, Jeong, Kitajima, and FT, 1603.02090

$$V(a) = V_{\rm QCD}(a) + V_{\not{\rm PQ}}(a)$$

$$V_{\rm QCD}(a) = m_a^2(T) f_a^2 \left(1 - \cos\frac{a}{f_a}\right)$$

$$V_{\not{\rm PQ}}(a) = \Lambda_H^4 \left[1 - \cos\left(N\left(\frac{a}{f_a} - \theta_H\right)\right)\right]$$

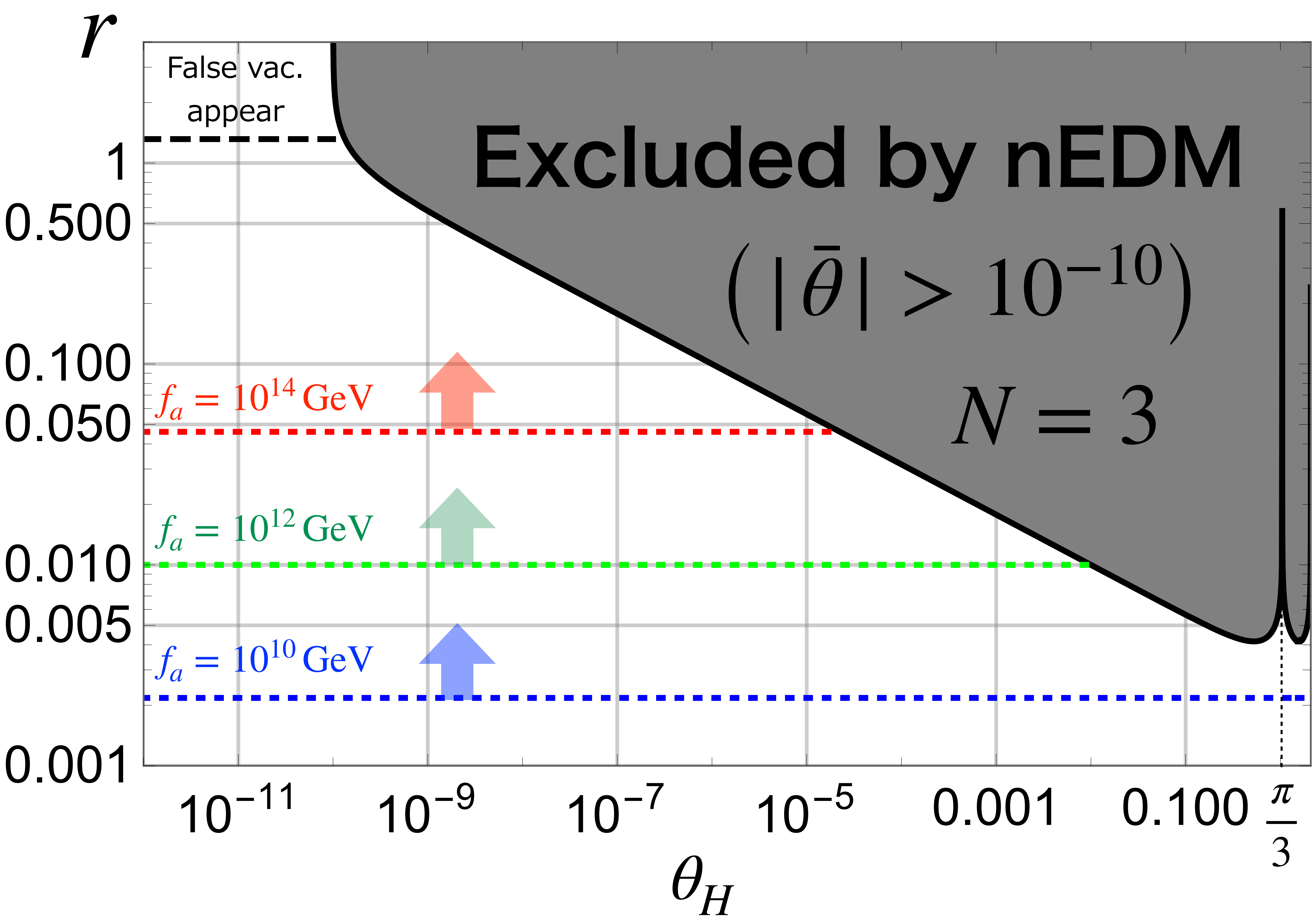
e.g. hidden non-Abelian gauge sym, higher dim. operator of the PQ scalar.



Relative height : $r \equiv \Lambda_H / \sqrt{m_{a,0} f_a}$

Relative phase : θ_H

The nEDM bound on the PQ breaking



In the region above the dotted line, the axion first starts to oscilalte due to $V_{\not{PQ}}$

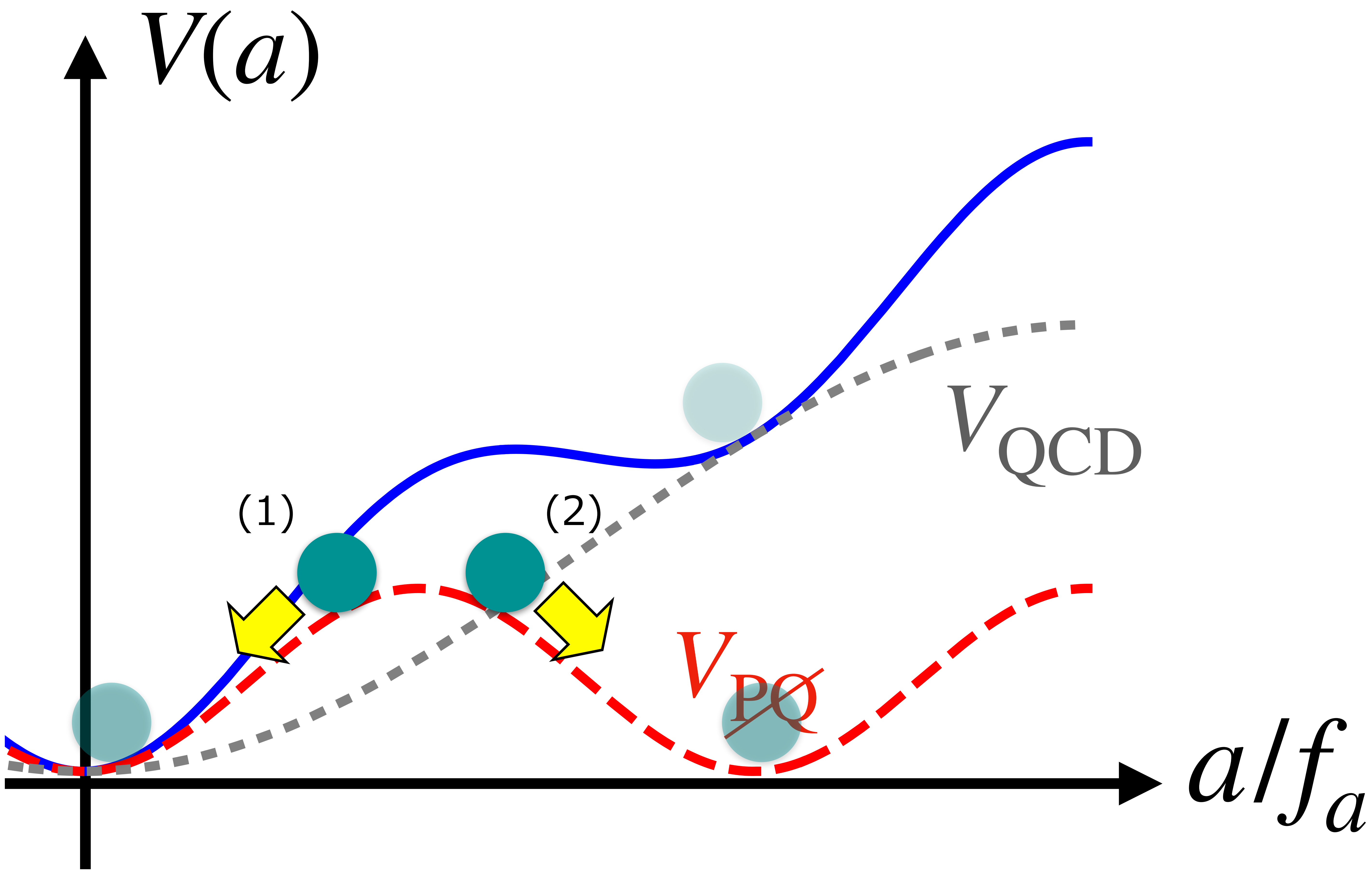
Depending on the initial value, the dynamics of the axion can be divided into two cases:

(1) Smooth-shift regime

$$|\theta_{\text{ini}} - \theta_H| < \pi/N$$

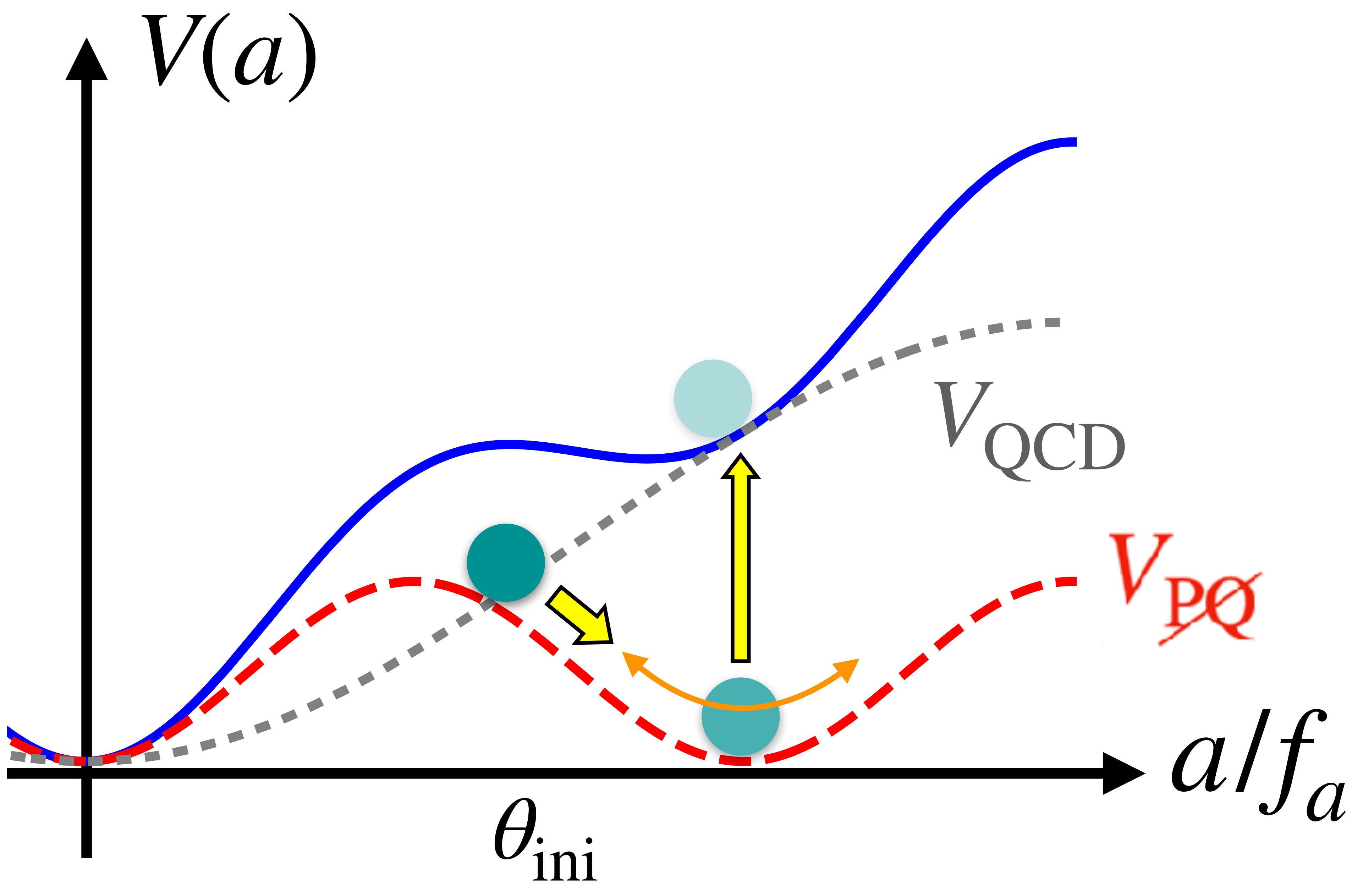
(2) Trapping regime

$$|\theta_{\text{ini}} - \theta_H| > \pi/N$$



(2) Trapping regime: $|\theta_{\rm ini} - \theta_H| > \pi/N$

The axion is trapped in a false vacuum until the $V_{\rm QCD}$ becomes important, and the onset of oscillation is delayed.



$$T_{\rm osc2} \sim 0.4 \left(\frac{N r^4}{3\times 10^{-4}} \right)^{-0.13} \ {\rm GeV}$$

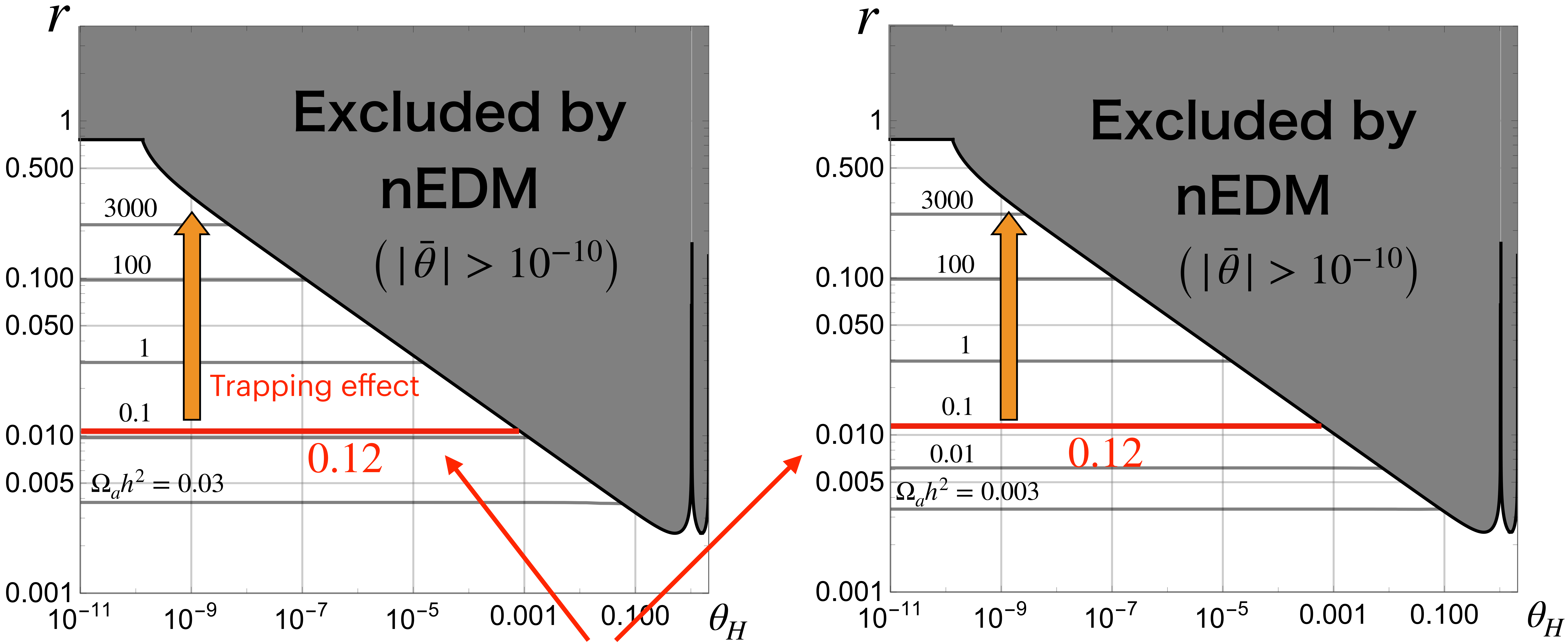
$$\Omega_a^{\rm (trap)} h^2 \simeq 0.25\, \theta_{\rm osc2}^2 \left(\frac{g_*(T_{\rm osc2})}{60} \right)^{-1} \left(\frac{N r^4}{10^{-6}} \right)^{0.88} .$$

$\theta_{\rm osc2} \sim (2k-1)\pi/N$

The axion abundance independen of f_a and $\theta_{\rm ini}$, and so, it can explain all DM even for $f_a \sim 10^8\,{\rm GeV}$. Also, isocurvature is suppressed.

The dependence of Ω_a on $\theta_{\rm H}$ and r

[Trapping regime: $\theta_{\rm ini} = 1.5$]

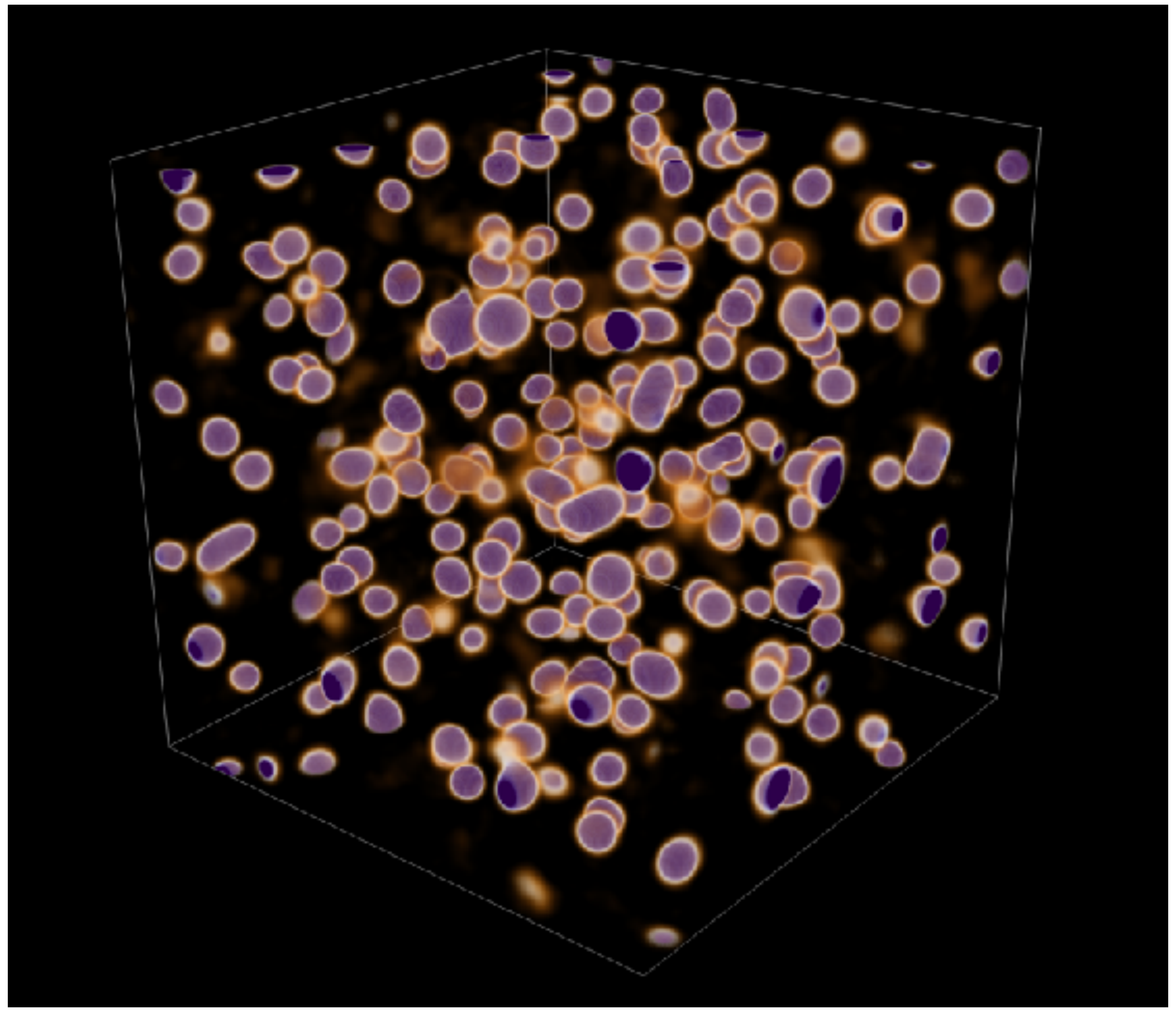


The axion explains DM for $r \simeq 0.01$

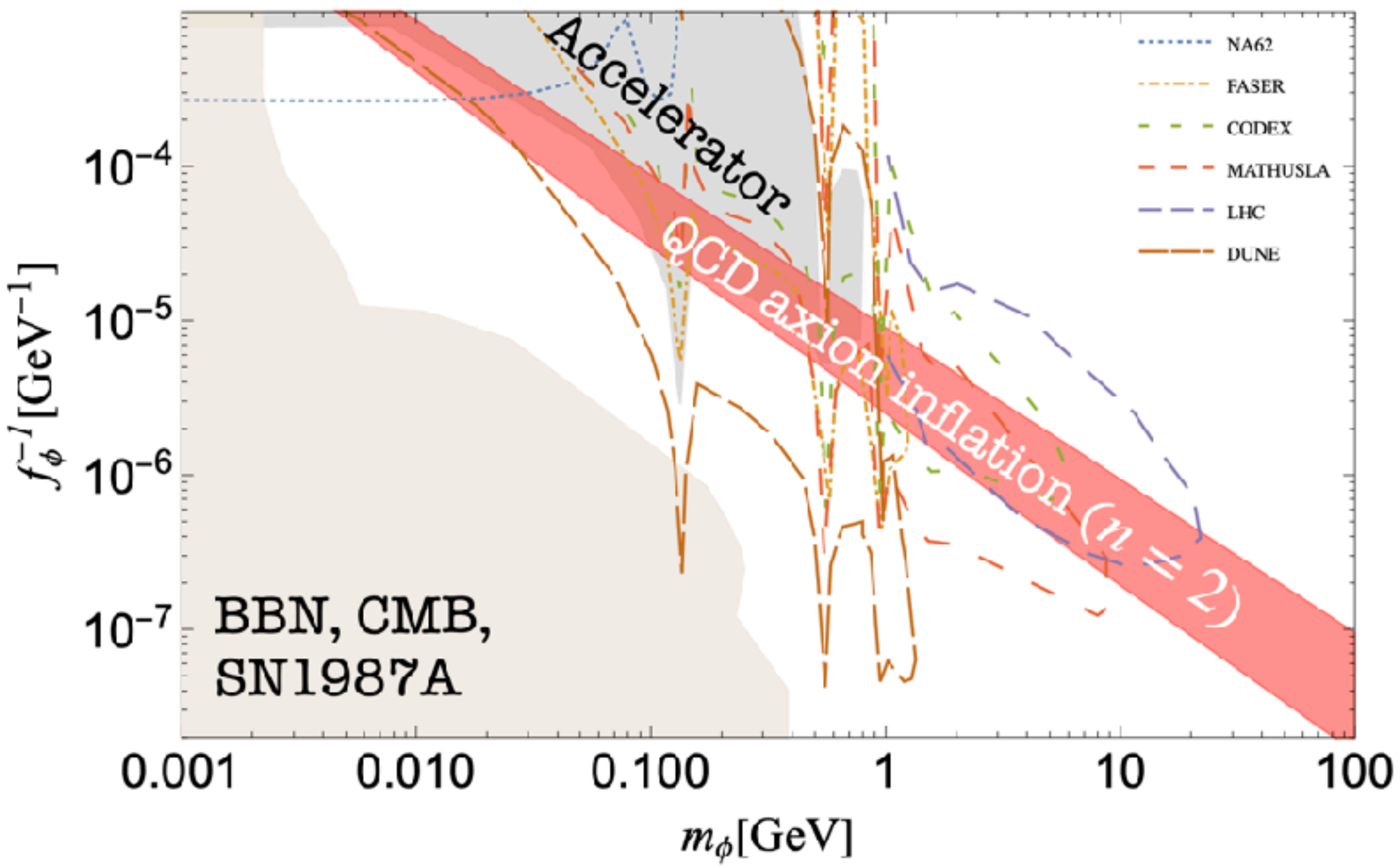
$f_a = 10^{11}\mathrm{GeV}$ $\quad$ $f_a = 10^{10}\mathrm{GeV}$

Summary

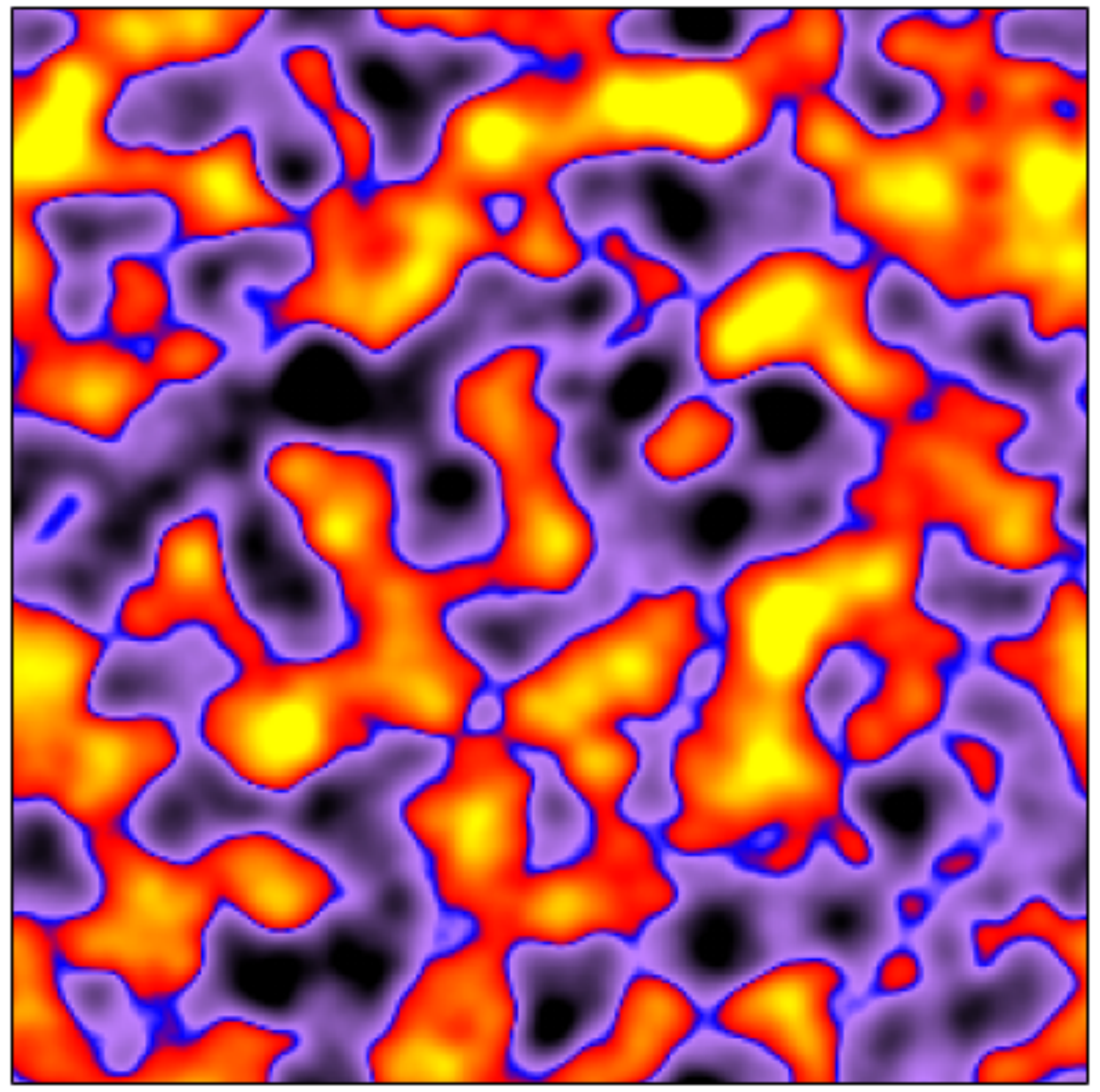
Research on light dark matter is progressing well. We will continue to study their production, evolution, and experimental implications to get closer to the nature of light DM.



Imagawa et al, 2110.05790



FT and Yin, 2105.10493



Kitajima, Kogai, Urakawa, 2111.05785