Cosmic Birefringence Triggered by Dark Matter Domination

Shota Nakagawa (Tohoku U.)

In collaboration with F. Takahashi & M. Yamada

Based on arXiv:2103.08153

Outline

1. Introduction : Cosmic birefringence

   Axion mass & coincidence problem

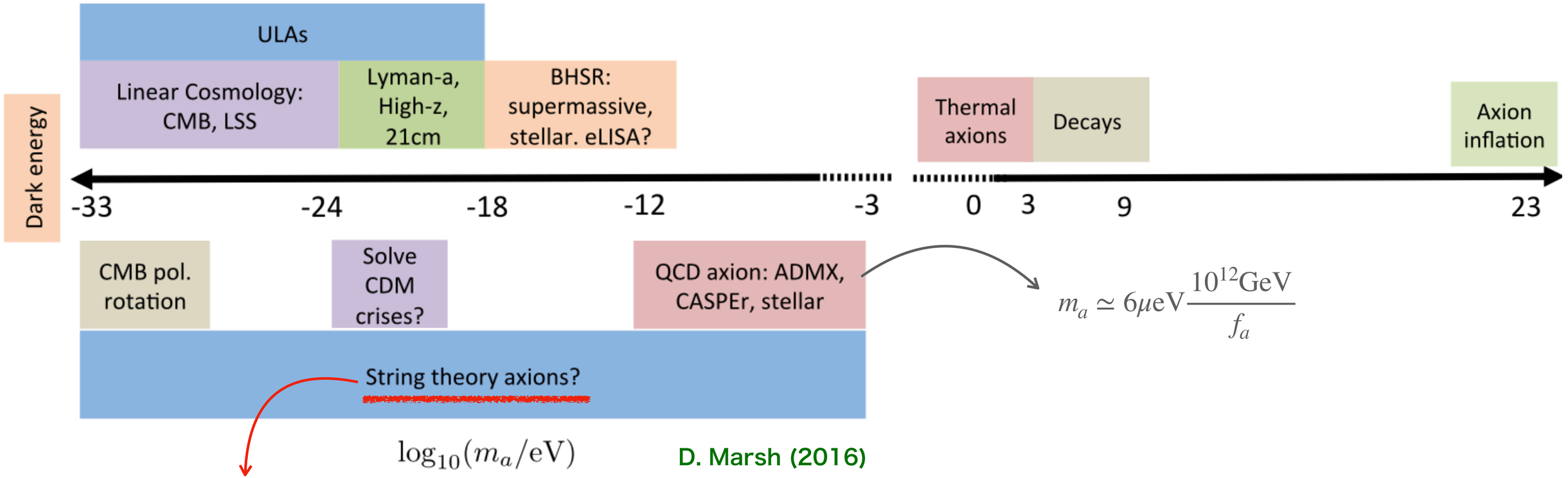
2. Birefringence triggered by DM domination

3. UV model : Witten effect on hidden monopole DM

4. Summary

1. Introduction

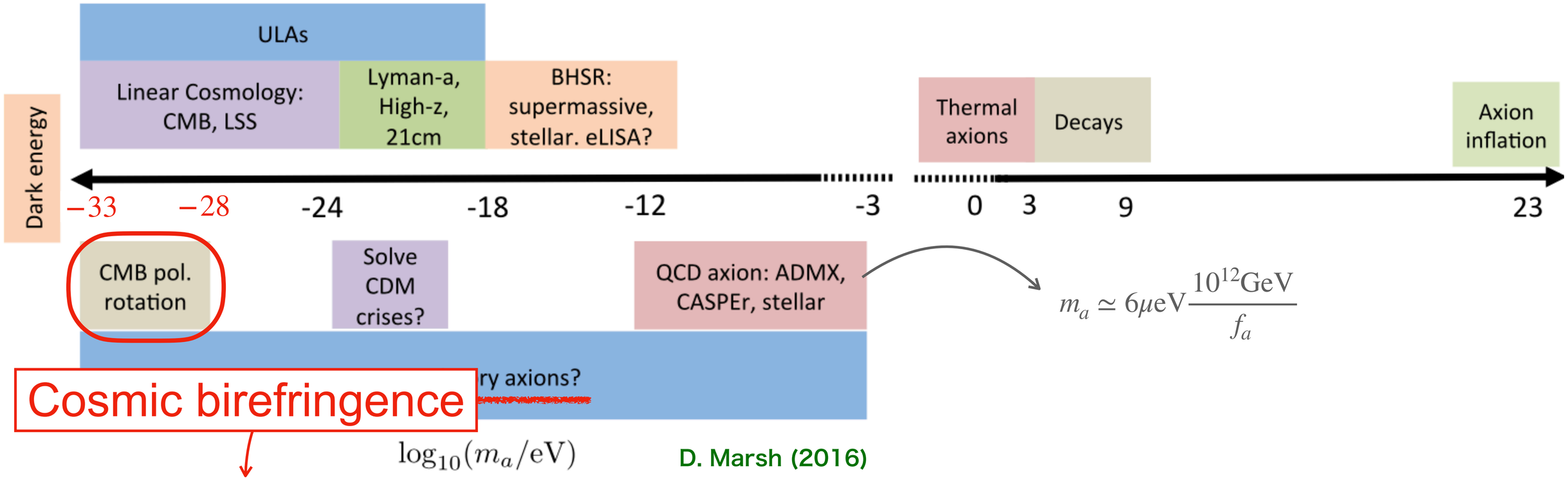
Axion cosmology has various interesting topics.



- It is produced from compafctification of the extra dimension.
- The mass is not related with the decay constant and arbitrary. → Various possibilities!!

1. Introduction

Axion cosmology has various interesting topics.



- It is produced from compafctification of the extra dimension.
- The mass is not related with the decay constant and arbitrary. → Various possibilities!!

Cosmic birefringence

CMB polarization plane can be rotated after the axion starts to move.

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - c_\gamma \frac{\alpha}{4\pi}\frac{\phi}{f_\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$\simeq \frac{1}{2}\left[\underbrace{\left(\vec{E} + c_\gamma \frac{\alpha}{2\pi}\frac{\phi}{f_\phi}\vec{B}\right)^2}_{\vec{D}} - \underbrace{\left(\vec{B} - c_\gamma \frac{\alpha}{2\pi}\frac{\phi}{f_\phi}\vec{E}\right)^2}_{\vec{H}}\right]$$

S.M. Carroll, G.B.Field, R.Jackiw (1990)
D.Harari, P.Sikivie (1992)
S.M.Carroll (1998)

$\vec{D}$ and $\vec{H}$ obey the free field equation and correspond to observable field.

Cosmic birefringence

CMB polarization plane can be rotated after the axion starts to move.

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - c_\gamma \frac{\alpha}{4\pi}\frac{\phi}{f_\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$\simeq \frac{1}{2}\left[\underbrace{\left(\vec{E} + c_\gamma \frac{\alpha}{2\pi}\frac{\phi}{f_\phi}\vec{B}\right)^2}_{\vec{D}} - \underbrace{\left(\vec{B} - c_\gamma \frac{\alpha}{2\pi}\frac{\phi}{f_\phi}\vec{E}\right)^2}_{\vec{H}}\right]$$

S.M. Carroll, G.B.Field, R.Jackiw (1990)
D.Harari, P.Sikivie (1992)
S.M.Carroll (1998)

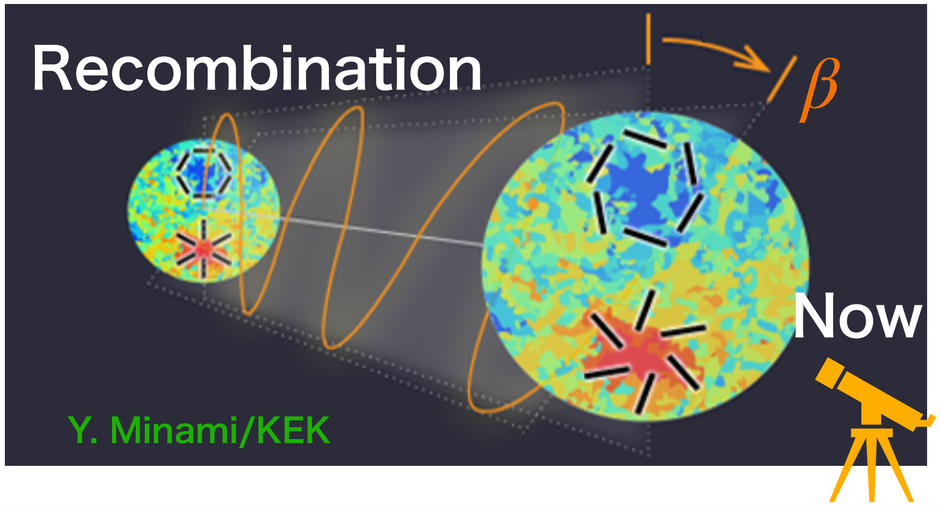
$\vec{D}$ and $\vec{H}$ obey the free field equation and correspond to observable fields.

Rotation angle β

$$\beta = c_\gamma \frac{\alpha}{2\pi}\frac{\Delta\phi}{f_\phi} \simeq 0.42\mathrm{deg} \times \left(c_\gamma \frac{\phi_{\mathrm{today}} - \phi_{\mathrm{rec}}}{2\pi f_\phi}\right)$$

$\Delta\phi/f_\phi \sim O(1) \rightarrow$ Expectation by Planck

$\beta = 0.35 \pm 0.14\mathrm{deg}$ Y.Minami & E.Komatsu (2020)



Axion mass & coincidence problem

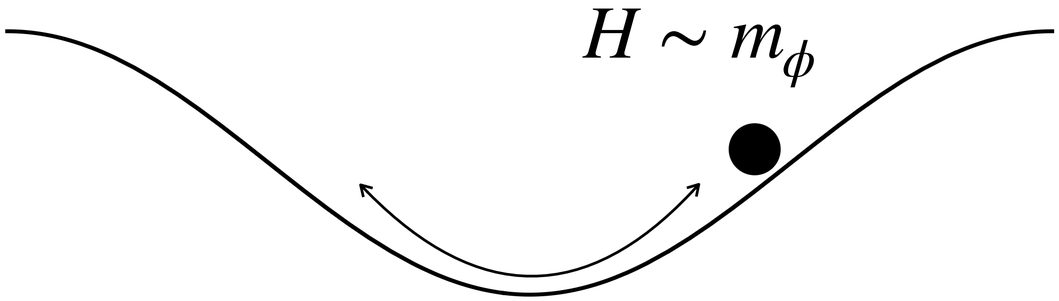
We need the below mass range to reproduce the Planck result :

$10^{-33}\mathrm{eV} \lesssim m_\phi \lesssim 10^{-28}\mathrm{eV} \rightarrow \Delta\phi/f_\phi \sim O(1) \rightarrow$

($\sim H_0$) ($\sim H_{\mathrm{rec}}$)

Expectation by Planck

$\beta = 0.35 \pm 0.14\mathrm{deg}$ Y.Minami & E.Komatsu (2020)



$$V(\phi) = m_\phi^2 f_\phi^2 \left(1 - \cos\frac{\phi}{f_\phi}\right)$$

Axion mass & coincidence problem

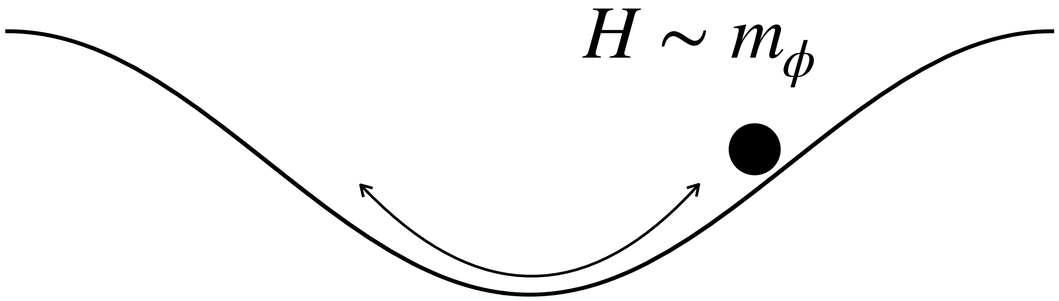
We need the below mass range to reproduce the Planck result :

$10^{-33}\mathrm{eV} \lesssim m_\phi \lesssim 10^{-28}\mathrm{eV} \rightarrow \Delta\phi/f_\phi \sim O(1) \rightarrow$

($\sim H_0$) ($\sim H_{\mathrm{rec}}$)

Expectation by Planck

$\beta = 0.35 \pm 0.14\mathrm{deg}$ Y.Minami & E.Komatsu (2020)



$$V(\phi) = m_\phi^2 f_\phi^2 \left(1 - \cos\frac{\phi}{f_\phi}\right)$$

Why such a mass range?

↔ Why does the axion start to move between the recombination and the present epoch? Coincidence problem

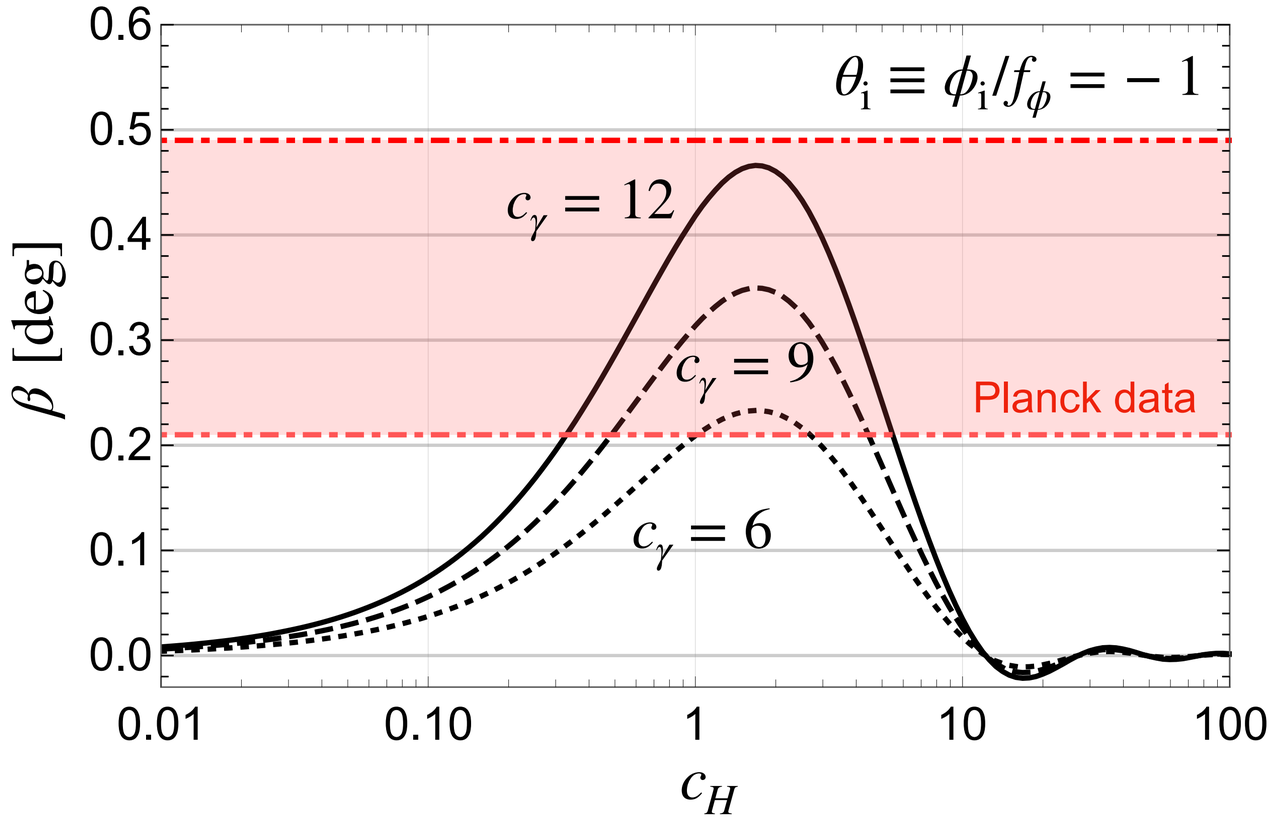
2. Birefringence triggered by DM domination

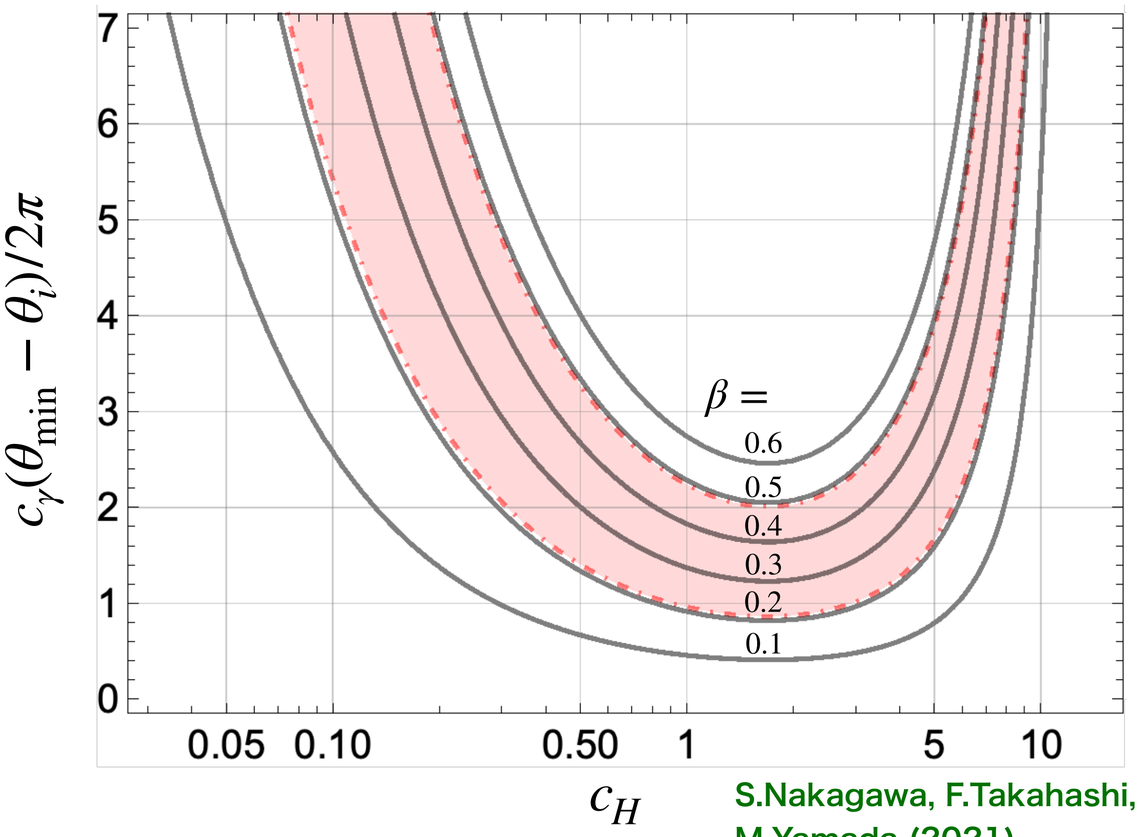
$$V(\phi) = \frac{1}{2} c_H H_{\rm DM}^2 \phi^2$$

$$H_{\rm DM}^2 \equiv \frac{\rho_{\rm DM}}{3M_{\rm Pl}^2}$$

$$c_H \sim O(1)$$

The axion starts to move triggered by DM domination.
(just before the recombination)





S.Nakagawa, F.Takahashi, M.Yamada (2021)

2. Birefringence triggered by DM domination

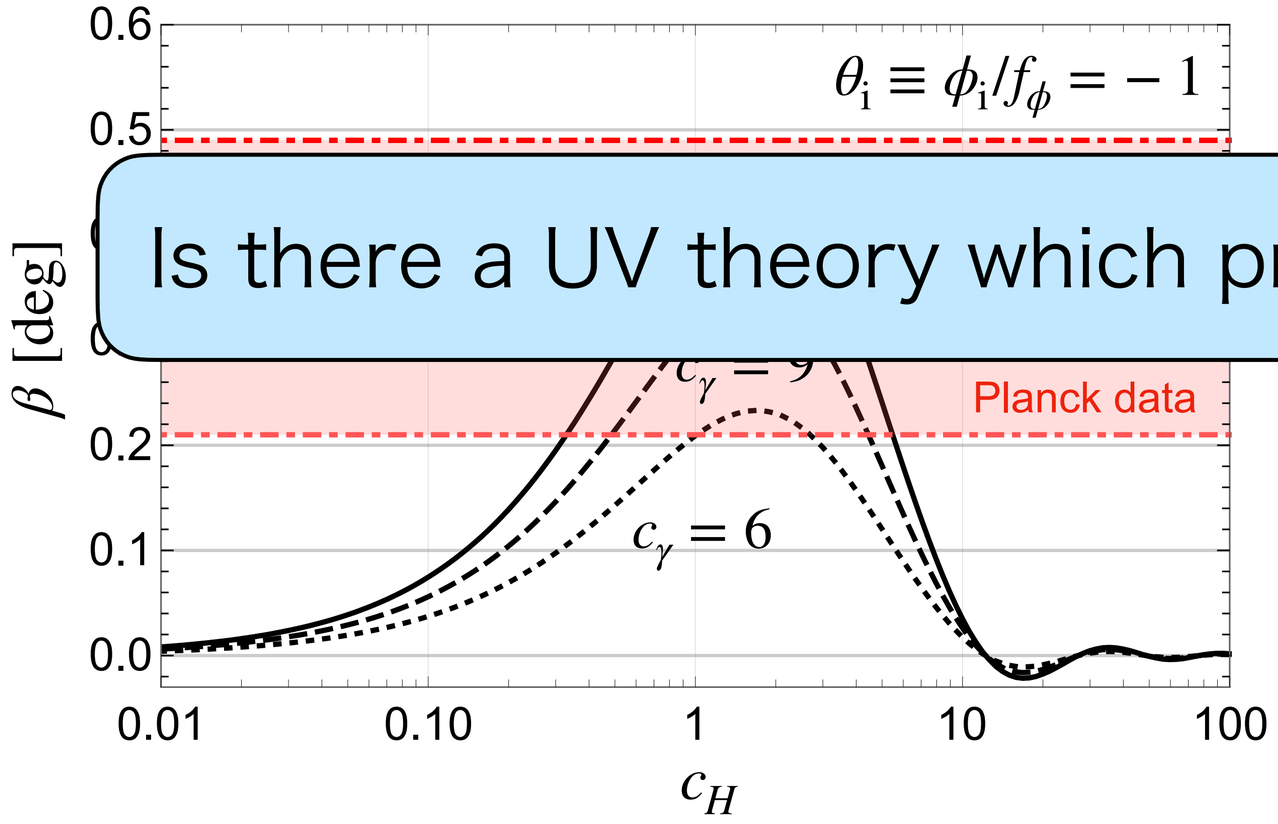
$$V(\phi) = \frac{1}{2} c_H H_{\rm DM}^2 \phi^2$$

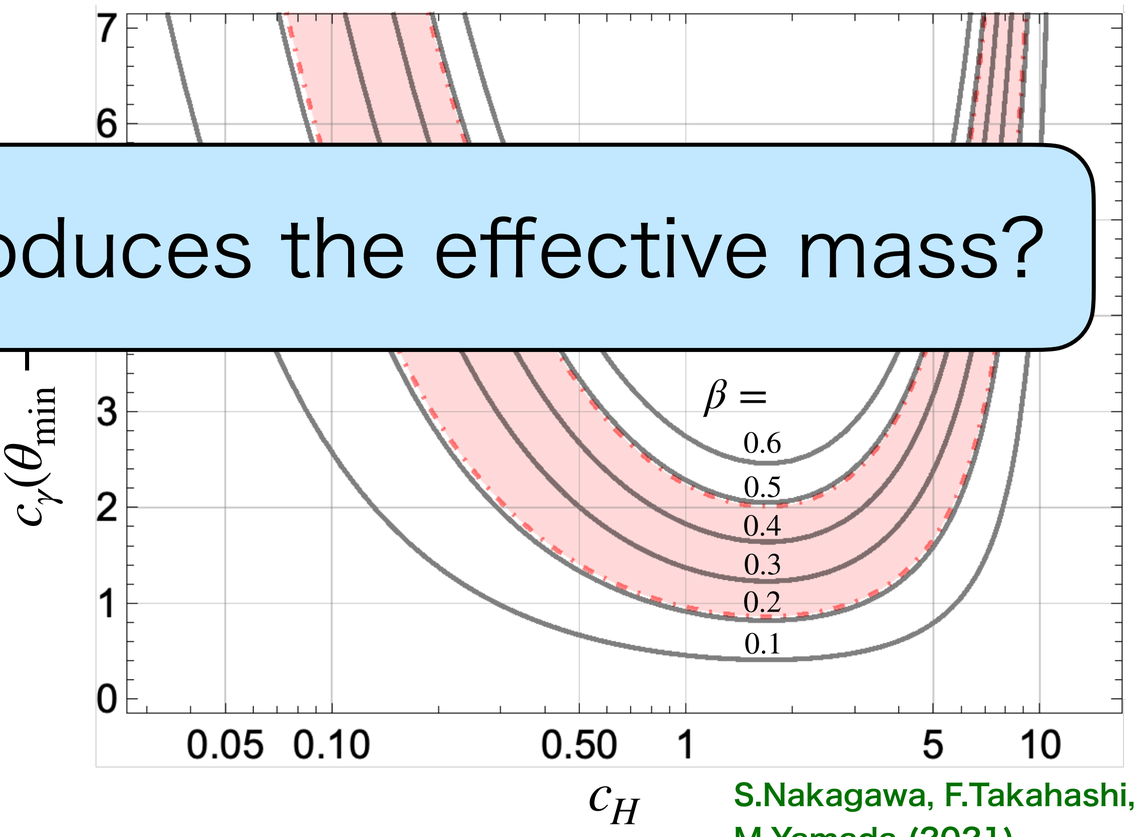
$$H_{\rm DM}^2 \equiv \frac{\rho_{\rm DM}}{3M_{\rm Pl}^2}$$

$$c_H \sim O(1)$$

The axion starts to move triggered by DM domination.
(just before the recombination)

Is there a UV theory which produces the effective mass?





S.Nakagawa, F.Takahashi, M.Yamada (2021)

3. UV model

Low energy EFT $\mathcal{L}_\phi = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}c_H H_{\rm DM}^2\phi^2 - c_\gamma \frac{\alpha}{4\pi}\frac{\phi}{f_\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$

Witten effect on hidden monopole DM

・Considering a breaking $\mathrm{SU}(2)_H \to \mathrm{U}(1)_H$, hidden magnetic monopole is produced as dark matter.

・If the axion has a $\mathrm{U}(1)_H$ coupling, the monopole acquires a hidden electric charge (Witten effect). E.Witten (1979)

$$\mathcal{L} \supset -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\alpha_H\phi}{8\pi f_\phi}X_{\mu\nu}\tilde{X}^{\mu\nu} \longrightarrow \nabla\cdot\vec{E}_H = -\frac{\alpha_H\phi}{2\pi f_\phi}\nabla\cdot\vec{B}_H \quad (\neq 0)$$

3. UV model

Low energy EFT $\mathcal{L}_\phi = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}c_H H_{\rm DM}^2\phi^2 - c_\gamma \frac{\alpha}{4\pi}\frac{\phi}{f_\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$

Witten effect on hidden monopole DM

・Considering a breaking $\mathrm{SU}(2)_H \to \mathrm{U}(1)_H$, hidden magnetic monopole is produced as dark matter.

・If the axion has a $\mathrm{U}(1)_H$ coupling, the monopole acquires a hidden electric charge (Witten effect). E.Witten (1979)

$$\mathcal{L} \supset -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{\alpha_H\phi}{8\pi f_\phi}X_{\mu\nu}\tilde{X}^{\mu\nu} \longrightarrow \nabla\cdot\vec{E}_H = -\frac{\alpha_H\phi}{2\pi f_\phi}\nabla\cdot\vec{B}_H \quad (\neq 0)$$

・The axion acquires an effective mass in the monopole plasma. W.Fischler, J.Preskill (1983)

$$m_{\rm eff}^2 = \left(\frac{\alpha_H}{4\pi f_\phi}\right)^2 \rho_M \longrightarrow c_H = 3\left(\frac{\rho_M}{\rho_{\rm DM}}\right)\left(\frac{\alpha_H}{4\pi}\frac{M_{\rm Pl}}{f_\phi}\right)^2 \sim O(1)$$

S.Nakagawa, F.Takahashi, M.Yamada (2021)

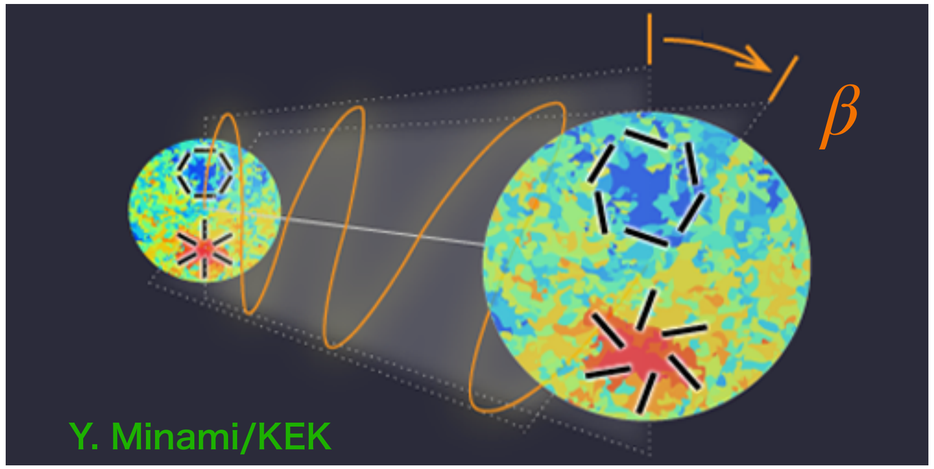
for $\rho_M \sim \rho_{\rm DM}$, $\alpha_H \sim O(0.01)$, $f_\phi \sim 10^{16}$GeV

4. Summary

・On the basis of Planck2018 result, CMB polarization angle has been reported:

$$\beta = 0.35 \pm 0.14 \mathrm{deg}$$

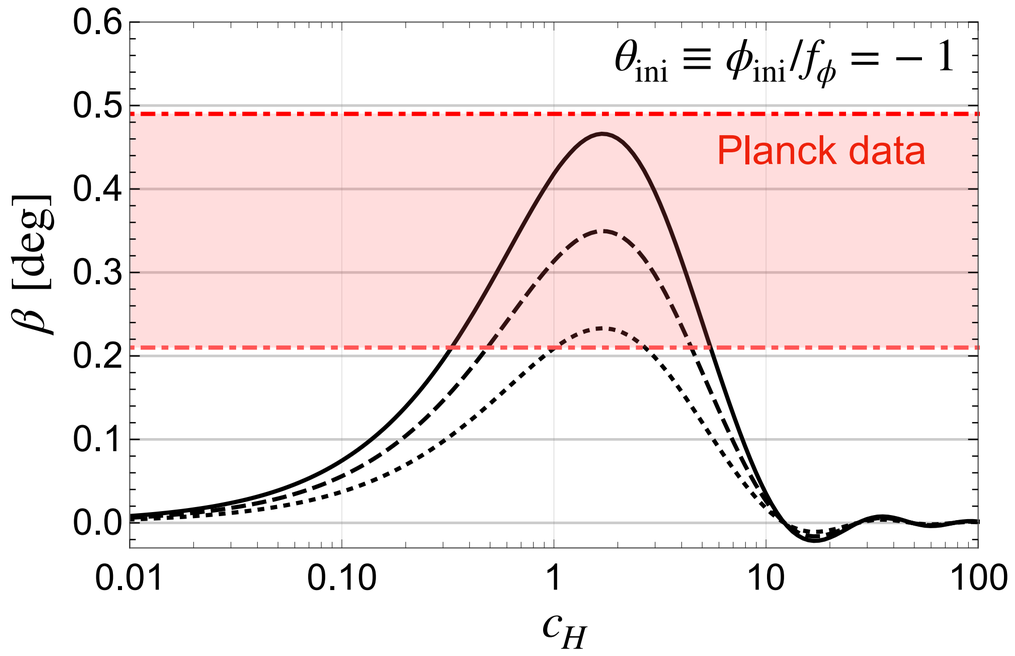
Y.Minami & E.Komatsu (2020)



・There is no theoretical reason “why now” (coincidence problem).

・The effective mass proportional to DM density can explain the problem.

・We propose a specific UV model:
The Witten effect on hidden monopole dark matter.



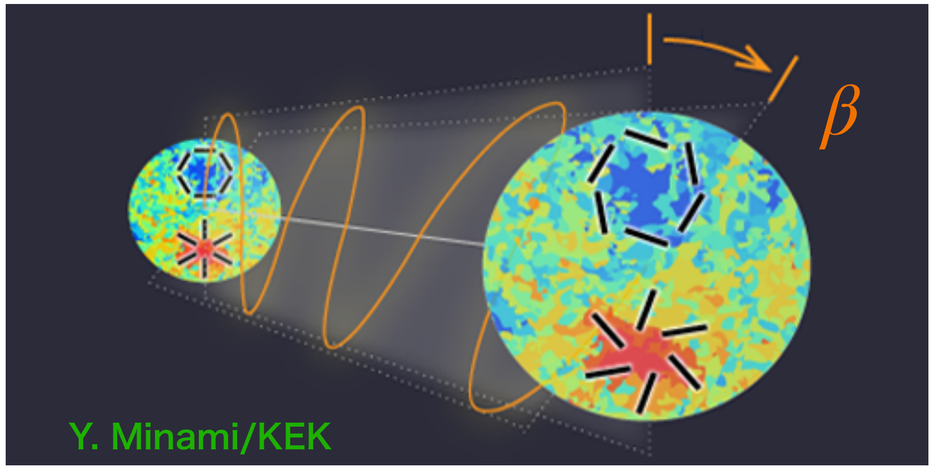
S.Nakagawa, F.Takahashi, M.Yamada (2021)

4. Summary

・On the basis of Planck2018 result, CMB polarization angle has been reported:

$$\beta = 0.35 \pm 0.14 \mathrm{deg}$$

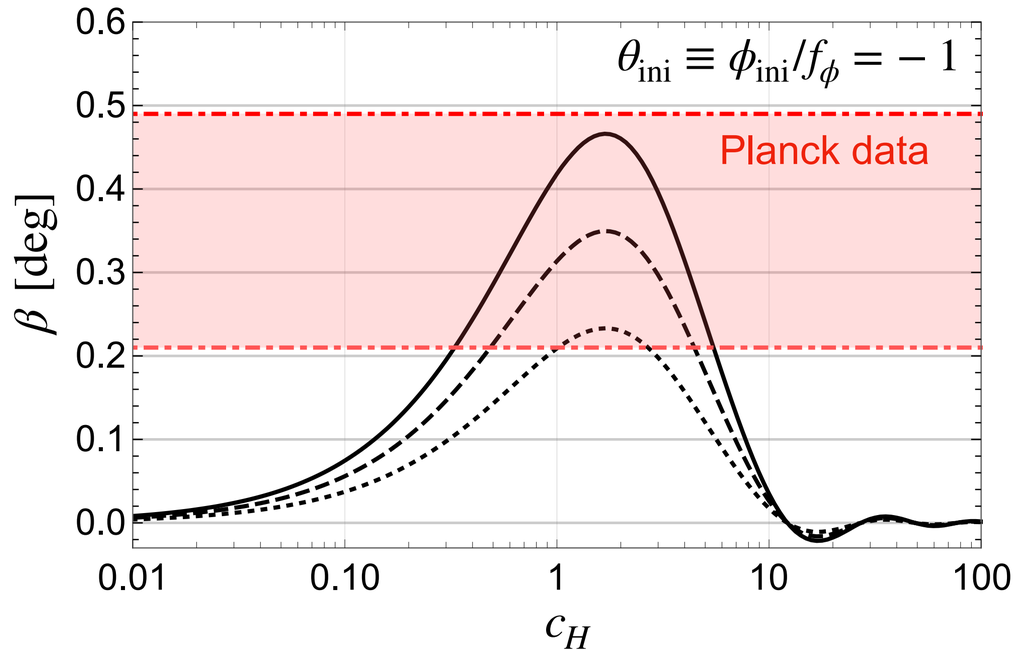
Y.Minami & E.Komatsu (2020)



・There is no theoretical reason “why now” (coincidence problem).

・The effective mass proportional to DM density can explain the problem.

・We propose a specific UV model:
The Witten effect on hidden monopole dark matter.



Thank you.

S.Nakagawa, F.Takahashi, M.Yamada (2021)

Back up

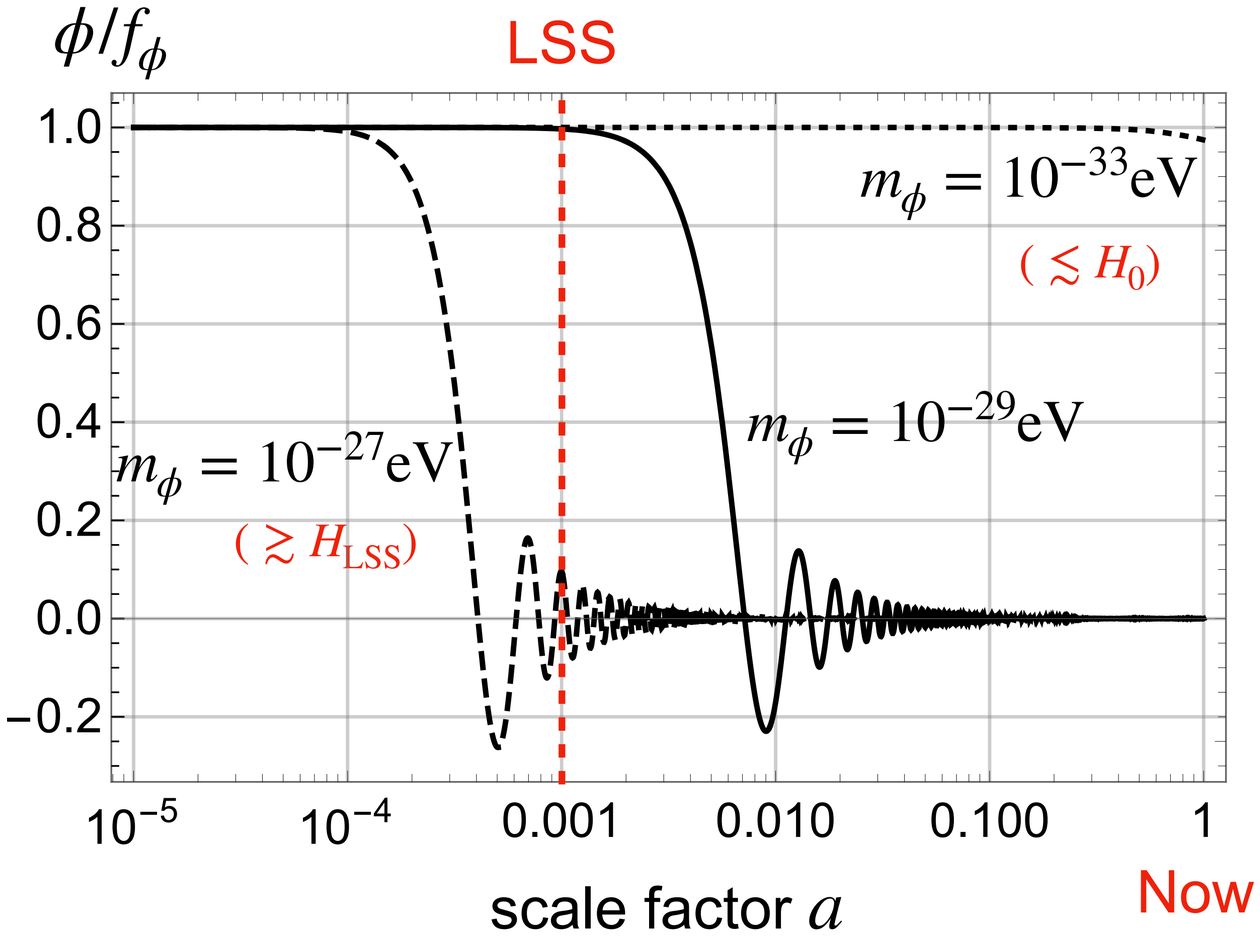
Axion dynamics

$10^{-33}\mathrm{eV} \lesssim m_\phi \lesssim 10^{-28}\mathrm{eV} \rightarrow \Delta\phi/f_\phi \sim O(1) \rightarrow$

$(\sim H_0)$ $(\sim H_{\rm rec})$

Expectation by Planck

$\beta = 0.35 \pm 0.14\mathrm{deg}$ Y.Minami & E.Komatsu (2020)



Another UV model

Low energy EFT $\mathcal{L}_\phi = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}c_H H_{\rm DM}^2\phi^2 - c_\gamma \frac{\alpha}{4\pi}\frac{\phi}{f_\phi}F_{\mu\nu}\tilde{F}^{\mu\nu}$

Non-minimal coupling to gravity

$$\mathcal{L} \supset -\xi R\phi^2 \simeq -3\xi H_{\rm DM}^2\phi^2 \quad \text{(Matter dominated era)}$$

S.Nakagawa, F.Takahashi, M.Yamada (2021)

$$\xi \sim O(1) \rightarrow c_H = 6\xi \sim O(1)$$

※$R \simeq 0$ during RD, so the axion was almost massless.