Cosmic Birefringence Triggered by Dark Matter Domination

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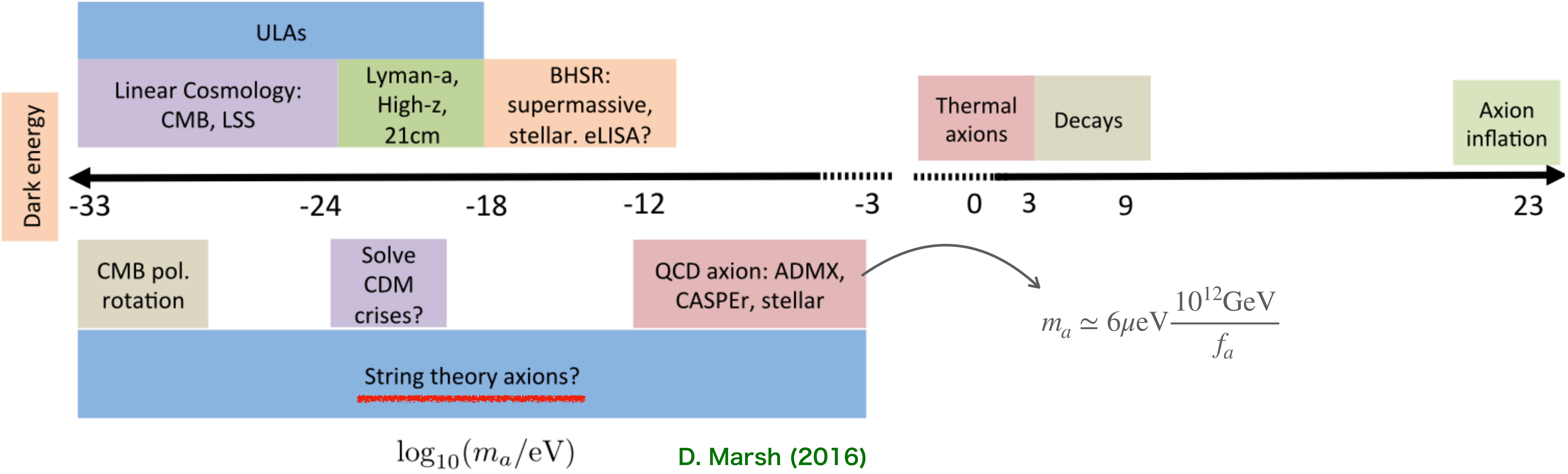
In collaboration with F. Takahashi & M. Yamada

Based on arXiv:2103.08153

1. Introduction

Axion cosmology has various interesting topics.



$$m_a \simeq 6\mu\mathrm{eV}\frac{10^{12}\mathrm{GeV}}{f_a}$$

D. Marsh (2016)

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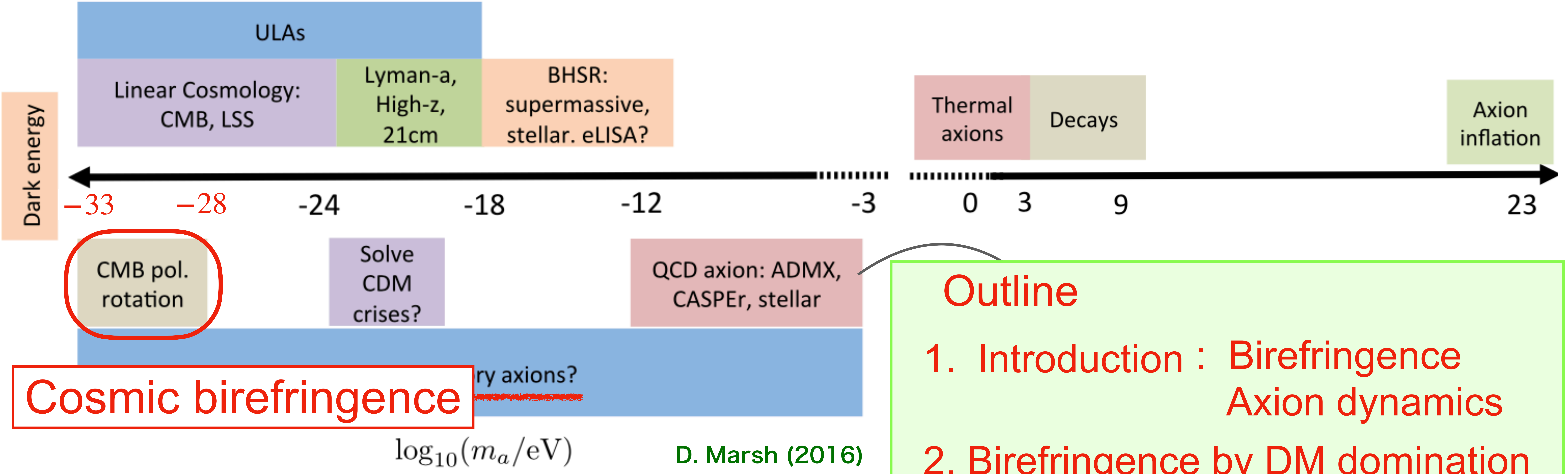

Outline

1. Introduction : Birefringence
   Axion dynamics
2. Birefringence by DM domination
3. UV theory
4. Summary

Cosmic birefringence

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

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

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

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

$\overrightarrow{D}$ and $\overrightarrow{H}$ obey the free field equation and corresponds to observable field.

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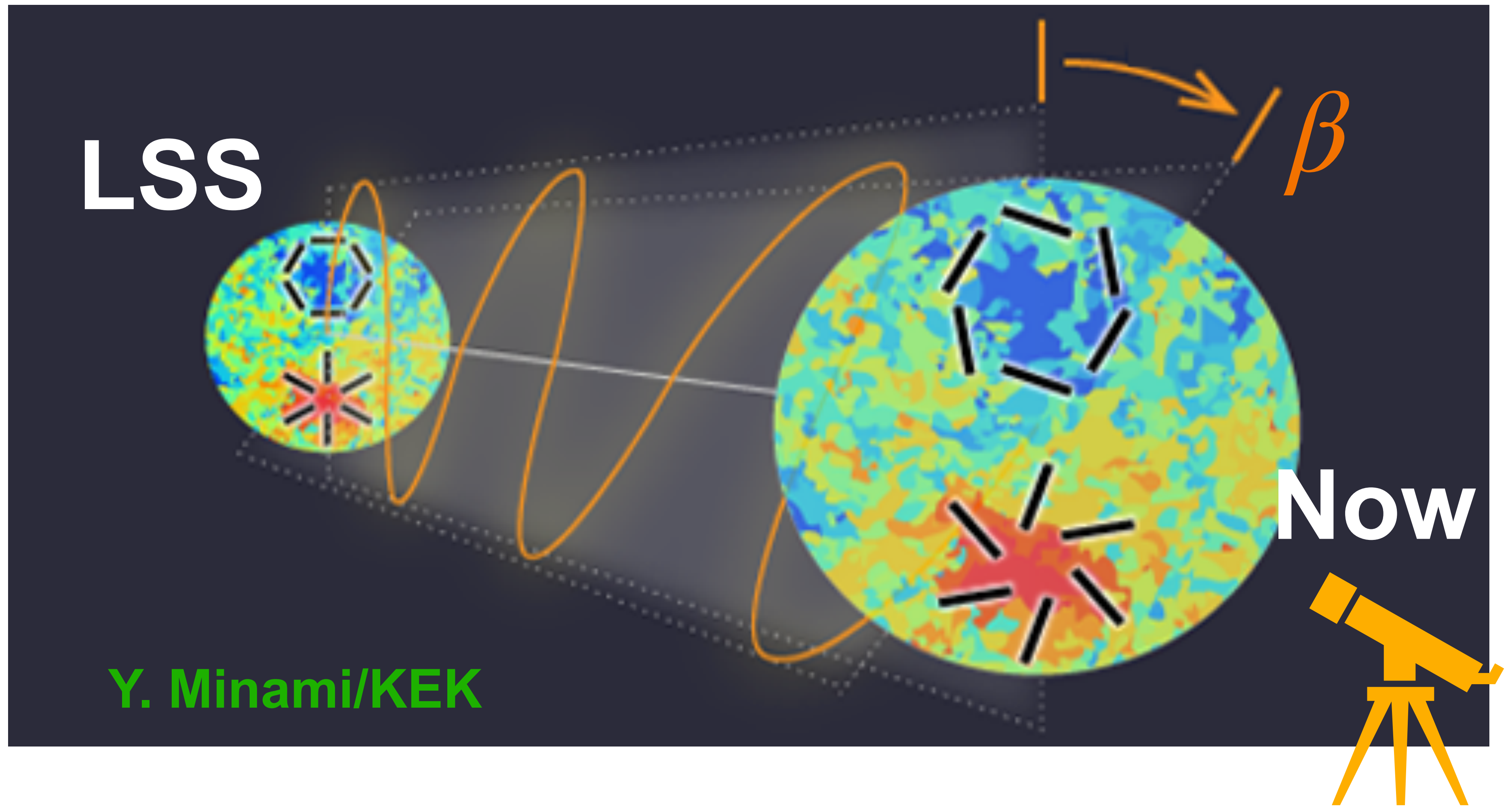
Rotation angle β

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

Expectation by Planck

$\Delta\phi/f_\phi \sim O(1) \rightarrow$ $\beta = 0.35 \pm 0.14\mathrm{deg}$ Y.Minami & E.Komatsu (2020)



Axion dynamics

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

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

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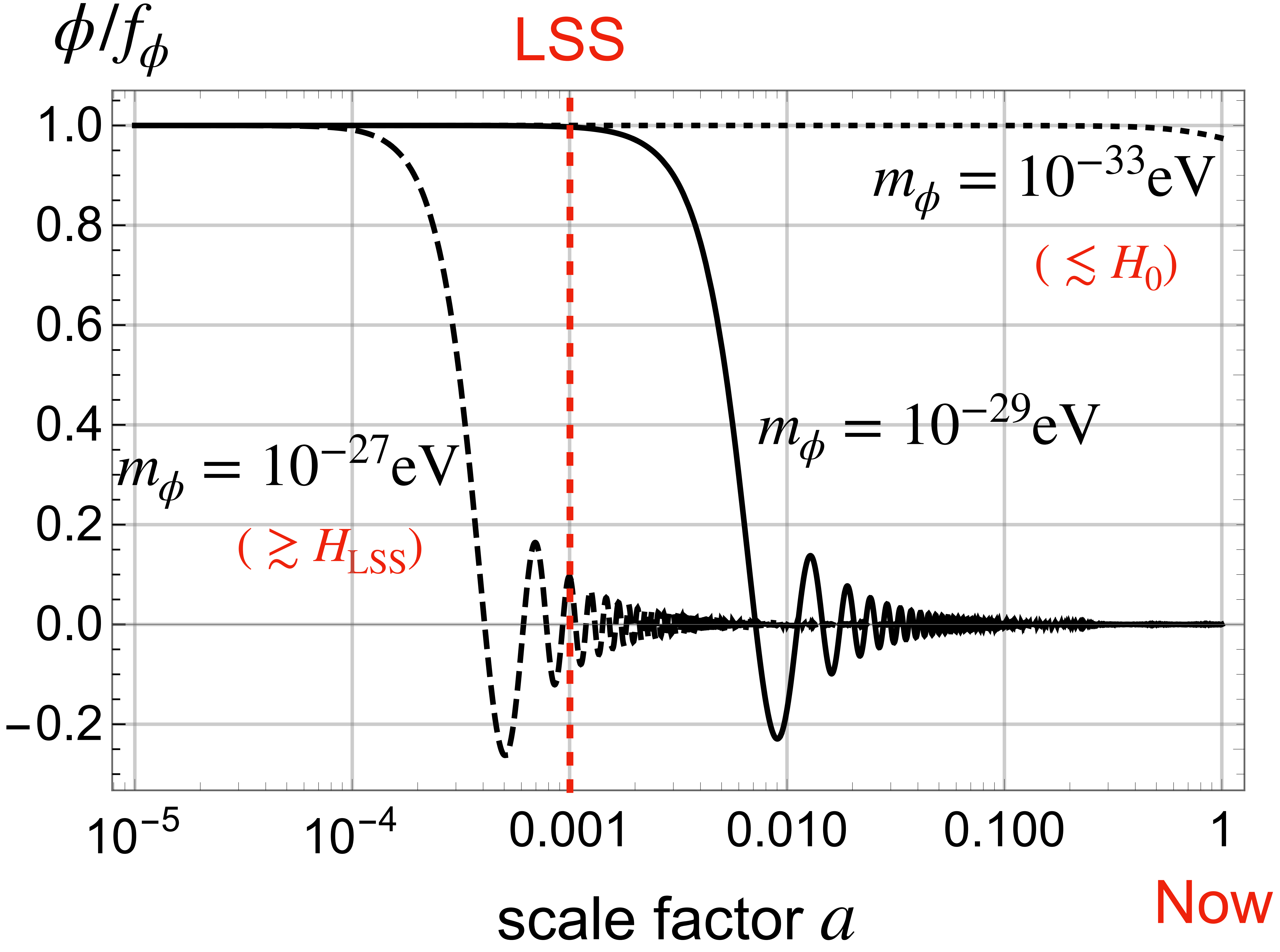

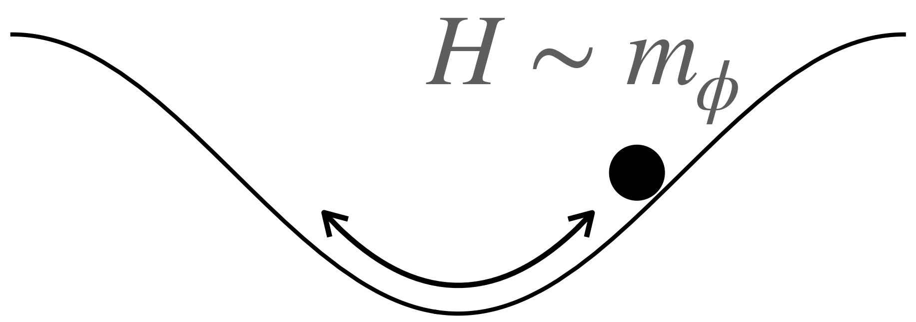

$V(\phi) = m_\phi^2 f_\phi^2 \left(1 - \cos\frac{\phi}{f_\phi}\right)$

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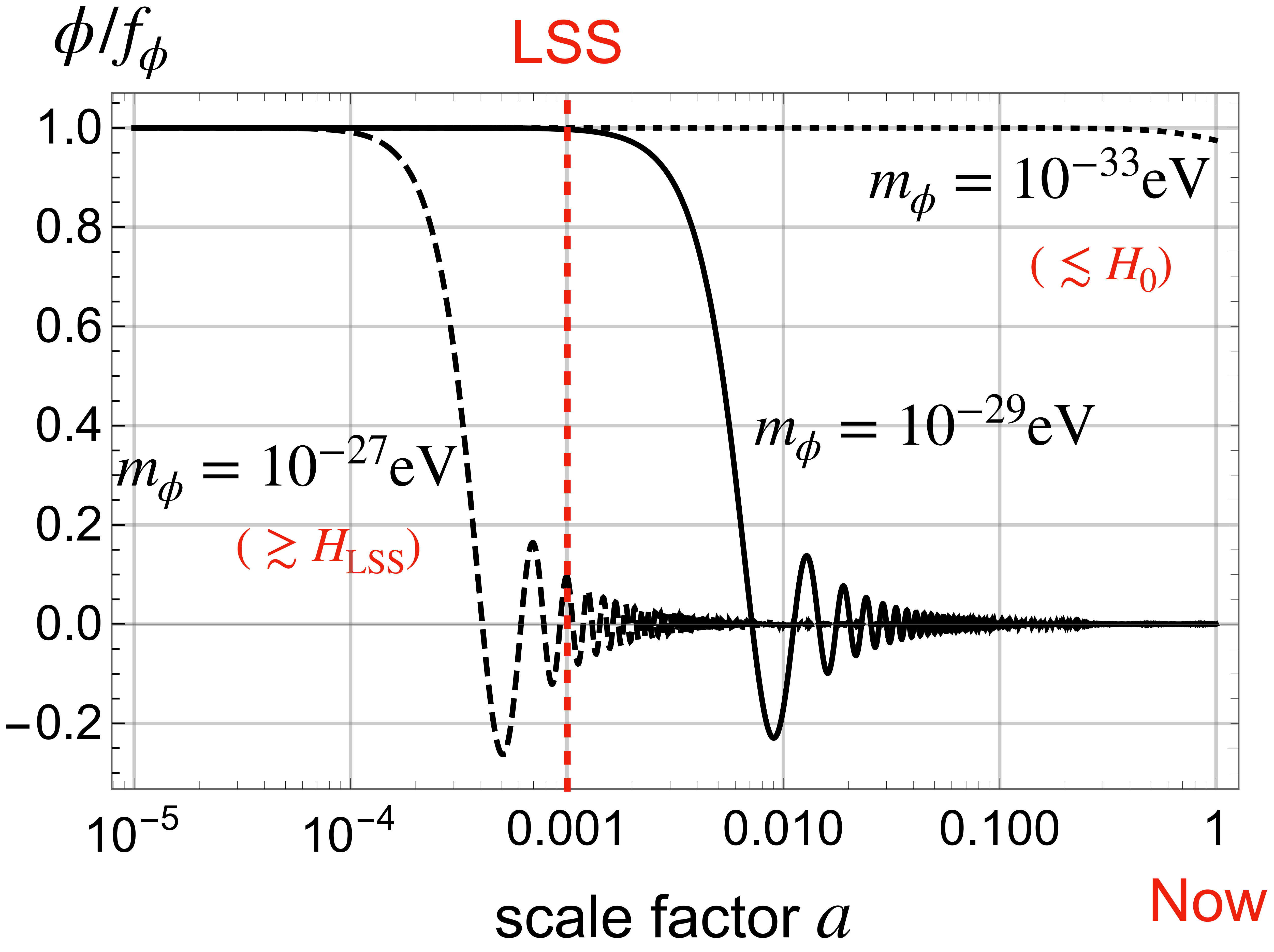

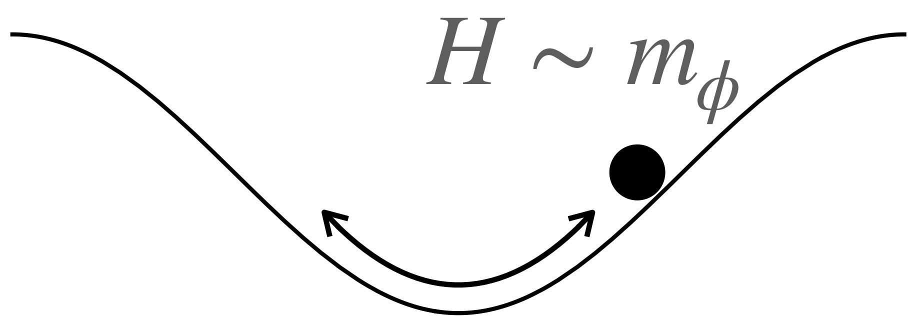

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Why does the axion start to move between the recombination and the present?

↔ Why such a mass region?

"Why now?"
(coincidence problem)

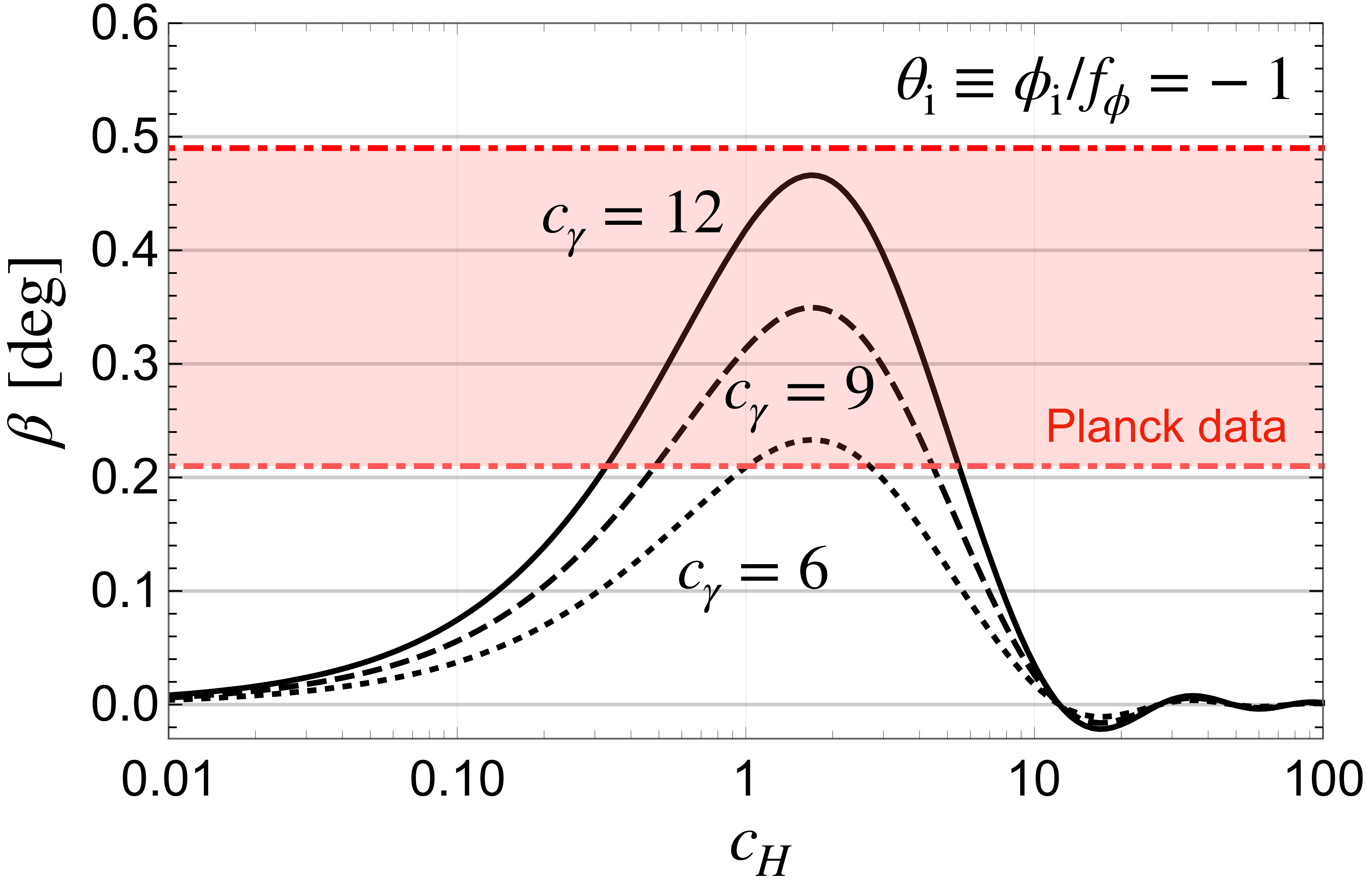
2. Birefringence by DM domination

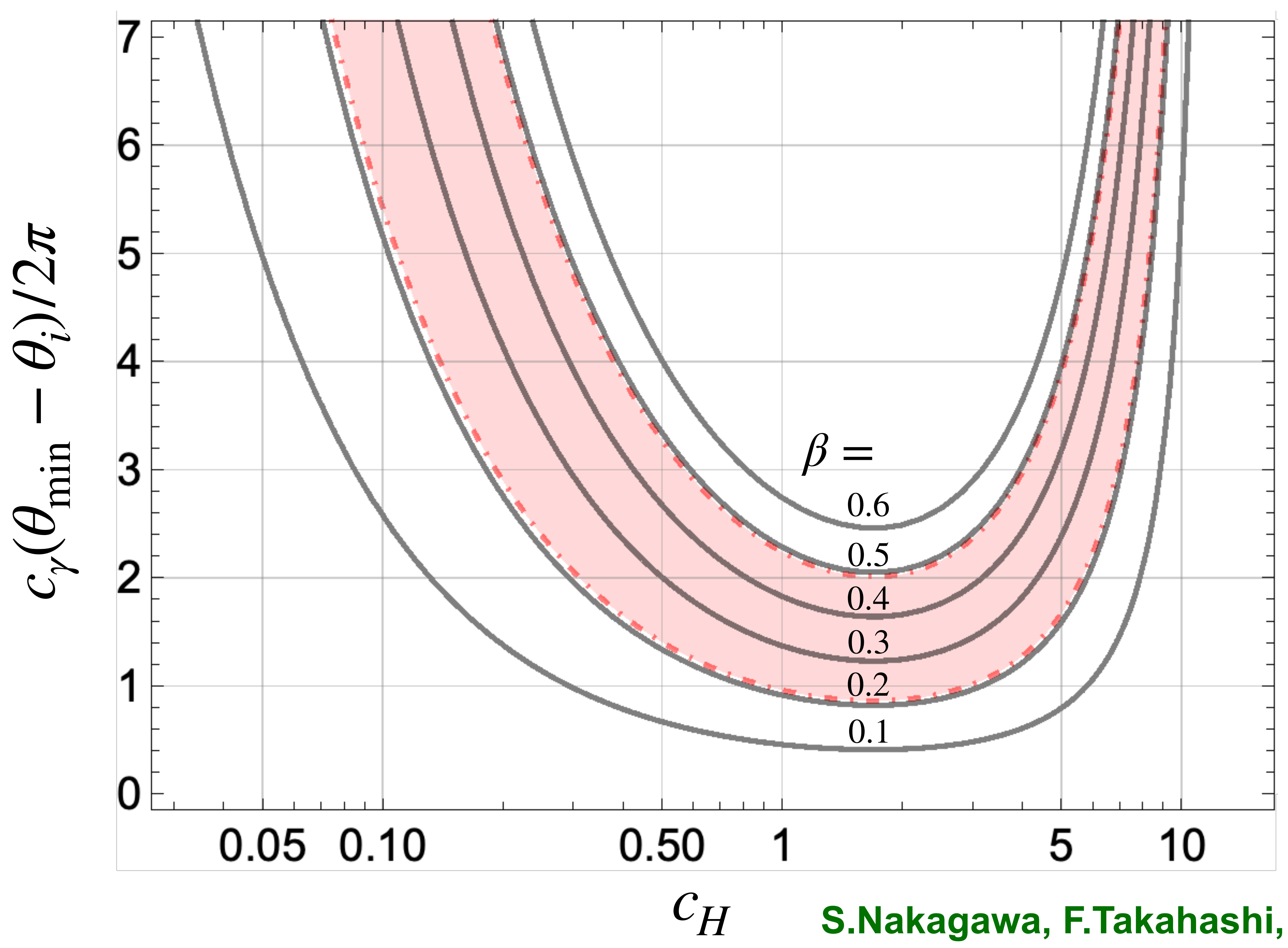
$$V(\phi) = \frac{1}{2} c_H H_{\rm DM}^2 \phi^2$$

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

$$c_H \sim O(1)$$

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





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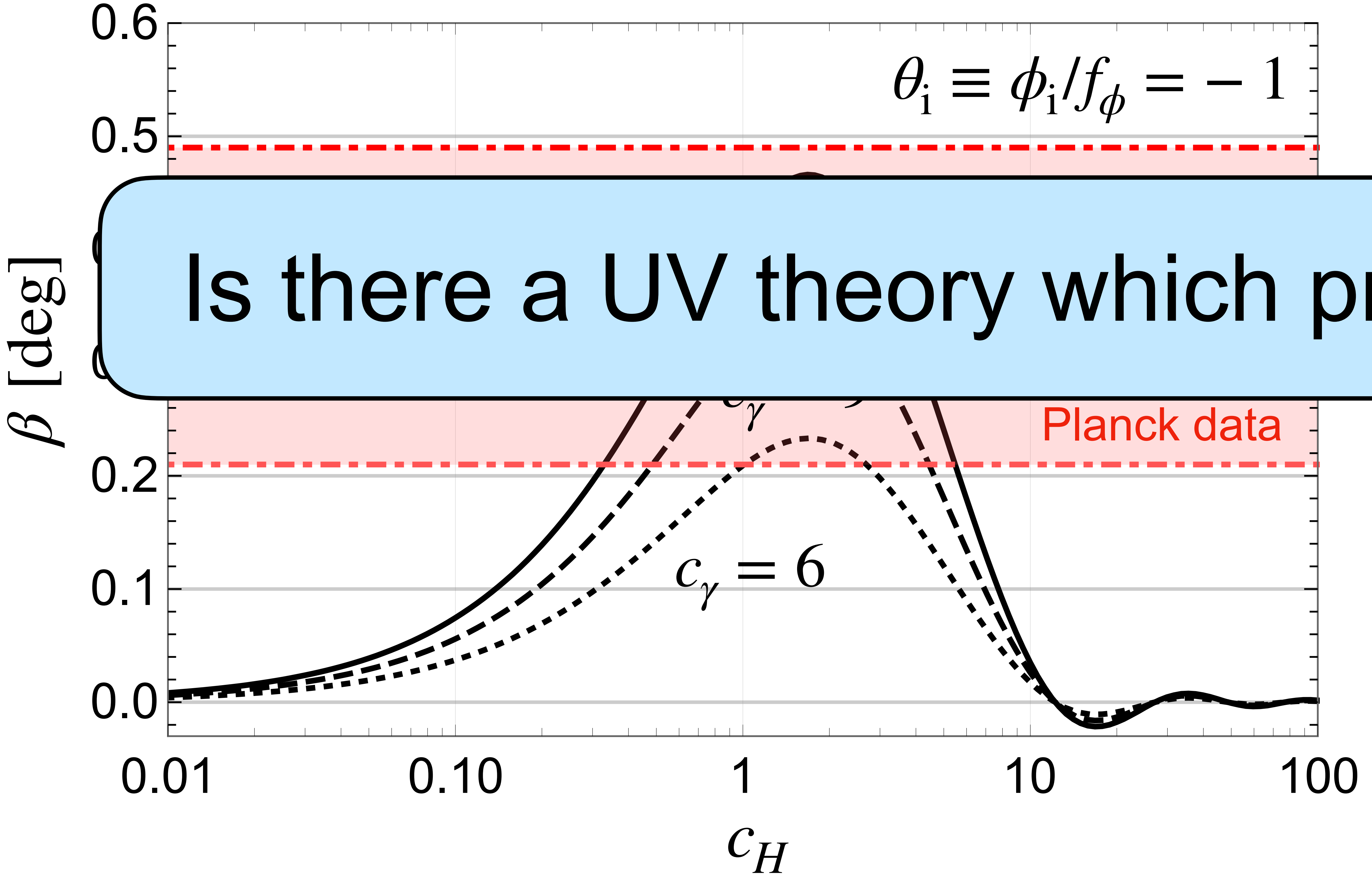

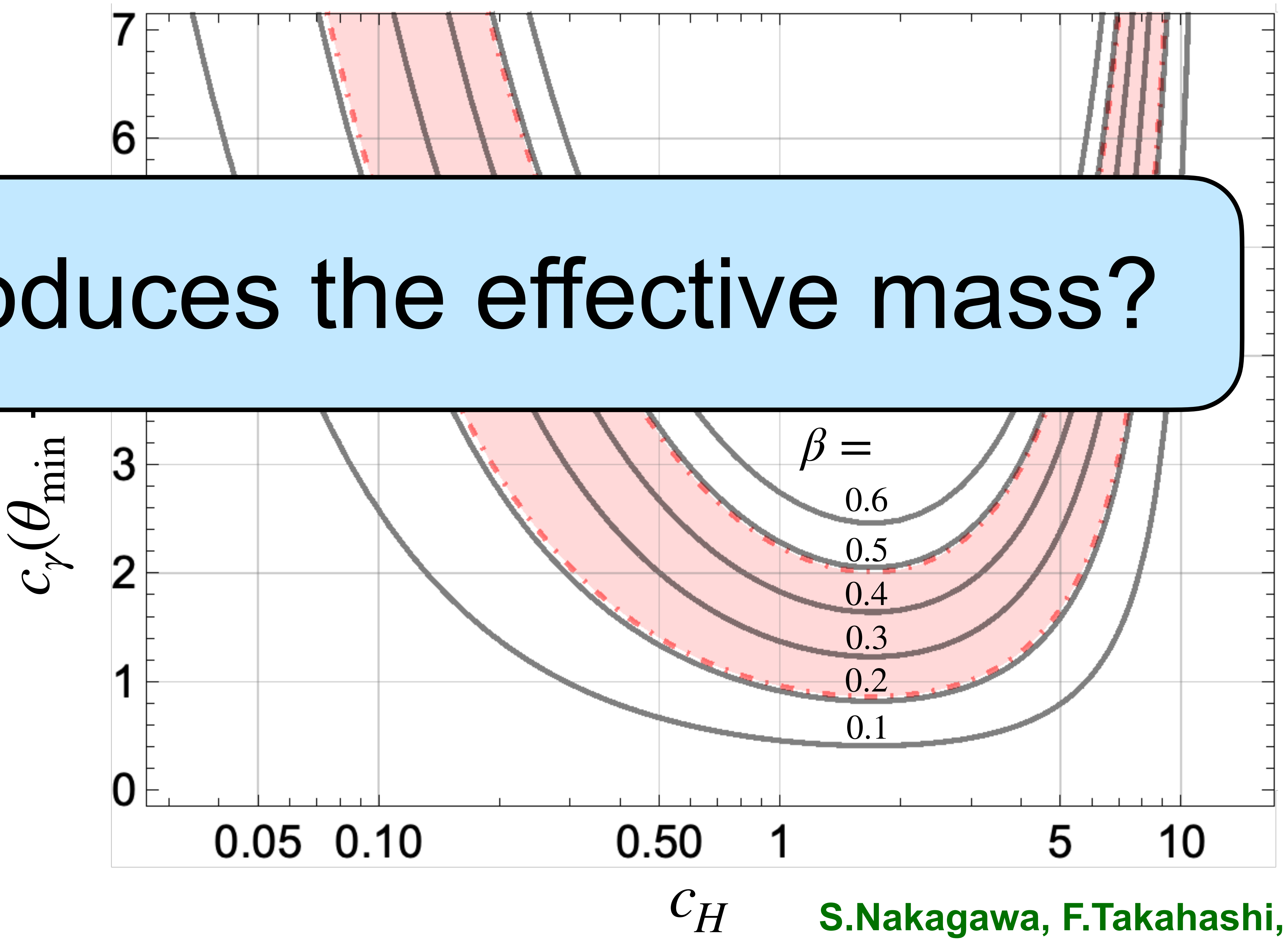

Is there a UV theory which produces the effective mass?

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3. UV theory

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

1. non-minimal coupling to gravity

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

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

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

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2. 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).

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

E.Witten (1979)

・The axion acquires an effective mass induced from $\vec{E}_H$.

W.Fischler, J.Preskill (1983)

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

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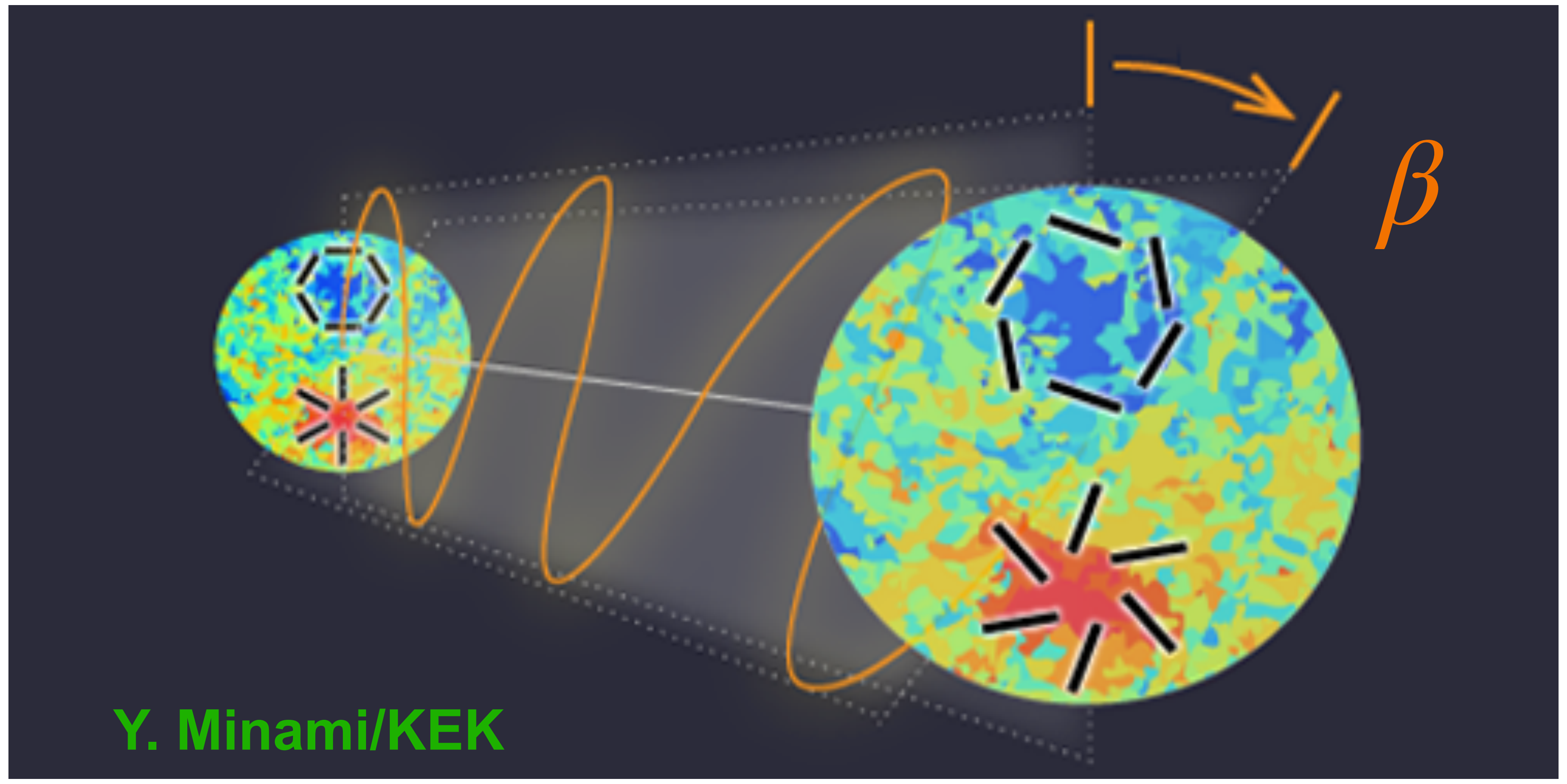
for $\rho_M \sim \rho_{\rm DM},\ \alpha_H \sim O(0.01),\ f_\phi \sim 10^{16}\,\mathrm{GeV}$

4. Summary

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

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

Y.Minami & E.Komatsu (2020)

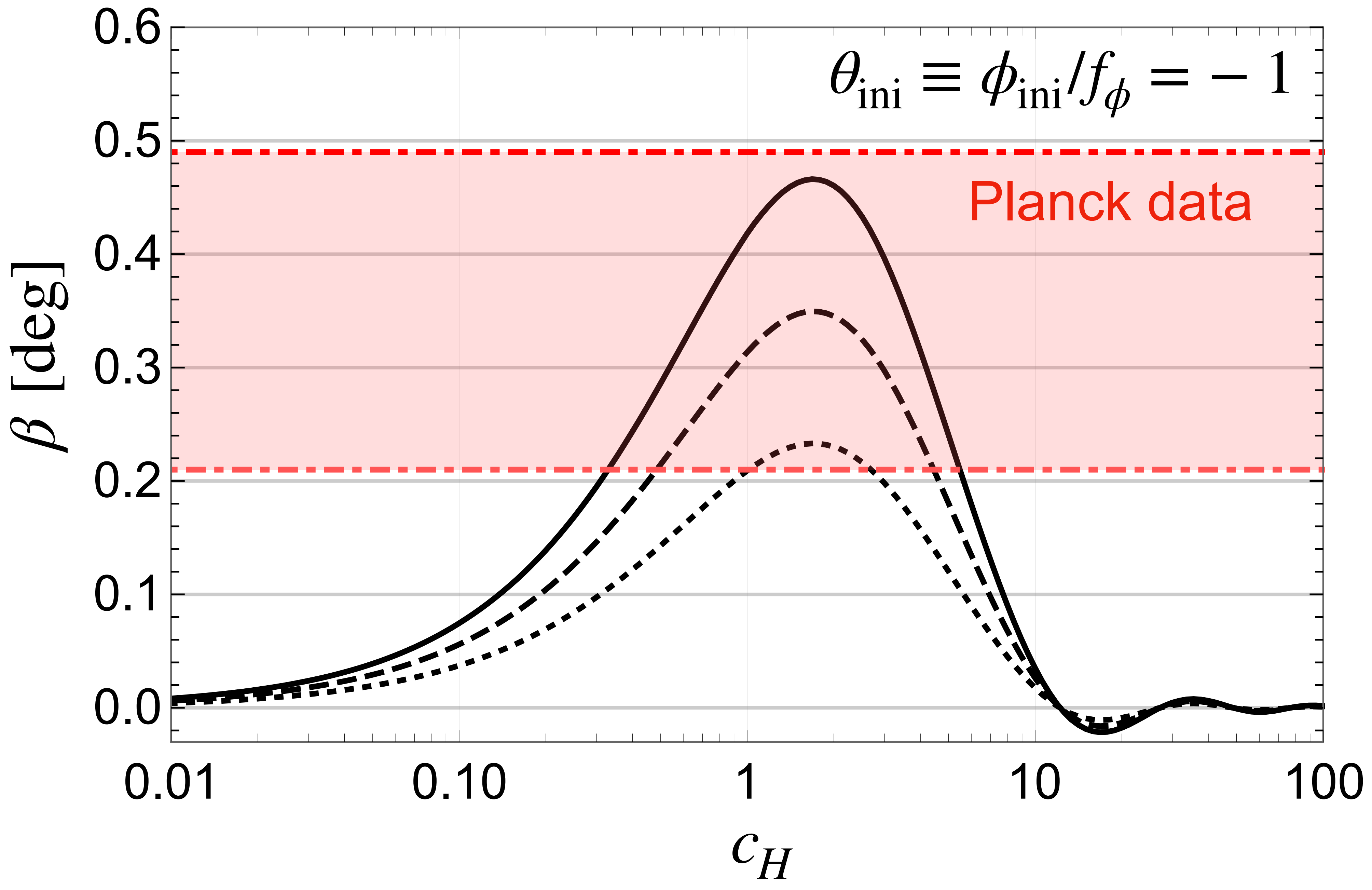


・There is no theoretical reason "why now" (coincidence problem).

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

・We propose two specific model:

1. non-minimal coupling
2. Witten effect



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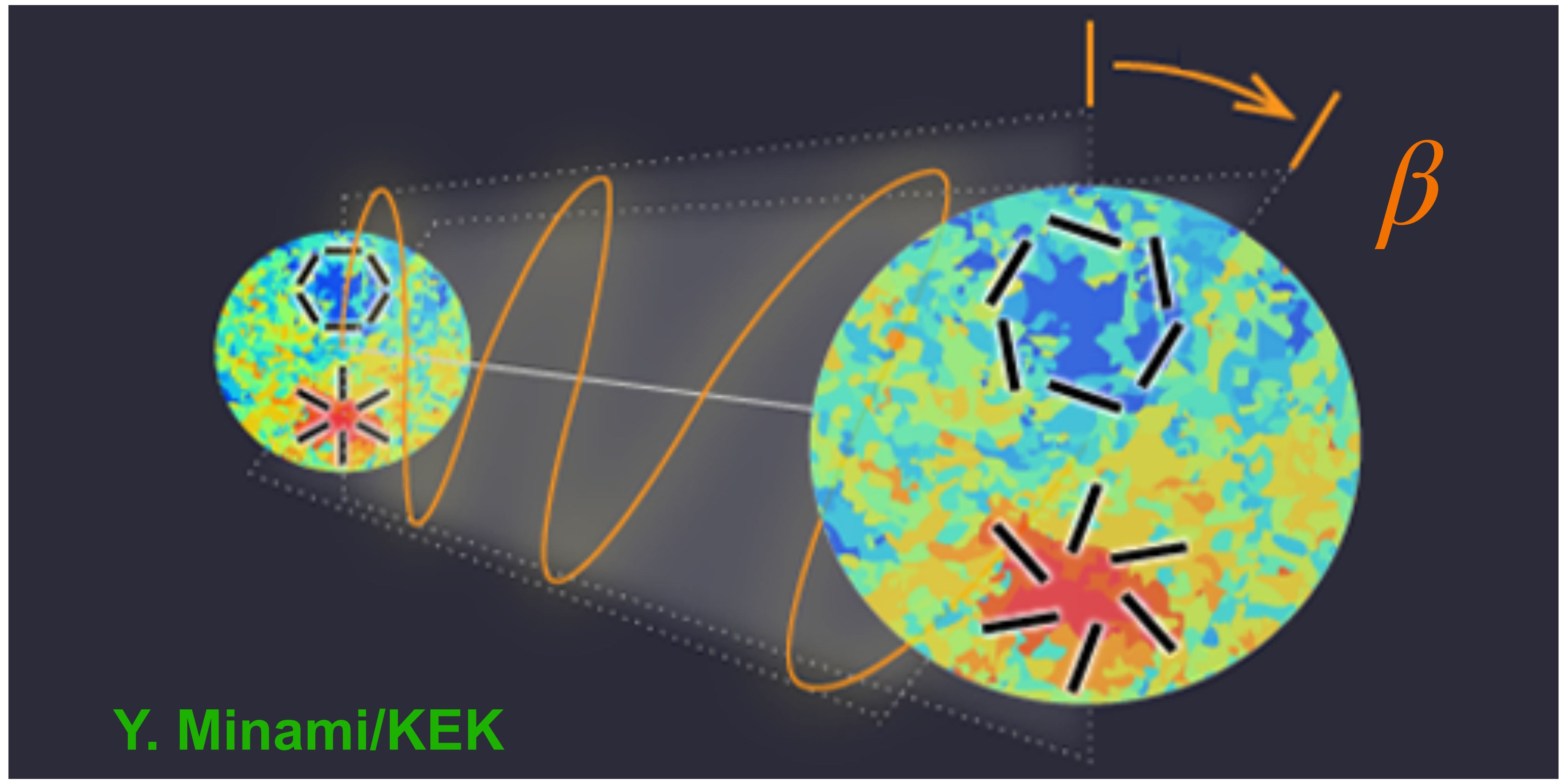

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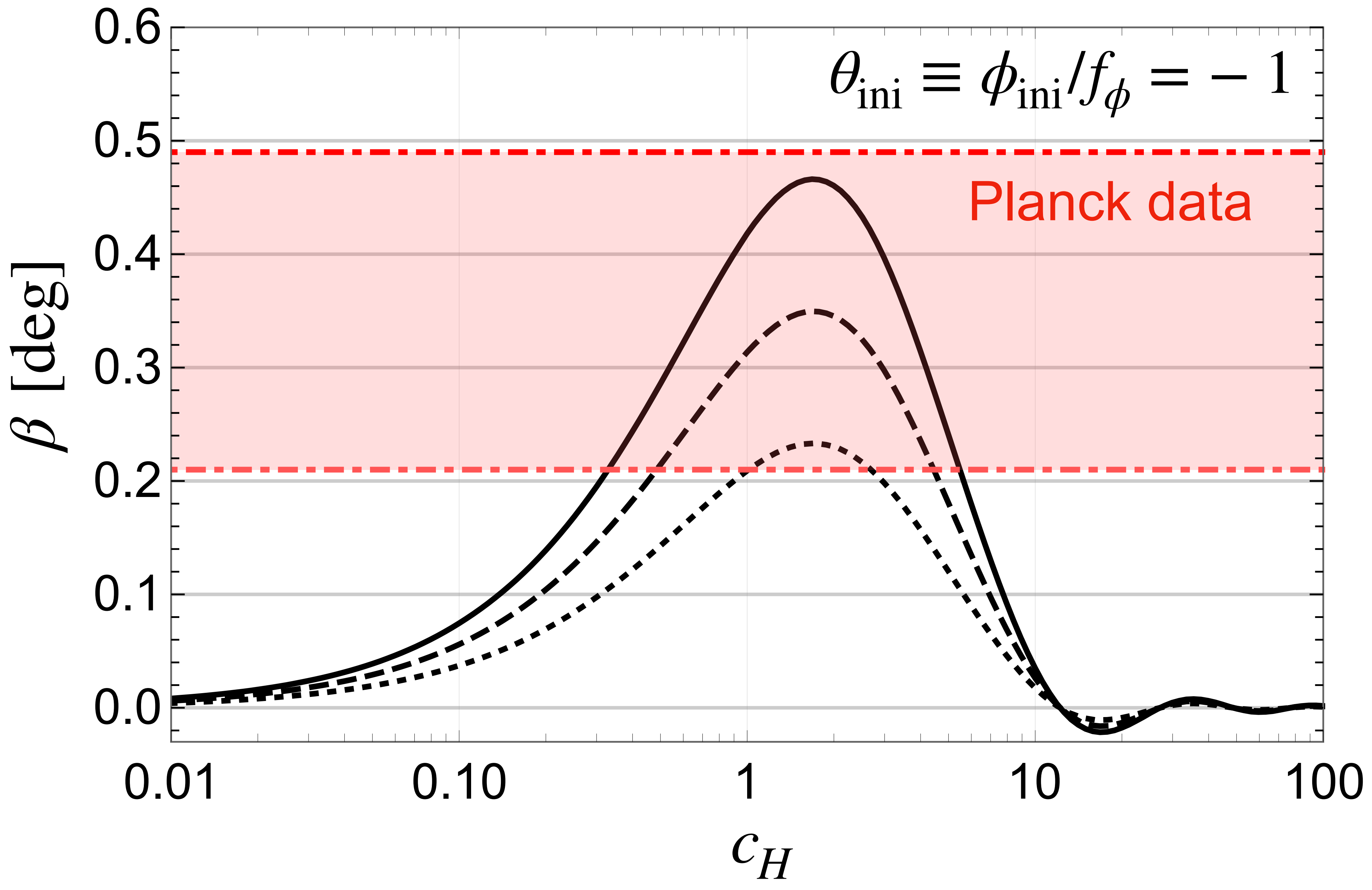

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Thank you.