UPPSALA UNIVERSITET

NORDITA
The Nordic Institute for Theoretical Physics

Stockholm University

Motivazioni teoriche per assioni leggeri, $(0.1 \div 1)\,\mu\mathrm{eV}$

Luca Visinelli

Uppsala University & NORDITA

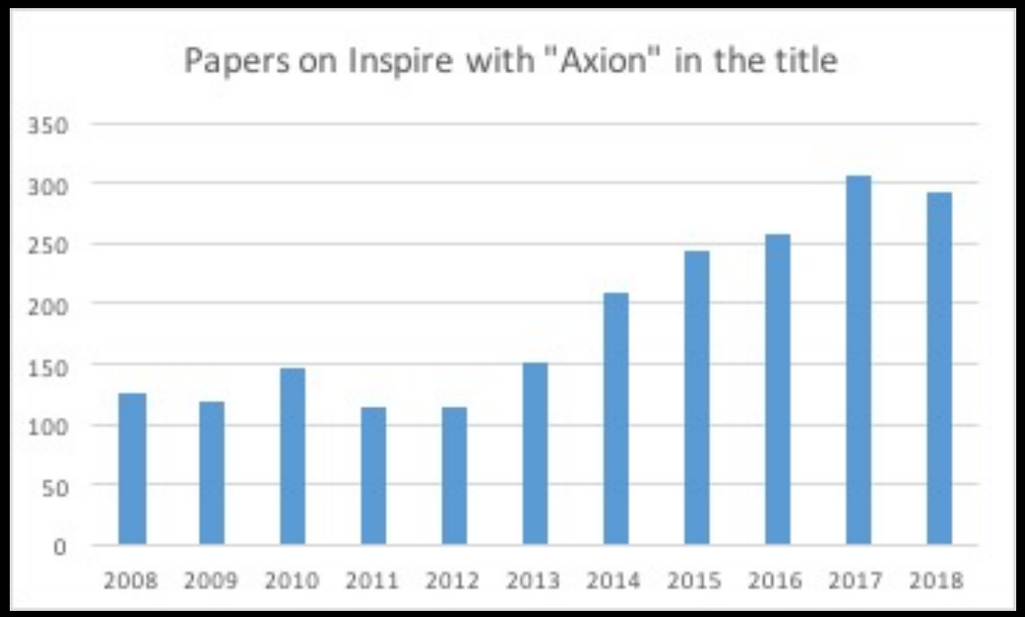
Based on:

LV, Redondo [1808.01879]

LV, Baum, Redondo, Freese, Wilczek, PLB **777**, 64 (2018) [1710.08910]

LV, Gondolo, PRL **113** 011802 (2014) [1403.4594]

Steady growth in the interest on the axion



Motivations

The value of $\bar{\theta}$ controls the matter-antimatter asymmetry in QCD

$$\mathcal{L}_{\text{strong,CP}} = \bar{\theta}\frac{\alpha_s}{2\pi}\text{Tr}\left(\text{E}^\mu \text{B}_\mu\right)$$

A similar term arises from EW, $\theta = \bar{\theta} + \theta_{\text{weak}} \sim \mathcal{O}(1)$

No observation of C and CP violation in Nature, $|\theta| \lesssim 10^{-10}$

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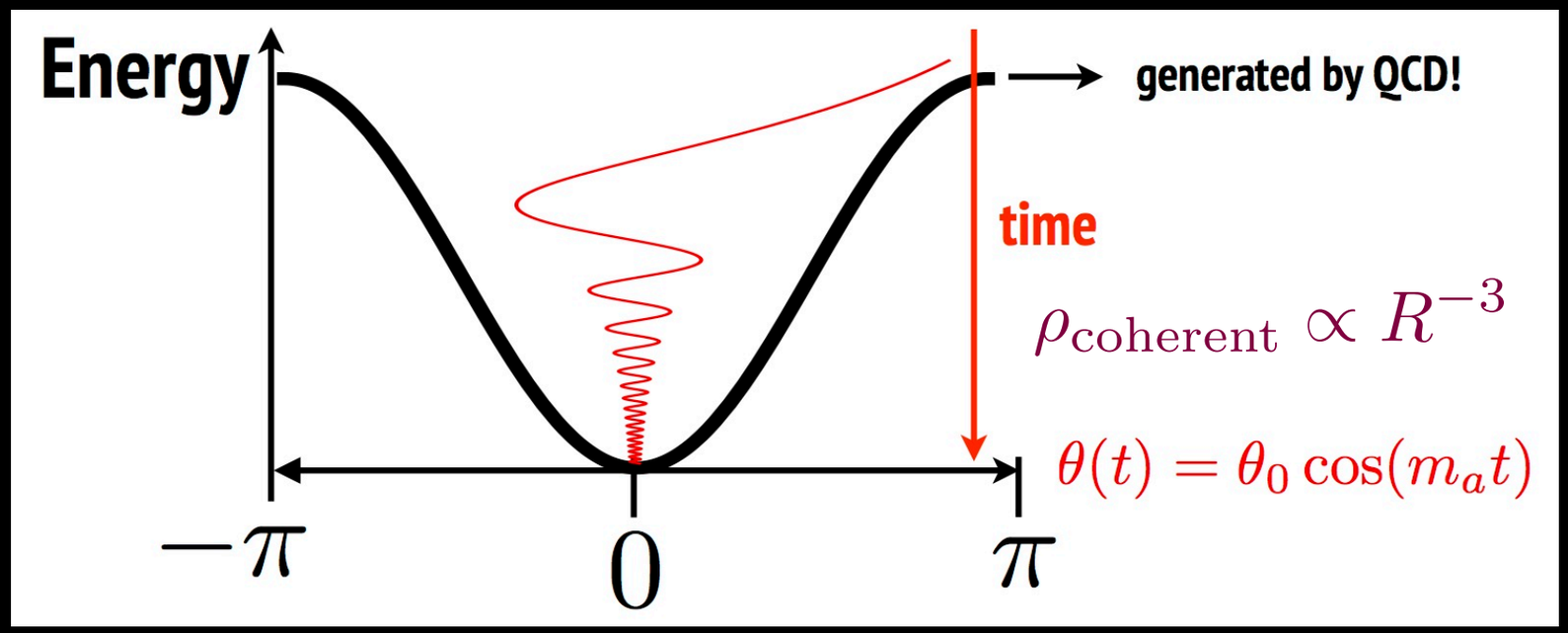
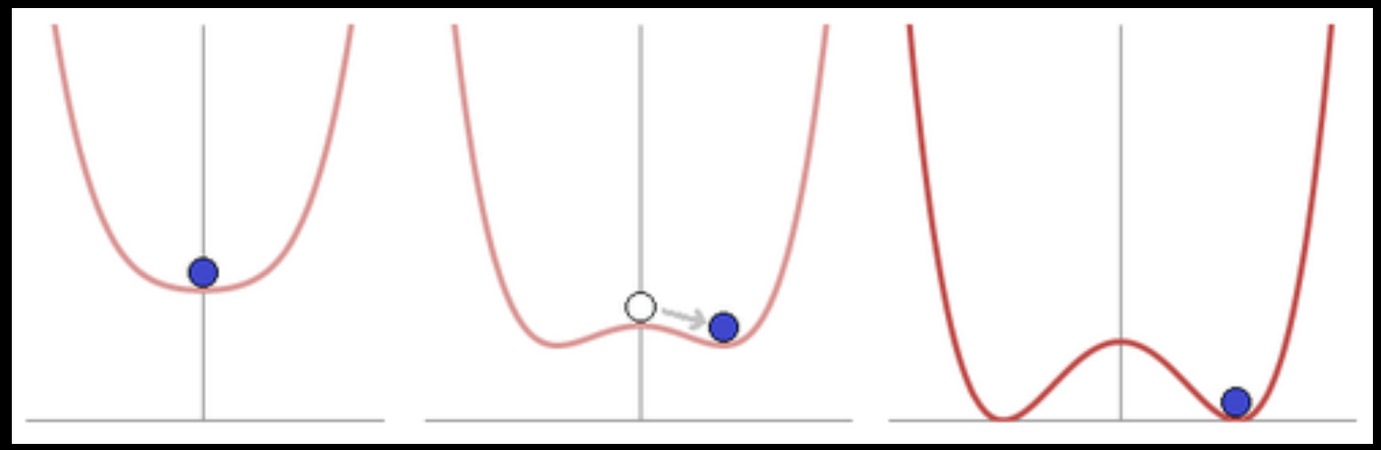
Maybe it is a dynamical field?

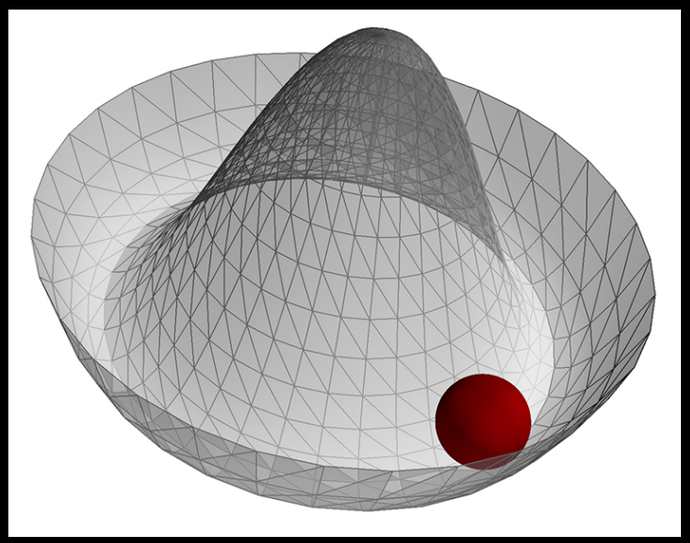
$$\theta = \theta(t, \mathbf{x})$$



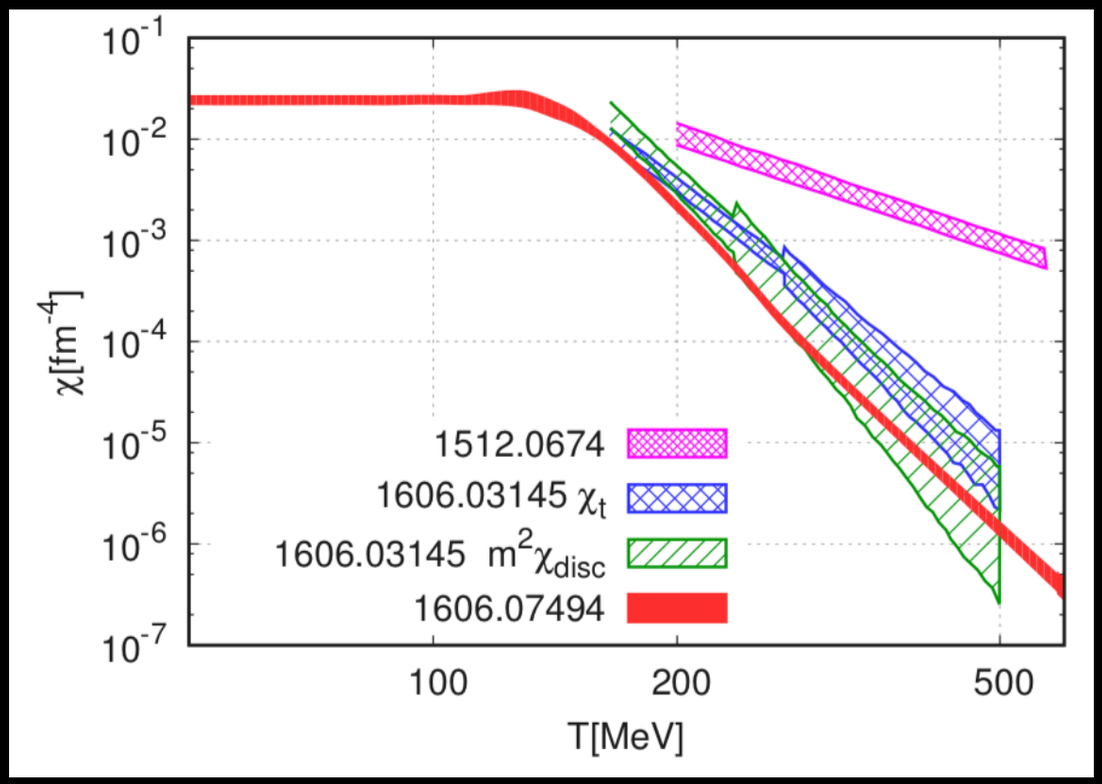
Early-Universe dynamics of the axion



$T \gtrsim f_a$ $T \sim f_a$ $T \lesssim f_a$

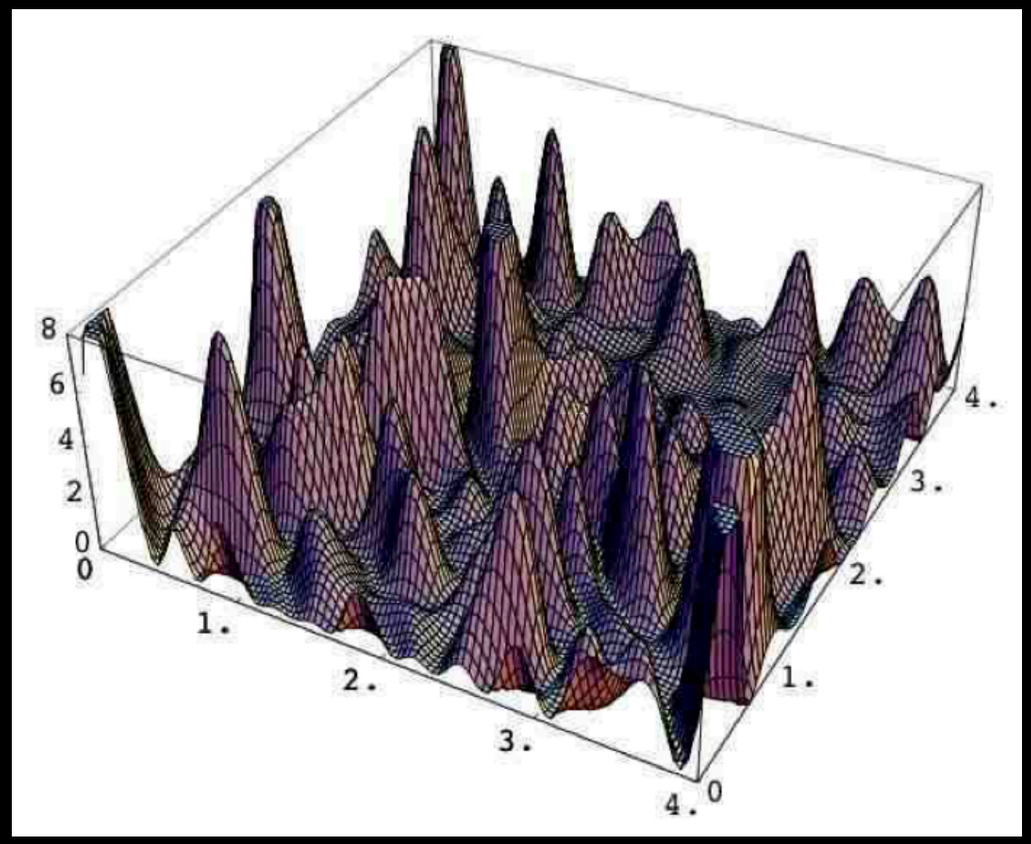


$T \sim \Lambda_{\rm QCD} \ll f_a$



Details on the temperature dependence still debated (semi-analytical, lattice simulations)

Post-inflation scenario



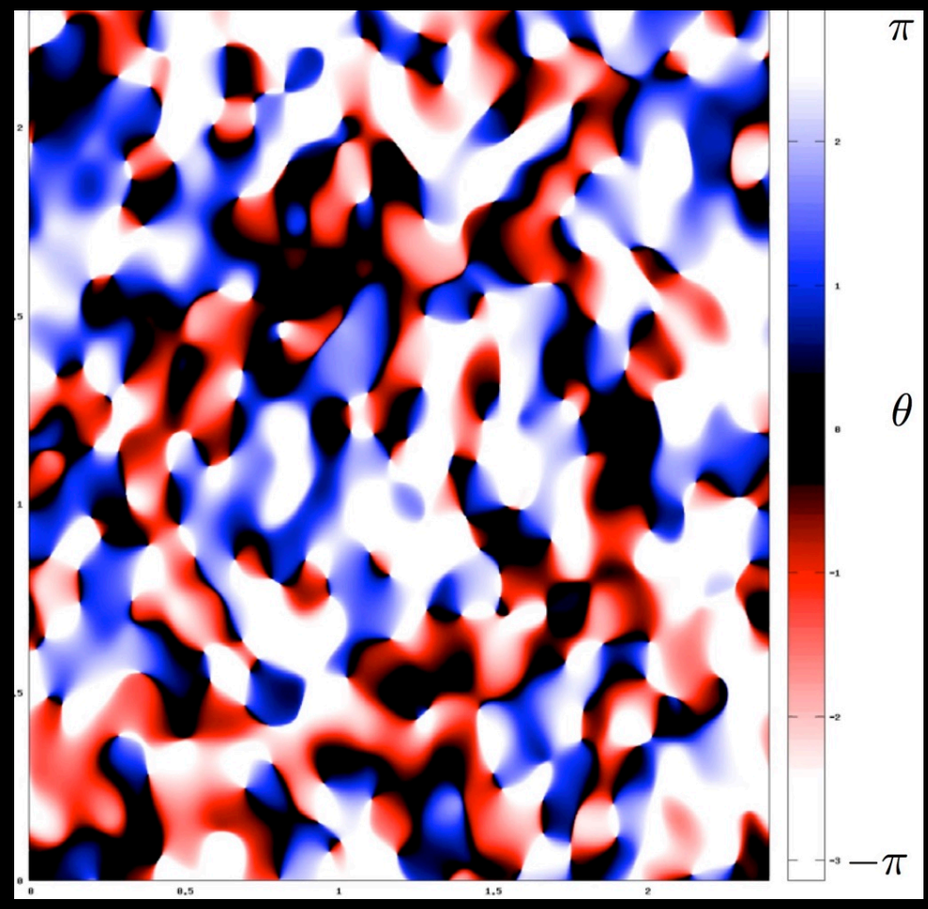
Random initial condition

→ we need a UV theory

Axion: angle of a complex scalar field

$$\mathcal{L} = \frac{1}{2}\left|\frac{d\phi}{dt}\right|^2 - \frac{1}{2a^2}\left|\nabla\phi\right|^2 - V(\phi)$$

$$\phi = |\phi| e^{i\theta}$$



$$T \sim f_a$$

The Kibble mechanism (Kibble76) leads to string network formation

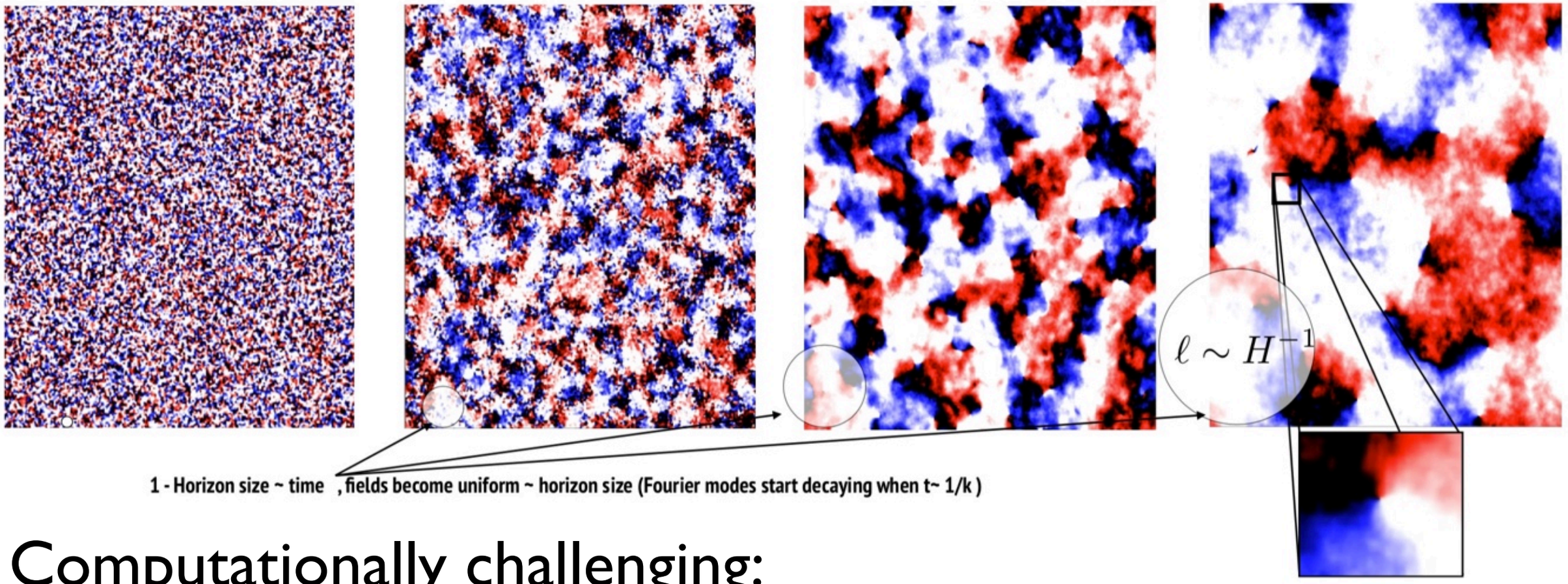
$$T \sim T_{\rm QCD}$$

Domain walls form and dissipate (Sikivie82; Georgi+82)

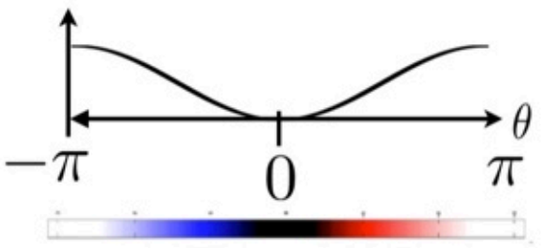
Destruction of the string-wall network

Courtesy of J. Redondo

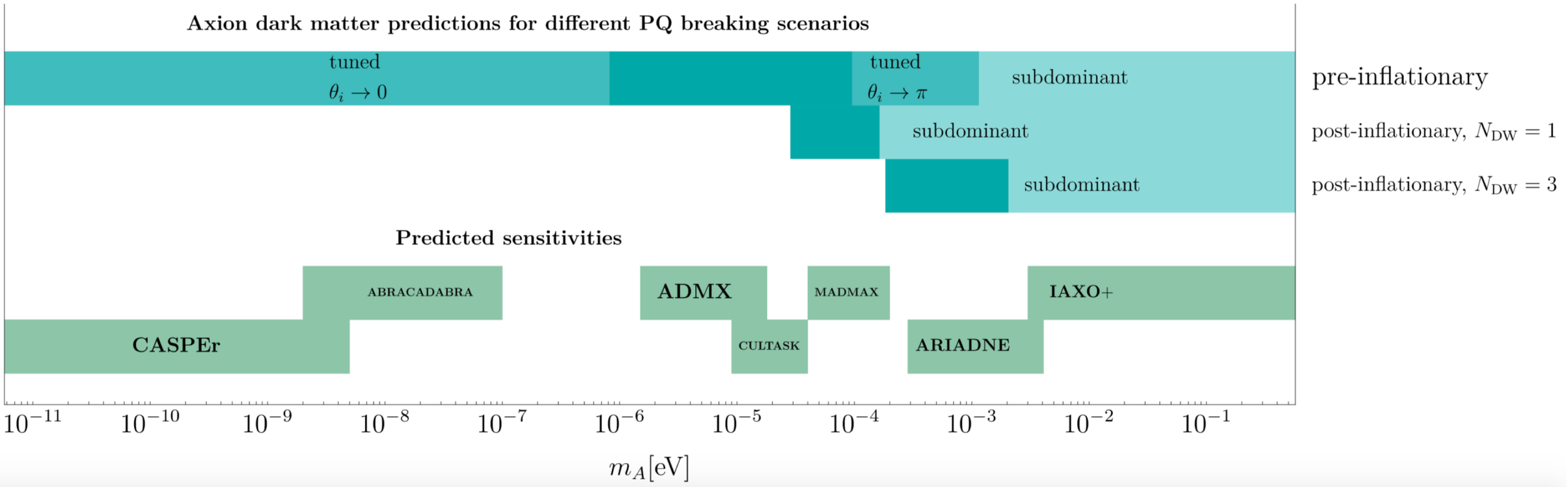
- Axion strings form by Kibble mechanism
- Energy logarithmically distributed around, tension $\mu \simeq \pi f_A^2 \log\left(\frac{f_A}{H}\right)$



Computationally challenging:
all scales from the size of the box $H_{\rm QCD}^{-1}$
to the string core f_a^{-1} have to be resolved!



Less crowded than other mass ranges for the QCD axion



Particularly well-motivated range: **No Tuning**

Andreas Ringwald 2018

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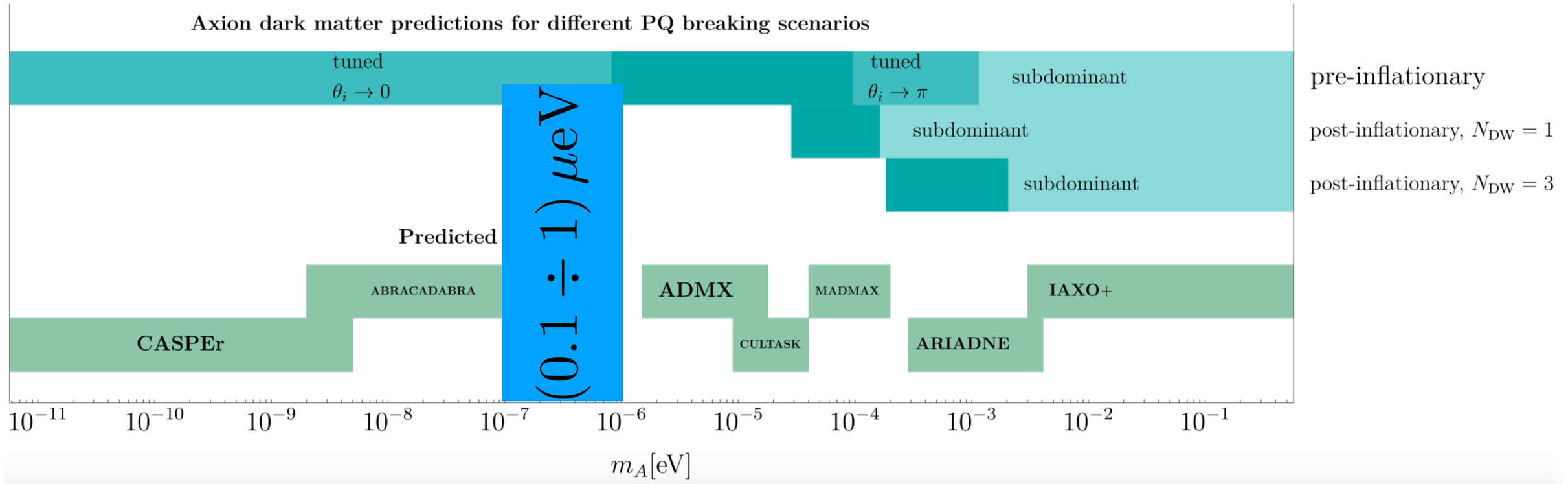

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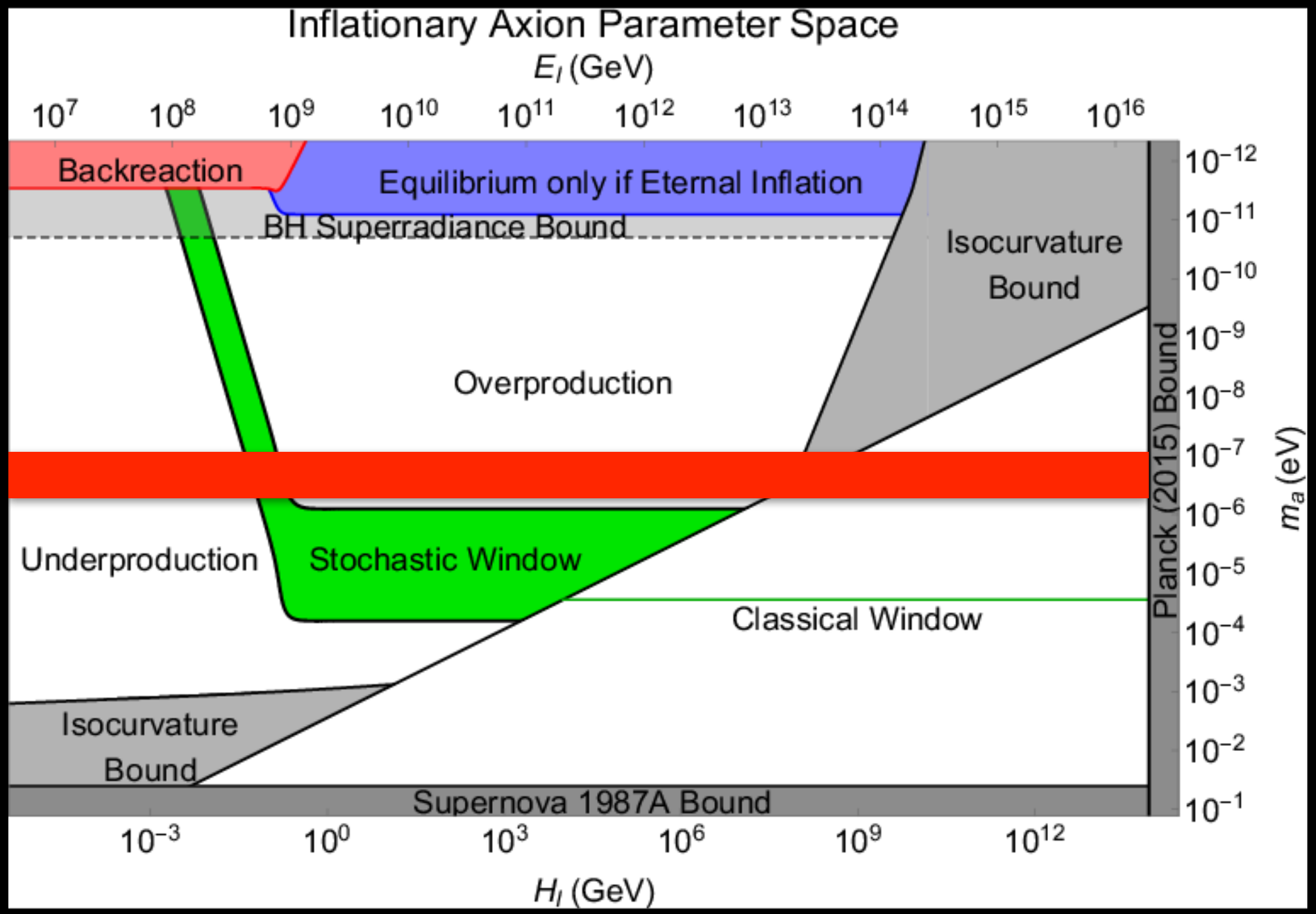
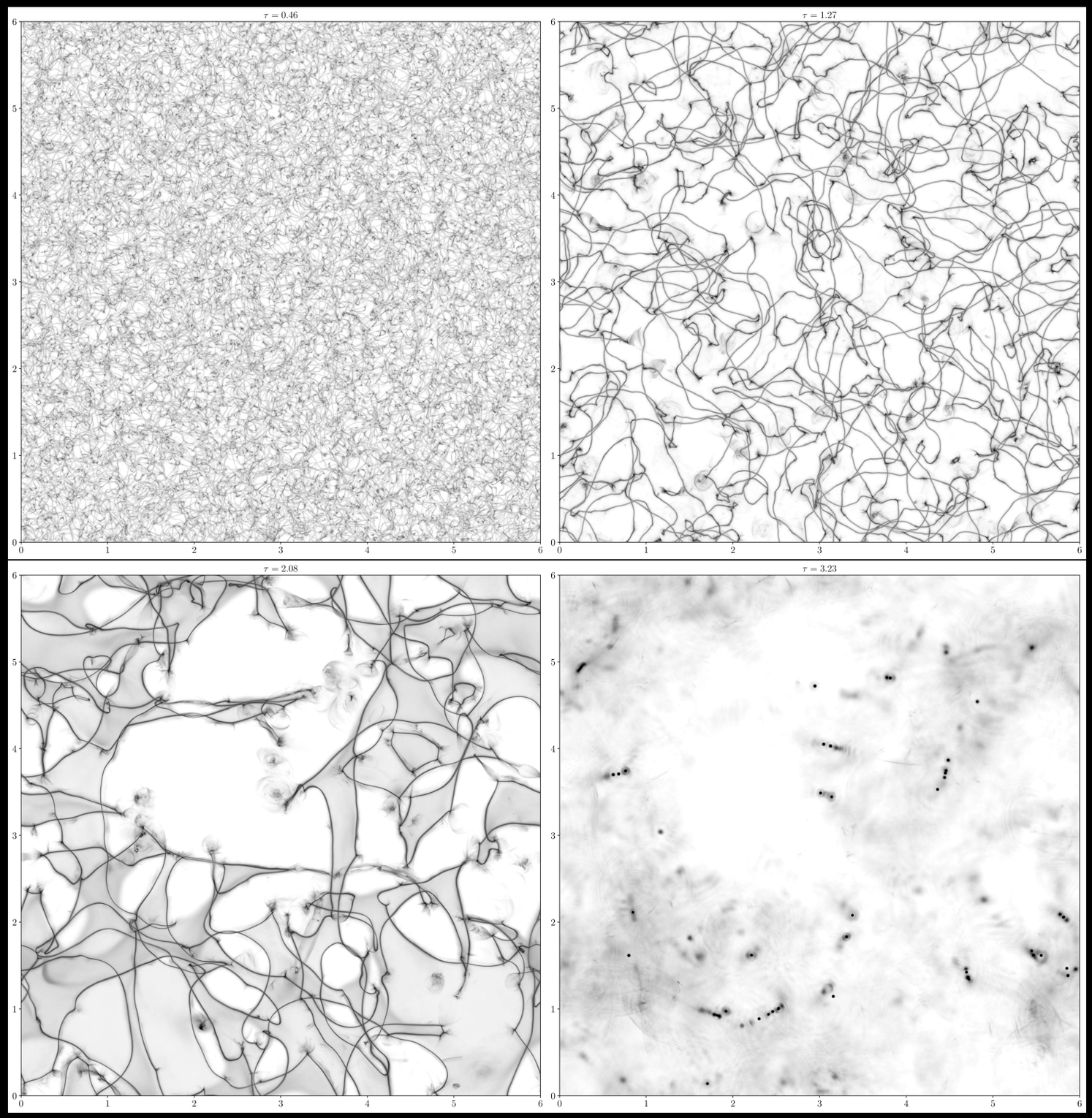
Axion as the dark matter?



Graham et al 2018

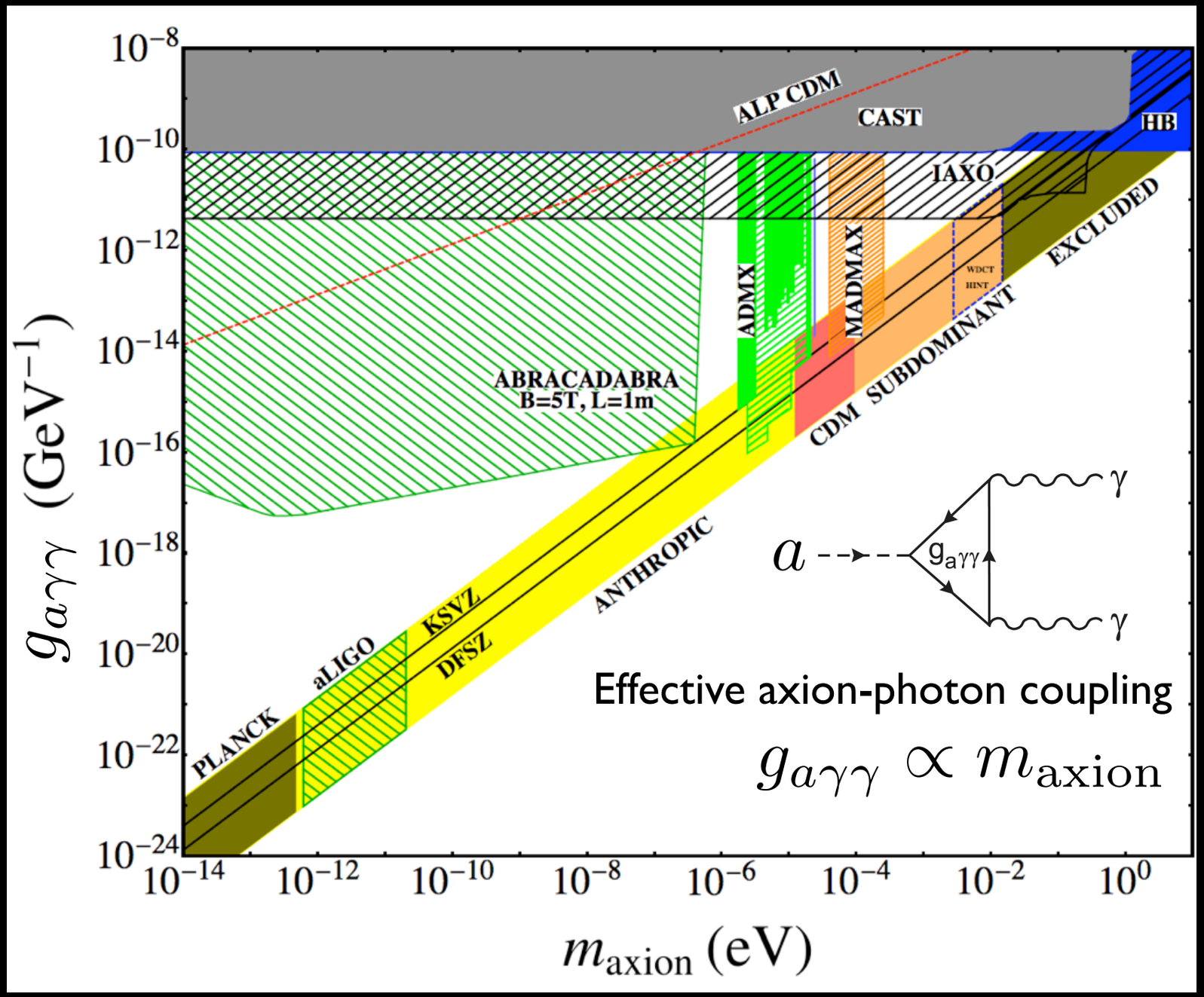
Takahashi et al 2018

Destruction of the string-wall network



Vaquero+2018

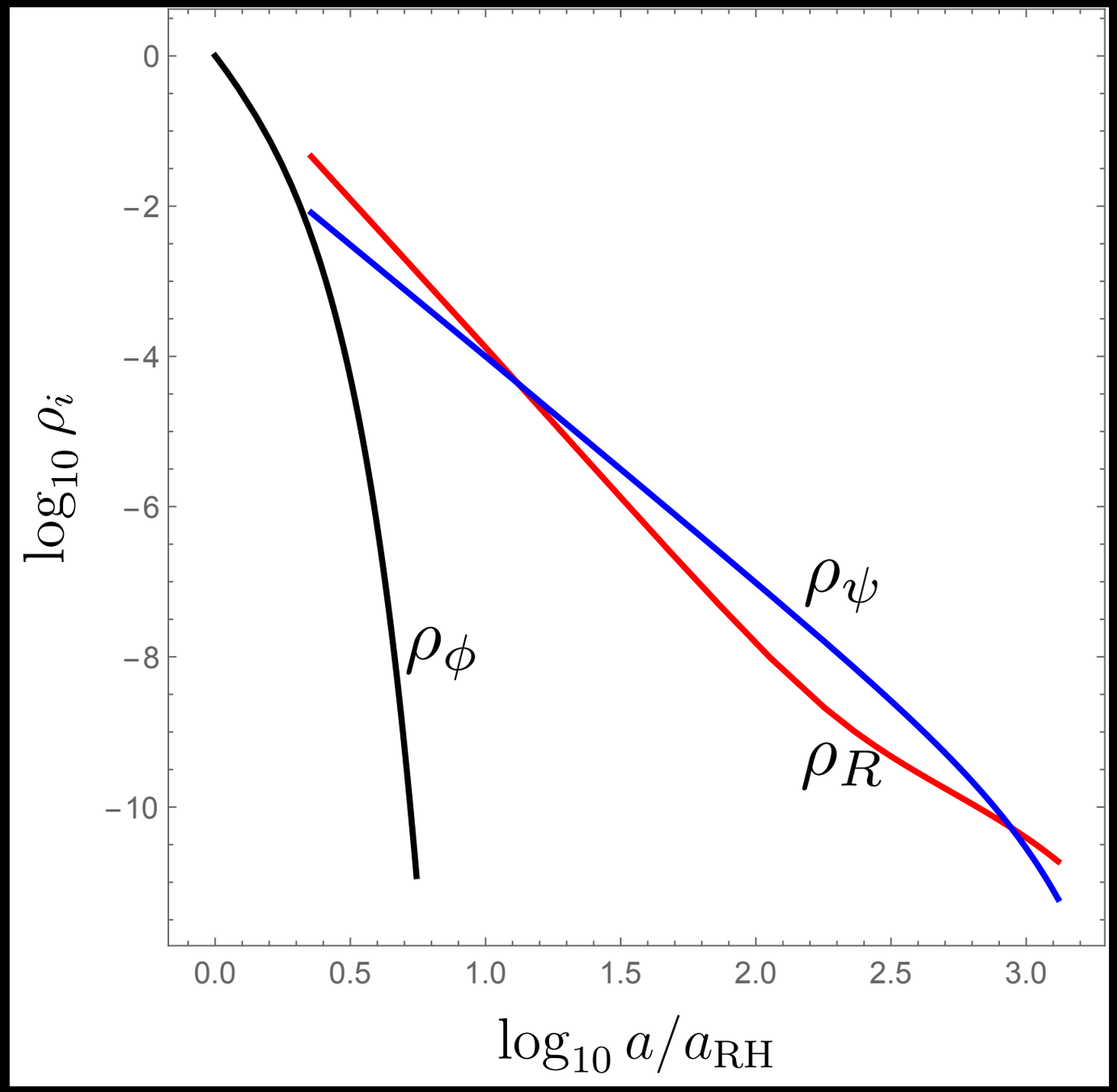
One-parameter theory, falsifiable



Alternative DM candidate: the QCD Axion

One-parameter theory, falsifiable

Modified cosmologies



Early matter-dominated cosmology

$$\rho_\phi + 3H\rho_\phi = -\Gamma\rho_\phi$$

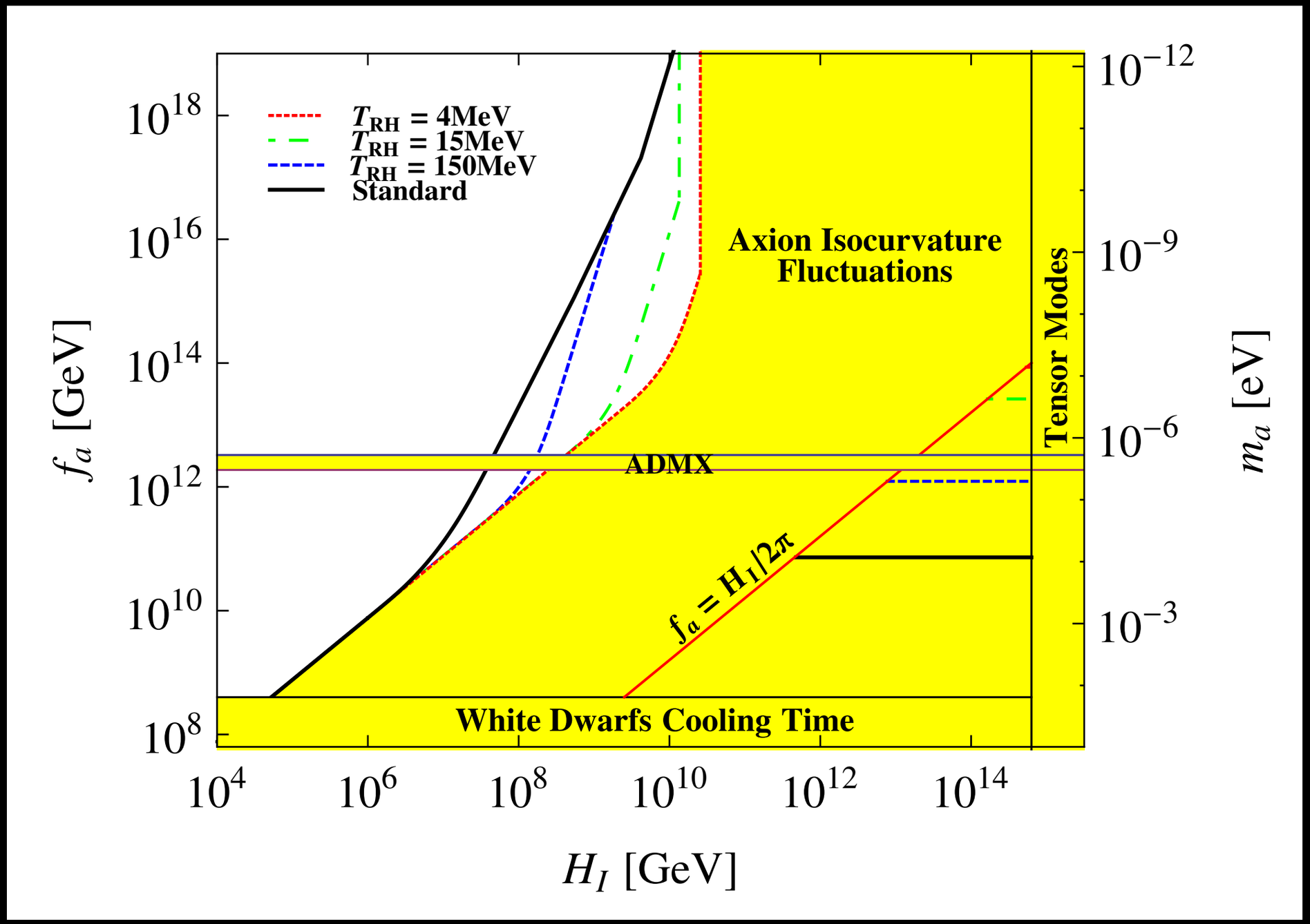
$$\rho_R + 4H\rho_R = b\Gamma\rho_\phi$$

$$\rho_\psi + 3H\rho_\psi = (1-b)\Gamma\rho_\phi$$

Structures grow linearly….

$m_a \sim 0.1 \div 10\,\mu\text{eV} \ll \text{standard scenario}$

$f_a \sim 10^{15}\,\text{GeV}$



Hidden photons

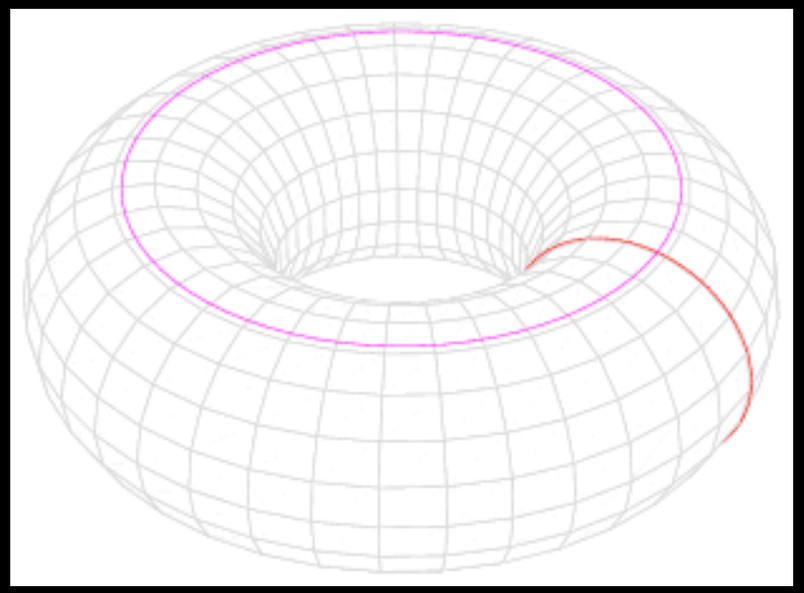
$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{2}\chi F^{\mu\nu}B_{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 B^\mu B_\mu$$

Cambio di base $B^\mu \rightarrow \tilde{B}^\mu - \chi A^\mu$

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}\tilde{B}^{\mu\nu}\tilde{B}_{\mu\nu} + \frac{1}{2}m_{\gamma'}^2(\tilde{B}^\mu\tilde{B}_\mu - 2\chi\tilde{B}^\mu A_\mu + \chi^2 A^\mu A_\mu)$$

photon - hidden photon mixing

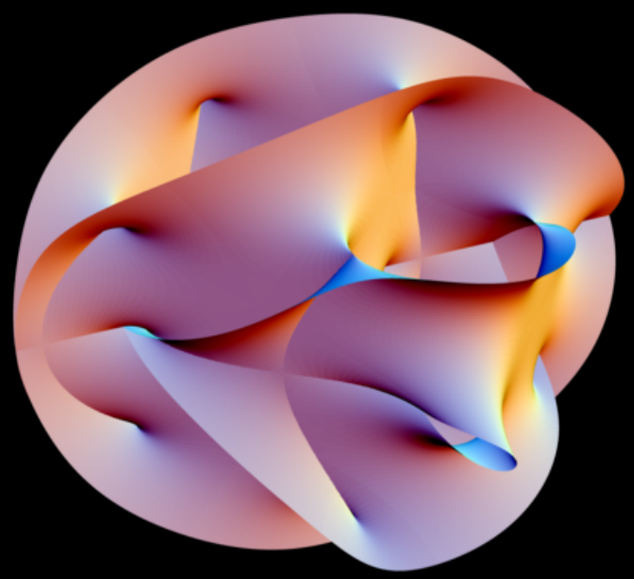
Axions from String Theory

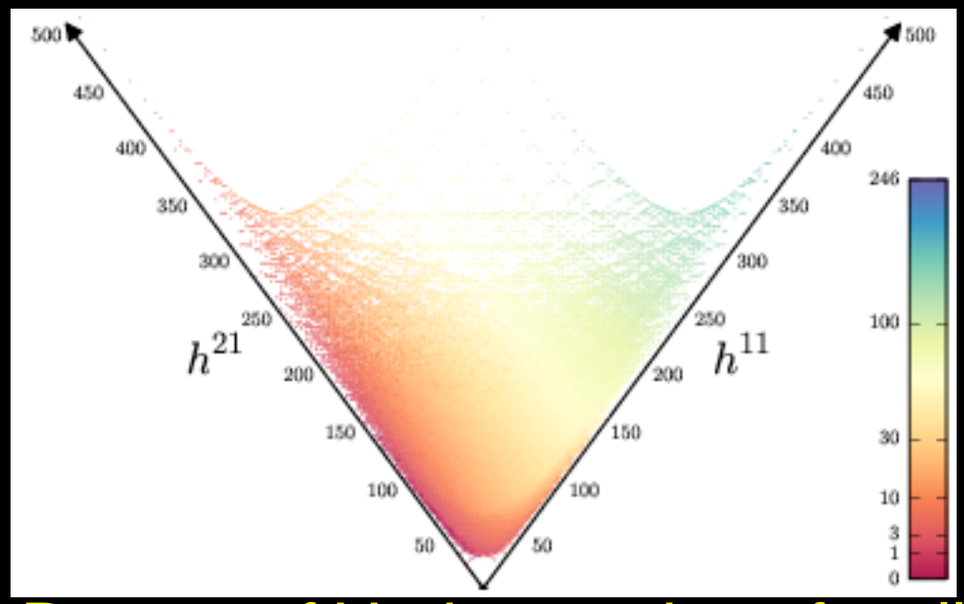


A torus has two "moduli" fields
In general, # fields given by the topology of the manifold

Moduli are paired with axions

A 6D manifold is more complicated than a torus...





Density of Hodge numbers for all known Calabi-Yau three-folds

Axion-like particles for multiple purposes

Strong-CP

Peccei, Quinn; Weinberg; Wilczek

Dark Matter

Preskill+; Abbot+; Dine+; Baldeschi+

Dark Energy

Frieman+; Coble+; Arvanitaki+

Baryogenesis

Ballestreros+

Inflation

Freese+