Axion Dark Matter from Fragmentation

Opening up the dark matter window

Collaborators: Cem Eröncel, Ryosuke Sato and Géraldine Servant

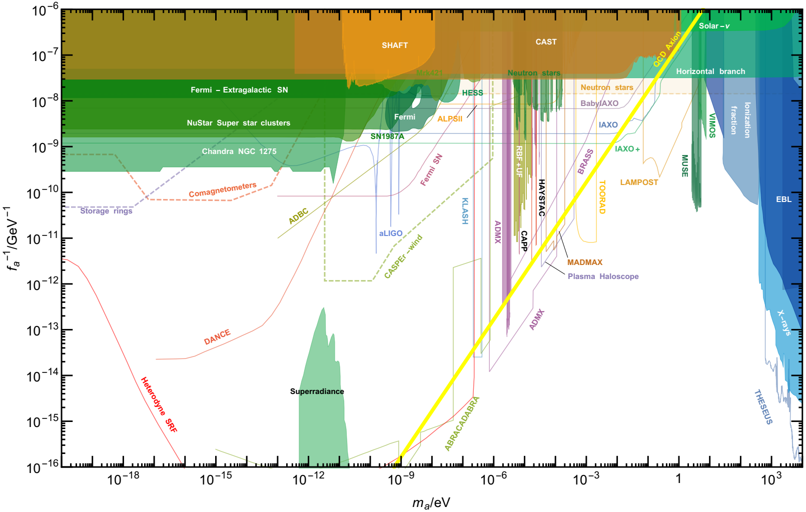
Philip Sørensen

Pascos 2021, June 14th 2021

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Motivation: Axion parameter space

Assuming KSVZ-like photon and neutron couplings:



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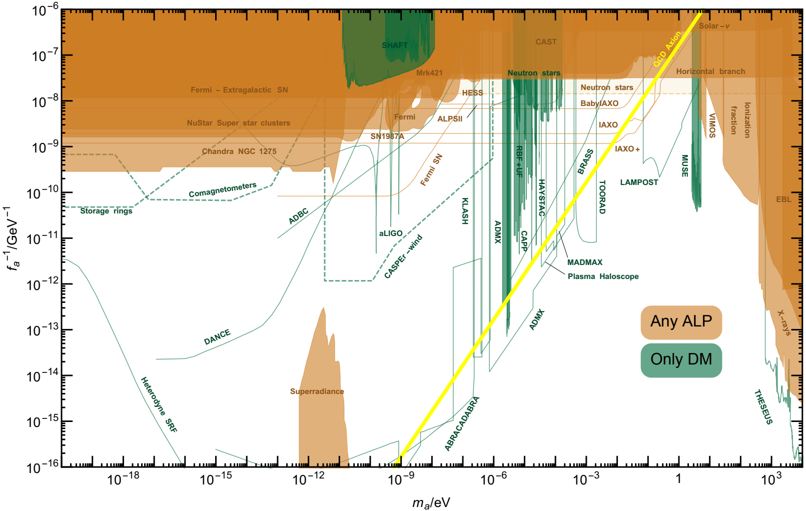


Motivation: Axion parameter space

?

Which ALPs can be dark matter?

Misalignment mechanisms

Conventional misalignment

Axion Lagrangian:

$$\mathcal{L} = \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - m^2(T) f_a^2 (1 - \cos(\phi/f_a))$$

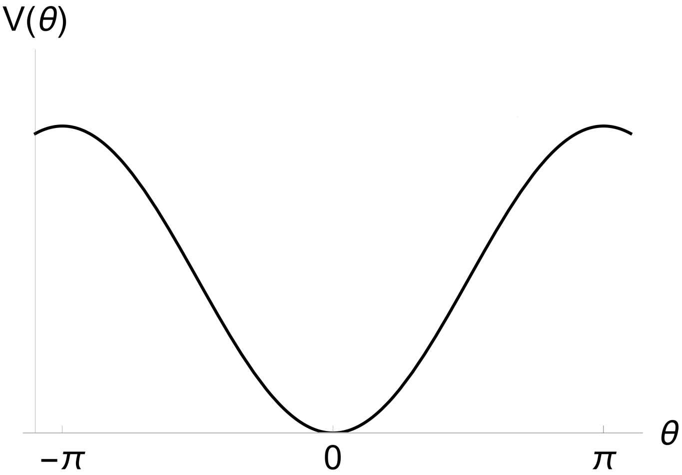
Equation of motion in FRW:

$$\ddot{\phi} + \underbrace{3H\dot{\phi}}_{\text{friction}} + m_a^2 \phi = 0$$

Two regimes:

- $m_a \ll 3H \iff \rho_a \propto a^0$ (Frozen)
- $m_a \gg 3H \iff \rho_a \propto a^{-3}$ (Oscillating)

Conventional misalignment



1. Inflation sets random $\theta_I = \mathcal{O}(1)$
2. Hubble frozen $=$ no redshift
3. Begins to oscillate at $m_a \sim 3H(T)$
4. Redshift as $\rho_a \propto a^{-3}$

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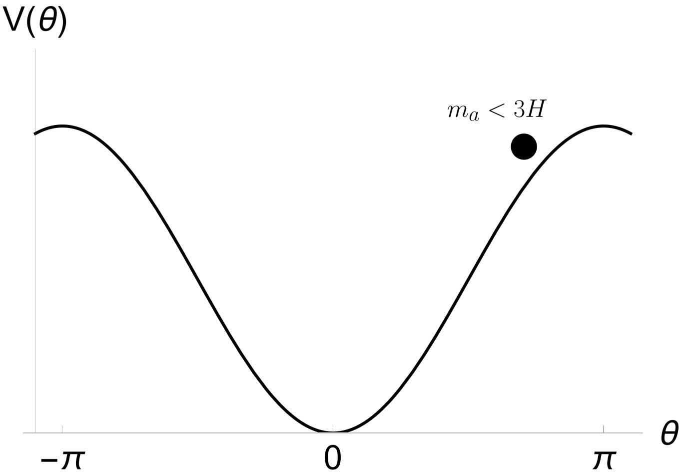

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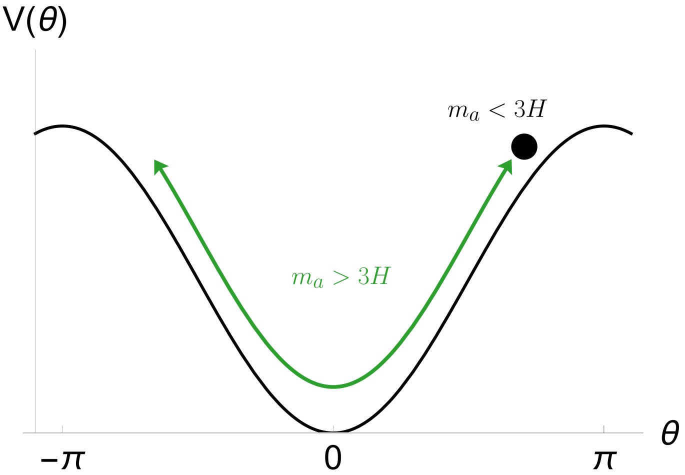

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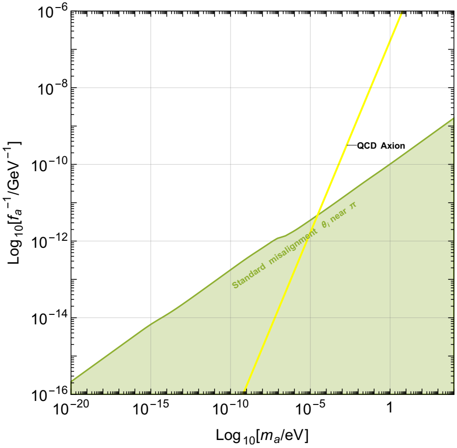
Conventional misalignment

Relic density: $\rho_\phi^{mis} \approx \frac{1}{2} m_* m_0 \theta_*^2 f_a^2 \left(\frac{a_*}{a_0}\right)^3$ where $_0 =$ today, $_* =$ time of onset of ocillations.



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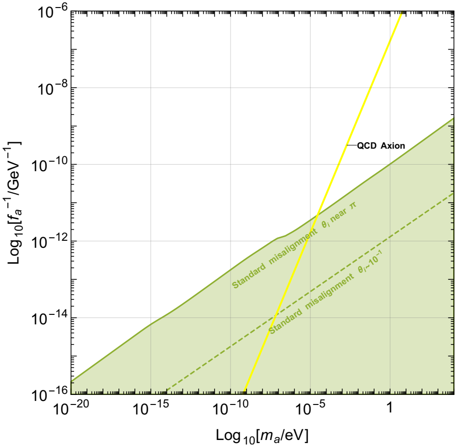

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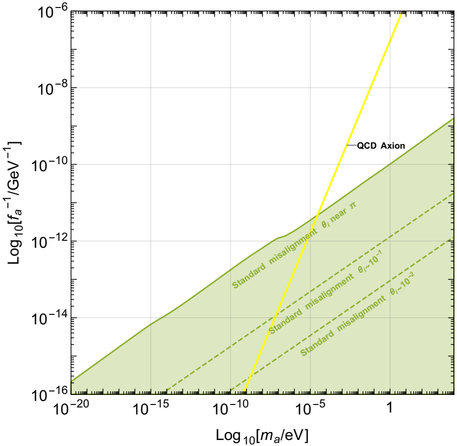

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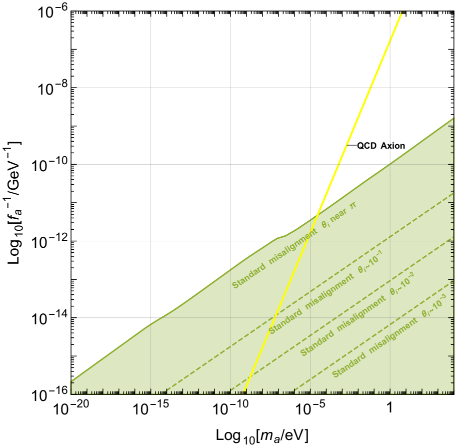

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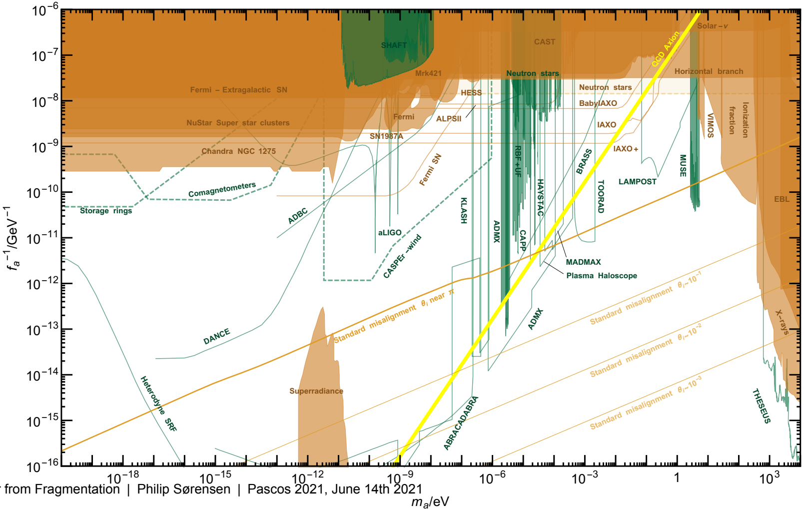

Kinetic misalignment

- Problem: Convention misalignment makes too little DM for low f_a
- Idea: Add kinetic energy to delay oscillations

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arXiv:1910.14152

Axion Kinetic Misalignment Mechanism

Raymond T. Co,[1] Lawrence J. Hall,[2,3] and Keisuke Harigaya[4]

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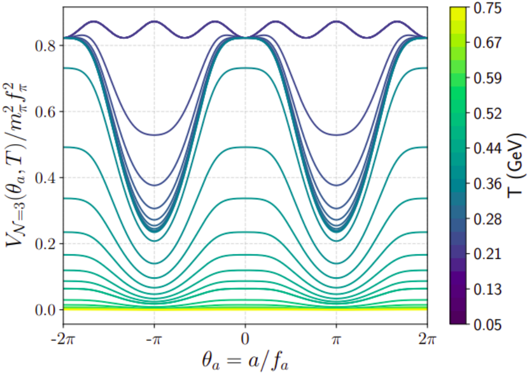
[2] *Department of Physics, University of California, Berkeley, California 94720, USA*
[3] *Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[4] *School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, USA*

(Dated: July 21, 2020)

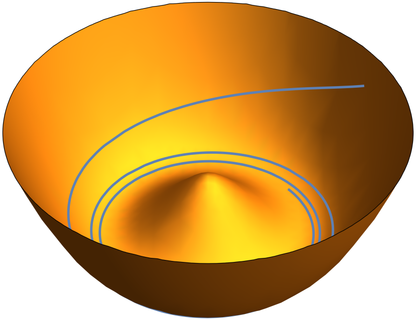
In the conventional misalignment mechanism, the axion field has a constant initial field value in the early universe and later begins to oscillate. We present an alternative scenario where the axion field has a nonzero initial velocity, allowing an axion decay constant much below the conventional prediction from axion dark matter. This axion velocity can be generated from explicit breaking of the axion shift symmetry in the early universe, which may occur as this symmetry is approximate.

Kinetic misalignment

Kicking mechanisms:

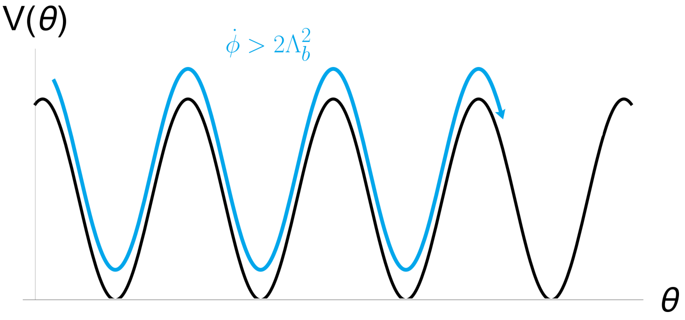


Trapped misalignment
2102.01082



Affleck-Dine-like kick
Affleck & Dine 1985, 1910.14152

Kinetic misalignment

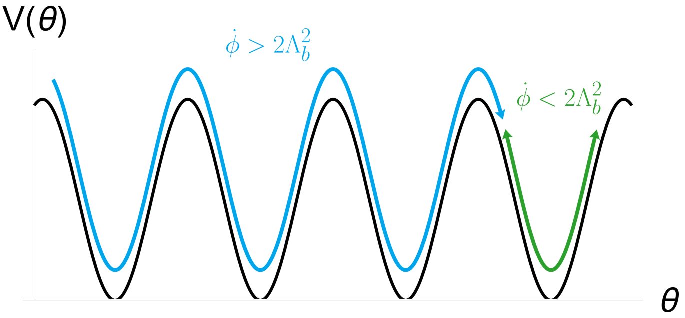


- Begins to oscillate at $\dot\phi \sim 2\Lambda_b^2$
- Delay oscillations
  $\Rightarrow$ less redshift
  $\Rightarrow$ more DM
  $\Rightarrow$ lower f_a

$$\rho_\phi^{kin} \approx m_a f_a \dot\phi_* \left(\frac{a_*}{a_0}\right)^3$$

where $_* =$ time of stopping.

Kinetic misalignment



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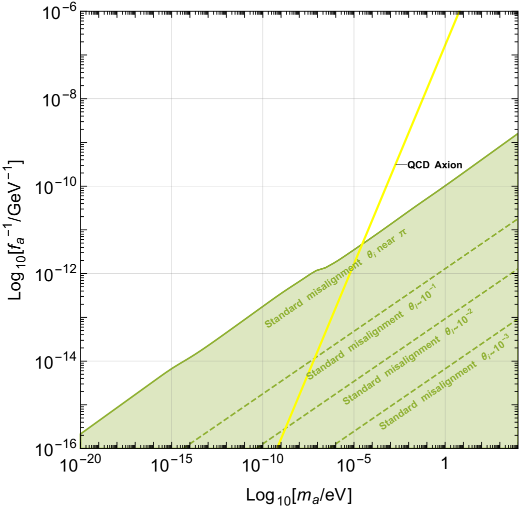

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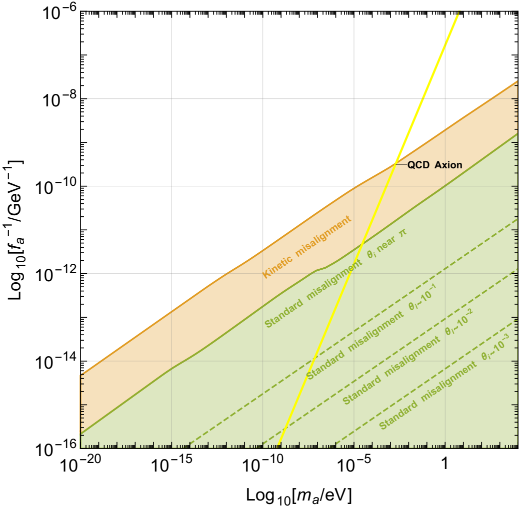

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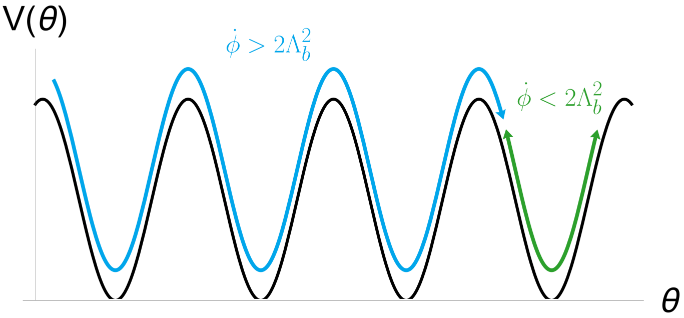


Axion fragmentation

Axion fragmentation

Originally discussed in 1911.08472
More details in Cem's talk:

15:30 - 16:50 Parallel 2B: Cosmology

Convener: Chang Sub Shin (IBS-CTPU)

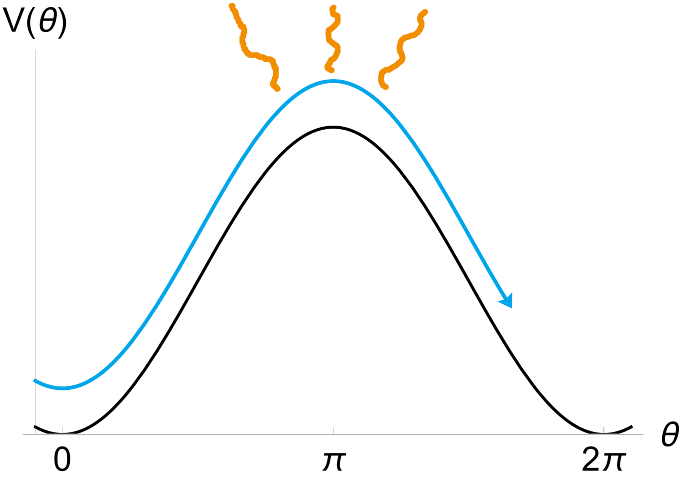
15:30 **Primordial gravitational waves revealed by a spinning axion** *20′*
Speaker: Peera SIMAKACHORN

15:50 **Axion Dark Matter from Fragmentation** *20′*
Speaker: Philip SOERENSEN

16:10 **Cosmic Axion Background: the QCD axion as a hot relic** *20′*
Speaker: Alessio NOTARI

16:30 **Fragmentation of the axion field in the early universe** *20′*
Speaker: Cem ERÖNCEL

Axion fragmentation



Instability band:

$$|k - k_{\text{cr}}| < \delta k_{\text{cr}}$$

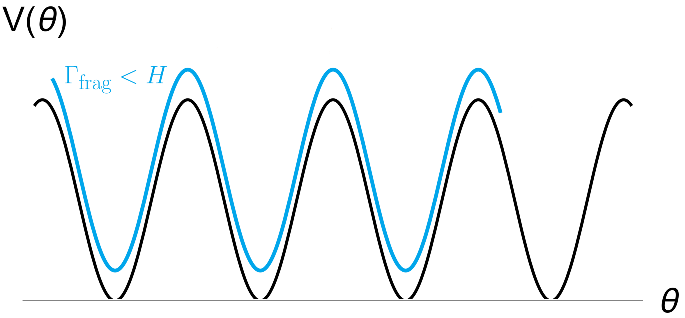
where $\quad k_{\text{cr}} = \frac{\dot\phi}{2f}, \qquad \delta k_{\text{cr}} = \frac{\Lambda_b^4}{2 f_a \dot\phi}$

Particle production:

$$\Gamma_{\text{frag}} = \frac{\pi \Lambda_b^8}{2 f_a \dot\phi^3} \left(\ln \frac{32\pi^2 f_a^4}{\dot\phi^2} \right)^{-1},$$

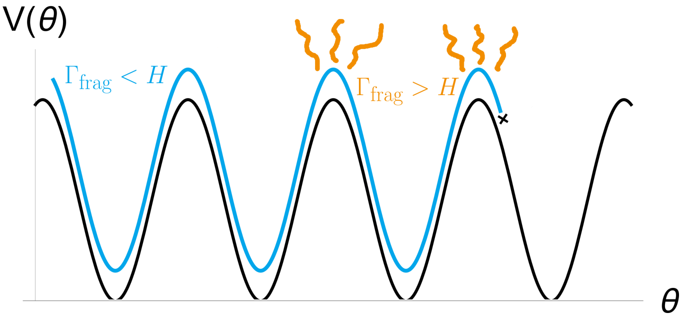
- Inefficient for large $\dot\phi$
- Efficient if $\Gamma_{\text{frag}} > H$

Axion fragmentation



- Rolls if $\Gamma_{\text{frag}} < H$ and $\dot{\phi} > \Lambda_b^2$
- Fragments if $\Gamma_{\text{frag}} > H$
- Fragmentation destroys homogeneity

Axion fragmentation



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$$\rho_\phi^{frag} \approx m_a \underbrace{f_a \dot{\phi}_*}_{n_{PQ}} \left(\frac{a_*}{a_0}\right)^3 \approx \rho_\phi^{KMM}$$

Axion dark matter from fragmentation

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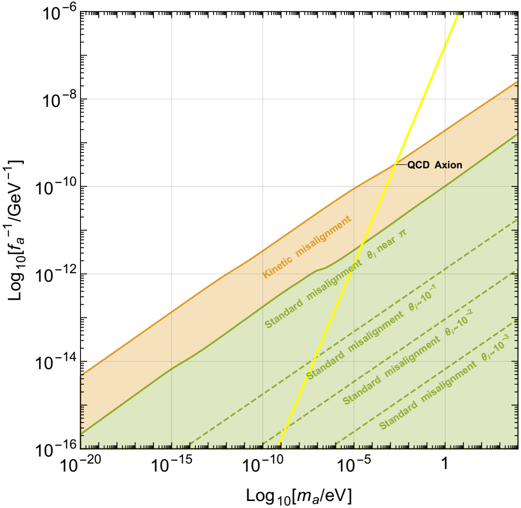

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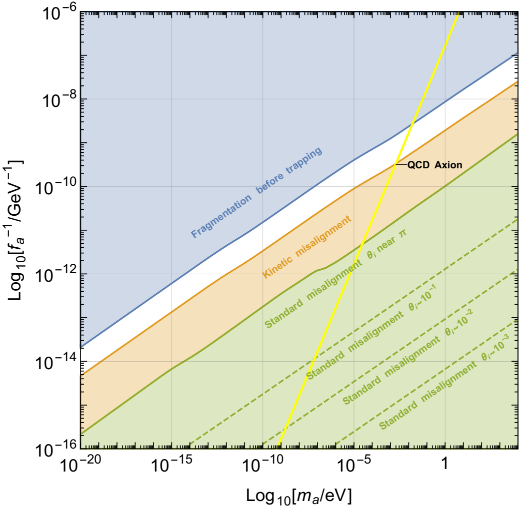

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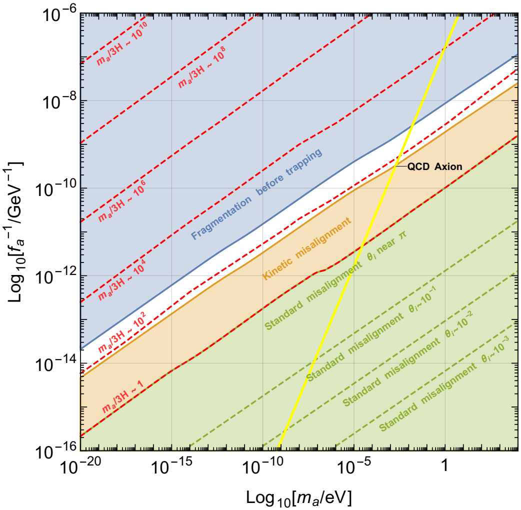

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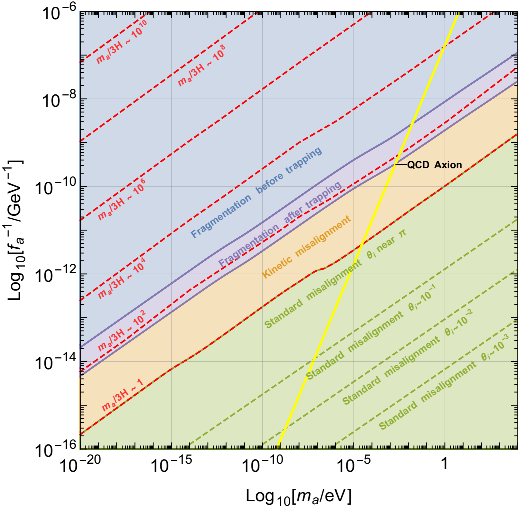

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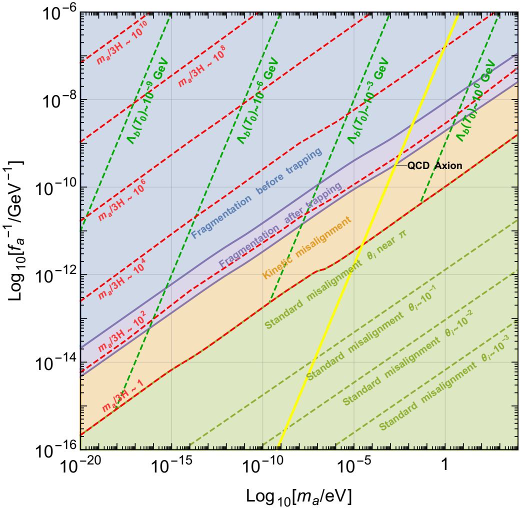

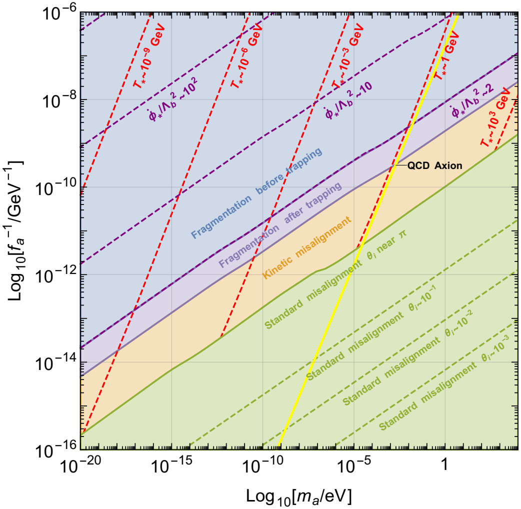

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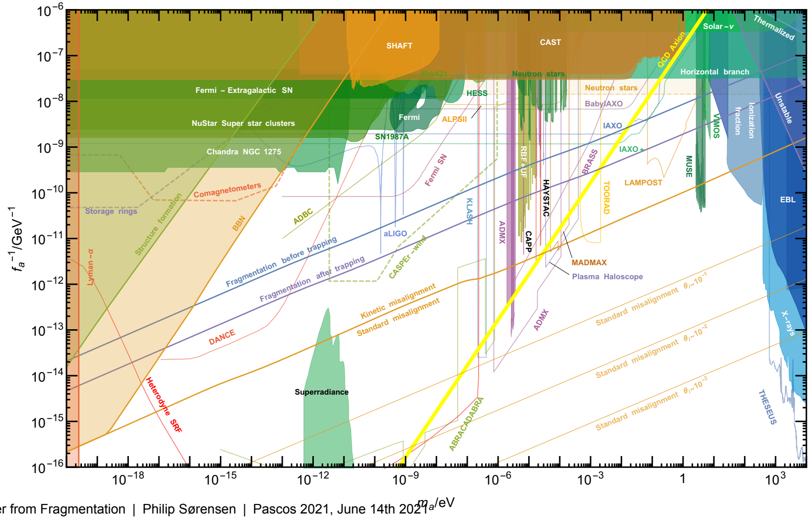

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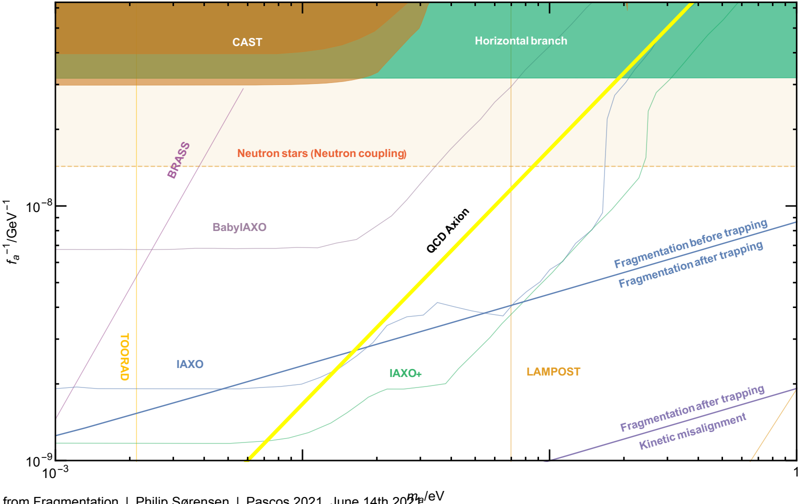

Signatures

Potential signatures:

- Many ALP experiments (Haloscopes etc.)
- Mini clusters? (Study in progress)
- Gravitational waves? (Study in progress)
- ???

Thank you!

Contact

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Elektronen-Synchrotron

www.desy.de

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Thank you!

Questions?

Contact

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