FLASH TDR meeting:
Physics reach

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TDLI & Shanghai Jiao Tong University

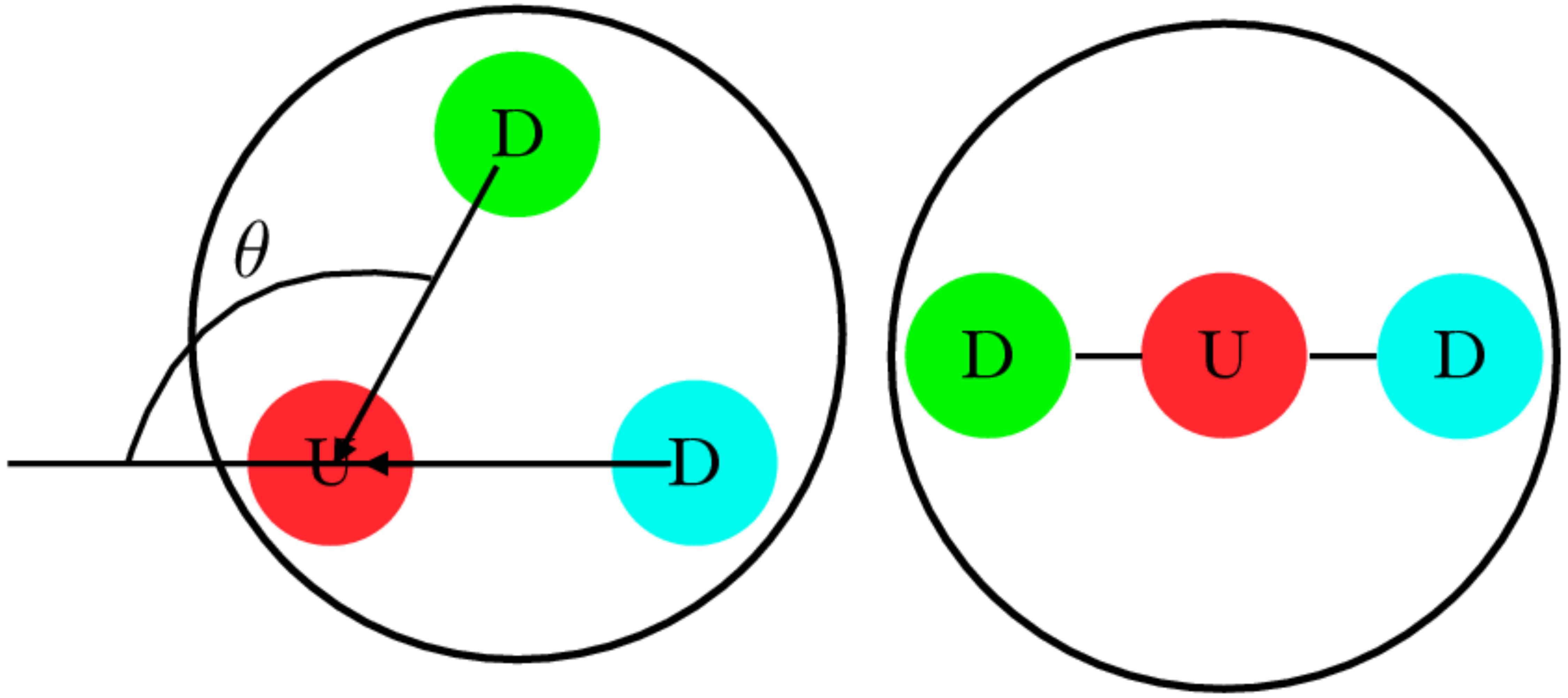
FLASH TDR meeting
May 15, 2024

QCD Axion: Theory motivations

Luca Visinelli

The QCD sector of particle physics demands solving the “strong-CP puzzle”

The distribution of quarks in a neutron defines the neutron’s **electric dipole moment**



Experimentally, this is remarkably small

$$|\theta| \lesssim 10^{-10}$$

Idea: the quantity θ is not a parameter but a field a (the axion)

[Peccei, Quinn, PRL **38** (1977) 1440]
[Weinberg, PRL **40** (1978) 223]
[Wilczek, PRL **40** (1978) 279]

$$\mathcal{L}_{\rm QCD} \supset \theta\, \tilde{G}G \longrightarrow \frac{a}{f_a}\, \tilde{G}G$$

G Gluon field

f_a New energy scale

Cold axions as dark matter

Luca Visinelli

[O'Hare, cajohare.github.io/AxionLimits/]

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Cold axions as dark matter

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Coupling of the axion with the photon

Interactions are set by the **pseudo-scalar nature** of the axion, with Lagrangian:

$$\mathcal{L} \supset g_{a\gamma}\, a\, \mathbf{E} \cdot \mathbf{B} + g_{af}\, (\nabla a) \cdot \mathbf{S} + g_{\rm EDM}\, a\, \mathbf{S} \cdot \mathbf{E}$$

Experimentally, how do they look like?

- Via $\mathbf{E} \cdot \mathbf{B}$ coupling (CP-odd) $\longrightarrow$ Additional electric current
- Via coupling to e^- and n spins $\longrightarrow$ Precessions

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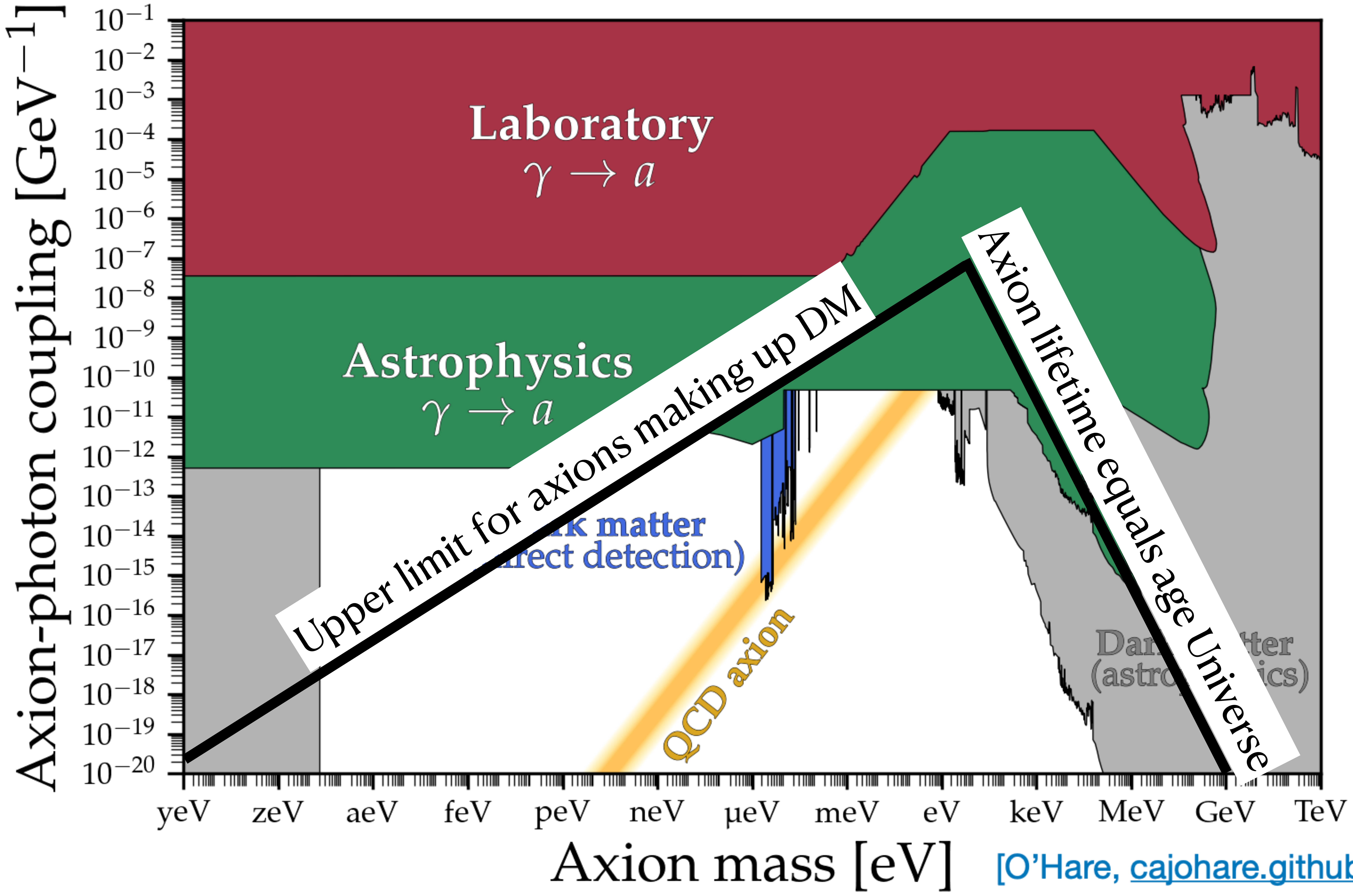
Coupling of the axion with the photon



[O'Hare, cajohare.github.io/AxionLimits/]

Hunting for axions **Haloscopes**

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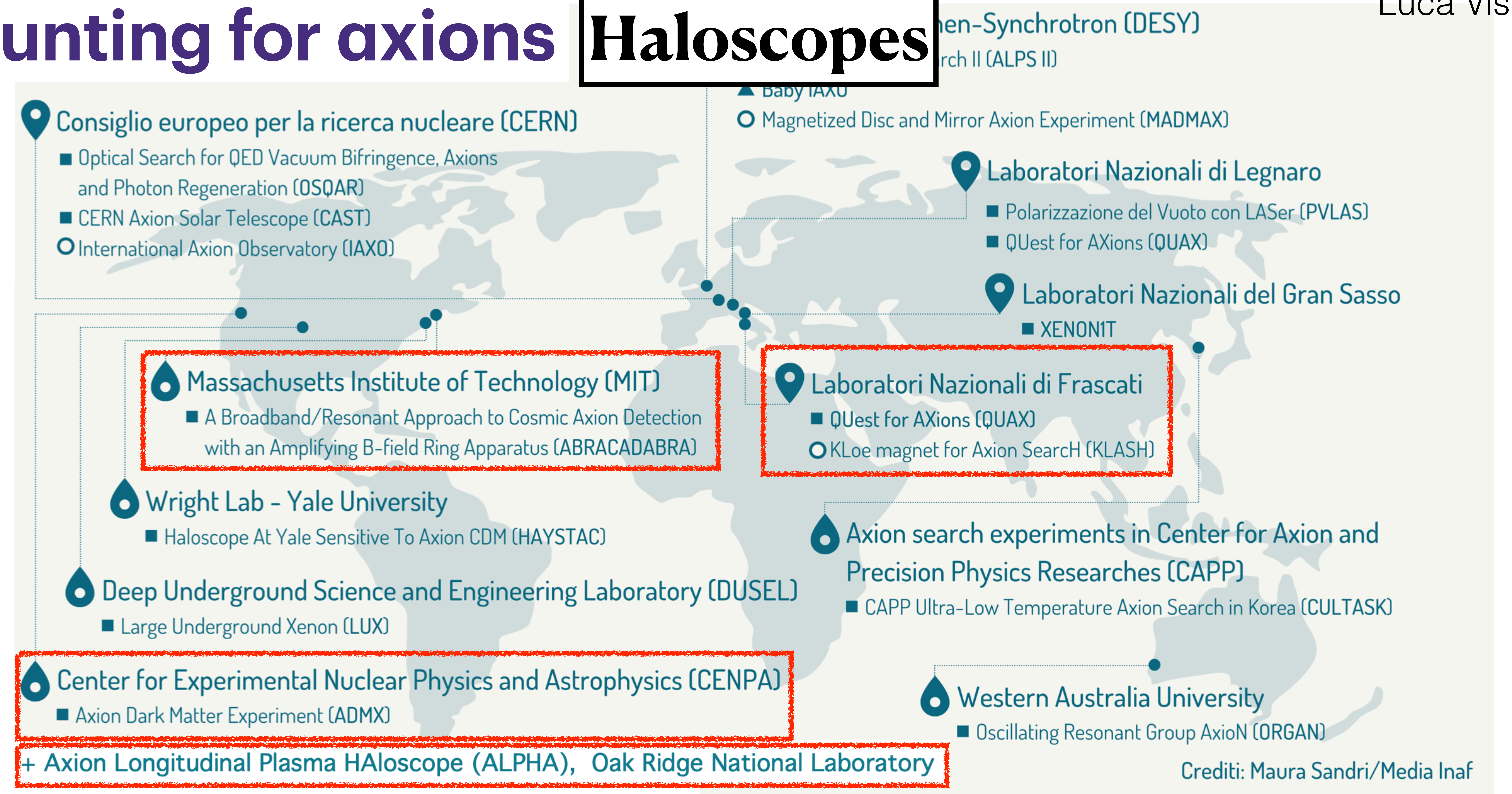

+ Axion Longitudinal Plasma HAloscope (ALPHA), Oak Ridge National Laboratory

+ Taiwan Axion Search Experiment with Haloscope (TASEH)

+ Cosmic Axion Spin Precession Experiment (CASPEr), Boston and Mainz

Courtesy of Caterina Braggio

Haloscope searches

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The axion-photon coupling $g_{a\gamma}\, a\, \mathbf{E}\cdot\mathbf{B}$ modifies Maxwell's equations

Cavity resonating at frequency ν_c

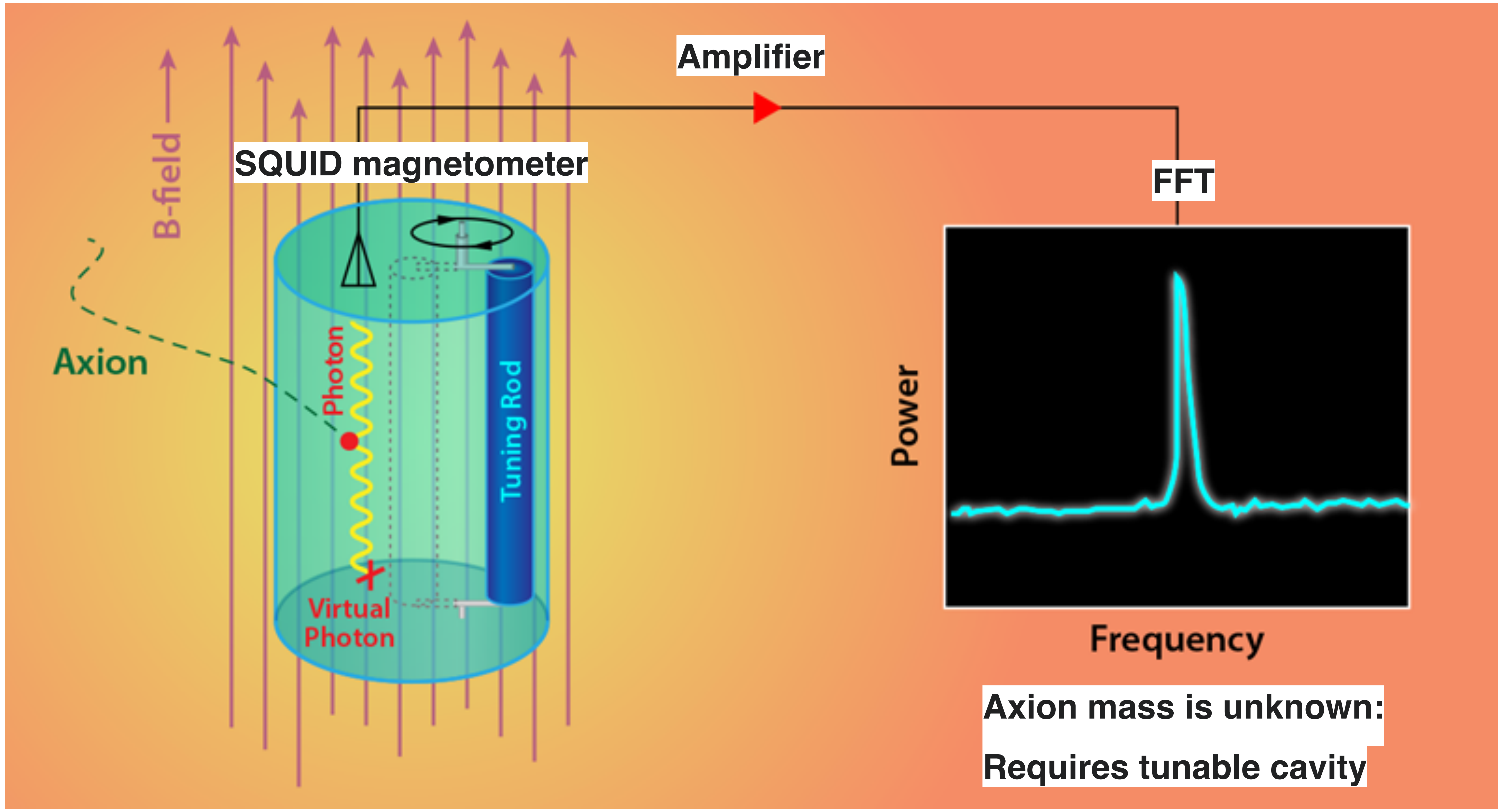
Significant enhancement when

$$2\pi\nu_c \approx m_a$$

$$m_a \sim \mu\text{eV} \longrightarrow \nu_c \sim \text{GHz}$$

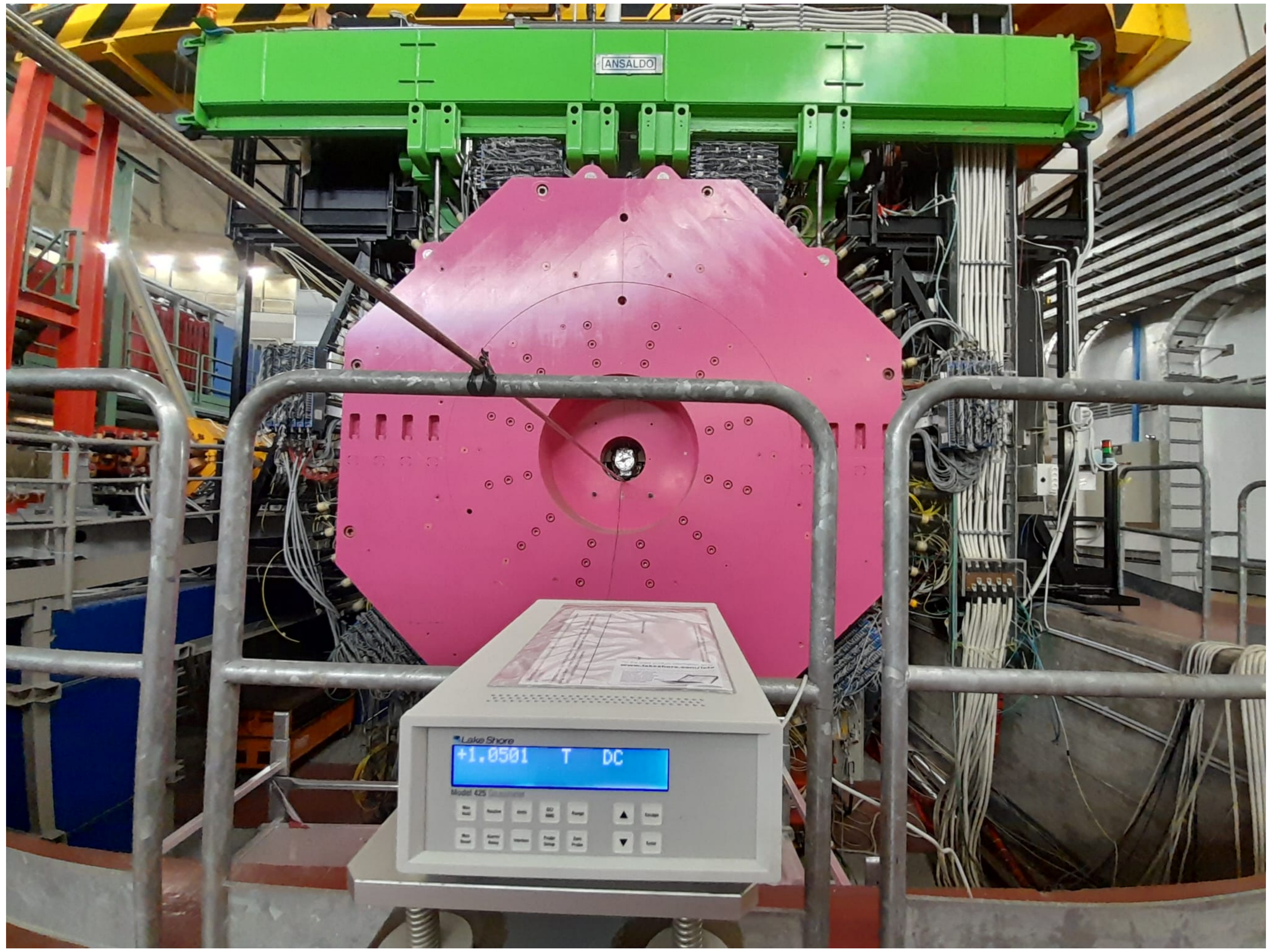
$$P_{\rm sig} = \left(g_{a\gamma}^2 \frac{\rho_{\rm DM}}{m_a}\right) \times \left(Q B_0^2 V\right)$$

Particle/astro Instrument

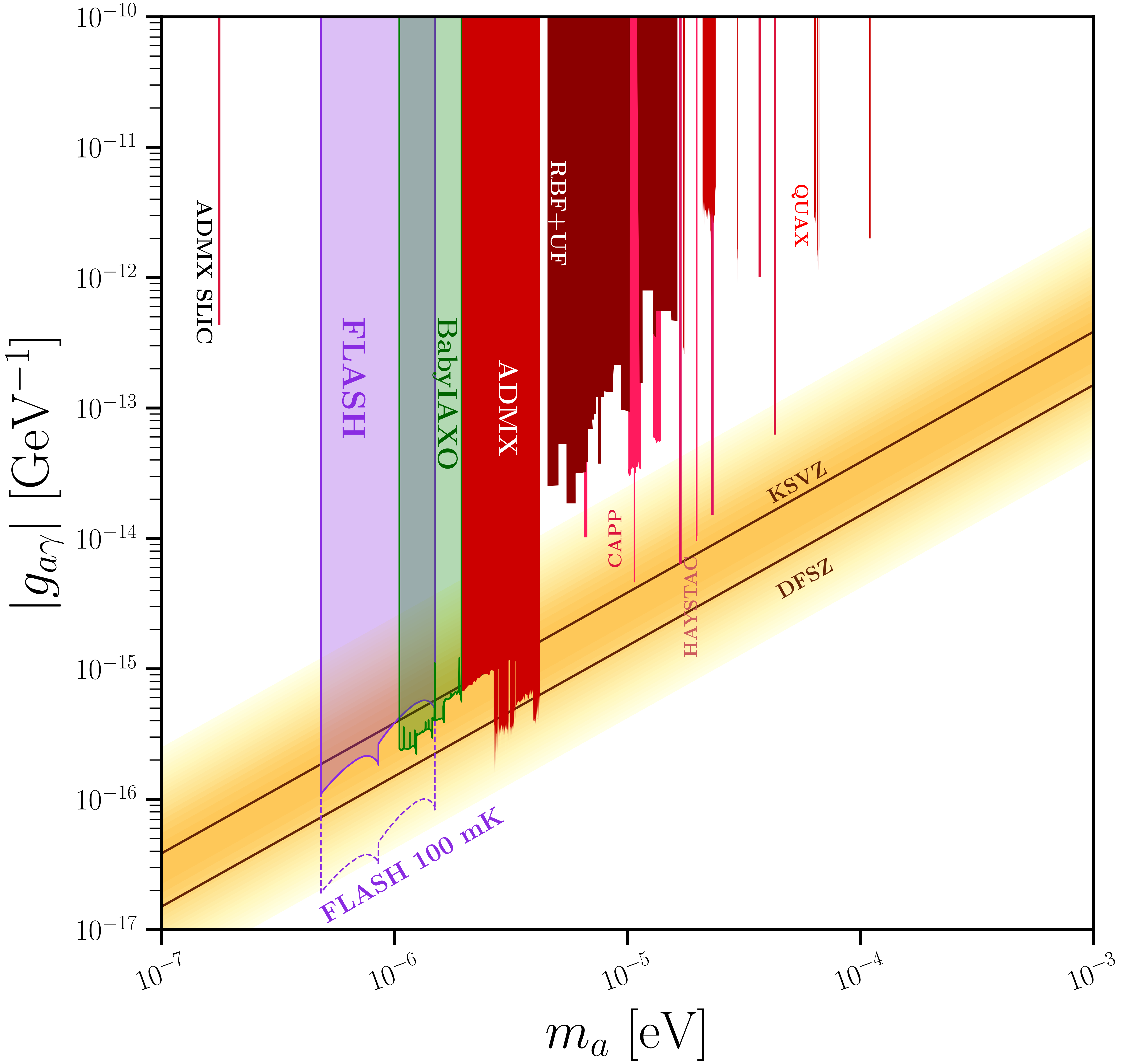


Courtesy of ADMX collaboration

Forecast reach of FLASH: axion

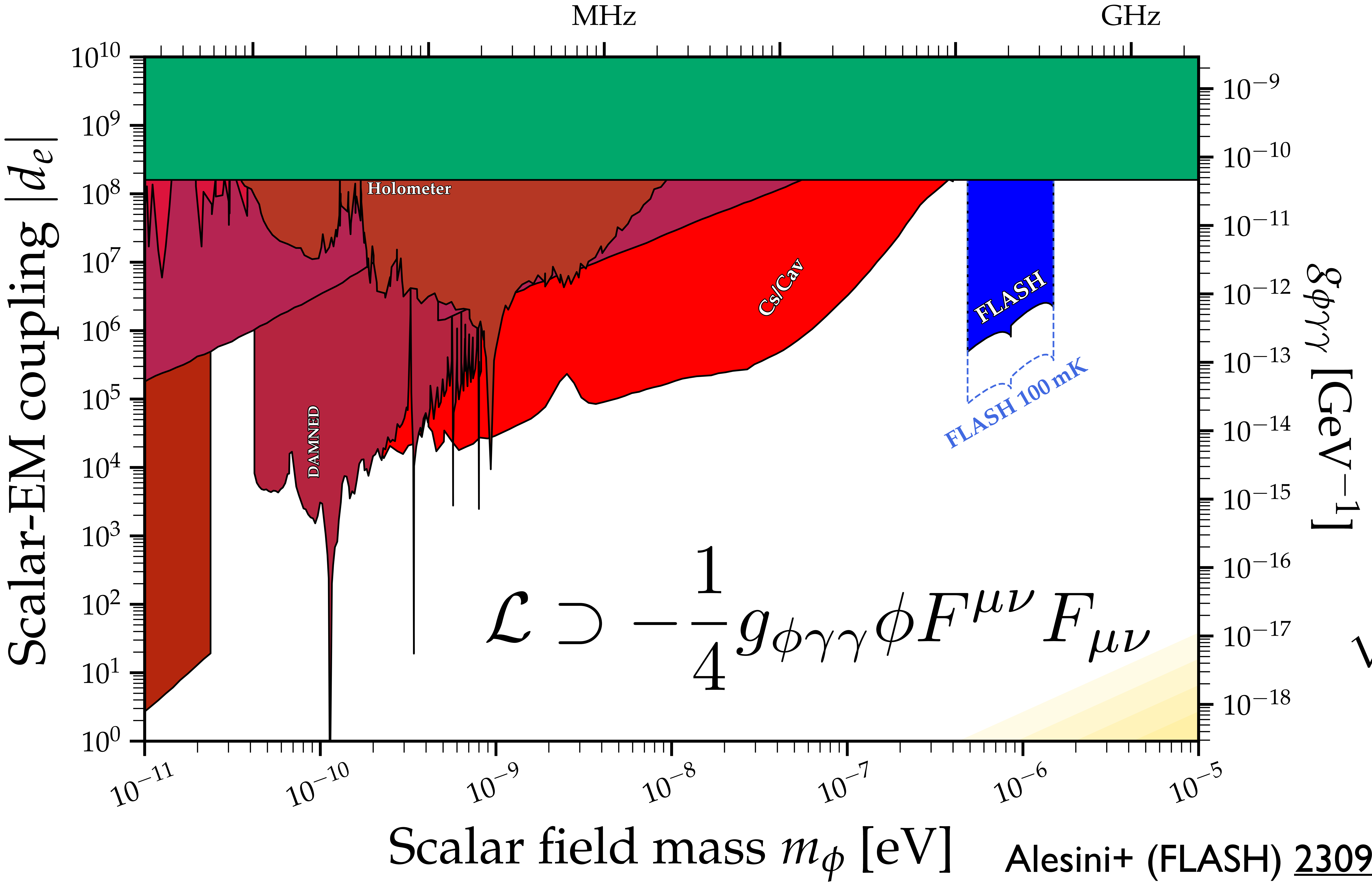


The magnet was successfully tested in January 2024



Alesini+ (FLASH) 2309.00351

Forecast reach of FLASH: scalar DM



Coupling with TE modes

$$C_{111} \approx 10^{-7}$$

$$C_{011} \approx 10^{-13}$$

$$\sqrt{C_{111}/C_{010}} \approx 10^{-3}$$

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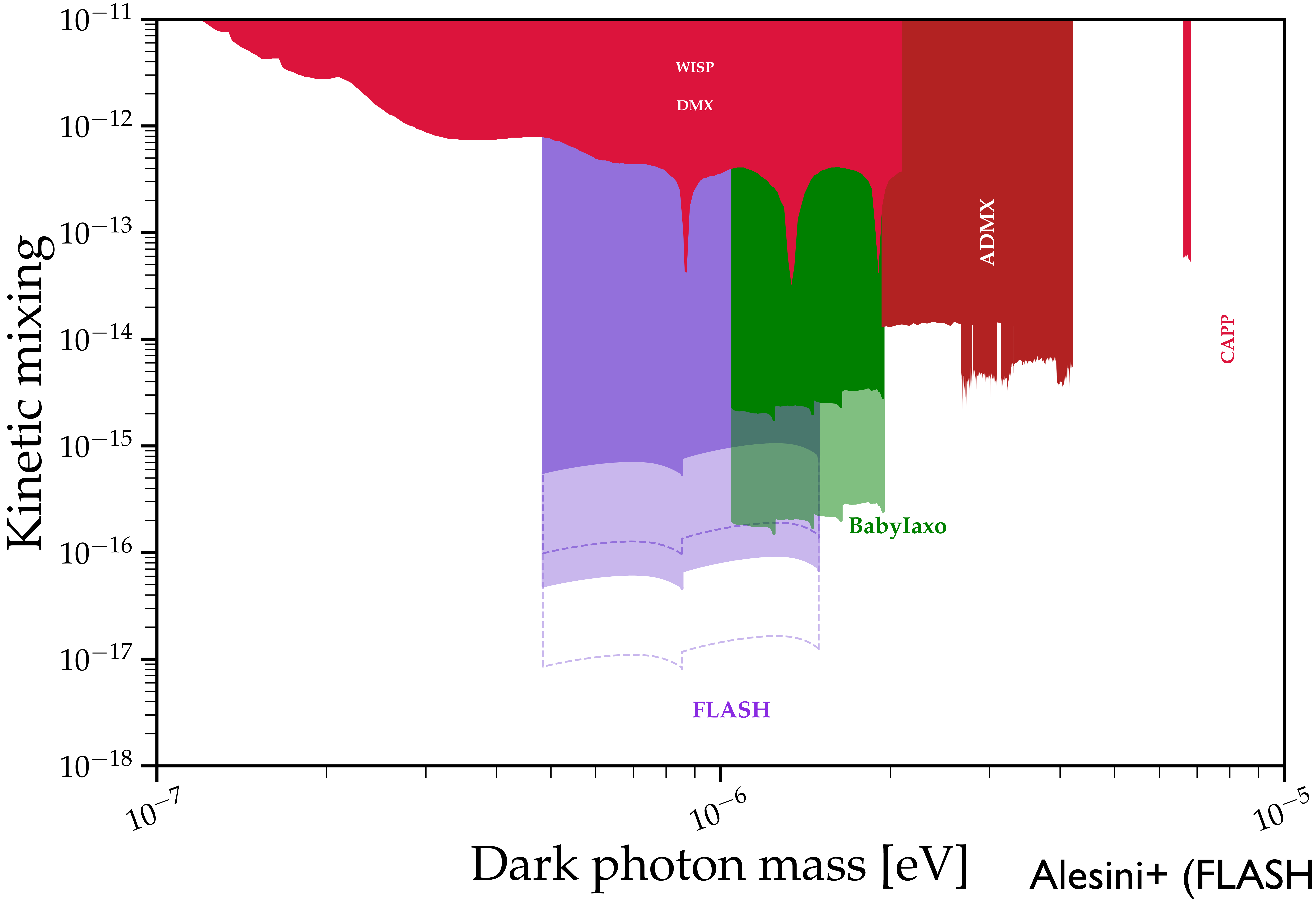
Forecast reach of FLASH: vector DM



$$\mathcal{L} \supset \frac{1}{2}\chi X_{\mu\nu} F^{\mu\nu}$$

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High-frequency gravitational waves

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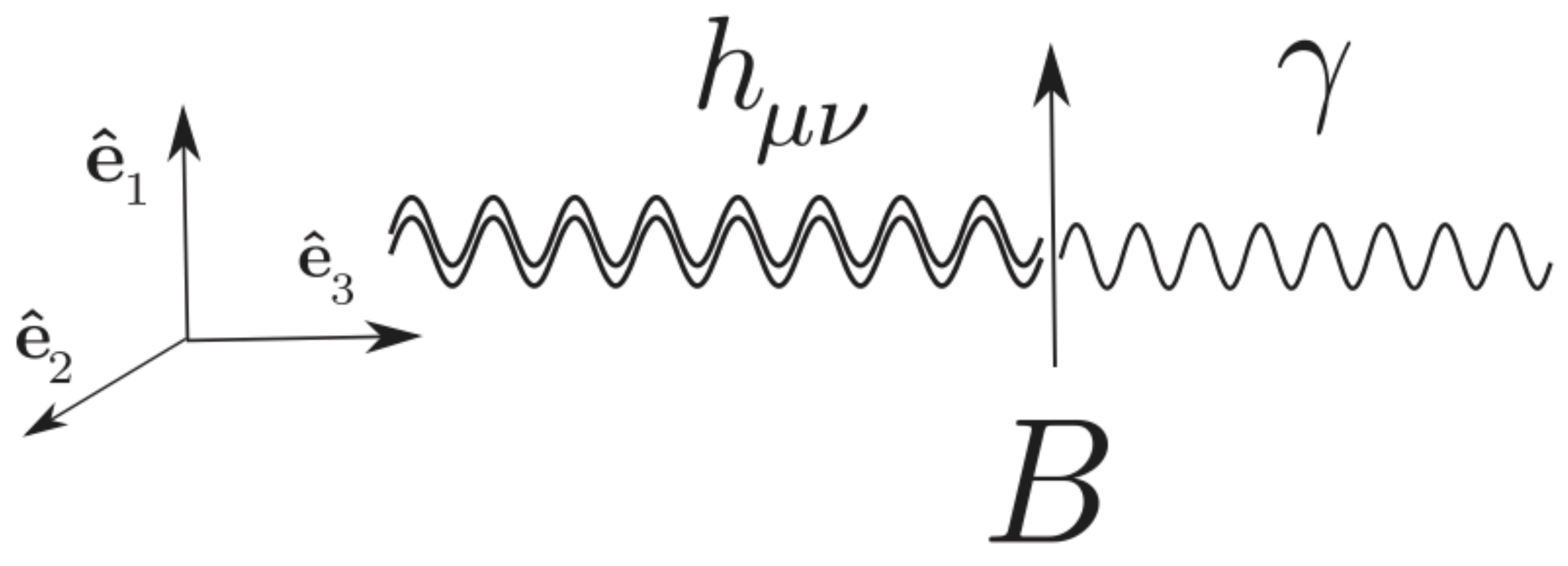
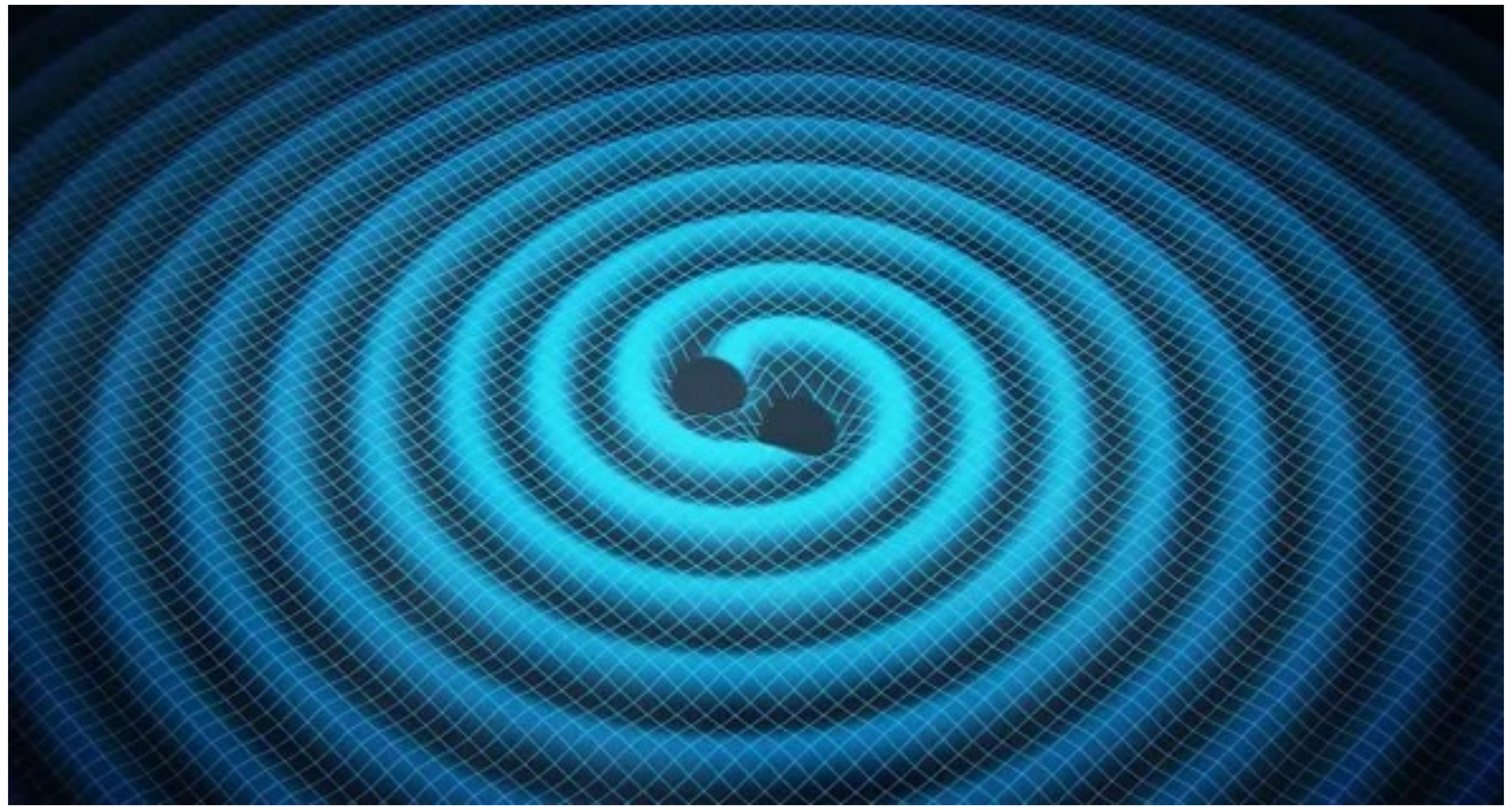
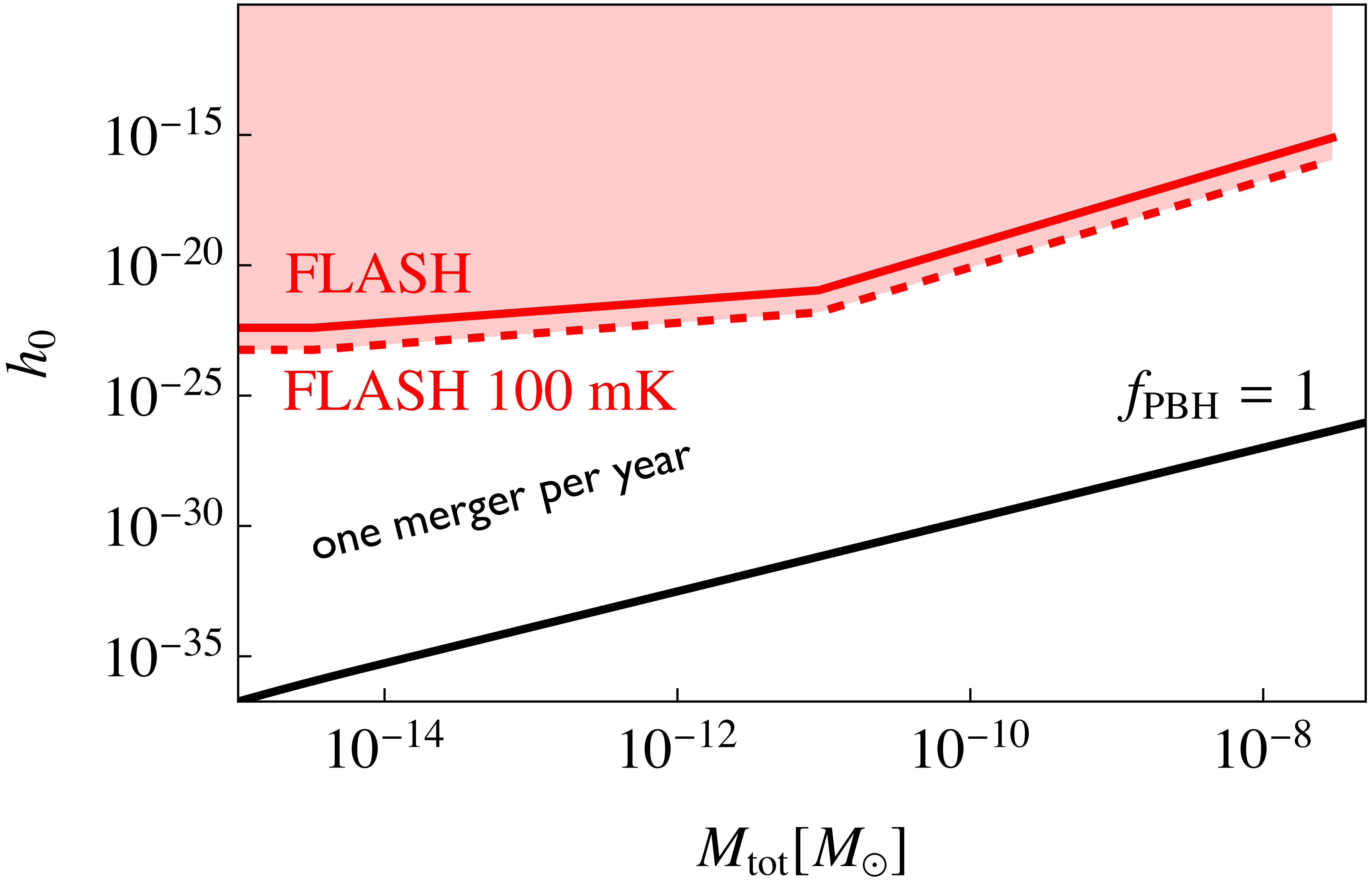
Inverse Gertsenshtein effect (Domcke&Garcia-Cely '21)

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h_0 \sim |h_{\mu\nu}|$$







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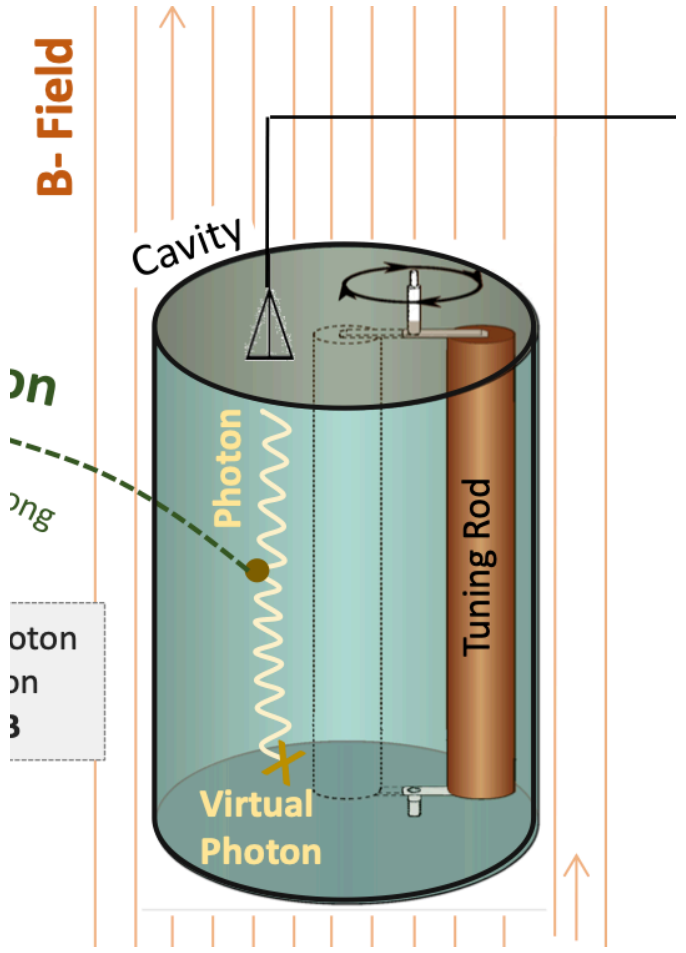
High-frequency gravitational waves

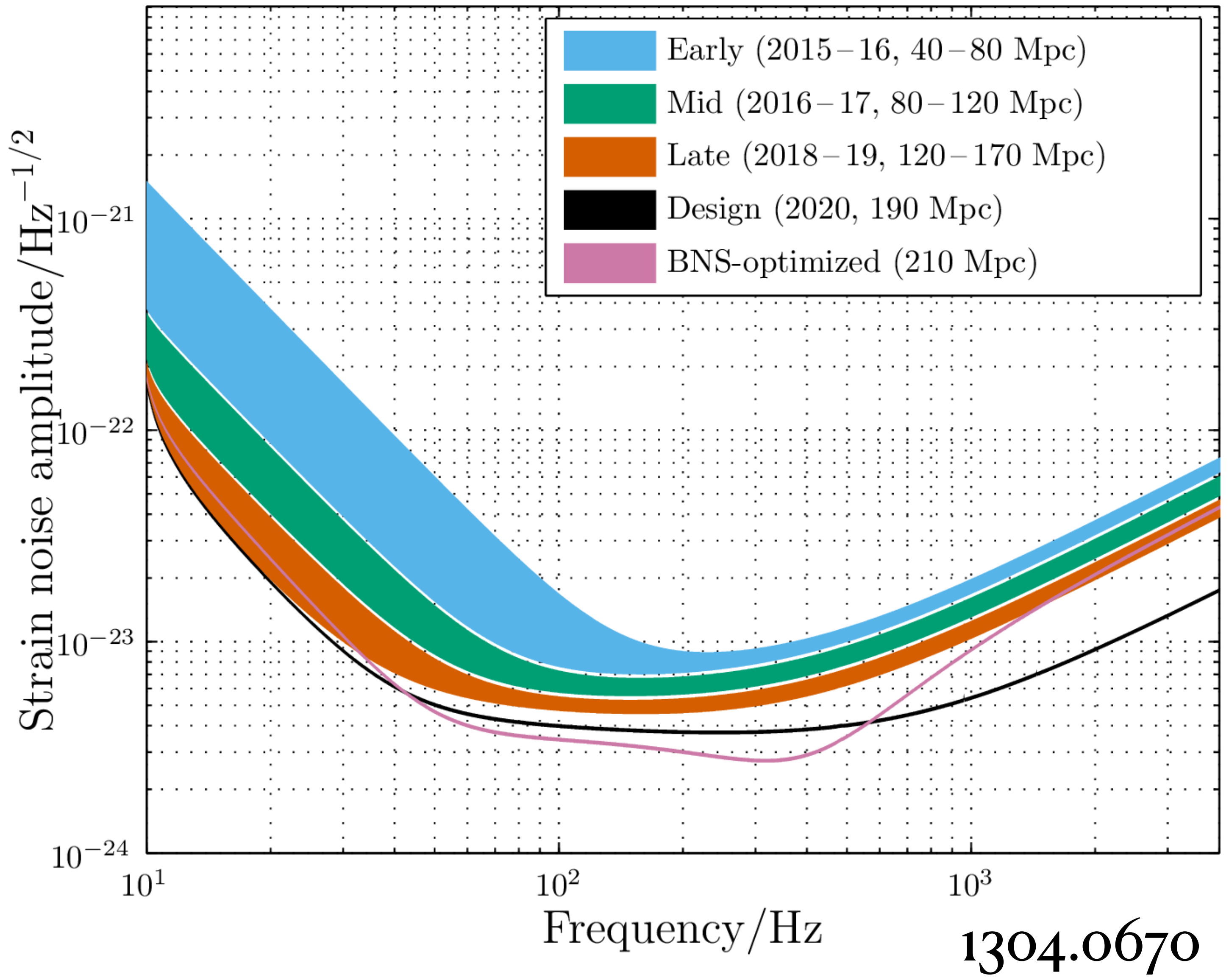
Vs.



Cavities resonate at much higher frequencies than those in LIGO/VIRGO/KAGRA

LVK $f \sim (10\text{-}1000)\,\mathrm{Hz}$: Solar-mass BHs

Cavity $f \sim (0.1\text{-}10)\,\mathrm{GHz}$: Primordial BHs



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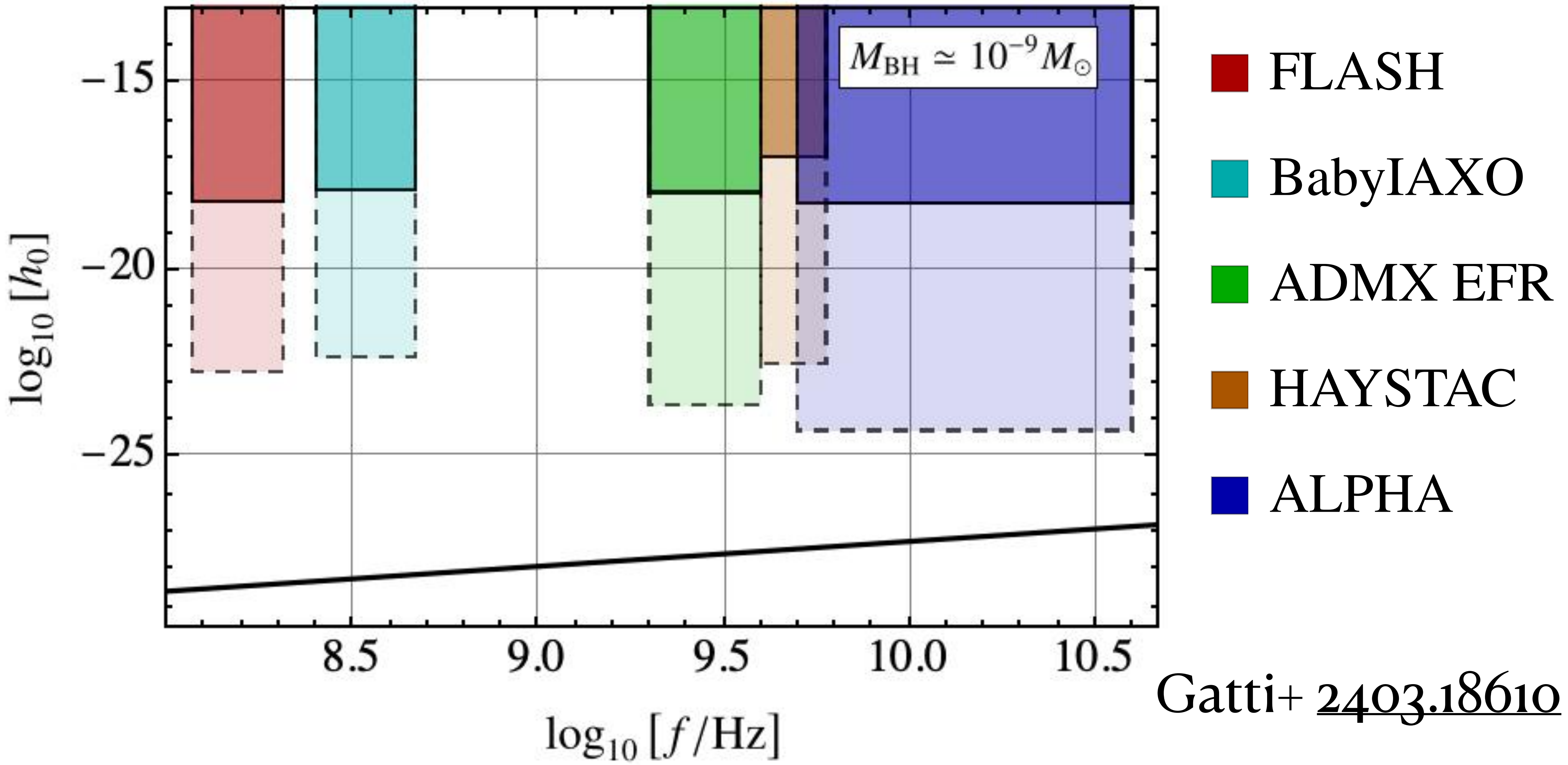

Gatti+ 2403.18610

Conclusions and future directions

Group goals:

- Motivate students into astroparticles: we need ideas!

- Synergy between theory, experiments, computer skills

- Boost networking between communities (e.g. I belong to COST actions and organize workshops)

Individual goals (besides getting grants and publish):

- Keep up with the theory motivations besides larger experiments

- Come up with new frameworks that challenge experimentalists

- Aspire to enter large collaborations (Xenon, LZ, IAXO) to further these theory lines

Conclusions and further read

Ideas can be found in the FLASH CDR: 2309.00351

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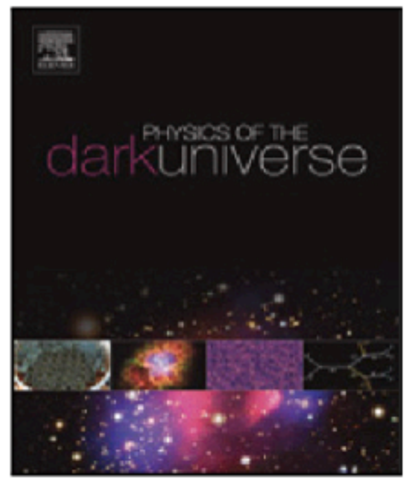

Full Length Article

Check for updates

The future search for low-frequency axions and new physics with the FLASH resonant cavity experiment at Frascati National Laboratories

David Alesini [a], Danilo Babusci [a], Paolo Beltrame [b], Fabio Bossi [a], Paolo Ciambrone [a], Alessandro D'Elia [a,*], Daniele Di Gioacchino [a], Giampiero Di Pirro [a], Babette Döbrich [c], Paolo Falferi [d], Claudio Gatti [a], Maurizio Giannotti [e,f], Paola Gianotti [a], Gianluca Lamanna [g], Carlo Ligi [a], Giovanni Maccarrone [a], Giovanni Mazzitelli [a], Alessandro Mirizzi [h,i], Michael Mueck [j], Enrico Nardi [a,k], Federico Nguyen [l], Alessio Rettaroli [a], Javad Rezvani [m,a], Francesco Enrico Teofilo [n], Simone Tocci [a], Sandro Tomassini [a], Luca Visinelli [o,p], Michael Zantedeschi [o,p]

Thanks to all my collaborators and to the audience!

QCD Axion: Theory motivations

The QCD sector of particle physics demands solving the "strong-CP puzzle"

Its most plausible solution predicts a new particle, the **QCD axion** [Peccei, Quinn, PRL **38** (1977) 1440]

The QCD axion is a pseudo-scalar boson resulting from the spontaneous symmetry breaking of a global U(1) symmetry [Weinberg, PRL **40** (1978) 223; Wilczek, PRL **40** (1978) 279]

SSB at energy f_a

Axion mass $m_a \propto \frac{1}{f_a}$

Couplings $g_a \propto \frac{1}{f_a}$