# FLASH TDR meeting. WP1: Physics reach

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INFN-LNF, March 10, 2025

# 1. The Axion opportunity

# Cold axions as dark matter


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

# Coupling of the axion with the photon

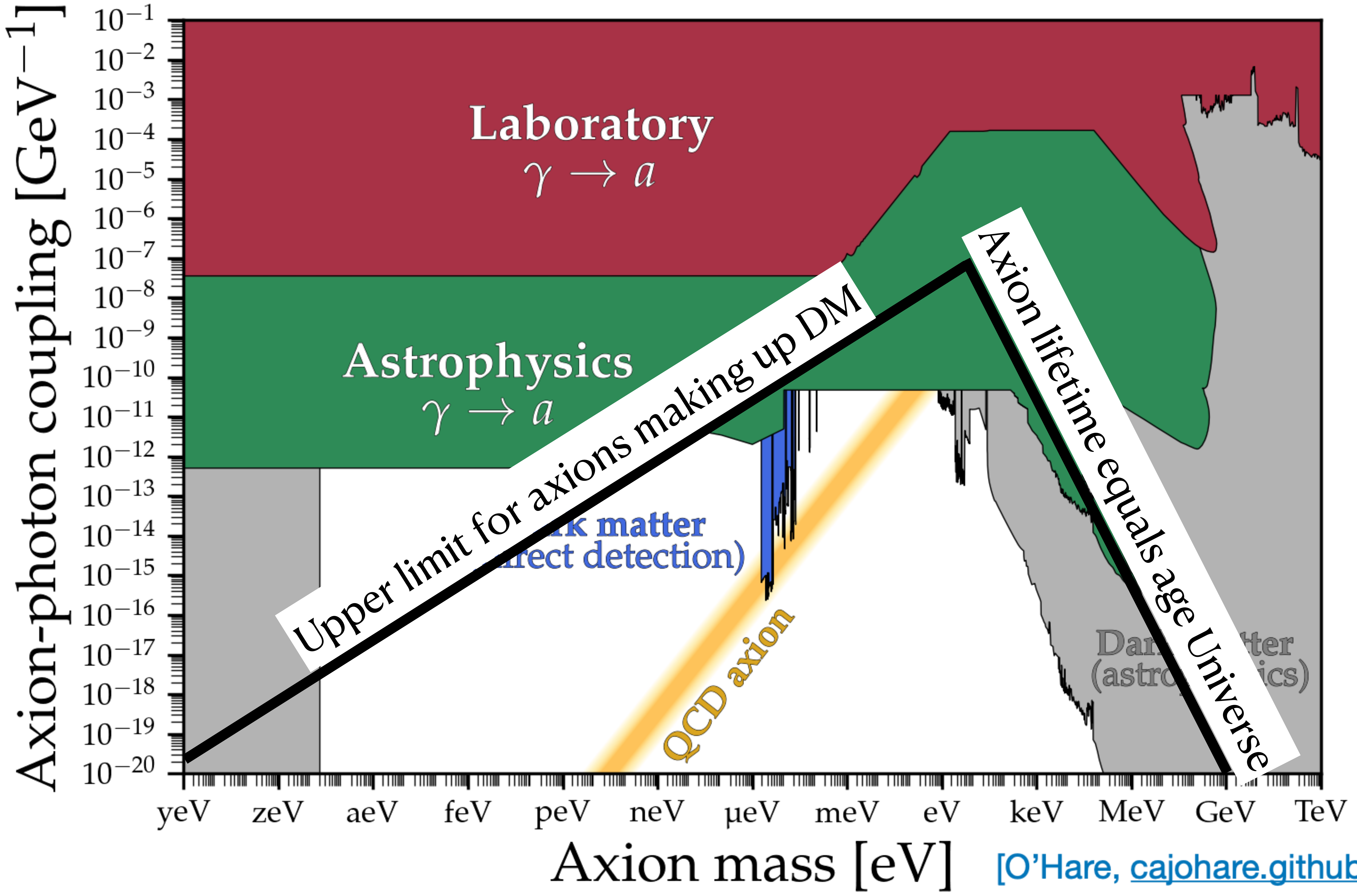
Interactions are set by the **pseudo-scalar nature** of the axion, with Lagrangian:

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

Experimentally, how do they look like?

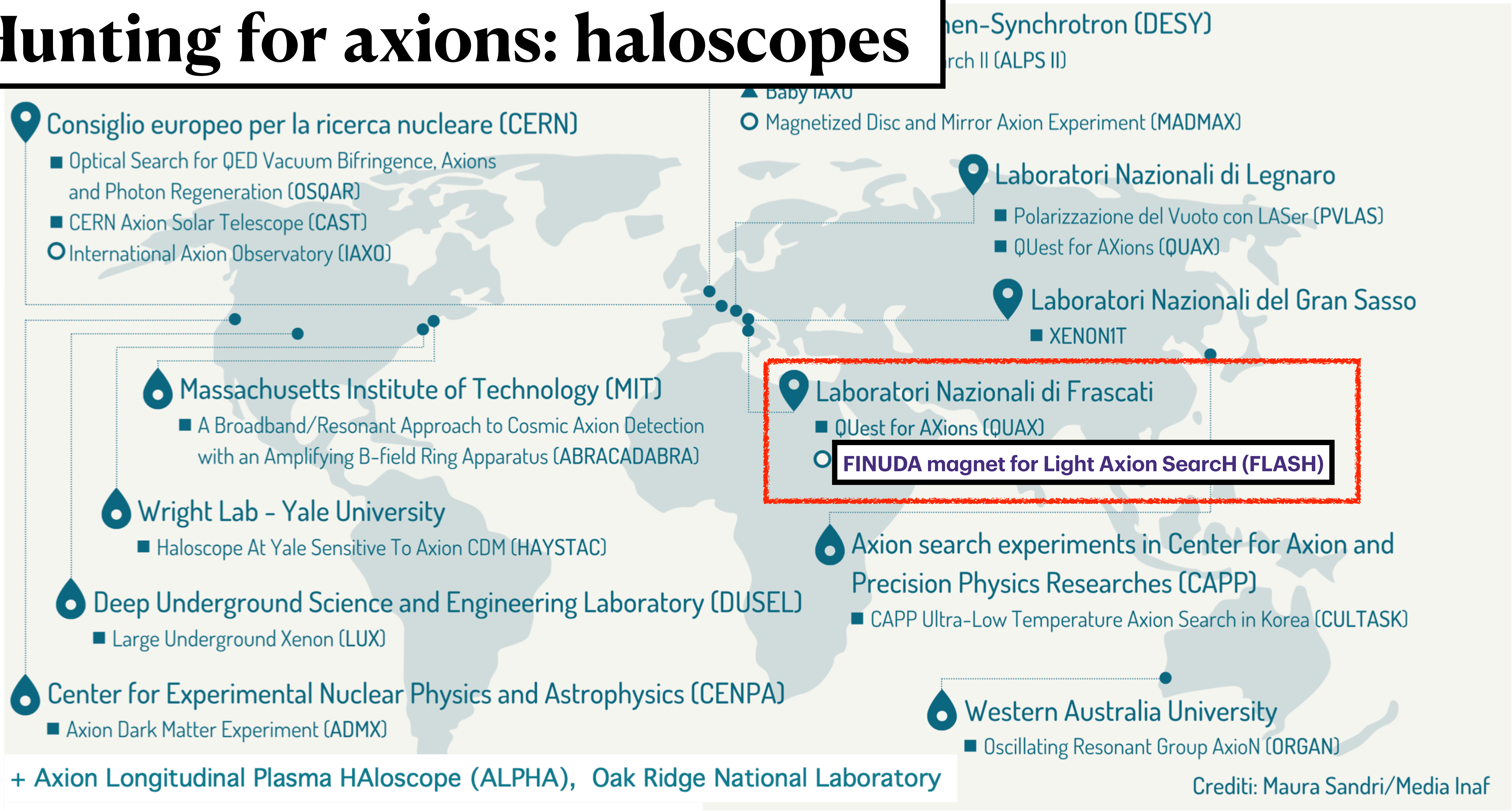
- Via $\mathbf{E} \cdot \mathbf{B}$ coupling (CP-odd) $\longrightarrow$ Additional electric current
- Via coupling to $e^-$ and $n$ spins $\longrightarrow$ Precessions

# Coupling of the axion with the photon




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

# Hunting for axions: haloscopes




+ 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

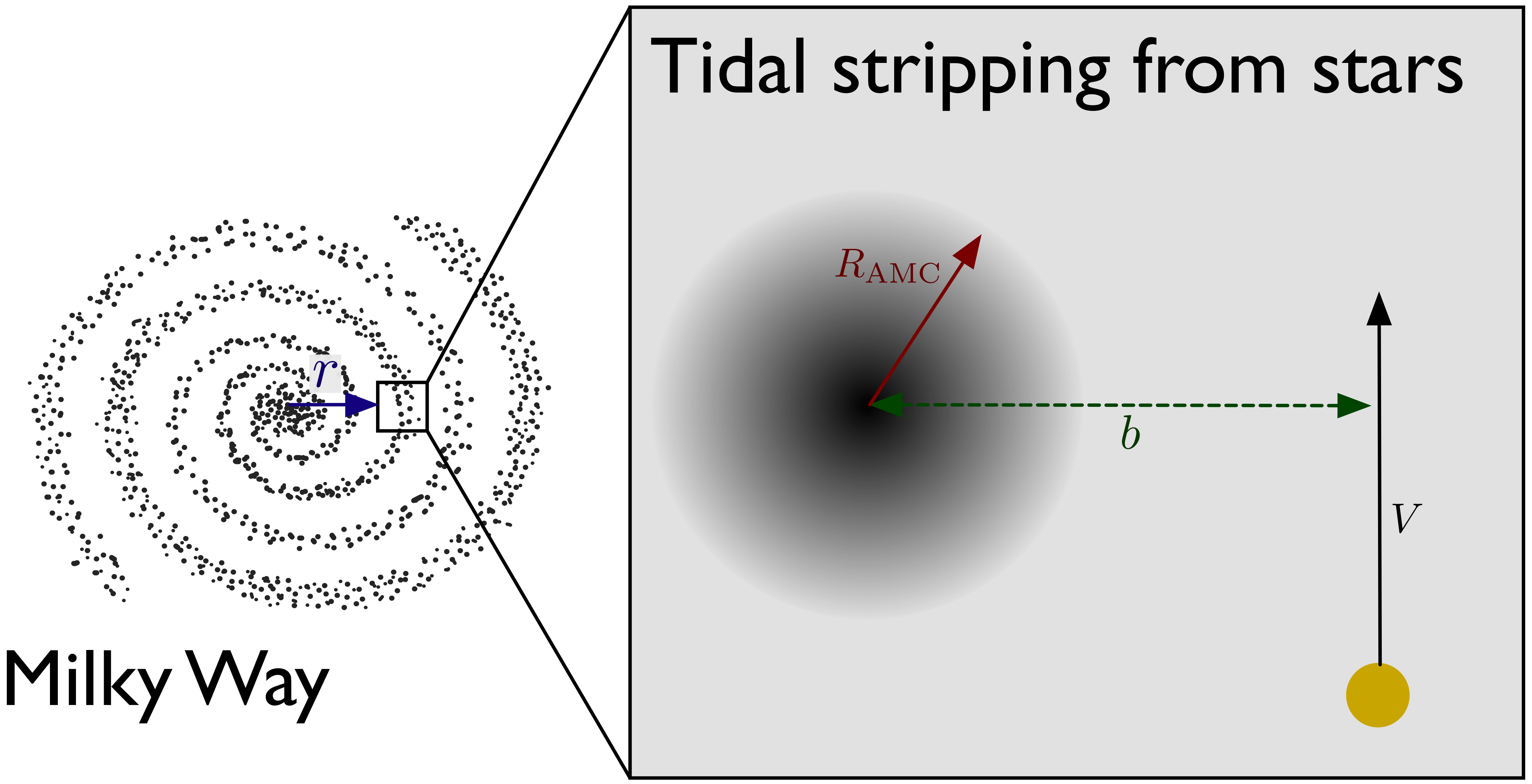
# Detecting axion miniclusters in FLASH?

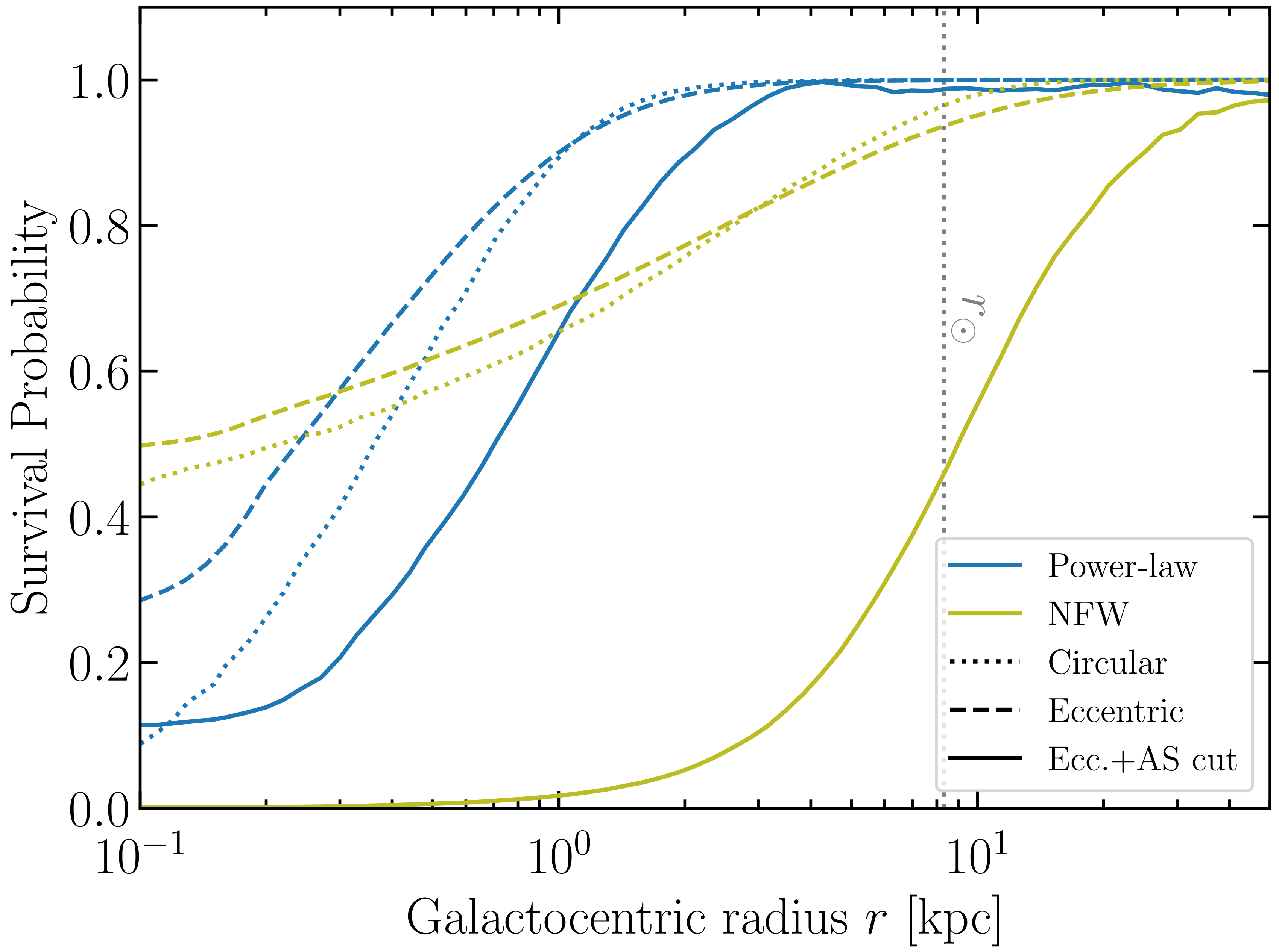
Overdensities produced in the early Universe act as "seeds" for bound axion *miniclusters* (Hogan, Rees 88)

For an overdensity $\delta \equiv 1 - \bar{\rho}/\rho$ the AMC density is $\rho_{\rm amc}(\delta) = 140\,(1+\delta)\delta^3 \rho_{\rm eq}$

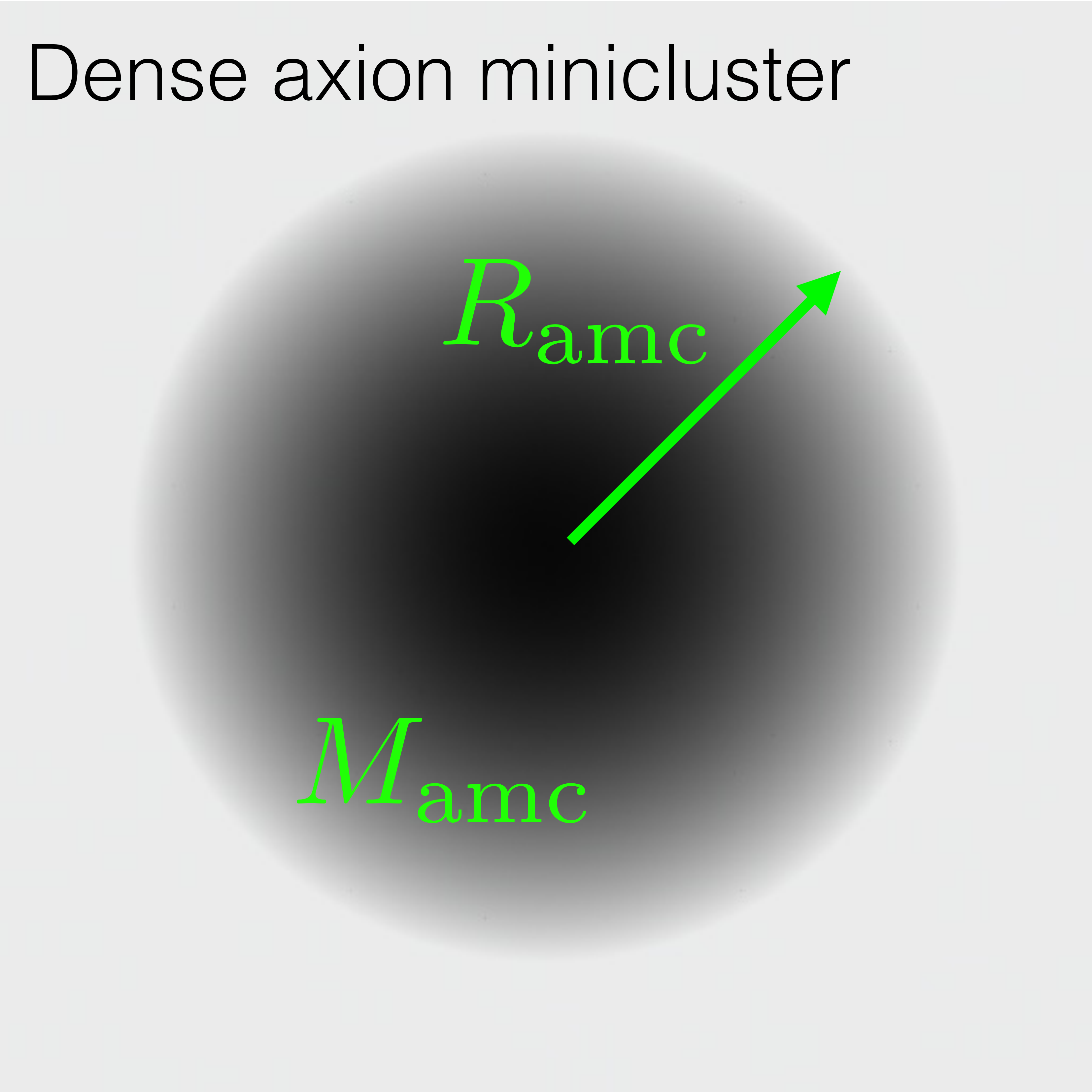
Kolb, Tkachev astro-ph/9311037

We first assessed the minicluster distribution in the Milky Way   Kavanagh, Edwards, **LV**, Weniger 2011.05377



# Detecting axion miniclusters in FLASH?




Velocity dispersion in the AMC: $\sigma_v^2 = \frac{G\,M_{\rm amc}}{R_{\rm amc}}$

$$\sigma_v \approx 1.4\,{\rm m/s}\,\left(\frac{M_{\rm amc}}{10^{-10}\,M_\odot}\right)^{1/3}\left(\frac{\delta}{10}\right)^{2/3}$$

This translates into the frequency width:

$$\delta f = f\,\left(\frac{v\sigma_v}{c^2}\right) \approx 0.23\,{\rm mHz}\,\left(\frac{f}{100\,{\rm MHz}}\right)\left(\frac{M_{\rm amc}}{10^{-10}\,M_\odot}\right)^{1/3}\left(\frac{\delta}{10}\right)^{2/3}$$

# Detecting axion miniclusters in FLASH?

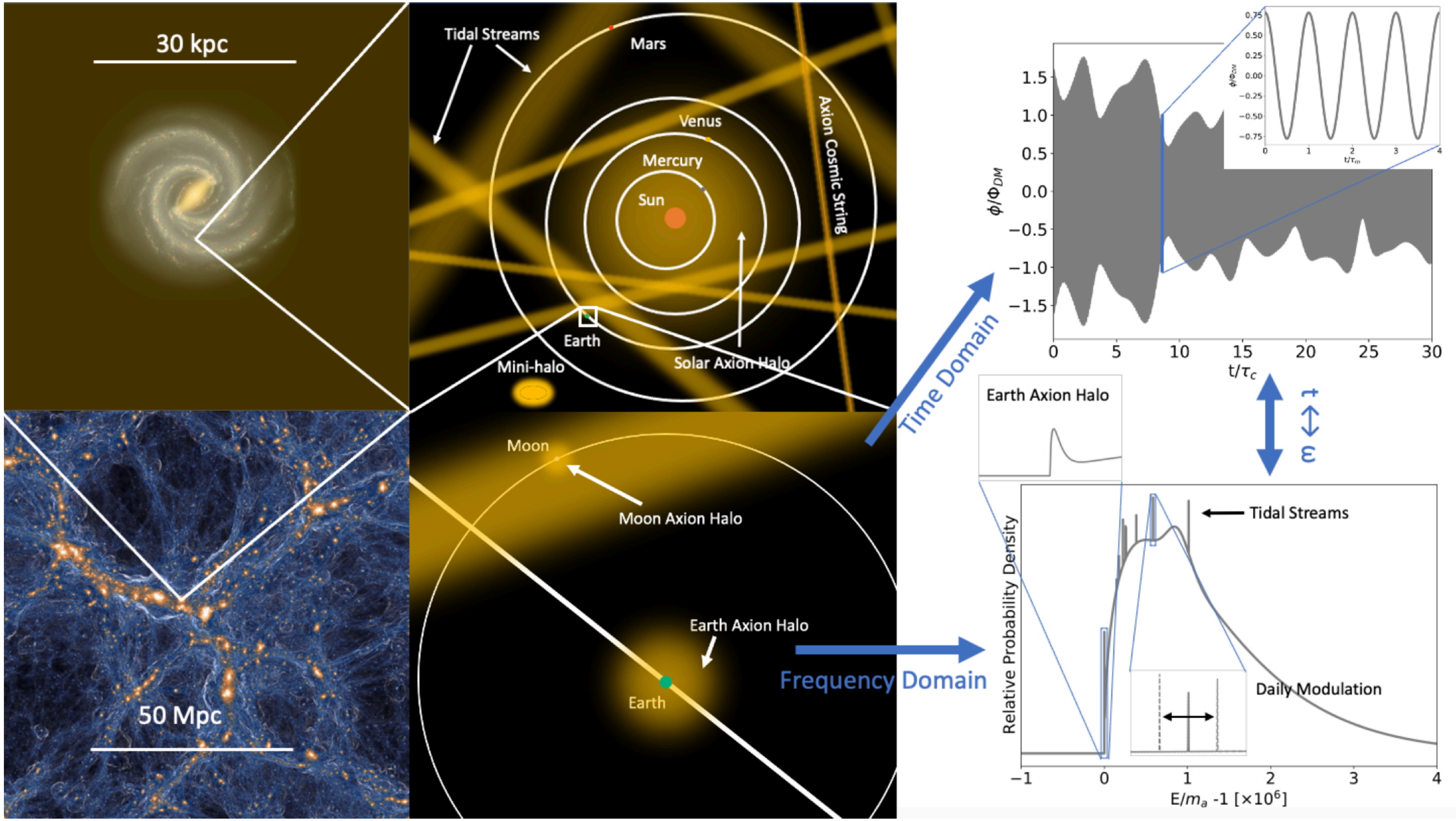



Figure from Snowmass 2021 (with **L. Visinelli**) 2203.14923

# Detecting axion miniclusters in FLASH?

Other things to do if we proceed for this!

Some simulations of minicluster dynamics that involve the axion DM in the mass range of FLASH.

This includes assessing the mass distribution of miniclusters for axions with $m_a = 1\,\mu\mathrm{eV}$

The mass distribution includes tidal stripping: my work 2011.05377 + recent work 2402.03236

Power in the cavity: $P(\omega) \propto g_{a\gamma}^2\,\rho_a\,f(\omega)$

Fourier decomposition at the frequency $\omega$

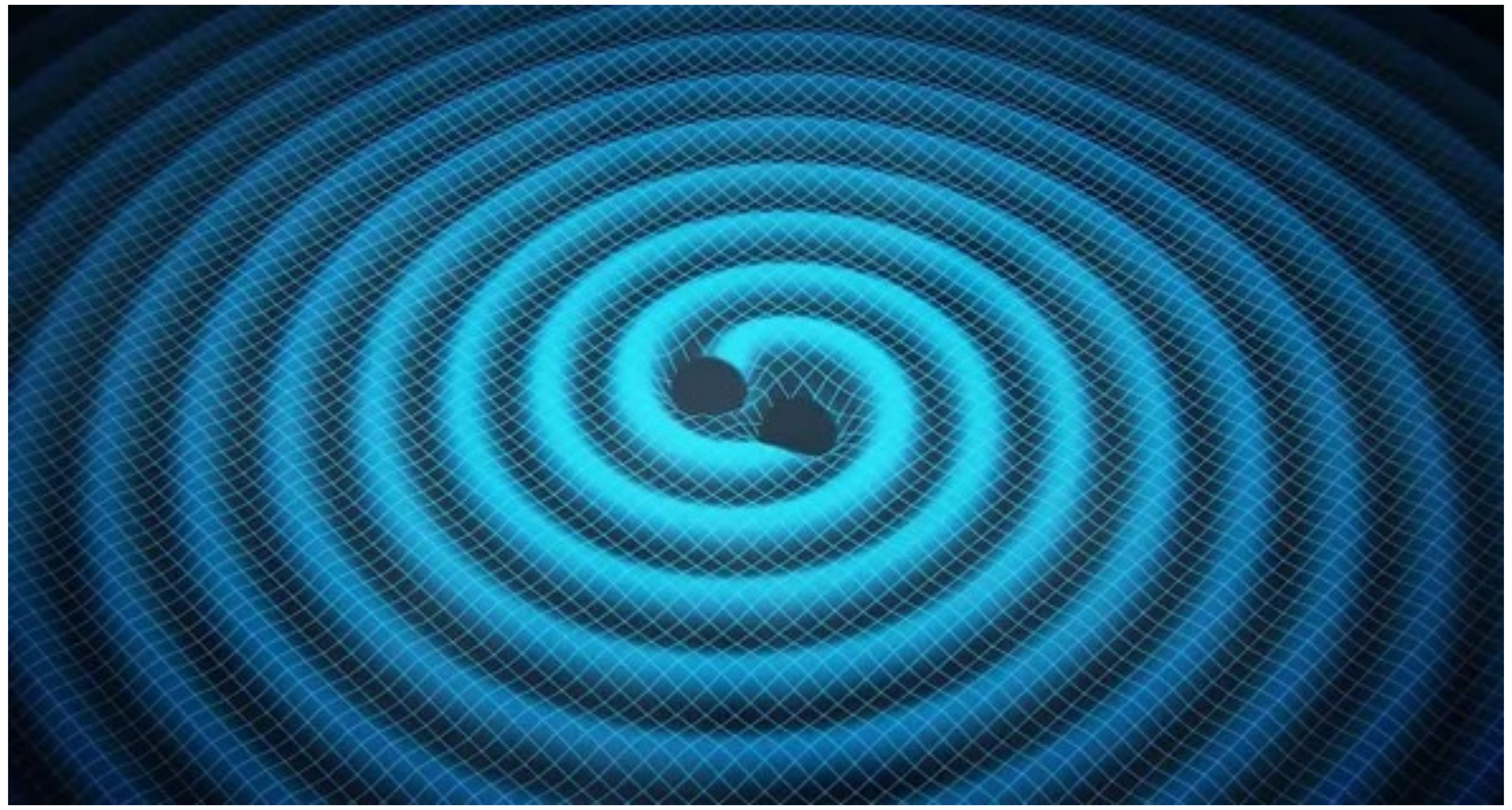
We need to account for the chance of encountering miniclusters and streams: 2212.00560

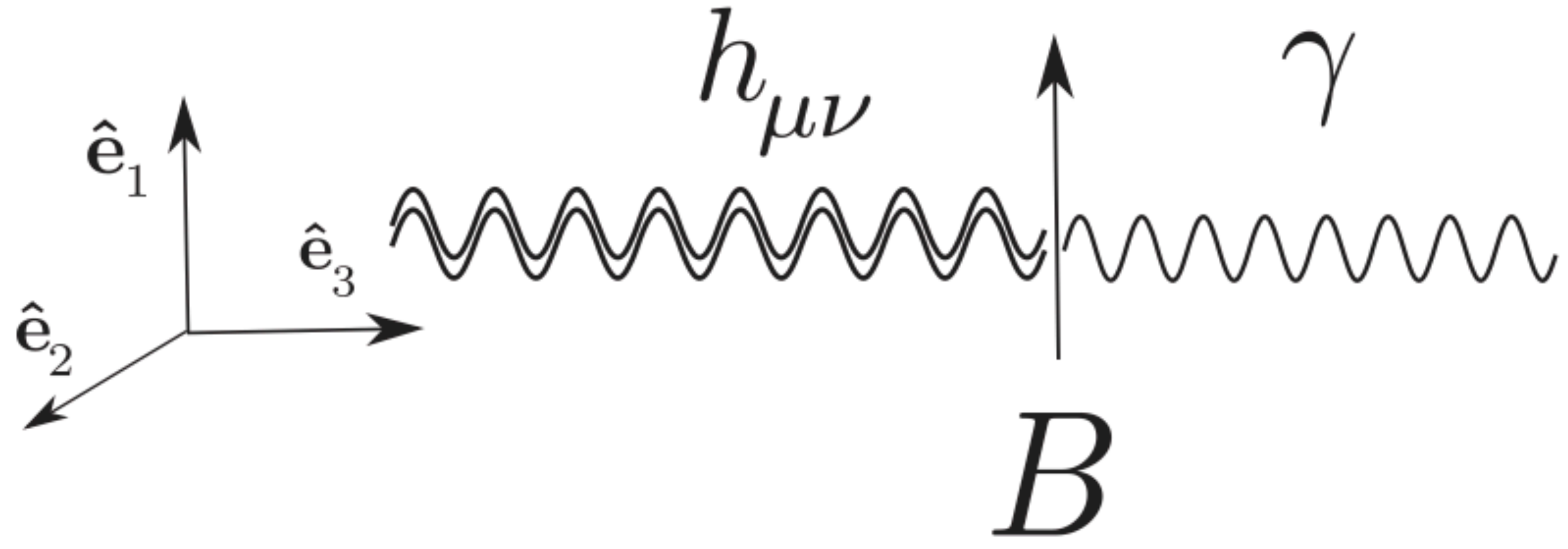
# 2. High-Frequency Gravitational Waves

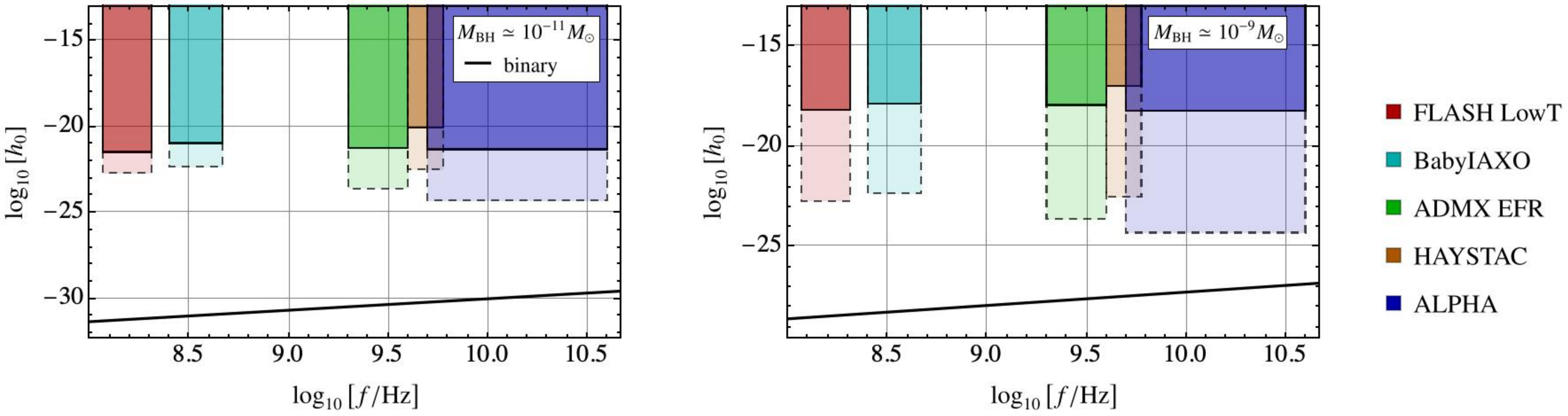
# High-frequency gravitational waves

Inverse Gertsenshtein effect (see e.g. Camilo Garcia work)

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



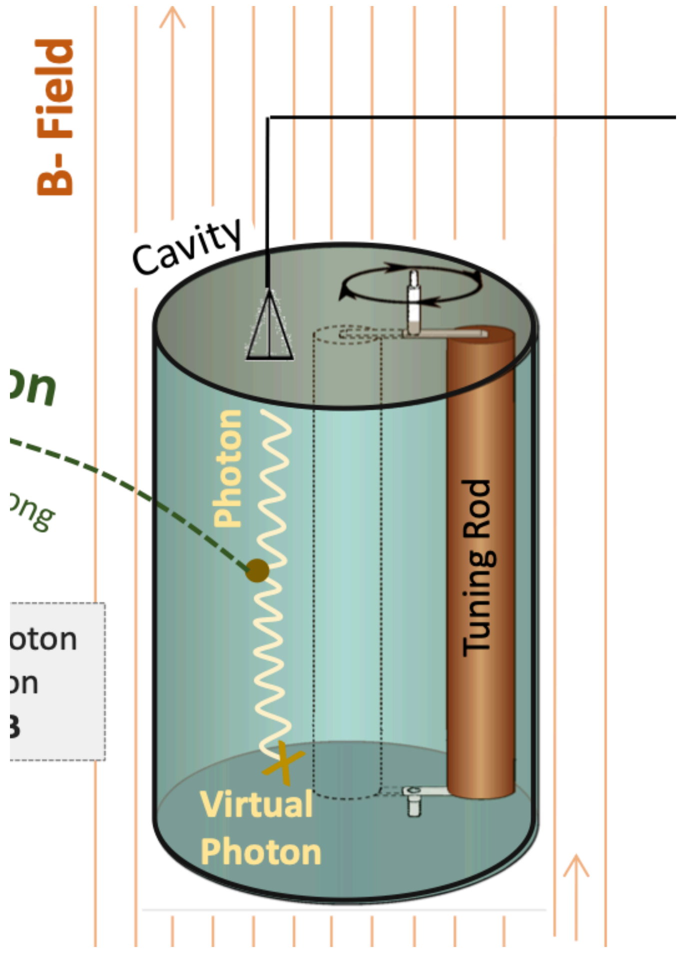



Gatti, **LV**, Zantedeschi 2403.18610, PRD

# High-frequency gravitational waves

Vs.

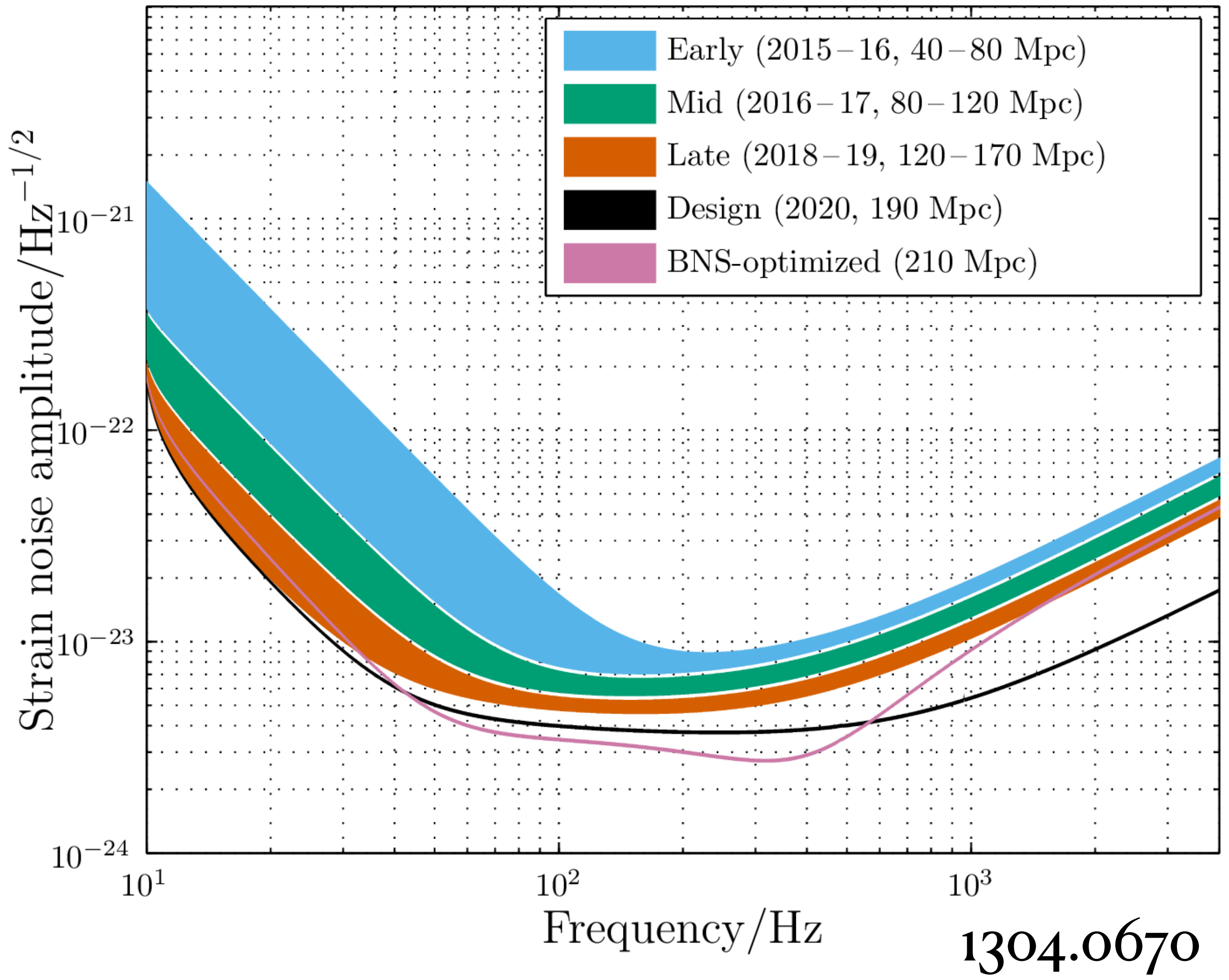



Cavities resonate at much higher frequencies than those in LIGO/VIRGO/KAGRA

Gatti, **LV**, Zantedeschi
[2403.18610](2403.18610)

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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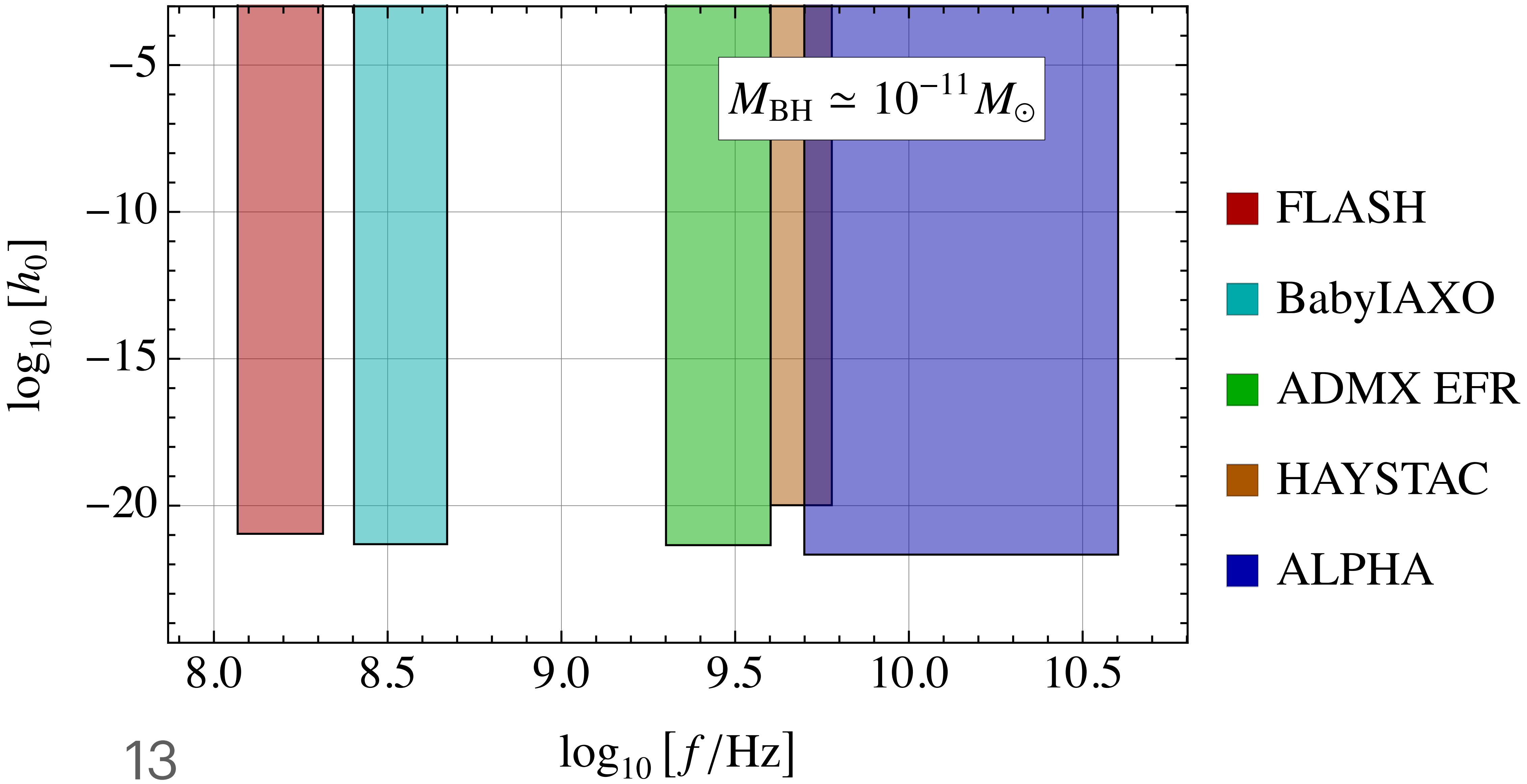


# High-frequency gravitational waves

Open theory questions, see for more: Gatti, **LV**, Zantedeschi 2403.18610

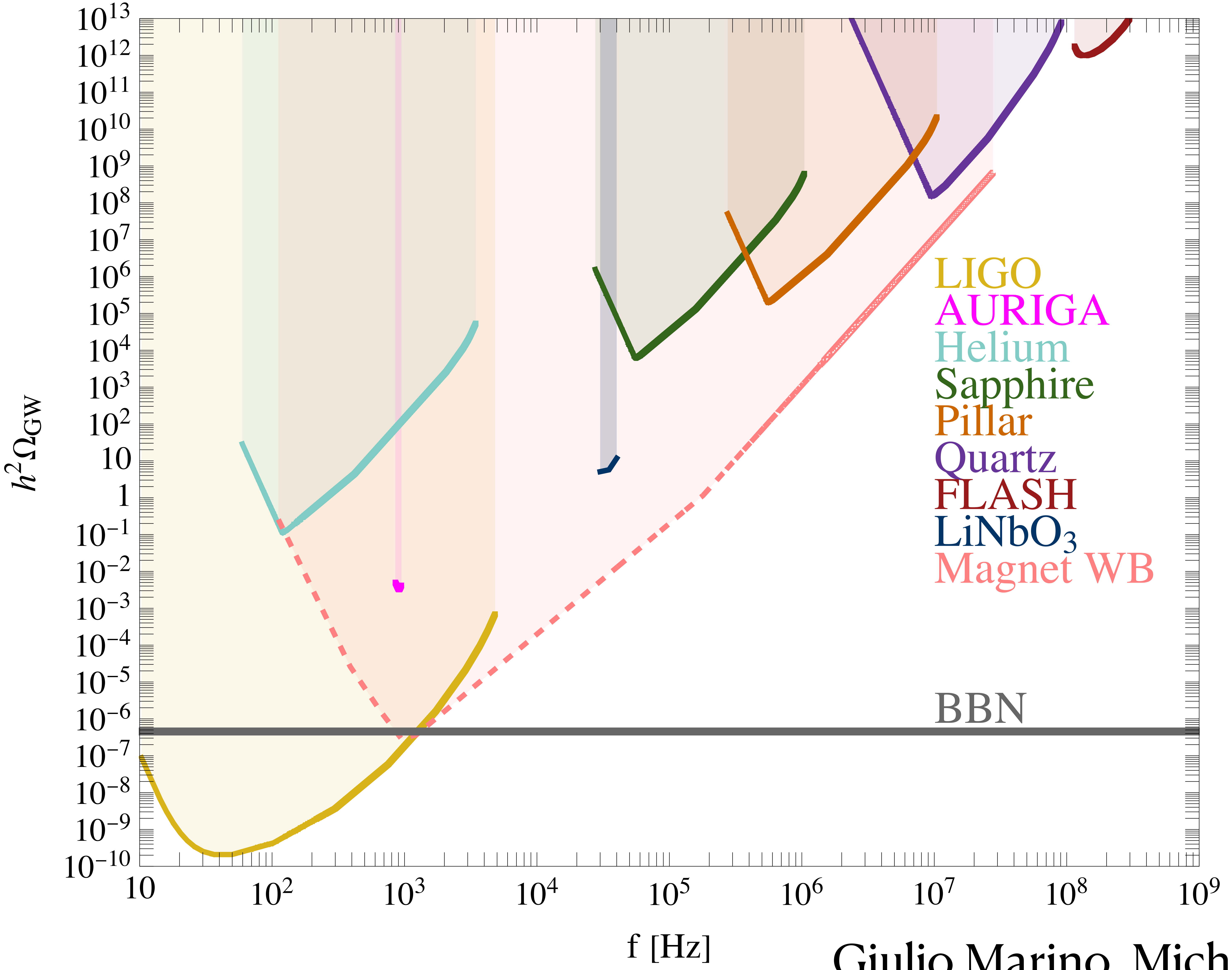
- How precisely can we infer the signal geometry using a single cavity?

- Multiple cavities help distinguishing between spin-0, spin-1, or spin-2 (pseudo-)fields and provide noise reduction

- Further work needed to characterize coherent versus stochastic signals, as well as continuous versus transient signals.

- Nevertheless, any potential detection would unequivocally point to new physics of astrophysical origin.

# High-frequency gravitational waves

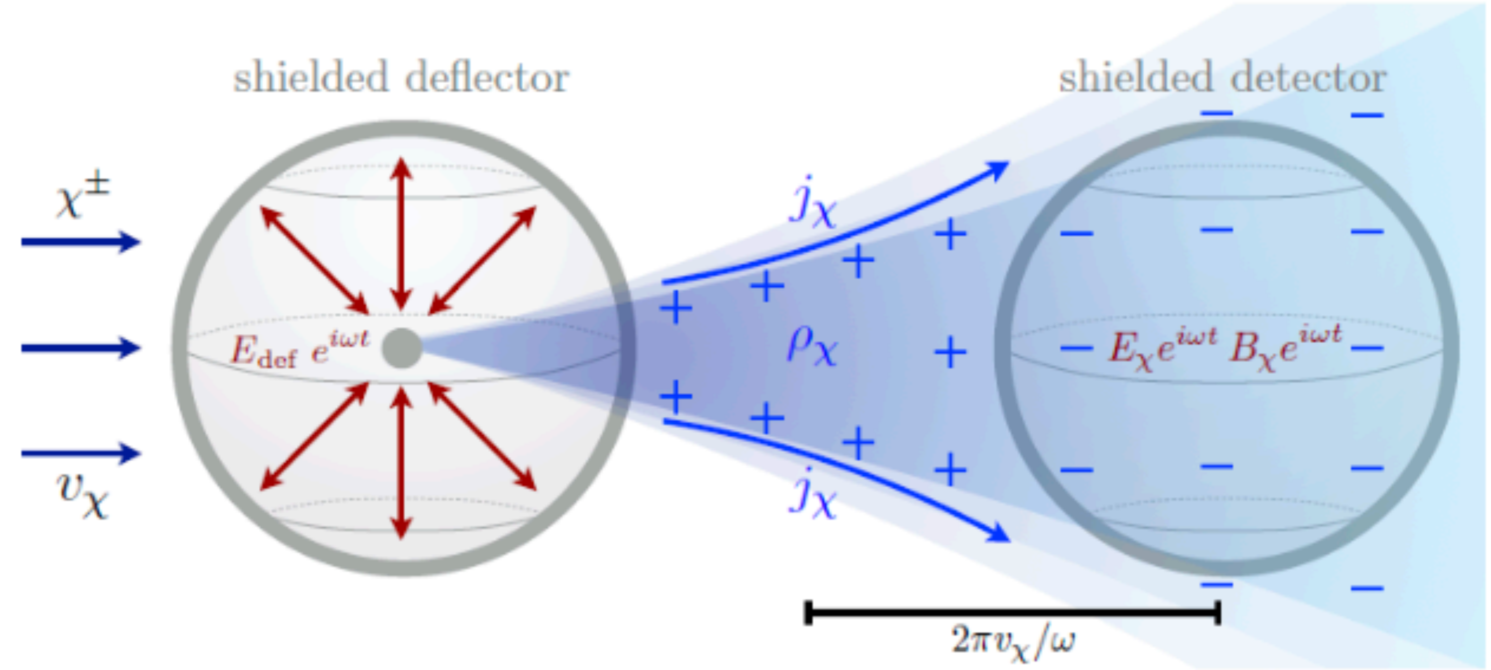



Giulio Marino, Michael Zantedeschi

# 3. Millicharged searches by the Flash cryostat

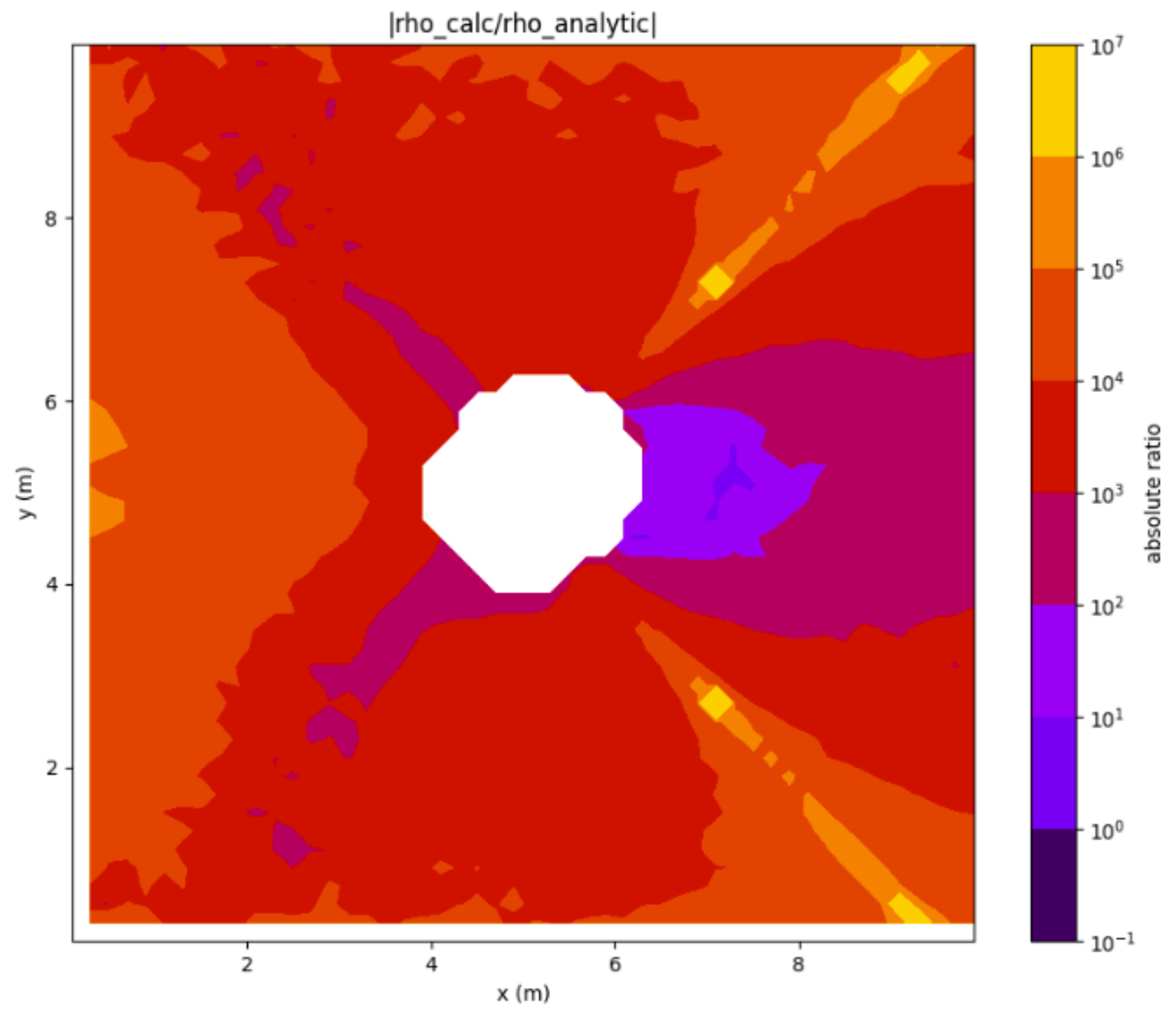
# FLASH Spherical deflector setup

- Consider a wind of millicharged DM particles of mass $m_\chi \sim 1$ eV, charge $q \sim 10^{-9}e$, traveling at a mean speed $v_\chi = 100$ km/s with Maxwell distribution of the velocity vector. The DM wind hits a grounded sphere of radius 1m with an internal central source of alternating electric field with amplitude $10^5$ V/m and frequency 100 kHz, falling quadratically with distance. Using a Monte Carlo simulation we obtain the steady state charge deflection and accumulation.
- The parameters of the simulation are taken from the paper *Direct Deflection of Particle Dark Matter* by A. Berlin et. al. (Phys. Rev. Lett. **124**, 011801, 2020). Their paper presents a diagram of the experimental setup:



# MC Simulation

- The cited paper presents an analytical formula for the deflected charge density of DM particles - equation (S25). We test this equation with the MC simulation and the ratio between the analytical and the simulation result is plotted on the graph here:



# Comments

- It can be noted that the analytic result fails the most along the diagonals.
- These results are strongly dependent on the DM charge, the DM mass and the particle number density, all constrained by cosmological considerations. For various parameters we might have better/worse match between the models.
- The agreement between the formula provided and the MC simulation is best for short distances.
- Specific parameters used for calculations in the Berlin et. al. paper are not provided, so we cannot have quantitative conclusion on the analyitical model applicability.