ALPHA PLASMA EXPERIMENT

See 2210.00017

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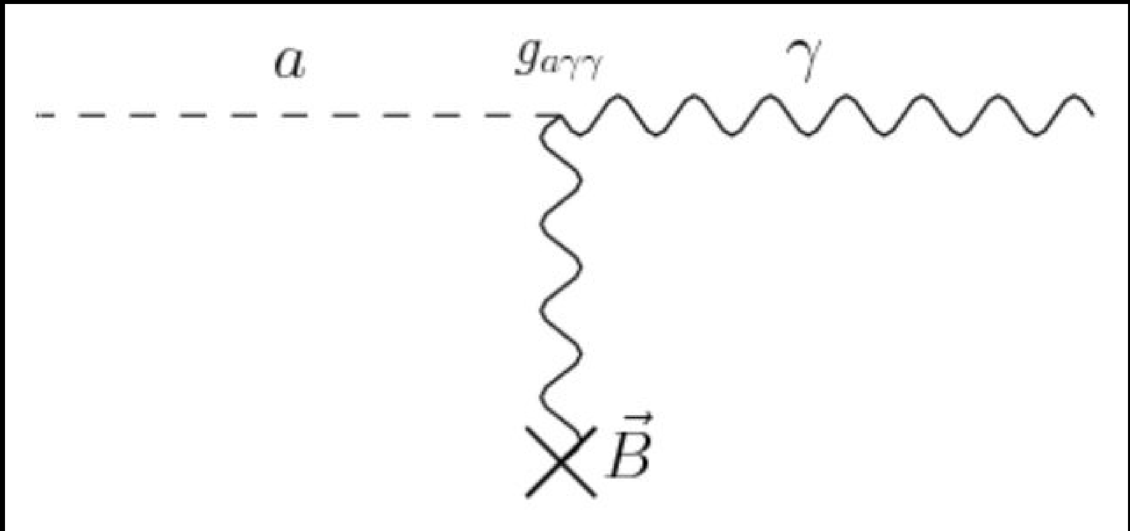
AXION-PHOTON CONVERSION

$$\mathcal{L} = -\frac{g_{a\gamma}}{4} F_{\mu\nu}\tilde{F}^{\mu\nu} a = g_{a\gamma}\vec{E}\cdot\vec{B}a,$$



- Important for detection
- Generic feature of ALPs
- $P_{a\gamma}$ drops with the ALP energy

THE CONVERSION PROBABILITY

$$\mathcal{A}_{\gamma_i \to a} = -i\frac{g_{a\gamma}}{2}\int_{-\infty}^{\infty} d\rho\, \mathrm{u}_{T,i} \cdot \mathrm{B}(\rho \mathrm{u}) e^{-i\Phi(\rho)}$$

$$\Phi(\rho) = \int_0^{\rho} d\rho' \, \frac{m_a^2 - \omega_{\mathrm{pl}}^2}{2\omega}$$

- This is the conversion probability at the lowest order
- Magnetic field and plasma frequency impact the conversion probabilty

ENHANCING THE CONVERSION PROBABILITY

$$\Phi(\rho) = \frac{m_a^2}{2\omega}\rho$$

$$\mathcal{A}_{\gamma_i \to a} = -i\frac{g_{a\gamma}}{2}\int_{-\infty}^{\infty} d\rho\, B_T \cos(\Delta_0 \rho) e^{-i\frac{m_a^2}{2\omega}\rho}$$

- Oscillating B can resonate with the ALP mass and increase the conversion probability
- Breaking translation invariance makes the conversion possible

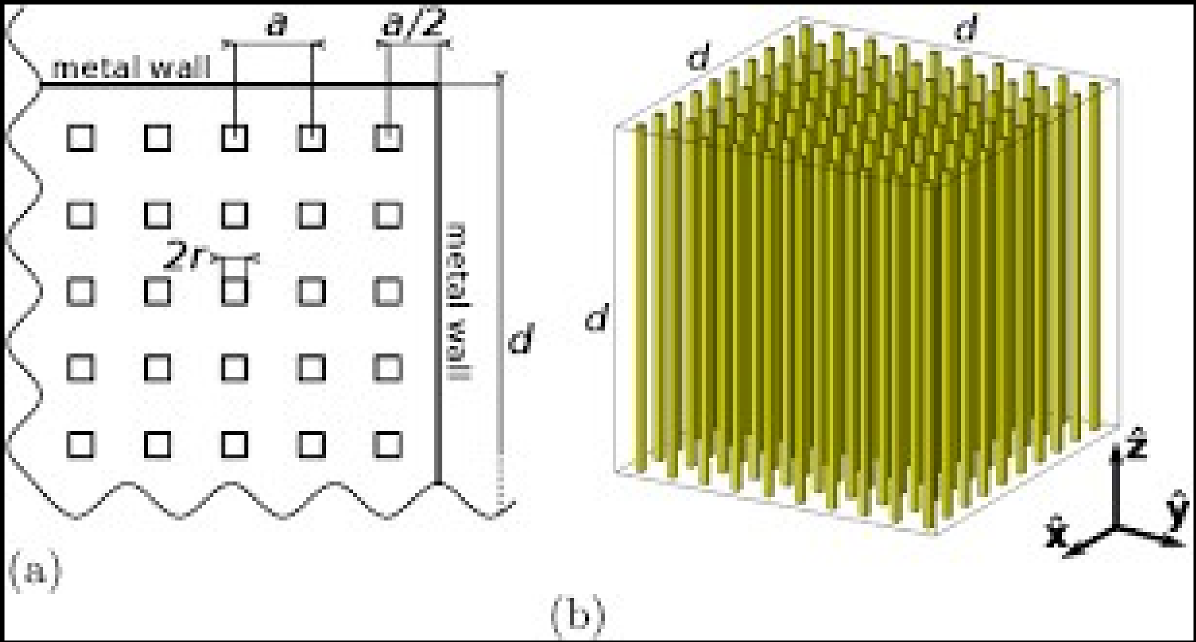
ENHANCING THE CONVERSION PROBABILITY

$$\mathcal{A}_{\gamma_i \to a} = -i \frac{g_{a\gamma}}{2} \int_{-\infty}^{\infty} d\rho \, B_T e^{-i \frac{m_a^2 - \omega_{\mathrm{pl}}^2}{2\omega} \rho}$$

- Match plasma frequency and ALP mass
- We need a tunable plasma frequency

WIRE ARRAY METAMATERIAL

See 2203.13945

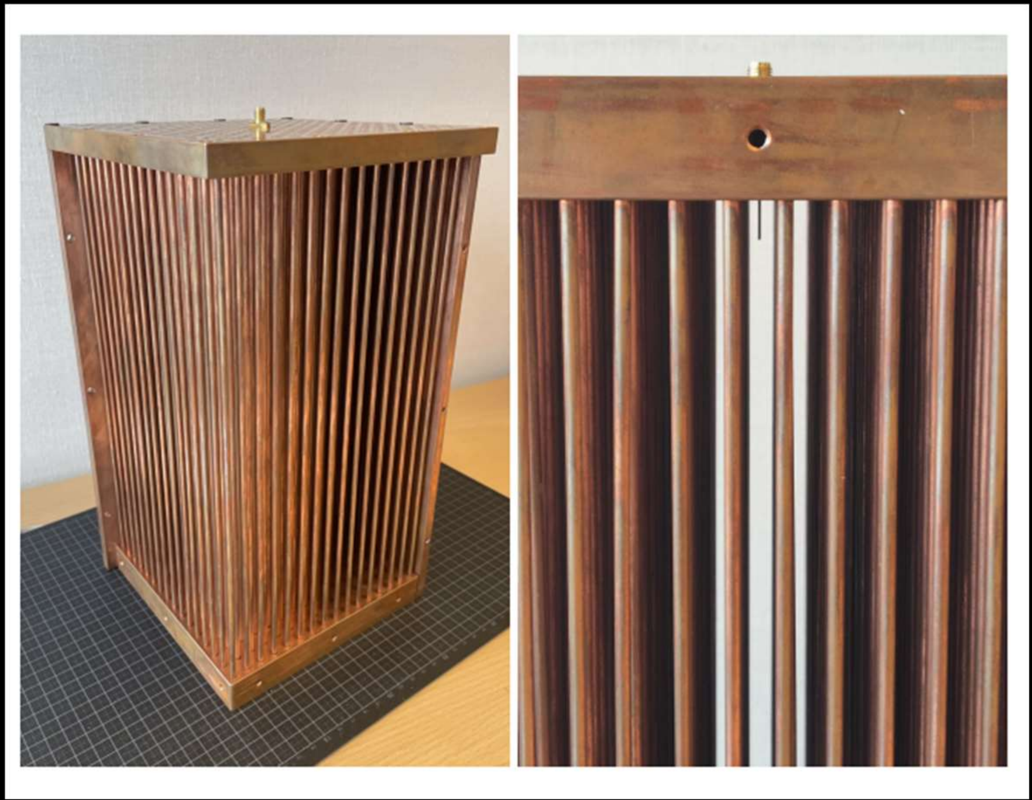


- Plasma frequency given in terms of

$$\omega_{\mathrm{pl}}^2 \sim \frac{1}{a^2 \ln\left(\frac{a}{r}\right)}$$

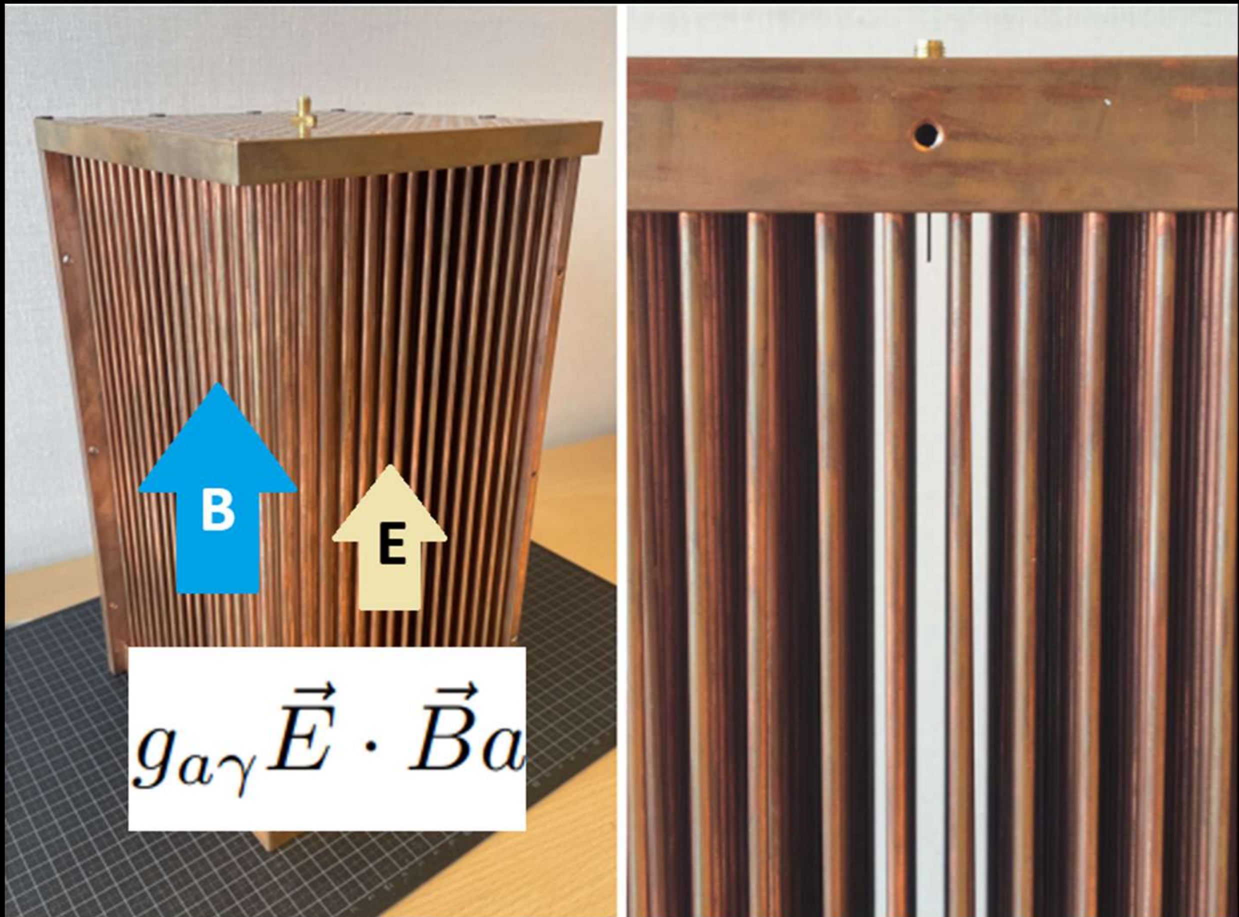
Where a is the spacing and r the tickness of the wires

THE PROTOTYPE



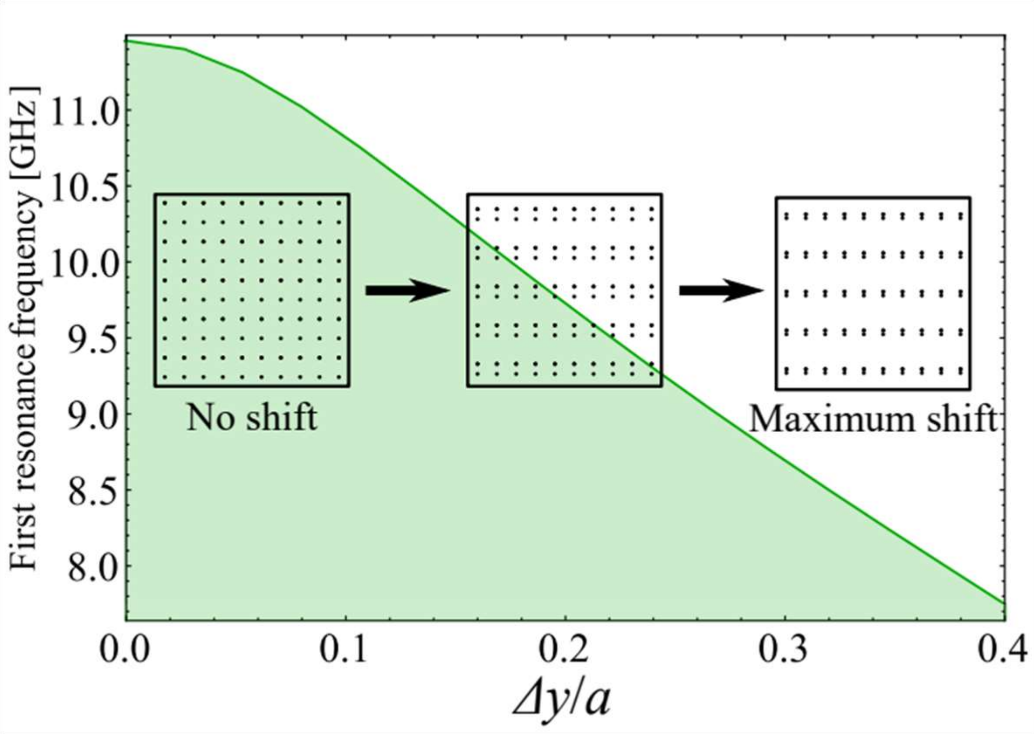
- Anisotropic material, vacuum for modes propagating along x and y
- Boundary conditions: closed by a conductor

THE PROTOTYPE



$$\hat{\mathbf{z}}\cdot\nabla_t\times\mathbf{B}_t = -i\omega\epsilon_z E_z - i\omega g_{a\gamma} a B_e\,,$$
$$\hat{\mathbf{z}}\cdot\nabla_t\times\mathbf{E}_t = i\omega B_z\,,$$
$$\hat{\mathbf{z}}\times\frac{\partial\mathbf{B}_t}{\partial z} + \nabla_t B_z\times\hat{\mathbf{z}} = -i\omega\mathbf{E}_t\,,$$
$$\hat{\mathbf{z}}\times\frac{\partial\mathbf{E}_t}{\partial z} + \nabla_t E_z\times\hat{\mathbf{z}} = i\omega\mathbf{B}_t\,.$$

CAVITY TUNING



- Move two parallel sets of wires to change the spacing
- Simple and efficient to span a factor of a few GHz in frequency

THE READOUT

Small E proportional to g_ag

$$E_z = -\frac{a g_{a\gamma} B_e}{\epsilon_z} + \frac{a g_{a\gamma} B_e}{\epsilon_z} \frac{J_0(\sqrt{\epsilon_z} r \omega)}{J_0(\sqrt{\epsilon_z} R \omega)},$$

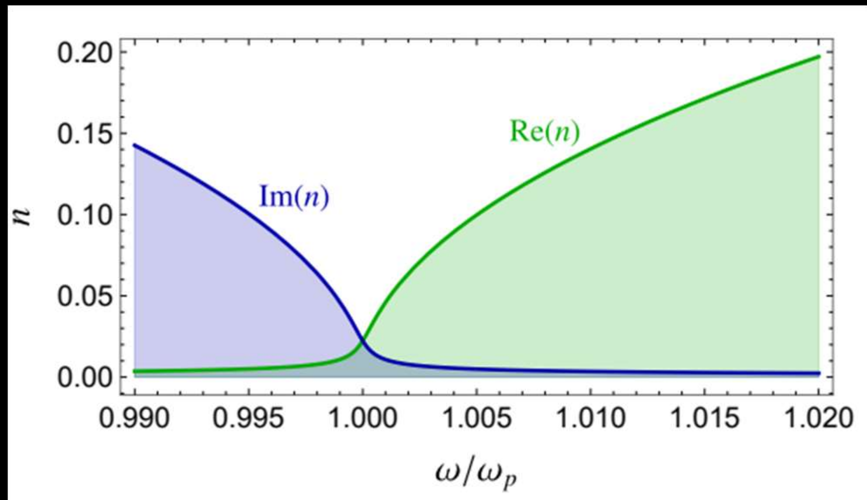
$$\epsilon = 1 - \frac{\omega_p^2}{\omega^2 + i\omega\Gamma_p} \simeq 1 - \frac{\omega_p^2}{\omega^2} + i\frac{\Gamma_p \omega_p^2}{\omega^3},$$

Energy deposited by axions

$$P \sim \boxed{\frac{\Gamma_a}{\Gamma_t}} \epsilon_z'' \int \boxed{|E|^2} dV$$

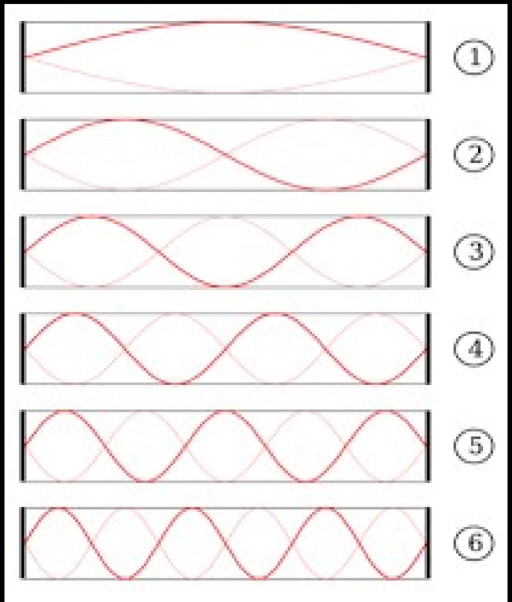
Energy in the antenna

- How to detect the induced electric field?



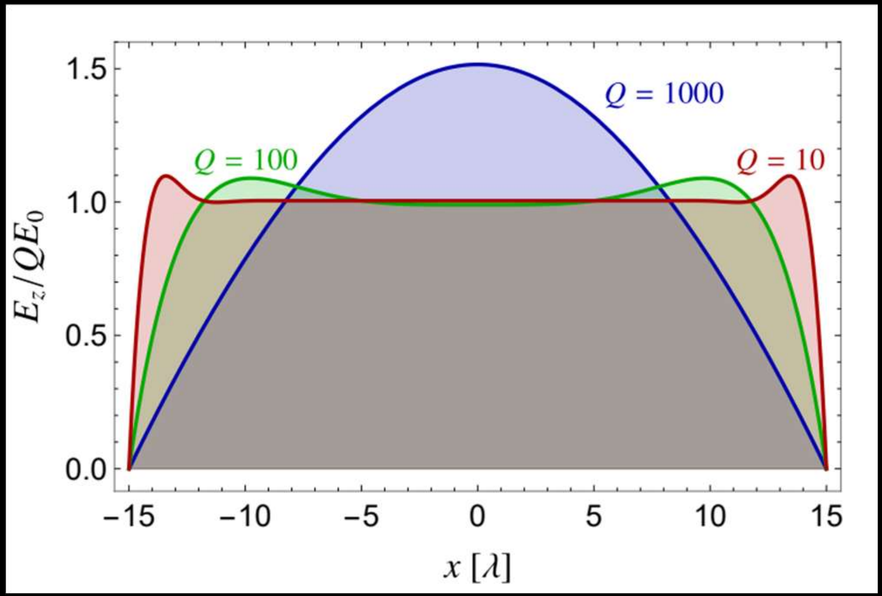
HOW IS THE INDUCED E-FIELD?

Standing wave in a cavity



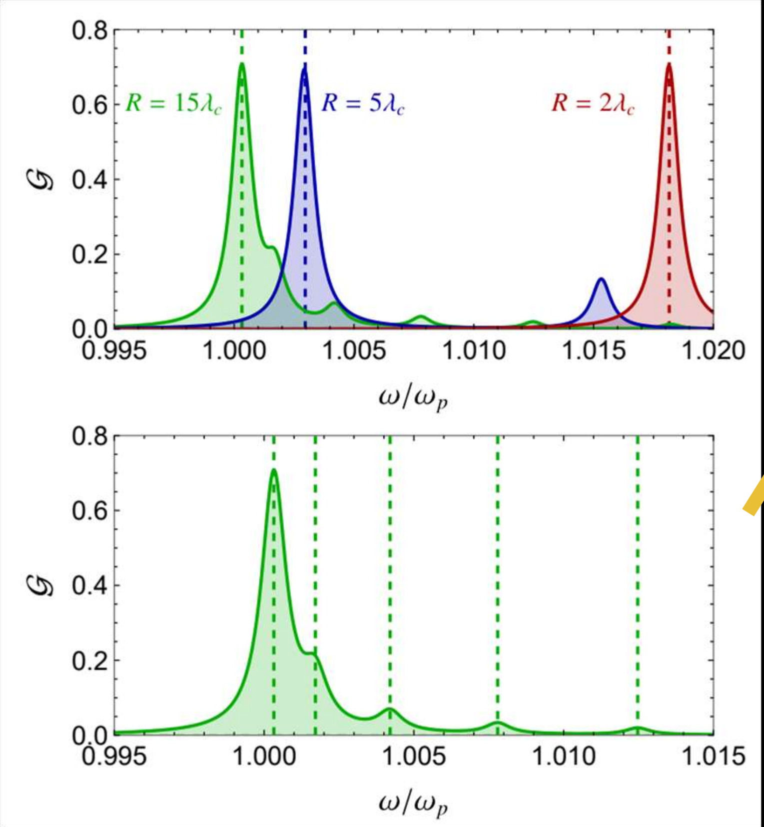
vs

Modes in a lossy medium



RESONANT MODES

Geometry factor for a cylindrical plasma



$$P_s = \kappa \mathcal{G} V \frac{Q}{m_a} \rho_a g_{a\gamma}^2 B_e^2 ,$$

- Resonance moved away from the plasma frequency
- Some modes overlap, careful with axion coupling to all the modes

STRUCTURE OF THE MODES

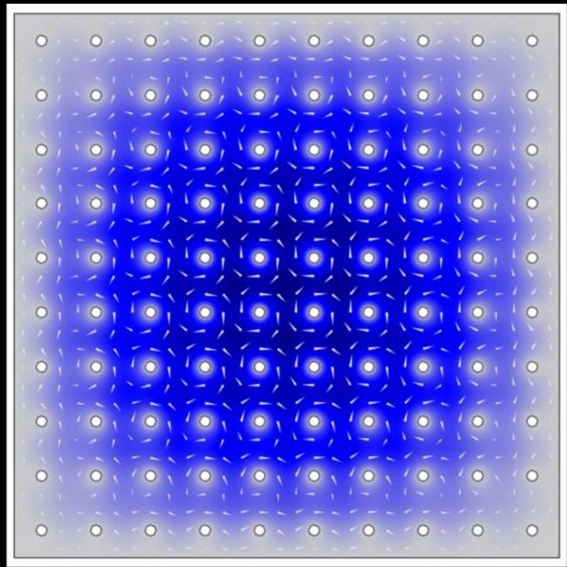
- B_T = TM modes, excited by axions
- E_z=0= TE modes, not excited by axions

$$\overset{B_T}{\nabla\times\mathbf{B}_a} - \overset{E_z}{\dot{\mathbf{E}}_a} = -g_{a\gamma\gamma}\left(\cancel{\mathbf{E}_0\times\nabla a} - \dot{a}\mathbf{B}_0\right)\,,$$

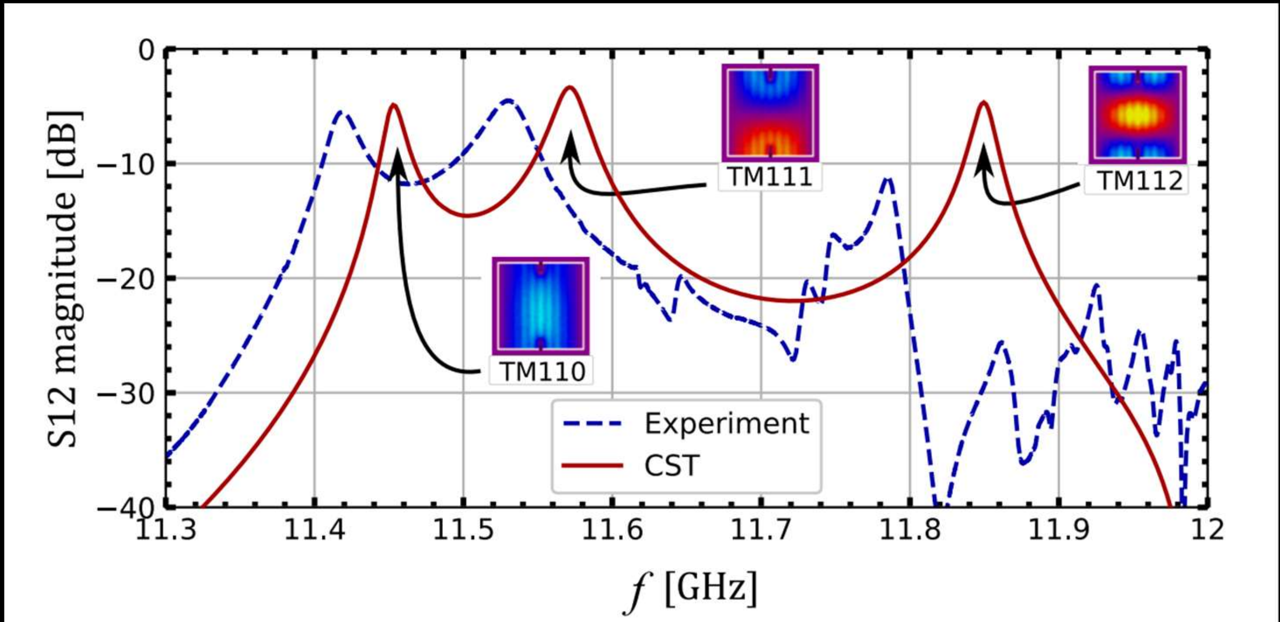
$$\nabla\times\mathbf{E}_a + \dot{\mathbf{B}}_a = 0\,,$$

$$\nabla\cdot\mathbf{B}_a = 0\,,$$

$$\nabla\cdot\mathbf{E}_a = -g_{a\gamma\gamma}\,\mathbf{B}_0\cdot\nabla a\,,$$



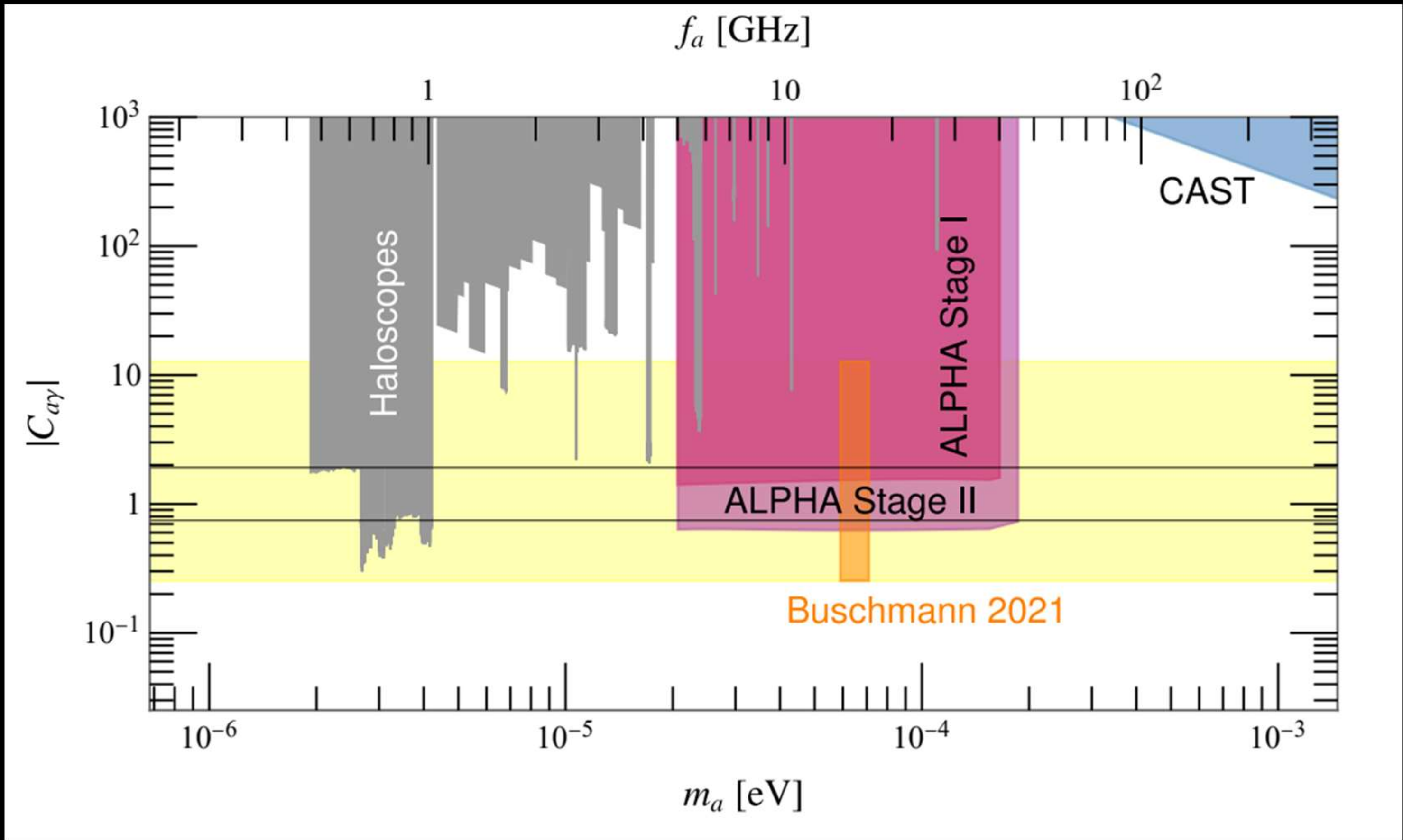
SIMULATION VS REALITY



- The agreement can be improved by better simulations

See 2203.10083

THE REACH



- Reaching the QCD axion band in 2yr of data taking
- Stage II upgraded detector design reaching the SQL

THANKS FOR YOUR ATTENTION!

Stockholm University

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Postdoctoral Fellow in Experimental Astroparticle Physics

https://www.su.se/department-of-physics/about-the-department/work-with-us/postdoctoral-fellow-in-experimental-astroparticle-physics-1.698316