MADMAX - Theoretical Foundations

Theory: Astro

Frank Daniel Steffen

Project Review
Max-Planck-Institut für Physik
Munich, December 18, 2017

The Theoretical Astroparticle Physics Group

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(until Sep 17)

Edoardo Vitagliano

Theoretical Astroparticle Physics Research Topics

- particle dark matter candidates

axions

➜ this talk

sterile neutrinos

axinos

gravitinos

- supernova neutrinos

neutrino oscillations in dense media

- physics beyond the standard model

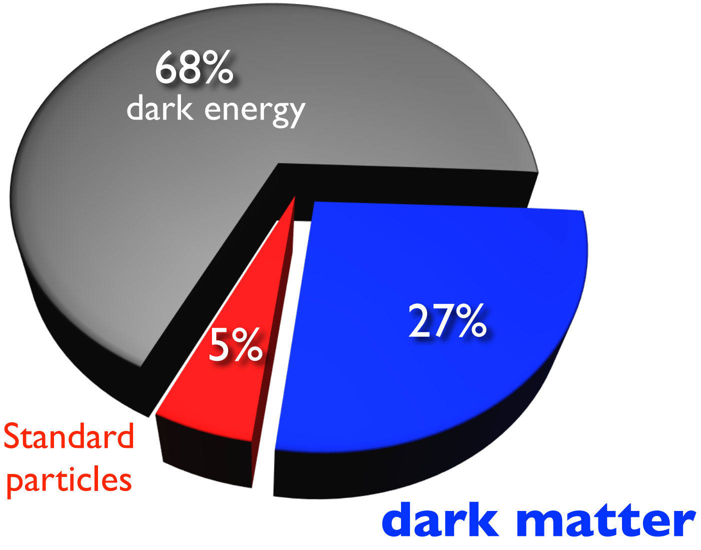
SUSY

neutrino masses

lepton-flavor violation (LFV)

Cosmology

- 2013: Planck CMB sky map



- Cosmological puzzles

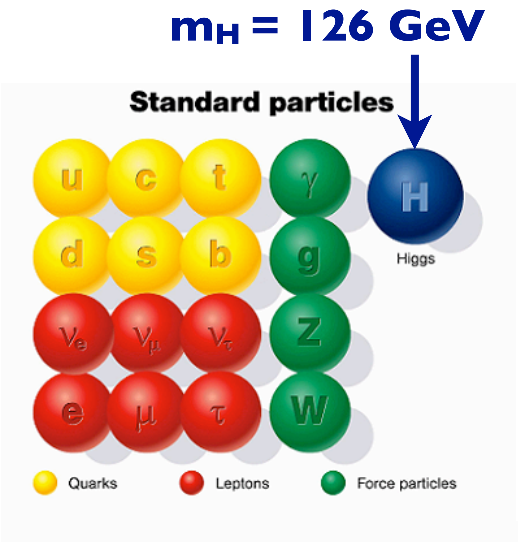
? Matter-Antimatter Asymmetry

? Particle Identity & Origin of Dark Matter

? Dark Energy = Cosmological Constant

Particle Physics

- 2012: LHC Higgs-boson discovery



- Intrinsic fine tuning problems

? Hierarchy Problem ($m_H << M_{Planck}$)

? Strong CP Problem ($\Theta_{QCD} << 1$)

? Small Neutrino Masses ($m_\nu << m_H$)

→ axions are well-motivated dark matter candidates

The strong CP problem

QCD Lagrangian - most general, gauge invariant form

$$\mathcal{L} = -\frac{1}{4}G^a_{\mu\nu}G^{a,\mu\nu} + \bar{q}(i\gamma_\mu D^\mu - \mathcal{M}_q)q + \frac{\alpha_s}{8\pi}\theta G^a_{\mu\nu}\tilde{G}^{a,\mu\nu}$$

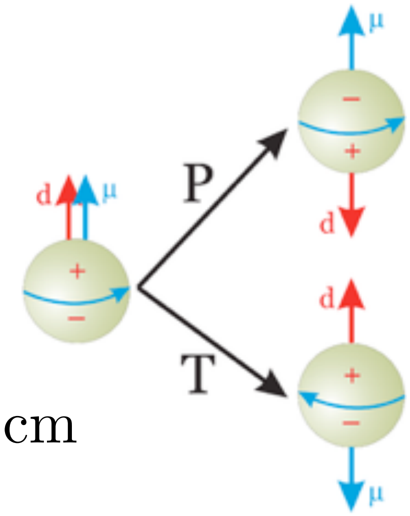
theta parameter

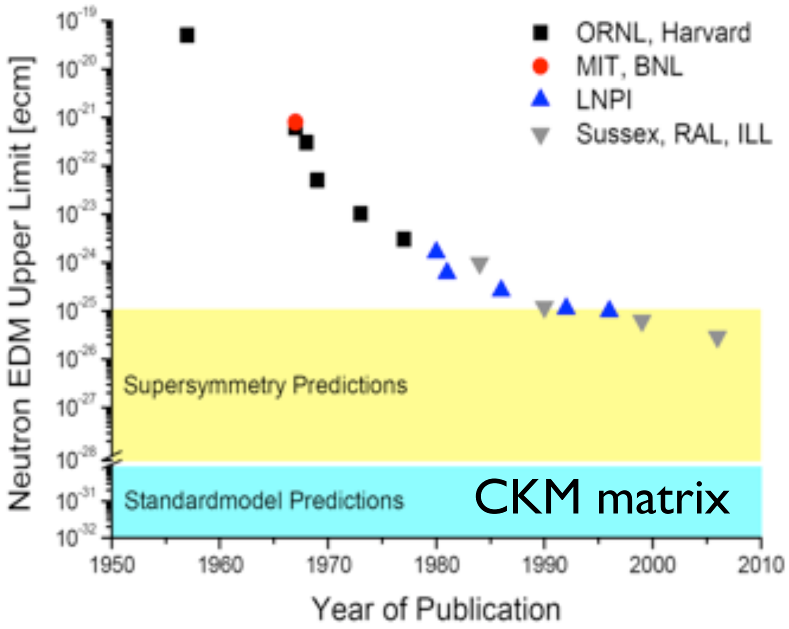
$$\bar{\theta} = \theta + \arg\det\mathcal{M}_q$$

quark mass matrix

$\propto \mathbf{E}^a \cdot \mathbf{B}^a$

neutron electric dipole moment (nEDM)





CKM matrix

$$|d_n| < 2.9 \times 10^{-26}\ e\,\mathrm{cm}$$

$$d_n(\bar{\theta}) \sim \frac{e\bar{\theta}m_u m_d}{(m_u + m_d)m_n^2} \sim 6 \times 10^{-17}\ \bar{\theta}\ e\,\mathrm{cm}$$

$|\bar{\theta}| \lesssim 10^{-9}$ unnaturally small

Peccei-Quinn Mechanism

[Peccei, Quinn, ’77]

QCD vacuum energy ← effective chiral Lagrangian

$$V(\bar{\theta}) = \frac{m_\pi^2 f_\pi^2}{2} \frac{m_u m_d}{(m_u + m_d)^2} \bar{\theta}^2 + \mathcal{O}(\bar{\theta}^4)$$

↑

minimum for zero theta parameter

Idea: Promote theta to a dynamical field with shift symmetry

$$a \to a + \text{constant}$$

↑

broken only by
anomalous CP-viol.

Eliminate theta by shift

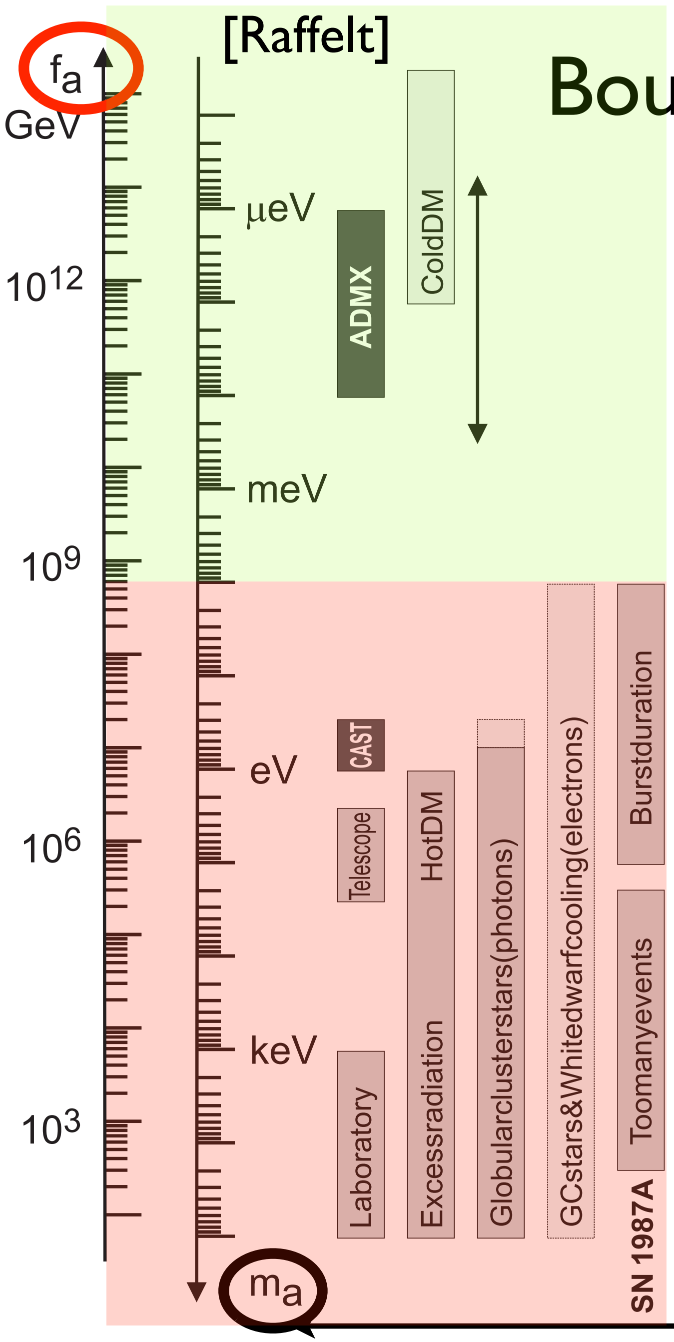
$$a(x) \to \overline{a}(x) \equiv a(x) + \bar{\theta} f_a$$

QCD dynamics: $\langle \overline{a} \rangle = 0$ → P,T & CP conserved

$$\mathcal{L} \supset \frac{1}{2} \partial_\mu a \, \partial^\mu a - \frac{\alpha_s}{8\pi} \left(\bar{\theta} + \frac{a}{f_a} \right) G^b_{\mu\nu} \tilde{G}^{b,\mu\nu} - \frac{\alpha}{8\pi} C_{a\gamma} \frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu} + \ldots$$

elementary particle excitation around the VEV → **axion**
pseudo Nambu-Goldstone boson [Weinberg ’78, Wilczek ’78]

Constraints on the Peccei-Quinn (PQ) scale f_{PQ}



Bounds from Axion Searches

Cosmological Axion Bounds

Astrophysical Axion Bounds

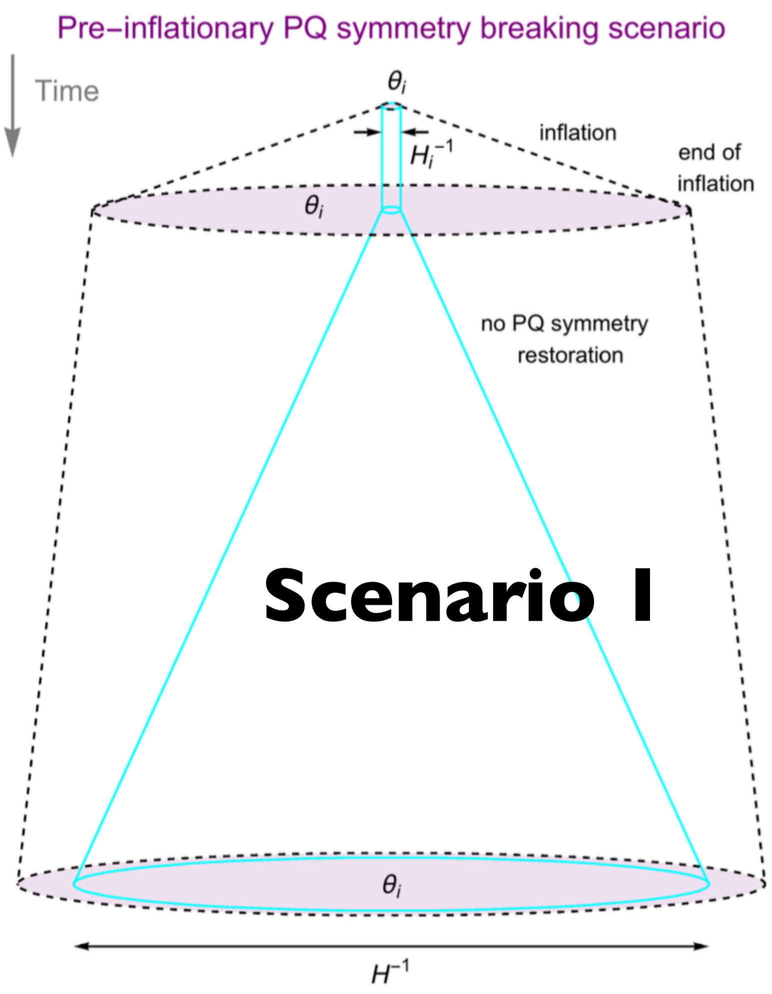
Peccei-Quinn Scale

$$f_a \gtrsim 6 \times 10^8 \,\mathrm{GeV}$$

Axion Mass

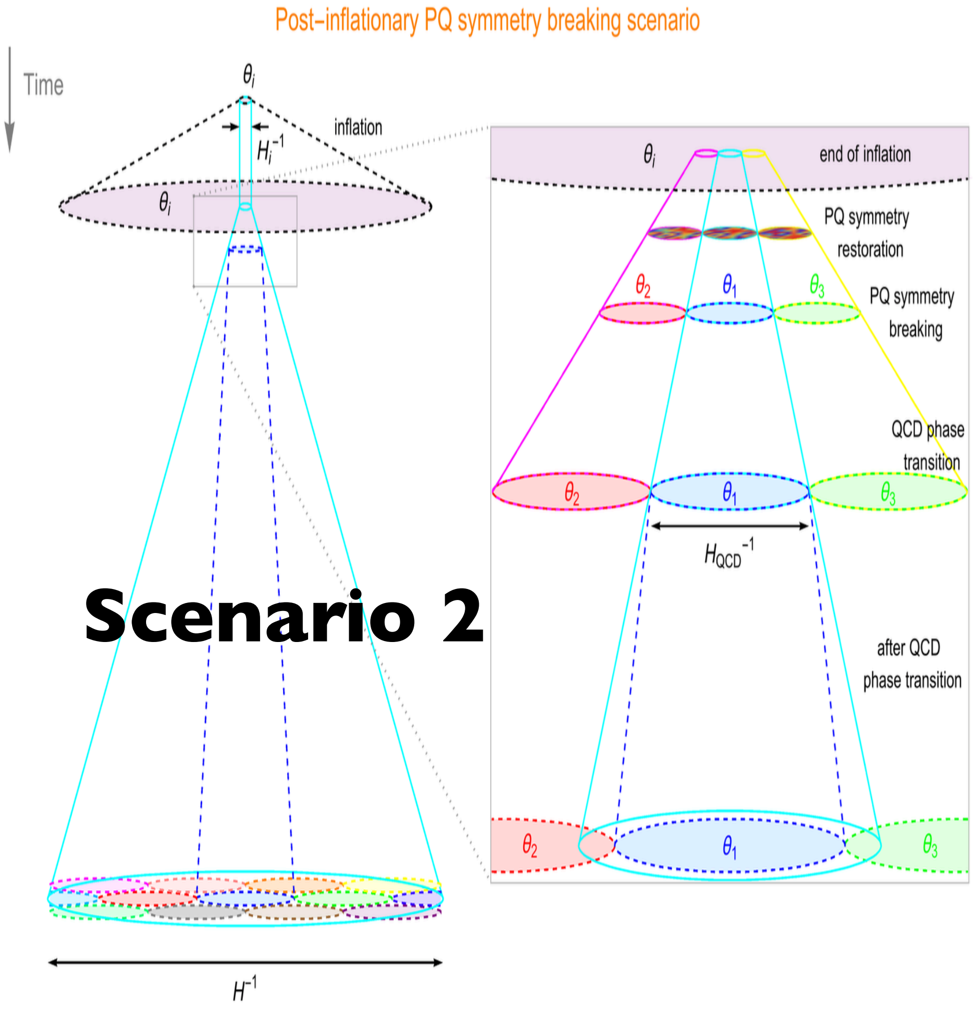
$$m_a \simeq 0.6 \;\mathrm{meV}\,(10^{10}\,\mathrm{GeV}/f_{\mathrm{PQ}})$$

What is the axion dark matter mass?



Scenario 1

[Saikawa]

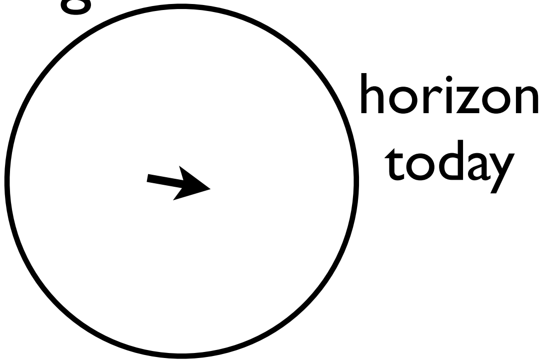


Scenario 2

[Saikawa]

Scenario 1

Peccei-Quinn symm.
breaking before inflation



$$\Omega_a^{\mathrm{MIS}} h^2 \sim 0.15\, \theta_i^2 (f_{\mathrm{PQ}}/10^{12}\,\mathrm{GeV})^{7/6}$$

anthropical - large f_{PQ} possible

+ thermally prod. axions

+ axion isocurvature fluct.

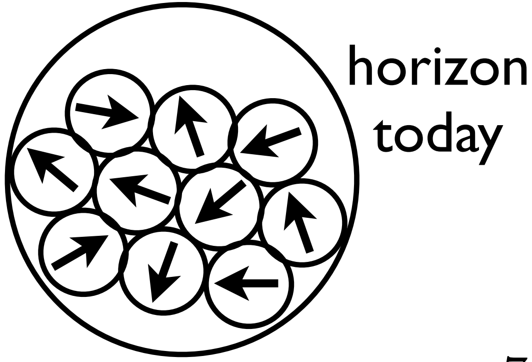
$\updownarrow$

gravitational waves B-modes

origin: inflation vs. dust

Scenario 2

Peccei-Quinn symm.
breaking after inflation



$$\Omega_a^{\mathrm{mis}} h^2 = 2.07\ (f_{a,12})^{7/6}$$

$$\uparrow$$

$$\langle \theta_i^2\, f(\theta_i) \rangle = 2.67\, \frac{\pi^2}{3}$$

[Visinelli, Gondolo'14]

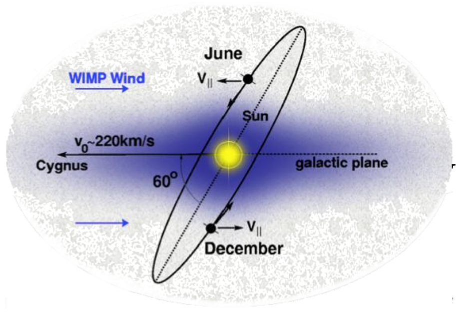
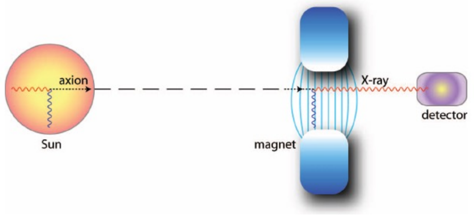
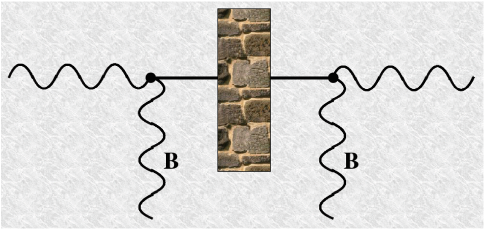
+ thermally prod. axions

+ axions from string decay

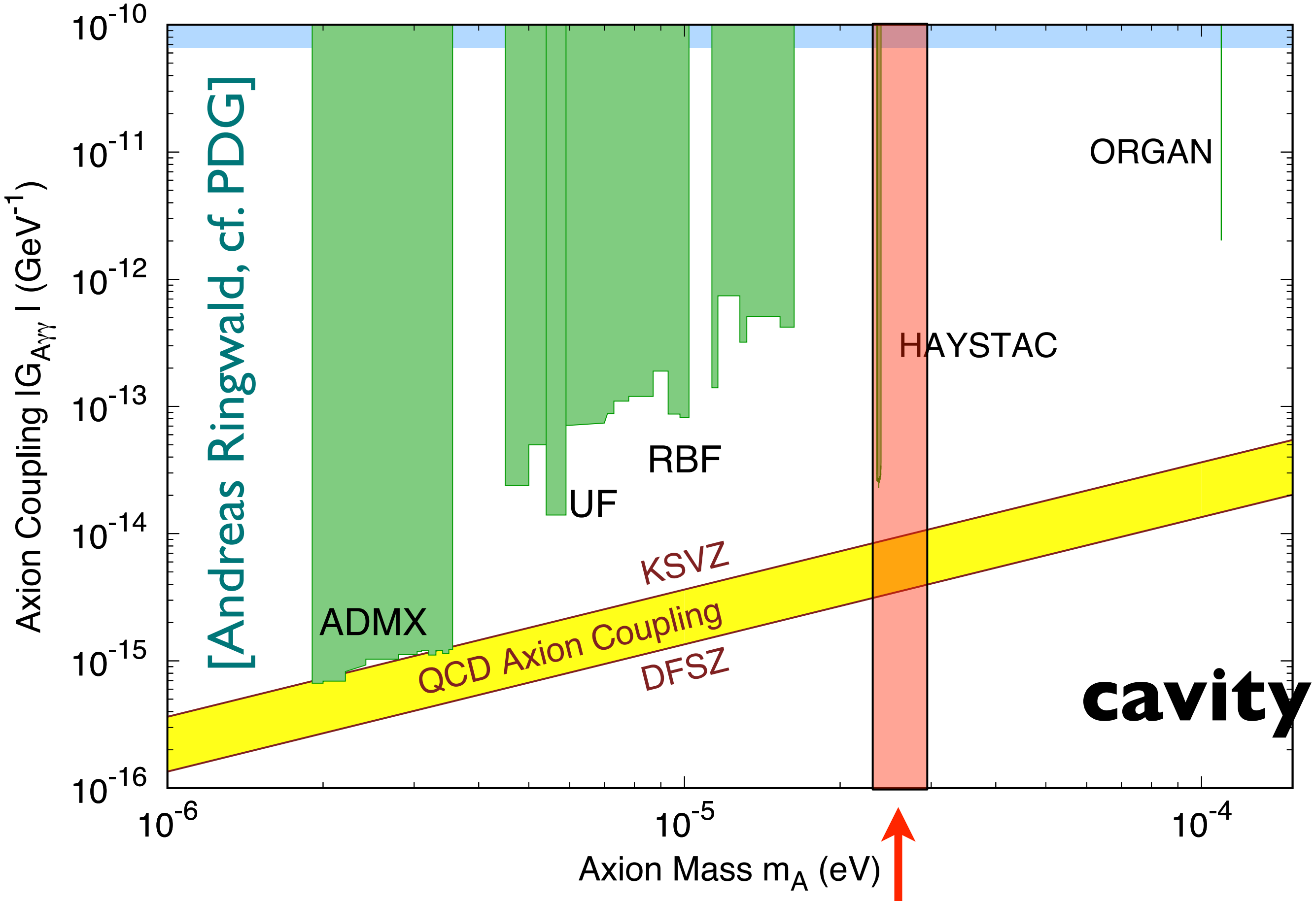
+ axions from domain wall decay

controversial results
O(10) uncertainty

Axion Search Experiments

- Dark Matter Axions 	cavity haloscopes	ADMX, HAYSTAC, ORGAN, CULTASK/CAPP, ORPHEUS
	spin couplings	CASPEr, QUAX
	magnetized mirror	BRASS
	dielectric haloscope	MADMAX + LC-circuit + ABRACADABRA
- Solar Axions 	helioscopes	CAST, TASTE, miniIAXO, IAXO
- Laboratory Axions 	light shining through wall	ALPS, ALPS II
	5th force/torsion balance	ARIADNE

Existing exclusion limits today



[Andreas Ringwald, cf. PDG]

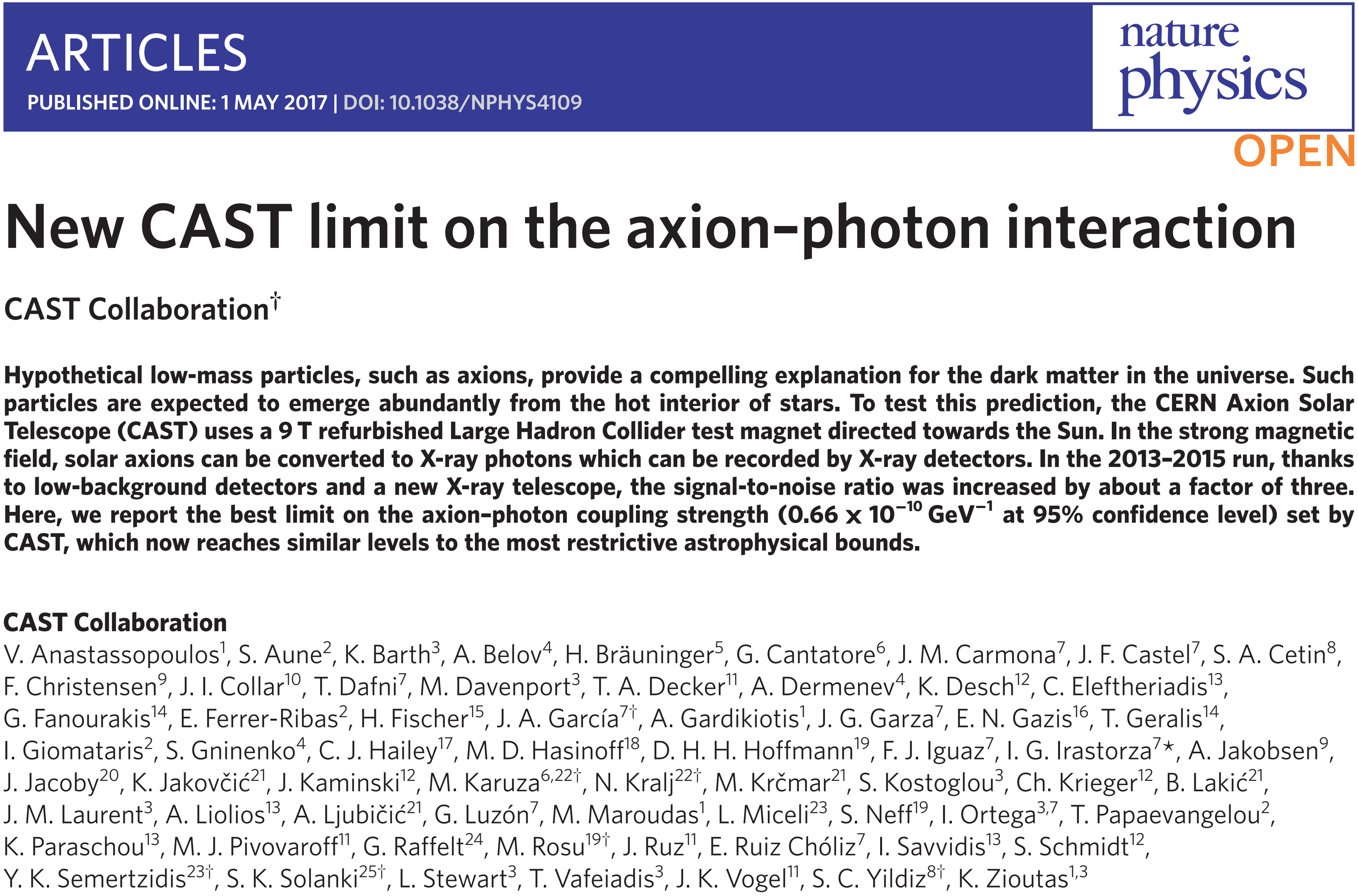
CAST
helioscope

cavity haloscopes

Scenario 2

$$m_A = 26.2 \pm 3.4\,\mu\text{eV}$$

[Klaer, Moore,'17]



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nature physics
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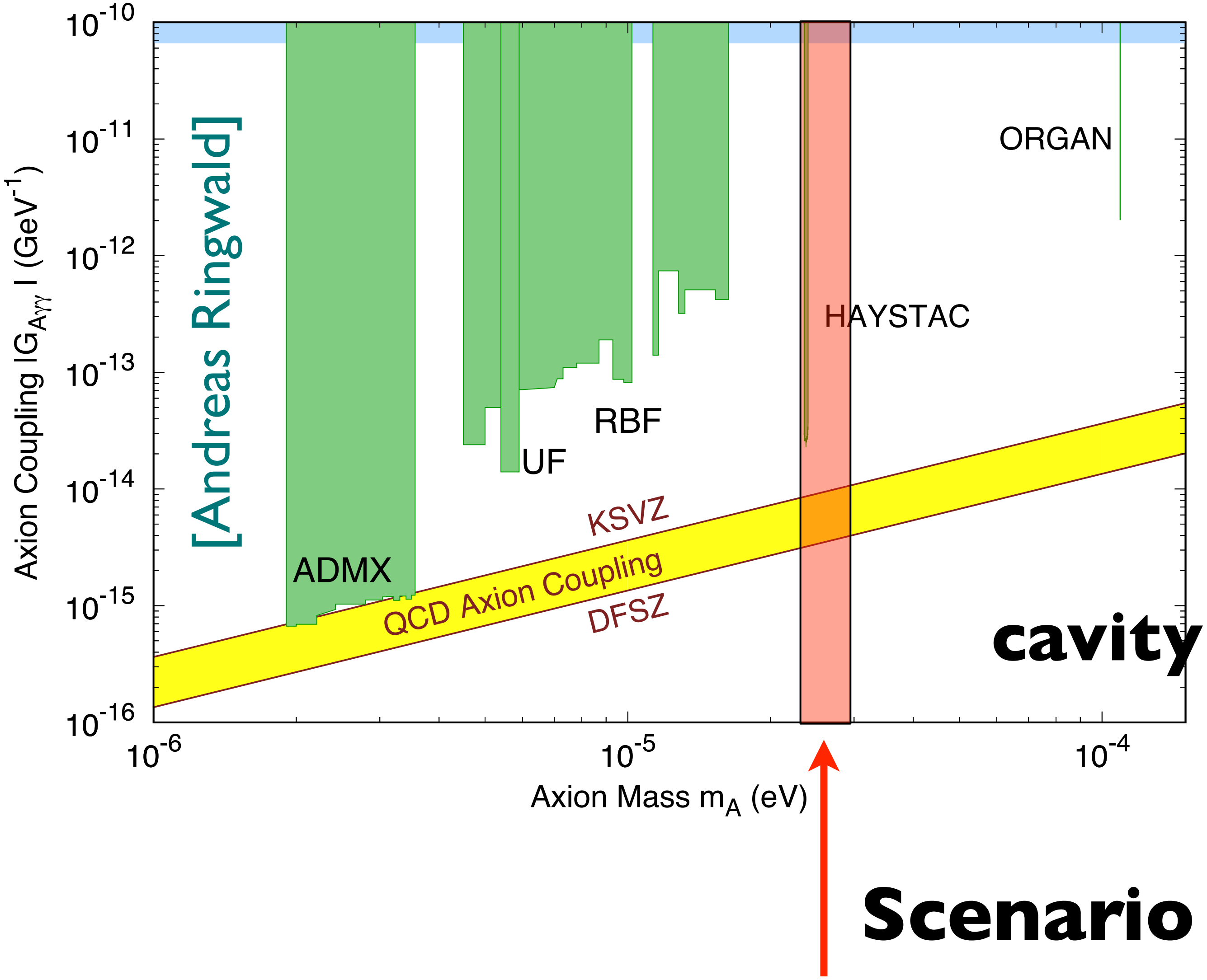
New CAST limit on the axion–photon interaction

CAST Collaboration†

Hypothetical low-mass particles, such as axions, provide a compelling explanation for the dark matter in the universe. Such particles are expected to emerge abundantly from the hot interior of stars. To test this prediction, the CERN Axion Solar Telescope (CAST) uses a 9 T refurbished Large Hadron Collider test magnet directed towards the Sun. In the strong magnetic field, solar axions can be converted to X-ray photons which can be recorded by X-ray detectors. In the 2013–2015 run, thanks to low-background detectors and a new X-ray telescope, the signal-to-noise ratio was increased by about a factor of three. Here, we report the best limit on the axion–photon coupling strength (0.66×10^{-10} GeV^{-1} at 95% confidence level) set by CAST, which now reaches similar levels to the most restrictive astrophysical bounds.

CAST Collaboration
V. Anastassopoulos[1], S. Aune[2], K. Barth[3], A. Belov[4], H. Bräuninger[5], G. Cantatore[6], J. M. Carmona[7], J. F. Castel[7], S. A. Cetin[8], F. Christensen[9], J. I. Collar[10], T. Dafni[7], M. Davenport[3], T. A. Decker[11], A. Dermenev[4], K. Desch[12], C. Eleftheriadis[13], G. Fanourakis[14], E. Ferrer-Ribas[2], H. Fischer[15], J. A. García[7†], A. Gardikiotis[1], J. G. Garza[7], E. N. Gazis[16], T. Geralis[14], I. Giomataris[2], S. Gninenko[4], C. J. Hailey[17], M. D. Hasinoff[18], D. H. H. Hoffmann[19], F. J. Iguaz[7], I. G. Irastorza[7⋆], A. Jakobsen[9], J. Jacoby[20], K. Jakovčić[21], J. Kaminski[12], M. Karuza[6,22†], N. Kralj[22†], M. Krčmar[21], S. Kostoglou[3], Ch. Krieger[12], B. Lakić[21], J. M. Laurent[3], A. Liolios[13], A. Ljubičić[21], G. Luzón[7], M. Maroudas[1], L. Miceli[23], S. Neff[19], I. Ortega[3,7], T. Papaevangelou[2], K. Paraschou[13], M. J. Pivovaroff[11], G. Raffelt[24], M. Rosu[19†], J. Ruz[11], E. Ruiz Chóliz[7], I. Savvidis[13], S. Schmidt[12], Y. K. Semertzidis[23†], S. K. Solanki[25†], L. Stewart[3], T. Vafeiadis[3], J. K. Vogel[11], S. C. Yildiz[8†], K. Zioutas[1,3]

Existing exclusion limits today



CAST
helioscope

cavity haloscopes

Scenario 2

$$m_A = 26.2 \pm 3.4\,\mu\text{eV}$$

[Klaer, Moore,'17]

The dark-matter axion mass

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Abstract. We evaluate the efficiency of axion production from spatially random initial conditions in the axion field, so a network of axionic strings is present. For the first time, we perform numerical simulations which fully account for the large short-distance contributions to the axionic string tension, and the resulting dense network of high-tension axionic strings. We find nevertheless that the total axion production is somewhat *less* efficient than in the angle-averaged misalignment case. Combining our results with a recent determination of the hot QCD topological susceptibility [1], we find that if the axion makes up all of the dark matter, then the axion mass is $m_a = 26.2 \pm 3.4\,\mu\text{eV}$.

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Calculation of the axion mass based on high-temperature lattice quantum chromodynamics

S. Borsanyi[1], Z. Fodor[1,2,3], J. Guenther[1], K.-H. Kampert[1], S. D. Katz[3,4], T. Kawanai[2], T. G. Kovacs[5], S. W. Mages[2], A. Pasztor[1], F. Pittler[3,4], J. Redondo[6,7], A. Ringwald[8] & K. K. Szabo[1,2]

Unlike the electroweak sector of the standard model of particle physics, quantum chromodynamics (QCD) is surprisingly symmetric under time reversal. As there is no obvious reason for QCD being so symmetric, this phenomenon poses a theoretical problem, often referred to as the strong CP problem. The most attractive solution for this[1] requires the existence of a new particle, the axion[2,3]—a promising dark-matter candidate. Here we determine the axion mass using lattice QCD, assuming that these particles are the dominant component of dark matter. The key quantities of the calculation are the equation of state of the Universe and the temperature dependence of the topological susceptibility of QCD, a quantity that is notoriously difficult to calculate[4–8], especially in the most relevant high-temperature region (up to several gigaelectronvolts). But by splitting the vacuum into different sectors and re-defining the fermionic determinants, its controlled calculation becomes feasible. Thus, our twofold prediction helps most cosmological calculations[9] to describe the evolution of the early Universe by using the equation of state, and may be decisive for guiding experiments looking for dark-matter axions. In the next couple of years, it should be possible to confirm or rule out post-inflation axions experimentally, depending on whether the axion mass is found to be as predicted here. Alternatively, in a pre-inflation scenario, our calculation determines the universal axionic angle that corresponds to the initial condition of our Universe.

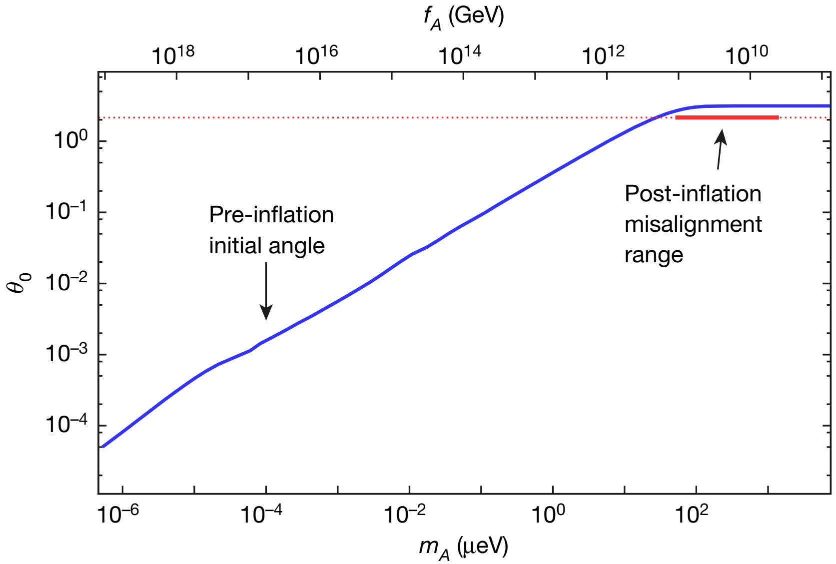
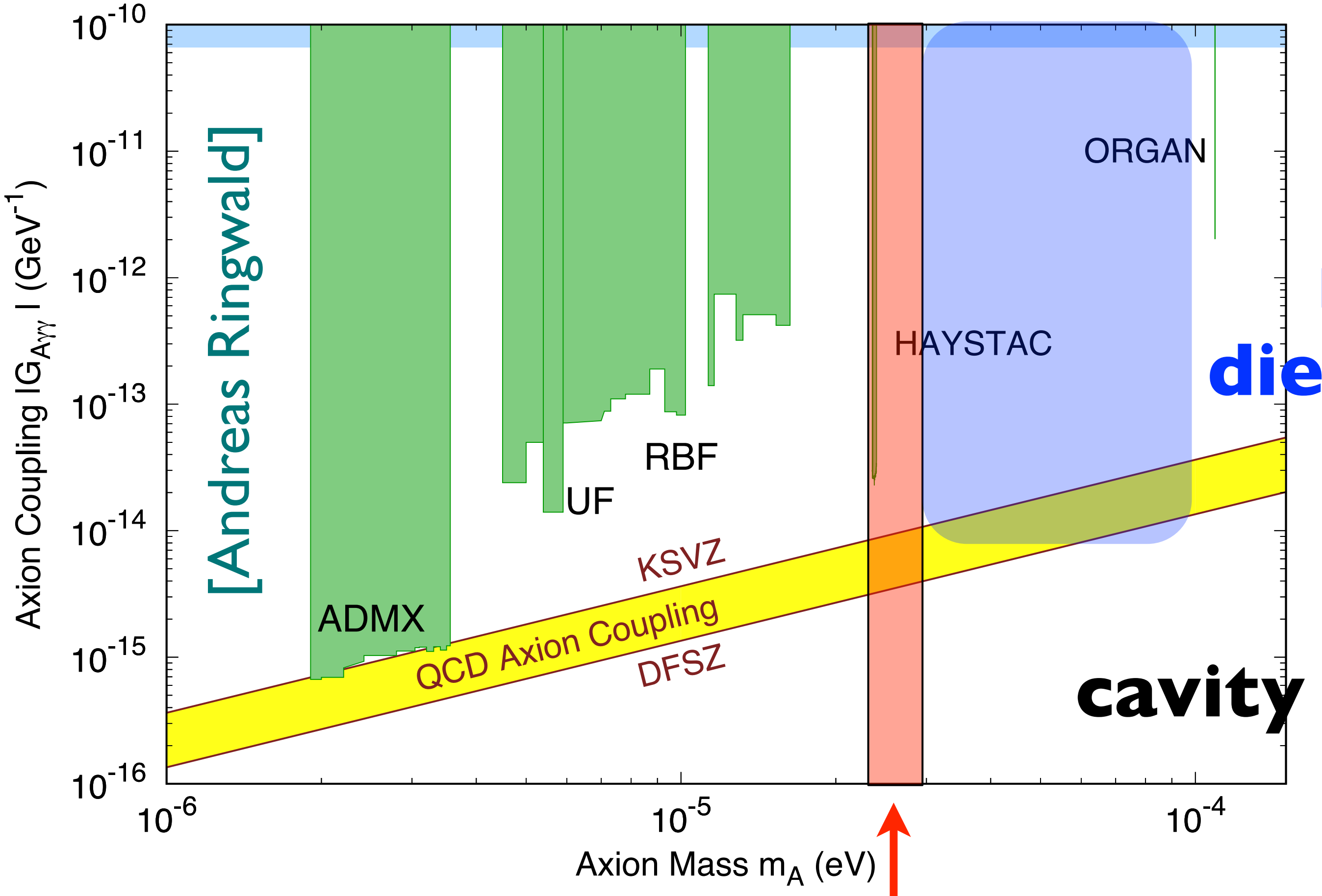


Figure 3 | The relation between the axion's mass m_A and the initial angle θ_0 in the pre-inflation scenario and the axion's mass range in the post-inflation scenario. For the pre-inflation scenario, our result is shown by the blue line; the error (s.e.m.) is smaller than the line width. The post-inflation scenario corresponds to $\theta_0 = 2.155$ with a strict lower bound on the axion's mass of $m_A = 28(2)\,\mu\text{eV}$. The thick red line shows our result for the axion's mass for the post-inflation case: for example, $m_A = 50(4)\,\mu\text{eV}$ if one assumes that axions from the misalignment mechanism contribute 50% to dark matter. Our final estimate is $50\,\mu\text{eV} < m_A < 1{,}500\,\mu\text{eV}$ (the upper bound assumes that only 1% is the contribution from the misalignment mechanism, the rest comes from other sources—for example, topological defects). An experimental set-up to detect post-inflationary axions is given in Supplementary Information. The slight bend around $m_A \approx 10^{-5}\,\mu\text{eV}$ corresponds to an oscillation temperature at the QCD transition[23,24].

Existing exclusion limits today



[Andreas Ringwald]

CAST
helioscope

MADMAX
dielectric haloscope

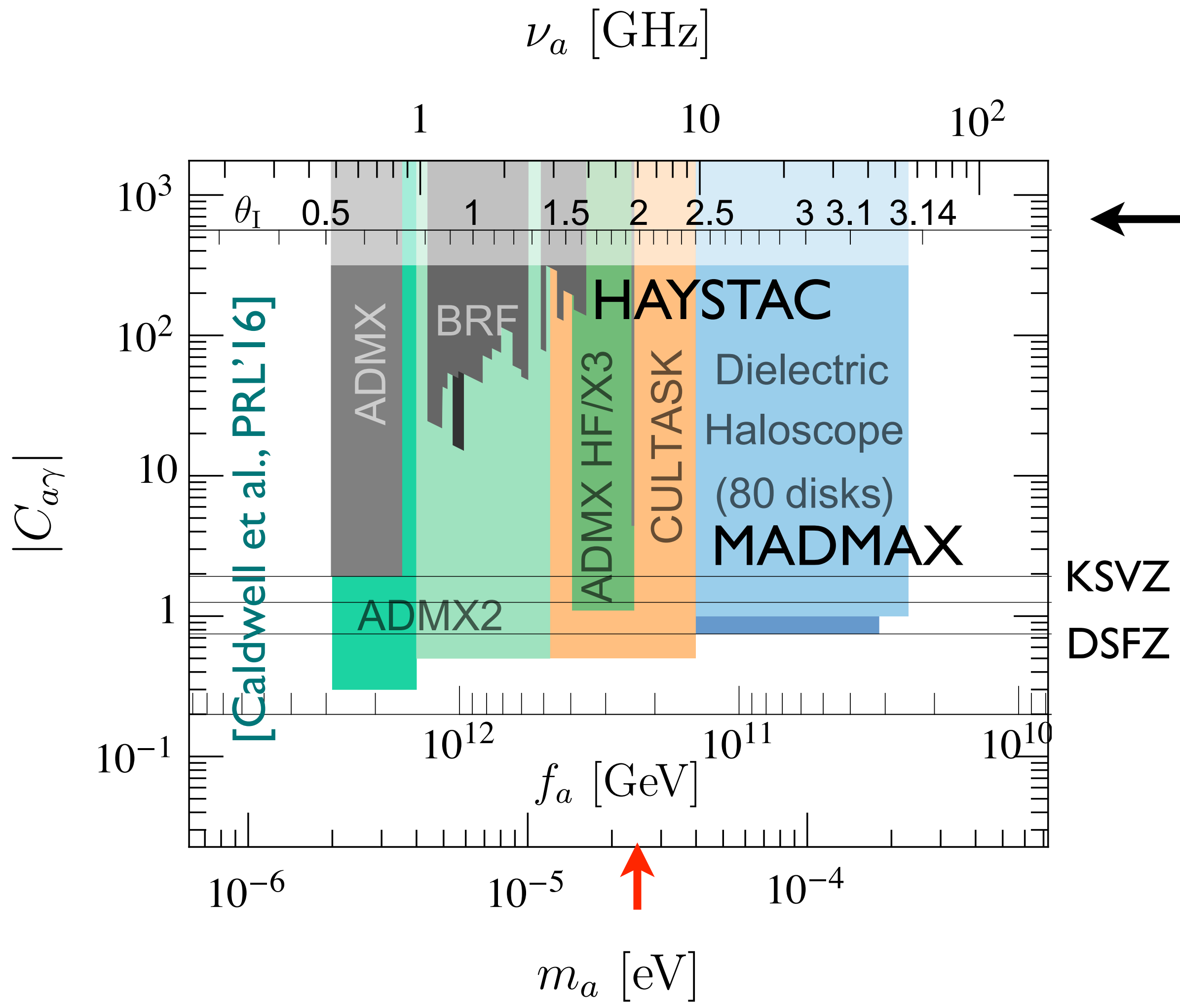
cavity haloscopes

Scenario 2

$$m_A = 26.2 \pm 3.4\,\mu\mathrm{eV}$$

[Klaer, Moore,'17]

MADMAX Goal - probe QCD axion DM scenarios



← **Scenario 1**

accidental inital misalignment

$m_A < 100\ \mu\mathrm{eV}$

Scenario 2

average inital misalignment

but computational challenge

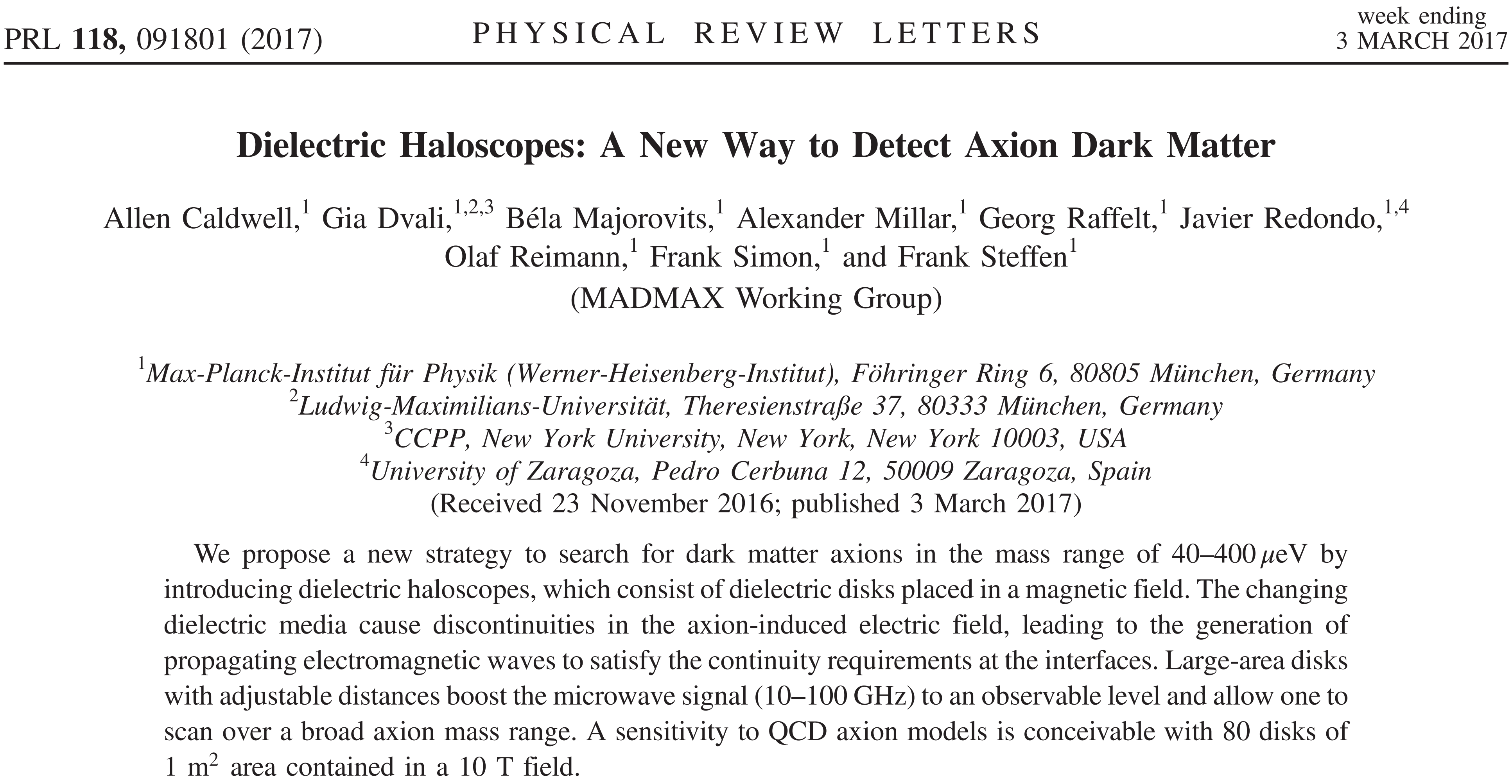
$$m_A = 26.2 \pm 3.4\,\mu\mathrm{eV}$$

[Klaer, Moore,'17]

$$g_{a\gamma} = -\frac{\alpha}{2\pi f_a} C_{a\gamma} = -2.04(3)\times 10^{-16}\ \mathrm{GeV}^{-1}\left(\frac{m_a}{1\,\mu\mathrm{eV}}\right) C_{a\gamma}$$

$$m_a = 5.70(6)(4)\,\mu\mathrm{eV}\left(\frac{10^{12}\,\mathrm{GeV}}{f_a}\right)$$

$$C_{a\gamma} = \frac{\mathcal{E}}{\mathcal{N}} - 1.92(4)$$ ← axion model dependent



PRL **118,** 091801 (2017) PHYSICAL REVIEW LETTERS week ending 3 MARCH 2017

Dielectric Haloscopes: A New Way to Detect Axion Dark Matter

Allen Caldwell,[1] Gia Dvali,[1,2,3] Béla Majorovits,[1] Alexander Millar,[1] Georg Raffelt,[1] Javier Redondo,[1,4]
Olaf Reimann,[1] Frank Simon,[1] and Frank Steffen[1]
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[4] *University of Zaragoza, Pedro Cerbuna 12, 50009 Zaragoza, Spain*

(Received 23 November 2016; published 3 March 2017)

We propose a new strategy to search for dark matter axions in the mass range of 40–400 μeV by introducing dielectric haloscopes, which consist of dielectric disks placed in a magnetic field. The changing dielectric media cause discontinuities in the axion-induced electric field, leading to the generation of propagating electromagnetic waves to satisfy the continuity requirements at the interfaces. Large-area disks with adjustable distances boost the microwave signal (10–100 GHz) to an observable level and allow one to scan over a broad axion mass range. A sensitivity to QCD axion models is conceivable with 80 disks of 1 m^2 area contained in a 10 T field.

Javier Redondo

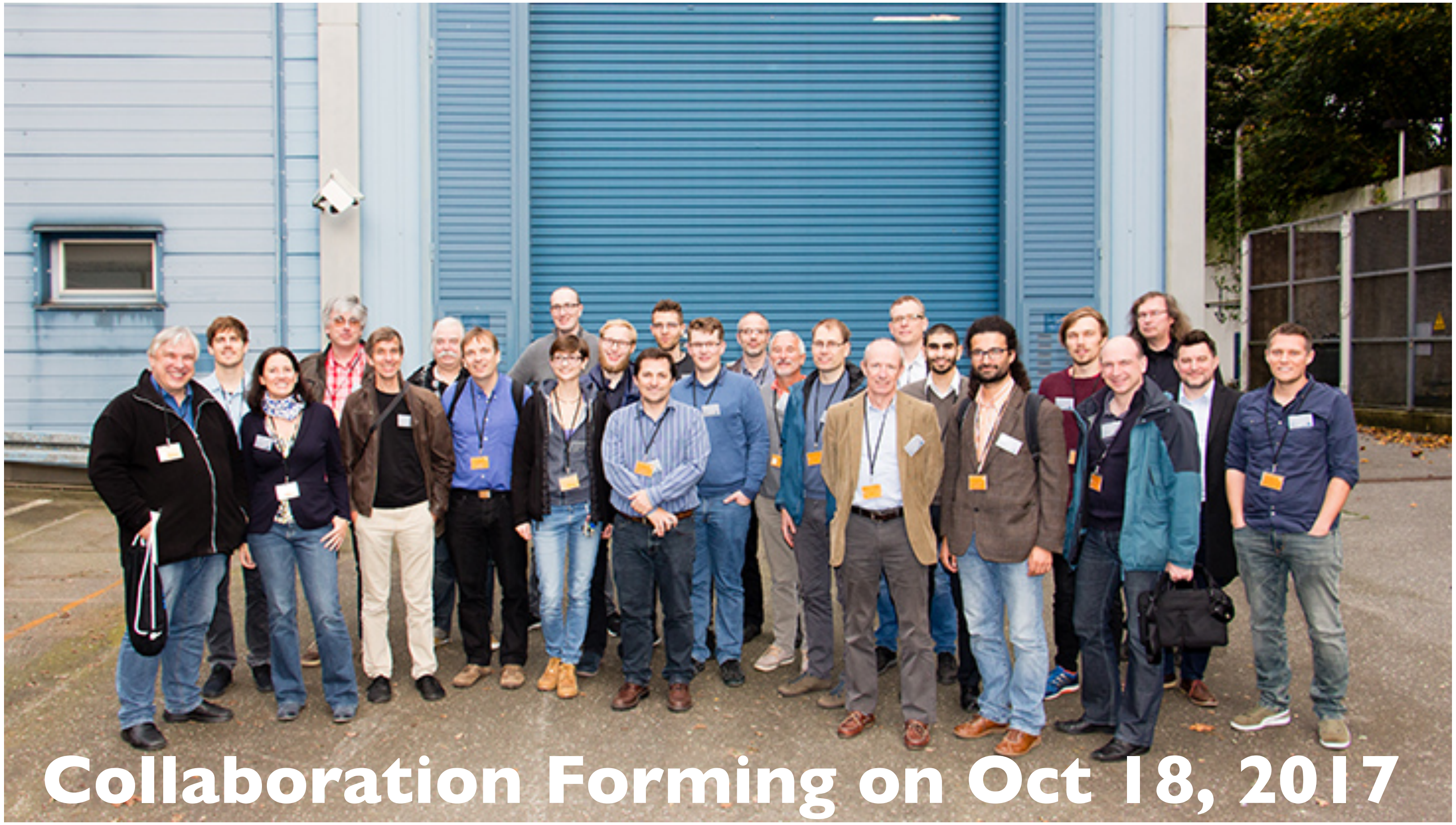
based on

Dish Antenna [Horns et al., JCAP'13, 1212.2970]

Dielectric Layers [Jaeckel, Redondo, PRD'13, 1308.1103]

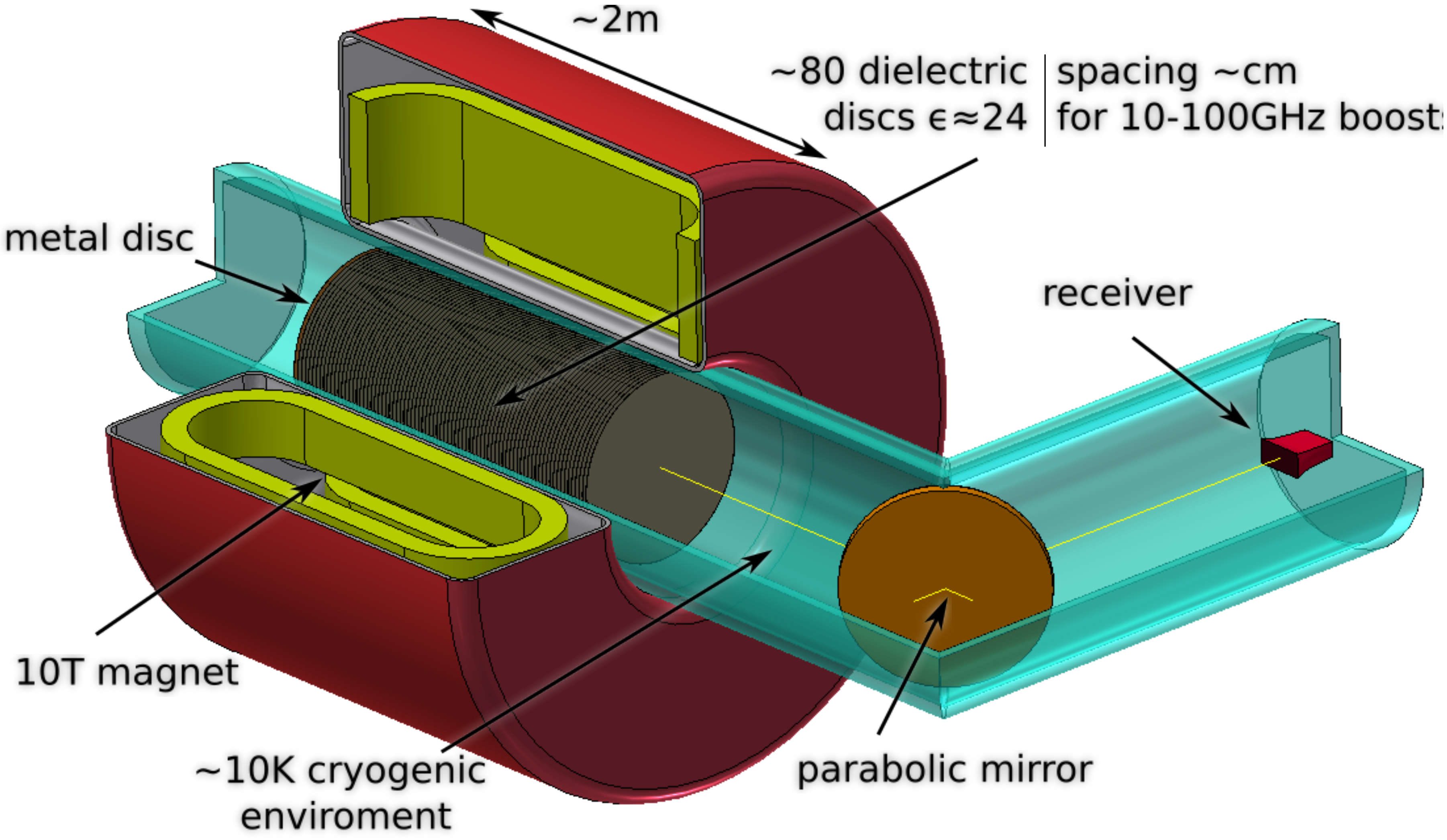
The MADMAX Collaboration

CEA IRFU, Saclay	RWTH Aachen
DESY Hamburg	Univ. of Hamburg
MPI for Radio Astronomy, Bonn	Univ. of Tübingen
MPI for Physics, Munich	Univ. of Zaragoza

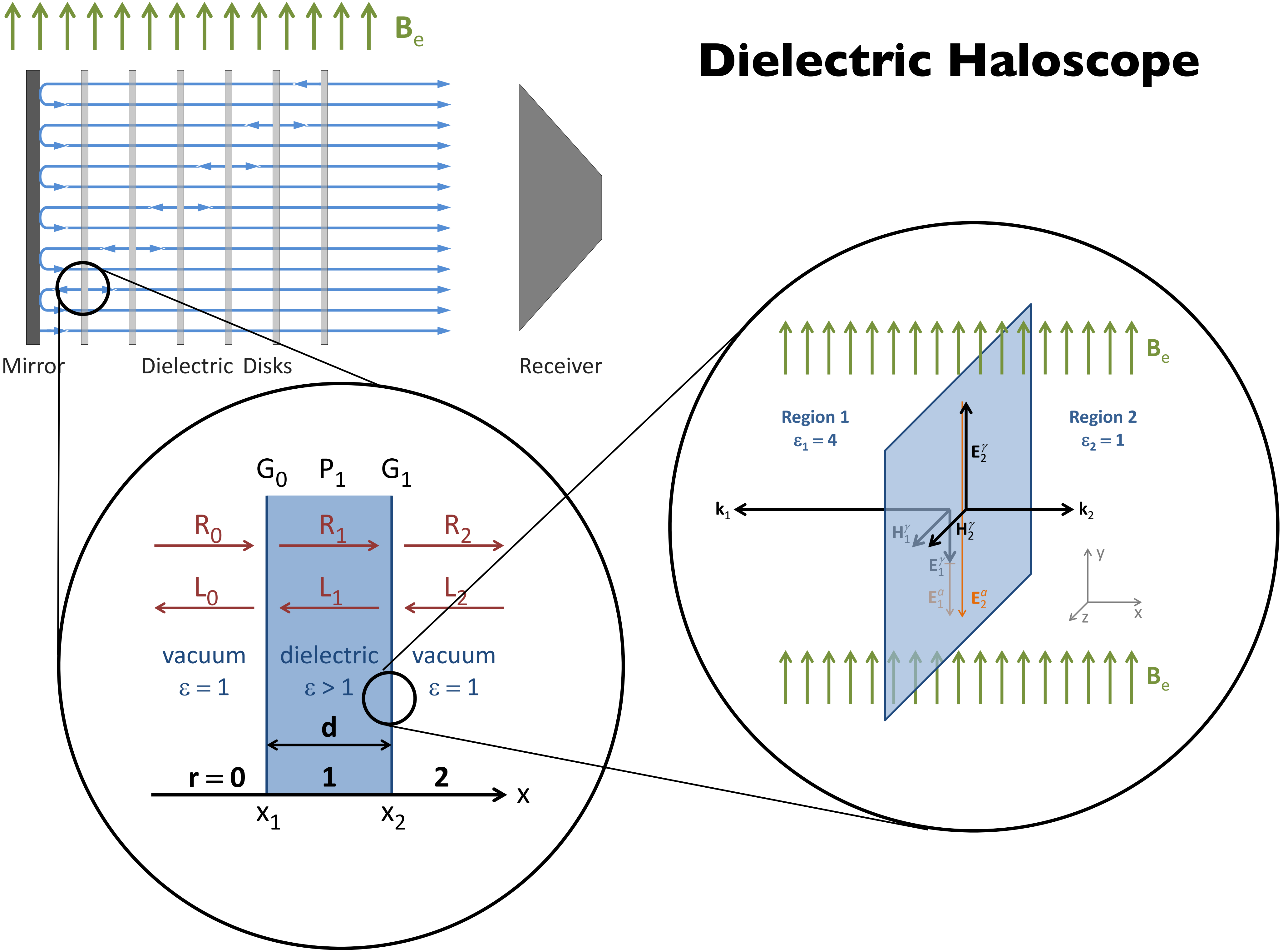

Collaboration Forming on Oct 18, 2017

MADMAX

MAgnetized Disc and Mirror Axion eXperiment



Dielectric Haloscope



Axion-Photon Interaction: Eqs. of Motion
Vacuum

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - J^{\mu}A_{\mu} + \frac{1}{2}\partial_{\mu}a\partial^{\mu}a - \frac{1}{2}m_a^2a^2 - \frac{g_{a\gamma}}{4}F_{\mu\nu}\widetilde{F}^{\mu\nu}a$$

- Euler-Lagrange Eqs.

$$J_a^{\nu} \equiv -g_{a\gamma}\partial_{\mu}(\widetilde{F}^{\mu\nu}a) = -g_{a\gamma}\widetilde{F}^{\mu\nu}\partial_{\mu}a$$

$$\partial_{\mu}F^{\mu\nu} = J^{\nu} - g_{a\gamma}\widetilde{F}^{\mu\nu}\partial_{\mu}a\,,$$

$$\left(\partial_{\mu}\partial^{\mu} + m_a^2\right)a = -\frac{g_{a\gamma}}{4}F_{\mu\nu}\widetilde{F}^{\mu\nu}$$

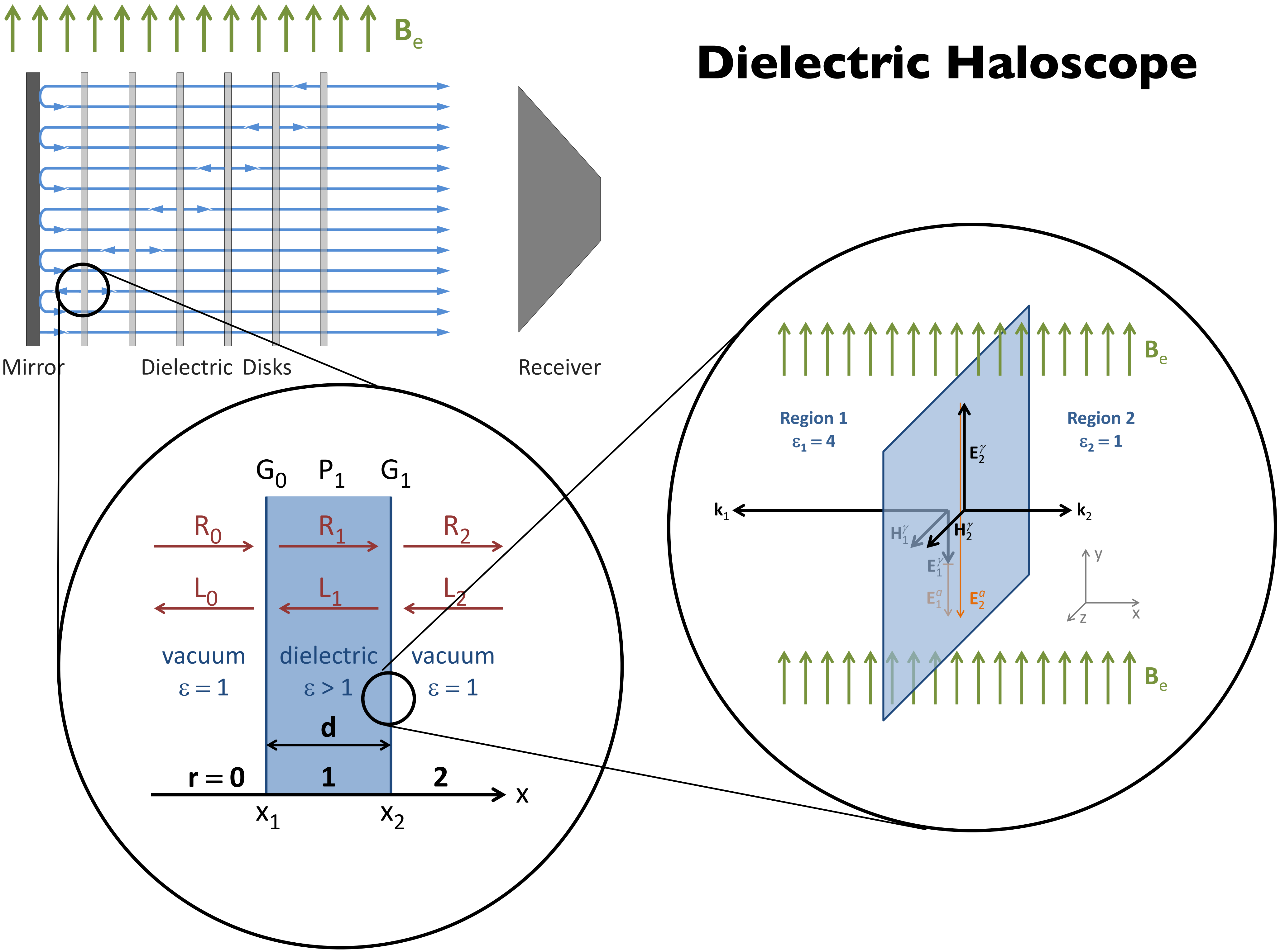
- Bianchi Identity

$$\partial_{\mu}\widetilde{F}^{\mu\nu} = 0$$

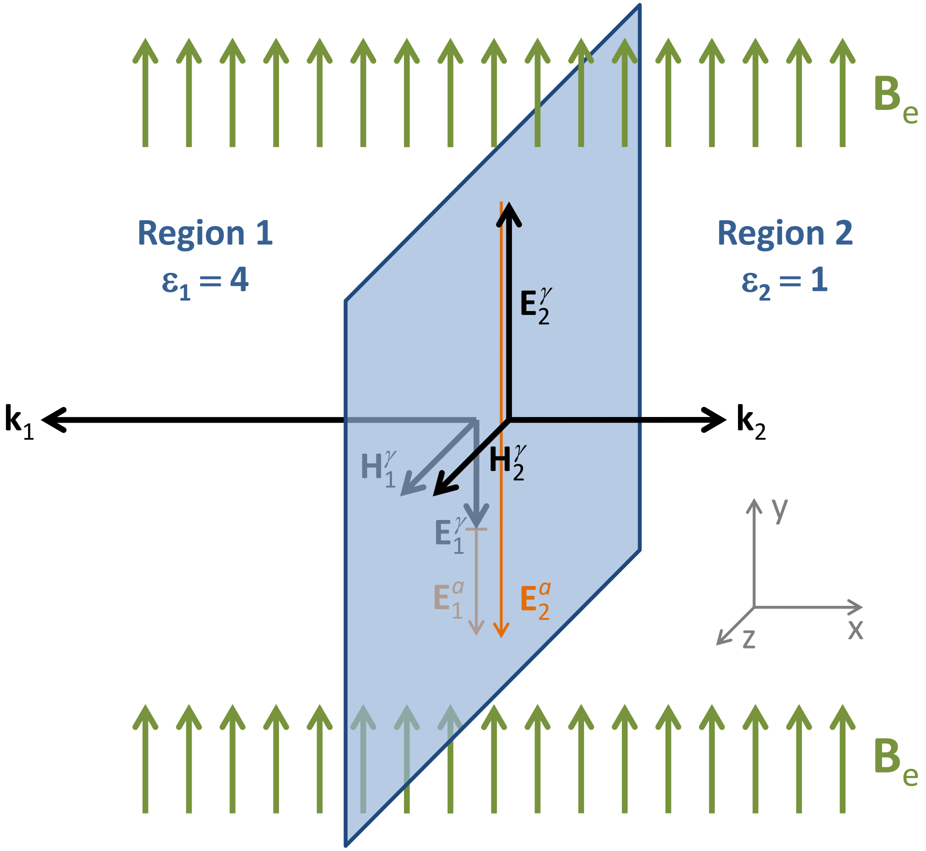
- Modified Maxwell Eqs.

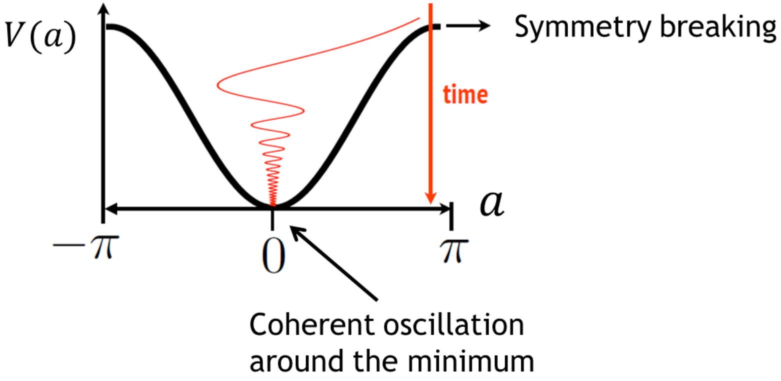
$$\begin{aligned}
\boldsymbol{\nabla}\cdot\mathbf{E} &= \rho - g_{a\gamma}\mathbf{B}\cdot\boldsymbol{\nabla}a\,,\\
\boldsymbol{\nabla}\times\mathbf{B} - \dot{\mathbf{E}} &= \mathbf{J} + g_{a\gamma}\left(\mathbf{B}\,\dot{a} - \mathbf{E}\times\boldsymbol{\nabla}a\right)\\
\boldsymbol{\nabla}\cdot\mathbf{B} &= 0\,,\\
\boldsymbol{\nabla}\times\mathbf{E} + \dot{\mathbf{B}} &= 0\,,\\
\ddot{a} - \boldsymbol{\nabla}^2a + m_a^2a &= g_{a\gamma}\mathbf{E}\cdot\mathbf{B}\,.
\end{aligned}$$

Dielectric Haloscope



Single Interface & Dark Matter Axions





$$\mathbf{E}_a(t) = -\frac{g_{a\gamma}\mathbf{B}_\mathrm{e}}{\epsilon}\,a(t)$$

$$a(t) = a_0 e^{-im_a t}$$

$$\rho_a = \frac{m_a^2|a_0|^2}{2} = f_\mathrm{DM}\,\frac{300\ \mathrm{MeV}}{\mathrm{cm}^3}$$

$$m_a = 5.70(6)(4)\ \mu\mathrm{eV}\left(\frac{10^{12}\ \mathrm{GeV}}{f_a}\right)$$

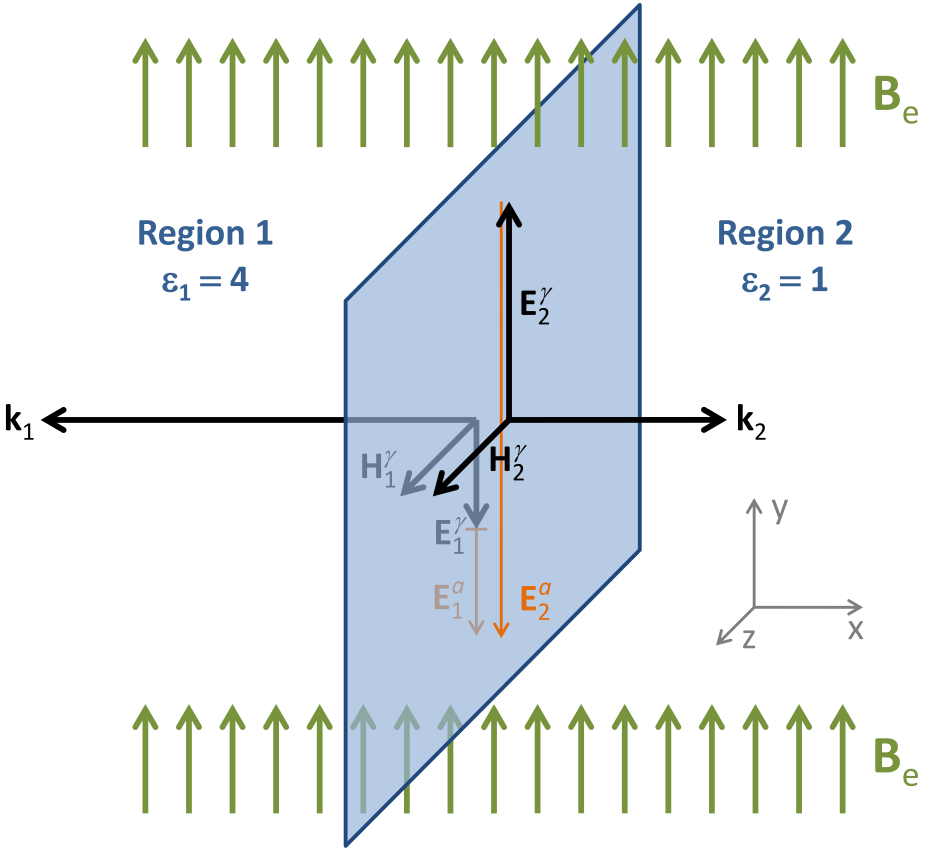
$$\lambda_a = \frac{2\pi}{m_a v_a} = 12.4\ \mathrm{m}\left(\frac{100\ \mu\mathrm{eV}}{m_a}\right)\left(\frac{10^{-3}}{v_a}\right)$$

$$v_a \lesssim 10^{-3}$$

$$\mathbf{E}_a(t) = -\frac{\mathbf{E}_0}{\epsilon}\,e^{-im_a t}$$

$$\mathbf{E}_0 \equiv g_{a\gamma}\mathbf{B}_\mathrm{e}a_0$$

Single Interface & Dark Matter Axions



- axion induced E field

$$\mathbf{E}_a(t) = -\frac{\mathbf{E}_0}{\epsilon}\, e^{-im_a t}$$

$$\mathbf{E}_0 \equiv g_{a\gamma}\mathbf{B}_e a_0$$

$$C_{a\gamma} = \frac{\mathcal{E}}{\mathcal{N}} - 1.92(4)$$

$$g_{a\gamma} = -\frac{\alpha}{2\pi f_a} C_{a\gamma} = -2.04(3)\times 10^{-16}\ \mathrm{GeV}^{-1}\left(\frac{m_a}{1\,\mu\mathrm{eV}}\right) C_{a\gamma}$$

- propagating EM waves

$$\mathbf{k}\times\mathbf{H}_\gamma + \omega\epsilon\mathbf{E}_\gamma = 0$$

- wave number $k = n\omega$

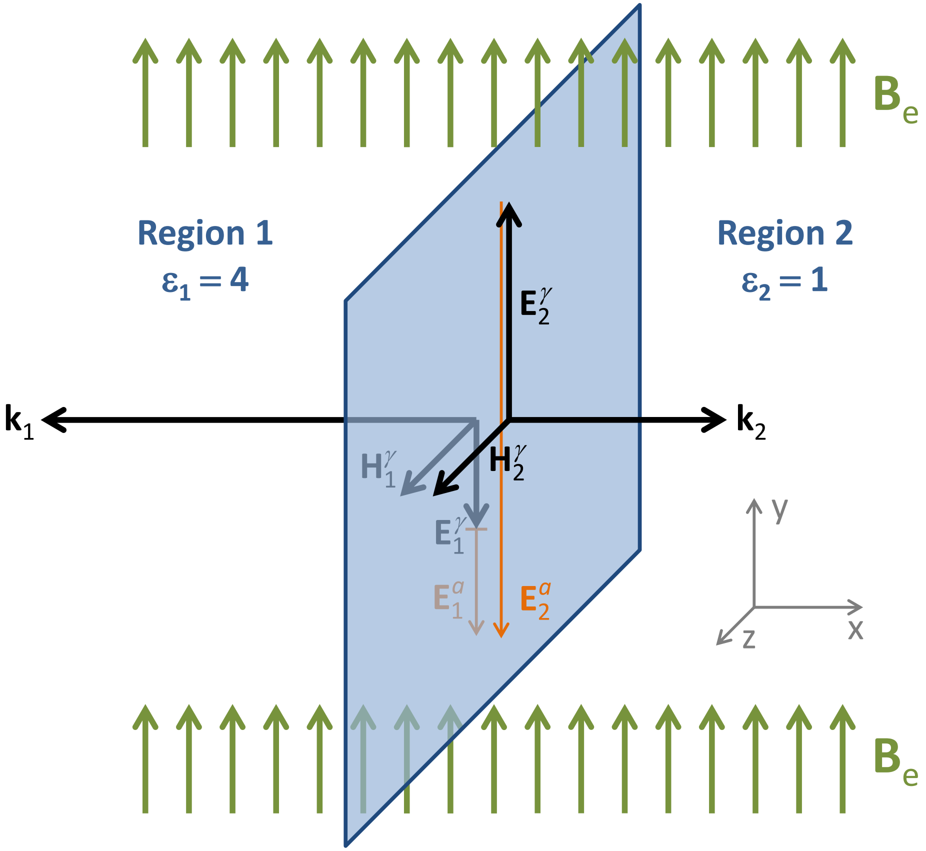
$$H_\gamma = \pm(\epsilon/n)\, E_\gamma$$

$$\epsilon/n = \sqrt{\epsilon/\mu}$$

- Continuity requirements

$\mathbf{H}_{\parallel,1} = \mathbf{H}_{\parallel,2}$	Continuity of $\mathbf{H}_\parallel$	$-\frac{\epsilon_1}{n_1}E_1^\gamma = \frac{\epsilon_2}{n_2}E_2^\gamma,$
$\mathbf{E}_{\parallel,1} = \mathbf{E}_{\parallel,2}$	Continuity of $\mathbf{E}_\parallel$	$E_1^\gamma + E_1^a = E_2^\gamma + E_2^a$

Single Interface & Dark Matter Axions



- axion induced E field

$$\mathbf{E}_a(t) = -\frac{\mathbf{E}_0}{\epsilon}\, e^{-i m_a t}$$

$$\mathbf{E}_0 \equiv g_{a\gamma}\mathbf{B}_{\rm e} a_0$$

$$g_{a\gamma} = -\frac{\alpha}{2\pi f_a} C_{a\gamma} = -2.04(3) \times 10^{-16}\ {\rm GeV}^{-1} \left(\frac{m_a}{1\,\mu{\rm eV}}\right) C_{a\gamma}$$

- propagating EM waves

$$E_1^\gamma = +\left(E_2^a - E_1^a\right) \frac{\epsilon_2 n_1}{\epsilon_1 n_2 + \epsilon_2 n_1}\,,$$

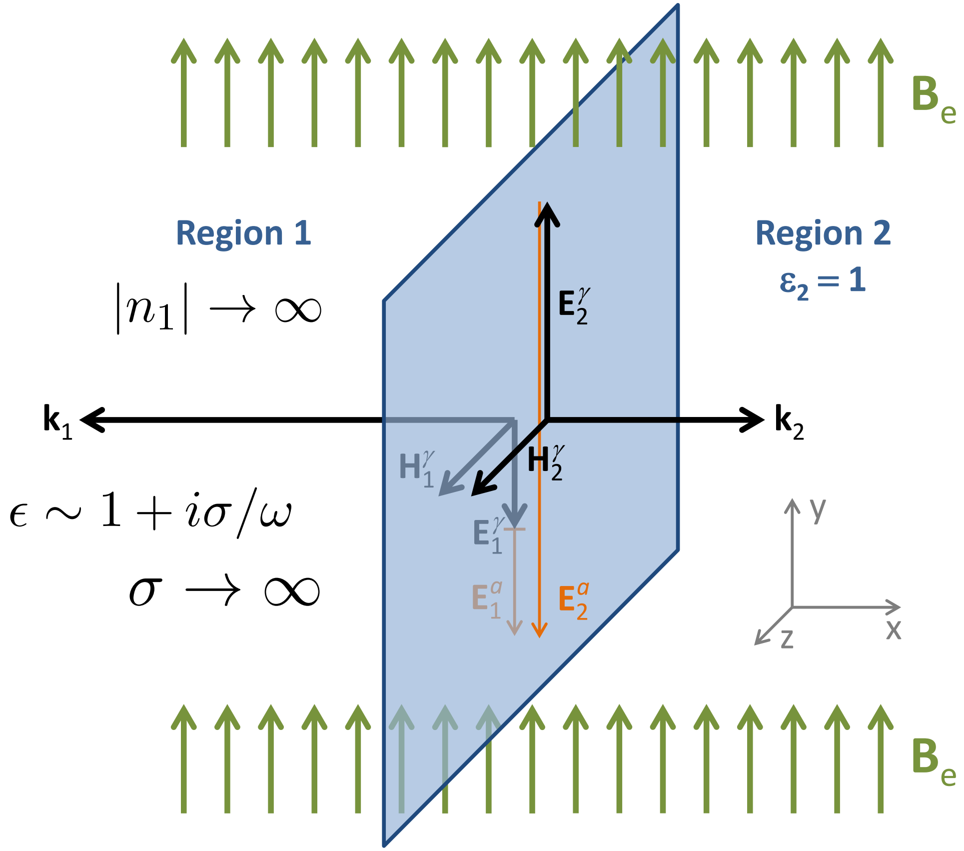
$$E_2^\gamma = -\left(E_2^a - E_1^a\right) \frac{\epsilon_1 n_2}{\epsilon_1 n_2 + \epsilon_2 n_1}\,,$$

$$H_{1,2}^\gamma = -\left(E_2^a - E_1^a\right) \frac{\epsilon_1 \epsilon_2}{\epsilon_1 n_2 + \epsilon_2 n_1}\,,$$

- physical fields (t, x) - real parts of the following expressions

$$E_{1,2}^a\, e^{-i\omega t}\,, \quad E_{1,2}^\gamma\, e^{-i(\omega t - k_{1,2}x)}\,, \quad \text{and} \quad H_{1,2}^\gamma\, e^{-i(\omega t - k_{1,2}x)}$$

Perfect Mirror & Dark Matter Axions



- axion induced E field

$$E_2^a = -E_0$$

$$E_0 = 1.3 \times 10^{-12}\ \mathrm{V/m}\ \frac{B_\mathrm{e}}{10\ \mathrm{T}}\ C_{a\gamma} f_\mathrm{DM}^{1/2}$$

$$C_{a\gamma} = \frac{\mathcal{E}}{\mathcal{N}} - 1.92(4)$$

- propagating EM waves

$$E_1^\gamma = 0 \ (\text{and } H_{1,2}^\gamma = 0)$$

$$E_2^\gamma = E_0$$

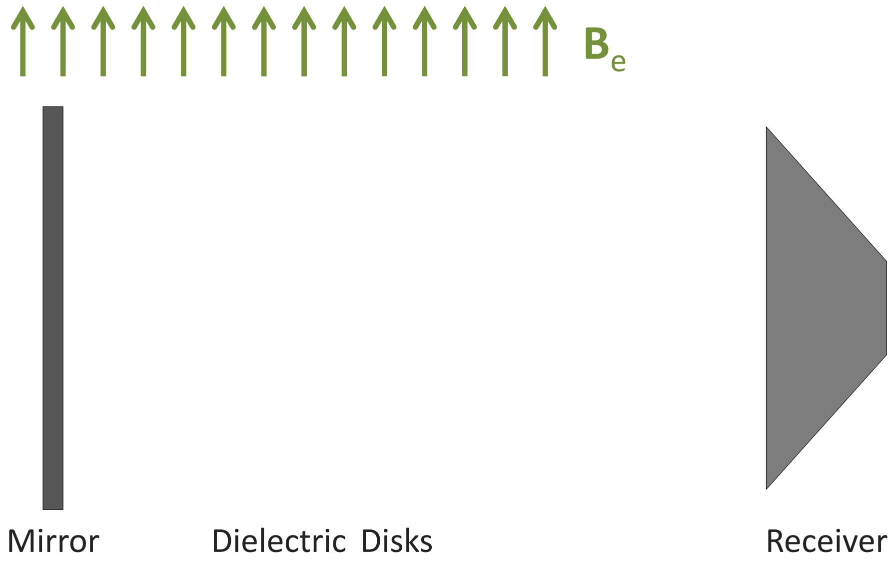
- power per unit area A in the positive x-direction (cycl. av. energy flux density)

$$\frac{P_\gamma}{A} = \bar{S}_2^\gamma = \frac{1}{2}\overline{\left[\mathrm{Re}\left(\mathbf{E}_2^\gamma\right) \times \mathrm{Re}\left(\mathbf{H}_2^\gamma\right)\right]_x} = \frac{E_0^2}{2} = 2.2 \times 10^{-27}\ \frac{\mathrm{W}}{\mathrm{m}^2}\left(\frac{B_\mathrm{e}}{10\ \mathrm{T}}\right)^2 C_{a\gamma}^2 f_\mathrm{DM}$$

- photon flux $F_\gamma = \frac{P_\gamma}{A\,\omega} = \frac{12}{\mathrm{m}^2\ \mathrm{day}}\left(\frac{100\ \mu\mathrm{eV}}{m_a}\right)\left(\frac{B_\mathrm{e}}{10\ \mathrm{T}}\right)^2 C_{a\gamma}^2 f_\mathrm{DM}$

Power Boost Factor β²

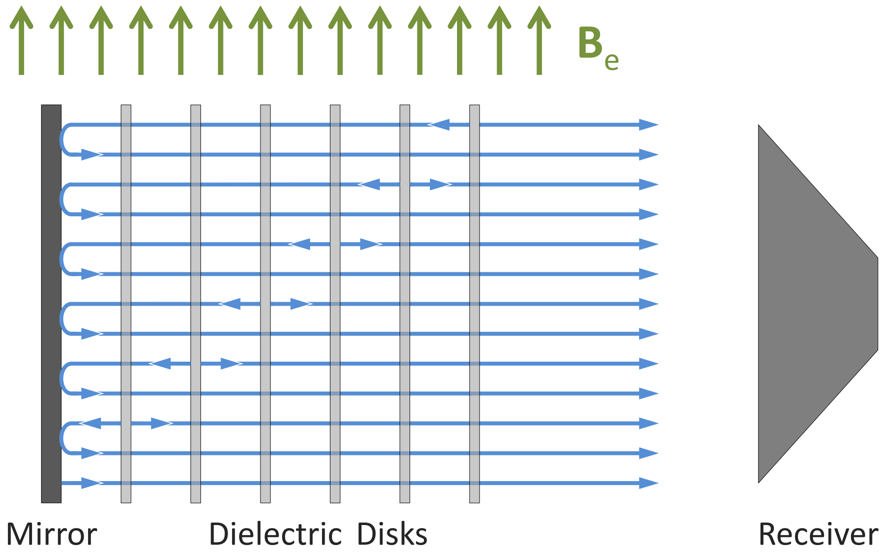
Magnetized Mirror



$$P/A = 2.2 \times 10^{-27}\,\mathrm{W\,m^{-2}} \left(\frac{B_e}{10\,\mathrm{T}}\right)^2 {C_{a\gamma}}^2 \cdot 1$$

Dish Antenna

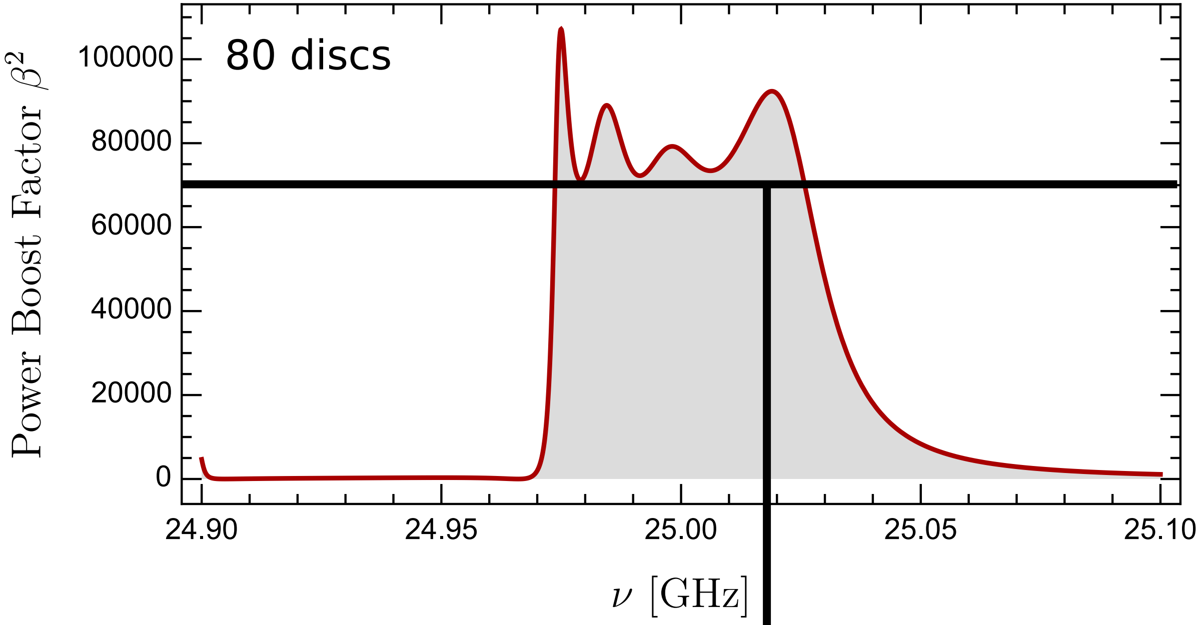
Dielectric Haloscope

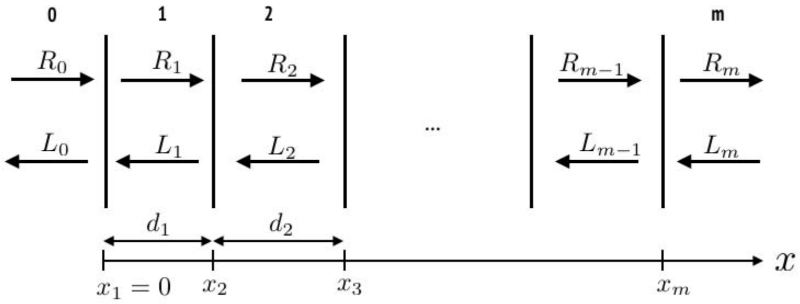


$$P/A = 2.2 \times 10^{-27}\,\mathrm{W\,m^{-2}} \left(\frac{B_e}{10\,\mathrm{T}}\right)^2 {C_{a\gamma}}^2 \cdot \beta^2$$

MADMAX

Power Boost Factor β²





calculated with a generalized transfer matrix formalism

- power per unit area A in the positive x-direction

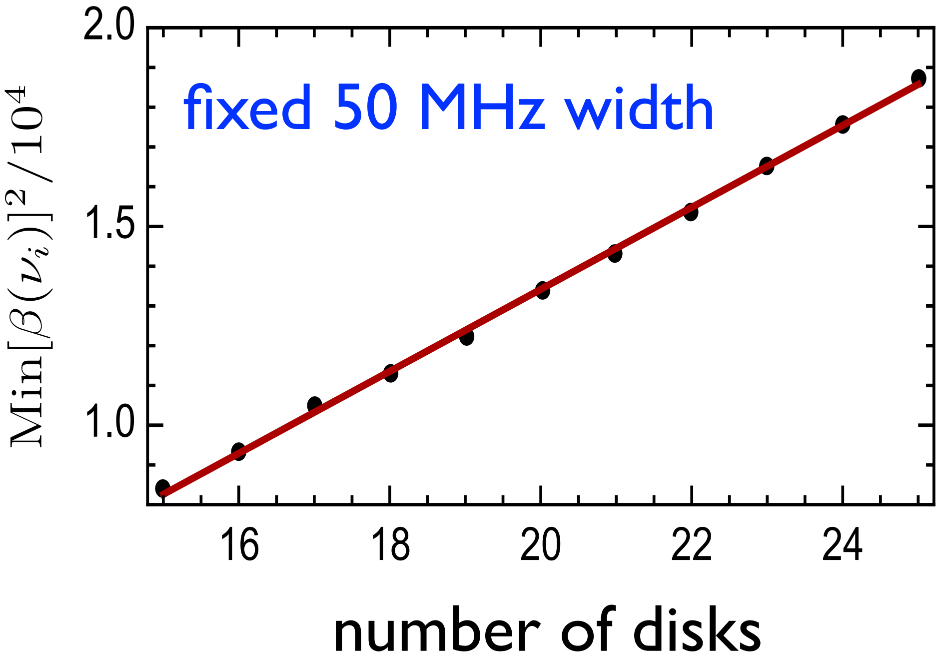
$$\frac{P}{A} = \beta^2 \frac{E_0^2}{2} = 2.2 \times 10^{-27}\, \beta^2 \frac{\mathrm{W}}{\mathrm{m}^2} \left(\frac{B_\mathrm{e}}{10\ \mathrm{T}}\right)^2 C_{a\gamma}^2$$

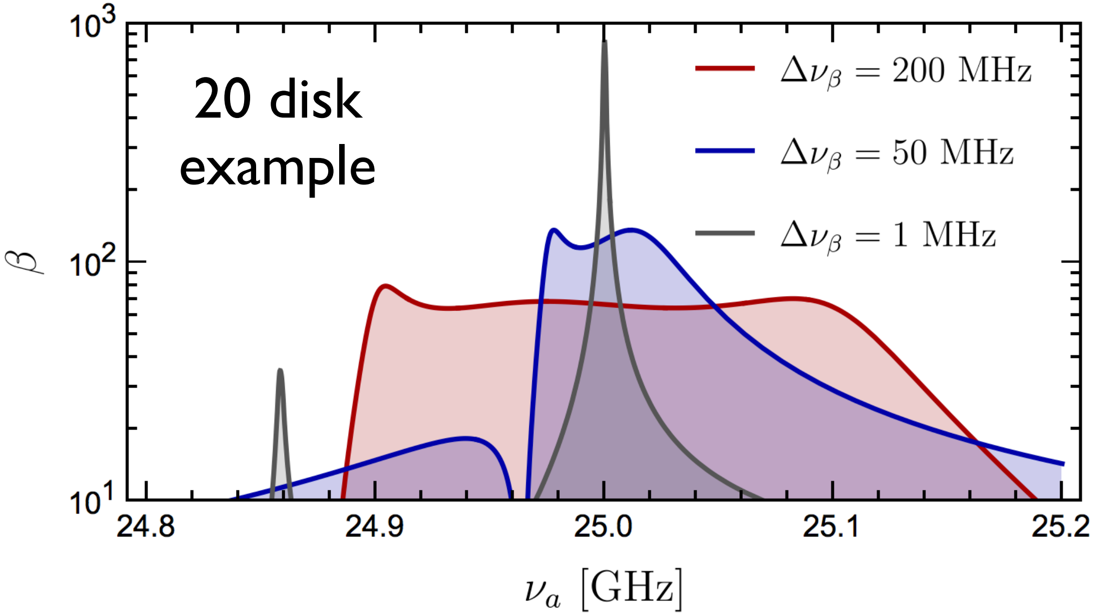
- boost factor $\beta(\nu_a) \equiv |E_\mathrm{out}(\nu_a)/E_0|$

Enhancement of 10^4-10^5 w.r.t. Magnetized Mirror

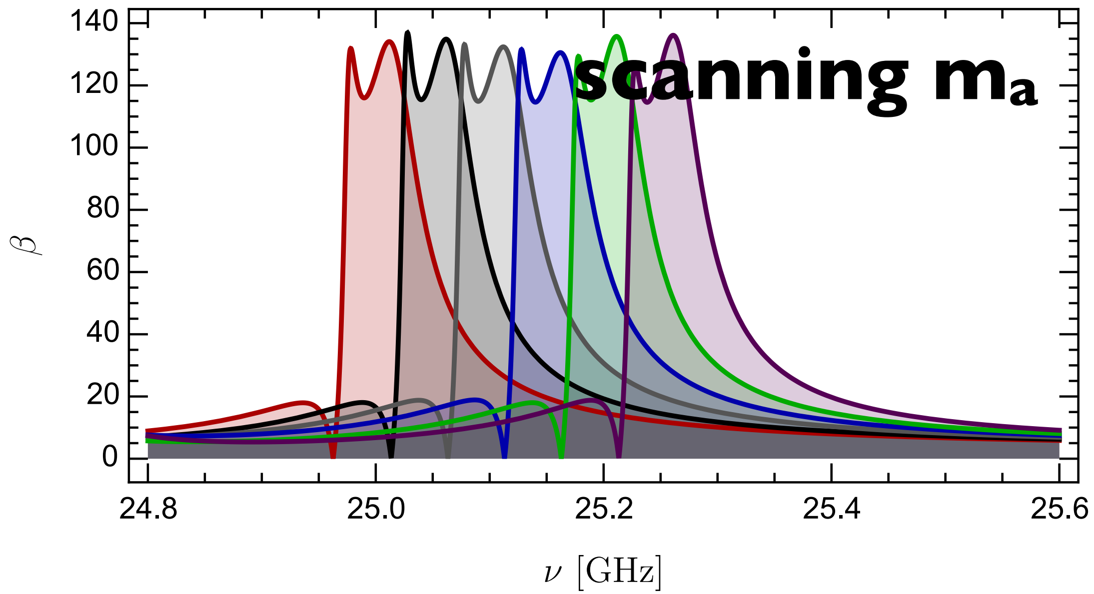
Power Boost Factor β^2

area law

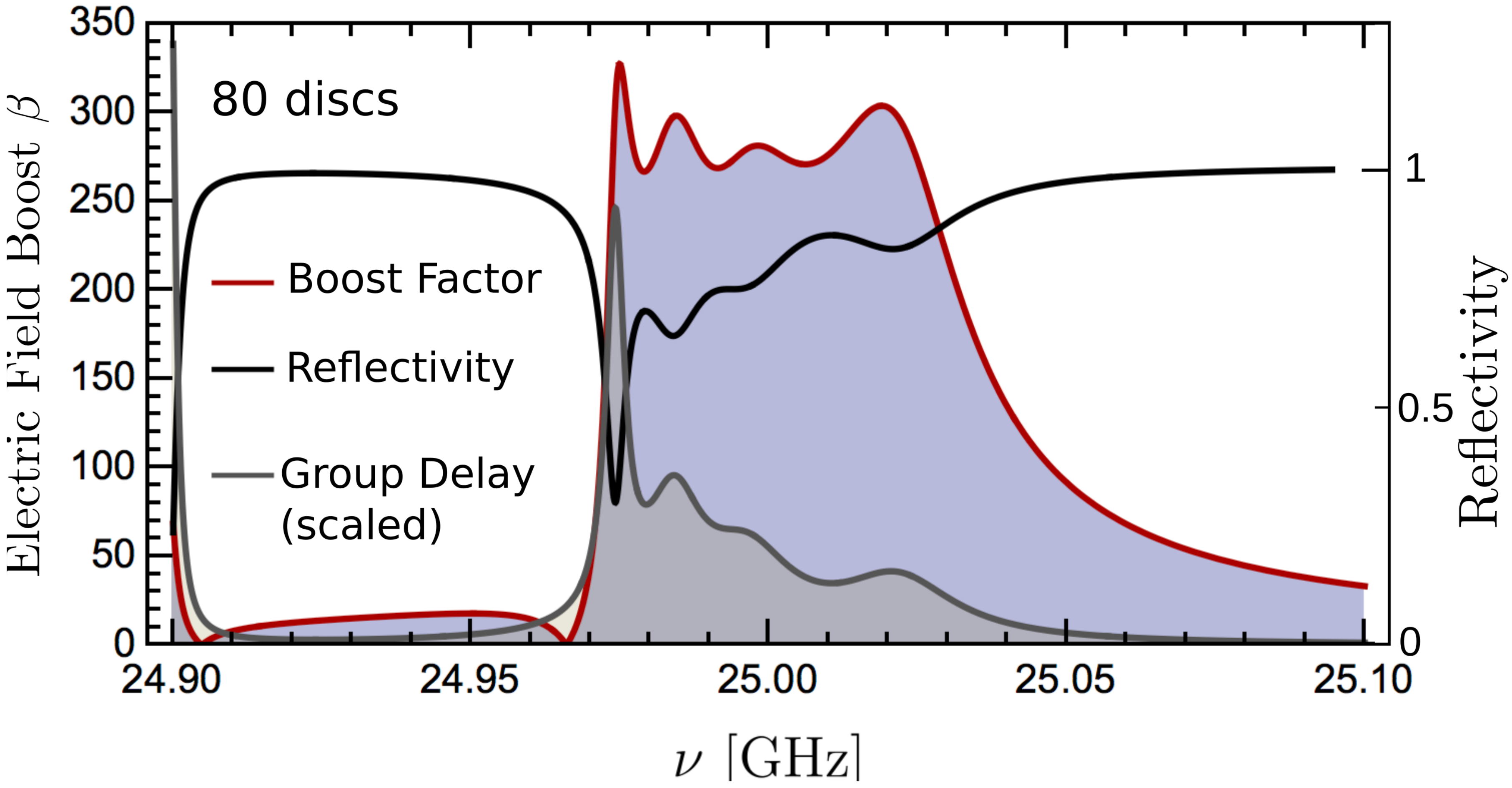

fixed 50 MHz width


20 disk example

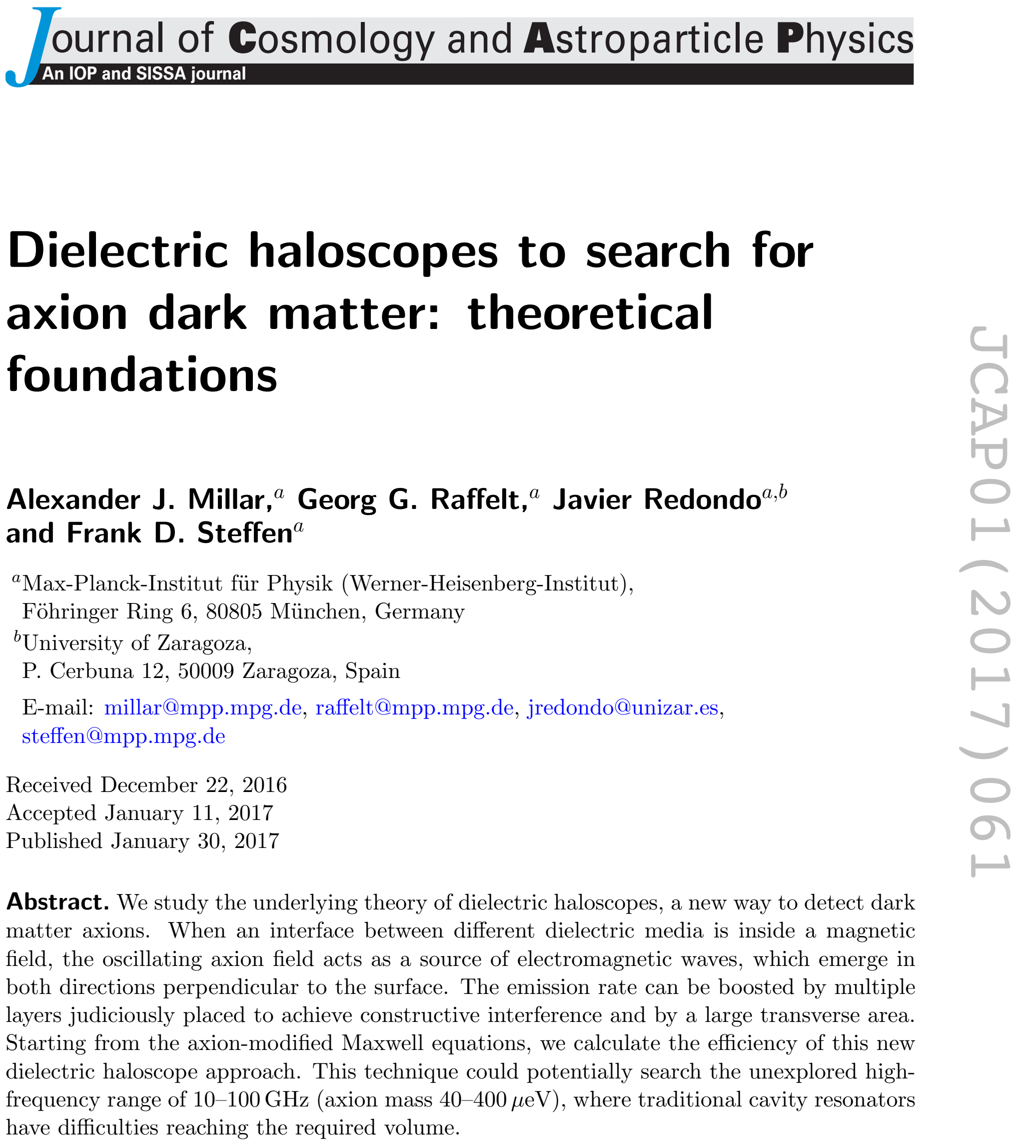
high degree of flexibility by optimizing disk spacings


scanning m_a

Power Boost Factor β² - Reflectivity



For more details, see …



Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Dielectric haloscopes to search for axion dark matter: theoretical foundations

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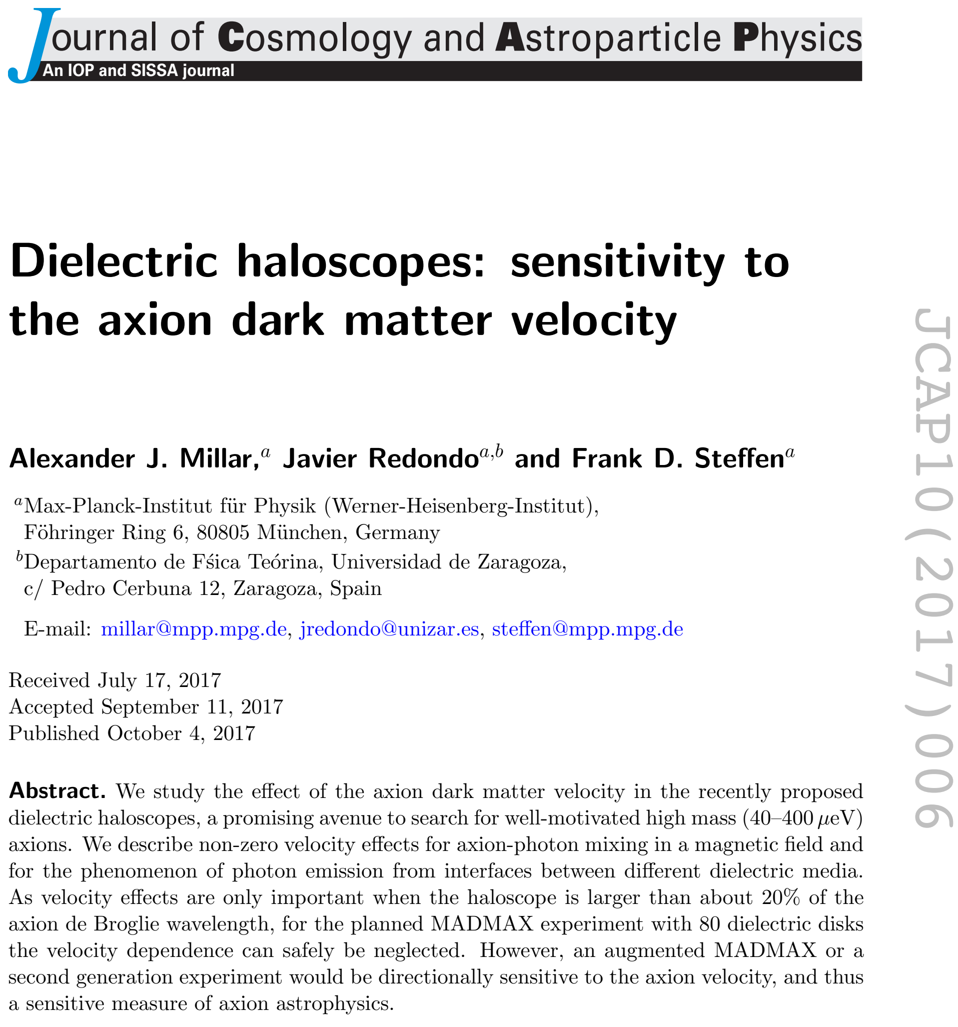
Abstract. We study the underlying theory of dielectric haloscopes, a new way to detect dark matter axions. When an interface between different dielectric media is inside a magnetic field, the oscillating axion field acts as a source of electromagnetic waves, which emerge in both directions perpendicular to the surface. The emission rate can be boosted by multiple layers judiciously placed to achieve constructive interference and by a large transverse area. Starting from the axion-modified Maxwell equations, we calculate the efficiency of this new dielectric haloscope approach. This technique could potentially search the unexplored high-frequency range of 10–100 GHz (axion mass 40–400 μeV), where traditional cavity resonators have difficulties reaching the required volume.

JCAP01(2017)061



Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Dielectric haloscopes: sensitivity to the axion dark matter velocity

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Abstract. We study the effect of the axion dark matter velocity in the recently proposed dielectric haloscopes, a promising avenue to search for well-motivated high mass (40–400 μeV) axions. We describe non-zero velocity effects for axion-photon mixing in a magnetic field and for the phenomenon of photon emission from interfaces between different dielectric media. As velocity effects are only important when the haloscope is larger than about 20% of the axion de Broglie wavelength, for the planned MADMAX experiment with 80 dielectric disks the velocity dependence can safely be neglected. However, an augmented MADMAX or a second generation experiment would be directionally sensitive to the axion velocity, and thus a sensitive measure of axion astrophysics.

JCAP10(2017)006

& [Brun et al., http://inspirehep.net/record/1592484/files/madmax_white_paper.pdf] White Paper

Conclusions

- axion dark matter mass search range?

  $m_A = 26.2 \pm 3.4\,\mu\mathrm{eV}$ [Klaer, Moore,'17]

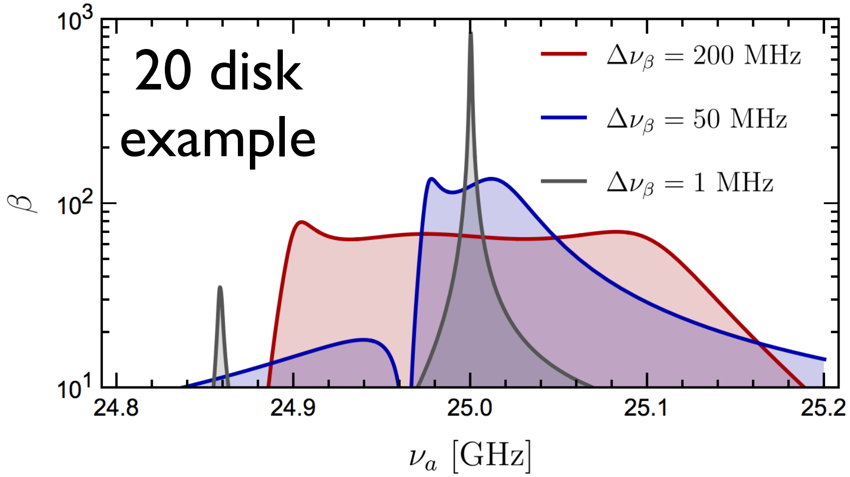
  ➔ Still depends on the scenario realized in nature (1 vs. 2)

- strongly growing exp. efforts to find the axion towards m_A ~ 100 μeV

  HAYSTAC, ORGAN, CAPP, ORPHEUS, QUAX, ...

  ➔ MADMAX is expected to be competitive towards m_A ~ 100 μeV

- MADMAX: unique potential with respect to seamless broadband m_A scans



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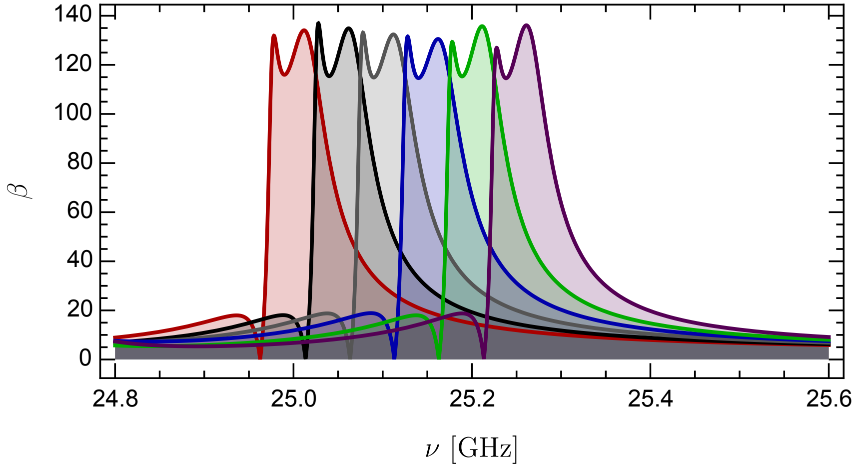

➔ MADMAX Talk by Bela Majorovits