Dielectric haloscopes: a new way to search for axion DM

Alex Millar on behalf of the MADMAX Working Group

See A. Caldwell et al arXiv:1611.05865
and A. Millar et al arXiv:1612.07057

invisiblesPlus
neutrinos, dark matter & dark energy physics

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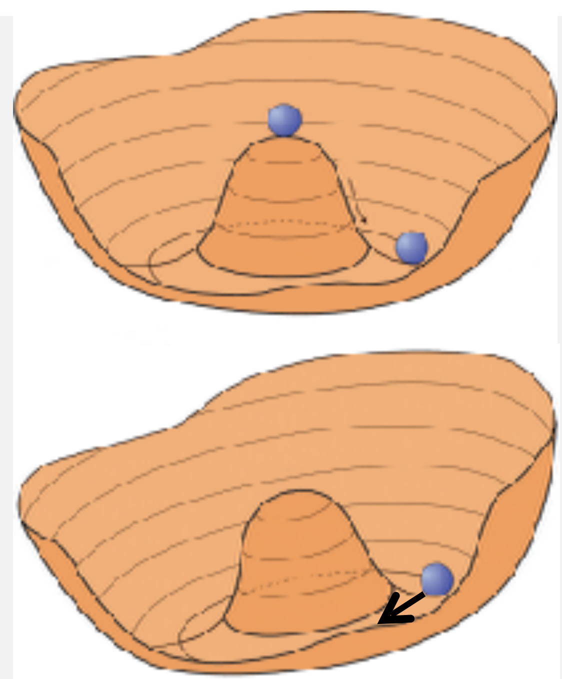
What are Axions?

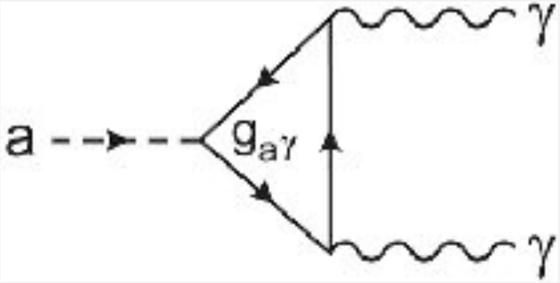
- Solves the strong CP problem by making the QCD θ term a field.
- New angular degree of freedom from breaking the Peccei-Quinn symmetry.
- Produced non-thermally in the early universe: dark matter!

$$\mathcal{L}_{\text{stand mod + axion}} = \cdots + \frac{1}{2}\partial_\mu a \partial^\mu a + \frac{g^2}{32\pi^2}\frac{a(x)}{f_a} G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$



Axion-electrodynamics

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



- Maxwell's inhomogenous equations get new terms: axion acts as a current

- The upshot is that in an external B-field the axion sources an E-field

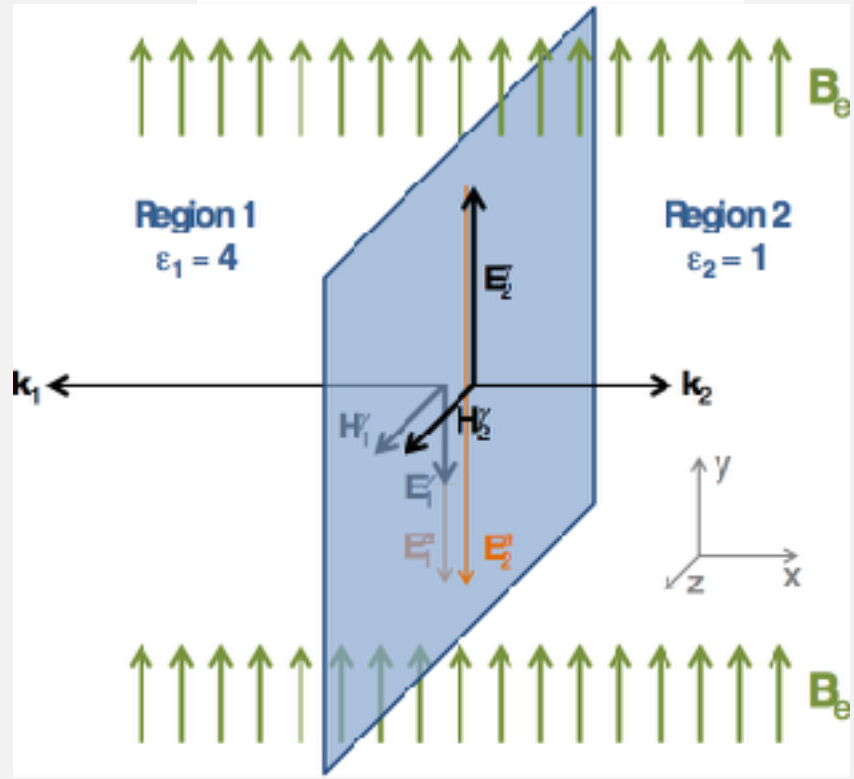
$$\mathbf{E}_a = -\frac{g_{a\gamma}\mathbf{B}_e a_0}{\epsilon} e^{-im_a t} = 1.3 \times 10^{-12}\ \mathrm{V/m}\ \frac{B_e}{10\ \mathrm{T}}\ \frac{C_{a\gamma} f_{\rm DM}^{1/2}}{\epsilon}\,.$$

Single interface

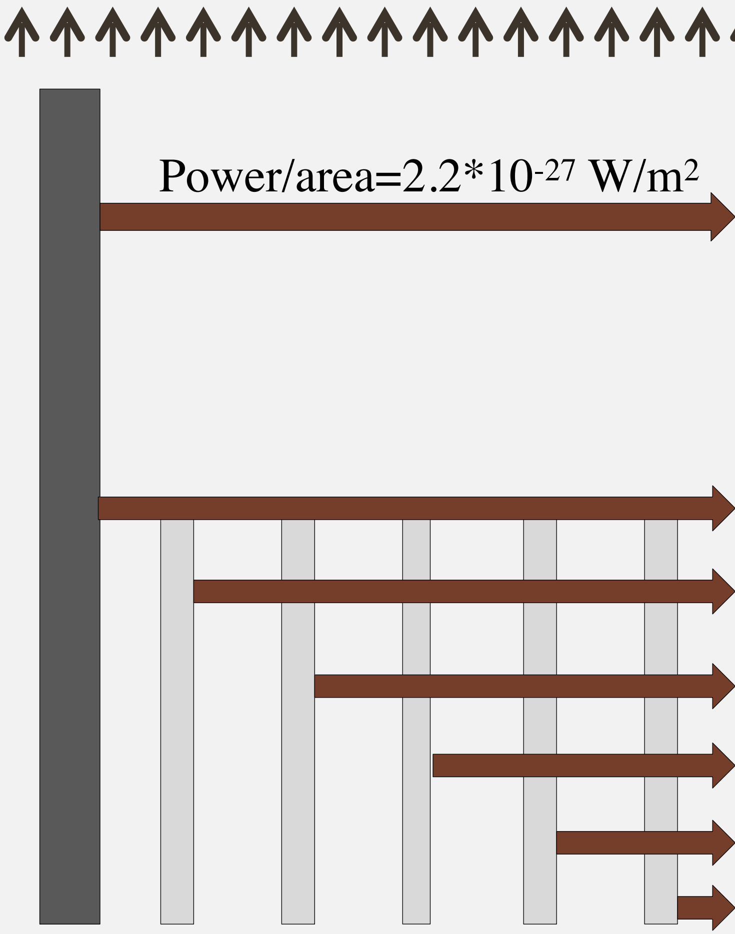
(fun with boundary conditions)

- E_a depends on the medium, so changing media causes a discontinuity.
- EM won't tolerate discontinuities in the parallel E and H fields
- Regular EM waves are emitted to compensate
- Not strong enough! Need 4-5 orders of magnitude more power…

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



Multiple layers: dielectric haloscope



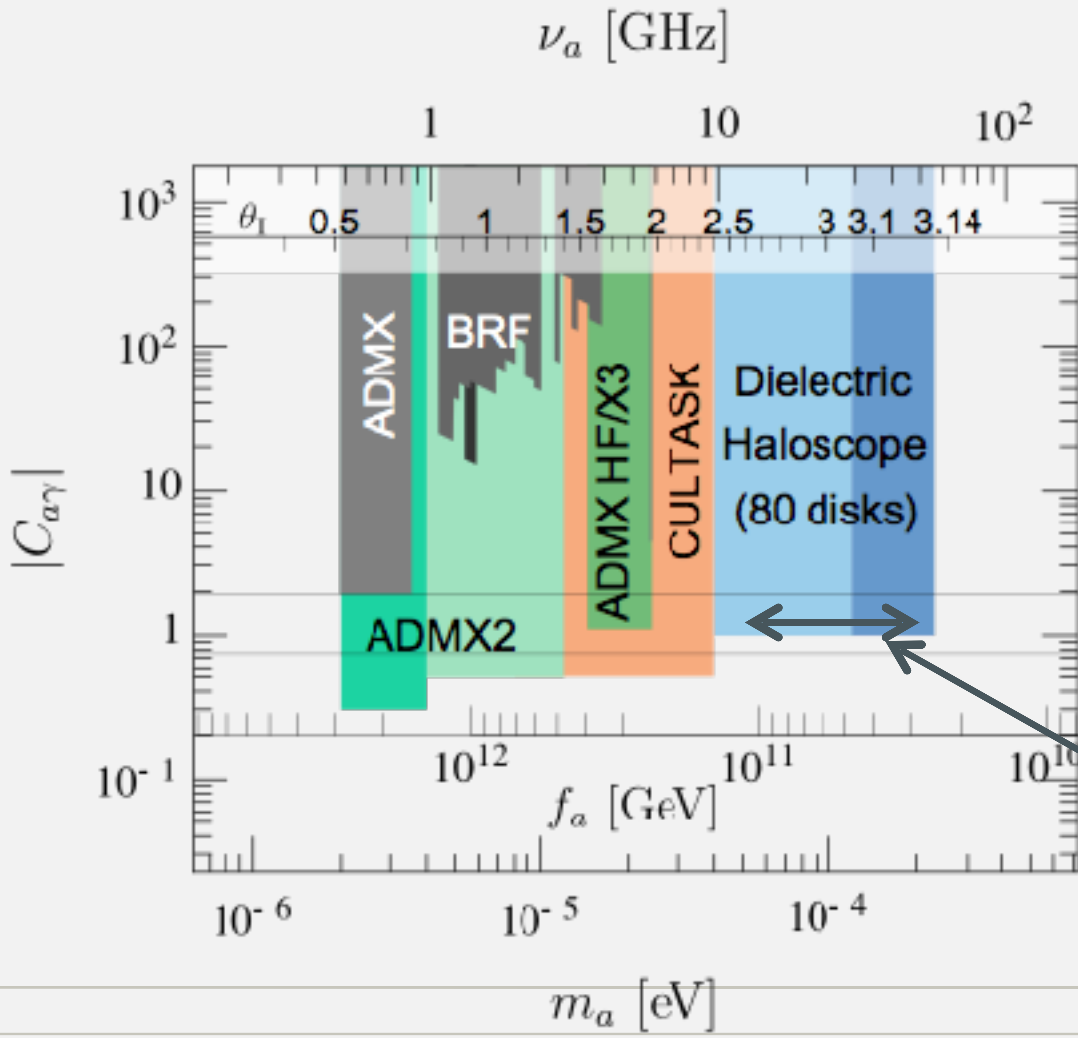
EM waves from each interface + internal reflections

Adjusting disc distances
➔coherent sum

Both transparent and resonant modes important

80 disks would give $10^{4\text{-}5}$ more power across ~50 MHz

Discovery potential



Peccei-Quinn symmetry broken after inflation

Conclusions

- Axions are a highly well motivated dark matter candidate with a unique phenomenology
- Dielectric haloscopes are an exciting new method for searching for axion dark matter
- They have the potential to detect axions produced in the predictive and currently unexplored post inflationary scenario for the first time