The DM Radio:

A Superconducting Lumped-Element Dark Matter Detector for Axions and Hidden Photons

DM Radio DJs: Dale Li, Arran Phipps, Saptashi Chaudhuri, Kent Irwin, Peter Graham, Surjeet Rajendran, Jeremy Mardon, Hsaiao-Mei Cho, Stephen Kuenstner, Harvey Mosley, Richard Mule, Max Silva-Feaver, Zach Steffen, Betty Young

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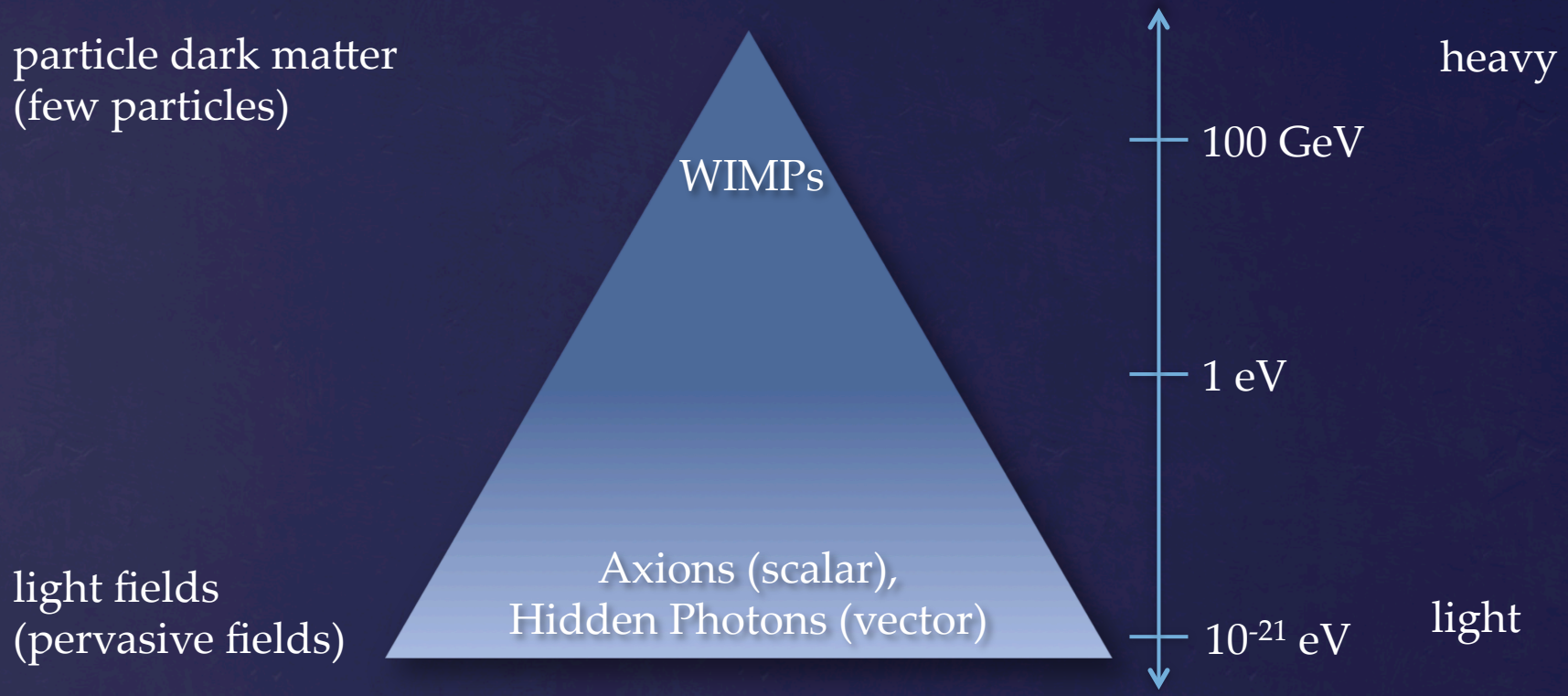
Dark Matter Constitution is Unknown



- WIMPs: LZ, XENON, CDMS, DAMIC, PICO, EDELWEISS, CoGeNT, CRESST…
- Axions: ADMX, CASPEr, ABRACADABRA, DM Radio
- Hidden Photons: ADMX, FUNK, DM Radio

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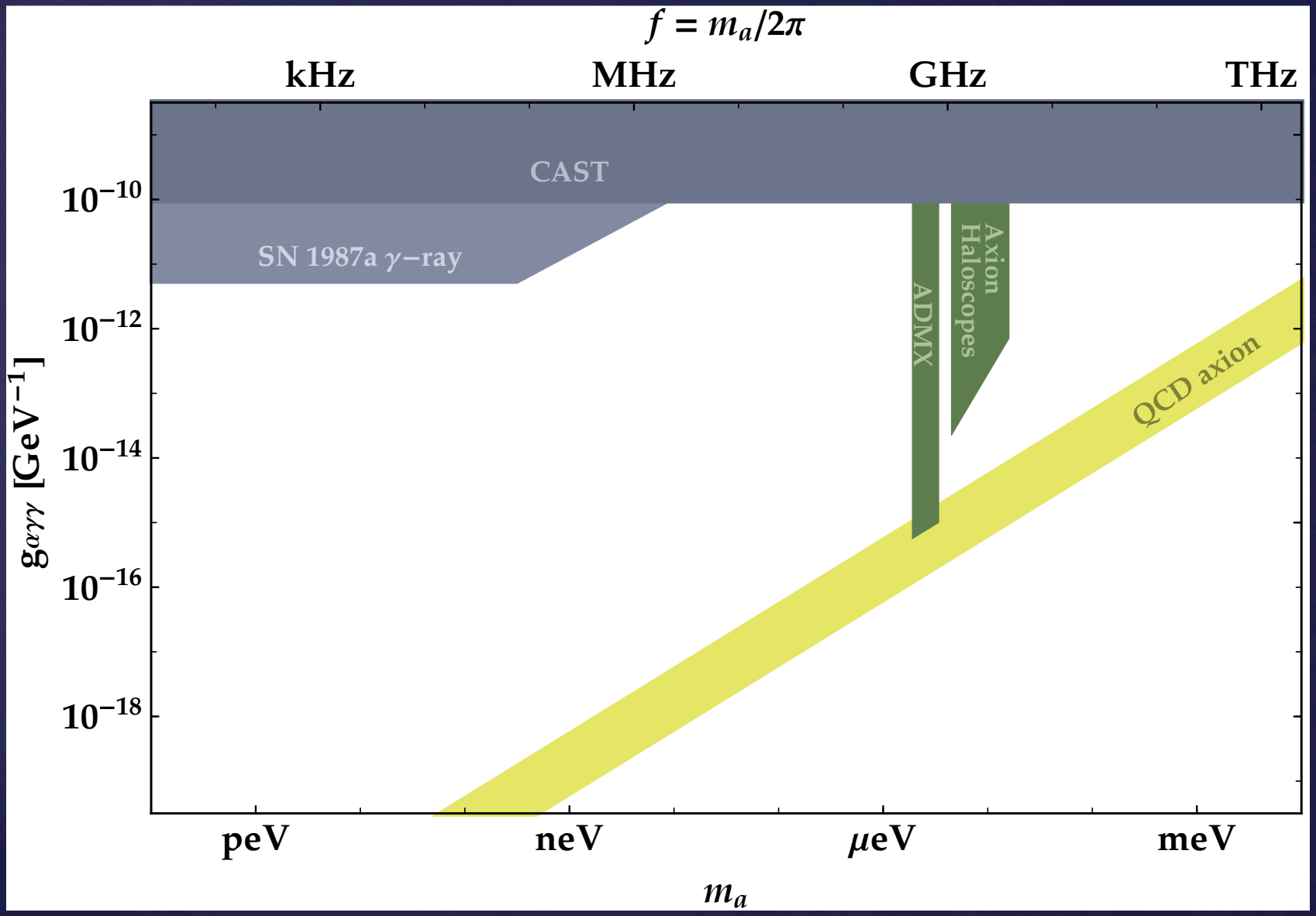
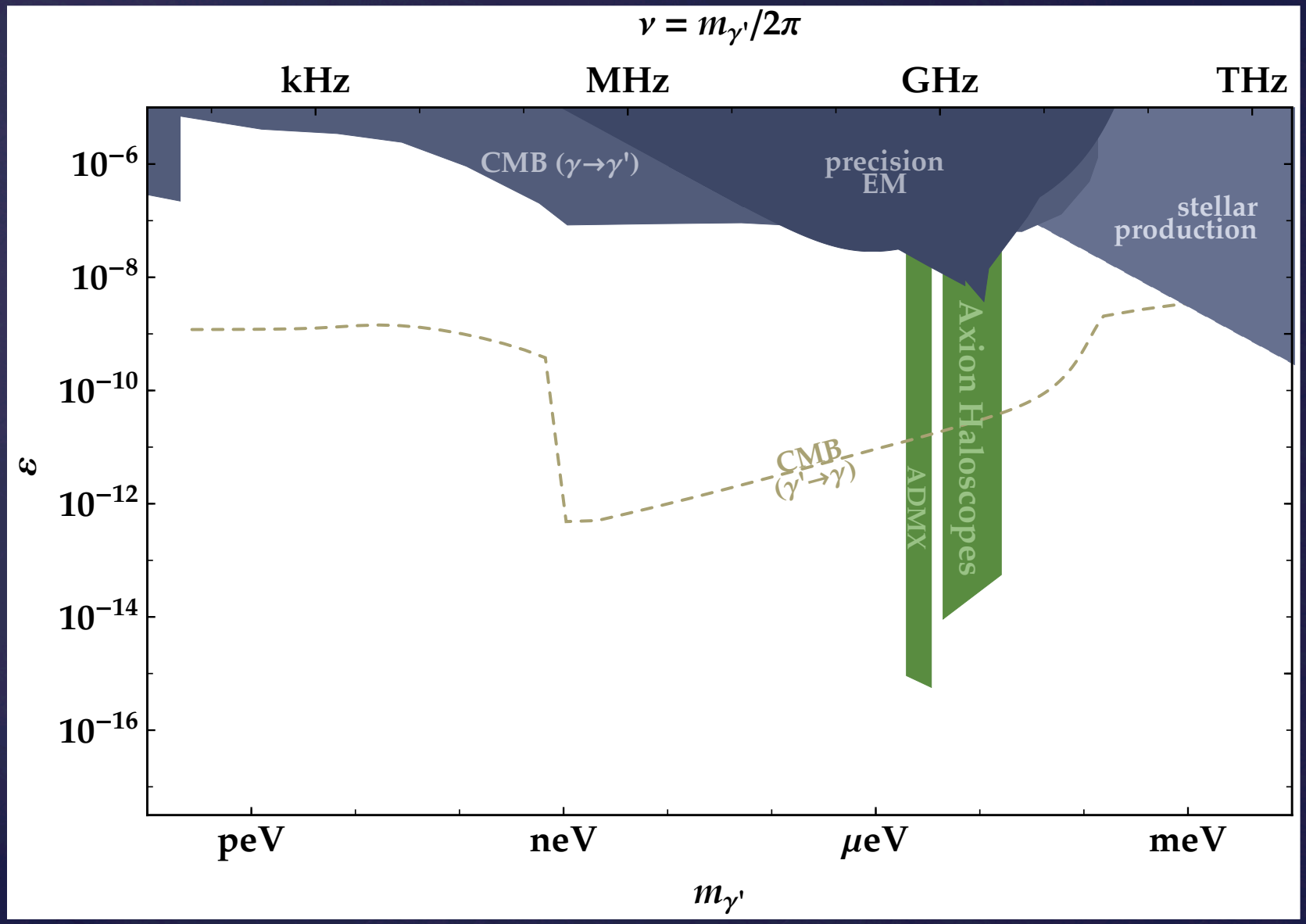
Axion Search leaves some unexplored regions…



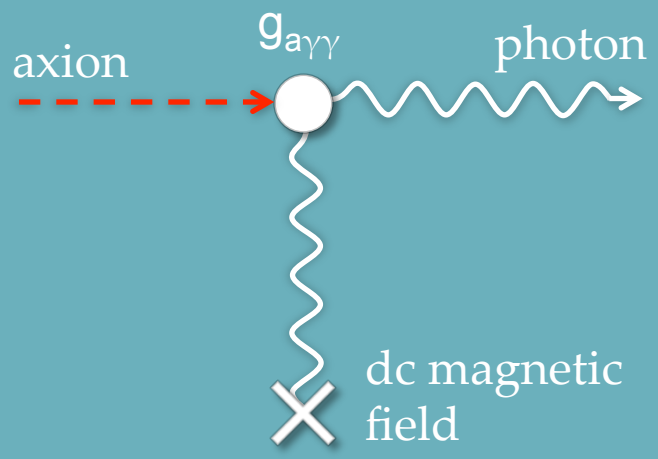
ADMX makes progress in hidden photon search too…



Axions

Hidden Photons

Axions



$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a \mathcal{F}_{\mu\nu} \widetilde{\mathcal{F}}^{\mu\nu}$$

Hidden Photons

$$\mathcal{L} \supset \varepsilon m_{\gamma'}^2 A'_\mu A^\mu - e J_\mu A^\mu$$
$$\supset (\varepsilon m_{\gamma'}^2 A'_\mu - e J_\mu) A^\mu$$

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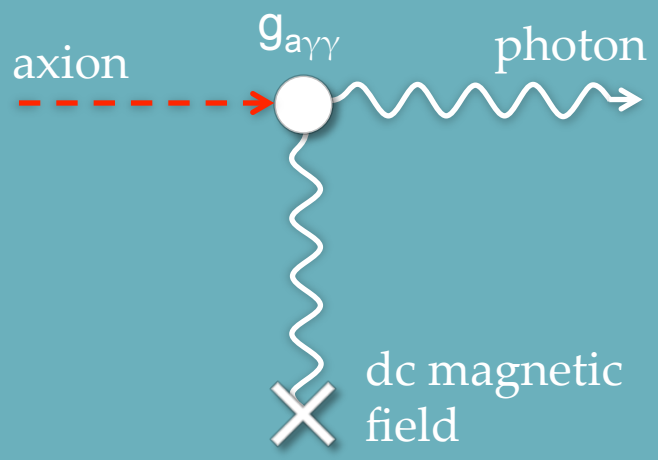
Axions



- pseudoscalar (spin 0) bosons
- conversion to photons by inverse Primakoff effect
- requires a large dc magnetic field
- resultant effective current is parallel/ antiparallel to the dc magnetic field
- virial velocity sets signal bandwidth
- frequency of the photon gives the mass, amplitude gives the coupling

Hidden Photons

- vector (spin 1) bosons
- conversion to photons directly by kinetic mixing
- may be generated by Inflation
- virial velocity sets signal bandwidth
- frequency of the photon gives the mass, amplitude gives the coupling

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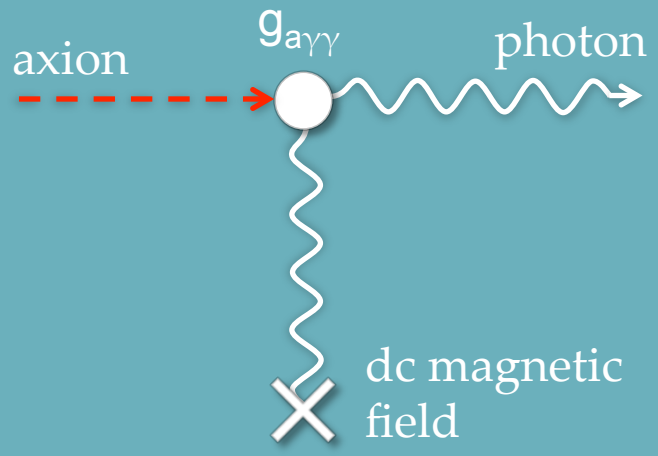
Axions



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$$\vec{J}_{\mathrm{HP}}(t)$$

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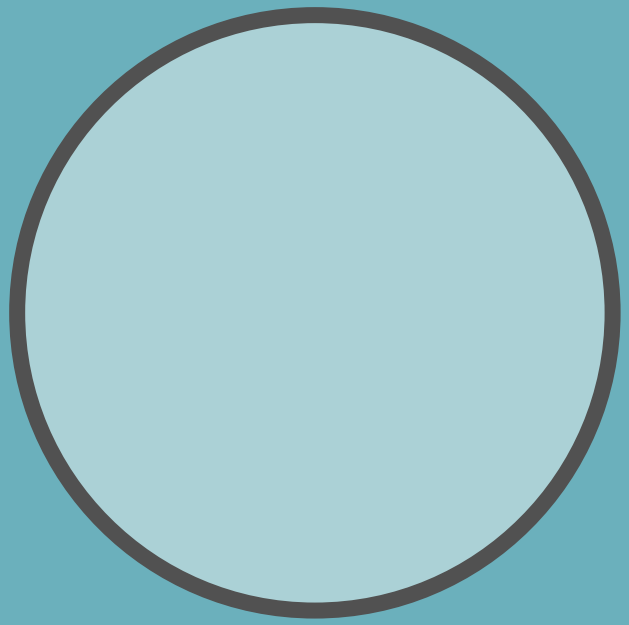
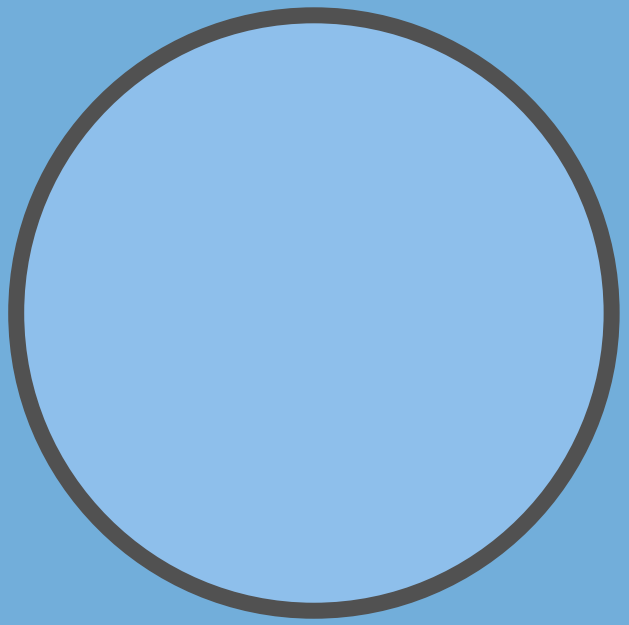
Axions



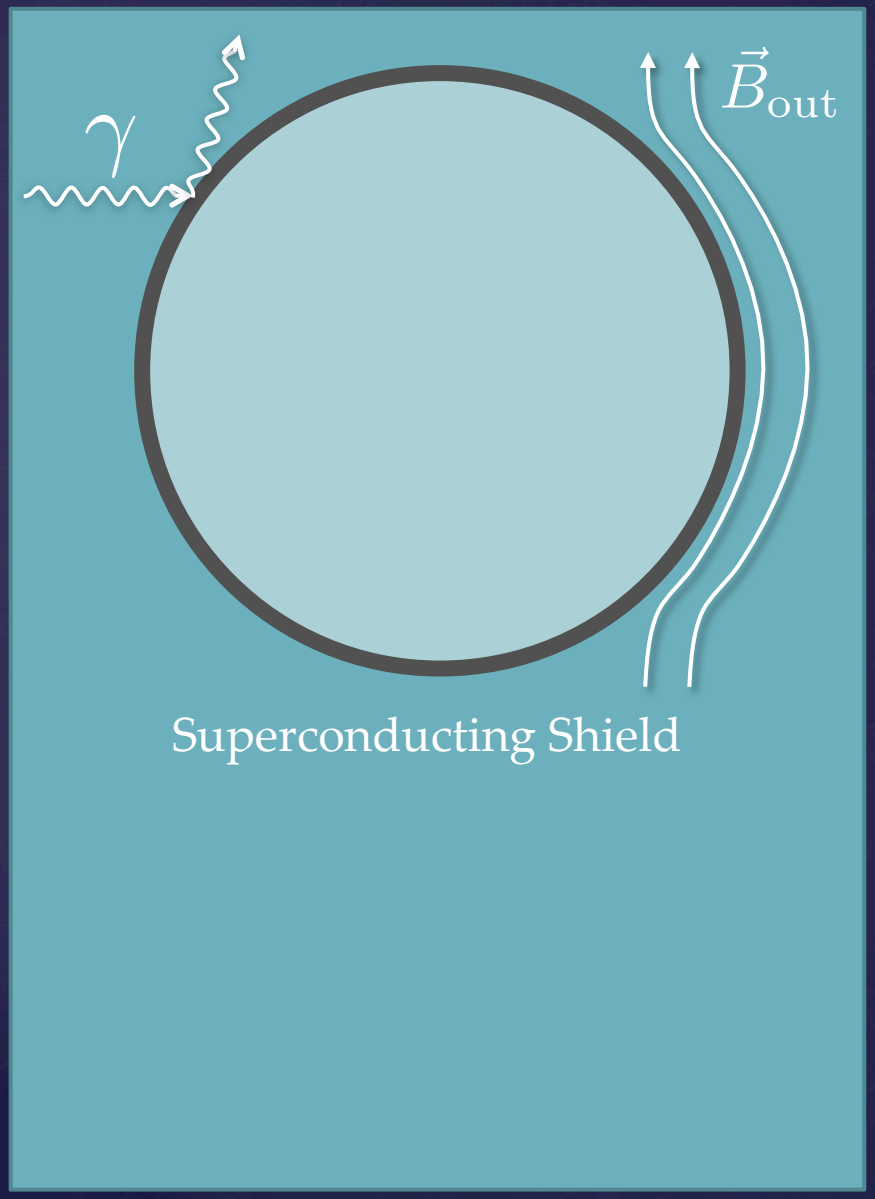
Superconducting Shield

Hidden Photons

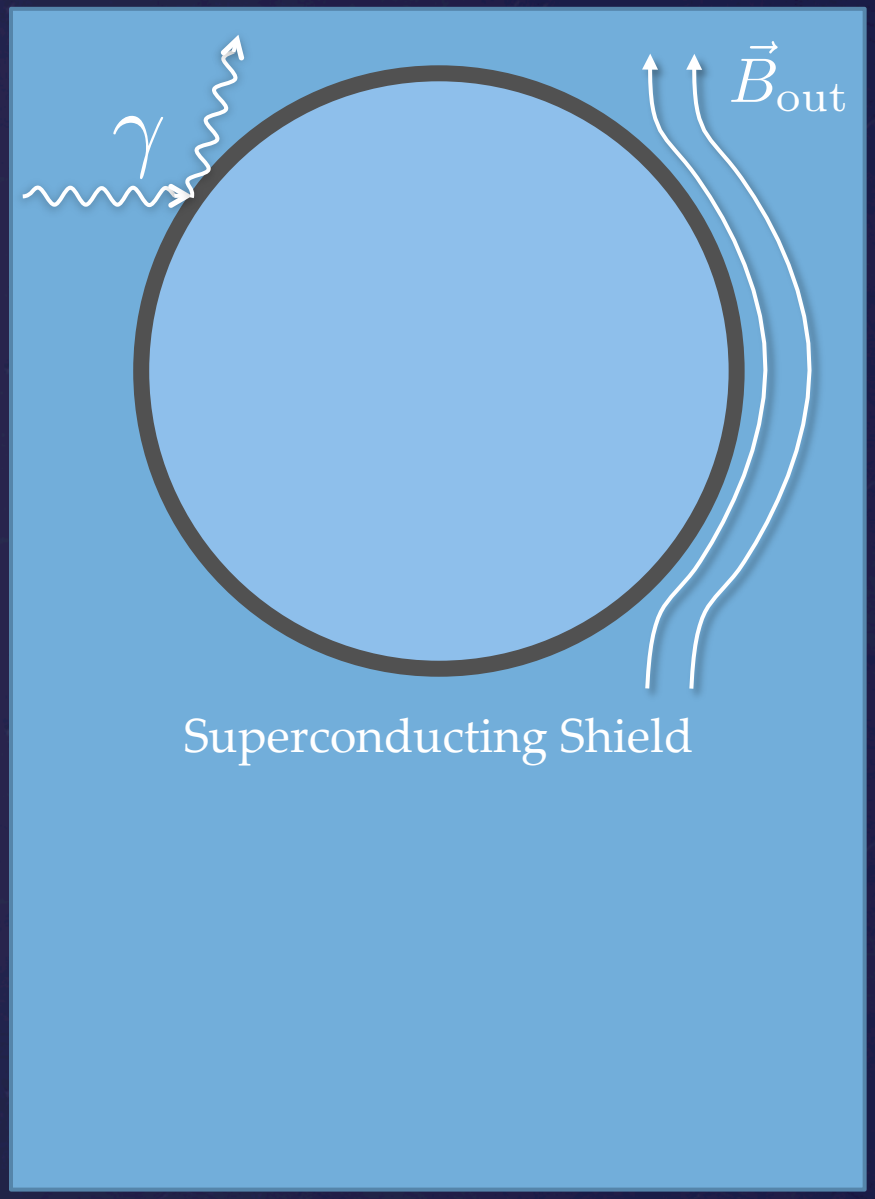


Superconducting Shield

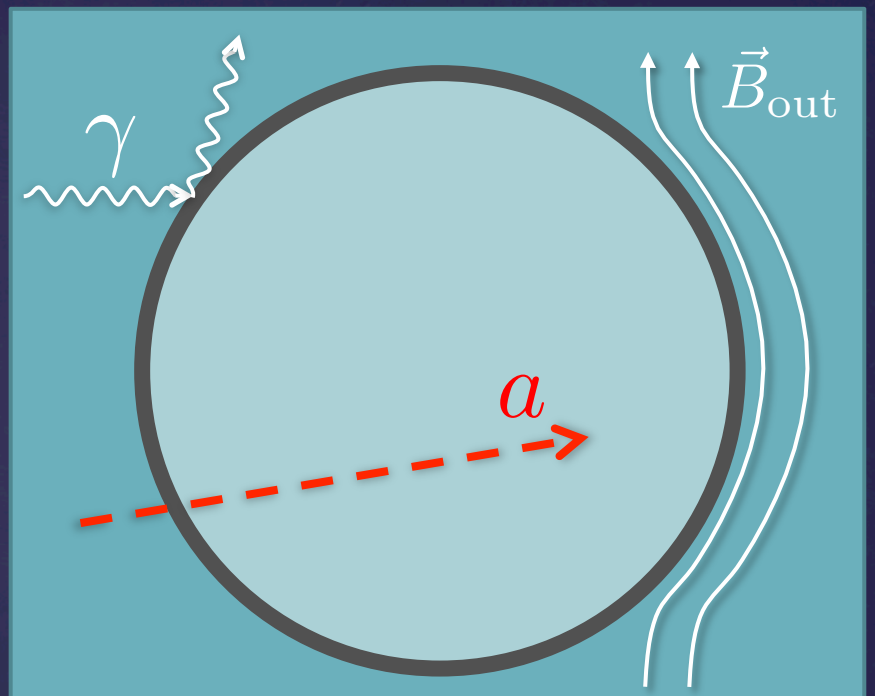
Axions



Hidden Photons



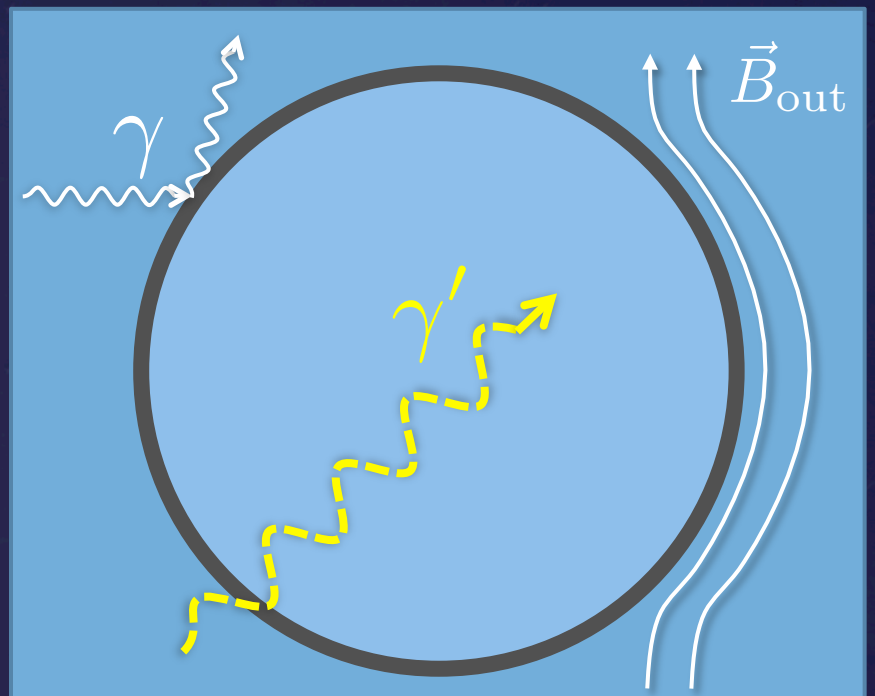
Axions



Superconducting Shield

A nice quiet place for axions

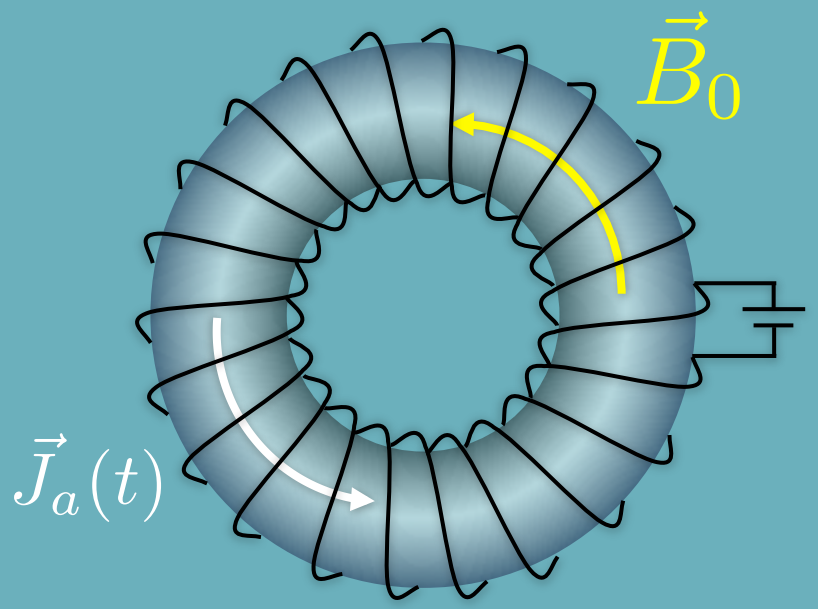
Hidden Photons



Superconducting Shield

A nice quiet place for hidden photons

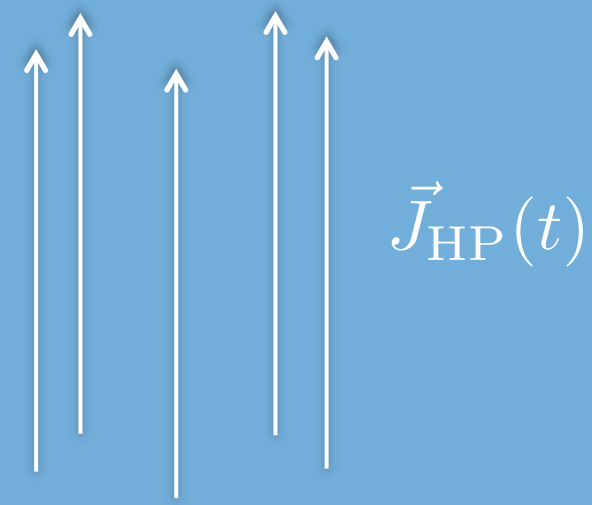
Axions



Inside the superconducting shield…

axions interact with a dc magnetic field to source a real effective electric current

Hidden Photons

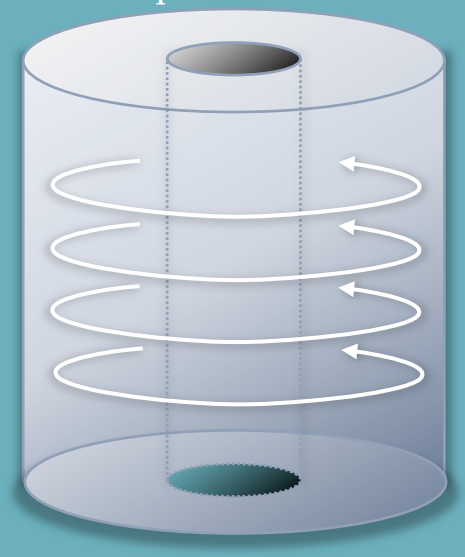


Inside the superconducting shield…

hidden photons source an effective electric current directly (no field required)

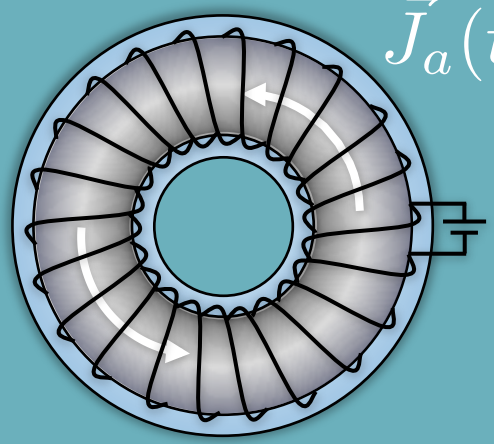
Axions

Add a hollow superconductor inside shield



B_0 toroid inside

$\vec{J}_a(t)$



$\vec{J}_a(t)$

Hidden Photons

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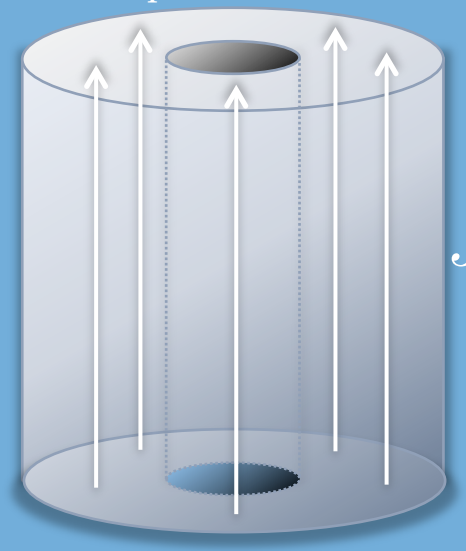
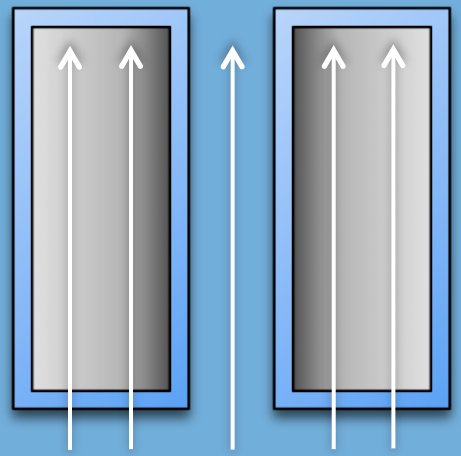
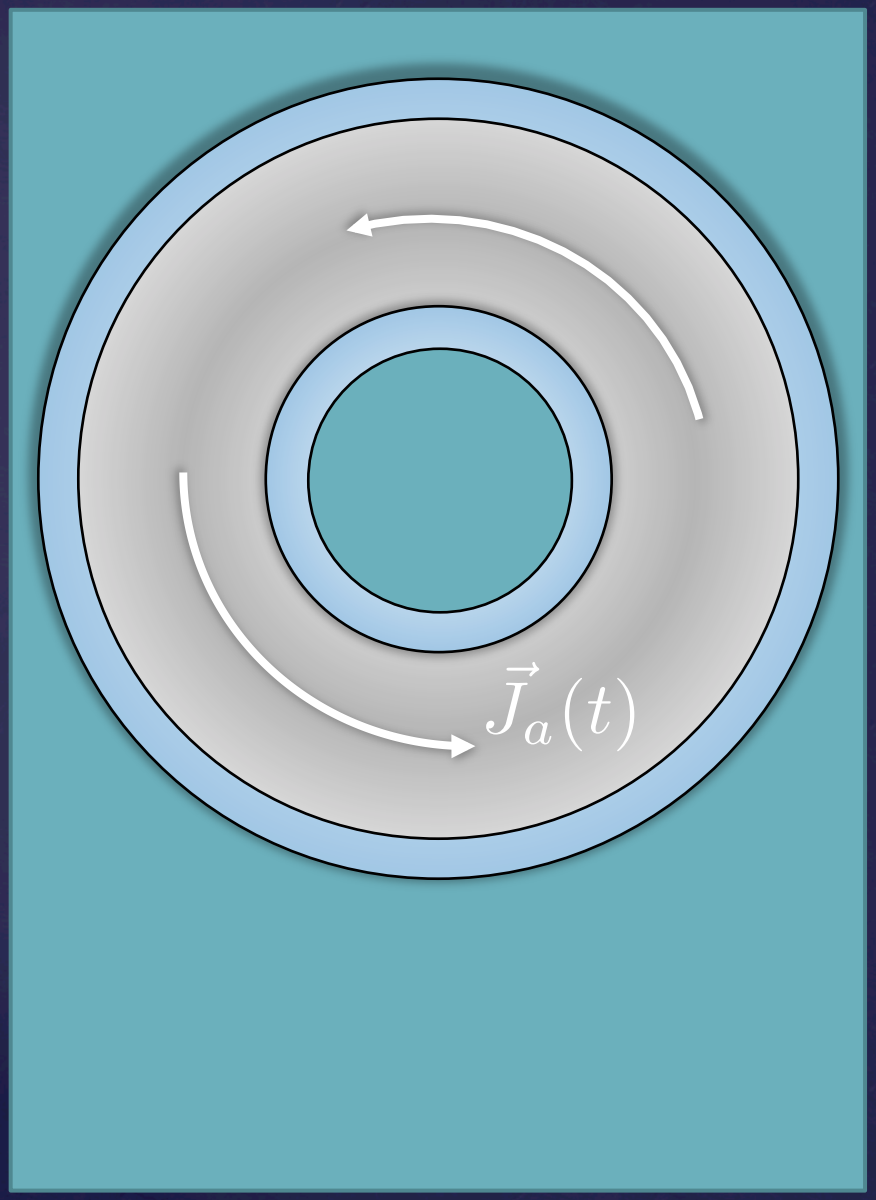


$\vec{J}_{\mathrm{HP}}(t)$

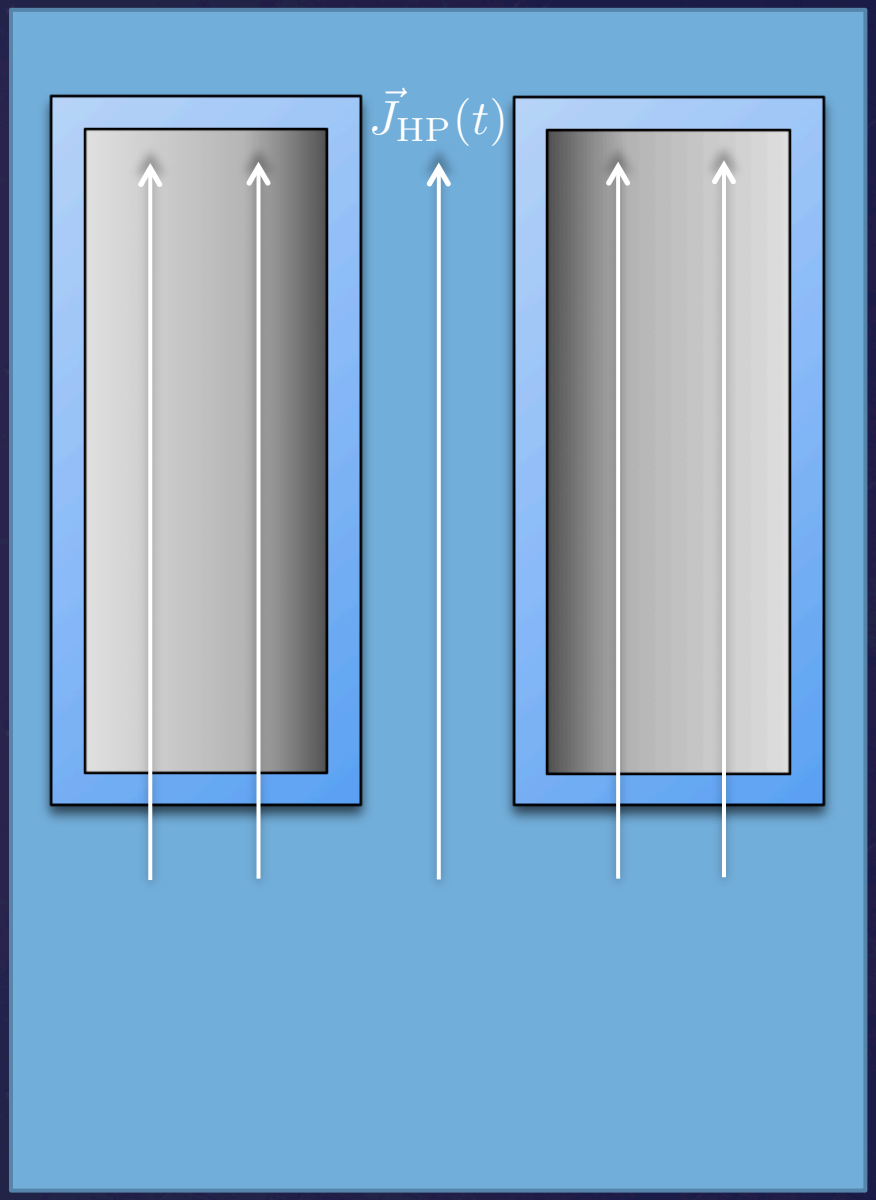


$\vec{J}_{\mathrm{HP}}(t)$

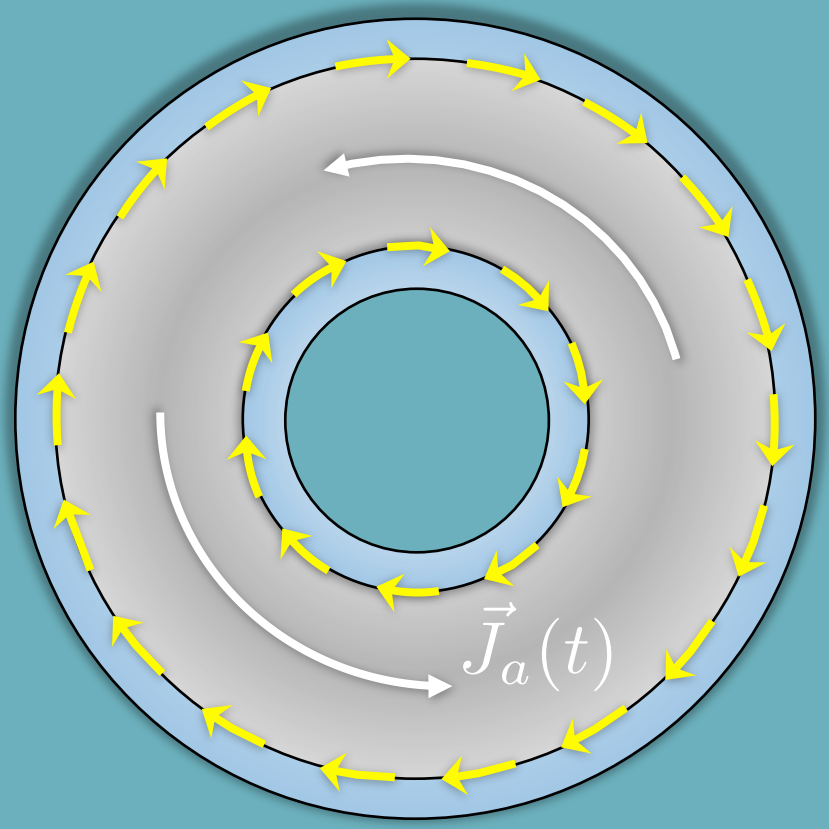
Axions



Hidden Photons

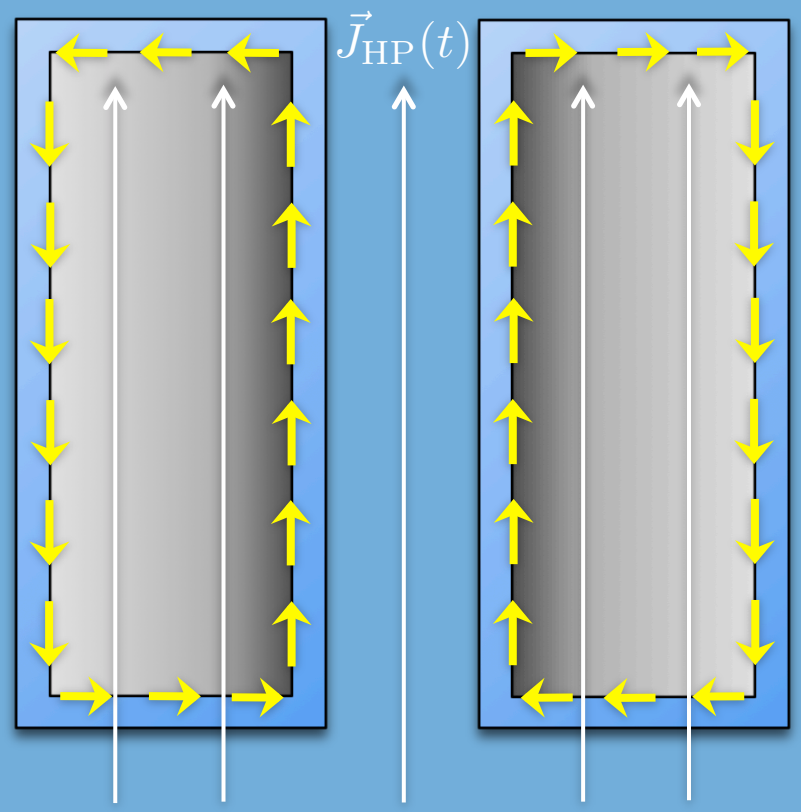


Axions



Screening currents in superconductor flow to cancel field in bulk

Hidden Photons



Screening currents in superconductor flow to cancel field in bulk

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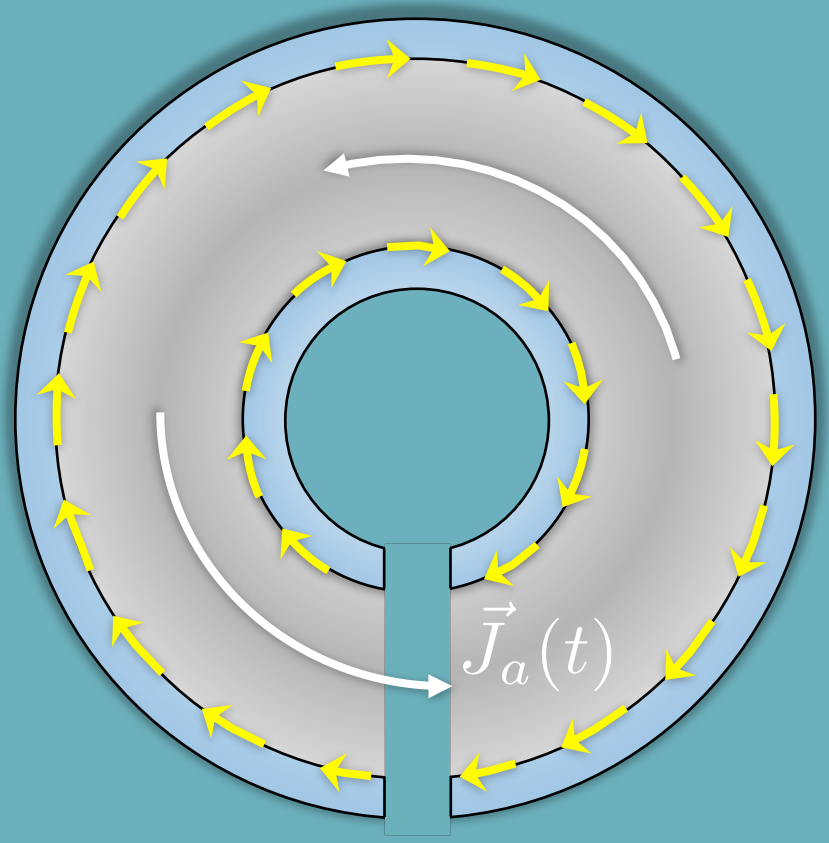
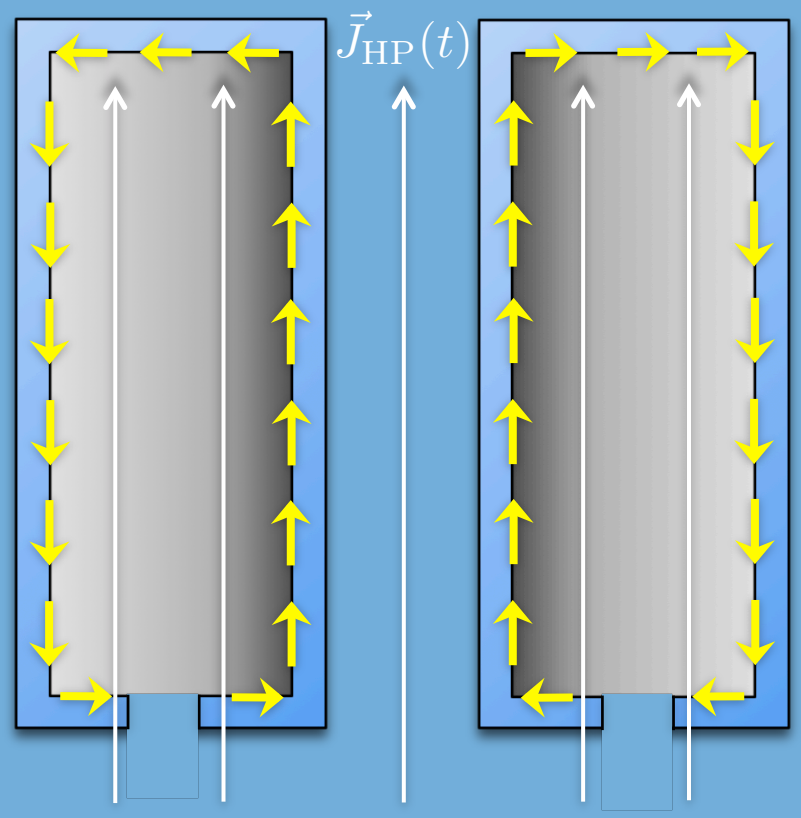
Axions



Cut a slit from top to bottom of superconducting cylinder

Hidden Photons



Cut a concentric slit at the bottom of the superconducting cylinder

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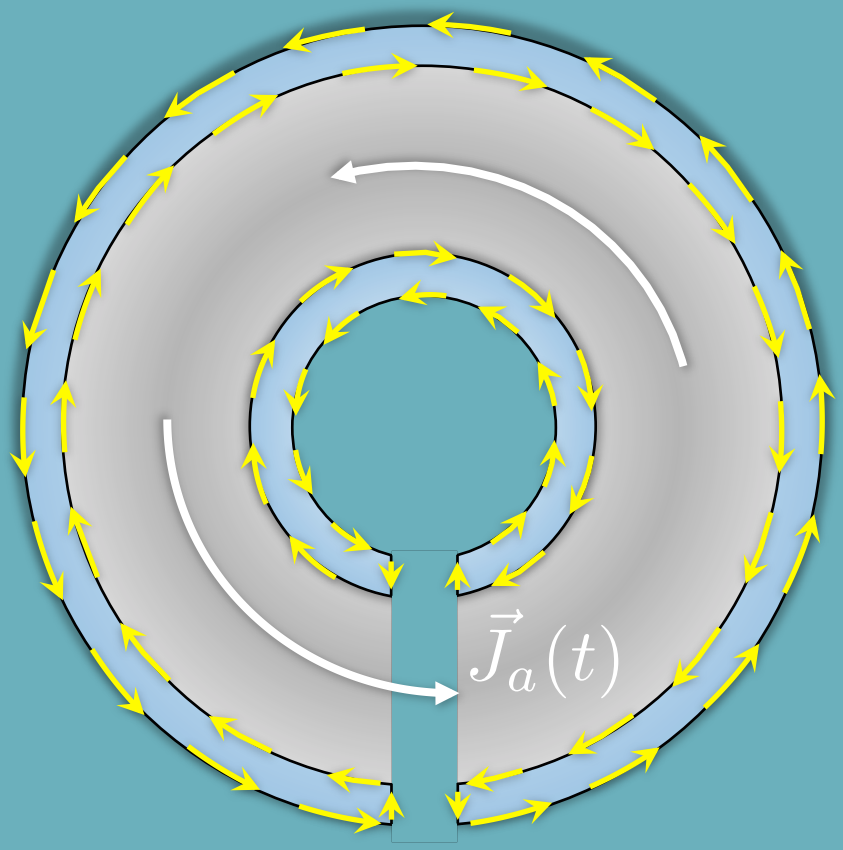
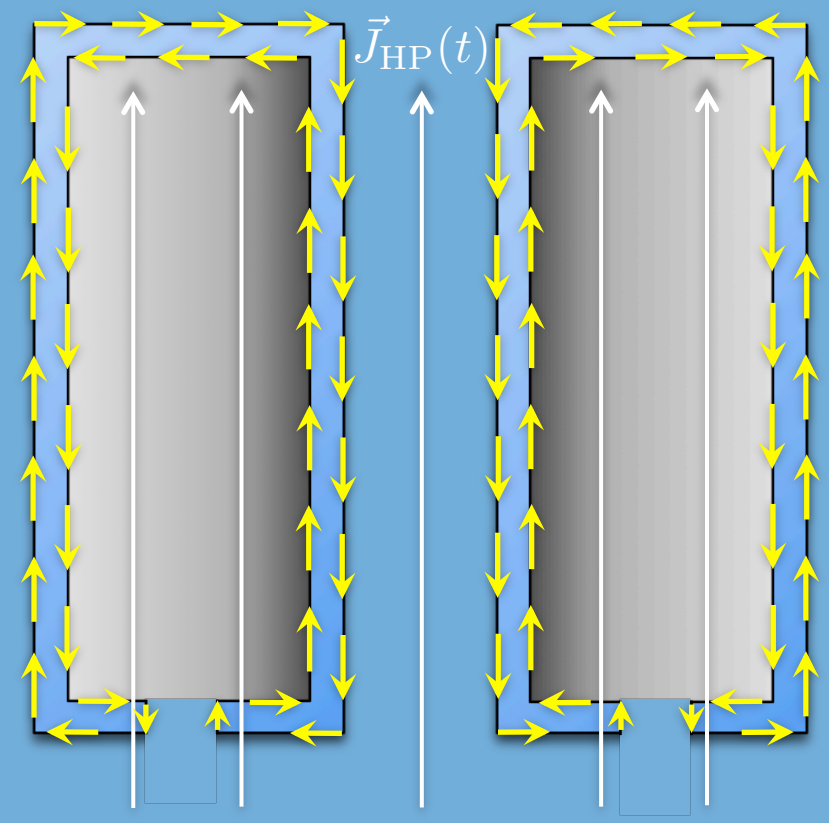
Axions



Screening currents continue along outer surface

Hidden Photons



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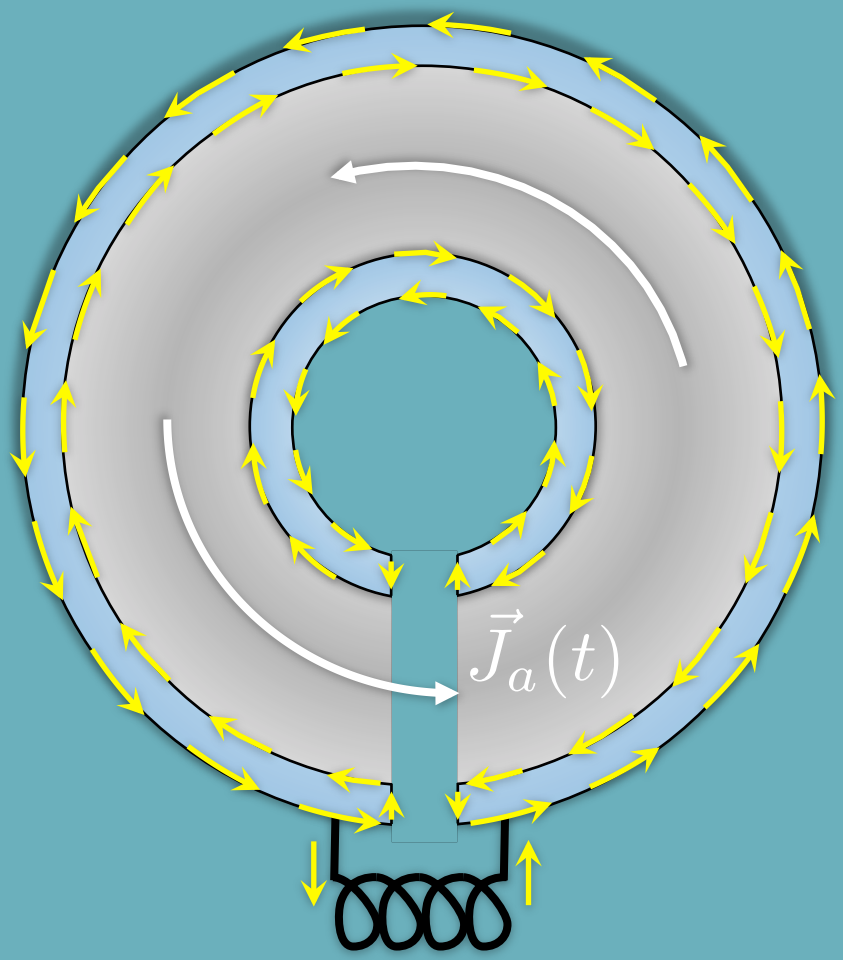
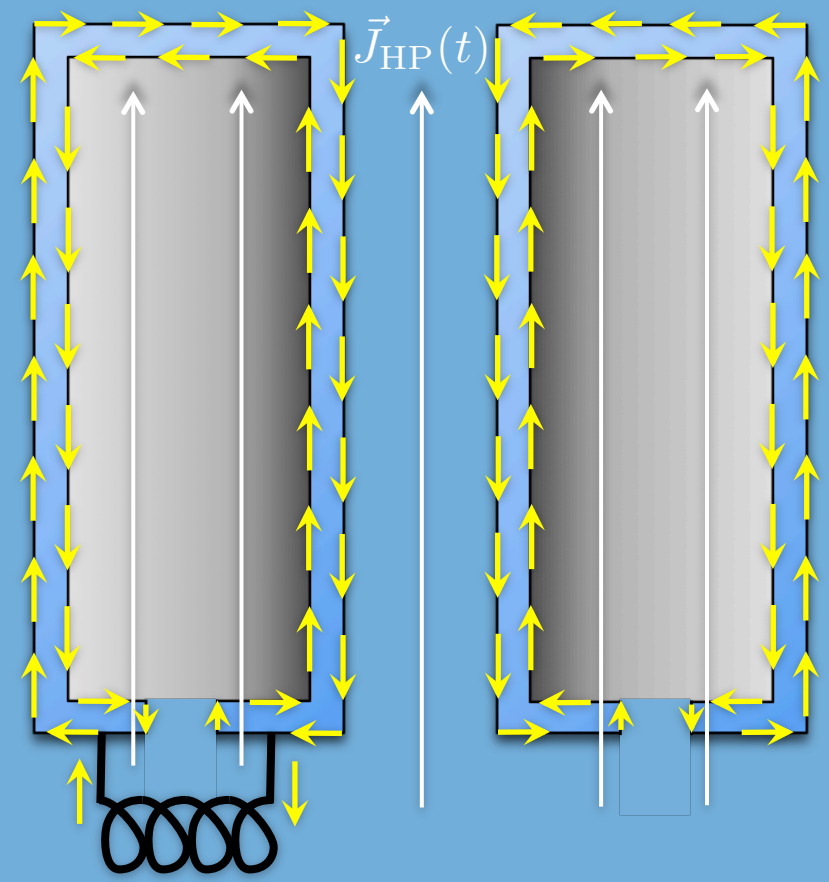


Add an inductive loop to siphon some of the screening current

Hidden Photons



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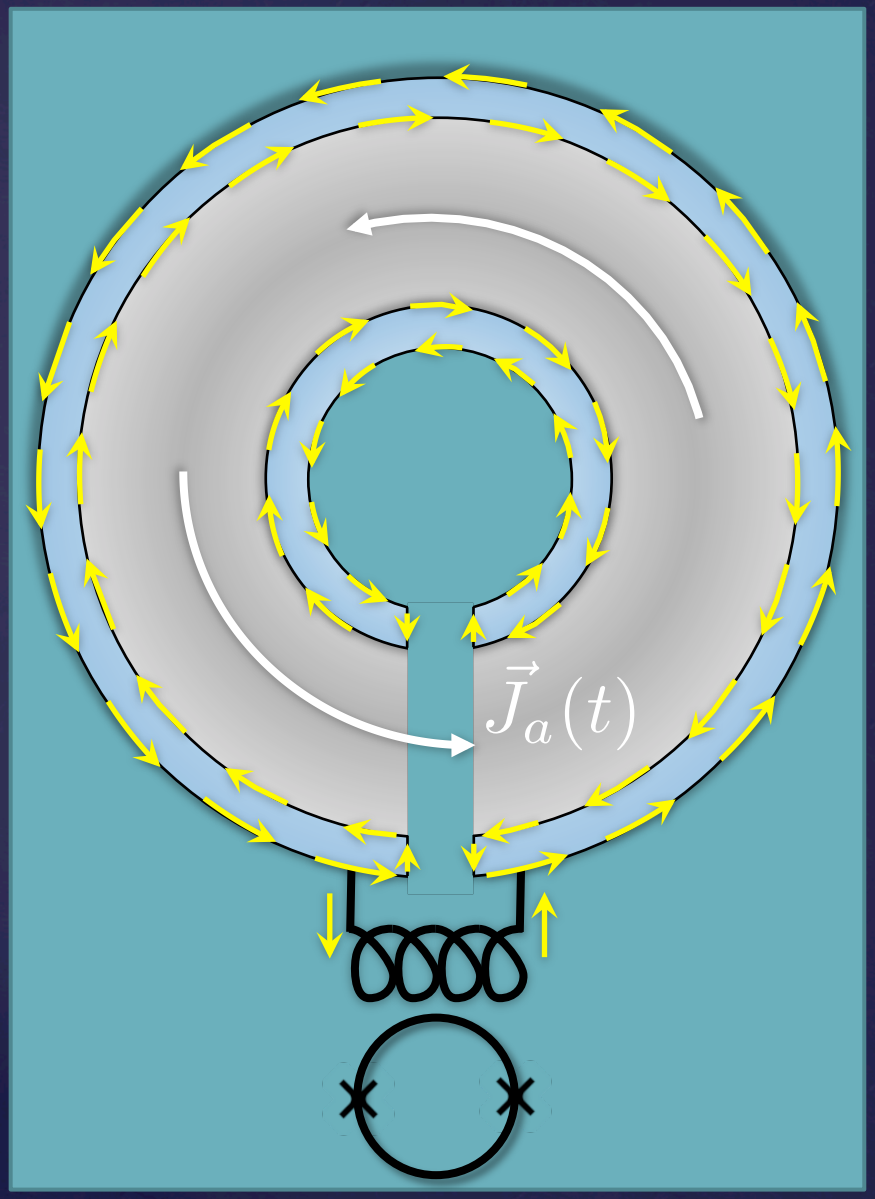

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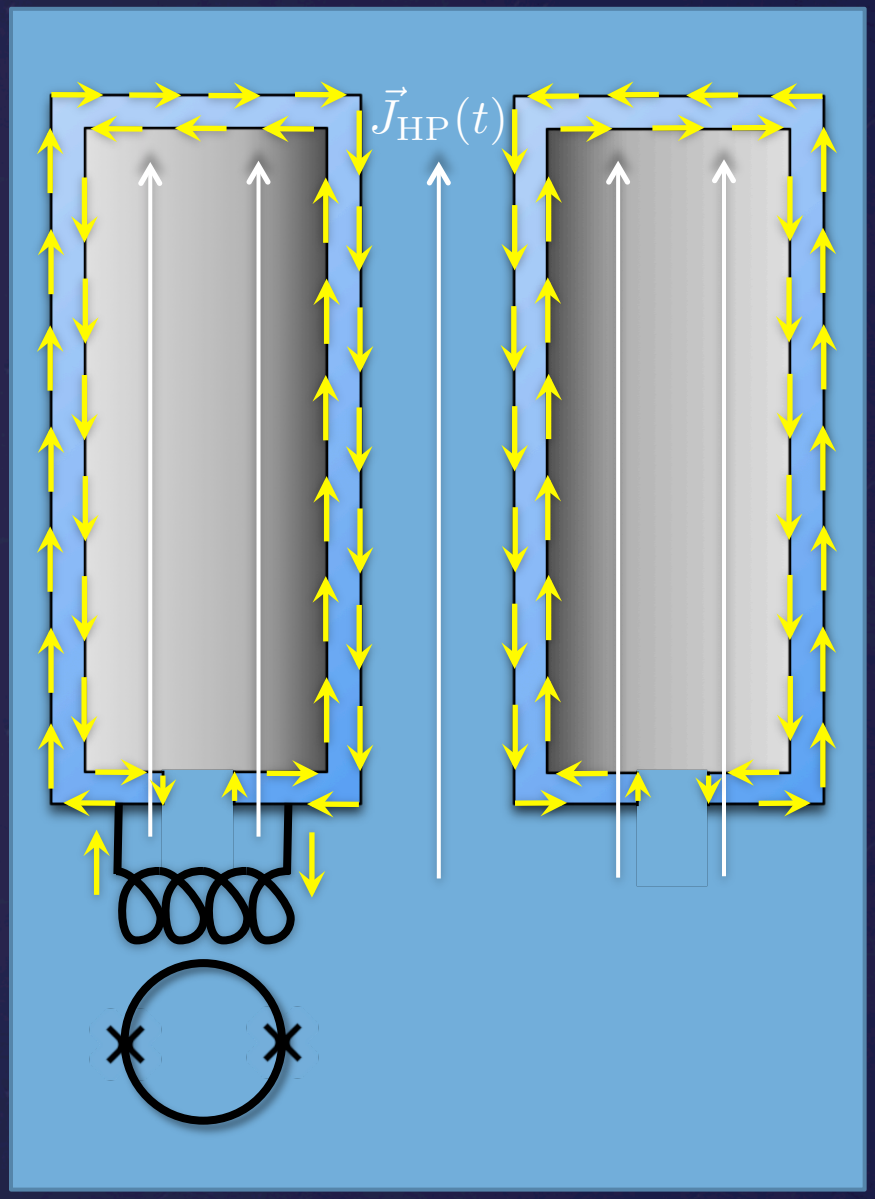

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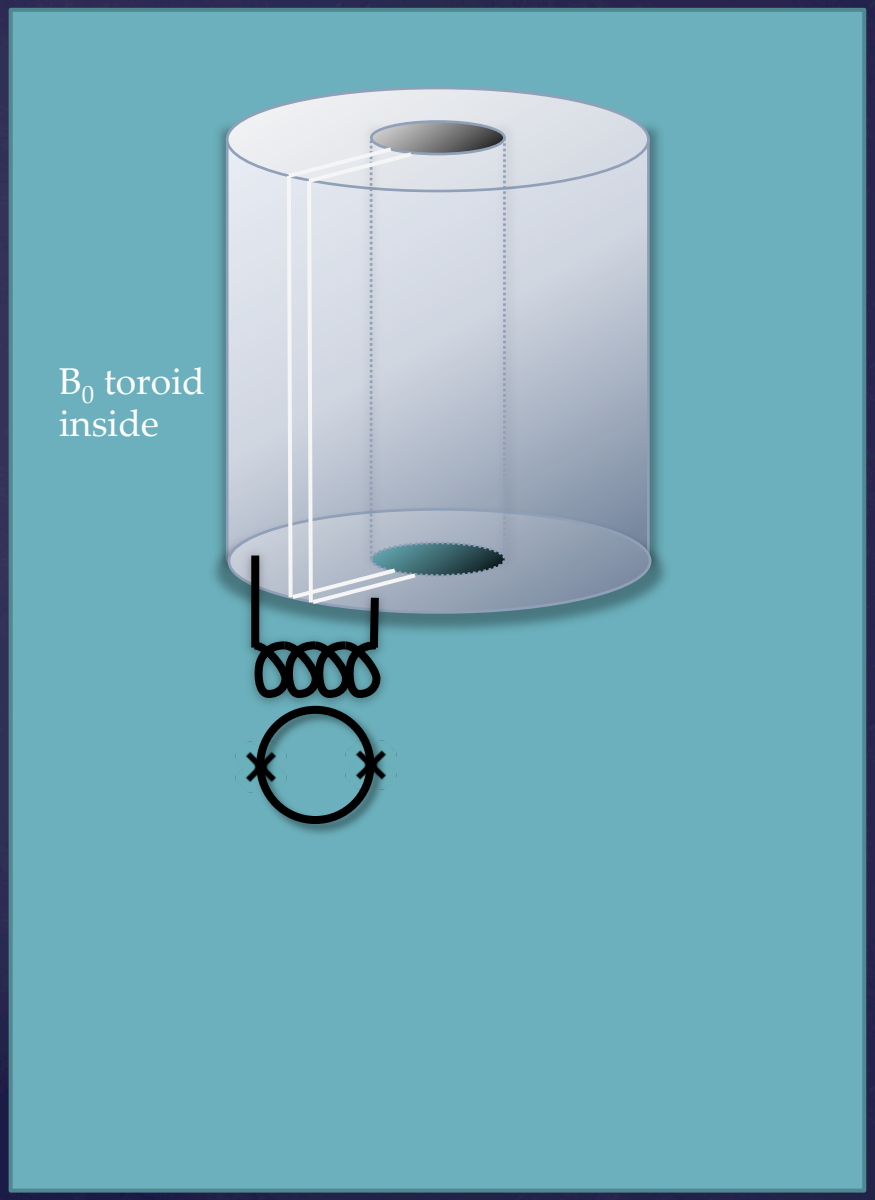

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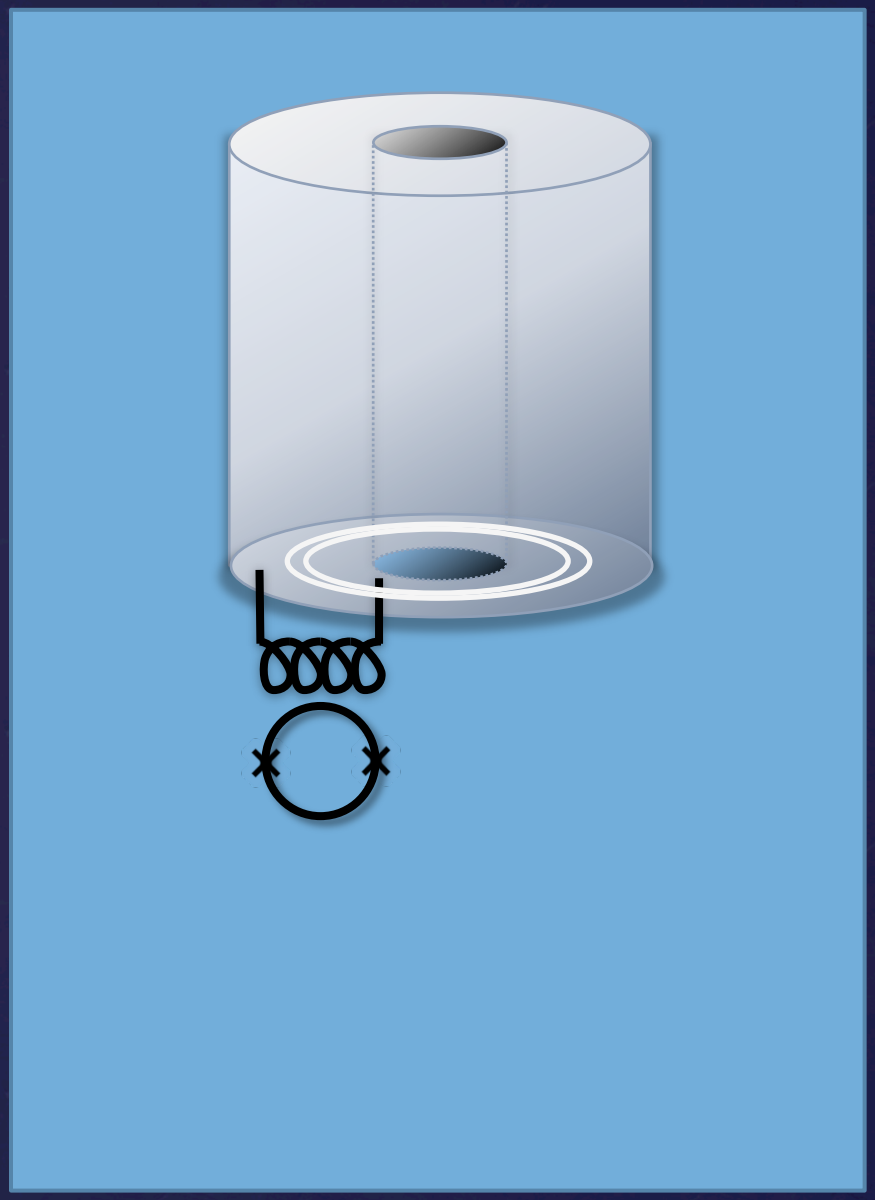

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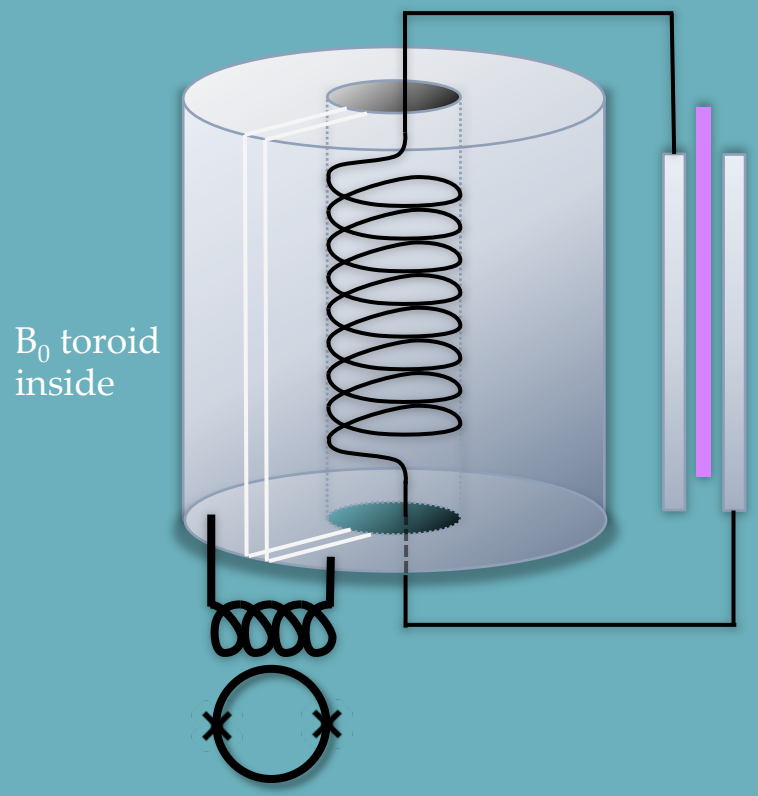
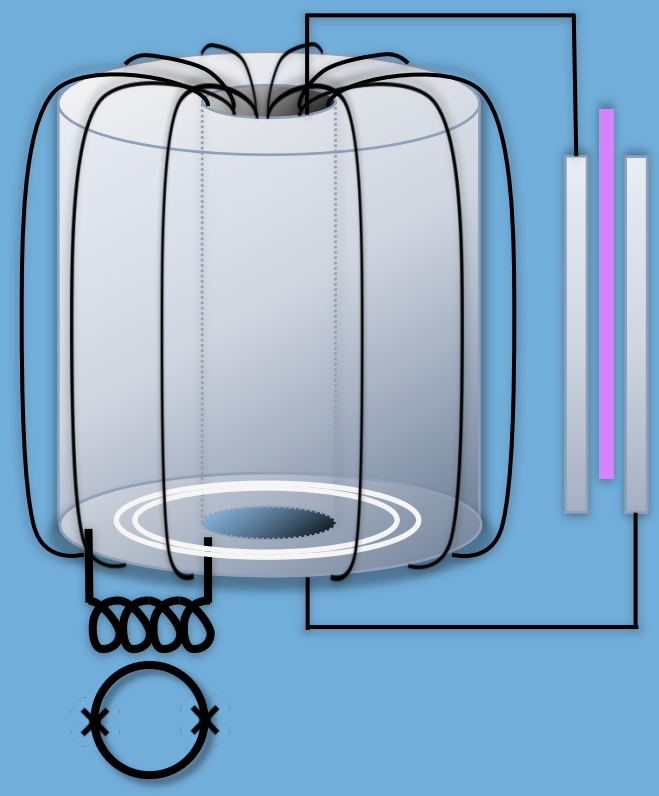


Add a tunable lumped-element resonator to ring up the magnetic fields sourced by $\vec{J}_a(t)$

Hidden Photons



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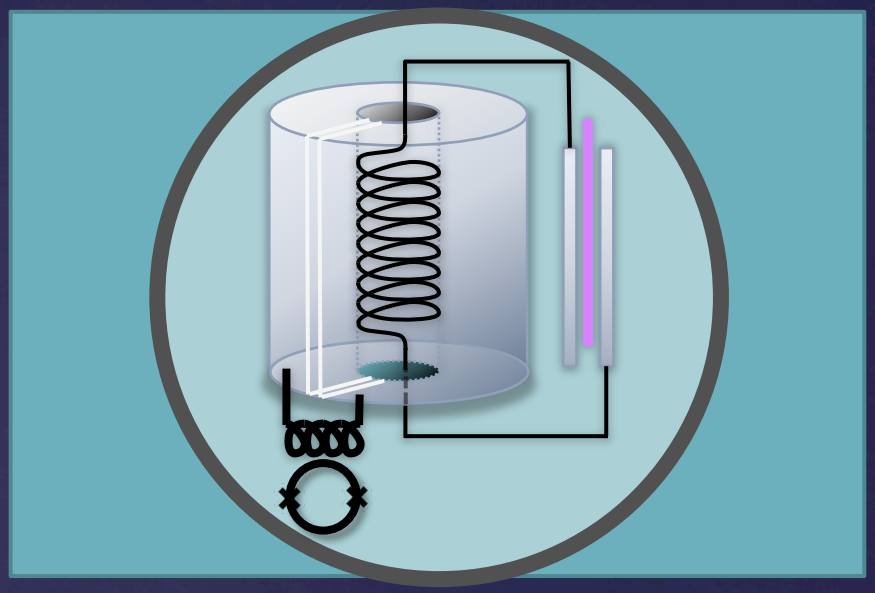
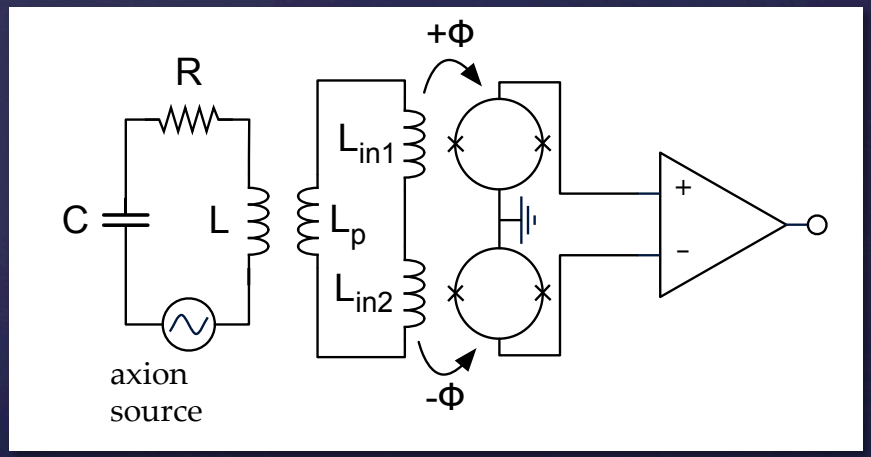
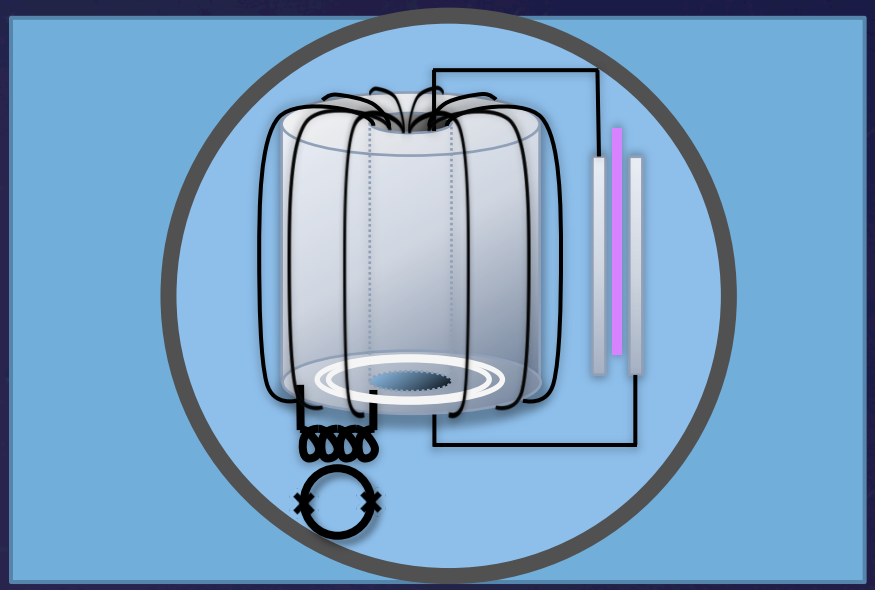
Axions

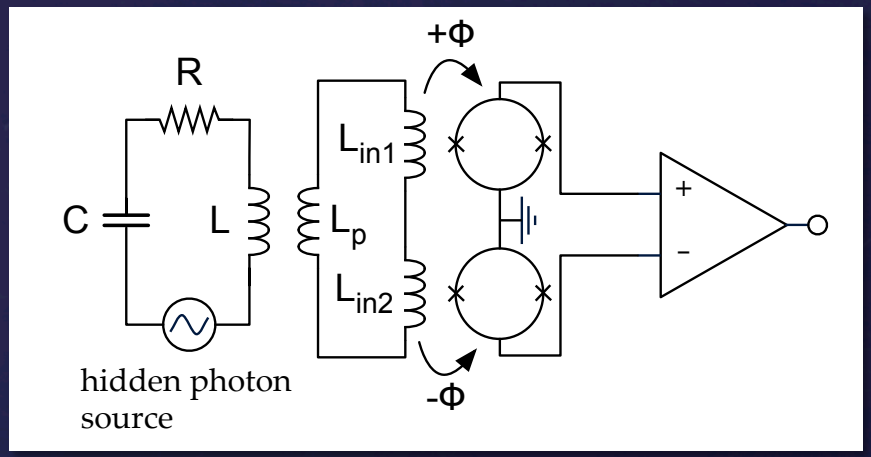




differential SQUIDs to reduce background

Hidden Photons





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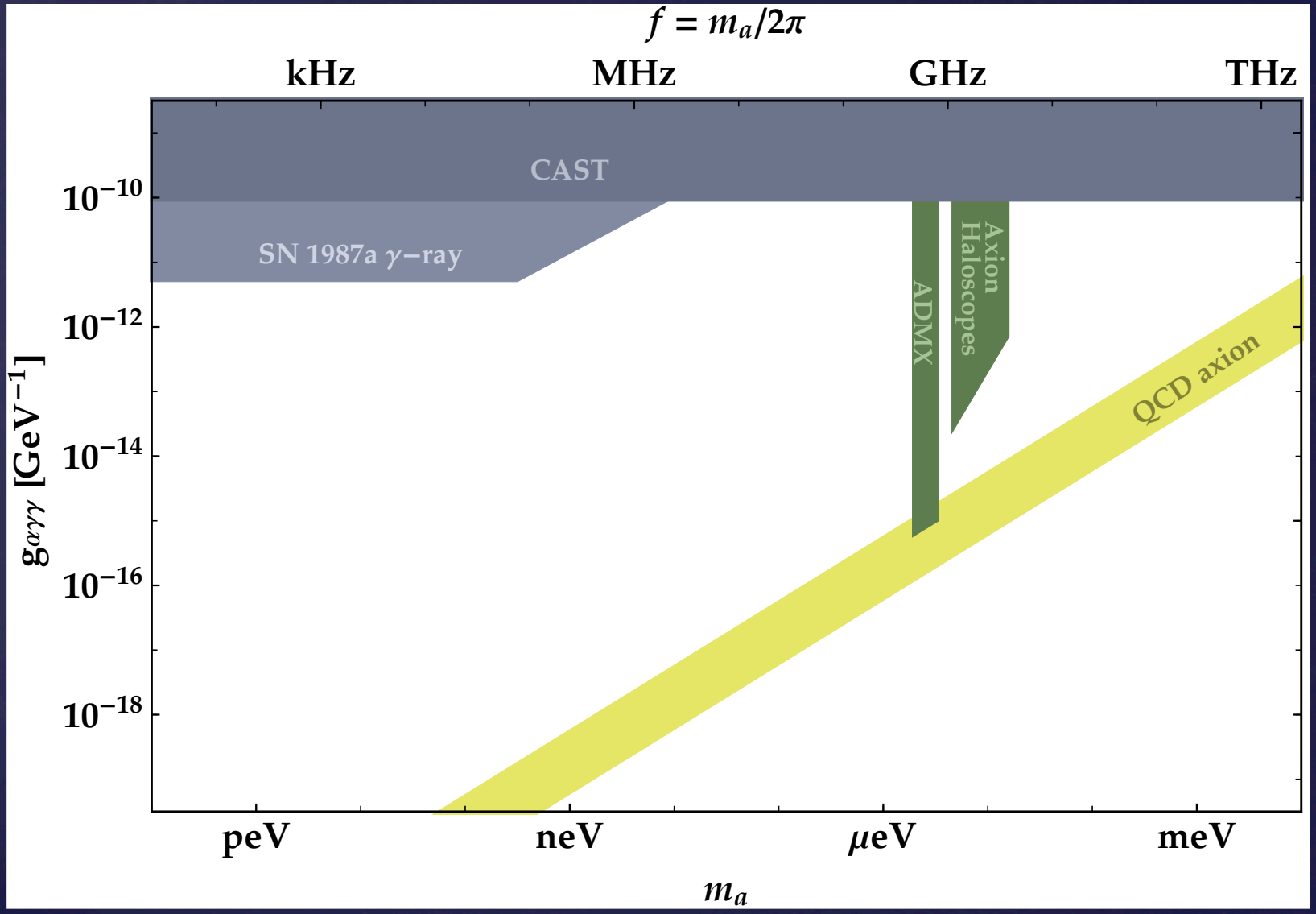
Axion Projections for DM Radio



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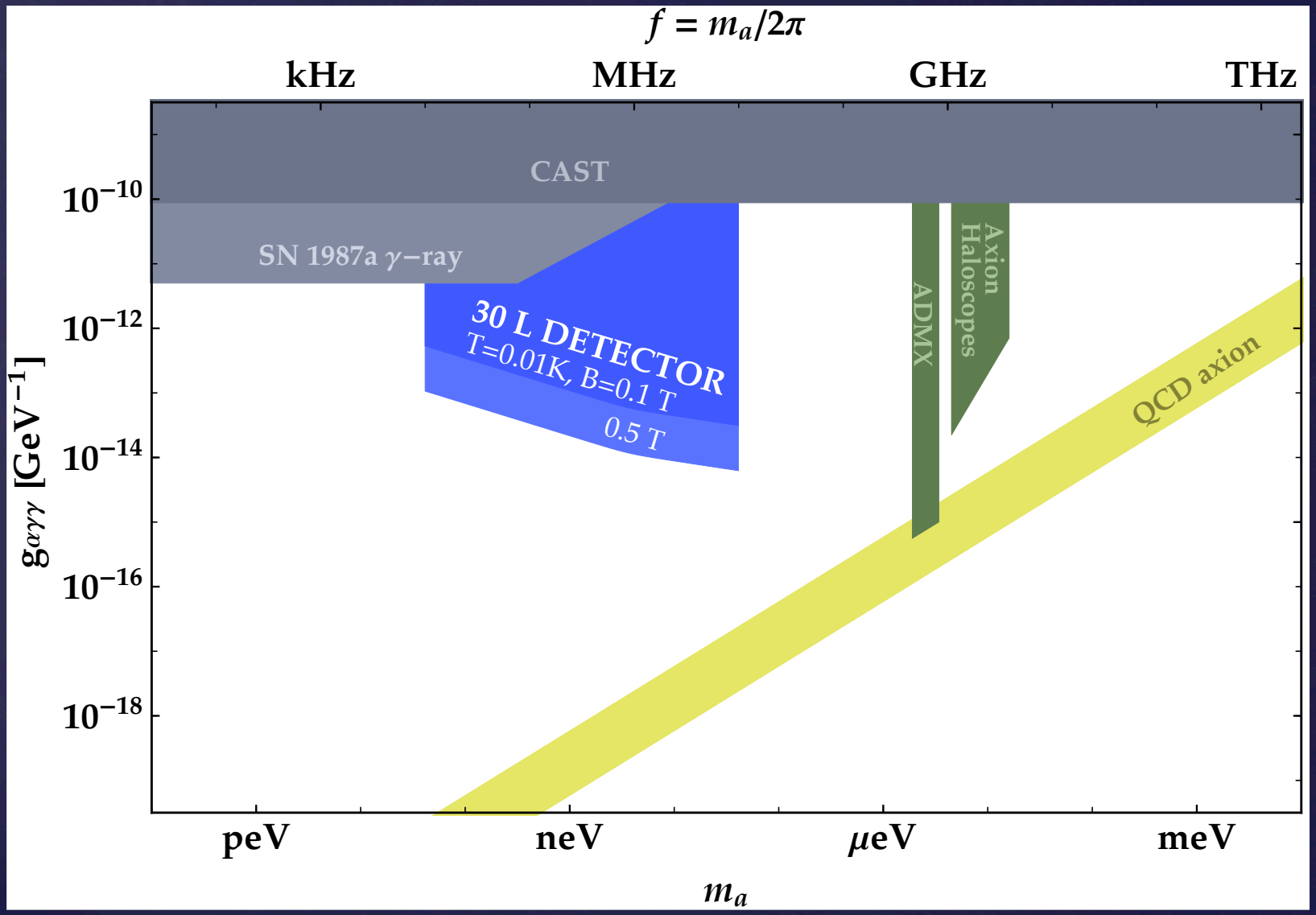

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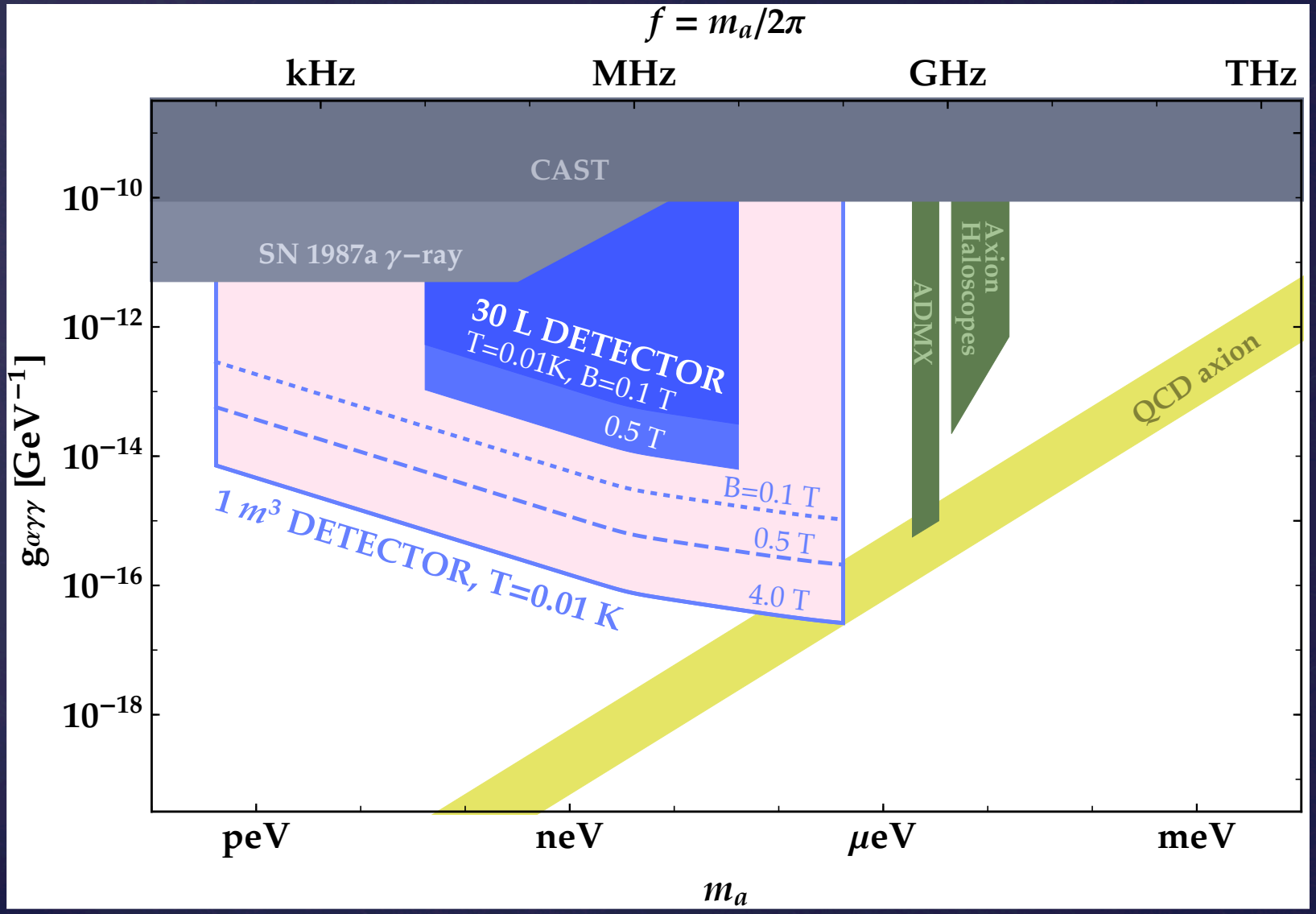
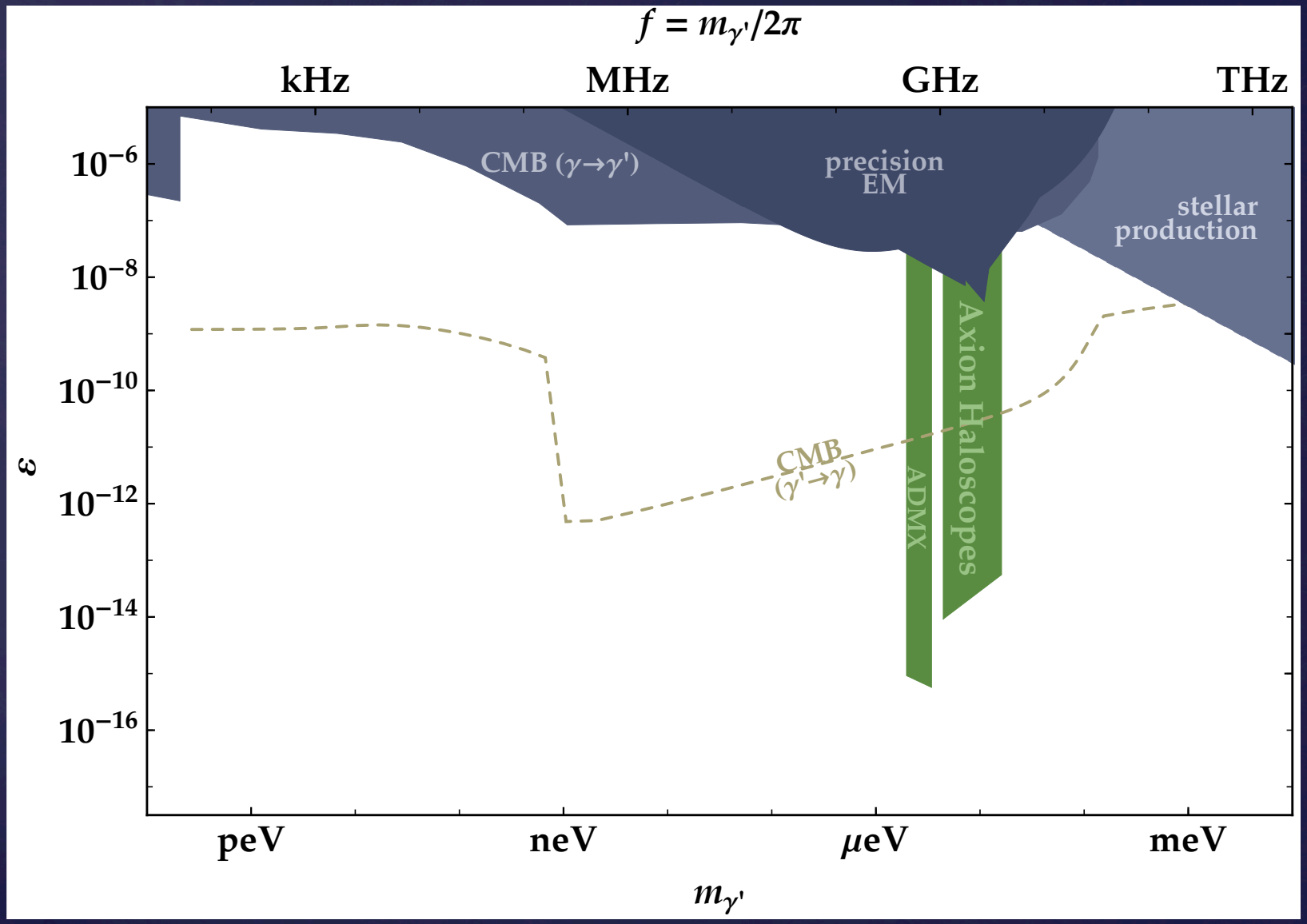


Hidden Photon Projections for DM Radio



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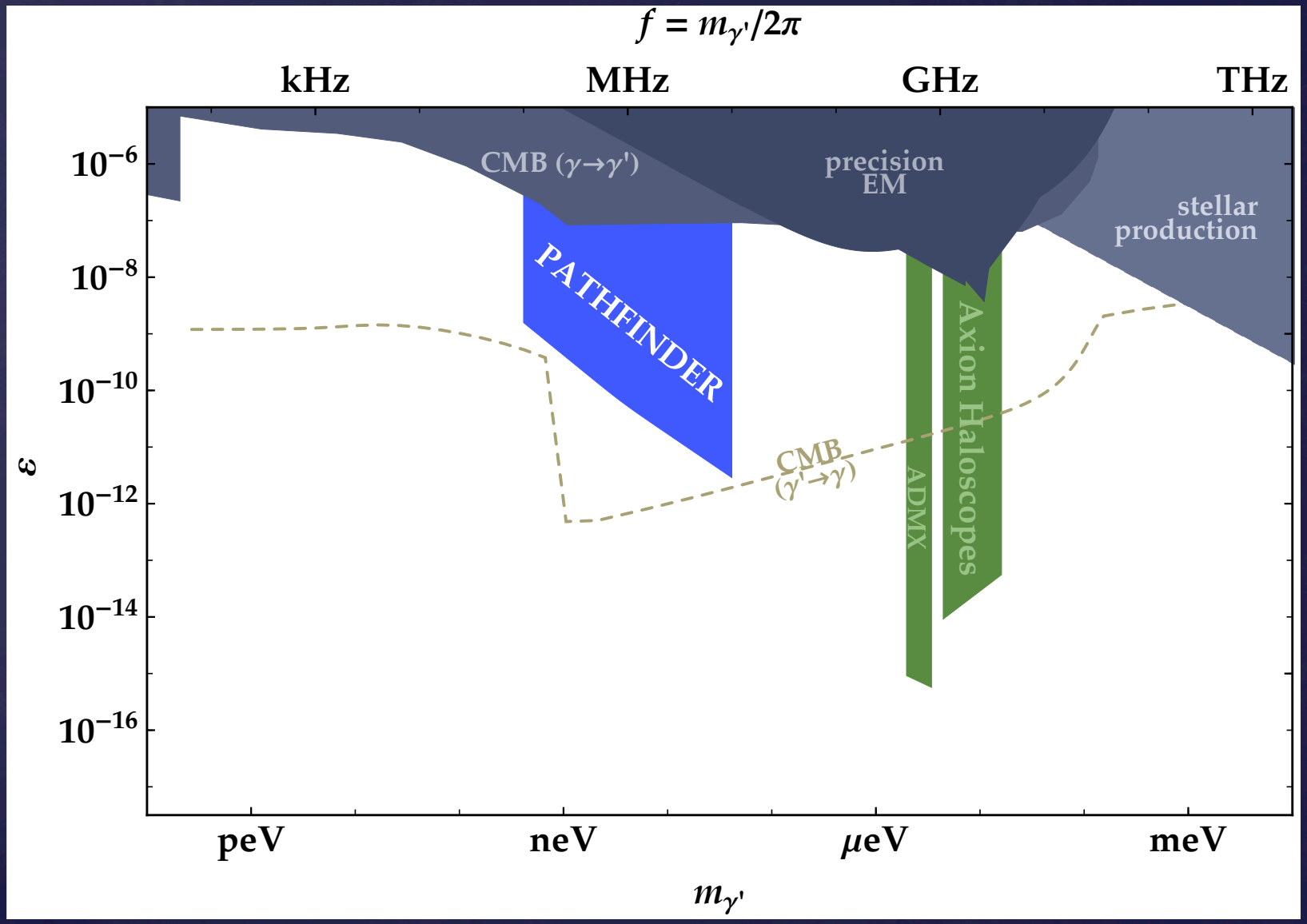

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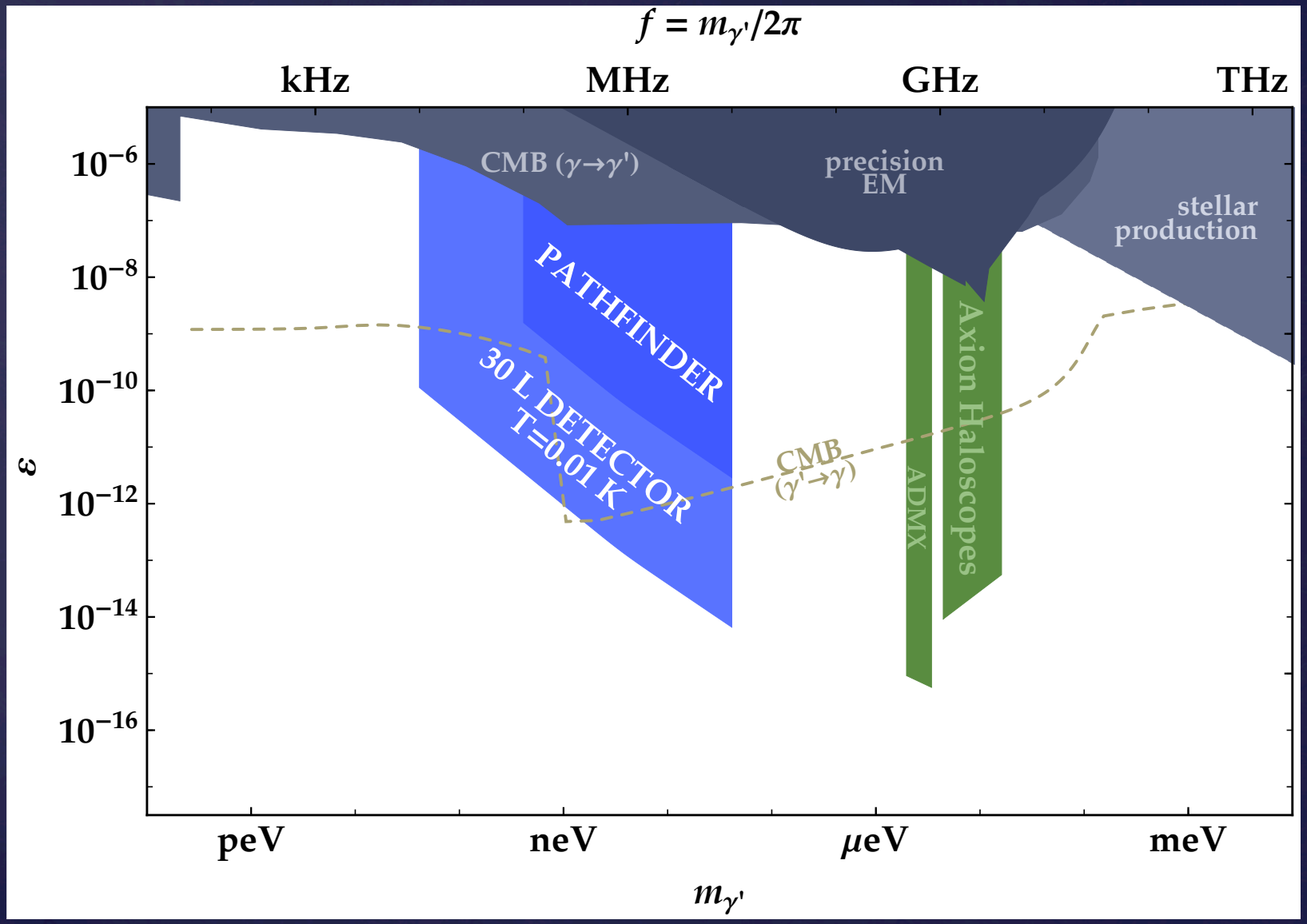

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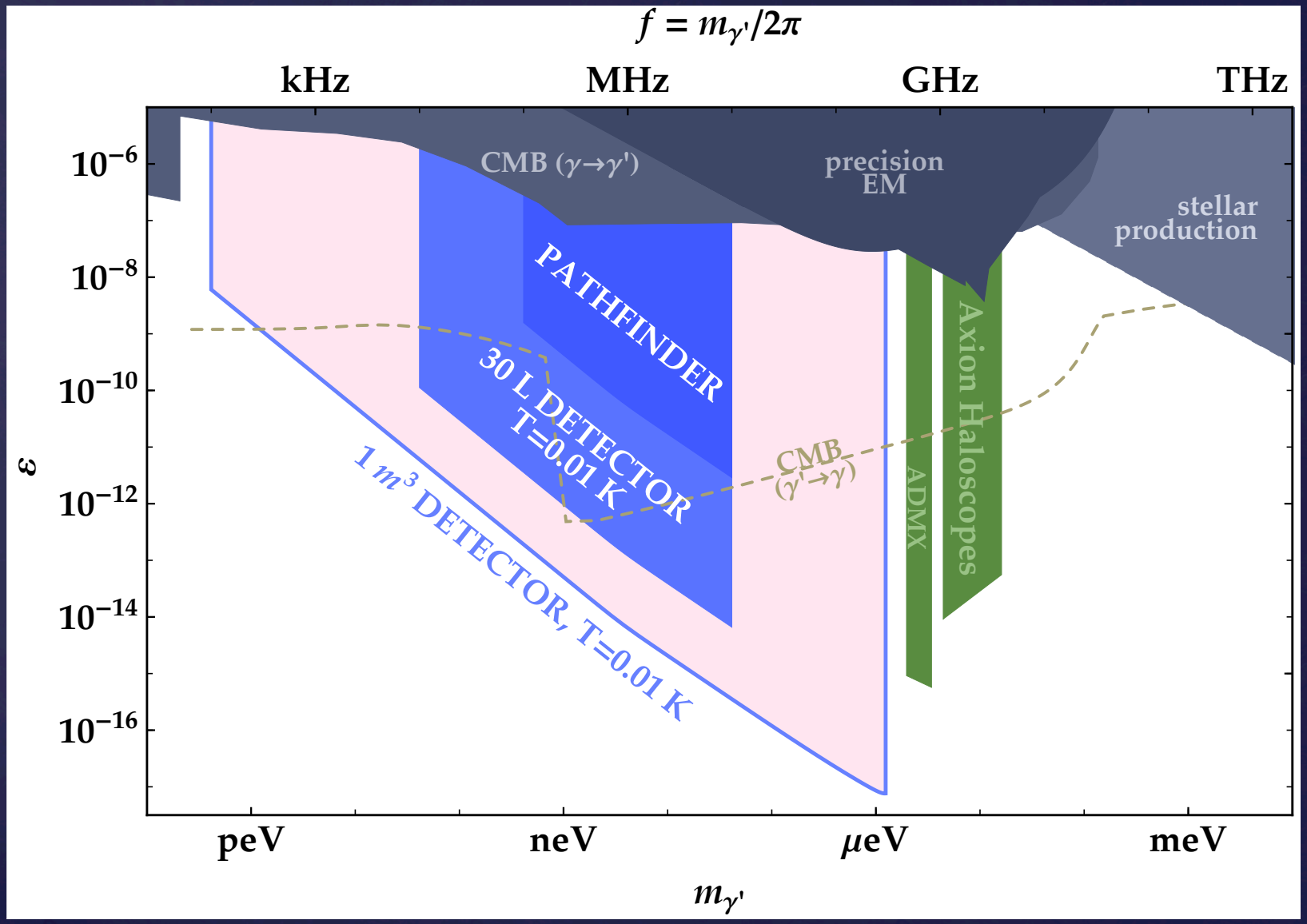

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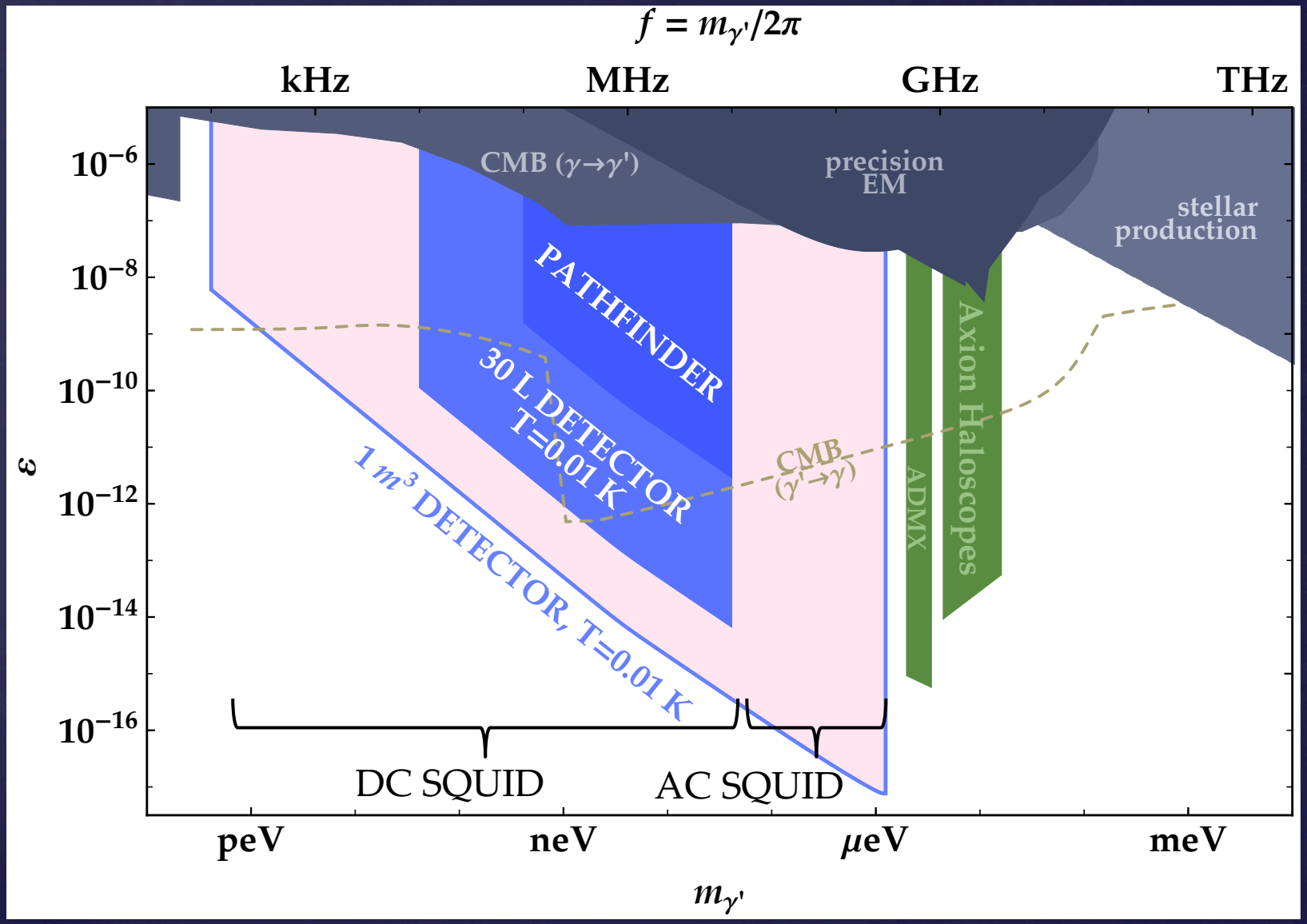
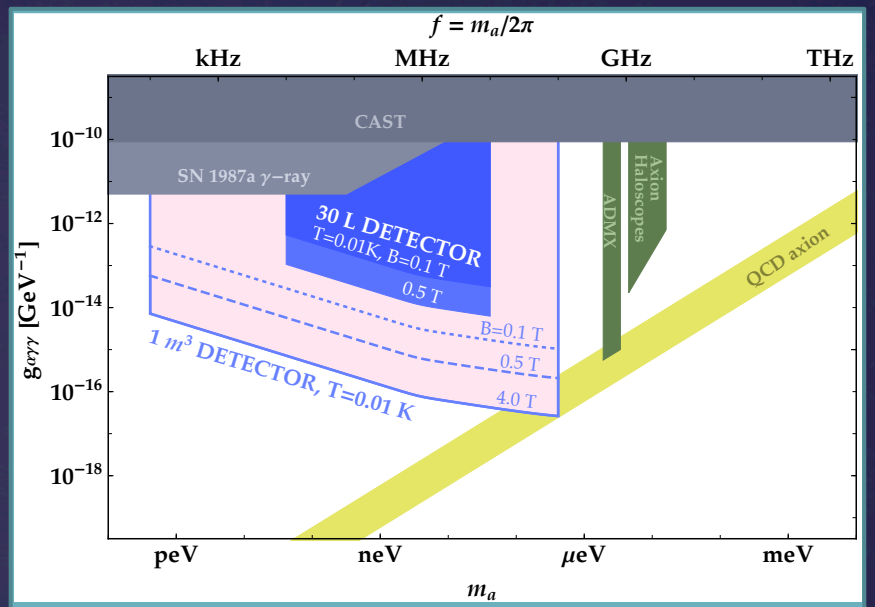
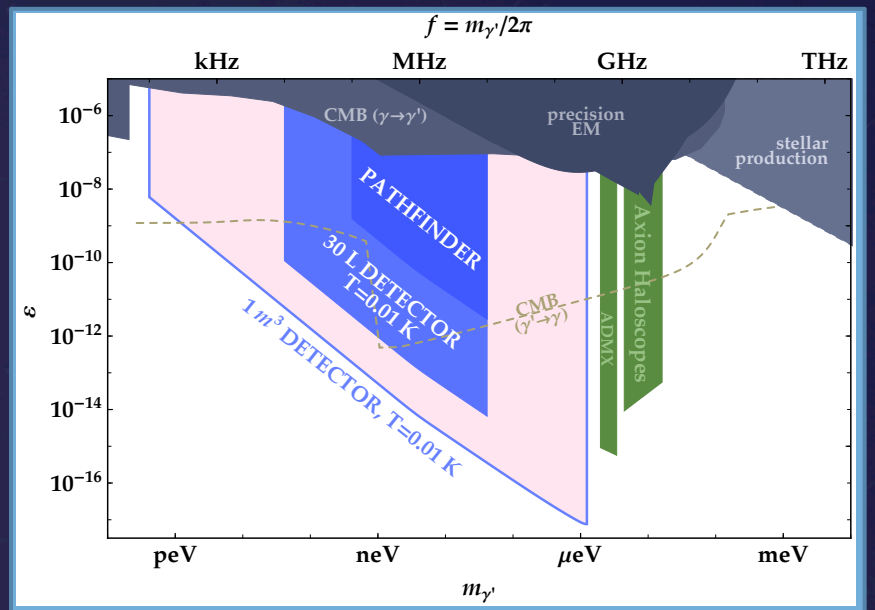


Axions



$$g_{a\gamma\gamma,\mathrm{min}} \propto \frac{T^{\frac{1}{2}}}{V^{\frac{5}{6}} t_{\mathrm{int}}{}^{\frac{1}{4}} \left(\frac{Q}{Q_{\mathrm{DM}}}\right)^{\frac{1}{4}}} \frac{1}{B_0}$$

Hidden Photons



$$\varepsilon_{\mathrm{min}} \propto \frac{T^{\frac{1}{2}}}{V^{\frac{5}{6}} t_{\mathrm{int}}{}^{\frac{1}{4}} \left(\frac{Q}{Q_{\mathrm{DM}}}\right)^{\frac{1}{4}}}$$

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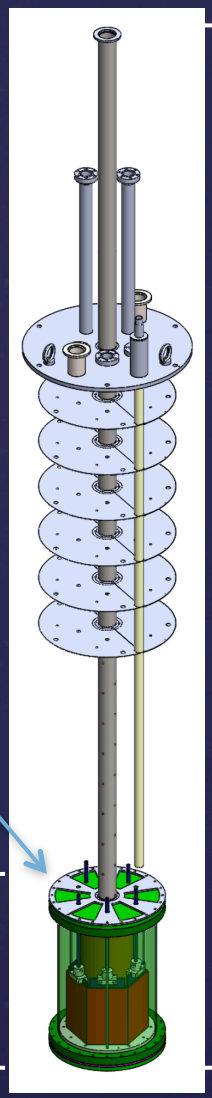
DM Radio Pathfinder

4K Dip Probe

Inserts into Cryoperm-lined helium dewar



67 inches

Detector inside superconducting shield

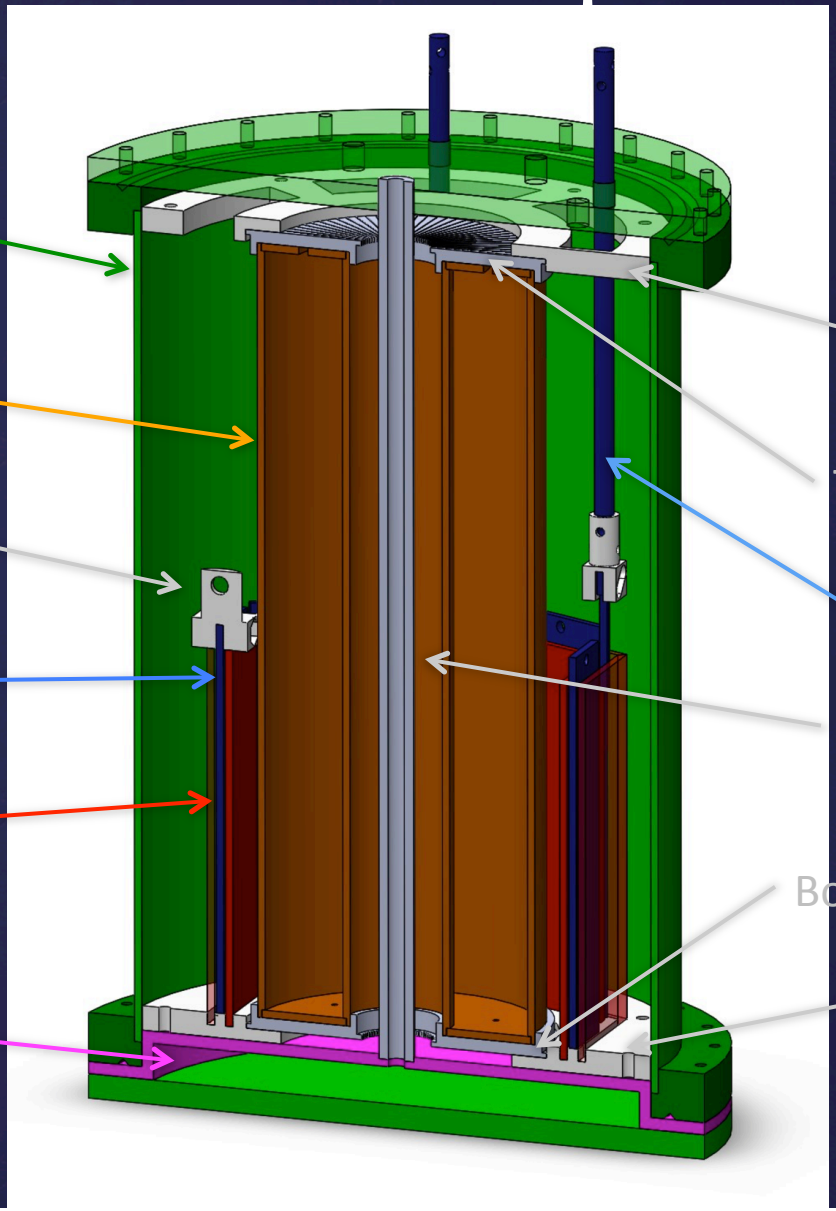
9.5 inches

750 mL Pathfinder funded, under construction

- Focus on hidden photons
- T=4K (Helium Dip Probe)
- Frequency/Mass Range:
  100 kHz – 10 MHz
  500 peV – 50 neV
- Coupling Range
  $\mathcal{E}$: $10^{-9} – 10^{-11}$
- Readout: DC SQUIDs

Design Overview of the DM Radio Pathfinder Experiment
arXiv:1610.09344 (ASC 2016 Conference Proceeding)

Pathfinder Components



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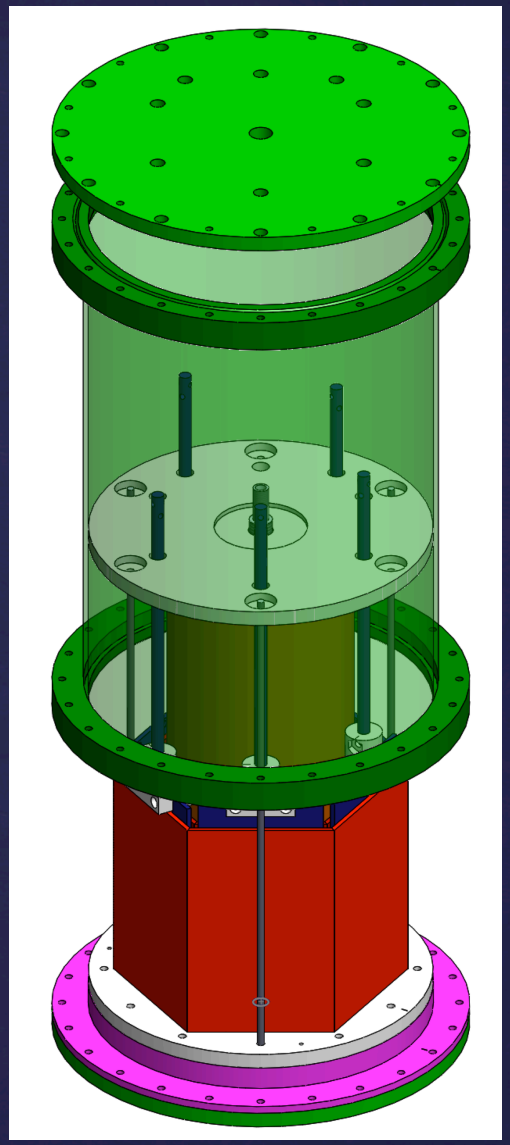

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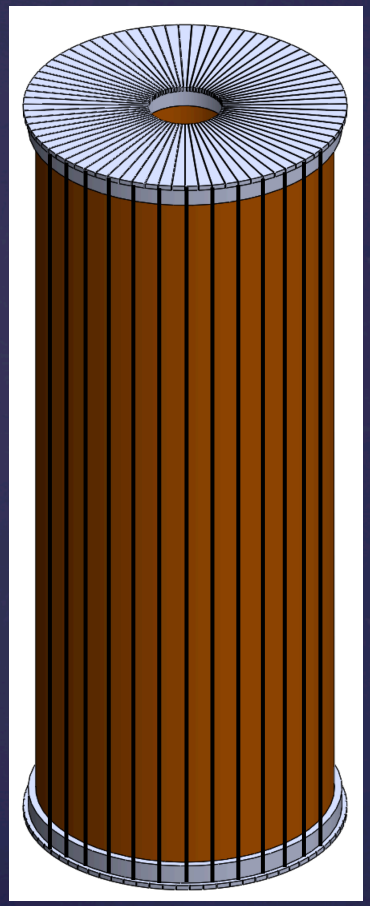

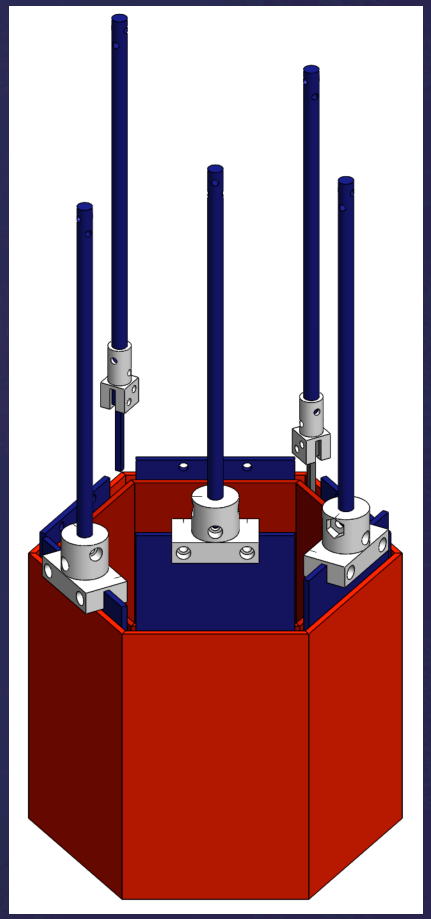

$$\frac{\Delta f}{f} \approx 1 \times 10^{-6}$$ per .001" of motion

Scan time

- 30 days/decade
- 3-6 months total

Ultra-coarse tuning

- fixed sapphire plate fully inserted/removed (tune C)
- change number of turns in solenoid coil (tune L)

Coarse tuning

- position of sapphire dielectric plates (3)

Fine tuning

- position of sapphire needle
- position of niobium needle

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DM Radio Pathfinder Status

- Stainless steel dip probe construction complete
- All major niobium/sapphire pieces have been procured
- Machining of niobium shield/SQUID annex complete, undergoing welding
- Readout electronics are being tested
- DM Radiolab cleanup/construction underway
- Proceeding with fixed resonator test to evaluate Q, material properties
- **Initial hidden photon results Summer 2017**

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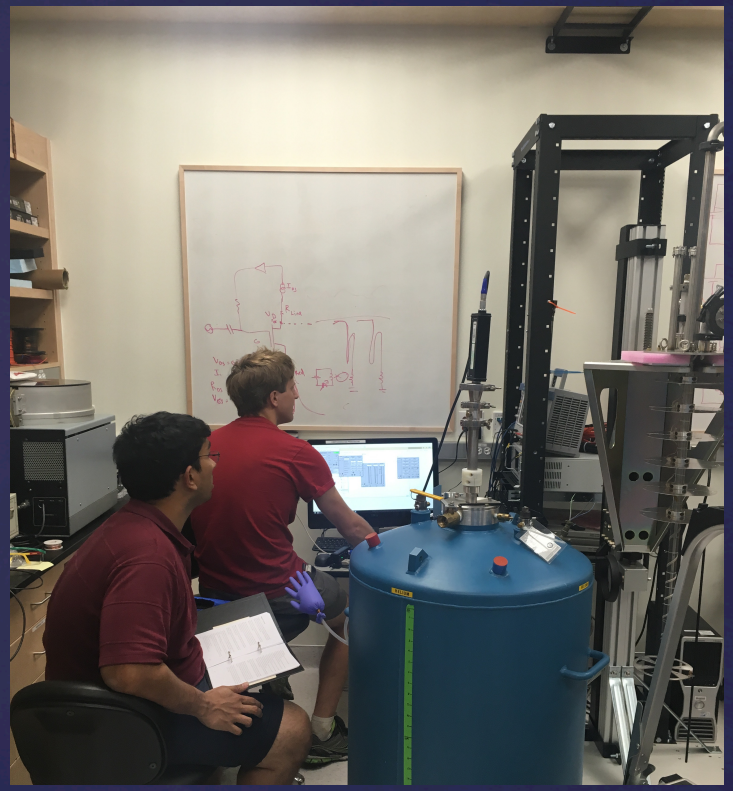

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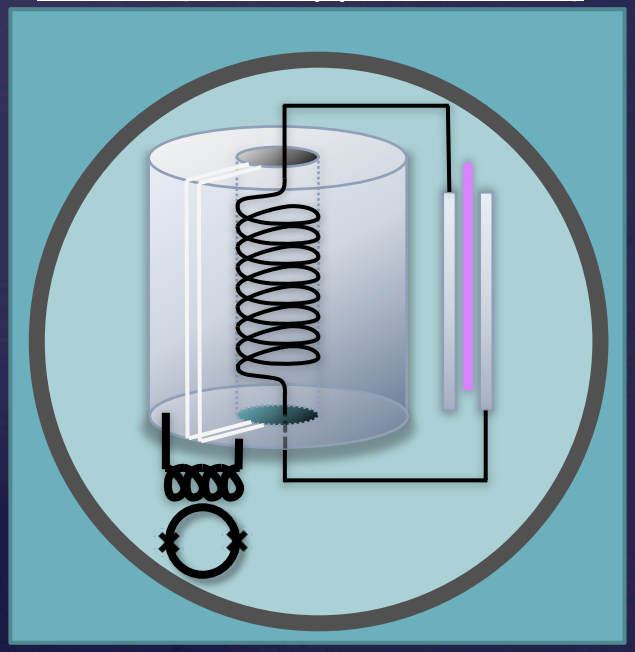
DM Radio

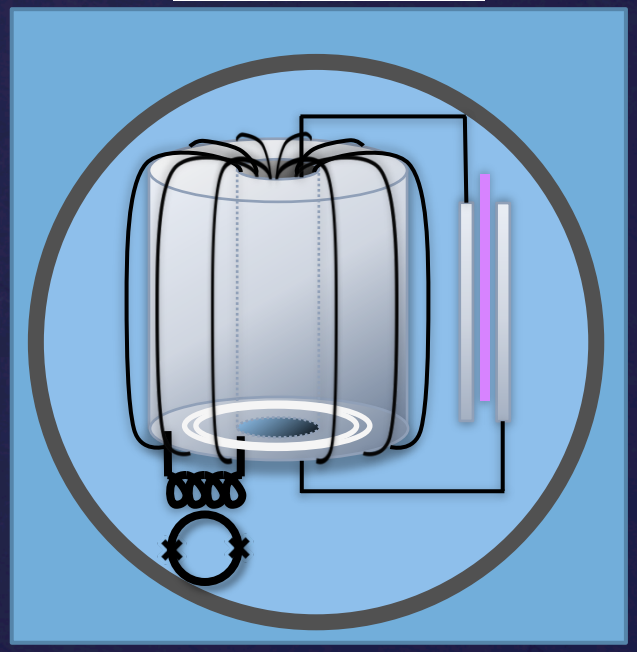
A Superconducting Lumped-Element Dark Matter Detector for Axions and Hidden Photons

Axions (with applied B-field)



- Axion/hidden photons induce screening currents along superconducting toroid
- Tunable, lumped-element resonator rings up signal
- Screening currents interrupted by slit, read out by SQUIDs
- Covers many orders of magnitude in both mass and coupling

Hidden Photons



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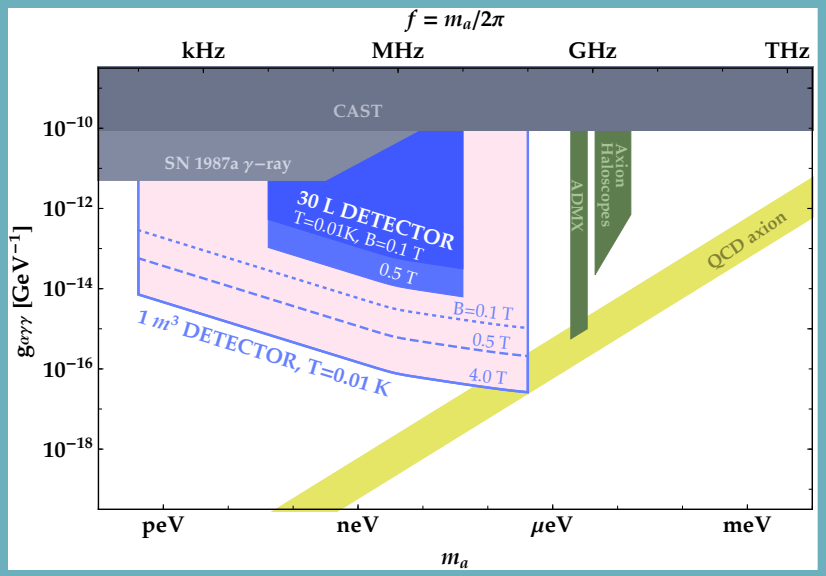

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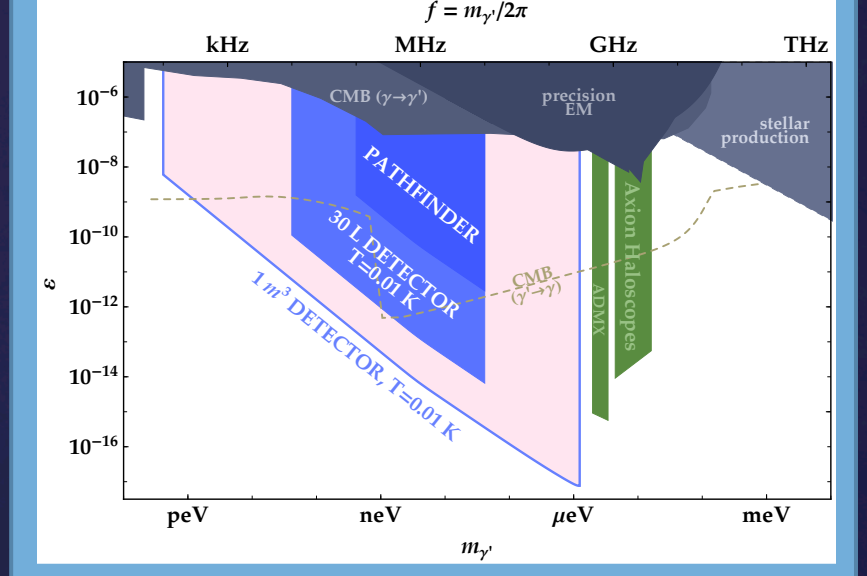

DM Radio

A Superconducting Lumped-Element Dark Matter Detector for Axions and Hidden Photons

Publications

Chaudhuri et al., **Radio for hidden-photon dark matter detection**
Phys. Rev. D 92, 075012 (2015) / arXiv:1411.7382

Silva-Feaver et al., **Design Overview of the DM Radio Pathfinder Experiment**
arXiv:1610.09344 (ASC 2016 Conference Proceeding, to be published)

Graham, Mardon, and Rajendran, **Vector dark matter from inflationary fluctuations**
Phys. Rev. D 93, 103520 (2016) / arXiv:1504.02102