Axion Production and Detection using Isolated Magnetic Fields

Ryan Janish

PHENO 2018

In collaboration with

Vijay Narayan, Surjeet Rajendran, and Paul Riggins

(work in progress)

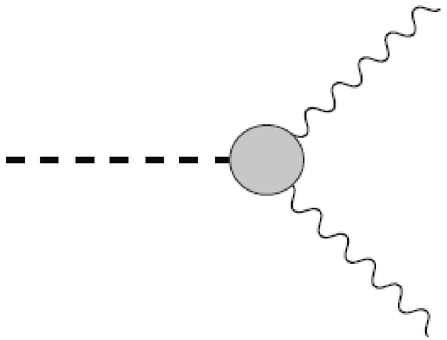
Axion Production and Detection

Axion Electrodynamics

[Sikivie, ‘83]

An axion field a can couple to EM fields with $\vec{E} \cdot \vec{B} \neq 0$,

$$\mathcal{L} \supset g\ a\ F_{\mu\nu}\widetilde{F}^{\mu\nu} = 4g\ a\ \vec{E} \cdot \vec{B}$$



Large EM fields can compensate for the small coupling g.

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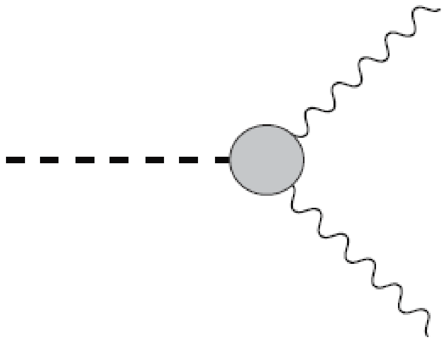
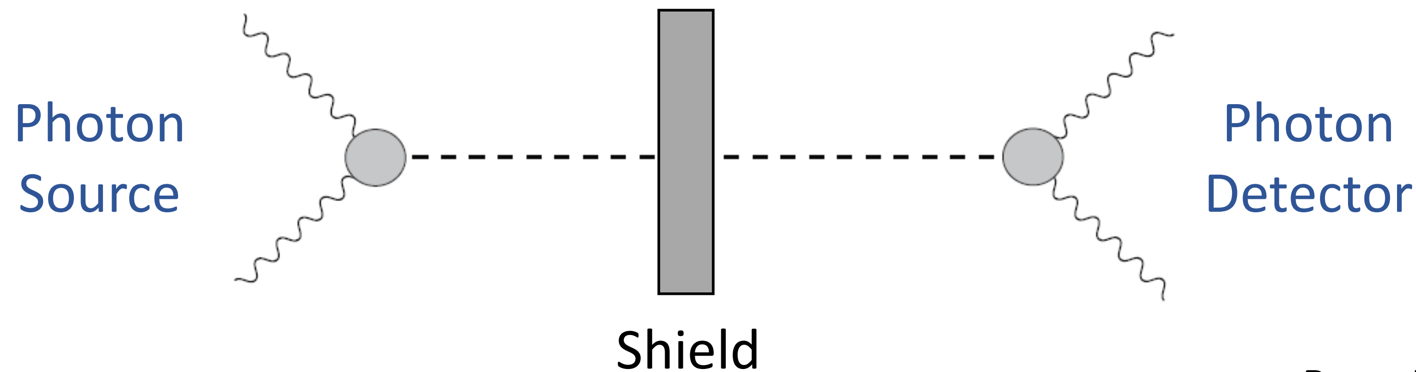


Light-shining-through-walls (LSW) Experiments

[Van Bibber et al, '87]

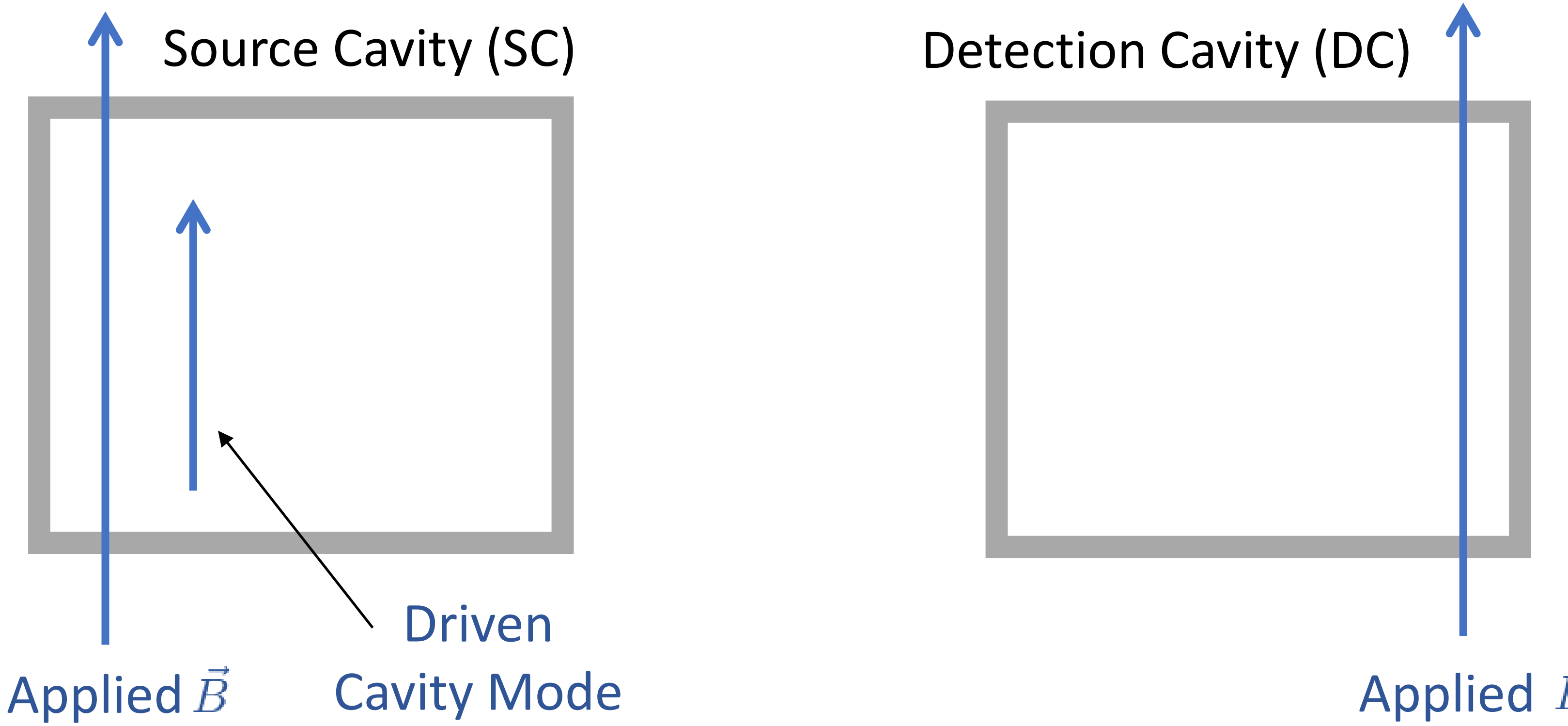
Forget DM – create and detect our very own axions.



Axion Production and Detection

LSW with RF Cavities

[Hoogeveen, '92]



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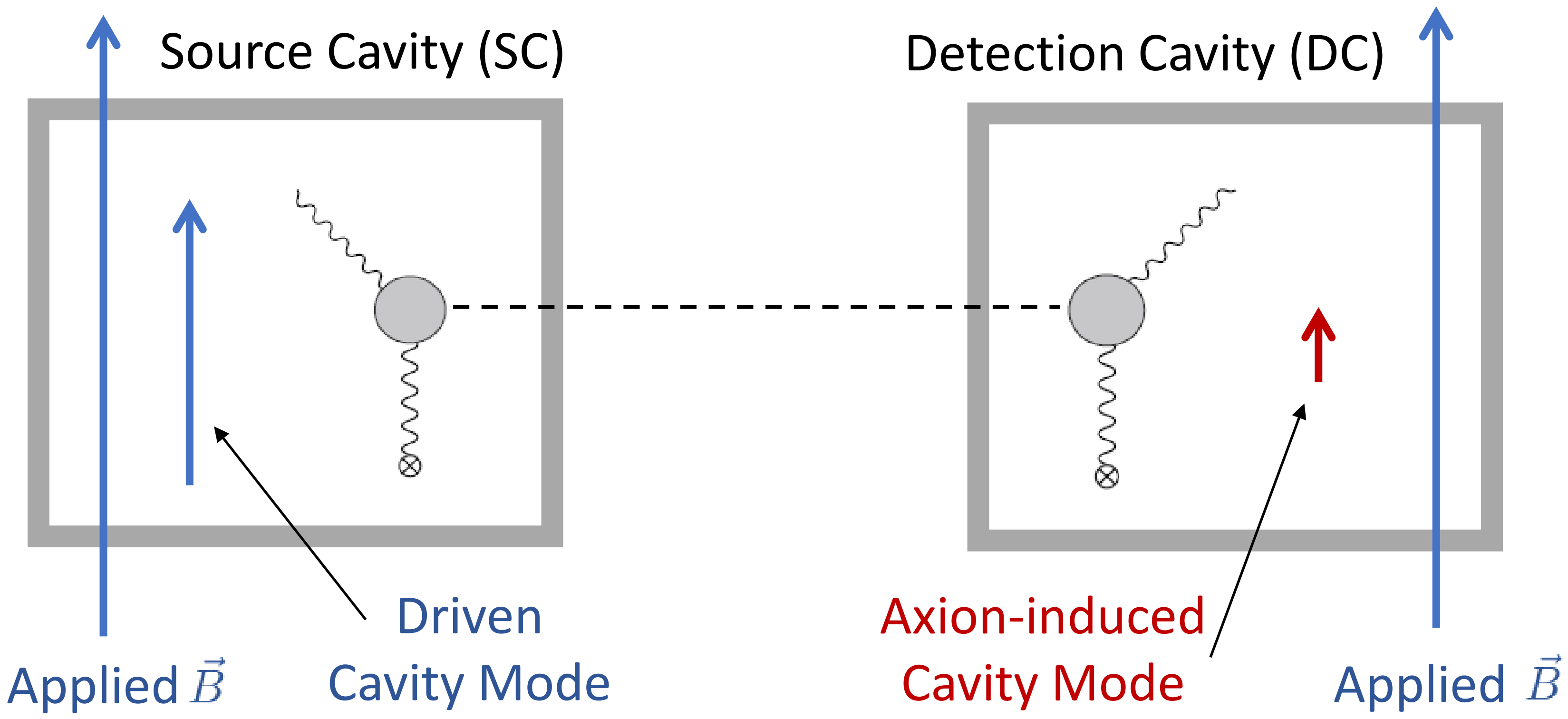

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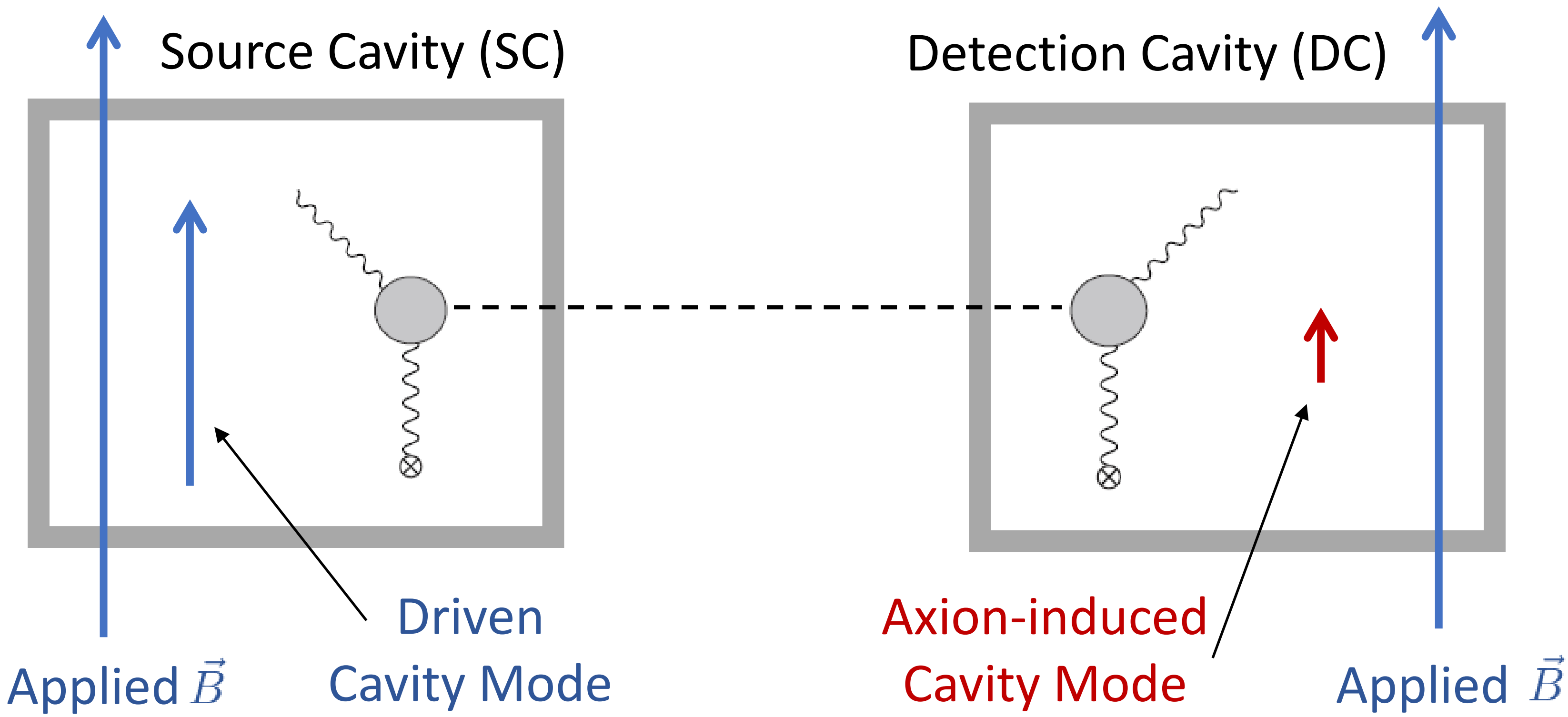

$$P_{\text{signal}} = P_{\text{input}} \cdot \left(\frac{gB}{\omega}\right)^4 Q_{\text{SC}} Q_{\text{DC}} |G|^2$$

$\mathrm{O}(1)$ Geometric Form Factor

Axion Production and Detection

LSW with RF Cavities

Current LSW results are significantly less stringent than astrophysical bounds from stellar cooling rates.

This is true even if we optimize design parameters (magnetic fields, integration time, etc.)

e.g, CROWS [Betz et al, '13]

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ALPS II [Spector, '16]

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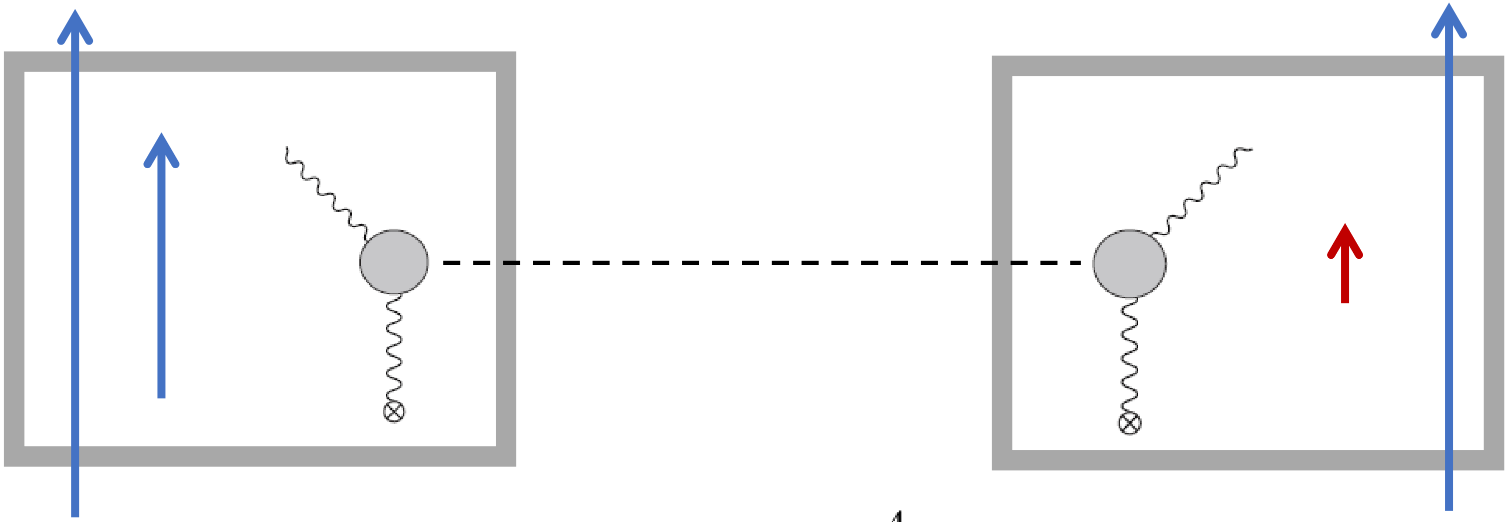
ALPS II [Spector, '16]

We propose a new strategy for RF LSW experiments which will beat stellar cooling bounds by an order-of-magnitude, constraining $g \gtrsim 2 \cdot 10^{-11}\ \mathrm{GeV}^{-1}$. (on par with ALPS II)

LSW with RF Cavities



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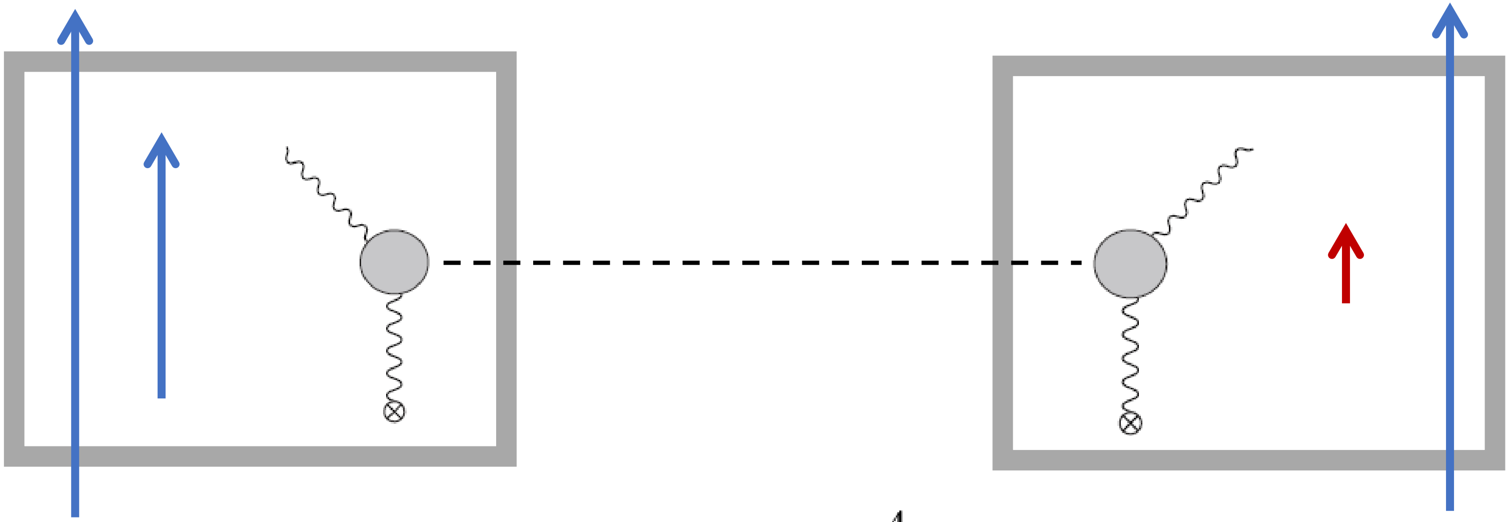

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Conventional RF Cavities

$$Q \approx 10^4$$

Superconducting RF Cavities

$$Q \approx 10^{10}$$

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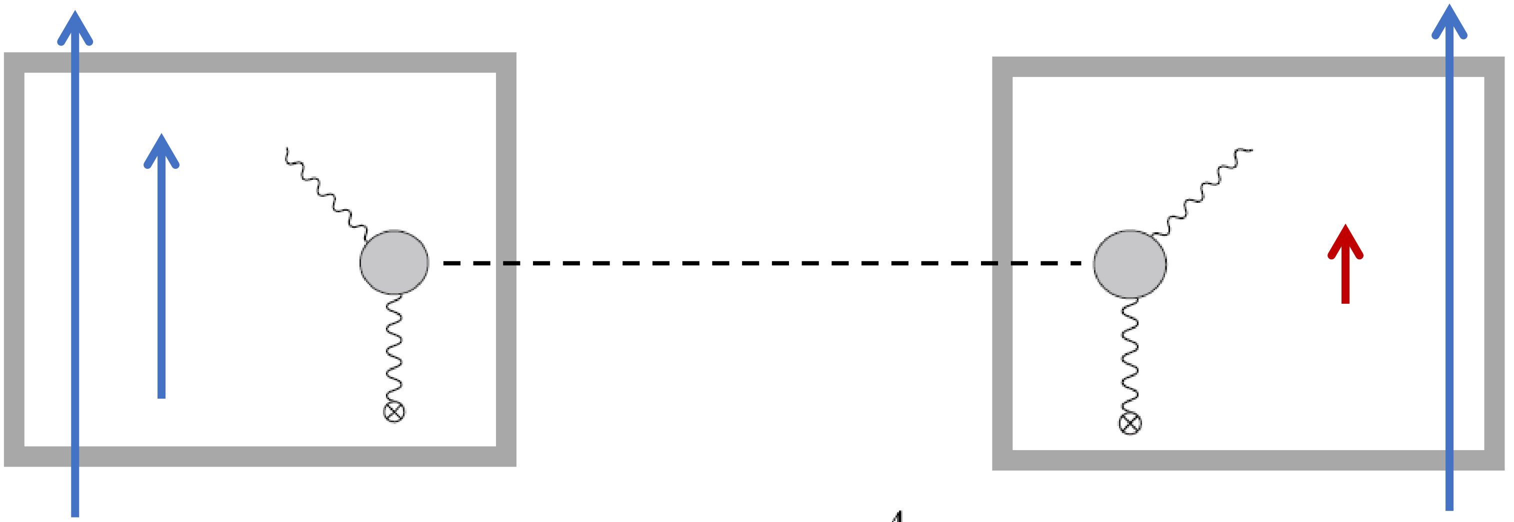

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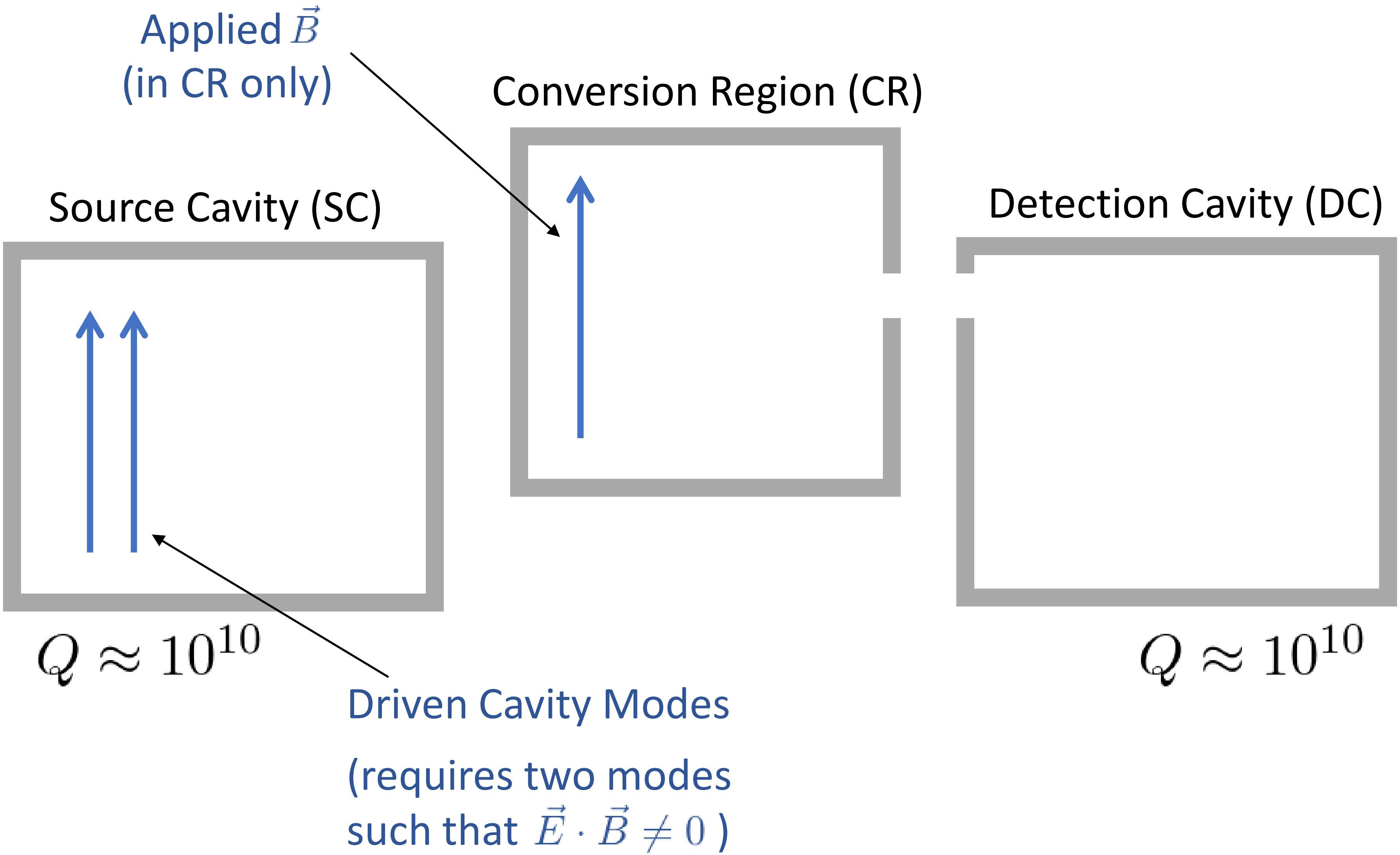
Problem: Magnetic Field will Quench Superconductivity

We must re-design the experiment to ensure no large magnetic fields pierce the superconducting cavities.

RF LSW with an Isolated Magnetic Field



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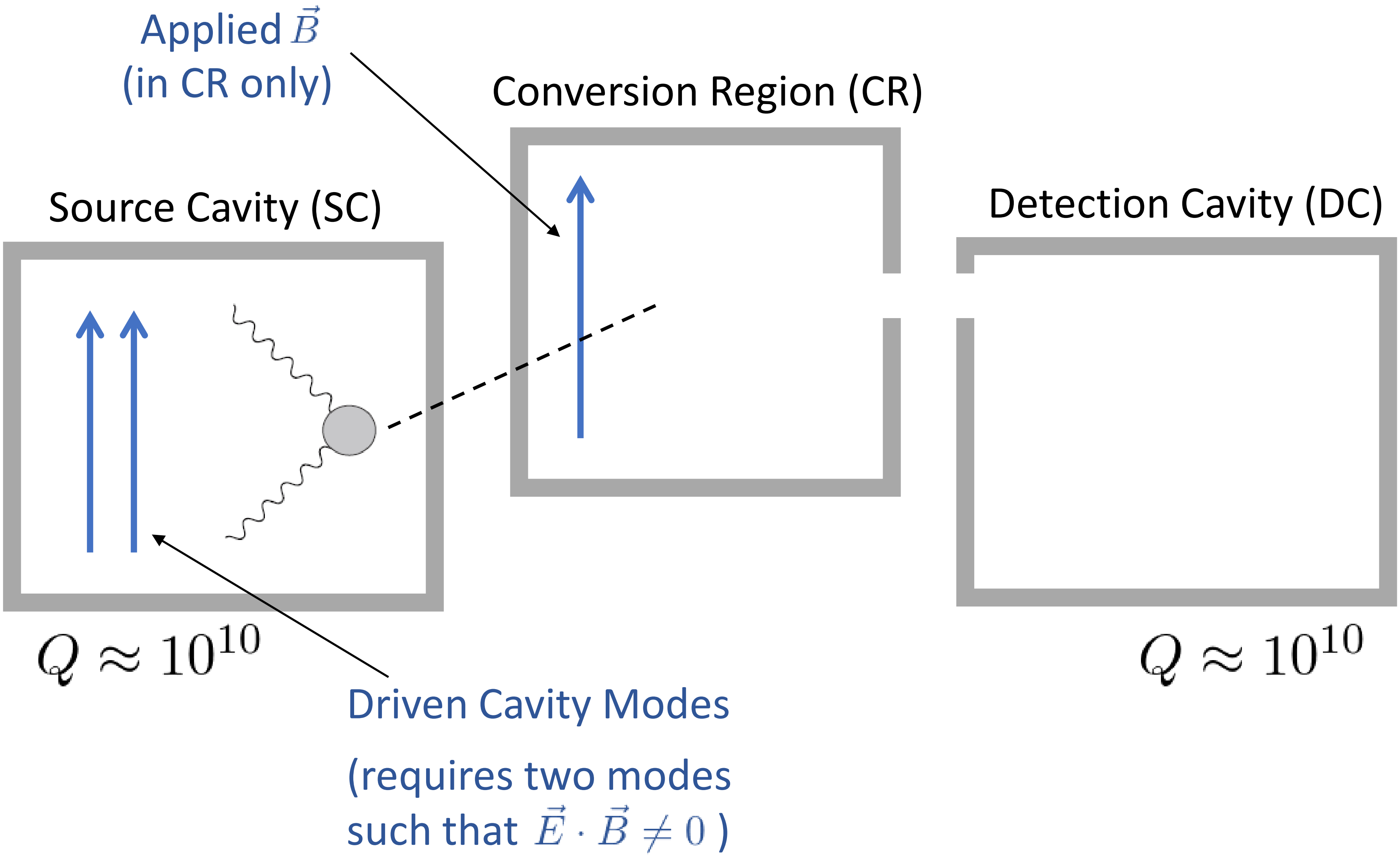

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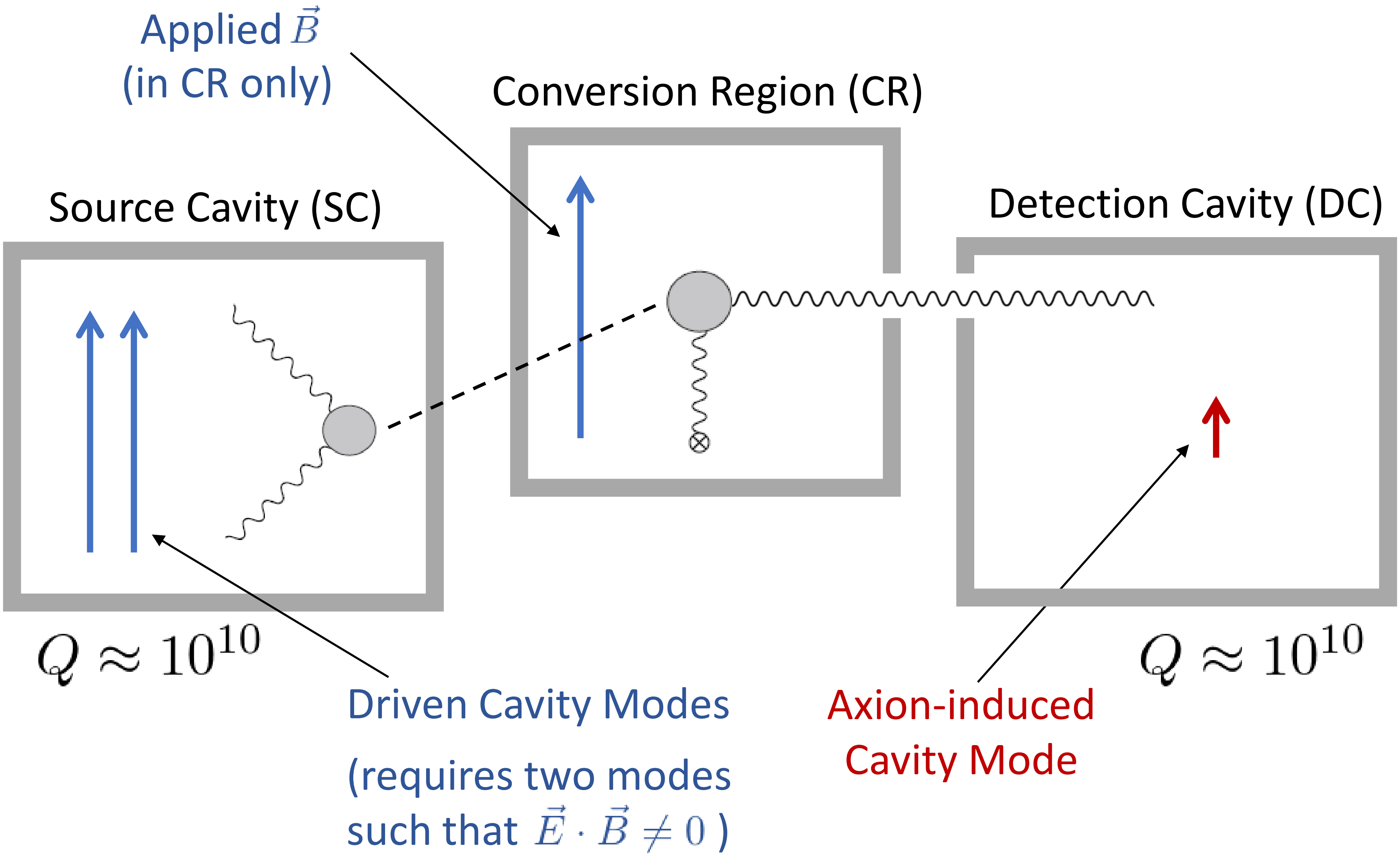
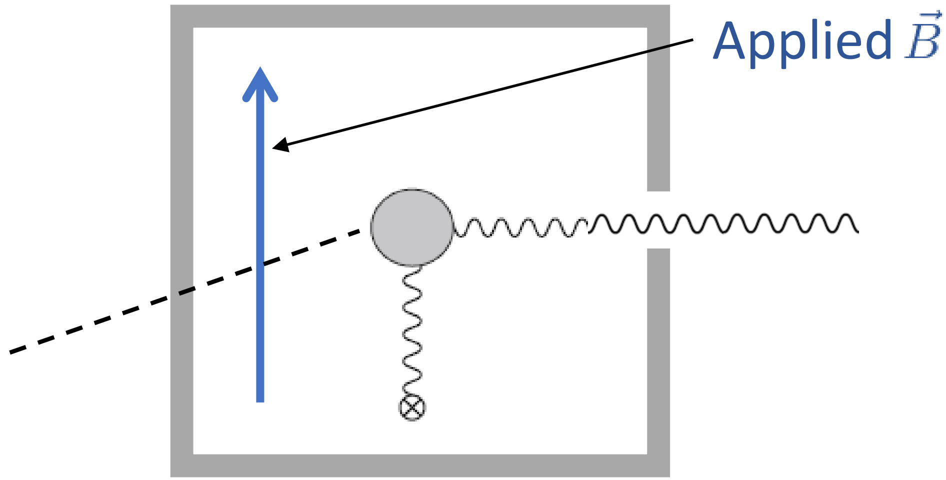


Escape of the Axion-induced Signal

Conversion Region

Confine the static magnetic field

Allow propagation of axion-induced EM signal



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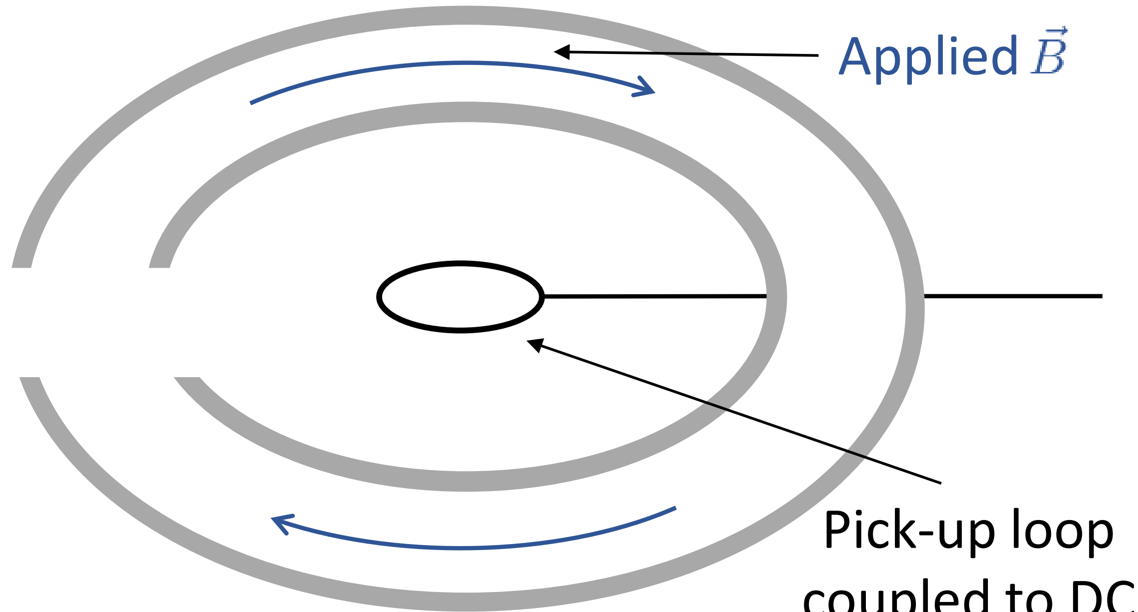

Conversion Region

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This can be achieved with a "gapped torus", i.e. a finite open cylinder bent into a torus-like shape without connecting the ends.

Inspired by recent work ABRACADABRA, which proposed using a "gapped torus" to search for DM axions. [Kahn et al, '16]

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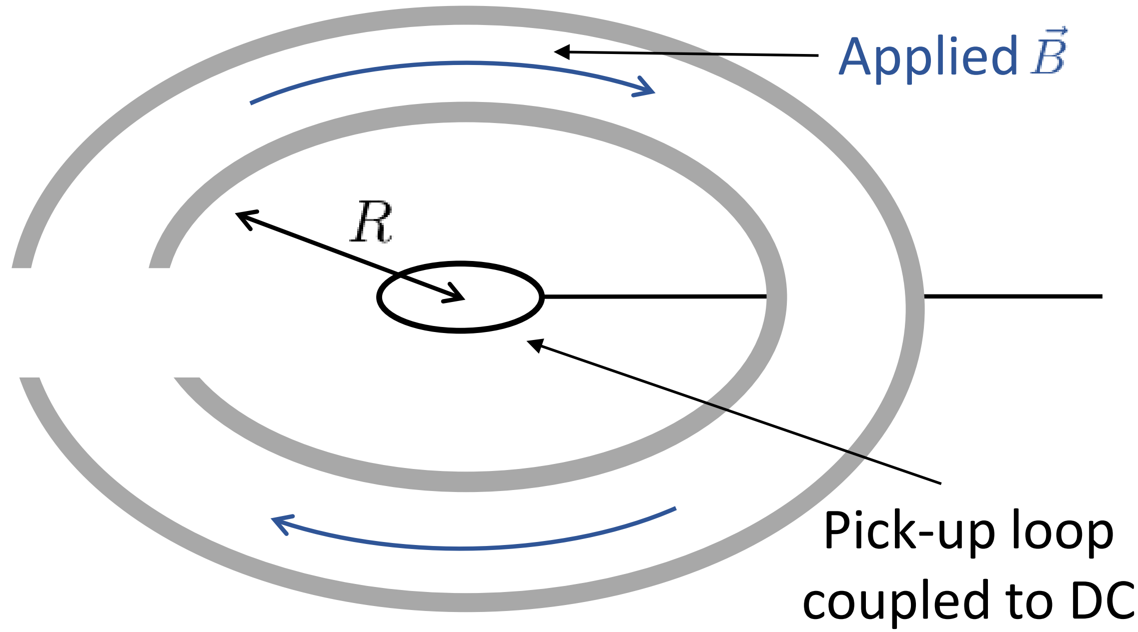

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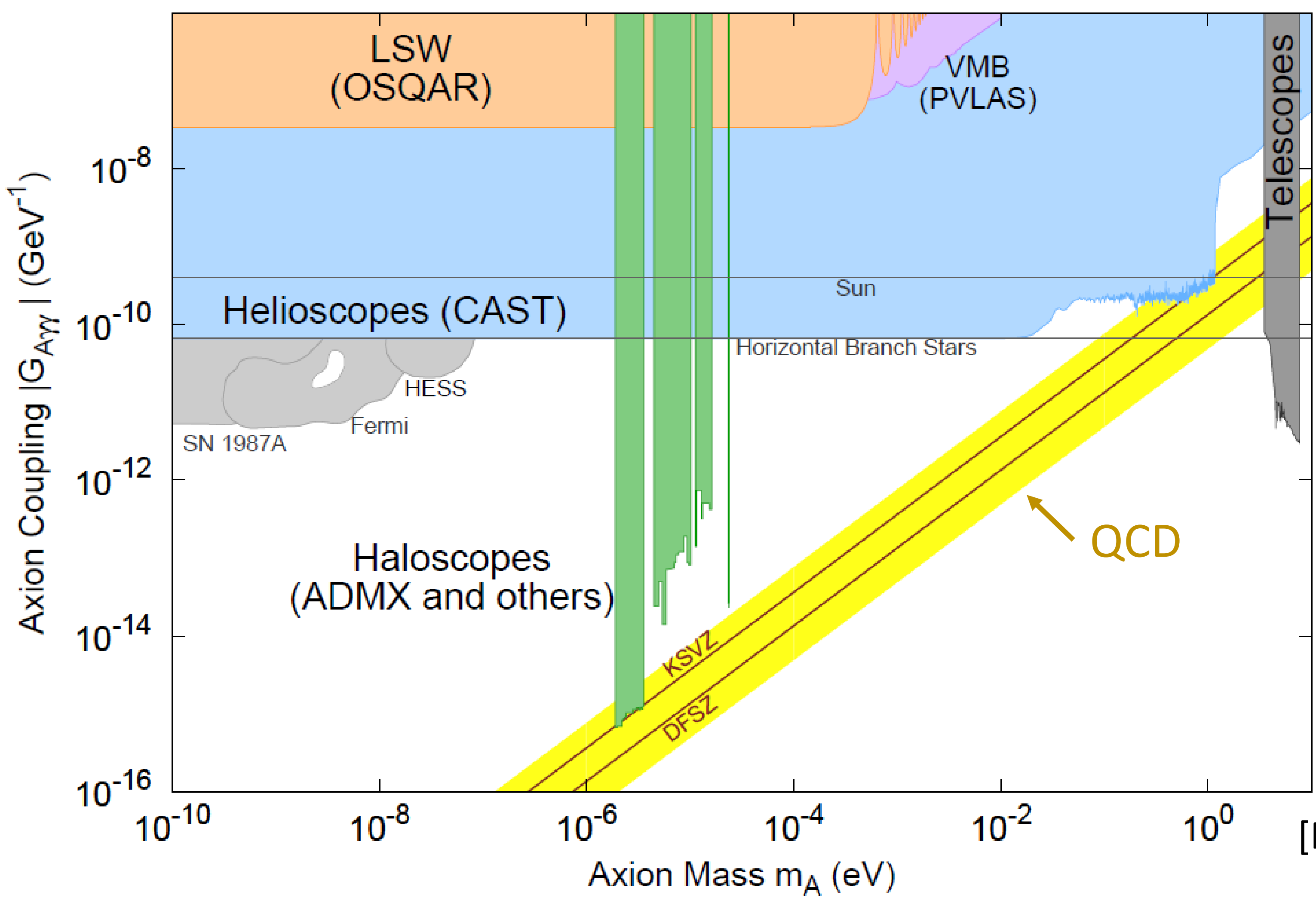
Viable in the quasistatic regime: $\omega \lesssim R^{-1}$

Sensitivity



[PDG, ‘17]

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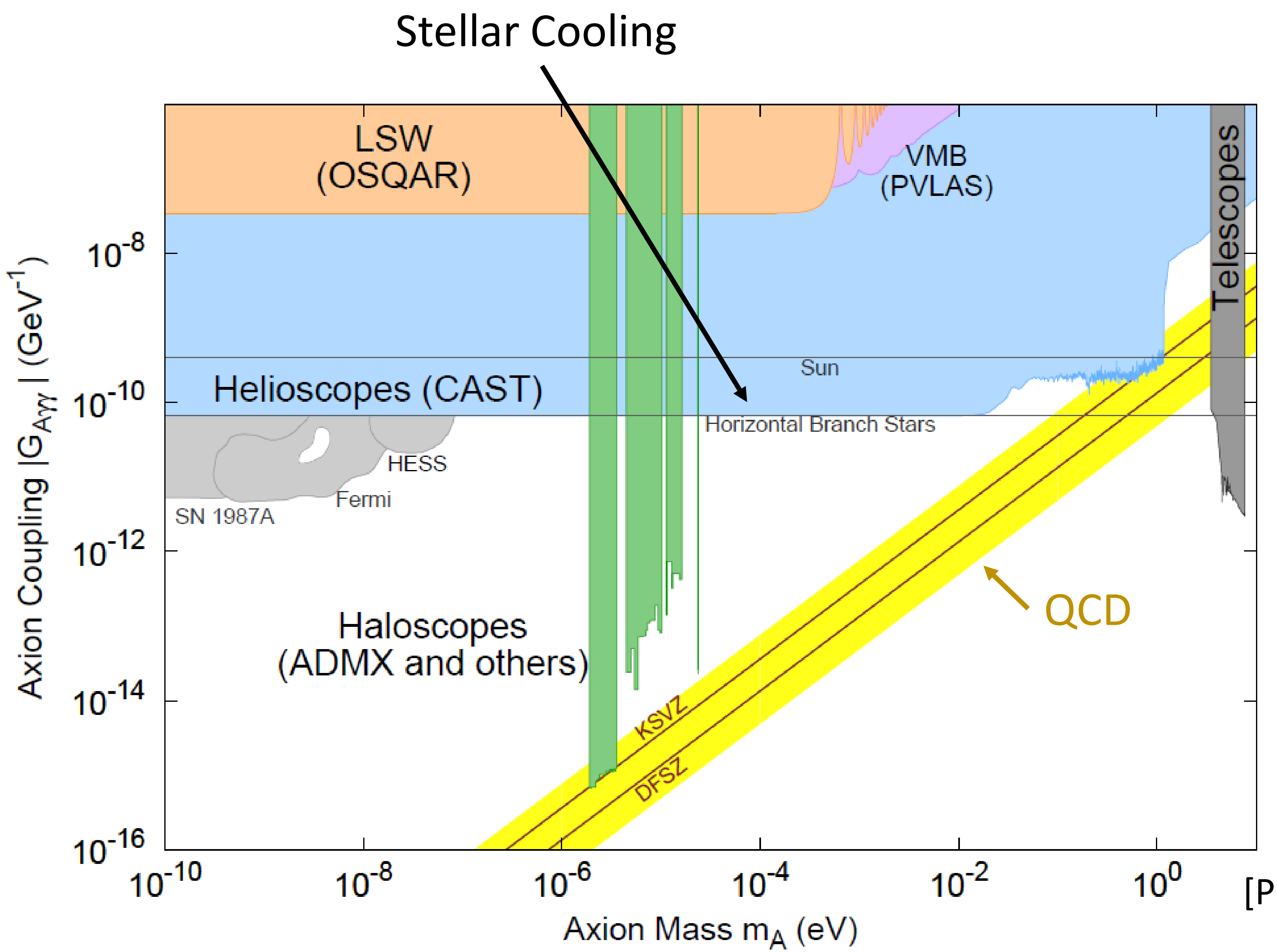

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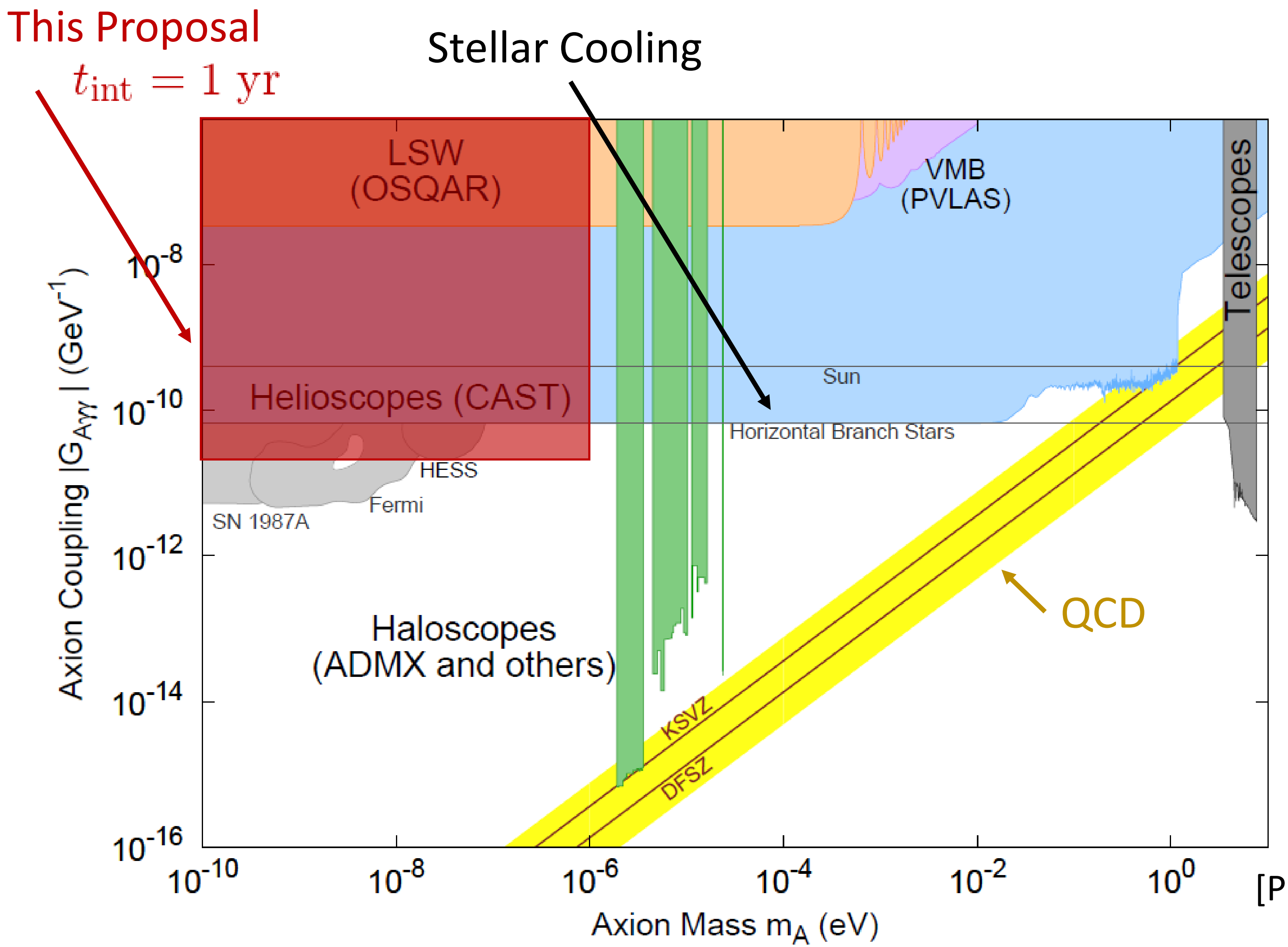

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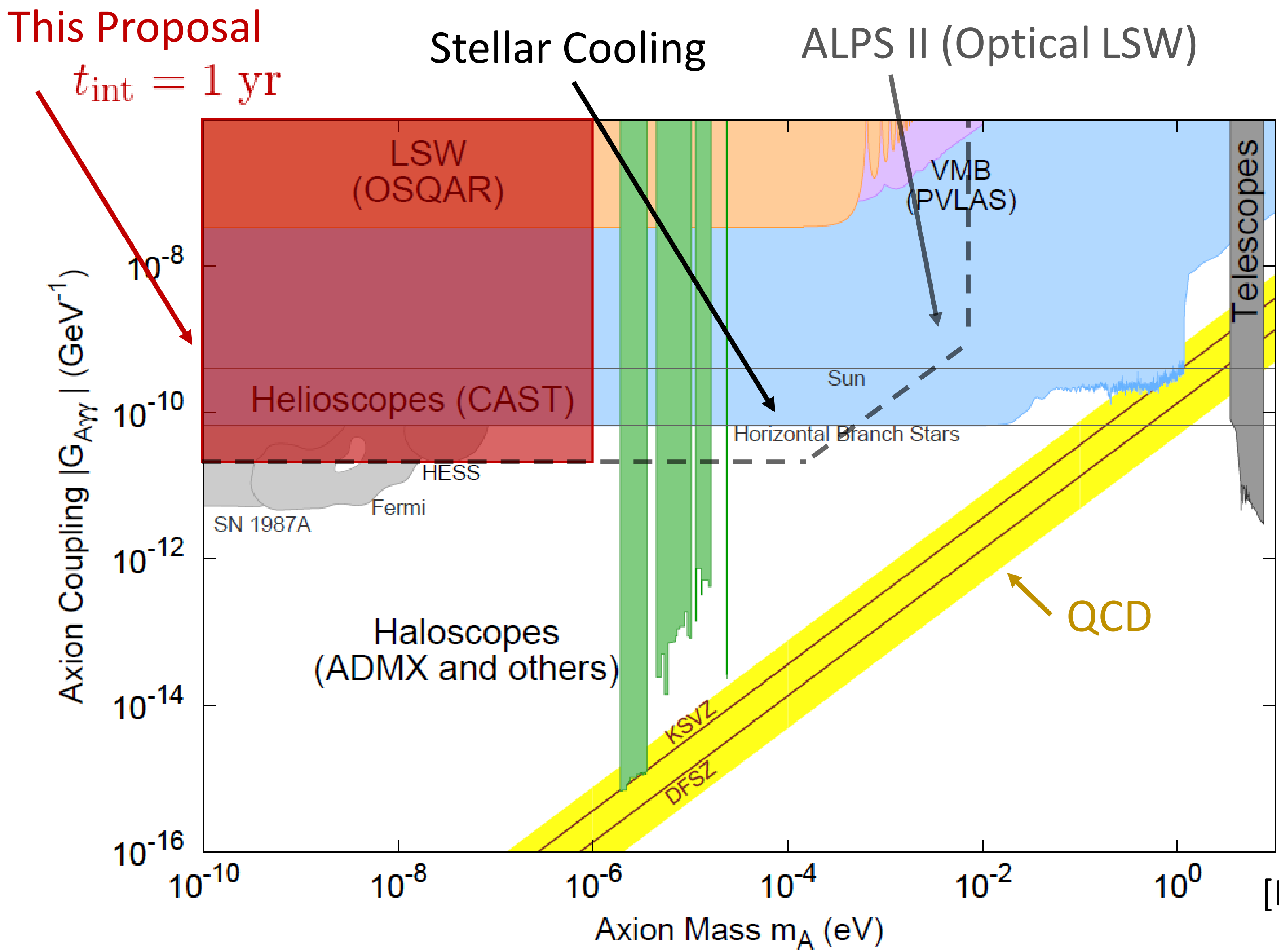

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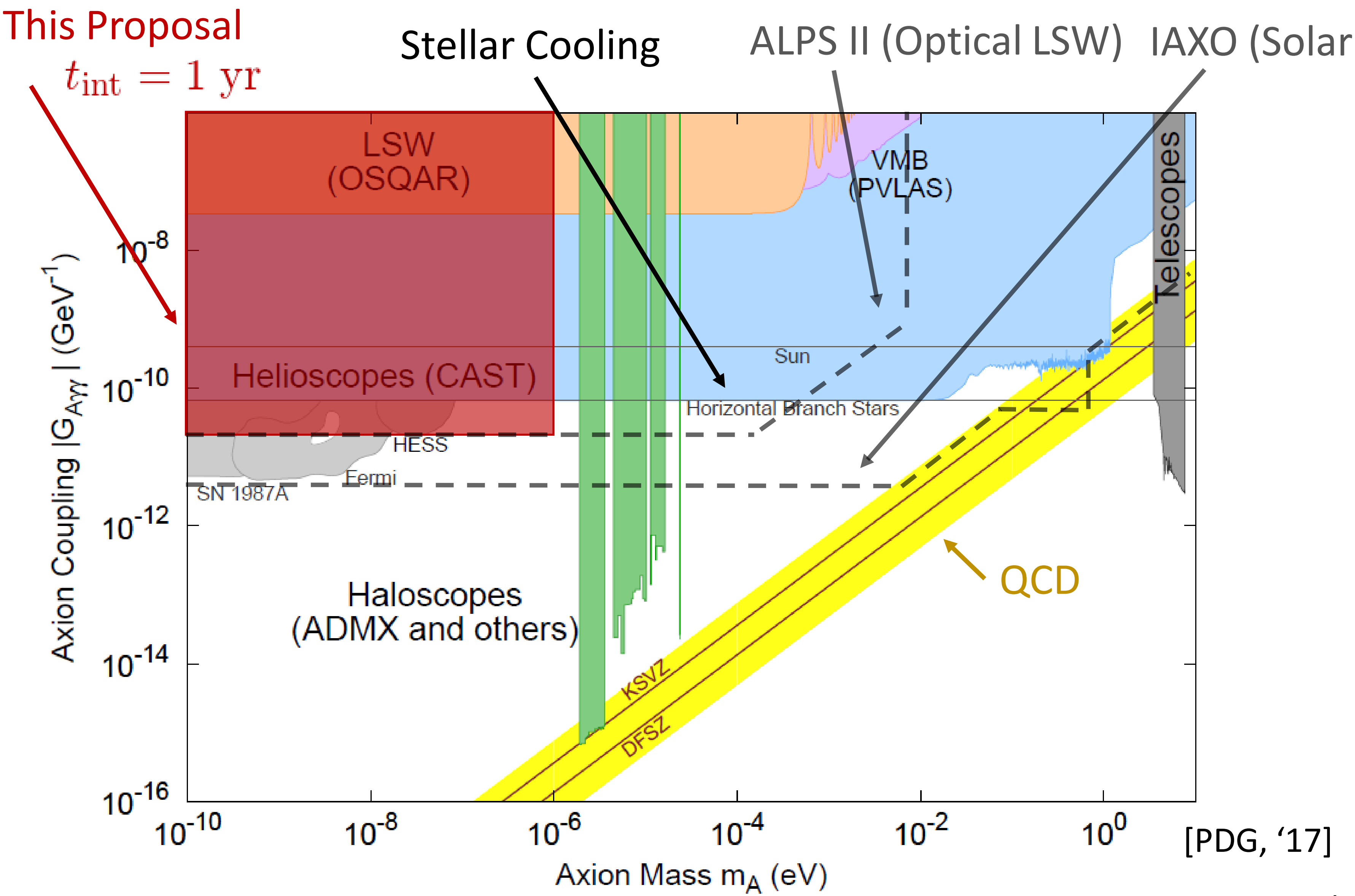

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Field isolation without screening of the axion-induced signal in the quasistatic regime is possible using a “gapped torus”.

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Complementary technology to next-generation optical LSW searches.

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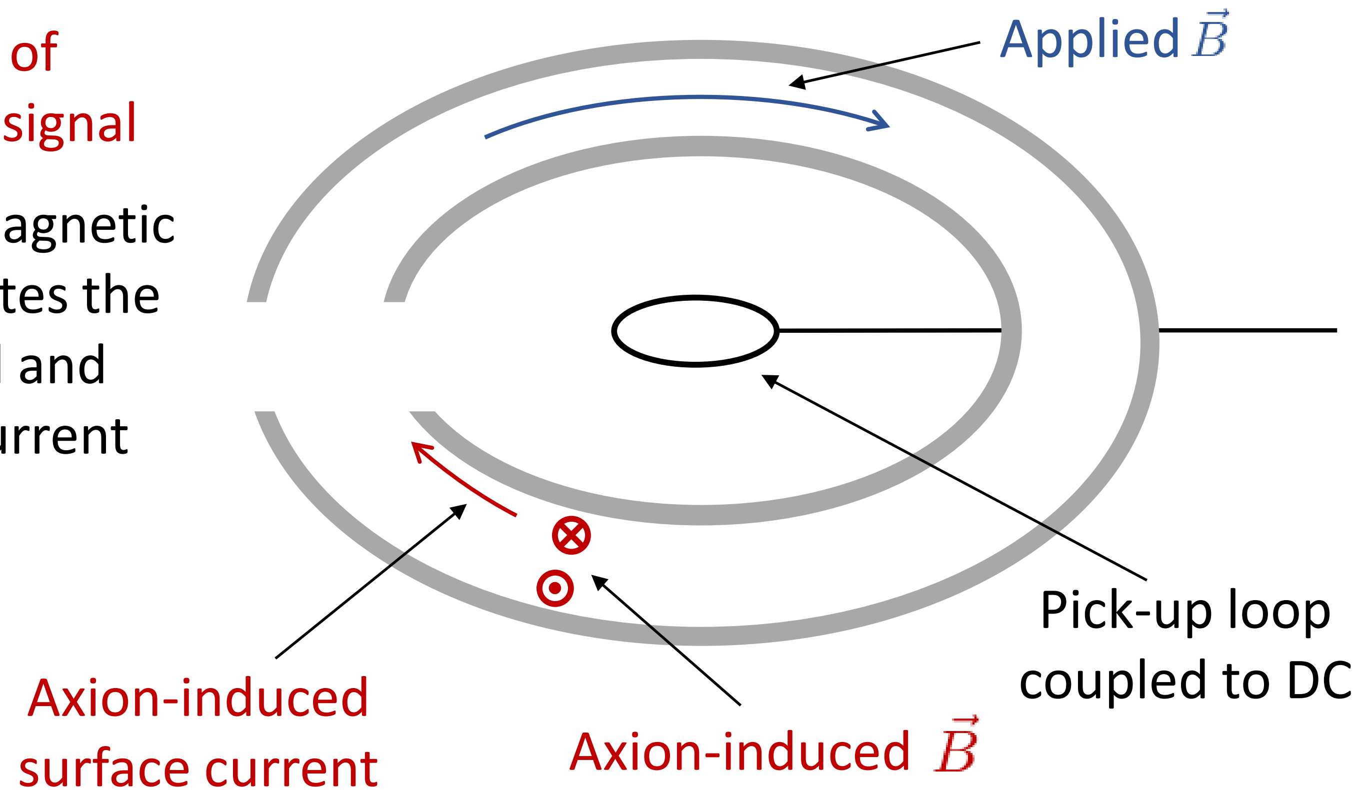
Extra Slides

Ryan Janish

Escape of the Axion-induced Signal

Allow propagation of axion-induced EM signal

Axion induces a magnetic field which circulates the applied static field and drives a surface current inside the torus.



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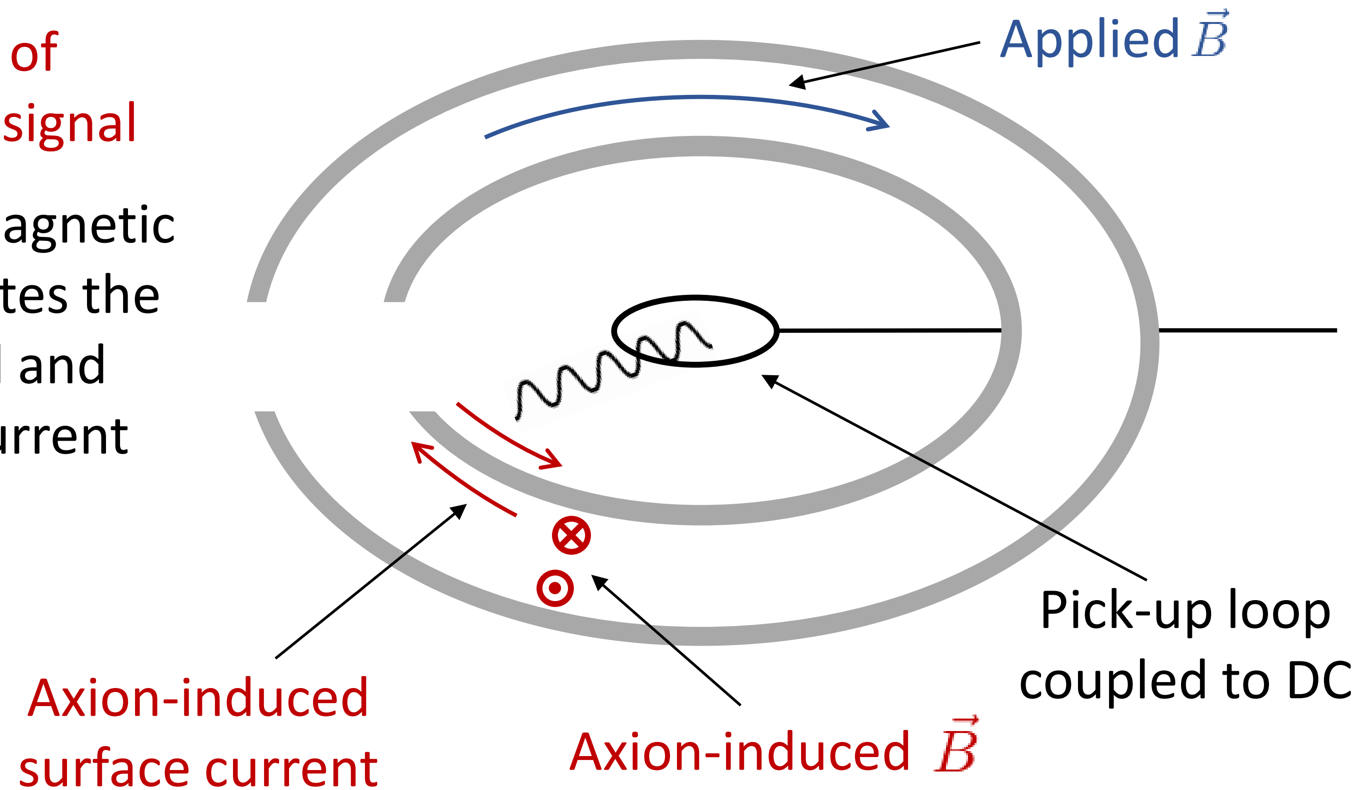

For sufficiently small ω, the current continues to the outside of the torus and sources a magnetic field in the central pick-up loop.

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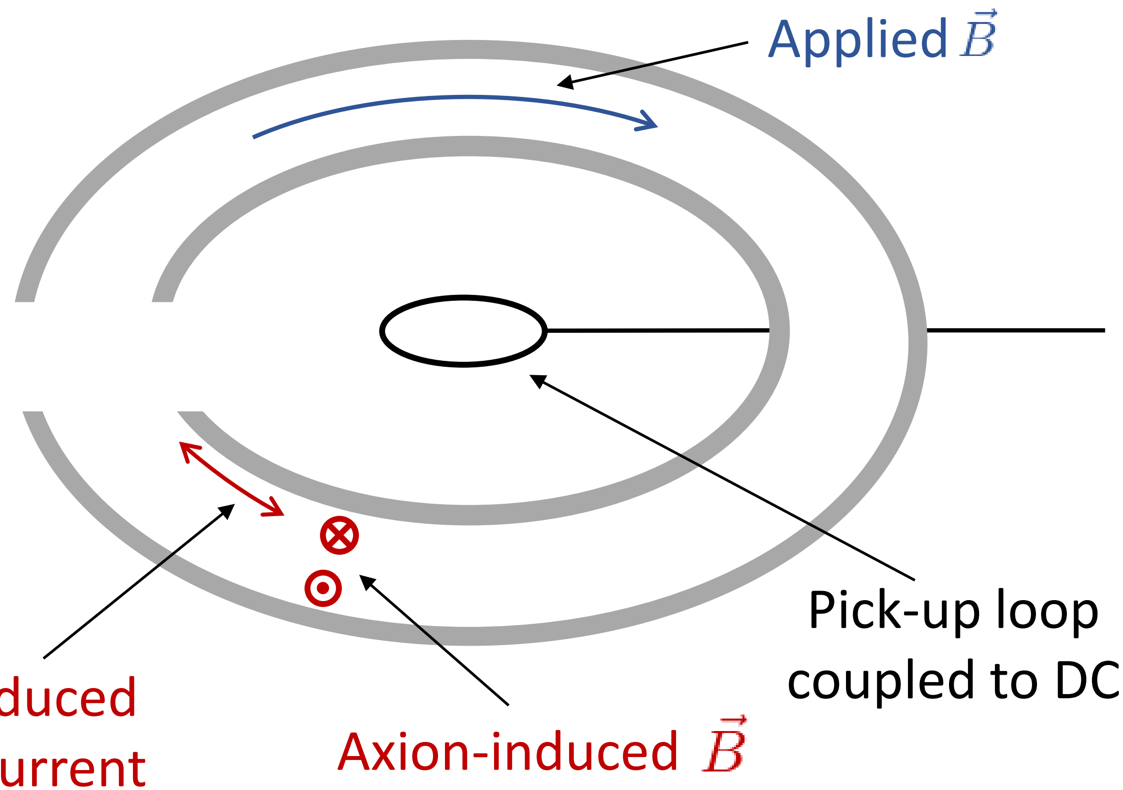

For large ω, the current does not propagate to the outside, and the axion-induced signal is screened.

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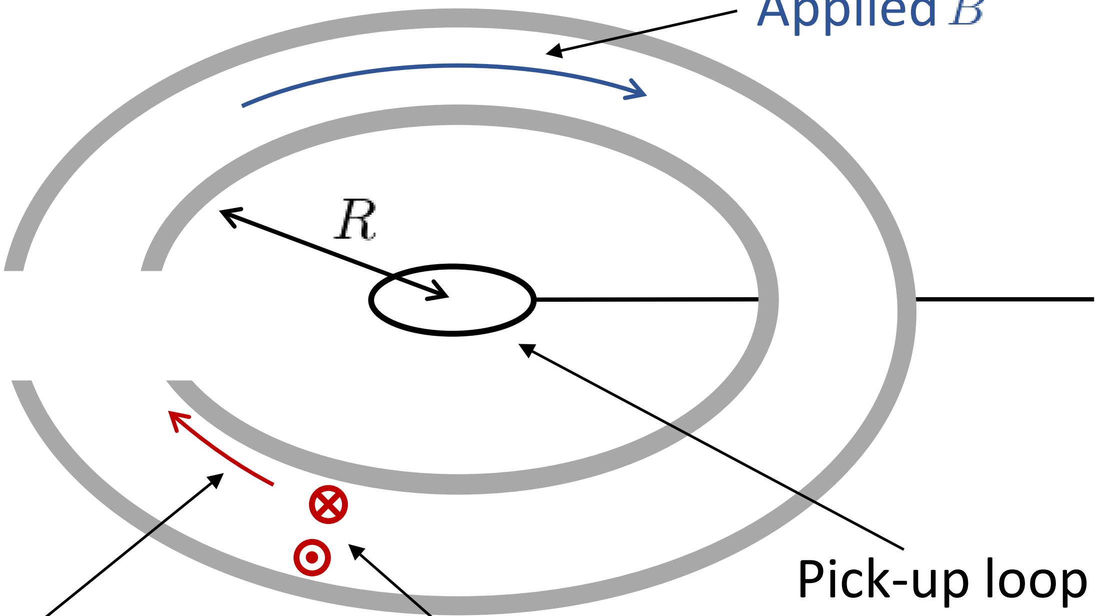

The critical scale is the torus radius R,

Maximal signal if: $R \sim \omega^{-1}$

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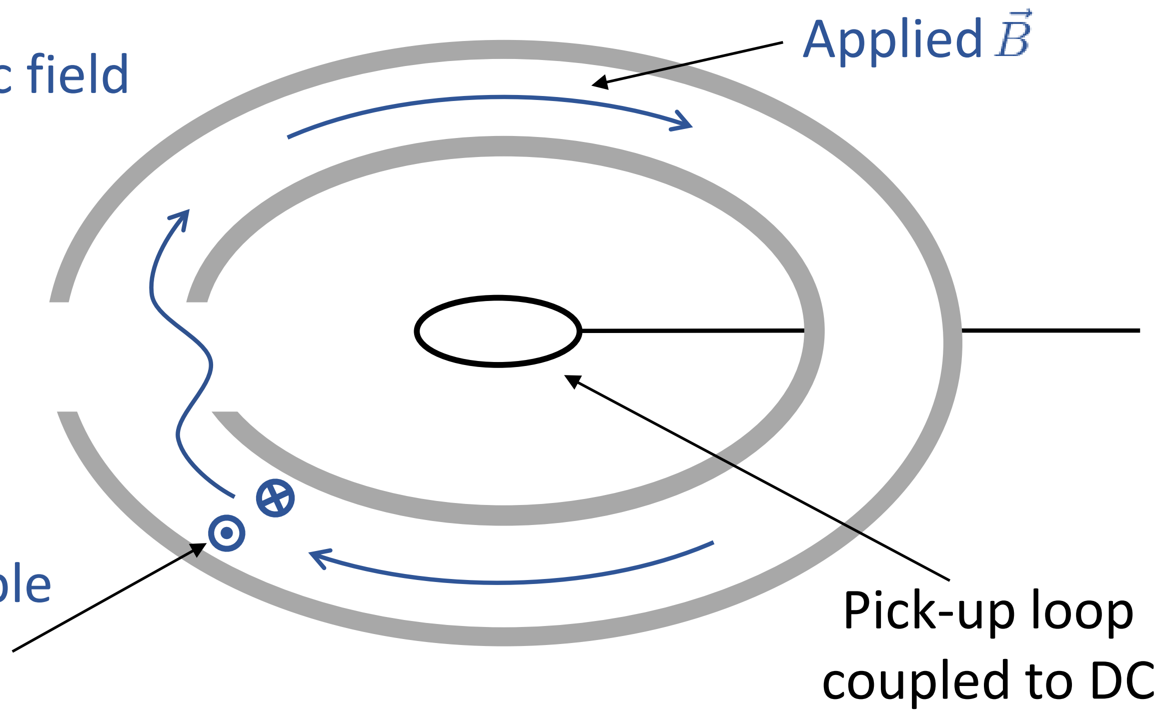
Confine the static magnetic field

The static magnetic field is generated by current loops wrapping the torus.



These currents never propagate to the outside of the torus.

The only leakage of the static field will be due to fringe effects at the gap, which can be made small.

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Sensitivity

Axion Mass

Sourced axions' total energy is set by the cavity resonance $\omega \approx 1\ \mathrm{GHz}$.

Sensitive to all $m_a \lesssim \omega \approx 10^{-6}\ \mathrm{eV}$.

Signal Power

$$P_{\mathrm{signal}} = P_{\mathrm{input}} \cdot \frac{g^4}{\omega^4} B_0^2\ B_{\mathrm{sc}}^2 Q_{\mathrm{sc}} Q_{\mathrm{dc}} |G|^2$$

Limited to $0.1\ \mathrm{T}$ by source-cavity Q

$\approx 10^{10}$

$\mathrm{O}\left(10^{-4}\right)$ due to more complicated geometry

Signal-to-Noise

Noise is dominated by thermal (Johnson) noise: $P_{\mathrm{noise}} = \frac{T}{t_{\mathrm{int}}}$

Operating at $T \approx 4\ \mathrm{K}$ for $t_{\mathrm{int}} \approx 1\ \mathrm{yr}$, $\mathrm{SNR} > 1$ yields:

$$g > 2 \cdot 10^{-11}\ \mathrm{GeV}$$

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