Ultralight Dark Matter

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Ultra-light bosons offer interesting path

Outline

1. Theory Motivations
    a. Origins
    b. Solutions
    c. Phenomenology
2. Experimental Opportunities
    a. Operators and Effects
    b. Parameter Space
    c. Bonuses
3. Conclusions

Theory Motivations

Origins

Interacting bosons with mass << 100 eV??

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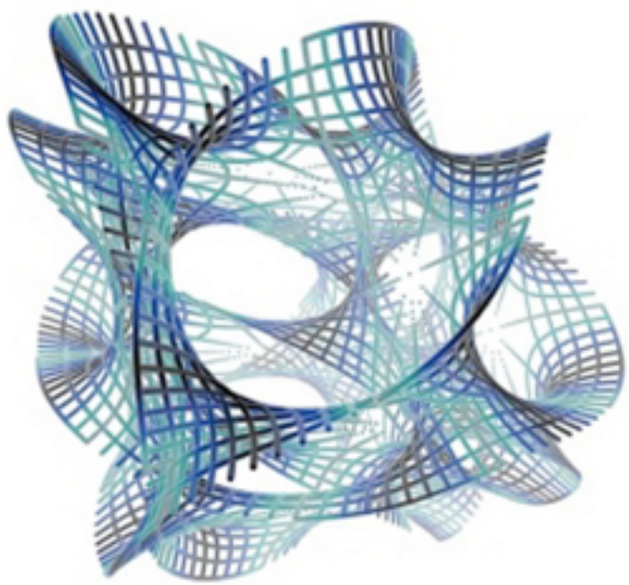
Goldstone bosons of broken symmetries

String theory or extra-dimensions naturally create goldstone bosons from non-trivial topology



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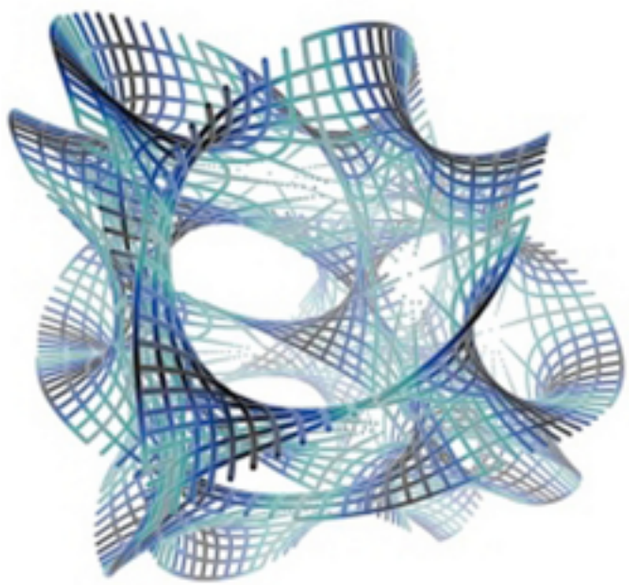

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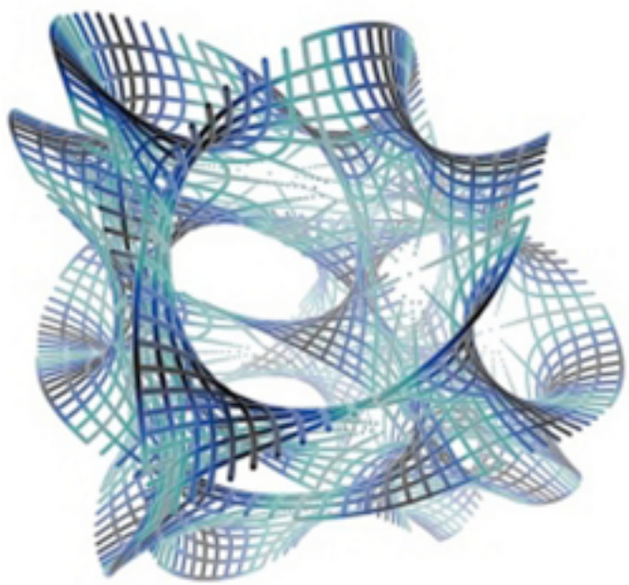

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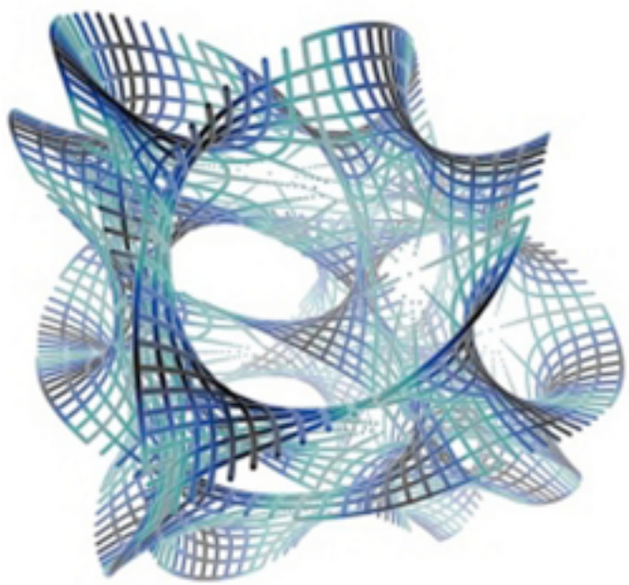

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What else can they do?

Particle Physics Applications

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Time Evolution?

Slow processes (like erosion) can tune. Ultra-light particles!

QCD Axion (Strong CP)/Relaxion (Hierarchy). Bosons in mass range 10^{-22} eV - meV

Phenomenology

Ultra-light Bosons + inflationary cosmology

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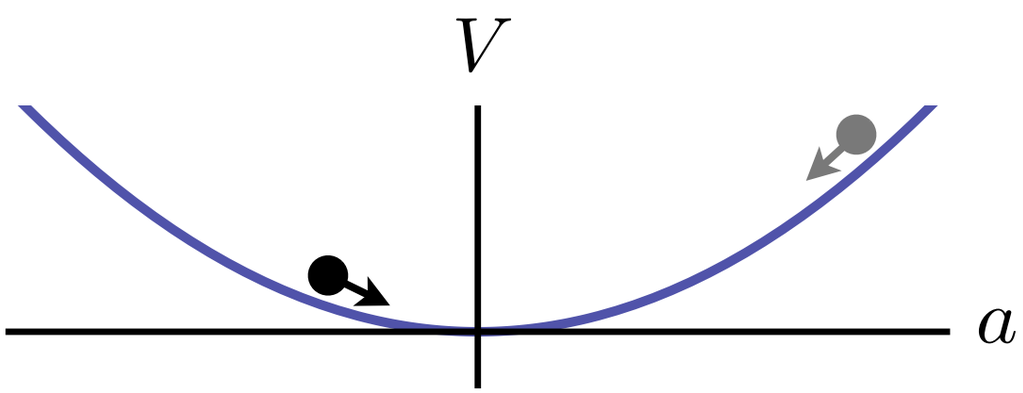
Misalignment Production

Field has non-zero initial value before inflation

$$a(t) \sim a_0 \cos(m_a t)$$



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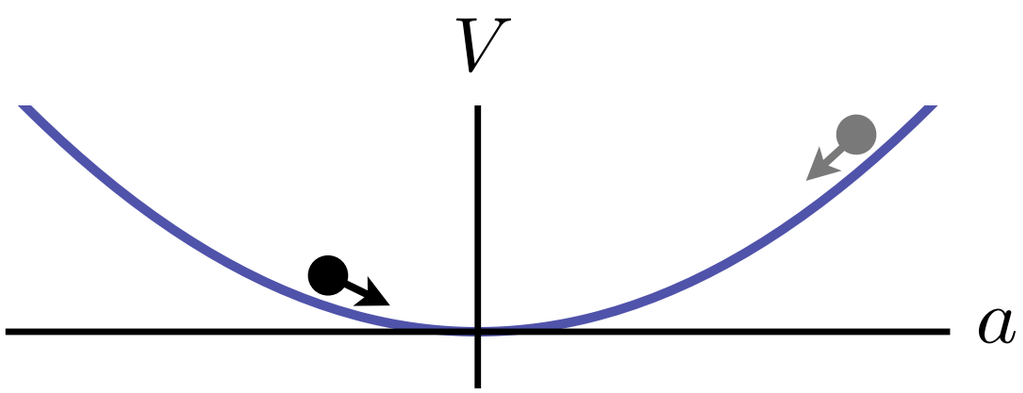

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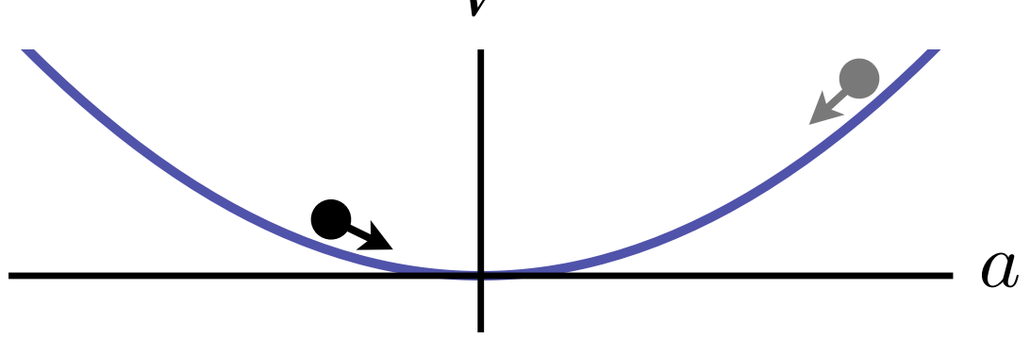

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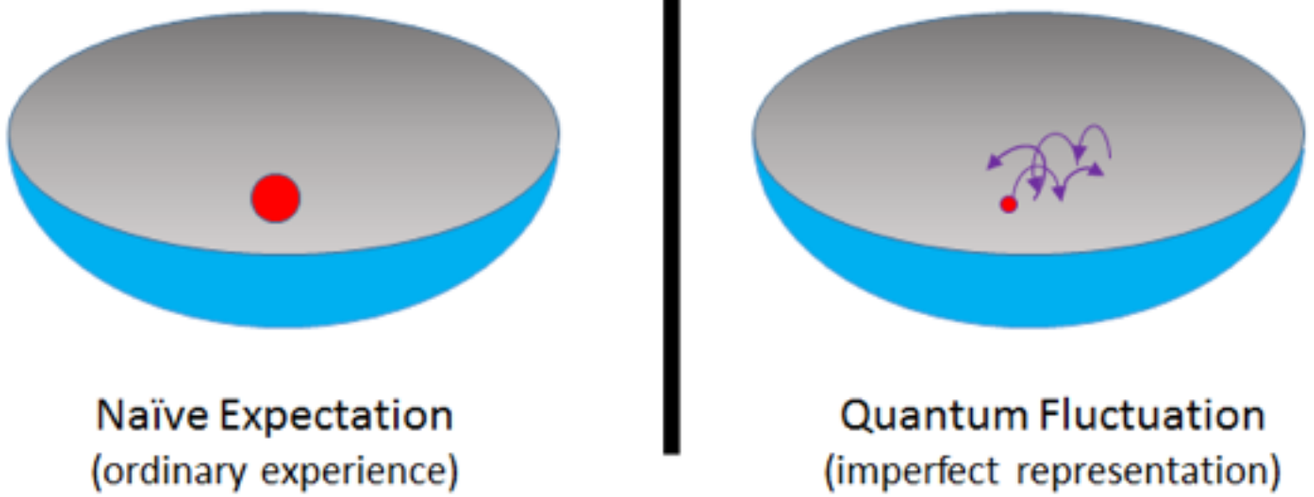

Super-horizon modes of massive vectors redshift differently from scalars/tensors

Right power spectrum at long wave-lengths

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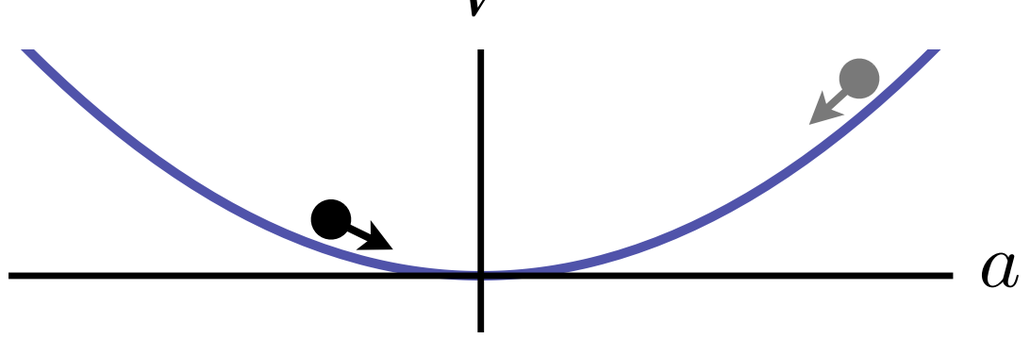

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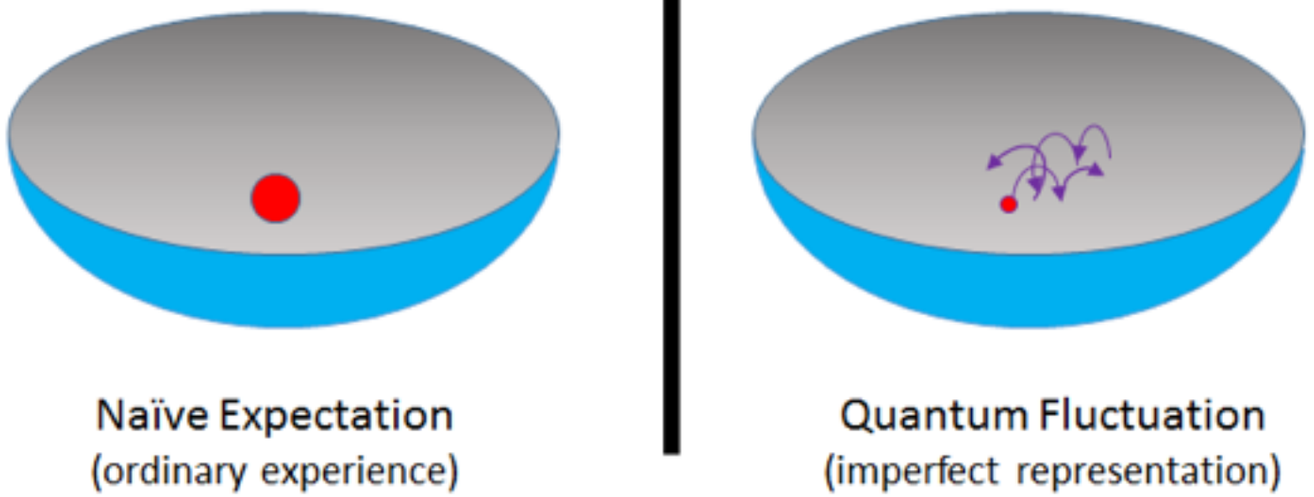

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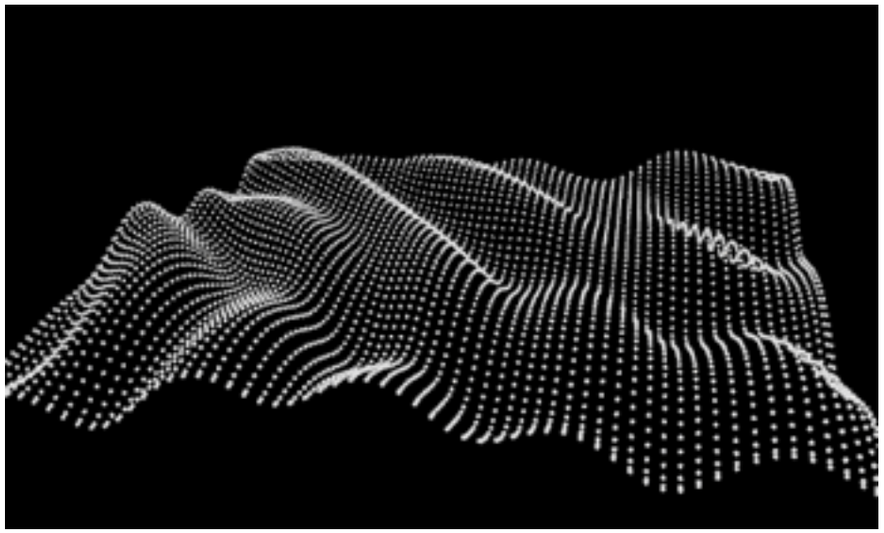
Guaranteed cosmic abundance. Natural Dark Matter Candidates.
Great potential to probe inflation!

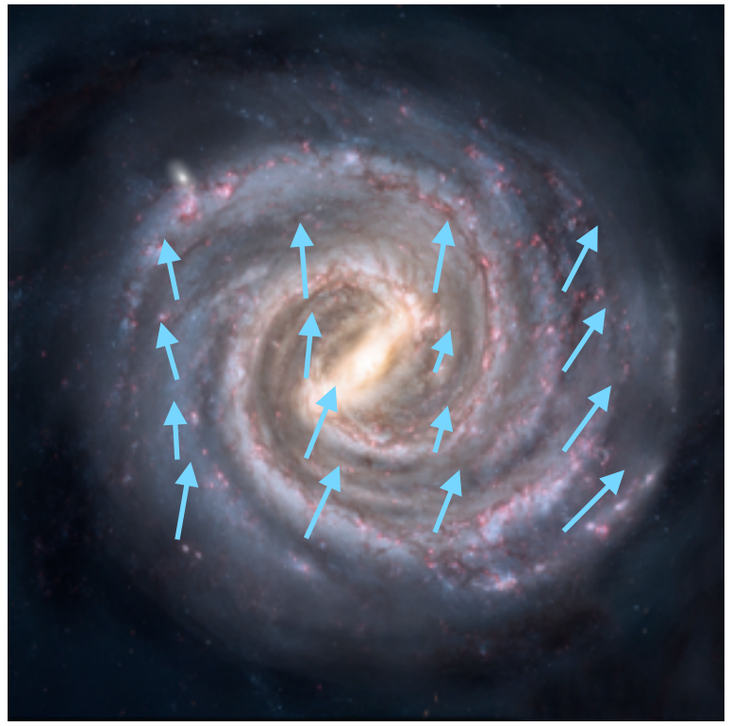
“Field” Dark Matter

What if ultra-light bosons are the dark matter?

particle DM

DM at long deBroglie wavelength
useful to picture as a “coherent” field:





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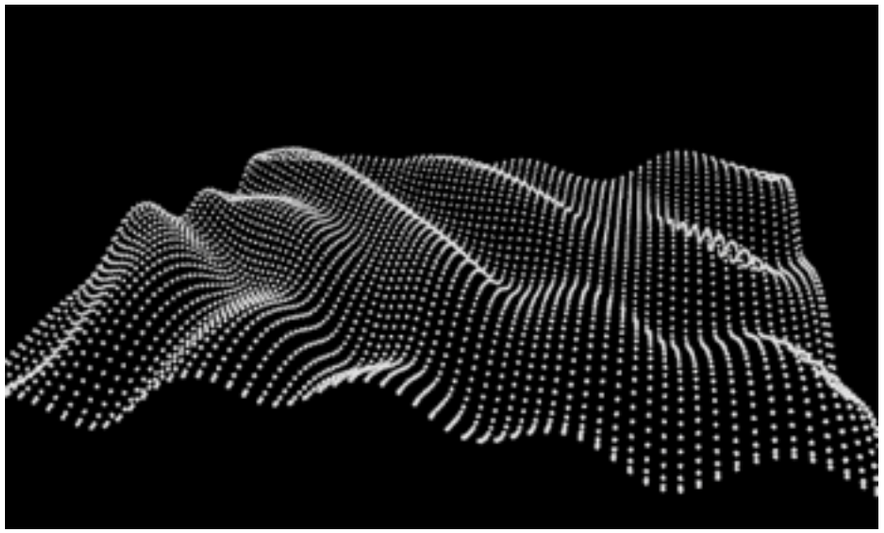

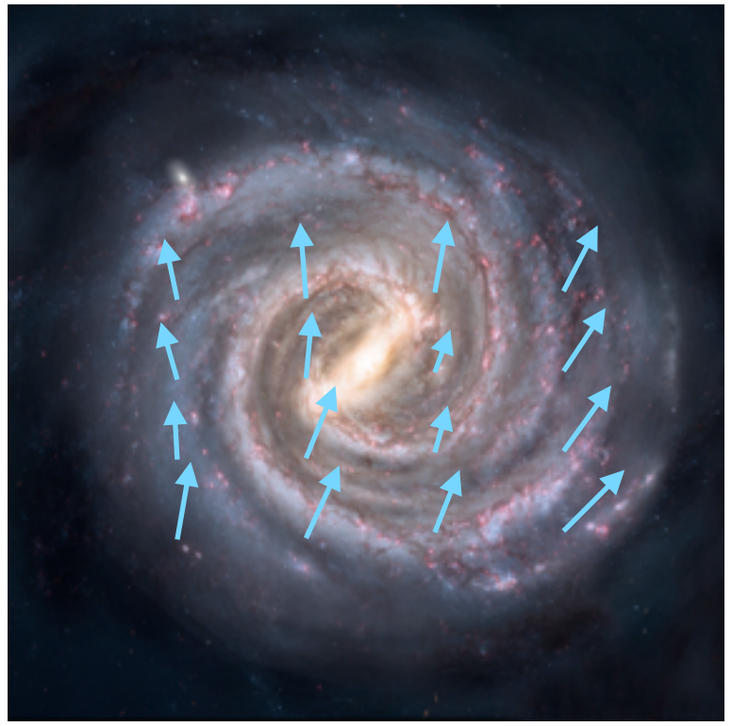

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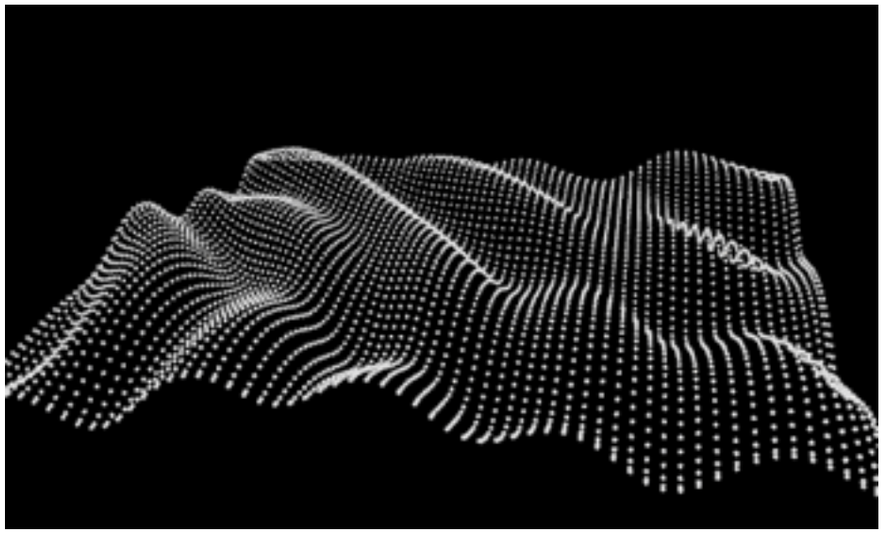

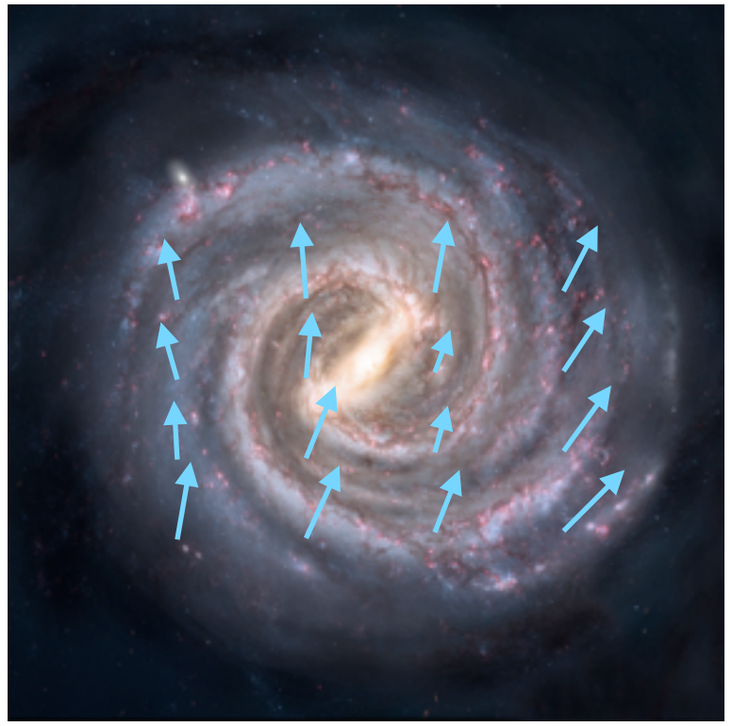

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What does this kind of dark matter field do?

Bosonic Dark Matter

Photons

$$\vec{E} = E_0 \cos(\omega t - \omega x)$$

Detect Photon by measuring time varying field

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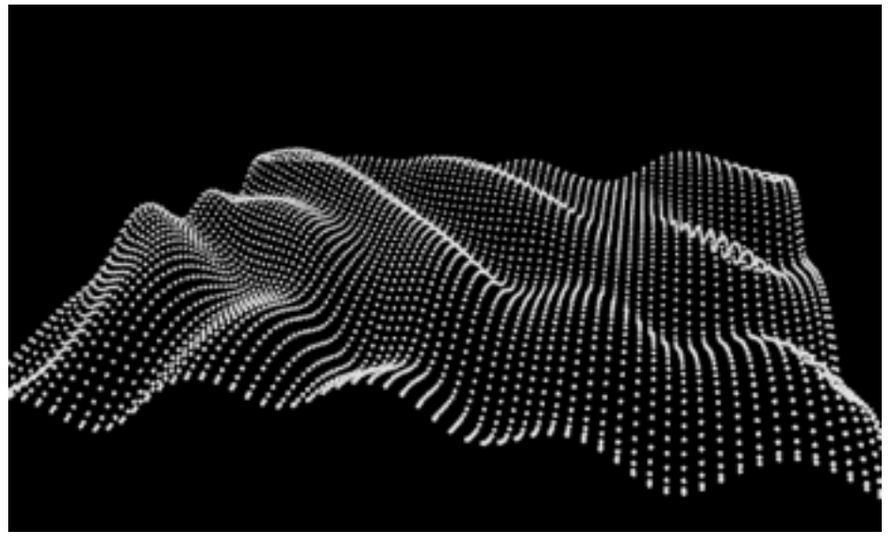

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Spatially uniform in early universe. Becomes stochastic during structure formation

Correlation length
$\sim 1/(m_a\, v)$

Coherence Time
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$\sim 1\ \mathrm{s}\ (\mathrm{MHz}/m_a)$

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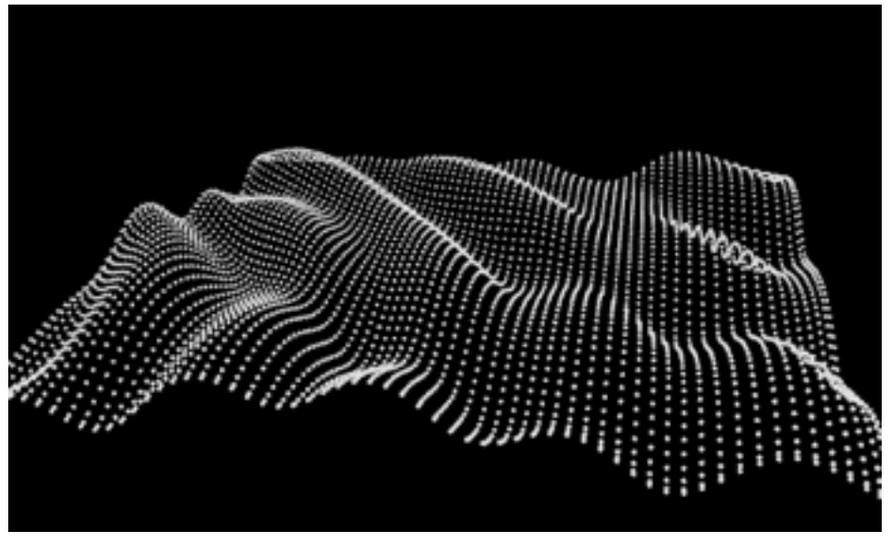

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Detect effects of oscillating dark matter field

Resonance possible. $Q \sim 10^6$ (set by $v \sim 10^{-3}$)

Experimental Opportunities

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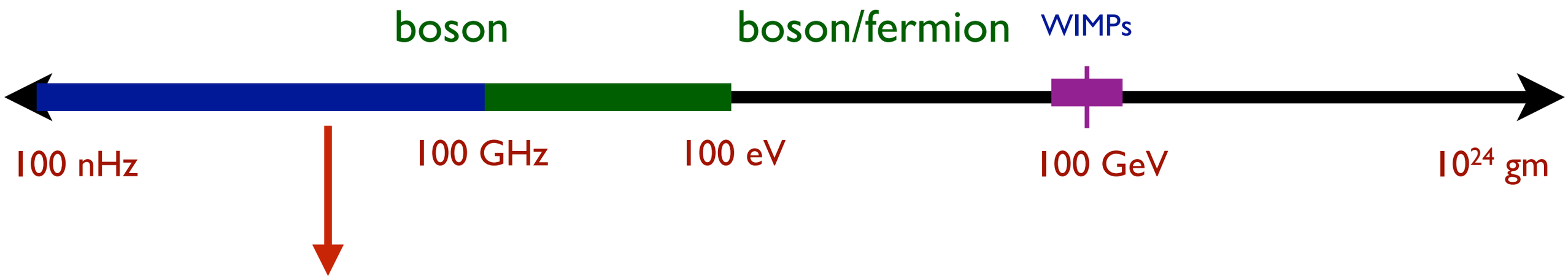

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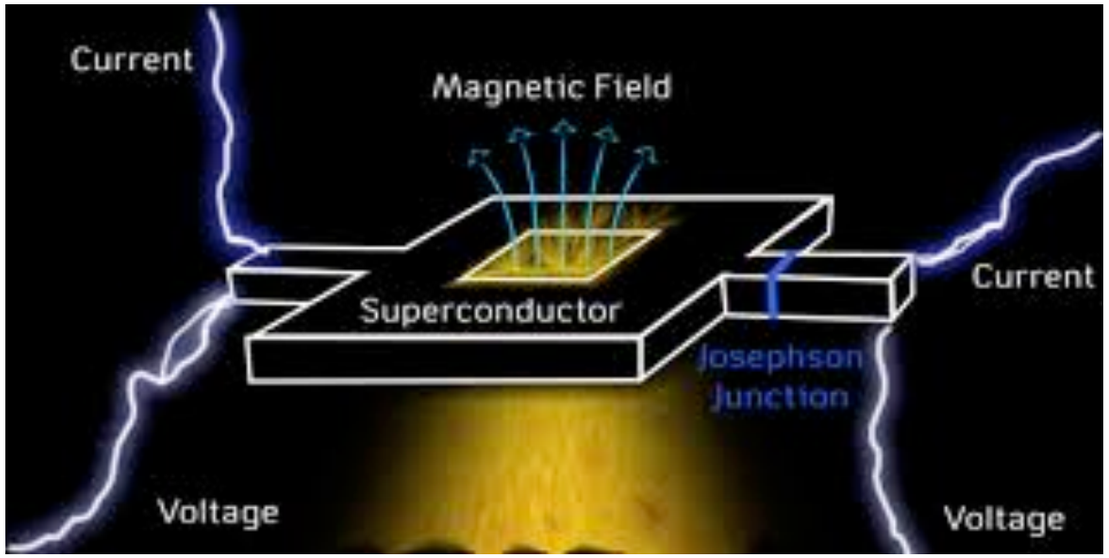
Need high precision to see weak effects

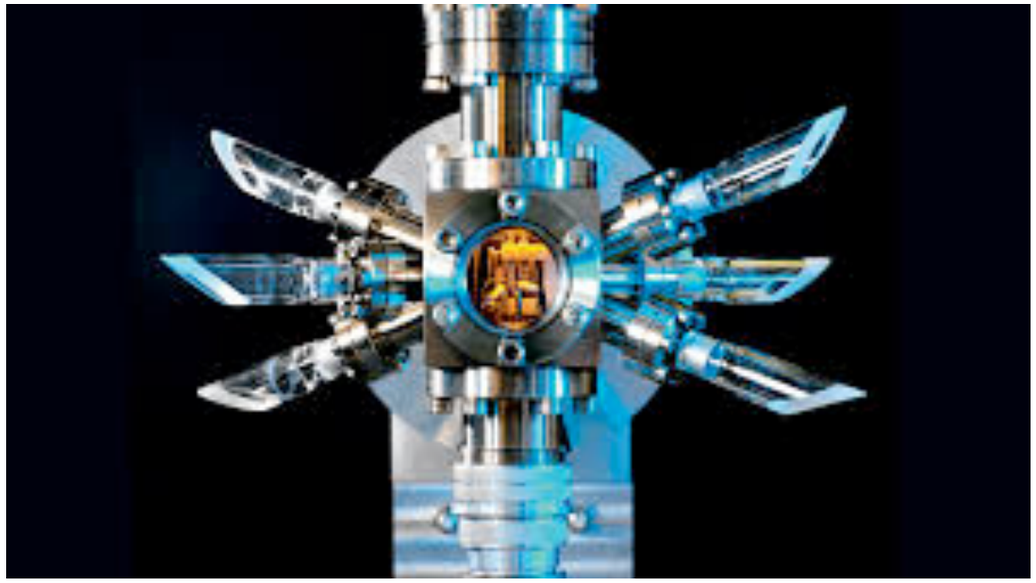
Precision Instruments

Impressive developments in the past two decades



$$\text{Magnetic Field} \lesssim 10^{-16} \frac{\text{T}}{\sqrt{\text{Hz}}}$$

(SQUIDs, atomic magnetometers)



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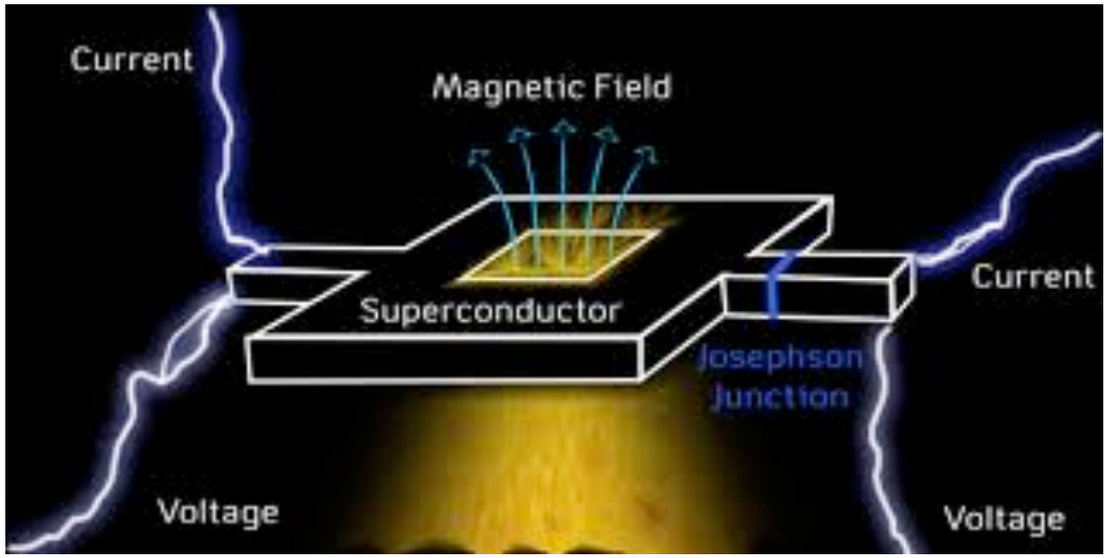

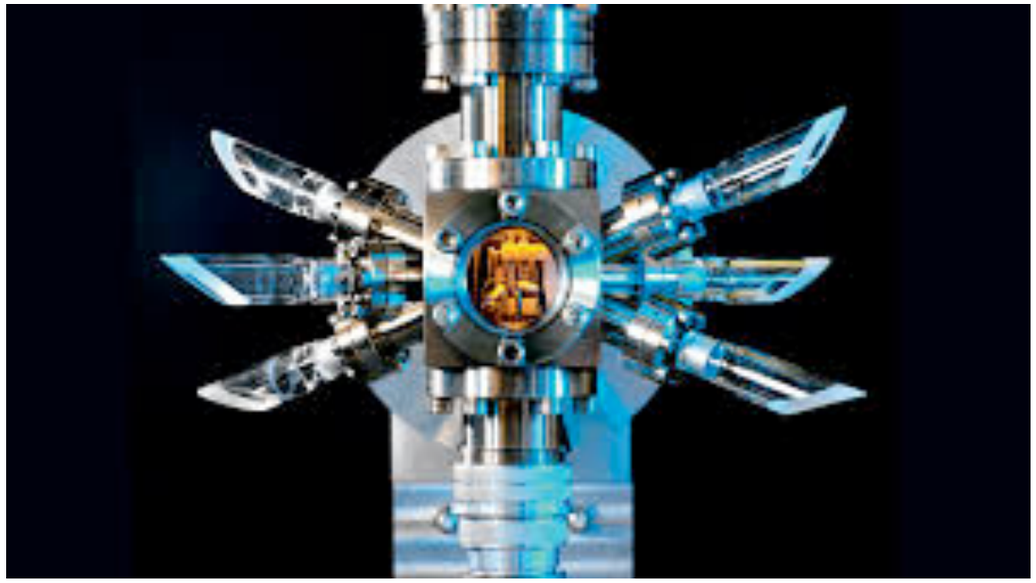

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Rapid technological advancements

Use to detect dark matter?

What are the effects of dark matter?

What kind of Effects?

Naturalness. Structure set by symmetries.

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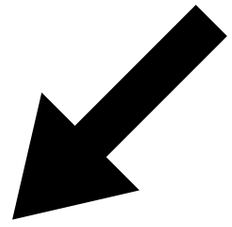

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Axions or ultra weak coupling

Many UV theories

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QCD Axion

Spin

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General Axions

Higgs

$\left(g\phi H^2\right)$

Higgs Portal/ Relaxion

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Dipole moment

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Kinetic Mixing

E&M

$\left(\epsilon F' F\right)$

B-L

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10^{-7} Hz < m_a < 100 GHz

Observable Effects

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Dark Matter

Oscillating Dark Matter Field (just like oscillating EM field from CMB)

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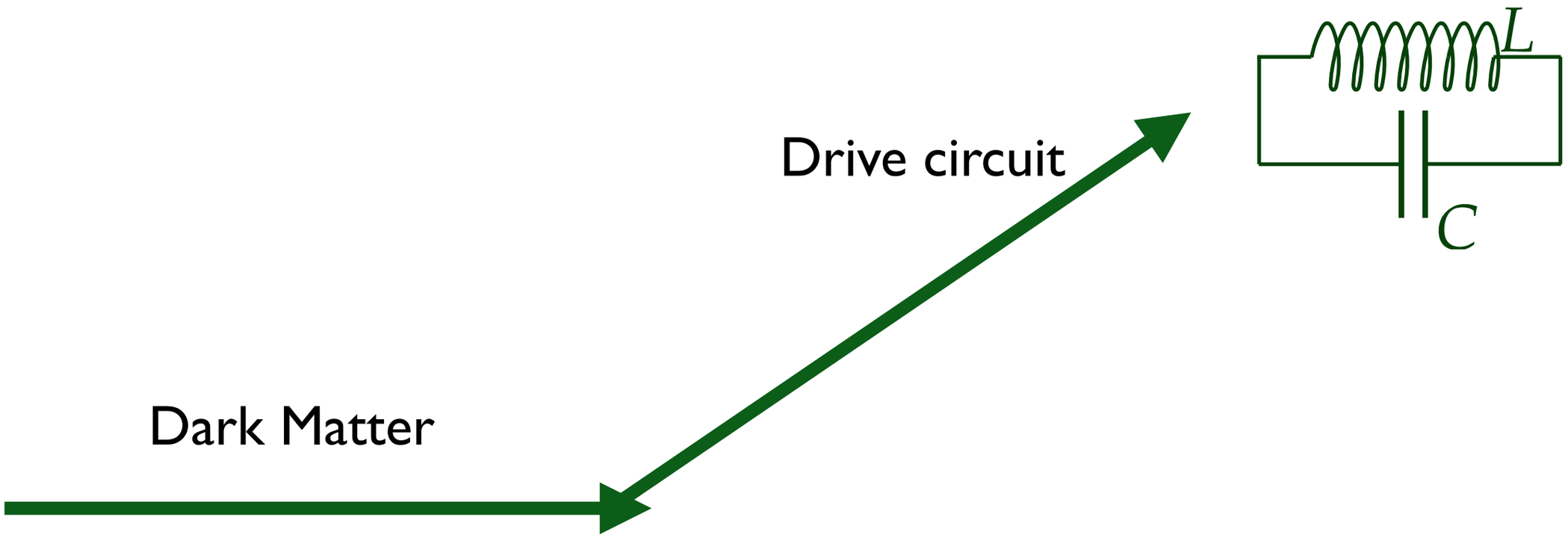

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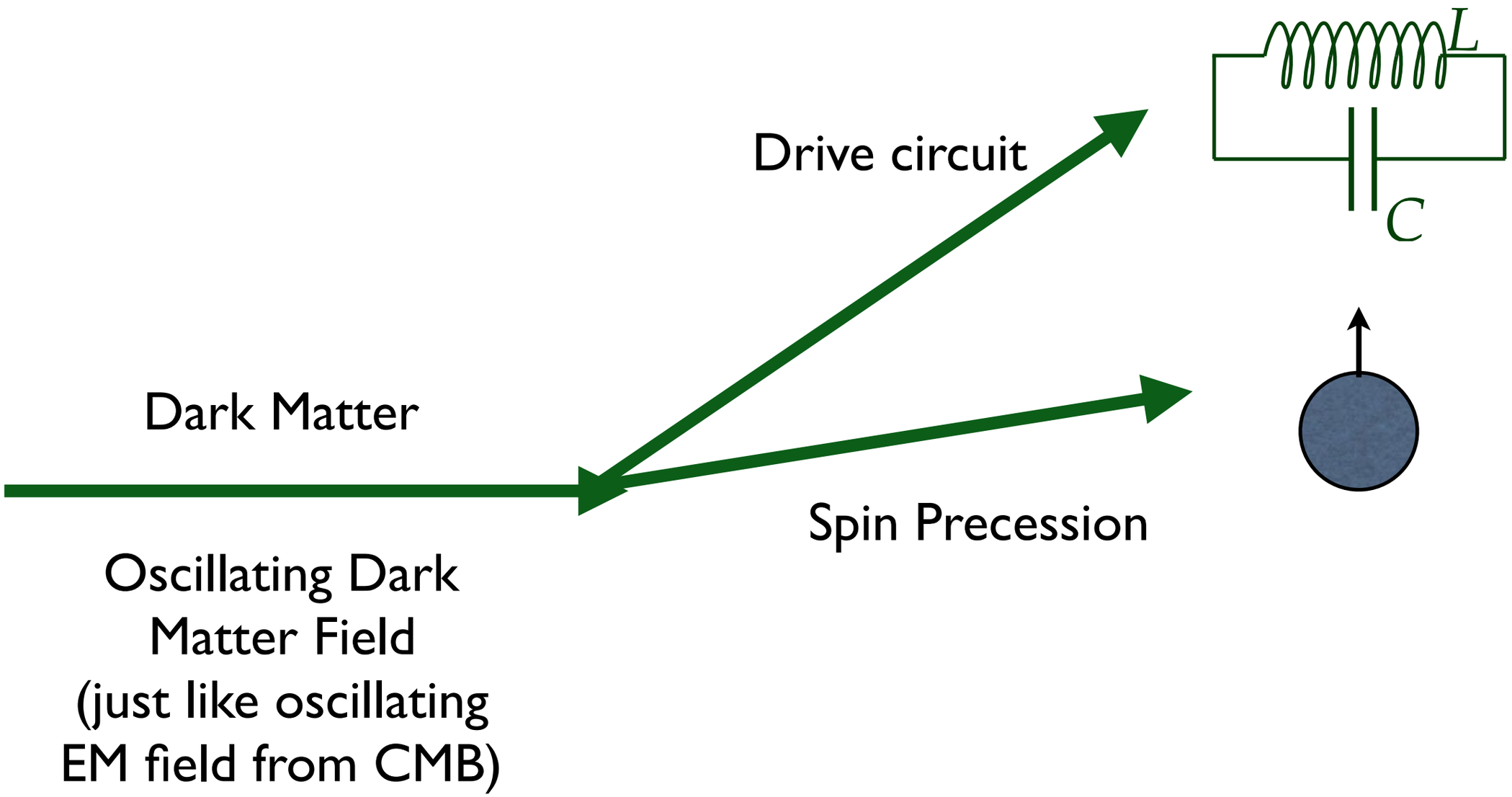

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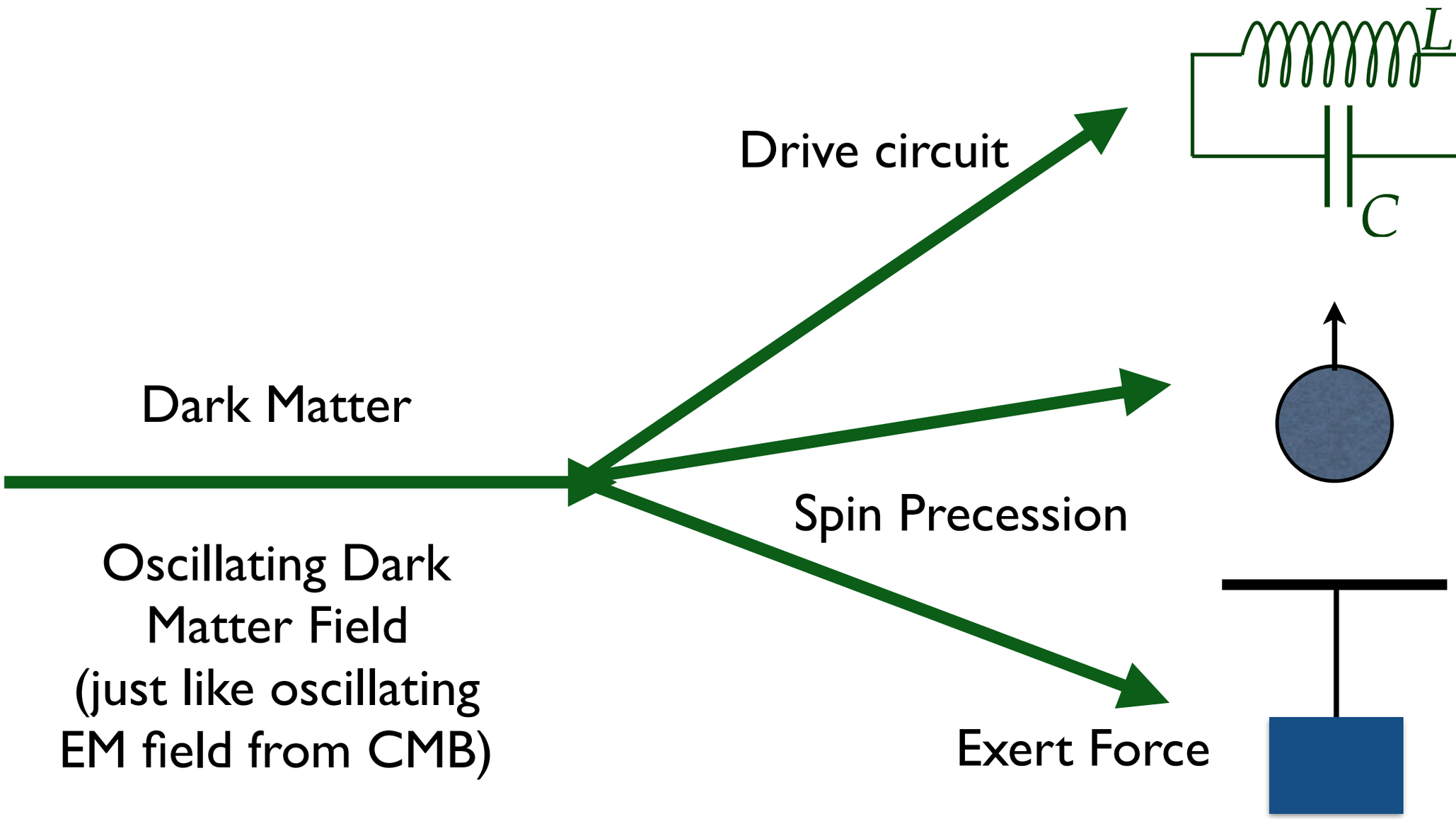

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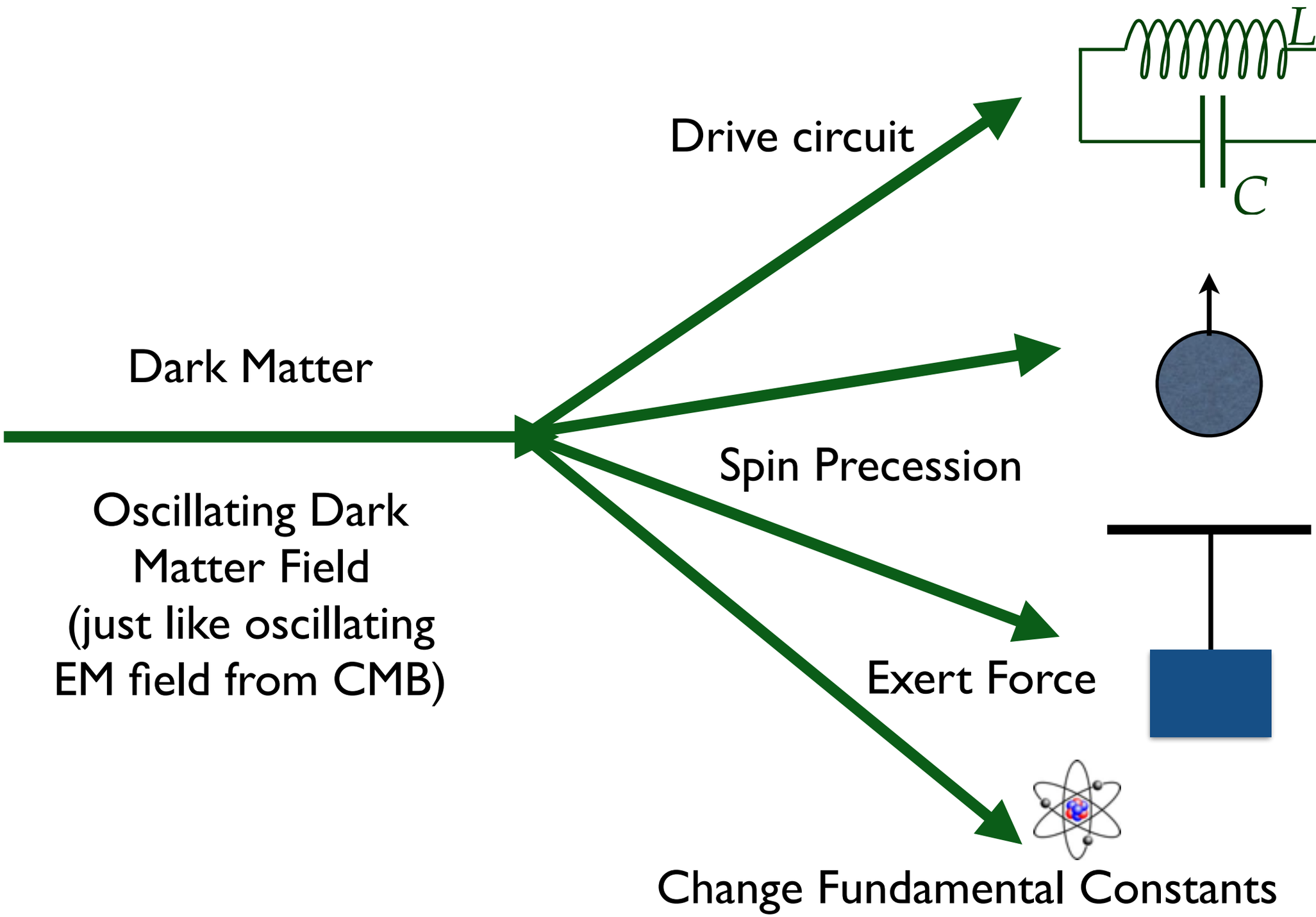

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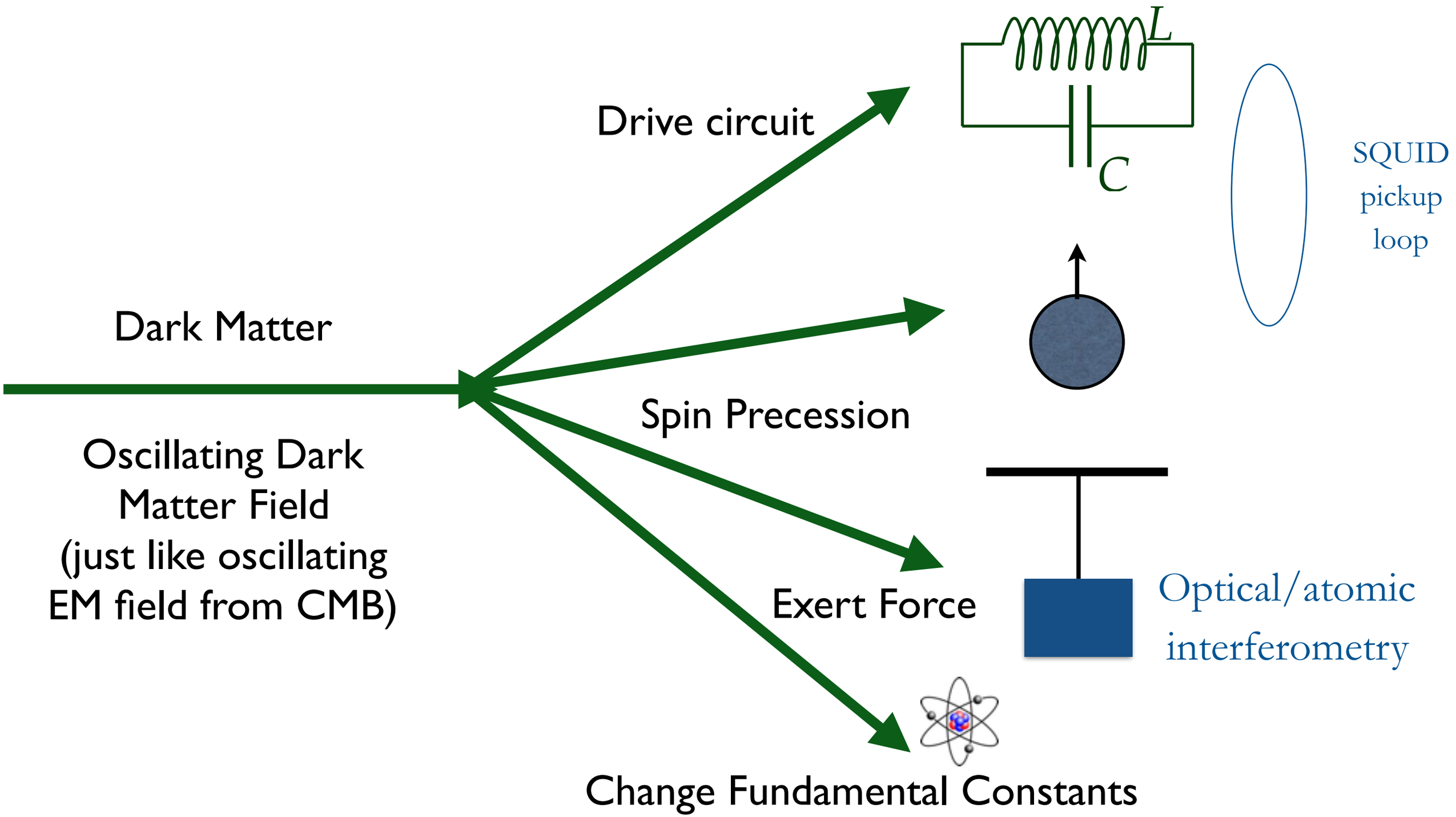

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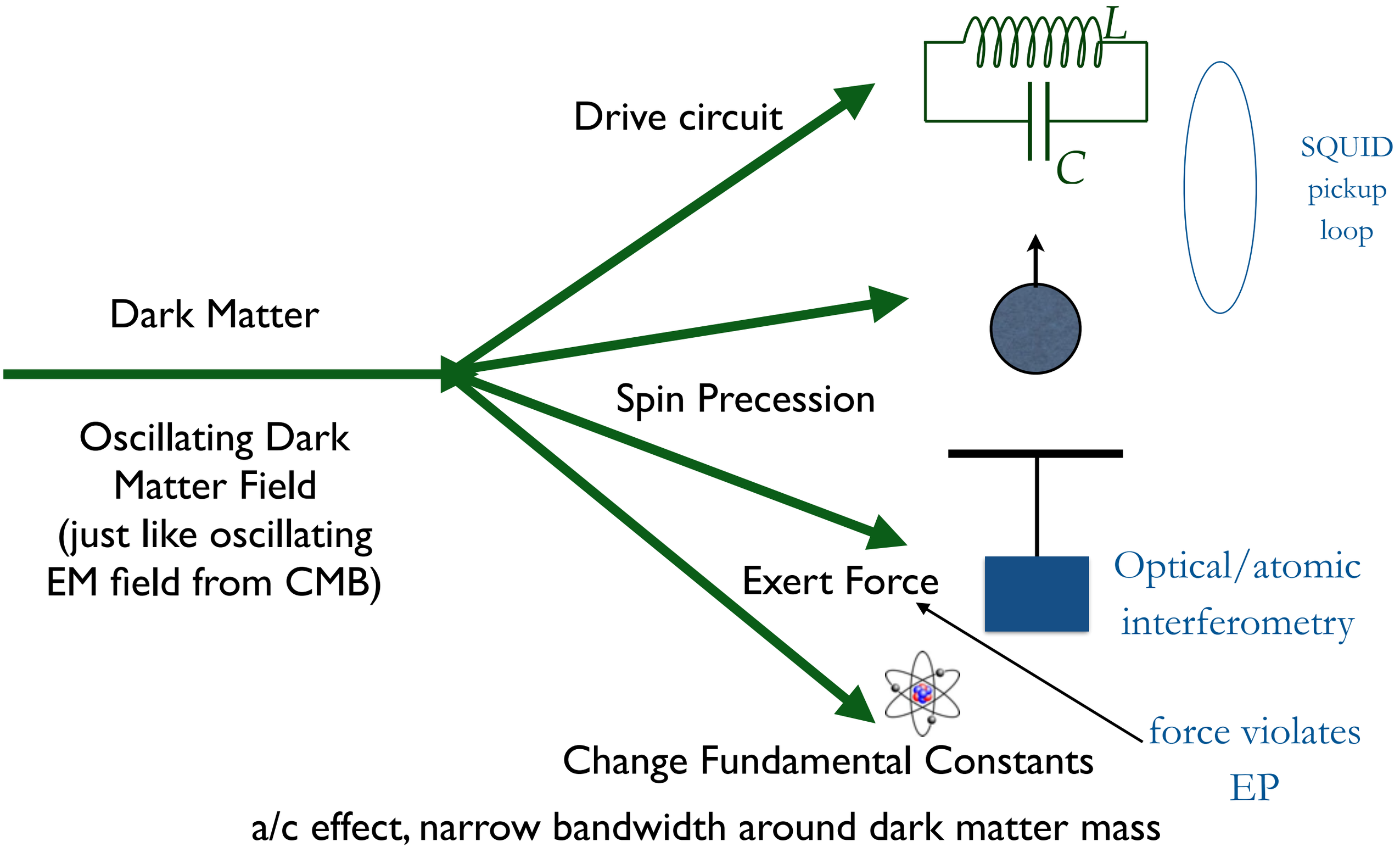
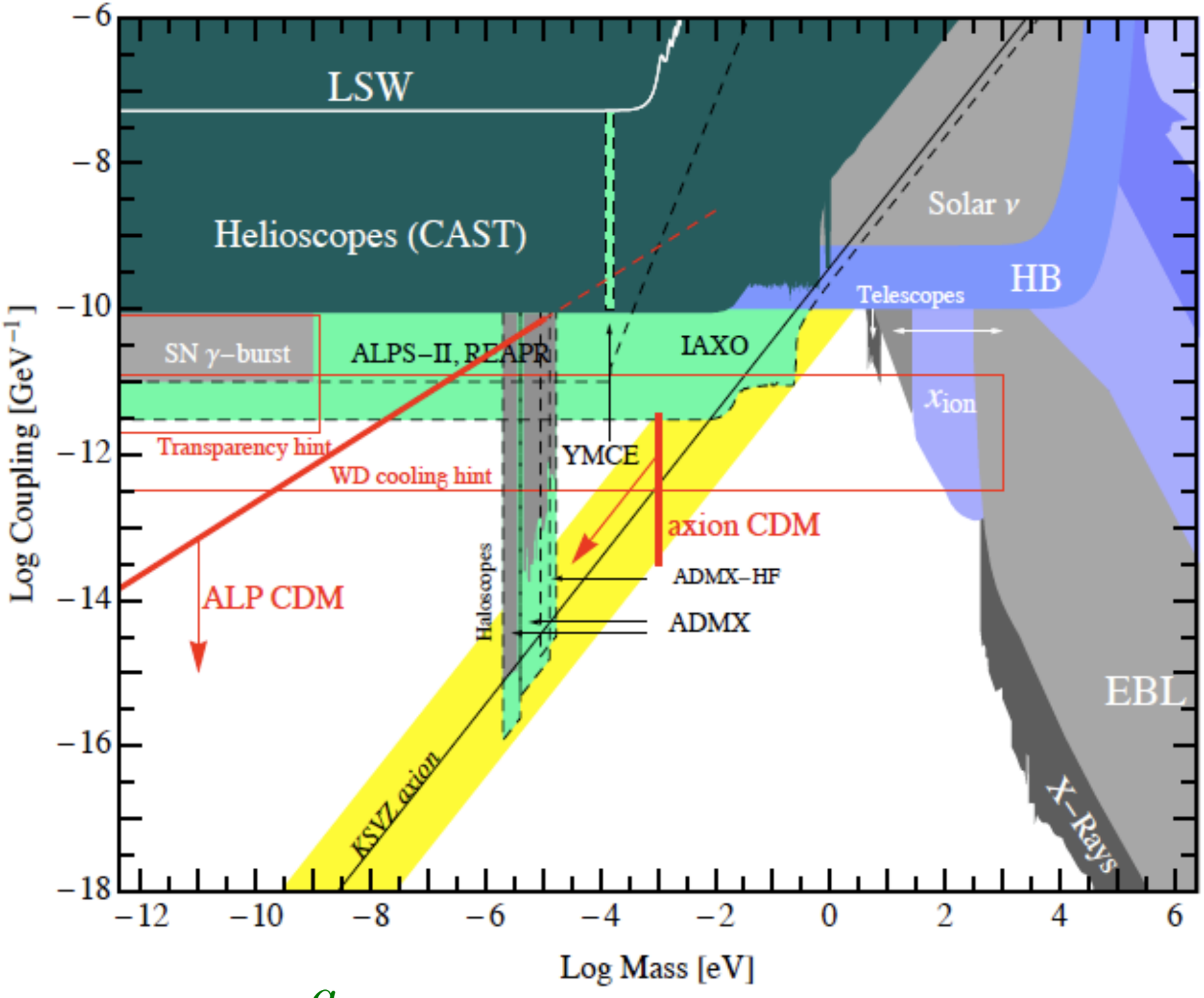
What can a classical field do?



a/c effect, narrow bandwidth around dark matter mass

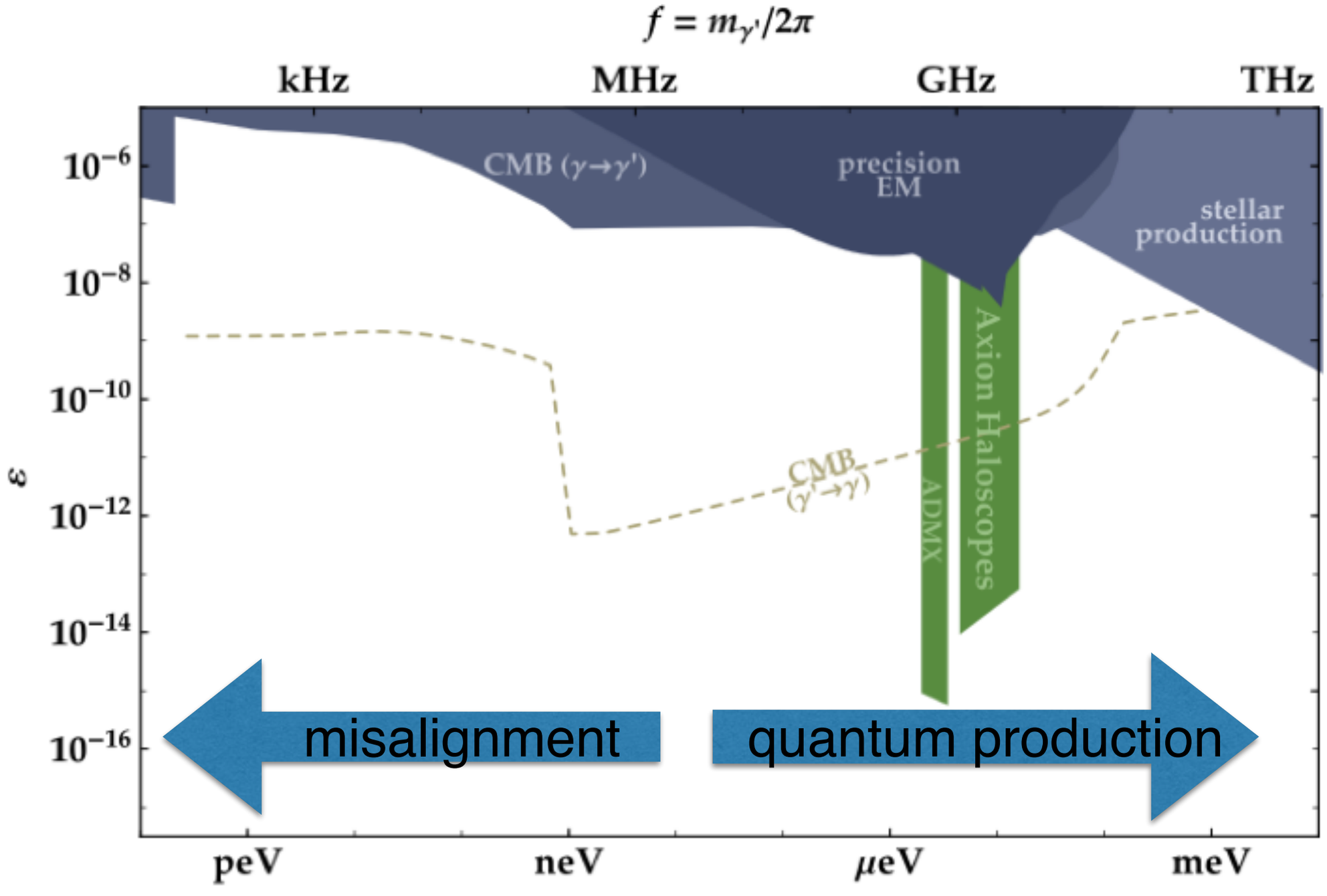
Electromagnetic Resonators



Operator: $\dfrac{a}{f_a} F\tilde{F}$

Target: QCD Axion

Electromagnetic Resonators

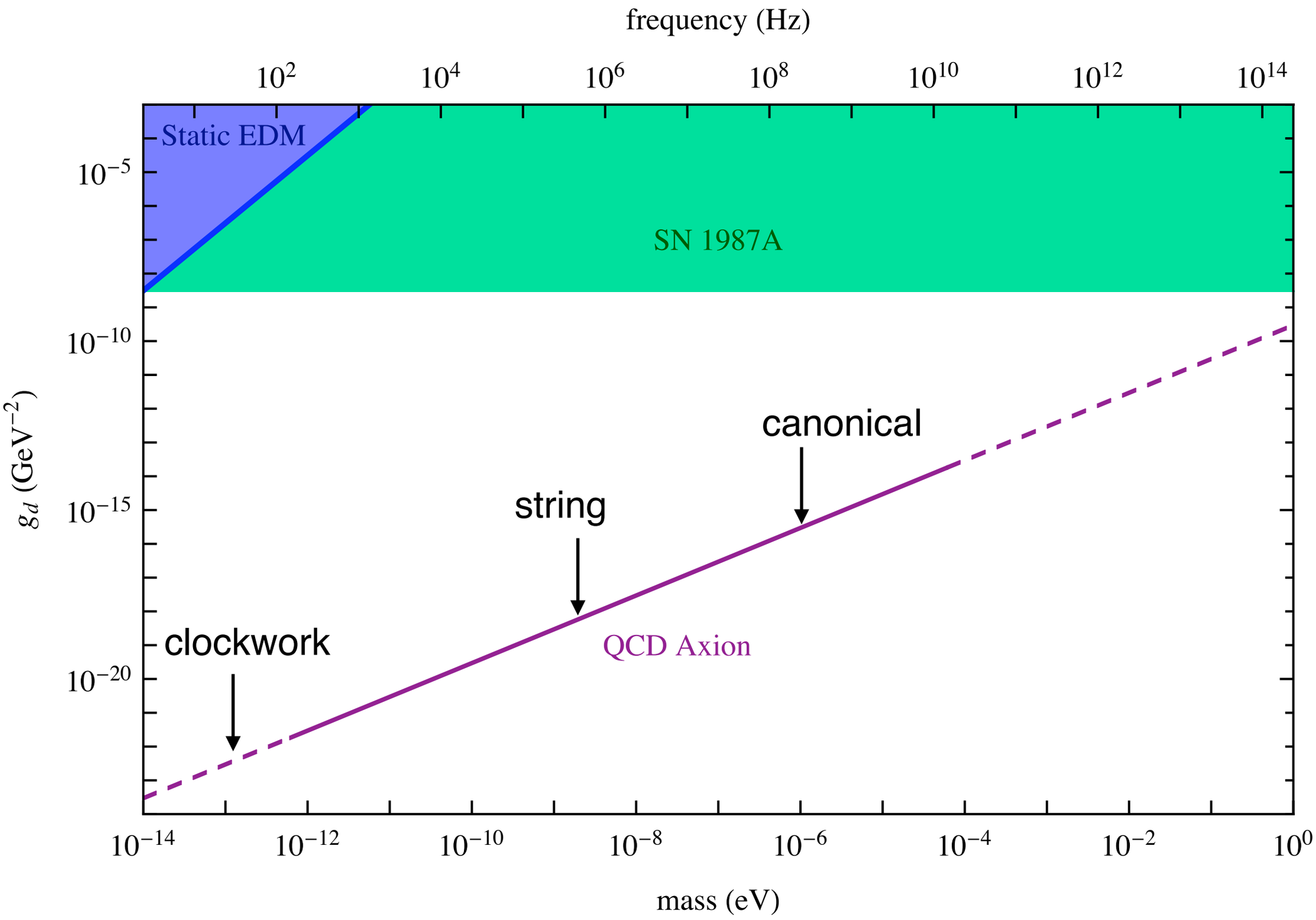


Operator: $\epsilon F F'$

Target: Hidden Photon

Probes Hubble scale at inflation

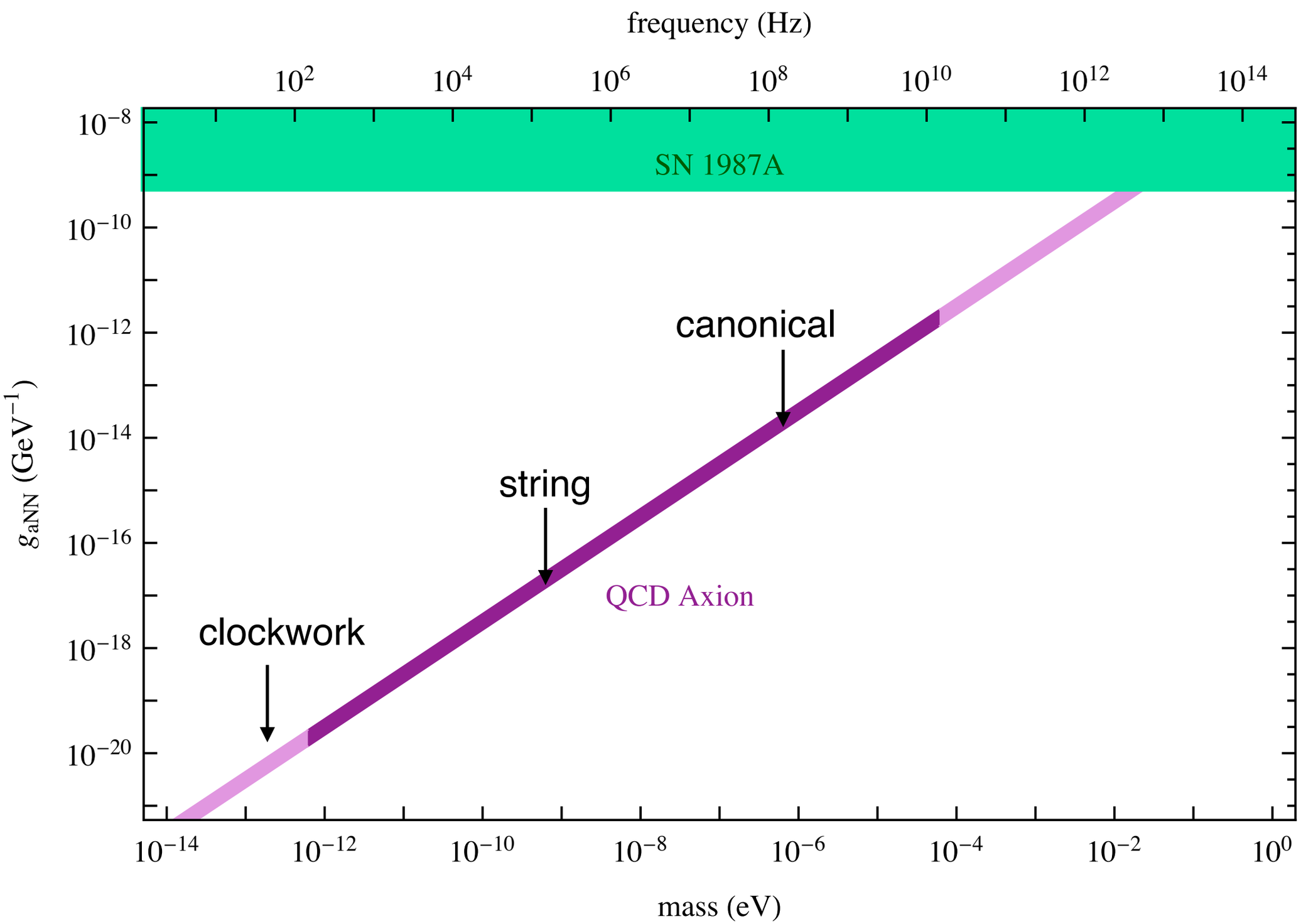
Spin Precession



Operator: $\frac{a}{f_a} G\tilde{G}$ (electric dipole moment)

Target: QCD Axion

Spin Precession

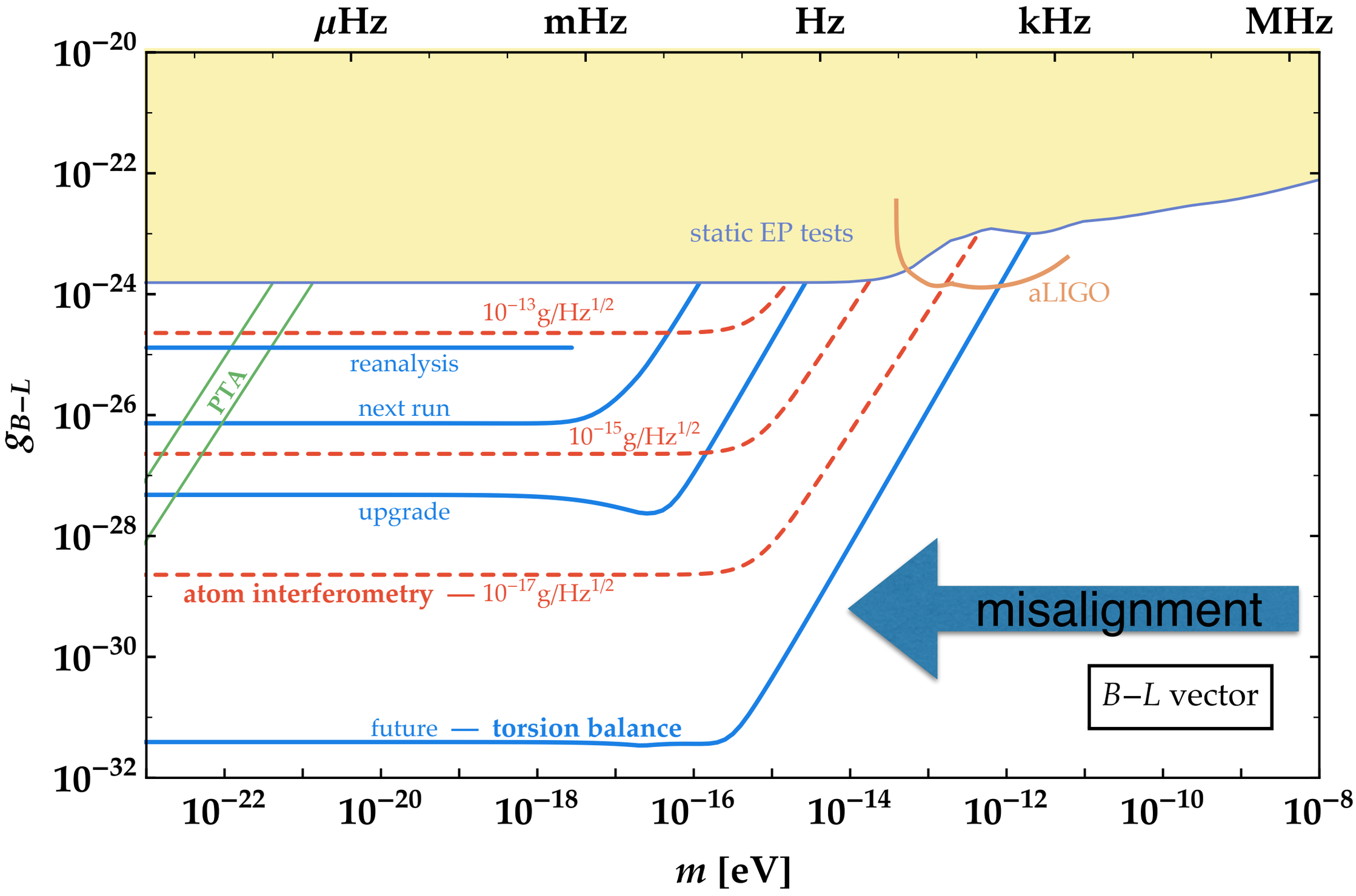


Operator: $\frac{\partial_\mu a}{f_a}\bar{\Psi}\gamma^\mu\gamma_5\Psi \supset \frac{m_a a}{f_a}\vec{v}.\vec{S}$

(axion wind)

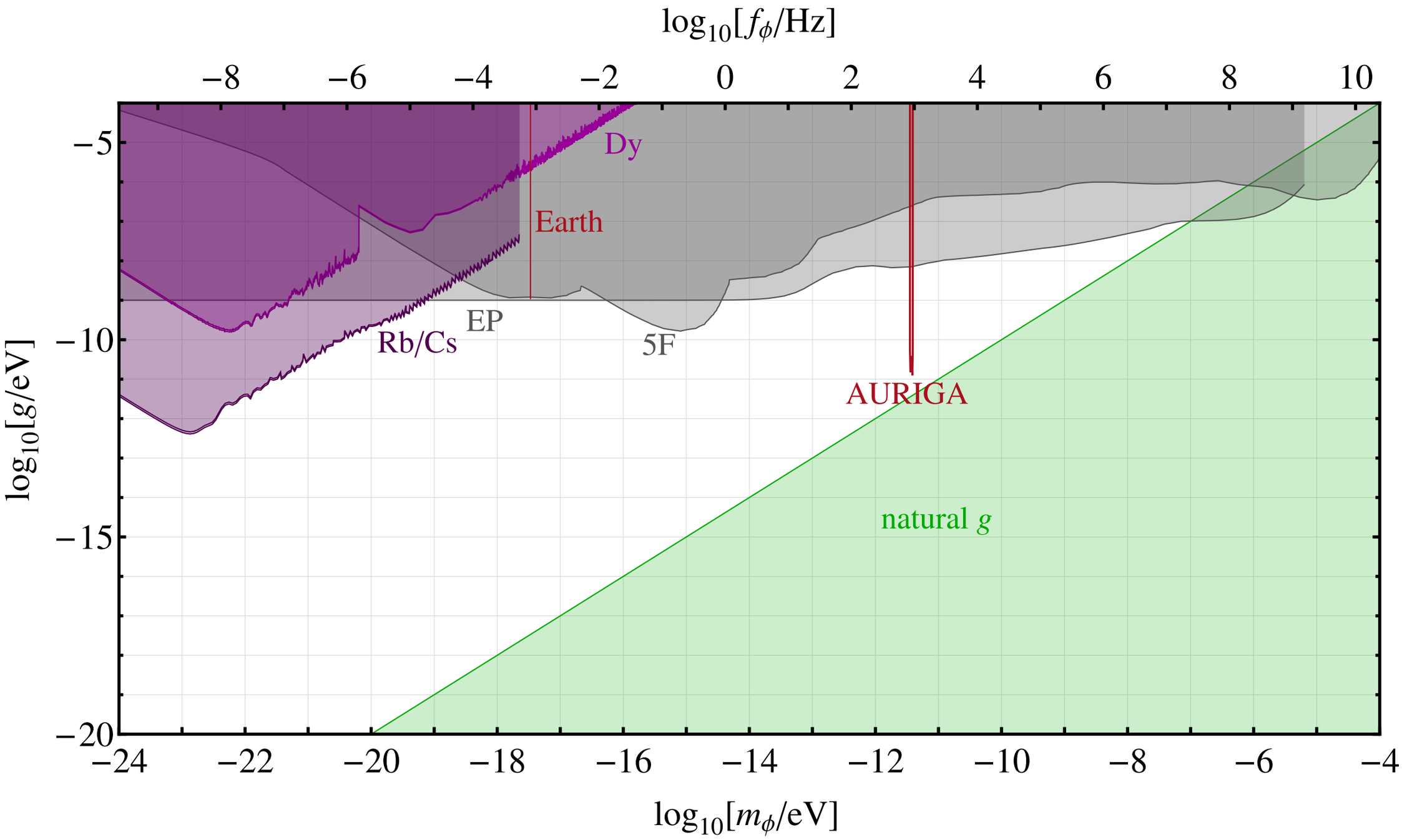
Target: QCD Axion

Accelerometers



Operator: $gA'_\mu J^\mu_{B-L}$

Fundamental Constants



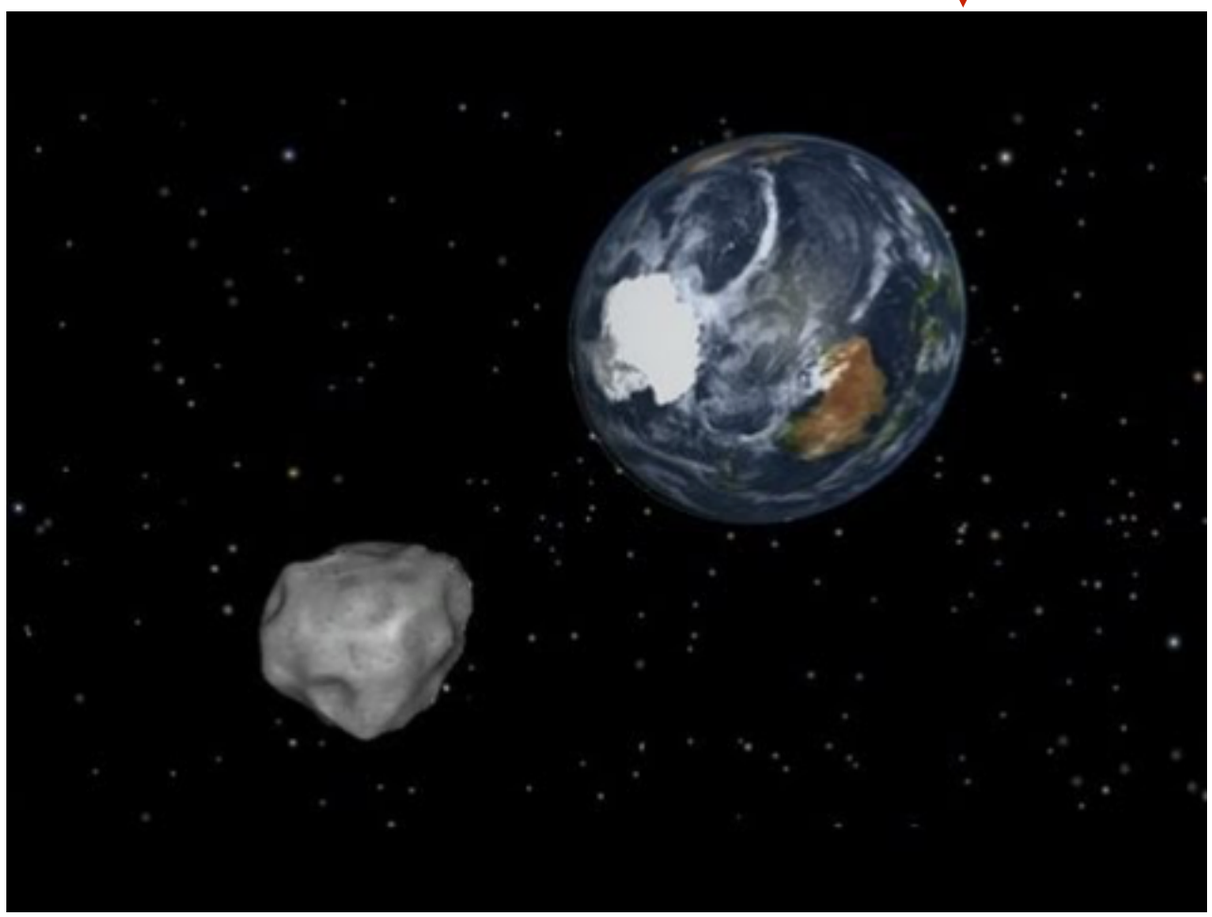
Operator: $g\phi H^2$

Target: Relaxion (natural g)

The Dark Matter Landscape

A complex dark matter sector. If there are strong self-interactions in the dark matter sector, the dark matter particles may collect into large lumps. Just like normal matter!

We have very weak constraints on dark matter self interactions



The Dark Matter Landscape

boson

boson/fermion

WIMPs

10^{-55} gm

10^{-31} gm
(100 eV)

10^{-22} gm
(100 GeV)

10^{8} gm

10^{24} gm

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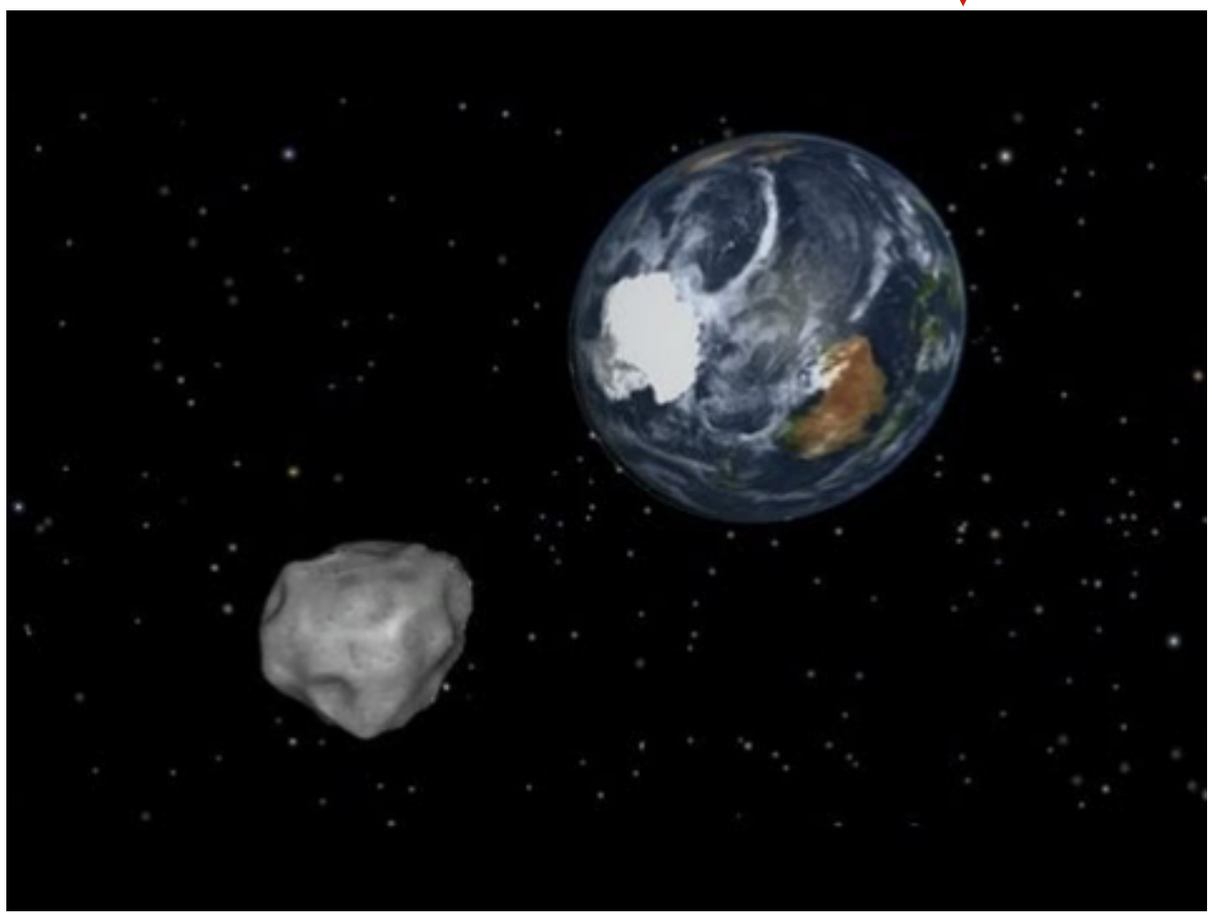


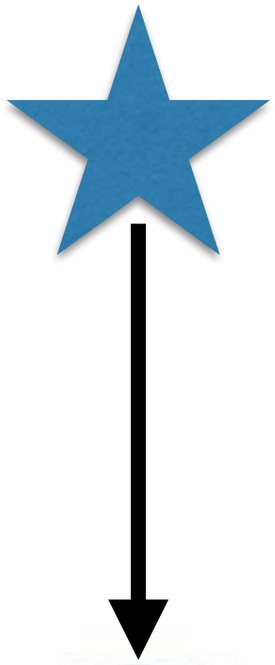
Low number density - need large, planet size detector

May source long range classical fields

Bonus: Ultra-Heavy Dark Matter

Rare Transit of Heavy
Dark Matter

Bonus: Ultra-Heavy Dark Matter

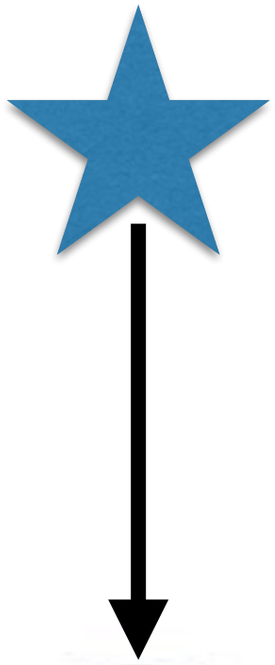


Rare Transit of Heavy Dark Matter

Classical field created by dark matter - correlated excitation of multiple detectors

Same class of effects as light dark matter - excitation of currents, spin precession, acceleration, variation of fundamental constants

Bonus: Ultra-Heavy Dark Matter



Rare Transit of Heavy Dark Matter

Classical field created by dark matter - correlated excitation of multiple detectors

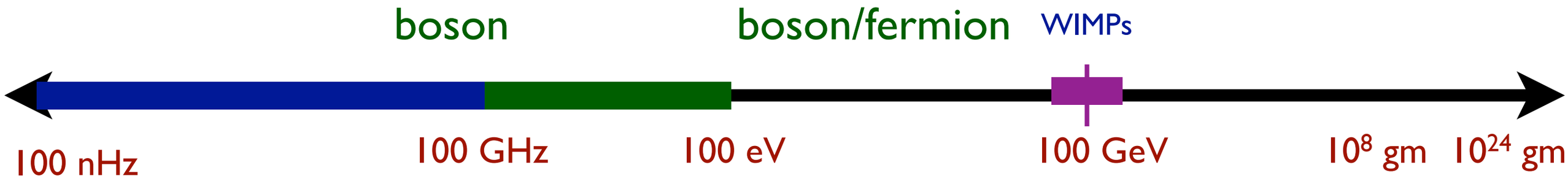
Same class of effects as light dark matter - excitation of currents, spin precession, acceleration, variation of fundamental constants

Instead of continuous, coherent a/c effect, look for correlated transients in network

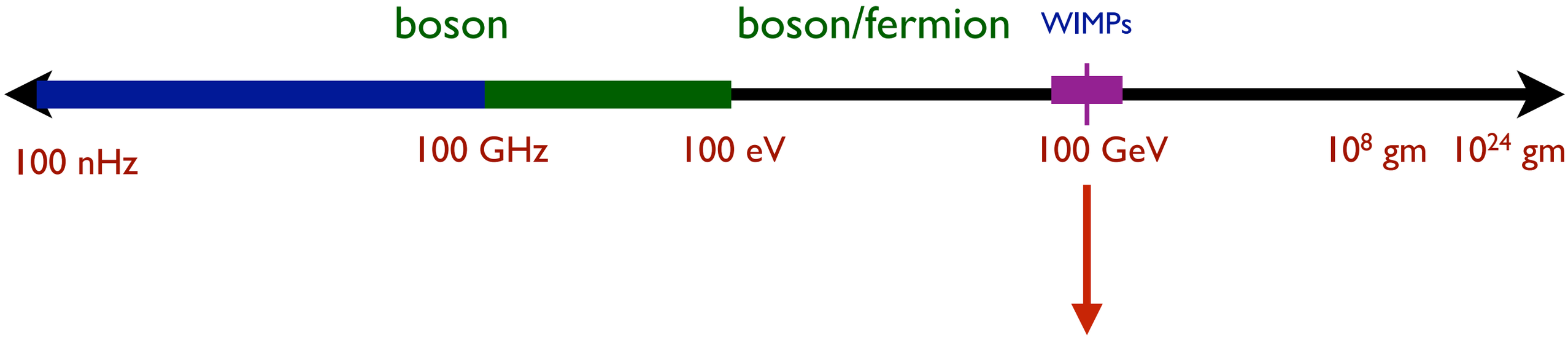
Up to dark matter mass ~ 10^8 gm

Conclusions

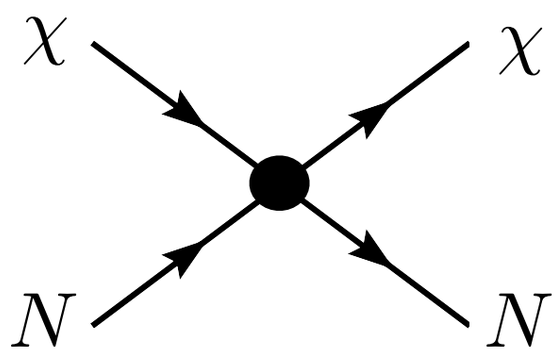
The Dark Matter Landscape



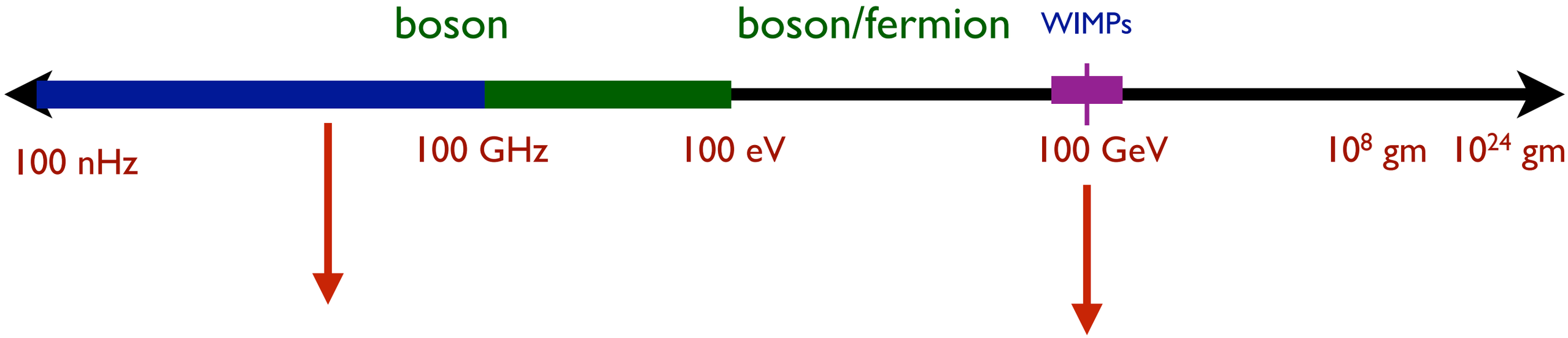
The Dark Matter Landscape



Search for single, hard particle scattering



The Dark Matter Landscape

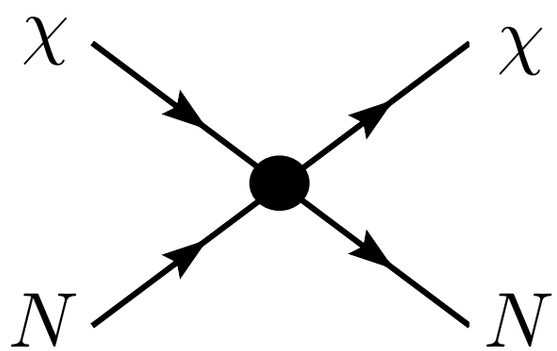


Natural from UV physics.
Solve strong CP/Hierarchy problem.

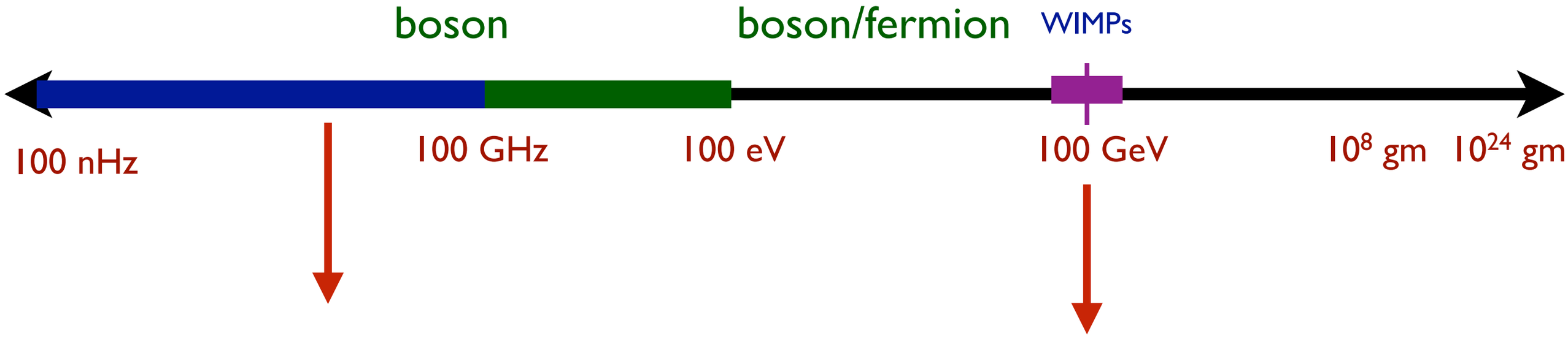
Will have cosmic abundance.
Probe inflation.

Search for narrowband a/c effects of classical dark matter field

Search for single, hard particle scattering



The Dark Matter Landscape



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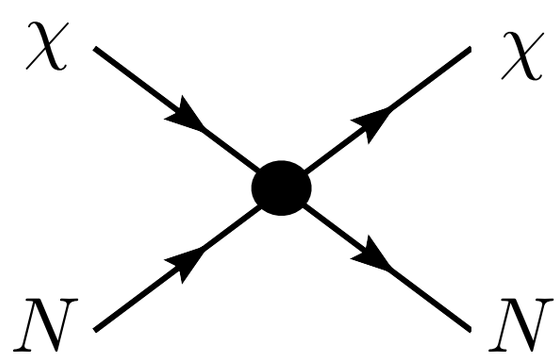

The Dark Matter Landscape

boson | boson/fermion | WIMPs

100 nHz | 100 GHz | 100 eV | 100 GeV | 10^8 gm | 10^{24} gm

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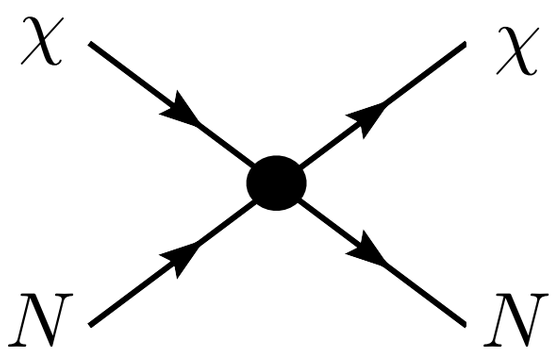

Transients in network of sensors could see ultra-heavy dark matter