The Story of Dark Matter

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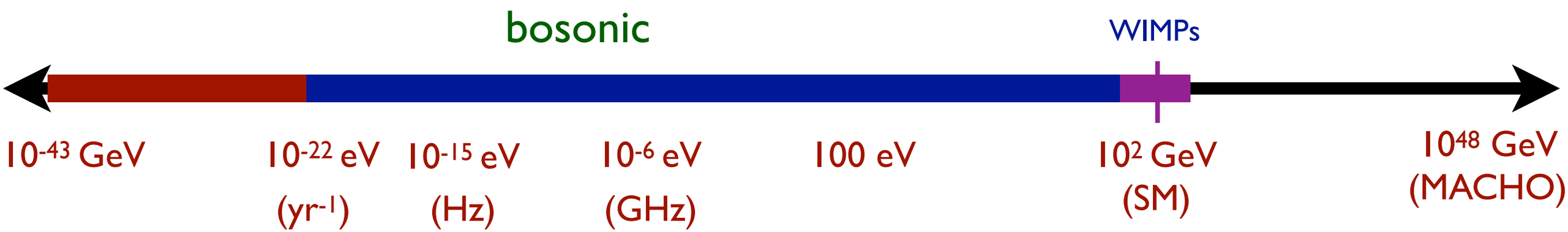
The Dark Matter Landscape



Fit in galaxy

Lots of theories: WIMPs, axions, hidden photons, relaxions,…

Any of these theories could be true - no overwhelming reason to believe a particular framework

How do we systematically make progress?

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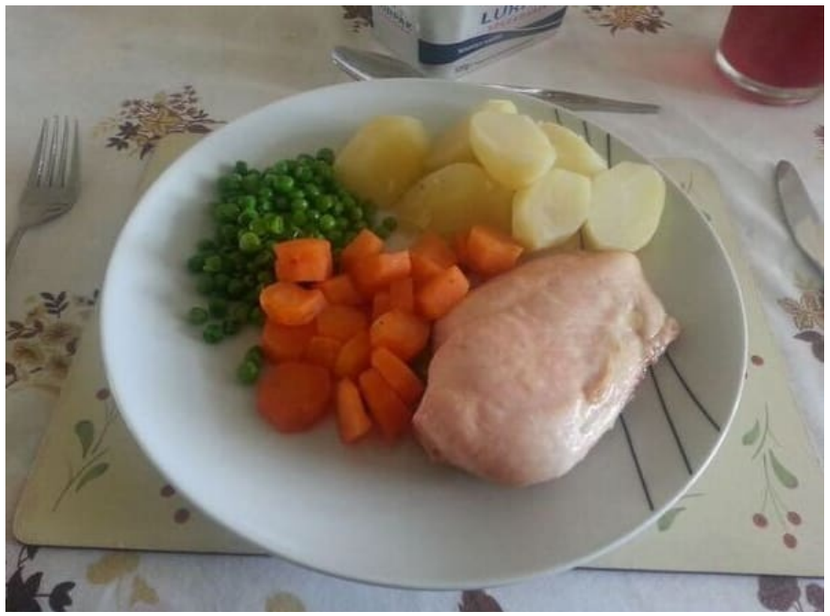


WIMP

ADMX Axion

QCD Axion

Hidden Photons

Ultralight

Ultraheavy

The Zagat's Guide

Naturalness. Structure set by symmetries.

Spin 0

Axions or ultra weak coupling

Many UV theories

Spin 1

Anomaly free
Standard Model couplings

E&M | QCD | Spin | Higgs | Spin | E&M | Current

$\left(\frac{a}{f_a} F\tilde{F}\right)$

Current Searches

(m_a ~ GHz)

$\left(\frac{a}{f_a} G\tilde{G}\right)$ QCD Axion

$\left(\frac{\partial_\mu a}{f_a} \bar{N}\gamma^\mu\gamma_5 N\right)$ General Axions

$\left(g\phi H^2\right)$ Higgs Portal/ Relaxion

$\left(\frac{F'_{\mu\nu}}{f_a} \bar{N}\sigma^{\mu\nu} N\right)$ Dipole moment

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

$\left(g A'_\mu J^\mu_{B-L}\right)$ B-L

This Talk

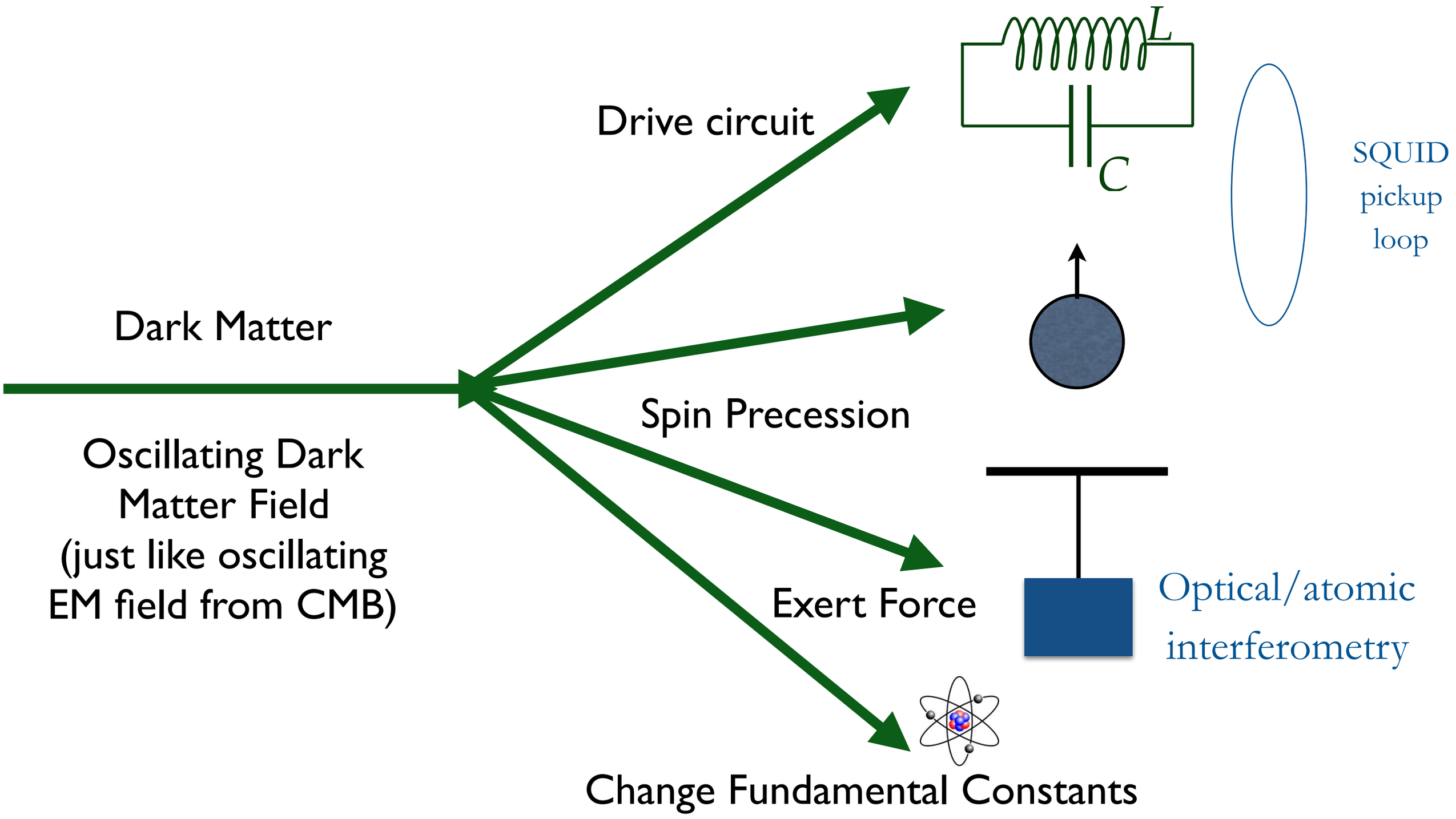
$$\text{Dark Matter} \implies a = a_0 \cos\left(m_a t\right)$$

$$10^{-7}\ \text{Hz} \lessapprox m_a \lessapprox\ \text{GHz}$$

Observable Effects

What can the dark matter wind do?

What can a classical field do?



a/c effect, narrow bandwidth around dark matter mass

Cosmic Axion Spin Precession Experiment (CASPEr)

with

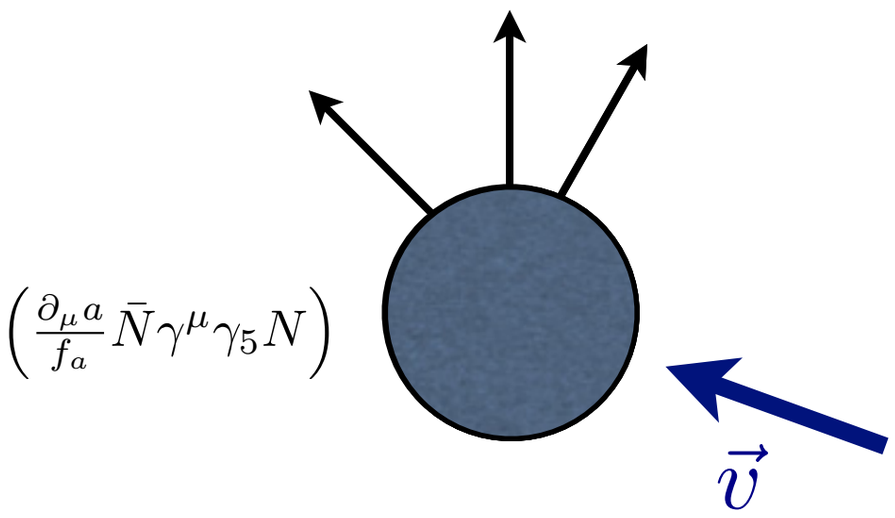
Dmitry Budker
Peter Graham
Micah Ledbetter
Alex Sushkov

PRX **4** (2014) arXiv: 1306.6089
PRD **88** (2013) arXiv: 1306.6088
PRD **84** (2011) arXiv: 1101.2691

CASPEr: Axion Effects on Spin

General Axions

Neutron in Axion Wind



$$H_N \supset \frac{a}{f_a}\vec{v_a}.\vec{S}_N$$

Spin rotates about dark matter velocity

Effective time varying magnetic field

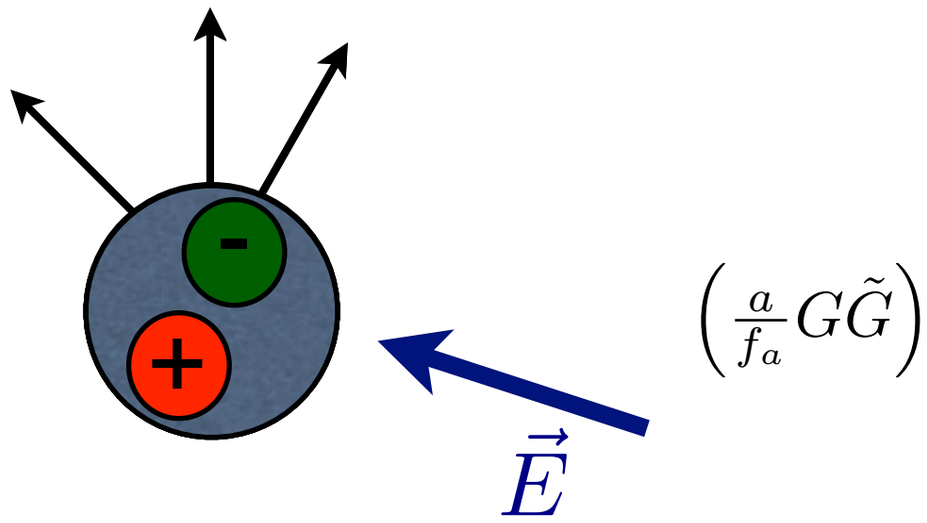
$$B_{eff} \lessapprox 10^{-16}\ \cos(m_a t)\ \mathrm{T}$$

Other light dark matter (e.g. dark photons) also induce similar spin precession

Measure Spin Rotation, detect Axion

QCD Axion

Neutron in QCD Axion Dark Matter



QCD axion induces electric dipole moment for neutron and proton

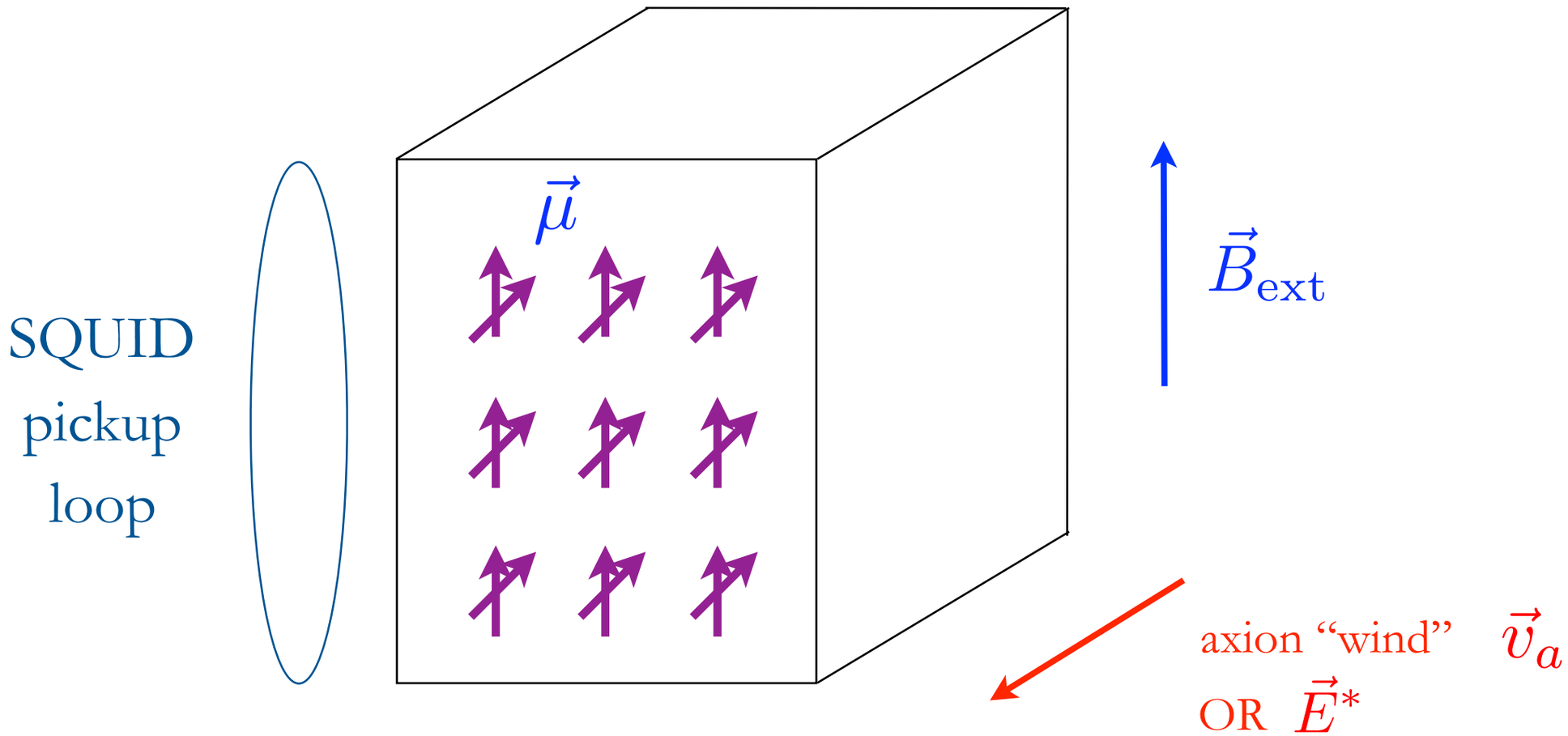
Dipole moment along nuclear spin

Oscillating dipole: $d \sim 3 \times 10^{-34}\ \cos(m_a t)\ e\,\mathrm{cm}$

Apply electric field, spin rotates

CASPEr

Axion affects physics of nucleus, NMR is sensitive probe



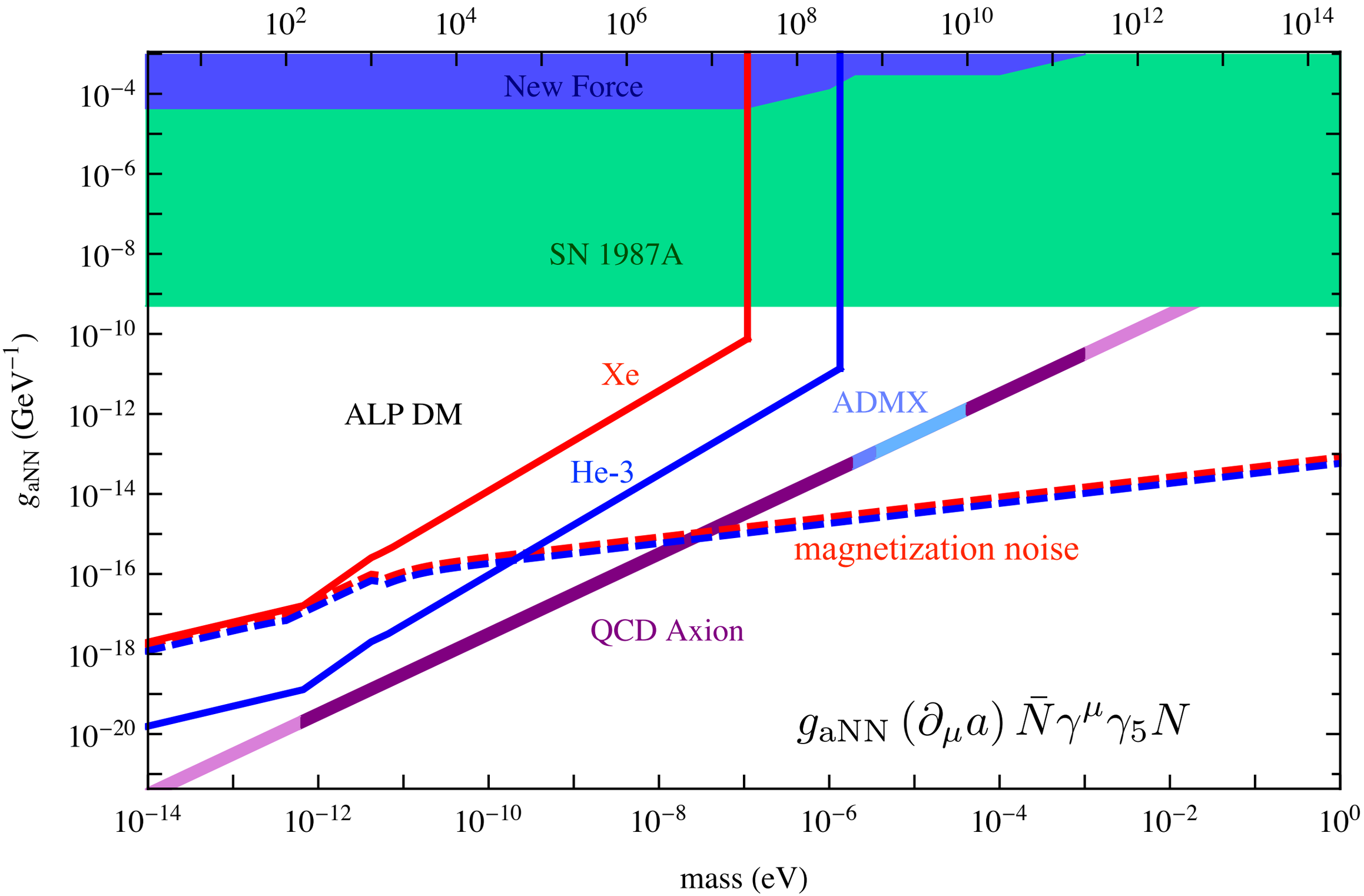
Larmor frequency = axion mass ➔ resonant enhancement

SQUID measures resulting transverse magnetization

NMR well established technology, noise understood, similar setup to previous experiments

Example materials: LXe, ferroelectric $PbTiO_3$, many others

CASPEr-General Axions



~ year to scan one decade of frequency