COSMIC AXION SPIN PRECESSION EXPERIMENT
&
GLOBAL NETWORK OF OPTICAL MAGNETOMETERS
FOR EXOTIC PHYSICS SEARCHES

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Cosmic Axion Spin Precession Experiment (CASPEr)

with

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Surjeet Rajendran

Alex Sushkov

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PRD **88** (2013) arXiv:1306.6088,

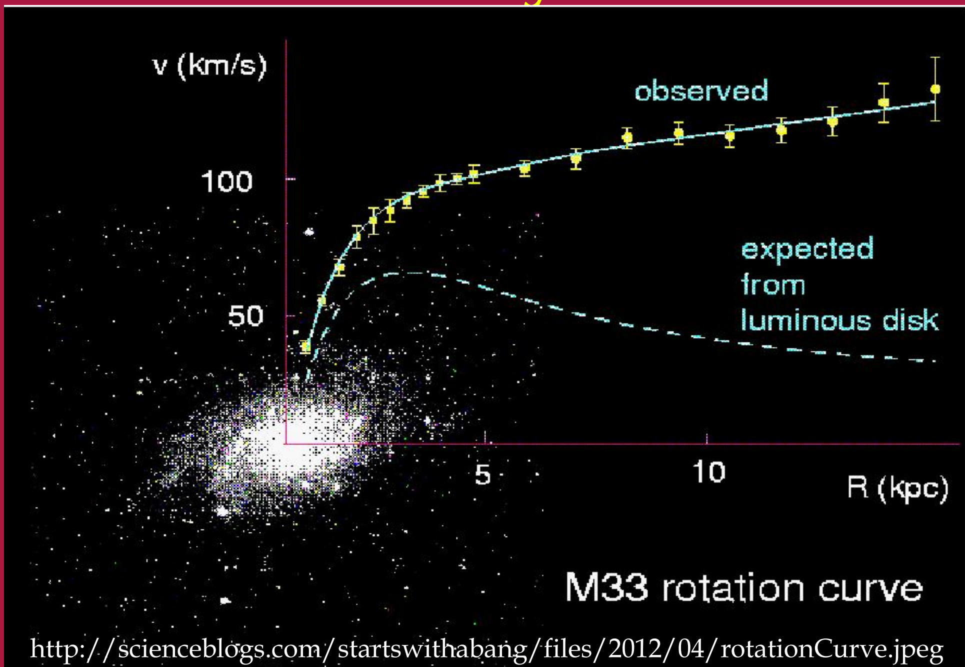
PRX (2014) arxXiv:1306.6089,

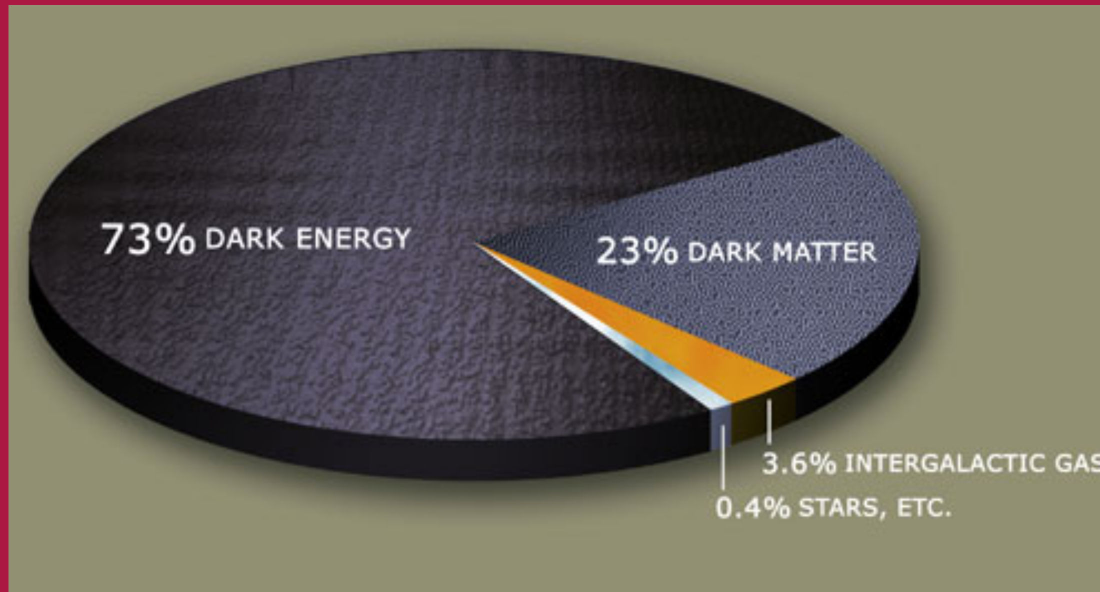
PRD **84** (2011) arXiv:1101.2691

AXIONS

Interactions	Gravity, Electromagnetic
Status	Hypothetical
Theorized	1977, Peccei and Quinn
Mass	10^{-12} to 1 eV/c^2
Electric charge	0
Spin	0

- Introduced to solve strong CP problem in QCD:
- why is n-EDM so small?
- Axions may also solve the **Dark Matter**





http://earthsky.org/space/

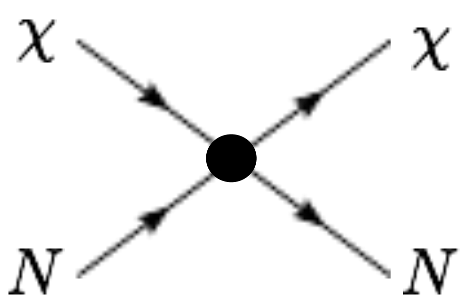
Dark Matter

Dark matter is proof of physics beyond standard model

heavy particle vs. light scalar field

(WIMPs) (axions)

Search for single particle scattering



Large phase-space density

Described as classical field *a(t,x)*

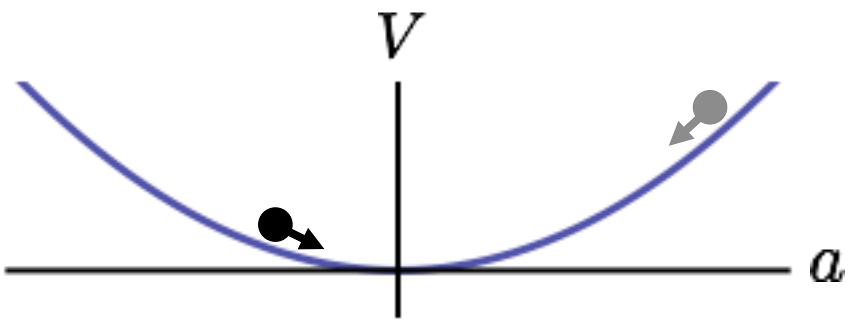
Search for coherent effects of the entire field, not single hard-particle scatterings

Axion Dark Matter

Misalignment production:

Early Universe: Field has some initial value ➔ oscillations carry energy density ➔ natural dark matter

For QCD axion mass turns on at $T \sim \Lambda_{\mathrm{QCD}}$



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

Preskill, Wise & Wilczek, Abott & Sikivie, Dine & Fischler (1983)

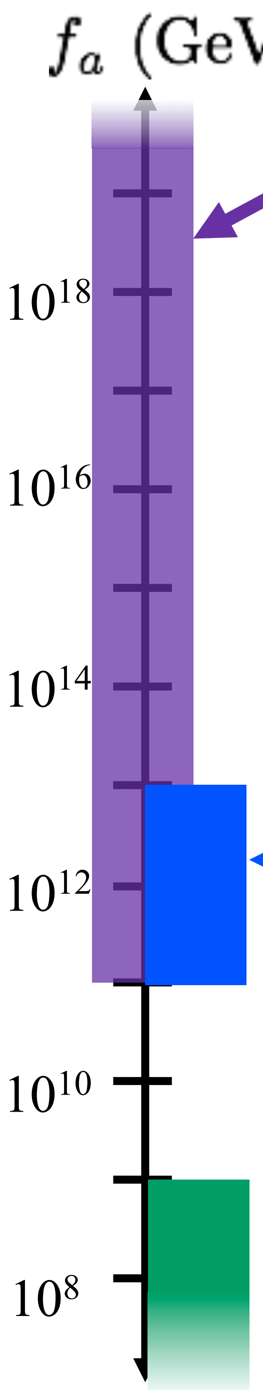
Axion easily produces correct abundance $\rho = \rho_{\mathrm{DM}}$

Many experiments search for WIMPs, only one (ADMX) can search for axion DM

Currently challenging to discover axions in much of parameter space

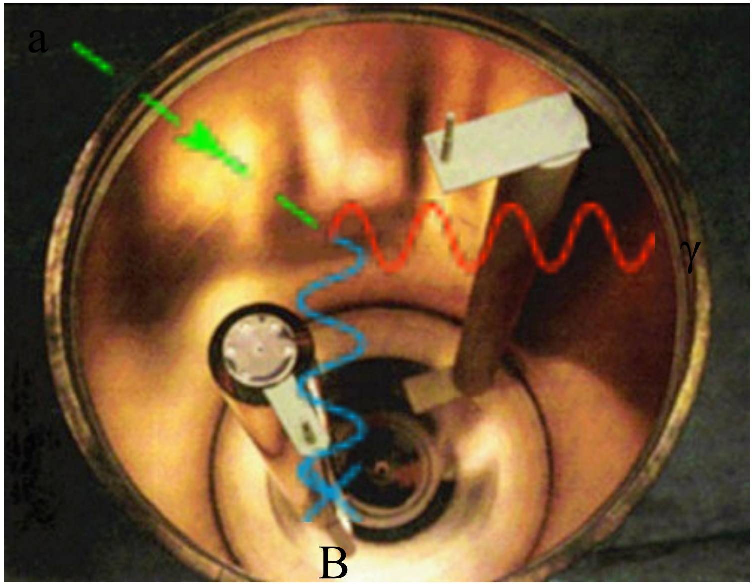
Important to find new ways to detect axions

Constraints and Searches



Axion dark matter

in most models: $\mathcal{L} \supset \frac{a}{f_a} F\widetilde{F} = \frac{a}{f_a} \vec{E} \cdot \vec{B}$



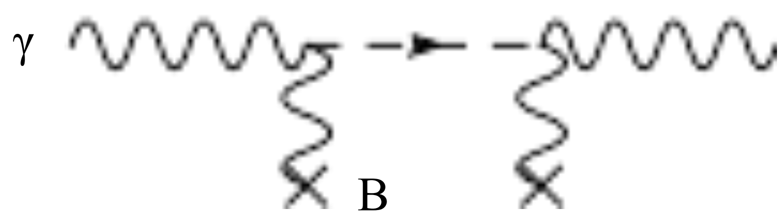
axion-photon conversion suppressed $\propto \frac{1}{f_a^2}$

size of cavity increases with f_a

signal $\propto \frac{1}{f_a^3}$

microwave cavity (ADMX)

laser experiments:



$\propto \frac{1}{f_a^4}$

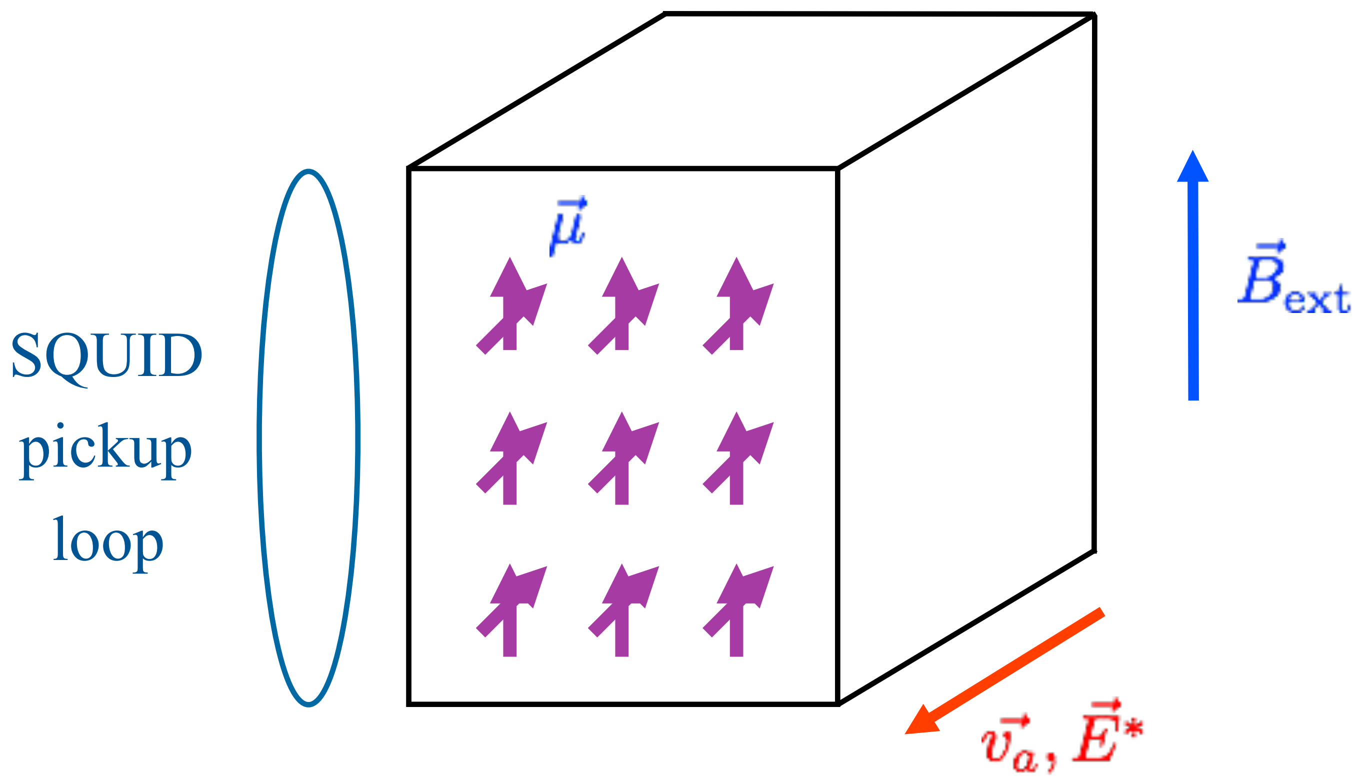
axion emission affects SN1987A, White Dwarfs, other astrophysical objects
collider & laser experiments, ALPS, CAST


ADMX
April 28, 2014
NOTICE
WEAR PROPER CLEANROOM CLOTHING BEFORE ENTERING THIS ROOM
THIS ROOM IS FOR YOUR CONVENIENCE
Please Keep it Clean
Prof. Leslie Rosenberg

CASPEr Overview

Axion dark matter causes precession of nucleon spins

Axis set by local velocity of axion or applied electric fields



Significant reach with existing technology

CASPEr Overview

Key ideas:

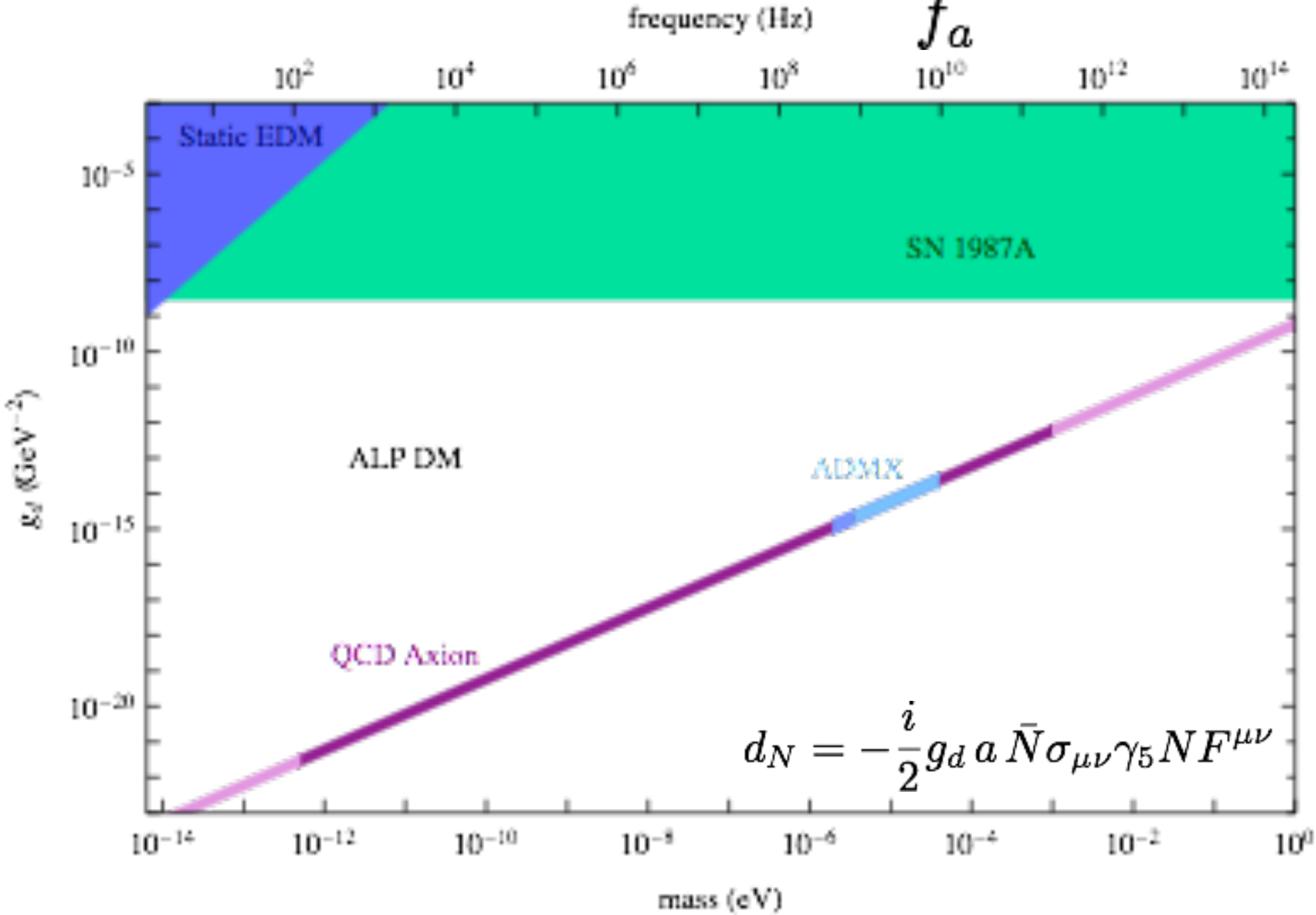
- Axion field oscillates
- at a frequency equal to its mass (kHz to GHz)
- ➔ time varying CP-odd nuclear moments:
- nEDM, Schiff, …
- Also: axion wind (like a magnetic field)

New Operators for Axion Detection with NMR

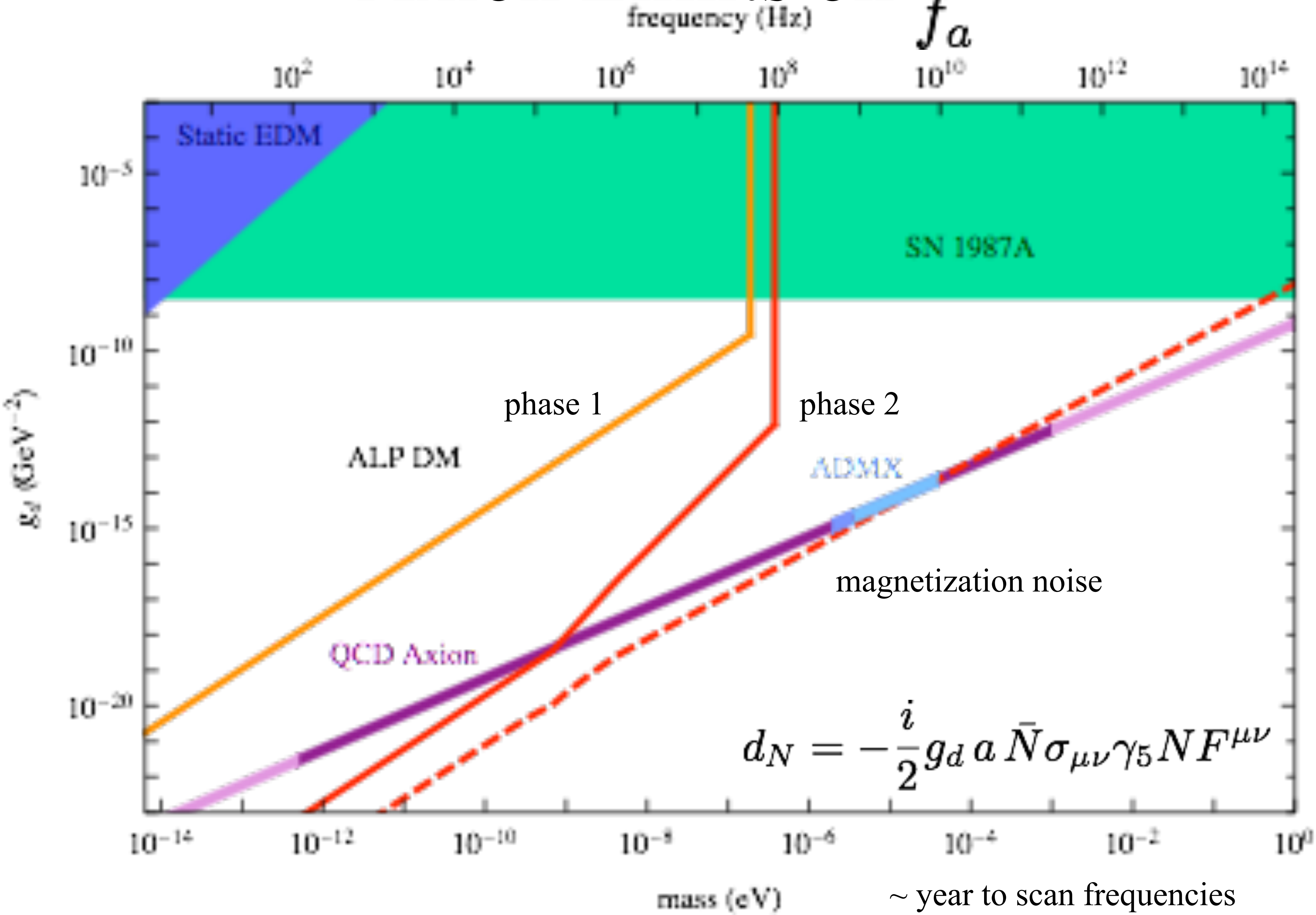
1. The QCD Axion $\left(\text{using } \frac{a}{f_a} G \wedge G\right)$

2. Axion Like Particles (ALPs) $\left(\text{using } \frac{\partial_\mu a}{f_a} \bar{N} \gamma_\mu \gamma_5 N\right)$

Axion Limits on $\frac{a}{f_a} G\widetilde{G}$



Axion Limits on $\frac{a}{f_a}G\widetilde{G}$



$$d_N = -\frac{i}{2} g_d \, a \, \bar{N} \sigma_{\mu\nu} \gamma_5 N F^{\mu\nu}$$

~ year to scan frequencies

Verify signal with spatial coherence of axion field

Oscillating-edm NMR

$$d_n \approx 10^{-34} \cos(m_a t)\, e \cdot \mathrm{cm}$$

Small, but with potential advantages over static EDM searches

Easier to fight technical noise at high frequency

Solid State NMR seems promising

Large spin density

Large intrinsic fields in polar crystals

Long T_2 with dynamic decoupling

Relates to work on solid state static EDM searches

nature COMMUNICATIONS

ARTICLE

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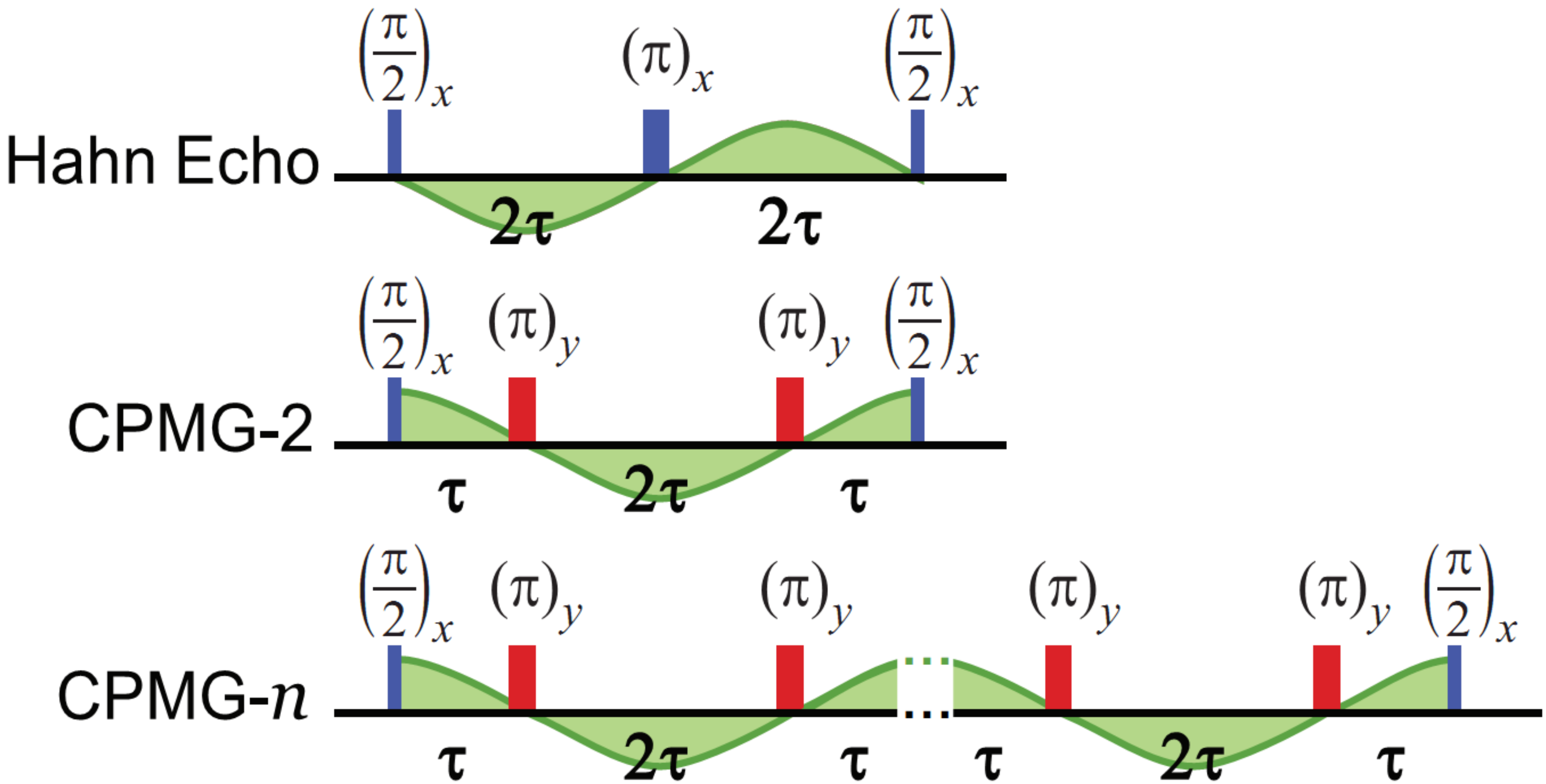
Solid-state electronic spin coherence time approaching one second

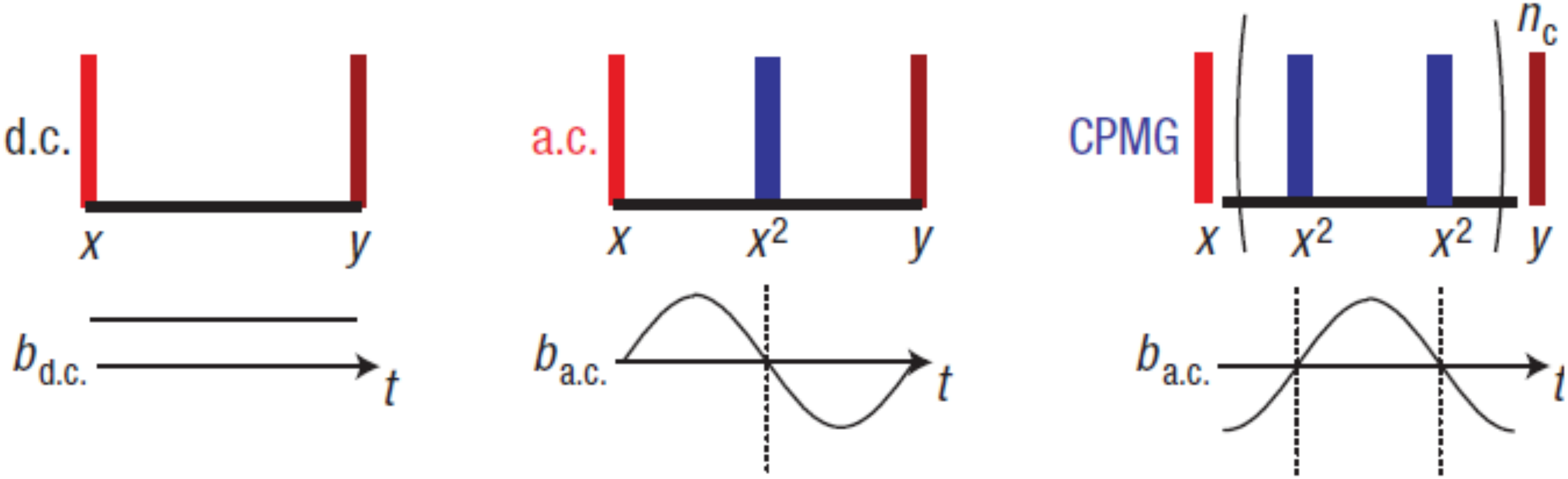
N. Bar-Gill[1,2], L.M. Pham[3], A. Jarmola[4], D. Budker[4,5] & R.L. Walsworth[1,2]

Pulse sequence



L. M. Pham, N. Bar-Gill, C. Belthangady, D. Le Sage, P. Cappellaro, M. D. Lukin, A. Yacoby, and R. L. Walsworth, Phys. Rev. B **86** 045214 (2012)

AC Magnetometry



High-sensitivity diamond magnetometer with nanoscale resolution

J. M. TAYLOR[1*], P. CAPPELLARO[2,3*], L. CHILDRESS[2,4], L. JIANG[2], D. BUDKER[5], P. R. HEMMER[6], A. YACOBY[2], R. WALSWORTH[2,3] AND M. D. LUKIN[2,3†]

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Structure, Symmetry and Stability of Matter and Antimatter

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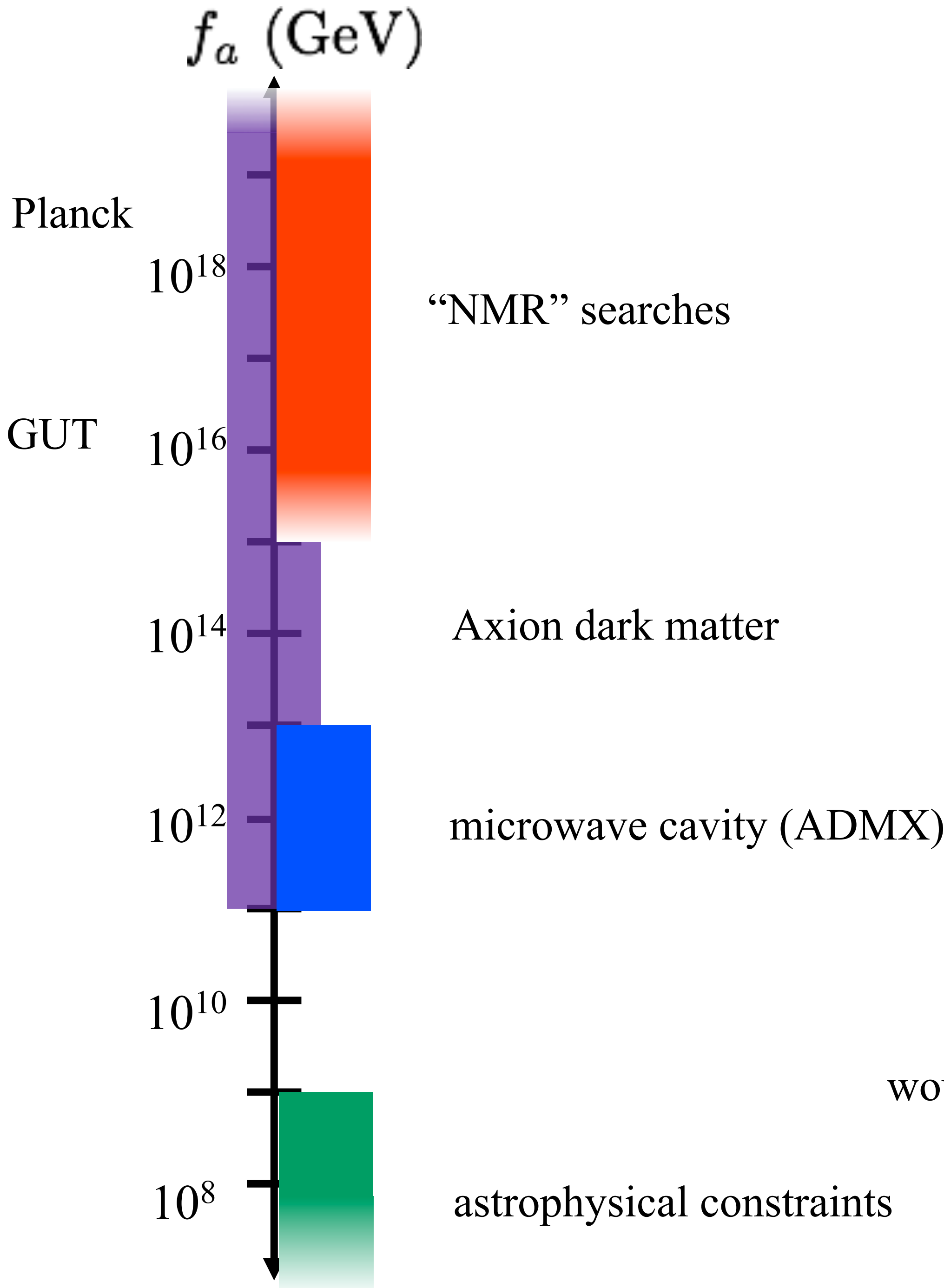
Summary

CASPEr Discovery Potential



laboratory experiment

significant reach in kHz - 10 MHz frequencies ➙ high f_a

technological challenges, similar to early stages of WIMP detection, axions deserve similar effort

technology broadly useful for community.

axion dark matter is very well-motivated, no other way to search for light axions (high f_a)

would be both the discovery of dark matter and a glimpse into physics at very high energies

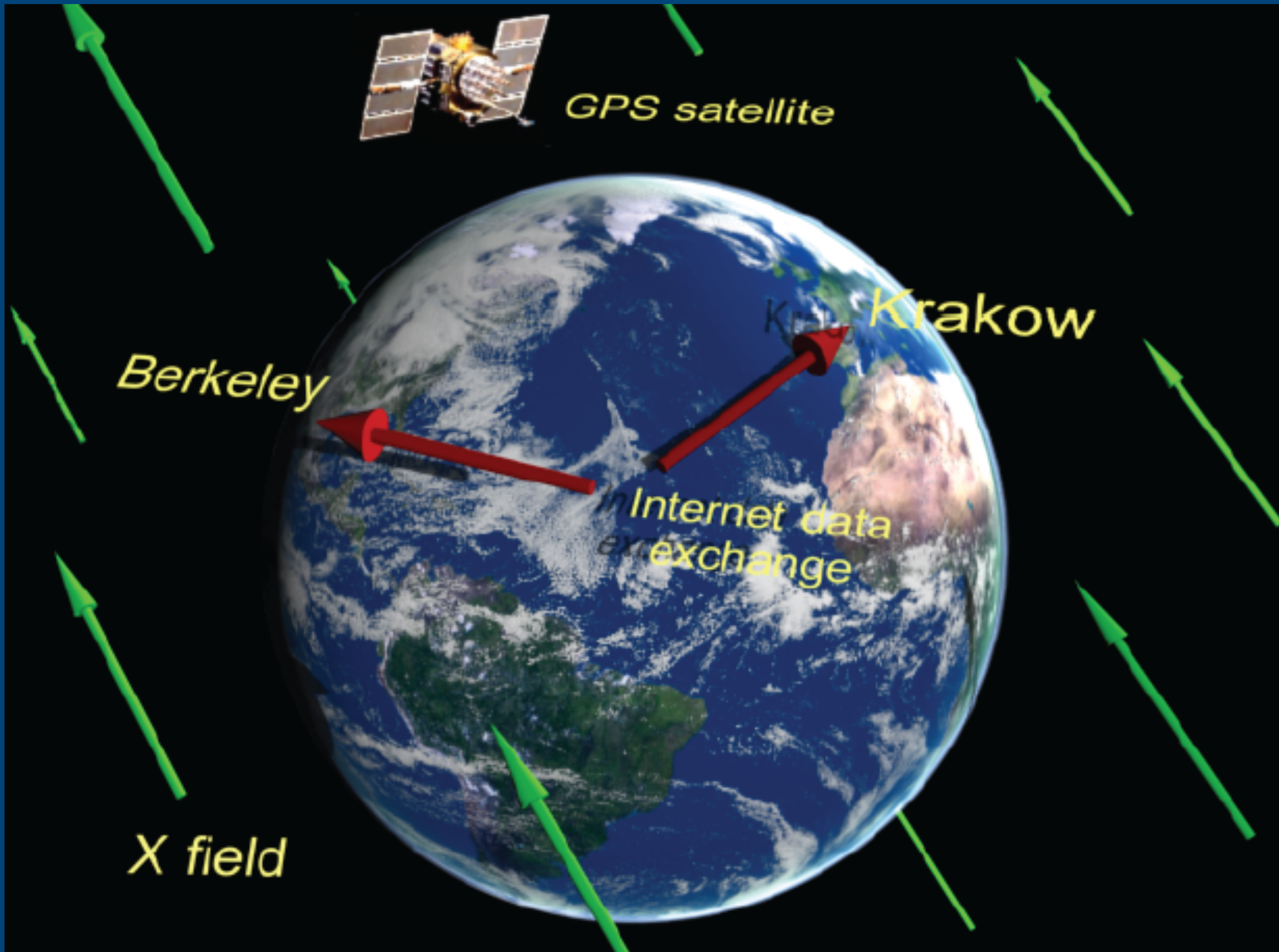
Another story:
How would you know you went through a wall?

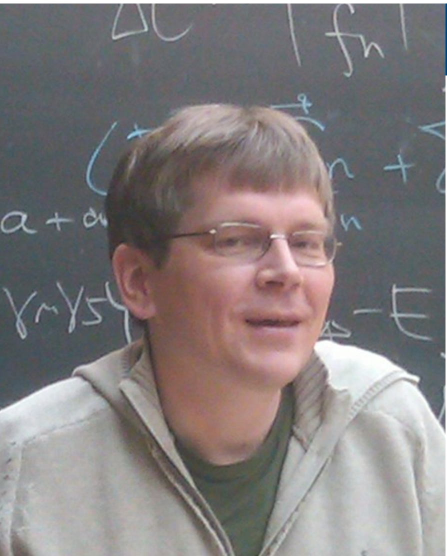
Correlated magnetometers…

- Modern atomic magnetometers are sensitive at the level of <1 fT/Hz$^{1/2}$
- Electron and nuclear spin based mags
- What can we learn comparing synchronized separated shielded mags?

Search for exotic fields: GNOME

Globabal **N**etwork **O**f **M**agnetometers for **E**xotic physics





PRL 110, 021803 (2013) PHYSICAL REVIEW LETTERS week ending 11 JANUARY 2013

Detecting Domain Walls of Axionlike Models Using Terrestrial Experiments

M. Pospelov,[1,2] S. Pustelny,[3,4,*] M. P. Ledbetter,[4] D. F. Jackson Kimball,[5] W. Gawlik,[3] and D. Budker[4,6,

[1]*Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 1A1, Canada*
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[4]*Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300*
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[6]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

(Dated: April 11, 2012)

- Ultralight (m_a~neV) axion-like fields forming domain networks
- Wall thickness $d \sim 2/m_a$
- Domain size $L = 10^{-2}$ ly consistent with Dark Energy density constraints
- We may be going through a wall every 10 y or so!
- Bottom line: **GNOME** is quite sensitive to such events!

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annalen der physik

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The Global Network of Optical Magnetometers for Exotic physics (GNOME): A novel scheme to search for physics beyond the Standard Model

Szymon Pustelny[1,2,], Derek F. Jackson Kimball[3], Chris Pankow[4], Micah P. Ledbetter[2,**], Przemyslaw Wlodarczyk[5], Piotr Wcislo[1,6], Maxim Pospelov[7,8], Joshua R. Smith[9], Jocelyn Read[9], Wojciech Gawlik[1], and Dmitry Budker[2,10]*

- Current collaboration: Berkeley→Mainz, CSUEB, Krakow, members of the LIGO analysis team, M. Pospelov
- Future members: ANL, BGU, UW, Oberlin, ...
- Test runs done and analyzed
- Hoping to see **GNOME** taking data in 2014!

CONCLUSION

Light axions may solve all our problems !