Searching for Monopole-Dipole Forces with Atom Interferometers

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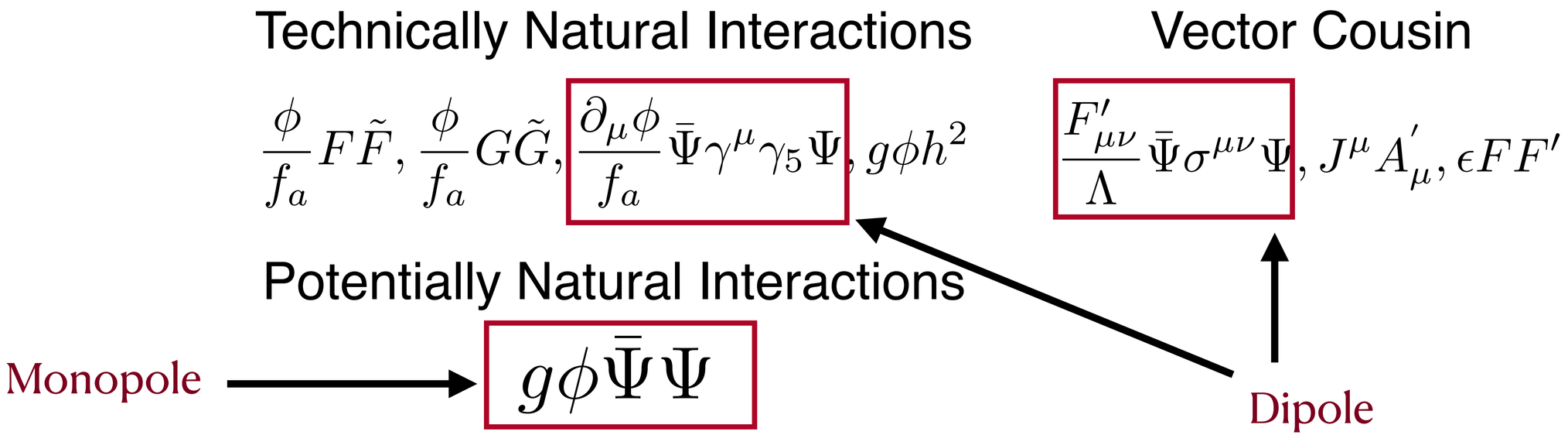
Light Weakly Coupled Bosons

Goal: Solve theoretical problems of the Standard Model
(Strong CP, flavor, hierarchy...)

Strategy: Propose global symmetry at some high scale, broken at low energy

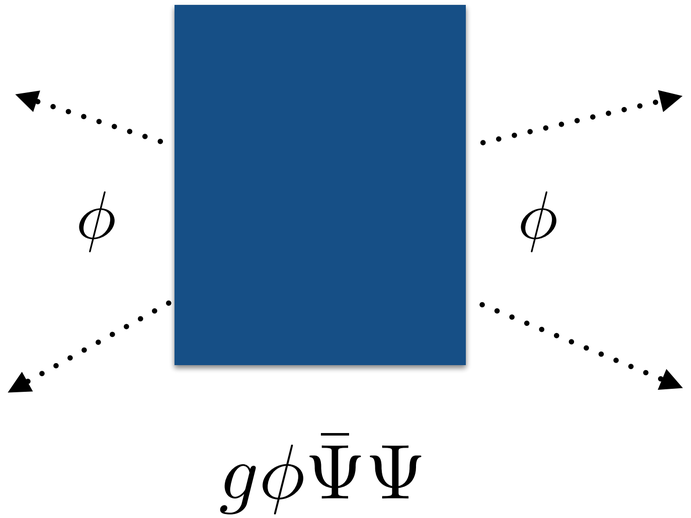
Generic Prediction: Light weakly coupled Goldstone Boson
(Axion, axion-like-particle, familon, relaxion...)



How do we find them?

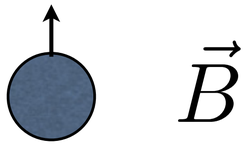
The Axion Landscape

Local Source



$g\phi\bar{\Psi}\Psi$

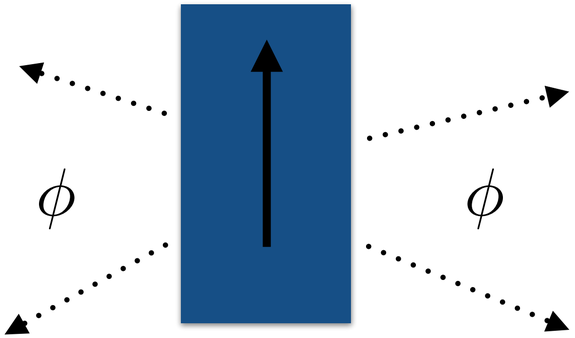
Monopole Source



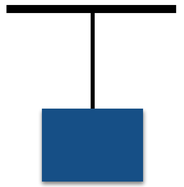
$$\frac{\partial_\mu \phi}{f_a}\bar{\Psi}\gamma^\mu\gamma_5\Psi$$

Spin Sensor

How about?



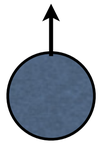
Dipole Source



Monopole Sensor

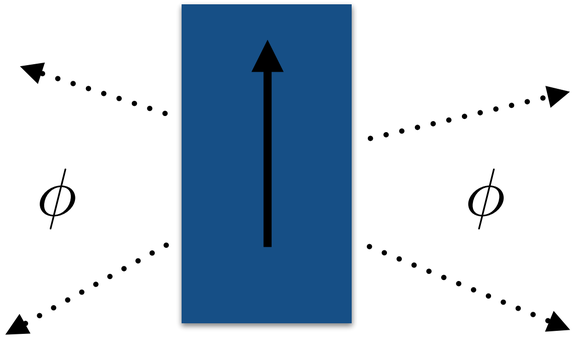
Monopole Dipole Forces

Monopole Source

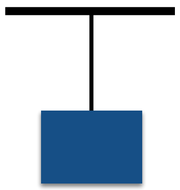


Spin Sensor

$$\delta\phi = \Delta E T$$



Dipole Source



Monopole Sensor

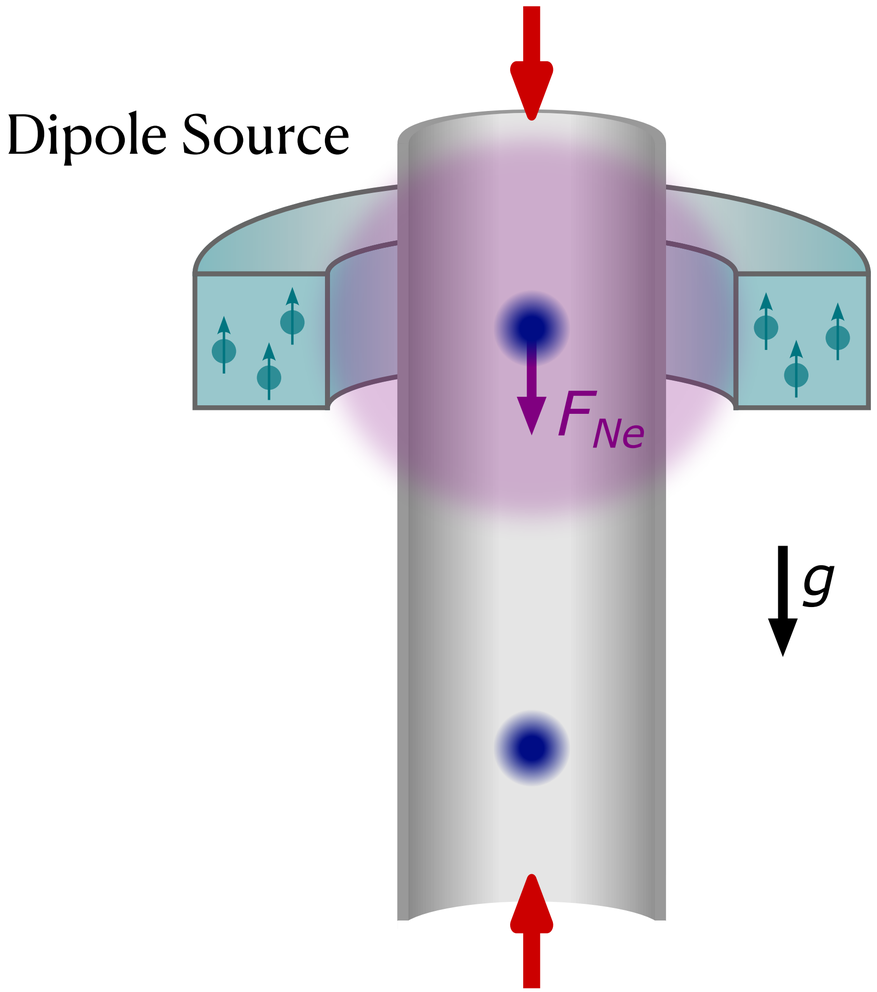
$$\delta\phi = kaT^2$$

Accelerometers gain with T

For macroscopic masses, limited by vibration and thermal noise

Use free falling atoms!

Theory Cartoon



Freely Falling Atom Gradiometer

Atoms are vibrationally decoupled

Can obtain T ~ 1 s

Axion range ~ 10 cm - set by size of atom cloud

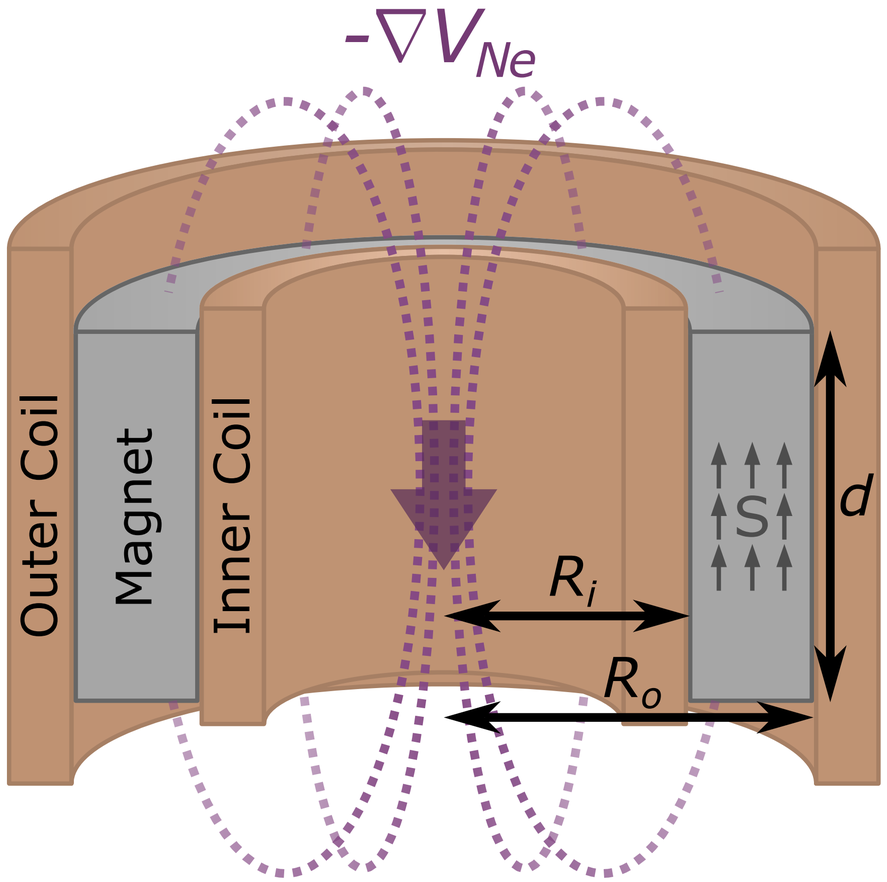
$$g_e g_N \sim 10^{-28} - 10^{-32}$$

Systematics

Source produces magnetic field - stability?

Gravity of Dipole Source

Magnetic Field



Magnetic field sourced by currents, orbital angular momentum and spins

Φ only sourced by spins

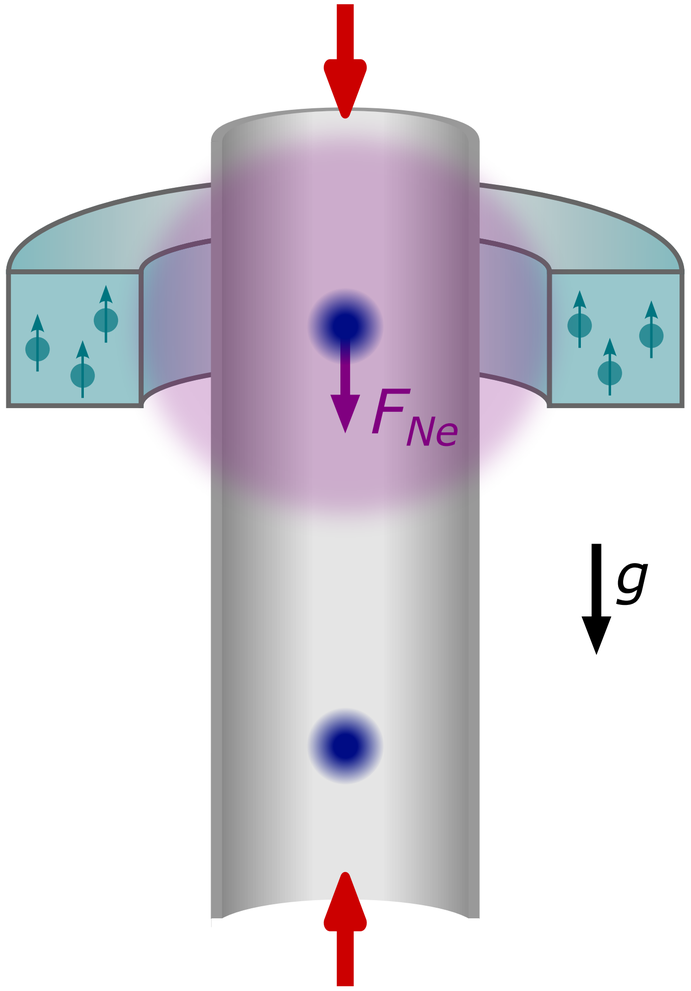
Cancel magnetic field from source by applying compensating current

Use electromagnet or superconducting shields. Could also use material shields where magnetic field is source by both spin and angular momentum

Could also operate magnetic gradiometer - one atom in magnetically insensitive state and another in magnetically sensitive state

A number of handles

Gravitational Backgrounds



General gravitational background (e.g. from earth) - toggle direction of spin in dipole

~160 kg source mass produces gravity
Gravity gradient from mass coupled to shot to shot fluctuation of atom position

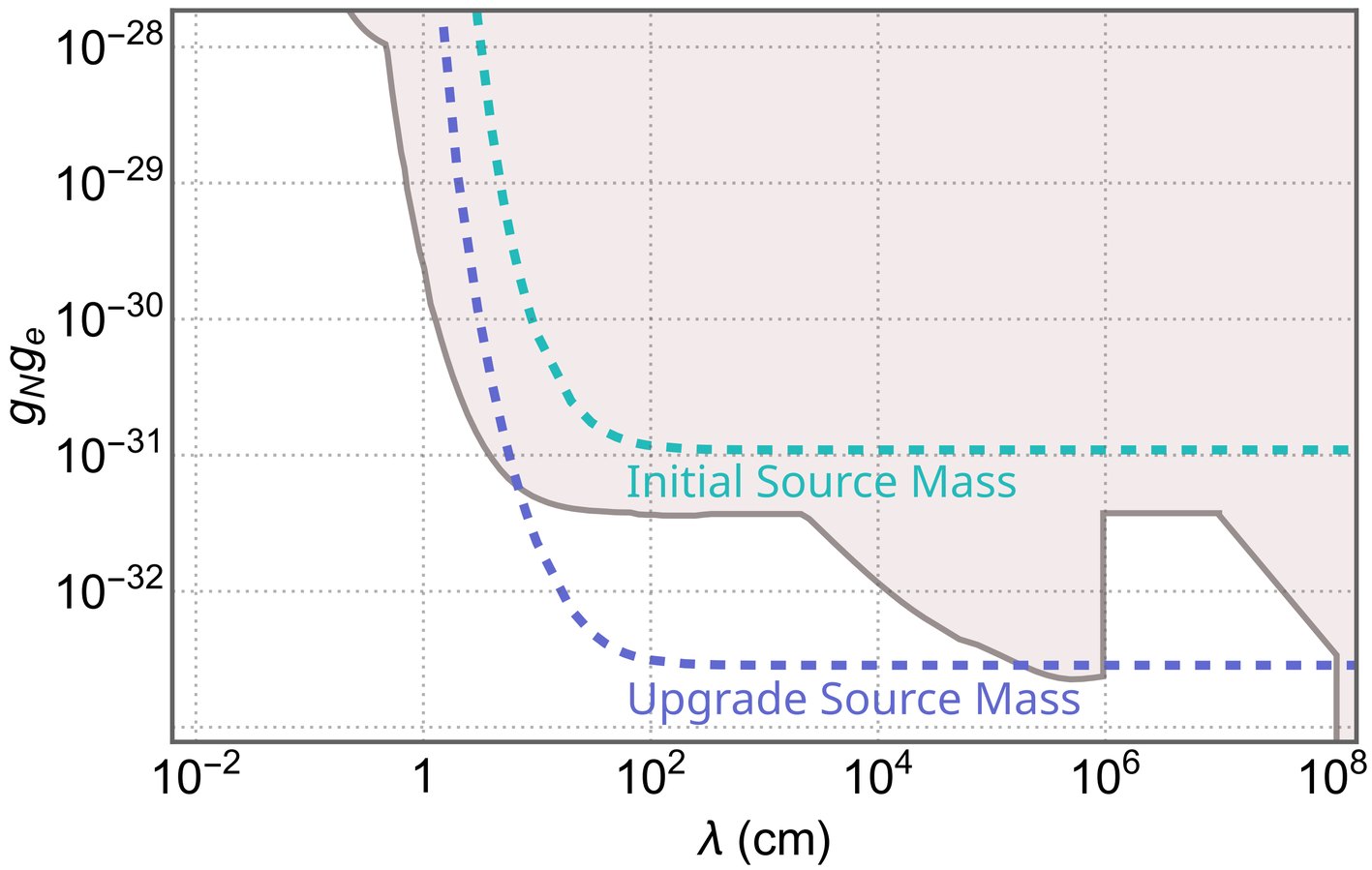
Can distinguish from signal by first unpolarizing source and characterizing the mass distribution

Use unpolarized masses to trim gravity gradient

Cancel linear gradient by suitable choice of laser phase - first characterize with unpolarized source

Use multi-pulse sequence to cancel position dependence + spin reversal during interferometer operation

Projected Sensitivity



N ~ 200 LMT, t ~ 0.5 s, h ~ 4 m, δ ~ 10^{-3}/rt(Hz)

Main difference: Heavier source mass, bigger ϕ

Conclusions

1. Great Case to search for new monopole-dipole forces

2. Science case for ~ 10 m class interferometers, while building up to ~km scale

3. Worth thinking about possibilities in space - science case for stand-alone interferometers