Opportunities for Mass-Spin Coupling searches using Atom Interferometers in Space

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- **Motivation**
- **Current Status**
- **GAUGE proposal**
- **Sensitivity**
- **Systematic Effects**
- **Summary**

Why look for Scalar-Pseudoscalar Couplings?

- **Predicted by several extensions to Standard Model:**
  - **Axion (Strong CP-Problem)**
  - **U(1)-Boson (Supersymmetry)**
  - **Schizon (Supersymmetry)**

- **Baryon Asymmetry of Universe probably requires new CP-Violating Interaction**

- **Massive mediating particles would be Dark Matter candidates**

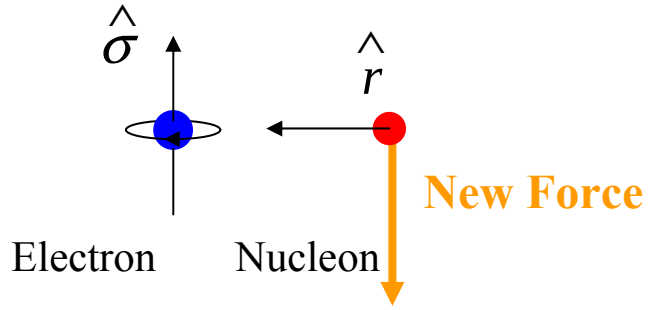
- **Spin is a fundamental particle property**

Two coupling constants to fermions, g_p and g_s, give rise to three possible interactions:

- **Mass-mass coupling (just like gravity except Yukawa)**
- **Mass-spin coupling (monopole-dipole)**
- **Spin-spin coupling (dipole-dipole)**

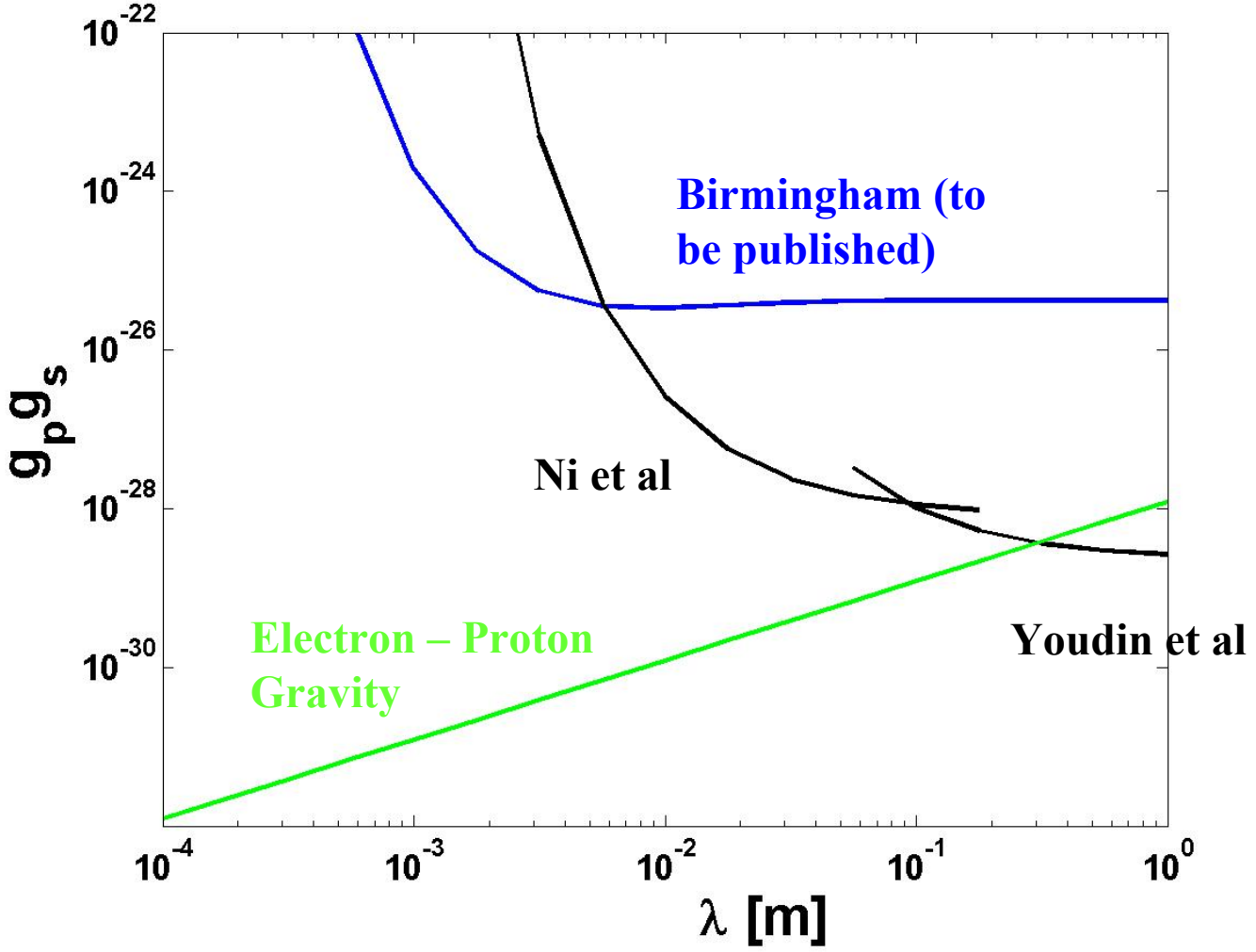
$$V(r) = g_p g_s \frac{\hbar^2}{8\pi m_e} \hat{\sigma}\cdot\hat{r}\left(\frac{1}{\lambda r} + \frac{1}{r^2}\right) e^{-r/\lambda}$$

violates *P,T*



→ In principle background-free (more on this later) …

Current Limits on Scalar - Pseudoscalar Couplings (Electron Spin – Nucleon)



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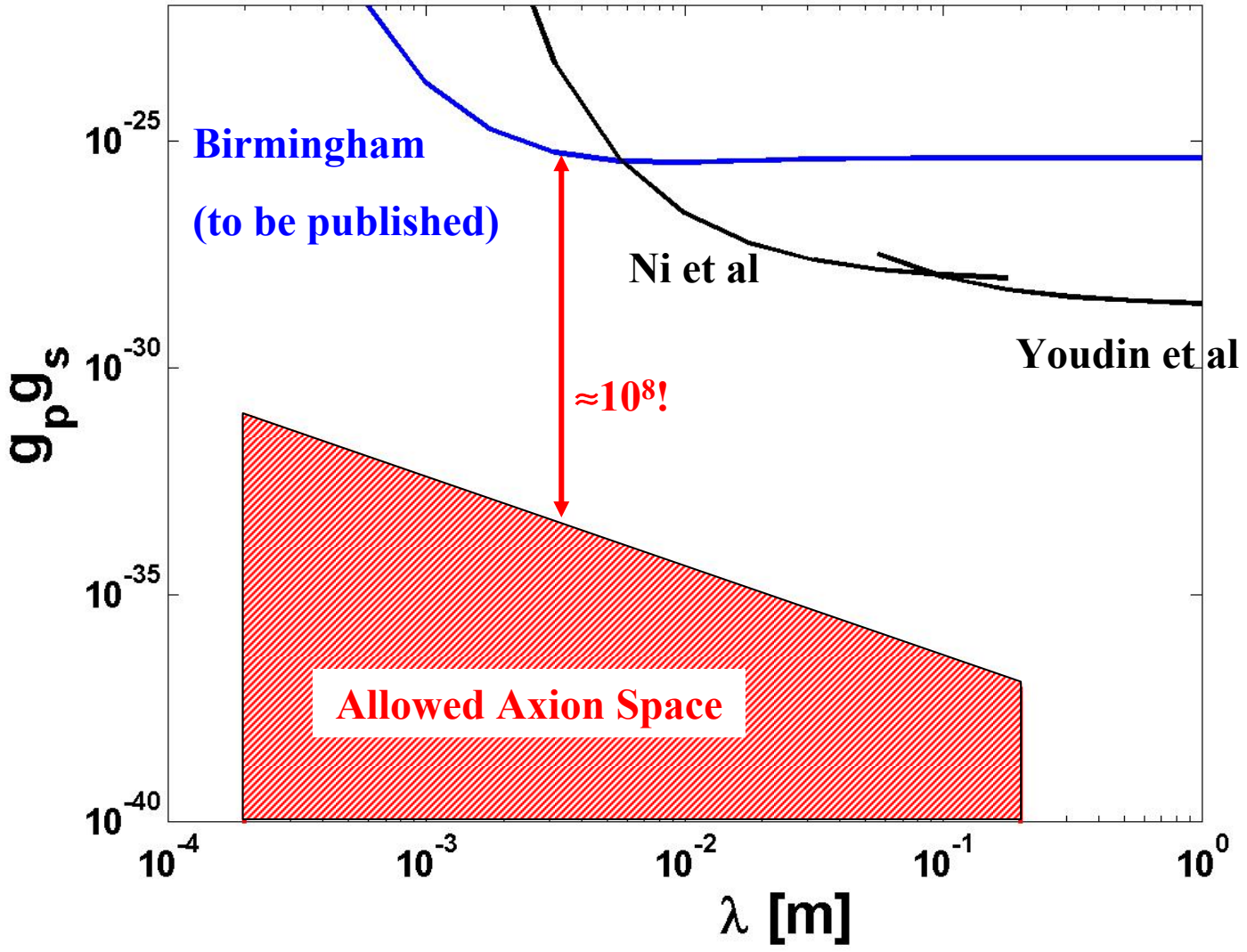


GAUGE proposal

In order to search for the axion we need to design experiments about 8 orders of magnitude more sensitive !

Need to worry about:

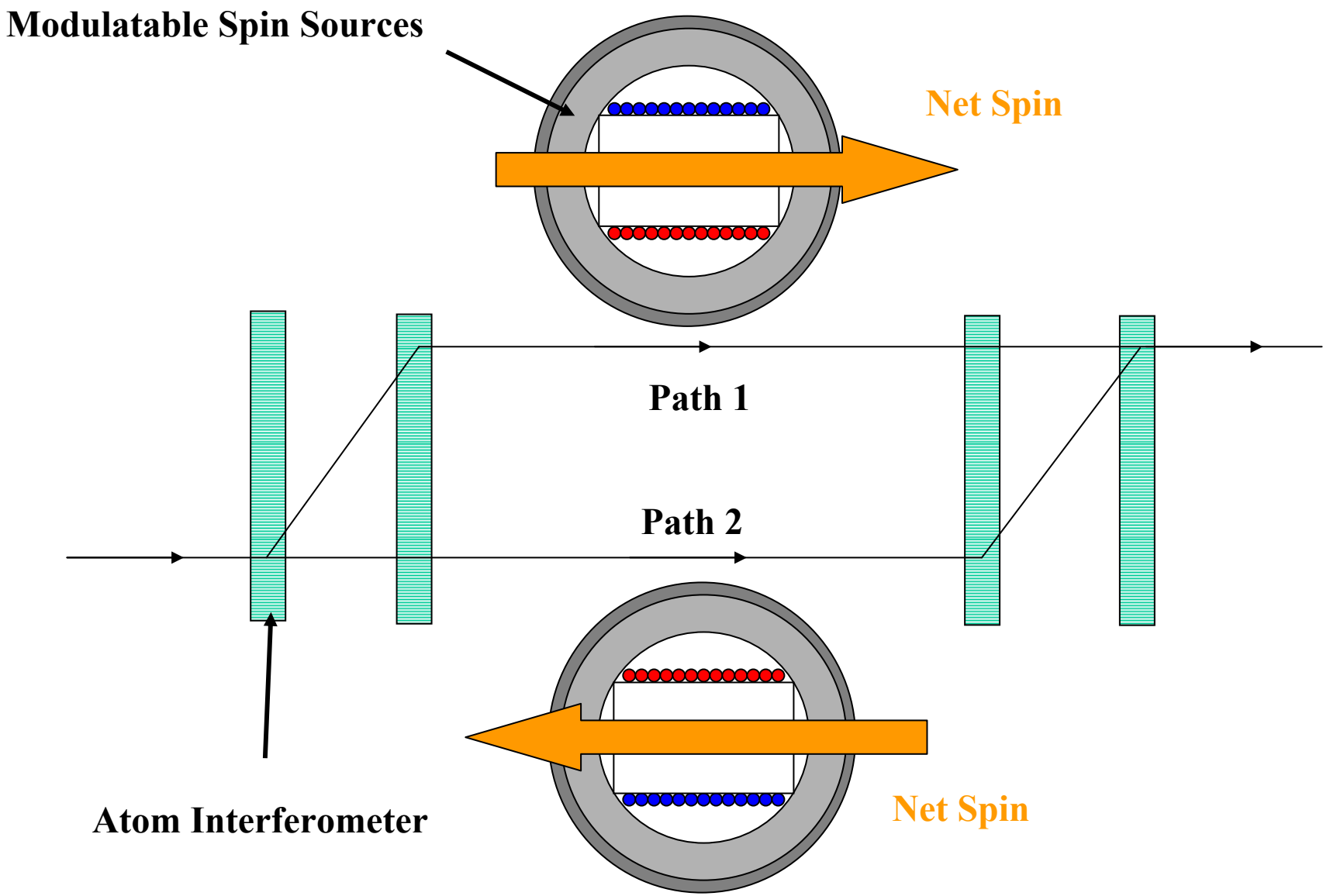
- Sensitivity

- **Spin Sources: strong signal**
- **Detector: high acceleration sensitivity**

- Systematic Effects

- **Magnetic properties of Spin Sources**
- **Magnetic properties of Test Masses**

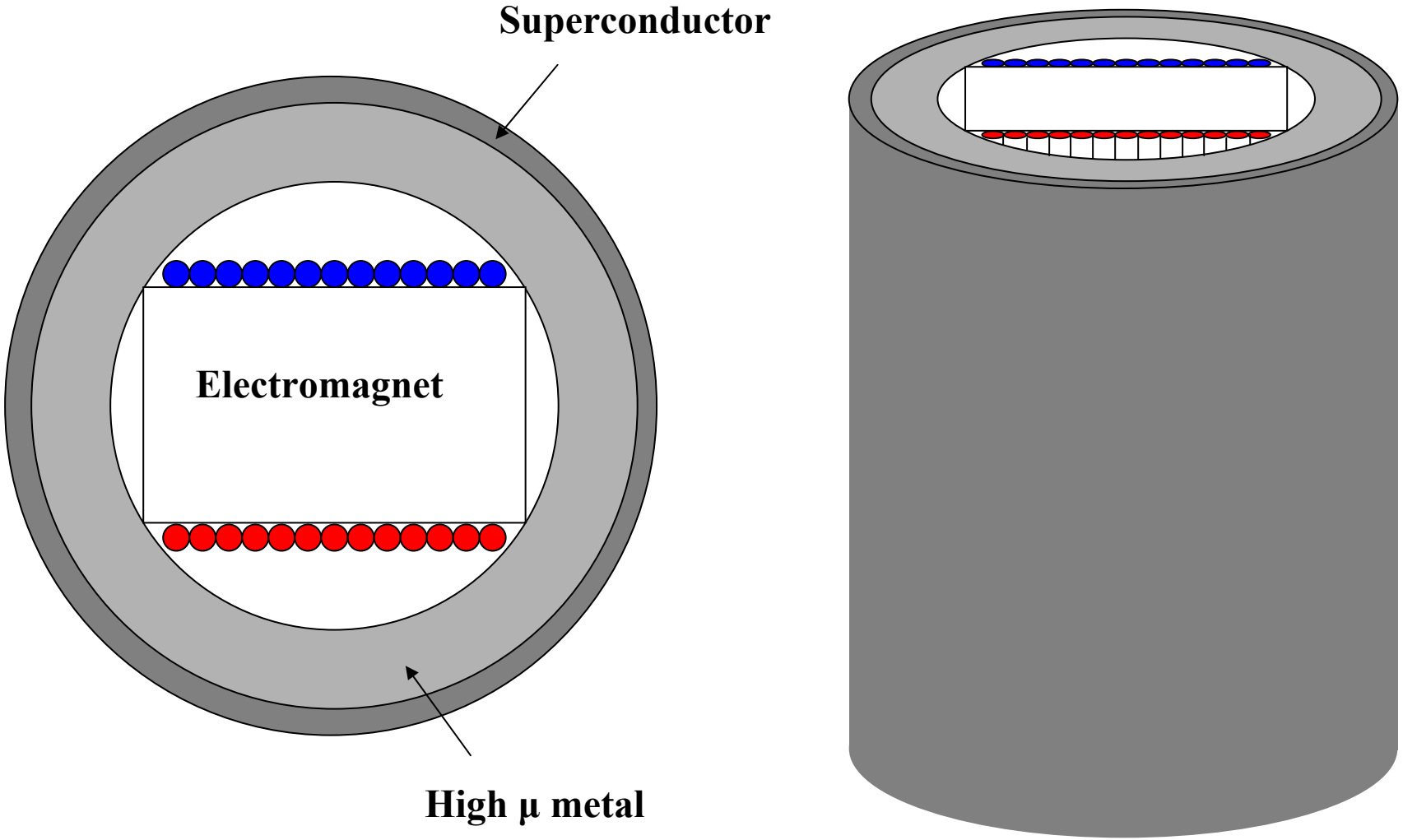
Proposal: combine Atom Interferometer with New Type of Spin Source



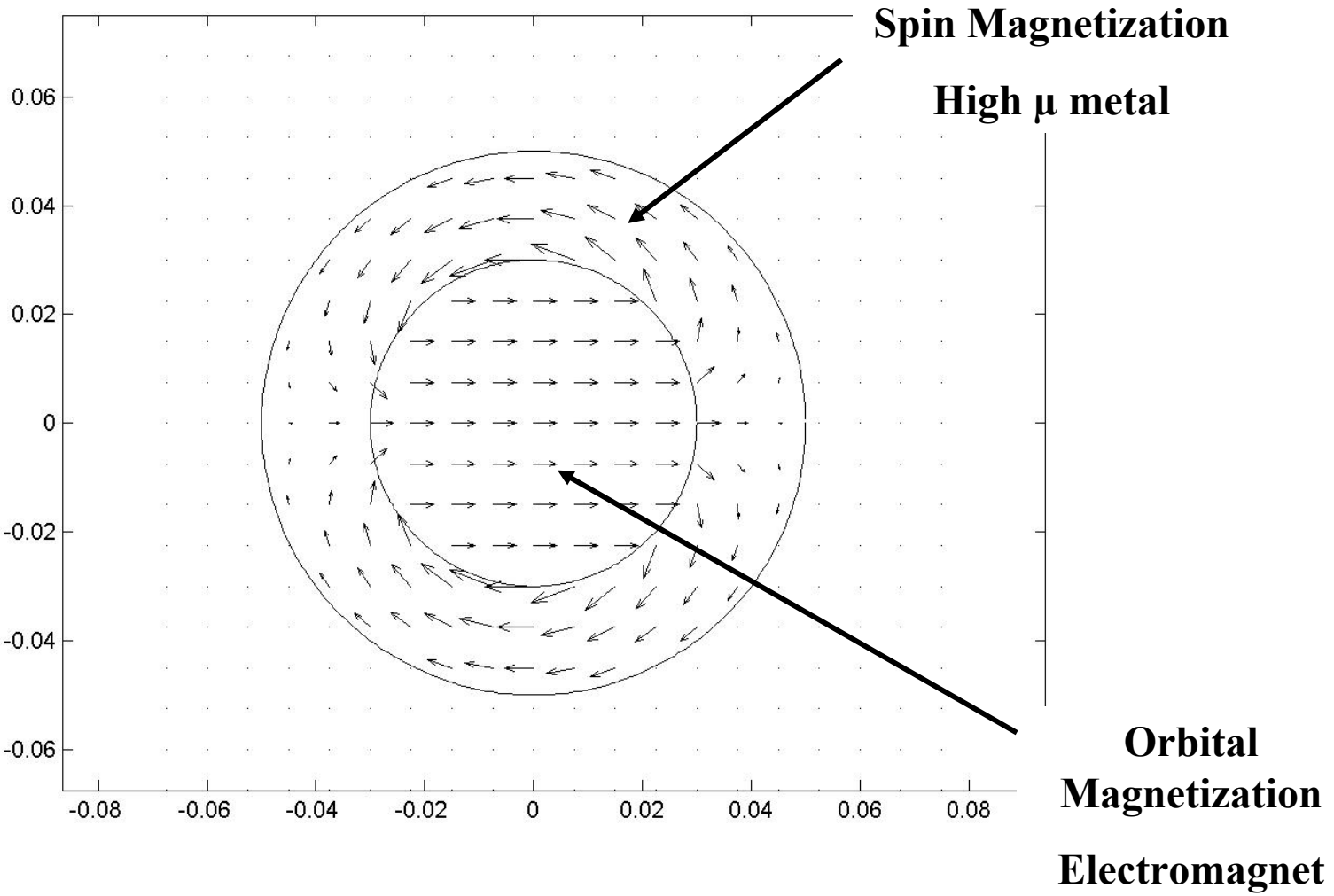
Axion signal can be nulled / combined / modulated as required

Macroscopic Spin Source

• **Key Idea: Magnetic field associated with polarised Spins *cancels* the field that is used to polarise them!**



Spin Source Modelling



Outside spin source, magnetic field due to electromagnet is cancelled by spins

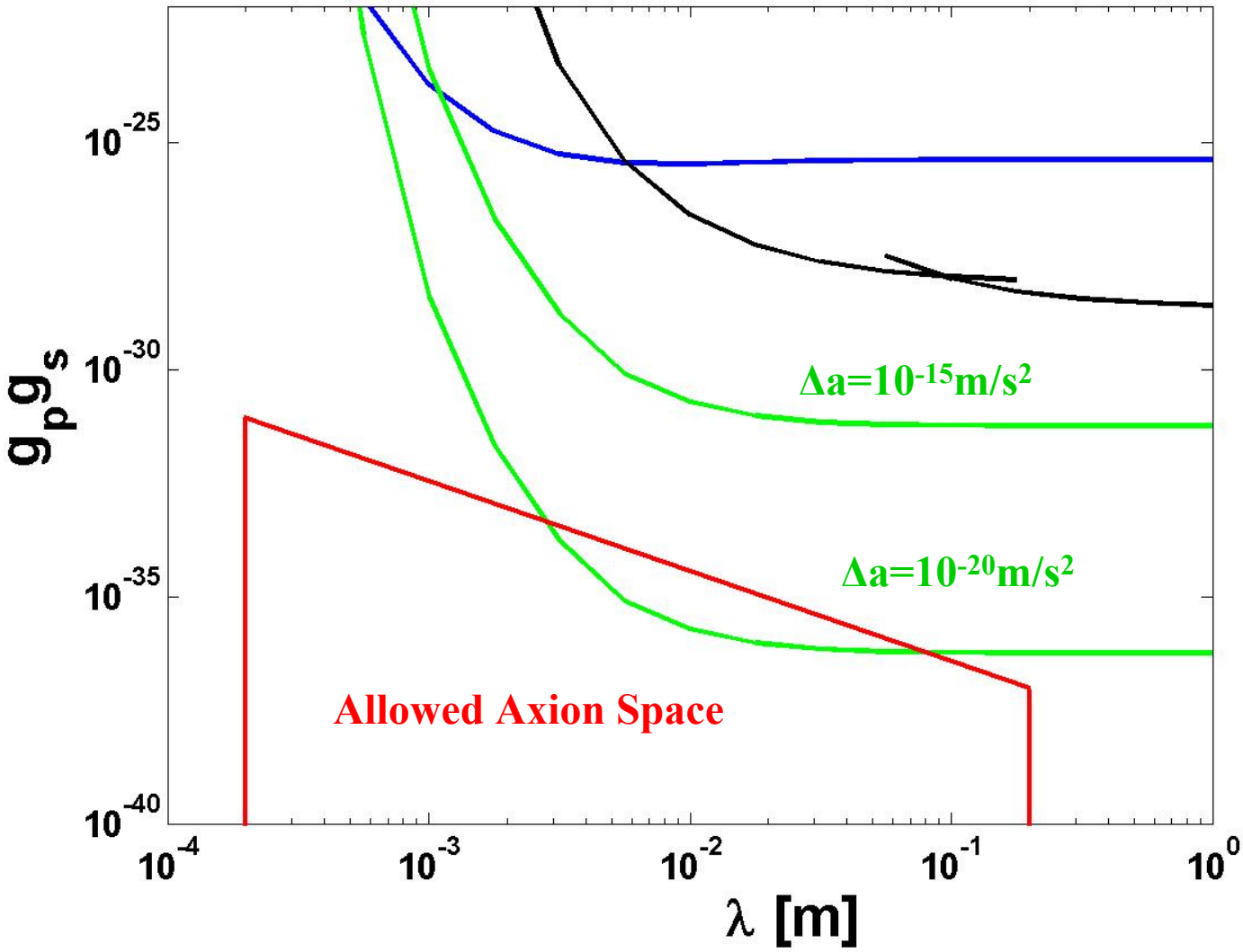
Sensitivity

- **Compute *differential* acceleration due to Spin Sources on nucleons on paths 1 and 2, as a function of axion potential parameters ($g_p g_s$ and λ)**
- **Assume equivalent acceleration sensitivity of Atom Interferometer (Input required!!)**
- **Example parameters:**

Parameter	Value [cm]
Spin Source OD	4.0
Spin Source ID	2.2
Min. Distance to path 1	1.0
Min. Distance to path 2	2.0

A VERY SIMPLE calculation has been carried out…

Potential Limits on Scalar - Pseudoscalar Couplings



*Note: differential acceleration to be measured over a few λ's

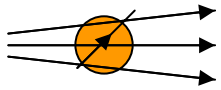
Systematic Background Effects

Axion signature: differential acceleration signal at spin source modulation frequency.

Most serious background: Residual magnetic interaction between "source mass" and "test mass"

- **Imperfect source mass shielding results in residual magnetic fields and field gradients at the test mass…**

- **… these will combine with any background field and couple to test mass dipole moments (permanent and induced).**



General interaction of test mass dipoles exposed to modulated source field B_{mod} and background field B_0:

$$U_{mag} = -(\vec{m} - \frac{\chi}{\mu_0} V(\vec{B}_0 + \vec{B}_{\mathrm{mod}})) \cdot (\vec{B}_0 + \vec{B}_{\mathrm{mod}})$$

$$= -(\vec{m} \cdot \vec{B}_0 + \vec{m} \cdot \vec{B}_{\mathrm{mod}} - \frac{\chi}{\mu_0} V\vec{B}_0 \cdot \vec{B}_0 - \frac{2\chi}{\mu_0} V\vec{B}_0 \cdot \vec{B}_{\mathrm{mod}} - \frac{\chi}{\mu_0} V\vec{B}_{\mathrm{mod}} \cdot \vec{B}_{\mathrm{mod}})$$

Modulate axion signal and eliminate terms symmetric in T → only two terms are a problem:

$$U_{mag} = -(\vec{m} \cdot \vec{B}_{\mathrm{mod}} - \frac{2\chi}{\mu_0} V\vec{B}_0 \cdot \vec{B}_{\mathrm{mod}})$$

Permanent Dipole

Induced Dipole

Potentially *VERY ATTRACTIVE* feature of Atom Interferometers:

Permanent / Induced moments are now atomic properties and very well known!

$$\vec{m} \qquad \frac{2\chi}{\mu_0} V$$

If dipole moments can be *controlled* as well…

… could lead to in situ measurement of residual background fields!

This would in principle allow unambiguous identification of magnetic background effects

Summary

- An experiment can be proposed which approaches the sensitivity required to search for the axion
- Crucial Ingredients:
  - New, “clean” Spin Source
    - Strong, modulatable signal
    - Intrinsically low background
  - Atom Interferometer
    - High sensitivity
    - Magnetic test mass properties under control
  - A lot of work / input required!