Probing fundamental physics with highly-coherent nuclear spins

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The physics / basic idea of the LOI

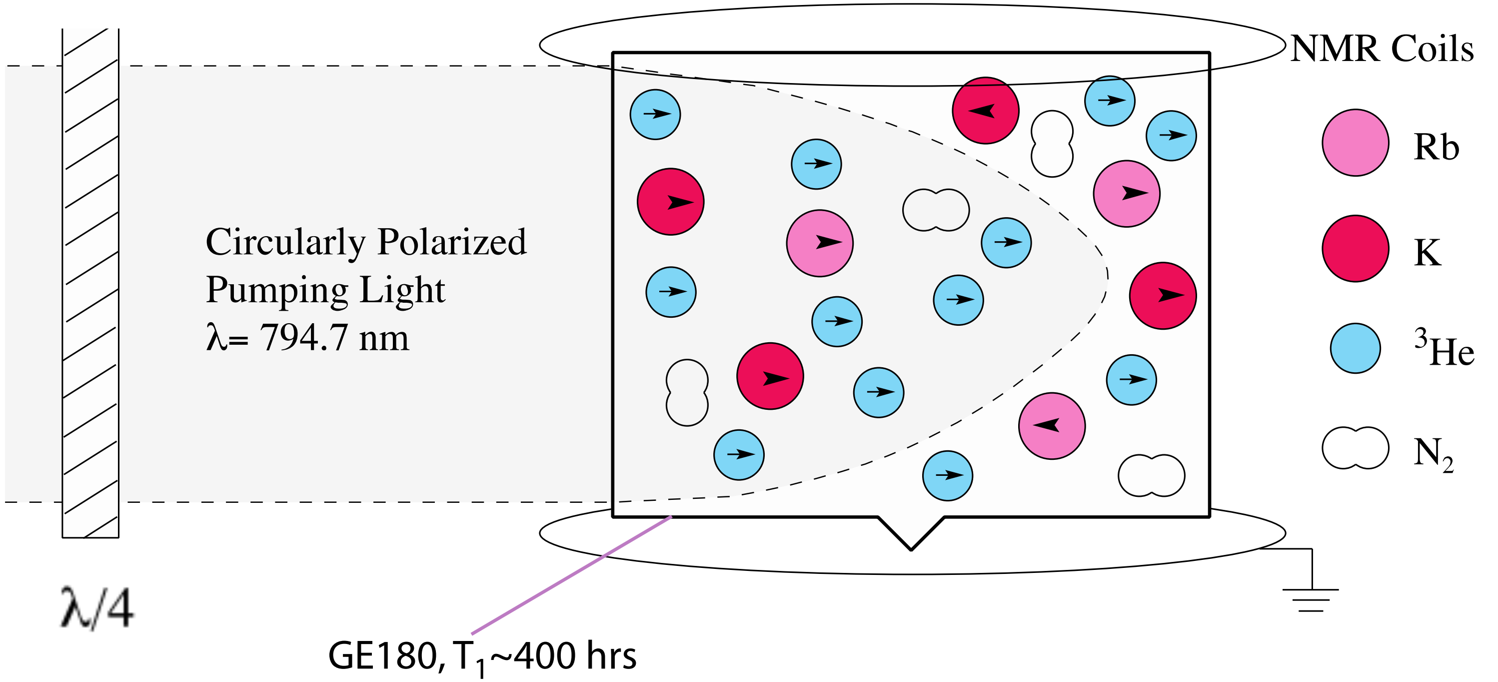
- Very large numbers of coherent nuclear spins (10^21) in an ensemble quantum state, and modern read-out systems (SQUIDs/atomic magnetometers) can greatly amplify minute contributions to the Hamiltonian.
- Sensitivity to new terms of 10^-24 eV currently possible; experiments are now grappling with very weak self-interactions, and back action of read-out on the nuclei: SNR limit > 1000x fold smaller than current limits
- New terms of particular interest: Electric Dipole Moments; Lorentz violation/preferred frames of fermions and photons; Axionic dark matter interactions; Fifth force
- Overlap with Cosmic Frontier (wavelike Dark Matter) and Instrumentation Frontier (low noise environments; quantum sensors of magnetic fields)

What does it look like?

angular momentum from photon -> electron -> nucleon

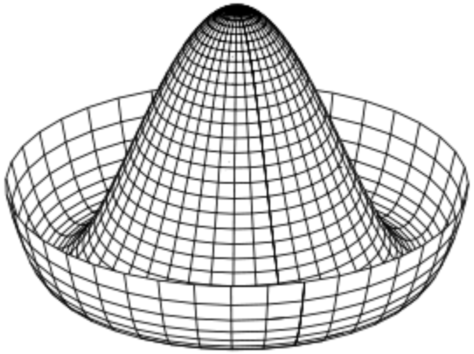
Induce Spin-Precession

Measure magnetic field of the spins (Pick-up loop + SQUID Optical rotation)



The physics / basic idea of the LOI

- Impact of sensitivity increase:
  - Nuclear EDM -> 10x improvement
  - Axionic dark matter (mass under 10^-11 eV): 1000x weaker coupling sensitivity; pushing up against GUT scale axion decay constant
  - CPT/Lorentz violation: 1000x improvement
  - Fifth-force: Could constraints on new symmetry breaking scales exceed those from stellar cooling?



$$\mathcal{L} = i\frac{1}{F}\partial_\mu \phi \bar{\psi}\gamma^\mu \gamma_5 \psi = i\frac{M_\psi}{F}\phi\bar{\psi}\gamma_5\psi$$

What is required for the LOI to succeed

- Parallel efforts on
  1) low background noise materials
  2) low noise read-out
  3) decoupling of very weak interactions
  4) fundamental physics measurements, each of which has different instrumentation and systematics requirements.

What do you plan to do during Snowmass

- A contributed paper; hopefully with more detailed simulations of potential systematics for the various experiments, and trade-offs for sensitivity. Targets of opportunity for separate work to increase sensitivity

What do you hope to get out of Snowmass

- Find overlap with other projects with similar needs re:
  - requiring low noise facilities and readout
  - quantum decoupling procedures

Experimental tests of gravity

- Test gravity <50 microns; equivalence principle
- Need lower noise facilities; lower noise materials
- Plan to participate in SnowMass
- Measurements are slow, collaborations on R&D needed.
- Low noise facilities and materials could be a community level investment.