Search for composite dark matter with optically levitated sensors

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OPTO-DM 2 Workshop, April 2021
TOWARDS MODEL-INDEPENDENT SEARCHES?

- What would a model-independent search look like?
- Search for gravitationally induced kicks from a passing dark matter particle in an array of test masses
- For DM masses > $m_{Pl}$ might be possible but very ambitious (30dB beyond SQL...)
- We use ~10 ng microspheres with ~100 ng/Hz$^{1/2}$ acceleration sensitivity

THE SYSTEM

- Variety of materials and sizes, isolated electrically and thermally
- Low NA gravito-optical configuration → $\sim \mu m$ probing distances
- Large spheres → better acceleration sensitivity $\sim 95 \text{ ng/Hz}^{1/2} \sim 1 \text{ aN/Hz}^{1/2}$
- DM searches couple to # constituents in sensor
- Trap > 1 month → LONG integration times

Below ~1 mbar, active feedback cooling is needed for stable trapping

- Low pressure (~$10^{-7}$ mbar), **Minimal damping** → High temperature (1K)
- **Increase damping** → Reduce temperature
- Center of mass $T = 50 \pm 22 \, \mu K$ (imaging laser noise limited)
- Noise squashing averted with out-of-loop sensor

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CHARGE CONTROL

- Controlled discharging/charging with single e precision
- Measure response to oscillating E field while flashing UV light
- Charging rates ~1 e/week (~1 yA) or lower

F. Monteiro, W. Li, GA, C.L. Li, M. Mossman and D. Moore., PRA 101, 053835 (2020)
DM-INDUCED RECOILS

- Consider heavy DM particles
- Interaction mediated by a long-range force carrier $m_\phi \lesssim $ eV
- Coherent enhancement!
- Need to be cold
- Low momentum threshold $\sim 200$ MeV/c
- Specific models exist

$V(r) = \alpha_n N_n \frac{e^{-m_\phi r}}{r}$

$\sigma \sim N_n^2 \sim 10^{29}$
MODEL-INDEPENDENT LIMITS on NEUTRON COUPLING

$$V(r) = \alpha_n N_n \frac{e^{-m_\phi r}}{r}$$
LIMITS on COMPOSITE DM

- Assuming specific composite dark matter model, can **compare to WIMP detectors**

- For sufficiently light mediators and large composite particles, **many orders-of-magnitude more sensitive**

This work, (5ng day), 10% of DM

- This work, (5ng day), 100% of DM

- Model dependent (Eot-Wash, $g_d \sim 1$)

- Future detector for low mass WIMPs, e.g. superfluid He (1kg yr @ 1meV)

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PLENTY of ROOM for IMPROVEMENT

- This first proof-of-principle already explores well beyond existing searches for certain classes of models

- **Next steps:**
  - Directionality
  - Large sensor arrays with longer exposure
  - Push to (beyond) SQL

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WHAT if DM COUPLES to $N_p-N_e$?

- **Particles with unity charge** under new dark force can have fractional charge under electromagnetism

- **Charge/mass ratio** $\sim 10^9$ worse than, e.g., single Sr$^{+2}$ ion or $\sim 10^{14}$ worse than a single $e$

- **Protons and electrons** form bound states

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Theorized enhancement in relic abundance of DM mCPs, accumulating in Earth

We probe **deep into** $10^{-17}$ / nucleon

~ 6 orders of magnitude under natural abundance of naturally occurring stable elements (10 parts in a quintillion…)

We set a $10^{-19}$ e / nucleon limit on the sum $|q_p + q_e + q_n|$


Using a Bohr binding-energy argument, can link charge to mass

For an abundance > $10^{15}$, explore new parameter space

Holds even in comparison with ambitious future experiment projections

Looking at relic abundance benefits from accumulation of mCPs on Earth

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Postdoc positions available

You?
CURRENTLY IN THE LAB...

Search for **recoils** from composite DM

![Graph showing limit on neutron coupling vs. DM mass](image)


Testing **charge quantization** and search for **mCP**

![Graph showing fractional charge distribution](image)


Testing **Newton’s law** at ~ um distances

![Diagram showing dipole background control](image)

**Controlling dipole backgrounds**

**Nuclear recoils** from single α/β decays

![Diagram of nuclear recoils](image)

Large arrays of ng masses

![Diagram of large arrays](image)

**Controlling dipole backgrounds**