Dark Matter Induced Power in Quantum Devices

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arXiv:2210.09313, Under review in PRL

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Daejeon

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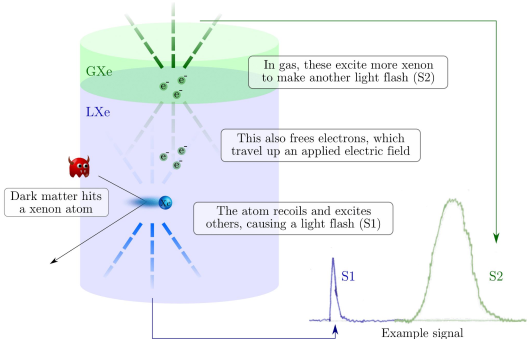
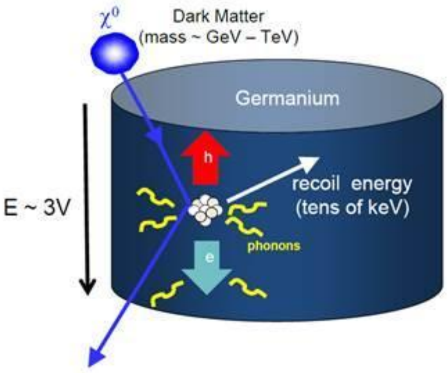
Outline:

- Dark matter power deposition & sensing
- Low power measurements
- Results

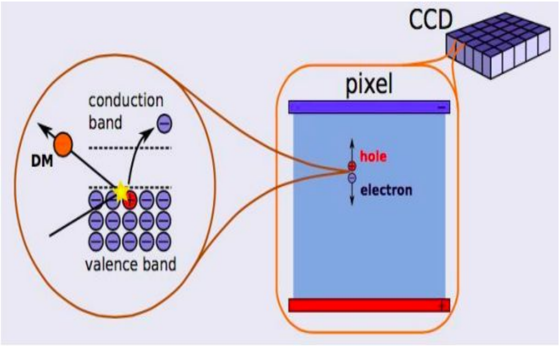
Conventional Direct Detection Experiments



XENON, LZ



SuperCDMS

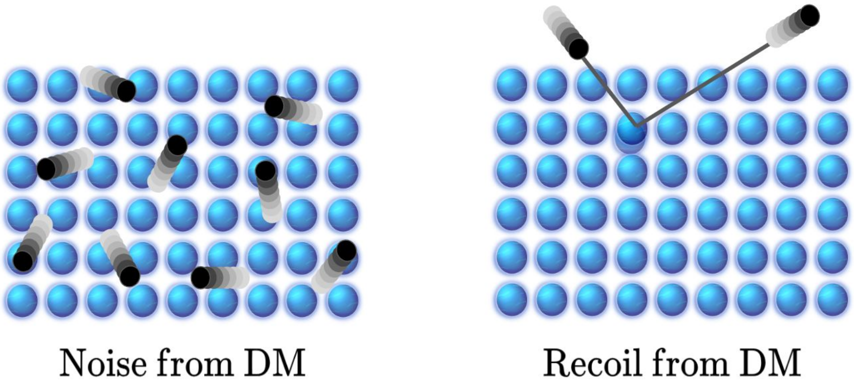


SENSEI, DAMIC-M

All looking for single scattering events from DM

Power Deposited by Dark Matter Scattering

Instead of individual events, use power/heat deposited by DM



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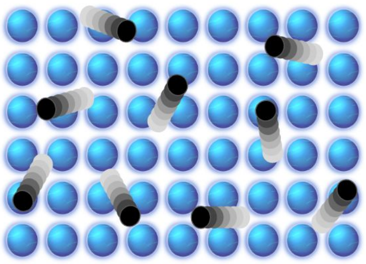
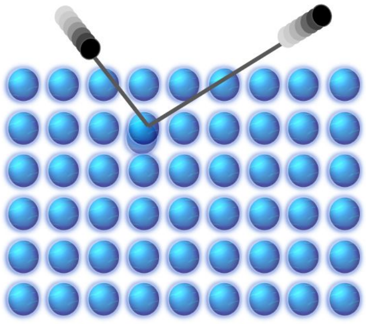
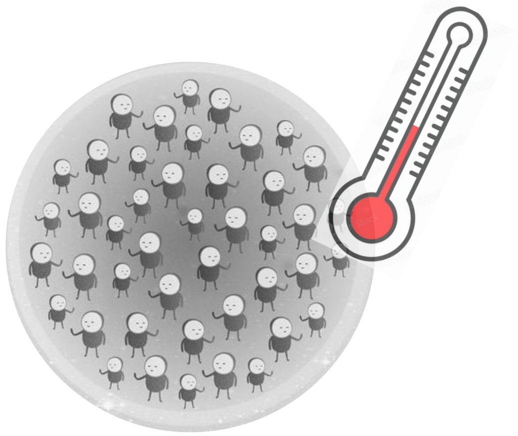


Noise from DM



Recoil from DM

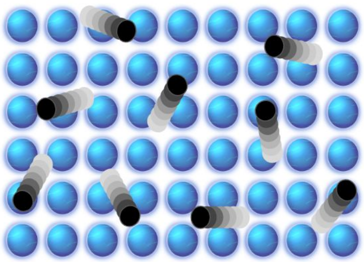


Using a very sensitive calorimeters

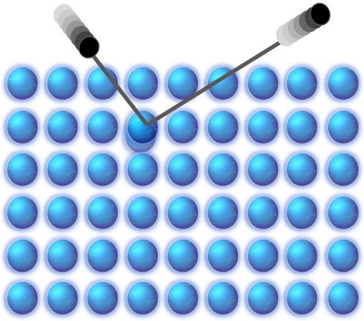
arXiv:2210.09313

Power Deposited by Dark Matter Scattering

Instead of individual events, use power/heat deposited by DM



Noise from DM



Recoil from DM

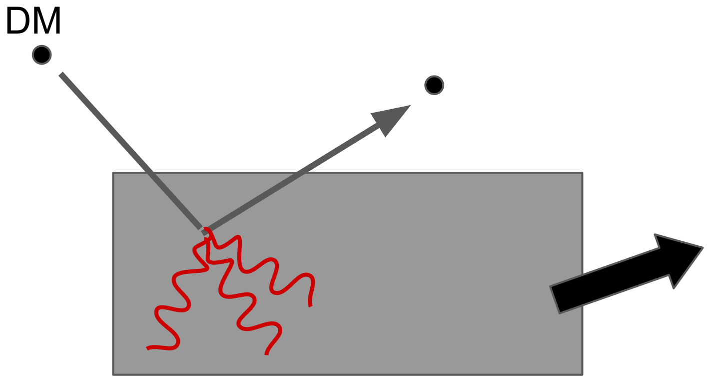
$$P_{\rm DM} = \int d\omega\, \omega \frac{d\Gamma}{d\omega}$$

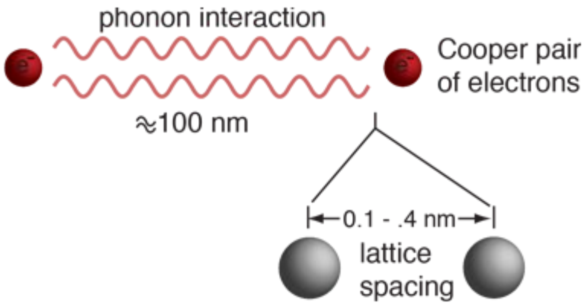
Scattering rate

arXiv:2210.09313

Power Deposition Mechanism

DM scattering creates phonons in the SC which break Cooper pairs & release quasiparticles that can be detected





When momentum transfer $q \simeq \frac{2\pi}{a}$

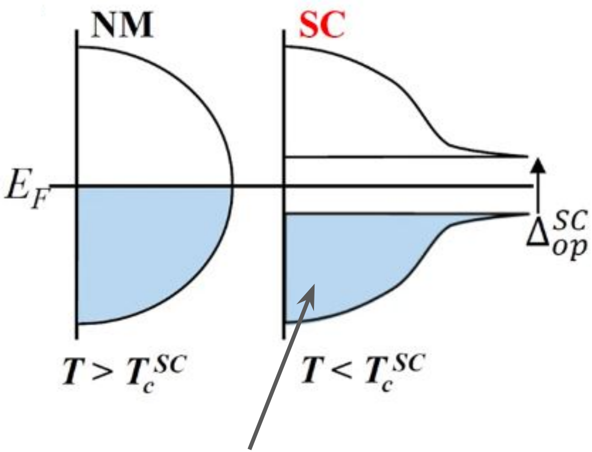
Power Deposited by Dark Matter Scattering

Instead of individual events, use power/heat deposited by DM

We already have data from devices that can measure very small power deposition

Quantum Devices Based on Superconductor

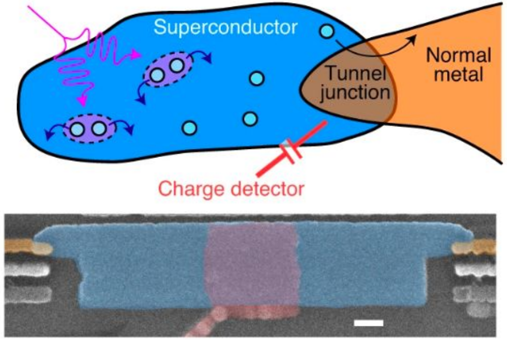
Electron DoS

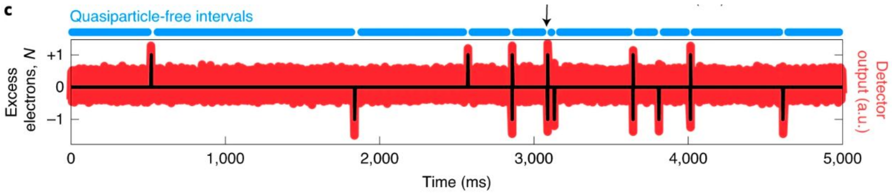


BCS ground state:
sea of Cooper pairs

Δ_{Al} = 0.34 meV

Low bkg quasiparticle device



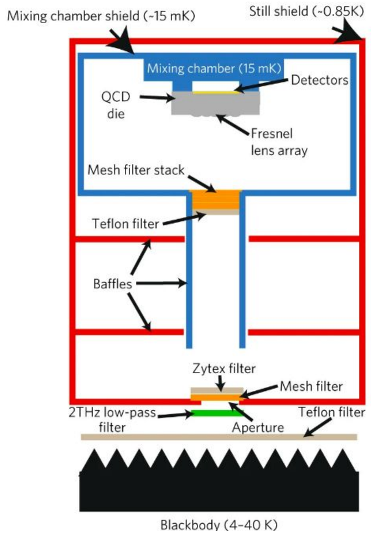


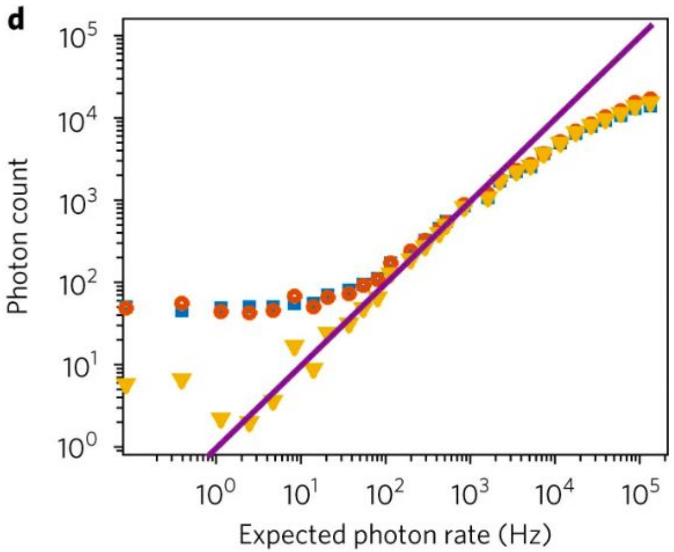
***P* = 6 x 10^{-25} Wμm^{-3}**

Nature Physics 18, 145-148 (2022)

Quantum Devices Based on Superconductor

Low noise bolometer, Cryogenic infrared sensor



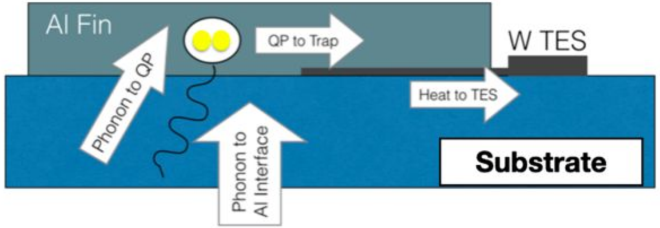


P = 1.7 x 10^{-20} Wμm^{-3}

Nature Astronomy 2, 90-97 (2018)

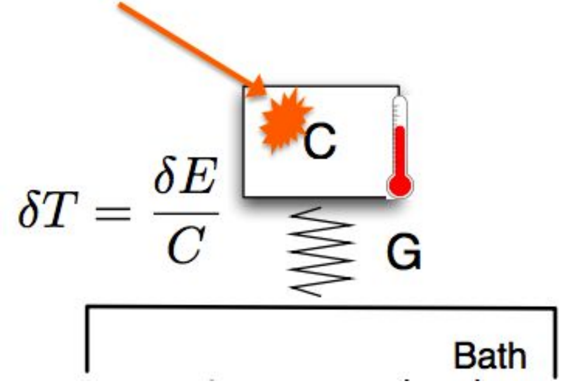
Quantum Devices Based on Superconductor

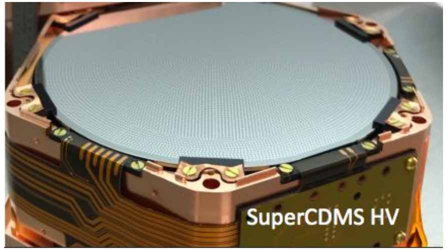
SuperCDMS Si detector covered with SC Al fins coupled to W TES



Athermal phonon sensor

External agent

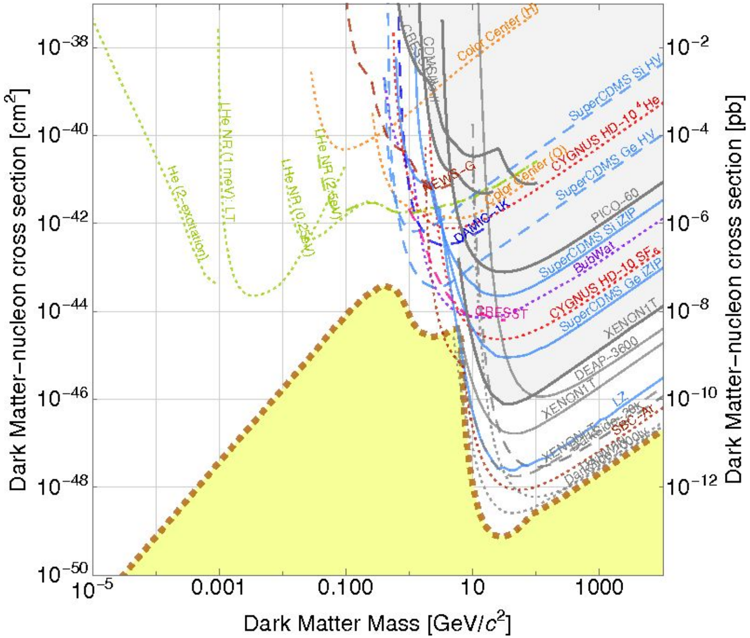




$P = 3 \times 10^{-21}$ Wμm^{-3}

PRD 104, 032010 (2021)
Matt Pyle, 2022

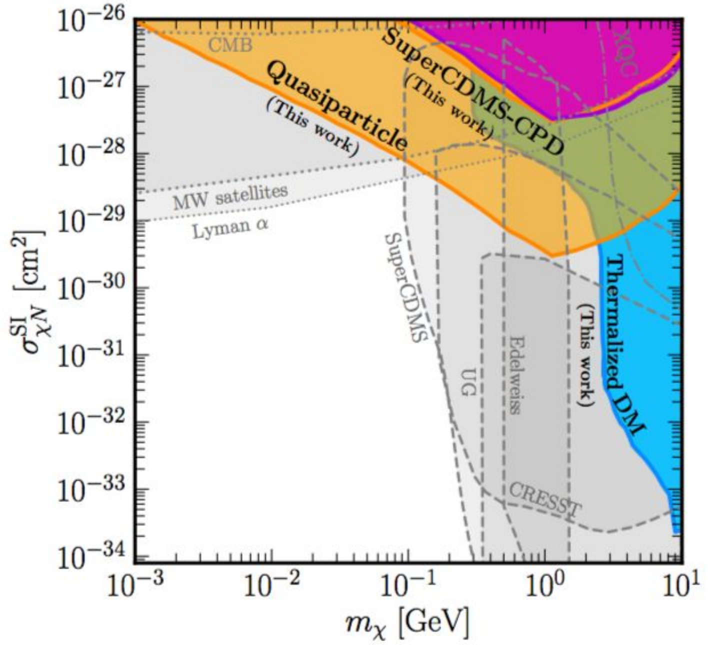
New Experiments Needed for Light DM Search



US cosmic visions 2017

New Limits on DM-nuclear cross section

$$P_{\rm DM} = \int d\omega\, \omega \frac{d\Gamma}{d\omega} \leq P_{\rm limit}$$



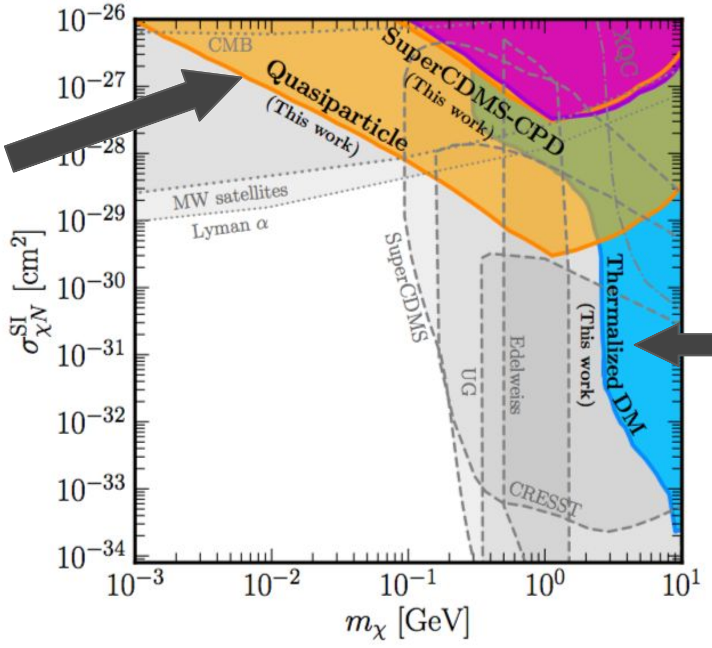
arXiv:2210.09313

Unprecedented power sensitivity helps us put new limits on DM-nucleon cross section for both thermalized and halo population

New Limits on DM-nuclear cross section

competitive limit for halo DM

$$P_{\rm DM} = \int d\omega\, \omega \frac{d\Gamma}{d\omega} \leq P_{\rm limit}$$

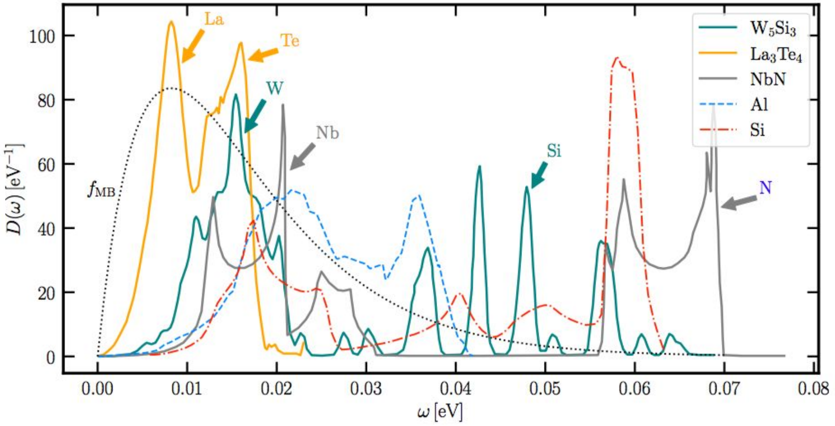


arXiv:2210.09313

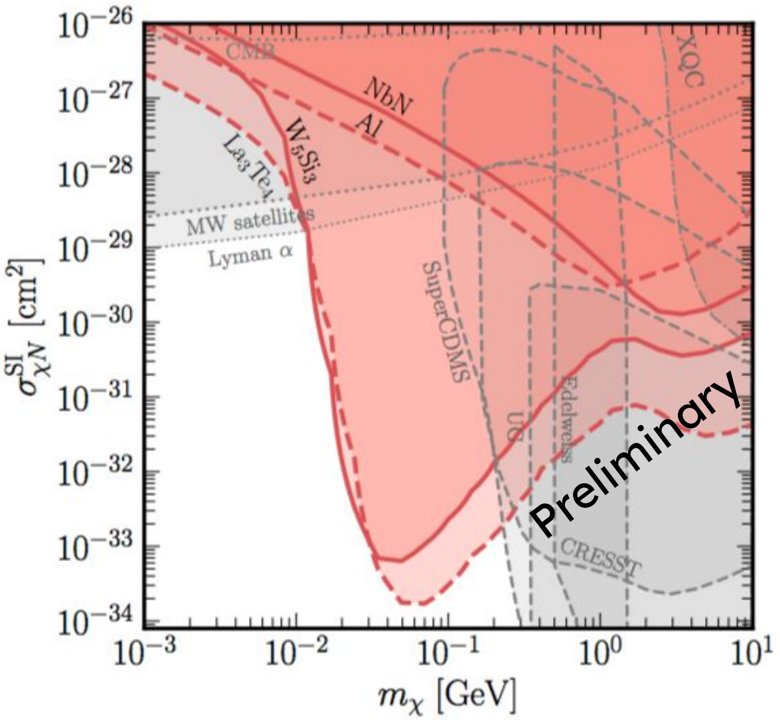
Limit on thermalized DM (only limited by DM evap.)

Unprecedented power sensitivity helps us put new limits on DM-nucleon cross section for both thermalized and halo population

Optimizing the absorber material



Better overlap with thermalized DM distribution

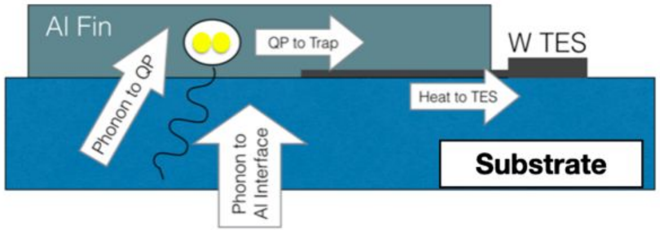


New materials with more phonon states at low energy

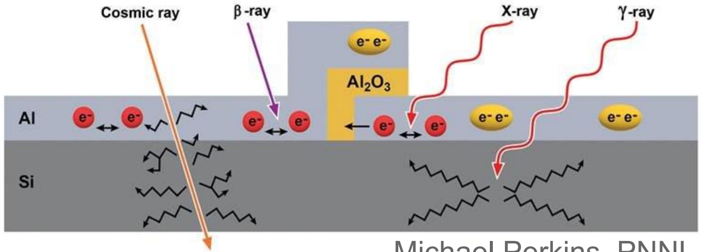
Challenges for detection:

- ❑ Power calibration of the calorimeter
- ❑ Neutron scattering
- ❑ Radioactivity & cosmic rays
- ❑ Unknown systematics

Similarity w/ superconductor-based Qubit



Athermal phonon sensor used in SuperCDMS



SC Al-based Qubit chip

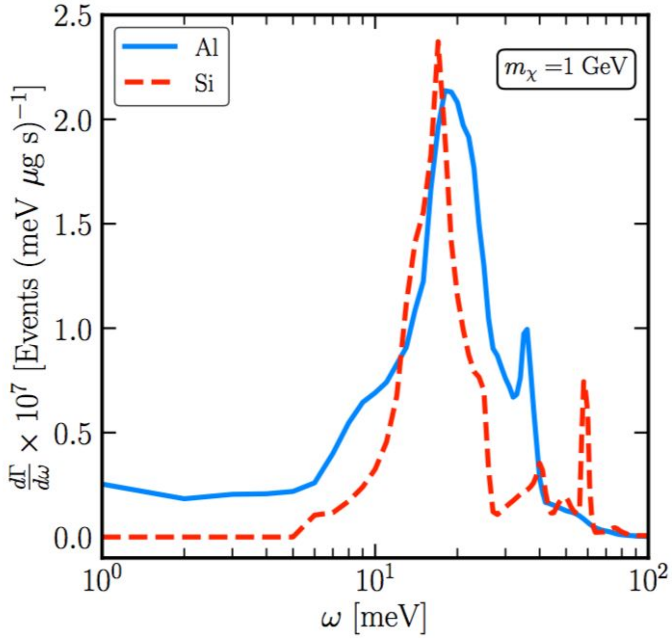
Technological similarity between Quantum sensors & Qubit chips

Cross-community collaboration will be critical

Final takeaways

- ➢ As DM searches dig deeper into the parameter space, it becomes more challenging
- ➢ New technique of measuring the power deposited by DM could be more useful in future
- ➢ Mesoscopic quantum devices are set to improve further in measuring small energy deposit
- ➢ Close technical connection with qubit development research
- ➢ Collaborative strategy with quantum computer research could be beneficial

Differential Scattering Rate in Al & Si



Phonon structure factors $S(q,\omega)$ in Al & Si are favorable for scattering with O(10 meV) energy DM

Captured Dark Matter on Earth

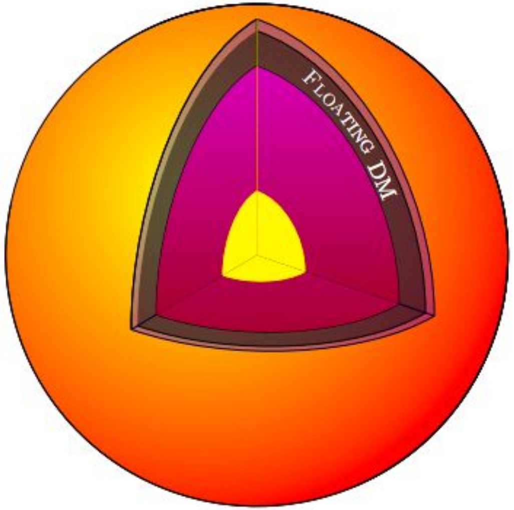


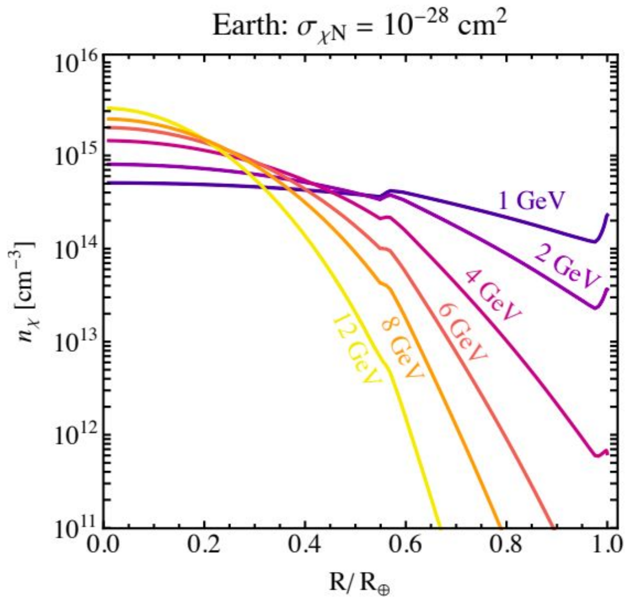
FIG. 1. Schematic of floating DM on the outer region of the celestial object as found in this work (dark shaded shell).

arXiv:2012.03957, 2209.09834, 2303.01516

Over time, halo DM may get captured in the Earth and can get thermalized

arXiv:2209.09834

Floating Dark Matter on Earth



For DM mass 1-10 GeV and xsec > 10^{-35} cm^2, the thermalized population can get very dense near Earth's surface

However, these DM particles have very low energy, $E_{DM} \sim O(10\text{ meV})$