Town Hall Participant Questions

Session: Dark Matter 2

Session Date and Time (PDT): **Wednesday, February 22, 11:05 am - 12:25**

Session Chair: Richard Schnee

Speakers: Matt Pyle, Gray Rybka, Tongyan Lin

We encourage you to submit your questions to the speakers ahead of time, if possible, however this document will continue to be live and monitored throughout the session.

Please provide the topic/speaker your question is addressed to, and we encourage you to provide your name, institution, and email address so we may follow-up with you if needed. If your question does not get answered during the session, we will work to have it answered subsequently. Thank you!

E.g. first name, last name, email address, speaker name: comment/question

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Matt Pyle

Lindley Winslow, lwinslow@mit.edu: The focus of the talk was on the DMNI projects which are the most advanced, can you say something about more speculative ideas including Dirac materials etc?

There are simply so many new and exciting ideas that could potentially meet all the light mass dark matter design drivers of

1) Small energy excitations
2) Single excitation measurements
3) Backgrounds

I give a very incomplete list on slide 34 of my talk and I specifically reference the benefit of going to smaller gap materials like dirac materials/small gap semiconductors on slide 18.

I also note that I mentioned specifically 4 LMDM experimental concepts (on top of the slide 34 list), 2 were funded by NIDM, but 2 aren't.

Peter Onyisi, ponyisi@utexas.edu: are there technologies/projects not developed in the US that we should be considering?

Not to my knowledge. I think the US is leading the world in exciting innovative ideas in light mass dark matter. We simply need funding to bring these ideas to fruition and stay in the lead.

Sarah Demers, sarah.demers@yale.edu : Can you say something about the ways that this line of research is pushing QS capabilities beyond HEP in addition to find applications for ideas developed in other contexts?

Your question and Sergey's below are quite similar.

Solid state QUBITs need exceptionally quiet and cold environments or else they will decohere. In particular one thing they need is the absence of any excitations within the environment with energies greater the QUBIT gap.

Light mass dark matter experiments have absolutely identical needs and in many ways our requirements are more severe because we can't use tricks to isolate our sensors for the absorber environment.
In particular, both high energy radiation and zero charge low energy excess events that are seen in light mass dark matter athermal phonon detectors will create athermal phonons that can destroy the quantum state in superconducting qubits. Infact, it's likely that one quantum sensor has already begun to be limited by these zero charge low energy excess backgrounds (arXiv: 2102.00484).

Thus, our research on these backgrounds will almost certainly have significant broader impact eventually in quantum computing.

Sergey Pereverzev pereverzev1@llnl.gov

Here is a question/comment to Matt Pule regarding solid-state dark matter detectors.

We have a long history of studying noises and backgrounds in superconducting photon detectors, SQUIDs other quantum sensors, and qubits. We see the patterns that noise is not thermal- it stops decreasing with cooling. The same effect with coherence time- it is not increasing with further cooling. The general expectation is that we see quantum effects: material is constantly changing due to tunneling two-level systems, quantum diffusion, etc. Parallel mechanisms can include releases of energy stored in materials- something in the spirit of Prigogine ideas about systems with energy flow, or Self-Organized Criticality theory. It is very difficult to distinguish when devices are "about quantum-limited". Presently all dark matter detectors- Nai(TI) , noble liquids TPC, and solid-state low-temperature detectors demonstrate excess backgrounds that have features of energy accumulation and uneven releases in materials. In a number of the solid-state detector at low temperatures, we see bursts of phonon and quasiparticles emission caused by the release of mechanical stress. The processes of energy accumulation and releases are difficult to model- we do not know the interactions of long-living excitations and defects in materials in sufficient detail. This is a general difficulty with non-equilibrium thermodynamics. Backgrounds due to stored energy releases may be not very exciting, but it is difficult to dismiss without experiments. Is someone working on this in the context of quantum detectors? The wider question to all P5 participants question is how to organize joint programs/experiments between the HEP and BES divisions –backgrounds in the most sensitive dark matter particle detectors and noise/decoherence in quantum sensors likely have similar material origins.

As discussed above, understanding these backgrounds are vital for both light mass dark matter and quantum computation. The program that has been funding most of this work the past 5 years is the DOE QUANTIZED program. For example, the QUANTIZED program funded this work on understanding microfractures (2208.02790). I believe that the DOE NP QUANTIZED program funded these background studies (2001.09190) too. To me, this QUANTIZED program is the natural place to fund these dual use background studies and it would be really nice to have this explicitly called out in the P5 report. In particular, Maurice seemed to indicate that the status and goals of this program were somewhat up in the air in his talk (https://indico.physics.lbl.gov/event/2382/contributions/7564/)

Gray Rybka

Chris Monahan, cjmonahan@wm.edu: Can you comment on how the technology of an axion centre based at a national lab could be used by other areas of particle physics or other complementary fields? In other words, what else can you do with a giant magnet, very cold temperatures and quantum sensors?
GR Response - oh, I could have also mentioned some ideas out there to use similar experimental setups to look for (unusually high frequency) gravity waves and (I think) equivalence principle violations, but these ideas are really in their infancy.

Tongyan Lin

Comment on searches involving excitations in materials. IF you look at WIMP search histrory, eventually there was one winning technology. This is because the interaction being probed is single particle pointlike. Material details do not matter to the interaciotn (only to the detectoring process). For low energy excitations the situaiton is different. Material details do matter to the DM coupling. A diversity of targets will always be needed. While a small experiment is cheap, 100 small experiments are not cheap. SO wll need ot have a way to maximize science but funding a subset of the possible diversity

TL: I agree, I think funding R&D to explore different materials and technologies is relevant to this and not necessarily being tied only to the very first ideas we had as a community through inertia. Material details can be used to discriminate the DM origin & potentially its properties, for instance a number of materials have large anisotropy, such that the DM scattering leads to daily modulation through direction-dependent scattering. The pattern of excitations in different materials depends on DM coupling.

Jeter Hall, jeter@snolab.ca: I think Matt's talk earlier made the point that backgrounds need to decrease across the board. At higher energies understanding backgrounds is an important thread of research. I would add backgrounds research to the list of needed research support. This may take the form of multi-disciplinary teams to address new background sources such as vibration and infrared/mm/microwave leakage.

Jeter Hall, jeter@snolab.ca: I hope P5 spends time thinking about the portfolio of experiments discussed here. The scale of these projects is smaller than what DOE Office of Science typically supports. An appropriate oversight regime may be needed to support this program, something like a light dark matter consortium.

TL: I think these are great points!