Dark Matter BRN Working Group

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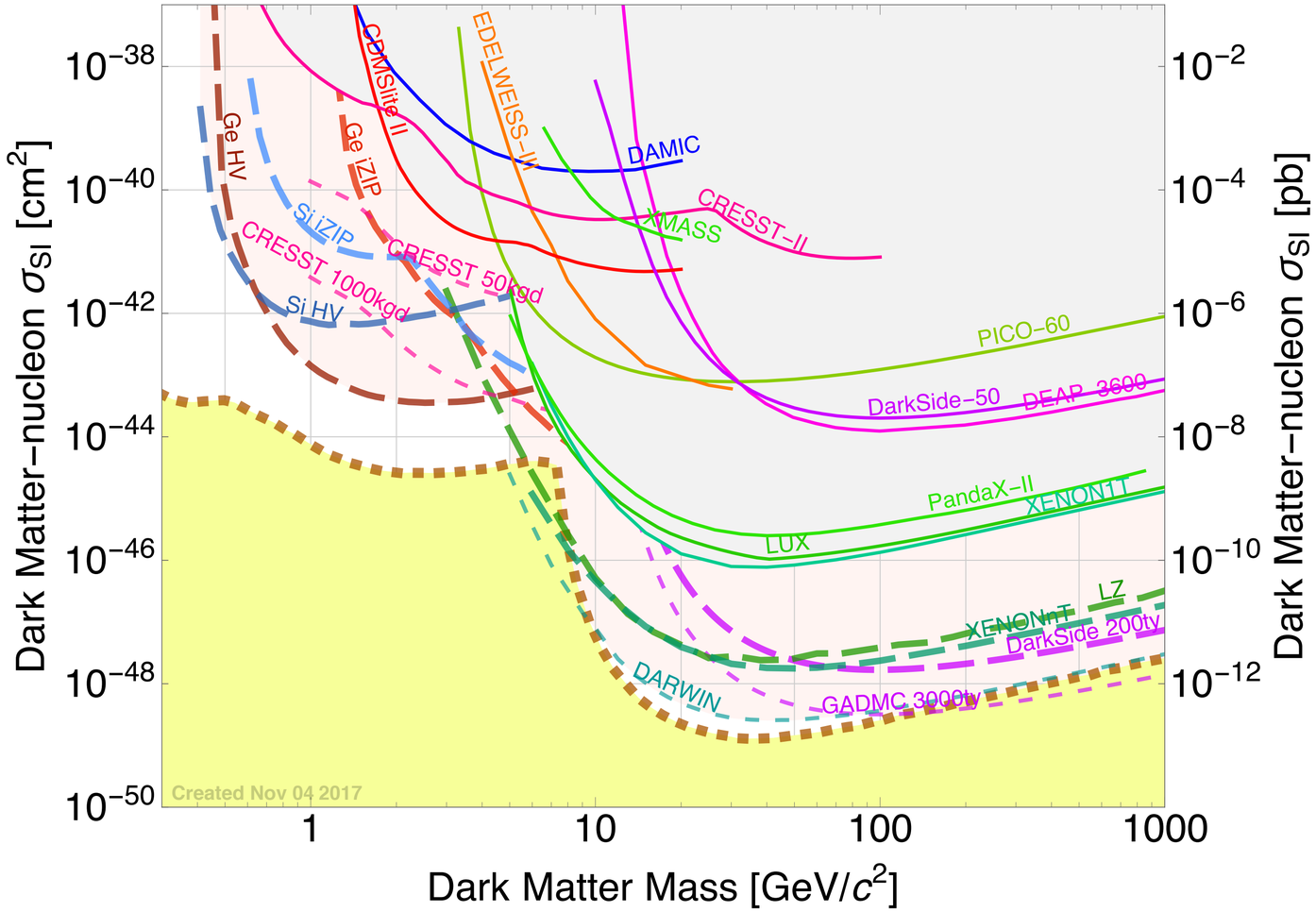
Science Drivers (1)

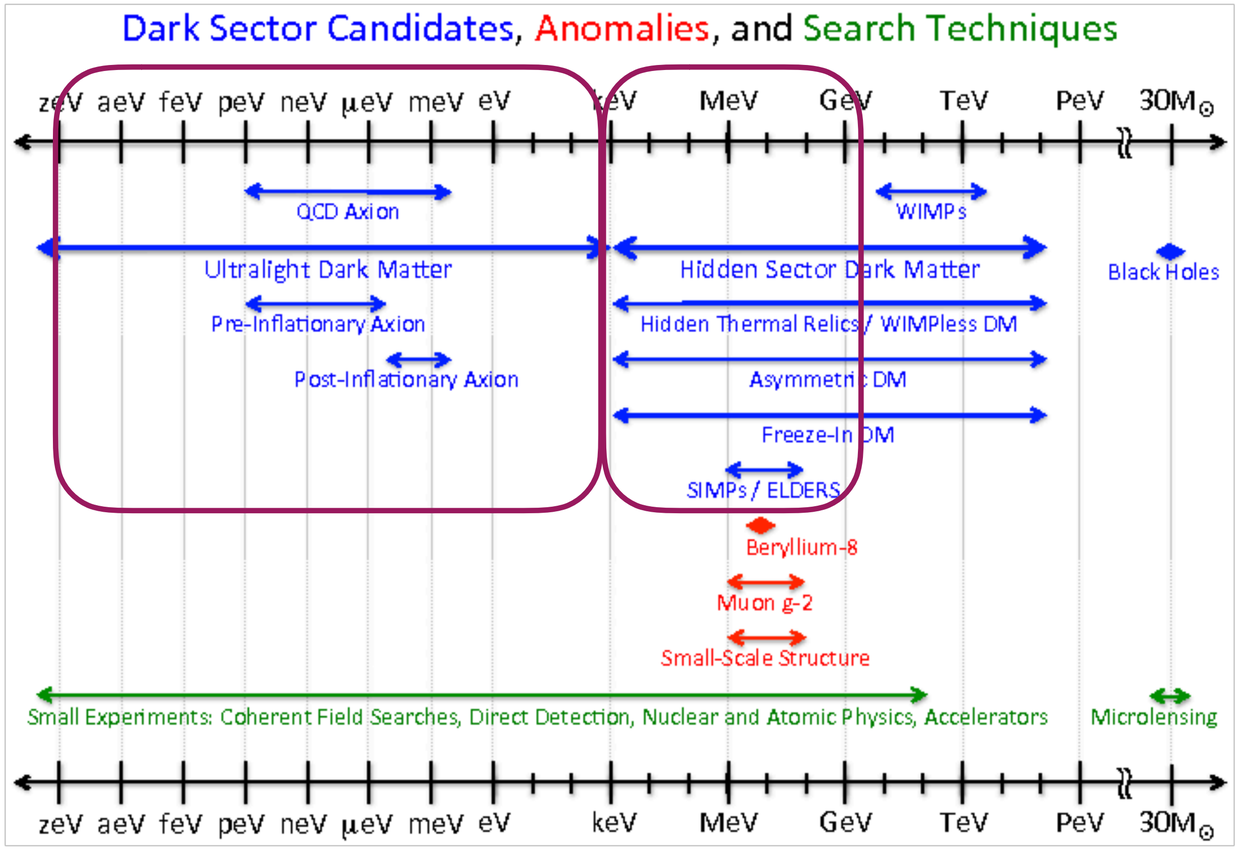
P5 identified the new physics of dark matter as one of six science drivers in its most recent report.

- Current direct detection experiments have made great progress in increasing sensitivity to dark matter interactions.
- G2 experiments will further constrain this space, but fall short of the neutrino floor.
  - Provides opportunities for **R&D in large detectors** to explore this final frontier.



Science Drivers (2)

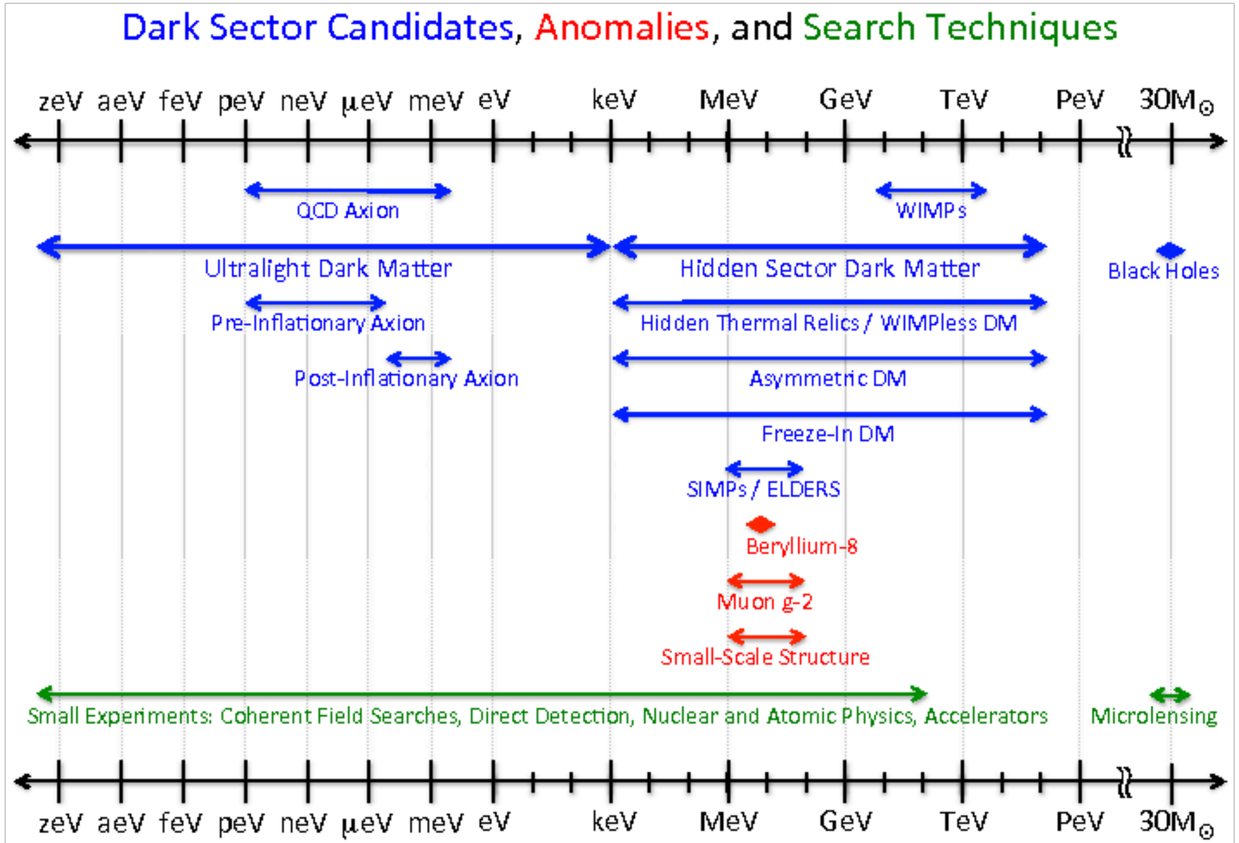
- Much work has gone into looking for the canonical WIMP
  - No evidence from direct searches and no evidence of SUSY from LHC
- If we broaden our perspective by loosening our cosmology or theory priors, we still have reasonable dark matter candidates — many with lower masses (1 MeV - 10 GeV)!
- There is theoretical work that indicate that very light dark matter may interact more like waves (QCD axions and ALPs).
- Exploration of these candidates provides opportunities for **R&D in developing new technologies.**



US Cosmic Visions: arXiv:1707.04591

Science Drivers (3)

- If the dark matter particle has mass above the TeV scale - indirect detection techniques may be the most feasible discovery technology.
- Searching for signals of dark matter annihilations or decays in multiple source classes across the sky.
- **Increasing the sensitivity of indirect detection experiments to these sources provides opportunities for R&D.**



US Cosmic Visions: arXiv:1707.04591

PRDs - Preliminary

1. **R&D on methods to extend the investments of DOE in G2 experiments to cover new physics reach to the neutrino floor.**

   -Examples from Liquid Noble Experiments:

   -Reduction of backgrounds would require a combination of R&D and engineering (e.g. distillation of LXe, Crystalline Xe, production & purification LAr, grid emission of electrons)

   -Improve photon collection efficiency would require some R&D.

   -Key Challenge: Quantum-enhanced photoproduction and photodetection over the full frequency spectrum

   -Reduction of backgrounds is a key challenge for dark matter detection AND for 0νββ decay searches. Qubits are decohered by radioactive backgrounds. Progress in this area would have great impact across the Office of Science.

   -Key Challenge: Reach instrumental and radioactive background levels below astrophysical neutrino irreducible backgrounds.

PRDs - Preliminary

2. **Lower thresholds to probe particle dark matter candidates with very small mass.**
   - R&D need to further study exploitation of low energy excited states in materials (i.e. quasiparticle excitations in superconductors and superfluids, vibrational modes in molecules, and electron-hole pairs in narrow gap semiconductors)
   - As energy thresholds decrease —> calibration and background mitigation challenges will appear. Hence, R&D in these areas are also needed.
   - **Key Challenge: Sub-eV and below the standard quantum limit detectors**
   - **Key Challenge: Advanced semi-conductor detectors and devices**

PRDs - Preliminary

3. **Improved angular resolution for point source identification (to reduce astrophysical backgrounds) and greater scalability to weak sources for indirect detection experiments.**
   - R&D needed to scale existing technology for use in future experiments, reducing cost per channel, data volume and rate, and instrument infrastructure.
   - New technologies beyond silicon tracking are needed to scale necessary detection area at reasonable cost.
   - A future space based telescope could be based on scintillators, fiber-based trackers and calorimeters. This requires R&D into low dark count photodetectors with sufficiently high sensitivity to ultraviolet.
   - **Key Challenge: Quantum-enhanced photoproduction and photodetection over the full frequency spectrum**
   - **Key Challenge: 5D Calorimetry over five orders of dynamic range**
   - **Key Challenge: The ultimate undetectable charged particle tracker**

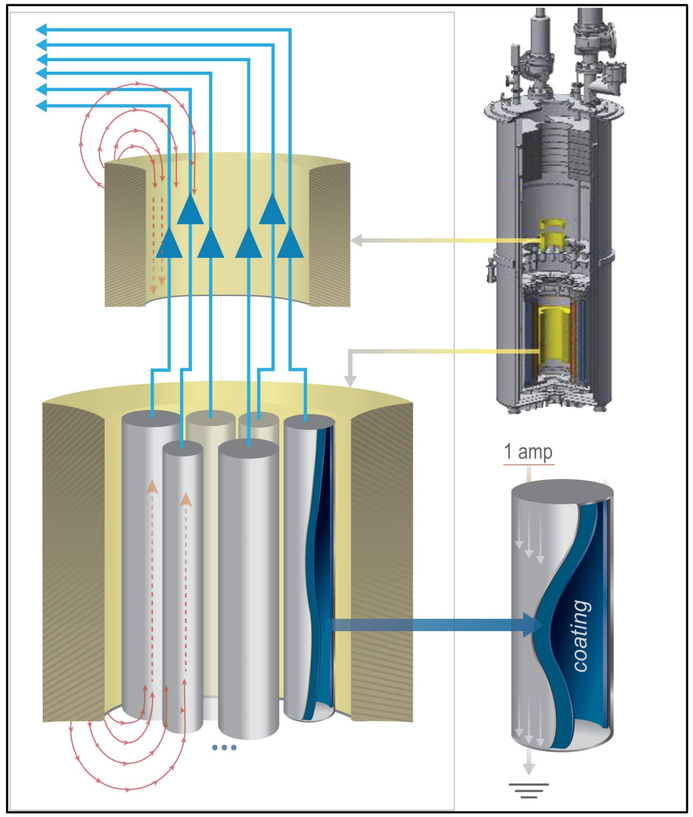
PRDs - Preliminary

4. **Develop quantum sensor technology needed to propel the entire QCD axion band. (See Quantum Sensor Talk)**
   - R&D is needed to improve sensitivity beyond the standard quantum limit for electromagnetic-coupling to QCD axions with mass between new and ~ 100 μeV.
   - New photon counting techniques are need to detected electromagnetic coupling to QCD axions about ~100 μeV.
   - New quantum protocols are necessary for the detection of short-range spin-dependent interactions above ~ 1 μeV.
   - **Key Challenge: Sub-eV and below the standard quantum limit detectors**

PRDs - Preliminary

5. Next Generation High-Q Resonators

- Next generation experiments also propose to combine signals from large arrays of cavities operating in parallel.
- They will poses challenges in terms of tuning and materials selection to maintain high-Q
- They will also require the development of new, high channel-count cryogenic electronics.
- New techniques for building these devices will be required and paradigm-shifting new techniques, such as active resonant digital feedback
- **Key Challenge: Sub-eV and below the standard quantum limit detectors**



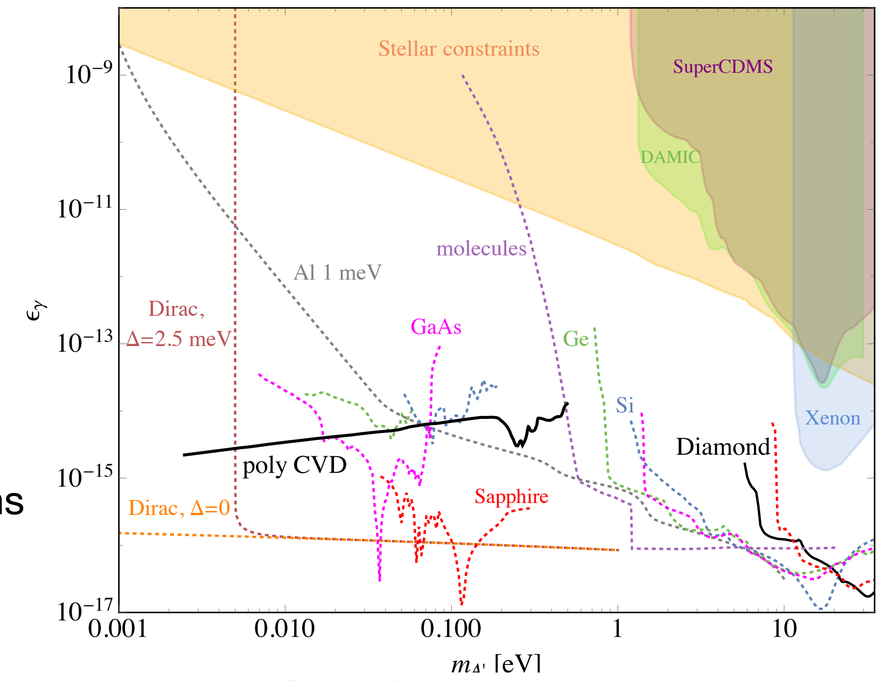
credit: Gp Carosi

PRD - Preliminary

6. **Identification of New Materials, Quantum Materials for Dark Matter Detection**

-R&D into new materials such as Dirac materials, polar materials and topological insulators could allow the investigation of dark matter candidates in the sub-MeV range.

- **Key Challenge: Sub-eV and below the standard quantum limit detectors**



Projected reach for absorption of kinematically mixed photons illustrating the potential for germanium, silicon, Dirac materials, polar crystals, molecules, and superconducting aluminum targets. *arXiv:1901.07569*

PRDs - Preliminary

7. **Single photon counters from near-infrared to microwave:**
   - Future searches for axions using electric field measuring techniques will become limited by the quantum noise that is a consequence of the non-commutative nature of measurements of the amplitude and phase of the field ("Standard Quantum Limit).
   - New photon counting techniques are need to detected electromagnetic coupling to QCD axions about ~100 μeV.
   - A dramatic improvement in technological capability such as this can be expected to have impacts well beyond the field of high energy physics.
   - **Key Challenge: Quantum-enhanced photoproduction and photodetection over the full frequency spectrum**

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PRDs - Preliminary

8. Background mitigation

- Backgrounds will continue to play a key role as dark matter experiments make progress in the next 5 - 20 years.
- R&D opportunities might include: Material handling, material cleaning (polymers, purification LXe and LAr,),material production (underground fabrication, sourcing of raw materials), measurement techniques for trace background analysis, identification of intrinsic backgrounds (acoustic sensors or other specialized instrumentation) and environmental controls.
- R&D may be needed to understand energy transport mechanisms in the 0.1 - 10 eV range (plasmons, interbank transitions and phonons) for potential "scattering" style detector concepts.

-Reduction of backgrounds is a key challenge for dark matter detection AND for 0νββ decay searches. Qubits are decohered by radioactive backgrounds. Progress in this area would have great impact across the Office of Science.

-Key Challenge: Reach instrumental and radioactive background levels below astrophysical neutrino irreducible backgrounds.

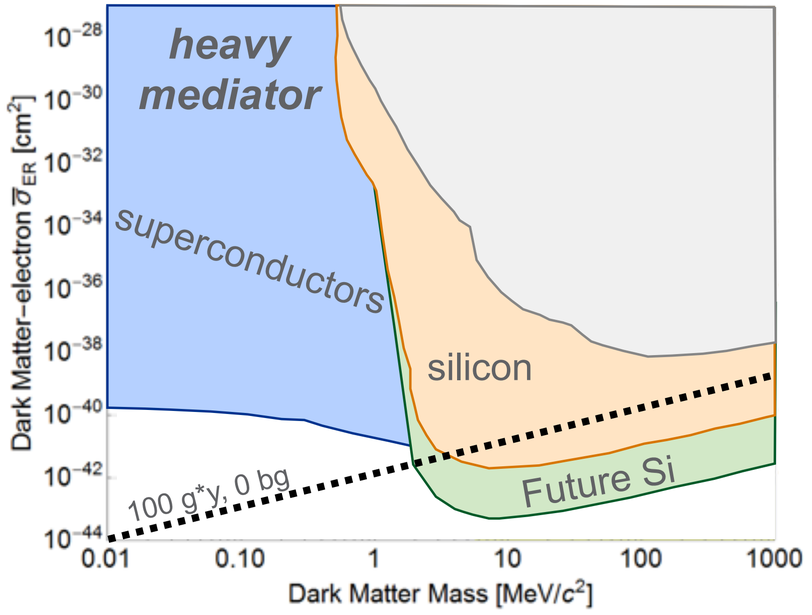
PRDs - Preliminary

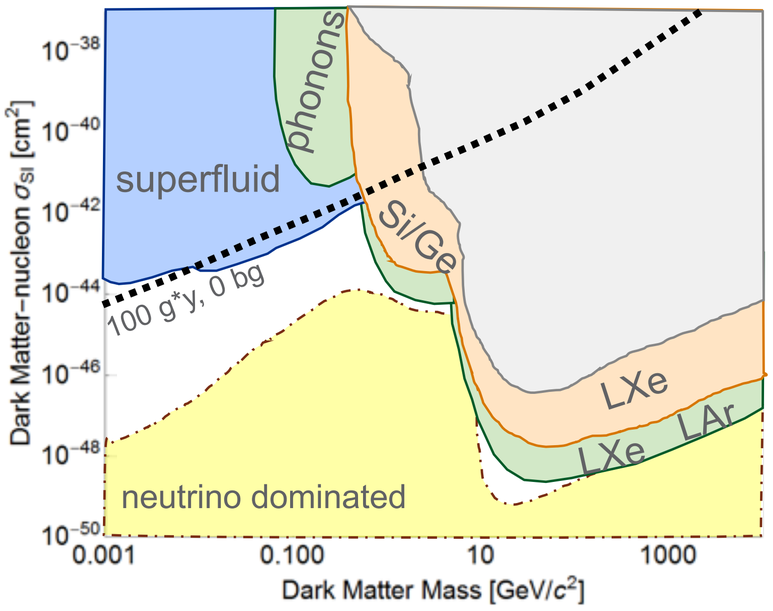
9. High-field, cost-effective superconducting magnets.

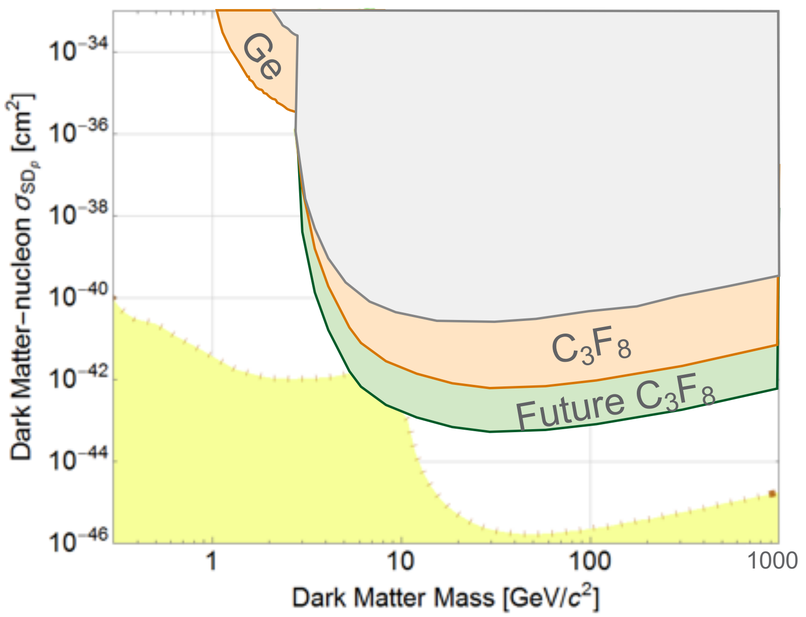
- Cavity-based axion searches rely on high-field magnets.
- Their is a synergy between the upsurge in interest in commercial Fusion reactors that has increased R&D in developing high-field, high-T_c superconducting magnets and the R&D needs of next generation large, high-field magnets.
- **This has impact for the accelerator community. Developments inside the accelerator community could have impacts here. Isn't this a key challenge?**

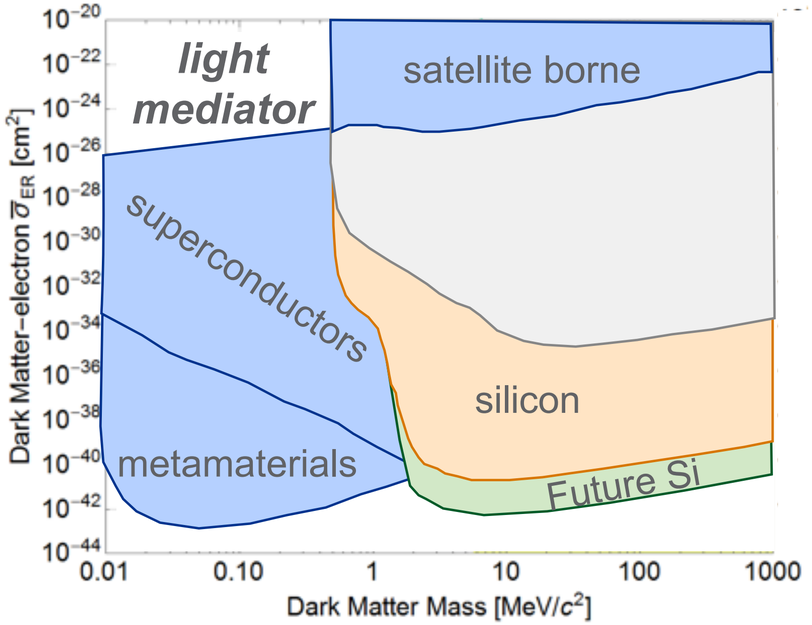
Facilities - Preliminary

1. **Ubiquitous cryogenics for cooling superconducting sensors**
   - Many new detector technologies, including space-based detectors, operate at sub-Kelvin temperatures.
   - Developing cost-effective and scalable methods to reach sub-Kelvin temperature would make these new technologies more accessible for R&D and allow implementation on scales that are currently unachievable.
   - Ways to enable cost-effective R&D — think an order of magnitude cost reduction in a cryogenic fridge, but we have no idea how to do it.



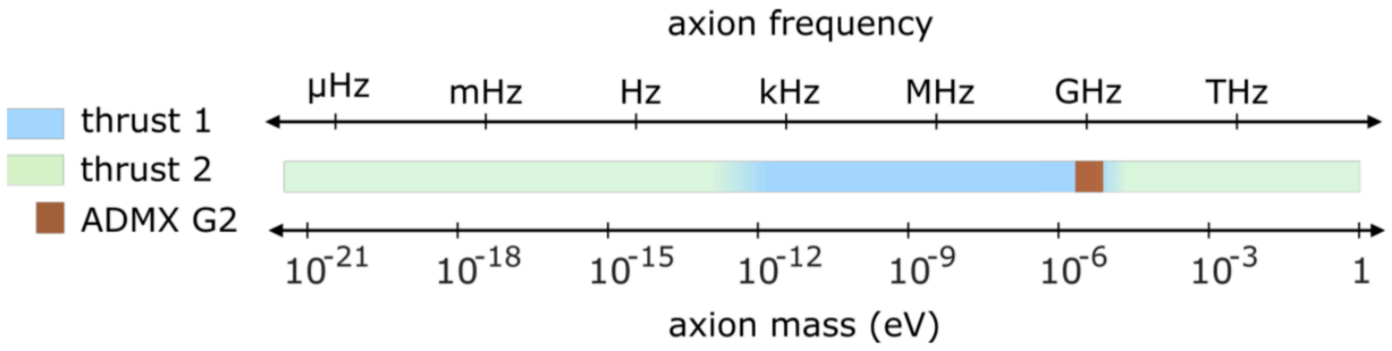


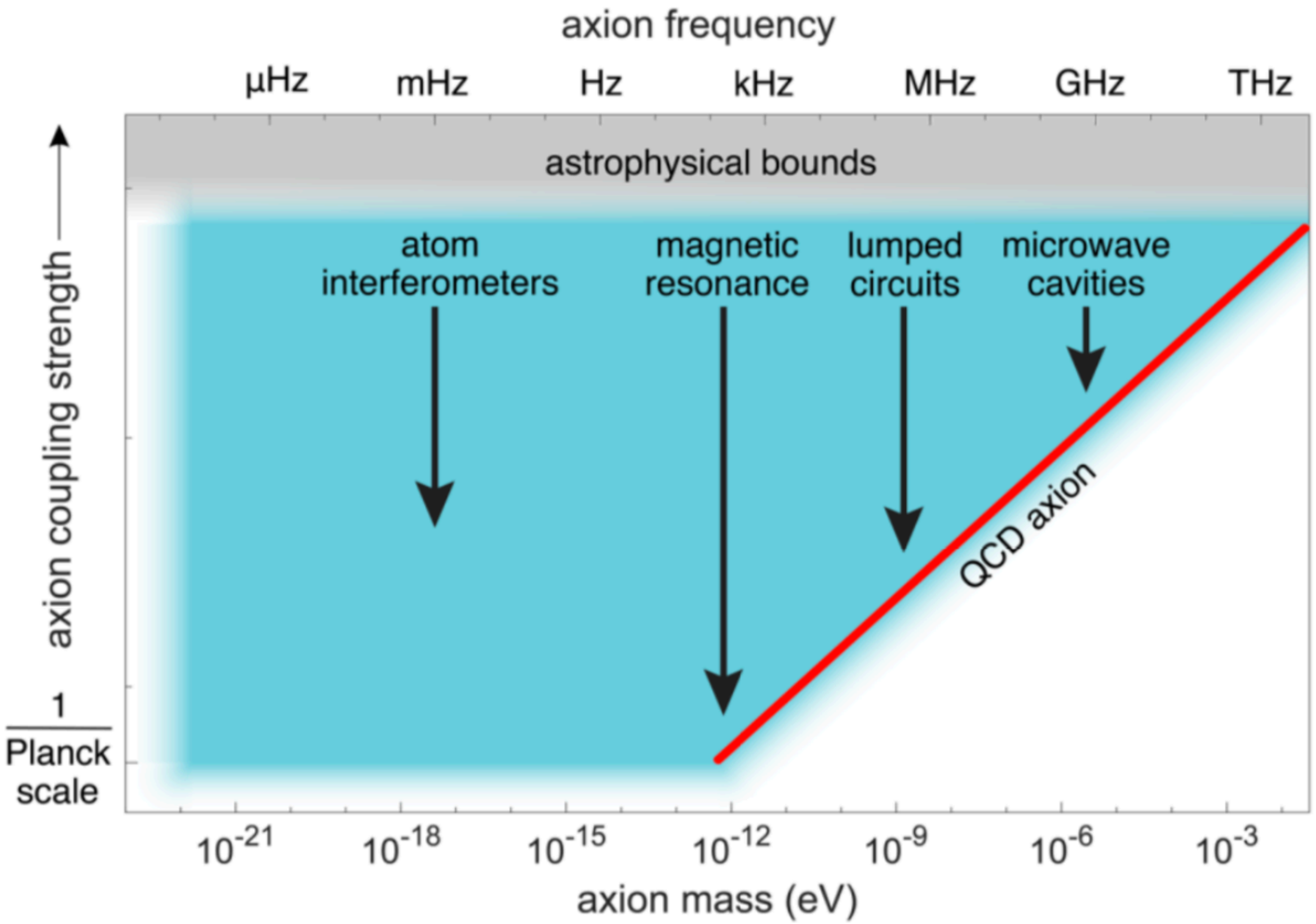




- Currently Excluded
- Current funded sensitivity (5 years)
- Next generation proposals (10 years)
- Future R&D (20+ years)

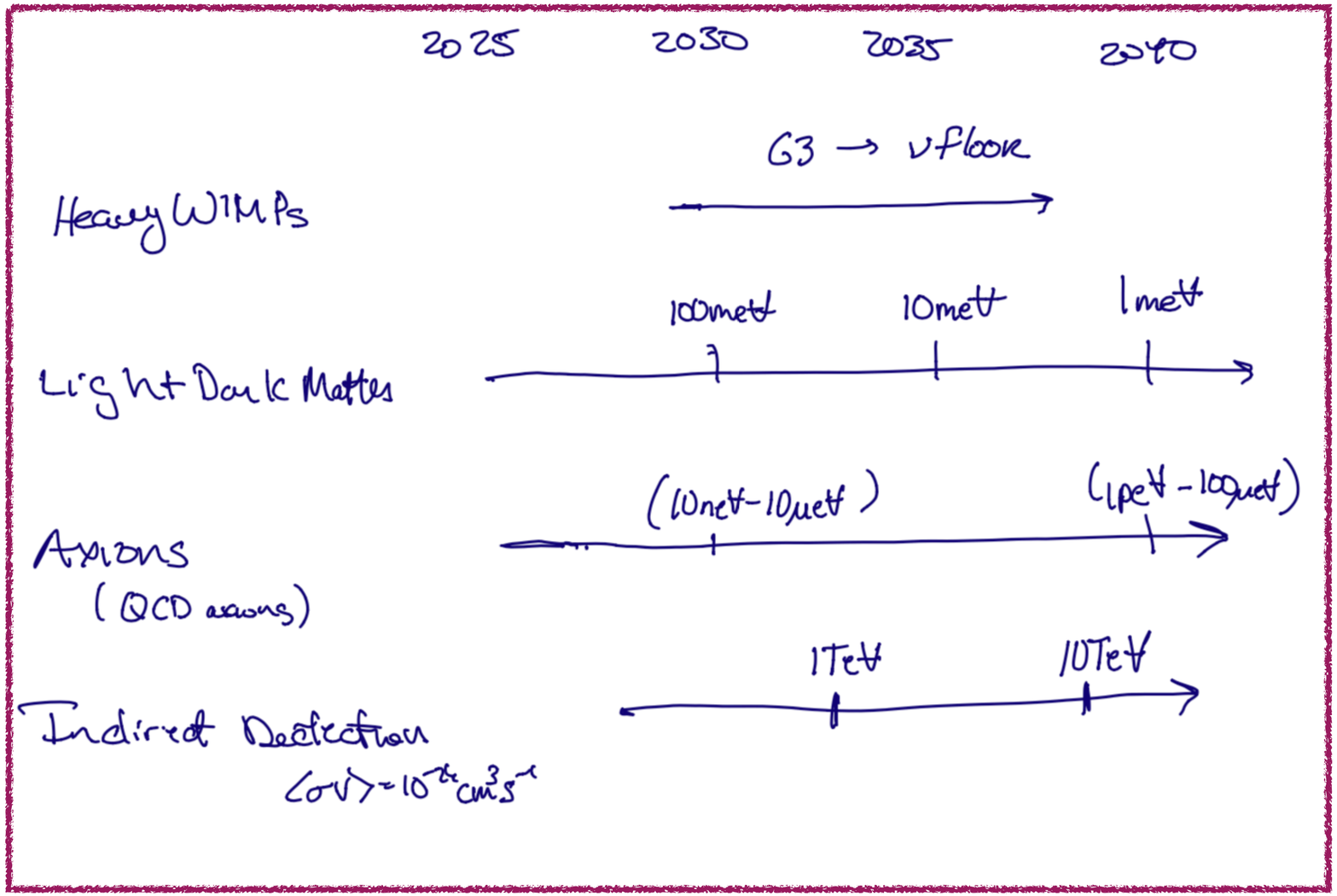
credit: John Orrell, adapted from DM BRN





credit: DM BRN

Notional Timeline



Thank You Contributors!

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