CF1 Particle Dark Matter Snowmass, July 20 2022

Convenors: Jodi Cooley, Hugh Lippincott, Tracy Slatyer, Tien-Tien Yu

Quick recap of how we got here

~150 LOIs submitted to CF1 (including cross lists) - huge amount of community interest and ideas, the most of any CF topical group!

We identified a few broad science themes split into 8 “Big Question” white papers.

“Big Questions” white papers - can still be updated! (barely)

Title	Editors	Arxiv
Dark Matter Direct Detection to the Neutrino Fog	P. Cushman, B. Loer, R. Gaitskell, C. Galbiati	2203.08084
The landscape of low-threshold dark matter direct detection in the next decade	R. Essig, G. Giovanetti, N. Kurinsky, D. McKinsey	2203.08297
Calibrations and backgrounds for dark matter direct detection	D. Baxter, R. Bunker, S. Shaw, S. Westerdale	2203.07623
Modeling, statistics, simulations, and computing needs for direct dark matter detection	Y. Kahn, M.E. Monzani, K. Palladino	2203.07700
The landscape of cosmic-ray and high-energy-photon probes of particle dark matter	T. Aramaki, S. Profumo, P. von Doetinchem	2203.06894
Puzzling Excesses in Dark Matter Searches and How to Resolve Them	L. Yang, R. Leane, S. Shin	2203.06859
Synergies between dark matter searches and multiwavelength/multimessenger astrophysics	P. Harding, S. Horiuchi, D. Walker	2203.06781
Ultraheavy particle dark matter	D. Carney, N. Raj	2203.06508

Many additional white papers submitted

Useful link to all Snowmass White Paper database compiled by Kristi Engel and Tiffany Lewis

CF1 Topical Group Summary report - https://www.overleaf.com/read/fjvszqjyrnpy

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Snowmass CF1: Particle Dark Matter - DRAFT

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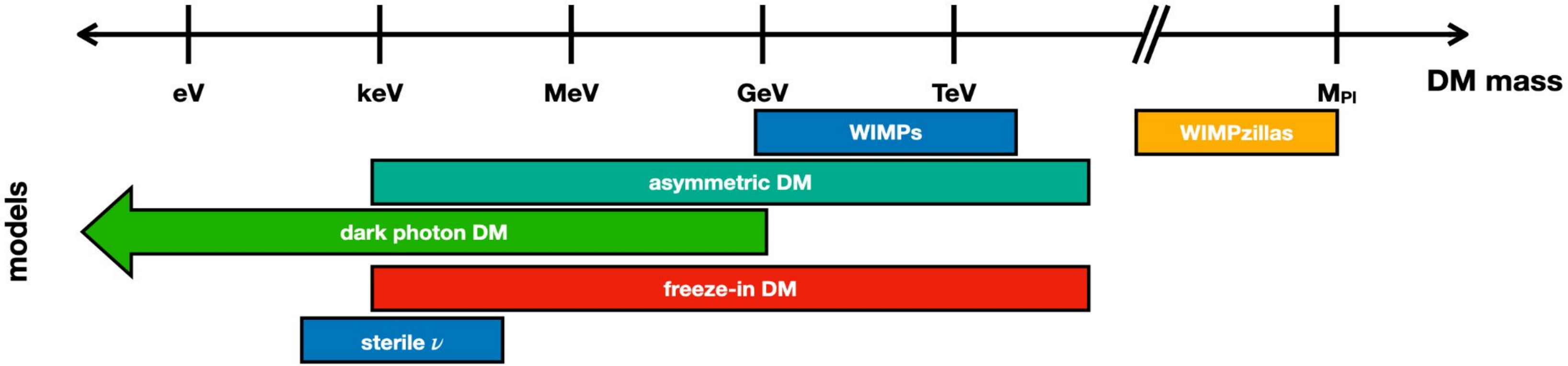
Will add other authors from our solicited white papers plus participants in discussion/figures

July 18, 2022

CF1: Particle-Like Dark Matter Exec Summary

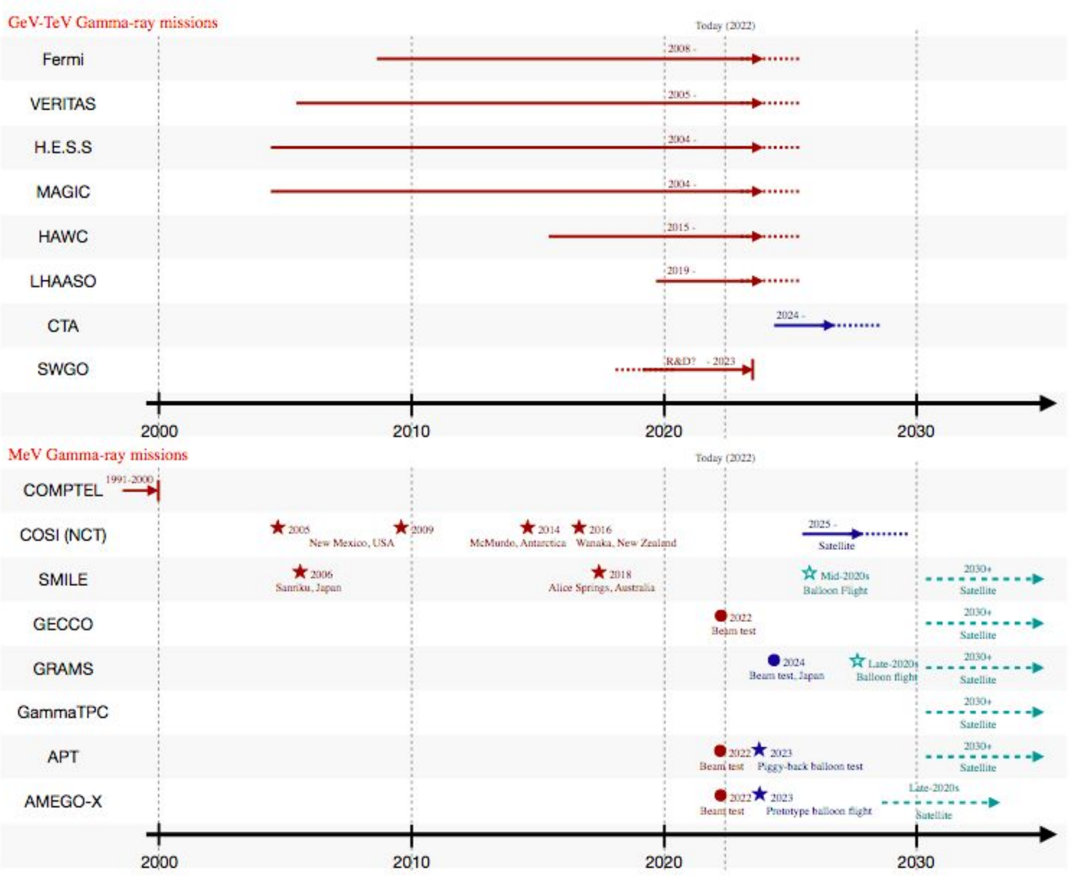
- Particle dark matter is theoretically well-motivated
- Dig deep, search wide - A diverse portfolio of experiments and tools maximizes the possibility of discovering particle dark matter
  - Motivation for experiments at various scales and level of technological maturity
- Understanding how signals and backgrounds manifest in a search is essential to making a robust detection
  - Support of calibration, modeling, and simulation efforts is crucial to enable discovery



Many theoretically-motivated models!

Indirect detection

Example: current/proposed gamma-ray experiments



Wide-ranging: Search for DM interactions throughout cosmos, probing enormous time/distance scales + novel environments

Rich signal space: Signals are naturally multi-messenger and multi-wavelength - multi-scale program maximizes sensitivity + provides powerful consistency checks

Tools for discovery: Essential to characterize astrophysical uncertainties and backgrounds - challenging & currently limit sensitivity

Prospects: Wealth of new ideas for experiments + methods/analyses to extract physics from rich datasets. DOE does not have current plans to fund future experiments.

Goals for indirect-detection experiments

General aims:

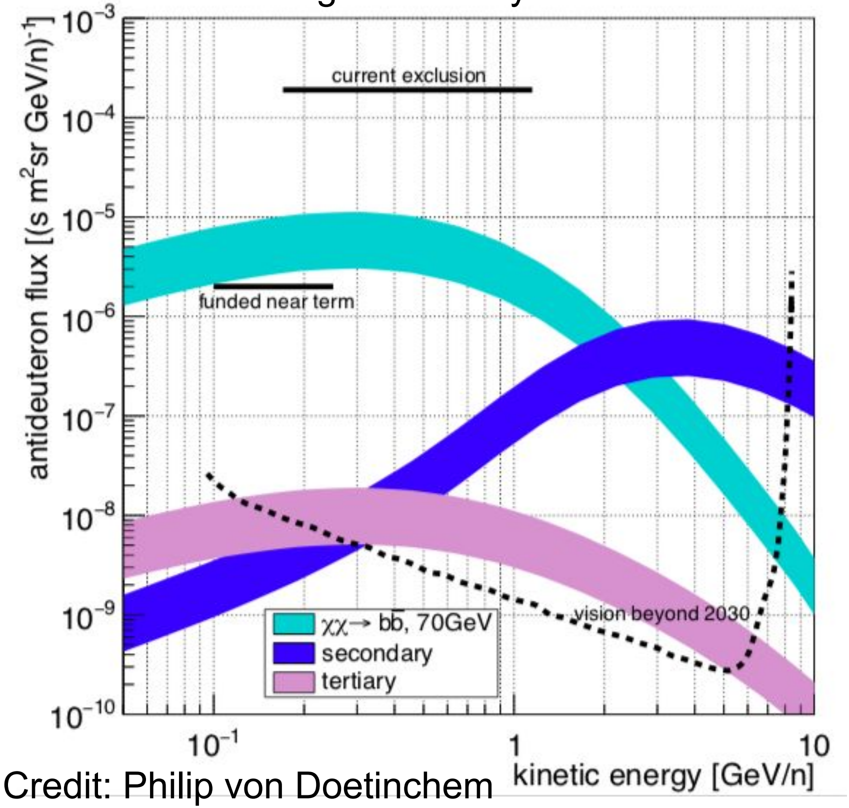
- Improve sensitivity to dark matter across the broadest possible energy range (we explore keV–Planck scale) using an array of cosmic messengers

Experiment-specific aims:

- Probe the minimal version of the thermal freezeout target over its full natural mass range, up to the O(100 TeV) scale set by the unitarity bound [APT, CTA, LHAASO, SWGO] - provides uniquely model-agnostic probe of (s-wave) thermal relics
- Close the “MeV gap” in gamma-ray sensitivity [AMEGO-X, COSI, GECCO, GRAMS, GammaTPC, SMILE]
- Pursue the first detection of low-energy antinuclei as a zero-background channel [ADHD, ALADinO, AMS-100, GAPS, GRAMS]
- Improve sensitivity to monochromatic line signals in X-rays and (not currently listed, but could be added) exclude the minimal sterile neutrino [XRISM, Micro-X, Athena, HEX-P]

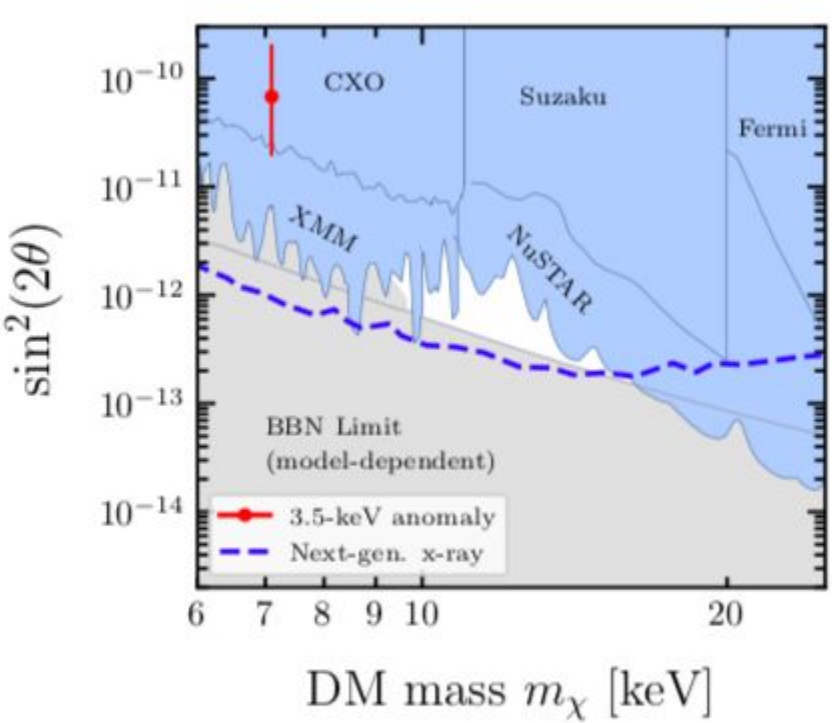
Some new preliminary figures

Discovering cosmic-ray antideuterons



Credit: Philip von Doetinchem

Closing the minimal sterile neutrino window



Credit: Brandon M. Roach

Importance of complementary probes

We discuss a number of avenues to better characterize:

- Cosmic ray production, composition, and propagation
- Galactic diffuse photon emission
- The dark matter density distribution
- etc…

These studies would enable future sensitive indirect searches and provide pathways to resolving current puzzling excesses in the data.

In addition, we discuss a range of theory and analysis needs and opportunities, including new sophisticated analysis methods, data sharing and open software, and production and propagation of signals from ultraheavy DM.

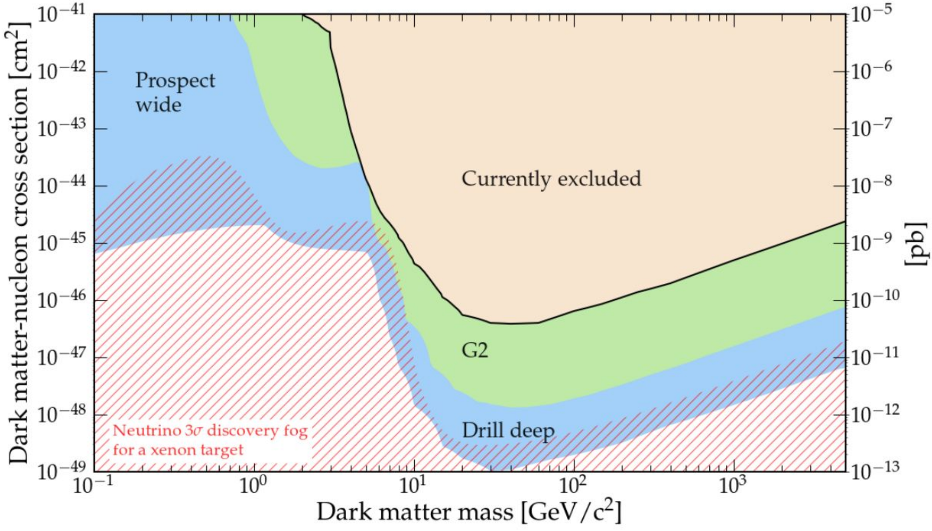
Direct detection

Adaptable: respond to excesses, mitigation of systematic backgrounds, built-in cross-checks

Model-agnostic: search simultaneously for multiple potential signatures; clean, configurable environment

Tools for discovery: need increased support for development of simulations. More precise modeling of signal and background rates

Prospects: *Current generation* in operation. *Next generation** (recommended by P5 in 2014) not yet started in US. Dark Matter New Initiatives (DMNI, 2018) program provides useful model for enabling future directions



*changed language in document away from G2/G3 framing

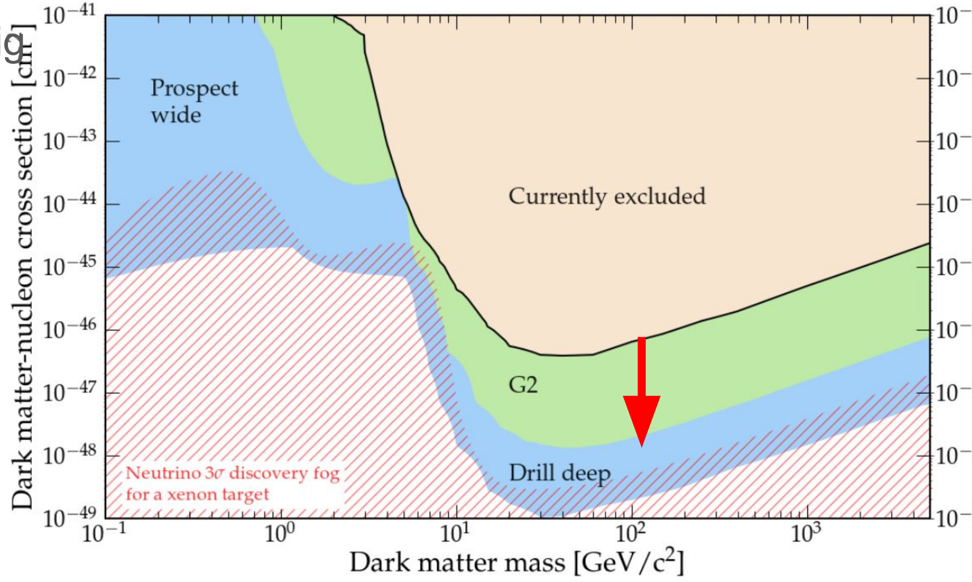
Goals: Digging deep - to the neutrino fog

Mature techniques with the capability to make big advances in sensitivity without significant new R&D

Focus on noble element and phase change detectors above 10 GeV, charge/photon detectors and phase change detectors for 1-10 GeV

Many well-motivated scenarios in this space, including (but not solely) classic WIMPs - how/if to choose benchmarks?

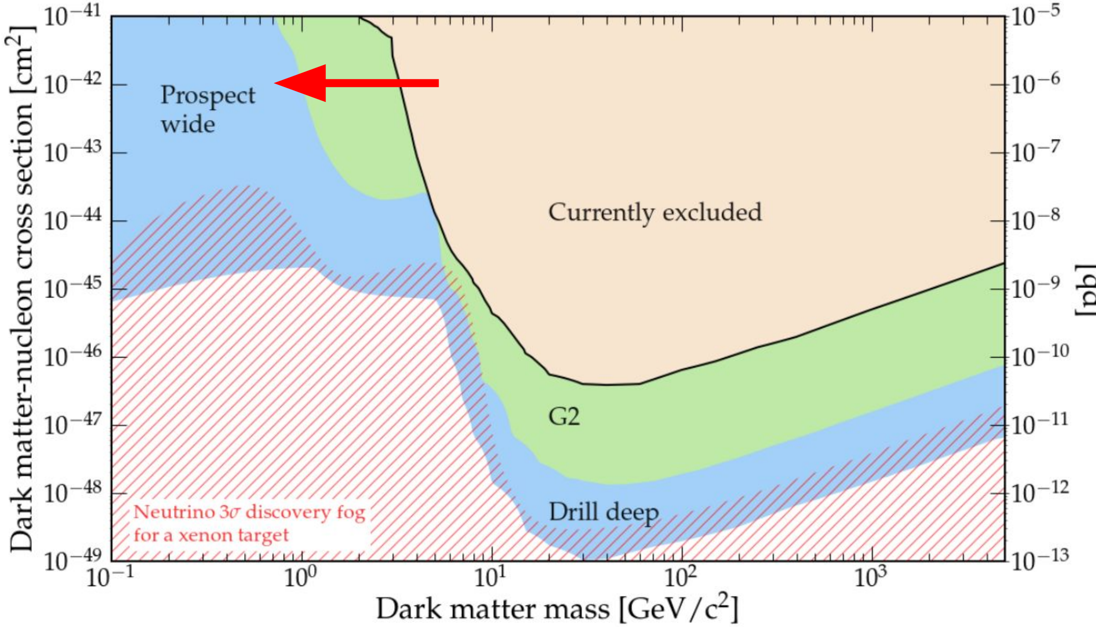
A target for next generation is the neutrino fog - at that point, there will still be more to do, but it may require new techniques and insights



Goals: Searching wide - low-threshold experiments

Enable detection of light dark matter causing tiny energy depositions via scattering, absorption, etc

Wealth of possibilities for detection techniques, explored in DMNI - possible synergies with photonics, materials science, condensed matter



Physics targets and reach

Near-term experiments will:

- probe eV-scale recoils
- test new possibilities for production of DM (eg via freeze-in)
- test new interactions (electron scattering, absorption)

In the further future, thresholds at the meV level may be reachable.

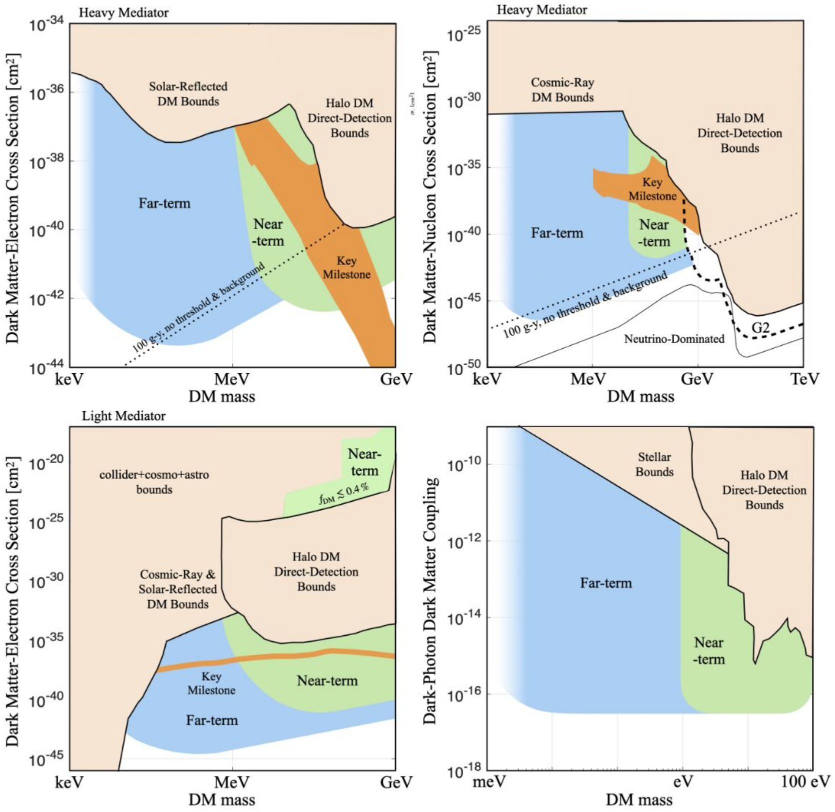
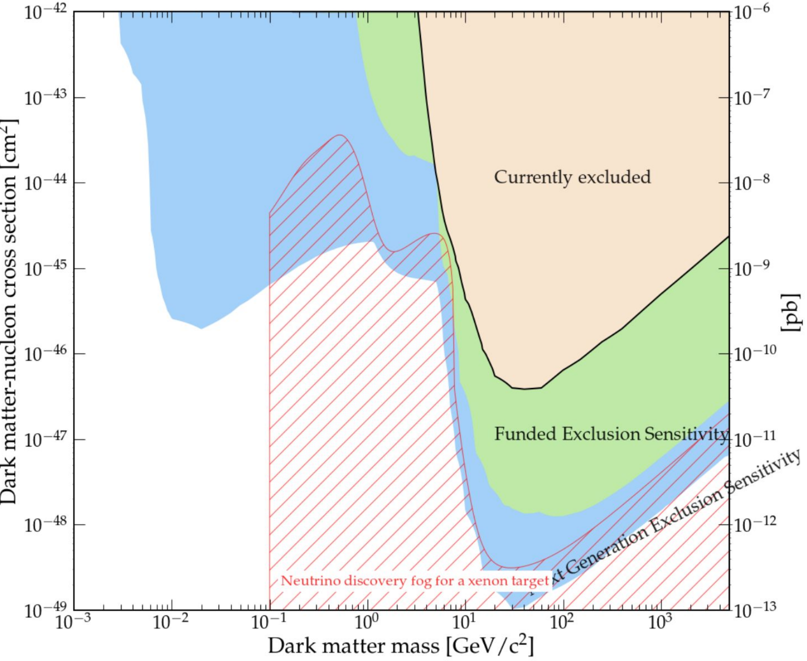
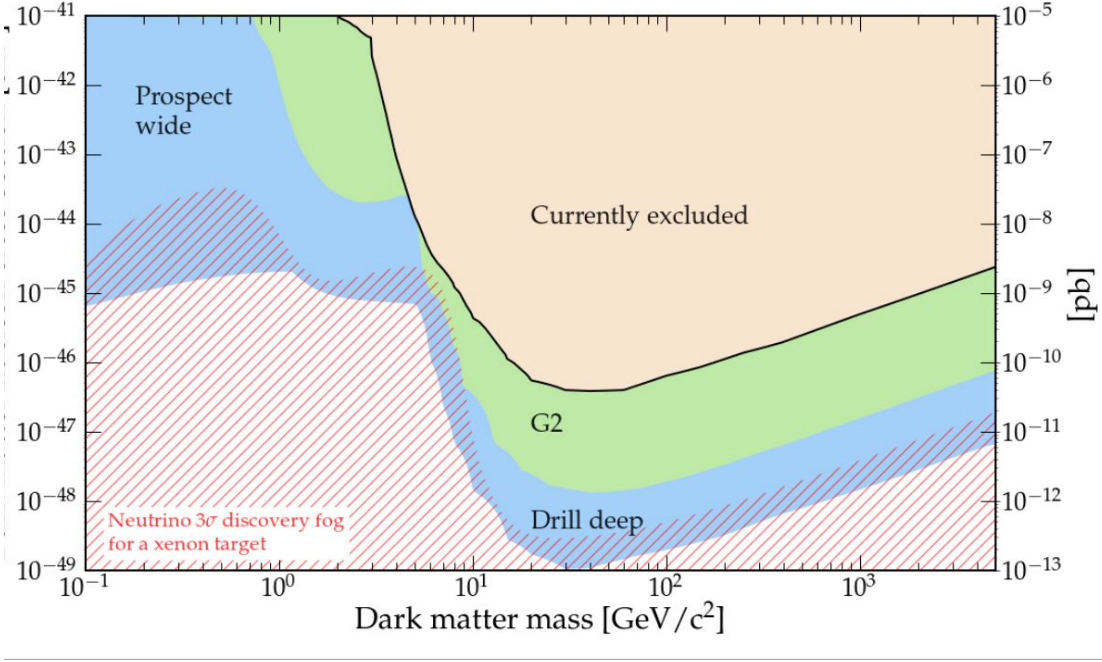


Figure 6: Figures are from Ref. [2] and updated from BRN report [29]. Current 90% c.l. constraints are shown in beige. Approximate regions in parameter space that can be explored in the next ~5 years ("near-term", green) and on longer timescales ("far-term", blue). Orange regions labelled "Key Milestone" represent concrete dark-matter benchmark models and are the same as in the BRN report [29]. Along the dotted line DM would produce about three events in an exposure of 100 gram-year, assuming scattering off electrons in a hypothetical target material with zero threshold.

Figure discussions ongoing - working session tomorrow at 2 pm





Amplify the larger DM message (CF1-3, NF, RF, EF, TF)

- Dark matter is high priority for particle physics over next decade
  - One of two 2014 science drivers that crosses all frontiers (along with Explore the Unknown…)
  - See plenaries from yesterday - huge increases in sensitivity on multiple tracks expected in next decade
- Parameter space has opened up since last Snowmass but we are following a strategy
  - Dig deep into particular regions that are well motivated with mature/maturing technologies - support for larger experiments
    - (although in CF at least, still moderate relative to other parts of HEP program)
  - Search wide to explore low hanging fruit, develop the new technologies and new generation of workforce - portfolio of smaller experiments

Are these the right messages to emphasize? Do you disagree with anything? Are we missing important elements?

Figures

Informative summary figures can effectively summarize key messages and are probably the elements of our report **most likely** to be widely reproduced

Informal feedback from CF conveners:

-focus on figures

-need a summary sensitivity figure for indirect detection [in progress]

-where not already present, consider adding benchmark models to demonstrate sensitivity

What figures are we missing? What needs to be improved? What (if any) benchmarks should we show? Should we think about shared figures with other TGs?

Fig. 1

From WP5

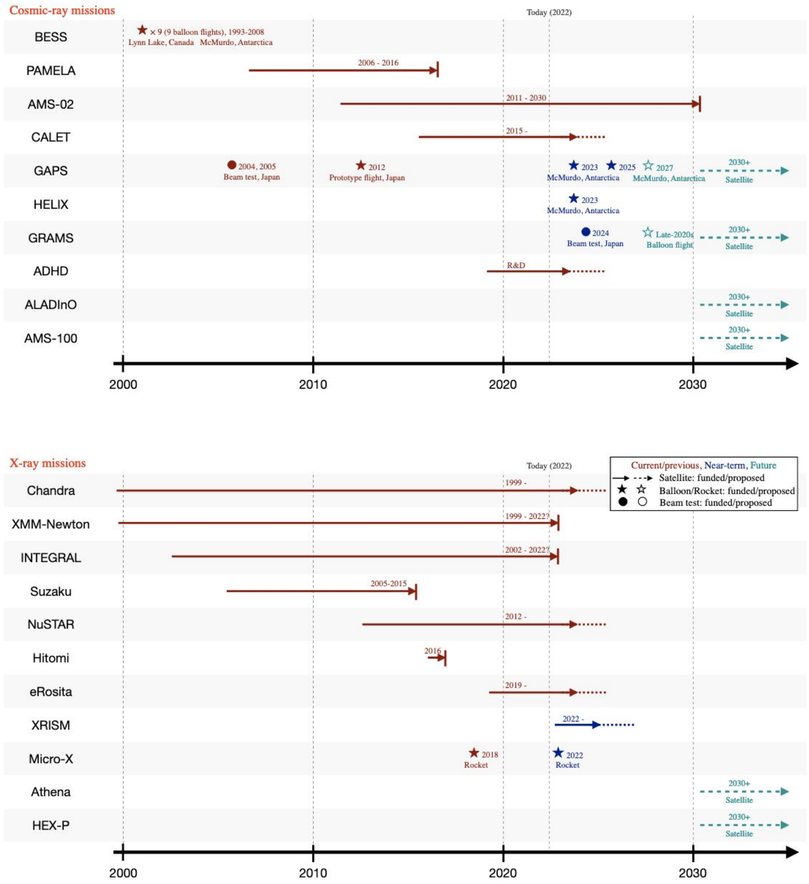


Figure 1: Overview of current, upcoming and proposed missions for cosmic rays (upper panel) and X-rays (lower panel). Current/previous, near-term, and further future missions are marked in red, dark blue and teal respectively. Solid lines/symbols indicate funded experiments while dashed lines or empty symbols indicated proposed experiments. Lines indicate satellite or ground-based missions, stars indicate individual balloon flights, and circles indicate beam tests. Reproduced from Ref. [5].

Fig. 2

From WP5

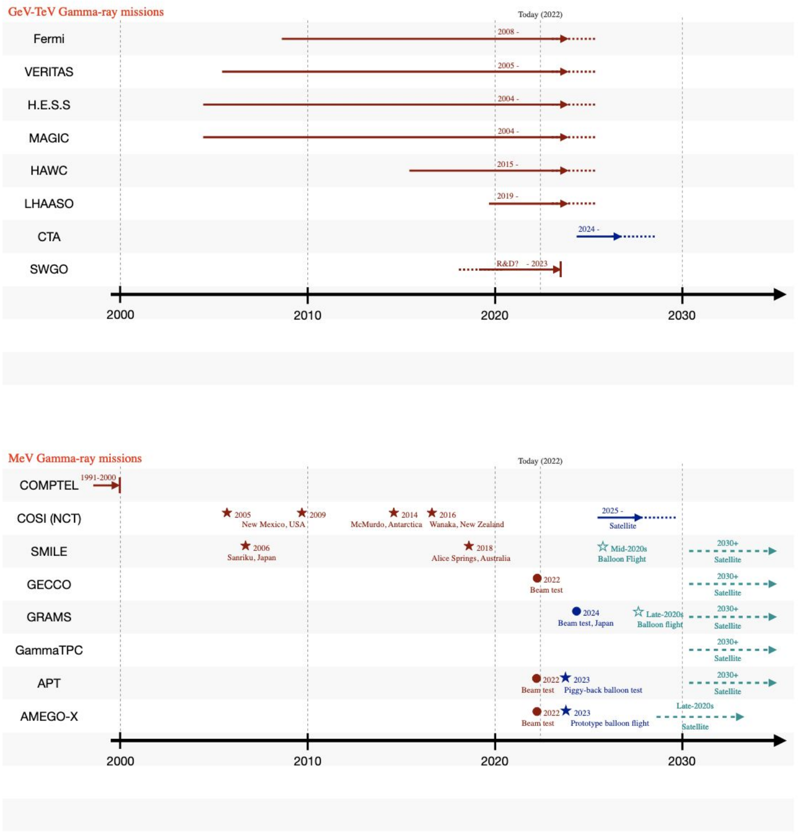


Figure 2: Overview of current, upcoming and proposed missions for gamma-rays in the GeV-TeV+ band (upper panel) and MeV band (lower panel). Current/previous, near-term, and further future missions are marked in red, dark blue and teal respectively. Solid lines/symbols indicate funded experiments while dashed lines or empty symbols indicated proposed experiments. Lines indicate satellite or ground-based missions, stars indicate individual balloon flights, and circles indicate beam tests. Reproduced from Ref. [5]

Fig. 3

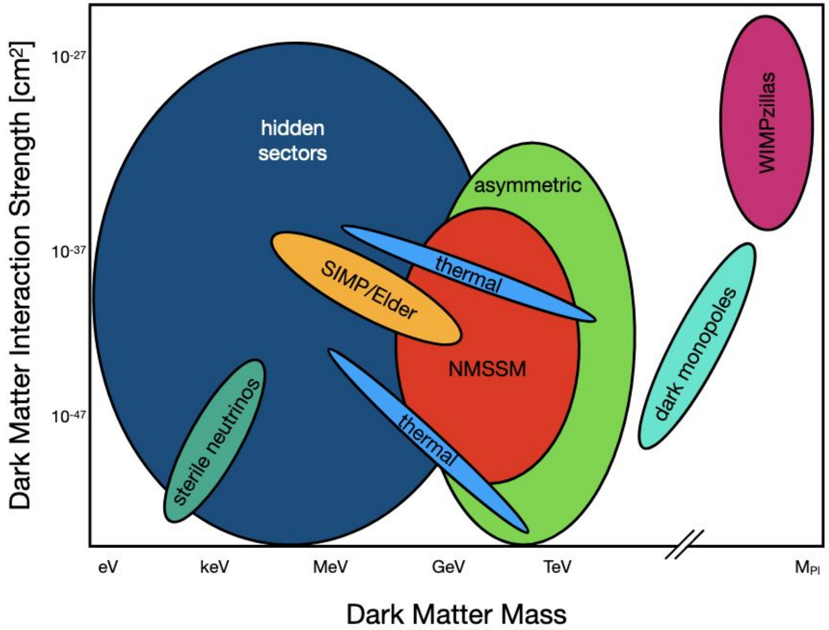


Figure 3: Cartoon figure of the model space for direct detection. Included are candidates of thermal dark matter, supersymmetry, asymmetric dark matter [183], SIMP/Elder [178–181], dark monopoles [184], WIMPzillas [14], and hidden sector dark matter [21]. Note that the interaction cross-section can be for either scattering with nucleons or electrons, depending on the specific model.

Fig. 4

From WP1

Current version from Ben Loer in slack

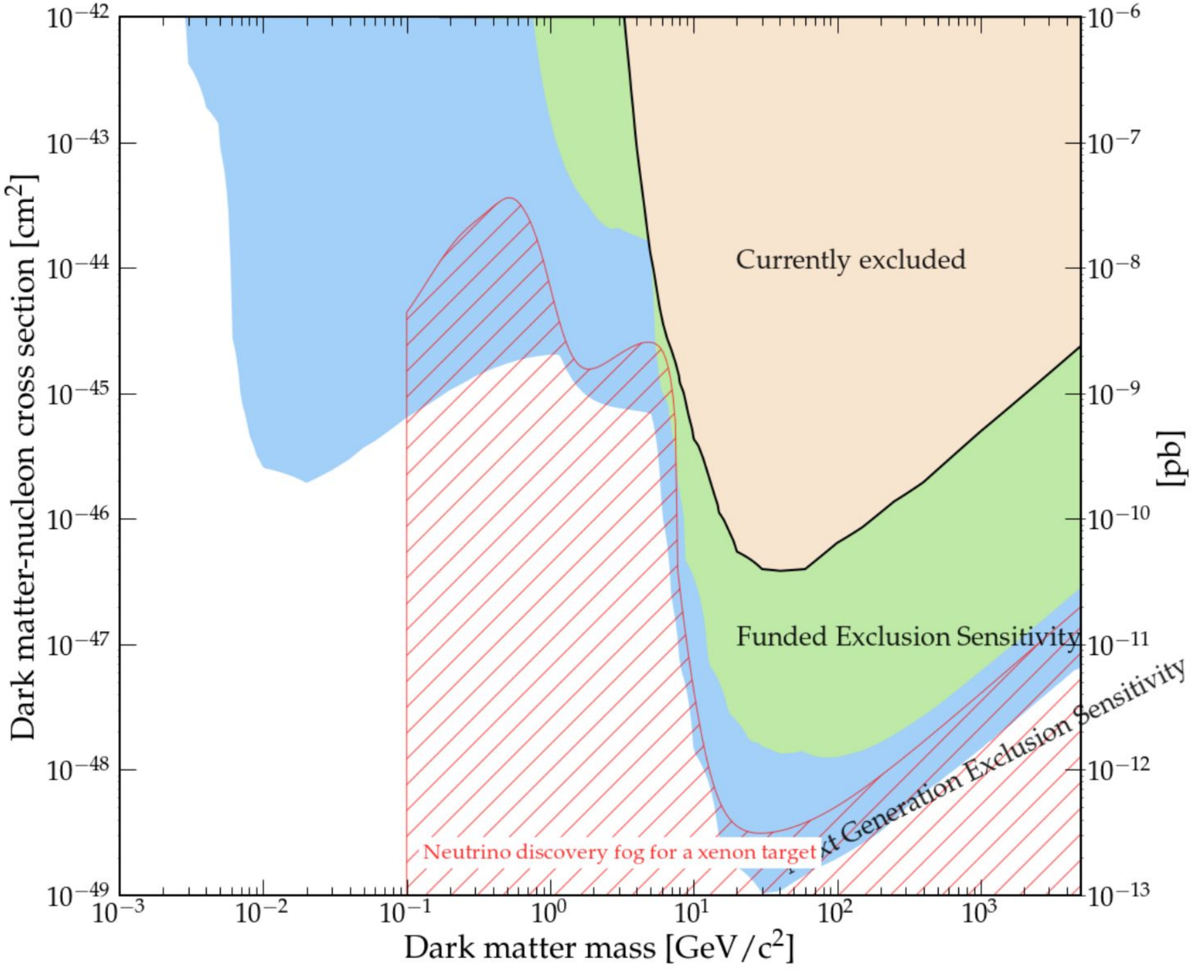


Fig. 6

From WP2

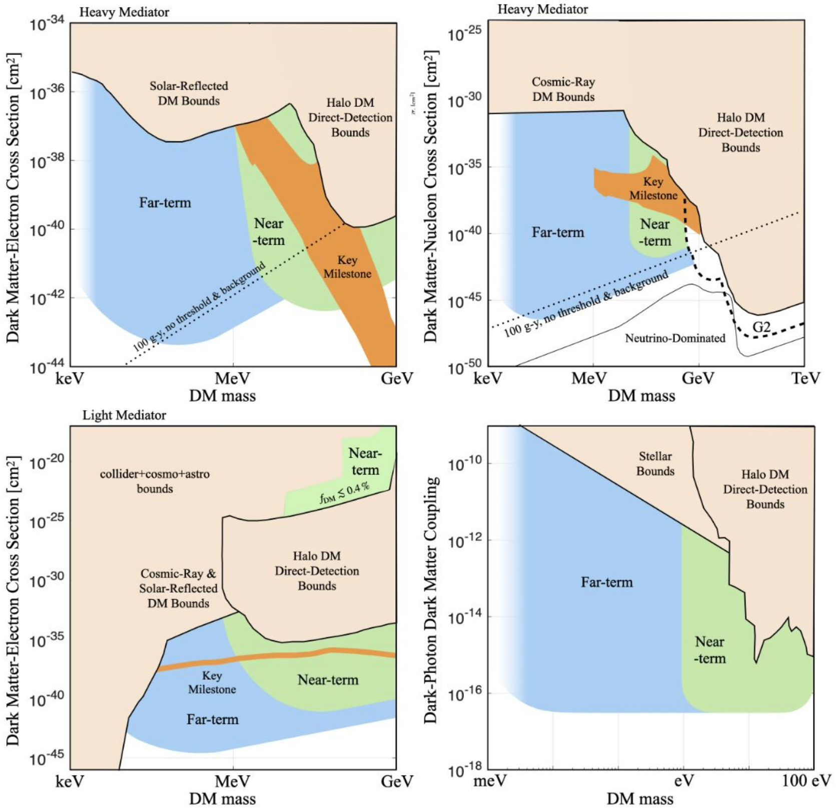


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Fig. 7

From WP8

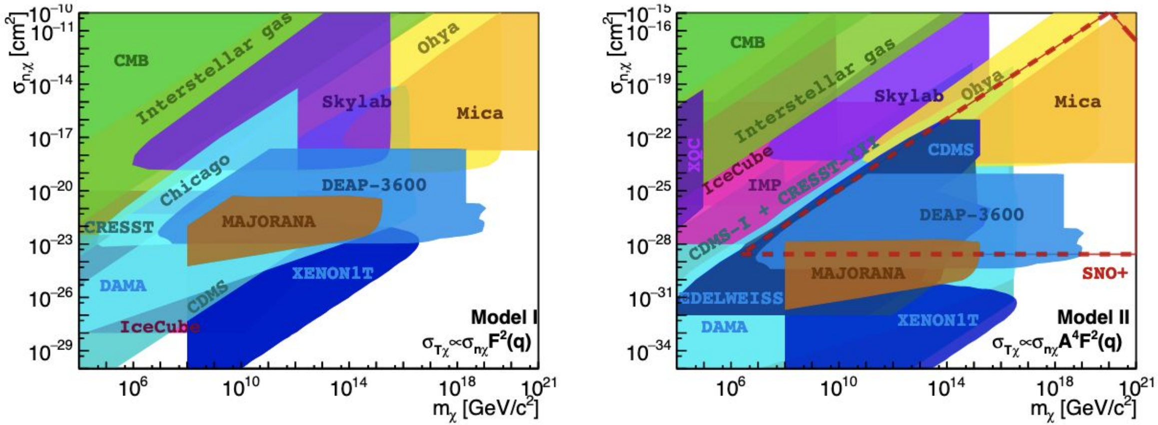
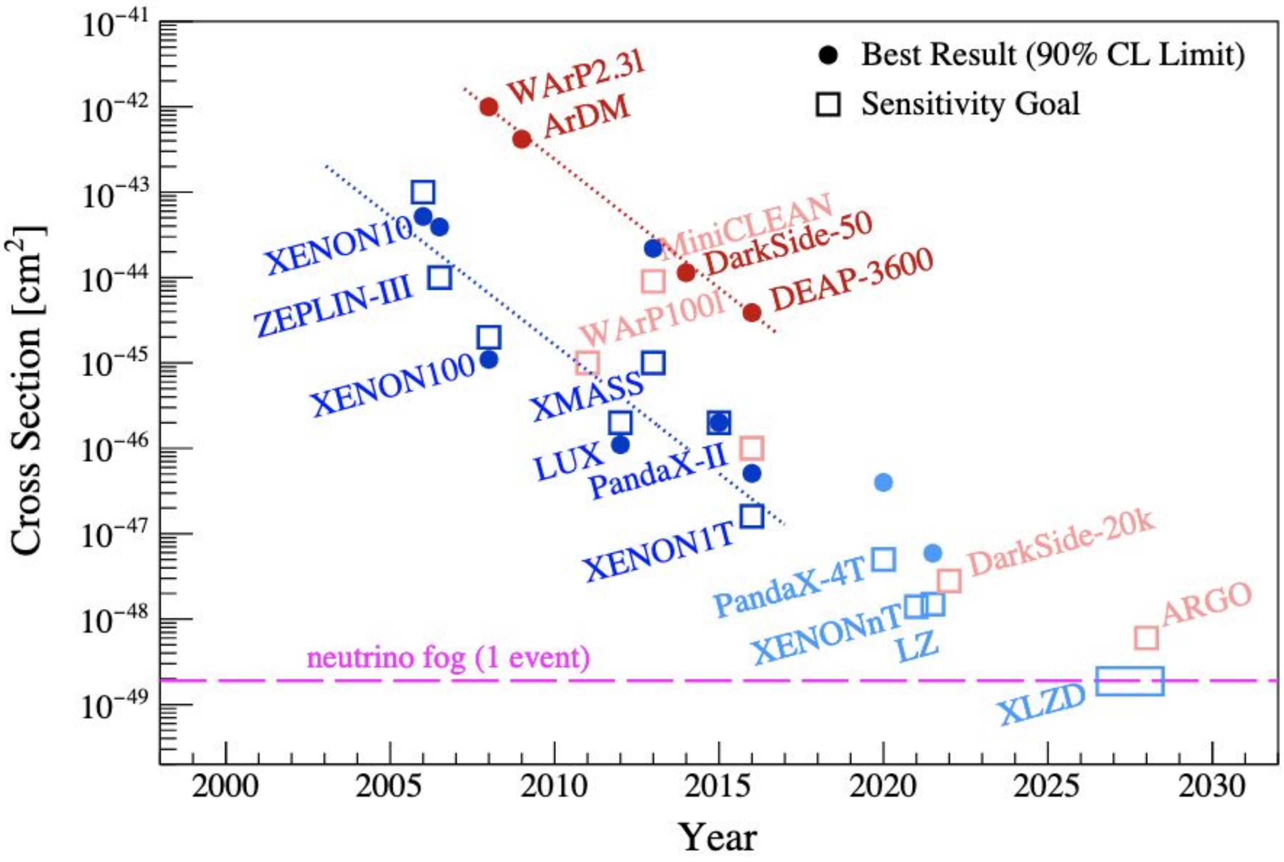


Figure 7: Current and projected experimental regions of ultraheavy parameter space excluded by cosmological/astrophysical constraints (green), direct detection DM detectors (blue), neutrino experiments (red/orange), space-based experiments (purple), and terrestrial track-based observations (yellow). Both models considered here assume different relations for the cross section scaling from a single nucleon to a nucleus with mass number A. In the left plot, we assume no scaling with A; in the right plot, we assume the cross section scales like A^4 (*e.g.* , with two powers coming from nuclear coherence, and two from kinematic factors). Limits are shown from DEAP-3600 [205], DAMA [206, 207], interstellar gas clouds [208, 209], a recast of CRESST and CDMS-I [210], a recast of CDMS and EDELWEISS [211, 212], a detector in U. Chicago [213], a XENON1T single-scatter analysis [214], tracks in the Skylab and Ohya plastic etch detectors [207], in ancient mica [215], the MAJORANA demonstrator [214], IceCube with 22 strings [216], XQC [217], CMB measurements [218, 219], and IMP [220]. Also shown is the future reach of the liquid scintillator detector SNO+ as estimated in [185, 221]. Reproduced from Ref. [8].

Fig. 8

From WP1



BONUS SLIDES

Executive summary first paragraph

One of the most important scientific goals of the next decade is to reveal the nature of dark matter (DM).

A diverse, continuous portfolio of experiments that includes both direct and indirect detection techniques at multiple scales maximizes the possibility of discovering particle dark matter.

Detailed calibrations and modeling of signal and background processes are required to make a convincing discovery.

The US has a leading role in both direct and indirect detection dark matter experiments – to maintain this leading role, it is imperative to continue funding major experiments and support a robust R&D program.