CF1 Particle Dark Matter Snowmass, July 18 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

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

Additional White Papers submitted to CF1

A. Aboubrahim, W.-Z. Feng, P. Nath, Z.-Y. Wang, “Hidden sectors and a multi-temperature universe”

M. Zaazoua, L. Truong, K. A. Assamagan, F. Fassi, “Higgs portal vector dark matter interpretation: review of Effective Field Theory approach and ultraviolet complete models”

Thomas G. Rizzo, “Portal Matter and Dark Sector Phenomenology at Colliders”

Krystal Alfonso, Gabriela R. Araujo, Laura Baudis, Nathaniel Bowden, et al. ”Passive low energy nuclear recoil detection with color centers – PALEOCCENE”

G. Wang, C. L. Chang, M. Lisovenko, V. Novosad, V. G. Yefremenko, J. Zhang. ”Light Dark Matter Detection with Hydrogen-rich Crystals and Low-Tc TES Detectors“

Additional White Papers submitted to CF1

J. Aalbers, K. Abe, V. Aerne), F. Agostini, S. Ahmed Maouloud, D.S. Akerib, et al. ”A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics”

Reza Ebadi, Mason C. Marshall, David F. Phillips, Tao Zhou, Michael Titze, et al. ”Directional Detection of Dark Matter Using Solid-State Quantum Sensing“

C. A. J. O'Hare, D. Loomba, K. Altenmüller, H. Álvarez-Pol, F. D. Amaro, et al. ”Recoil imaging for dark matter, neutrinos, and physics beyond the Standard Model”

A. Abed Abud, B. Abi, R. Acciarri, et al. (DUNE Collaboration). ”DUNE Physics Summary”

Tao Han, Zhen Liu, Lian-Tao Wang, Xing Wang. ”WIMP Dark Matter at High Energy Muon Colliders”

Pouya Asadi, Saurabh Bansal, Asher Berlin, Raymond T. Co, Djuna Croon, Yanou Cui, et al. ”Early-Universe Model Building”

Additional White Papers submitted to CF1

Benjamin Monreal. ”High-pressure TPCs in pressurized caverns: opportunities in dark matter and neutrino physics”

Alaina Attanasio, Sunil A. Bhave, Carlos Blanco, Daniel Carney, Marcel Demarteau,, et al. (Windchime Collaboration). ”The Windchime Project”

Junhui Liao, Yuanning Gao, Zhuo Liang, Zebang Ouyang, Chaohua Peng, Fengshou Zhang, Lei Zhang, Jian Zheng, Jiangfeng Zhou. ”Introduction to a low-mass dark matter project, ALETHEIA: A Liquid hElium Time projection cHambEr In dArk matter”

Andrea Mitridate, Tanner Trickle, Zhengkang Zhang, Kathryn M. Zurek. ”Light Dark Matter Direct Detection at the Interface With Condensed Matter Physics”

Additional White Papers submitted to CF1

M.F. Albakry, I. Alkhatib, D.W.P. Amaral, T. Aralis, T. Aramaki, I.J. Arnquist, I. Ataee Langroudy, et al. ”A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility“

Alexander Aryshev, Ties Behnke, Mikael Berggren, James Brau, Nathaniel Craig, et al. ”The International Linear Collider”

A. Avasthi, T. Bezerra, A. Borkum, E. Church, J. Genovesi, J. Haiston, C. M. Jackson, et al. ”Low Background kTon-Scale Liquid Argon Time Projection Chambers”

The ATLAS and CMS Collaborations. ”Physics with the Phase-2 ATLAS and CMS Detectors”

Rouven Essig, Yonatan Kahn, Simon Knapen, Andreas Ringwald, Natalia Toro. ”Theory Frontier: Theory Meets the Lab”

CF1-pertinent sessions in Seattle (all times local)

Monday 7/18	8am-9am: CF1 discussion (18I) - discuss feedback and organize teams for outstanding needs for CF report	
Tuesday 7/19	8am-12pm: CF/EF/RF/TF dark matter complementarity (20L)	
	3.30pm-5pm: Paths to discovery at the Cosmic Frontier (half-plenary, 3 talks)	
Wednesday 7/20	8am-12pm: all-CF discussion (23Q)	will include presentation of key messages from topical groups,
		discussion of cross-topical-group plots, tables, etc for Frontier Report
Thursday 7/21	8am-12pm: all-CF discussion (24M)	all CF report discussion, panel on synergies with between astrophysics and particle physics
	5.30pm-7pm: Colloquium on Cosmic Frontier Probes of Fundamental Physics (plenary, introduction + panel)	
Saturday 7/23	8am-12pm:	IF/CF/NF instrumentation for dark matter and neutrino detectors (21G/22J, merged) - mostly organized by NF so far - talks and panel discussion, looking for dark matter contributors
		IF/CF/CompF instrumentation for the cosmic frontier (21H)
		TF/CF cosmic frontier theory (19K) - panel + talks
Sunday 7/24	10am-12pm: NF/CF/TF high energy and ultra-high energy astrophysical neutrinos	

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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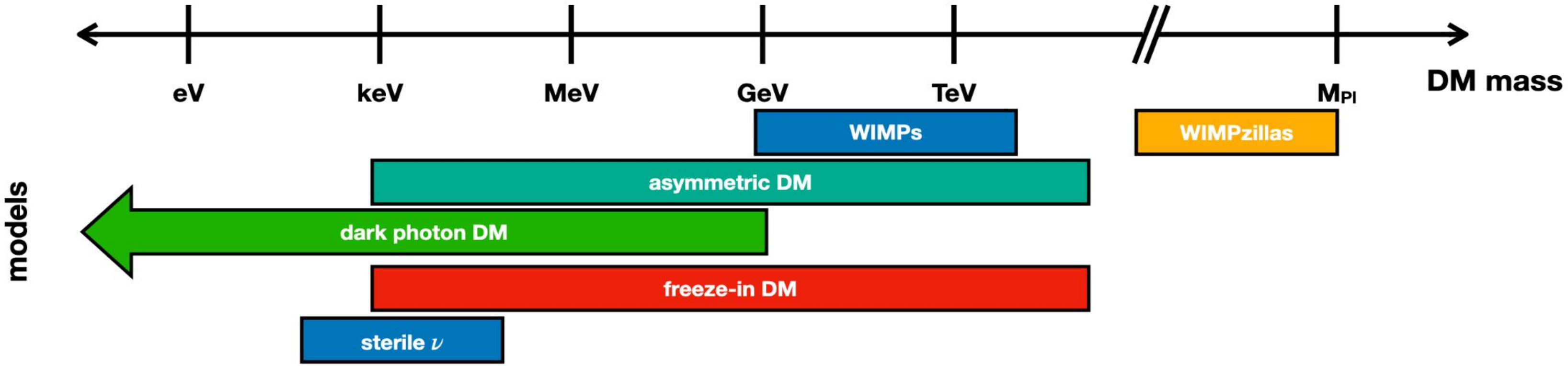
CF1: Particle-Like Dark Matter

- Particle dark matter is theoretically well-motivated
- 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

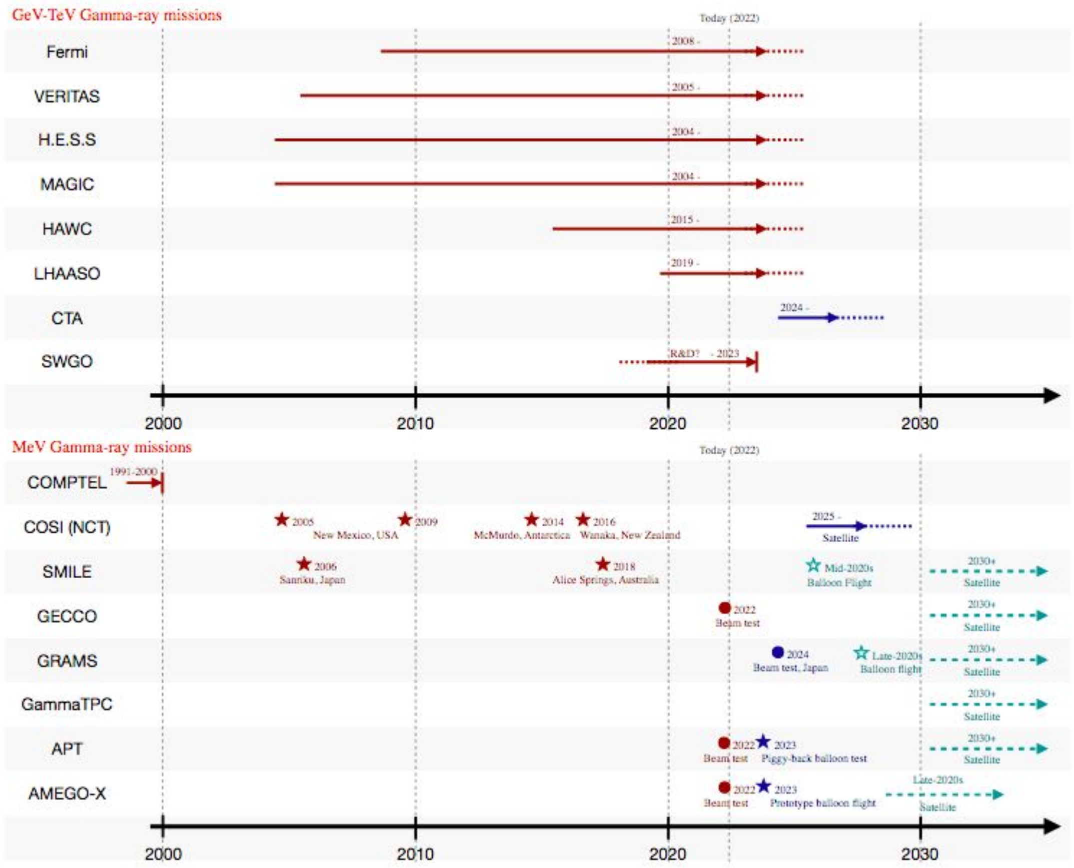
Wide-ranging: Search for DM interactions throughout cosmos, probing enormous time/distance scales + novel environments

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 systematic uncertainties and backgrounds - challenging & currently limit sensitivity

Prospects: Many new ideas for experiments and methods/analyses

Example: current/proposed gamma-ray experiments



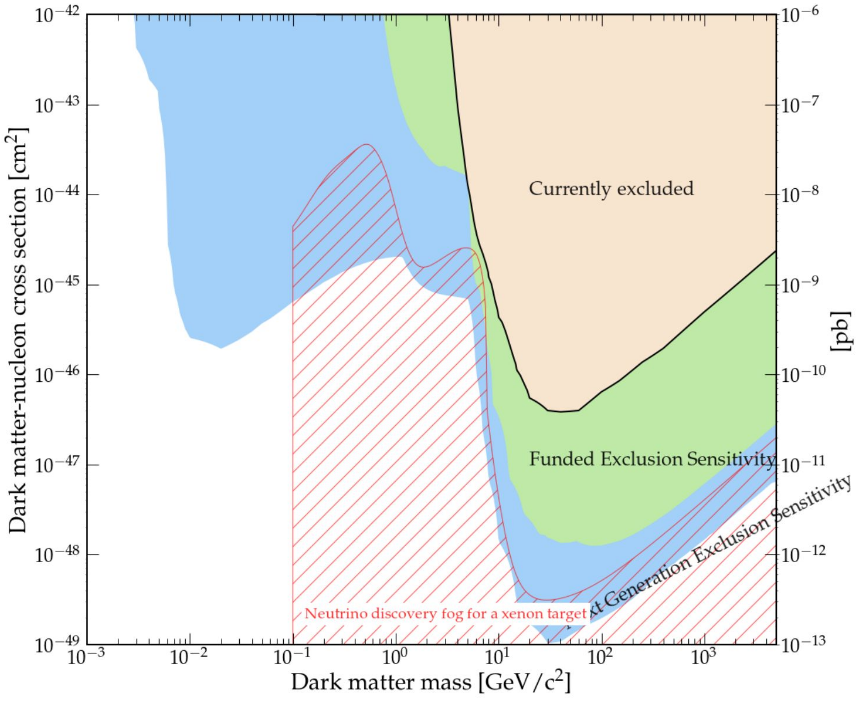
Direct detection

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

Model-independent: 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: *G2* in operation. *Next generation* (recommended by P5 in 2014) not yet started in US. New Initiatives in Dark Matter (2018) provide useful model for enabling future directions



Planned CF1-relevant statements for half-plenary talk

Mature direct-detection technologies will probe orders of magnitude of new parameter space, into the neutrino fog, covering a range of highly-motivated and parsimonious models (in particular classic WIMPs, which remain well-motivated)

New technologies allowing detection of very low-energy recoils will test entirely new physical regimes and scenarios for DM production

Photon and cosmic-ray telescopes will have the capability to test thermal relic dark matter up to the unitarity bound and seek signals in new background-free channels

- From draft: we named some indirect-detection goals as probing the thermal relic across its full natural mass range, closing the “MeV gap” in sensitivity, & seeking to detect low-energy antinuclei - are these OK? Others?

A broad and multi-scale experimental program allows us to test many different scenarios, to cross-check possible signals, and to triangulate the properties of the dark matter in the case of a detection

Support for theory and study of systematics, backgrounds, and calibration are essential to understand what these sensitive experiments will tell us

DD message

- Balance between large scale experiments, small scale experiments, and R&D
  - A few comments along these lines
    - Ex: “Text is in danger of making the pursuit of direct dark matter detection sound like a cross between a rolling R&D program and a range of small scale experiments? Can we try to get a more appropriate emphasis on the large-scale program commensurate with the fraction of researchers pursuing that type of work?”
- See also Figure 4 discussion
- Need to agree on final message
  - Support for large scale/next generation/G3/… experiments to drill deep
  - Support for mechanism to enable small scale program
  - Support of simulations/backgrounds/calibrations - all the things that enable a discovery

Example wording starting from suggestion from Rafael Lang: "To address this grand challenge, we must employ multiple experimental techniques spanning the entire range of the HEP program, including both direct and indirect detection techniques. Moderate- and large-scale experiments drill deep into particular DM scenarios such as WIMPs, whereas small-scale experiments improve our versatility and ability to test a broader range of models."

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

Figures

Informative summary figures are the elements of our report **most likely** to propagate to the Frontier Report / Snowmass Report and to be used in widely-seen presentations

Informal feedback from CF conveners:

-focus on figures

-need a summary sensitivity figure for indirect detection

-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?

Fig. 1

From WP5

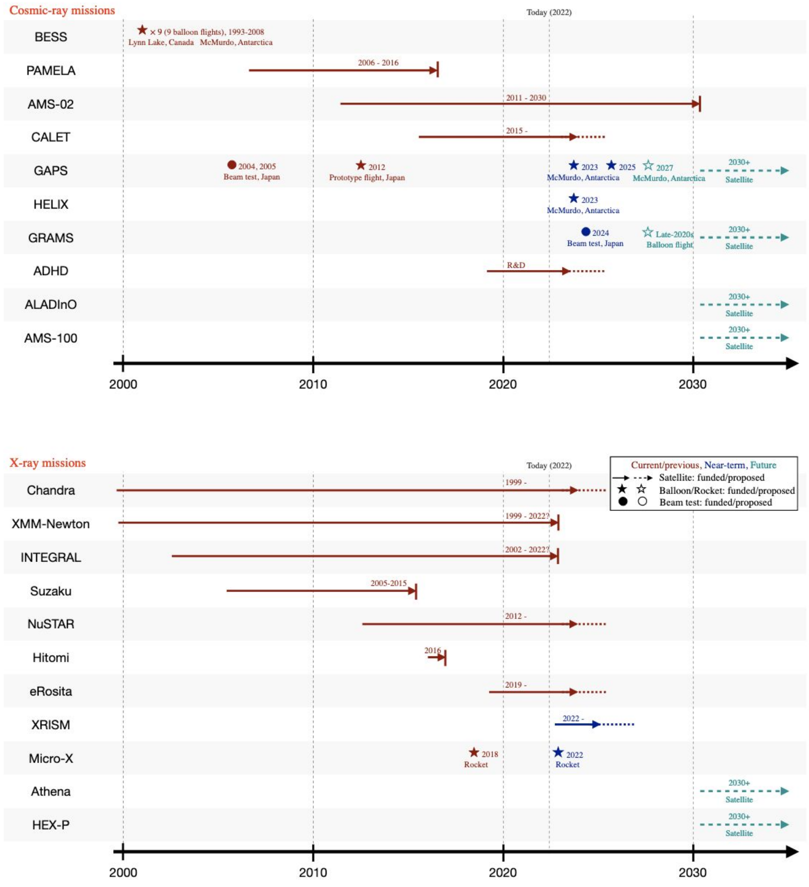


Figure 1: Overview of current, upcoming and proposed missions for cosmic rays (upper panel) and X-rays (lower panel). Current/previous, near-term, and further future missions are marked in red, dark blue and teal respectively. Solid lines/symbols indicate funded experiments while dashed lines or empty 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

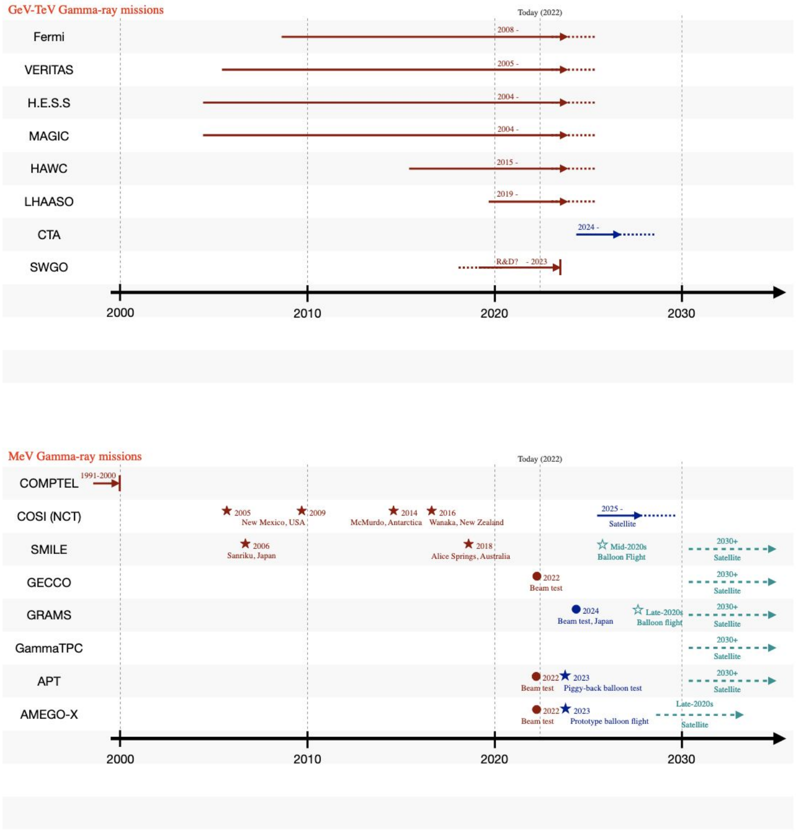


Figure 2: Overview of current, upcoming and proposed missions for gamma-rays in the GeV-TeV+ band (upper panel) and MeV band (lower panel). Current/previous, near-term, and further future missions are marked in red, dark blue and teal respectively. Solid lines/symbols indicate funded experiments while 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

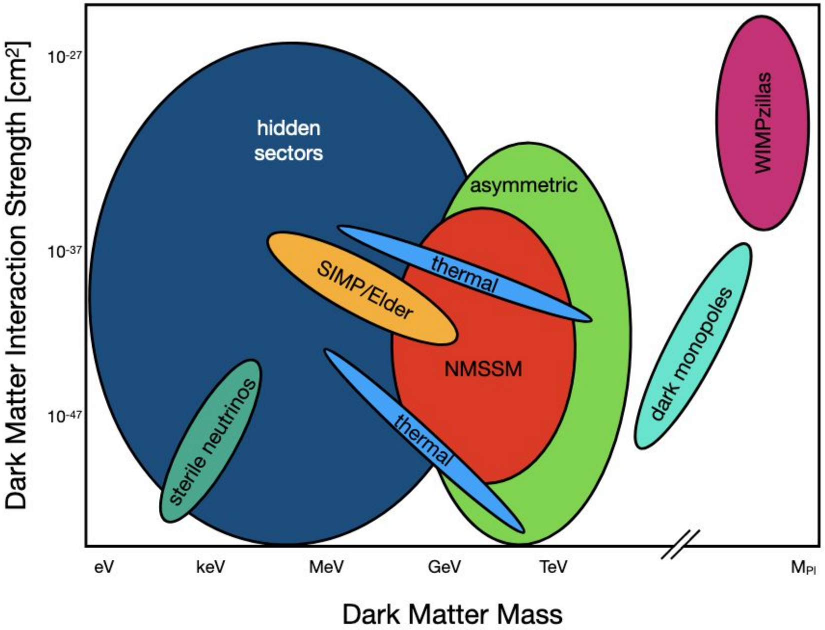


Figure 3: Cartoon figure of the model space for direct detection. Included are candidates of thermal dark matter, supersymmetry, asymmetric dark matter [183], SIMP/Elder [178–181], dark monopoles [184], WIMPzillas [14], and hidden sector dark matter [21]. Note that the interaction cross-section can be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

Fig. 4

From WP1

Current version from Ben Loer in slack

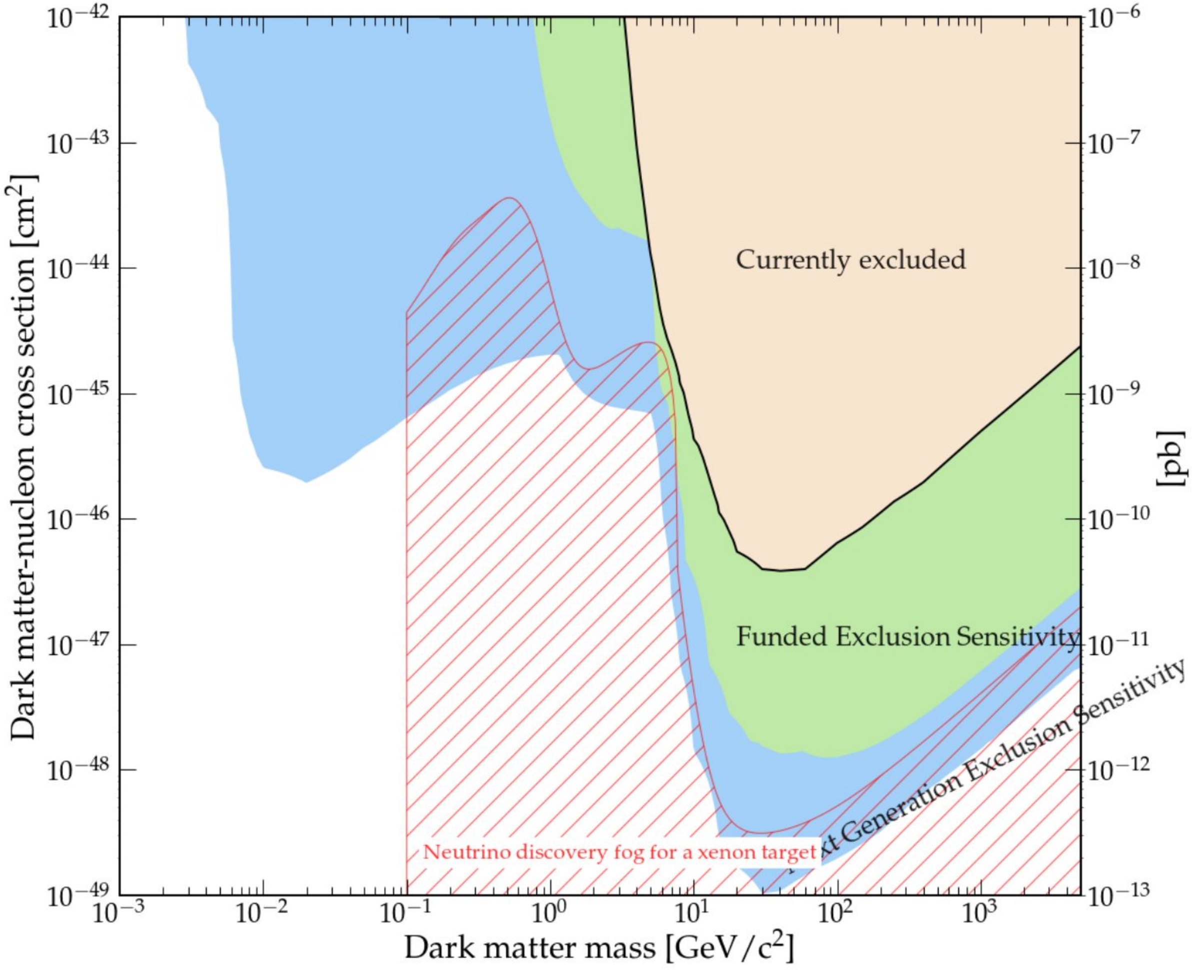


Fig. 6

From WP2

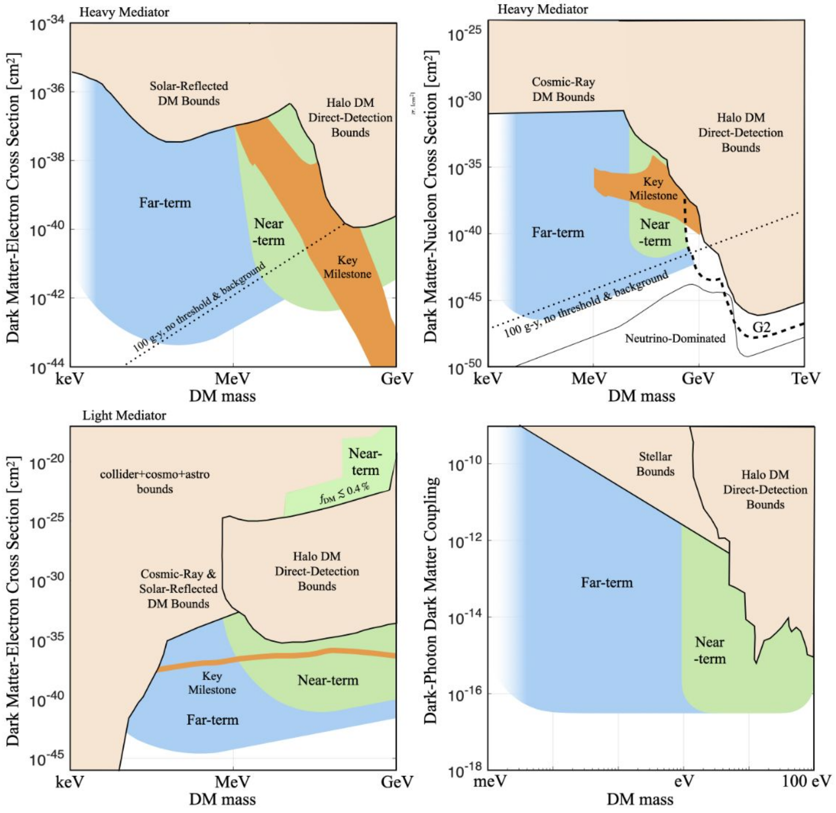


Figure 6: Figures are from Ref. [2] and updated from BRN report [29]. Current 90% c.l. constraints are shown in beige. Approximate regions in parameter space that can be explored in the next ∼5 years ("near-term", green) and on longer timescales ("far-term", blue). Orange regions labelled "Key Milestone" 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.

Fig. 7

From WP8

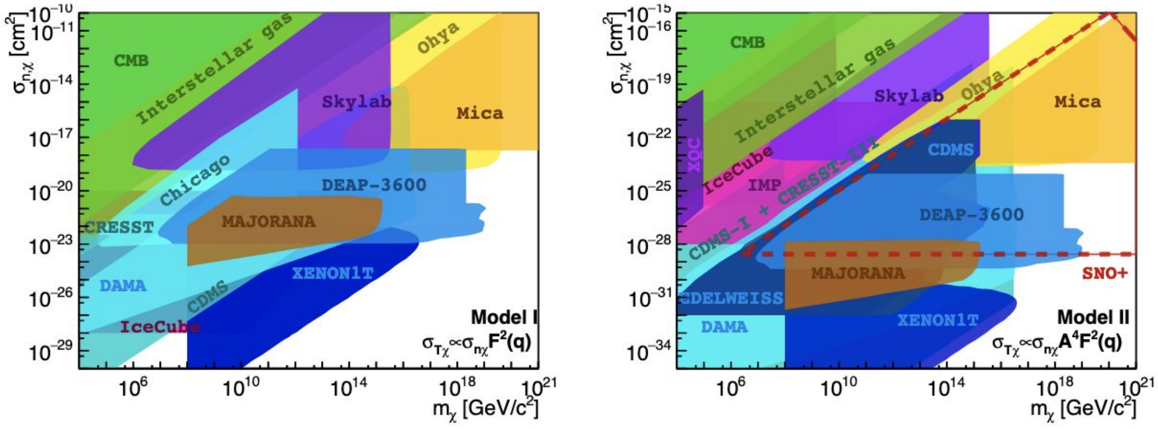


Figure 7: Current and projected experimental regions of ultraheavy parameter space excluded by cosmological/astrophysical constraints (green), direct detection DM detectors (blue), neutrino experiments (red/orange), space-based experiments (purple), and terrestrial track-based observations (yellow). 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

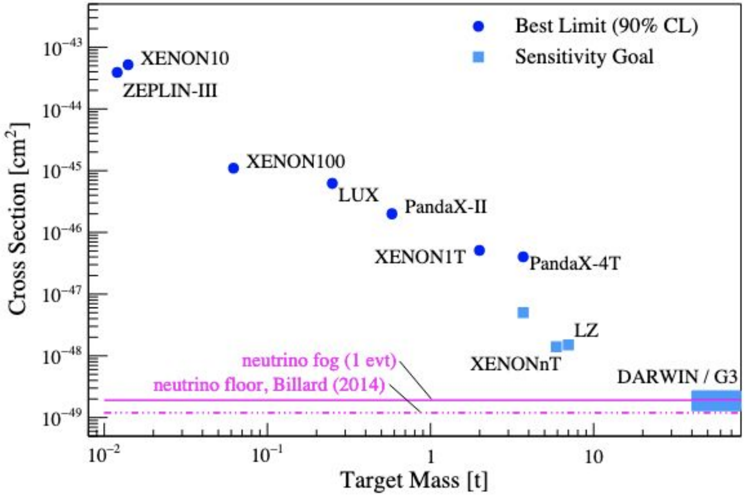


Figure 8: Figure taken from Ref. [1]. Development of LXe-TPC technology. The plot shows the improvement in sensitivity to spin independent WIMP-nucleon coupling (for a mass of 50 Gev/c^2) achieved by LXe experiments of increasing target masses. Sensitivity goals are also reported for experiments that have not yet been completed. Cross section values and background rates are extracted from Ref. [174, 235–243].