P5 Townhall Virginia Tech (June 27)

Complementarity of Dark Matter Studies

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with thanks to Caterina Doglioni, Alex Drlica-Wagner, Yu-Dai Tsai, and the other editors and authors of the Snowmass Cross-Frontier Report on Dark Matter Complementarity

Dark matter complementarity in Snowmass

- How should we think about different searches for dark matter?

- We are in an **exploratory phase** where new ideas can be implemented on short timescales, operating alongside longer-term projects (eg HL-LHC, FCC, Gen-3 direct detection)
→ Key point for DM discoveries and characterization: **work together**!

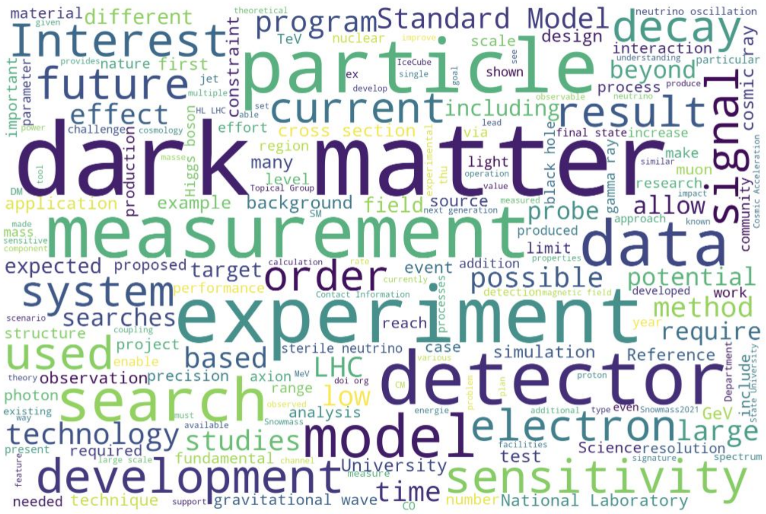
- Snowmass DM complementarity report (arXiv:2211.07027, extended version arXiv:2210.01770) was written with input from all Frontiers, summarizes general strategy + provides specific case studies

https://gordonwatts.github.io/snowmass-loi-words

Word Clouds

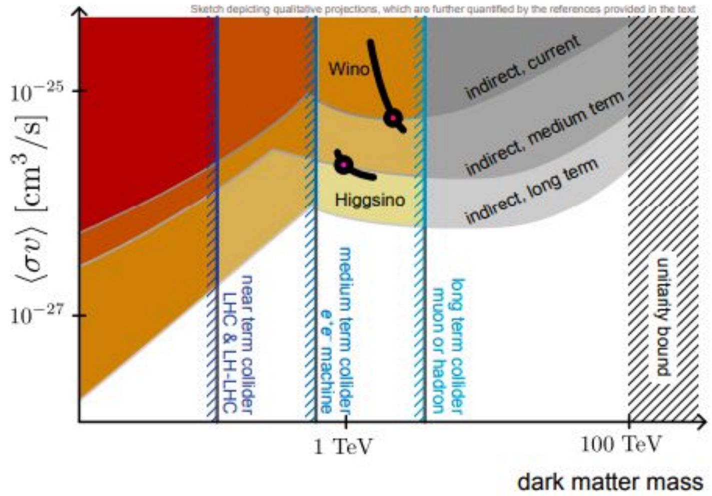
Word clouds are made by looking at the word frequency in the LOI's. The more frequent the word, the larger the font-size in the word cloud.

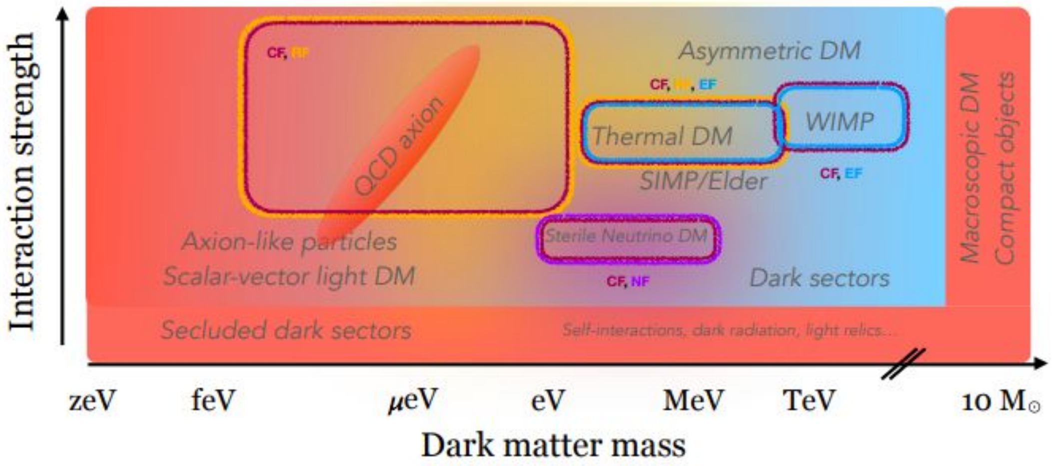
All LOI's



Aspects of complementarity

- Different approaches to DM search allow us to probe **different fundamental properties** of DM (will be necessary to fully identify the DM and understand its physics).
- Different approaches to DM search offer **unique discovery sensitivity** to distinct scenarios and regions of parameter space.
- Results from any one class of searches can **continuously inform the interpretation** of other measurements.
- Different DM experiments can be co-located and/or profit from the same or similar technological infrastructure.





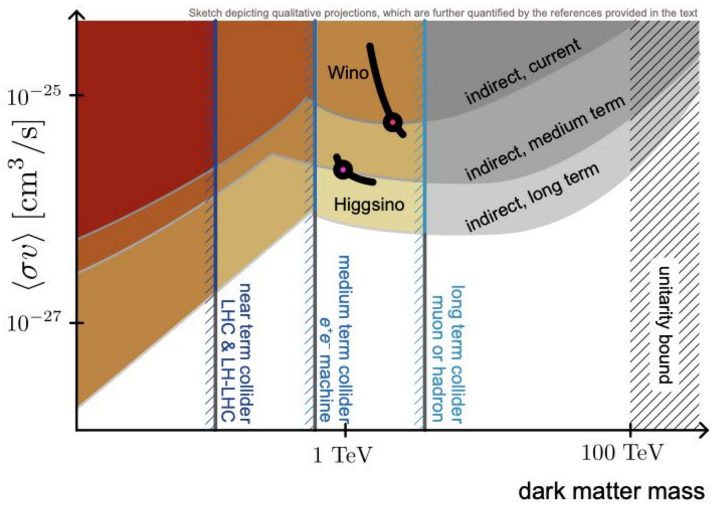
A cross-Frontier discovery strategy

- Build a **portfolio of experiments of different scales**
    - Scale up mature technologies that can promise significant sensitivity gains
    - Maximize and make accessible large projects' science output
    - Develop potentially transformative new technologies to maturity
    - Build experience with (small-scale) project execution and train the next generation
    - Build a broad and compelling DM portfolio and accelerate the pace of discovery
    - Specific example at small-scale: execute DMNI program and similar future calls
- **Leverage US expertise** in international projects
- Further **strengthen the theory program**
    - key for new insights, analysis methods, and cross-connections between Frontiers
- Develop mechanisms to **support interdisciplinary collaborations** that enable discovery
    - also beyond HEP: relevant expertise in nuclear physics, metrology, astrophysics, condensed matter, atomic physics, etc
- **Dedicated/targeted research funding** is key

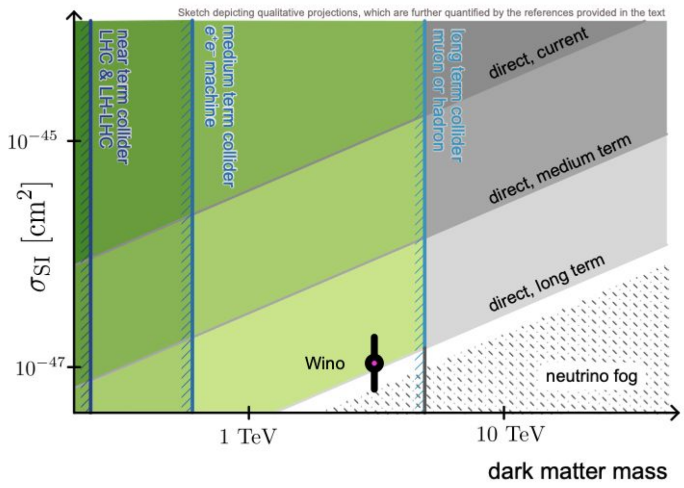
Backup slides

(images from arXiv:2210.01770 and from the participants
to the Snowmass DM complementarity meetings!)

Energy Frontier / Cosmic Frontier complementarity



(a)



(b)

Figure 2: Indicative sketches depicting qualitatively how future collider and indirect detection ((a)) or direct detection ((b)) may complement each other during a discover of Wino or Higgsino DM. The qualitative coverage shown is further quantified by the references provided in the text. Each figure sketches two types of constraints representative of those in Refs. [1, 4, 17, 65]: the present experimental coverage of the annihilation of spin-independent WIMP-nucleon cross-section as a function of WIMP mass, as well as the projections for medium- and long-term experimental proposals described in the references. Regions of overlapping coverage, where complementary observations in both types of experiments would be possible, are indicated by saturated colors. Regions accessible by one of the two types of experiments only are shown in muted colors or grayscale. Solid points indicate approximate targets for Wino and Higgsino DM, as discussed in the text. Also shown are regions at lower cross-section values where neutrino interactions with direct detection experiments contribute background to a search.

Energy Frontier / Cosmic Frontier complementarity

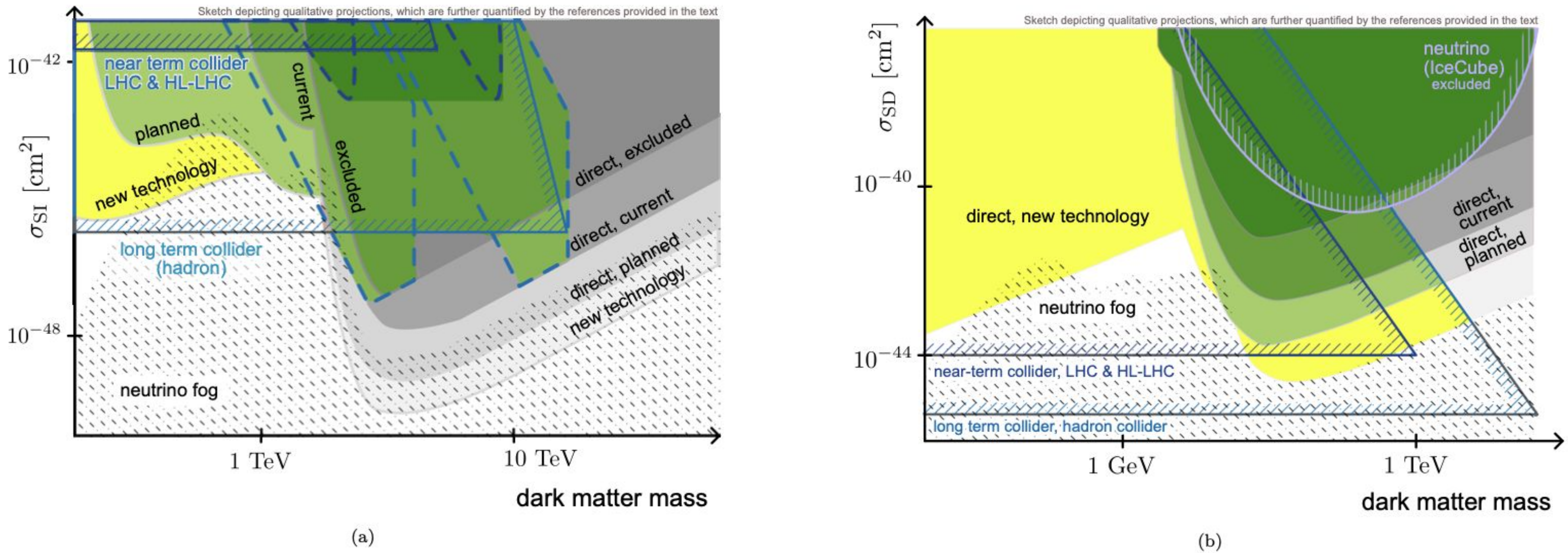


Figure 3: Sketches of the complementary regions of the ((a)) spin-independent or ((b)) spin-dependent WIMP-nucleon cross-section for a BSM-mediated simplified model of DM, as discussed in the Energy Frontier reports and contributions [4, 17, 65], where future colliders and direct detection experiments could simultaneously establish the astrophysical origin of a DM signal and study its interactions with SM particles. The qualitative coverage shown is further quantified by the references provided in the text. The solid (fixed couplings) and dashed contours (fixed DM and/or mediator masses) illustrate the wide variance in how specific combinations of Lagrangian parameters affect the extrapolation of collider limits on the simplified model to this plane. Regions of overlapping coverage, where complementary observations in both types of experiments would be possible, are indicated by saturated colors. Regions accessible by one of the two types of experiments only are shown in muted colors or grayscale. Also shown are regions at lower cross-section values where neutrino interactions with direct detection experiments contribute background to a search.

Rare processes and precision frontier / Energy Frontier complementarity

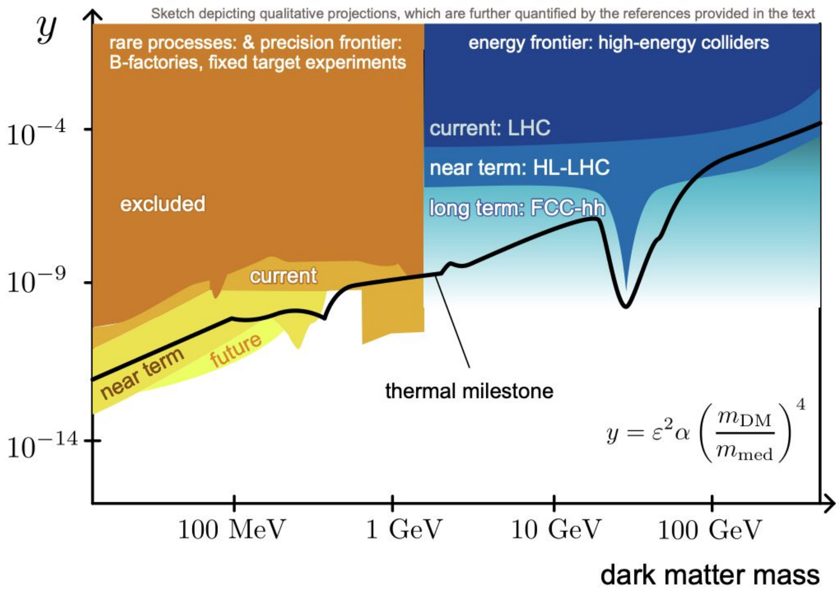


Figure 4: Sketch of how collider and accelerator experiments together can reach sensitivity across many orders of magnitude of DM mass to couplings expected for thermal-relic vector portal DM production. Shown are current and projected exclusions for both types of experiments, taken from Refs. [17, 65, 77]. The qualitative coverage shown is further quantified by the references provided in the text. The solid black line indicates the parameters which yield a thermal relic, as discussed in the frontier topical reports.

Neutrino Frontier / Cosmic Frontier complementarity

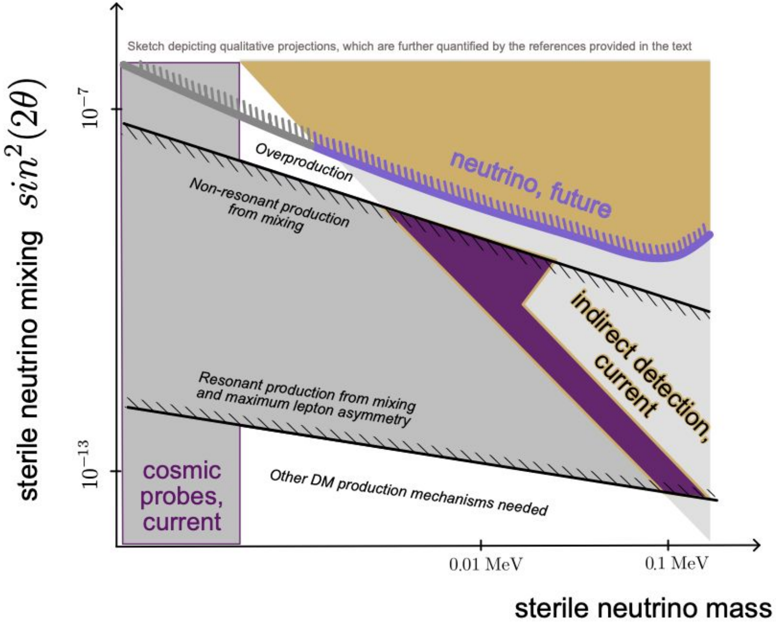
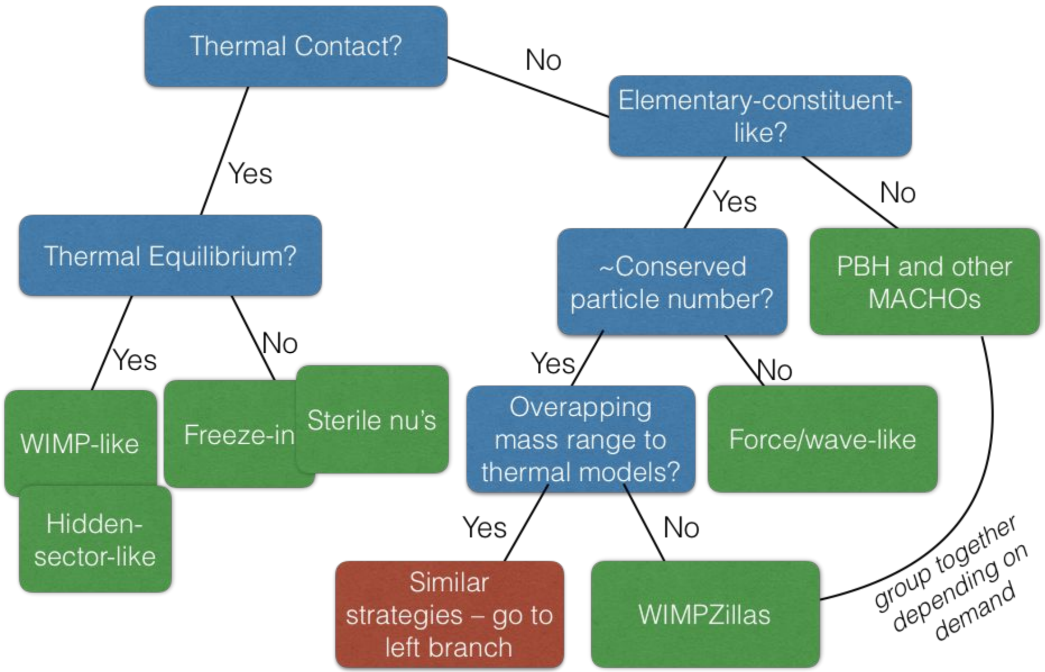


Figure 5: Sketch of constraints on the mass and mixing angle of resonantly produced sterile neutrino dark matter from indirect detection in X-rays (blue; e.g., [78] and references therein), cosmic probes of small scale structure (green; e.g., [79] and references therein), and projected sensitivity of terrestrial tritium beta-decay neutrino experiments (purple; [80] and references therein). The qualitative coverage shown is further quantified by the references provided in the text. The solid black lines indicate the region of parameter space in which resonantly produced sterile neutrinos can constitute all of the dark matter in the neutrino minimal standard model [81, 82]: the upper line represents non-resonant production via active-sterile neutrino mixing, while the lower line corresponds to resonant production from mixing in the presence of the maximally allowed lepton asymmetry in the early Universe. Below this line, other production mechanisms can produce the observed amount of dark matter.

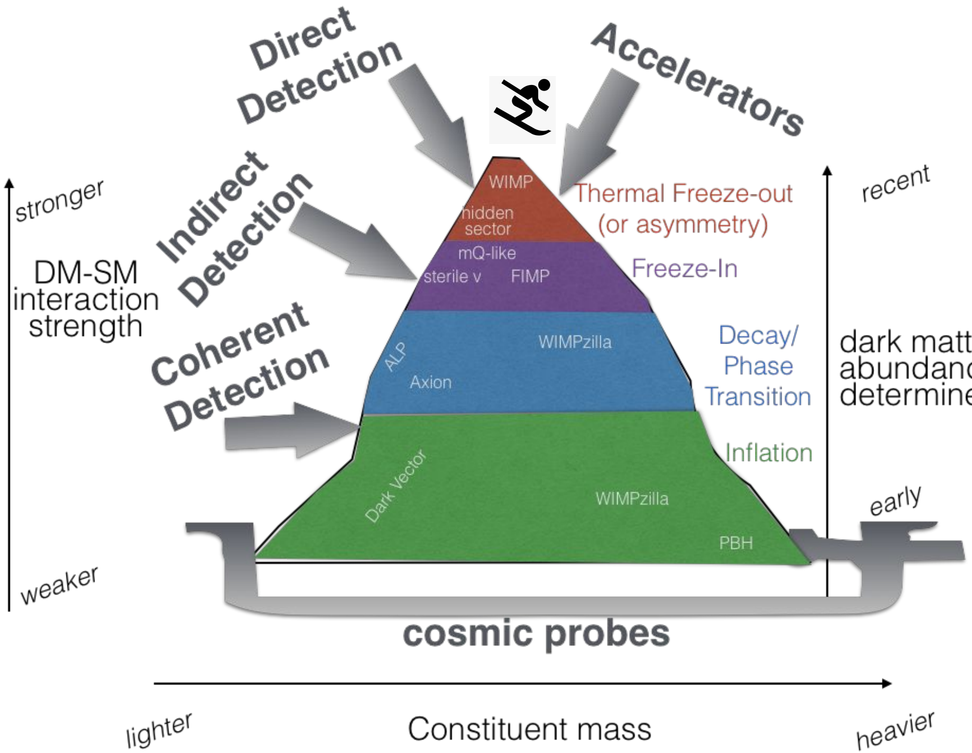
Dark matter flowchart [N. Toro, A. Berlin, N. Blinov]

Sketches from complementarity meetings



Dark matter mountain [N. Toro]

Sketches from complementarity meetings



Dark matter Aspen landscape [S. Gardner]

Sketches from complementarity meetings