DPF Core Principles and Community Guidelines (CP&CG)

- By participating in this meeting, you agree to adhere to the CP&CG
    - **Respect and support community members**
    - **Commit to constructive dialogue and take initiative**
    - Details of what this means, expectations for behavior, and accountability procedures are provided in the CP&CG document linked at: https://snowmass21.org/cpcg/start

- Everyone is invited to invoke the CP&CG as needed to encourage constructive and supportive collaboration

- The conveners of this meeting are your recommended first point of contact for reports of CP&CG violations occurring here
    - The conveners have received training in the CP&CG and how to handle reports
    - The CP&CG accountability procedure is designed to encourage early intervention and is flexible enough to appropriately address issues ranging from the discourteous to the egregious
    - Please do not hesitate to contact us!

- Snowmass is most successful when everyone's voice can be heard!

Dark matter complementarity #150

The organizers of the Snowmass CPM
Dark Matter sessions

Dark Matter is Everywhere!

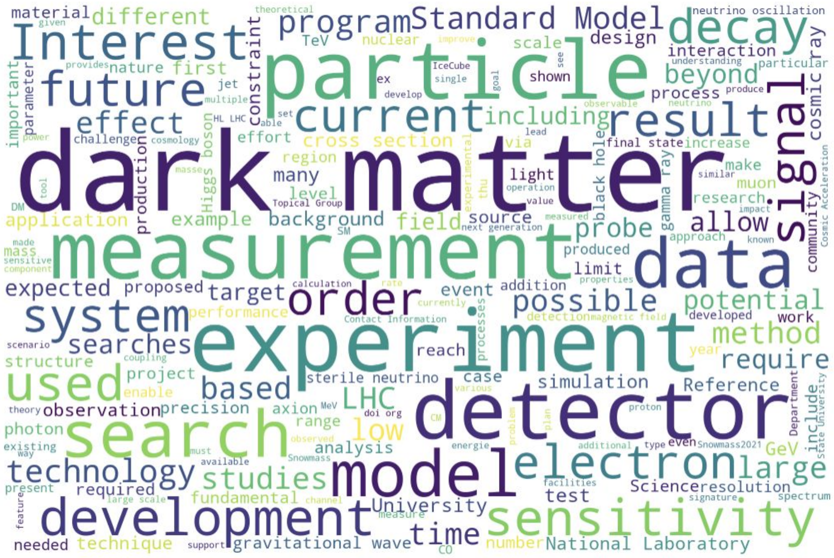
- **Since the last Snowmass, there has been a fundamental shift in how we think about searches for dark matter.**
- **We are in an exciting exploratory phase where new ideas can be implemented on short timescales.**
- **Dark matter crosses every frontier.**
- **In order to get a full picture of the “elephant”, we need to combine information.**

- **Conversation Starter: Dark matter should be *the* focal topic of this Snowmass Report.**

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



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

Dark matter complementarity ideas from session #137

HE and UHE Neutrino Experiments

Organizers: Ke Fang (CF7), Erin O'Sullivan (NF4), David Schmitz (NF10), André de Gouvêa (TF11), Abigail Vieregg (IF10)

Brief summary of the session

Panel 1: Detection techniques

Topics:
- Optical detection in ice and water: **Olga Botner**
- Askaryan radiation detection in ice: **Albrecht Karle**
- Radio detection in atmosphere: **Abby Vieregg**
- Cherenkov detection in space: **Angela Olinto**
- Air shower detection on the ground: **Stephanie Wissel**

How mature is the technique? What is the major technical difficulty?
What would be a unique advantage of the technique?
How should we, as a community, plan the development of experiments for the maximum science return?

Brief summary of the session

Panel 2: Future observations and science discoveries

<u>**Topics**</u>:

- Neutrino physics, including flavor composition, interaction cross sections, decay: **Hallsie Reno**
- Dark matter and dark energy: **Carlos Argüelles**
- BSM, including non-standard interactions, Lorentz and CPT invariance violation: **Mauricio Bustamante**
- Astrophysics: **Tonia Venters**

Are there any unique discovery in this area that can only be made by high and ultrahigh energy neutrino observations?
What detector sensitivity and which energy band are needed to achieve the discovery?
Do the studies require any specific observation strategies, such as all-flavor detection and large field-of-view?

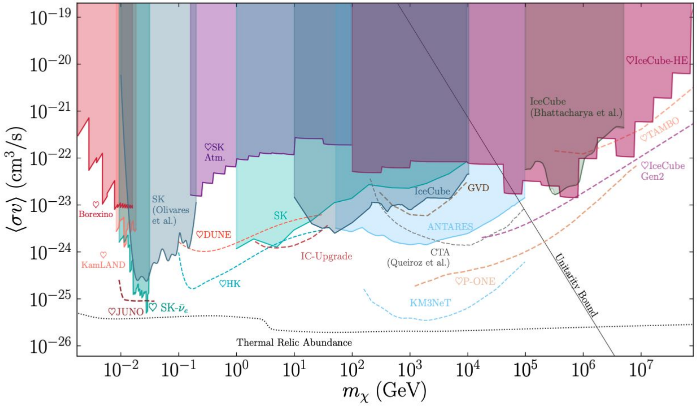
Complementarity questions/points

- What can neutrinos add to the picture? Neutrinos are complementary to direct and accelerator searches for dark matter as indirect probes (if dark matter annihilates or decays to produce neutrinos)
- Neutrinos allow us to “see” into places where detection is difficult for other messengers. The galactic centre has no large background in neutrinos. Also, neutrinos can escape even when other messengers cannot (centre of the Sun).
- This could also be a special channel. If dark matter produces neutrinos, then neutrino detectors are a good way to look for them.
- HE and UHE neutrinos in particular are good (unique?) probes of heavy dark matter (10^4-10^8 GeV)

Practical work needed for these ideas

- Two areas of planning: among the neutrino experiments to cover the mass space (could be within the neutrino frontier), among direct and accelerator community as well as theory community to address complementarity (across frontiers)
- More effort needed to identify benchmarks and other concrete work than what will be explored in #137. But please include HE and UHE neutrino dark matter LOIs in future topical workshops and plans in order to elucidate this!

Carlos Argüelles et al. arXiv:1912.09486



Dark matter complementarity ideas from session #72

Dark Energy, Origins (Inflation), and Light Relics

Alex, but probably someone better...

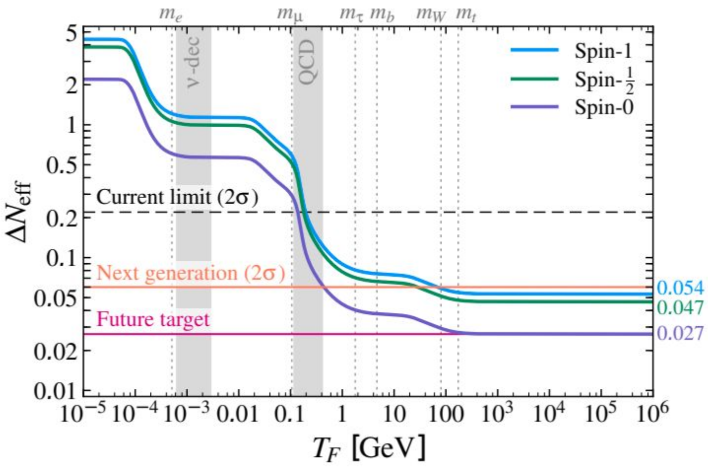
https://indico.fnal.gov/event/44870/sessions/16362/#20201006

Brief summary of the session (1-2 slides)

Session Topic: “Dark Energy, Origins (Inflation), and ***Light Relics***”

Light relics are most relevant for the discussion here. In particular, measurements of *Neff* (number of relativistic species) and BBN (Big Bang Nucleosynthesis), have implications for the number of light degrees of freedom (particles) in the universe.

Cosmological measurements from Big Bang Nucleosynthesis (BBN; e.g. helium abundance), Cosmic Microwave Background (CMB; e.g. CMB-S4), and Baryon Acoustic Oscillations (BAO; e.g. DESI) constrain properties of neutrinos, hidden sectors, axion-like particles etc.



[“Insights for Fundamental Physics and Cosmology with Light Relics” Meyers et al.]

Complementarity questions

What are the most important questions from your communities to raise in the complementarity whitepaper(s)?

- How do we build understanding between the cosmology community and the particle physics community? (Couldn't agree on what "dark sector" meant…)
- In the scenario where future CMB experiments measure Neff to be inconsistent with the SM prediction, how does the broader community respond?
- Assuming hidden sector signatures in another experiment, how does the Cosmic Frontier respond?
- How do we build the case for dark matter as a science driver for current/future cosmic survey experiments of the early universe?

Practical work needed for these ideas

- Enhance communication/understanding between cosmic frontier and other frontiers. There is a growing community focused on beam dump experiments and light hidden sectors. Already started to engage in #127.
- Lots of ground work on cosmological light relics has been done already (i.e., in the context of CMB-S4 and Neff); need to further advertise these results. For example, distributing CF LOIs to other frontiers.

Dark matter complementarity ideas from session #74

Atomic to Cosmic: Wave Dark Matter and Beyond

Brief Summary #74, Part 1

Wave dark matter covers a enormous range of energies and length scales, and correspondingly an enormous assortment of experimental techniques and astrophysical observables.

We broke into 10 groups of 5-10 people each and discussed synergies, directions, and target white papers.

Brief Summary #74, Part 2

The poster-child of wavelike dark matter is the QCD axion, but other similar particles are growing in popularity.

Last snowmass, axion haloscopes (e.g. ADMX) were the only experiment type on the menu, but a host of new ideas have LOIs now, most with strong overlap with the instrumentation frontier, greatly expanding the accessible theories.

Large length-scale wavelike dark matter has peculiar structure properties that may have consequences for both cosmology and terrestrial experiment.

The field is growing rapidly and forming connections with other subgroups.

Complementarity questions

Technological Complementarity

- -Quantum Sensors
- -Magnets, superconductors

Theory Complementarity

- -What else beyond the QCD axion do we target?
- How do QCD the preferred masses and couplings of QCD evolve?

Astrophysical Complementarity

- -Small Scale Structure
- -Gravitational Waves and Black Holes
- -Stellar Astrophysics, gamma rays

Practical work needed for these ideas

Communication between frontiers - the Snowmass process does this.

For overlaps between fields that have not traditionally overlapped (e.g. Atomic Physics + Dark Matter), we need to make sure these don’t slip between the cracks of different funding agencies.

Unification of different groups working with the same technologies

Dark matter complementarity ideas from session #75

Cosmic Probes of Dark Matter Physics

Brief summary of the session (1-2 slides)

Cosmology and astrophysics currently provide the ***only*** robust, positive, experimental measurements of dark matter. We **must** extract as much information as possible from these positive measurements.

Cosmic probes measure the properties of dark matter ***directly through gravity*** (the only force through which it is known to couple). The macroscopic distribution of dark matter is a sensitive prove of the microphysical properties of dark matter.

Also measure dark matter ***indirectly*** through standard model particles that can be produced through couplings to the standard model (i.e., what this community usually thinks of as "indirect detection").

Session will cover ~70 LOIs on Experiments, Facilities, Observations, Simulations, Modelling, and Theory.

Brief summary of the session (1-2 slides)

- **Future observational facilities to probe DM** (CMB-S4/HD, Rubin/LSST, Extremely Large Telescopes, Maunakea Spectroscopic Explorer/MegaMapper, LIGO-Virgo/KAGRA/Einstein Telescope/Cosmic Explorer/LISA, Pulsar Timing Arrays/SKA, Roman/Euclid)
- **Multi-messenger probes of DM indirect detection signals:** X-rays and gamma rays (GECCO, GRAMS, LArTPC-based Gamma ray instrument, CTA, SWGO), antimatter/charged cosmic rays (GAPS, lunar orbiting satellites), and neutrinos (P-ONE/ONC, IceCube)
- **Novel probes of the distribution of DM below the threshold for galaxy formation** (halometry, pulsar timing, stellar streams, strong lensing, microlensing, 21 cm, Lyman-alpha)
- **Cosmologica/astrophysical signatures of theories beyond CDM** (WIMPs, axions, PBH, warm DM, self-interacting DM, fuzzy DM, freeze-in DM, decaying DM, late-forming DM, ...)
- **Next-generation simulations/modelling that incorporate both novel DM physics and baryonic physics** (critical for testing different DM theories with observations)

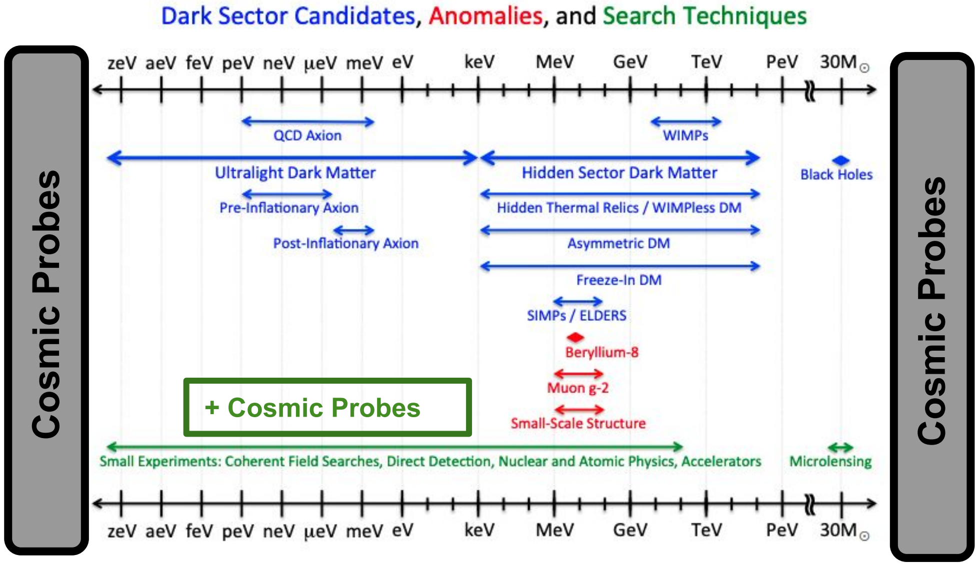
Discussion in this Zoom Room directly after this session.

Cosmic Visions: New Ideas in Dark Matter [1707.04591]

Complementarity questions

What are the most important questions from your communities to raise in the complementarity whitepaper(s)?

- The session hasn't happened yet, but...
- How do we build understanding between the observational community and the particle physics community?
- How does improved knowledge of the distribution of dark matter inform searches for the nature of dark matter?
- What does discovery through cosmic probes look like? How does it complement discovery in other domains?
- When is a subdominant component of dark matter no longer "dark matter"?



The bounds on this figure come from Cosmic Probes of dark matter.

Cosmic Probes are sensitive to a wide range of models over the allowed space.

Practical work needed for these ideas

Practical work needed / planning (e.g. choice of benchmarks, simulations...)

- We generally haven't been thinking in terms of benchmarks, but this would be a useful discussion to have with other groups (thermal relic WIMP and QCD axion are obvious; benchmark for light relics, warm dark matter, self-interacting dark matter, etc.?)
- How do we present cosmic constraints in a context that can be easily understood (and valued) by the rest of the community?
- How do we brand cosmic surveys as dark matter experiments?

Table 1
Summary of Scenarios

2014 P5 Report

Project/Activity	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contributions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, some reductions with redirection to PIP-II development	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C
DM G3	Y, reduced	Y	Y			✓			C
PINGU	Further development of concept encouraged				✓	✓			C
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I
Additional Small Projects (beyond the Small Projects Portfolio above)									
DESI	N	Y	Y		✓		✓		C
Short Baseline Neutrino Portfolio	Y	Y	Y		✓				I

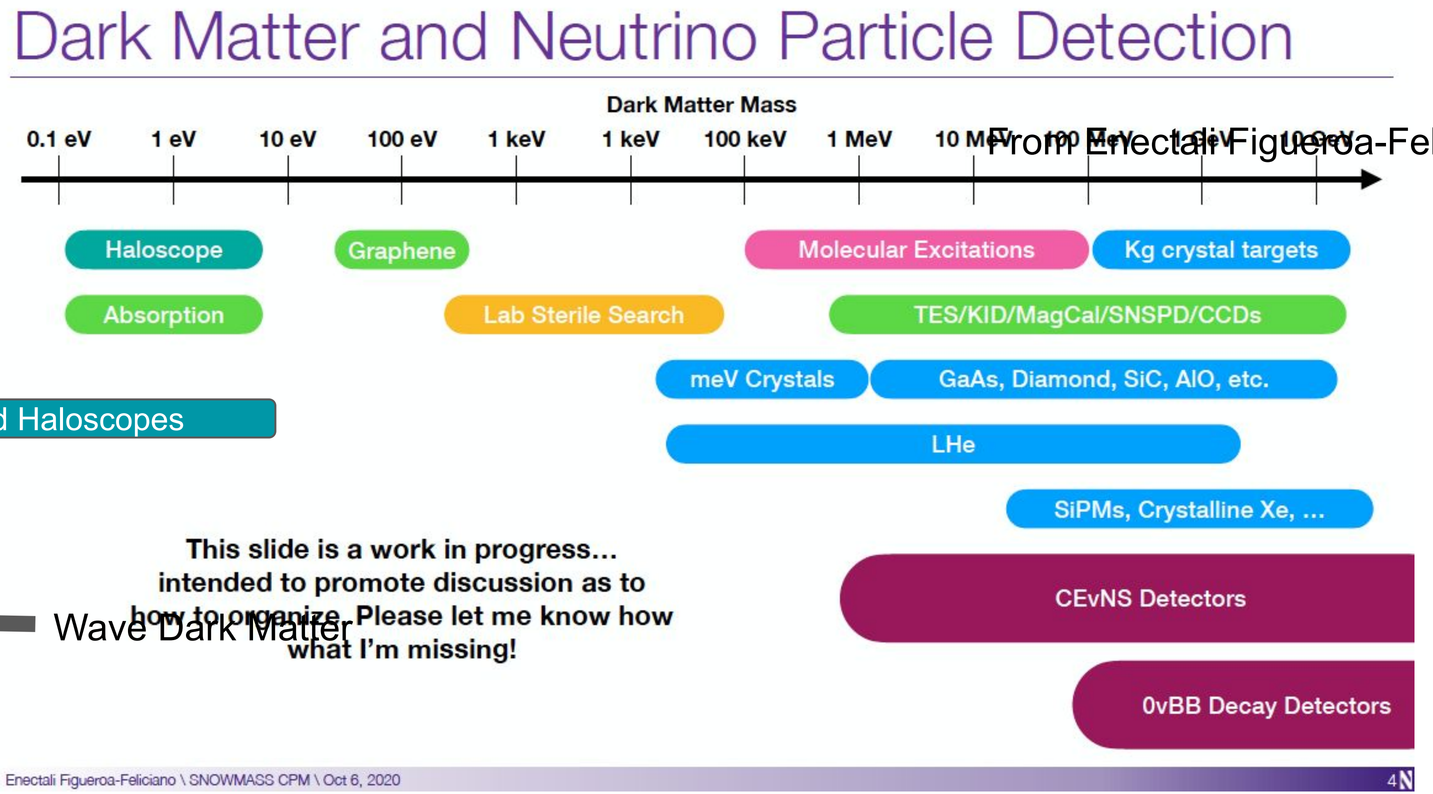
Dark matter complementarity ideas from session #77

Quantum Sensors for Wave and Particle Detection

CPM 77 Organizers IF1, IF2, CF1, CF2, NF
Jodi Cooley, Enectali Figueroa-Feliciano, Maurice Garcia-Sciveres, Roni Harnik, Kent Irwin, Juan Estrada Vigil and Lindley Winslow

Brie

From Enectali Figueroa-Feliciano



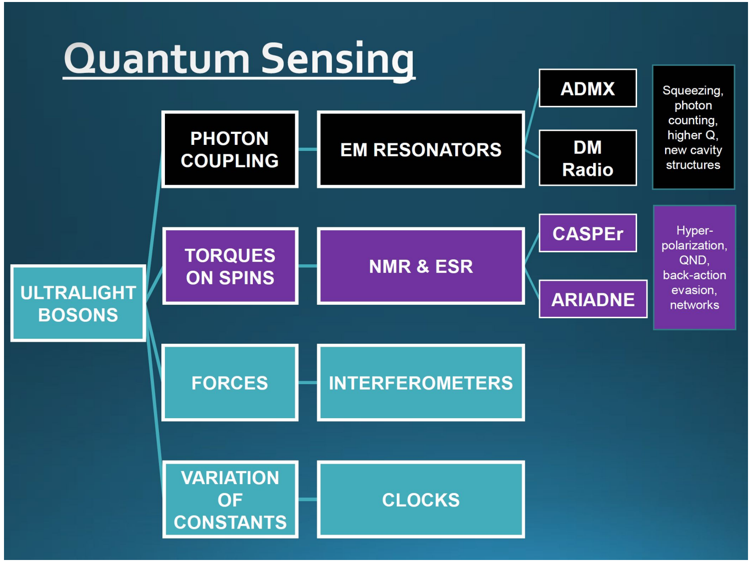
LC and Haloscopes

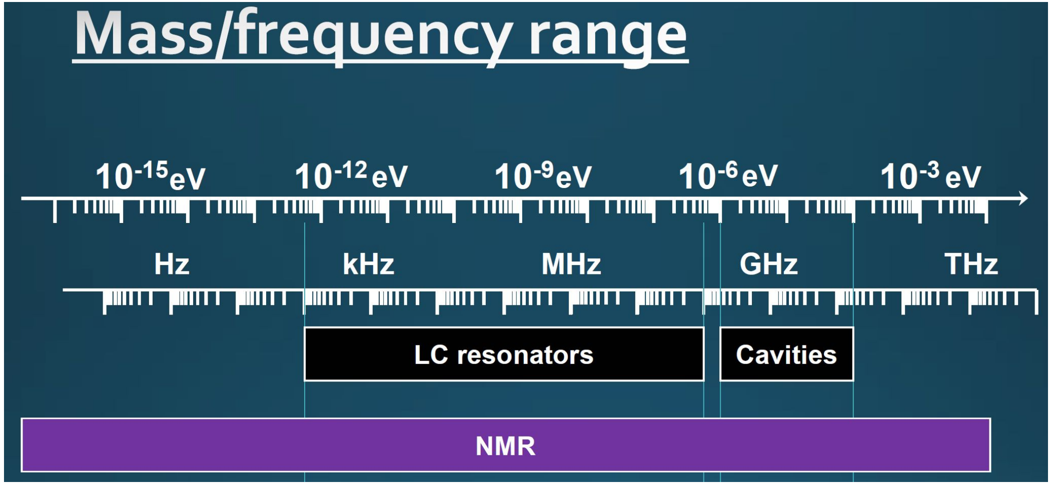
Wave Dark Matter

Brief summary of Session 77

Wavelike Dark Matter Detection

<u>From Derek Jackson Kimball</u>
A wavelike companion to Tali's Slide, also intended to promote discussion about organization

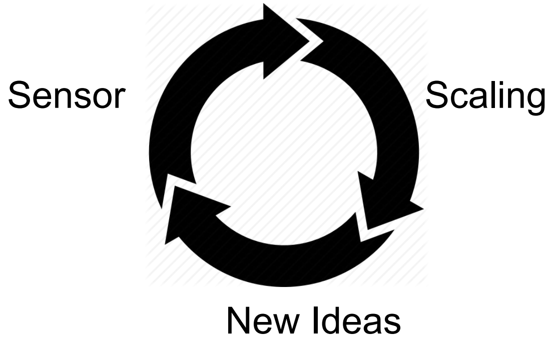




Brief summary of Session 77

There is a nice portfolio of projects at different stages.

- Sensor and Readout R&D to improve the performance especially the noise characteristics (sometime pushing the standard quantum limit) of the detector systems themselves.
- Scaling R&D, how do deploy quantum sensors in mid-scale experiments (here you find multiplexing and the needs of neutrino experiments for CEvNS and 0nuBB).



Complementarity questions for 77.

- Quantum Information not just for sensing, we should also think about complementarity of readout, infrastructure and using QI to study the physics of the sensors themselves.
- **Gravitational wave detectors** and experiments using **atomic techniques** provide new windows and complementary technology challenges to the current suite of experiments.

Practical work needed for these ideas in #77

- A theme is emerging that we need a high level summary of the techniques and the physics they can probe. Some of this was done for the BRN for New Initiatives.
- We need to decide on the best way to group techniques. We tend to default to the candidate mass.
- We need a theory effort to guide preferred parameter space and perhaps help with design consideration that would allow us to probe different physics (for instance the number and size of a multi-detector system).
- We need to summarize the common infrastructure needs of this work (cryogenic systems, shielding, magnets etc.)
- Others we haven’t considered?

Dark matter complementarity ideas from session #97

Neutrinos as Probes of Standard and BSM Particle Physics

CPM 97 Organizers TF11, NF03 - 06, CF01
Baha Balantekin, Carlo Giunti, Erin O'Sullivan, Irina Mocioiu, Jae Yu, Jodi Cooley, and Saori Pastore

Brief summary of the session

- Neutrinos as probe of standard physics
  - Neutrino-nucleon and nucleus interactions from low to high energies
  - SN neutrinos, BSM in SN
  - Standard oscillations
  - Neutrino experiments across energies
  - ...
- Neutrinos as probe of BSM physics
  - Sterile neutrinos as DM
  - Cosmogenic dark matter in neutrino detectors
  - Neutrino as signal of indirect detection of DM
  - Standard and BSM physics in atmospheric and astrophysical neutrinos
  - ...

Neutrinos really bring excitement to a very diverse group of scientists

Complementarity questions

- Are sterile neutrinos the dark matter?
- Possible use of neutrino detectors to detect interactions of cosmogenic dark matter (*i.e.* boosted DM) to make a direct detection.
- Possible detection of dark matter annihilation and decay products in neutrino detectors.
- Neutrinos are an irreducible background to traditional direct detection DM experiments. More precise understanding of this background could be important for G3 experiments.

Practical work needed for these ideas

- Collaborative efforts across different expertise (e.g., HEP, NP, THEO, EXPT, Computer Science, Event generators, ...)
    - Development of reliable generators
    - Accurate measurements of nuclear interactions
    - Theoretical calculations of cross sections at different energy scales (LQCD, HEP, NP)
    - Recent progress in effective field theories exposed several possible couplings of DM with matter
    - ...
- Understanding standard neutrino physics is a crucial prerequisite for using them as probes of BSM physics
- Need a well-coordinated effort to organize summary white papers and avoid duplicates
- Others we haven't considered?

Dark matter complementarity ideas from session #108

Accelerator Probes of Light Dark Matter (keV-GeV)

CPM #108 Organizers: Brian Batell (RF6), Jodi Cooley (CF1), Caterina Doglioni (EF10), Josh Ruderman (TF9), Alex Sousa (NF02), Lian-Tao Wang (EF10), Jae Yu (NF03)

https://indico.fnal.gov/event/44870/sessions/16307/#20201006

Brief summary of session #108

- Nikita Blinov, “Light Dark Matter Targets for Accelerator Searches”
    - Dark sectors and portals theoretical framework; Cosmology - Thermal, “thermal-ish” (e.g., SIMP), non-thermal (e.g., freeze-in) DM production; Relic density targets for accelerators.
- Gordan Krnjaic, “Dark Matter Production at High Intensity Facilities” (RF6)
    - Overview of suite of intensity frontier searches for light DM, including B/K factories, beam dumps, missing energy/momentum experiments.
- Wooyoung Jang, “Searching for Light Dark from Accelerator-driven Neutrino Programs” (NF02,NF03)
    - Present and future prospects for light DM at neutrino experiments; on- vs. off-axis detectors; discussion on low, medium, high energy proton facilities.
- Suchita Kulkarni, “Light Dark Matter at High Energies” (EF10)
    - Collider / Direct Detection interplay, light DM from heavy particle decays, complementarity across frontiers, …

See also CPM sessions #72, #97, #127, #136, #173 for complementary discussion

Complementarity questions

- How do we best promote inter-experimental efforts to identify and combine complementary measurements to maximize sensitivity to discovery?
  - Across accelerator experiments (Meson factories, Neutrino experiments, Beam Dumps, Missing Energy/Momentum, LHC,…)
  - Accelerators vs. cosmic probes (direct detection, cosmic ray, neutrino telescopes, CMB, …)
- What simulation tools are required for near-future accelerator searches?
  - Dedicated tools (e.g. BdNMC), Multi-purpose generators (e.g., Pythia, Madgraph5_amc@NLO), hybrid tools (DM module in GENIE)
  - Joint theory/experiment effort (e.g. model-specific production/scattering/decay, simulation of neutrino beam line, ultra-rare background simulation techniques in GEANT, ...)
  - Interpretations for variety of light dark matter models (e.g., building model catalog for Madgraph5, …)
- In the event of a light dark matter discovery(!!!):
  - What experiments are needed and what are the prospects for measuring the properties (masses, couplings) of DM particles and mediators?
  - Related - how do we evolve the present program to make precision measurements of DM properties?

Practical work needed for these ideas

- Continue developing a standardized set of physical limits for sensitivity plots and promote their use across relevant experiments,
  - E.g., minimal portal models, thermal targets in vector portal models, ...
  - Broader discussion on light dark matter /dark sector benchmarks is underway during Snowmass 2021
- When feasible, encourage experiments to produce well-documented and comprehensive data releases:
  - The contents of the data to be shared should be arrived at in consultation with other stakeholders in the community.
  - Allow quick and accurate reinterpretation of experimental results across the diverse dark matter model landscape (even after experiments cease operations)
- Survey existing generator tools, identify where improvements / additions needed, merge tools if appropriate, create new tools, …
- Theory/pheno/experiment studies of discovery scenarios :
  - What experiments/measurements are needed? Experimental agenda, possible timelines, …
  - Highlight complementarity of different experiments, bolster light dark matter science case!
  - See also DOE Basic Research Needs Dark Matter Small Projects New Initiatives Report https://science.osti.gov/-/media/hep/pdf/Reports/Dark_Matter_New_Initiatives_rpt.pdf

Dark matter complementarity ideas from session #127

Searches for Dark Sectors

see Indico and live-notes

Brief summary of the session (part 1)

- Intro talk (Tongyan Lin) and discussion
  - What is a Dark Sector? How do we present a coherent & compelling motivation
  - Operating definition= “physics neutral under SM gauge interactions [focus on eV-GeV].” DM is among core motivations, but not all DM candidates are dark sectors

some topics with obvious synergy were discussed elsewhere (accelerator-based DM production #108, cosmological probes of ~MeV-scale and/or self-interacting DM #72, #75)

- Sub-GeV Direct Detection (Rouven Essig)
  - Was very small at Snowmass 2013; still P5 *prioritization of Dark Matter* and *recommendation of small projects* has been pivotal in enabling growth into broad, vibrant field
- Dark Sectors at Energy Frontier (James Beacham)
  - Long-lived particles [dedicated forward and transverse detectors, inelastic DM, dark QCD], precision Higgs couplings; pitch for developing and centering non-minimal models too
  - Opportunities at future accelerators...and what about a PeV collider on the moon?

Brief summary of the session (part 2)

- Neutrino Frontier Probes of Dark Sectors (Kevin Kelly)
  - Opportunities for Higgs portal mediator & HNL searches at DUNE (see also #108 talk for DM production); both beam dump mode and neutrino mode (for neutrino-philic dark sectors) searches are important
- Dark Sectors in Rare Processes Frontier (Stefania Gori)
  - Production and detection of relativistic dark sector particles (mediator, DM, and DM excited states) in high-intensity accelerator experiments; strong dark matter motivations and connections to all 3 types of results
- Gravitational Waves and Black Holes (B.S. Sathyaprakash and R. Caldwell)
  - Nice overview of whole GW program; DM connections include primordial black holes, mini-charges, ultra-light boson clouds/bose-novas
  - Potential connections to CF2 & 3 deserve flagging for future discussion; thematically distinct from the rest of the session

Complementarity questions

- ***Structurally***, how will complementarity of different approaches be reflected in the Snowmass Report (more prominently than just one complementarity whitepapers among hundreds)?
- ***In principle***, how best to highlight complementarity of different techniques,
  - **Broadly shared sentiment that light DM science is exciting, with opportunities for discovery across many different approaches – how do we convey this?**
  - *Benchmark models* (i.e. plots where you can overlay qualitatively different searches)
  - *Theory targets and/or regions* (e.g. thermal freeze-out for various DM spins, light-mediator freeze-in, SIMP/ELDER, ...)
  - *Basic differences in physical processes* (e.g. relativistic vs. non-relativistic; DM-DM vs. SM-SM vs. DM-SM aspects of the same physics)?
  - Support for DMNI BRN approach – merged all of the above + *post-discovery complementarity*
- Nuts and bolts of existing comparisons:
  - Some cases need more apples-to-apples comparisons (e.g. commonly shown LHC/direct detection overlay relies on assuming all couplings=1)
  - In some cases (especially non-minimal models) basic mapping doesn't exist between high-energy and direct detection signals

Practical work needed for these ideas

- Seemed to be broad interest in a Light DM complementarity workshop
  - Deeper and broader than a CPM session, more limited in scope than the "Big Complementarity Workshop"
  - Discussion between sub-GeV direct (and indirect?) detection, accelerator production of DM, Small-scale structure & cosmic relic constraints (CF3), supernova and astrophysical probes of long-lived particles, theory (bringing in topics from 127, 108, 72, 75, …)
- RF6 welcomes community input on table of benchmarks and milestones (see [Stefania's slide 5)](#) !
  - Needed for full picture of accelerator-based Dark Sector efforts (RF6 experiments don't share a common pseudo-observable like $\sigma_{\chi e}$)
  - Happy to use them across TGs *if and where it makes sense*
  - Please provide input via this [google form](#)

Possible benchmark models

Preliminary

Benchmarks in Final State x Portal Organization

	DM Production (1.)	Mediator Decay Via Portal (2.)	Structure of Dark Sector (3.)
Vector	*m_χ vs. y [$m_{A'}/m_\chi$=3, α_D=.5]* **$m_{A'}$ vs. y** [α_D=0.5, 3 m_χ values] <u>m_χ vs. α_D [$m_{A'}/m_\chi$=3, $y=y_{th}$]</u> m_χ vs. $m_{A'}$ [α_D=0.5, $y=y_{th}$] ***Millicharge m vs. q***	<u>$m_{A'}$ vs. ϵ [decay-mode agnostic]</u> ***$m_{A'}$ vs. ϵ [decays]***	**iDM m_χ vs. y** [$m_{A'}/m_\chi$=3, α_D=.5] (anom connection) **SIMP-motivated cascades** [slices TBD] $U(1)_{B-L / \mu-\tau / B-3\tau}$ (DM or SM decays)
Scalar	m_χ vs. $\sin\theta$ [λ=0, fix m_S/m_χ, g_D] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of S→SM of mediator searches	*m_S vs. $\sin\theta$ [λ=0]* *m_S vs. $\sin\theta$ [λ=s.t. Br(H→ϕϕ ~10^{-2})]?*	Dark Higgsstrahlung (w/vector) scalar SIMP models? Leptophilic/leptophobic dark Higgs?
Neutrino	e/μ/τ a la1709.07001?	*m_N vs. U_e* *m_N vs. U_μ* *m_N vs. U_τ* Think more about reasoanble flavor structures	Sterile neutrinos with new forces?
ALP	m_χ vs. fq/l [λ=0, fix m_a/m_χ, g_D] (thermal target excluded) What about f_γ, f_G?	*m_a vs. f_γ* *m_a vs. f_G* *m_a vs. f_q=f_l* (separate?) Think more about reasoanble coupling relations including $f_{W/Z}$	FV axion couplings

\+ Neutron portal? Hidden valleys (or are these out-of-scope?)? See e.g. 2003.02270

Bold = BRN benchmark, *italic=PBC benchmark*, others are new suggestions. <u>Underline=CV benchmarks that were not used in BRN</u>

Ongoing call for new benchmarks & theory targets:

https://docs.google.com/forms/d/e/1FAIpQLSeNWJ7oVvjl6UoRS39ZHwpji_IN-hbJaI-d-JO9QRYavBiOtA/viewform

41

S.Gori

Session

136. Heavier particle dark matter >~ 10 GeV

Oct 6, 2020, 5:30 PM
Zoom 13

Conveners

136. Heavier particle dark matter >~ 10 GeV

- Tracy Slatyer (Massachusetts Institute of Technology)
- Caterina Doglioni (Lund University)
- Hugh Lippincott (UCSB)
- Liantao Wang (University of Chicago)
- Tulika Bose (University of Wisconsin-Madison)

Dark matter complementarity ideas from session #136

Heavier dark matter (~10 GeV)

Agenda / Notes & LOIs & Session "live notes"

Brief summary of the session

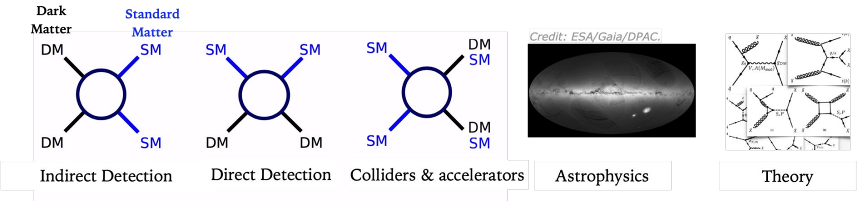
Some motivations to look for heavier dark matter:

- *Theoretical:*
  - The WIMP (mass: EW-scale and above, couplings: weak-like) is a great thermal relic
  - We need something that sets the weak scale at around 100 GeV
  - Cosmological history can be linked to new physics
- *Experimental:*
  - Much uncovered phase space (even if in some plots it looks like all the “low hanging fruit” has been picked), both at lower cross-sections and at (much) higher DM masses
  - Well-established complementarity across frontiers (EF/CF)

Main experimental players:

- High-energy colliders
- Direct detection
- Indirect detection (including astrophysical surveys)

New to the complementarity picture: GW instruments



Goals of EF/CF for high-mass DM

Energy Frontier (EF10, EF08):

- Understand how future colliders can best test the WIMP paradigm
  - The collider community uses **models** for these comparisons:
    - minimal WIMP (SUSY-inspired), models of simple mediation between SM and DM

Cosmic Frontier (CF1):

- Direct Detection: Transition from Gen-2 to Gen-3 experiments:
  - Much new data expected from Gen-2
  - Building Gen-3 is starting and requires effort/resources
- Indirect detection: Many searches, where do we go next / what do we need?
  - e.g. backgrounds, sensitivity, targets

Interesting to both frontiers:

- Understand how to best portray complementarity with other experiments

Input needed:

- Solid & motivated theory picture (TF9), inclusion of astrophysics constraints (CF)

Complementarity questions

Thoughts are coming from the 25' "randomized" breakout sessions according to [this template]

Complementarity is part of making **the case for DM as a central priority**

- The older idea that 2-3 flagship US experiments could cover everything is just not correct - much broader landscape of possibilities!
  → Argue for a broad range of models and masses rather than for only one specific topic/mass range, as we can't guarantee that DM is anywhere specific, highlighting the huge range of possible masses which necessitates multiple approaches
- Emphasize that dark matter is fundamentally a question for particle physics, because what we need is a particle (wave-like DM included). This is different from dark energy, which has several possibilities.

How do we **portray complementarity** of different frontiers?

- Change the mindset from "this plot shows where my technique does better than yours" to "where more techniques can do things together"
  - Together with that, keep in mind metaphor of "keys and streetlights": individual lights shining in different directions will help us find DM
- Understand what point we are making on prioritization based on theoretical/astrophysical motivation, then think about scenarios and key plots that can best convey that point

Thoughts **on "summary plots"**

- Parameters relevant for colliders differ from those relevant for DD/ID, a given model behaves differently in different experiments
  - Non-trivial to sort this out, maybe least of necessary evils is to find information about a *model* rather than about a *particle*
- Be as broad as possible within resources available:
  - Scans of simplified models/pMSSM, keeping limitations into account and balancing accuracy of model with excessive specialization
- Not everyone in CF is fully supportive of common summary plots as they may be interpreted without paying attention to caveats/limitation

Practical work needed for these ideas

Interaction with community and LOI writers

- We have 150 LOIs only in CF, it's unlikely something is missing
- But we need to "boil things down" to get a big picture

Benchmark models:

- We need to agree across different frontiers whether currently used complete / simplified & portal models are OK with everyone involved (including more model-independent CF!).

Relic density:

- The usual relic calculations rely heavily on cosmology assumptions → probing regions beyond the thermal relic is useful to constrain scenarios with different cosmology.
- We can include examples in a whitepaper connecting astrophysical probes to DD/ID experiments

Comparisons with different experiments:

- How to take uncertainties into account when discussing complementarity (e.g. when ruling out models)
    - Links with astrophysical probes of DM density (session #75 today)

A closing slide

What happens next?

Plan forward

- Taking inspiration from CF3, we will have an “Open Organizational Meeting” in the next month or so
- This is to identify topics and directions, and plan topical 1-2 (half-)day workshops
  - Everyone will welcome (date/time may not work for everyone → notes will appear)
- In the next couple of months, we will have and work together on contributed papers
  - This will make sure complementarity doesn’t get lost in single-TG reports
  - Possibility of advocating for complementarity mentions upwards to the Snowmass organization (needs some well-identified directions and topics)
- Also stay tuned for “Planning” sessions at the start of CPM tomorrow!

Dark matter complementarity ideas from sessions

Title of the session

Brief summary of the session (1-2 slides)

Brief summary of the session (1-2 slides)

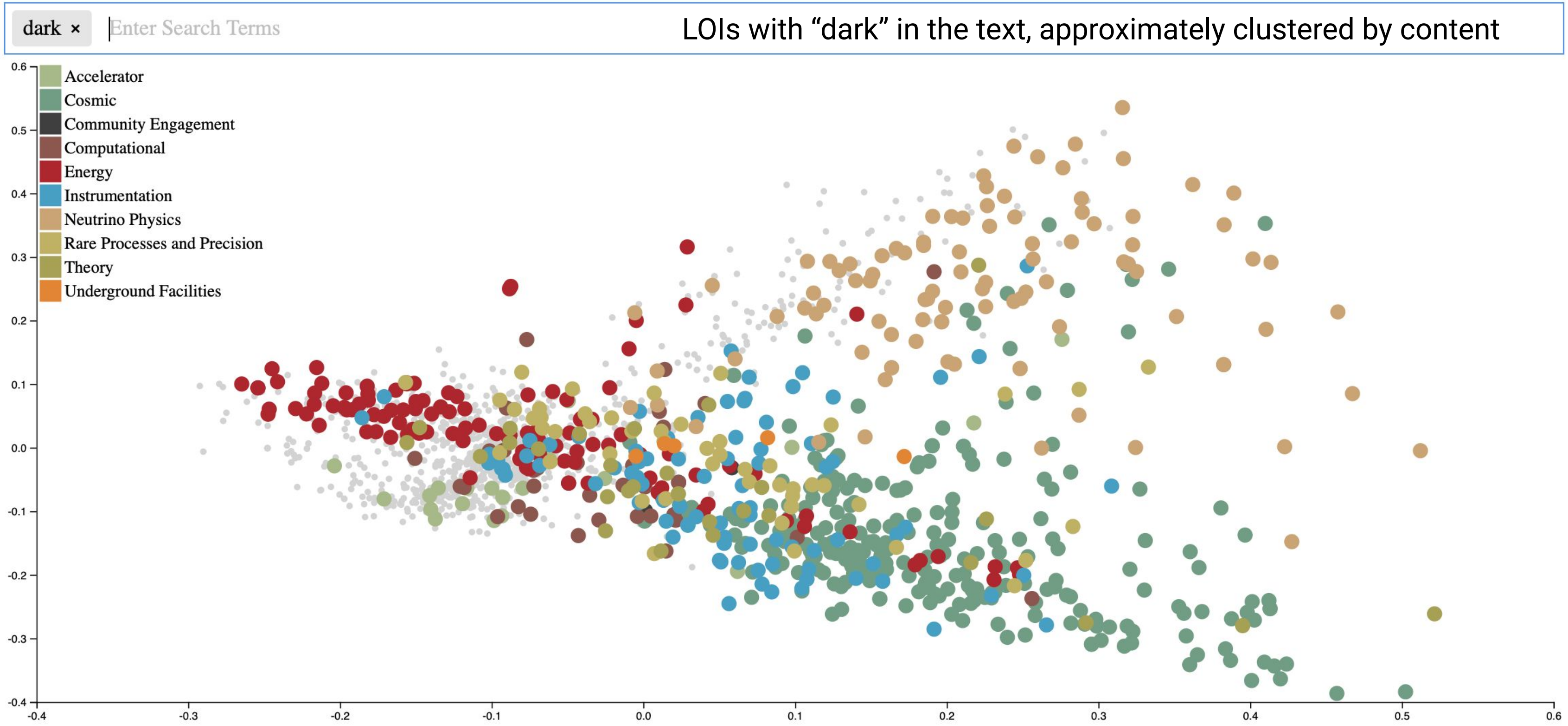
Complementarity questions

- What are the most important questions from your communities to raise in the complementarity whitepaper(s)?

Practical work needed for these ideas

- Practical work needed / planning (e.g. choice of benchmarks, simulations...)

Graphical outcome of the LOI process



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