# CF03: Cosmic Probes of Dark Matter Physics


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# Timeline and Logistics

May 25th: Snowmass travel grant application deadline (link)
May 31st: Requested first draft for CF conveners (start to assemble CF report)
July 17th-26th: Snowmass meeting in Seattle. (Do we know key dates?)
July 31st: Snowmass reports due to Snowmass (do we know the actual deadline?)
Oct 30th: Final report due to APS + agencies?

Draft of CF03 Report: link
Comments and Feedback: link

# Key Opportunities

- These will mostly likely be where the CF conveners go for the takeaways from CF03.
- Propose we spend this meeting focusing on them.

# Figures

- We are now able to test ΛCDM at unprecedented level of precision by measuring the cosmic distribution of dark matter. These measurements span a range of scales from the most massive bound structures to ultra-compact mini-halos and primordial black holes (1–3). **Cosmic probes of dark matter halos and primordial black holes should be supported as a complement to terrestrial dark matter experiments.**

- Only mention of PBHs in “Key Opportunities”. Do they need/merit their own bullet point?
- Neelima: Does “dark matter halo” associate with P(k). A number of probes focus on P(k). Maybe “structure distribution” and “halo density profile”. Is halos cutting out 21-cm and weak lensing?
- Is “supported as a complement” too weak? Probably. Strengthener words “essential”, “unique”, “critical”.
- Hai-bo: Bring in something about “only robust experimental measurement”, “only accessible to cosmic probes”.
- Neelima: Remove terrestrial experiments from this bullet. To make progress, we might need to focus more on astro/cosmo observations
- Hai-bo: Not sure the right place to talk about PBHs. Very specific candidate. Looks strange to pull it out.
- Alex: Can we include all topics by talking about the power spectrum
- Neelima: Maybe re-write bullet to: “Cosmic probes of the dark matter distribution, such as the number of halos, the matter power spectrum, the halo density profile, and primordial black holes should be supported as a key element of the Cosmic Frontier program.

- The ΛCDM model makes the strong prediction that the mass spectrum of dark matter halos extends below the threshold at which galaxies form (4). This is a strong, testable prediction of the ΛCDM model. **The HEP community should pursue the detection of dark matter halos below the threshold of galaxy formation as an exceptional test of the ΛCDM model.**

- Neelima: “dark matter distribution” or “halos”. Hai-bo: Think halos.
- Keith: Pushing into a different part of parameter space. But also a more clean and robust test of DM microphysics because avoids some baryonic physics. Maybe “clean” or “robust” probe.
- Ethan: Lead with the dark matter physics that is probed rather than the galaxy formation threshold.
- Keith: Think of science opportunity first in terms of range of dark matter physics effects that are probed. Connection to early universe physics; synergies with dark energy and neutrino physics.
- Hao-Bo:

- Extreme astrophysical environments provide unique opportunities to explore dark matter couplings to the Standard Model (5). **Astrophysical observations of extreme environments should be leveraged to constrain the expanding landscape of theoretical dark matter models.**

- "Leveraged" is probably not quite strong enough. "Supported" would be better. "Enabled"?
- Neelima: Maybe re-write to: "Astrophysical observations of extreme environments such as exhibited by compact objects and the early Universe should be leveraged to constrain the expanding landscape of theoretical dark matter models."
- Kerstin: Give us money! "Supported"? Physics program that falls between the cracks of DOE, NSF, and NASA. How much can we say? Supporting observation campaigns, instruments, and theory for interpretation.
- Hai-bo: Need to establish "new agency mechanisms" to enable the research we are proposing. Combine with support on facilities.
- Tesla: Need collaborative structures for some agency support. (Alex: I think we have a sub-section where we want to talk about this; also emphasized in the LSST DESC paper.)

- Numerical simulations of structure formation and baryonic physics are critical to robustly interpret observational studies of dark matter. These simulations are synergistic with simulations used to inform studies of dark energy and inflation. **Numerical simulations of structure formation and baryonic physics will play a key role in addressing particle physics questions about the nature of dark matter. HEP computational resources and expertise should be leveraged to advance numerical simulations of dark matter physics.**

- Feedback for simulation group?
- “Leveraged” again…

- Dark matter discovery may be just around the corner, and cosmic probes of dark matter will be critical to interpret such a discovery in a cosmological context. **Strong support for cosmic probes is essential for interpreting any dark matter discovery in a terrestrial experiment.**

- We do not really discuss this in the text (a bit in the intro). Should be something that goes into the outlook (i.e., cosmic discovery of dark matter and cosmic probes in the event of dark matter discovery elsewhere)
- “Dark matter discovery” has already happened :). “The discovery of particle dark matter”(?)
- Keith: Is this intended to be a discovery in terrestrial experiments? Alex: yes, but we should be sure to cover discovery in cosmic probes.
- Chanda: Language is important. What are we trying to achieve now? What constitutes a dark matter “discovery” from astro/cosmology?
- Keith: I think this is actually the most important question, and is hard to answer.
- Simon: This is a particle physicists phrasing. Can we re-cast it as we would like to see it?
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- Current/near-future experiments in the HEP Cosmic Frontier have direct sensitivity to dark matter physics (6–8). **Cosmological studies of dark matter should be supported as a key component of the Cosmic Frontier program.**

- Josh Simon: I would like to see a stronger statement in the Key Opportunities bullet point about facilities. What's written now appears to presume that a variety of next-generation facilities will exist independent of Snowmass/P5/HEP community endorsement, and suggests that dark matter should be part of the (funded) science portfolio for those facilities. However, I think the point of view of the group working on facilities is that HEP involvement would be a key factor in getting some of these facilities built. Our baseline assumption should be that MSE/MegaMapper/SpecTel/CMB-HD will not happen without DOE participation, not that all of these are definitely getting built and we just want some money to do science with them.
- Josh Simon: The same thing basically applies to Section 3.7.2. I would describe many of these facilities (with the ELTs as perhaps the main exception, although even those are not actually approved yet) as "proposed" rather than "upcoming", which implies that they're happening. The opportunity I see for Snowmass is to help build momentum to take some of these from "proposed" to real projects.
- Neelima Sehgal: I completely agree with Josh's sentiments above. As we have discussed on telecons before, the **small ask** here is that dark matter be considered as part of the core mission of multifaceted facilities. The **big as**k is that the proposed future facilities be built **because of how well** they will probe dark matter. That latter message does seem lost a bit.

- Proposed facilities across the electromagnetic spectrum, as well as gravitational waves, can provide sensitivity to dark matter physics, as well as physics of dark energy and the early universe (9). **The construction of future cosmology experiments is critical for expanding our understanding of dark matter physics.**

- “*the* physics of dark energy”
- “cosmology experiments” may not be perfect; “on-sky experiments”
- Neelima: why isn’t this the first bullet point?
- Alex: We’ve been told

- The landscape of dark matter models and their observable signatures is rich and diverse. This makes it difficult to characterize, compare, and optimize the physics potential of future experiments. **A "Dark Matter Task Force" (based on the successful "Dark Energy Task Force" of the late 2000s) should be formed to help design a framework assess the strengths of various observational techniques to constrain dark matter.**

- **Is this really something we want as a community?**
- Simon Birrer: How much work do we anticipate with a 'Dark Matter Task Force' in addition to what we have done? In other words, could we already sell this report as a 'Dark Matter Task Force report'? I am just thinking of the timing for this report to be relevant. If we suggest 'we need another committee first' that is a convenient way to delay things. I am just painting a bit the devil on the wall. I was not involved in the 'Dark Energy Task Force'.
- Ethan Nadler: It's not immediately clear to me that a "Dark Matter Task Force" would be effective compared to a "Dark Energy Task Force" precisely because the landscape of viable dark matter models is so rich and varied.
- Keith: To gain traction with the DOE, dark matter science needs to be "projectized" with clear objectives for benchmarking progress, but there is a tension with what we would want as a community.
- Neelima: Any task force represents the biases of the its members. Not sure we'll get what we are hoping for.
- Hai-bo: Need to have an item to promote "a new mechanism". Language is confusing "difficult to optimize" is confusing. Haven't we done that as CF03?
- Alex: What if we instead focus on the "new mechanism" and instead point to the success of the dark energy task force rather than requesting the formation of a task force. Simon: Create something that is "as impactful" as the DETF report.
- Chanda: This is too easy as an out. They can hand us the task force and say: "come back to us at the next snowmass". There will be an array of proposals, and we will need to select between them?
- Neelima: Isn't P5 the selection? Chanda: part of the selection that they could recommend is a task force.
- Chanda: Find language that suggests to P5 that they are the task force? Neelima: We have given them the menu.
- Chanda: We want them to allocate the resources and establish a mechanism to make a decision and move things forward.
- Alex: Check grammar…

- Cosmic probes provide robust sensitivity to the microphysical properties of dark matter due to enormous progress in theoretical modeling, numerical simulations, and astrophysical data. **Theory, simulation, and experiment must all be supported to maximize the efficacy of cosmic probes of dark matter physics.**

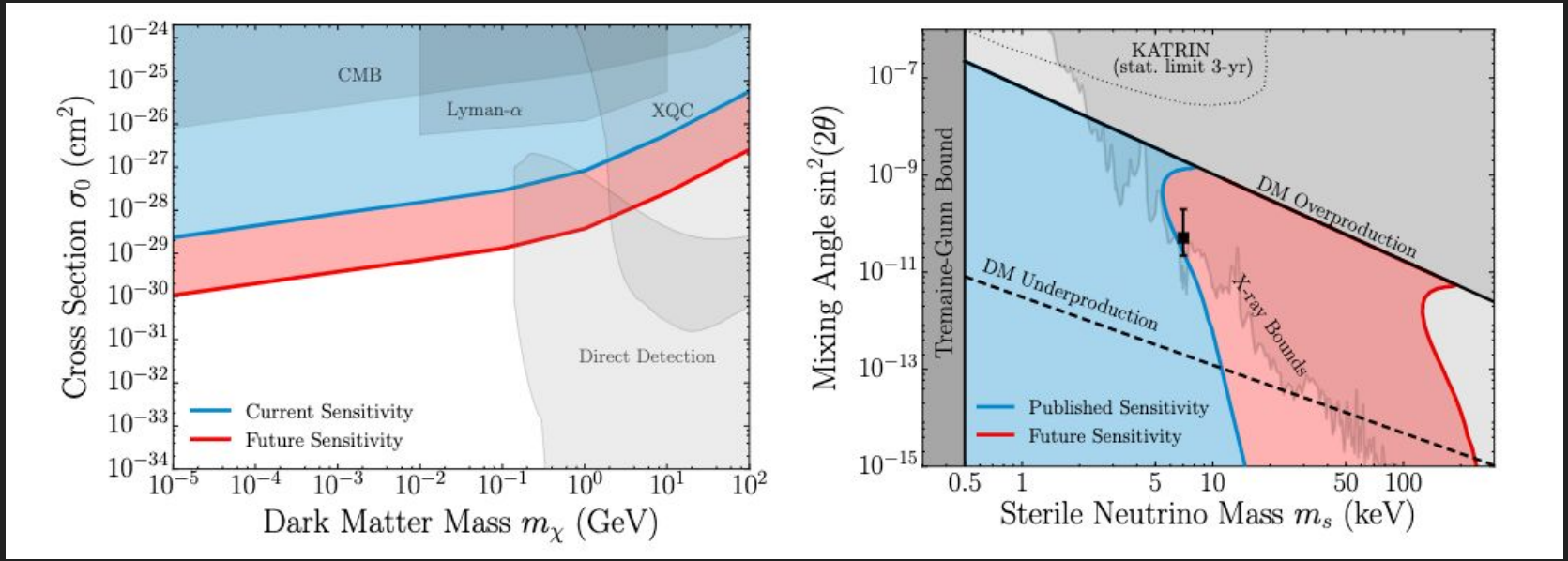
- This is our concluding bullet. It is fairly general, but seems important.

# Outlook Section

- We think that it is important to have an outlook section that will be largely new content relative to the white paper.
- Examples of dark matter discovery with cosmic probes.
  - WDM/SIDM with Milky Way Satellites?
  - Discovery of PBHs with Rubin, Roman, etc.?
  - Discovery in extreme astrophysical environments?
  - Vision of cosmic probes in the event of a discovery in a terrestrial experiment
- Summary of our vision/description of the dark matter task force (or something like a DMNI funding for cosmic probe experiments)

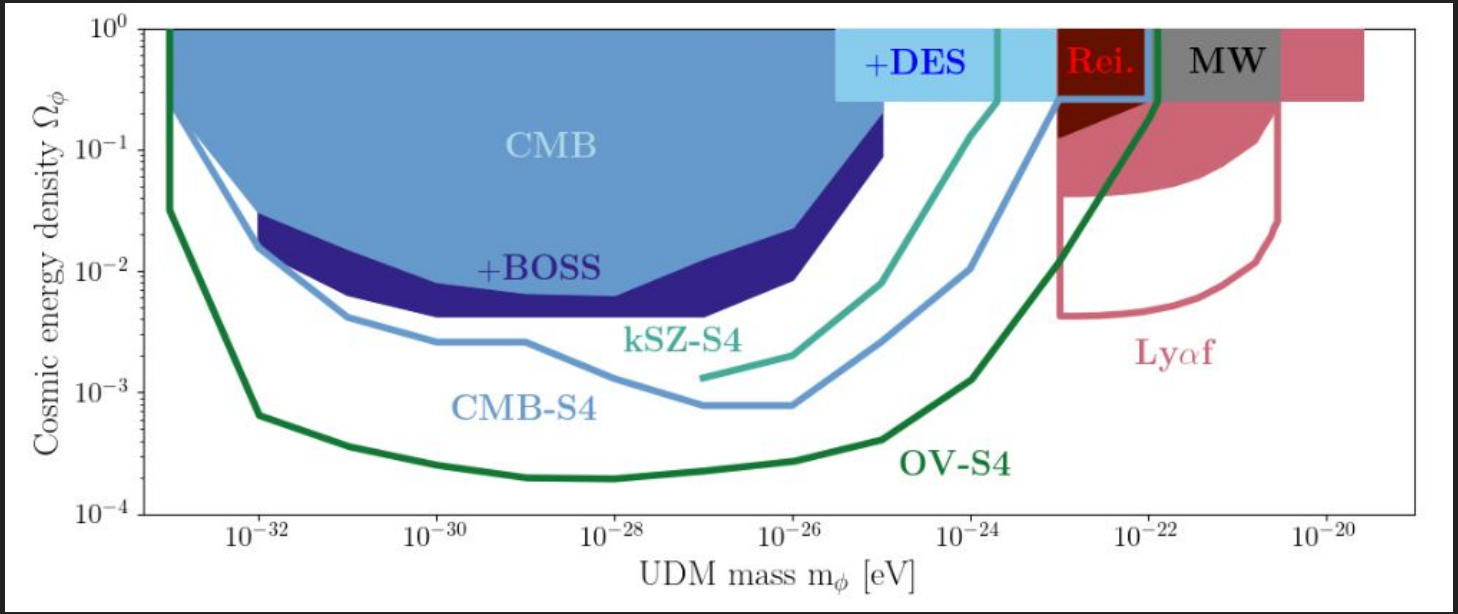
# Additional Figures

- Do we need some projected sensitivity figure?
- This might be important for convincing particle physicists.
- We do not want this to be a competition or downselect between experiments.
- We would like to be inclusive.




- Some kind of halo sensitivity projection plot?
- Add CMB + Ly-alpha + ???
- Complements PBH projection figure.

- Extreme environments future sensitivity figure?
- Something related to axion/ALP sensitivity?




- Ultra-light axion figure?
- https://keirkwame.github.io/DM_limits/
- Neelima: this figure is CMB-S4 focused. Would be good to have other experiments on it.

- Halos discovery plot?
- Something similar for extreme environments or PBH?