CF1 Direct Detection overview

Focus here on Low-Mass Dark Matter (Sectors): past, present, and future in 10 mins

Rouven Essig

Yang Institute for Theoretical Physics

Stony Brook University

Snowmass CPM, #127, Searches for Dark Sectors, Oct 6, 2020
CF1: Particle-like Dark Matter

Covers dark matter in the regime where it appears in experiments as *individual quanta*, rather than coherently via wave phenomena. Includes direct searches through its interaction with detector materials and indirectly from products of its annihilation.

- Distinguished from CF2 (Dark Matter: Wave-like) by focus on higher masses (roughly >1 eV)
- Distinguished from CF3 (Dark Matter: Cosmic Probes) by focus on particle signals of DM-SM interactions

**CF1 activities: past and future**

- Series of nine CF1 meetings through August and September ([https://indico.fnal.gov/category/1193/](https://indico.fnal.gov/category/1193/))
- Dark matter is in all frontiers. We want to update our understanding of complementarity between different searches and techniques, including developments since last Snowmass
  - Session #150 at CPM is a start
  - Dedicated complementarity workshop early in 2021
Snowmass CF1 2013 report: one paragraph on DD of sub-GeV DM

Snowmass CF1 Summary: WIMP
Dark Matter Direct Detection
7.2 Other non-WIMP dark matter searches

In addition to axions, there are many classes of non-WIMP dark matter candidates that may be detected by experiments designed to search for WIMPs. These include searches for dark photons, inelastic dark matter, lightly ionizing fractionally charged particles (LIPs) and may more. Searches for these particles are distinct from the traditional WIMP search in that the WIMP interacts with the detector through a means other than elastic scattering off nuclei. This may include, but is not limited to, ionization, elastic scattering off electrons, or excitation of the molecular system. Often the resulting interaction is detected as an electron recoil. One set of models, lumped under the description of “sub-GeV dark matter” [79] includes the “WIMP-less” scenario, axinos, and gravitinos. XENON10 has published limits based on a search for particles that induce ionization of individual electrons and was able to set limits on particle interactions that produce one two or three electrons [80]. Ultra-low threshold detectors such as CDMS-lite are also expected to have excellent sensitivity to such models. Searches for LIPs require identification of minimum ionizing particles that produce a track within the detector or detecting array. In many cases these searches are complementary to searches at colliders, fixed target experiments or underground neutrino experiments.
7.2 Other non-WIMP dark matter searches

In addition to axions, there are many classes of non-WIMP dark matter candidates that may be detected by experiments designed to search for WIMPs. These include searches for dark photons, inelastic dark matter, lightly ionizing fractionally charged particles (LIPs) and may more. Searches for these particles are distinct from the traditional WIMP search in that the WIMP interacts with the detector through a means other than elastic scattering off nuclei. This may include, but is not limited to, ionization, elastic scattering off electrons, or excitation of the molecular system. Often the resulting interaction is detected as an electron recoil. One set of models, lumped under the description of “sub-GeV dark matter” [79] includes the “WIMP-less” scenario, axinos, and gravitinos. XENON10 has published limits based on a search for particles that induce ionization of individual electrons and was able to set limits on particle interactions that produce one two or three electrons [80]. Ultra-low threshold detectors such as CDMS-lite are also expected to have excellent sensitivity to such models. Searches for LIPs require identification of minimum ionizing particles that produce a track within the detector or detecting array. In many cases these searches are complementary to searches at colliders, fixed target experiments or underground neutrino experiments.

only a few papers on this topic in 2013…

We’ve come a long way since then!
Significant theory progress
Significant theory progress

many ideas for probing

- DM scattering: $m_\chi \gtrsim \text{keV}$
Significant theory progress

many ideas for probing

- DM scattering: $m_\chi \gtrsim$ keV
- (bosonic) DM absorption: $m_\chi \gtrsim$ meV

BRN DM report
Significant theory progress

many ideas for probing

- DM scattering: $m_{\chi} \gtrsim \text{keV}$
- (bosonic) DM absorption: $m_{\chi} \gtrsim \text{meV}$
- both for various interactions

BRN DM report
Significant theory progress

many ideas for probing

- DM scattering: $m_\chi \gtrsim \text{keV}$
- (bosonic) DM absorption: $m_\chi \gtrsim \text{meV}$
- both for various interactions

well above 100 papers now on this topic
Exciting experimental progress

2013
Exciting experimental progress
Exciting experimental progress
Exciting experimental progress
CF1 letters of interest

147 LOIs cross listed with CF1 - the most of any topical group!

Around 70 LOIs related to this session:

- ~21 LOIs on theory of dark sectors and searches (cross listed with TF)
- ~24 LOIs on R&D and experiments for direct detection of sub-GeV dark matter (cross listed with IF)
- ~21 LOIs on dark sector searches with neutrino experiments, sterile neutrino dark matter searches, and proposed accelerator experiments (cross listed with AF, RF, and NF)
- ~10 LOIs on astro probes (many others within CF3)
Several community “summary” reports available

Valuable resources for new Snowmass reports on “dark sectors”, including particle-like DM, wave-like DM, and accelerator probes of DM + dark sectors:

- Fundamental Physics at the Intensity Frontier 2012 1205.2671
- Dark Sectors 2016: Community Report 1608.08632
- DOE Basic Research Needs for:
  - DM Small Projects New Initiatives Report 2019
  - High Energy Physics Detector Research and Development Report 2020

https://science.osti.gov/hep/Community-Resources/Reports
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]

1. Sharpen theory predictions for the DM signal expected in various target materials (primary and secondary interactions)
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]

1. Sharpen theory predictions for the DM signal expected in various target materials (primary and secondary interactions)
2. Calibrate low-energy signals and backgrounds
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]

1. Sharpen theory predictions for the DM signal expected in various target materials (primary and secondary interactions)
2. Calibrate low-energy signals and backgrounds
3. Increase target mass/size of promising detector technologies already able to probe $m_\chi \gtrsim 1 \text{ MeV}$ (scattering) and $m_\chi \gtrsim 1 \text{ eV}$ (absorption)
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]

1. Sharpen theory predictions for the DM signal expected in various target materials (primary and secondary interactions)

2. Calibrate low-energy signals and backgrounds

3. Increase target mass/size of promising detector technologies already able to probe $m_\chi \gtrsim 1$ MeV (scattering) and $m_\chi \gtrsim 1$ eV (absorption)

4. Improve detector’s energy sensitivity (while controlling dark counts) to probe $m_\chi \lesssim 1$ MeV (scattering) and $m_\chi \lesssim 1$ eV (absorption)
The challenges ahead for low-mass DD

Significant recent progress, but much remains to be done.

Over next decade, there are at least 5 major goals:

[order does not imply relative importance]

1. Sharpen theory predictions for the DM signal expected in various target materials (primary and secondary interactions)
2. Calibrate low-energy signals and backgrounds
3. Increase target mass/size of promising detector technologies already able to probe $m_\chi \gtrsim 1$ MeV (scattering) and $m_\chi \gtrsim 1$ eV (absorption)
4. Improve detector’s energy sensitivity (while controlling dark counts) to probe $m_\chi \lesssim 1$ MeV (scattering) and $m_\chi \lesssim 1$ eV (absorption)
5. Understand, characterize, and mitigate low-energy backgrounds
How to solve these challenges & enable a discovery?
How to solve these challenges & enable a discovery?

- Support theory research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.
How to solve these challenges & enable a discovery?

- Support **theory** research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.
- Support R&D for **multiple** target materials and sensor technologies (e.g., Skipper-CCD, TES, SNSPD, MKID, DEPFET)
How to solve these challenges & enable a discovery?

- Support **theory** research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.
- Support R&D for **multiple** target materials and sensor technologies (e.g., Skipper-CCD, TES, SNSPD, MKID, DEPFET)
- Support underground **facilities**, including R&D user facilities for quick vetting of prototypes
How to solve these challenges & enable a discovery?

• Support theory research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.

• Support R&D for multiple target materials and sensor technologies (e.g., Skipper-CCD, TES, SNSPD, MKID, DEPFET)

• Support underground facilities, including R&D user facilities for quick vetting of prototypes

• Support multiple experiments, even for covering the same masses (in next ~5–10 years, many experiments will still be “small” & relatively inexpensive)
How to solve these challenges & enable a discovery?

- Support **theory** research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.
- Support R&D for **multiple** target materials and sensor technologies (e.g., Skipper-CCD, TES, SNSPD, MKID, DEPFET)
- Support underground **facilities**, including R&D user facilities for quick vetting of prototypes
- Support **multiple experiments**, even for covering the same masses (in next ~5–10 years, many experiments will still be “small” & relatively inexpensive)

This latter is crucial for making a convincing discovery claim
How to solve these challenges & enable a discovery?

- Support **theory** research: particle theory, but also interdisciplinary work w/ e.g. condensed matter theory, AMO theory, etc.
- Support R&D for **multiple** target materials and sensor technologies (e.g., Skipper-CCD, TES, SNSPD, MKID, DEPFET)
- Support underground **facilities**, including R&D user facilities for quick vetting of prototypes
- Support **multiple experiments**, even for covering the same masses (in next ~5–10 years, many experiments will still be “small” & relatively inexpensive)

This latter is crucial for making a convincing discovery claim

If challenges are overcome — and I strongly believe they will be — the next 10 years will probe particle-like DM over multiple orders of magnitude in (several) coupling vs mass parameter spaces
For discussion:

What should be the main outcome of Snowmass/P5 report for dark sectors and low-mass DM?
For discussion:

What should be the main outcome of Snowmass/P5 report for dark sectors and low-mass DM?

Build on success of P5 report in 2014:
For discussion:

What should be the main outcome of Snowmass/P5 report for dark sectors and low-mass DM?

Build on success of P5 report in 2014:

- 2014 P5 report stated that the search for dark matter particles is high priority science and recommended that a diversity of project scales in the program should be maintained.

- Funding for “small projects portfolio” was part of all funding scenarios.

- Has been important also for sub-GeV DM: DoE is now supporting “small DM projects” (at R&D level) for particle-like DM, wave-like DM, and accelerator probes of DM.
For discussion:

What should be the main outcome of Snowmass/P5 report for dark sectors and low-mass DM?

Build on success of P5 report in 2014:

- 2014 P5 report stated that the search for dark matter particles is high priority science and recommended that a diversity of project scales in the program should be maintained
- Funding for “small projects portfolio” was part of all funding scenarios
- Has been important also for sub-GeV DM: DoE is now supporting “small DM projects” (at R&D level) for particle-like DM, wave-like DM, and accelerator probes of DM

By showcasing incredible breadth of detection concepts, technologies, and experimental progress, Snowmass report will make it easy for P5 to argue again for the importance of R&D & a small projects portfolio
Many thanks to the conveners for all their efforts!!