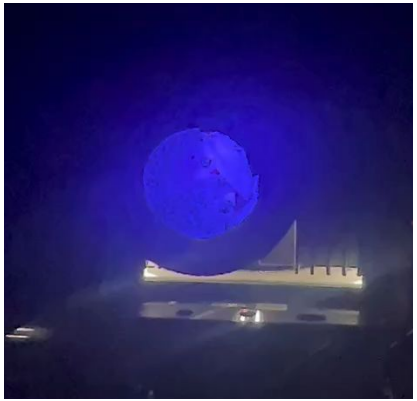
A Directional MeV Scale Dark Matter Experiment

Nora Hoch (they/them)
CPAD 2025
October 8, 2025



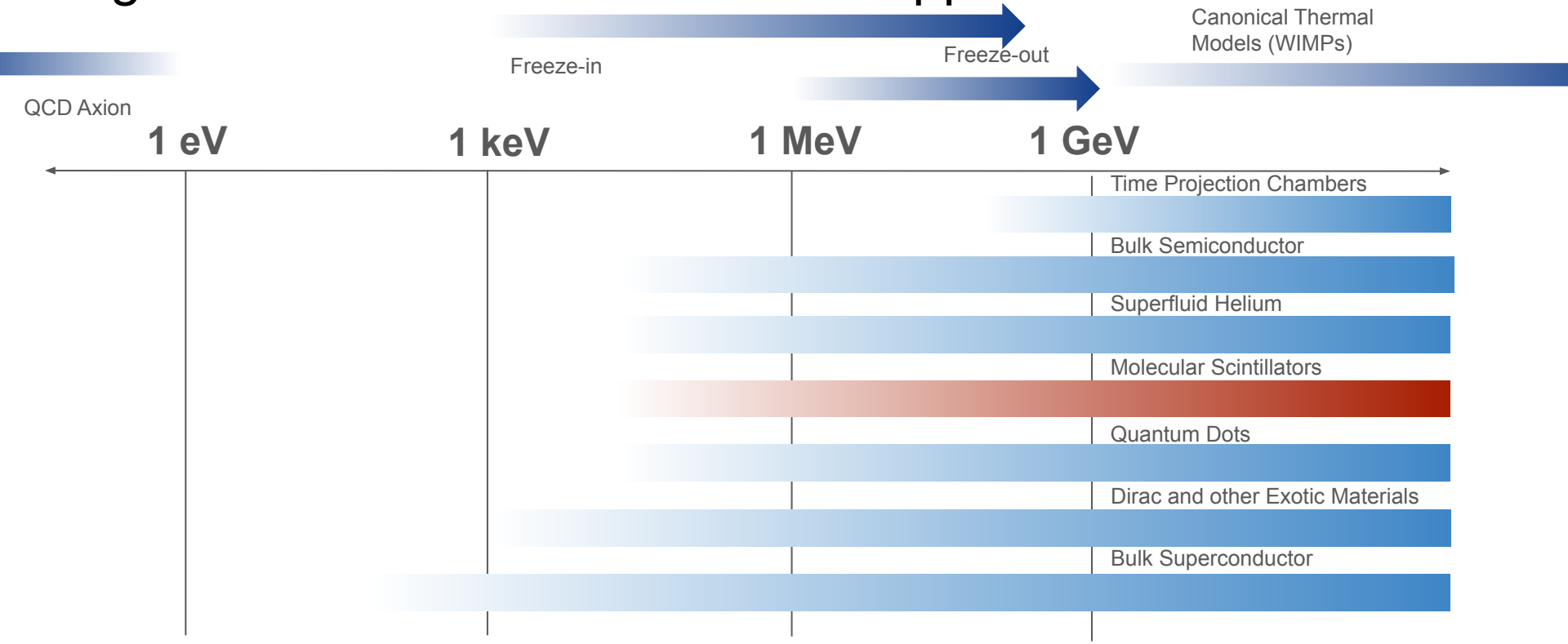
Scintillating crystal

Outline

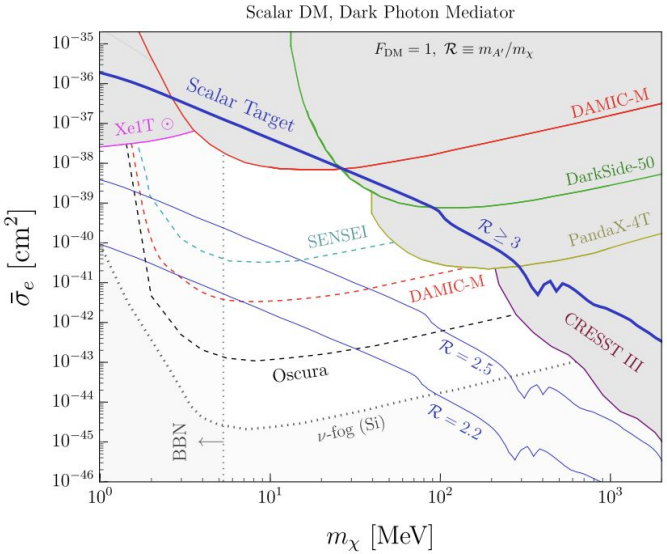
1. Primer on Light Dark Matter
2. Motivation for a Directional Detector
3. Progress on a Demonstration of Directional Light Dark Matter Detector

The Search for Particle Light Dark Matter

Light dark matter direct detection approaches



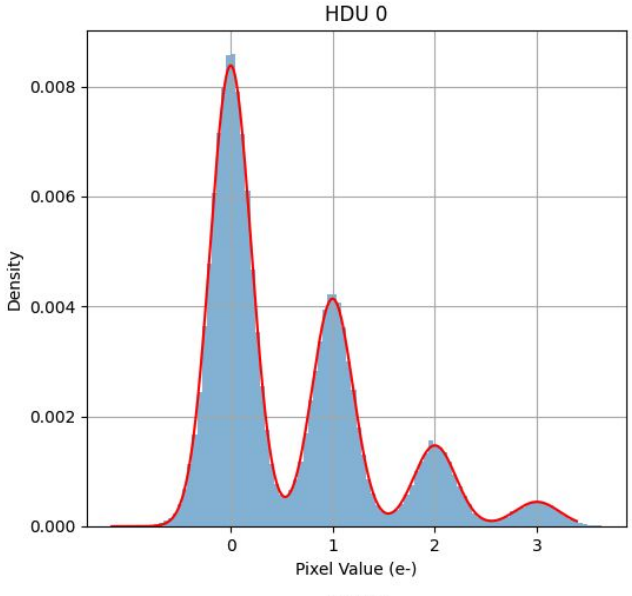
Current State of the field



G.Krnjaic https://arxiv.org/pdf/2505.04626

- Current low mass best limits are set by **Skipper-CCD** experiments
- These experiments have made great strides in the development of Skipper-CCDs with single photon resolution
- Still have several orders of magnitude to go to exclude benchmark models

Current State of the field



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- These experiments have made great strides in the development of Skipper-CCDs
  - **Single photon resolution**
  - **Low dark rates**
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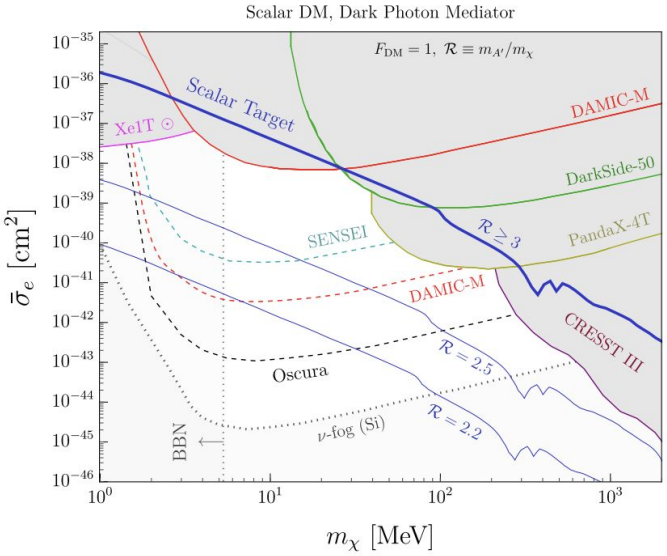

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One Way Forward: Combining the Strengths of Different Techniques

Cutting Edge Photodetectors + Unique Detector Mediums

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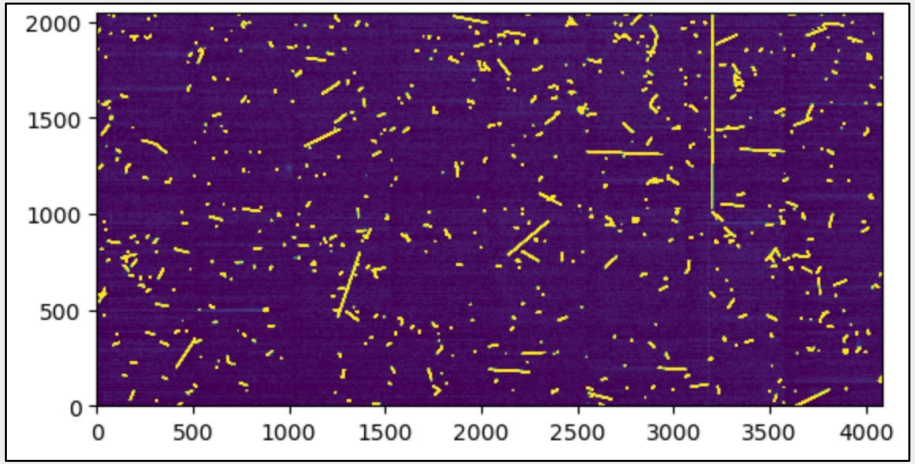
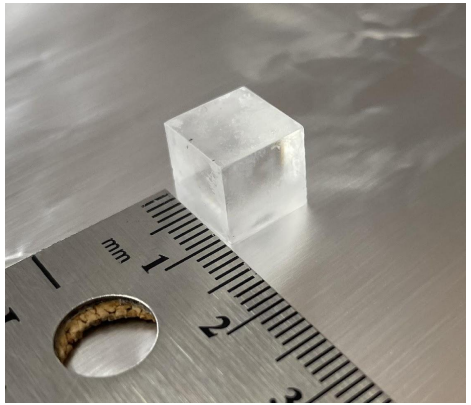
Skipper CCDs



Trans Stilbene Crystals

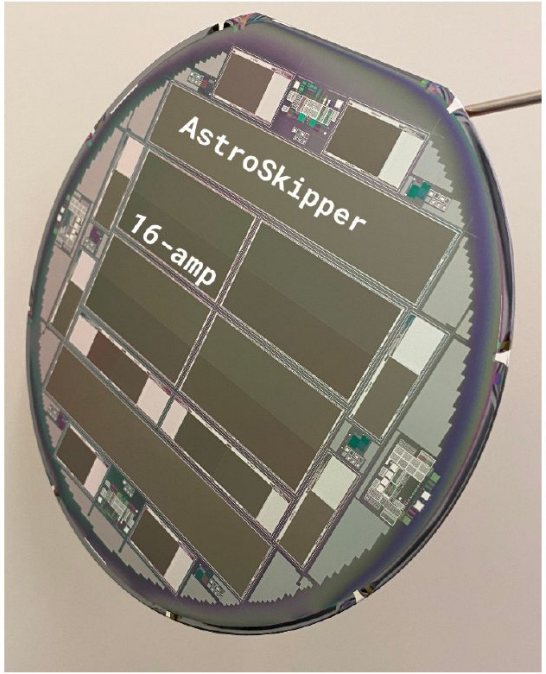


Building off the development of AstroSkippers

- Processed to same standards as DESI/DEScam CCDs
- Thinned from 650 μm to 250 μm
- Use an anti-reflective coating to increase QE at short wavelengths

Our CCD

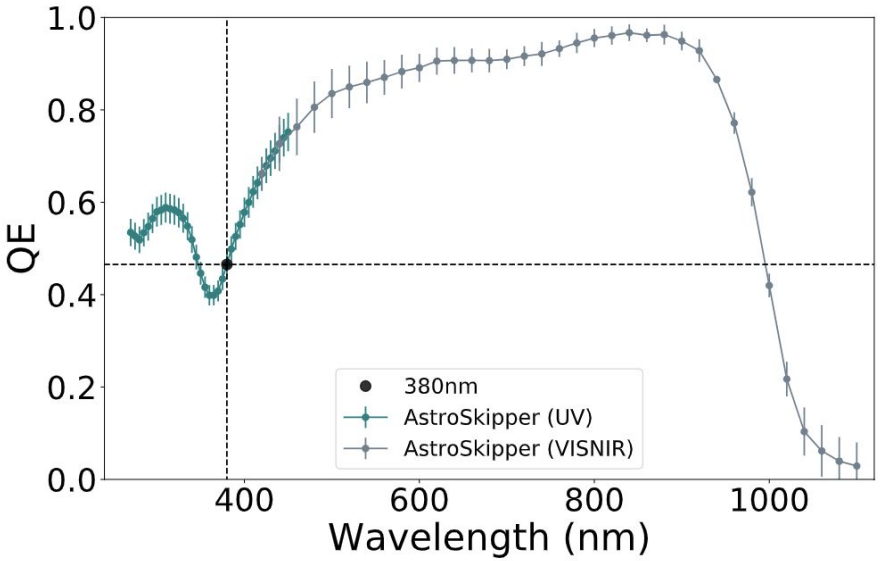
- 16 amplifiers
- 4k x 2k 10 μm pixels



Credit: Edgar Marrufo Villalpando (U Chicago)

UV Quantum Efficiency

- First quantum efficiency measurements <400 nm
- Trans Stilbene scintillates around 380 nm

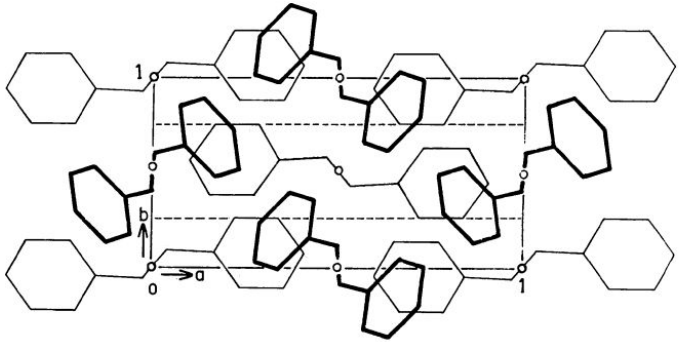


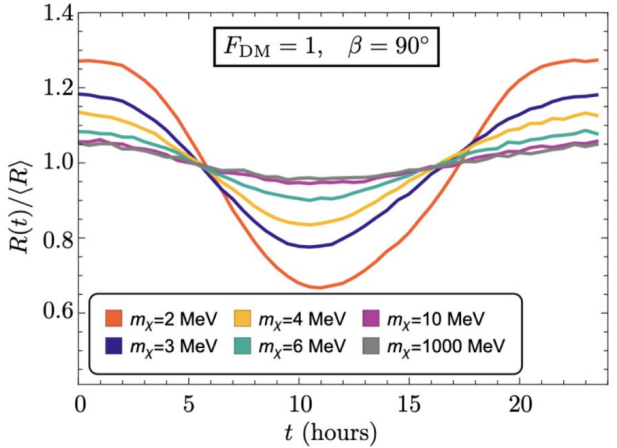
Credit: Edgar Marrufo Villalpando (U Chicago)

Organic Crystal Scintillators

Benefits of using them as sensors

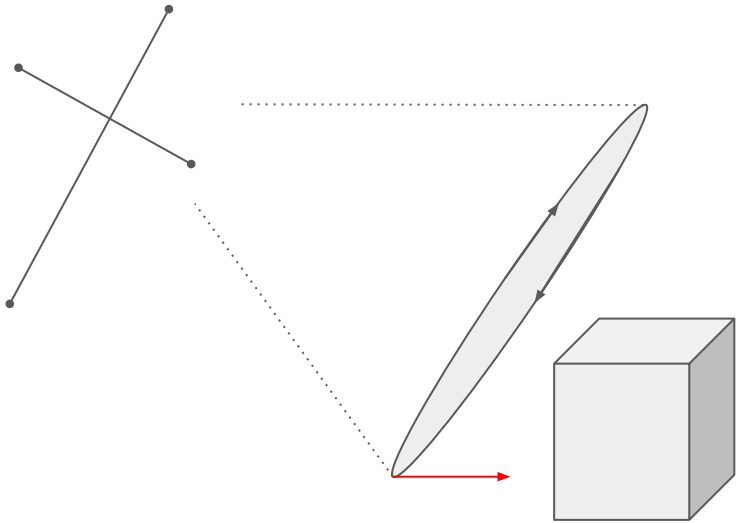
- Scalable synthesis
- Very bright scintillators - high quantum efficiency and low reabsorption
- They have anisotropic momentum response

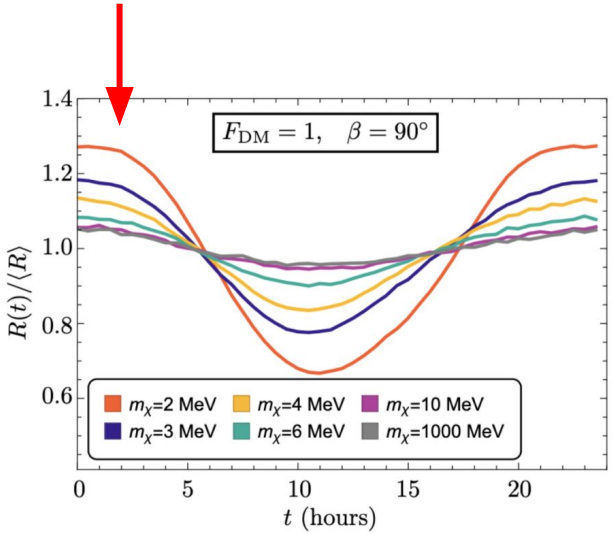




Blanco et al https://arxiv.org/pdf/2103.08601

Anisotropy -> Signal Modulation





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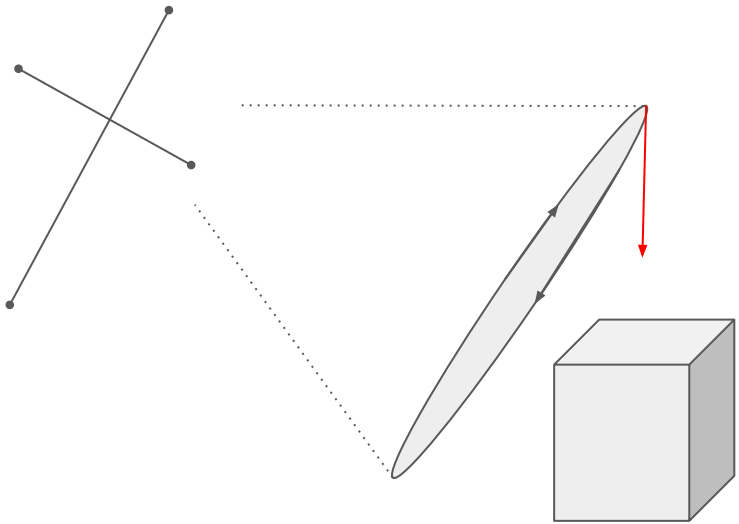

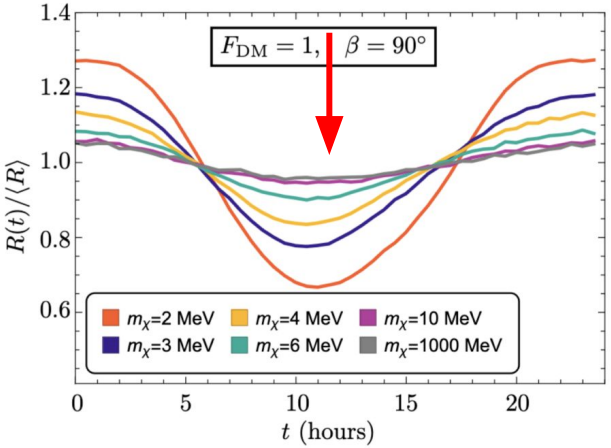

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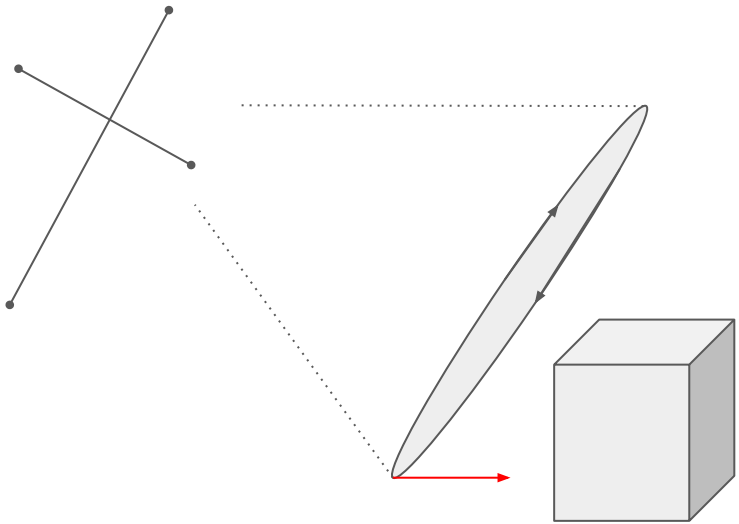
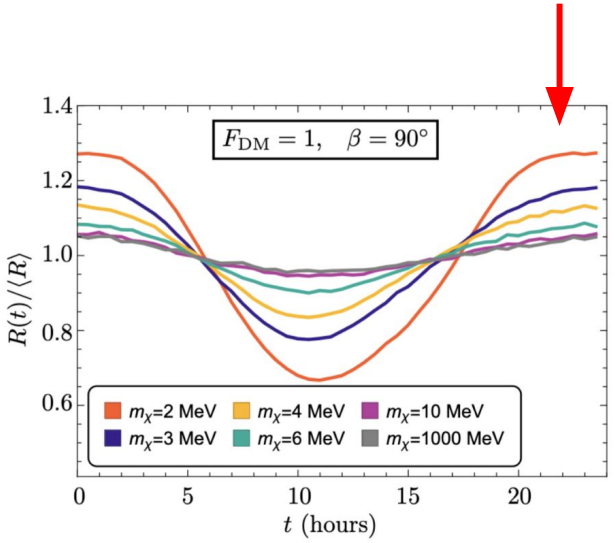
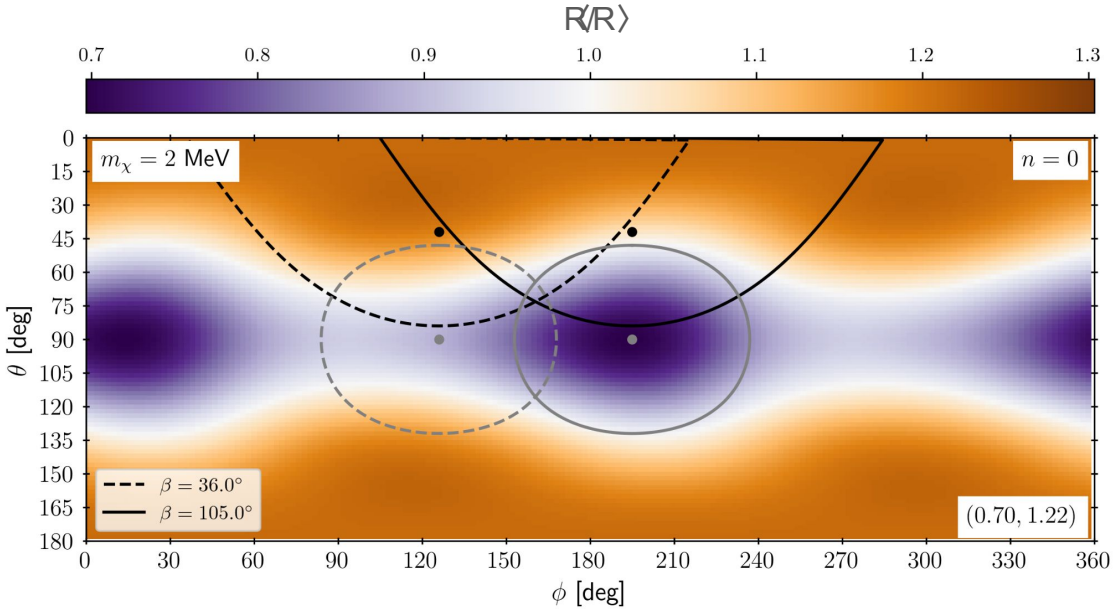




Possibilities with Daily Modulation

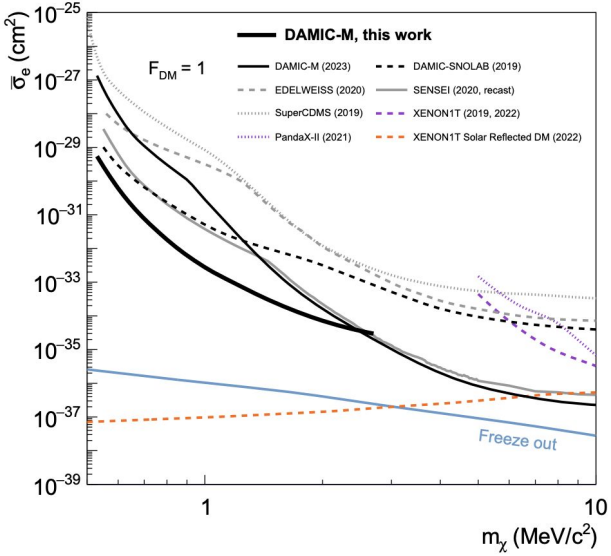


Here the curves show different trajectories for the dark matter over 24 hours with different crystal orientations

— modulation turned off
- - modulation over 12 hrs
— maximal modulation
- - variation on modulation

Credit to Ben Lillard (University of Oregon)

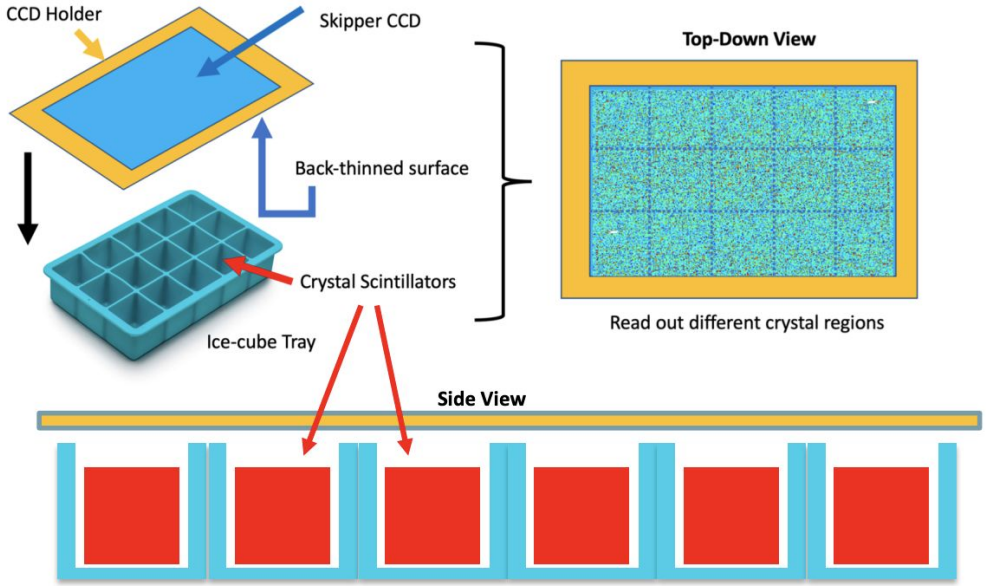
Modulation and Directionality



I. Arnquist et al. [DAMIC-M collaboration]
https://arxiv.org/pdf/2307.07251

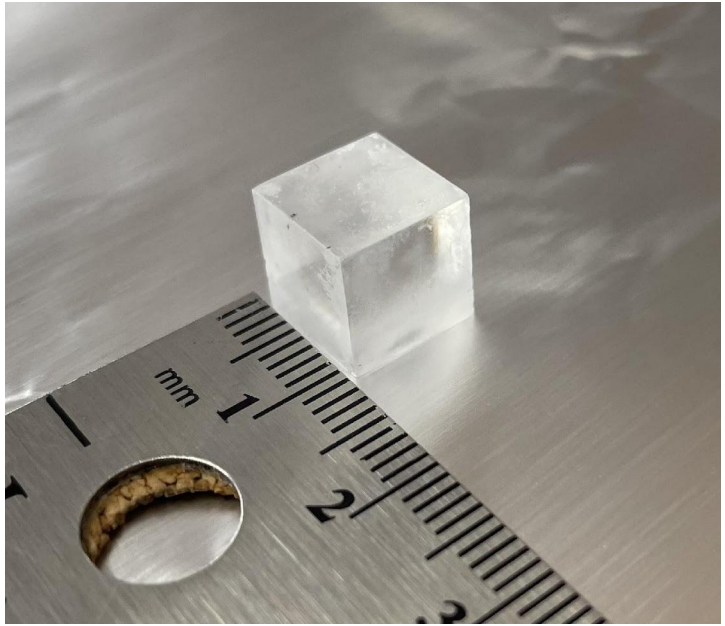
- DAMIC-M's recent analysis shows how **modulation can improve sensitivity**
- This analysis relies on a unique property of ~1 MeV dark matter that it scatters in the Earth
- Our experiment instead relies on the **inherent anisotropy** of the detector

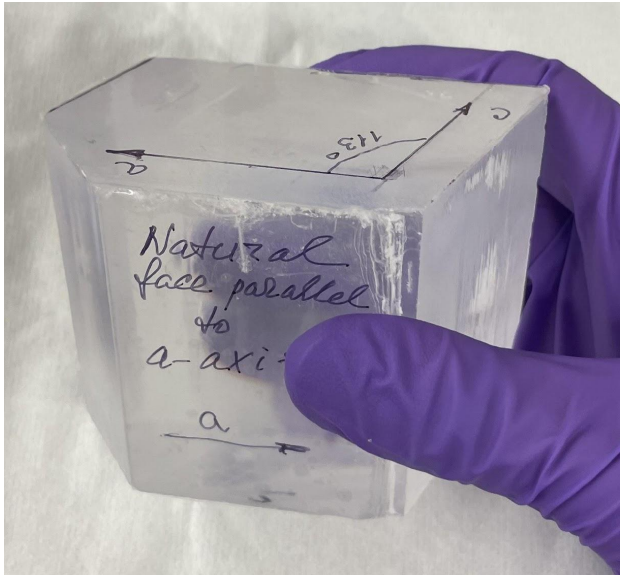
Experiment Concept



Credit to Daniel Baxter (FNAL)

Trans Stilbene Crystals

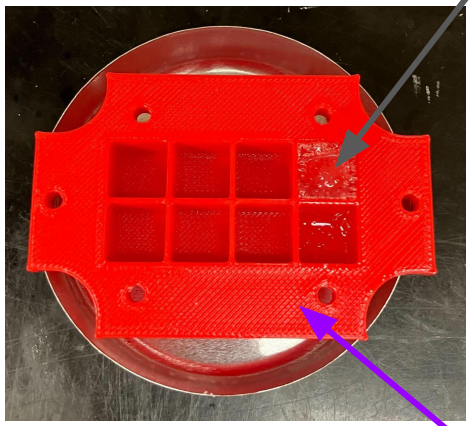


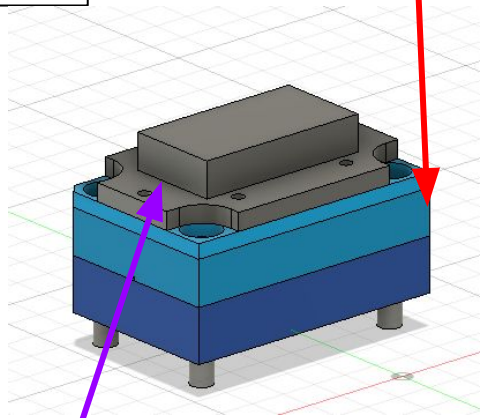


Credit to Dane Johnson (MIT)

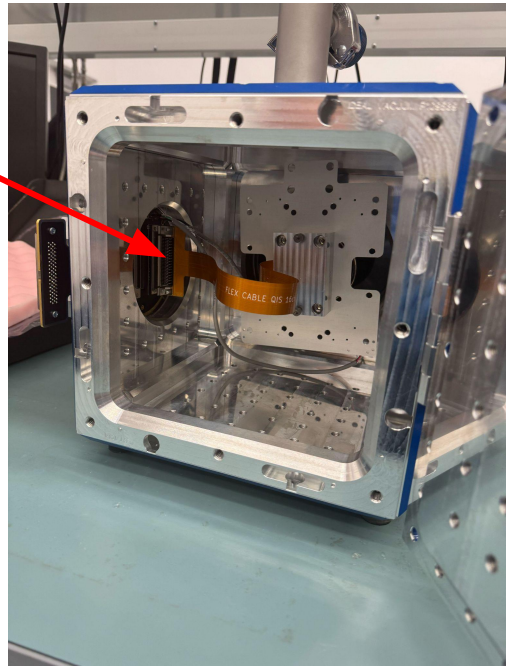
Progress on Prototyping

Epoxied Crystal





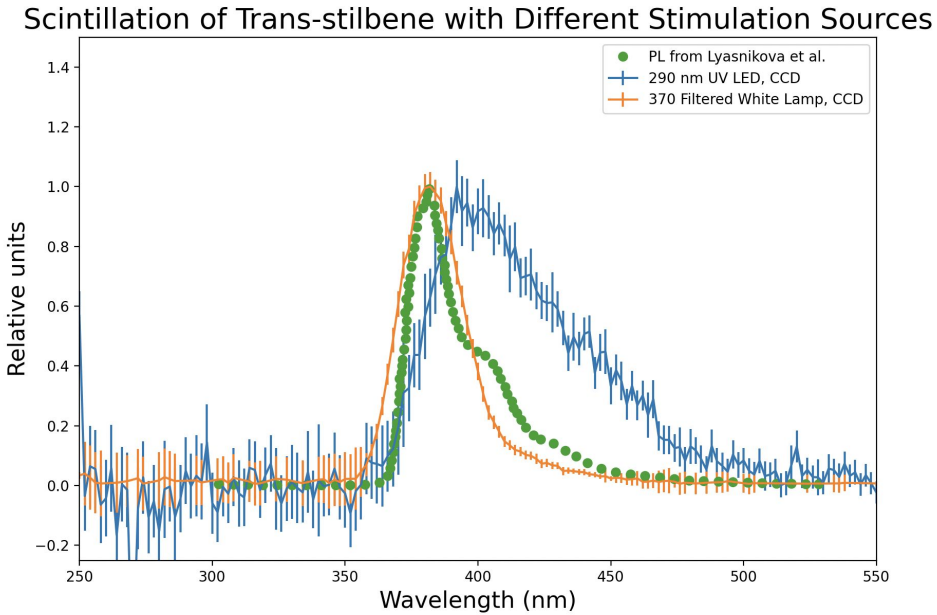
Skipper CCD



“Ice cube tray”

Optical Set-up for Scintillation Measurements

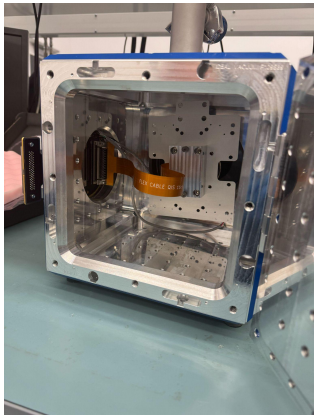
That light can be seen by the Skipper CCDs



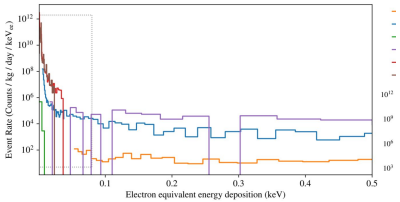
Lyasnikova et al. https://doi.org/10.1134/S1063774523600278

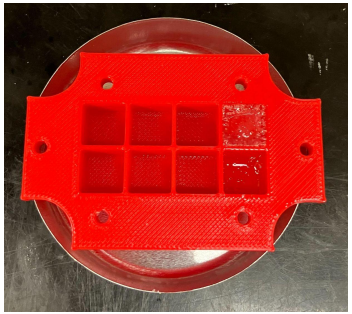
The Plan

Finish the Test Stand



Characterize the Backgrounds





Install the Crystals

Deploy Underground

People Involved

MIT - Nora Hoch, Lindley Winslow, Danna Freedman, Dane Johnson

FNAL/Uchicago - Edgar Marrufo Villalpando, Abby Williams, Brandon Roach, Alex Drlica-Wagner, Dan Baxter, Javier Tiffenberg

UIUC - Peter Abbamonte, David Balut, Laura Haske, Liam Thompson, James Oh

University of Toronto - Yoni Kahn

Penn State - Carlos Blanco, Ben Lillard

UOregon - Aria Radick

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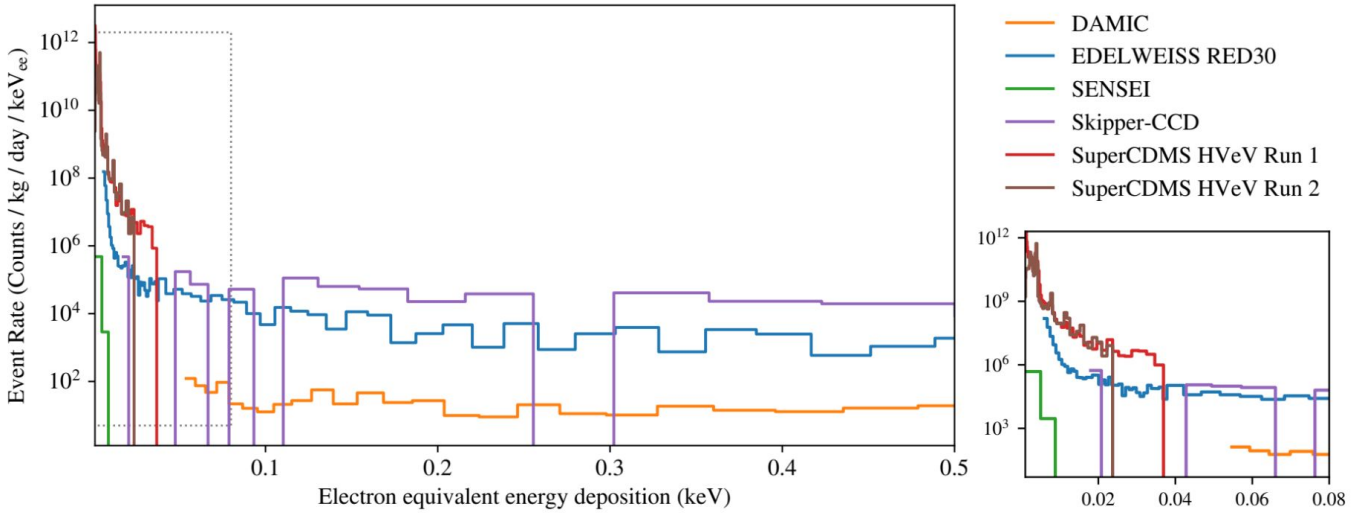
Back-up Slides

Excess Backgrounds



P. Adari, et al. (EXCESS Workshop), SciPost Phys. Proc. 9, 001 (2022) [arXiv:2202.05097]
See also: https://arxiv.org/abs/2503.08859