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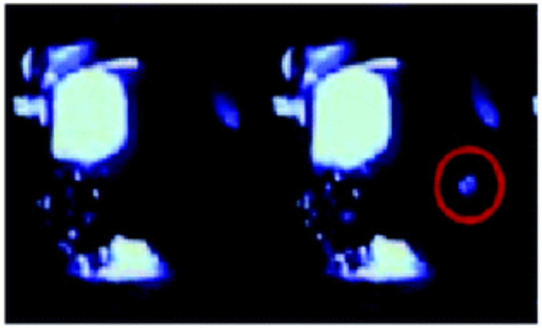
Issue 24, 2021

From the journal:
Physical Chemistry Chemical Physics

Basic Energy-Threshold Modeling for Snowball Chambers

(first tests: 20 mL)



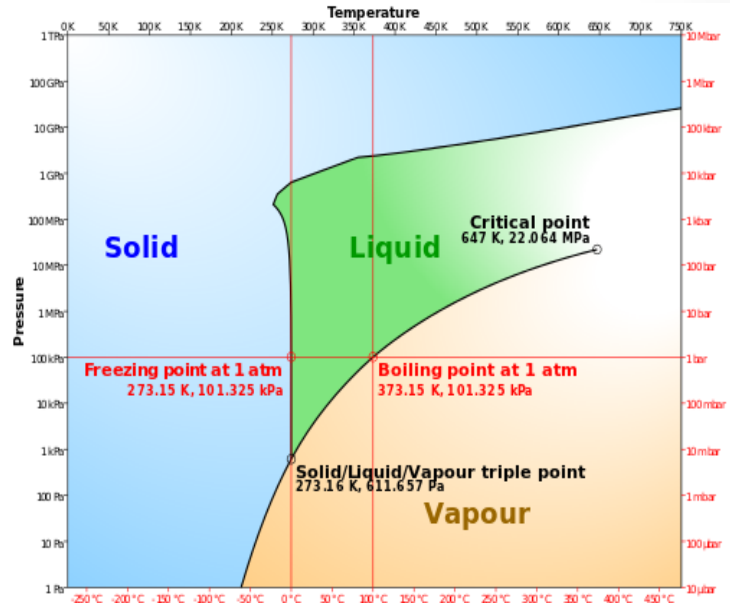
Prof. Matthew Szydagis UAlbany SUNY August 27, 2024

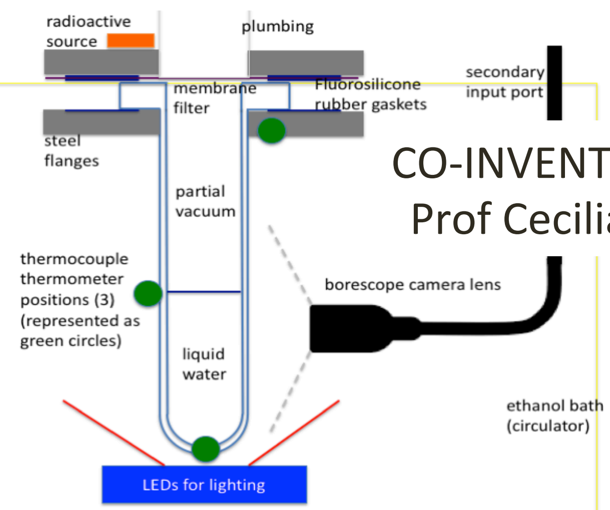
Also available on **arXiv** https://arxiv.org/pdf/1807.09253.pdf

What is a Snowball Chamber?

done before, but only with betas and gammas, most recently by Varshneya (*Nature*, 1971) Physics Dept., Univ. of Roorkee, India

- The snowball chamber is analogous to the bubble & cloud chambers
  - It also relies on a phase transition
  - But it is a new instrument in nuclear & particle physics
- Supercooling of pure water in clean, smooth containers
  - Although, as with bubble chambers almost any other liquid should be usable
  - A liquid such as water can be cooled below its normal freezing point. Metastability

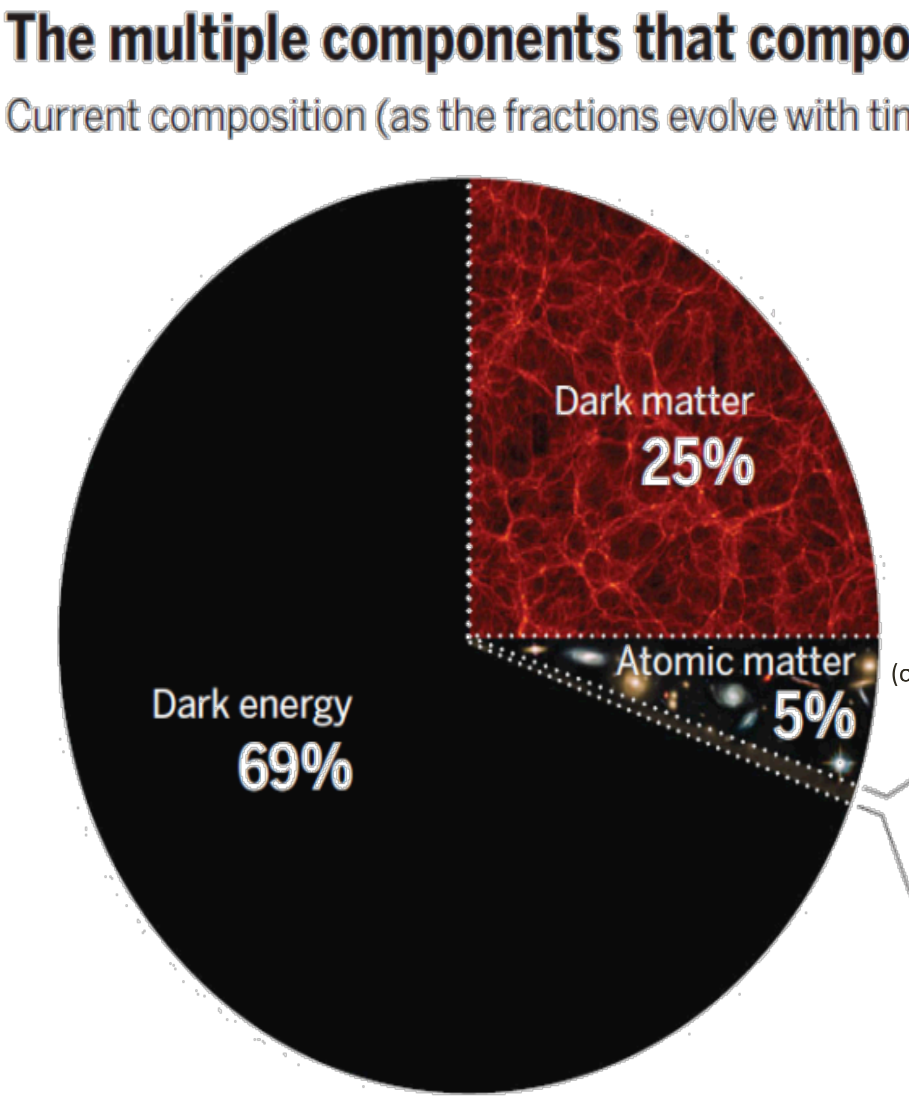


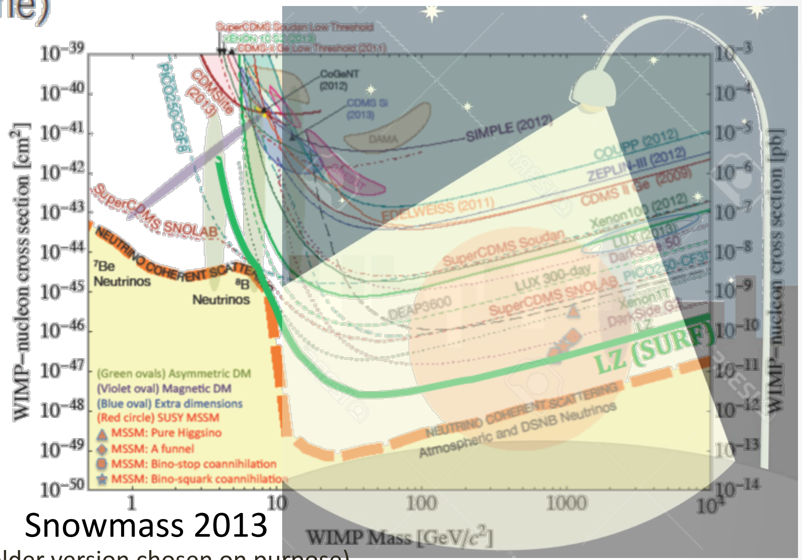


CO-INVENTED w/ Prof Cecilia Levy

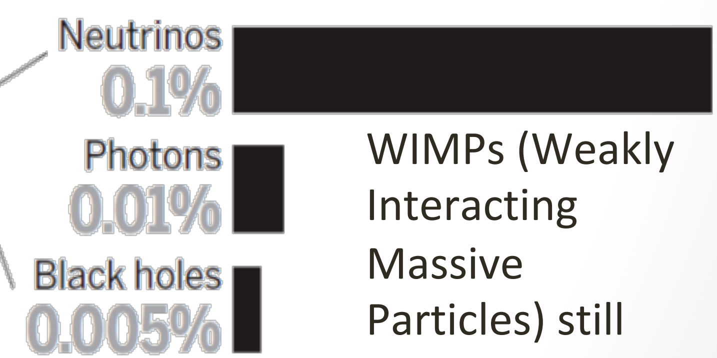
Dark Matter: A Lamppost Effect

(or, streetlight)





Snowmass 2013
(older version chosen on purpose)



WIMPs (Weakly Interacting Massive Particles) still well motivated

The Advantages and The Merits

- Scalability: ν project examples (H_2O Cherenkov detectors)
  - Either in bulk or modular (many small tubes) OR in droplet form
- Purity: water is cheap and easy to purify. Done regularly
  - We've used a 20nm filter. Can upgrade to 5 but also try 100 (speed)
- No cryogenics (-30 °C isn't very cold) nor high voltage necessary
  - In general, excellent safety: no superheated liquid for instance
- The lightest possible element to search for the lightest dark matter still producing nuclear recoils: Hydrogen
  - Plus sensitivity to medium-mass dark matter with Oxygen
  - Possible recoil differentiation with AI/ML (more on this later)
- Lower "neutrino fog" for hydrogen than other elements

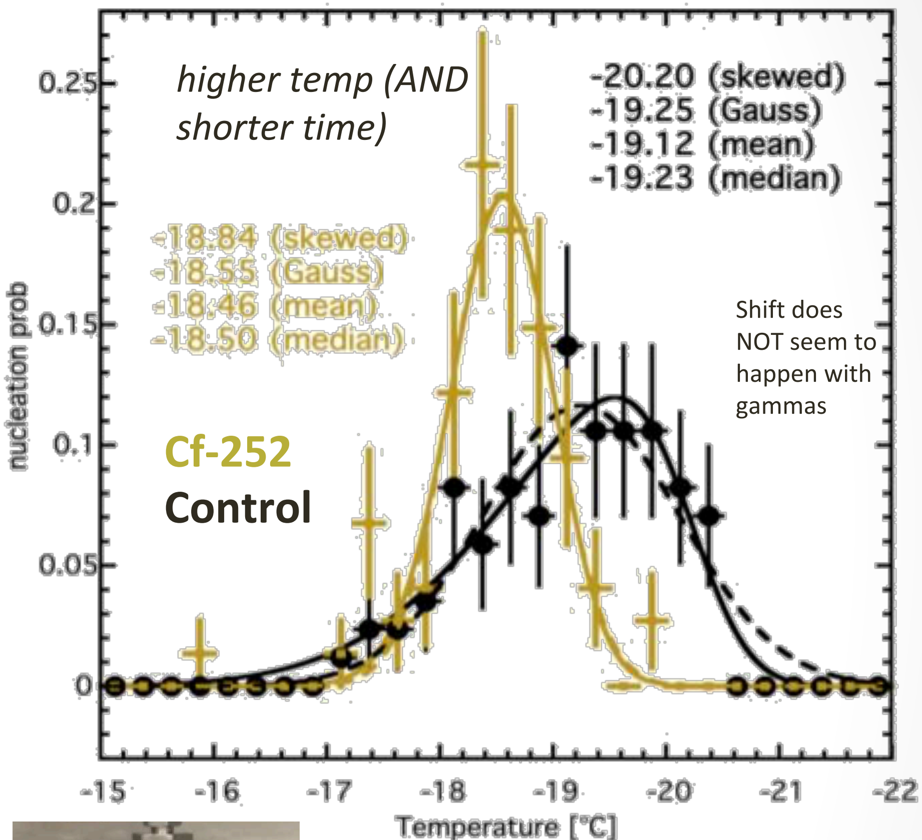
WHY possible? H bonding

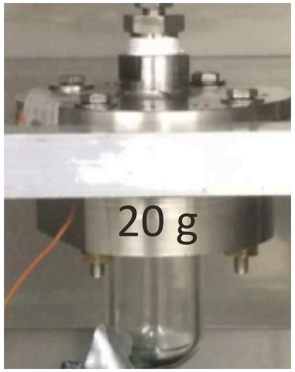
- ***Directionality***, the holy grail of dark matter direct detection
  - In the bulk of a liquid, not in gas. For rejecting solar νs
- Energy reconstruction: last summer we demonstrated the supercooling of WbLS (water-based liquid scintillator). A first!

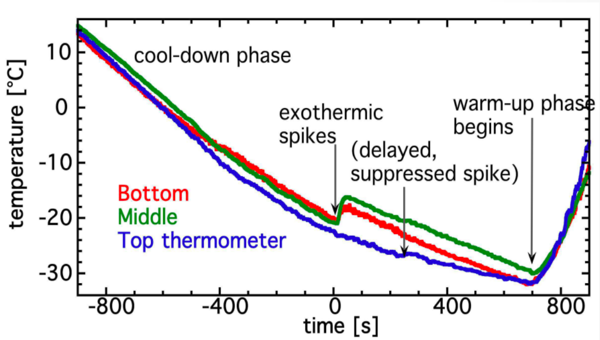
https://www.mdpi.com/2218-1997/10/2/81

Critical Proof of Concept (2018)

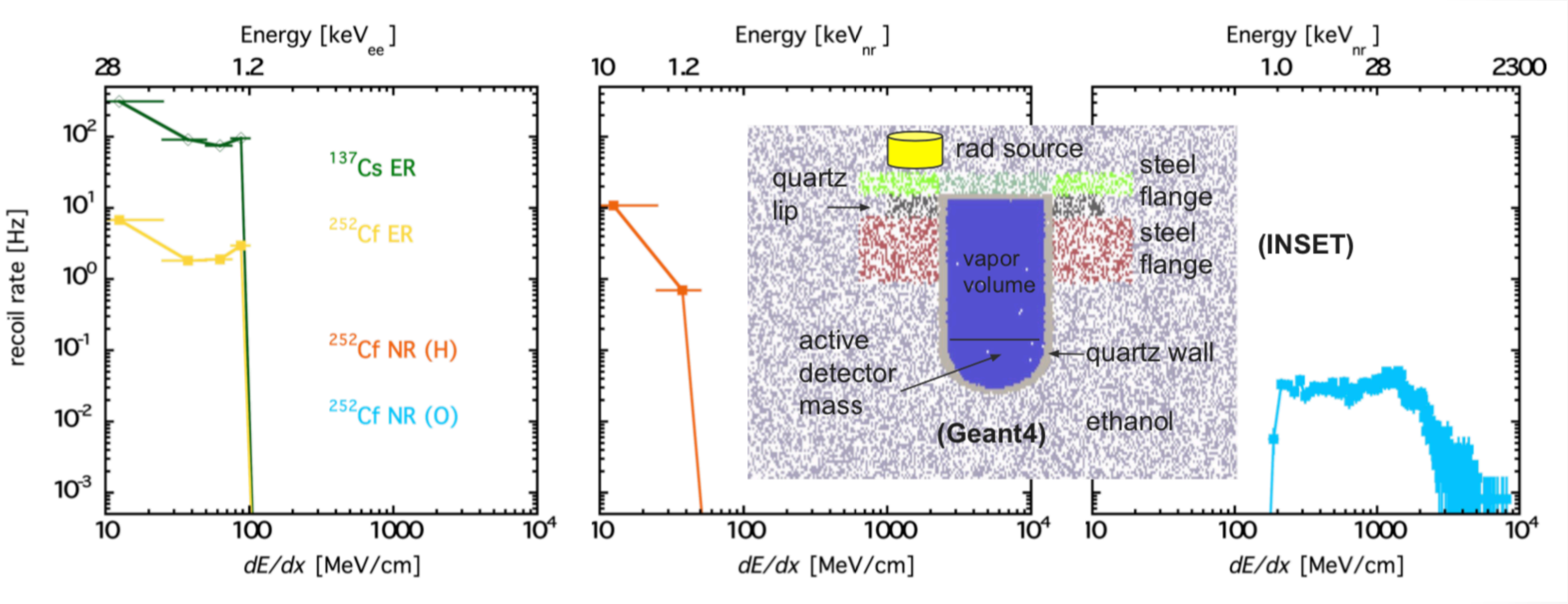
- Neutrons (^{252}Cf) are able to freeze supercooled water
  - A world first. Made the journal cover (see slide 1)
- Yet another advantage: neutrons will multiply scatter in water (with a few-cm mean free path)
  - Won't mistake for WIMP
  - Observed in cam (slide 1)
- Our first results are consistent with keV-scale energy threshold
  arXiv:2401.15064
  - Theory papers suggest sub-keV very possible
- Cf corroborated by AmBe







Comparison of (Geant4) Simulations with the Data



- Stopping power spectra for each possible type of recoil. Corresponding initial species *E*s for which this is the mean *dE*/*dx* are along upper x-axes. A ~100 MeV/cm threshold assumption explains a lack of discernible response from a γ source
- (**Inset**) Geant4 geometry: cross-sectional view

Critical Energy and Radius

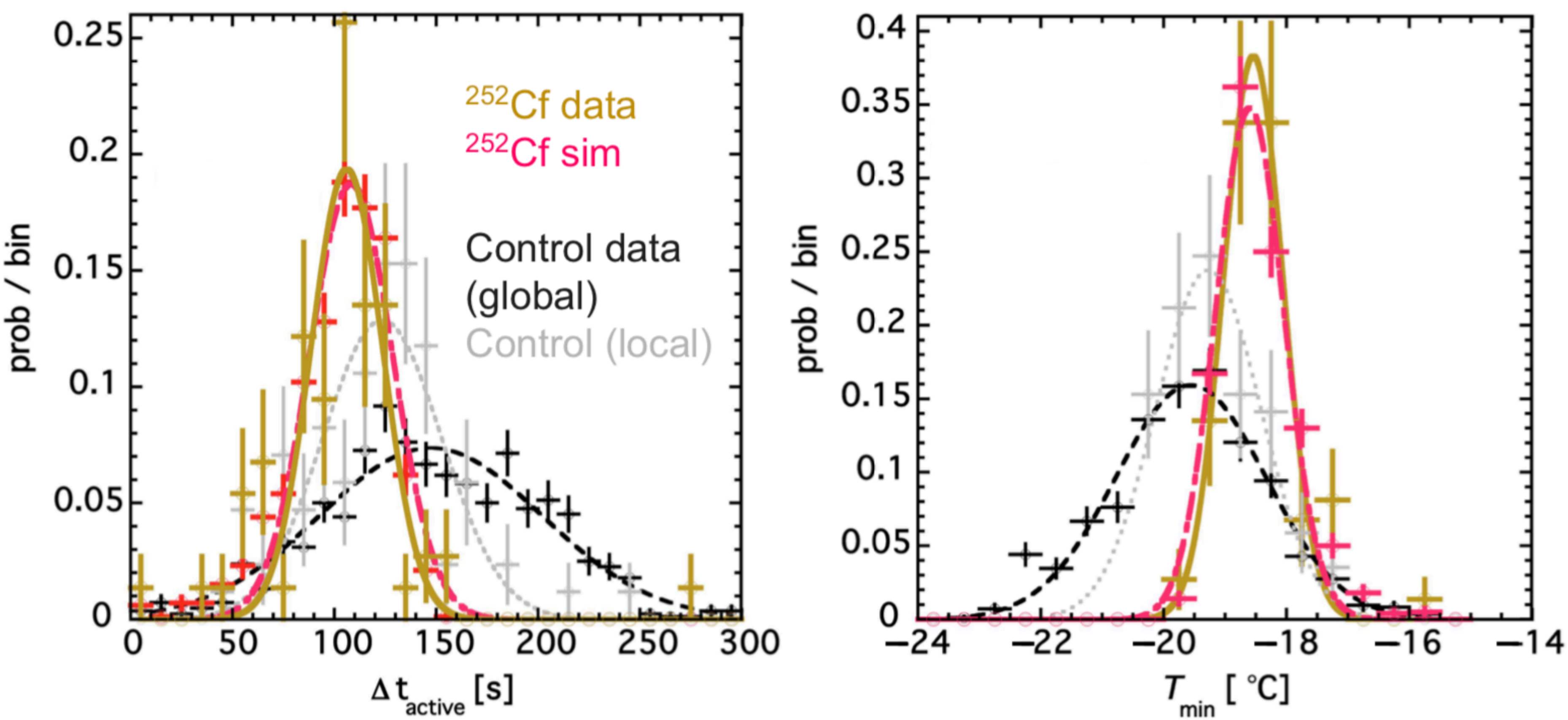
(1) $$E > E_c = 0.2\ \text{keV}_{nr}$$

After conservatively applying Equations (2) and (3), $E_c = 1.2\ \text{keV}_{nr}$ effectively

(2) $$\frac{dE}{dx} > \frac{E_c}{r_c} = \frac{200\ \text{eV}}{20\ \text{nm}} = 100\ \text{MeV / cm};$$

(3) $$l > (2r_c) = 40\ \text{nm};$$

(4) $$Efficiency = 1/\left[1 + (T/\,(252.8 \pm 1.1\ \text{K}))^{540\ \pm\ 150}\right].$$



What are the Backgrounds?

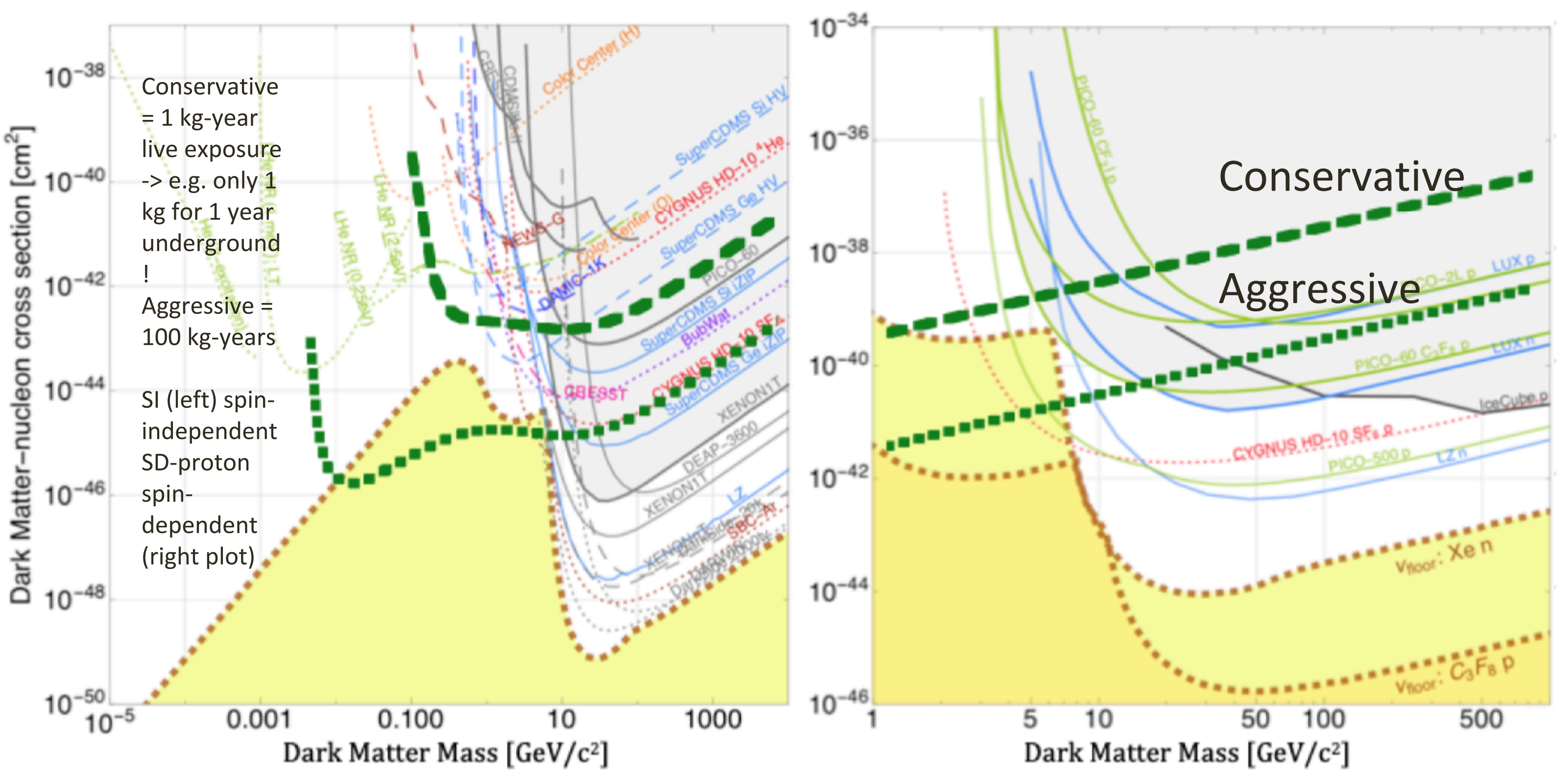
- Promises of dark matter search results without an understanding of **backgrounds** cannot be trusted.

- **Cosmic-ray muons**: minimize flux by going underground and adding shielding (either active or passive)
- **Neutrons**: covered (**neutrinos** also covered)
- **Beta and gammas (e- recoils)**: adjust temperature to avoid them, and make experiment out of low-background materials
- **Alphas**: purify water, use timing as in PICO, use piezo-electric acoustic sensors as in PICO, adjust temperature to avoid (so we have plans A, B, C, D). Colder = lower energy, *dE/dx* thresholds
- **The Wall**: fiducialization, smooth vessels sourced from same suppliers as used for bubbler chambers, hydrophobic materials, super-hydrophobic coatings (again, multiple backup plans)
- **Spontaneous bulk nucleation**: perhaps no such thing! But!! optimize *T* just in case (Goldilocks). Go modular. Vibration iso

Projected WIMP Sensitivities

plots from DoE Cosmic Visions Report (arXiv:1707.04591) with our own curves overlaid. <u>No directionality assumed</u>

- No past, present, future (planned) experiment has comparable sensitivity at 1 GeV for WIMP-proton coupling (spin-dependent)
  - That is true even if the energy threshold is > 1 keV_{nr} not lower value
- Readiness: need *O*(4) yr. at least for calibrations + optimizations



➔ The Future

- Calibrate with mono-energetic neutron beam (e.g. TUNL, but UAlbany also has beam) at different Ts, n fluxes, n Es, etc.

- Goal: become the first dark matter experiment to deploy 2 detectors, one in the Northern and one in the Southern Hemisphere, to study annual modulation and disprove false positives trivially

AGILE!

- While scale up would be nice, already competitive at *O*(1 kg) scale, so emphasis on LONG-TERM stable running
  - If underground and away from cosmic rays, we will not even need to solve major challenge from surface of the melting time

- Made it into Snowmass reports (and P5/HEPAP spoke highly of small-project funding)

Concluding with Sample Videos

- The snowball chamber captures the imagination like few other experiments can *PUBLIC ENGAGEMENT*
- These are the most recent videos, from BNL (sabbatical)
  - FLIR (low FPS) and high-speed camera (6,000 FPS example)

- FLIR.mov ~15 second start
- Evt14BNL.mp4 (both too large to embed) ~half-way through