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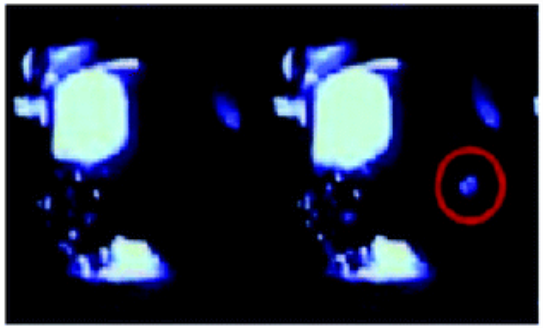
(first tests: 20 mL)



Intro to the Snowball Chamber

Prof. Matthew Szydagis UAlbany SUNY May 21, 2024

THANK YOU *for the opportunity to present on this to you today!*

Also available on **arXiv** (open access) https://arxiv.org/pdf/1807.09253.pdf

Informal Collaboration Right Now

- UCLA, BNL, RPI, Penn State, Duke/TUNL, with UAlbany

Faculty and lab staff : Alvine Kamaha, Milind Diwan, Aleksey Bolozdynya, Minfang Yeh, Ethan Brown, Carmen Carmona, Luiz de Viveiros, Phil Barbeau, + **Matthew Szydagis & Cecilia Levy** (AND: Peter Wilson, Australia)

UNIVERSITY AT ALBANY
State University of New York

Brookhaven
National Laboratory

PennState

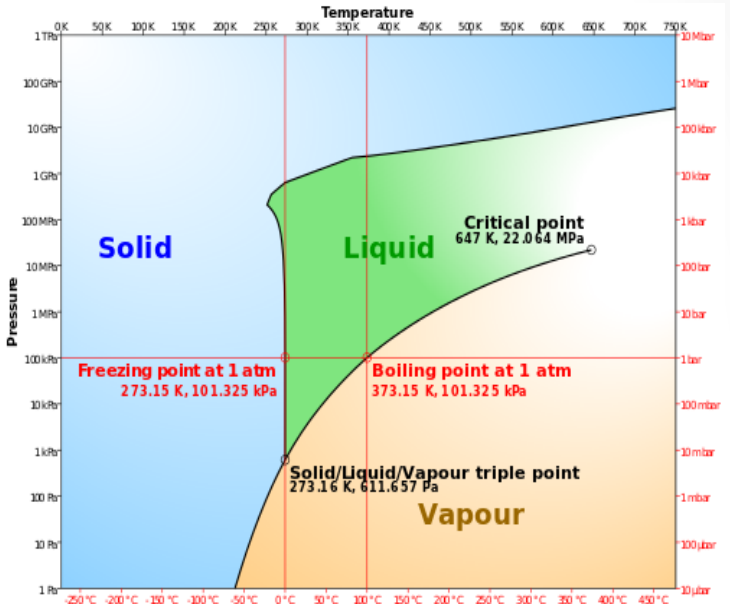
Duke
UNIVERSITY

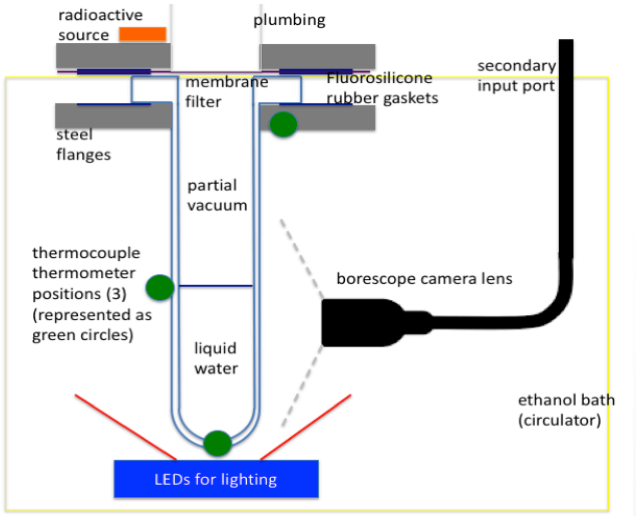
TUNL
TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

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

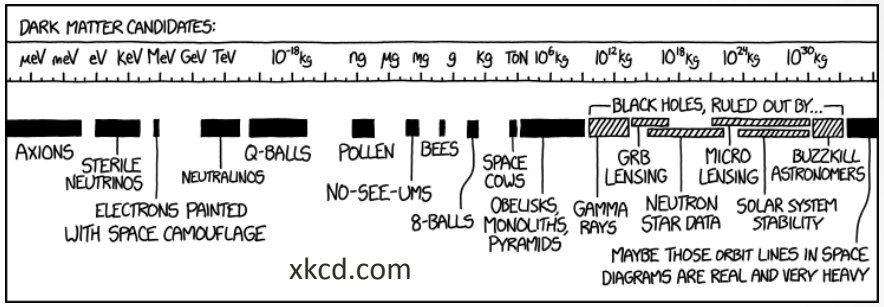
- The snowball chamber is analogous to the bubble & cloud chambers
  - It also relies on a phase transition
  - But it is a new instrument in nuclear & particle physics
- Supercooling of pure water in clean, smooth containers
  - Although, as with bubble chambers almost any other liquid should be usable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

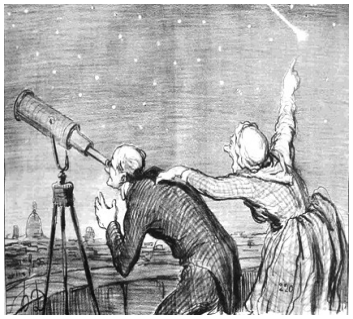




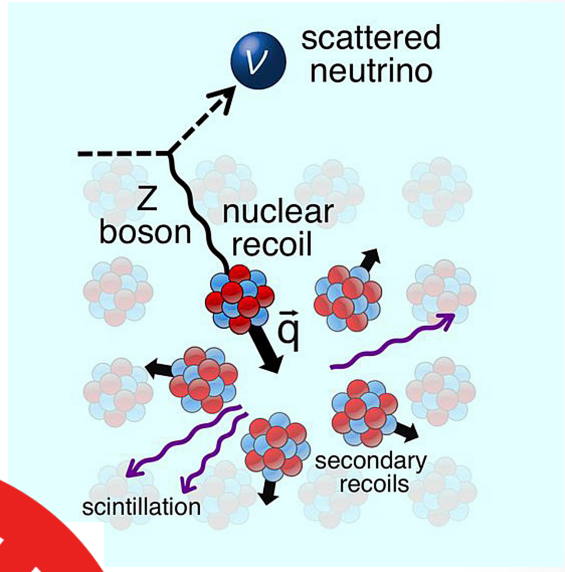
Motivations

- ***Dark Matter!***
  - Low masses: low threshold coupled to low-mass target (Hydrogen)
- Neutrinos (ν)
  - Not just pure physics. Applied physics
  - Reactor monitoring: fuel rod theft
  - Channel: coherent scattering
- Neutrons: similar to both above -- elastic scattering
  - Fissile materials
  - Calibration for above
- Atmospheric physics





Honoré Daumier, "Mr. Babinet, warned by his concierge of the arrival of the comet", illustration for Le Charivari, 22 Sept., 1858.

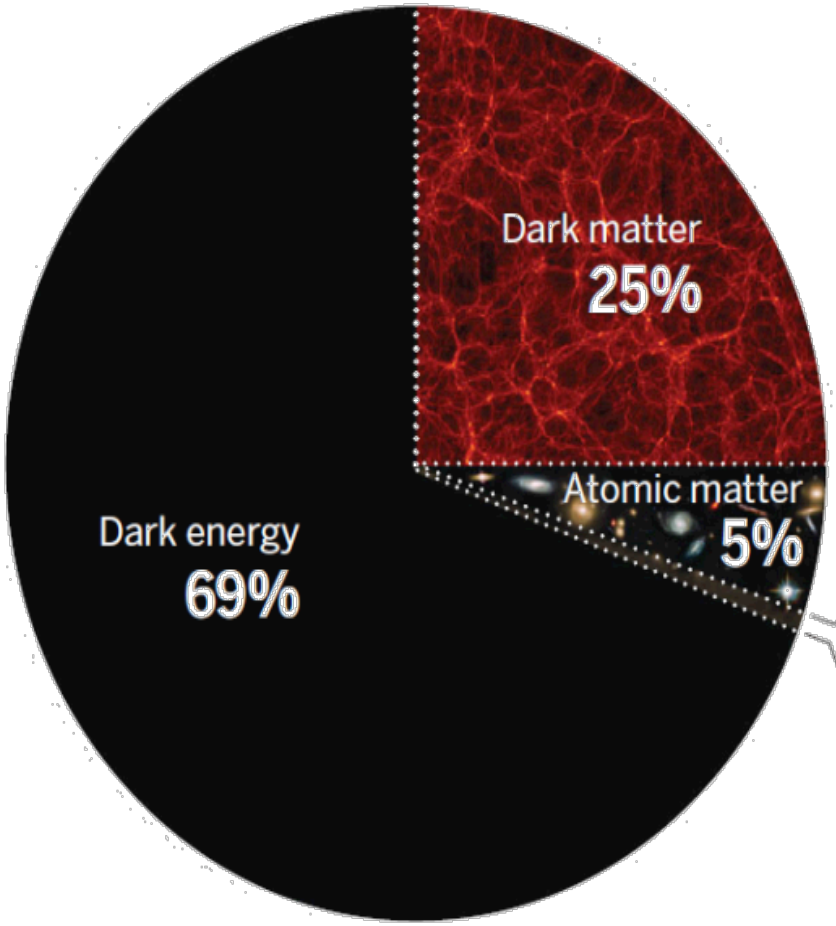


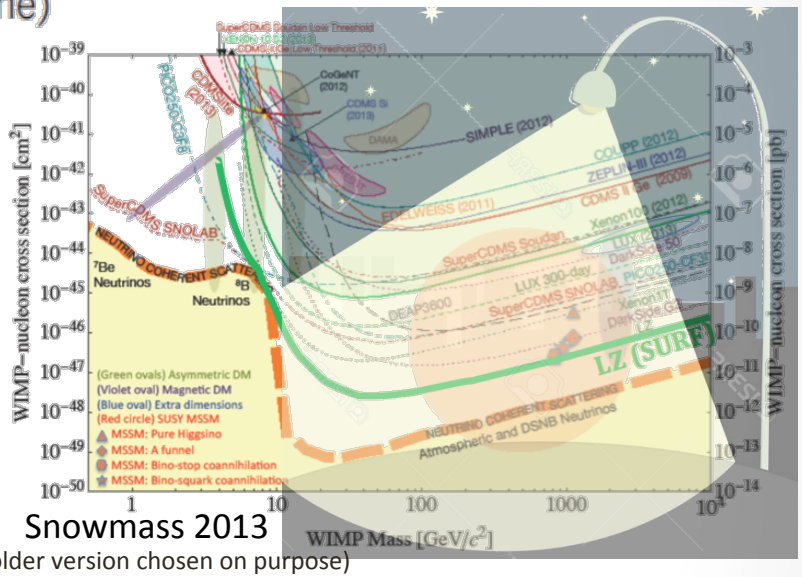
Dark Matter: A Lamppost Effect

(or, streetlight)

The multiple components that compose our universe

Current composition (as the fractions evolve with time)





Snowmass 2013

(older version chosen on purpose)

Neutrinos 0.1%

Photons 0.01%

Black holes 0.005%

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

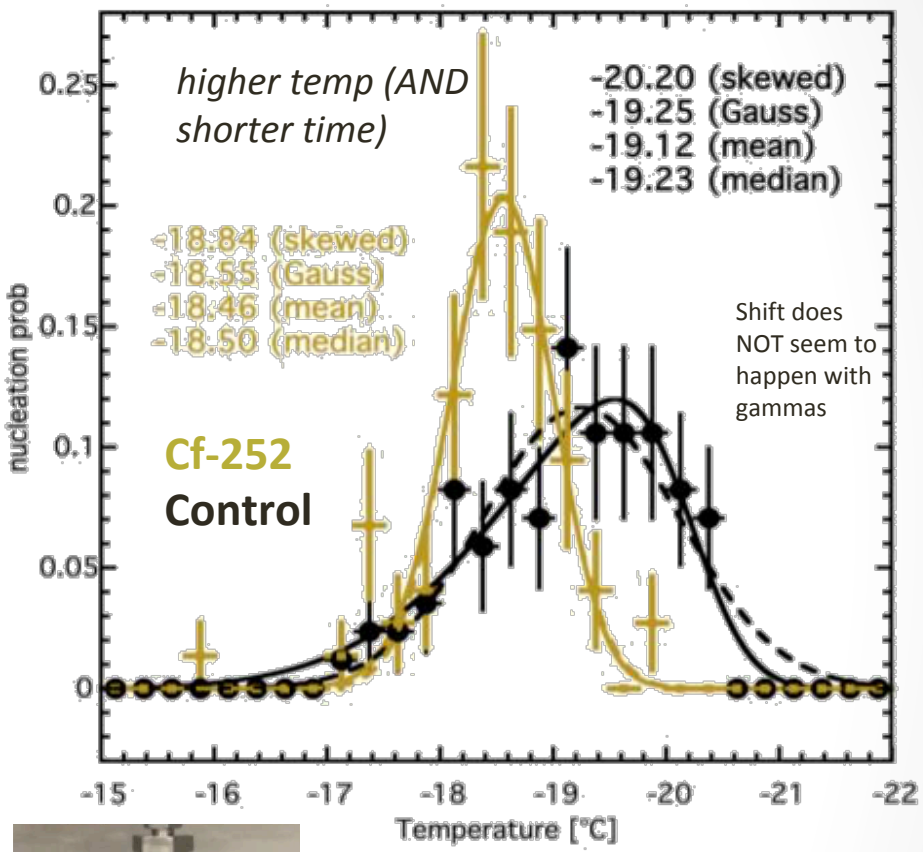
WHY possible? H bonding

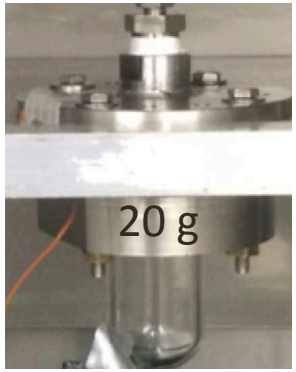
- ***Directionality***, the holy grail of dark matter direct detection
  - In the bulk of a liquid, not in gas. For rejecting solar νs
- Energy reconstruction: last summer we demonstrated the supercooling of WbLS (water-based liquid scintillator). A first!

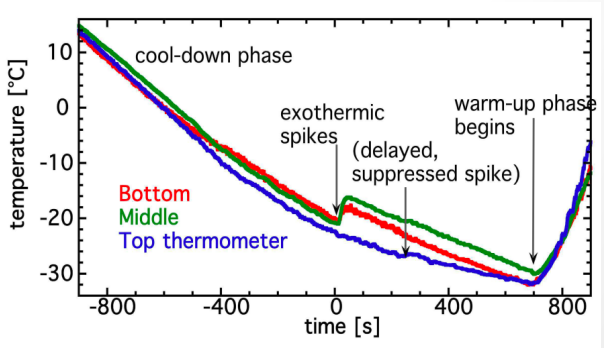
https://www.mdpi.com/2218-1997/10/2/81

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







What are the Backgrounds?

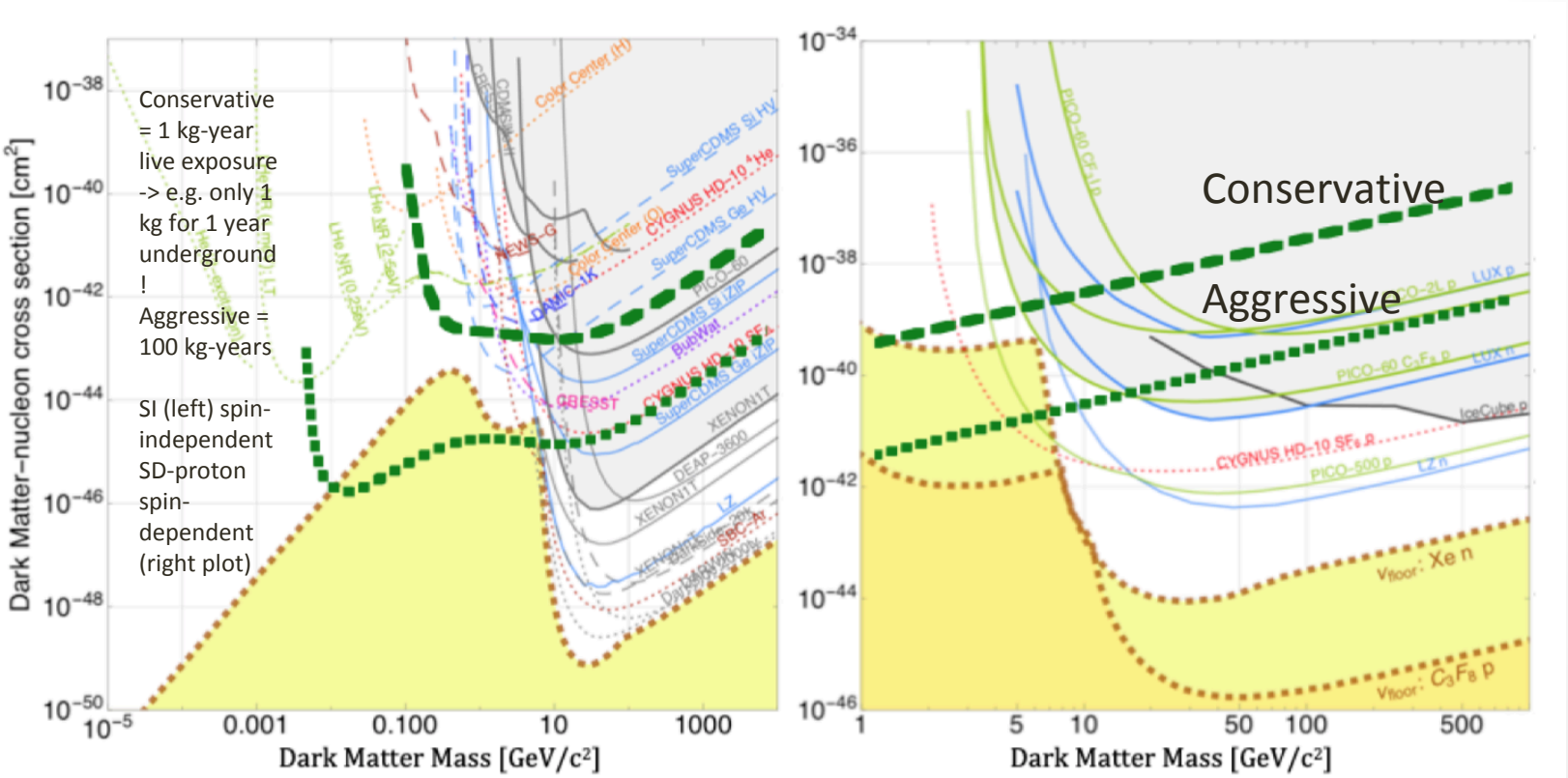
- Promises of dark matter search results without an understanding of **backgrounds** cannot be trusted.

- **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. No directionality assumed

- 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*(3) yr. at least for calibrations + optimizations



Practicalities: Costs & Timeline

- Low cost: can deploy with minimal funds, as R&D effort first
  - Ideally need a postdoc and a graduate student, and some faculty (summer) salary but no luck with NSF, DOE (not even DMNI)
  - BUT already have most of the equipment, materials, supplies needed thanks to large startups and other types of seed funding
- So, another merit here clearly is the extreme inexpensiveness and simplicity of the project
  - Already had months-long surface-run tests sans major problems
- SURF Support: Monitoring, which can be infrequent
  - Remote monitoring by SnowBall collaboration members ideal too
  - Collaborators on other SURF projects: could kill 2 birds w/1 stone
- Space needs: very humble. ~1-2 m^3 for everything
  - The water vessels, the thermo-regulating fluid (oil or alcohol), the shielding (can be one and the same), the computer (DAQ)

➔ The Future

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

  Penn State?!

- 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
  - Conversations with Stawell gold mine in Australia have already begun through Dr. Peter Wilson. Objective: identical units
- 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 (HEP decadal survey) reports (and P5/ HEPAP spoke highly of small-project funding)

  AGILE!

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
- Evt14BNL.mp4 (both too large to embed in a PowerPoint)