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Metastable Liquids

Breakthrough Technologies for Dark Matter & Neutrinos

Prof. Matthew Szydagis, The University at Albany SUNY CPAD March 19, 2021

The Basics: How This Works

- A pure liquid can be made "metastable," making it sensitive to incoming particles
 - For supercooling, this involves dropping temperature below freezing sans freezing, relying on a sufficiently clean, smooth container
- Controlling the temperature and/or pressure allows one to control the thresholds in both energy as well as dE/dx or critical radius for nucleation, enabling signal vs. background discrimination (e.g., betas and gamma-rays)
 - Lower temperature means both thresholds lower, in supercooling. Like bubble chamber, but in reverse!
- Have only done water so far. What does it have to do with noble elements? Could do Xe or Ar to capitalize on scintillation for *E*



Advantages / Strengths

- Low energy threshold (sub-keV?)
 - A large body of work exists already
- Physical setup
 - Unmistakable signature for trigger
 - Inexpensive even given purification
 - While cold, not "cryogenic"
 - Calm, slow phase transition
- Data-taking and analysis
 - High-speed images may be info-rich
 - Simplicity of DAQ at least pre-ton
 - Potential for world module program
- Directionality in a liquid?
 - Due to intense hydrogen bonding

Recognized Challenges

- Full threshold characterizations
 - Energy unknown: threshold detector

• Dead-time / backgrounds

- Low live-time due to melting
- Heterogeneous nucleation (e.g. dust)
- Homogeneous nucleation if "too" cold
- Maintaining purity in the long run
- Vibration / acoustic isolation
- More backgrounds: bulk, wall
 - Reduction in that evil Radon
 - Smoothness of container surfaces
- Liquid surface
 - Hydrophobic buffer, or a vacuum?

Scalability is NOT an issue: a modular approach, à la PICASSO or CDMS, is doable ₃

Purity of the Water Matters: 20 nm Filter (NovaMem)

- About -20 °C and lower achieved on first use of this membrane
 - Max cooling rate of about 1.9 °C / minute
 - Water may be able to get as cold as < -40 °
- To combat water purity going down with time after initial distillation, control data always mixed in
 - Also, going to 5 nm filter in the near future!



Non-linear (twisty) holes in the thin flat sheet 4

Temperatures, Times of Freezing: Different Sources



"Muon Veto" (Scintillating Counter)





Technology for simple (plastic) scintillator with SiPM attached.

Useful for public outreach!

looking "elsewhere"





How "Loud" Are the Snowballs? PICO-inspired Idea

- Inspired from superheating: if pressure rises faster (and piezos detect more sound too) from multiple (macro or micro) bubbles is there a similar effect with supercooling and dT / dt slope?
- The preliminary evidence says YES
- May even be seeing peaks in the right spots for doubles, troubles, etc. at right, but not enough statistics yet for conclusive fit to multiple peaks



Most Interesting Results: Cf



threshold of ~0.2-1.2 keV_{nr} (for oxygen recoil). Expected! 9

Controlling for Systematics: Alternating Source on/off



"People who say it cannot be done, should not interrupt those who are doing it" - guote attributed to George Bernard Shaw

- Alternated the source and background (no source i.e. control) runs carefully, in 24-48 hour chunks (see stats at left)
 - Approximately equal amounts of data day and night, weekend/weekday, room temps, etc.
- Can conclude unequivocally that radiation can freeze (supercooled) water
 - But, is it neutrons, or gamma-rays? (²⁵²Cf, as well as AmBe, have lots of both)
- Based on rates and energies from Geant4 simulations and on dE/dx-based arguments, probably neutrons
 - Story of gammas isn't completely clear, but that is telling in and of itself: unclear if effect in ¹³⁷Cs

Sensitivity Projections: Spin-Independent, Dependent

- Shamelessly copied plot from DOE Cosmic Visions Report (arXiv:1707.04591) overlaying our own curves
- SI at left, SD-proton at right. Neutrino floor, for H, much lower than depicted here, huge advantage of H₂O
- Look for dark matter using lightest element, and with recoil discrimination a potential multi-element signal



- Upper curve is only 1 kg-yr live exposure, underground.
 - 12 eV threshold (H)
 - No BG events
- Lower, aggressive, is 100 kg-years
 - 16 meV threshold
- In either case, water leads at few GeV for spin-dep p⁺ (b/c H)

Other Potential Physics Applications: Neutrino Physics

Supercooled water Cherenkov detectors? Positions!

- Utilizing the CEvNS interaction on different nuclei. NSI?
- Low-cost and modular designs would enable searches for sterile neutrinos with a total neutral current disappearance experiment at multiple baselines
- A large-scale world-wide deployment could also play a role in supernova neutrino burst detection (on top of dark matter annual modulation)
- A detector using deuterated water could be a viable technology for normalizing low-energy neutrino fluxes from stopped-pion beams
- Electron and gamma-ray interactions visible, at low enough temperatures?

• High-risk, but high-return R&D (cannot pursue any of this without people, \$\$\$)

Building a Collaboration

Ethan Brown



Carmen Carmona and Luiz de Viveiros



Peter Wilson



Cecilia Levy



Matthew Szydagis

UNIVERSITYATALBANY

State University of New York



Phillip Barbeau



Outlook: The Collaboration is Still Informal (Unfunded)

- A good deal more R&D to be done. Have tried and tried and tried to secure funding, especially given our good preliminary data. No luck yet
 - More cameras, for 3D position reconstruction
 - Detailed simulation models of what is happening. Not just Geant4: also molecular dynamics?
 - Lower thresholds through lower temperature, achieved through greater purification
 - Reverse approach: superheating. And/or other liquids: scintillator like LXe. Pluses / minuses
- Lots of other future work still
 - Increase the cycling speed/live-time: microwaves, lasers, thermoelectrics, modularity, droplets
 - Quantify all types of backgrounds: Radon e.g. alphas, surface imperfections, surprises
- Energy threshold, dE/dx or LET threshold, the critical radius, the efficiency (sigmoidal turn-on or sharp?)
 - For H and O separately if possible as the targets, and for different incoming particle types
 - Quasi-monoenergetic sources (like the TUNL neutron beam) best for this. Change the T & P.

LET'S WORK TOGETHER, not at cross purposes: Wish to work together with PICO, SBC on 1 whitepaper