Bubble Chambers:
The Seitz and Sounds of Dark Matter

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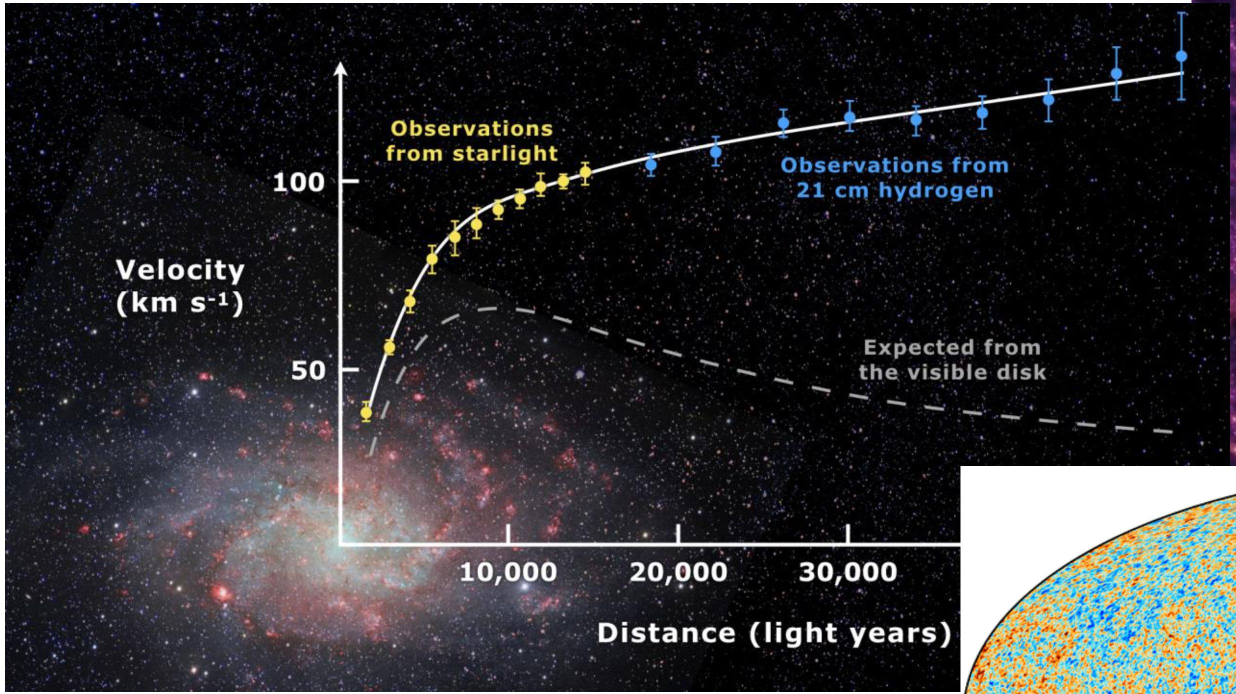
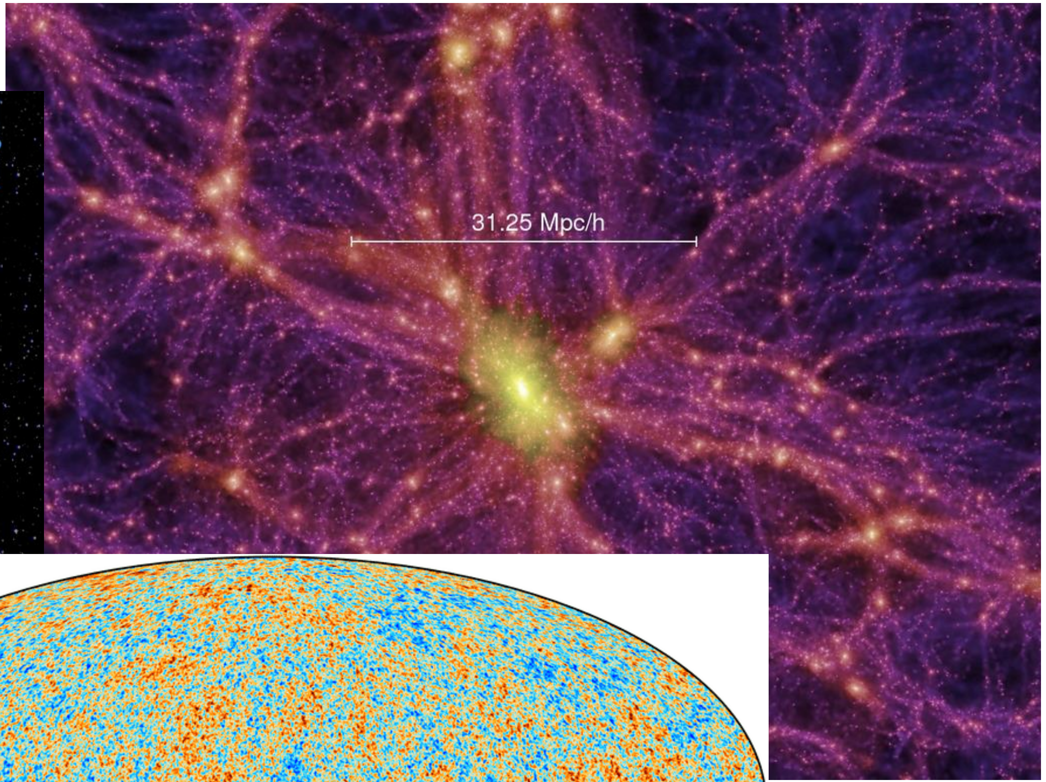
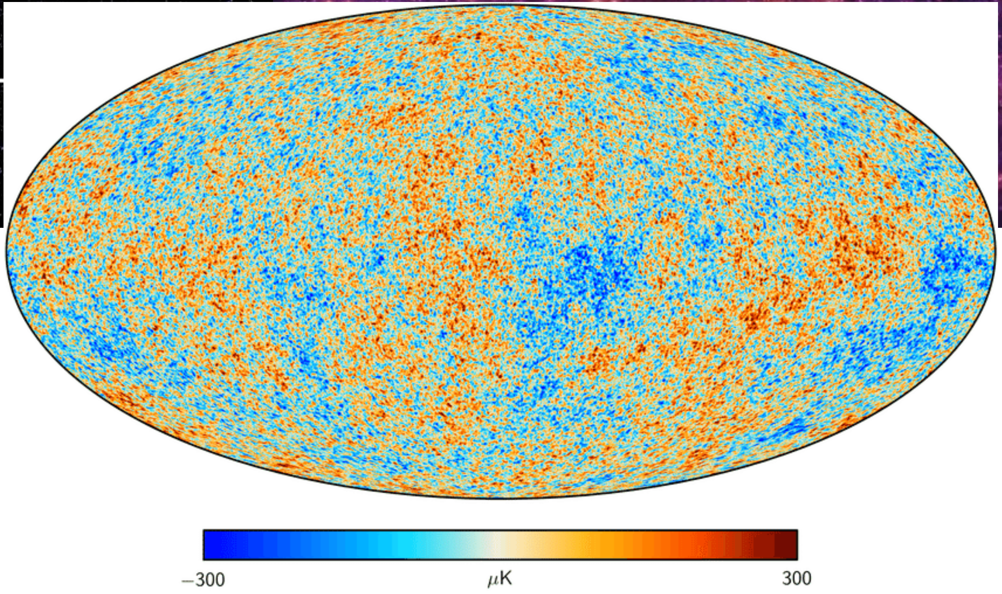
EIEIOO
May 12, 2020

Dark Matter

Tons of evidence!



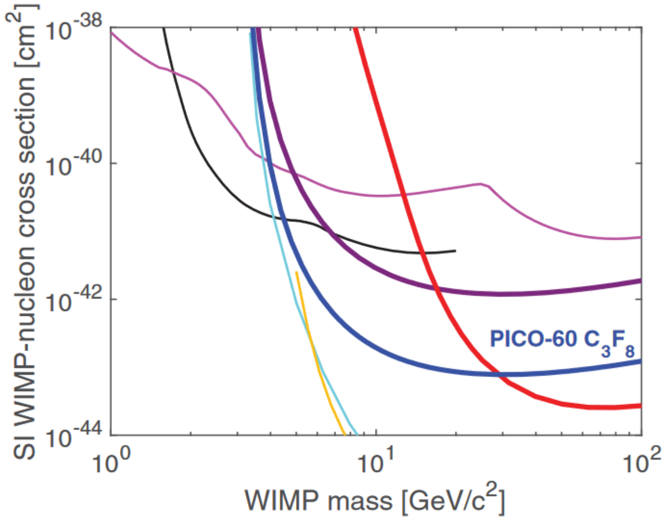




Dark Matter Interactions

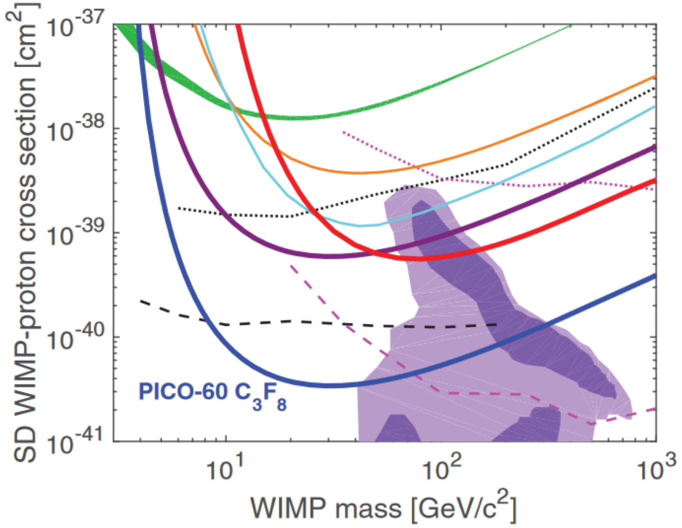
Spin-Independent

- WIMP-proton and WIMP-neutron coupling equal
- Interaction rate grows as square of nucleon number
  - Heavier target nuclei = higher expected rate
- Common targets: argon, xenon, germanium, etc.



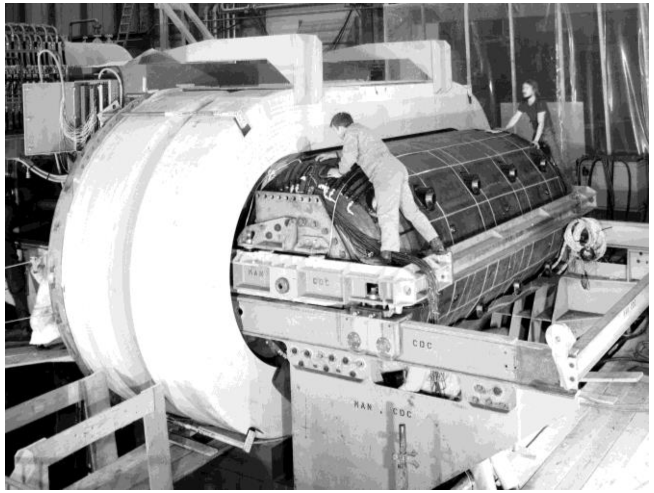
Spin-Dependent

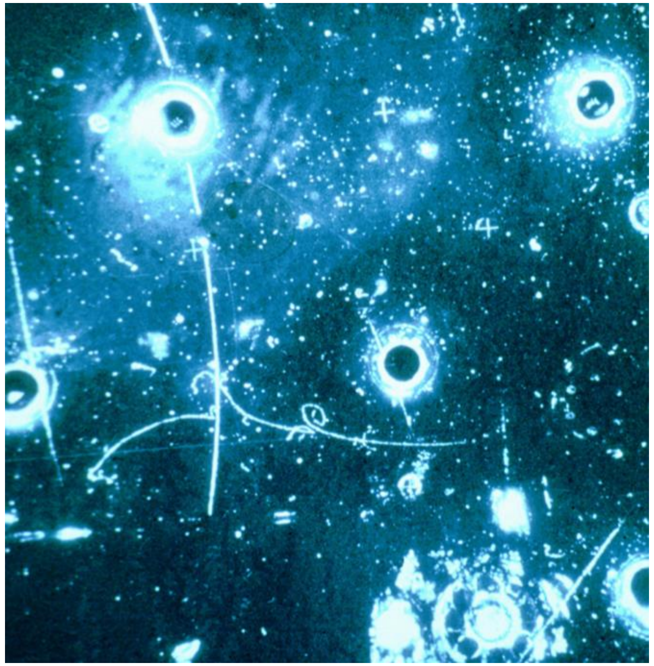
- WIMP-proton and WIMP-neutron coupling not equal
  - Experiments specify WIMP-proton or -neutron
- Interaction rate depends on nuclear response
  - Must be calculated on a per-target basis
- Common proton targets:
  - **fluorine (100)**, sodium (100), iodine (100)
- Common neutron targets:
  - xenon 129 (25), xenon 131 (21), germanium 73 (7.7)



What are Bubble Chambers?

- Old technology used to study particles from cosmic rays/accelerators
- Pioneered in 1950s, saw use into 1980s
  - D. Glaser awarded Nobel Prize in Physics in 1960 for development of bubble chambers
- Used in discovery of Z^0 boson
- Superseded by newer technologies

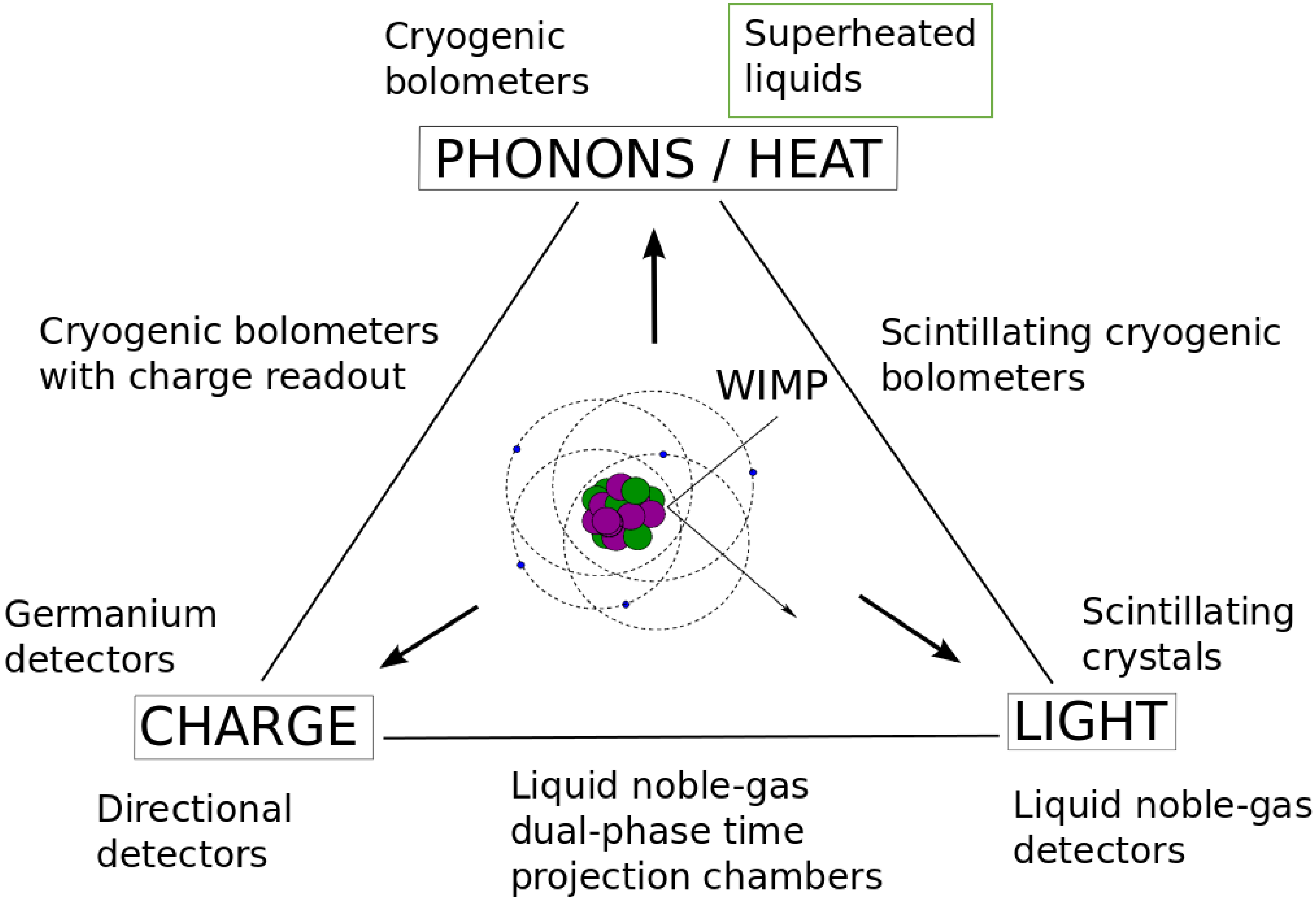




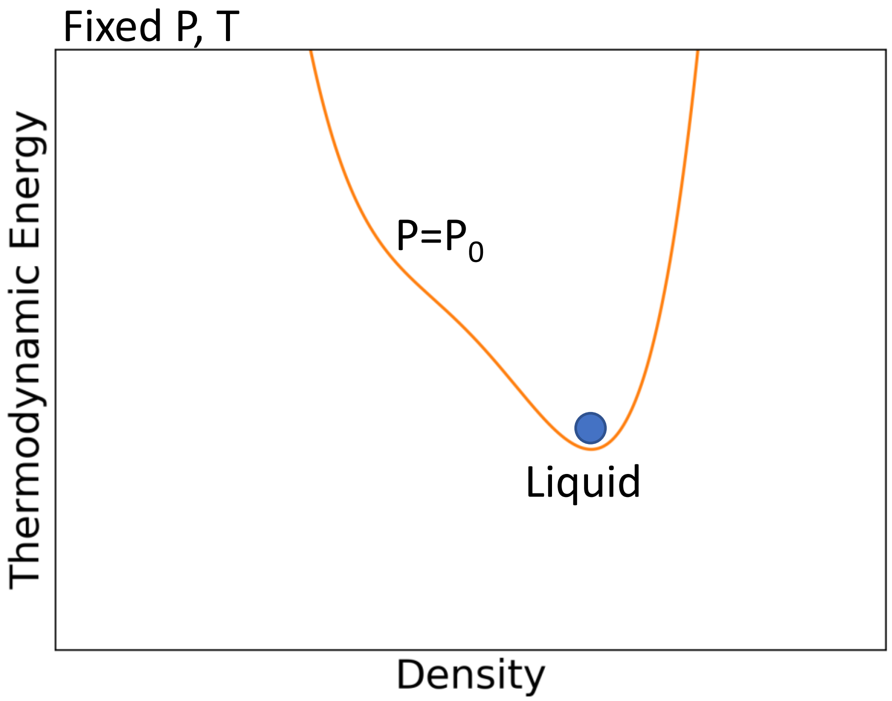
Images, CW from top left:
- Big European Bubble Chamber
- Gargamelle
- Event from Gargamelle

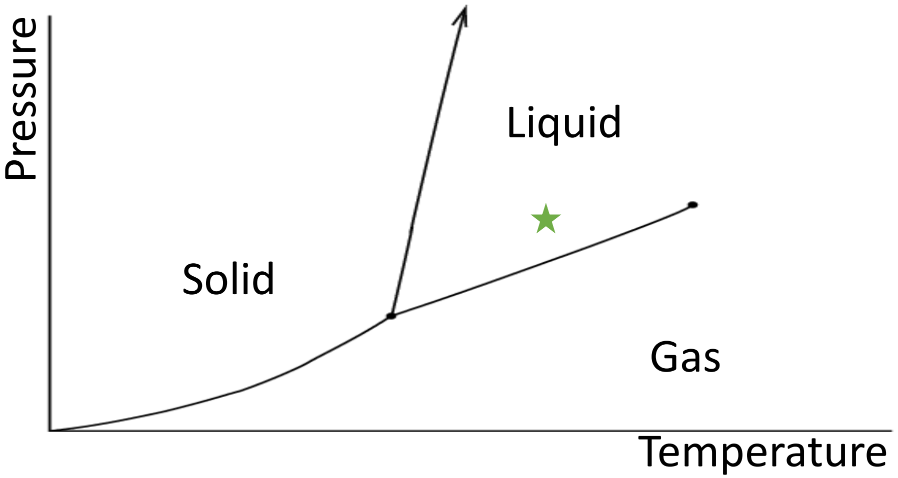
- Bubbles caused by energy deposition in superheated liquid
- Images of bubbles recorded through windows in pressure vessel

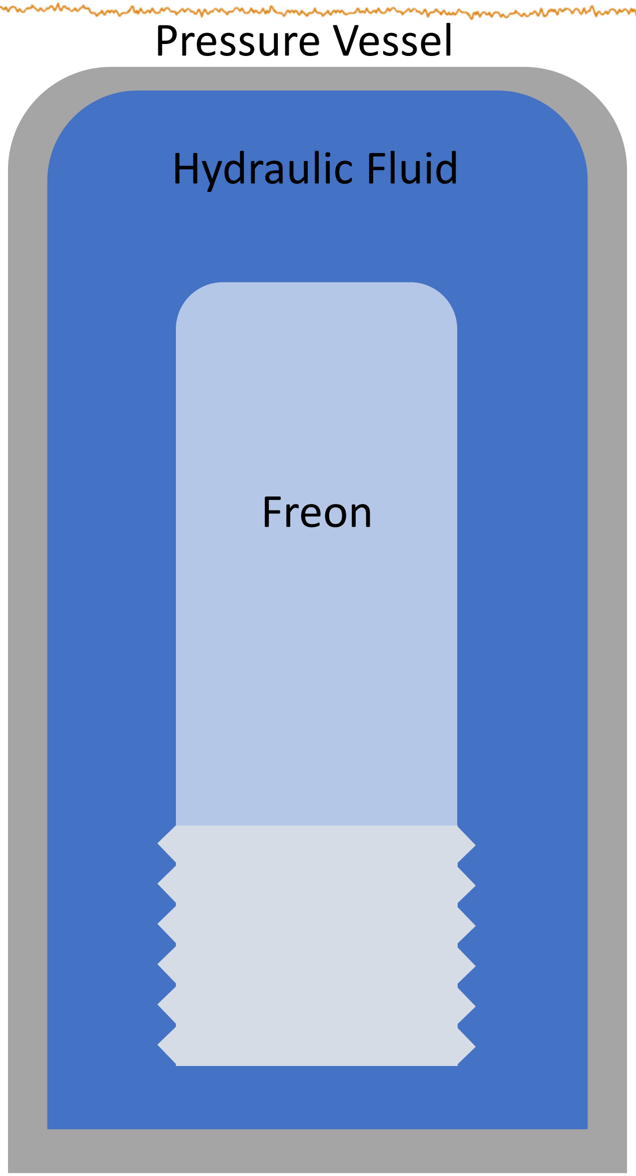
What are Bubble Chambers?



Bubble Chamber Principles







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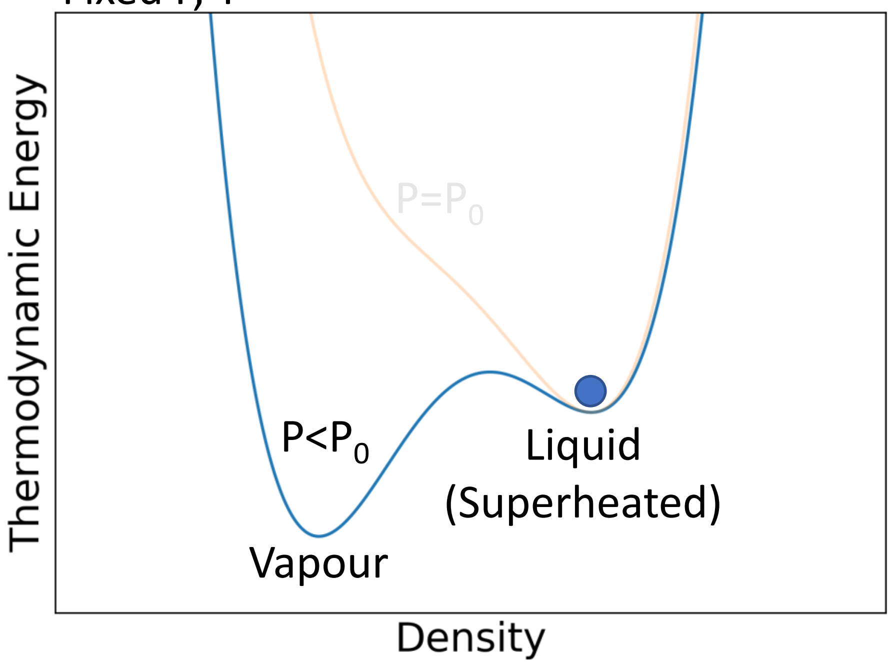

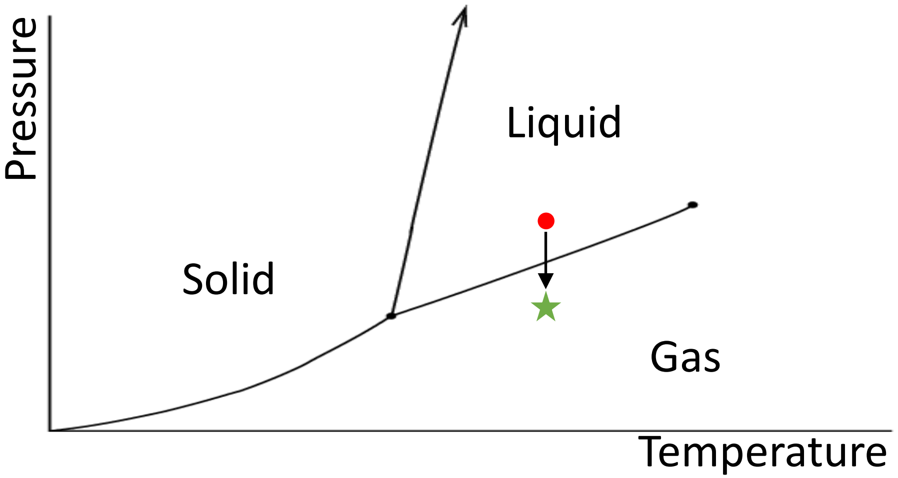

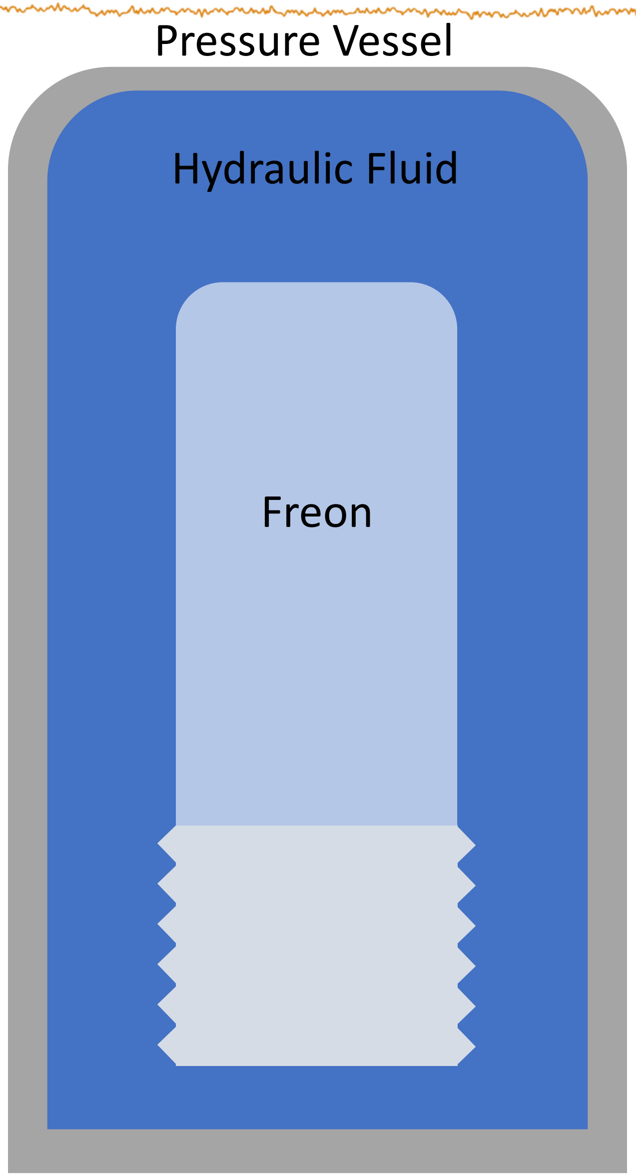

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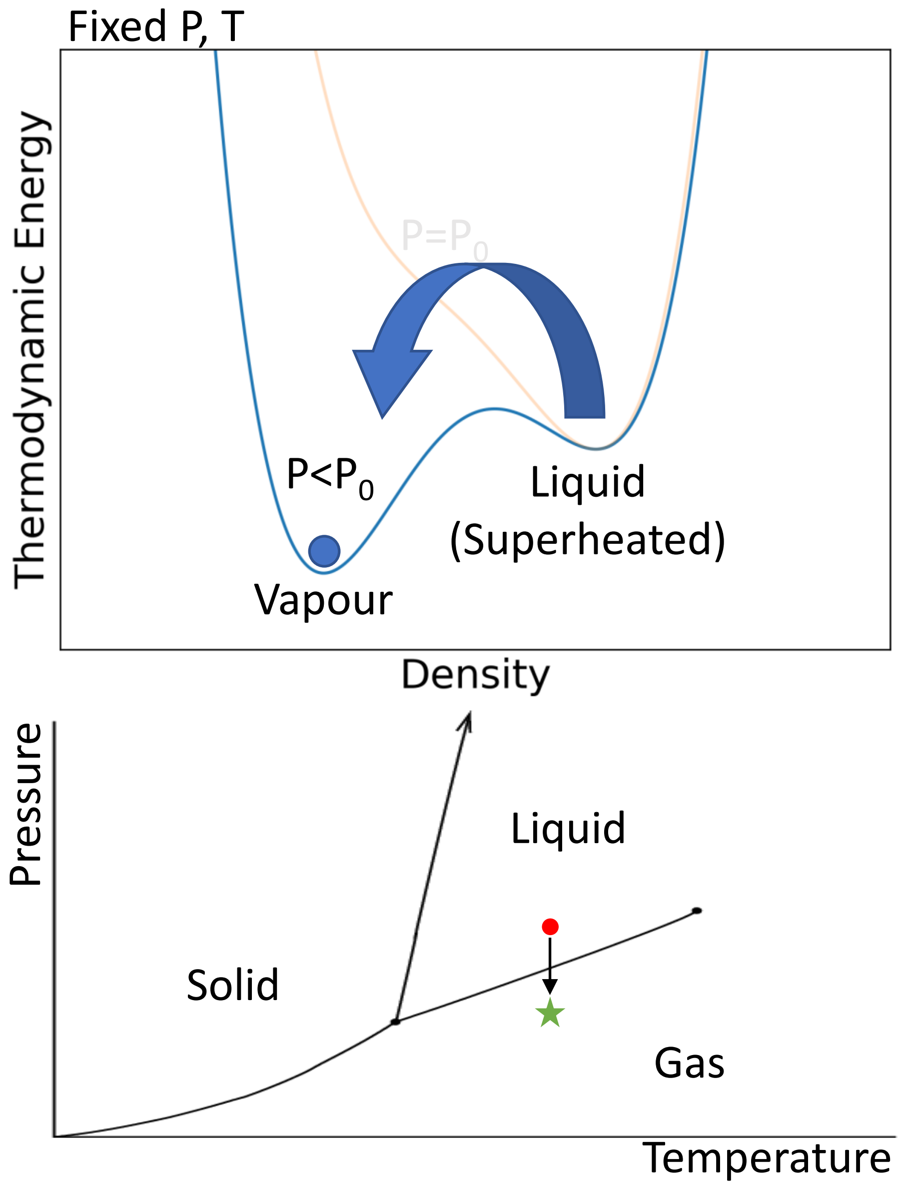

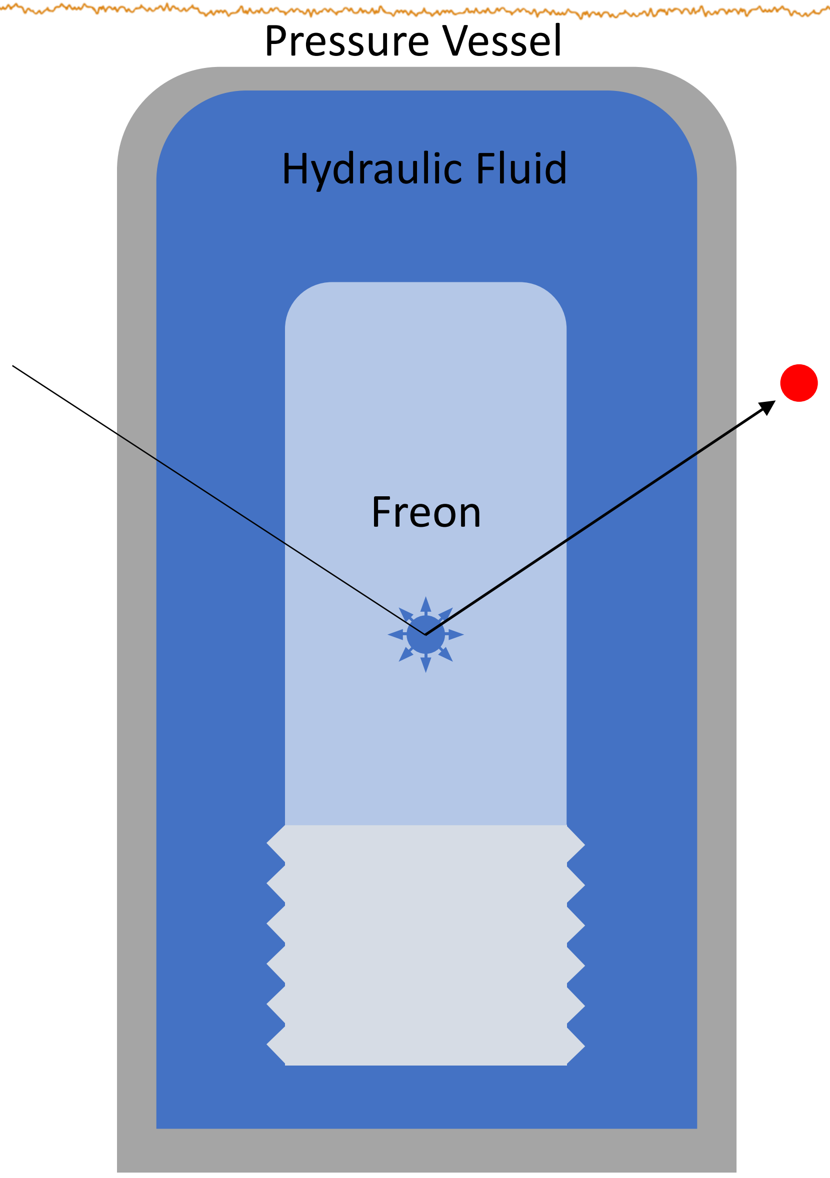

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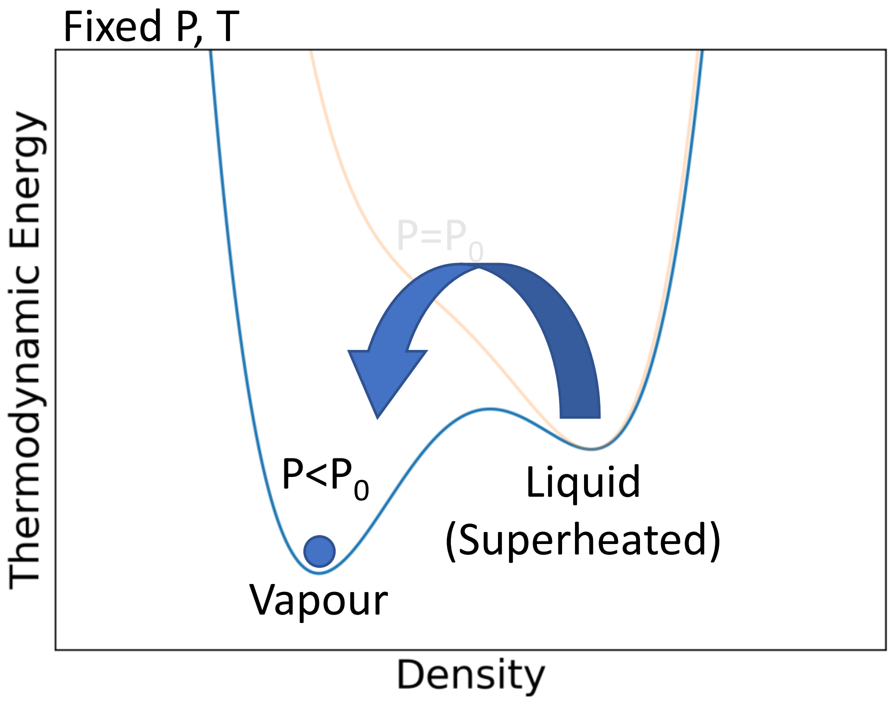
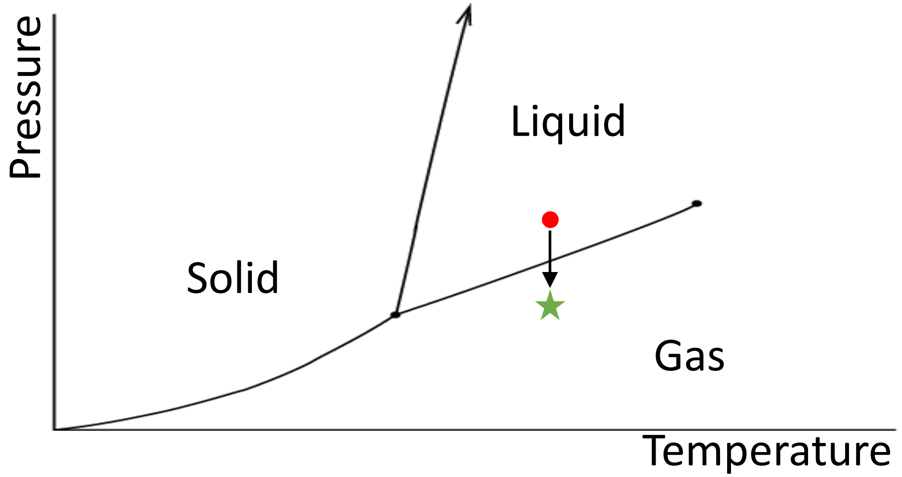
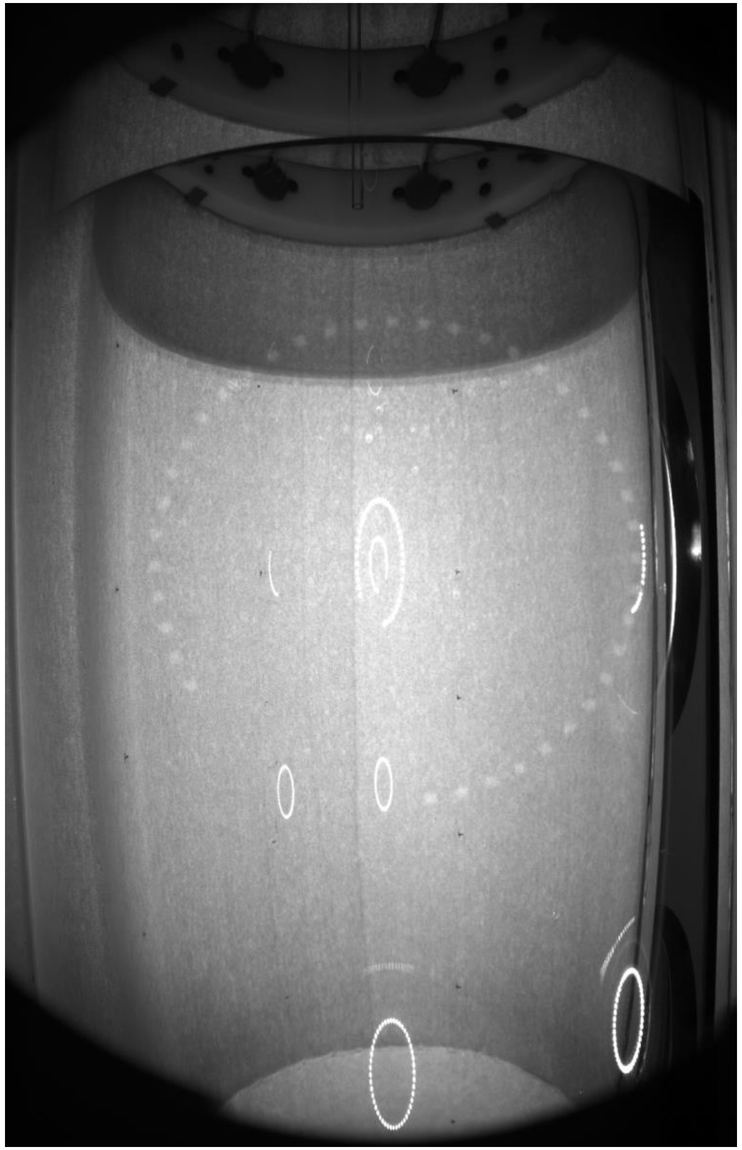






How are Bubbles Formed?

- Any bubble larger than the (fluid-specific) critical radius will continue to grow to macroscopic size

$$r_c = \frac{2\sigma}{P_b - P_l}$$

  - PICO's active fluid: r_c = 20 nm
  - How does a bubble grow to the critical radius?

- Energy threshold:

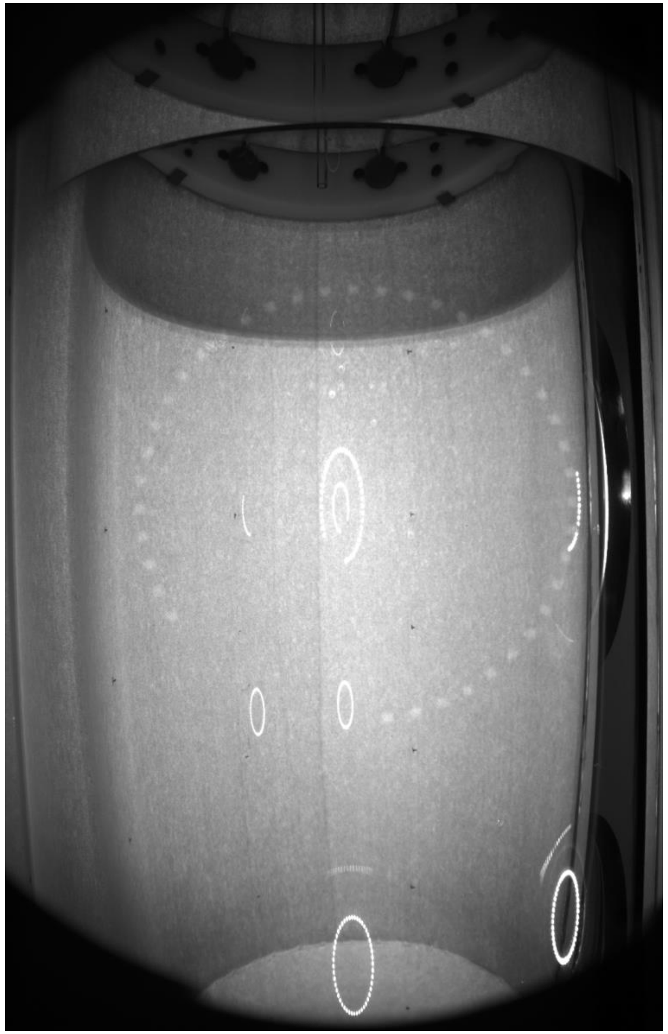
$$Q_{Seitz} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)} + \boxed{\frac{4\pi}{3} r_c^3 \rho_b \left(h_b - h_l\right)} - \boxed{\frac{4\pi}{3} r_c^3 \left(P_b - P_l\right)}$$

Surface tension | Converting liquid to gas | Expansion of vapour

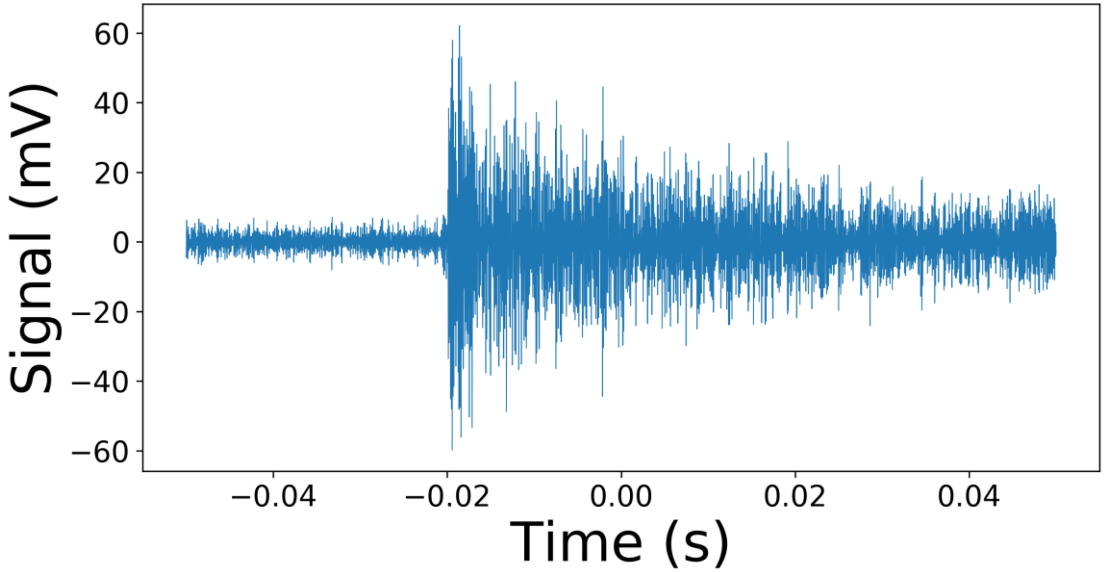
- Energy deposited causes region to "literally explode into bubbles of larger than critical size"

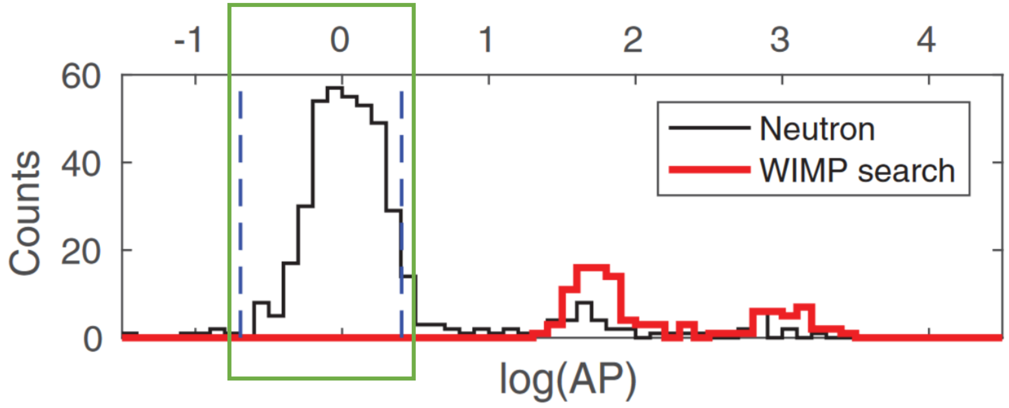
What does PICO data look like?

Optical



Acoustic





WIMP Search Region

Advantages of Bubble Chambers

Advantages

- Fairly simple design/operation
- Inherently insensitive to electron-recoil interactions
- Alpha rejection via acoustics
- Variable threshold
- Ability to change active fluid to exploit different sensitivities
  - Fluorine: WIMP-proton sensitive
  - Hydrogen: low-mass WIMPs

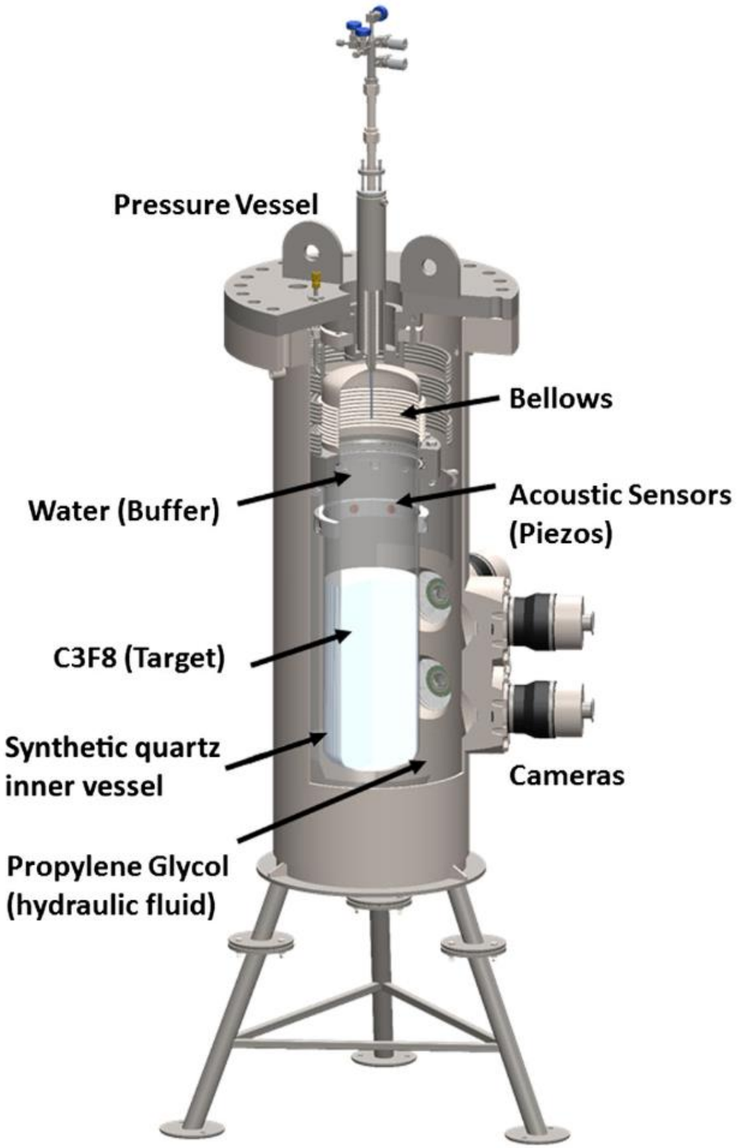
Disadvantages

- No energy information
- Large deadtime between events

PICO-60

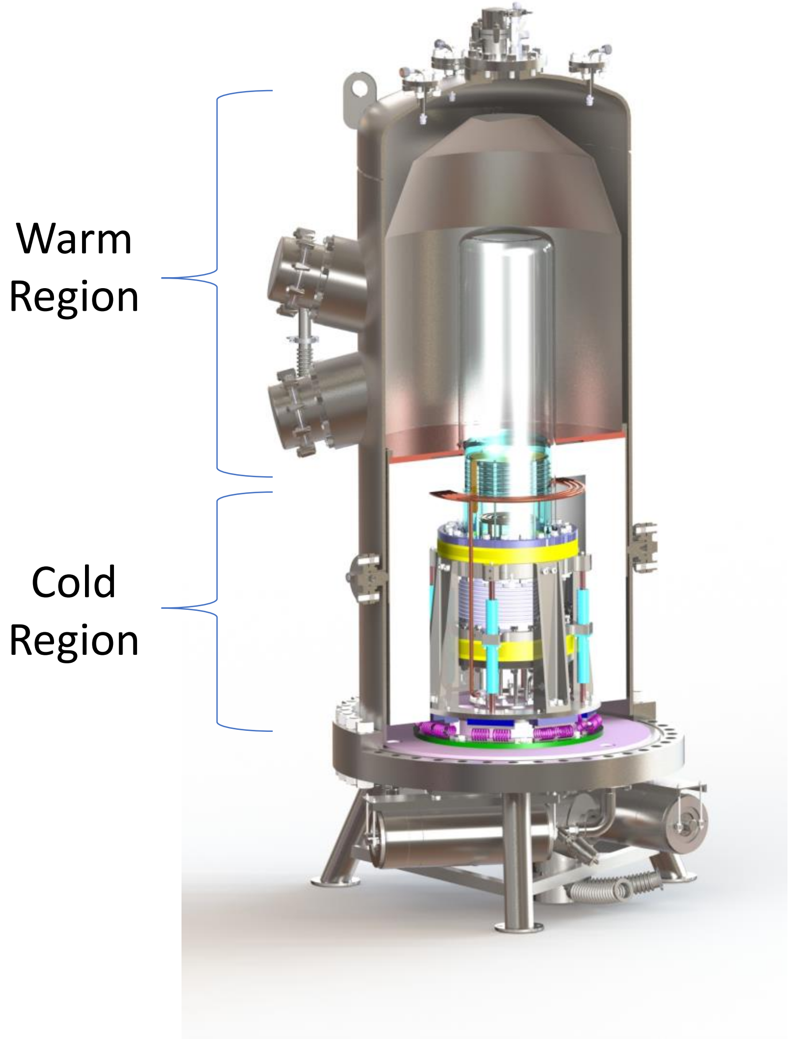
- Previous large-scale detector
- Active target: C_3F_8
  - Spin-dependent sensitivity due to fluorine
- Operated at SNOLAB
- Used same design as all previous PICO bubble chambers
- Produced world-leading WIMP-proton limit

- Water buffer and bellows caused issues with spurious nucleation
  - Particulate entering active region
  - Water and freon mix

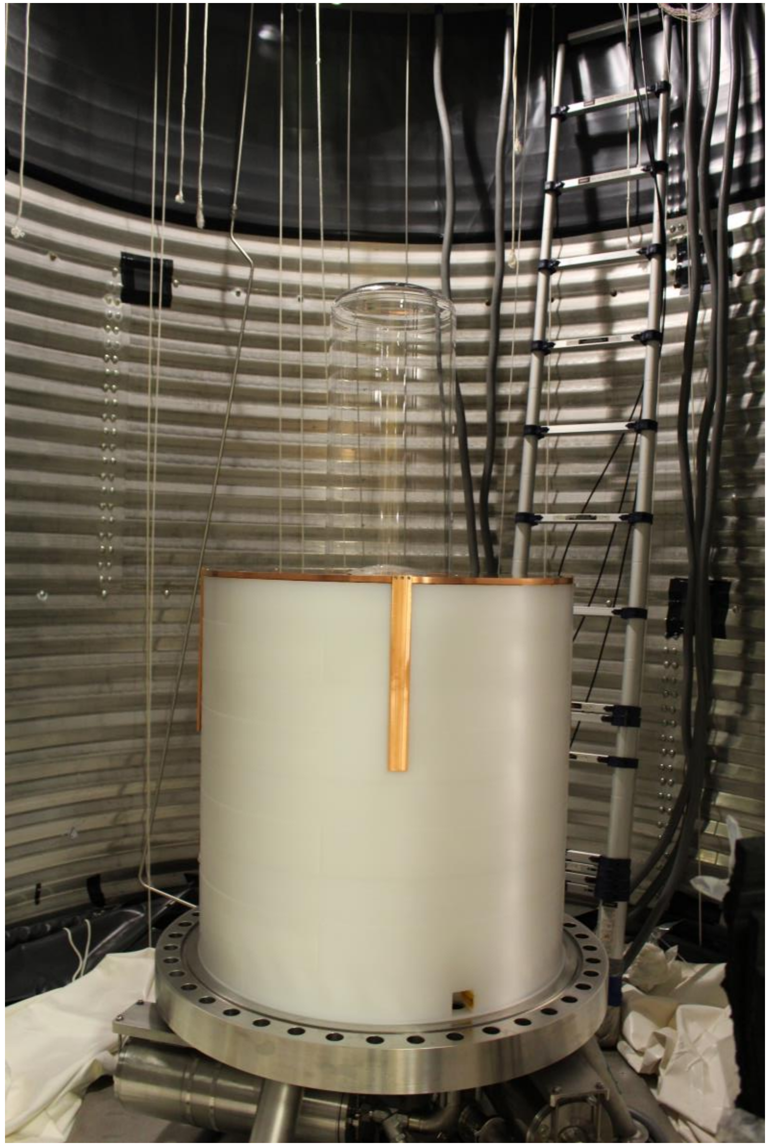


PICO-40L

- Uses new “Right-Side-Up” chamber design
- Water buffer replaced by second inner jar
- Two thermal regions. At 30 psia:
  - Warm region (15°C): C_3F_8 is superheated
  - Cold Region (-25°C): C_3F_8 is liquid
- First large-scale use of RSU design
- Proof of concept for PICO-500

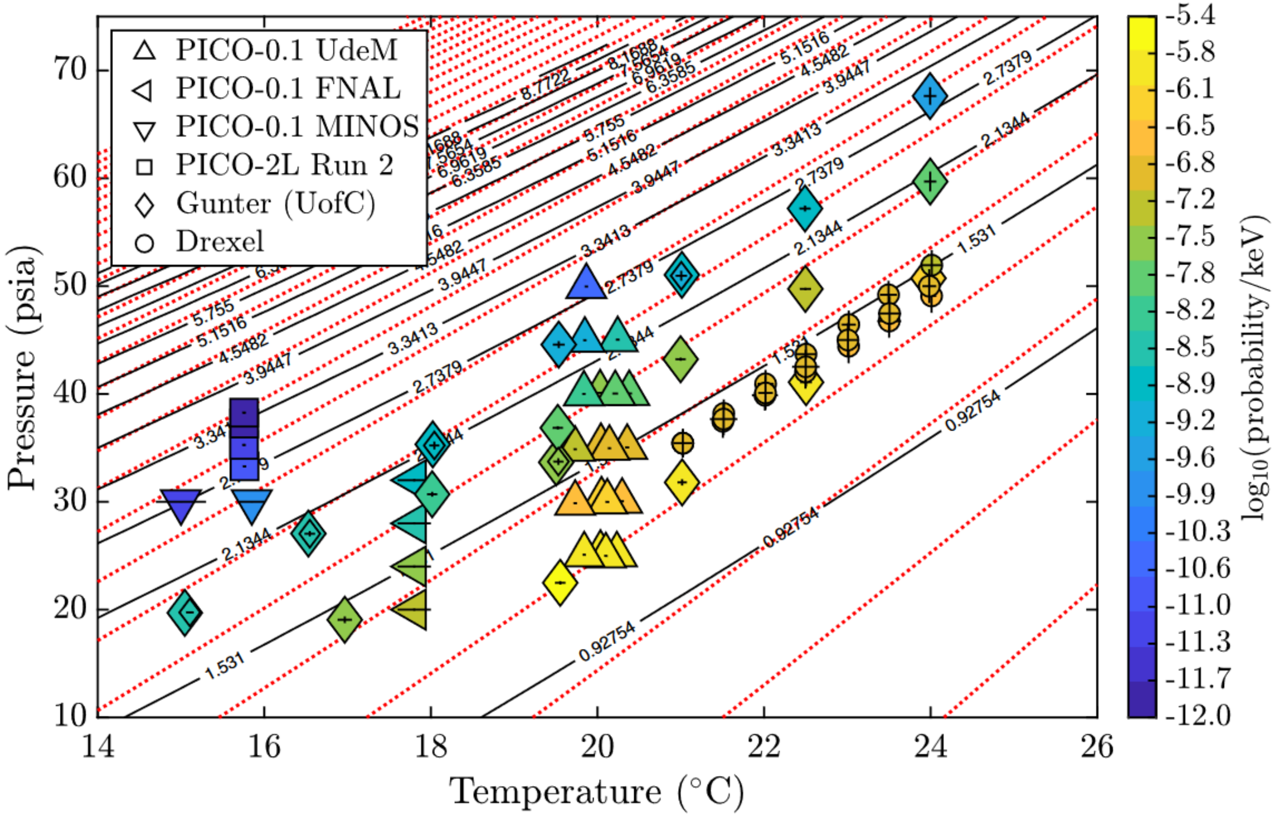


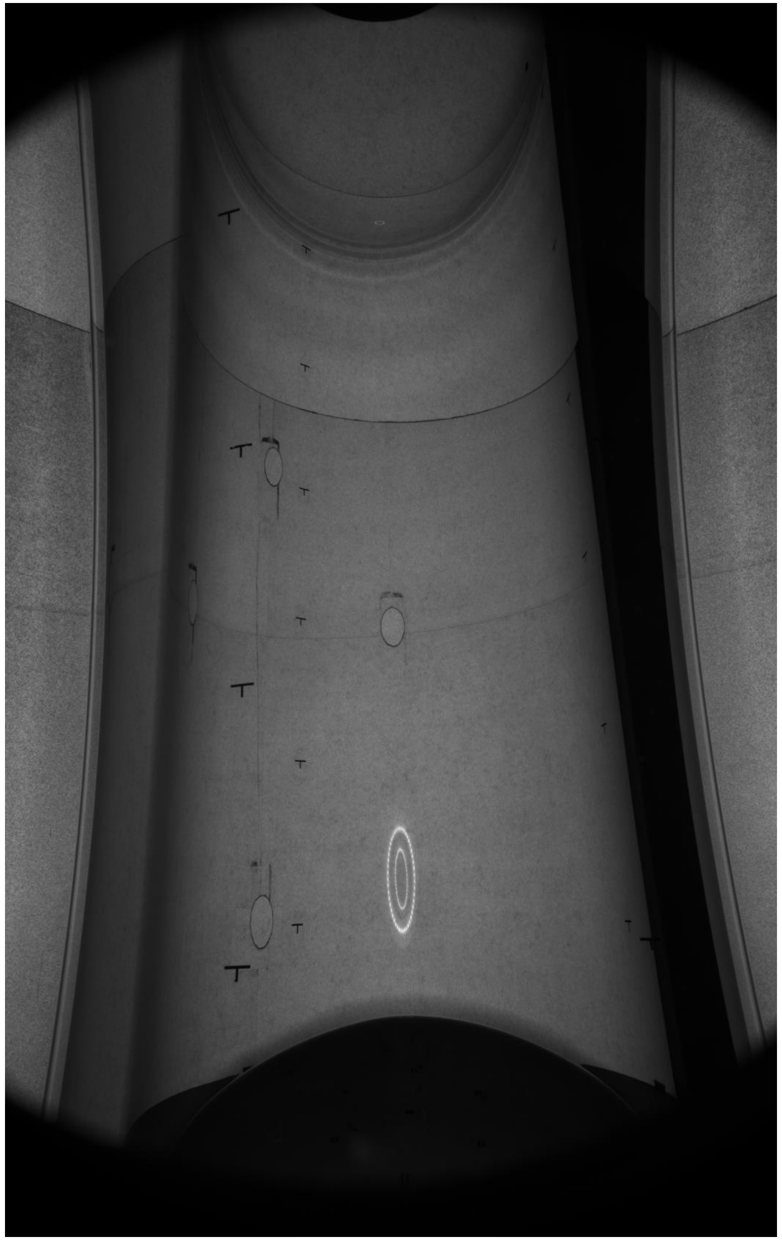
State of PICO-40L



State of PICO-40L (and new physics!)

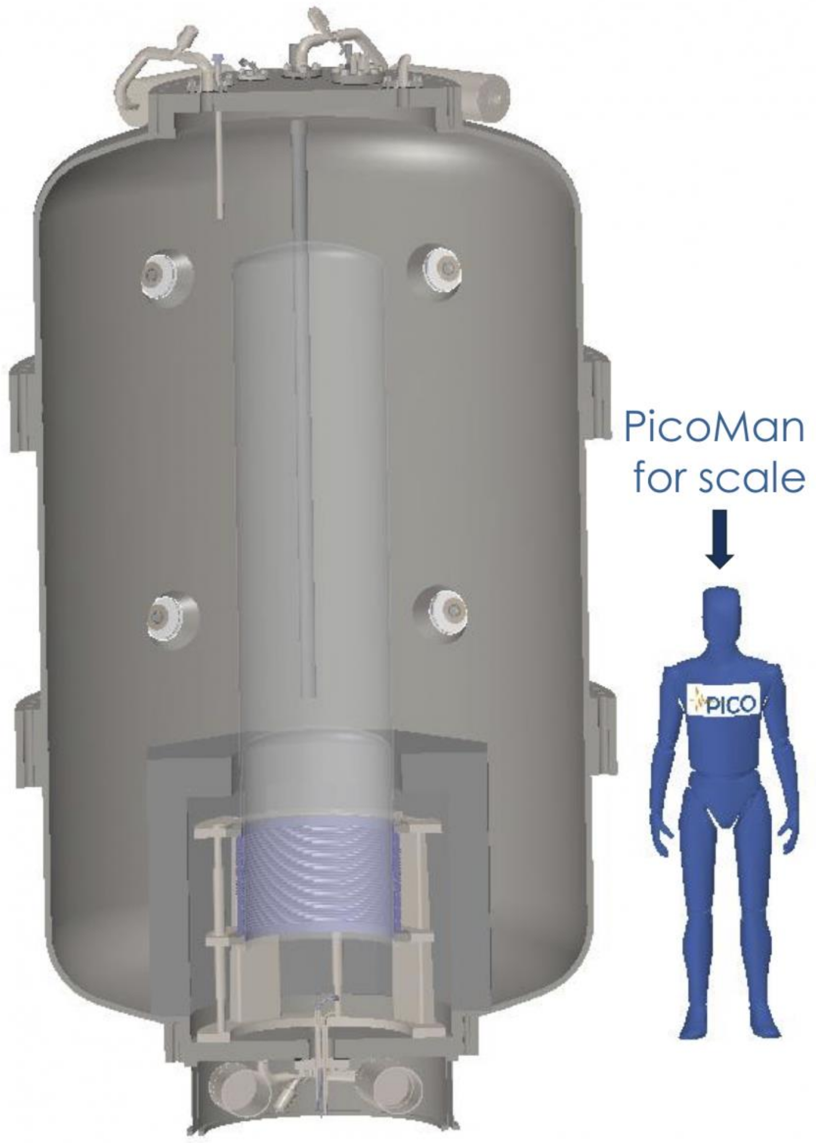
- Early data taking
- (Almost) everything is working!
- Waiting on water shield fill





PICO-500

- Next-generation, tonne-scale bubble chamber
- Housed in SNOLAB cube hall (next to DEAP-3600)
- Currently in design phase



Thanks for listening!

Image Sources

- Slide 2:
  - Rotation curve: https://commons.wikimedia.org/wiki/File:Rotation_curve_of_spiral_galaxy_Messier_33_(Triangulum).png
  - CMB Anisotropies: DOI: 10.13140/RG.2.2.36598.19528
  - DM Simulation: Springel, V. et al. Max Planck Institute for Astrophysics, https://wwwmpa.mpa-garching.mpg.de/galform/press/
- Slide 3:
  - C. Amole *et al.* (PICO Collaboration), Phys. Rev. Lett. 118, 251301 – Published 23 June 2017
- Slide 4:
  - Gargamelle: https://en.wikipedia.org/wiki/Gargamelle
  - BEBC: https://en.wikipedia.org/wiki/Big_European_Bubble_Chamber
- Slide 5:
  - DM Triangle: https://www.arxiv-vanity.com/papers/1509.08767/
- Slide 6:
  - Phase diagram: DOI: 10.1119/1.1399044 (https://www.researchgate.net/figure/Phase-diagram-of-a-simple-substance-in-the-pressure-temperature-plane_fig1_1825860)
- Slide 11:
  - C. Amole *et al.* (PICO Collaboration), Phys. Rev. Lett. 118, 251301 – Published 23 June 2017
- Slide 13:
  - PICO-60 picture: arxiv 1902.04031