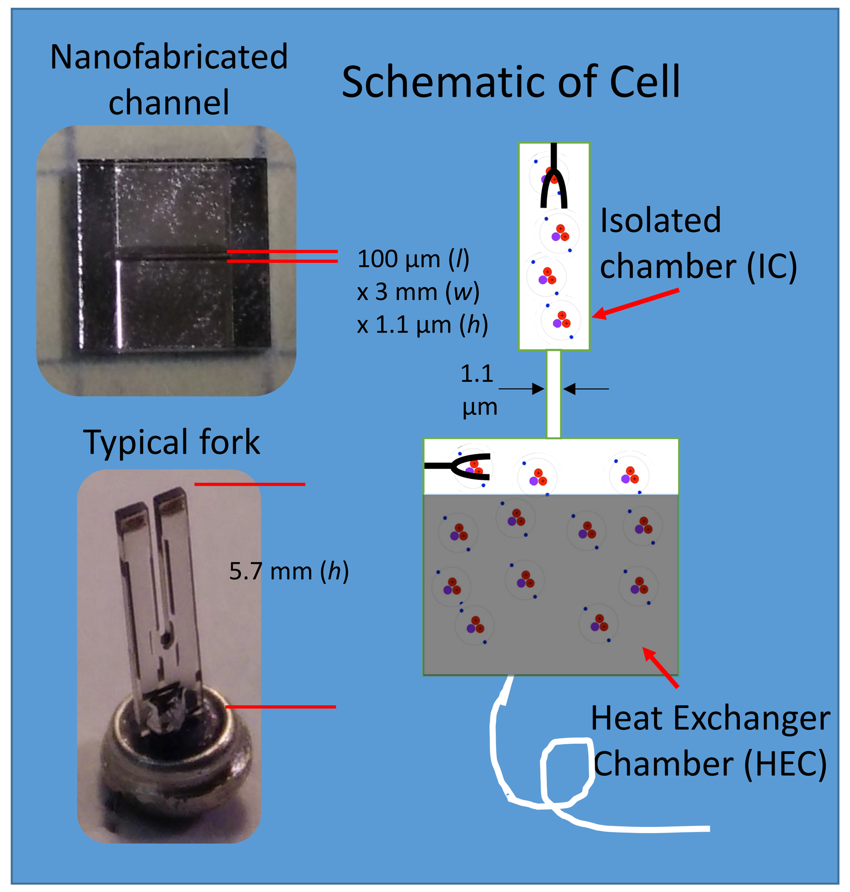
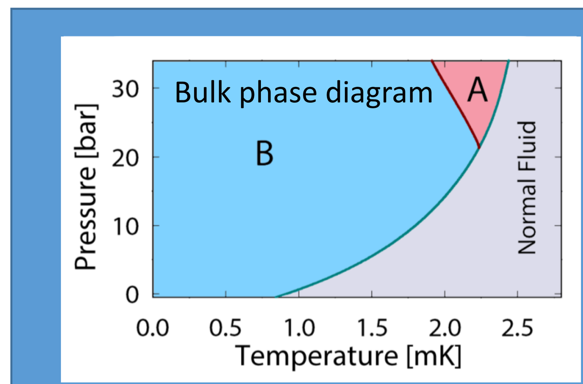
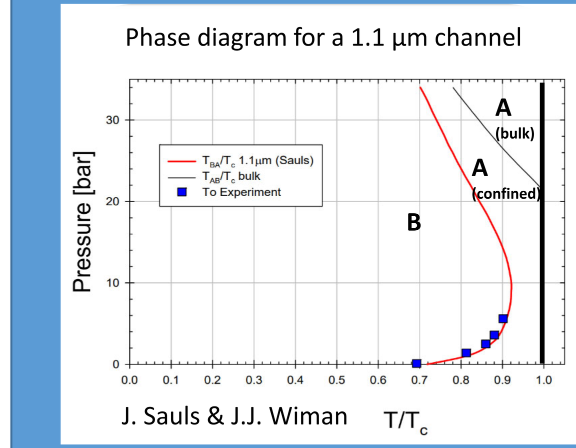
Memory Effect and Supercooling of the ^{3}He-A phase in zero magnetic field

Lotnyk, D., Eyal A., Zhelev N., Abhilash T.S., Smith E.N., Terilli, M., Wilson J., Mueller E., Parpia J.
Dept. of Physics, Cornell University, Ithaca, NY USA







Expectations & Motivation:

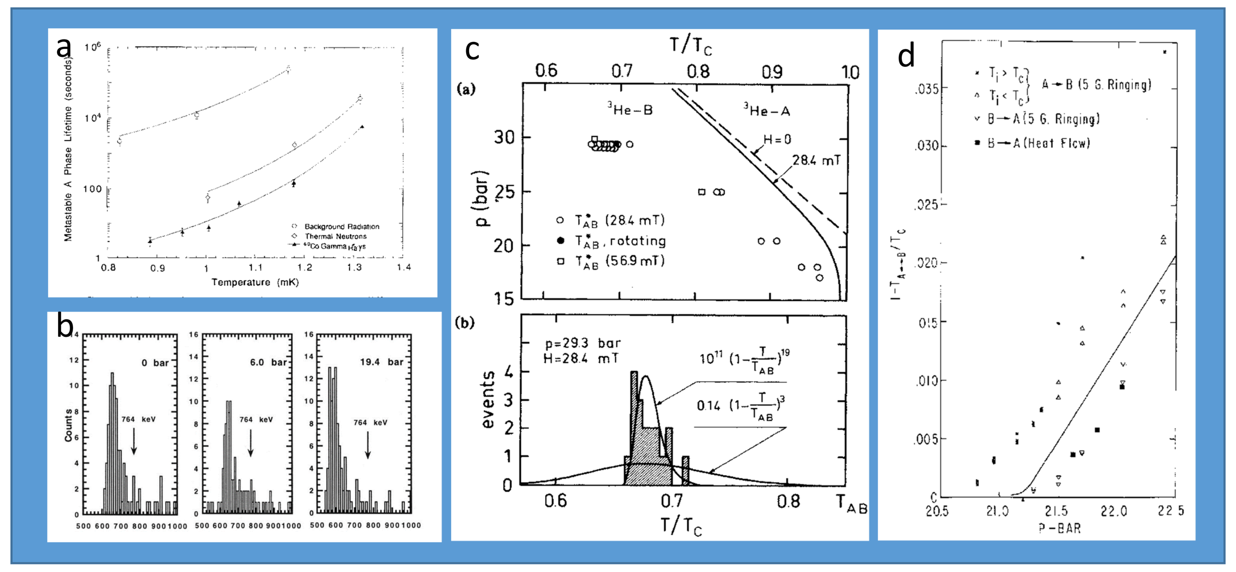
1. Observe and map supercooling and nucleation statistics near the polycritical point in "zero" field.
2. Locate A-B line in 1.1 μm channel
3. explore models of nucleation.

Experimental Details

Quartz Fork's Q informs whether fluid is in A or B phase.

B phase is nucleated independently in IC and HEC. Channel stabilizes the A phase by confinement.

The A phase supercools below its equilibrium point.



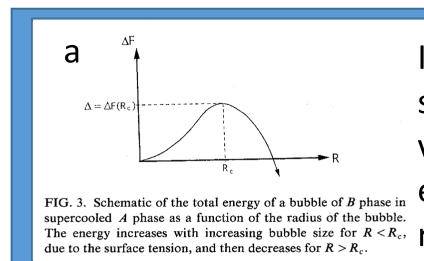
Past Experiments on supercooling of ^{3}He-A:

a) Osheroff[1] found lifetime of supercooled A phase decreased by exposure to Co source. Leggett's "Baked Alaska" scenario.[2]

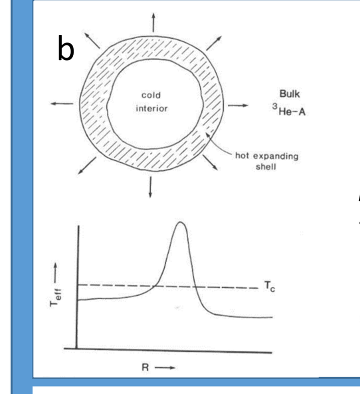
b) Grenoble experiment[3] observed missing energy in heat deposited. Led to vortex tangle, Zurek "Cosmological" and "Aurore de Venise" scenarios.[4]

c) Hakonen *et al*[5] observed a temperature distribution of nucleation inconsistent with Baked Alaska.

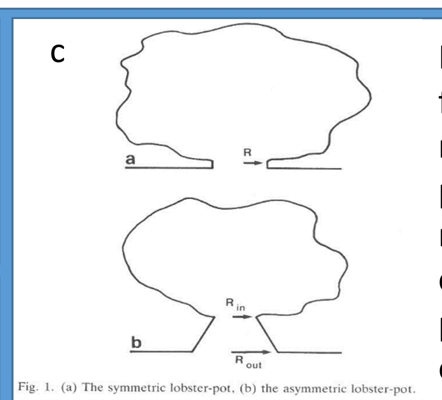
d) Early Wheatley experiments[6] show unexpected behavior near tri-critical point.



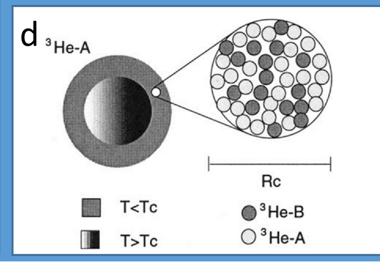
Interplay between surface energy and volume energy establishes critical radius for nucleation.



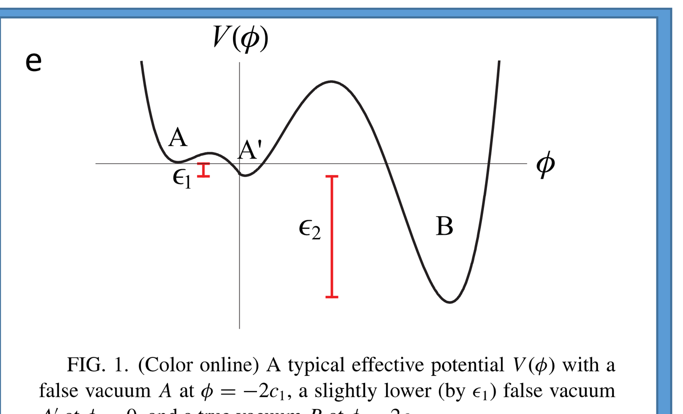
Baked Alaska model requires sudden heating (*eg cosmic ray passage*) to raise local temperature, allowing re-nucleation on cooling to B phase.



Lobster pot allows fluid in interior to nucleate in a different phase through a restricted thermal contact channel. Can provide memory effect.



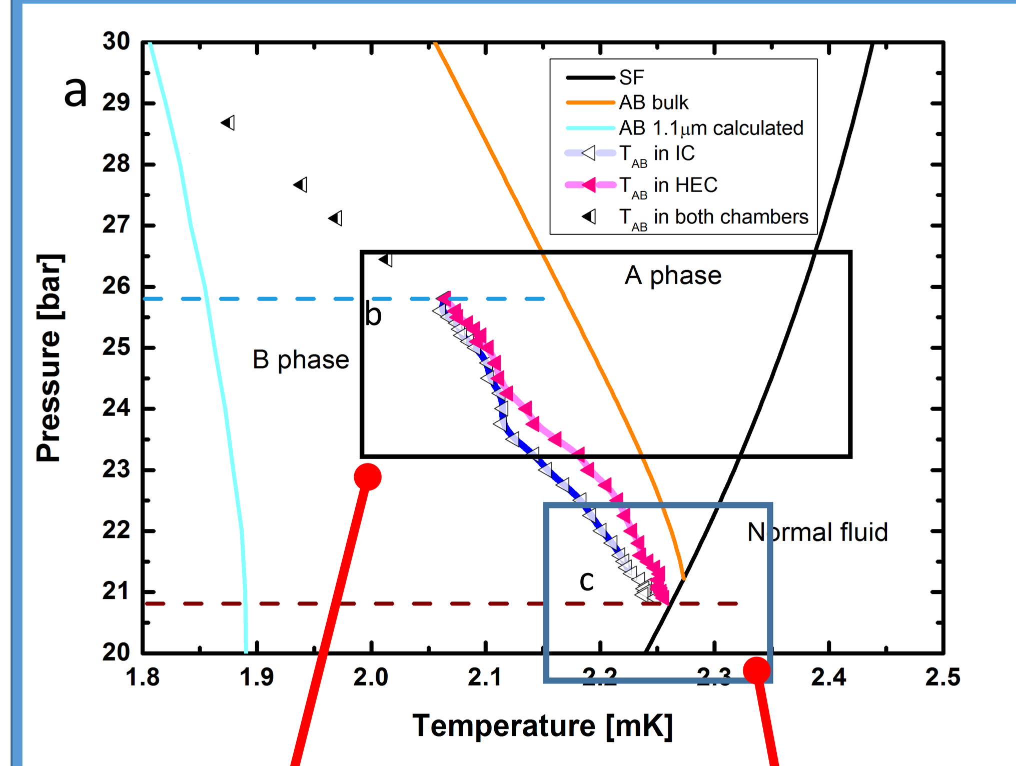
"Aurore de Venise" allows for individual bubbles of A & B phase to nucleate around a heated core. Accounts for lost energy.



Resonant tunneling model[7] avoids low tunneling probability by postulating intermediate states (other phases) that might enhance tunneling probability at specific T,P.

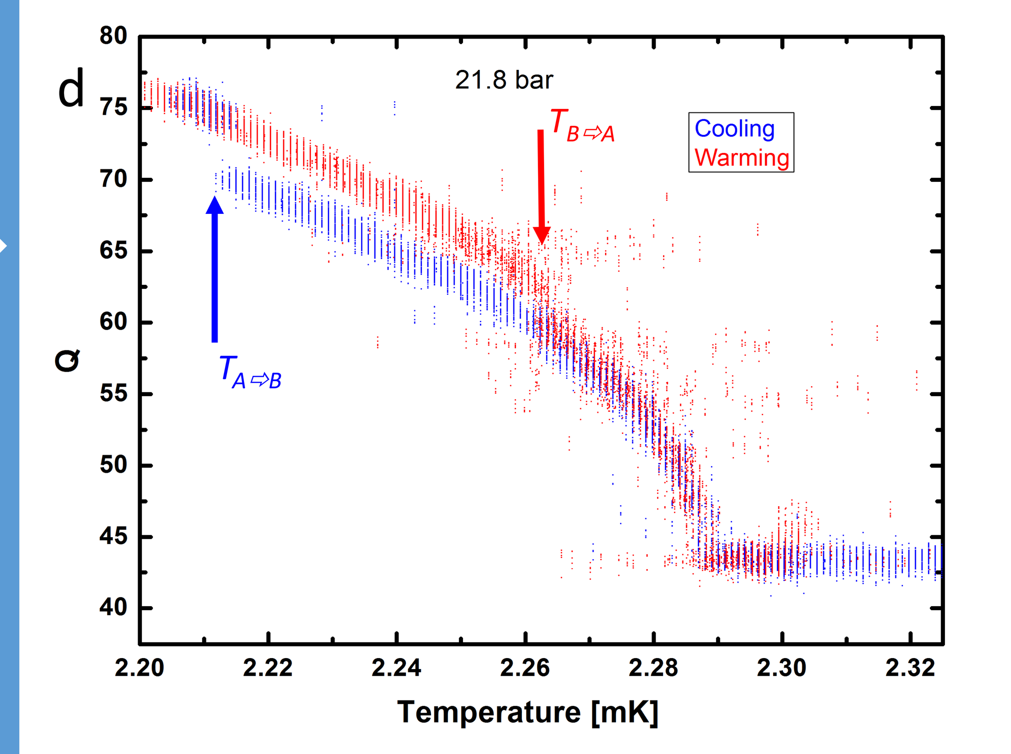
Fundamentally, extreme purity and low temperature implies ^{3}He B phase should never be nucleated from the A phase. Baked Alaska model correctly predicted some nucleation due to cosmic rays or charged particles. Other models address specific issues. No model is perfect.

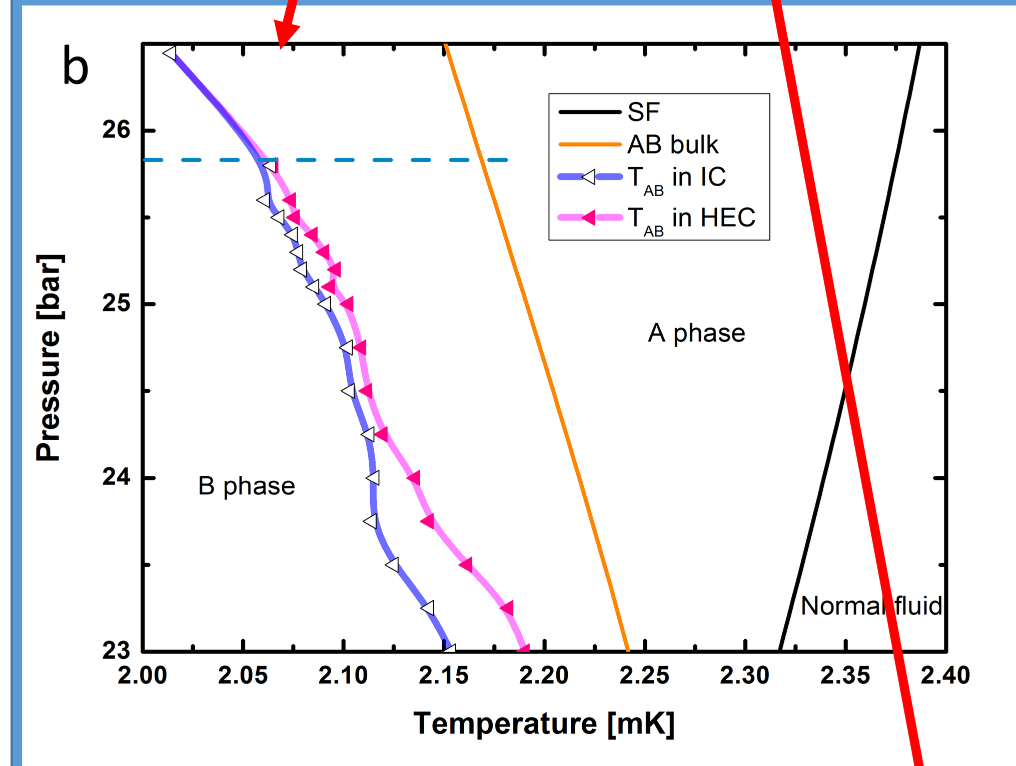
Experimental Results for Supercooling of ^{3}He-A



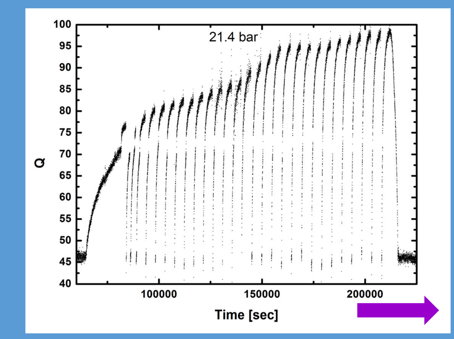
a) The overall phase diagram near the tri-critical point (TCP). The cyan line shows the calculated A-B line (Sauls) for a 1.1 μm channel. On cooling at constant pressure, the A⇨B transition in the HEC (heat exchange chamber) in pink, and in the IC (isolated chamber) in grey. Above 25.8 bar (blue dashed line) they occur simultaneously. Above 23.6 bar they occur closer together as pressure increases. The channel promotes A⇨B once the HEC has its A⇨B transition. A⇨B in the channel is likely higher in T than calculations suggest.

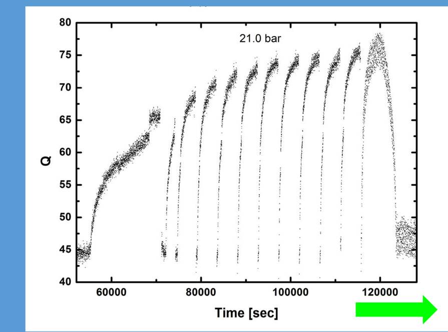
d) Q *vs.* T at 21.8 bar showing A⇨B transition in warming and cooling traces.



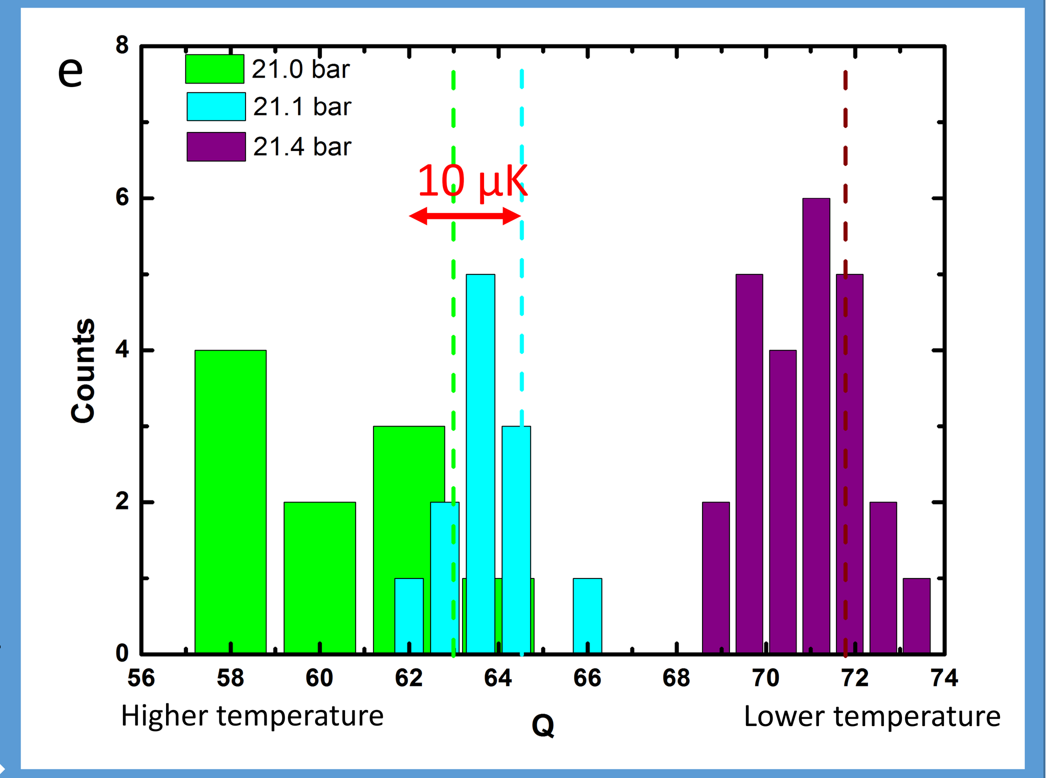


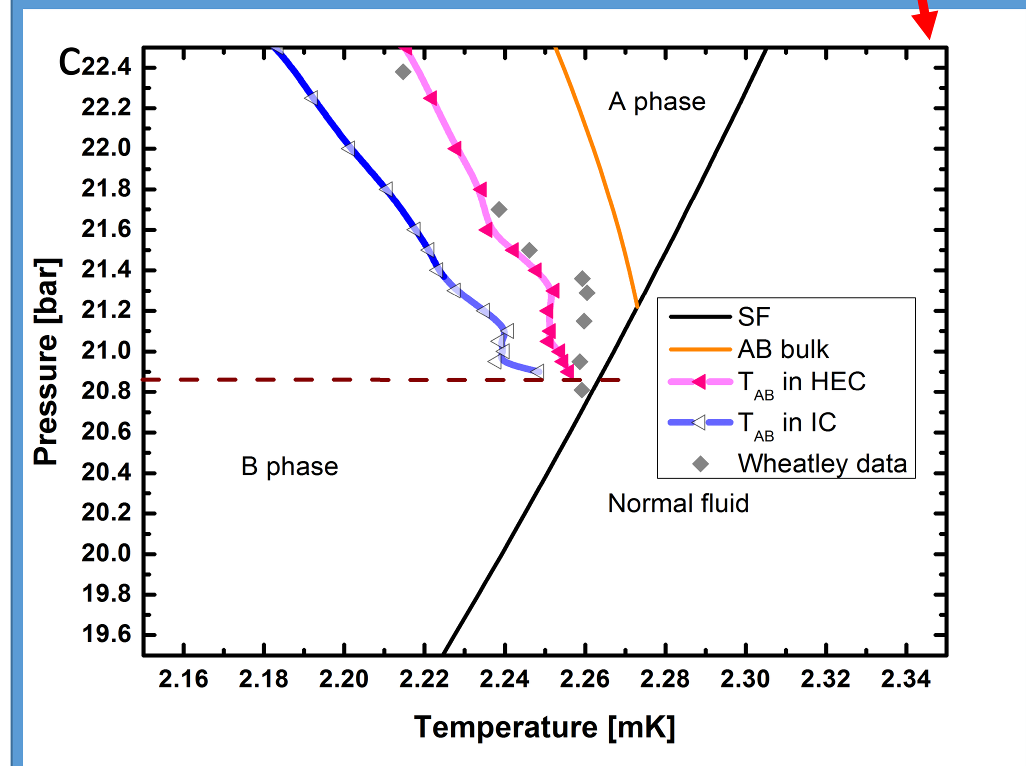
b) Enlarged view of A⇨B transition mediated by channel





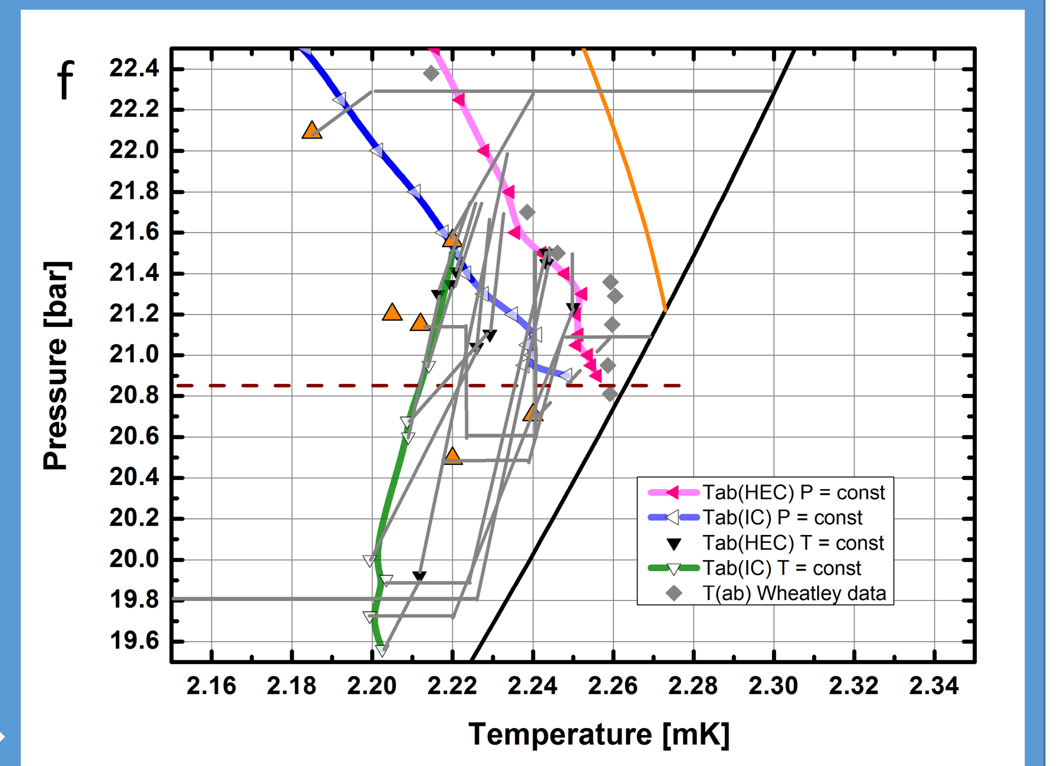
e) Dashed lines show Q's for the A⇨B transition in slow cooling. Histograms show A⇨B distribution following heat pulses that warm IC above T_c. Cooling rate ~150 μK/Hr from pulse, 10 μK/Hr slow cooling. Data for 21.4 bar and 21.0 bar pulses at left.





c) Enlarged view of A⇨B transition near Tri Critical Point. ◆ from Wheatley powdered CMN Cell[6]. No A⇨B is seen for runs at constant P below 20.85 bar. These results are similar to the "catastrophe" experiment observed in Helsinki.

f) Compare c to f. By cooling at P= constant then depressurizing while maintaining T= constant or cooling slowly, we are able to reliably cross the pink and blue lines. This extends the region of supercooled A phase. The supercooled A phase is stablized below 19.8 bar, and a new A⇨B transition line (green) is seen.



1. Schiffer & Osheroff *Reviews of Modern Physics*. 67 491-501. 1995
2. Leggett & Yip, *in Helium Three, Pitaevskii and Halperin*, eds. p523, 2014
3. C. Bauerle *et al* in *Topological Defects… Bunkov & Godfrin*, eds. p105 2000
4. Bunkov, in *Topological Defects… Bunkov & Godfrin*, eds. p121 2000
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6. Kleinberg *et al*, JLTP **17** 521 1974
7. Tye & Wohns Phys. Rev. B **84** 184518 (2011).

Discussion on Results for Supercooling of ^{3}He-A

We have observed supercooling of the A phase in an isolated chamber (IC) cooled via a 1.1 μm channel. The A phase intervenes in the channel between the normal state and the B phase at all pressures. The magnetic field on the sample is less than 5 Gauss.

1. The Heat Exchanger Chamber (HEC) and IC show supercooling and independent nucleation of the A phase, except above 25.8 bar where the A-B transition line in the channel crosses the supercooling lines in the HEC, IC. (Panels:a,b)

2. Near the Tri-Critical Point, we observe supercooling in both chambers that extends below the TCP pressure (21.2 bar). Supercooling in the IC extends further than that in the HEC. Sinter's surface may promote A phase nucleation at T_c below the Tricritical pressure. But B phase may also emerge in the sinter due to favorable surface irregularities. Below 20.85 bar, B-phase nucleated in both chambers upon cooling through T_c (Panel:c,d)

3. By pulsing, we can rapidly cycle through T_c in the IC. We see narrow distributions of A⇨B transitions centered around the slow cooling $T_{A⇨B}$ except at the lowest pressure (Panel:e)

4. By cooling at constant P and then depressurizing, we readily cool through the points obtained at constant pressure. We demonstrate supercooled A phase down to 19.8 bar and 2x colder than results at constant P. **Memory Effect** Supercooling is similar but does not perfectly reproduce free energy difference. (Panel:f).

Acknowledgements: NSF – DMR 1708341, Sauls & Wiman: Confined ^{3}He Phase Diagram, Leggett, Tye, Widom: Discussion. Fabrication CNF

Conclusions: Observations inconsistent with Baked Alaska, Aurore de Venise and Resonant Tunneling models. "Lobster pot" can provide memory by retaining A/B phase information as sample is cooled through reduced T_c of neck. But, all features are not replicated by Lobster pot model.

A-B line in channel likely 2.0-2.1 mK not 1.8-1.9 mk as calculated.