Memory Effect and the Metastability of the A to B Transition in Superfluid ^3He.

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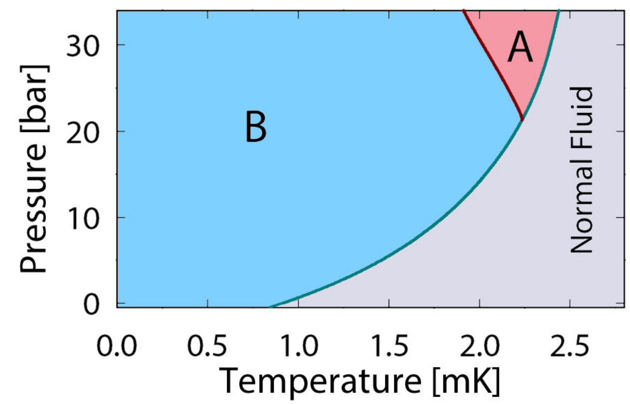
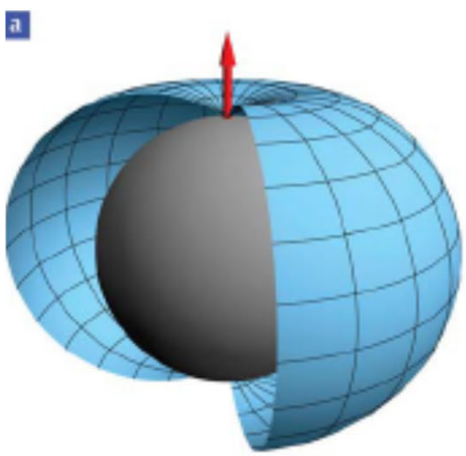
National Science Foundation
Directorate for Mathematical & Physical Sciences (MPS/DMR)

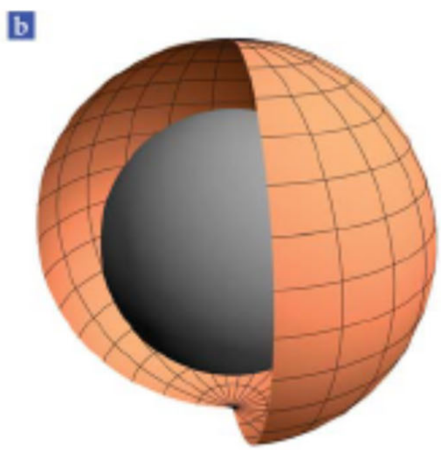
Introduction to ^{3}He



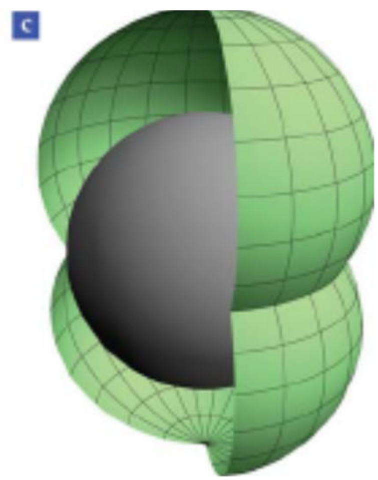
A Phase



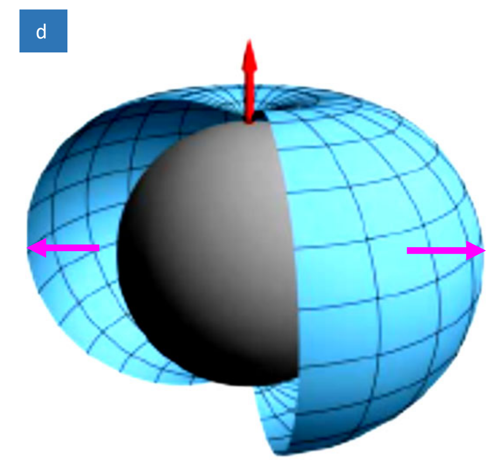
B Phase



Polar Phase



Planar Phase



Unsolved Issues around A-B - Origin of Supercooling

The ^{3}He A-B Interface

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I review the experimental and theoretical situation regarding two problems connected with the transition between the superfluid A and B phases of liquid ^{3}He, namely (1) what is the mechanism of nucleation of the strongly hypercooled first order transition between the two phases, (2) what factors govern the expansion of the stable B phase once formed, i.e. what determines the mobility of the A-B interface? It is concluded that in both cases there are a number of intriguing questions which at present remain unanswered.

1. THE ^{3}He A-B INTERFACE; THE B-PHASE NUCLEATION PUZZLE*

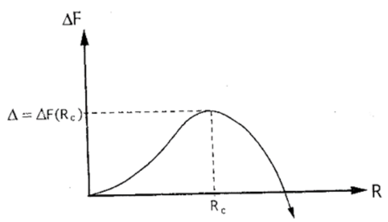
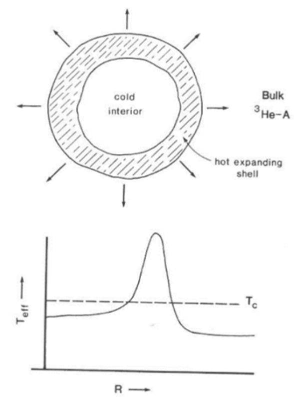


FIG. 3. Schematic of the total energy of a bubble of B phase in supercooled A phase as a function of the radius of the bubble. The energy increases with increasing bubble size for $R < R_c$, due to the surface tension, and then decreases for $R > R_c$.

The 3He A-B Interface, A.J. Leggett, JLTP, 1992 571-593



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

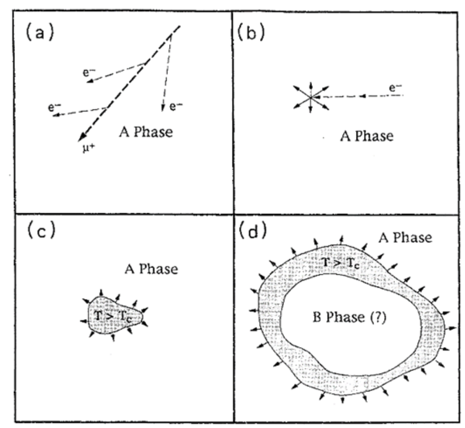


FIG. 4. Schematic representation of the baked Alaska process as described in the text.

Alternative to "Baked Alaska"

PHYSICAL REVIEW B **84**, 184518 (2011)

Resonant tunneling in superfluid ^{3}He

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(Received 1 July 2011; revised manuscript received 3 October 2011; published 15 November 2011)

The A phase and the B phase of superfluid He-3 are well studied, both theoretically and experimentally. The decay time scale of the A phase to the B phase of a typical supercooled superfluid ^{3}He-A sample is calculated to be $10^{20,000}$ years or longer, yet the actual first-order phase transition of supercooled A phase happens very rapidly (in seconds to minutes) in the laboratory. We propose that this very fast phase transition puzzle can be explained by the resonant tunneling effect in field theory, which generically happens since the degeneracies of both the A and the B phases are lifted by many small interaction effects. This explanation predicts the existence of peaks in the $A \to B$ transition rate for certain values of the temperature, pressure, and magnetic field. Away from these peaks, the transition simply will not happen.

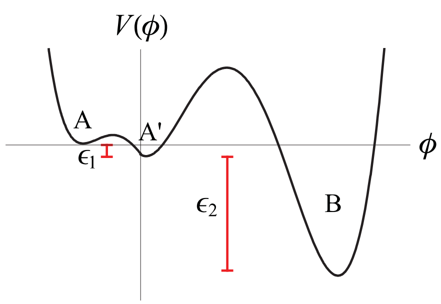
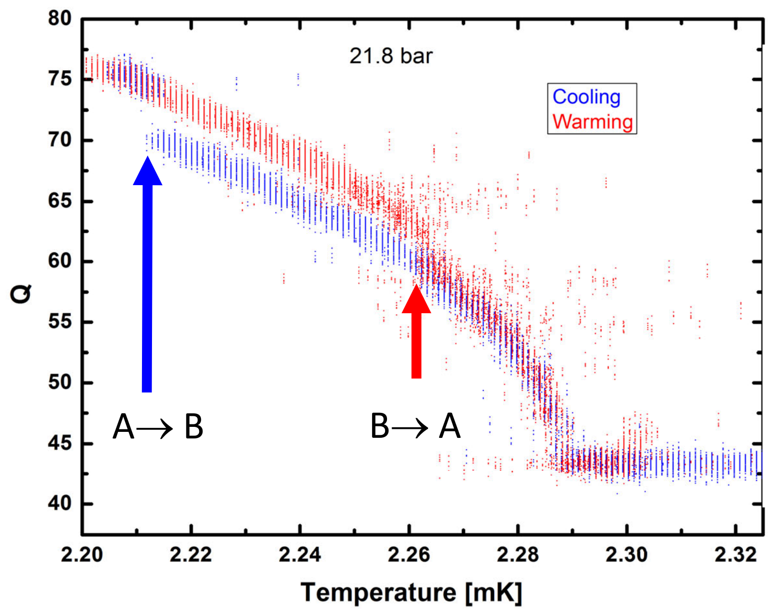
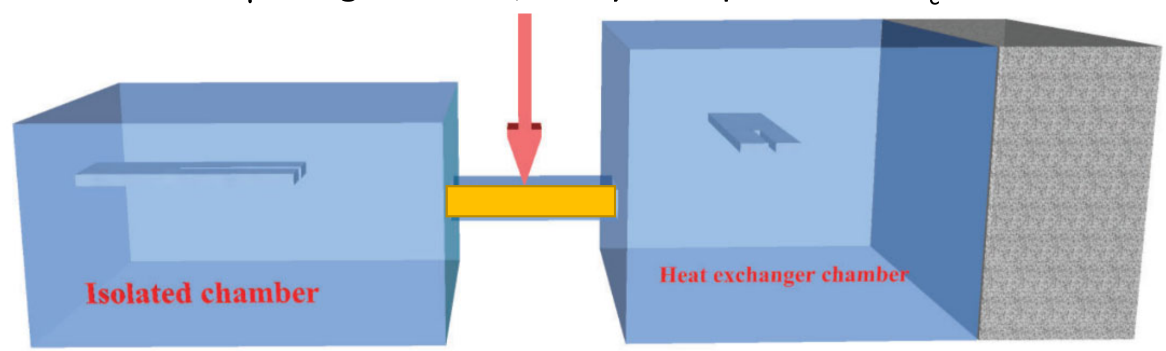


FIG. 1. (Color online) A typical effective potential $V(\phi)$ with a false vacuum A at $\phi = -2c_1$, a slightly lower (by ϵ_1) false vacuum A' at $\phi = 0$, and a true vacuum B at $\phi = 2c_2$.

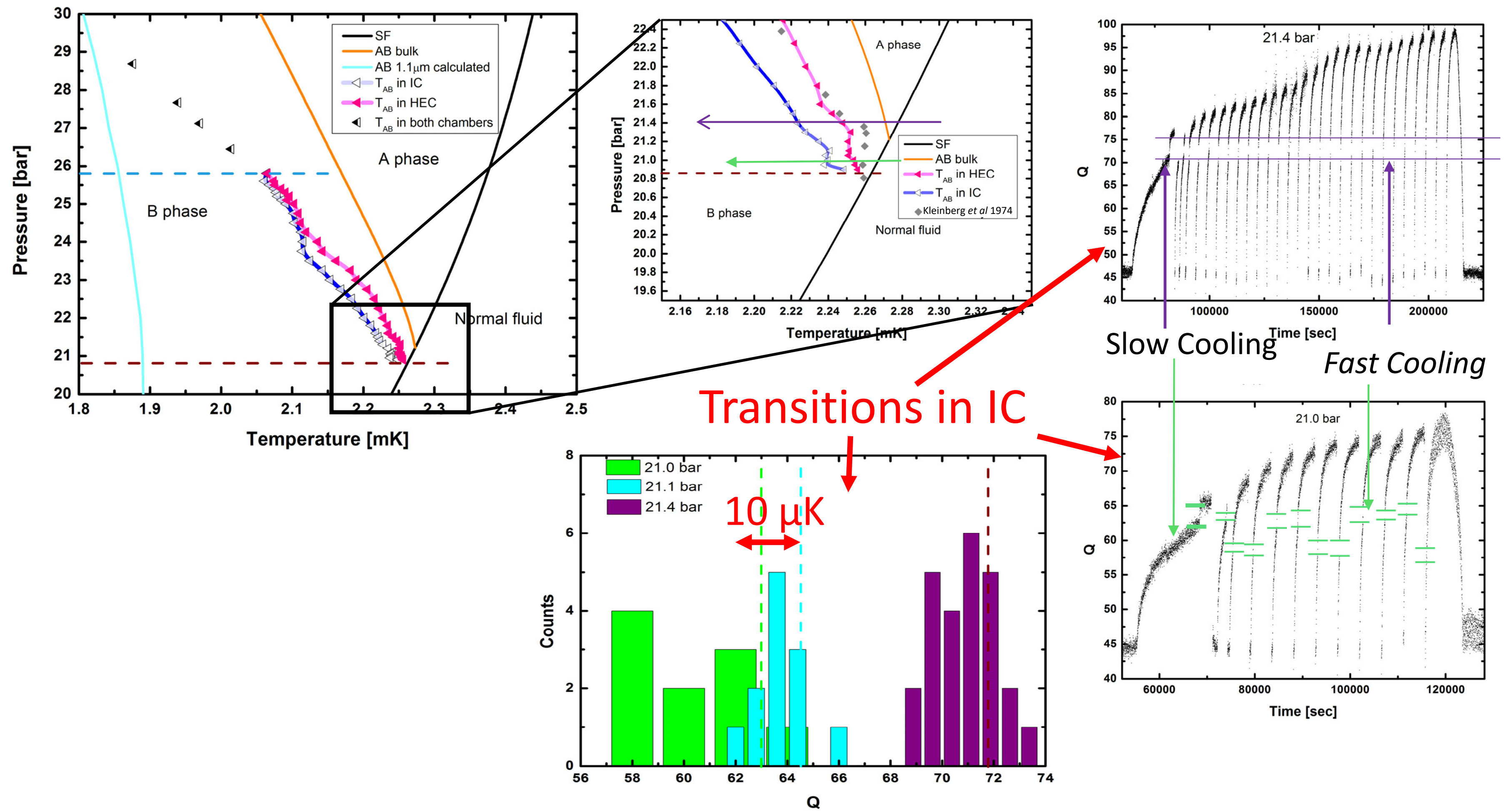
II - New Cornell experiment (originally for thermal conductivity)



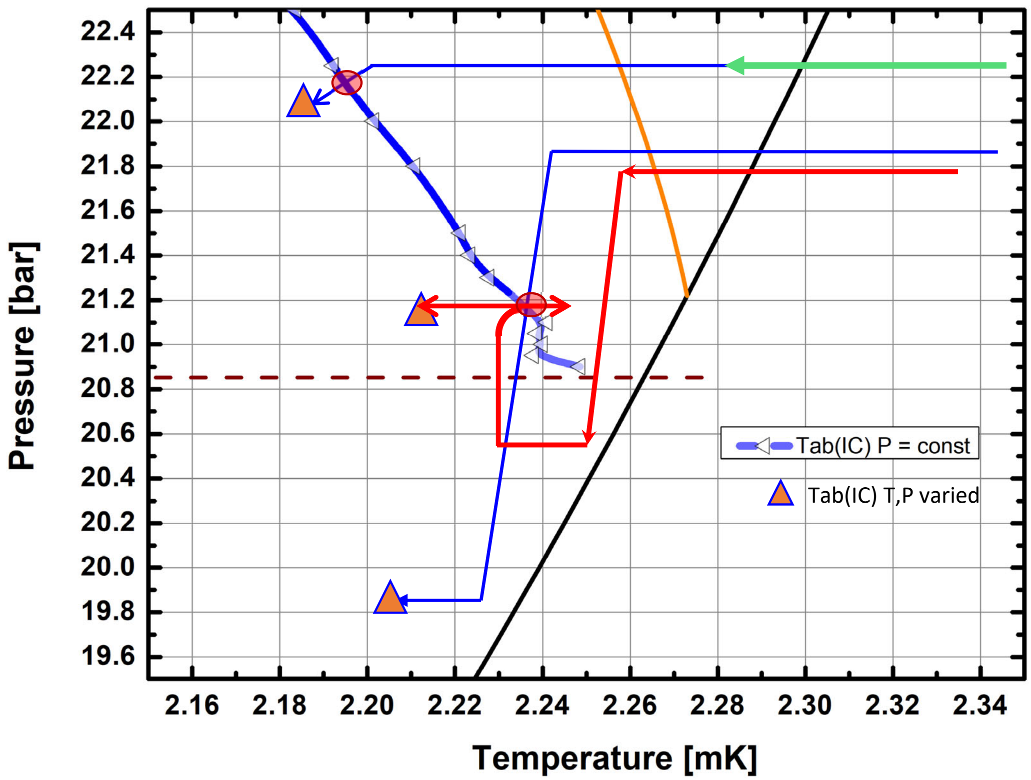


Experiment has two chambers separated by a channel that is 1.1 μm tall x 100 μm long x 3mm wide.
Chamber IC (Isolated Chamber) is monitored by its own quartz "tuning fork", chamber HEC (Heat Exchange Chamber) is also monitored by an identical fork. **We will mainly discuss the A→B transition in the Isolated Chamber**

II - New Cornell experiment inconsistent with all



II – Observations in IC while varying pressure



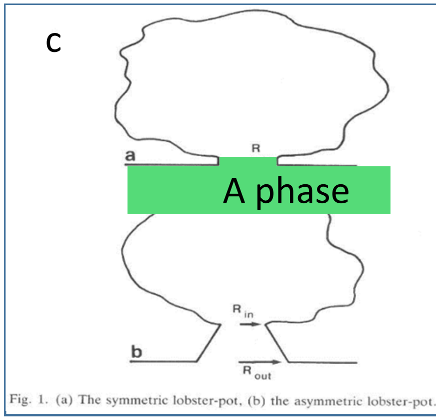


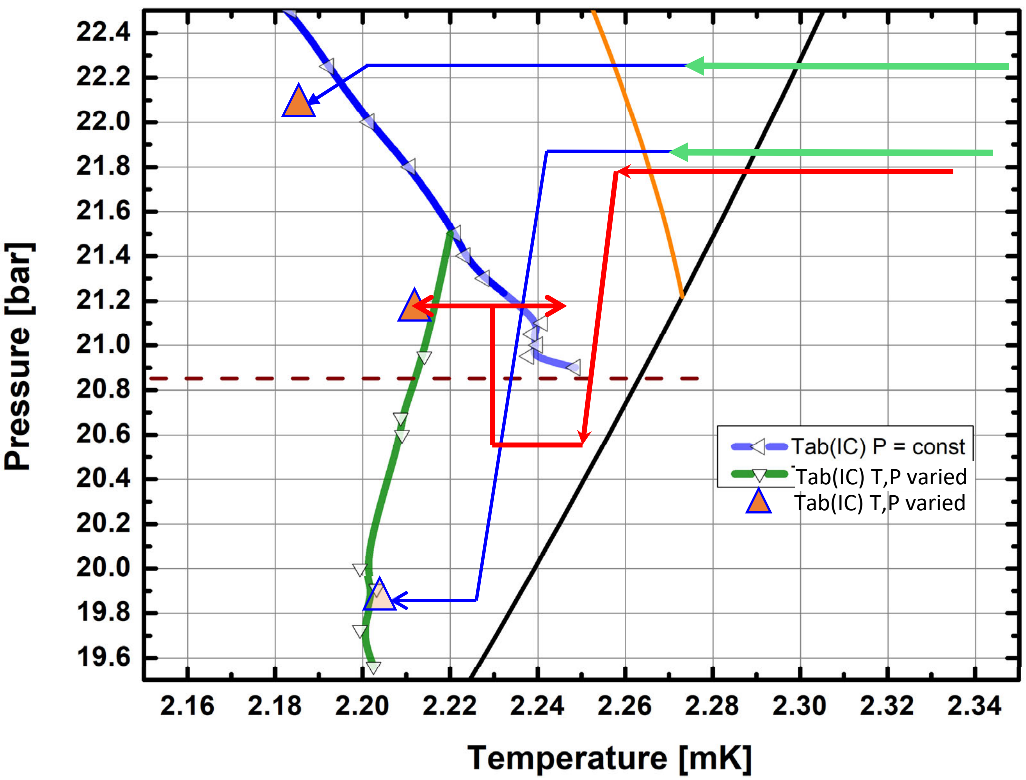
Fig. 1. (a) The symmetric lobster-pot, (b) the asymmetric lobster-pot.

Lobster pot model states fluid in interior nucleates in the phase governed by (*T,P*) through a restricted thermal contact channel. Can provide memory effect.

Starting at some pressure, we cool to the metastable A phase, then decrease pressure. We find that the A→B transition happens at a lower *T,P* than constant pressure cooled samples.

Test for Resonant Tunneling model.
We do not see A-B transition with peaked probability at particular (*T,P*).

II – Observations while varying pressure



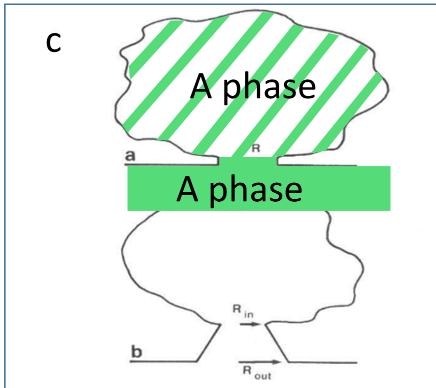


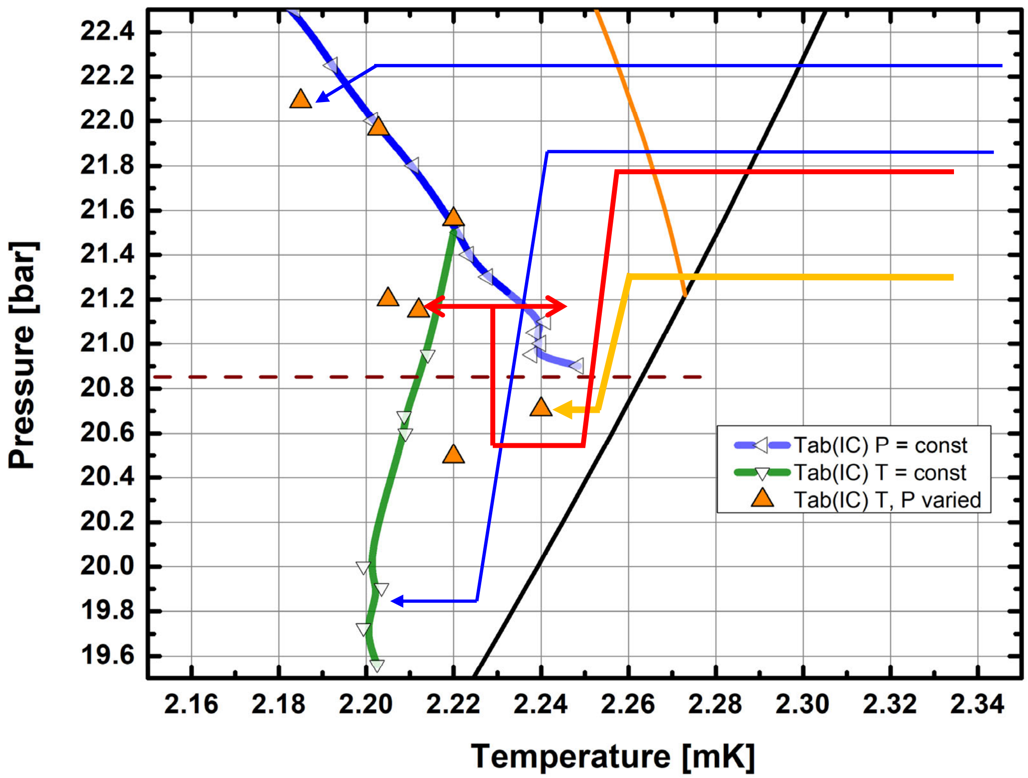
Fig. 1. (a) The symmetric lobster-pot, (b) the asymmetric lobster-pot.

Fluid in lobster pot nucleates in the A phase (equilibrium phase at that *T,P.*)
If we start at a lower pressure, the lobster pot could fill with B phase at some *T,* and nucleate A→B "early".

Starting at some pressure, we cool to the metastable A phase, then decrease pressure. We find that the A→B transition happens at a lower *T,P* than constant pressure cooled samples.

Test for Resonant Tunneling model.
We do not see A-B transition with peaked probability at particular (*T,P*).

II – Observations while varying pressure



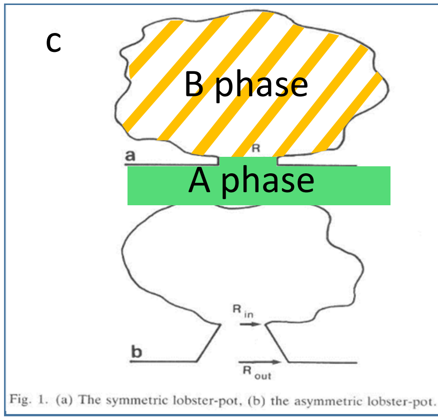


Fig. 1. (a) The symmetric lobster-pot, (b) the asymmetric lobster-pot.

Fluid in lobster pot nucleates in B phase (equilibrium phase at that *T,P.*) Chamber is still in A phase. Similar process as in Baked Alaska

We see less supercooling than we can achieve starting from a high pressure.

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. Hakonen *et al* PRL **54**, 245 1985
5. Kleinberg *et al,* JLTP **17** 521 1974
6. Tye & Wohns Phys. Rev. B **84** 184518 (2011).

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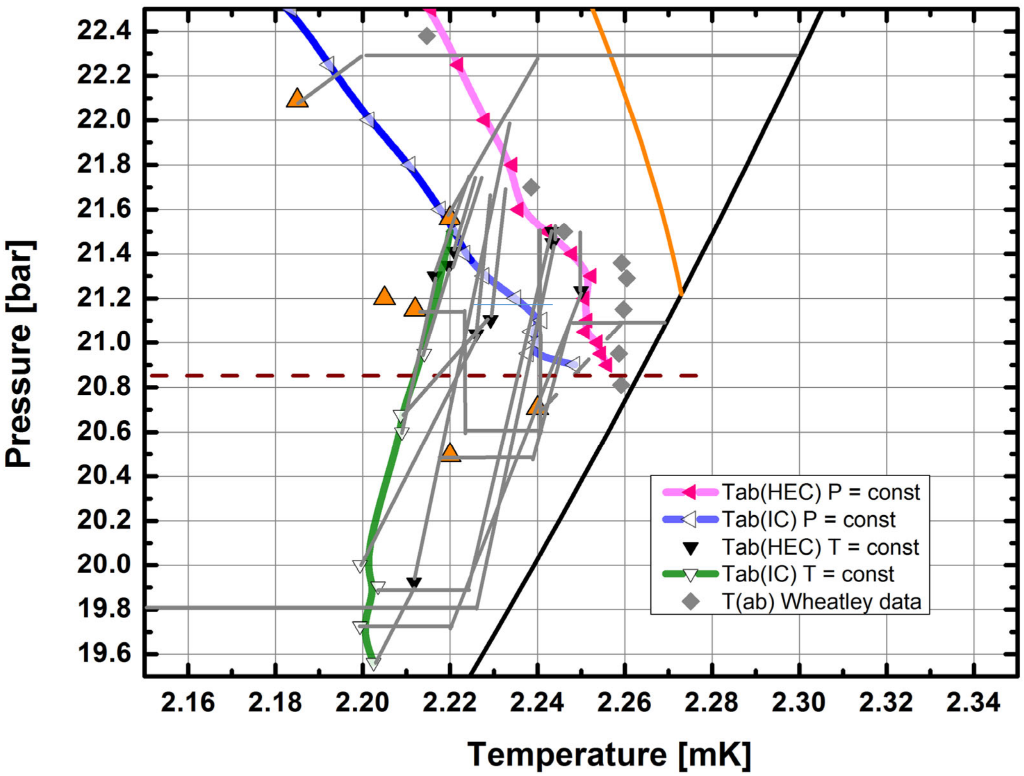

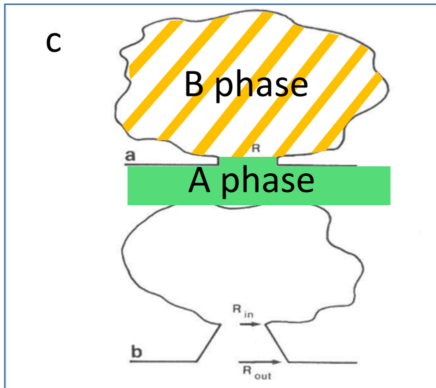

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Fluid in lobster pot nucleates in B phase (equilibrium phase at that *T,P.*) Chamber is still in A phase. Similar process as in Baked Alaska

We see less supercooling than we can achieve starting from a high pressure.

Generally, we find that if we cool through T_c at a high pressure, then depressurize, we supercool more than if we start at a low pressure.
However, there is no "perfect" correspondence between pressure at cooling through T_c and the degree of supercooling.
Bottom line - lobster pot is an imperfect model.
However, it can provide a memory effect

1. Schiffer & Osheroff *Reviews of Modern Physics*. 67 491-501. 1995
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III - Conclusion

The metastable A $\rightarrow$B transition exhibits an unexpected "memory effect", related to the pressure at which T_c is traversed. Doesn't fit the usual spinodal picture of classical phase transitions.

The A $\rightarrow$B transition occurs reliably, and is not successfully modelled by the Baked Alaska or Resonant Tunneling Models.

The A phase is nucleated while cooling at constant pressure down to 20.85 bar, **less than** the poly-critical point at 21.22 bar in B=0

The A phase in B=0 is seen to be stable down to at least 19.6 bar when cooled through T_c around 22 bar, then depressurized.

Consequences for other metastable (1st order) transitions between phases to be observed in confined geometries.

Possible implications for Kibble Zurek and other scenarios concerned with phase transitions in the so-called Inflationary Epoch in the evolution of the early universe.