Unexplained phenomena in solid ^4He

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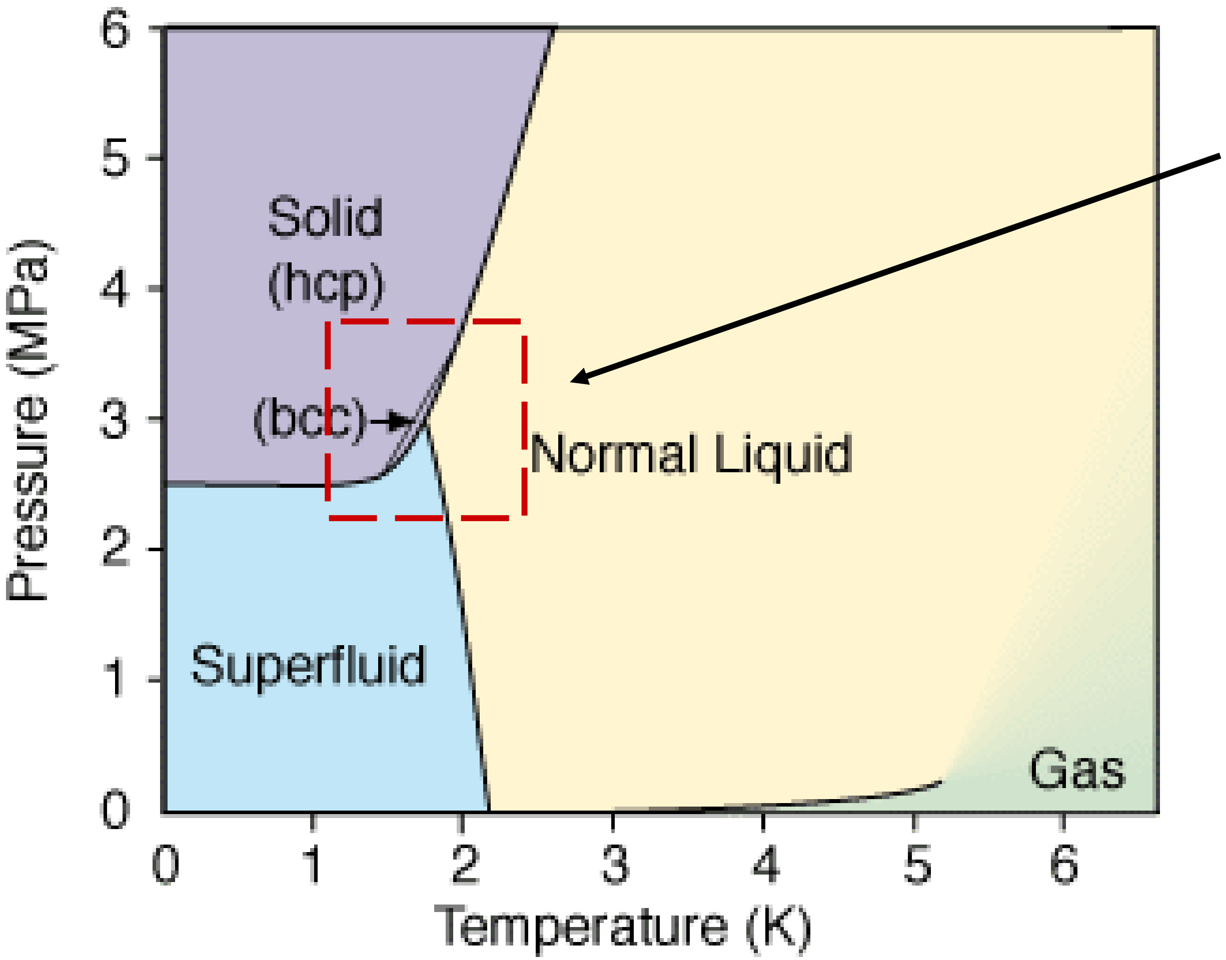
The Phase Diagram of ^4He



Solid bcc phase

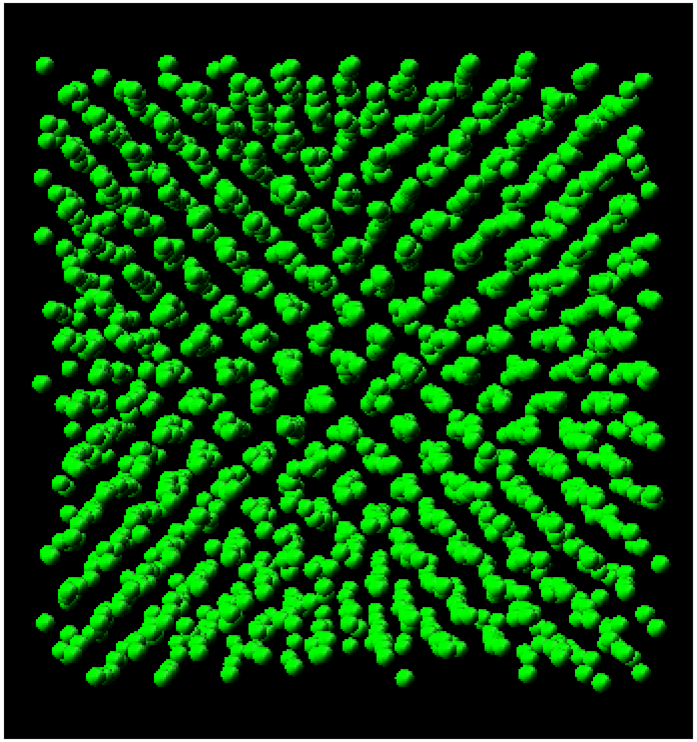
1.47K-177K

Max temperature width: 50 mK

Max pressure width: 0.6 bar

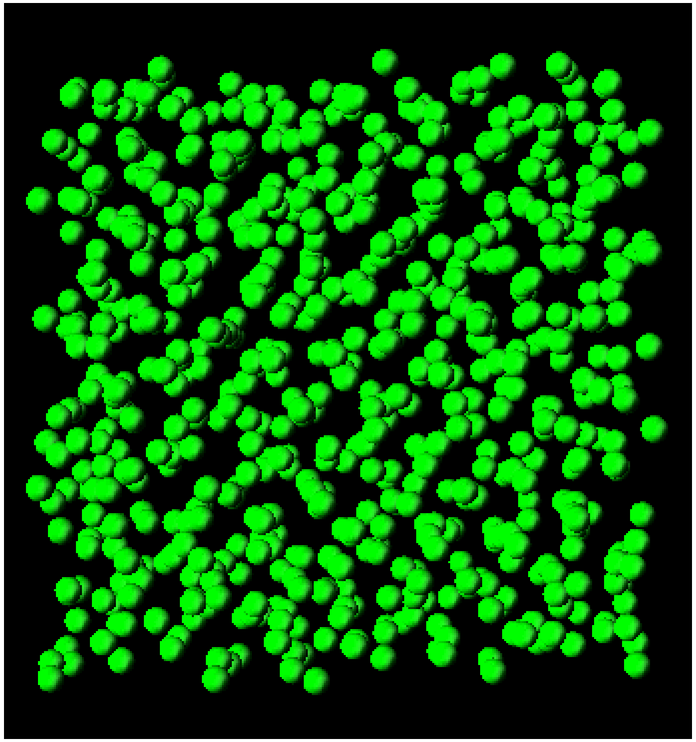
Visualization of atomic motion in bcc solids*

Vanadium T=2000K



Melting point-2150K

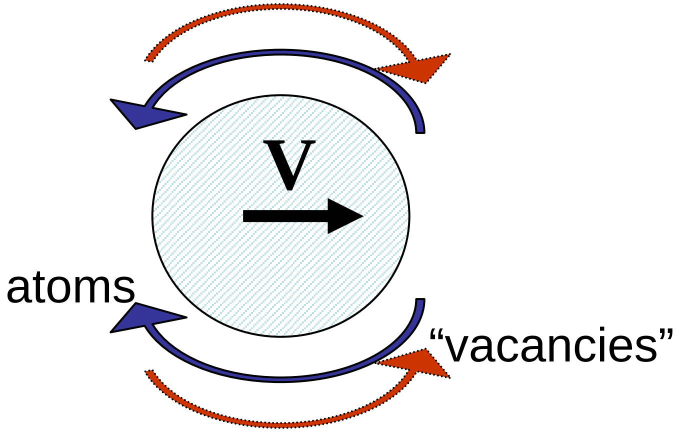
Helium T=0K



-Path Integral Monte Carlo Simulations- Slava Sorkin, PhD Thesis

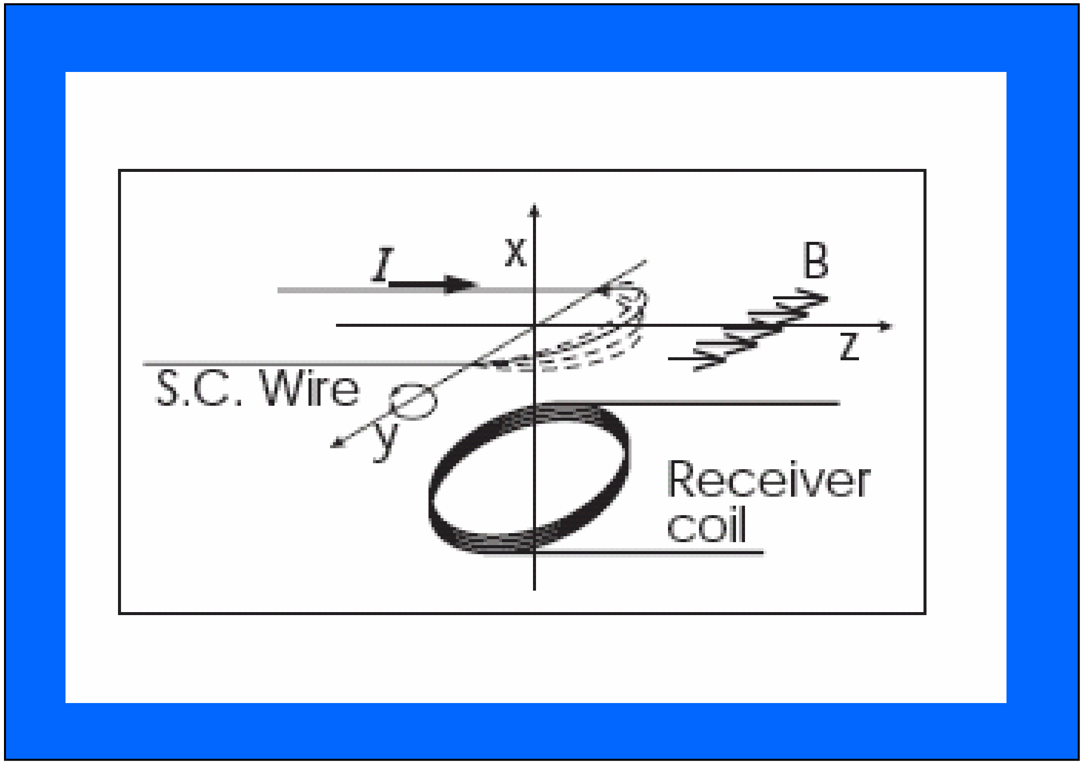
(*) Slava Sorkin webpage : http://phycomp.technion.ac.il/~phsorkin/

Pushing a wire of radius R through solid He(**)



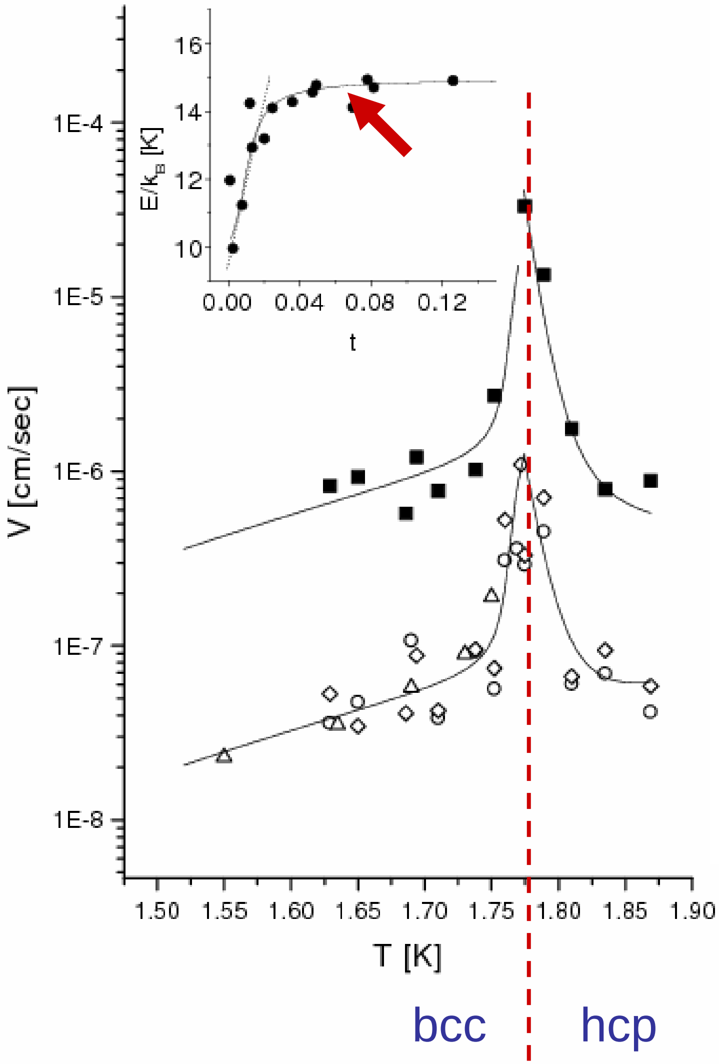
$$v = \frac{D}{2RkT}\sigma$$

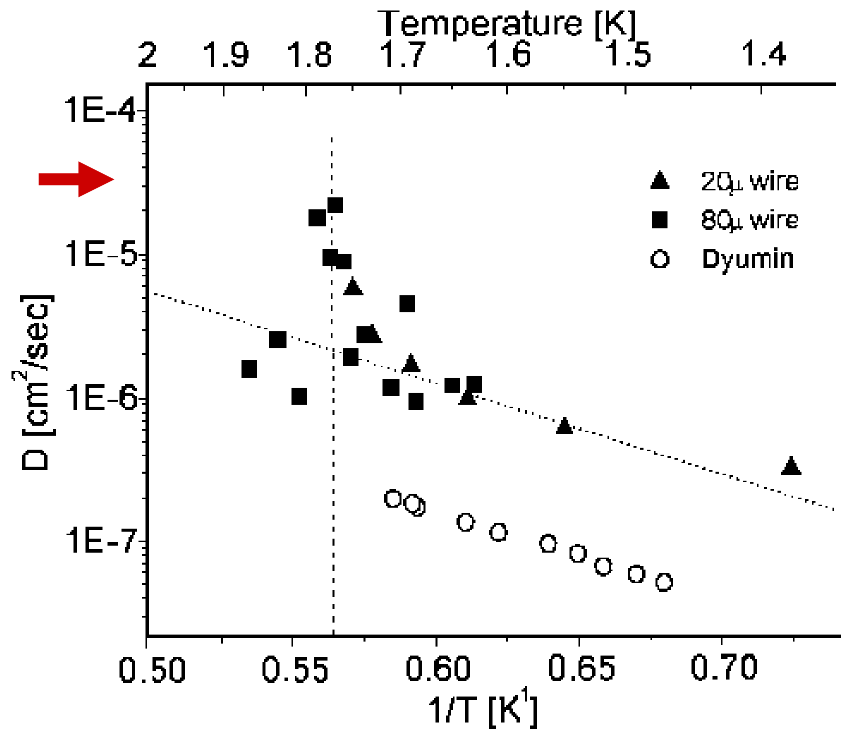
$$D = D_0\, e^{-E/kT}$$



(**)Inon Berent, PhD thesis

Wire speed vs. temperature under a constant stress

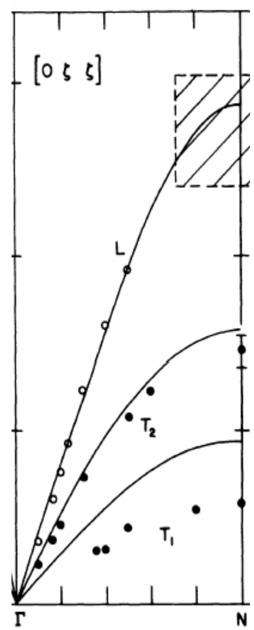


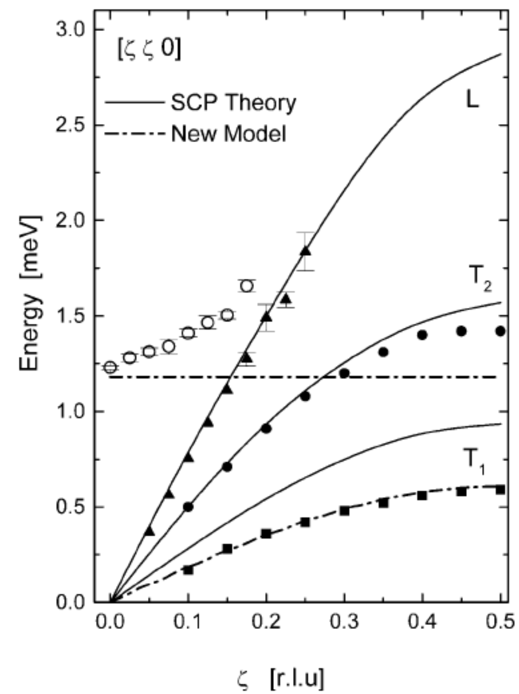


Self diffusion coefficient vs. temperature

Looking for a soft phonon…

A simple cubic crystal with one atoms per unit cell can have only 3 acoustic phonon branches





Minkiewicz et. al Phy.Rev A 8 1513 (1973)

Markovich et al. PRL , 88, 195301(2002)

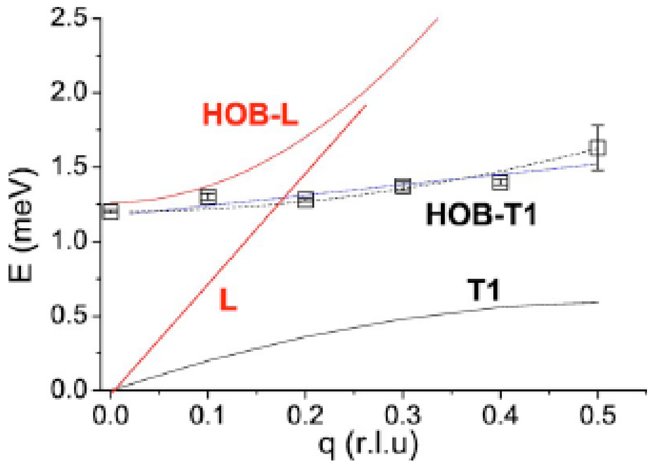
Did not find any softening. Instead, we found two unexpected optical excitation branches, called Higher optical branch and Lower Optical branch

Summary of the properties of the Higher Opticlike Branch

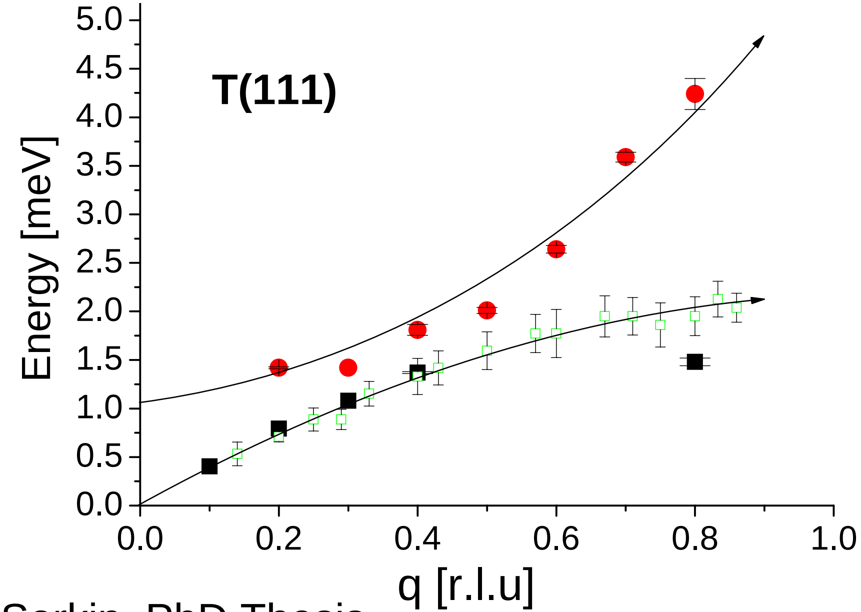
- The HOB has a small intrinsic dispersion.

$$\varepsilon(q) = \varepsilon_0 + \frac{(\hbar q)^2}{2m^*}$$

$$\varepsilon_0 = 1.2 meV \quad m^* = 0.7 m_{He}$$



- The HOB is a propagating excitation
- The energy line-width of the phonons increases abruptly when the phonon and the HOB branches cross.
- Hence, the HOB interacts with acoustic phonons.
- HOB was seen in the L(110), T1(110), T(111) and L(100) directions.

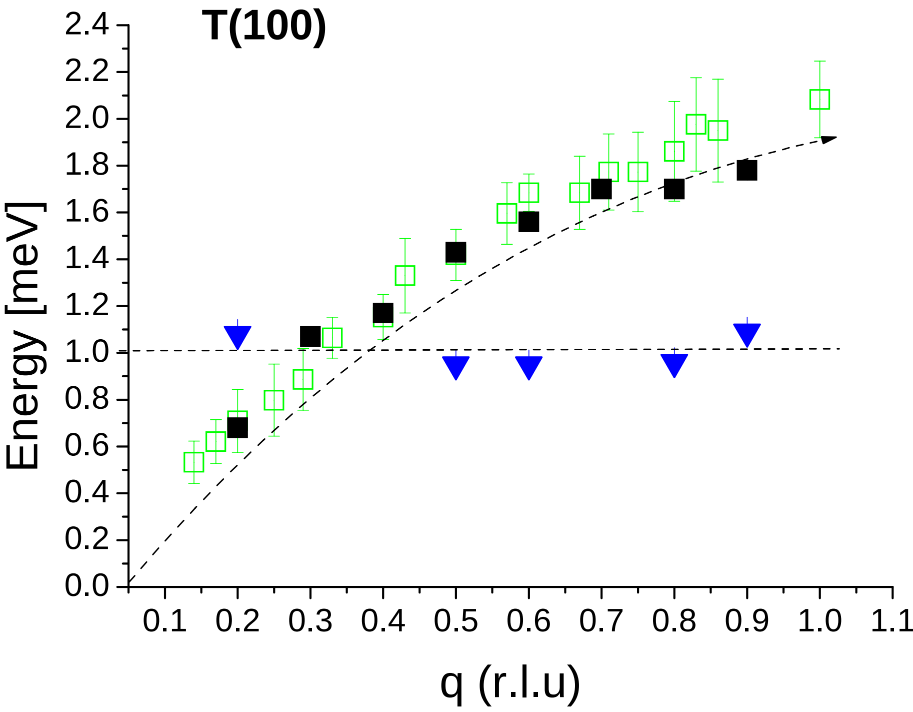


-Path Integral Monte Carlo Simulations- Slava Sorkin, PhD Thesis

Neutron scattering data- Oshri Pelleg, PhD thesis

Summary of the properties of the Lower Opticlike Branch

- Typical energy of the LOB is 0.95 ±0.1 meV (~11K).
- The LOB is dispersionless excitation.
- The energy line-width is small, limited by the experimental resolution
- The LOB doesn’t couple to the acoustic phonons.
- LOB was seen only in the (100) and L(111) directions.



-Path Integral Monte Carlo Simulations- Slava Sorkin, PhD thesis

Neutron scattering data – Oshri Peleg, PhD thesis

What are these excitations?

HOB excitation:

- Gov et al.(1) predicted a dispersionless mode in the (110) direction with a correct value of the energy.
- In contrast, our data indicate that this mode has intrinsic dispersion and is seen also in other directions, not only (110). It is a propagating mode.
- The energy of the HOB is the same as the energy of the excitation responsible for mass transport through self diffusion(2). This suggests that mass transport in bcc ^{4}He can be wavelike(??).
- No such excitations were seen in hcp ^{4}He, where mass transport is an order of magnitude lower than in bcc ^{4}He.

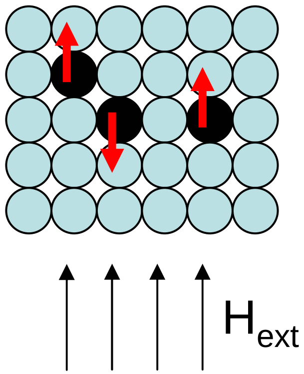
(1) Gov et al. **PRB** 60 1019 (1999)
(2) Dyumin et al. **Low temp. Phys**. 19, 696 (1993)

LOB excitation:

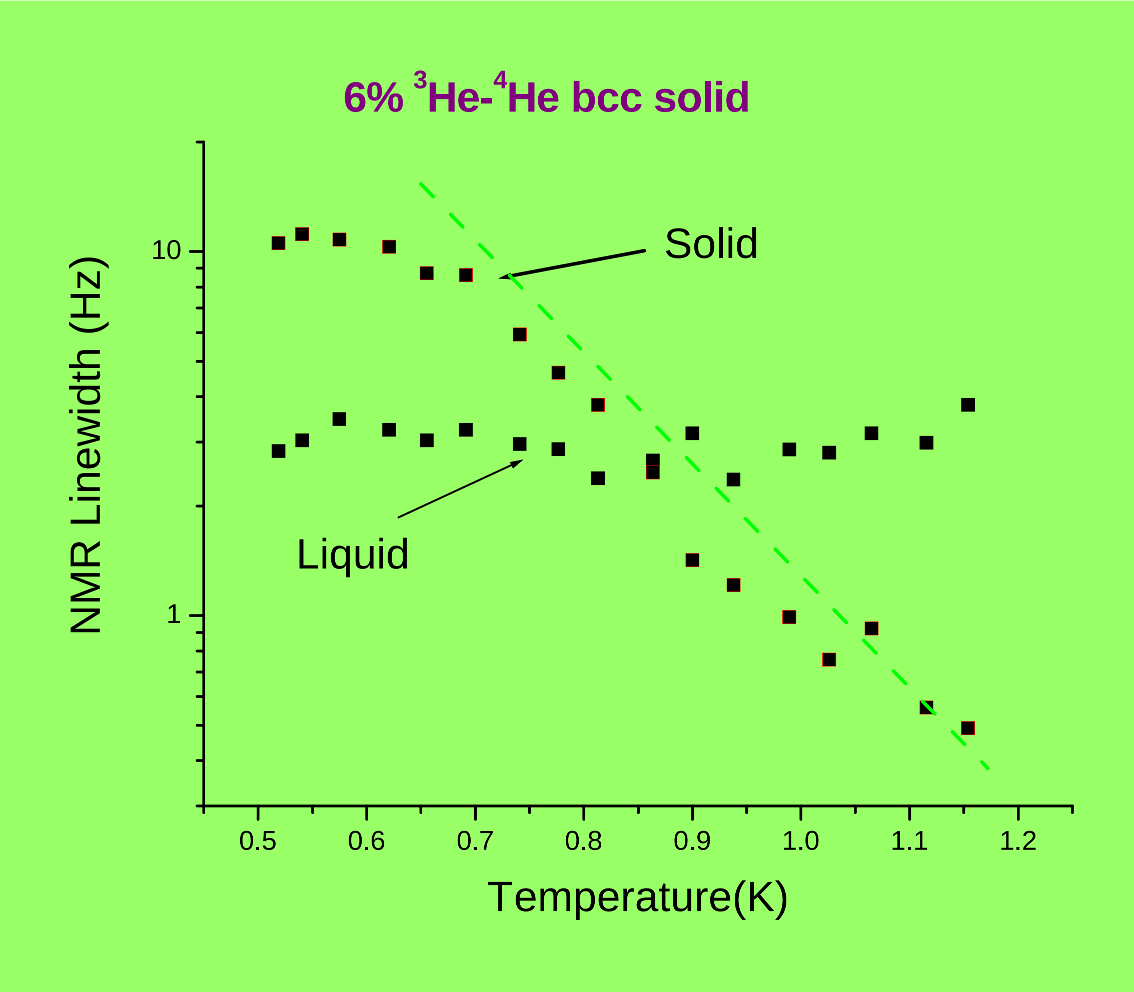
- Absence of dispersion suggests a localized excitation such as point defect.
- The energy of LOB is close to the creation energy of a vacancy. But, a neutron can only remove an atom from its site and so create a Vacancy-Interstitial pair. The expected energy line-width of such process is large and inconsistent with the small energy line-width of the LOB which is measured.
- Resonance mode of a point defect can be a possible interpretation. There are no calculations of such modes in solid Helium.

Our unexplained problem is: what excitations other than phonons can exist in a quantum solid?

Atomic Motion and NMR Linewidth



$$\mu(H_{ext} + H_{\text{int}}) = \hbar\omega$$



If the atoms move, H_{int} averages to zero over time (motional narrowing). Solid He is the only substance where the NMR linewidth in the solid is smaller than in the liquid

Schuster et al., *Europhys. Lett.*