Superphenomena in solid Helium-4

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main collaborators:

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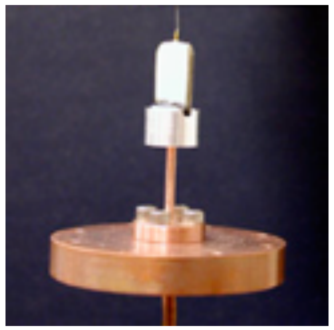
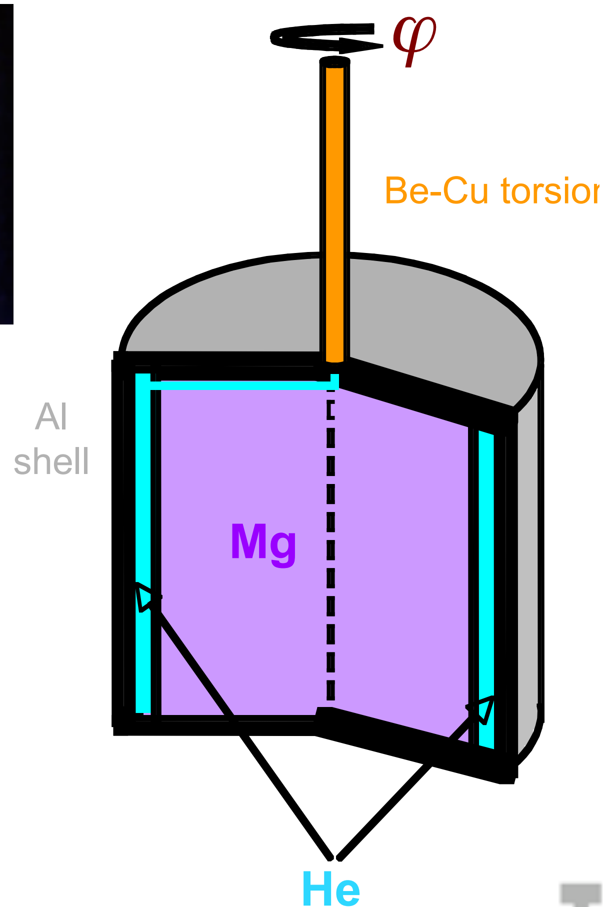
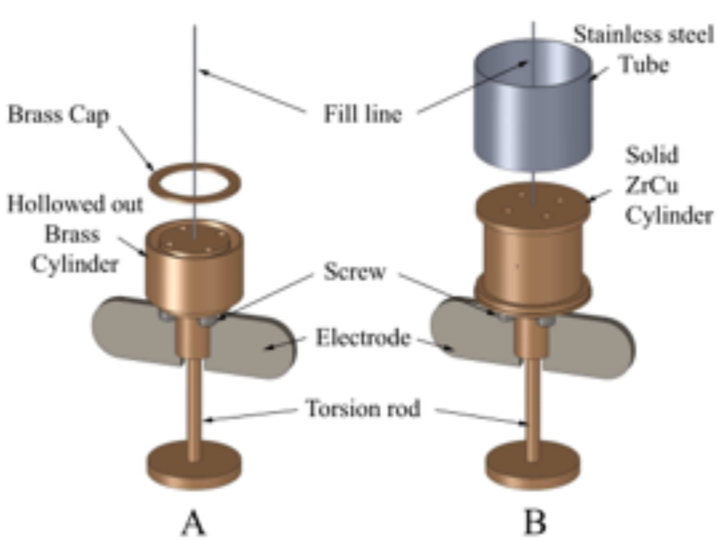
Boris Svistunov
Nikolay Prokofev

torsional oscillators







Absence of supersolidity in solid helium in porous Vycor glass

Duk Y. Kim and Moses H. W. Chan*
Department of Physics, The Pennsylvania State University, University Park, PA 16802, USA
(Dated: July 31, 2012)

Upper limit of supersoldity in solid helium

Duk Y. Kim and Moses H. W. Chan*
Department of Physics, Pennsylvania State University, University Park, Pennsylvania 16802, USA
(Dated: July 9, 2014)

$$\rho_s < 10^{-6}$$

THE SUPERSOLID'S NEMESIS

John Reppy has come out of retirement to question the high-profile discovery of a new kind of quantum matter.

reasons: design, elasticity effects

the „knobs"

Perfect crystal: huge zero point motion, yet insulator
Temperature: range from few mK to few K
Defects :

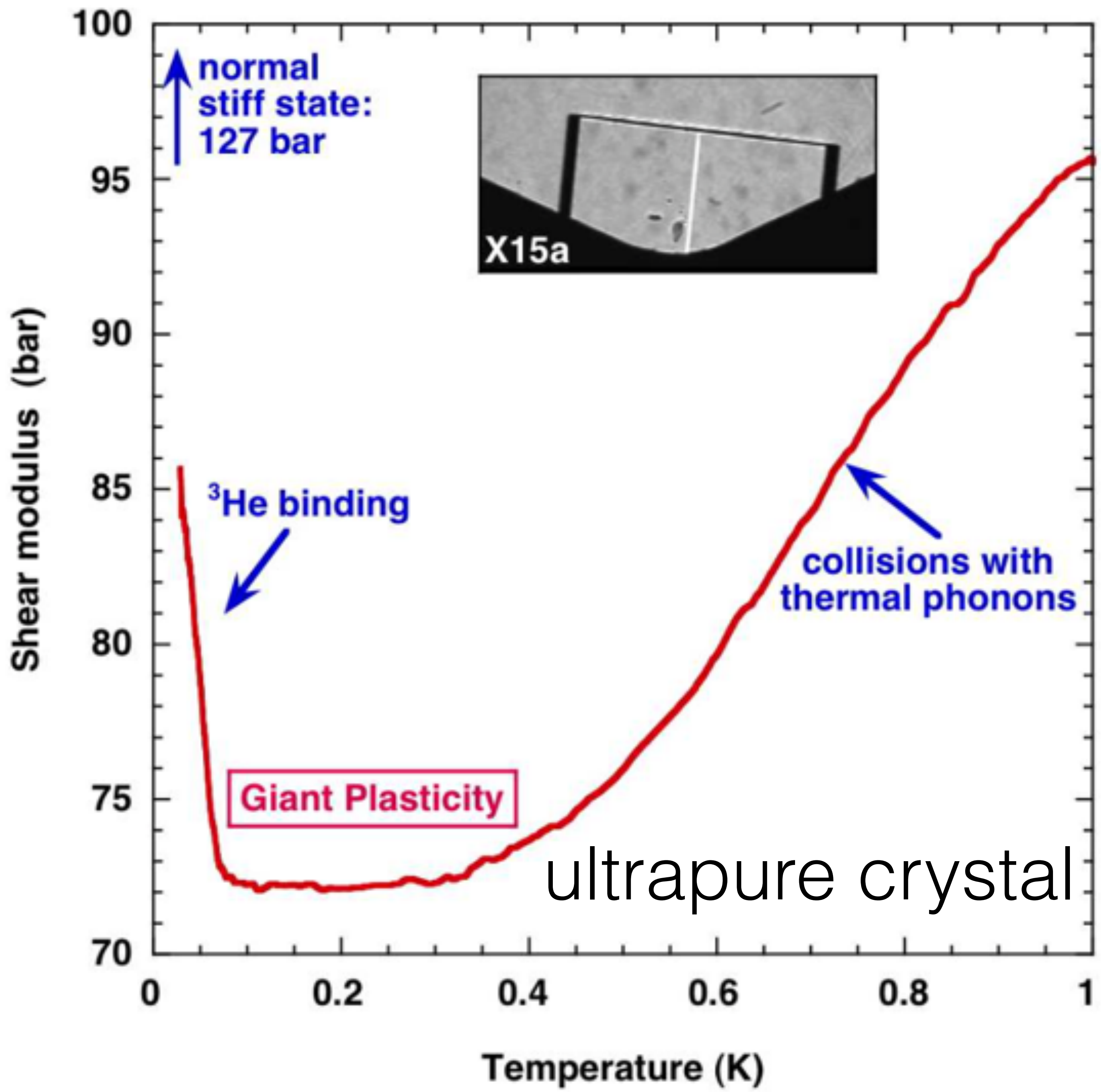
- vacancies: activation energy > 10K
- dislocations: can be superfluid or insulating
- grain boundaries: can be superfluid or insulating

He-3 impurities: ppm to ppb range, but big impact; for higher concentrations phase separation

He3 impurities can bind to dislocations with Eb ~ 0.8K (macrolevel) and block superflow (microlevel)

not understood

(reversible) giant plasticity



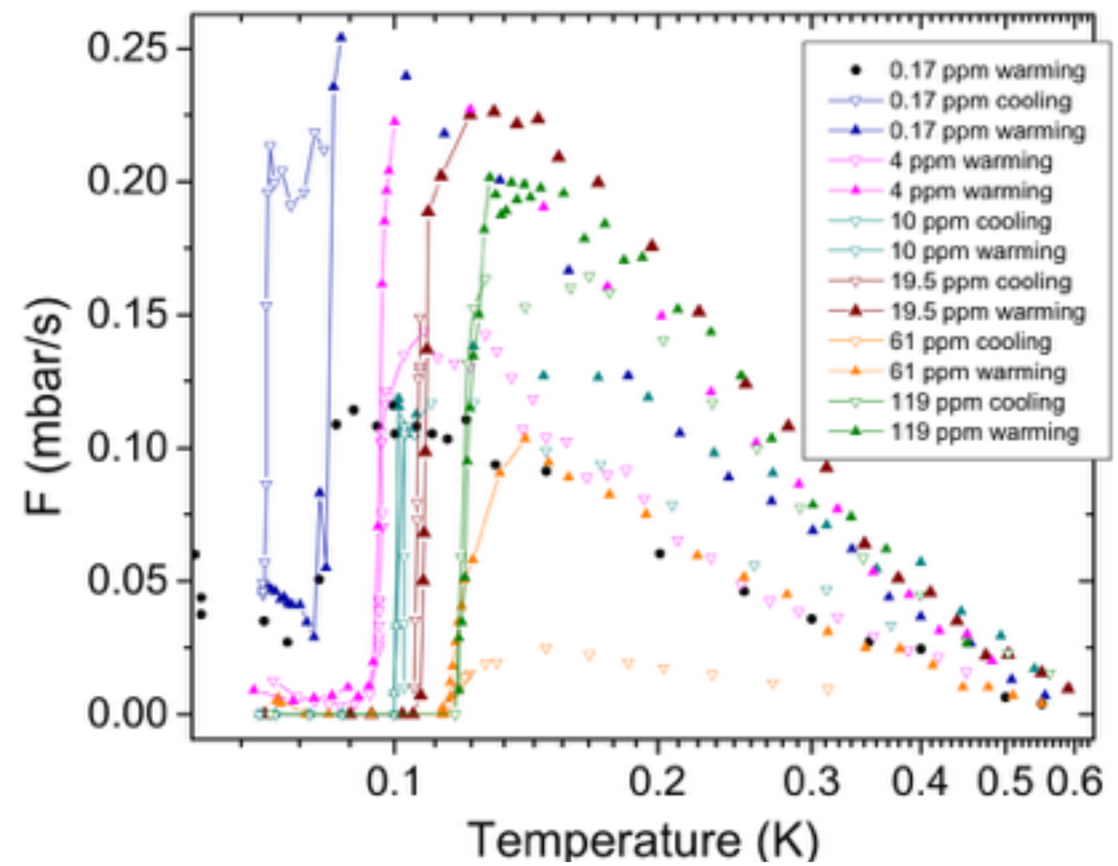
anisotropic (gliding of dislocations in basal planes)

30 million Burger vectors per second

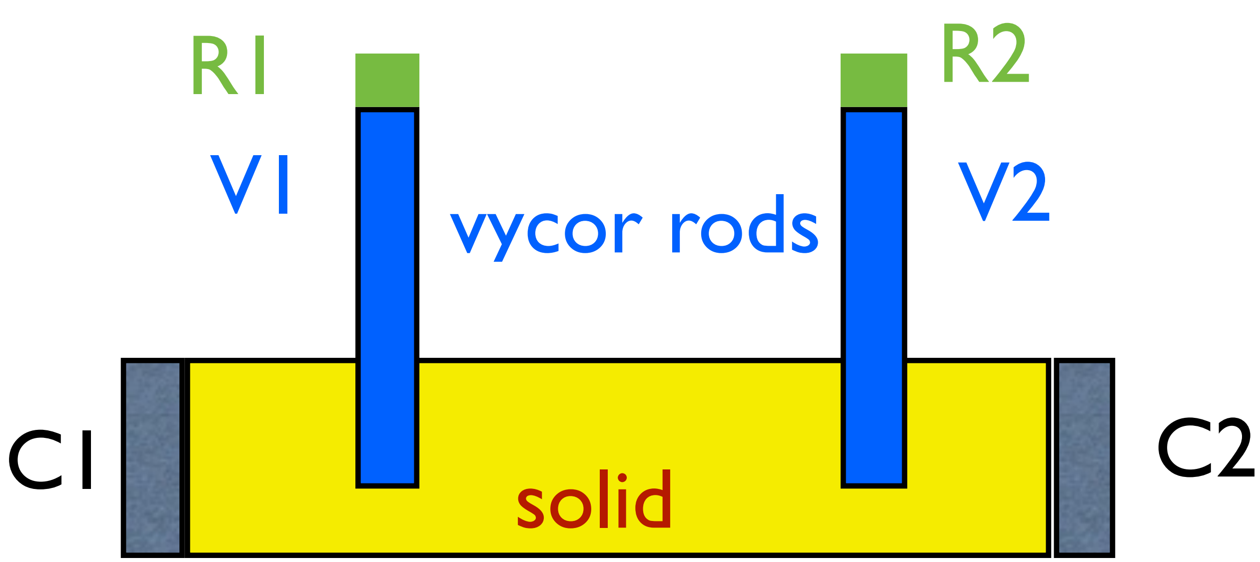
Ariel Haziot, Xavier Rojas, Andrew D. Fefferman, John R. Beamish, and Sébastien Balibar, Phys. Rev. Lett. 110, 035301 (2013)

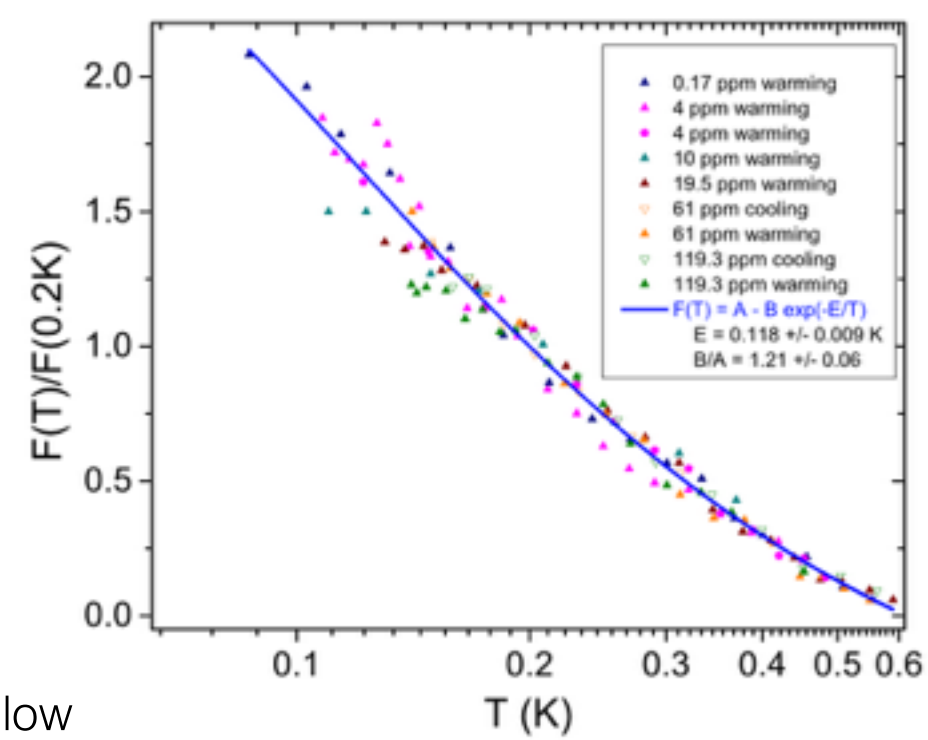
mass supertransport

Ye. Vekhov, W. Mullin, R. Hallock, arXiv:1311.4913 (2013)



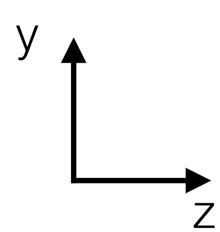
Umass sandwich
(group of R. Hallock)

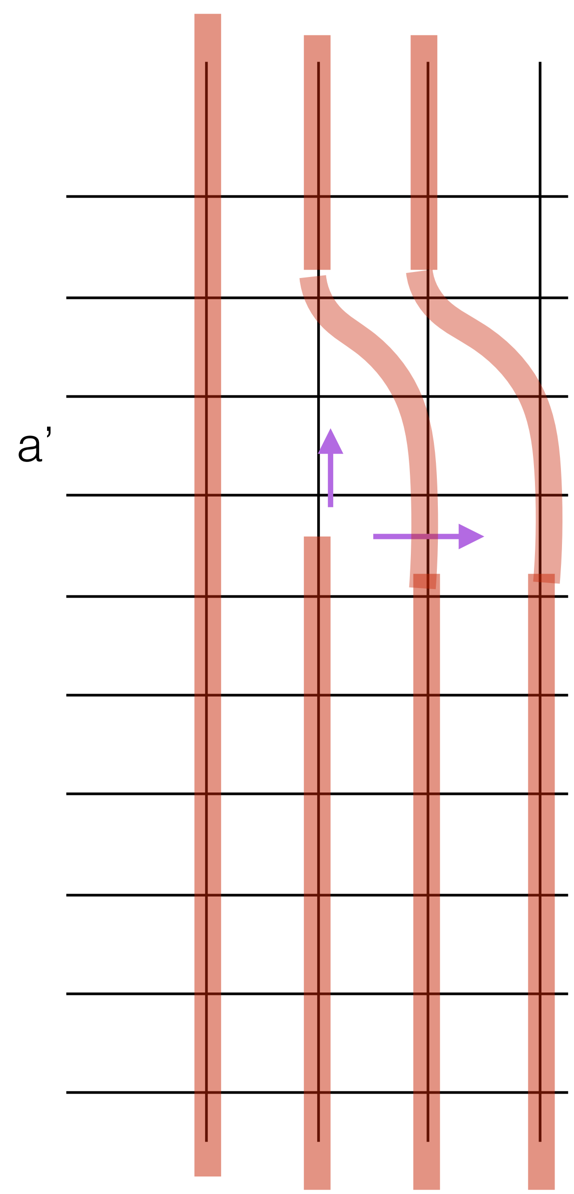




some flow characteristics compatible with 1d flow

Quantum dislocations





Peierls barrier

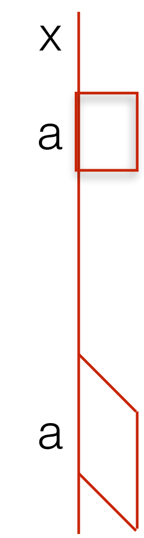
glide : kinks

climb : jogs

$$\xi = aa'$$

$$\delta y(x,t) = \xi \delta n(x,t)$$

=mass transport



semiclassical tunneling rate:

$$\tau^{-1} \sim \sqrt{\frac{u}{ma^2}} e^{-S}$$

(u: interatomic potential, m atomic mass)

$$S \approx \pi N \sim \pi u / E_0 \sim \pi (10K)/(\hbar\omega_D) \sim 1$$

ie, tunneling time below 0.1 ns

isochoric compressibility (syringe effect)

$\xi = aa'$

$$S = \int_0^\beta d\tau dx[-i\xi y\dot{\phi} + \frac{\rho_s}{2}(\partial_x \phi)^2 - \mu\xi y]$$

superfluid phase and displacement are conjugate

(simplified)

$$+ \int_0^\beta \int dx[\frac{n_1 v_d^2}{2}(\partial_x y)^2 - u\cos(\frac{2\pi y}{a'})]$$

vibrating string (Granato-Lucke) subject to Peierls potential

at high T or for rough dislocations (slanted dislocation forest): cos(.) is irrelevant; this predicts:

$\delta y \propto L^2 \delta\mu$ superclimb; anomalous isochoric compressiblity

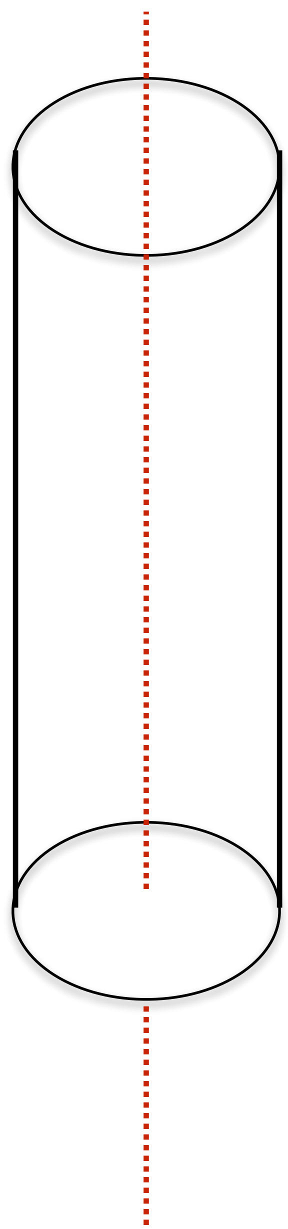
$\omega \sim q^2$ spectrum of superfluid excitations is not soundlike

$K \sim L$ Luttinger parameter depends on pinning length

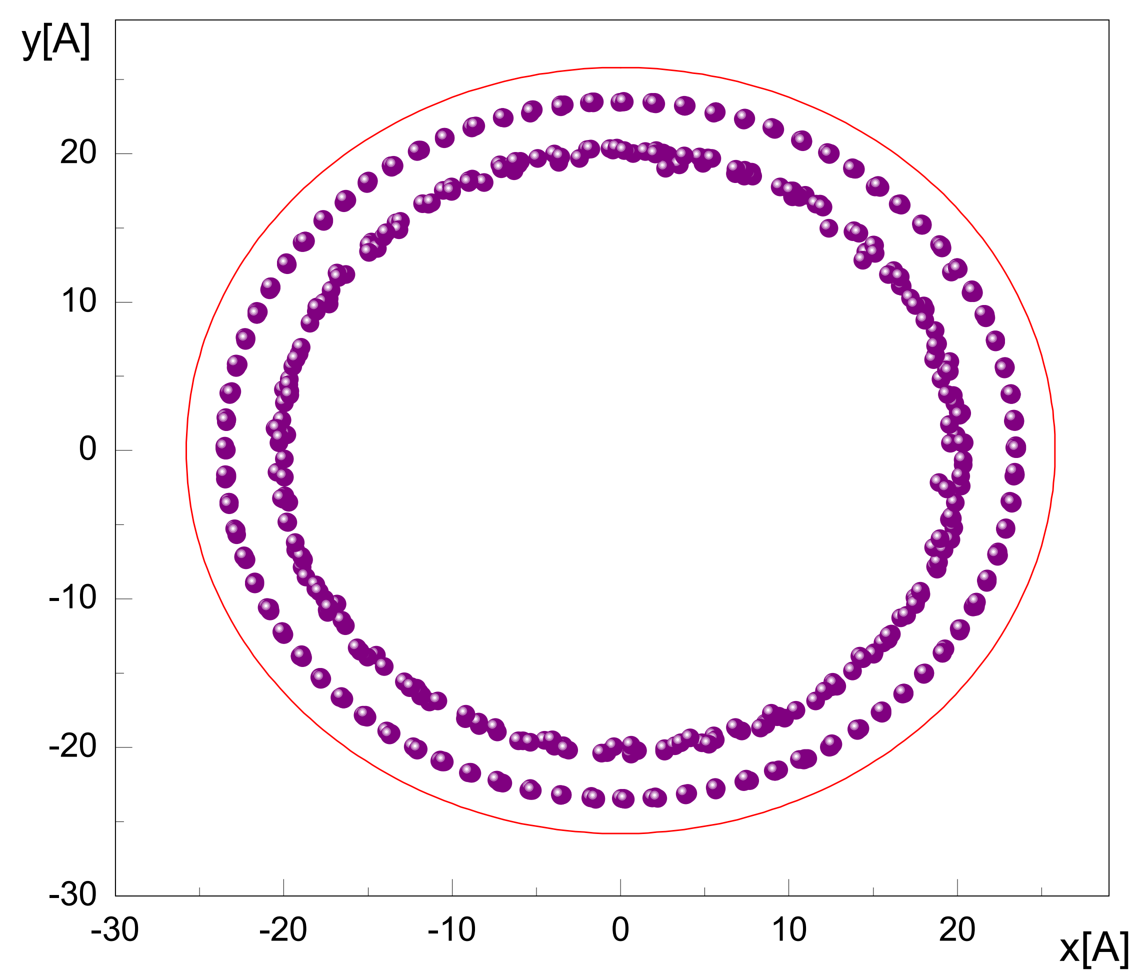
picture of quantum liquids of kinks and jogs

phenomena of giant plasticity and syringe effect are related, but nevertheless quite different!

cylindrical nanopore



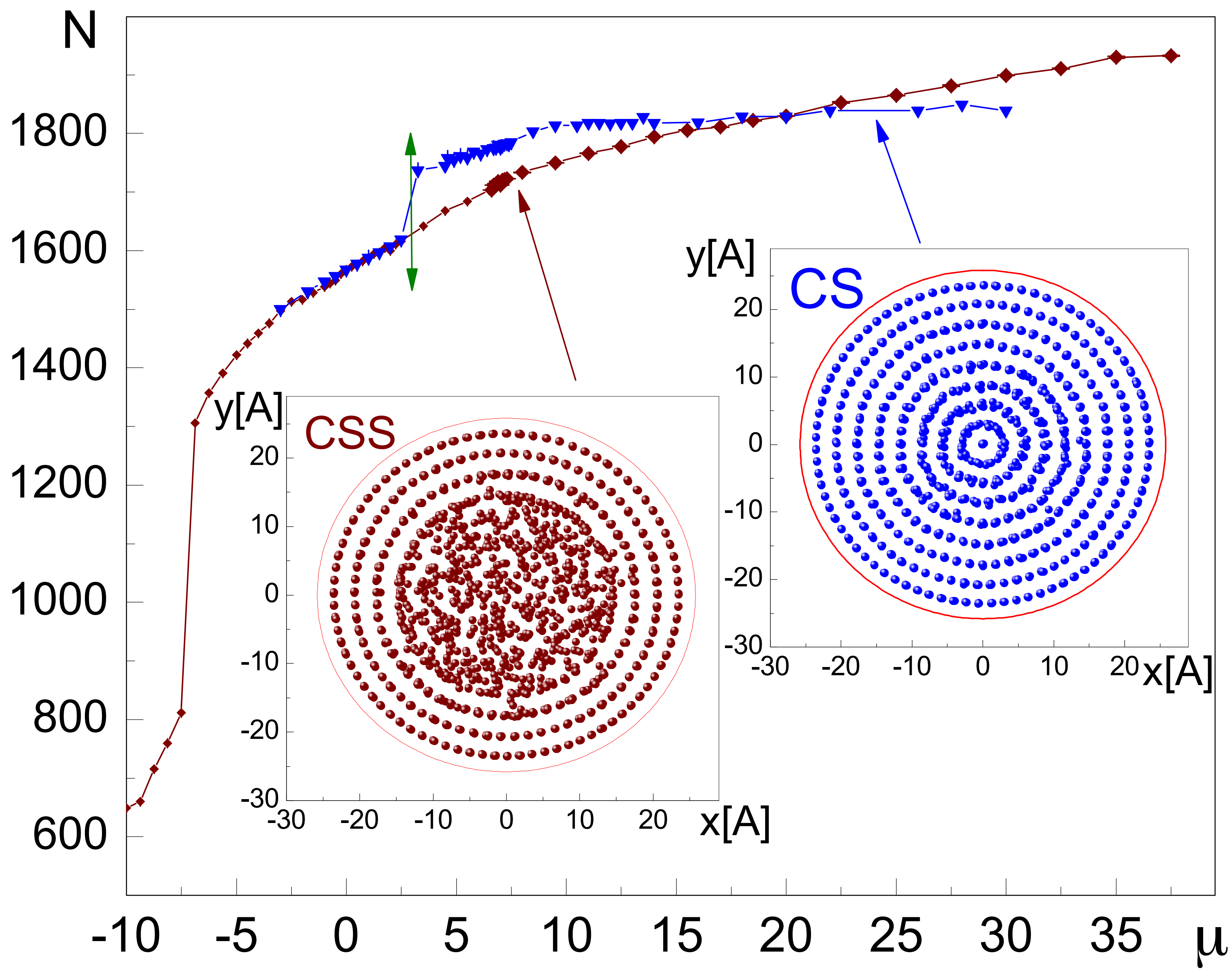
Del Maestro, Affleck, Boninsegni:
Luttingerliquid at SVP



strong attraction to the wall

we investigate systematic
increase in chemical potential

cylindrical nanopore

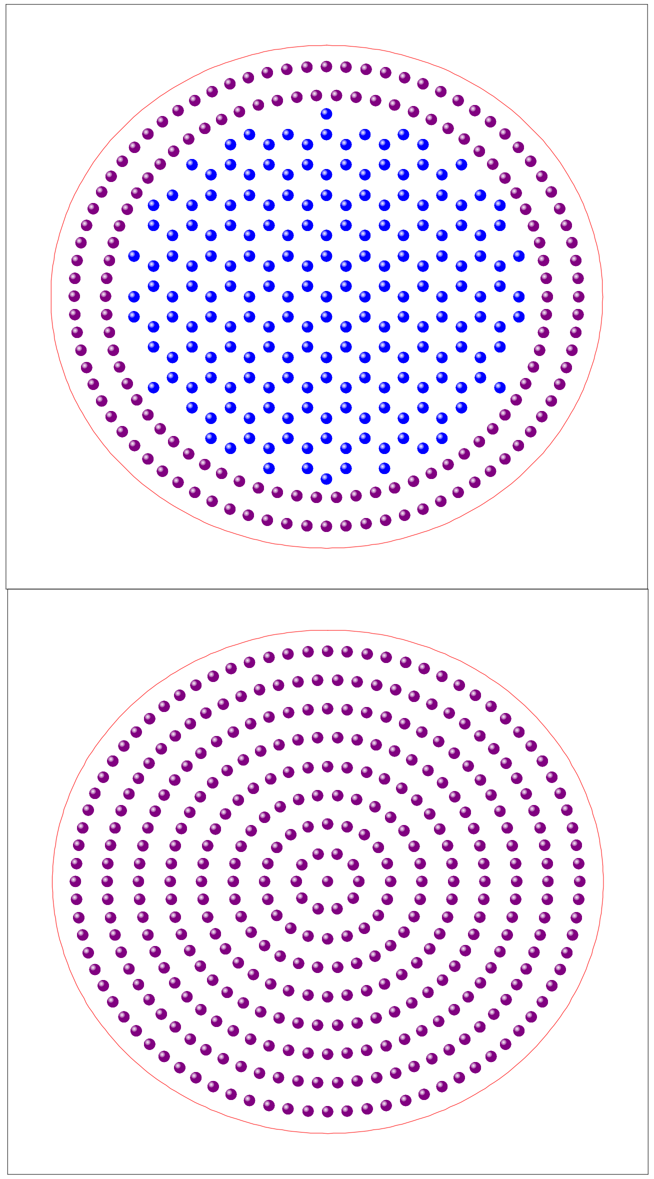


huge hysteresis loop

local melting:
there is a disclination with Frank index n=1 in the center of the pore (the c-axis wraps around the symmetry axis)

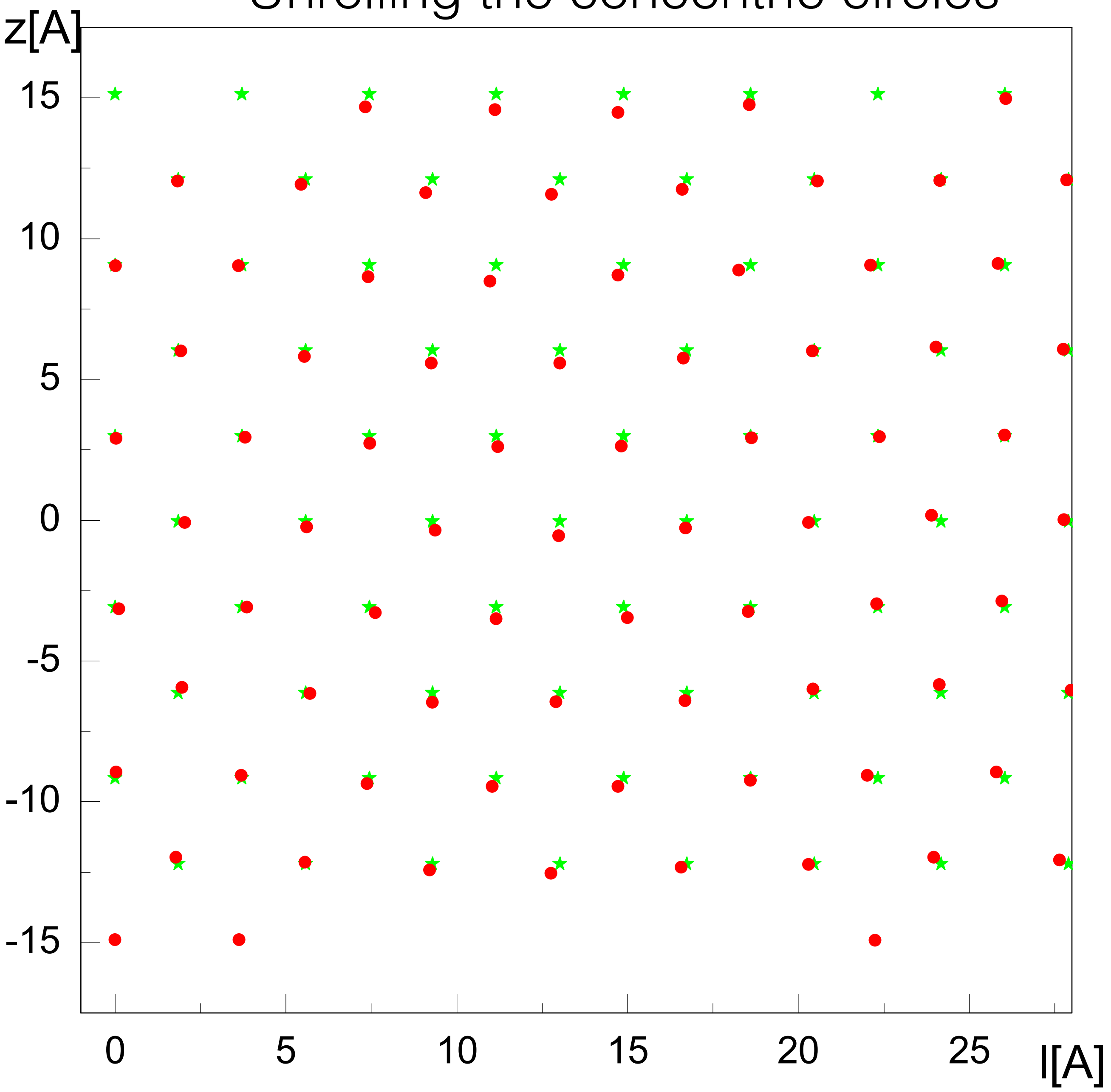
the local melting reduces the splay

cylindrical nanopore



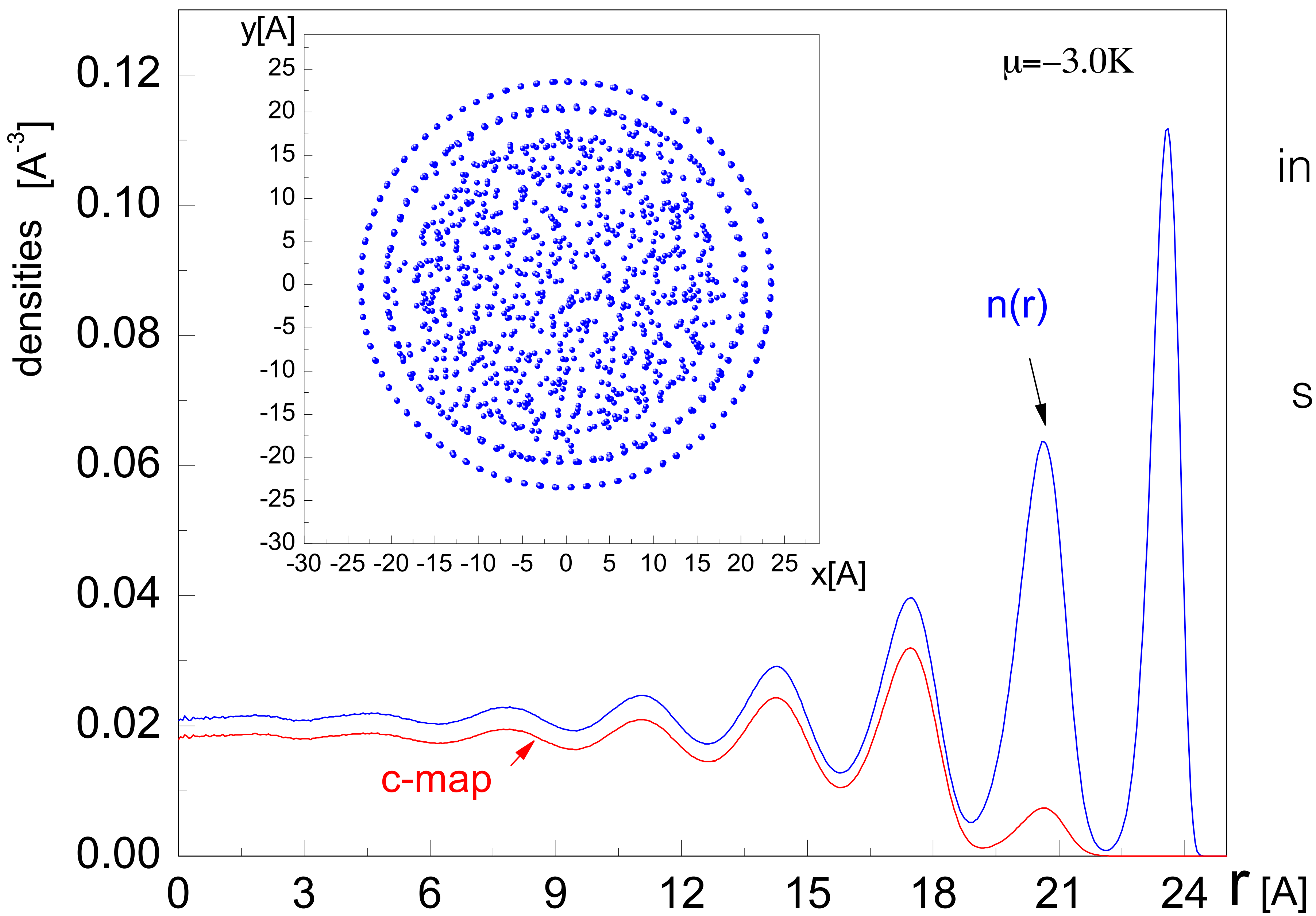
estimate: hcp structure
stable for R>300A

Unrolling the concentric circles



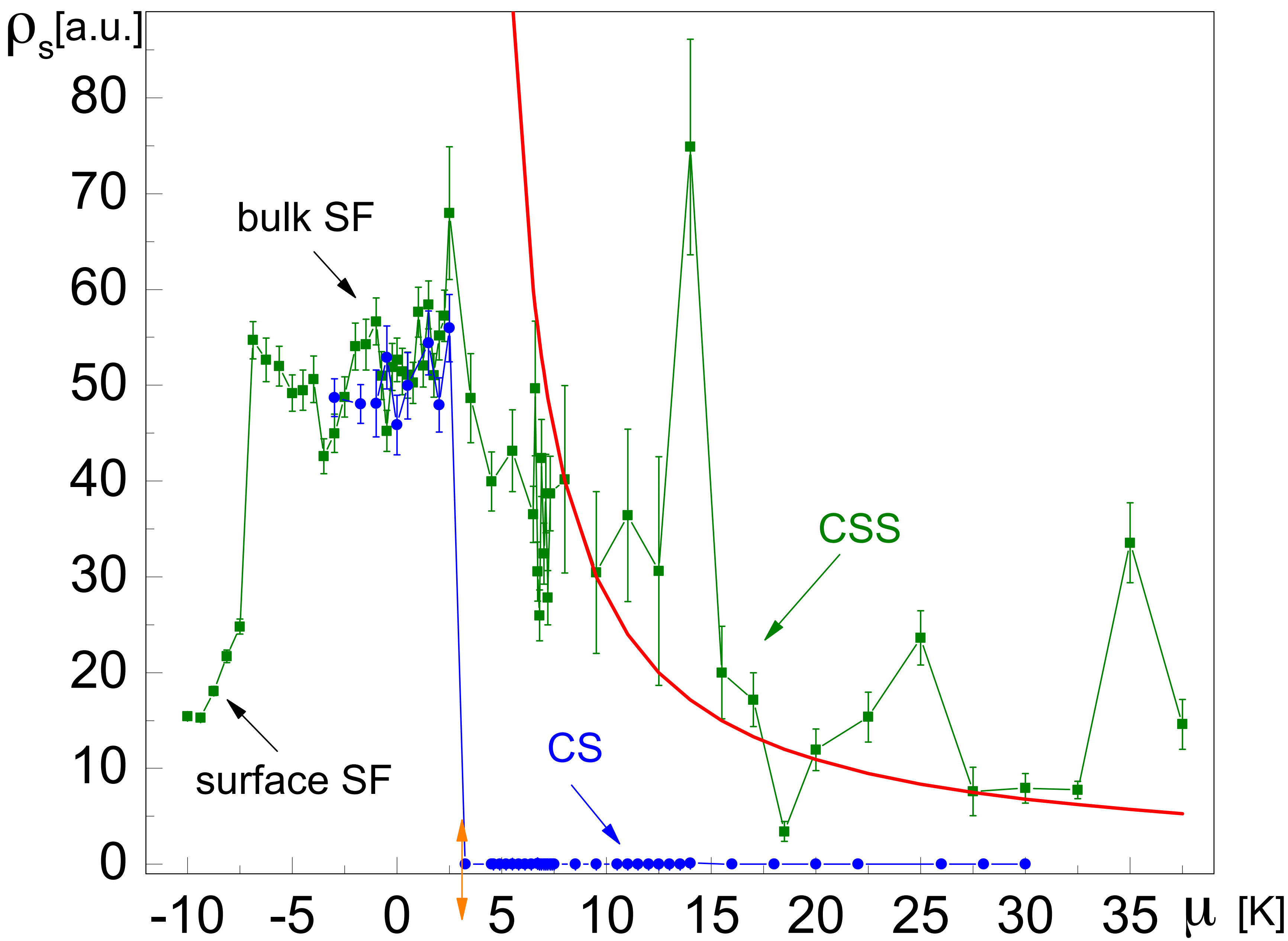
…yields positions identical to hcp

cylindrical nanopore



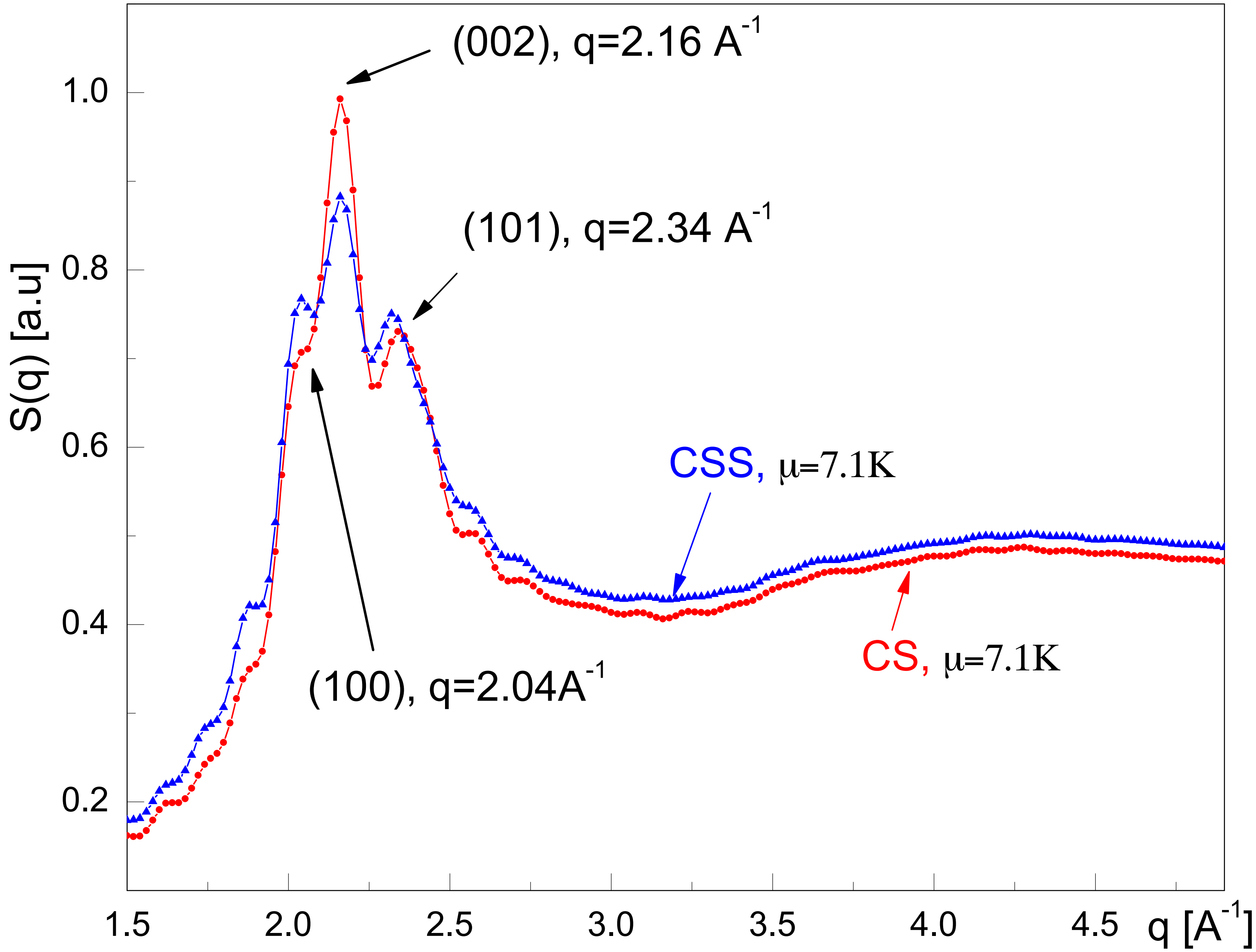
in the CSS Phase there is simultaneous density and superfluid order

cylindrical nanopore



the superfluid order can persist to immense pressure

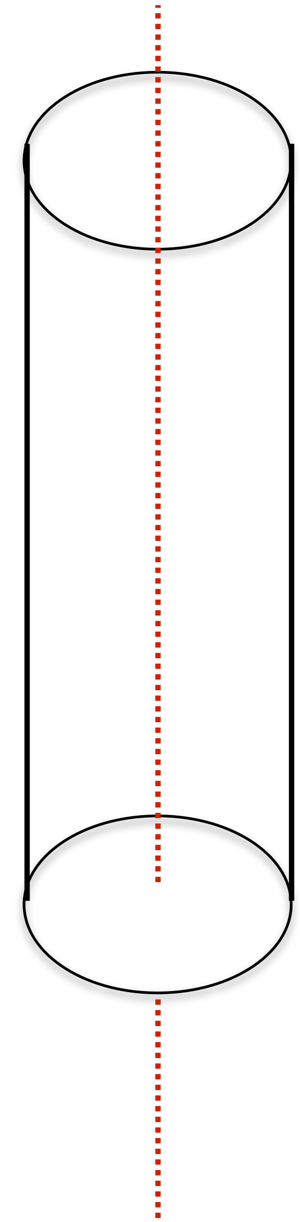
cylindrical nanopore

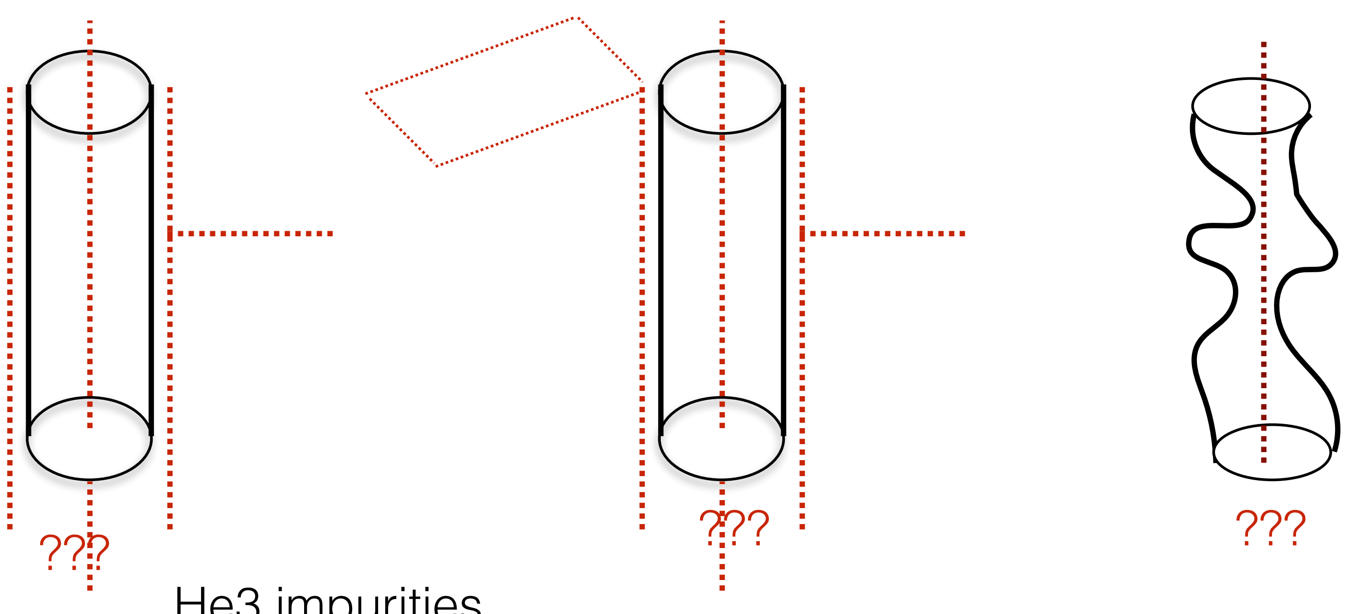


the structure factor gives a main peak close to hcp and is not inconsistent with experiments

UMass sandwich setup

how the flow connects and flows through (the defects of) the crystal?





Conclusions

- No indication of bulk supersolidity in torsional oscillators
- it’s all about *topological defects*
- Novel effects:
  - Giant plasticity
  - dc Mass superflow (UMass sandwich setup)
  - syringe effect
- quantum liquid state of kinks and jogs
- interactions between dislocations, He3 impurities, grain boundaries not understood
- vycor, nanocylinders, … with Helium should be understood from the topological defect (disclination)