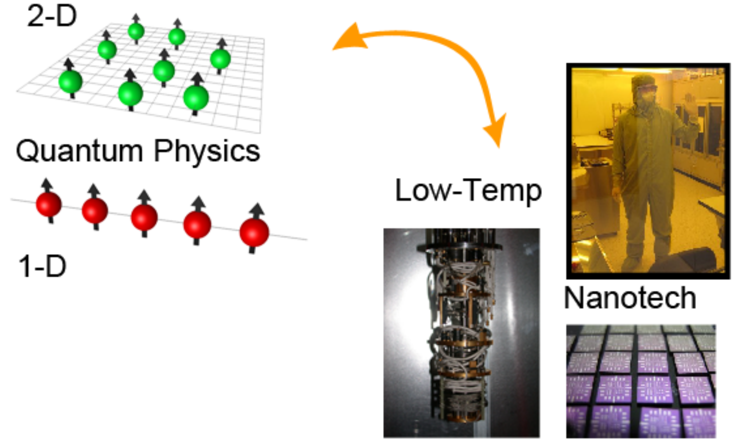
(Algebraic) Superfluidity

Guillaume Gervais
McGill



NSF Quantum Fluids and Solids Grand Challenges
Buffalo, August 7th 2015

Introduction

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α) Interactions

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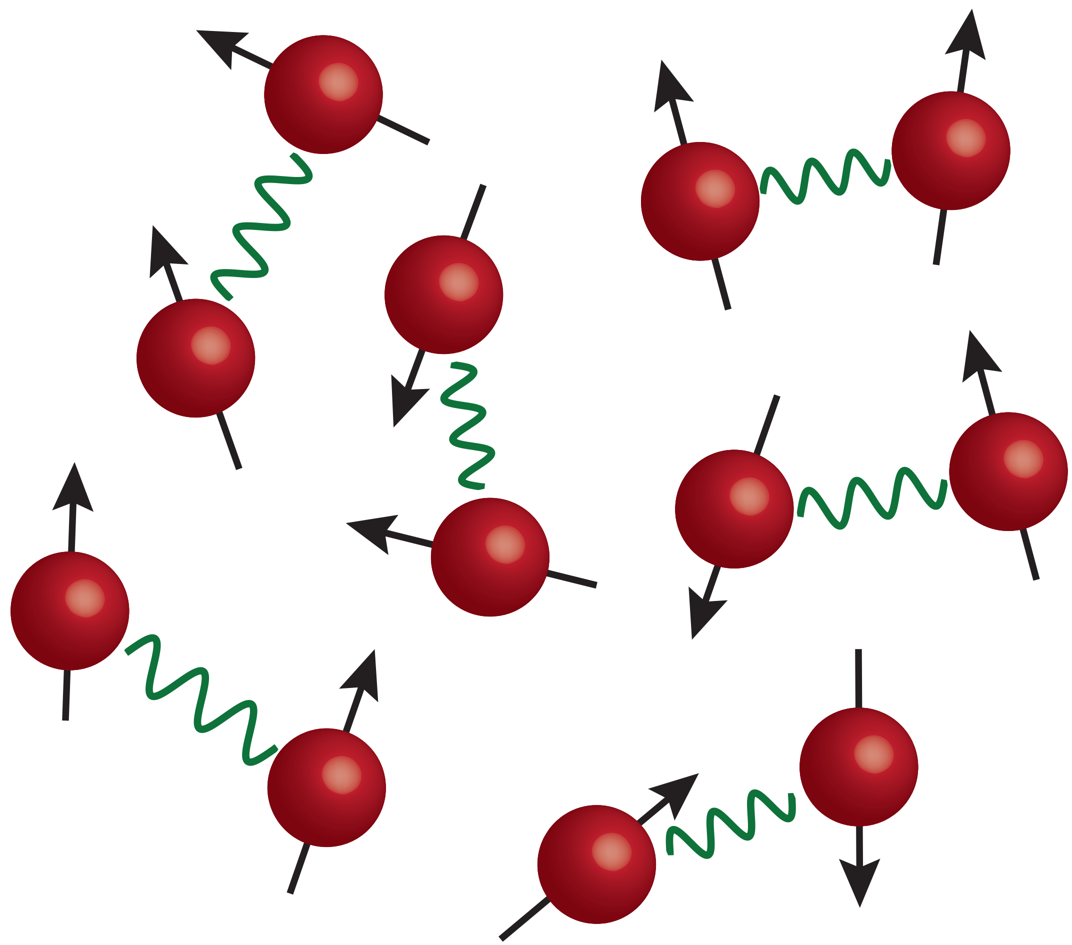
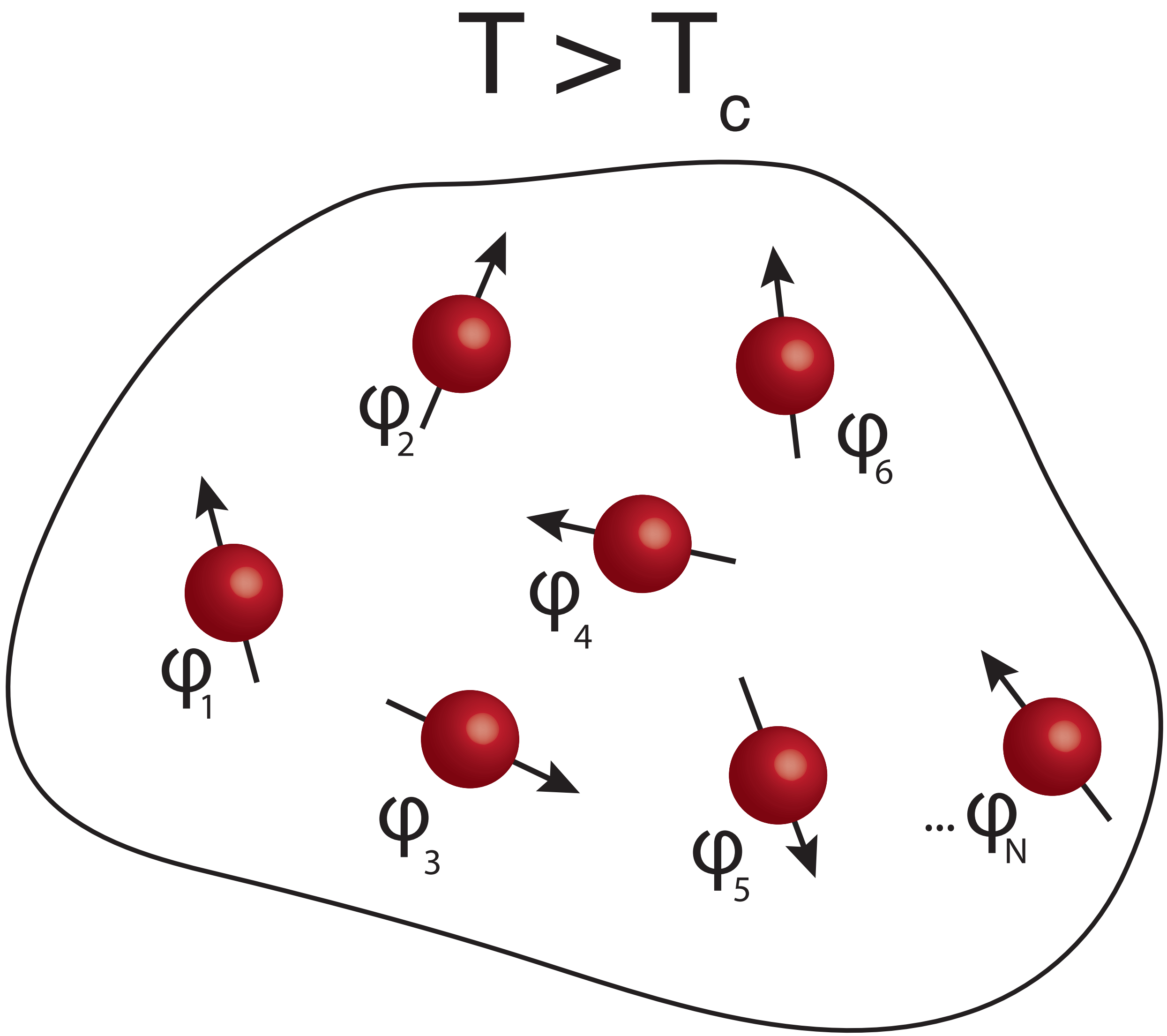
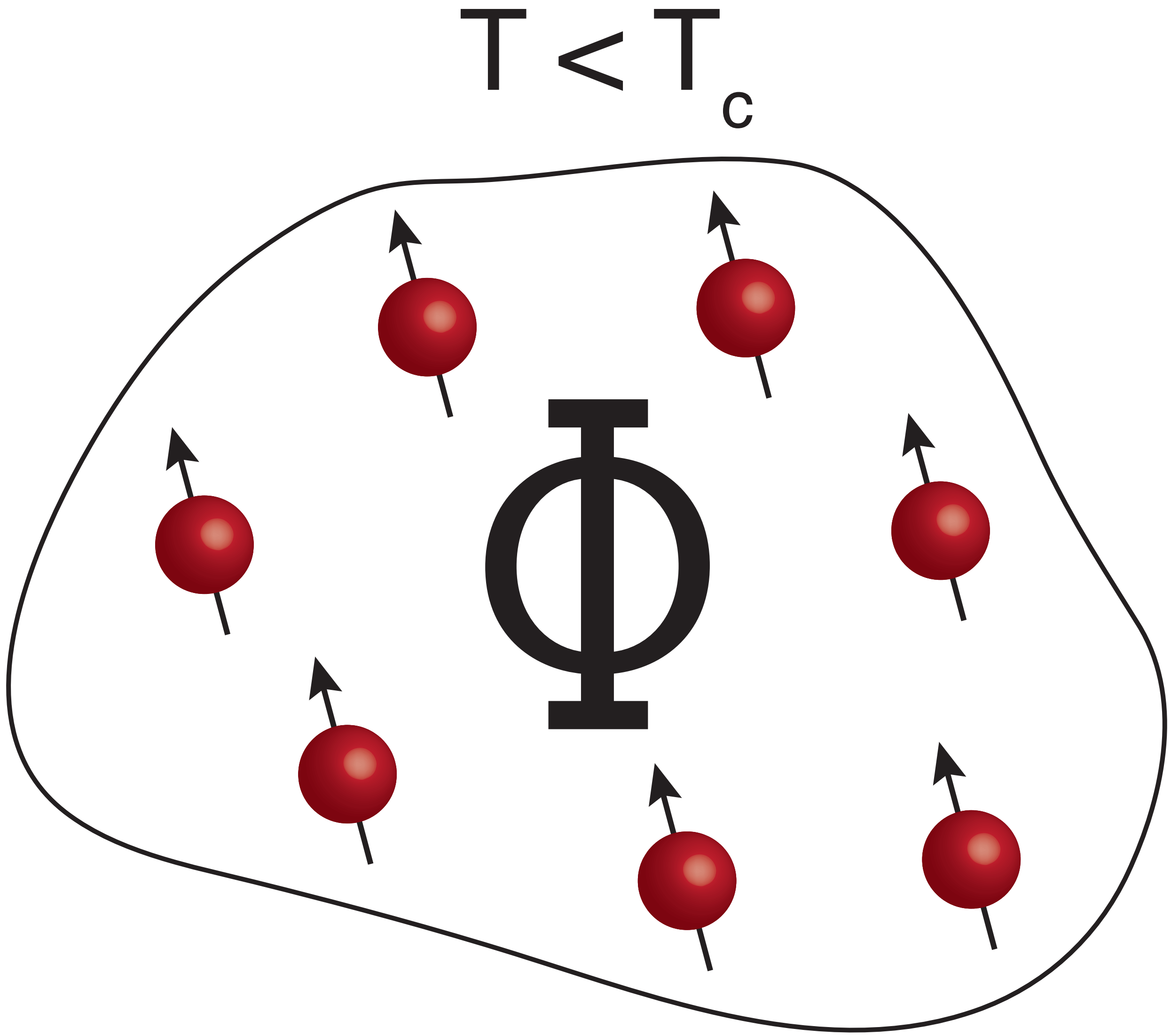
N interacting particles



N interacting particles with phases



N interacting particles with a single phase



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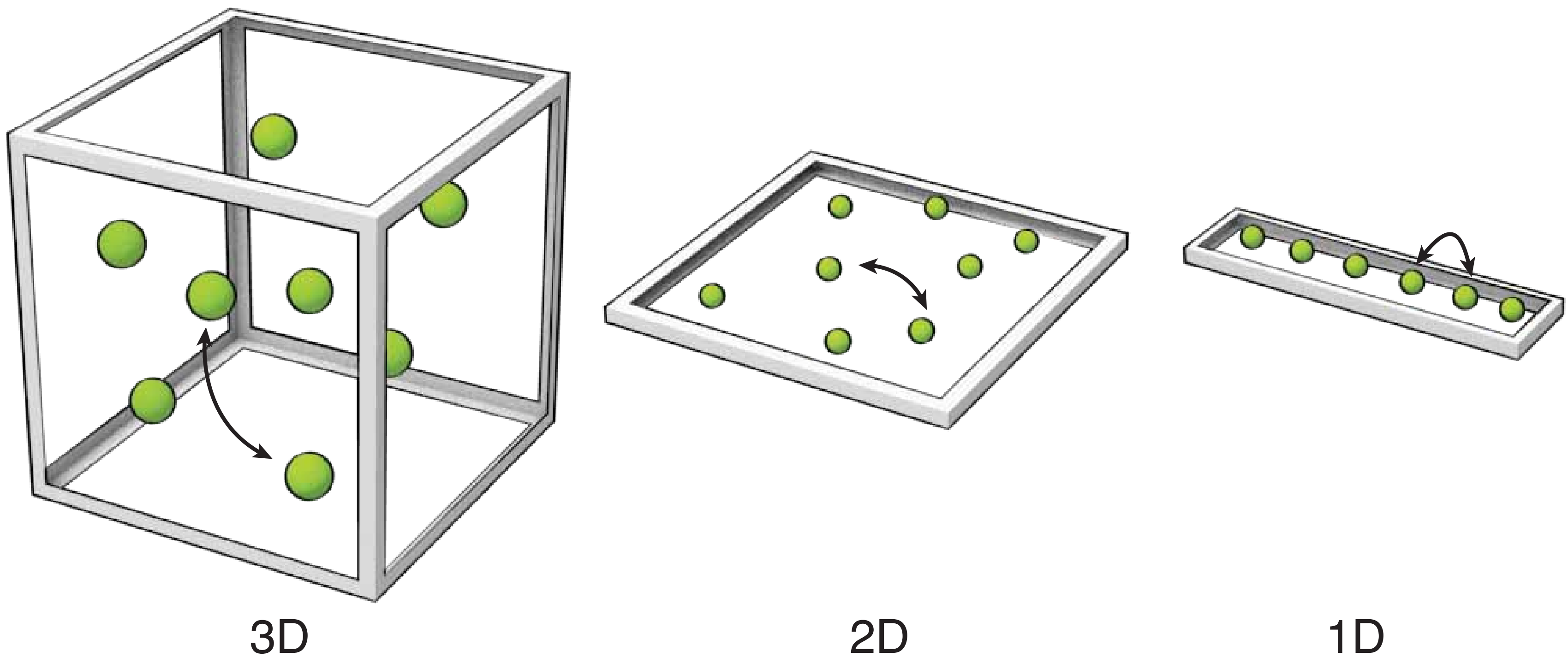
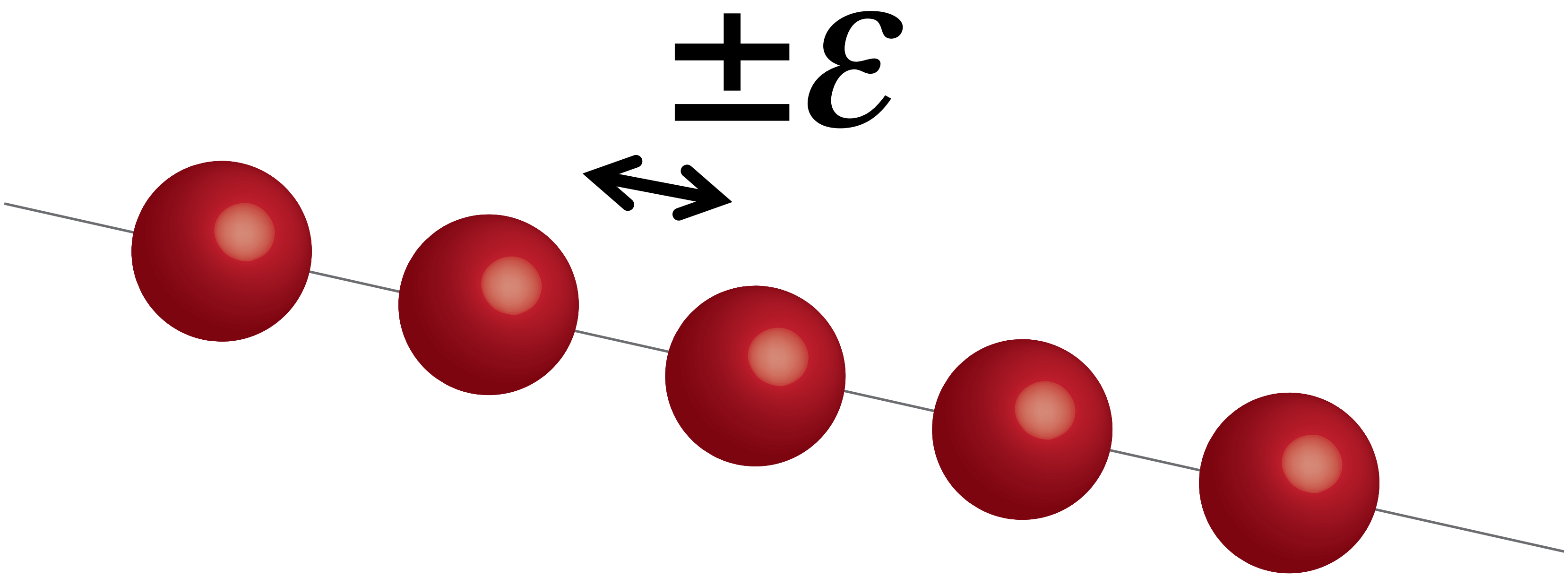
β) Dimensionality

How about particle-particle interactions?



Interactions on a line



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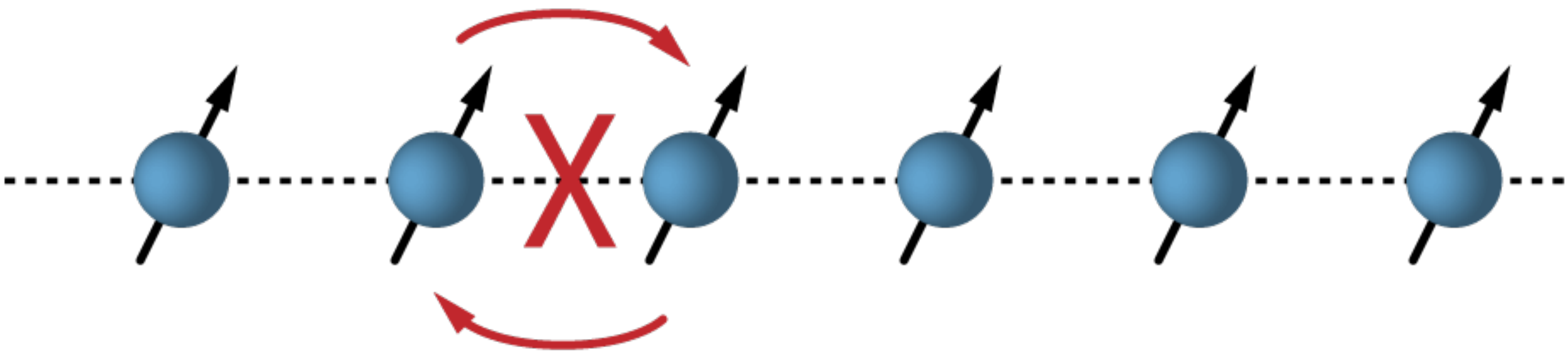
γ) Statistics

Fermions/Bosons

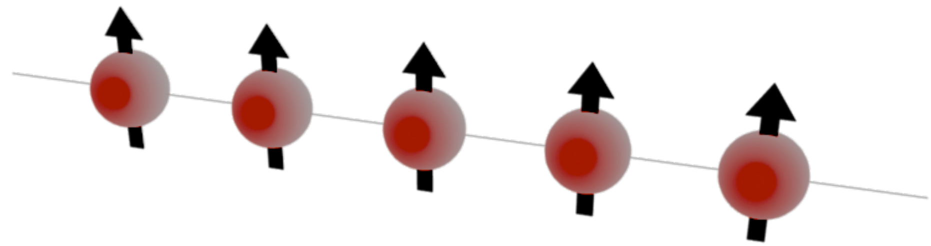
In the true 1D regime: particle exchange ain't allowed



Quantum statistics should be quenched: 3He (fermions) 'should' resemble 4He (bosons) in 1D

Quantum Condensed Matter in 1D

⊗



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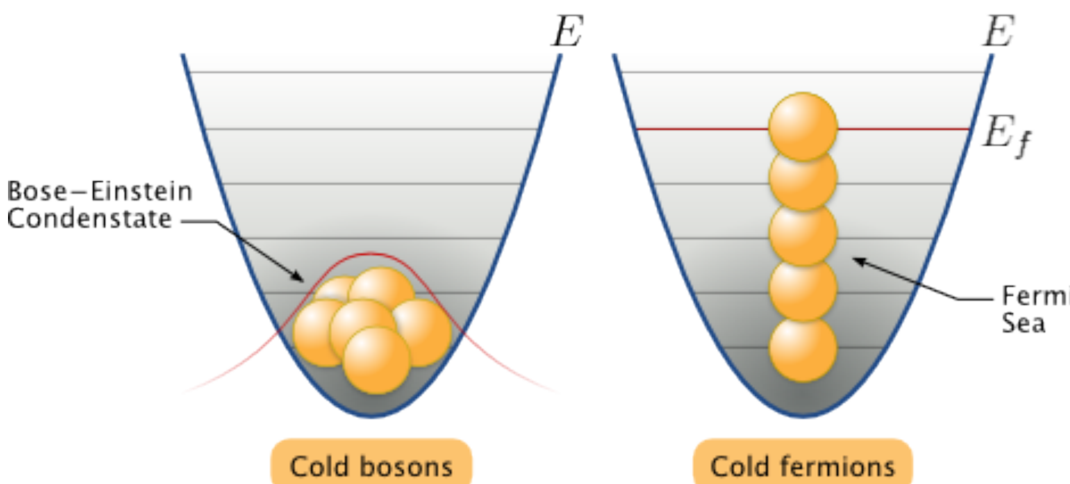

= ?

The One-Dimensional Quantum Fluid

Sin-Itiro Tomonaga

Prog. Theor. Phys. 5, 544–569 (1950)

Joachim Luttinger

J. Math. Phys. 4, 1154–1162 (1963)

Duncan Haldane

Phys. Rev. Lett. 47, 1840–1843 (1981)

$$H_i = \frac{\hbar}{2\pi}\int\left[\left(\partial_z\phi_i\right)^2 u_i / K_i + K_i u_i \left(\partial_z\theta_i\right)^2\right]dz$$

$$i = \rho,\sigma \qquad H_{TLL} = H_\rho + H_\sigma$$

K<1 (repulsive) K>1 (attractive)

0 (algebraic superfluid) 1 (solid) ∞

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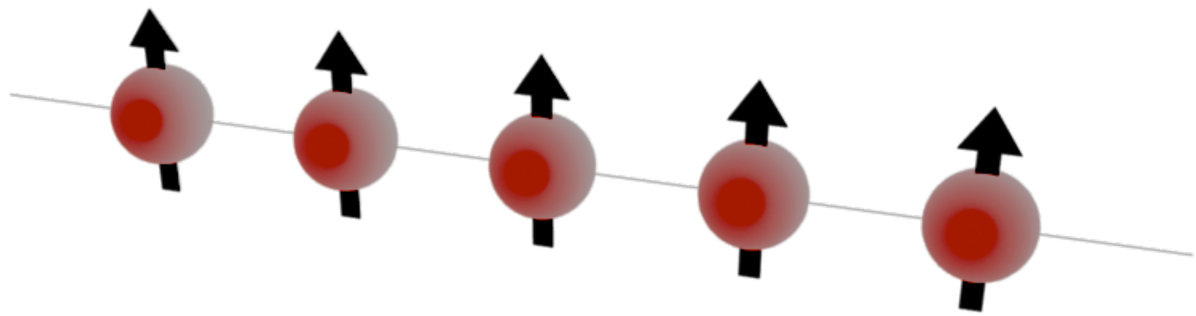
If Helium-3 was in 1D

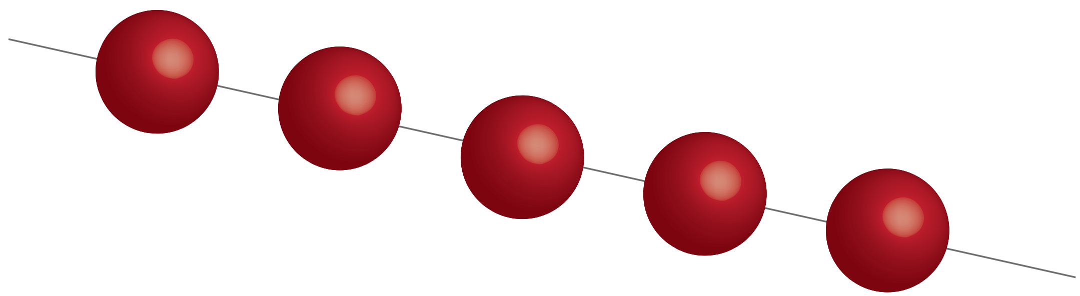


$$H_{TLL} = H_\rho + H_\sigma$$

$$H_i = \frac{\hbar}{2\pi}\int\left[\left(\partial_z\phi_i\right)^2 u_i / K_i + K_i u_i \left(\partial_z\theta_i\right)^2\right]dz$$

$$i = \rho, \sigma$$

If Helium-4 was in 1D



$$H_{TLL} = H_\rho + \cancel{H_\sigma}$$

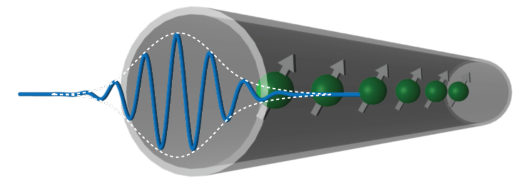
$$H_i = \frac{\hbar}{2\pi} \int \left[\left(\partial_z \phi_i \right)^2 u_i / K_i + K_i u_i \left(\partial_z \theta_i \right)^2 \right] dz$$

$$i = \rho, \cancel{\sigma}$$

What is a ‘must-have’ for Tomonaga-Luttinger in helium ?

Lengthscales for 1D Physics

Confining atoms in a tube of radius a =1nm :



Helium 4 coherence length: $\xi_0 \approx 0.345nm$

The transverse energies are: $\Delta_\perp = \frac{\hbar^2}{2m_{He}}\left(\frac{j_{ml}}{a}\right)^2$ ~350 mK

De Broglie wavelength: $\Lambda(T) = \sqrt{2\pi\hbar^2 / mk_B T} \approx 1nm$

Thermal length: $L_T = \hbar c_1 / k_B T \approx 1nm$

Bottom line: a small radial confinement dimension (~nm)

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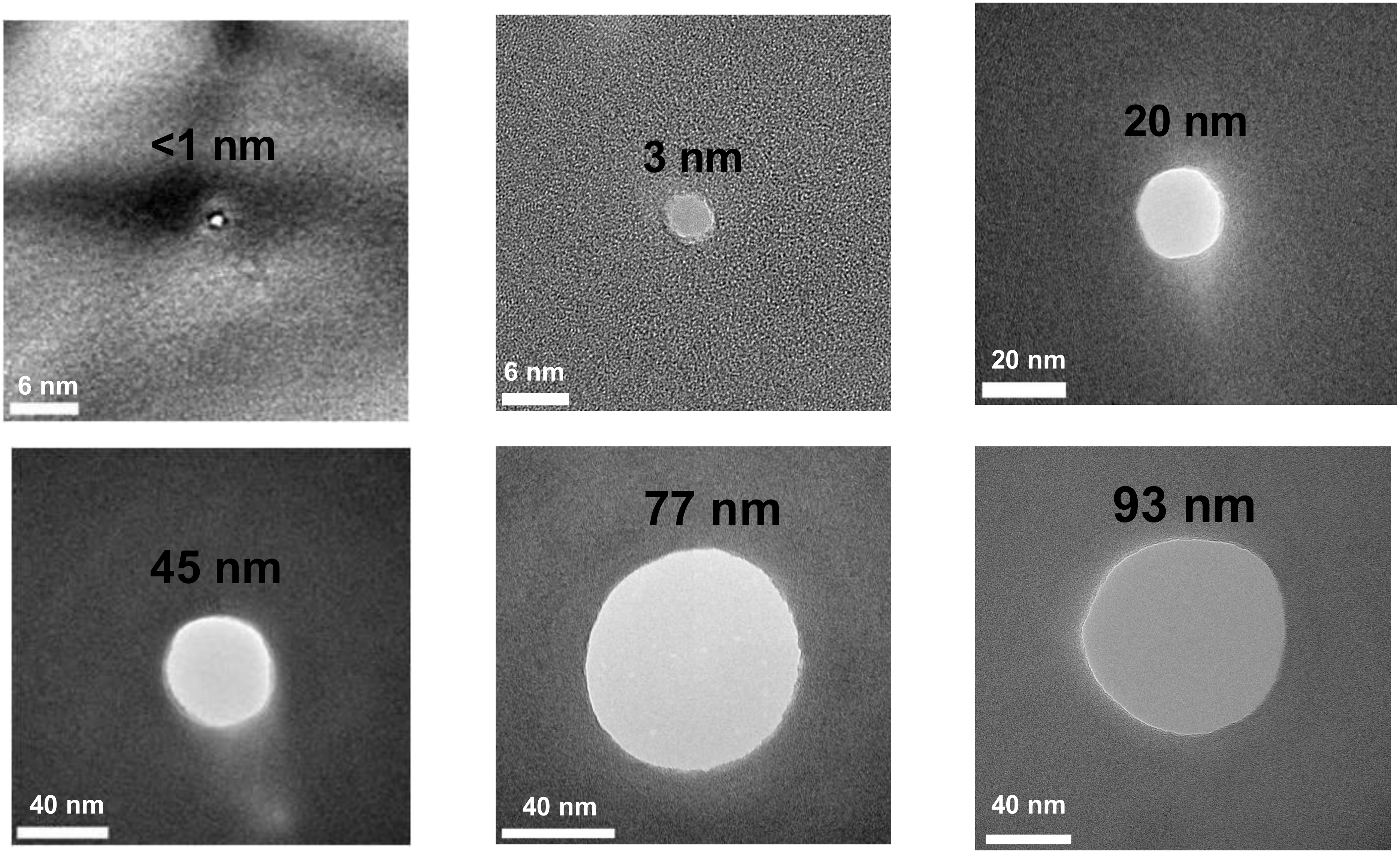
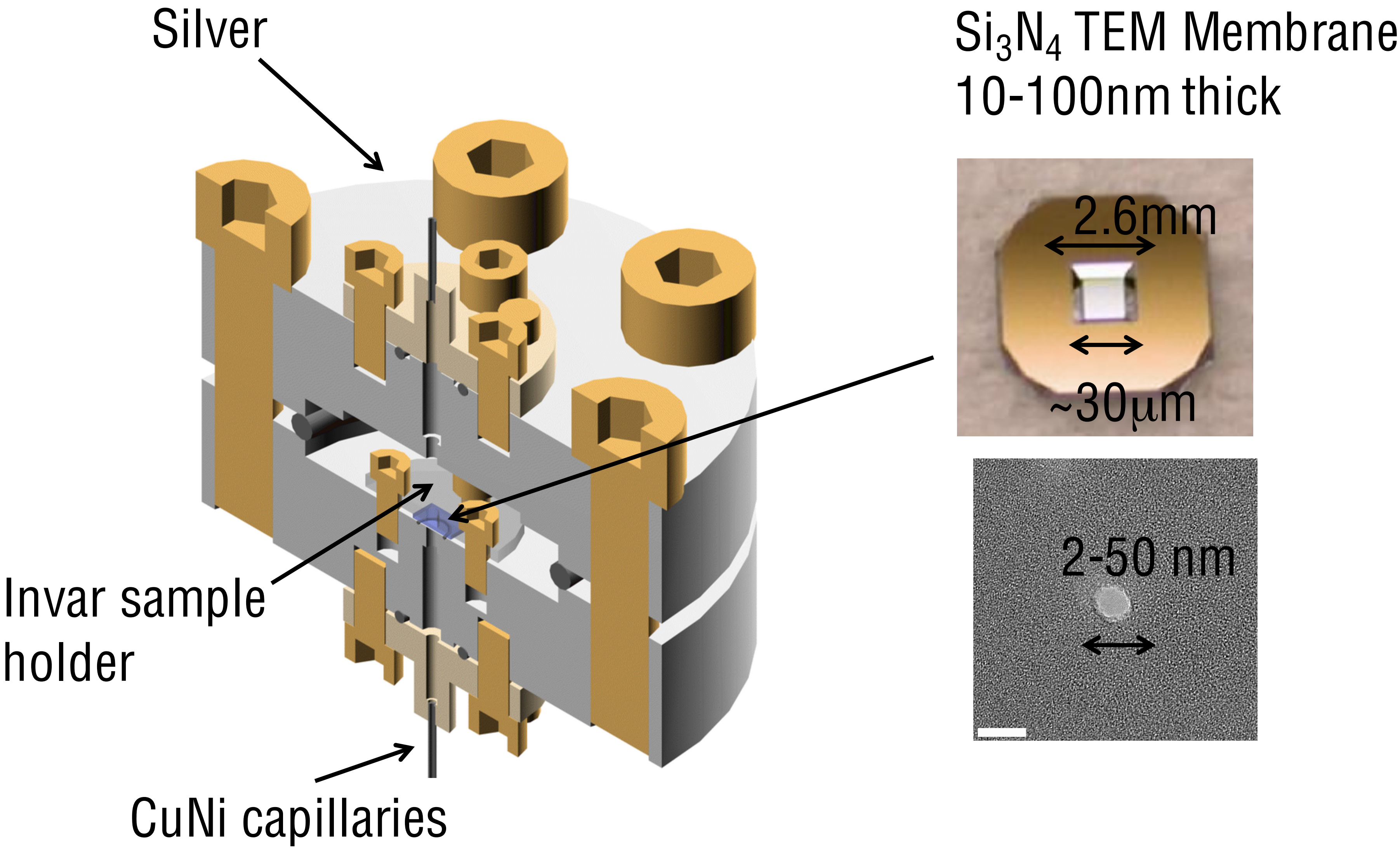
Tailor-made Lone Nanopore



A.J. Storm, J.H. Chen, X.S. Ling, H.W. Zandbergen and C. Dekker, Nature Mat. , 2 , 537 (2003);

In ~2 weeks, see http://gervaislab.mcgill.ca/theses.php for Michel Savard thesis.

Mini 'UHV-style' Homemade Flow Cell



P-F Duc, M.Savard, M. Petrescu, B. Rosenow, A. Del Maestro, and G. Gervais, Science Advances **1**, el1400222 (2015)

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What kind of Physics would someone (perhaps) do?

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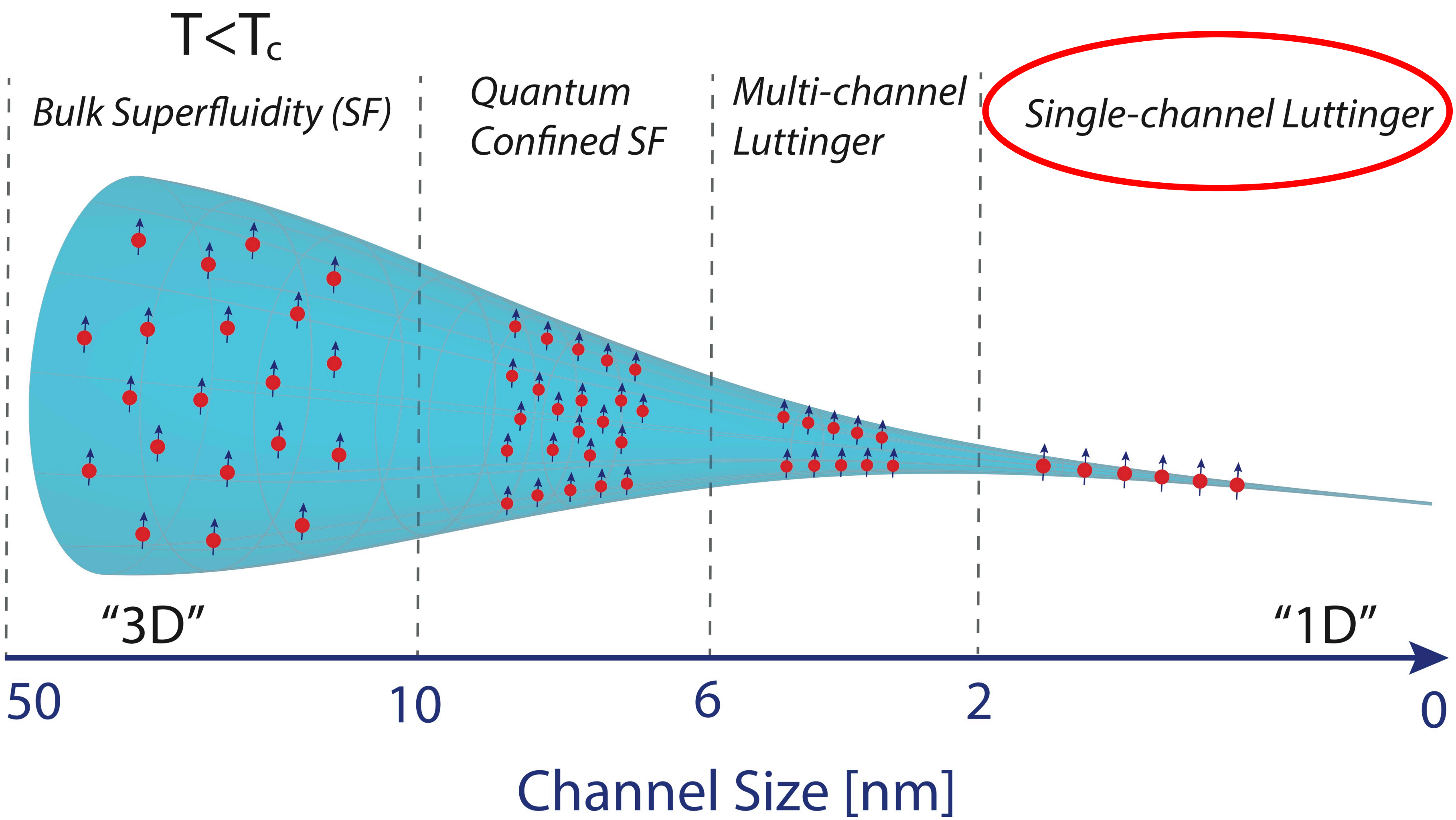
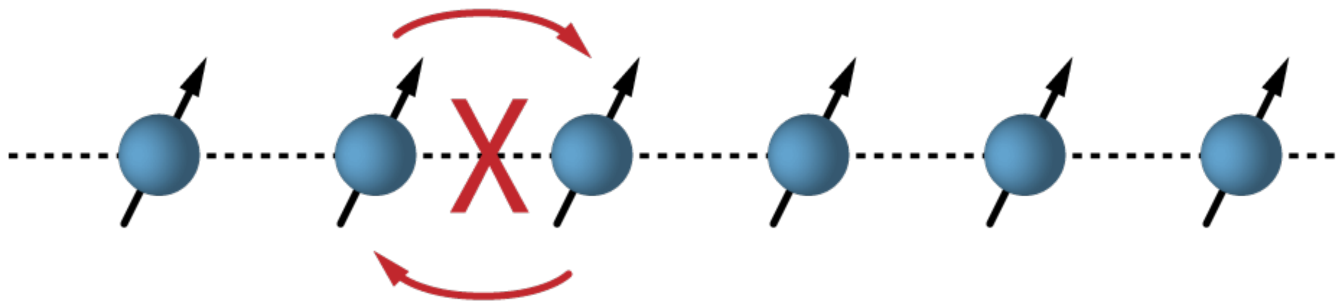
Broad Expectations from QMC and Literature



Special thanks to Ian Affleck, Adrian del Maestro, Bernd Rosenow, Ady Stern, Thierry Giamarchi, and Leonid Glazman for stimulating discussions!

From my own ‘*Mission-Driven’* curiosity

Quantum Statistics Quenching



Can we show the quenching of the quantum statistics in 1D in the case of a strongly interacting liquid, using 3He, 4He and/or 3He/4He mixtures?

(hard to do with electronic systems)

A Fully Tunable Tomanaga-Luttinger System

$$H_i = \frac{\hbar}{2\pi}\int\left[\left(\partial_z\phi_i\right)^2 u_i / K_i + K_i u_i\left(\partial_z\theta_i\right)^2\right]dz$$

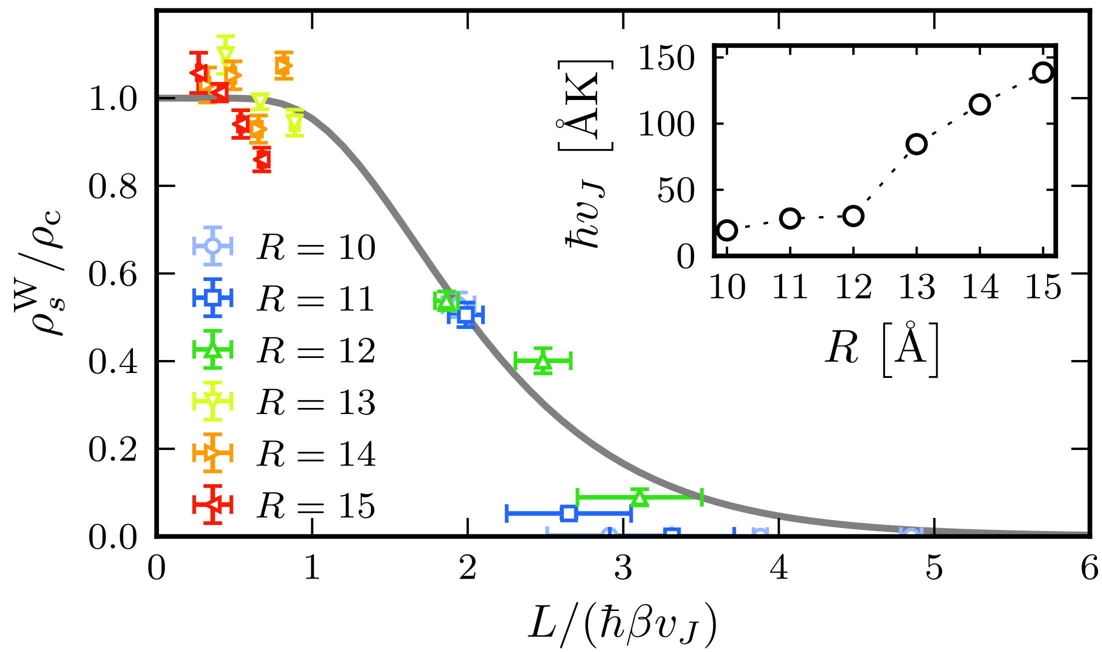
$$i = \rho, \sigma$$

Can we engineer a Luttinger system for which the K parameter containing all interactions can be tuned continuously by pressure and/or use of different atomic species?

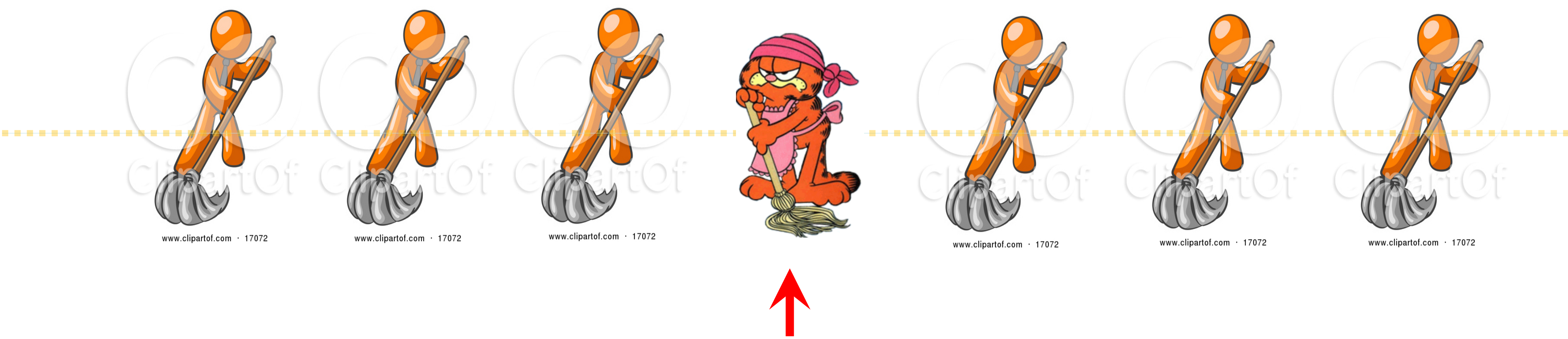
In the Clean 1D Limit

Can we demonstrate the existence of the algebraic superfluid?

In the Clean 1D Limit

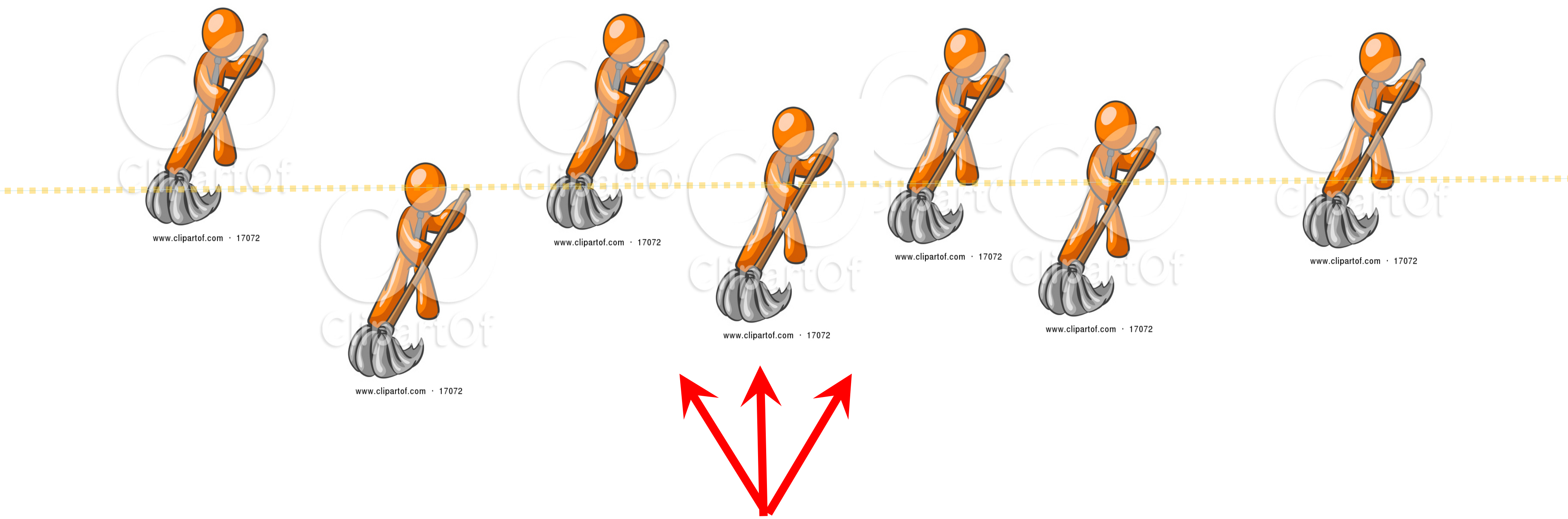


But what if disorder strikes? I



A ‘quantum’ impurity

But what if disorder strikes ? II



Disorder Scattering

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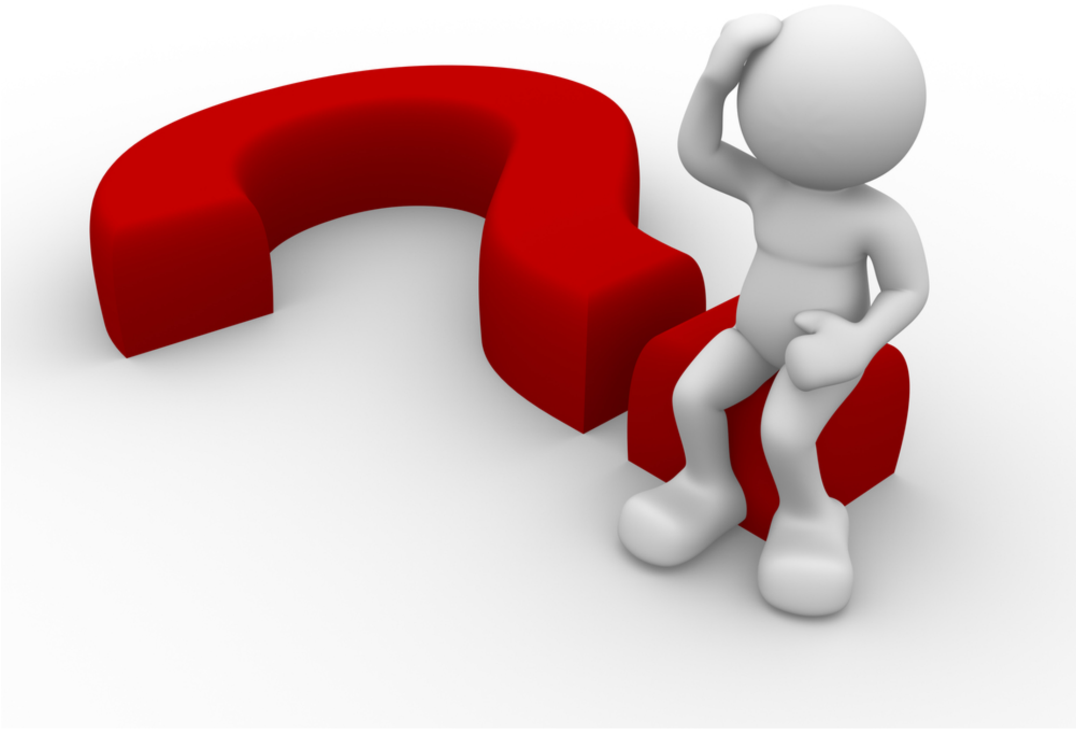
‘Beau Risque’



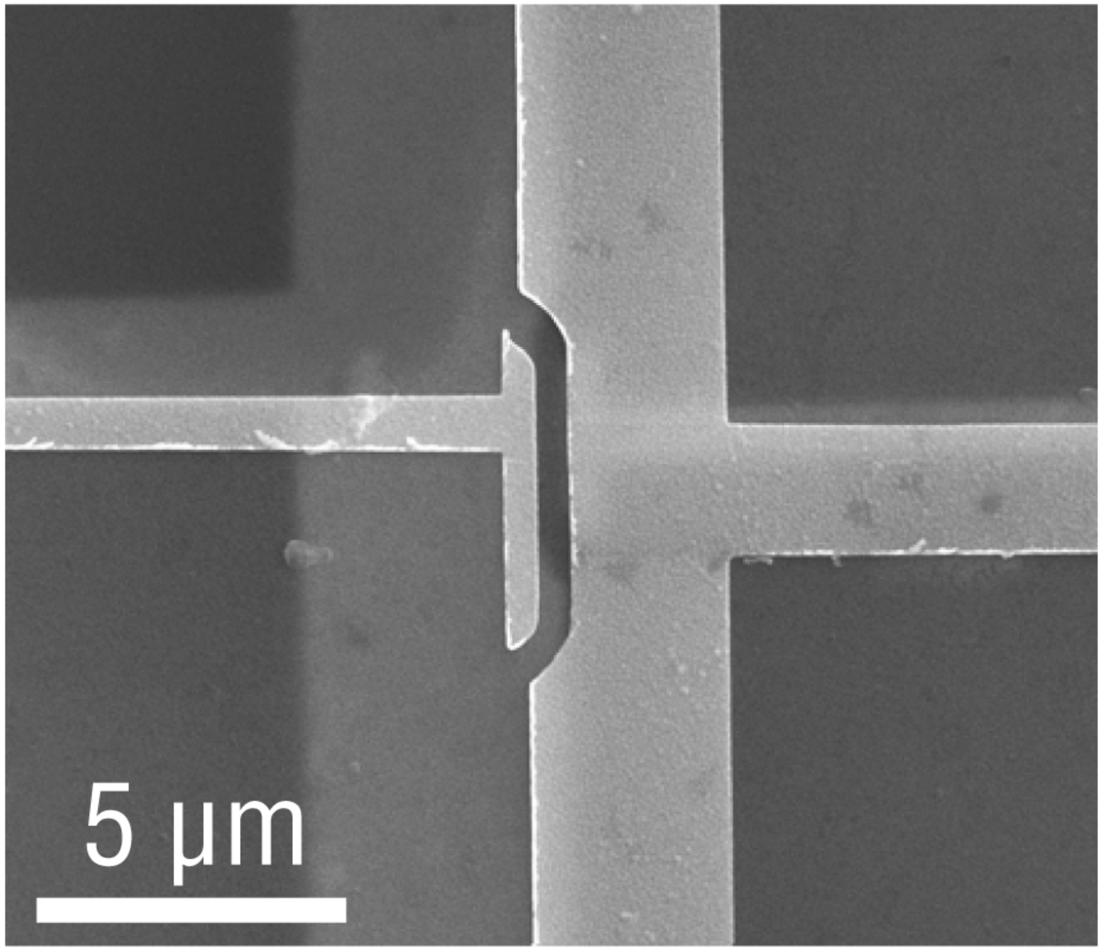
Localization and/or crystallization in a 1D or a quasi-1D neutral liquid.

I could go on and on….and it drives me nuts

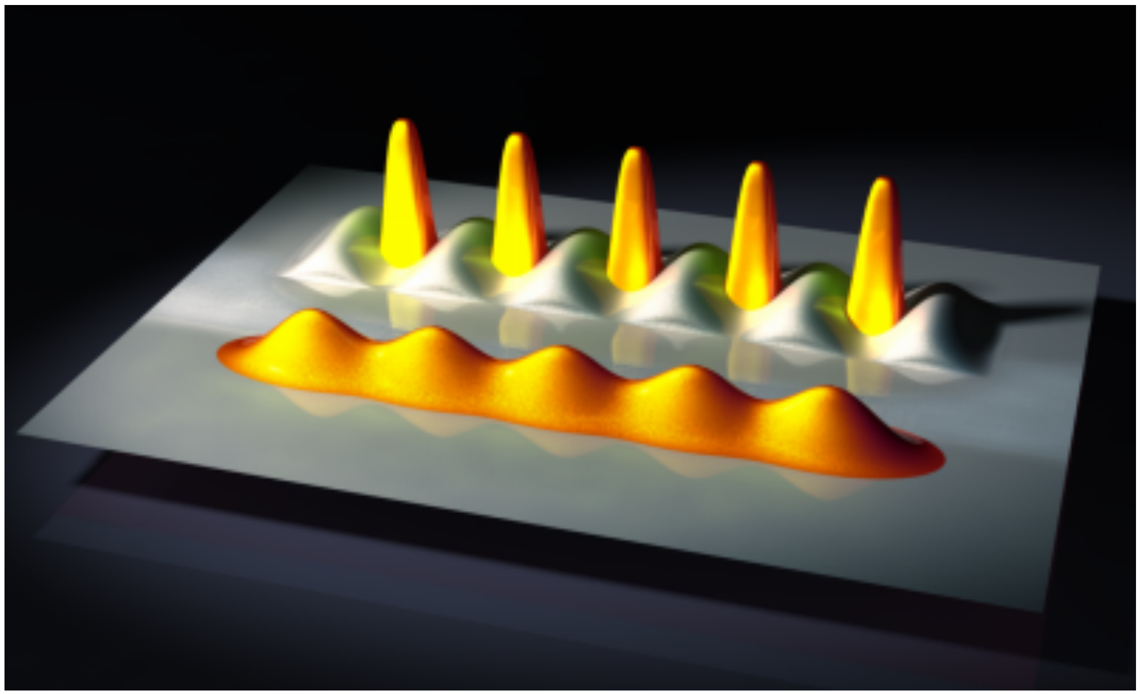
So, to conclude

It is believed that both the one-dimensional ‘metal’





and the (Super) Tonks gas in cold atoms



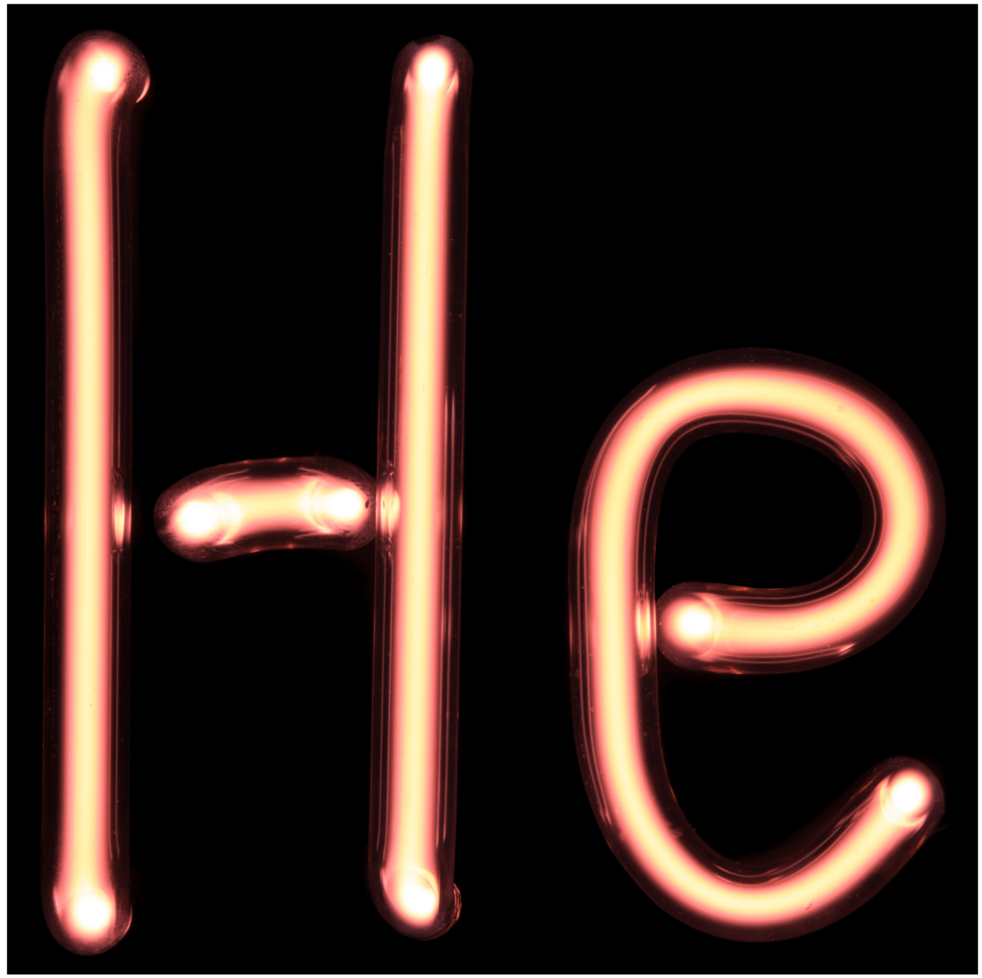
follow a ‘Mathematically-exact’ and ‘Universal’ prescription.

$$H_{TLL} = H_{\rho} + H_{\sigma}$$

$$H_i = \frac{\hbar}{2\pi}\int\left[\left(\partial_z\phi_i\right)^2 u_i / K_i + K_i u_i\left(\partial_z\theta_i\right)^2\right]dz$$

$$i = \rho, \sigma$$

So, why not in a 'real' tangible quantum fluid?



OK, I'm done!