Cryogenic Turbulence in Helium 4

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What is so special with Helium 4 ?

- The least viscous fluid of all

Under cryogenic conditions

$T = 4.2\,\mathrm{K}, P = 1\,\mathrm{bar}$

$$\nu_{\mathrm{He}} = 2.5 \cdot 10^{-8}\,\mathrm{m}^2/\mathrm{s}$$

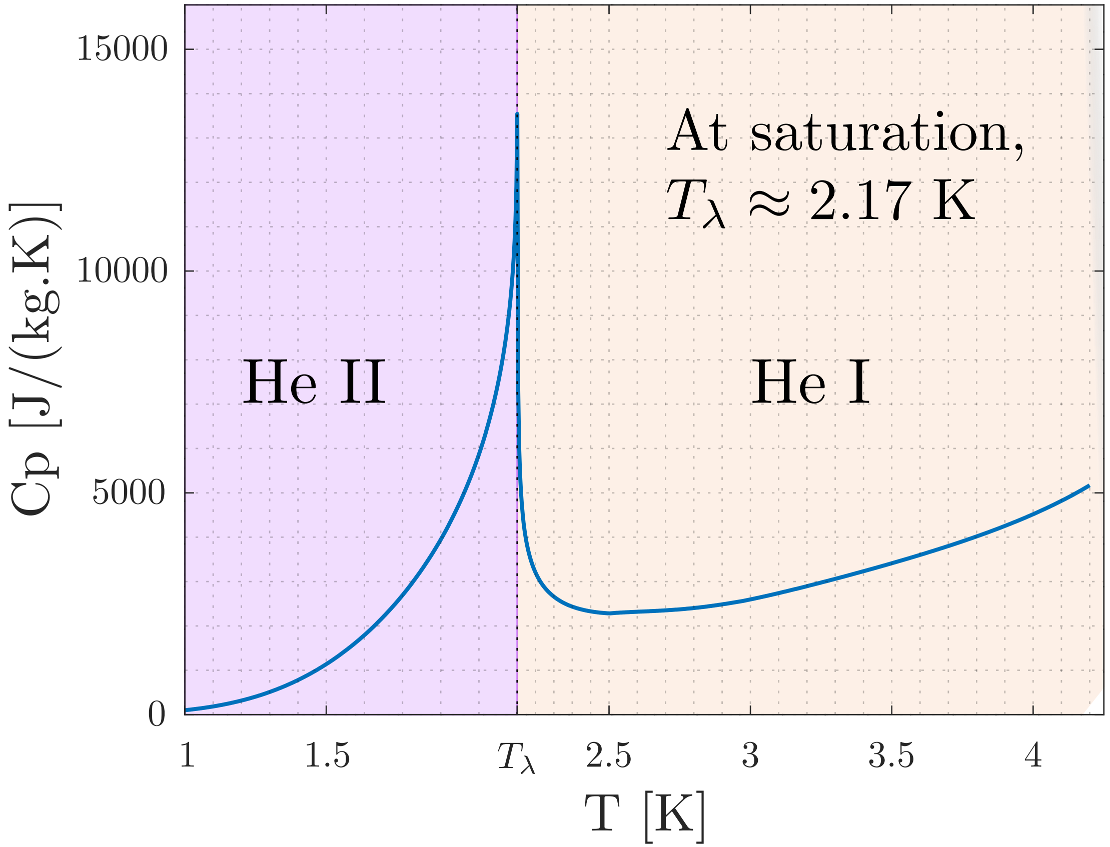
In comparison, under ambient conditions

$$\nu_{\mathrm{air}} = 1.5 \cdot 10^{-5}\,\mathrm{m}^2/\mathrm{s}$$

$$\nu_{\mathrm{H_2O}} = 1 \cdot 10^{-6}\,\mathrm{m}^2/\mathrm{s}$$

$$Re = \frac{UL}{\nu}$$

- Exibits weird properties for $T < T_\lambda$



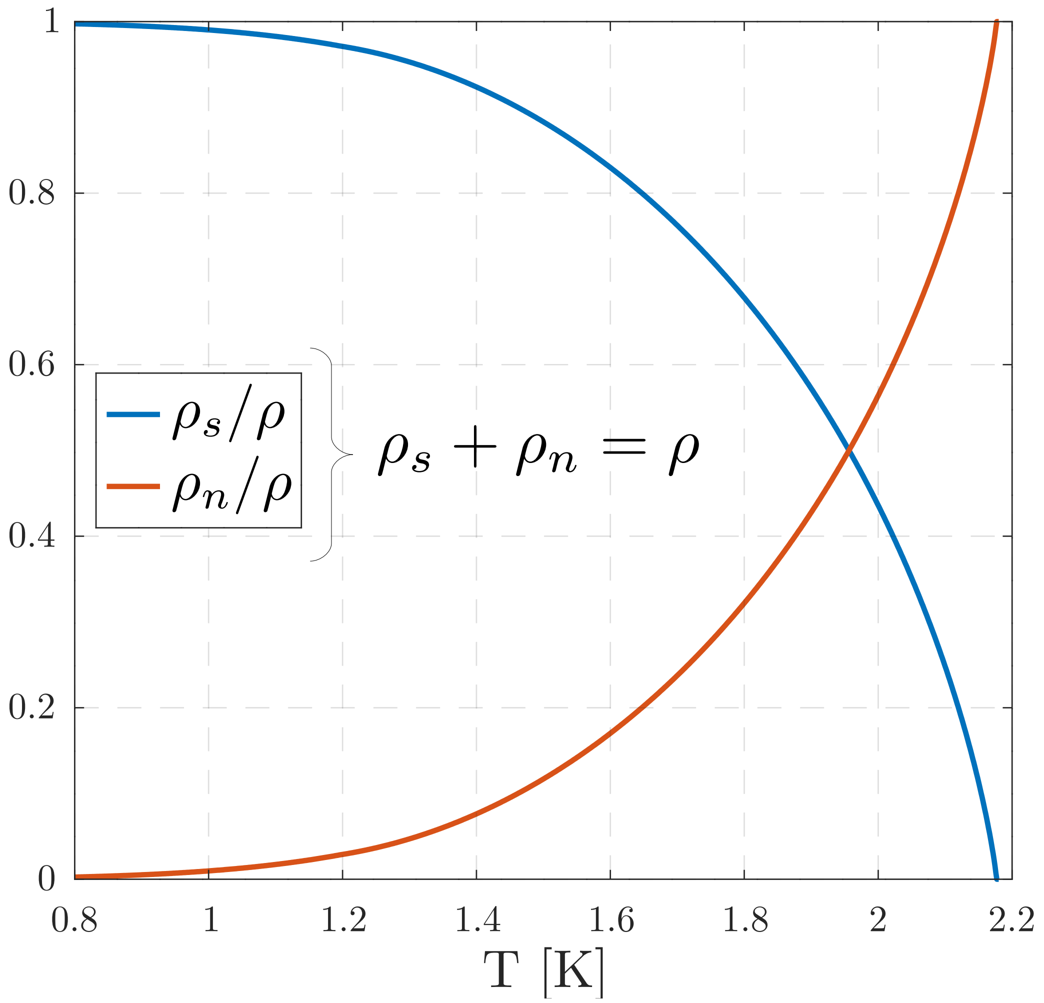
What is so special with Helium 4 ?

The two-fluid model of He II (Landau & Tisza)

- A "normal" viscous component carrying all the fluid entropy (ρ_n, $\mathbf{v}_n$, $\mu_n > 0$)

- A "superfluid" quantum component that flows without viscosity (ρ_s, $\mathbf{v}_s$, $\mu_s = 0$)

- The closer you get to absolute 0 the more superfluid you get

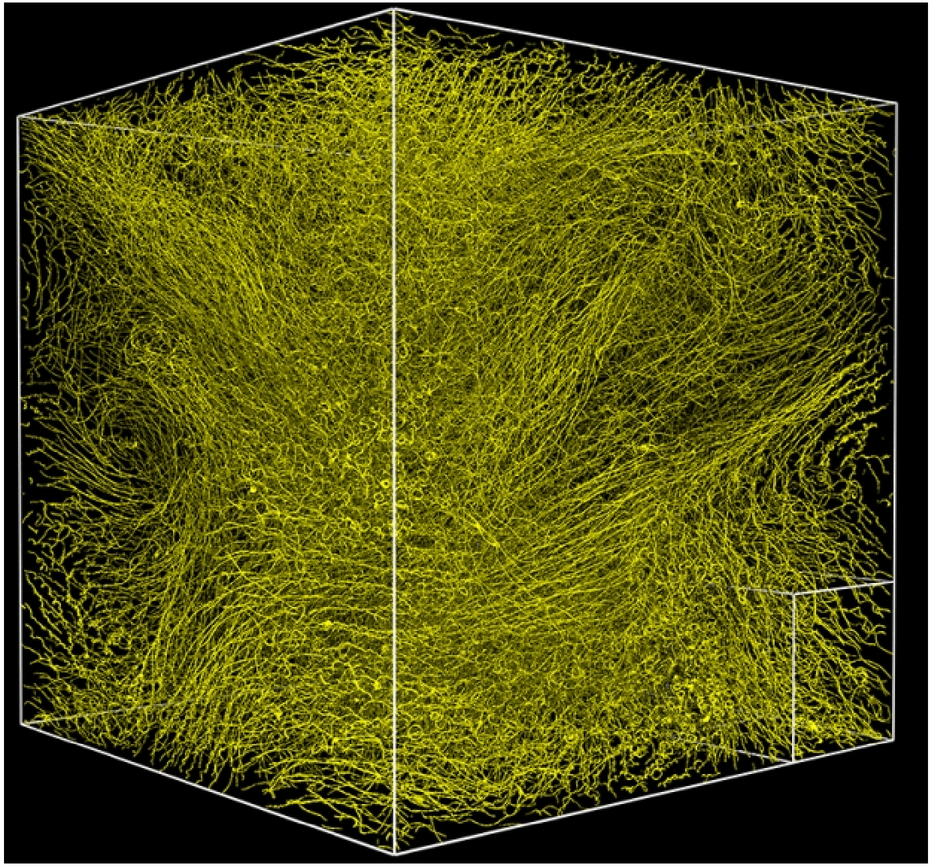


What is so special with Helium 4 ?

The two-fluid model of He II
(Landau & Tisza)

- The superlfuid component can be described as a potential flow with additional "defects" of vortex lines (core dimension of the order of 1 Å) carrying a quanta of vorticity
$(\kappa = 0.997 \cdot 10^{-7}\ m^2/s)$

- Turbulence in He II generates a tangle of vortex line



Visualization of tangled vortex lines in a numerical simulation of Quantum Turbulence,
(Müller, Polanco and Krstulovic, 2021)

What is so special with Helium 4 ?

The Hall-Vinen-Bekharvich-Khalatnikov (HVBK) equations

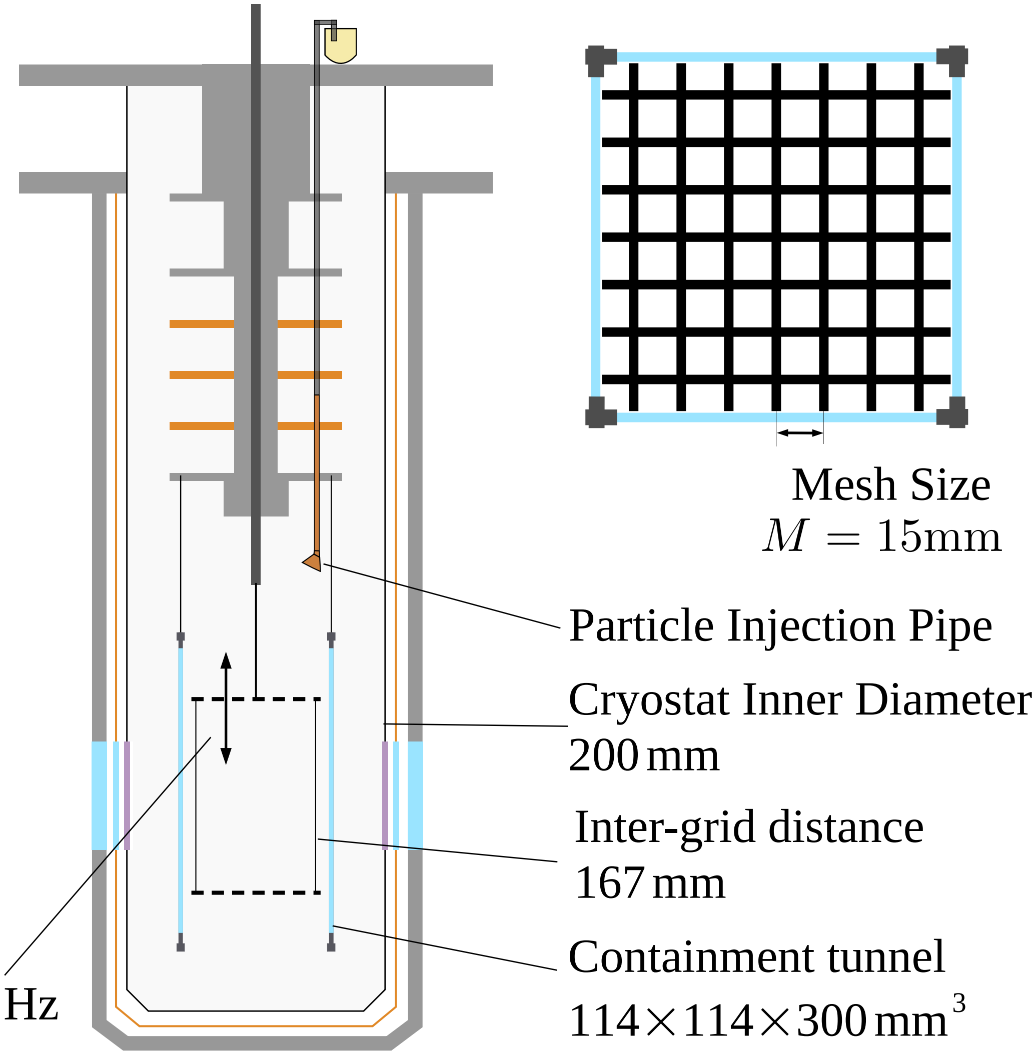
$$\begin{cases} \rho_n \left(\dfrac{\partial \mathbf{v}_n}{\partial t} + (\mathbf{v}_n \cdot \nabla)\mathbf{v}_n \right) = -\dfrac{\rho_n}{\rho} \nabla P + \mu_n \boldsymbol{\Delta} \mathbf{v}_n - \rho_s \sigma \nabla T + \mathbf{F}_{ns} \\ \rho_s \left(\dfrac{\partial \mathbf{v}_s}{\partial t} + (\mathbf{v}_s \cdot \nabla)\mathbf{v}_s \right) = -\dfrac{\rho_s}{\rho} \nabla P + \rho_s \sigma \nabla T - \mathbf{F}_{ns} \\ \dfrac{\partial \rho}{\partial t} + \nabla \cdot (\rho_n \mathbf{v}_n + \rho_s \mathbf{v}_s) = 0 \\ \dfrac{\partial (\rho\sigma)}{\partial t} + \nabla \cdot (\rho \sigma \mathbf{v}_n) = 0 \end{cases}$$

- The mutual friction force : Interaction of the 2 component through the vortex lines

$$\mathbf{F}_{ns} = -\frac{B\kappa}{2} \frac{\rho_n \rho_s}{\rho} \sin^2(\theta) \mathcal{L} (\mathbf{v}_n - \mathbf{v}_s)$$

- Vortex lines are not described individually but are coarse grained into the vortex line density $\mathcal{L}$

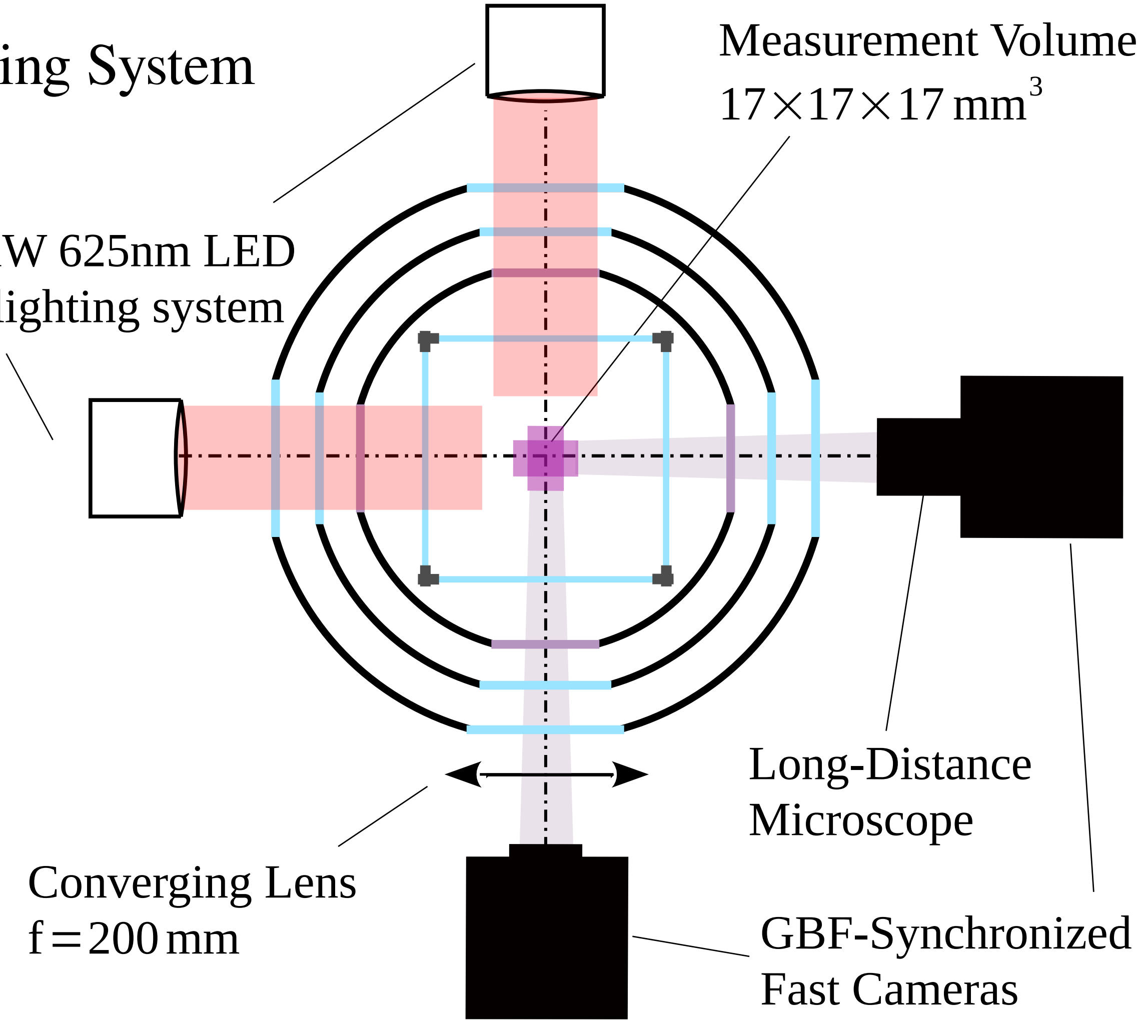
Experimental Apparatus – OGRES (Oscillating GRid Experiment in Superfluid)



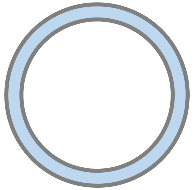
Motor Forcing Range : $A_{\text{mot}}=0-16\,\text{mm}$, $f_{\text{mot}}=0-12\,\text{Hz}$

Experimental Apparatus – Capturing 3D Lagrangian Trajectories

Imaging System



Flow Seeding



- Hollow glass microspheres
- Silver Coated
- Diameter $D = 83 \pm 8\mu\mathrm{m}$
- Density $\rho_p = 148 \pm 30\mathrm{kg/m}^3$

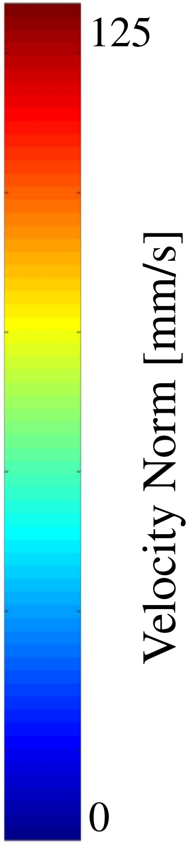
In a 2.3K saturated Helium 4 bath :

$$v_{sed} = \frac{1}{18}\frac{(\rho_p - \rho_f)gD^2}{\mu_f} \approx 2.8\mathrm{mm/s}$$

$$\tau_p = \frac{D^2}{36}\frac{\rho_f + \rho_p}{\mu_f} \approx 20\mathrm{ms}$$

Experimental Data – Reconstruction of 2D Lagrangian Trajectories

2 x 2D Particle Tracking (Field Size : $800 \times 800\,\text{px} \Leftrightarrow 17 \times 17\ \text{mm}^2$)



Today Practical Session

Capture 2D particle trajectories in OGRES water replicates