Visualization of grid-generated turbulence in He II using PTV

CEC-ICMC Madison, WI

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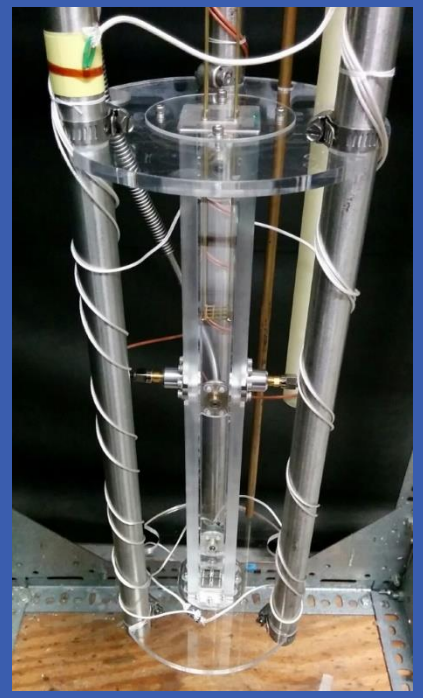

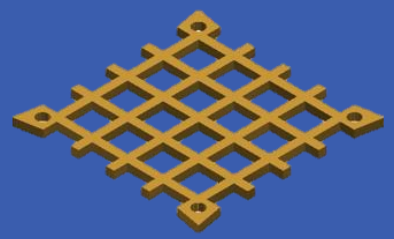

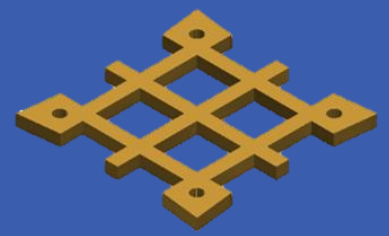

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Talk outline

Background and Motivation

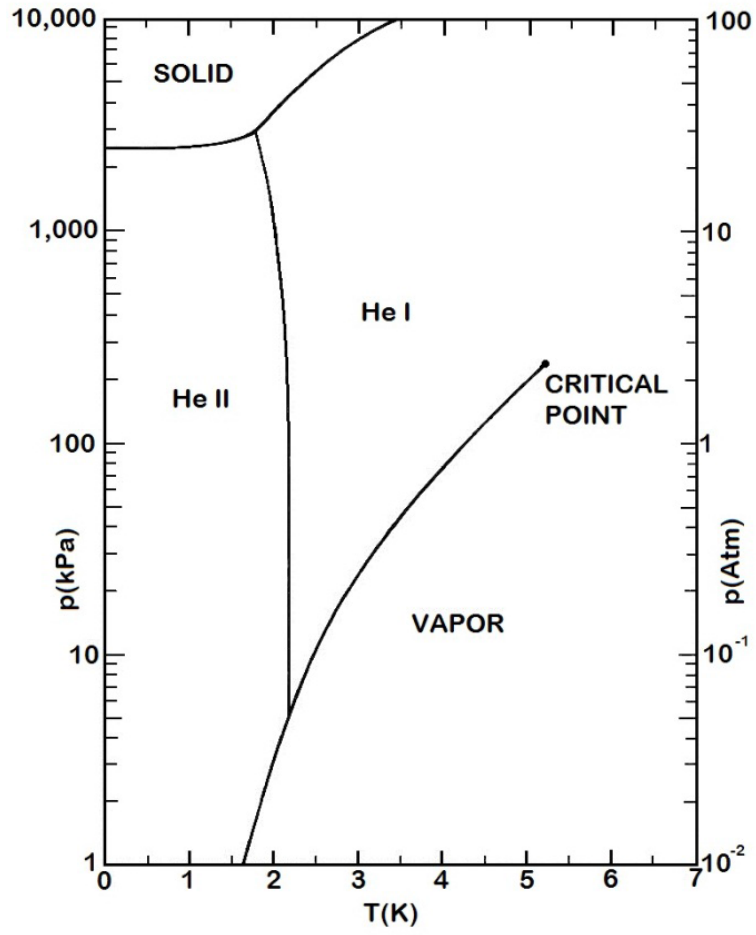
- Properties of He II
- Potential as experimental working fluid

Development of Visualization Experiment

- Particle tracking velocimetry
- Grid turbulence facility design
- Particle motion in turbulent He II

Characterization of He II Turbulence

He II is a non-classical fluid modeled by two fully miscible fluid components

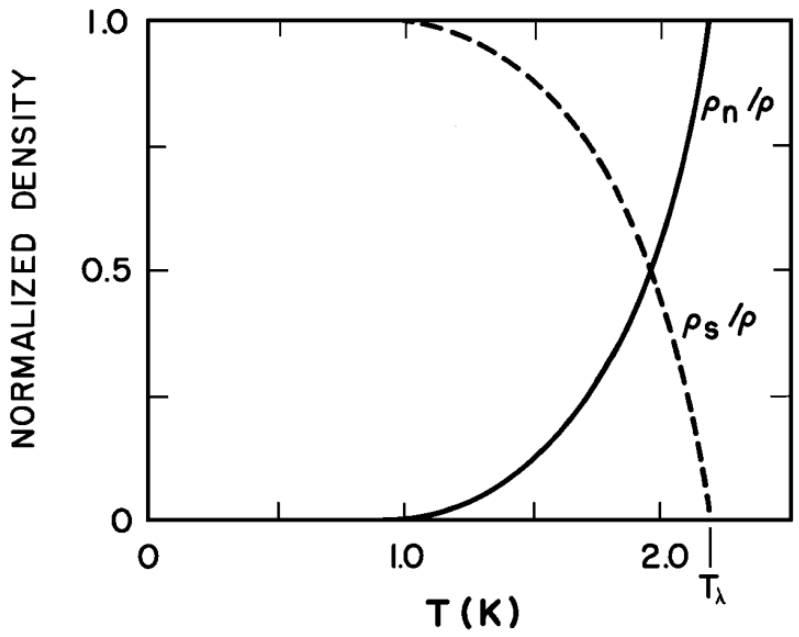


Low temperature phase diagram for helium-4

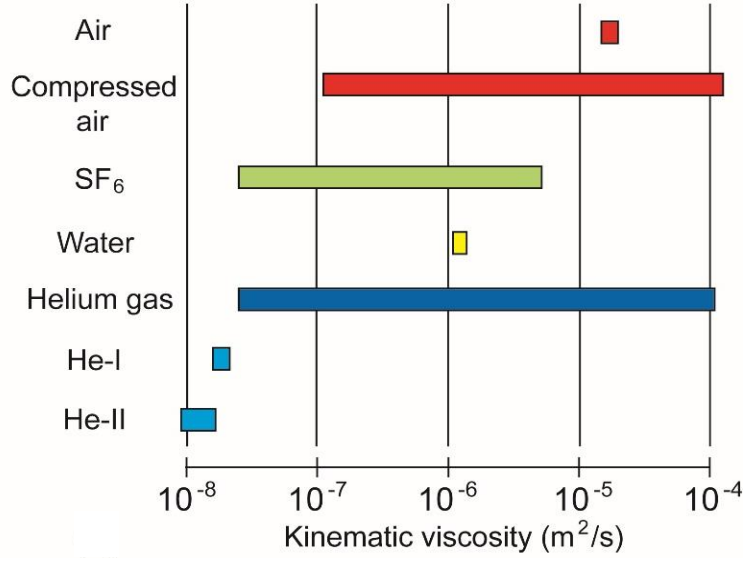
Second order phase transition from liquid He I to liquid He II at $T_\lambda \approx 2.17$ K

Normal fluid component (density ρ_n) is a classical Navier-Stokes fluid

Superfluid component (density ρ_s) is inviscid and carries no entropy



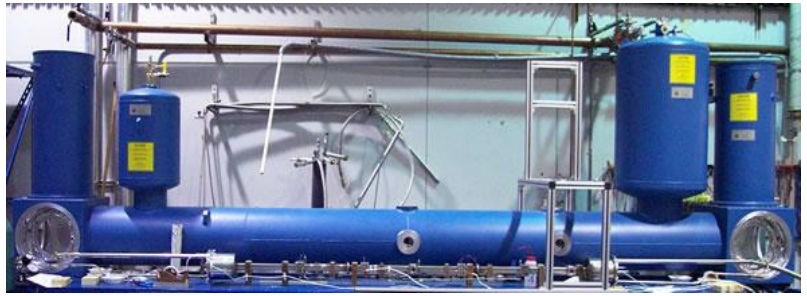
Cryogenic helium has potential in fluids research due to its extreme hydrodynamic properties



He II has smaller kinematic viscosity than any other fluid ($\nu < 10^{-8}$ m²/s) [1]

High Reynolds number flow ($Re = {}^{UD}/_{\nu}$) can be achieved in He II (10^7 already achieved [2,3])

Economical flow studies in compact apparatus



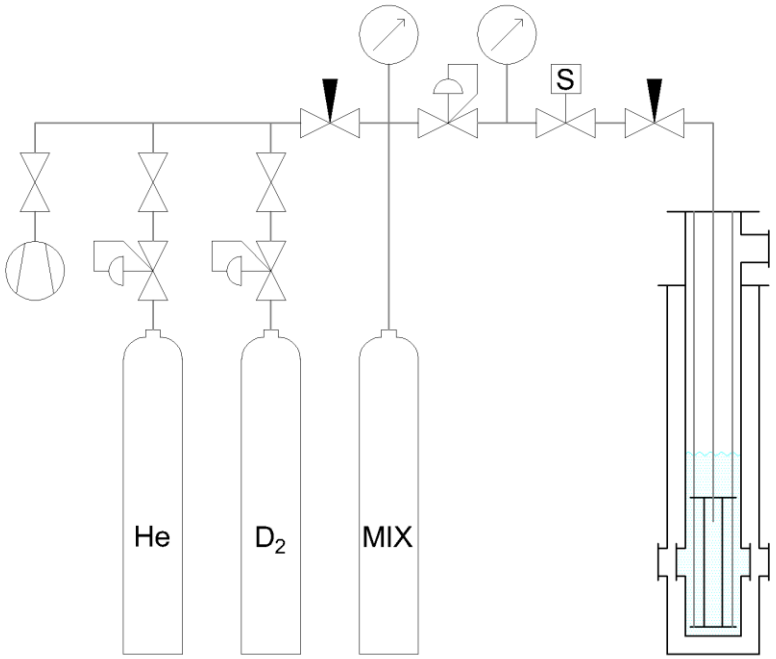
Research **suggests** that mechanically driven flow behaves classically, but comprehensive evidence from **simple, well controlled turbulence** is lacking

→

Develop a suitable technique to **visualize** turbulence in the wake of a **towed grid**

[1] R. J. Donnelly and C. F. Barenghi, J. Phys. Chem. Ref. Data **27**, 1217 (1998)
[2] S. Fuzier, B. Baudouy, and S. W. Van Sciver, Cryogenics **41**, 453 (2001)
[3] SHREK Collaboration, Physics of Fluids **26**, 125109 (2014)

Flow visualization offers high resolution and non-invasive flow field measurement

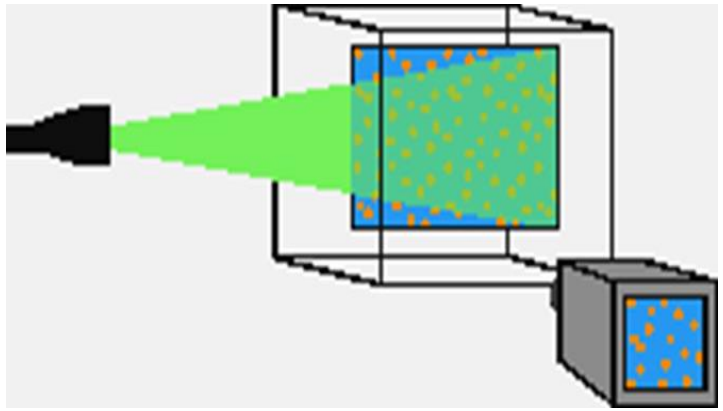


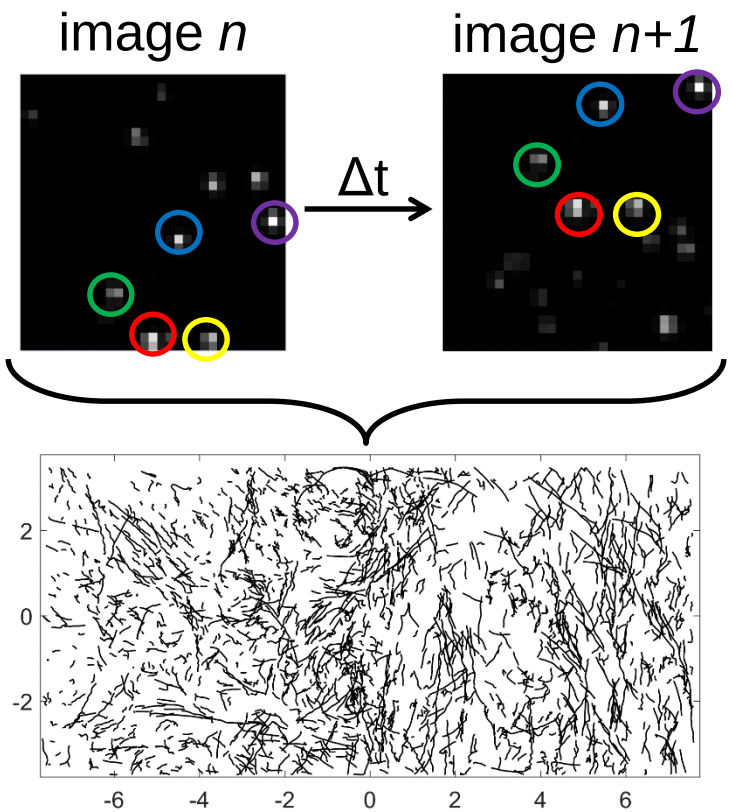
Fluid seeded with tracer particles that faithfully follow its motion

In this case tracer particles are solidified deuterium

Laser light sheet illuminates tracer particles in flow field

High-speed video camera records particle motion

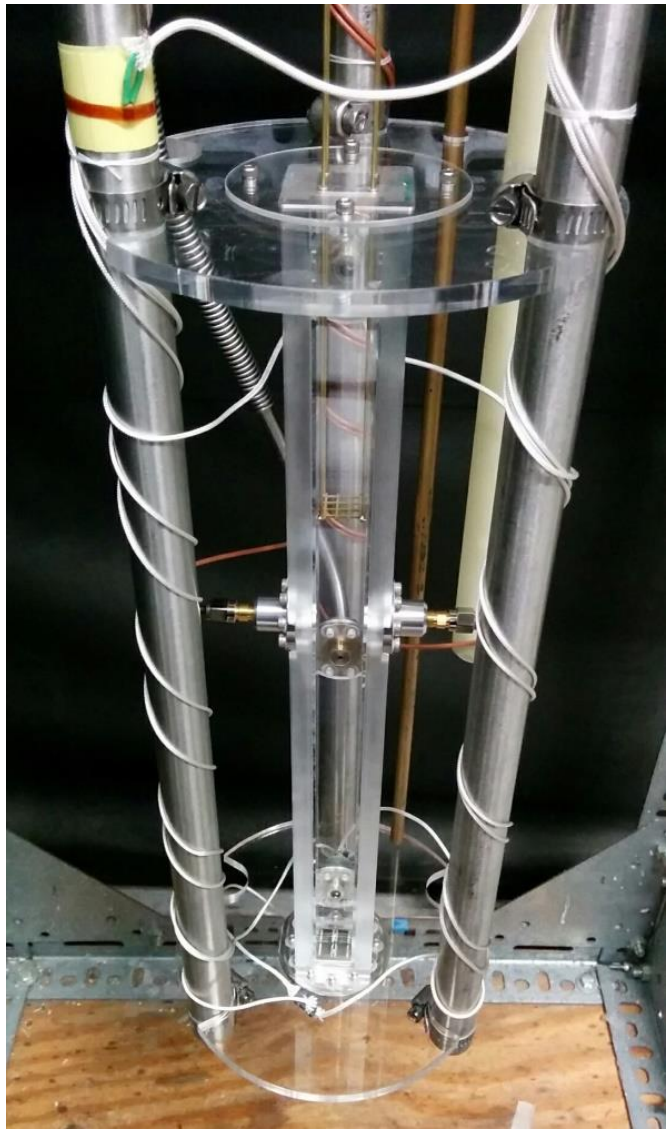




Customized PTV algorithm identifies particles and resolves velocity field [1]

[1] I. Sbalzarini and F. Koumoutsakos, J. Struct. Biol. **151**, 182 (2005)

We have designed and constructed a device to visualize simple well-controlled turbulence in He II

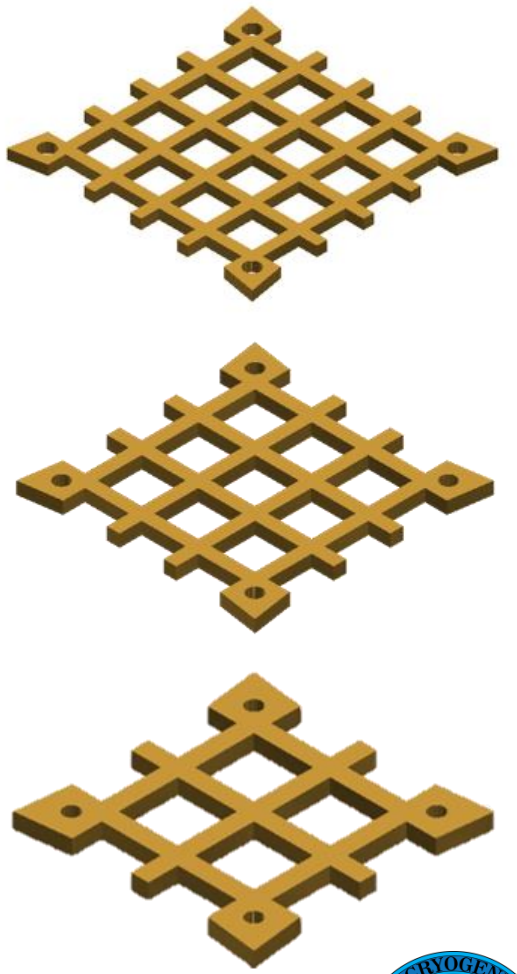


Flow channel

Design Goals	Solutions
• Transparent imaging region • Smooth uniform interior walls • Instrumentation mounting	• Four-piece cast acrylic construction

Mesh grids

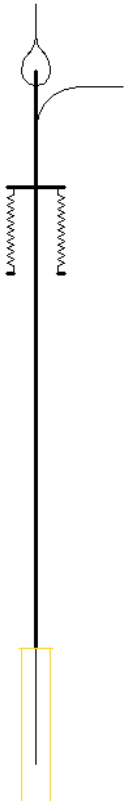
Design Goals	Solutions [1]
• Generates homogeneous isotropic turbulence	• Less than 40% solidity • Symmetric in channel walls • Contact with channel isolated to corners



[1] HJS Fernando and PD De Silva, J. Fluid Mech. **5**, 1849 (1993)

Linear grid motion is generated by a custom pulling system

Computer controlled stepper motor winds cable that pulls a linear drive shaft

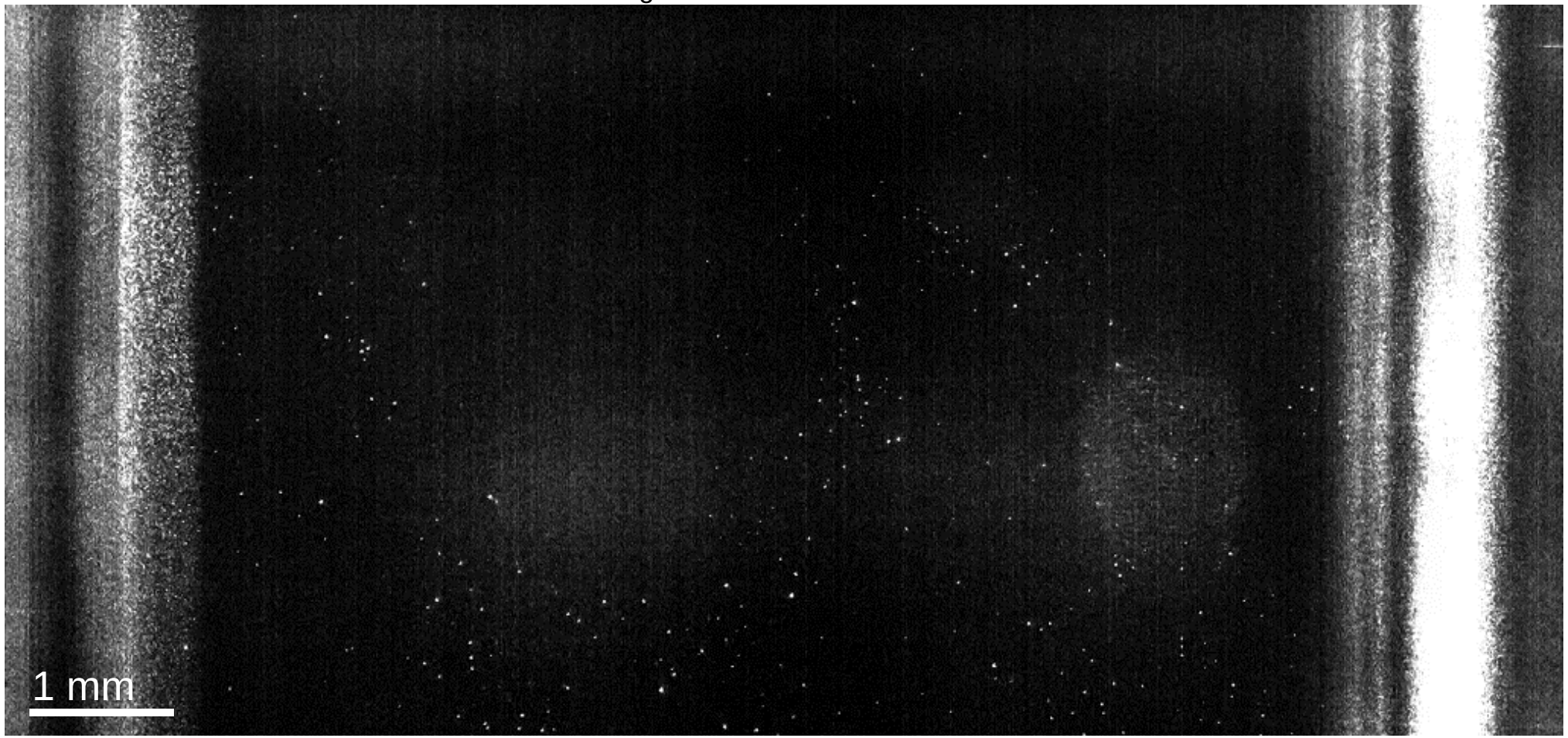


Edge-welded bellows seals grid drive shaft to cryostat throughout 30 cm stroke

Grid can be pulled through the channel at speeds from 0.1 to 60 cm/s with constant speed maintained for middle third of stroke

We have achieved the goal of developing a system to visualize grid turbulence in He II

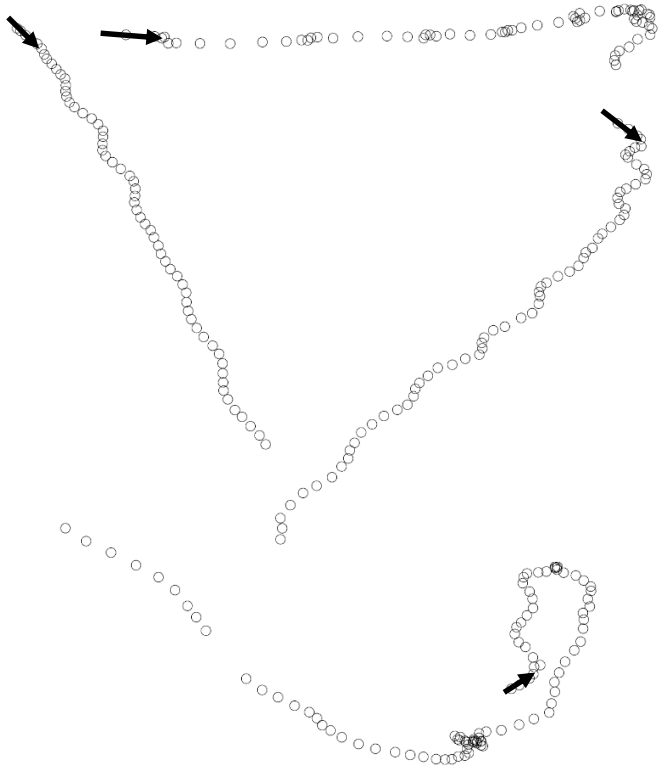
T = 2.0 K, v_{grid} = 30 cm/s, M = 3.75 mm



Playback is reduced to 30% of original speed

Visualization data will be used to characterize the turbulent flow and address some open questions about turbulence in He II

Some particle tracks extracted from the video (ensemble of (x, y, t) coordinates)



Effective kinematic viscosity ν' governs turbulent energy decay

$$C_1 \frac{dL}{dt} + C_2 \frac{d}{dt} u'^2 = -\nu'(\kappa L)^2$$

All quantities except ν' are known or can be measured with our apparatus (u'^2 was not accessible before flow visualization [1])

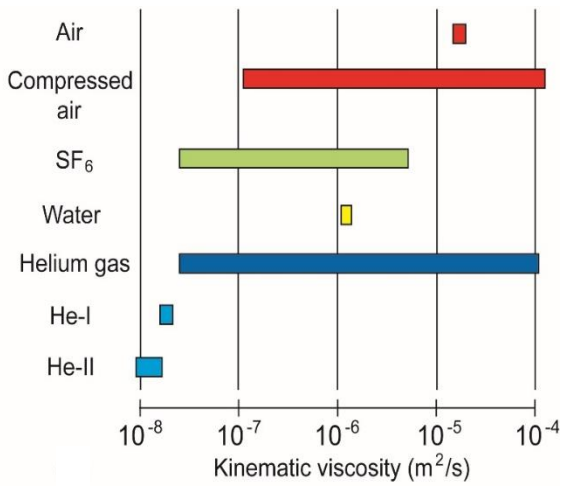
Energy spectrum $E(k)$ describes kinetic energy distribution across turbulent eddies of different size

$$E(k) = 4 \int_0^\infty \frac{\overline{u(t)u(t-\tau)}}{u'(t)u'(t-\tau)} \cos(2\pi k\tau)\, d\tau \quad [2]$$

Predictions for energy spectrum evolution exist [3,4] but $E(k)$ has not yet been measured directly

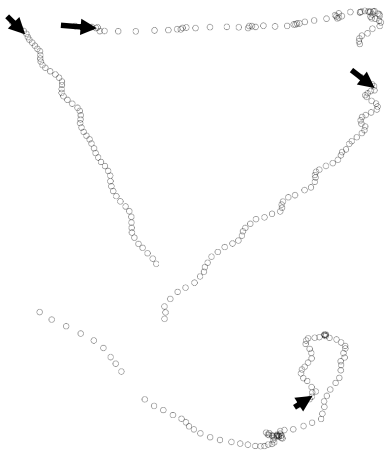
[1] J Gao, W Guo, WF Vinen, Phys. Rev. B **94**, 094502 (2016)
[2] Y Sato and K Yamamoto, J. Fluid Mech. **175**, 183 (1987)
[3] SR Stalp, L Skrbek, RJ Donnelly, Phys. Rev. Lett. **82**, 4831 (1999)
[4] L Skrbek, JJ Niemela, RJ Donnelly, Phys. Rev. Lett. 85, 2973 (2000)

Conclusions

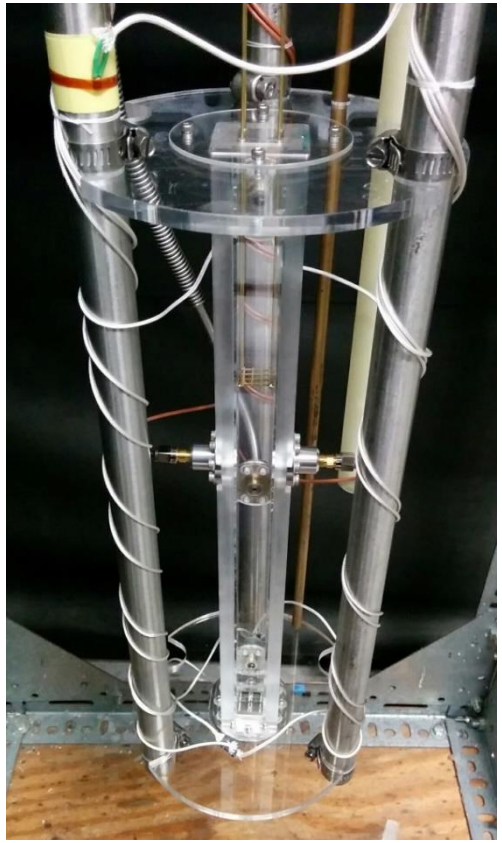


Low kinematic viscosity of He II make it useful for simulating high Re flow and testing models

We have developed a novel experimental apparatus and applied the PTV technique to visualize turbulence in the wake of a grid pulled through He II



Visualization results will play a key role in characterizing the behavior of turbulent flow in He II



THANK YOU