Viscous-free Drag in a Quantum Wind Tunnel

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Superfluid free fall

Drop a bowling ball and a feather from a height. Which object reaches the ground first in a:

- **Vacuum** (no friction)
- **Traditional fluid** (friction due to viscosity)
- **Superfluid** (no viscosity)

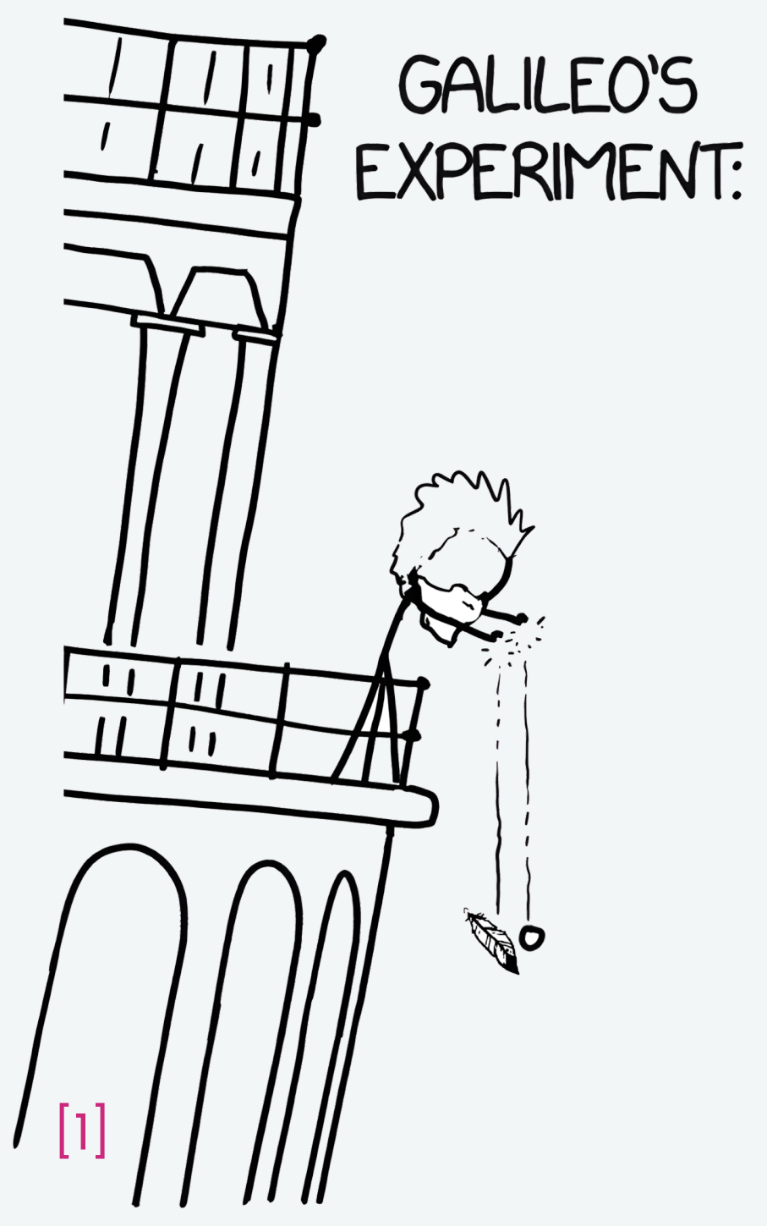
Superfluidic drag does not occur at low velocities but only turns on after reaching a shape dependent **critical velocity**.

Rather than from **viscosity**, the drag originates from the **quantum pressure**.

Drag plays an important role in classical turbulence:

- How (dis)similar are classical and superfluidic drag?
- Is superfluidic drag **scale invariant**, like its classical counterpart?
- Can we **experimentally measure** superfluidic drag?

Use a **quantum wind tunnel** to find out!



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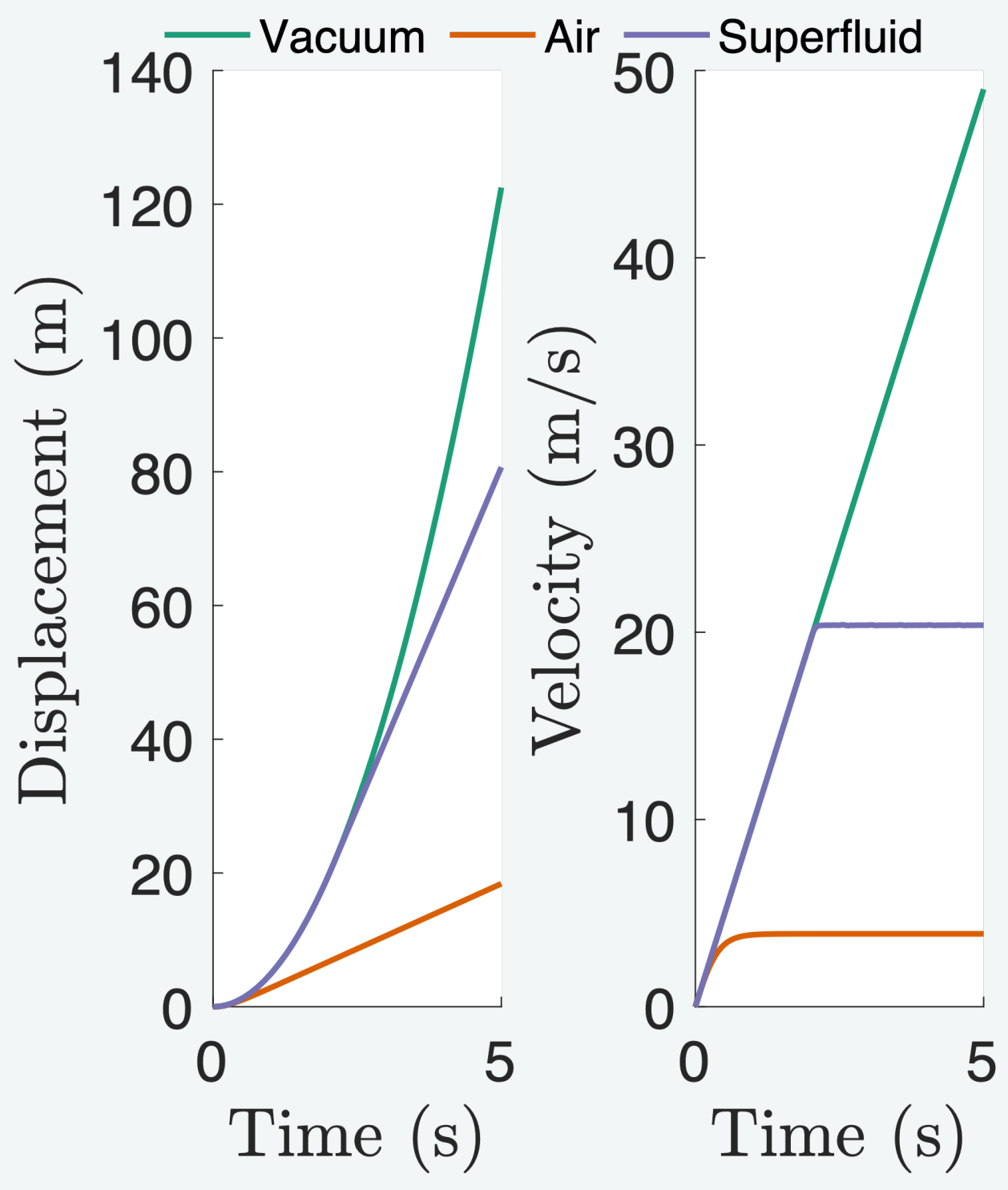
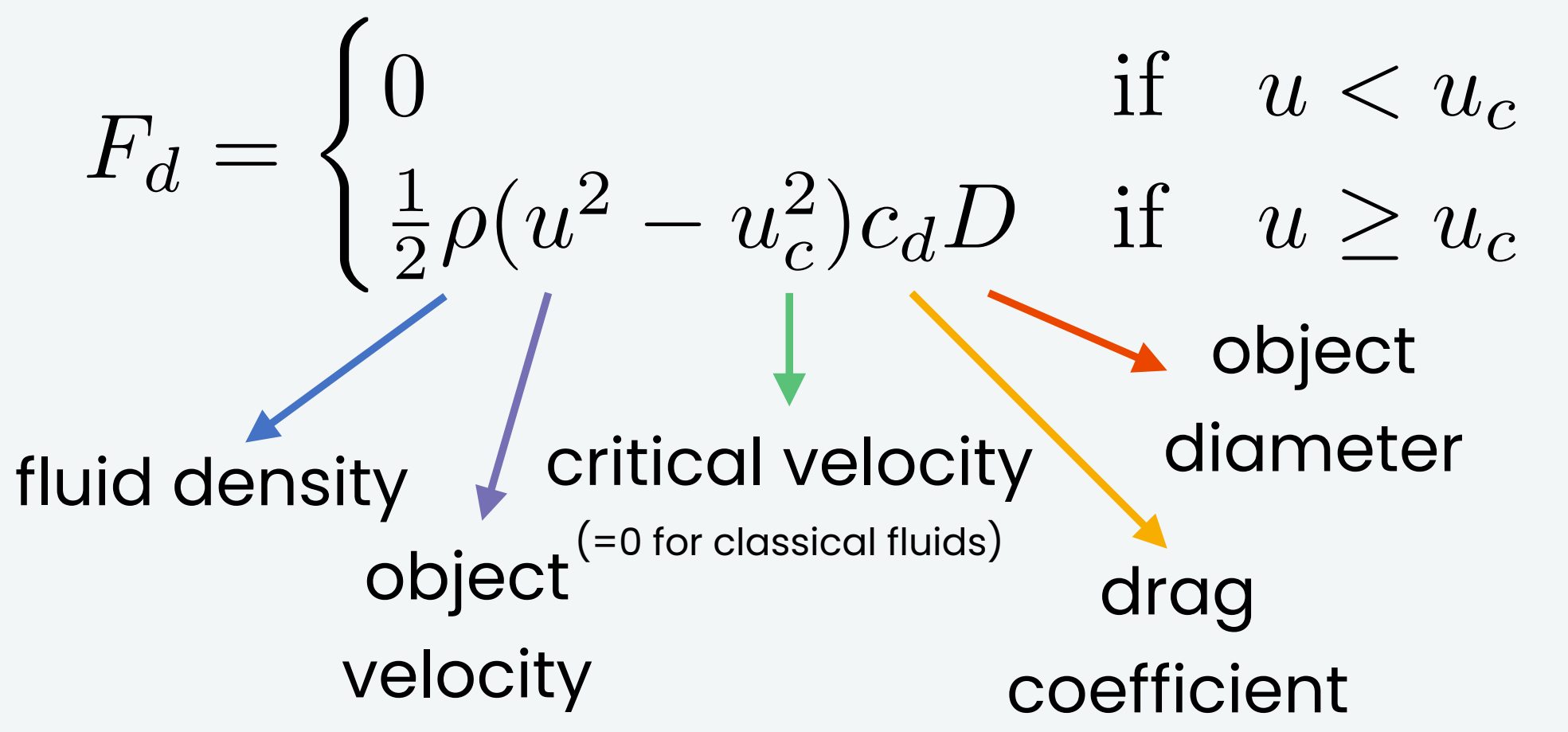




$$F_d = \begin{cases} 0 & \text{if} \quad u < u_c \\ \frac{1}{2}\rho(u^2 - u_c^2)c_d D & \text{if} \quad u \geq u_c \end{cases}$$

fluid density
object velocity
critical velocity
(=0 for classical fluids)
object diameter
drag coefficient

Classical wind tunnels

- Drag forces are measured using **strain gauges** and string.
- Experiments are done across a range of **Reynolds numbers** for different **object sizes** and **wind tunnel velocities**.

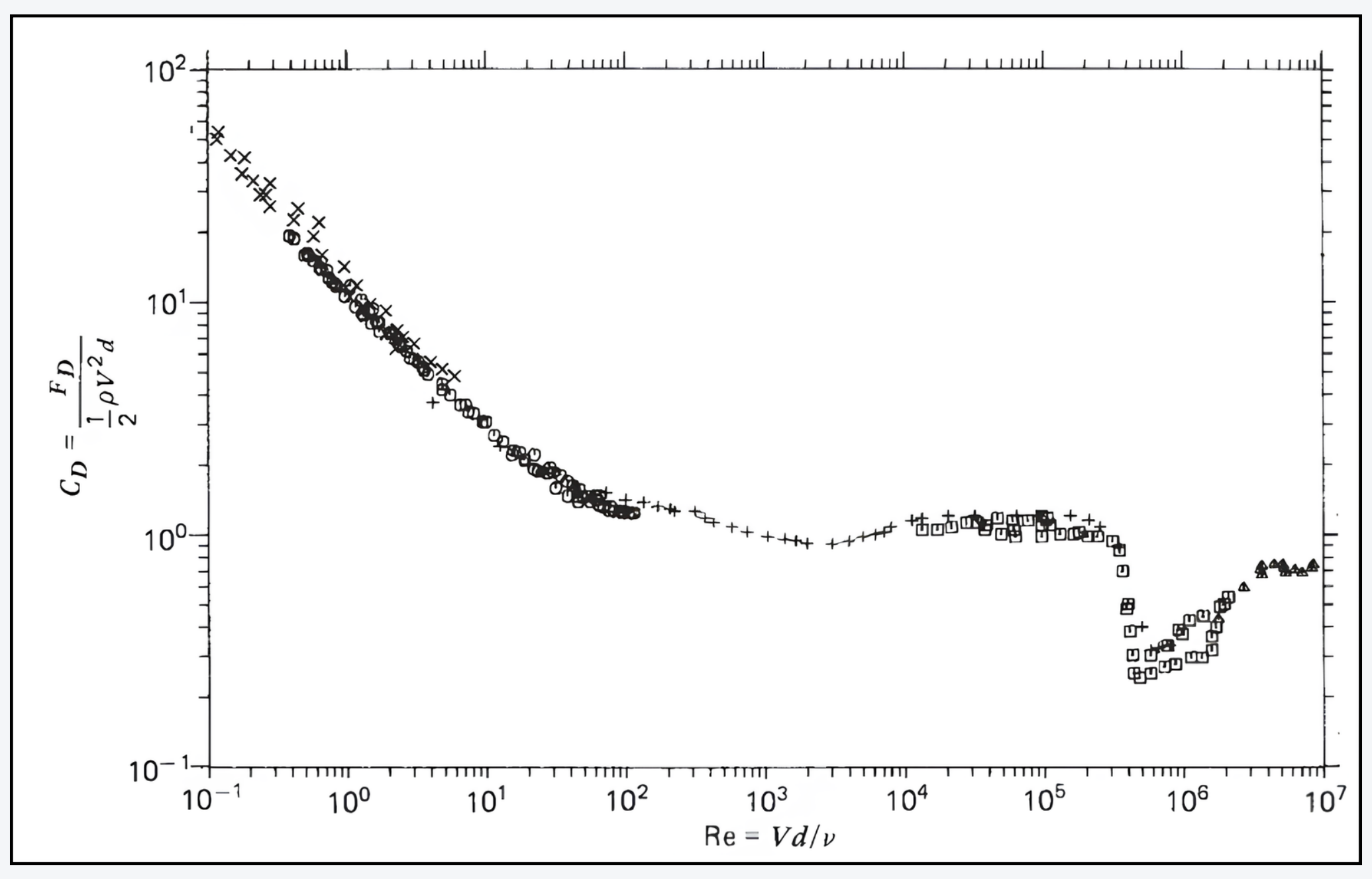
Drag coefficient

$$c_d = \frac{2F_d}{\rho u^2 D}$$

Reynolds number

$$\mathrm{Re} = \frac{uD}{\nu}$$

viscosity



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Quantum wind tunnels

- Drag forces are obtained from the superfluid **wavefunction**.
- The absence of viscosity requires a **superfluid Reynolds number**[3].
- Below the critical velocity, there is no drag. We implement a **superfluid drag coefficient**.

SF Drag coefficient

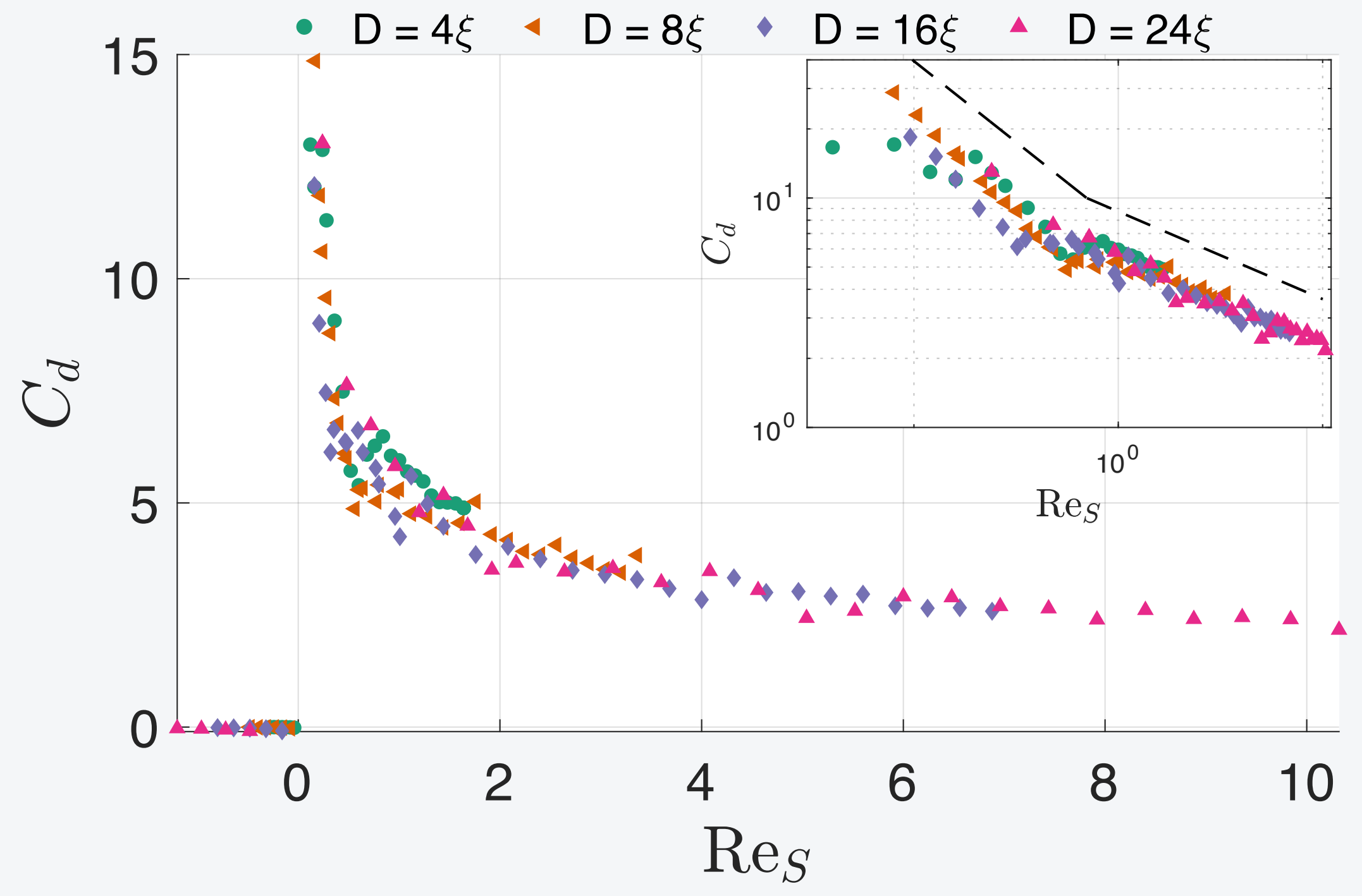
$$c_d = \frac{2F_d}{\rho(u^2 - u_c^2)D}$$

critical velocity

SF Reynolds number

$$\mathrm{Re}_S = \frac{(u - u_c)D}{\kappa}$$

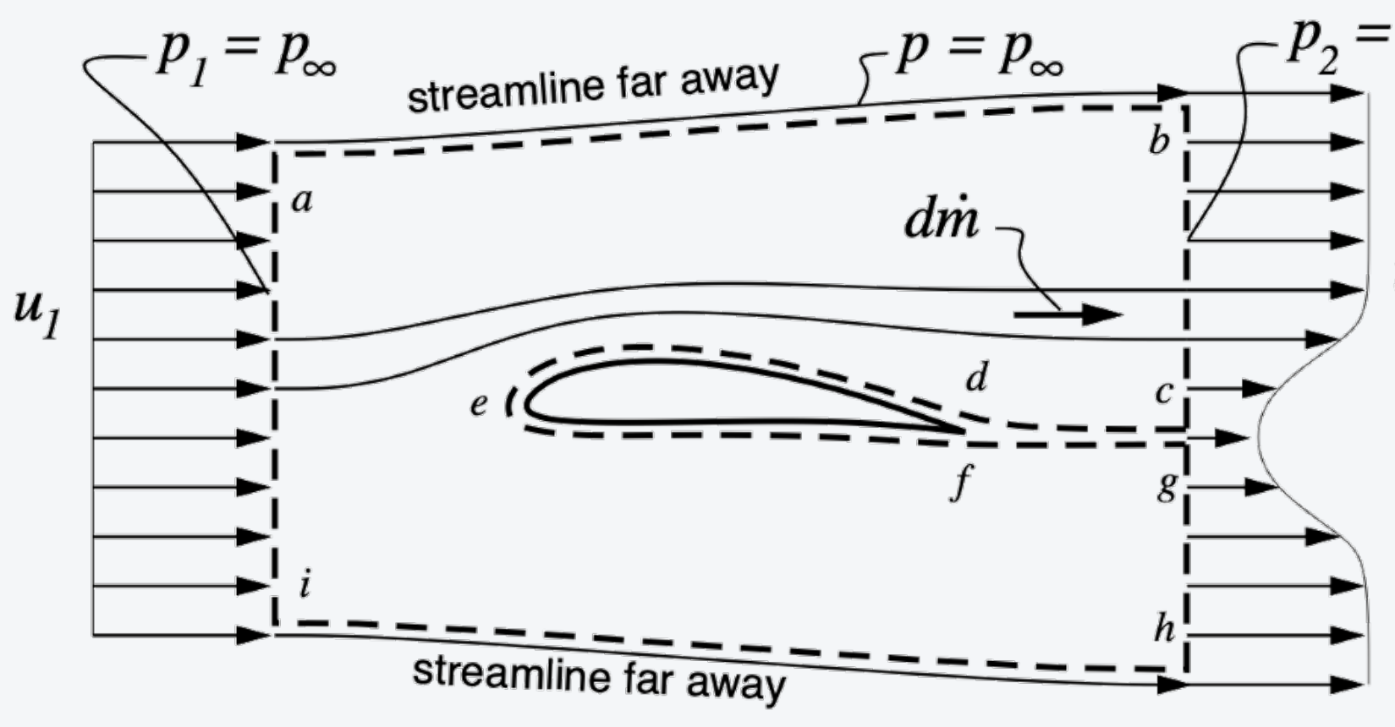
$\kappa = h/m$



Experimental implementation

The Superfluid wavefunction is not experimentally accessible. **Control surface method**[6] from classical hydrodynamics:

- **Momentum flow in and out** a surface around the obstacle gives transferred momentum.
- Transferred momentum corresponds to drag force.
- **Momentum field and density are experimentally accessible.**



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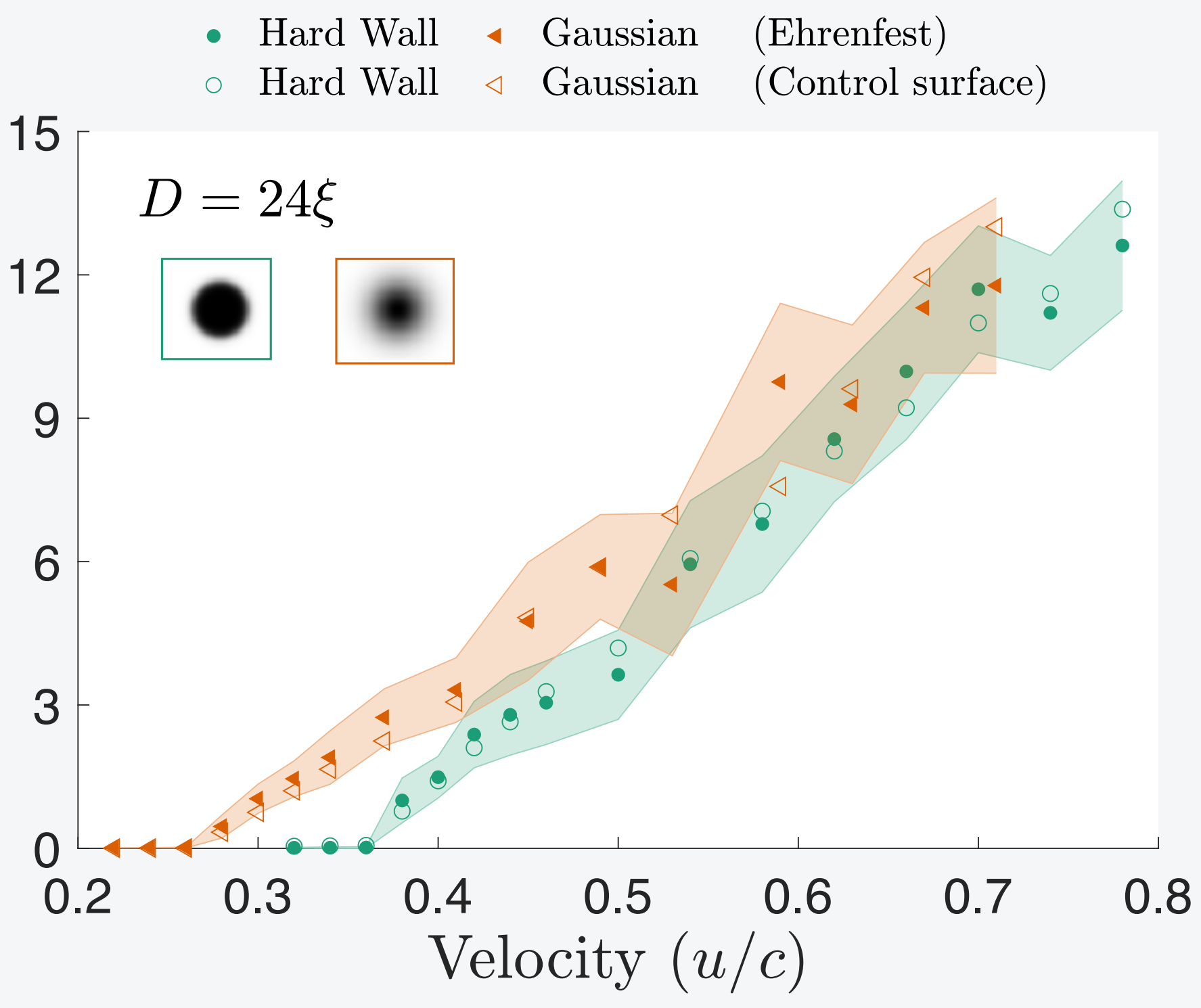


Ehrenfest: $F_x = \int d^2\mathbf{r}\ \psi^* \left(\partial_x V(\mathbf{r})\right) \psi$

Control surface: $F_x = \oint_\Gamma ds\, \rho\, (\mathbf{v} \cdot \hat{\mathbf{n}})^2$

Dynamical similarities

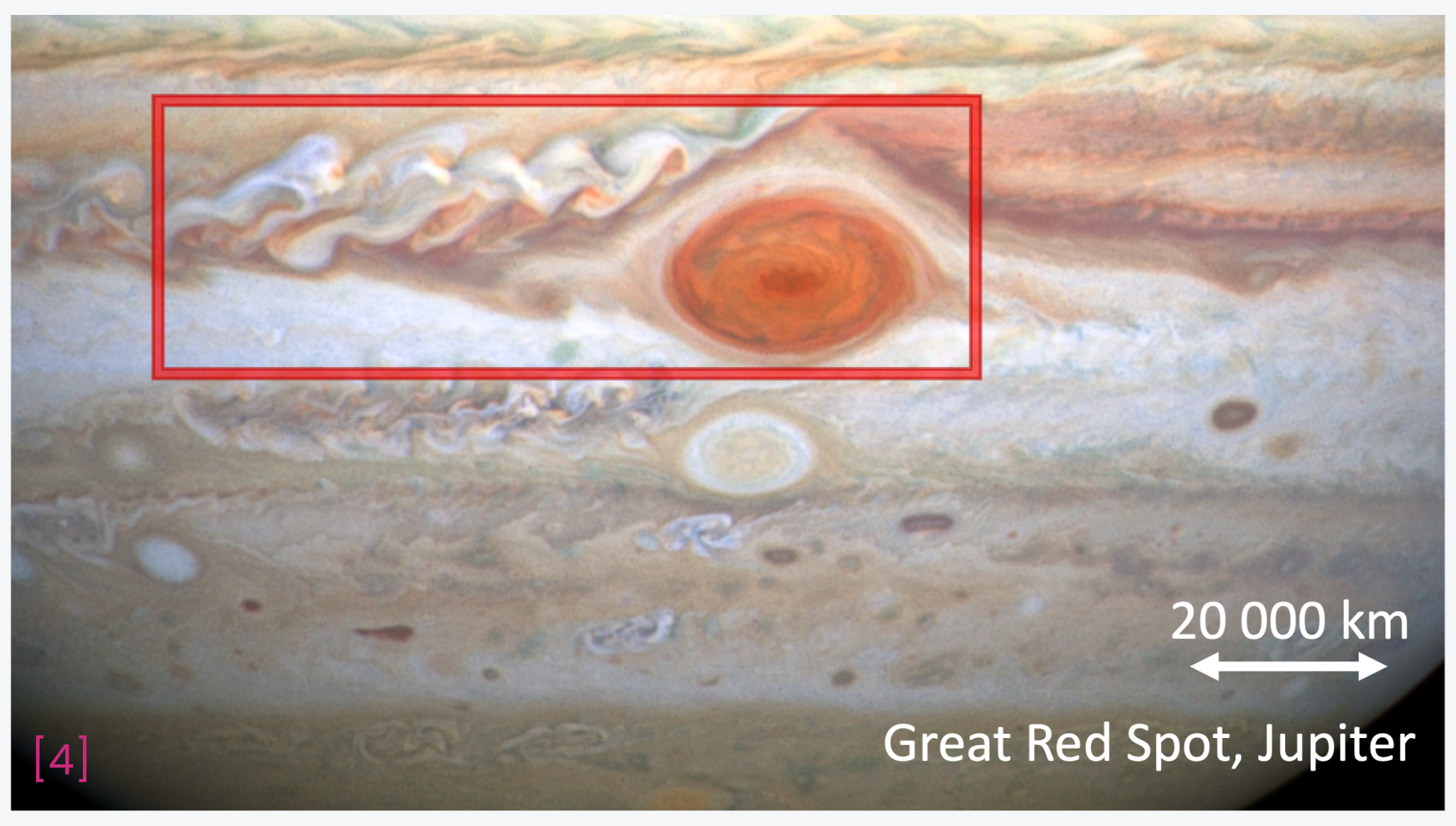
The dimensionless Navier-Stokes equations are **scale invariant** under the **Reynolds number**.

Large scale flows and small scale flows can be **dynamically similar**.

Navier Stokes:

$$\partial_t \mathbf{u} + (\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p + \underset{\mathrm{Re} = \frac{uD}{\nu}}{\frac{1}{\mathrm{Re}}} \boxed{\nabla^2 \mathbf{u}} \rightarrow \text{viscosity}$$

Does the same principle apply for a superfluid?



Great Red Spot, Jupiter

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Juan Fernández Islands, Chile

[5]

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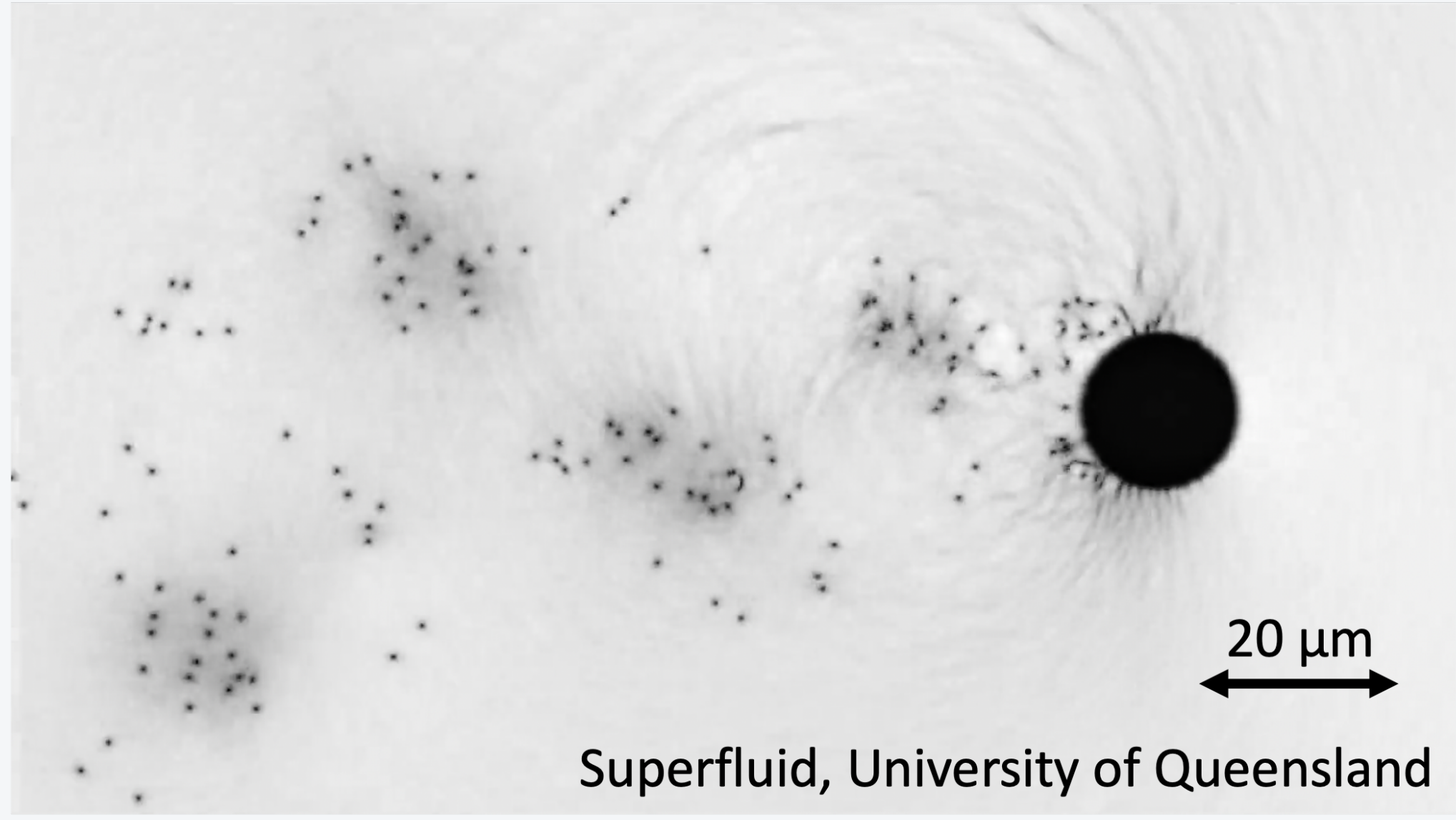

Superfluid, University of Queensland

Conclusions & Outlook

- The superfluid drag coefficient is scale invariant under the Reynolds number, similar to classical hydrodynamics.
- A control surface method is a feasible way to measure superfluidic drag experimentally.
- Experimental superfluidic drag force measurements open new experimental avenues.
- Does the dissipation anomaly[8]; non-vanishing dissipation at Re → ∞ ($\nu \rightarrow 0$), exist in superfluids?
- Are the constant drag coefficients of shapes in superfluids the same as their classical counterparts?

References

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