The Abdus Salam
International Centre for Theoretical Physics

United Nations
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2023-16

Workshop on Topics in Quantum Turbulence

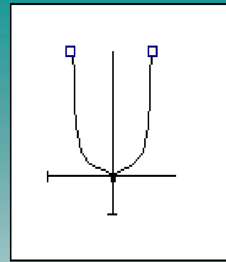
16 - 20 March 2009

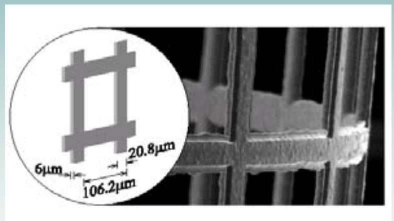
Experiments on Large Vibrating Structures in 4He

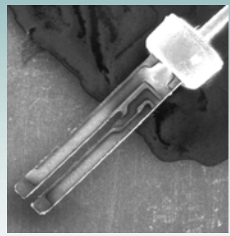
L. Skrbek

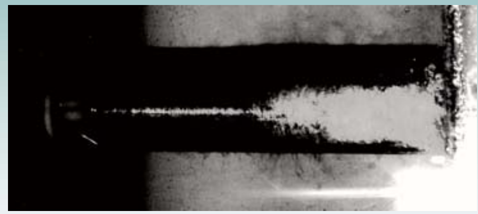
*Charles University, Dept. Low Temperature Physics Prague
Czech Republic*

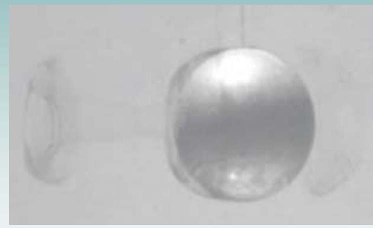
Experiments on Large Vibrating Structures in 4He

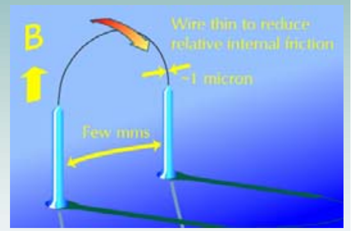












L. Skrbek

Faculty of Mathematics and Physics

Charles University in Prague

M. Blažková, T. Chagovets, V. Pilcová, D. Schmoranzer

Workshop on topics in quantum turbulence
Trieste, March 16-20, 2009

Outline

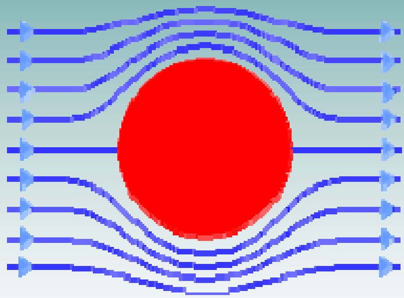
- Introduction- transition to turbulence in steady viscous flows and oscillatory boundary layer flows due to various oscillating objects
- A bit of history
- Drag on oscillating objects (in viscous flows and in superflows)
- Baker visualization technique
- Irregular, “virgin” versus “regular” behaviour
- Conclusions

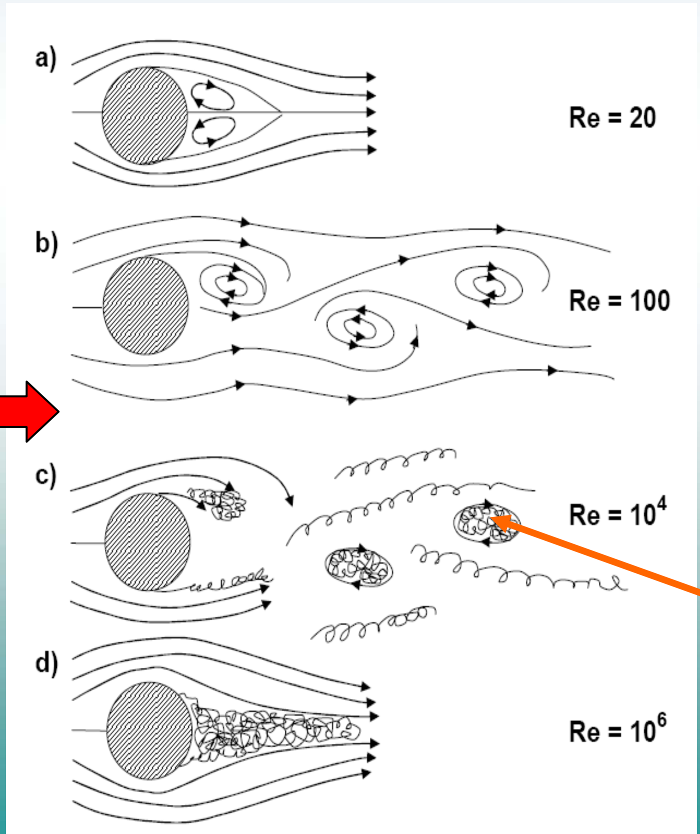
Viscous steady flow

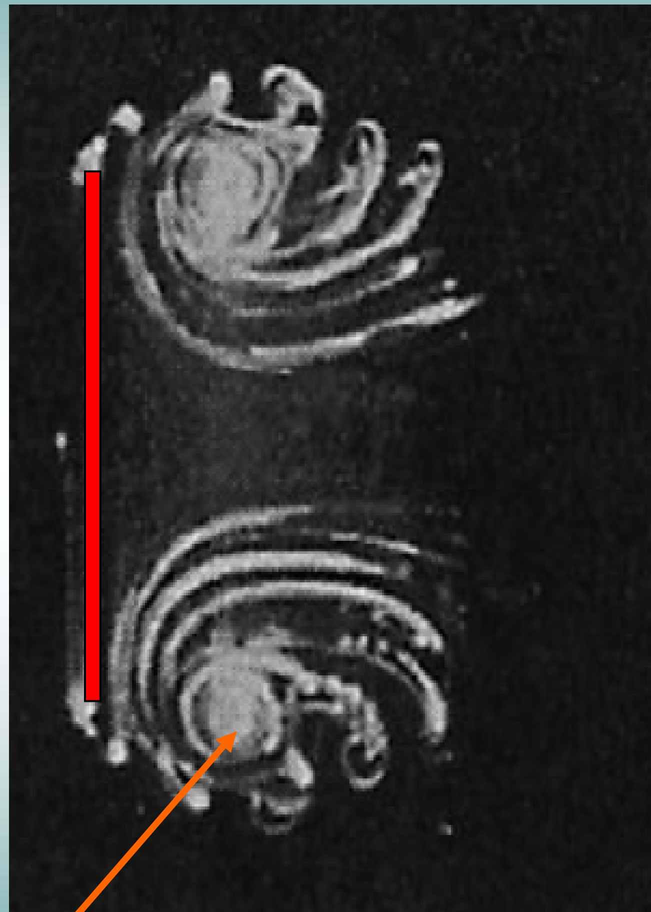
circular cylinder

circular disc

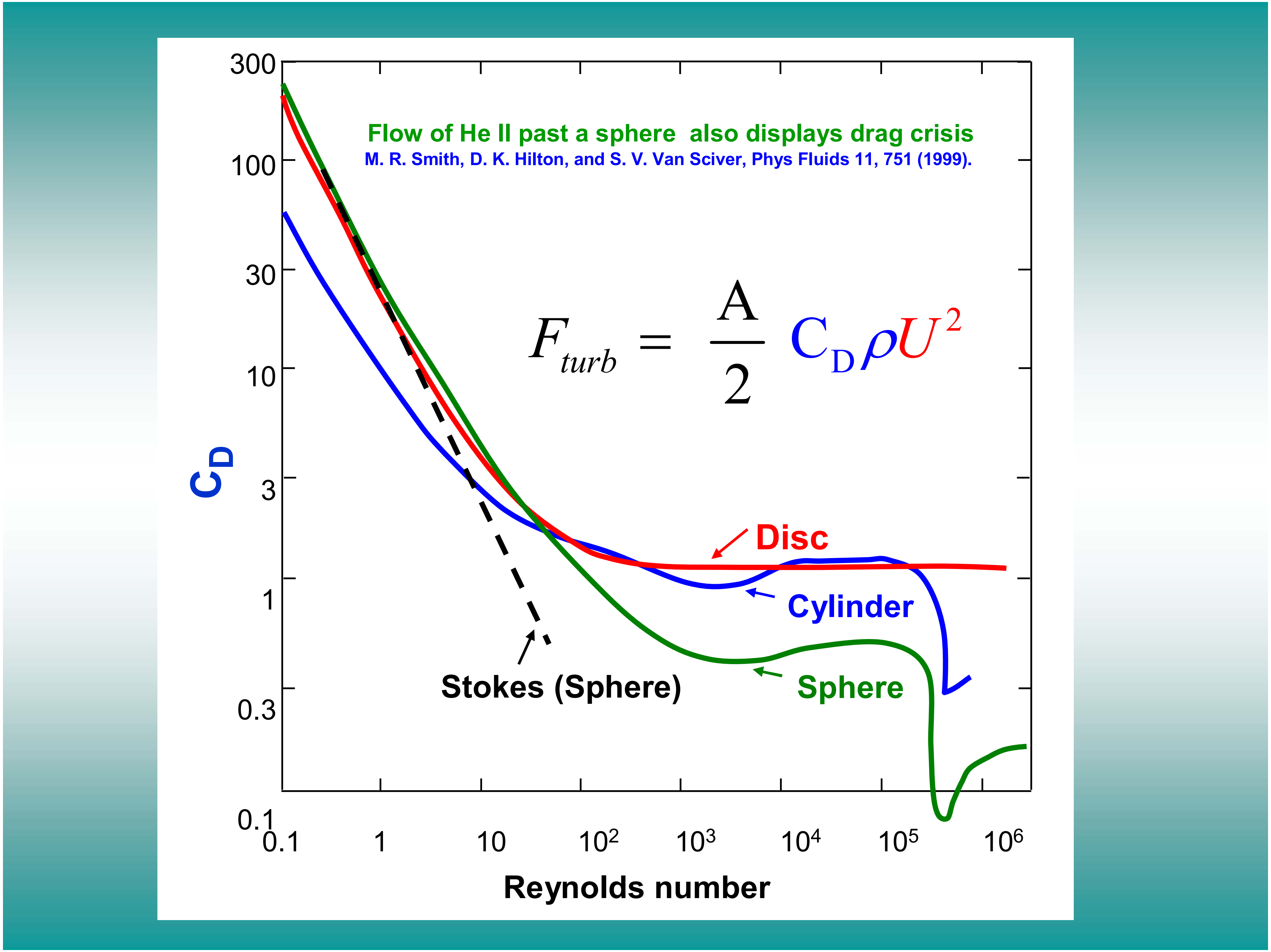
$$\mathrm{Re} = \frac{UD}{\nu}$$



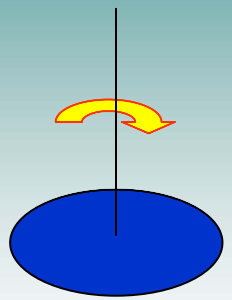




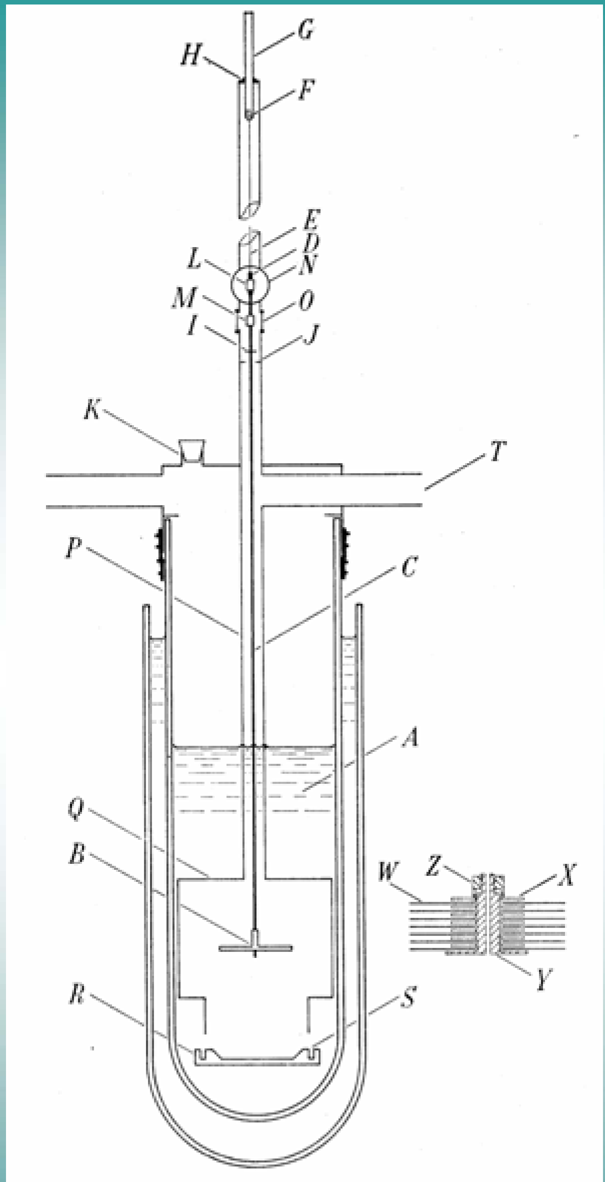
Large structures


Flow of He II past a sphere also displays drag crisis
M. R. Smith, D. K. Hilton, and S. V. Van Sciver, Phys Fluids 11, 751 (1999).
$F_{turb} = \frac{A}{2} C_D \rho U^2$
C_D
300
100
30
10
3
1
0.3
0.1
0.1
1
10
10^2
10^3
10^4
10^5
10^6
Disc
Cylinder
Sphere
Stokes (Sphere)
Reynolds number

Discs and
piles of discs



Torsional
oscillators



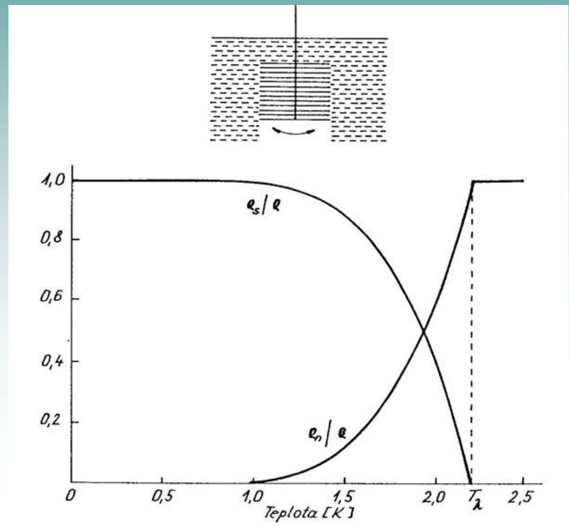
**The cryostat designed by Hollis Hallett
for oscillating disk experiments**

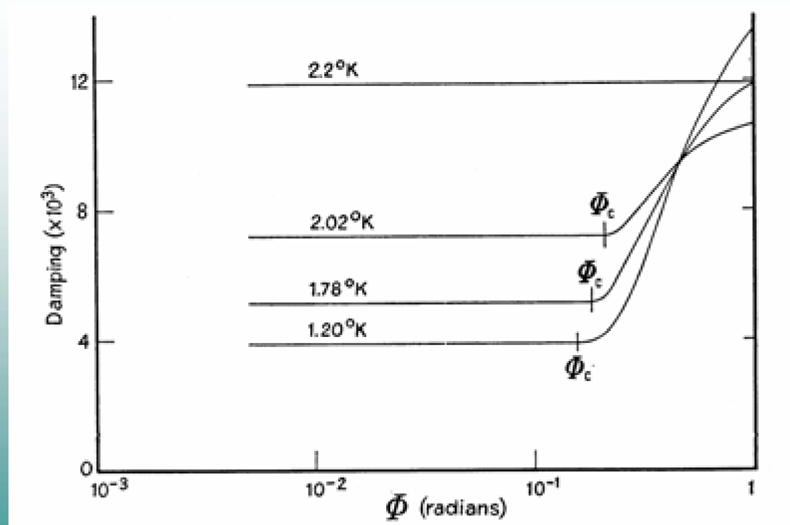
A.C. Hollis Hallett: Proc. R. Soc. A210 (1952) 404

E.L. Andronikashvili

J. Phys. (Moscow) 10 201 (1945)

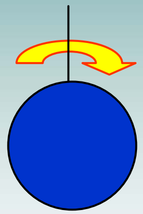
Design by P.L. Kapitza

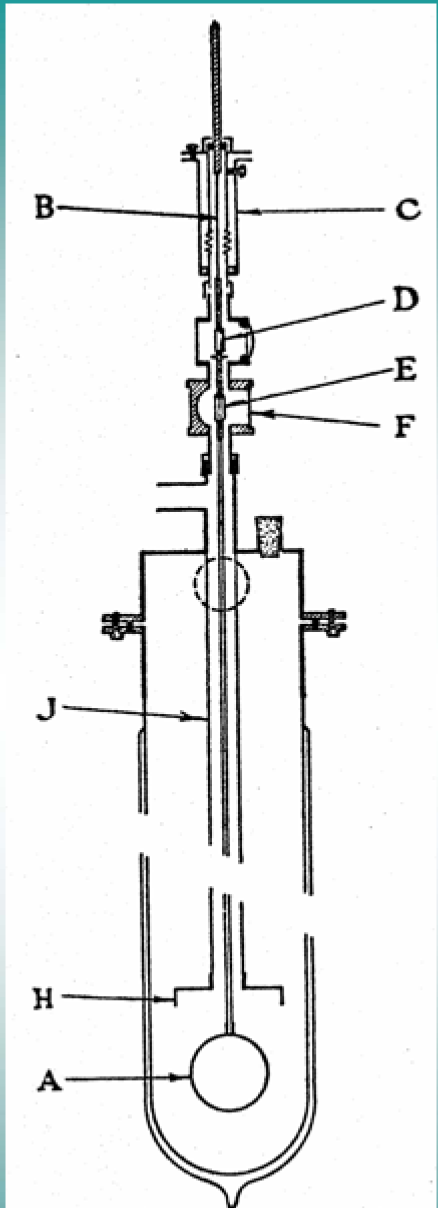


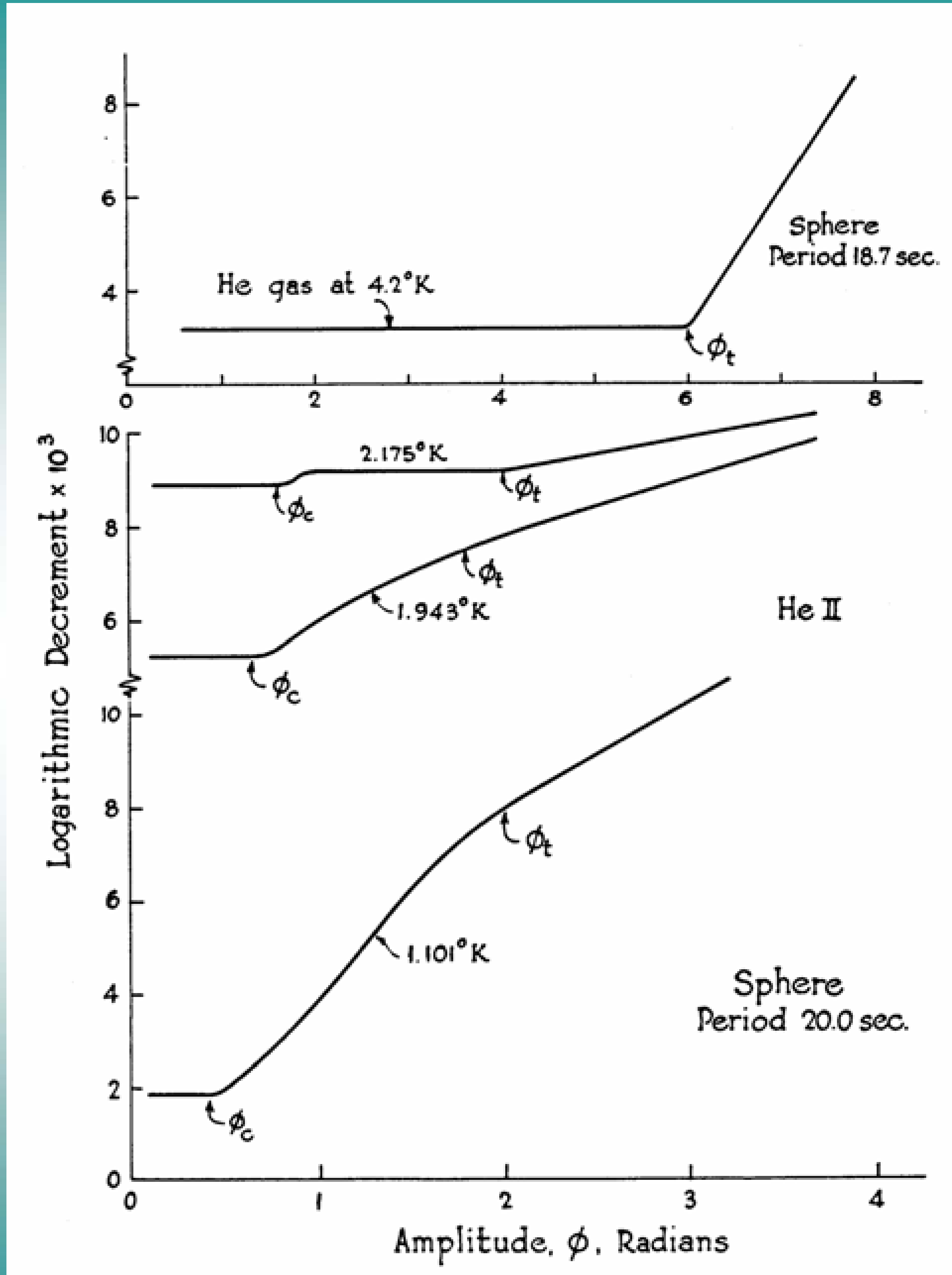


**The variation with amplitude of the damping
of an oscillating disk with a period of 11.0 s**

Torsionally oscillating sphere





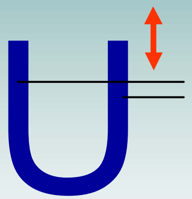


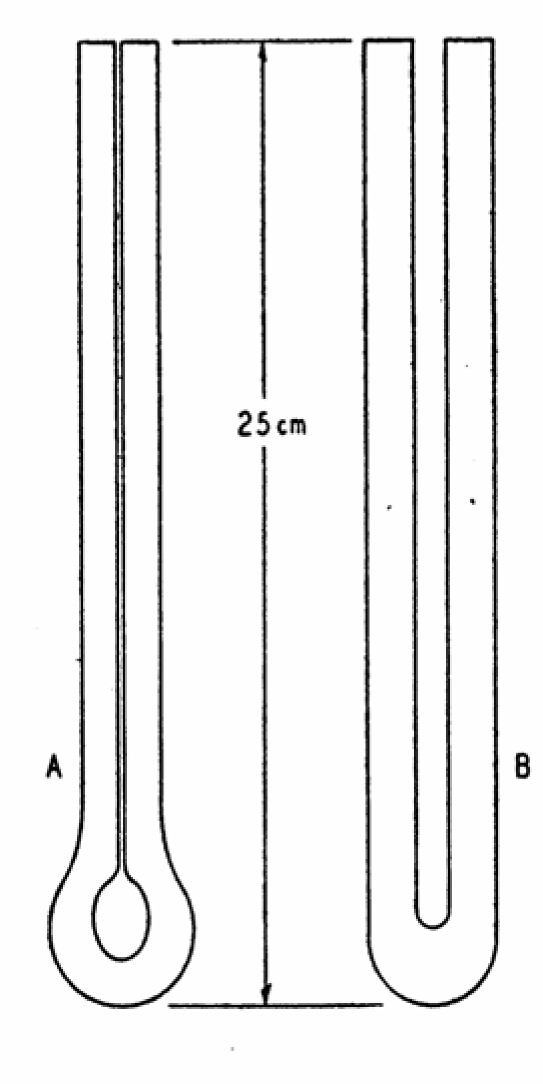
The cryostat of Benson and Hollis Hallett for torsionally oscillating sphere experiments

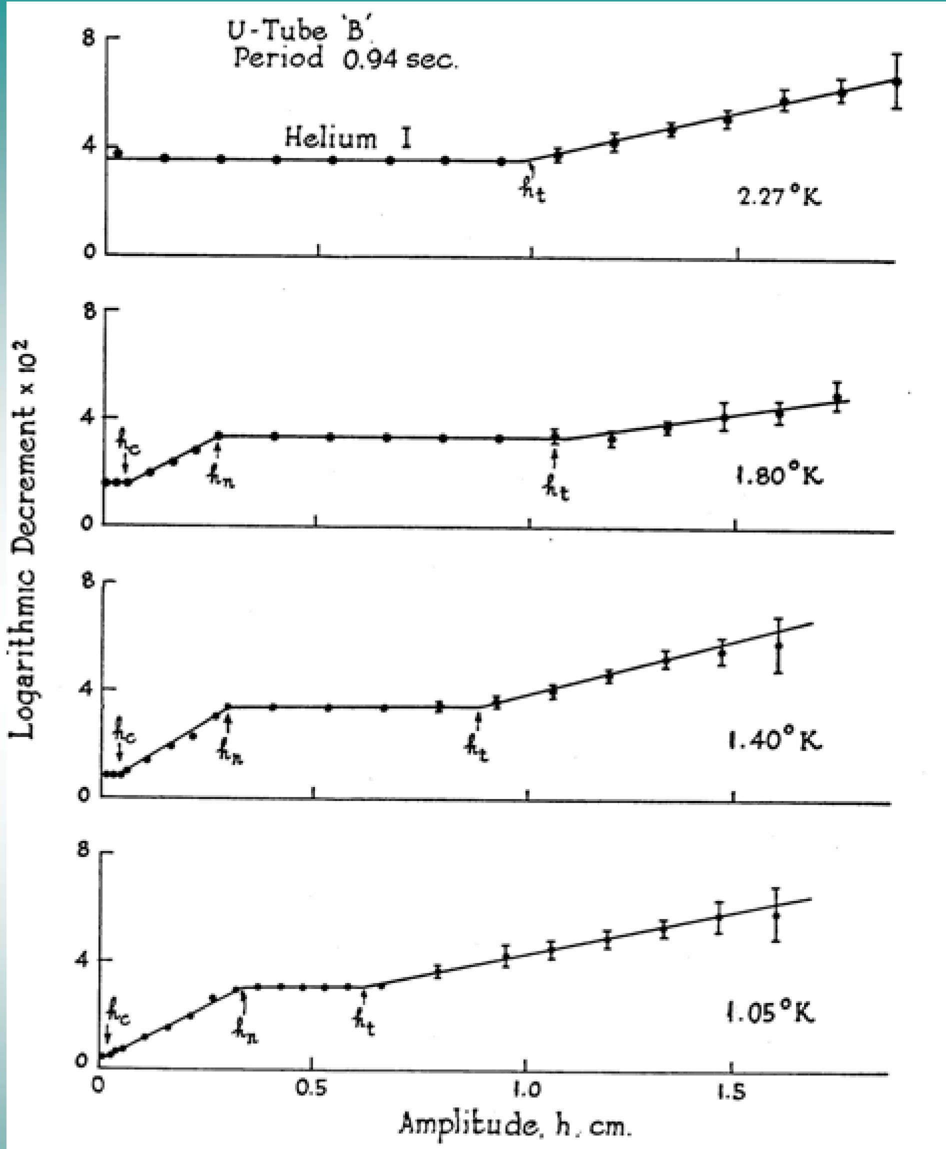
C.B. Benson and A.C. Hollis Hallett: Can. J. Phys. 34 (1956) 668

U-tubes

Donnelly
Penrose







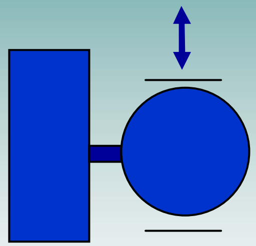
U-tubes used by Donnelly and Penrose

R.J. Donnelly, O. Penrose Phys Rev. 103 (1956) 1137

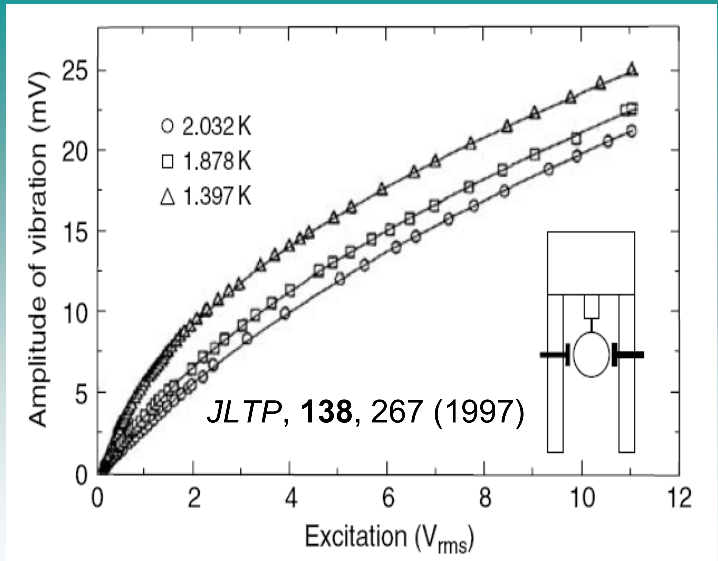
R.J. Donnelly, A.C. Hollis Hallett: Annals of Physics 3 (1958) 320

The variation with amplitude of the damping of gravity oscillations of liquid helium in a *U* – tube at a period of 0.94 sec.

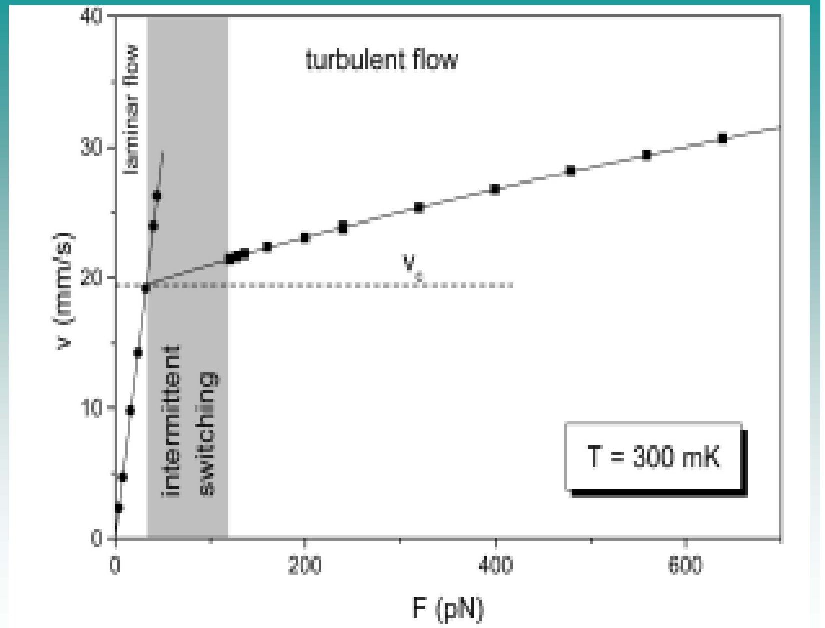
Tranversally oscillating sphere

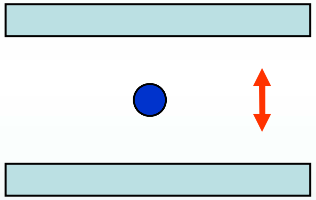


Luzuriaga



Nice data, but no calibration provided



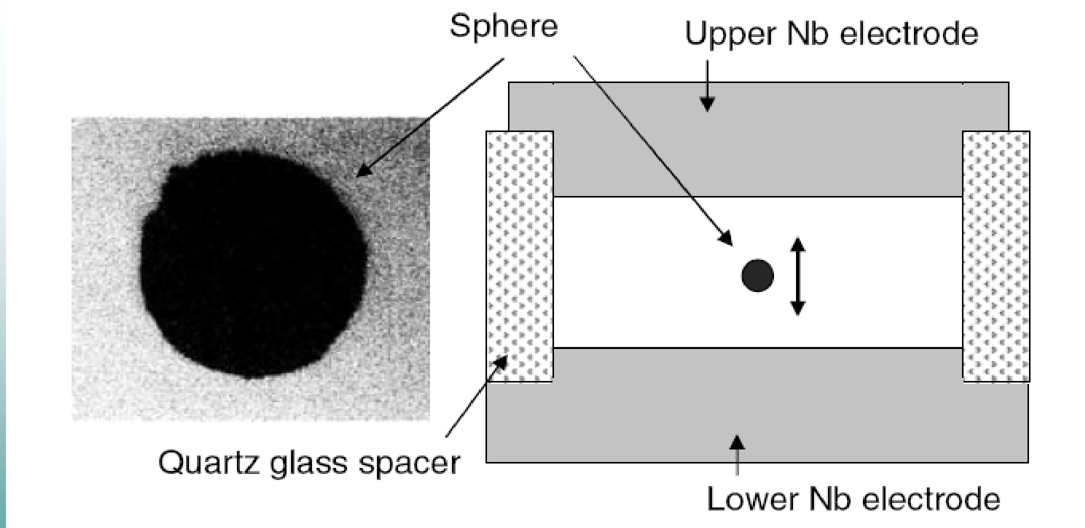


Schoepe *et al*

University of Regensburg, Germany

S. VanSciver *et al*

Florida State University



Niemetz, M., Kerscher, H. and Schoepe, W. JLTP **126**, 287(2002)
Jäger, J., Schuderer, B. and Schoepe, W. PRL **74**, 566 (1995)

Grid

P.V.E. McClintock *et al*

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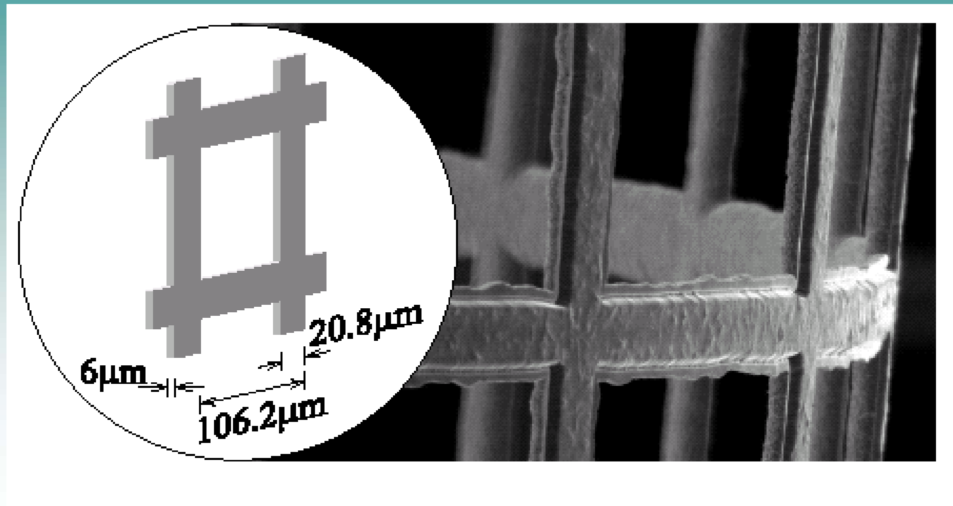
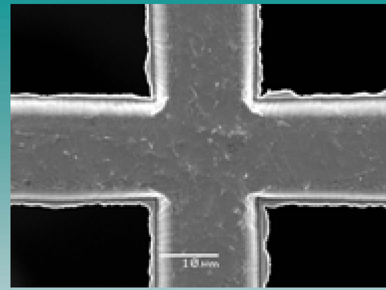
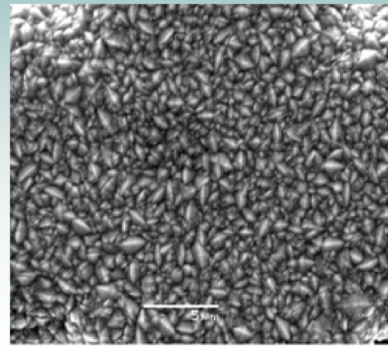
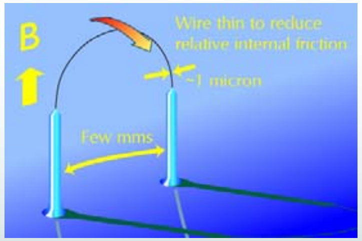






Wires
(numerous exp.)



大阪市立大学

H. Yano *et al*

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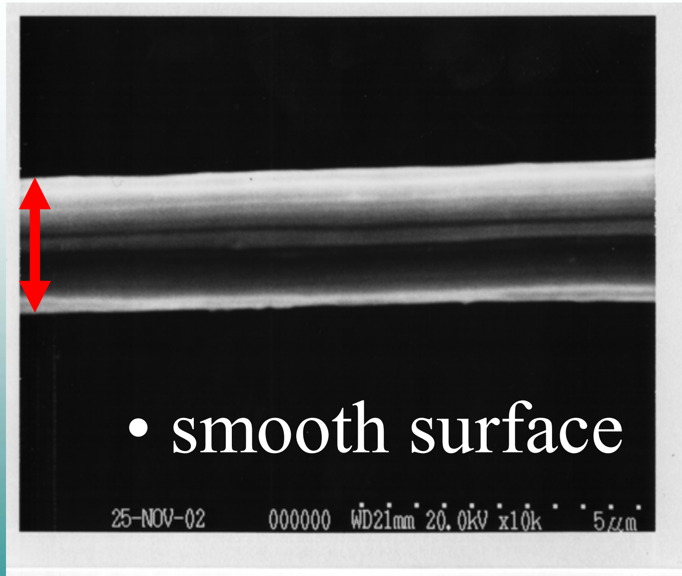
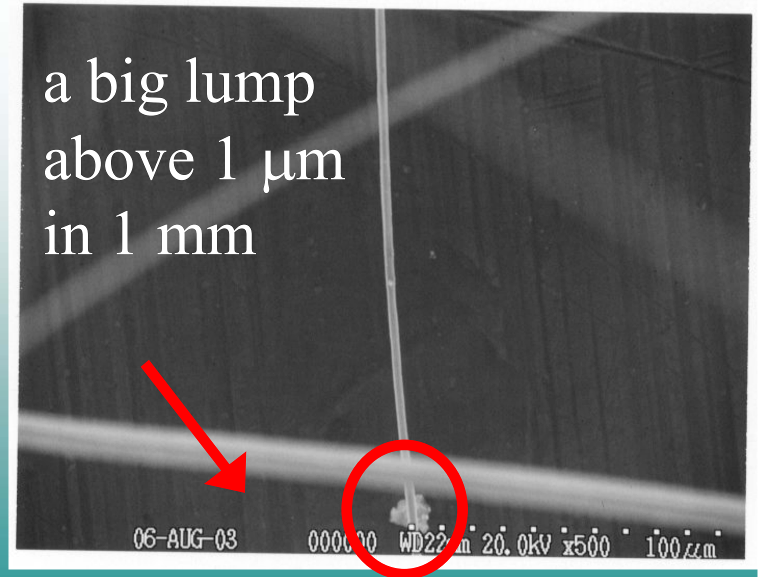
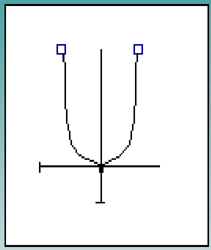
G. Pickett *et al*





Quartz tuning forks



Commercially produced piezoelectric oscillators, used as frequency standards in watches (2^{15} Hz = 32 768 Hz at room temperature)

- a probe to investigate physical properties of cryogenic fluids, especially gaseous He, He I, He II and ^{3}He-B
- Cheap, robust, widely available, easy to install and use, extremely sensitive ($Q \approx 10^5 – 10^6$ in vacuum at low T)

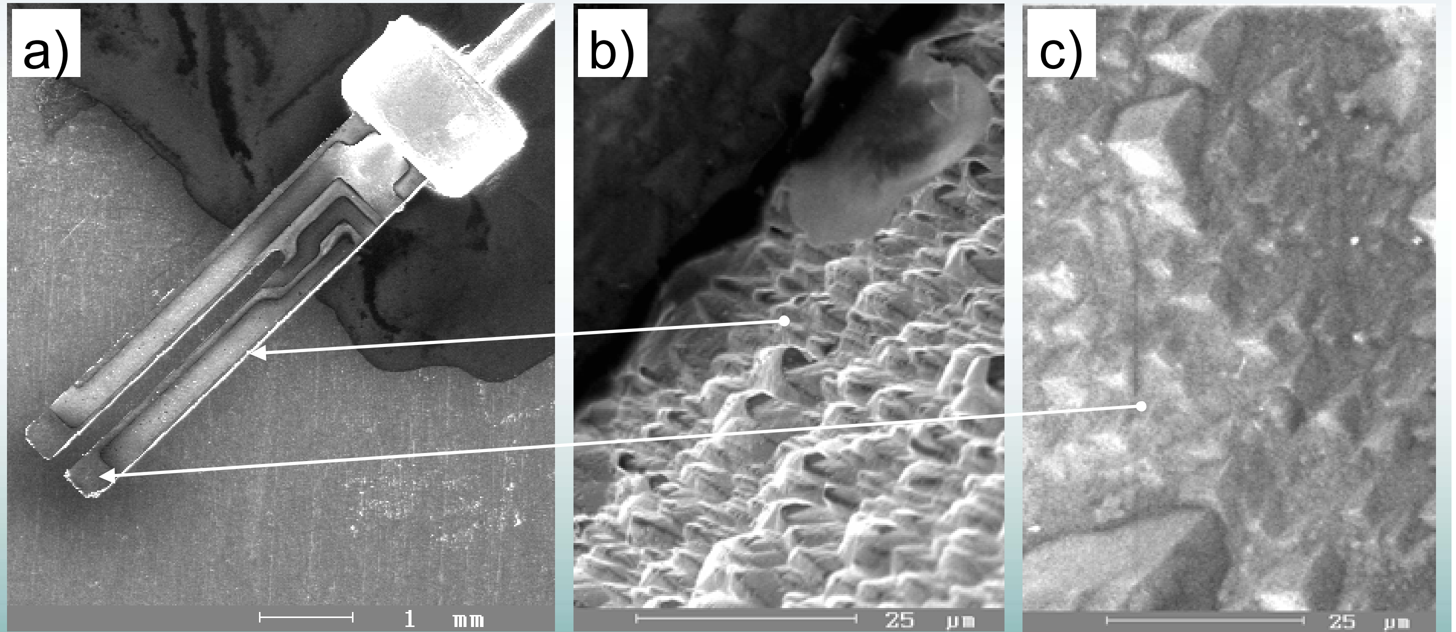
Prague

Lancaster, Košice

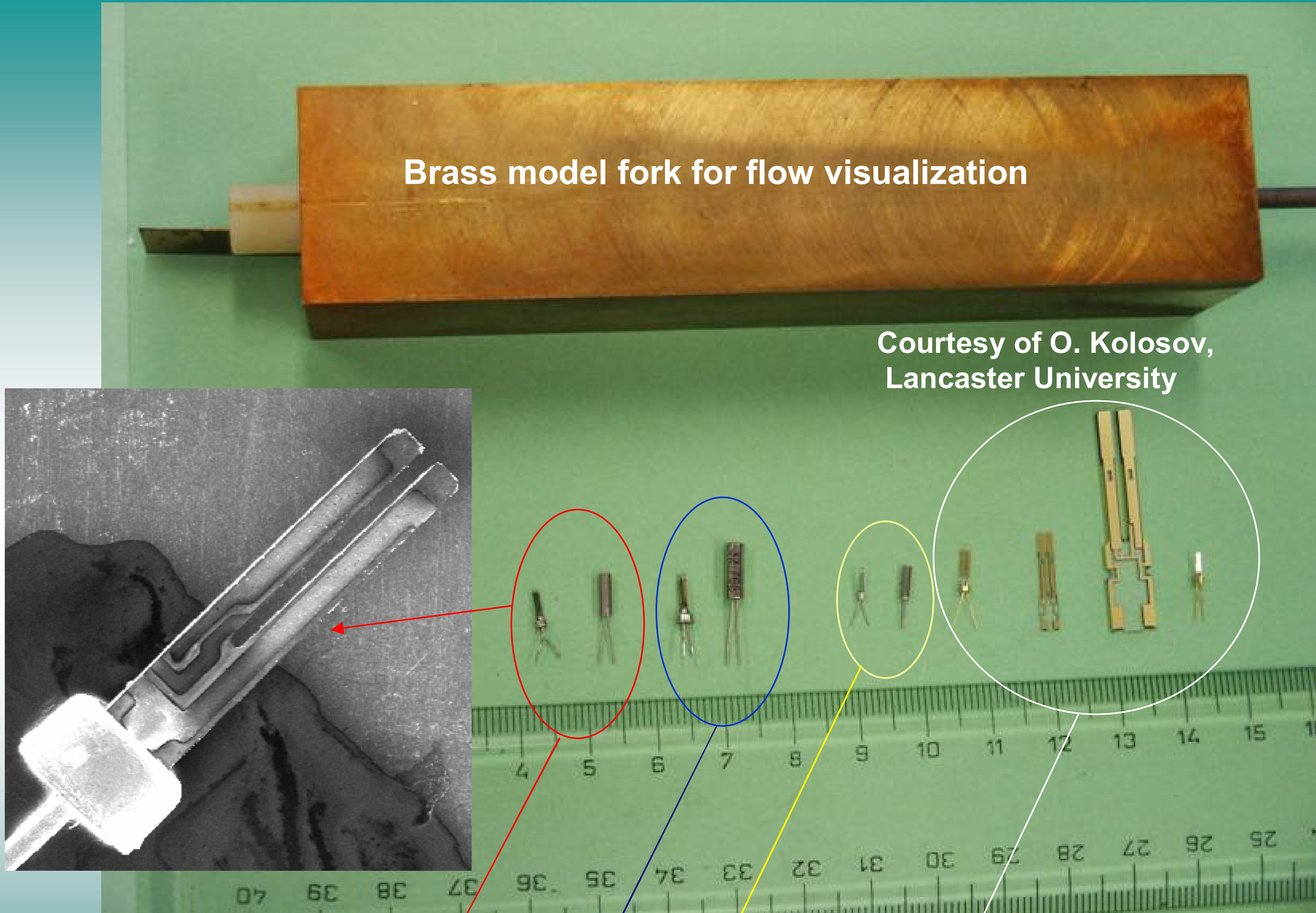
Osaka

Regensburg, Kharkov

Birmingham, Helsinki



An electron micrograph of the quartz tuning fork (a) and details of its side (b) and top (c) quartz surface.

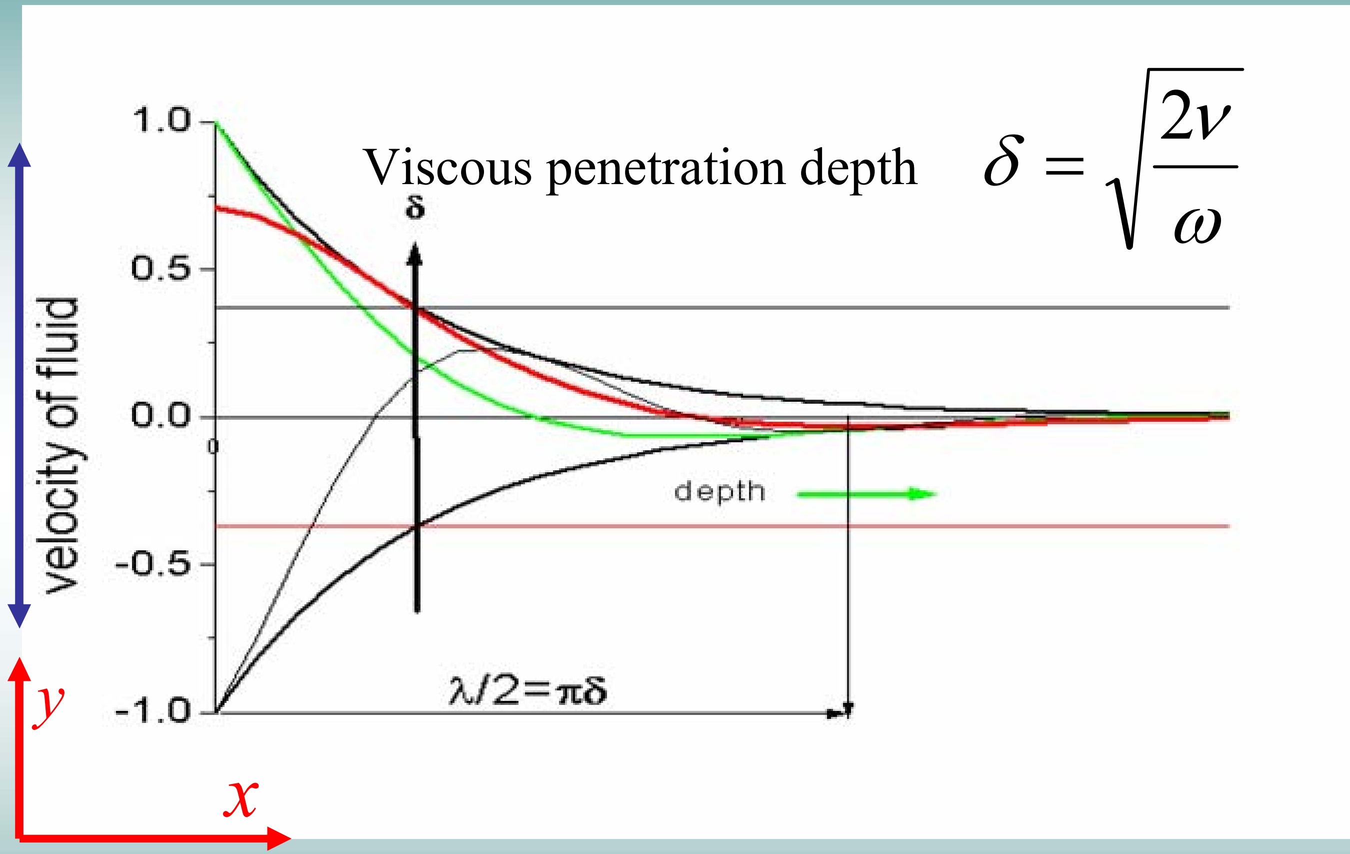


Standard fork, type A, 32 kHz
Standard fork, type B, 32 kHz
Smallest commercially available fork, 32 kHz

Middle sized fork, type U2, 8 kHz
Big fork, type U1, 4 kHz
Torsional fork, 74 kHz

Oscillatory (laminar) boundary layer flow

• **Simplest case – a plane oscillating along itself in a viscous fluid**



There is a viscous wave with rapidly decreasing amplitude inside the fluid

$$\mathbf{v}_y = \mathbf{v}_0 \exp\left\{-\frac{x}{\delta}\right\} \exp\{i[\frac{x}{\delta} - \omega t]\}$$

Drag force ~ (i+1), phase shifted by π/4

Oscillations of a submerged body in a viscous fluid laminar flow

Simple harmonic oscillator:

$$m\ddot{x} + kx = 0$$

$$m\ddot{x} + F_{damp} + kx = 0$$

damping

$$m\ddot{x} + F_{damp} + kx = F_0 \cos(\omega t) \leftarrow$$ harmonic drive

damping

Damping in a Newtonian viscous fluid:

$$F_{damp} = \Delta m\, \ddot{x} + \gamma\, \dot{x} \leftarrow$$ viscous drag

hydrodynamic mass enhancement

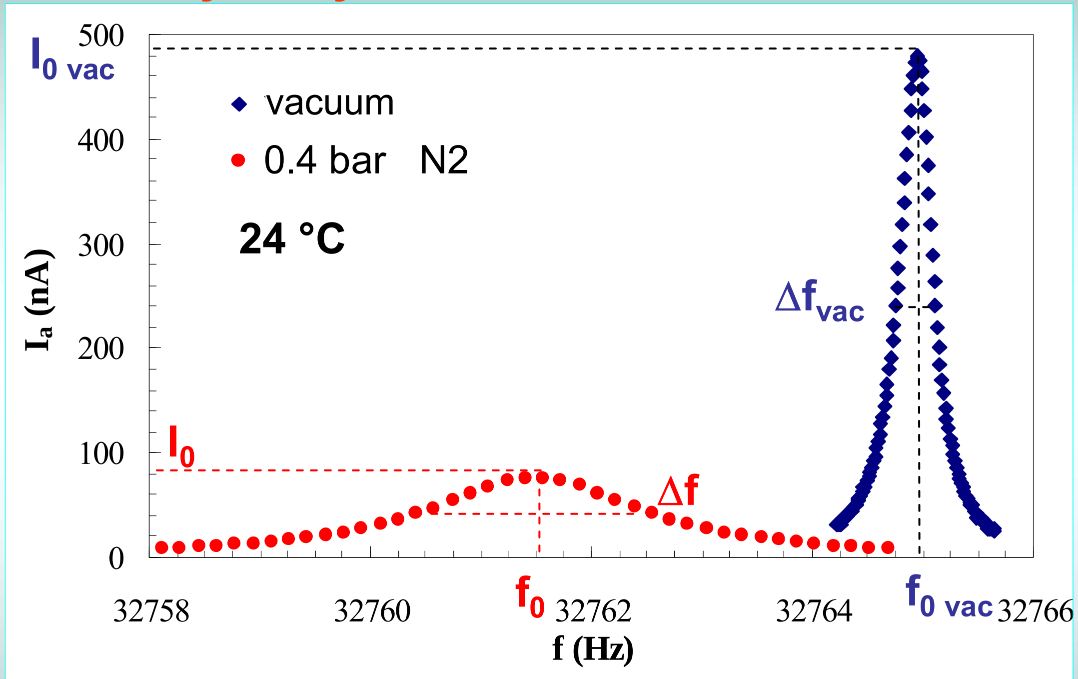
These depend on liquid density and viscosity.

! F_{damp} is phase-shifted relative to velocity

Equation of motion: $m_{eff}\, \ddot{x} + \gamma\, \dot{x} + k\, x = F_0 \cos(\omega t)$

Influence of surrounding medium on the oscillating fork

Hydrodynamic mass enhancement



$$\boxed{\Delta f,\quad f_0,\quad I_0}$$

$$\Downarrow$$

$$\boxed{\rho,\ \eta,\ v_0}$$

P. Skyba

$$\left(\frac{f_{0vac}}{f_0}\right)^2 = 1 + \frac{\rho}{\rho_f}\left(\beta + B\frac{S}{V}\sqrt{\frac{\eta}{\pi\rho f_0}}\right)$$

$$\Delta f - \Delta f_{vac} = \frac{1}{2}\sqrt{\frac{\rho\eta f_0}{\pi}}\frac{CS}{m_{vac}}\left(\frac{f_0}{f_{0vac}}\right)^2$$

ρ_f Fork's density

ρ Density of the working fluid

η Dynamic viscosity

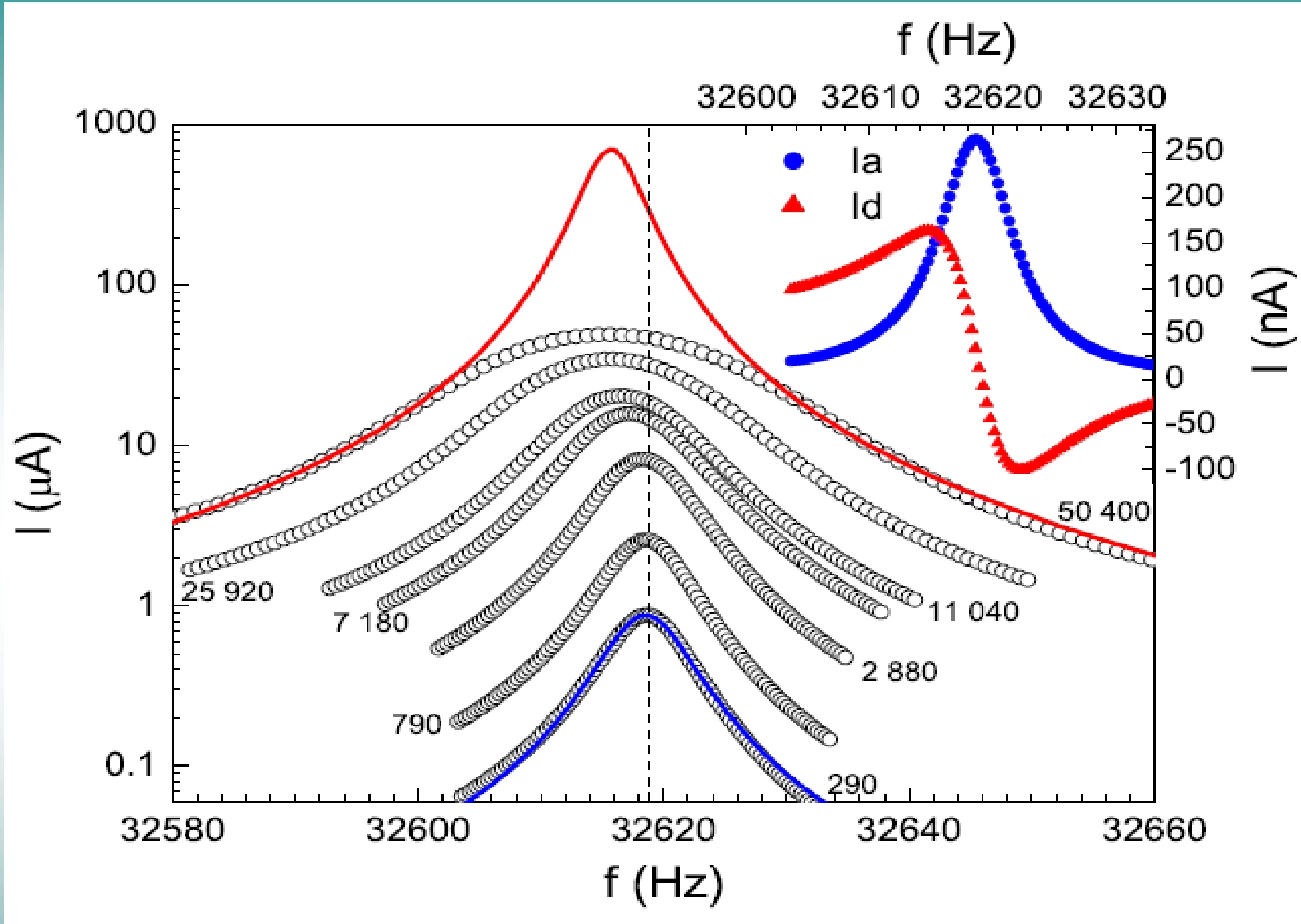
S Surface of the oscillating body

V Volume of the oscillating body

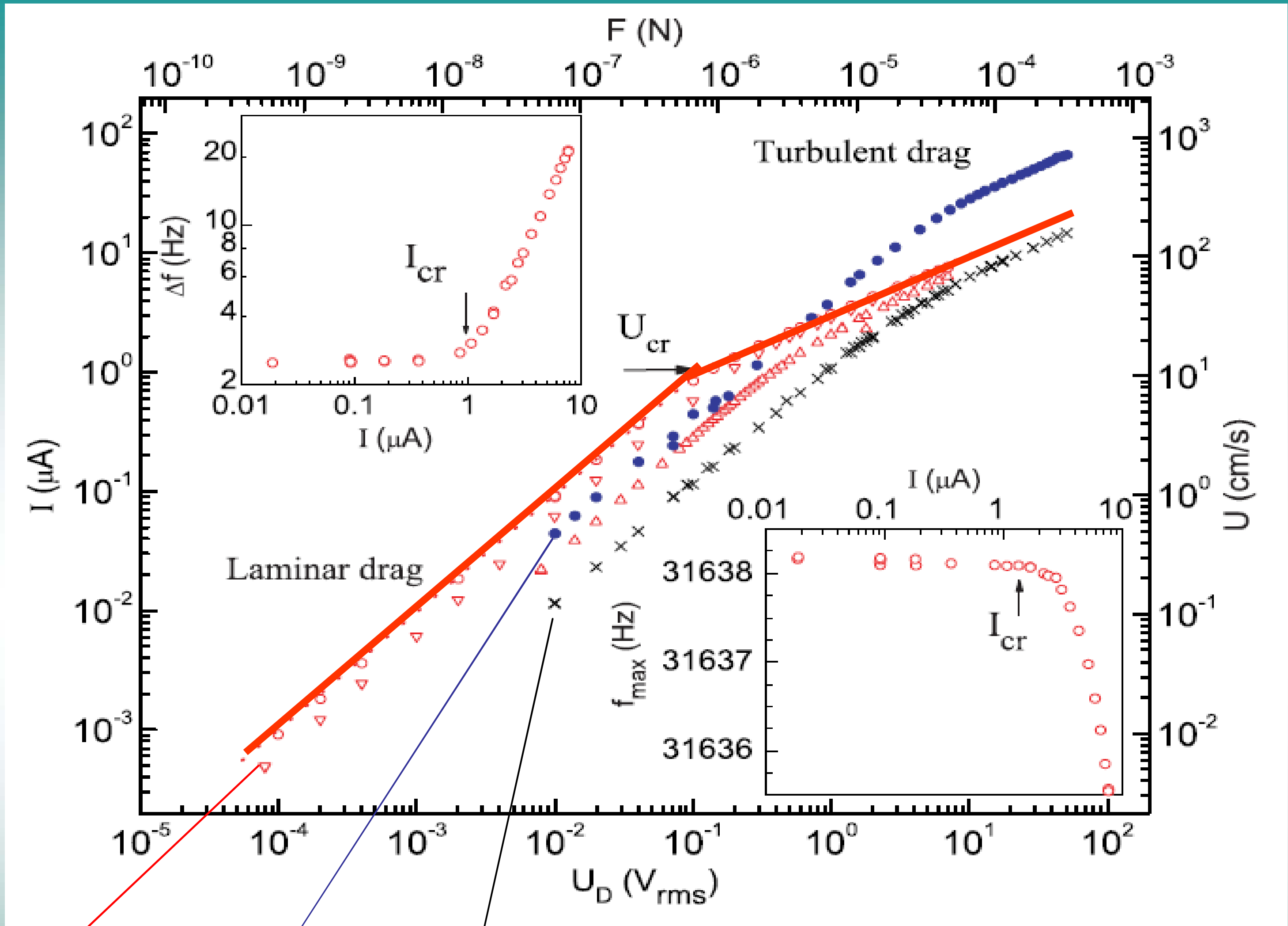
β, **B, C** numerical constants ~ geometry

β, B, C – fitting parameters, characterize determined fork

Quartz fork as a generator and detector of turbulence



The in-phase resonant response of the driven quartz fork versus applied frequency measured for various drive voltage levels (in mV_{rms}) as indicated. The solid curves are Lorentzian fits to the data.



He II cryogenic helium gas He I

^{4}He - a fluid-dynamical playground

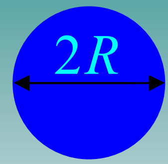
of working fluids spanning the range of kinematic viscosity: $1\cdot10^{-4}$ - $200\cdot10^{-4}$ cm^2/s

Experiments with forks in the same experimental pressure cell using the same sample of He throughout, starting with the highest density which was gradually released in order to prevent gathering of any solid particles on the fork's surface

In a flow due to an oscillating object there is an important length scale:

viscous penetration depth $\boxed{\delta = \sqrt{2\nu / \omega}}$

Exactly soluble example – an oscillating sphere in the limit $\delta << R$

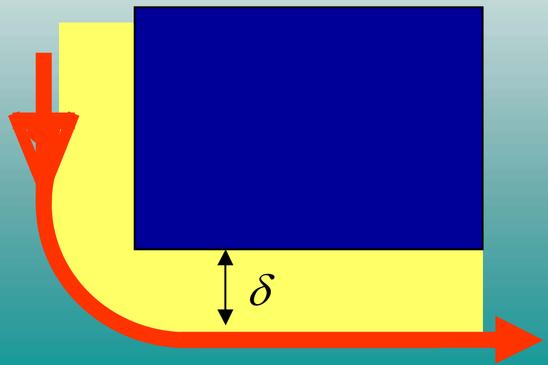


Laminar drag force $$F_{lam} = \lambda U = 6\pi\eta \mathrm{R} \mathrm{U} \left(1 + \frac{\mathrm{R}}{\delta}\right)\Bigg|_{R>>\delta} \simeq 6\pi\eta \mathrm{R} \frac{\mathrm{R}}{\delta} \mathrm{U}$$

Turbulent drag force $$F_{turb} = \gamma U^2 = 0.5\ \mathrm{C_D} \pi\rho \mathrm{R}^2 U^2$$

Crossover $$U_C = \frac{\lambda}{\gamma} = \frac{6}{C_D}\sqrt{2\nu\omega} \simeq 21\sqrt{\nu\omega}$$

This gives about: 10 cm/s **for a sphere of any size, oscillating at 200 Hz**
1.3 m/s **for a sphere of any size, oscillating at 32 kHz**
(factor of 4 higher than what is observed for our forks)
in He I at SVP right above the superfluid transition



velocity enhancement at the corner (L&L)

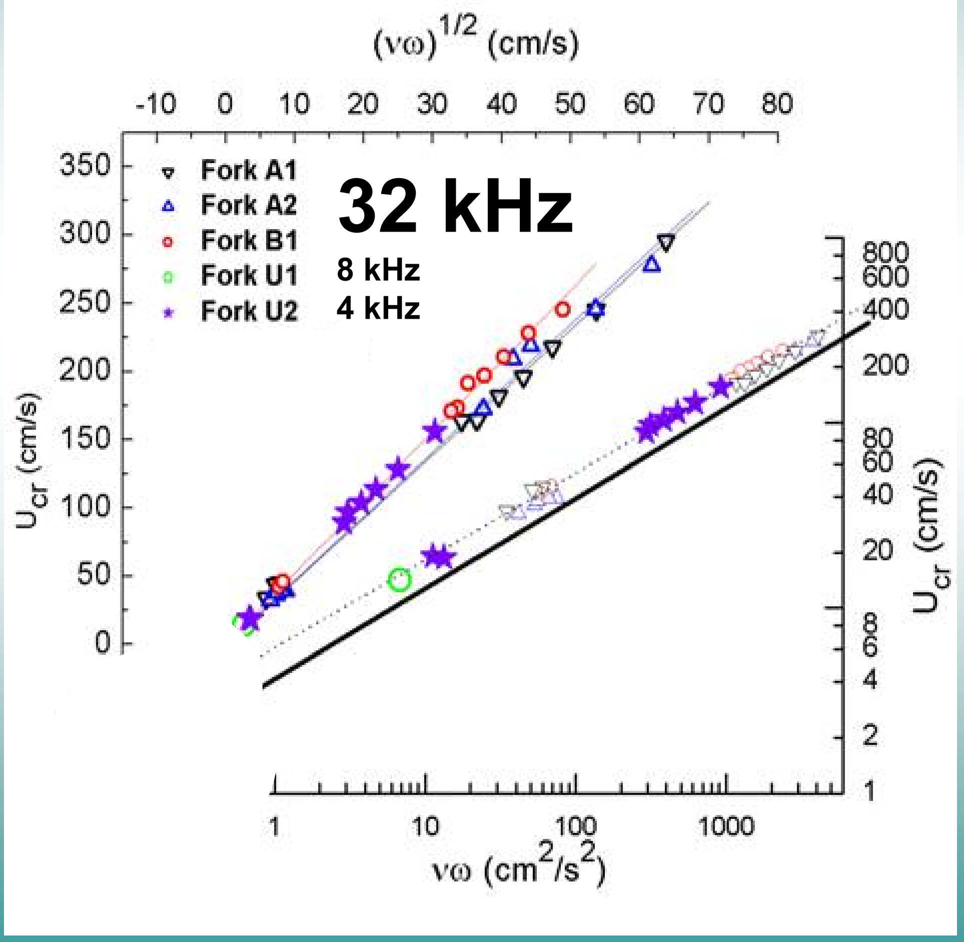
$$U_{enh} \approx \left(d / r\right)^{1/3} U \approx 5\ U$$

gives better agreement with the experiment

Critical velocities (classical fluids)

Critical velocity scaling:

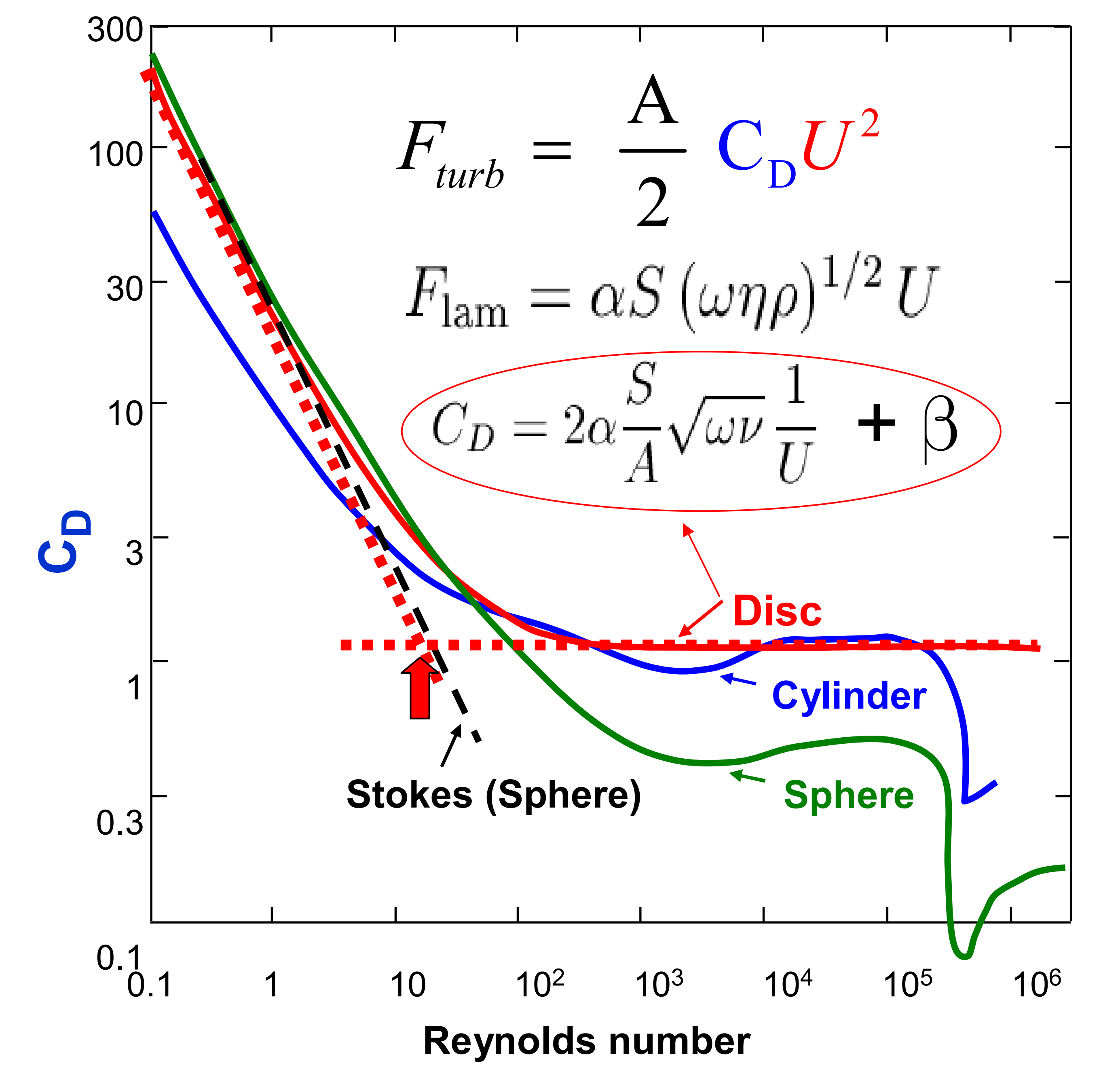
$$U_C \approx \sqrt{\nu\omega}$$



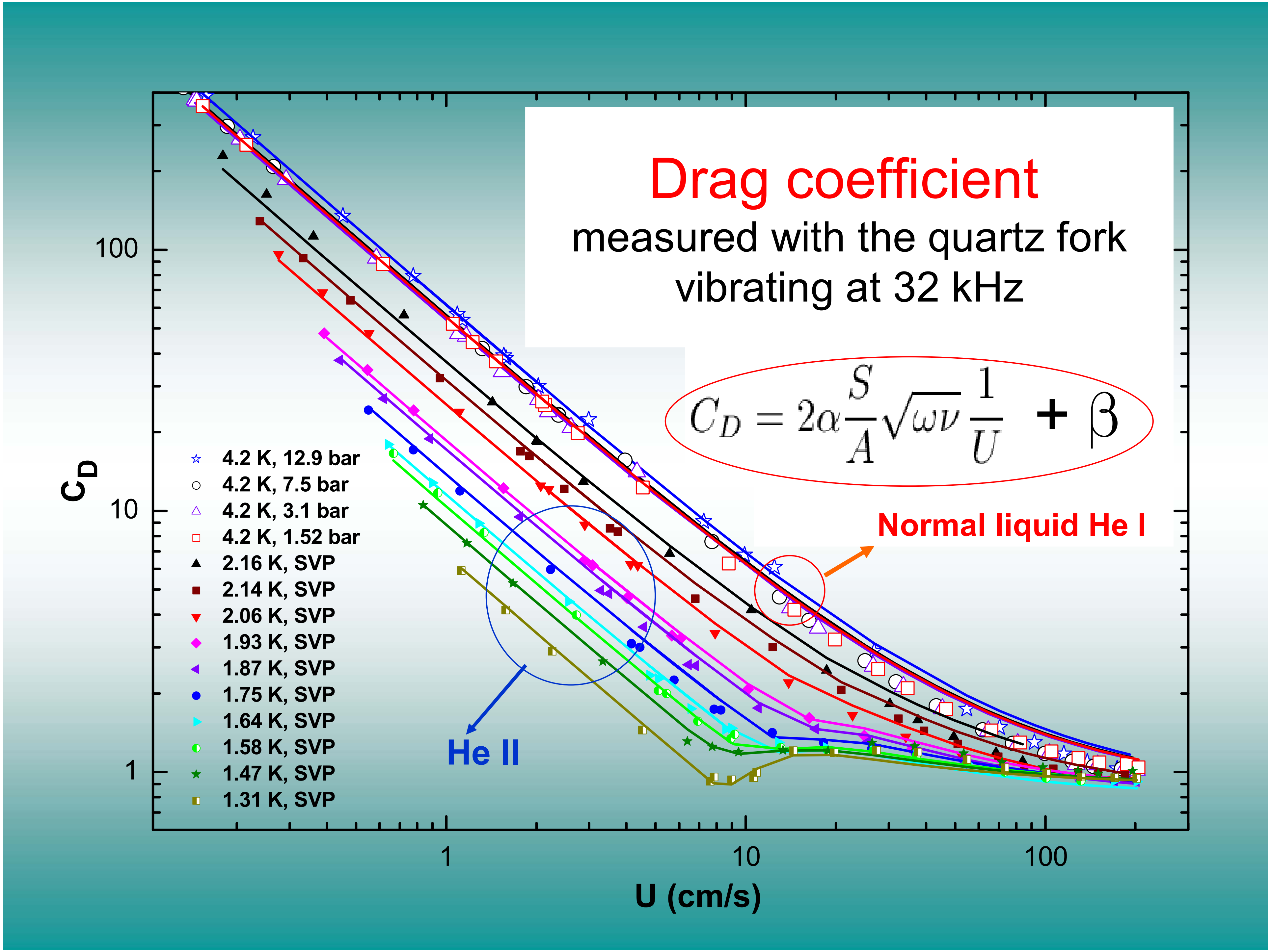
It is experimentally verified (using He I at SVP and elevated pressures and He gas at nitrogen temperature as working fluids) that this scaling indeed holds.

The logarithmic graph gives a gradient 0.48 ± 0.04

M. Blažková, D. Schmoranzer, L. Skrbek, *Phys. Rev. E75, 025302R (2007)*



$F_{turb} = \frac{A}{2} C_D U^2$
$F_{\mathrm{lam}} = \alpha S (\omega\eta\rho)^{1/2} U$
$C_D = 2\alpha \frac{S}{A}\sqrt{\omega\nu}\frac{1}{U} + \beta$
Disc
Cylinder
Sphere
Stokes (Sphere)
C_D
300
100
30
10
3
1
0.3
0.1
0.1
1
10
10^2
10^3
10^4
10^5
10^6
Reynolds number


Drag coefficient
measured with the quartz fork vibrating at 32 kHz
$$C_D = 2\alpha\frac{S}{A}\sqrt{\omega\nu}\,\frac{1}{U} + \beta$$
Normal liquid He I
He II
4.2 K, 12.9 bar
4.2 K, 7.5 bar
4.2 K, 3.1 bar
4.2 K, 1.52 bar
2.16 K, SVP
2.14 K, SVP
2.06 K, SVP
1.93 K, SVP
1.87 K, SVP
1.75 K, SVP
1.64 K, SVP
1.58 K, SVP
1.47 K, SVP
1.31 K, SVP
C_D
U (cm/s)
1
10
100
1
10
100

Assumption – transition is a two-step process:

First: at U_{cS} a dense random vortex tangle is created resulting in building up of an effective kinematic viscosity and He II behaves quasiclassically, mimicking the classical boundary layer flow

Second: This quasiclassical flow displays transition from (quasi)laminar to (quasi)turbulent drag regime

Mathematical expression of these ideas is:

$$C_{\mathrm{D}} = 2\alpha \frac{S}{A} (\omega x_{\mathrm{e}} \nu_{\mathrm{e}})^{1/2} \frac{1}{U} + x_{\mathrm{e}} \beta \,,$$

where

$$x_{\mathrm{e}} = x + (1 - x)\Phi(U - U_{\mathrm{cS}}) \frac{(U - U_{\mathrm{cS}})^2}{\varepsilon + (U - U_{\mathrm{cS}})^2} \,;$$

$$\nu_{\mathrm{e}} = \nu + (\nu_{\mathrm{c}} - \nu)\Phi(U - U_{\mathrm{cS}}) \frac{(U - U_{\mathrm{cS}})^2}{\varepsilon + (U - U_{\mathrm{cS}})^2} \,;$$

Classical viscous fluids

$$C_D = 2\alpha \frac{S}{A} \sqrt{\omega \nu} \frac{1}{U} + \beta$$

U **velocity amplitude**

$\Phi(y)$ **Heaviside step function**

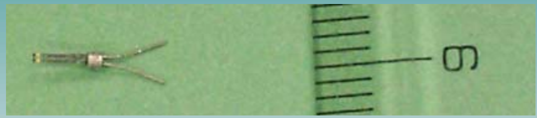
ν_{c} **Eff. kin. visc. of fully coupled fluids**

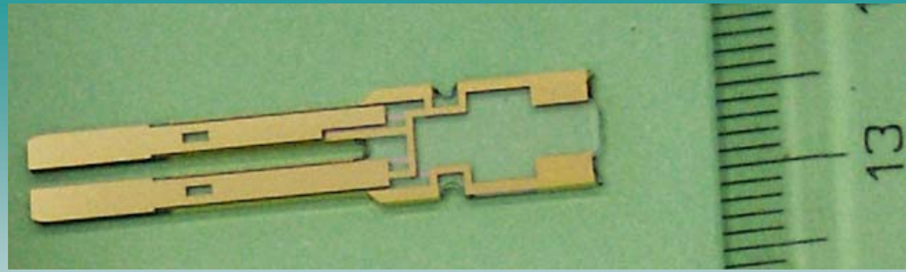
α, β and ε **constants**

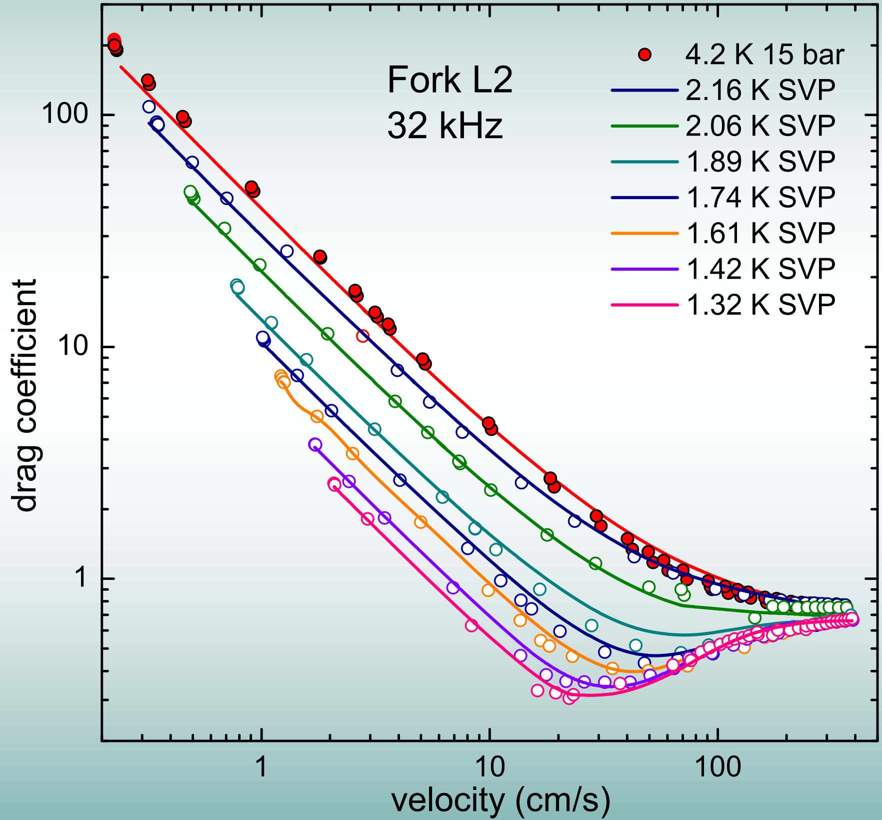
$\nu = \eta_{\mathrm{n}} / \rho$

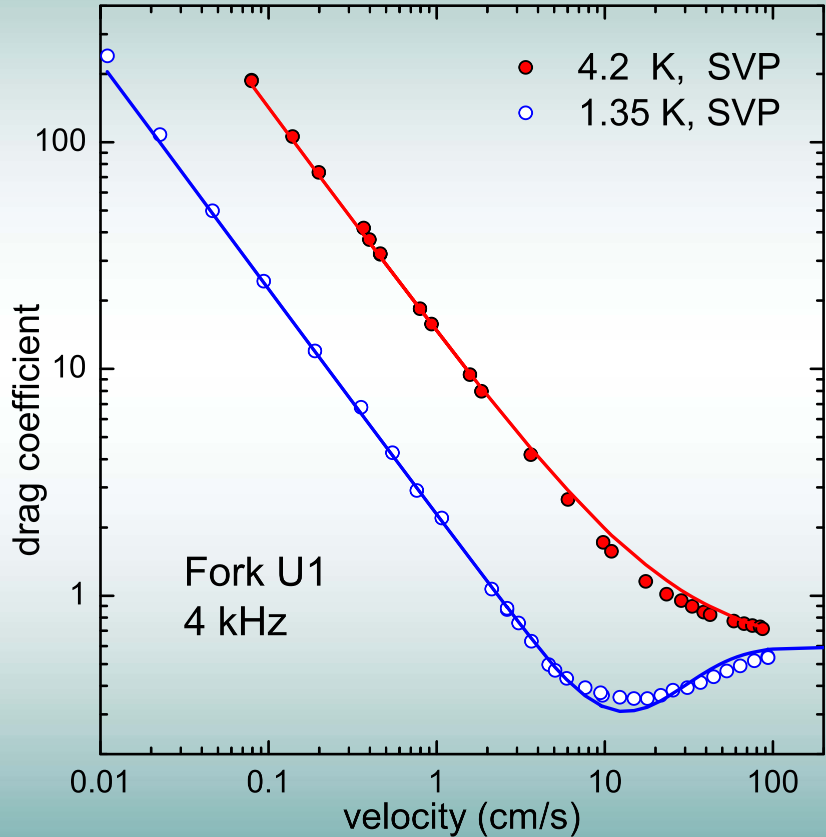
L. Skrbek, W.F. Vinen: „The Use of Vibrating Structures in the Study of Quantum Turbulence“ Chapter 4 in Progress in Low Temp. Physics XVI, Halperin Tsubota ed., Springer 2009

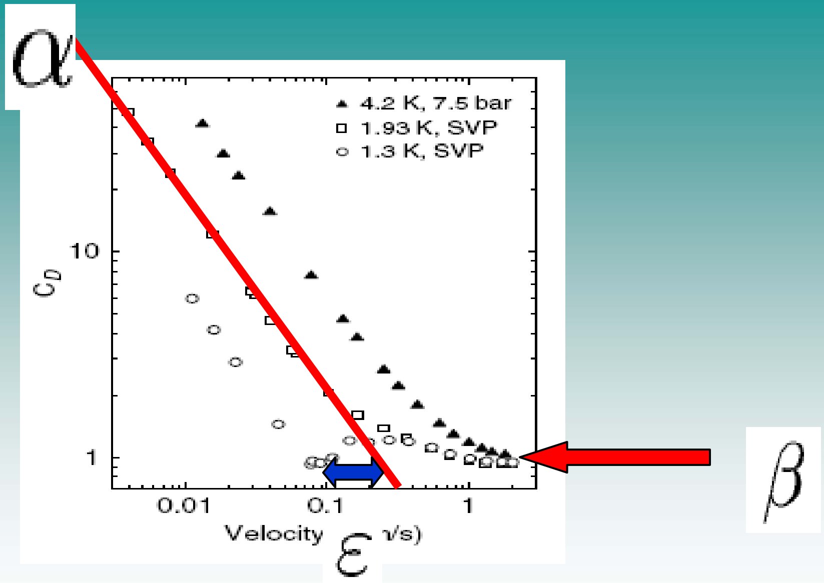
Detailed approach see Blazkova, Schmoranzer, Skrbek, Vinen: Phys. Rev. B79, 054522 (2009)

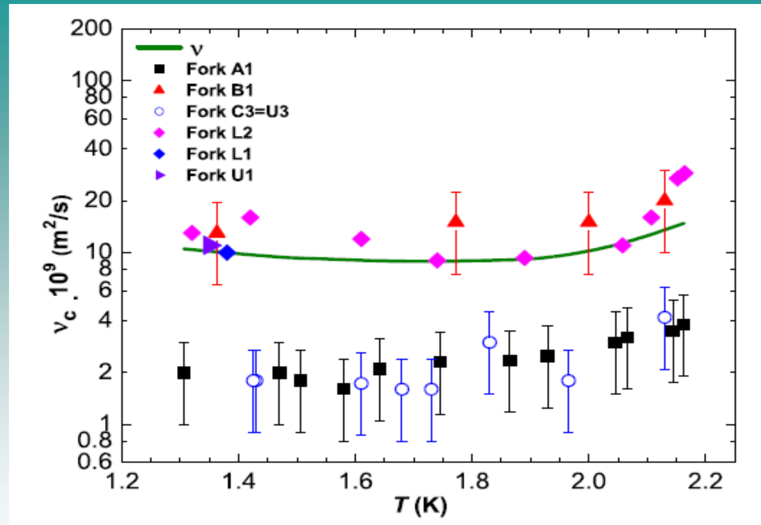





Fork L2
32 kHz
4.2 K 15 bar
2.16 K SVP
2.06 K SVP
1.89 K SVP
1.74 K SVP
1.61 K SVP
1.42 K SVP
1.32 K SVP
drag coefficient
velocity (cm/s)
100
10
1
1
10
100


4.2 K, SVP
1.35 K, SVP
Fork U1
4 kHz
drag coefficient
velocity (cm/s)
100
10
1
0.01
0.1
1
10
100



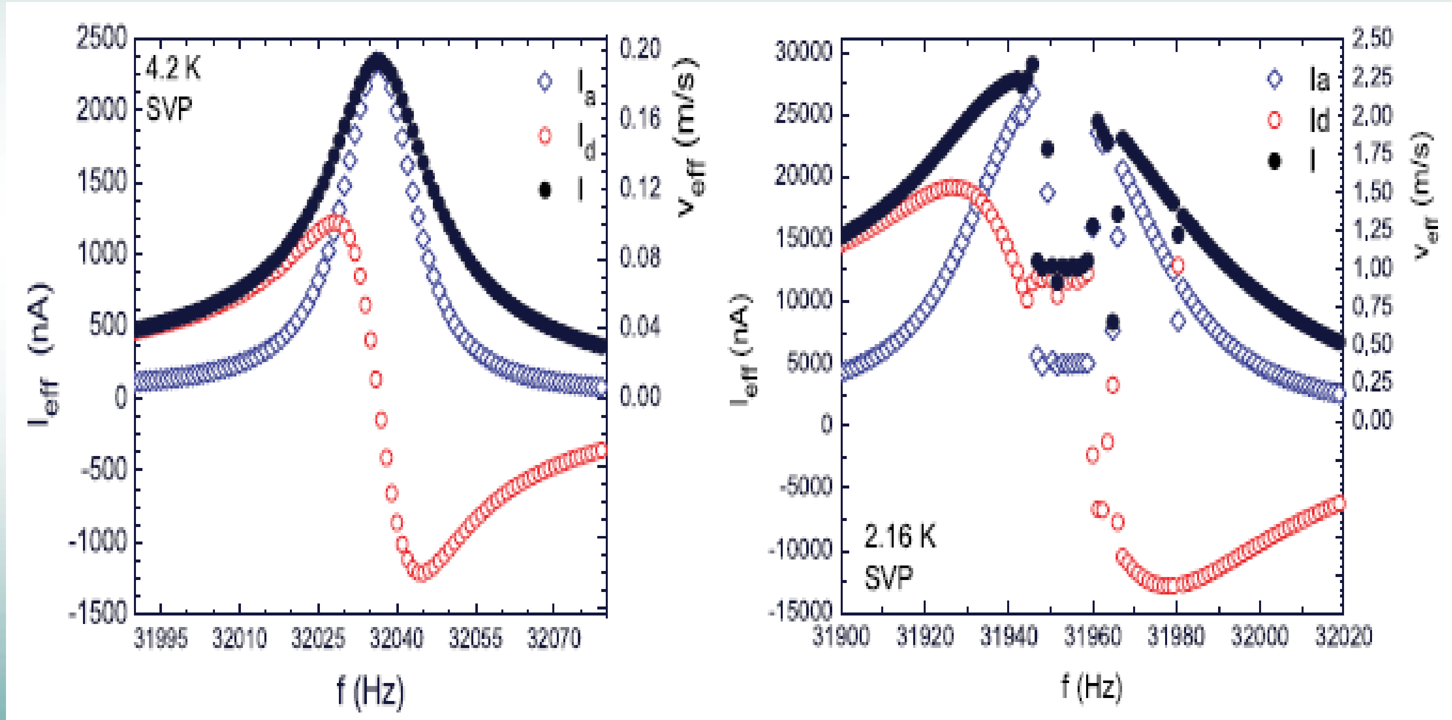


α, β and ε

do not depend on temperature

Fork	Freq kHz	L mm	T mm	W mm	D mm	α	β	ϵ
A1	32	3.71	0.42	0.35	0.21	0.72	0.85	0.015
B1	32	3.65	0.68	0.46	0.18	0.65	0.43	0.045
C3	32	2.51	0.25	0.10	0.13	0.36	0.42	0.075
U1	4	19.70	2.20	0.80		0.26	0.52	0.14
U2	8	9.50	0.45	0.90	0.50	0.27	0.5	
L2	32	2.17	0.21	0.10	0.12	0.4	0.63	0.85
L1	32	2.17	0.21	0.10	0.12	0.38	0.63	0.95
K1	32	3.9	0.39	0.28		0.55	0.85	0.003

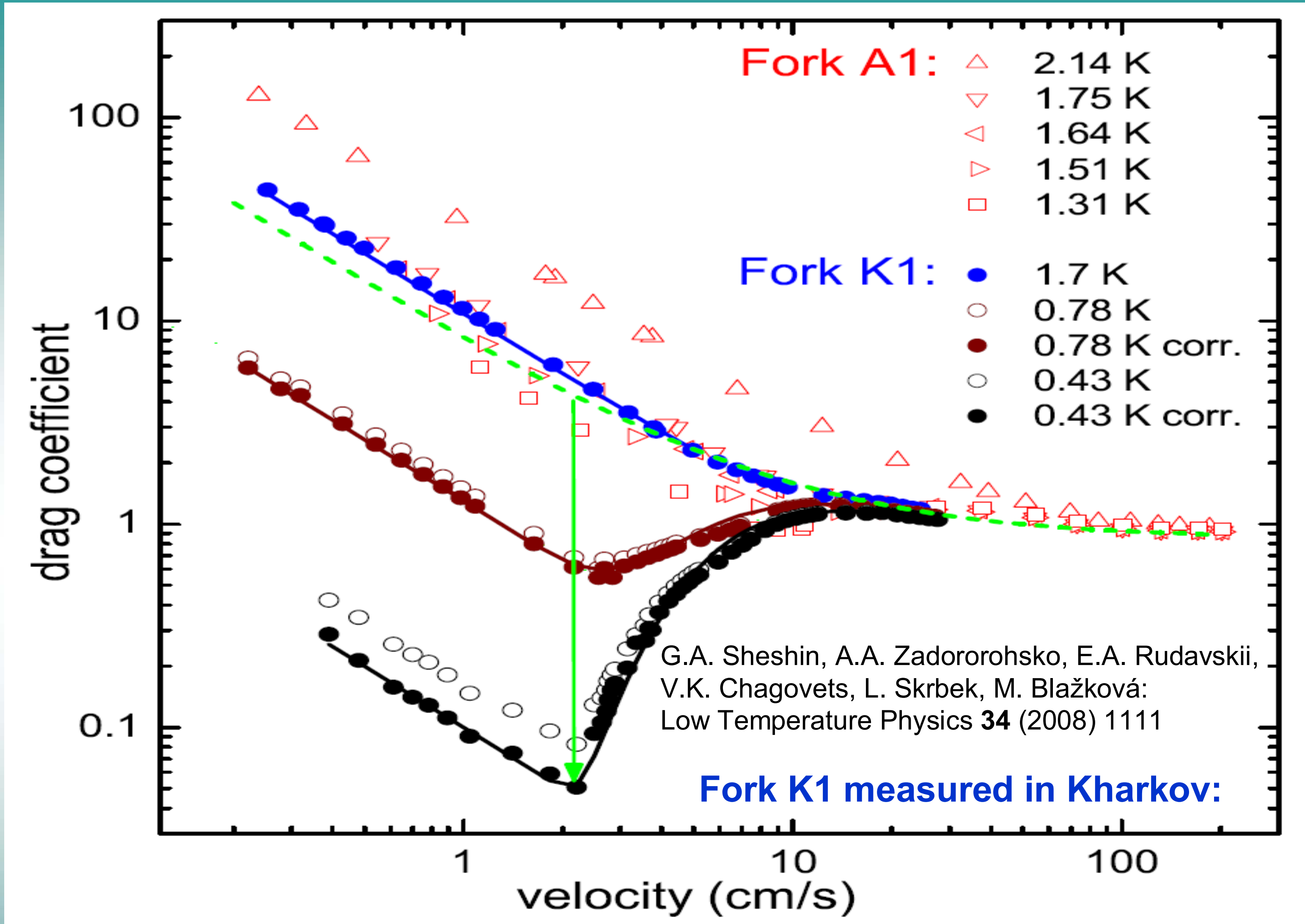
Classical and quantum cavitation in liquid 4He



M. Blažková a dr., J. Low Temp. Phys. **150**, 154 (2008)

On cavitation in liquid helium in a flow due to a vibrating quartz fork

M. Blazkova, D. Schmoranzer, L. Skrbek: Low Temp. Physics 34, 380–390 (2008)



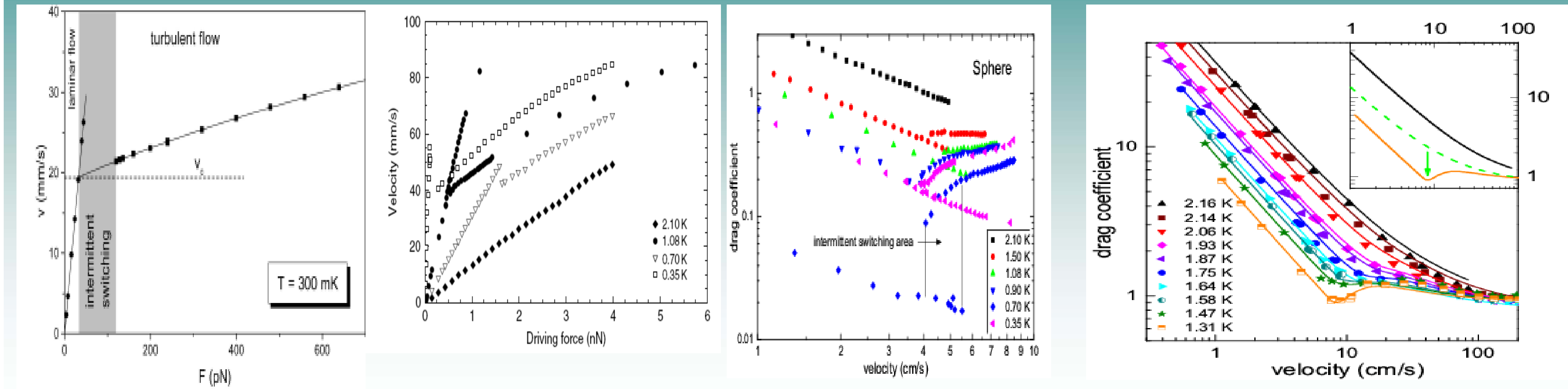
Below 1 K our model has to be modified

1. Internal damping is withdrawn
2. We put x=0 and add a linear damping term of the form

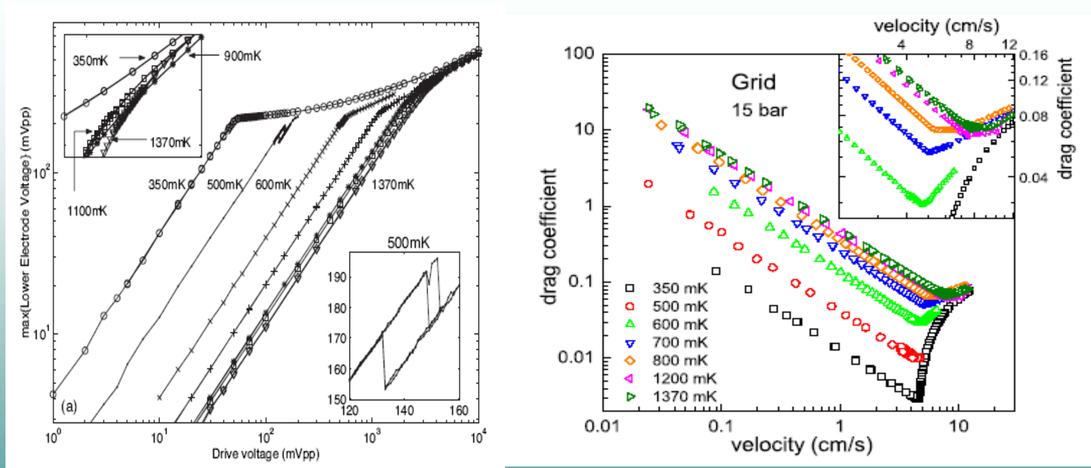
$\gamma(T)/U$ to represent the effect of the ballistic phonon scattering

$$\gamma(0.78\ \mathrm{K}) = 0.013\ \mathrm{ms}^{-1}$$
$$\gamma(0.43\ \mathrm{K}) = 0.001\ \mathrm{ms}^{-1}$$

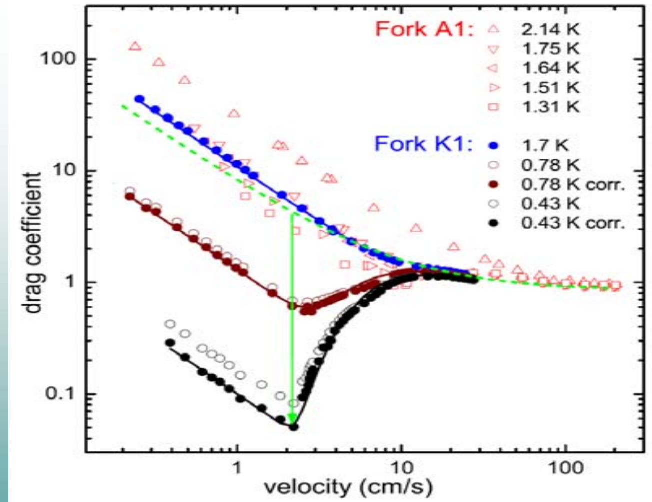
Observed drag coefficients in classical fluids and superfluid ^{4}He - "regular behaviour" with drag coefficient of oder unity at high velocities



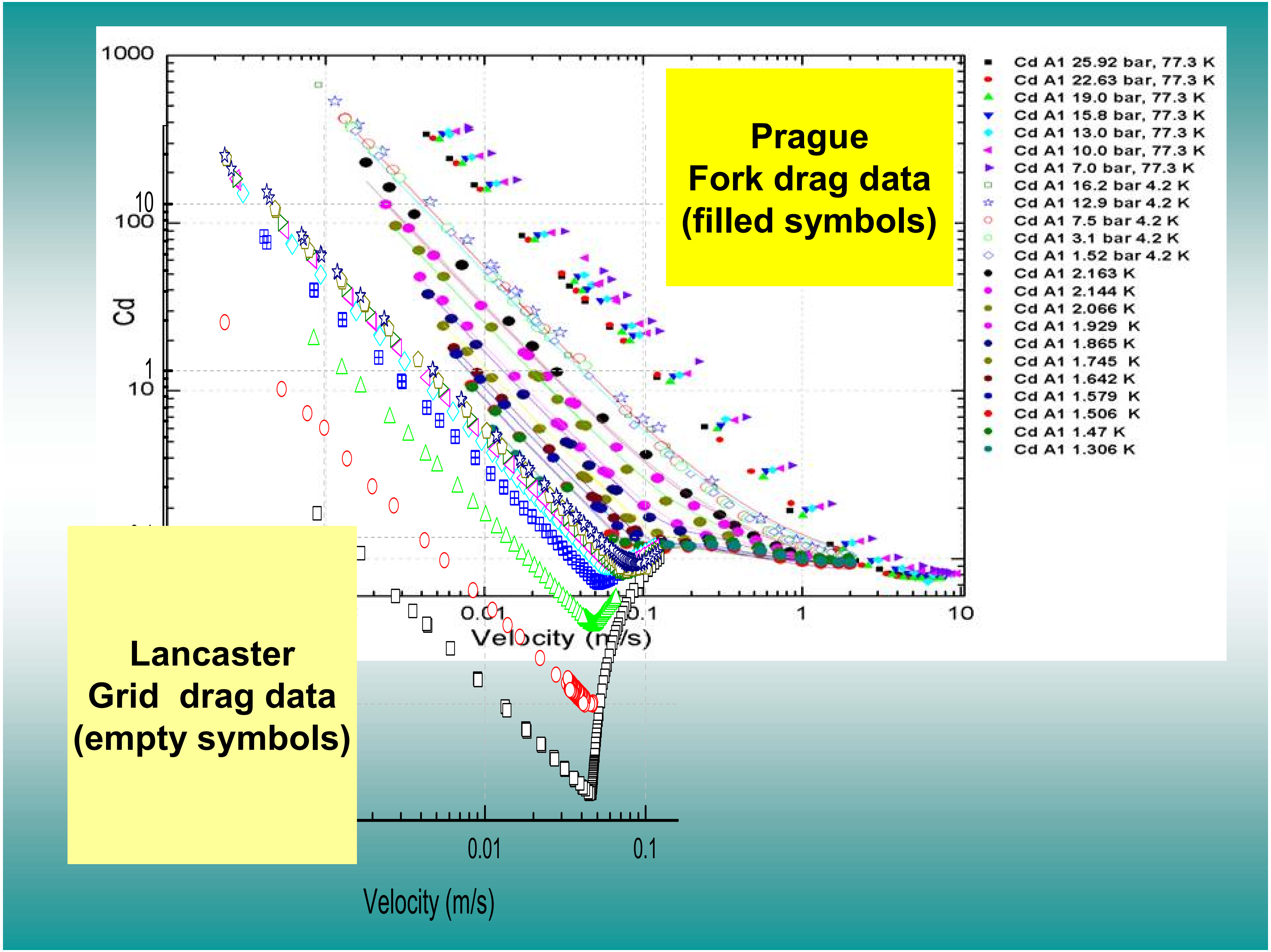
Sphere Regensburg – Schoepe et al

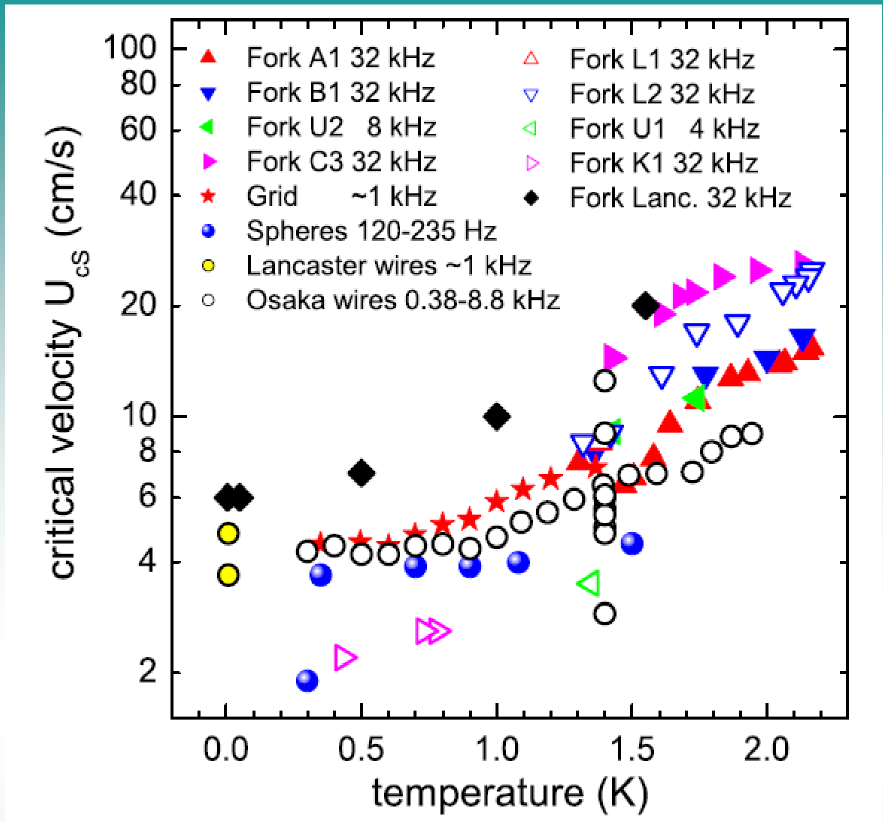


Grid Lancaster – McClintock et al



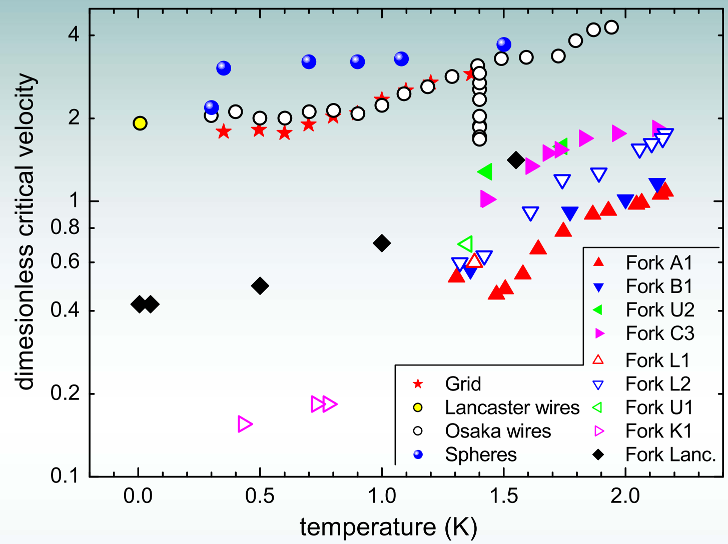
Forks Prague + Kharkov


Prague
Fork drag data
(filled symbols)
Lancaster
Grid drag data
(empty symbols)
Cd
1000
100
10
1
0.01
0.1
1
10
Velocity (m/s)
Cd A1 25.92 bar, 77.3 K
Cd A1 22.63 bar, 77.3 K
Cd A1 19.0 bar, 77.3 K
Cd A1 15.8 bar, 77.3 K
Cd A1 13.0 bar, 77.3 K
Cd A1 10.0 bar, 77.3 K
Cd A1 7.0 bar, 77.3 K
Cd A1 16.2 bar 4.2 K
Cd A1 12.9 bar 4.2 K
Cd A1 7.5 bar 4.2 K
Cd A1 3.1 bar 4.2 K
Cd A1 1.52 bar 4.2 K
Cd A1 2.163 K
Cd A1 2.144 K
Cd A1 2.066 K
Cd A1 1.929 K
Cd A1 1.865 K
Cd A1 1.745 K
Cd A1 1.642 K
Cd A1 1.579 K
Cd A1 1.506 K
Cd A1 1.47 K
Cd A1 1.306 K
0.01
0.1
Velocity (m/s)



Classical viscous fluids

$$U_C \approx \sqrt{\nu\omega}$$



$$\cancel{U_{cS} = \mathrm{const}(\omega\kappa)^{1/2}}$$

$$U_{cS} = \frac{\alpha}{2\beta}\frac{S}{A}(\omega\nu_c)^{1/2}$$

Thus we predict that the critical velocity is proportional to the square root of the frequency only if the parameters α, β, S/A and v_c are constant.

The critical velocity seems to depend to a significant extent on the detailed geometry of the structure, perhaps also on the state of roughness of the surface and it may depend also on the form of the remanent vortices.

To describe an oscillatory boundary layer flow, two dimensionless numbers are needed:

Reynolds number

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

Strouhal number

$$St = \frac{U\tau}{D}$$

Professor Čeněk Strouhal,
Charles University, Prague

Stokes number

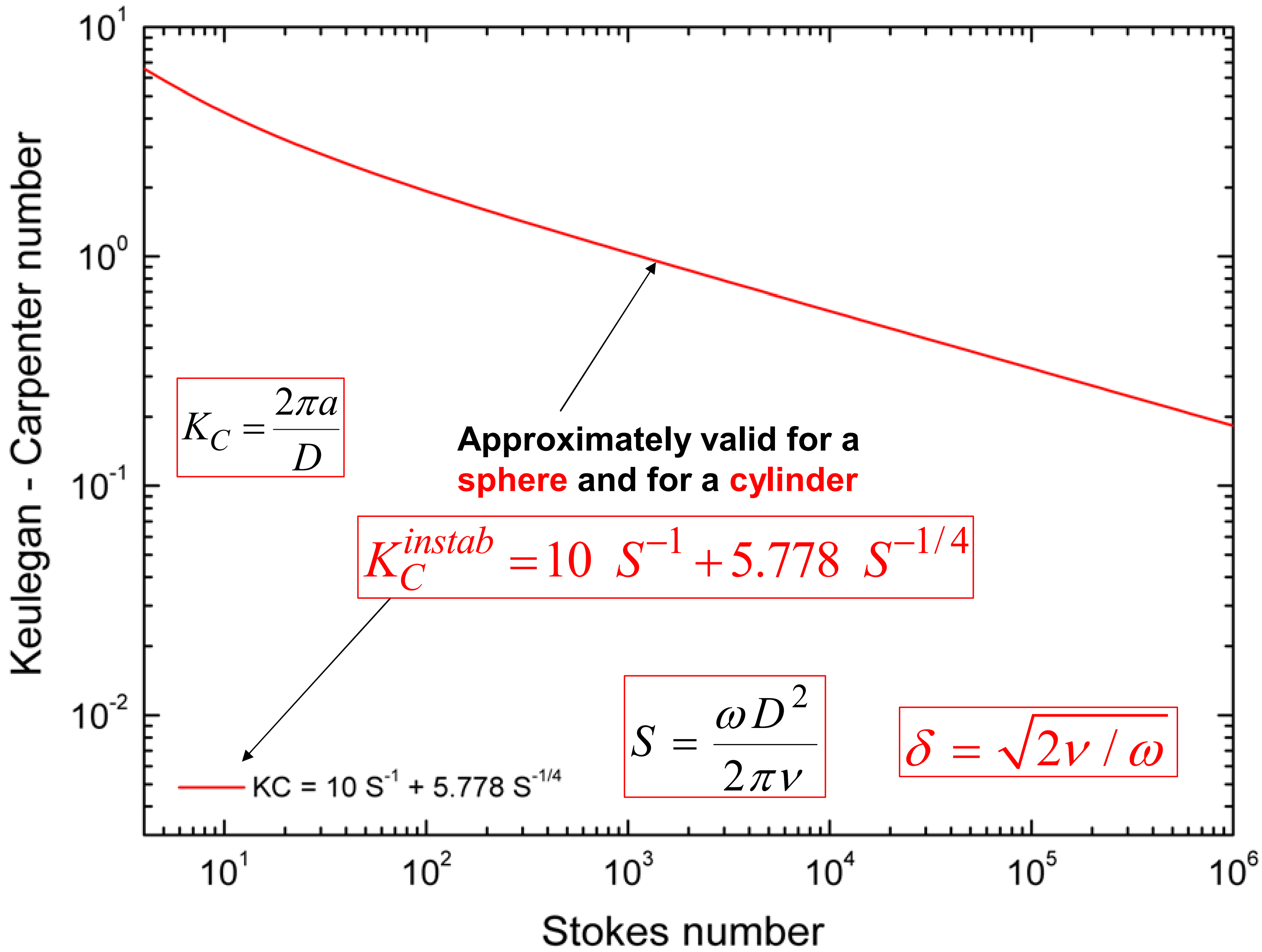
$$\boxed{S = \frac{\omega D^2}{2\pi\nu}}$$

Keulegan-Carpenter number

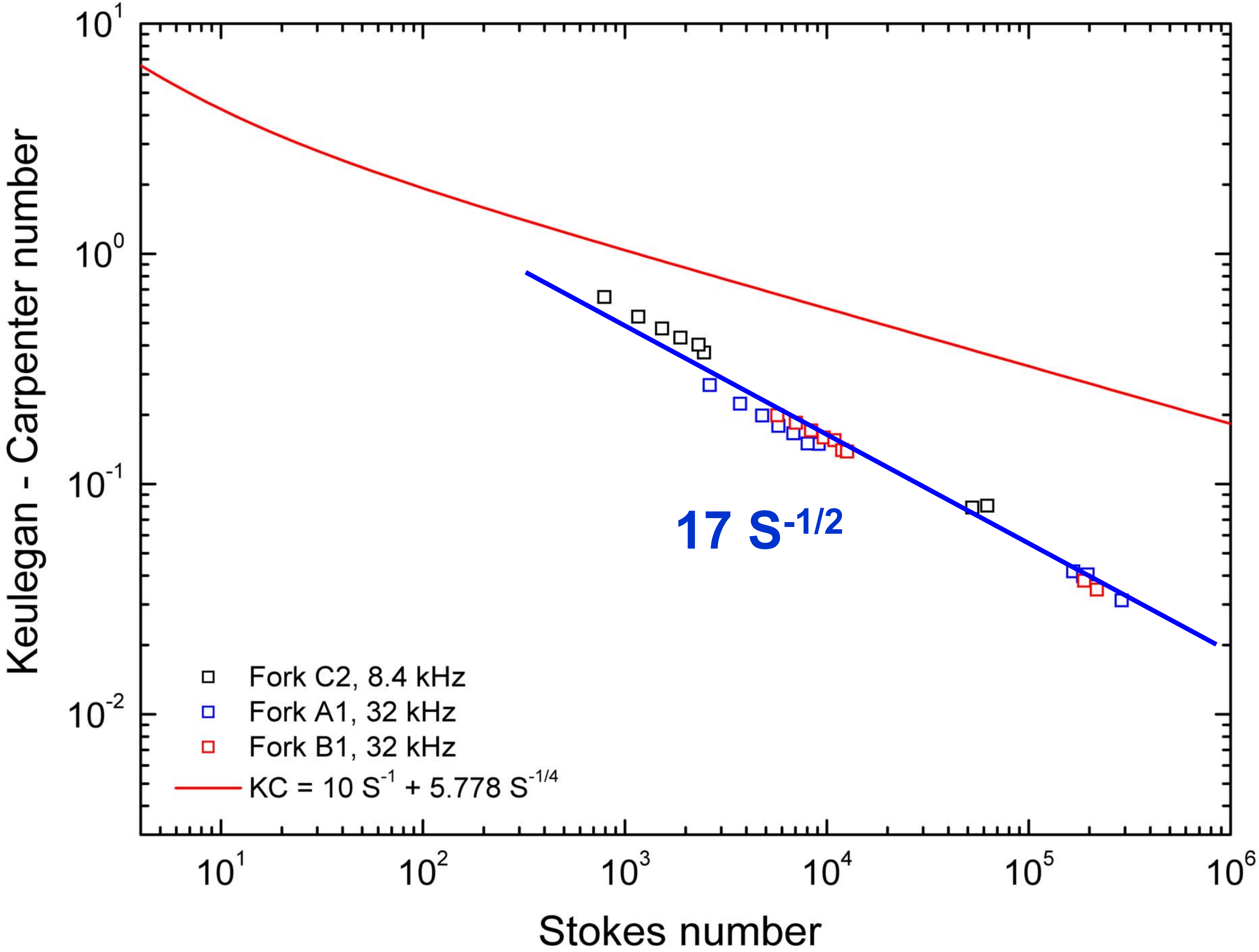
$$\boxed{K_C = St = \frac{2\pi a}{D}}$$

$$\boxed{\delta = \sqrt{\frac{2\nu}{\omega}}}$$

$$\boxed{\omega = \frac{2\pi}{\tau}}$$



Keulegan - Carpenter number
Stokes number
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}
$K_C = \frac{2\pi a}{D}$
Approximately valid for a
sphere and for a cylinder
$K_C^{instab} = 10\ S^{-1} + 5.778\ S^{-1/4}$
KC = 10 S^{-1} + 5.778 $S^{-1/4}$
$S = \frac{\omega D^2}{2\pi\nu}$
$\delta = \sqrt{2\nu / \omega}$

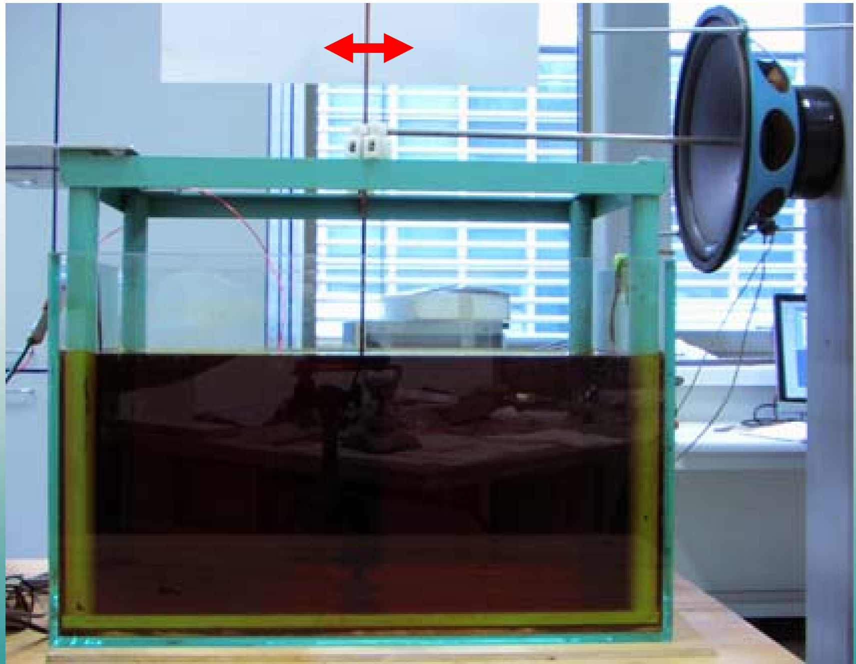


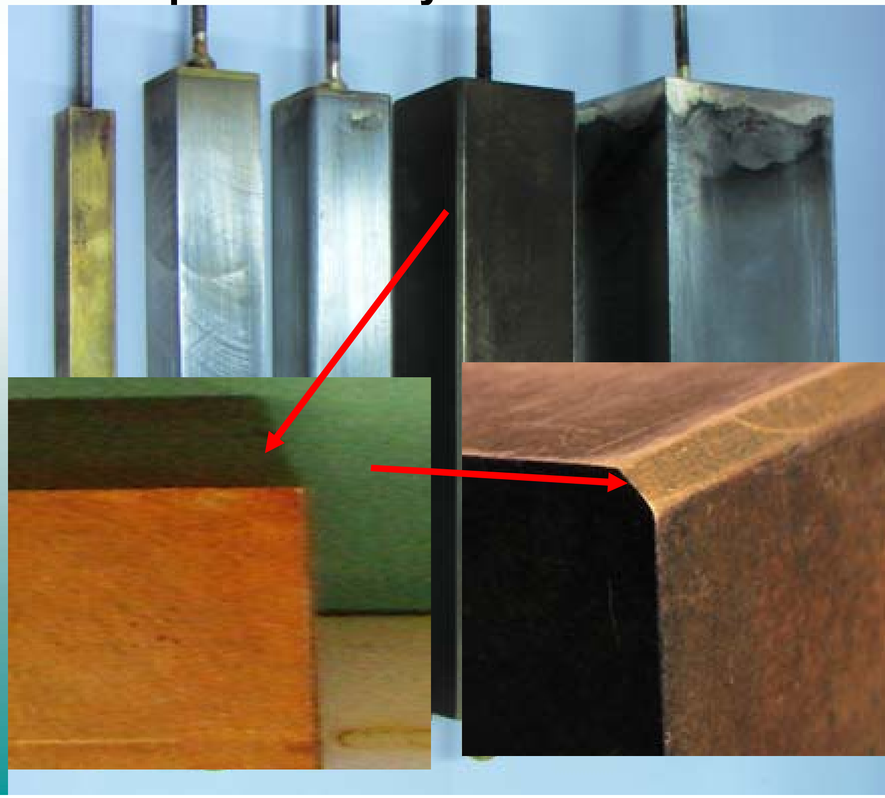
Keulegan - Carpenter number
Stokes number
$17\ S^{-1/2}$
Fork C2, 8.4 kHz
Fork A1, 32 kHz
Fork B1, 32 kHz
$KC = 10\ S^{-1} + 5.778\ S^{-1/4}$

The pH Baker visualization technique

Veronika Pilcova, David Schmoranzer

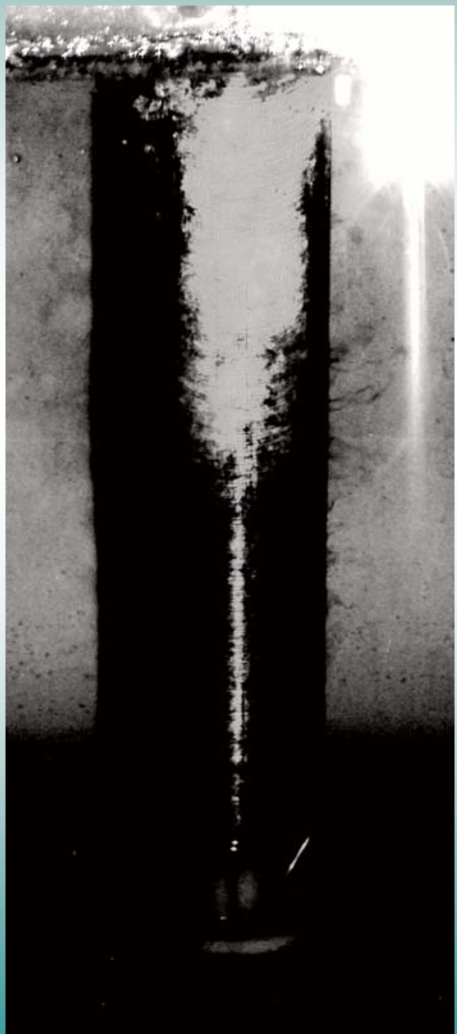
- solution of a pH indicator (thymol blue), an acid (HCl) and an alkali (NaOH)
- bluff body made of a conducting material is placed inside the liquid (+)
- set of metal electrodes located usually at the walls of the tank (-)
- bias 10-15 V → pH in the vicinity of the body changes, colour from orange to dark blue
- fairly precise way of studying flow patterns at low velocities of order 1 cm/s
- critical amplitudes for frequencies 2-11 Hz by recording the position of the cylinder's central shaft by a standard 25 Hz digital video camera
- camera movies are processed by VideoMach software with suitable video filters providing a series of monochromatic images, which are further processed by self-made software



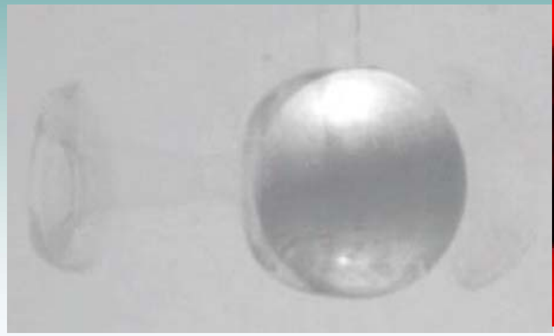


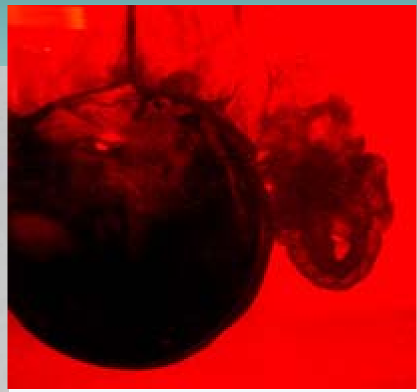
Flow visualization Baker pH technique

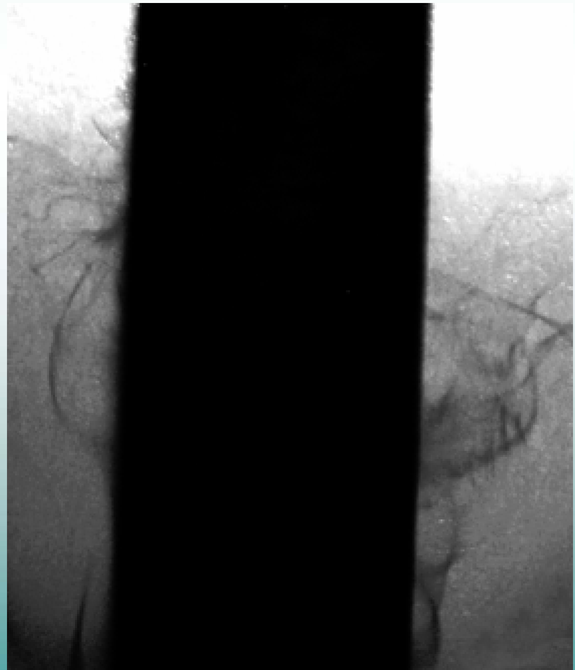
"Fork"

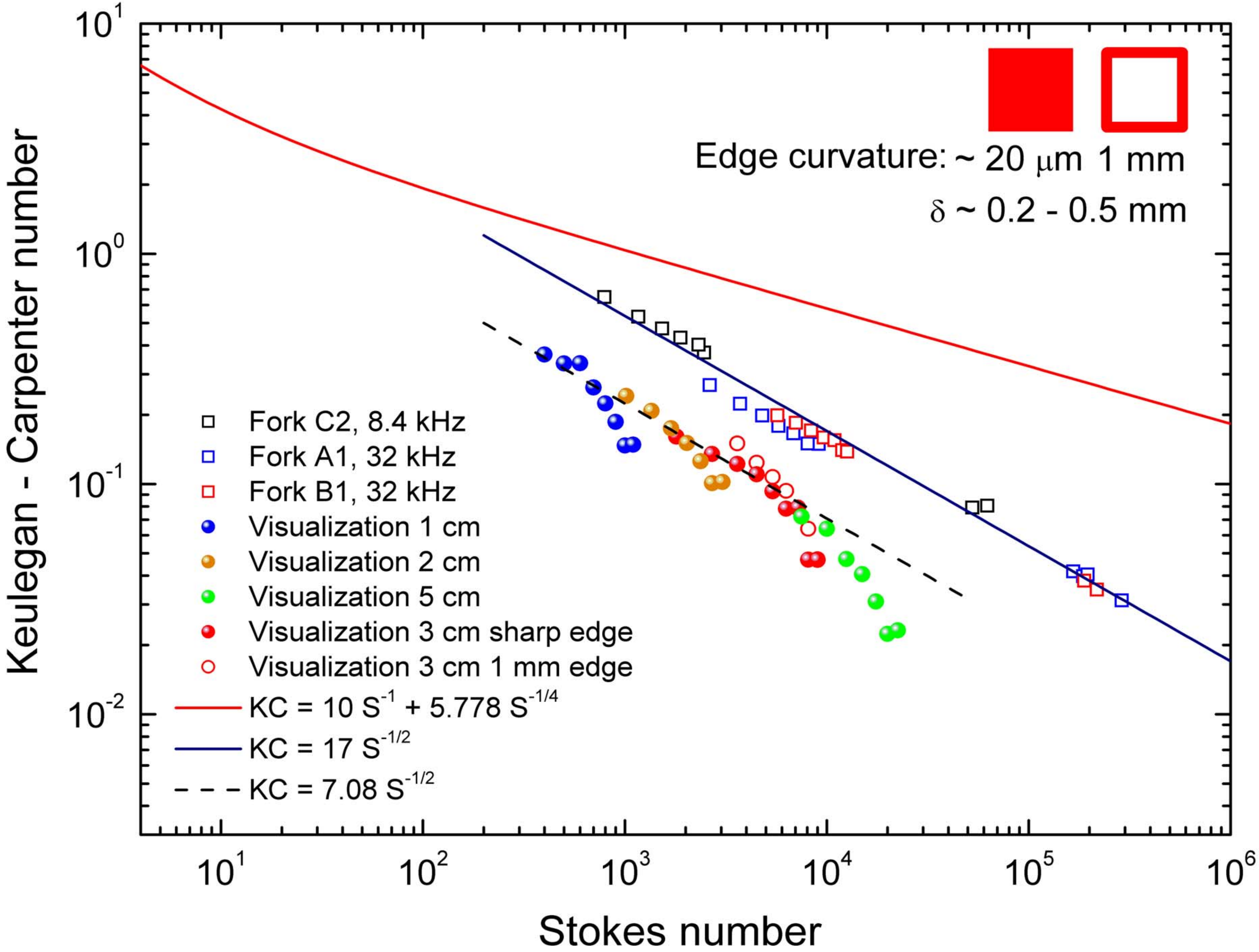


Solid steel sphere

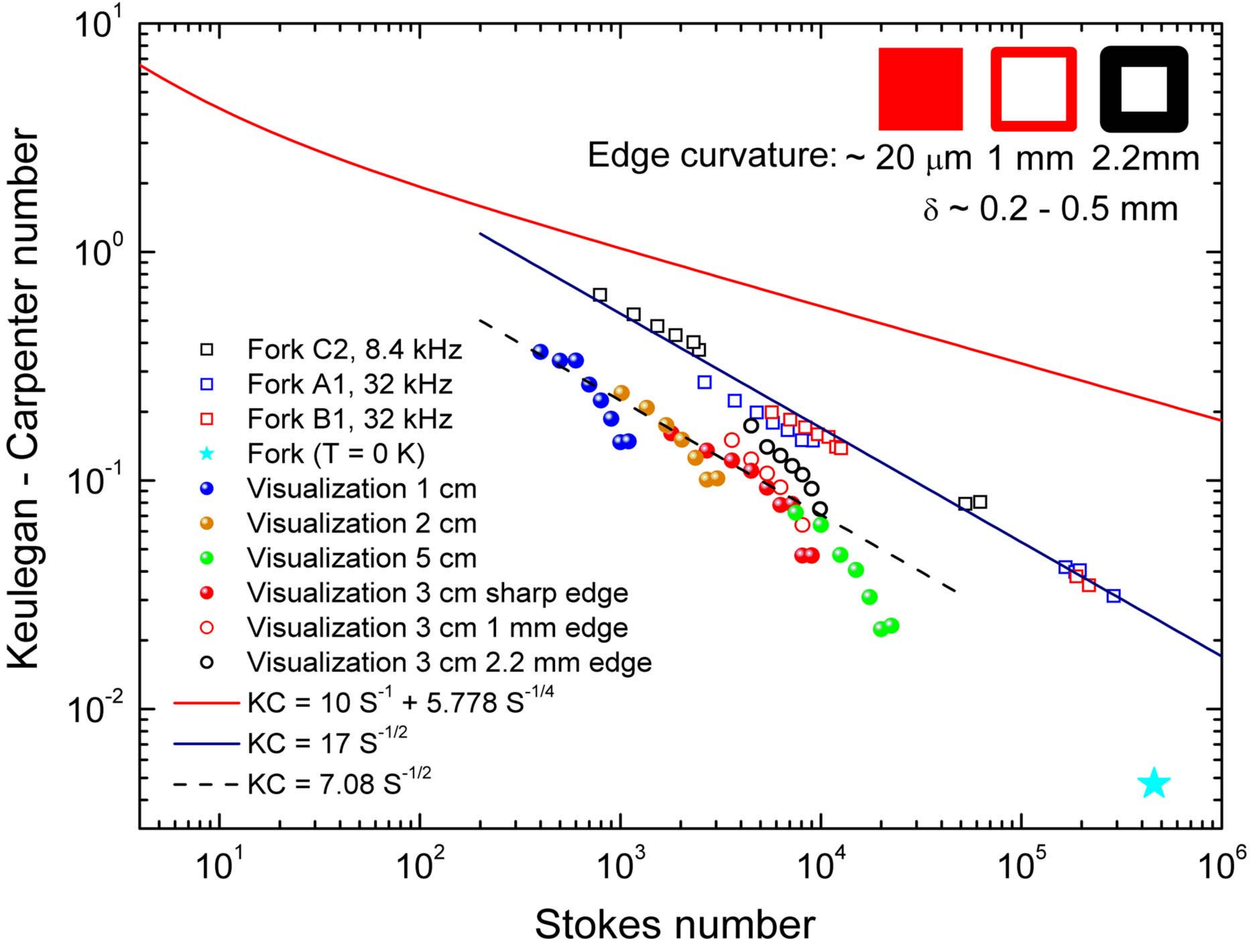




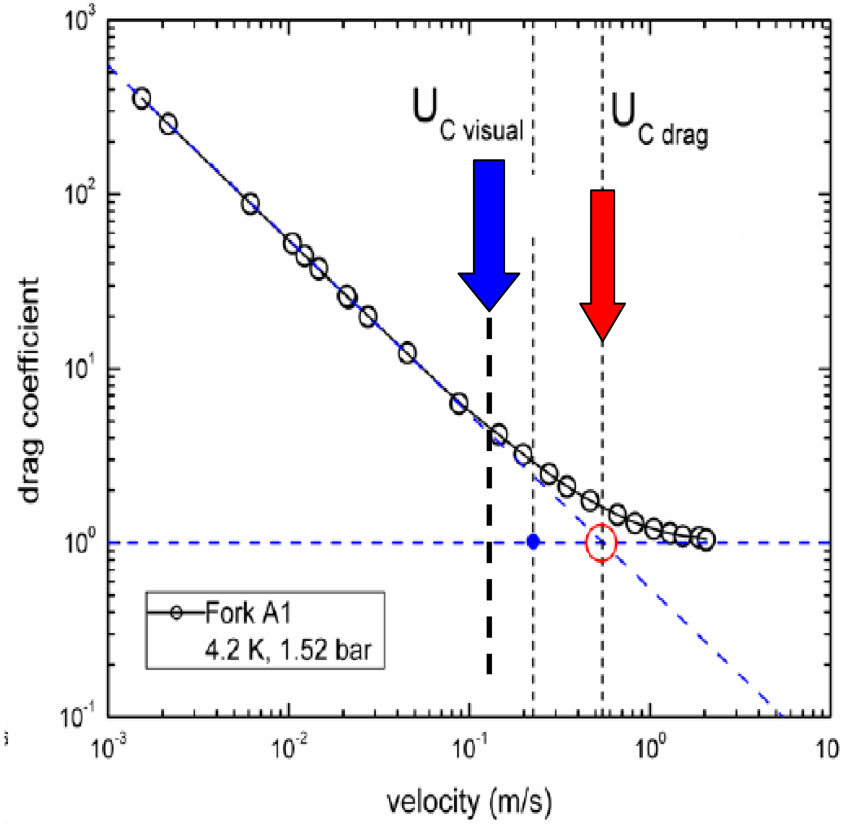


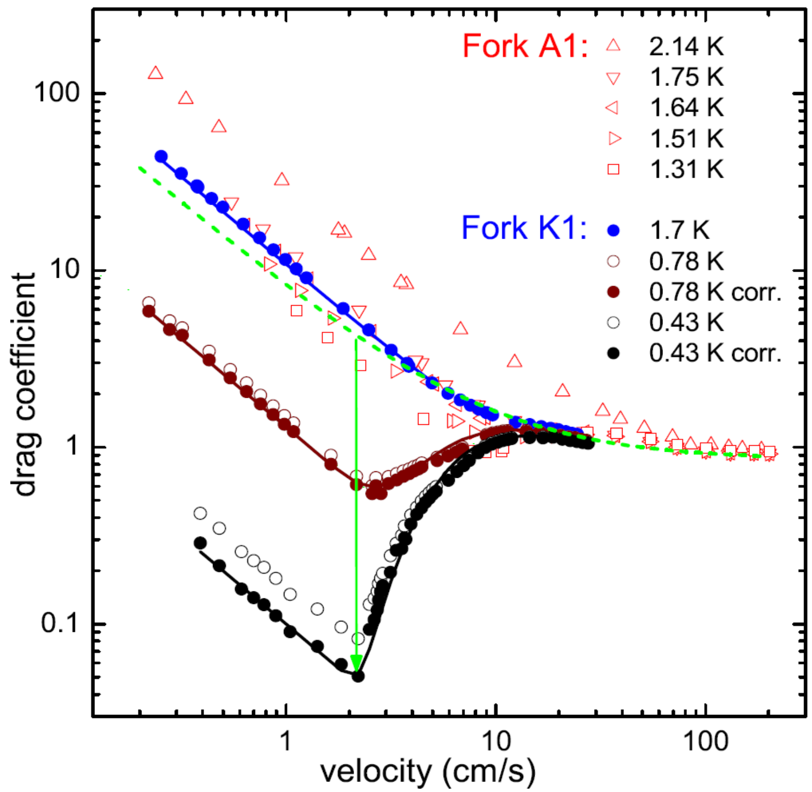


Edge curvature: ~ 20 μm 1 mm
δ ~ 0.2 - 0.5 mm
Fork C2, 8.4 kHz
Fork A1, 32 kHz
Fork B1, 32 kHz
Visualization 1 cm
Visualization 2 cm
Visualization 5 cm
Visualization 3 cm sharp edge
Visualization 3 cm 1 mm edge
KC = 10 S^{-1} + 5.778 S$^{-1/4}$
KC = 17 S$^{-1/2}$
KC = 7.08 S$^{-1/2}$
Keulegan - Carpenter number
Stokes number
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}



Edge curvature: ~ 20 μm 1 mm 2.2mm
δ ~ 0.2 - 0.5 mm
Fork C2, 8.4 kHz
Fork A1, 32 kHz
Fork B1, 32 kHz
Fork (T = 0 K)
Visualization 1 cm
Visualization 2 cm
Visualization 5 cm
Visualization 3 cm sharp edge
Visualization 3 cm 1 mm edge
Visualization 3 cm 2.2 mm edge
KC = 10 S^-1 + 5.778 S^-1/4
KC = 17 S^-1/2
KC = 7.08 S^-1/2
Keulegan - Carpenter number
Stokes number
10^1
10^0
10^-1
10^-2
10^1
10^2
10^3
10^4
10^5
10^6



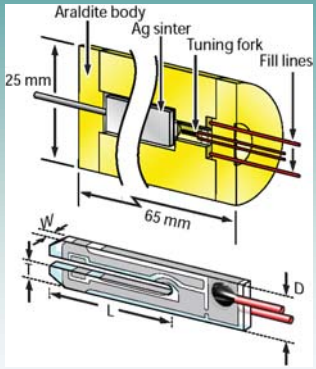


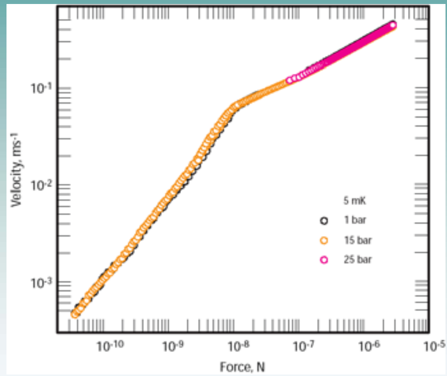
The quasiclassical description seems to work ….

Does it work at very low T, where there is no normal fluid???

Lancaster group unpublished fork data, courtesy of Rich Haley

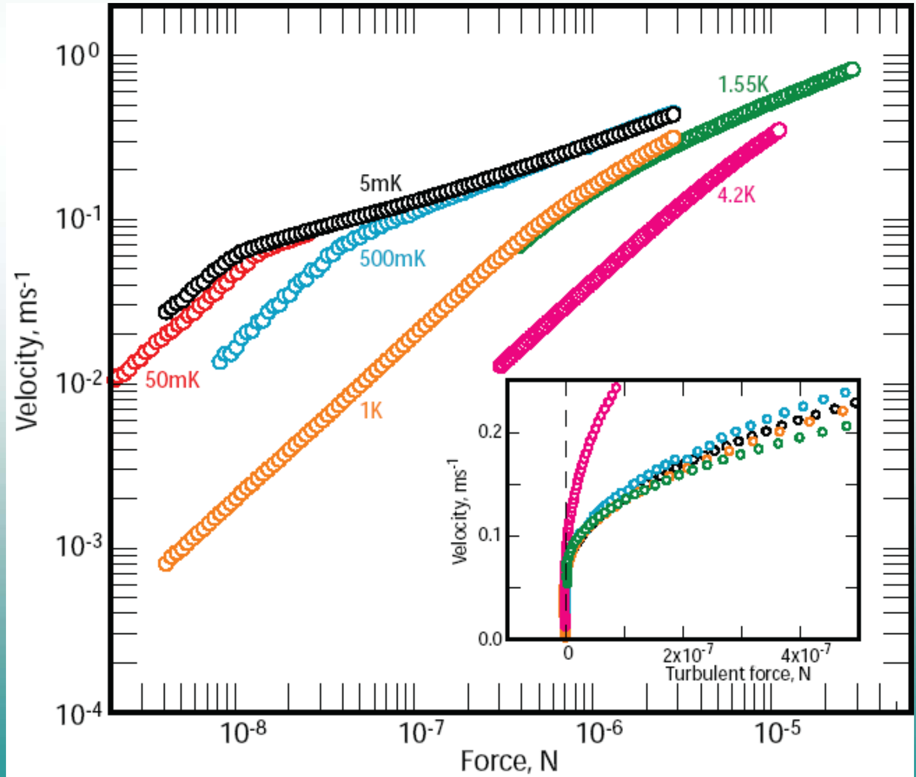
D.I. Bradley, C. Lawson, A.M. Guénault, M.J. Fear, S.N. Fisher, R.P. Haley, G.R. Pickett, R. Schanen, V. Tsepelin, L.A. Wheatland

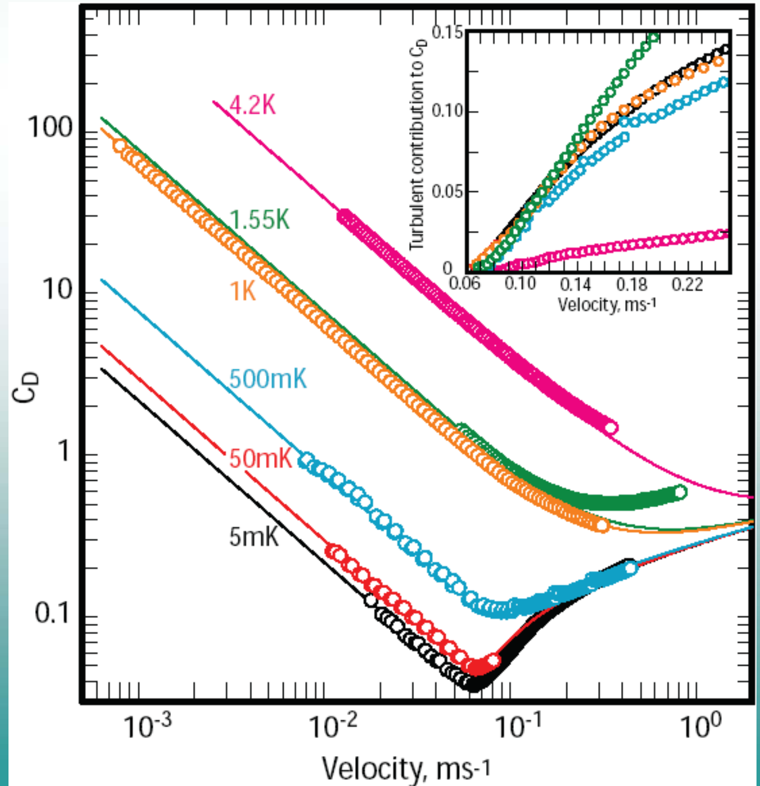




At very low T, no dependence on pressure (in agreement with the Lancaster grid data)

- **Different phenomenological expression is used to fit the drag data (works well below 1K but poorly above it)**
- **There is a claim that by withdrawing the linear damping term the data indicate a temperature independent critical velocity of order 6 cm/s**





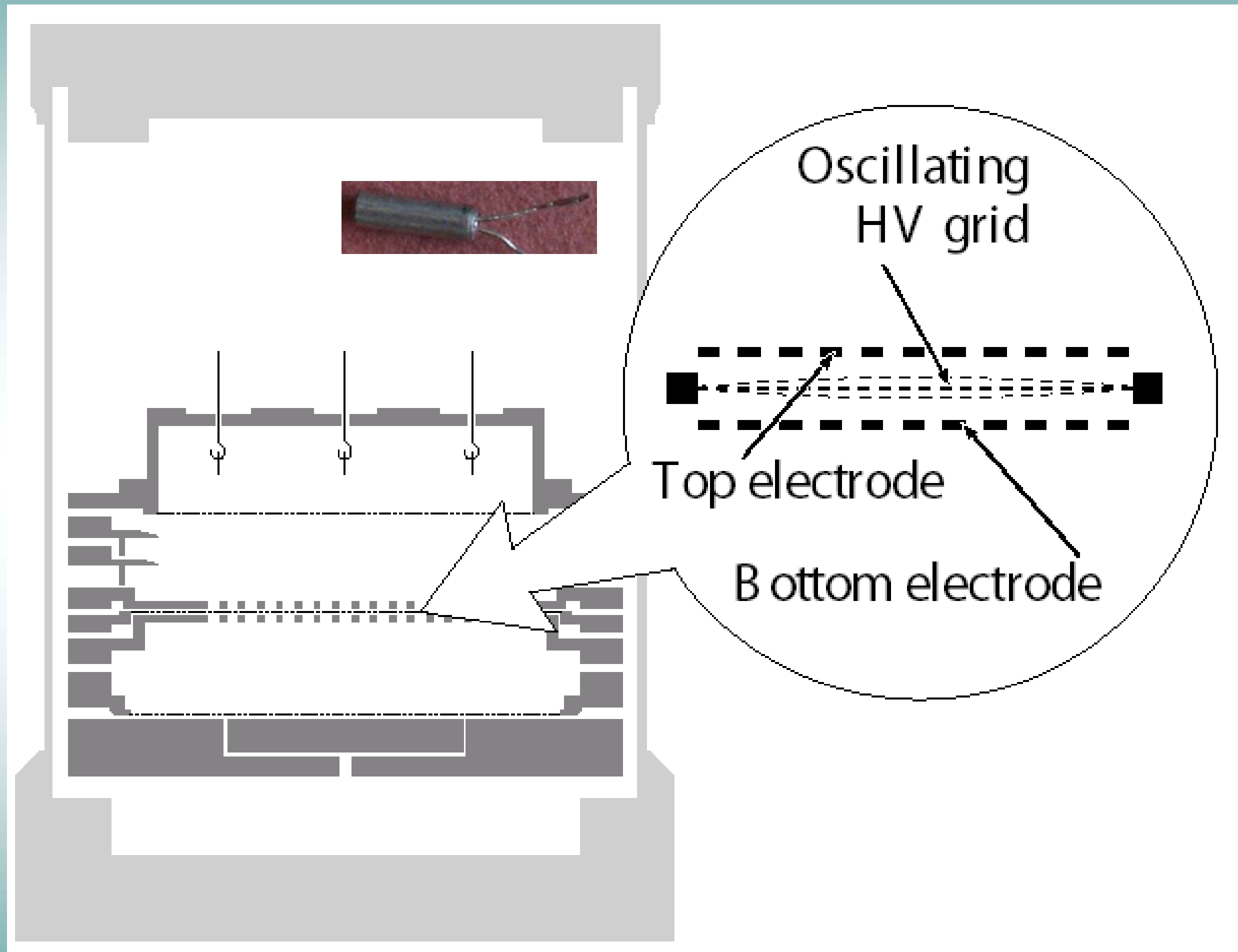
Lancaster group of P.V.E. McClintock

H. Nicol, D. Charalambous, P. Hendry, D. Garg, V. Efimov, M. Giltrow, Joe Vinen, LS

Several grids used over years

Recently quartz tuning forks added

Experimental cell containing 1.5 litre of spectrally pure He II, attached to the dilution refrigerator (base T about 10 mK)

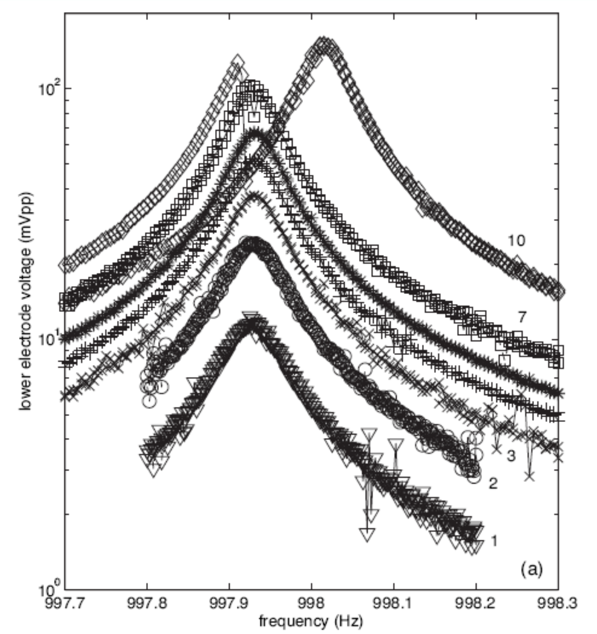


H.A. Nichol, L. Skrbek, P.C. Hendry, P.V.E. McClintock: Phys. Rev. Lett **92** (2004) 244501; Phys. Rev. E **70** (2004) 065307
D. Charalambous, P.C. Hendry, L. Skrbek, P.V.E. McClintock, W.F. Vinen: Phys. Rev. E 74, 036307 (2006)

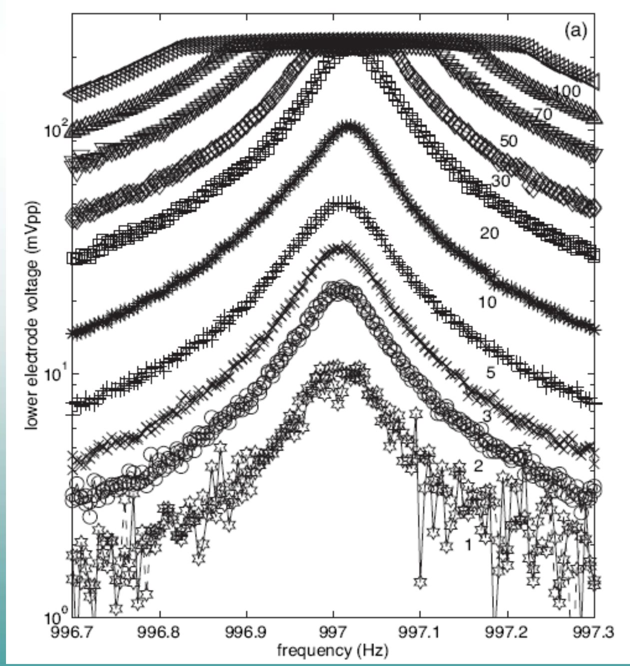
"Virgin" versus "regular" behaviour

"virgin" behaviour
– obtained immediately after the desired pressure in the cell is established.
Irreproducible effects observed, such as changes in resonant frequency and linewidth.

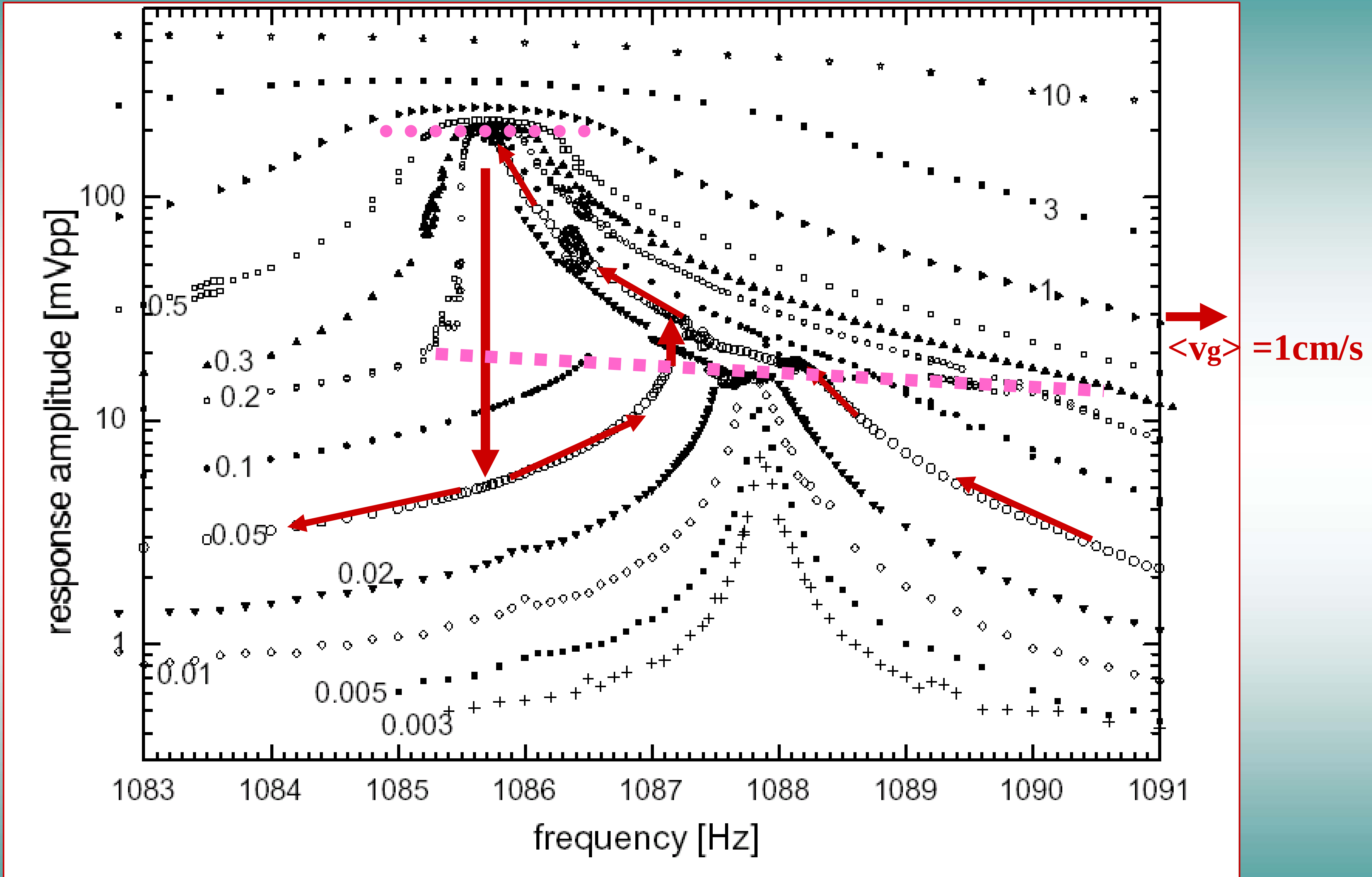
"regular" – reproducible behaviour of the grid, after applying the highest available drive 10Vpp. After applying this "cleaning" procedure, all* observed effects found stable within time scale of days.



Grid



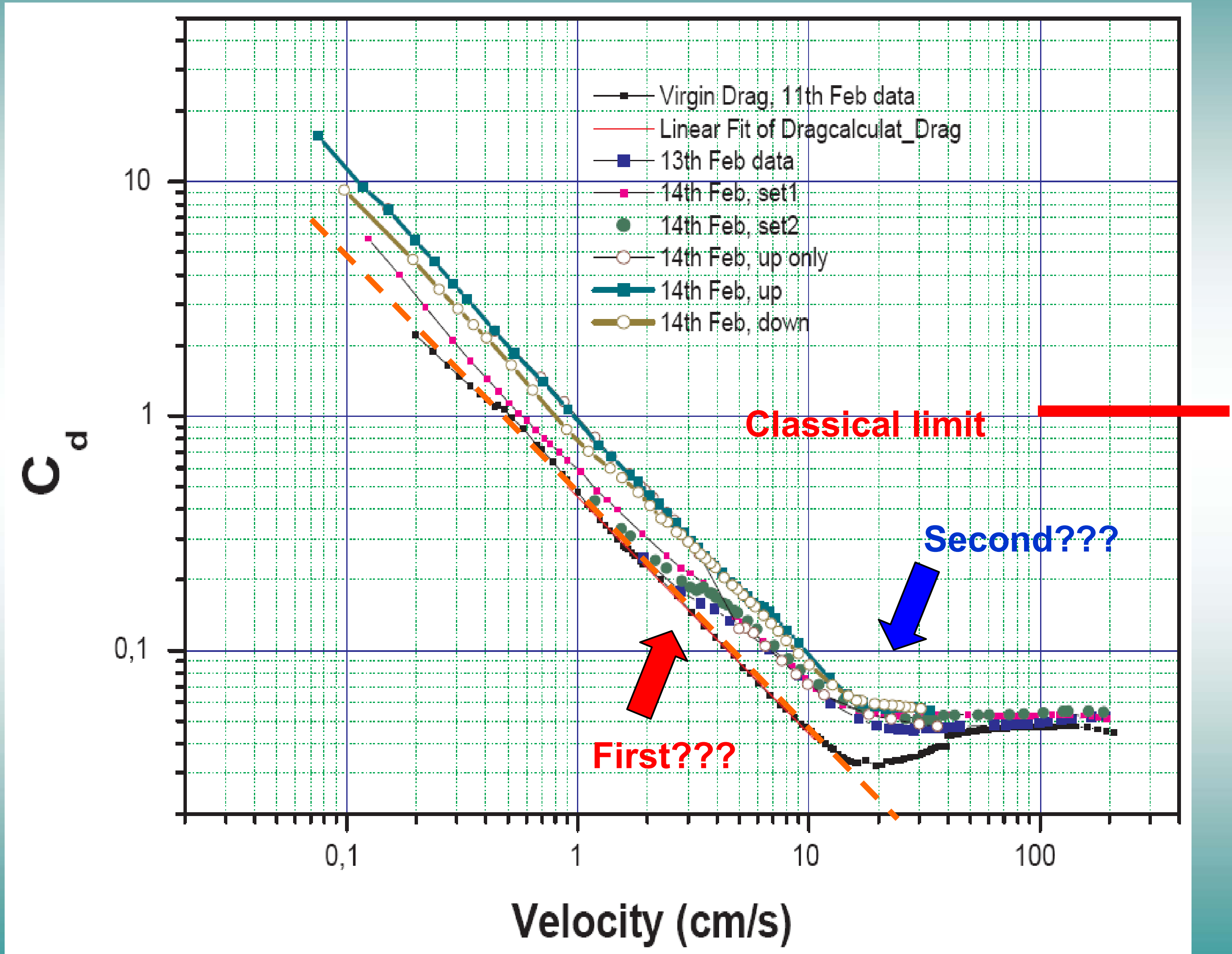
Two critical velocities, hysteresis and history dependent effects

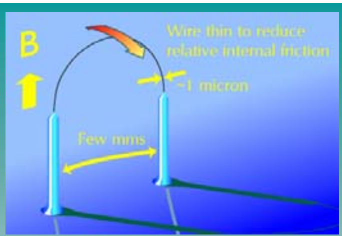


Lancaster data (McClintock *et al*) 1[st] at ~ 1cm/s 2[nd] at ~ 10 cm/s

decreases with pressure by factor of two **stable**

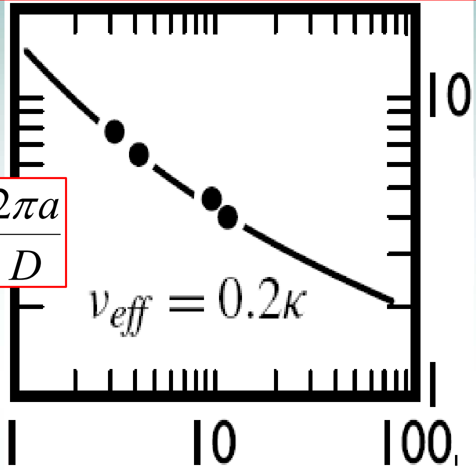
Standard 32 kHz fork, ultra-pure 4He, base temperature of the dilution fridge (Lancaster, McClintock's group, unpublished data)





D.I. Bradley · S.N. Fisher · A.M. Guénault · R.P. Haley · V. Tsepelin · G.R. Pickett · K.L. Zaki: The Transition to Turbulent Drag for a Cylinder Oscillating in Superfluid 4He: A Comparison of Quantum and Classical Behavior J Low Temp Phys (2009) **154**: 97

$$K_C^{instab} = 10\ S^{-1} + 5.778\ S^{-1/4}$$

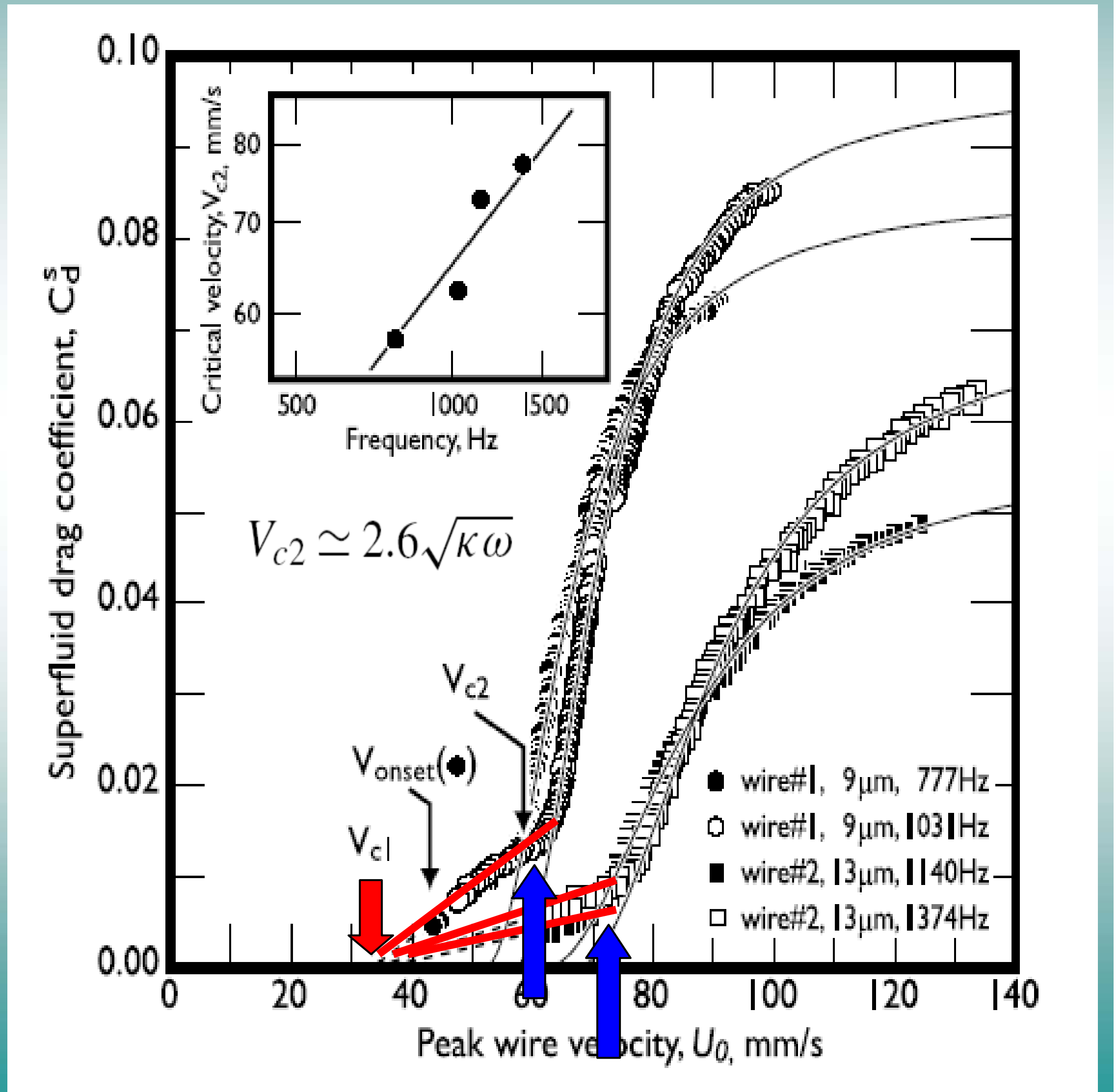


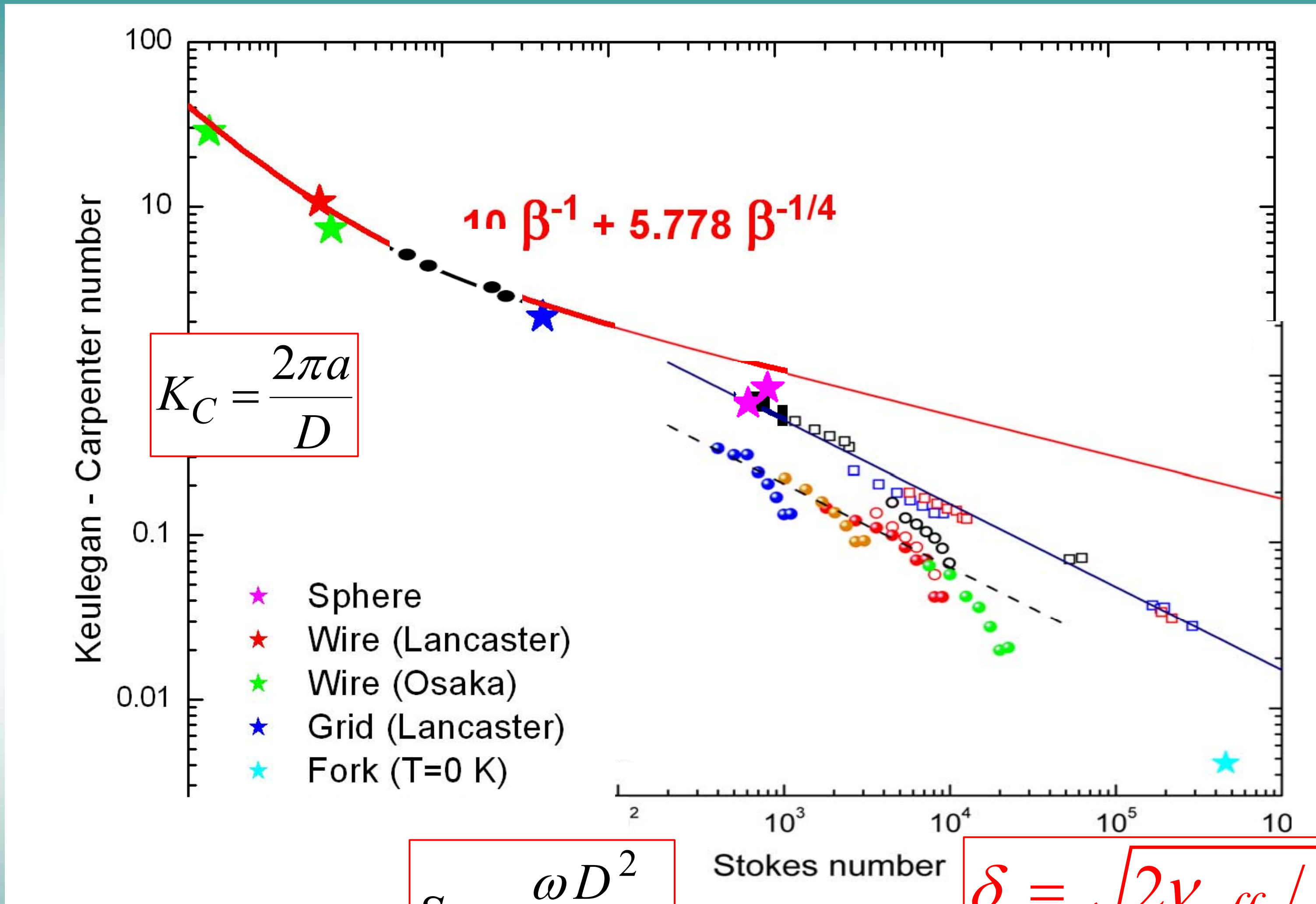
$$K_C = \frac{2\pi a}{D}$$

$$S = \frac{\omega D^2}{2\pi\nu}$$

$$C_d^s = \gamma \frac{(V - V_0)^2}{\epsilon^2 + (V - V_0)^2} \quad \text{for } V > V_0$$

Drag coefficient for high velocities << 1





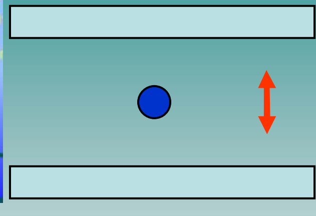
$$K_C = \frac{2\pi a}{D}$$

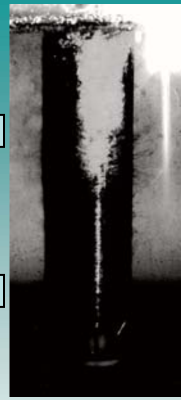
$$S = \frac{\omega D^2}{2\pi \nu_{eff}}$$

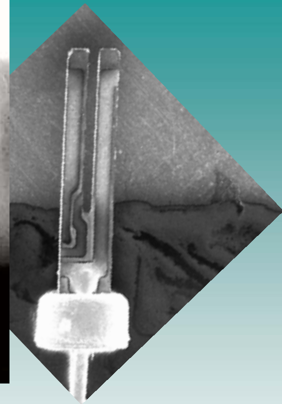
$$\delta = \sqrt{2\nu_{eff} / \omega}$$

L. Skrbek, W.F. Vinen: chapter 4 „The Use of Vibrating Structures in the Study of Quantum Turbulence“ , Progress in Low Temp. Physics, Springer 2009

Conclusions







- **A number of experiments has been performed over more that half a Century displaying the transition from laminar to turbulent drag regime in boundary layer flows due to oscillating submerged objects (discs, spheres, wires, grids, tuning forks) in gaseous helium, He I and He II:**
- **Complementary experiments in classical fluids (mostly air and water) exist and provide both qualitative (visualization) and quantitative data**
- **Experiments in He II, in two fluid regime above about 1 K, in most cases behave in a regular reproducible way, they display similarity with their classical counterparts and, on a phenomenological level, seem to be fairly well understood**
- **He II experiments in the zero temperature limit, performed even with “large” vibrating structure display additional features such as intermittent switching, hysteresis, and possibly two critical velocities**

- **There is a clear call for more carefully planned systematic measure-ments and theoretical support that should lead to better understanding of an interesting problem of generation of quantum turbulence by various vibrating structures**