The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA
International Atomic Energy Agency

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Workshop on Topics in Quantum Turbulence

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Decay at Low Temperatures in 3He

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Decay of Quantum Turbulence in superfluid ^{3}He-B at T~0

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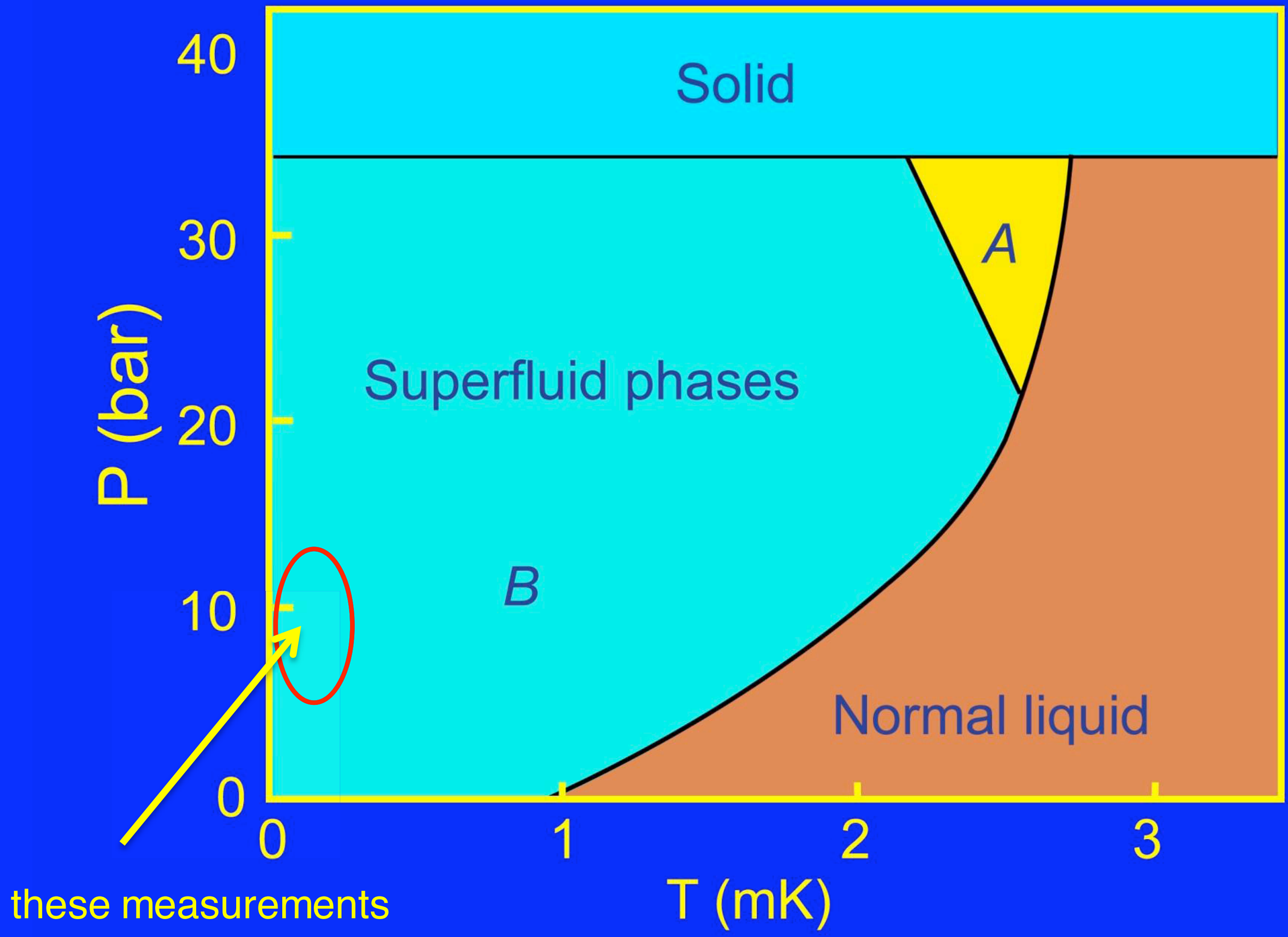
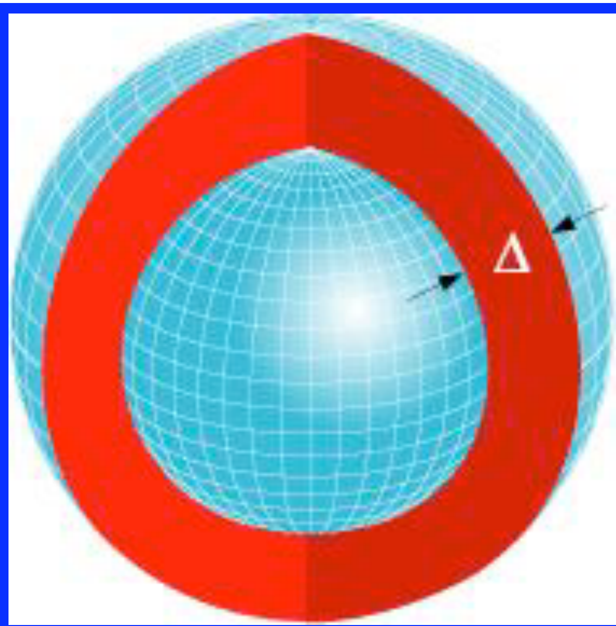
Low temperature phase diagram of ^3He



The B-phase of superfluid ^{3}He

- Equal mixtures of $S_z = +1, 0, -1$ pairs
- Isotropic energy gap in low magnetic fields



At low temperatures, quasiparticle excitation number falls rapidly

$$n_{ex} \propto \exp(-\Delta/k_B T)$$

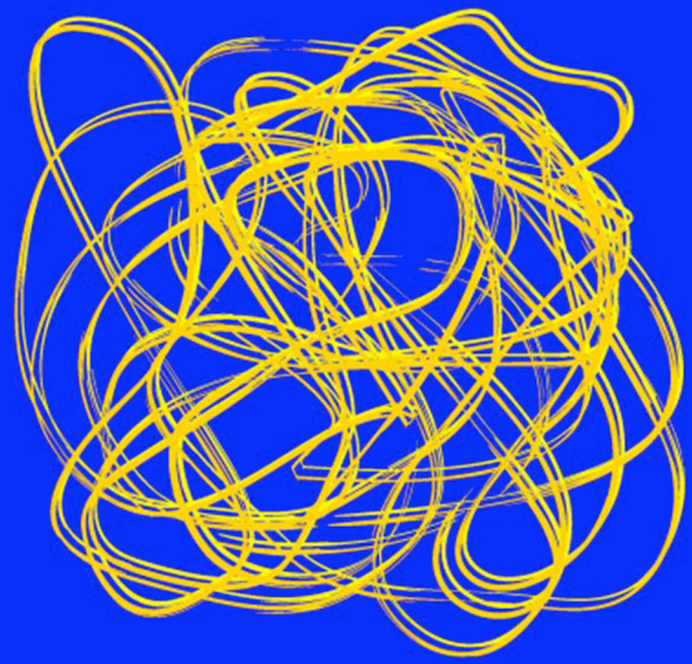
Mean free path virtually infinite (ballistic quasiparticles)

The normal fluid viscosity so large -
turbulence in the normal fluid impossible

→ pure superfluid turbulence

Vortices in the B-phase

Usual 2π phase change in the wavefunction around the core

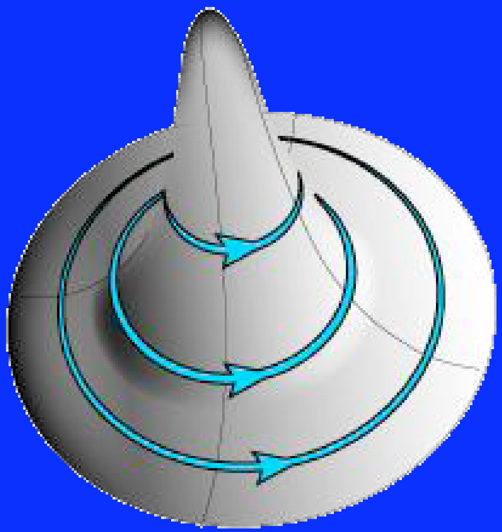


vortices singly quantised with circulation :

$$\kappa = h/2m_3$$

superfluid flows around core with velocity,

$$v_S = \kappa/2\pi r$$



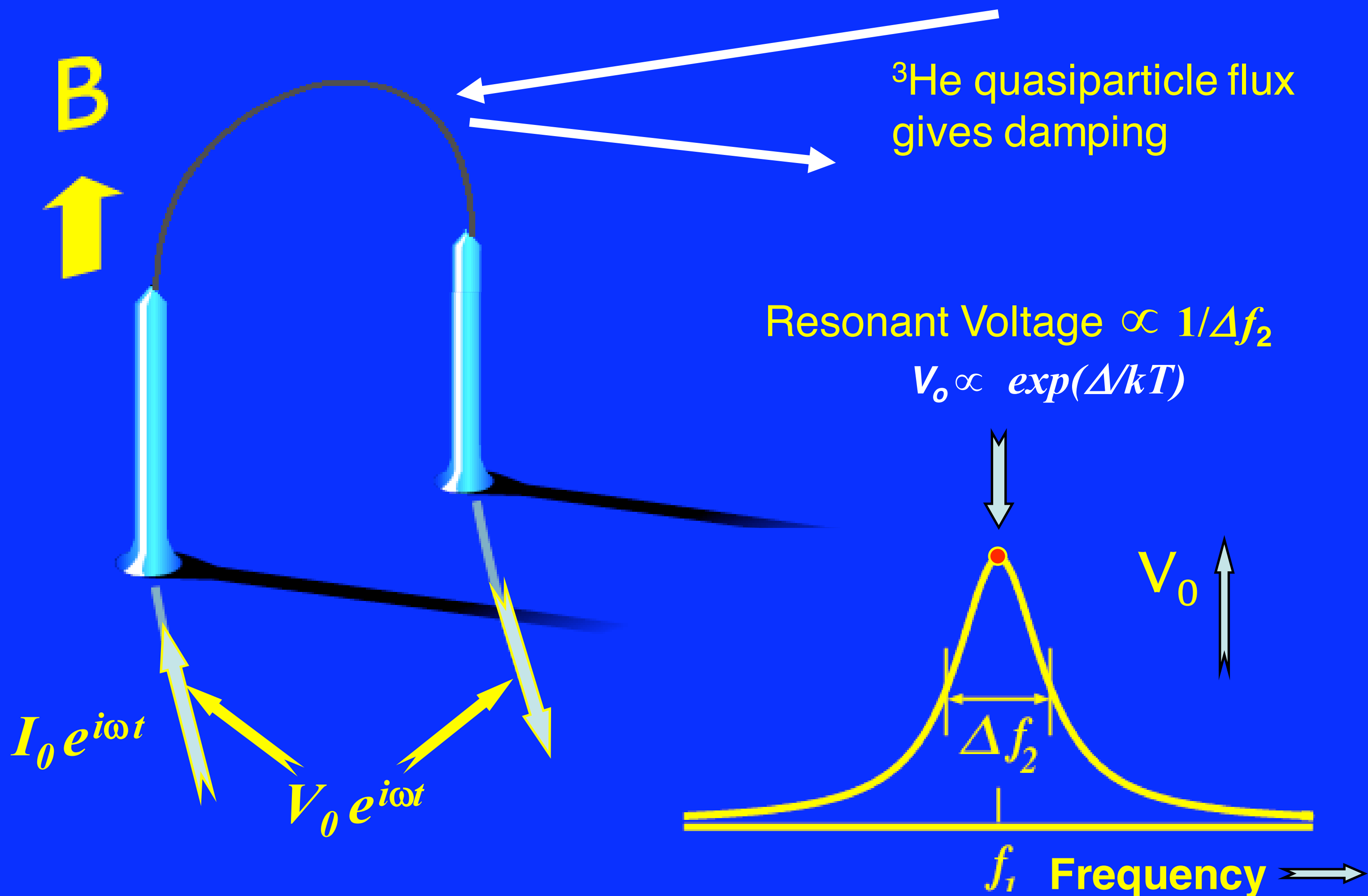
Energy per unit length of a vortex

$$\boxed{\varepsilon \approx \frac{\rho}{4\pi}\kappa^2 \ln\left(\frac{b}{\xi_0}\right)}$$

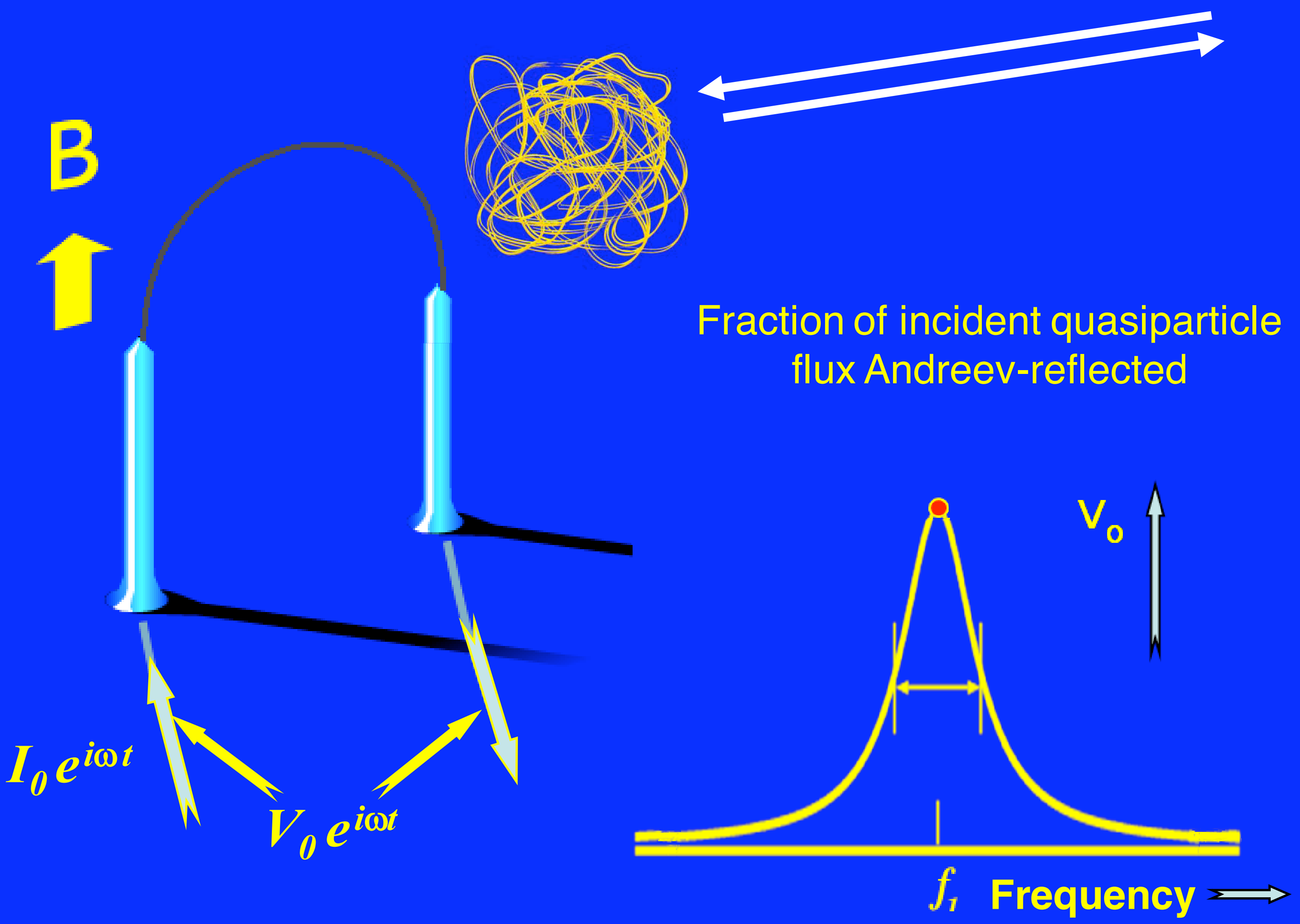
Pressure dependent coherence length $\xi_0 \sim 65$ - 15 nm

$b \sim$ intervortex spacing

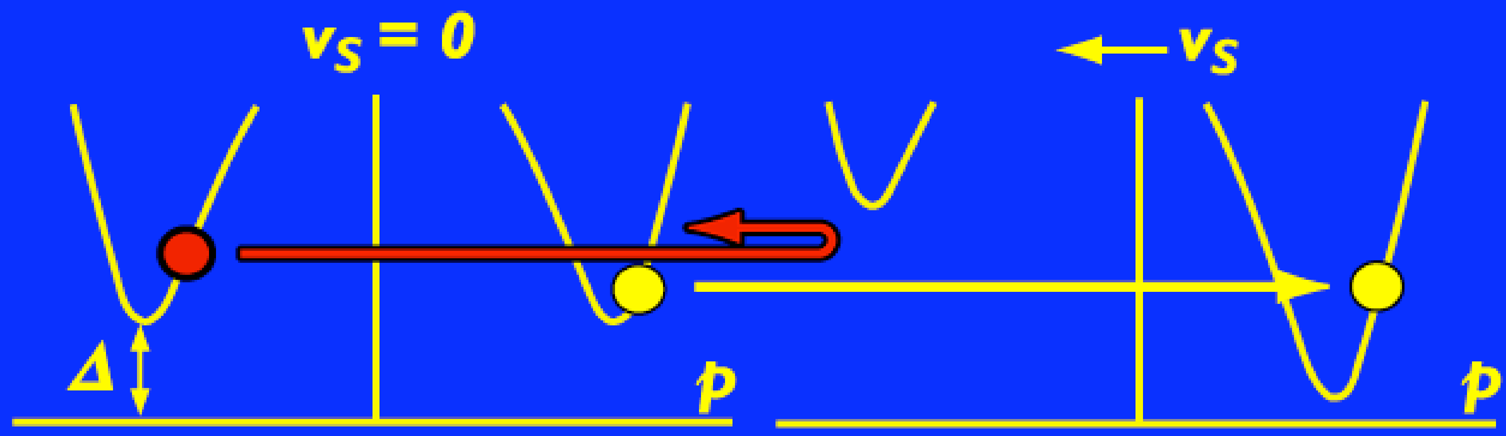
Vibrating wire resonator (Ballistic regime)

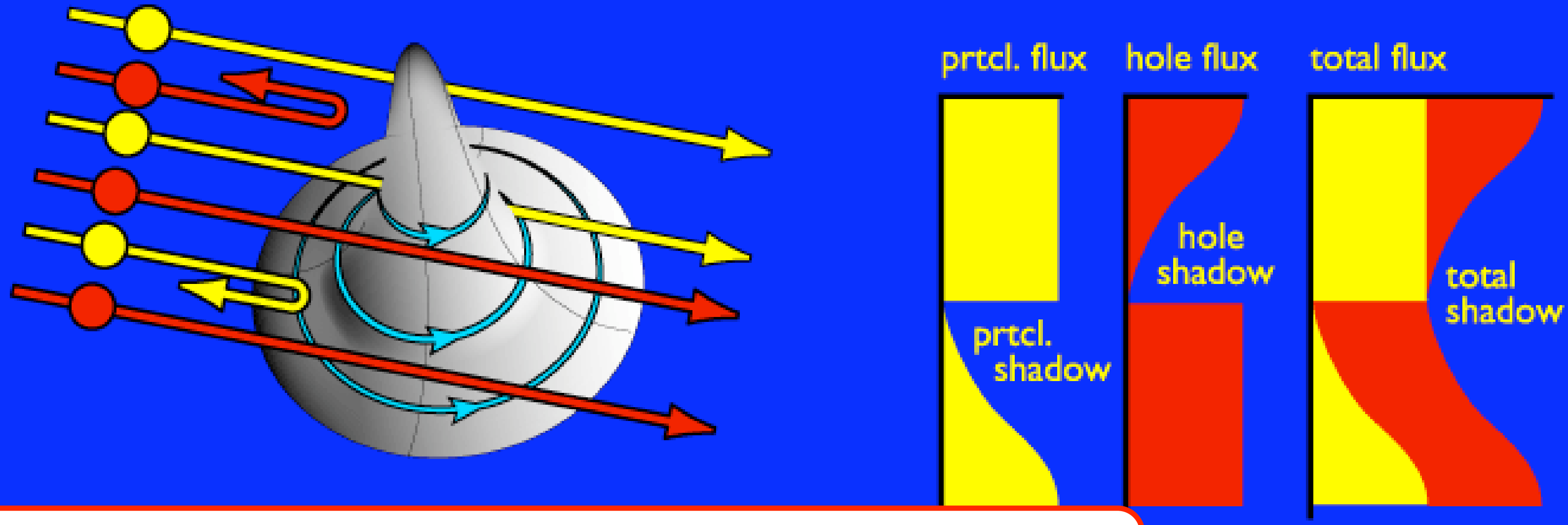


Turbulence Detection



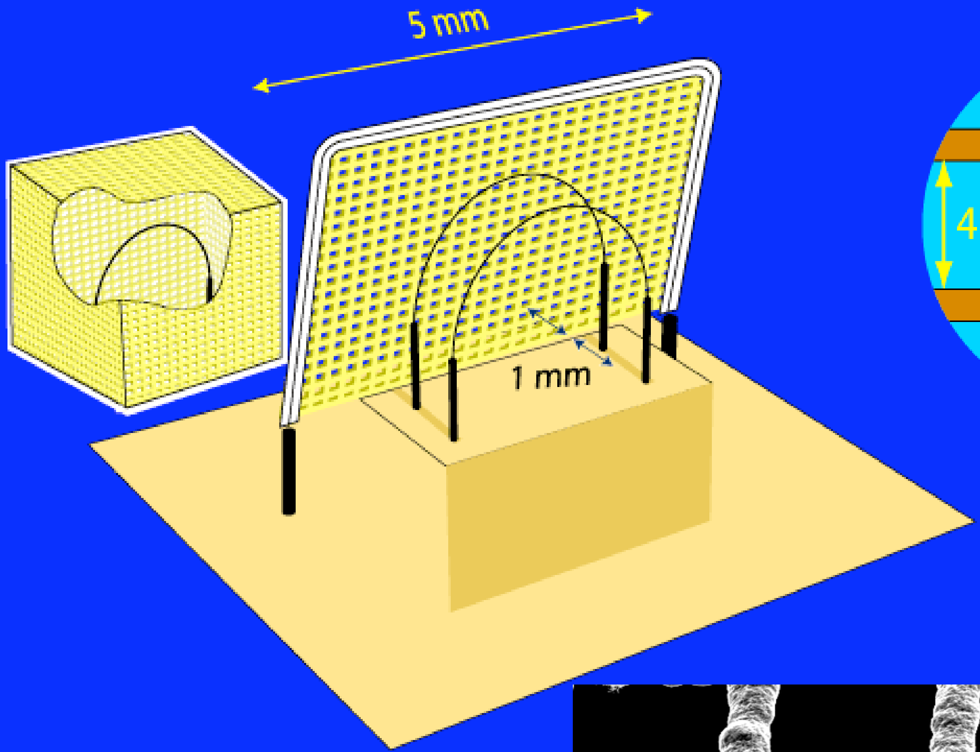
Andreev's Reflection

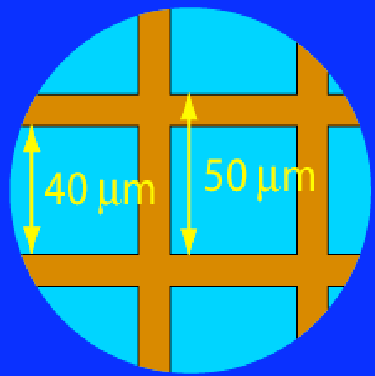


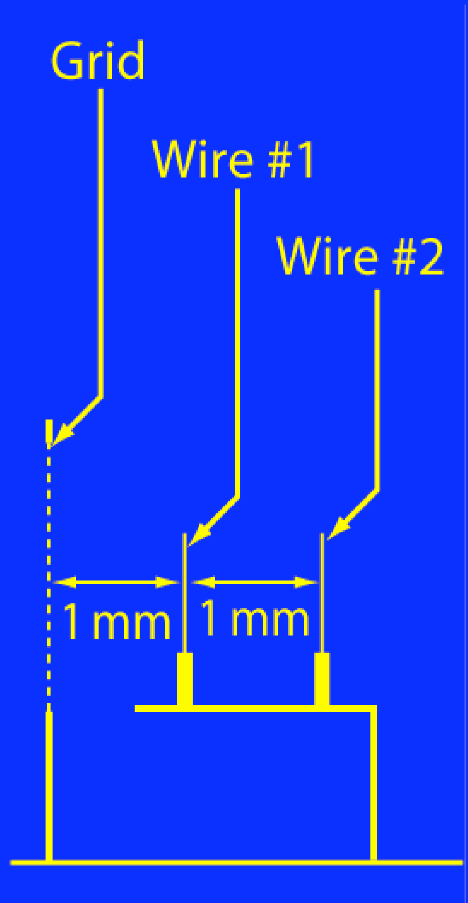


turbulence casts a quasiparticle shadow

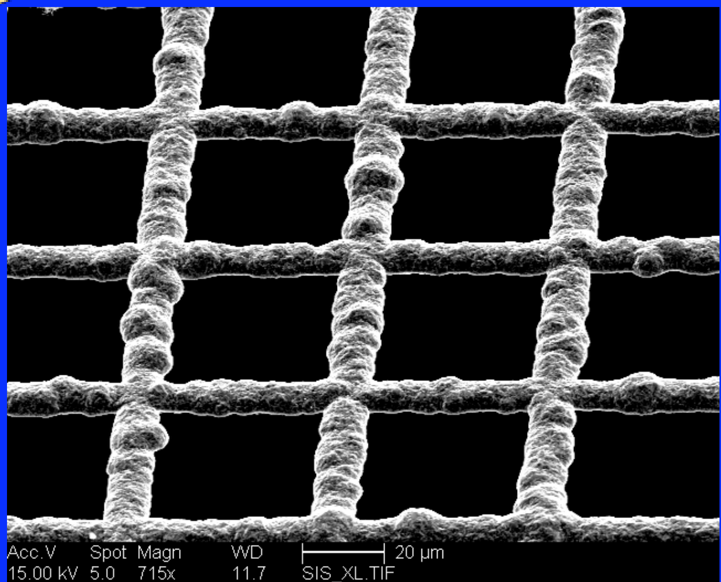
The Vibrating Grid Resonator

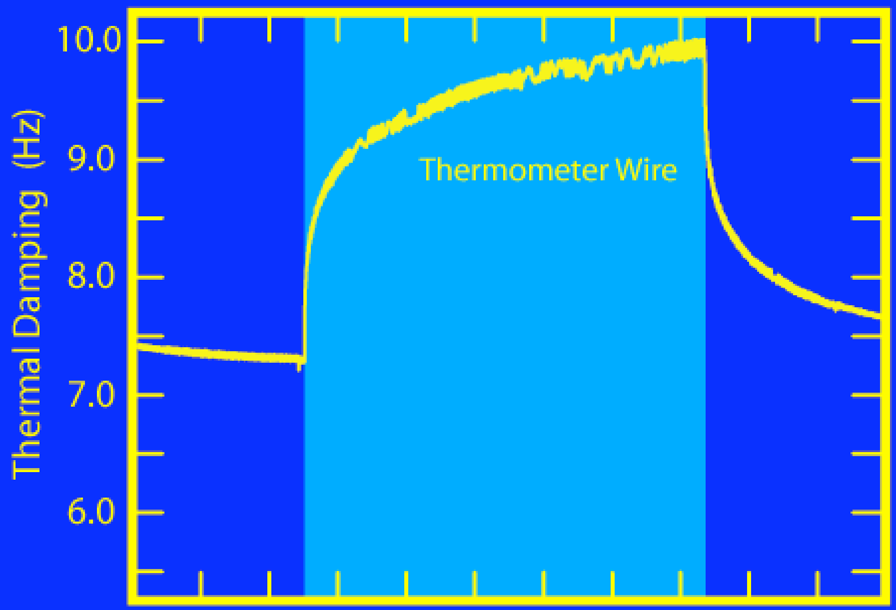




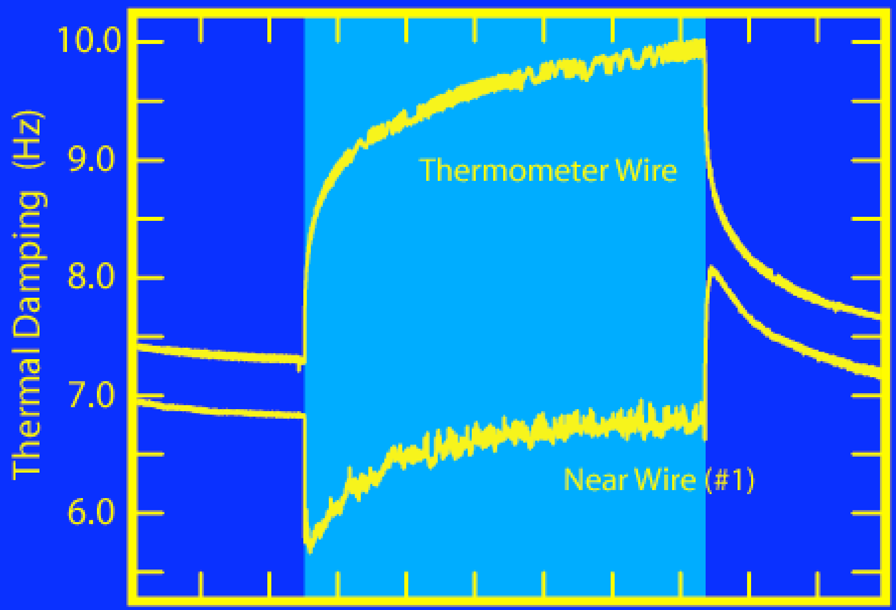


$T < 0.2T_c$
$P = 12$ bar



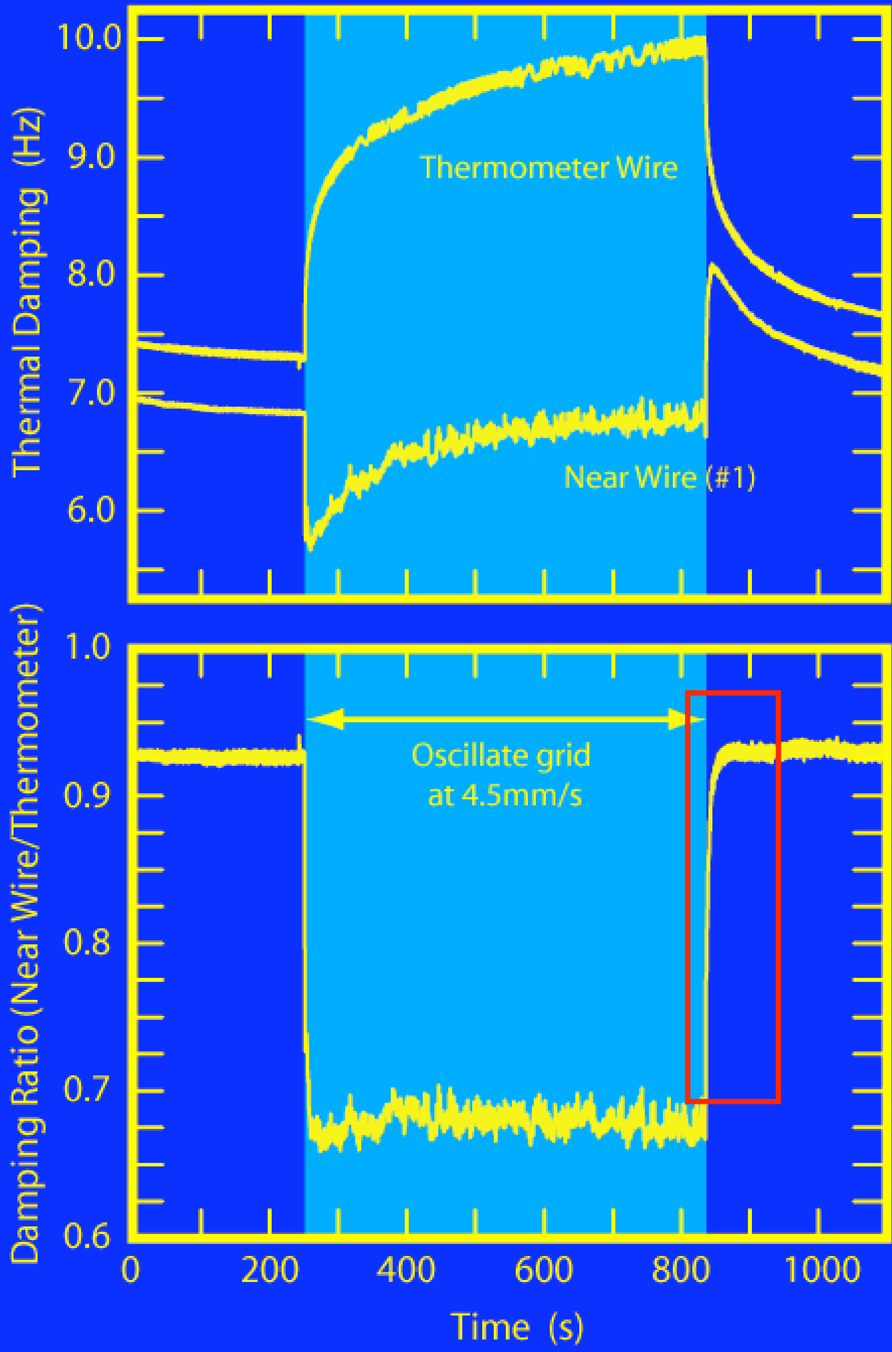


Oscillating the grid has a large warming effect on the cell.

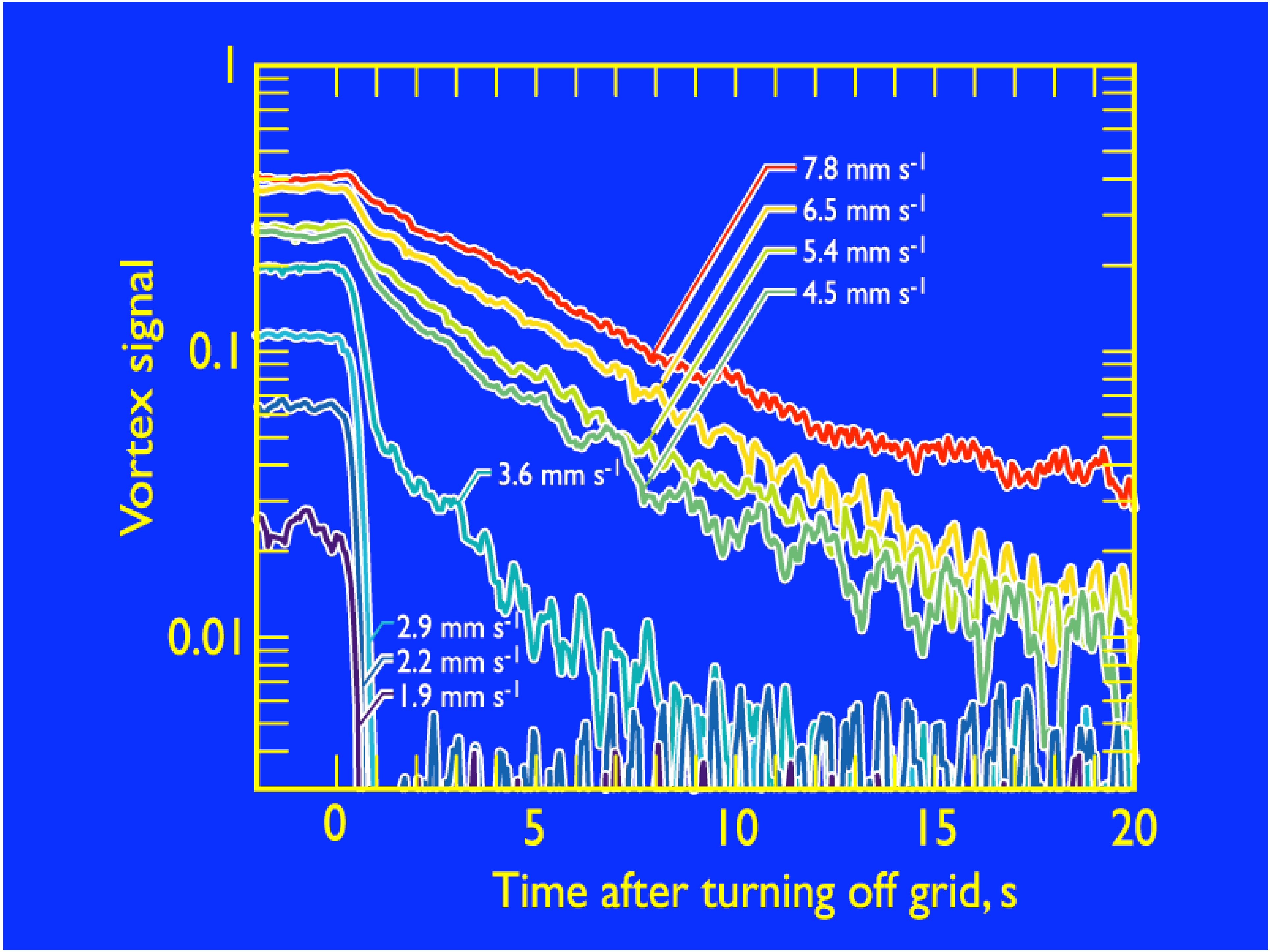


10.0
9.0
8.0
7.0
6.0
Thermal Damping (Hz)
Thermometer Wire
Near Wire (#1)

Giving the damping suppression by vortices.



Investigate Recovery of Vortex Signal



1
0.1
0.01
Vortex signal
7.8 mm s-1
6.5 mm s-1
5.4 mm s-1
4.5 mm s-1
3.6 mm s-1
2.9 mm s-1
2.2 mm s-1
1.9 mm s-1
0
5
10
15
20
Time after turning off grid, s

Conclusion from these observations:

- two different processes

• grid velocity < 3 mm/s produces small individual vortex rings
• fast recovery means vorticity must disperse from the grid at speeds ~10mm/s
• implies rings < 5μm in size

• grid velocity > 3 mm/s produces static long-lived turbulent tangle

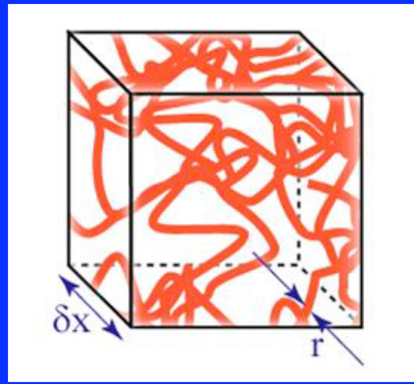
Look in more detail at the decay of the 'long-lived' tangle

Determine the vortex line length

- deduce the fractional screening f by the turbulence on the detector wires
- measure the damping $\Delta f_2(0,T)$ in the absence of turbulence
- measure the $\Delta f_2(v,T)$ when the grid is driven at velocity v
- define $\Delta f_2(v,T) = (1-f)\ \Delta f_2(0,T)$
- to determine L use a simple idea…
- more sophisticated calculation recently published

  Barenghi et al PRB 77, 104512, 2008

Take a thin slab of homogeneous vortex tangle of unit area, line density *L* and thickness δx



Mean quasiparticle energy = $k_B T$

Gap distortion by flow speed *v* is $p_f v$

Quasiparticle Andreev scattered if $k_B T < p_F v(r)$

As $v(r) = \kappa / 2\pi r$, quasiparticles scattered if approaches within a distance

$$\boxed{r = \frac{h}{2m_3} \frac{p_F}{2\pi\, k_B T}}$$

effective diameter $2r \sim 8$ μm at 150 μK

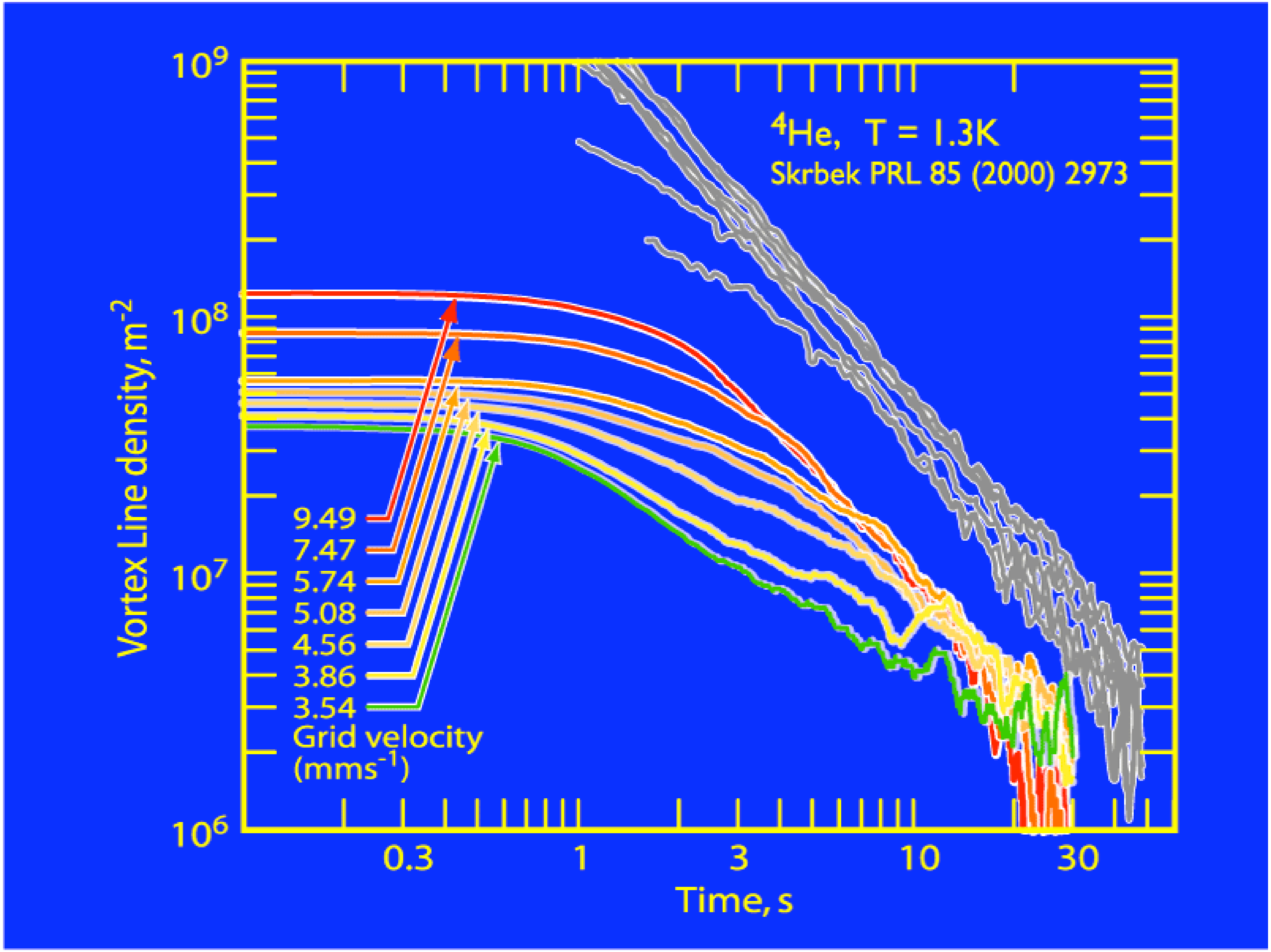
Fraction quasiparticle flux reflected by thickness δx is $f \sim r L \delta x$

Hence

$$\boxed{L = f \frac{2 m_3 k_B T}{p_F \hbar\, \delta x}}$$

previously measured vortex extent to be ~ 2 mm

Bradley et al, *Physica* B 329, 104, 2003



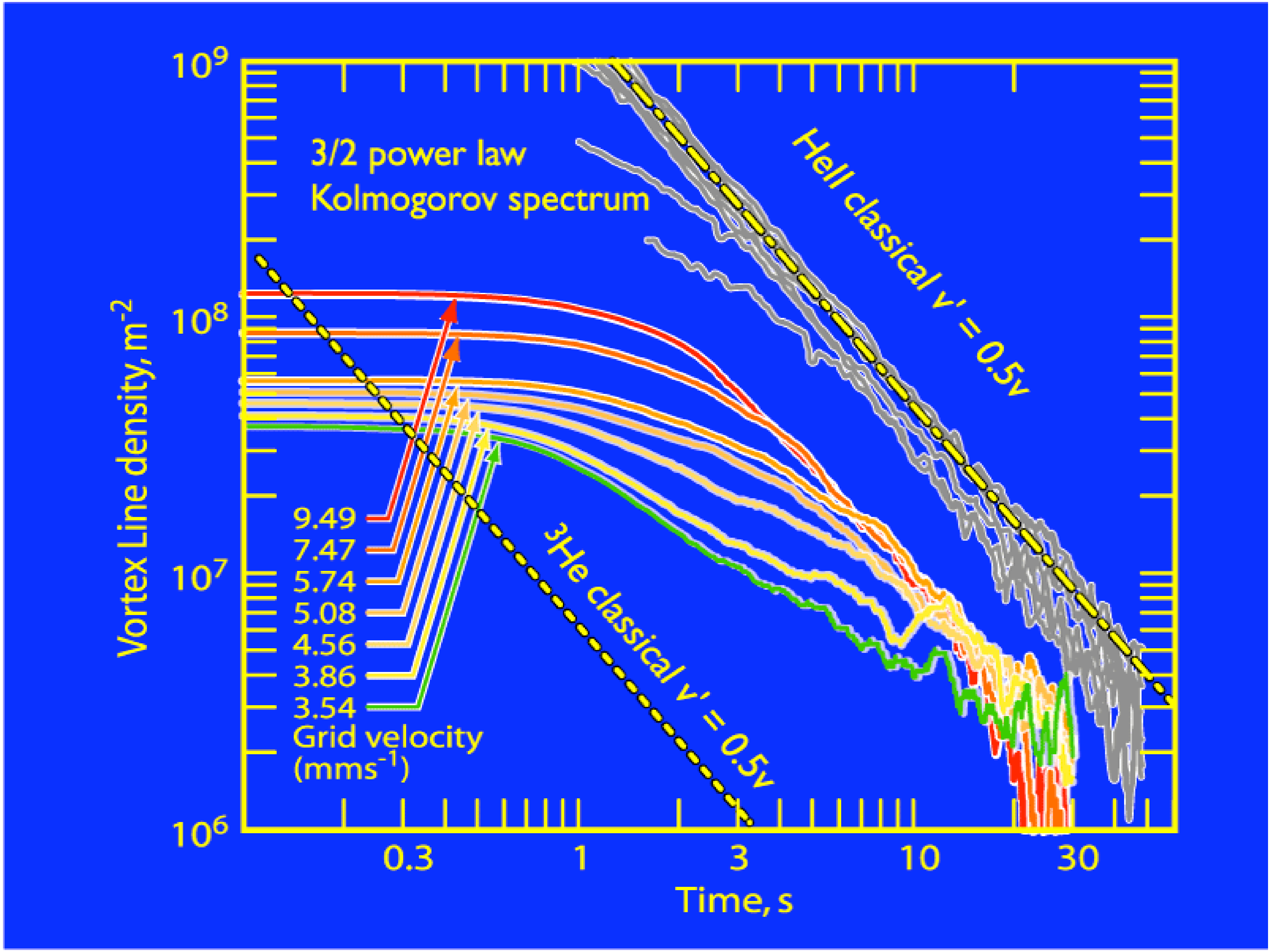
^{4}He, T = 1.3K
Skrbek PRL 85 (2000) 2973
Vortex Line density, m^{-2}
10^9
10^8
10^7
10^6
9.49
7.47
5.74
5.08
4.56
3.86
3.54
Grid velocity
(mms^{-1})
0.3
1
3
10
30
Time, s

Expect for Kolmogorov decay on basis of classical turbulence of combined normal/superfluid components

$$\boxed{L(t) = \frac{d}{2\pi\kappa}\sqrt{\frac{27C^3}{\nu'}}t^{-3/2}}$$

d – characteristic size

ν' -kinematic viscosity



3/2 power law
Kolmogorov spectrum
HeII classical v' = 0.5v
3He classical v' = 0.5v
9.49
7.47
5.74
5.08
4.56
3.86
3.54
Grid velocity
(mms-1)
Vortex Line density, m-2
Time, s
10^9
10^8
10^7
10^6
0.3
1
3
10
30

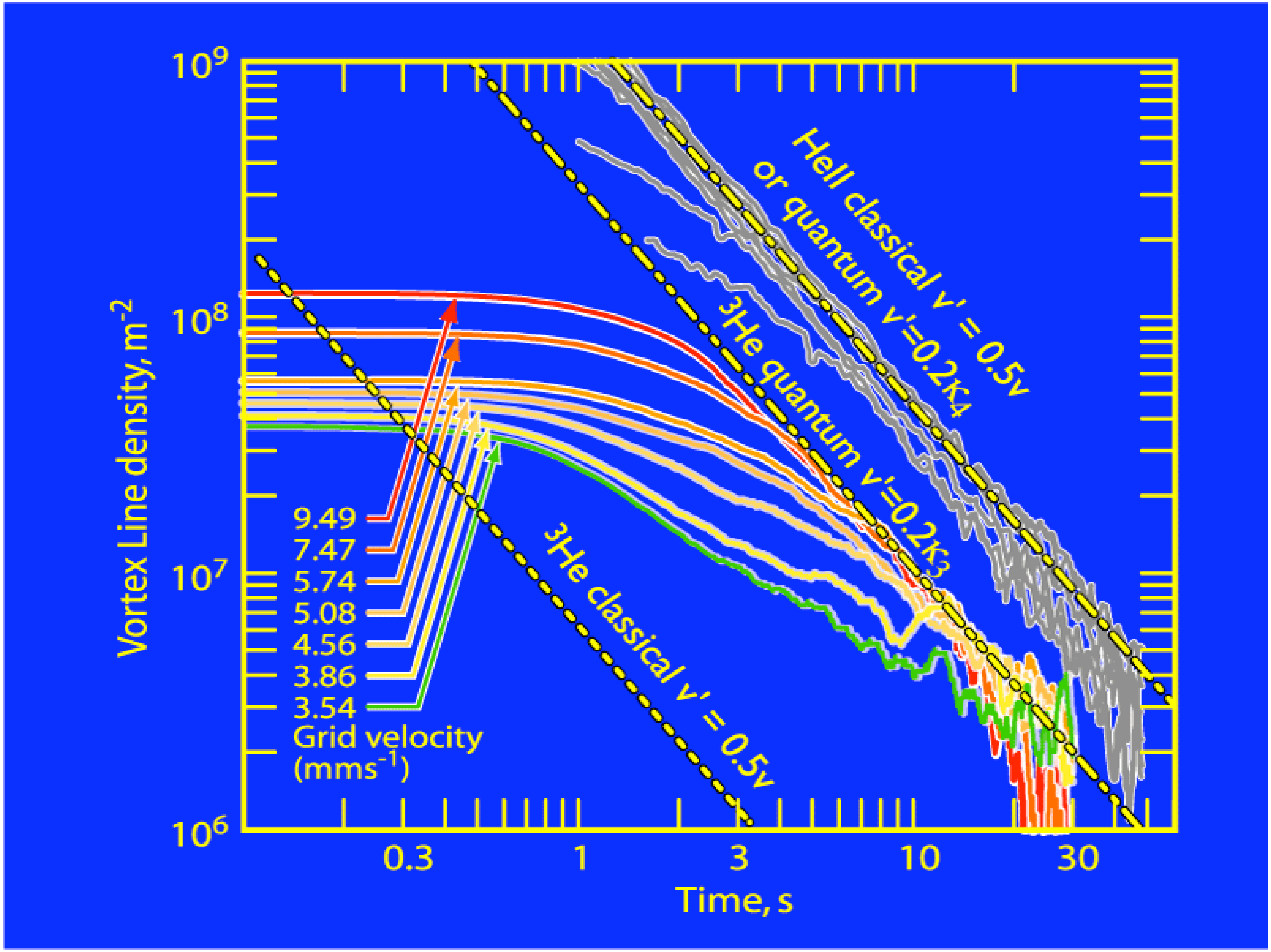
Expect for Kolmogorov decay on basis of classical turbulence of combined normal/superfluid components

$$L(t) = \frac{d}{2\pi\kappa}\sqrt{\frac{27C^3}{\nu'}}t^{-3/2}$$

d – characteristic size
ν' -kinematic viscosity

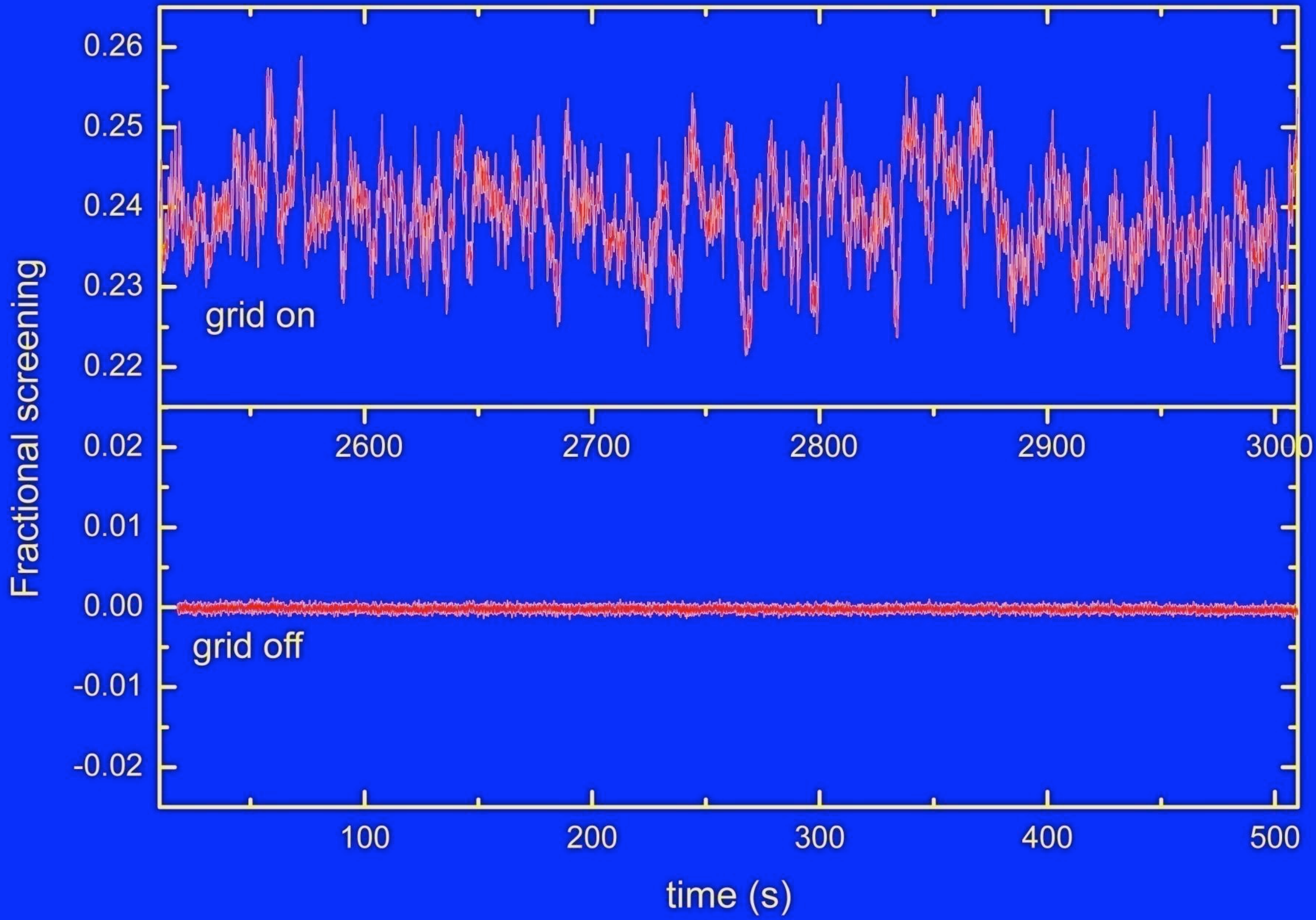
^{3}He normal fluid viscosity much higher

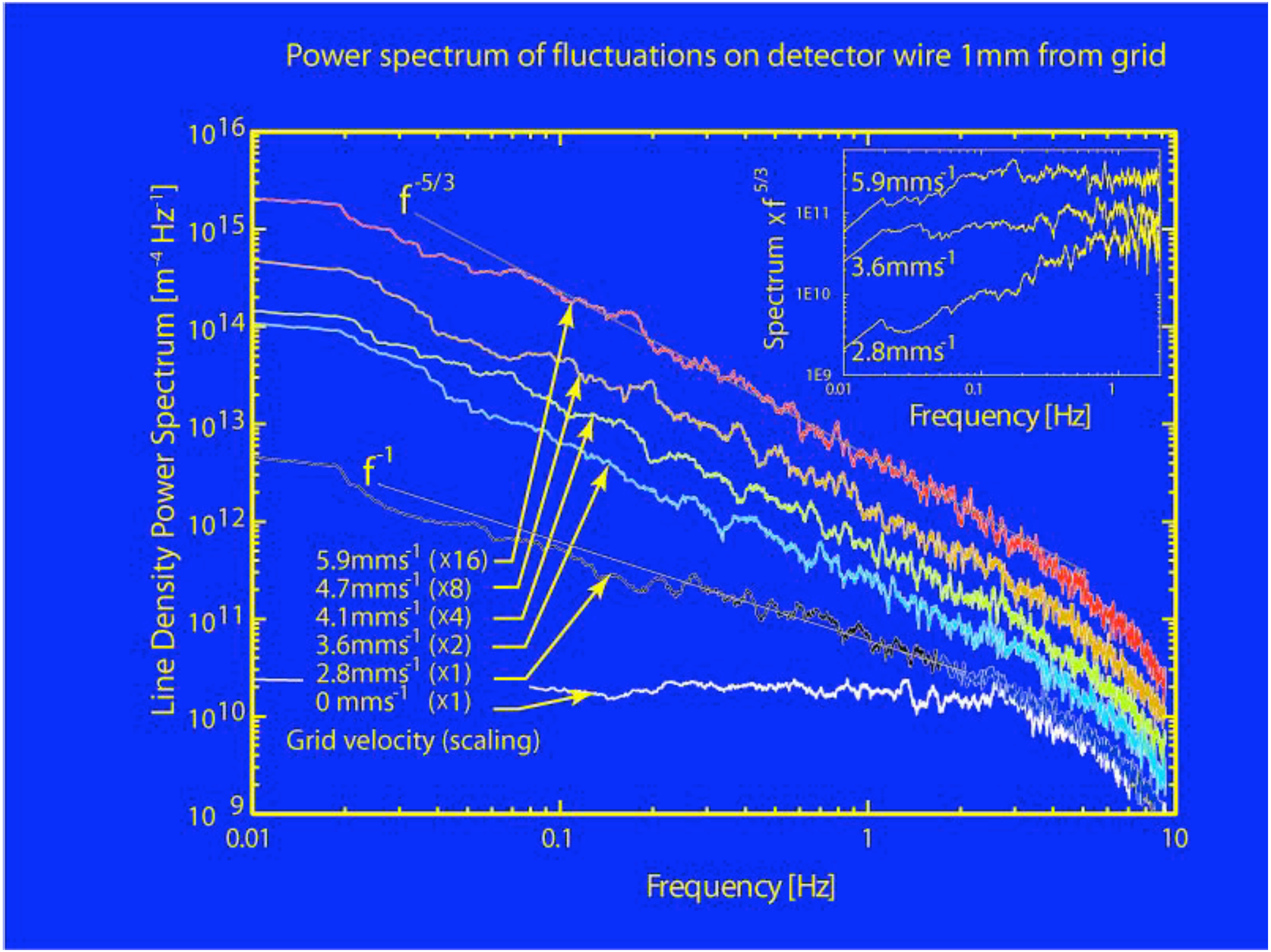
If use Vinen's suggestion of replacing the kinematic viscosity by the circulation quantum κ



10^9
10^8
10^7
10^6
Vortex Line density, m^-2
0.3
1
3
10
30
Time, s
HeII classical v' = 0.5v
or quantum v'=0.2κ4
3He quantum v'=0.2κ3
3He classical v' = 0.5v
9.49
7.47
5.74
5.08
4.56
3.86
3.54
Grid velocity
(mms^-1)

Turbulent fluctuations on detector wire from grid, 5.8 mm/s




Power spectrum of fluctuations on detector wire 1mm from grid
Line Density Power Spectrum [m-4 Hz-1]
Frequency [Hz]
f-5/3
f-1
5.9mms-1 (x16)
4.7mms-1 (x8)
4.1mms-1 (x4)
3.6mms-1 (x2)
2.8mms-1 (x1)
0 mms-1 (x1)
Grid velocity (scaling)
Spectrum x f 5/3
5.9mms-1
3.6mms-1
2.8mms-1
Frequency [Hz]

Next experiment

- Detect the heat released as turbulence decays
- Energy per unit length of a vortex

$$\boxed{\varepsilon \approx \frac{\rho}{4\pi}\kappa^2 \ln\left(\frac{b}{\xi_0}\right)}$$

~ 3 x 10^{-13} J/m initially

  only logarithmically dependent on the intervortex spacing
- Expect decay to produce quasiparticles

previously measured grid produced turbulence density

$L \sim 2 \times 10^8\, t^{-3/2}\ \mathrm{m}^{-2}$ ⇨ decay rate $\sim -3 \times 10^8\, t^{-5/2}$

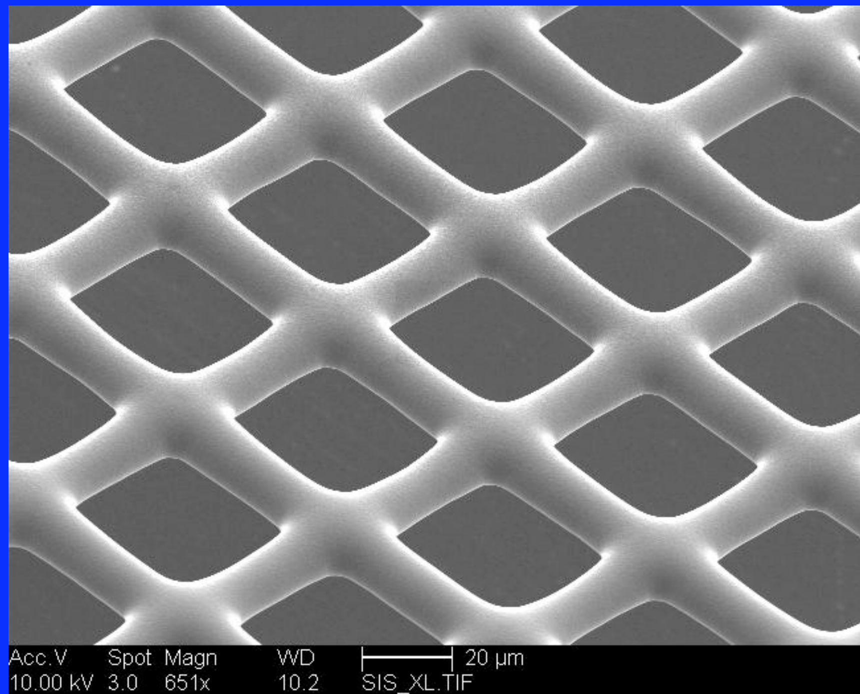
dissipation $\sim 6 \times 10^{-11}\, t^{-5/2}$ W per cm^3

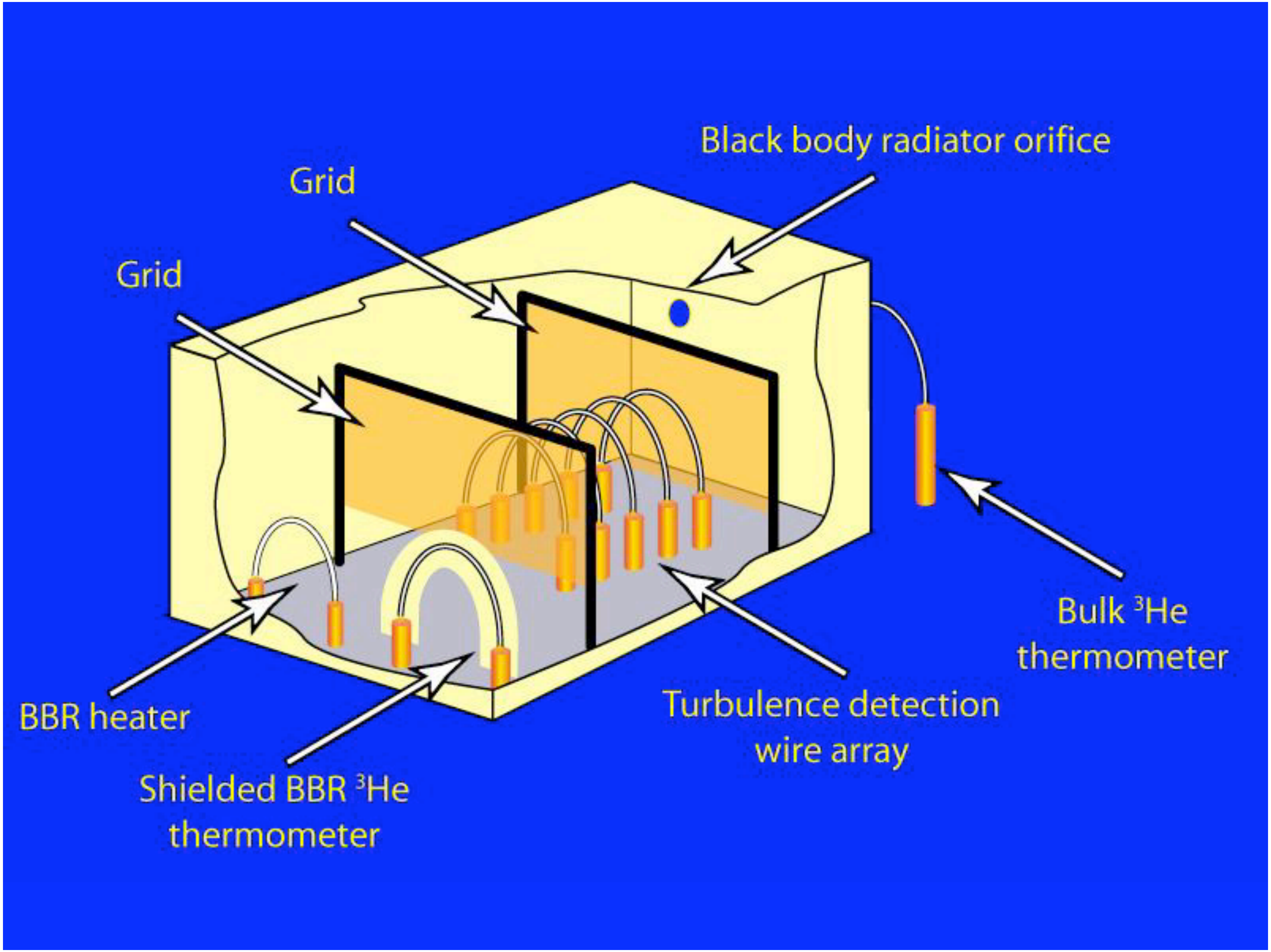
can be detected using a ^{3}He quasiparticle black body radiator as a calorimeter – these can have 10^{-15} W resolution

New grid type:

• Precision E-forming LLC

• very smooth
• 34 μm hole
• 17 μm 'wires'




Black body radiator orifice
Grid
Grid
Bulk ^{3}He thermometer
BBR heater
Shielded BBR ^{3}He thermometer
Turbulence detection wire array

Summary

Turbulence in ^{3}He-B at low Temperatures:

- Grid produces line densities are $\sim 10^8 m^{-2}$, corresponding to a line spacing $\sim 100 \mu m$
- Spatial extent of turbulence ~ mm
- For a grid, ballistic vortex rings generated above a velocity ~ 1mm/s, becoming turbulent above ~ 3mm/s
- Grid Turbulence decays similar to He II (suggests Kolmogorov spectrum with $\nu' \sim 0.2\kappa$).
- Noise analysis give a Kolmogorov $k^{-5/3}$ decay law
- New experiment just starting to detect energy release from decaying turbulence