Exotic turbulence opportunities in superfluid helium

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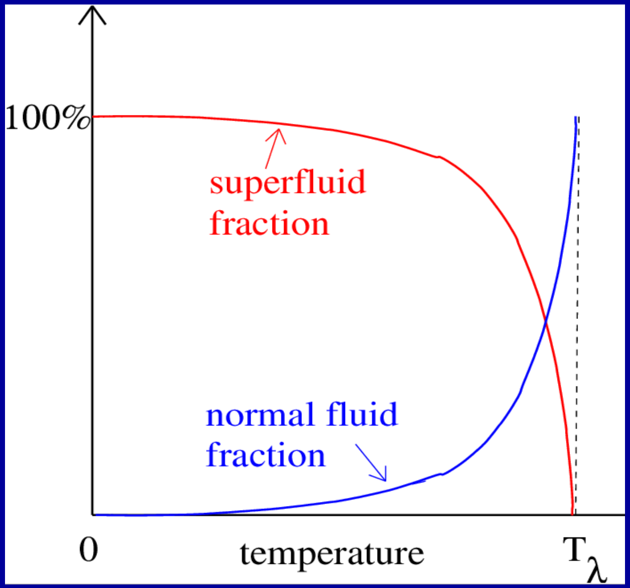
Helium II

- Normal fluid component:
  (related to thermal excitations)
  Viscous. Vortices can have any size and strength
- Superfluid component:
  (related to quantum ground state)
  Inviscid. Only vortex lines of fixed circulation & core radius



Relative proportion of superfluid and normal fluid depends on T

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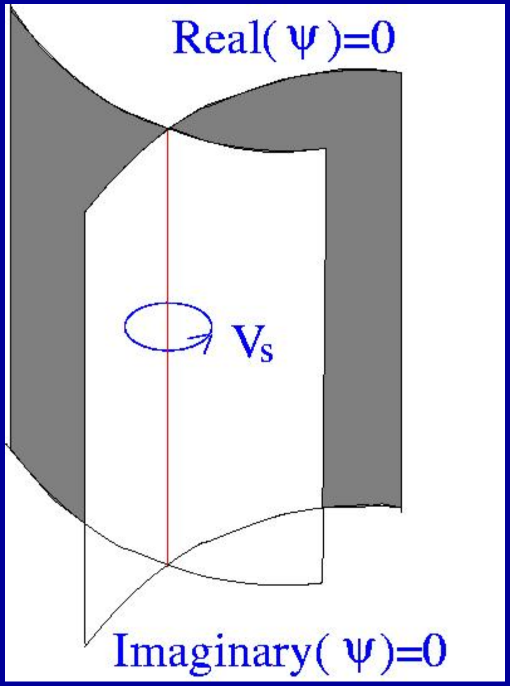
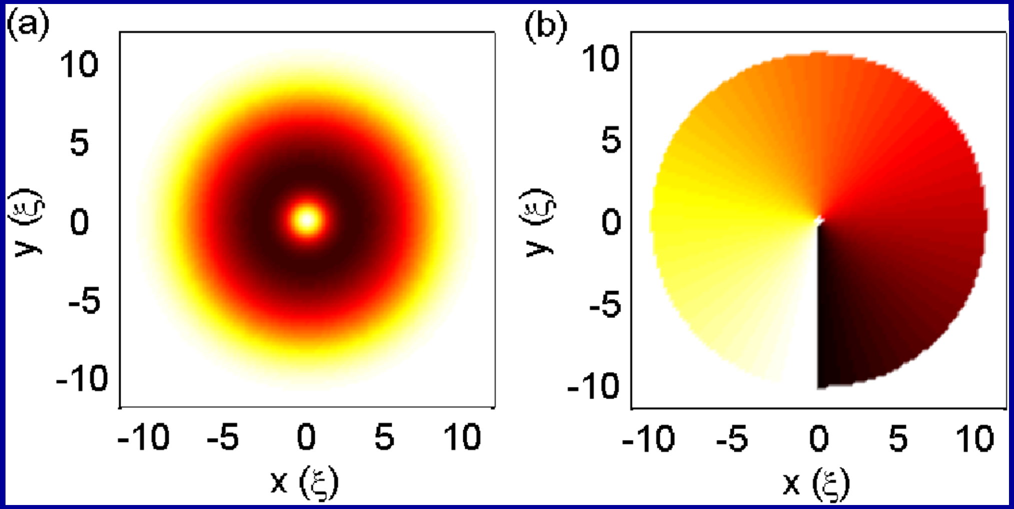
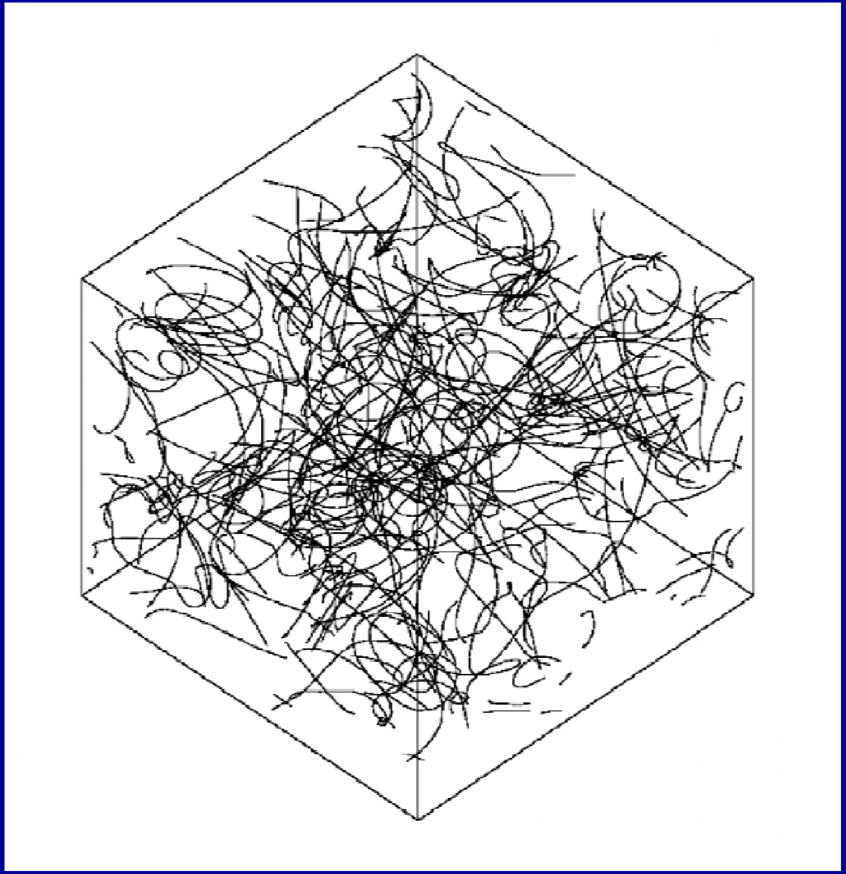




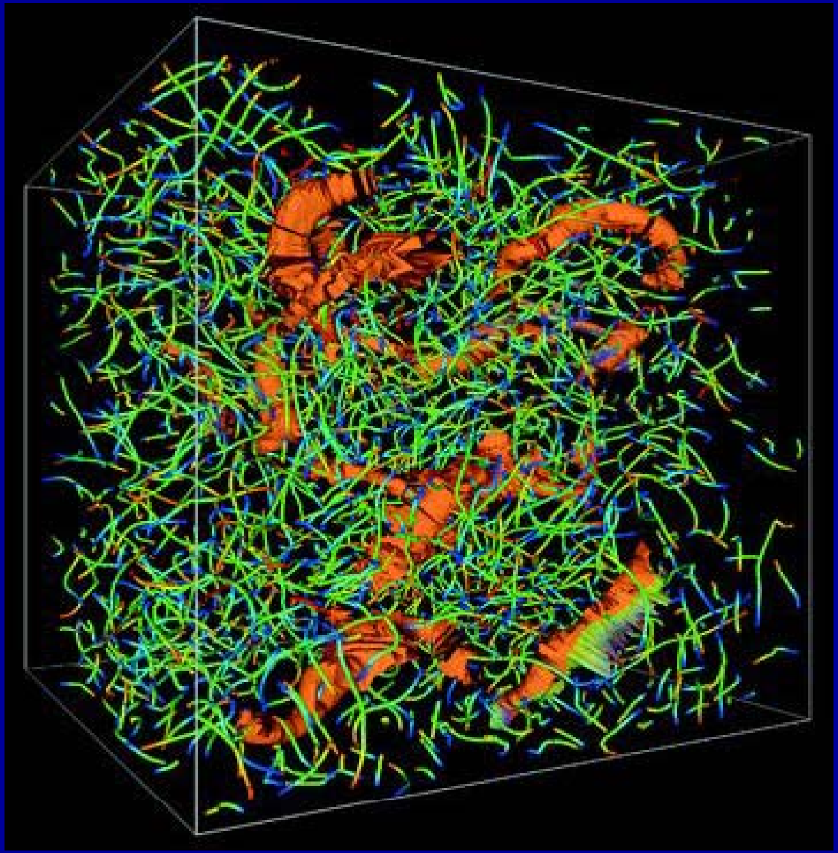
Quantised vortices as topological defects
No classical vortex core stretching

Superfluid turbulence

Ordinary turbulence

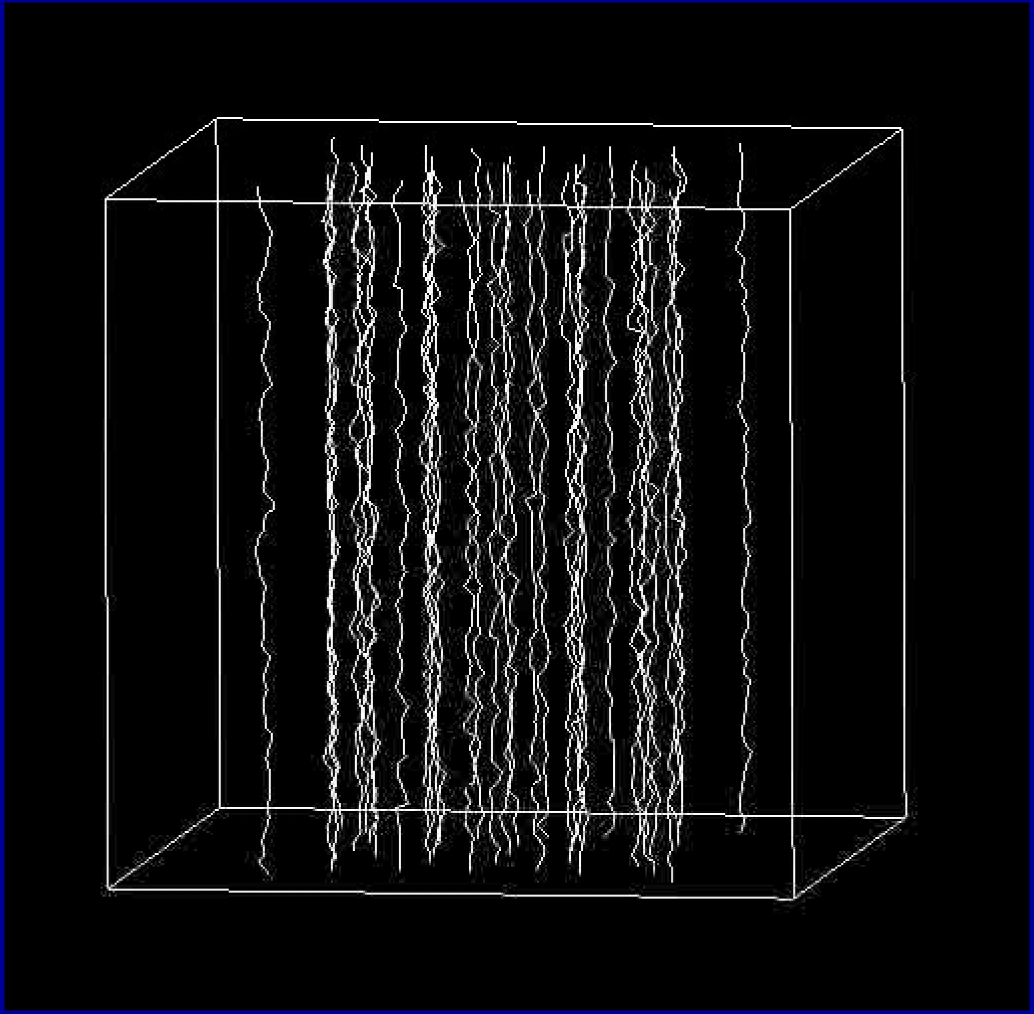


(Newcastle)



(Kida)

Example of superfluid turbulence: destabilization of rotating vortex array into a vortex tangle



Tsubota, Araki and Barenghi, Phys. Rev. Lett. 90, 20530, 2003

KNOWN SUPERFLUIDS

^{4}He

^{3}He

atomic Bose-Einstein condensates

neutron stars

TURBULENCE

Relevant to all known superfluids

MANY FORMS OF TURBULENCE

1) ^{4}He at low T, ^{3}He at low T:
Single quantised turbulence

2) ^{3}He at high T:
Single quantised turbulence with simple dissipation against stationary normal fluid

3) ^{4}He at high T:
Double turbulence (one quantised, one not)

4) ^{4}He counterflow (heat transfer):

5) 1-dim turbulence along vortices in ^{4}He and ^{3}He at low T: Kelvin wave cascade

1) ^{4}He at low T, ^{3}He at low T: Single quantised turbulence

Experiments show that superfluid turbulence decays (Davis et al, Physica B 280, 43) and that it diffuses (Fisher et al, PRL 86, 244, 2001).

Numerical simulations (NLSE model: Nore et al, PRL 78, 3896, 1997; vortex dynamics model: Araki et al, PRL 89, 145301, 2002) predict $k^{-5/3}$ energy spectrum.

Energy sink ? Sound emission at vortex reconnections (Leadbeater et al PRL 86, 1410, 2001) and by high-k Kelvin waves radiation (Vinen, PRB 64, 134520, 2001)

2) ^{3}He at high T: Single quantised turbulence with simple dissipation against stationary normal fluid

Experiments
Finne et al, Nature 424, 1022, 2003

Prediction of spectrum
L’vov, Nazarenko & Volovik, JETP Lett 80, 479, 2004,
Vinen, J Phys Chem Solids 66, 1493, 2005

3) ^{4}He at high T: Double turbulence (one quantised, one not)

Experiments: $k^{-5/3}$ spectrum for energy (Maurer & Tabeling, Europhysics Lett 43, 29, 1998) and vortex line density (Roche et al 2007); $t^{-3/2}$ temporal decay (Smith et al, PRL 71, 2583, 1993), drag crisis past sphere (Smith et al PoF 11, 751, 1999)

Superfluid has Kolmogorov spectrum driven by imposed Kolmogorov normal fluid (Kivotides et al PRL 57, 845 2002)

Prediction of unusual pressure spectrum (Kivotides et al PRL 87, 275301, 2001)

Coupled, self-consistent 2-fluid calculations done only for vortex ring (Kivotides et al, Science 290, 777, 2000)

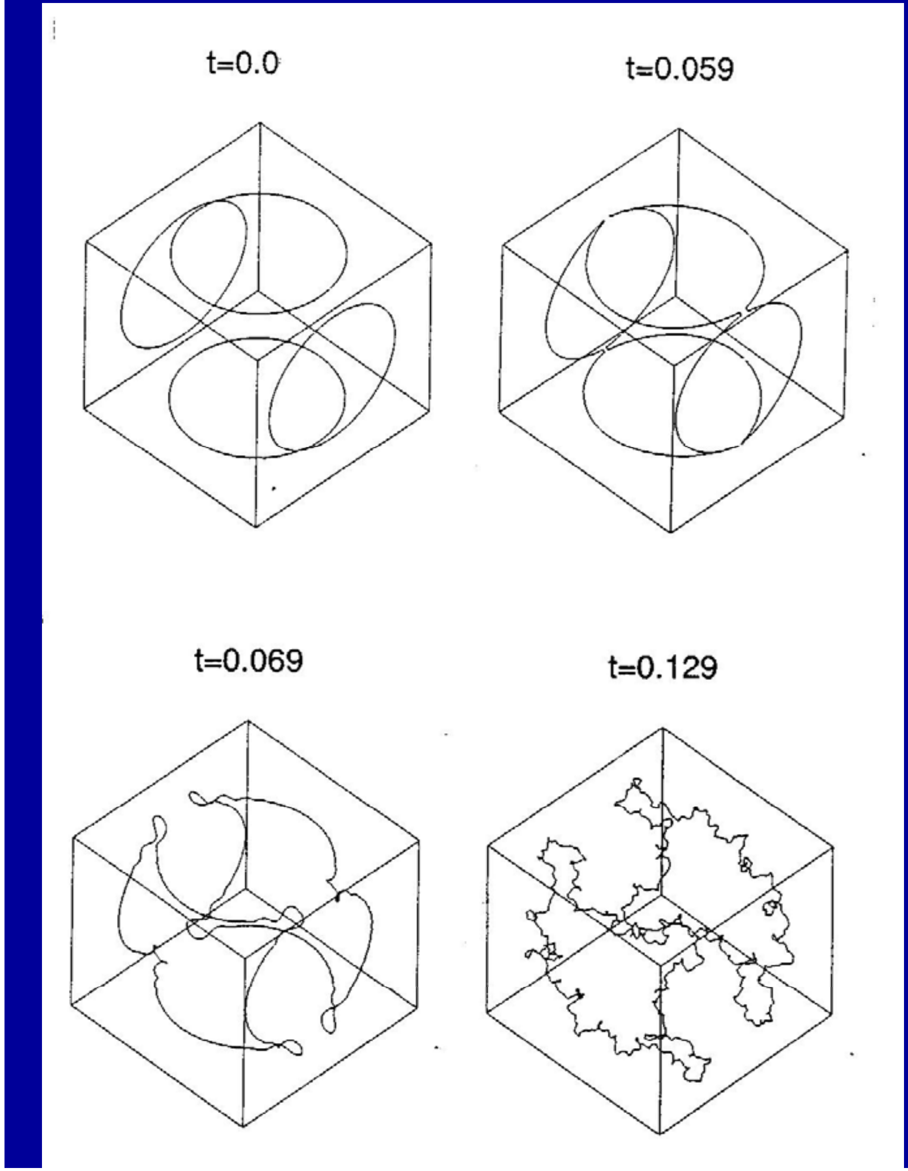
4) ^{4}He counterflow (heat transfer):

The most studied case (from Vinen, Donnelly, Tough and Schwarz, to eg Blaztkova et al, PRE 75, 025302, 2007)

Experiments show $t^{-3/2}$ decay (Barenghi, Godeev, Skrbek, PRE 74, 026309, 2006)

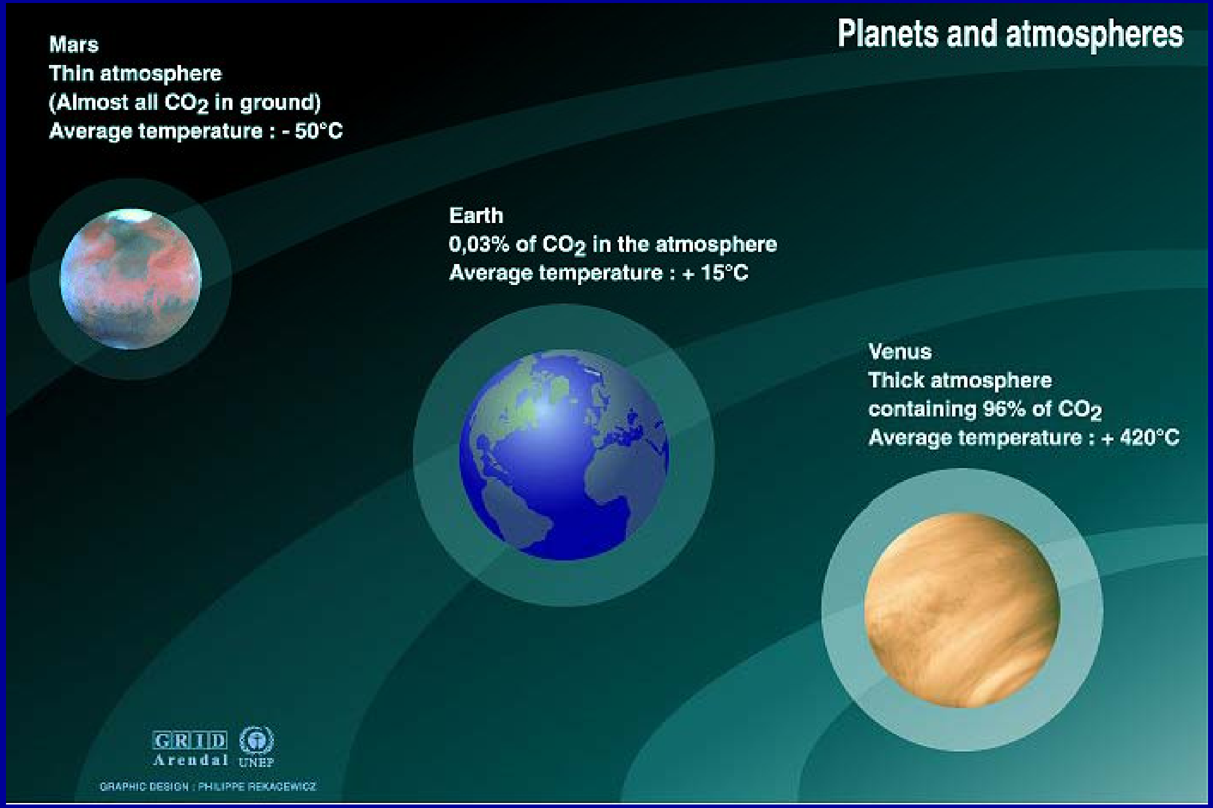
Large scale motion V_n and V_s must be different

5) 1-dim Kelvin wave cascade along vortices in ^{4}He and ^{3}He at low T



-Kivotides, Vassilicos, Samuels & Barenghi, PRL 86, 3080, 2001)
-Vinen, Tsubota & Mitani, PRL 91, 135301, 2003
-Kozik & Svistunov PRL 92, 035301, 2004
-Nazarenko, JETP Lett 84, 585, 2007

AN ANALOGY



We know more about the Earth's atmosphere because we can test our toolkit of ideas and methods on other planets

Examples:
-greenhouse effect of Venus vs global warming
-dust storms on Mars vs volcanic eruptions / nuclear winter

HOW TO WRITE A SUCCESSFUL PROPOSAL ?

A successful EU proposal requires a PUNCHLINE strong enough to be the focus and to attract the attention

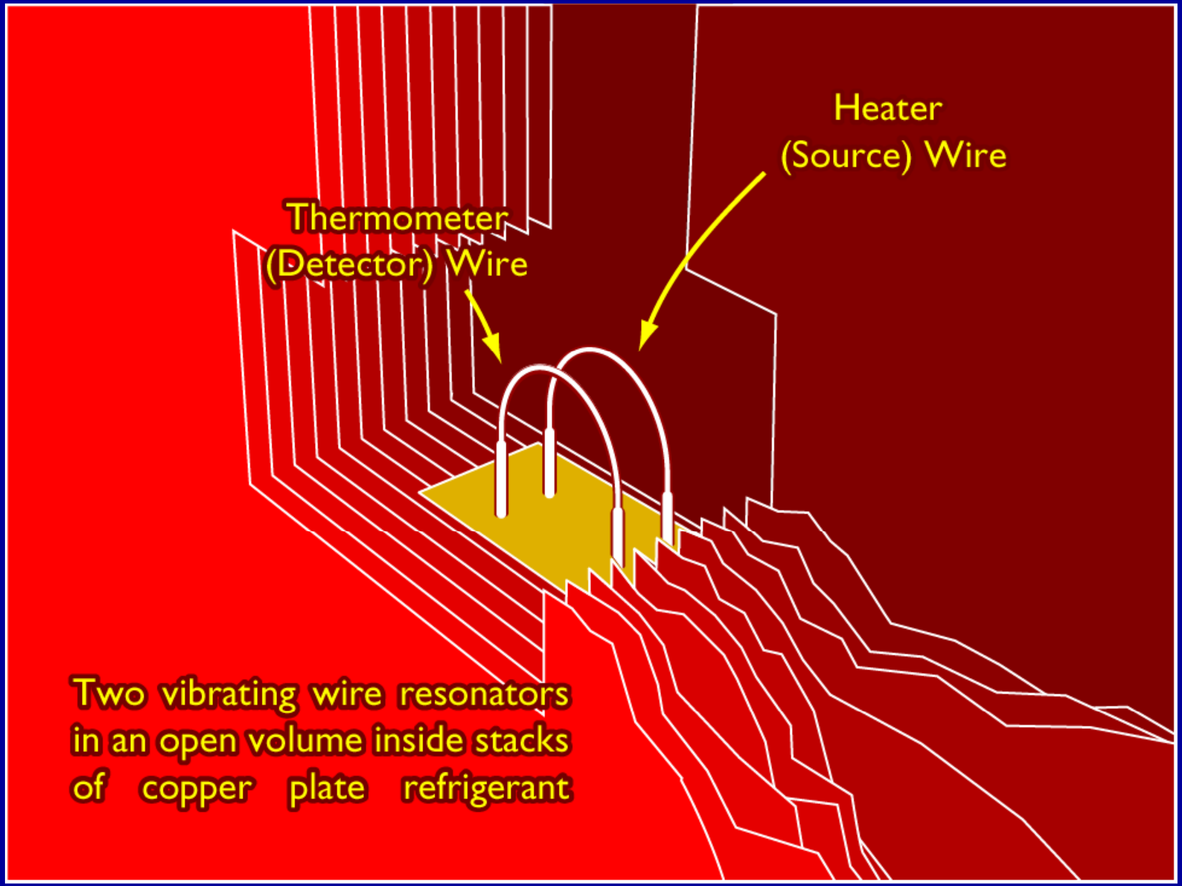
Achieving relatively large Rayleigh / Reynolds numbers in He gas, HeI or high-T HeII is not strong enough

It is the rich VARIETY of turbulence problems available in superfluid ^{3}He and ^{4}He which provides us with a punchline

CONCLUSIONS

- Labs involved in ^{3}He and low-T ^{4}He are essential nodes
- Crucial role of theoretical / numerical modelling

Superfluid turbulence created at low T in 3He-B by a vibrating wire diffuses away in space.

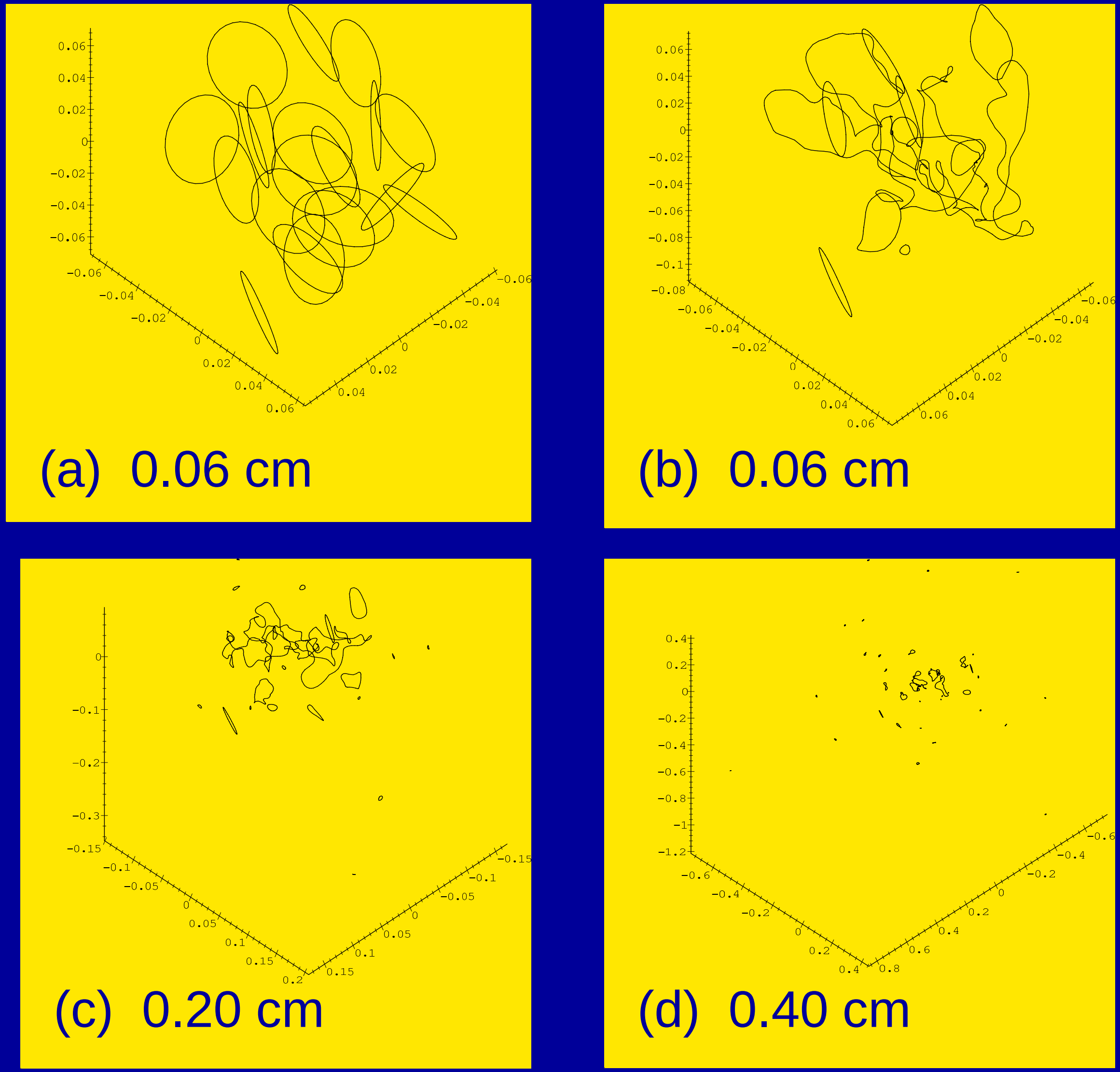


Two vibrating wire resonators in an open volume inside stacks of copper plate refrigerant

S.N. Fisher, A.J.Hale, A.M.Guénault, and G.R.Pickett, *PRL* 86, 244, 2001

“Evaporation” of a packet of vortex loops

Turbulent diffusion in ^{3}He at low T



(a) 0.06 cm

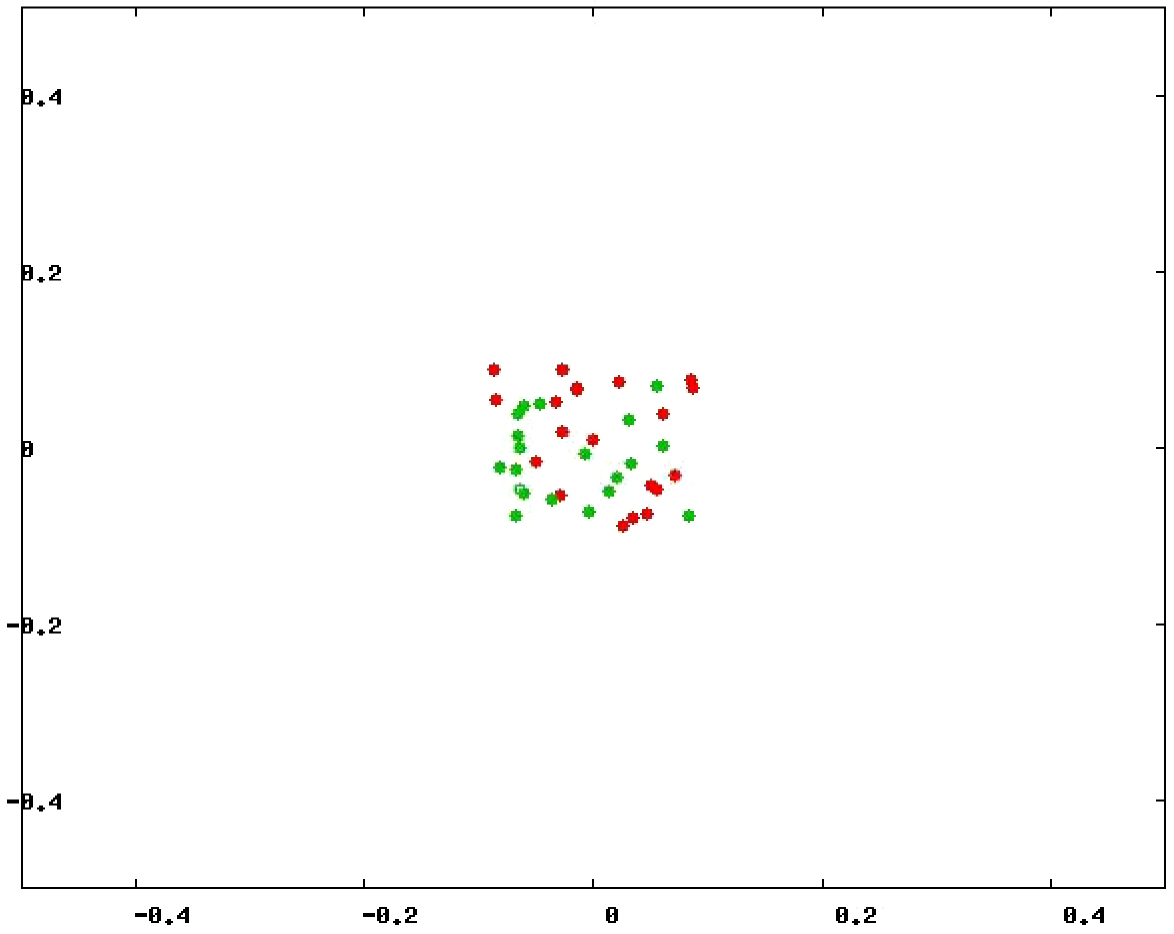
(b) 0.06 cm

(c) 0.20 cm

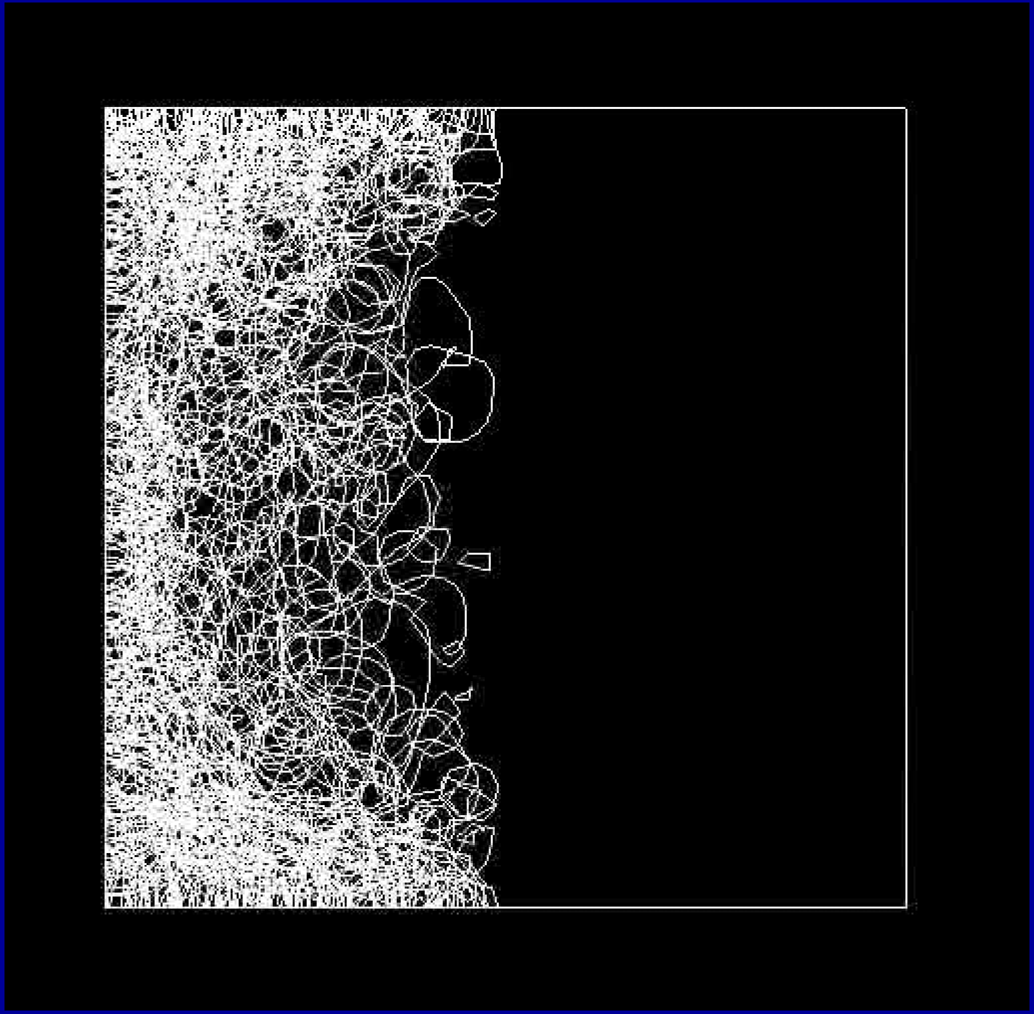
(d) 0.40 cm

Computed radius of vortex cloud vs time agrees with experiment at Lancaster

Barenghi & Samuels, Phys. Rev. Lett. 89, 155302 (2002)



2-dim example



Tsubota, Araki & Vinen,
Physica B, 329, 224 (2003)