

Realization of inverse Kibble–Zurek scenario with trapped Bose gases

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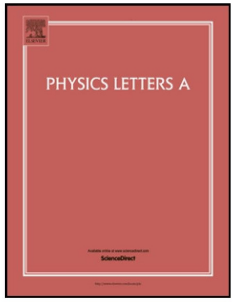


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Valley Hall effect in a quantum dot coupled to a quantum wire

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Abstract
 We show that there exists the linear Hall-like anomaly, when we start with an equilibrium system with broken spin symmetry and, by imposing perturbation, transform it to a strongly nonequilibrium spin-symmetric state through the sequence of states with spontaneously arising topological defects. We demonstrate the linear Hall-like anomaly both experimentally by analyzing the time-dependent conductance of coupled ¹⁵⁵GaAs quantum dot and quantum wire, and theoretically by calculating analytical formulas for the same setup. © 2015 Elsevier B.V. All rights reserved.

Kibble–Zurek mechanism (KZM)

characterizes the spontaneous formation of defects in the process of system equilibration from an initial strongly nonequilibrium symmetric state to an equilibrium state with broken symmetry

$$\varphi(\vec{r}) \rightarrow e^{i\alpha} \varphi(\vec{r})$$

Bose-Einstein condensate

macroscopic number of atoms are collected in the ground state of the system

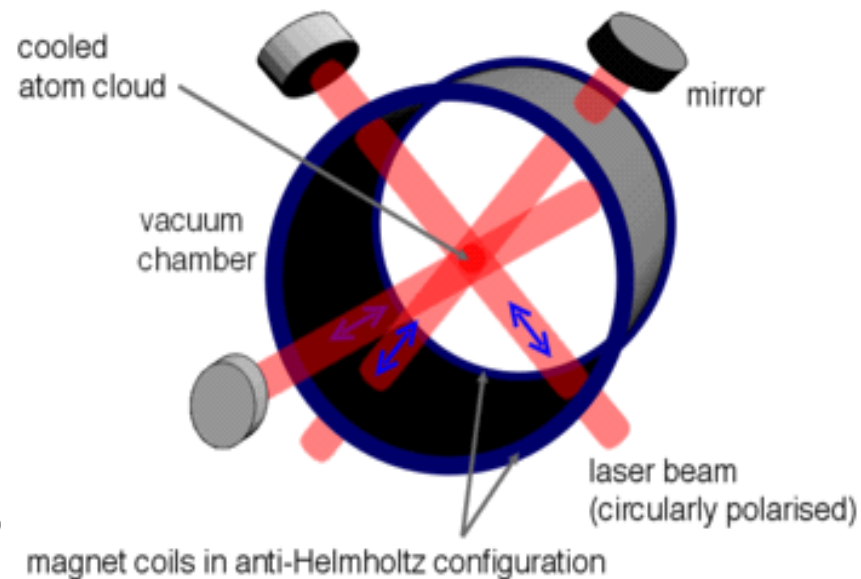
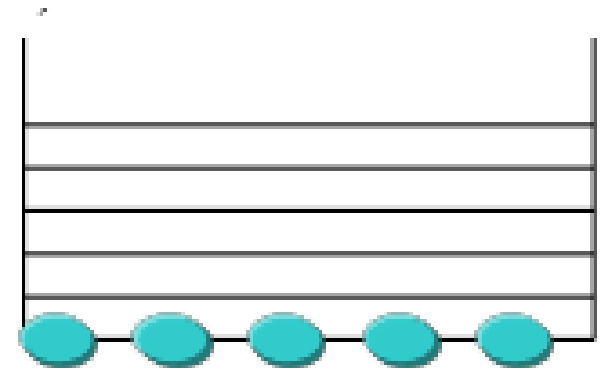
Main properties:

dilute gas of **weakly interacting** atoms

precise control and manipulation of the system properties

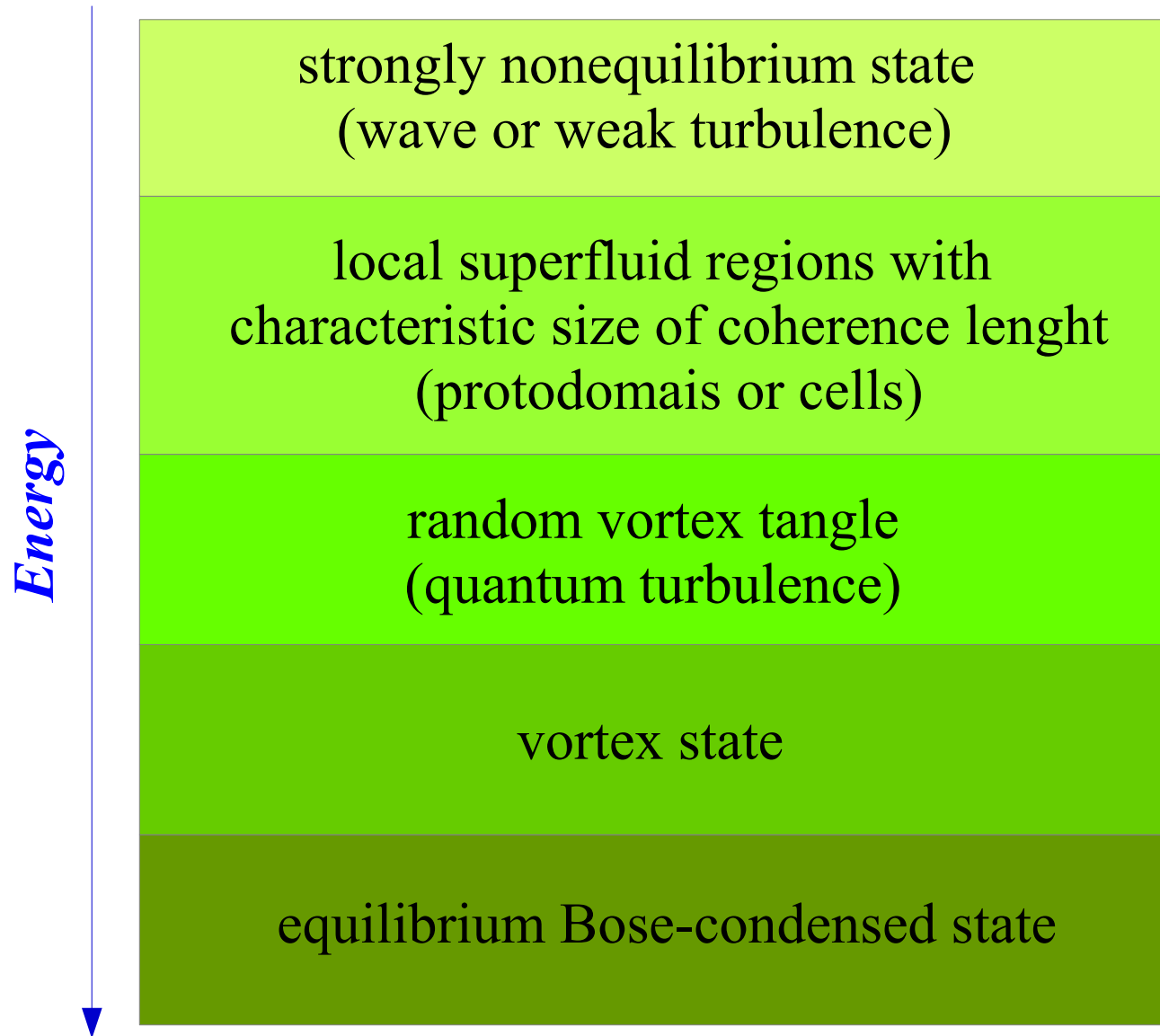
Gross-Pitaevskii equation

$$i\hbar \frac{\partial}{\partial t} \Psi(\vec{r}, t) = \left(-\frac{\hbar^2}{2m} \nabla^2 + V_{\text{ext}}(\vec{r}) + g|\Psi(\vec{r}, t)|^2 \right) \Psi(\vec{r}, t)$$



Equilibration of an uncondensed system

E. Levich, V. Yakhot, Phys. Rev. B 15 (1977) 243 H.T.C. Stoof, Phys. Rev. A 45 (1992) 8398



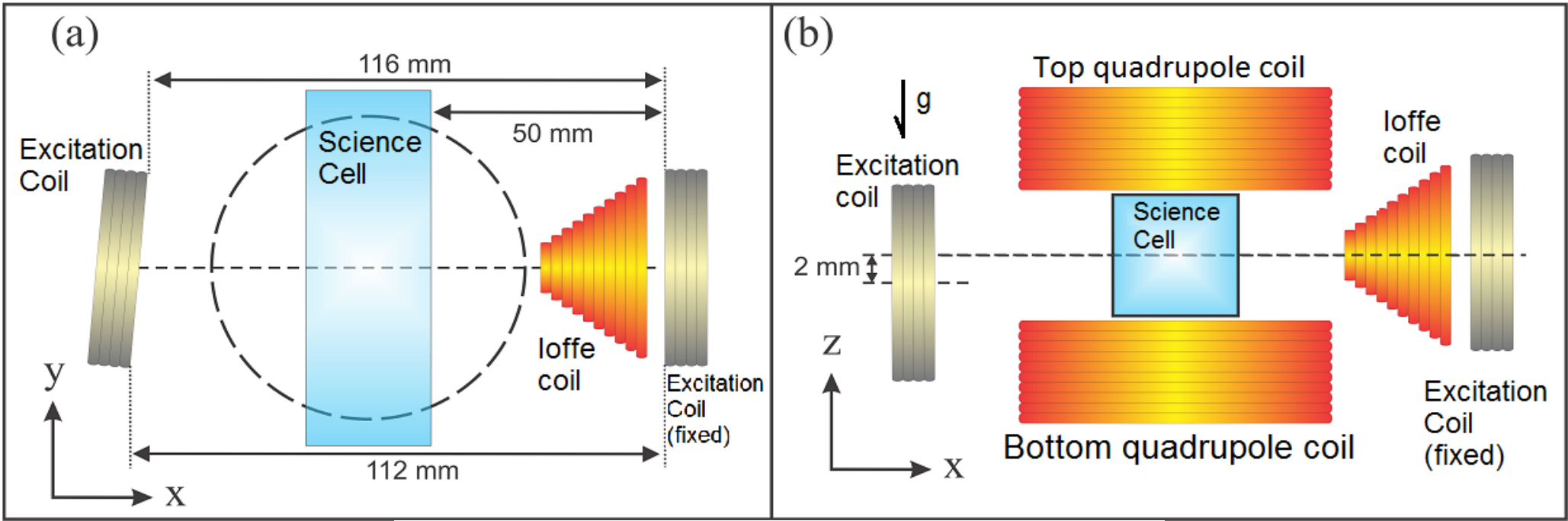
Possibility of inverse mechanism?

Condensate perturbation

$$\hat{H} = \int \eta(\vec{r}, t) \left[-\frac{\nabla^2}{2m} + U \right] \eta(\vec{r}, t) d\vec{r} + \frac{1}{2} \Phi \int |\eta(\vec{r}, t)|^4 d\vec{r}$$

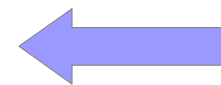
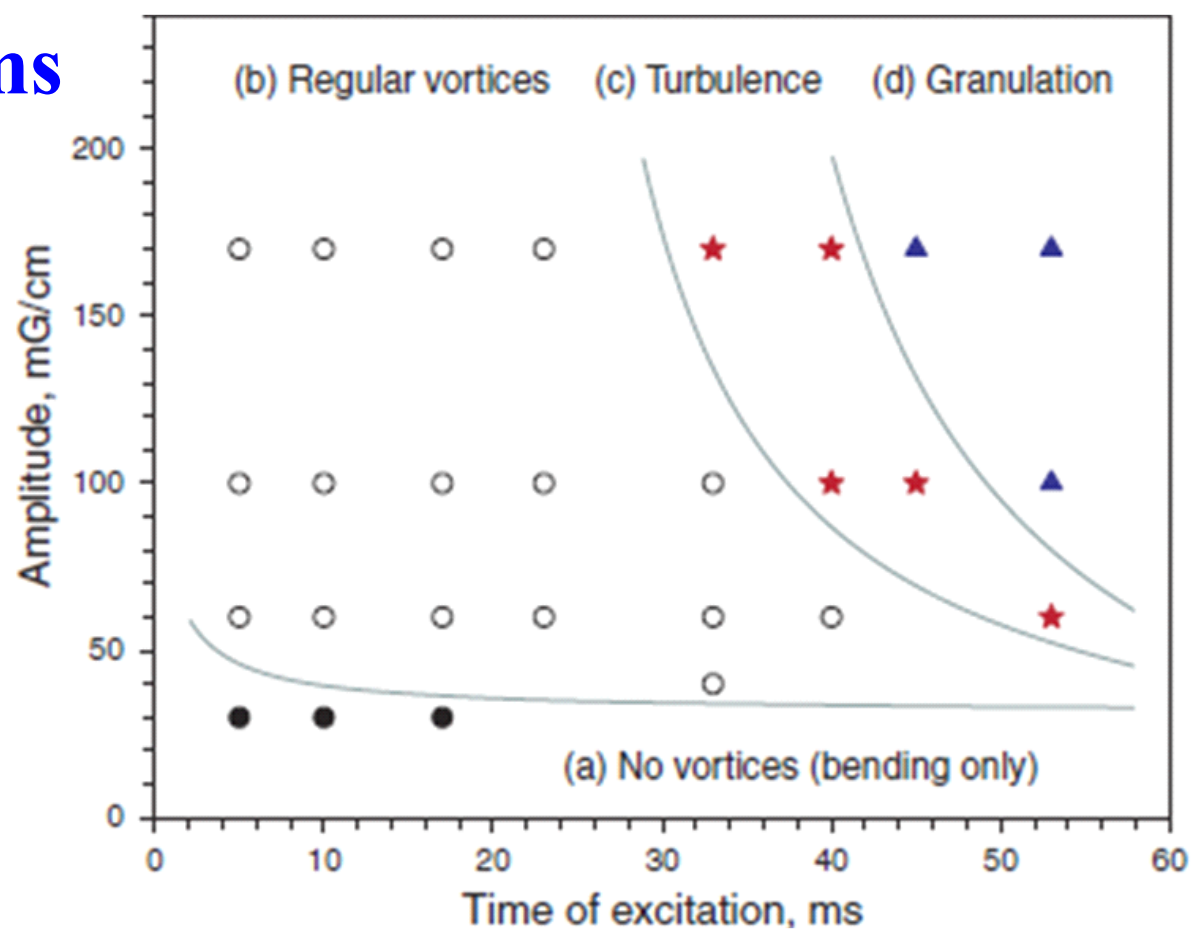
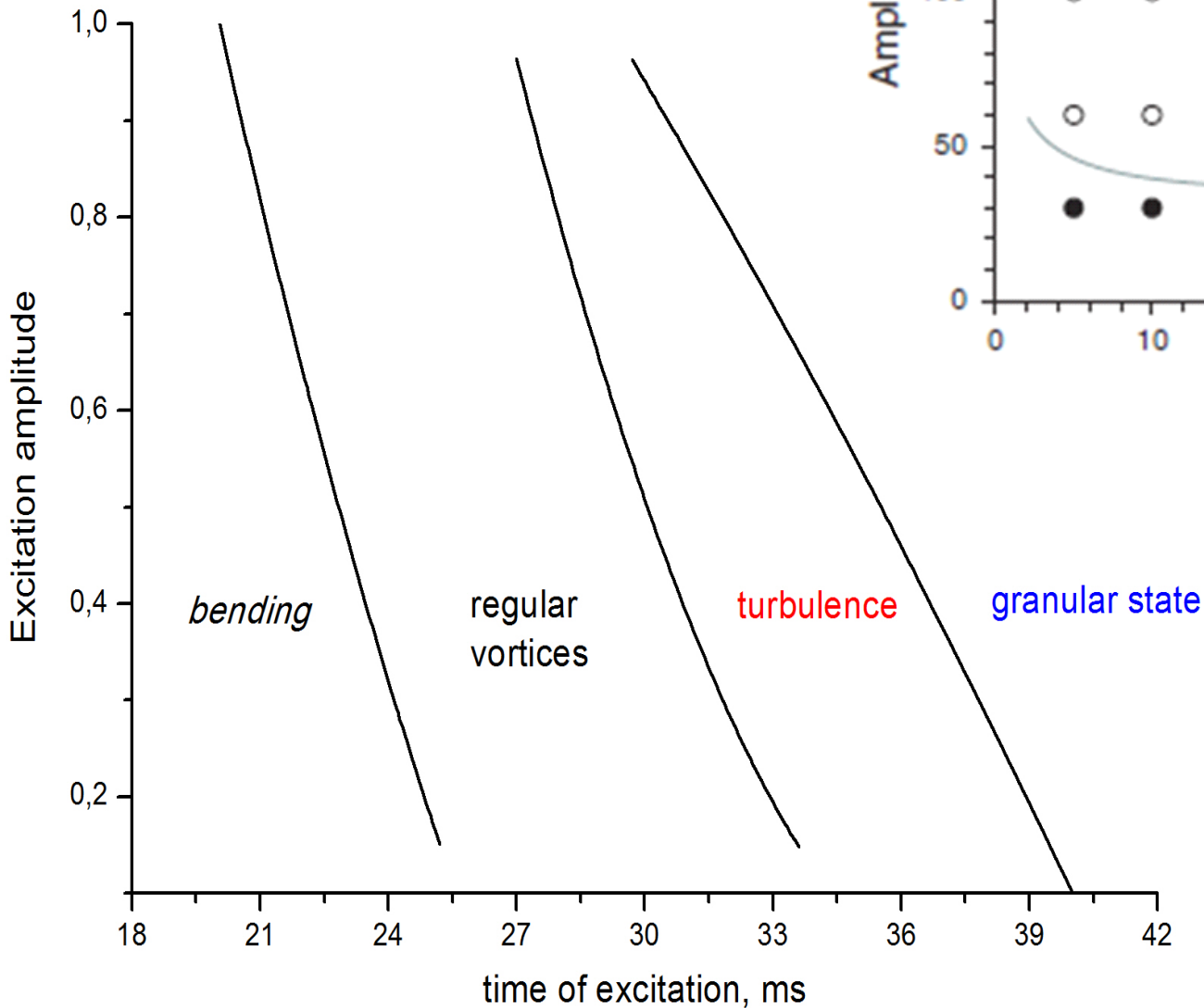
$$U(\vec{r}, t) = U(\vec{r}) + V(\vec{r}, t) \qquad E_{inj} = \int_0^t \left| \left\langle \frac{\partial \hat{H}}{\partial t} \right\rangle \right| dt$$

Experimental setup



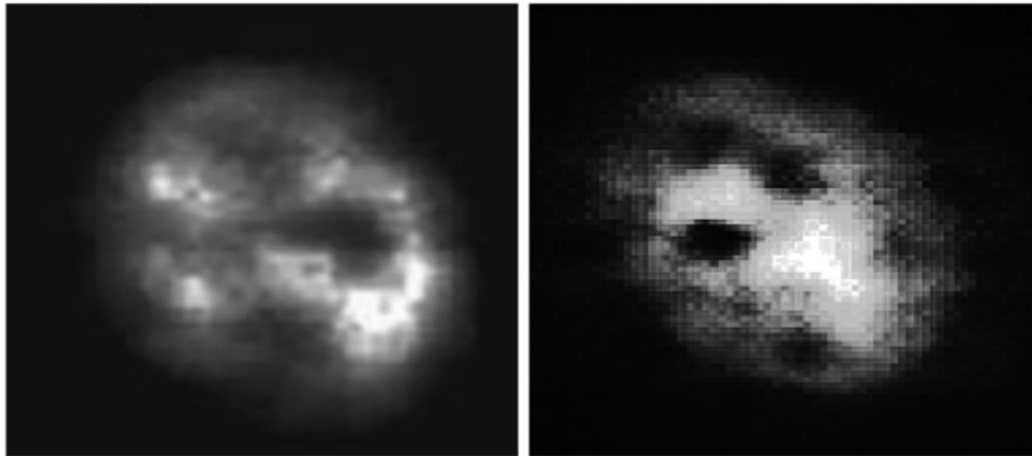
No rotation moment imposed!

Time-amplitude diagrams



The sequence of observed states: theory vs experiment

1. quantum vortices

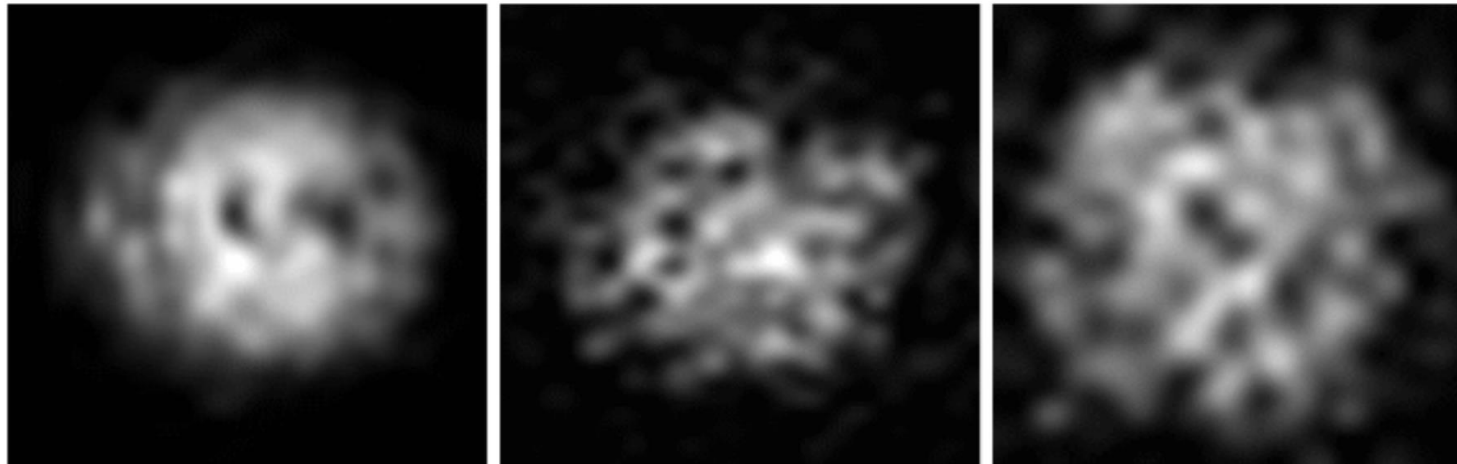


$$E_{vor} < E_{inj} < E_{tur}$$

$$E_{tur} = N_c E_{vor}$$

$$N_c \sim \left(\frac{r_x}{4\xi} \right)^2$$

$$N_c \approx 25$$



Coherence length

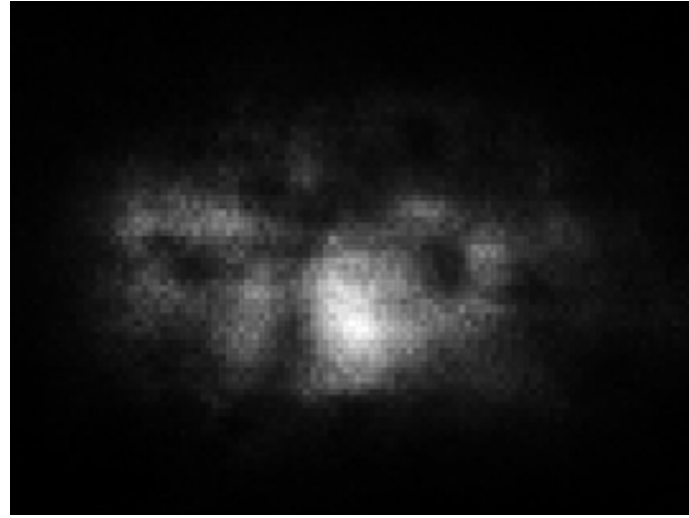
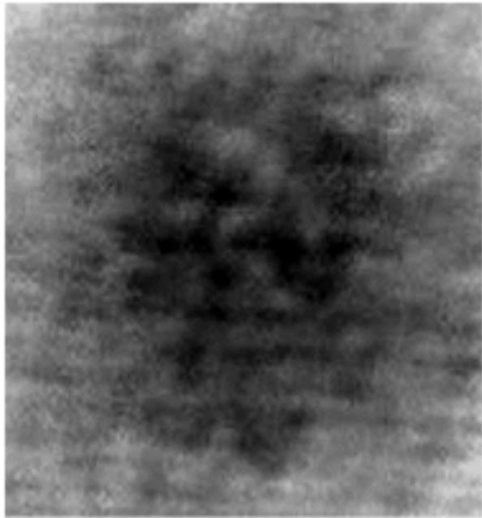
$$\xi \sim \frac{\hbar}{m c},$$

$$c \sim \frac{\hbar}{m} \sqrt{4\pi\rho a_s}$$

2. quantum turbulence

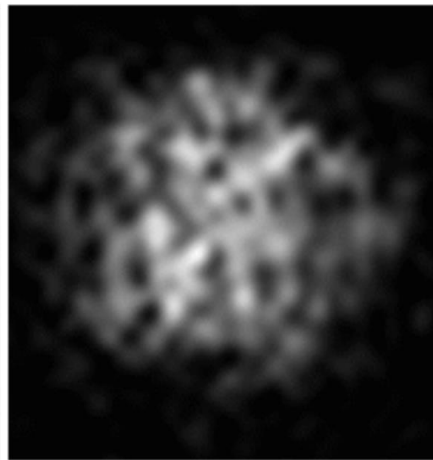
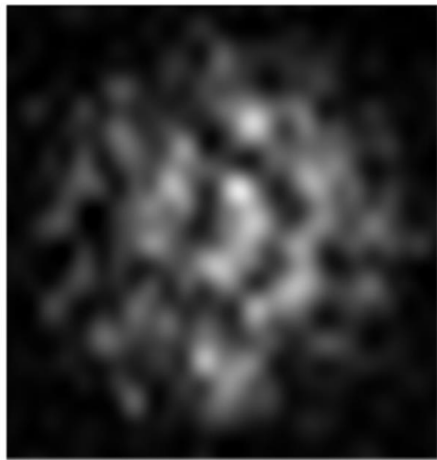
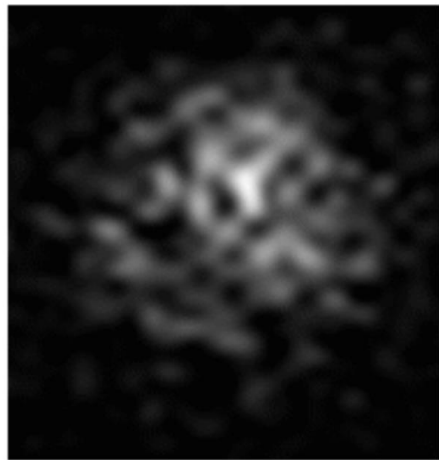
Quantum turbulence = random vortex tangle

R.P. Feynman, Prog. Low Temp. Phys. 1, 17 (1955)

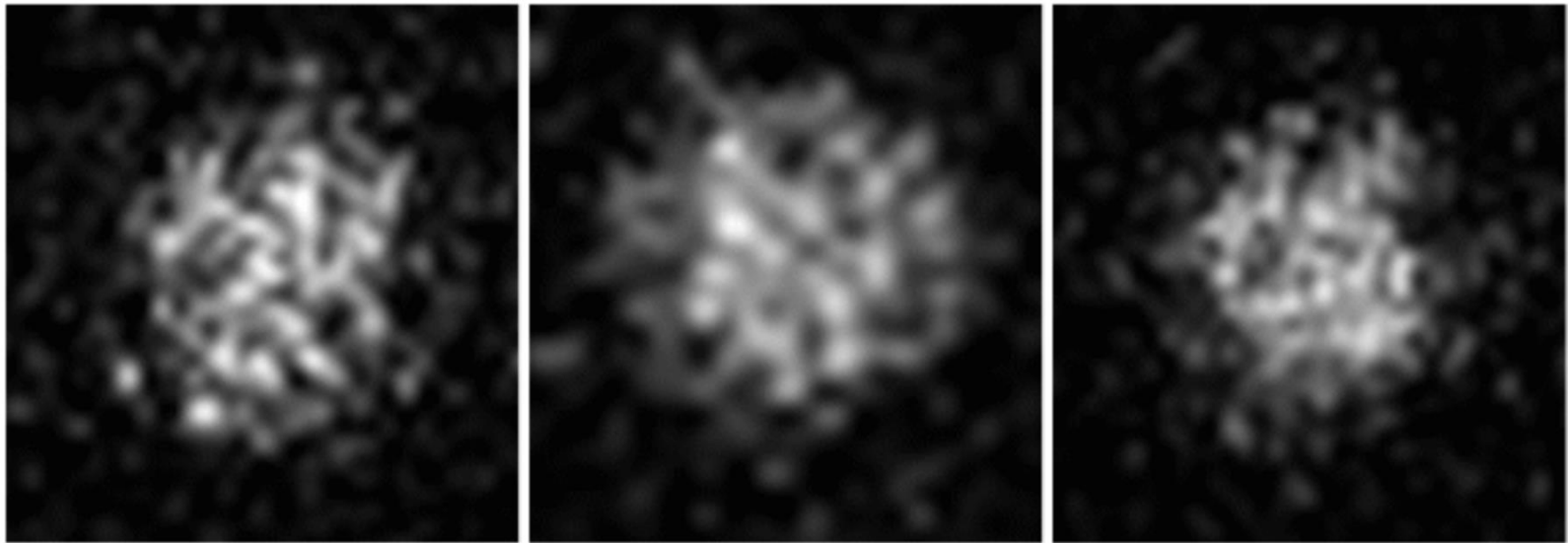
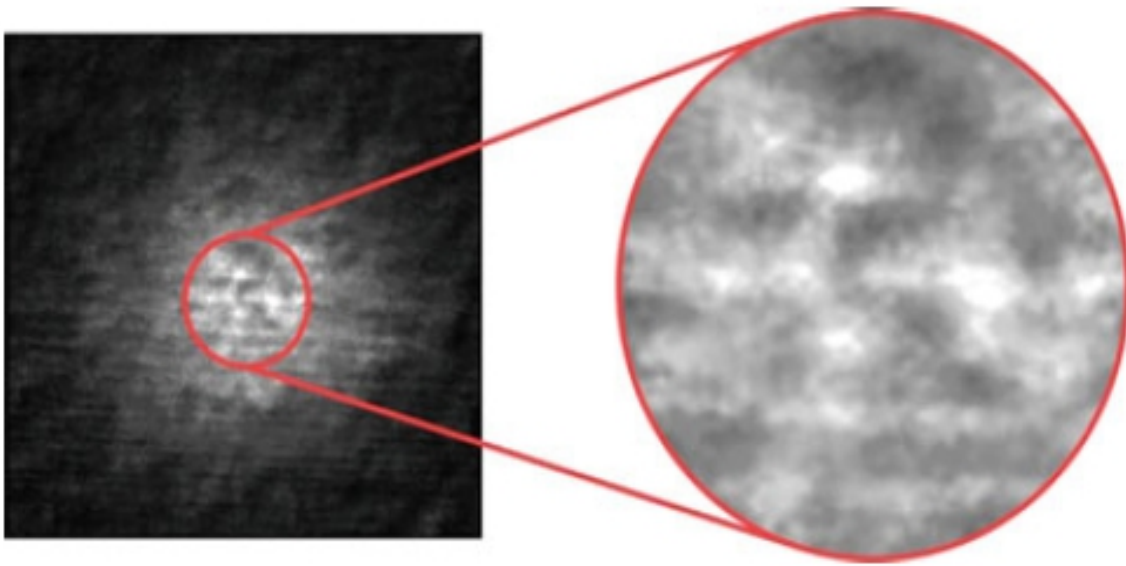


$$E_{tur} < E_{inj} < E_{fog}$$

$$E_{fog} = N_c^* E_{vor}$$

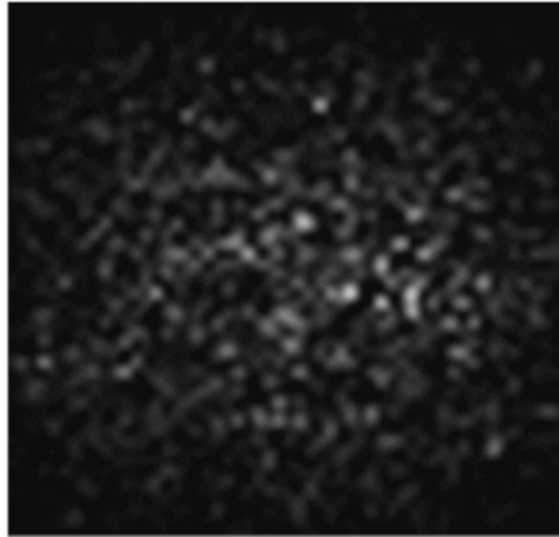


3. granular state

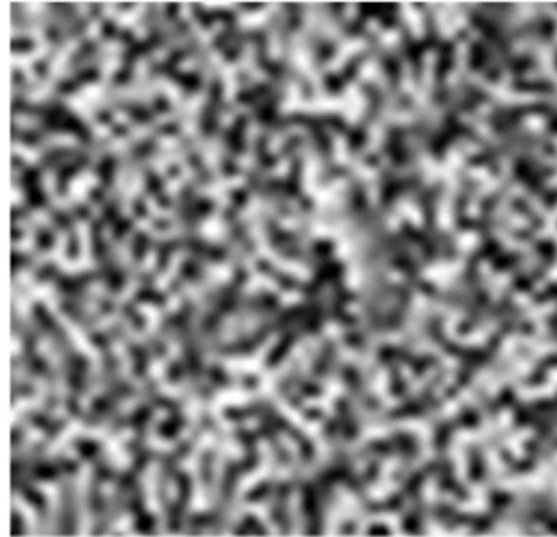


4. wave (weak) turbulence: not observed in the experiment!

density



phase



Grain
turbulence

$$\rho_{dr} / \rho_{sur} \sim 100$$

constant phase inside

$$E_{kin} / E_{int} \sim 3$$

$$l_{dr} \sim 10^{-5} \text{ cm}$$

$$l_{dr} \sim \xi$$

Wave
turbulence

$$\rho_w / \rho_{sur} \sim 3$$

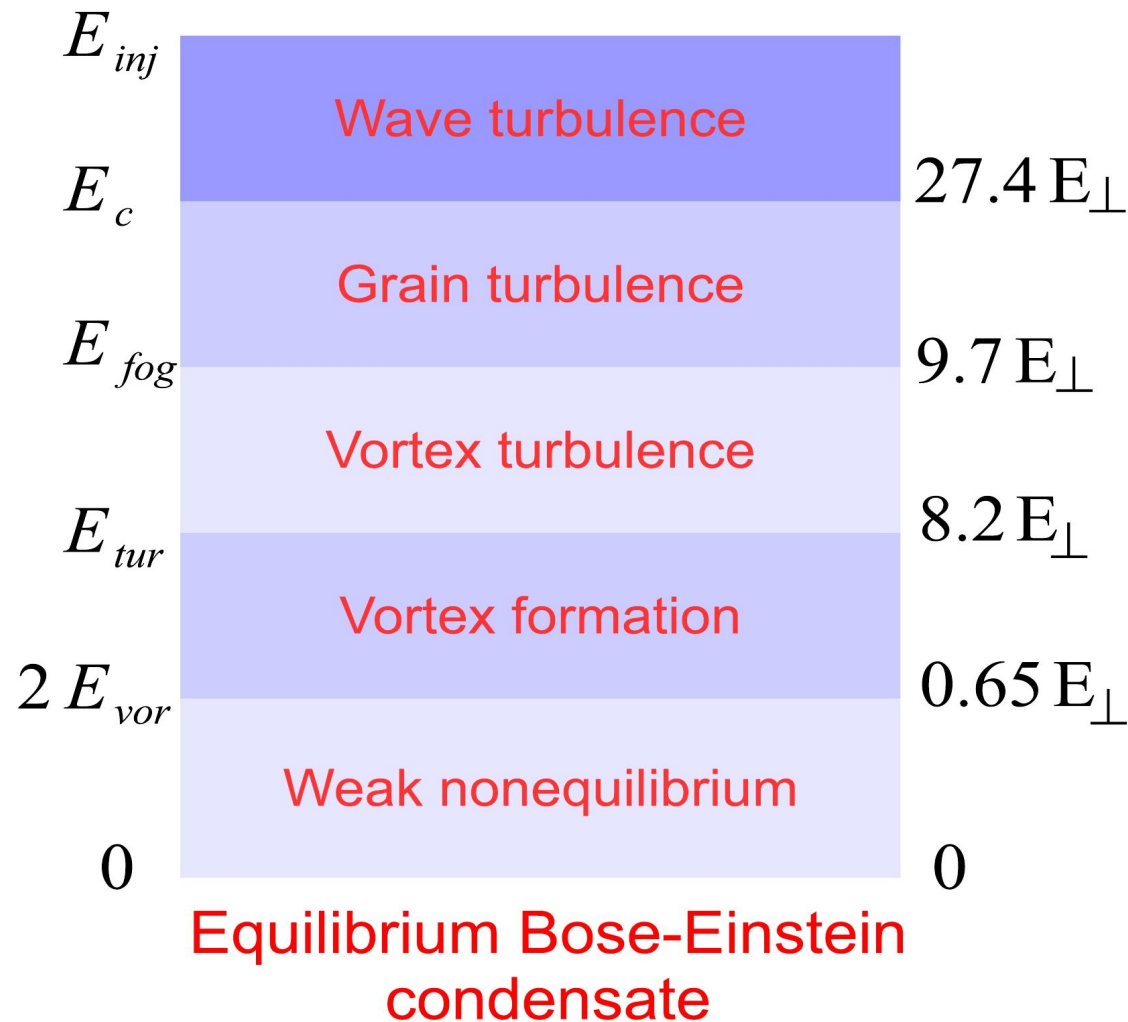
random phase inside

$$E_{kin} / E_{int} \sim 300$$

$$l_w \sim 10^{-4} \text{ cm}$$

$$l_w \gg \xi$$

Conclusion



Inverse Kibble–Zurek mechanism is observed!

**Thanks a lot for your
attention!**