Realization of inverse Kibble–Zurek scenario with trapped Bose gases

Alexander N. Novikov

BLTP JINR, Dubna, Russia and IFSC USP, Sao Carlos, Brasil

Vyacheslav I. Yukalov

Vanderlei S. Bagnato

Alushta - 2015

Physics Letters A 379 (2015) 1366–1371

Contents lists available at ScienceDirect

Physics Letters A

www.elsevier.com/locate/pla

ARTICLE INFO

ABSTRACT

Inverse Kibble–Zurek scenario

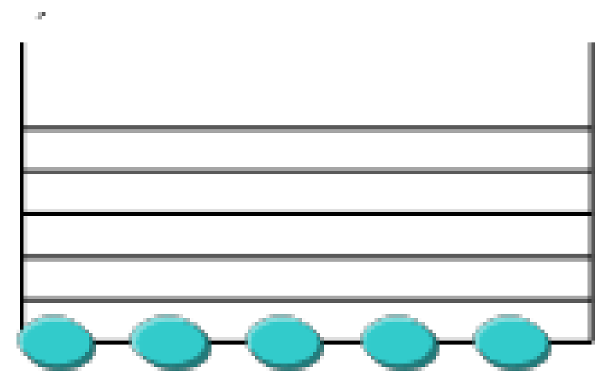
Kibble–Zurek mechanism (KZM)

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

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

Bose-Einstein condensate

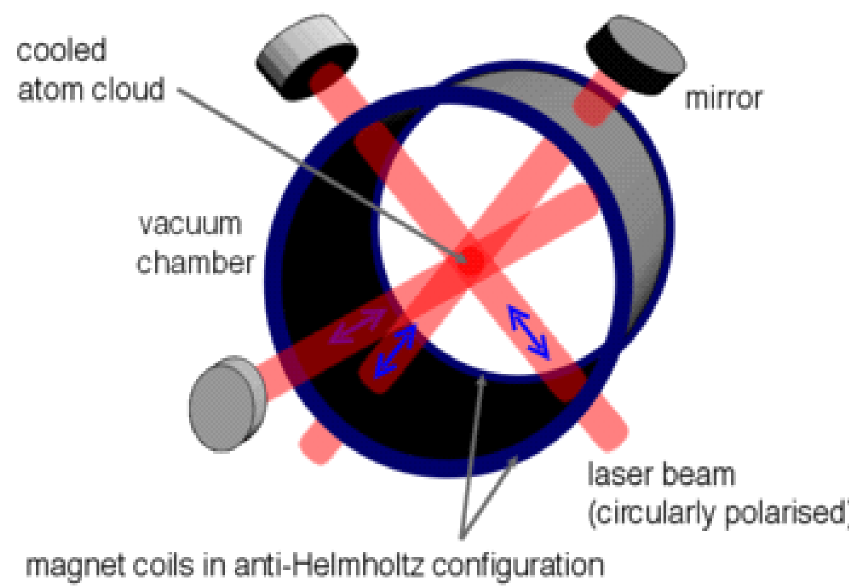
macroscopic number of atoms are collected in the ground state of the system



Main properties:

dilute gas of **weakly interacting** atoms

precise control and manipulation of the system properties

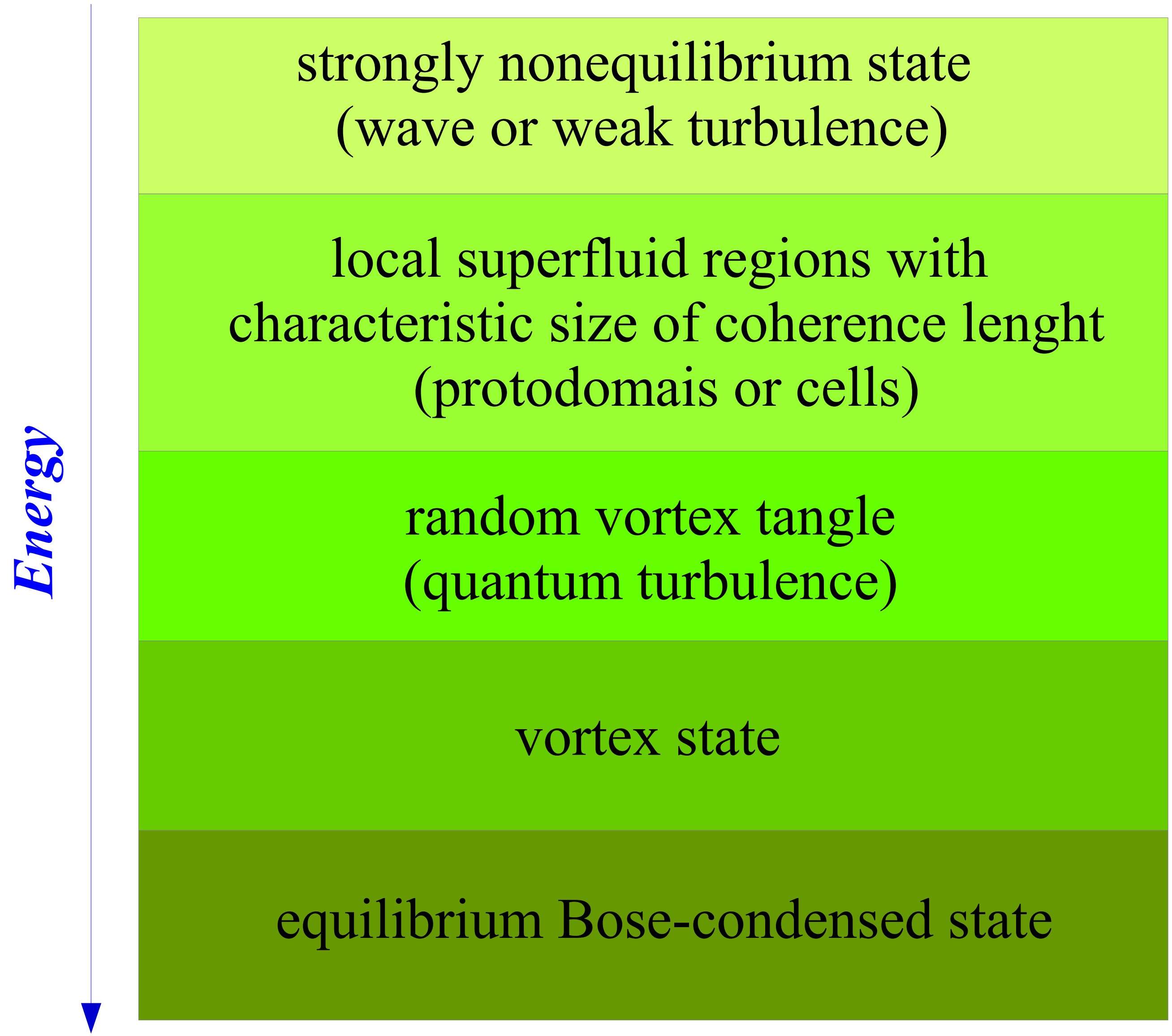


Gross-Pitaevskii equation

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

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



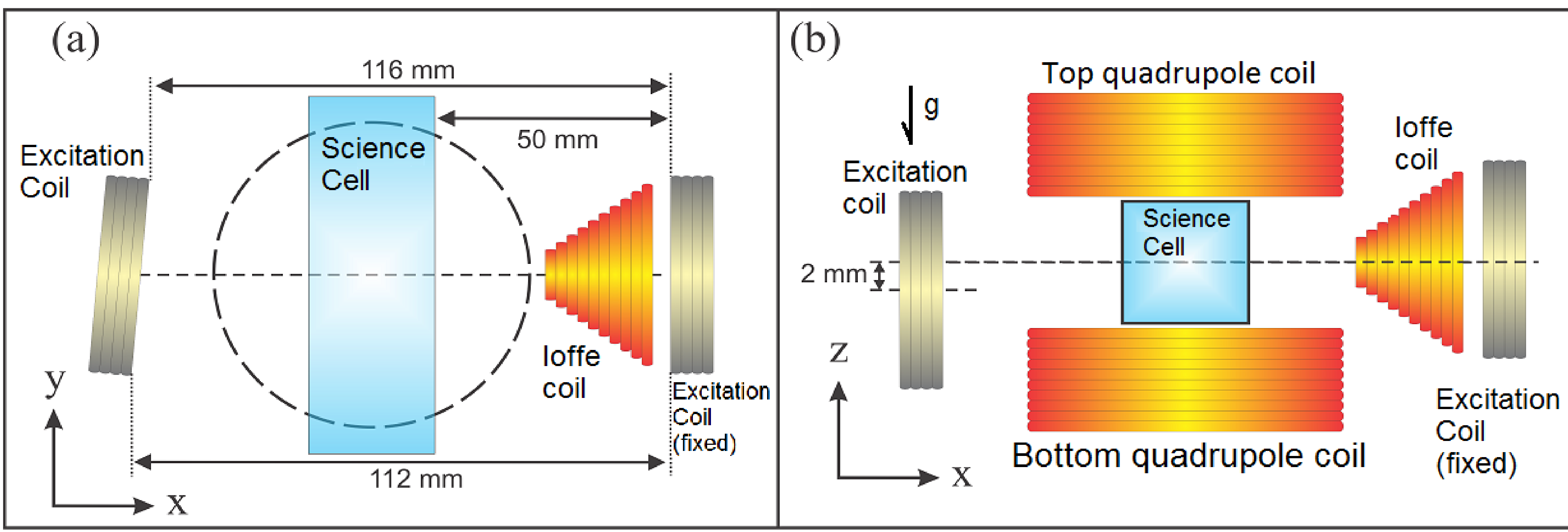
Possibility of inverse mechanism?

Condensate perturbation

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

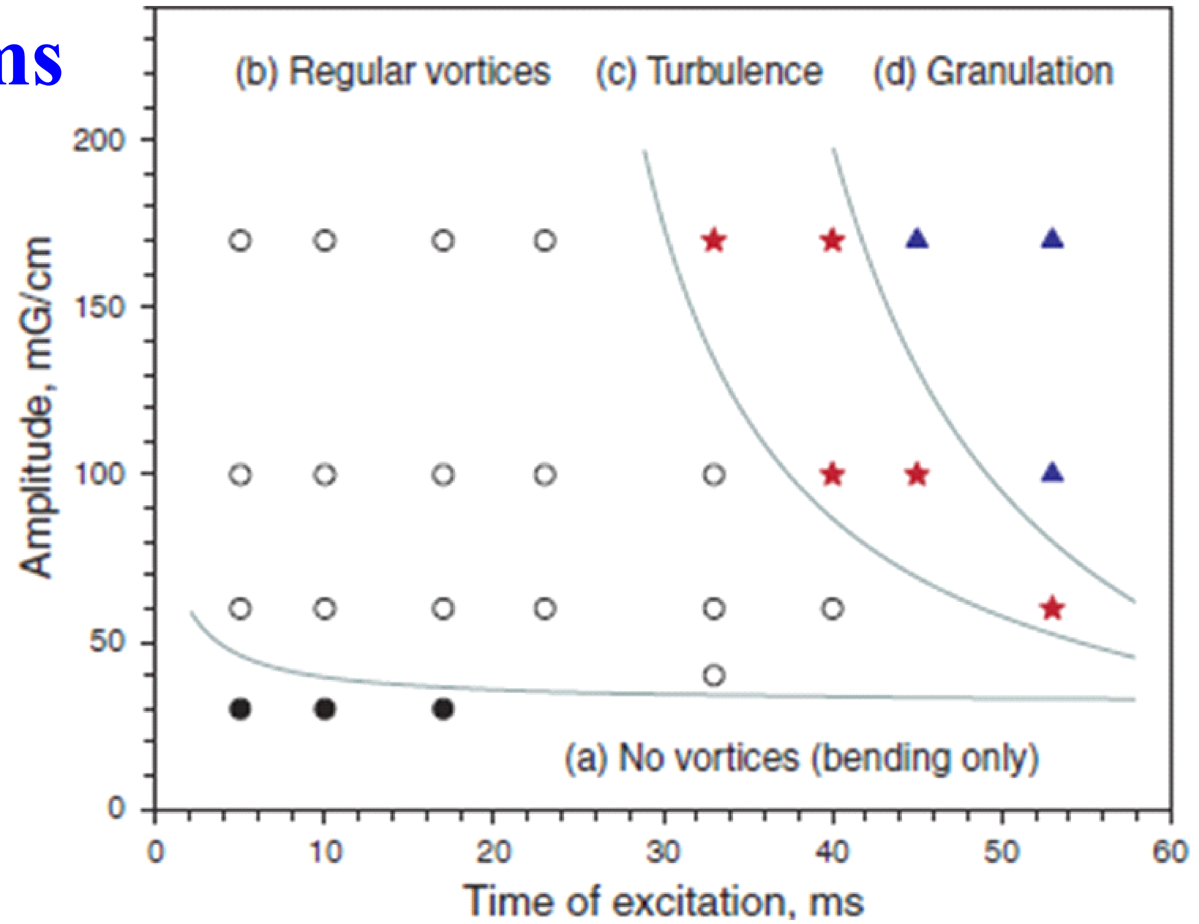
$$U(\vec{r},t) = U(\vec{r}) + V(\vec{r},t) \qquad E_{inj} = \int_0^t \left|\left\langle \frac{\partial \hat{H}}{\partial t}\right\rangle\right| dt$$

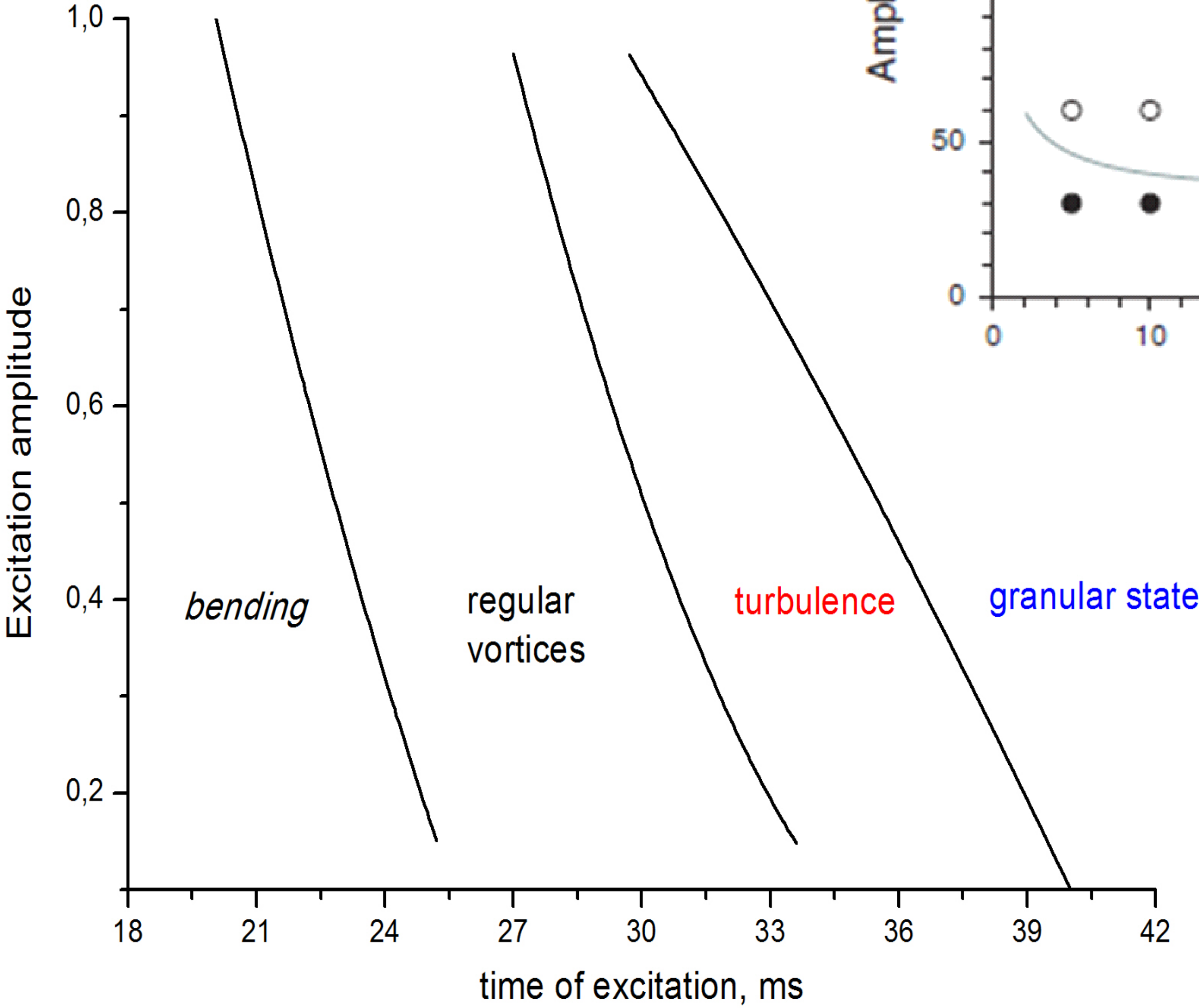
Experimental setup



No rotation moment imposed!

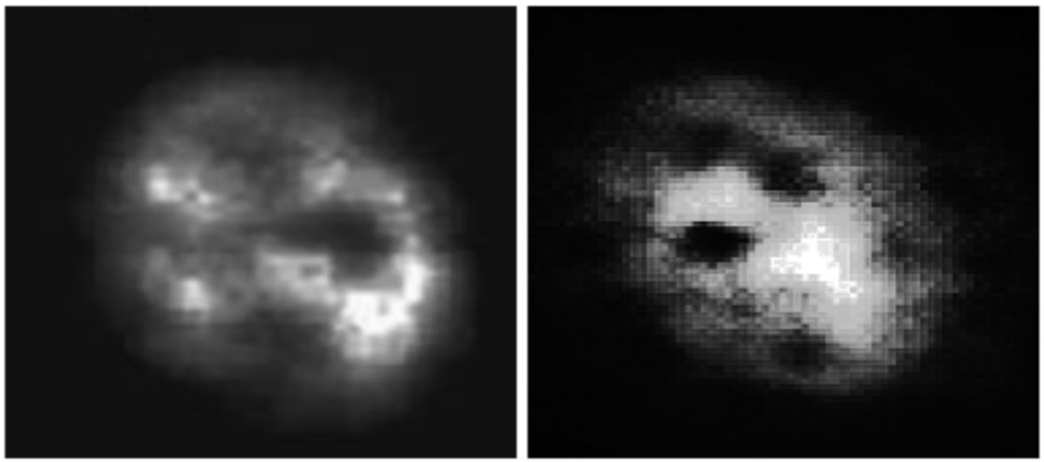
Time-amplitude diagrams





The sequence of observed states: theory vs experiment

1. quantum vortices

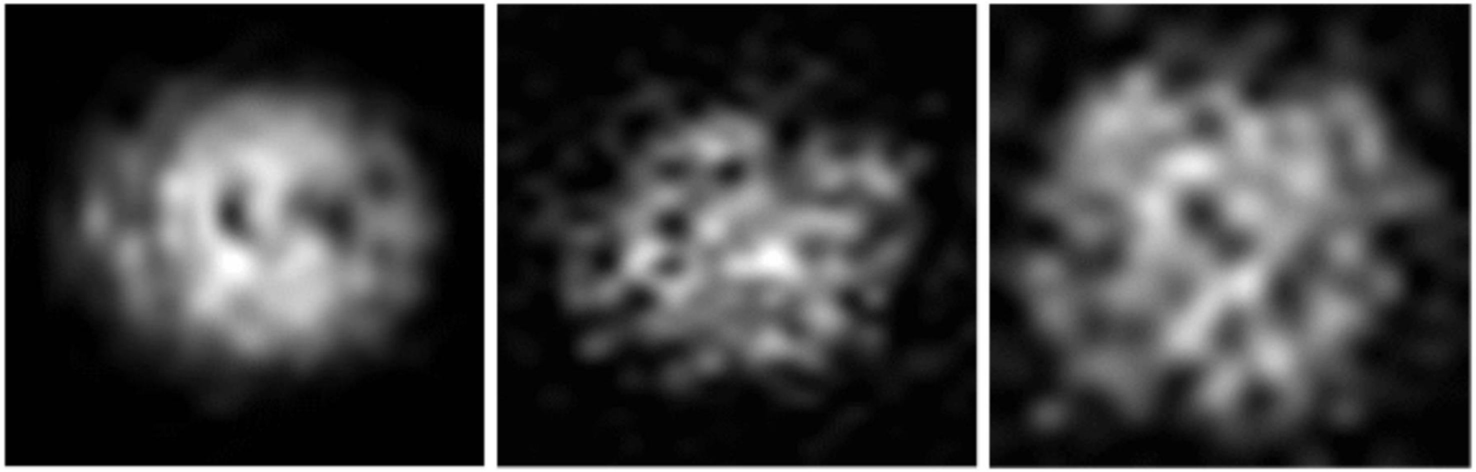


$$E_{vor} < E_{inj} < E_{tur}$$

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

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

$$N_c \approx 25$$



Coherence length

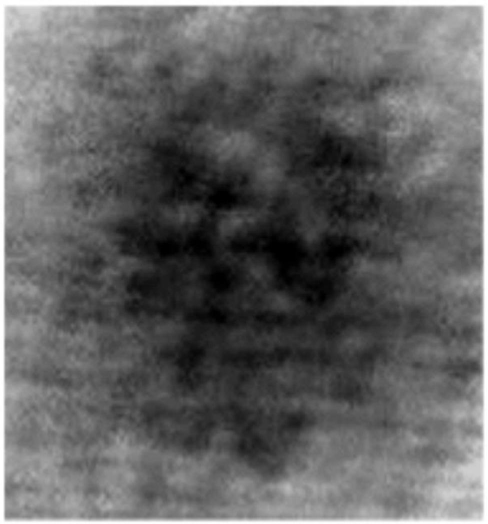
$$\xi \sim \frac{\hbar}{mc},$$

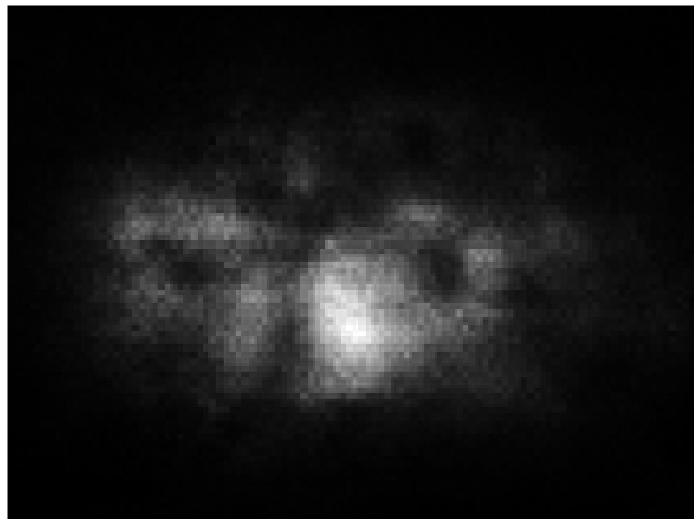
$$c \sim \frac{\hbar}{m} \sqrt{4\pi\rho a_s}$$

2. quantum turbulence

Quantum turbulence = random vortex tangle

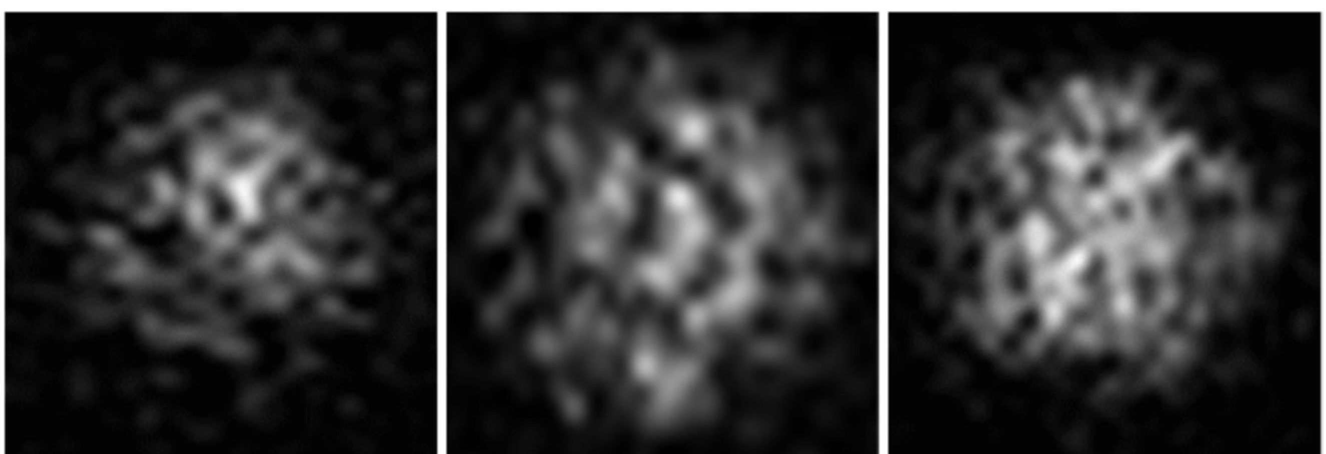
R.P. Feynman, Prog. Low Temp. Phys. 1, 17 (1955)



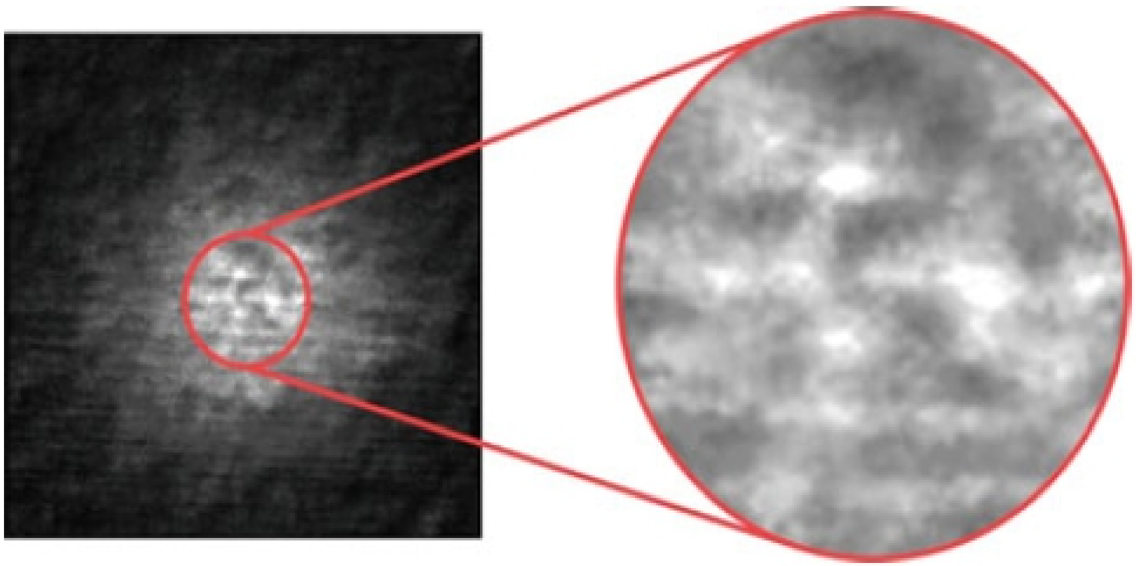


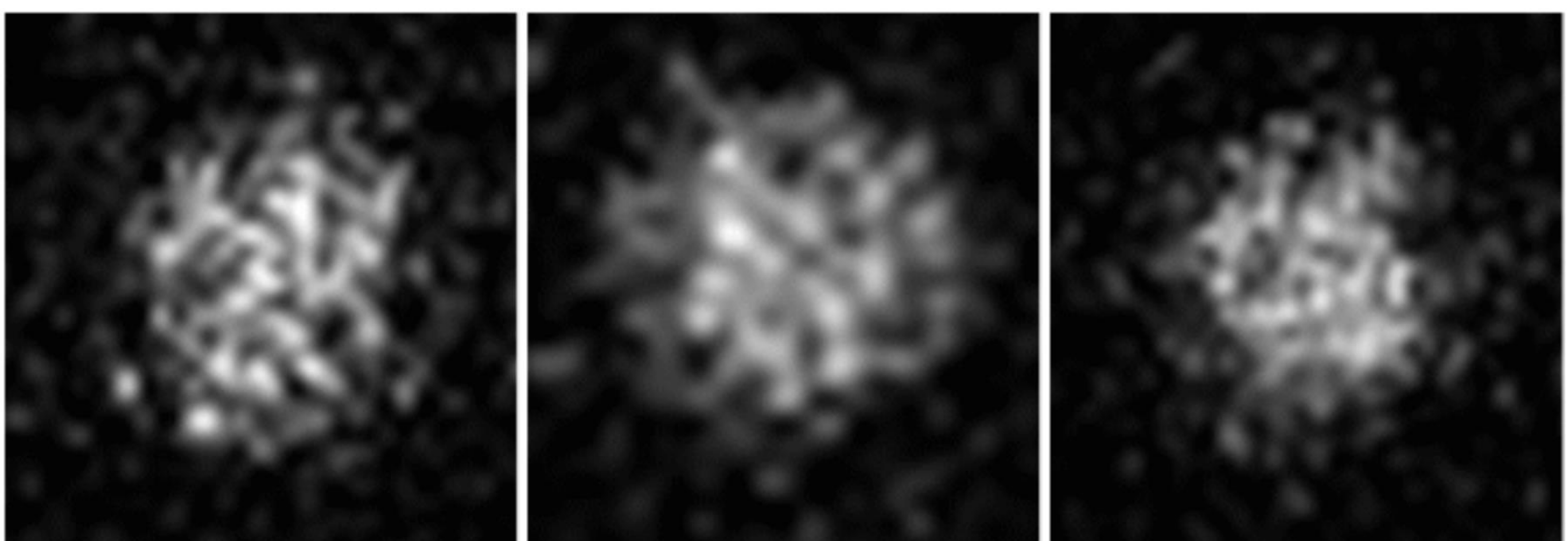
$$E_{tur} < E_{inj} < E_{fog}$$

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

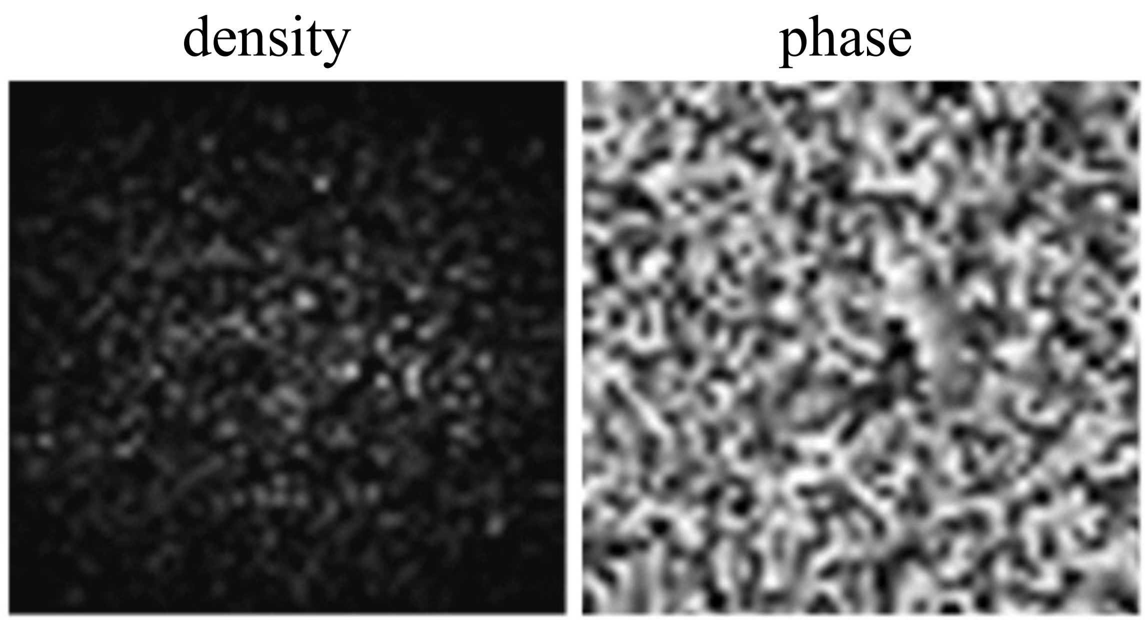


3. granular state



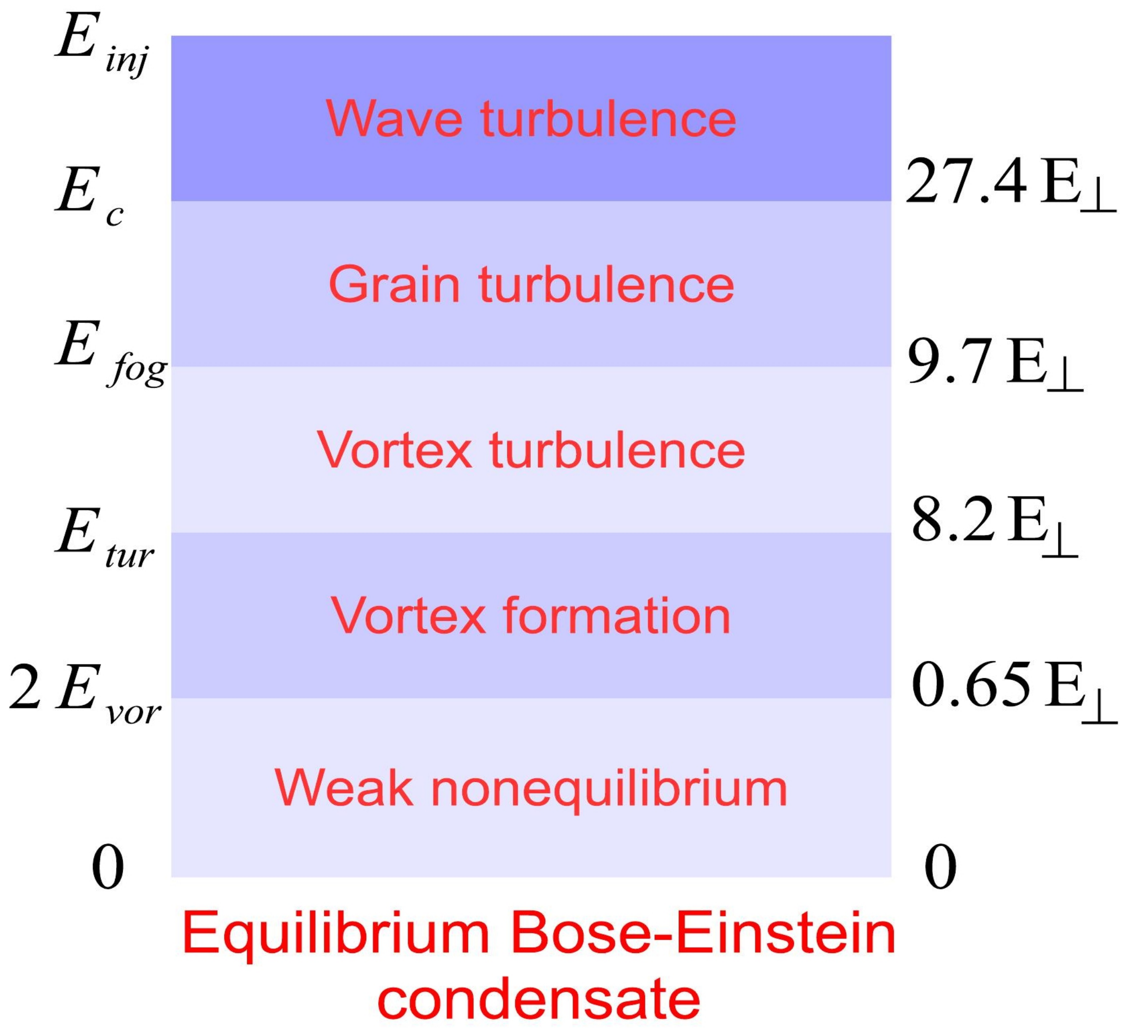


4. wave (weak) turbulence: not observed in the experiment!



Grain turbulence	Wave turbulence
$\rho_{dr} / \rho_{sur} \sim 100$	$\rho_{w} / \rho_{sur} \sim 3$
constant phase inside	random phase inside
$E_{kin} / E_{int} \sim 3$	$E_{kin} / E_{int} \sim 300$
$l_{dr} \sim 10^{-5}$ cm	$l_{w} \sim 10^{-4}$ cm
$l_{dr} \sim \xi$	$l_{w} \gg \xi$

Conclusion



Inverse Kibble–Zurek mechanism is observed!

Thanks a lot for your attention!