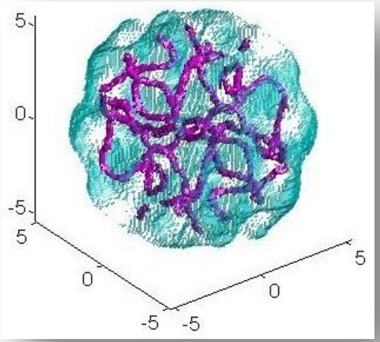
EXCITATION OF A TRAPPED BEC: GENERATION OF TURBULENCE AND ITS CHARACTERIZATION



Dr. Mônica A. *Caracanhas*

(V.S. Bagnato)

University of São Paulo

Brazil

Critical Stability 2014

External Collaborators:

Prof. V. Yukalov (Dubna)
G. Roati (Florence)
A. Novikov (Dubna)
Prof. A. Fetter (Stanford)
Prof. M. Tsubota (Osaka)

Part of the Group:

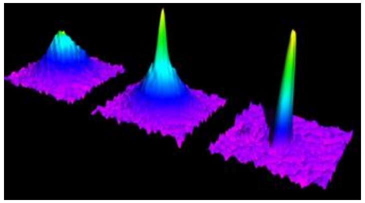
Prof. E. Henn

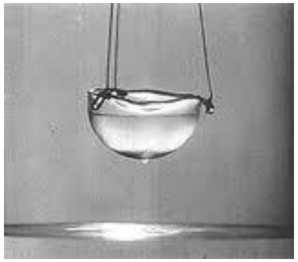
F. Poveda-Cuevas, P. Castilho, P. Tavares, R. Poliseli, E. Pedroso,
F. Vivanco, A. Smaira, A. Cidrim, A. Fritsch, A. Bahrami

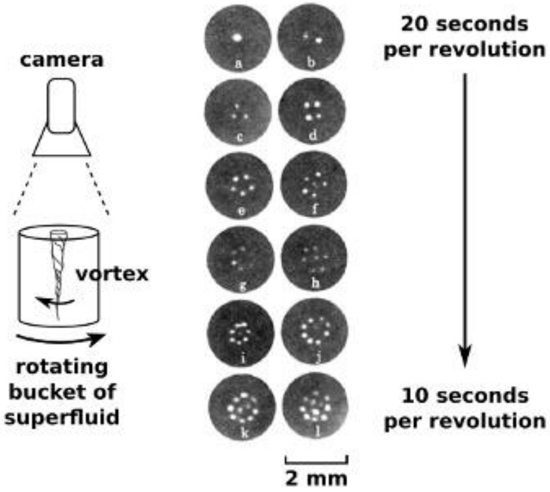
K.. Magalhães, G. Telles, M. Caracanhas
E. Santos, M. Tsatsos

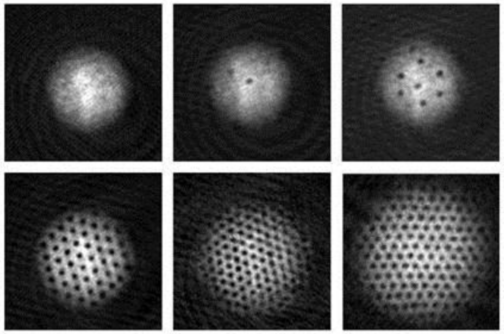
- 3 BEC experiments: Rb-I, Rb-II, Na/K
- Theory group

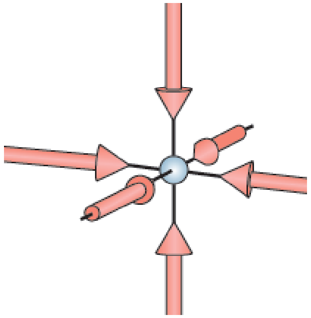
SUPERFLUIDITY - BEC

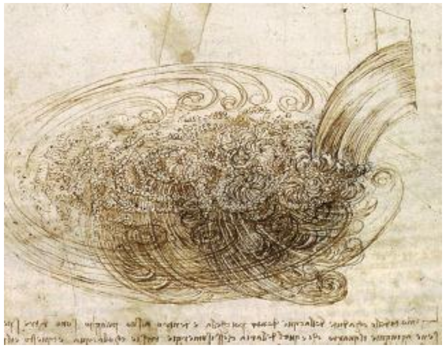


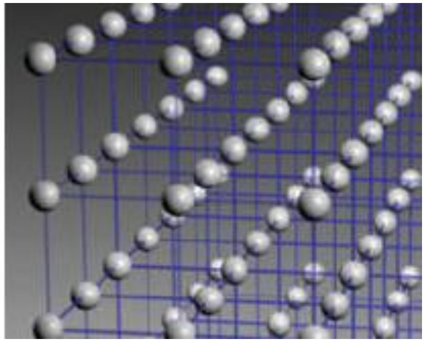












QT

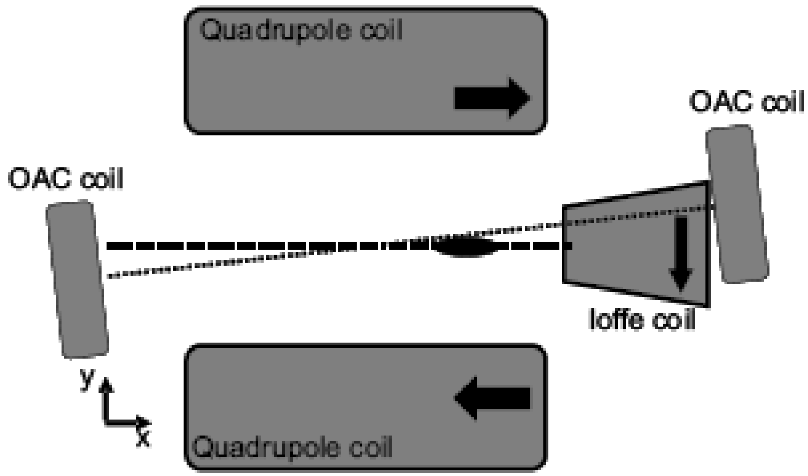
In atomic BEC

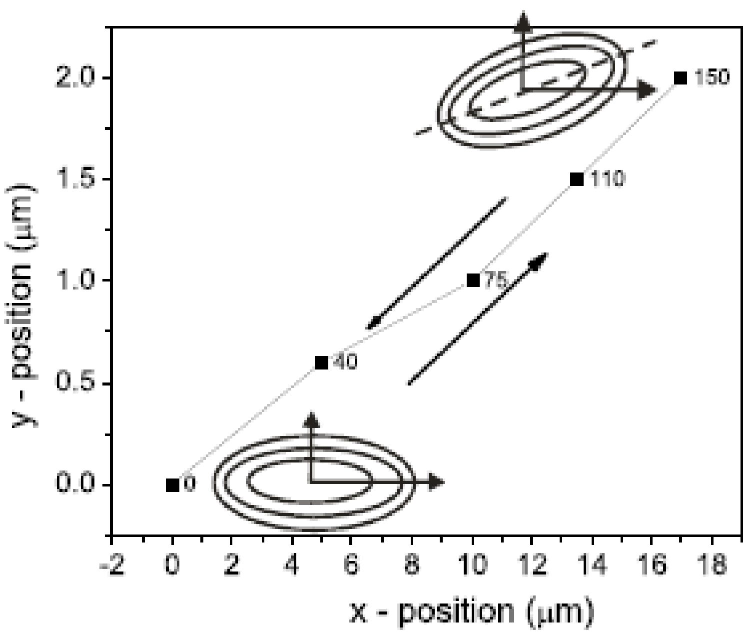
Experimental: generate and characterize

Theory:

New possibilities to generate QT

EXCITATION BY OSCILLATION OF THE POTENTIAL





Atomic washing machine

ADDITION OF “SHAKING” COILS

↓

Displacement,

Rotation and

Deformation of the potential

EXPERIMENTAL SEQUENCE

PRODUCING BEC (1 min)

↓

EXCITATION (0 to 70 ms)

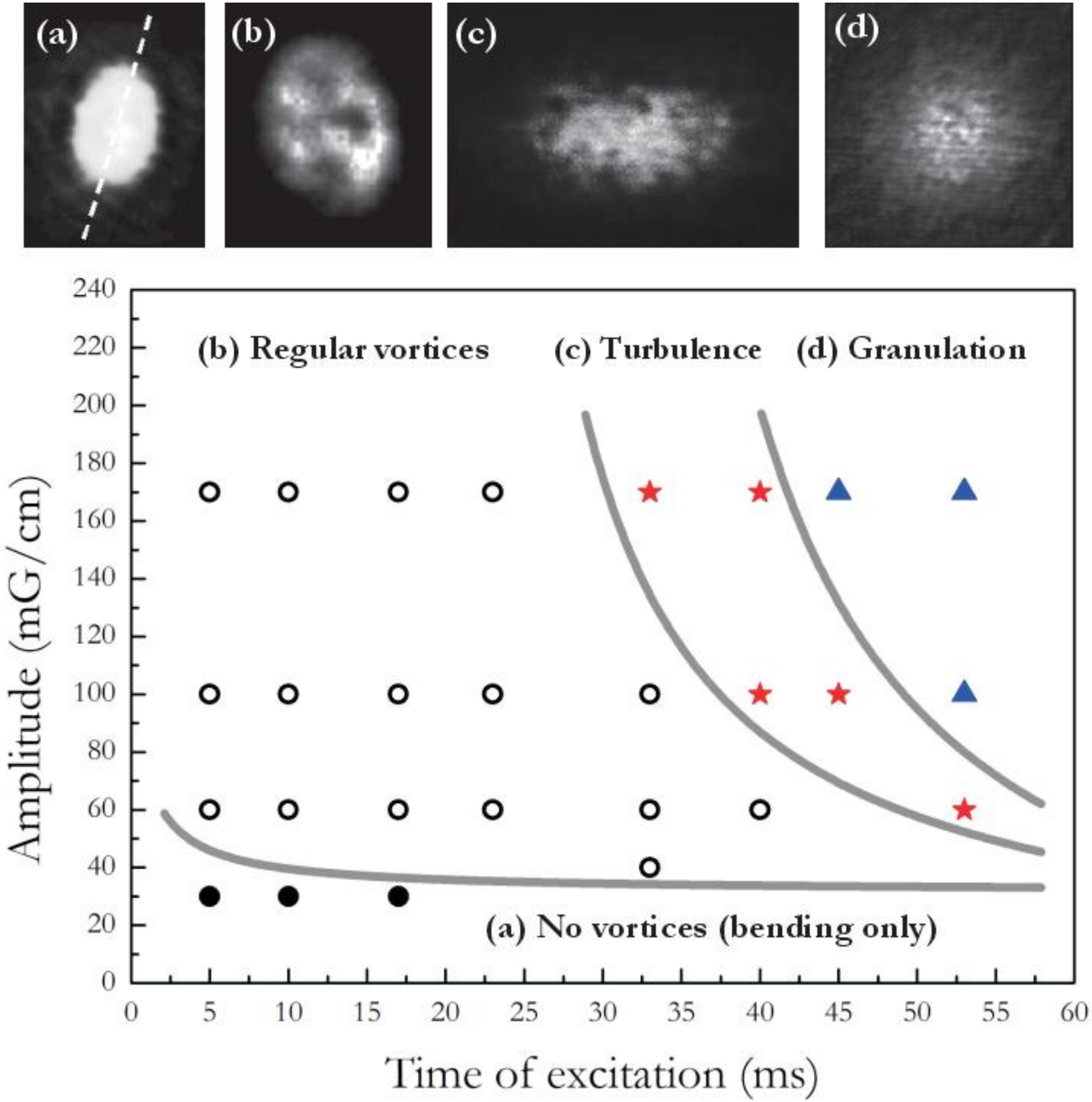
Time and amplitude

↓

HOLDING TIME (20 ms)

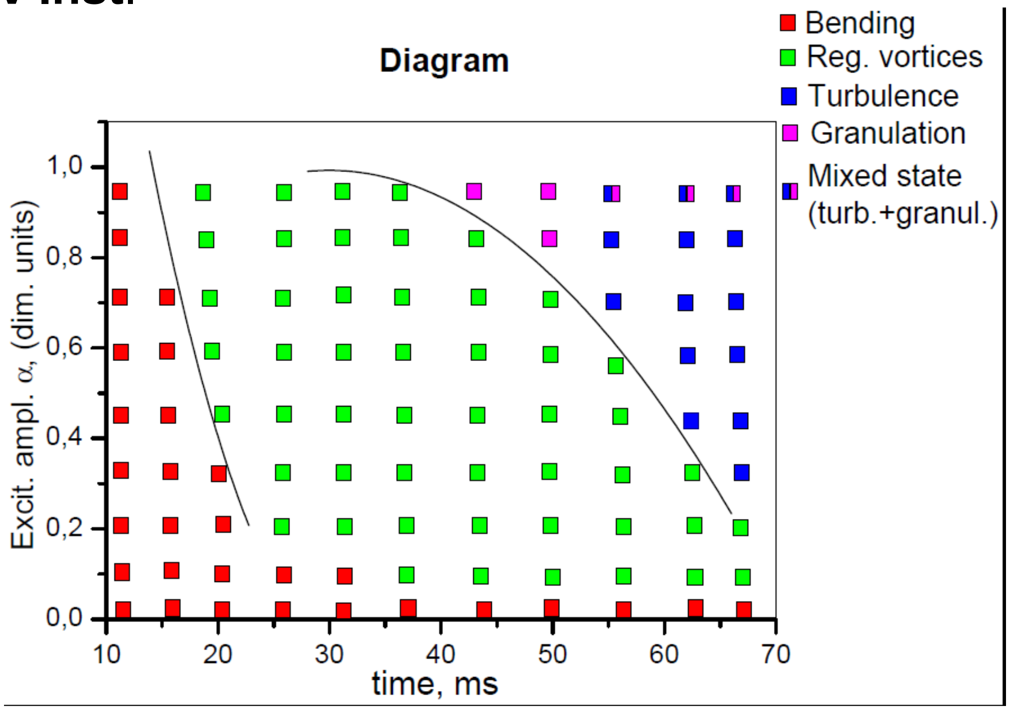
↓

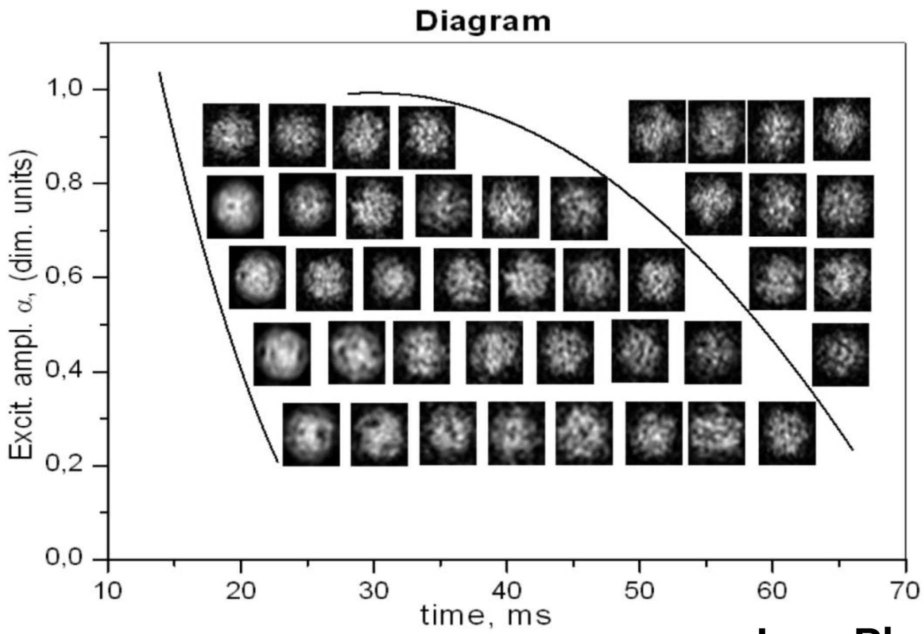
TOF FOLLOWED BY ABSORPTION IMAGE



Las. Phys. Lett. 8,691 (2011).

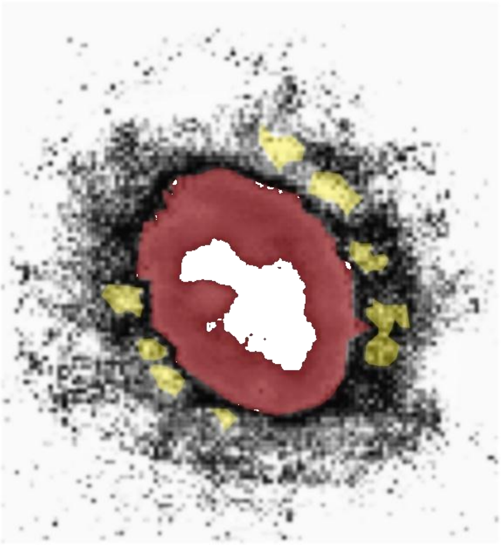
Dubna – Bogoliubov Inst.

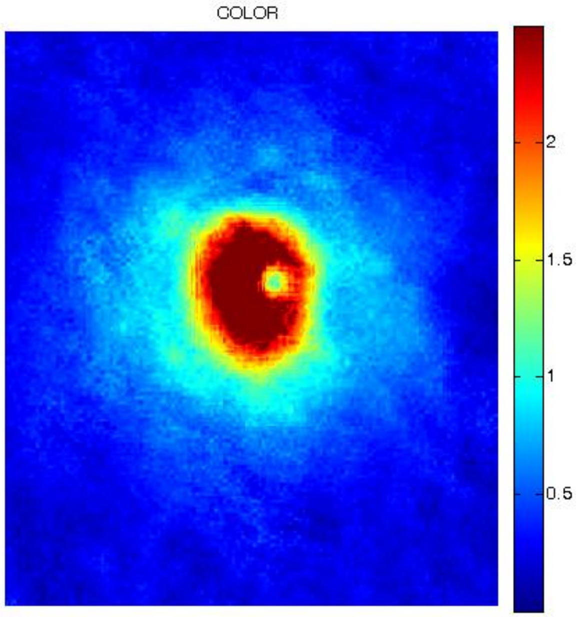




Las. Phys. Lett., v.11, 8 jun 2014.

VORTEX FORMATION

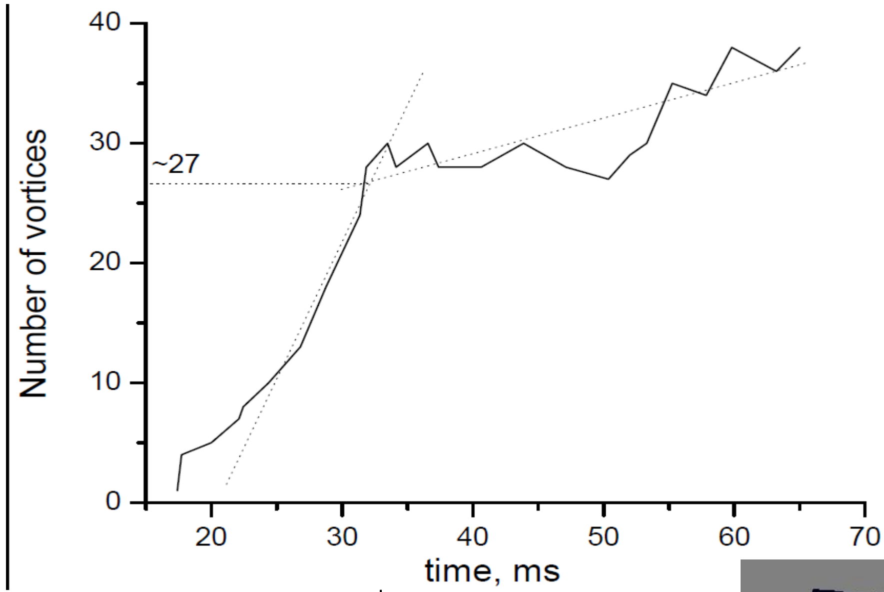


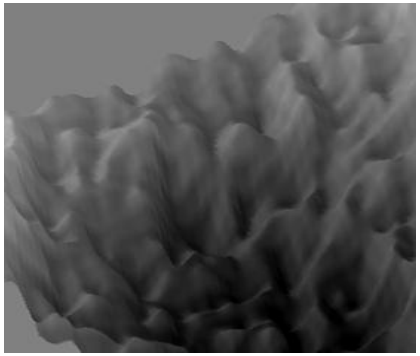


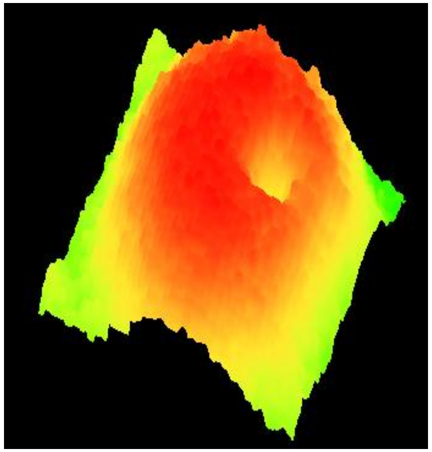
J. Low. Temp. Phys. 158, 435-442 (2010).

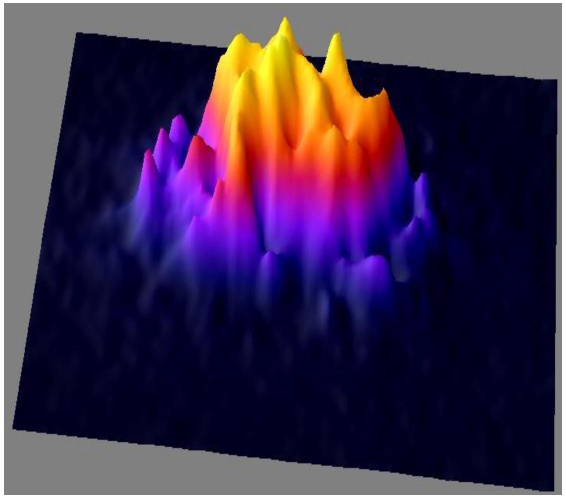
EVOLUTION TO TURBULENCE

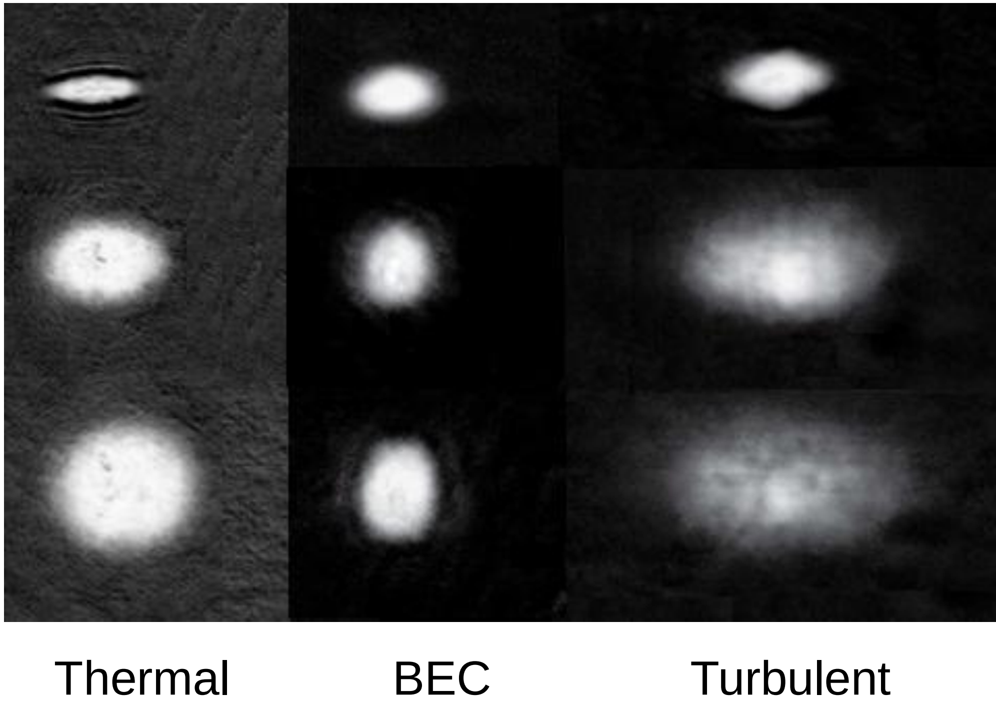
Drop → decay
to granulation



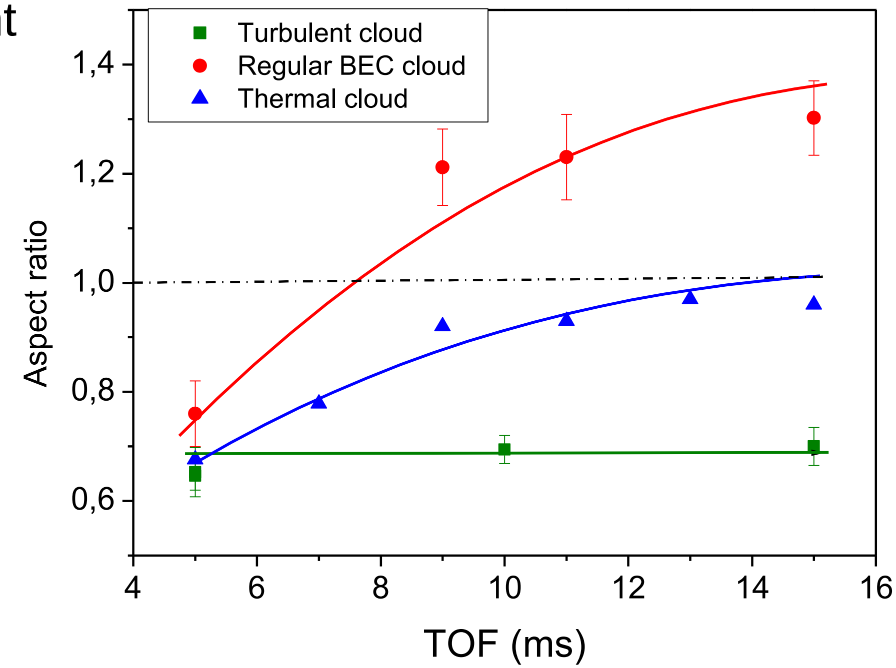








Cloud expansion as identification of QT



J. Phys. Conf. Ser. 264,012004 (2011), J. Low Temp. Phys. 170, 133 (2013).

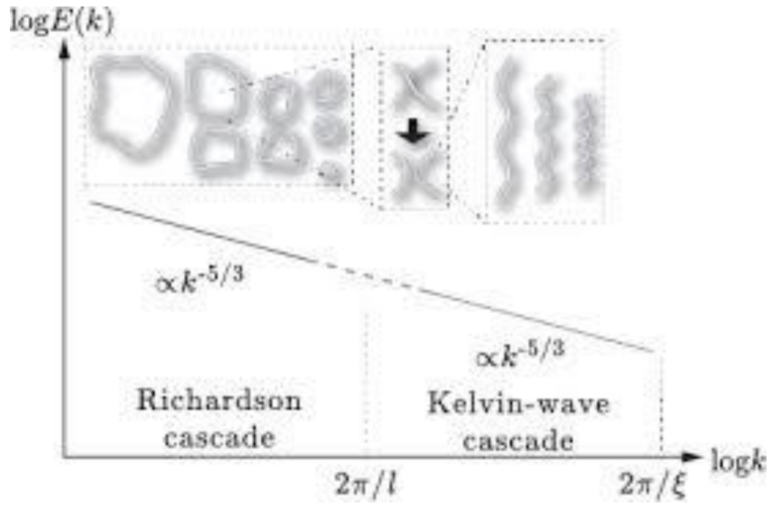
QT

Energy is injected at large scale

(vortex filaments)

Special configuration

(Turbulence)

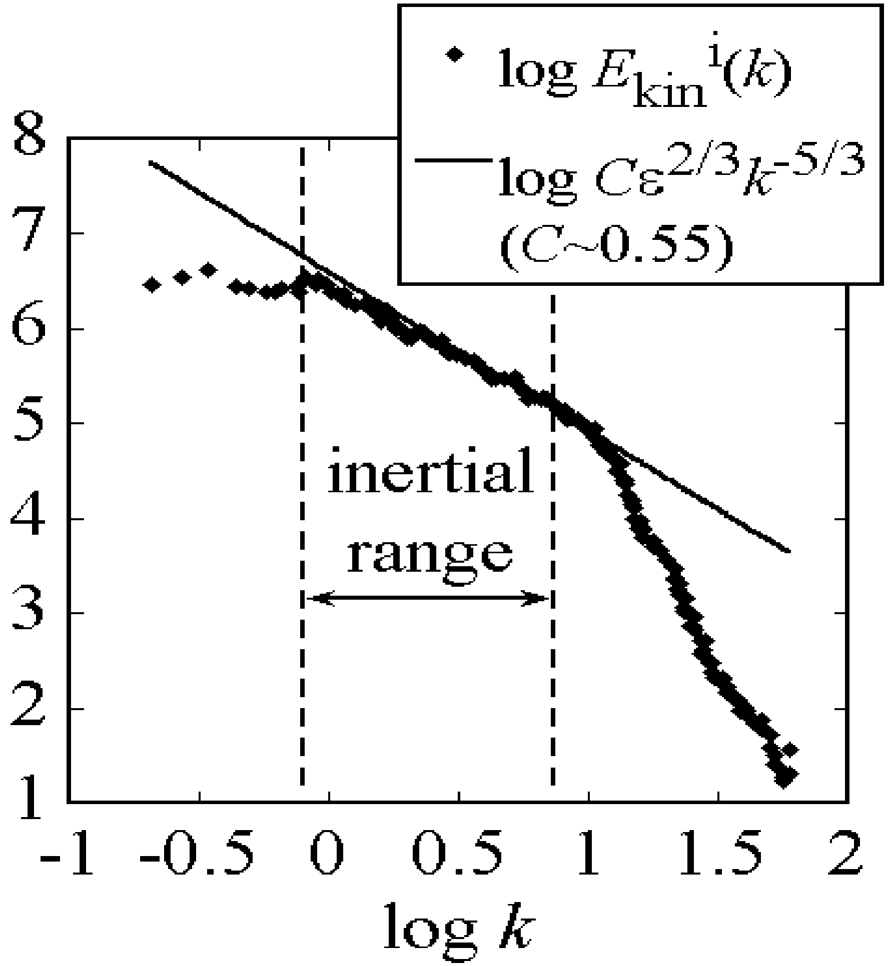


Reconnection allow energy to flow to small scale

(Kelvin cascade)

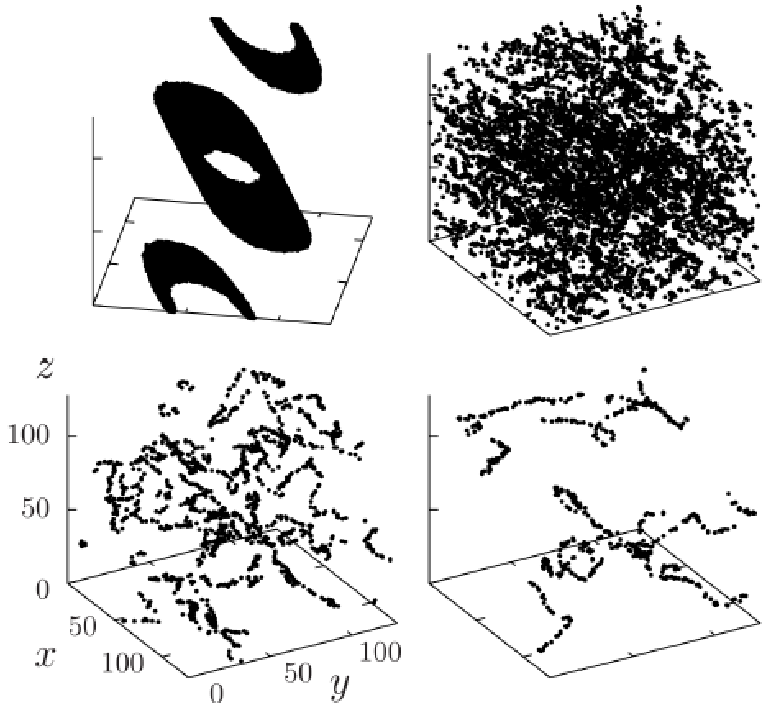
Phonon Emission

(equivalent to effective kinematic viscosity)

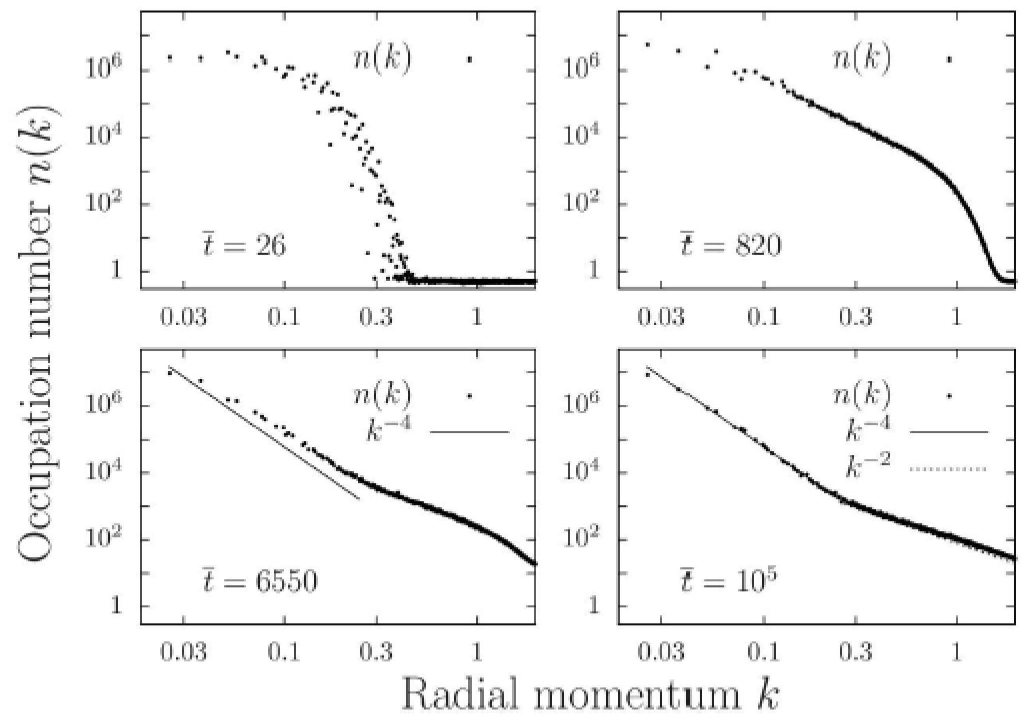


M. Kobayashi and M. Tsubota, PRL94,065302 (2005), JPSJ 74, 3248 (2005).

MOMENTUM SPECTRUM

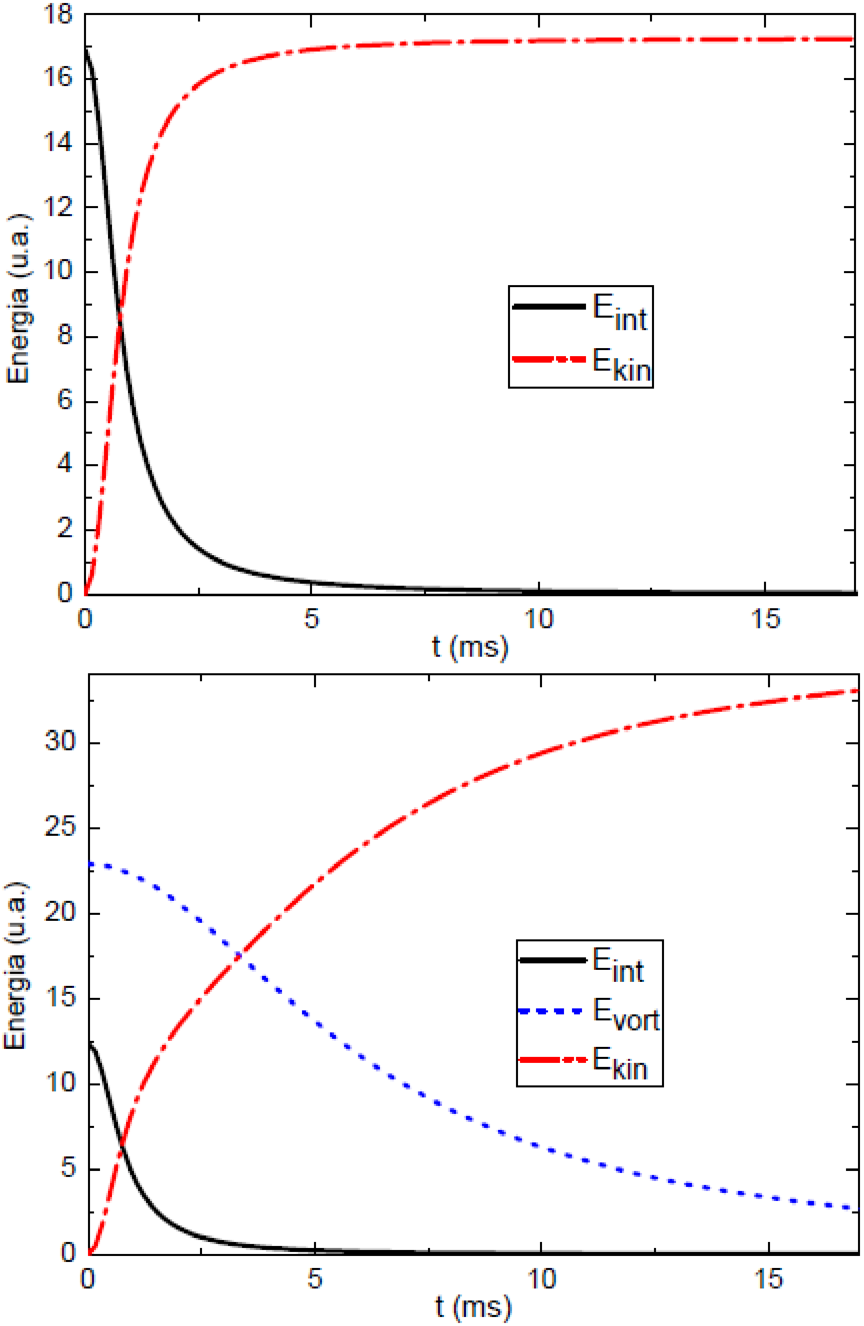


B. Nowak et al (arXiv: 1012.4437)



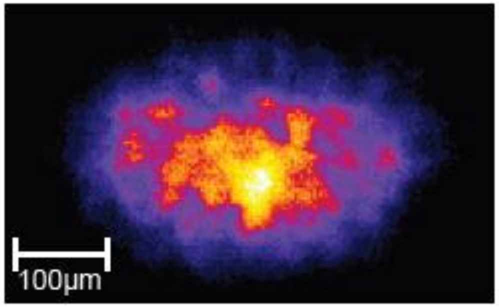
HOW TO OBTAIN n(k) in a trapped superfluid?

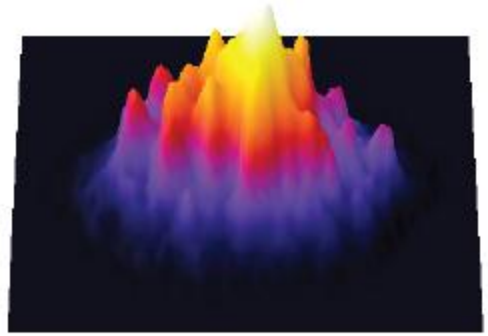
Time dependence on the free expansion

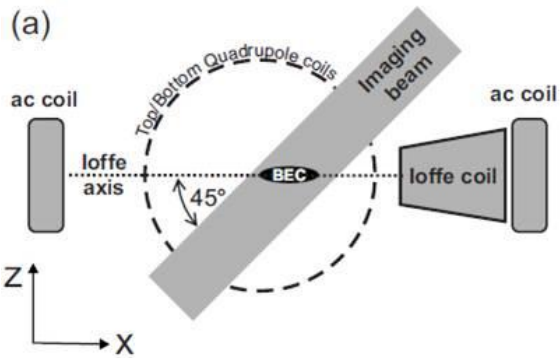


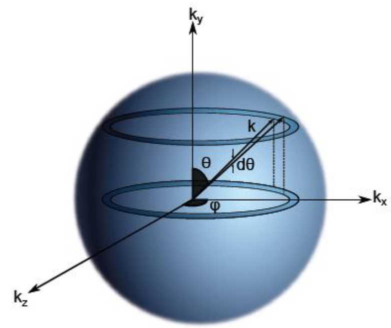
Interactions *vs* kinetic

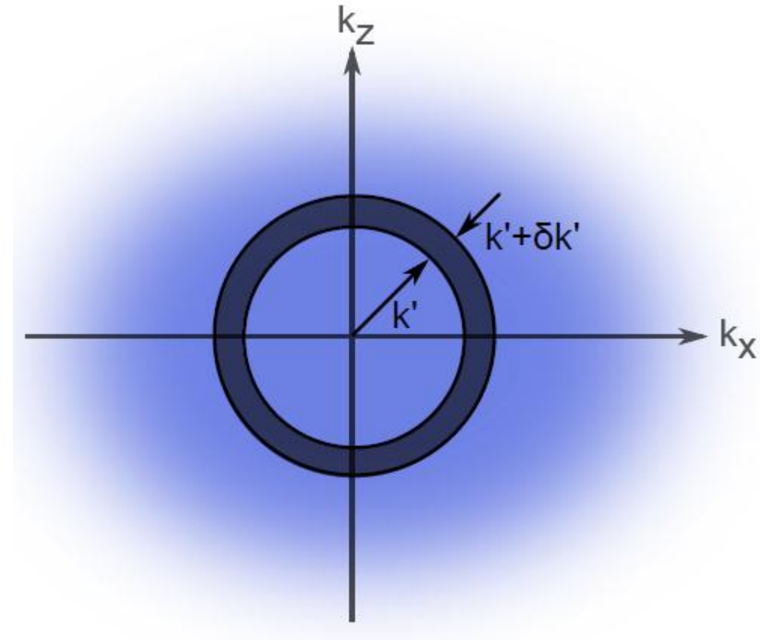
Self-similar → kinetic
Lower density → kinetic

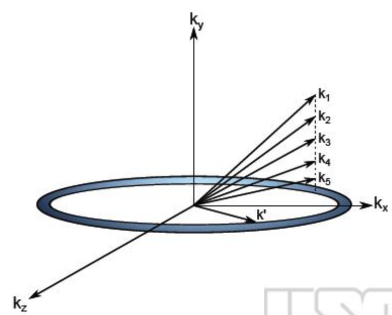












$$g(k') = 2\pi \int_{k'}^{k'+\delta k'} n'(k')\ k'\ dk'$$

$$\int n'(k')\ k'\ dk' = N$$

BEC turbulento

$$R_\rho(0) = 2,65\ \mu\text{m}$$

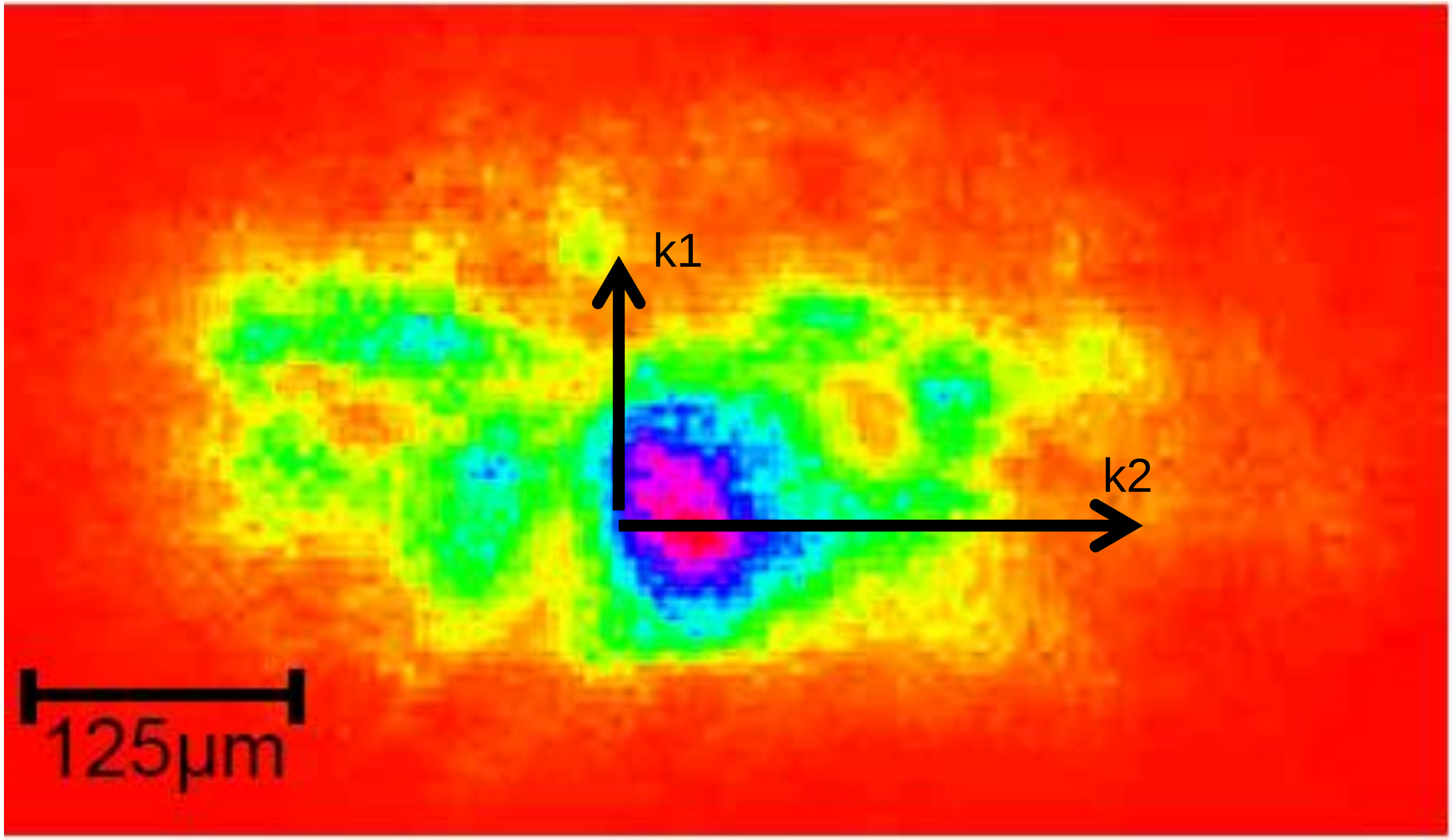
$$R_x(0) = 51,33\ \mu\text{m}$$

$$R_\rho(15) = 60\ \mu\text{m}$$

$$R_x(15) = 105\ \mu\text{m}$$

$$n'(k') = 2\int_{k'}^{\infty} \frac{n(k)\,dk}{\sqrt{1-(\frac{k'}{k})^2}}.$$

VALIDITY



K_2 - largest k → cut off : $3\ 10^7$ m-1

K_1 - about $1.5\ 10^7$ m-1

Laser Phys. Lett., 11, 015501 (2014).

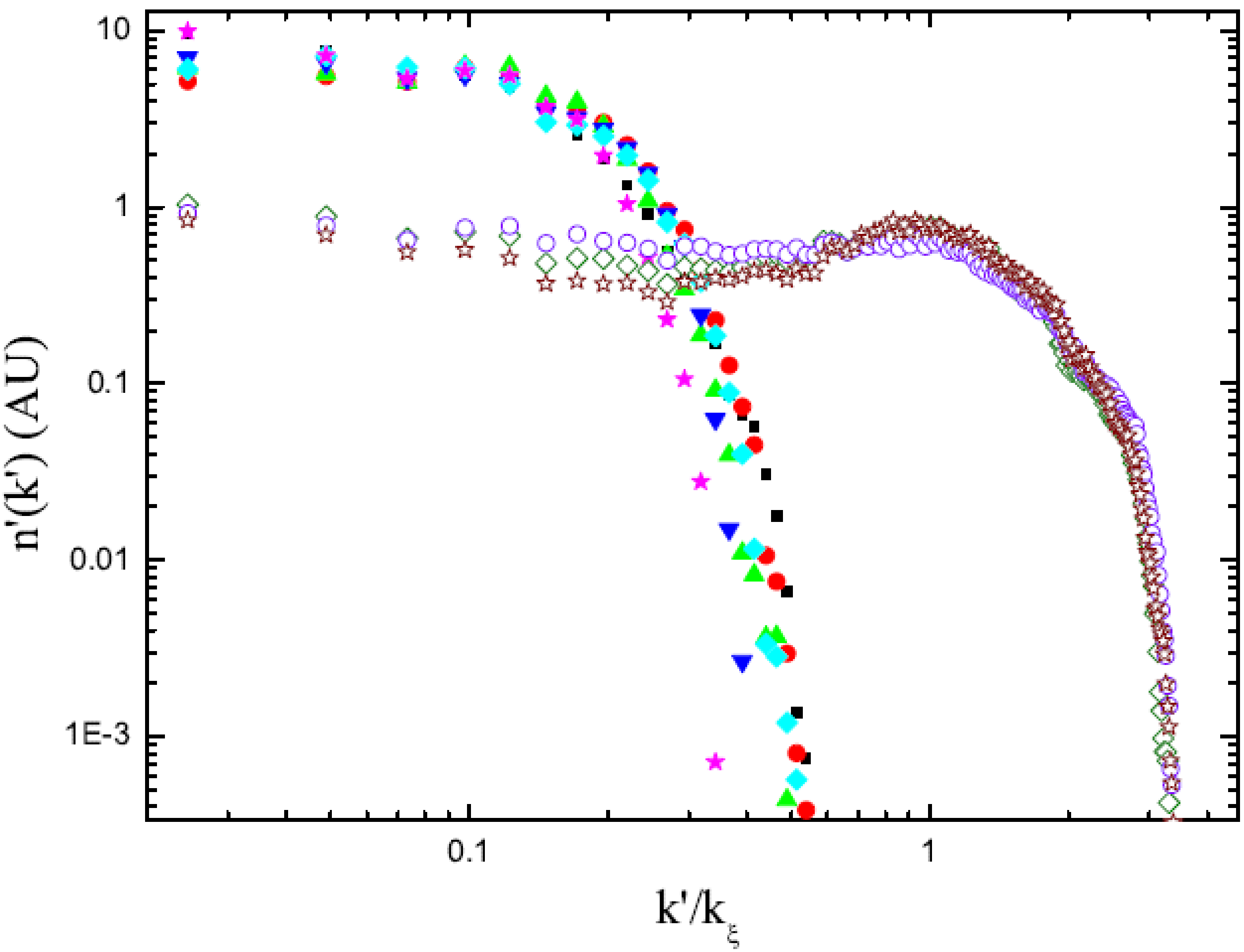
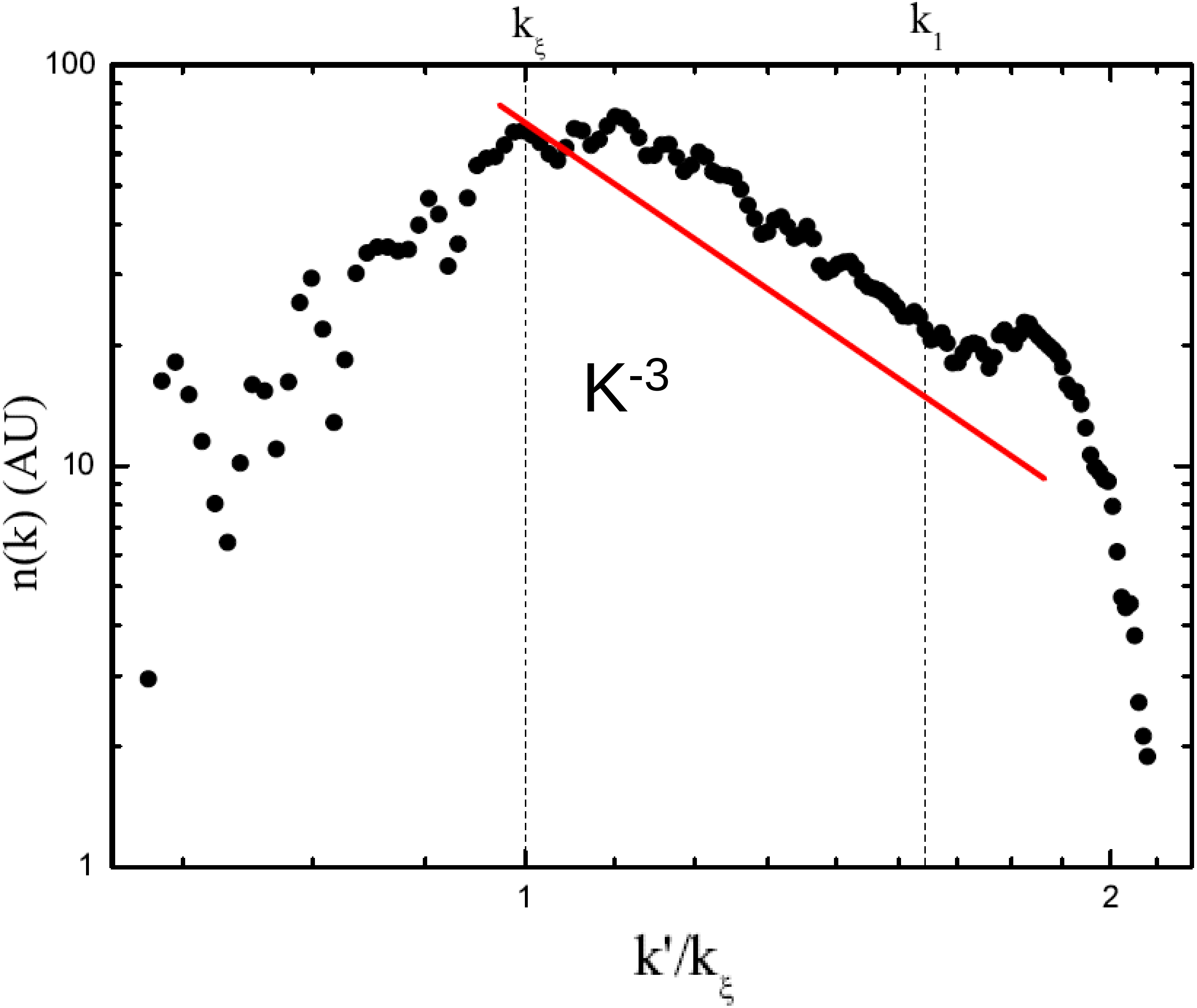


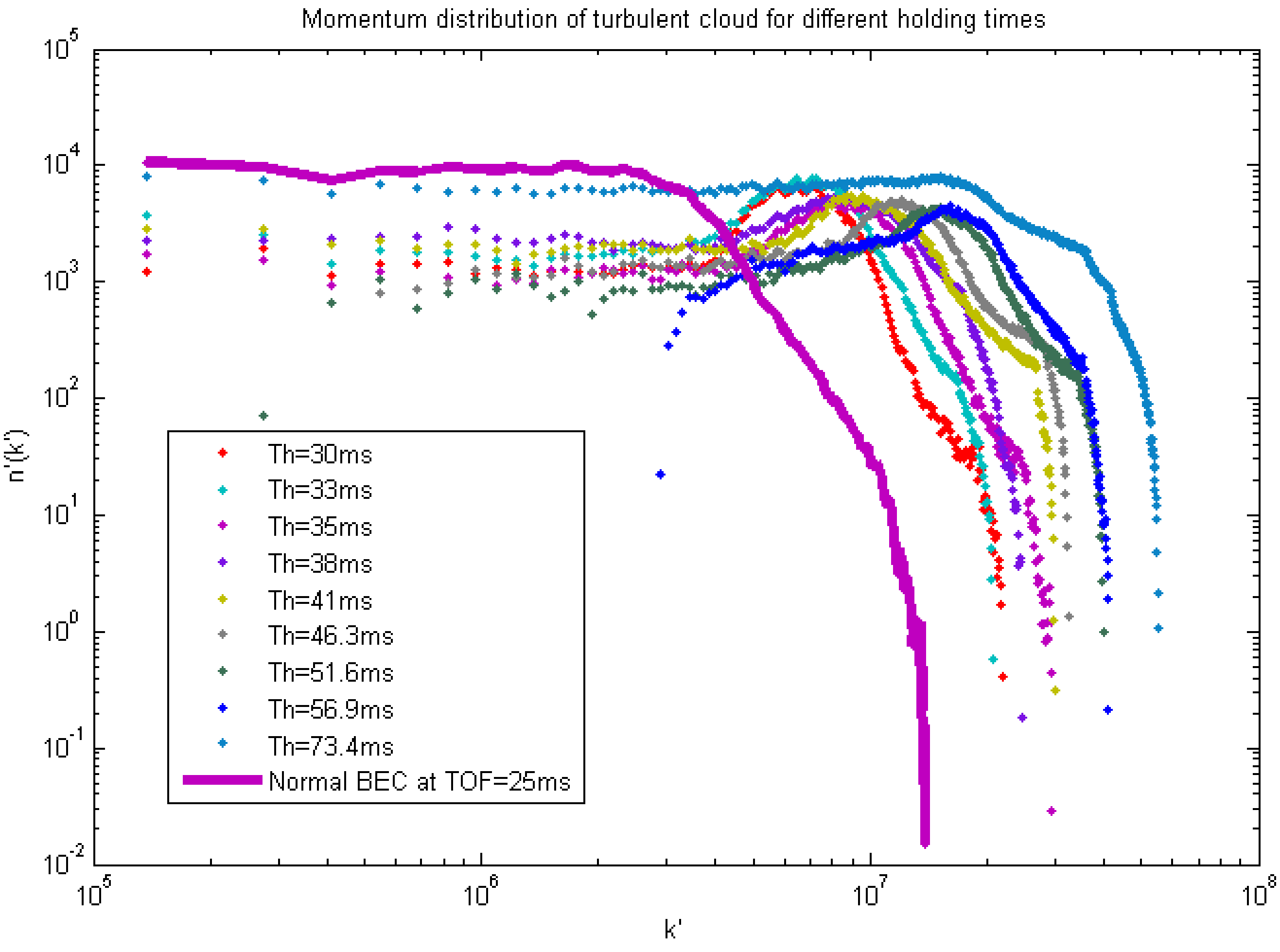
Figure 6: This figure shows the two dimensional projected momentum density, $n'(k')$, on a log-log plot. The Thomas-Fermi and condensates with a low number of vortices are shown in closed symbols. The ■, ●, ▲, ▼, ◆, and ★ symbols represent condensates with 0, 1, 2, 3, 4, and 5 vortices respectively and the open symbols are data from three different realizations of a turbulence. The distinction between the behavior of condensates with energy dominated by internal and kinetic energy are clear from the different behavior.

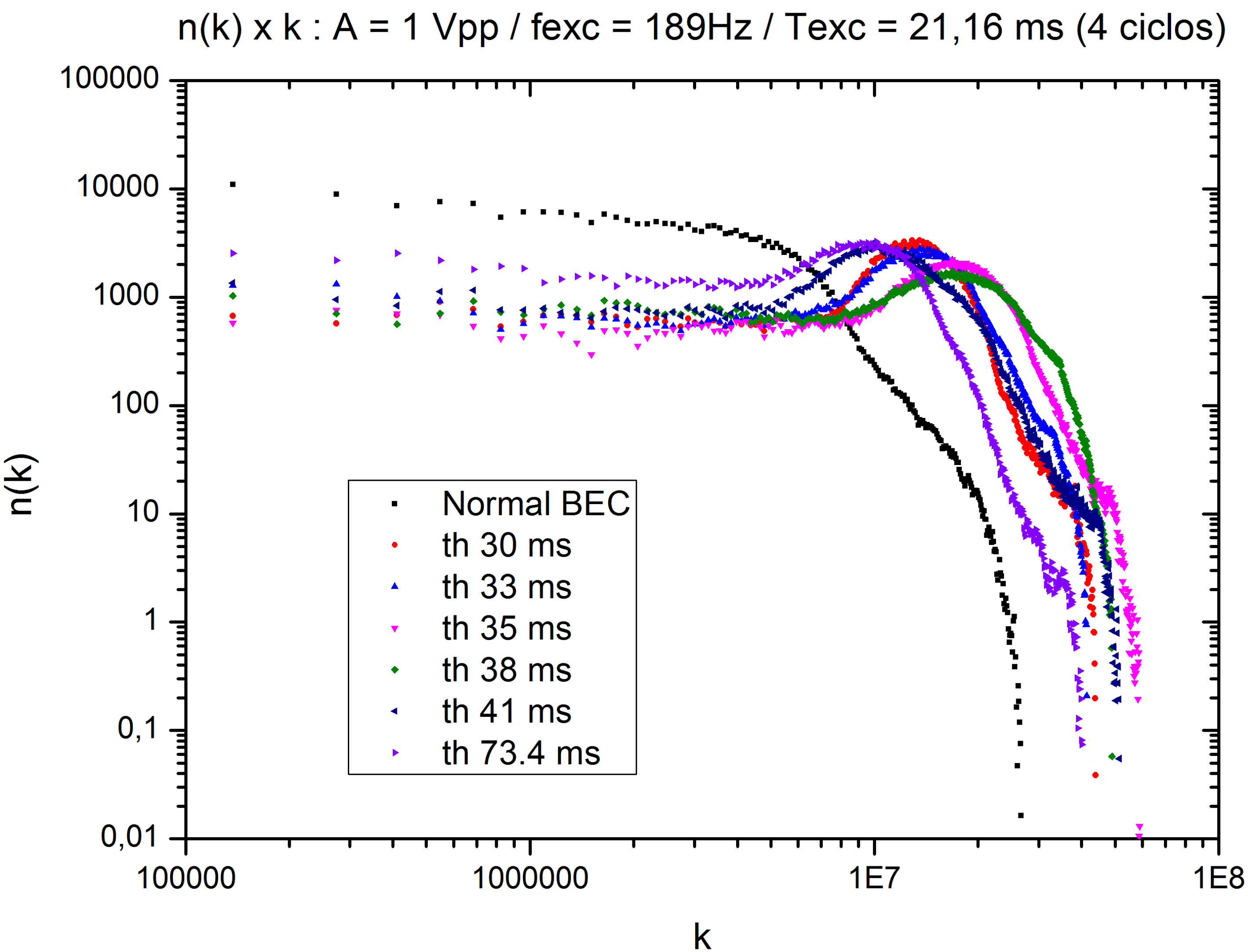


k$_\xi$
k$_1$
100
10
1
n(k) (AU)
K^{-3}
1
2
k'/k$_\xi$

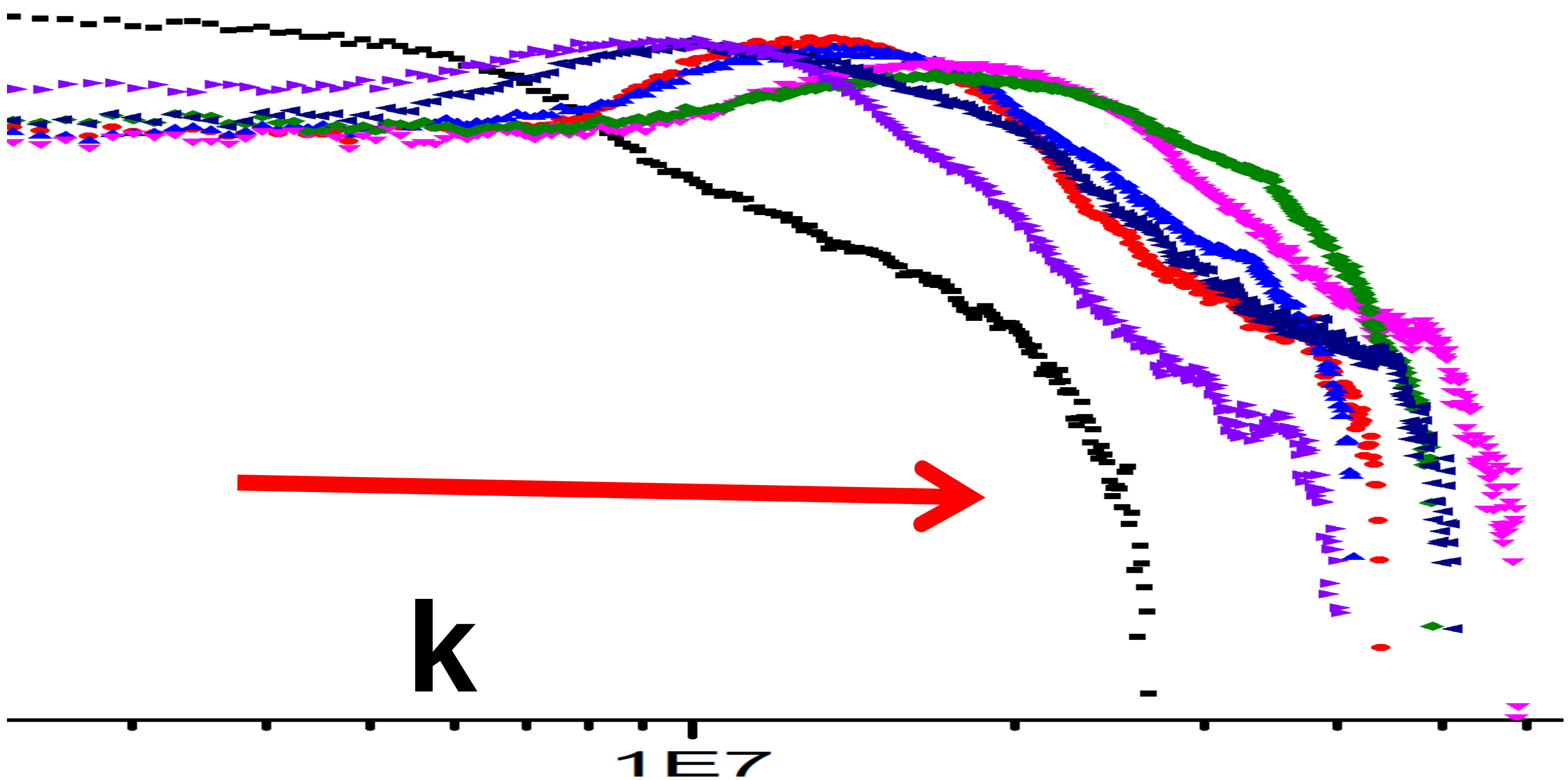
Direct versus inversed cascade : 3D versus 2D Time evolution

COLLECTIVE MODES




n(k) x k : A = 1 Vpp / fexc = 189Hz / Texc = 21,16 ms (4 ciclos)
100000
10000
1000
100
10
1
0,1
0,01
n(k)
100000
1000000
1E7
1E8
k
Normal BEC
th 30 ms
th 33 ms
th 35 ms
th 38 ms
th 41 ms
th 73.4 ms

Demonstration of direct cascade of energy.....

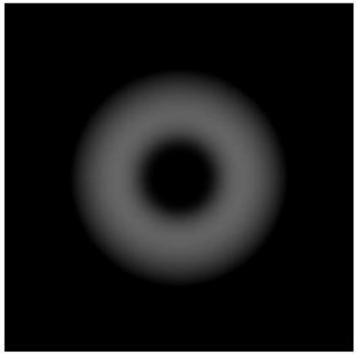


Spontaneous generation of two-dimensional quantum turbulence through the decay of a giant vortex

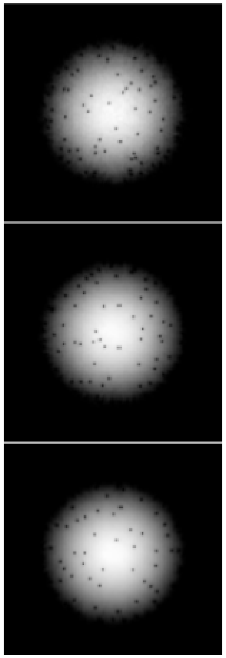
arXiv:1405.0992 [cond-mat.quant-gas]

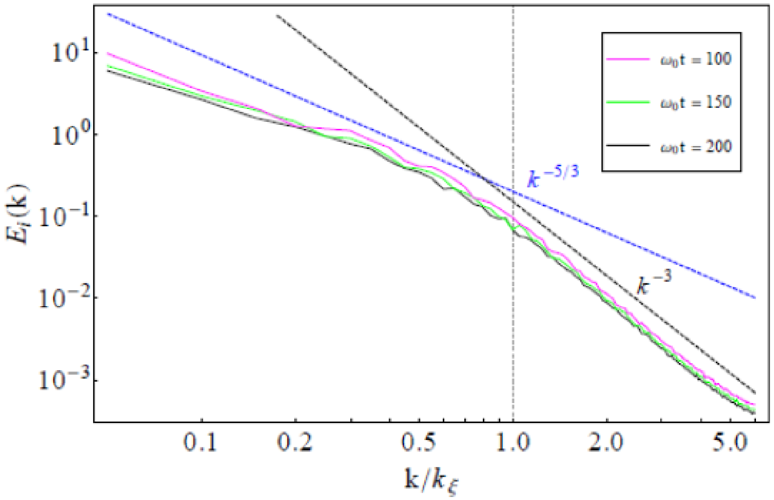
SPONTANEOUS GENERATION OF TURBULENCE

- Initial giant vortex state with charge $\kappa = 40$.



- Closer look into the stationary state of the decaying turbulence.



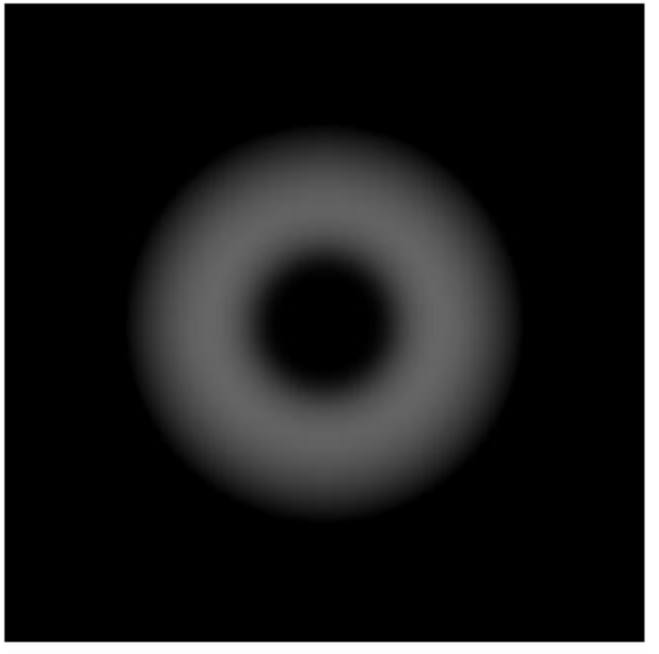


- Simulations of the phenomenological dissipative Gross-Pitaevskii equation

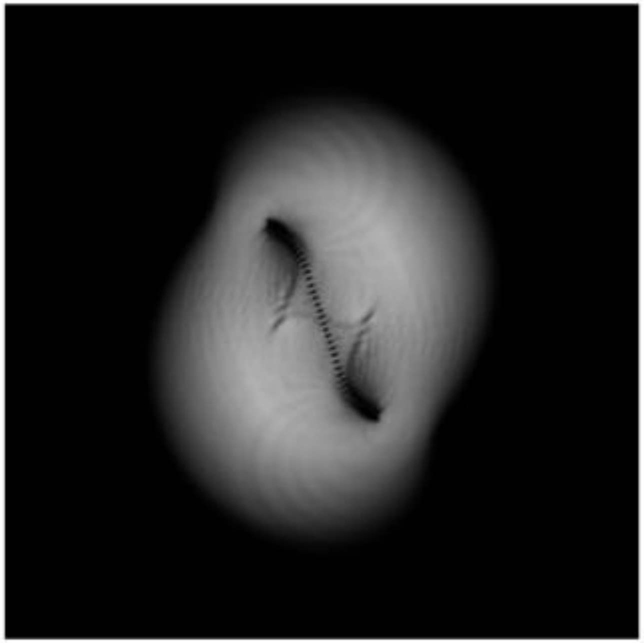
$$\frac{\partial \psi(\mathbf{r})}{\partial t} = (\gamma - i)\left(-\frac{1}{2}\nabla^2 + V(\mathbf{r}) + g\,|\psi|^2 - \mu\right)\psi(\mathbf{r}).$$

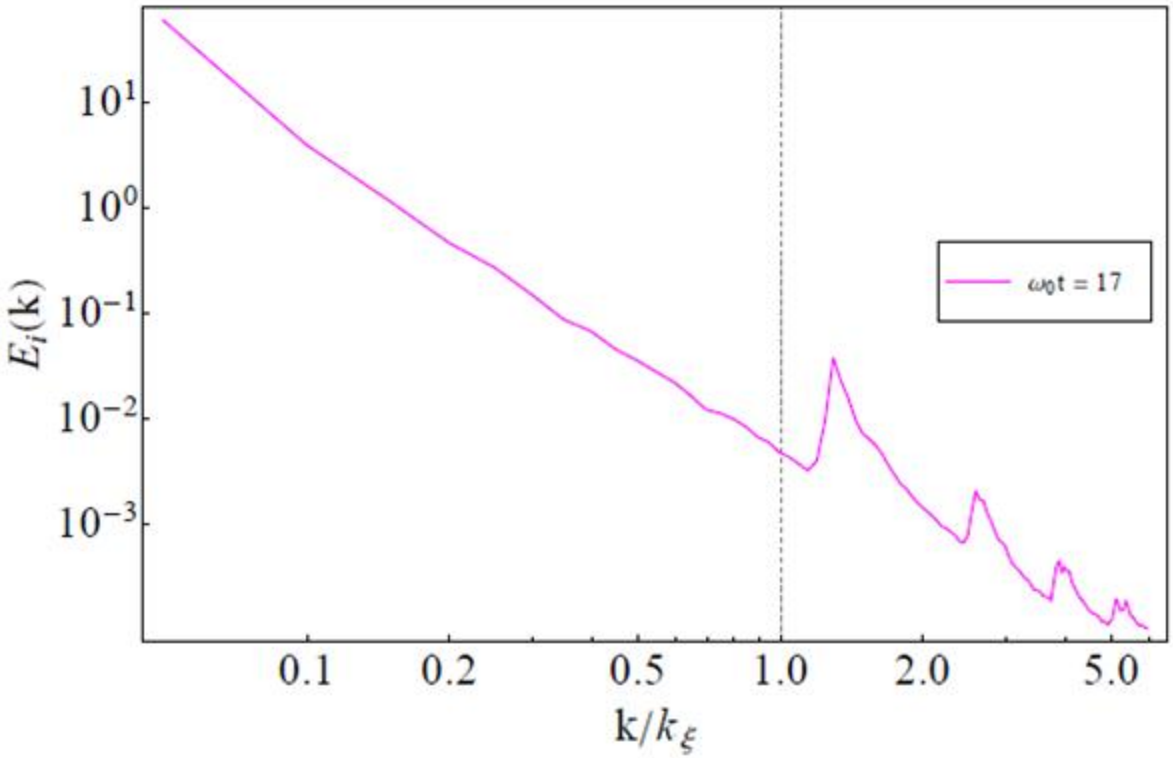
- Initial state: giant vortices with several different circulations.
- Unstable to linear perturbations $\rightarrow$ Bogoliubov modes are excited.

- Initial giant vortex state with charge $\kappa = 40$.

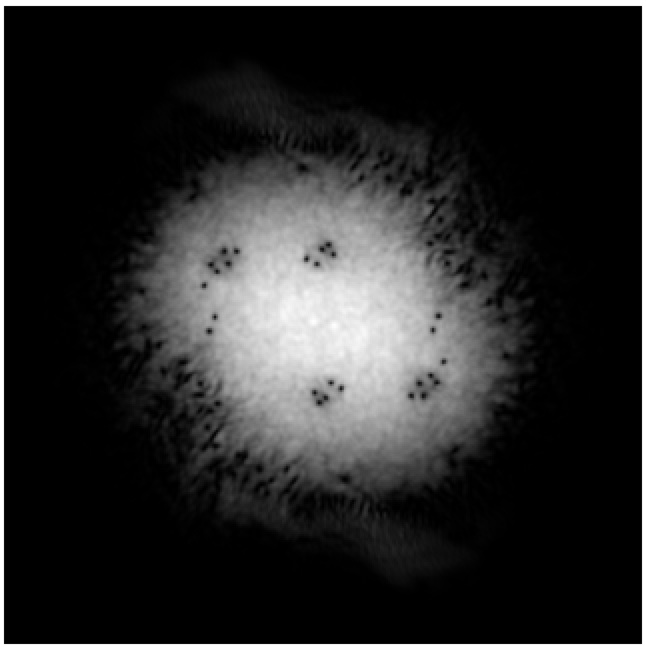


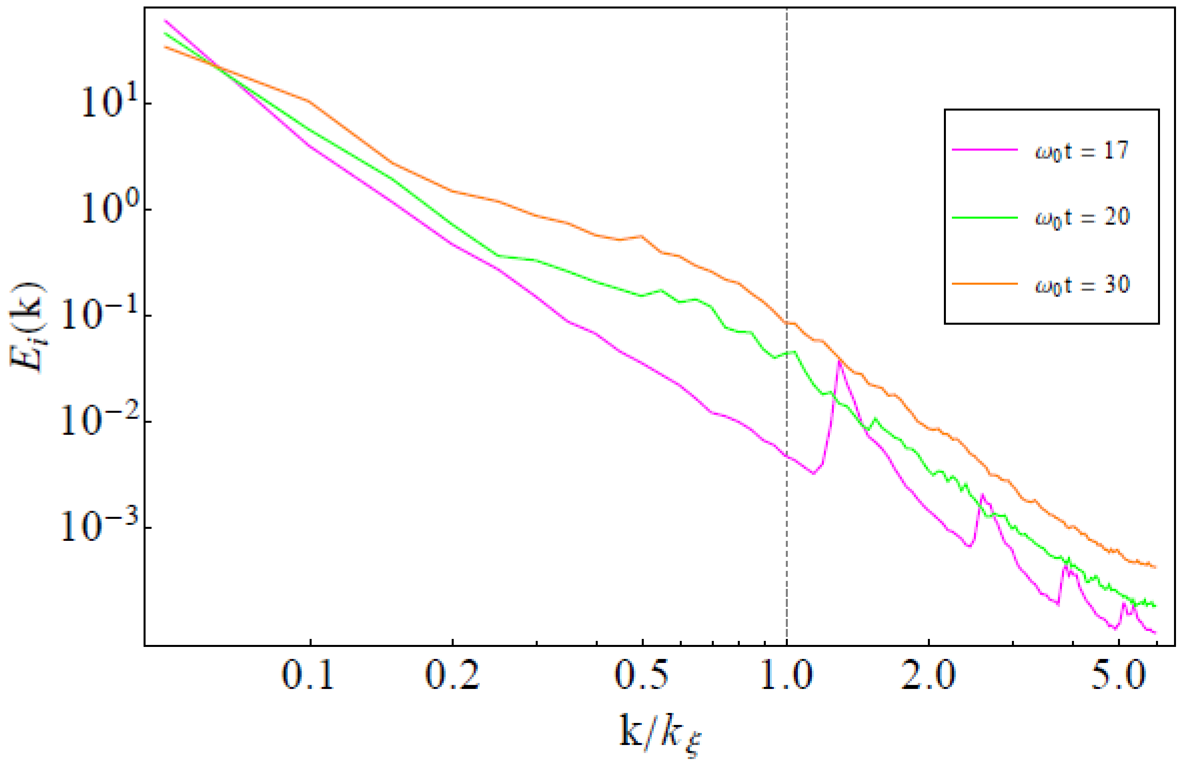
- Peaks suggest injection of energy into small scales due to the giant vortex decay.



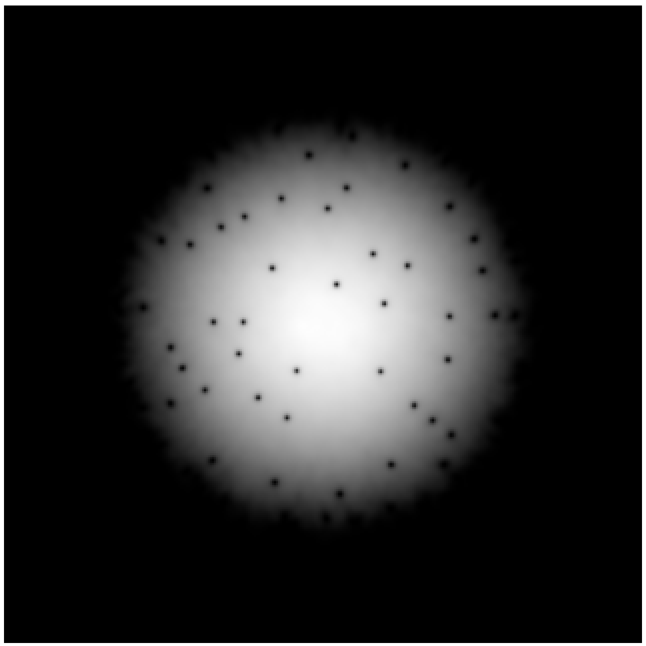


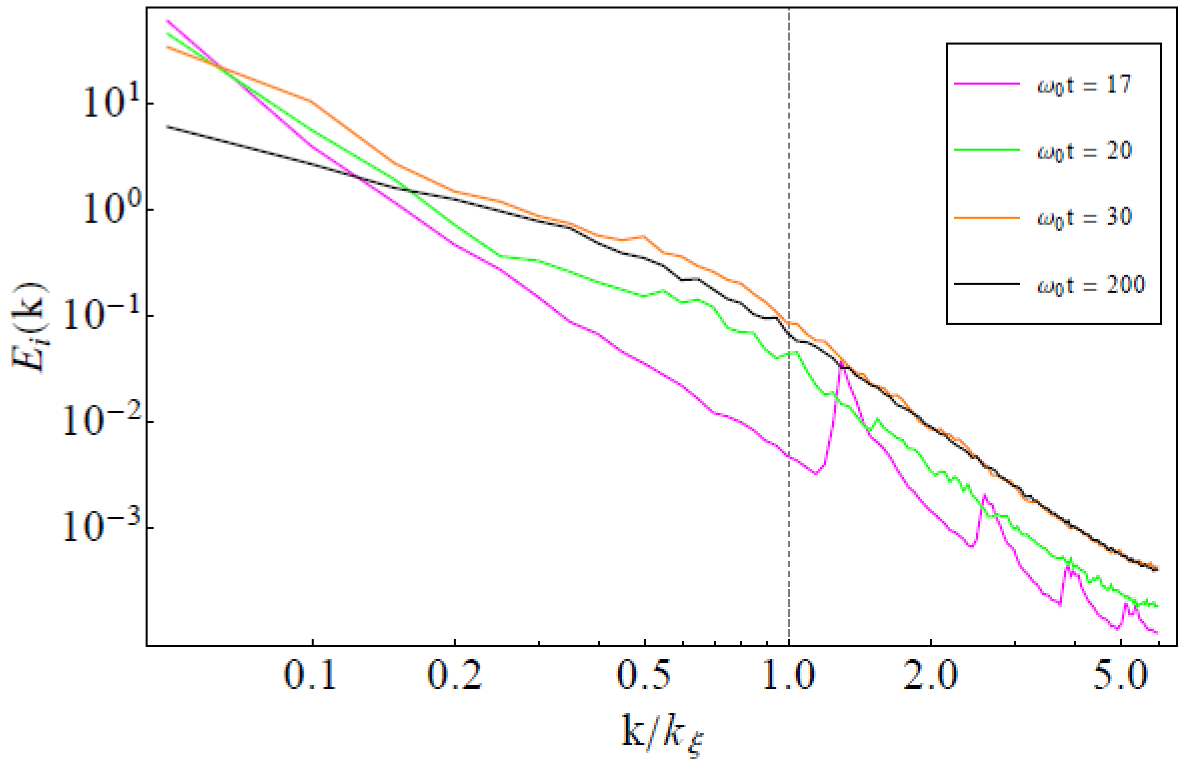
- Evolution and enlargement of clusters suggest that energy flows from large to small k (inverse cascade).



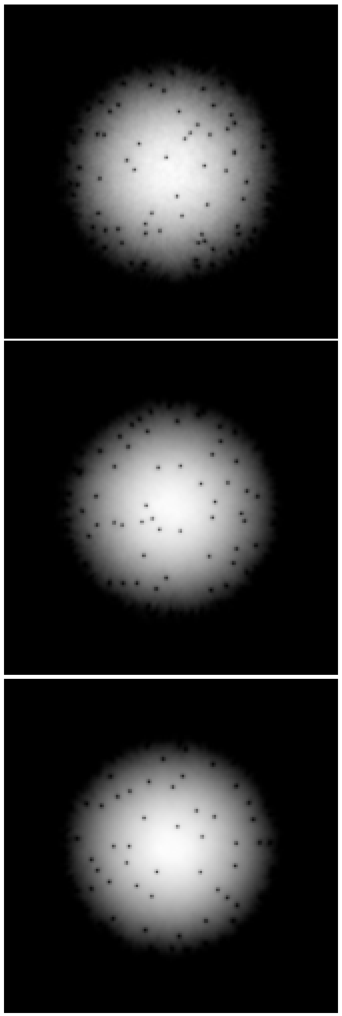


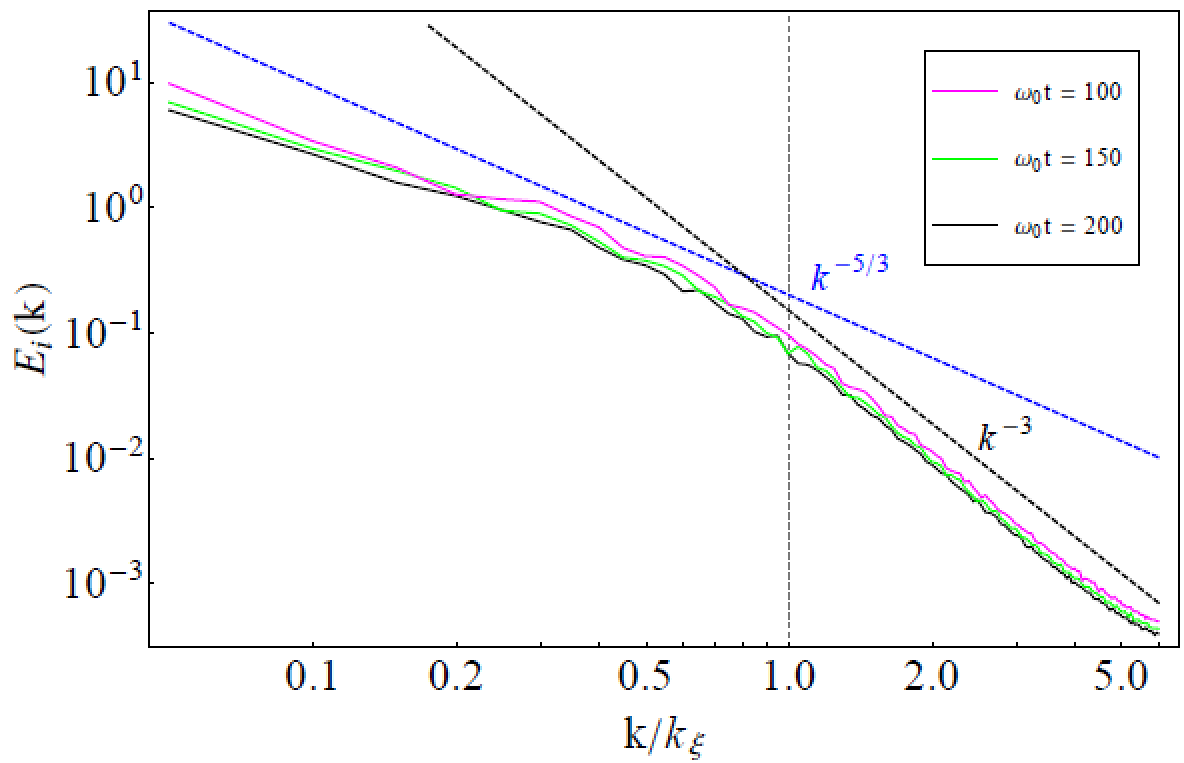
- Enlargement of vortex structures and stationary state. Dissipation acts effectively for small k.



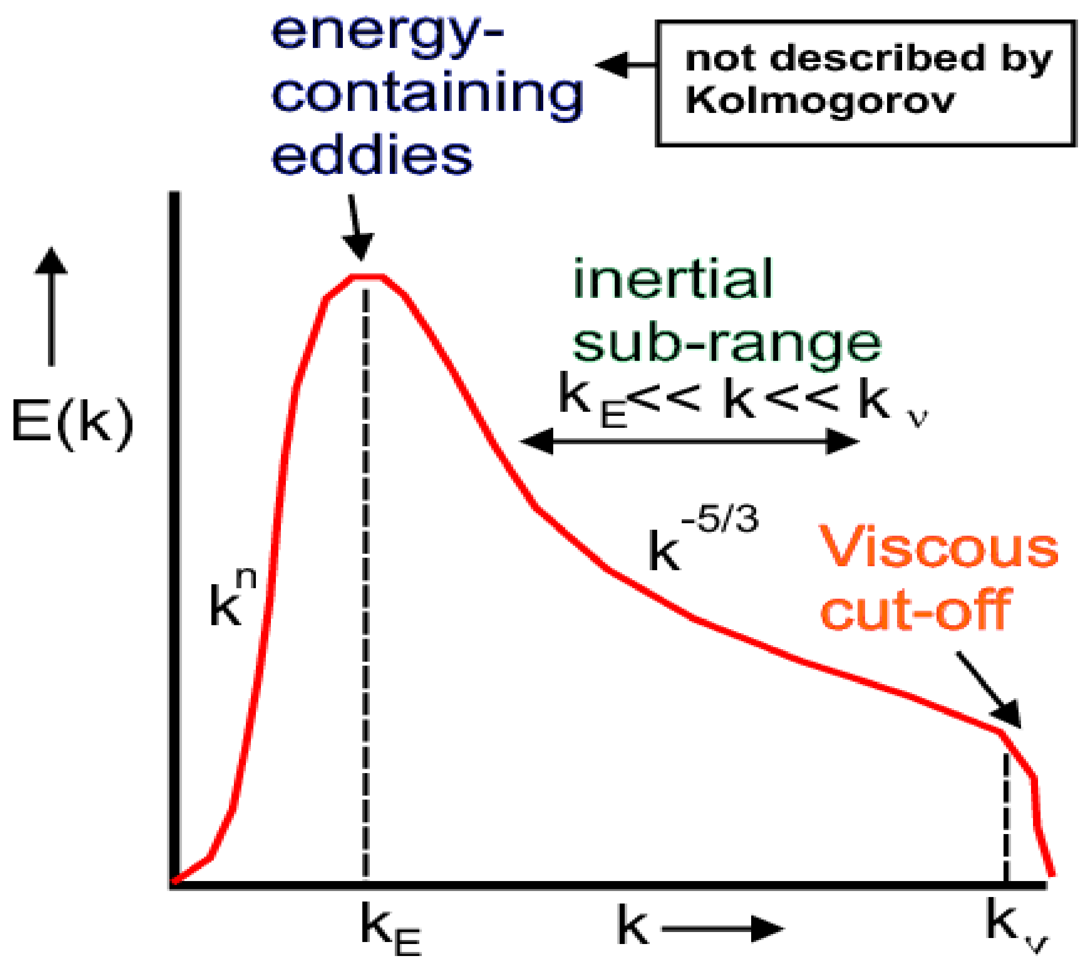


- Closer look into the stationary state of the decaying turbulence.

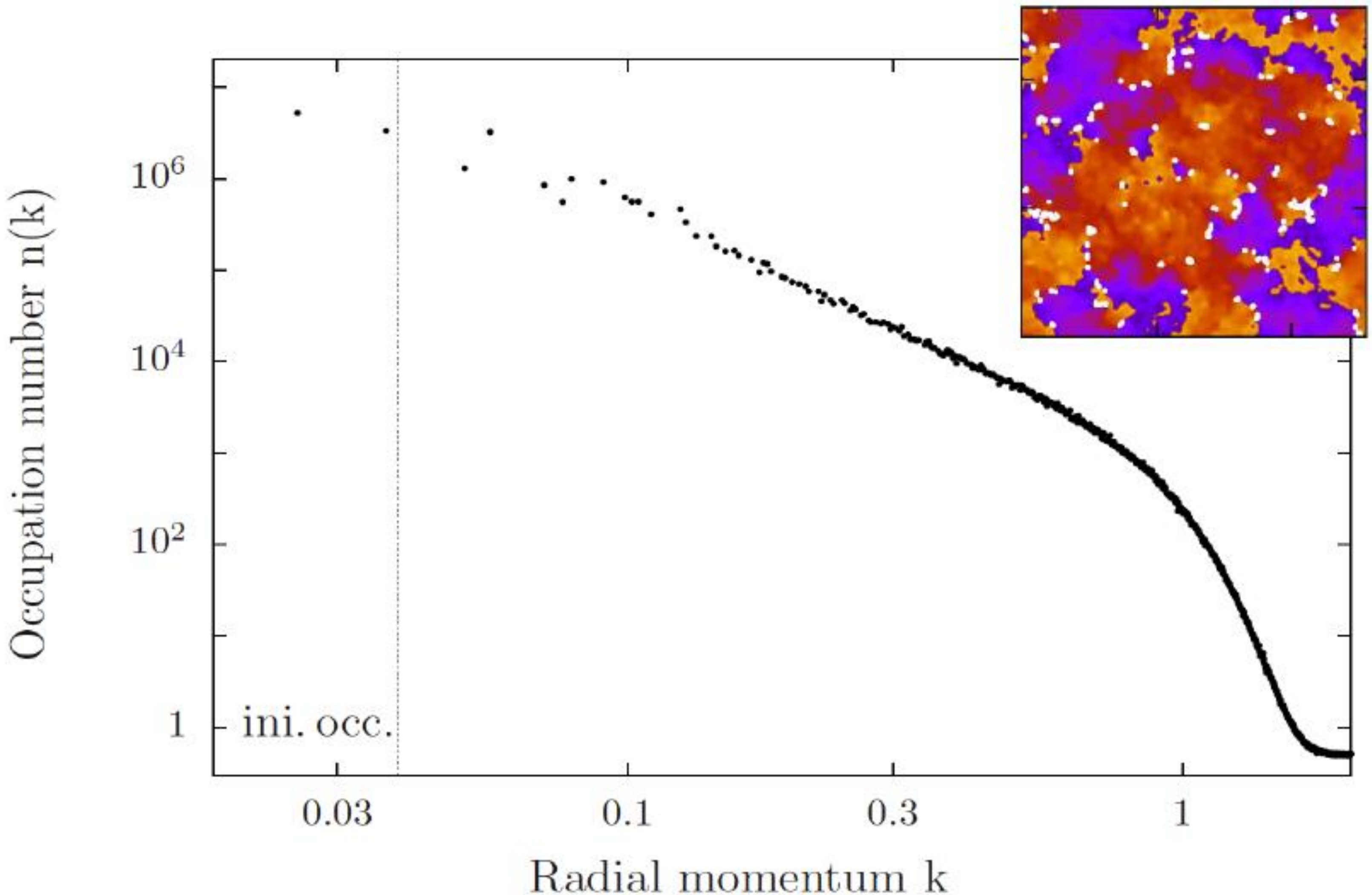




Thanks for your attention!



Kolmogorov: In the inertial sub-range, no dissipation and local interactions



B. Nowak, D. Sexty, TG (arXiv:1012.4437)