QUANTUM TURBULENCE IN AN ATOMIC TRAPPED SUPERFLUID

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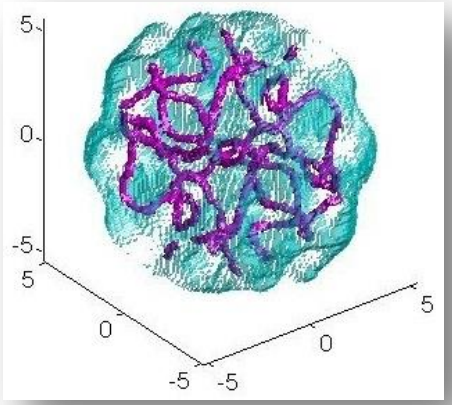
http://cepof.ifsc.usp.br



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CePOF
Centro de Pesquisa em Óptica e Fotônica

INOF
Instituto Nacional de Óptica e Fotônica

INOF Instituto Nacional de Óptica e Fotônica

CePOF Centro de Pesquisa em Óptica e Fotônica

AMO Atomic, Molecular and Optical Physics

bio photonics

Nano plasmonics

Diffusion

Innovation

Innovation with
Social responsibility

http://cepof.ifsc.usp.br

BEC project: 3 Experimental projects

3 Theoretical projects

http://cepof.ifsc.usp.br

Researchers

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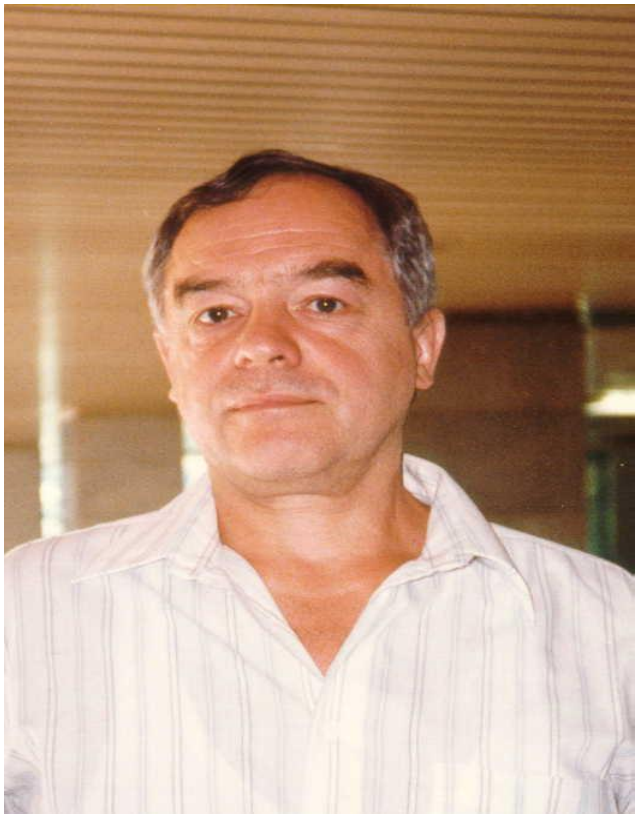
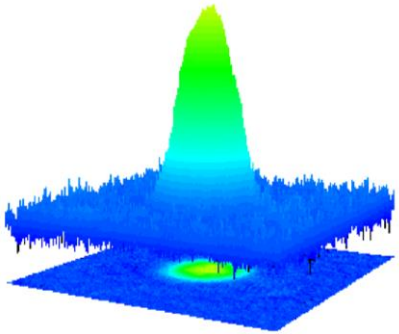
A. Cidrin

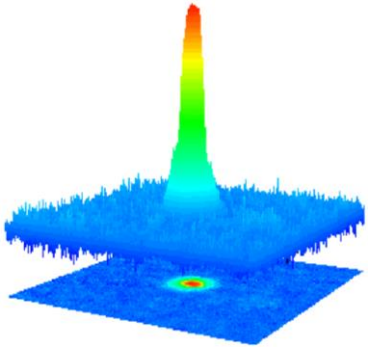
Collaborators: E. Santos, M. Tsubota, A. Fetter, G. Bain, G. Roati, V. Romero,



Collaborators from JINR : V. Yukalov and A. Novikov



$T > T_c$



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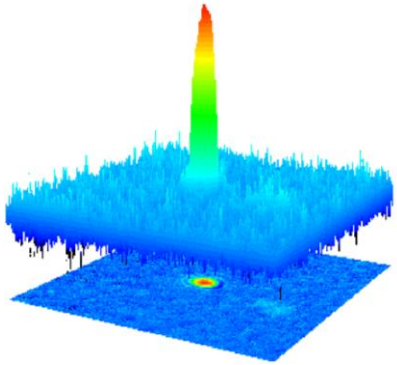
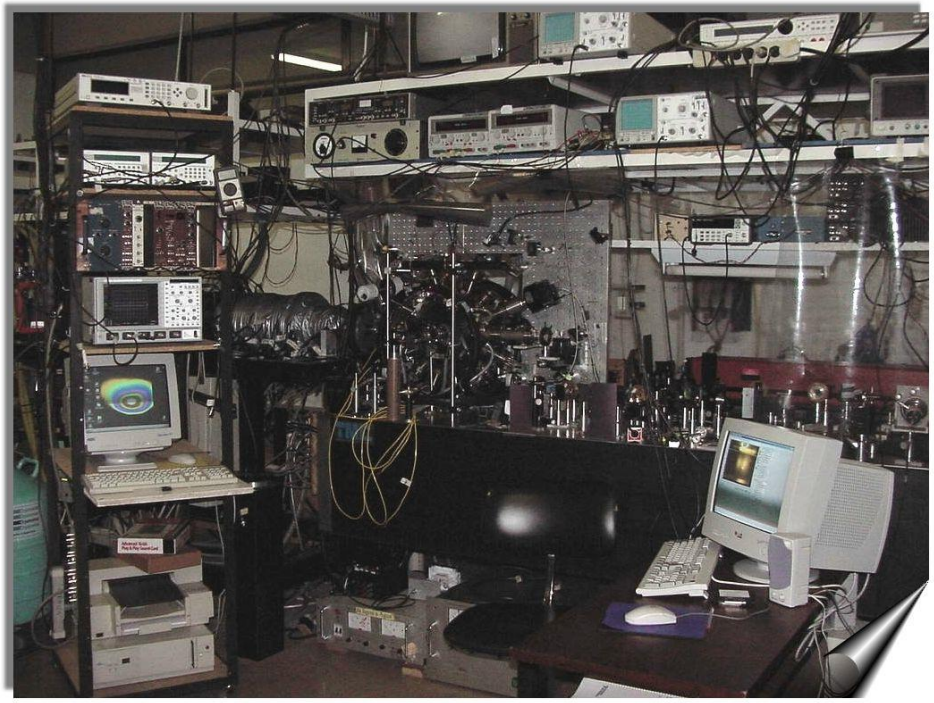
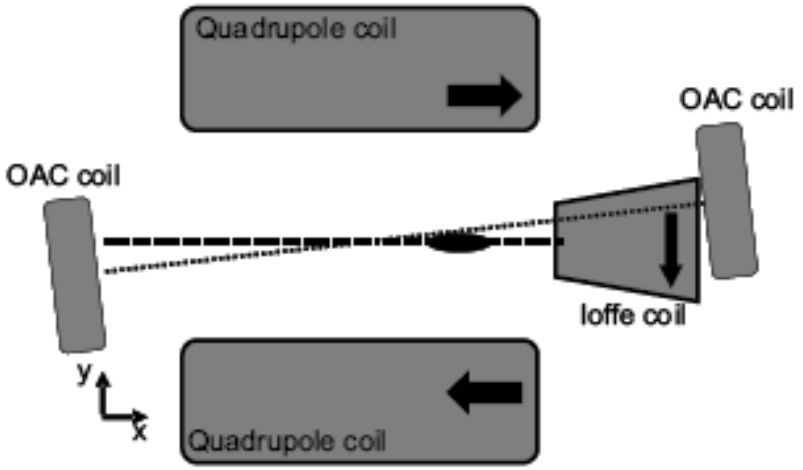


$T << T_c$



EXCITATION BY OSCILLATION OF THE POTENTIAL

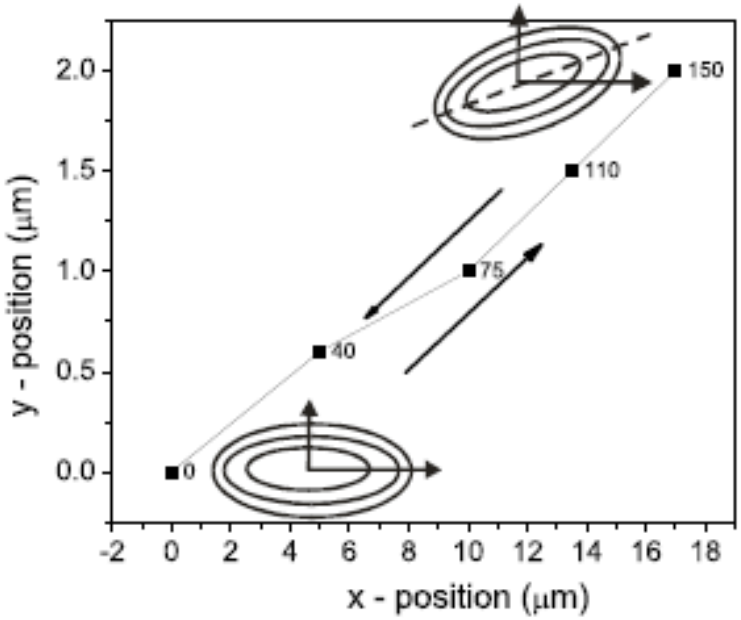


ADDITION OF "SHAKING" COILS

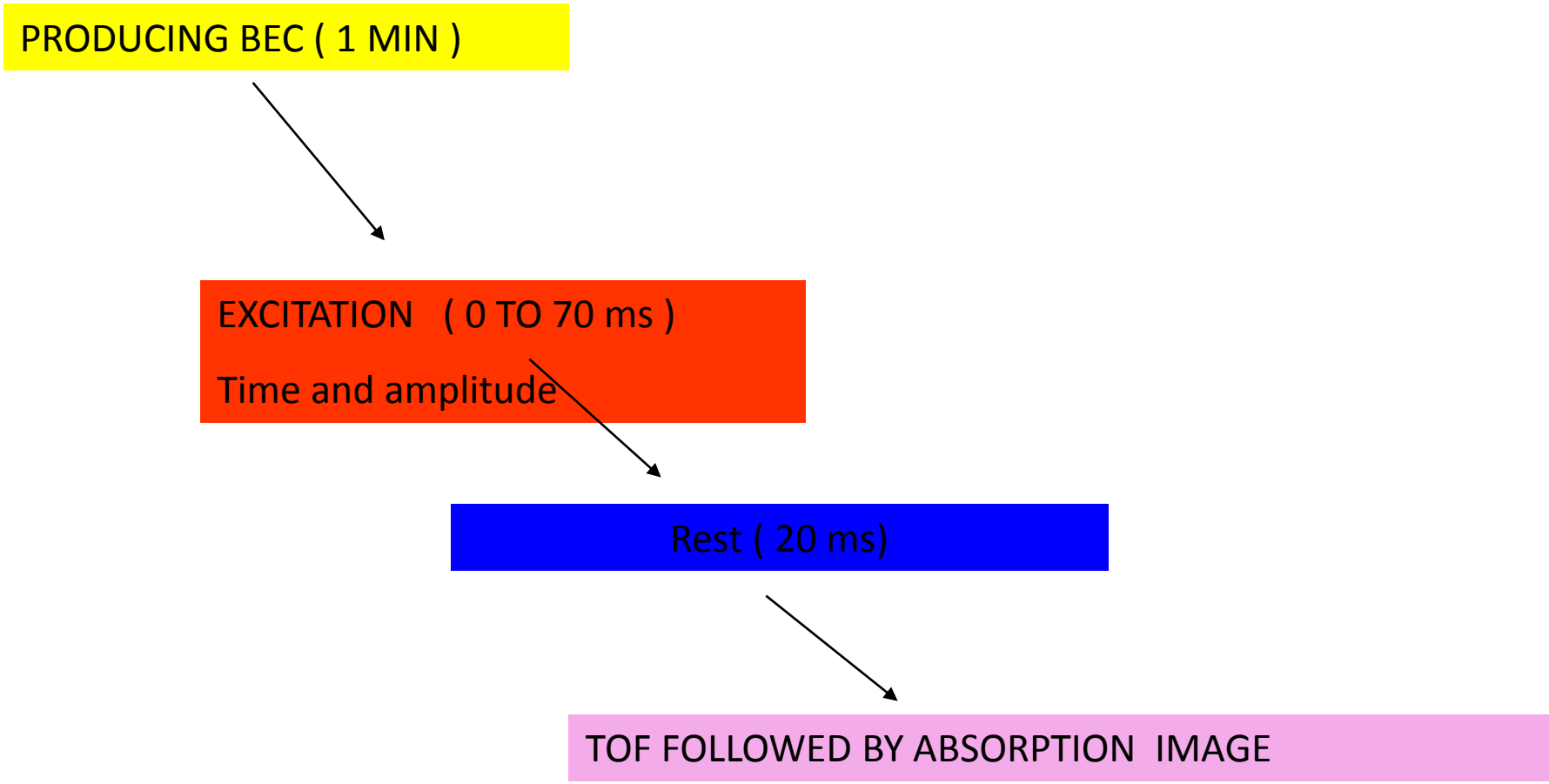
Displacement,

Rotation and

Deformation of the potential

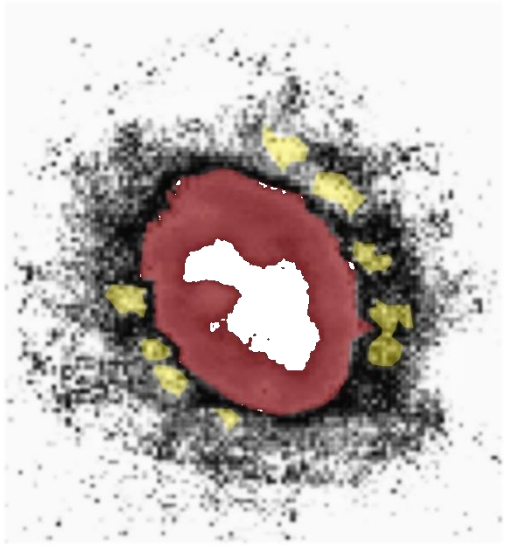


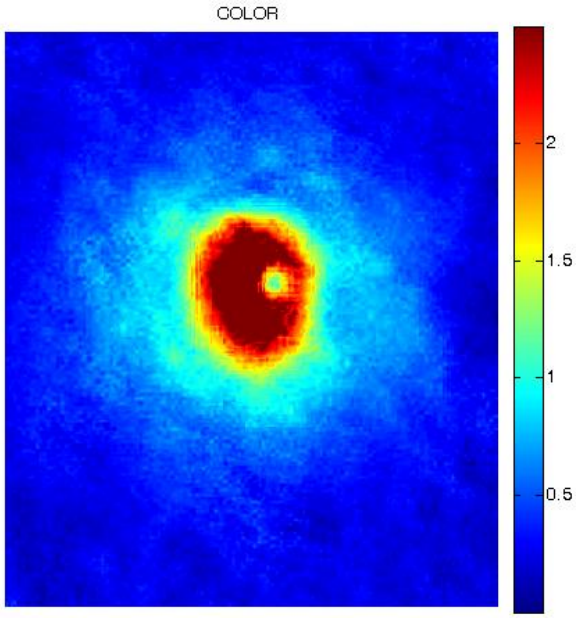
Atomic washing machine


PRODUCING BEC (1 MIN)
EXCITATION (0 TO 70 ms)
Time and amplitude
Rest (20 ms)
TOF FOLLOWED BY ABSORPTION IMAGE

Vortex formation

COLLECTIVE MODES





Phys. Rev. A 79, 043618 (2009)

Vortices and anti-vortices are together)

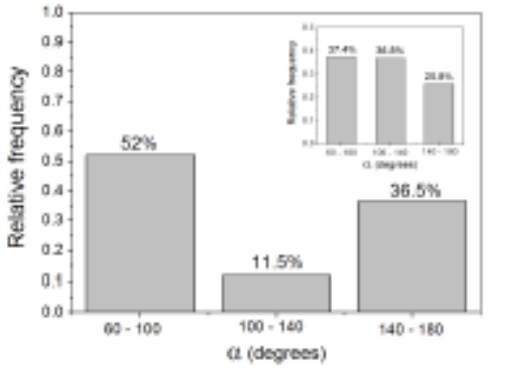
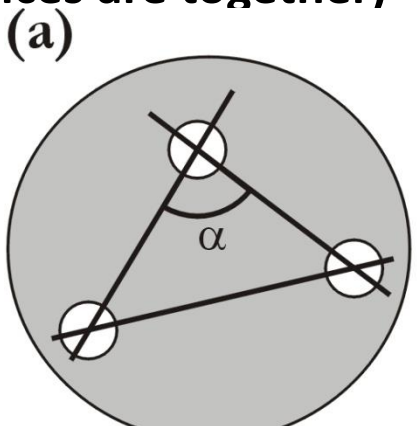
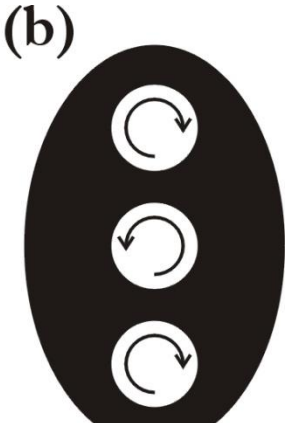
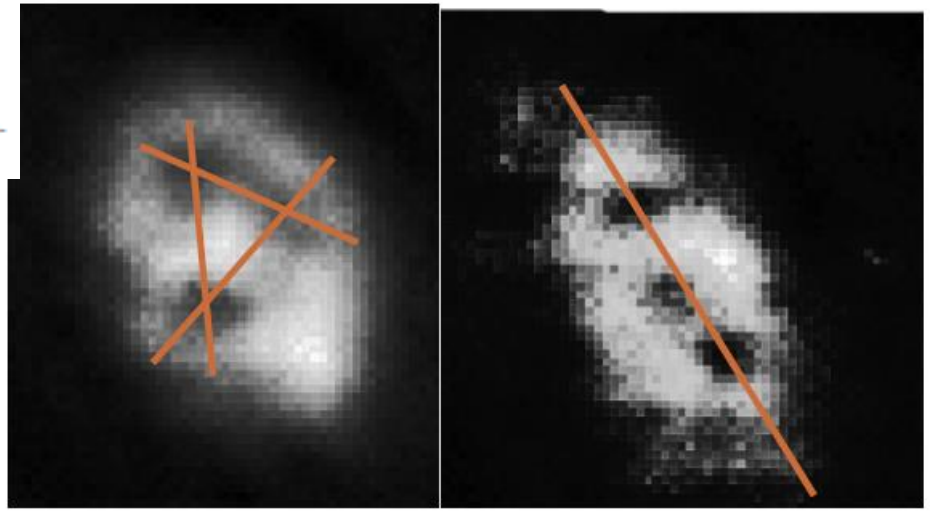


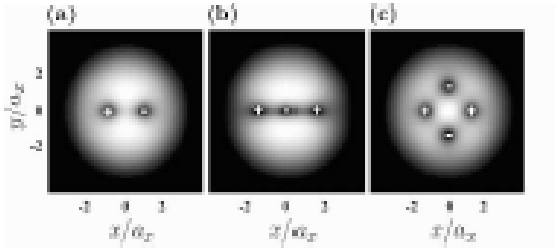
FIG. 3: Relative frequency of 3-vortex configuration as a function of the angle α.





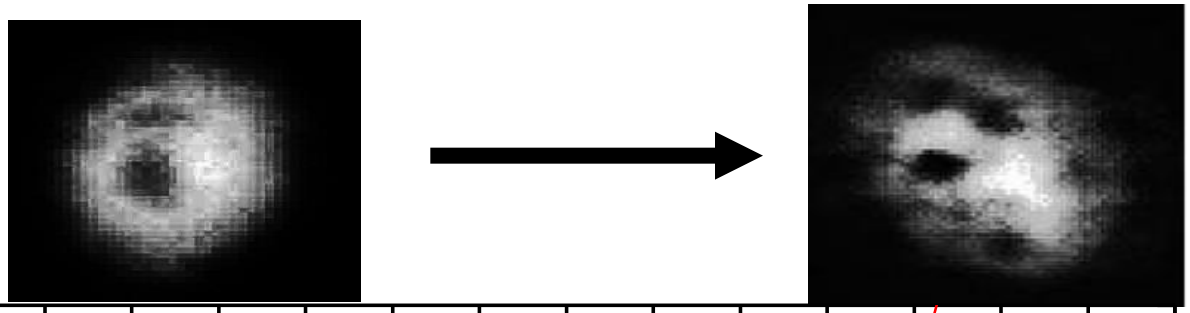


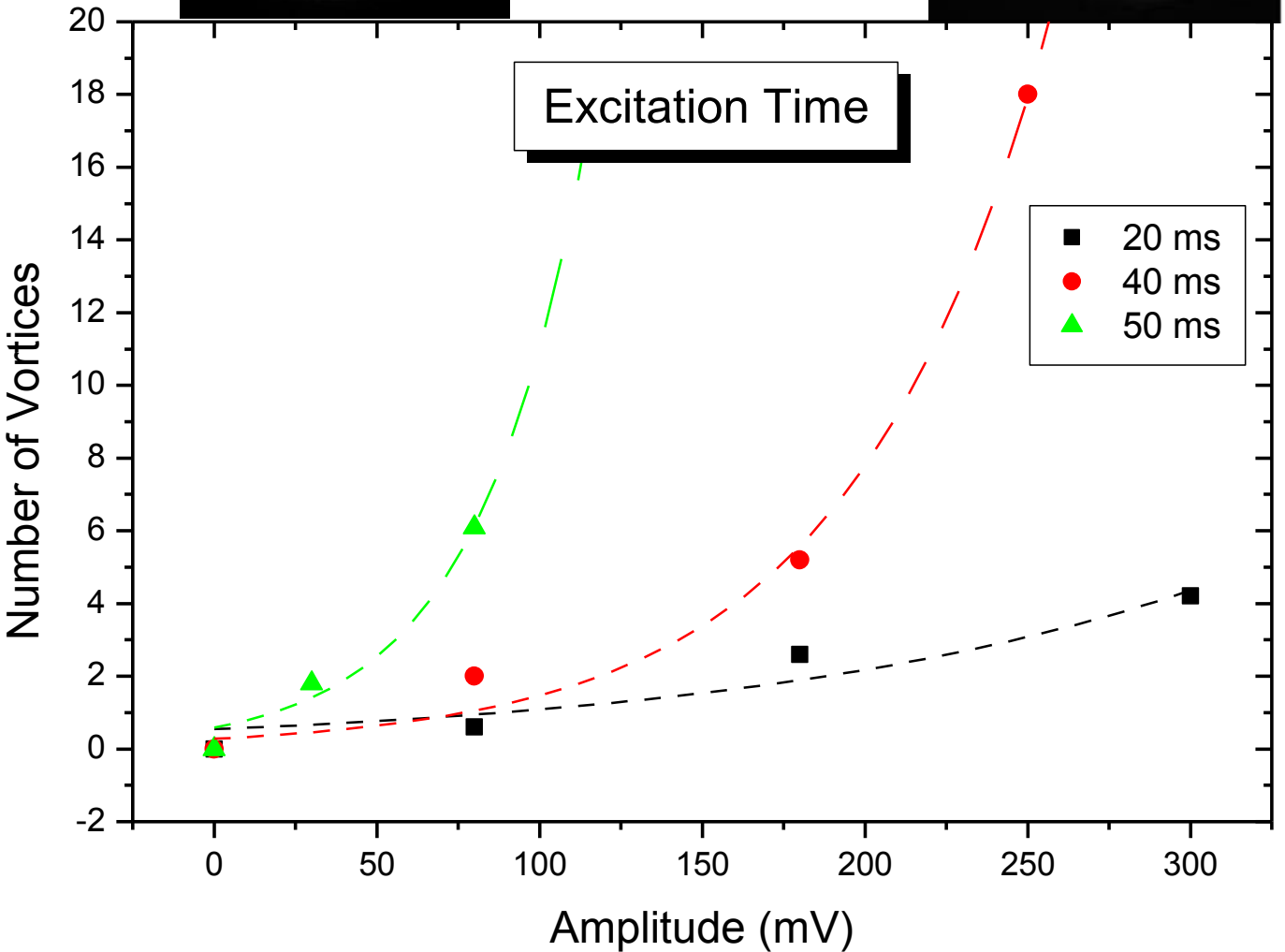
Three-vortex configurations in trapped Bose-Einstein



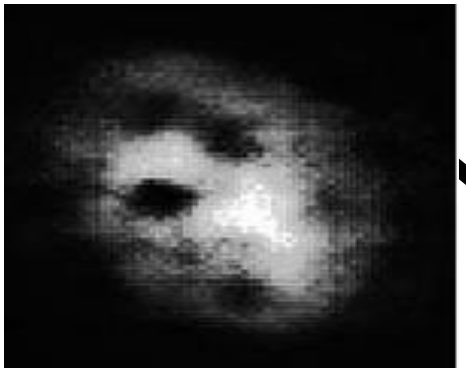
Phys. Rev. A 82,033616(2010)

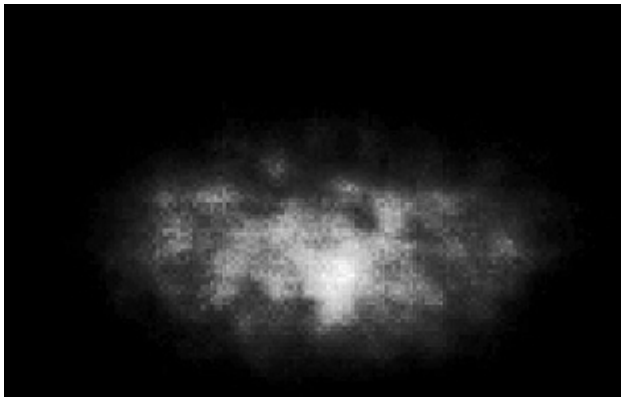
PROLIFERATION

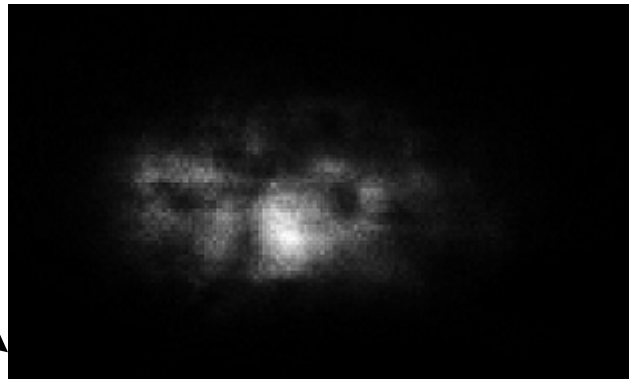


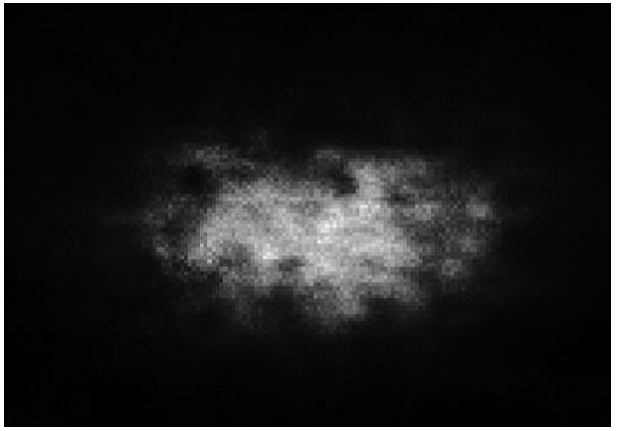


Increasing amplitude or time of excitation:
Explosion and proliferation of many vortices but no regular pattern and hard to count









Vortices to tangle vortices

"TURBULENCE"

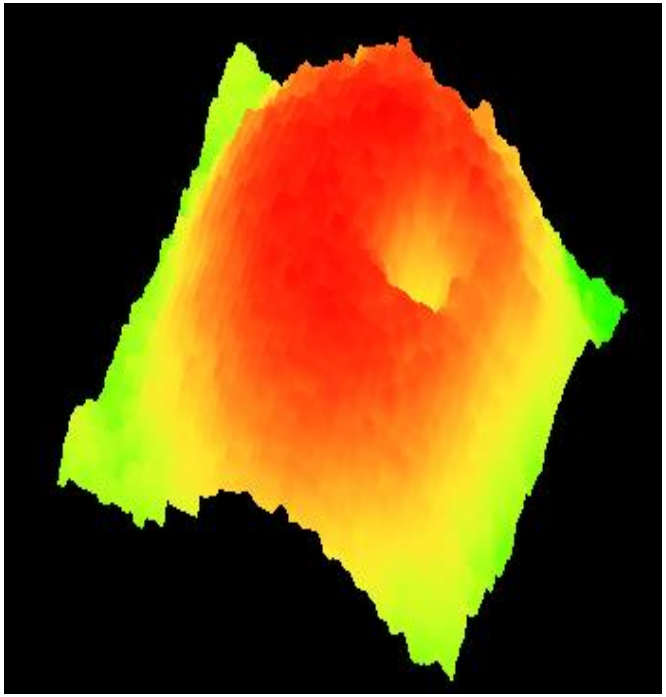
NON REGULAR – MANY POSITIONS

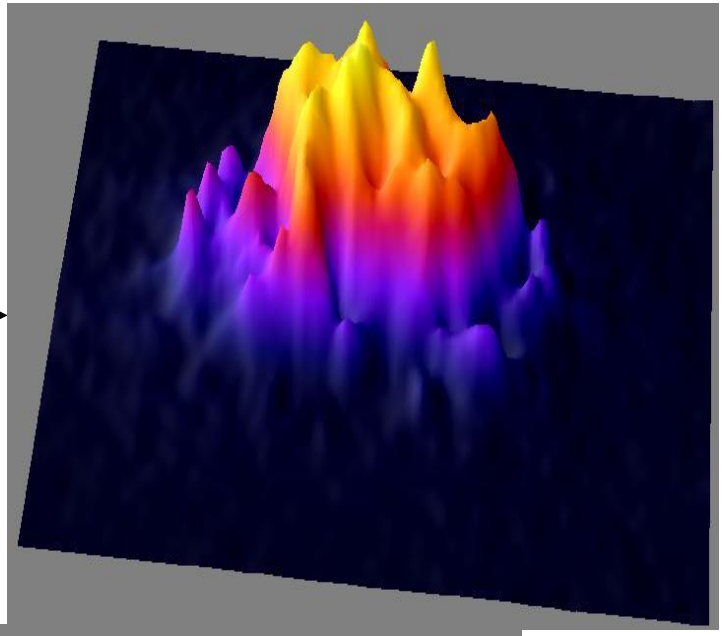
ORIENTATIONS AND LENGTH

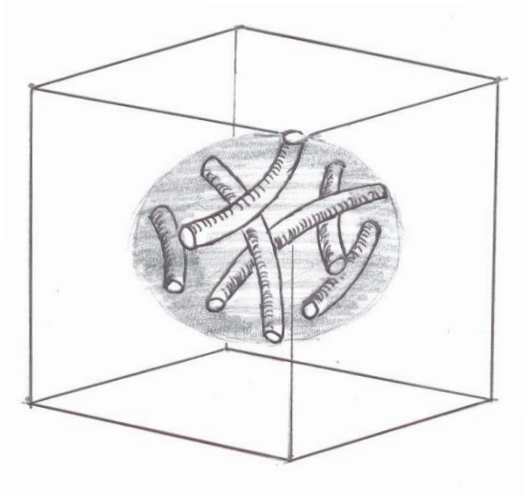
J Low Temp Phys (2010) 158: 435–442

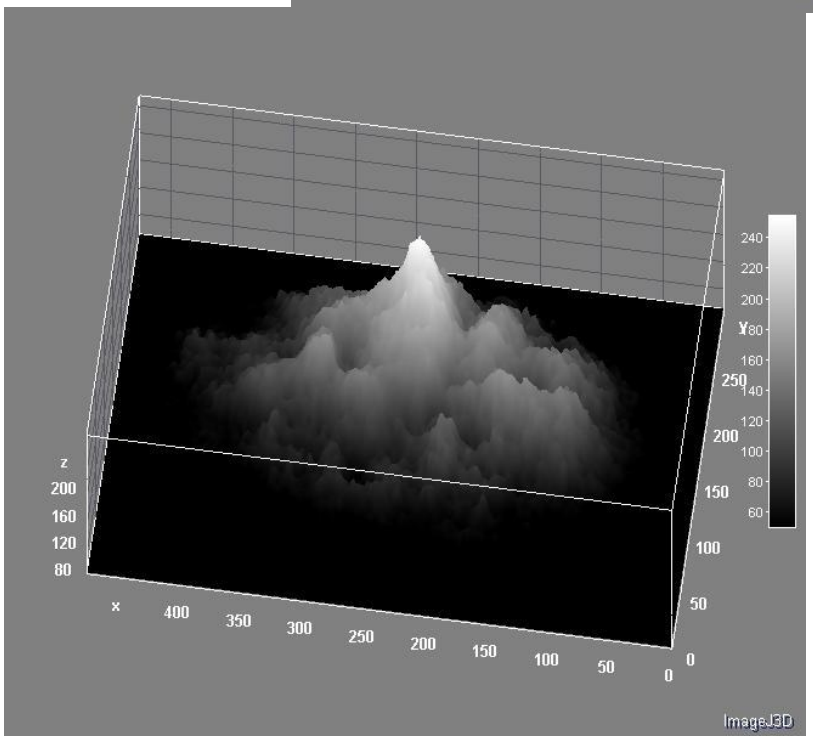
Phys. Rev. Lett. 103, 045301 (2009)

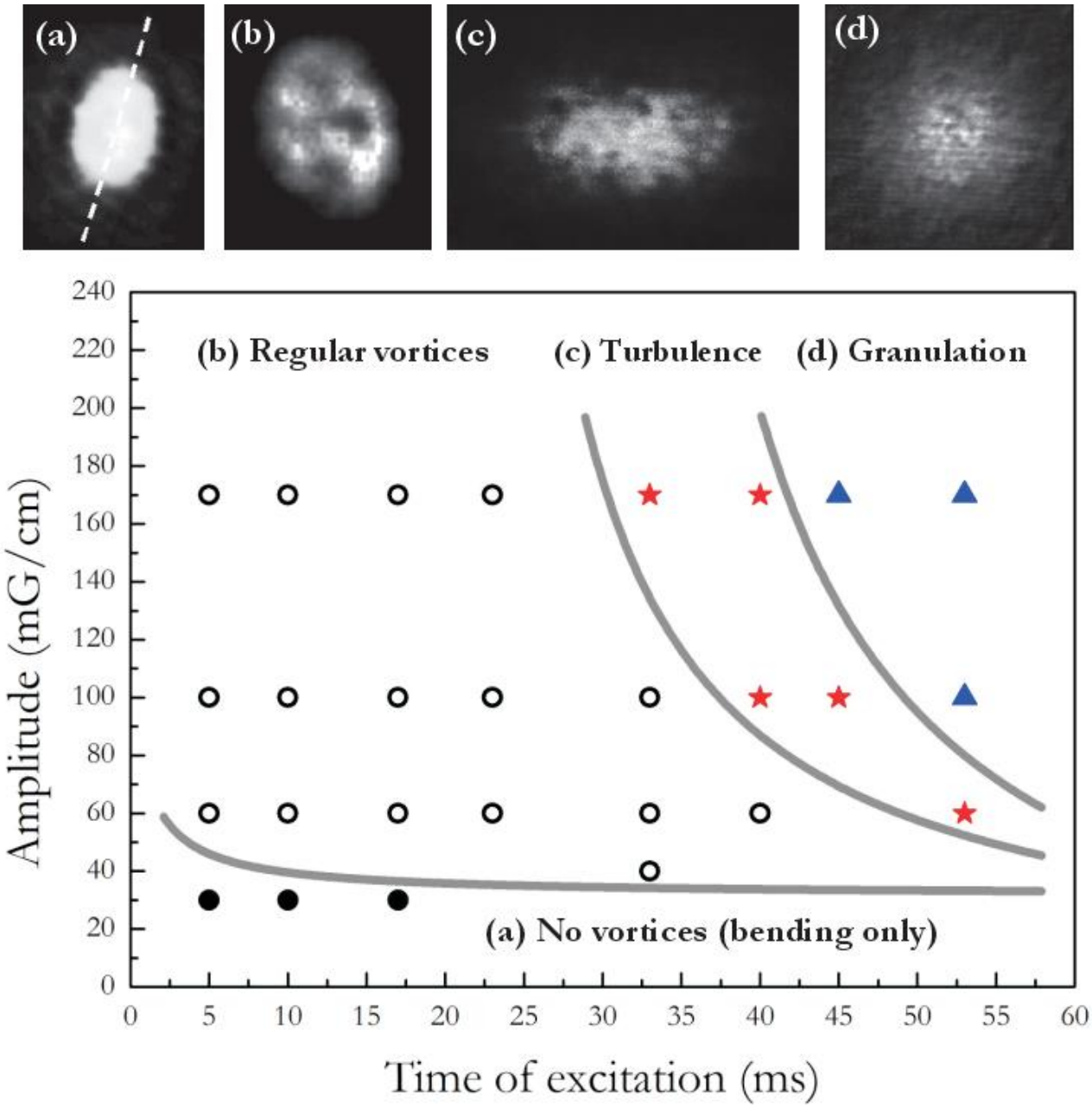
Tangle vortices region





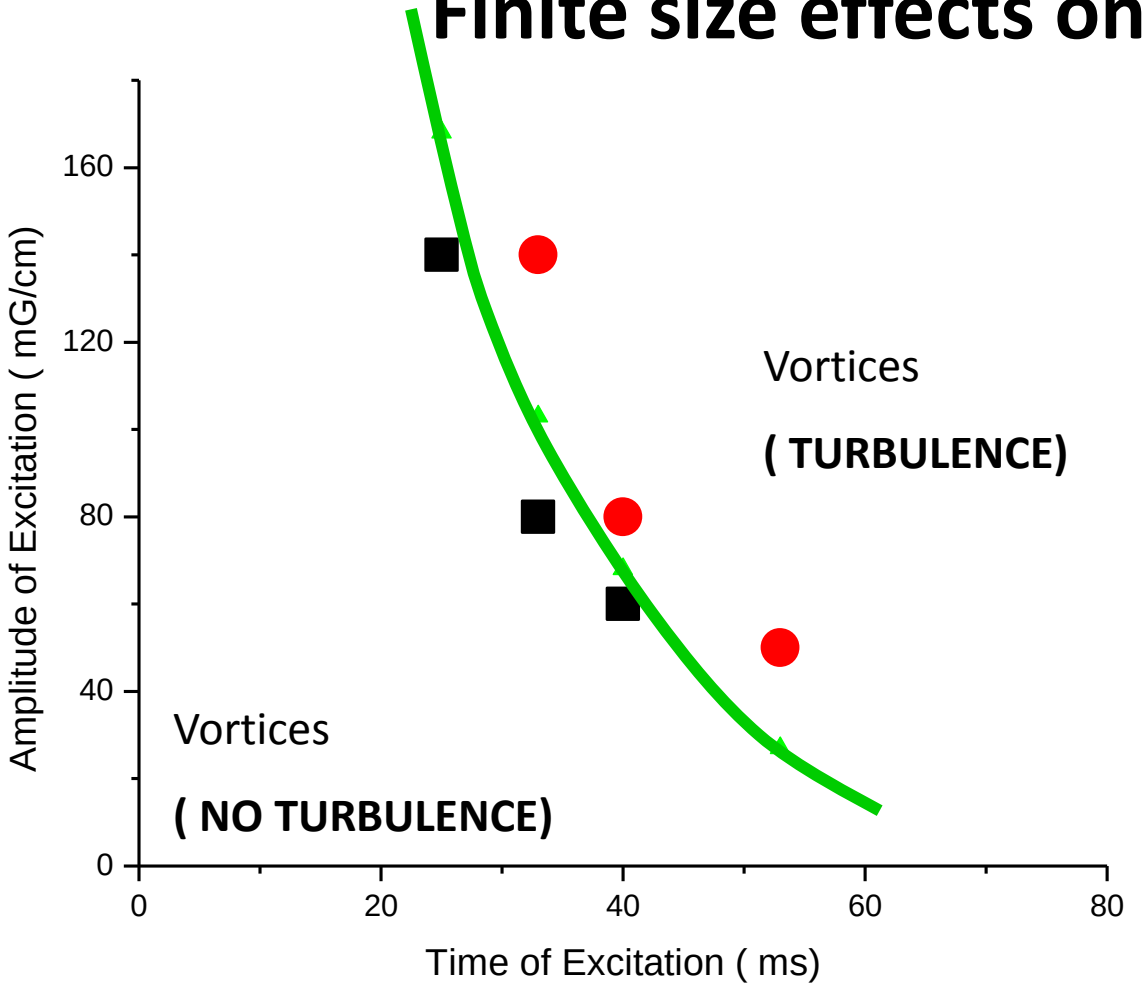






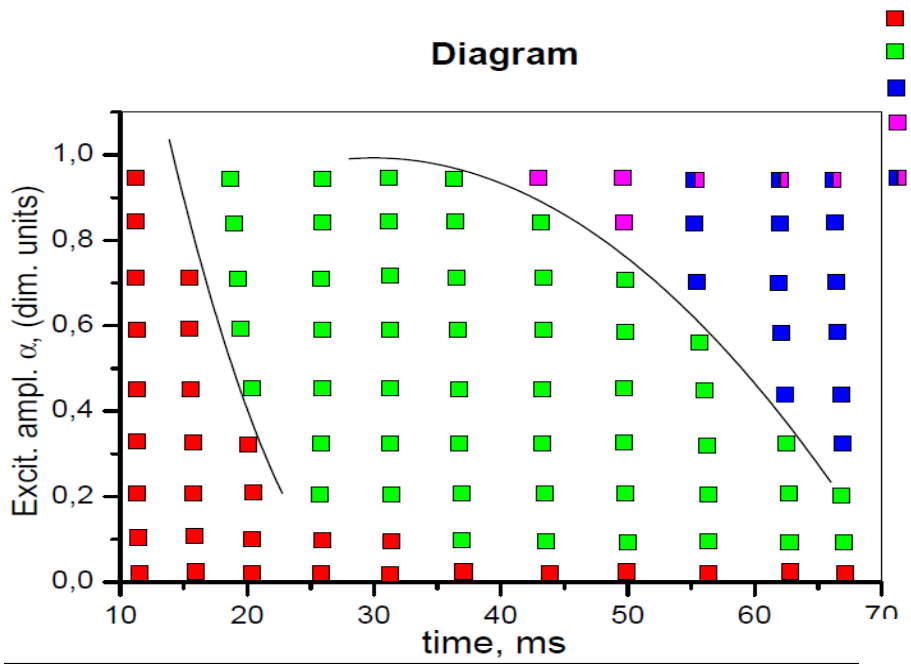
Las. Phys. Lett. 8,691(2011)

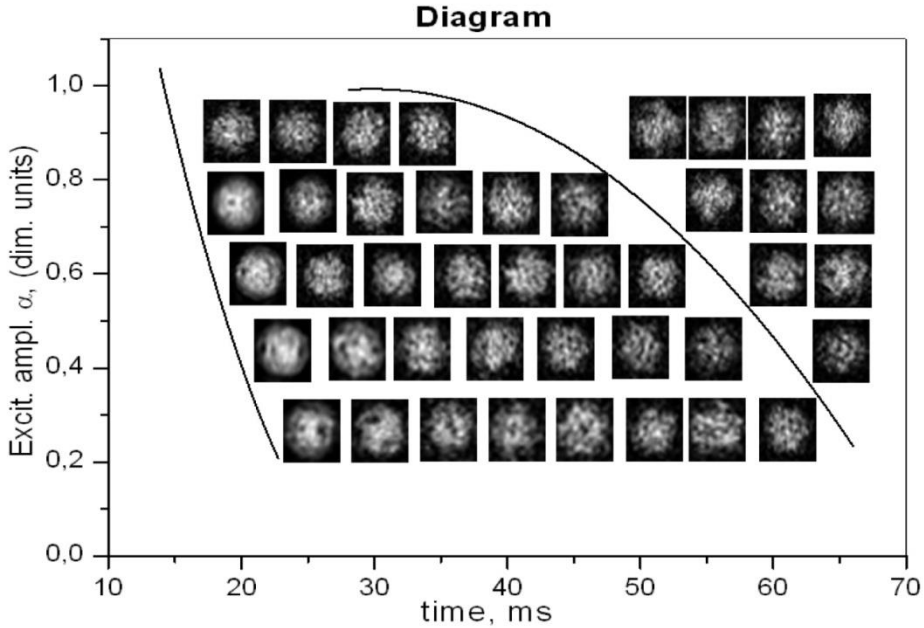
Finite size effects on the QT



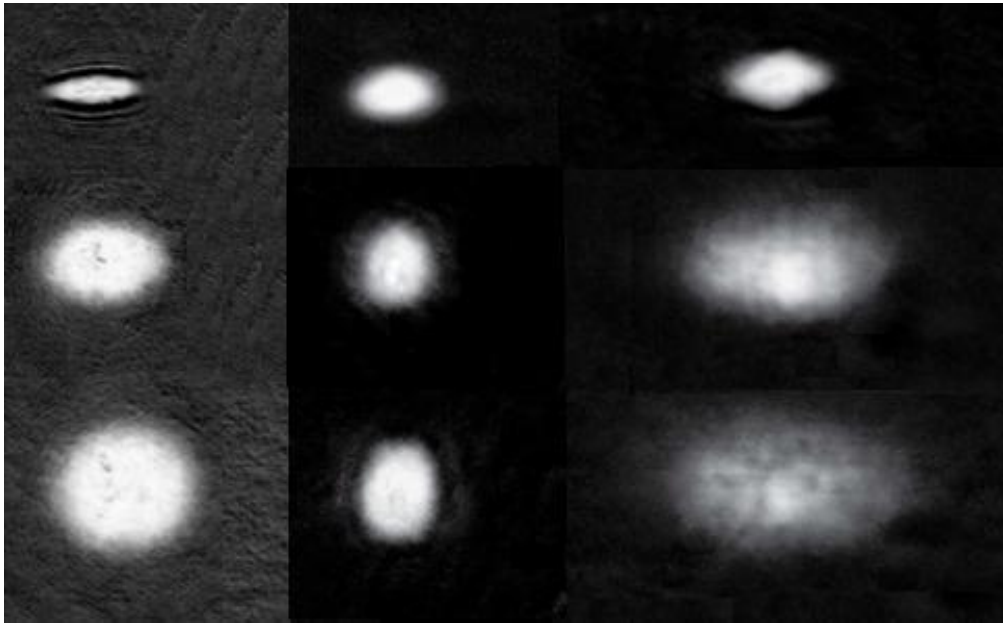
CRITICAL LINE ------ Fitting: A+Ao = C/t

Laser Phys. Lett. 8,393(2011)





Dubna collaboration: A.Novikov – V. Yukalov

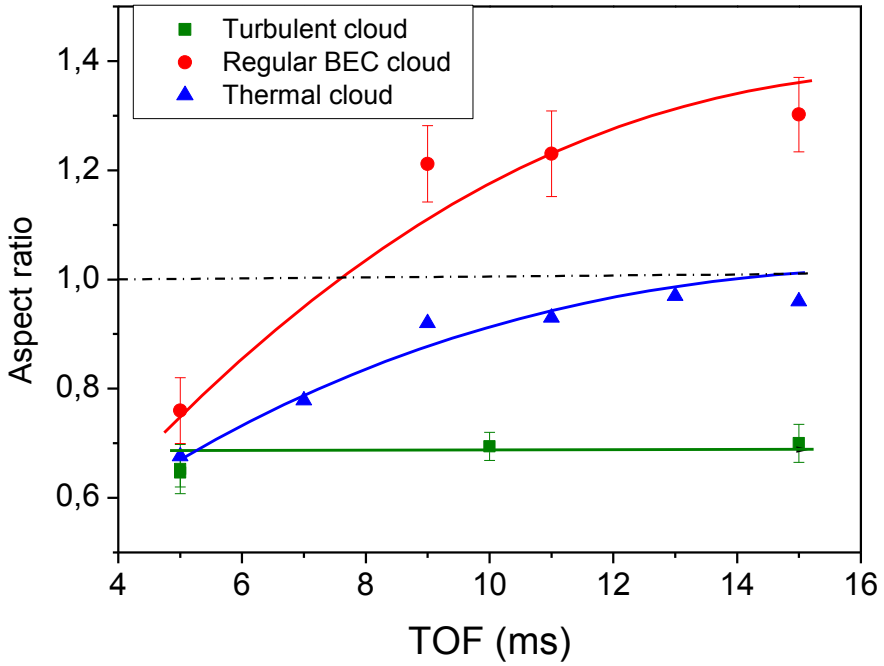


Thermal BEC Turbulent

Cloud expansion

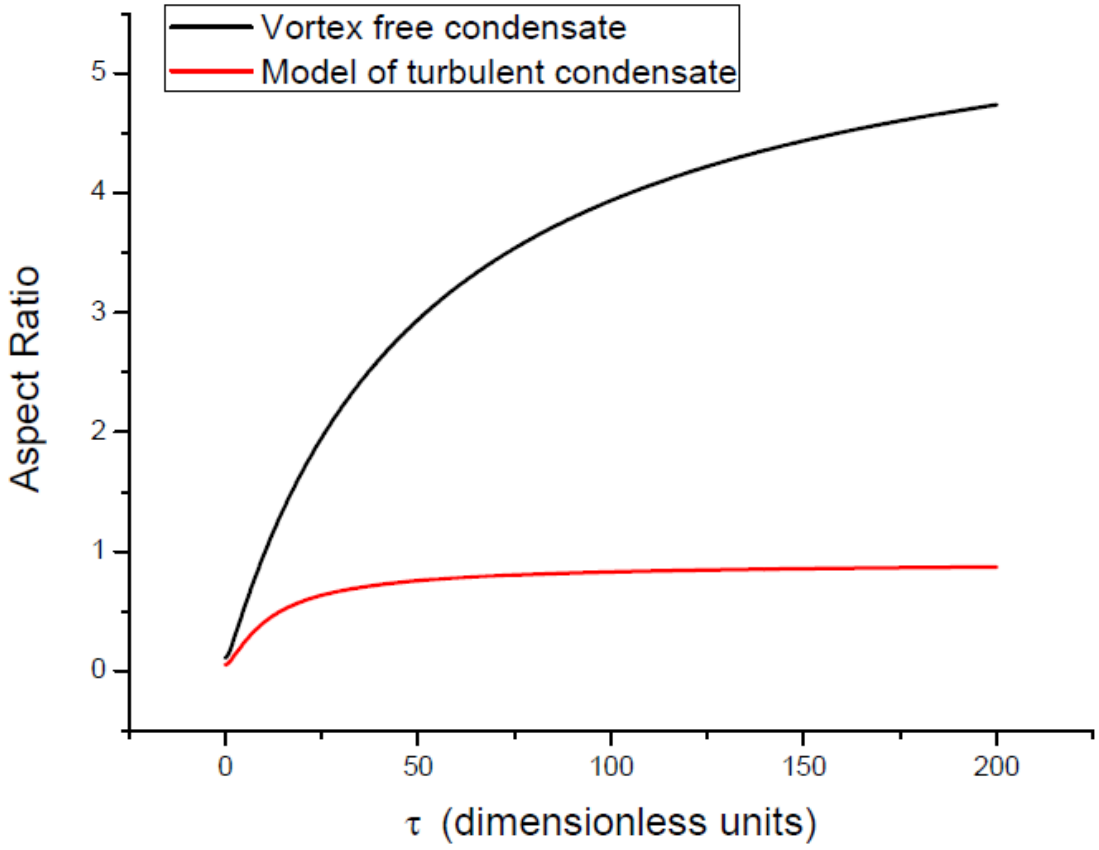
(hydrodynamics)

J. Phys. Conf.Ser.264,012004(2011)



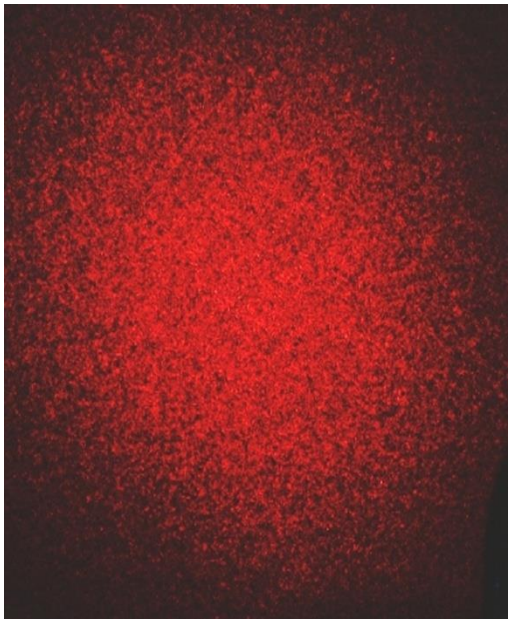
M. Caracanhas · A. L. Fetter · G. A. Baym · S. R. Muniz · V. S. Bagnato

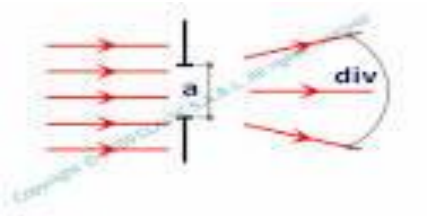
Self-similar expansion of a turbulent Bose-Einstein condensate: a generalized hydrodynamic model



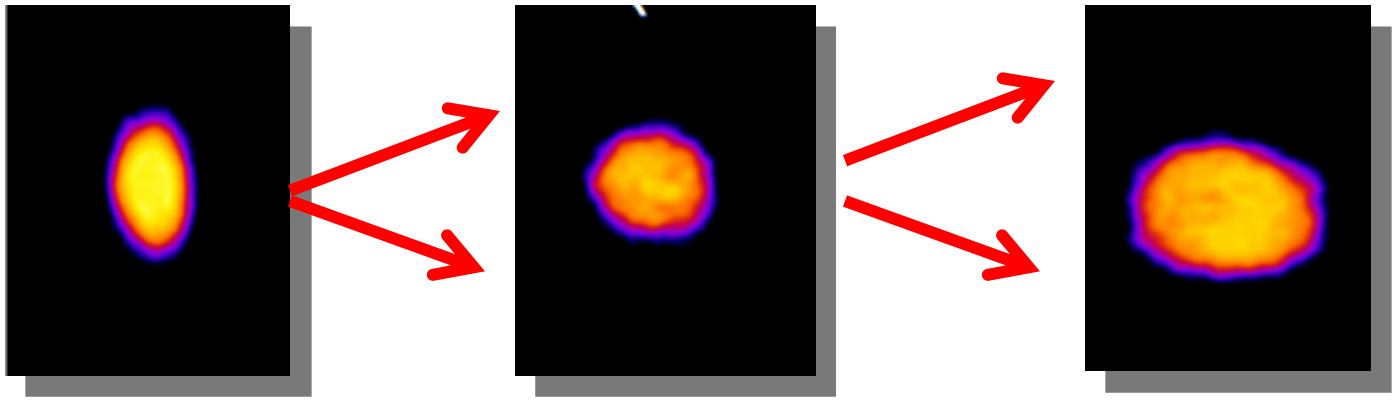
Journal of low temperature Physics,166,, 49-58 (2012)

Light speckles

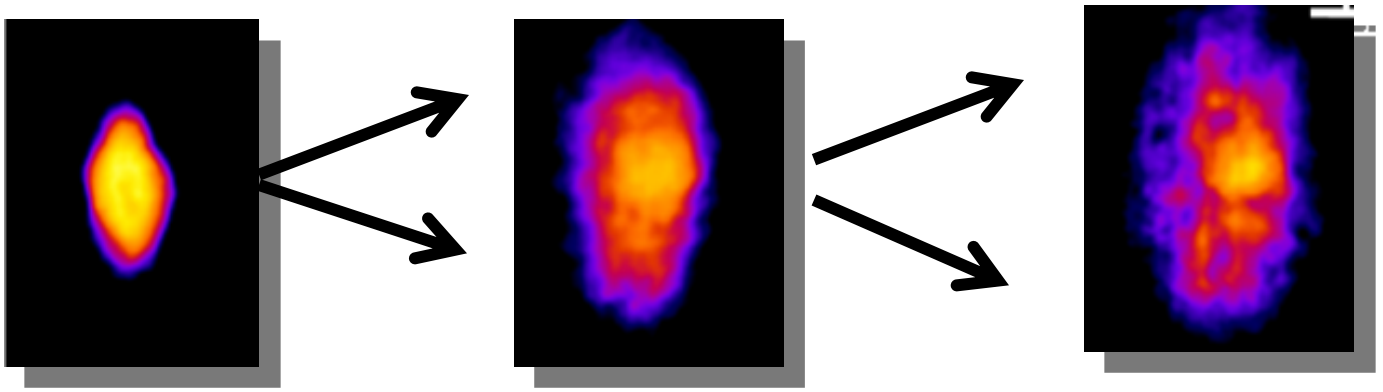




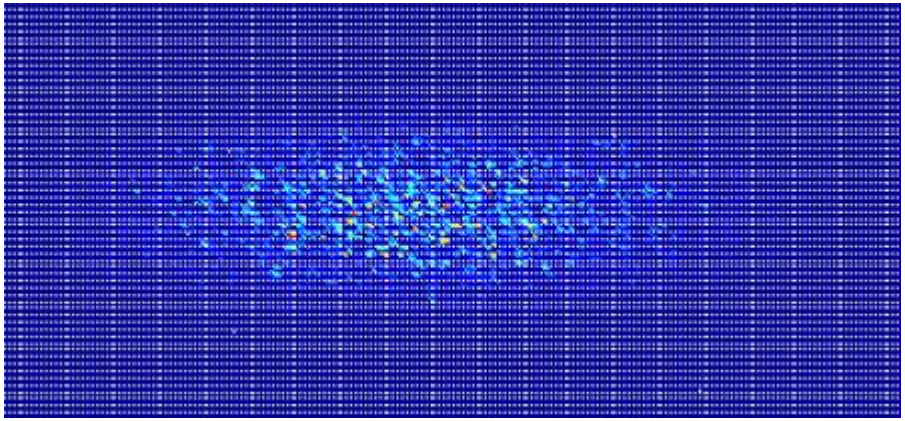
Diffraction of matter waves

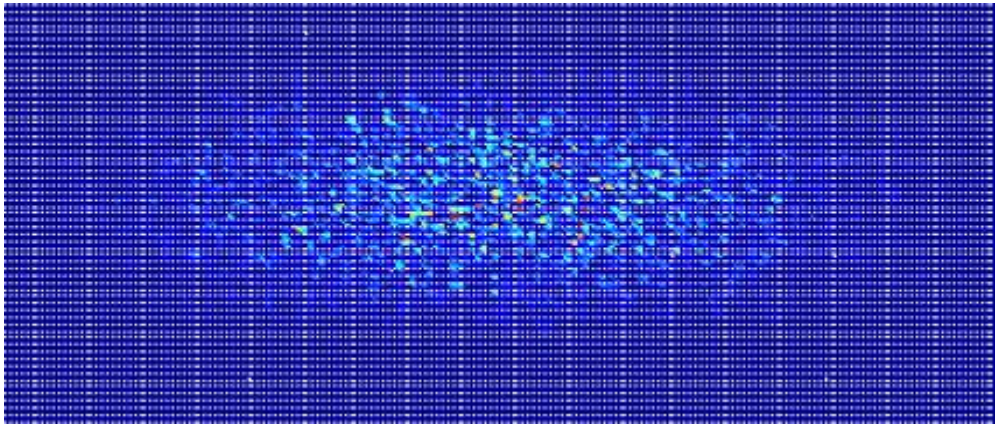


normal

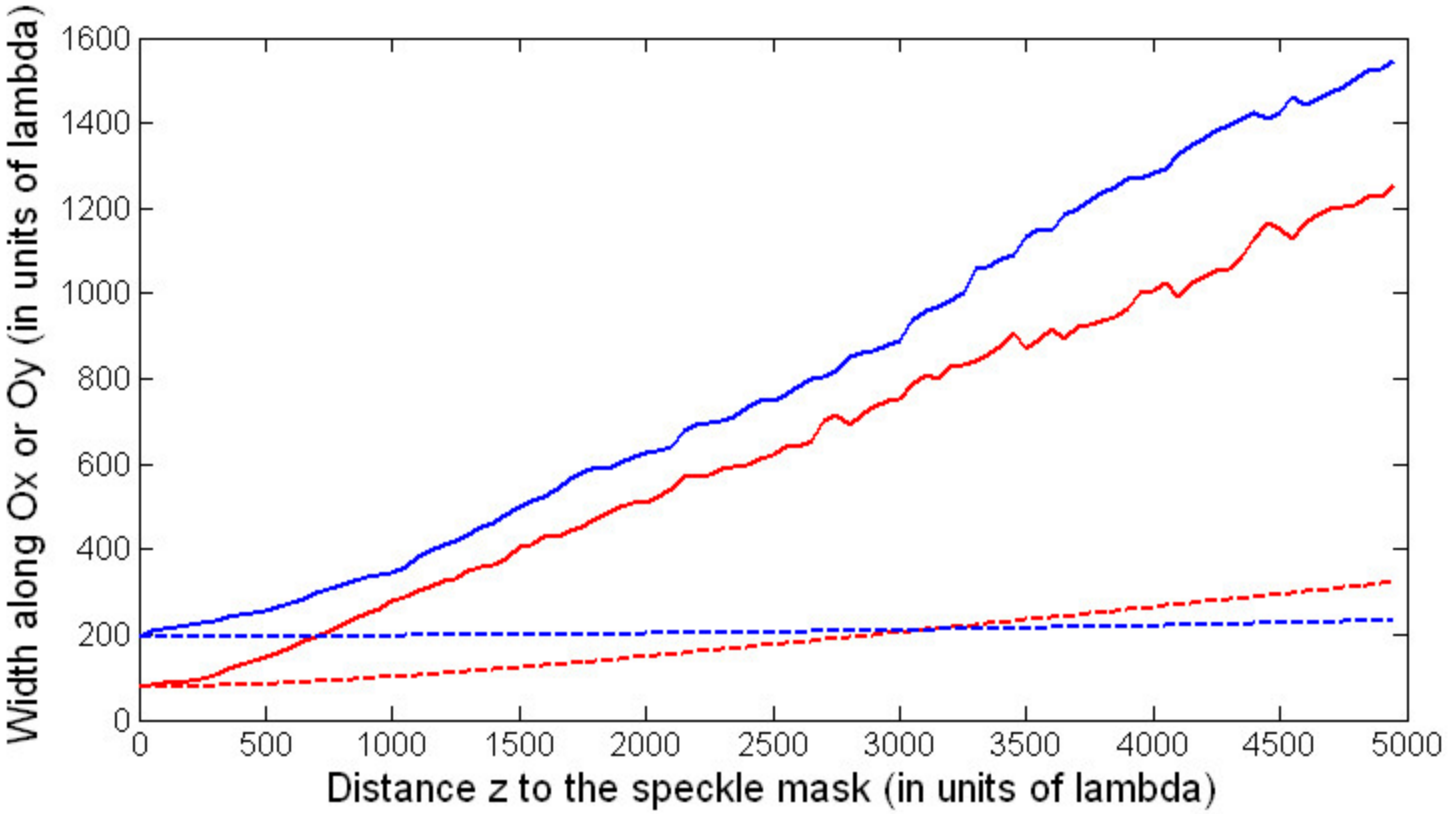


turbulent





Wx=20, Wy=50, L_corrx=L_corry=30

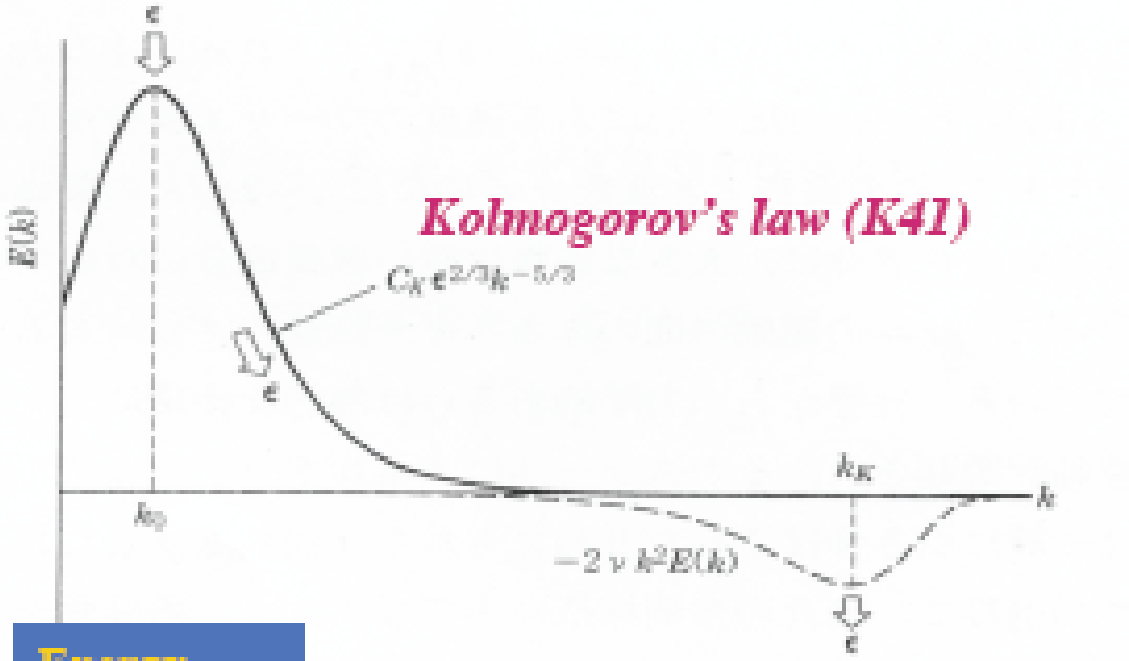


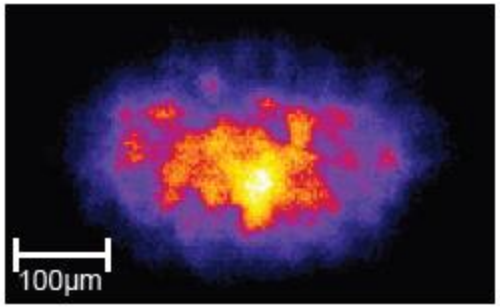
Similarities (Differences) to classical Turbulence - KOLMOGOROV

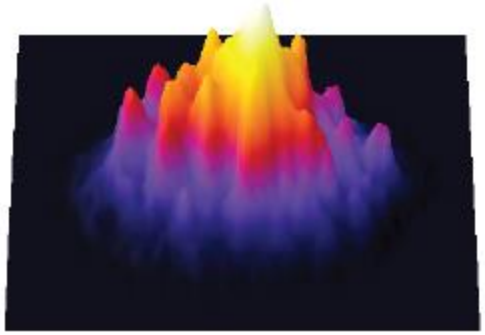
Energy spectrum of the velocity field

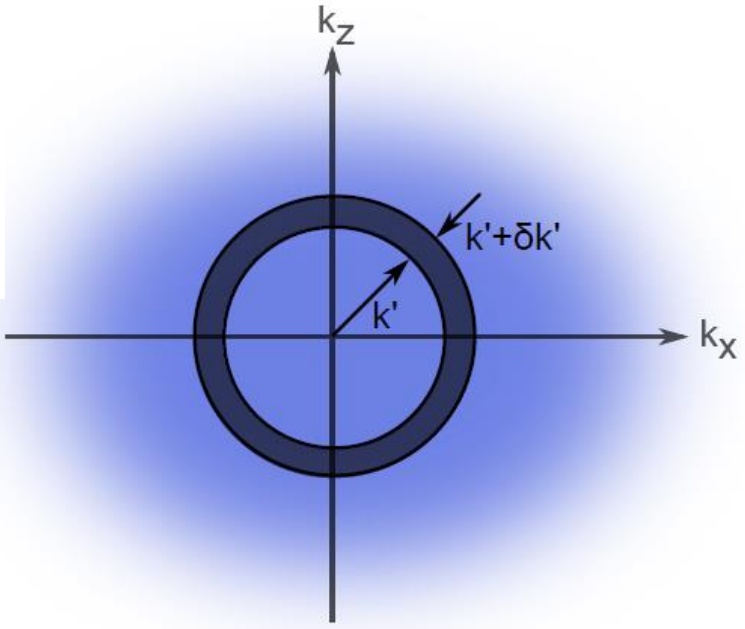
$$E = \frac{1}{2}\int \mathbf{v}^2 \, d\mathbf{r} = \int E(k)\,dk$$

$$E(k) = C\varepsilon^{2/3} k^{-5/3}$$









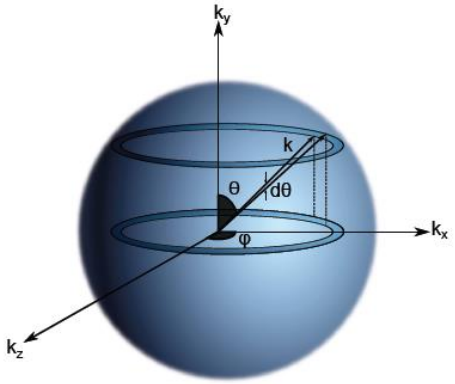
s BEC turbulento

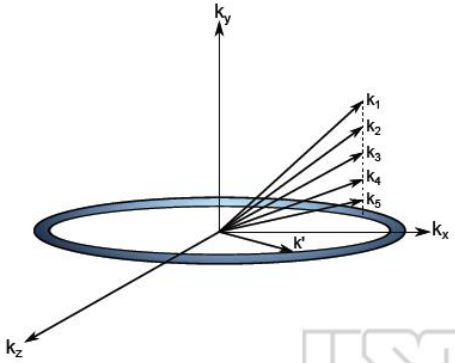
$$R_\rho(0) = 2,65\ \mu\text{m}$$

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

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

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





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

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

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

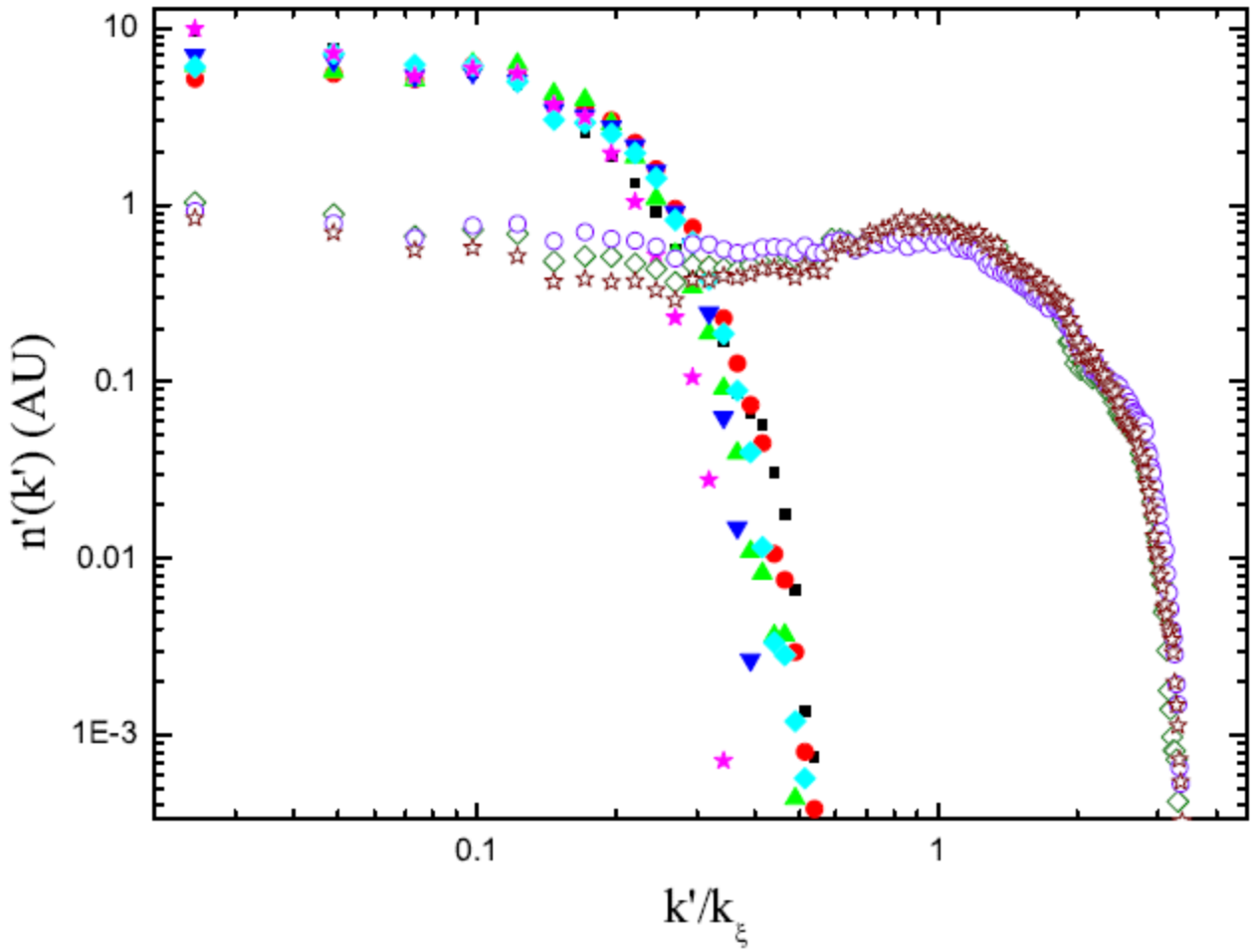
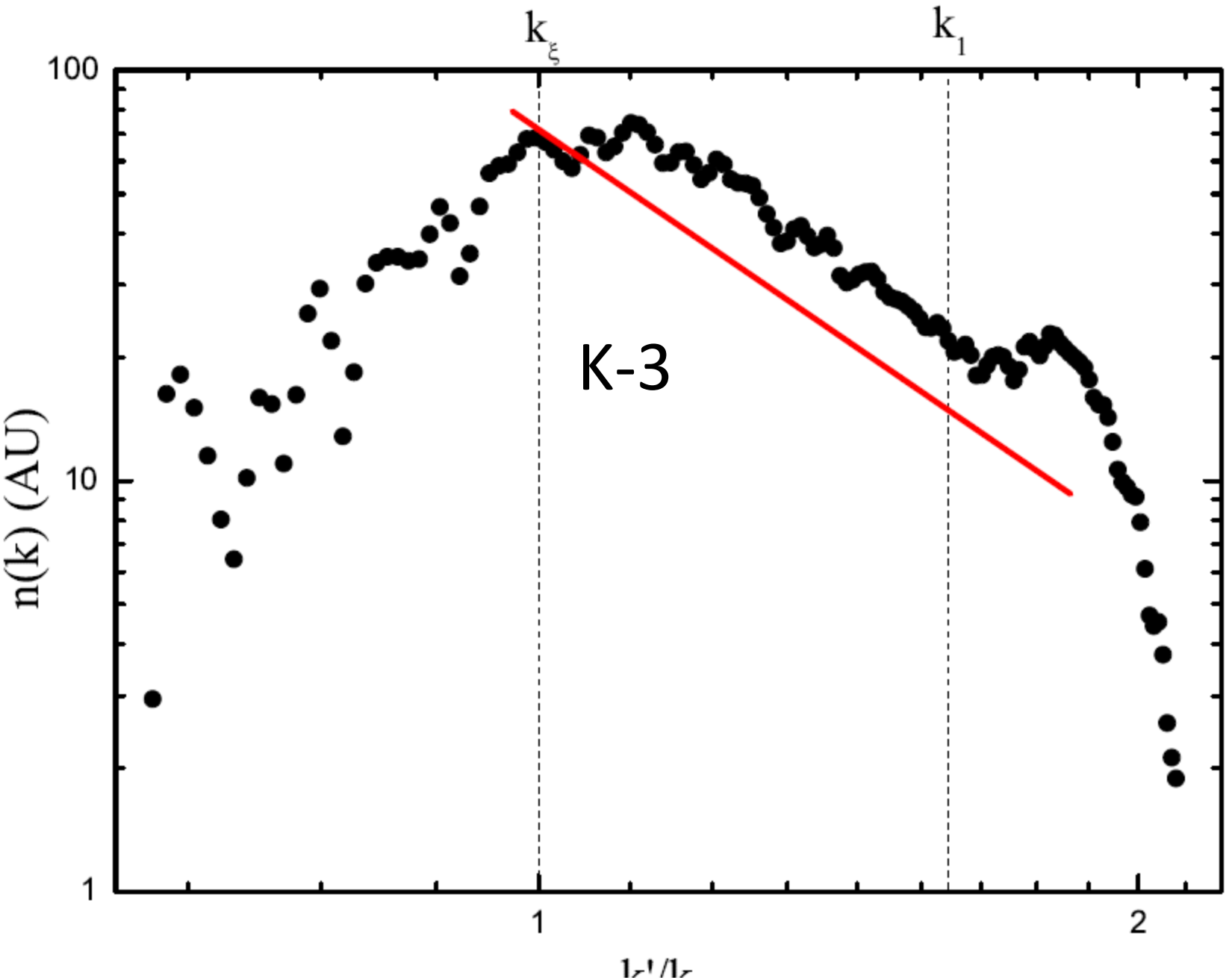
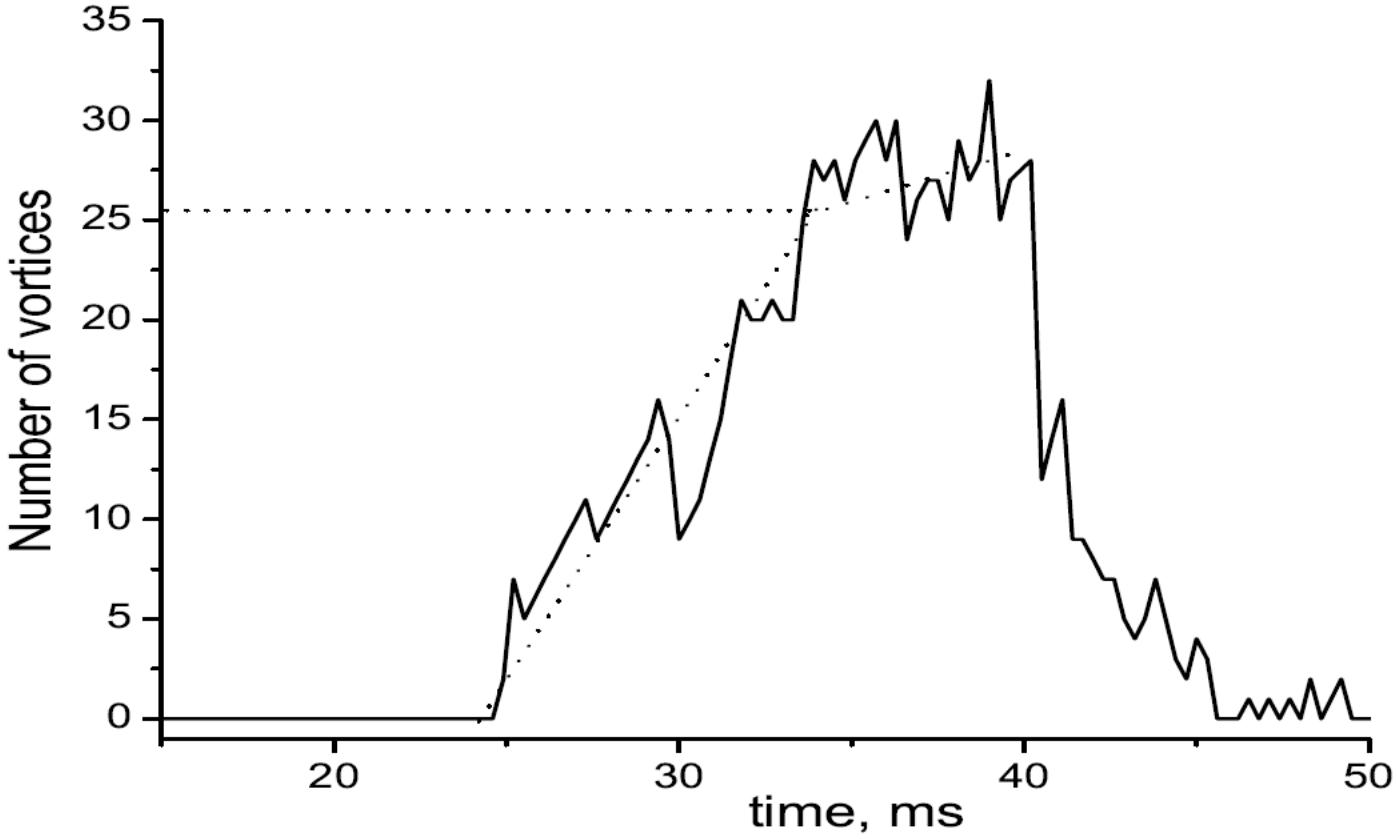
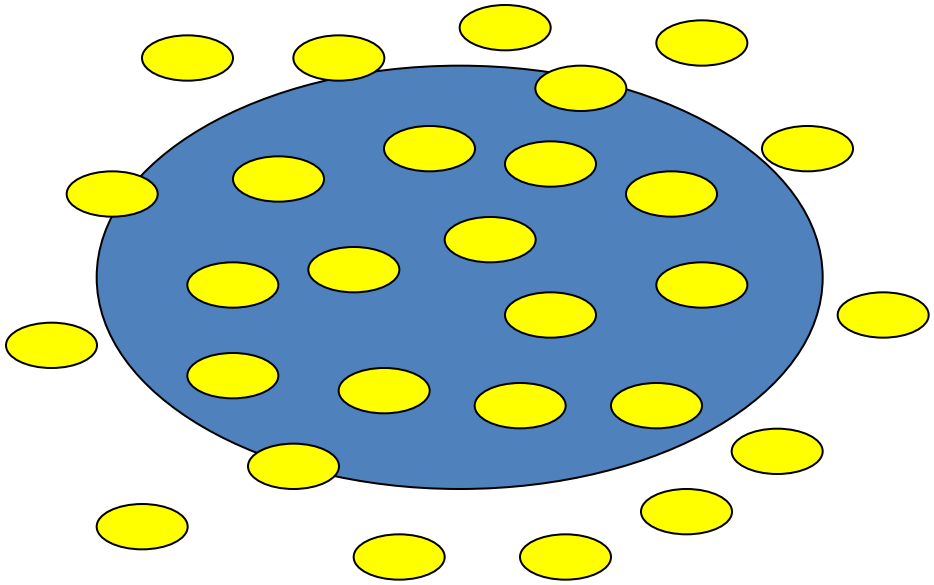


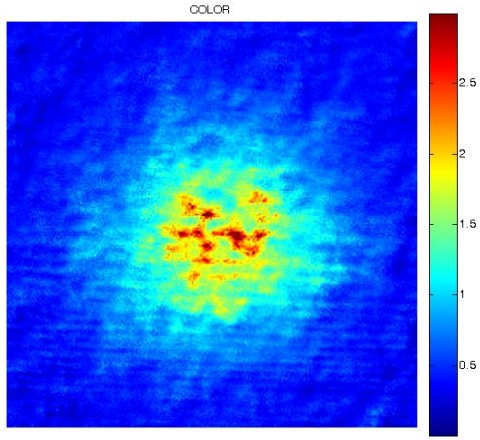
Figure 6: This figure shows the two dimensional projected momentum density, $n'(k')$, on a log-log plot. The Thomas-Fermi and condensates with a low number of vortices are shown in closed symbols. The ■, ●, ▲, ▼, ♦, and ★ symbols represent condensates with 0, 1, 2, 3, 4, and 5 vortices respectively and 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_ξ
k_1
100
10
1
n(k) (AU)
K-3
1
2

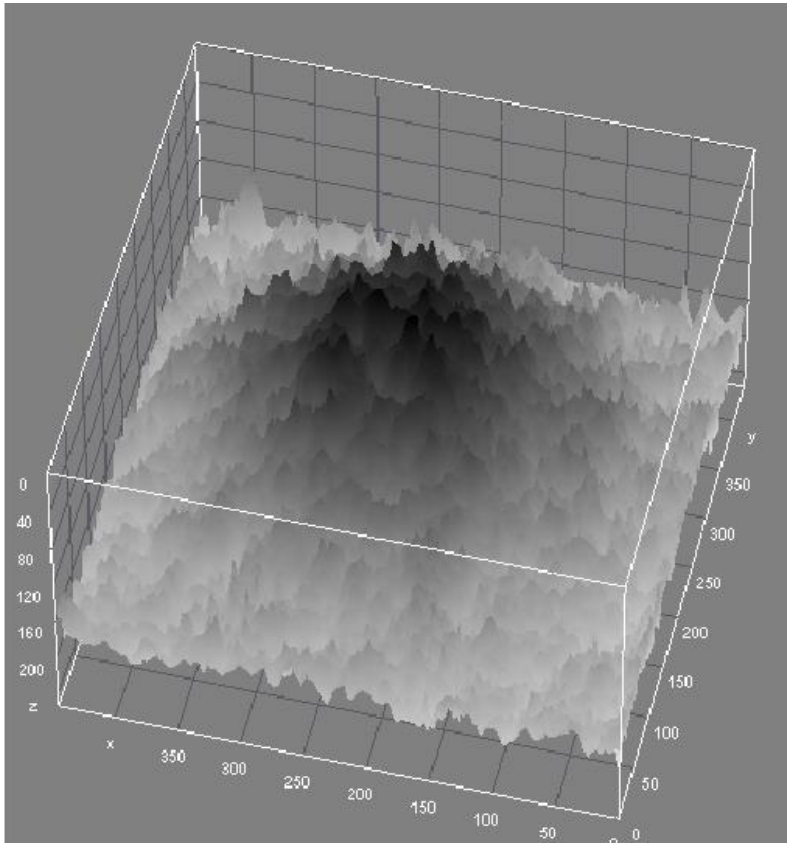

Number of vortices
35
30
25
20
15
10
5
0
20
30
40
50
time, ms

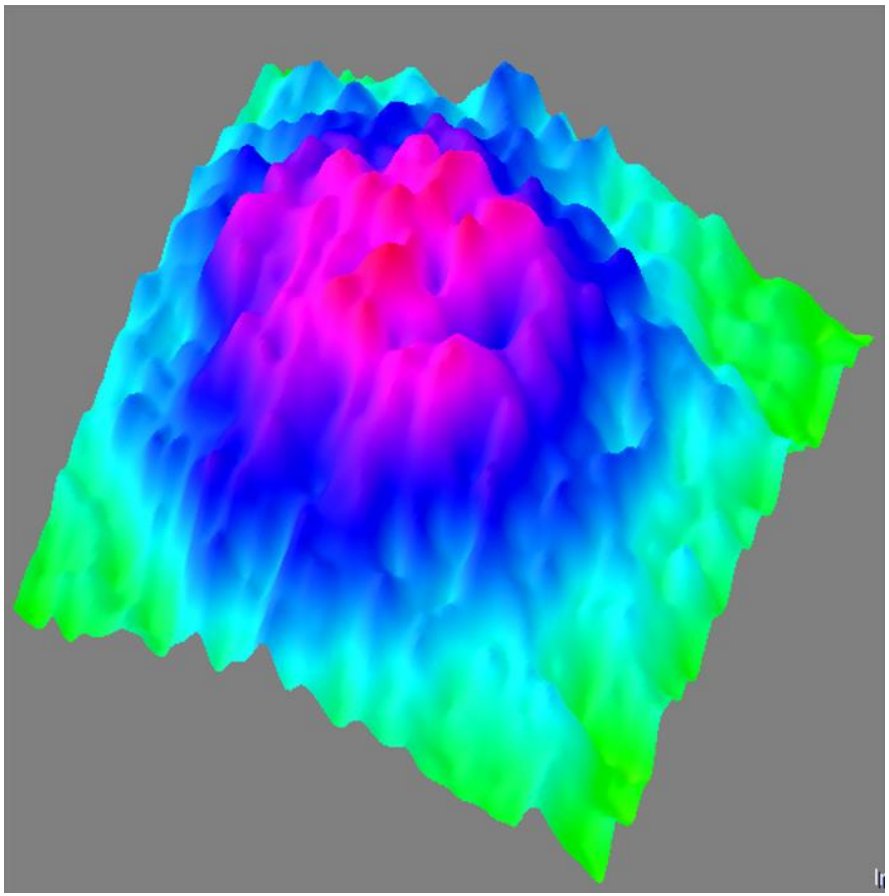
Granulation



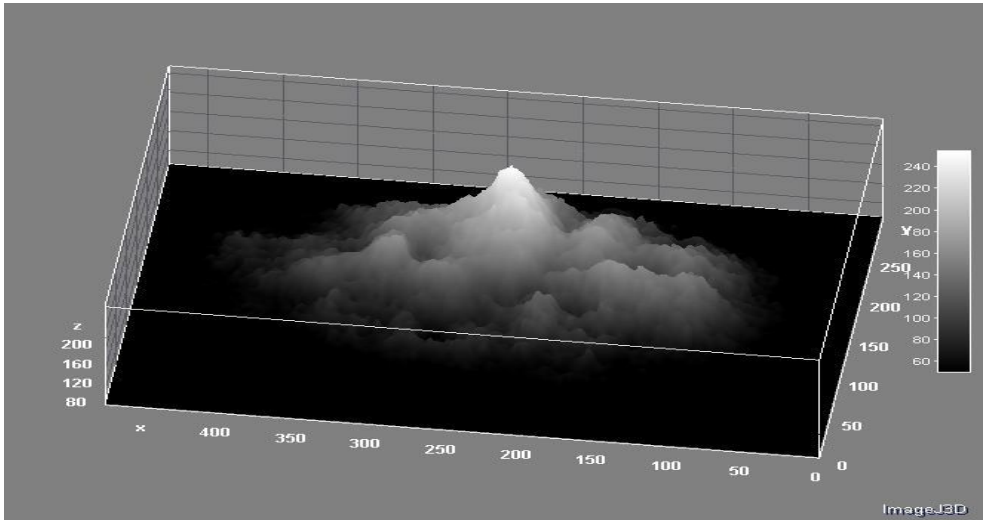


HIGH DENSITY FLUCTUATIONS



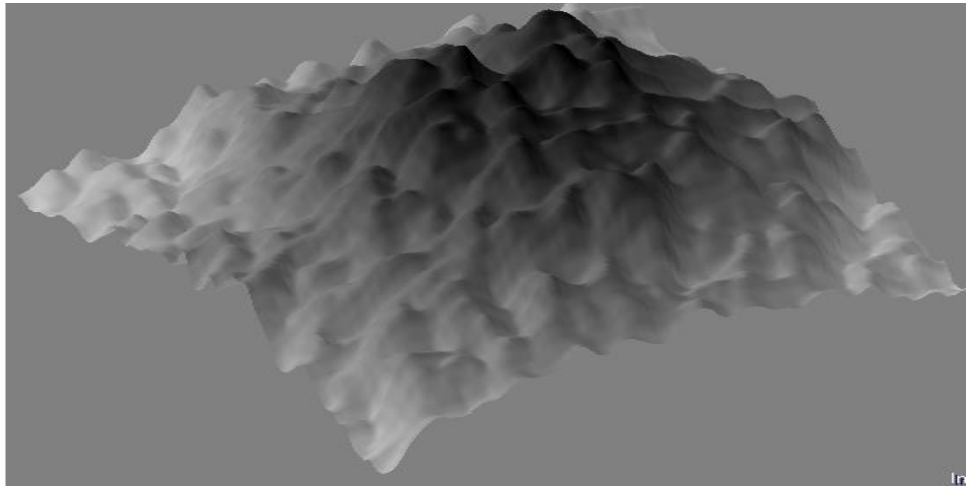


At the moment two possible routes to explain



Superfluid turbulent

External oscillatory field



Weak turbulent???????

Berloff &Svistunov – PRA (2002)

MODULATION OF SCATT. LENGTH

$$a(B) = a_{BC}\left(1 - \frac{\Delta}{B - B_\infty}\right);$$

$$\downarrow$$

$$B(t) = B_{av} + \delta B\cos(\Omega t),$$

$$\downarrow$$

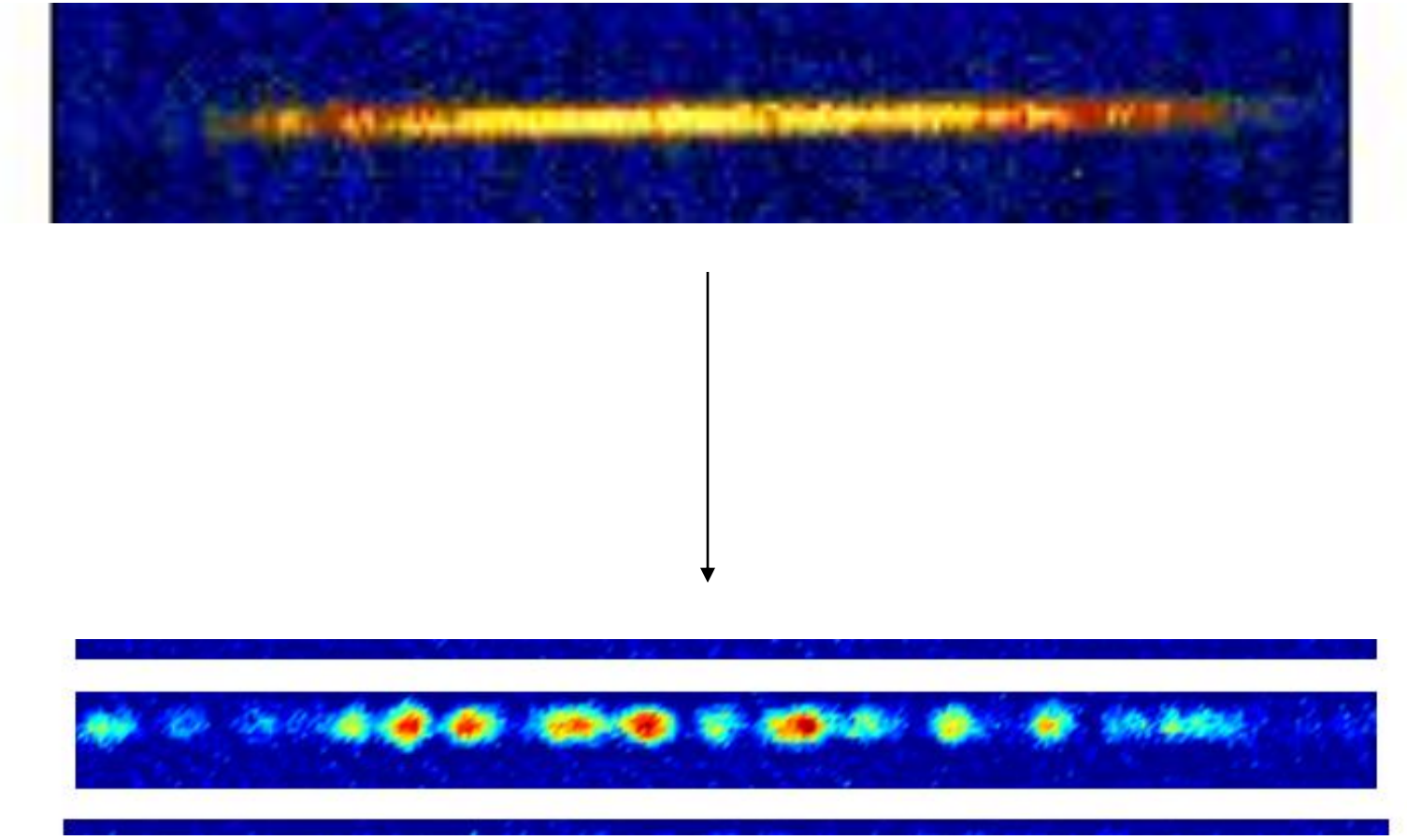
$$a(t) \simeq a_{av} + \delta a\cos(\Omega t),$$

granulation in another context

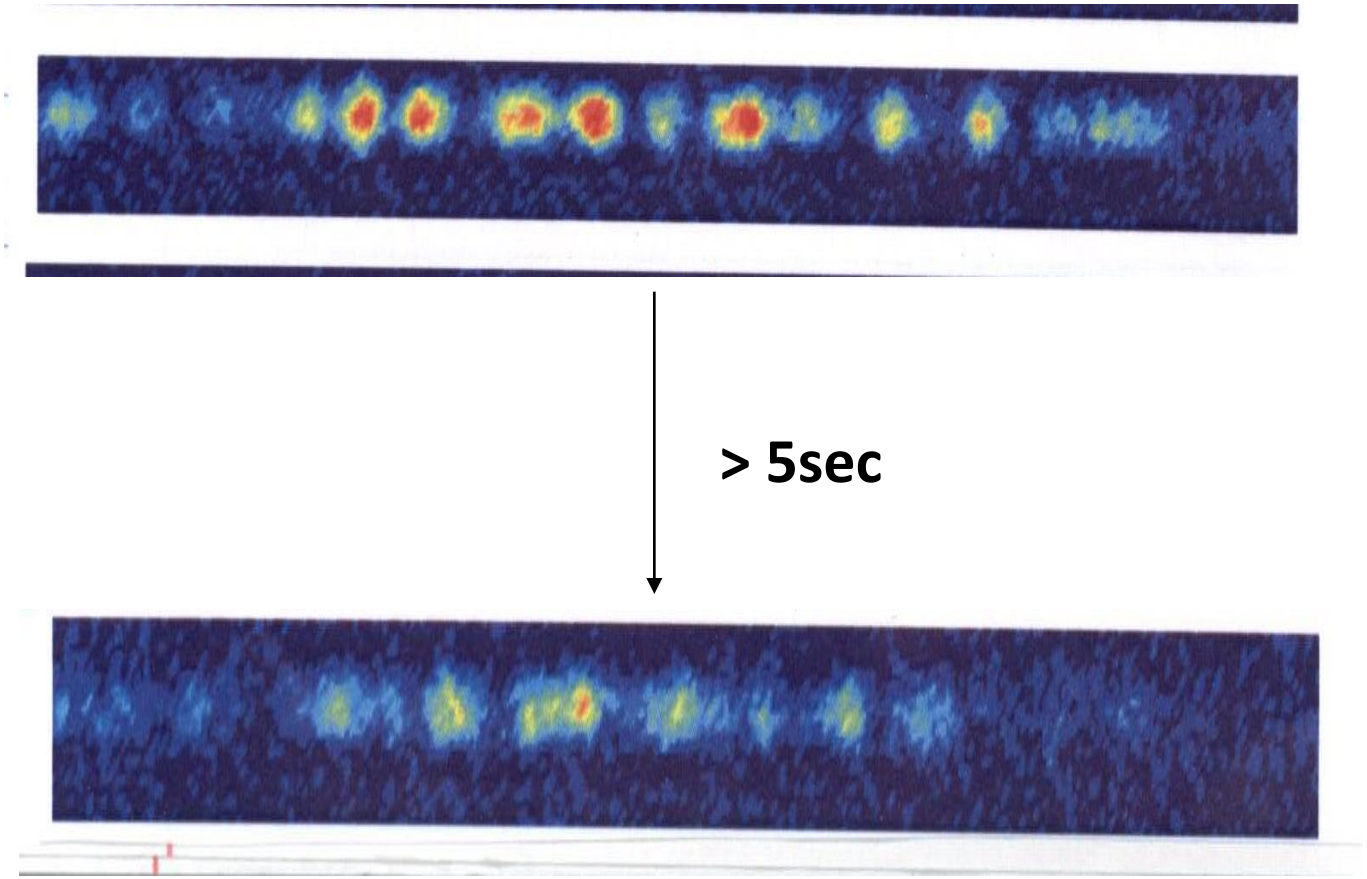
Collaboration with Hulet´s group

E. R. F. Ramos, F. E. A. Santos, M. A. Caracanhas, V. S. Bagnato - *Coupling collective modes in a*

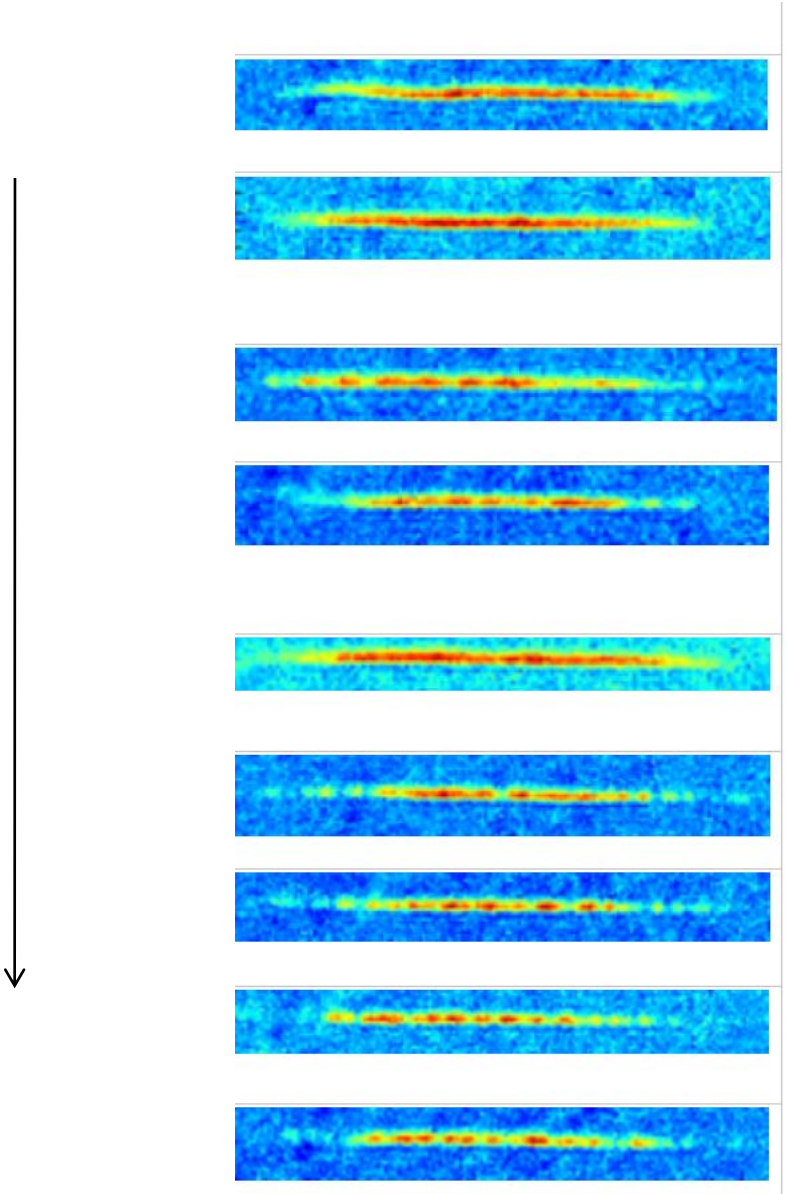
- Higher amplitudes take to “granulation”

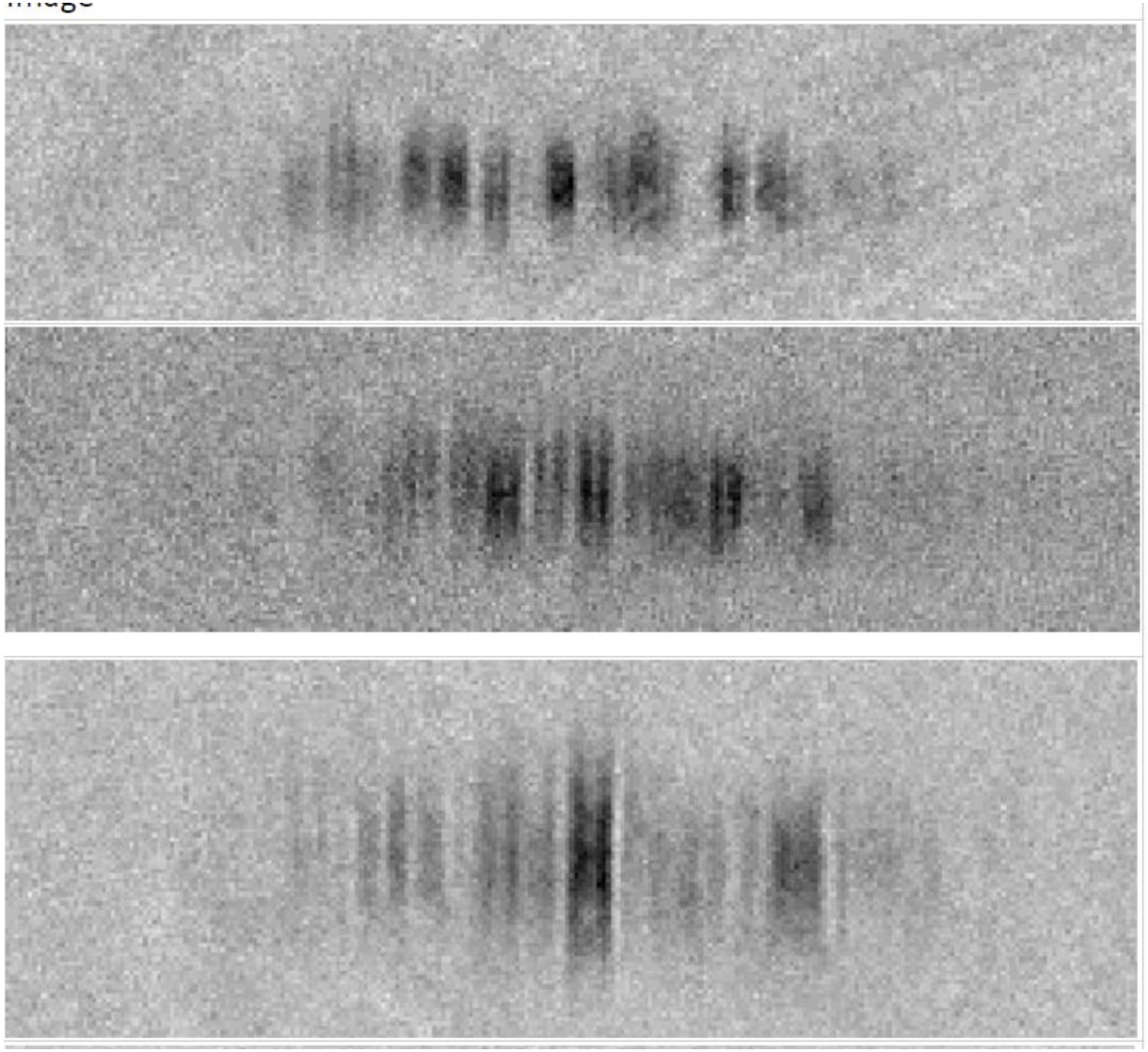


Long living after excitation!!!!



Time of excitation





Physics Letters A 379 (2015) 1366–1371

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Realization of inverse Kibble–Zurek scenario with trapped Bose gases

V.I. Yukalov [a,b,*], A.N. Novikov [a,b], V.S. Bagnato [a]

[a] Instituto de Fisica de São Carlos, Universidade de São Paulo, CP 369, 13560-970 São Carlos, São Paulo, Brazil
[b] Bogolubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia

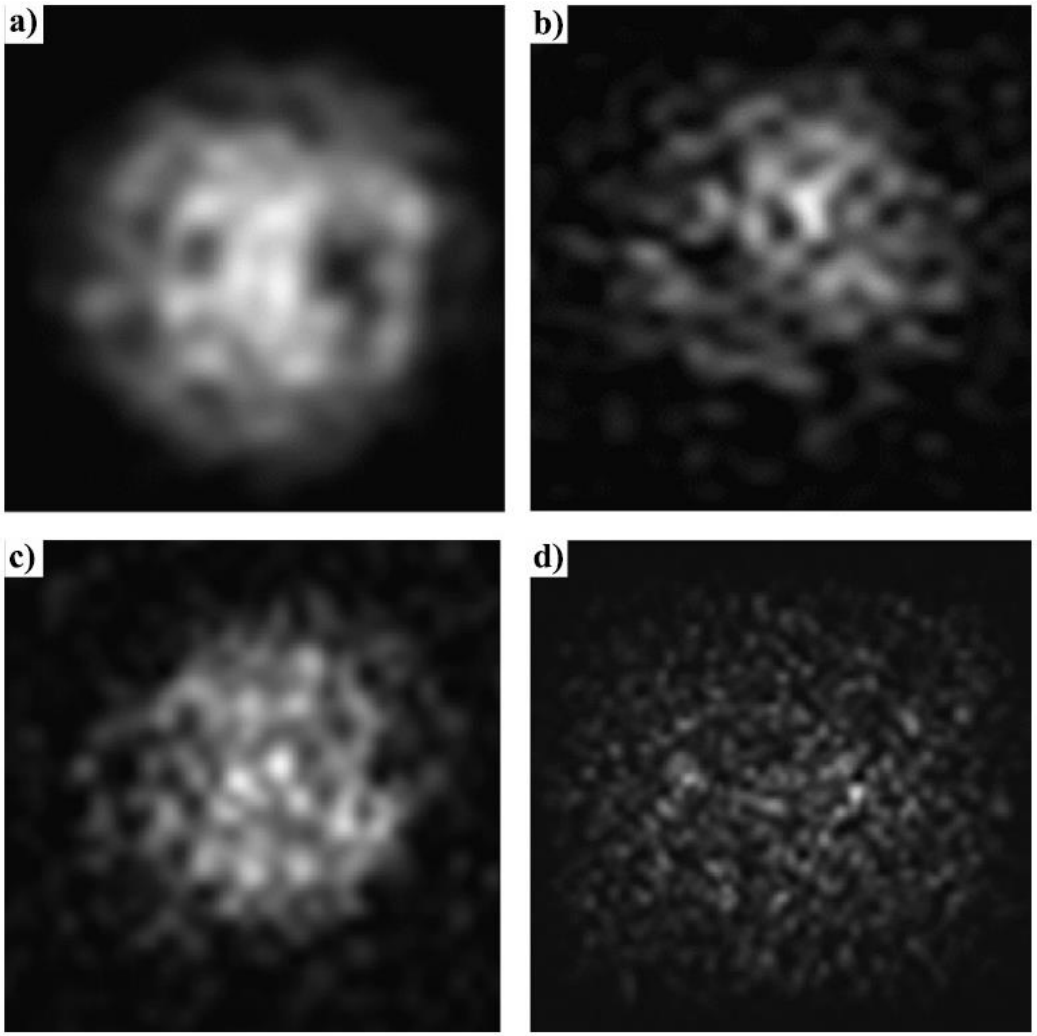
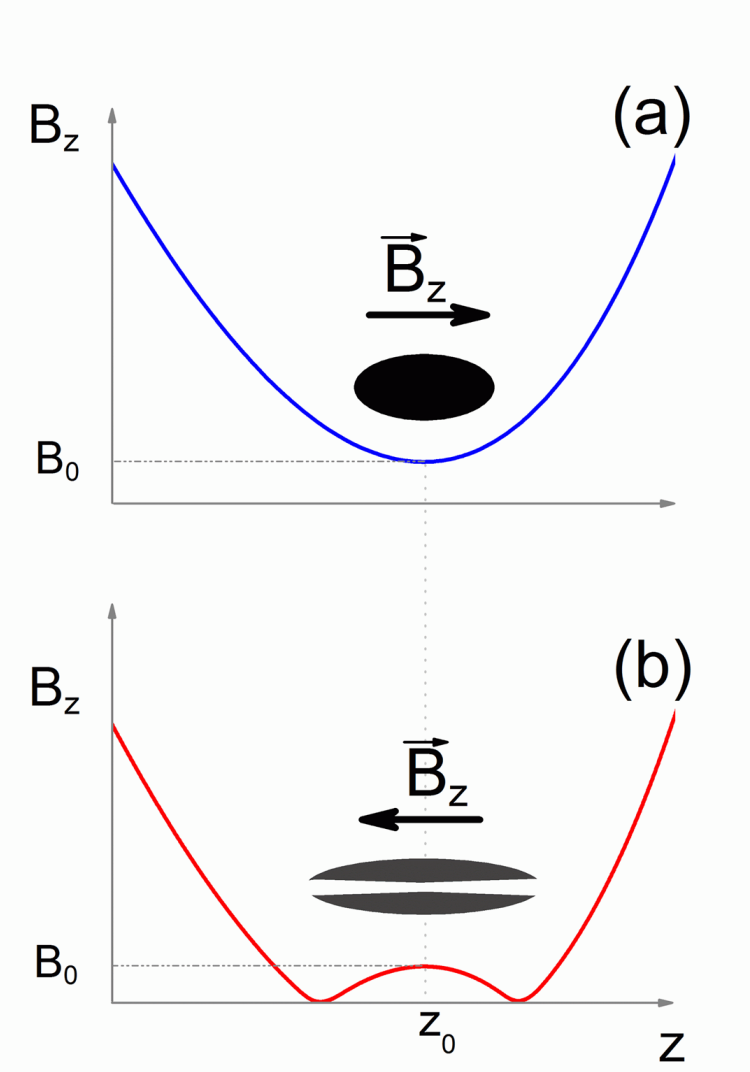


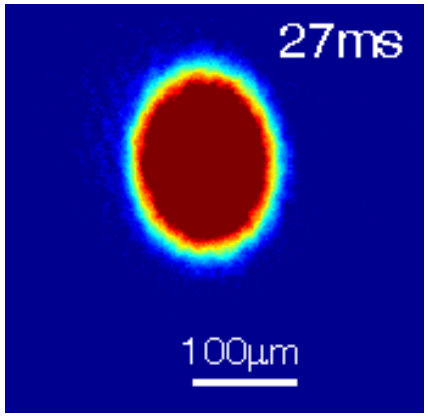
Fig. 3. The sequence of nonequilibrium states realized in numerical modeling: (a) vortex state, (b) vortex turbulence, (c) grain turbulence, (d) wave turbulence. The density cross-sections are demonstrated. Brighter color corresponds to higher density.

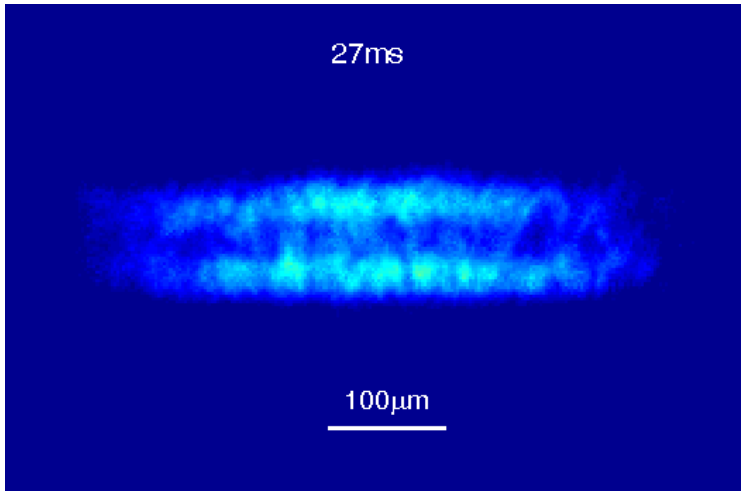
Multi-charged vortex using (magnetic) topological phase imprinting in São Carlos

BEC 1 laboratory, CePOF - USP, 2015

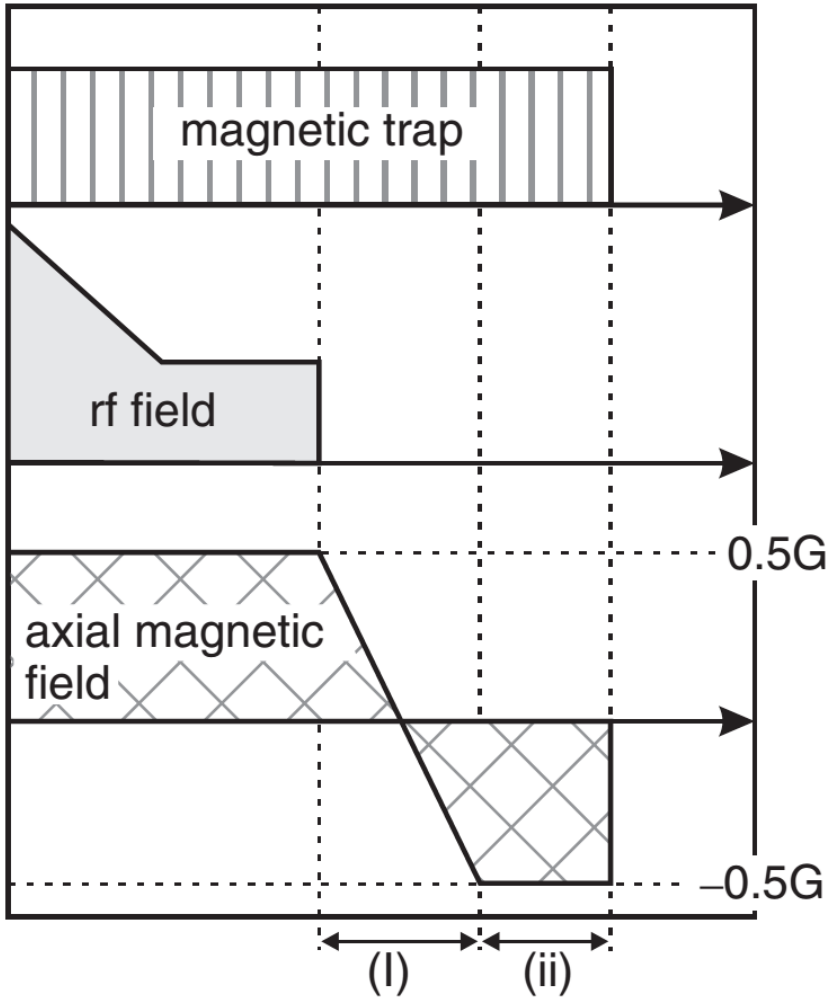
Previously (Aug-Sep 2014)

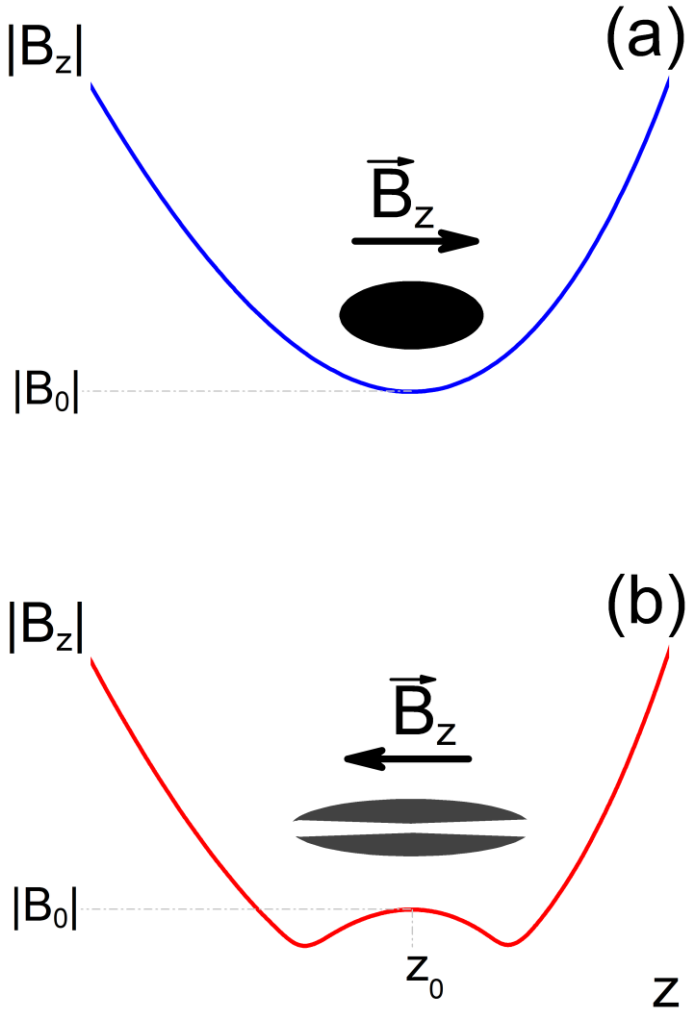




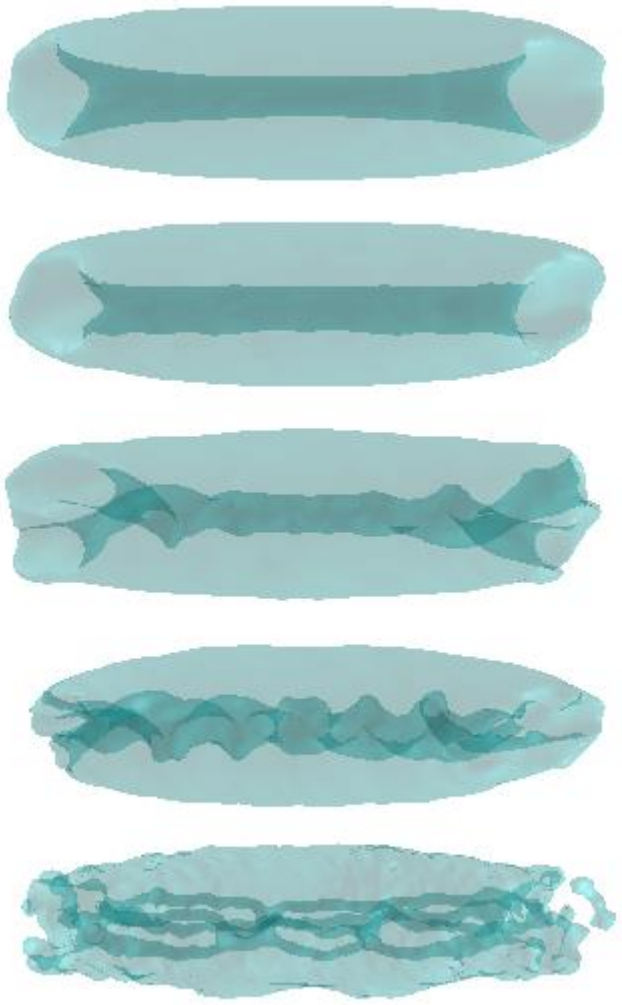


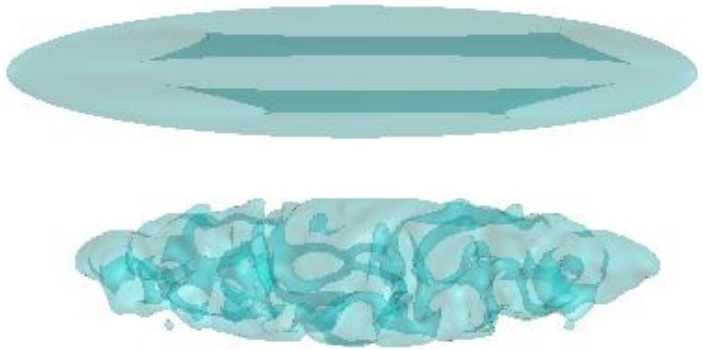
Multicharged vortex: bias inversion





Collaboration: Newcastle & São Carlos

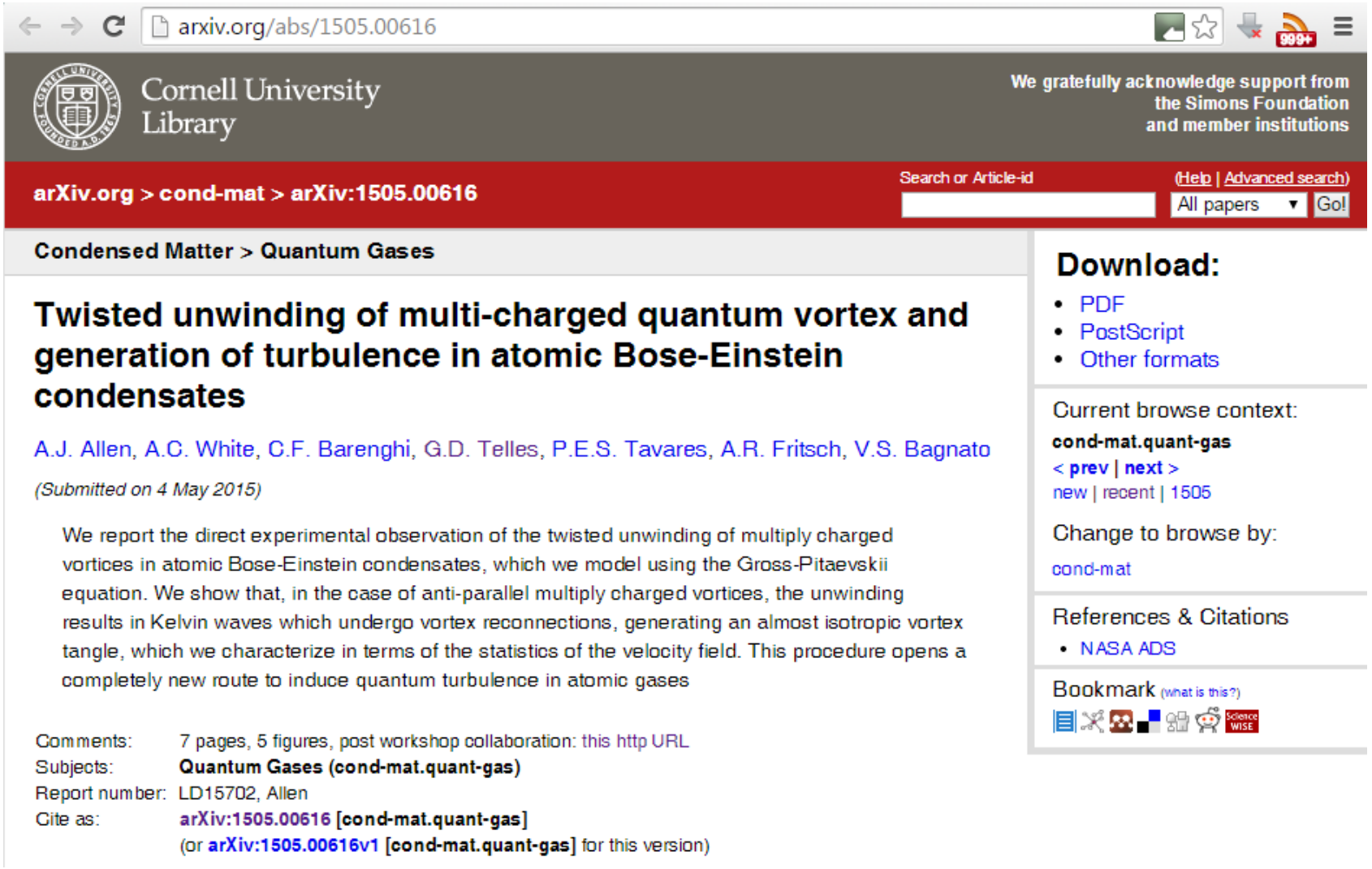




Twisted Unwinding…: PRL submmitted

arXiv:1505.00616

ArXiv version available



arxiv.org/abs/1505.00616

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We gratefully acknowledge support from the Simons Foundation and member institutions

arXiv.org > cond-mat > arXiv:1505.00616

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Condensed Matter > Quantum Gases

Twisted unwinding of multi-charged quantum vortex and generation of turbulence in atomic Bose-Einstein condensates

A.J. Allen, A.C. White, C.F. Barenghi, G.D. Telles, P.E.S. Tavares, A.R. Fritsch, V.S. Bagnato

(Submitted on 4 May 2015)

We report the direct experimental observation of the twisted unwinding of multiply charged vortices in atomic Bose-Einstein condensates, which we model using the Gross-Pitaevskii equation. We show that, in the case of anti-parallel multiply charged vortices, the unwinding results in Kelvin waves which undergo vortex reconnections, generating an almost isotropic vortex tangle, which we characterize in terms of the statistics of the velocity field. This procedure opens a completely new route to induce quantum turbulence in atomic gases

Comments: 7 pages, 5 figures, post workshop collaboration: this http URL
Subjects: **Quantum Gases (cond-mat.quant-gas)**
Report number: LD15702, Allen
Cite as: **arXiv:1505.00616 [cond-mat.quant-gas]**
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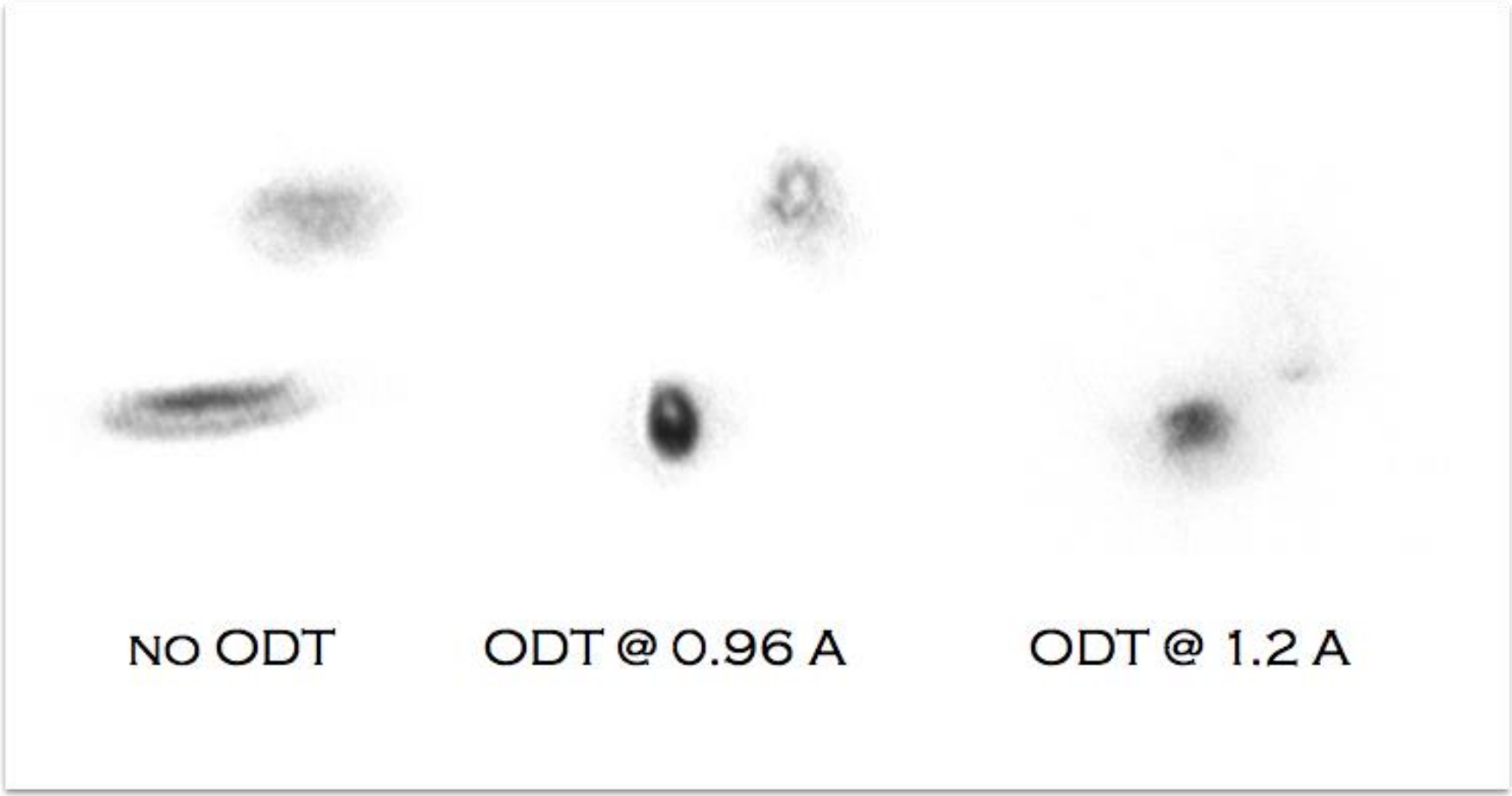
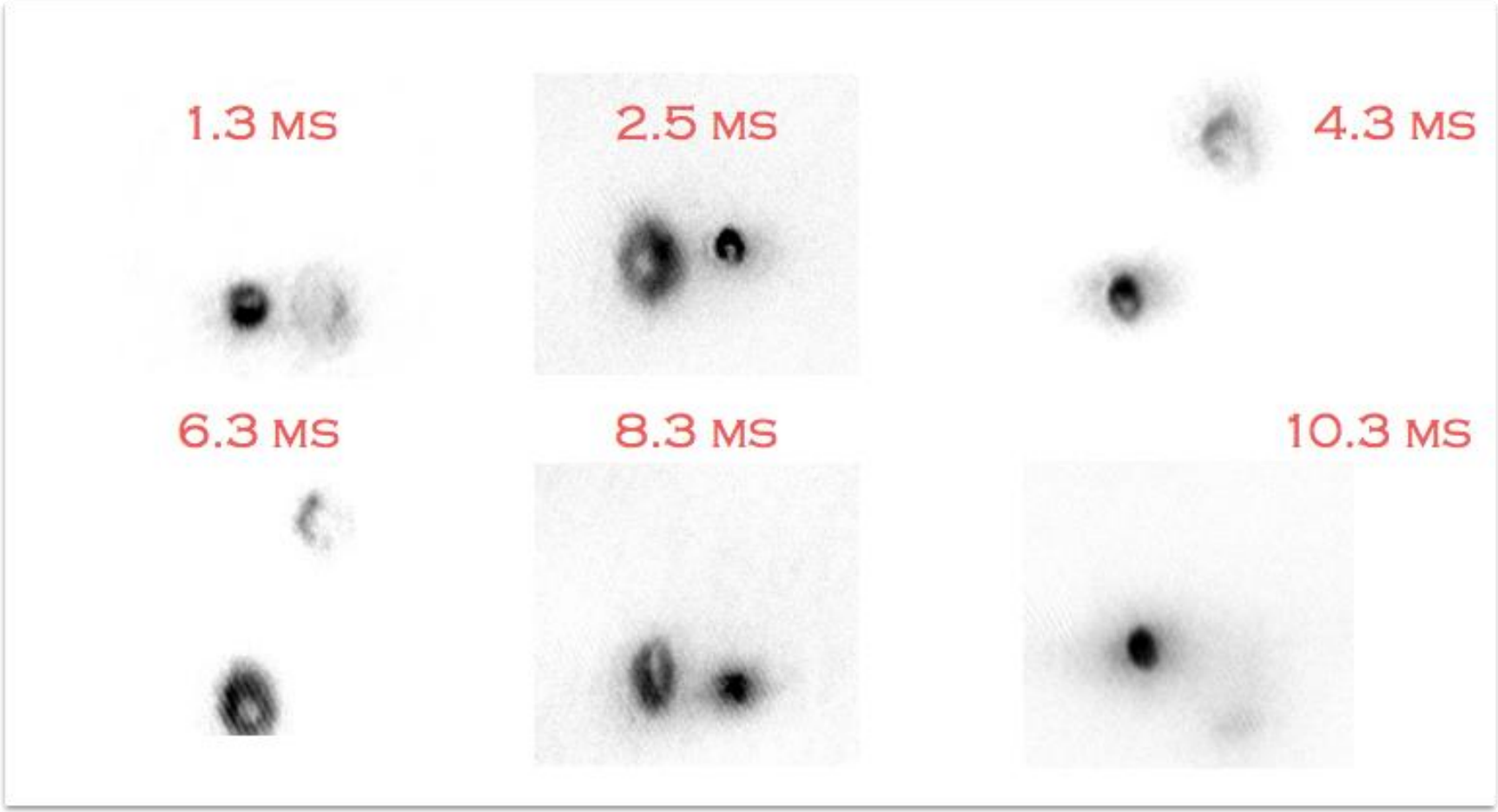
New data! (May 2015)



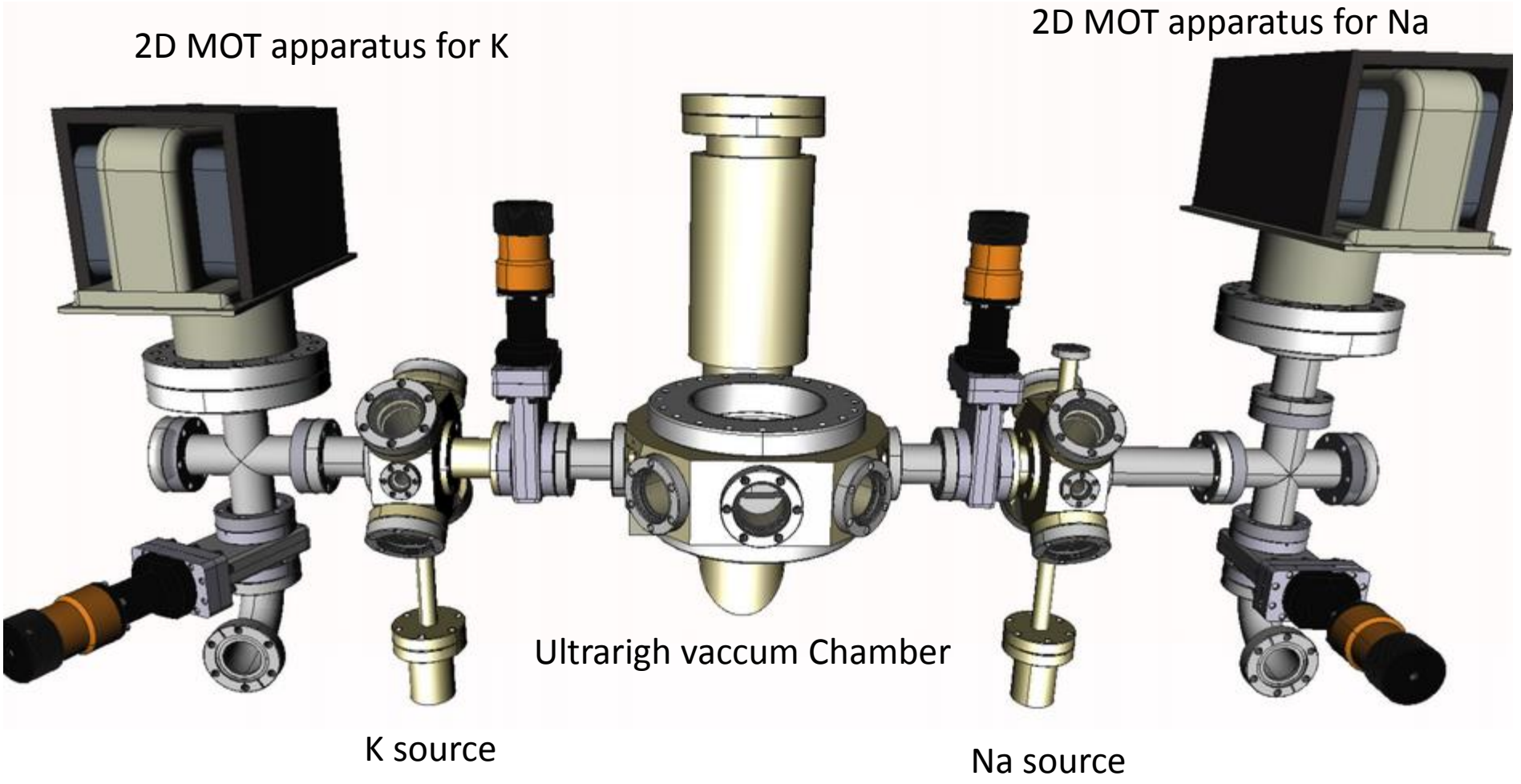
Vortex line 90º flips when the trap is compressed in the axial (weak) direction, at fixed hold time (May/2015)

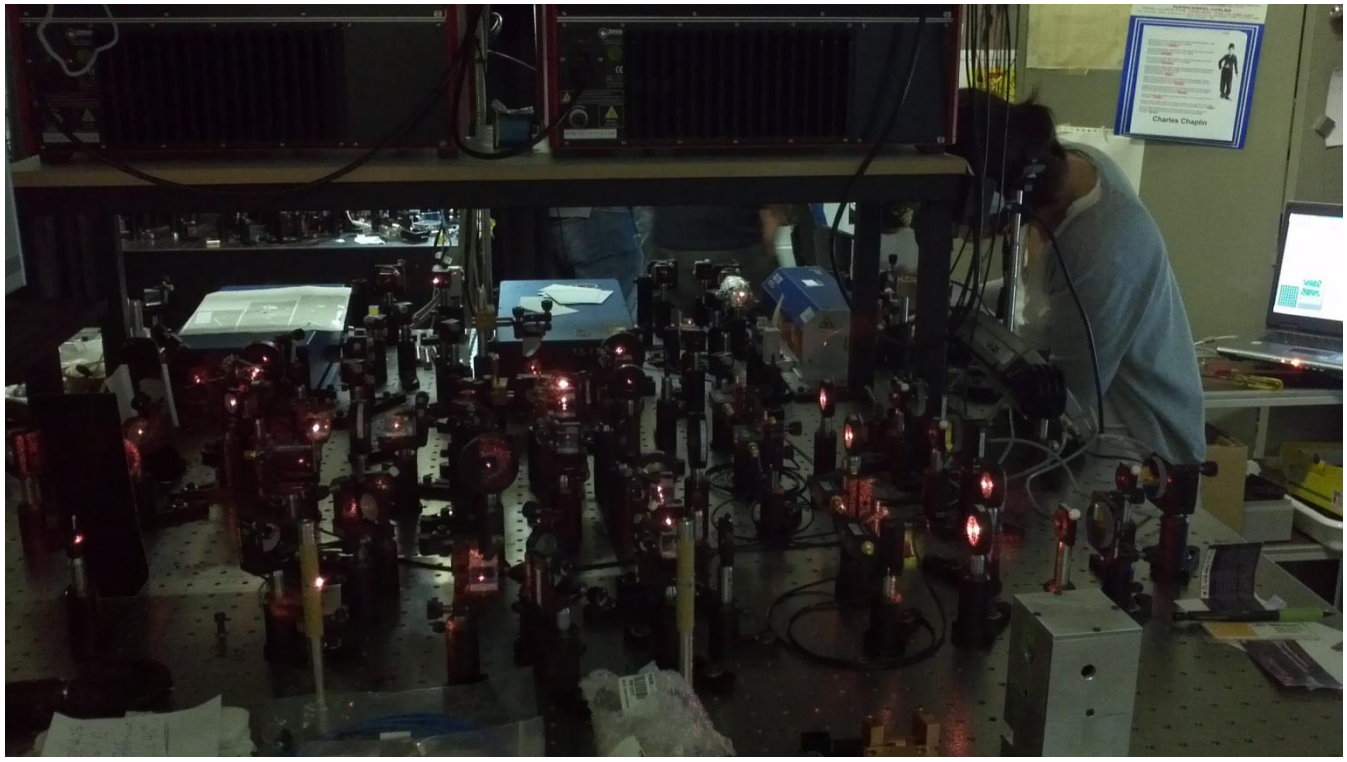
Dynamics in a compressed trap

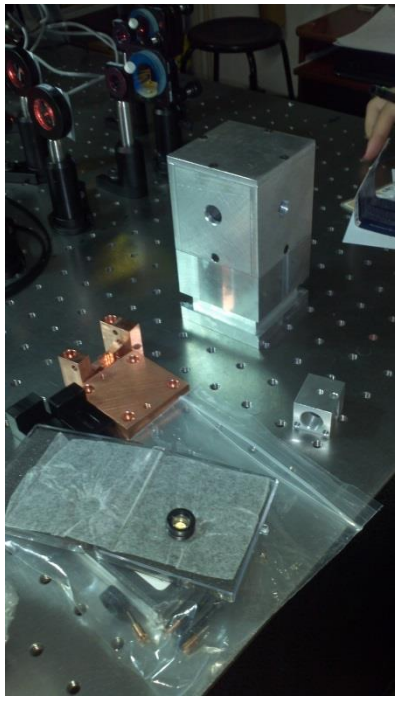


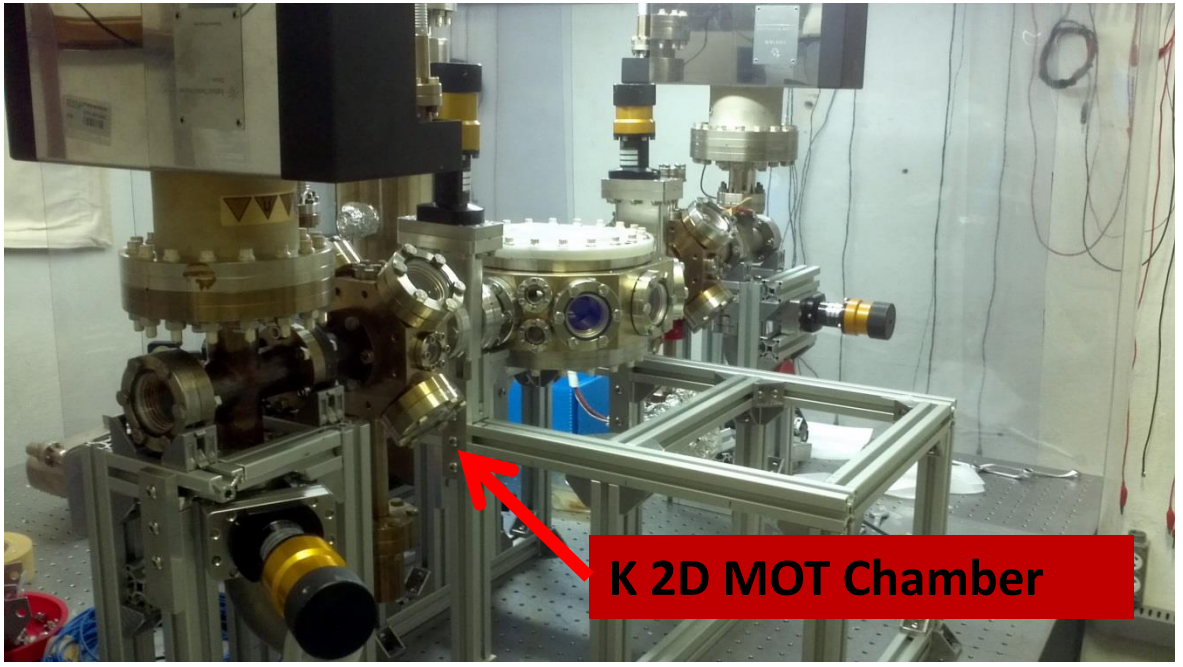
Vortex dynamical evolution at average compressed hybrid trap (ODT@ 0.96A) versus the hold time (May/2015)

Vacuum System




Charles Chaplin




K 2D MOT Chamber

Updated experimental setup