Momentum Occupations of a Quenched Bose Gas

I-Kang Liu (Gary)

PI: Prof. Shih-Chuan Gou

Department of Physics and Institute of Photonics, National Changhua University of Education, Taiwan

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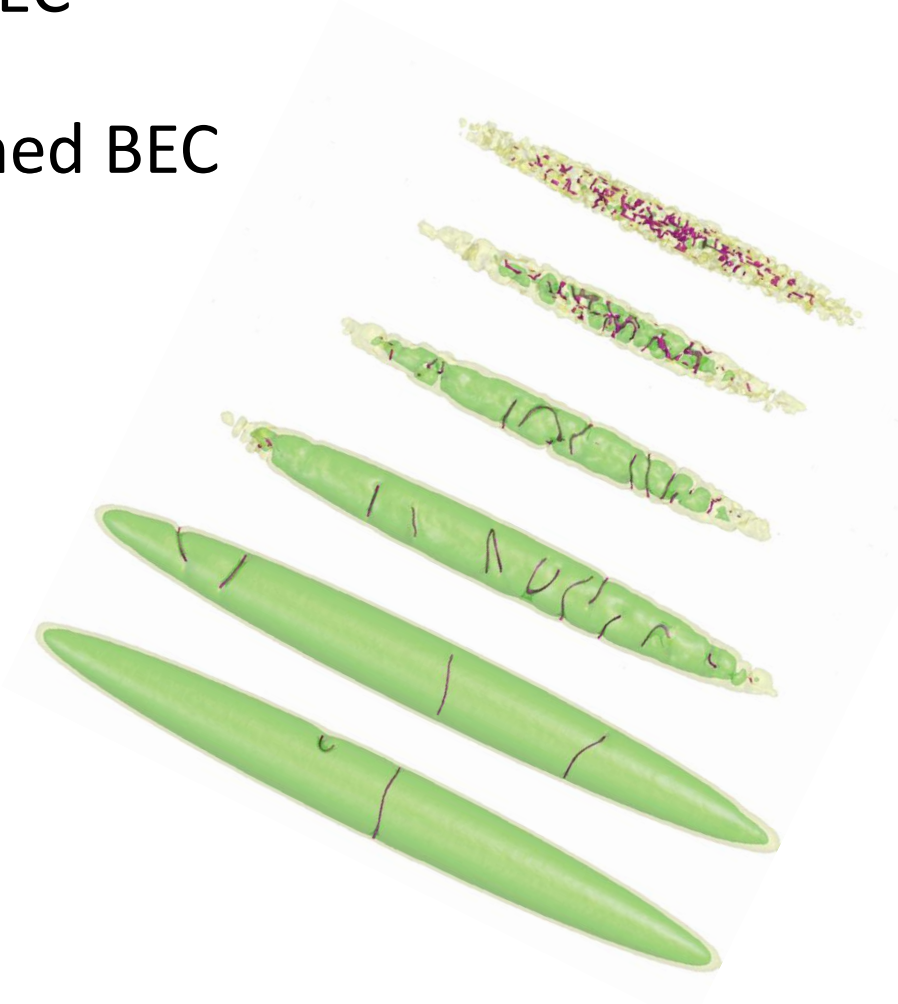
Outline

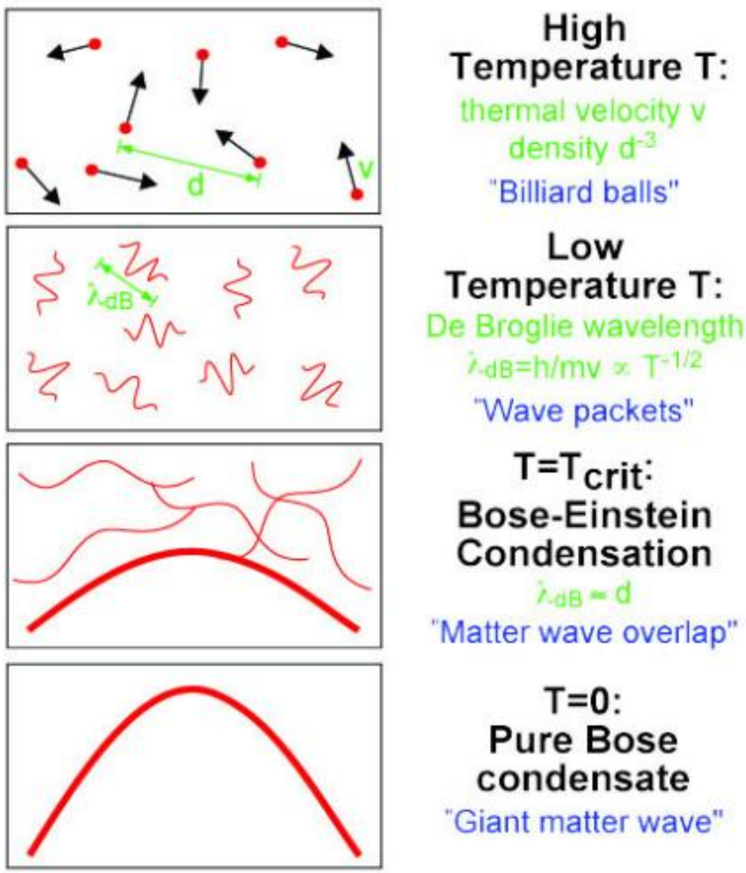
- Introduction and Motivation
- Momentum Occupations of BEC
- Preliminary Results in Quenched BEC
- Remarks



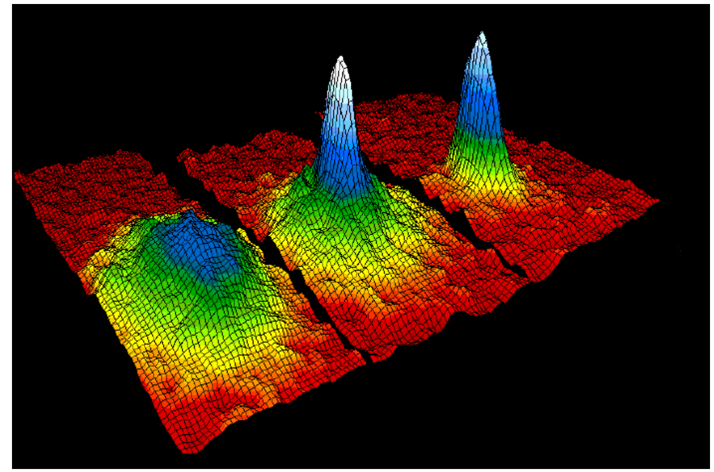
Introduction and Motivation

- **Macroscopic Quantum Matter Wave**

Bose-Einstein condensation

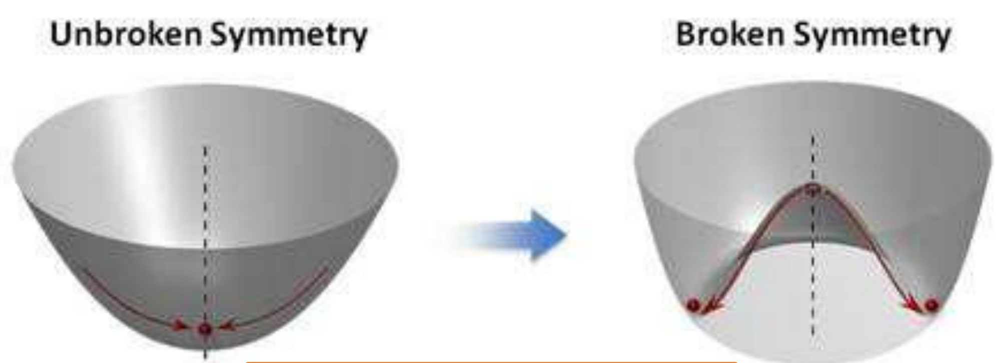


$$T_{\rm crit} \propto N_{tot}^{1/Q}$$



Gross-Pitaevksii equation (GPE)

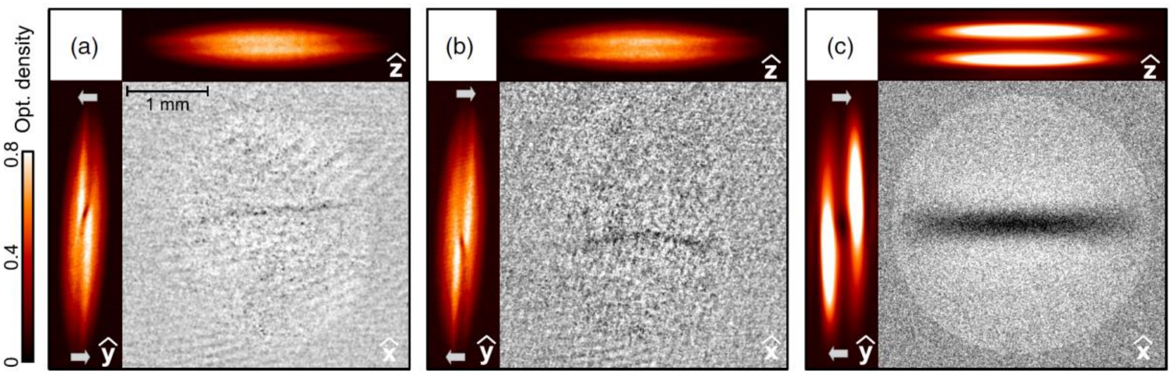
$$i\hbar\frac{\partial}{\partial t}\psi(\mathbf{r}) = \left[-\frac{\hbar^2\nabla^2}{2M} + V(\mathbf{r}) + g|\psi(\mathbf{r})|^2 - \mu\right]\psi(\mathbf{r}),$$

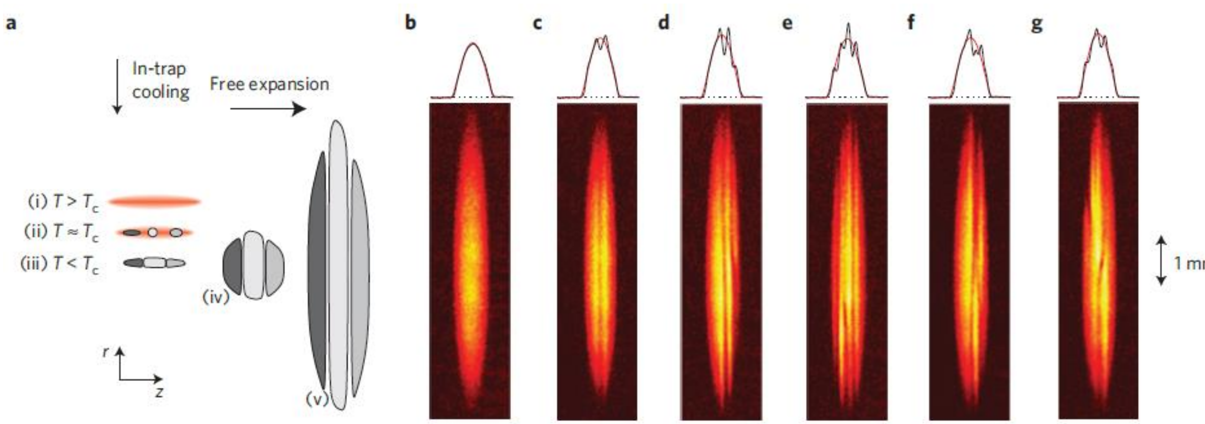


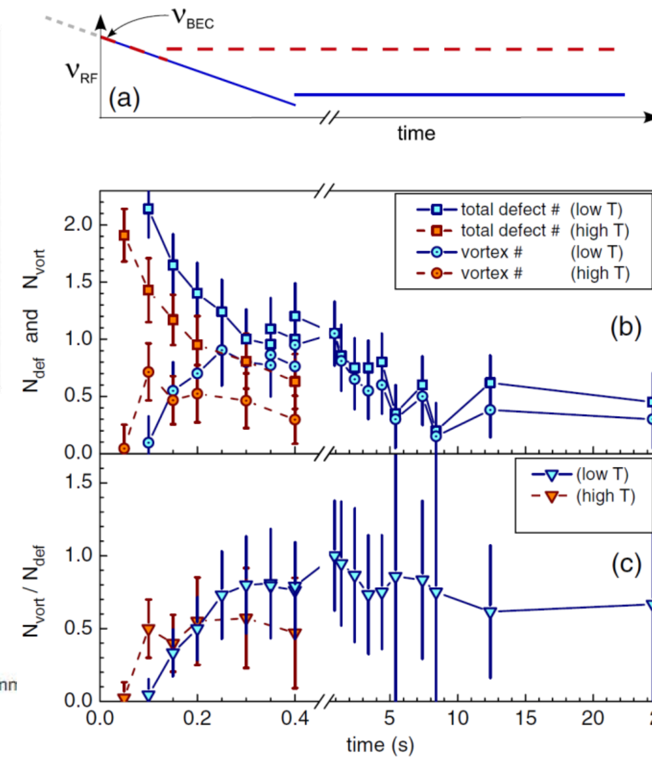
Breaks U(1) Symmetry

Introduction and Motivation

Kibble-Zurek Mechanism: Recent Experiments in Trento

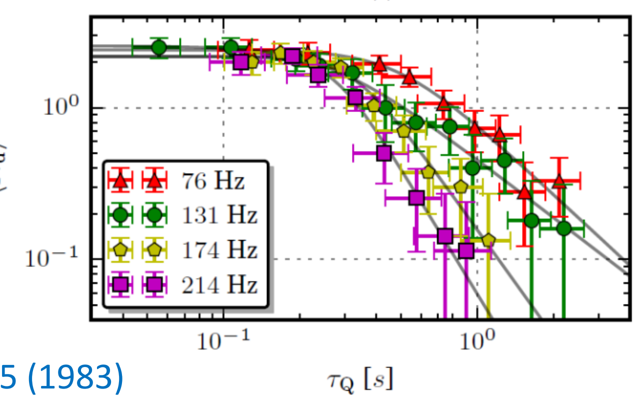






G. Lamporesi et al., Nat. Phys. 9, 656–660 (2013)
S. Donadello et al., PRL 113, 065302 (2014)
S. Donadello et al., Phys. Rev. A 94, 023628 (2016)

$$n_D \sim \xi^d/\xi^s\Big|_{t=-\hat{t}} \propto \tau_Q^{-\alpha}$$

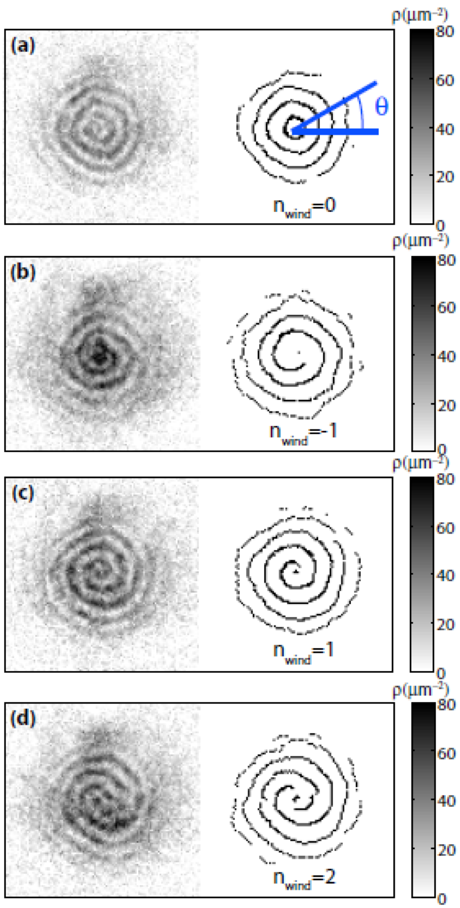


W. Zurek, Nature 317, 505 (1983)

Introduction and Motivation

Kibble-Zurek Mechanism

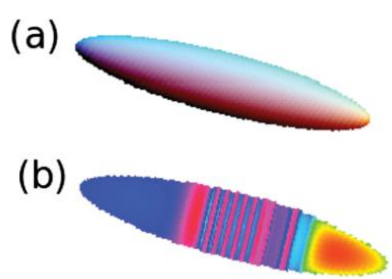
Winding Number in a Ring Trap



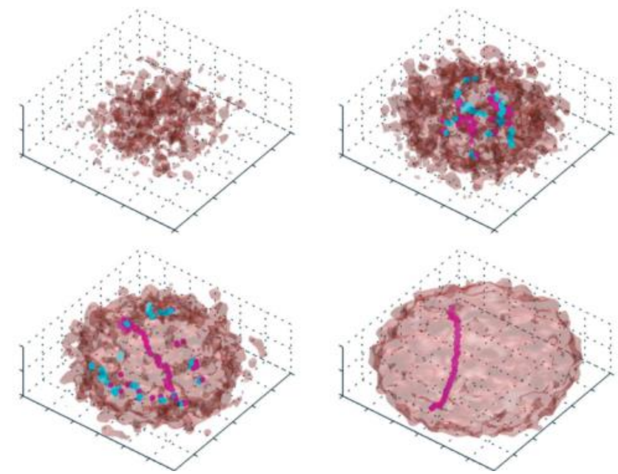
L. Corman et al.,
PRL 113, 135302 (2014)

Soliton formation:

W. H. Zurek
PRL. **102**, 105702 (2009)
B. Damski and W. H. Zurek
PRAL. **104**, 160404 (2010)

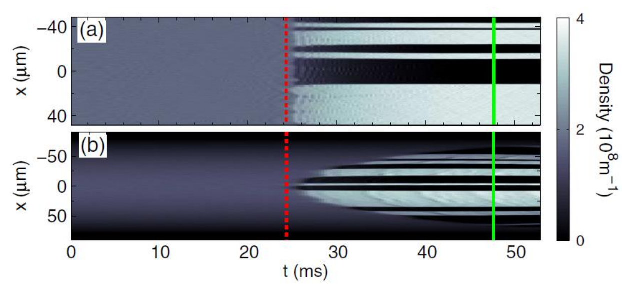


Vortices formation

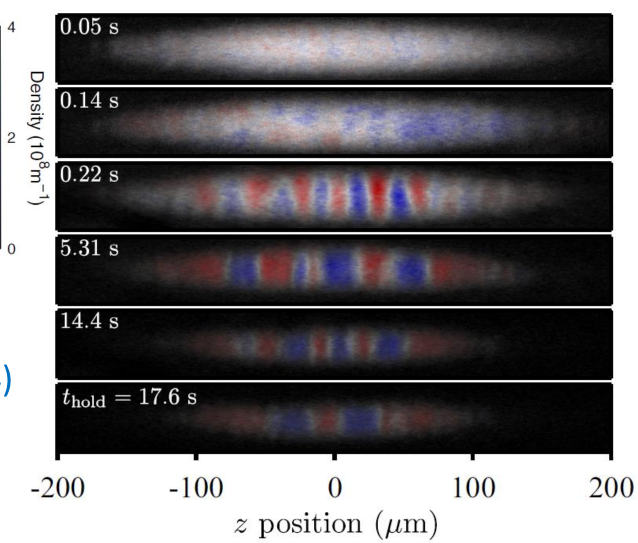


C. N. Weiler et al., Nat. 455, 7215 (2008)

Domain-Wall formation

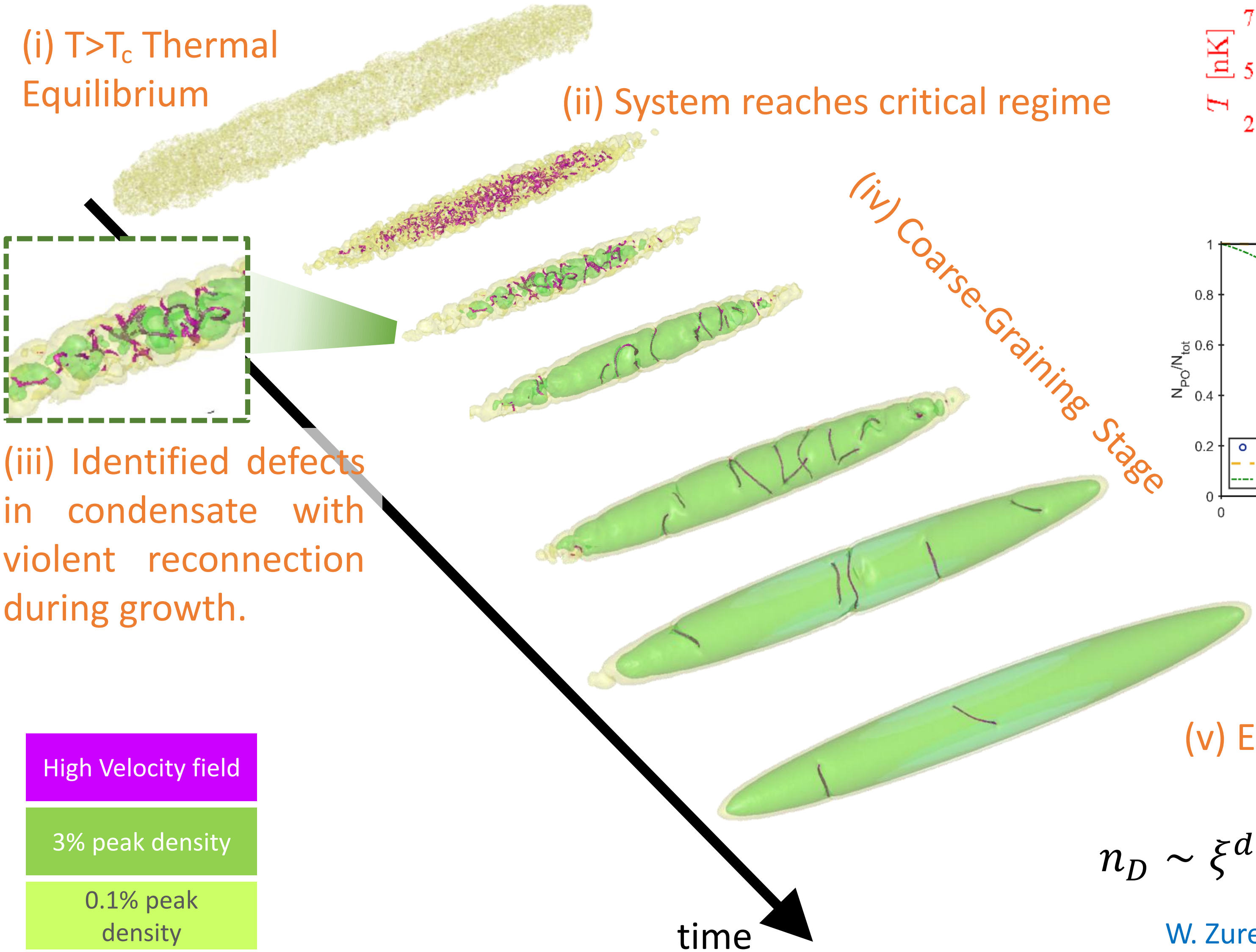


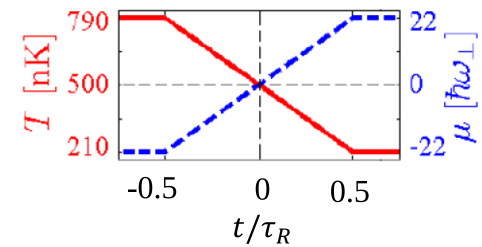
J. Sabbatini, PRL 107, 230402 (2011)
Compell et al., PRA **89**, 033631 (2014)

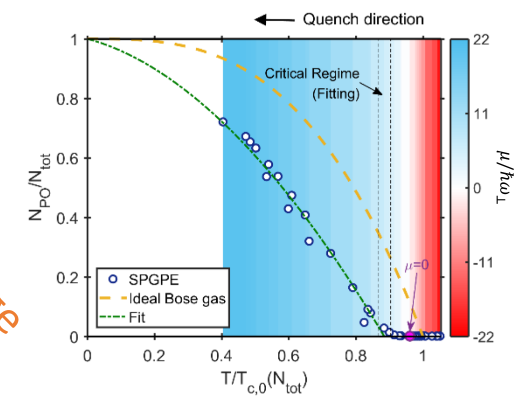


Introduction and Motivation

Universal Emerging Features of Quenched Growth (SPGPE simulation)







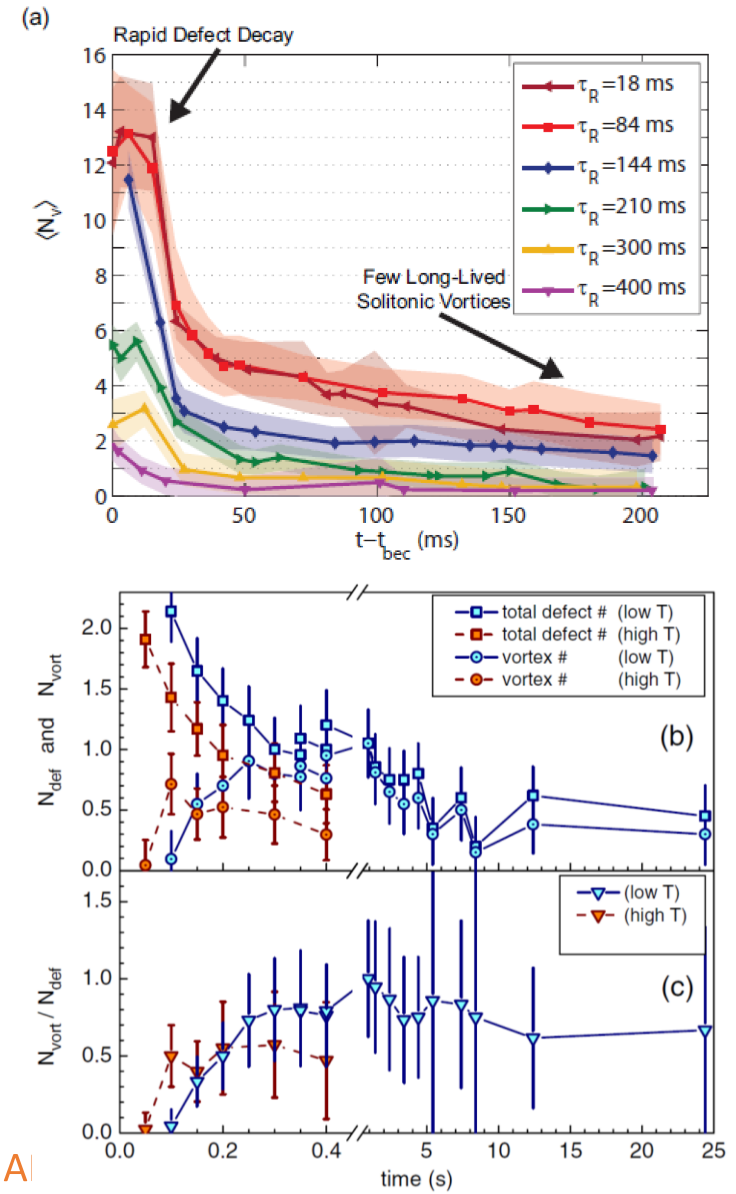
(v) Equilibrated T>0 BEC

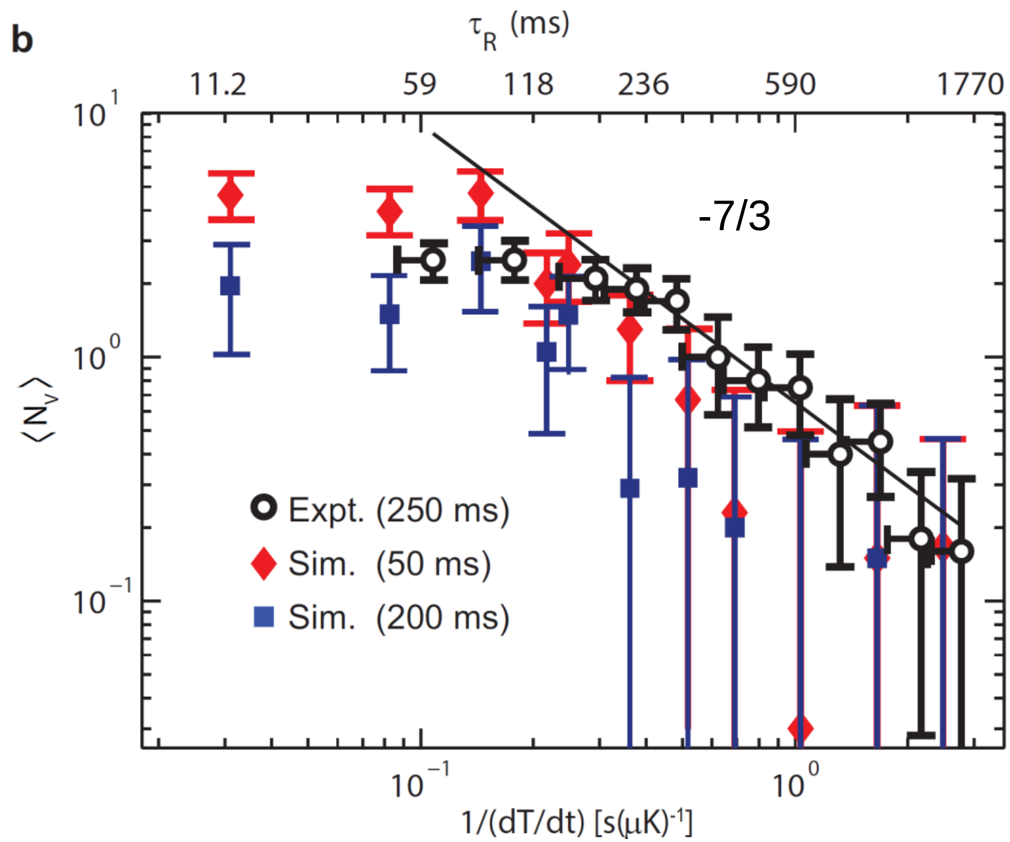
$$n_D \sim \xi^d/\xi^s\Big|_{t=-\hat{t}} \propto \tau_Q^{-\alpha}$$

W. Zurek, Nature 317, 505 (1983)
Liu et al., Comm. Phys. 2018

Motivation and Introduction

- **Evolution of Number of Defects**





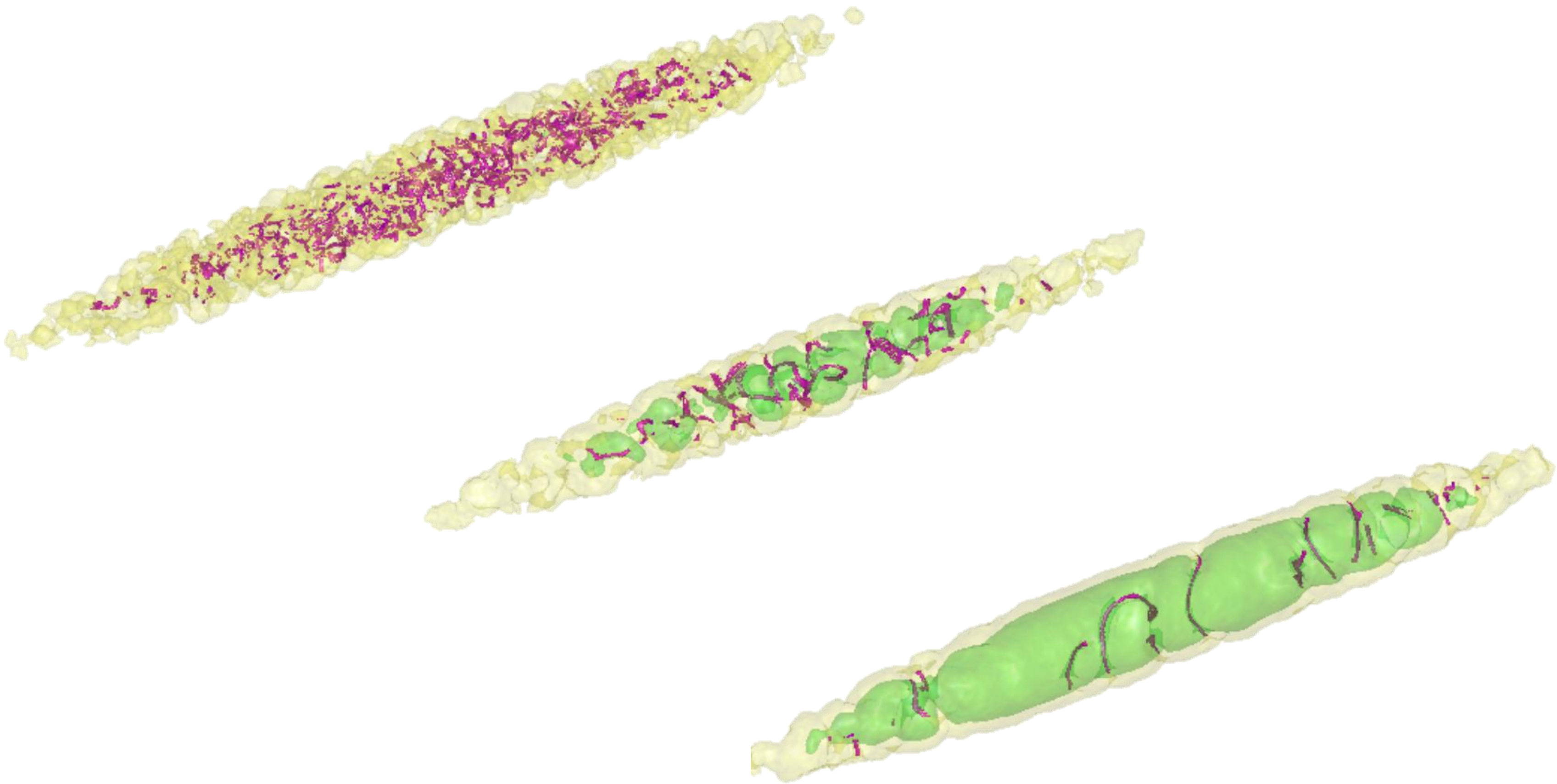
Liu et al., Comm. Phys. 2018

S. Donadello et al., PRL 113, 065302 (2014)

Introduction and Motivation

- **Question:**

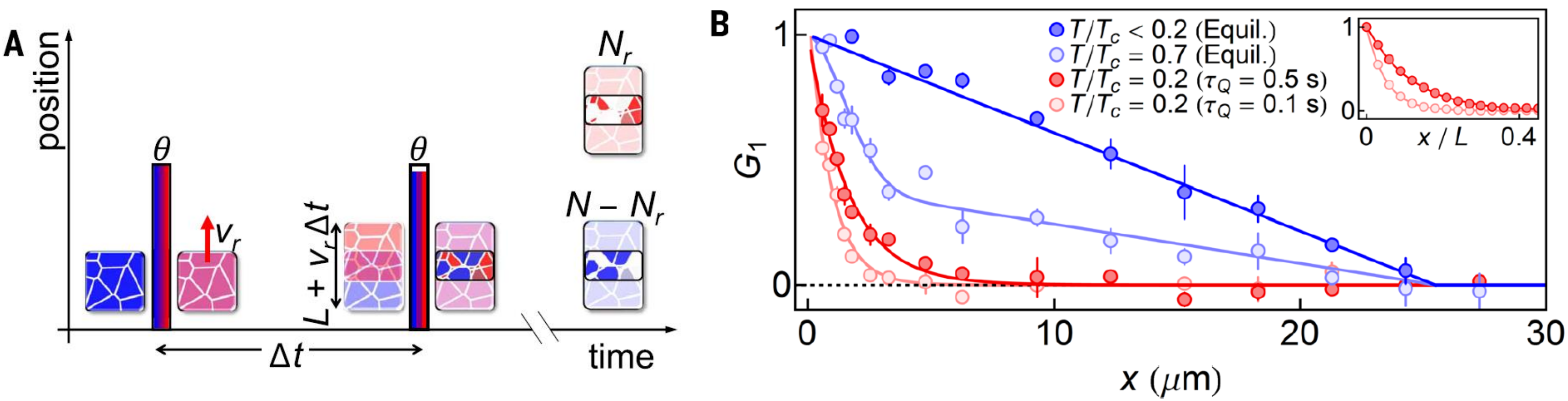
  Can we overcome the difficulty for the BEC measurement when the system is a mess?

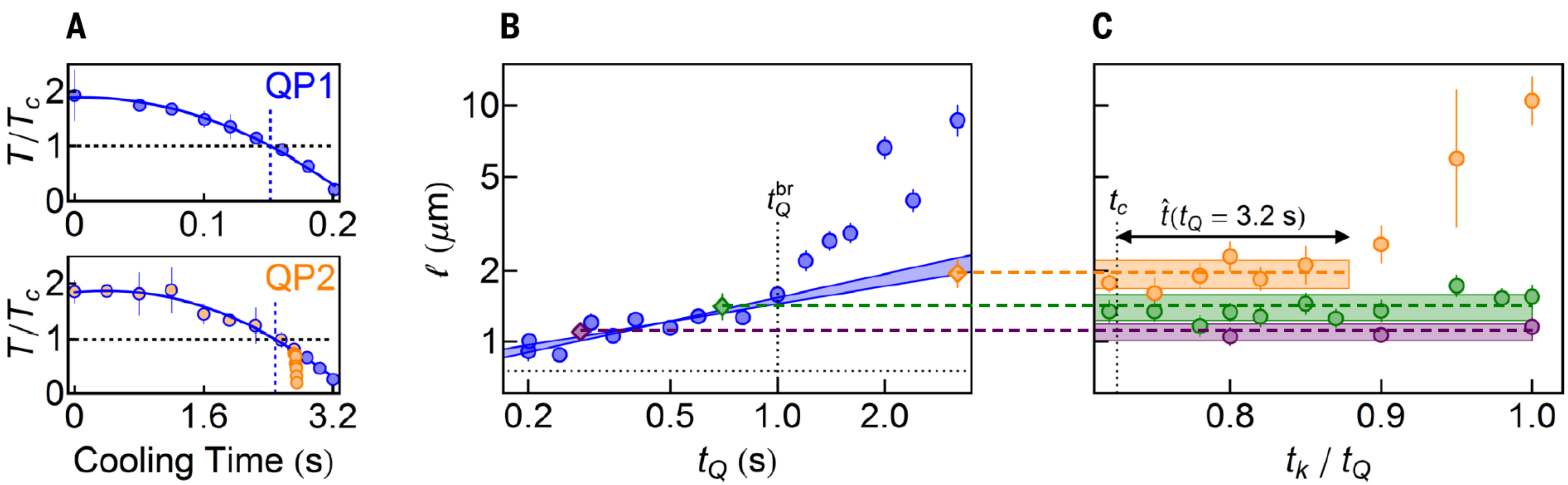


Introduction and Motivation

Solution: Correlation length

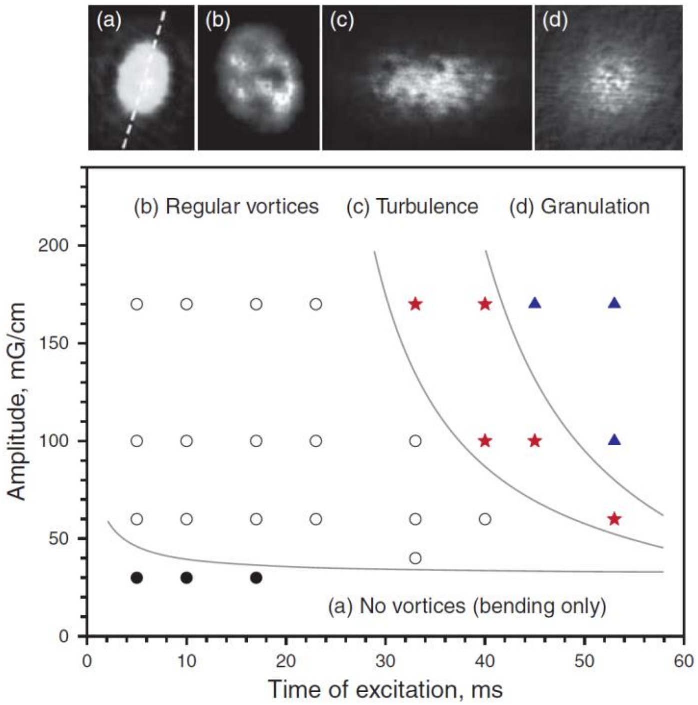
[N. Navon et al., Nat. 347, 167 (2015)]



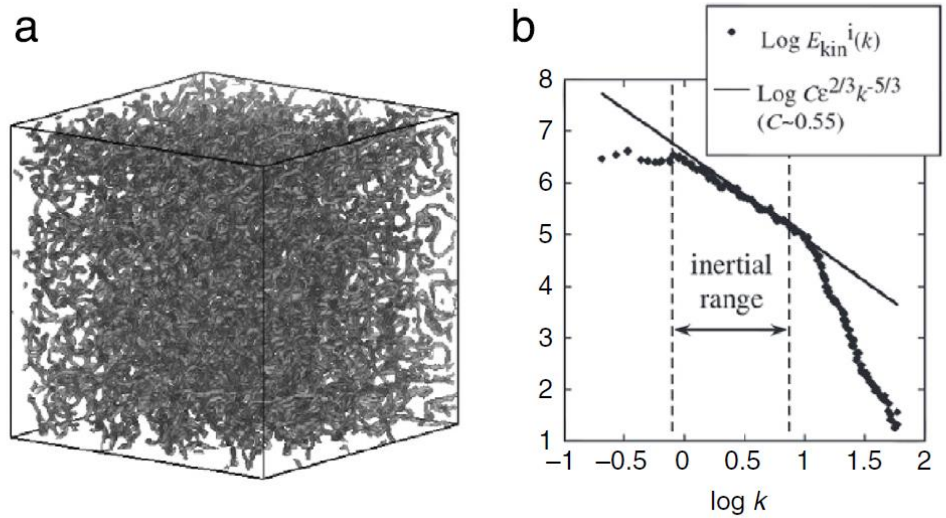


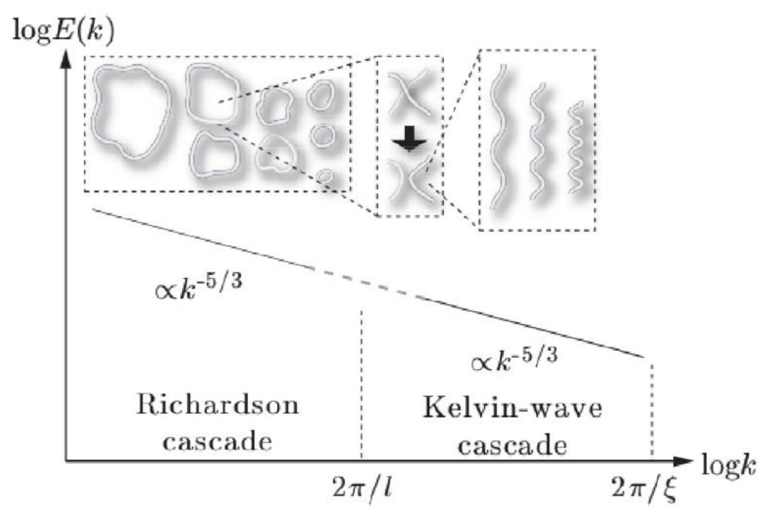
Momentum Occupations of BEC

- **Superfluid Turbulence**



J.A. Seman et al.,
Laser Phys. Lett. 8, 691 (2011)



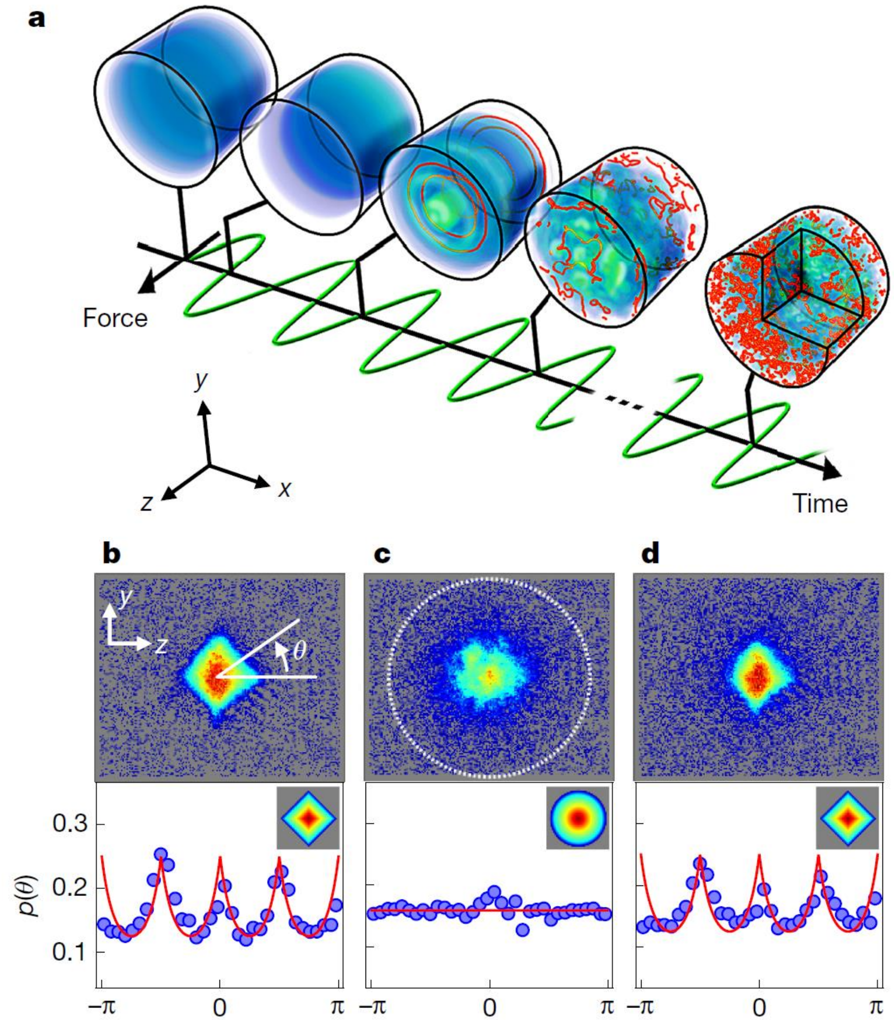


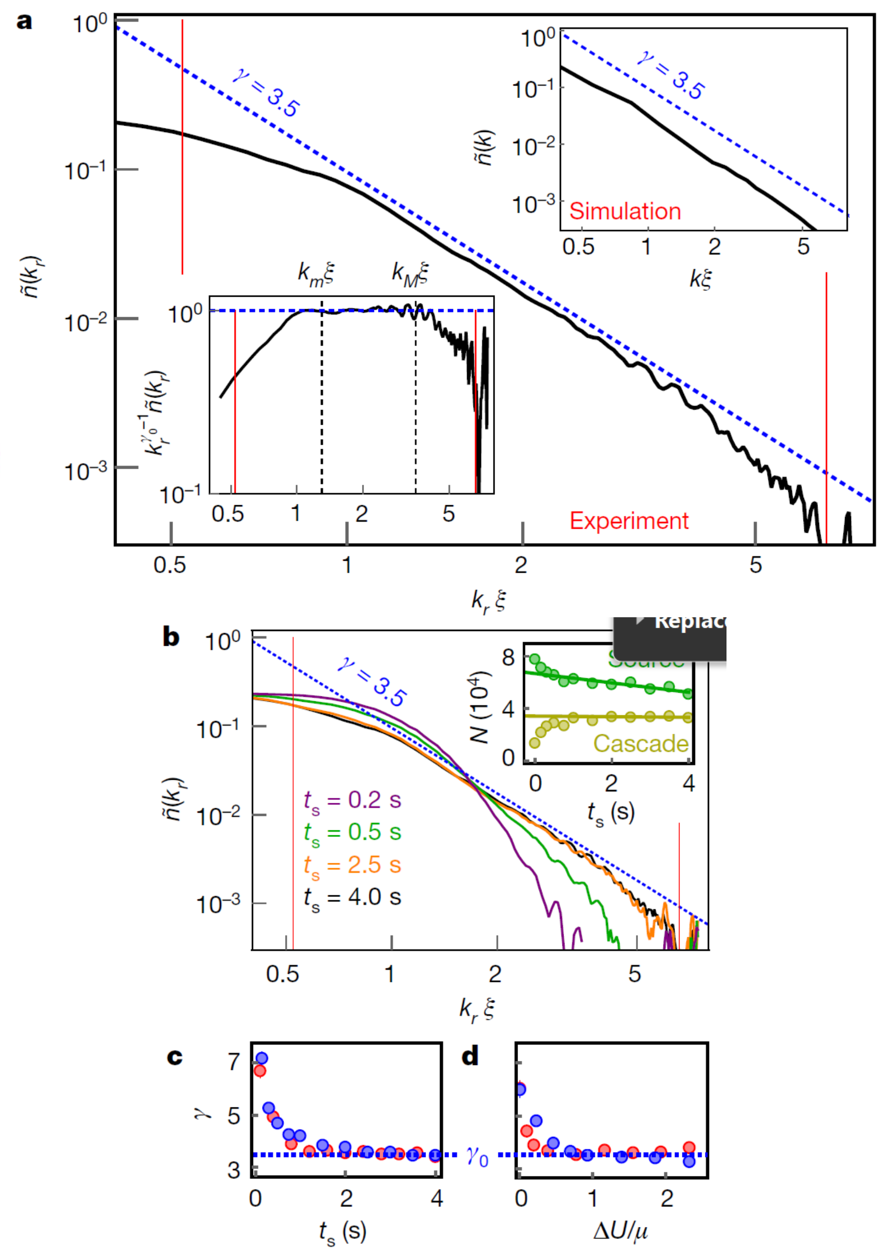
M. C. Tsatsos et al., Physics Reports 622, 1 (2016)

Momentum Occupations of BEC

- **Superfluid Turbulence**

N. Navon et al., Nature 73, 539 (2016)

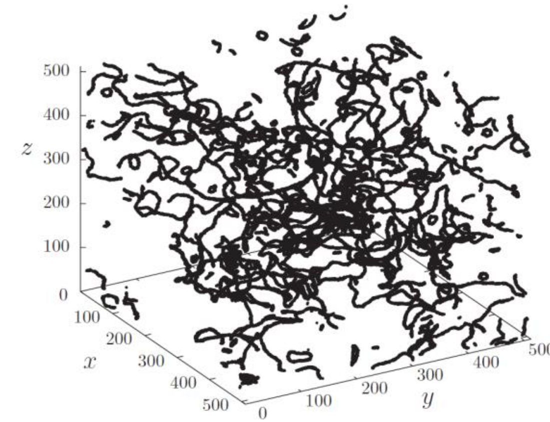




Momentum Occupations of BEC

- **Momentum Distribution and Vortices**

B. Nowak et al., PRA 85, 043627 (2012)



$$E_v(\mathbf{x}) = \frac{m}{2}\langle|\mathbf{v}(\mathbf{x})|^2\rangle = \frac{m}{2}\left\langle\left|\int d^2x'\,\tilde{\mathbf{v}}(\mathbf{x}-\mathbf{x}')\,\rho(\mathbf{x}')\right|^2\right\rangle,$$

$$n(k) \simeq 2mk^{-2}E_{\mathbf{v}}(k).$$

$$n(k) = \int d^{d-1}\Omega_k\,\langle\phi^*(\mathbf{k})\phi(\mathbf{k})\rangle_{\text{ensemble}}.$$

3D:

$n(k) \sim k^{-2}$: near-circulated vortex ring

$n(k) \sim k^{-3}$: Anti-circulated pair of vortices

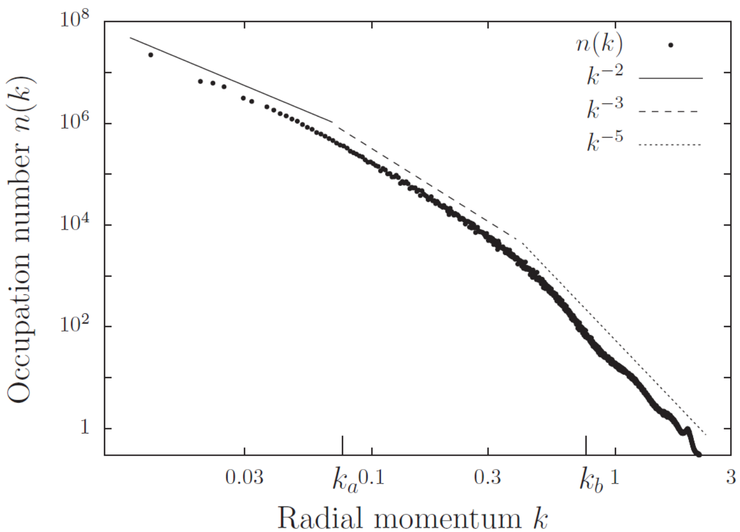
$n(k) \sim k^{-5}$: vortex ring

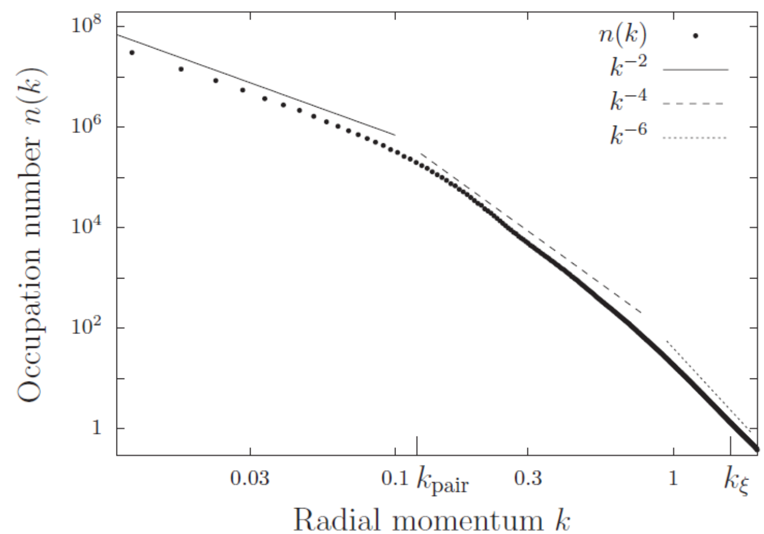
2D:

$n(k) \sim k^{-2}$: Random vortex pairs

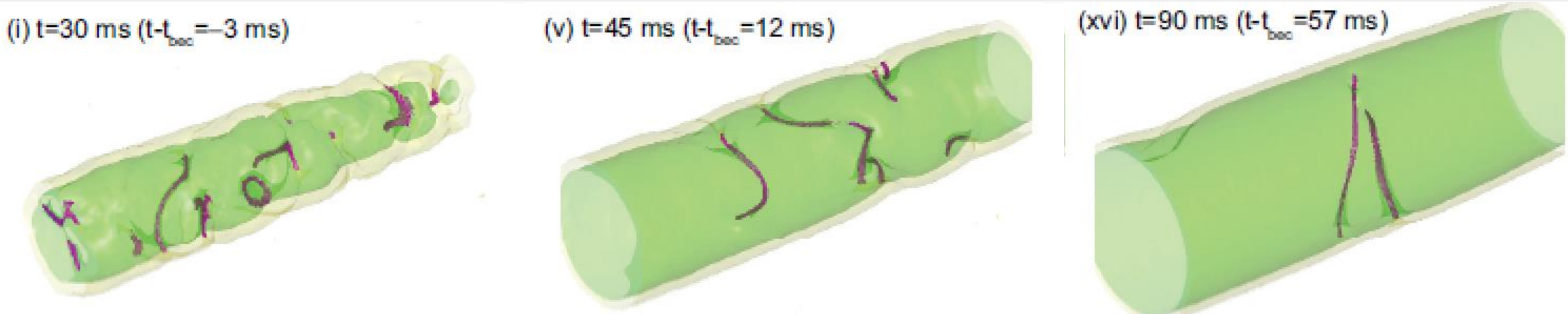
$n(k) \sim k^{-4}$: Independent vortices

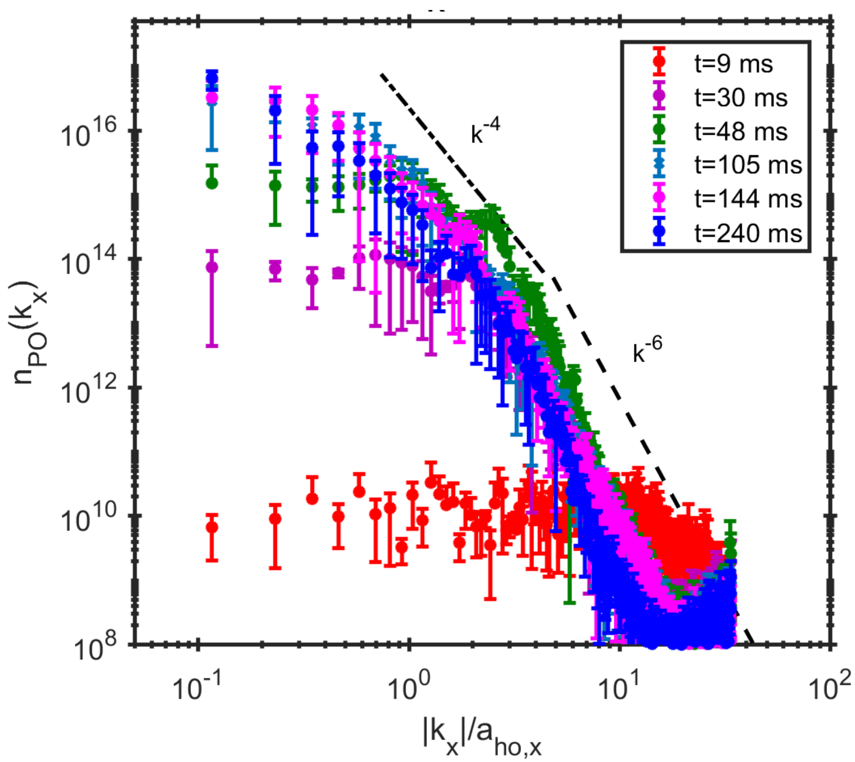
$n(k) \sim k^{-6}$: Healing length

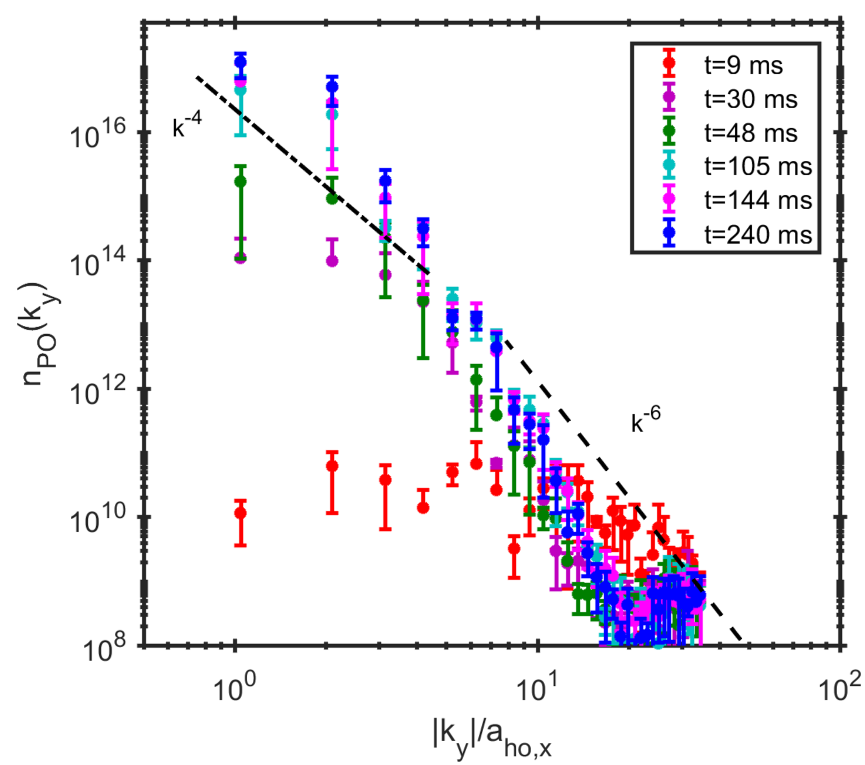




Preliminary Results in Quenched BEC

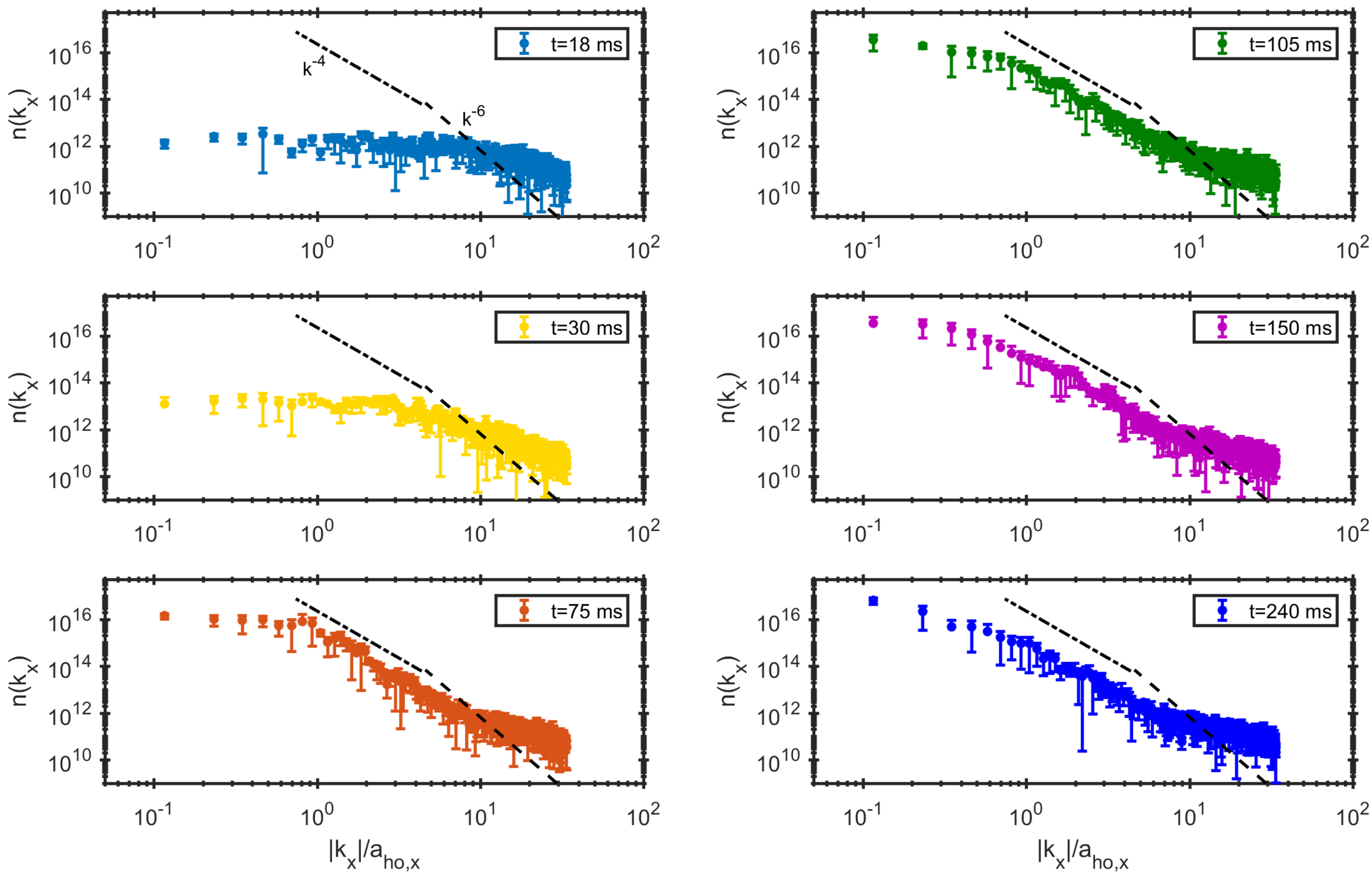






Preliminary Results in Quenched BEC

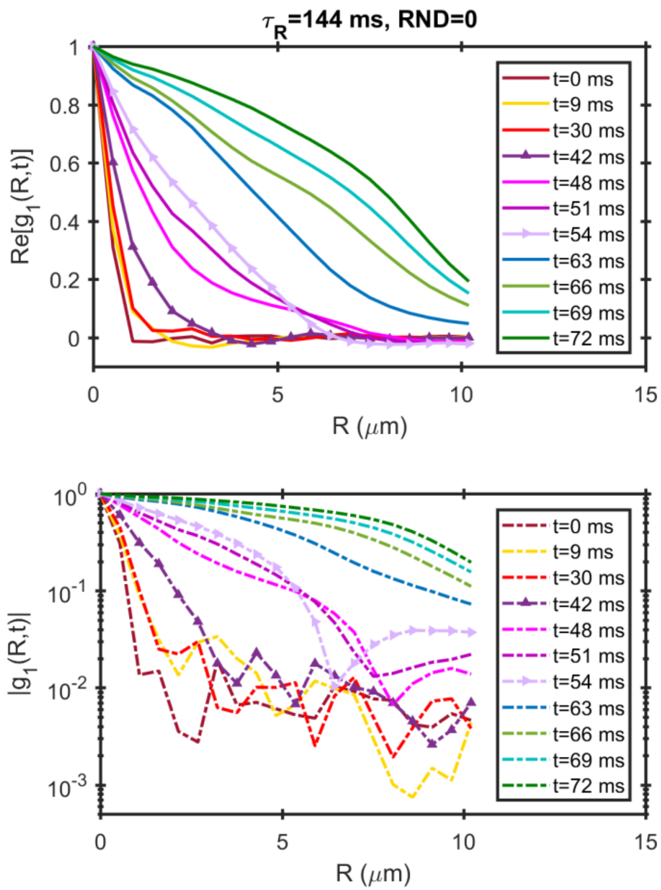
- Intensity to the thermal components

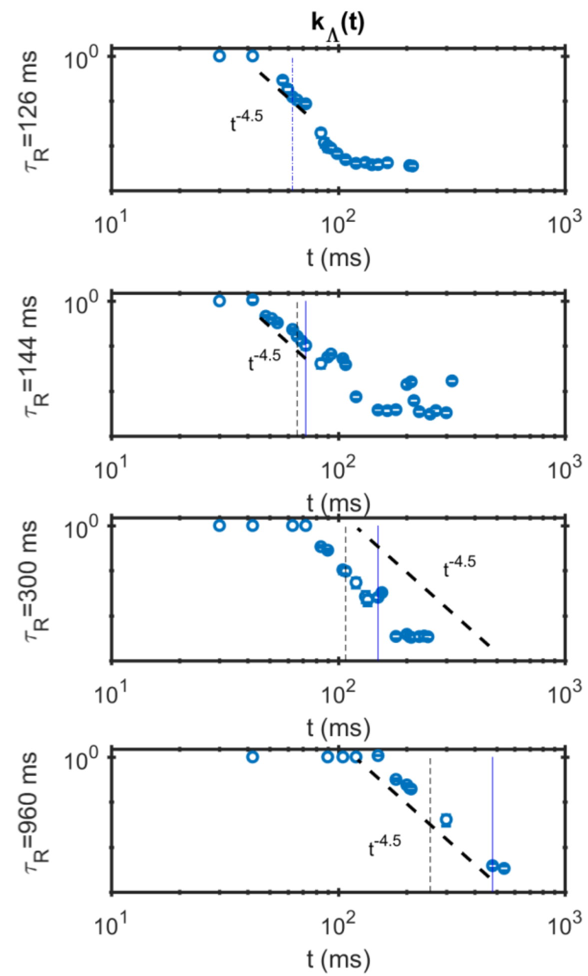


Preliminary Results in Quenched BEC

C.-M. Schmied et al., arXiv:1807.07514

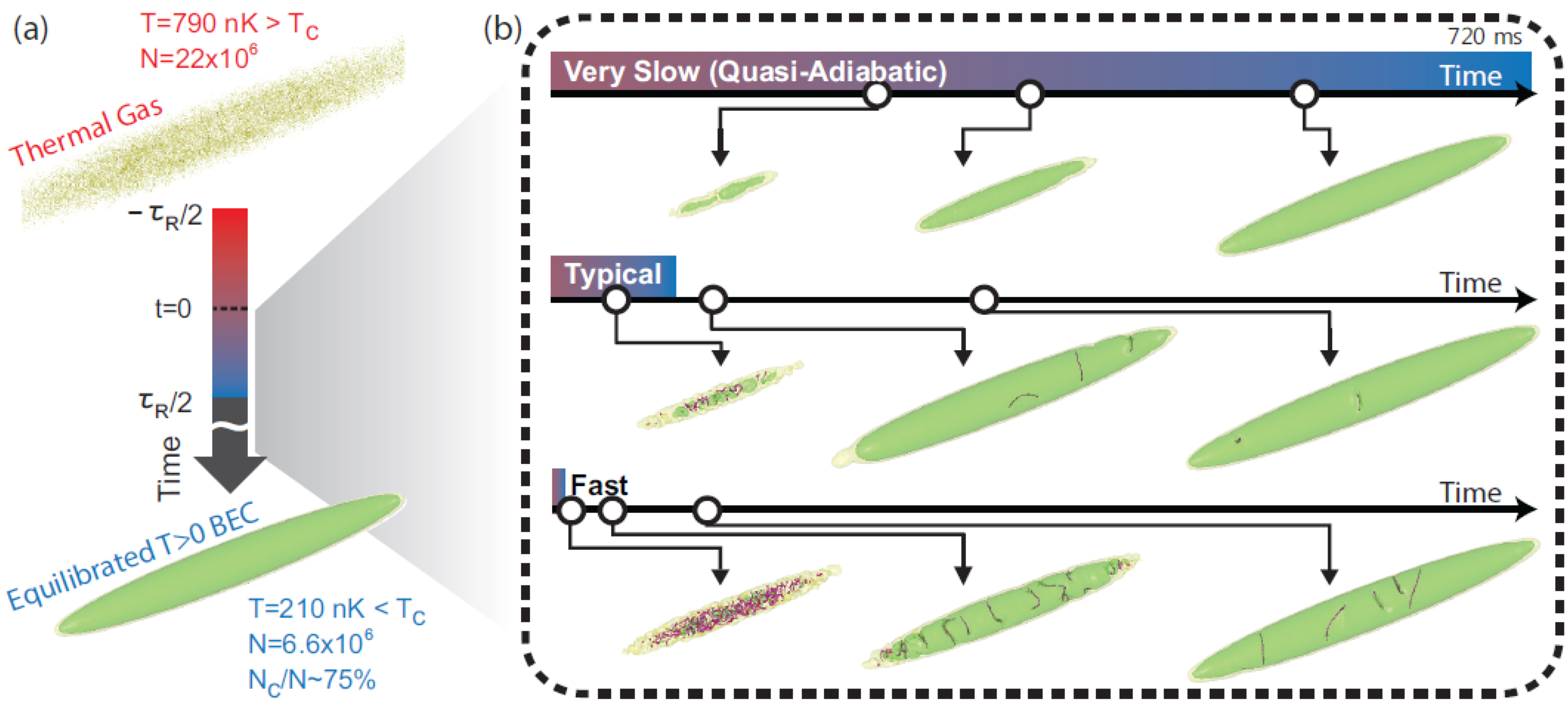
$$g_1(R) = \frac{\int d\Omega \psi^*(0,t)\psi(\mathbf{R},t)}{\sqrt{\langle \int d\Omega |\psi(\mathbf{R},t)|^2 \rangle \langle |\psi(0,t)|^2 \rangle}} \sim e^{-k_\Lambda(t)R} \text{ with } k_\Lambda(t) \sim t^{-\beta}$$





Remarks

- The implementation of classical-field approach (SPGPE) to simulate the recent experiment provides good agreement with experimental observation, and provide insightful physics for the growth of condensate.
- Inspired by the turbulence physics, the momentum distribution is a powerful tool for analyzing the structure inside the condensate when it is a mess.
- We are going to investigate the coarse-graining dynamics for the enlongated Bose gas passing through a phase transition.



Liu et al., Comm. Phys. 2018

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