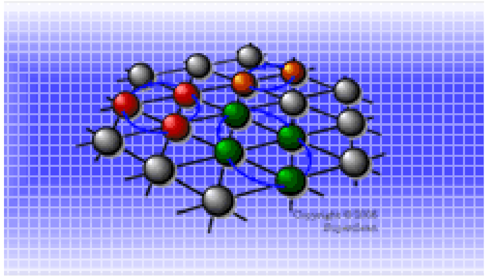
Quantum Turbulence Realized in Trapped Atomic Bose-Einstein Condensates



Michikazu Kobayashi

Makoto Tsubota

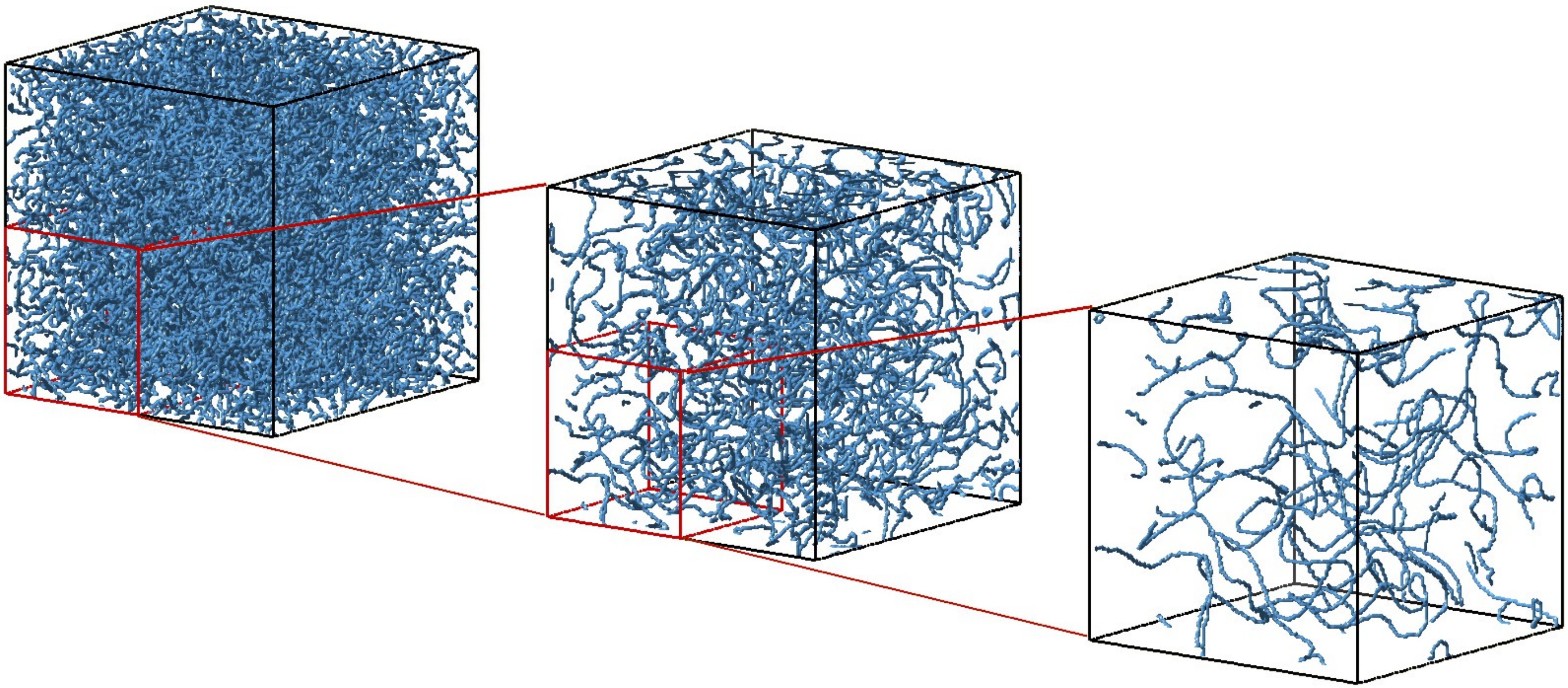
Osaka City University

ELEMENTARY EXCITATION PHYSICS LABORATORY
THEORY OF CONDENSED MATTER

"International Symposium on Physics of New Quantum Phases in Superclean Materials", 29 Oct. – 1 Nov, 2007.

Quantum Turbulence

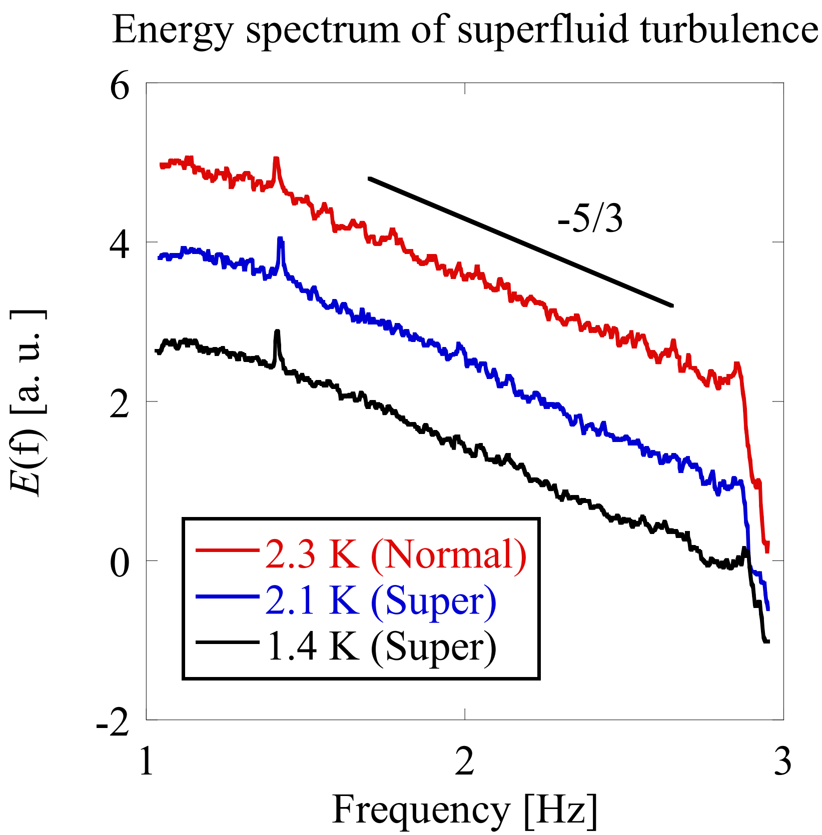
Quantum turbulence is realized as tangled state of quantized vortices

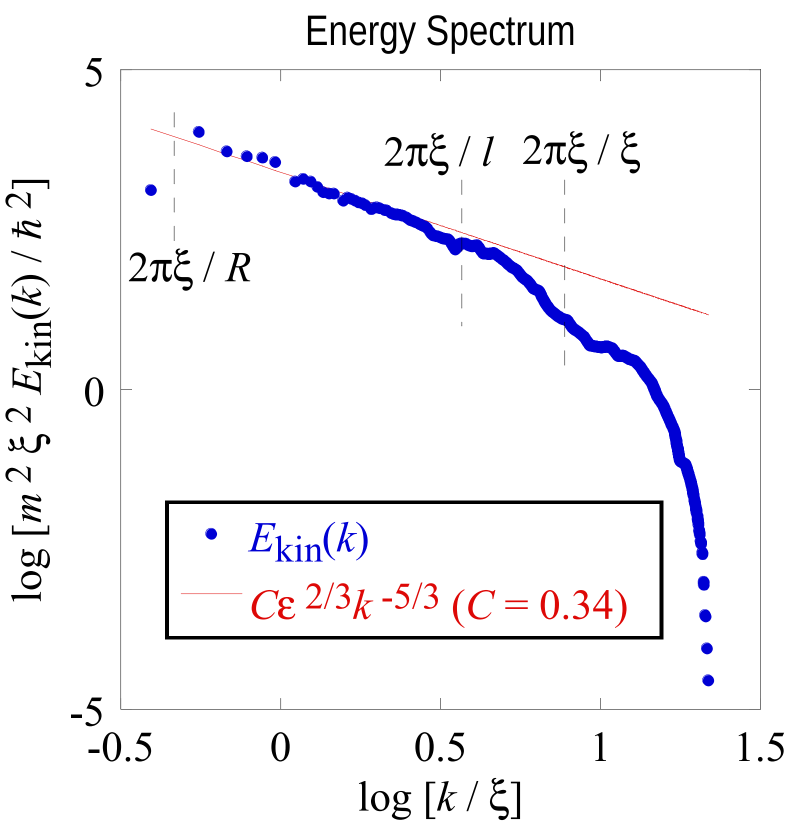


Energy Spectrum of Quantum Turbulence

J. Maurer and P. Tabeling,
Europhys. Lett. **43** (1), 29 (1998)

MK & MT, J. Phys. Soc. Jpn
(English), **74**, 3248 (2005).





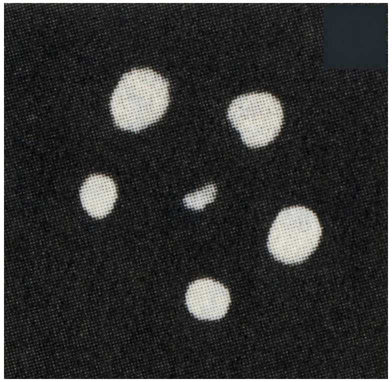
Quantized Vortices in Superfluid Helium

Observation of vortices in superfluid helium

- Second sound
- Vibrating wire
- NMR satellite peak

→ Only (total) vortex length (density)

It is very difficult to observe the spatial distribution of vortices in superfluid helium

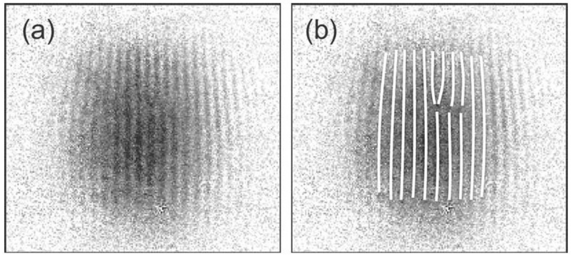


Yarmchuk et. al. J. Low. Temp. Phys. **46**, 479 (1982)

G. P. Bweley et. al. Nature **441**, 588 (2006)

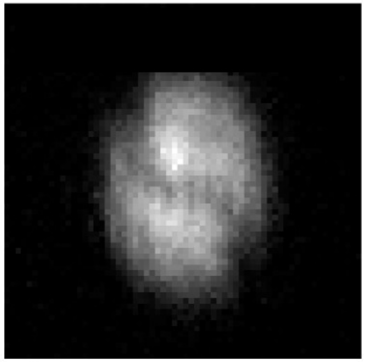
Quantized Vortices in Atomic BECs

Direct observation of quantized vortices is possible in atomic BECs

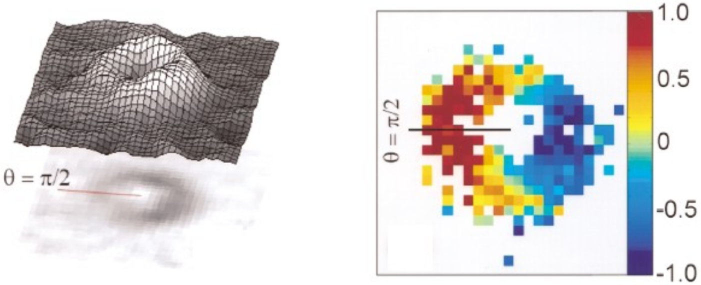


Y. Shin et al. PRA **72**, 021604(2005)

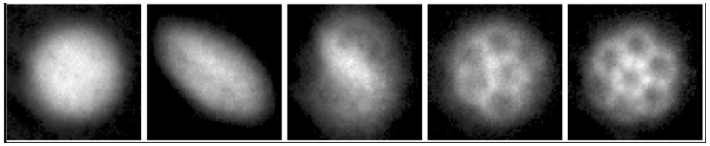
V. Bretin et al. PRL **90**, 100403(2003)



M. R. Matthews et al. PRL **83**, 2498(1999)

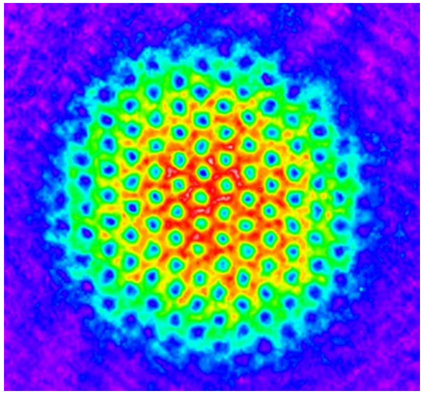


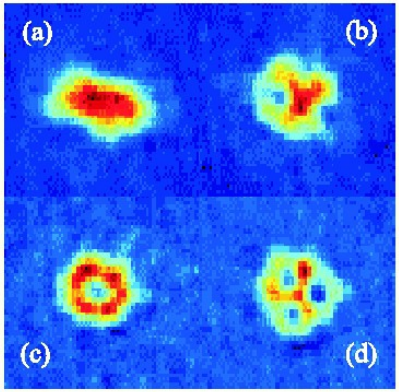
K. W. Madison et al. PRL **86**, 4443(2001)

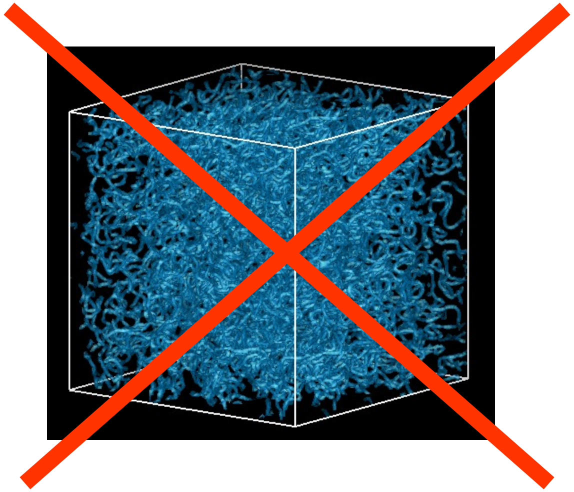


Turbulence in Atomic BECs

In Atomic BECs, only one vortex and vortex lattice state have been experimentally studied.

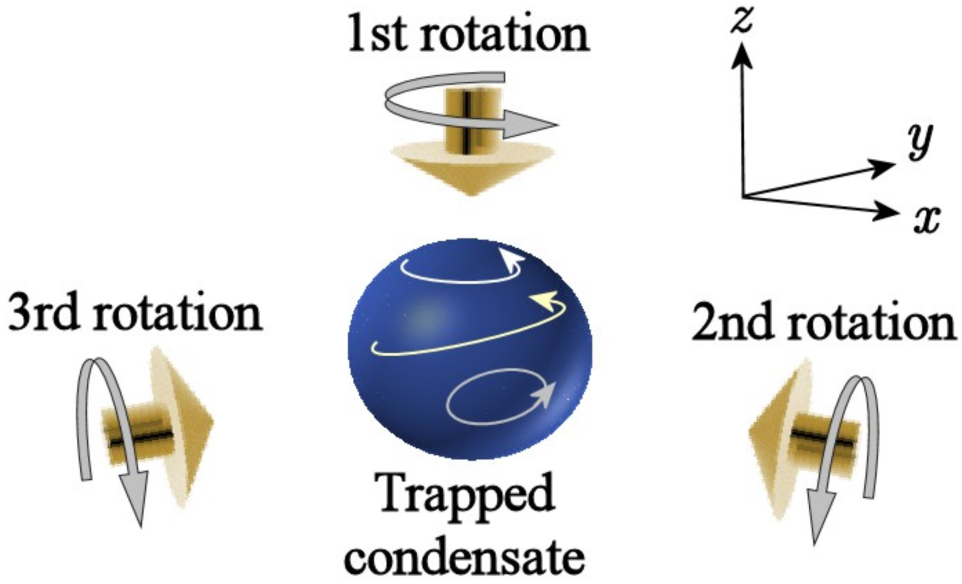


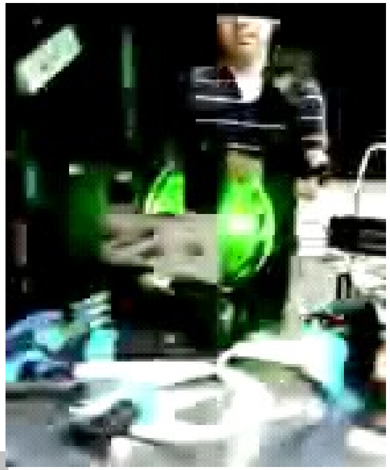




Even the concept of quantum turbulence has not existed

Atomic BECs Under Combined Rotation Around Two or Three-axis





S. Goto et. al. Phys. Fluids **19**, 061705 (2007)

- Without a other rotation, simple rotation is realized.
- Each rotation does not commutate each other.
- 3rd and 2nd rotation are weak : rotating vortex lattice.
- 3rd rotation is weak : 2-D turbulence.

Numerical Simulation of the Gross-Pitaevskii Equation

$$\hbar[\mathrm{i}-\gamma(\boldsymbol{x})]\frac{\partial}{\partial t}\Phi(\boldsymbol{x})=\left[-\frac{\hbar^2}{2m}\nabla^2-\mu+U(\boldsymbol{x})+\frac{4\pi\hbar^2 a}{m}|\Phi(\boldsymbol{x})|^2-\boldsymbol{\Omega}(t)\cdot\boldsymbol{L}(\boldsymbol{x})\right]\Phi(\boldsymbol{x})$$

$U(\boldsymbol{x})$: Magnetic trap potential a : s - wave scattering length

$\boldsymbol{\Omega}(t)$: Rotational frequency $L(\boldsymbol{x})$: Angular momentum

$$U(\boldsymbol{x})=\frac{m\omega^2}{2}[(1-\varepsilon_1)(1-\varepsilon_2)x^2+(1+\varepsilon_1)(1-\varepsilon_2)y^2+(1+\varepsilon_2)z^2]$$: Anisotropic trap

$$\boldsymbol{\Omega}(t)=(\omega_x\cos\omega_y t+\omega_z\cos\omega_x t\sin\omega_y t,\omega_y+\omega_z\sin\omega_x t,\omega_x\sin\omega_y+\omega_z\cos\omega_x t\cos\omega_y t)$$

$\gamma(\boldsymbol{x})$: Dissipation obtained from BdG equation (MK & MT, PRL. **97**, 145301 (2006))

Numerical Simulation of the Gross-Pitaevskii Equation

Numerical parameters

$$^{87}\text{Rb atoms}: m = 1.46\times 10^{-25}\ \text{kg}, a = 5.61\,\text{mm}, N = 250000$$

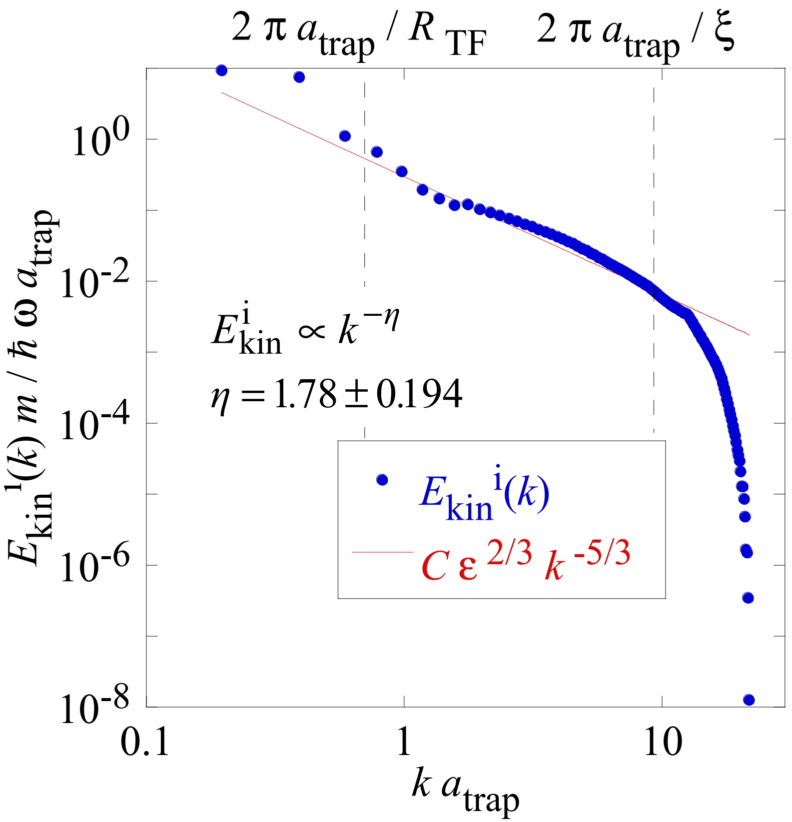
$$\omega = 150\times 2\pi\ \text{Hz}, \boldsymbol{\Omega} = (0.2\omega, 0.05\omega, 0.9\omega), \varepsilon_1 = \varepsilon_2 = 0.01$$

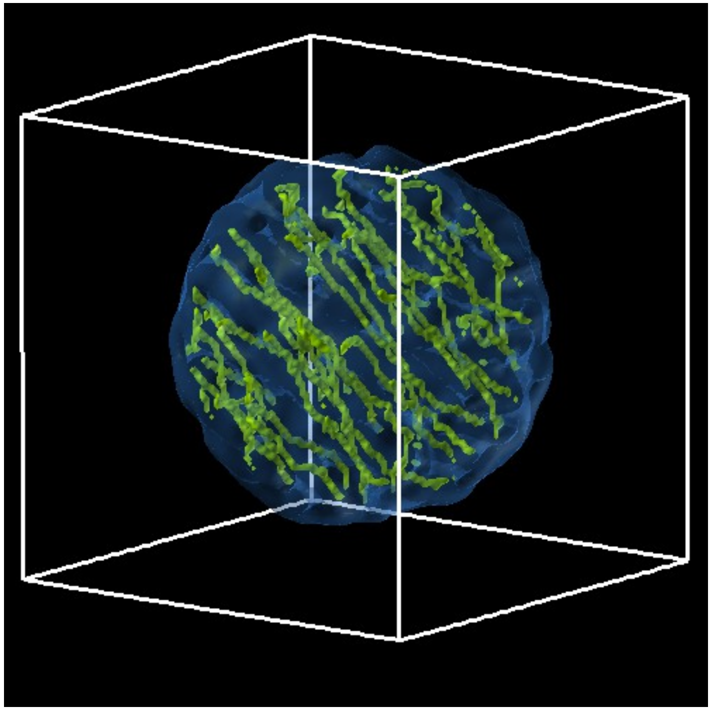
Numerical method

Chebyshev-tau pseudo-spectral method with 512^3 grid points (volume $=100\mu m^3$) Initial state : stationary state without rotation and anisotropy of potential

Numerical Results

$\omega_y = 0$: biaxial rotation

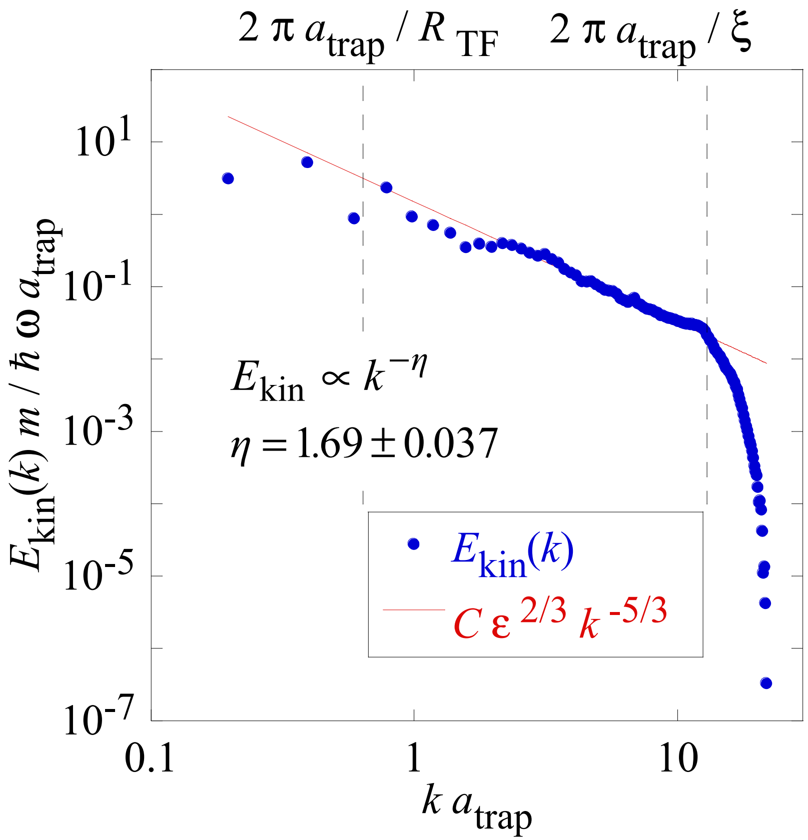


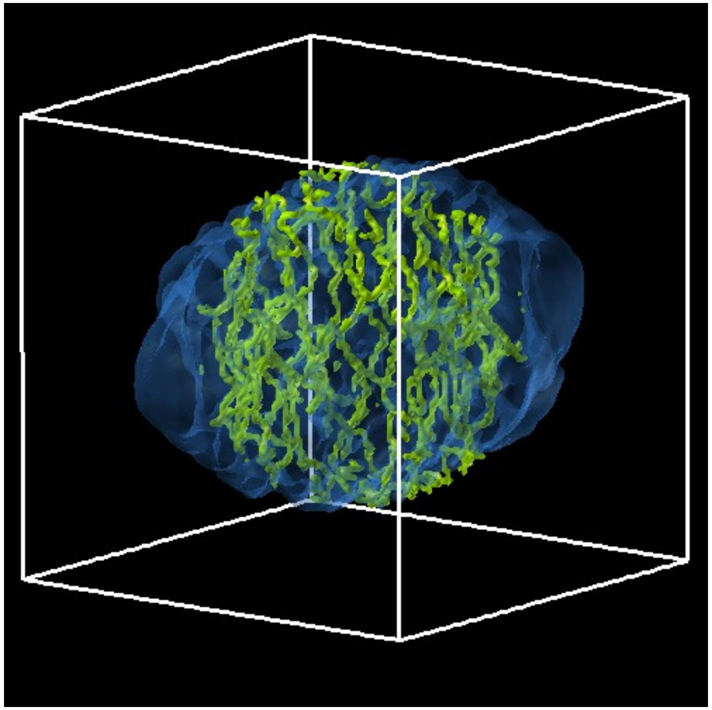


$$(I_x, I_y, I_z) = \frac{1}{L}\left(\int d\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{x}}]^2, \int d\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{y}}]^2, \int d\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{z}}]^2\right) = (0.353, 0.276, 0.371)$$

Numerical Results

$\omega_y \neq 0$: triaxial rotation





$$(I_x, I_y, I_z) = \frac{1}{L}\left(\int \mathrm{d}\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{x}}]^2, \int \mathrm{d}\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{y}}]^2, \int \mathrm{d}\xi[\boldsymbol{s}\cdot\hat{\boldsymbol{z}}]^2\right) = (0.326, 0.327, 0.347)$$

Summary

- Atomic BECs can become a nice candidate to study quantum turbulence.
- Atomic BEC can become a system to study quantum turbulence with tangled quantized vortices by using precession rotation.