Breaking of Josephson junction oscillations and onset of quantum turbulence in Bose-Einstein condensates

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Abstract:

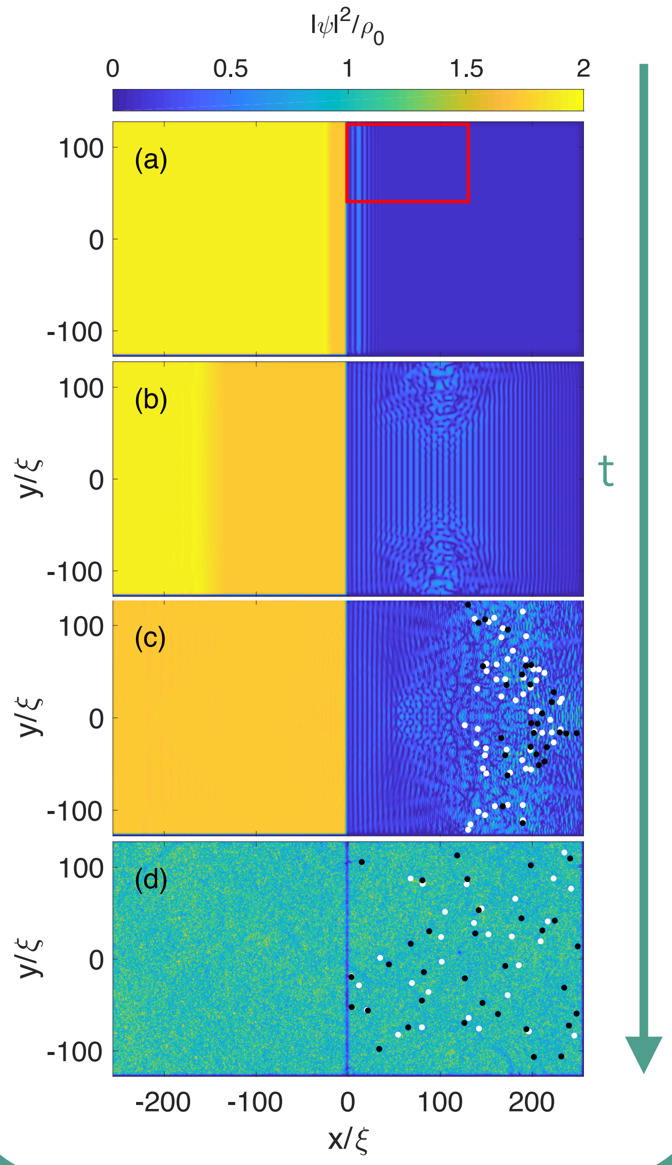
- We analyse the formation and the dynamics of quantum turbulence in a two-dimensional Bose--Einstein condensate with a Josephson junction barrier
- A high initial superfluid density imbalance leads to generation of turbulence
- The Josephson junction barrier allows us to create two turbulent regimes: acoustic turbulence on one side and vortex turbulence on the other
- We present the optimal configurations for the density imbalance and barrier height in order to create the desired turbulent regimes which last as long as possible

Simulations of Gross-Pitaevskii equation:

$$i\frac{\partial\psi}{\partial t} = (-\nabla^2 + V(\mathbf{x},t) + |\psi(\mathbf{x},t)|^2)\psi(\mathbf{x},t)$$

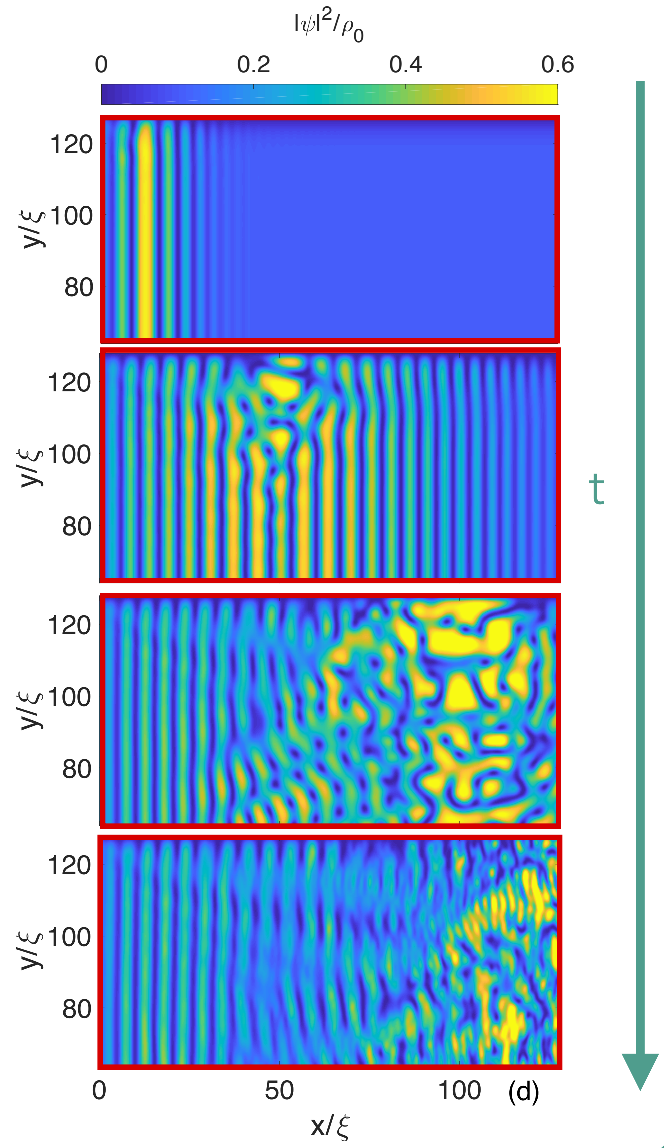
$$V(x,y,t) = V_0 e^{-\frac{x^2}{\sigma^2}} + V_d \tanh(x) H(t^\star - t)$$

Creation of Vortices:



- Initially left box with higher density
- Shock wave passes barrier and is regularised by a train of solitons
- Snake instability triggers nucleation of vortices
- Vortices in low region have large cores, once there are many they do not act as hydrodynamic vortices (ghost vortices)
- Density continues to equilibrate causing the vortices to become hydrodynamic
- End with acoustic turbulence in one box and vortex turbulence in the other

Zoom of Creation:



Important quantities:

V_0/μ	- Barrier strength
Z_0	- Initial imbalance
$\bar{N}_v$	-Mean number of vortices
E_c	-Proportion of compressible energy
β	- Vortex decay rate
σ	- Standard deviation of Z(t) (imbalance)

Key observations:

- 1(a) Number of vortices has maximum away from no barrier case
- 1(b) The number of vortices does not always increase with imbalance
- 1(c) The compressible energy increases almost linearly
- 2(a) Vortex decay rate increase with imbalance/ compressible energy
- 2(b) Decay rate is independent of barrier size
- 2(c) Large oscillations are damped by the barrier