Out-of-equilibrium dynamics crossing the BEC transition

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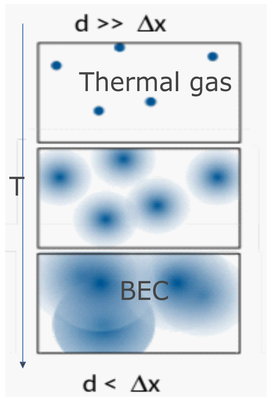
Ultracold quantum gases are an ideal platform for quantum simulation:
-high degree of flexibility & tunability (atomic species, number of atoms, geometry, interactions, ...) + high degree of control
-clean systems where the physical phenomenon of interest can be highlighted
-possibility of simulating other more complicated and/or often inacessible systems (cosmology, nuclear physics, solid-state systems, ...)

Bose Einstein Condensation Transition



d = average interparticle distance
Δx = extension of the single particle wavepacket

$$\Delta x \simeq \frac{\hbar}{\Delta p} = \frac{\hbar}{\sqrt{3mk_BT}}$$

De Broglie wavelength

Cooling down the system below a critical temperature Tc
the phase space density becomes larger than 1

$$T \leq T_c = \frac{\hbar\omega_{ho}}{k_B}\left(\frac{N}{\zeta(3)}\right)^{1/3} \qquad \mathrm{PSD} = n\lambda_{\mathrm{db}}^3 \propto \frac{n}{T^{3/2}} \propto \left(\frac{\Delta x}{d}\right)^3 > 1$$

2° order phase transition: spontaneous symmetry breaking

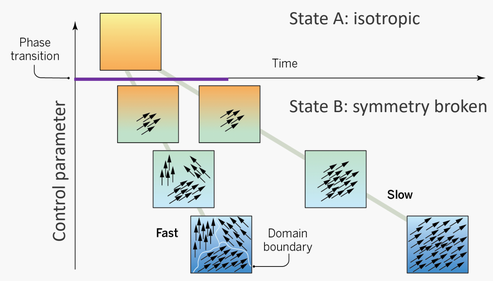
- Macroscopic occupation of the ground state
- Coherent system
- Single wavefunction $|\psi\rangle = e^{i\phi(\vec{r})}\sqrt{n(\vec{r})}$

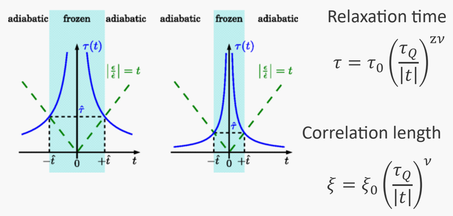
phase factor

Kibble-Zurek mechanism

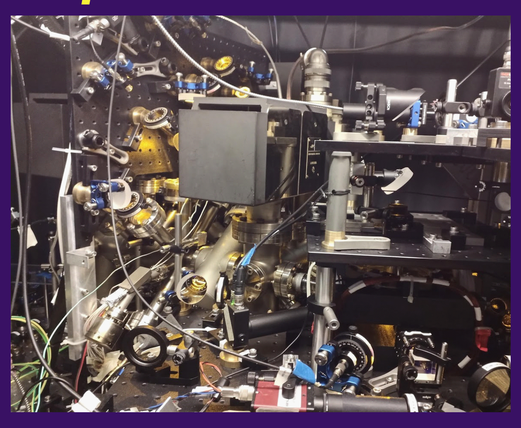
Theory that describes the out-of-equilibrium dynamics and topological defect formation in a system that is driven through a continuous phase transition

- originally formulated by KIbble to explain formation of anisotropies in the early universe
- Zurek: generalization to other systems. Relation between quench rate and density of defects





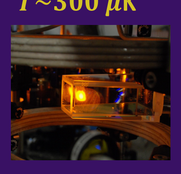
Experiment

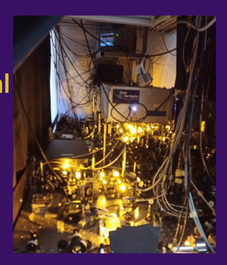


- initially: atomic vapour of ^{23}Na at **T>300 K**

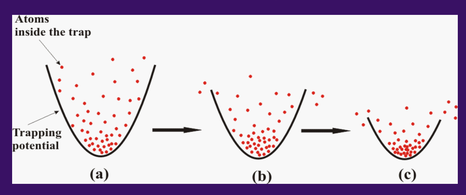
laser cooling

- **3D Magneto-Optical Trap**
- **T~300 μK**

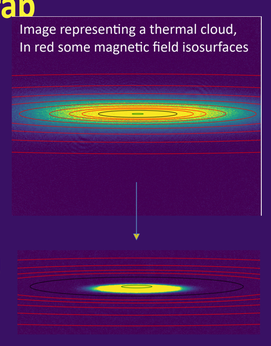




Evaporative cooling in magnetic trap



goal:
reach lower temperature by evaporating the warmest atoms away from the trap



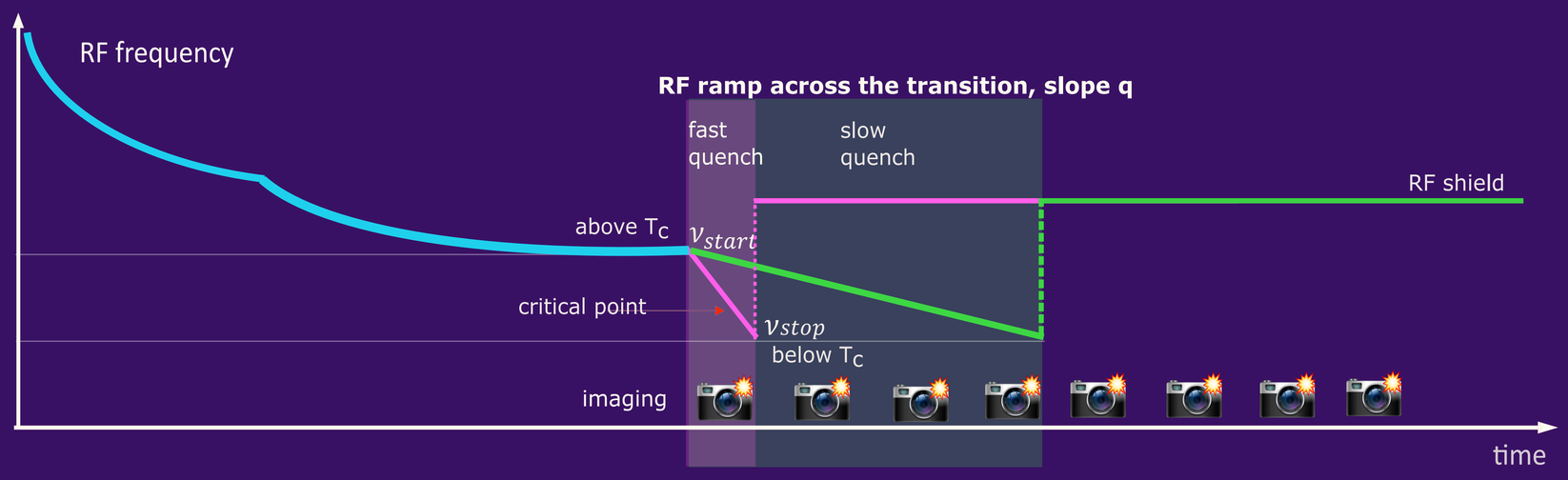
How?

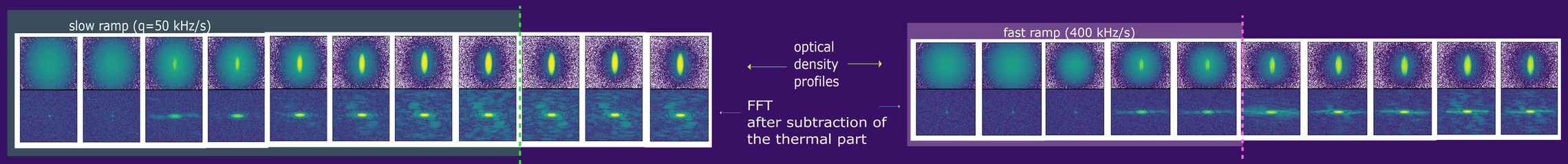
- We apply RF field to transfer atoms in |1,+1>, antitrapped.
- Inhomogeneity of magnetic field: the frequency difference between the levels is spatially dependent (Zeeman effect)
- RF ramp to gradually remove the atoms with higher energy
- **Reach T~300 nK < Tc**

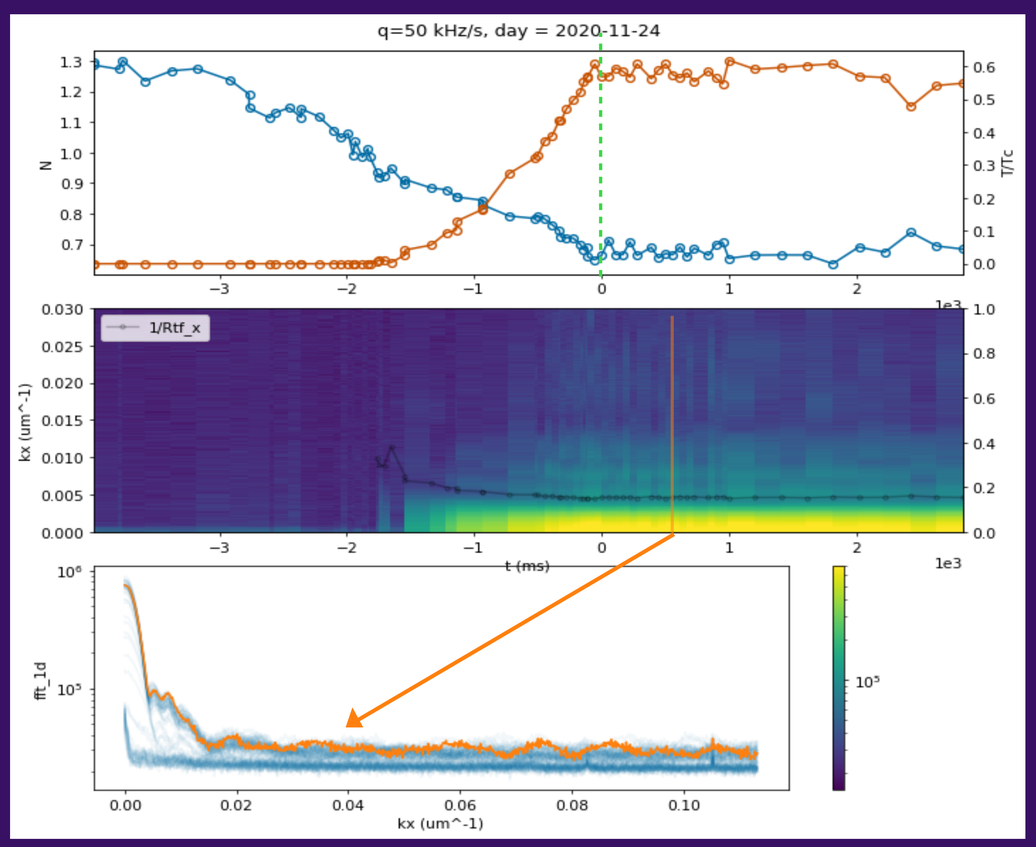
Quenches across the BEC transition

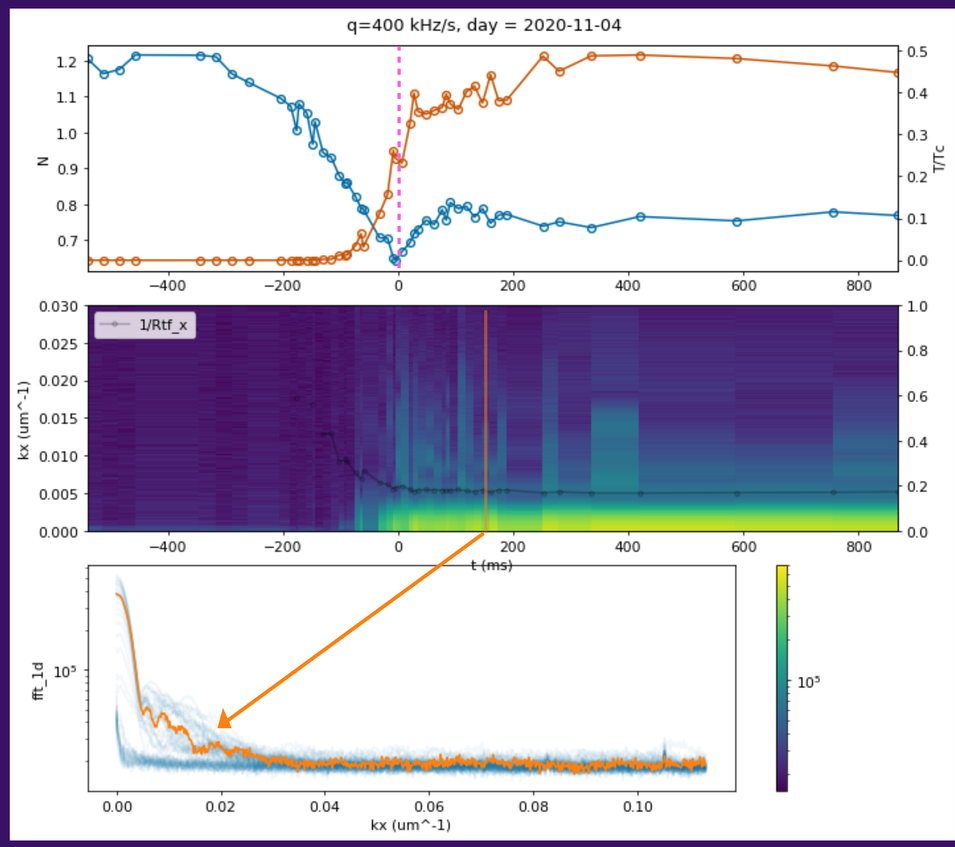
Our goal: Study the evolution of the system after quenching the evaporation RF frequency across the BEC transition, focusing on the early-time dynamics and on the re-equilibration and relaxation processes.

After producing a thermal cloud with a temperature T~T_C , the RF frequency is further ramped down, crossing the critical point. We change the quench rate by changing the slope q of the ramp. For different quench rates we observe the evolution of the system, taking absorption images (after 50 ms of time of flight) during and after the ramp.









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