Coherent *vs.* Incoherent Dynamics of BECs

- Extracting physical quantities from BEC experiment
- 1D Bosons as a model for noninteracting 1D Fermions
- BECs in optical lattices: energy bands, dissipation of superfluidity, Josephson arrays, decoherence, and chaos

[PRL97,PLA99,PLA00,EPJD00,PRA01,PRL01,JPB01,EPL01, PRA01,JLTP02,PRE00,PRE00,PLA02,PRL02,JCP02]

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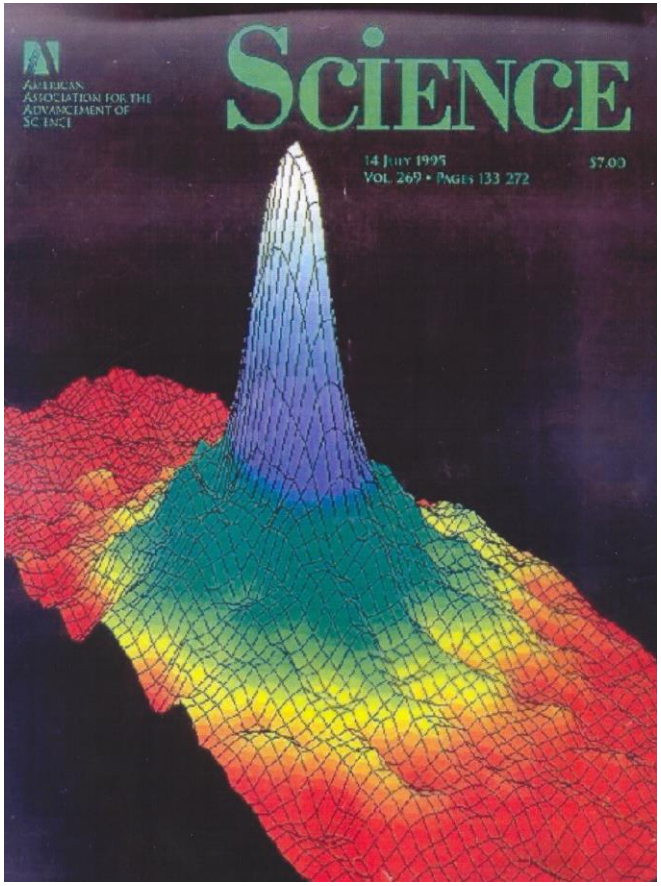
Past research activity…

- **The very original idea of Bose and Einstein was first realized in 1995 at JILA in the groups of Cornell and Wieman and MIT in the group of Ketterle, after cooling trapped ^{87}Rb and ^{23}Na atomic gases down to nK temperatures below the threshold for BEC**

- **The vapour was kept in metastable state (dilute gas) against the formation of drops. The required low T and high n were obtained after using a combined technique of laser cooling, magnetic trapping and evaporative cooling**

- **Opened terrific perspectives for fundamental physics and applications under highly controllable conditions, with nonlinearities from tunable interactions and external drivings**



➢ **This has opened terrific perspectives for fundamental physics and applications under highly controllable conditions, since ultracold atomic gases:**

❖ **can be driven by tunable intrinsic (e.g. atomic interactions) and/or extrincsic (e.g. external fields) nonlinearities**

❖ **their chracterizing dimensionality, interaction strength (making them also noninteracting, a=0, by Feshbach resonance mechanism) and temperature are separately tunable**

❖ **their quantum state can be manipulated and addressed with high precision: from coherent to squeezed to topological states, in the future may be also Schroedinger-cat states,…**

❑ **One of the first basic questions was: how to extract the physical quantities from the primary exp information, that is the optical imaging (absorption or dispersion) and thus the density profile after switching off the trap and expansion?**

- **Temperature: fit from the wings of the distribution (Maxwell-Boltzmann, noncondensed gas)**
- **N: from the 0-th moment of the density distribution**

- **Kinetic energy: from $\langle r^2 \rangle$ in ballistic expansion because**

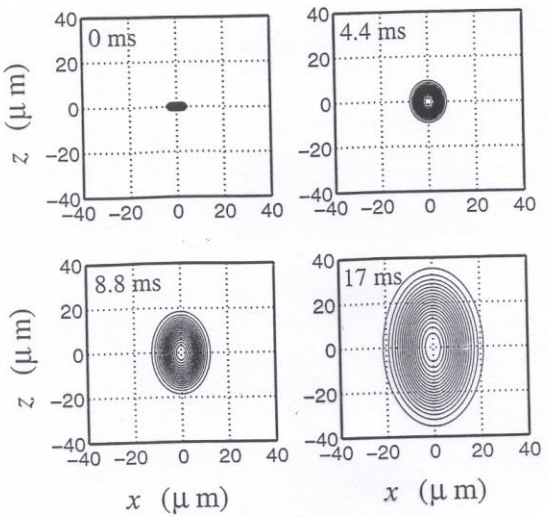
$$\langle r^2 \rangle \langle p^2 \rangle \geq |\langle r \mathrm{g} p \rangle|^2 = \frac{1}{4} |\langle \{r, p\} + [r, p] \rangle|^2$$

$$\frac{1}{2} m \left(\frac{\partial \langle r^2 \rangle}{\partial t} \right)^2 = \frac{1}{8m \langle r^2 \rangle} \langle r \mathrm{g} p + p \mathrm{g} r \rangle^2 = \frac{\langle p^2 \rangle}{2m} = E_k$$

Expanding cloud: numerical solution of the GPE equation for the condensate wf. Ψ(r,t)

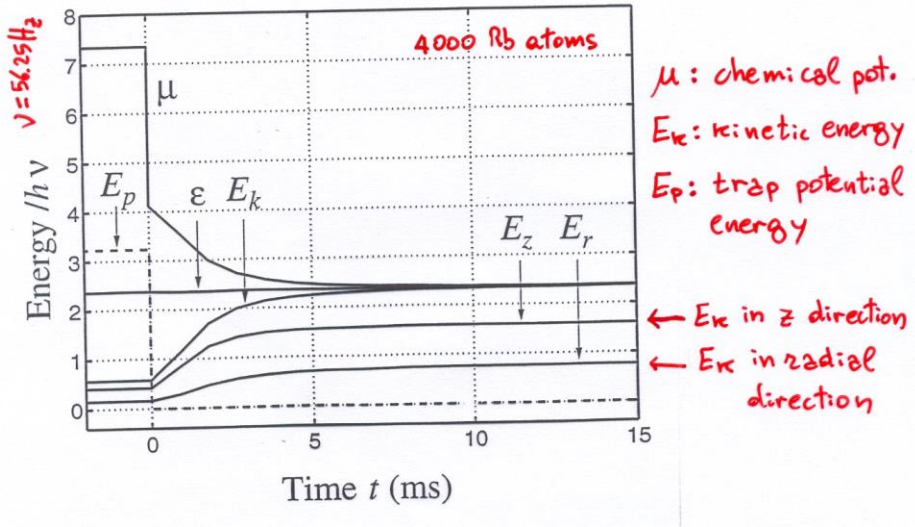
$$i\hbar\frac{\partial\Psi(r,t)}{\partial t}=[-\frac{\hbar^2\nabla_r^2}{2m}+V_{trap}(r)+\frac{4\pi\hbar^2 aN}{m}|\Psi(r,t)|^2]\Psi(r,t)$$

Expanding cloud : numerical solution of GPEq.



- Release energy, $\mathcal{E} = E_K + E_{int}$

$\mathcal{E} \sim \frac{1}{2} E_{TOT}$ → measure of the internal energy



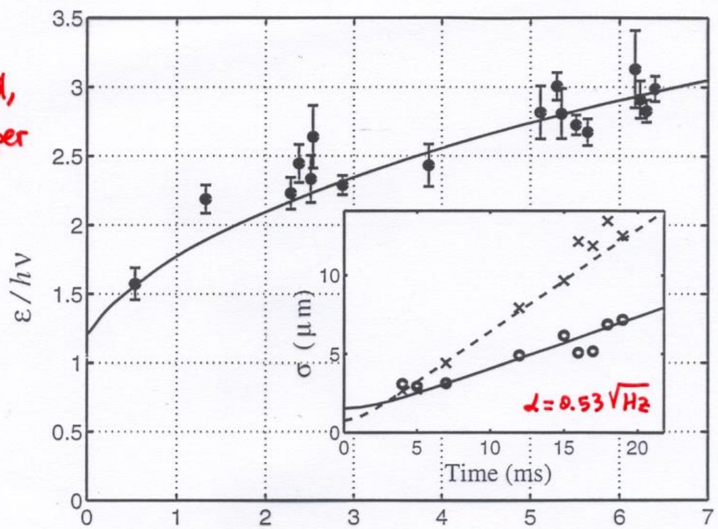
Past research activity…

- Comparison between theo and exp.

ε and σ

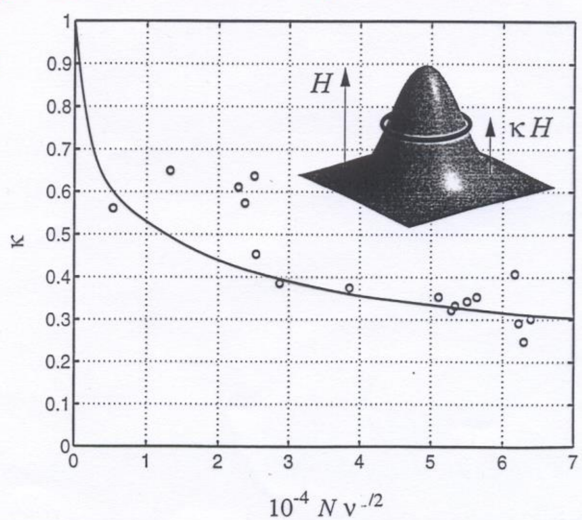
M. Holland, D.S. Jin, M.L. Chiofalo, J. Cooper PRL (1997)

(JILA data)



$\alpha = 10^{-4} N \nu^{1/2}$ ← Interaction strength parameter

- **Note**: no effective fitting parameters!
- Kinetic energy effects are important even for the most interacting clouds!!



➢**This method has been used and is currently in use at JILA to analyse the experimental data**