Measurement of the spatial coherence of a trapped Bose gas at the phase transition

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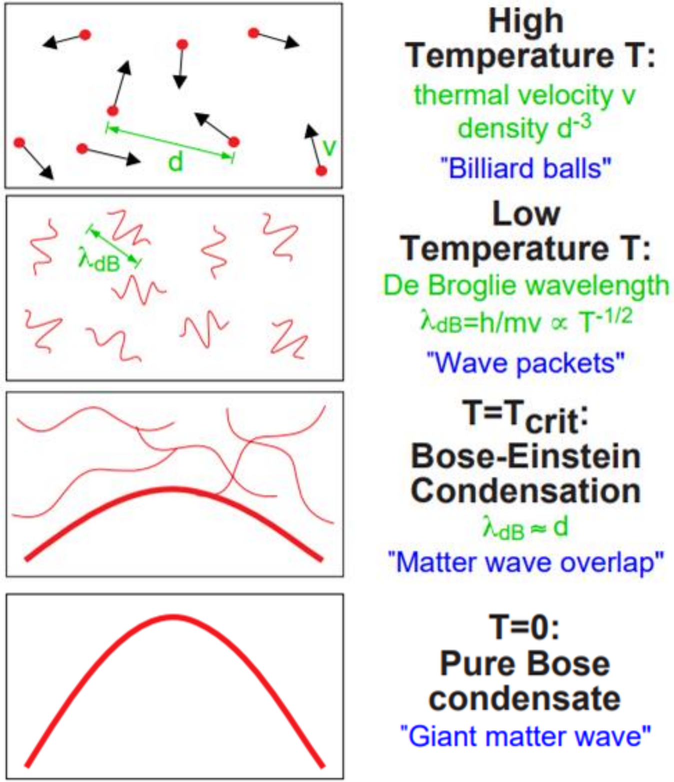
ref:Bloch, I., et al. “Measurement of the Spatial Coherence of a Trapped Bose Gas at the Phase Transition.” Nature, vol. 403, no. 6766, 2000, pp. 166–170., doi:10.1038/35003132.

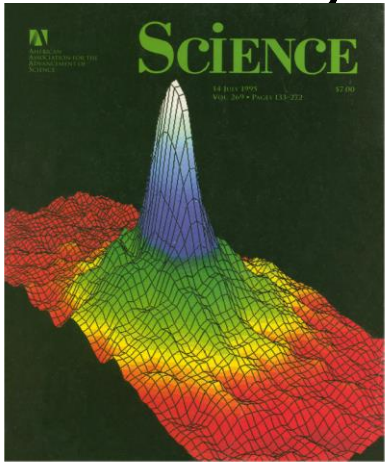
Wave coherence in Bose-Einstein Condensate (BEC)

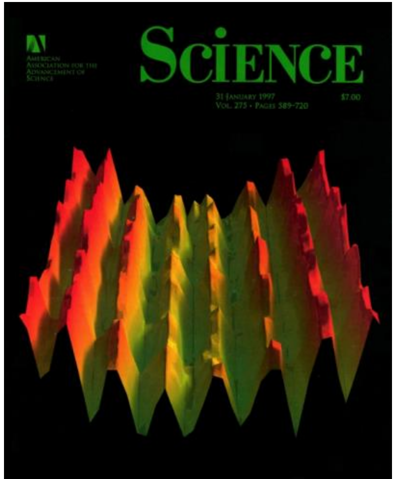
- Authors want to experimentally create a BEC
- They want to study the temperature dependence of the BEC coherence and long-range interference



ref:Durfee, Dallin S., and Wolfgang Ketterle. “Experimental Studies of Bose-Einstein Condensation.” Optics Express, vol. 2, no. 8, 1998, pp. 299–313.

Discovery of Bose-Einstein Condensate (BEC)





- In 1995 B-E condensation was first observed via evaporative cooling of Ru-87

- In 1997 coherence and long-range interference shown qualitatively among condensates

- In 1999 spectroscopy showed B-E condensate has a coherence length equal to its size

- Previous experiments were mostly concerned with temperatures well below critical temperature.

ref:Anderson, M. H., Ensher, J. R., Matthews, M. R., Wieman, C. E. & Cornell, E. A. Observation of Bose-Einstein condensation in a dilute atomic vapor. Science 269, 198±201 (1995).

Andrews, M. R.et al. Observation of interference between two Bose condensates. Science 275, 637±641 (1997).

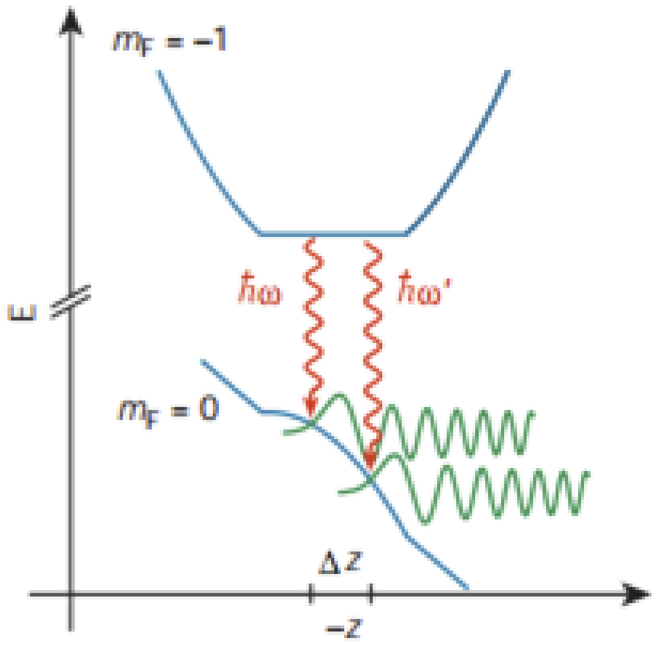
Stenger, J. et al. Bragg spectroscopy of a Bose±Einstein condensate. Phys. Rev. Lett. 82, 4569±4573 (1999).

Goals of the experiment:

- BEC is "laser-like" and exhibits spatial coherence. As such, two coherent BEC sources can exhibit interference patterns. Bloch *et al.* set out to **observe and measure the interference pattern of the Bose-Einstein condensates**.
- Near the critical Temperature, T_c, the coherence range changes quickly. This experiment also sought to **measure the spatial range of coherence below and above T_c.**

Potential Setup of the Experiment

- Set up potential with magnetic field and gravitational field
- Magnetic field traps nonzero m_F atoms
- Gravitational potential dominates zero m_F states
- Distortion occurs because of condensates interaction

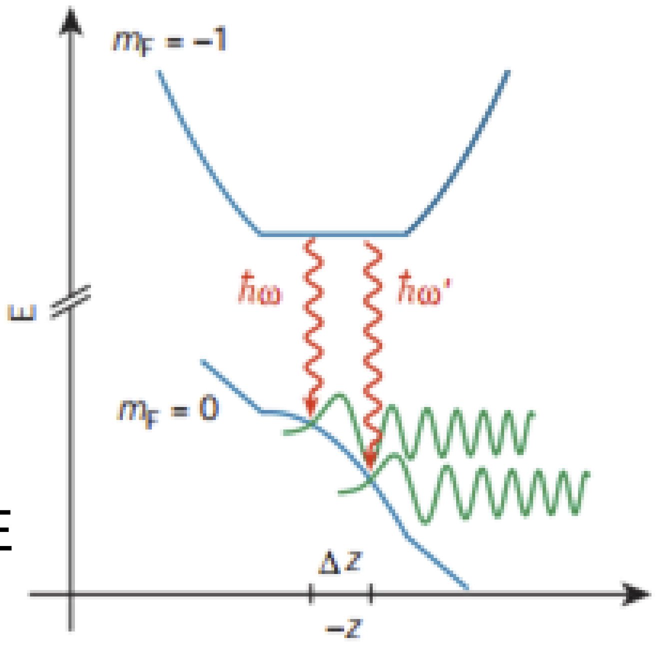


Experiment Setup Diagram

Motion of Atoms in m_F=0 state

- Solution in gravitational potential:

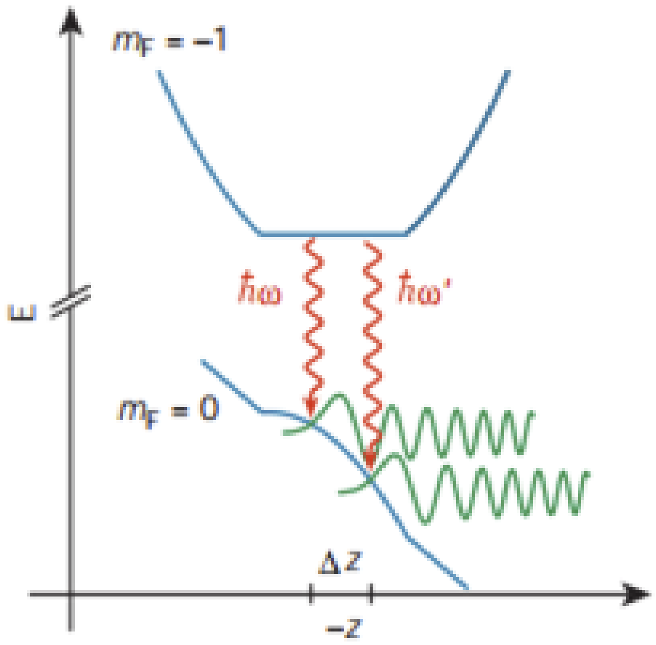
  $\xi = (z-E/mg)/l, \quad \phi_{out} \sim |\xi|^{-1/4} \exp(i(3/2)|\xi|^{2/3})$
- “Frequency” in z only depends on natural length scale l
- Phase only depends on origin, energy E and natural length scale



Experiment Setup Diagram

Method of experiment

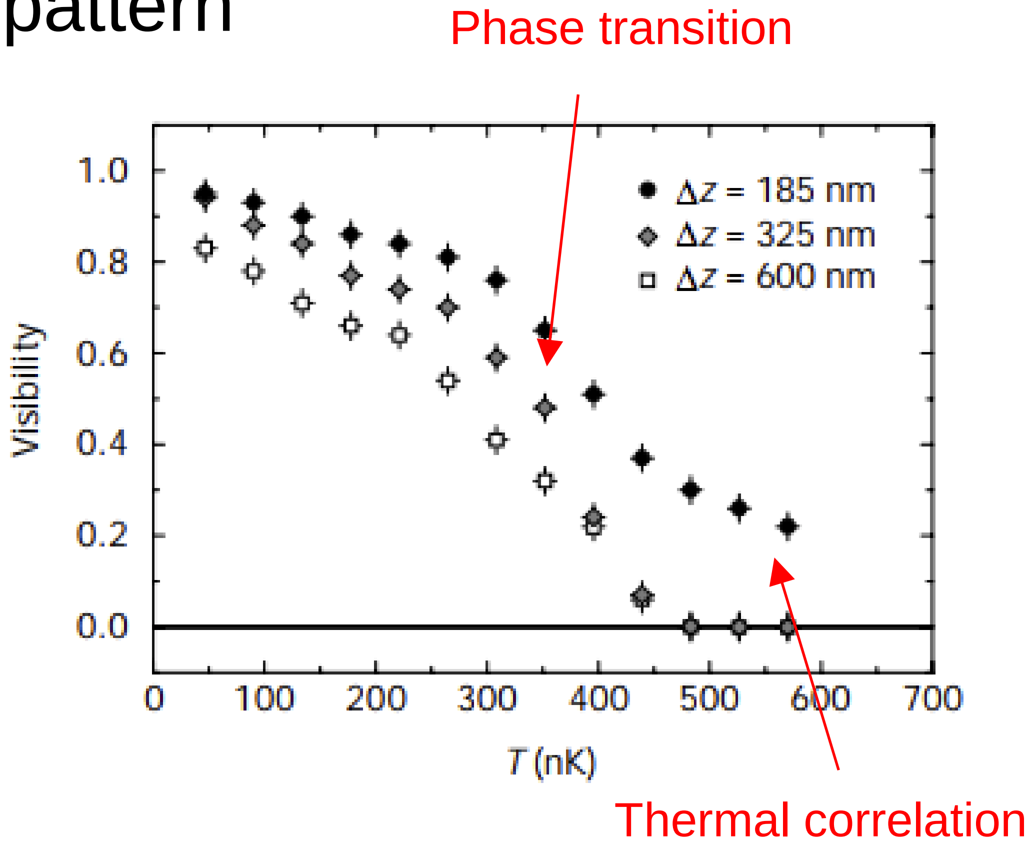
- Optically pump Rubidium-87 atoms to m_F=-1 level
- Use two different frequency EM wave perturbation to free particles
- Two different free locations: double slits
- Bose-Einstein condensation fixes phase difference between two releasing position



Experiment Setup Diagram

Visibility of interference pattern

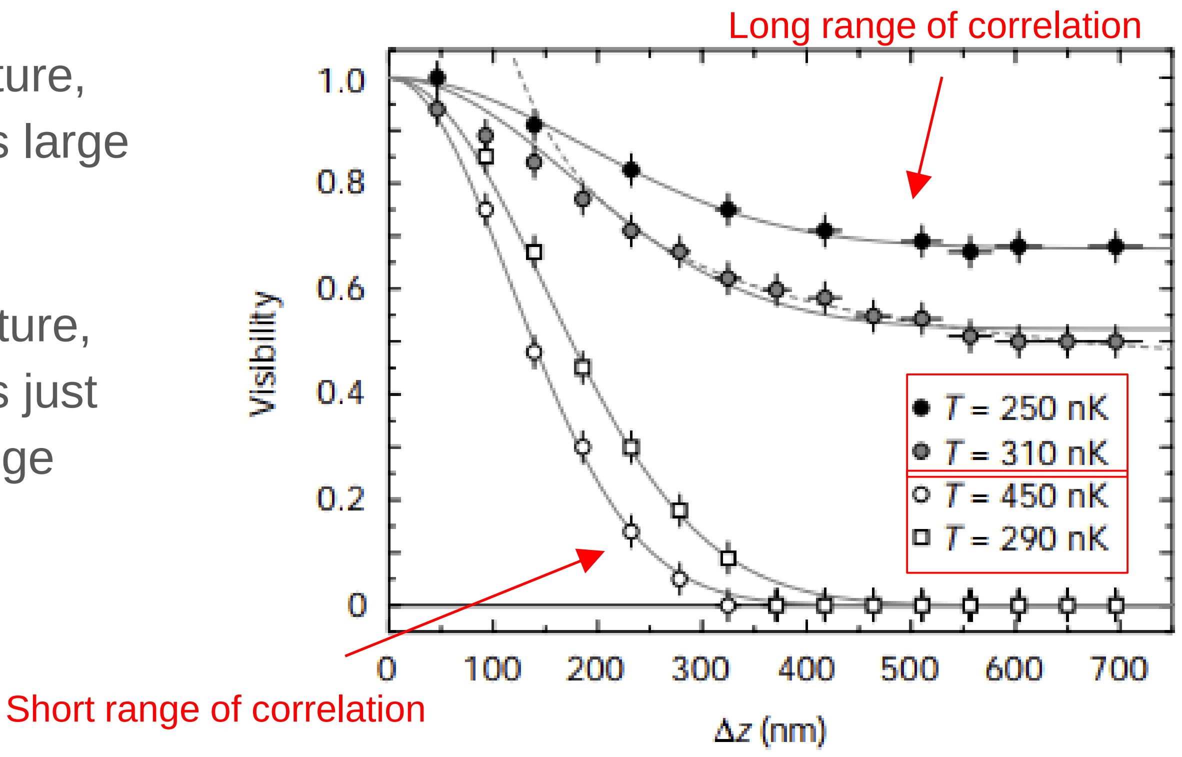
- Transition occurs around 400 nK (critical temperature)
- Does not vanish for 185 nm width is due to thermal correlation.



Measured correlation function

- Below critical temperature, the coherence range is large (>700 nm)

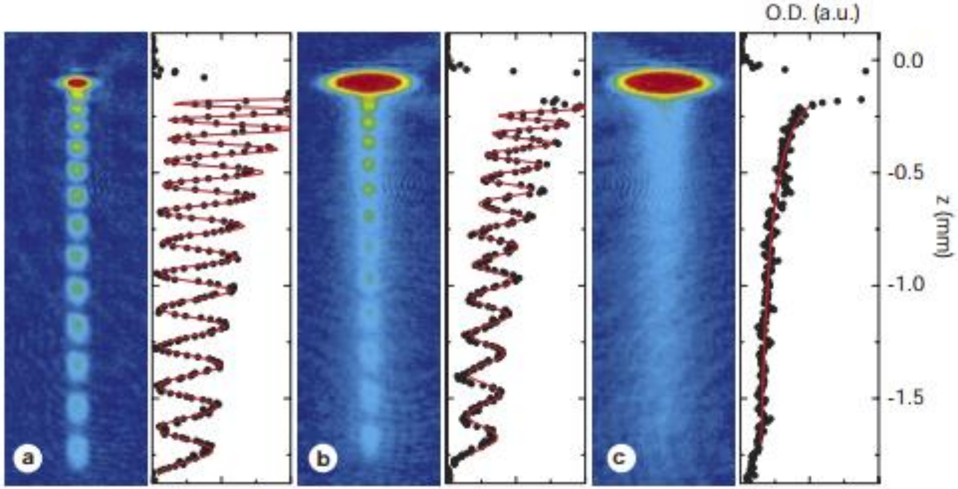
- Above critical temperature, the coherence range is just thermal correlation range (5% difference from theoretical value)



Measurable interference patterns of BEC

We and the author share the same conclusion:

Bose-Einstein condensation can increase coherence spatial range as all atoms are in the same state and share the same information.



Interference pattern of Bose Einstein Condensates

Critiques

Pros:

- Article presents a precision test of BEC theory
- Direct measurement of coherence between matter waves
- Previous experiments used only the free BEC, whereas this experiment measured the trapped Boson gas

Cons:

- While no groundbreaking results were presented, the article provided further experimental confirmation of several key aspects of BEC theory

Citations & Impact

Since its publication in 2000, *Measurement of the spatial coherence of a trapped Bose gas at the phase transition* has been cited 218 times. Two examples below.

Many-body physics with ultracold gases

- Bloch, I., Dalibard, J., Zwerger, W., 2008
- Reviews of Modern Physics, 80 (3), pp. 885-964
- A review paper covering the advances in the study of many-body phenomena via the use of ultracold gases
- Cited 3870 times since publication in 2008.

Bose-Einstein condensation of exciton polaritons

- Kasprzak, J., Richard, M., Kundermann, S.
- Nature, Volume 443, Issue 7110, 28 September 2006, Pages 409-414
- Creation of BEC from “exciton polaritons”
- Opens the door for BEC occurring at cryogenic temperatures.
- Measurement of an interference pattern shows that a high occupation of the ground state was achieved.

Summary

BEC was experimentally realized in 1995

Key aspects of BEC theory include phase coherence and state transition at critical temperature.

Bloch *et al.* presented a direct measurement of the phase coherence properties of a weakly interacting Bose gas of Rb atoms.

Above the critical temp, the correlation function shows a rapid Gaussian decay. The correlation function has a slow decay towards a plateau (long range phase-coherence), as expected.