More News from Flatland: a 2D Bose gas at NIST

W. D. Phillips, P. Cladé, C. Ryu, A. Ramanathan, K. Helmerson

Joint Quantum Institute, University of Maryland and National Institute of Standards and Technology, Gaithersburg MD 20899-8424

Theoretically, a uniform, interacting, Bose gas in two dimensions is known to undergo a phase transition from a non-superfluid to a superfluid at a non-zero temperture $T_{\rm BKT}$. This Berezinski-Kosterlitz-Thouless transition occurs in a gas, a quasi-condensate without long-range order, and results in a first-order (field-field) correlation function that decays to zero at large separation only as a power law. For $T > T_{\rm BKT}$ the quasi-condensate is non-superfluid, and is fractured by free vortices into regions of near-uniform phase whose size, near $T_{\rm BKT}$, is larger than the themal deBroglie wavelength $\lambda_{\rm th}$, leading to a correlation function that decays to zero exponentially, but over a distance larger than $\lambda_{\rm th}$. For higher temperatures the gas becomes "thermal" and the correlation function decays over a distance on the order of $\lambda_{\rm th}$.

Experiments with ^{4}He films have seen signatures of the BKT transition [1]. More recently, important features of this BKT physics have been observed in experiments with a trapped (non-uniform) atomic Bose gas at the Ecole Normale Supérieure-Paris [2] [3]. Those latter experiments observed the interference between two or more planes of atoms. Changes in the contrast of interference fringes and the appearance of a bimodal density distribution after time-of-flight were seen as evidence of the BKT transition.

Using a single plane of optically trapped Na atoms (quasi-2D in the sense that there are some thermal excitations in the tight confinement direction), we have observed interference within that single plane by creating two interfering "copies" of the atomic gas using successive Raman scatterings with momentum transfer. We measure the correlation function and see a clear evolution from a thermal gas to a quasi-condensate as the atomic density increases. We also observe the density distribution after a period of time-of-flight, a procedure that in our case reveals both bimodal and trimodal distributions. We identify both the appearance of a trimodal distribution, and an abrupt discontinuity of the rate of change of the distribution width with density, as signatures of the BKT transition. Our identification of the transition point for various temperatures is in excellent agreement with theoretical predictions [4] taking into account thermal excitations in the tight confinement direction [5]. We unambiguously see a bimodal distribution in a regime where $T > T_{\rm BKT}$, the regime of the previously unobserved non-superfluid quasi-condensate.

[1] D. J. Bishop and J. D. Reppy, Phys. Rev. Lett. **40**, 1727 (1978)
[2] Z. Hadzibabic, et al., Nature **441**, 1118 (2006)
[3] P. Krüger, et al., Phys. Rev. Lett. **99**, 040402 (2007)
[4] N. Prokof'ev, et al., Phys. Rev. Lett. **87**, 270402 (2001)
[5] M. Holzmann, et al., Europhys. Lett. **82**, 30001 (2008)