

Single shot phenomena in quantum atom optics

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A recent trend in ultracold atom physics has been to look into phenomena that are not describable by the usual single particle observables or low order correlation functions. They can be called “single-shot phenomena” by virtue of being visible only when single realizations of the system are individually analyzed.

Recent prominent experimental examples include the study of the full distribution of phase contrast between two elongated quasicondensates [1] and the detection of spontaneously formed defects in single realizations [2]. Interesting cases studied theoretically include the prediction of a soliton phase in the 1D Bose gas in which solitons are created and destroyed spontaneously within a thermal gas [3], or the widespread formation of solitons and phase domains after disturbances of the temperature or interaction strength [4, 5].

Ultracold atoms, particularly bosons are amenable to this, by virtue of the fact that the majority of the system can be described with highly occupied bosonic modes. On the other hand they bear many common features with photonic quantum optics, such as being widely described by a Hamiltonian with a Kerr nonlinearity that describes the inter-atomic interactions.

Imaging of an atomic cloud corresponds to the simultaneous measurement of the position of a large proportion of the atoms. While in the early years of ultracold atom physics this could be taken to be selfsame with a measurement of the usual quantum mechanical density averaged over the *ensemble*, there are increasingly many experimental and theoretical studies that involve fundamentally single-shot phenomena. For example, the effect of spontaneously formed many-body defects such as solitons or vortices is completely washed out in the ensemble-averaged density because of their random position in each realization. However, they can be very well visible in images from each single experimental run.

This shows that one should distinguish ensemble-averaged single particle measurements from spatially resolved single-shot measurements when many-body correlations are important. Under such conditions, different runs of the experiment (i.e. independent samples from the ensemble) are indeed independent, but the location of individual atoms in a particular cloud is not.

Describing the behaviour of single shot phenomena poses a challenge for theory and simulation which have mostly been tailored to low-order observables over the history of quantum mechanics. Quantities such as the one-particle density give no useful information on randomly located many-body collective phenomena, while few-body

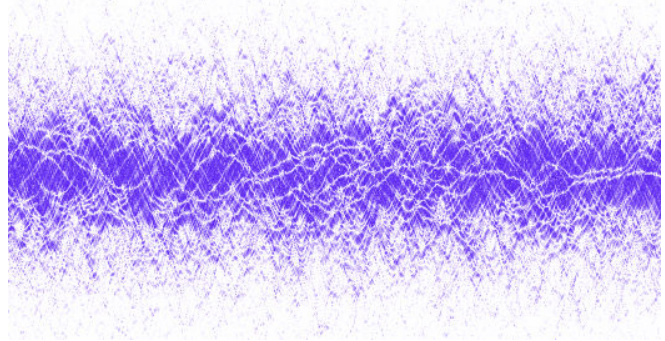


FIG. 1. Spontaneous solitons in the thermal state of a 1D trapped Bose gas, as shown by the time evolution of a single member of the ensemble. Time advances to the right.

correlation functions can even act as false friends [6].

I will elaborate on two physical examples:

- solitons appearing in samples of the equilibrium distribution[3], as seen in Fig. 1, and
- measurement of spontaneous phase defects in single shots of experiments similar to those reported in [1],

as well as on the methods used to study them:

- benchmarking the accuracy of the “classical field” approximation that is usually used [7, 8], and
- ways to include quantum and thermal fluctuations in such systems in a unified way. [9]

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