PhD Open Days

Information compression at a stable-to-turbulent phase transition in cold atomic gases

Advanced Program in Plasma Science and Engineering (*APPLAuSE*)

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The cold atom experiment

The study of phase transitions in complex systems has been a matter of extensive research for a long time. Recently, a possible extension of the methods used in thermodynamics to far-from-equilibrium scenarios has been proposed by resorting to information theory. In this context, a phase transition is interpreted as a manifestation of a phenomenon called **information compression**. By describing the state of a system by a field $\phi(\boldsymbol{r},t)$ and by some *effective temperature* δ, and given a complete and orthogonal basis for the space of square-integrable functions, the field can be uniquely identified by the projections onto the basis elements. The coefficients of the expansion can then be interpreted as the superposition of physical modes or as a spectrum of information, providing a link between both information and thermodynamic theories. Information compression is thus identified as the deviation from a uniform distribution (i.e., the state of maximum uncertainty state).

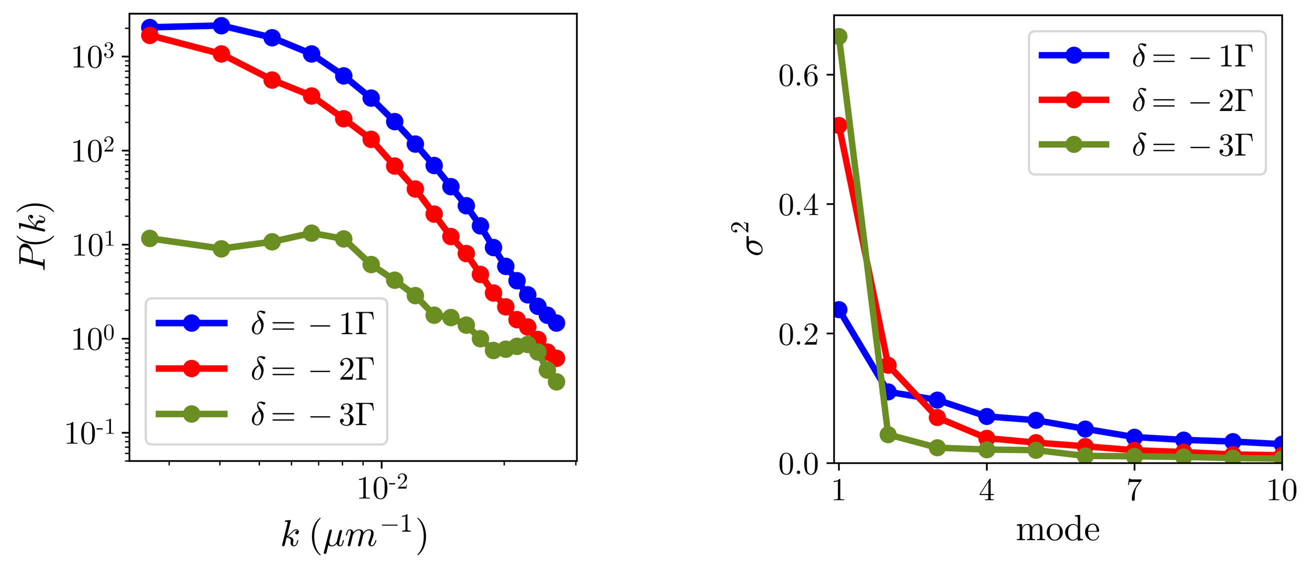

FIG 1: Average projection spectrum of two different basis, Fourier (left panel) and principal components (right panel), in the stable (green), transition (red) and turbulent (blue) regimes.

Here we report the **observation of information compression in the stable-to-turbulent phase transition of a quasi-2D cloud of ^{85}Rb atoms cooled at 200 μK**, occurring when the cooling laser frequency is set near an atomic transition. At such close-to-resonance condition, multiple scattering of light is responsible for collective forces between the atoms and photons propagate diffusively. As a result, the system goes into a turbulent phase of formation and bursting of quasi-coherent structures known as photon bubbles. We observe that:

- at the critical point, a sudden drop in the entropy arises. The system goes from a stable-symmetric phase to a turbulent one, where the global symmetry is lost and quasi-coherent structures emerge;
- at criticality the system spontaneously organizes, showing both a long-range local order and formation of oscillating global patterns.

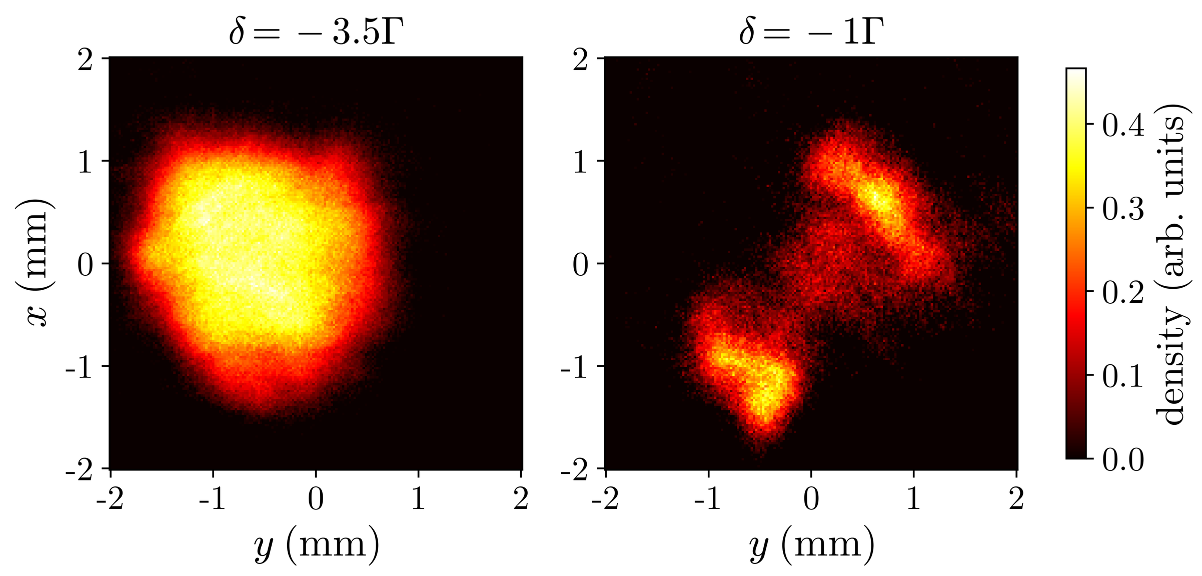

FIG 2: Snapshots of the atomic cloud density (which plays the role of the field ϕ) in the both the stable (left panel) and turbulent (right panel) phases. The detuning (δ) is defined as the difference between the laser and the atomic transition frequencies, and Γ is the transition linewidth.

Spectral and PCA decomposition

The modal decomposition was performed on two distinct basis: the standard spectral (or Fourier) basis, with modes labelled by wavevector $\boldsymbol{k}=(k_x,k_y)$ denoting well-defined oscillations with wavelength $\lambda=2\pi/|\boldsymbol{k}|$; and the so-called Principal Component (PC) basis, which provides the global spatial patterns associated with the most significant variation of the data set. Both basis are orthogonal and complete, hence each frame can be totally recovered by providing the projections onto each of the basis elements (see Fig. 1). We interpret each set of projection coefficients as a message encoded in each realization of the atomic cloud, in the light of information theory. Information compression is thus a characterization of how complex are each of the messages regarding mode dispersion.

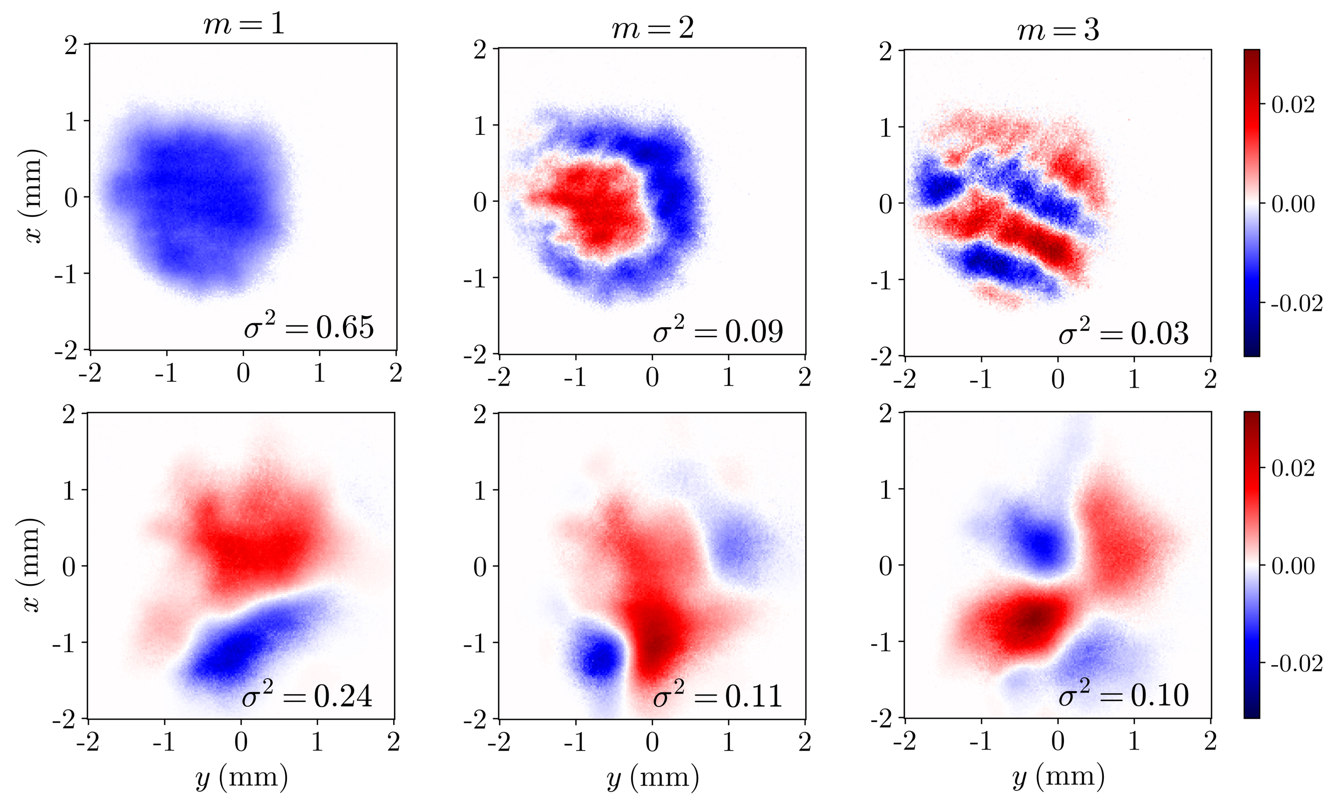

FIG 3: The first three principal components in the stable (top row) and turbulent (bottom row) regimes. In the stable phase, most of the information is contained in the first mode (the projection is close to one), which stems from the variation of the number of atoms. On the contrary, in the turbulent regime, a higher number of modes is necessary to accurately characterize the data set.

Below we show the entropy profiles calculated for both basis sets. We notice that, as the detuning is brought from the stable to the turbulent region, the entropy in the Fourier basis is reduced, due to the progressive loss of spatial symmetry. Conversely, the increase in the PC entropy is connected to the increase in the system dispersion across different spatial patterns. We thus say that the two basis are complementary: far from the critical point, high S_F implies low S_{PC} and vice versa. However, **we observe that the transition point can be interpreted as a state of maximum organization both in the spectral and spatial content.**

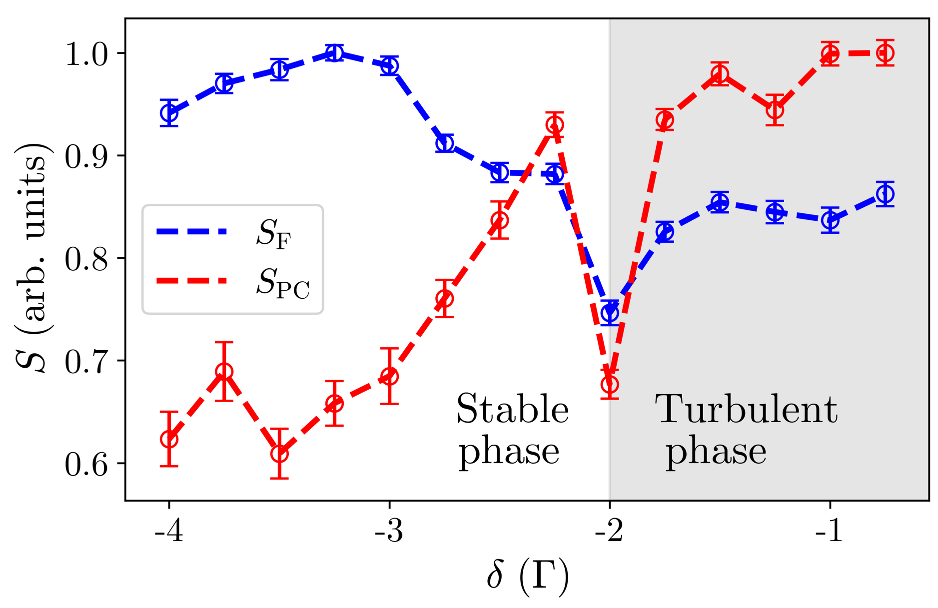

FIG 4: Entropy profiles vs. detuning for the Fourier and PC basis, both attaining a minimum at criticality, which can be interpreted as organization (compressibility) along the different basis. Given a set of normalized projections $\{p_i\}$, we calculate the entropy using $S=-\sum_i p_i \log(p_i)$

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