

Supplementary material: Imaging the collective excitations of an ultracold gas using statistical correlations

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We provide here supplementary material to support the results and conclusions of our paper.

Figure S1 shows the result of a Thomas-Fermi fit[1, 2] to the experimental data for the data set of figure 2. While the center of mass oscillations are correctly extracted, the angle of the cloud shows no clear oscillating time variation, as would be expected for a scissors excitation[3]. For this particular experiment, PCA is able to extract more information on the system than a fitting procedure, see figure 3.

Figure S2 displays the time dependent weights of the simulated density profiles on the first five principal components. We empirically find that components with a variance above 1% of the total variance follow a sinusoidal oscillation, while components with a smaller variance are not well identified and do not oscillate at a single frequency.

Figure S3 shows a Fourier analysis of the simulated density profiles. Because of the finite time sampling only discrete frequencies are present in the analysis. The scissors-like and monopole-like density profiles are spread over several frequency components: this FFT method is thus less efficient to decorrelate the modes than PCA, for this particular time sampling. Obviously by choosing a better time sampling the FFT signal could be optimized.

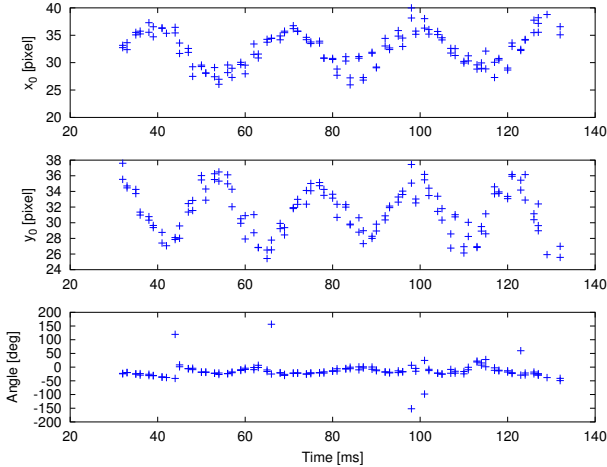


FIG. S1. Supplementary material image. Center of mass of the cloud and angle of the density profile extracted from a Thomas-Fermi fit of the experimental images. The angle shows no clear oscillation. The relative noise on the cloud positions is of the same order of magnitude as the noise on the PCA computed weights.

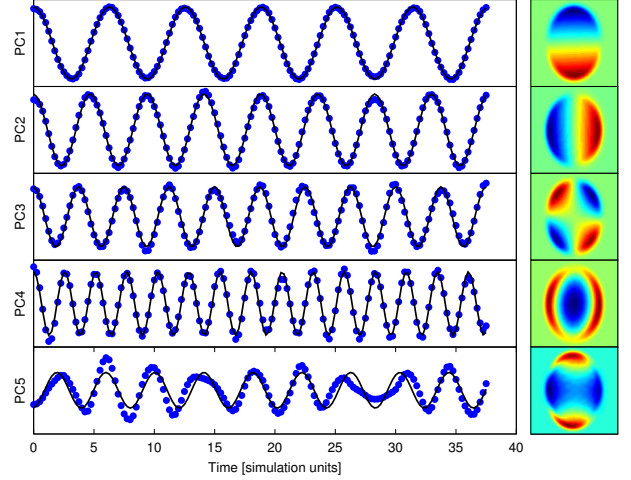


FIG. S2. Supplementary material image. Time dependent weight of the simulated density profiles on the first five principal components (filled blue circles) and fit by a sinusoidal model (black solid line).

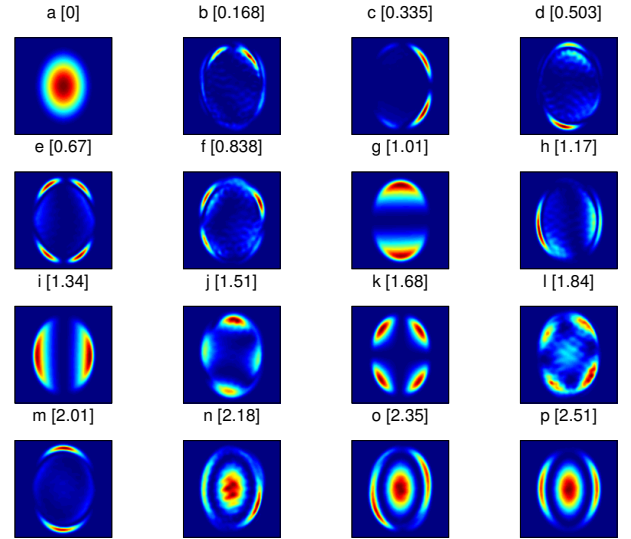


FIG. S3. Supplementary material image. Fourier transform analysis of the simulated data set. One can identify the excited modes, but the analysis is complicated by frequency aliasing. Moreover the monopole-like mode is spread over multiple frequencies. The number between square brackets gives the discrete frequency, in units of ω_x .

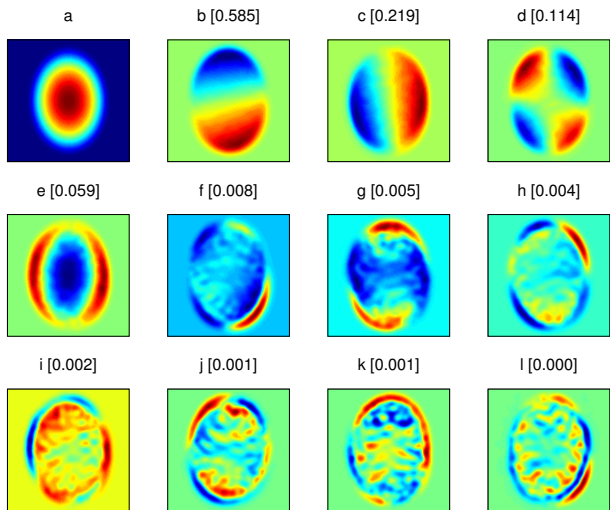


FIG. S4. Supplementary material image. PCA for a set of 15 simulated density profiles using a sparse time sampling. In particular for the monopole-like PC (figure e), there is on average less than one sampling point per period.

However PCA provides a more straightforward method to identify multiple excitations, with less constraints on the data sampling.

Figure S4 displays the result of PCA applied to the simulated density profiles where the result of the simulation has been undersampled by keeping only one image out of ten. PCA is still efficient and identifies four modes with 96% fidelity out of the five dominantly excited modes.

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- [1] Castin Y and Dum R 1996 *Phys. Rev. Lett.* **77**(27) 5315–5319 URL <http://link.aps.org/doi/10.1103/PhysRevLett.77.5315>
- [2] Kagan Y, Surkov E L and Shlyapnikov G V 1996 *Phys.*

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- [3] Guéry-Odelin D and Stringari S 1999 *Phys. Rev. Lett.* **83**(22) 4452–4455 URL <http://link.aps.org/doi/10.1103/PhysRevLett.83.4452>