Atomic-Density Based Optimization of Arbitrary 2D Optical Potentials:
Applications in vortex dynamics and phase imprinting of supercurrents

Guillaume Gauthier[1], Thomas Bell[1], Yevgeni Bondarchuk[1], Matthew Davis[1], Halina Rubinsztein-Dunlop[1], Mark Baker[1], Tyler W. Neely[1]

[1]ARC Centre of Excellence for Engineered Quantum Systems (EQuS), School of Mathematics and Physics, University of Queensland, Brisbane 4072, Australia.

Advances in the control over novel trapping potentials has been a driving factor behind the development of the cold atoms field. As such, the direct imaging of a digital micromirror device (DMD) onto a plane has become a popular technique which has expanded the range of dynamic potentials available for 2D cold atom experiments [1]. One of the drawbacks of this technique is that direct imaging does not allow for correction of aberrations in the projecting optical system, and non-uniformity and imperfections in the illumination field cause imperfection in the projected potential. To this end, we have developed a density-based feedforward optimization technique which uses the grayscaling and dynamic capabilities of the DMD to correct imperfections in the projected trapping potential. This technique can be used to correct for non-uniformity in the trapping potential (See Fig. 1), with unprecendented control over the trapping landscape.

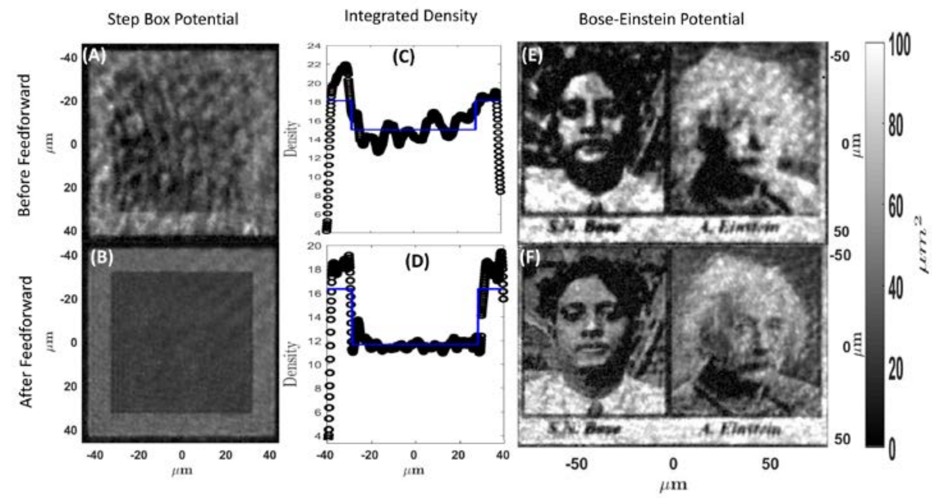
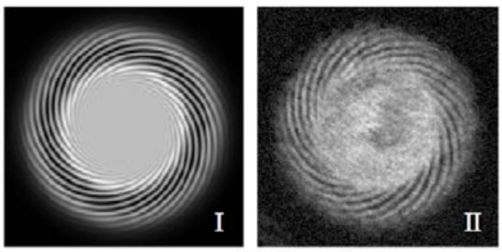


Figure 1: Experimental atomic density (A) of initial guess as to the "optimal" DMD pattern to create 2 grey level boxes and (B) after feedforward. (C,D) are the mean integrated atomic density profiles of (A,B). (E,F) are as per (A,B) but for the creation of an atomic density pattern depicting Bose (Left) and Einstein (Right).

In recent work, with this system we have studied the dynamics of long-lived Onsager vortex clusters in 2D reservoirs of a BEC superfluid [2]. Here we present our successful demonstration of phase imprinting of a supercurrent in a ring BEC, which makes use of the applying an azimuthal gradient in the DMD potential landscape, to generate a large phase windings (Fig. 2). Our hybrid method simultaneously and continuously imprints phase while adiabatically stirring. Our preliminary work demonstrates windings q = 21 using 300 ms acceleration.



References

[1] G. Gauthier, et al, *Optica* **3**,1136 (2016).
[2] G.Gauthier, et al, arXiv:1801.06951
[3] A. Kumar et al, *Phys. Rev. A* **97**, 043615 (2018)
[4] L. Corman, et al, *Phys. Rev. Lett.* **113**, 135302 (2014).

Figure 2: (I) Numerical simuation and (II) experimental demonstration of our scheme for imprinting a n=21 quanta supercurrent onto a 40 um radius ring condensate, imaged at 8 ms time-of-flight. The ring is interfered with a target condensate, which acts as a phase reference for the interference [4]