On Demand Formation of Polar Core Vortices in Ferromagnetic Spinor Bose Einstein Condensates

Zachary Kerr[a], Guillaume Gauthier[a], Halina Rubinsztein-Dunlop[a], Tyler W. Neely[a], Matthew J.Davis[a,b]

[a]*Australian Research Council Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, St. Lucia, QLD 4072, Australia.*

[b]*Australian Research Council Centre of Excellence in Future Low-Energy Electronics Technologies, School of Mathematics and Physics, University of Queensland, St Lucia, QLD 4072, Australia.*

Spinor BECs are Bose-Einstein condensates (BECs) where all the spin states, for example $\{m_F = +1, 0, -1\}$ for a spin-1 system, are accessible [1]. These novel ultracold atomic systems can exhibit both ferromagnetic and antiferromagnetic order and thus offer enhanced opportunities for exploring phenomena beyond those accessible in scalar BECs, such as new classes of topological defects [2]. The polar core vortex (PCV) is one such topological defect occurring in the easy-plane phase of ferromagnetic spinor BECs. A PCV exhibits quantised spin circulation with zero mass circulation, with a vortex core populated with unmagnetized atoms in the $|F = 1, m_F = 0\rangle$ state. These properties lead to the PCV exhibiting unusual dynamics. While the dynamics of a vortex in a scalar BEC approximate those of a point-like structure with no mass, PCVs are predicted to behave like massive charged particles in a two-dimensional Coulomb potential [3].

PCVs were first experimentally observed by Sadler et al. in 2006 [2], where the vortex spontaneously formed following a magnetic field quench. Due to this non-deterministic nature of creating PCVs, further experimental study of their properties and dynamics has been limited. Controlled creation of PCVs will enable such studies, including few-body PCV dynamics, PCV driven spin turbulence, and help to determine the thermodynamic equilibrium properties of PCV ensembles. In this work, we describe our efforts to realise on-demand PCV creation in quasi-2D ^{87}Rb spinor BEC with uniform density, created in an optical trap enabled by digital-micromirror devices (DMDs) [4].

[1] D . M. Stamper-Kurn, et al, Optical Confinement of a Bose-Einstein Condensate, Phys. Rev. Lett. 80 (1998) 2027–2030.

[2] L. E. Sadler, et al, Spontaneous symmetry breaking in a quenched ferromagnetic spinor Bose-Einstein condensate, Nature 443 (2006) 312.

[3] Williamson, L.A., Blakie, P.B.: Phys. Rev. Res 3, 013154 (2021)

[4] G. Gauthier et al, Direct imaging of a digital-micromirror device for configurable microscopic optical potentials. Optica 2016, 3, 1136–1143.doi:10.1364/OPTICA.3.001136.