A line of Dirac monopoles embedded in a BEC

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INTRODUCTION

In a seminal experiment the Spielman group have imprinted a magnetic field onto a BEC [1]. We take advantage of the flexibility presented by their setup to create a magnetic field configuration not possible in a physical system: a line of magnetic monopoles. This presents a unique opportunity to study the motion of a charged particle around a monopole. Here we:

- Outline the experimental scheme to create the monopolar field
- Uncover a transition in the ground state vortex structure
- Demonstrate how the collective modes expose the underlying behavior

The proposed experimental geometry is shown in Fig. 1. Applying Gaussian-Laguerre beam lasers transfers angular momentum to an atomic gas with the energy levels shown in Fig. 2. This dresses the gas with the effective gauge field $\mathbf{A} = \hbar\ell\cos\theta\mathbf{e}_\phi/\rho$, so that the effective magnetic field shown in Fig. 3 acts on the BEC.

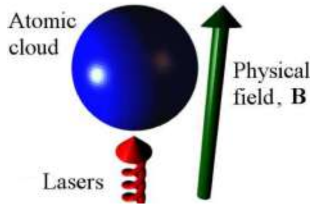

Fig. 1. Geometric scheme: two Gaussian-Laguerre beams illuminate the atomic gas

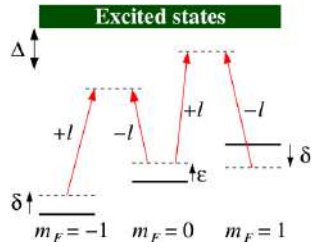

Fig. 2. The energy levels for the three-level system

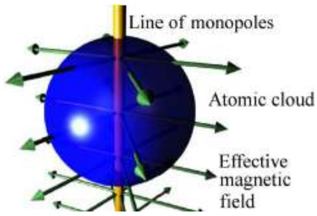

Fig. 3. The effective magnetic field realized

PHASE BEHAVIOR

In Fig. 4 when there are 4 monopoles trapped the flux escapes solely out of the top and bottom of the cloud. On increasing the trapped monopoles to 12, flux starts leaking out of the sides of the cloud, with 6 quanta still leaving out of the top/bottom. When 55 monopoles are trapped the majority of flux escapes out of the cloud walls.

As seen in Fig. 5 a transition from flux escaping out the top/bottom of the cloud to through the cloud walls emerges when ~6 monopoles are trapped. This occurs when the energy cost of having multiple flux quanta escaping along the same vortex line exceeds the energy cost of a longer vortex exiting out of the side of the cloud.

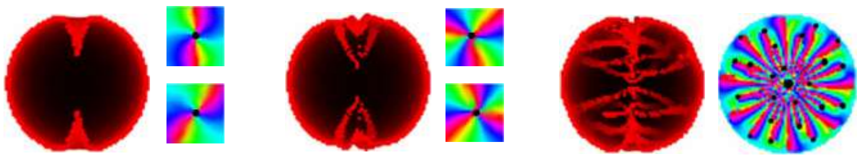

Fig. 4. The isopycnals of the BEC with (left) 4 embedded monopoles, (center) 12 monopoles, and (right) 55 monopoles. The hue-indexed phase maps reveal the number of flux quanta escaping along the vortices

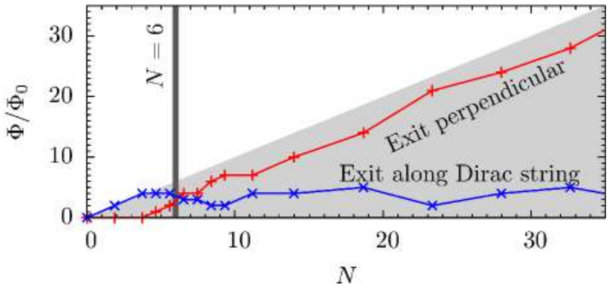

Fig. 5. The renormalized flux Φ/Φ_0 exiting through the top and bottom of the cloud (blue), and (red) through the cloud walls with number of embedded monopoles N

DYNAMICAL MODES

The collective modes in Fig. 6 expose further signatures of the transition.

With no trapped monopoles the mode frequencies are those of the trapping potential, which are then split due to the cylindrical symmetry. When many monopoles are trapped the mode frequencies are those of a 2D sheet penetrated by vortices.

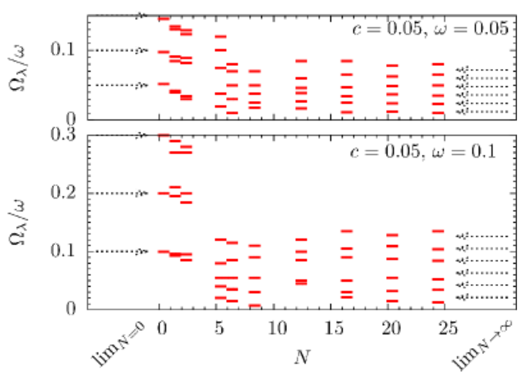

Fig. 6. Collective mode spectra with number of embedded monopoles N. The lower plot is for a gas with double the trapping frequency ω

CONCLUSIONS

- We have proposed an experimental scheme to embed a line of monopoles into a BEC
- The escaping flux undergoes a transition when ~6 flux quanta are trapped
- The collective mode frequencies reveal phase behavior that could help characterize the flux escaping from the system

[1] Lin *et al.*, Nature **462**, 628 (2009)