Giant Vortex in a Harmonically-Trapped Rotating Dipolar ^{164}Dy Condensate

S K Adhikari[1] and L E Young-S[2]

[1] *Institute of Theoretical Physics, Universidade Estadual Paulista, São Paulo, Brazil*
[2] *Departamento de Física, Facultad de Ciencias Exatas e Naturales , Universidade de Cartagena, Cartagena de Indias, Colombia*
Contact Email: sk.adhikari@unesp.br

A harmonically-trapped strongly dipolar quasi-three-dimensional (quasi-3D) Bose-Einstein condensate (BEC) of ^{164}Dy atoms can have an eigenstate in the form of a hollow cylinder with ring topology aligned along the polarization z direction of the dipolar atoms [1]. We demonstrate that if this hollow cylindrical BEC is rotated around the polarization direction, it can host giant vortices of angular momentum l greater than unity ($l > 1$) [2]. This theoretical investigation is based on the numerical solution of an improved mean-field model including a Lee-Huang-Yang-type interaction, meant to stop a collapse at high atom density. These giant vortices are stationary, obtainable by imaginary-time propagation using a Gaussian initial state, on which the appropriate phase of the giant vortex is imprinted.

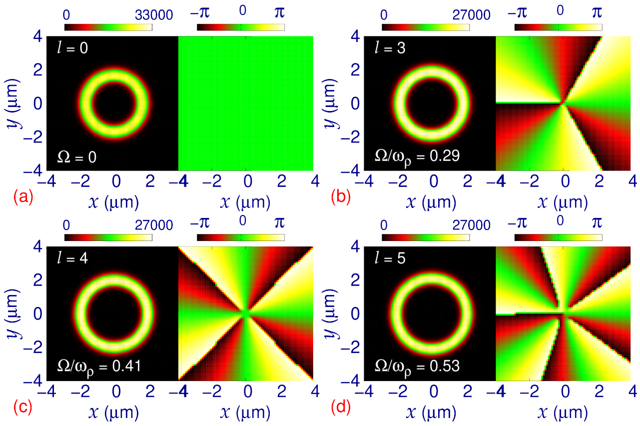

Figure 1: Contour plot of quasi-2D density $n_{2\text{D}}(x,y)$ (left panel) and phase of the wave function $\psi(x,y,0)$ (right panel) of the giant-vortices of angular momentum and angular frequency of rotation (a) $l = 0, \Omega = 0$, (b) $l = 3, \Omega/\omega_\rho = 0.29 = 2\pi \times 36$ Hz, (c) $l = 4, \Omega/\omega_\rho = 0.41 = 2\pi \times 51$ Hz, (d) $l = 5, \Omega/\omega_\rho = 0.53 = 2\pi \times 66$ Hz. The parameters of the model are $N = 200000$, $a = 80a_0$, $a_{\text{dd}} = 130.8a_0$, $\omega_z = 2\pi \times 167$ Hz, $\omega_\rho = 2\pi \times 125$ Hz

In this investigation we consider a BEC of $N = 200000$ ^{164}Dy atoms in a quasi-3D axially-symmetric harmonic trap of radial and axial frequencies $\omega_\rho = 2\pi \times 167$ Hz and $\omega_z = 2\pi \times 125$ Hz ($\omega_\rho \approx \omega_z$). The stationary giant vortices were obtained by a numerical solution of the improved mean-field model by imaginary-time propagation employing the Crank-Nicolson discretization rule. In Fig. 1(a) we illustrate the contour plot of integrated quasi-2D density $n_{2\text{D}}(x,y) = N \int dz |\psi(x,y,z)|^2$ for the nonrotating $l = 0$ hollow cylindrical state (left panel) and the corresponding uniform phase of the wave function $\psi(x,y,0)$ (right panel). In Figs. 1(b)-(d) we present the same for the stable giant vortex states of angular momenta $l = 3,4,5$ obtained by rotating the hollow cylindrical state of plot (a) around the z axis with angular frequencies of rotation $\Omega = 2\pi \times (36, 51, 66)$ Hz, respectively. The dynamical stability of these giant vortices is established by real-time propagation during a long interval of time after a small change of a parameter.

Quantum states of distinct topology are of general interest [3]. The hollow cylindrical state of Fig. 1(a) can be realized dynamically using real-time simulation starting from a Gaussian solid cylindrical state [1].

References

[1] L E Young-S and S K Adhikari, Phys. Rev. A **108**, 053323 (2023)

[2] L E Young-S and S K Adhikari, Physica D **475**, 134590 (2025)

[3] Md Shafayat Hossain, F Schindler, R Islam, *et al.*, Nature **628**, 527 (2024)