Skyrmions in trapped BECs

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Experimental dilute gas BECs achieve the conditions of the classical field Gross-Pitaevskii approximation, allowing topologically interesting structures to be investigated with unprecedented flexibility. We have previously identified, and shown how to overcome, the specific instabilities of skyrmions in trapped two-species atomic BECs, and hence demonstrated numerically their energetic stability [1]. The separate conservation of the two atomic species can stabilize the skyrmion against shrinking to zero size, while drift of the skyrmion due to the trap-induced density gradient can be prevented by sufficiently fast rotation, or by a laser potential.

Since then we have numerically surveyed the experimental parameters for which skyrmions are stable. We have found that the range of rotation speeds over which the skyrmions are stable is small. For example, for too high speeds an unwanted vortex enters the outer skyrmion component, see right figure below. This sensitivity to parameters may be a difficulty for experiments. A particular goal was to reduce the number of atoms required for stability against skrinkage to below the nine million used in reference [1]. In a spherical trap we could only reduce this number by a factor of two or so, at the expense of even smaller stable parameter ranges.

However we discovered a link between the superfluid velocity and the stability. The BEC component with the ring vortex, the outer component in the figure, is circulating around the ring singularity and back through the central core threading the line singularity of the other component. Since the volume of the central core is small the speed is high. The skyrmion becomes unstable as this speed becomes comparable to the speed of sound.

The central speed of the ring vortex component may be reduced by changing the symmetry of the trap to cylindrical, with the long axis parallel to the line vortex singularity. This is because the circulation is fixed at one quantised unit, so as the length increases the speed decreases. This enables us to reduce the number of atoms to around one million while remaining stable against shrinking of the ring vortex.

To stabilise these low atom number skyrmions against drift of the line vortex out of the trap we found that both rotation and laser pinning were required.

The conclusion of our investigations is that it will be challenging to create stable skyrmions in an experiment due to their sensitivity to a range of parameters.

Figure: (Left) 3D density profile of a trapped skyrmion. The central torus is an isosurface of the atomic state forming a line vortex. The other atomic state forms a ring vortex: isosurfaces are shown for $x < 0$. On the $y – z$ plane between the isosurface sections, density is indicated by a colormap. (Right) An additional line vortex enters the outer component due to fast rotation.

References