TYING QUANTUM KNOTS

K. Tiurev[1], D. S. Hall[2], M. W. Ray[2], E. Ruokokoski[1], A. H. Gheorghe[2] and M. Möttönen[1,3]

[1]QCD Labs, COMP Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 13500, FI–00076 Aalto, Finland
[2]Department of Physics, Amherst College, Amherst, Massachusetts 01002–5000, USA
[3]University of Jyväskylä, Department of Mathematical Information Technology, PO Box 35, FI-40014 University of Jyväskylä, Finland

The theory of knots has a long history in mathematics and physics since Lord Kelvin proposed knots in ether as a model of atoms [1]. Although this proposal did not work in physical reality, it gave a birth to mathematical study of knots [2]. Recent experiments have observed knots in a variety of classical contexts, including nematic liquid crystals, DNA, optical beams and water. However, no experimental observations of knots have yet been reported in quantum matter. We demonstrate the controlled creation and detection of knot solitons in the order parameter of a spinor Bose-Einstein condensate [3]. The observed texture corresponds to a topologically nontrivial element of the third homotopy group and exhibits the celebrated Hopf fibration, which unites many seemingly unrelated physical phenomena. The very good agreement between the experiments and theory provides conclusive evidence for the existence of the knot soliton. Our observations establish an experimental foundation for future studies of knot stability and dynamics within quantum systems.

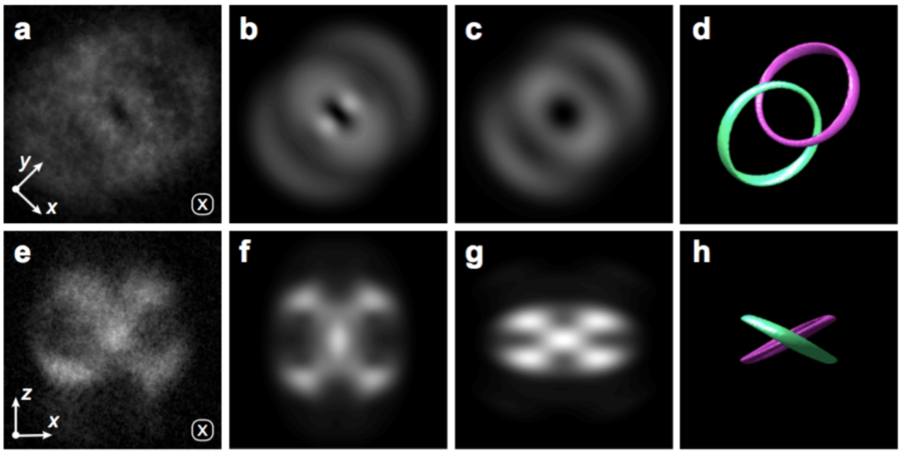

Figure 1: **Linked preimages.** (**a, e**) Experimentally obtained images of the $|0\rangle$ component of the condensate taken along the vertical (**a**) and horizontal (**e**) axes, and (**b, f**) results of corresponding numerical simulations. (**c, g**) and (**d, h**) show vertically and horizontally integrated densities and Hopf fibrations before time of flight.

[1] W. Thomson. On vortex atoms. Proc. R. Soc. Edinburgh **VI**, 197-206 (1867)
[2] C. C. Adams. *The Knot Book* (W. H. Freeman, 1994)
[3] D. S. Hall, M. W. Ray, K. Tiurev, E. Ruokokoski, A. H. Gheorghe and M. Möttönen. Nature Physics (2016), doi:10.1038/nphys3624