X-ray coherent diffractive imaging of quantum vortices in helium droplets

A. Vilesov

Department of Chemistry, University of Southern California, Los Angeles, USA

vilesov@usc.edu

Helium nanodroplets have long been considered ideal model systems to explore quantum hydrodynamics in self-contained, isolated superfluids. However, the dynamic properties of individual droplets, such as vorticity, remained beyond the reach of experimentalists. Here, we investigate the rotation of single, superfluid ^{4}He droplets (D=200-2000 nm) via single-shot femtosecond X-ray coherent diffractive imaging [1]. As indicated by large centrifugal deformations, the droplets' angular velocities span a range from vanishing to those close to the disintegration limit. The shapes of rotating viscous and superfluid droplets are compared. The formation of quantum vortex lattices inside the droplets is confirmed by observing characteristic Bragg patterns from Xe clusters trapped in the vortex cores. The vortex densities are up to five orders of magnitude larger than observed in bulk liquid He, accessing a previously unattainable regime of quantum rotation. The images of the vortex filaments in the droplets, such as in Figure 1, were obtained from the diffraction images via phase retrieval techniques [2]. Excessive doping by Xe changes equilibrium arrangement of vortices in the droplet and leads to stabilization of widely spaced configurations. Evidence for non-stationary vortex dynamics comes from observations of asymmetric formations of vortices in some droplets. This collaborative work was performed at Linac Coherent Light Source, the free electron laser within SLAC National Accelerator Laboratory.

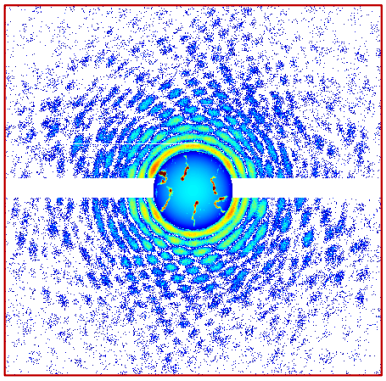

Figure 1: Image of a 600 nm diameter superfluid 4-He droplet (blue) with six vortex filaments (red) as obtained from the x-ray diffraction pattern shown in the background. The figure is based on materials published in Ref. [2].

[1] L.F. Gomez, K.R. Ferguson, J.P. Cryan, C. Bacellar, R.M.P. Tanyag, C. Jones, S. Schorb, D. Anielski, A. Belkacem, C. Bernando, R. Boll, J. Bozek, S. Carron, G. Chen, T. Delmas, L. Englert, S.W. Epp, B. Erk, L. Foucar, R. Hartmann, A. Hexemer, M. Huth, J. Kwok, S.R. Leone, J.H.S. Ma, F.R.N.C. Maia, E. Malmerberg, S. Marchesini, D.M. Neumark, B. Poon, J. Prell, D. Rolles, B. Rudek, A. Rudenko, M. Seifrid, K.R. Siefermann, F.P. Sturm, M. Swiggers, J. Ullrich, F. Weise, P. Zwart, C. Bostedt, O. Gessner, and A.F. Vilesov, Science, 345: 906-9 (2014).

[2] R.M.P. Tanyag, C. Bernando, C.F. Jones, C. Bacellar, K.R. Ferguson, D. Anielski, R. Boll, S. Carron, J.P. Cryan, L. Englert, S.W. Epp, B. Erk, L. Foucar, L.F. Gomez, R. Hartmann, D.M. Neumark, D. Rolles, B. Rudek, A. Rudenko, K.R. Siefermann, J. Ullrich, F. Weise, C. Bostedt, O. Gessner, and A.F. Vilesov. Structural Dynamics, 2: 051102-1-9 (2015).