Holographically controlled 3D atomic population structures

Adam Selyem[1], Sylvain Fayard[2], Thomas W. Clark[1,3], Aidan S. Arnold[4], Neal Radwell[1] and Sonja Franke-Arnold[1]

[1]School of Physics and Astronomy, SUPA, University of Glasgow, G12 8QQ, Glasgow, United Kingdom
[2]Institut d'Optique Graduate School, 91127 Palaiseau, France
[3]Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Budapest, Hungary
[4]Department of Physics, SUPA, University of Strathclyde, G4 0NG, Glasgow, United Kingdom

We demonstrate the use of 3D light structures to shape the local atomic population distributions and a technique to visualise these distributions in a hot vapour. Structured light is often analysed in terms of its 2D beam profile, but on propagation interesting 3D structures can be realised, including optical vortex knots, bottle beams and 3D lattices. We have developed a method to reconstruct the full 3D structure by measuring light scattered from an atomic vapour [1]. The structured light in [1], however, also affects the electronic levels of the atoms in the vapour. Atoms are pumped between electronic levels at rates dependent on the local light intensity, generating 3D population structures. We use a structured control beam shaped by a spatial light modulator to deplete an upper hyperfine ground state ($5^2S_{1/2}$ F=3, $|1\rangle$) of rubidium 85 via excitation of a short-lived excited state ($5^2P_{1/2}$ F=3, $|C\rangle$) and subsequent spontaneous decay into the lower ground state ($5^2S_{1/2}$ F=2, $|0\rangle$), see figure 1a). In dark regions of the beam, atoms remain in $|1\rangle$ and we can probe this remaining population with an unshaped laser at a different frequency, analogous to electron shelving. We then tomographically reconstruct the 3D population pattern from the fluorescence of this probe laser. Bright regions of the control beam coincide with suppressed fluorescence from the probe laser, as $|1\rangle$ is depleted. The retrieved 3D fluorescence patterns are therefore complementary to each other as shown in figure 1b) and c). We also establish a link between fluorescence rates and populations using a spatially resolved rate equation model. We expect this work to have implications for 2D and 3D atomic memories.

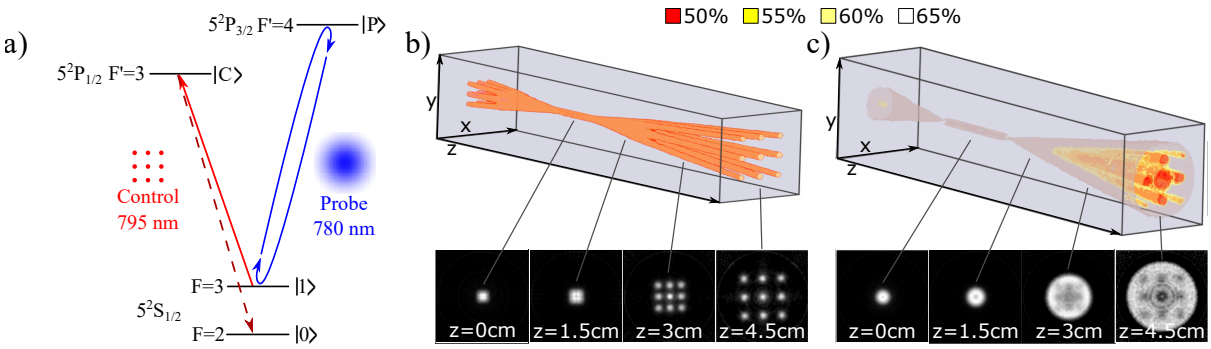

Figure 1. a) Level scheme used in the experiments showing spectroscopic notation, and b) sample reconstructed control beam and c) probe fluorescence visualised as isosurfaces drawn at the indicated fractions of peak intensity. Insets show sample cross-sections.

[1] N. Radwell, M. A. Boukhet and S. Franke-Arnold, 3D beam reconstruction by fluorescence imaging, Opt. Express, **21**, 22215-22220 (2013).