Towards a visual atomic compass

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Abstract: A demonstration, in theory and practice, of how the spherical orientation of a magnetic field can be seen through the interaction between light with Orbital Angular Momentum (OAM) and a cold atomic cloud. Applying two vector vortex beams to a cloud of atoms, the azimuth angle of the magnetic field is seen in the linear rotation of the transmitted pattern, and the inclination is reflected in a fracturing of the observed image.

In a typical Electromagnetically Induced Transparency (EIT) configuration, two lower atomic states are coupled to a common upper state with two near-resonant laser beams. EIT is often characterized by scanning a laser beam across the atomic transition, with transparency occurring for two-photon resonance. Here, on the other hand, we show that EIT also depends on the relative phase between the two driving laser beams, so that a vector vortex beam, which possess locally varying phase structure, results in spatially varying dark states, and hence spatially varying EIT. We called this Spatially dependent EIT (SEIT) [1].

In general, typical Electromagnetically Induced Transparency is not phase dependent, but in our case the lower states of the transition are coupled by a residual transverse magnetic field, resulting in a closed atomic system which displays phase dependence. This can be used to know about the alignment of the **B** field.

To achieve this in our lab we prepare an ^{87}Rb atomic sample with $2\cdot 10^{11}$cm^{-3} density in the lower F =1 ground state. A magnetic field of about 0,1 G is directed mainly along the propagation direction of the beam, with only a fraction in the transverse plane. We structure the phase of our EIT beams by use of q-plates, which for a charge of q = ℓ/2, and linearly polarized input light generate a field with opposite OAM in the right and left handed polarization component

$$E \propto \sigma_+ e^{-i\ell\varphi} + \sigma_- e^{+i\ell\varphi}$$

This means that from linearly polarized light passing through the q-plate comes out a beam with correlations between polarization and azimuthal angle of the probe laser, which also results in the generated beams containing OAM. The interaction between this shaped light beam and the atoms is analyzed from the absorption imaging. Additional information on the magnetic field could be gathered by looking at the difference in relative absorption of the two beams. The scheme of the experimental setup is shown below in Fig. 1.

We have shown theoretically that the absorption pattern changes as a function of both the transverse and the longitudinal direction of the magnetic field, so that the system could offer a new point of view on the physics of the magnetic field rotation detector.

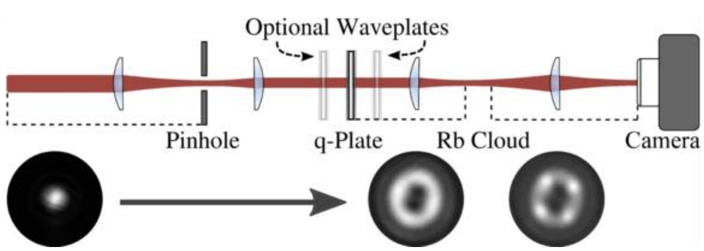

Fig. 1. Simplified account of the imaging path. The lens are selected so that both the near field and the far field of the OAM beam can be imaged on the camera. The insets are cropped images of the beam intensity, as observed on the camera under conditions of no q-plate (Left), no atomic cloud (Middle) and normal operation (Right) and serve to indicate the state of the beam at the regions indicated for q = 1.

[1] N. Radwell, T.W. Clark, B. Piccirillo, S. M. Barnett, and S. Franke-Arnold, “Spatially dependent electromagnetically induced transparency”, *PRL* **114**, 123603 (2015).