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Optical microscopy with kinky photons

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Photons emitted from atomic transitions may be twisted; angular momentum opposite to the atom's internal configuration change is distributed between the photon's spin (polarization) and orbital angular momentum depending on the angle of observation. Photons twisted perpendicular to their angle of observation propagate through an aperture at an angle, and measuring the photon's displacement at an image plane constitutes a weak angular momentum measurement. Remarkably, photons from an elliptical dipole are not only twisted, but kinky, with more than $\pm\hbar$ of angular momentum per photon at the aperture, larger than the angular momentum of the dipole eigenstates or the corresponding atomic transitions.

Such 'supermomentum' is a consequence of weak measurement amplification in a spin-orbit coupled optical field. Chiral light-matter interactions of this kind promise exciting new capabilities for photonic devices, and both consequences and opportunities for super-resolution microscopy. We measure optical spin-orbit coupling and supermomentum from two dipole photon sources.

We image single photons emitted from a trapped atom at the focus of a high-aperture objective and demonstrate wavelength-scale, chirality-dependent shifts between photons from opposing dipole transitions. Our elliptical dipole light source is a sub-wavelength gold nanoparticle and we observe supermomentum in the small-aperture nanoparticle image. This supermomentum becomes arbitrarily large as the aperture vanishes.

This optical spin-orbit effect can lead to systematic wavelength-scale errors in the localization of an elliptically polarized emitter. Such errors are present even for ideal, focussed, aberration-free imaging systems and reveal that the paraxial approximation is fundamentally inadequate for optical super-resolution microscopy, even when the observation aperture is very small. This finding applies to the localization of objects using any wave carrying angular momentum orthogonal to the direction of observation, and is relevant for super-resolution microscopy techniques, which achieve resolutions two orders of magnitude smaller than the supermomentum shifts observed here.

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