Picometrology with topologically structured light

Kevin F. MacDonald,[1] **Cheng-Hung Chi,**[1] **Thomas A. Grant,**[1] **Anton Vetlugin,**[2]
Eric Plum,[1] **and Nikolay I. Zheludev,**[1,2]
[1] Optoelectronics Research Centre, University of Southampton, UK
[2] Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore
Email – kfm@orc.soton.ac.uk

It is now well understood that complex optical fields can be structured at deeply subwavelength scales, with point-like singularities, zones of energy back-flow and strong phase and intensity gradients. The scattering of light from an object can thus depend strongly on exactly where it is located within such a field. This is the foundational idea of metrology with topologically structured light whereby, for example, single-shot optical measurements can yield positional precision better than 100 pm (around one five-thousandth of the wavelength) in the localization of a nanowire, via a deep-learning analysis of its scattering patterns. Here, we explain how such performance – reaching orders of magnitude beyond the conventional diffraction limit – is possible, through a Fisher Information analysis of the technique; we demonstrate how network training can make measurements robust against instrumental/ambient noise; and we show how the concept can be extended to enable studies of dynamic processes (e.g. thermal and driven motion in nanostructures), and from metrology to elementary imaging of complex objects.