Measuring the topological charge of ultra-broadband optical-vortex beams with a triangular aperture

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Abstract

A technique for determining the topological charge of supercontinuum optical vortices is presented. Spatial dispersion is compensated with a unique double-pass arrangement, and charge is consistently measured across a wide range of colors by observing diffraction through a triangular aperture.

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[2] K. Bezuhanov, A. Dreischuh, G. G. Paulus, M. G. Schätzel, and H. Walther, "Vortices in femtosecond laser fields," Opt. Lett. 29, 1942–1944 (2004).

[3] I. Zeylikovich, H. I. Sztul, V. Kartazaev, T. Le, and R. R. Alfano, "Ultrashort Laguerre-Gaussian pulses with angular and group velocity dispersion compensation," Opt. Lett. 32, 2025–2027 (2007).

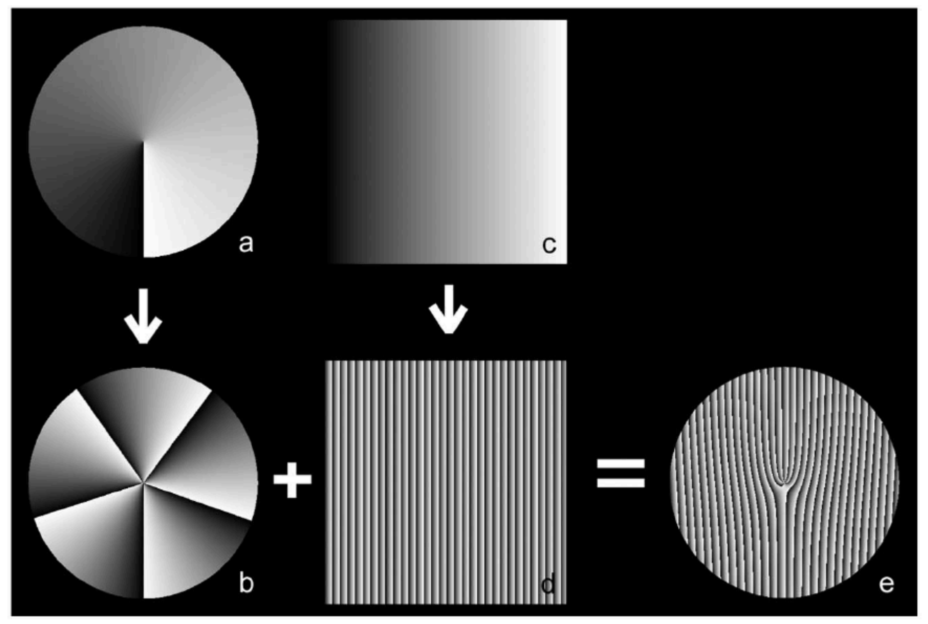
[4] J. M. Hickmann, E. J. S. Fonseca, W. C. Soares, and S. Chavez-Cerda, "Unveiling a truncated optical lattice associated with a triangular aperture using light's orbital angular momentum," Phys. Rev. Lett. 105, 053904 (2010).

[5] L. E. E. de Araujo and M. E. Anderson, "Measuring vortex charge with a triangular aperture," Opt. Lett. 36, 787–789 (2011).

[6] M. E. Anderson, H. Bigman, L. E. E. de Araujo, and J. L. Chaloupka, "Measuring the topological charge of ultra-broadband, optical-vortex beams with a triangular aperture," JOSA B 8, 1968-1976 (2012).

Spiral Phase Plates for Vortex Generation

In order to generate optical vortex beams [1-2], a spiral phase ranging from 0 to $2\pi m$ (a) is applied to the near field of an incident laser beam. This phase is encoded modulo 2π (b) on a spatial light modulator (SLM) to maximize the dynamic range of the device. In this example, the pinwheel structure with five 0-2π segments represents a spiral phase with a topological charge of 5. A uniform phase tilt (c) is also applied to steer the modulated beam away from the unshifted background, say, due to reflections off of windows or other interfaces. When encoded modulo 2π, the phase tilt resembles a blazed diffraction grating (d). The sum of the spiral phase and the blazed grating results in the total phase applied to the SLM (e).



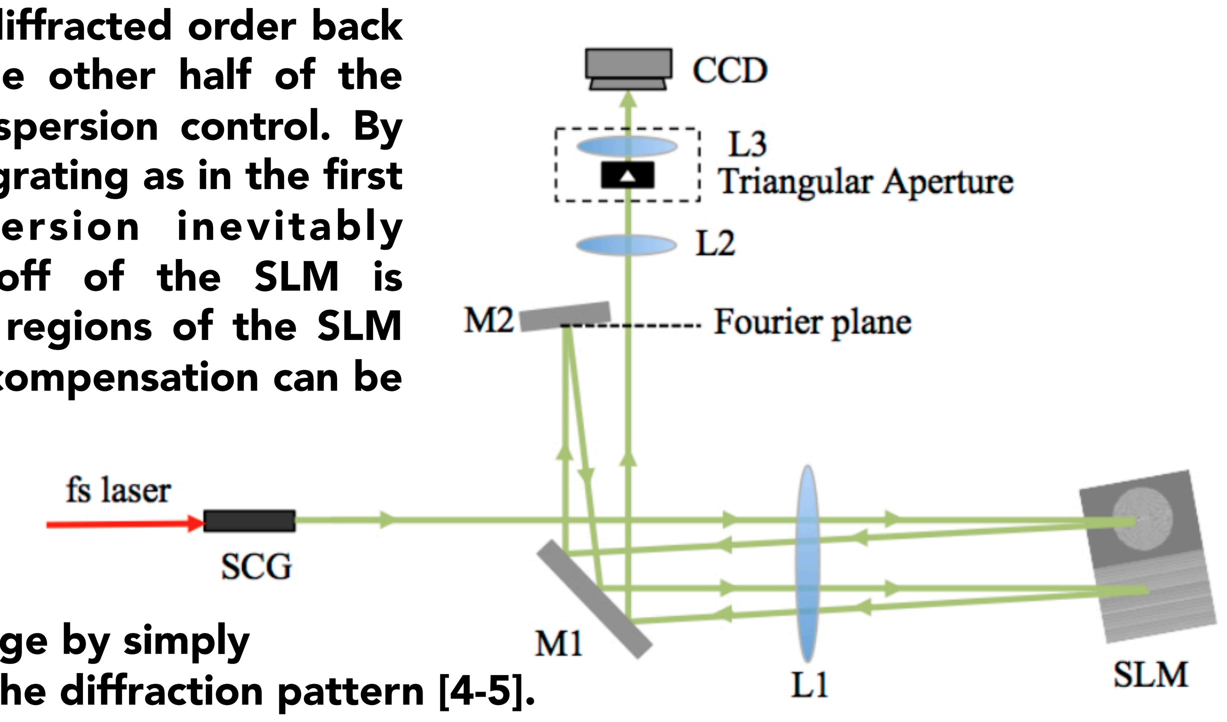
It is important to note that by encoding the phase pattern and diffraction grating together on the SLM, that only the properly shifted portion of the beam will be diffracted to the first order, regardless of the calibration of the device. This is a crucial point when shaping ultra-broadband light, and allows for excellent vortex generation for all colors within the super-continuum.

Experimental Arrangement for Dispersion Compensation

A home-built Ti:S femtosecond oscillator emits 50fs pulses at 80 MHz and 75 mW. The laser output is coupled into the microstructured fiber (NKT Femtowhite 800) with a 20x microscope objective. The super-continuum output spans from 500nm to over 1.1 μm. The broadband output is collimated with an achromatic lens and makes a first pass off of the SLM (Hamamatsu X8267-14). Here, the spiral phase and blazed grating is applied to the beam.

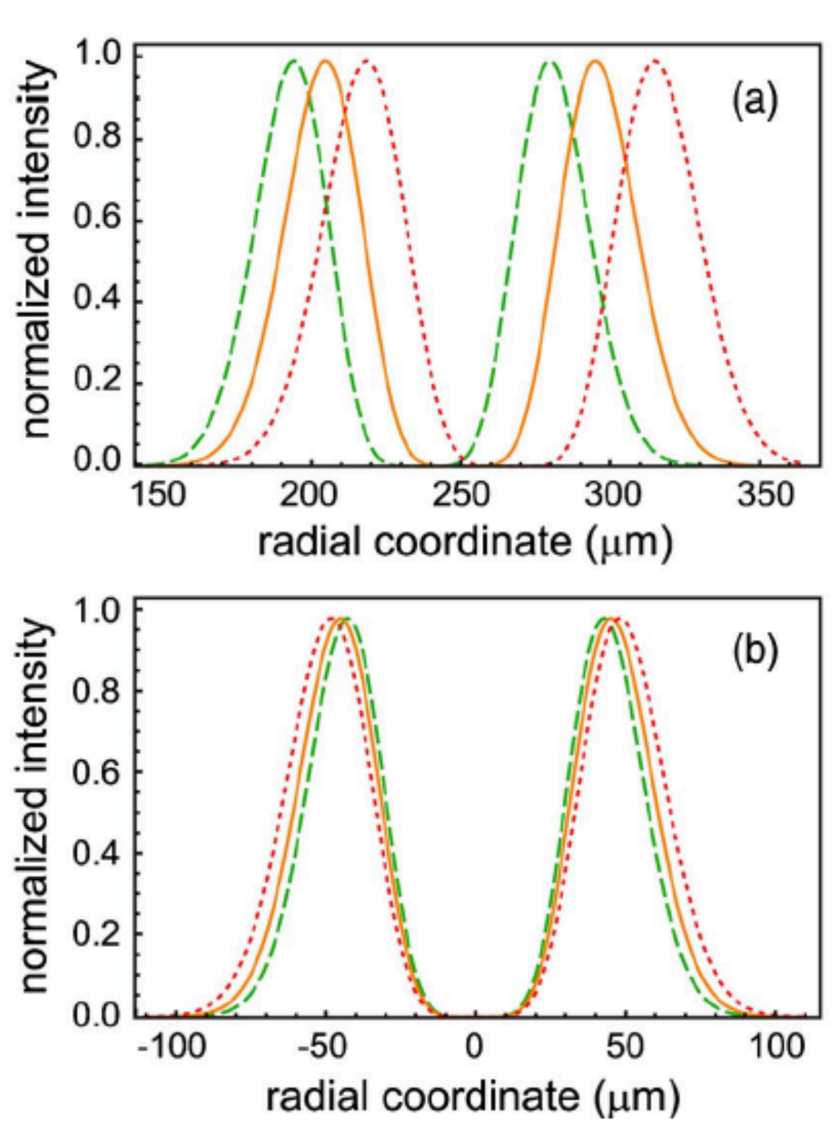
Mirror M2 then directs the first diffracted order back to the SLM, where it strikes the other half of the large-area SLM, dedicated to dispersion control. By encoding an identical diffraction grating as in the first region, the chromatic dispersion inevitably introduced by the first pass off of the SLM is compensated [3]. Since the two regions of the SLM are independent, the dispersion compensation can be freely tuned.

Finally, the corrected white-light vortices are focused through a triangular aperture, enabling the determination of topological charge by simply counting the number of spots in the diffraction pattern [4-5].



Calculations Confirm Dispersion Compensation

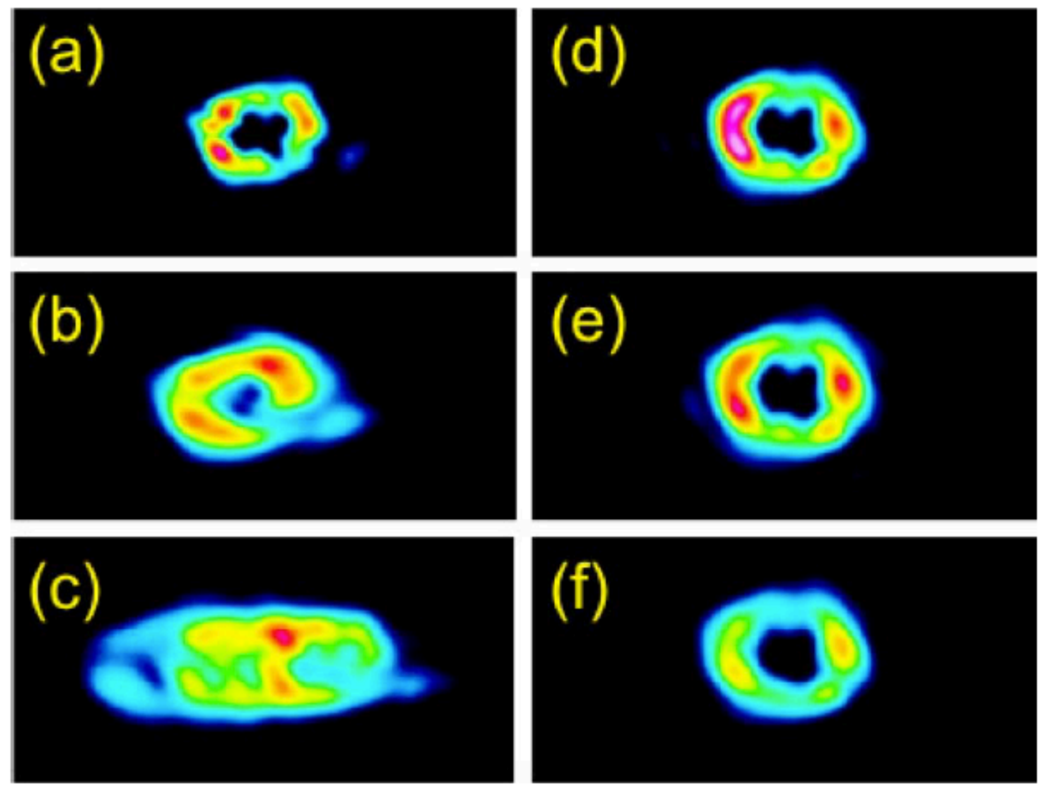
The propagation of a broadband optical beam through our experimental arrangement is calculated by evaluating the Kirchoff-Fresnel integral for each path segment. The cross-sectional profiles for charge 3 vortices are shown below. The doubly dispersed case (a) demonstrates the effect on the diffraction order that would be ordinarily discarded, showing large spatial separation between the green (550nm), orange (580nm), and red (619nm) light. The corrected case (b) shows excellent spatial overlap for all of the colors.

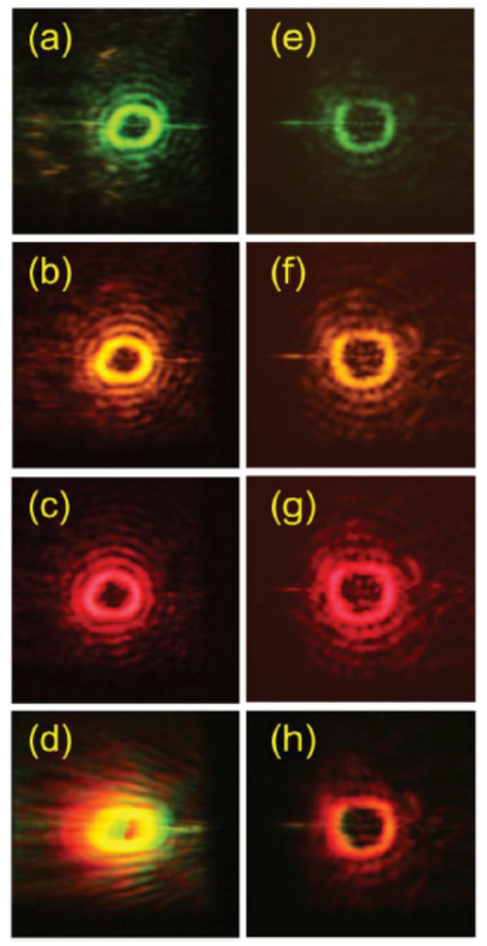


Experimental Results Demonstrate Excellent SuperContinuum Vortices & Topological Charge Measurement

The combination of an applied spiral phase and blazed grating along with the dispersion-correcting double-pass arrangement results in high-quality optical vortices across a broad bandwidth. Inspection of the diffraction pattern generated by a triangular aperture allows for a straightforward method to reliably measure the topological charge of these super-continuum vortices [6].

Charge 3 vortices (below) are generated in the doubly dispersed arrangement for continuous-wave (a), femtosecond (b), and super-continuum (c) beams. The ultra-broadband SC vortices are severely distorted by spatial chirp. The dispersion corrected vortices, CW (d), FS (e), SC (f), are all formed perfectly, regardless of spectral bandwidth.





True-color images of doubly dispersed (left column) and dispersion-corrected (right column) vortices are shown for 550nm (a,e), 580nm (b,f), 619nm (c,g) and the full spectrum (d,h). The full-spectrum case clearly demonstrates the severe spatial chirp in the doubly dispersed case and the excellent overlap in the dispersion-corrected case.

False-color diffraction patterns through a triangular aperture for the doubly dispersed case (left column) and the dispersion-corrected case (right column) for CW (a,d), FS (b,e) and SC (c,f) beams. While the patterns are still discernable for the CW and FS beams in both cases, the extreme bandwidth in the SC beams makes the dispersion correction essential in order to measure the vortex charge (equal to $m = n-1$, where n is the number of spots along each edge).