Supercontinuum optical vortices: generation, characterization, and control

CUPhI
Colorado Ultrafast Photonics Initiative
Workshop 2015

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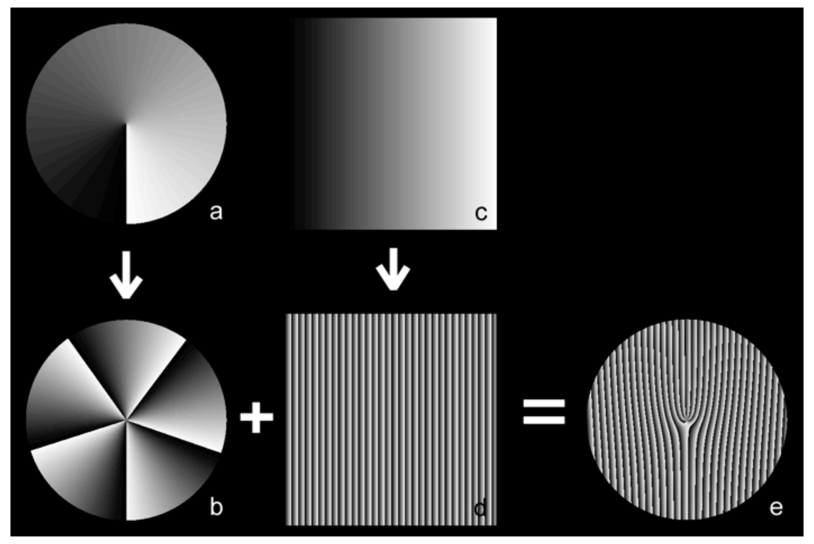
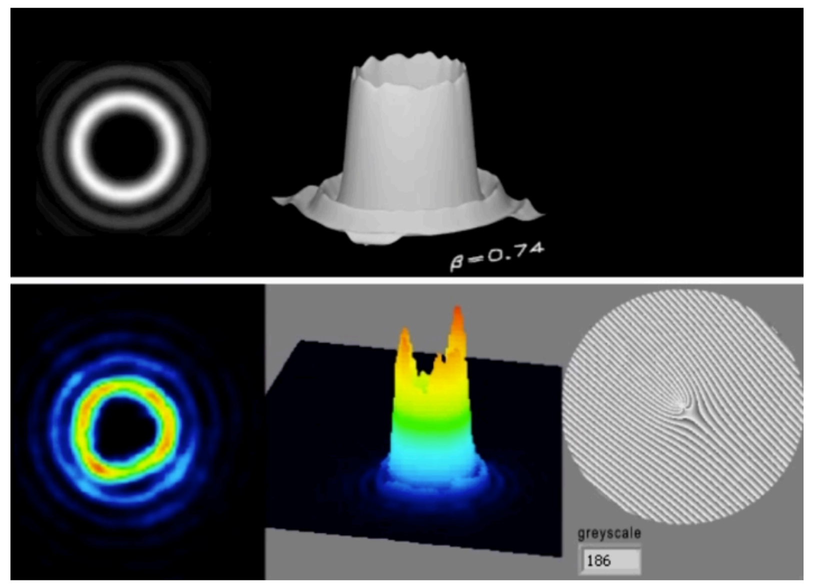
Abstract

We create coherent, ultrabroadband optical vortex beams, characterize their topological charge, and control the interaction of multiple vortices. Ultrafast laser pulses are first injected into a microstructured fiber, generating a wide spectrum of supercontinuum light. Then, a large-aperture, high-resolution, reflective spatial light modulator (SLM) is used to create single and multiple vortices across a broad range of colors. Exquisite full-color interference patterns are investigated, showing excellent agreement with numerical simulations. Also, by using different colored filters in front of the SLM, multiple single-color vortices can be generated and independently controlled simultaneously. Finally, the topological charge of broadband vortices is characterized by inspecting the diffraction pattern through a triangular aperture. Significant spatial dispersion is compensated through the use of a double-pass arrangement utilizing a single SLM, allowing for the consistent measurement of topological charge across a wide range of colors. These studies pave the way for applications in particle trapping and manipulation, imaging, and information science.

Vortex Generation

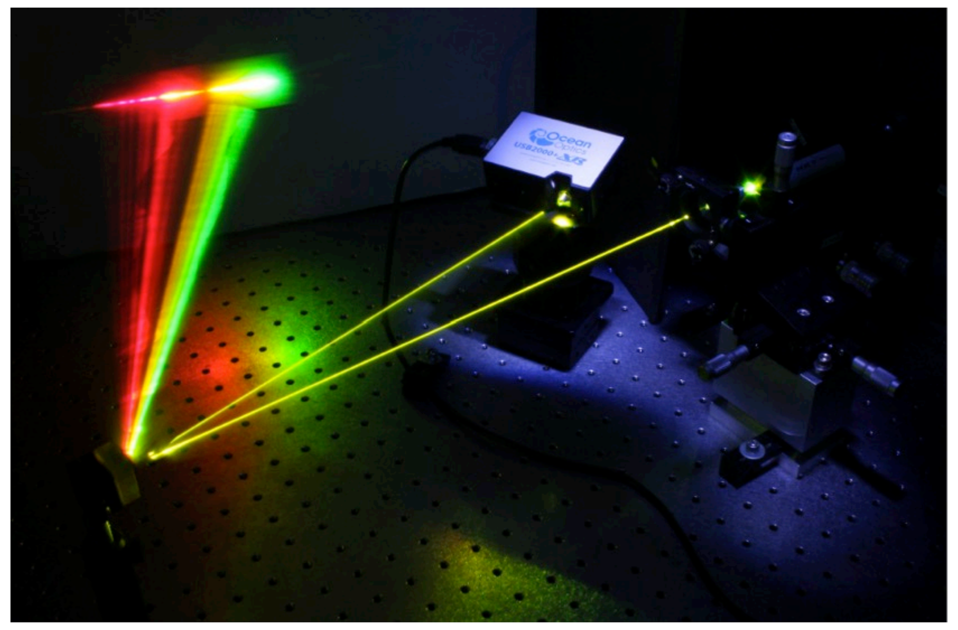


An optical vortex is created in the far field by adding a spiral phase to a coherent beam in the near field. The familiar forked phase pattern is the result of a spiral phase added to a phase tilt, and then displayed modulo 2π. The phase tilt redirects the properly shifted portions of the beam from the unwanted zeroth order reflections. Here, (a) a spiral phase ranging from 0–10π is (b) displayed modulo 2π, resulting in a phase plate with five 0–2π segments. Likewise, (c) a phase tilt is (d) displayed modulo 2π, resulting in a blazed grating. The addition of these two patterns results in (e) a forked phase pattern.



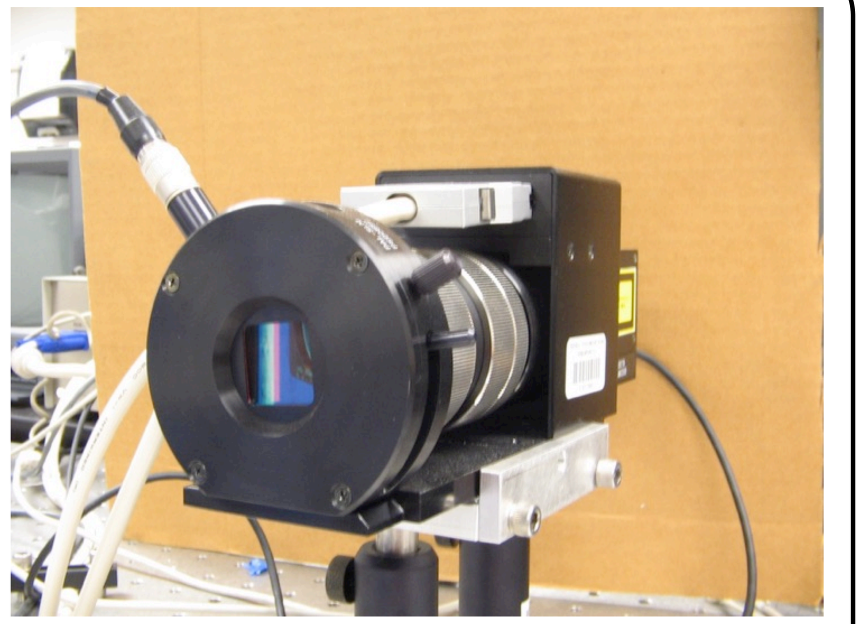
Excellent vortex beams are generated across a wide range of colors, *regardless of the calibration* of the phase on the spatial light modulator. The use of the phase tilt (equivalent to a blazed grating when displayed modulo 2π) ensures that only the properly converted portions of the beam are diffracted to the first-order angle. Beam quality will be excellent and only the diffraction efficiency will suffer. In the upper panel, theoretical vortex beams for a 0-2πβ forked pattern. In the lower panel, experimental results for the same conditions. Typically, the SLM is calibrated to the central wavelength of the incident light, but the calibration can be shifted to a weaker portion of the spectrum to effectively enhance that spectral region.

Supercontinuum



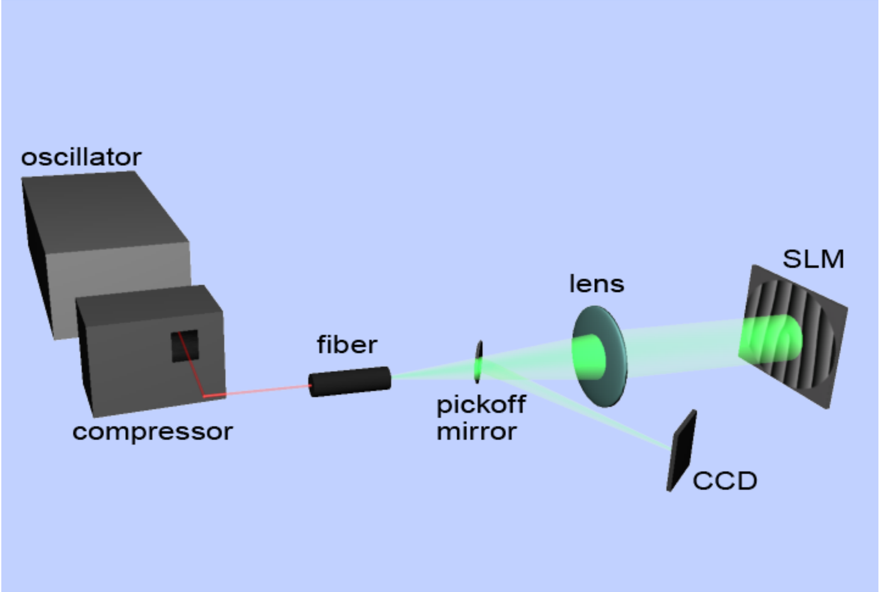
A Nd:YAG-pumped Ti:Sapphire oscillator generates 20-fs modelocked pulses with a central wavelength of 800 nm. After the oscillator, the beam passes through a pulse compressor, allowing for control of the temporal chirp of the pulses. A 20× microscope objective is mounted onto an XYZ translation stage to couple the beam into the nonlinear photonic crystal fiber (NKT Photonics FemtoWhite 800), which is also mounted on an XYZ stage. The fiber consists of a honeycomb structure with a central core surrounded by air gaps. The fiber has a core diameter of 1.8 μm and a 12-cm length. A broad spectrum ranging from 500nm to over 1000nm is generated.

Spatial Light Modulator

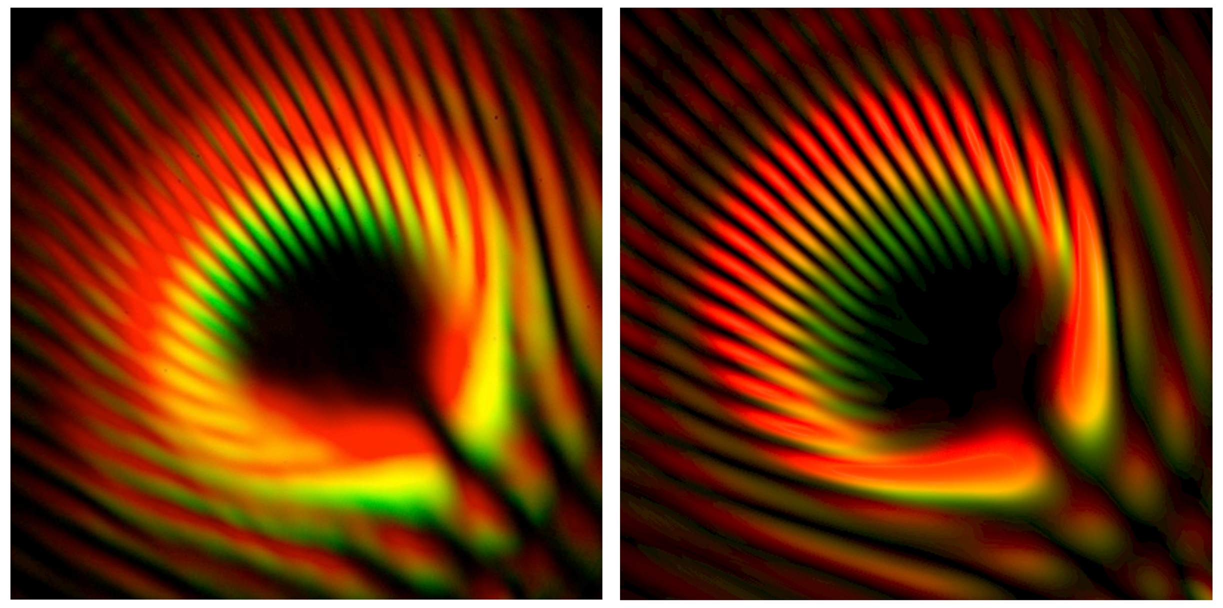


The spatial light modulator (SLM) is a Hamamatsu model X8267-14. It employs a back-illuminated liquid crystal-on-silicon design that eliminates pixilation and has a 100% fill factor. The reflective nature of this device is well-suited for high power beams and can handle an amplified system. It has an antireflection (AR) coating at 800 nm, but with our ample incident power, it performs well over a wide range of wavelengths. It has a large active area of 2cm×2cm with 768×768 pixels, easily allowing for "segmentation" into at least four regions with excellent results.

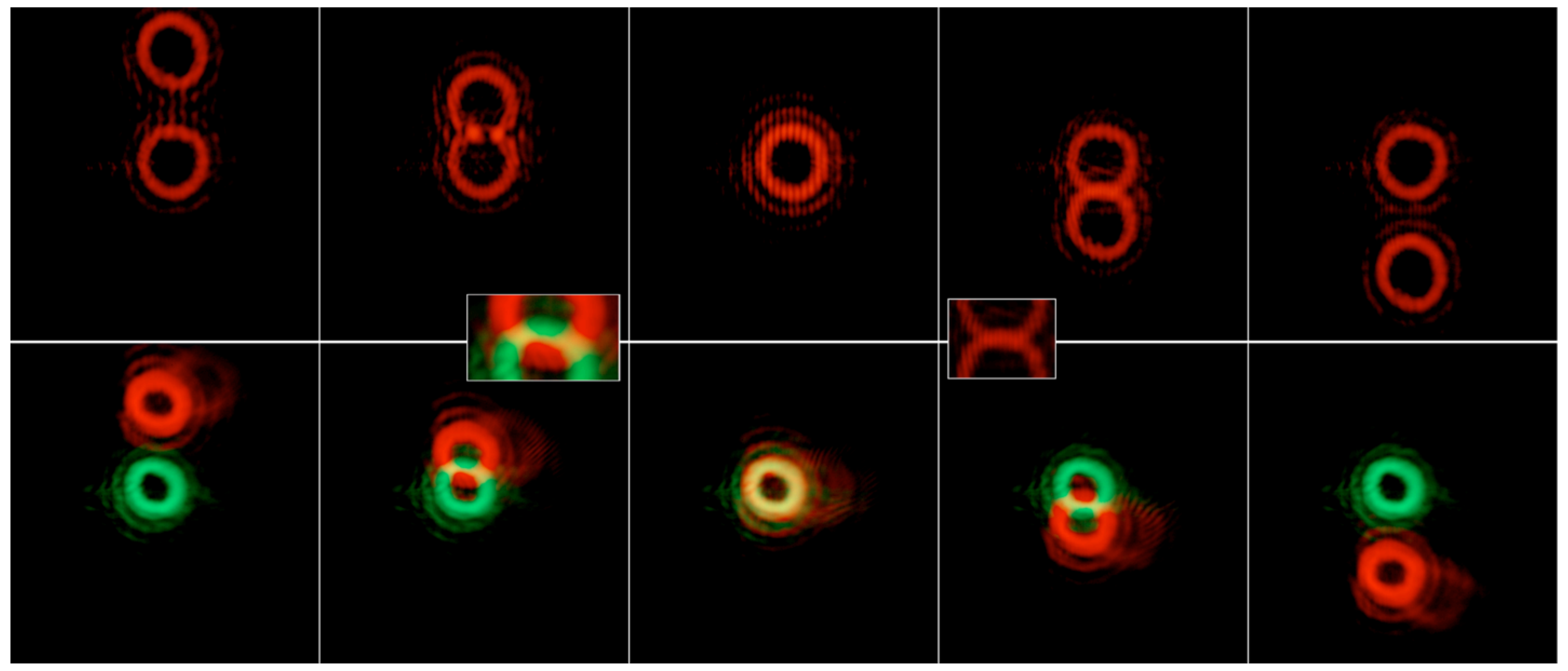
Broadband Vortices



Pulses generated with the Ti:S oscillator are optimized with a pulse compressor and injected into the "holey" fiber, generating a diverging beam of supercontinuum light. An f=70cm lens collimates the light before it strikes the SLM. The reflected light is refocused by the lens onto a CCD via a pickoff mirror.



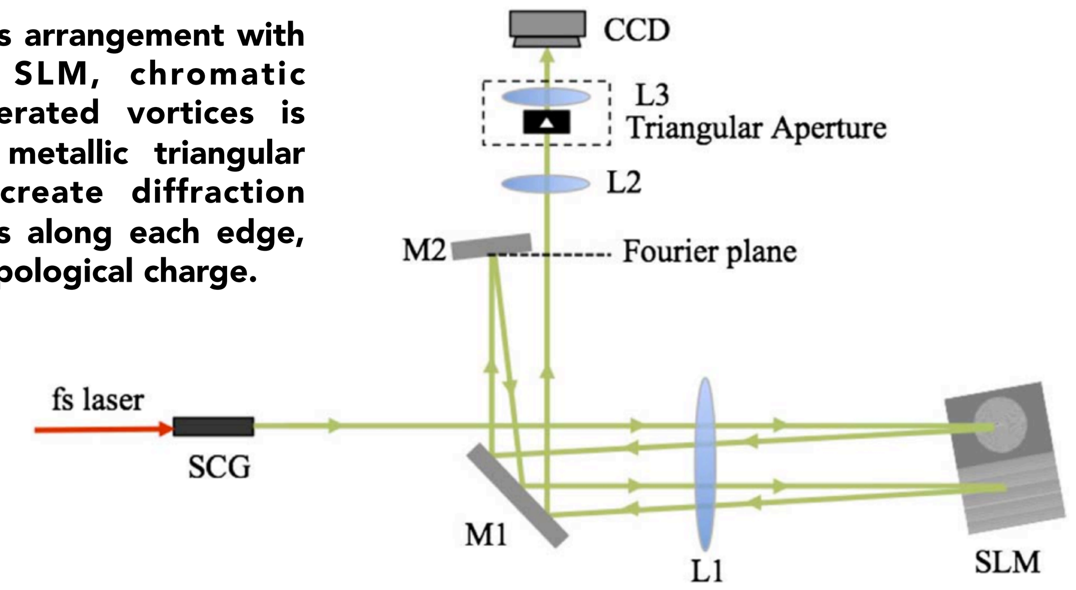
Two independent forked patterns are encoded onto the SLM, simultaneously generating two broadband vortices that are made to interfere on the CCD. Here, the brilliant interference pattern generated with vortices of opposite topological charge (+10, -10) are captured in full color with a Nikon D70s DSLR camera (left panel). Numerical calculations (right panel) show excellent agreement.

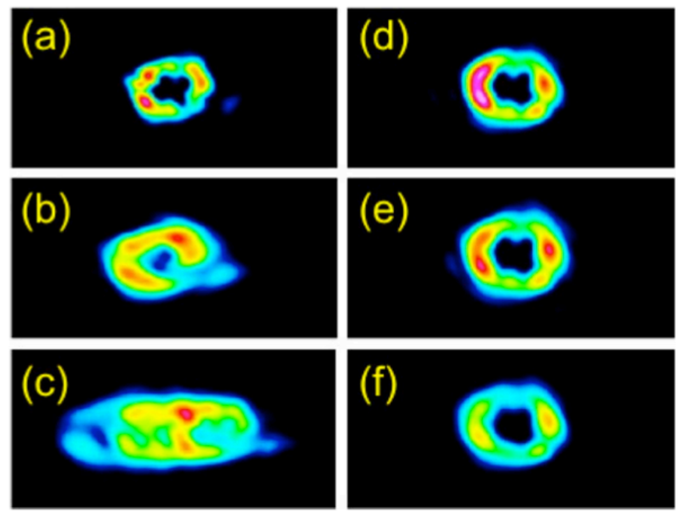


By using colored filters in front of the SLM, monochromatic vortices can be easily generated. The phase tilt encoded into each forked pattern can be smoothly varied, allowing for independent, real-time control of the vortices. Here, two red vortices exhibit interference as they pass through each other, while a red and green vortex beam pass through each other without interference.

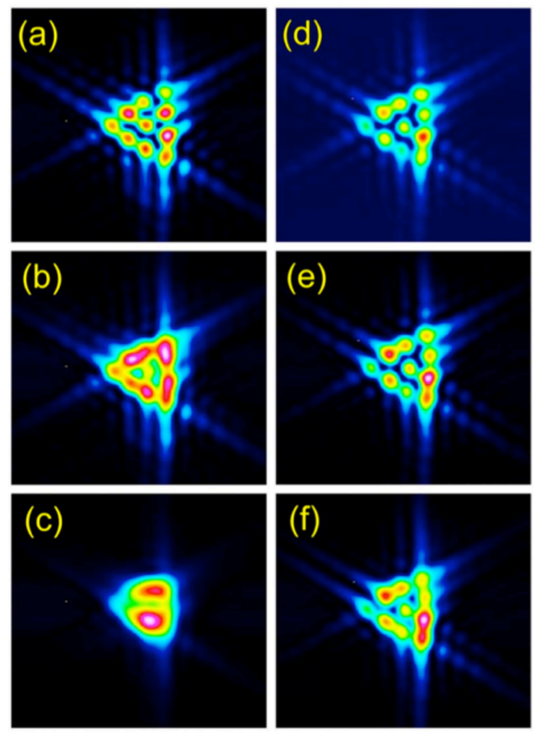
Measuring Topological Charge

By utilizing a double-pass arrangement with a single, large-area SLM, chromatic dispersion in our generated vortices is virtually eliminated. A metallic triangular aperture is used to create diffraction patterns with *m+1* spots along each edge, where *m* is the vortex topological charge.





Dispersed charge 3 vortices are shown using a) CW, b) femtosecond, and c) supercontinuum light. The SC vortex shows extreme chromatic dispersion. By employing the double-pass compensation technique, vortices from d) CW, e) fs, and f) SC light exhibit excellent shape.



Diffraction patterns from the triangular aperture for the dispersed a) CW, b) fs, and c) SC light show significant degradation for broad bandwidths. But by utilizing compensation, excellent patterns are generated with d) CW, e) fs, and f) SC. Even the topological charge of the ultrabroadband supercontinuum vortex is readily measured.

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