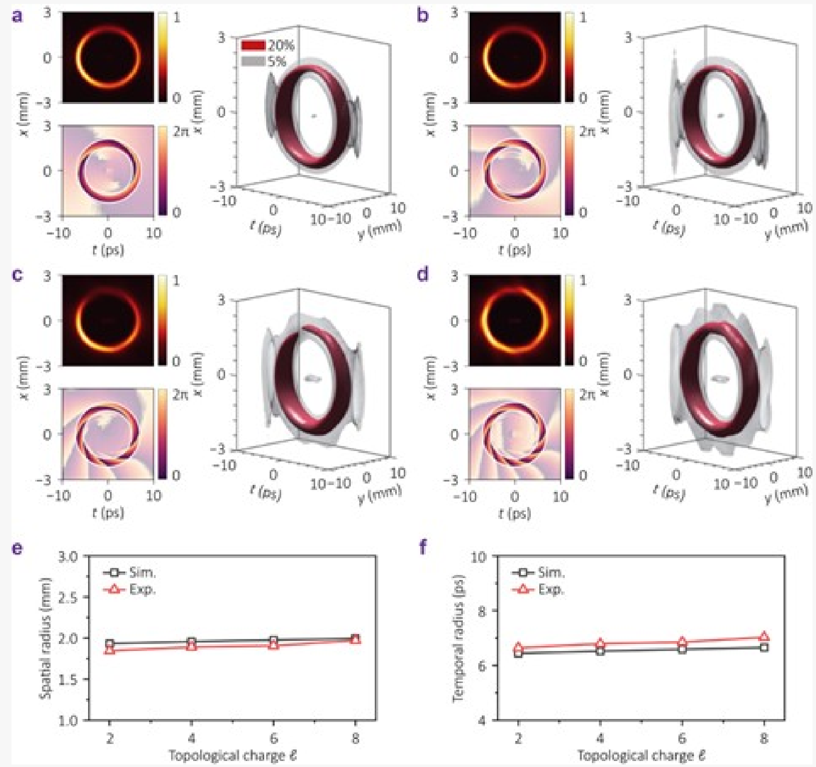
Polygonal Generalized Perfect Spatiotemporal Optical Vortices for Advanced Field Manipulation

A new class of perfect optical vortices with tunable geometry and higher energy efficiency

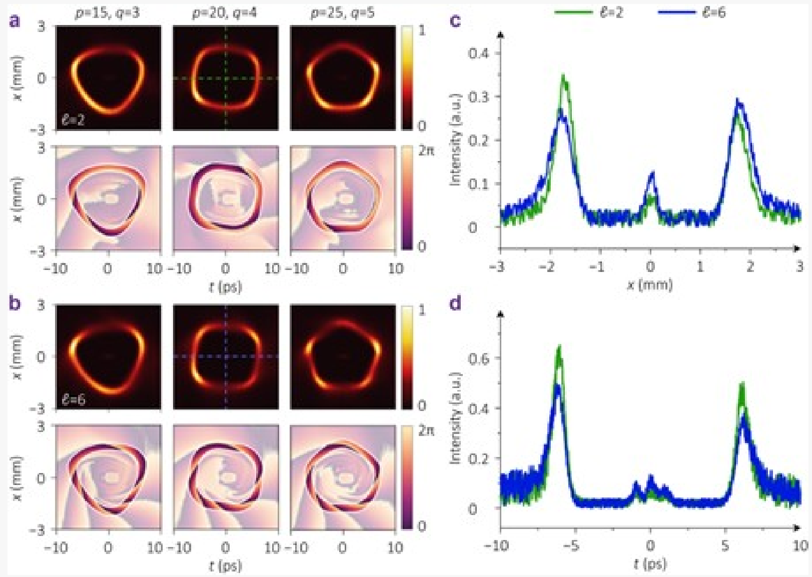


Generation and characterization of annular PSTOVs with varying topological charges

SHANNON, IRELAND, April 27, 2026 /EINPresswire.com/ -- A new class of perfect optical vortices with tunable geometry and higher energy efficiency

Researchers led by Professor Ting Mei (Northwestern Polytechnical University) and Professors Xiaocong Yuan & Yuquan Zhang (Shenzhen University) introduced generalized PSTOVs (GPSTOVs), published as the cover paper in [Opto-Electronic Science] (Vol. 5, Issue 3) on March 24, 2026. GPSTOVs feature topological-charge-independent spatiotemporal sizes and controllable geometric shapes. Using pure-phase modulation with a shape-controllable digital axicon and vortex phase, the method avoids amplitude modulation, achieving higher efficiency and energy utilization.

Sculpting light in space and time can provide unprecedented opportunities in many areas of science and technology, ranging from extreme nonlinear optics to quantum information processing. The past few years have witnessed numerous advances in spatiotemporally structured light fields. Among them, spatiotemporal optical vortices (STOVs) have attracted particular attention due to their unique space–time coupling structures and their ability to carry transverse orbital angular momentum. Similar to spatial optical vortices, STOV pulses typically exhibit an annular-shaped intensity distribution in the x–t plane, with a radius that strongly depends on the topological charge. This dependence limits their applicability in scenarios requiring the superposition of multiple vortices with different topological charges. To address this limitation, perfect STOVs (PSTOVs) have been proposed, whose intensity distribution is independent of the topological charge.



High-efficiency generation of polygonal GPSTOV pulses with tunable topological charge

Although PSTOVs lift the dependence between beam size and topological charge, existing studies mainly focus on the simplest annular profiles, and their generation typically relies on spatiotemporal complex-amplitude modulation techniques. These approaches require simultaneous control of both the amplitude and phase of the input pulse, which inevitably leads to significant energy loss, particularly for large topological charges. Therefore, achieving efficient generation of PSTOVs with controllable spatiotemporal distributions remains a critical challenge that urgently needs to be addressed.

To fill this research gap, the research group led by Professor Ting Mei at Northwestern Polytechnical University, China, in collaboration with the team of Professor Xiaocong Yuan and Associate Professor Yuquan Zhang from Shenzhen University, China, introduces the concept of generalized PSTOVs (GPSTOVs). Their findings were made available online and published as the Cover Paper in Volume 5, Issue 3 of the journal Opto-Electronic Science on March 24, 2026. As a new class of PSTOVs, GPSTOV pulses possess two remarkable features simultaneously: topological-charge-independent spatiotemporal sizes and fully controllable geometric shapes. Methodologically, the group moves beyond conventional complex-amplitude modulation schemes and proposes a new generation strategy based on pure-phase modulation. The core idea of their method is to encode a shape-controllable digital axicon and a vortex phase in the spatiotemporal frequency domain. By introducing an azimuthal modulation to the axicon parameter, the intensity profiles of the generated GPSTOV pulses can be flexibly engineered while preserving the intrinsic "perfect" properties. Importantly, since amplitude modulation is not required, the proposed method achieves higher modulation efficiency and improved energy utilization.

Through precise adjustment of the phase parameters in the spatiotemporal frequency domain, the researchers successfully demonstrate high-efficiency generation of both PSTOV pulses with annular profiles [Fig. 1] and GPSTOV pulses with polygonal shapes [Fig. 2]. The measured modulation efficiency exceeds 90%, which cannot be attained using complex-amplitude modulation techniques.

In addition to their conceptual novelty, GPSTOV pulses provide a new degree of freedom for the manipulation of spatiotemporal vortex fields through their tunable geometric structures, thereby offering great potential for a wide range of photonic applications, including optical communications, particle manipulation, and other fields requiring precise spatiotemporal control of ultrafast light pulses. In principle, the concepts and physical mechanisms proposed in this work can be further extended beyond electromagnetic fields to other wave systems, such as acoustic waves, electron waves, and water waves.

Reference

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About Northwestern Polytechnical University, China
The Nanophotonics Research Group at Northwestern Polytechnical University was established in 2013. It currently consists of two professors (Ting Mei and Wending Zhang), one associate professor (Lixun Sun), one postdoctoral researcher (Shuoshuo Zhang), and twenty-five doctoral and master's students. The group's research areas primarily focus on surface-enhanced spectroscopy, chiral sensing devices, phase-change materials and reconfigurable photonic devices, as well as photonic artificial neural networks. Related results have been published in journals such as Advanced Functional Materials, Advanced Photonics Nexus, Nano Letters, and Advanced Optical Materials. Several projects were supported by the Key Program and the General Program of the National Natural Science Foundation of China.

About Shenzhen University, China
The Nanophotonics Research Center at Shenzhen University was founded in 2013 by Prof. Xiaocong Yuan. Its major research areas include micro/nano-scale light field manipulation, optical mode multiplexing and interconnects, photoacoustic diagnosis, novel optical tweezers, ultra-sensitive sensing, and super-resolution imaging. The center currently has nearly 20 full-time faculty members, including one Member of Academia Europaea (MAE), one Distinguished Professor of the Yangtze River Scholar, two Excellent Young Scholars of the National Natural Science Foundation of China (NSFC), 2 New Century Excellent Talents in University of Ministry of Education, 1 Leading Talent of Guangdong Province, and 8 Overseas High-Caliber Personnel of Shenzhen. Since 2013, the center has published more than 400 SCI-

indexed papers, including publications in Nature Physics, Nature Communications, Science Advances, PNAS, Advanced Photonics, Light: Science & Applications, and Physical Review Letters.

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