Supertoroidal Electrodynamics

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Toroidal electrodynamics is a recently established research area of electromagnetism that involves the study of doughnut-shaped excitations in matter and in free-space. Despite being first considered over 60 years ago, toroidal excitations have been often omitted from the description of matter as they were considered negligible, high order corrections. Owing to the rapid recent advances in metamaterials, toroidal excitations were experimentally observed for the first time in arrays of toroidal metamolecules, providing dominant contributions to the metamaterial response and resulting in counter-intuitive phenomena, such as non-radiating configurations (anapoles) and vector potential sources. More recently, the field of toroidal electrodynamics expanded to include free-space propagating excitations in the form of toroidal light pulses. Such pulses, also known as Flying Doughnuts, are single cycle, space-time non-separable, broadband pulses of toroidal topology. They have been shown to preferentially excite toroidal and anapole resonant modes in nanoparticles and were generated only recently for the first time.

In this talk, we will present our latest contributions to the field of toroidal electrodynamics. In particular, we will review the generation and characterization of toroidal pulses and discusss their generalization to the family of supertoroidal pulses. Supertoroidal pulses exhibit a number of intriguing features, such as topological structures similar to skyrmions in condensed matter and exotic propagation properties, e.g. non-diffracting propagation over arbitrary distances and energy transfer reminiscent of “vortex streets” in fluid dynamics. Moreover, we will show that the spatiotemporal structure of supertoroidal pulses can lead to very fine spatial and temporal features occurring at length and temporal scales smaller than what one would anticipate from the angular spectrum of the pulses, a phenomenon that we term space-time superoscillations. Finally, we will demonstrate that the light-matter interactions of toroidal pulses with doughnut-shape particles lead to the excitation of supertoroidal current modes, fractal iterations of poloidal currents, which lead to new types of non-radiating sources.

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