Manipulating waves with spatiotemporal symmetry breaking

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Recent progress into highly nonlinear natural and artificial materials has sparked renewed interest in the extension of the metamaterial concept to the temporal domain. Until very recently, however, the temporal duals of the most basic concepts in wave physics, reflection and diffraction, were never achieved for electromagnetic waves. Recently, following the establishment of new theory advances [1], we designed and implemented a microwave temporal metamaterial, i.e. a structure capable of abruptly changing its electromagnetic properties within a time interval much shorter than a single temporal oscillation cycle of the waves propagating in it. In other words, these metamaterials can realize temporal interfaces dual to spatial mirrors, at which waves are homogeneously reflected. As a result, we were able to observe temporal reflection of a broadband pulse, and the temporal analogue of an antireflection coating [2]. By exploiting the temporal interference between multiple waves, counter propagating through the time-metamaterial, we were also able to engineer synthetic collisions between microwave pulses, whose nature can be tuned from inelastic to super-elastic by varying the relative phase between the pulses, realizing a broadband, phase-tunable temporal analogue of coherent control phenomena such as coherent perfect absorption and lasing, and enabling a new form of pulse shaping based on the mutual sculpting of electromagnetic waves [3].

In optics, the extreme nonlinearities of indium tin oxide (ITO) allowed us to realize a temporal double-slit experiment, whereby two subsequent pump pulses modulate abruptly an ultrathin perfect absorber, turning it into a highly reflecting mirror at femtosecond timescales. We demonstrate how the speed of the pump-induced index modulation of ITO is much faster than previously thought, cannot be described by a conventional third-order nonlinearity, and approaches the single-cycle timescale, hinting at a path to optical time-reflection [4]. From a theoretical standpoint, new amplification phenomena and optical drag occur in synthetically moving media [5-7]. Finally, further opportunities to enhance light-matter interactions arise when manipulating symmetry in the subwavelength scale. Inspired by the exotic hyperbolic polaritons recently found in monoclinic crystals, we designed and developed reconfigurable twisted metasurfaces, whose modes acquire a chiral nature from deeply subwavelength shear phenomena [8].

Bio: *Dr Emanuele Galiffi is a Junior Fellow of the Simons Society of Fellows at the Advanced Science Research Center of the City University of New York. His research interests include exotic wave phenomena in time-varying and space-time modulated media, transformation optics, surface waves in low-symmetry crystals and metamaterials, and singular nanophotonic structures. He completed his undergraduate studies at Imperial College London and the University of Heidelberg in 2016, and received his PhD from Imperial College in 2021, where he worked with Prof. Sir John Pendry. After spending one year at Imperial College as a Doctoral Prize Fellow, he moved to his current post as Simons Fellow. He was awarded the Junior Fellowship of the Simons Society of Fellows, the EPSRC Doctoral Prize Fellowship, the Johnson Matthey Prize for the best PhD thesis from the Centre for Doctoral Training in Theory and Simulation of Materials, several best paper awards and a best poster award, as well as various outreach prizes. He has published 30+ peer reviewed articles on high-profile journals including Science, Nature Physics, Nature Communications and Physical Review Letters, and led the effort that produced the current leading review on time-varying media. His work was recognized with 1000+ citations.*

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