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Rogue Waves and Extreme Events in Optics - Challenges and Questions

John Dudley (1), Pierre-Ambroise Lacourt (1), Goery Genty (2), Frederic Dias (3), and Nail Akhmediev (4)

(1) CNRS Institut FEMTO-ST, University of Franche-Comte, France (john.dudley@univ-fcomte.fr), (2) Department of Physics, Tampere University of Technology, FIN-33101 Tampere, Finland, (3) Centre de Mathématiques et de Leurs Applications, ENS Cachan, Cachan France, (4) Optical Sciences Group, Research School of Physics and Engineering, Institute of Advanced Studies, The Australian National University, Canberra ACT 0200, Australia

A central challenge in understanding extreme events in physics is to develop rigorous models linking the complex generation dynamics and the associated statistical behavior. Quantitative studies of extreme phenomena, however, are often hampered in two ways: (i) the intrinsic scarcity of the events under study and (ii) the fact that such events often appear in environments where measurements are difficult. A particular case of interest concerns the infamous oceanic rogue waves that have been associated with many catastrophic maritime disasters. Studying rogue waves under controlled conditions is problematic, and the phenomenon remains a subject of intensive research.

On the other hand, there are many qualitative and quantitative links between wave propagation in optics and in hydrodynamics, and it is thus natural to consider to what degree (if any) insights from studying instability phenomena in optics can be applied to other systems. In this context, significant experiments were reported by Solli et al. in late 2007 ["Optical rogue waves," Nature 450, 1054 (2007)], where a wavelength-to-time detection technique allowed the direct characterization of shot-to-shot instabilities in the extreme nonlinear optical spectral broadening process of supercontinuum generation. Specifically, although the process of supercontinuum generation is well-known to exhibit fluctuations in both the time and frequency domains, Solli et al. have shown that these fluctuations contain a small number of statistically-rare "rogue" events associated with a greatly enhanced spectral bandwidth and the generation of localized temporal solitons with greatly increased intensity.

Crucially, because these experiments were performed in a regime where modulation instability (MI) plays a key role in the dynamics, an analogy was drawn with hydrodynamic rogue waves, whose origin and dynamics has also been discussed in terms of MI or, as it often referred to in hydrodynamics, the Benjamin-Feir instability. The analogy between the appearance of localized structures in optics and the rogue waves on the ocean's surface is both intriguing and attractive, as it opens up possibilities to explore the extreme value dynamics in a convenient benchtop optical environment. In addition to the proposed links with solitons suggested by Solli et al., other recent studies motivated from an optical context have experimentally demonstrated links with nonlinear breather propagation. The purpose of this paper will be to discuss these results that have been obtained in optics, and to consider possible similarities and differences with oceanic rogue wave counterparts.