Emergence of Rogue Waves in Optical Parametric Generation

G Steinmeyer[1,2], W Chen[3], H Shi[4], Y Lu[5], J Fan[3], and M Hu[3]

[1] *Institut für Physik der HU, Berlin, Germany*
[2] *C2, Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany*
[3] *College of Precision Instruments and Opto-electronics Engineering, Tianjin University, Tianjin, China*
[4] *State Key Laboratory for Precision Spectroscopy, East China Normal University, Shanghai, China*
[5] *Institute of Physics, Humboldt University, Berlin, Germany*
Contact Email: steinmey@mbi-berlin.de

Optical parametric generation (OPG) is a remarkably simple scheme for wavelength conversion of short pulses as it does not require a coherent seed for the signal wave [1]. This simplicity comes at the price of a fully incoherent signal output. We have analyzed the signal pulse train of an optical parametric generator at the full 53 MHz repetition rate, using both the dispersive Fourier transform (DFT) and dispersive time-domain interferometry (DTI). This provides access to pulse energy fluctuations (shot noise), carrier-envelope phase variations (Schawlow-Townes noise) as well as to timing jitter noise and wavelength shifts. As expected phase noise is univariate random in $[-\pi, \pi[$, and shot noise underlies a Poissonian statistics with a characteristic photon number near zero (Fig. 1b,c). Moreover, timing jitter and spectral shifts follow energy fluctuations. For comparison, we seeded our OPG with 8 mW from a cw laser, which increases the average output energy by a factor of 3.5 and greatly reduces virtually all fluctuations to the detection noise floor of DFT and DTI. Nevertheless, while OPG produces average pulses that clearly do not saturate parametric amplification, we observe occasional events in the OPG pulse train that exceed pulse energies of the coherently seeded parametric amplifier by a large factor and strongly saturate amplification. From a statistical analysis we find that the pulse train follows rogue statistics, with numerous events that exceed the average energy and amplitude of the upper third of the pulses by a factor larger than two (Fig. 1a). These rogue pulses exhibit significantly different spectral shapes than the average pulse and also give rise to the observed non-Gaussian statistics of timing jitter and spectral shift (Fig. 1d,e). Other than optical rogue waves in supercontinuum generation, OPG rogue waves really do exhibit pulse energies that exceed any expectation drawn from coherent seeding, and their timing and wavelength is also affected by extreme value statistics. In much closer analogy to ocean rogue waves, therefore, it appears fair to say that OPG rogue waves appear out of nowhere and disappear without a trace, *i.e.*, they are completely unexpected in many more ways.

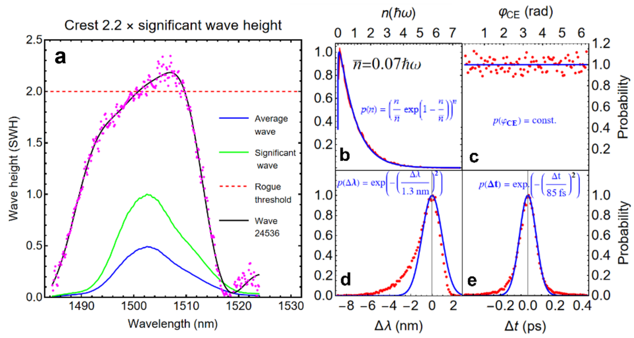

Figure 1: DFT and DTI results based on 26,500 individual real-time measurements. a: rogue spectrum (magenta symbols and smoothed black line) in comparison to average (blue) and significant wave (green). The threshold for rogue waves is shown as a dashed red line. b: pulse energy statistics with Poissonian fit (blue). c: measured univariate CEP noise. d and e: skewed Schawlow-Townes noise and timing jitter noise. Gaussian fits have been included (blue curves) to highlight deviations from normal distributions

References

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