Observation of Black Vector Rogue Waves in the Normal Dispersion Regime of Optical Fibers

***B. Frisquet*[1], *B. Kibler*[1], *J. Fatome*[1], *P. Morin*[1], *F. Baronio*[2], *M. Conforti*[3], *G. Millot*[1], *S. Wabnitz*[2]**

1. Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB), UMR 6303 CNRS - Université de Bourgogne, F-21078 Dijon, France

2. Dipartimento di Ingegneria dell'Informazione, Università di Brescia, Brescia 25123, Italy

3. PhLAM/IRCICA UMR 8523/USR 3380 CNRS - Université de Lille 1, F-59655 Villeneuve d'Ascq, France

Originally studied in oceanography, extreme waves have attracted in recent years a great deal of attention in nonlinear optics, in particular in the context of optical fiber propagation [1-2]. In fact the first clear-cut observation of a prototype extreme wave "that appears from nowhere and disappears without a trace", the Peregrine soliton, was reported in a fiber optics experiment of 2010 [3]. The next frontier of rogue wave research is the study of multi-component wave systems, e.g., parametric three-wave interactions in quadratic media [4].

We present here the first experimental observation, to the best of our knowledge, of a vector rogue wave. We consider rogue wave solutions of the two component nonlinear Schrödinger equation or Manakov system, that describes polarization coupling in a randomly birefringence telecommunication optical fiber [5-6]. Multimode wave coupling leads to totally new mechanisms for rogue wave creation with respect to scalar nonlinear wave models. Indeed, thanks to cross-phase modulation and dispersive group-velocity walk-off, two orthogonally polarized CW pump waves at different frequencies experience modulation instability (MI) even in the normal dispersion regime of the fiber [6]. The nonlinear evolution of the MI process may lead, under suitable conditions, to the generation of spatio-temporally localized black rogue waves characterized by the appearance of a sudden dip of the optical intensity [6].

Figure 1, left, shows the experimental setup used for the seeded-MI experiments, where MI is induced by the initial intensity modulation of the two pumps at a proper frequency Ω (see also panels (a-b) of Fig.1, right.). Nonlinear propagation occurs in a reverse TrueWave fiber, with a chromatic dispersion of -14 ps/nm/km, a nonlinear coefficient γ=2.4W^{-1}.km^{-1} and an attenuation of 0.25 dB/km at λ_0 = 1554.7 nm. This fiber has the very low PMD value of 0.017 ps.$km^{-1/2}$. Panels (e,f) of Fig.1, right compare the experimentally observed output intensity after propagation in 3 km of fiber (red curves) with the intensity profile of the analytical black rogue solution (black curves). As can be seen, an excellent agreement is achieved, although the initial modulation is much deeper than the exact solution (see Fig.1 (a,b)). A temporal periodic experimental waveform is obtained because of experimental constraints: in principle an isolated rogue dip could be observed by decreasing the initial modulation frequency Ω [3]. Note that the signature of the rogue dip in the frequency domain is the development of a spectral asymmetry (see Fig1, (g,h)).

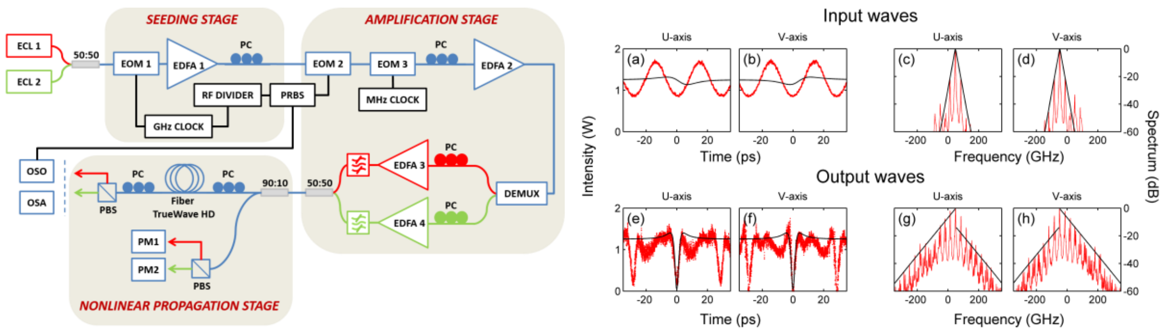

Fig. 1 Left: experimental setup. Right: Experimental observation of black vector rogue wave. **a & b** temporal profile of power in the U and V polarization modes at the fiber input **c & d** power spectra at the fiber input **e & f** output intensities after 3 km of optical fiber. **g & h** power spectra at the fiber output. Red solid traces are experimental results and black solid curves represent the analytical black vector rogue wave.

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