

Distorsion of the nonlinear spectrum of solitonic pulses induced by stimulated Raman scattering

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Solitons in optical fibers were first discovered fifty years ago as pulses of light that propagate indefinitely without alteration of their shape or spectrum. Introduced in the early 70', they have been extensively studied in the context of ultra-fast telecommunications. Immediately afterwards, the soliton self-frequency shift (SSFS) was discovered as a consequence of stimulated Raman scattering (SRS) [1]. SSFS is responsible for the drifting of solitons' spectrum to lower frequencies which is associated with a variation of velocity (desceleration). SRS is also responsible for the splitting of a powerful pulse into several solitons, the soliton fission, a process involved in the generation of supercontinua.

There is a revival of the solitons studies in a framework of nonlinear telecommunications. This topic is based on the inverse scattering theory (IST) which is the proper mathematic tool for studying integrable systems in which solitons are eigenmodes. The IST of a signal indicates its solitonic content through a discrete set of complex eigenvalues, a nonlinear spectrum, that is preserved during the propagation and in which the real axis is associated to the velocities of the solitons and the imaginary one with the amplitudes.

In this work, we studied how SRS breaks the conservation of the nonlinear spectrum of N-solitons. We generate an intense light pulse composed with up to 2 solitons (depending on the input power) and we are able to record both their intensity and phase after they have propagated in either 500 m or 1 km of single-mode fiber. Using a heterodyne timelens system we recorded in single shot both phase and amplitude [2] of the 2-soliton before and after splitting. Thanks to the recording of the whole electrical field we computed the IST spectrum and revealed a strong deterministic deformation in the nonlinear spectrum (see Fig.1).

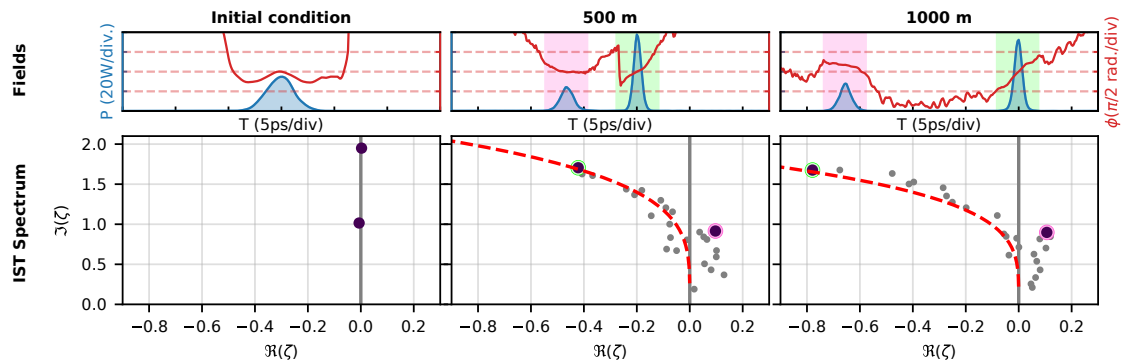


Figure 1: First row: single shot recordings of respectively the initial pulse, the split pulse after 500 m and 1000 m with in blue the amplitude and in red the phase. Second row: IST spectrum of the signals. In dashed red lines is the theoretical position of the strongest eigenvalue depending on its input power.

Figure 1 shows the results we obtained with the maximum power we could get. The first IST panel shows a signal composed with two eigenvalues (two solitons). The second one shows the IST spectrum of the signal after 500 m of propagation. The violet points correspond to the points of the initial condition at maximum power. In grey we presented the other powers, revealing the deformation of the spectrum. On the last panel the same experiment was achieved with a 1000 m fiber showing the emphasis of the phenomenon with the propagation. We then compared the results with the perturbative theory of the soliton and revealed a good match between theory and experiments. This work is a first step for understanding the effect of higher orders on larger objects such as soliton gas [3].

1. Mitschke, F. M. & Mollenauer, L. F. Discovery of the soliton self-frequency shift. *Optics Letters* **11**, 659 (1986).
2. Tikan, A., Bielawski, S., Szwarz, C., Randoux, S. & Suret, P. Single-shot measurement of phase and amplitude by using a heterodyne time-lens system and ultrafast digital time-holography. *Nature Photonics* **12**, 228–234 (2018).
3. Zakharov, V. E. Kinetic Equation for Solitons. *JETP* **33**, 538 (1971).