Nonlinear dynamics of spatio-temporal waves in multimode fibres

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Abstract: Nonlinear multimode fibers provide an intriguing test-bed for exploring complex spatio-temporal beam dynamics. We overview recent experimental observations of Kerr beam self-cleaning, parametric sideband series and supercontinuum generation in passive and active multimode optical fibers.

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Multimode optical fibers (MMFs) had so far limited applications, mainly because of their inherent inability to maintain a good beam quality due to mode scrambling. In recent years however, nonlinear MMFs have emerged as an easily accessible playground to explore complex spatio-temporal optical pulse propagation phenomena [1]. In the anomalous dispersion regime, femtosecond multimode optical solitons have been observed in graded-index (GRIN) MMFs [2]. Their longitudinal periodic intensity oscillations have led to the controlled generation of ultra-wideband dispersive wave sideband series [3,4]. Whereas in the normal dispersion and with picosecond to nanosecond pump pulses, sideband series spanning from the visible till the mid-infrared (MIR) have been generated, resulting from the modulation instability of quasi-continuous waves, induced by the periodic beam self-imaging effect [5,6]. Far-detuned parametric frequency conversion was also achieved in a few mode GRIN fiber pumped at 1064 nm: multiple sidebands spanning in the visible down to 405 nm and in the near infrared up to 1953 nm were generated via a complex cascaded process involving inter-modal four-wave mixing [7].

Before the onset of spatio-temporal instabilities, as shown in figures 1-2, the Kerr effect alone has been shown to produce, for peak powers above a certain threshold, unexpected spatial beam self-cleaning towards a well-defined, and robust bell-shaped transverse profile after propagation over about 1 m of GRIN MMF [8]. The interplay between Kerr effect and Raman scattering in GRIN MMF has been shown to generate a spectrally flat, and spatially single-mode supercontinuum extending from the visible till the MIR [9]. As shown in figure 2, a temporally resolved analysis reveals significant (tenfold) temporal compression in the spectral sidebands [9]. Spatial Kerr-induced beam self-cleaning was observed with increased efficiency (i.e., with input peak powers below 1 kW) in an active, ytterbium doped MMF with a step-index profile [10]. Finally, by optical poling a GRIN MMF, we generated a photo-induced charge distribution and a permanent modulated quadratic nonlinearity, leading to quasi-phase-matched second-harmonic (SH) generation. We observed that the self-imaging of the pump wave led to the generation of a spectral sideband series around the SH wave. Moreover, the simultaneous spatial self-cleaning of pump and SH beams was observed [11].

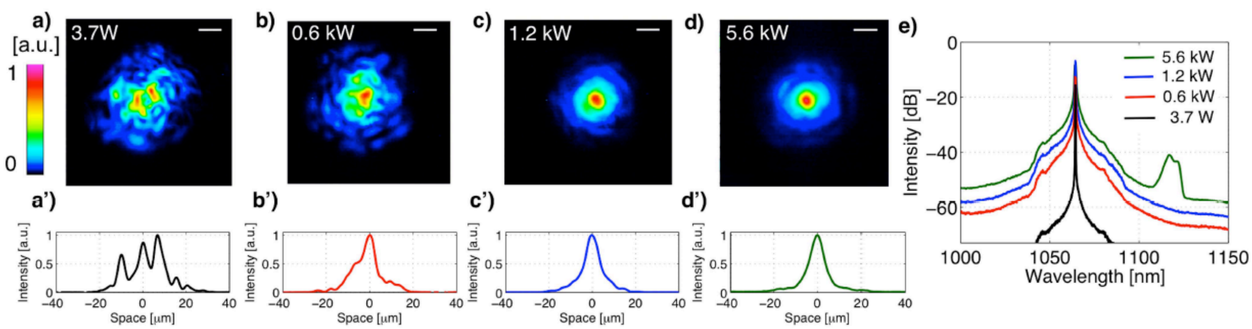

Fig. 1. Experimental demonstration of spatial Kerr beam self-cleaning. (a-d): Intensity profile of output transverse beam from 12 m of GRIN MMF for different peak pulse powers; (a'-d'): corresponding beam cross-sections; (e) output spectral intensity.

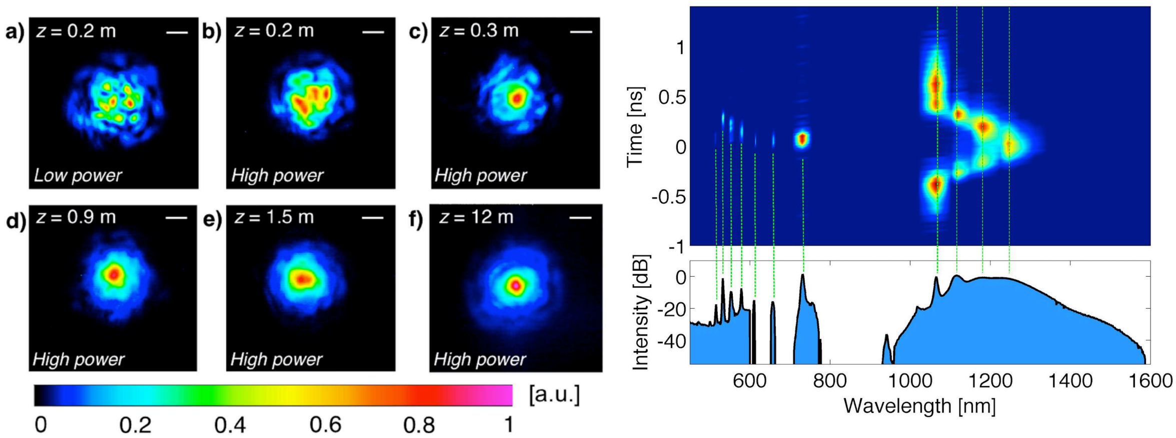

Fig. 2. (a-f) Intensity profile of output transverse beam from GRIN MMF for different fiber lengths at low power and high power, respectively; right panel: output spectral intensity profile (top) and spectrogram (bottom) showing sideband series and supercontinuum generation.

All of these observations may pave the way to the future development of a new class of photonic devices for a wealth of applications, based on combining an effective spatial single-mode environment with large fiber-core diameters.

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