

# Experimental and numerical investigation of fundamental noise on supercontinuum generated in microstructure fiber\*

**K. L. Corwin, N. R. Newbury, B. R. Washburn, S. A. Diddams**

*National Institute of Standards and Technology, 325 Broadway, Boulder, Colorado 80305*

*Tel: (303) 497-4217, Fax: (303) 497 -3387, E-Mail: [corwink@boulder.nist.gov](mailto:corwink@boulder.nist.gov)*

**J. M. Dudley**

*Laboratoire d'Optique P. M. Duffieux, Université de Franche-Comté, 25030 Besançon, FRANCE*

**S. Coen**

*Service d'Optique et Acoustique, Université Libre de Bruxelles, Av. F. D. Roosevelt 50, CP 194/5, B-1050 Brussels, BELGIUM*

**R. S. Windeler**

*OFS Laboratories, 700 Mountain Avenue, Murray Hill, New Jersey 07974*

**Abstract:** Supercontinua generated in microstructure fiber can exhibit amplitude fluctuations of 70 %. Experimental and numerical studies of the broadband noise reveal its fundamental and quantum origins: input pulse shot noise and spontaneous Raman scattering.

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Supercontinuum generation in microstructure and tapered fibers creates a remarkable coherent light source spanning the visible spectrum [1, 2]. However, a significant broadband amplitude noise renders the supercontinuum too noisy for some applications. This white, broadband noise extends well beyond the frequency roll-off of any laser technical noise (such as pump power or beam-pointing fluctuations), and corresponds to amplitude fluctuations in the time-domain approaching 100 %. We have found that the origin of this broadband noise is the amplification of quantum fluctuations.

Figure 1 shows a comparison of experiment and theory for both the generated spectrum and relative intensity noise (RIN). Experimentally, a mode-locked titanium:sapphire laser provides pulses with a bandwidth of  $\sim 45$  nm FWHM centered at 810 nm. Pulses with variable chirp and 0.9 nJ energies are injected into a 15 cm long microstructure fiber with zero group-velocity-dispersion at 770 nm [1]. The resulting supercontinuum is spectrally filtered by a monochromator (8 nm bandwidth) before photodetection. The resulting RF noise power is measured at high Fourier frequencies ( $>3$  MHz), where the Ti:Sapphire laser is approximately shot-noise limited. The RIN in dBc/Hz is obtained from this noise power, divided by the RF electrical bandwidth and the total detected power.

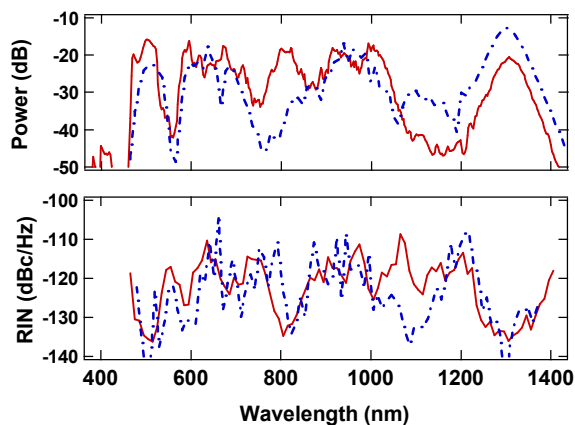


Fig. 1: (a) Spectrum and (b) total RIN as a function of wavelength across the supercontinuum for experiment (solid lines) and theory (dashed line) for an input pulse duration of 22 fs FWHM (*i.e.*, with minimal chirp).

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We numerically simulate supercontinuum generation using a stochastic nonlinear Schrödinger equation that rigorously includes both input shot noise and spontaneous Raman scattering [3]. No free parameters are used, and the quantum input noise terms have no adjustable parameters. We find that input shot noise is the dominant source of supercontinuum RIN.

Both the spectral width and the RIN increase with input pulse energy, as shown in Fig. 2 for a moderately chirped input pulse. Here, the median RIN value is given, calculated across all wavelengths for which there is sufficient optical power. Fig. 3 shows experimental measurements (triangles) and numerical simulations (circles) of the supercontinuum spectral width and the median RIN as a function of induced chirp from  $-500 \text{ fs}^2$  to  $+600 \text{ fs}^2$  (22 – 92 fs FWHM pulse duration).

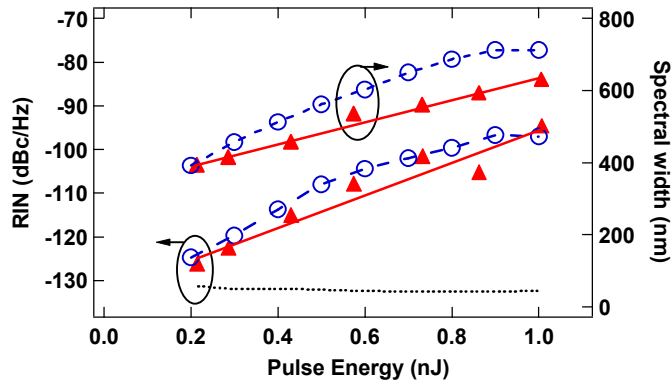


Fig. 2: The RIN and corresponding  $-20 \text{ dB}$  width of the supercontinuum as a function of the average input pulse energy for experiment (triangles, solid lines) and theory (circles). The dotted line is the detection shot noise limit. (Input pulse chirp:  $-282 \text{ fs}^2$ , pulse duration: 47 fs FWHM.)

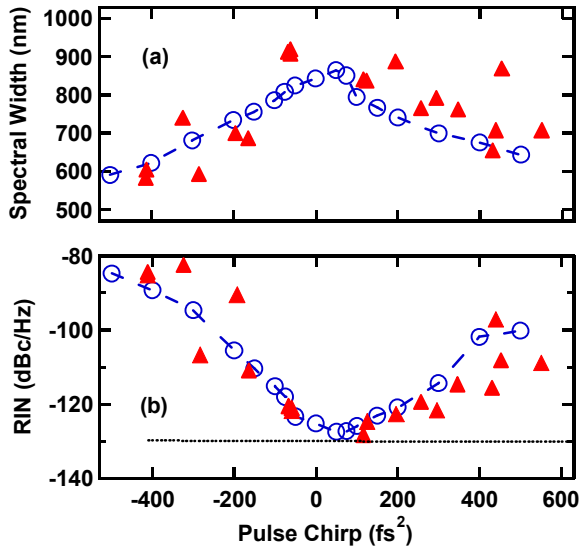


Fig. 3: The supercontinuum spectral width and median total RIN as a function of pulse chirp for experiment (triangles) and theory (circles). The dotted line is the detection shot noise limit.

We show through good agreement between numerical and experimental results that the large supercontinuum amplitude noise arises directly from the shot noise on the input laser pulse. By using pulses with the shortest input pulse duration, the noise is minimized while the spectral width of the supercontinuum is maximized

**References**

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