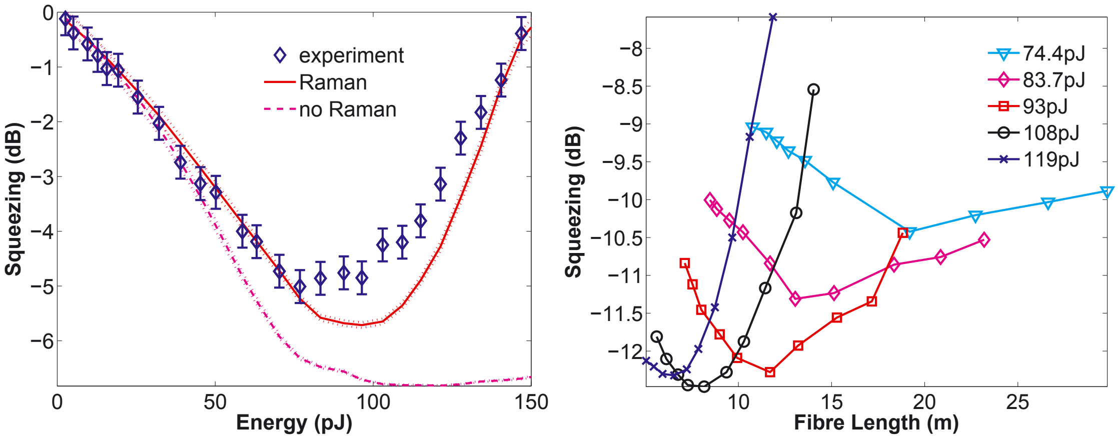
Quantum dynamics of polarisation squeezing in optical fibres

J. F. Corney[1], P. D. Drummond[1], J. Heersink[2], V. Josse[2], G. Leuchs[2] and U. L. Andersen[2]
[1]*ACQAO, School of Physical Sciences, The University of Queensland, QLD 4072, Australia*
[2]*Institut für Optik, Information und Photoniks, Universität Erlangen-Nürnberg, Germany*

Polarisation squeezing in optical fibres is an efficient means of producing highly squeezed light[1]. Because the experiments operate in a very nonclassical regime, the results are very sensitive to additional nonlinear and thermal effects in the fibre. To quantitatively characterise such experiments, we perform first-principles, quantum dynamical simulations of intense, ultrashort pulses in a fibre, including all significant quantum and thermal noise. We compare simulation and experiments to find excellent agreement over a wide range of pulse energies and fibre lengths[2]. From the simulations, we can identify the particular noise sources that are the limiting factors at high and low input energy.

In the experiment, two equal-intensity pulses propagate along orthogonal polarisation axes of a polarisa maintaining fibre, emerging simultaneously with a $\frac{\pi}{2}$ phase difference. The squeezed pulses are combined on a half-wave plate and the squeezing is measured at a frequency of $17.5\mathrm{MHz}$, to avoid technical noise. Most of the excess noise induced by the fibre is common-mode and is thus cancelled.

We use a quantum model that includes the electronic $\chi^{(3)}$ nonlinear responses of the material and nonresonant coupling to phonons in the silica. The phonons provide a non-Markovian reservoir that generates additional, delayed nonlinearity, as well as spontaneous and thermal noise. The coupling is based on the experimentally determined Raman gain $\alpha^R(\omega)$. The simulations are performed with a truncated Wigner technique[3], which provides an accurate simulation of the quantum dynamics for short propagation times and large photon number. The quantum effects enter via initial vacuum noise, which makes the technique ideally suited to squeezing calculations.



Left: Comparison of simulations and experiment for $L = 13.35\mathrm{m}$. Dashed line is the simulation with a fully electronic nonlinearity (i.e. no Raman effects). **Right**: Predicted optimum squeezing for various fibre lengths. Parameters: $t_0 = 74\mathrm{fs}$, $z_0 = 0.52\mathrm{m}$, $\overline{n} = 2 \times 10^8$, $E_s = 54\mathrm{pJ}$, $\lambda_0 = 1.51\mu\mathrm{m}$, linear losses 20%.

The figures illustrate the importance of Raman effects. The level of squeezing at first increases with input energy, as expected from the Kerr effect. However, at high intensity, Raman effects degrade the squeezing, leading to an optimum energy for maximum squeezing. This optimum energy is larger for shorter fibre lengths. The simulations predict that the best squeezing will be obtained for at $L = 7\mathrm{m}$, where the optimum energy equals the soliton energy.

References

[1] J. Heersink, V. Josse, G. Leuchs and U. L. Andersen, Opt. Lett. **30**, 1192 (2005).
[2] J. F. Corney *et al*, Phys. Rev. Lett. **97**, 023606 (2006).
[3] P. D. Drummond and J. F. Corney, J. Opt. Soc. Am. B **18**, 139 (2001).