

Entanglement dynamics under atmospheric turbulence

Giacomo Sorelli¹, Nina Leonhard², David Bachmann¹,
Francesco Campaioli¹, Timon Eichhorn¹, Jan Schuler¹,
Claudia Reinlein², Vyacheslav N. Shatokhin¹, Andreas Buchleitner^{1,3}

¹ Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, 79104 Freiburg i.Br.

² Fraunhofer-Institut für Angewandte Optik und Feinmechanik, Albert-Einstein-Straße 7, 07745 Jena

³ Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, Albertstr. 19, 79104 Freiburg i.Br.

Abstract

Due to the unbounded dimension of the associated Hilbert space, orbital angular momentum (OAM) states of light promise to enhance the transmission of quantum information in free space. However, given the sensitivity of the OAM states' wave fronts against turbulence-induced fluctuations of the refractive index, such states' information content appears to be fragile. We analyse the trade-off between enhanced dimensionality and that very fragility, and discuss possible strategies to mitigate the turbulence-induced loss of quantum information content.

The transmission of orbital angular momentum (OAM) states of light [1] across a turbulent atmosphere defines an intriguing problem, both under a theoretical perspective as well as with respect to potential applications. On the theory side, the turbulence-induced scrambling of the phase front structure over a broad range of length-scales, together with the associated transverse spreading of the pulse, induces a progressive loss of purity and signal upon transmission, as a consequence of the concomitant disorder average and final state projection [2, 3]. On the application side, this immediately raises the question on the theoretical limits for the efficient transmission of quantum information as e.g. inscribed in bi-photon states entangled in their OAM degree of freedom [4, 5]. How do turbulence strength, transmission distance, and the effective dimension and structural properties of the injected state affect the transmission fidelity, and in particular the entanglement properties of the transmitted state? Which are the prospects offered by adaptive optics tools to reduce the loss of purity and entanglement under turbulence? The talk will present some recent results to elucidate these questions.

- [1] L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman, *Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes*, Phys. Rev. A **45**, 8185 (1992)
- [2] N. Leonhard, V. N. Shatokhin, and A. Buchleitner *Universal entanglement decay of photonic-orbital-angular-momentum qubit states in atmospheric turbulence*, Phys. Rev. A **91**, 012345 (2015)
- [3] D. Bachmann, V. N. Shatokhin, and A. Buchleitner, *Universal entanglement decay of photonic orbital angular momentum qubit states in atmospheric turbulence: an analytical treatment*, arXiv:1903.04539
- [4] N. Leonhard, G. Sorelli, V. N. Shatokhin, C. Reinlein, and A. Buchleitner, *Protecting the entanglement of twisted photons by adaptive optics*, Phys. Rev. A **97** 012321 (2018)
- [5] G. Sorelli, N. Leonhard, V. Shatokhin, C. Reinlein, and A. Buchleitner, *Entanglement protection of high-dimensional states by adaptive optics*, New J. Phys. **21** 023003 (2019)