Investigating the quantum advantage of non-classical light sources for the control of biological systems

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From photosynthesis to vision, the variety of forms in which biological organisms on Earth have evolved to respond to light is astonishing. The use of light to measure, stimulate and control biological systems has therefore become ubiquitous. On the other hand, technological advances in quantum optical science currently allow the precise generation of quantum light: non-classical photon fields whose statistics and/or correlations can differ drastically from those of sunlight and lasers. Though it is known that quantum light could be valuable for biological measurement, the potential that it may offer for influencing biophysical function is not fully understood. This project aims to develop a joint theory-experimental study of the advantages of entangled photon pairs for controlling biological function.

It is known that non-classical states of light have can provide enhancement in terms of low noise and low intensities which will prevent photodamage in the investigation of biological samples. But less in known about the fundamental understanding of the interactions of non-classical light with complex photoreceptors that are used to control biological systems in fields such as optogenetics.

In this project the student will develop theoretical investigations of the interactions between entangled photon pairs and prototype photoreceptors, which display rich electronic-vibrational quantum dynamics, with the objective to provide insight into the matter characteristics that can enhance the quantum advantage provided by the interaction with non-classical light sources. Through this interdisciplinary project, the student will gain experience with physical chemistry techniques as well as open quantum system dynamics, light-mater interaction, and quantum optics beyond standard approximations [1, 2]. This PhD project therefore lies at the interface of two critical areas of research: Engineering Biology and Quantum Technologies.

The project will be developed in close collaboration with Dr Alex Jones at the National Physical Laboratory (UK), expert in biometrology, optogenetics and photophysical dynamics of light-activated proteins, and with Prof Rob Thew at the University of Geneva, expert in developing quantum technologies for emerging applications in quantum information science [3].

[1] E J O'Reilly and A. Olaya-Castro, Non-classicality of the molecular vibrations assisting exciton energy transfer at room temperature, *Nature Communications* **5**, 3012 (2014)

[2] C Nation, V Notatarigo, HO Gestsson, L Sapienza, A Olaya-Castro, Two-colour photon correlations probe coherent vibronic contributions to electronic excitation transport under incoherent illumination, arXiv preprint arXiv:2403.00857 (2024).

[3] D Tabakaev et al, Energy-time-entangled two-photon molecular absorption, Phys. Rev. A 103, 033701 (2021)

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