Quantum-mechanical imaging of complex dynamics in networks of neurons

This project is to undertake experimental and high-performance computer simulations of complex dynamics in networks of neurons, and in the state-of-the-art quantum systems used to image them.

It will be supervised jointly by Dr Noah Russell of the Faculty of Engineering Neurophotonics Research Laboratory, and Prof. Mark Fromhold of the School of Physics and Astronomy.

Together, the Neurophotonics Research Laboratory and the School of Physics and Astronomy are developing new technologies that exploit complex quantum processes and interactions in order to study how information is encoded and processed in networks of neurons. A key part of this technology is the ability to monitor neural activity across a whole network and to understand the interaction of that network with the quantum sensor systems used to image it. The focus of the project is the development of novel sensor technology and its applications in non-invasive imaging of activity in networks of neurons.

The quantum imaging technology to be developed will be based on plasmonic and NV-diamond sensors, which respond to small perturbations in electric and magnetic fields. Plasmons are complex collective oscillations of electrons in a metal or semiconductor that are highly sensitive to electrochemical perturbations associated with neural spiking. NV centres in diamond, formed by nitrogen dopants, fluoresce in a way that depends sensitively on changes in magnetic field that result from ionic currents during neuronal spiking. These new quantum sensing techniques will be used to monitor cultured neuronal networks, grown on the sensors themselves, and network regeneration processes. Analysis of the system and its dynamics will require a combination of experimental work and computer modelling of the current flow patterns in the neural network, the resulting magnetic field landscape, and its effect on the sensors.

This cross-Faculty inter-disciplinary project will enable the student to develop skills in physics, engineering and biology, in particular the interface between all three fields. She/he will therefore become an expert in a diverse range of complex systems and techniques including optics, electrophysiology, cell culture, and the dynamics of networks of neurons. The results will establish a new collaboration between physicists with expertise in complex quantum systems and engineers working on the collective behaviour of neurons.

The project is suitable for Science or Engineering graduates from a wide range of backgrounds including physics, electrical or electronic engineering, applied mathematics, and computing science. Its emphasis will be shaped to match the skills of the applicant.