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Research interests

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Indefinite Quantum Causality (Theoretical & Experimental). Causal relations are normally established on the basis of an underlying background against which all events are positioned and which we call ‘space-time’. However, in order to depict the interplay between quantum mechanics and general relativity, modern physics may have to revise this paradigm. In particular, in order to fully represent both theories, causal structures may need to be both dynamic (as required by general relativity) and indefinite (due to quantum theory). Until a few years ago, this assumption seemed impossible to formalise, as both standard quantum mechanics and quantum field theory assume a background space-time and predefined causal relation. The landscape has changed over the past decade, with a large body of work devoted to this avenue of research. The cornerstone of this development is the formulation of extensions of quantum theory that do not presuppose a defined underlying causal structure. This has not only proven to be important from the point of view of the foundations of physics, but also opened the way to new opportunities in the processing and transmission of quantum information. This topic has been one of the research areas that has most profoundly characterised my past and, in some respects, current research activity.
Integrated Photonics Technologies (Experimental). The high competitiveness between the various approaches to quantum information devices has stimulated their rapid development. Integrated photonics is currently among the most favoured areas in this race, and the different tools derived from it are of a variety of uses. However, while the development of quantum foundations usually fuels the field of quantum technologies, the benefits of these for the design of new foundational experiments are often realised with some delay. My main experimental research objective is to apply the notions of modern quantum optics and quantum engineering to the analysis of frontier topics of quantum information theory and quantum foundations. My goal is to bring both fields to significant progress. In fact, I believe that not only the study of time and causality in quantum physics will benefit from the results of the experimental realisation of very challenging experiments, but also integrated photonics will benefit from the conjunction of experimental techniques that, though individually state-of-the-art, have rarely been combined in the realisation of such sophisticated circuits.
Theory of Quantum Thermodynamics (Theoretical). In thermodynamics, work is defined as the product of an applied force and the distance along a particular trajectory. However, this definition cannot be adopted in quantum mechanics, as quantum objects do not always travel along specific trajectories. In quantum mechanics, physicists typically define work as the difference between the final and initial energy of a system (the so-called ‘two-point measurement scheme’). Yet, this requires measuring the system at two different times, which destroys any coherence that may exist in the initial state. The question of how to provide an operationally accessible definition of quantum work is still open, and this has been one of my theoretical research interests in recent years. The reason why it is important to find such a definition stems in part from the development of quantum devices, such as nanoscale motors and refrigerators, in which quantum effects can dominate. In these systems, thermodynamic fluctuations are sometimes so large that assuming thermal equilibrium is no longer adequate. Consequently, the basic thermodynamic properties of these systems, such as entropy and free energy, require new formulations based on appropriate quantum definitions of the work done on (or extracted from) such systems.

Employment

Royal Commission 1851 Fellow and Proleptic Lecturer
School of Physics
Faculty of Science
United Kingdom
1 Oct 2023 → present

Research outputs

Inferring work by quantum superposing forward and time-reversal evolutions
Rubino, G., Manzano, G., Rozema, L. A., Walther, P., Parrondo, J. M. R. & Brukner, Č., 18 Mar 2022, In: Physical Review Research. 4, 1, 12 p., 013208.

Experimental entanglement of temporal order
Rubino, G., Rozema, L. A., Massa, F., Araújo, M., Zych, M., Brukner, Č. & Walther, P., 11 Jan 2022, In: Quantum. 6

Quantum superposition of thermodynamic evolutions with opposing time's arrows
Rubino, G., Manzano, G. & Brukner, Č., 26 Nov 2021, In: Communications Physics. 4, 10 p., 251.

Experimental Quantum Communication Enhancement by Superposing Trajectories
Rubino, G., Rozema, L. A., Ebler, D., Kristjánsson, H., Salek, S., Guérin, P. A., Abbott, A. A., Branciard, C., Brukner, Č., Chiribella, G. & Walther, P., 29 Jan 2021, In: Physical Review Research. 3, 1, 19 p., 013093.

Communication through quantum-controlled noise
Guérin, P. A., Rubino, G. & Brukner, Č., 17 Jun 2019, In: Phys. Rev. A. 99, 6, 062317.

Experimental verification of an indefinite causal order
Rubino, G., Rozema, L. A., Feix, A., Araújo, M., Zeuner, J. M., Procopio, L. M., Brukner, Č. & Walther, P., 24 Mar 2017, In: Sci. Adv.,. 3, 3