Dr. Esteban Castro Ruiz

Quantum clocks and the physical realisation of indefinite causal structures

Supervisor: Caslav Brukner

Abstract:

The usual formulation of quantum theory assumes a definite causal order of events — given two events, A and B, A is either in the causal past, causal future, or is causally disconnected from B. This thesis is a collection of works that explore the physical realisation and the theoretical description of indefinite causal structures, with emphasis on the interplay between quantum theory and general relativity. We show that highly accurate quantum clocks interacting gravitationally lead to an indefinite metric field, putting fundamental limitations to the measurability of time. We show that global causal structures are invariant under continuous and reversible dynamics, thus proving that a causally definite processes cannot be transformed into causally indefinite ones under such dynamics. We explore the connection between indefinite causality and spatiotemporal quantum reference frames. We introduce the idea of quantum reference frame transformations, and use it to show that, when reference frames are quantum, entanglement and superposition become relative notions. Afterwards, we study processes with indefinite causal structure from the perspective of temporal reference frames, defined by a quantum clock. We use this to show that that the temporal localisability of events becomes relative in the presence of gravitating quantum systems.