Contribution ID: **62** Type: **Quantum Foundations and QG**

Quantum Reference Frames and the Localisation of Events in Superpositions of Spacetimes

Thursday 9 May 2024 15:40 (15 minutes)

When describing a physical system, it is very common to do so with respect to a reference frame - a ruler used to determine the position of a particle, for example, or a clock, which tracks the time that elapses while it is moving. Usually, reference frames are treated as purely classical objects with well-defined properties. But what happens if we take into account the quantum properties of the reference frame itself? This question has motivated a recent wave of research on quantum reference frames (QRFs), which investigates how the description of our world changes when described relative to different quantum systems.

When dealing with QRFs, quantum features previously thought to be absolute, such as superposition and entanglement, become dependent on the frame. Here, we provide a novel explanation for this frame-dependence by tracing it back to the question of how configurations or locations are identified across different branches in superposition. We show that, in the presence of symmetries, whether a system is in "the same"or "different" configurations across the branches depends on the choice of QRF. Thus, sameness and difference - and, as a result, superposition and entanglement - lose their absolute meaning.

These ideas carry over to the context of semi-classical spacetimes in superposition, such as the one - arguably - sourced by a gravitating object in superposition. This regime serves as a useful platform to examine the conceptual implications of QRF changes on the interface between quantum theory and gravity. In particular, one can see that, in this context, there is no preferred way of identifying points across the branches of the superposition - and thus no absolute meaning to the statement that the gravitational source is in a superposition in the first place. We make this idea concrete by using coincidences of four scalar fields to construct a comparison map between all spacetimes in superposition, which allows us to determine whether a system or an event is located at the "same"or "different"points across the branches. Different choices of scalar fields can be understood as different instantiations of QRFs and give rise to different ways of comparing spacetime points across the superposition. As an explicit application of this formalism, we explore how the localisation of events is relative to the choice of QRF and discuss the implications thereof for a generalisation of Einstein' s famous hole argument, indefinite causal order and the locality of interaction.

Authors: KABEL, Viktoria (IQOQI Vienna); DE LA HAMETTE, Anne-Catherine; APADULA, Luca (IQOQI Vienna); CEPOLLARO, Carlo (University of Vienna); GOMES, Henrique (Oxford University); BUTTERFIELD, Jeremy (Cambridge University); BRUKNER, Časlav (University of Vienna)

Presenter: KABEL, Viktoria (IQOQI Vienna)

Session Classification: Quantum Foundations and QG