Research project

Open quantum systems in a gravitational environment: probes of quantized gravity

There is yet no clear theoretical understanding of gravitational fields sourced by quantum systems, like delocalized masses, since the classical and quantum description of such fields appear significantly different. This crucial issue was already emphasized long ago by Feynman [1]: quantum field theory predicts that the gravitational field is entangled with the superposed positions of the source, thus resulting in a superposition of field configurations when probed by a test particle. However, this picture is at odds with general relativity since a superposition of field configurations is not a valid solution of the Einstein equations in general [2]. From the observational point of view, experiments to discriminate between classical and quantum gravitational effects on test particles have always been deemed hopeless, due to the weakness of gravity as epitomized by the smallness of the Planck Length. Even conceptually, a quantum gravitational field could also give rise to a potential paradox in a thought experiment in the laboratory (possibly resolved invoking graviton emission) [3]. A change of perspective is happening thanks to the ongoing progress in experimental techniques which has allowed to put objects of increasing mass in spatial superposition and to have much finer quantum control. Decoherence remains the main obstacle in realizing the abovementioned kind of experiments [4]. Experimental settings have been "realistically" considered which could probe the quantum nature of gravity through the entanglement that a quantum gravitational field can induce between two masses, being both delocalized from the onset [5, 6] or one delocalized and the other delocalizing while evolving in the field of the former [7]. Aim of the project is to analyze these settings theoretically by means of open quantum system techniques to properly characterize decoherence effects [8]. Additionally, possible resolutions of the paradox above in terms of small-scale nonlocality will be investigated based on the existence of a minimum length scale [9]. The purpose of this task is to improve our understanding of how the gravitational interaction could depart from the classical general relativity picture from very fundamental principles. If sufficiently large, these departures might also allow for searching signatures of quantum gravity in the laboratory.

[1] R.P. Feynman, in The Role of Gravitation in Physics, C.M. DeWitt and D. Rickles eds., Report from the 1957 Chapel Hill Conference.
[2] W.G. Unruh, in Quantum Theory of Gravity: Essays in honor of the 60th birthday of Bryce S. DeWitt, edited by S.M. Christensen (1984) 234.
[3] A. Belenchia et al., Phys. Rev. D 98 (2018) 126009.
[4] M. Aspelmeyer, Fundamental Theories of Physics 204 (2022) 85.
[5] S. Bose et al., Phys. Rev. Lett. 119 (2017) 240401.
[6] C. Marletto, V. Vedral, Phys. Rev. Lett. 119 (2017) 240402.
[7] A. Pesci and P. Pieri, Phys. Rev. A 108 (2023) 6, 062801.
[8] E. Joos, H.D. Zeh, C. Kiefer, D. Giulini, J. Kupsch, I.-O. Stamatescu, Decoherence and the appearance of a classical world in quantum theory (Springer, Berlin Heidelberg, 2003).
[9] A. Pesci, Quantum Rep. 5 (2023) 426.

Plan of activities

Beside the research specified above, the position will involve a thorough study of all the necessary mathematical techniques of advanced quantum field theory and general relativity, including existing ways to embody a minimum length scale in our description of spacetime.
The successful applicant will become member of the INFN FLAG network, as part of the agreement with the co-founding INFN. Moreover, several collaborations and visits are expected, both in Italy (specifically with the FLAG units in Catania, Como, Pisa, Trento and Trieste, and other national groups) and at the international level (in Austria, Germany, UK and North America). The successful applicant will also be expected to attend national and international meetings and conferences.