PhD in PHYSICS – University of Trieste – XXXVIII cycle

Candidate presentation

Candidate: Angeli Oliviero
Cycle: XXXVIII
Supervisor: Bassi Angelo
Co-supervisor: Benatti Fabio
Research Title: Signatures of quantum and classical gravity on non-relativistic quantum systems

The Candidate has successfully accomplished the required educational activities as approved by the Teachers Board, including the Ph.D. courses, exams and the attendance of schools and conferences.

Brief description of the candidate research activity

The candidate's research activity focused on identifying signatures of gravitational effects on non-relativistic quantum systems, with the aim of clarifying how gravity may influence quantum coherence and dynamics in experimentally relevant regimes. Two main directions were pursued: investigating decoherence induced by quantum gravitational environments; and studying models of classical gravity coupled to quantum matter in order to assess their observable consequences.

Regarding the first research line, a central outcome was the clarification that different yet equivalent Lagrangians can lead to inequivalent reduced dynamics because they imply different system–environment partitions. This result has relevant ramifications in any open-quantum-system analysis from fundamental interactions, like open Quantum Electrodyncamics (QED) or linearized General Relativity (GR); in particular in regard to the proper identification of the decoherence basis. This analysis led to an operational criterion for selecting the appropriate partition which was used, in the gravitational case, to derive an unambiguous prediction for the gravitational decoherence. In contrast with previous literature, it was found that a noisy gravitational environment induces decoherence in the position basis, with a characteristic tidal dependence on the background dynamics.

Secondly, the candidate investigated the predictions of theories in which gravity is described classically but coupled to quantum matter. Firstly, it was proved - in a model independent way-, that any classical gravitational interaction must induce diffusion in the motion of quantum systems. This new signature can be tested with non-interferometric setups and indicates a route to testing non-classical nature of gravity which is more technologically viable than the current efforts to detect gravitationally induced entanglement (GIE). In regards to the latter proposals, the candidate also analyzed their robustness in discriminating between quantum and classical gravity theories. In particular, the entanglement properties of specific models of hybrid classical–quantum theories of gravity were investigated. Counterintuitively, regimes in which entanglement generation can take place were found within such models. Motivated by this, the entanglement generated in the Tilloy-Diósi model and that generated by the standard Newtonian potential where analyzed within one of the experimental proposals to detect GIE. The analysis indicates that entanglement detection should still quantitatively discriminate quantum gravity from hybrid theories.

Role of the Candidate and main achievements.

In work [1] the candidate identified that different albeit equivalent Lagrangians determined different open quantum systems dynamics and contributed to the theoretical discussions which eventually lead to identifying the root of the in-equivalence as well as the criterion to choose the most appropriate description. Furthermore, he derived the master equation describing the bremsstrahlung of an accelerated particle in non-relativistic open Quantum Electrodynamics.

In the work [2], applying the results of work [1] and adopting a GR framework only recently applied to OQS, the candidate derived a novel master equation describing the evolution of a pair of masses under the influence of a noisy background of quantized gravitational waves. They analyzed the predictions of the master equation, showing its consistency with classical GR when applied to semiclassical states, and, furthermore, identifying novel tidal signatures of the decoherence rate for states delocalized in position.

In the work [3] the candidate contributed to the theoretical discussion of the central gedankenexperiment that proves that classical gravity induces diffusion, highlighting the critical role which is played by (the absence of) entanglement to reach such conclusion. Then, modelling a classical gravity channel via a Lindblad equation, the candidate derived the bound that the diffusion coefficients of any model of classical gravity coupled to quantum matter ought to satisfy. Furthermore, using a Heisenberg-Langevin framework, he calculated the density noise spectrum of two gravitationally interacting trapped masses, and found its dependence on the diffusion coefficients, thus relating the theoretical bound to an experimentally accessible observable in non-intereferometric experimental setups.

For the work [4] the candidate found a necessary and sufficient condition for the positivity of a class of Gaussian Markovian master equations and, applying this result to the partially transposed evolution, proved that a variety of classical gravity models admit regimes where entanglement generation can take place. He further quantitatively analyzed the predictions of the Tilloy-Diosi model against an existing experimental proposal to detect GIE.

General evaluation of the candidate by the supervisor:

The candidate has shown a remarkable aptitude for the foundations of physics, with particular strength in quantum mechanics and in the precise clarification of open questions. He does not accept proposed solutions uncritically, but always seeks to verify them carefully and independently. He has very good mathematical skills and shows strong commitment in exploring new paths to solve complex problems. He also displays considerable independence in both study and research. As documented in the previous sections, he has contributed significantly to the research activity, with contributions ranging from conceptual analysis and mathematical proofs to the modelling of problems, their solution, and phenomenological analysis. He is collaborative, intelligent, and scientifically mature, with a clear ability to contribute constructively to discussions and research activities.

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Summary:
In summary, the Teachers Board agrees that the candidate fully achieved the training and scientific targets set at the beginning of his Ph.D. program.

Presentations to Conferences, workshops, and meetings

1. Contributed Talk "The Noise of Gravitational Waves" – A Look at the Interface between Gravity and Quantum Theory – 2023,

2. Contributed Talk "A Fundamental Ambiguity in Open Quantum Systems" – A Look at the Interface between Gravity and Quantum Theory – 2024,

3. Contributed Talk "Ambiguities in Open Quantum Systems" – Fundamental Problems in Quantum Physics 2024

4. Contributed Talk "Probing The Nature of Gravity Via Diffusion" – A Look at the Interface between Gravity and Quantum Theory – 2025,

5. Contributed Talk "Entanglement in Hybrid Classial-Quantum Models of Gravity"– Fundamental Problems in Quantum Physics 2025

6. Contributed Talk "Probing the Nature of Gravity via Diffusion" – Bridging High and Low Energies in Search of Quantum Gravity 2025 (Bridgeqg 2025)

7. Seminar "Signatures of Classical Gravity on Quantum Systems", Department of Physics, University of Palermo, 18.3.2026

8. Poster "Positivity and Entanglement in Hybrid Models of Gravity" –Quantum 2025" From Foundations of Quantum Mechanics to Quantum Information and Quantum Metrology & Sensing, 2025

9. Poster "Probing the Nature of Gravity through Diffusion" – From Puzzles to New Insights in Fundamental Physics, 2025

Publications

1. A. Gundhi, O. Angeli, A. Bassi. "From Equivalent Lagrangians to Inequivalent Open Quantum System Dynamics." Physical Review Research 8.1 (2026): 013133. https://doi.org/10.1103/4rpx-zj2x

2. O.Angeli, A.Gundhi, A. Bassi "Gravitational Decoherence.", manuscript in preparation.

3. O. Angeli, M. Carlesso "Entanglement in Markovian Hybrid Classical-Quantum Theories of Gravity". Physical Review D, 2025, 112.2: 024047. https://doi.org/10.1103/jzht-fbwt

4. O.Angeli, S. Donadi, G. Di Bartolomeo, J.L.G. Reyes, A. Bassi "Probing the Quantum Nature of Gravity through Classical Diffusion." submitted for publication, arXiv preprint: https://arxiv.org/2501.13030