Summary and Outlook of QUANTUM

INFN Sezione di Perugia, Italy

July 17, 2023

Aims & Scope of QUANTUM

Study puzzling aspects of quantum theory, that were considered paradoxical until a couple of decades ago, and view them as useful resources enabling implementation of protocols and technologies precluded in the classical world.

The research activity is focused on:

- Entanglement (quantum correlations, complex systems, quantum and topological phase transitions, etc.)
- Quantum simulations (of quantum field theories for fundamental interactions, condensed matter, quantum gravity, etc.)
- Quantum control (open quantum systems, quantum channels, error correction, quantum thermodynamics, etc.)

QUANTUM involves 9 research units and $\approx$ 100 FTE

Involved scientists @ PG

- Stefano Mancini (PO UNICAM 100%, national coordinator 24-26)

- Bel-Hadj-Aissa Ghofrane (PhD student UNISI 100%)
- Belfiglio Alessio (PhD student UNICAM 100%)
- Franzosi Roberto (RTD UNISI 100%)
- Gharahighahi Masoud (PhD student UNICAM 100%)
- Lapponi Alessio (PhD student SSM 100%)
- Luongo Orlando (RTD UNICAM 100%)
- Parisi Vincenzo (PhD student UNICAM 100%)
- Rexiti Milajiguli (PostDoc UNICAM 100%)
- Svampa Ilaria (PhD student UNICAM 100%)
- Vesperini Arthur (PhD student UNISI 100%)

Past Research Activity: Quantum channel and coding

We studied LOCC-assisted quantum capacity of bosonic dephasing channel with energy constraint on the input states. Upper bound found by means squashed entanglement of the channel. Lower bound found by means of reverse coherent information of the channel. $Q_{\leftrightarrow}(\mathcal{N}_\gamma) \approx Q_{\rightarrow}(\mathcal{N}_{\gamma/2})$.

A. Arqand, L. Memarzadeh, S. Mancini, *Entropy* 25, 1001 (2023)

We developed a procedure for constructing decoherence-free stabilizer codes for systems governed by Lindblad master equation. This is done by pursuing an extension of stabilizer formalism beyond the group structure of Pauli error operators.

F. Revson Pereira, S. Mancini, G. La Guardia, *Scientific Reports* 13, 10540 (2023)

We provided a general method to construct EAQEC codes from classical cyclic codes. Performance evaluated by means of quantum Singleton bound. Three families have been created: two are MDS, and one is almost MDS.

F. Revson Pereira, S. Mancini, *Entropy* 25, 37 (2023)

Past Research Activity: Relativistic quantum information

We investigated entanglement production by inhomogeneous perturbations over a homogeneous and isotropic cosmic background, $g_{\mu\nu} = a^2(\tau)(\eta_{\mu\nu}+h_{\mu\nu})$, $|h_{\mu\nu}| \ll 1$, demonstrating that the interplay between quantum and geometric effects can have relevant consequences on entanglement entropy.

A. Belfiglio, O. Luongo, S. Mancini, *Physical Review D* 105, 123523 (2022)

We singled out the geometric corrections in particle creation during inflation. The corresponding particle density leads to a nonzero entanglement entropy whose effects are investigated at primordial time of Universe evolution. We interpreted the geometric (quasi)particles as dark matter candidates.

A. Belfiglio, O. Luongo, S. Mancini, *Physical Review D* 107, 103512 (2023)

Past Research Activity: Relativistic quantum information

We investigated the evaporation of a black hole in vacuum taking into account the effects given by the shrinking of horizon area. Analog model of accelerating mirror was used: $\dot{M}_{BH} = -F_m(t, M_{BH}, \dot{M}_{BH}, \ddot{M}_{BH}, \dddot{M}_{BH})$. We studied the consequences of this modified evaporation on the black hole entropy.

M. Good, A. Lapponi, O. Luongo, S. Mancini, *Physical Review D* 107, 104004 (2023)

We proposed a model of communication employing two harmonic oscillator detectors interacting through scalar field in a background Minkowski spacetime. The classical and quantum capacities of the communication channel were found, assuming that the detectors spatial dimensions are negligible compared to their distance.

A. Lapponi, D. Moustos, D. E. Bruschi, S. Mancini, *Physical Review D* 107, 125010 (2023)

Past Research Activity: p-adic quantum mechanics

$$\mathbb{Q}_p \ni x = x_{-n}p^{-n} + \ldots + x_0 + x_1 p^1 + x_2 p^2 + \ldots, \quad n \in \mathbb{Z},\ x_i \in \{0, 1, \ldots, p-1\}$$

We derived the structural properties of the groups $SO(3, \mathbb{Q}_p)$ for all primes p. In particular, we showed that any $R \in SO(3, \mathbb{Q}_p)$ is a rotation around an axis. We found that $SO(3, \mathbb{Q}_p)$ admits a representation in terms of Cardano angles, in close analogy to the real case. This works only for certain orderings of the product of rotations around the coordinate axes; there is no general Euler angle decomposition.

S. Di Martino, S. Mancini, M. Pigliapochi, I. Svampa, A. Winter, *Lobachevskii Journal of Mathematics* 44, 2133 (2023)

By considering physics taking place in a three-dimensional p-adic space, rather than Euclidean space, we introduced the notion of a p-adic quantum bit. It arose from 2-dimensional irreps of $SO(3, \mathbb{Q}_p)$.

I. Svampa, S.Mancini, A. Winter, *Journal of Mathematical Physics* 63, 072202 (2022)

Past Research Activity: p-adic quantum mechanics

We proposed a model of a quantum system based on a Hilbert space $\mathcal{H}_p$ over a quadratic extension of $\mathbb{Q}_p$. States and observables are implemented by suitable linear operators in $\mathcal{H}_p$. Owing to the peculiarities of p-adic probability theory, states are implemented by p-adic statistical operators (trace-one selfadjoint operators). Accordingly, we introduced SOVM as a suitable p-adic counterpart of a POVM.

P. Aniello, S. Mancini, V. Parisi, *Journal of Mathematical Physics* 64, 053506 (2023)

We focused on the special case where $|\mathcal{H}_p| = 2$, thus providing a complete characterization of p-adic qubit states and 2-dimensional SOVMs. Analogies/differences w.r.t. the qubit states of standard quantum mechanics were analyzed.

P. Aniello, S. Mancini, V. Parisi, *Entropy* 25, 86 (2023)

Future Research Activity

- Quantum channel and coding

  Continuous variable quantum arbitrarily varying channels

   S. Khabbazi-Oskouei, S. Mancini, A. Winter, *in preparation*

  Quantum reading of quantum information

   S. Khabbazi-Oskouei, M. Rexiti, S. Mancini, *submitted*

  On the capacity of a quantum neuron for storing biased patterns

   F. Benatti, G. Gramegna, S. Mancini, *submitted*

- Quantum discrimination

  On the usefulness of side entanglement in quantum channel discrimination

   S. Khabbazi-Oskouei, S. Mancini, M. Rexiti, *submitted*

  Discrimination of bosonic dephasing channels with energy constraint

   S. Khabbazi-Oskouei, M. Rexiti, S. Mancini, *in preparation*

Future Research Activity

- Relativistic quantum information

  Entanglement entropy for regular black holes

   O. Luongo, S. Mancini, P. Pierosara *submitted*

  Entanglement area law violation in curvature spacetimes

   A. Belfiglio, O. Luongo, S. Mancini, *submitted*

  Quantum communication between two detectors in a curved spacetime

   A. Lapponi, S. Mancini, *in preparation*

- p-adic quantum mechanics

  Invariant measures on p-adic Lie groups

   P. Aniello, S. Mancini, V. Parisi, I. Svampa, A. Winter, *in preparation*

  Tensorial representations of $SO(3)_p$ and entanglement

   S. Mancini, I. Svampa, A Winter *in preparation*

Miscellanea

- Collaborations: P. Aniello (UNINA), F. Benatti (UNITS), C. Cafaro (SUNY at Albany), M. Good (Nazarbayev University), S. Khabbazi-Ouskei (Islamic Azad University, Teheran) L. Memarzadeh (Sharif University, Teheran), H. Quevedo (UNAM Mexico City), A. Winter (Universitat Autonoma Barcelona)

- Talks: *Entanglement Measure from a Minimum Distance Principle*, @ "108th SIF Congress", Milano, September 2022.

  Towards p-adic quantum bits via representations of $SO(3)_p$, @ "VI Pyrenees Winter School on Quantum Information", Setcases, Spain, February 2023

  Quantum communication through a partially reflecting accelerating mirror, @ "QFTCS Workshop II" Granada, Spain, May 2023

  Relativistic quantum communication between harmonic oscillator detectors, @ "ISRQI-North 2023" Chania, Greece, July 2023

  (invited) *Towards p-adic quantum bits*, @ "Int. Conf. on Math. Phys." Teheran, Iran, July 2023

Requested fund 15k€