Giuseppe Di Molfetta

Associate Professor in Quantum Computing

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Italian, speaks Italian, French, English, Spanish, C, Fortran, Python.
Born on the 29th of July 1985, Bari (Italy)
1 children

Permanent positions

Aix-Marseille Univ./Associate Professor
2016–

Research at the LIS laboratory. Teaching ~220hrs/y. at the DII.

Research leaves

Keio University/JSPS Bridge Fellowship
2020 (shortened due to pandemics)

Research at the IBM Quantum Computer Center.

NINS, Okazaki/JSPS Summer Program
2014

PhD-level. Research in the Shikano Group, in the IMS.

Previous positions

Universidad de Valencia/PostDoc
July 2016 - September 2016
including one month visiting at Perimeter Institute (Waterloo, Canada).

Degrees

Univ. Aix-Marseille Université/Habilitation à Diriger les Recherches
2020 *(17.12.2020)*

Title: **Quantum Walks, limits and transport equations.** Jury: Emmanuel Jeandel (report), Renato Portugal (report), Jingbo Wang (report), David Meyer, Olivier Bournez, Hachem Kadri, Pablo Arrighi, Eric Cances (invited).

Université Sorbonne & ENS de Paris/PhD
2012-2015 *(28.07.2015)*

Teaching ~64hrs/y.
Title: **Quantum Walks : from gauge field to thermalization**. Supervisor: Fabrice Debbasch and Marc Brachet. Jury: Jean Michel Raimond (president), Dieter Meschede (report), Pablo Arrighi (report), Yutaka Shikano, Fabrice Debbasch, Marc Brachet . Viva : July 2015. Graduation: July 2015. Funded by EDPIF & JSPS.

Paris School of Economics & Paris 1/MSc Theoretical Economics
2013–2014

Sorbonne Université & ENS de Paris/MSc Theoretical Physics
2011–2012

Sorbonne Université /MSc Fundamental Physics
2010–2011

Sapienza University/BSc Mathematical Physics
2006–2010

Liceo Statale Scientifico Enrico Fermi/Italy, Bari
1999-2003

Responsibilities

Aix-Marseille Univ./Head of the 1st year in Informatics/Mathematics/Physics/Mechanics (Portail Descartes) at Luminy
2018 -- *Member of the committee that designed the new program for the shared first year in Informatics/Mathematics/Physics/Mechanics.* Promoting the degree, welcoming the ~200 students, late admissions, handling particular cases, managing the juries.

Aix-Marseille Univ./Head of the 1st year in Informatics at Luminy
2017–2018

Promoting the degree, welcoming the ~200 students, late admissions, handling particular cases, managing the juries.

Lab seminar organization
2018– LIS > Pôle calcul
2017 LIF

Scientific production

~37 publications (35 refereed), see a more up-to-date list.

35 international-level refereed journals including *Quantum Information Processing, Quantum, Scientific Reports, Physical Review Letters.*

3 international-level refereed conferences.

7 invited talks at international-level refereed conferences.

Major contributions

Quantum Walks and manifolds. Quantum Walks have taken on great importance in many areas of fundamental computer science, particularly in quantum simulation. We proved, in full rigour, using numerical analysis methods, that they efficiently compute geodesics on arbitrary manifolds and converge to curved PDE. These PDE describe a very broad spectrum of physical phenomena, particularly wave propagation in curved spacetime, in spite of QW fixed background grid. We finally constructed a universal and minimal set of local quantum gates from which to build arbitrary manifolds, suggesting a quantum circuit paradigm for spacetime dynamics.

Gauge invariance in Cellular Automata. Cellular Automata constitute the most established distributed model of computation on space-time grid. It is clearly physics-like, in the sense that it shares some fundamental symmetries such as homogeneity (invariance of the physical laws in time and space), causality, and often reversibility. When a CA is invariant under a transformation identically performed at every point of the configuration space, they are said to have a global symmetry. Typical global symmetries include reflections, rotations, time inversion. Local symmetries, the cornerstone of gauge theories, is a stronger constraint. We provided a constructive method, a step-by-step procedure, to make cellular automata invariant under the local action of a gauge group and the notion of gauge-equivalence will be formalized.

Quantum Walks as simulators of fundamental laws. Quantum simulate physical fundamental theories is the first milestone in order to model strongly correlated materials or complex behavior. We collected a long series of results, rigorously proving that quantum walks ought to be used to simulate quantum particles coupled to an arbitrary field (electromagnetic, weak, strong interaction), where the field is externally encoded by hand in the local rules coupling next neighboring cells. In all these cases, the corresponding field interaction is external, not dynamical. Yet, this result paved the way to quantum simulate more realistic quantum systems.

Quantum cellular automata for simulating particles. Can the field itself be dynamically implemented in the very fabric of the quantum simulator ? We provided a quantum cellular automata model for real-life interacting particles, namely electrons and photons, a.k.a quantum electrodynamics, albeit in one-dimension of space for now. We motivated our construction by proposing a discrete version of a fundamental symmetry of Physics, namely gauge symmetry, which turns out to be reminiscent of fault-tolerance in Computer Science. This opens the way for natively discrete formulations of quantum field theories, otherwise renowned for their ill-definedness.

Quantum cellular automata and multiscale description. inspired by the classical coarse graining procedures, we defined supercells for the QCA (that might include many unit cells and time steps) and construct effective dynamics for different sizes of the supercell. The most low-level coincide with the fully microscopic and reversible quantum dynamics; while for increasing supercell size the quantum features are gradually suppressed and a non-reversible dynamic emerges. There is still a long way to go : what kinds of phenomenology can emerge looking at finite resolution ? Is it possible to describe some of these dynamics in an efficient way by a classical computer, or are there intrinsic quantum properties that render the description unavoidably quantum?

Natural occurring quantum search. We have provided first evidence that an analog quantum system, governed by a linear PDE, may spontaneously behave as a quantum search algorithm. The main result behind is the proof that under certain initial conditions, which can be prepared by the observer, a spinning quantum particle may look for topological defect in a material in a Grover-like fashion. This may be the path to a serious technological leap, whereby experimentalists would finally bypass the rather artificial grover oracle, replacing it by a surface defect. It seems way more practical in terms of experimental realizations, whatever the substrate. At a more abstract level, this suggests using PDE to search, not just for 'good' configurations within a space, but rather for a topological property of the configuration space itself.

Quantum Bandit. We have designed and studied an amplitude amplification based multi-armed bandit algorithm. The basic idea of a classical bandit algorithm is that an agent, disposing only partial information about the system, has to efficiently identify the arm with the largest expected reward. In the quantum version of such a problem, that we call quantum bandit, the arms are accessed in superposition by applying a quantum oracle and we show that we can find the best arm quadratically faster than in the classical case.

Research aims

Distributed quantum computational models, towards quantum simulation and distributed algorithms, with application from physics to machine learning.

Multi-scale quantum simulation, towards semi-quantum (classical) model of computation with application to noisy intermediate scale quantum computing.

Scientific recognition

Prizes

2020-2024 Prime d'Encadrement Doctorale et de Recherche
2016 Prix de la Ville de Marseille (MLR/IP N 2016/165)

Organizer

Jan. 2020 QSQW20 9th International Conference on Quantum Simulation and Quantum Walk (~100 pers., CIRM, Marseille)
June 2017 Quantum Simulation Models Workshops, LIS, Marseille

PhD/Jury member

Dec. 2019 Ivan Marquez (LIS & IFIC, Valencia)
April 2018 Pedro Costa (CBPF & Joint Center for Quantum Information, Rio de Janeiro)

Referee

For QINP, QIC, TCS, Royal Society, Quantum, NJP, QIC, PRA

Selected research invitations

01/05/2020–01/06/2020 **Visiting Professor**, Macquarie University Center for Quantum Eng., Sydney, Australia, by Prof. Gavin Brennen

28/02/2020–31/3/2020 **Visiting Professor,** Quantum Computing IBM center, Tokyo, Japan, by Prof. Yutaka Shikano

01/06/2019–29/06/2019 **Visiting Researcher,** IFIC, Valencia, Spain by Prof. Armando Perez

01/06/2018–29/06/2018 **Visiting Researcher,** CBPF, Rio de Janeiro, by Prof. Fernando de Melo

01/12/2017–20/12/2017 **Visiting Researcher,** LTCI, Paris, by Dr. Filippo Miatto

01/10/2018–30/10/2018 **Visiting Researcher,** CBPF, Rio de Janeiro, by Prof. Fernando de Melo

01/10/2018–30/10/2018 **Visiting Researcher,** ICQ, Waterloo, by Prof. Norbert Lütkenhaus

PhD supervisions

Kevissen Sellapillay (co-directed with Alberto Verga) on Quantum topological codes and quantum networks

2020–

Nathanaël Eon (co-directed with Pablo Arrighi) on Gauge-invariant quantum cellular automata

2019–

Casale Balthazar (co-directed with Hachem Kadri) on Quantum techniques in machine learning

2020 –

Ivan Marquez (co-supervised with U. Valencia) on Quantum walks: background geometry and gauge invariance.

2017–2019

Master 2 thesis supervisor for many students including

Mathieu Roget (ENS - Lyon)

2019 & 2021

Mohamed Hatifi (ENS-Ulm), now a researcher at OIST (Okinawa).

2016-2017

Basile Herzog (Sorbonne Univ.), now a PhD at Univ. de Lorraine

2019–2020

Collaborative networks & grants

Quantum Information Structure of Spacetime/JTF Large grant

2020–2023

Initiated, and composed this 14 site international consortium made of the top researchers, worldwide, on the question of the interaction between quantum information and quantum gravity. The 2M$ grant is managed by the board of this center. We will have shared postdocs and three colloquiums.

Discrete Time Quantum Simulator/AMIDEX, PI

2019–2021

This grant is the first large grant in Marseille in quantum computing, with a focus on digital quantum simulation based on quantum walks.

International grants/Leader

2018–2021 **Quantum Walk and geometry**/PICS CNRS France-Spain. I initiated this new international collaboration between UV and AMU.

International networks grants/Member

2019–2022 CAPES - PrInt/UPM on QCA and new materials

2016–2018 Stic-Amsud Foundations of Quantum Computation : Syntax and Semantics with Argentina

National networks grants/Leader

2021 INS2I Fault invariant distributed quantum algorithms with I2M

2018 PEPS Infiniti Lattice Quantum Simulation Theory with UPMC

2017 INS2I Quantum Networks and growing with Filippo Miatto (LTCI Paris)

National networks grants/Member

2019–2021 ANR JCJC Quantum Machine Learning at LIS

CNRS research networks/Member

GdR IQFA, GdR IM > GT Quantum Information

Teaching > graduates

Responsibilities/Master level

2019–2020 Complexity theory, ~80 students/y. (M1, AMU)

2018– Quantum Computation,, ~20 students/y. (M1, AMU)

2018–2019 Security, Internet, Networks, ~20 students/y. (M2, AMU)

Courses/Master level

2016– Models of Natural Computing (M2, AMU)

2020– Computer security watch (M2, AMU)

2018–2019 Security, internet, networks (M1, AMU)

2016– 2020 Complexity (M1, AMU)

2018– Quantum Computation (M1, AMU)

Teaching > undergraduates

Responsibilities/Undergraduate level

2020– Introduction to Informatics, ~200 students/y. (L1, AMU)

2018– Probability for computer scientists, ~100 students/y. (L2, AMU)

2017–2018 Head of the 1st year in Informatics at Saint Charles, ~200 students/y. (L1, AMU)

2018– Head of the 1st shared year in Math/Info/Phys/Mech (Portail Descartes) at Luminy, ~200 students/y. (L1, AMU)

Courses/Undergraduate level

2018– Probability for computer scientists (L2, AMU)

2016–2018 Introduction to informatics and programming (L1, AMU)

2018– Introduction to informatics (L1, AMU)

Publications list

All published references listed below are in chronological order and they are accessible at arXiv/DiMolfetta.

Citations and metrics: google scholar

2021

[32] Duranthon, O. & Di Molfetta, G. (2020). Quantum cellular automata, coarse graining, Goldilocks rules. *Accepted in PRA (in production) https://arxiv.org/abs/2011.04287*

[31] Manighalam, M & Di Molfetta, G, (2020). Continuous Time Limit of the DTQW in 2D+ 1 and Plasticity, *Quantum Information Processing* 20 (2), 76 https://link.springer.com/article/10.1007/s11128-021-03011-5

Pre-prints:

[S1] Arrighi, P., Di Molfetta, G. & Eon, N., (2020). Gauge-invariance in cellular automata, arXiv preprint arXiv:2004.03656 (submitted to Theoretical Computer Science)

2020

[30] Roget, M, Herzog, B & Di Molfetta, G, (2020). Control dynamics using quantum memory, *Scientific reports 10 (1), 1-8 https://www.nature.com/articles/s41598-020-78455-3*

[29] Herzog, B & Di Molfetta, G (2020). Searching via non linear quantum walk on the 2D-grid, *Algorithms* 13 (11), 305

[28] Casalé, B., Di Molfetta, G., Kadri, H., & Ralaivola, L. (2020) Quantum Bandits, *Quantum Machine Intelligence* 2, 1-7 Springer Link

[27] Roget, M., Guillet, S., Arrighi, P., & Di Molfetta, G. (2020). Grover Search as a Naturally Occurring Phenomenon. *Physical Review Letters*, *124*(18), 180501. https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.124.180501 [Editor suggestion]

[26] Di Molfetta, G, and Pablo A. "A quantum walk with both a continuous-time limit and a continuous-spacetime limit." *Quantum Information Processing* 19.2 (2020): 47, https://link.springer.com/article/10.1007/s11128-019-2549-2

[25] Aristote, Q., Eon, N. and Di Molfetta, G (2020). Dynamical triangulation induced by quantum walk, accepted 04 January 2020 on Symmetry, Special Issue: The Quantum Simulation of Everything (and Beyond). https://www.mdpi.com/2073-8994/12/1/128

[24] Arnault, P., Macquet, A., Anglés-Castillo, A., Márquez-Martín, I., Pina-Canelles, V., Pérez, A., Di Molfetta, G, Arrighi P. & Debbasch, F. (2020). Quantum simulation of quantum relativistic diffusion via quantum walks. *Journal of Physics A: Mathematical and Theoretical*, *53*(20), 205303. https://iopscience.iop.org/article/10.1088/1751-8121/ab8245

[23] Jnane, H., Di Molfetta, G., & Miatto, F. M. (2020). Growing Random Graphs with Quantum Rules. Electronic Proceedings in Theoretical Computer Science 315, pp. 38–47, https://arxiv.org/abs/2004.01061

2019

[22] Hatifi, M., Di Molfetta, G., Debbasch, F., & Brachet, M. (2019). Quantum walk hydrodynamics. Scientific reports, Nature 9(1), 2989. (https://www.nature.com/articles/s41598-019-40059-x)

[21] Arrighi, P., Di Molfetta, G., Márquez-Martín, I., & Pérez, A. (2019). From curved spacetime to spacetime-dependent local unitaries over the honeycomb and triangular Quantum Walks. Scientific reports, Nature, 9(1), 10904. (https://www.nature.com/articles/s41598-019-47535-4)

[20] Arrighi, P., Di Molfetta, G., and Eon, N. "Non-abelian Gauge-Invariant Cellular Automata." *International Conference on Theory and Practice of Natural Computing*. Springer, Cham, 2019.
[19] Pires, M. A., Di Molfetta, G, and Duarte Queirós, S. "Multiple transitions between normal and hyperballistic diffusion in quantum walks with time-dependent jumps." *Scientific Reports* 9.1 (2019): 1-8.

2018

[18] Arrighi, P., Di Molfetta, G., & Facchini, S.. Quantum walking in curved spacetime: discrete metric. Quantum 2, 84 (2018) (https://quantum-journal.org/papers/q-2018-08-22-84/pdf/)

[17] Di Molfetta, G., Soares-Pinto, D. O., & Queirós, S. M. D. Elephant quantum walk. Physical Review A, 97(6), 062112., (2018) (https://journals.aps.org/pra/abstract/10.1103/PhysRevA.97.062112)

[16] Arrighi, P., Di Molfetta, G., & Eon, N.. A gauge-invariant reversible cellular automaton. In International Workshop on Cellular Automata and Discrete Complex Systems (pp. 1-12). Springer, Cham. (2018)(https://link.springer.com/chapter/10.1007/978-3-319-92675-9_1)

[15] Márquez-Martín, I, Arnault, P., Di Molfetta, G., and Pérez, A. Electromagnetic lattice gauge invariance in two-dimensional discrete-time quantum walks, Physical Review A 98 (3), 032333, (2018)

[14] Arrighi, P., Di Molfetta, G., Márquez-Martín, I., & Pérez, A. (2018). Dirac equation as a quantum walk over the honeycomb and triangular lattices. Physical Review A, 97(6), 062111. (https://journals.aps.org/pra/abstract/10.1103/PhysRevA.98.032333)

2017

[13] Márquez-Martín, I., Di Molfetta, G., & Pérez, A. (2017). Fermion confinement via quantum walks in (2+ 1)-dimensional and (3+ 1)-dimensional space-time. *Physical Review A*, *95*(4), 042112.(https://journals.aps.org/pra/abstract/10.1103/PhysRevA.95.042112)

2016

[12] Di Molfetta, G., & Debbasch, F. (2016). Discrete-time quantum walks in random artificial gauge fields. *Quantum Studies: Mathematics and Foundations*, *3*(4), 293-311.(https://link.springer.com/article/10.1007/s40509-016-0078-6)

[11] Arnault, P., Di Molfetta, G., Brachet, M., & Debbasch, F. (2016). Quantum walks and non-Abelian discrete gauge theory. *Physical Review A*, *94*(1), 012335.(https://journals.aps.org/pra/abstract/10.1103/PhysRevA.94.012335)

[10] Bru, L. A., De Valcarcel, G. J., Di Molfetta, G., Pérez, A., Roldán, E., & Silva, F. (2016). Quantum walk on a cylinder. *Physical Review A*, *94*(3), 032328.(https://journals.aps.org/pra/abstract/10.1103/PhysRevA.94.032328)

[9] Di Molfetta, G., & Pérez, A. (2016). Quantum walks as simulators of neutrino oscillations in a vacuum and matter. *New Journal of Physics*, *18*(10), 103038.(https://iopscience.iop.org/article/10.1088/1367-2630/18/10/103038/meta)

2015

[8] Di Molfetta, G., Honter, L., Luo, B. B., Wada, T., & Shikano, Y. (2015). Massless Dirac equation from Fibonacci discrete-time quantum walk. *Quantum Studies: Mathematics and Foundations*, *2*(3), 243-252.(https://link.springer.com/article/10.1007/s40509-015-0038-6)

[7] Di Molfetta, G., Krstlulovic, G., & Brachet, M. (2015). Self-truncation and scaling in Euler-Voigt- α and related fluid models. *Physical Review E*, *92*(1), 013020. (https://journals.aps.org/pre/abstract/10.1103/PhysRevE.92.013020)

[6] Di Molfetta, G., Debbasch, F., & Brachet, M. (2015). Nonlinear optical Galton board: Thermalization and continuous limit. *Physical Review E*, *92*(4), 042923.(https://journals.aps.org/pre/abstract/10.1103/PhysRevE.92.042923)

2014

[5] Di Molfetta, G., Brachet, M., & Debbasch, F.(2014). Quantum walks in artificial electric and gravitational fields. *Physica A: Statistical Mechanics and its Applications*, 397: 157-168.(https://www.sciencedirect.com/science/article/pii/S0378437113011059)

2013

[4] Debbasch, F., & Di Molfetta, G. (2013). Discrete time quantum walks continuous limit in 1+ 1 and 1+ 2 dimension. *Journal of Computational and Theoretical Nanoscience*, *10*(7), 1621-1625 Link

[3] Di Molfetta, G., Brachet, M., & Debbasch, F.(2013) Quantum walks as massless Dirac fermions in curved space-time. *Physical Review A*, 88.4: 042301.(https://journals.aps.org/pra/abstract/10.1103/PhysRevA.88.042301)

2012

[2] Debbasch, F., Di Molfetta, G., Espaze, D., & Foulonneau, V. (2012). Propagation in quantum walks and relativistic diffusions. *Physica Scripta*, *2012*(T151), 014044. (https://iopscience.iop.org/article/10.1088/0031-8949/2012/T151/014044/meta)

[1] Di Molfetta, G. & Debbasch, F. (2012) Discrete-time quantum walks: continuous limit and symmetries. *Journal of Mathematical Physics*, 53.12: 123302. (https://aip.scitation.org/doi/10.1063/1.4764876)