

List of publications of Pablo Arrighi

Theses

- Pablo Arrighi, *Quantum cellular automata*, Habilitation à Diriger les Recherches thesis, Université de Grenoble, June 2009.
- Pablo Arrighi, *Representations of Quantum Operations, with applications to Quantum Cryptography*, Ph.D. thesis, University of Cambridge, September 2003.
- Pablo Arrighi, *Automatic Signature Extraction for Mimetic Viruses*, Psion prize of the best end of year thesis, Imperial College London, June 2000.

Popular science

1. Pablo Arrighi, *L'informatique quantique*, a chapter of the book *L'information et la communication*, an initiative of the “La main à la pâte” foundation, to appear in ed. Belin.
2. Pablo Arrighi, Simon Perdrix, *L'ordinateur quantique pour simuler... la physique quantique*, La Recherche, **501 – 502**, 66, (2015).
3. Pablo Arrighi, *L'informatique quantique : l'ultime frontière ?*, Programmez! **175**, 8-12, Juin 2014.
4. Pablo Arrighi, Jonathan Grattage, *The Quantum Game of Life*, Features section, Physics World, 23-26, June (2012). Re-edited in the Cosmos magazine, Australia, March (2013).
5. Pablo Arrighi, Jonathan Grattage, *Le monde comme un ordinateur quantique*, La Recherche, (2012).
6. Pablo Arrighi, *Quantum Computation explained to my Mother*, Bulletin of the EATCS, **80**, 134-142, (2003). Re-edited as a book chapter in Current Trends in Theoretical Computer Science, Eds. G. Paun, G. Rozenberg, A. Salomaa, World Scientific, (2004). Pre-print arXiv :quant-ph/0212062.

Book chapters

1. Pablo Arrighi, Simon Perdrix, *Modèles de Calcul Quantique*, Lecture notes “Informatique Mathématique : une photographie en 2016” of EJCIM 2016, Strasbourg, March (2016).

2. Pablo Arrighi, Gilles Dowek, *The principle of finite density of information*. Book chapter in Irreducibility and Computational Equivalence. Ed. Hector Zenil, Springer-Berlin, 127-134, (2013).

International-level refereed journals

1. Pablo Arrighi, Giuseppe Di Molfetta, Iván Márquez-Martín, Armando Pérez, *The Dirac equation as a quantum walk over the honeycomb and triangular lattices*, Phys. Rev. A., **97**, 062111, (2018). Pre-print arXiv :1803.01015.
2. Pablo Arrighi, Giuseppe Di Molfetta, Stefano Facchini, *Quantum walking in curved spacetime : discrete metric*, Quantum **2**, 84 (2018). Pre-print arXiv :1711.04662.
3. Pablo Arrighi, Simon Martiel, Vincent Nesme, *Cellular automata over generalized Cayley graphs*. Mathematical Structures in Computer Science, **28**(3), 340–383, (2018). Pre-print arXiv :1212.0027.
4. Pablo Arnault, Armando Pérez, Pablo Arrighi, Terry Farrelly, *Discrete-time quantum walks as fermions of lattice gauge theory*, Phys. Rev. A, **99**(3), 032110, (2019) . Pre-print arXiv :1807.08303.
5. Pablo Arrighi, Simon Martiel, *Quantum Causal Graph Dynamics.*, Phys. Rev. D. **96**(2), 024026, (2017). Pre-print arXiv :1607.06700.
6. Pablo Arrighi, Stefano Facchini, *Quantum Walking in Curved Space-time : (3 + 1) dimensions, and beyond.*, Quantum Information and Computation, Rinton Press, **17**(9 – 10), 810–824, (2017). Pre-print arXiv :1609.00305.
7. Pablo Arrighi, Alejandro Díaz-Caro, Benoît Valiron, *The vectorial λ -calculus*, Information & Computation **254**, 105–139, (2017), Pre-print arXiv :1012.4032.
8. Pablo Arrighi, Gilles Dowek, *Lineal : A linear-algebraic λ -calculus*, LMCS **13**(1), (2017). Pre-print arXiv :quant-ph/0612199.
9. Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Bounds on the Speed-up in Quantum signalling*, Phys. Rev. A **95**(1), 012331, (2017). Pre-print arXiv :0910.4461.
10. Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Quantum Walking in Curved Space-time*, Quantum Information Processing, **15**(8), 3467–3486, (2016). Pre-print arXiv :1505.07023.
11. Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Discrete Lorentz covariance for Quantum Walks and Quantum Cellular Automata*, New J. Phys., **16**, 093007, (2014). Pre-print arXiv :1404.4499.

12. Pablo Arrighi, Marcelo Forets, Vincent Nesme, *The Dirac equation as a quantum walk : higher dimensions, observational convergence*, J. Phys. A : Math. Theor., **47**, 465302, (2014). Pre-print arXiv :1307.3524.
13. Pablo Arrighi, Stefano Facchini, *Decoupled quantum walks, models of the Klein-Gordon and wave equations*, Europhysics Letters, **114**(6), 60004, (2014). Pre-print arXiv :1309.7773.
14. Pablo Arrighi, Nicolas Schabanel, Guillaume Theyssier, *Stochastic Cellular Automata : Correlations, Decidability, and Simulations*, Fundamenta Informaticae **126**(2 – 3), 121–156, (2013).
15. Pablo Arrighi, Gilles Dowek, *Causal graph dynamics (long version)*, Information and Computation **223**, 78–93, (2013). Pre-print arXiv :1202.1098.
16. Pablo Arrighi, Alejandro Díaz-Caro, *A polymorphic type system accounting for scalars*, Logical Methods in Computer Science journal, **8** 1-11, (2012). Pre-print arXiv :0903.3741.
17. Pablo Arrighi, Gilles Dowek, *The physical Church-Turing thesis and the principles of quantum theory*, Int. J. Found. of Computer Science, **23**(5), 1131-1145, (2012). Pre-print arXiv :1102.1612.
18. Pablo Arrighi, Jonathan Grattage, *Intrinsically universal n-dimensional quantum cellular automata*, J. of Computer and Systems Sciences, **78**, 1883-1898, (2012). Pre-print arXiv :0907.3827.
19. Pablo Arrighi, Jonathan Grattage, *Partitioned quantum cellular automata are intrinsically universal*, Natural Computing, **11**(1), 13-22, (2012). Pre-print arXiv :1010.2335.
20. Pablo Arrighi, Vincent Nesme, Reinhard Werner, *One-dimensional quantum cellular automata*, J. of Unconventional Computing **7**(4), 223-244, (2011).
21. Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Unitarity plus causality implies localizability (full version)*, J. of Computer and Systems Sciences **77**(2), 372-378, (2010). Pre-print arXiv :0711.3975.
22. Pablo Arrighi, Renan Fargetton, Zizhu Wang *Intrinsically universal one-dimensional quantum cellular automata in two flavours*, Fundam. Informaticae, **21**(2), 197-230, (2009). Pre-print arXiv :/0704.3961.
23. Pablo Arrighi, Louis Salvail, *Blind Quantum Computation*, Int. J. of Quantum Information, **4**(5), (2006). Pre-print arXiv :quant-ph/0309152.
24. Pablo Arrighi, *Quantum Decoys*, Int. J. of Quantum Information, **2**(3), (2004). Pre-print arXiv :quant-ph/0308050.
25. Pablo Arrighi, Christophe Patricot, *On Quantum Operations as Quantum States*, Annals of Phys. **311**, 26-52, (2004). Pre-print arXiv :quant-ph/0307024.

26. Pablo Arrighi, Christophe Patricot, *A Note on the Correspondence between Qubit Quantum Operations and Special Relativity*, J. Phys. A, **36**, L287-L296, (2003). Pre-print arXiv :quant-ph/0212135.
27. Pablo Arrighi, Christophe Patricot, *The Conal representation of Quantum States and Non Trace-Preserving Quantum Operations*, Phys. Rev. A, **68**, 042310, (2003). Re-edited in the Virtual Journal on Quantum Information, **3**, 10. Pre-print arXiv :quant-ph/0212062.

International-level refereed conferences

1. Pablo Arrighi, Nicolas Durbec, Aurélien Emmanuel, *Reversibility vs local creation/destruction*, Proceedings of RC 2019, June 2019, Lausanne. Pre-print arXiv :1805.10330.
2. Pablo Arrighi, Clément Chouteau, Stefano Facchini, Simon Martiel, *Causal dynamics of discrete manifolds*, to appear in the Proceedings of NCMA 2018, Kosice, Slovakia, OCG book series, (2018). Pre-print arXiv :1805.10051.
3. Pablo Arrighi, Giuseppe Di Molfetta, Nathanaël Eon, *A gauge-invariant reversible cellular automaton*, Proceedings of AUTOMATA 2018, Ghent, Belgium, June 2018, to appear in LNCS.
4. Pablo Arrighi, Simon Martiel, Simon Perdrix, *Reversible Causal Graph Dynamics*, Proceedings of RC 2016, LNCS **9720**, 73-88, (2016).
5. Pablo Arrighi, Gilles Dowek, *Free fall and cellular automata*, Proceedings of DCM 2015, EPTCS **204**, 1-10, (2016).
6. Pablo Arrighi, Gilles Dowek, *Discrete geodesics and cellular automata*, Proceedings of TPNC 2015, LNCS **9477**, 137-149, (2015).
7. Pablo Arrighi, Simon Martiel, Simon Perdrix, *Block Representation of Reversible Causal Graph Dynamics*, Proceedings of FCT'15, LNCS **9210**, 351-363, (2015).
8. Pablo Arrighi, Johan Girard, Miguel Lezama, Kévin Mazet, *The GOOL system : a lightweight object-oriented programming language translator*, In Proceedings of the 9th International Workshop on Implementation, Compilation, Optimization of Object-Oriented Languages, Programs and Systems PLE, 5-9. ACM, IC00OLPS 2014, Uppsala, July, (2014).
9. Pablo Arrighi, Simon Martiel, Zizhu Wang, *Causal dynamics of Discrete Surfaces*, Proceedings of DCM 2013, Buenos Aires, August 2013, in EPTCS **144**, 30-40 (2014).

10. Pablo Arrighi, Nicolas Schabanel, Guillaume Theyssier, *Intrinsic Simulations between Stochastic Cellular Automata*, AUTOMATA & JAC 2012, La Marana, Corsica, September 2012. EPTCS **90**, 208-224, (2012). Pre-print arXiv :1208.2763.
11. Pablo Arrighi, Simon Martiel, *Generalized Cayley graphs and cellular automata over them*, GCM 2012, Bremen, September 2012. Pre-print arXiv :1212.0027. Local proceedings.
12. Pablo Arrighi, Gilles Dowek, *Causal graph dynamics*, ICALP 2012, Warwick, July 2012. LNCS **7392**, 54-66, (2012). Pre-print arXiv :1202.1098.
13. Pablo Arrighi, Alejandro Díaz-Caro, Benoît Valiron, *A Type System for the Vectorial Aspect of the Linear-Algebraic Lambda-Calculus*, DCM'11, Zurich, July 2011. EPTCS **88**, 1-15, (2012). Pre-print arXiv :1012.4032.
14. Pablo Arrighi, Vincent Nesme, *A simple block representation of reversible cellular automata with time-symmetry*, 17th International Workshop on Cellular Automata and Discrete Complex Systems, AUTOMATA 2011, Santiago de Chile, November 2011. Local proceedings.
15. Pablo Arrighi, Gilles Dowek, *The physical Church-Turing thesis and the principles of quantum theory*, QIPC 2011, Zurich, September 2011. Pre-print arXiv :1102.1612. Local proceedings.
16. Pablo Arrighi, Renan Fargetton, Vincent Nesme, Eric Thierry, *Applying causality principles to the axiomatization of probabilistic cellular automata*, Proceedings of CiE 2011, Sofia, June 2011. LNCS **6735**, 1-10, (2011). Pre-print arXiv :1102.0860.
17. Pablo Arrighi, Jonathan Grattage, *A quantum Game of Life*, Proceedings of JAC 2010, Turku, December 2010. TUCS Lecture Notes **13**, 31-42, (2010). Pre-print arXiv :1010.3120.
18. Pablo Arrighi, Vincent Nesme, *The block neighbourhood*, Proceedings of JAC 2010, Turku, December 2010, TUCS Lecture Notes **13**, 43-53, (2010). Pre-print arXiv :1012.1334.
19. Pablo Arrighi, Gilles Dowek, *On the Completeness of Quantum Computation Models*, Proceedings of CiE 2010, Azores, June 2010. LNCS **6158**, 21-30, (2010). Pre-print arXiv :1004.1027.
20. Pablo Arrighi, Jonathan Grattage, *A simple intrinsically universal n-dimensional quantum cellular automata*, Proceedings of LATA 2010, Trier, May 2010. LNCS **6031**, 70-81, (2010). Pre-print arXiv :1002.1015.
21. Pablo Arrighi, Renan Fargetton, *The Bloch representation of quantum states*, Proceedings of QCMC'08, Calgary, 2008. AIP Conference proceedings series, **1110**, 87-90, (2009).

22. Pablo Arrighi, Alejandro Díaz-Caro, *Scalar system F for Linear-Algebraic Lambda-Calculus : Towards a Quantum Physical Logic*, Proceedings of QPL'09, Oxford, April 2009. ENTCS **270**(2), 219–229, (2011). Pre-print arXiv :0903.3741.
23. Pablo Arrighi, Alejandro Díaz-Caro, Manuel Gadella, Jonathan Gratage, *Measurements and confluence in quantum lambda calculi with explicit qubits*, Proceedings of QPL'08, Reykjavik, July 2008. ENTCS **270**(1), 59-74, (2011). Pre-print arXiv :0806.2447.
24. Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Unitarity plus causality implies localizability (short version)*, QIP 2010, selected for a long talk, Zurich, January 2010. Pre-print arXiv :0711.3975. Local proceedings.
25. Pablo Arrighi, Gilles Dowek, *Linear-algebraic λ -calculus : higher-order and confluence*, Proceedings of RTA'08, Hagenberg, July 2008. LNCS **5117**, 17, (2008). Pre-print arXiv :quant-ph/0612199.
26. Pablo Arrighi, Vincent Nesme, *Quantizations of Cellular Automata*, Proceedings of JAC'08, Uzès, April 2008. MCCME Publishing House, Moscow, 204–215, (2008). Pre-print arXiv :0903.0258.
27. Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Quantum cellular automata upon finite, unbounded configurations*, Proceedings of LATA'08, Tarragona, March 2008. LNCS **5196**, 64-75, (2008). Pre-print arXiv :0711.3517.
28. Pablo Arrighi, *An algebraic study of unitary linear quantum cellular automata*, Proceedings of MFCS 2006, Stara Lesna, 2008. LNCS **4162**, 122-133, (2006). Pre-print arXiv :quant-ph/0512040.
29. Pablo Arrighi, Renan Fargetton, *Intrinsically universal one-dimensional quantum cellular automata*, DCM'07, Wroclaw, July 2007. Pre-print arXiv :/0704.3961. Local proceedings.
30. Pablo Arrighi, Gilles Dowek, *A computational definition of the notion of vectorial space*, Proceedings of 5th International Workshop on Rewriting Logic and its Applications 2004 (WRLA), Barcelona, March 2004. ENTCS **117**, 249-261, (2005). Pre-print arXiv :0911.4051.
31. Pablo Arrighi, Gilles Dowek, *Linear-algebraic lambda-calculus*, Proceedings of QPL'04, Turku, July 2004. TUCS General Publication, **33**, (2004). Pre-print arXiv :quant-ph/0501150.

Invited talks in international-level conferences

1. *TBA*, invited talk at QWQS 2020, the 9th international conference on

- quantum walks and quantum simulation, Marseille, France, January 2020.
2. *Quantum cellular automata, computability and universality*, invited talk at AUTOMATA 2019, Guadalajara, Mexico, June 2019.
 3. *Quantum Causal Graph Dynamics*, invited talk at UQT 2018 : Towards Ultimate Quantum Theory, Växjö, Sweden, June 2018.
 4. *Causal Dynamics of Graphs and Discrete Manifolds*, invited talk at SCW 2014, the 7th Spatial Computing Workshop, Paris, May 2014.
 5. *Quantum Walks for Relativistic Particles : Convergence, decoupling*, invited talk at Discrete and Analogue Quantum Simulators, WEHeraeus Workshop 553, Bad Honnef, February 2014.
 6. *From causality to computability : a quantum version of Gandy's theorem*, invited talk at CiE 2011, Sofia, June 2011.
 7. *The quest towards universal physical phenomena*, invited talk at “Physics and Computation”, Azores, September 2009.
 8. *Unitarity plus causality implies localizability*, invited talk in “Foundational Structures for Quantum Information and Computation”, Obergurgl, September 2008.

Selected workshops and seminars

- Pablo Arrighi, *Mécanique quantique : Calculabilité et Universalité*, Séminaire Logique Mathématique Informatique et Raisonnement, organised by the Institut de Recherches Philosophiques de Lyon, April 2019.
- Pablo Arrighi, *Quantum automata, Computability, Universality*, Séminaire du Pôle ASD de l'IRIF, February 2019.
- Pablo Arrighi, Simon Martiel, *Quantum Causal Graph Dynamics*, at the Gravity in Qubits workshop, Bratislava, December 2018
<http://www.qsimspacetime.com/gravity-in-qubits.html>.
- Pablo Arrighi, *Towards quantum digital physics*, Séminaire du LSV, ENS-Paris-Saclay, June 2017.
- Pablo Arrighi, Alejandro Díaz-Caro, Benoît Valiron, *Towards a quantum Curry-Howard correspondence*, Cerisy-la-Salle, May 2017, proceedings at <http://ls.informatik.uni-tuebingen.de/cerisy/>.
- Pablo Arrighi, Simon Martiel, *Quantum Causal Graph Dynamics*, JTF Quantum Causal Structures Kickoff workshop, Vienna, April 2017.
- Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Discrete Lorentz covariance for quantum walks and quantum cellular automata*, FoQCoSS

- Kickoff Workshop on Foundations of Quantum Computation : Syntax and Semantics, Buenos Aires, December, 2016.
- Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Quantum Walks in Curved Spacetime*, GdR IQFA 7th Colloquium, Paris, October 2016.
 - Pablo Arrighi, *Quantum walks, cellular automata and relativistic spacetime*, Journées annuelles du GdR CNRS GT-SDA2, Lyon, July 2016.
 - Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Quantum Walks in Curved Spacetime*, joint McGill-Oxford workshop on Causality in Quantum Foundations, Barbados, March 2016.
 - Pablo Arrighi, *Quantum walks, cellular automata and relativistic spacetime*, Chronos seminar, Collège de France, May 2015.
 - Pablo Arrighi, *Relativité restreinte et automates cellulaires*, Colloque “Le calcul et le temps”, Colloque de philosophie de l’informatique organisé par l’Institut de Recherches Philosophiques de Lyon, Novembre 2014.
 - P. Arrighi, S. Facchini, M. Forets, *Discrete Lorentz covariance for QWs and QCA*, DICE 2014, Castiglioncello, September (2014).
 - Pablo Arrighi, *Quantum Walks for Relativistic Particles*, EU COST Action MP1006, workshop on Foundations of Quantum Mechanics and Quantum Gravity, London, April 2014.
 - Pablo Arrighi, Stefano Facchini, Marcelo Forets, *Quantum Walks for Relativistic particles*, Workshop on Quantum Metrology, Interaction, and Causal Structure, Beijin, December 2013.
 - Pablo Arrighi, Gilles Dowek, *The physical Church-Turing thesis and the principles of quantum theory*, QISW, Oxford, March 2012.
 - Pablo Arrighi, Gilles Dowek, *Causal Graph Dynamics*, Physics and computability, Paris, June 2012.
 - Pablo Arrighi, *Computational universality : a tool for theoretical physics ?*, Seminar series on “Philosophie de la logique, de l’informatique et de leurs interfaces”, ENS Ulm, Paris, May 2012.
 - Pablo Arrighi, Alejandro Díaz-Caro, Benoît Valiron, *Subject reduction in a Curry-style polymorphic type system with a vectorial structure*, QAPL presentation report, Saarbrücken, April 2011.
 - Pablo Arrighi, Alejandro Díaz-Caro, Benoît Valiron, *A vectorial System F*, TYPES, Warsaw, Octobre 2010.
 - Pablo Arrighi, Gilles Dowek, *A quantum extension of Gandy’s theorem*, Journée quantique du GdR CNRS IM GT-IQ, Paris, Septembre 2010.
 - Pablo Arrighi, Zizhu Wang, *A tutorial introduction to Regge calculus from a Computer Science perspective*, “Journées Informatique et Géométrie” JIG 2010, Grenoble, September 2010.

- Pablo Arrighi, Vincent Nesme, *Quantized neighbourhoods*, FRAC 2010, Caen, April 2010.
- Pablo Arrighi, *Superpositions quantiques, probabilités et causalité.*, Seminar series on “Philosophie des Mathématiques”, ENS Ulm, Paris, March 2009.
- Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Unitarity plus causality implies localizability*, final workshop of the GdR Information Quantique, Paris, October 2008 and QuPa, Paris, February 2009.
- Pablo Arrighi, Alejandro Díaz-Caro, *A vectorial System F*, Q-NET workshop, Oxford, December 2009.
- Pablo Arrighi, Renan Fargetton, Zizhu Wang, *Intrinsically universal one-dimensional cellular automata in two flavours*, FRAC 2008, Nice, December 2008.
- Pablo Arrighi, Vincent Nesme, Reinhard Werner, *Quantum cellular automata upon finite, unbounded configurations*, Second QICS workshop, April 2008.
- Pablo Arrighi, Gilles Dowek, *A quantum extension of Gandy’s theorem*, “La thèse de Church : hier, aujourd’hui, demain”, Sorbonne, Paris, April 2008.
- Pablo Arrighi, Renan Fargetton, *Intrinsically universal one-dimensional cellular automata*, “Journée quantique du GdR IM GT-IQ”, Grenoble, June 2007. Workshop of the GdR Informatique Quantique, Aspet, June 2007. MCU’07 open session, Orléans, July 2007.
- Pablo Arrighi, Reinhard Werner, *Superluminal signalling in the quantized XOR cellular automata*, FRAC 2006, Marseilles, June 2006.
- Pablo Arrighi, Gilles Dowek, *Linear-algebraic λ -calculus : higher-order, encodings, confluence*, Q-NET workshop, Glasgow, July 2006.
- Pablo Arrighi, *An algebraic study of unitary linear quantum cellular automata*, JQAC, Lyon, November 2005.
- Pablo Arrighi, Gilles Dowek, *Higher-order in the Linear-algebraic λ -calculus*, Q-DAY-II, Paris, December 2005.
- Pablo Arrighi, Gilles Dowek, *ρ -Calcul et réécriture quantique*, Workshop of the ρ -Calcul and applications, Nancy, March 2004.
- Pablo Arrighi, *Représentation des opérations quantiques : cryptographie quantique et relativité restreinte*, 2nd workshop of the GdR Informatique Quantique du CNRS, Les Houches, June 2002.
- Pablo Arrighi, Christophe Patricot, *Information gain versus disturbance tradeoff in the conal extension of the Bloch sphere*, 2nd “Cambridge-MIT” workshop on quantum information, Cambridge, June 2002.

Pre-prints, submitted

- Pablo Arrighi, Simon Martiel, Simon Perdrix, *Reversible Causal Graph Dynamics : Invertibility, Vertex-preservation, Block representation*, Pre-print arXiv :1502.04368.
- Pablo Arrighi, Giuseppe Di Molfetta, Iván Márquez-Martín, Armando Pérez, *From curved spacetime to spacetime-dependent local unitaries over the honeycomb and triangular Quantum Walks*.
- Pablo Arrighi, *An overview of Quantum Cellular Automata*.
- Pablo Arrighi, Cédric Bény, Terry Farrelly, *A quantum cellular automaton for one-dimensional QED*.

Very advanced drafts

- Giuseppe Di Molfetta, Pablo Arrighi, *A quantum walk with both a continuous-time discrete-space limit and a continuous spacetime limit*.
- Pablo Arrighi, Antonin Lentz, Clément Theron, *Stochastic Causal Graph Dynamics*.
- Pablo Arrighi, Nicolas Durbec, Matthew Wilson, *Full quantum networks dynamics*.