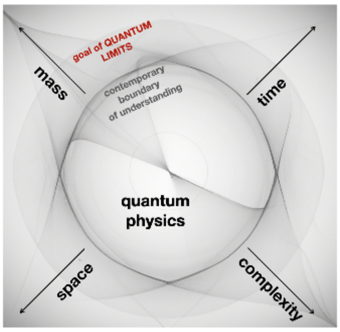

# 1st Quantum Limits Open Call

January 31st, 2025

## Introduction

With recent advances in quantum information and nanotechnology, we are closing in on the famously enigmatic limitations of quantum theory itself. Whether in terms of complexity, space, time, or mass — many fundamental questions about these limits of quantum physics remain unanswered, questions that could point the way to new fundamental breakthroughs. Can two objects become entangled purely through the gravitational force from their mass? At which stage of complexity do classical descriptions become insufficient in describing quantum correlations? Can we realize a quantum system that stays quantum indefinitely over time? And do quantum effects introduce a granularity of space at the very smallest scales?
The Quantum Limits consortium explores these foundational and highly relevant questions both theoretically and in experiments.

For more detailed description of the scope of the envisioned research, please see Annex B.

The Quantum Limits Open Call aims to support research by PhD candidates and Postdocs who will be working on projects towards the goals of the Quantum Limits grant and who will be co-supervised by at least two PIs. The main applicant must be a PI from either LION, QuTech or QN. The second PI is also encouraged to be from one of these institutes. Outside supervision is generally allowed however, in particular if specific expertise is not available at one of the 3 institutes.

The proposals will be judged on:

- **Fit** with the theme and goals of Quantum Limits (not limited to the example topics stated in Annex B). (40%)
- **Scientific excellence** of the proposal. Is the research original, new and exciting? Is the proposal scientifically sound and thought through? (40%)
- **Scientific track record** of the applicant(s) in relation to the proposed research. (20%)

Every PI can be connected to at most one application. The maximum budget per project is one PhD position or one 2-year Postdoc position + running costs incl. 5 k€ bench fee. We anticipate to fund around ten PhD positions and six Postdoc positions for this round, however this balance could be shifted depending on the proposals we receive.

The submission **deadline** for this first call is **January 31st, 2025**. Please send applications to SummitQL-QuTech@tudelft.nl with the subject line “Quantum Limits Open Call”. We expect another similar call in 2027 and a smaller one in 2029.

After the closing date of the call, the consortium members of Quantum Limits will make a selection. The results are expected to be communicated by March 31st, 2025 and we expect all awarded positions to be filled within 9 months.

Appendices:

A. Proposal template
B. Research themes of the program Quantum Limits

QuTech TU Delft QN Universiteit Leiden Leiden Institute of Physics

## Appendix A: Format for a Summit Quantum Limits Proposal

The following material must be provided:

i. The project proposal, formatted as indicated below.
ii. A short curriculum vitae of both applicants with link to the publication list.

1. Applicants
Provide the name of the applicants and 3 of their recent and most significant publications each.

2. Title of the project
Provide a brief, yet clear title for the project.

3. Abstract
Provide a brief abstract of the project.
Indicate along which axis (axes) of Quantum Limits the research focus lies.

4. Fit to the goals of Quantum Limits
Explain how this proposal will help reach the goals of Quantum Limits and stimulate synergy within program.

5. Research proposal
Describe your research proposal, preferably by mentioning:
1. Background/state of the art of the research
2. Aim of the project
3. Approach
Please write a clearly articulated statement describing the research to be undertaken. Narrow technical details and the use of jargon may not be understood by those outside of your field and can therefore be viewed less favorably.

6. Budget
The requested position (PhD, postdoc) and running budget.7,5 k€/year for a theorist and 15 k€/year for an experimental researcher, including a 5 k€ bench fee per researcher.

The total length of the project proposal should not exceed 2 pages, excluding references.

## Appendix B: Research themes of the program Quantum Limits

In the early 1900s, the limits of the known laws of physics led to the birth of quantum physics, overthrowing the classical deterministic description of our world and replacing it with one based on probability and information: the wavefunction. We do not experience phenomena such as quantum superpositions and entanglement in our daily life - we never see two teams scoring on opposite sides of the field at the same time. This is the main reason why quantum mechanics is counterintuitive. Yet the theory has become the most successful and well tested description of fundamental particles, propelling existing applications, ranging from lasers to transistors, and opening completely new applications in the form of quantum computation, communication and sensing.

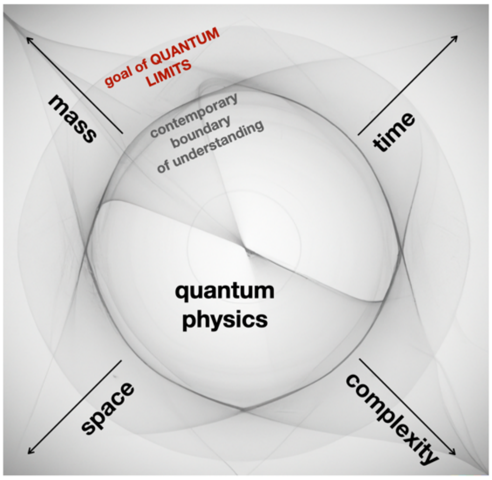

*Fig. 1: We will push the boundary of our understanding of quantum physics along four axes.*

Despite its success, quantum theory itself raises important new scientific questions when taken to its limits. Some questions have posed a central challenge in physics for decades while others have emerged in recent years through advances in quantum information. **The answers stand to transform our understanding of physical reality itself in a similar fashion as the advent of quantum physics has done a century ago**.

Now, using the modern tools of quantum physics and nanotechnology we developed in recent years, we will finally be able to explore the questions that emerge at the edges of our current understanding. We will study the limits of quantum physics along four axes: **mass, complexity, time, and space**.

### MASS – *Gravitational limits to quantum physics*

While quantum theory describes matter at small length and mass scales, the theory of gravity – general relativity – successfully describes the motion of objects on the human-scale up to the scale of galaxies. Combining the two theories into a unified framework remains an open challenge despite a century of theoretical work. Part of the challenge lies in the limited experimental access to regimes where both theories predict observably large forces.

*Is there a limit to what mass quantum physics holds?*

Our consortium recently achieved tremendous progress in the experimental control of large quantum systems **[Guo2019**, **Rod2019, Bou2020, Fia2021, Rod2021, Mar2022]**[1] (see also figure 3 in Section 3.2). Soon we will be able to prepare objects into quantum states where effects of gravity should become relevant and observable. Achieving this highly ambitious goal will require a concerted effort and several breakthroughs. We will prepare a superposition of two micrometer-scale objects (such as levitated spheres or membranes), the most macroscopic spatial superposition to date [Nim2013], extending the limit to where quantum physics still holds to ever larger masses [Sch2020, Bas2013, Vin2016, Gel2021].

*Can gravitational forces create entanglement?*

Next, the “Mass” theme will address a question of utmost importance: *is gravity quantum?* According to general relativity, a massive object bends the spacetime around it, resulting in a gravitational pull on nearby objects. When an object’s location is in a quantum superposition, is the corresponding bending of spacetime described by a superposition state too? Recently, a proposal [Bos2017, Mar2017] was put forward for an experiment to answer this question.

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By preparing spatial superpositions of two micrometer-scale objects, we will test whether entanglement can be created [**Ter2000**] between the masses through their mutual gravity (see figure 2). If entanglement is indeed generated and the only interaction between the systems is gravity, we can conclude that spacetime must be considered a quantum system that supports superpositions [**Pfi2016,** Bos2017, Mar2017, Bel2018, Car2019, Mar2020, Dan2022, Bos2022, Chr2023]. Experimentally, this is an extremely challenging task, requiring creating not only superposition states of massive objects but also realizing an environment where no other forces than gravity can act between two systems.

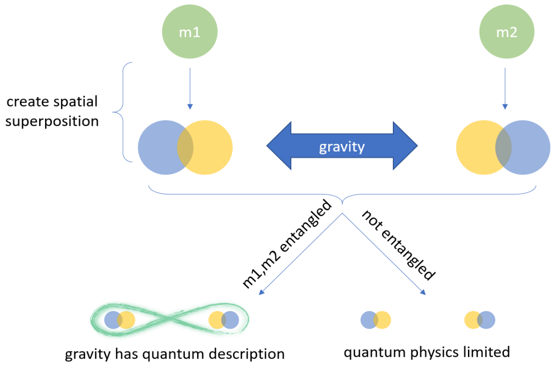

*Fig. 2: Schematic depiction of the proposed experiment to test whether gravity is of quantum nature.*

Understanding if entanglement can be created at all, and if so, its limits and evolution over time, will allow us to look deeply into the inner workings of the interplay between the Schrödinger equation and gravity/space-time.

## COMPLEXITY – *What are the quantum limits of complexity?*

It has been a central challenge in quantum information theory to characterize the complexity and the computational power of quantum processors: for what quantum algorithms do we have efficient classical simulations and which quantum computations produce a computational advantage? Early results, by our consortium and others, established the classical simulatability of a subset of quantum algorithms [Got1998, **Ter2002**, **Ter2004**, Bra2019, Dia2023, **Bee2004**, Tan2023], but fundamental questions remain about what quantum theory implies in a computational sense.

### *Can quantum algorithms help us understand the world's most complex systems: interacting quantum particles?*

A foundational result in classical computer science, the PCP theorem, shows that classical optimization problems can be hard to solve even approximately. A quantum version of this result is known as the Quantum PCP conjecture and has been an open problem for 10+ years [Aha2013]. By considering fermionic problems (describing the interactions between electrons), we believe that we have a unique and promising angle to attack the question of approximation within the quantum setting [**Her2023a, Her2023b**]. Our new algorithms will be tested experimentally on the quantum many-body systems that are the topic of the "Time" theme.

### *Does quantum physics allow more transparent and understandable artificial intelligence?*

An issue of central importance in artificial intelligence (AI) is our capacity to explain the decisions or predictions made by a complex system. It is risky to employ an algorithm that functions as a "black box". One speaks of a "white box" algorithm, or explainable AI (XAI), if the principles underlying the decision making can be understood. The search for such algorithms is well developed in the context of classical machine learning. Our ambition is to translate this search to quantum machine learning, by providing methods to interpret the quantum models and by investigating their potential to simulate, predict, and interpret complex systems [Ite2020, **Gre2020**, **Val2022**, **Her2023**], thereby laying the foundations for explainable quantum AI (XQAI) [Ste2022, Hee2023, Fla2023, Fro2023].

### *Does quantum spatial non- locality improve quantum algorithms?*

Entanglement lies at the heart of the nonlocal character of quantum physics and is captured by a violation of Bell inequalities. More recently, following up on [**Ter2004**], it has been found that Bell nonlocality also underpins the quantum computational capability of constant depth quantum circuits

[Bra2018]. Our goal is to establish deeper ties between quantum correlations and quantum computational complexity. On the one hand, self-testing statements derived from nonlocality serve as a robust tool for certification of quantumness, based on a bare minimal set of assumptions on the inner workings of the devices [Sal2017**, Bac2020]**. On the other hand, this framework extends naturally to quantum computing scenarios, especially those involving distributed architectures [Sun2022].

### TIME – *Limits to quantum coherence and thermodynamics*

*Can we realize a system that stays quantum indefinitely over time?* As we know, nothing lasts forever. For a system consisting of many particles, energy will spread evenly over all of them as time goes by. We say that the system thermalizes. In quantum physics, a phenomenon that breaks this thermalization is called many-body localization (MBL). Interesting physics appears when we periodically drive MBL systems [Zal2023]. Here, quantum many-body states will oscillate seemingly forever and form what is best described as a crystal in time (see figure 3). The first experimental observations consistent with the hallmark features of a time crystal were recently reported [**Ran2021**, Mi2022, Fre2022]. However, what are the ultimate limits for the stability of time crystals in real experimental systems? How do we distinguish generic long-lived responses from asymptotic time crystals?

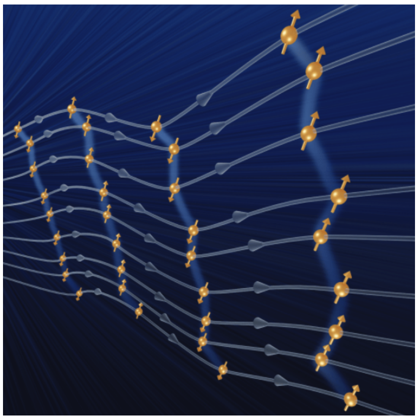

*Fig. 3: Artist's impression of the discrete time crystal made at QuTech **[Ran2021]**. A chain of connected spins is locked in a phase where they periodically invert their state, despite a noisy environment.*

*How fast can quantum information spread across interacting particles?*

Quantum systems, especially those with many interacting parts, display complex behaviors that raise deep questions about the nature of time. Out-of-time-ordered correlators (OTOCs) are key tools in this exploration. They've been crucial in recent studies [Bra2022, Jos2020, Mi2021] for distinguishing key quantum behaviors. In essence, OTOCs probe how quickly and in what ways quantum information spreads. OTOCs will help us unravel open mysteries such as the speed at which quantum states become entangled and chaotic [Rob2016, Zon2022, Ahm2022].

*What are the limits for feedback control of quantum systems?*

There is an intrinsic contradiction when transitioning from a quantum system to a classical system during a measurement – this has been an unresolved question since the early days of quantum physics [Sch1935]. Recent developments suggest that this transition appears gradual and coherent as trajectories in time [Gle2007, Say2011, Vij2012, Min2019]. Furthermore, the time dynamics of monitored quantum systems during the finite duration of measurement processes implies intrinsic delays in quantum feedback [Wis2009, **Vin2009**, **Lan2014**, Gri2015, Pic2016, Guo2017]. Now, we will investigate the intrinsic limits on quantum feedback control.

### SPACE – *Limits to multipartite nonlocality and quantization of space*

The counterintuitive features of quantum theory take center stage in the combination of quantum phenomena (superposition, entanglement) and spatial dimensions (see the Nobel prize in Physics 2022). In recent years, inspired by novel theory insights and bolstered by rapidly advancing experimental capabilities, new fundamental questions on limits of quantum and space have come to the forefront:

*Is the famous "spooky action at a distance" really instantaneous?*

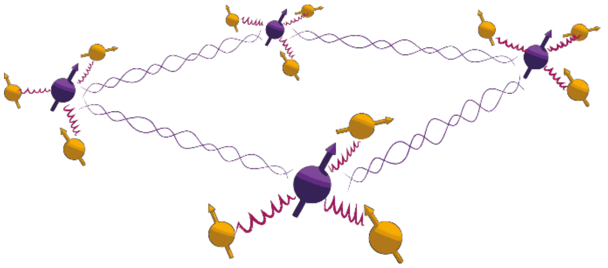

*Fig. 4: Four-node quantum network to probe whether wavefunction collapse is instantaneous.*

While the most basic Bell test has now convincingly been performed with all loopholes closed [**Han2018**], more sophisticated questions on nonlocality are coming within experimental reach. In particular, while standard quantum theory predicts an instantaneous effect of measurement in one location on the possible measurement outcomes far away, experimentally the violation of Bell's inequality only provides a lower bound to the speed of that influence. Devising an experiment using not 2 but 4 observers in a particular space-time setting (figure 4) will allow us to answer the question whether the effect is truly instantaneous [Ban2012].

*Does nature exploit nonlocality of quantum correlations?*

Quantum entanglement enables correlations and coordination between the evolution of distant physical systems that cannot be explained classically [**Bru2014**]. First known examples indicate that quantum correlations can enhance coordination such as in the rendezvous problems of agents on a graph: here, two agents at distant sites try to find a common location, a task which they can perform better in a quantum world by exploiting non-local correlations [Mir2023]. It is presently unknown whether nature itself takes advantage of such non-local correlations for coordination, which would push the ultimate limits of coordination allowed in nature. It is a compelling question to understand the possibilities and ultimate limits that the existence of non-local correlations brings to the coordination between the actions of distant systems.

*Can we measure the effects of space quantization?*

When reaching the smallest length scales, the Planck length ($1.6\ \mathrm{x}\ 10^{-35}\ \mathrm{m}$), it is expected that the usual continuous space breaks down, and space itself will need to be discretized, as is done in string theory, for example. A large number of theoretical approaches to quantize spacetime result in modified commutation relations between position and momentum. Although the deviations become largest for length scales near the Planck length, such a modification can still be bounded for larger systems for very precise measurements of position and momentum [Pik2012]. Existing results [Mar2013, Baw2015, Bus2019] are all dominated by random thermal motion, providing limited information on the quantum Heisenberg limit. Here, we will aim to design an ideal system for testing such modifications: an optomechanical device with large cooperativity **[Fia2021]**, which is a measure of how strongly a single photon and a single photon interact before decaying. In doing so we can test which kind of theory may describe a quantized spacetime.

## References

**[Abo2022]** M.H. Abobeih, Y. Wang, J. Randall, S.J.H. Loenen, C.E. Bradley, M. Markham, D.T. Twitchen, **B.M. Terhal**, **T.H. Taminiau**, Fault-tolerant operation of a logical qubit in a diamond quantum processor, Nature 606, 884 (2022)

[Aha2013] D. Aharonov, I. Arad, T. Vidick, The Quantum PCP Conjecture, arXiv:1309.7495

**[Ahm2022]** A. Ahmadi and **E. Greplova**, Quantifying non-stabilizerness via information scrambling, arXiv:2204.11236

[Bac2020] F. Baccari, R. Augusiak, I. Šupić, J. Tura, and A. Acín, Scalable Bell Inequalities for Qubit Graph States and Robust Self-Testing, Phys. Rev. Lett. 124, 020402 (2020)

[Ban2012] J.-D. Bancal, S. Pironio, A. Acin, Y.-C. Liang, V. Scarani, N. Gisin, Nature Physics 8, 867 (2012)

[**Bar2022**] H. P. Bartling, M. H. Abobeih, B. Pingault, M. J. Degen, S.J.H. Loenen, H. P. Bartling, C. E. Bradley, J. Randall, M. Markham, D. J. Twitchen, **T. H. Taminiau**, Coherence and entanglement of inherently long-lived spin pairs in diamond, Phys. Rev. X 12, 011048 (2022)

[Bas2013] Bassi, A., Lochan, K., Satin, S., Singh, T. P. & Ulbricht, H. Models of wave-function collapse, underlying theories, and experimental tests. Rev. Mod. Phys. 85, 471–527 (2013)

[Baw2015] M. Bawaj, C. Biancofiore, M. Bonaldi, F. Bonfigli, A. Borrielli, G. Di Giuseppe, L. Marconi, F. Marino, R. Natali, A. Pontin, G. A. Prodi, E. Serra, D. Vitali & F. Marin. Probing deformed commutators with macroscopic harmonic oscillators. Nat Commun 6, 7503 (2015)

**[Bee2004] C.W.J. Beenakker**, D. DiVincenzo, C. Emary, and M. Kindermann, Charge detection enables free-electron quantum computation, Phys. Rev. Lett. 93, 020501 (2004)

[Bel2018] A. Belenchia, R.M. Wald, F. Giacomini, E. Castro-Ruiz, Č. Brukner, & M. Aspelmeyer. Quantum superposition of massive objects and the quantization of gravity. Phys. Rev. D 98, 126009 (2018)

[**Ber2022**] D.W. Berry, Y. Su, C. Gyurik, R.King, J. Basso, A.D.T. Barba, A. Rajput, N., Wiebe, **V. Dunjko**, and R. Babbush, Quantifying Quantum Advantage in Topological Data Analysis, arXiv:2209.1358

[Bos2017] S. Bose, A. Mazumdar, G.W. Morley, H. Ulbricht, M. Toroš, M. Paternostro, A.A. Geraci, P.F. Barker, M.S. Kim & G. Milburn. Spin Entanglement Witness for Quantum Gravity. Phys. Rev. Lett. 119, 240401 (2017)

[Bos2022] S. Bose, A. Mazumdar, M. Schut & M. Toroš. Mechanism for the quantum natured gravitons to entangle masses. Phys. Rev. D 105, 106028 (2022)

**[Bou2006]** D. Kleckner and **D. Bouwmeester**, Sub-kelvin optical cooling of a micromechanical resonator, Nature 444, 75 (2006)

**[Bou2020]** D.C. Newsom, F. Luna, V. Fedoseev, W. Löffler, and **D. Bouwmeester**. Optimal optomechanical coupling strength in multimembrane systems. Phys. Rev. A 101, 033829 (2020)

[Bra2018] S. Bravyi, D. Gosset, and R. König, Quantum advantage with shallow circuits, Science 362, 308 (2018)

[Bra2019] S. Bravyi, D. Browne, P. Calpin, E. Campbell, D. Gosset, and M. Howard, Simulation of quantum circuits by low-rank stabilizer decompositions, Quantum 3, 181 (2019)

[Bra2022] J. Braumüller et al., Probing quantum information propagation with out-of-time-ordered correlators. Nat. Phys. 18, 172–178 (2022)

[**Bru2014**] N. Brunner, D. Cavalcanti, S. Pironio, V. Scarani, and **S. Wehner**, Bell nonlocality, Rev. Mod. Phys. 86, 419 (2014)

[Bus2019] P.A. Bushev, J. Bourhill, M. Goryachev, N. Kukharchyk, E. Ivanov, S. Galliou, M.E. Tobar & S. Danilishin. Testing the generalized uncertainty principle with macroscopic mechanical oscillators and pendulums. Phys. Rev. D 100, 066020 (2019)

[Car2019] D. Carney, P.C.E. Stamp & J.M. Taylor. Tabletop experiments for quantum gravity: a user's manual. Class. Quantum Grav. 36, 034001 (2019)

[**Cha2021**] **A. Chatterjee**, P. Stevenson, S. De Franceschi, A. Morello, N.P. de Leon, F. Kuemmeth. Semiconductor qubits in practice, Nature Reviews Physics 3, 157-177 (2021)

[Chr2023] M. Christodoulou, A. Di Biagio, M. Aspelmeyer, Č. Brukner, C. Rovelli & R. Howl. Locally Mediated Entanglement in Linearized Quantum Gravity. Phys. Rev. Lett. 130, 100202 (2023)

[Dan2022] D.L. Danielson, G. Satishchandran & R.M. Wald. Gravitationally mediated entanglement: Newtonian field versus gravitons. Phys. Rev. D 105, 086001 (2022)

[Del2020] U. Delić, M. Reisenbauer, K. Dare, D. Grass, V. Vuletić, N. Kiesel & M. Aspelmeyer. Cooling of a levitated nanoparticle to the motional quantum ground state. Science 367, 892–895 (2020)

[Del2020b] U. Delić, D. Grass, M. Reisenbauer, T. Damm, M. Weitz, N. Kiesel & M. Aspelmeyer. Levitated cavity optomechanics in high vacuum. Quantum Science and Technology 5, 025006 (2020)

[Dia2023] B. Dias and R. Koenig, Classical simulation of non-Gaussian fermionic circuits, arXiv:2307.12912

**[Dvi2023]** T. Dvir, G. Wang, N. van Loo, C.-X. Liu, G. Mazur, A. Bordin, S. ten Haaf, J.-Y. Wang, D. van Driel, F. Zatelli, X. Li, F. Malinowski, S. Gazibegovic, G. Badawy, E. Bakkers, **M. Wimmer** & L. Kouwenhoven, Realization of a minimal Kitaev chain in coupled quantum dots, Nature (2023)

[Fei2019] Y.Y. Fein, P. Geyer, P. Zwick, F. Kiałka, S. Pedalino, M. Mayor, S. Gerlich & M. Arndt. Quantum superposition of molecules beyond 25 kDa. Nature Physics 15, 1242–1245 (2019)

**[Fia2021]** N. Fiaschi, **B. Hensen**, A. Wallucks, R. Benevides, J. Li, T.P.M. Alegre & **S. Gröblacher**. Optomechanical quantum teleportation. Nat. Photon. 15, 817–821 (2021)

[Fla2023] F. Flamini, M. Krumm, L. J. Fiderer, T. Müller, and H. J. Briegel, Towards interpretable quantum machine learning via single-photon quantum walks, arXiv:2301.13669

[Fre2022] P. Frey et al., Realization of a discrete time crystal on 57 qubits of a quantum computer. Sci. Adv.8, eabm7652 (2022)

[Fro2023] F. Frohnert and E. van Nieuwenburg, Explainable Representation Learning of Small Quantum States, arXiv:2306.05694

**[Gel2021]** M.F. Gely & **G.A. Steele**. Superconducting electro-mechanics to test Diósi–Penrose effects of general relativity in massive superpositions. AVS Quantum Science 3, 035601 (2021)

[Gle2007] S. Gleyzes et al. Quantum jumps of light recording the birth and death of a photon in a cavity. Nature 446.7133, 297-300 (2007)

[Got1998] D. Gottesman, The Heisenberg representation of quantum computers, arXiv:quant-ph/9807006

**[Gre2020] E. Greplova**, A. Valenti, G. Boschung, F. Schäfer, N. Lörch, and S.D. Huber, Unsupervised identification of topological phase transitions using predictive models, New J. Phys. 22, 045003 (2020)

**[Gre2023]** G. Jin & **E. Greplova**. Topological Entanglement Stabilization in Superconducting Quantum Circuits, Phys. Rev. Research 5, 023088 (2023)

[Gri2015] A.L. Grimsmo. Time-delayed quantum feedback control. Physical review letters 115, 060402 (2015)

[Guo2017] L. Guo et al. Giant acoustic atom: A single quantum system with a deterministic time delay. Physical Review A 95, 053821 (2017)

**[Guo2019]** J. Guo, R. Norte & **S. Gröblacher**. Feedback Cooling of a Room Temperature Mechanical Oscillator close to its Motional Ground State. Phys. Rev. Lett. 123, 223602 (2019)

**[Haa2023]** S.L.D. ten Haaf, Q. Wang, A.M. Bozkurt, C.-X. Liu, I. Kulesh, P. Kim, D. Xiao, C. Thomas, M.J. Manfra, T. Dvir, **M. Wimmer**, **S. Goswami**, Engineering majorana bound states in coupled quantum dots in a two-dimensional electron gas, https://arxiv.org/abs/2311.03208

**[Han2018] R. Hanson** & K. Shalm. Spooky Quantum Action Passes Test, Scientific American 319, 58-65 (2018)

**[Har2022]** P. Harvey-Collard, J., Dijkema, G. Zheng, A. Sammak, **G. Scappucci**, G., and **L.M.K. Vandersypen**, Coherent spin-spin coupling mediated by virtual microwave photons, Phys. Rev. X 12, 021026 (2022)

[Hee2023] R. Heese, T. Gerlach, S. Mücke, S. Müller, M. Jakobs, and N. Piatkowski, Towards Explainable Quantum Machine Learning, arXiv:2301.09138

**[Hen2015] B. Hensen**, H. Bernien, A. E. Dréau, A. Reiserer, N. Kalb, M. S. Blok, J. Ruitenberg, R. F. L. Vermeulen, R. N. Schouten, C. Abellán, W. Amaya, V. Pruneri, M. W. Mitchell, M. Markham, D. J. Twitchen, D. Elkouss, **S. Wehner**, **T. H. Taminiau** & **R. Hanson** Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres,. Nature 526, 682–686 (2015)

**[Hen2021]** W. Hendrickx, W.I.L. Lawrie, M. Russ, F. van Riggelen, S.L. de Snoo, R.N. Schouten, A. Sammak, **G. Scappucci**, **M. Veldhorst**, A four-qubit germanium quantum processor, Nature 591, 580-585 (2021)

**[Her2022]** S.L.N. Hermans, M. Pompili, H.K.C. Beukers, S. Baier, J. Borregaard & **R. Hanson**, Qubit teleportation between non-neighboring nodes in a quantum network, Nature 605, 663–668 (2022)

**[Her2023]** V. Hernandes and **E. Greplova**. Modeling Neuronal Activity with Quantum Generative Adversarial Networks. In 2023 IEEE International Conference on Quantum Computing and Engineering (QCE) (Vol. 2, pp. 330-331). IEEE.

**[Her2023a]** Y. Herasymenko, M. Stroeks, J. Helsen, and **B. Terhal**, Optimizing sparse fermionic Hamiltonians, Quantum 7, 1081 (2023)

**[Her2023b]** Y. Herasymenko, A. Anshu, **B. Terhal**, J. Helsen, Fermionic Hamiltonians without trivial low-energy states, arXiv.org:2307.13730

[Hua2022] H.-Y. Huang, et al. Quantum advantage in learning from experiments, Science 376, 1182 (2022)

[Ite2020] R. Iten, T. Metger, H. Wilming, L. del Rio, and R. Renner, Discovering physical concepts with neural networks, Phys. Rev. Lett. 124, 010508 (2020)

[Jos2020] M.K. Johsi et al, Quantum Information Scrambling in a Trapped-Ion Quantum Simulator with Tunable Range Interactions. Phys. Rev. Lett. 124, 240505 (2020)

[Kit2003] A. Kitaev, Fault-tolerant quantum computation by anyons, Annals of Physics, 303, 2-30 (2003)

**[Lan2014]** G. de Lange, D. Ristè, M. J. Tiggelman, C. Eichler, L. Tornberg, G. Johansson, A. Wallraff, R. N. Schouten, and **L. DiCarlo**, Reversing quantum trajectories with analog feedback. Phys. Rev. Lett. 112, 080501 (2014)

[Lei2017] R. Leijssen, G. R. La Gala, L. Freisem, J. T. Muhonen & E. Verhagen. Nonlinear cavity optomechanics with nanomechanical thermal fluctuations. Nat Commun 8, ncomms16024 (2017).

[Leo2021] L. Leone et al., Quantum Chaos is Quantum, Quantum 5, 453 (2021)

[Mag2020] P. Magnard, et al., Microwave quantum link between superconducting circuits housed in spatially separated cryogenic systems, Phys. Rev. Lett. 125, 260502 (2020)

[Mar2013] F. Marin, F. Marino, M. Bonaldi, M. Cerdonio, L. Conti, P. Falferi, R. Mezzena, A. Ortolan, G. A. Prodi, L. Taffarello, G. Vedovato, A. Vinante & J.-P. Zendri. Gravitational bar detectors set limits to Planck-scale physics on macroscopic variables. Nature Phys 9, 71–73 (2013)

[Mar2017] C. Marletto & V. Vedral. Gravitationally Induced Entanglement between Two Massive Particles is Sufficient Evidence of Quantum Effects in Gravity. Phys. Rev. Lett. 119, 240402 (2017)

[Mar2020] R.J. Marshman, A. Mazumdar & S. Bose. Locality and entanglement in table-top testing of the quantum nature of linearized gravity. Phys. Rev. A 101, 052110 (2020)

**[Mar2022]** J.F. Marques, B.M. Varbanov, M.S. Moreira, H. Ali, N. Muthusubramanian, C. Zachariadis, F. Battistel, M. Beekman, N. Haider, W. Vlothuizen, A. Bruno, **B. M. Terhal**, and **L. DiCarlo**, Logical-qubit operations in an error-detecting surface code, Nature Physics 18, 80 (2022)

[Mi2021] X. Mi et al., Information scrambling in quantum circuits, Science 374, 1479-1483 (2021)

[Mi2022] X. Mi et al., Time-crystalline eigenstate order on a quantum processor. Nature 601, 531 (2022)

[Min2019] Z.K. Minev et al. To catch and reverse a quantum jump mid-flight. Nature 570.7760, 200-204 (2019)

[Mir2023] P. Mironowicz. Entangled rendezvous: a possible application of Bell non-locality for mobile agents on networks, New J. Phys. 25 013023 (2023)

[Nim2013] S. Nimmrichter & K. Hornberger. Macroscopicity of Mechanical Quantum Superposition States. Phys. Rev. Lett. 110, 160403 (2013)

**[Nor2016]** R.A. Norte, J.P. Moura & **S. Gröblacher**. Mechanical Resonators for Quantum Optomechanics Experiments at Room Temperature. Phys. Rev. Lett. 116, 147202 (2016)

[**OBr2018**] T.E. O'Brien, P. Rozek, and **A.R. Akhmerov**, Majorana-based fermionic quantum computation, Phys. Rev. Lett. 120, 220504 (2018)

**[Pas2023]** M. Pasini, N. Codreanu, T. Turan, A. Riera Moral, C.F. Primavera, L. De Santis, H.K.C. Beukers, J. M. Brevoord, C. Waas, J. Borregaard, **R. Hanson**. Nonlinear quantum photonics with a tin-vacancy center coupled to a one-dimensional diamond waveguide, arXiv:2311.12927

[Pet2019] G.A. Peterson, S. Kotler, F. Lecocq, K. Cicak, X.Y. Jin, R.W. Simmonds, J. Aumentado & J.D. Teufel. Ultrastrong Parametric Coupling between a Superconducting Cavity and a Mechanical Resonator. Phys. Rev. Lett. 123, 247701 (2019)

**[Pfi2016]** C. Pfister, J. Kaniewski, M. Tomamichel, A. Mantri, R. Schmucker, N. McMahon, G. Milburn & **S. Wehner**. A universal test for gravitational decoherence. *Nat Commun* **7,** 13022 (2016).

**[Phi2022]** S.G.J. Philips, M.T. Mądzik, S.V. Amitonov, S.L. de Snoo, M. Russ, N. Kalhor, C. Volk, W.I.L. Lawrie, D. Brousse, L. Tryputen, B. Paquelet Wuetz, A. Sammak, **M. Veldhorst**, **G. Scappucci** and **L.M.K. Vandersypen**, Universal control of a six-qubit quantum processor in silicon, Nature 609, 919 (2022)

[Pic2016] H. Pichler & P. Zoller. Photonic circuits with time delays and quantum feedback. Physical review letters 116, 093601 (2016)

[Pik2012] I. Pikovski, M.R. Vanner, M. Aspelmeyer, M. S. Kim & Č. Brukner. Probing Planck-scale physics with quantum optics. Nature Physics 8, 393–397 (2012)

**[Ran2021]** J. Randall, C.E. Bradley, F.V. van der Gronden, A. Galicia, M.H. Abobeih, M. Markham, D.J. Twitchen, F. Machade, N.Y. Yao and **T.H. Taminiau**, Many-body–localized discrete time crystal with a programmable spin-based quantum simulator. Science 374, 1474 (2021)

[Rob2016] D.A. Roberts & B. Swingle. Lieb-Robinson bound and the butterfly effect in quantum field theories. Phys. Rev. Lett. 117, 091602 (2016)

**[Rod2019]** I.C. Rodrigues, D. Bothner & **G.A. Steele**. Coupling microwave photons to a mechanical resonator using quantum interference. Nature Communications 10, 5359 (2019)

**[Rod2021]** I.C. Rodrigues, D. Bothner & **G.A. Steele**. Cooling photon-pressure circuits into the quantum regime. Science Advances 7, eabg6653 (2021)

[Rus2016] M. Russ, F. Ginzel, and G. Burkard, Coupling of three-spin qubits to their electric environment, Phys. Rev. B 94, 165411 (2016)

[Sal2017] A. Salavrakos, R. Augusiak, J. Tura, P. Wittek, A. Acín, and S. Pironio, Bell inequalities tailored to maximally entangled states, Phys. Rev. Lett. 119, 040402 (2017)

[Say2011] C. Sayrin et al. Real-time quantum feedback prepares and stabilizes photon number states. Nature 477.7362, 73-77 (2011)

[**Sca2021**] **G. Scappucci**, P. Taylor, J. Williams, T. Ginley, and S. Law, Crystalline materials for quantum computing: Semiconductor heterostructures and topological insulators. MRS Bulletin 46, 596–606 (2021)

[Sch1935] E. Schrödinger. The present status of quantum mechanics. Die Naturwissenschaften 23.48, 1-26 (1935)

[**Sch2023**] B. Schiffer and **J. Tura**, Quantum eigenstate broadcasting assisted by a coherent link, arXiv:2302.03017

[Ste2022] P. Steinmüller, T. Schulz, F. Graf, and D. Herr, eXplainable AI for Quantum Machine Learning, arXiv:2211.01441

[**Ste2023**] T.V. Stefanski, **C.K. Andersen**, Flux-pulse-assisted Readout of a Fluxonium Qubit, https://arxiv.org/abs/2309.17286

**[Sto2023]** G.L. van de Stolpe, D.P. Kwiatkowski, C.E. Bradley, J. Randall, S.A. Breitweiser, L.C. Bassett, M. Markham, D.J. Twitchen and **T.H. Taminiau**, Mapping a 50-spin-qubit network through correlated sensing. arXiv:2307.06939 (2023)

[Sun2022] W. Sun, and Z. Wei, Equivalence checking of quantum circuits by nonlocality, npj Quantum Inf. 8, 139 (2022)

[Tan2023] N. Tantivasadakarn, A. Vishwanathan, and R. Verresen, Hierarchy of topological order from finite-depth unitaries, measurement and feedforward, PRX Quantum 4, 020339 (2023)

[Teb2021] F. Tebbenjohanns, M. L. Mattana, M. Rossi, M. Frimmer & L. Novotny. Quantum control of a nanoparticle optically levitated in cryogenic free space. Nature 595, 378–382 (2021)

[**Ter2000**] **B.M. Terhal**, Bell Inequalities and the Separability Criterion, Physics Letters A, 271, 319 (2000)

**[Ter2002] B.M. Terhal** and D. DiVincenzo, Classical simulation of noninteracting-fermion quantum circuits, Phys. Rev. A 65, 032325 (2002)

**[Ter2004] B.M. Terhal** and D. DiVincenzo, Adaptive Quantum Computation, Constant Depth Quantum Circuits and Arthur-Merlin Games, Quant. Inf. Comp. 4, 134 (2004)

**[Val2022]** A. Valenti, G. Jin, J. Léonard, S. D. Huber, and **E. Greplova**. Scalable Hamiltonian learning for large-scale out-of-equilibrium quantum dynamics. Physical Review A, 105(2), 023302 (2022)

[Vij2012] R. Vijay et al. Stabilizing Rabi oscillations in a superconducting qubit using quantum feedback. Nature 490.7418, 77-80 (2012)

**[Vin2009]** I.T. Vink, K.C. Nowack, F.H.L. Koppens, J. Danon, **Y.V. Nazarov**, and **L.M.K. Vandersypen**, Locking electron spins into magnetic resonance by electron-nuclear feedback, Nature Physics 5, 764 (2009)

[Vin2016] A. Vinante, M. Bahrami, A. Bassi, O. Usenko, G. Wijts & T.H. Oosterkamp. Upper Bounds on Spontaneous Wave-Function Collapse Models Using Millikelvin-Cooled Nanocantilevers. Phys. Rev. Lett. 116, 090402 (2016)

[Wes2021] T. Westphal, H. Hepach, J. Pfaff & M. Aspelmeyer. Measurement of gravitational coupling between millimetre-sized masses. Nature 591, 225–228 (2021)

[Wis2009] H.M. Wiseman and G.J. Milburn. Quantum measurement and control. Cambridge university press, 2009.

**[Xue2022]** X. Xue, M. Russ, N. Samkharadze, B. Undseth, A. Sammak, **G. Scappucci** and **L. M. K. Vandersypen**, Quantum logic with spin qubits crossing the surface code threshold, Nature 601, 343–347 (2022)

**[Yu2023]** Y. Yu, D. Oser, G. Da Prato, E. Urbinati, J. Carrasco Ávila, Y. Zhang, P. Remy, S. Marzban, **S. Gröblacher**, and W. Tittel, Frequency tunable, cavity-enhanced single erbium quantum emitter in the telecom band, Phys. Rev. Lett. 131, 170801 (2023)

[Zal2023] M. P. Zaletel et al., Quantum and classical discrete time crystals. Rev. Mod. Phys. 95, 031001 (2023)

[Zon2022] Zonnios et al., Signatures of Quantum Chaos in an Out-of-Time-Order Tensor, Phys. Rev. Lett. 128, 150601 (2022)