Brief CV of Dimitris G. Angelakis

Associate Professor and Principal Investigator
Centre for Quantum Technologies
National University of Singapore
Email: dimitris.angelakis@nus.edu.sg
Telephone: +65 83709350
https://www.linkedin.com/in/dimitris-g-angelakis-a3432a11/
Research page: www.dimitrisangelakis.org

CV summary

Dimitris G. Angelakis is a Principal Investigator and Associate Professor at Centre for Quantum Technologies, (CQT) at the National University of Singapore (NUS) where he is leading the theory group on Quantum Computing and Quantum Simulation. He also is serving as a **Coordinator** in the Quantum Computing Pillar of the Singapore Quantum Engineering Program Phase 2, where he is in charge of QEP Quantum Hardware Partnerships with Cloud providers such as IBM, AWS, Google and others

Angelakis did his PhD in quantum optics at Imperial College in 2002, supervised by Professor Sir Peter Knight, and then moved to Cambridge University as a St Catharine's College junior research fellow. He held this position at DAMTP Cambridge and the Cambridge Centre for Quantum Computing until 2008, before taking over joint professor positions in Crete and Singapore. In Crete, he is a tenured associate professor of quantum physics and quantum computing at the School of Electrical Engineering and Computer Science (ECE) at the TU Crete (TUC), where he is currently on leave since 12/2019. He has served and taught in TUC for more than 12 years and has been a CQT PI since its inception in 2008. He is also serving as the Greek representative in the Quantum Community Network QCN of the European Flagship in Quantum Technologies. He was the leading coordinator of the **Greek Quantum Technology Flagship 2019-2020.** He is also a member of the **National Council for Research Technology and Innovation** of Greece since 2020.

In parallel to his academic work, he consults different industries on the possible applications of quantum computing and is co-founder and scientific officer of an early stage quantum computing start up in based in Singapore.

Research record

Angelakis is known for his research in different areas in quantum physics, topological physics and quantum technologies. His contributions range from **fundamental works** in quantum optics and photonics, to implementations of analog and digital quantum computation and simulation, to quantum engineering aspects of superconducting, ion and photonic technologies, to topological physics for quantum computing. He is one the pioneers of the novel area merging quantum optics, quantum photonics, and quantum simulation known as "Quantum Simulations and Many-Body Physics with Light"**,** a field he co-founded while he was at Cambridge UK roughly 15 years ago with his early works in the field.

Angelakis is also known for his contributions in **applications of quantum computing for problems with industrial relevance** including quantum and quantum inspired optimization and quantum machine learning for supply chain, finance, energy and materials sectors with NISQ devices. Among his past **industry collaborations** include the Kantar Group**,** a leading international market research company founded in UK with strong presence in Singapore. His Kantar collaboration projects include developing

quantum enhanced machine learning algorithms for market research for Kantar use cases. The latter range from quantum enhanced machine learning solutions for customer segmentation, to classification, to quantum inspired regression algorithms and software for market forecasting. With support from the **Quantum Engineering Program**, he will be working with the **Singapore Stock Exchange on transactions settlement use cases**, and with **Exxon Mobil and the Singapore Energy Centre** on a LNG shipping network optimization problem

His **academic** publications have attracted the interest of world leading experimental groups and high-tech companies in Europe and US. The most recent ones include a **collaboration with Google** and the quantum hardware group based Santa Barbara, California. He has a joint publication with them in **PRL in 2016** on "Topological pumping with interacting photons", and in **Science in December 2017 on quantum simulations with interacting photons in their superconducting chips**. The collaboration with the Google group, was supported by **two Google research awards in 2018 awarded to his group at NUS**. He is currently exploring further collaboration in the area of implementing quantum chemistry and quantum optimization/machine learning algorithms, in their latest chips, including the Sycamore 53 qubits one where quantum supremacy was recently demonstrated.

Other international collaborations include **Prof. A. Szameit and his photonics** group at the Institute of Optics, Jena and now the Rostock University in **Germany.** Joint works include articles in Optica in 2015 on **integrated photonic chips for quantum simulations** of exotic physics like the Majorana equation. The work was highlighted in a focus article in **Optics & Photonics News** (OPN) "Using light to simulate unphysical particles!". He is continuing the collaboration in the area of topologically robust photonic chips for optical communications and quantum computing. Some of this work will be done also with the photonics group of **Mikael Rechtsman** in University of Pennsylvania.

Other international collaborations (only projects that have led to several joint publications already) include groups at: **University of Oxford** (D Jaksch) on a series of works in quantum simulation and quantum many-body physics; **University College London** (S Bose) on quantum simulation with interacting photons and quantum information; **Technical University of Berlin** (late Tobias Brandes) on driven quantum systems; **Korea Advanced Study Institute** (S Flach); **Institute of Photonics Seoul National University** (C Noh, ex postdoc of his); **C. N. Yang Institute** for Theoretical Physics (V Korepin); **Japan NTT** with Victor Bastidas who was his postdoc and now at Bill Munro's NTT group; **Stony Brook** (Figuroea group) Dr Smirnova at **ANU Australia** and **China** (See selected publications section further down for more details).

Overall Angelakis has published **more 65 research papers**, with a total of ~**3100 citations and H index=28**, i10= 48 **including papers in Science and several in Physical Review Letters, Optica** and other high impact factor journals. He has been invited to write review articles for **IOP Reports in Progress in Physics,** edited **two volumes for Springer** in the area of Quantum Computing and Quantum Simulations (2006, 2017), and also **three focus issues**. The latter are on "Many-body Physics with Photons and Polaritons Quantum Simulations" for New Journal of Physics (2018), on "Quantum Simulations" for EPJ: Quantum Technologies (2017) and one "The Science Behind Quantum Technology" Physics Letters A (2020).

Invited talks, awards and conference organization

Angelakis has been invited to deliver more **55 invited talks** including several keynotes and plenaries in **international conferences** including the annual American Physical Society meetings, the KITP workshops in theoretical physics, the ICTP workshops and the Fermi Schools of Physics in Lake Como. He has also delivered more than **100 invited seminars and colloquia** in universities and research institutions worldwide. Awards he has received include the **2018 Google Quantum Innovation Award, the Valerie Myerscough Award from University of London 2000**, the **Greek Ministry of Defence Scholar Abroad Prize 2005**, as well as the **Institute of Physics Quantum Electronics Thesis Prize 2002** for the best thesis in the area of quantum electronics.

He has also organised and secured funding to organize for more than 15 international conferences as chairman or member of the organizing and program committee, including NATO ASIs, the Quantum Communication and Computing (QCMC) series, and several high profile Asian and European level conferences.

Research funding

To fund his research group activities including PhD scholarships, during the last ten years Angelakis has attracted the equivalent of more than **7.5 million S$** in UK, Greece-EU, and Singapore from competitive grants (including PhD scholarships). His funding sources include national research councils, the Singapore National Research Foundation (NRF), the Singapore Ministry of Education (MOE), the CQT core funding, the Monetary Authority of Singapore (MAS), and the EU Horizon program and the Greek MOE (see detail for grants awarded in the detailed CV).

Teaching, training and mentorship experience

Angelakis has successfully supervised as main supervisor a number of Honours, Diploma, MSc students both in Cambridge UK, Crete and Singapore. In **Singapore** these include **12 postdoctoral scholars**, **three PhD students (completed**) and currently **supervising six more PhDs, two postdocs and several undergraduate and diploma students**. Most of his past students are either still in academia in tenure or tenure track positions, and some have moved in the industry sector, including one who has made his own quantum technology company in Thailand where Angelakis is an advisor.

Angelakis has been **teaching for more than 15** years a variety of **undergraduate and postgraduate** courses in **Physics, Science, and Engineering in Cambridge, Singapore and Crete**. This includes **departmental** courses with 200 hundred students enrolled, with parallel labs (Greece), as well as **college tutorial teaching** in St Catharine's Cambridge. Departmental courses he has taught in the TU Crete (as a professor initially the Science department (2008-2012), and later at the ECE department (2012-2020)) include **1st and 2nd year courses including Mechanics, Thermodynamics, Optics, Electricity, and Electromagnetism.** These courses include laboratory exercises where he was supervising a team of lab assistants. He has also been teaching **for more 13 years advanced 3rd and 4th year** courses (and **graduate** courses) on **Quantum Computing and Simulation, Laser Physics, Quantum Optics, and Quantum Technologies** for TUC students from ECE and other departments. He has introduced and setup the first Quantum Technology courses in the TUC ECE department in 2014 and has been teaching them every spring semester since until his leave in 2020.

During **his college research fellowship at St Caths**, he was engaged in college **tutorial teaching for Part IA and Part IB Cambridge Natural Science Tripos courses**, including courses on Mechanics, Optics, Relativity, and Quantum Physics.

Part of his **college duties** also included the **Wardenship of St Catharine's Graduate Hall of Residence in Russell Street**. Warden duties included the **welfare** and **mentorship** of the 60 graduate students living in the Hall. His college accommodation was located at the same Hall.

Service and outreach activities

Academic service: He has served in **various faculty** committees regarding hiring, promotional, administrative and teaching decision making in **St Catharine's College, University of Cambridge**, the **ECE departmental** executive committee at the **Technical University of Crete**, and the **Centre for Quantum Technologies NUS** Executive Committee (ExCo). He has also participated in more than 20 PhD and MSc committees as examiner or co-supervisor in Crete, Singapore, EU, UK, and internationally. Angelakis has also served as **evaluator** of research proposals for the ERC Starting and Consolidator Grant scheme,

European Young Investigator Award Scheme, the Netherlands Organization for Scientific Research, the Polish Research Council, the Swiss Research Council and the Russian Research Council among others.

In Singapore: Angelakis is one of the **coordinators** for the Singapore Quantum Engineering Program (QEP) 2020-2025 for the **Quantum Computing and Simulation pillar.** QEP is a 96 million SGD national program on quantum technologies with roughly 20M S$ for quantum computing and simulations. This is in addition to QEP 1 which was 25M S$. Angelakis is in charge of the QEP partnerships with quantum hardware providers as the QEP Cloud Quantum Computing Coordinator leading the discussions for onboarding quantum hardware providers such as AWS, to enlarge and diversify access to cloud quantum processors for the Singapore Quantum Ecosystem. He is also a m**ember of the recently formed Quantum Processor Strategy Working Group (QPSWG)**. The purpose of the work group is to produce a strategy recommendation to the Steering Committee of the QEP. Angelakis is also the **main coordinator with the New Businesses Office of the Singapore Economic Development Board (EDB)**, and the Singapore Agency of Science, Technology and Research (ASTAR) of the workshop and call for proposals for quantum computing and simulation for chemistry, materials, energy and the environment.

In EU and Greece: Angelakis is currently serving at the European Quantum Community Network (QCN) for Flagship in Quantum Technologies representing Greece (one scientist per country, since 2018), chaired by Prof. Calarco. He has also served in the Core group and the Management Committee of the EU COST Action "Nanoscale Quantum Optics". Finally, he was the **leading coordinator** of the recently announced **Greek Quantum Technology Flagship 2019-2020.** He is also a member since 2020 of the Greek **National Council for Research Technology and Innovation, the Engineering Sciences sector (**14 members selected from all disciplines)

Outreach: Angelakis has participated in numerous open days in University of Cambridge, Imperial College, TU Crete, and CQT NUS. He has delivered more than 100 non-specialist introductory talks **to schools, public stakeholders, and corporates mainly in Singapore but also in Europe**. He also regularly speaks at general audiences, companies and industrial events. In **CQT NUS he has co-hosted several visits** by industry teams and senior public servants including the **Singapore EDB, the Defense Science Technology Agency (DSTA), Defense Science Laboratories (DSO), the Ministry of Defense (MoD)** and others. Highlights include hosting the visit to the **HR Princess of Thailand**, the ***Feynman 100 years exhibition*** held in the **Arts and Science Museum Singapore in 2018-19.** Part of the exhibition was a **quantum chip donated by his Google collaborators to Singapore,** which was exhibited at the Museum**.** Finally he has given numerous interviews and written articles for various national and international media like the Straits Times, Innovation Magazine, South China Morning Post, SKY TV, CNN and others

Industry collaborations

As CQT Principal Investigator, Angelakis has been consulting for different corporations in the area of quantum computing for data analytics and AI sectors for the last 3-4 years. He is also the founder and chief advisor of AngelQ quantum computing. Collaborations include local and international banks and market research companies in Singapore and in Europe. The engagement varied from giving introductions to quantum computing and AI awareness lectures, short courses, advising on POCs, all the way to quantum computing programming and training workshops.

Example corporates he has worked with

- **Societe Generale,** Singapore Branch-Quantum computing for finance workshop
- **Kantar Group**, Singapore, Quantum machine learning workshop

- **The Hinrich Foundation** for Sustainable Trade, Singapore Headquarters- two workshops on quantum computing and quantum cryptography
- **Starttech Ventures** (Greece)- two short training courses on quantum computing for applications (quantum programming, basic algorithms, and optimization)
- **CloudXlab**, India – one workshop on the basics of quantum computing
- **Ansys Hellas**, Greece- one workshop on the basics of quantum computing

He has also been engaged in proof of concept projects **(POCs)** using **quantum algorithms that he and his group have developed for use cases provided by the industrial partners**. These algorithms are run on classical simulators and/or cloud quantum processors depending the use case at hand.

One example of such a project is with **Kantar Asia**, and the **Expert Solutions Lab** based in Singapore. With them he has an ongoing collaboration for different projects relating to **customer segmentation and media consumption using quantum AI algorithms**. Some of these projects have led to joint press releases and also a patent (filled by and for Kantar) Details of one of those can be found here[1]

With support from the Quantum Engineering Project, he will be working with the **Singapore Stock Exchange on transactions settlement use cases**, and with **Exxon Mobil and the Singapore Energy Centre** on a LNG shipping network optimization (grant size 1.2M S$, 2022-2025, in process of approval).

Finally In 2019 he has been **awarded a grant from 4th Request-for-Proposals under the Research Track of the Artificial Intelligence and Data Analytics (AIDA)**. The grant was not unfortunately accepted by NUS due to a mismatch between MAS T&Cs and what NUS was comfortable with at the point. The grant value was S$ 230.000 for 18 months.
Objectives were
to a) educate the local financial industry in the basics of AI and the latest developments in quantum AI and b)
to train the local financial institutions to be ready to utilize the incoming quantum computing technology that could potentially revolutionize AI

[1] https://markets.businessinsider.com/news/stocks/kantar-brand-growth-lab-is-developing-quantum-machine-learning-solutions-in-singapore-1029327724

Ten selected publications

65 publications with 3100 citations (Google Scholar 1/2021). **H index 28/ i-10 index 48**,. Since 2016: 1660 citations**,** 5 PRLs, 1 Science, three special issues edited (EPJ QT and NJP), two invited books for Springer, one review for Reports Progress in Physics. Highest cited paper in 2007 **> 500 citations**. 6 papers with more than **100 citations**

1. ***Spectral signatures of many-body localization with interacting photons in supeconducting qubits Roushan, …Angelakis, Martinis, Science, 01 Dec 2017: Vol. 358, Issue 6367, (2017), 260 citations*.**

Work from the second collaboration with **the Google Quantum Group** in analog quantum simulation of condensed matter in superconducting qubits. Quantized eigenenergies and their associated wave functions provide extensive information for predicting the physics of quantum many-body systems.Using a chain of nine superconducting qubits, we implemented a technique for resolving the energy levels of interacting photons. We benchmarked this method by capturing the main features of the intricate energy spectrum predicted for two-dimensional electrons in a magnetic field—the Hofstadter butterfly. We introduce disorder to study the statistics of the energy levels of the system as it undergoes the transition from a thermalized to a localized phase. Our work introduces a many-body spectroscopy technique to study quantum phases of matter.

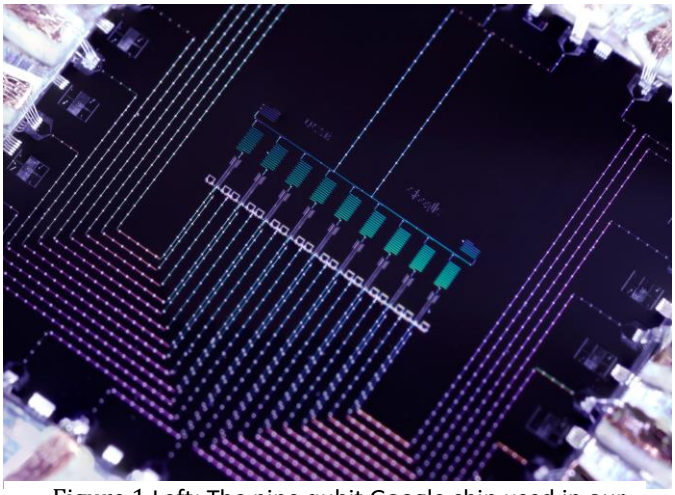

Figure 1 Left: The nine qubit Google chip used in our joint work on quantum simulation

The work is **considered a milestone in the area of quantum simulations with interacting photons, an area I cofounded with my theory work (next item) roughly 10 years before this while a postdoc at Cambridge** and led since then with numerous works and collaborations in the field. The work was **highlighted** in various media including Strait Times, phys.org, eurekalert, sciencedaily, tech2.org, housseniawriting, tuc.gr , asian scientist, technology networks, nanowerk, alphagalileo, mgronline

2. ***Photon blockade induced Mott transitions and XY spin models in coupled cavity arrays Angelakis, et al , Phys. Rev. A(R). 2007. Highest cited publication with 600 citations.*** The work widely recognized the founding work in the field of quantum simulators and many-body physics with strongly interacting photons. It was the first to connect photons in cavity QED systems to many-body physics and discuss the possibility to simulate Mott transitions with light. Among others while still a preprint was made the cover of in New Scientist: Mark Buchanan, Issue 2586, 11 January 2007 entitled "E*ngaging photons in light conversation" One of the most cited paper every published Physical Review.*

3. ***Fractional quantum Hall state with photon in coupled cavities* Cho, Angelakis, Bose, Physical Review Letters 101, 246809, (2008) 180 citations**. One of the earliest and the founding work in the

area of using photonic systems as quantum simulators to understand and probe topological and condensed matter physics. We showed how to recreate and simulating the Fractional Hall state with photons in arrays of QED resonators. Selected for Virtual Journal of Nanoscale Science & Technology — December 22, 2008.

4. ***Luttinger liquid photons and spin-charge separation with photons Angelakis,*** et al. Phys. Rev. Lett. 106, 153601 (2011) 70 citations. One of the early works in the area of simulating 1D strongly correlated models from condensed matter with light-matter systems. More specifically using slow-light polaritons the phenomenon of spin-charge separation in strongly interacting 1D electronic systems was simulated. The paper was highlighted as an "Editors Suggestion", as a Viewpoint article in Physics: In a tight spot, spin and charge separate and a Research Highlight in Nature: A liquid of photons, Nature, 472, 262 (2011)

5. ***Experimental simulation of charge conservation violation and Majorana*** **dynamics** Keil, Noh, Rai, Stutzer, Nolte, **Angelakis,** A. **Szameit** Optica 2,454 (2015). One of the earliest experimental implementation of relativistic exotic physics with photonic systems, verifying our earlier theory work published two years earlier. We simulated the dynamics of a charged Majorana particle by light propagation in a tailored photonic waveguide chip. Our results illustrate the potential of investigating theories beyond the standard model in a compact laboratory setting. This work was chosen for a **focus article** in Optics & Photonics News (OPN) *"Using light to simulate unphysical particles".* It has also appeared in the Science Section, International Business Times, as well as phys.org and sciencedaily

6. ***Topological pumping with photons in nonlinear resonator arrays***, Tangpatinanon, Bastidas, Roushan **Angelakis** Physical Review Letters, 117, 213603 (2016) Our first joint work with the Google group. We showed how to implement topological or Thouless pumping of interacting photons in one-dimensional nonlinear resonator arrays by simply modulating the frequency of the resonators periodically in space and time. The interplay between the interactions and the adiabatic modulations enables robust transport of Fock states with few photons per site. We analyze the transport mechanism via an effective analytic model and study its topological properties and its protection to noise. We conclude by a detailed study of an implementation with existing circuit-QED architectures.

Media Highlight *" Topological scheme for transporting quantum particles inspired by Nobel winner's work " The inspiration for a new scheme to transport interacting quantum particles has its roots in Ancience Greece. In Thouless pumping, transport happens because of the topology of fields acting on the quantum particles – similar to the way that an Archimedes' screw pump can move water up a hill,.. "* This work was also featured at EurekaAlert!, Phys.org, Health Medicinet, Nanowerk, Nanotechnology Now, Sky Nightly, and Space Daily.

7. ***Expressibility and trainability of parameterized analog quantum systems for machine learning applications*** Tangpanitanon, Thanasilp, Lemonde, Dangiam, **Angelakis** **Phys. Rev. Research 2, 043364 (2020)**. Recent work from my group showing how existing analog quantum simulators can be used for quantum machine learning tasks. Our approach can be implemented with a variety of available quantum platforms including cold ions, atoms, light-matter systems and superconducting circuits. **Highlighted** at ***"Doing quantum machine learning without going digital CQT researchers and their collaborators show that analogue quantum systems can be trained"***

8. ***Qubit efficient algorithms for binary optimization,*** *Tan, Lemonde, Thanasilp, Tangpanitanon,* ***D. G. Angelakis*** Quantum 5, 454 (2021) Work from my group in binary optimization problems discussing

how to tackle the high qubit requirements in all current methods for optimization problems, be it quantum annealing, QAOA or VQAs which all require as many qubits as in the classical variables. Realistic industry related quadratic optimization problems (QUBO) usually entail **10.000 classical variables** which means current approaches using NISQ devices are very far from achieving anything of real application (Google for example recently managed to barely do 23 qubits for a MaxCut 3-regular graph). In this work, we proposed and analyzed a set of novel variational quantum algorithms for QUBO where n classical variables can be implemented on O(log n) number of qubit**s** making implementations with NISQ possible. We give examples by solving a 42-variable Max-Cut problem using only 8 qubits where we exploit the specific topology of the problem and discuss industrially relevant cases of **f**ew thousand classical variable for 50-100 qubits. **Highlighted** at "*Good choices from fewer qubits: new scheme solves optimisation problems efficiently. Work by the group of CQT Principal Investigator Dimitris Angelakis could allow existing quantum devices to solve real-world binary optimisation problems*

9. ***Quantum supremacy and quantum phase transitions J. Tangpanitanon, S. Thanasilp, M. A. Lemonde, N. Dangiam, D. G. Angelakis*** **Phys. Rev. B 103, 165132 (2021)** Recent works for quantum supremacy include boson sampling (China) and random quantum circuits (Google). Here **we show** how to extend this family of systems to include to quantum many-body systems in analog quantum simulators settings and include a whole new area of analog experimental systems including cold atoms, ions and superconducting qubits**.** The work and the proof is based on the eigenstate thermalization hypothesis and strongly held conjectures in complexity theory which we used to show that sampling from the output distribution of thermalizing quantum systems is #P hard arxiv.org/2002.11946. In this second work, we describe how the approach proposed, can be extended to explore dynamical quantum phase transitions. We showed for the first time how quantum phases of matter are intricately connected to the hardness of sampling and simulating their corresponding dynamics.

10. ***Photonic band structure design using persistent homology, D. Leykam, D. G. Angelakis*** ***APL Photonics 6, 030802 (2021)*** **T**he machine learning technique of persistent homology classifies complex systems or datasets by computing their topological features over a range of characteristic scales. There is growing interest in applying persistent homology to characterize physical systems such as spin models and multiqubit entangled states. Here we propose persistent homology as a tool for characterizing and optimizing band structures of periodic photonic media. Using the honeycomb photonic lattice Haldane model as an example, we show how persistent homology is able to reliably classify a variety of band structures falling outside the usual paradigms of topological band theory, including "moat band" and multi-valley dispersion relations, and thereby control the properties of quantum emitters embedded in the lattice. Our method is promising for the automated design of more complex systems such as photonic crystals and Moire superlattices. Research **highlight** at ***Machine learning technique could aid photonic crystal design***