Earl Campbell

Quantum error correction, algorithms & architectures

Summary

I am a highly accomplished quantum computing expert with 20 years of experience and over 80 publications driving innovation in both academic and industry settings. My track record shows experience leading large research teams and as a successful individual contributor developing cutting-edge quantum algorithms, error correction protocols and fault-tolerant architectures. I have secured significant funding for quantum computing initiatives including an $81 million Series C VC round at Riverlane.

Personal data

Full name:	Earl Terence Campbell
E-mail:	earltcampbell@gmail.com
Homepage:	earltcampbell.com
Date of birth:	November 26, 1981
Nationality:	United Kingdom citizen

Employment: industry roles

Sept 2023 - — **Riverlane**, *Vice President for Quantum Science*, Cambridge UK.
Head of science function and member of the executive board leading the scientific direction for a startup with 100 staff building a quantum error correction hardware stack composed of custom FPGAs and ASICs. Responsible for technical aspects of a pitch that successfully led to a $81 million Series C round venture capital investment. Leads science function of 30 scientists (direct and indirect reports). I directly mentor staff in their scientific work and help them with scientific writing. I also established a new career development framework.

Jan 2022- Sept 2023 — **Riverlane**, *Head of Architecture*, Cambridge UK.
Led cross-functional team of 10 scientists and engineers developing new protocols and software tools for quantum error correction. My team also partnered with quantum computing hardware companies and academic labs. Part of senior leadership setting company-wide technical roadmap and advised on strategy and direction of other teams.

May 2020- Dec 2022 — **Amazon Web Services**, *Senior research scientist*, Cambridge UK.
Senior researcher and people manager with 4 direct reports at the AWS Centre for Quantum Computing. I led a team developing novel quantum algorithms, and also made contributions to quantum error correction research and the architecture of AWS's cat-qubit quantum computer.

Feb 2019 - Dec 2019 — **Riverlane**, *Senior Research Scientist*, Cambridge UK.
A part-time 20% role in a quantum computing start-up company. I advised the company on business & research strategy and undertook research into quantum computing & software in collaboration with other research staff.

Employment: academic roles

Jan 2025– **University of Sheffield**, *Professor*, Sheffield UK.
I designed and teach a 4th year quantum computing module and contribute to the research environment at Sheffield. This is a part-time 10% FTE role.

Jan 2014– **University of Sheffield**, *Research fellow then Senior lecturer*, Sheffield UK.
Jan 2025 The role included carrying out independent research in the field of quantum computation, publishing papers in scientific journals, speaking at international conferences, writing grant applications, teaching, PhD student supervision and post-doc management. I was promoted to the Senior grade in Dec 2019 (equivalent to US Associate Professor). This role was full time until May 2020, and then I took a 2 year unpaid leave to work at AWS, returning in May 2022 in a part-time 10% capacity.

Jan 2014– **University of Sheffield**, *Research associate*, Sheffield UK.
Mar 2015 A post-doctoral research position in the field of quantum computation. Duties included: publishing papers in scientific journals and speaking at international conferences. My line managers were Dr. P. Kok and Sir Prof. K. Burnett.

Sept 2010– **Freie Universität Berlin and University of Potsdam**, *Research associate*, Potsdam
Feb 2014 and Berlin, Germany.
A post-doctoral research position in the fields of quantum computation and quantum communication. Duties included: publishing papers in scientific journals, speaking at international conferences and teaching. My line manager was Prof J. Eisert.

Sept 2008– **University College London**, *Royal Commission of 1851 research fellow*, London, UK.
Oct 2010 Principle investigator of Royal Commission of 1851 research fellowship grant. This is a highly prestigious fellowship, awarded by the Royal Commission of 1951 following a competitive grant application. It enabled me to carry out independent post-doctoral research (without a line manager) in the field of quantum computation, publishing papers in scientific journals and speaking at international conferences.

Education

2005-2008 **Ph.D. in quantum computing**, *Oxford University*.
Thesis title: Distributing entanglement for quantum computing. Defended on 26th Sept. 2008. Supervisors: Dr. S. Benjamin and Dr. P. Kok

2001-2005 **M.Sci. in physics & philosophy**, *University of Bristol*,
1st class MSci joint honours degree in Physics and Philosophy.

Selected recent research highlights

2025 **A real-time, scalable, fast and highly resource efficient decoder for a quantum computer**, *Nature Electronics (2024)* .
This is Riverlane's flagship paper on the company's first fast real-time FPGA and ASIC decoders for quantum error correction with the surface code. It is notable for presenting the world's first ASIC design for a decoder and forming the basis of Riverlane's Deltaflow 1 product. Follow-up work includes a demonstration of this decoder with Rigetti using their Ankaa-2 system (see https://arxiv.org/abs/2410.05202).

2022 **Building a fault-tolerant quantum computer using concatenated cat codes**, *PRX Quantum* **3**, *010329 (2022)*.

This was a collaboration between hardware and theory teams at AWS, setting out the vision for Amazon's in-house quantum computing development. We proposed a detailed architecture including a full fault-tolerant resource analysis for an example quantum algorithm. I was one of the key contributors (note the asterisk in the author list): together with Chris Chamberland I designed the error correction architecture and approach to logic; and I was solely responsible for algorithmic resource estimates. Published in a top tier physics journal. This is # 5 in my most cited publications (see below).

2019 **Random compiler for fast Hamiltonian simulation**, *Phys. Rev. Lett.* **123**, *070503 (2019)*.

My single author paper proposed a novel random algorithm qDRFIT especially useful for simulating complex quantum systems with many interactions. This work was published in Physical Review Letters (a top-tier Physics journal). It is highly cited (357 Google scholar citations as of Jan 2025) with many of these papers building on my original algorithm. This is # 3 in my most cited publications (see below).

Scientific publications

Overview of publication track record.

My h-index is 41 (from Google scholar profile)

I have over 80 papers (mostly on Quantum computing) available on the arXiv pre-print server and available at arxiv.org/a/campbell_e_2.html. These are published in prestigious scientific journals including 2 Nature reviews, 1 Nature communications, 1 Nature Electronics, 8 Physical Review Letters and 3 Physical Review X.

Top 6 most highly cited publications, *as ranked by Google scholar on Jan 2025*.

1 **Roads towards fault-tolerant universal quantum computation (681 cites)**.
ET Campbell, BM Terhal, C Vuillot. *Nature* **549**, 172 (2017)

2 **Simulation of quantum circuits by low-rank stabilizer decompositions (366 cites)**.
S Bravyi, D Browne, P Calpin, E Campbell, D Gosset, M Howard. *Quantum* **3**, 181 (2019)

3 **Random compiler for fast Hamiltonian simulation (357 cites)**.
ET Campbell. *Physical Review Letters* **123**, 070503 (2019)

4 **Application of a resource theory for magic states to fault-tolerant quantum computing (334 cites)**.
M Howard, ET Campbell. *Physical Review Letters* **118**, 090501 (2017)

5 **Building a fault-tolerant quantum computer using concatenated cat codes (254 cites)**.
J O'Gorman, ET Campbell. *PRX Quantum 3* **3**, 010329 (2022)

6 **Magic-state distillation in all prime dimensions using quantum reed-muller codes (249 cites)** .
ET Campbell, H Anwar, DE Browne. *Physical Review X* **2**, 041021 (2012)

Patents

Overview of patent record.

I have 5 publicly disclosed and granted patents. These are listed below. I have several additional filed patents under consideration.

Quantum computing decoder and associated methods.
E. Campbell, L. Skoric, United States Patent Application, Pub. No.: US 18/410,972,
Date of Award: Dec. 2024.

Lattice surgery techniques using twists.
C. Chamberland, E. Campbell, United States Patent Application, Pub. No.: US 12,008,438 B1,
Date of Award: June. 2024.

Error correction decoding techniques for lattice surgery..
C. Chamberland, E. Campbell, United States Patent Application, Pub. No.: US 11,900,221 B1,
Date of Award: Feb. 2024.

Toffoli gate preparation for a quantum hardware system comprising hybrid acoustic-electrical qubits.
C. Chamberland, E. T. Campbell and F. G.S.L. Brandão, United States Patent Application, Pub. No.: US 11,468,219 B2,
Date of Patent: Oct. 2022.

Toffoli gate distillation from Toffoli magic states.
E. T. Campbell and C. Chamberland, United States Patent Application, Pub. No.: US 2022/0156441 A1,
Date of Award: May. 2022.

Teaching Experience

2022 -	**Lecturer for quantum computing**, *University of Sheffield*.
	I designed the syllabus and course contents for a new 4th year course on quantum computing. I also delivered the course: each year of teaching included 12 lectures $+$ 3 problem classes, exam preparation and marking.
2018 - 2020	**Lecturer for advanced quantum mechanics**, *University of Sheffield*.
	For 2 academic years, I taught half of a 4th year course on advanced quantum mechanics. Each year of teaching included 12 lectures $+$ 6 problem classes, exam preparation and marking.
2017 - 2018	**Lecturer for vector integration**, *University of Sheffield*.
	I taught a 4 week course on vector integration for all 1st year students, including setting and marking exam papers. This module was taught in the "flipped" style, with content delivered by video and combined with a 3 hours problem class each week.
2016 - 2018	**Academic tutor for PHY101**, *University of Sheffield*.
	I tutored $\sim$15 students on 1st year core physics, including: optics, waves, electromagnetism, thermal physics and quantum physics. This included weekly tutorial groups meetings and marking weekly homework assignments.
2016 - 2020	**Project supervisor for 3rd and 4th year projects**, *University of Sheffield*.
	Four student projects supervised to date.
2014 - 2015	**Lecture cover for advanced quantum mechanics**, *University of Sheffield*.
	Delivered lecturers for 4th year course on advanced quantum mechanics at Sheffield University (4 hours total).
2013 - 2014	**Tutor for 2nd year quantum mechanics**, *Freie Universität, Berlin*.
	I tutored 2nd year quantum mechanics at the Freie Universität, and with other tutors developed problem sheets and the final examination paper.
2012	**Lecture cover for advanced statistical mechanics**, *Freie Universität, Berlin*.
	I lectured part of the Masters course on advanced statistical mechanics at the Freie universität, and developed problem sheets.
2006-2008	**Mathematics tutor**, *University of Oxford*.
	I tutored the 1st and 2nd year courses on mathematics for material scientists.

Honours, awards and grants

2022 -   **Overall scientific leader on portfolio of projects**, At Riverlane, I lead the scientific strategy that directs research activities supported by a portfolio of government-funded grants (totalling £19 million to date) and venture capital investment (over $125 million to date).

Feb 2018 -   **QuantERA QCDA project**.
Feb 2021   Coordinator and lead PI of European consortium on quantum error correction. Total value approx €1.5 million.

Feb 2018 -   **Honorary lectureship University College London**.
A formal honorary lectureship position at University College London.

Aug 2017 -   **Industrial collaboration award**.
Aug 2019   Project "Developing simulation software for quantum computers" in collaboration with IBM New York and Oxford NQIT hub. Joint funded by Sheffield IIKE funding and NQIT partnership fund. Full economic cost £102,135.

Apr 2015 -   **EPSRC fellowship award**.
Apr 2020   Grant EP/M024261/1 on project "Towards fault-tolerant quantum computing with minimal resources", Full economic cost £824,914.

Sep 2008 -   **Royal commission of 1851 fellowship award**.
Sep 2010   Awarded fully funded 2 year independent fellowship.

Sep 2007 -   **Una Goodwin scholarship**.
Sep. 2008   Scholarship awarded by St. Anne's college for academic excellence, including a prize of £2000.

Conference talks

September 2024   **Seeking Quantum Advantage**, *Merton College Oxford, UK*.
Invited talk:"Real-time decoding in hardware".

August 2024   **Copenhagen QMATH workshop.**, *Copenhagen, Denmark*.
Invited tutorial speaker at summer school, delivering 3 hours of content on simulation algorithms.

July 2024   **An ICAP2024 Satellite Workshop on trapped ion quantum computing, quantum error correction and applications.**, *Brighton, UK*.
Invited talk:"Real-time decoding in hardware".

April 2024   **Cambridge Innovation Capital, Annual meeting**, *Cambridge, UK*.
Invited talk:"Quantum error correction explainer".

March 2024   **APS March meeting**, *Minneapolis, US*.
Invited talk:"A real-time, scalable, fast and highly resource efficient decoder for a quantum computer".

August 2023   **qSIM conference**, *Telluride, US*.
Invited talk:"Randomized quantum algorithms".

March 2023   **APS March meeting**, *Las Vegas, US*.
Contributed talk:"Parallel window decoding enables scalable fault tolerant quantum computation".

July 2022   **IBM Quantum Error Correction summer school**, *Yorktown Heights, US*.
Invited talk:"Lectures on circuit-level decoding".

Nov 2020   **Byron Bay Quantum Computing Workshop**, *Australia & virtual*.
Invited talk:"Fault-tolerant quantum computing with biased-noise hardware".

Sept 2020   **Quantum week of fun**, *Cambridge & virtual*.
Invited plenary talk: "On random circuits and their use in compilation".

Nov 2019	**Symmetry, phases of matter, and resources in quantum computing**, *Perimeter Institute, Waterloo, Canada*. Invited talk: "Magic monotones and classical simulation".
Feb 2019	**Coogee Quantum Information Workshop**, *Sydney, Australia*. Invited talk: "A theory of single-shot error correction for adversarial noise".
Jan 2019	**QIP conference**, *Boulder, US*. Contributed talk: "A theory of single-shot error correction for adversarial noise" and co-author on "Simulation of quantum circuits by low-rank stabilizer decompositions" presented by David Gosset. Highly competitive conference with success rate $\sim 18\%$.
Nov 2018	**London Mathematical Society computer science colloquium**, *London*. Invited talk to LMS colloquium on theme of "Quantum Computing: Unique Mathematical Perspectives" and presented "Homological and hypergraph product codes for quantum error correction".
Sept 2018	**Quantum programming languages**, *Schloss Dagstuhl, Germany*. Invited participant, presented "Phase polynomials, T-count optimisation and Lempel's algorithm".
Aug 2018	**Discrete Phase Space Methods for Quantum Fault-Tolerance**, *Bad Honeff, Germany*. Invited plenary talk: "Simulation of quantum circuits by low-rank stabilizer decompositions".
Apr 2018	**Heilbronn Quantum Algorithms**, *Cambridge, UK*. Invited plenary talk: "Fault-tolerance overheads on the back of an envelope" .
Jun 2018	**NQIT Industry day**, *Oxford*. Invited talk at NQIT (Networked Quantum Information Technologies) hub industry facing event, gave a presentation summarising collaboration with IBM.
Jan 2018	**QIP conference**, *Delft, the Netherlands*. Contributed talk: "Shorter gate sequences for quantum computing by mixing unitaries". Highly competitive conference with success rate 19% (57/296).
Nov 2017	**ThinkQ conference**, *IBM Watson, New York, US*. Invited talk: "Classical simulation of quantum computers with few nonClifford gates".
Sept 2017	**Quantum Error Correction (QEC)**, *Maryland, US*. Invited talk: "Small angle rotations: exotic magic states vs gate synthesis".
Jun 2017	**Qcumber UCL-CDT summer school**, *Windsor, UK*. Invited talk to summer school for University College London Center for Doctoral studies: "The magic state model of quantum computing".
Jan 2017	**QIP conference**, *Seattle, US*. Contributed talk: "Unifying gate-synthesis and magic state distillation" and co-author on talk "Application of a resource theory for magic states to fault-tolerant quantum computing", presented by Mark Howard. Highly competitive conference with success rate 58/247 = 23%.
Apr 2016	**19**[th] **Symposium on Topological QI**, *Leeds, UK*. Invited talk: "Cellular automata decoders on the toric code".
Mar 2016	**SIQS consortium annual conference**, *Venice, Italy*. Invited talk: "Fault tolerant dynamical decoders for topological quantum memories".
Dec 2015	**UCL CDT winter school**, *Chicheley Hall, UK*. Invited winter school talk for University College London Center for Doctoral Training.
May 2015	**TQC conference**, *Brussels, Belgium*. Contributed talk: "Thermalisation and decoherence in open Majorana systems". Co-author on two other talks presented at the conference.
Apr 2015	**Symposium on Topological QI**, *MPQ Garching, Germany*. Invited talk: "Thermalisation and decoherence in open Majorana systems".

Dec 2014	**Quantum Error Correction (QEC)**, *Zurich, Switzerland*.
	Invited talk: "The advantages of qudit fault tolerance" and co-author on one other paper.
Sept 2011	**ESF workshop**, *Azores*.
	Invited talk: "Non-locality, a Generalized Mermin Paradox and Measurement-based Quantum Computing".
Mar 2011	**GDR - IQFA colloquium**, *Nice, France*.
	Invited talk: "Hybrid matter-optical proposals for MBQC".
Jan 2011	**QIP conference**, *Singapore*.
	Featured talk: "Catalysis and activation of magic states in fault tolerant architectures. Highly competitive with success rate below 25% and further selected as a featured talk.
Apr 2010	**Symposium on Topological QI**, *Leeds, UK*.
	Invited talk: "Correlated noise in magic states".
May 2009	**TQC conference**, *Waterloo, Canada*.
	Contributed talk: "Neither Magical nor Classical".
	Local seminars.
	I have given numerous group and departmental seminars, including at: Caltech, Microsoft research, IBM research, Maryland, Aachen, Cambridge, Leeds, Bristol, Durham, Oxford, University College London, Imperial, Singapore, Waterloo, Hanover.

Conference Organisation

Aug 2020	**FTQT workshop**, *virtual*.
	One week virtual workshop on Fault Tolerant Quantum Computing (replaced a planned workshop at the Centro de Ciencias de Benasque Pedro Pascual). Co-organised with Barbara Terhal and Steve Flammia.
Jul 2019	**Quantum Error Correction (QEC)**, *London, UK*.
	Chair of Programme Committee & conference co-chair.
Jun 2019	**Reversible Computation**, *Lausanne, Switzerland*.
	Programme Committee for selection of contributed talks.
Aug 2016	**FTQT workshop**, *Benasque, Spain*.
	Two week international workshop on Fault Tolerant Quantum Computing hosted at the Centro de Ciencias de Benasque Pedro Pascual. Co-organised with Dan Browne and Michael Kastoryano. Approx 40 participants and €8,000 external sponsorship.
Mar 2015	**QuTe workshop**, *Sheffield*.
	Lead organiser for one-day workshop on quantum technologies. Approx 50 participants and £2,600 external funding.
Jan 2014	**COST conference**, *Potsdam-Berlin*.
	Local organiser for workshop on quantum thermodynamics.
2008-2010	**Seminar organiser**, *University College London*.
	Arranged weekly quantum information seminars at University College London.
Nov 2009	**QuCoCo, workshop**, *Oxford*.
	Organised a 2-day workshop on "*Quantum Computation and Correlations*", that took place on 9th-10th November 2009. Co-organised with Klearchos Loukopoulos.
Mar 2007	**MBQC workshop**, *Oxford*.
	Assistant organiser for workshop on measurement based quantum computing.

PhD Examiner

2024	External examiner for Dr. Boris Varbanov (QuTech Delft, the Netherlands)

2019   External examiner for Dr. Antoine Grospellier (INRIA Paris, France)

2019   External examiner for Dr. Suguru Endo (Oxford, UK)

2019   External examiner for Dr. Sam Roberts (Sydney, Australia)

2019   Internal examiner for Dr. Scott Vinay (Sheffield, UK)

2017   External examiner for Dr. Nikolas Breuckmann (RWTH Aachen University, Germany)

2017   External examiner for Dr. James Auger (University College London, UK)

2015   Internal examiner for Dr. Mark Pearce (Sheffield, UK)

Service to the community

2020 -   **QEC conference steering committee**, *virtual*.
Member of the steering committee for the leading international conference on quantum error correction.

2019-2020   **QIP Programme Committee member**.
Programme Committee member for QIP2019 and QIP2020, and regular PC external review in other years. QIP is the most prestigious conference for quantum computing and information theory.

2019   **QEC Programme Committee chair**.
PC chair for QEC2019. QEC is the most prestigious conference for the quantum computing sub-field of quantum error correction.

2018-2023   **Quantum journal editor**.
Quantum is a non-profit and open access peer-reviewed journal that provides high visibility for quality research on quantum science and related fields. It is an effort by researchers and for researchers to make science more open and publishing more transparent and efficient.

2018-2020   **Editorial board for Proc. Royal Soc. A**.
Editorial board for Royal Society journal *Proceedings of the Royal Society A: Mathematical, Physical & Engineering Sciences*.

2016-2019   **Committee member for QQQ group IoP**.
QQQ is the quantum subject group of the Institute of Physics.

2015-   **Active member of EPSRC Peer Review College**.
EPSRC is the largest UK funding body for quantum science. I have provided many referee reports on grant proposals submitted to EPSRC.

2007-   **Journal review**.
Referee for journals inc. *Physical Review Letters*, *Nature Communications* and *New Journal of Physics.*

2006-2008   **St Anne's college Middle Common Room committee**.
As a PhD student, I held various MCR committee positions.

Public engagement

2022-   **Blog post**.
Regular contributor to Riverlane company blog posts

2021   **Blog post**.
Co-authored blog post summarising the AWS architecture proposal pre-print click here to read the blog post. As of November 2021, this blog post has the highest traffic of all posts on the AWS Quantum Computing Blog.

2018	**Outreach video**.
	In collaboration with Maksym Sich and graphic design company 23i, I produced a short scientific outreach video on topological quantum computing. You can watch the video here https://www.youtube.com/watch?v=0U9_mrxLl3g
2017-	**Podcast appearances**.
	I have been interviewed on a couple of podcasts: Meet the meQuanics (episode 31); the Future Tech Podcast (Jan 2017); The superposition's guy (Dec 2023)
2015	**Quantum light exhibit at Oxford public event**.
	I presented Sheffield's "quantum light" exhibit in Oxford as part of a public evening event linked with the launch meeting for the UK National Quantum Technology Programme.
2006	**St. Anne's College subject family lecture**, *Oxford*.
	Popular audience talk on non-locality and quantum entanglement.

Supervision & Management Experience

2022-	Science function head with over 30 indirect reports, and 6 direct reports.
2020-2022	People manager at AWS, with 4 direct reports (quantum computing research scientists).
2019-2019	Dr. David White: Post-doc.
2019-2020	Dr. Yingkai Ouyang: Post-doc on my quantERA QCDA project grant.
2018-2020	Dr. Joschka Roffe: Post-doc on my quantERA QCDA project grant.
2018-2022	Armanda Quintavella: Current PhD student at Sheffield.
2017-2021	James Seddon: CDT PhD student at University College London under remote supervision. Thesis submitted and defence pending.
2016-2021	Luke Heyfron: PhD student at Sheffield. Graduated.
2015-2018	Dr. Mark Howard: Post-doc on my EPSRC research grant. Left position to take up a Royal Society fellowship.
2013-2014	Michael Herold: Physics Master's project at Freie Universität Berlin.
2013-2014	Stephan Wäldchen: Physics Master's project at Freie Universität Berlin.
2013	Joris Dolderer: Physics Bachelor's project at Freie Universität Berlin.
2011-2012	Alexander Kegeles: Physics Master's project at Freie Universität Berlin.
2009-2013	Dr Hussain Anwar: PhD at University College London. Assisted Dr Dan Browne with supervision.
2008-2011	Dr Matty Hoban: PhD at University College London. Assisted Dr Dan Browne with supervision. Currently, a lecturer at Goldsmith's