

Earl Campbell

Quantum error correction, algorithms & architectures

Personal data

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

Employment

- Jan 2022- **Riverlane**, *Tech lead: Head of Architecture*, Cambridge UK, Technical lead and researcher for development of quantum computing software architecture..
- May **Amazon Web Services**, *Senior research scientist*, Cambridge UK.
- 2020-Dec Senior researcher and people manager at the AWS Centre for Quantum Computing. Development of AWS's quantum computing capabilities and novel quantum algorithms.
2022
- Jan 2020- **University of Sheffield**, *Senior lecturer (eq. Associate Professor US)*, Sheffield UK.
Same as Sheffield role below, but at senior lecturer level (equivalent to Associate Professor in US system). I am currently on a leave of absence from this position.
- Feb 2019 - **Riverlane**, *Senior Research Scientist*, Cambridge UK.
- Dec 2019 A part-time 20% role in a quantum computing start-up company. I advised the company on their business & research strategy and undertook research into quantum computing & software in collaboration with other research staff.
- Jan 2015- **University of Sheffield**, *Research fellow (eq. Assistant Professor US)*, Sheffield UK.
- Dec 2019 Principal investigator on a 5 year EPSRC grant EP/M024261/1. The position is equivalent to Associate Professor in the US system, but with research focused duties. 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.
- 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 1851 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.

Recent research highlights

- 2020 **Building a fault-tolerant quantum computer using concatenated cat codes**, *arXiv:2012.04108*.
The pre-print "Building a fault-tolerant quantum computer using concatenated cat codes" was a collaboration between hardware and theory teams at AWS. We proposed an architecture for quantum computers and included 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)
- 2019 **Random compiler for fast Hamiltonian simulation**, *arXiv:1811.08017*.
My single author paper proposed a novel random algorithm especially useful for simulating complex quantum systems with many interactions. This work was published in Physical Review Letters (a top tier Physics journal) and has been highly cited (112 Google scholar citations as of October 2021). This recent paper is # 5 in my most cited publications (see below).
- 2017- **Consistent QIP success**, *At least 1 talk accepted every year over 5 years*.
In quantum computing theory, the most prestigious conference is QIP (Quantum Information Processing) which regularly has over 400 attendees. QIP has a selective programme committee with typically below 20% success rate. During 2017-2020, I had 7 accepted talks to QIP, with 3 presented myself and 4 by collaborators.
- 2018 **Simulation of quantum circuits by low-rank stabilizer decompositions**, *arXiv:1808.00128*.
This research project introduced new techniques for classical simulation of quantum computers and was presented at at QIP 2019. I initiated this international and industrial collaboration between Sheffield, IBM research and UCL, and for which I secured funding from UK (NQIT and IiKE) funding sources. The paper was published in Quantum journal and was also an accepted talk at QIP. An implementation of our simulator has been integrated into IBM's QISKIT platform. This recent paper is # 6 in my most cited publications (see below).

Scientific publications

Overview of publication track track.

I have over 50 pre-prints (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 8 Physical Review Letters and 2 Physical Review X. Based on this research, patent applications have been filed for 5 inventions. My h-index is 26 and my most cited publications are:

Top 6 most highly cited publications, as ranked by Google scholar on Nov 2021.

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

12b New Road – Melbourn, Cambridgeshire, UK

✉ earlrcampbell@gmail.com

- # 2 **Application of a resource theory for magic states to fault-tolerant quantum computing.**
M Howard, ET Campbell. *Physical Review Letters* **118**, 090501 (2017)
- # 3 **Magic-state distillation in all prime dimensions using quantum reed-muller codes.**
ET Campbell, H Anwar, DE Browne. *Physical Review X* **2**, 041021 (2012)
- # 4 **Quantum computation with realistic magic-state factories.**
J O’Gorman, ET Campbell. *Physical Review A* **95**, 032338 (2017)
- # 5 **Random compiler for fast Hamiltonian simulation.**
ET Campbell. *Physical Review Letters* **123**, 070503 (2019)
- # 6 **Simulation of quantum circuits by low-rank stabilizer decompositions.**
S Bravyi, D Browne, P Calpin, E Campbell, D Gosset, M Howard. *Quantum* **3**, 181 (2019)

Skills

Softwares: Mathematica (intermediate), LaTeX, Illustrator, C++ (beginner), Python (beginner)

Teaching Experience

- 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 ~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 lectures 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

- Feb 2018 - **QuantERA QCDA project.**
- Feb 2021 Coordinator and lead PI of European consortium on quantum error correction. Total value approx €1.5 million. For more details see www.qcda.eu
- Feb 2018 - **Honorary lectureship University College London.**
A formal honorary lectureship position at University College London.

12b New Road – Melbourn, Cambridgeshire, UK

✉ earlrcampbell@gmail.com

- 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 IIFE 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

- 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".
- Sep. 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 Honnef, 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 $57/296 = 19\%$.
- Nov 2017 **ThinkQ conference, IBM Watson, New York, US.**
Invited talk: "Classical simulation of quantum computers with few nonClifford gates".
- Sep 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 **19th 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

- 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 (Aachen, 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

- 2019-2020 **QIP programme committee member.**
PC 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- **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

- 2021 **AWS outreach video screened at NeurIPS2021.**
Panel member on discussion with seven quantum scientists on the current state of quantum computing]<https://t.co/Obx5MmKof1>
- 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_mrxL13g
- 2017 **Podcast apperances.**
I have been interviewed on a couple of podcasts: meet the meQuanics (episode 31) and the Future Tech Podcast (Jan 2017)
- 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

- 2019- People manager at AWS, managing a team of quantum computing research scientists.
- 2019 Dr. David White: Post-doc.
- 2019-2020 Dr. Jingkai Ouyang: Post-doc on my quantERA QCDA project grant.
- 2018-2020 Dr. Joschka Roffe: Post-doc on my quantERA QCDA project grant.
- 2018- 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