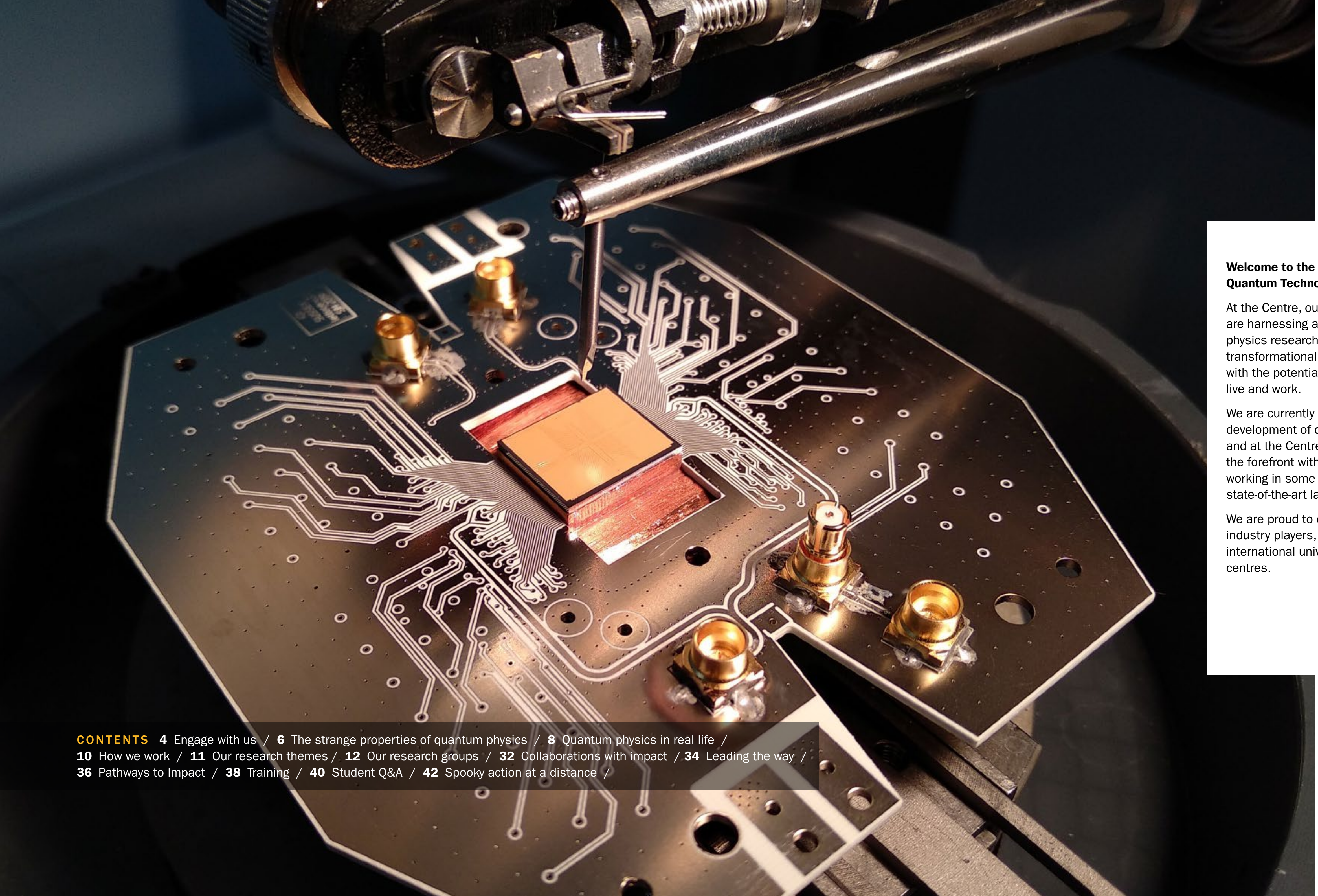
SUSSEX CENTRE FOR
QUANTUM TECHNOLOGIES

LET US INSPIRE YOU

UNIVERSITY
OF SUSSEX



CONTENTS

Welcome to the Sussex Centre for Quantum Technologies.

At the Centre, our seven research groups are harnessing and exploiting quantum physics research in order to create transformational commercial products with the potential to change the way we live and work.

We are currently at a critical time for the development of quantum technologies, and at the Centre, we are working at the forefront with over 100 researchers working in some of the largest dedicated state-of-the-art laboratories in the UK.

We are proud to collaborate with major industry players, as well as numerous international universities and research centres.

Our mission is to ensure that the UK remains a leader in quantum technology, by attracting and increasing the number of researchers trained in the realisation of quantum technologies in order to satisfy the growing industry demand for highly skilled personnel.

Our influence is visible internationally, with invitations to speak at the White House and to develop public policy in the UK and other countries. We are viewed as world leading across multiple quantum technologies.

Let us inspire you.

FIND OUT MORE:

www.sussex.ac.uk/scqt
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Significant investment by the University, along with a multi-million pound grant portfolio, has transformed Sussex into one of the leading incubators for a broad range of quantum technologies.

At the Sussex Centre for Quantum Technologies (SCQT) our research groups work hand-in-hand with leading industry partners in commercialising our ground-breaking research.

The critical mass of seven research groups allows us to tackle challenges and invent technologies that will change the way we live. The SCQT Doctoral and Industry Training Academy provides authentic quantum technology training for a wide range of stakeholders including industry short courses, undergraduate training, our pioneering Quantum Technologies MSc. and a comprehensive doctoral training centre. Beyond SCQT, we have established the Sussex Program for Quantum Research which brings together expertise from across the disciplines, including Neuroscience, Engineering, Informatics, Life Sciences, Medicine and Psychology – in a single network of collaborative translational research.

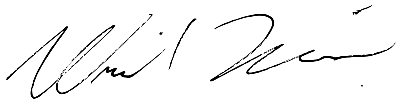
We appreciate that the development of quantum technologies requires engagement far beyond traditional physics research. So, while we are experts in the underlying physics, we recognise the engineering challenges needed to transform our ideas into real-world technologies. As well as training our students in the basics of technology, we emphasise entrepreneurship and engineering excellence.

Quantum technologies will provide highly disruptive capabilities for numerous industry sectors – and we are ready for the challenge. Our specialised facilities and expertise are unique and have given rise to numerous world firsts.

Our research groups want to change the way we live. We want to make a difference. And we are here to listen.

I invite you to work with us, whether it is to carry out research with impact, learn critical quantum technology skills, make the world a better place or simply learn about what we do.

We can change the world – together.



Professor Winfried Hensinger
Director, Sussex Centre for Quantum Technologies

TALK TO US ABOUT WHAT YOU WANT TO DO

Professor Winfried Hensinger
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QUANTUM

n. (*plural:* quanta)

/ˈkwɒntəm/

A discrete quantity of energy proportional in magnitude to the frequency of the radiation it represents.

Quantum refers to the most fundamental theory of nature and provides the working principles for modern quantum technologies.

SUPERPOSITION

n. (*plural:* superpositions)

/suːpəpəˈzɪʃ(ə)n/

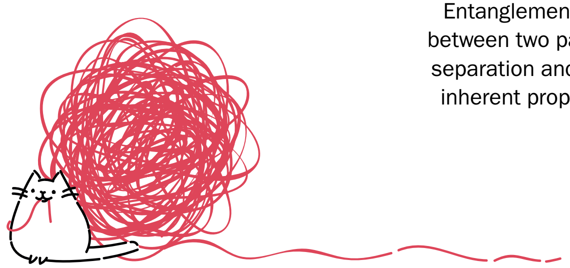
Quantum theory predicts that an atom can be at two places at the same time. This phenomenon, known as ‘superposition’, is being harnessed to build a wide range of quantum technologies.

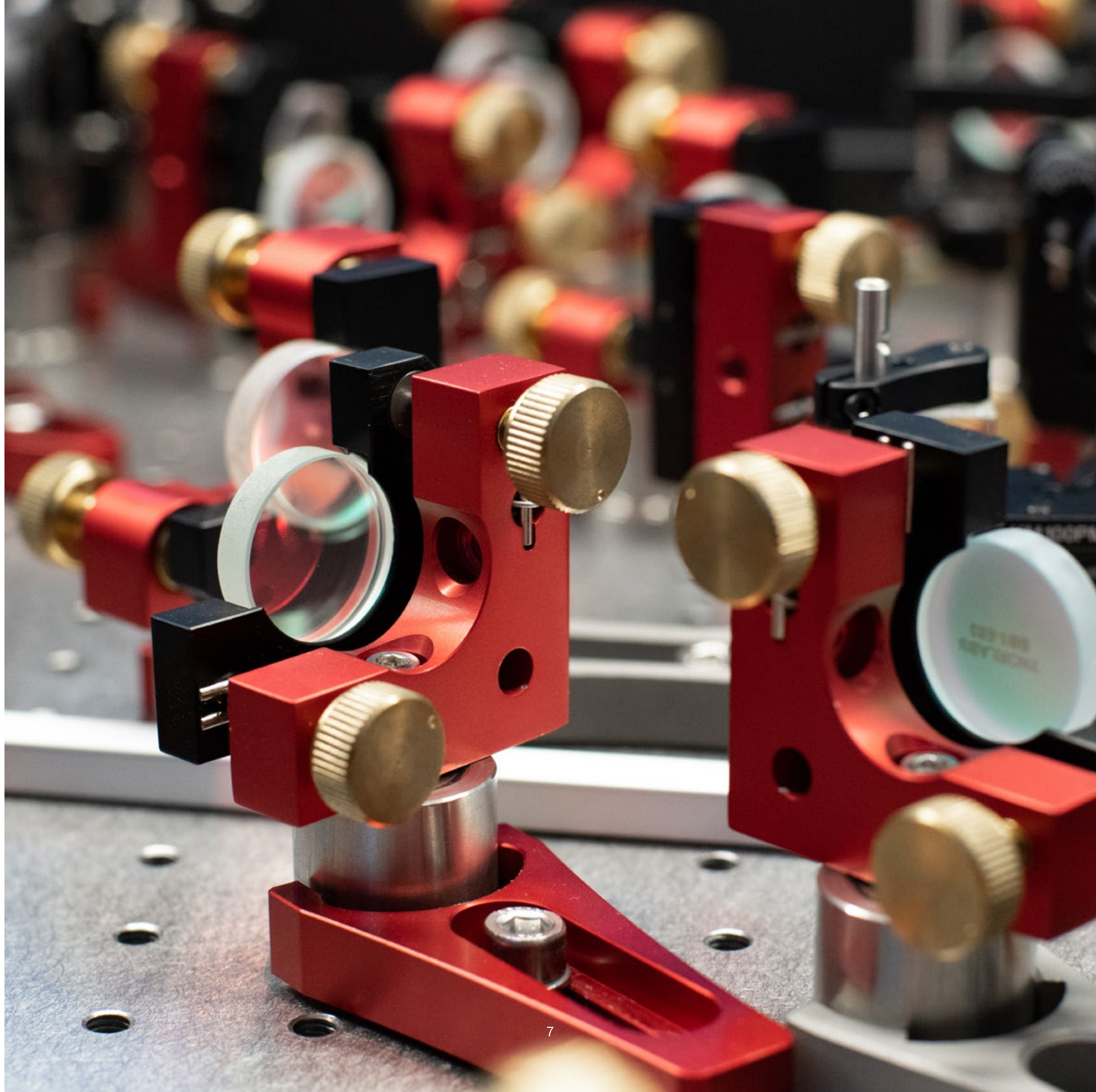
ENTANGLEMENT

n. (*plural:* entanglements)

/ɪnˈtaŋɡ(ə)lm(ə)nt/

Entanglement describes a strange correlation between two particles that persists even at large separation and that may not be explained by the inherent properties of each individual particle.

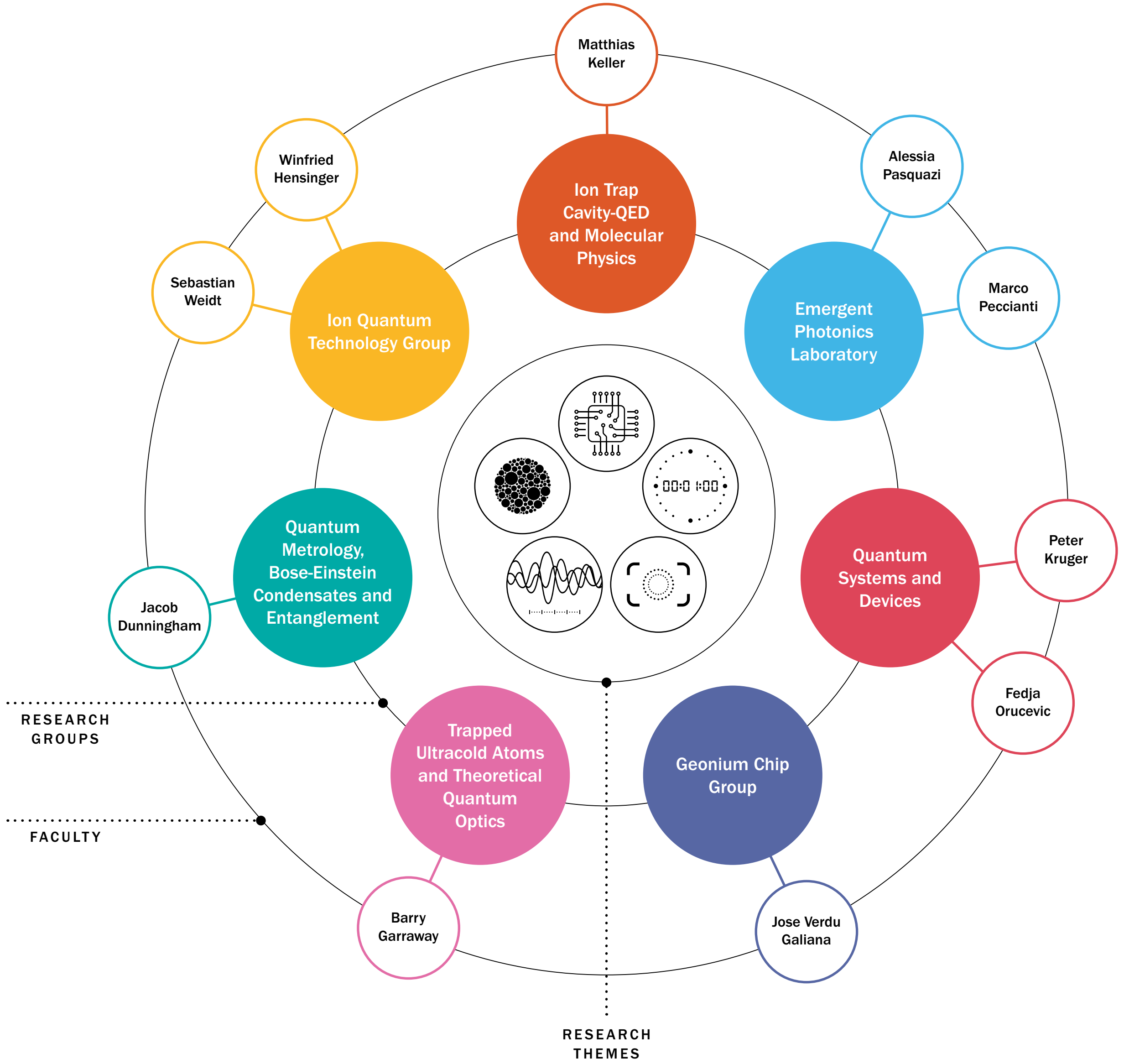




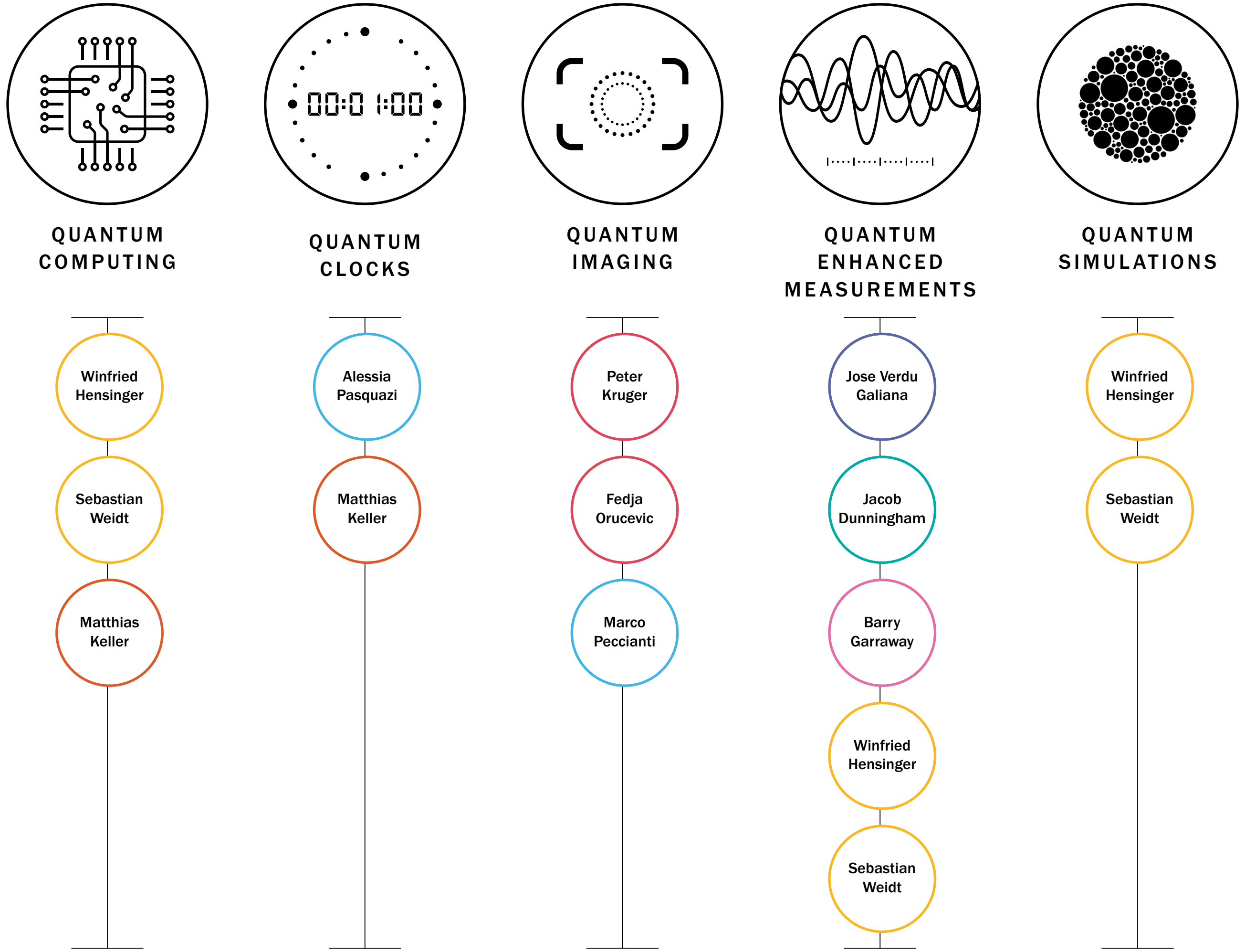
Atoms are 99.9999999999999 per cent empty space. Just a few tens of atoms, used as quantum bits, have the capability to outperform the world's supercomputers. The 'pendulum' of an atomic clock oscillates at hundreds of trillions of times per second. A quantum computer could solve certain problems that would take billions of years to calculate on even the fastest supercomputer. Optical atomic clocks are at the pinnacle of time measuring devices, losing less than one second every 10 billion years. A grain of sand contains about 10^18 (1 000 000 000 000 000 000) atoms. Quantum theory predicts that an atom can be in two places at the same time. In the many-world theory there is/are an infinite number of you/s reading this.

Our matter-wave interferometers can be so sensitive that they can detect the tides, the twisting of continental plates over hours and days, and the crashing of waves on the distant beaches.

HOW WE WORK



OUR RESEARCH THEMES



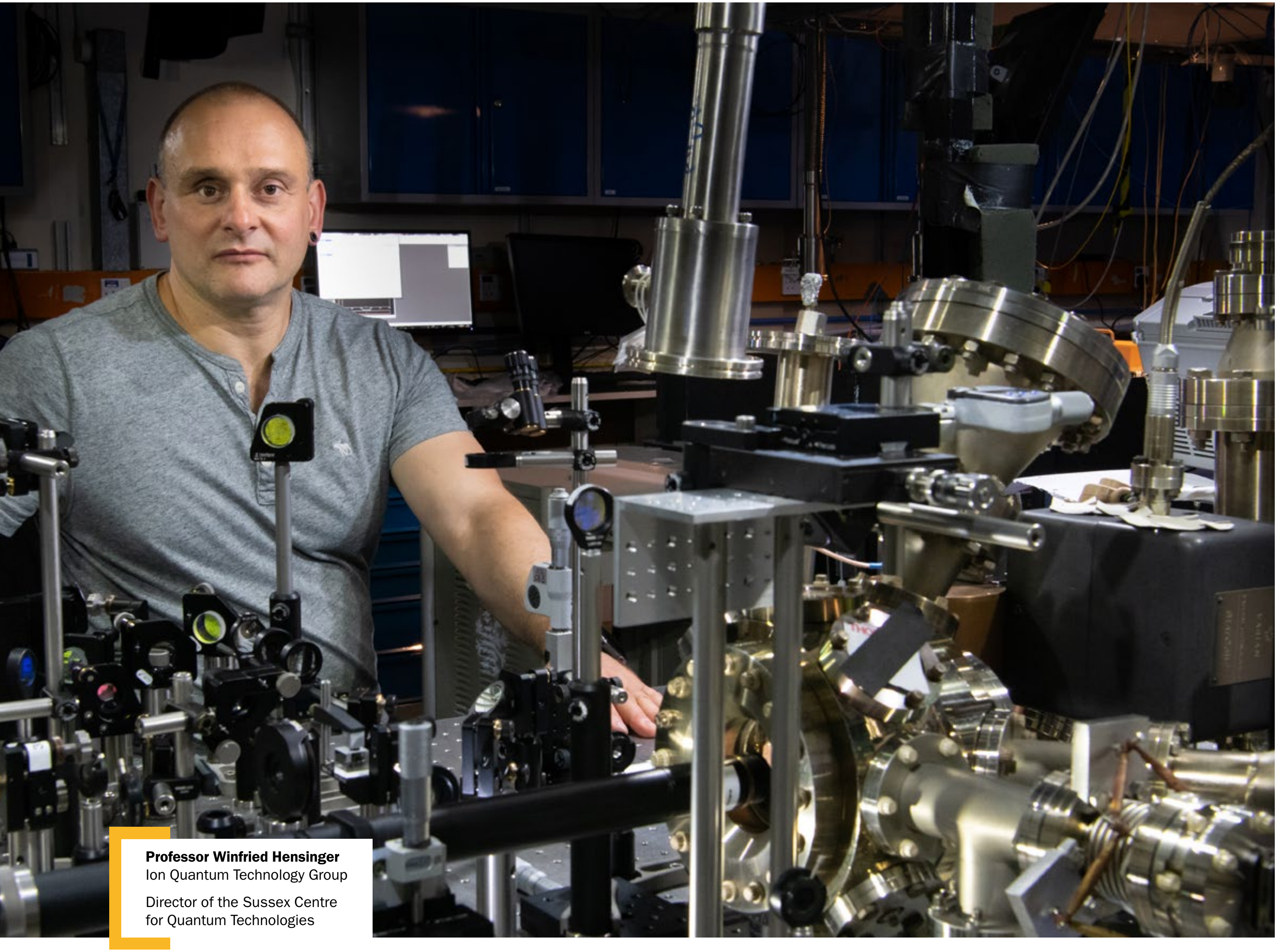
We develop practical quantum computers as well as quantum networks using ions and photons.

Quantum phenomena are used to realise ultra precise portable clocks.

Cold atoms are utilised for surface studies and brain imaging. THZ radiation for imaging explosives and biological composites (e.g. proteins, amino-acids, DNA).

A new generation of sensors capable of detecting magnetic fields, rf radiation, gravity, and very small forces.

Trapped ions power quantum simulators, allowing us to simulate other quantum systems to enable powerful real-life applications.



Professor Winfried Hensinger
Ion Quantum Technology Group

Director of the Sussex Centre for Quantum Technologies

"For many years people said that it was completely impossible to construct an actual quantum computer. With our work we have not only shown it can be done but together with a team of extraordinary scientists in my group at Sussex, we will build a practical quantum computer."

PROFESSOR WINFRIED HENSINGER

ION QUANTUM TECHNOLOGY GROUP

Building a practical quantum computer has often been referred to as one of the holy grails of modern science.

Quantum computers harness some of the strangest phenomena of quantum physics, namely entanglement and superposition, in order to allow solving certain problems that would take billions of years to calculate even on the fastest supercomputer. Our group works on developing practical quantum computers as well as quantum computing microchips which form the core of these machines. Previous ideas for building practical quantum computers involved aligning billions of laser beams to execute computations. At Sussex, we invented a new approach that replaces these laser beams with voltages applied to a microchip. In 2017, we delivered a nuts and bolts construction plan to build a quantum computer and we are now working on constructing real devices.

We also operate first quantum computer prototypes in order to understand their full potential. Besides building quantum computers, we develop quantum simulation engines, devices that have the ability to simulate other important but yet intractable physical systems. Quantum physics provides the ability to develop a new generation of powerful sensors and we develop rf quantum sensors capable of detecting and amplifying extremely low-level rf and microwave signals.

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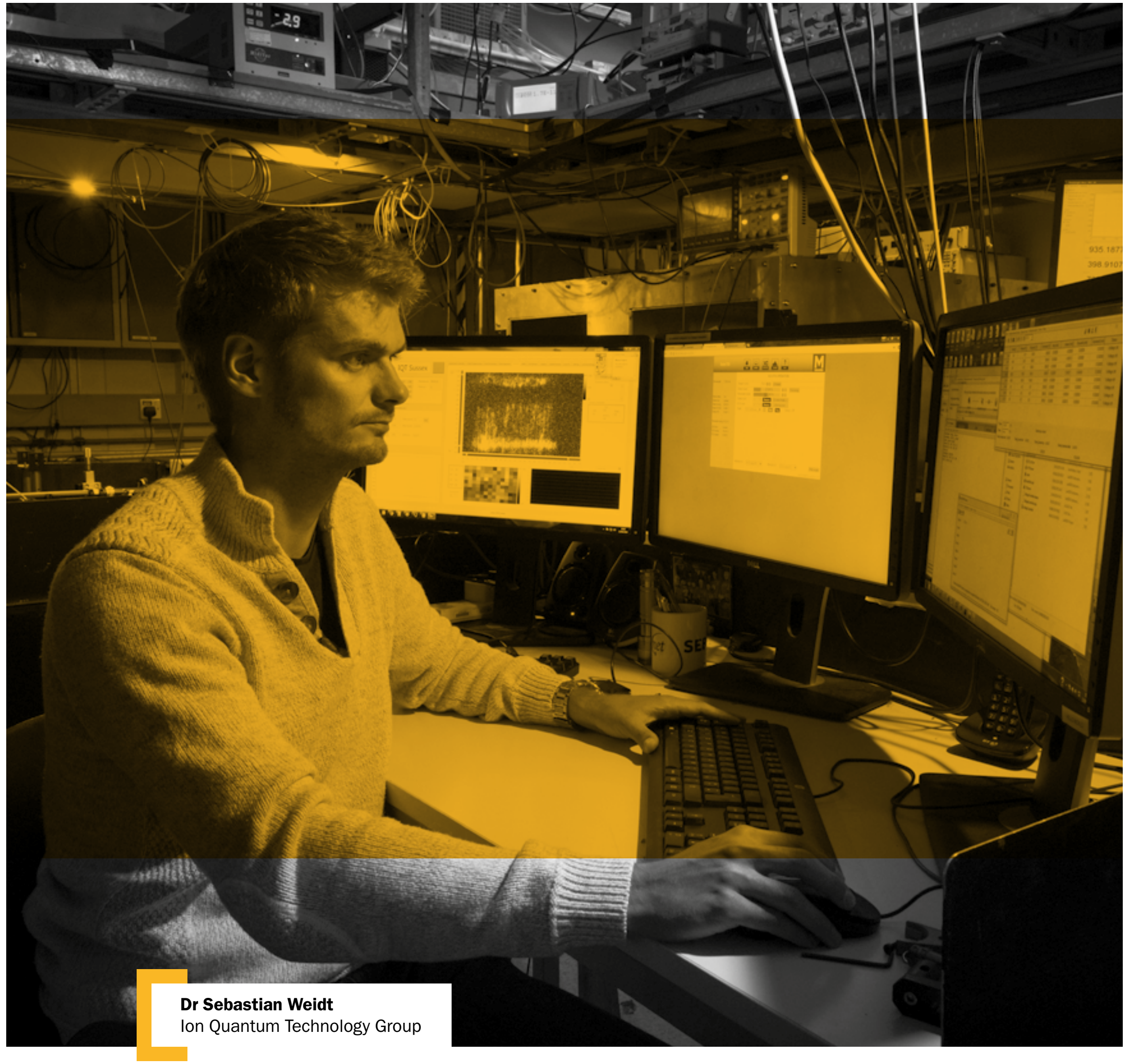
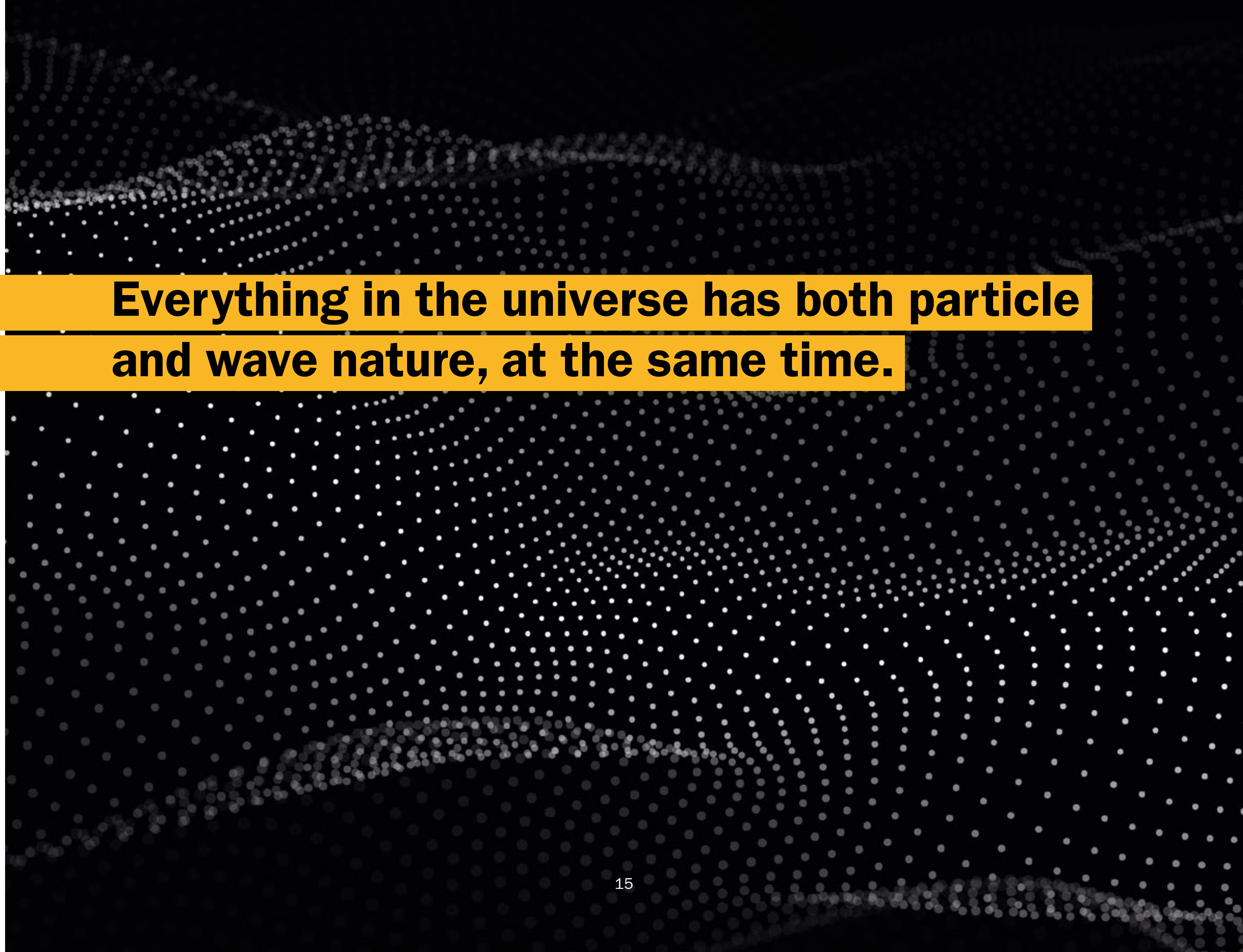


Dr Sebastian Weidt
Ion Quantum Technology Group



Everything in the universe has both particle and wave nature, at the same time.

> "Quantum technologies will change the future of technology and we are at the forefront of this revolution."

PROFESSOR MATTHIAS KELLER

ION TRAP CAVITY-QED AND MOLECULAR PHYSICS

In the Ion Trap Cavity-QED and Molecular Physics Group, we are strongly focused on the development and exploitation of quantum technologies.

Co-trapping ions and photons (particles of light) allows us to create novel computer interfaces to interconnect quantum computers to build the quantum internet and large scale distributed quantum computers. This technology has the potential to revolutionise the way we use computers for difficult tasks.

Employing tightly integrated fibre optics in ion traps, we are developing compact, portable atomic clock systems with unparalleled performance for its power consumption and size. These systems can have a major impact on modern navigation, telecommunication and time keeping.

Working with industry partners is an essential part of this research and we have developed close links with several companies within the UK and beyond.

We are also applying the quantum technologies that we are developing to improve our understanding of fundamental physics. Performing ultra-high spectroscopy on molecules, we are probing the limits of modern physics and hunt for dark matter.

Contact

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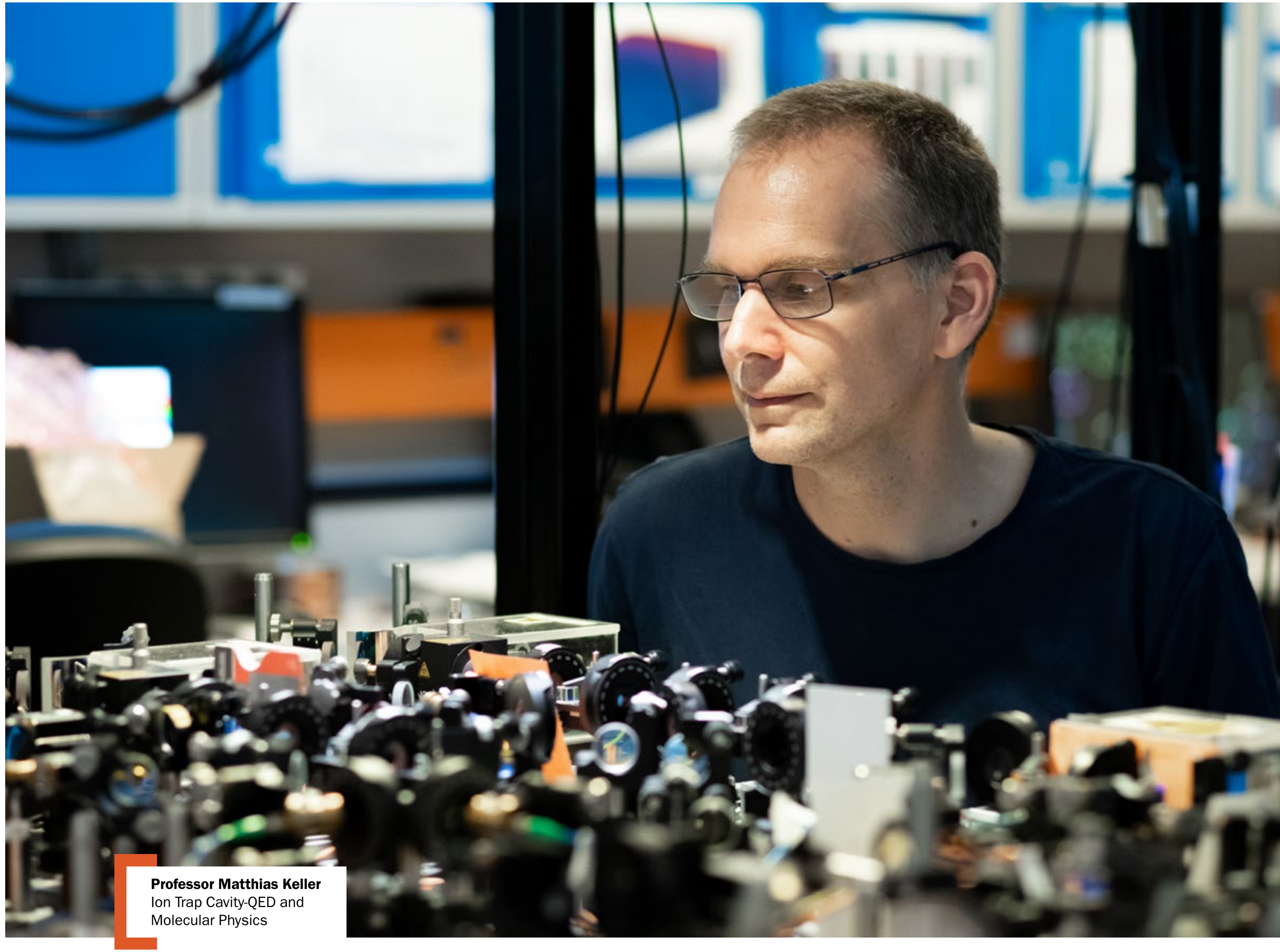
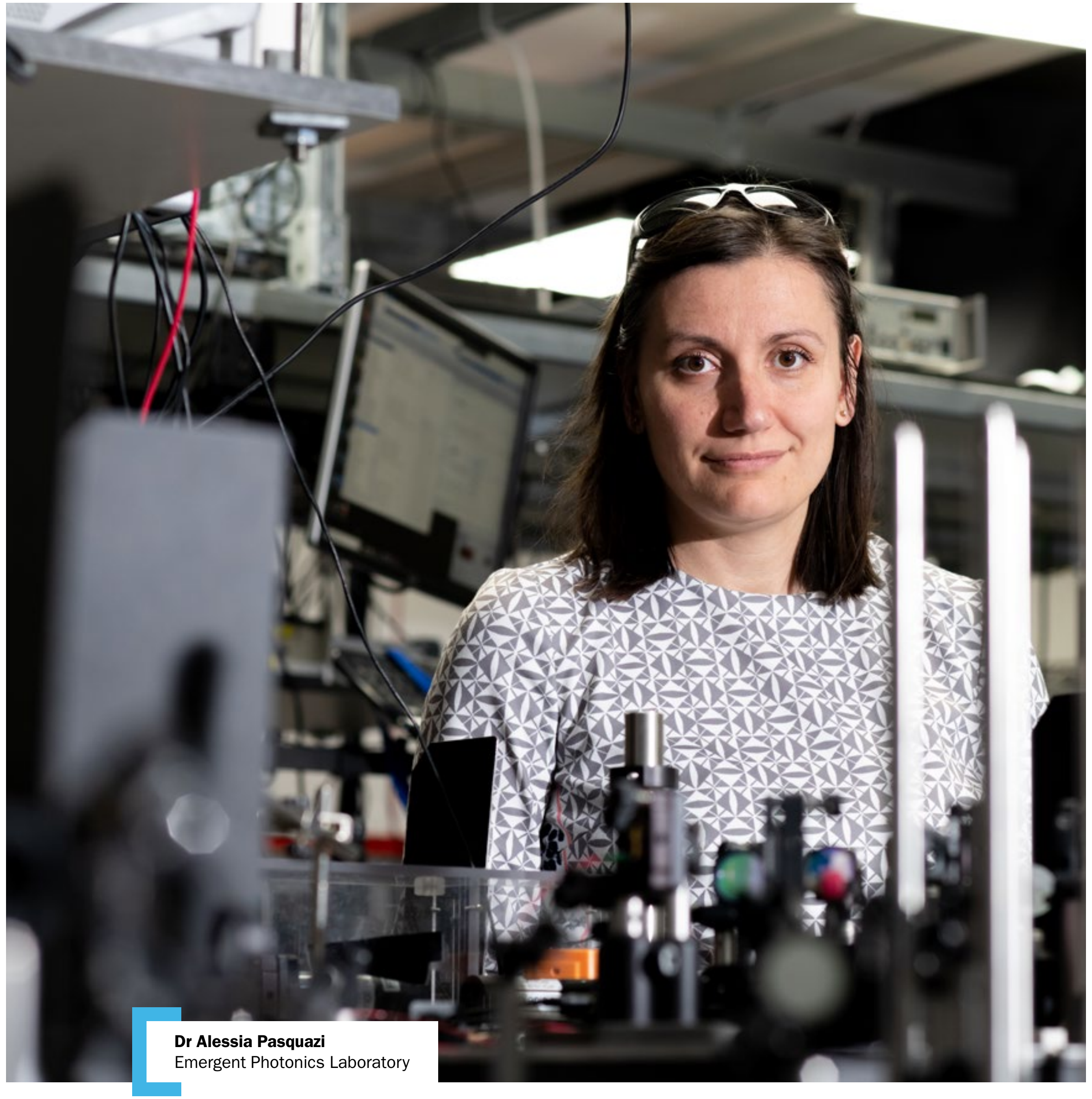
OUR RESEARCH GROUPS



Professor Matthias Keller
Ion Trap Cavity-QED and Molecular Physics



Dr Alessia Pasquazi
Emergent Photonics Laboratory

OUR RESEARCH GROUPS

"Light can do many things by herself. You just have to provide nonlinearity."

DR ALESSIA PASQUAZI

EMERGENT PHOTONICS LABORATORY

The Emergent Photonics (EPic) Lab is a fertile research environment focused on the 'emergent' photonic properties in complex nonlinear optical systems.

The lab currently hosts the work of 12 researchers directed by Alessia Pasquazi and Marco Peccianti, the lab founders. Our research interests extend into two major directions, on integrated complex photonic systems and their application in quantum technologies and in cutting edge terahertz science.

The scientific output of the group in the last five years includes about 30 publications on international Journals, 65 conference contributions (with several invited and keynotes), supported by a multi-million GBP research income from different funded projects, including among others, two European Research Council grants (H2020), an EPSRC research fellowship and multiple Marie-Curie (H2020) Fellowships.

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Professor Marco Peccianti
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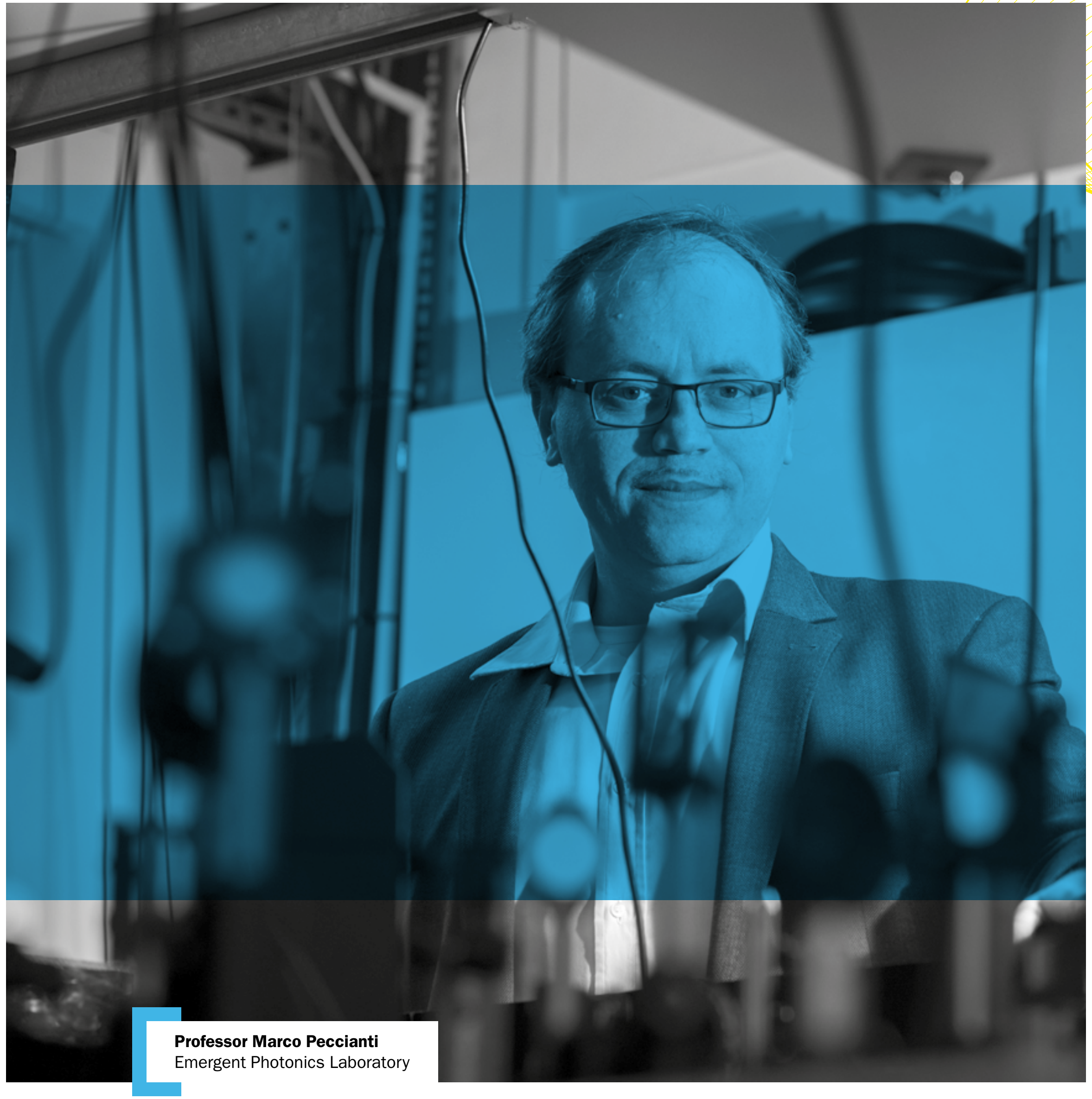


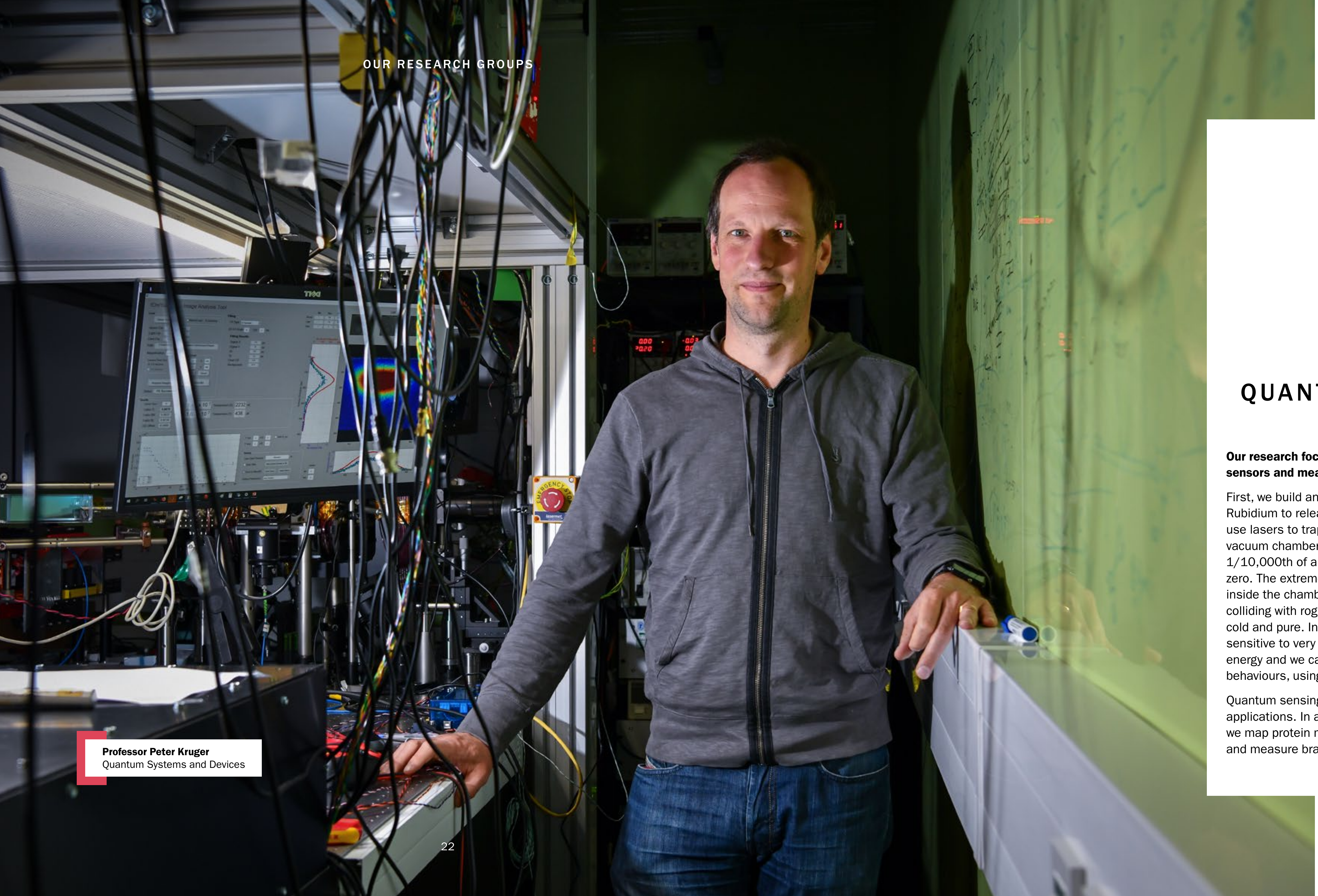
Professor Marco Peccianti
Emergent Photonics Laboratory

OUR RESEARCH GROUPS

LOOKING WITH TERAHERTZ EYES

We can take an image of a tree by looking at the sun.

We gain ‘terahertz vision’ by converting extremely short light pulses into terahertz waves and using the Ghost Imaging method, which removes the need to look directly to an object to know its image.



Professor Peter Kruger
Quantum Systems and Devices

“Right now, quantum devices fill a room. We want to make them portable.”

PROFESSOR PETER KRUGER

QUANTUM SYSTEMS AND DEVICES

Our research focuses on quantum sensors and measurement.

First, we build an atom trap! We heat Rubidium to release atoms as gas and use lasers to trap the particles in a vacuum chamber, where we cool them to 1/10,000th of a degree above absolute zero. The extremely diluted atmosphere inside the chamber prevents atoms colliding with rogue particles; they remain cold and pure. In this state, they are ultra-sensitive to very low scales of magnetic energy and we can study and control their behaviours, using magnetic microscopy.

Quantum sensing has diverse applications. In a joint project with BSMS, we map protein movement inside cells and measure brain activity with sensitive imaging. Working with an industrial partner, we are developing sensors to measure real-time current density in electric vehicle batteries. There is also potential for devices that measure gravity and ‘see’ below the earth’s surface.

Our aim is to provide fundamental knowledge for future generations and deliver practical devices that are ready to move out of the laboratory and into our everyday lives.

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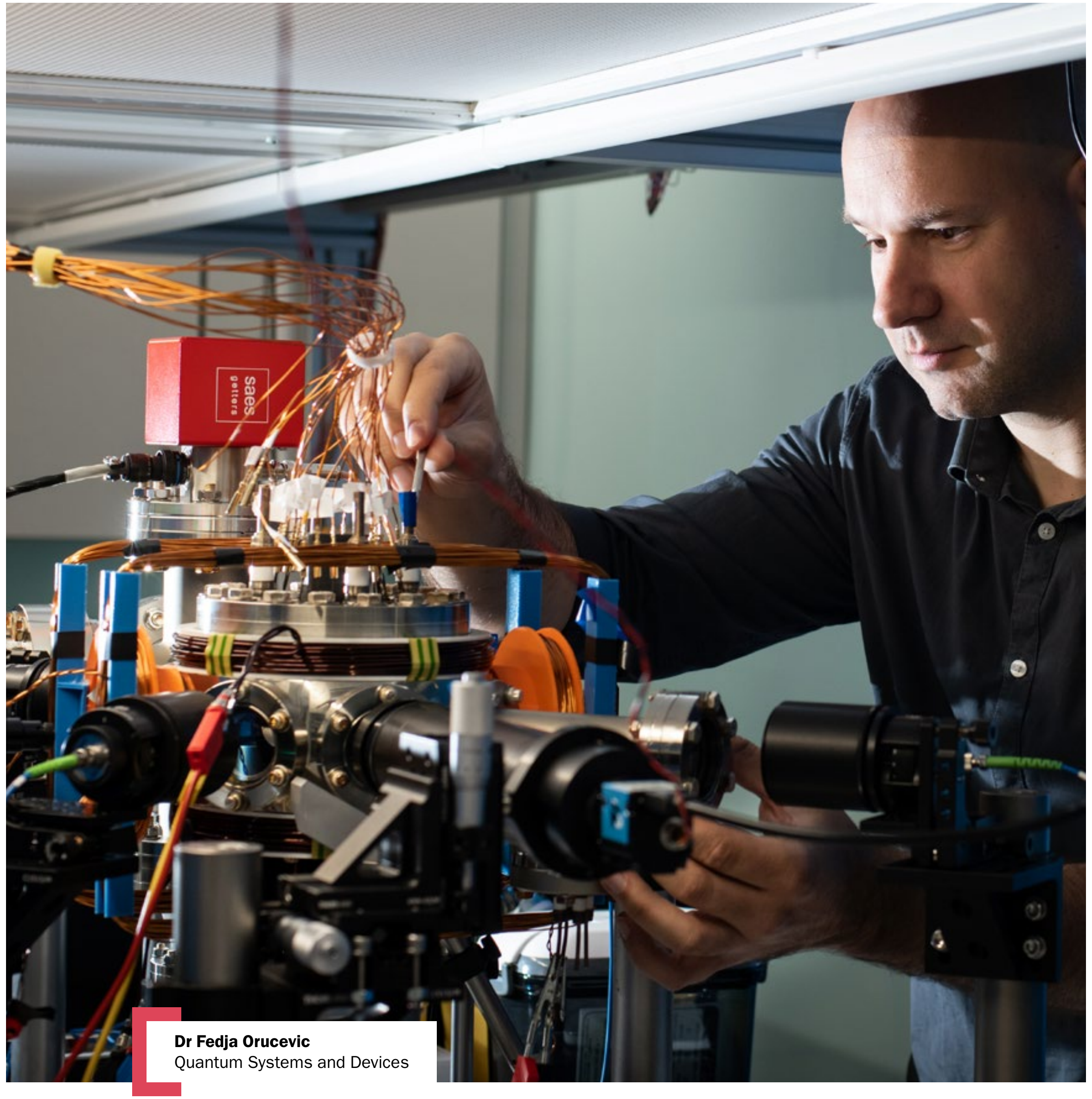

Dr Fedja Orucevic
Quantum Systems and Devices

"My biggest inspiration has always been other physicists."

DR FEDJA ORUCEVIC

Dr Jose Verdu Galiana
Geonium Chip Group

OUR RESEARCH GROUPS

"With our research, a single trapped electron might become the key to future revolutionary applications, such as quantum microwave microscopy, quantum radar, quantum microwave imaging and others."

DR JOSE VERDU GALIANA

GEONIUM CHIP GROUP

Single trapped electrons have been, and still are, a very powerful research tool, providing some of the most precise and stringent experimental tests in fundamental physics.

The immense potential of trapped electrons for practical quantum technology applications still remains fully unexploited. We are developing a novel ion trap technology fabricated on a chip, that promises to radically change that situation. A single trapped electron is also known as a 'geonium atom' and this is why we call our ion trap a 'geonium chip'. With our research a single trapped electron might become the key to future revolutionary applications, such as quantum microwave microscopy, quantum radar, quantum microwave imaging and others.

We also work closely together with some of the world-leading quantum physics theorists and are devising new quantum metrology methods that might open our research to applications we have not even imagined yet.

Contact

Dr Jose Verdu Galiana
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"Quantum physics is often said to be hard to understand as it appears to go outside our normal experience: however, the development of quantum technology is actively bringing quantum physics applications into our everyday world."

PROFESSOR BARRY GARRAWAY

TRAPPED ULTRACOLD ATOMS AND THEORETICAL QUANTUM OPTICS

We are working on the physics of trapping and manipulating cold atoms in different topologies. We also study quantum optics and the decoherence of light and matter.

Ultra-cold atoms are a useful resource for quantum technology: our group is working on the theory of trapping the atoms in rings and other loops for applications to inertial sensing. The behaviour of coherent quantum matter, as matter-waves, or as a Bose-Einstein condensate, is analysed in different topologies to understand fundamental behaviour and practical issues. The physics of trapping in a bubble topology is studied and is being tested on the International Space Station – we have close collaborative activity with several leading experimental groups.

The study of decoherence, that is the decay of the useful property of quantum coherences and entanglement, is crucial for the understanding of wave function collapse (the result in the much discussed Schrödinger cat paradigm). We have used the techniques of quantum optics to study such decoherence processes, which have implications for the viability of quantum computers and quantum information processing. On the other hand, we have also been developing alternative approaches to quantum information processing. These, for example, have been based on using photons for quantum logic, and also based on arrays of ultra-cold atoms holding the quantum information.

Contact

Professor Barry Garraway
b.m.garraway@sussex.ac.uk

Professor Barry Garraway
Trapped Ultracold Atoms and Theoretical Quantum Optics

Professor Jacob Dunningham
Quantum Metrology, Bose-Einstein Condensates and Entanglement

> “Quantum physics is transforming measurement technology, giving us an ever better window into the deepest workings of the universe.”
>
> PROFESSOR JACOB DUNNINGHAM

QUANTUM METROLOGY, BOSE-EINSTEIN CONDENSATES AND ENTANGLEMENT

Measurement underpins all of science.

It is by making measurements that theories are tested and refined and a new light is shone on the universe and its workings. Galileo went as far as to say that the aim of science is to “measure what is measurable and make measurable what is not so”.

New developments in quantum physics are revolutionising this.

My team at Sussex is developing pioneering theory to show how quantum systems can be harnessed to probe nature with a precision beyond anything currently possible.

We collaborate widely with scientists in Europe, Japan, Australia and the US.

We are working on transformative new measurement technologies such as quantum-enhanced clocks, navigation systems and radar. In the longer term, the hope is that improved measurements will uncover a deeper understanding of physics that will, in turn, lead to an even newer generation of measurements, continuing the process.

Contact:

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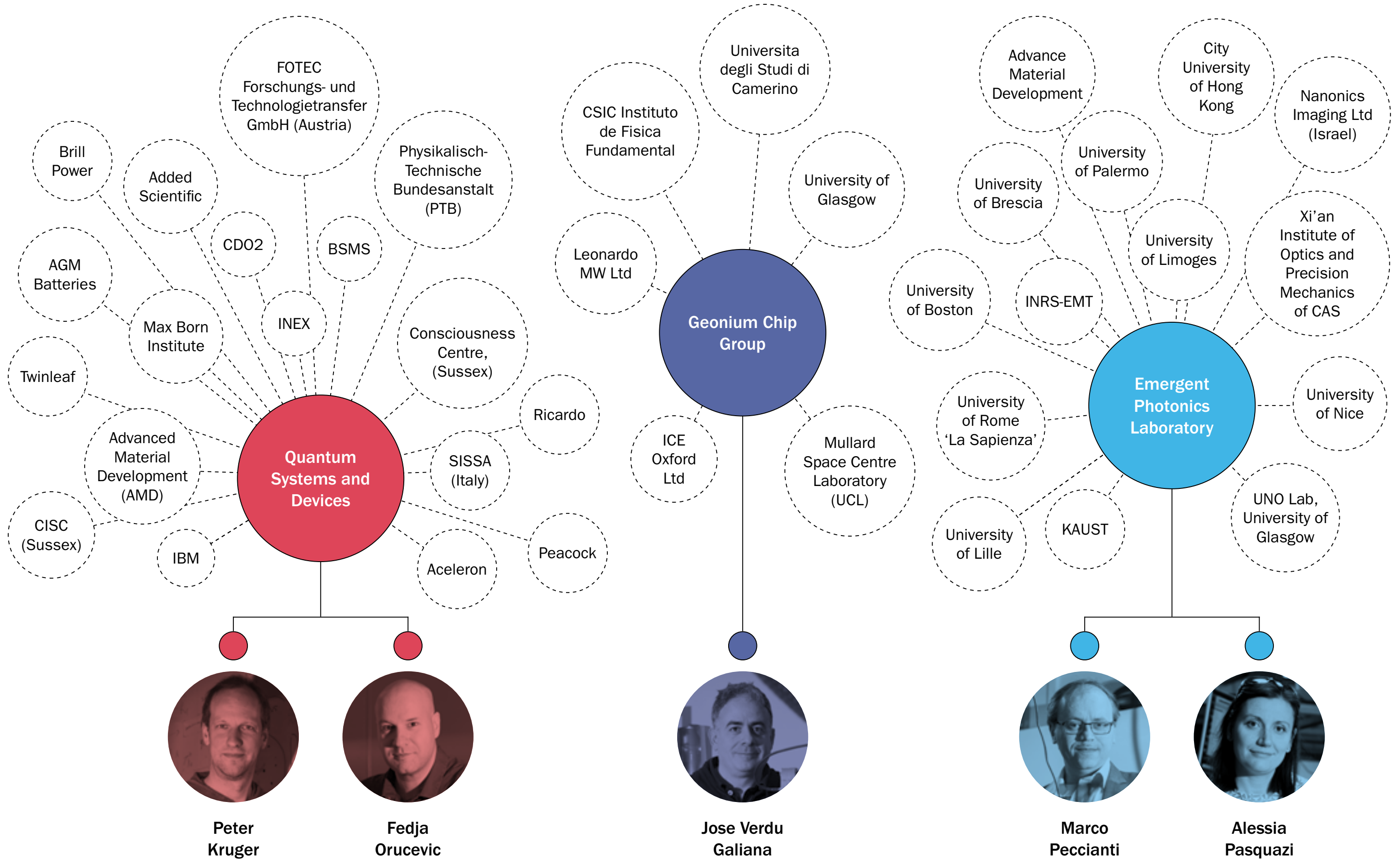
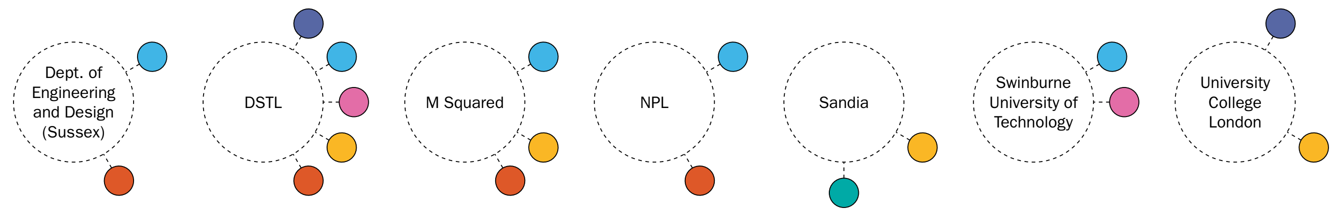
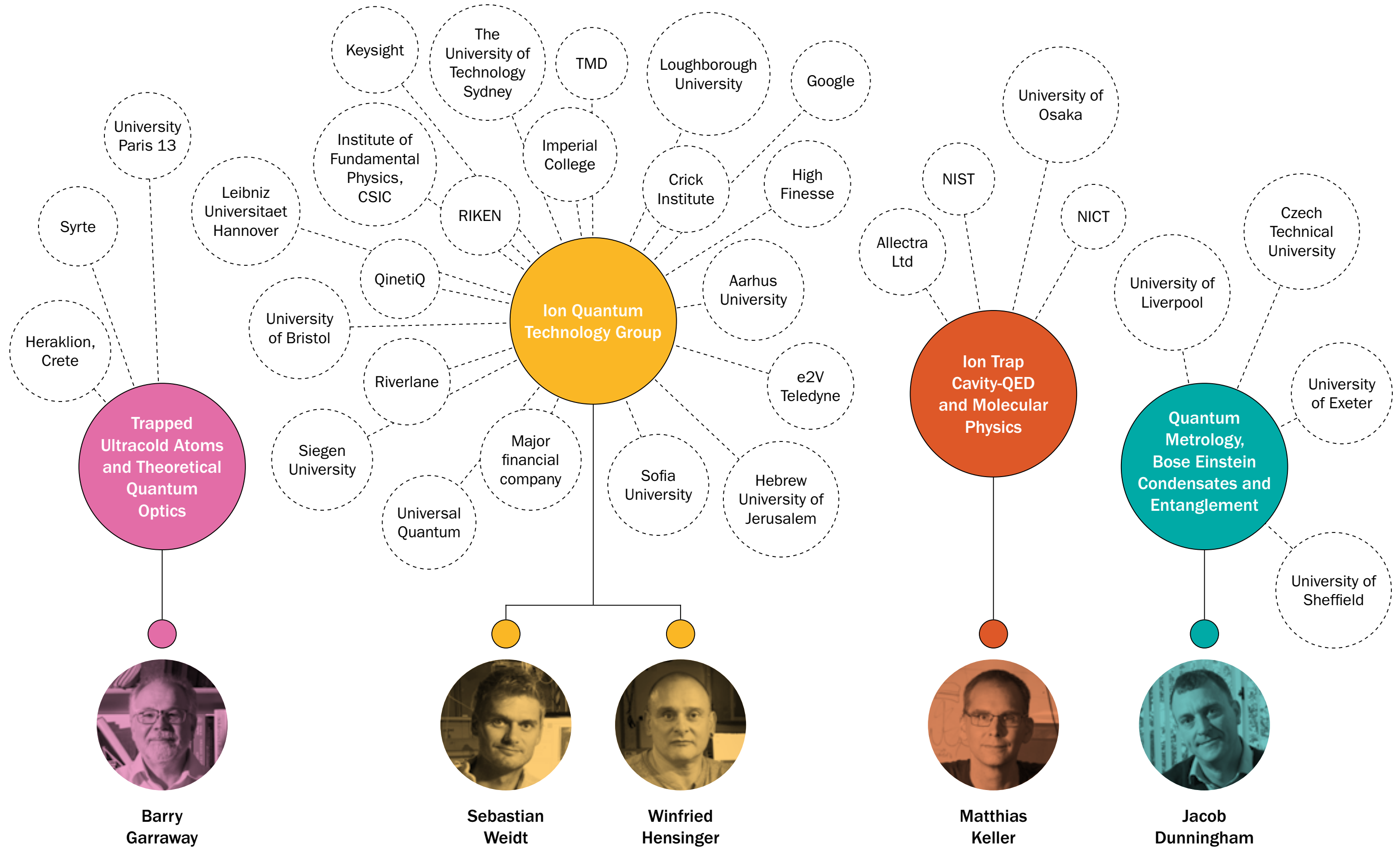


COLLABORATIONS WITH MULTIPLE RESEARCH GROUPS



Note: (Sussex) = University of Sussex

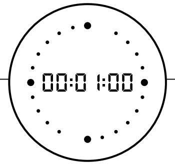


COLLABORATIONS WITH MULTIPLE RESEARCH GROUPS

QUANTUM CLOCKS

Sussex is currently the only place in the UK to offer facilities for the development of low-energy microcombs.

Together with our development of trapped ion optical frequency references, it allows for the next-generation compact optical clocks.



QUANTUM COMPUTING

Previous ideas for building practical quantum computers involved aligning billions of pairs of laser beams to execute computations.

The Sussex Ion Quantum Technology Group invented a new approach to quantum computing with trapped ions replacing these laser beams with voltages applied to a quantum computing microchip making use of modern microwave technology such as used in mobile phones.

Leading an international consortium including Google, Aarhus University, Riken and Siegen University, the Sussex Ion Quantum Technology Group created the first nuts-and-bolts construction plan to build a practical quantum computer.

Individual ions are transported from one quantum computing module to another giving rise to connection speeds 100,000 faster than current state-of-the-art fibre link technology.

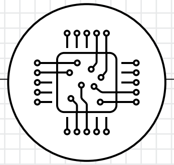
ION TRAPPING EXPERIMENTS

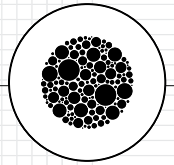
We run the largest number of ion trapping experiments in the UK.

The first cryogenic ion trap setup in the UK.

The first and only ion trap cavity QED set-up in the UK.

One of the largest centres for ion trapping in the world.





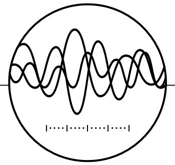
Building a quantum computer:
Our new construction plan adopts a modular approach – much like stacking lego.

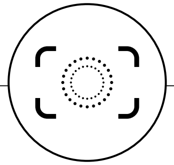
LEADING THE WAY

QUANTUM MEASUREMENTS

Professor Jacob Dunningham made ground-breaking progress on applying quantum theory to metrology and sensing, allowing unprecedented precision in detection schemes.

He has made major advances in our understanding of measurement theory, how this can be used in practical applications and the advantages of networks of entangled sensors.





QUANTUM IMAGING

We are the first to translate a nonlinear quantum imaging approach into the Terahertz domain.

QUANTUM NETWORKS

Linking small-scale quantum processors to form a large-scale quantum computer is a promising approach to realising the promise that quantum computing may hold. Essential for this approach, is to create a link between the local quantum bits and photons that carry the quantum information between the quantum processors.

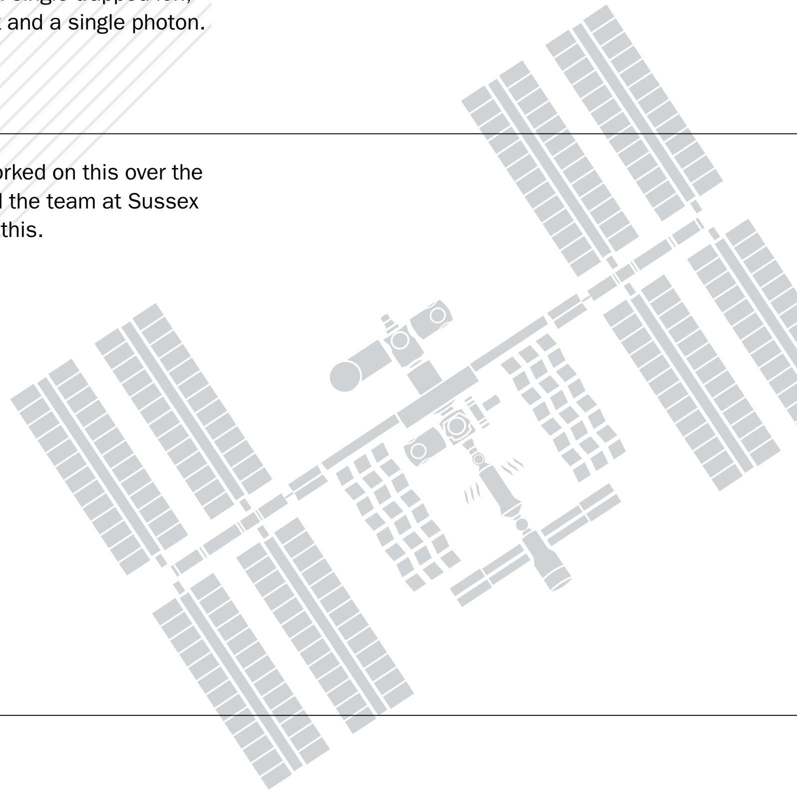
The ITCM-group, led by Professor Matthias Keller, have realised an essential milestone in this endeavour: the strong interaction between a single trapped ion, the local quantum bit and a single photon.

Many groups have worked on this over the last two decades and the team at Sussex have finally achieved this.

QUANTUM THEORY

Professor Barry Garraway's theoretical research on trapping atoms in unusual shapes and topologies has recently been taken up by the International Space Station.

The experimental module, which is now orbiting the earth, aims to make a bubble of matter-waves for research purposes. Experimental groups world-wide have been using Professor Garraway's techniques in their experiments over the last decade.



OUT & ABOUT

HIGHLIGHTS

EXHIBITION

Science Museum, London

Our researchers revealed the secrets of quantum computers to the UK public at the Science Museum in London. Dr Sebastian Weidt and colleagues talked to members of the public at a series of live events held over three days.

A model of the vacuum system used in our quantum computer prototype was on display. The exhibition also showed a silicon wafer comprising 64 quantum computing microchips, which is the heart of the quantum computer we are developing.

Visitors had the chance to remotely take control of a small-scale quantum computer that is located at the University of Sussex.

Dr Weidt said: "It has been a fantastic experience and a great pleasure to work with the Science Museum on this exhibition and help explain this potentially world-changing technology to the public. I'm thrilled visitors were able to see some of the core quantum computer components currently under development at the University. It helps people get a real feel for what these machines look like."

The exhibition was part of the Tomorrow's World section of the Museum which had over 660,000 visitors.

In addition, the general public had 70,000 interactions with a quantum computing focused access panel that was designed as part of the exhibition.

Professor Winfried Hensinger at the walk-in installation, Spitalfields Markets.

Quantum theory predictions include that an object can be in two places at the same time.

WALK-IN QUANTUM COMPUTER INSTALLATION

Spitalfields Markets

This was the first time a UK university took Quantum Technology out on the streets – inviting the public along to see the ground-breaking work being carried out in order to develop quantum computers.

The designed structure houses an authentic quantum computing experience incorporating four amazing exhibits that help develop a greater understanding of quantum computing for anyone entering the space.

Visitors to the installation quizzed the team on how their discoveries may shape the future, and watched immersive video projections of experiments being carried out in the lab.

Other exhibits included real chips used in a quantum computer, as well as a model of our quantum computer prototype currently under construction at Sussex.

British Science Festival

Sussex researchers also exhibited the walk-in installation at the British Science Festival allowing hundreds of visitors to interact with state-of-the-art quantum computing technology.

The editors of the Conversation reported quantum computing as the highlight of the British Science Festival in their festival podcast.

SUSSEX CENTRE FOR QUANTUM TECHNOLOGIES

DOCTORAL AND INDUSTRY TRAINING ACADEMY

Our academy offers a rigorous PhD doctoral training centre pathway, training future pioneers in the realisation of the next generation of quantum technologies.

Beyond training doctoral students, we recognise the importance of developing much wider training pathways for the emerging quantum technology sector. This includes a Master level qualification in quantum technologies as well as bespoke industry short courses that can be tailored to individual needs.

THE ACADEMY

The key aim of the training academy is to train the next generation of quantum engineers. Rather than offering traditional physics training we cater for the needs of the emerging quantum technology sector. We host the pioneering Quantum Technology MSc. We offer training allowing you to work on emerging quantum technologies such as quantum computing, quantum simulation, quantum imaging, quantum clocks and quantum networks. You will be able to learn relevant engineering skills as well as the development of relevant subsystems.

Beyond allowing you to take modules in relevant skills to work on quantum technologies, we also offer training in entrepreneurship in collaboration with the University of Sussex Business school.

The SCQT Doctoral and Industry Training Academy includes seven research groups with a vast range of unique facilities such as specialised lasers, clean room and microchip production, Terahertz imaging, ultrafast science including high energy lasers, quantum integrated photonics included microcombs, vacuum technologies, state of the art sensors, and electronics subsystem production facilities. Having a critical mass of a wide range of quantum technology groups allows for training that can be tailored to meet particular needs.

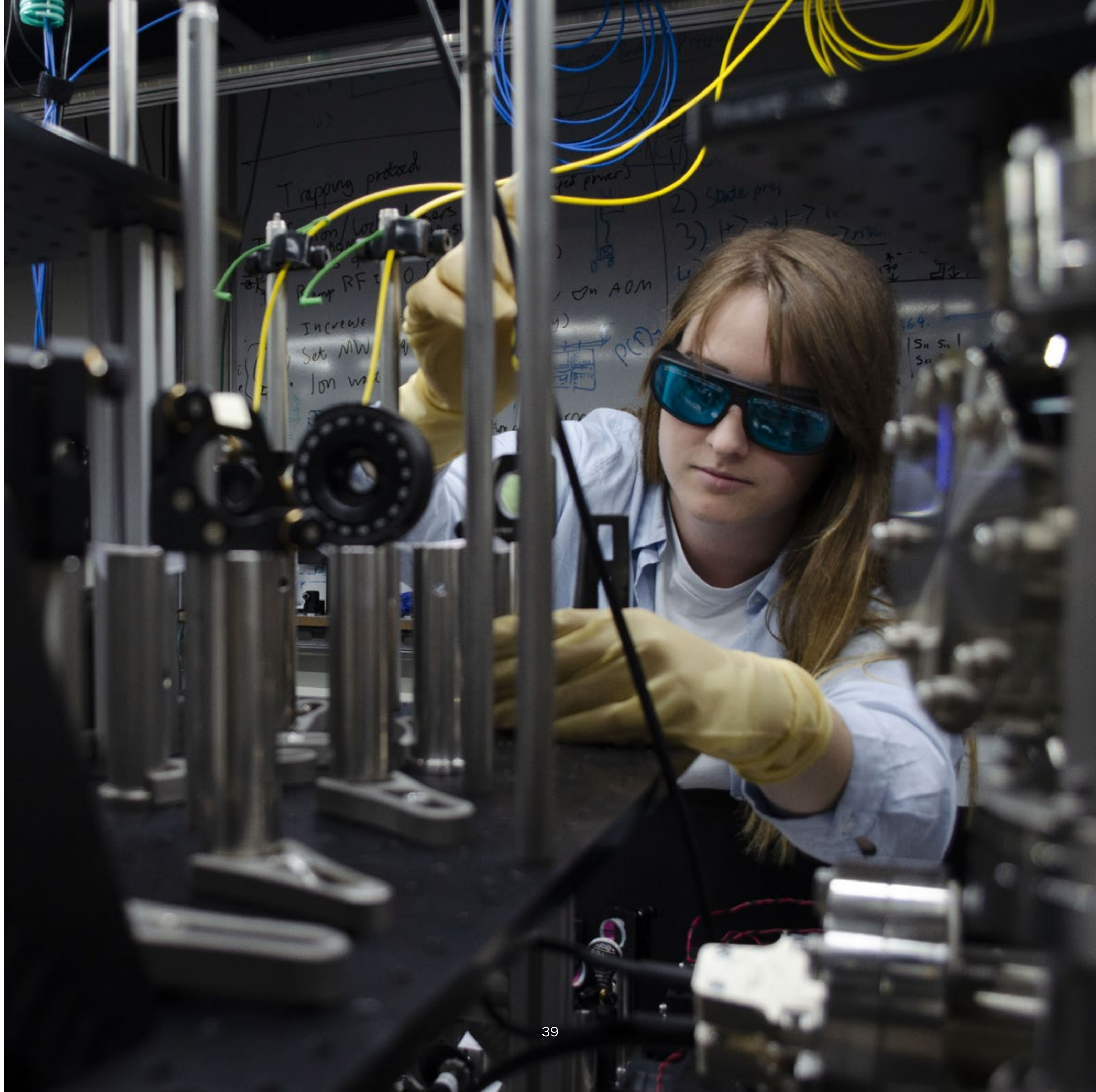
OUR TRAINING

Training is focused on harnessing quantum theory to develop and commercialise disruptive quantum technologies. Our aim is to translate the mysteries of quantum physics into cutting-edge technologies. By collaborating with industry and other leading UK universities as part of the UK National Quantum Technology Programme, we have the capacity to build real world devices. From super-fast computers to quantum simulation engines, our research has the potential to change lives by creating new materials and medicines.

Our research groups are involved in UK's National Quantum Technology Programme and we are part of the EPSRC Hub in Quantum Computing and Simulation and the UK National Quantum Technology Hub in Sensing and Timing.

FIND OUT MORE:

www.sussex.ac.uk/scqt



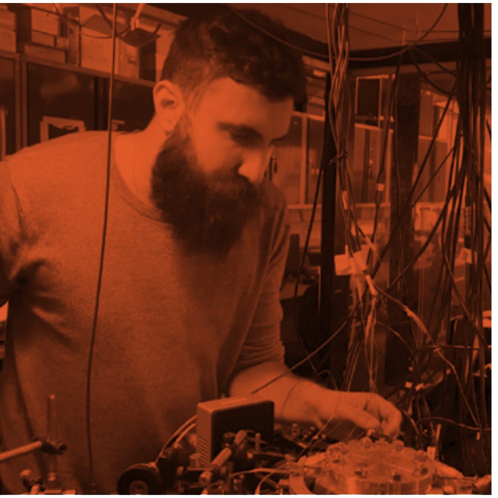
RESEARCH

I am working on the development of a new terahertz camera...

INSPIRATION

It's about using new rules, the rules of quantum mechanics...

Q&A



SOLUTIONS

The scalability problems are what interest me...

Q&A with three of our PhD students

Luana Olivieri
Emergent Photonics Laboratory

Foni Raphaël Lebrun-Ricalens
Ion Quantum Technology Group

Costas Christoforou
Ion Trap Cavity-QED and Molecular Physics

Tell us a bit about your research.

Luana / I am working on the development of a new terahertz camera, with a very powerful laser... The frequency range is absorbed by water and air, so it's difficult to measure, detect and emit. Materials such as clothes and paper are transparent in this range so it could eventually be used for security, scanners and food control.

Foni / Within the group I am now trying to build a small prototype quantum processor, a demonstrator device, acting as a fundamental building block for future larger devices. It's about rethinking the way we do computing at its very core. It's about using new rules, the rules of quantum mechanics, and with these new rules find computational shortcuts that classical computers just cannot see.

Costas / We are trying to incorporate fibre cavities into ion traps. My goal is to link nodes together so instead of having one trap with thousands of ions, we hope to have many little ones with say five ions – all linked together making a quantum network. It's a modular approach to quantum computation.

Why quantum technologies?

Quantum mechanics, the branch of physics that provides the framework describing the infinitely small and by extension everything around us, is incredibly counter-intuitive. It forces you to relinquish some of the initial logical bias you may have regarding your understanding of nature. It forces you accept uneasy consequences, to step out of your comfort zone. It's wonderful!

What attracted you to Sussex?

...the campus is amazing, relaxing. The main thing that attracts students is that we have so many opportunities right now. These groups do very good research. They give you lots of support, the School office is amazing! The people here are the main factor. The people, the support and the opportunities.

I talked to people and they are really happy working here. When I came here I saw the facilities are great, I met the people, they are great, really professional, really educated with great experience, and that made me choose Sussex.

Any advice for a new PhD student?

Never give up! Persevere. Sometimes you don't see the end of the frustration period but it is there. Don't give up!

Don't be deterred by the steep learning curve in your first year. Learn your working pattern and build a strong network of friends around you. Yes, the mountain is high, and yes, it has to be climbed.... you just have to take one step at a time. Eventually you'll get there.

Make every minute count, in work and every aspect, as this is one of the best parts of your life. It's a great place to be – make the most of it.

What is a typical day?

Wake up, come to lab, have a coffee, do my admin stuff, set programme for the day (and adjust if necessary). Work in lab. The PhD students are close, we go for lunch together. Although we work in different groups it feels like a big family. Hopefully I will finish at a reasonable time, go home, rest, repeat!

Best things about living in Brighton?

It's just filled with life and buzzing with activities, whether you are going hiking, wild swimming or bouldering. Wherever you are in Brighton you're never too far away from incredible friends... barbecues, and the beach.

I was born in a seaside town so the best thing for me is going to the beach, walking there. I like the vibrant nightlife, different places to go, and all the gigs happening in Brighton.

Is the forest there when we do not look?

Is the forest there when we do not look, or does its existence actually depend on us looking?

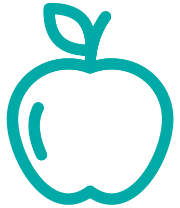
This refers to the concept of realism.

Is there anything that could happen on the other side of the world – right now – that would cause this very apple in my hand to have a worm inside?

This relates to the concept of locality.

One of the strange predictions of quantum physics is that if the world is independent of us observing (the forest is still there when we do not look), then the world is not local according to quantum physics.

This gives rise to what Einstein referred to as ‘spooky action at a distance’.



QUESTION EVERYTHING

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