Centre for
Quantum
Technologies

ANNUAL REPORT 2008

National University of Singapore

Contents

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Centre for Quantum Technologies website: www.quantumlah.org

From the Director

On a daily basis any research progress is incremental, sometimes barely visible, but from a yearly perspective it can be conspicuous, and, in our case, indeed it is. There is no doubt that over the last year our joint efforts have created a truly promising research environment at the Centre. We have put in place an impressive research infrastructure, established our own graduate programme, conducted a series of popular colloquia, and organized workshops which have brought the best researchers in the field to Singapore. Our outreach programme, in its noble effort to explain quantum weirdness to public at large, has managed to the engage local media. Many Singaporeans, to be sure, may still have been baffled by quantum physics when reading about the 2008 National Science Award. This was given to our researchers for pioneering work on the foundations of quantum theory, but explaining the importance of quantum technologies is well on its way. Last, but not least, is our research. I am very happy to say that, despite all the interruptions of moving labs, changing offices and the like, we have produced several remarkable results, some of which are described briefly in this report. Our publications, a not inconsiderate number, have been very well received and even noticed by the popular press. We have an excellent interdisciplinary team of theorists and experimentalists which have acquired international visibility. The community of quantum scientists already knows that something good is brewing in Singapore, not just Tiger beer of course. An increasing number of people have expressed serious interest in joining us. All we need do now is to build upon this. Our long term goal, as I explained to reporters from ***Nature*** a couple of months ago, is “To boldly go where no man has gone before, of course, into the quantum world, or worlds” and I hope next year we will make a step in that direction. After this foundational year of hard work I am confident that we can be among the leaders in the field of quantum technologies. Yes we can!

Artur K. Ekert

Origins

1998 - 2001: Heroic Years

Research in quantum technology in Singapore goes back to 1998, when local researchers Lai Choy Heng, Oh Choo Hiap, Kwek Leong Chuan, Kuldip Singh and, subsequently, Dagomir Kaszlikowski, decided to meet after hours to discuss emerging trends in quantum theory and in particular in quantum computation. What started as an informal journal club became a series of seminars, attracting local researchers and resulted in the formation of the Quantum Information Technology (QIT) Group, informally referred in Singlish as "quantum lah".

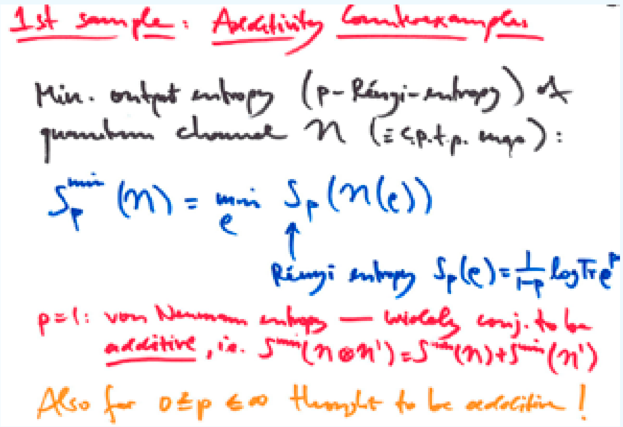
2002 - 2006: Consolidation period

The QIT group became remarkably successful and attracted attention and support from the Agency for Science, Technology and Research (A*STAR) in the form of the Temasek Project. Artur Ekert, appointed as a Temasek Professor at the National University of Singapore, helped consolidate local research efforts in quantum information science and, building upon the growing strength of the group, attracted to Singapore Berge Englert, Christian Kurtsiefer, and Antia Lamas Linares. The arrival of Antia and Christian in 2003 marked the beginning of experimental activities in the field. They established a quantum optics laboratory and within few years managed to put Singapore at the frontiers of experimental research in quantum technologies. Their team of local researchers developed excellent sources of entangled photons and pioneered experimental quantum cryptography in Singapore.

2007 - present: RCE period

In 2007 the QIT group was awarded SGD 150 million to form the first Research Centre of Excellence (RCE) in Singapore. The Centre is funded jointly by the National Research Foundation and Ministry of Education, and is hosted by NUS. Since early 2008 it has been known as the Centre for Quantum Technologies (CQT).

Research Highlights



Andreas Winter showed that an important and longstanding conjecture regarding the additivity of the minimum output Renyi entropies of quantum channels is false. This, and a subsequent result by Hastings which builds on it, imply that entangled inputs can enhance the capacity of memoryless quantum channels for transmitting classical information. These results are widely regarded as real breakthroughs in the theory of quantum information.

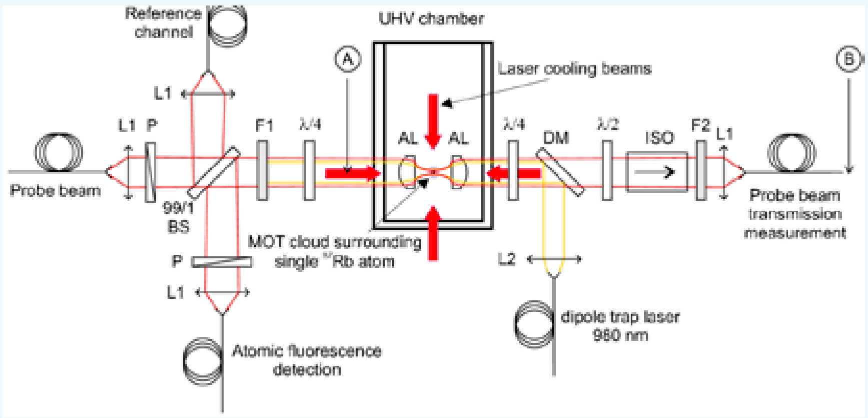
Christian Kurtsiefer, Antia Lamas-Linares and Valerio Scarani were awarded the National Science Award Singapore 2008 for "outstanding theoretical and experimental studies on quantum entanglement". Their work on the refutation of the Leggett model on nonlocal hidden variables generated significant attention world-wide. In the Lab Notes section of this report Valerio Scarani, gives a personal account of the story behind this notable achievement.

Valerio Scarani, in collaboration with Renato Renner, showed that secure quantum key distribution is possible with finite resources. All previous proofs relied on unrealistic assumptions that the cryptographic system runs for an infinite time, thereby exchanging an infinite amount of communication. As things stand, quantum cryptography can be made secure in practice, but only if a finite-communication bound, derived by Renato and Valerio, is used instead of the usual asymptotic bounds.

Our quantum cryptographic set up was tested against the toughest adversaries in the world. The CQT Quantum Optics Group sided with our colleagues from the National Institute of Standards and Technology in the US and jointly presented quantum key distribution systems at the two largest hackers conferences in the world: Black Hat (for the corporate types) and DEFCON (for the alternative version) in Las Vegas. Antia Lamas Linares shares her experience of these events in the Lab Notes section.

Our studies of entanglement in many-body and macroscopic systems resulted in some surprising findings, as described by Dagomir Kaszlikowski in the Lab Notes section, and in a number of papers, including a comprehensive review of the subject by Vlatko Vedral, published in Nature.

The single atom experiment by the CQT Quantum Optics group demonstrates that a propagating light field can be strongly coupled to a single atom by just focusing it with usual lenses. Apart from generating excitement among colleagues in the field this work has also attracted attention of popular press and featured in New Scientist.



People

Governing Board

Mr LAM Chuan Leong (Chairman)
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Chairman, Infocomm Development Authority
Chairman, Competition Commission of Singapore

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Carnegie Mellon University

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Director
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Institute of Quantum Computing, University of Waterloo

Dave WINELAND
NIST Fellow
Ion Storage Group, National Institute of Standards and Technology

Umesh VAZIRANI
Director, Berkeley Quantum Computation Center (BQIC)
Computer Science Division, Colleage of Engineering, UC Berkeley

Principal Investigators

Interdisciplinary Theory

Prof. OH Choo Hiap

Born in Sabah, Malaysia. Selected under the Colombo Plan to study in New Zealand, where he completed his Ph.D. (University of Otago, 1972), returned to serve at University of Science of Malaysia (1972-1983), and joined NUS in1983. He started his career as a theoretical physicist, specializing in the Yang-Mills gauge fields, particle phenomenology, integrable models. As the Head of Physics Department (2000-2006) at NUS, he recruited a number of researchers in the fieldof quantum information, all of whom subsequently contributed to forming CQT. (National Science Award 2006).

Prof. Berthold-Georg ENGLERT

Born and educated in Germany, Berge was a postdoc at UCLA after receiving his doctorate in 1981. He taught at the University in Munich 1985-1995, and then became a "physicist at large" until arriving at NUS late 2002, becoming professor 6 months later. He contributed to semiclassical atomic physics, to quantum optics, to the foundations of quantum physics, and to quantum information. His early work on the semiclassical theory of many-fermion systems finds a continuation in his ongoing research on ultra-cold atomic fermion gases. Other current interests concern quantum computation as well as the question of what can be known about quantum systems. (National Science Award 2006)

Asst. Prof. Dagomir KASZLIKOWSKI

In 2001, soon after he received his doctoral degree from the University of Gdansk (2000), in Poland, Dagomir joined NUS as a Research Fellow. In 2004 he was appointed an Assistant Professor in the Department of Physics. With CQT since 2007. His research interests are in the foundations of quantum theory, properties of entanglement, in particular in many-body systems. (National Science Award 2006)

Prof. Andreas WINTER

Andreas Winter received his Ph.D. in Mathematics from the University of Bielefeld in 1999. Since then he has been at the University of Bristol, first as a post-doctoral researcher in the Department of Computer Science, then as a lecturer in Mathematics and currently as a Professor in Mathematics. Since 2007, he has also held a joint appointment at the CQT, National University of Singapore. His research interests cover quantum information theory, discrete mathematics, and statistical physics.

Prof. Vlatko VEDRAL

After undergraduate studies and PhD at Imperial College, London, in 1998, Vlatko went to Oxford as a JRF at Merton College. From 2000-2003 he was Governor's lecturer at Imperial College and promoted to Reader in 2003. He became a Professor at Leeds in 2004 and at NUS in 2007. He has held visiting professorships in Vienna and at Perimeter Institute in Canada. Vlatko has written 2 textbooks: on Quantum Optics and Quantum Information and has published more than 140 research papers in quantum mechanics and quantum information.

Assoc. Prof. KWEK Leong Chuan

Born and bred in Singapore, Kwek completed his undergraduate degrees in New Zealand under a Colombo Plan scholarship. After his return to Singapore, he served his government bond as a teacher for eight years before pursuing his doctoral degree at the National University of Singapore. He completed his PhD on condensed matter and integrable models in 1999 and, one year later, joined the National Institute of Education at the Nanyang Technological University. He is primarily responsible for initiating research in quantum information science in Singapore and the formation of the CQT. His current research interests include the foundations of quantum theory and distributed quantum computing. (National Science Award 2006)

Quantum Optics

Assoc. Prof. Christian KURTSIEFER

In 1997, after completing his doctorate in experimental physics in Konstanz, Germany, Christian joined IBM Almaden Research Center in California, where he worked on an ion trap experiment. Between 1999 and 2003, while a research staff at the at Ludwigs-Maximilians-Universität München, he focused mostly on quantum optical experiments, constructing one of the best sources of entangled photons. He joined NUS in 2003, as an Associate Professor, and CQT in 2007. He is chiefly responsible for the development of experimental quantum optics in Singapore. (National Science Award 2008).

Asst. Prof. Anti LAMAS-LINARES

Originally from Galicia, in northern Spain, Antia studied optics at Imperial College, London and University of Oxford, with a clear temptation to control photons at the quantum level. She demonstrated that entangled photons can be generated in the process of stimulated emission. In 2003, after she was awarded her doctoral degree from Oxford, and spending some time at the University of California in Santa Barbara, she joined NUS as an Assistant Professor . Her current research interests involve quantum communication, cryptography and the foundations of quantum physics. (National Science Award 2008).

Assoc. Prof. Valerio SCARANI

Valerio, our European polyglot, received his PhD in 2000 from Ecole Polytechnique Federale de Lausanne (Switzerland), with experimental work in nanoscience. He then moved to the Group of Applied Physics of the University of Geneva, working as a theorist in the group of Nicolas Gisin. In 2007 he moved to NUS. His main research topics are quantum cryptography and quantum correlations. He is also an author of a popular book on quantum physics and is leading CQT outreach activities. (National Science Award 2008)

Microtraps

Asst. Prof. Murray BARRETT

Born and educated in Otago, New Zeeland, Murray, started experimenting with cold atoms and trapped ions while working on his Ph.D. at the Georgia Institute of Technology, in US. In 2002, after completing his doctoral project, he moved to NIST in Boulder, Colorado, where, among other things, he demonstrated quantum teleportation of atomic qubits. He joined NUS as an Assistant Professor in 2006 and CQT in 2007. His current research interest involve atom and ion cavity electrodynamics.

Computer Science

Prof. Miklos SANTHA

Born and educated in Budapest, Hungary, Miklos moved to France in 1980 and received his Ph.D. in Mathematics from the Université Paris 7 in 1983. To satisfy his growing interest in Computer Science, he spent two years at the University of California in Berkeley, and then obtained a Doctorat d'Etat in this field from the Université Paris-Sud, Orsay in 1988. In 1988 he also joined the Centre National de la Recherche Scientifique where he is a senior researcher in Computer Science. He works in the Laboratoire de Recherche en Informatique at Orsay where he is the head of the Algorithms and Complexity Division. He was a Humboldt Fellow in the Max Planck Institute in Saarbrücken from 1990 to 1991. Since 2008 he is also a Visiting Research Professor at NUS, in charge of building up the Computer Science component at CQT. His research interests include quantum computing, randomized algorithms and complexity theory.

Asst. Prof. Rahul JAIN

Rahul obtained his PhD in Computer Science from Tata Institute of Fundamental Research, Mumbai, India in 2003. He was a post doctoral fellow for two years at University of California at Berkeley, USA (2004-2006) and for two years at Institute for Quantum Computing (IQC), University of Waterloo, Canada (2006-2008). In 2008, he joined NUS as Assistant Prof. in the Computer Science Department with cross appointment with CQT. His research interests are in the areas of Information Theory, Quantum Computation, Cryptography, Communication Complexity and Computational Complexity Theory.

Visiting Appointments

Visiting Research Assoc. Prof. Simon BENJAMIN
University of Oxford, United Kingdom

Visiting Research Assoc. Prof. Benoit GREMAUD
CNRS, Jussieu, France

Visiting Research Prof. Christian MINIATURA
CNRS, Nice, France

Visiting Scholar Charles W. CLARK
National Imstitute of Standards and Technology, Gaithersburg, United States

Visiting Research Assoc. Prof. Dieter Hans JAKSCH
University of Oxford, United Kingdom

Research Staff

Research Fellows

Cedric BENY
CHEN Lin
CHEN Qing
FENG Xun-Li
Ilja GERHARDT
Amir KALEV
Timothy LIEW
Gleb MASLENNIKOV
Tomasz PATEREK
Philippe RAYNAL
Wonmin SON
SUN Hui
TEY Meng Khoon
WU Chunfeng
YU Sixia
ZHANG Qi
ZHANG Xiaolong

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CHENG Mei Yuen Brenda
CHUAH Boon Leng
Aarthi Lavanya DHANAPAUL
FANG Yiyuan Bess
Libby HEANEY
Caleb HO
Andreas KEIL
Ravishankar RAMANATHAN
Arpan ROY

Artur and Evon and complexity of logistics

Administration

Artur EKERT
Director

LAI Choy Heng
Deputy Director

Kuldip SINGH
Administrative Director

CHAN Chui Theng
Administrative Manager

TAN Hui Min Evon
Administrative Executive

Building & Infrastructure

CHU Siang Yian, Alan
Facilities Manager

Jessie HO
Facilities Executive

Centre Support

GAN Eng Swee
Laboratory Technologist

Mohammad IMRAN
Technical Support Specialist

Finance and Procurement

CHAN Hean Boon Thomas
Finance Manager

CHIN Pei Pei
Procurement Manager

TAN Lay Hua
Finance Executive

Mashitah Bte Mohammad MOASI
Procurement Executive

Human Resource

Valerie HOON
Human Resource Manager

TAN Ai Leng Irene
Human Resource Executive

IT Support

Darwin GOSAL
IT Manager

Arthur TADENA
Systems Engineer

Library

FANG Yiyuan Bess
Librarian

Calender of Events

Colloquia

Date	Speaker	Affiliation	Title
10.1.2008	Nicolas Gisin	University of Geneva, Switzerland	Quantum Teleportation and Nonlocality
28.2.2008	Nobuyuki Imoto	Osaka University, Japan	Implementation of Basic Quantum Information Processing
27.3.2008	Hans Briegel	Universität Innsbruck, Austria	New Developments in Measurement Based Quantum Computation
17.4.2008	Scott Parkins	University of Auckland, New Zealand	Cavity QED: Quantum Control with Single Atoms and Single Photons
29.5.2008	Howard Carmichael	University of Auckland, New Zealand	Open Quantum Systems, Entanglement, and the Laser Quantum State
17.7.2008	Rosario Fazio	Scuola Normale Superiore, Italy	Quantum Phase Transitions in Arrays of Coupled QED Cavities
28.8.2008	Dieter Jaksch	Oxford University, UK	Optical Lattice Immersions for Direct Quantum Simulations
210.2008	Kazimierz Rzazewski	Center for Theoretical Physics of the Polish Academy of Science	Bose-Einstein Condensation, Classical Fields and Decaying Vortices
2.12.2008	Alain Aspect	Institut d'Optique, France	From Einstein Intuitions to Quantum Bits: A New Quantum Age?
2.12.2008	Jun Ye	Univesity of Colorado, USA	Precision Quantum Metrology
3.12.2008	Philippe Grangier	Institut d'Optique, France	Schrödinger's cats and kittens : new tools for quantum communications

CQT Colloquia were initiated in January 2008. The talks, although broadly in the area of quantum science, are aimed to be of general interest. We hosted eleven prominent researchers from Europe, America, Japan and Australia, who covered topics from quantum teleportation to precision quantum metrology and managed to attract a significant number of students from NUS and local schools.

Colloquia series fueled by Spinelli

COFFEE COMPANY SPINELLI SAN FRANCISCO ™

Fuel for Thought

Participants of the Workshop on Quantum Algorithms and Complexity Theory held at the Centre for Quantum Technologies from the 17th to 21st November 2008

Conferences and Workshops

Start Date	End Date	Title	Focus
28.7.2008	21.9.2008	Mathematical Horizons for Quantum Physics	Operator Theory and Operator Algebra Theory form the mathematical basis of Quantum Physics and provide the indispensable mathematical language for theoretical studies in Quantum Physics. Not only are they used in Quantum Physics as powerful tools, but also they are often directly influenced by problems which arise in Quantum Physics. Thus, the unifying mathematical theme of the Programme is Non-Commutative Analysis.
17.11.2008	21.11.2008	Workshop on Quantum Algorithms and Complexity Theory	The objective of this workshop is to give the opportunity to a few outstanding researchers to share their knowledge about the latest developments in the field of quantum algorithms and complexity theory.
4.12.2008	6.12.2008	Workshop on Quantum Cryptography with Finite Resources	The workshop brought together theorists and experimentalists involved in practical quantum cryptography. Discussion was on how to derive security bounds for keys of finite length and to promote the implementations of these bounds in experiments, prototypes and commercial systems.

Antia Lamas-Linares (left), Christian Kurtsiefer (second from right), and Valerio Scarani (right) receiving a National Science award from Mr Lim Hng Kiang, Minister for Trade and Industry.

CQT Symposium - One Year On

Senior researchers, school kids, professionals and all those who are just curious about the weird quantum reality packed the auditorium of the University Hall, to listen to Alain Aspect, Jun Ye and Philippe Grangier. The three eminent researchers shared their perspective on quantum theory and its applications. The event marked the first anniversary of our existence.

Talks by Visiting Researchers

Date	Speaker	Affiliation	Title
24.1.08	Vladimır Buzek	Slovak Academy of Sciences	Quantum infodynamics
5.2.08	Huzihiro Araki	Kyoto	Dynamics and Potential
14.2.08	Erik Gauger	Oxford University	Adiabatic Control of Solid State Spin Qubits
21.2.08	Mariusz Gajda	Inst. of Physics Polish Academy of Sciences	Resonant Einstein-de Haas effect in a rubidium condensate
5.3.08	Amir Kalev	Technion, Israel	The No-Broadcasting Theorem and its Classical Counterpart
6.3.08	Tomasz Paterek	Austrian Academy of Sciences	Experimentally friendly geometrical entanglement criteria
1.4.08	Alok Pan	Bose Institute	Observability of arrival time distribution and empirical testability of the Bohmian Model
3.4.08	Lin Chen	Zhejiang University	Rank three entangled states are distillable
8.4.08	Karoline Wiesner	University of Bristol	Intrinsic Quantum Computation
10.4.08	Cedric Beny	University of Waterloo	Unsharp Quantum Information: Correction and Broadcasting
16.4.08	Rahul Jain	University of Waterloo	Information Theoretic Methods In Communication Complexity and Cryptography
22.4.08	Blair Blakie	University of Otago	The ultra-cold Bose pancake
24.4.08	Lluis Masanes	University of Bristol	No-signaling key distribution
12.6.08	Sean Barrett	Imperial College London	Scalable quantum computing with atomic ensembles
19.6.08	Sean Barrett	Imperial College London	Phase transitions in the computational power of a many-body system
20.6.08	David Hutchinson	Otago University	Disorder in ultra-cold gases: the quest for Anderson localisation
25.6.08	Timothy Liew	University of Southampton	Early steps toward the use of Exciton-polaritons for computation

15.7.08	Andreas Wallraff	ETH Zurich	Cavity Quantum Electrodynamics in Electronic Circuits: Quantum Optics Experiments with Single and Multiple Photons
16.7.08	Dimitris Angelakis	Technical University of Crete, Chania, Greece	The story of coupled cavity arrays and quantum simulations: A realistic alternative to optical lattices/ion traps
22.7.08	Madalin Guta	University of Nottingham	Local asymptotic normality in Quantum Statistics
24.7.08	Luigi Amico	University of Catania	Quantum Many particle systems in ring-shaped optical lattices
31.7.08	Tony Leggett	University of Illinois at Urbana-Champaign	Some thoughts about zero modes and topological quantum computing in (p+ip) Fermi superfluids
5.8.08	Hugo Cable	Louisiana State University	Linear Optical Quantum Information Processing, Imaging and Sensing, via N00N states
6.8.08	Stefano Pironio	Institut de Ciències Fotòniques	Semidefinite programming relaxations for polynomial optimization with non-commutative variables
7.8.08	Elicia Kioseva	University of Sofia	Entangling distant quantum dots with classical interference
7.8.08	Kavan Modi	University of Texas at Austin	The role of state preparation in quantum process tomography
12.8.08	Oleg Gittsovich	Institut für Quantenoptik und Quanteninformation	Covariance Matrix Criterion for Separability
14.8.08	Man Hong Yung	University of Illinois at Urbana-Champaign	Robustness of Adiabatic Quantum Computation against Thermal Noise
28.8.08	Dieter Jaksch	Oxford University	Optical Lattice Immersions for Direct Quantum Simulations
2.9.08	Mile Gu	University of Queensland	More Really is Different
9.9.08	Seng-Tiong Ho	Northwestern University	Nanophotonic Devices for Potential Atomic Physics Applications
17.9.08	Kai Dieckmann	Max-Planck Institute	Ultracold Quantum Gases
30.9.08	Bjorn Hessmo	Technical University of Vienna	Atom detectors and Photon statistics
7.10.08	Chris Ogden	Queen's University	Distributed Quantum Information Processing in a Coupled Cavity System
9.10.08	Joonwoo Bae	KIAS	Structural approximations to positive maps and entanglement breaking channels
23.10.08	Mark Wilde	University of Southern California	Closed Timelike Curves Enable Perfect State Distinguishability
4.11.08	Guido Burkard	University of Constance	Spin Qubits in Graphene
11.11.08	Mark Wilde	University of Southern California	Entanglement-Assisted Quantum Error Correction
17.11.08	Florian Schreck	Institut für Quantenoptik und Quanteninformation	Exploring an ultracold Fermi-Fermi mixture: Interspecies Feshbach resonances and scattering properties of 6Li and 40K
24.11.08	Charles Clark	University of Maryland	Relativity at a billionth of the speed of light
9.12.08	Francesco Ciccarello	University of Palermo	Entanglement & Scattering Dynamics in a quantum Fabry-Perot interferometer

Other Events

Date	Events
10.7.2008	Governing Board Meeting
Aug 2008	Quantum Roadtrip
21.8.2008	National Science Award 2008
8-14.9.2008	Scientific Advisory Board Visit
2-3.12.2008	CQT Symposium -One Year On

Scientific Advisory Board at CQT. No meeting in Singapore would be complete without food.Oh Choo Hiap (left) and Umesh Vazirani (right).

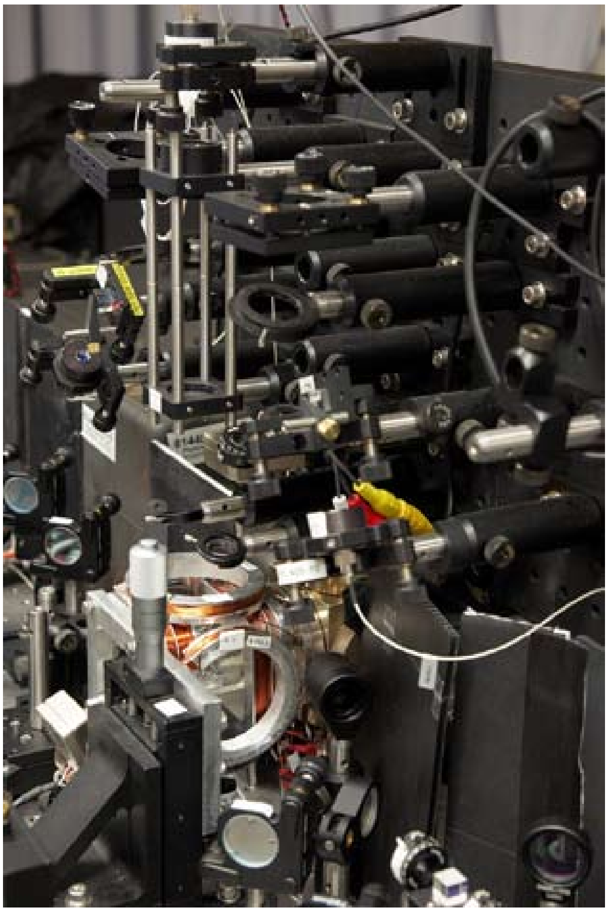
Research Directions*

The Centre for Quantum Technologies (CQT) started its activities in January 2008, focusing on combining theoretical and experimental research in Quantum Information Science (QIS).

* Adapted from the Scientific Advisary Board report, September 2008

Overview

Research activities at the CQT spans both theory and experiment. The CQT has two theory research groups, the Interdisciplinary Theory Group looking at quantum physics and its applications, and the Computer Science Group which studies quantum computation. There are two experimental groups: the Quantum Optics Group, which also has a theory component, and the Microtraps Group, focused on trapping and manipulating atoms and ions. A third experimental group in cold atoms physics is being established.



Scattering of light from a single trapped atom

A major event after the establishment of the CQT was the move to its new location, a renovated building with modern infrastructures especially suited for theoretical and experimental work in quantum information science (QIS). The efficiently planned and executed move saw many of its experimental activities running at full speed in a short span of time.

Researchwise, the CQT has published some 30 papers in top journals, (such as Nature, Nature Physics, Physical Review Letters) along with 20 preprints on electronic archives. In theoretical activities in particular, where the time to obtain results is much shorter than in experimental ones, these numbers clearly indicate that the CQT is poised to compete with similar leading centres around the world. More importantly, the quality of research speaks for itself. For example, showing that a longstanding conjecture regarding the additivity of the minimum output Renyi entropies of quantum channels is false is a real breakthrough in the field. Another remarkable experimental achievement was the observation of violations of Leggett's inequalities, a work with a very high international impact. This work was later awarded the National Science Award of Singapore.

Other awards and distinctions include Christian Kurtsiefer's election as a fellow of the American Physical Society, and Antia Lamas-Linares receiving the NUS Young Scientist Award. Berge Englert was named by the American Physical Society in their Outstanding Referee Recognition 2008. Artur Ekert was awarded the Royal Society 2007 Hughes Medal, putting him in the same league as previous winners Alexander Graham Bell and Stephen Hawking, and his 1991 paper on quantum cryptography was selected as one of the milestone letters by Physical Review Letters. Milestone Letters are papers published in Physical Review Letters that made long-lived contributions to physics, either by announcing significant discoveries, or by initiating new areas of research.

The first CQT Workshop on Quantum Algorithms and Complexity Theory, organised by Miklos Santha and Rahul Jain, brought to SIngapore leading experts in the field of quantum computation.

Computer Science

A major expansion of research activities is currently underway in the area of Computer Science. This was initiated by the appointment of Prof. Miklos Santha (CNRS, Université Paris-Sud, Orsay, France) on a part-time basis, and he has been leading the effort to establish a high-quality critical mass of expertise in quantum computer science. Miklos is a world renowned researcher in both classical and quantum algorithms and complexity theory, and is the leader of an excellent group in Paris. He organized a small workshop at CQT in quantum algorithms and complexity in November 2008. This drew many leading researchers in the field from around the world. CQT has also hired Dr. Rahul Jain jointly with the Computer Science department. Rahul is one of the top young stars in quantum communication complexity and related areas. Furthermore, two new members with expertise in Quantum Computer Science (M. Mosca and U. Vazirani) have joined CQT's Scientific Advisory Board (SAB). Further expansions are in the book. CQT is actively looking into recruiting additional star researchers as faculty, especially in the core area of quantum algorithms and complexity theory. The plan also calls for the strategic use of an active visitor program, conferences and workshops, and part-time appointments, in order to establish a vibrant and attractive environment for researchers in quantum computer science.

We anticipate further collaborations between the members of CQT as the experience of this year has shown, they can lead to innovative ideas and original experimental results.

Interdisciplinary Theory

The research carried out during the last months can be divided into two parts. The first one concentrates in the development of an abstract theory of QIS, addressing fundamental questions of general interest in the field. The second one is mainly motivated by experiments, and deals with specific set-ups where one could observe intriguing quantum phenomena, or build specific parts of quantum information processors.

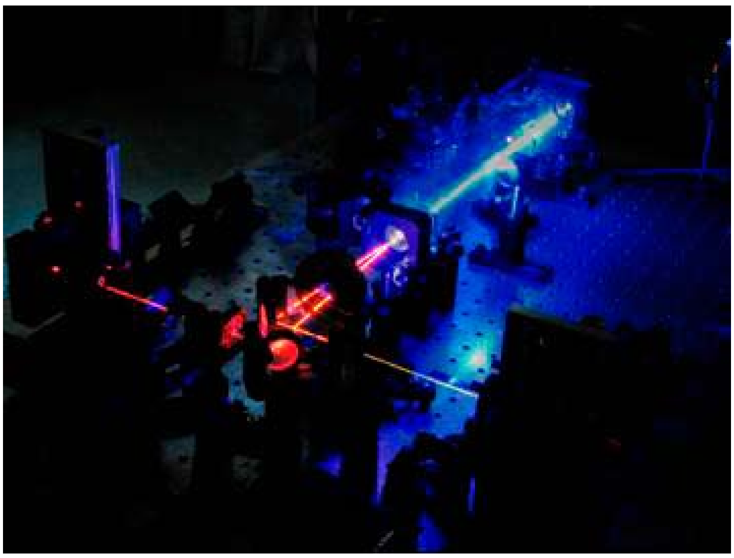
In the first category, there have been several important highlights. For example, a very important and longstanding question regarding the additivity of the minimum output Renyi entropies of quantum channels has been established. In the field of Quantum Information Theory, this can be considered as one of the most important discoveries of the last few years. In the second category, the strong collaboration between the theoretical and experimental quantum optics groups has given rise to the observation of the violation of Leggett´s inequality mentioned above (see the article by Prof. Scarani which gives a personal view of its discovery). Apart from that, the security of quantum cryptographic protocols which use finite keys has been very thoroughly studied, giving rise to new bounds on the tolerable error rates.

For the next period, the theory activities will be extended with new projects which will broaden the research activities, and will incorporate the investigation of new fundamental questions as well as new experimental set-ups., for example the cold fermion project lead by Berge Englert on the theory side, and the new hires, Kai Dieckmann and Wenhui Li, on the experimental side. We anticipate further collaborations between the members of CQT as the experience of this year has shown, they can lead to innovative ideas and original experimental results. Collaborations with visitors and other scientists in foreign institutions will certainly enrich the current theoretical activities at the centre.

Quantum Optics

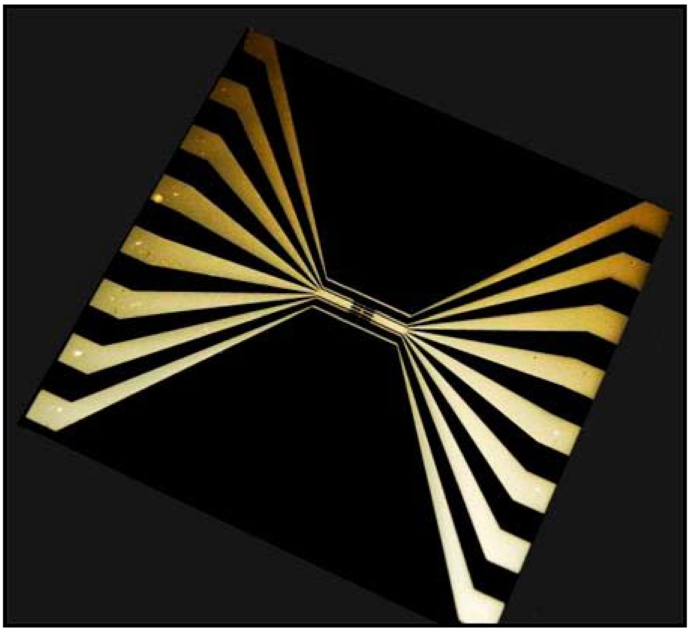
The Quantum Optics Group headed by Christian Kurtsiefer and Antia Lamas-Linares have demonstrated some notable results. The main highlight has been the experimental test of Leggett´s non-local hidden variable model. Given the continued high interest in performing tests of local realism and non-locality in different contexts this experiment has received significant attention in the international community and resulted in a National Science award.

There has been continued work on quantum cryptography. A system using entangled photons distributed over a free space channel (about 1km) was demonstrated with very low error rate. The system was exposed to the scrutiny of the computer hacking community at two conferences, 24C3 in Berlin, and Black Hat/DEFCON16 in Las Vegas.



Source of entangled photons.

The single atom experiment by the Quantum Optics group of CQT demonstrates that a propagating light field can be strongly coupled to a single atom by just focusing it with usual lenses. In a vacuum chamber individual atoms Rubidium are trapped into an area no wider than a few 10s of nanometres. The trap itself is set between two aspheric lenses which focus a beam of light down to a spot centred on the trapped atom. Under this arrangement the atom collides with around 10% of the photons, despite the fact the rubidium atom is just a fraction of a nanometre across - much smaller than the width of the focused light. With better quality lenses it should be possible to raise that 10% figure to somewhere approaching 100%. This system may be used to reliably transfer quantum information between light and matter. Currently, there is interest from other groups that pur-



Magnetic atom chip for trapping, moving and manipulating cold atoms

sue closely related work. For example, the University of Erlangen has a very similar project, whose goal is to "reverse spontaneous emission" with a single photon incident on a single atomic ion. The CQT quantum optics group, which currently has the lead in this area, will address this, and other directions of research. The single atom experiment is not working yet at full capacity but the experimental results are very encouraging and the experiment is entering an exciting stage (10% light scattering of a single photon is very remarkable already). Current plans include building a narrow band squeezed source and to study its interaction with an atomic ensemble at room temperature. The experiment is already built, and initial results can be expected in the next year.

Atoms Chips and Cavity QED

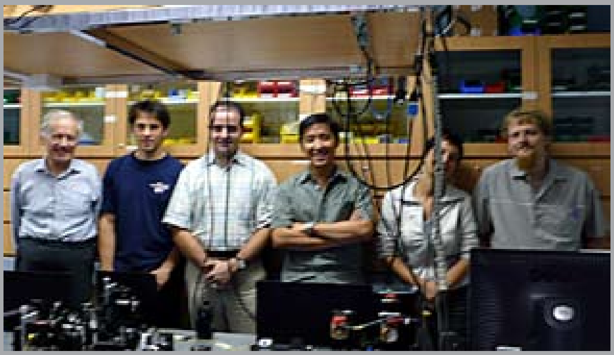
The Microtrap Group headed by Murray Barrett has initiated new experiments into ion traps. The planar configuration of the trap has a novel geometry which should shield the trapped Barium ions from charges on insulating surfaces in the vicinity of the trapping region. By this means, heating problems, which have been an important issue for all ion trapping experiments so far, may be studied and potentially suppressed. The laser systems have been installed and their operation is being fine-tuned.

Another project in the preparatory stages is cavity QED. The group is working on creating small, high quality cavities in which laser trapped atoms will be suspended. A related effort to create micro-toroid resonators has had less success and its contination will be reviewed. The originally planned project for constructing atom chips is progressing well. Several prototypes have been constructed and exposed to vacuum to test. This will allow the creation and manipulation of Bose-Einstein condensates via magnetic fields just above the surface of a micro-fabricated device.

New Hires

There has been considerable effort to hire new researchers to lead a new group in cold atom physics, Kai Dieckmann (as Assoc. Prof) and Wenhui Li (as Asst. Prof). Kai Dieckmann is an Assistant in the group of Ted Hänsch at the Ludwig-Maximilians-Universität Munich, Germany, and is responsible for the cold atom activities there. He has recently been able to trap and cool to degeneracy three atomic species in a magnetic trap, namely Lithium (Li), Potassium (K), and Rubidium (Rb). The Rubidium Bose condensate may be used to cool the other two atomic gases which are fermions. From this, Li-K molecules may be formed. This experiment will be continued at the CQT. Wenhui comes to the CQT from the group of Randy Hulet at Rice Universoty in Texas, USA. Kai and Wenhui will also be examining Fermions in a 2D hexagonal optical lattice. Theoretical support for this experiment will be provided by the group led by Berge Englert. This experiment will involve particpation of researchers from the French Centre national de la recherche scientifique (CNRS).

Lab Notes



Prof. Valerio Scarani gives a personal account of the story behind the notable achievement of the CQT in the experimental falsification of the Leggett Inequalities.

This story is about physics – quantum physics, to make it worse. Fortunately for me and you, the reader, it was not physics "in cold blood": there was the sudden discovery, working around the clock, headaches, success, a zest of polemics... Oh, nothing Homer would have made great fuzz about: rather the kind of situations that Anthony Powell would pick.

Tony's Way

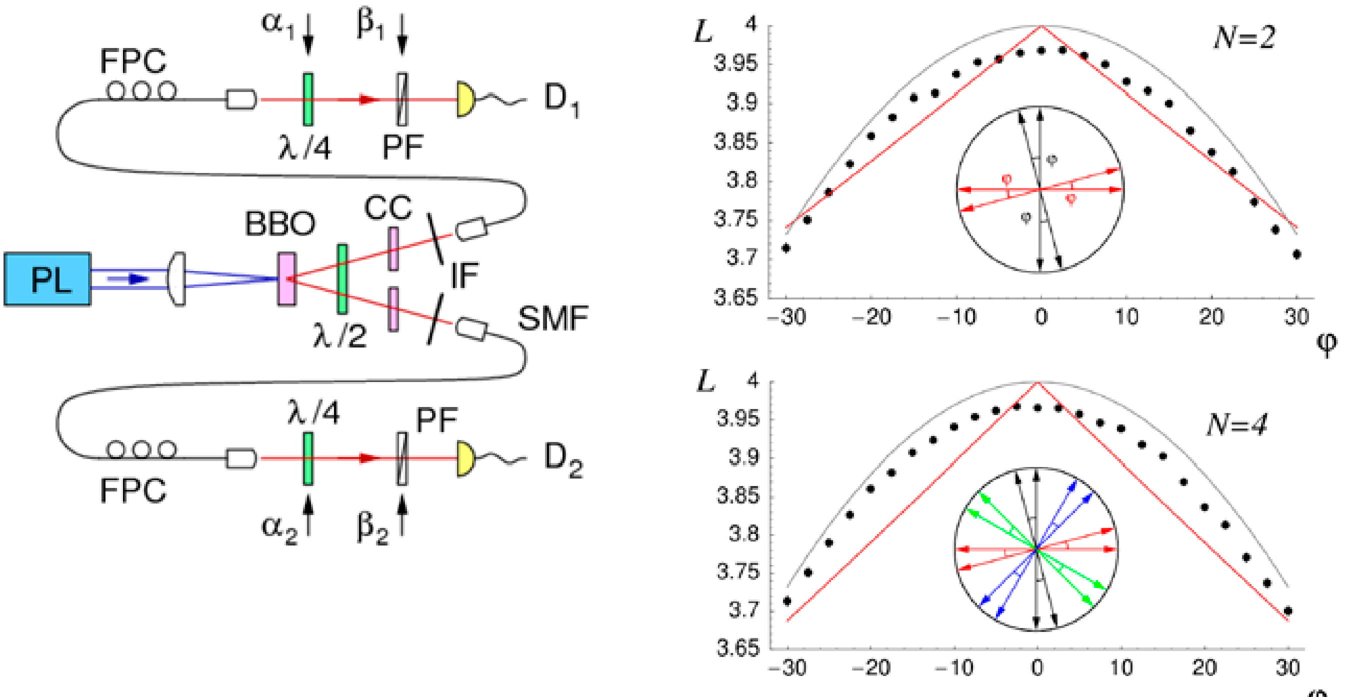
It all starts with Anthony Leggett, 2003 Nobel-Prize winner in physics. Tony, as he wants to be called, is a regular visitor to NUS. Among the people with which he interacts during his visits are Christian Kurtsiefer and Antia Lamas-Linares, who have set up a laboratory of quantum optics (dealing with lasers and more exotic forms of light). In one of his visits, he mentioned to Christian and Antia that he was working on a "non-local variable model". What is this? Well, quantum theory predicts some very counter-intuitive features for the behavior of atoms, molecules etc. In order to show that these features are not a fantasy of some theorists, that nature is really weird, some physicists invent alternative models that seem "more reasonable", then set out to prove that experimental data are at odds with them. At this point, you should be able to read again the buzzwords that appear at the beginning of this piece and understand roughly what is at stake: performing an observation that would "falsify" (rule out) the "reasonable" model proposed by Leggett and thus confirm that our physical world indeed exhibits unexpected features, as predicted by quantum physics. This is the story of how this happened.

(You may be tempted to stop reading here, but remember that, even if you don't care about atoms, there are some human adventures coming up).

We left Christian and Antia listening to Leggett: they were familiar with the famous "local variable model" proposed by John S Bell in 1964, falsified first in 1982 and many times since. Apparently, the study of Leggett's model would require sources of light of much higher quality than those used in previous experiments. Now, the NUS people were building precisely such a high-quality source. There was only one other laboratory in the world which possessed sources of the required quality: the one directed by Anton Zeilinger at the University of Vienna. The odds of history decreed that Leggett had met Zeilinger shortly after his model was finally completed. The Vienna group started to set the experiment up.

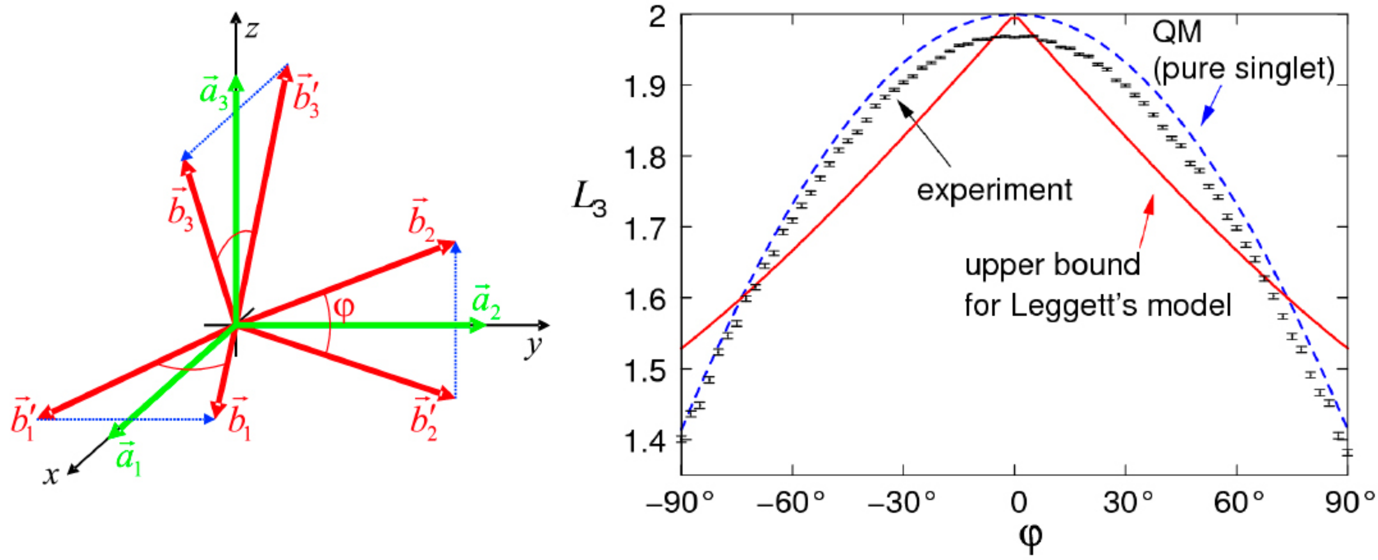
Secret Experiment

At that time, I was based in Geneva. In spring 2004, I was invited to visit the Vienna group. During my stay, Markus Aspelmeyer and Caslav Brukner, the senior scientists in charge of the project, told me that they were working on a non-local variable model – my curiosity was triggered – "of which unfortunately we cannot tell you more for the moment". This attitude may surprise the reader: is not the scientific endeavor a disinterested quest for knowledge and wisdom? Indeed it is, but human beings are in charge of it; as in all of society, most of them are indeed trustworthy but... well, not all. You have to decide how to cope with this



C. Branciard, A. Ling, N. Gisin, C.K. A.Lamas-Linares, V.Scarani, PRL **99**, 210407 (2007)

Leggett Inequality Experimental Set-Up



Leggett Inequality Simplified Test

fact. Markus and Caslav, at least in that occasion, had opted for a circumspect attitude: I respected their choice and stopped inquiring.

Years passed. In April 2007, I joined NUS and the same group as Antia and Christian. The high quality light source was fully operational; Alex Ling was using it for the experiments which were to earn him a Ph.D. In the very same week of my arrival, the report of the experiment performed in Vienna was published in Nature. Though the introduction is a bit boastful, overall it is a remarkable piece of experimental work supported by solid mathematics – this was my conclusion after a rapid reading: I had to settle down in my new country and job, so I planned to study again this work when a moment of calm would come.

Breakthrough

I was admittedly naïve: as you all know, there is never a moment of calm for someone who works in Singapore – but for someone who visits, that's another matter. In July, Cyril Branciard, a former student of mine in Geneva, came to spend three weeks in NUS. After he had finished a tough piece of work, I suggested that he read the report of the Vienna experiment. One day later, Cyril came to see me and said: "There is a problem in the Vienna paper – and I know how to correct it". What had happened? Remember that the goal is to check that nature is really weird. The criterion that Leggett had proposed to perform the test and that had been used in Vienna requires the experimentalists to perform infinitely many measurements – obviously impossible. To circumvent the problem, the Viennese had performed a few measurements and made an assumption about all the measurement that they could have, but did not perform. The assumption was explicitly mentioned in the text, which is therefore honest and scientifically accurate – but it still meant that the Leggett model had not been conclusively falsified. What Cyril discovered is that the measurements performed in Vienna were definitely not sufficient to support their conclusion: their experimental data, without the additional assumption, could be explicitly reproduced by Leggett's model. In addition, Cyril had found the critical step in the mathematics and had been able to rectify it: now we had a new criterion that could be tested with only seven measurements instead of infinitely many! Christian and Antia immediately realized that they had everything to perform the experiment, and with Alex they set out to work. But the pace of events accelerated.

The Race Is On

Tony Leggett was in Singapore for precisely those days so we went and talked to him. He appreciated our work, confirmed that the Vienna group was indeed aware of the weak point of their first experiment – so much so that they were studying how to remove it! You can imagine my train of thoughts: Cyril, no doubt, is smart; but if he has found a solution in one day, that solution is not so hard to find after all... so maybe in Vienna they are working on the same idea as us! When one realizes this, one can rush to the lab and computers to finish as fast as possible in order to win the race; but we decided to switch from a competitive mood to a friendly mood – in short, call Vienna. We caught them by surprise: they had indeed had a similar idea, but had postponed the experiment after the summer holidays. We came to an agreement: we don't write a common report, but we coordinate the posting of our reports on the internet on the same day, scheduled for two weeks later. In Austria, Markus rushed to find who was left in the laboratories; in Singapore, we had almost finished and prepared to relax – or so we thought.

Potholes in the Road of Science

The measurement of the Leggett criterion is quite demanding from the technical point of view. Not only does it require a high quality source, as mentioned above: it also requires checking assumptions and details that one normally takes for granted. Alex and Christian started these verifications almost out of perfectionism and suddenly found that something was going wrong – seriously wrong when they multiplied the verifications. The exact issue does not concern us; it is enough for you to know that days passed: the night before the scheduled joint Singapore-Vienna submission to the internet, our experiment still refused to behave as it should. I am useless in a lab, so went home, praying that Christian, Antia and Alex find a way out (not that a miracle was needed in the technical sense, this is just about science – but I felt I could pray that my colleagues keep the necessary lucidity, even after two tiring weeks of work around the clock). The next morning, I rushed to open the internet: our report was there, with excellent experimental results: they had fixed the problems! The report of the Viennese was also there, as planned. We celebrated these events by having a picture of us with Tony Leggett taken in front of the experiment; but since Murphy's law must be obeyed even in the middle of success, the flash did not flash, the exposure time was too long and all the pictures came out blurred (as can be seen on the first page of this article). Cyril and Tony left the same day before we realized this, so no photo.

Epilogue

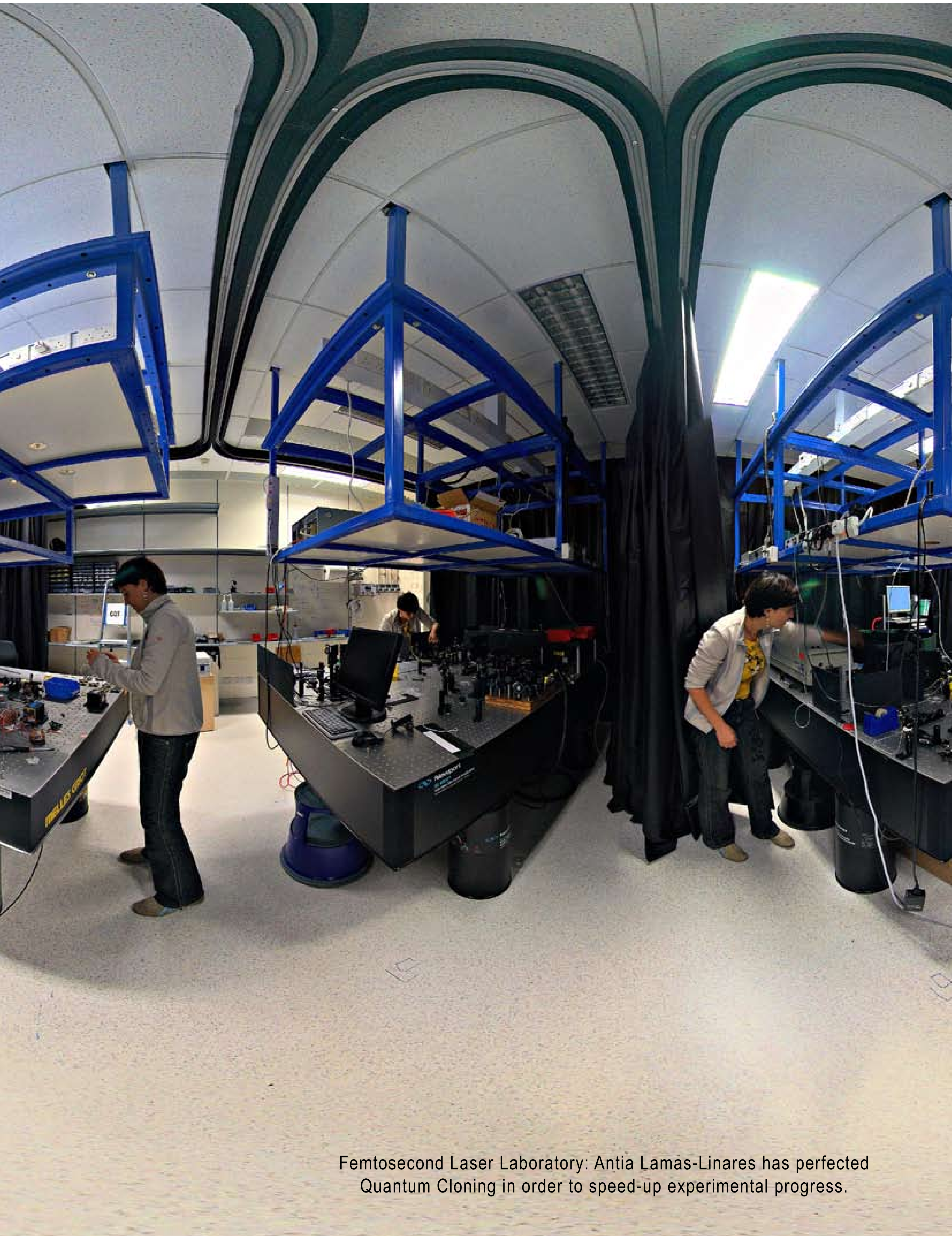
And so ended those two intense weeks of July 2007, in which we were able to provide the first conclusive falsification of the Leggett model, i.e. a confirmation of the counter-intuitive weirdness of nature. Of course, the story goes on. The two reports were published together in a prestigious journal. Cyril continued elaborating on the mathematics back in Geneva and, with the help of Nicolas Gisin and Nicolas Brunner, found a much more elegant approach; this triggered another experiment in Singapore, and an even more prestigious common publication. The relations with Vienna did suffer some tension because of the way each one quoted the work of the others, but peace reigns again and Tomasz Paterek, one of the members of the Vienna team, is joining NUS soon as a research fellow. Alex has finished his Ph.D. and is currently working in the United States. Christian and Antia have just come back from their latest challenge: they have shipped to Las Vegas another of their setups ("quantum cryptography", a technique to send secret messages using photons) and have operated it first in an international meeting of hackers, then across the Grand Canyon. As for myself…

Leggett's model and the weirdness of nature

Think at two opposite arrows. You picture one arrow pointing in a well-defined direction, and another arrow, also pointing in a well-defined direction – and the two directions happen to be opposite. In the 1930s, physicists realized that quantum physics allowed for a weirder situation: two "quantum arrows" (spins) can be such that none has a well-defined direction, and yet when observed they are always found to be opposite. You cannot picture this situation with everyday's arrows.

So much for the theory, but is this real? Is this not just a convenient mathematical formulation of a much simpler situation, namely, that each arrow always has a well-defined direction independent of the other arrow and we just don't know which it is? In 1964, John Bell proved that one can test this "reasonable" model in an experiment. The conclusive experiment was realized in 1982 by Aspect in Orsay (close to Paris): the reasonable model is falsified. The two arrows must be somehow connected even when they are distant from one another, as quantum physics predicted. Many other experiments have confirmed this conclusion since –also by some of the protagonists of our story: Zeilinger, Gisin, and more recently the NUS group.

Leggett's model is, in a sense, the "next reasonable" one after the one studied by Bell. It admits the existence of some connection at a distance (as we have just seen, you cannot avoid this) but tries to save the fact that each arrow may still keep well-defined individual properties, possibly unknown to us. The falsification of this model implies the existence in nature of arrows whose individual directions are not defined, and yet are always perfectly opposite – more generally, the existence of well-defined properties for composite systems that do not derive from well-defined properties of each of the components.



Femtosecond Laser Laboratory: Antia Lamas-Linares has perfected Quantum Cloning in order to speed-up experimental progress.

Quantum Roadtrip

The Quantum Optics group tested their quantum cryptography against the toughest adversaries in the world, delegates at the hacker conferences, Blackhat/DEFCON16 in Las Vegas. Assistant Professor Antia Lamas-Linares relates the group's roadtrip across the US including a stop-over at the Grand Canyon...

A team from the quantum optics group recently took their quantum key distribution system quite literally into the "wilderness". It started with an invitation from our friends at NIST to do a joint exhibition of QKD systems at the two largest computer security (a.k.a. hackers) conferences in the world: Black Hat (for the corporate types) and DEFCON (for the alternative version) in Las Vegas. The CQT team had done this before in the European hacking scene (24c3) so it was possible. The decision to go ahead generated a flurry of activity to get the system ready, packaged, and sent, as well as some modifications for an additional crazy idea ...

Experimental quantum key distribution system demonstrated at the Black Hat conference

Black Hat

On the 4th of August Antia and Christian set out for Vegas from Singapore, while Ilja flew from Zurich. We all met at Caesar's Palace and found out that our equipment had been retained in customs for "fumigation". The day before the conference, our equipment finally arrives. We need to make sure it survived, realign all the optics, and get all the bits and pieces to work together, including the new stars of the show, a pair of OLPCs which will run the whole protocol. At 4:30 am, just a few hours before the conference attendees flow into the exhibition floor, the system is finally ready and producing quantum generated key at Black Hat!

DEFCON

Two full days of explanations later, it is time to pack up and move to a different hotel. We are now going for DEFCON, the real hackers conference. No photos of people are allowed and the conference badge is a printed circuit board ... need I say more? Another crazy night of setting up, but again, the equipment survives the move. Two more days of explanations with little sleep follow. In the mean time Christian flies off to give a lecture in Waterloo (Canada); fittingly it is about "Practical Quantum Cryptography". Ilja and Antia pack up and move the equipment to yet another hotel for the last leg of the adventure.

Grand Canyon

As it turns out Las Vegas is near grand Canyon, and what a better place to prove that QKD can be done anywhere, and that entanglement sources can be robust? We buy camping supplies and lots of batteries and contact again the people from the National Park Service at Grand Canyon. Our little "addition" to the hackers conference can go ahead. Alessandro from the NIST team joins us and Caleb and Matt fly in from Waterloo where they were attending the workshop on quantum crypto. We hire two cars and off we go for the Grand Canyon.

Left-Right: M. Peloso, A. Restelli (NIST), C. Kurtsiefer, A. Lamas-Linares, I. Gerhardt & C. Ho at the Grand Canyon.

Sending Station "Alice". A source produces a pair of photons which are entangled in their polarization. One photon is kept at Alice's side and measured, the other is sent to Bob.

We set up initially on the south rim of the Grand Canyon on two places separated by around 3km. The place is spectacular and the setup phase goes smoothly among the amused looks of the tourists. The first night we managed to see coincidences between the two sides and leave it for the next day to make further progress. As it turns out, this is as far as we got. Two detectors broke and our field fix allowed us for one more try ... but the weather gods were not with us and a huge electrical storm broke on top of the testing sites. We waited in vain for it to pass, but it was not to be, it was the last night at the canyon. We found out later that it was a major storm that broke a damm and forced the evacuation of several hundred people ... but by then we were on a plane headed back to Singapore.

Lessons

We learned a lot from the trip; our equipment worked flawlessly from batteries, the modified astronomical telescope worked for receiving the photons and while the key was not exchanged, it is for sure within our reach for the next attempt.

SPECIAL THANKS: To Carl Bowman from the National Park Service for helping with site selection and all the friendly advice.

Above: Receiving station "Bob". A modified telescope receives photons sent by Alice. The polarisation is measured in a basis chosen at random. The results are then compared with those obtained by Alice.

Below: Electrical Storm. Lightning and other adverse weather conditions prevented further testing of the QKD system at the Grand Canyon

Entanglement Theory

Entanglement is a fundamental aspect of quantum mechanics which makes it entirely different from the other "classical" physical theories. One could say, paraphrasing Richard Feynman, that entanglement is the only mystery of the quantum world. Dagomir Kaszlikowski explains.

Spooky Action At A Distance

It was a long time since the discovery of the phenomenon of entanglement by Erwin Schroedinger in the early 1930s before people realized that, far from being a mere curiosity of the mathematical formalism of quantum mechanics, entanglement can be harnessed for practical purposes. This realization came when it was shown by David Deutsch and others that quantum systems can be used to perform certain computations more quickly and efficiently than any classical computer. The entirely new paradigm of quantum computing was born.

The recent discovery of the so-called "one-way quantum computation" by Hans Briegel has demonstrated that entanglement is an essential ingredient for universal quantum computing. Moreover, it seems that this way of performing quantum computing may be easier to implement experimentally than the rival circuit-based model which gives hope that the day we press "enter" on the first quantum computer is not so far away.

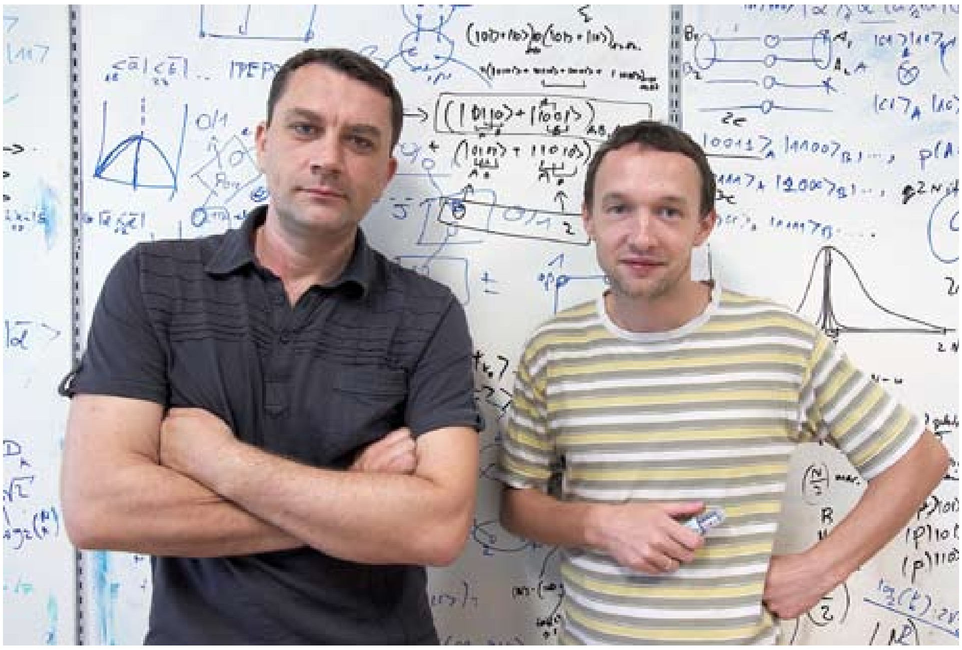
Entanglement is not only important in the context of quantum computing. It plays a fundamental role in recent research efforts which expand our understanding of physical processes of many-body quantum systems.

Research in my group mainly concentrates on the analysis of many-body entanglement in the context of quantum computing, and the thermodynamics of condensed matter systems. The main goal is to understand to what extent entanglement in large quantum systems is responsible for their physical properties. We hope that a thorough understanding of this problem will allow us to develop new techniques to analyze such quantum systems and investigate if they can be used for the purpose of quantum information processing.

To highlight this, I shall describe two recent results obtained by my group together with Vlatko Vedral, Andreas Winter, Ravishankar Ramanathan and Marcin Wiesniak. The first is related to the still unsolved problem of high temperature superconductivity and the other one to the nature of many body correlations.

High Temperature Superconductivity

The solution of the mystery of superconductivity by Bardeen, Schriefer and Cooper (BCS) in the late 1950s was a triumph of the quantum physics of strongly correlated electrons. It is difficult to imagine now, after BCS theory has become a part of the standard physics curriculum, how exhilarating it was for the community to finally come to terms with the phenomenon discovered experimentally at the beginning of the twentieth century. However, this euphoria did not last for long with the discovery in the late 1980s by Bednorz and Muller of a new class of materials that have superconducting properties at comparatively high temperatures, a regime where the BCS theory fails. In spite of many attempts we still do not have a satisfactory theory of this phenomena of high temperature superconductivity (HTS).


Dagomir Kaszlikowski (author, left) and Tomasz Paterek (right). The group of Dagomir Kaszlikowski and his collaborators examines fundamental issues in quantum theory, some of which may have practical application to such problems such as computation, communication and the development of new materials.

One of the theoretical attempts to explain HTS has been proposed by Anderson. The basic idea of his theory is based on the assumption that the insulating phase of high temperature superconductors is described by the Resonating-Valence-Bond (RVB) state. This state, after introducing dopants (atoms of different kind than the ones forming the insulating sample) becomes superfluid. An interesting aspect of Anderson theory is that it is capable of predicting an optimal doping (10% - 15% of dopants) when the superconductivity of a sample becomes the most robust against thermal noise.

Interestingly, the RVB states are a very successful concept to describe a wide range of physical phenomena such as resonance of covalent bonds in organic molecules, superconductivity in organic solids, and the Mott insulator – low temperature superconductor phase transitions in boron doped diamond to name a few.

We have analyzed entanglement properties of RVB states as a function of the amount of doping to understand this highly non-trivial quantum phase transition. The results show that the many-body entanglement of the system has a maximum for a relatively low concentration of dopants which is close to the optimal doping. Moreover, two-body entanglement decreases as the density of dopants is increased indicating that it is not related to the phase transition. As far as we know this is the first result clearly identifying many-body entanglement as a possible candidate for an order parameter (a quantity which characterises the abrupt change of behaviour of the system) capable of detecting quantum phase transitions.

Currently we are investigating if this discovery sheds some more light on the nature of HTC and how to experimentally test this (there are already proposals of how to experimentally prepare RVB states on optical lattices). We are also trying to answer the question if the RVB states can be used for the one-way quantum computing, which would be remarkable as they are readily exist in Nature.

The Nature of Correlations

The second strand of research examines the concept of correlations, which lies at the heart of sciences, mathematics and technology. The Laws of Quantum physics describe correlations between preparations and measurement outcomes of certain physical systems. In biology, DNA replication relies on correlations between the four bases making up the DNA. The field of statistics in mathematics has grown out of our need for a deeper description of correlated events in nature.

However the importance of correlations stretches far beyond science and mathematics. The emerging quantum technology crucially depends on peculiar correlations not found in "classical" physics (that if Newton and Einstein). This rests on the fact that quantum physics allows for different and more subtle correlations, namely entanglement.

Since quantum physics should contain classical physics as a special case (as Newtonian gravity is the weak-field approximation in General Relativity), we may think that reducing entanglement will in the same way ultimately lead to the reduction of all correlations to those of classical correlations only. We have shown that this common intuition is not true in case of more than two sub-systems, or parties. Surprisingly, genuine multiparty entanglement can exist on its own without the need of genuine multiparty classical correlations!

This discovery changes our understanding, among others, of the boundary between the classical and the quantum world, quantum phase transitions and the possibility of classical simulation of quantum systems. It also shows how far away we still are from a complete understanding of the very notion of correlations.

Vlatko Vedral gives this perspective on the nature of Entanglement:

We usually think of entanglement as correlations that are over and above any classical correlations. This would imply that whenever we have entanglement in any quantum state we also have to have classical correlations present there. The opposite is, of course, not necessarily the case, as is clear from classically correlated, but disentangled, states.

For two qubits this conclusions is certainly correct. Whenever the qubits are entangled, we also have to have individual spin-spin correlations (classical correlations in one basis) present. However, this is surprisingly not true for three qubits and more which is what we found in the paper: Kaszlikowski, Dagomir; Sen(De), Aditi; Sen, Ujjwal; Vedral, Vlatko; and Winter, Andreas. "Quantum Correlations without Classical Correlations". Physical Review Letters 101, 070502 (2008). Here we have a class of states which are entangled, but possess no classical correlations between spins.

This result is certainly surprising, but it may also have implications for wider physics. We usually characterise phase transisions in materials by enhancement in classical correlations between its constituents. However, if it is possible that all classical correlations vanish and still have entanglement present between constituents, it might be that entanglement is simply a better order parameter in some natural critical systems. This exciting question is still very much open for further investigation.

Outreach Activities

The Centre for Quantum Technologies is not only active in research but also in the education and promotion of science and technology. A team of CQT researchers conducted many various activities throughout the year.

The fascination for quantum physics can be conveyed to large audiences. Outreach, in Singapore and beyond, is one of the missions of CQT. The activities are coordinated by a team of three PIs, lead by Assoc. Prof. Valerio Scarani and including Assoc. Prof. Kwek Leong Chuan and Asst. Prof. Antia Lamas-Linares. Several members of CQT have participated in outreach activities including, presentations to visitors, talks for the general public and for secondary school students, articles in newspapers. CQT also contributes to the outreach activities promoted by the Faculty of Science and its Departments.

Christian Kurtsiefer demonstrating his quantum optics experiment to a future scientist

Future developments will include:
- More active collaborations with Singapore schools: along with already established contacts. These will include tutorial talks, mentorship of students, workshops for teachers.
- Collaboration with Raffles Junior College in the establishment of a quantum optics laboratory on their premises.

Date	Activity	Who	Audience	Additional Information
3.10.08	Discussion with RJC teachers	V. Scarani, Kwek LC, A. Lamas-Linares, C. Kurtsiefer	Raffles Junior College students	Discussion about setting up a Quantum Technology teaching lab at RJC; lab tour through quantum optics labs
30.9.08	Collaboration	Kwek L.C., V. Scarani, C. Ho	Schools	Visit to Victoria JC
18.9.08	Collaboration and talk	V. Scarani	High School Students	NUS High School
4.9.08	Popular Science Talk	V. Scarani	Large public	Event at Science 08
28.8.08	Visit to CQT	A. Ekert, A. Lamas-Linares	VIP@NUS	Visit by Ms Tan Gee Keow, MOE Director of Higher Education
27.8.08	Collaboration	A. Ekert, C. Kurtsiefer, V. Scarani	Young people	Meeting on how to promote science among young people
2-10.8.08	Live QKD demo in Black Hat and DEFCON	Christian Kurtsiefer and Antia Lamas Linares (+QO group members)	Public Demo	Quantum Spookshow Black Hat and DEFCON
23.8.08	Article in Straits Times	V. Scarani	Media	"Sudden discovery and quantum headaches"
10-13.8.08	Collaboration	E. Tan, D. Gosal, V. Scarani	Universities	Visit to Perimeter Institute & IQC, Waterloo, Canada
26.7.08	Article in Straits Times	A. Ekert	Media	"The unbreakable code: Is this the lock?"
8.7.08	Visit to CQT	C. Kurtsiefer, M. Barrett	VIP@NUS	Visit by Dr Ong Cheong, US Office of Naval Research
3.6.08	Popular Science Talk	V. Scarani	High School Students	Physics Open House 2008
4.4.08	Collaboration	Kwek L.C., V. Scarani	Schools	Visit to Raffles JC; sketch of collaboration involving (1) workshop for teachers, (2) lecture series, (3) elective courses, (4) student mentorship
3.4.08	Visit to CQT	A. Ekert	VIP@NUS	Visit by U21 PVC meeting participants
27.3.08	Collaboration	Kwek L.C., V. Scarani	Schools	Visit by a delegation from Raffles JC
25.3.08	Visit to CQT	V. Scarani	Visitor to NUS	Visit by Prof. John Baez, UC Riverside
23.2.08	Article in Straits Times	V. Vedral	Media	"Is reality a quantum hocus pocus?"
18.2.08	Visit to CQT	C. Kurtsiefer, Lai H.C., V. Scarani	VIP@NUS	Visit by Dr Gregory Kovacs, Deputy Director of the Microsystems Technology Office at DARPA.
13.2.08	Visit to CQT	C. Kurtsiefer	VIP@NUS	Visit by Mr Nick Bowen, VP of IBM Research Technical Strategy and World Wide Operations.
17-21.12.07	Academic Contact	L.C. Kwek and V. Scarani	Universities overseas	Peking University (Beida) & Tsinghua University Beijing
13.12.07	Cafe scientifique	V. Scarani	Large audience	Singapore Science Centre

Graduate School

The Centre for Quantum Technologies attracts highly talented students from around the world to undertake PhD studies, and offers top-class education in a vibrant environment. Supported by a generous scholarship, research and training at CQT are multidisciplinary, with each student having a focus in Science, Computing, or Engineering.

The Centre for Quantum Technologies includes in its mission the training of graduate students at a high level. For this purpose CQT has put in place a programme for graduate studies by which the selection of excellent candidates, their supervision at CQT, and the monitoring of their progress are ensured. These students receive a competitive scholarship from CQT. Research and training at CQT are multidisciplinary, with each student having a focus in Science, Computing, or Engineering.

The aim of the CQT Graduate Training Programme (GTP)) is to train approximately 80 PhD students over 10 years in all disciplines in which research is carried out in the Centre. In order to achieve this, an intake of 8 students per year is planned with 30 to 40 students in the programme when fully launched. The programme had it's first intake in August 2008 with 9 students and several more applicants under consideration.

Dagomir Kaszlikowski (right) discussing the phenomenon of superfluidity with a masters student Adam Chowdhry (centre) while Dimitris Angelakis (left) eavesdrops

In addition to PhD students under the CQT Graduate Training programme, principle investigators at CQT also supervise students funded from other sources, such as the Faculty of Science or NGS. At the end of the first year of the CQT, in addition to the 9 students under the CQT GTP, 10 other students are supervised under these alternative arrangements.

Already, there have been successful graduands of the Centre. Dr Alex Ling completed a PhD in Quantum Optics and has joined the Joint Quantum Institute and University of Maryland as a post-doctoral research fellow. Dr Janet Anders completed a PhD in Theoretical Quantum Information and is now a post-doctoral research fellow at University College London (UCL). Dr Tey Meng Khoon completed a PhD in Quantum Optics and is now a research fellow at the CQT.

CQT GTP PhD Student	Supervisor
ARUN	Prof. Englert
Marta WOLAK	Prof. Englert
NG Tien Tjuen	Assoc. Prof. Kurtsiefer
SYED Abdullah Aljunid	Assoc. Prof. Kurtsiefer
Kyle ARNOLD	Asst. Prof. Barrett
Elisabeth RIEPER	Prof. Vedral
Eilidh GUDGEON	Prof. Winter
HAN Rui	Prof. Englert
Penghui YAO	Asst. Prof. Jain

CQT PhD Student	Supervisor
DAI Li	Assoc. Prof. Kwek
KOONG Chee Weng	Prof. Englert
LE Huy Nguyen	Prof. Englert
LEE Jianwei	Assoc. Prof. Kurtsiefer
LEE Kean Loon	Prof. Englert, Assoc. Prof. Gremaud
LIEW Ding Yuan	Prof. Oh
LU Yin	Asst. Prof. Barrett, Prof. Englert
Matthew PELOSO	Assoc. Prof. Kurtsiefer
POH Hou Shun	Asst. Prof. Lamas-Linares
SYED Md. Assad	Prof. Englert
WANG Guangquan	Prof. Englert, Prof. Miniatura
ZHU Huangjun	Prof. Englert

Alongside the PhD programme, the Centre also educates students at the Masters level.

Masters Students

Anushya CHANDRAN

Adam Zaman CHOWDHRY

Tabia GELO Noel Macuja

Darwin GOSAL

CQT Academic Committee

Prof. Berthold-Georg Englert (Chair)

Prof. Vlatko Vedral (CQT)

Asst Prof. Antia Lamas-Linares (CQT)

Prof. Ji Wei (Faculty of Science, NUS)

Prof. Mark Breese (Dept of Physics, NUS)

Publications

Scientifically, the Centre for Quantum Technologies has been very productive in its first year with many publications in prestigious journals. Research topics span the entire field from fundamental physics to experimental techniques.

Strong interaction between light and a single trapped atom without the need for a cavity
M. K. Tey, Z. Chen, S. A. Aljunid, B. Chng, F. Huber, G. Maslennikov & C. Kurtsiefer
Nature Physics 4, 924-927 (2008)

Counterexamples to additivity of minimum output p-Renyi entropy for p close to 0
T. Cubitt, A. W. Harrow, D. Leung, A. Montanaro & A. Winter
Comm. Math. Phys. 284, 281 (2008)

Fractional Quantum Hall state in coupled cavities.
J. Cho, D. G. Angelakis & S. Bose,
Phys. Rev. Lett. 101, 246809 (2008)

Robust adiabatic approach to optical spin entangling in coupled quantum dots.
E. M. Gauger, A. Nazir, S. C. Benjamin, T. M. Stace & B. W. Lovett,
New J. Phys. 10 073016 (2008)

Measurement based entanglement under conditions of extreme photon loss.
E. T. Campbell & S. C. Benjamin
Phys. Rev. Lett. 101, 319007 (2008)

Symmetric construction of reference-frame-free qudits
J. Suzuki, G. N. M. Tabia & B.-G. Englert
Phys. Rev. A 78, 052328 (2008)

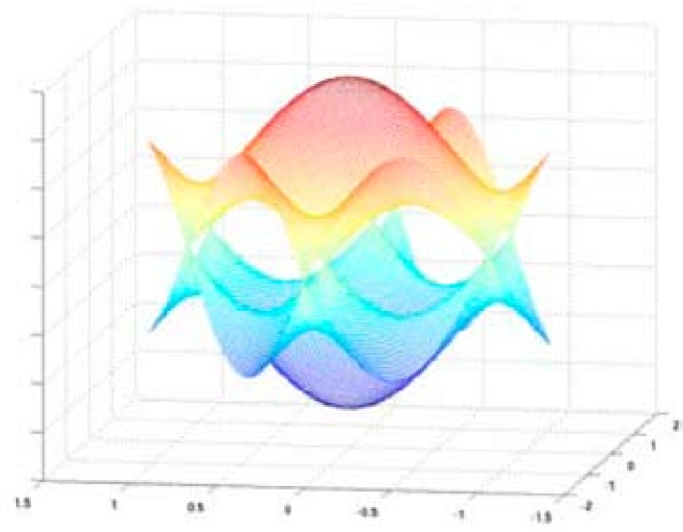
Simulation of partial entanglement with nonsignaling resources
N. Brunner, N. Gisin, S. Popescu & V. Scarani
Phys. Rev. A 78, 052111 (2008).

Security Bounds for Quantum Cryptography with Finite Resources
V. Scarani & R. Renner
Proc. of TQC 2008, Lecture Notes in Computer Science 5106 (Springer Verlag, Berlin), pp.83-95 (2008)

Spin orbit interaction induced spin-separation in platinum nanostructures
K. C. Weng, N. Chandrasekhar, C. Miniatura & B.-G. Englert
Electron Transport in Nanosystems, Eds J. Bonca & S. Kruchinin (Springer Verlag 2008), pp. 49-58, Ch. 5.

Testing quantum correlations versus single-particle properties within Leggett's model and beyond.
C. Branciard, N. Brunner, N. Gisin, C. Kurtsiefer, A. Lamas-Linares, A. Ling, V. Scarani
Nature Physics 4, 681-685 (2008).

Weaving light-matter qubits into a one way quantum computer.
D. G. Angelakis & A. Kay,
New J. Phys. Vol. 10, 023012 (2008).



Hexagonal Optical Lattice Potential

Reproducing spin lattice models in strongly coupled atom-cavity systems.
A. Kay & D. G. Angelakis,
Eur.Phys. Lett. 84, 20001 (2008).

Heralded generation of two-photon polarization entanglement with coupled cavities.
J. Cho, D. G. Angelakis, S. Bose,
Physical Review A, vol. 78, 022323 (2008),

Quantum Correlation Without Classical Correlations.
D. Kaszlikowski, A. Sen (De), U. Sen, V. Vedral & A. Winter,
Phys. Rev. Lett. 101, 070502 (2008).

A Witness of Entanglement Strata.
D. Kaszlikowski & A. Kay
New J. Phys. 10, 053026 (2008).

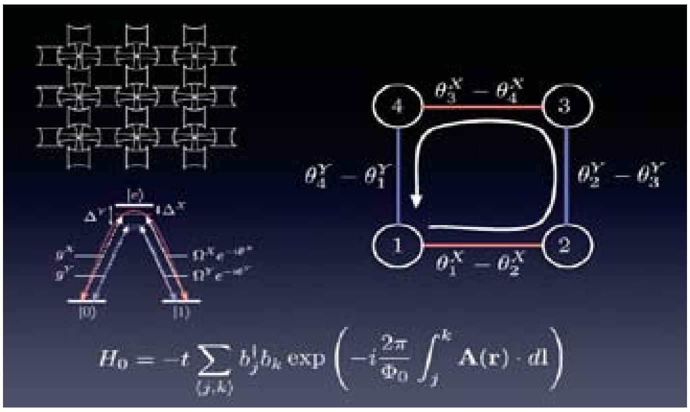
Generalized flying-qudit scheme in arbitrary dimensions.
T. Durt, L. C. Kwek & D. Kaszlikowski,
Physical Review A 77, 042318 (2007).

Heat capacity as an indicator of entanglement.
M. Wiesniak, V. Vedral & C. Brukner,
Phys. Rev. B 78, 064108 (2008).

Extending Bell inequalities to more parties
Y.-C. Wu, P. Badziag, M. Wiesniak & M. Zukowski,
Phys. Rev. A 77, 032105 (2008).

Experimental quantum key distribution based on a Bell test.
A. Ling, M. P. Peloso, I. Marcikic, V. Scarani, A. Lamas-Linares & C. Kurtsiefer.
Phys. Rev. A 78, 020301(R) (2008).

Quantum walk based search algorithms
Miklos Santha
Proc. of 5th Theory and Applications of Models of Computation (TAMC08), LNCS 4978, pages 31-46, 2008.



Cavity QED to study polaritonic states of light.

Testing the dimension of Hilbert spaces
N. Brunner, S. Pironio, A. Acin, N. Gisin, A. Allan Methot, & V. Scarani
Phys. Rev. Lett. 100, 210503 (2008).

Quantum cryptography with finite resources: Unconditional security bound for discrete-variable protocols with one-way post-processing
V. Scarani & R. Renner
Phys. Rev. Lett. 100, 200501 (2008)

Experimental demonstration of a quantum protocol for Byzantine agreement and liar detection
S. Gaertner, M. Bourennane, C. Kurtsiefer, A. Cabello & H. Weinfurter
Phys. Rev. Lett. 100 (2008) 070504

Absolute emission rates of Spontaneous Parametric Down Conversion into single transverse Gaussian modes.
A. Ling, A. Lamas-Linares & C. Kurtsiefer.
Phys. Rev. A 77, 043834 (2008)

Local and nonlocal content of bipartite qubit and qutrit correlations
V. Scarani
Phys. Rev. A 77, 042112 (2008)

An efficient quantum algorithm for the hidden subgroup problem in nil-2 groups
G. Ivanyos, L. Sanselme & M. Santha
Proc. of 8th LNCS vol. 4957, pages 759-771, 2008

Upper bounds for the security of two distributed-phase reference protocols of quantum cryptography
C. Branciard, N. Gisin & V. Scarani
New J. Phys. 10 (2008) 013031

Quantifying Entanglement in Macroscopic Systems
V. Vedral
Nature 453, 1004-1007 (2008).

How much of one-way computation is just thermodynamics?
J. Anders, M. Hajdusek, D. Markham & V. Vedral
Found. of Phys. 38, 506-522 (2008)

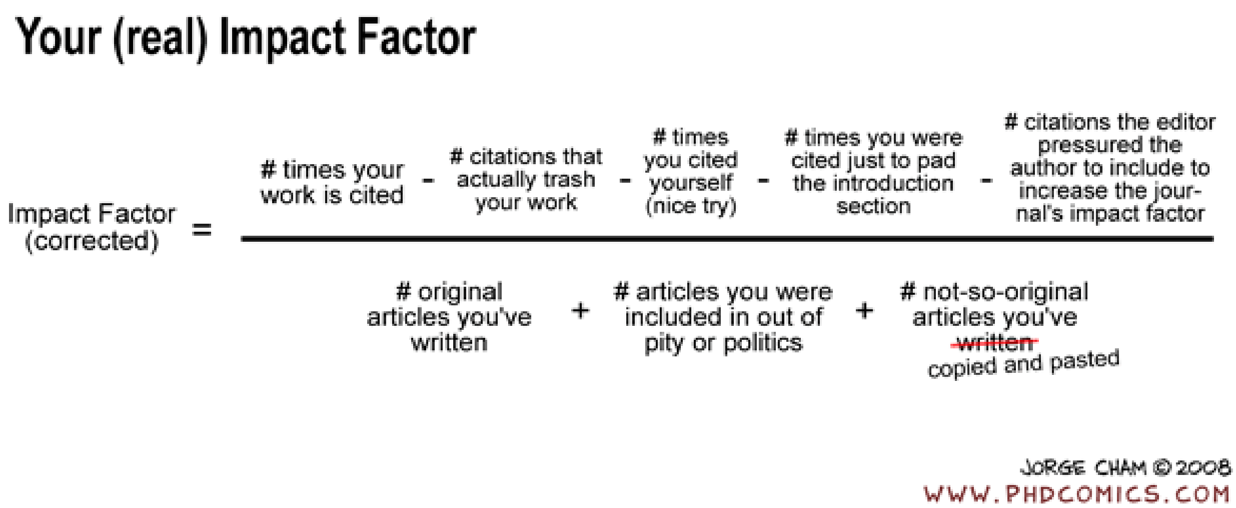
Survival of entanglement in thermal states
D. Markham, J. Anders, V. Vedral, M. Murao & A. Miyake,
Eu. Phys. Lett. 81, 40006, (2008).

Nonadditive quantum error-correcting code
S. X. Yu, Q. Chen, C. H. Lai & C. H. Oh
Phys. Rev. Lett. 101, 090501 (2008).

Bell inequalities for three particles
J. L. Chen, C. F. Wu, L. C. Kwek & C. H. Oh
Phys. Rev. A 78, 032107 (2008).

Repeat-until-success distributed quantum computation by using single-photon interference at a beam splitter
X. L. Feng, J. Qian, L. C. Kwek & C. H. Oh
Phys. Rev. A 78, 012354 (2008).

Graphical nonbinary quantum error-correcting codes
D. Hu, W. D. Tang, M. S. Zhao, Q. Chen, S. X. Yu & C. H. Oh
Phys. Rev. A 78, 012306 (2008).

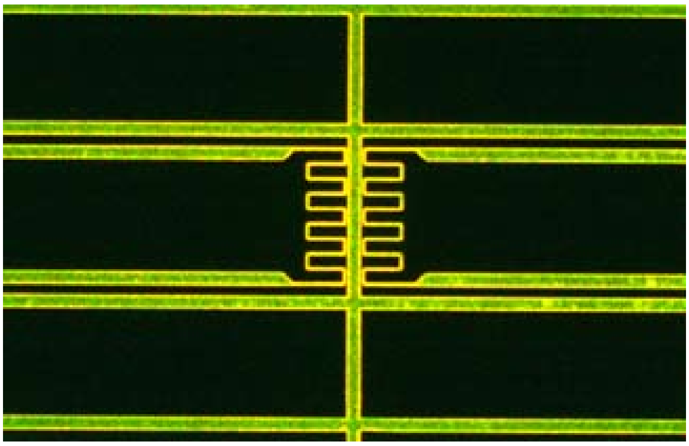


Universal quantum computation with trapped ions in thermal motion by adiabatic passage
X. L. Feng, C. F. Wu, C. H. Lai & C. H. Oh
Phys. Rev. A 77, 062336 (2008).

Correlation-function Bell inequality with improved visibility for three qubits
C. F. Wu, J. L. Chen, L. C. Kwek & C. H. Oh
Phys. Rev. A 77, 062309 (2008).

Examination of the adiabatic approximation in open systems
D. M. Tong, X. X. Yi, X. J. Fan, L. C. Kwek, & C. H. Oh
Phys. Lett. A 372, 2364 (2008).

Geometric phase induced by quantum nonlocality
Z. S. Wang, C. F. Wu, X. L. Feng, L. C. Kwek, C. H. Lai, C. H. Oh & V. Vedral
Phys. Lett. A 372, 775 (2008).



Current carrying wire structure of an atom chip for trapping and moving neutral atoms.

Murray Barrett (left) showing Ignacio Cirac (second from right) and Michele Mosca (right) around the microtrapping lab. Also present Ng Tien Tjuen (second from left) and Syed Abdullah Aljunid (middle)

Quantum spin current induced through optical dipole transition process in semiconductors
X. J. Liu, L. C. Kwek & C. H. Oh
Int. J. Mod. Phys. B 22, 44 (2008).

On the Chernoff distance for asymptotic LOCC discrimination of bipartite quantum states.
W. Matthews & A. Winter,
arXiv:0710.4113

Wave-particle duality in multi-path interferometers: General concepts and three-path interferometers
B.-G. Englert, D. Kaszlikowski, L. C. Kwek & W. H. Chee,
Int. J. Quant. Inf. 6, 129-157 (2008)

Experimental Falsification of Leggett's non-Local Variable Model.
C. Branciard, A. Ling, N. Gisin, C. Kurtsiefer, A. Lamas-Linares & V. Scarani,
Phys. Rev. Lett. 99, 210407 (2007).

Abbreviated Journal Title	Impact Factor	CQT Publications	%
NATURE	28.751	1	3%
NAT PHYS	14.677	2	5%
PHYS REV LETT	6.944	8	22%
NEW J PHYS	3.264	4	11%
PHYS REV B	3.172	1	3%
PHYS REV A	2.893	15	41%
EPL-EUROPHYS LETT	2.206	2	5%
COMMUN MATH PHYS	2.07	1	3%
FOUND PHYS	0.951	1	3%
INT J MOD PHYS B	0.647	1	3%
INT J QUANTUM INF	0.568	1	3%

Table of journals in which CQT articles were published, along with their respective impact factors. Publication census date 7th December 2008.

Visitors to the CQT 2008

Name	Institution
Alain Aspect	Institut d'Optique, Palaiseau, France
Alastair Kay	University of Cambridge, United Kingdom
Alexander Holevo	Steklov Mathematical Institute, Moscow
Alok Pan	Bose Institute, India
Ambainis Andris	University of Latvia, Latvia
Amir Kalev	Technion, Israel
Amodsen Chotia	Laboratoire Aimé Cotton, CNRS, France
Andreas Wallraff	ETH Zurich, Switerland
Angie Qarry	University of Vienna, Vienna, Austria
Anthony Leverrier	Université Libre de Bruxelles , Belgium
Anton Zavrier	MagiQ Technologies, Inc, New york, USA
Attila Pereszlenyi	University of Technology , Budapest
Avinash Kolli	Oxford University, United Kingdom
Benoit Gremaud	CNRS, France
Bjorn Hessmo	Institute of Optics and Atomic Physics, Technical University of Berlin, Austria
Blair Blakie	University of Otago, New Zealand
Brendon Lovett	Oxford University, United Kingdom
Buhrman Harry	Centrum Wiskunde & Informatica, Amsterdam, Netherlands
Burkhard Kummerer	University of Darmstadt, Germany
Caroline Rogers	University of Warwick, United Kingdom
Cedric Beny	University of Waterloo, Canada
Charles Clark	National Institute of Standards and Technology, USA
Chris Ogden	Queen University Belfast, Canada
Christian Gogolin	University of Wurzburg, Germany
Christian Miniatura	Institut non lineaire de Nice (INLN), CNRS, France
Christopher Hadley	University of Leeds, United Kingdom
Claudia Tenen	Massachusetts Institute of Technology, USA
Cord Muller	University of Bayreuth, Germany
Cristhian Avila	University of Leeds, United Kingdom
Cyril Branciard	University of Geneva,Switzerland
Dan Browne	University College London, United Kingdom
Daniel Oi	University of Strathclyde, United Kingdom
Daniel Zemann	University of Innsbruck Austria
David Hutchinson	University of Otago, New Zealand
David Moehring	Max-Planck Institute for Quantum Optics, Germany
David Wilkowski	CNRS, France
de Wolf Ronald	Centrum Wiskunde & Informatica, Amsterdam, Netherlands
Debbie Leung	University of Waterloo, Canada
Denes Petz	Budapest University of Technology , Budapest, Hungary
Dieter Jaksch	University of Oxford, United Kingdom
Dimitris G.Angelakis	Technical university of Crete, Chania, Greece
Du Jiang Feng	University of Science and Technology of China, China
Earl Campbell	Oxford University, United Kingdom
Elica Kioseva	Sofia University, Bulgaria
Erik Gauger	Oxford University, United Kingdom
Fabio Benatti	University of Trieste, Italy
Fedor Jelezko	University of Stuttgart, Germany
Florian Schreck	Institut für Quantenoptik und Quanteninformation,, Austria
Frances Ling	University of Leeds, United Kingdom
Francesco Ciccarello	University of Palermo, Italy

Frédéric Grosshans	Université Libre de Bruxelles , Belgium
George Batrouni	Institut non lineaire de Nice (INLN), CNRS, France
Geza Giedke	Institute for Quantum Electronics, Switzerland
Glen Evenbly	University of Queensland, Australia
Hans Briegel	Institute for Theoretical Physics, University of Innsbruck Austria
Hartmut Klauck	Institut für Informatik, Germany
Hermann Kamperman	University of Duesseldorf, Germany
Howard Carmichael	University of Auckland, New Zealand
Hoyer Peter	University of Calgary, Canada
Hsi-Sheng Goan	National Taiwan University, Taiwan
Hugo Cable	Louisiana State University, USA
Huzihiro Araki	Research Institute for Mathematical Sciences, Kyoto University, Japan
Ignacio Cirac	Max-Planck-Institute for Quantum Optics, Garching, Germany
Ivanyos Gabor	Informatics Laboratory , MTA, Budapest
Jacob Dunningham	University of Leeds, United Kingdom
Jaeyoon Cho	University College London, United Kingdom
James Chou Chin-Wen	CalTech, California, USA
Janet Anders	University College London, United Kingdom
Janus Wesenberg	University of Oxford, United Kingdom
Jean Christian Boileau	University of Toronto, Canada
Jenny Hide	University of Leeds, United Kingdom
Jess Cooper	University of Leeds, United Kingdom
Joe Cotter	University of Leeds, United Kingdom
Joe Fitzsimons	Oxford University, United Kingdom
John Goold	University of Leeds, United Kingdom
Joonwoo Bae	KIAS-Korea Institute for Advanced Study, Korea
Juan Pablo Paz	University of Buenos Aires, Argentina
Jun Suzuki	National Insitute of Information, Japan
Jun Ye	National Institute of Standards and Technology and University of Colorado
Kai Dieckmann	Ludwig-Maximilians-Universität München, Germany
Karim Bouadim	CNRS, France
Karoline Wiesner	University of Bristol, United Kingdom
Kavan Modi	The University of Texas, USA
Kazimierz Rzazewski	Center for Theoretical Physics of the Polish Academy Sciences, Poland
Kazuo Iwama	Kyoto University, Japan
Keiji Matsumoto	National Institute of Informatics, Tokyo
Kerenidis Iordanis	CNRS, Université Paris-Sud, France
Laplante Sophie	LRI, Université Paris-Sud, France
Lawrence Ioannou	University of Cambridge, United Kingdom
Lee Troy	Rutgers University, USA
Li Dafa	Tsinghua University, China
Li Wenhui	University of Waterloo, Canada
Libby Heaney	University of Leeds, United Kingdom
Lim Ho Kiat	Queen's University, Canada
Lin Chen	Zhejiang University, China
Liu Xiong Jun	Nankai University, China
Luigi Amico	University of Catania, Italy
Luis Masanes	University of Cambridge, United Kingdom
Luke Rallan	University of Leeds, United Kingdom
Madalin Guta	University of Nottingham , United Kingdom
Magniez Frederic	CNRS, Université Paris-Sud, France
Mang Feng	Wuhan Institute of Physics & Mathematics, Chinese Academy of Sciences, China
Man-Hong Yung	University of Illinois at Urbana-Champaign, USA
Marc-André Dupertuis	Ecole Polytechnique Fédérale de Lausanne, Switzerland
Mariusz Gajda	Institute of Physics, Polish Academy of Sciences, Poland
Mark Fannes	Katholieke Universiteit Leuven, Belgium
Mark Wilde	University of Southern California, USA
Mark Williamson	University of Leeds, United Kingdom
Markus Grassl	University of Innsbruck Austria
Martin Aulbach	University of Leeds, United Kingdom
Mary Beth Ruskai	Tufts University, USA
Masahito Hayashi	Tohoku University, Japan
Masato Koashi	Osaka University, Japan
Massar Serge	Université Libre de Bruxelles, Belgium
Matthew McKague	University of Waterloo, Canada
Michael Bremner	University of Bristol, United Kingdom

Michal Hajdusek	University of Leeds, United Kingdom
Michele Mosca	University of Waterloo, Canada
Milan Monsonyi	Tohoku University, Japan
Mile Gu	University of Queensland, Australia
Nayak Ashwin	University of Waterloo, Canada
Ng Hui Khoon	CalTech, California, USA
Nicolas Gisin	University of Geneva,Switzerland
Nicolas Lewty	University of Leeds, United Kingdom
Nobuyuki Imoto	Osaka University, Japan
Norbert Lutkenhaus	Institute for Quantum Computing,University of Waterloo, Canada.
Oleg Gittsovich	Institut für Quantenoptik und Quanteninformation, Austria
Oscar Dahlsten	Institut f. Theoretische Physik, Zurich
Ouyang YingKai	CalTech, California, USA
Peter Janotta	University of Wurzburg, Germany
Philippe Grangier	Institut d'Optique, Palaiseau, France
Philippe Raynal	CEA Centre de Cadarache, France
Pieter Kok	University of Sheffield, United Kingdom
Rahul Jain	University of Waterloo, Canada
Raymond Rudy	Tokyo Research Lab., IBM Research, Japan
Regev Oded	Tel-Aviv University, Israel
Reichardt Ben	University of Waterloo, Canada
Reinhard Werner	Institut für Mathematische Physik, Germany
Renato Renner	ETH Zurich, Switzerland
Richard Low	University of Bristol, United Kingdom
Robert Alicki	Gdansk University, Poland
Rosario Fazio	Scuola Normale Superiore(SNS), Italy
Sangeetha Gnanapragasam	The Australian National University, Australia
Scott Parkins	University of Auckland, New Zealand
Sean Barret	Imperial College London, United Kingdom
Serge Massar	Université Libre de Bruxelles, Belgium
Shash Virmani	Imperial Colleage London, United Kingdom
Shmuel Gurvitz	Weizmann Institute of Science, Israel
Shparlinski, Igor	Macquarie University, Australia
Simon Benjamin	Oxford University, United Kingdom
Sonia Schirmer	University of Cambridge, United Kingdom
Sougato Bose	University College London, United Kingdom
Spalek Robert	Google, Mountain View, USA
Stefano Pironio	ICFO – The Institute of Photonic Sciences, Spain
Stephanie Wehner	Caltech, California, USA
Thomas Durt	Université Libre de Bruxelles, Belgium
Thomas Jennewein	University of Vienna, Vienna, Austria
Timothy Liew	University of Southampton, United Kingdom
Tomasz Karpiuk	University of Bialystok, Poland
Tomasz Paterek	Austrian Academy of Sciences, Austria
Toner Ben	Centrum Wiskunde & Informatica, Amsterdam, Netherlands
Tong Dian-Min	Shandong Normal University, China
Tristan Moriarty	University of Bristol, United Kingdom
Umesh Vazirani	University of California at Berkeley , USA
Vincent Boyer	National Institute of Standards and Technology, USA
Vladimir Buzek	Institute of Physics, Slovak Academy of Sciences Bratislava, Slovak Republic
Wen Hui Li	Rice University, USA
Wieslaw Laskowski	University of Gdańsk, Poland
William Matthews	University of Bristol, United Kingdom
Wonmin Son	University of Leeds, United Kingdom
Xiong Feng Ma	Institute for Quantum Computing,University of Waterloo, Canada.
Xu Ming	Sichuan Normal University, China
Yang Yi	University of Science and Technology of China, China
Yao Peng Hui	China
Yu Zongwen	Tsinghua University, China
Zeynep Nilhan Gurkan	İzmir Institute of Technology, Turkey
Zhang Pengfei	Shanghai Insitute of Optics and Fine Mechanics, China
Zhang Shengyu	The Chinese University of Hong Kong, Hongkong
Zhiliang Yuan	Toshiba Research Europe Ltd Cambridge Research Laboratory, United Kingdom

Money Matters

We Spent Some Money.

Expenditure for the First Year from December 2007 to November 2008

	SGD$
Expenditure on Manpower (EOM)	3,856,347
Equipment	1,770,957
Other Operating Expenditure (OOE)	5,146,706
Total	**10,774,010**

The Centre for Quantum Technologies is funded by

National Research Foundation

Ministry of Education
SINGAPORE

We are hosted by

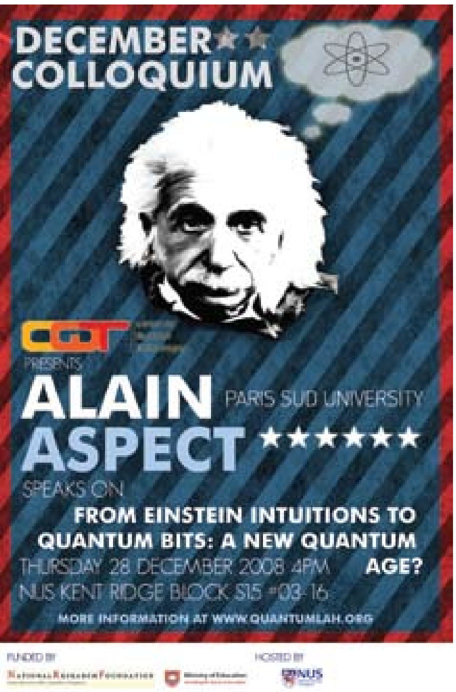
NUS National University of Singapore

Some of our projects are also supported by

DSTA Defence Science & Technology Agency

Agency for Science, Technology and Research SINGAPORE

DSO National Laboratories


DECEMBER
COLLOQUIUM
PRESENTS
ALAIN ASPECT
PARIS SUD UNIVERSITY
SPEAKS ON
FROM EINSTEIN INTUITIONS TO QUANTUM BITS: A NEW QUANTUM AGE?
THURSDAY 28 DECEMBER 2008 4PM
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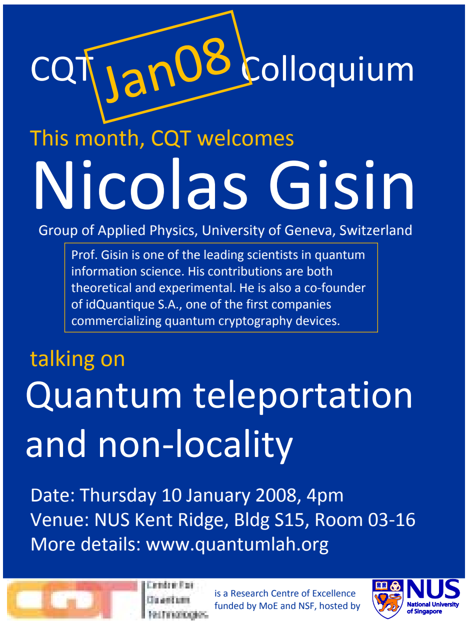
CQT Jan08 Colloquium
This month, CQT welcomes
Nicolas Gisin
Group of Applied Physics, University of Geneva, Switzerland
Prof. Gisin is one of the leading scientists in quantum information science. His contributions are both theoretical and experimental. He is also a co-founder of idQuantique S.A., one of the first companies commercializing quantum cryptography devices.
talking on
Quantum teleportation and non-locality
Date: Thursday 10 January 2008, 4pm
Venue: NUS Kent Ridge, Bldg S15, Room 03-16
More details: www.quantumlah.org
Centre for Quantum Technologies
is a Research Centre of Excellence funded by MoE and NSF, hosted by
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Centre for Quantum Technologies
PRESENTS
FEBRUARY 2008
COLLOQUIUM
NOBUYUKI IMOTO
OSAKA UNIVERSITY, JAPAN
SPEAKS ON
IMPLEMENTATION OF BASIC QUANTUM INFORMATION PROCESSING
THURSDAY 28 FEBRUARY 2008 4PM
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Centre for Quantum Technologies
MARCH 2008
COLLOQUIUM
HANS BRIEGEL
UNIVERSITY OF INNSBRUCK, AUSTRIA
SPEAKS ON
NEW DEVELOPMENTS IN MEASUREMENT-BASED QUANTUM COMPUTATION
THURSDAY 27 MARCH 2008 4PM
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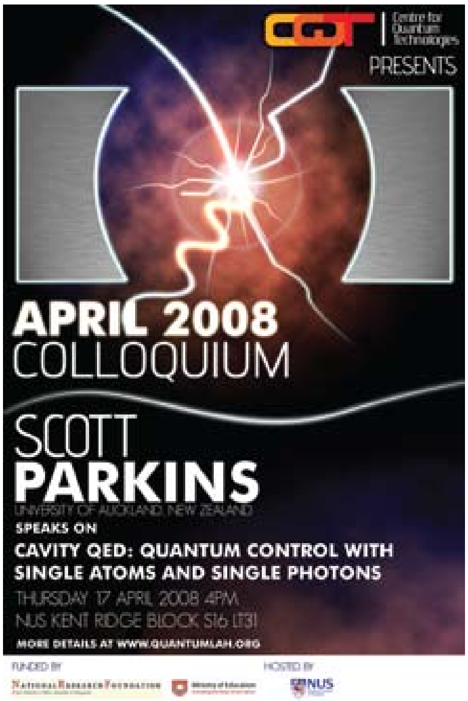
Centre for Quantum Technologies
PRESENTS
APRIL 2008
COLLOQUIUM
SCOTT PARKINS
UNIVERSITY OF AUCKLAND, NEW ZEALAND
SPEAKS ON
CAVITY QED: QUANTUM CONTROL WITH SINGLE ATOMS AND SINGLE PHOTONS
THURSDAY 17 APRIL 2008 4PM
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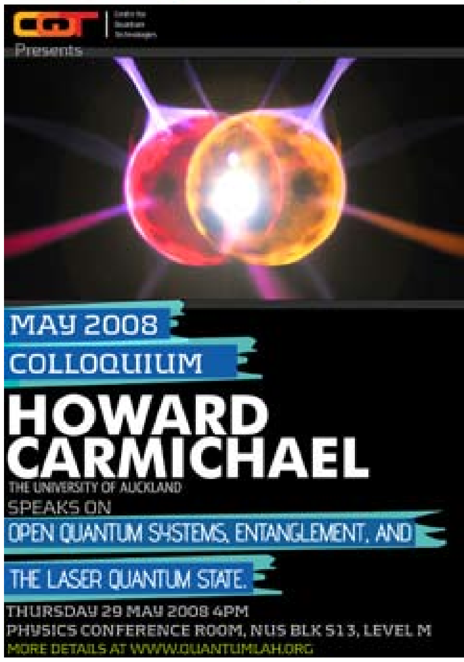
Presents
MAY 2008
COLLOQUIUM
HOWARD CARMICHAEL
THE UNIVERSITY OF AUCKLAND
SPEAKS ON
OPEN QUANTUM SYSTEMS, ENTANGLEMENT, AND THE LASER QUANTUM STATE.
THURSDAY 29 MAY 2008 4PM
PHYSICS CONFERENCE ROOM, NUS BLK S13, LEVEL M
MORE DETAILS AT WWW.QUANTUMLAH.ORG
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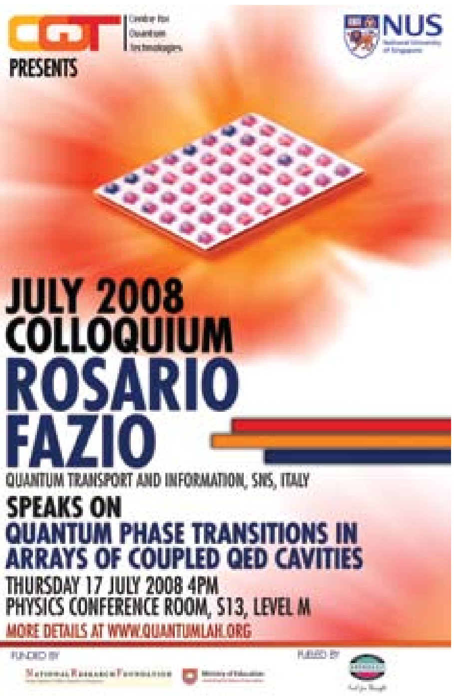
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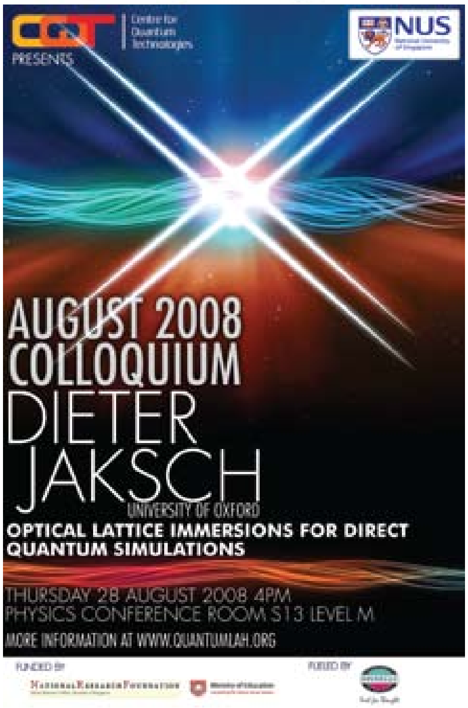
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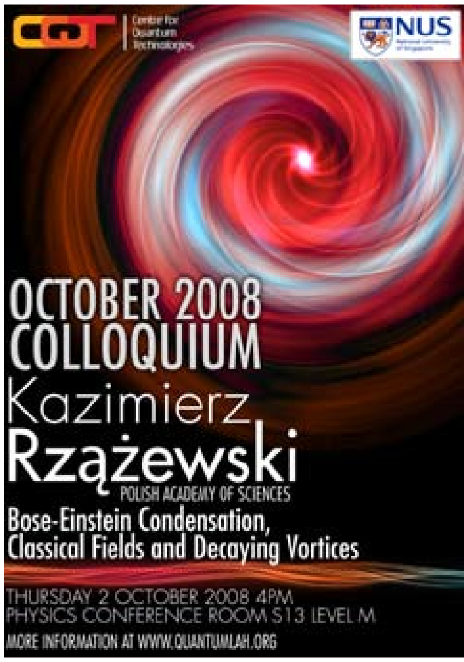
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