



INTERNATIONAL MAX PLANCK PARTNERSHIP 'Measurement and Observations at the Quantum Limit'

**Annual Report to the
Scottish Funding Council**

For the period 1 August 2014 to 31 July 2015

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Introduction

Following the award of seed funding from SFC and EPSRC/STFC, the International Max Planck Partnership (IMPP) was initiated with a technical start-up meeting, with representation from all interested parties, at Crieff Hydro in April 2013 and then formally launched by Dr Alasdair Allan on 19 December 2013 at the Royal Society of Edinburgh. This report summaries the IMPP activities between 1st of August 2014 and 30th of July 2015 and demonstrates that IMPP has successfully delivered on all relevant targets.

The IMPP is a collaboration between the Universities of Glasgow, Strathclyde, Heriot-Watt, St Andrews and Edinburgh with the Max Planck Institute (MPI) for Gravitational Physics (Albert Einstein Institute), Hannover and Golm, the MPI for the Science of Light (Erlangen), the MPI for Chemical Physics (Dresden), the MPI for Quantum Optics (Garching) and the MPI for Solid State Research (Stuttgart). The collaborative area of research is *Measurement and Observation at the Quantum Limit*, highly relevant to the Scottish Innovation centre CENSIS and the recently initiated Quantum Technologies Hubs in the UK, in particular the Glasgow led Hub on Quantum Enhanced Imaging Concepts (QuantIC).

The web page for the partnership can be found at <http://www.impp.uk/>.

Funding

Seed funding of £500K has been provided by SFC and £243K from EPSRC/STFC and this has leveraged a high level of funding from a number of other areas including the Universities, the Humboldt Foundation and STFC. In total leveraged funding in the Universities in posts and infrastructure exceeds £10M, supporting research related to the IMPP.

New academic posts include:

- Prof Steve Barnett and Dr Sarah Croke at Glasgow;
- Prof Andrew Daley and Dr Alison Yao at Strathclyde;
- Prof Sven Höfling at St Andrews;

with research staff and infrastructure investment in each case.

Further, a Humboldt Fellow, Dr Sebastian Steinlechner continued his fellowship in Glasgow supported by the IMPP and he has now obtained a prestigious Marie Curie fellowship to continue his work Dr S Hild. Dr Jessica Steinlechner has been working as research assistant, funded by STFC for the IMPP, also in Glasgow. Dr L Tagliacozzo, who has strong existing collaborations with the Max Planck Institute for Quantum Optics (Dr M C Banuls and Prof I Cirac) has been appointed as Chancellor's Fellow/Lecturer at the University of Strathclyde.

The Universities are also providing direct operational funding. For example Glasgow is contributing £470K over four years and St Andrews has committed £250k as start for its IMPP chair Prof. Sven Höfling over five years. Strathclyde University has invested in excess of £700k for the start-up packages for Prof Andrew Daley and Dr Alison Yao.

How external funding is been used.

EPSRC/STFC

The seed funding from EPSRC/STFC plus some University money is being used to fund visits and workshops: To date the following workshops have received funding:

- Condensed Matter Systems for Future Quantum technologies (<http://www.mqt2014.co.uk/>), August 2014. This meeting held at St Andrews was organised by Dr P Wahl (St Andrews), Dr P King (St Andrews) Dr J-P Reid (St Andrews) Prof A Mackenzie (Max Planck Institute for Chemical Physics of Solids, Dresden, and St Andrews). (£22k support from IMPP)
- Workshop on Many-body Dynamics and Open Quantum Systems (<http://doqs2014.phys.strath.ac.uk/>), October 2014. This meeting, held in Glasgow, was organised by Prof S Kuhr and Prof A Daley at Strathclyde and Prof I Bloch and Prof I Cirac, both from the Max Planck Institute for Quantum Optics, Garching. Invited speakers have included Prof K Hammerer (Max Planck Institute for Gravitational Physics, Hannover) and Dr M C Banuls and Dr U Schneider (both Max Planck Institute for Quantum Optics, Graching). (£25k support from IMPP)
- Macroscopic Quantum Coherence Workshop (www.st-andrews.ac.uk/~mqcweb2015/), June 2015. This workshop held in St Andrews was organised by Dr N Korolkova (St Andrews) and Dr C Marquart (Max Planck Institute for the Science of Light, Erlangen). Invited speakers included Prof G Leuchs (Max Planck Institute for the Science of Light, Erlangen) and Prof R Schnabel (Max Planck Institute for Gravitational Physics, Hannover). (£24k support from IMPP)
- The Combined Lecture week of IMPP and the International Max Planck Research School (IMPRS) at the Max Planck Institute for Gravitational Physics, Hannover, was organised by Dr S Hild (Glasgow) and Prof K Danzmann (MPI Hannover). Forty PhD students and postdocs from the Max Planck Institute in Germany and the University of Glasgow participated in the School, which was held in Crieff in June 2015. (£23k support from IMPP)

The following upcoming workshops will be supported by IMPP

- Optical Analogues for Fundamental Quantum Field Theories, 2016. This meeting (to be held close to Edinburgh) is organised by Prof D Faccio (Heriot-Watt), Dr J Leach (Heriot-Watt), Dr A Di Falco (St Andrews) Dr A Aiello (Max Planck Institute for the Science of Light, Erlangen). (£12k support from IMPP)
- Following from the success of the Many-body Dynamics and Open Quantum Systems workshop, organised by Strathclyde in 2014, a follow-up workshop is planned by Prof S Kuhr and Prof A Daley (both Strathclyde) to be held in August/September 2016. (£25k support from IMPP)

In addition IMPP has supported the Inauguration event of the new Ultra-low vibration laboratory and clean room at St Andrews. On 21st of May 2015, Angela Constance, the Cabinet Secretary for Education & Lifelong Learning, performed the opening ceremony and Prof K Kern (Max Planck Institute for Solid State Research Stuttgart) was an invited speaker. (£6k support from IMPP)

The Scottish Universities Summer School (SUSSP71) in ‘Frontiers in Quantum Dynamics and Quantum Optics’ organised by Dr J Jeffers (Strathclyde) was held in Glasgow in July 2015

(<http://sussp71.phys.strath.ac.uk>). Prof G Leuchs, Director at the Max-Planck-Institute for the Science of Light was one of the lecturers of the summer school.

Also a visit by researcher (C. Peuntinger) at Erlangen to the University of St Andrews (Dr N Korolkova) was funded, as well as visits of a team from Strathclyde (Prof A Daley, Dr S McEndoo and Mr J Yago) to the Max Planck Institute for Quantum Optics Garching (Prof Cirac and Dr Banuls).

SFC

The majority of the seed funding from SFC of £500K is being split evenly between the four main collaborating Scottish Universities – Glasgow, Strathclyde, Heriot-Watt and St Andrews each receiving £120K – with the remaining £20K going to Edinburgh with the intention that the funding is used to support graduate student stipends, training etc.

The Glasgow student – Mariella Masso – is working on opto-mechanics relevant to allow gravitational wave detectors to reach the quantum limit. The Heriot-Watt student – David Carvalho – is working in collaboration with the MPI Erlangen on the optical analogues of quantum field theory in and gravity in graphene. In addition St Andrews has leverage several PhD students linked to the IMPP work from other funding sources: 5 PhD students in collaboration MPI in Dresden (Jack Bartlett, Lishan Zhou, You-Sheng Li, Dan Brodsky and Mark Barber), 1 PhD student who spend the first half of his PhD studies at the MPI in Stuttgart (Ramakrishna Aluru) and another 2 have started in St Andrews on joint MPI-SUPA projects (Matthew Neat and Christopher Trainer). Strathclyde has recruited two IMPP students to work with Dr M Piani and Dr E Haller.

List of collaborative visits in the reporting period:

- Prof S Barnett (Glasgow) gave a colloquium at the Max Planck Institute for Quantum Optics in Garching (June 2015).
- Prof I Bloch from the Max Planck Institute for Quantum Optics visited Prof S Kuhr and Prof A Daley (Strathclyde).
- Dr A Rost (Max Planck Institute for Solid State Research, Stuttgart) visited St Andrews.
- MPI Hannover researcher H Wittel visited Glasgow (Dr S Hild).
- A team from the Max Planck Institute for the Science of Light (Prof G Leuchs, Dr C Marquart, Dr Peuntinger and V Chille) visited St Andrews (Dr N Korolkova).
- St Andrews student M Neat visited the Max Planck Institute for Solid State Research, Stuttgart.
- Dr H Lueck and Dr C Mow-Lowry from MPI for Gravitational Physics visited Glasgow (Dr S Hild)
- Dr M Lavery (Glasgow) has made an extended visit to the Max Planck Institute for the Science of Light Erlangen (Prof G Leuchs).

Prestigious awards and Fellowships

Prof M Padgett (Glasgow) was awarded by the European Physical Society the Prize for Research into the Science of Light. Prof R Hadfield (Glasgow) has been awarded an ERC consolidator grant. Dr S Hild (Glasgow) was awarded the Sir Thomas Makdougall Brisbane Medal 2015 of the Royal Society of Edinburgh. Prof A MacKenzie (St Andrews and MPI for Chemical Physics of Solids, Dresden) was

awarded Fellowship of the Royal Society. Dr S Hild (Glasgow) has been selected as member of the Global Young Academy. Prof S Rowan (Glasgow) was giving the prestigious 2014 Women and Physics lecture tour of the Australian Institute of Physics. Prof Rowan has also been elected as chair of the Gravitational Wave International Committee (GWIC).

Further Funding Applications

The IMPP has been exceptionally successful in obtaining funding from UK Quantum Technologies initiative. IMPP partners are involved in all four Hubs and also lead the Quantum Sensing Hub, based in Glasgow. In detail:

- Quantum Sensing/Imaging Hub: The University of Glasgow-led hub involves also the IMPP partners Universities of Edinburgh, Strathclyde and Heriot-Watt.
- Quantum Sensing and Metrology Hub: The IMPP partners University of Glasgow and University of Strathclyde participate in the University of Birmingham-led hub.
- Quantum Computing/Simulation Hub: University of Oxford leads this hub. It collaborates with IMPP partners University of Edinburgh and Strathclyde.
- Quantum Communications Hub: IMPP partners University of Edinburgh and Strathclyde participate in this University of York-led hub.

A number of new grant applications to Horizon 2020 have been submitted or are in the process of being worked up, with German partners, under Integrating Infrastructures, Marie Curie Training networks and Future Emerging Technologies. However it is too early for any award announcements.

Notable Publications relevant to IMPP

Spatially structured photons that travel in free space slower than the speed of light

D Giovannini, J Romero, V Potoček, G Ferenczi, F Speirits, S M Barnett, D Facio and M J Padgett
Science, 347, 857–860 (2015)

Self-consistent projection operator theory in nonlinear quantum optical systems: A case study on degenerate optical parametric oscillators

Peter Degenfeld-Schonburg, Carlos Navarrete-Benlloch, and Michael J. Hartmann
Phys. Rev. A 91, 053850 – (2015)

Quantum nature of Gaussian discord: Experimental evidence and role of system-environment correlations

Vanessa Chille, Niall Quinn, Christian Peuntinger, Callum Croal, Ladislav Mišta, Jr., Christoph Marquardt, Gerd Leuchs, and Natalia Korolkova
Phys. Rev. A 91, 050301(R) – (2015)

New design of electrostatic mirror actuators for application in high-precision interferometry

H Wittel, S Hild, G Bergmann, K Danzmann and K A Strain:
Classical and Quantum Gravity, Volume 32, Number 17 (2015)

Thermal noise reduction and absorption optimization via multimaterial coatings

J Steinlechner, I. W Martin, J Hough, C Krueger, S Rowan and R Schnabel
Physical Review D, Vol. 91 (4), pp. 042001 (2015)

Preparation of magnetic tips for spin-polarized STM on $Fe_{1+y}Te$

U.R. Singh, R. Aluru, Y. Liu, C. Lin, and P. Wahl

Physical Review B **91**, 161111 (2015)

Tomography by noise

G. Harder, D. Mogilevtsev, N. Korolkova, Ch. Silberhorn

Phys. Rev. Lett. **113**, 070403 (2014)

Quantum Spin Dimers from Chiral Dissipation in Cold-Atom Chains

Tomás Ramos, Hannes Pichler, Andrew J. Daley, and Peter Zoller

Physical Review Letters, **113**, 237203 (2014)

Quantum Optics of Chiral Spin Networks

H. Pichler, T. Ramos, A. J. Daley, and P. Zoller,

Phys. Rev. A. **91**, 042116 (2015)

Dirac Surface States and Nature of Superconductivity in Noncentrosymmetric BiPd

Z. Sun, M. Enayat, A. Maldonado, C. Lithgow, E. Yelland, D.C. Peets, A. Yaresko, A.P. Schnyder,
and P. Wahl

Nature Communications **6**, 6633 (2015)