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### Department of Physics Review 2013/14

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Introduction

Head of Departments Statement

The Physics Department has continued to thrive during 2013-14 and inside you will find an overview over the past two years across the considerable breadth of our activities. I took over as Head of Department in May 2014 from Jo Haigh and want to thank Jo on behalf of the department for her outstanding leadership which has left the department in fantastic shape going forward.

The department thrives as an environment where we can provide outstanding teaching delivered by world class researchers. We also have a mission to engage the public with the excitement of our work to try and encourage the next generation of physicists.

Inside this report you will find an overview of the world leading research, which is going on within the nine research groups in the department. You will find a description of the activities of the staff members as well as a listing of a few of their key publications during this period. We have also listed the research grants which the department has received and which enable us to carry out our work, as well as the many awards and prizes which members of staff have received.

We teach around 840 undergraduates and around 400 postgraduate students. Inside you will find an overview of our undergraduate programmes as well as an indication of the many destinations where our undergraduate students continue after graduation. We were also delighted to introduce summer student exchanges with MIT, UBC, SNU, and KAIST allowing some of our top undergraduates to gain research experience overseas.

Postgraduate degrees are available as both taught Masters programmes as well as PhD programmes. You will find inside an overview of the degree courses as well as the topics of projects for the degrees which were awarded during the period of this review. Our Centres for Doctoral Training (CDTs) have been a real success and allowed us to provide a great training programme across these multi-disciplinary centres. In addition, the report provides a summary of the destinations for our PG students. We have continued to provide opportunities for our students to interact with commercial partners through our Industry Club, and a particularly successful event is the annual postgraduate research symposium.

Outreach remains an important fundamental part of our mission and as part of this we were delighted to sponsor an artist in residence some of whose work you will find inside the report.

The department renewed its Athena SWAN silver award in 2012, and immediately began planning as to apply for an upgrade to a gold award. This involves representatives from across the department on our JUNO committee looking at how we can improve the workplace environment and improve the gender and racial imbalance in physics departments.

We have also been working to keep our graduates in contact with the work which is going on here by sponsoring events inviting alumni into the department to hear about our research.

The report inside will give you a sense of the strength of the department, which remains one of the top destinations worldwide for research in and studying physics, and which is in an excellent position to continue to attract the best and brightest students and researchers.

Jordan Nash
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Mr Geoffrey Barber – Project Engineer
Mr Simon Fayer - Computing System Support/Administrator in Grid Computing
Dr Jonathan Fulcher – Data Acquisition System Computing Specialist
Mr Michael Huffman - Computing System Support/Administrator
Dr Gregory Michel Iles - Electronics Engineer
Dr Per Jonsson – Senior Instrument Manager
Dr Andrew Rose - Electronics Engineer
Mr Peter James Savage - Project Engineer
Mr Trevor Edward Savidge - Project Engineer

Photonics Group
Mr Ian Munro - Research Officer

Plasma Physics
Mr Stephen Johnson – Hypersonis & High Speed Impact Laboratory Supervisor

Space & Atmospheric Physics
Dr Seyed Adeli – Instrument Engineer
Dr Leah-Nani Soledad Alconcel - Scientific
Dr Anthony Allen - Scientific
Dr Richard John Bantges – Scientific
Mr Maciej Bendyk – Instrumentation Engineer
Mr Sujit Bhattacharya – Instrument FPGA Designer
Mr Md Rashid – Software Developer
Dr Adi Peter Sloatweg - Research Officer
Mr Lawrence Soung-Yee – Instrument Engineer
Dr Nathan Sparks - Community Support Scientist

Research Support Leavers in 2013/14
Mr Alan Ashton-Smith - Project Administrator
Mrs Piera Brambilla - Technician
Dr Shrawan Jha - Res Engineer

Administrative and Support Staff

Head of Department's Office
Kalvinder Chana - Senior Administrator
Louise Hayward – Research Operations Manager
Linda Jones - Operations Manager for Physics
Caroline Jackson - Executive Assistant (maternity leave)
Victoria Garland – Executive Assistant (maternity cover)

Research Groups
Cluster Office (Astrophysics, Plasma, Space & Atmospherics)
Rachel Barker – Senior Group Administrator
Sandie Bemor - Group Administrator

Condensed Matter Theory & Experimental Solid State Physics Groups
Carolyn Dale - Senior Group Administrator
Juraci Didone - Administrative Assistant
Bhavna Patel - Administrator

High Energy Physics Group
Carol Barlow - Experiments Manager
Paula Brown - Group Administrator
Paula Consiglio – Assistant Group Administrator
Academic, Research and Support Staff

Institute of Shock Physics (ISP)
Alice Moore – Programme Manager
Ciara Mulholland - Senior Administrator for ISP

Optics (Photonics & Quantum Optics Groups)
Judith Baylis - Senior Group Administrator
Marcia Salviato - Deputy Group Administrator
Sanja Maricic - PA to the Centre for Cold Matter Prof Ed Hinds FRS

Theoretical Physics Group
Graziela De Nadai-Sowrey - Group Administrator

DTC
Dr Sophie Armstrong-Brown - Programme Manager
Ms Lisa Cheung – Administrative Assistant
Dr Simon Foster – Outreach Officer
Miss Miranda Smith - DTC Administrative Assistant

Student Administration
Postgraduate Office
Loli Sanchez Rey - Postgraduate Administrator
Dr Andrew Williamson - Postgraduate Development Officer

Undergraduate Office
Edward Charnley – Examinations and Informations Officer
Mery Fajardo - Admissions Administrator
Amira Hussain – Undergraduate Administrator and Year in Europe Coordinato
Derryck Stewart - Undergraduate Education Manager
Geetika Tewari – Undergraduate Administrator

Facilities
Paul Brown - Mechanical Instrumentation Workshop Manager
Vivienne Frater - Departmental Facilities Manager
Simon Graham - Maintenance
Malcolm Hudson - Departmental Buildings Manager
Ranjana Poudel - Common Room Assistant
Alice Powell - Common Room Assistant
Neal Powell - Reprographics
Meilin Sancho - Reprographics
Harry Vine - Departmental Services Manager

Outreach
Anna Lal – Outreach Coordinator

Teaching Laboratory Technicians
Harish Dawda - 1st Year Laboratory
Robert Whisker - 1st Year Laboratory
Graham Axtell - 2nd Year Laboratory
Paul Beaumont - 2nd Year Laboratory

Geoffrey Green - 3rd Year Laboratory
Lee Parker - 3rd Year Laboratory

Mechanical Instrumentation Workshop and Groups Technicians
Trevor Beek (SPAT)
Sofia Bekou (EXSS)
David Bowler
Stephen Cussell (EXSS)
Jonathan Dyne (QOLS)
Alan Finch (PLAS)
Andrew Gregory (QOLS)
Simon Johnson (PHOT / QOLS)
Stephen Johnson (ISP)
Kevin Ladhams (HEPH)
Alan Last (SPAT)
Stephen Maine
Steven Nelson
Melvyn Patmore (PHOT)
Martin Pettifer
David Pitman (ISP)
Alan Raper
Andrew Rochester
Peter Ruthven (QOLS)
James Stone (PHOT / QOLS)
Brian Willey (QOLS)
David Williams

Electronics Workshop Technicians
Valerijus Gerulis
Shahid Hanif
Susan Parker
Bandula Ratnasekara

High Energy Physics Group
Mechanical Workshop
David Clark
Ian Clark

High Energy Physics Group
Electronics Workshop
Sarah Greenwood
Vera Kasey
Maria Khaleeq

Optical Mechanical Workshop
Martin Kehoe

Research and Administrative Support
Staff Leavers
Mrs Sima Fulford - LCN Research Administrator
Dr Christine Thompson - Programme Director
Ms Lilian Wanjohi - Senior Administrator
Miss Hannah Wood - Outreach Coordinator
In October 2013 we welcomed 250 new students, making the total number of undergraduates 844, one of the largest Physics departments in the country. This was the second cohort in which home students were paying fees of £9000 per annum. Students are enrolled onto one of six programmes leading to an MSci or BSc degree. Transfers are easy between most of the programmes in the early years.

All three of our MSci degrees are four-year programmes. The MSci in Physics is by far the most popular, while Physics with a Year in Europe and Physics with Theoretical Physics supply more specialist needs.

We offer three-year BSc programmes in Physics and in Physics with Theoretical Physics. The four-year BSc in Physics and Music Performance, offered jointly with the Royal College of Music, is unique, and attracts small numbers of exceptional candidates. In the summer of 2014 the second cohort of students graduated on our new BSc in Physics with Science Education, offered jointly with Canterbury Christ Church University, which gives students a Physics degree as well as a teaching qualification in 3 years. From October 2015 we will also offer a 4 year MSci version of this programme.

Typically 12% of new students register for BSc degrees and the remainder for MSci. Just over 24% of our students are women, which although short of where we would like it to be is higher than the national average. Many of our exceptional overseas students are female.

The basic structure of the degree programmes is two years of core physics and mathematics, followed by one or two years of advanced options in selected areas of physics.

All students, including those on theoretical physics degrees, do about 6 hours/week of laboratory work during the first 2 years.

All programmes include a research project. Many students find that the project is the most enjoyable part of their degree as they are then able to get to grips with a topic that may be at the frontier of research.
In the third year students can choose from a wide range of physics options and can also take a Humanities or Business School course. Students on the MSci degrees take advanced physics options in their final year, alongside their major research project.

Changes to our lecture courses are made regularly to ensure that they remain topical, but from October 2012 we have been rolling out a revised programme.

We understand that arriving in a class of 250 students can be daunting and impersonal, so alongside the lectures we have activities where students meet in smaller groups and are able to get to know each other better. Each student is a member of a group of about 20, who meet regularly for tutorials as well as laboratory and professional skills sessions. Two members of the academic staff are associated with each group and act as personal tutors, remaining with the group throughout their time at Imperial. On each course in years 1 and 2 students have a tutorial each week in addition to lectures. Tutors encourage discussion about other topics within physics to help students see the wider relevance of their studies.

We have exchange agreements with 14 universities in western Europe. In 2013, 24 students went abroad for a full year in Europe programme and we welcomed 35 visiting students to the department.

Introduced for the first time in 2012, we have begun to set up an overseas summer research project scheme for undergraduate students in their third year who are on a four year integrated Masters degree. The project is eight weeks in length and fully funded through the international office, the Blackett Laboratory industry club on page 18.
The high standard of our lecturing is regularly recognised in the College’s Teaching Awards. Nominations for these awards come from the students themselves. In 2014, the Faculty of Natural Sciences Awards for Teaching Excellence were awarded to:

- Prof Steven Cowley
- Prof Matthew Foulkes
- Dr Subhanjoy Mohanty
- Prof Terry Rudolph
- Dr Richard Hendricks
- Dr Edward Hill
- Dr Alexander Richards
- Dr Francisco Suzuki Vidal
- Miss Giulia Ferlito
- Mr Peter T Fox
- Mr Jeremy Turcaud
- Mr John Wood

The Department was also recognised in the Student Union’s “Student Academic Choice Awards”: Joachim Hamm (Best Supervision), Toby Wiseman (Best teaching for PGs). The department is keen to make sure its students have positive memories of their time at Imperial. It is gratifying, therefore, to see the results from the National Student Survey (NSS) continuing to improve, with notable progress on “overall satisfaction” and on “assessment and feedback”.

The Commemoration Day Reception late in October each year is the setting for our departmental prize giving. In 2014, 28 students were awarded prizes.

Many of our graduates continue their studies within the physics area either by direct entry into a PhD research programme, or a specialist MSc degree such as those discussed in the following section.

Other graduating students use their physics skills in areas such as the financial services industry or information technology. Since a physics degree develops skills such as problem solving and communication as well as technical skills, our graduates are in heavy demand from a wide range of employers.
**Undergraduate**

**Destinations**

<table>
<thead>
<tr>
<th>Destination</th>
<th>Graduates</th>
</tr>
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<tbody>
<tr>
<td>Entered Employment</td>
<td>54</td>
</tr>
<tr>
<td>Further Study</td>
<td>67</td>
</tr>
<tr>
<td>Unemployed</td>
<td>9</td>
</tr>
<tr>
<td>Time Out / Unavailable for Work</td>
<td>12</td>
</tr>
</tbody>
</table>

**Graph 1** – Destinations of 2013 graduates

**Graph 2** – Comparison with previous year

**Graph 3** – Sector of employment entered

www3.imperial.ac.uk/physics
Examples of employers and occupations for Physics graduates who entered employment:

**Examples of Employers:**
- AMEC
- Aon
- Applied Laser Engineering Ltd.
- BAE Systems Detica
- Bank of America Merrill Lynch
- BlackRock
- British Army
- Codis Ltd
- Deloitte
- Dollar Finance Group
- Dorset Software
- EDF
- Encraft
- EY
- Greenhill & Co
- Growth Intelligence
- Holland Park School
- Home Office
- IBM (GBS)
- Imperial College London
- JP Morgan
- KPMG
- Lockton
- MBDA Missile Systems
- Microsoft
- MU Innovation Ltd
- Newton Europe
- Open GI Ltd
- Precision Microdrives Ltd.
- PwC
- Ramboll
- Renishaw plc
- Rolls Royce plc
- Royal Navy
- Schlumberger
- Siemens PLM Software
- STFC Innovations Ltd
- Teach First
- TradeRisks Ltd
- UBS

**Examples of Occupations:**
- Actuarial Analyst
- Actuary
- Analyst
- Analyst - Penetration Tester
- Associate - Accounting
- Audit Associate
- Business Consultant
- Compliance Officer
- Consultant/Engineer
- Cyber Security Consultant
- Developer
- Development Engineer
- Efficiency Consultant
- Engineer
- Event Technician
- Finance Advisory Analyst
- Financial Modelling Analyst
- FX Options Trader
- Geophysicist
- Graduate Engineer
- Graduate Optical Engineer
- Graduate Safety Case Consultant
- Graduate Software Developer
- Investment Banking Analyst
- IT Consultant
- Officer in the British Army
- Operations Director
- PA to the CEO
- Project Manager/Busine
- Royal Naval Officer
- Sales Engineer
- Scientific Officer
- Secretary
- Software Developer
- Software Engineer
- Sub-editor for New Scientist magazine
- Tax Associate
- Teacher
- Technology Consulting Analyst
- Trainee Building Physics Consultant

**Examples of courses for those Physics graduates who entered further study or training:**
- ACA
- Astroparticle Physics Research
- BBMRC Doctoral Training Program; Year 1: MRes in Systems and Synthetic Biology
- Biomedical and Medical Imaging Doctoral Training Programme
- Cancer Research
- Japanese Language, Tokyo School of Japanese Language
- Condensed Matter Physics Research
- DPhil in Atmospheric, Oceanic and Planetary Physics
- DPhil in Atomic and Laser Physics
- DTC in Nanoscience
- Economics, Finance & Management
- Elementary Particle Physics Research
- EngD in Non-destructive Evaluation
- Graduate Diploma in Law
- Masters in Management Science & Engineering
- MBBS Medicine
- MPhil in Scientific Computing
- MPhil/PhD in Telecom munications
- MRes/PhD in Controlled Quantum Dynamics
- MRes Photonics Systems Development
- MSc Aerospace Dynamics
- MSc Epidemiology
- MSc Applied Physics
- MSc Astrophysics
- MSc Biotechnology, Bio processing and Business Management
- MSc Computational Statistics and Machine Learning
- MSc Environmental Technology
- MSc Information Security
- MSc Integrative Neuroscience
- MSc Nanotechnology
- MSc Philosophy of Science
- MSc Physics
- MSc Physics and Engineering in Medicine
- MSc Physics and Technology of Nuclear Reactors
- MSc Plasma Physics
- MSc Quantum Fields and Fundamental Forces
- MSc Space Technology and Planetary Exploration
- Optical Projection Tomography Research
- PGCE (Secondary - Physics with Maths)
- PhD in Climate Science
- PhD in Condensed Matter Theory
- PhD in Controlled Quantum Dynamics
- PhD in High Energy Physics
- PhD in Low Carbon Technologies
- PhD in Meteorology
- PhD in Physics
- PhD in Space Plasmas
- Quantum Computing Research

What do Physics Undergraduates do?
Undergraduate

International summer research exchange scheme for undergraduate students

Introduced for the first time in 2012, the international summer research project exchange scheme for undergraduate students is designed to exchange students with some of our closely linked partner universities overseas. The exchange means that we also host students for the summer from MIT Boston, the University of Vancouver in British Columbia, and Seoul National University. In 2014 we also sent six students to join the KAIST one month summer workshop program. The following records some impressions by the students who were sent out in the summer of 2014. More details on the scheme can be found at the following link https://www.imperial.ac.uk/students/global-opportunities/ug/studentexp/.

SNU
We sent Kofi Mundy-Castle, Tim Harrington, and Andrew Warwick to Seoul National University. Here is a short description from Tim:
Spending eight weeks in Seoul National University, South Korea, was a fantastic, once in a lifetime experience. It gave me the opportunity to live in a country surrounded by an interesting culture, working alongside accomplished physicists in an area of research I was interested in. I managed to meet lots of people in order to live like a true Seoulite while also travelling the country and exploring the vibrant, dynamic capital on weekends.

UBC:
Thomas Whiting and Leon van Riesen-Haupt travelled to Vancouver. Here is part of Leon’s exchange description:
After a nine hour flight and a long taxi ride to the student accommodation I arrived in my room and realised this would be my home for the next eight weeks. My project was in the Astrophysics group and was self-contained making it ideal as a summer project. Living on campus meant that I had a ten minute walk to work every day and could buy a coffee on my way in. I worked in a room with other undergraduates and a friend from imperial was a few doors away from me making it a very pleasant working environment. The aim of the project was to statistically analyse images from the sky and try to determine the underlying brightness distribution of the resulting blurred image. The project involved accessing a super computer using a Linux based system and writing up code in python. I had never used Linux before and only learnt C++ in Uni part of the challenge was to learn the two new languages and get used to them. The people I worked with were very friendly and helpful making this a very enjoyable and valuable experience. After that my job was to write up code that could simulate the sky and then apply a fitting algorithm on it to see whether it would come up with the original distribution. Unfortunately I didn’t have time to apply my code to...
strengthened and refined my practical skills in handling technical equipment, which is a fundamental aspect of science that can sometimes be overshadowed by the mathematics and the formulae: theory would be pure speculation if there were no experimental devices able to test it. I am now very competent in using various kinds of data analysis software, also employed in several other fields of science, which I will almost certainly get to use again. The group held two weekly meetings: these trained me in summarising the progress that had been made and explaining it to an audience unfamiliar with the specifics of my experiment, in order for others to make suggestions on how to tackle any problems. They also allowed me to reflect upon other people’s difficulties, whilst becoming acquainted with what everyone was working on. At the end of my stay, I wrote a report detailing the research I carried out and I gave a power point presentation summarising the main results obtained: these enhanced my oral and written skills in presenting scientific work to an expert audience.

This is a short description from Cyprian

During my placement I joined Prof. Levitov’s group within the department of Condensed Matter Theory. My research centred on a variety of topics related to graphene. Every problem required different set of methods and techniques to be employed, which although challenging at first, was immensely educational. The main project focused on investigation of properties of a circular p-n junction, which arises due to the interplay of Fabry-Perot resonances and quantum tunnelling into the system from an STM tip. Together with Prof. Levitov we developed a model, which potentially, in addition to providing qualitative understanding, will also describe experimental data quantitatively too. Aside of the research project to which I dedicated most of my time, I really enjoyed the summer at MIT. Together with fellow exchange students we went on several sightseeing excursions and I found a little bit of time to enjoy Cambridge and Boston as well, not to mention the variety of wonderful running routes alongside Charles river. Overall I found the summer research placement at MIT extremely useful and given another chance I would have applied for it again!

KAIST
Malik, Yasmin, Jonas Evaes, Jan Piech, and Alexander Soloviev all travelled to KAIST for the summer
Here is a short description from Yasmin:

Annyeonghaseyo! This summer I was lucky enough to complete a 4 week research placement, along with 5 other students from the physics department, at the Korea Advanced Institute of Science and Technology (KAIST). The university is situated in Daejeon - the country’s fifth largest city, south of the capital city Seoul.

Aside from our placements, we partook in numerous excursions and cultural activities, ranging from all terrain vehicle and rafting in Muju, to ceramics painting in Icheon. We also took trips to Seoul, where we visited old and new attractions alike, for example the Changdeokgung and Gyeongbokgung palace as well as the Namsan Tower. We were even treated to a tour of Samsung Electronics’ flagship showroom. I thoroughly enjoyed my time in South Korea, and I would like to thank the international offices of both Imperial College and KAIST as they were extremely helpful over the course of the trip. I would definitely recommend doing an international research placement to any students that may be considering it for next summer.
actual data, however, my supervisor said he was still pleased about my progress and that I should contact him if I wanted to apply for a post grad at UBC. The exchange was also a wonderful cultural experience. Living in Vancouver for two months meant that I got a proper experience of the city and not just what a tourist would see. UBC itself was on first nation grounds and right next to the Pacific spirit forest. It is situated at the end of a peninsular west of downtown Vancouver meaning that it was almost completely surrounded by coast. The ride into the city took less than half an hour with the 24/7 bus service so it was easy to go sightseeing or just downtown with a few friends. All this meant that during the week there was always a lot to discover after work. I also rented a car and crossed the US border twice; once to go camping in the North Cascade national park with a group of people I had met at UBC and once to go to Seattle for a week end with a group of other Imperial students.

MIT: Rosanna Nichols, Cyprian Lewandowski, and Matteo Sbroscia, travelled to MIT. Matteo has submitted the following description of his visit. The Massachusetts Institute of Technology has been ranked 1st university in the world this year (2014): it has a history of accomplishments that has established its role in the advancement of science and it continues to stand out as one of the most exciting centres of scientific research in the world. As a consequence, it attracts scientists from all over the world who represent the very best of their countries’ academic excellence. I had the privilege of working in an international environment, with nearly 10 different nationalities in my group alone: discussion about everyone’s habits and culture was a very enriching experience, and one which resulted in a friendly rivalry during the Football World Cup matches that we watched together. Our hall of residence was also rich in cultural diversity: there were 10 nationalities within our exchange group, plus American students enrolled at MIT with whom we socialised and discussed. The focus of my studies is mainly theoretical, as I am pursuing a degree in Theoretical Physics, which is what motivated me to undertake a summer internship in experimental physics. It
2014 Activities
The department has a dedicated Outreach office, managed by a Senior Teaching Fellow, Dr Mark Richards and employing full-time two other members of staff (Hannah Woods replaced part way through by Vinita Hassard and Dr Simon Foster). Funding in support of these activities has been awarded by the Ogden Trust and the RCUK School University Partnership Initiative. Simon Foster trains and supports staff and students to participate in outreach and public engagement, as well as undertaking his own bespoke Outreach activities associated with the three EPSRC funded Centres for Doctoral Training.

During 2014 the department undertook numerous activities such as talks, workshops, and interactive demonstrations with schools, local societies, teacher groups, and other likeminded institutions (such as the Institute of Physics). We have attended HE fairs, science careers events and national science events (including the Expo Science Fair, Cheltenham science festival, Big Bang fair, Science Uncovered, and the Royal Society Summer Exhibition).

In 2014 Physics staff members presented many outreach and public understanding talks. These activities are listed at http://www3.imperial.ac.uk/physics/about/outreach.

Engaging Young People

Insights Work Experience Programme:
In 2014, the department ran its flagship Insights work experience scheme for the third year running. The scheme is designed for year 12 students in schools with little or no previous connection to the College, thereby widening access. It offers an opportunity for able students who attend such schools to obtain a glimpse into research as well as experiencing the life of an undergraduate. We received nearly 800 applications for the 2014 insights scheme, and recruited a cohort of 40 students.

Open Days:
The Department Open Days continue to be a great success; around 20% of our final student intake attended our open days. They are aimed at showcasing recent research, providing an insight into physics courses, and examples of careers that can result from a physics degree. Throughout the year, special emphasis may be placed on attracting GCSE students (years 10-11), A-Level physics students (years 12-13), and girls through the Juno annual Women In Physics open day. In 2014, we welcomed approximately 1500 students in the department.

Special Events:

Tutored sessions with the Amos Bursary. Led by Dr Mark Richards, a short course was prepared and delivered (by physics UG students) to recipients of the Baroness Amos Bursary – a charity that encourages state educated British young men of African and Caribbean heritage to realise their study and career ambitions. Primarily intended for students studying both A-level
Outreach

mathematics and physics the aim was to show how the two subjects are intertwined whilst also preparing them for some of the more challenging aspects on the syllabus. This event was run twice in 2014.

Teachers

Communicating Physics:
Undergraduate students can nominate Communicating Physics, as one of their accredited option courses in either their second or third year. Students are placed in a London school for ½ day per week over a period of 10 weeks. The course is expanding year-on-year, and the number of participating schools has reached 20 (in 2013/2014).

BSc Physics with Science Education: With the aim of helping to provide quality, specialist physics teachers who can inspire the next generation, in 2012 the department launched the three year BSc Physics with Science Education degree, the first of its kind in England and Wales. Students must have completed Communicating Physics in their second year, and then spend their third year carrying out a mixture of teaching practices and core physics. Students graduate with a physics degree that is fully accredited by the Institute of Physics and with Qualified Teacher Status.

Teachers Workshops: In 2011 a fully funded Teachers’ Workshop was set-up aimed at helping non-specialist science teachers, required to teach physics but who may not have a physics degree. The event is designed to help improve a teachers’ understanding of the subject, boosts their confidence and provide them with resources to take back into the classroom, including motivational material on current physics research. All this is aimed at making physics a more engaging subject for teacher and student alike. Over 50 (mainly state school) teachers attended 2014, potentially impacting on thousands of schoolchildren.

INSPIRE: Simon Foster is the physics tutor for the College’s teacher training programme called INSPIRE. This is a scheme run in conjunction with Canterbury Christy church (http://www3.imperial.ac.uk/inspire) giving hands on practical advice on how to teach the various modules of the physics syllabus/curriculum.

Public Debates and Lectures 2014

Fringe/Festival Festive Fringe.
11 Dec 201416:00 - 20:00
Shedding new light on Schrödinger’s cat (live streamed lecture) Physics Nobel Laureate Professor Serge Haroche delivers the annual Schrödinger Lecture. 12 Nov 2014

Roberto Trotta – Book Launch

Science Museum Lates Lecture-STEM in the Community (at home and abroad): The Physics Outreach team at Imperial College London hosted an event together with CADSTI and BFUWI. 08 Nov 2014.

Event for schools ‘The Universe’ A talk about The Universe given to Primary School pupils by Arttu Rajantie, Professor of Theoretical Physics. 21 Oct 2014.

Talk at NBC studios: Professor Jerome Gauntlett on “A Brief History of the Science of Stephen Hawking”, preceding screening for the film “The Theory of Everything” 2014. It was a ‘How to academy’ event.

School talk by Professor Jerome Gauntlett: Kings College School, Wimbledon, Mar 2014 The Higgs boson: what is it and why it matters?

Lecture The many facets of time: An evening exploring time as perceived through music, dance, psychology, and a talk by Nobel Prize winning physicist, Professor Brian Josephson: 01 Oct 2014.

Open days Undergraduate Open Day 20 Sep 2014.

Event for schools Year 11 Project STEM Summer School 21-25 Jul 2014.

Event for schools Stand at a Science Fair: Professor Arttu Rajantie presents a Particle Physics and Cosmology Stand at a Science Fair. 21 Jul 2014.

Event for schools Talk- ‘What does the Higgs Say?’ Talk for GCSE and A-Level students by Arttu Rajantie, Professor of Theoretical Physics at Imperial College London. 09 Jul 2014. Event for schools Insights Work Experience 2014: 40 Year 12 students attended the Insights work experience placement in the Physics Department at Imperial College London. 30 Jun-11 Jul 2014.

Open days Physics Project Open Day for A Level Students: The Project Open Day is a great opportunity for current A-level students to gain a first-hand insight into studying physics at Imperial College London 20 Jun 2014.

Open days Physics Open Day for GCSE Students: The GCSE Open Day is a great opportunity for students who might be considering studying Physics beyond year 11. 19 Jun 2014.

Lecture Firewalls around black holes: What would you experience if you jumped into a black hole? Public talk by Caltech physicist Sean Carroll and science writer Jennifer Ouellette. 05 Jun 2014.

Event for schools Women in Physics This exciting event was aimed at Years 10, 11 and 12, students who were already studying or were considering studying A level physics. 04 Jun 2014 10:30 - 16:00.

General Imperial Festival 2014: With demonstrations, talks, music, dance and more, Imperial’s ground breaking research at the third Imperial Festival 09-10 May 2014 Event for schools High Energy Physics Masterclass: A particle physics masterclass for sixth form students and teachers: 02 Apr 2014 11:00 - 17:00.
**Outreach**

Event for schools **Beetles, Black Holes and Editing History** On March 24th 2014, Professor McCall from the Physics Department at Imperial College presented to students at The Judd School.

Event for schools **The Solar System with Fruit and Veg** Dr Roberto Trotta from the Physics Department at Imperial College London presented to students from Norland Place School. 05 Feb 2014.

Event for schools **Physics at Imperial**: On January 28th, school students visited the Physics Department at Imperial College London to hear Dr Daniel Mortlock and Dr Robert Forsyth present. 28 Jan 2014.

Event for schools **Schools Science Partnership Launch Event**: staff from the Physics Department at Imperial College London presented to students from three south London schools. 22 Jan 2014.

Event for schools **Training Course** Dr Vijay Tymms from the Physics Department at Imperial College presented to students from The Royal Central School of Speech and Drama. 12 Jan 2014.

Event for schools **“What Does the Higgs Say?”** On 12th December 2013, Professor Arttu Rajantie from the Physics Department at Imperial College London presented to students from Highdown School. 12 Dec 2013.

Event for schools **Space Weather and Solar Storms**: On Friday 6th December 2013, Professor Schwartz from the Physics Department at Imperial College London presented to students from The Elmgreen School. 06 Dec 2013.

Lecture **RCSU Science Challenge Launch** On 3rd December 2013, Dr Simon Foster from Imperial College London took part in the Royal College of Science Union’s Science Challenge.

External **Uncovering the Dark Side of the Universe** On Tuesday 3rd December, Dr Roberto Trotta from Imperial College London.

ASTR has run small sci-fi workshops for writers yearly since 2010 – Science for Fiction. Approximately 30 people have attended each year. HEPP participates in the annual National Particle Physics Master Class.

QOLS PG students present an annual Quantum Show (running since 2009) with talks and demonstrations on recent developments in quantum physics for a diverse public audience numbering around 350. Based on the success of the shows the students have produced a series of workshops for teachers and have repeated the show at a variety of schools within the London area, along with a number of music festivals. The students have also undertaken a women in science lecture series at four or five London schools in the 2012-13 period.
Postgraduate
The Department of Physics at Imperial College is one of the largest Physics departments in the UK. The Department’s research covers a comprehensive range of topics in theoretical and experimental fields and has a flourishing postgraduate research and taught MSc community. We offer seven Master’s level taught postgraduate courses, as well as the extended Masters in Physics as a two year full time course. Our first students in this extended Masters graduated recently. A new element in our one year MSc in Physics are two streams dedicated to Shock Physics, and to Nanophotonics.

Three of our masters courses are associated with EPSRC Centres for Doctoral Training (CDTs), the areas of which are Controlled Quantum Dynamics, Plastic Electronics and Theory and Simulation of Materials. The CDT courses can lead directly to PhD studies and were successfully renewed this year.

PhD research fields extend from astronomy, space and plasma physics to high energy, theoretical and atomic physics, and condensed matter theory. Solid state physics, plastic electronics, laser physics, applied optics and photonics, nanophotonics/plasmonics and metamaterials as well as quantum information are all areas where there are close collaborations with industry, as well as providing opportunities to study fundamental underlying principles. The Department has had a successful year in attracting the best students worldwide via the Imperial College PhD Scholarship scheme (six students funded) and the joint Imperial / National University of Singapore (NUS) PhD programme, where two students have joint.

There are many examples of international and industrial collaboration involving our research groups and we are also very strongly involved in interdisciplinary research centres around the College. We are directly linked to the Thomas Young Centre (TYC), the Shock Institute, the Centre for Plastic Electronics (CPE), the Institute of Chemical Biology, the Centre for Plasmonics and Metamaterials and the Grantham Institute for Climate change – all of which are centres of interdisciplinary research within the Imperial College campus. Many groups are involved in research using large scale facilities. The Department has extensive internal facilities and a tremendous range of research topics available to postgraduate research students.
Rebecca Lane  
**Group:** HEPP  
**Supervisor:** Dr D Colling

Rebecca’s Ph.D research focused on analysing proton-proton collision data from the world’s largest particle accelerator: the Large Hadron Collider (LHC). The data was taken by the Compact Muon Solenoid (CMS) detector throughout the years of 2011 and 2012 and analysed in different ways to probe the properties of the Higgs boson discovered at the LHC. The Higgs boson is observed via the final states it decays into, and Rebecca’s work was to study the final state of two tau leptons. Only by observing the Higgs boson in all of its predicted decays and making precision measurements of their relative decay rates can we ensure that this discovered particle is the Higgs boson predicted by the Standard Model of Particle Physics.

During Rebecca’s Ph.D, she spent two years based at CERN near Geneva. She worked as part of a group of researchers from many institutes across the world to develop an analysis to study the Higgs in the final state of two taus. Only by observing the Higgs boson in all of its predicted decays and making precision measurements of their relative decay rates can we ensure that this discovered particle is the Higgs boson predicted by the Standard Model of Particle Physics.

Oliver Pike  
**Supervisor:** Prof Steven Rose  
**Group:** Plasma

Oliver Pike has been a PhD student in the Plasma Physics Group at Imperial College for the last three years, funded by an EPSRC studentship with a CASE top-up award from AWE Aldermaston. His work focuses on theoretical aspects of high energy density plasma physics and he has published several first author papers in the area of relativistic effects in plasmas. One of his most notable pieces of work explained how it may now be possible to use ultra-high-power lasers to study fundamental quantum physics in the laboratory. Oliver was the lead author on a recent Nature Photonics paper that showed theoretically how the elusive Breit-Wheeler two-photon pair-production process could be studied in the laboratory, some 80 years after it was first proposed. This process is the "simplest" method by which light can be transformed into matter, but has proven remarkbly difficult to demonstrate experimentally due to the very extreme conditions required. The paper received an astonishing amount of publicity in the scientific and popular press. Oliver has since been working closely with AWE on practical designs for an experiment that can be undertaken on their large ORION laser facility, hopefully in 2015.
Nuclear power is a reliable and clean source of energy that offers low CO2 emissions. As the industry progresses, it is crucial that nuclear reactor technology continues to become safer. During the MSc I modelled a diffusion mechanism that is responsible for the embrittlement of nuclear fuel cladding. This involved the classical field theory of the interaction between the diffusing species and continuum fracture using Green tensors and singular integral equations. In my current PhD research, I am using conformal mapping to describe the concentration profiles ahead of elliptical voids in the component. This work builds on another PhD project in which many-body quantum mechanical simulations were used to identify the role of the diffusing species within the cladding material. I work at the boundary between condensed matter physics and engineering, interfacing theoretical and computational methods; I am supervised by Daniel Balint (Mechanics of Materials, Mechanical Engineering), Mark Wenman (Centre for Nuclear Engineering) and Adrian Sutton (Condensed Matter Theory, Physics). We are applying fundamental physics to a problem of major industrial importance and we work in close collaboration with Rolls-Royce.

Michel Buck's thesis was in the area of the causal set approach to quantum gravity. The focus was investigating a privileged state, the Sorkin-Johnston (SJ) state, for scalar quantum field theory derived from the causal structure of spacetime. In a causal diamond in 2 dimensional flat space, he found that for the massless scalar field the SJ state approximates the state between two perfect mirrors positioned at the spacelike corners of the diamond. In deSitter spacetime, which is of great interest to cosmologists both because of inflation and the acceleration of the expansion of the universe today, the SJ state depends on the spacetime dimension, mass of the field, and on the choice of subregion, differing in many cases from the usual Bunch-Davies vacuum. This may have implications for early universe cosmology, indicating a physical role for certain deSitter invariant “alpha” states.

Michel published 4 papers before graduating and in November 2014 he took up a postdoctoral research position in the Department of Physics at Northeastern University, Boston MA, USA.
Nipol Chaemjumrus
Nipol Chaemjumrus came to the MSc in Quantum Fields and Fundamental Forces from Thailand on a prestigious Queen Sirikit Scholarship. He did exceptionally well, coming first in the QFFF examinations and in consequence was awarded the Salam prize for this accomplishment, shared with the student who came second. His MSc Dissertation was entitled “Non-Geometric Flux and Double Field Theory”, supervised by Professor Chris Hull. He is now working on his PhD at Imperial, supervised by Professor Chris Hull and building on the work he did in his MSc project.

Wenjun Guo
Wenjun Guo obtained a BSc in Optical Science and Technology from Sun Yat-sen University, China, before starting his postgraduate study in MSc in Optics and Photonics at Imperial. His MSc project was on characterising the temperature-dependent performance of diode-pumped Alexandrite laser under the supervision of Prof. Mike Damzen. During the project, he first designed a temperature-controlling laser crystal holder, which had a temperature-tuning range from 20°C to 150°C with an active cooling capability, and was then utilised to characterise the performance of diode-pumped Alexandrite laser in terms of the threshold pump power, the slope efficiency, the output power, and the output wavelength under various temperatures. Experimental results revealed that, in contrary to most other lasers, Alexandrite laser can have an enhanced performance at temperatures higher than the room temperature, which can be explained by the vibronic nature of its laser crystal. The results also provided some preliminary data on the optimal operating temperatures for different laser operation modes, contributing to the development of a diode- pumped Alexandrite laser system with a higher wall-plug efficiency that is especially suitable for the space-borne lidar applications. Currently, Wenjun is a PhD candidate in the Francis Crick Institute and the Photonics Group of Imperial College London, working with Dr. Peter Thorpe, Prof. Paul French, and Dr. Chris Dunsby, on investigating the role of the protein Rdh54 in the mitotic checkpoint using the optical technique FLIM FRET.
Postgraduate

PhD Degrees awarded in the Department in 2012

<table>
<thead>
<tr>
<th>Group</th>
<th>(M)</th>
<th>(F)</th>
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<tr>
<td>Astrophysics</td>
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<td>Condensed Matter Theory</td>
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<td>Experimental Solid State</td>
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<td>High Energy Physics</td>
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<td>Quantum Optics &amp; Laser Science</td>
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<td>Plasma Physics</td>
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<td>Space &amp; Atmospheric Physics</td>
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<td>Theoretical Physics</td>
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<td>Totals</td>
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</table>

### Astrophysics

- W. Ball (M) "Observations and Modelling of Total and Spectral Solar Irradiance" Supervisor: Dr Y Unruh
- M. March (F) “Advanced Statistical Methods for Astrophysical Probes of Cosmology” Supervisors: Prof A Jaffe & Dr R Trotta

### Condensed Matter Theory

- P.W. Avraam (M) “Linear-Scaling First-Principles Calculations of Entire Semiconductor Nanorods” Supervisor: Prof M Haynes
- P. Expert (M) “An Odyssey with complexity and network science: From the brain to social systems” Supervisors: Prof K Christensen & Prof H Jensen
- J. S. Gill (M) “Morphology and vascular transport in the human placenta” Supervisor: Prof D Vvedensky
- Y. Luo (M) “Transformation optics applied to plasmonics” Supervisor: Prof Sir J Pendry
- A. Pusch (M) “Self-induced transparency solitons in nanophotonic waveguides” Supervisor: Prof O Hess
- S. Wuestner (M) “Gain and Plasmon Dynamics in Active Nanoplasmonic Metamaterials” Supervisor: Prof O Hess
- W. Elder (M) “Semi-empirical modelling of SiGe heterostructures” Supervisor: Prof J Zhang
- M. Faist (M) “Spectroscopy of the charge transfer state and device studies of polymer:fullerene photovoltaic blends” Supervisors: Prof J Nelson & Prof J De Mello
- J. Frost (M) “Computational Modelling and Design of Conjugated Molecular Electronic Materials” Supervisor: Prof J Nelson
- L. Hirst (F) “A spectroscopic study of strain-balanced InGaAs/GaAsP quantum well structures as absorber materials for hot carrier solar cells” Supervisor: Dr N Ekins-Daukes

### High Energy Physics

- A. Alekou (F) “Ionisation Cooling Lattices for the Neutrino Factory” Supervisor: Dr J Pasternak
- G. Ball (M) “Cross section studies of the Z and neutral supersymmetric Higgs bosons decaying to tau leptons at CMS” Supervisor: Dr DJ Colling
- C. Blanks (M) “V production ratios at LHCB and the alignment of its RICH detectors” Supervisor: Prof U Egede
- A. Currie (M) “Direct searches for WIMP dark matter with ZEPLIN-III” Supervisor: Dr HdOP Araujo
- M. Cutajar (M) “Search for supersymmetric neutral Higgs bosons decaying to \( \tau^+ \tau^- \) pairs in the e+\tau-jet final state with calibration using Z\ell\ell events at CMS” Supervisor: Dr DJ Colling
- J.E. Dobson (M) “Neutrino Induced Charged Current \( \nu^+ \) Production at the T2K Near Detector” Supervisors: Dr Y Uchida & Dr C Andreopoulos
- R. Ward (M) “Modelling of Silicon-Germanium Alloy Heterostructures using Double Group Formulation of k.p Theory” Supervisors: Dr P Stavinou & Prof J Zhang
- H. Yoon (M) “Highly localised surface plasmon polaritons in active metallo-organic multilayer structures” Supervisors: Dr P Stavinou & Prof S Maier & Prof DDC Bradley

### Optics - Photonics

- A. Favaro (M) “Recent Advances in Classical Electromagnetic Theory” Supervisors: Prof M McCall

**PhD Thesis Awarded**

- A.E. Gunaratne Bryer (M) “A Search for Supersymmetry with Same-Sign Tau and Lepton Final States at the CMS Experiment” Supervisor: Prof O Buchmueller
- Z. P. Hatherell (F) “Searching for SUSY in events with Jets and Missing Transverse Energy using \( \alpha_{\mu} \) with the CMS Detector at the LHC” Supervisor: Prof J Nash
- P. Maslia (M) “Study of muon neutrino disappearance in the T2K experiment” Supervisor: Dr M Wascko
- R.J. Nandi (M) “A Search for Supersymmetry in Events with Photons and Jets from Proton-Proton Collisions at \( \sqrt{s} = 7 \) TeV with the CMS Detector” Supervisors: Dr J Hays & Dr C Seez
- P.N. Schaack (M) “Measurement of the decay BS\ell\ell\ell at LHCB” Supervisor: Prof A Golutvin
- A.G. Sparrow (M) “Measurement of the Polarisation of the W Boson and Application to Supersymmetry Searches at the Large Hadron Collider” Supervisors: Dr A Tapper & Prof T Virdee
- T. Whyntie (M) “Constraining the supersymmetric parameter space with early data from the Compact Muon Solenoid experiment” Supervisor: Prof G Hall

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Department of Physics Review 2013 -14
Postgraduate

PhD Thesis Awarded

E. Kelleher (M) “Advancements in modelocked fibre lasers and fibre supercontinua” Supervisor: Prof JR Taylor

P. Ramirez Hernandez (M) “Extended Depth of Field” Supervisor: Prof P Török

G. Thomas (F) “High power modelocking using a nonlinear mirror” Supervisor: Prof M Damzen

Optics - Quantum Optics and Laser Science - MPHIL

S. Begley (M) “Toward implementing conditional quantum logic on-chip using the Kerr nonlinearity” Supervisor: Prof E Hinds

Optics - Quantum Optics and Laser Science

S. Donnellan (M) “Towards Sideband Cooling of a Single 40Ca+ ion in a Penning Trap” Supervisors: Prof RC Thompson & Prof D Segal

H. W. Doyle (M) “Creating and Probing Warm Dense Matter and High Energy Density Blast Waves” Supervisor: Prof R Smith

D. Herrera-Marti (M) “Implementation of Fault-Tolerant Quantum Devices” Supervisors: Dr S Barrett & Prof T Rudolph

I. R. Hill (M) “Development of an Apparatus for a Strontium Optical Lattice Frequency Standard” Supervisors: Dr E Curtis & Dr BE Sauer

M Kohnen (M) “Detecting Atoms with Integrated Optics and Frequency-Synthesised Light” Supervisor: Prof EA Hinds

Plasma Physics

J. Bissell (M) “Magnetically Transported and Instability in Laser Produced Plasmas” Supervisor: Dr RJ Kingham

D. J. Moulton (M) “Numerical Modelling of H-mode Plasmas on JET” Supervisors: Prof W Fundemanski & Prof S Rose

N-P. Niassse (M) “Development of a Pseudo Non-LTE model for Z-pinch simulations” Supervisor: Prof JP Chittenden

C. Palmer (M) “Approaching the radiation pressure regime of proton acceleration with high intensity lasers” Supervisors: Prof R Evans & Prof Z Najmudin

A. Rehman (F) “Optical Probing of high-intensity laser propagation through plasmas” Supervisors: Dr B Dangor & Prof Z Najmudin

G. Swadling (M) “An experimental investigation of the azimuthal structures formed during the ablation phase of wire array z-pinches” Supervisors: Prof SV Lebedev

C. Willis (M) “Dust in Stationary and Flowing Plasmas” Supervisor: Dr M Coppins

Space & Atmospheric Physics

R. Beeby (M) “Validation of the far-infrared foreign-broadened water vapour continuum from airborne field campaign measurements” Supervisor: Dr J Pickering

C.H.J. Cheung (M) “A Study of Stratosphere-Troposphere Coupling with an Aquaplanet Model” Supervisors: Dr A Czaja & Prof JD Haigh

C. Dancel (M) “An analysis of the hydrological cycle and poleward heat transports simulated by two climate models” Supervisor: Dr AC Czaja

A. Flint (F) “Model Sensitivities and Stratosphere - Troposphere Interactions” Supervisor: Prof JD Haigh

E-M. Giannakopoulou (F) “Land - Boundary Layer - Sea Interactions in the Middle East” Supervisor: Prof R Toumi

N. Sparks (M) “Measurement and analysis of local urban CO2 emissions” Supervisor: Prof R Toumi

R.H. White (F) “New Bias Correction Methods for Simulating Precipitation and Runoff in the Weather Research and Forecasting Model” Supervisor: Prof R Toumi

Theoretical Physics

B. Hoare (M) “The S-matrix of the Pohlmeyer-reduced AdS5 x S5 superstring” Supervisor: Prof A Tseytlin

Y. Iwashita (M) “Quantum aspects of Pohlmeyer-reduced AdS5xS5 superstring” Supervisor: Prof A Tseytlin

J. J. Noller (M) “Disformal Gravity” Supervisor: Prof J Magueijo

T. Pugh (M) “Chiral Supergravities” Supervisor: Prof K Stelle

W. Rubens (M) “On The Black Hole / Qubit Correspondence” Supervisor: Prof MJ Duff

C. Strickland-Constable (M) “Generalised Geometry of Supergravity” Supervisor: Prof DJ Waldram

D.B. Thomas (M) “A Change is as Good as a Test: Observational Tests of Extensions to the Concordance Cosmological Model” Supervisor: Dr C Contaldi

G. Torri (M) “Counting gauge invariant operators in supersymmetric theories using Hilbert series” Supervisor: Prof A Hanany

PhD Degrees awarded in the Department in 2013

Group (M) (F)
Condensed Matter Theory 1
Controlled Quantum Dynamics 2 1
Experimental Solid State 9
Grantham Institute 1
High Energy Physics 9 2
Photonics 1 1
Quantum Optics & Laser Science 12
Plasma Physics 10 1
Plasma Institute of Shock Physics 1
Space & Atmospheric Physics 2 2
Theoretical Physics 4 1
Theoretical Physics – MPHIL only 1
Totals 52 9
Condensed Matter Theory

E. Barkhudarov (M) "Renormalization Group Analysis of Equilibrium and Non-Equilibrium Charged Systems" Supervisor: Prof D Vvedensky

Controlled Quantum Dynamics CDT

S Jevtic (F) "Large Consequences of Quantum Coherence in small systems" Supervisor: Prof T Rudolph

M. Pusey (M) "Is quantum steering spooky?" Supervisor: Prof T Rudolph

M.P. Woods (M) "Orthogonal Polynomials and Open Quantum Systems" Supervisors: Prof M Plenio & Prof M Kim

Experimental Solid State Physics

N. Chan (M) "Solar electricity from concentrator photovoltaic systems" Supervisors: Dr N Ekins-Daukes & Dr H Brindley & Dr B Chaudhuri

F. Colleaux (M) "Novel Solution-Processable Dielectrics for Organic and Graphene Transistors" Supervisors: Prof DDC Bradley & Prof T Anthopoulos

R. Fernandez Garcia (M) "Simulation and characterization of optical nanoantennas for field enhancement and waveguide coupling" Supervisor: Prof S Maier

S. Foster (M) "On the influence of physical and chemical structure on charge transport in disordered organic semiconducting materials and devices" Supervisor: Prof J Nelson

D. James (M) "Developing Structural Probes for Designed Molecular Architectures" Supervisor: Dr J-S Kim

J. McGurk (M) "Analysing Gain for Organic Laser Applications" Supervisors: Dr P Stavrinou & Prof DDC Bradley

R. Stanley (M) "A structural and spectroscopic investigation of polyfluorene copolymers in solution and the solid-state" Supervisor: Dr A Campbell

M. Taylor (M) "Resolving spin physics in self-assembled InAs/GaAs quantum dots" Supervisor: Prof R Murray

I. Usman (M) "Investigating Inhomogeneous FM at SC/FM Interfaces Using Point-Contact Andreev Spectroscopy" Supervisor: Prof L Cohen

High Energy Physics

P. Guzowski (M) "Reconstruction of neutrino induced neutral current neutral pion events with the T2K ND280 Tracker and ECAL" Supervisor: Dr M Wascko

S. Ives (F) "Study of the kaon contribution to the T2K neutrino beam using neutrino interactions in the Near Detector" Supervisor: Dr Y Uchida

M. Jarvis (M) "Measurement of the electron charge asymmetry in inclusive W production in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ in the CMS experiment" Supervisor: Prof T Virdee

E. Mitchell (M) "Development of a miniaturised particle radiation monitor for Earth orbit" Supervisor: Dr Hdp Araujo

C. Parkinson (M) "The angular analysis of the B0 to $K^0\bar{\nu}_\tau$ decay at LHCb" Supervisors: Dr U Egede & Dr M Patel

S Rogerson (M) "A search for supersymmetry using the $\zeta T$ variable with the CMS detector and the impact of experimental searches for supersymmetry on supersymmetric parameter space" Supervisors: Dr D Collin & Prof O Buchmueller

Grantham Institute

E.L. Thompson (F) "Modelling North Atlantic Storms in a Changing Climate" Supervisors: Prof W Distaso & Prof B Hoskins

M. Scott (M) "Measuring Charged Current Neutrino Interactions in the Electromagnetic Calorimeters of the ND280 Detector" Supervisor: Dr Y Uchida

A. Shires (M) "Exploring $b$ to $s$ electroweak penguin decays at LHCb" Supervisor: Prof U Egede

J. Cerrillo Moreno (M) "Laser Cooling of Quantum Systems" Supervisor: Prof M Plenio

S. Short (F) "Study of neutrino-induced neutral current neutral pion production in the T2K near detector" Supervisors: Dr M Wascko & Prof J Nash

P. Stejskal (M) "Radiation Effects in Optical Link Components for Future Particle Physics Detectors" Supervisor: Prof G Hall

M. Wardle (M) "Observation of a new particle in the search for the Standard Model Higgs boson at the CMS detector" Supervisors: Prof G Davies & Dr J Hays

Optics - Photonics

I. E. Kepiro (F) "High-resolution retinal imaging with a compact adaptive optics ophthalmoscope" Supervisor: Dr C Paterson

A. Thompson (M) "Developing endoscopic instrumentation and techniques for in vivo fluorescence lifetime imaging and spectroscopy" Supervisors: Prof M Neil & Dr C Dunsby & Prof PW French & Dr D Elson

Optics - Quantum Optics and Laser Science

M. Ahmadi (M) "Resource theory of asymmetry and some of its applications" Supervisor: Prof T Rudolph

N. Bulleid (M) "Slow, cold beams of polar molecules for precision measurements" Supervisors: Dr MR Tarbutt & Prof B Sauer

G. Lepert (M) "Integrated optics for coupled-cavity quantum electrodynamics" Supervisor: Prof EA Hinds
S. Mavadia (M) “Motional Sideband Spectra and Coulomb Crystals in a Penning Trap”
Supervisors: Prof RC Thompson & Prof D Segal

S.I. Olsson Robbie (M) “High Energy Density Physics In Cluster Media”
Supervisor: Prof R Smith

M. Oppermann (M) “Resolving Strong Field Dynamics in Cation States of CO2 via Optimised Molecular Alignment”
Supervisor: Prof J Marangos

M. Siano (M) “Measuring Ultrafast Chemical Dynamics with New Light Sources”
Supervisors: Prof J Tisch & Prof J Marangos

I. Smallman (M) “A New Measurement of the Electron Electric Dipole Moment Using Ytterbium Fluoride”
Supervisors: Prof B Sauer & Dr J Hudson

R.J. Squibb (M) “Probing molecular structure and dynamics with coherent extreme ultraviolet and X-ray pulses”
Supervisor: Prof L Frasinski

S. Truppe (M) “New physics with cold molecules; precise microwave spectroscopy of CH and the development of a microwave trap”
Supervisor: Dr MR Tarbutt

Plasma Physics

C. R. D Brown (M) “Spectroscopic Studies on Warm and Hot Dense Matter”
Supervisor: Prof S Rose

G.C. Burdiak (M) “An investigation of cylindrical liner z-pinches as drivers for converging strong shock experiments”
Supervisor: Prof S Lebedev

N. Dover (M) “Exploring novel regimes for ion acceleration driven by intense laser radiation”
Supervisors: Dr S Mangles & Prof Z Najmudin

E. Khoory (M) “Experimental Study of Plasma Implosion Dynamics in a Two-Stage Wire Array Z-Pinch Configuration”
Supervisor: Prof S Lebedev

H.T. Kim (M) “Physics and Computational Simulations of Plasma Burn-through for Tokamak Start-up”
Supervisors: Prof W Fundamenisky & Prof S Rose

R.D. Lloyd (M) “Collisional Particle In Cell Modelling Of The Propagation Of Fast Electrons In Solid Density Plasma”
Supervisors: Prof R Evans & Dr R Kingham

L. Pickworth (F) “Experimental investigation of supersonic plasma jets colliding with thin metallic foils”
Supervisors: Dr S Bland & Prof S Lebedev

J.W. Skidmore (M) “Experimental study of pulsed power driven radiative shockwaves in noble gases”
Supervisors: & Prof S Lebedev & Dr S Bland

A. E. Turrell (M) “Processes driving non-Maxwellian distributions in high energy density plasmas”
Supervisors: Dr M Sherlock & Prof S Rose

Supervisor: Dr R Kingham

W. Neal (M) “The Role of Particle Size in the Shock Compaction of Brittle Granular Materials”
Supervisor: Dr B Proud

Space & Atmospheric Physics

C. Ansell (F) “Evaluating mineral dust aerosol retrieval and its direct radiative effect with a view towards improving forecasts in the UK Met Office NWP model”
Supervisors: Prof R Touni & Dr H Brindley

K.P. Chan (M) “Analysis of Outgoing Longwave Radiation (OLR) in different timescales over Africa and Atlantic Ocean”
Supervisor: Prof J Harries

J. Farley Nicholls (M) “Modelling of the Caspian Sea”
Supervisor: Prof R Touni

U. Hausmann (F) “The signature of mesoscale eddies on sea surface temperature and its associated heat transport”
Supervisor: Dr A Czaja

Theoretical Physics

D. Benincasa (M) “The Action of a Causal Set”
Supervisor: Prof F Dowker

C.N. Clark (F) “Data Analysis And Modelling For Observations Of Polarisation Of The Microwave Sky”
Supervisor: Dr G Contaldi

A.J. Coimbra (M) “Generalised Geometries for Type II and M Theory”
Supervisor: Prof D Waldram

S. Orani (M) “Cosmological Perturbations from Hilltop Potentials”
Supervisor: Dr A Rajantie

R-K Seong (M) “Brane Tilings and Quiver Gauge Theories”
Supervisor: Prof A Hanany

M Szmigiel (M) “Massless preheating with full Einstein gravity”
Supervisor: Dr A Rajantie
MSc in Physics

Achilleas Athanasiou
Analyses of CMS data for the H→invisible group
Supervisor: David Colling

Frangkoulis
Supervisor: Henrique Araujo

Experiments
in the astrophysical neutrino background on the future
by astrophysical neutrino

Jarand Narbuvold
Theory and simulation of electron transmission
Supervisor: Arash Mostofi

Matthew Parker
Comparing methods of fabricating bowtie-nanoantennas to change the optical properties of molecules
Supervisor: Stefan Maier

Jens Petersen
Path length distribution in random directed acyclic graphs
Supervisor: Tim Evans

Daven Raithatha
Interactions of the interplanetary cosmic rays environment with space based gravitational wave detectors
Supervisor: Peter Wass

Anna Clare Sales
Electromagnetic Compatibility (EMC) studies for the Solar Orbiter instrument boom
Supervisor: Tim Horbury

Ao Shi
Kelvin probe force microscopy and its application in graphene characterisation
Supervisor: Lesley Cohen

Malcolm Simpson
Resolved sideward cooling of a single ion to the quantum mechanical ground state in a Penning Trap
Supervisor: Richard Thompson

Panagiota Theodoulou
Impact of restricted radiative emission from compressively strained quantum wells on the photonic coupling
Supervisor: Diego Alonso Alvarez

Kevin van der Meij
The solar wind at 0.3 AU - new observations from the NASA Messenger spacecraft
Supervisor: Robert Forsyth

Samual White
Using symbolic regression to data mine the laws of physics
Supervisor: Jony Hudson

Renjie Yun
Many-body Green’s function theory of Penning ionisation widths for sub-Kelvin atom-molecule collisions
Supervisor: Vitali Averbukh

MSc in Physics with Shock Physics

Stefan Heufelder
Optimisation of the optical imaging system and methods for image analysis in symmetric Taylor impact experiments
Supervisor: David Chapman

Lucas Schickhofer
Blast biomechanics of the human head
Supervisor: Mazdak Ghajari (Aeronautics)

MSc in Physics with Extended Research

Luc Sagnières
The Influence of local ionization on ionospheric densities in Titan’s upper atmosphere
Supervisor: Marina Galand

MSc in Optics and Photonics

Mathilde Barré
Establishment of a model and characterization of performance of the solar simulator of SIMDIA space environment simulation chamber
Supervisor: Jenny Nelson

Hao Chen
Exploring a new method to produce plasmonic bowtie nanoantennas
Supervisor: Stefan Maier

Chenhao Cui
Automated chemical classification of single cereal grains using NIR spectroscopy
Supervisor: Kenny Weir

Maxime Dubois
Fluorescence super resolution microscopy and conical diffraction
Supervisor: Martin McCall

Biniyam Erkihun
Characterisation of the electromagnetic field in nanosstructures
Supervisor: Stefan Maier

Gabriel Geraci
Simulations of Young’s interference in plasmonic structures
Supervisor: Stefan Maier

Wenjun Guo
Temperature-control and characterisation of a diode-pumped alexandrite laser
Supervisor: Mike Damzen

Yichuan Huang
Adaptive spatial laser control with liquid lens
Supervisor: Mike Damzen

Wentao Huang
Phase Object Imaging: A comparison between interferometry and moiré deflectometry
Supervisor: Stuart Mangles

Koppány Kőrmöczi
Trade-Off analysis of 3D full-space electromagnetic cloaks using inhomogeneous, anisotropic, non-magnetic materials in respect of efficiency and feasibility
Supervisor: John Pendry

Asilatun Nisa Mohd Azmi
“Digistain” Mid-Infrared chemical imaging for cancer diagnosis; trialling a new technology
Supervisor: Chris Philips

Michael Ramamonjisoa
3D imaging using a synthetic

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Department of Physics Review 2013 -14
Postgraduate

Masters Projects List

aperture LIDAR
Supervisor: Chris Dunsby

Fransessca Shirley
A comprehensive comparison of metal and dielectric nanostructures for enhanced scattering in solar cells
Supervisor: Nicholas Ekins-Daukes

Chengze Song
Study of methods separating Brillouin signal
Supervisor: Peter Török

Christos Theodorakis
Photoreflectance spectroscopy for the optical characterisation of InGaAs quantum wells
Supervisor: Nicholas Ekins-Daukes

Zizhen Xue
Hong-Ou-Mandel effect from spontaneous parametric down converted photons
Supervisor: Danny Segal

Lydia Zajiczek
An optical interferometer for investigating the coherence properties of a photon Bose-Einstein condensate
Supervisor: Robert Nyman

Daqin Zha
Phase object imaging: Comparing interferometry with wave front sensing
Supervisor: Stuart Mangles

Xiangnan Zhou
Design of an optimised optical projection tomography instrument
Supervisors: Paul French/James McGinty

Daniel Owton
Modelling a radiation shield for an infra-red detector
Supervisor: Kenny Weir

MRes in Photonics

Thorin Duffin
Tetra-Pixel compressive sensing Polarimetry
Supervisor: Peter Török

Rebecca Feeney Barry
Investigation of the implementation of laser-scanning light sheet formation for the OPM system
Supervisor: Chris Dunsby

Thomas Watson
Characterisation of a microscope stage plate-insert designed for optical projection tomography on a commercially available microscope
Supervisor: James McGinty

MSc in Quantum Fields and Fundamental Forces

Marc Arene
Instability of extreme Reissner-Nordström black holes
Supervisor: Toby Wiseman

Paul Boes
Closure and stability in quantum measure theory
Supervisor: Fay Dowker

Christopher Bray
Dust grain charging in tokamak plasmas
Supervisor: Michael Coppins

Sonny Campbell
Models of non-singular gravitational collapse
Supervisor: Joao Magueijo

Nipol Chaemjumrus
Non-geometric flux and double field theory
Supervisor: Chris Hull

Clement Delcamp
Entanglement on spin networks in loop quantum gravity
Supervisor: Joao Magueijo

Stylianos Gregoriou
Time in quantum mechanics and aspects of the time-of-arrival problem
Supervisor: Jonathan Halliwell

Mohammed Hakeem
Five dimensional SUSY gauge theories in the context of M theory
Supervisor: Amihay Hanany

Shane Keane
Arrival time in quantum mechanics
Supervisor: Jonathan Halliwell

Dong Woon Kim
Double field theory
Supervisor: Chris Hull

Martyna Kostacinska
Primordial non-Gaussianities in Horava-Lifshitz gravity
Supervisor: Joao Magueijo

Katerina Apostolidou
Cooling complex molecules for quantum interferometry and measurements of parity violation in chiral molecules
Supervisor: Michael Tabutt

Benjamin Dive
Quantum control of open systems
Supervisor: Daniel Burgarth

Edward Gillman
Defect formation in quantum phase transitions
Supervisor: Arttu Rajantie

Daniel Goldwater
Examining the noise spectra of levitated nanospheres: Towards an experimental test of collapse theories
Supervisor: Myunkshik Kim

Pavel Hrmo
Sideband cooling to the motional ground state of an ion in a Penning trap
Supervisor: Danny Segal

Jieyi Liu
Configurations of ion coulomb crystals in a Penning trap
Supervisor: Danny Segal

Maximilian Lock
Developing new relativistic quantum technologies
Supervisor: Myunkshik Kim

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Postgraduate

Masters Projects List

Joseph Muñns
Towards noise suppression in a broadband quantum memory in warm caesium vapour
Supervisor: Myungshik Kim

Jonathan Richens
Reversible dynamics is generalised probabilistic theories
Supervisor: Terry Rudolph

John Selby
A process theory approach to modal quantum theory
Supervisor: Terry Rudolf

Jimmy Stammers
Characterisation of a compact single-beam tetrahedral MOT
Supervisor: Ed Hinds

James Tarlton
Magnetic field generation and stabilisation for 43Ca+ clock qubits
Supervisor: Danny Segal

Andrew Tranter
Quantum computation for electronic structure theory
Supervisor: Florian Mintert

MRes in Plastic Electronic Materials
Andika Asyuda
Hybrid solar cells based upon mesostructured inorganic-organic nanocomposites
Supervisor: Saif Haque

Iain Andrews
Room temperature MASER – search for new masing materials
Supervisor: Martin Heeney

Philip Bridges
Charge and ionic transport in organic-inorganic perovskite semiconductors
Supervisor: Jenny Nelson

Nathan Cheetham
Supramolecular manipulation of organic blends for stimulated emission
Supervisor: Paul Stavrinou

Tony Chiu
Enhancing OPV performance by light and thermal process engineering
Supervisor: Joao Cabral

Satyajit Das
Electron transport in low-dimensional solution-processed metal oxide semiconductors
Supervisor: Thomas Anthopoulos

Matthew Dyson
Excitation and charge transfer among conjugated (macro)molecules
Supervisor: Natalie Stingelin

Alexander Giovannitti
A new transport materials platform for bioelectronics
Supervisor: Iain McCulloch

Iain Hamilton
Fabricating efficient nanostructured OLED lighting and display devices
Supervisor: Ji-Seon Kim

Faldo Maldini Zaitul
Scanning-probe patterning of electronic and photonic properties in molecular semiconductors
Supervisor: Donal Bradley

Jameel Marafie
Making materials Liquid: a theoretical model of the dynamics of sweet/sour corrosion scales
Supervisor: Alexei Kornyshev

Nicola Molinari
Towards a predictive model of elastomer materials
Supervisor: Arash Mostofi

Prospero Taroni
Junior Conductive polymers and polymer nanocomposites for flexible thermoelectrics - “NANOFLEXTE”.
Supervisor: Nathalie Stingelin

Gwen Wyatt-Moon
Plastic nanoelectronics by sticky-tape lithography
Supervisor: Thomas Anthopoulos

Yiren Xia
Energy transfer and supramolecular manipulation of organic blends
Supervisor: Paul Stavrinou

MSc in Theory and Simulation of Materials
Amanda Diez
Modelling damage tolerant structural ceramic systems
Supervisor: Ferri Aliabadi

Peter Fox
Nanoplasmonics and metamaterials at the classical/quantum boundary
Supervisor: Ortwin Hess

Frederike Jaeger
Modelling damage in environmental barrier coatings on woven SiC/SiC composite substrates
Supervisor: Daniel Balint

Mitesh Patel
Stress-driven transport of hydrogen in zirconium alloy cladding of nuclear fuel rods
Supervisor: Daniel Balint

Andrew Pearce
Theory and simulation of self-assembled nanoplasmonic metamaterials and devices
Supervisor: Alexei Kornyshev

Elisabeth Rice
Tight-binding approach to the simulation of the electronic and optical properties of porous conjugated molecular materials
Supervisor: Jenny Nelson

Jacqueline Tan
Making materials Liquid: designing “room temperature” molten salts
Supervisor: Patricia Hunt

Markus Tautschning
Scale Formation: Developing a theoretical model of the dynamics of sweet/sour corrosion scales
Supervisor: Nicholas Harrison

Vadim Nemytov
Nanocrystals by design: combining the power of atomistic force fields and linear-scaling density functional theory
Supervisor: Paul Tangney

Premyuda Ontawong
Atomistic-to-continuum theory of martensitic transformations
Supervisor: Dimitri Vvedensky

Farnaz Ostovari
Modelling damage in environmental barrier coatings on woven SiC/SiC composite substrates
Supervisor: Daniel Balint

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Table 1 - There were 87 known destinations of the 2013 postgraduates (Home & EU students)

<table>
<thead>
<tr>
<th>Destination</th>
<th>Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entered Employment</td>
<td>21</td>
</tr>
<tr>
<td>Further Study</td>
<td>57</td>
</tr>
<tr>
<td>Unemployed</td>
<td>4</td>
</tr>
<tr>
<td>Time Out / Unavailable for Work</td>
<td>5</td>
</tr>
</tbody>
</table>

Destinations of 2013 postgraduates

Comparison with previous years

Sector of employment entered
What do Physics Postgraduates do?

Examples of employers and occupations for Physics taught-course postgraduates who entered employment:

Examples of Employers:
- Bloomberg New Energy Finance
- M & C Saatchi Mobile
- Royal United Services Institute

Examples of Occupations:
- Media Analyst
- Renewable Energy Analyst
- Research Intern

Examples of courses for those Physics taught-course postgraduates who entered further study or training:
- EngD in Optics and Photonics Technologies (Heriot-Watt University)
- MRes Controlled Quantum Dynamics (Imperial)
- MSc Photonics (Imperial)
- MSc Physics (Ecole Centrale Lyon & Universite Aix Marseille)
- MSc Shock Physics (Imperial)
- MSc Theoretical Physics (Utrecht University)
- PhD in Atmospheric Physics (Imperial)
- PhD in Materials (Imperial)
- PhD in Mathematical Physics (Durham University)
- PhD in Mathematics (University of Cambridge)
- PhD in Optical Engineering (Heriot-Watt University)
- PhD in Particle Physics (Imperial)
- PhD in Physics (Imperial)
- PhD in Physics (University of Glasgow)
- PhD in Theoretical Physics (University of Southampton)
- Theoretical Physics Research (University of Bremen)
- University of Birmingham
- Velocix

Examples of Occupations:
- Business Informatics Developer
- CAD Draughtsman
- Consultant
- Engineer
- Outsourcing Manager
- Plasma Physicist
- Post-Doctoral Fellow
- Post-Doctoral Research Associate
- Research Associate
- Research Fellow
- Research Scientist
- Software Developer
- Software Test Developer

Examples of employers and occupations for Physics research postgraduates who entered employment:

Examples of Employers:
- AWE plc.
- Brunel University
- Carallon
- Dalcour Maclaren
- Element Energy
- Element Six Ltd
- IIT
- Imperial College London
- ISAGRI
- Palantir Technologies
- Perimeter Institute for Theoretical Physics
- Permasense
- TU Dortmund

Examples of courses for those Physics research postgraduates who entered further study or training:
- Biomedical Engineering Research (Imperial)
- CDT in Controlled Quantum Dynamics (Imperial)
- MPhil/PhD in Physics: Nanophotonics and Metamaterials (University of Southampton)
- MRes Controlled Quantum Dynamics (Imperial)
- PhD in Chemistry (Imperial)
- PhD in Controlled Quantum Dynamics (Imperial)
- PhD in Controlled Quantum Dynamics (University of Bristol)
- PhD in Plastic Electronics (Imperial)
- PhD in Photonics (Imperial)
- PhD in Physics (Imperial)
- PhD in Physics (University of Cambridge)
- PhD in Theory and Simulation of Materials (Imperial)
Research

Research Groups
Astrophysics
Condensed Matter Theory
Experimental Solid State Physics
High Energy Physics
Photonics
Plasma Physics
Quantum Optics & Laser Science
Space and Atmospheric Physics
Theoretical Physics

Research Centres
Centre for Cold Matter
The Laser Consortium
Institute of Shock Physics
Centre for Plastic Electronics
Astrophysics

The Astrophysics group studies the Sun, the birth of stars in the Milky Way, the formation and evolution of galaxies over cosmic time, the cosmic microwave background, and the nature of dark matter. The sophisticated use of statistics in interpreting astronomical data is a common theme in the group’s activities.

SUN, STARS AND PLANETS
Unruh, Mohanty.
The radiation of the parent star and its variability is crucial to the habitability of exoplanets. Unruh works on solar and stellar magnetic activity and the its effect on the radiation emitted by the star. This is relevant to the influence of the Sun on climate change on the Earth, and to the habitability of extrasolar planets.

Thousands of planets have been discovered around other stars in recent years, and it now seems likely that every star has one or more planets around it. Mohanty’s research focuses on understanding how these planets are formed out of the disks of gas and dust surrounding newborn stars; how this process is linked to the formation of the stars themselves; and how stellar properties influence the characteristics - in particular, the habitability - of the orbiting planets.

GALAXY AND QUASAR FORMATION AND EVOLUTION
Clements, Warren, Mortlock, Pritchard

How did the population of galaxies that we see around us, including spiral galaxies, elliptical galaxies, quasars and galaxy clusters, come about? When did the first galaxies form, and what processes dominated their formation and led to the evolution of the universe we see today? We use data across the electromagnetic spectrum to answer these questions, using telescopes such as UKIRT, Herschel, JCMT, the SMA, and ALMA, with an emphasis on the highest redshifts observable, z>6. Pritchard is leading activities to predict the 21cm radio signature of neutral hydrogen from the first billion years to study the nature and evolution of the first stars and galaxies.

COSMOLOGY
Heavens, Jaffe, Mortlock, Pritchard

We aim to develop and apply new, principled statistical methods to the inference of cosmological parameters and model selection, focussing on the cosmic microwave background, weak gravitational lensing, large-scale structure and 21cm radiation, with scientific goals which include neutrino masses, measurement of dark energy properties and testing of Einstein gravity. The group has strong involvement in current and future cosmology experiments including Planck, PolarBear, Euclid and the Square Kilometer Array.

DARK MATTER
Trotta, Scott

Decades of studies have led to the conclusion that 80% of the matter in the Universe is made of a new type of particle, and the experimental hunt for this dark matter is now in a crucial phase. The question of the nature of dark matter is one of the most important in all physics. Our work aims to put constraints on the physical parameters of theoretical models for dark matter (such as Supersymmetry) by combining four complementary probes: cosmology, direct detection, indirect detection and colliders. Our group has developed the world-leading “global fits” approach to the problem, allowing us to explore in a statistically convergent way theoretical parameter spaces previously inaccessible to detailed numerical study.
The incredible success of the Herschel mission, and especially its deep, cosmological surveys, has continued to shed light on the role that dusty galaxies play in the formation of large scale structure and the history of galaxy formation. Multiwavelength followup observation campaigns are underway to determine the nature of the reddest, and thus potentially most distant, objects seen in these surveys. The first fruit of this work was the discovery of HFLS3, a massive, rapidly star forming dusty galaxy at the unprecedented redshift of 6.34. Finding such an object just 880 million years after the Big Bang is wholly unexpected in current cosmological models. As well as seeking individual high redshift sources, we have been cross-matching Herschel and Planck data to look for groups or clusters of star forming galaxies at somewhat lower redshifts. The first results of this work have uncovered four candidate galaxy clusters whose constituent galaxies are forming stars at a very high rate, and which lie at significantly higher redshifts than conventional optical/IR or X-ray observation can easily detect clusters. We appear to be detecting these objects during a formative but otherwise inaccessible phase in their formation and evolution.


The first Planck cosmology results were published in 2014, showing that primordial non-Gaussianity in the map is constrained to be very close to zero, in agreement with the standard inflation model for the early Universe. The robustness of the result was shown using a statistical technique partly developed and applied by us.

A key observable in cosmology is the sound horizon (the ‘BAO’ scale), which leaves an imprint in the clustering of galaxies. We have determined the length of this standard ruler, for the first time in a model-independent way, not even assuming General Relativity. The Universe still looks like the standard LCDM model and the number of neutrino species is constrained almost model-independently to be 3.5 ± 0.3. Published in PRL.

We applied our method of 3D weak lensing analysis to the leading survey (CFHTLenS). Results show for the first time hints of baryon feedback or suppression of power on small scales due to non-zero neutrino masses.


Our work has concentrated on the analysis and interpretation of data from the cosmic microwave background (CMB). In particular, we have a team (Jaffe along with PDRAs Ducout and Feeney) dedicated to working with data from the Planck Satellite which has released two rounds of cosmological results and is poised for completion in 2016. We have been involved in all aspects of the analysis, from detailed examination of the optical properties of the instrument to the use of Planck data to limit the large-scale topology of the Universe on scales of billions of parsecs. We also apply this expertise to ground- and balloon-based CMB experiments such as EBEX and PolarBear. The latter was the first to directly detect anisotropy in the polarization of the CMB from gravitational lensing of structures along the line of sight; this will prove a strong test of instrumental properties, astrophysical sources of microwave emission, and, eventually, of cosmological parameters that will inform us about the possibilities of an early epoch of cosmic inflation responsible for both the large-scale geometrical structure of the observable Universe and the...
small-scale structures within it.


Ground and space-based missions have uncovered thousands of exoplanets around other stars in the last few years. My work focusses on how these planets form out of the primordial disks of gas and dust around young stars, and how the properties of the host star influence planetary characteristics (particularly habitability). Highlights over the last year include determining average disk masses (which ultimate set the planetary masses), from dust emission, for a broad range of stellar types (reference [1]), and building a theory of how magnetohydrodynamical processes affect the disk structure and evolution (reference [2]). Ongoing work includes devising a semi-analytic model for forming super-Earth size planets very close to the host star (which empirically seems to be the dominant mode of planet formation), and constructing a model of X-ray and UV-driven photoevaporation of terrestrial planetary atmospheres within the habitable zone of red dwarf stars. The latter two projects are in collaboration with colleagues at the University of Florida and IAS at Princeton, respectively; the research is supported by both STFC funds and a Royal Society International Exchange grant.


This last year has been a critical phase in the design of the Square Kilometer Array, reviewing an initial baseline design for its scientific suitability and updating the 10 year old science case. I have played a leading role in both aspects of this – speaking at Science Working Group meetings at SKA-HQ in Manchester to review the baseline design and, in my role as co-chair of the Epoch of Reionization SWG, leading the study [3]. I have been involved in theoretical efforts to understand the population of quasars in the early Universe and in interpreting the signatures of the cosmological ionisation process as revealed in their spectra. I have also applied Bayesian inference techniques to several areas of astrophysics in which they have not previously been used, including the assessment of the total power emitted by the Sun ([4], relevant in particular for climate science) and the search for the origin of the most energetic cosmic rays [5].

2. ‘Finding the most distant quasars using Bayesian selection methods’ Mortlock, D.J., 2014, Statistical Science, 29, 50
3. Paper 2 of SJW

This last year has been a critical phase in the design of the Square Kilometer Array, reviewing an initial baseline design for its scientific suitability and updating the 10 year old science case. I have played a leading role in both aspects of this – speaking at Science Working Group meetings at SKA-HQ in Manchester to review the baseline design and, in my role as co-chair of the Epoch of Reionization SWG, leading the
rewrite of epoch of reionization/cosmic dawn sections of the SKA science case and co-writing four chapters. This connects to my new role as a member of the UK-SKA science committee to promote involvement in SKA science within the UK. Alongside this, with my student Catherine Watkinson, I have completed two papers demonstrating the importance of 1-point statistics of the 21cm signal for determining the reionization topology and the impact of small absorbing systems. Finally, I completed part of a review on atomic physics in the early universe covering topics from the CMB & recombination to the 21cm signal and reionization.


Solar and stellar surface magnetic fields and their evolution are the cause of much of solar and stellar variability on time scales of a few hours to months and even decades. The emergent magnetic surface flux forms dark spots as well as bright points that contribute to the changing solar and stellar emission. The wavelength dependence of their emission is still an outstanding question, though much progress has been made in the case of the Sun where we are now able to model the wavelength dependent irradiance changes to a high degree of accuracy which is needed for modelling the Earth’s (upper) atmospheric response (e.g., Ball et al, 2014). Comparable stellar variability is usually considered as ‘noise’ and presents a nuisance in the detection and characterisation of exoplanets. The importance of including stellar variability in the exoplanet modelling so as to minimise spurious detections and allow the characterisation of exoplanets around more variable stars was
Research

Astrophysics

presented in Haywood et al. (2014) where we were able to use simultaneous radial-velocity and photometric data to estimate the radial-velocity variations due to magnetic activity.


I am an observational astronomer mostly interested in using telescopes to find things that are hard to find, either because they are rare or faint. Over the past 7 years I have been particularly interested in using a new wide-area deep survey at near-infrared wavelengths (0.9-2.3micron) to find brown dwarfs and distant quasars. Brown dwarfs are collapsed clouds of gas where the mass is too low for the central temperature to get high enough to ignite hydrogen. These are some of the closest objects to Earth. Nathalie Skrzypek and I have developed a new method for finding brown dwarfs that has produced the largest sample yet of these objects, over 1000. The near-infrared is also useful for finding very distant quasars where the light has been stretched by the redshift beyond optical wavelengths. These are some of the most distant objects known. Daniel Mortlock and I recently found the first quasar at redshift z>7, the most distant quasar known, which provides crucial information on conditions in the Universe when it was only a few percent old.


Professor Stephen Warren
Condensed Matter Theory

The Condensed Matter Theory group studies properties, processes and emergent behaviour in solids, liquids, nanomaterials, metamaterials, and less obvious aggregates such as ant colonies and heart muscles. Our research draws on many areas of physics including quantum and classical mechanics, electromagnetism, statistical mechanics, quantum optics, and thermodynamics.

MATERIALS PHYSICS
Prof Mike Finnis, Prof Matthew Foulkes, Prof Peter Haynes, Dr Arash Mostofi, Prof Adrian Sutton, Dr Paul Tangney, Prof Dimitri Vvedensky

Materials have played a central role in the development of civilisation from the Bronze Age to the Semiconductor Age. We aim to understand and predict the properties of materials and the processes by which they grow or transform. We also provide guidance for experimental research, help to interpret observations, and seek ways to enhance materials’ properties. Our theoretical work is often helped by simulations, which include accurate quantum mechanical calculations, atomistic and more coarsely-grained approaches, and continuum models.

We specialise in spanning time and length scales by coupling methods to achieve a consistent understanding all the way from electrons and atoms to the macroscopic continuum. Much of the software that we use is developed in-house and used by researchers around the world.

COMPLEXITY AND NETWORKS
Prof Kim Christensen

Through data-driven research and modelling, we investigate the properties of systems whose complex behaviour emerges from large numbers of interacting components. For example, why are ant societies, whose elaborate highly-organised macroscopic (colony-level) properties emerge from microscopic interactions between ants, so successful? Organs such as the brain and the heart function through the collective behaviour of complex networks. Understanding how their behaviour emerges can help us to identify and treat medical conditions that arise when these networks malfunction. For example, simple models can help explain how age-related changes in a heart muscle’s underlying network causes atrial fibrillation.

CORRELATED QUANTUM SYSTEMS
Dr Derek Lee, Prof Angus MacKinnon

Using theoretical techniques from quantum field theory and computer simulations, we study the cooperative collective behaviour of nanoscale quantum systems. Specific systems of interest include dissipationless phases of matter, which may be useful for quantum information processing, and the dynamics of nanoscale mechanical systems driven far from equilibrium. Our work continually throws up fundamental questions relating to quantum mechanics and how thermodynamics may be adapted to nanometer length scales.

METAMATERIALS
Prof Sir John Pendry, Prof Ortwin Hess

Metamaterials are artificial solids designed to guide electromagnetic fields or acoustic waves. The properties of conventional materials are determined by chemical composition and how the atoms are arranged. Metamaterials, on the other hand, consist of arrays of specially-engineered units organised on much larger length scales. They can be designed to manipulate photons and electrons in ways that cannot be achieved with conventional materials. This has inspired scientists to conceive perfect lenses, new lasers, ‘invisibility cloaks’ and opened the door to slow and stopped broadband light.

KNbO3 is a ferroelectric. It is almost cubic, but it spontaneously polarizes by moving each Nb (yellow) slightly towards three of its six O neighbours (red). The electron density is shown as contours and isosurfaces.

Metamaterials are lattices of metamolecules, such as “split-ring resonators” (left). A layered metamaterial can slow a light packet while spatially separating its colours to make a “trapped rainbow” (right).
Research

Universal relationships between city size and pace of life have inspired a unified theory of urban living but individual variation within societies poses a challenge for planning and prediction. Controlled experiments are essential. We demonstrate a universal relationship in ant societies: average ant speed is higher for longer activity events. This suggests that activity duration is already specified when the ant begins to move and this approach may inform the engineering and control of artificial social systems.

We are convinced that our main conclusion that the duration of an activity event is determined before it commences is likely to be applicable as a general principle of animal behaviour across taxa including humans. Complex data series that arise during interaction between humans and advanced technology in a controlled and realistic setting have been explored. The purpose is to obtain quantitative measures that reflect quality in task performance: on a ship simulator, nine crews have solved the same exercise, and detailed maneuvering histories have been logged. Quantitative measures of task performance have been constructed and the crews differ significantly under these objective measures. Our approach may be useful for other qualitative concepts in social science that contain important information on the society.


We have developed further the theme of calculating high-temperature properties of materials, linking macroscopic thermodynamic properties with quantities that can be calculated at the atomic scale using density functional theory, empirical interatomic potentials (e.g. ref.2) or a combination of the two. Within an ongoing project for understanding the stability of ceramics at high temperature I derived (ref.1) the relation between parameters of the standard CALPHAD formulation of free energy (the Compound Energy Formalism) and the energies that can be calculated with the defect-centric approach of our crystal chemistry/physics communities. This will facilitate the translation of calculated total energies into phase diagram calculations. A new tool for free energy calculation was described in ref. [3], an application of biased Monte Carlo ‘flat histogram’ methods, which addresses the problem of calculating the configurational free energy of oxides bearing a high concentration of charged point defects. Ongoing research is aimed at understanding the growth mechanism of oxide films and how it can be controlled (ref.4). A new insight from this work is the need to understand grain boundary electrical conductivity, since it is of the same importance for the growth rate as ionic conductivity.


Compressed hydrogen gas solidifies at high pressure to form a crystal of H2 molecules. As the pressure is increased the crystal undergoes several phase transitions, but hydrogen atoms scatter X-rays so weakly that the structures of the...
new phases are unknown. Eventually, at high enough pressure, hydrogen is thought to become not only a metallic atomic solid (believed present in large quantities in the interiors of Saturn and Jupiter) but also a high-temperature superconductor. Investigating the phase diagram of solid hydrogen was the focus of much of our work this year. We started by using density functional theory to calculate the low-temperature phase diagram [1], but concluded that the results were too inaccurate to be useful. This led us to combine quantum Monte Carlo simulations with a fully anharmonic study of zero-point fluctuations [2]. Attempts to create metallic H on Earth have not yet succeeded for sure, but our highly accurate results support recent experimental hints that success is close. Other work has included the development (with undergraduates Nick Blunt and Tom Rogers) of a new finite-temperature quantum Monte Carlo method [3] and a detailed study [4] of the formation of protective oxide scales on alloys of aluminium.


and inorganic nanoparticles. Niccolò Corsini has been using ONETEP to study structural phase transformations in nanoparticles under pressure [3]. Both projects are part of a wider effort by my group to develop the capability to perform large-scale theoretical spectroscopy: the computational simulation of experimental spectra such as electron energy-loss spectroscopy [4].


Superfluid helium has long been a testing ground for the physics of Bose-Einstein condensation and superfluidity. Nevertheless, it continues to come up with surprises that challenge our understanding. Recent experiments [1] on thin helium films on graphite appear contradict all textbook descriptions. Since this is found near the solidification of the film, a tantalising candidate for this new phase of matter is the elusive supersolid — dissipationless mass flow in a crystal, originally proposed for bulk helium but recently refuted by new evidence.

In a theoretical collaboration involving Imperial, Royal Holloway University of London and Rutgers, we are developing a theory of a spatially modulated superfluid where both superfluidity and broken translational symmetry coexist, described by a non-Abelian order parameter. The strange behaviour may be connected to the fact that the system is close to a quantum phase transition to a solid. Quantum criticality is an important area of research in condensed matter physics. Indeed, the rich physics behind the cuprate superconductors may be tied to its proximity to a quantum transition to a magnetic insulator. This helium system is...
cleaner than any solid state system, and may shed light quantum criticality from a new setting.


Nano-Electro-Mechanical-Systems, NEMS, represent an important class of potentially useful nano-devices, as well as a test system for understanding the more fundamental aspects of the transition between classical and quantum behaviour. Our work continues in collaboration with Muhammad Tahir, Concordia University, Canada, Udo Schwingenschlögl, KAUST, Saudi Arabia, and Lev Kantorovitch, King's College. We have extended our non-equilibrium Green's function approach to systems driven by an external electric field and have developed a methodology for dealing with systems subject to a general time dependent potential. Current work includes the study of shot noise, especially in the quantum shuttle system.


Dr Arash Mostofi

Our research is dedicated to the application and development of theory and computational simulation tools for solving problems in materials. We are motivated by problems related to energy, environment and advanced technology. We work predominantly at the atomistic length-scale, either using quantum mechanics or simpler models of interatomic bonding to describe systems of interacting electrons and nuclei. Such theory and simulation is invaluable for understanding the structure of matter and providing microscopic insight into the behaviour of materials. The state-of-the-art computational tools that are developed in our group are shared with the wider community, either through commercial, academic or open-source license, to benefit the pursuit and dissemination of knowledge in this field. In collaboration with colleagues at universities including Cambridge and Southampton, and the scientific software company BIOVIA, we continue to develop the linear-scaling density-functional theory code ONETEP (www.onetep.org); and in collaboration with colleagues at Oxford, EPFL (Switzerland), Rutgers (New Jersey), and San Sebastian, we continue to enhance the Wannier90 code (www.wannier.org) for computing maximally-localized Wannier functions. Our current research interests include: transport properties of nanowires and carbon nanotube networks; surfaces, interfaces and defects in perovskite oxide materials; and the structure and function of elastomer seals and polymer desalination membranes.


Professor Sir John Pendry FRS

Metal surfaces support electron density waves known as surface plasmons which can couple to externally incident light waves. Since the surface plasmons have wavelengths of the order of a few tens of nanometres or less, they can be focussed into extremely small areas. This extreme concentration has the potential for single molecule sensing, enhanced optical non linearity at low power input and many other applications where an
intense concentration of optical energy is needed. Surface plasmon properties are extremely sensitive to surface structure, particularly to singular features such as two touching curved surfaces. We use the technique of transformation optics, developed here in London, to explore relationships between geometrically distinct structures, but which can be mapped into one another by coordinate transformations that preserve all the spectral properties. Apparently complex systems can be related to simpler ones and their spectra solved analytically. Furthermore, it has often proved to be the case that the simpler system is highly symmetric enabling the spectrum to be classified by the symmetry representations. We call this ‘hidden symmetry’ and it has given powerful insight into systems which previously were thought to be just a complex mathematical mess.


I am a theoretical and computational materials physicist working with a wide range of colleagues across Imperial College and industrial collaborators. Some of our most exciting recent work has concerned fundamental aspects of dislocation dynamics in metals. They include the first truly elastodynamic simulations of dislocation generation and motion under shock-loading [1,2], and the first theory of the temperature-independent contribution to the mobility of highly mobile dislocations in some metals [3]. We have also shown there is a previously unrecognised intermediate length scale associated with dislocations that move by a kink mechanism, between atomistic and the continuum scales [4]. With Rolls-Royce we have two research projects underway on fundamental aspects of delayed hydride cracking in Zr-alloys and cold-dwell fatigue in Ti-alloys. We are working on the molecular structure of polyamide membranes with BP-ICAM for filtration applications. We have two projects with Baker-Hughes modelling the absorption and trapping of gases under high pressure in oil well elastomer seals, which can lead to rupture when they are decompressed. We are developing the first molecular theory for the viscoelastic properties of aligned polyethylene. There is also a project with Element Six on modelling the dynamics of very small cracks in diamond composites.


technologically-important oxides. One example is alumina, where we have studied defect structures and diffusion mechanisms with a view to better understanding the growth of oxide layers on superalloys [2]. Force fields can generate realistic structures and the electronic properties of these structures can then be calculated with DFT.

We are also interested in the nanoscale statistical mechanics of multiferroic perovskites, the simplest of which are BaTiO3 and SrTiO3. With force fields we can reach a new understanding of the mechanism of the ferroelectric phase transition [3] - an issue that has been debated for half a century; we can go further by using advanced statistical techniques to elucidate the complex process by which ferroelectric domains nucleate, grow, and coalesce. Controlling this process is key to improving the performance of ferroelectric memory (FeRAM) devices.


Graphene growth kinetics. In collaboration with Lev Kanotorovich (KCL), Ian Ford (UCL), and Joel Posthuma de Boer (Physics-CDT), we are developing approaches to the kinetics of graphene growth. Our work has included the first comprehensive review of theoretical and experimental work in this area [1], an optimization algorithm for rate models [2], and a phase-field model for describing the growth kinetics of graphene.


Inverted pyramidal quantum dots. In collaboration with Emauele Pelucchi’s group (Cork), reaction-diffusion equations have been used to model the fabrication of quantum dots (QDs) on GaAs(111) surfaces patterned with inverted pyramids using metalorganic vapor-phase epitaxy. Patternning provides pre-determined sites for QDs and endows the rates of all surface processes with a facet-dependence. The rates of these processes are determined from systematic experiments [3], and the resulting theory accounts for the measured concentration, temperature, and time-dependence of QD formation.


Statistical physics of the human placenta. In collaboration with Dr Carolyn Salafia, we have been analysing the statistical properties of the human placenta at scales ranging from the morphology of the placenta [4], to the network statistics of the vasculature, and finally to diffusional oxygen transport from the maternal to the fetal blood. Our goal is to obtain sufficient statistics on relevant placental characteristics to obtain clinically significant results.

EXSS is a large group comprising 19 members of staff, 40 research staff and over 50 PhD students. Research spans all areas of solid state physics and main themes are highlighted below. The group has strong links with other centres within Imperial College including the Energy Futures Lab and the Grantham Institute for Climate Change.

**Plastic Electronics**  

Organic semiconductors (conjugated polymers and small molecules) are finding increasing applications in light emission, displays, energy conversion, sensors engineering and healthcare. Experimental and theoretical programme.

**Energy and efficient energy use**

**Solar Cell Research**  

The two main drivers in solar cell research are the development of lowercost materials and improving efficiencies. Organic photovoltaic materials such as conjugated polymers, fullerenes and nanoparticles can have efficiencies around 10% - they are relatively cheap and are readily processed from solution. Inorganic semiconductors can achieve efficiencies of 40%, particularly under “many suns” illumination, and are well suited to satellite applications or terrestrial light concentrators.

**Materials for Energy Efficient Refrigeration**  
K. Sandeman, L.F. Cohen and A. D. Caplin

Utilising magnetic magnetocaloric materials offers a route to efficient refrigeration which avoids the use of environmentally damaging chemicals.

**Nanoscience and Technology**

**Frustrated Magnetic Nanostructures**  
W. R. Branford and L. F. Cohen

Arrays of magnetic nanostructured honeycomb lattices impose frustration on the magnetic order resulting in monopole defects according to “spin ice” rules.

**Nanostructured Narrow Gap Semiconductors**  
L.F. Cohen and S.A. Solin

Narrow gap semiconductors such as InAs exhibit high electron mobilities and low surface depletion making them ideal candidates for high sensitivity, ultra high resolution, ballistic nanosensors.

**Quantum Dots**  
R. Oulton, N.J. Ekins-Daukes and R. Murray

QDs have applications in lasers, optical amplifiers, micro-lasers, qubits, single photon sources for quantum cryptography and tunnel junctions for efficient tandem solar cells.

**Mid-infrared Imaging for Cancer detection**  
C.C. Phillips

Mid-IR radiation is absorbed by exciting localised vibrations in chemical bonds in a way that gives each biomolecule an easily recognisable spectral “fingerprint”. If we image a slice of human tissue at the right wavelengths, we can “see” chemicals (e.g. the acids in DNA). Clinical trials are showing that this technique detects cancer earlier and with greater confidence.

**Nanophotonics, Plasmonics and Metamaterials**  

Here we utilise metallic nanostructures in to break the diffraction limit of light. Examples include ultrafast nanoscale plasmon lasers, highly sensitive biodetectors, quantum plasmonics and optical nanoantennas for use in nonlinear nanooptics. Nanophotonic structures are also fascinating materials for combination with graphene for novel optoelectronic devices. At mid-infrared frequencies, we have developed the concept of quantum metamaterials based on highly doped semiconductors for novel sub-resolution imaging applications.
My research programs are centered on understanding the physical properties of functional electronic materials and applying this fundamental understanding to develop improved materials and devices for application in electronics, displays, lighting, energy generation & harvesting and different sensor technologies. I am also interested in innovative manufacturing technologies for large-area nano-electronics where device –and ultimately system– performance is determined by key device dimensions rather than strictly by the physical properties of the active material(s) used. Ultimate aim is the development of advanced device concepts and their application in future generations of ubiquitous large-area opto-electronics. Current research interests falls into three broad themes:

Theme 1: Functional materials and novel fabrication paradigms
Theme 2: Devices and circuits for opto/electronics and energy harvesting applications
Theme 3: Bottom-up fabrication technologies for nano-scale opto/electronics

Solution processed semiconductors offer the prospect of cheap solar power, but the stability of the materials is often limited. We have accelerated aging in photovoltaic devices based on low processing cost materials such as CH3NH3PbI3 perovskites, conjugated polymers, and dye sensitised solar cells (DSSCs) by using high intensity light sources to expose devices to the equivalent of a year’s flux of photons on the time scale of a few days.[1] Our approach enables us to assess the extent of photo-degradation and mechanisms for change in behaviour in these the materials. DCCS proved to be the most stable but can suffer from electrolyte sealing issues. To overcome this we are exploring routes to improve the performance of solid-state DSSCs using lateral transport of holes through dye monolayers attached to surfaces. This ‘molecular wiring’ phenomenon also has potential applications in batteries, solar fuel photoelectrodes, and molecular scale electronic devices. We have developed a new method to experimentally measure the reorganisation energy of charge hopping in these molecular monolayers which shows excellent agreement with our theoretical calculations.[2] This allows us to predict the mobility of holes for different molecules and environments, suggesting interesting new possibilities for the design of organic electronic devices.[3]
onics). Our work spans fundamental studies of electronic and photophysical properties and the development of efficient device structures including organic light emitting diodes, lasers, transistors and photodiodes/solar cells. In addition to molecular materials (conjugated polymers, small molecules, fullerenes, CuSCN, etc) we also work with solution processed metal oxides (MoOX, ZnO, ZrO2, etc) and combined (‘hybridi’) devices are of increasing interest. In addition, photonic structures incorporating conformational metamaterials, microcavities and plasmonic metals are of strong interest. Close collaborations exist with Paul Stavrinou, Thomas Anthopoulos, Ji-Seon Kim and Jenny Nelson in Physics and with colleagues from our Chemistry and Materials Departments. We participate in the EPSRC Centres for Innovative Manufacturing in Large Area Electronics (http://www.large-area-electronics.eng.cam.ac.uk/) and Doctoral Training in Plastic Electronic Materials (http://www3.imperial.ac.uk/plasticel/electronics/pecdt). Strong and growing international collaborations exist with colleagues in Switzerland (ETH), China (Nanjing Tech, CIAC, NJUPT), Korea (SNU, KAIST), Brazil (CSEM) and Hong Kong (HKBU) and we are supported by EPSRC, Unilever, Sumitomo Chemicals, CDT and Molecular Vision.


We have ongoing work engineering arrays of ferromagnetic nanobars to induce a type of magnetic frustration known as the Ice rules and characterizing their magnetic and transport properties. The Ice rules initially described the residual disorder in ice at zero temperature. They also describe the local ordering principle of the spins in spin ice materials and "artificial spin ice" nanoarrays. In the last year we explored how we can use the properties of ferromagnetic domain walls to direct magnetic charges move through these artificial spin ice structures.[1] To do this we developed new methods of imaging this magnetic charge flow (including central facilities work at Advanced Light Source (Berkeley).[2] Paul Scherrer Institute (Switzerland) and Diamond (UK) and collaboration with Solveig Felton (Queens, Belfast).[3] We have explored the interplay between structure and magnetotransport properties in graphene and other Dirac cone materials, including graphene device structures from Thomas Anthopoulos (EXSS)[4] and crystals from Oak Ridge. We also began a collaboration with Lesley Cohen (EXSS) and Peter Petrov (Materials), producing magnetic Skyrmion crystals in bulk form. We are now using these bulk samples to develop thin film growth of these Skyrmionic materials.


Experimental Solid State Physics


3. Influence of Cu substrate topography on the growth morphology of chemical vapour deposited graphene: Xiao, Ye; Kim, HoKwon, Mattevi, Cecilia; et al., CARBON 65 7 (2013)


and organic phototransistors which emit and detect circularly-polarised (CP) light [1, 2]. Such devices have application in protein detection, CP based tomography, optical spintronics and quantum computing, and displays, and a patent from this work has led to further funding and an industrial collaboration [3]. We also have strong activity in the POLARIC (printed organic large-area realisation of integrated circuits) EC FP7 project, which has involved printing high performance organic transistors and complementary circuits. As well as ultra-thin contact printed dielectric dielectrics [4], we have successfully created high-frequency nanoscale self-aligned transistors and circuits using a combination of nanoimprint lithography and conventional photolithography. Work has also been conducted in the area of hybrid inorganic-organic light emitting diodes and transistors, involving the creation of inverted and conventional devices using transition metal oxide and hybrid hole and electron injection layers. New activity has also begun on organic bioelectronic sensors and transistors.


3. “Electroluminescent Compositions” Fuchter, M. J.; Campbell, A. J., Yang, Y. PCT/GB2013/052007


graphene materials characterisation and integration with plasmonic structures has become an active area in the group and we are working with Rupert Oulton and Stefan Maier to develop our interests in graphene photoconductivity detectors and dynamics of photoinduced carriers. Our interests in materials for energy applications continue: We have studied the vortex pinning properties in single crystals superconducting pnictides, in collaboration with colleagues at UFRJ in Brazil, and the magnetotransport properties of the parent compounds; Raman spectroscopy of solid oxide fuel cell electrodes together with colleagues in the Energy Futures Laboratory; and the entropy change contribution in La0.7Ca0.3MnO3 for solid state magnetic cooling applications. One of the most interesting areas has been to understand the potential influence of Andreev bound states in the electrical conductance spectra generated at a superconducting ferromagnet interface. This work was performed in collaboration with Matthias Eschrig and colleagues at Royal Holloway.

1. Spontaneous magnetization above TC in polycrystalline La0.7Ca0.3MnO3 and La0.7Ba0.3MnO3: Turcaud, J. A.; Pereira, A. M.; Sandeman, K. G.; et al., PHYSICAL REVIEW B Volume: 90 Issue: 2 024410 (2014)

Our work on CVD graphene materials characterisation and integration with plasmonic structures has become an active area in the group and we are working with Rupert Oulton and Stefan Maier to develop our interests in graphene photoconductivity detectors and dynamics of photoinduced carriers. Our interests in materials for energy applications continue: We have studied the vortex pinning properties in single crystals superconducting pnictides, in collaboration with colleagues at UFRJ in Brazil, and the magnetotransport properties of the parent compounds; Raman spectroscopy of solid oxide fuel cell electrodes together with colleagues in the Energy Futures Laboratory; and the entropy change contribution in La0.7Ca0.3MnO3 for solid state magnetic cooling applications. One of the most interesting areas has been to understand the potential influence of Andreev bound states in the electrical conductance spectra generated at a superconducting ferromagnet interface. This work was performed in collaboration with Matthias Eschrig and colleagues at Royal Holloway.

1. Spontaneous magnetization above TC in polycrystalline La0.7Ca0.3MnO3 and La0.7Ba0.3MnO3: Turcaud, J. A.; Pereira, A. M.; Sandeman, K. G.; et al., PHYSICAL REVIEW B Volume: 90 Issue: 2 024410 (2014)

One of the first ever demonstrations of a hot carrier photovoltaic device was demonstrated in the group, showing a hot carrier photocurrent at a device cooled to 10K. Research is on-going in collaboration with Sharp Laboratories Oxford to demonstrate a hot carrier photovoltaic device at higher working temperature and with a broader absorption profile. A new milestone for multi-junction solar cell development was passed in a collaborative project with the University of Tokyo where a 1.15eV band-edge using aggressively strain-balanced GaAsP/InGaAs quantum well was demonstrated. Further research has shown that radiative transport within a 4J structure will lead to efficiencies in excess of 50%. Further, we have discovered remarkable microsecond minority carrier lifetimes present in lateral GaAsP/InGaAs quantum wire solar cells in collaboration with the Fraunhofer Institute for Solar Energy Systems in Freiburg. Our research
on the application of metal nanoparticles to promote scattering has been conducted in collaboration with Stefan Maier and Vincenzo Giannini and recently demonstrated that aluminium nanoparticles offer low loss scattering across most of the solar spectrum.


Plastic Electronics enables electronic devices to be printed onto a range of surfaces for large area, flexible and low-cost applications. While innovation in new organic semiconductors and hybrid materials as well as solution-processing techniques continues to improve the performance of devices, further research is required to gain crucial insights into the fundamental relationships between nanostructures of materials and their optoelectronic properties to inform future design strategies. To achieve this goal, our principal research has been focused on two main themes, Nanoscale Functional Materials and Nanometerology: (a) to facilitate the rational design of functional materials, device architectures and fabrication methods via increased understanding and control of the nanostructures and fundamental properties of these materials; (b) to develop advanced structural nanoimaging techniques that have the unique capability to probe non-periodic structures with high chemical sensitivity and high spatial resolution. Our research benefits from strong collaborative links to Physics, Chemistry, Engineering, Materials-based groups at Imperial under the Centre for Plastic Electronics and the Centre for Doctoral Training in Plastic Electronic Materials (http://www3.imperial.ac.uk/plasticel ectronics/pecdt), as well as local/international universities and industrial organisations, which include SNU, KAIST, POSTECH, UNIST, BNU, Ewha (Korea), Technion (Israel), CDT/ Sumitomo Chemicals (UK/ Japan), Samsung Electronics (Korea) and NPL (UK).


Our work in nanophotonics advanced substantially over the last year with a big push towards active materials for optoelectronic control on the nanoscale. Together with researchers of the Naval Research Laboratory and the University of Manchester, we demonstrated a new class of materials for high-confinement and enhancement of radiation at mid-infrared frequencies, based on hexagonal boron nitride [1]. Furthermore we demonstrated gigantic enhancement of higher harmonic generation in hybrid plasmonic nanoantennas based on indium tin oxide decorated with gold nanoantennas [2]. We also showed Bose-Einstein condensation at room temperature in an organic material, an important step towards practical polariton lasers[3]. Lastly, in research led by our colleague Rupert Oulton, we demonstrated ultrafast lasing modulation in a plasmonic nanolaser based on zinc oxide nanowires coupled to surface plasmon polaritons in a silver thin film [4].

QDs are contenders for quantum computation schemes and accessing spin information to/from quantum dots (QDs) is crucial. We have developed methods of determining the polarisation states and g-factors for QD ensembles using circularly polarised light. In conjunction with the Oxford and Hitachi Cambridge we have studied the coupling of cavities defined by the local modulation of the waveguide width using confocal photo-luminescence microscopy. We are able to spatially map the profile of the antisymmetric (antibonding) and symmetric (bonding) modes of a pair of strongly coupled cavities (photonic molecule) and follow the coupled cavity system from the strong coupling to the weak coupling regime in the presence of structural disorder. GaN and its alloys have large exciton binding energies which makes them ideal candidates for studies of strong light matter coupling using optical cavities, paving the way for electrically driven room temperature (RT) polariton laser devices. Cavity polaritons form a macroscopic condensate in the ground state. We have demonstrated an organic polariton condensate at room temperature in a microcavity. At threshold we observe the spontaneous formation of a linearly polarized condensate which exhibits a superlinear power dependence, long-range order and a power dependent blueshift: a clear signature of Frenkel polariton interactions.

My research involves engineering the interaction of light and matter. The stark difference in characteristic length scales of photons and electrons makes optical interactions extremely weak despite light being our primary means of experiencing the world around us. However, the characteristic wavelength light can be matched with that of electrons in materials with metal optics. Metal surfaces support excitations, called surface plasmons, that can be squeezed into spaces just tens of nanometres in size where light-matter interaction are greatly accelerated. While this technique can be used to make brighter and more efficient light sources, Dr. Oulton is currently using this concept to create ultrafast lasers capable of turning on and off within a few hundred femtoseconds. The approach also strengthens the weakest non-linear optics effects. Metal-optics, or plasmonics, allows light focussing down to the nanometre scale, far beyond the diffraction limit of conventional optics. This boosts light’s intensity to enhance non-linear response. The concept is also used in reverse: artificial material states are created in the form of metallic nano-particles that scatter light more strongly than atoms or molecules. This leads to diverse optical methods from coupling light into photonic microchips to characterizing aberrations in optical systems.


We with the help of a new EPSRC grant we have assembled a team to put our “Quantum Ratchet” Solar cell idea to the test. Our modelling has shown conversion efficiencies exceeding 60% are possible, and now we are exploring practical implementations, with collaborators in Japan, the US, Diamond, Sheffield and Sharp labs. Mostly they use nanostructured semiconductor devices based on GaAs/AlGaAs and the nitrides. The race is on to be the first to convincingly demonstrate the sequential photon absorption that lies at the heart of the idea.

In a similar vein, we make quantum metamaterial “superlenses”, using quantum theory to design structures where light beams propagate without spreading by diffraction. To test them we have developed a new s-SNOM microscope, capable of mapping IR spectra at a resolution of 100th of a wavelength, and we are using it to measure chemical distributions within single cells for the first time. Our “Digitain” IR imaging method for earlier cancer detection is undergoing clinical trials in Charing Cross Hospital, and work with Southampton and Bath promises a new form of coherent radiation emitter, that uses a quantum-optical effect known as “Rabi flopping” in an asymmetric nanostructure, to generate tunable THz beams.

High Energy Physics

The High Energy Physics Group has activity across a broad front in exploiting particle physics experiments at existing facilities as well as designing detectors and accelerators for future experiments. These investigate the fundamental particles and the forces between them, with a primary aim to address basic questions such as the origin of mass and the charge-parity (CP) asymmetry between matter and antimatter. The group have also been exploring possible applications of accelerator technology in healthcare, working jointly with the Imperial College Medical Faculty.

HIGH ENERGY PARTICLES
High Energy Particle Collider Studies
O. Buchmueller, D. J. Colling, P. D. Dauncey, G. J. Davies, P. J. Dorman, U. Egede, A. Golutvin, G. Hall, J. A. Nash, M. Patel, A. Tapper, T. Virdee

We have been heavily involved in the CMS detector at the LHC and in the discovery of the Higgs since inception. The trigger (a real-time background rejection) and the entire tracking detector and forward calorimeters will be replaced within the next decade. We develop custom readout electronics for the new tracker and trigger and we lead the design of a novel high granularity calorimeter.

Neutrino and Charged Lepton Physics

The Tokai-to-Kamioka (T2K) experiment in Japan is the flagship of the global neutrino oscillation programme. In 2013 we published the world’s first high-significance measurement of electron neutrino appearance and muon neutrino disappearance.

SuperNEMO searches for neutrinoless double-beta decay, a process that allows access to the fundamental nature of the neutrino mass. We lead the software development. Intense beams of muons at high energy can give neutrino beams with a well known composition and energy spectrum – the so called Neutrino Factory (NF). We lead the MICE experiment to provide the proof of principle for the technique. Many models for new physics predict lepton flavour violation, such as muon to electron conversion. COMET/PRISM will be sensitive to this process, with COMET Phase-I currently under construction as a flagship experiment at the J-PARC laboratory alongside T2K.

Particle Phenomenology
O. Buchmueller

The Standard Model leaves open significant questions in particle physics and cosmology that may be answered by new physics at TeV masses. Our work through the London Centre for TeraUniverse Studies is directly connected to our experimental activities and focuses on dark matter and new physics at the LHC.

The custom readout board for the CMS trigger upgrade

The LHCb detector at the LHC is optimised for measuring b-quark hadrons. Imperial’s main contributions to the detector were the Ring Imaging Cherenkov detector, and the High Level Trigger that makes the current physics programme possible. We lead the search for CP violation and new physics. We have also continued to jointly lead Higgs studies at DZero at the Tevatron, culminating in further evidence for a 125GeV Higgs boson in fermion decays, along with a measurement of its spin state.

Gravitational Wave Detection
H. Araujo, T. J. Sumner

We have recently seen two major milestones in the LISA low-frequency gravitational wave ‘telescope’ in space. We have delivered flight hardware for the ESA LISA Pathfinder technology mission for launch in mid-2015 and also ESA has earmarked LISA for the 2034 L3 launch slot.

MEDICAL APPLICATIONS
Accelerator Developments and Hadron Therapy
K. Long, J. Pasternak, P. A. Posocco, J. Pozimski

We have established a comprehensive programme on proton accelerators for science and medical applications. The group is leading the high-intensity proton beam Front End Test Stand project to test technologies required for a Neutrino Factory, a neutron spallation source, and LHC upgrades. The activities include the development of a compact proton accelerator based on laser-plasma technology and the design of innovative beam gantries using FFAG technology.

e-SCIENCE
D. J. Colling

We have been one of the most active groups within the GridPP distributed computing project since its formation and provide regional coordination through our leadership of LondonGrid. We also have significant experiment-specific development activities.
This year saw the publication of the world’s best exclusion limits on the interaction of dark matter particles from the LUX experiment, which is operating a mile underground at the Sanford Lab in South Dakota. Our result rules out previous ‘hints’ for light particles reported by other teams. A reanalysis to enhance our sensitivity to even lower particle masses is near publication, led by Alastair Currie from Imperial. A year-long run is now underway which should see LUX extend its reach into unexplored parameter space. In parallel, the LUX-ZEPLIN (LZ) next-generation experiment, presently completing the conceptual design phase, was selected by the US funding agencies to become a construction project from 2015. LZ counts some 30 institutes mostly in the US and in the UK (the UK contribution is led by Imperial). We are continuing our LZ-related R&D programme here: our team is investigating the phenomenology of high-field breakdown processes in liquid xenon, studying in particular the emission of photons and electrons from thin wires at several hundred kV/cm. Another strand of our work involves radiation detection high above the Earth, rather than underground. We are developing the Highly Miniaturised Radiation Monitor (HMRM) with RAL and ESA.

A first HMRM prototype was launched recently onboard the TechDemoSat-1 satellite.

1. First Results from the LUX Dark Matter Experiment at the Sanford Underground Research Facility, Akerib, D.S.; et al.; Phys. Rev. Lett. 112, 091303

My work in CMS focused on the final physics exploitation of the RUN1 data taking campaign (2010-2012) analysing the so-called “parked data”, which since the middle of 2013 have been made available for analysis. Furthermore, in 2014 I have continued my coordination role for the planning of the CMS trigger upgrade strategy for the High-Luminosity LHC. This work has come to a first conclusion by assembling a Technical Design Report, to which I have made very significant contributions. This report will be made public in early 2015. In addition I have further expanded my work on particle physics phenomenology, establishing closer links to theorists via the award of a Senior Experimental Fellowship with the IPPP (Institute for Particle Physics Phenomenology in Durham). This has resulted in two publications on how to characterise Dark Matter searches at colliders and direct detection experiments. In addition I have also contributed to new work of the MasterCode collaboration.

CMS Technical Design Report for Phase2
CMS collaboration, to be published in early 2015

Characterising dark matter searches at colliders and direct detection experiments: Vector mediators
Oliver Buchmueller (Imperial Coll., London), Matthew J. Dolan (SLAC), Sarah A. Malik (Imperial Coll., London), Christopher McCabe (Durham U., IPPP), submitted to JHEP

Interplay and Characterization of Dark Matter Searches at Colliders and in Direct Detection Experiments
Sarah Malik (Imperial Coll., London), Christopher McCabe (Durham U.), Henrique Araujo (Imperial Coll., London), A. Belyaev, Celine Boehm, J. Brooke, Oliver Buchmueller (Imperial Coll., London), et al., submitted to Journal for Physics of the Dark Universe.

The NUHM2 after LHC Run 1
O. Buchmueller (Imperial Coll., London), R. Cavanaugh (Fermilab & Illinois U., Chicago), M. Citron (Imperial Coll., London), A. De Roeck (Antwerp U. & CERN), M.J. Dolan (SLAC), J.R. Ellis (King’s Coll, London & CERN), H. Flaccher (Bristol U.), S. Heinemeyer (Cantabria U., Santander), S. Malik (Rockefeller U.), J. Marrouche (Imperial Coll., London) et al., submitted to JHEP
My major research project is the CMS experiment at the LHC. Following the discovery of the Higgs Boson by the CMS and ATLAS collaborations in 2012, the main aim of our work has been to characterise the newly discovered particle as precisely as possible. In particular, we need to check if the production rates (in several production modes) and the decay rates (in several decay channels) are consistent with the theoretical predictions. I have concentrated on one particular decay mode, which is Higgs to two photons. This was one of the two main channels contributing to the discovery, mainly because it can be reconstructed efficiently and so gives high statistical power. As part of this, we produced a paper describing a new statistical method to allow for background uncertainties. A final paper on H→γγ decays using all the CMS data from the 2012/13 LHC runs was recently produced and so far, all measurements are consistent with the theory. However, the LHC will turn on again in 2015 and run for three years at a higher centre-of-mass energy, increasing the Higgs data sample by an order of magnitude and allowing improved precision.

2. Observation of the diphoton decay of the Higgs boson and measurement of its properties, V. Khachatryan et al., EUROPEAN PHYSICAL JOURNAL C, Volume: 74 3076 (2014)

My research has continued to focus on characterisation of the recently observed Higgs boson, both with the CMS experiment at the LHC and the D0 experiment at the Tevatron, as well as searching for non-standard model Higgs boson at CMS. We published the legacy paper in the Higgs to diphoton decay mode, one of the principal discovery channels, achieving single channel evidence. The combination of results from the various decay modes continues to yield results for the couplings and spin in agreement with expectations for the SM Higgs boson. Our searches for invisible decay modes constrain new physics theories, including dark matter models. Returning to this topic has been the other thread in my recent research, and I was very pleased to welcome a JRF, Bjoern Penning, in this area.


As Professor Emeritus I now use my time to take an overall view of the state of particle physics and explore new directions which I feel can be positive for the group. The recent observation of the Higgs boson at the LHC completes the standard model and although this explains almost all particle interactions there remain areas such as neutrino oscillation, gravity, the matter-antimatter asymmetry and dark matter still to be understood. Thus our experiments must now search for signals from the physics beyond the standard model. New avenues must be explored in addition to the ongoing LHC programme which has yet to uncover any evidence. Neutrino oscillation is one observation not predicted by the standard model and hence the lepton sector is a prime area to search for new physics and the great prize would be to see charged lepton violation.
such as a muon changing to an electron. I therefore now support the COMET experiment at the JPARC laboratory in Japan to search for mu to e conversion. Additionally more accurate experiments are necessary in the neutrino area and for this a neutrino factory, long supported in this group, remains the optimal procedure.

Professor Ulrik egede

The exploitation of the very large datasets produced by the LHCb experiment located at the Large Hadron Collider has been my main involvement. Effort has concentrated on looking for signatures that can constrain the nature of dark matter or explain the prevalence of matter over antimatter in the Universe. This means a continuation of the analysis of B meson decays where new types of particles are created within virtual loops. The discovery of a resonant structure in the dimuon mass spectra of the $B^+\rightarrow K^+\mu^+\mu^-$ decay led to subsequent big developments for the theory required to determine the influence of possible particles not described within the Standard Model. A new direction of research is related to semileptonic decays of B mesons, with an emphasis on measuring the strength of the coupling between the $b$ and the $u$ quark. A precision measurement is important for measuring the least well constrained free parameter of the Standard Model. The present measurements suffer from systematic uncertainties that can be reduced by an analysis of the decay $\Lambda_b\rightarrow p\mu\nu$, something that can only be done with the data from the LHCb experiment. Further developments have been made in particle physics phenomenology to improve the interpretation of future experimental measurements.

Professor Andrey Golutvin

Recent results from the LHC experiments, ATLAS, CMS and LHCb, have provided further strong confirmation of the Standard Model. However, a number of experimental shortcomings, such as the finite mass of neutrinos, the absence of a candidate for dark matter and the baryon dominated Universe, require further dedicated experiments. Together with my colleagues I have recently proposed a new experiment, SHIP, which will be based at CERN’s Super Proton Synchrotron. The experiment will search for heavy Majorana neutrinos and any other new particles that could be messengers between the Standard Model particles and some “Hidden Sector” of new physics. In particular, the existence of Majorana neutrinos is strongly motivated by both theory and experimental evidence, as such particles can simultaneously explain the matter-antimatter asymmetry of the Universe and account for the non-zero neutrino masses. I have been elected spokesperson of SHIP and represent the 35 collaborating institutes. CERN has asked our collaboration to produce an engineering design by the spring.

The LHCb experiment has recently started a dedicated programme on the exploration of hidden portals of the Standard Model. Analyses of large, and nearly background free data samples of B decays to the final states with muons have lead to strong constraints on the couplings of the Majorana neutrino and low energy s-goldstinos.

1. Proposal to search for heavy neutral leptons at the SPS, CERN-SPSC-2013-024 / SPSC-EOI-010
2. Search for rare $B(s)\rightarrow \mu\mu\mu\mu$ decays, LHCb collaboration, Phys. Rev. Lett. 110 (2013) 1528276
3. Search for Majorana neutrinos in $B\rightarrow\pi\mu\mu$ decays, LHCb collaboration, Phys. Rev. Lett. 112 (2014) 131802
4. First observation of the rare decays $B\rightarrow K\tau\bar{\nu}$ and $B\rightarrow q\bar{q}\mu\nu$, LHCb collaboration, JHEP10 (2014) 064
I am the UK PI for the CMS experiment at the CERN LHC. This includes many activities on the experiment, including supervision of the UK detector operational responsibilities, especially on the Tracker which involved much Imperial effort and hardware, and other managerial activities. CMS is preparing an upgrade and much of my time is spent on that, where our group is currently replacing the Level-1 calorimeter trigger and engaged in R&D for new tracker detector modules based on silicon microstrips and a specialised front-end electronic integrated circuit. This module will provide new functions by selecting data to permit reconstruction of many of the charged particle tracks emerging from p-p collisions, and allowing this information to be used in the L1 trigger for the first time. This will increase the power of the trigger, allowing CMS to be more selective in data which are preserved for full analysis, by selecting high transverse momentum tracks and associating them with calorimeter and muon system information. A prototype module of this type was demonstrated in a DESY test beam last December for the first time. We have also carried out experiments on silicon crystal channeling in CERN proton beams.


G. Hall, D. Newbold, M. Pesaresi, A. Rose A time-multiplexed track-trigger architecture for CMS 2014 JINST 9 C10034 http://dx.doi.org/10.1088/1748-0221/9/10/C10034


The CMS collaboration. Alignment of the CMS tracker with LHC and cosmic ray data 2014 JINST 9 P06009 http://dx.doi.org/10.1088/1748-0221/9/06/P06009

I remain on Leave of Absence, promoting technologies derived from Particle Physics into a wider technical and commercial sphere. Our HEP-derived company deltaDOT has gone from strength to strength with tools built on early CMS pattern recognition algorithms (with Dr David Colling) and vertex finding in b quark decays. It has been adopted by the largest vaccine programme in the US, a highly topical development, and has been used in a wide range of biomedical applications, most notable in novel point-of-care cardiovascular biomarker analytics. In Sept 2012, I was appointed Senior Advisor to Sir Magdi Yacoub’s Qatar Cardiovascular Research Centre. We have also been adopted by several oil companies in the MENA region for real-time oil analytics and production allocation. Our team – mostly physicists – has set up a new company in Bahrain, to address the Saudi market, and to complement our Qatari company. We also have a contract within Dubai and will establish a company there in 2014. In addition, our gas sensing technologies (as demonstrated in the 2012 London Olympics, and built on HEP heavy quark separation algorithms) is being adopted by a GCC nation for air quality sensing, and is being studied by a National Oil Company, as a means of rapidly detecting the leakage of Toxic Industrial Chemicals.

Publications
The Internet of Things: Smart Cities: Meeting the Threat. Invited talk at University of Shanghai, December 2011

FICCI Conference, Chemical, Biological, Radiological, Nuclear, Explosives (CBRNE) Conference, Home Office Invitee and Plenary Speaker. New Delhi, February 2012


Muon accelerators have been proposed as intense neutrino sources and as a means to deliver...
multi-TeV lepton-antilepton collisions. What makes the muon ideal for these applications is its mass, 200 times that of the electron, and the fact that its decays are precisely calculable. We have played seminal and leading roles in the international and European design studies that have established the feasibility of such facilities. Within these studies we have contributed designs for the proton source, the muon acceleration systems and the muon storage ring. The muon beam is produced from the decay in flight of pions, which means that it occupies a large volume of phase space. Before the muons can be accelerated it is necessary to reduce the phase-space volume that the beam occupies, a process referred to as cooling. The muon lifetime is so short that a novel technique, ionization cooling, is required to compress the phase space. We have taken the lead in the execution of the international Muon Ionization Cooling Experiment by which we hope to prove the principle of the ionization cooling thereby establishing high-intensity, cold muon beams as a new technique for particle physics.


My research is primarily focused on the LHCb experiment at CERN's Large Hadron Collider. I am particularly interested in the use of rare decay modes as probes for physics beyond the current "Standard Model" of particle physics. My recent papers include the first measurements of the rare decay B0\(\rightarrow\mu^+\mu^-\) that has been sought for more than 30 years. The measurements constrain the properties of any new scalar particles and have implications for many new physics models. My measurements of B\(\rightarrowK^*_0\mu^+\mu^-\) show some tension with the Standard Model that may indicate the existence of a new vector particle. Further measurements of this and related decays should help clarify the situation. Similarly, my measurements of B\(\rightarrowK^+\ell^+\ell^-\) decays, where \(\ell=e, \mu\), show electrons and muons, which behave identically in the Standard Model, have different decay rates. This has stimulated interest in a whole raft of similar measurements. Finally, I have also made new asymmetry measurements to probe anomalous results obtained at other experiments. I am also a member of the SHiP collaboration. We are proposing a new and uniquely sensitive experiment at CERN to search for new light particles that could help

Jaroslaw Pasternak was focusing on MICE experiment and nuSTORM project for the last year. In particular as the Imperial responsibilities in MICE have increased significantly with Prof. K. Long taking the position of the Spokesman in November last year, Jaroslaw took over the leadership of the Imperial MICE group. He also accepted a role of the Accelerator Integration Scientist and he leads the preparation for commissioning of the MICE experiment at Step IV including the beam commissioning currently envisaged in summer 2015. Recently he led the redesign effort of the final stage of MICE experiment dedicated to demonstration of ionization cooling with RF re-acceleration to be operational in 2017. He is also working with his RA Dr J-B. Lagrange on the design of the nuSTORM FFAG ring option, which is one of the main options. He published 2 papers: one on nuSTORM and another on older work within IDS-NF project and two more are in preparation.

1. Adey D et al., Light sterile neutrino sensitivity at the nuSTORM facility. PHYSICAL REVIEW D 89(7):7 pages Articles number ARTN 071301 09 Apr 2014.
solve a number of problems of the Standard Model.
http://lhcb.web.cern.ch/lhcb/;
http://ship.web.cern.ch/ship
4. Measurement of the $B^0 \rightarrow \mu^+ \mu^-$ branching fraction and search for $B^0 \rightarrow \mu^+ \mu^-$ decays at the LHCb experiment, R. Aaij et al, [LHCb Collaboration], Phys.Rev.Lett. 111 (2013) 101805 (10.1103/PhysRevLett.111.101805)

We have been working in a multidisciplinary team with members of the Faculty of Medicine on the development of new approaches to proton therapy. We have identified three different applications of our expertise, namely proton acceleration using laser-plasma technology [1], proton delivery using the FFAG technology [2], and evaluating the effects of proton therapy combined with new metabolic drugs like ADI-PEG20. We extended our work towards modern challenges in medical diagnostics, like the worldwide shortage of Tc-99m for SPECT by devising a technique to tailor the wide laser-generated proton spectrum to maximise the yields in the Mo-100 ($p$, n) Tc-99m channel for direct production. Our approach is based on a revised design of the Gabor lens, which soon will be tested with beam at the Cerberus laser facility at Imperial.


Within the area of neutrino physics, neutrinoless double beta decay (NDBD) - a rare, lepton-number violating, nuclear decay process – is of particular current interest. The observation of neutrino oscillations demonstrated that neutrinos have mass; a consequence of this new, beyond the Standard Model physics is renewed activity in NDBD experiments which provide the only way to determine the fundamental nature of the neutrino (Dirac or Majorana). In addition, NDBD experiments offer the possibility of determining the absolute neutrino mass scale.

An international collaboration is currently constructing a next-generation experiment, SuperNEMO, to search for NDBD as evidence for Majorana neutrino masses down to a level below 0.05eV (equivalent to a half-life of about $10^{26}$ years), the region suggested by neutrino oscillation experiments. The first SuperNEMO module will be installed in the Modane underground laboratory, France, over the next two years and will then begin data-taking. I lead the SuperNEMO group at Imperial and the software development group within the collaboration. The Imperial group’s main activities are development of physics analysis and software with contributions also to the tracking detector and its commissioning.

This year has seen delivery of our flight hardware for the European Space Agency LISAPathfinder mission. This mission will be launched next year (2015) and it is a technology precursor for the ESA L3 mission in gravitational waves. ESA recently selected the gravitational wave theme for L3 and this represents the successful culmination of two decades of work in developing the technology and promoting the pioneering new science opportunities in the fields of astrophysics, cosmology and particle physics. Following the completion of our ZEPLIN direct dark matter search programme we now moved on with collaboration on...
the US-led project LUX which has published the world’s best result to date and continues with a second more sensitive run at the moment. In addition the LUX-ZEPLIN project, which we co-founded in 2008, has gone through an extensive design/R&D phase and has been selected as one of two next generation direct dark matter search projects in the US. The UK is intending to provide a significant share of the experiment with Imperial playing key roles, and an application for funding is ongoing.


My research has focused recently on completing the analysis of the data taken in the first physics run of the Large Hadron Collider (LHC) at CERN from 2010 to 2012, and preparing for the restart of the LHC, at higher energy in 2015. Together with colleagues from Imperial College, Bristol, STFC and the US my group have been searching the data taken by the CMS experiment at the LHC for evidence of new particles predicted by the theory of Supersymmetry. So far no evidence has been found and we have two papers in preparation, which will complete the searches with the available data, and set stringent limits on the allowed theoretical parameter space.

The other focus of my work is preparations for the restart of the LHC at higher energy and luminosity in 2015. To fully benefit from the improved performance of the LHC the CMS experiment must be upgraded and working with colleagues from Bristol, STFC and the US my group is delivering an improved triggering system for the experiment. This will benefit our searches for new physics, with exciting prospects for the new run next year!

1. Measurement of the inclusive electron neutrino charged current cross section on carbon with the T2K near detector: K. Abe et al (T2K Collaboration); PHYSICAL REVIEW LETTERS (accepted November 2014)


3. Experimental Proposal for Phase-I of the COMET Experiment at J-PARC: R. Akhmetshin et al (COMET Collaboration); KEK/J-PARC-PAC 2012-10


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My research probes the most fundamental aspects of the nature of matter and energy. In particular, I am engaged in the study of neutrino flavour oscillation, which is the first—and so far only—discovery that lies outside the current predictions of the standard model of particle physics. I work on accelerator neutrino experiments, currently focussing on the T2K experiment in Japan.

T2K sends a beam of muon neutrinos from the J-PARC facility in Tokai-mura across the main island of Japan to the Super-Kamiokande detector deep within the Kamioka mine. We have recently published a stunningly large excess of electron neutrino events allowing us to measure the heretofore unobserved subdominant oscillation and its mixing angle, \( \theta_{1-3} \). These are the next steps toward the goal of searching for violation of charge-parity symmetry with neutrinos.

I am also a member of the Hyper-Kamiokande collaboration, which is working toward a megatonne scale water Cherenkov detector. This experiment would provide exquisite sensitivity to the search for violation of charge-parity symmetry in neutrinos, which could explain why the universe is made of matter and not antimatter.

http://t2k-experiment.org


The Photonics Group conducts fundamental research into optical science and develops and applies new technologies for the physical and life sciences, medicine and ICT. Our projects are mostly interdisciplinary and we work closely with industry and external agencies.

**LASER TECHNOLOGY**
*Prof R. Taylor, Prof M. Damzen, Dr S. Popov, Dr E. Kelleher, Dr G. Thomas*

We conduct a world-leading research activity on fibre and all-solid-state lasers developed for many real-world applications from precision laser manufacturing, remote sensing through to medical imaging and therapeutics.

**Fibre Lasers**
This activity is currently focused on development of compact and high power fibre laser sources, engineered to create new wavelengths and ultra-short pulse formats including: supercontinuum generation in photonic crystal fibres; visible fibre sources by Raman or parametric conversion of IR fibre-lasers; near and mid-infrared sources based on novel Bismuth and Thulium-doped fibre lasers; ultrashort pulse generation using carbon nanotubes or graphene as 'universal' saturable absorbers that can operate across all wavelength regions.

**Diode-Pumped Solid-State Lasers**
This activity develops all-solid-state lasers and nonlinear optical technologies to provide efficient sources of high energy pulses including: diode-pumped micro-slab lasers (commercialised by Mike Damzen’s spin-out company, Midaz Lasers Ltd); world-leading diodepumped Alexandrite lasers, supported by the European Space Agency (ESA) for next-generation satellite-based remote sensing and future femtosecond laser applications; and resilient "selforganising" lasers based on dynamic nonlinear optical holography that selfcorrect for thermally-induced aberrations in high power lasers.

**BIOPHOTONICS**
*Prof P. French, Prof M. Neil, Prof P. Török, Dr C. Paterson, Dr C. Dunsby, Dr J. McGinty*

Our optical imaging and metrology encompasses technology development for biomedical applications in research, drug discovery and healthcare, including microscopy, endoscopy and tomography as well as automated imaging for high content analysis and sensing and manipulating pathogenic bacteria. We have particular strengths in fluorescence lifetime imaging (FLIM) for quantitative molecular contrast, including of protein-protein interactions, superresolved microscopy (including STED, PALM and STORM) for imaging below the diffraction limit, and confocal Brillouin scattering microscopy to measure the micromechanical properties of biological tissues. Our fluorescence imaging and measurement technology is being applied in hospitals to clinical diagnostic challenges for cancer, osteoarthritis, heart disease and ophthalmology and to preclinical tomographic imaging of disease models.

**ELECTROMAGNETIC THEORY & PHOTONIC STRUCTURES**
*Prof M. McCall, Prof P. Török, Dr K. Weir*

Rigorous electromagnetic theory and experimental analysis is applied to photonic and nanophotonic structures such as chiral media and metamaterials. The theoretical development of "space-time cloaking" was founded in our group; ultrahigh-resolution micropolarimetry is being applied to plasmonics, metamaterials, micromagnetics and to optical data storage using polarisation to encode multiple bits into each pit of an optical disc.
We have performed the world-first high power development of diode-pumped Alexandrite as a new laser technology with broad wavelength tunability [ref. 1]. This work is being supported by the European Space Agency as a new technology for satellite-based remote sensing of the atmosphere and ground vegetation. It also has potential as a low-cost replacement for the femtosecond Ti-sapphire laser. We have generated > 26W, more than an order of magnitude higher than previous diode end-pumping systems, highest ever slope efficiency 49%, and the first Q-switched laser operation of diode-pumped Alexandrite producing ~mJ-pulse energy at 1kHz pulse rate in fundamental TEM00 mode. It was recently presented as an invited Keynote talk at the Optical Engineering and Design conference and reported in trade journal [ref. 2]. We have also patented and implemented a novel technique for obtaining enhanced control of pulsing parameters in a laser [ref. 3]. The method uses a secondary laser cavity to control the gain in a Q-switched primary laser cavity and has enabled clean single-pulse Q-switched operation to be obtained across a very wide repetition rate range of 1–800 kHz and control of pulse energy. In another project supported by Paul Instrument Fund (Royal Society), we are using liquid lenses, whose focal length can be rapidly adjusted with a control current. The liquid lenses have been used to construct a laser beam quality measurement instrument; laser colour marking of metals; and recently adaptive spatial control of a laser cavity.


The main focus of our work is the application of photonics technology to quantitative fluorescence imaging and sensing. This includes collaborations with clinicians that aim to exploit endogenous tissue autofluorescence for the detection and diagnosis of disease. Currently, we (PF&CD) have an EPSRC funded project with the National Heart and Lung Institute and the Kennedy Institute for Rheumatology to apply point-probe and endoscopic measurements of fluorescence lifetime to study of heart disease and arthritis. We also have a second EPSRC funded project (CD,PF,MN&CP) in collaboration with the University of Bath to develop novel multiphoton microscopes and endoscopes for clinical applications. Our technology (PF&CD) is also applied to measurements of exogenous fluorophores, for e.g. quantification of photosensitisers penetration with Moorfields Eye Hospital, or in cells through fluorescence lifetime imaging of protein-protein interactions, including in multi-well plate formats. We also have projects developing optical superresolution techniques (PF,MN&CD) including stimulated emission depletion microscopy. A recent collaboration with colleagues at King’s College London and the Department of Bioengineering at Imperial has translated optical methods for superresolution imaging to ultrasound superresolution imaging, including in vivo, for the first time. Finally, we continue to develop a high speed 3-D fluorescence microscopy technique called oblique plane microscopy.

4. Application of time-resolved autofluorescence to label-free in vivo optical mapping of changes in tissue matrix and metabolism associated with myocardial infarction and heart failure J. Lagarto*, B. T. Dyer*, C. Talbot, M. B. Sikkell, N. S. Peters, P. M. W. French, A. R. Lyon** and C. Dunsby** Accepted for publication in Biomedical Optics Express (*) and ** indicates equal contributions
In the last year I have continued to develop and apply multi-dimensional fluorescence imaging technology, particularly for super-resolved microscopy (SRM), high content analysis (HCA) and preclinical and clinical imaging, in close collaboration with Chris Dunsby, James McGinty, Mark Neil and Carl Paterson. All of our projects are inherently multidisciplinary with collaborations across College and beyond. With respect to SRM, we (with CD, MN) are funded to work with the MRC Clinical Sciences Centre to develop 5 advanced SRM instruments for the study of cellular structure and function beyond the diffraction limit. For HCA, we (with CD) are developing automated multiwell plate readers incorporating fluorescence lifetime imaging (FLIM) technology to assay protein interactions and cellular metabolic processes. We are also developing open source software tools for automated acquisition, rapid analysis and management of image data – particularly developing OMERObased tools in collaboration with the University of Dundee. For preclinical imaging we (with JM) are working with Department of Life Sciences and UCL to develop a platform longitudinal imaging of whole zebrafish from larvae to adults, which is being applied to studies of cancer, inflammation and bacterial infection.

For clinical imaging we (with CD) are working on the application of novel instrumentation to measure autofluorescence lifetime for readouts of heart disease and osteoarthritis and (with CD, MN, CP) are working on a compact handled multiphoton microscope and an ultrasnarrow multiphoton endoscope exploiting adaptive optics to eliminate need for distal scanning or focussing systems. 3-D stimulated emission depletion microscopy with programmable aberration correction, M. O. Lenz, H. G. Sinclair, A. Savell, J. H. Clegg, A. C. N. Brown, D. M. Davis, C. Dunsby, M. A. A. Neil and P. M. W. French, J. Biophotonics 7 (2013) 29-36 doi: 10.1002/jbio.201300041


Dr Edmund Kelleher

My work on ultrafast nonlinear fibre optics is conducted in close collaboration with Prof. Roy Taylor and Dr. Sergei Popov and is a key theme within the Photonics activity at Imperial. Our shared interest in the development of high-brightness, short-pulse fibre laser sources for target wavelengths in the visible and mid-infrared is supported by industrial collaborations with IPG Photonics Inc. and Gooch and Housego PLC, and is focussed on bio-photonic specific applications – lead by Prof. French.

My interest in power-scaling mode-locked fibre lasers has led to research studying the formation and stabilisation of dissipative solitons and involvement in a project run my the University of British Columbia: using such lasers as seed-sources for frequency upconverted systems based on high-harmonic generation in passive femtosecond enhancement cavities, providing a source of synchrotron-level energy XUV for table-top ARPES experiments. I also continue to work closely with the Graphene Centre at the University of Cambridge on the fundamental study, and application of low-dimensional materials in ultrafast optics, recently broadening the scope of this study – through a collaboration with Nanjing University, China – to include graphene-enabled plasmonic devices. Additionally, diversification of theories and models applied widely in my research in optics has led to collaboration with the Swinburne University of Technology, where nonlinear Schrödinger-type equations are applied to understand the dynamics of deep ocean waterwaves. In particular, modulation instability and the formation of rogue solitons have particularly strong analogues in both the optical and hydrodynamic context.

Our recent research has sought to understand some of the implications of our introduction of the so-called Spacetime cloak in 2011. This new type of cloak was based on a radically novel interpretation of transformation optics which allowed the concealment of events rather than objects. It was subsequently demonstrated experimentally. We have studied how event cloaks can be designed for simple wave systems, and have examined their directional nature – events concealed in one direction are visible, but distorted, in another. We have considered applications in optical processing, where an ‘interrupt-without-interrupt’ functionality potentially allows priority processing whilst a clock signal remains undistorted, despite being temporarily suspended.

In another project, we have recently been able to calculate the modes of a laser for which the active medium is structurally chiral. Such lasers issue circularly polarized light, of potential interest and application to 3-D display technology.


My main area of research is centred on developing techniques for quantitative 3-D optical imaging of mesoscopic sized samples (~mm-cm), with particular emphasis on biological and biomedical applications. One such imaging technique for 3-D imaging of transparent samples that is scalable to cm sized volumes is optical projection tomography (OPT). OPT is the optical analogue of X-ray CT, where wide-field images of a transparent sample are acquired while the sample rotates. I have been working on improvements to enhance both the spatial resolution and light efficiency while minimising the acquisition time. The condition for transparency can be realised for ex vivo samples by chemical clearing processes – essentially exchanging the water in the sample for a liquid of higher refractive index that matches that of the tissue and therefore suppresses the scattering of light. For in vivo imaging, samples that are inherently transparent can be used, for example the nematode worm and the zebrafish embryo (~mm scale). In addition to producing 3-D structural reconstructions, I am also translating the quantitative techniques applicable in microscopy to OPT. In particular I am working on techniques to realise time-lapse 3-D imaging of dynamic processes and fluorescence lifetime imaging for measuring protein interactions using Förster resonance energy transfer.


The work of the Femtosecond Optics Group is directed towards the development of spectral and temporal versatility in fibre based sources with the objective of applications and potential commercialization. Compact, short pulse, moderate average power (~10s W), fully fibre integrated, chirped pulse, master-oscillator power fibre amplifier configurations are being developed, with the emphasis on Yb-doped systems for operation in the 1 μm window. Following first stage pulse compression in conventional grating pairs, generation of pulses ~100s femtoseconds allows further compression in gas filled photonic crystal fibre grating assemblies to pulses ~10s femtoseconds that can be applied to non-linear conversion studies in gases, allowing tuneable uv generation. Extension of the technique to Tm based fibre assemblies has supplied moderate average power, femtosecond pump pulses for broad band supercontinuum generation in the 2-3.5 μm range in silica based fibres containing a high Germania content. With planned power scaling, through initial pulse compression spectral coverage up to 5 μm should be possible. Broadly tuneable visible generation in compact all fibre configurations has been achieved through using frequency-doubled, laser-diode seeded, single-pass cascaded Raman generation in integrated silica fibre assemblies. With near infra-red pumping, highly efficient optical parametric generation in photonic crystal fibres has also allowed spectral generation towards visible wavelengths. In collaboration with Polytechnique Montreal pulse compression of pulses from giant chirped pulsed fibre lasers has been demonstrated in long (up to 0.5m) chirped fibre Bragg gratings, confirming theoretical models on the performance of this unique class of laser.


Our group is developing advanced techniques in optical imaging, sensing and microscopy. Our work on Brillouin scattering sensing and imaging, done in collaboration with Carl Paterson from Physics and Rob Krams and Darryl Overby from Bioengineering, includes sub-cellular resolution confocal Brillouin microscopy to observe elastic properties of endothelial cells of the Schlemm canal, both low and high resolution Brillouin imaging to study the stiffness of coronary artery walls and Brillouin endoscopy to provide in-vivo analysis of membrane stiffness of plaques in coronary arteries. Our Brillouin microscope is also used to study mechanical properties of biofilms and those matrices they populate. This work is carried out in collaboration with Thorsten Wohland and Yehuda Cohen of NUS. Simultaneously, in collaboration with Stefan Maier, capitalising on our earlier work on Müller matrix polarimeter microscopy, we are in the process of building a spectroscopic version of this microscope that will permit 3D functional imaging of plasmonic structures and photonic crystals. We also have developed, together with Stefan Maier, a novel form of super-resolving optical microscope to map the electromagnetic field around subwavelength plasmonic structures, such as nanoantennae that cannot be observed by any other means.


Plasma Physics

We are one of the largest plasma physics groups in the world, and deal with plasmas ranging from the low densities and temperatures found in industrial processes to the extreme conditions at the centre of a laser driven capsule of fusion fuel or the core of a star. The group’s research links experiments, many performed on in-house facilities to complex theory and numerical simulations using super computers. We also host the Centre for Inertial FusionStudies which connects high energy density science to the search for fusion energy production, and the Institute of Shock Physics which creates and studies materials and systems under extremes of pressure.

STRONGLY MAGNETISED PLASMAS
S Lebedev, RA Smith, J Chittenden, S Bland, F Suzuki-Vidal.

We build and operate multi-terawatt (10^{12}W) electrical machines and short-pulse lasers to create and study exotic plasma conditions. The group’s 1.4 million amp Z-pinch MAGPIE is the largest open-access machine of its kind in the world and linked to the UK’s largest University based laser system Cerberus. MAGPIE allows us to create plasmas from arrays of wires or foils and then accelerate or ‘pinch’ them with strong magnetic fields. We use this to launch high-speed ~100 kms^{-1} plasma jets or shock waves which simulate astrophysical processes such as star formation in the laboratory.

The group’s experimental work is supported by complex computer simulations using tools we develop such as the 3D Magneto-hydrodynamics computer code GORGON. This is now used to simulate plasma dynamics in experiments in laboratories across the world including the 26 mega-amp Z facility in the US. Gorgon is also used to simulate complex laser based experiments such as the stability of NIF inertial fusion implosions.

HIGH ENERGY DENSITY PLASMAS
Z Najmudin, S Mangles, RA Smith, R Kingham

The group creates and studies high energy density plasmas using powerful lasers, both at Imperial and major laboratories worldwide. Lasers can accelerate particles to very high energies over remarkably short distances and we have produced GeV electron beams in just 1 cm of plasma. These beams can be used to create ultrabright x-ray sources and could one day replace low energy synchrotrons. We have used them to trial new applications including medical imaging and we are also exploring similar laser driven techniques for cancer therapy, where the short stopping distance of a proton beam may be used to target tumours with low collateral damage and high precision.

INERTIAL FUSION
S Rose, J. Chittenden, R Kingham, Z Najmudin

Compressing and heating a mix of hydrogen isotopes can lead to thermonuclear fusion and potentially a huge energy release that might one day underpin a new generation of power stations. In fusion ignition experiments the plasma density and temperatures created far exceed those at the centre of the sun. Through experiment and computer simulations we study both fundamental plasma processes at these conditions, and advanced fusion concepts such as “fast ignition” and “shock ignition” that may allow us to reach “breakeven”, the point where more energy is released from the plasma than required to heat and confine it.

The tools and concepts we develop for inertial fusion research also allow us to study in the laboratory scale models of some of nature’s most extreme phenomena. In "laboratory astrophysics" experiments we probe the formation of accretion disks around black holes and the dynamics of supernova explosions.

MAGNETIC CONFINEMENT FUSION
M Coppins, S Cowley, M. Lilley

We investigate magnetic confinement fusion using a doughnut shaped Tokamak, in which a low density plasma is held inside strong magnetic fields and heated over multiple seconds with a combination of electric current, microwaves and particle beams. The world’s largest and most successful Tokamak JET is based at Culham, along with a more compact machine, MAST.

Tokamaks are affected by dust, small grains of solid material that are carried along with the plasma. Dusty plasmas occur naturally in space and are also found in industry and affect the production of materials and components. We study them because of their potential to trap radioactive tritium and disrupt future magnetic fusion test machines.
On the MAGPIE facility a series of experiments examined the production of radiative shock waves within gas filled cylindrical liners, and how the application of a magnetic field affected their dynamics (1). Such experiments could influence the design of magnetised inertial fusion targets, and in collaboration with Loughborough University a 10Tesla magnetic field system is being developed to aid experiments.

A new method of isentropically compressing a cylinder of material to extreme pressures (>>Mbar) has been explored (2). Critically this technique produces large volumes of compressed material, held at pressure for many ns, hopefully enabling phase changes – e.g. metallisation of hydrogen – to occur. The technique is presently being examined at Sandia National labs. Working with colleagues at CEA Gramat, an ‘X-pin’ system has been developed to provide X-ray diffraction measurements of materials being dynamically compressed (3). In a separate series of collaborations with the CEA and ESRF, a low energy (50J) laser was used to drive very small samples of iron to MBar pressures, whilst the high precision, micron sized X-ray beam from the synchrotron was used to explore the states produced. This technique demonstrates the ability to miniaturise high pressure experiments, and, with the X-pin, could provide a new probing method for large facilities.


Our work concentrates on numerical modelling of high energy density physics experiments relating to Inertial Confinement Fusion and magnetised Z-pinch plasmas. We have recently developed a new 3D radiation hydrodynamics model ‘Chimera’, designed to simulate ICF experiments on the National Ignition Facility. We have been collaborating with LLNL on understanding the influence of radiation asymmetry and capsule defects on the energy yield from fusion. Much of this can be inferred from detailed analysis of the distribution of neutron energies emerging from the reacting region. Similarly, using our magneto-hydrodynamics codes, we have studied the role of material strength in determining the dominant instability wavelengths in imploding cylindrical fusion targets driven by the 20MA generator at Sandia National Laboratory. We have adapted this work to develop new techniques for isentropic compression of materials which can be used to recreate the extreme conditions at the centre of gas giant planets. We are also utilising kinetic models of the fast particle species within these plasmas to study the generation of K-alpha photons by runaway electrons, the generation of secondary nuclear fusion reaction products, beam-target reaction processes due to runaway ions and the ignition of a fusion plasma by energetic alpha particles.


Our work on dusty plasmas concentrates on the basic physics of the dust-plasma interaction, and dust in tokamaks. We collaborate with John Allen (Oxford), Umberto
On the basic physics side, three topics can be mentioned from the last 12 months. Firstly, we have found the equilibrium charge distribution for large (i.e., larger than a Debye length) dust grains [1], due to fluctuations in the charge. Secondly, the planar source-sheath configuration has been studied computationally and theoretically [2]. Although dust is not directly involved, results from this work have subsequently been used to construct a new model for the charging of large dust grains. Thirdly, the charging of small dust grains in a flowing plasma, and the formation of associated structures in the surrounding plasma, has been studied using kinetic theory [3]. In contrast to the large grain case, we find upstream structures.

In the other area, dust in tokamaks, we are currently preparing a paper on hypervelocity dust [4], i.e., particles with speeds > 1.0 km/s which have been reported in some tokamaks. It has been suggested that such particles may significantly damage the vessel walls. Our studies indicate that this is not the case.


Our recent work focuses on theory and simulation of high-power laser-plasma interaction, in the context of Inertial Fusion Energy and High Energy Density Plasmas. We have been developing and using a new computational approach for calculating transport of laser-generated relativistic electron beams for igniting pre-compressed fuel. Our semi-kinetic treatment of the background plasma, including magnetic field, has revealed new mechanisms capable of altering beam propagation. In collaboration with colleagues at the University of York and LLNL, we are using our Vlasov-Fokker-Planck codes to validate and improve the heat flow model used in radiation-hydrodynamic codes, for improved modelling of the NIF. We continue research into the dynamics of under-dense plasma heated by nanosecond laser beams. We have extended our magneto-thermal instability to include both hydrodynamics and non-equilibrium thermodynamics due to non-Maxwellian electron distributions. To get a complete self-consistent description of the entire system, refraction and filamentation of the laser beam has been added. We are collaborating on several, multi-institutional laser experiments at UK laser facilities (Vulcan and Orion) to explore this complex physics.

affect the shock structure; we detected existence of protons trapped and accelerated to MeV energies by the MHD processes in the laboratory magnetic-tower jets under conditions scalable to the dynamics of magnetised astrophysical jets. We continue collaborations on this work with colleagues at Rochester, Cornell, Rice and Sorbonne Universities.


Following our work on characterisation of laser wakefield driven betatron x-ray sources [1], a successful experiment performed on the Astra Gemini Facility was able to demonstrate the application of this source for medical imaging, with both soft tissue phase-contrast imaging and tomographic reconstruction of bone demonstrated. A collaborative experiment with QUB also demonstrated the potential for using interaction of the laser wakefield electron beam with a colliding high power laser to produce a bright source of γ-rays [2]. For the generation of ion beams work continued both at the Rutherford Lab [3] and on experiments performed at the ATF (Brookhaven National Laboratory), where a successful experiment to demonstrate the importance of plasma profiling on shock wave acceleration of ions was reported. An initiative to develop an ion source in the basement of Blackett Lab in collaboration with Roland Smith and Piero Posocco has also begun. Our development of a plasma source for the planned proton driven wakefield experiments at CERN continued with the extension of the grant for a further year [4], and improved reliability of the plasma discharge.


My research group works in the area of High Energy Density Physics (HEDP) which is the study of matter in the plasma state at temperatures typically in excess of a million degrees at solid density and above. Our work is theoretical and we develop new models of HED plasmas. We are also involved in the design and analysis of experiments which use high-power lasers or pulsed-power machines to test the validity of those models and generally to better understand the HED regime. Our work is relevant to Inertial Confinement Fusion (ICF) which attempts to produce energy gain by thermonuclear reactions in HED plasmas. Energy gain has not yet been demonstrated and our group is working with scientists at the US Lawrence Livermore National Laboratory, home to the National Ignition Facility laser system, to try to get closer to that goal. We are also interested in developing fundamental physics experiments using HED plasmas produced by high-power lasers. Recently we published the design of an experiment that will, for the first time, demonstrate the two-photon Breit-Wheeler QED process in the laboratory (turning pure light into matter). We are now working closely with several groups around the world to undertake that ground-breaking experiment.


My research focuses on the development and exploitation of advanced laser sources to produce ultra-short and ultra-high-intensity light pulses. We use these to create and probe exotic states of matter, ranging from laboratory scale simulations of supernova remnants and plasma jets launched during star formation through to the sub-femtosecond dynamics of nanometer scale "clusters" of atoms. To underpin our experiments we operate the UK’s largest University based laser Cerberus, which delivers high energy ns and sub-ps pulses to multiple experimental areas. Cerberus is also linked to MAGPIE, one of the world’s largest Z-pinches. This combination of pulsed power and laser systems allows us to explore the complex behaviour of high-energy-density plasmas in which huge magnetic fields play a dominant role. We also develop new types of target for laser-matter interaction studies, most recently a unique optical levitation trap able to fix isolated few-micron objects with micron precision in vacuum. We have recently used high-energy laser probes to measure the distribution of magnetic fields dragged about by a high velocity plasma flow impacting...
a surface. We have also shown that levitated droplet targets provide a unique way of creating small, high-brightness x-ray sources with minimal debris, and extremely low electromagnetic pulses.


My research is aimed at reproducing astrophysical phenomena by the means of carefully scaled laboratory experiments, a new field also known as Laboratory Plasma Astrophysics. The experiments are typically conducted on the MAGPIE pulsed-power facility at Imperial College, with astrophysical applications ranging from the formation of jets in young stars, the physics of accretion discs, and supersonic, magnetised plasma flows and shocks. The experiments are part of collaborative work with researchers worldwide including Observatoire de Paris (France), Universidad de las Palmas de Gran Canaria (Spain) and University of Rochester (US). In early 2015 I will be leading a series of experiments looking at the formation of radiative shocks of astrophysical interest at the world-class Orion laser at AWE Aldermaston, as part of a successful bid on their academic access program.


The Institute of Shock Physics

Over the past few years the Institute of Shock Physics has established a diverse research profile probing the response of condensed matter under ultra-fast and extreme compression. These necessarily multi-scale, multi-disciplinary studies require both experimental and computational activities extending to MBar pressures, intermediate to very high strain rate regimes, and from kilometers to sub-micrometer length scales. Supported by a unique suite of state-of-the-art experimental facilities the institutes’ research activities understanding fundamental processes occurring in materials under extreme conditions, find relevance to a wide range of applications in both natural and man-made environments; from fusion technologies to astrophysical events such as interplanetary impact.

Synchrotron X-ray Studies of Extreme Processes
Dr Daniel Eakins, Dr David Chapman

We are developing a new capability for the X-ray imaging of extreme physical processes which leverages the brilliance of third generation light sources. Classically our understanding of materials under extreme conditions is determined indirectly using non-penetrating diagnostics (visible light); the use of X-rays provides a unique opportunity to probe within a material while it is dynamically loaded, to directly study its equation of state, strength and failure properties. By integrating a purpose-built impact system with the I12 high-energy beamline at the Diamond Light Source, we have performed the first experiments involving time-resolved synchrotron X-ray imaging of dynamic compression in high-Z materials. This pioneering experimental work will enable more faithful macroscopic representation of statistical microstates in heterogeneous systems, the study of shock energy localization during instability growth, and direct density probing of material states under extreme conditions. The team also collaborates internationally participating in dynamic X-ray experiments in both Europe and the US. A recent highlight is the involvement in the first EXAFS experiment on Fe driven to Mbar pressures using a high-power laser at the ESRF.

Royal British Legion Centre for Blast Injury Studies
Dr William G Proud

CBIS conducts research into understanding the process of blast injury on people. It has strong links to the Institute of Shock Physics. The institute has designed and instrumented a range of loading devices for the centre including shock tubes and Split Hopkinson Pressure Bars (SHPB). Our overall aim is to ensure that the loading conditions on these complex materials are understood and are in the correct pressure-time space for blast processes.

Two specific research projects highlight the synergistic nature of the interaction. (a) examining the effect of representative pressure pulse from the blast waves on STEM cells. The SHPB was used to provide the loading and a sample cell was developed which had to be fully calibrated mechanically, able to withstand the pressures imposed on it and also be biologically inert. The results indicate that pressures as low as 100 atmospheres for 100 microseconds can result in the destruction of 10% of STEM cells. The debris from these cells is biologically active and may cause longer term pathologies. (b) Modifying the output of the Shock Tube to produce the blast loading seen from a range of explosive masses, over distance through a variety of mitigation. This required precise control of the shock tube operation. As a result of this we can produce blast loadings equivalent to 25 kg of TNT at 2 m distance or, at the other extreme, the loading produced inside a vehicle from a small external charge.

Pulsed Power driven High Pressure Physics Experiments
Dr Simon Bland, Dr Jeremy Chittenden

We are developing a series of new capabilities to drive matter into high pressure states without the use of shock waves. Such capabilities allow new areas of the equation of state to be explored, enabling low temperature phase changes to be examined and provide the basis for studying the cores of giant planets planetary cores. The new 2 Mega-Ampere current generator, MACH, has recently begun operations, demonstrating methods of tailoring the pressure drive onto a target. Simultaneously the use of convergent targets, to significantly increase the available pressures, has been explored using the world leading Gorgon MHD code. To directly probe the states produced in these experiments, a new, ns timescale, multi-KeV X-ray source is being developed with colleagues at CEA Gramat. Already this source has been used to demonstrate X-ray diffraction and future experiments will explore its use in X-ray absorption spectrometry.

Acknowledgements ; The Institute acknowledges the support of Imperial College London and AWE, Aldermaston
My research is directed toward the mechanisms of deformation in condensed matter at extreme strain-rates, from the bulk to sub-micron scale. I focus on the transition between elastic and plastic behaviour, with specific attention to the processes of ultrafast inelastic deformation (defect generation, plasticity, localisation, fracture, etc.). My work seeks to resolve the relationship between the structure of solid phases and their pathway through various defect states, from the early moments of loading to their bulk conclusions. Within this area, I am presently working on the effect of alloying and other impurities on ultrafast elastoplasticity, new analytical methods for simulating true dislocation dynamics under dynamic loading, and the temperature dependence of dynamic fracture mechanisms.

My work also involves the study of heterogeneous materials, and the statistical representation of non-uniform material response at various microstructural levels. This area extends my earlier work on powder systems into new territory through the coupling of novel experimental techniques and spatially-resolved diagnostics with 2D/3D numerical simulation. One of the primary drivers for this work is to establish a “Materials by Design” theme, whereby improved understanding of the role of defects/interfaces can lead to a new design capability for materials with predefined shock properties.


2014 has been very productive for the Institute of Shock Physics. A lynchpin is the application of time-resolved diagnostic techniques to well-controlled loading scenarios. This allows excellent interact with modellers, theoreticians and experimental groups. Linkage to other Imperial departments and cross-faculty is a strength.

My personal research is best summarised as:(a) the high-rate loading of granular and piezo-electric materials, determining how their non-linear behaviour changes with stress level, load duration, strain-rate, and temperature (b) optical effects of shock in birefringent materials to develop a fundamental understanding of non-isotropic materials (c) biological and other soft materials under blast and impact loading. I also retain a strong interest in energetic materials. The references below are relatively brief conference papers, more detailed articles can be found visiting the Institute of Shock Physics Website. The area of shock physics is multi-disciplinary and this research has progressed quickly thanks to colleagues in bio-engineering, civil engineering, medicine, materials science and earth sciences and engineering. I am closely involved with the management and research direction of The Royal British Legion Centre for Blast Injury Studies and the Institute of Security Science and Technology, both of which are stimulating and vibrant research centres cutting across traditional research boundaries.

Research
Quantum Optics and Laser Science

The research mission of QOLS is to carry out basic science using lasers and to investigate, utilize and control photonic and material states and processes down to the quantum level.

LASER CONSORTIUM
Jon Marangos, Vitali Averbukh, Leszek Frasinski, Peter Knight, John Tisch and Amelle Zair

This major grouping of experimental and theoretical physicists is concerned with the interaction of high-intensity and ultra-short laser pulses with matter.

Attosecond (As) Science We are pioneering new methods to measure electron motion in matter in real time. Through this we are learning how electrons move inside molecules and solids on a timescale of ~100 As vital for revealing the correlations in many electron quantum systems. Ultrafast science with X-ray free electron lasers Free electron lasers are opening new frontiers in the imaging of matter at the nanoscale with full time resolution. We are studying ways to make few-fs time resolved measurements using these instruments.

Development of ultrafast, high power, laser sources. The group has pioneered the development of new sources including high power fiber based systems. High energy density science with intense lasers In collaboration with the Plasma Physics group this research uses various high power laser facilities at CLF as well as our in-house Cerberus laser system.

CENTRE FOR COLD MATTER
Ed Hinds, Jony Hudson, Rob Nyman, Ben Sauer, Danny Segal, Mike Tarbutt and Richard Thompson

Cold atoms and Molecules: We use the techniques of laser cooling and trapping to control and manipulate matter onto microchips (Atom chips) at temperatures a few billionths of a degree above absolute zero. With these devices, we aim to build ultra precision sensors and components for quantum information processing. Ultracold molecules offer new opportunities because of increased degrees of freedom and because they interact strongly with applied electric fields and with one another, allowing for the study of the physics of strongly-interacting many-body quantum systems. Electron electric dipole moment We measure the shape of the electron – its electric dipole moment. This is a test of physics beyond the Standard Model of particle physics and a test of time-reversal symmetry violation.

Quantum nanophotonics Single photons are the essential building blocks for photonic information processing. We use single organic dye molecules at cryogenic condition because they can serve as an efficient source of indistinguishable single photons. Bose-Einstein condensation of photons At low temperature and high density, the properties of a fluid depend on the quantum nature of its constituents, whether they are bosons or fermions. Bosons tend to bunch together, and in extreme cases form a giant wave called a Bose-Einstein Condensate (BEC). We are making a room temperature BEC of photons. Our aim is to understand how photon BECs form, study their properties and their interactions. Ion traps Here we test the predictions of Quantum Electrodynamics (QED) using highly-charged ions and also investigate the fascinating physics of "ion Coulomb crystals", which can be used in applications such as quantum simulation and studies of quantum tunnelling. We carry out our experiments with a Penning trap, which uses static electric and magnetic fields to confine atomic ions. We use laser cooling to reduce the temperature of calcium ions to less than 1 kelvin and study the ions using precision laser spectroscopy and high resolution imaging of the ions.

CONTROLLED QUANTUM DYNAMICS THEORY
David Jennings, Myungshik Kim, Peter Knight, Florian Mintert, Geoff New and Terry Rudolph

The theoretical research interest of the group is the control and manipulation of physical systems to exhibit manifestly quantum mechanical effects such as quantum correlations and quantum interference. The emphasis is on using these effects to perform novel protocols in e.g. quantum computing in hybrid architectures, quantum communication and quantum simulations or to uncover the subtle role quantum mechanics may play in natural phenomena. Our general approaches can also be used, for instance, to elucidate the role of fundamental symmetries in nature, as well as metrology (precision measurement). Finally, the study of controlled quantum dynamics may lead us to new insights in the foundations of quantum mechanics itself.
The main direction of our work has been development and theoretical modelling of time-resolved attosecond spectroscopic techniques for the study of ultrafast electron hole migration in molecules. We have suggested several such techniques that are now being at various stages of experimental realisation: (1) single-photon laser-enabled Auger decay (spLEAD) spectroscopy of hole migration, (2) high-order harmonic generation spectroscopy of electron correlation-driven hole dynamics, (3) time-dependent Auger spectroscopy of hole migration. In addition, we have provided theoretical support for one of the first two time-resolved measurements of the inter-atomic Coulombic decay in clusters. Finally, we have developed the first of its kind first-principles molecular method for numerical modelling of many-electron dynamics in strong external field based on B-spline single-electron basis and the many-body Green’s function approach, B-spline algebraic diagrammatic construction (B-spline ADC). First successful applications of the new methodology to molecular strong field processes have been published and more are in progress.


4. J. P. Marangos, B. Cooper, P. Kolorenč, L. Frasinski, and V. Averbukh, “Analysis of a measurement scheme for ultrafast hole dynamics by few femtosecond resolution experiments performed at the Linac Coherent Light Source (LCLS) at Stanford [1,2] and the free electron laser (FLASH) in Hamburg [3]. His main contribution to this collaboration was adaptation of the covariance mapping technique to the high event rate induced by free electron lasers. The success of these experiments led to theoretical developments of the technique [4]. The aim of this research is to gain understanding into electron dynamics of atoms and molecules under intense x-ray irradiation. It is expected that this understanding will allow us to study large biological molecules, such as viruses, with atomic resolution on the femtosecond timescale.

5. J. P. Marangos and M. Ivanov, “High-order harmonic generation spectroscopy of hole migration, (2) high-order harmonic generation spectroscopy of electron correlation-driven hole dynamics, (3) time-dependent Auger spectroscopy of hole migration. In addition, we have provided theoretical support for one of the first two time-resolved measurements of the inter-atomic Coulombic decay in clusters. Finally, we have developed the first of its kind first-principles molecular method for numerical modelling of many-electron dynamics in strong external field based on B-spline single-electron basis and the many-body Green’s function approach, B-spline algebraic diagrammatic construction (B-spline ADC). First successful applications of the new methodology to molecular strong field processes have been published and more are in progress.


9. J. P. Marangos, B. Cooper, P. Kolorenč, L. Frasinski, and V. Averbukh, “Analysis of a measurement scheme for ultrafast hole dynamics by few femtosecond resolution experiments performed at the Linac Coherent Light Source (LCLS) at Stanford [1,2] and the free electron laser (FLASH) in Hamburg [3]. His main contribution to this collaboration was adaptation of the covariance mapping technique to the high event rate induced by free electron lasers. The success of these experiments led to theoretical developments of the technique [4]. The aim of this research is to gain understanding into electron dynamics of atoms and molecules under intense x-ray irradiation. It is expected that this understanding will allow us to study large biological molecules, such as viruses, with atomic resolution on the femtosecond timescale.

measurement techniques [1] and are currently engaged in a comprehensive set of technical upgrades to the apparatus. These will build on our world-leading 2011 measurement, aiming to improve our sensitivity by over three orders of magnitude [2]. One of the techniques we are developing, laser cooling for simple molecules [3], looks particularly promising, and has broad applicability beyond our field. I have also started a new research direction, applying the techniques of machine learning and artificial intelligence to data mine laws of physics directly from experimental data.


[3] Laser cooling and slowing of CaF molecules By: Zhelyazkova, V.; Couroul, A.; Wall, T. E.; et al. PHYSICAL REVIEW A Volume: 89 Issue: 5 Article Number: 053416 Published: MAY 16 2014

In the period 2013-2014 I (together with collaborators) have put 9 papers on the arxiv, with most of these now published. The topics included work on geometric properties [1] of quantum entanglement, the development of entropic uncertainty relations [2,3] and several papers on quantum thermodynamics [4], which is a very active and important field in recent times. The geometric work on entanglement is currently being extended by a PhD student, under my supervision, and Ref [1] has already had good impact in the community. The uncertainty relations work was extremely timely — much dispute had emerged on the correct way of quantifying measurement-disturbance in quantum theory, and we were able to place very general constraints on what form this could ever take. The thermodynamic work has aimed to identify the genuinely quantum-mechanical aspects of thermodynamics. Ref [4] is currently under review in Nature Communications, and we are in the process of revising the manuscript. This too has attracted attention in the community, and I expect this to initiate a meaningful and significant new line of research.


The paradoxical ideas that quantum mechanics promotes are well-developed for simple quantum systems. However, it is hard to observe its unique properties in macroscopic systems which is why quantum mechanics was thought to be applied only to a sub-atomic system. Kim’s research interests in the foundations of quantum physics are concentrated on the issues of the manifestations of wave-particle duality and the quantum-to-classical transition. Why is it not possible to observe quantum superpositions and nonlocality in everyday life? For this question, he came up with a possible solution based on fuzziness in operations [1]. His suggestion is in contrast to the usual assumption based on decoherence and coarsening of measurements. He then considered another fundamental problem in relation to the wave-particle duality and the impact of measurements on this [2]. The quantum-mechanical superpositions are more easily generated in an isolated system such as a cavity. However, in order to characterise and control the superpositions, we need to bring them out. He and his colleagues show how those quantum states can be taken out from the cavity in [3].

My main activity as Director of the Blackett Laboratory Laser Consortium has been in leading the research in the Attosecond Science Programme, which is funded by two grants (EPSRC Programme Grant “Attosecond electron dynamics in molecular and condensed phase systems”, and ERC Advanced Grant “Attosecond science by emission and transmission of X-rays”). The research has been progressing in the following main areas: (a) development of high harmonic generation (HHG) sources driven by few-cycle mid-IR pulses for attosecond transient absorption measurements, (b) HHG spectroscopy for direct measurement of attosecond resolved electronic and nuclear motion in molecules following ionization, (c) development of sources for attosecond pump-probe measurements, (d) measurement of the photoelectric effect from solid surfaces with attosecond resolution and (e) development of X-ray pump/X-ray probe methods for ultrafast structural dynamics studies using X-ray free electron lasers. This has resulted in the publication of more than 18 journal papers in the 2013-14 period including:


During the last year, the main focus of our work was on the optimal control of quantum systems through polychromatic driving. We developed a framework to identify effective Hamiltonians with renormalization techniques in Floquet theory [1] and developed a formalism for the construction of polychromatic control fields that realise desired effective dynamics with high accuracy [2]. Currently, we are extending these endeavors to open quantum systems, and we identified means to devise approximate solutions for driven open quantum systems that respect the fundamental property of complete positivity [3] (which is imposed by the probabilistic nature of quantum mechanics). As specific goal of control we target the creation of long-distance entanglement in disordered spin chains. A description in terms of matrix-product states allows us to describe systems of one hundred interacting spins. We implemented a method based on Lyapunov control in terms of this description and designed control fields that establish strong entanglement in chains with ten percent relative fluctuation in the nearest neighbor interaction [4].


Published 18 papers since January 2013. Topics covered include foundations of quantum thermodynamics, new mathematical representations of quantum states, some important simplifications of...
photonic quantum computation (for which IP protection is currently being sought) and a variety of abstract results in quantum foundations and quantum information.

[arXiv:1405.2188 [pdf, other]
Thermodynamic laws beyond free energy relations Matteo Lostaglio, David Jennings, Terry Rudolph (Acceptance to Nature Communications appears likely)

arXiv:1303.4724 [pdf, other]

arXiv:1311.2913 [pdf, other]

arXiv:1306.2724 [pdf, ps, other]

I have been working on improvements to our experiment to measure the permanent electric dipole moment (EDM) of the electron, and on experiments to directly laser cool CaF molecules. While the EDM experiment did provide the most stringent limit on the size of this time-reversal violating effect, it was recently surpassed in sensitivity by the ThO experiment run by a Harvard-Yale collaboration. We are making a number of improvements to the apparatus to regain the lead. On CaF, there is strong interest to make an ultra cold gas of polar molecules, not least to study dipole-dipole interactions in this strongly quantum limit. We have made measurements of cooling and slowing in CaF and are currently working on a slow CaF source so that we can bring the molecules to rest.


Our work focuses on the production of cold molecules and their applications in fundamental physics. We have made extremely precise frequency measurements of microwave transitions in the CH molecule and have compared these laboratory measurements to astrophysical measurements of the same transitions in CH observed in cold molecular clouds in the Milky Way. Through this comparison, we have tested whether the values of the fundamental constants depend on the local density of matter, as hypothesized in some extensions of the Standard Model. We found no dependence and set new bounds on such variations of the constants [1]. We then extended this work to precise measurements of millimetre-wave transitions in CH [2]. These transitions have been observed in extra-galactic sources at high redshift, and so can be used to test whether the fundamental constants vary with time. Precise measurements using molecules benefit from cooling the molecules to very low temperatures. We have demonstrated that laser cooling, a method commonly used to cool atoms, can also be used to slow and cool a beam of CaF molecules [3]. We then analysed how laser cooling can be used to make a magneto-optical trap of these molecules [4].


My research within the Blackett Laboratory Laser Consortium is concerned with Attosecond Science and Technology and can be divided into three interconnected themes: i) the development of state-of-the-art ultrafast laser technology, ii) the use of these lasers to develop novel short-wavelength (UV to X-ray) coherent light sources, with focus on those providing attosecond (10-18 sec) pulse durations, iii) the application of i) and ii) to implement novel techniques for tracking attosecond time-scale electron dynamics in matter. Recent work on theme (i), in collaboration with LOA Paris, has been a detailed study [1] of the hollow-fibre pulse compression technique used by labs around the world to produce high-power laser pulses of durations approaching 1 optical cycle. Towards theme (ii), we have demonstrated for the first time the generation of synchronised VUV and XUV attosecond pulses for pump probe experiments, with support from collaborators in Hannover [2]. Also, we have made the first spatial coherence measurements of high order harmonic radiation generated in laser-ablated plumes [3]. A recent highlight from theme (iii) is the first measurement of temporal broadening of attosecond photoelectron wavepackets from solid surfaces [4], in collaboration with Imperial colleagues from the EXSS group and from CFEL in Hamburg.

Space and Atmospheric Physics

The group studies interplanetary space and planetary environments, as well as the Earth’s atmosphere and oceans. A major part of the group’s activity is the development and operation of numerical models and sensitive instrumentation for space science and Earth observation.

SPACE PLASMA PHYSICS
Dr Jonathan Eastwood, Dr Bob Forsyth, Prof Tim Horbury, Prof Steve Schwartz

Fundamental Plasma Processes: Magnetic reconnection, turbulence, and shock waves govern much of the dynamics of plasmas, giving rise to the transport of momentum and energy while accelerating charged particles to high energies in the process. Our internationally recognised leadership in understanding these fundamental plasma processes employs spacecraft data, theory, and modelling. We lead the magnetic field instruments on important current spacecraft (ESA’s Cluster and Cassini missions) and future missions (ESA’s Solar Orbiter and JUICE). Applications of Space Plasma Physics: Interplanetary space is pervaded by a supersonic solar wind emanating from the Sun’s corona. Variability in this solar wind, due to solar activity and eruptions from the solar surface, often termed “Solar Storms” leads to “Space Weather” which can energise the Earth’s radiation belts and lead to spectacular aurorae. Space Weather also has a huge impact on satellites and ground-based systems (e.g., electricity grids) representing risks to vital services and expensive infrastructure, and now forms a major element in the national risk register.

CLIMATE PHYSICS
Dr Helen Brindley, Dr Arnaud Czaja, Dr Heather Graven, Prof Joanna Haigh FRS, Dr Juliet Pickering, Prof Ralf Toumi, Dr Apostolos Voulgarakis

Modelling: We study the physical processes and composition in the atmosphere and ocean using idealised, regional and global models (e.g., HadGEM, NASA GISS). Key expertise lies in the impact of key physical processes on our climate system, such as solar variability, the coupling of tropical and extra-tropical storms with the ocean, the impact of changes in atmospheric composition on radiation and precipitation, and the role of fires in the Earth System.

Earth Observation: Scientific lead for the Geostationary Earth Radiation Budget (GERB) project, the only instrument to observe the broadband energy emitted and reflected by the Earth at high temporal resolution. GERB data are used to quantify, the diurnal variability in Saharan dust net radiative forcing at the top of the atmosphere, the surface, and within the atmosphere. Our Tropospheric Airborne Fourier Transform Spectrometer (TAFTS) participates in national campaigns to assess the radiative effect of cirrus clouds across the electromagnetic spectrum, again with the ultimate aim of using observations to improve modelling capability. Satellite observations from instruments such as the Tropospheric Emission Spectrometer (TES) and Infrared Atmospheric Sounding Interferometer (IASI) play a vital role to better understand feedbacks operating in the Earth system. A new activity relates to the carbon cycle via measurements and modelling of atmospheric CO2 and CO2 isotopes.

INSTRUMENTATION
Chris Carr, Dr Helen Brindley, Dr Heather Graven, Dr Juliet Pickering

Our research is underpinned by instrumentation projects for spaceflight, research aircraft, and in the laboratory. Our magnetometers fly on the Cluster, Cassini, Solar Orbiter and JUICE missions. The Plasma Consortium instrumentation on the Rosetta mission, and the GERB instruments for the Meteosat 2nd Generation spacecraft. In the laboratory, our unique visible-vacuum ultraviolet Fourier Transform Spectrometer studies atomic and molecular spectra of importance for interpretation of spectral measurements of planetary atmospheres and astrophysical objects. Measurements of atmospheric CO2 and its isotopic composition are being developed to study anthropogenic emissions and their impacts on the global carbon cycle.
Research

Dr Helen Brindley

Work over the last year has had three main foci: 1. The role of mineral dust in shaping the Earth’s Radiation Balance over Africa and the Middle East; 2. The use of spectrally resolved radiances, measured from satellite, to diagnose climate change; 3. The assessment of different dust/aerosol retrieval schemes and application of these in multi-disciplinary areas (e.g. solar energy resources). All of these topics are areas of ongoing activity and have resulted in the establishment of a number of collaborations and associated publications. Specific examples include the first ever quantification of the net top-of-atmosphere dust radiative effect over the Sahara at a sub-diurnal timescale; the use of multi-platform observations to provide recommendations regarding the strengths and weaknesses of various commonly used dust retrieval products; the assessment of the relative importance of environmental factors influencing energy production from a multi-junction concentrating solar photovoltaic system; and, as part of the NASA led CLARREO Science Definition Team, the development of a robust strategy for climate monitoring space mission design. These activities have led to a major role for Imperial in the recently reshaped National Centre for Earth Observation (NCEO).


Dr Arnaud Czaja

Efforts in my group have recently focused on understanding how warm and fast ocean currents such as the Kuroshio and the Gulf Stream impact on storms and atmospheric motions of larger scales in the extratropics. Using a combination of high resolution numerical experiments (UK Met Office Model) and atmospheric reanalysis data (ERA interim, 1979-present), we have shown that the Gulf Stream affects both the cold and warm sectors of cyclones, although with very different mechanisms (shallow convection and moist inertial instability, respectively). We have also shown that atmospheric heat transport in the storm track is sporadic in nature, with a large contribution to the mean arising from shirt-lived and extreme bursts of heat transport.


Dr Jonathan Eastwood

My research currently centres on understanding how magnetic reconnection across current sheets in collisionless space plasmas works. This process lies at the heart of many solar, space and astrophysical plasma phenomena such as solar flares and geomagnetic storms. Working with postdoc Dr. Heli Hietala and PhD student Rishi Mistry, and in collaboration with UC Berkeley, the University of Maryland, and the University of Delaware, we have recently published new research...
showing for the first time how the energy explosively released by reconnection is partitioned, and demonstrating how reconnection can operate in a bursty fashion over a prolonged period of time. This work is intimately related to the applied science of space weather, which represents a threat to infrastructure resilience and is now included on the UK national risk register. In collaboration with the plasma physics group (Prof. Jerry Chittenden), and PhD student Lars Mejnertsen we have adapted the Gorgon computer code (used for laboratory plasmas) to simulate the solar wind-magnetosphere interaction, most recently using the DiRAC high performance computing facility. These simulations, informed by our group’s research into the underpinning physics, will be both useful for interpreting satellite observations and are directly relevant for improving future space weather forecasts.


My research focuses on atmospheric CO2 and the global carbon cycle. I study the influences of fossil fuel combustion and natural exchanges with the ocean and terrestrial biosphere on CO2 by combining observations and models in regional and global-scale studies. In a recent paper in Science we showed long-term changes in the observed seasonal cycle of CO2 concentration. The observations show a 50% increase in the amplitude of the seasonal cycle, reflecting changes in northern ecosystems that are much larger than predicted by current IPCC models.
models. Before joining Imperial in late 2013, I began a collaborative project to study CO2 fluxes from fossil fuel emissions and biospheric exchange in California with a grant from NASA’s Carbon Monitoring System. I was also awarded funding from the European Commission and the Royal Society in 2013-14. I am developing new collaborations in the UK with researchers at Imperial and at the University of Oxford, University of Bristol, Queens University Belfast, and the University of East Anglia. Themes that will be explored involve the oceanic sink of CO2 and its sensitivity to ocean circulation change, and development of innovative atmospheric observations to distinguish anthropogenic from natural influences on the carbon cycle.


My work concerns how variations in solar UV radiation influence the structure of the stratosphere and how changes in the stratosphere influence the climate below. Measurements from the SORCE satellite suggest larger solar cycle trends in UV than previously thought and we have shown that they imply very different impacts on ozone and surface climate. The calibration of these data is being continuously revised, and the remaining lifetime of the satellite is uncertain, while the successor mission is not expected to launch until mid-2017. With no other measurements having the calibration required for the investigation of multi-year trends there will not only be a gap in the record but also insufficient new data to confirm the SORCE measurements. To address this data gap, in such an important climate variable, we have proposed a new approach for measuring the solar spectrum. The basis of the method is to take measurements of atmospheric ozone, and other parameters sensitive to solar irradiance, and to analyse variations in these to deduce what changes in the spectrum must have produced them. To date we have demonstrated the statistical methods but not produced a robust change in solar spectrum. Nevertheless the technique is promising and we are developing new ways in which it might be refined.


Professor Jo Haigh FRS

Development of the Solar Orbiter magnetometer continues well, led by the Instrument Manager Helen O’Brien, with launch planned for 2017. Major challenges remain from the thermal, vibration and electromagnetic environment of the spacecraft but the magnetometer team are on track for our first hardware delivery, of our Electrical Model, by the end of 2014: the final, Flight Model is due for delivery by the end of 2015.

Research work has concentrated on collaborations regarding solar wind
waves and turbulence (with Lorenzo Matteini and Junior Research Fellow Chris Chen) and, with PhD student Martin Archer, dynamics of the interaction of the solar wind with the Earth’s magnetosphere.


My research focuses on space plasma physics in diverse planetary environments. Work in this area is driven by in situ data returned by missions to explore the Solar System, such as Cassini-Huygens and MESSENGER, and also involves analytical modelling. The programme covers a range of space plasma phenomena and processes, including Kelvin-Helmholtz instability, collisionless shock waves, and magnetic reconnection. Advances have implications for energy transport through the space environments surrounding different planets, can be extrapolated to exoplanets, and have the potential to change our fundamental understanding of how space plasma systems work in our Solar System and beyond. Results published in recent years include: 1. Data taken by the Cassini spacecraft at Saturn shows that we need to revise our understanding of how the solar wind interacts with the planet’s magnetic field; 2. Modelling of magnetic reconnection between Uranus’ magnetic field and the solar magnetic field reveals the uniqueness of the Uranian system; 3. The detection of relativistic electrons in the near-Saturn solar wind shows that high-Mach number shock waves are more efficient cosmic particle accelerators than previously thought. This work is supported by a wide international network of collaborators, most notably at the Japan Aerospace Exploration Agency.


Work initiated with a previous STFC post-doc on the heating of electrons at the bow shock located sunward of the Earth’s magnetosphere has reached a definitive, though provocative conclusion. We showed that the high mobility of the collision free electron population together with the curved nature of the bow shock couples distant regions of the shocked plasma (the magnetosheath). The result, predicted based on simulations and tested with data from the Cluster and THEMIS spacecraft, is that, despite the strong variation in Mach number and therefore total heating rate around the bow shock, the magnetosheath electron temperature is roughly constant, implying a varying proportion of heat taken up by other species. The electron heating is controlled by as yet unknown processes that occur at the point where the interplanetary magnetic field first touches the bow shock, i.e., where it is tangent to the surface. Other work, with post-doc Matteini, has explored the dynamics of different solar wind ions in the presence of interplanetary turbulence, and a first look at data from the European Space Agency’s comet chaser, Rosetta at comet P67 Churyumov-Gerasimenko.

Our principal work is on regional climate modelling (1-4) and stochastic weather generators to gain a physical understanding of processes particularly as they relate to extreme events such as cyclones and floods. We are strongly engaged with industry. In the Climate KIC we lead the OASIS project (www.oasislmf.org) which is an exciting project to develop open source catastrophe modelling for insurance and other sectors. One of the highlights of our recent work is that we have demonstrated how tropical cyclones become larger in a warmer environment (1). This discovery of the size effect is important for impacts which are directly proportional to the footprint of cyclones.

The composition-climate team investigates the interactions between atmospheric constituents and climate change, from regional to global scales. For this, global climate models that involve interactive composition are used in conjunction with observations, especially from satellites. A major focus over the past few years is the study of fire-atmosphere interactions. Recent work in the team investigates the interannual variability of pollution from wildfires, its climatic drivers, and its effects on human health (Marlier et al., 2013). Furthermore, the impact of the temporal resolution of fire emissions on atmospheric composition and climate forcing has been explored, using global atmospheric models and remote sensing observations (Marlier et al., 2014). A further focus of the team has been understanding the changes of short-lived gaseous constituents in the atmosphere from pre-industrial times to present-day, and into the future (Voulgarakis et al., 2013a). This has also included the study of aerosol interactions (Voulgarakis et al., 2013), which is also a topic currently investigated in the team from a hydrological perspective. Voulgarakis, the leader of the team, is currently analysis lead for the international Chemistry-Climate Model Initiative (CCMI) and a member of the Scientific Steering Committee of the Precipitation Driver and Response Model Intercomparison Project (PDRMIP).


Theoretical Physics

STRING/M-THEORY AND QUANTUM FIELD THEORY
Duff, Gauntlett, Hanany, Hull, Stelle, Tseytlin, Waldram, Wiseman

Within this subtheme we work on the physical and mathematical structure of string/M-theory as a proposed framework for unifying the Standard Model of Particle Physics with General Relativity. In addition, string/M-theory provides deep insights into the non-perturbative structure of quantum field theory.

The AdS/CFT correspondence, which relates strongly coupled quantum field theory to weakly coupled gravitational descriptions in higher spacetime dimensions, is one of the most profound discoveries in string/M-theory and is a major focus of the group. Our activities of the Group in this area are supported by two ERC Advanced Grants. One is focussed on exploring integrability structures present in particular systems. The second is focussed on trying to apply the AdS/CFT correspondence to poorly understood strongly coupled systems that arise in condensed matter physics, such as the high temperature superconductors. The properties of black holes play a central role in this work, as they do in other areas of research in this subtheme.

The Group also actively investigates the very rich mathematical structure of string/M-theory. This line of research could lead to a precise mathematical definition of what string/M-theory is. It is also important in connecting string theory with particle phenomenology and in obtaining exact non-perturbative results in quantum field theory. This area is supported by an EPSRC Programme Grant.

COSMOLOGY AND QUANTUM FIELD THEORY
Contaldi, Dowker, Magueijo, Rajantie, Wiseman.
Emeritus: Jones, Kibble and Rivers

The principal objective in this subtheme is to discover ways of testing innovative particle physics and quantum gravity theories against hard astrophysical data. A particular strength of the Group is the leading expertise in both theoretical cosmological models and the extraction of phenomenology from the data. We have made significant contributions to the inflationary theory of cosmological perturbations, using both analytical and lattice techniques. One focus is on the physics arising at the end of inflation, particularly in relation to defect production. Alternatives to inflation are also investigated including cyclic universe models and varying speed of light theories. Modified theories of gravity obviating the need for dark matter are another focus. The cosmology group has been pioneering the extraction of phenomenology from quantum gravity in several guises and testing it against data. On the more observational side, we continue to work on the development and application of methods of CMB data analysis, including involvement in a number of experimental efforts such as Planck and Spider.

QUANTUM GRAVITY AND FOUNDATIONS OF QUANTUM MECHANICS
Dowker, Halliwell. Emeritus: Isham

The Group also works on other approaches to quantum gravity including causal set theory, which posits that spacetime is fundamentally discrete. The foundations of quantum mechanics, including the emergence of classicality, are investigated both in connection to low energy phenomenology and to provide insights into the structure of quantum gravity.

COMPLEXITY AND NETWORKS
Evans Emeritus: Rivers

The group also has a keen interest in statistical physics arising in classical systems. This ranges from applications of graph theory, to discrete space times, to citation networks and to studies of how spatial constraints alter the structure of networks, both in theoretical models and in data from actual
In a highly cited paper, showed how suppression of primordial perturbations on the largest cosmological scales could reconcile the observations announced by BICEP2 collaboration in April 2014. We also introduced a new formalism to reconstruct the acceleration trajectory during inflation from existing data. With student Jonathan Horner we also showed how to obtain the latest constraints in general Hubble flow inflationary trajectories from the Planck satellite observations. A second paper with Horner calculated non-Gaussianity from the same generalised trajectories. We continued work in preparation for the SPIDER balloon-borne CMB polarisation telescope that is scheduled to fly in Antarctica during the first week of December 2014 after suffering a delay last year due to Antarctic operations being curtailed by the U.S. government shutdown.

1. Suppressing the impact of a high tensor-to-scalar ratio on the temperature anisotropies, Contaldi, Carlo R.; Peloso, Marco; Sorbo, Lorenzo, Journal of Cosmology and Astroparticle Physics, Issue 07, article id. 014, pp. (2014).

My research on the causal set approach to quantum gravity continued with the discovery of a family of discrete non-local Lorentz invariant D’Alembertian operators for scalar fields extending results in 2 and 4 dimensions to all dimensions. I continued my work on Foundations of Quantum Mechanics with work on characterising non-locality from the perspective of a sum-over-histories approach to quantum theory. We discovered a strong connection between a condition on sets of experimental probabilities – a quantum analogue of a non-contextuality condition – that arises naturally in a histories approach and a condition that is known in the quantum information literature as “Almost Quantum.” We did work highlighting the fact that a relativistic quantum field theory lacks a set of rules specifying what interventions by external observers, including measurements, are possible. Restricting measurements and interventions to those that do not violate relativistic causality puts constraints on the processing of quantum information using quantum fields.

1. Causal Set D’Alembertians for various dimensions, by Fay Dowker and Lisa Glaser, Class. Quantum Grav. 30 195016
4. Quantum Information Processing and Relativistic Quantum Fields, by Dionigi M.T. Benincasa, Leron Borsten, Michel Buck and Fay Dowker, Class. Quantum Grav. 31 075007

My recent work in collaboration with Leron Borston and my students Alex Anastasiou, Leo Hughes and Silvia Nagy is devoted to finding a consistent quantum theory of gravity. We address the question of whether gravity, a force traditionally described by Einstein’s general relativity, can be regarded as the product of two Yang-Mills theories (quantum field theories used in the standard model of particle physics to describe the strong, weak and electromagnetic forces). There has already been some progress in this direction at the level of scattering amplitudes in momentum space but our goal is more ambitious. We aim to find an exact correspondence at the level of off-mass-shell fields in coordinate space. A key ingredient will be our recent unified description of all supersymmetric Yang-Mills theories [3] in terms of the four division algebras; real (R), complex (C), quaternion (H) and octonion (O). The global symmetries that result
from tensoring one (R, C, H, O) theory with another are then just those of the so-called Freudenthal magic square, well-known to mathematicians [2.4]. But even more interesting is the Yang-Mills origin of local gravitational symmetries such as general coordinate invariance and local supersymmetry [1].


I pursued my interest in complexity and networks in two main directions. My new programme of research on temporal networks has produced its first paper (Clough et al. 2014) with others submitted. On the other hand my long standing interest in networks constrained by space continues. I gave three invited talks at international venues in November 2013 on different aspects of this work while my collaboration with archaeologist in Toronto produced several more publications (e.g. Evans, 2014).

I organised two international meetings at Imperial in September, attended by around fifty academic each. This was part of my involvement in a UK EPSRC NetworkPlus collaboration on Emergence and Non-Equilibrium Physics.

I continue to work as scientific advisor for two companies: Symplectic Ltd (part of the Digital Science division of Macmillan) and the start-up Newflo. This has included some consultancy work.

My paper on 3D printing and complexity published in December 2013 (Reiss et al, 2013) was selected by the editors of the journal, and received widespread coverage resulting in the sixth highest ever rating for an article in that journal (EPL) on altmetrics.com.

The AdS/CFT correspondence, which arose out of string theory, is a powerful theoretical tool to study strongly coupled quantum field theories using weakly coupled gravitational descriptions in higher spacetime dimensions. In recent years there has been a concerted effort to apply these “holographic” techniques to vexing condensed matter systems such as high temperature superconductors and strange metal phases using, amongst other things, novel black hole solutions. In ref 4 we used these techniques to model the rapid quench of a superconductor and discovered an emergent temperature scale in the superconducting phase below which the approach to equilibrium is oscillatory and above which it is not. We have pioneered the study of spatially modulated phases and in ref 3 we investigated the competition between striped phases and superconducting phases and in the process discovered black holes describing meta-magnetic phases. In refs 1 and 2 we pioneered the construction of a class of black hole solutions that incorporate momentum dissipation and hence provide more realistic models of metals. We found models of coherent metals, with Drude peaks, incoherent metals (with some similarity to the strange metals) and insulators as well as transition between these states.
1. Novel metals and insulators from holography, A. Donos and J.P. Gauntlett, JOURNAL OF HIGH ENERGY PHYSICS Issue: 6, Article Number: 007, Published: JUN 3 2014
2. Holographic Q-lattices, A. Donos and J.P. Gauntlett, JOURNAL OF HIGH ENERGY PHYSICS Issue: 4, Article Number: 040 Published: APR 7 2014

In the last year or so I completed two substantial papers with my postdoc Dan Bedingham, which demonstrate two closely related results for a point particle system: both quantum-mechanical reflection off a simple step potential and the Zeno effect arising from very frequent position measurements are suppressed as a result of environmental decoherence. The classical limit of these two non-classical effects is thereby obtained. With four undergraduate project students, I wrote a paper on how to generate an exhaustive class of backflow states, states of positive momenta but negative current so that the probability flows backwards, an intriguing non-classical effect awaiting experimental confirmation. I also wrote a short letter offering a new and transparent proof of Fine's theorem, which is essentially the logical converse of Bell's theorem -- it states that the CHSH inequalities are not only a necessary condition for the existence of an underlying hidden variables theory, they are also a sufficient condition.


During this year the attention was devoted to the study of the Coulomb branch of N=4 supersymmetric gauge theories in 3 dimensions. We developed a new formula for the Coulomb branch Hilbert series, and this is based on the contributions from monopole operators to the chiral ring. This led to a collection of new results. In 9 we showed how to get new mirror pairs by gauging a global symmetry, which amounts to ungauging a gauge symmetry in the mirror. In 8, 7, 1 we developed technical tools related to this formula that involve Hall Littlewood polynomials in various forms. In 5 we used these results to predict moduli spaces of Argyres Douglas theories. In 2 we solved a long standing problem of finding the moduli space of instantons for exceptional groups. Other topics of study included the moduli space of vortices in 6, the deformation of brane tilings by mass terms in 4, and development of Hilbert series techniques in 3.

8. Coulomb branch Hilbert series and Hall-Littlewood polynomials Stefano Cremonesi, Amihay Hanany (Imperial Coll., London), Noppadol Mekareeya (CERN), Albert Zaffaroni
Mirror Symmetry in Three Dimensions via Gauged Linear Quivers

In joint work with Neil Lambert, the possibility of time emerging from a theory without time was discussed. We argued that the strong coupling limit of the maximal super-Yang-Mills theory in 5 Euclidean dimensions has an emergent time dimension and gives a description of the 5+1 dimensional M5-brane theory, compactified on a timelike circle. The discussion involved questions of how to quantise Euclidean theories without time, and indeed the meaning of quantum theory in such systems. Issues of space-time signature, emergent dimensions and periodic time were also addressed.

String theory has duality symmetries, which allow the construction of non-geometric backgrounds. String theory on a torus requires dual coordinates conjugate to winding number. This leads to physics and novel geometry in a doubled spacetime. This is formulated in double field theory, introduced by Hull and Zwiebach in a highly cited paper from 2009. The geometry and physics of doubled spacetime were developed and discussed in [2]. Explicit forms were found for finite gauge transformations, elucidating the nature of tensors and showing the relation with generalised geometry. The development of these results and their application to the global structure of doubled geometry is the subject of on-going research.


Over the past year I continued to investigate the cosmology of models with deformed dispersion relations, and their relation to dynamical dimensional reduction, as seen in many quantum gravity schemes. A remarkable dual picture was discovered in [1] dispensing with the dubious concept of spectral dimension, replacing it by the straightforward Hausdorff dimension of momentum space, and shedding light on they scale-invariance of the associated cosmological fluctuations. A better understanding of how departures from exact scale-invariance may arise was also obtained in a couple of papers (e.g. [2], where a connection with intermediate inflation was found). More importantly, a method was found for introducing deformed dispersion relations representative of dimensional reduction without picking out a preferred frame. This may prove to be the best set up for studying these scenarios, with a minimal number of free parameters. On different front I continued to

Professor Chris Hull FRS

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Professor Sir Tom Kibble FRS

Not a lot to report! Much of my activity in the last two years has been directed towards giving historical talks about the origins of the Higgs mechanism and the unified electroweak theory, or the wider standard model. None has been published yet, but one, given at DICE2014 in Castiglioncello will be published next year. A semi-popular invited talk I gave at the annual meeting of the Academia Europaea in Wroclaw has been published [1]. I also provided some theoretical input to a project undertaken by Richard Lieu and his student Lingze Duan of the University of Alabama at Huntsville on possible methods of improving astrophysical measurements, of which the first has been published [2]. There is however an ongoing dispute about the validity of this work.

Research

Theoretical Physics

investigate the cosmological consequences of Cartan gravity, e.g. regarding signature change (see [4]). This followed up on earlier work on torsion and spin cosmology.


I have investigated the cosmological implications of the Higgs field and other possible light scalar fields. Together with my PhD student Laura Bethke and Daniel Figueroa from University of Geneva, we showed that in the presence of a light scalar field, the gravitational wave background from the end of inflation in the early universe would be anisotropic, and that if observed, these anisotropies could be used to test and constrain cosmological theories.2,4 With another PhD student Stefano Orani, we showed a light scalar field can arise from a supersymmetric theory, with interesting cosmological consequences.3 I am also a member of the new MoEDAL experiment at the Large Hadron Collider at CERN, which will be searching for magnetic monopoles. I have worked on identifying theories that would predict light magnetic monopoles and developed methods for calculating their predictions from quantum field theory.1


Our work on AdS/CFT duality continued along several directions. We developed an integrability-based approach to superstrings in AdS3 x S3 space discovering that the corresponding dispersion relation for elementary magnons has a novel form different from the one in the much studied AdS5 x S5 case. We also investigated integrable deformations of AdS5 x S5 supercoset models finding new relations between previously known integrable sigma models in AdS2 x S2 and AdS3 x S3 cases. We also studied vectorial AdS/CFT between singlet sector of free scalar or free fermion conformal theory in n-1 dimensions and higher spin theory in AdSn space showing the equality of the corresponding partition functions and Casimir energies on a spatial sphere. The higher spin theory in AdSn is also closely related to higher-derivative conformal higher spin theory in n-1 dimensions for which we determined the conditions of cancellation of conformal anomalies.


2. B. Hoare, A. Stepanchuk and A. A. Tseytlin, Giant magnon solution and dispersion relation in string theory in AdS3 x S3 x T4 with mixed flux, Nucl. Phys. B 879, 318 (2014)


My work has focused on understanding the geometric structures underlying string theory generalisations of Einstein gravity, with implications for the AdS/CFT correspondence, flux compactifications and more generally the symmetry structure underlying M theory. In collaboration with two (now former) PhD students, André Coimbra and Charles Strickland-Constable, we defined a generalised notion of Riemannian geometry, based on exceptional groups, that gives a reformulation of type II and eleven-
dimensional supergravities as generalised pure Einstein theories [1,2]. With Strickland-Constable (then at DESY) and a postdoc at Imperial College, Kanghoon Lee, we used this formalism to derive a universal description of consistent truncations of supergravities as generalised Scherk-Schwarz reductions, giving for the first time a geometrical understanding of the remarkable sphere consistent truncations first discovered in the late 1980s. With Mariana Graña (IPhT, Saclay), Jan Louis (Hamburg Univ and DESY) and Ulrich Theis (Hannover) we analysed the structure of string and quantum corrections to type II reductions on SU(3) structure manifolds, showing that they closely mirror the correction on conventional Calabi-Yau manifolds. Finally with Coimbra, Ruben Minasian (IPhT, Saclay) and Hagen Triendl (CERN) we showed how the string corrections to heterotic supergravity could again be described using the formalism of generalised geometry. Results from these last three projects all appeared as preprints during the year.


During the period 2013-2014 my research has been focussed on the gravitational aspects of the AdS-CFT correspondence. I have continued to use numerical methods to solve the bulk gravitational Einstein equations in situations of relevance for dual field theory physics. In particular I showed how quench dynamics relevant for describing holographic superconductors can be reproduced [1], and also discussed a new class of black holes with non-Killing horizons [2] which is important in understanding plasma flow in strongly coupled gauge theory via holography. I co-authored an invited review [3] on these and related topics applying gravitational methods to study strongly coupled field theory. I have also developed new methods to understand the emergence of black hole physics in thermal supersymmetric gauge theory, starting with the work [4], and this is now an on-going program.


3. Holographic thermal field theory on curved spacetimes: D. Marolf, M. Rangamani, T. Wiseman; Class.Quant.Grav. 31 (2014) 063001

Technical Development, Intellectual Property and Commercial Interactions, the Blackett Laboratory Industry Club

Research in the Physics Department at Imperial College is a mix of fundamental and end-user-inspired interdisciplinary science. This profile promotes the primary role of physics in advancing elemental knowledge and also highlights its crucial role in stimulating economic growth and in tackling key global issues.

We engage with over 60 external companies through collaborative research, consultancy, knowledge transfer and patenting/licencing of our intellectual property. We also contribute to economic growth through setting up commercially successful spinout companies.

We collaborate with the commercial sector at all levels and of course PhD students within the Department benefit from direct industrial sponsorship and EPSRC CASE awards.

The Department set up an industry club in 2010 in order to interact on a more regular basis with companies who are interested to recruit our students and postdocs and engage with the department on collaborative research projects.
The technology developments and commercial activities within our research groups include the following:

**Astrophysics**
Both the Herschel and Planck teams continue the development of data reduction and analysis software for these two missions. For Planck our work is aimed at the determination of beam shapes and focal plane geometry from actual survey data using either scans across individual bright sources or through combination of data on large numbers of fainter sources. This work is crucial to the science goals of the Planck mission. For Herschel we are coordinating the development of data reduction and analysis software for the whole of the SPIRE instrument and have special responsibility for mapmaking codes through a contract from the European Space Agency which will be used for both the SPIRE and PACS instruments.

**Condensed Matter Theory**
The group has a wide-ranging computational and theoretical research portfolio with a strategic focus on materials for structural, electronic and photonic applications, providing theoretical and computational expertise. Many projects have direct relevance to the next generation of technologies. Our work on metamaterials has shown how to create perfect lenses that beat the diffraction limit, how to harvest light efficiently, and how to make objects invisible. Our work on functional and structural materials includes studies of radiation damage in fusion and fission reactors, surfaces and grain boundaries in perovskites for functional applications, the high-temperature corrosion of Ni- and Fe-base structural alloys, thermoelectrics for power generation, capacitors for energy storage, and plasticity under shock loading.

The Group enjoys working relationships with Accelrys, Astron, Antenova, Argonne National Laboratory, Baker Hughes, BP, BAE, Element Six, Materials Design, Placental Analytics, Rolls-Royce, the UK Atomic Energy Authority, the UK Defence Science and Technology Laboratory, and the US Air Force Office of Scientific Research. We hold several patents.

**Experimental Solid State Physics**
The experimental Solid State Physics Group develops technologies across a broad range of areas that have impact on the displays and lighting sector, the information and communication technologies sector, the solar energy sector, and the health care and security sectors. Our innovations derive largely from expertise in molecular electronic materials and devices, inorganic semiconductors and devices, nanomagnetism and transition metal oxides and devices. Programmes span materials design, synthesis and processing, device fabrication and optimization and applications assessment. Well-developed skills in optical and electrical materials and device characterization and modelling underpin this activity. Much of the work in the group proceeds through collaborative research programmes frequently involving industrial partners. Leading international companies that have supported our work include BP Solar, Merck, DuPont Teijin Films, Sumitomo Chemical Co., Philips Research Labs., Solvay, Unilever, CDT, Toshiba, BASF, LG, Solenne B.V., Toyota, and Oxford Instruments. The group also benefits from collaborations with the NPL at Teddington.

The group also has a strong record of protecting intellectual property and exploiting it through spinout companies such as QuantaSol and Molecular Vision.

**High Energy Physics**
The dark matter experimental part of the High Energy Physics group is dedicated to the development of advanced particle detectors for 1-100 keV energies and associated technology (high precision ultra-high vacuum technology in copper, partper-billion level gas purification, charge/light readout technologies, cryogenics). A joint development programme has being undertaken with UK-based ET Enterprises Ltd (formerly Electron Tubes Ltd) to develop a photomultiplier tube with ultra-low radioactive background. This work is in its final stages and promises to deliver the world’s most radio-pure phototube, which will find world-wide application in large experiments for neutrino detection, dark matter searches, and neutrinoless double-beta decay. The underground laboratory at Boulby represents a symbiotic relationship between industry (CPL mine) and university research. The gravitational-wave project drives charge control systems and associated technology (UV light sources, particle guns, satellite instrumentation). For this work the group collaborates with EADS (Astrium UK, Astrium Germany), Carlo Gavazzi Space (Italy), ETL, the European Space Agency, SciSys and SEA.

**Plasma Physics**
The Group is engaged in work involving the development and exploitation of high-voltage pulsed power sys-
tems and high-power lasers. Our research using lasers has led to developments in the field of 'compact' plasma-based particle accelerators with many potential applications ranging from advanced light sources to medical imaging and hadron therapy. We also investigate dusty plasmas, an understanding of which is important in integrated circuit manufacture and for future fusion power plant designs.

We collaborate with many companies and organisations that provide support for our activities in a broad range of ways including commercial contracts, knowledge transfer secondments, PhD support and through joint grant awards. These include UKAEA Culham, the Rutherford Appleton Laboratory, AWE Aldermaston plc, Sandia National Laboratory, the Laboratory for Laser Energetics (University of Rochester), the Institute of Laser Engineering (University of Osaka), the US Naval Research Laboratory and the Lawrence Livermore National Laboratory. We also host the Centre for Inertial Fusion Studies (CIFS) and the Institute of Shock Physics (ISP) which has substantial links with commercial and industrial organisations, include QinetiQ, THALES and BAE as well as its major sponsor, AWE. These involve investigations of high-speed impacts e.g. on electronic components, high strain-rate loading of engineering and biological materials and the development of robust predictive capabilities for systems under extremes of strain and pressure.

Laser Consortium
Our technology is associated with developing high intensity and ultra short laser pulses. Theoretical descriptions of the effect of these intense fields have led to technology that can be used to produce microscopic optical structures by laser induced modification (through multiphoton ionisation) of media. The attosecond basic
technology programme promises to open up new fields
of ultra high time resolution measurement in surface sci-
ence etc. Technology recently developed as part of this
project has been spun out and a second custom system
for hollow fibre pulse compression to generate 10 fs
pulses has been delivered to RAL under contract. A
broadband phase shaper for high intensity laser pulses
is also in the process of being patented. Plasmas pro-
duced by interaction of short pulse lasers with sub
wavelength clusters and micronscale objects are a
promising source for x-ray generation at lithographically
important wave-lengths. They also produce high energy
density plasmas of interest for the testing of numerical
codes. Blast waves in extended cluster media can be
used to model astrophysical and other strongly driven
systems and produce high quality data useful in the
benchmarking of complex radiation hydrocodes. We
have an active collaboration with AWE including fund-
ing, personnel exchange and equipment loan.

Quantum Optics and Laser Science

The Group applies cutting edge laser technology, quan-
tum-enhanced technology and detailed numerical mod-
ing to a broad range of measurement and control
problems in information processing, metrology, sensing
and basic physics research. The Centre for Cold Matter
has an ongoing collaboration with the K. J. Lesker com-
pany investigating transparent conductive films for poly-
mers. There are also links with PG Technology
(Precision machining company) on design of molecular
decelerators, and with Shimadzu Research Laboratories
(Europe) on the development of novel THz detectors
which has recently resulted in a joint patent.

There are ongoing collaborations with the National
Physical Laboratory (NPL) on ion trapping and the
development of ultra-stable lasers. This has included
supervision of students funded by the NPL who carry
out most of their experimental work there, but who are
registered as students at Imperial College. The Quan-
tum Information Theory sub group has links with a
number of companies including Toshiba and NTT.

Photonics

In the Photonics group, most of our projects are interdis-
ciplinary and we work closely with industry. Direct sup-
port for research into high throughput and
multidimensional fluorescence imaging, particularly fluo-
rescence lifetime imaging (FLIM) has come from Perkin
Elmer Life and Analytical Sciences (UK) Ltd and GE
Healthcare. ‘in kind’ support has come from
AstraZeneca UK Ltd, GlaxoSmithKline R&D, Kentech
Instruments Ltd, Leica Microsystems (UK) Ltd, Olympus
Optical Co UK Ltd. We also have a founding interest in
Aurox Ltd, a spin-out from Oxford University, manufac-
turing optical microscopy equipment. Our fibre laser pro-
gramme addresses wavelength and pulse length
versatile, all-fibre configurations primarily deploying
MOPFA (Master Oscillator Power Fibre Amplifier) tech-
nology including development of versatile compact seed
sources, to generate high average power, spectrally
bright single mode sources. The fibre laser work has
long-standing collaboration and support from the IPG
Group of Companies. Direct support in the area of high
power diode-pumped solid-state lasers and nonlinear
optics has come from the Electro-Magnetic Remote
Sensing (EMRS) Defence Technology Centre, estab-
lished by the UK Ministry of Defence and run by an
industrial consortium of SELEX Sensors and Airborne
Systems, Thales Defence, Roke Manor Research and
Filtronic. This involves novel adaptive sensors and laser
sources for enhancing signal and information retrieval in
complex remote sensing scenarios. Pilkington Optronics
(now Thales) have supported CASE awards and ‘in
kind’ support has come from Shell Research Labs,
Spectra-Physics and Spectron Laser Systems. The
European Space Agency is sponsoring the development
of new high efficiency tunable lasers for next genera-
tion satellite-based remote sensing for atmospheric and
earth science addressing climate change, weather pre-
diction and monitoring the health of the Earth’s bio-
system.
Space and Atmospheric Physics
The group has a long history of leading magnetometer instruments for space research. Our continued collaboration with Ultra Electronics Ltd has resulted in a new fluxgate design which at 100g is half the mass of any sensor we have previously flown in space. We completed a collaboration with EADS Astrium, MSSL (UCL) and SciSys Ltd to validate new data-handling architectures for future small satellites where processing power and resources will need to be shared amongst many users.
We have also completed a first stage of testing new, commercially available, solid state magnetoresistive sensors, with promising results.

As part of an EU Marie Curie Research Training Network GLADNET we are also studying the characteristics of Glow Discharges, used as an analytical method in industrial applications for example in quality testing of thin coatings.

The group is strongly engaged with the Climate knowledge Innovation Community (KIC) and is developing the next generation catastrophe model software for the insurance sector.

Theoretical Physics
The dominant part of the Group's activities lie in studying theories of the fundamental nature of the universe and associated commercial applications arise in the very long term. However, there are some subsidiary consultancy activities.
Tim Evans is a consultant with Digital Science http://www.digital-science.com/ who produce software to collate and analyse information for academics and academic institutions, for instance Digital Science produces Symplectic's Elements software which manages the publications of academics at Imperial College. He is also a Scientific Advisor to NewsffFlo http://www.newsfflo.net who produce software to collate and analyse information from News outlets for academic institutions.
Jerome Gauntlett is a Scientific Advisor for the Arts Club in Mayfair and he was the Theoretical Physics consultant for the film the Theory of Everything.
BLACKETT LABORATORY INDUSTRY CLUB

In 2010 the department set up the Industry Club, with the aim to enhance the good working relationships that exist between the Imperial College Physics Department and a number of companies and to develop such relationships with new partners. The department set about creating two departmental wide events per year inviting all Industry club members. The PGR Research Symposium event which is held in June each year, is a show casing event where all second year PhD students present posters and all third year PhD students give talks. Industry club members are involved in choosing poster prize winners. The second major event of the year is the industry club recruitment event, which is a more traditional career fair. Both events are well attended.

In 2014, the industry club co-sponsored our international undergraduate summer research exchange programme (i-UROP) at Massachusetts Institute of Technology, University of British Columbia, and Seoul National University creating the opportunity for seven of our third year Physics undergraduates to enjoy a state of the art research experience.

The industry club also sponsors a PhD thesis prize and two of our club members AWE and Winton Capital also sponsor their own named post graduate thesis prize.

2014 Industry Club members include:
AWE, BP, Bloomberg, Electronic Arts National Physical
Prizes and Awards

Prizes & Awards 1.1.13-31.12.14

Astrophysics

- Astrophysics Group – The Herschel-SPIRE Team, in which Imperial’s Astrophysics Group played a major role, has been awarded the 2014 Royal Astronomical Society Group Achievement Award.
- Dr Dave Clements – The Herschel-Spire Team, of which Imperial is a part has been awarded the 2013 Arthur C Clarke Award for Academic Study/Research 2014
- Dr Jonathan Pritchard – Awarded the Rees Rawlings Prize for the best PGCert portfolio of 2013 (by the Imperial EDU Group) - 2014
- Mr Hikmatali Shariff – 3 Minute Thesis Competition winner – 2014
- Dr Roberto Trotta - awarded an STFC Impact Acceleration Account award entitled “From Supernovae to Road Safety: Astrostatistical data analysis techniques for accident prevention” - 2014

Condensed Matter Theory

- Prof Sir John Pendry – Won the Isaac Newton Medal of the Institute of Physics 2013
- Prof Sir John Pendry – Awarded the Julius Springer Prize for Applied Physics 2013
- Prof Sir John Pendry - awarded a share of the 2014 Kavli Prize in Nanoscience – 2014
- Prof Mike Finnis - received a von Humboldt Research Award from the Alexander von Humboldt Foundation in Germany. The award comprises 60K Euros in Germany - 2014

Experimental Solid State

- Prof Donal Bradley – Received the Founders Prize Lecture of the IOP/RSC Polymer Physics Group at the Physical Aspects of Polymer Science biennial meeting in Sheffield – 2013
- Professor Donal Bradley - awarded an Honorary DSc from the University of Sheffield – 2014
- Professor Jenny Nelson - awarded a Fellowship of the Royal Society – 2014
- Dr John Labram has been awarded the Elings Prize Fellowship from the University of California Santa Barbara - 2014
- Mr Gianluca Bovo – awarded a Spring E-MRS’ 2014 Graduate Student Award - 2014
- Mr James Semple – 3 Minute Thesis Competition winner - 2014
- Mr Ed Yoxall – Awarded the Solid State Physics Prize - 2014
- Ms Katharina Zeissler - Awarded the Winton Capital Prize - 2014

High Energy Physics

- Prof Tijinder Virdee – received Honorary Doctorate (Honoris Causa) from Queen Mary University of London – 2013
- Prof Tijinder Virdee – Received Honorary Doctorate from the Universite Claude Bernard Lyon 1, Lyon, France; Awarded the Asian GG2 Award; Named 37th on the list of Britain’s 101 Most Influential Asians.
- Prof Sir Tejinder Virdee was knighted in the 2014 Queen’s Birthday Honours List - 2014
- Dr Lyn Evans - is a Visiting Professor in High Energy Physics – is the first winner of the prestigious St David Award for Innovation and Technology - 2014
- Dr Gregory Iles – Received the CMS 2013 Achievement Award from the CMS Experiment at CERN – ‘For his leading contribution to electronics design’ - 2014
- Mr Nick Wardle – Awarded the Winton Capital Prize - 2014
- Prof Lyndon Rees Evans – Awarded Dirac Medal by the International Centre for Theoretical Physics at Trieste and won the Glazebrook Medal and Prize – Institute of Physics – 2013

ISP

- Miss Chiara Bo – Awarded AWE PhD Prize – 2014
- Mr Michael Rutherford – Won 1st place at the RAL High Power Laser meeting Student Poster Competition - 2014

PE CDT

- Mr Joseph Shaw – awarded both a Fall and a Spring E-MRS’ 2014 Poster Prize - 2014

Photonics

- Mr Ben Chapman – Awarded the Blackett Laboratory – Industry Club Thesis Prize - 2014

Plasma Physics

- Professor Steve Cowley - awarded a Fellowship of the Royal Society – 2014
- Professor Steve Cowley - awarded a Fellowship of the Royal Academy of Engineering in recognition of his outstanding and continuing contributions to engineering - 2014
- Mr Arthur Turrell - Awarded AWE PhD Prize - 2014

Quantum Optics & Laser Science

- Prof Sir Peter Knight – Received Imperial College Medal – 2013
- Prof Sir Peter Knight awarded Honorary Degree of D
Prizes and Awards

**Lett by Macquarie University – 2014**
- Prof Sir Peter Knight elected Honorary Fellowship of the Institute of Physics - 2014
- Dr Ben Brown – EPSRC Doctoral Prize Fellowship - 2014
- Mr Steffen Driever – Awarded a Newport Research Excellence Travel grant to attend the Photonics west Conference in San Francisco. Also won the best student paper award - 2014
- Mr Sandeep Mavadia - Awarded the Anne Thorne Thesis Prize - 2014
- Mr Malte Oppermann – Awarded the Anne Thorne Thesis Prize - 2014
- Mr Stefan Truppe - Awarded the Blackett Laboratory – Industry Club Thesis Prize - 2014

**Space & Atmospheric Physics**
- Prof Michele Dougherty and the Magnetometer Team – won the Group Achievement Award in Geophysics, awarded by the Royal Astronomical Society – 2014
- Professor Michele Dougherty - awarded a Royal Society Research Professorship - 2014
- Emeritus Prof John Harries – Awarded Fellowship of Aberystwyth University (equivalent to an Honorary Degree elsewhere) - 2014
- Ms Minyi Liang - awarded a Kristian Gerhard Jebsen Scholarship within the Grantham Institute to undertake research in the Department of Physics - 2014

**Theoretical Physics**
- Prof Tom Kibble – Awarded Dirac Medal by the International Centre for Theoretical Physics at Trieste and Honorary Fellow status of the Institute of Physics – 2013
- Professor Tom Kibble - received the 2014 Einstein Medal of the Albert Einstein Society of Bern, Switzerland - 2014
- Professor Tom Kibble - awarded the Royal Medal of the Royal Society of Edinburgh – 2014
- Professor João Magueijo - awarded a Leverhulme Research Fellowship for “Dimensional reduction at
the Planck scale and models of the early universe” - 2014

Teaching
• These members of staff were shortlisted as nominees for the Student Academic Choice Awards: Dr Simon Bland, Dr Tim Evans, Dr Joachim Hamm, Prof Martin McCall, Prof Peter Torok - 2013
• Faculty of Natural Sciences Awards for Teaching Excellence were awarded to:
  • Prof Steven Cowley
  • Prof Matthew Foulkes
  • Prof Terry Rudolph
  • Dr Richard Hendricks
  • Dr Edward Hill
  • Dr Subhanjoy Mohanty
  • Dr Alexander Richards
  • Dr Francisco Suzuki Vidalm
  • Miss Giulia Ferlito
  • Mr Peter T Fox
  • Mr Jeremy Turcaud
  • Mr John Wood

UG Student
• Leo Hughes - awarded the Julian Schwinger Prize for the Best Student Presentation - 2014
• Renjie Yun - awarded a prestigious Lee Family PhD Scholarship - 2014

Abdus Salam Postgraduate Prize 2013
For annual award to a student in the Department of Physics for the best performance in the Quantum Fields and Fundamental Forces MSc

Adrian Sutton Prize
Prize for a major contribution to the life of the Centre for Doctoral Training in Theory and Simulation of Materials

Gladys Locke Prize in Applied Optics
For annual award to the student who achieves the best overall performance in the Applied Optics MSc course, taking into account written examinations, laboratory and project work.

Winton Capital Prize for the Best PhD Thesis in Physics
For annual award to the student with the best PhD thesis in Physics using computational methods.

Directors Prize
For annual award to the student with the best overall performance in the Plastic Electronics MRES.

Anne Thorne Thesis Prize
A PhD thesis in experimental physics concerned with the development and / or use of new experimental instrumentation or techniques.

Research Prize for best MRes Project in PE CDT
The MRes in Plastic Electronics will have a prize sponsored by Sigma-Aldrich for best MRes Project
Prizes and Awards

For 5 years from 2011
In recognition of doctoral thesis work that has made a significant scientific or technology contribution as measured by peer review publications or patents filed in an area of applied physics.

- Ben Chapman (M) £200
- Stefan Truppe (M) £200
- Ned Yoxall (M) £200

Materials Design Prize - For 5 years from 2011
For annual award to students who make the most significant progress at the early stage assessments.

- Gabriel Lau (M) £300
- Thomas Swinburne (M) £300

Prize for Outstanding Contribution to the Life Centre for Doctoral Training in Theory and Simulation of Materials for 7 years from 2013
For Outstanding Contribution to the Life Centre for Doctoral Training in Theory and Simulation of Materials

- Anthony Lim (M) £200

Prize for Outstanding Contribution to outreach or public engagement by a student in the Centre for Doctoral Training in Theory and Simulation of Materials for 7 years from 2013
For Outstanding Contribution to outreach or public engagement by a student in the Centre for Doctoral Training in Theory and Simulation of Materials

- Marc Coury (M) £200

Prize for Outstanding Contribution to the Life of the TSM CDT - For 5 years from 2011
For annual award to the student who makes the most outstanding (non-academic) contribution to the success and development of the Centre.

- Mohammed Khawaja (M) £100
- Daniel Rathbone (M) £100
- Chiara Liverani (F) £100

College Prize for award for outstanding achievement
College Prize for award for outstanding achievement

- Jassell Majevadia (F) £250

Aeneas Wiener (M) £250

Sir Peter Knight Award
Best overall performance in the MRes year by a Controlled Quantum Dynamics Centre for Doctoral Training student.

- Antony Milne (M) £200
Prizes and Awards

PGR Symposium (25/06/2013)
Winner of talk Session 1  Peter Sinclair (M) £200

PGR Symposium (25/06/2013)
Winner of runner up talk Session 1  Andrew Gilbert (M) £100

PGR Symposium (25/06/2013)
Winner of talk Session 2  Giuliana Di Martino (F) £200

PGR Symposium (25/06/2013)
Winner of runner up talk Session 2  Ben Chapman (M) £100

PGR Symposium (25/06/2013)
Winner of talk Session 3  Joe Fallon (M) £200

PGR Symposium (25/06/2013)
Winner of runner up talk Session 3  Gabriele Messori (M) £100

PGR Symposium (25/06/2013)
Winner of talk Session 4  Lionel Fafchamps (M) £200

PGR Symposium (25/06/2013)
Winner of talk Session 5  Alex Perevedentsev (M) £200

PGR Symposium (25/06/2013)
Winner of talk Session 6  Aisha Kaushik (F) £200

PGR Symposium (25/06/2013)
Winner of runner up talk Session 6  Matthew Kenzie (M) £100

PGR Symposium (25/06/2013)
Winner of poster  Michel Buck (M) £100

PGR Symposium (25/06/2013)
Winner of poster  Zara Abdelrahman (F) £100

PGR Symposium (25/06/2013)
Winner of poster  Anthony Lim (M) £100

PGR Symposium (25/06/2013)
Winner of poster  Leo Hughes (M) £100

PGR Symposium (25/06/2013)
Winner of poster  Yen-Hung Lin (M) £100

PGR Symposium (25/06/2013)
Winner of poster  Joshua Chadney (M) £100
ASTRO

Imperial College STFC Impact Acceleration Account
Dr Roberto Trotta, Pathways to Impact - Astrostatistical data analysis £14,836

Science and Technology Facilities Council
Prof Stephen Warren, STFC studentship enhancement programme for Nathalie Skrzypek £12,958

CMTH

Engineering & Physical Science Research Council
Dr Yan Francescato, Doctoral Prize Fellowship £47,306

Engineering & Physical Science Research Council
Prof Peter Haynes, Capital Equipment for Centres for Doctoral Training £397,033

The Leverhulme Trust
Prof Ortwin Hess, Extreme nonlinear chirality in THz metasurfaces £184,819

Engineering & Physical Science Research Council
Prof Ortwin Hess, Programme Grant: Mathematical fundamentals of Metamaterials for multiscale Physics and Mechanics (led by Department of Maths) £589,286

European Office Of Aerospace Research & Development
Prof Ortwin Hess, Full-Time-Domain Maxwell-Bloch Modelling of Semiconductor Lasers £28,546

Engineering & Physical Science Research Council
Prof Ortwin Hess, Programme Grant: Nano-Optics to controlled Nano-Chemistry Programme Grant (NOICH) (led by University of Cambridge) £1,039,871

The Royal Society
Dr Johannes Lischner, University Research Fellowship (held jointly with Department of Materials) £612,046

EXSS

Cambridge Display Technology Ltd
Prof Thomas Anthopoulos, Solution-processed hybrid complementary circuits on plastic £195,000

Imperial College EPSRC Impact Acceleration Account
Prof Donal Bradley, Knowledge Transfer Secondment for Jeff Bailey to NPL £44,588

Imperial College EPSRC Impact Acceleration Account
Prof Donal Bradley, Pathways to Impact - Copper thiocyanate as an anode-enhancing overlayer for low-temperature solution-processed optoelectronic devices £113,015

Imperial College Trust
Dr Will Bradford, Topological Spin Textures £20,223

Engineering & Physical Science Research Council
Dr Alasdair Campbell, Asymmetric Synthesis and Study of Platinum Metal-helicalenes in Circularly Polarised Phosphorescent Organic Light Emitting Diodes (led by Department of Chemistry) £88,824

Imperial College EPSRC Impact Acceleration Account
Dr Alasdair Campbell, Pathways to Impact (led by Department of Chemistry) £69,470

Imperial College Trust
Dr Amanda Chatten, Photo-chemical reactor £5,034

Imperial College EPSRC Impact Acceleration Account
Prof Lesley Cohen, Knowledge Transfer Secondment for Milan Bratko to Croygenic Ltd £23,492

European Space Agency / Estec
Dr Ned Ekins-Daukes, Highly Radiation Tolerant Multi-Junction Solar Cells £61,538

Commission of the European Communities
Dr Worawat Khunsin, Marie Curie Fellowship: Photonic-plasmonic hybrid for optical switching and biosensing application £171,319

The Leverhulme Trust
Prof Stefan Maier, Nano-particle assisted super-resolution microscopy for live cell imaging £68,089

Office Of Naval Research Global
Prof Stefan Maier, Beyond Nanophotonics Platform £54,286

Engineering & Physical Science Research Council
Prof Stefan Maier, Programme Grant: Mathematical fundamentals of Metamaterials for multiscale Physics and Mechanics (led by Department of Maths) £569,856

The Leverhulme Trust
Prof Stefan Maier, Hybrid nanoantennas £197,120

Engineering & Physical Science Research Council
Prof Stefan Maier, TERACELL: Integrated Microwave-to-Terahertz Sensors for label-free circulating tumour cell detection (led by Department of Materials) £293,308

Commission of the European Communities
Prof Jenny Nelson, CHEETAH - Cost reduction through material optimisation and Higher EnErgy output of solar Pho-tovoltaic modules - joining Europe’s Research and Development efforts in support of its PV industry (led by Department of Chemistry at Imperial) £41,692

Met Office
Prof Jenny Nelson, AVOID 2 (led by Grantham Institute) £2,318

Imperial College EPSRC Impact Acceleration Account
Prof Jenny Nelson, Knowledge Transfer Secondment for Wing Chung Tsoi to NPL £52,558

Engineering & Physical Science Research Council
Prof Jenny Nelson, SUPERSOLAR Solar Energy Hub £185,749

Engineering & Physical Science Research Council
Dr Paul Stavrinou, FPP3D: Coupling frontal photopolymerisation and interfacial wrinkling for single shot 3D patterning (led by Department of Chemical Engineering) £13,138

Engineering & Physical Science Research Council
Dr Paul Stavrinou, Capital Equipment for Centres for Doctoral Training £384,892

Engineering & Physical Science Research Council
Dr Katharina Zeissler, Doctoral Prize Fellowship £49,724
Grants Awarded

**HEP**
- Science and Technology Facilities Council
  - Prof Ulrik Egede, STFC studentship enhancement programme for Greg Ciezarek: £9,719

- Science and Technology Facilities Council
  - Prof Geoffrey Hall, Added Capital Equipment for CMS: £109,000

- Science and Technology Facilities Council
  - Prof Ken Long, MICE Spokesperson support: £263,501

- Wellcome Trust internal scheme
  - Dr Piero Posocco, Towards a compact proton irradiator for in-vitro radiobiological studies: £62,430

- Science and Technology Facilities Council
  - Prof Tim Sumner, LISA Pathfinder Mission Support: £125,696

- Science and Technology Facilities Council
  - Dr Yoshi Uchida, STFC studentship enhancement programme for Ben Smith: £9,719

- Science and Technology Facilities Council
  - Dr Morgan Wascko, The Hyper-K UK Proposal: £98,328

**PHOTONICS**
- Imperial College EPSRC Impact Acceleration Account
  - Prof Paul French, Pathways to Impact - Translating automated FLIM-HCA to drug discovery, systems biology and basic research: £124,591

- The Leverhulme Trust
  - Prof Paul French, Nano-particle assisted super-resolution microscopy for live cell imaging (led by Experimental Solid State): £56,055

- Royal Academy Of Engineering
  - Dr Edmund Kelleher, RAE Fellowship: Next generation short-pulse lasers for the visible and ultraviolet: £434,126

- Commission of the European Communities
  - Prof Martin McCall, GoPhoton! £39,773

- Biotechnology and Biological Sciences Research Council
  - Dr James McGinty, Enhancing spatial and temporal resolution for isotropic volumetric imaging and 3D cell tracking: £163,322

**Imperial College EPSRC Impact Acceleration Account**
- Prof Mark Neil, Pathways to Impact - Micro led array optical projection systems & applications in optogenetics: £66,091

**PLASMA**
- US Department of Energy
  - Dr Simon Bland, Pulsed Power High Energy-Yr 3: £132,353

- Engineering & Physical Science Research Council
  - Dr Michael Coppins, Dust in Magnetized Plasmas: £417,696

- Commission of the European Communities
  - Dr Christos Kamperidis, Marie Curie Fellowship: Construction and Optimization of a Novel, Ultra-Compact, Ultra-Fast X-Ray Coherent Source: £164,153

- Science and Technology Facilities Council
  - Prof Zulfikar Najmudin, Plamsa wakefield acceleration: £88,948

- Defence Science and Technology Laboratory (DSTL)
  - Dr William Proud, Frangible Simulants: £1,876

- AWE Plc
  - Prof Steven Rose, ORION opacity Phase 2: £330,000

- Imperial College EPSRC Impact Acceleration Account
  - Prof Roland Smith, Knowledge Transfer for Centres for Doctoral Training: £163,353

**QOLS**
- Engineering & Physical Science Research Council
  - Dr Ben Brown, Doctoral Prize Fellowship for Ben Brown: £36,370

- Imperial College EPSRC Impact Acceleration Account
  - Prof Edward Hinds, Knowledge Transfer Secondment for Ben Yuen to NPL: £81,242

- The Royal Society
  - Prof Michele Dougherty, Royal Society Professorship: £912,156

- Qatar Foundation
  - Prof Myungshik Kim, Quantum state engineering - Y3: £63,211

**The Leverhulme Trust**
- Prof Myungshik Kim, Proposal for quantum optical tests of the minimum length scale: £118,662

**Engineering & Physical Science Research Council**
- Prof Myungshik Kim, Capital Equipment for Centres for Doctoral Training: £116,557

**Commission of the European Communities**
- Dr Florian Mintert, ERC Starting Grant: Optimal dynamical control of quantum entanglement (grant transferred from Freiburg): £356,980

**U.S Army (US)**
- Prof Terry Rudolph, Photonic Quantum Characterization, Verification and Validation: £23,435

**Engineering & Physical Sciences Research Council**
- Prof Terry Rudolph, Programme Grant: Engineering Photonic Quantum Technologies (led by University of Bristol): £612,782

**The Royal Society**
- Dr Vijay Singh, Newton Fellowship: Design for a fountain of YbF molecules to measure the electron’s electric dipole moment: £66,000

**Engineering & Physical Science Research Council**
- Dr William Okell, Doctoral Prize Fellowship: £62,124

**SPAT**
- Science and Technology Facilities Council
  - Mr Chris Carr, Cluster FGM (2014): £103,959

- Science and Technology Facilities Council
  - Prof Michele Dougherty, Cassini (2014): £330,702
<table>
<thead>
<tr>
<th>Organization</th>
<th>Project Description</th>
<th>Amount (£)</th>
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<tbody>
<tr>
<td>Commission of the European Communities</td>
<td>Dr Jonathan Eastwood, Heliospheric Cataloguing, Analysis and Techniques Service (HELCATS)</td>
<td>£172,190</td>
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<td>Commission of the European Communities</td>
<td>Dr Heather Graven, Marie Curie Career Integration Grant: Observing Carbon Dioxide Emissions at Regional Scales (OCDERS)</td>
<td>£74,074</td>
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<td>Science and Technology Facilities Council</td>
<td>Prof Tim Horbury, STFC studentship enhancement programme for Martin Archer</td>
<td>£12,958</td>
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<td>Science and Technology Facilities Council</td>
<td>Prof Tim Horbury, Solar Orbiter additional equipment</td>
<td>£52,000</td>
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<td>Science and Technology Facilities Council</td>
<td>Prof Steven Schwartz, Cluster CSC (2014)</td>
<td>£102,169</td>
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<td>Imperial College EPSRC, NERC and STFC Impact Acceleration Accounts&quot;</td>
<td>Prof Steven Schwartz, Support for SpaceLab conference 2014</td>
<td>£18,000</td>
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<tr>
<td>Indian Institute of Tropical Meteorology</td>
<td>Prof Ralf Toumi, Stochastic Parameterization and Forecasting of Wind Energy in India</td>
<td>£191,472</td>
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<tr>
<td>Theoretical Physics</td>
<td>Commission of the European Communities</td>
<td>£1,402,530</td>
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<tr>
<td>Theoretical Physics</td>
<td>Prof Jerome Gauntlett, ERC Advanced Grant: GravQuantMat - Gravity, black holes and strongly coupled quantum matter</td>
<td>£1,402,530</td>
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<tr>
<td>Science and Technology Facilities Council</td>
<td>Prof Jerome Gauntlett, Consolidated Grant: M Theory, Cosmology and Quantum Field Theory</td>
<td>£1,909,894</td>
</tr>
<tr>
<td>Imperial College Trust</td>
<td>Prof Jerome Gauntlett, String Theory, Quantum Field Theory and Cosmology</td>
<td>£20,000</td>
</tr>
<tr>
<td>Commission of the European Communities</td>
<td>Dr Steffen Gielen, Marie Curie Fellowship: Cosmology from QGó What quantum gravity teaches us about the origin of the universe: Extension of early universe cosmology by using non-perturbative quantum gravity.</td>
<td>£164,152</td>
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<td>John Templeton Foundation</td>
<td>Prof Joao Magueijo, What banged?</td>
<td>£269,881</td>
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<td>The Leverhulme Trust</td>
<td>Prof Joao Magueijo, Research Fellowship: Dimensional reduction at the Planck scale and models of the early universe</td>
<td>£41,610</td>
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<tr>
<td>Science and Technology Facilities Council</td>
<td>Prof Arttu Rajantie, STFC studentship enhancement programme for Laura Bethke</td>
<td>£12,958</td>
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</tbody>
</table>
Early in 2014, the department was approached by the 1974 undergraduate cohort, a subset of which keeps in regular contact with each other. The group got in touch with Linda Jones, now Departmental Administrator, asking whether a function could be held for them over the Imperial Festival in May. The request resulted in the Department hosting a social event for over 100 alumni within (the very fondly remembered) Blackett level 8 common room. Linda toured many of the alumni to visit the level1 main lecture theatre and other familiar haunts.

Inspired by the success of this event, and recognising the need to provide Physics focused alumni visits, the department contacted the College Alumni office to ask them to help organise the first formal Departmental alumni function. In September 2014, over 120 alumni attended an exclusive Physics event to hear Professor Sir Tom Kibble talk about his role in the prediction of the Higgs Boson, the elusive particle whose existence was finally confirmed at CERN in 2012. Alumni were offered tea and cake in the Blackett Laboratory foyer (a trip down memory lane for many) followed by a champagne reception in the common room and the 8th floor roof terrace overlooking the West London skyline and the Royal Albert Hall. The appeal of such a prestigious speaker was apparent as the event attracted a huge range of alumni from recent graduates through to those who were taught by Professor Kibble himself.

Friends of Imperial Theoretical Physics

In 2013 the Theoretical Physics Group at Imperial College initiated a new association called "Friends of Imperial Theoretical Physics" or FITP for short. The purpose of FITP is to host periodic popular talks at South Kensington campus allowing members to keep abreast of the exciting research that is currently going on in the Group and in theoretical physics more generally.
In 2013 FITP hosted a Symposium celebrating Tom Kibble's 80th Birthday concluding with a keynote talk by Nobel Laureate Steven Weinberg to a packed audience of over 700 people in the Great Hall. In 2014 FITP organised a talk titled "The World in Eleven Dimensions" by Professor Michael Duff FRS, the Abdus Salam Professor of Theoretical Physics.

A Grand Day Out!
Imperial Festival 2014, the dates went straight into our calendar when we received our email from the Friends. This was our third Festival, and it didn’t disappoint, the event seems to be going from strength to strength. First of all, a visit to the Alumni base in the Senior Common Room. Always a cheerful welcome with a good cup of coffee and biscuits to get us going. Everyone is keen to chat and within minutes we had been exchanging words with an alumnus of 1958 Elec Eng who was visiting with a fellow student and a recent alumnus of 2013 Computer Science who had climbing the Queen’s Tower firmly on her agenda. Next the big marquee. So much to see, so much to learn about, so much to try. Knowledgeable students keen to share their enthusiasm; explaining, demonstrating and inspiring the Festival visitors. Great to see so many children who had come along with their families having such a good time controlling skiing penguins by nodding their head, whizzing cars down tracks to simulate DNA, looking at tape worms in jars, ugh! My own favourites included the 3D printer attached to the scanning fluid pipette which generated amazing models such as of the eye of a fly. Also the enthusiastic epigenetics student whose patience whilst trying to explain to two physicists what it was all about was impressive. Lectures to go to, workshops to try out, Jezebel and Bo to visit, the day sped by but we were keeping an eye on the time as we had an important date at 4:30pm. The Physics Department had invited alumni for a nostalgic visit to the department- and they did it in style. We met in the Senior Common Room on level 8, scene of our post finals party so many years ago. We were warmly welcomed by organiser Linda Jones, the Physics Department Operations Manager, and Professor Lesley Cohen, Director of External Liaison. Wine and a superb buffet ensured that people relaxed, mixed, reminisced and generally had a really good time. Thank you for a day to remember for alumni like us. It is also great to see that IC is doing such an excellent job in getting the message that science is fun, worthwhile, interesting and exciting out to the next generation. Janet (nee Eccles) and Gwyndaf John Physics 1971
Juno Transparency and Opportunity Committee
http://www3.imperial.ac.uk/physics/staff/juno
The Juno Transparency and Opportunity Committee meets monthly throughout the year. The business of the meetings is driven by (i) the evaluation of progress on the action plan from the last Athena-SWAN application, and (ii) new and on-going initiatives related to wider issues, such as the gender and the racial imbalance among physics students. Information about the committee’s activities, including the minutes, are disseminated to the department through the committee website, which is accessible through the departmental website.

The activities of the committee are often driven by an individual member, which is then supported by the committee as a whole through advice and concrete action. During the previous year, the main output of the committee is as follows:

1. Following a meeting between several members of the committee and Elizabeth Truss MP (at the time Parliamentary Under-Secretary of State for Education and Childcare) at the Department for Education (DoE) an invitation was issued and accepted for her to visit Imperial in 2014. That visit happened on May 14, 2014, when the Under-Secretary emphasised the need for better math and science teaching to encourage more pupils to take up STEM subjects after the age of 16, particularly girls and those from less affluent backgrounds. This was also a central theme during the visit to the DoE.

2. As an outgrowth of Mark Richards’ Insights programme, Lesley Cohen spearheaded a Women’s Day on June 4, 2014. Presentations included an overview, female researchers/academics talking about their journey, tours and lunch, where staff talked informally with the students about all aspects of academic life at Imperial.

3. Following the successful initiation of the PDRA committee to provide a forum for the concerns of that community, Rob Nyman (Juno Committee member) has established a committee for Early Career Researchers.

4. Training sessions for the new form for the personal review and development plan (PRDP) began in November 2013, with additional sessions to be added as needed. The new form is designed for use across all job categories and to focus the interview on the personal and career development of the appraisee. The new form has already been used in PRDP cycle during 2014.

5. One of the main activities of the Juno Committee is the preparation of the Department’s application for an Athena-SWAN Gold Award, which will be submitted in April 2015. The Department currently holds the Silver Award, which was first awarded in 2009, and renewed in 2012. There is only one department within Imperia (Chemistry) and one physics department in the UK (Cambridge) with Gold Awards.
Artist in Residence

FINDING PATTERNS
Report for 2014
Geraldine Cox
Finding Patterns began in April 2011 with a Leverhulme Trust artist in residence award. It aims to share so much of Nature that is hidden from the view of everyday life using the expressive power of art. Here is a summary of achievements for 2014.

Poems about Light Exhibition, 28th May till 12th June

Four new bodies of work were created and presented at the 'Poems about Light' exhibition at Imperial College. They spanned the Cosmic Microwave Background; Quantum Entanglement; the Sun and Discovery.

The preview night was well attended by members of the Physics Department and from elsewhere. The Blyth Centre hosting the event said that feedback throughout was excellent. E.g. "Inspiring and beautiful, mind expanding and awesome in the truest sense of the word. Thank you for this artistic interpretation of the universe", Peter Fudakowski, Film Director & Producer.

I hosted a talk for the Quantum Information Research Group and another informal discussion with Jonathan Halliwell for students at the end of the exhibition.

The Ogden Trust is now looking to tour the show to Liverpool and I am seeking other venues and funding.

Images from top: ‘Dance’, oil on canvas, 140 x 88 cm, ‘Map’, oil on linen, 15 x 21cm ‘Seaside’, oil on linen, 76 x 160 cm.

Catalogue: http://www.poemsaboutlight.com/
Moscow Film Festival with Polytechnic Museum, 9th-12th October 2014

The short film, 'Writing' of scientists' notes photographed in Peter Torok's lab was screened for 3 days in Moscow by the Polytechnic Museum as part of the Moscow film festival.


Action at a Distance, Naughton Gallery, Queens University Belfast, 5th – 30th November 2014

The Naughton Gallery showed 'Nature's Imagination' in 'Action at a Distance', an exhibition celebrating the life of John Bell. 'Nature's Imagination' was made with the help of Jonathan Halliwell, David Jennings, Terry Rudolph and Mike Tarbutt and explores some of the most striking characteristics of the quantum world; It was screened throughout November. The exhibition was supported by a printed catalogue with a still from the film and the programme included talks by scientists including Anton Zeilinger.

http://www.naughtongallery.org/sites/NaughtonGallery/Exhibitions/ExhibitionArchive/Archive2014/JSBell/Id.en.468029

'First Light' Film Online

I completed the silent short film of pencil drawings: 'First Light', telling the story of the Universe from the perspective of the Cosmic Microwave Background. Andrew Jaffe, Alan Heavens and Mike Tarbutt helped put the story together.

It was screened as part of the 'Poems about Light' exhibition and launched online where it has been viewed 1,300 times.

http://vimeo.com/geraldinecow/firstlight
Presentations and Discussions

December 2013: Physics Department lecture to students and staff, numbering over 100 attendees.

February: talks at Kingston and Portsmouth Universities to students of graphic design and fine art respectively. Over 100 students attended the first talk and around 40 the second.

March 2014, Southwark Cathedral, London: I was on the panel of a pre-concert discussion on the relationship between science, religion and art with Father Christopher Jamison, writer Iain McGilchrist & film producer Peter Fudakowski. There were over 150 attendees.

Educational Projects in Schools

Sun project at Salford Secondary School, April - June

Working with Cambridge Physicist, Helen Mason, I helped 30 10-12 year old gifted and talented children learn about the Sun and express their discoveries using art. The final result was an exhibition and catalogue. The project was facilitated by Heather MacRae of Venture Thinking.

Exhibition catalogue: http://issuu.com/ideasfoundation/docs/st_ambrose_hot_spot_exhibition_cata

Brentford School for Girls

I gave a talk to 30-40 sixth form girls of this inner city school about art, physics and life.

Projects Currently Underway

Nature’s Notes: I am developing a new body of work about oscillators, the cover painting ‘Rose Garden’ is part of this work. Various people have input their thoughts so far: Terry Rudolph, Tom Kibble, Jonathan Halliwell, Mike Tarbutt, Carl Paterson, Peter Torok.

Fabric of Nature: Discussions are taking place with professors in textiles (weaving, knitting and printing) at the London University of the Arts to explore possible collaborations taking some of the patterns we have developed at Imperial into fabrics.

Plans for 2015

- Begin a new project about symmetry in Nature and the physical laws.
- Launch ‘Poems about Light’ exhibition in Liverpool with Ogden Trust (provisional). Also seek additional venues with funding for this readymade exhibition.
- Continue programme of talks, including:
  - Undergraduate talk, end January.
  - TEDx talk in Marrakech in February.
- To judge as part of a panel, a physics inspired fashion design competition for undergraduate fashion and textile students. http://www.fad.org.uk/archives/4110the_brief/index.php

Acknowledgements

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Cover page image: ‘Rose Garden’, oil on canvas, 132 x 120 cm.