# Contents

## Department of Physics Review 2014/15

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The Physics Department has continued to flourish during 2014-15 and inside you will find an overview over the past year across the considerable breadth of our activities.

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, carried out by 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 very many awards and prizes which members of staff have received.

Overall we teach around 880 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 continue our undergraduate summer student exchanges with MIT, UBC and SNU allowing some of our top undergraduates to gain exemplary international research experiences.

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 continued to blossom and have 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 many staff across the department participate in visits to schools, public science events and fairs and of course the Open day visits to the department. 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 department renewed its Athena SWAN silver award in 2015 and continues to work hard to maintain the various initiatives that it has instilled and introducing new activities as we progress with our action plans. Representatives from across the department sit on our JUNO committee to see how we can improve the workplace environment and improve the gender and racial imbalance across staff and student populations.

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

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In October 2014 we welcomed 236 new students, making the total number of undergraduates 879, one of the largest Physics departments in the country. This was the third cohort in which home students were paying fees of £9000 per annum. Students are enrolled initially 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 2015 the third cohort of students graduated on our 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. A 4 year MSci version of this programme is now also available. Students can opt to transfer on to the Science Education programmes at the end of Year 2 once their suitability for teaching has been assessed.

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 2014, 10 students studied abroad in Year 3 of the Year in Europe programme and we welcomed 34 visiting students to the department. This marked downturn in the number of our students studying abroad coincides with the first cohort paying higher fees and the reasons are not obvious given that studying abroad under the Erasmus scheme is financially advantageous compared to remaining in London. We are working hard to advertise the benefits of the programme. 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 and the Department. In the summer of 2015 we sent Jana Smutna and Martik Aghajanian to MIT, Ray Otsuki and Miha Zgubic to the University of Vancouver in British Columbia, and Thomas Laird and Aaron Zack to Seoul National University. See the full report on page 16.
Undergraduate

Teaching Awards

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 2015, the Faculty of Natural Sciences Prizes for Excellence in Teaching were awarded to:
• Dr Marina Galand
• Dr Jonathan Pritchard

Faculty Prizes for Excellence in the support of Teaching and Learning were awarded to
• Mr João Arnauth Pela
• Dr Nicholas Dover
• Dr Megumi Ito
• Mr Matteo Lostaglio
• Dr Benjamin Sherlock
• Dr Benoit Vanniere
• Ms Jessica Wade

The Commemoration Day Reception late in October each year is the setting for our departmental prize giving where 30 students were awarded prizes in 2015.

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

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<td>Further Study</td>
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<td>Seeking employment</td>
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<td>Time Out / Unavailable for Work</td>
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Graph 1 – Destinations of 2014 graduates

Graph 2 – Comparison with previous year

Graph 3 – Sector of employment entered
Undergraduate

What do Physics Undergraduates do?

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/Business Analyst
• 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
• BBSRC 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 Atmospheric 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
Undergraduate

International summer research exchange scheme for undergraduate students

2015 International UROP Summer Placement Scheme

This year we sent two students to UBC Canada, MIT Boston and SNY South Korea. Here is a short report from each of them describing their research and cultural experiences. Enjoy!

UBC Victoria

Miha Zgubic

My placement at the University of British Columbia (UBC) in Canada was enjoyable both culturally and academically. An additional perk was being able to compare the research culture in the North America to that of the UK. Furthermore the placement has consolidated my decision to continue my education with a PhD. UBC has a joint department of physics and astronomy and is strongly involved in cosmology, which was the research field of my supervisor. The research project itself was about neutrinos of cosmological origin, which lies at the interface of particle physics and cosmology.

Cosmic neutrino background are neutrinos that have last interacted with matter only 1 second after the Big Bang, and have been free-streaming in the expanding Universe ever since. It is the equivalent of the more well known Cosmic Microwave Background, which is composed of photons rather than neutrinos and is extensively studied. As a part of my research I’ve calculated the effect of our motion in this neutrino background and found that it is very similar to the effect on the CMB. Additionally I have calculated a crude estimate of the neutrino spectrum originating from the processes inside the stars. This brief description should be concluded with a remark that while the neutrino background is very rich in structure and would provide a glimpse of the Universe at the tender age of 1 second, it is also notoriously hard to detect – and will probably not happen for decades.

At the end of the placement summer students were also given the opportunity to give a talk on their work to the audience composed of other summer and PhD students, postdocs, and professors, which proved to be a very valuable experience. The research placement at the University of British Columbia in Canada was certainly one of the highlights of my undergraduate degree, providing the hands on experience in physics research and consolidating the decision to continue my education by pursuing a PhD. The weekends were mostly spent together with other students from Imperial exploring downtown Vancouver and hiking along many of the popular trails in the area, offering some of the most beautiful scenery I have ever seen.

Ray Otsuki

I had the good of fortune of working under Dr. Wojciech Fedorko in the physics department at the University of British Columbia (UBC) in British Columbia, Canada. My project was to extend a program called ‘BumpHunter’ which searches for and quantifies the statistical significance of ‘bumps’ (excesses in data) over any smooth (generally decaying) background. The project was to code a method to iteratively fit a curve over binned data sets whilst excluding successively wider ‘windows’ in the data set and then calculating the significance of any excesses found without requiring any particular model for the background i.e. to make the search as model-independent as possible. Whilst rooted in particle physics (Drell-Yan Z’ searches), the project has extended applicability in any context and could, for example, be implemented in the financial sector or data mining to search for unknown phenomena.

Being an analysis tool, there were no direct results from the coding; the target dataset on which it was to be used was yet to be produced (Run 2 of LHC) but implementation wise,
the project was a success. The core functionality can be applied to arbitrary datasets (though the fitting may need to be tailored to the project) with a numerical quantification obtained at the end.

In terms of personal developments, the project gave plenty of insight into the workings of a very large collaboration (ATLAS). I participated in group meetings, seminars and lectures, and finished off the placement with a presentation of my project in the final group meeting. On the coding side, my knowledge of C++ was augmented in this placement by the boost library and C++11. Overall a very dynamic project, the main focus was not concretely laid out and required a lot of independent thinking given my supervisor spent the majority of the time away in Europe. Contact was frequent, though, with useful input coming readily.

The atmosphere at UBC was very different from what I had experienced in my placement the previous year at Imperial; the people in the group were generally much more relaxed and friendly than at Imperial though remaining professional throughout. In fact, the people of Canada were generally much more pleasant to deal with; bus drivers were quick to give directions and recommendations, waiters were courteous and many were even quite humorous. The campus at UBC was very different from what I had experienced in my placement the previous year at Imperial; the people in the group were generally much more relaxed and friendly than at Imperial though remaining professional throughout. In fact, the people of Canada were generally much more pleasant to deal with; bus drivers were quick to give directions and recommendations, waiters were courteous and many were even quite humorous. The campus at UBC was very different from what I had experienced in my placement the previous year at Imperial; the people in the group were generally much more relaxed and friendly than at Imperial though remaining professional throughout.

A fantastic experience throughout and due thanks to all who organised the exchange

**MIT Boston**

Martik Aghajanian

The UROP programme I undertook at Massachusetts Institute of Technology was based in the Condensed Matter Theory group in the Department of Physics, and was both an engaging academic learning experience, and a vital piece of my professional development. I had never been across the Atlantic before, and was worried about how different the academic environment would be. I was pleasantly surprised to find that adjusting to work at MIT fit neatly into the intercultural experience. The facilities and the department were brand new and well organised, being the central working environment to a myriad of immensely intelligent academics in various stages of their careers. After meeting my senior supervisor and his post-docs to discuss the exact nature of the project and the plan for my work over the summer I was ready to begin immediately with the research. My research group comprised of American, Chinese and Dutch researchers, instructing me in a wonderfully diverse spectrum of problem-solving methods.

Throughout the placement I developed useful skills in research which can only be practically obtained, and interacted with some of the most accomplished minds in the specialisation of Physics I aspire to work in. The guidance received by academics who have already been through a great deal of their career is priceless, and by working in a foreign environment, your adaptability both tested and improved. Furthermore, the most satisfying element of my placement was to see the Physics that I had learned in lectures, and the Physics I had yet to learn, manifest itself in real-life research.

The project was tailored to my particular interests in many-body quantum mechanics and computational physics, and was modelling and studying the surface states of a specific superconducting topological crystalline insulator. As a computational project, I worked quite independently and regularly visited my supervising post-docs to discuss my approaches and results. They had not venture into this project themselves, so meetings consisted more of brainstorming ideas on how physical concepts interplay efficiently with computational methods, and means of testing my model. I began reading many publications and using textbooks in the library to grasp essential concepts, followed by refreshing myself on computational techniques. I also had opportunity to talk to non-supervisory academics to ask general questions in Condensed Matter. After several weeks of work I constructed 3D graphs and data that revealed key quantum and topological properties of Tin Telluride,
and following that, superconducting flux was added to the model, allowing me to develop my own formalism for efficiently constructing finite-crystal-coordinates. I now have a fully working model of a Topological Superconductor, and when I access higher-level computational resources upon my return to Imperial I intend to continue the project in the search for the Majorana fermions bound to the TSC’s surface.

On top of the research, I had ample time to explore the historical and diverse cities of Boston and Cambridge. As I expected, there were plenty of American burger houses and diners to sink my teeth into, but alternatively Chinatown in Boston had much to offer. I also found many Irish-themed pubs and sports bars where I could grab a beer at the end of the week. During the placement I had chance to spend a weekend in New York and be unmistakably blinded by the mammoth lifestyle and about ten million lights per square metre, but also seeing the mesmerising view of the entire city from the top of the Rockafella building. Conversely, visiting the quiet town of Cape Cod the subsequent weekend revealed a more relaxed and liberal side of the United States. Throughout my stay in the United States, I had chance to try all types of food and drink, in enormous portions, as well as talk to the amiable inhabitants and find out a lot about life there. For example, Boston was a renowned seafood spot, and proffered many chances to eat lobster and oysters.

Jana Smutna
This summer at MIT was the most exciting research opportunities I’ve had so far and possibly one of my best summers as well. I was part of the Neutrino Physics Group working on Project 8, a one of a kind particle physics nowadays. Other particle physics experiments are extremely big or require extraordinary amounts of energy. Just think about Large Hadron Collider or any of the direct detection Dark matter experiments. Instead, Project 8 measures neutrino mass in a rather elegant way, by measuring the radiation emitted by a single electron trapped in a magnetic field (single electron cyclotron radiation). This allows to find the energy spectrum of the electrons from tritium beta decay and from that find the neutrino mass in a fairly straightforward way. Of course, as in all physics, it’s not actually this simple, you still have to deal with errors and ensure that every component of your experimental setup actually works the way you need it to. But at least the basics of this one are easy to understand.

Of all the possible projects I could have been doing, I think I was very lucky to be involved in this one. I have been working on the data analysis of all this, so I found it really beneficial to have a reasonably good understanding of what is going on in the previous experimental stage. Moreover, this experiment is just in the right stage for things to be working enough to produce results, but I could still contribute to it as an Undergraduate. And at the end, I my research advanced and aspect of Project 8. There were even a couple of exciting moments where I found some features in the signal never seen before. First of them was just one of the clocks in the experiment being unstable and wasn’t very interesting, but the second one was actually a real physics phenomenon that we started seeing as the resolution improved.

Of course, there were other things I got to do that didn’t have anything to do with research. It was interesting to get to know not only the MIT environment, but also Boston outside of MIT campus. The Independence day celebrations were probably the most notable, with a concert and fireworks, they almost made me forgive the US that they stopped issuing visas for a couple of weeks before the placement was supposed to start. I thought I am ready for it, but I still found it really strange to live in an English speaking country where so many little things are unfamiliar, even when it comes to just shopping in a supermarket. It was certainly a lot better to come with a group of other Imperial students and have somebody to share all these experiences with.
Thomas Laird

For a period of two months over the summer I participated in a research project conducted in Seoul National University. In it I got to participate in academic research in a manner similar to a graduate student. The importance of this experience for me lies not only in the academic and technical experiences gained, but also in the opportunity I had to witness a cultural sphere completely new to me.

Although its subject matter was condensed matter physics, my project was to write a programme simulating certain systems and as such was mainly computational. Upon arriving at the department I was given a desk of my own in the research group office. There I would spend my time working on my project, while being amongst graduate and postgraduate researchers. This enabled me to interact with them and, together with my own endeavours, form a better understanding of how research is properly conducted on the graduate level. I view this opportunity as the most valuable academic opportunity the placement had to offer.

Towards the end of the placement I was surprised to find that I had to give a presentation and hand in a report about my project, something other participants in the same placement scheme weren’t required to do. I quickly found out that this was something my own hosting group arranged for me to do as a participant in group meetings, as part of my full integration into the group’s activities.

Throughout my time there I have indeed acquired invaluable skills, such as the art of reading research papers and coding MATLAB. But since these come naturally in time, it is the impression of research as a vocation, together with the connection I made, which I feel are my most important academic gains. I now find myself determined more than ever to pursue a career in academic research in the future, and though I don’t yet see myself as necessarily following my research topic into condensed matter, I still value the knowledge I have gained into the subject and its structure.

In the weekends I would spend my time exploring Seoul as much as I could. Due to the sheer vastness of the city I found myself completely satisfied with exploring just it (leaving only once for the neighbouring Suwon). The many palaces, markets and museums in the city are a testament to its prominent role in the historical development of South Korea, and of its culture as a whole. Dining in traditional Korean restaurants and participating in the different aspects of nightlife in Seoul, I managed to catch a glimpse of the distinct lifestyle experienced by Korean people.

Korean society exhibits a hierarchical structure based on respecting ones seniors. Indeed throughout my stay I had observed many cultural habits, such as exclusively pouring drinks for each other and waiting silently for everyone to finish at the end of a meal, which demonstrated the importance of respect in Korean society. To my surprise, I myself have adapted such habits, and since returning from my placement have even found myself many times demonstrating those habits on my own everyday setting.

In my eyes the strength of the cultural encounter offered by the placement is its length - the two month period is long enough to form a large pool of cultural experiences. The additional structuring produced by the placement serves to project these experiences in a manner of everydayness not normally encountered in, say, typical holiday trips. Beyond the strangeness commonly ascribed to societies we are not part of lies just another standard way of living, and it is this way of living that the placement exactly aids in exposing.

Aaron Zack

My placement, undertaken in the Centre for Novel States of Complex Materials Research (CeNSCMR) at Seoul National University between June 29th and August 28th, focused on the growth and characterisation of novel superconductors. Superconductors are materials that conduct electricity with zero resistance below a certain temperature, called the superconducting transition temperature, which is different for each compound. Before I could work on any new samples, I first had to spend time learning the laboratory techniques common in the research group, so my first task was to create a polycrystalline samples (made up of multiple small crystals rather than a single crystal) of a particular praseodymium-based compound. An examination of this sample’s
qualities (crystal size, transition temperature, and conductivity profile) is normally used as a first test of new researchers’ skills in the research group.

Surprisingly, many of these techniques were somewhat reminiscent of cooking – precise weighing of “ingredients” (stoichiometric mixtures of high-purity elements), grinding with a mortar and pestle (albeit one cleaned with nitric acid and used under a fume hood), and baking in an “oven” (a high-temperature furnace) for a few days. Once the sample was created, a tiny, millimetre-scale section of the crystal was cleaved from one of the edges to use for conductivity measurements. Handling this sample, and manually attaching micron-scale gold wire filaments to it at regular sub-millimetre intervals, required a steady hand and a lot of patience. Patience was a common theme throughout the placement – some samples take a week or more in the furnace before they’re ready to be tested.

Towards the end of my placement, I had moved on to working on new compounds to test for superconducting transitions. I was working on iron arsenide compounds, so naturally, my first task was to create iron arsenide powder to use as a precursor for new testing materials. Many iron arsenide compounds exhibit superconductivity (at temperatures up to 38 Kelvin), but the exact mechanism behind it isn’t understood – the more examples we have of iron arsenide superconductors, the more likely it is we can find out why they have a superconducting transition. After making the precursor powder, stoichiometric amounts of new elements are added, the sample is placed back into the furnace, and is tested for superconductivity by passing a current through it at different temperatures, cooling it as low as 1.8 Kelvin (-271 degrees centigrade). These new elements are not chosen randomly, of course – we select likely candidates for superconducting samples by looking at known cases of iron arsenide superconductors, and choosing elements that create similar crystal structures to known superconducting compounds.

One of my novel samples (i.e.: not yet reported in any journals or publications) exhibited superconductivity. More research must be carried out on this compound first, of course – new samples of the same material must be created, and more measurements performed. But nonetheless, I’m extremely proud to have been part of a discovery of something new in this field, no matter how small, and am looking forward to reading future research on this compound and other similar ones.

Naturally, one of the most striking things about this placement was the cultural experience of staying in a different country, and the contrast between the cultural norms of South Korea and the United Kingdom. Respect of seniority, and of elders, plays an enormous part in South Korean culture. Inside the lab, the head of the research group (Professor Kee-Hoon Kim, who was also my project supervisor), commanded the confidence and obedience of all members of the research group.

The food in Korea is delicious, and quite distinct from Western cuisine, with most meals being comprised of one or two main dishes and several smaller side dishes, or banchan, including the ubiquitous kimchi, or pickled cabbage. Kimchi is served with every meal in Korea. It’s quite tasty, especially if (like me) you enjoy spicy food. Learning hangul, the Korean alphabet, proved a huge advantage in daily life in Seoul, and I would recommend doing so to anyone undertaking a similar placement in future.

Overall I found my placement extremely rewarding, both in the academic challenge presented by my tasks in the lab, and in the personal challenge of learning about another country’s culture, language, and history. I would recommend this placement both to any physics student with an interest in an academic career, and to any student interested in broadening their cultural horizons. I look forward to seeing the fruit of my research, and to visiting Korea again someday.
Postgraduate
The Department of Physics at Imperial College London 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. Of these, our general MSc in Physics has additional options for a focus in nanophotonics, shock physics, or extended research.

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 are all successful renewals.

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, and specialized country-specific scholarship and exchange opportunities.

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.
Simon Schöller  
Group: Institute of Shock Physics  
Supervisor: Prof. Jeremy Chittenden

Simon Schöller obtained a BSc in Physics at ETH Zürich before starting his MSc in Physics with Shock Physics. His Master’s project was supervised by Prof. Jeremy Chittenden and focussed on simulating current-driven implosion of solid material samples (mainly aluminium and plastic) in cylindrical geometry using a magneto-hydro code. It made some first theoretical steps towards reaching regimes in density and temperature that were, thus far, mainly accessible via laserdriven ablation experiments. A current driven scheme would, however, allow for a longer time scale and a larger sample volume. It was looked into how the current pulse should be optimised to avoid shock formation and to reach high density, low temperature states comparable to those inside large planets and relevant for inertial confinement fusion. First evidence was found towards the feasibility of such multi-terapascal compression histories, e.g., applicable to the Z Pulsed Power Facility at SNL, but further simulations would be required.

In October, Simon will start a PhD in Imperial’s Applied Mathematics and Mathematical Physics section of the Mathematics department, focussing on computational low Reynolds number fluid dynamics.

Cheryl Kai Seow  
Group: Photonics  
Supervisor: Prof. Peter Torok

I obtained a BSc(Hons) in Applied Physics from Nanyang Technological University, Singapore, in 2010. After working for 4 years in DSO National Laboratories, I came to Imperial College to do my MSc in Optics and Photonics. During the MSc, I worked on the implementation of a single-pixel camera which reconstructs images via Compressive sensing. Traditional imaging acquires images using an array of pixels in a single shot. In contrast, the single-pixel camera reconstructs the image from successive measurements. The spatial information is encoded in the data through the projection of multiple light patterns on the scene. Single-pixel imaging allows smaller cameras to be built. In particular, it has its advantages when imaging in domains such as the thermal infrared, where detectors are bulky and expensive. Furthermore, encoding the spatial information higher up the imaging chain makes the camera more resistant to scatterers which lie in between the object and detector. In other words, it offers the possibility of imaging objects on the opposite side of translucent media, and this is the motivation behind our work. However, single pixel cameras require the same number of measurements as the number of desired pixels in the image. This means that the time taken for image acquisition increases with image resolution. In this project, the number of measurements required for accurate reconstruction is reduced through the use of Compressive sensing. Experimental results with the designed system showed that exact reconstruction could be achieved with 50% of the pixel count, while the object could be distinguished with as little as 20% of the pixel count. In addition, when objects were placed behind highly scattering diffusers, images were successfully reconstructed by the designed system while the object was imperceptible in images taken by a typical smartphone camera.

The developed camera would be used during my PhD, where I aim to study whether the eigenfunctions of the scattering matrix of a random dynamic scattering media can be used to reconstruct an image of an object hidden behind it. Potential fields of applications include biomedical imaging and defence.

Gleb Siroki  
Programme: MSc in Theory and Simulation of Materials  
Supervisors: Dr Vincenzo Giannini, Dr Derek Lee and Prof Peter Haynes

Gleb's project is on interaction of topological insulators with light. In less than ten years since their discovery, topological insulators have become a focus of active research worldwide. The name of these materials stems from the fact that small modifications to their band
structure leave some of their properties unchanged. The key among those is the presence of protected electron states on their surface. In contrast to the case of ordinary insulators, these states cannot be removed by defects and impurities. During the MSc project Gleb has found that the protected surface states modify optical properties of a topological insulator nanoparticle. He aims to extend this work by studying the behaviour of coupled nanoparticles. In addition to fundamental interest, this project may provide new avenues for manipulation of light at THz frequencies where applications are still limited by the lack of suitable materials.

Max Boleininger
Programme: PhD in Theory and Simulation of Materials
Supervisor: Dr Andrew Horsfield

Imaging molecular orbitals with sub-femtosecond time resolution (<10^{-15}s) has long been a dream in science. This timescale can involve both nuclear and electronic dynamics, and is hence fundamental for many chemical and physical processes, such as charge transfer, photo-isomerization, and polaron formation, to name a few. Obtaining information directly from experiments about the dynamics of the excited electrons is very difficult; for now we have to turn to computer simulations. While there already exist models for these systems, these are often prohibitively expensive for any study on dynamics of systems with more than a few dozen atoms. We have developed a new computational method capable of describing matter under the influence of extremely powerful, time-dependent laser fields at merely a fraction of the simulation time. We have built on the Tight-Binding model, whose conception dates back to well over sixty years ago, but with a particular twist; our theory derives itself systematically from first principles and is hence systematically improvable.

We have augmented our model with modifications that lead to a more physical description of the systems we wish to investigate. This enables us to simulate electron dynamics in organic clusters, crystals, and surfaces in strong electric fields in a computationally efficient manner.

Joshua Chadney
Group: SPAT
Supervisors: Dr M Galand (SPAT) & Dr Y Unruh (Astro)
Submitted thesis 04/04/2015

The new frontier in exoplanet science is the characterisation of atmospheres of transiting exoplanets and their suitability for life. This original research carried out by Joshua Chadney, first in his Master project (MSc in Physics) and then in his thesis, is highly multidisciplinary in nature, covering both stellar physics and planetary, atmospheric physics. So far, comparable published studies have only focused on one aspect, either stellar (with the planetary processes simplified) or planetary (with the stellar radiation spectral shape reduced to the solar one). Joshua’s thesis has been the first study to bridge the gap between science areas and communities, bringing together stellar physics and planetary aeronomy. This work has been carried out through close collaborations with colleagues from the Center for Astrobiology near Madrid (Spain) and from the Lunar and Planetary Laboratory, University of Arizona (USA). The results of his work have been published in two papers in leading international journals, with a further third to be submitted. Among others, Joshua has derived a parameterization of the EUV-to-X-ray stellar flux ratio in order to derive the EUV flux from X-ray observations. Joshua has assessed atmospheric escape regimes in details. This has implications on the evolution of the exoplanet’s atmosphere. He has also developed a model of the plasma in an exoplanet’s atmosphere irradiated by stellar fluxes from low-mass stars. It is the most comprehensive plasma model to date. Joshua left Imperial College London recently for taking up a postdoctoral research position at the School of Physics and Astronomy at the University of Southampton.

Ruth Geen
Group: SPAT
Supervisors: Dr A Czaja & Prof JD Haigh
Submitted Thesis 05/11/2015

Ruth was funded for 3 years by the Grantham Institute (Imperial’s hub for climate change and environment). Her thesis concerned the development
and application of a computer model of the climate and she has made significant original contributions to this field.

She developed a new and efficient module to calculate heating and cooling by absorption and emission of radiation in climate models of intermediate complexity. She has tested and validated this module using a comprehensive radiative transfer code and she has applied it to the MIT atmospheric general circulation model run in an idealised (aquaplanet) geometry. As a result of this Ruth was invited to spend a couple of months at MIT to interact with the climate modelling group there and to set-up her radiative transfer module, specifically for paleo-climate applications. A manuscript is in preparation to describe the module so that it can be used by the international climate community more widely.

Using the MIT model with her enhancements Ruth went on to design innovative numerical experiments in which she artificially enhanced the saturation vapour pressure of the model atmosphere. Through these she has been able to isolate the effect of water vapour on the dynamics of weather systems from its effect on radiation. This has provided new understanding of the role of storms in the latitudinal transfer of heat, an important component of the climate system. A manuscript reporting these findings has recently been accepted for publication in a leading climate journal.

Jack Devlin  
Group: QOLS  
Supervisors: Prof EA Hinds & Dr JJ Hudson  
Submitted thesis: 27/07/2015

Jack’s research involved measuring the electron’s electric dipole moment (eEDM). This is an important quantity to measure because a non-zero eEDM violates time-reversal symmetry and it would be evidence for new physics beyond the Standard Model. Joining an established experiment based in the Blackett laboratory, Jack developed new techniques in precision spectroscopy of ytterbium fluoride which will allow eEDMs as small as $10^{-29}$ e.cm to be detected. This is the size of eEDM predicted by many alternatives to the Standard Model. Jack developed novel methods of molecular state preparation and detection which greatly increase the number of molecules able to participate in the measurement, hence reducing the uncertainty in the determination of the value of the eEDM. Designing these methods required a new theoretical understanding of how multi-level molecular systems interact with many driving fields, with potential applications to the laser cooling and trapping of molecules. He also successfully discovered and characterised a number of new systematic effects that could mimic an eEDM signal. Jack is currently continuing his investigations as a research associate in the Centre for Cold Matter at Imperial College.

Anthony Lim  
Group: CMTH and TSM CDT  
Supervisors: Matthew Foulkes (Department of Physics) and Andrew Horsfield (Department of Materials)  
Submitted thesis 26/09/2014  
Collaborators: Daniel Mason (Culham Centre for Fusion Energy); Alfredo Correa, Andre Schleife, and Erik Draeger (Lawrence Livermore National Laboratory)

A 14 MeV fusion neutron in a tokamak may penetrate far into the reactor wall before colliding with a nucleus. From then on, all hell breaks loose as a cascade of collisions shares the neutron’s energy between millions of atoms. Radiation damage cascades have been well explored at a classical level, but little is known about the quantum mechanical energy transfer from moving atoms to electrons in real solids. Anthony’s PhD used state-of-the-art time-dependent density functional simulations to investigate the “electronic friction” caused by the irreversible transfer of kinetic energy from moving atoms to electrons. He concentrated on insulators, where the presence of an energy gap between the highest occupied electronic energy level at the valence band maximum (VBM) and the lowest unoccupied electronic energy level at the conduction band minimum (CBM) suggests that electronic excitation may be impossible below a threshold atomic speed. Experimental data on the threshold effect is confused, with
some groups seeing it and others not. By simulating a single "projectile" atom moving through an otherwise perfect crystal, Anthony found that many projectiles host an electronic energy level in the band gap. As the projectile moves, the energy of the gap state changes from just above the VBM to just below the CBM. When the gap-state energy is low, a valence electron may hop into it via Landau-Zener tunnelling; as the atom moves on and the gap level rises, the energy of this electron also rises until it is able to tunnel out into the conduction band. The gap state acts as an elevator, ferrying electrons from the valence band to the conduction band, even at low atomic speeds. Anthony's work on the electron elevator is about to appear in Physical Review Letters.

Christiana Pantelidou
Group: THEO
Supervisor: Prof Jerome Gauntlett
Submitted Thesis: 07/05/2014

Christiana's research centred on the AdS/CFT correspondence in string theory. This provides a remarkable framework for studying strongly coupled quantum systems using dual gravitational descriptions in higher spacetime dimensions. Her PhD was devoted to studying this correspondence with the aim of trying to illuminate strongly coupled systems that arise in condensed matter systems. She published five papers. In one direction she made an innovative study of the gravitational instabilities of black hole solutions that arise in the presence of magnetic fields. This worked demonstrates that the dual quantum system must undergo a novel kind of thermal phase transition in the presence of a magnetic field. An interesting connection with supersymmetry was also studied. In another direction Christiana analysed the dual description of p-wave superconductors by constructing novel black hole solutions. The competition between p-wave and (p+ip)-wave superconductors was explored and she determined the zero temperature ground states of the system. In a final direction she using gravitational techniques to study a new kind of deformation of a four-dimensional conformal field theory with a helical structure, and calculated the novel thermoelectric properties of the system by studying perturbations of the dual black holes. She is now a postdoc at the University of Barcelona.

James Pecover
Group: PLAS
Supervisor: Prof JP Chittenden
Submitted thesis 08/05/2015

James' PhD research focused on using large-scale 3D magneto-hydrodynamics computer simulations to model, explain and understand instability growth in magnetized liner inertial fusion (MagLIF) experiments. The MagLIF scheme consists of a millimetre-scale metallic cylinder (liner) containing pre-magnetised and preheated deuterium-tritium fuel which is brought to thermonuclear fusion conditions by a magnetically driven implosion, causing a 30 times decrease in radius over a timescale of ~100 ns. Such a system is, however, unstable at the interface between magnetic field and liner, with high amplitude instability growth during implosion one of the main barriers to the success of MagLIF. James has investigated how early time, low amplitude instabilities develop in 3D prior to implosion, and the subsequent seeding of those which develop during implosion. The inclusion of new physics, including material strength, to the code has improved computational treatment of the liner transition from solid to plasma through intermediate states. As a result, he has achieved better agreement with and understanding of previously unexplained experimental results, leading to a first author paper. MagLIF experiments take place primarily at Sandia National Laboratories in Albuquerque, with whom James has enjoyed fruitful collaborations, including several trips to Albuquerque. During the most recent of these he gave a seminar, and has also given talks at the APS and ICOPS international conferences in the USA. James was awarded his doctorate in September 2015; since then he has been working as a research associate at Imperial College. He recently received funding for a knowledge transfer secondment working jointly with Imperial College and an industrial partner in the defence sector, drawing on his experience and skills in modelling complex plasma experiments, and continuing his research in plasma physics.
Ben Krikler  
Group: HEP  
Supervisor: Dr Y Uchida

The focus of Ben's Ph.D has been the COMET experiment, which will begin searching for COherent Muon To Electron Transitions at the Japanese Proton Accelerator Research Complex (J-PARC) in 2018. Testing for this process pushes the boundaries of our current best theory of the sub-atomic universe. Such a decay is forbidden in the Standard Model (SM) of particle physics, and even with neutrino oscillations included the process remains immeasurably rare. Nonetheless, many extensions to the SM predict such a process to occur at testable rates. This, together with the hard-to-fake signal of a single 105 MeV electron, make this an extremely attractive search experimentally.

Ben's work has led him all across the world, participating in data-taking with particle beams in Sendai, Japan and Zurich, Switzerland; studying particle detector instrumentation effects in Novosibirsk, Russia; and to workshops in Beijing, China, in Chicago, USA and in Paris, France. The primary focus of his thesis has been producing a fully up-to-date estimation of the capabilities of the COMET experiment. However Ben has also been the lead developer for the offline software framework which is now being used throughout the collaboration. In August 2015, Ben had the opportunity to present both the COMET experiment and Alcap, a related experiment on which he has worked, at the NuFact 2015 conference in Rio De Janeiro, and is now presenting his work in a series of seminars in the UK and Germany.

Throughout his time at Imperial, Ben has responded in a remarkably creative and effective way to the many different challenges that the experiment has thrown at him, be they technical, intellectual, or more demanding of his interpersonal skills. We believe that this has given him the experience that will allow him to make unique contributions to any project that he puts his talents to in the future.
Postgraduate PhD Thesis Awarded

PhD Degrees awarded in the Department in 2015

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Astrophysics

A. Hyde (F) Far Infrared Galaxies: Star Formation and AGN
Supervisor: Dr D Clements,
C. Scott (F) Active and merging galaxies
Supervisors: Prof S Warren & Dr S Kaviraj
J. Tottle (M) Atmospheric and Disk Properties of Young Low Mass Stars and Brown Dwarfs: An Infrared Study
Supervisor: Dr S Mohanty
C. Watkinson (F) Understanding the first stars and galaxies with observations of the 21--cm line of hydrogen.
Supervisors: Prof A Jaffe & Dr J Pritchard
L. Watson (F) Signatures of Cosmic Topology in the Polarisied Cosmic Microwave Background
Supervisor: Prof A Jaffe

CQD CDT

I. Barr (M) Investigating the Dynamics of a Bose Einstein Condensate on an Atom Chip
Supervisor: Prof E Hinds
R. Freytag (M) Simultaneous magneto-- optical trapping of Ytterbium and Caesium
Supervisor: Dr M. Tarbutt
J. Goodwin (M) Sideband Cooling an Ion in a Penning Trap to the Quantum Ground State
Supervisors: Prof R Thompson & Prof D Segal
J. Iles-Smith (M) Excitation dynamics of strongly dissipative quantum systems
Supervisors: Prof T Rudolph & Dr A Nazir
A. Kaushik (F) Trapping, transport and polarisation of ultracold Lithium
Supervisors: Dr M. Tarbutt & Prof E Hinds
P. Lewis (M) The foundations of superposition and its use in quantum walks on complex networks
Supervisors: Dr D Jennings & Prof T Rudolph
G. Mikelsons (M) Microwave-Based Controlled Quantum Dynamics in Trapped Ions
Supervisor: Prof M Plenio
D. Nohlmans (M) A permanent magnet trap for buffer gas cooled atoms
Supervisors: Dr M Tarbutt & Prof E Hinds,
V. Venkataaraman (M) Understanding Open Quantum Systems with Coupled Harmonic Oscillators
Supervisor: Prof M Kim
F. Watson (F) Performance of Topological Codes for Quantum Error Correction
Supervisors: Prof T Rudolph & Dr D Browne

Experimental Solid State Physics

J. Bailey (M) Role of Thin Organic Interlayers inserted at the Electrode Interfaces for Efficient Polymer LEDs
Supervisors: Dr J-S Kim & Prof D Bradley
L. Drummond (M) Absorption spectral imaging in the mid- infrared and its application in cancer diagnosis
Supervisor: Prof C Phillips
S. Higgins (M) Organic Transistors and Complementary Circuits
Supervisor: Dr A Campbell
Y-H. Lin (M) Large-Area Flexible Electronics Based on Low-Temperature Solution - Processed Oxide Semiconductors
Supervisor: Prof T Anthopoulos
D. Moia (M) Intermolecular charge transport in dye monolayers
Supervisors: Dr P Barnes & Prof J Nelson

High Energy Physics

K. Jan de Vries (M) Global Fits of Supersymmetric Models after LHC Run 1
Supervisor: Dr O Buchmueller,
P. Hamilton (M) A Study of Neutrino Interactions in Argon Gas
Supervisors: Prof J Nash, Dr M Wascko & Dr A Kaboth

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www3.imperial.ac.uk/physics
Department of Physics Review 2014 -15
C. Lane (F) Searches for neutral Higgs bosons in the tau tau final state at CMS
Supervisor: Dr D Colling

R. Lucas (F) Searches for Supersymmetry with compressed mass spectra using monojet events with the CMS detector at the LHC
Supervisors: Prof J Nash & Dr A Tapper,

D. Mirarchi (M) Crystal collimation for LHC
Supervisor: Prof G Hall

E. Perdigao Dos Santos (M) Progress at the Intensity Frontier on Neutrino- Nucleus Interaction Cross Sections and Muon Ionization Cooling
Supervisor: Prof K Long

PE CDT

J. Bannock (M) Controlled synthesis of semiconducting polymers in droplet flow microreactors
Supervisors: Dr J de Mello, Dr P Stavrinou & Dr M Heeney

D. Beesley (M) Patterning for Organic and Nanoscale Processible Electronics
Supervisors: Prof T Anthopoulos & Dr J de Mello

M. Chaudhary (M) Charge Transport, Injection and Optical Gain in Fluorene Based Copolymers
Supervisors: Dr I McCulloch, Prof D Bradley & Dr M Heeney

R. Dattani (M) Solution Processing: Impact on Thin Film Morphology of Hybrid Organic/Metal Sulfide Solar Cells
Supervisors: Dr N Cabral & Prof J Nelson

S. Few (M) Theoretical Studies of Charge Transfer Excitations, Absorption, and Polarisation in Organic Photovoltaic Materials
Supervisor: Prof J Nelson & Dr A Horsfield,

M. Juozapavicius (M) Mechanisms and Kinetics of Electron Injection in Dye-Sensitized Solar Cells
Supervisors: Dr P Stavrinou, Dr B O’Regan & Dr M Heeney

S. Logan (M) Charge Injection and Transport in Organic Semiconductors
Supervisors: Dr I McCulloch & Dr A Campbell,

A. Maclachlan (M) Tuning Morphology of Hybrid Organic/Metal Sulfide Solar Cells
Supervisors: Dr S Haque & Prof J Nelson

R. Piper (M) Bimolecular Triplet-Triplet Annihilation Upconversion for Photovoltaics
Supervisors: Dr S Haque & Dr N Ekins-Daukes

J. Shaw (M) Nanopatterning and Nanoscale Characterisation of Solution Processible Electronics
Supervisors: Prof T Anthopoulos & Dr C Mattevi

S. Wood (M) Directly Probing Thin Film Morphology - Optoelectronic Property Relationships in Organic and Hybrid Solar Cells
Supervisors: Prof J Nelson & Dr J-S Kim

Photonics

L. Chaudet (M) Micro-optics for Opto-genetic Neuro-stimulation with Micro-LCD Arrays
Supervisor: Prof M Neil

J. De Jesus Reis Lagarto (M) Development of instrumentation for autofluorescence spectroscopy and its application to tissue autofluorescence studies and biomedical research
Supervisors: Prof P French & Dr C Dunsby

L. Fafchamps (M) Aperture Correlation Microscopy
Supervisor: Prof M Neil

H. Sinclair (M) Development of 3D- STED microscopy and its application to luminescent defects in diamond, nanoparticles and biological samples
Supervisors: Prof M Neil, Dr C Dunsby & Prof P French

Photonics MREs

R. Murray (M) Nonlinear wavelength conversion with optical fiber based technology
Supervisor: Prof J Taylor

H. Sparks (M) Development and biomedical application of fluorescence lifetime imaging endoscopes
Supervisors: Prof P French & Dr C Dunsby

Plasma Physics

M. Bennett (M) Experimental study of differentially rotating supersonic plasma flows produced by Aluminium wire array z-pinch
Supervisor: Prof S Lebedev

M. Bloom (M) Studies on the relativistic electrons and x-rays generated by laser wakefield accelerators
Supervisors: Prof Z Najmudin & Dr S Mangles

C. Davie (M) Symmetry Issues in Shock Ignited Inertial Fusion Energy
Supervisors: Prof J Chittenden & Prof R Evans

J. Pecover (M) Instability Growth for Magnetised Liner Inertial Fusion seeded by Electro-thermal, Electro-choric and Material Strength Effects
Supervisor: Prof J Chittenden

O. Pike (M) Particle Interactions in High Temperature Plasmas
Supervisor: Prof S Rose

N. Somboonkittichai (M) Computational and theoretical studies of metallic dust transport in tokamaks
Supervisor: Dr M Coppins,

L. Suttle (M) Experimental study of reverse shock structure in magnetised high energy density plasma flows driven by an inverse wire array z pinch
Supervisor: Prof S Lebedev

Plasma ISP

M. Collinson (M) On the characterisation of shock-induced sliding at multi-material interfaces
Supervisors: Dr W Proud, & Dr D Eakins

D. Jones (M) Dynamic Fracture and Fragmentation: Studies in Ti-6Al-4V
Supervisors: Dr D Eakins & Dr W Proud

Quantum Optics and Laser Science

L. Bahmanpour (F) Theory of ultrafast inter-atomic (inter-molecular) electronic decay processes in polyatomic clusters
Supervisors: Dr M Ivanov & Dr V Averbukh

J. Devlin (M) Progress towards a more sensitive measurement of the electron electric dipole moment with

C. Lane (F) Searches for neutral Higgs bosons in the tau tau final state at CMS
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M. Juozapavicius (M) Mechanisms and Kinetics of Electron Injection in Dye-Sensitized Solar Cells
Supervisors: Dr P Stavrinou, Dr B O’Regan & Dr M Heeney

S. Logan (M) Charge Injection and Transport in Organic Semiconductors
Supervisors: Dr I McCulloch & Dr A Campbell,

A. Maclachlan (M) Tuning Morphology of Hybrid Organic/Metal Sulfide Solar Cells
Supervisors: Dr S Haque & Prof J Nelson

R. Piper (M) Bimolecular Triplet-Triplet Annihilation Upconversion for Photovoltaics
Supervisors: Dr S Haque & Dr N Ekins-Daukes

J. Shaw (M) Nanopatterning and Nanoscale Characterisation of Solution Processible Electronics
Supervisors: Prof T Anthopoulos & Dr C Mattevi

S. Wood (M) Directly Probing Thin Film Morphology - Optoelectronic Property Relationships in Organic and Hybrid Solar Cells
Supervisors: Prof J Nelson & Dr J-S Kim

Photonics

L. Chaudet (M) Micro-optics for Opto-genetic Neuro-stimulation with Micro-LCD Arrays
Supervisor: Prof M Neil

J. De Jesus Reis Lagarto (M) Development of instrumentation for autofluorescence spectroscopy and its application to tissue autofluorescence studies and biomedical research
Supervisors: Prof P French & Dr C Dunsby

L. Fafchamps (M) Aperture Correlation Microscopy
Supervisor: Prof M Neil

H. Sinclair (M) Development of 3D- STED microscopy and its application to luminescent defects in diamond, nanoparticles and biological samples
Supervisors: Prof M Neil, Dr C Dunsby & Prof P French

Photonics MREs

R. Murray (M) Nonlinear wavelength conversion with optical fiber based technology
Supervisor: Prof J Taylor

H. Sparks (M) Development and biomedical application of fluorescence lifetime imaging endoscopes
Supervisors: Prof P French & Dr C Dunsby

Plasma Physics

M. Bennett (M) Experimental study of differentially rotating supersonic plasma flows produced by Aluminium wire array z-pinch
Supervisor: Prof S Lebedev

M. Bloom (M) Studies on the relativistic electrons and x-rays generated by laser wakefield accelerators
Supervisors: Prof Z Najmudin & Dr S Mangles

C. Davie (M) Symmetry Issues in Shock Ignited Inertial Fusion Energy
Supervisors: Prof J Chittenden & Prof R Evans

J. Pecover (M) Instability Growth for Magnetised Liner Inertial Fusion seeded by Electro-thermal, Electro-choric and Material Strength Effects
Supervisor: Prof J Chittenden

O. Pike (M) Particle Interactions in High Temperature Plasmas
Supervisor: Prof S Rose

N. Somboonkittichai (M) Computational and theoretical studies of metallic dust transport in tokamaks
Supervisor: Dr M Coppins,

L. Suttle (M) Experimental study of reverse shock structure in magnetised high energy density plasma flows driven by an inverse wire array z pinch
Supervisor: Prof S Lebedev

Plasma ISP

M. Collinson (M) On the characterisation of shock-induced sliding at multi-material interfaces
Supervisors: Dr W Proud, & Dr D Eakins

D. Jones (M) Dynamic Fracture and Fragmentation: Studies in Ti-6Al-4V
Supervisors: Dr D Eakins & Dr W Proud

Quantum Optics and Laser Science

L. Bahmanpour (F) Theory of ultrafast inter-atomic (inter-molecular) electronic decay processes in polyatomic clusters
Supervisors: Dr M Ivanov & Dr V Averbukh

J. Devlin (M) Progress towards a more sensitive measurement of the electron electric dipole moment with
PhD Thesis Awarded

YbF
Supervisors: Prof E Hinds & Dr J Hudson

S. Driever (M) Development of a Ytterbium fibre based chirped pulse amplification laser system for high harmonic generation
Supervisors: Prof R Smith & Dr A Zair,

D. Fabris (M) Ultrafast light sources and methods for attosecond pump-probe experiments
Supervisors: Prof J Tisch & Prof J Marango

J. Garvie-Cook (M) Measurement and Manipulation of Ultracold Bosons using Microfabricated Optics
Supervisor: Prof E Hinds

S. Hutchinson (M) Apparatus design and experimental studies of XUV initiated HHG
Supervisors: Prof J Tisch & Prof J Marango

F. McGrath (F) Extending HHG Spectroscopy to new molecular species
Supervisors: Prof J Marango & Prof J Tisch,

C. Price (M) Intense Laser Interactions with Optically Levitated Liquid Microdroplets
Supervisor: Prof R Smith

Theoretical Physics

J. Horner (M) Stuart Numerical Calculation of Inflationary Non-Gaussianities.
Supervisor: Prof C Contaldi

S. Nagy (F) A New Gauge/Gravity Dictionary via the Division Algebras
Supervisor: Prof M Duff,

A. Thomson (M) Partition functions in superstring theory and SQCD
Supervisor: Prof A Hanany

TSM CDT

J Alsaei (M) Theory and simulation of electronic and optical properties of thin film barium strontium titanate
Supervisors: Prof N Alford, Dr A Mostofi & Dr P Tangney,

R. Broadbent (M) A Model for Polymer Membranes
Supervisors: Dr A Livingston, Dr A Mostofi & Dr J Spencer

N. Corsini (M) Pressure-induced structural transformations in nanomaterials: towards high accuracy large length- and time-scale simulations
Supervisor: Prof P Haynes

A. Lim (M) Ion Channelling and Electronic Excitations In Silicon
Supervisors: Prof M Foulkes, & Dr A Horsfield

T. Poole (M) Calculating derivatives within quantum Monte Carlo
Supervisors: Prof P Haynes, Dr J Spencer & Prof M Foulkes

T. Swinburne (M) Stochastic Dynamics of Crystal Defects
Supervisor: Prof A Sutton

D. Trevelyan (M) Molecular and Multiscale Simulations of Complex Fluids
Supervisors: Dr D Dini, Prof P & Dr F Bresme,

T. Zuehlsdorff (M) Computing optical properties of large systems
Supervisors: Dr N Harrison, Prof P Haynes & Dr J Riley

www3.imperial.ac.uk/physics
MRes in Controlled Quantum Dynamics

Sebastien Boissier
Supervisor: Ed Hinds

- Nanophotonic enhancement of molecular photon sources for quantum-enabled technologies

Xiaxi Cheng
Supervisor: Ed Hinds

- Towards inertial force sensing using atom interferometry in a noisy environment

Cristina Cirstoiu
Supervisors: David Jennings/ Terry Rudolph

- The laws of thermodynamics at the quantum scale

Henry Hesten
Supervisors: Florian Mintert/ Rob Nyman

- Quantum coherence and condensation in driven quantum gases

Alexander Jones
Supervisor: Myungshik Kim

- Many-photon quantum interference

Adam Lawrence
Supervisor: Florian Mintert

- Quantum control of spins in superconducting cavities

David Newman
Supervisors: Ahsan Nazir/ Florian Mintert

- Probing open quantum systems in the strong coupling regime (Thermo version)

Andrew Simmons
Supervisors: Terry Rudolph

- Contextuality, nonlocality, preparation independence and the power of quantum computers

Sarah Thomas
Supervisor: Myungshik Kim

- Integrated Raman memories

Zizhen Xue
Supervisor: Richard Thompson

- Efficient production and verification of exotic quantum states

MSc in Optics and Photonics

Siti Nabila Aidit
Supervisor: Alasdair Campbell

- Circularly polarised light organic light emitting diodes

Pauline Boucher
Supervisor: Kenny Weir

- Propagation of a polariton condensate in a reconfigurable potential landscape

Erasogie Eweka
Supervisor: Nicholas Ekins-Daukes

- Demonstrating concentrated photovoltaic solar power

Bin Gao
Supervisor: James McGinty

- Design and evaluation of a flexible 3-D imaging system based on optical projection tomography

Nicolas Goualard
Supervisor: Kenny Weir

- Feasibility study for an endo-illuminator used in conjunction with an endoscope

Hann-Rong Hsu
Supervisor: Nicholas Ekins-Daukes

- Low emissivity coatings for c-Si photovoltaic/thermal solar cells

Tianran Jin
Supervisor: Kenny Weir

- Biomimetics design and construction of a scatterometer to investigate complex optical structures within the natural world

Wei Ying Lim
Supervisor: Martin McCall

- Structurally chiral laser modes

Qi Lu
Supervisor: Mark Neil

- Aberrations in achromatic prism systems

Haoyang Mao
Supervisor: Mark Neil

- Aperture correlation microscopy

Teerawat Piromjitrpong
Supervisor: Kenny Weir

- Electrical and electro-optical characterization of advanced materials for optical interconnects

Gratianus Putra Data
Supervisor: Kenny Weir

- Optical methods for the assessment of rice quality

Aude Rola
Supervisor: Kenny Weir

- Intense lasers for testing embedded electronics

Illya Tarasenko
Supervisor: Ortwin Hess

- Numerical modelling of hyperbolic metamaterials based on active graphene

Meihui Yang
Supervisor: Kenny Weir

- Hyperspectral imaging system based on industrial applications

Lam Chee Yong
Supervisor: John Tisch

- Optimisation of hollow-fibre pulse compression for few cycle pulses

Yue Zhu
Supervisor: Thomas Anthopoulos

- Adhesion lithography for coplanar nanogap devices

MSc in Physics

Kawthar Al Rasbi
Supervisor: Richard Thompson

- Theory and simulation of singleband cooling of ions in a Penning trap

Geoffroy-Alexandre Brinks
Supervisor: Ben Sauer

- Laser cooling and slowing of Ca f molecules

Vichitra Chandra
Supervisor: Stephen Brickley

- Is the difference in morphology of the X and Y type relay neurons in the dLGN of the thalamus responsible for the differences in their inhibitory post-synaptic currents?

Ming Chen
Supervisor: Florian Mintert

- Quantum logic gate with trapped ions beyond Lamb-Dicke limit

Hannah Collingwood
Supervisor: Patrick Brown

- Charging at Jupiter

Alexandra Crai
Supervisor: Ortwin Hess

- Hot electrons in nanophotonic systems

Robert Dickens
Supervisor: Apostolos Voulgarakis

- The effects of clouds on photolysis rates and OH concentrations in the CCMI Models

Stephen Kelly-Hannon
Supervisor: Jerry Chittenden

- Modelling diagnostic data from inertial confinement fusion experiments

Christian Kruse
Supervisor: Jon Marangos

- The free electron laser simulator: Imaging nanoparticle injectors using strong-field ionization time-of-flight mass-spectrometry

Siu Tung Lau
Supervisor: Bill Proud

- Experimental study of sound propagation in granular materials

MRes in Photonics

Jack Maxwell
Supervisor: Carl Paterson

- Wavefront sensor spatial filtering for adaptive optics in confocal microscopy

PGT Research Projects

www3.imperial.ac.uk/physics

Department of Physics Review 2014-15
Yin Long Lin  
Supervisor: Jonathan Halliwell  
Geometrical perspective on tunnelling in quantum and post-quantum theories

Alexander Lozinski  
Supervisor: Adam Masters  
Modelling magnetopause reconnection at Saturn

Jamie McMillan  
Supervisor: Richard Thompson  
Dynamics of laser cooled ions in a Penning trap

Martin Rey  
Supervisor: Jonathan Pritchard  
Probing helium reionization using fast radio bursts

Andrea Rocchetto  
Supervisor: Terry Rudolph  
Quantum algorithm for a multipartite Systems

Lara Román Castellanos  
Supervisor: Peter Török  
Changing the optical properties of molecules via nanoantennas

August Roos  
Supervisor: Stefan Maier  
Changing the optical properties of molecules via nanoantennas

David Schubert  
Supervisor: Dimitri Vvedensky  
Machine learning of transport network in the human placenta

Pak To Sin  
Supervisor: Roberto Trotta  
Constraining cosmic expansion using type 1a supernovae

Conor Whelan  
Supervisor: Roland Smith  
Characterisation of a position sensitive device for optically levitated liquid micro-droplets

Ziyun Zhang  
Supervisor: Bill Proud  
Sound speed in granular material

MSc in Physics with Nanophotonics

Linjie Dai  
Supervisor: Rupert Oulton  
Research into generating a general phase and polarisation of light by metasurfaces made of metallic nanorods

MSc in Physics with Shock Physics

Schöller  
Supervisor: Jeremy Chittenden  
Cylindrically convergent compression simulations using the fictitious flow method

MSc in Physics with Extended Research

Martinus Den Ronden  
Supervisor: Claudia Clopath (Bioengineering)  
Astrocytes modulate plasticity: A phenomenological model of the tripartite synapse

Wanchen Liang  
Supervisor: Mitesh Patel  
The angular study of $B^0 \rightarrow K_{0s}^0 \mu^+ \mu^-$ decay and search for new physics at LHCb

MRes in Plastic Electronic Materials

Ali Afshar  
Supervisor: Saif Haque (Chemistry)  
Mesoscopic and thin film solar cells based upon printable non-toxic Cu2ZnSnS4 (CZTS) absorbers

Stefan Bacheviller  
Supervisor: Natalie Stingelin (Materials)  
Solution-processed line and point defect waveguides/dielectric mirrors and coatings

MSc in Quantum Fields and Fundamental Forces

Oliver Holmes  
Supervisor: Ji Seon Kim  
Controlling microstructure of organic semiconductors via solution processing

Rebecca Kilmurray  
Supervisor: Martyn McLachlan (Chemistry)  
Developing AC-Hall as a characterisation tool for organic semiconductors

Adam Marsh  
Supervisor: Martin Heeney (Chemistry)  
Investigations of nido-carboranes in electronic polymers

Nkechinyerem Adannaya Onwubiko  
Supervisor: Iain McCulloch (Chemistry)  
High performance organic transistor materials

Sebastian Pont  
Supervisor: James Durrant (Oxford)  
Functional evaluation of new materials for solution processed organic solar cells

Adam Wright  
Supervisor: Laura Herz  
(Chemistry)  
Photon-to-charge conversion routes in novel hybrid solar cells

Hua-Kang Yuan  
Supervisor: Paul Stavrinou  
Solution-processed line and point defect waveguides/dielectric mirrors and coatings

Robert Benkel  
Supervisor: Jonathan Halliwell  
On the decoherent histories approach to quantum theory

Kevin Blanchette  
Supervisor: Roberto Trotta  
Cosmological parameter inference in a Bayesian hierarchical model with redshift dependent Hubble residuals

Santiago Cabrera  
Supervisor: Amihay Hanany  
An approach to quiver gauge theories with dual non-toric geometries

Gianluca Carnielli  
Supervisor: Fay Dowker  
Kaluza-Klein theory

Siyuan Chen  
Supervisor: Ali Mozaffari  
Gravitational waves in modified general relativity

Ka Hei Cheng  
Supervisor: Chris Hull  
Topics in string theory and double field theory

Costas Christoforou  
Supervisor: Chris Hull  
T-duality and double field theory

Christopher Cookson  
Supervisor: Astrid Eichhorn  
The asymptotic safety scenario in quantum gravity

Yi-Hsien Du  
Supervisor: Arkady Tseytlin  
Integrable systems of gauge theory and spin chains

Louis Gall  
Supervisor: Chris Hull  
Kähler geometry in supergravity

Can Gao  
Supervisor: Arkady Tseytlin  
Pohlmeier reduction for strings moving in symmetric coset and super-coset

Eduardo Garcia Valdecasas  
Supervisor: Chris Hull  
T-duality, double field theory and its geometry
David Gunneweg  
Supervisor: Steffen Gielen  
Group field theory: Second quantisation of loop quantum gravity

Christian Günther Reichelt  
Supervisor: Kelly Stelle  
F-theory and grand unified theories

Thomas Helfer  
Supervisor: Astrid Eichhorn  
Multicritical behavior in systems with competing order parameters from functional Renormalization Groups flows

Florin Iancu  
Supervisor: Fay Dowker  
The role of axions in baryogenesis

Nikolaos Iliopoulos  
Supervisor: Jonathan Halliwell  
Two measures of quantum correlations and some applications

Eric Jones  
Supervisor: Fay Dowker  
Stress-energy in the conical vacuum and its implications for topology change

Imran Khan  
Supervisor: Fay Dowker  
Causal set theory and the study of evaporating black holes

José Antonio García  
Supervisor: Kelly Stelle  
The black hole information paradox

John Ronayne  
Supervisor: Carlo Contaldi  
Cosmic inflation: The Starobinsky and supergravity models

Joseph Schwartz  
Supervisor: Amihay Hanany  
Modern methods in moduli space

Joëlle Gullon  
Supervisor: Fay Dowker  
Causal set theory and the study of evaporating black holes

MSc in Quantum Fields and Fundamental Forces
  (part time)

Claves Do Amaral  
Supervisor: Kelly Stelle  
The role of axions in baryogenesis

Stephen Palma  
Supervisor: Toby Wiseman  
AdS/CFT and QCD - a review

Eulbyung Park  
Supervisor: Joao Magueijo  
Cosmological inflation

Havelok Symes  
Supervisor: Chris Hull  
Double field theory: A review

Anton Zajac  
Supervisor: Amihay Hanany  
Moduli spaces of $N = 4 \ d = 2 + 1$ quiver gauge theories on branes and nilpotent orbits

MSc in Theory and Simulation of Materials

Christopher Abitt  
Supervisors: Nicholas Bristowe (Materials)/Arash Mostofi (Materials/Physics)
  First principles lattice dynamical study of ferroelectric and negative-thermal-expansive Ruddlesden-Popper oxides

Lars Blumenthal  
Supervisors: Johannes Lischner/Paul Tangney (Materials/Physics)  
Electronic excitations at solid-liquid interfaces: combining many-body perturbation theory with molecular dynamics simulations

Robert Charlton  
Supervisors: Peter Haynes (Materials/Physics)/Andrew Horsfield (Materials)  
Computational excitonics of doped organic molecular crystals for a room temperature maser

Luca Cimbaro  
Supervisor: Adrian Sutton/Daniel Balint (Mechanical Engineering)  
Embedding of nickel-based superalloys by oxygen

Jacek Golebiowski  
Supervisors: Peter Haynes (Materials/Physics)/Arash Mostofi (Materials/Physics)  
Self-diagnosing polymeric CNT composites – first-principles atomistic simulation of the effects of CNT functionalization

Hikmatyar Hasan  
Supervisors: Vassili Vlontsov (Materials)/Peter Haynes (Materials/Physics)  
Designing next generation high-temperature Co-Al-W based superalloys

Behnam Najafi  
Supervisors: Nick Jones (Mathematics)/Thomas Ouldridge (Mathematics)  
Simulating the self-assembly of DNA origami

Eduardo Ramos Fernandez  
Supervisors: Daniele Dini (Mechanical Engineering)/David Heyes (Mechanical Engineering)  
Atomistic modelling of Hydrodynamic lubrication and friction

Iacopo Rovelli  
Supervisor: Adrian Sutton  
High temperature loss of strength in ferritic/martensitic steels for fusion energy applications

Gleb Siroki  
Supervisors: Vincenzo Gianinni/Derek Lee  
Optical properties of topological insulator nanoparticles

Jonas Verschuere  
Supervisors: Daniele Dini (Mechanical Engineering)/Daniel Balint (Mechanical Engineering)  
Fundamentals of dislocations in motion

Alise Virbule  
Supervisors: Jenny Nelson/Johannes Lischner  
Design of high absorption organic semiconductors for applications to solar cells and light emission

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Table 1 - There were 81 known destinations of the 2014 postgraduates (Home & EU students)

<table>
<thead>
<tr>
<th>Destination</th>
<th>Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entered Employment</td>
<td>29</td>
</tr>
<tr>
<td>Further Study</td>
<td>45</td>
</tr>
<tr>
<td>Seeking Employment</td>
<td>4</td>
</tr>
<tr>
<td>Time Out / Unavailable for Work</td>
<td>3</td>
</tr>
</tbody>
</table>

Destinations of 2014 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)

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

**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 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)
Prizes and Awards

Prizes & Awards 1.1.15-31.12.15

Astrophysics
- Ms Emma Chapman, Awarded a Royal Astronomical Society Fellowship
- Dr Dave Clements, Received a UKSA Certificate of recognition for work on the Planck Project
- Dr Jonathan Pritchard, FoNS Award for Excellence in Teaching

Condensed Matter Theory
- Mr Max Boleininger, Received the Materials Design Advanced Graduate Research Prize
- Mr Benat Gurutxaga Lerma, Awarded first place in the IoP Computational Physics Group Thesis Prize
- Mr Kishan Manani, PGR Symposium - winner - Oral Session
- Mr Nicola Molinari, Received the Materials Design Graduate Research Prize
- Dr Prineha Narang, Received a Royal Society Newton Fellowship
- Prof Sir John Pendry, Received an Honorary Doctorate in Science for the Hong Kong University of Science and Technology
- Prof Sir John Pendry, Received the 2015 European Physical Society Quantum Electronics Prize
- Mr Tom Swinburne (TSM-CDT Student), Awarded a Springer Thesis Prize
- Mr Tim Zuehlsdorff (TSM-CDT Student), Awarded a Springer Thesis Prize

CQD CDT
- Mr Matteo Lostaglio, FoNS Award for the Excellence in Support of Teaching and Learning
- Mr James Tarlton, Poster Prize - Microwaves Go Quantum Conference, Bad Honnef, Germany

Experimental Solid State
- Mr Dave Bowler, Awarded the Provost’s Team Award for Excellence in Health and Safety
- Mr Jack Carter-Gartsie, PGR Symposium - winner - Poster Session
- Dr Nikolas Chastas, Received a Marie Curie Fellowship
- Dr Emiliano Cortes, Received a Marie Curie Fellowship
- Mr Jorge Costa Dantas Faria, PGR Symposium - winner - Oral Session
- Mr Alexandre de Castro Maciel – Awarded a fellowship from CNPq
- Dr Ned Ekins-Daukes, Awarded a Royal Society Industry Fellowship
- Dr Adam Gilbertson, FoNS Award for Excellence in Health and Safety
- Dr Dr Anne Guilbert – Awarded the Thomas Young Centre PDRA Prize
- Dr Megumi Ito, FoNS Award for the Excellence in Support of Teaching and Learning
- Mr Yen-Hung Lin, Received one of the 2015 MRS Fall Meeting Graduate Student Awards
- Dr Alex Mellor, Received a Marie Curie Fellowship
- Dr Themis Sidiropoulos, Received a EPSRC Doctoral Prize Fellowship
- Dr Kornelius Tetzner, Received a Marie Curie Fellowship
- Ms Jessica Wade (PhD Student), FoNS Award for the Excellence in Support of Teaching and Learning
- Ms Jessica Wade (PhD Student), PGR Symposium - winner - Oral Session

Facilities
- Mr Malcolm Hudson, The Jan de Abela-Borg Support Staff Award for Excellence in Health and Safety

High Energy Physics
- CMS Group, Awarded the President’s Award for Excellence in Research 2015
- Dr Sarah Malik, Awarded a STFC Ernest Rutherford Fellowship
- Dr Sarah Malik, Awarded a Royal Society University Research Fellowship
- Mr Joao Arnauth Pela, FoNS Award for the Excellence in Support of Teaching and Learning
- Mr Andy Rose, Awarded the Spokesman’s Award and Prize for Young Researcher 2015 by the CMS Collaboration at CERN

Ms Jessica Wade (PhD Student), Won the Institute of Physics (IoP) Early Career Physics Communicator Award.
Prizes and Awards

• Dr Yoshi Uchida, Shared the Fundamental Physics Breakthrough Prize for work on the KamLAND neutrino experiment and also the same prize for the T2K neutrino experiment.
• Prof Sir Tejinder Virdee, Awarded the President’s Award for Excellence in Research 2015
• Prof Sir Tejinder Virdee, Won the IoP Glazebrook Medal and Prize

ISP
• Mr Michael Rutherford, Awarded 2nd Prize in the Student competition at the Christmas High Power Laser Science Community Meeting 2015, RAL
• Mr John Winters, PGR Symposium - winner - Oral Session

Photonics
• Dr Irina Kabakova, Awarded a Junior Research Fellowship
• Dr Benjamin Sherlock, FoNS Award for the Excellence in Support of Teaching and Learning
• Mr Rob Woodward (Student), Awarded the Gold Award for Physics (Cavendish Medal)
• Mr Rob Woodward (Student), Overall winner award (Westminster Medal)
• Dr Rob Woodward, Received a EPSRC Doctoral Prize Fellowship
• Dr Edmund Kelleher, Won the IoP Paterson Medal and Prize

Plasma Physics
• Mr Jason Cole, Joint winner in the #SummerDataChallenge:
  • Dr Nicolas Dover, FoNS Award for the Excellence in Support of Teaching and Learning
  • Dr Ed Hill, Awarded a Junior Research Fellowship

Quantum Optics & Laser Science
• Mr James Almond, PGR Symposium - winner - Oral Session
• Dr Dane Austin, Received an Imperial College Junior Research Fellowship
• Dr Alex Clark, Received a Marie Curie Fellowship
• Mr Jon Dyne, Awarded the Provost’s Team Award for Excellence in Health and Safety
• Prof Sir Peter Knight, Honorary Doctorate Glasgow University
• Prof Sir Peter Knight, Honorary Doctorate Huddersfield University
• Mr Daniel Walke, Awarded the Postgraduate Award of the Worshipful Company of Scientific Instrument Makers
• Mr Chris Sparrow, PGR Symposium - winner - Poster Session

Space & Atmospheric Physics
• Dr Richard Bantges, Contributing author to an article that won the NASA Langley Rein Award
• Dr Helen Brindley, Contributing author to an article that won the NASA Langley Rein Award
• Dr Jonathan Eastwood, Award from the UK Space Agency’s International Partnership Space Programme - Project ‘Space Weather - the economic case’.
• Dr Marina Galand, FoNS Award for Excellence in Teaching
• Dr Hannah Nissan, Received a Fulbright Award to the US
• Prof Steve Schwartz, Awarded a Leverhulme Research Fellowship
• Prof David Southwood, Reappointed to the Advisory Council Jet Propulsion Laboratory
• Mr Arjav Trivedi, PGR Symposium - winner - Poster Session
• Dr Erik van Sebille, Won the 2016 Outstanding Young Scientist Award of the European Geosciences Union (EGU) Ocean Sciences Division.
• Dr Benoit Vanniere, FoNS Award for the Excellence in Support of Teaching and Learning
• Ms Sian Williams, PGR Symposium - winner - Oral Session

Theoretical Physics
• Dr Claudia de Rham – Wolfson Research Merit Award
• Prof Joao Magueijo, Awarded second prize in the 2015 Gravity Research Foundation essay Competition
• Dr Andrew Tolley – Wolfson Research Merit Award
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
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.
Research

Dr David Clements

Followup observations of extragalactic objects uncovered by surveys conducted with the Herschel and Planck missions continue to be highly productive. Many more very high redshift dusty star forming galaxies in addition to the current distance record holder (HFLS2 at z=6.34, Riechers et al., 2013) have been uncovered, and it is now clear that this population of objects is a significant challenge for the current generation of galaxy formation and evolution models (Dowell et al., 2014; Asboth et al., 2016). The combination of Herschel and Planck observations have also uncovered many candidate high redshift clusters of rapidly star forming galaxies (Clements et al., 2014; Planck Collaboration, 2015) and these are now being followed up at other wavelengths so they can be confirmed and the galaxies within them can be fully characterised.


Professor Alan Heavens

The most important work in this period is the development of a Bayesian Hierarchical Model for weak gravitational lensing, which gives the ICIC the leading analysis technique. It is led by Imperial student Justin Alsing (Alsing et al 2015). We have also published in PRL the first and only model-independent determination of the Baryon Acoustic Oscillation length, a crucial ruler for measuring the geometry of the Universe (Heavens et al 2014). In a recent paper (Sellentin & Heavens 2015) we showed that the normal method for statistical analysis of Gaussian data is flawed, when the covariance matrix is estimated from simulated data. We anticipate that the correct method presented in this paper will become standard in cosmology. Finally, in Planck Collaboration XVII (2015), extremely tight constraints on non-gaussianity of the primordial conditions of the Universe were published, ruling out many inflation and non-inflation models. This is the culmination of optimised 3-point analysis that began with a paper by Heavens in 1998.


Professor Andrew Jaffe

Andrew Jaffe’s research continued to focus on cosmological data analysis. As a member of the Planck Satellite Collaboration (along with PDRAs Ducout and Feeney and staff members Clements, Heavens, and Mortlock), he published a series of papers discussing Planck data and its cosmological interpretation. In particular, the Planck and BICEP2 teams collaborated to put the strongest limits on the cosmological gravity-wave background as predicted by the inflationary paradigm for the early Universe [1], in the process disproving the original BICEP2 claim of a detection. Further Planck results are forthcoming in 2015-2016. At the same time, Jaffe remains involved in smaller-scale ground- and balloon-based CMB experiments. The lack Faraday rotation observed by the Polarbear experiment limits the interaction of CMB photons with primordial magnetic fields and other sources of so-called "cosmological birefringence" [2]. The difficulty in getting these results highlight the importance of systematic effects in present-day CMB experiments. Jaffe helped develop formalism and tools for monitoring and mitigating such errors in future experiments [3].


S. Mohanty’s most important work in this period has been a study of the atmospheres of young very low mass stars and brown dwarfs, with his PhD student J. Tottle. The study focussed on confronting state-of-the-art model atmospheres for these objects with photometric observations in the infrared. The models were found to be systematically discrepant from the data, indicating that dust opacities in these atmospheres are currently significantly underestimated. The result is a substantial underestimation of the mass and age of young very low mass stars and brown dwarfs, with important implications for the shape of the initial stellar mass function, and thus for the theory of star formation.


Astronomy is an observational, not an experimental, science - there is only limited freedom to design an experiment - and so it is vital to make the best possible use of whatever data can be obtained. I have been pioneering efforts to do this in the most powerful way by applying the modern statistical technique of Bayesian inference to a variety of problems at the forefront of modern astrophysics. One example is the search for the origin of the highest energy cosmic rays - sub-atomic particles accelerated to such speeds that they can hit the Earth with the energy of a tennis ball served by Roger Federer. PhD student Alexander Khanin and I have found [1] that around half of these particles are probably produced in nearby active galactic nuclei, the most popular explanation, but that not all can come from this source. I have also been searching for brown dwarfs - faint failed stars that have just a hundredth of the Sun’s mass and glow primarily at infrared wavelengths - and, with Prof Steve Warren and PhD student Nathalie Skrzypek, have compiled [2] the largest single sample of such objects. Finally, I have been using data from the most distant known quasar [3], seen as it was when the Universe was 5% of its current age, to chart the progress of hydrogen reionization caused by the first stars and galaxies. A careful calculation of the absorption properties of hydrogen have shown that the existing standard results are inaccurate [4], leading to a re-evaluation of this important question in cosmology.


My research is focussed on developing a better understanding of the currently unobserved first billion years of the Universe and the nature of the first stars and galaxies. The most exciting avenue for this is via low-frequency radio observations of the redshifted 21cm line of neutral hydrogen. I am chair of the Epoch of Reionization science working group for the Square Kilometre Array, assisting in the telescope design and preparations for observations [1]. This has been a busy year beginning the formation of an
international collaboration to carry out this SKA science and also becoming more involved in HERA, a US/SA radio array currently under construction that will allow us to test some of the techniques needed for SKA.

As these efforts ramp up, I was fortunate to receive an ERC Starting Grant in 2015 – FIRSTDAWN - enabling me to build one of the leading UK groups in this area. Our work links theory with numerical simulations and statistical techniques to develop the tools for analysis and interpretation of early 21cm data. Key results this year include showing that 21cm observations could constrain the CMB optical depth [2]; simulations showing the effect of neutral absorbers on the 21cm signal [3]; and developing a detailed analysis pipeline for DARE [4], a proposed NASA lunar orbiter to observe the sky-averaged 21cm experiment.


My work is focussed on working out what dark matter is, and what other new particles might be associated with it. I make predictions for the outcomes of experiments like high-energy colliders (such as the LHC), gamma-ray and neutrino probes of dark matter annihilation, direct searches for dark matter in deep mines, and impacts of dark matter on stars. I improve the theoretical predictions and methods relevant for individual experiments (like the upcoming Cherenkov Telescope Array [1]), but the bigger task is statistically combining the results of all experiments, to test many different theories for new physics. My main effort in this direction has been the GAMBIT project [2], where I lead a large team developing a new suite of tools and applications for these techniques.

I also measure the chemical composition of the Sun [3] -- a crucial yardstick for all of astronomy -- and try to understand why it differs depending on whether one looks at the solar spectrum or helioseismology. One very intriguing possibility is that the discrepancy is a signature of trapped dark matter. I recently showed that the discrepancy can be explained by one specific model for dark matter [4]. This is so far the only solution to this conundrum that has been shown to work.

[2] gambit.hepforge.org
considered the problem of determining the correct inflationary model from a statistically principled point of view, by performing a never-before-attempted systematic comparison between all the available single-field, slow-roll models for the inflaton potential (198 models in total). The models considered represented an almost complete and systematic scan of the entire landscape of inflationary scenarios proposed to date. The analysis singled out the most probable models (from an Occam's razor point of view) that are compatible with Planck data. Given its exhaustiveness, this analysis has become a reference point in the literature.


Being able to model the wavelength dependence of solar and stellar variability is at the basis of understanding the effects of stellar irradiation on the atmospheres of solar-system and exoplanets alike. Solar variability has been monitored closely since the late 1970s, though its wavelength dependence is subject to controversy, with disagreements between different models as well as measurements. The disagreements are most salient for near-UV wavelengths that play an important role in modelling the response of the Earth's stratosphere.

In Yeo et al (2015), we show that the lower near-UV variability of the empirical model used by most climate models is due to the presence of noise in solar spectral irradiance variations. At these wavelengths, physics-based models such as the SATIRE model (developed in collaboration with researchers at the Max-Planck Institute for Solar Systems Research) provide more reliable estimates of solar variability.

In collaboration with Drs M Galand and J Chadney (Space & Atmospheric Physics Group), we investigated the upper atmospheres of ‘Hot Julpies’ that are subject to extreme and variable radiation. In Chadney et al (2015) we illustrate the importance of accounting for the relative strength of extreme UV (EUV) and X-ray emission for atmospheric mass-loss calculations and provide a new scaling prescription for stellar EUV fluxes based on their X-ray emission.

1) KL Yeo, WT Ball, NA Krivova, SK Solanki, YC Unruh & J Morrill 2015, UV solar irradiance in observations and the NRLSSI and SATIRE-S models, Journal of GeoPhy. Res. 120, 6055

2) JM Chadney, M Galand, YC Unruh, TT Koskinen & J Sanz-Forcada 2015, XUV-driven mass loss from extrasolar giant planets orbiting active stars, Icarus 250, 357

Over several years I have worked on implementing a new deep survey of the sky at infrared wavelengths, called the UKIRT Infrared Deep Sky Survey (UKIDSS). The survey mapped over 3000 sq degs of the northern sky, in several filters between 1 and 2 micron i.e. the near-infrared. This wavelength region is of particular interest for discovering cool (< 2000K) objects that are very faint or invisible at optical wavelengths. I have used UKIDSS for a search for brown dwarfs, which are collapsed clouds of gas where the mass is too low to ignite hydrogen in the core. The first brown dwarf was discovered in 1995, and new spectral types L, T, and Y have been devised to categorise them. Over the past year, with Nathalie Skrzypek, I have been preparing a catalogue of over 1000 L and T dwarfs, that is the largest in existence. Over the next few years this sample will be used to quantify the characteristics of the L and T populations, such as space density, and spatial distribution.

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 cause 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 AND PLASMONICS**  
Prof Sir John Pendry, Prof Ortwin Hess and Dr Vincenzo Giannini

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.

*Figures: 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

The 21st century will be characterised by the need to master chronic diseases as the population ages, and among the greatest challenges is the disrupted cardiac electro-mechanics of the diseased heart that leads to atrial fibrillation. Atrial fibrillation (AF) is the single biggest cause of stroke. Ablation, destroying regions of the atria, is applied empirically and may be curative but with a disappointing clinical success rate. In collaboration with Prof. Peters (Faculty of Medicine, Imperial) we have designed a simple model of activation wave front propagation on an anisotropic structure mimicking the branching network of heart muscle cells. This integration of phenomenological dynamics and pertinent structure shows how AF emerges spontaneously when the transverse cell-to-cell coupling decreases, as occurs with age for example due to fibrosis, beyond a threshold value. We identify critical regions responsible for the initiation and maintenance of AF, the ablation of which terminates AF. The simplicity of the model allows us to calculate analytically the risk of arrhythmia and express the threshold value of transversal cell-to-cell coupling as a function of the model parameters. This new mechanical insight will allow us to suggest novel therapies for AF once we have access to the underlying heart muscle structure.

My research in 2015 has been following 4 strands:
1. Transport in Alumina. Besides the atomistic description, e.g. [1]. I have been developing with a student Markus Tautschnig (supported by BP) and his first supervisor Nic Harrison, a three-dimensional reaction-diffusion model to describe the transport of matter and charge along grain boundaries during scale growth.
2. High temperature ceramics. With a postdoc Andrew Duff supported by the XMat project we have greatly accelerated the method for calculating high-temperature thermodynamic properties with DFT accuracy [2, 3]. We continue with a student Theresa Davey to work on the incorporation of DFT calculations in phase diagrams.
3. Hydrogen in steel. With a postdoc funded by the HEmS project and a CDT student (Chiara Liverani) we have been working on the theory of hydrogen transport in steel, and the structure of iron carbides.
4. Quantum rattles. This is a collaboration with Biomaterials, which started with ref. [4]. I am working with a student Amanda Diaz to quantify drug uptake and delivery by hollow silica nanoparticles containing gold clusters.


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Carlo (DMQMC) method, invented at Imperial College a couple of years ago, yields the quantum statistical properties up to 50 interacting electrons. We are currently using DMQMC to look at “warm dense matter” (WDM), which is warm and dense only to the astrophysicists who named it. To us it is very hot (kT is comparable to the Fermi energy) and no denser than ordinary matter. WDM can be found in laser fusion and shock wave experiments, radiation damage cascades, and planetary cores. Our DMQMC simulations of the warm dense electron gas [1] have just resolved a serious disagreement between results obtained using other methods.

Other work this year includes the introduction of a new technique for coarse graining inter-atomic force fields [2], a study of the structural and electronic properties of grain boundaries in alumina [3], and an investigation of finite-size errors in QMC simulations of metals [4].


Our research focus on light matter interaction problems, in particular, excitation of surface plasmons in metal nanoparticles and their interaction with graphene. We are exploring the possibility of using graphene as a plasmon wave-guide for sensing purposes or metal nanoparticles that allow better solar cells efficiency.

Recently, with Professor Peter Haynes and Dr Derek Lee we started the study of novel excitations in topological nanoparticles; more in detail, we analysed the excitation of localized surface polaritons in such nanoparticles, a very promising alternative to conventional, metal-based plasmonic systems for the realization of nanophotonic components at low energy. We are also looking for possible new analytical approaches to the light scattering formulation in plasmonics.

productive first year with various publications (such on thermal emitters) with Stefan Maier and and Jeremy Baumberg and colleagues from Cambridge.


Topological insulators are crystalline materials with surface states that are robust to defects and impurities. They are protected by global symmetries such as time-reversal symmetry.

In collaboration with Bogdan Galilo and Ryan Barnett (Maths) [1], we have explored a way to populate these surface states in an ultra-cold condensate of rubidium atoms trapped in an optical lattice. Although these atoms would naturally occupy a lowest state which extends throughout the system, we devised a ‘quantum quench’ protocol which switches the system into an unstable state which then collapses into these surface modes. This gives a new way to achieve spatial structures in an atomic condensate without the need for extra laser beams. More generally, it may offer a new route to controlled quantum dynamics, an important area of research for quantum information processing.

In collaboration with Gleb Siroki and Vincenzo Giannini, we are studying the optical response of a bismuth selenide nanoparticle. Being insulating in the bulk, we hope that they provide an alternative which has significantly less dissipation than commonly used metallic nanoparticles.


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 non-Equilibrium Green’s Functions represent a powerful technique for the study of transport in nano-scale systems. Having generalised this approach to include a general time-dependent potential, together with Michael Ridley & Lev Kantorovich (King’s) we are applying this to several different nano-systems. Besides standard a.c. current effects and associated transient effects, we have studied random or noisy potentials and quantum pumps. In a quantum pump a net current results from a periodic potential difference across the system, even if the average voltage is zero. The effect of a noisy potential across a small system is almost indistinguishable from a change in the coupling between the system and the leads. Work so far has been on simple model systems, but the technique has potential to be generalised to a wide range of more realistic systems, such as a quantum shuttle or transport through single molecules, as well as the study of other quantum effects such as shot noise.
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.


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.

[1] Designing Plasmonic Gratings with Transformation Optics
Kraft, Matthias; Luo, Yu; Maier, S. A.; et al.

[2] Transforming the optical landscape
Pendry, J. B.; Luo, Yu; Zhao, Rongkuo

[3] van der Waals interactions at the nanoscale: The effects of nonlocality
Luo, Yu; Zhao, Rongkuo; Pendry, John B.

Kraft, Matthias; Pendry, J. B.; Maier, S. A.; et al.

I am a theoretical and computational materials physicist working with a wide range of colleagues working at the interface between Imperial College and industrial collaborators. Our work on dislocation dynamics at high strain rates has continued apace, with the publication of our investigation into the attenuation of the dynamic yield stress under conditions of shock loading [1]. We have also published on the mechanisms of dislocations nucleation [2] and on image interactions with free surfaces at these high strain rates. We published our analytic model of the plasticity in aligned polyethylene[3]. This work provided a detailed
molecular mechanism of plasticity and viscoelasticity in aligned polyethylene based on the nucleation and motion of solitons. Working with two undergraduates I wrote a paper to address the shortest distance between two grain boundaries in the five-dimensional space that characterises them [4]. This work addressed a fundamental problem which arises when one wishes to interpolate physical properties of grain boundaries between those of two boundaries where the properties are known either experimentally or theoretically. With Dr Olivier Hardouin DuParc I wrote a biographical memoir of Jacques Friedel ForMemRS for the Royal Society. Friedel was the leading condensed matter physicist in France after the second World War.


Our recent work has focussed on understanding and modelling electric fields and screening in heterogeneous oxide materials. We are particularly interested in functional oxides, such as thin film ferroelectrics and nanocrystals for photovoltaic applications. In the last year we have developed new and more accurate atomistic models of the ferroelectric (Ba,Sr)TiO3 which can describe the redistribution of ionic charges in response to phase transformations or local changes in electrostatic potential due to defects and interfaces.

We have also used atomistic models and density functional theory to study structural and electronic properties of grain boundaries in alumina. A good understanding of grain boundaries is crucial to improving the properties of the oxide scales that form on aluminium-containing alloys and which protect them in aggressive (e.g. high T) operating environments.

We have also been developing ways to use atomistic models to construct coarser-grained models for studying thermodynamics and statistical mechanics of materials on large length and time scales. The next step will be to apply these methods to study polarization domain switching processes in ferroelectric devices.


Dr Paul Tangney

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Professor Dimitri Vvedensky

Theory and Simulation of Multi-scale Phenomena in Materials

Most properties of materials result from interactions which are competitive over a range of spatial scales, from the atomic scale, which includes bonding and energy barriers, to macroscopic scales, which is the realm of continuum mechanics. The theoretical description of such properties requires special methods to be developed that either feed into one another, such as the parameterization of a continuum theory with an atomistic calculation, or by the direct incorporation of many scales through, for example, renormalization-group methods.

We have been developing a variety of approaches to multiscale phenomena in various settings, including (i) the adaptation of the phase-field method for the epitaxial kinetics of graphene, with an application to graphene
growth on polycrystalline copper, (ii) Ginzburg–Landau theories and density-functional theories for complex structural phase transitions, such as martensitic transformations, the cooperative Jahn–Teller effect and the formation of amorphous metallic alloys, (iii) Monte Carlo methods for the evaluation of classical path integrals for flow through porous media, in analogy with the evaluation of quantum mechanical path integrals, and (iv) the applications of methods of statistical mechanics and machine learning for the analysis of the vasculature of the human placenta, with the goal of obtaining 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.

**Experimental Solid State Physics**

**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.

**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.

**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.

**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.
We are interested in understanding the physical properties of functional electronic materials and applying this fundamental understanding to develop improved materials / material-systems and devices for application in electronics, displays, lighting, energy generation / harvesting and sensor technologies [1-4]. We are 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) employed. Ultimate aim is the development of advanced materials and device concepts and their application in the emerging opto/electronics and bio-/sensors.


[3] Hybrid perovskite materials offer the prospect of using cheap precursor solutions to manufacture photovoltaics at low temperature with efficiencies (> 20%) similar to silicon solar cells. Before perovskites can be commercialised several challenges must be overcome, in particular, improving the stability of the materials. My group has discovered that aging of these materials is related to the hysteresis observed in devices where the transient current and voltage characteristics depend on their operational history.[1] We have found that a major degradation pathway is the reversible formation of hydrated phases on exposure to moisture which results in a non-reversible increase in hysteresis.[2] Our neutron scattering studies and modelling show that this hysteresis is unlikely to result from ferroelectric effects which could be coupled to the rotation of methylammonium dipoles in the crystal lattice,[3] and is instead almost certainly related to the migration of ionic defects within the material to screen internal electric fields.[4] We are now developing measurements and simulations that allow us to directly infer the evolution of electric fields within the devices enabling us to understand the influence of ionic migration on hysteresis enabling us to account for some remarkable device behaviour.


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. Frustrated lattices such as these “artificial spin ice” nanoarrays have no ordered state and the excitations act as mobile magnetic charges. Last year we explored how to inject magnetic charges into specific locations to control the magnetic state. To do this we developed new methods of exploring the dynamics of domain walls in magnetic nanostructures and to control the direction of flow with the angle of the applied field using focussed MOKE spectroscopy.[1] We explored the challenges associated with controlling the direction of propagation solely with the chirality of the domain wall.[2] We discovered that injecting domain walls directly into nanowires is possible using the tip of a magnetic force microscope. We have also explored the interplay between structure and magnetotransport properties in the BaFe\textsubscript{2}As\textsubscript{2} family of materials, using crystals grown at Oak Ridge. These compounds can exhibit either superconductivity[3] or Dirac cone transport properties[4] with correct doping. We also produced bulk and thin film samples of magnetic Skyrmion crystal materials in collaboration with Lesley Cohen (EXSS) and Peter Petrov (Materials).


Experimental Solid State Physics

In collaboration with the National Physical Laboratory we examined the performance of InSb quantum well Hall structures as multifunctional sensors of electric, magnetic and optical fields, utilising our newly developed scanning photoconductivity rig [1]. Sensitivity to electron charge of the order of 0.05e/√Hz from this simple semiconductor micro-Hall cross is comparable to single electron transistors. We also studied the dynamic carrier response in hybrid graphene – nanostructured metal structures, finding plasmon-induced optical anisotropy and electron temperatures in the graphene of the order of 500K at short timescales [2]. This has led us to think further about potential enhancement of the graphene photothermoelectric effect using plasmonic nanostructures. Separate to our work at the nanoscale, is our continued interest in materials for energy applications. We examined the influence of the local demagnetisation field on the nucleation and growth of the magnetocaloric transition [3]. The work helped identify the importance of the magnetic dipole interaction and thermal linkage across the material as components to the transition process itself. We also studied the limitations of the magnetocaloric effect in managanites, showing how the intrinsic properties that made this system so important for colossal magnetoresistance two decades ago, contribute to their relatively modest performance for solid state magnetic cooling applications [4].


The very highest solar cell power conversion efficiencies are achieved using multi-junction solar cells. Much of the QPV research group’s activity is concerned with the development of semiconductor materials that can efficiently absorb sunlight in the 1-2um wavelength range which can push multi-junction solar cell efficiency over 50%. A collaboration with the University of Tokyo resulted in the demonstration of a 1.15eV sub-cell formed of aggressively strain balanced GaAsP/InGaAs quantum wells. We established that under certain growth conditions, this strain-balanced structure spontaneously formed quantum wire in well structures with carrier lifetimes in excess of 1µs. An alternative approach to this problem using GaAsSbN has been evaluated in partnership with IQE PLC and Nanyang Technical University, SiGeSn with IQE PLC and Translucent Inc and finally GaAsBi with Sheffield University. Working in collaboration with Stefan Maier’s research group, the potential for using nanophotonic structures to improve the efficiency of solar cells was investigated as part of a European Space Agency contract. At a more fundamental level, the criteria for establishing strong sequential absorption in an intermediate band and up-converting system was established as part of the Quantum Ratchet project with Professors Chris Phillips and Ortwin Hess.

Research in Plastic electronics has a very broad scope with many promising applications, including: displays, solar cells, transistors, biosensors and photonic devices. Despite the diversity of uses, all these applications are based on thin films of functional materials and in each case their performance is critically dependent upon the precise arrangement and packing structure of the functional molecules. The principal research in my group focuses on this fundamental issue, seeking to understand and establish the correlation between nanostructures of functional materials and the performance of associated devices, hence to develop plastic electronics for next generation technology (http://www.imperial.ac.uk/nanoanalysis-group/). Our current research is progressing towards establishing a solid science platform in the field of Nanoscale Functional Materials and Devices including organic and organic/inorganic hybrids, perovskites, nanomaterials and related applications, as well as developing novel Nanometrology for controlling and analysing these functional materials and devices. Our research is based on a collaborative endeavour ranging from material synthesis, processing, characterisation and device fabrication and measurement, which include collaborations with chemistry, physics, materials, engineering-based groups at academia and in industry.


[4] “Highly efficient inverted polymer light-emitting diodes using surface modifications of ZnO layer”, B. R. Lee et al., 2014, Nature Comm, 5, ISSN: 2041-1723


Our research in the areas of nanoplasmonics and nanophotonics finds novel ways of focusing light to the nanoscale, in order to exploit ultrasmall light spots of high intensity for the enhancement of light/matter interactions. Apart from fundamental research conducted using numerical modelling, nanofabrication and experimental investigations, we work in a number of applied fields such as biosensing, photovoltaics, as well as optoelectronics. Highlights from this year include the demonstration of surface-enhanced molecular sensing using silicon nanoantennas, control of nonlinear light generation and quantum emission with plasmonic antennas, and fundamental studies of polariton condensates.


Finding new materials to harvest and store solar energy is critical to future clean energy supply. We study the physics, chemistry, materials
science and device engineering of new, solution processible materials for solar cells. These include organic semiconductors such as conjugated polymers and small molecules, hybrid inorganic:organic materials and - with Dr Piers Barnes - dye sensitised and perovskite materials. The central aim of the group’s research is to understand how chemical structure and physical organisation of materials controls material properties and device function. Our main research activities span: The device physics of organic and hybrid solar cells. We study the factors controlling current generation and charge recombination in solar cells, such as the role of trap states, doping and interface recombination. We use detailed analysis to determine the sources of loss in practical devices and find ways to reduce such losses. Property – function relationships in molecular electronic materials: We use a wide range of characterisation techniques to study how material structure controls the processes of light absorption, charge generation and charge transport. A particular goal is to probe the structure of disordered molecular materials, where neutron scattering combined with molecular dynamics has proved useful. Multi-scale simulation of the electronic and structural properties of organic electronic materials. We have developed methods to simulate the physical structure of materials, and the resulting electronic and optoelectronic properties. Our long term aim is the rational design of functional electronic materials. Together with the Grantham Institute for Climate Change, we also research the potential of new renewable technologies to contribute to carbon emissions reductions. Using this concept to create ultrafast lasers capable of turning on and off within a few hundred femtoseconds [1]. Metal-optics also allows light focussing down to the nanometre scale, far beyond the diffraction limit of conventional optics. In work this year, we have achieved nano-focussing using a silicon photonics architecture [2], which could lead to incredibly strong optical nonlinear effects for telecommunications [3]. In these work, we demonstrate efficient light focussing 100 fold stronger than the diffraction limit and show theoretically the viability of four-wave mixing. We have also developed a novel approach to localize light in both time and space using coupled metallic resonator optical waveguide[4].

We have assembled a team to put our "Quantum Ratchet" Solar cell idea to the test. It uses extra optical transitions, designed into a nanostructured PV material that enable conversion efficiencies up to ~60%, i.e. the sort of numbers that are critical if PV is to become a significant contribution to carbon mitigation. We are exploring practical implementations, with collaborators in Japan, the US, Diamond, and Sheffield with GaAs/AlGaAs and antimonide nanostructures. The race is on to be the first to convincingly demonstrate the sequential photon absorption that lies at the heart of the idea [1].

We also make quantum metamaterial "superlenses", using quantum theory to design structures where light beams propagate without spreading by diffraction. We look at them with a new s-SNOM microscope, that maps IR spectra at a resolution of 100th of a wavelength, and we also use it to measure chemical distributions within single cells for the first time [2]. Our "Digistain" 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, an asymmetric nanostructure, to generate tunable THz beams[3] in ultra-strongly coupled semiconductor microcavities [4].

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. Golotvin, 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.

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.

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 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.

Limits on masses of SuperSymmetric particles from LHC data

DARK MATTER AND GRAVitational WAVES

Direct Dark Matter Searches
H. Araujo, T. J. Sumner

We are heavily involved in direct searches for the dark matter particles, which are thought to account for most of the mass in the Universe. Currently, the LUX experiment at the Sanford Lab in the US places the most stringent limits on the interaction of these particles with ordinary matter. In parallel with this, we lead the UK programme towards the next-generation experiment, LUX-ZEPLIN, which is entering its construction phase.

Gravitational Wave Detection
T. J. Sumner

This year culminated in the successful launch of LISA Pathfinder by the European Space Agency from Kourou, French Guiana, in December 2015. It is currently in orbit around the L1 Lagrange point and carries critical flight hardware built by Imperial College. The mission will test technology needed for the space gravitational wave observatory to be launched as the L3 ESA mission. We have also successfully completed the first phase of laboratory research on a technology update specifically for L3 funded by ESA.

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.
Research

Dr Henrique Araújo

The search for the illusive dark matter continues apace, as exciting as ever, both with underground experiments and at the LHC. The LUX-ZEPLIN (LZ) experiment has started construction and this is my main research activity. LZ now counts with over 200 scientists and engineers in 32 institutes in the US, UK, Portugal, Russia and South Korea. As UK Principal Investigator I coordinate the UK contribution to LZ. We have completed most of the design and have started construction of several sub-systems already, after a long R&D campaign and extensive pre-screening and selection of materials for radioactivity. The aim is to commission this next-generation experiment one mile underground at the Sanford Lab (South Dakota, USA) in 2018/19. In the meantime we continue to operate LUX which is running in the same site. This year saw the publication of improved limits on the interaction of dark matter particles following a very successful calibration campaign using novel calibration sources. The publication on spin-independent results and a companion paper on spin-dependent interactions were both led by our team at Imperial. The year-long LUX run is still underway, due to complete in mid-2016.


Dr Oliver Buchmueller

My work in CMS focused on the final physics exploitation of the RUN1 data taking campaign and the preparation for the RUN2 of the LHC. At the end of 2015, we have released a first public result for SUSY searches using RUN2 data. Furthermore, in 2015 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. The report became public in the middle of 2015. For 2016 I have been appointed the chair of the Tracker Review board in CMS, which is another important role in the CMS upgrade programme. In addition I have continued my work on particle physics phenomenology, especially focusing on my leadership role in global fits using the MasterCode Tool [http://mastercode.web.cern.ch/master code/] and on the characterisation of Dark Matter searches at colliders and other experiments. This phenomenology activity has resulted in several publications in 2014/15. Today the MasterCode collaboration is one of the strongest scientific activities in the field of global fits to collider and cosmology data, and has produced many impact publications receiving almost 1000 citations so far. The Imperial MasterCode group is spearheading this activity.

[1] Search for new physics in final states with jets and missing transverse momentum in sqrt(s) = 13 TeV pp collisions with the aTtiriable CMS Collaboration 2015 CMS-PAS-SUS-15-005

Dr David Colling

There are two aspects to my current research activities:

1. Researching the properties of the newly discovered Higgs boson at the CMS experiment on the LHC
2. Researching and developing the very large scale computing infrastructures required for the modern world of “Big Data”. This includes the data produced by the LHC experiments.

The LHC represents one of the world's
greatest scientific endeavours. At the centre of its four experiments it creates conditions that existed fractions of a second after the Big Bang. In doing do it enables physicists to study some how the particles and forces interact at a very basic level. In doing so we are testing the Standard Model (SM) of particle physics and looking for physics beyond it (BSM).

One of the great success of the LHC was the discovery of the Higgs boson in 2012. The Imperial College team that I lead are studying this Higgs boson (produced in the CMS experiment at the LHC) through two of its decay modes. The first is through its decay to tau leptons. Through this decay mode we and our CMS collaborators were able to see the direct evidence for the Higgs coupling to fermions. This is decay mode is also very sensitive to BSM physics and we have managed to exclude much of the previously favoured parameter space for BSM models. The second is through the decay of the Higgs to invisible particles that cannot be detected in the CMS detector. Such decays would, if observed, would be a clear indication that the Higgs particle couples to particles that would be strong candidates for Dark Matter.

The LHC experiments currently produce more data than any other research activity. Yet it is possible for physicists to analyse the data taken by the experiments and to produce meaningful results only a few days after it has been collected. This is only possible because of the very large scale R&D undertaken by the LHC community on how to handle and process such very large data volumes. In the UK this activity has (largely) been through the GridPP project. Other research communities are now producing quantities of data approaching those of the LHC and so it is important to develop a more general “Big Data” architecture capable of providing for the diverse needs of these activities. In doing this it is important to learn from the lessons learned by the particle physics community and so as the GridPP Technical Director, my team and I are playing a leading role in the development of this new infrastructure in the UK.


**Professor Paul Dauncey**

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 [1] describing a new statistical method to allow for background uncertainties. The LHC run in 2015 was at a higher energy than before but did not produce a large enough Higgs sample to improve on the precision of earlier data. Much higher volumes of data are expected over the next few years.

In the longer term, a significant upgrade of the CMS experiment is planned [2]. As part of this, I am involved in studies for a much-improved forward calorimeter, which will be used for future precision Higgs measurements. This upgrade will be completed around ten years from now.


searches for exotic decays to tau leptons as well as strengthening of the so-called Higgs to invisible limits. Such decay modes constrain new physics theories, including dark matter models; the expanding team in this area now includes a JRF Fellow and a Schrodinger Scholarship PhD student. Increased effort has also gone into advancing the very exciting High Granularity Calorimeter, which CMS recently chose as preferred option for the High-Intensity LHC upgrade.

[3] Searches for a heavy scalar boson H decaying to a pair of 125 GeV Higgs bosons h or for a heavy pseudoscalar boson A decaying to 2h, in the final states with h→ττ, Submitted to Phys Lett B.

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 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.


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. A precision measurement of the strength |Vub| of the coupling between the b and the u quark has been made. It was made using the baryonic decay Λb→pμν which allowed for a further measurement of the level of right handed couplings between quarks and leptons and as such widens up an existing discrepancy between older measurements. I now work on discovering the purely leptonic decay B+→μ+μ−μ+ν which will be able to cast further light on inconsistencies in old |Vub| measurements and possibly reveal physics beyond the Standard Model. Work has continued on the analysis of B meson decays where new types of particles are created within virtual loops. A new method was developed to enable better determinations from the data with reduced biases.

Recent results from the LHC experiments, ATLAS, CMS and LHCb, have provided further strong confirmation of the Standard Model. However, a number of experimental evidence beyond the Standard Model requires further dedicated experiments. Together with my colleagues, I have recently proposed a new experiment, SHiP 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. I have been elected spokesperson of SHiP and represent the 45 collaborating institutes. The CERN SPSC committee has recently reviewed the SHiP Technical and Physics Proposal and recommended that the SHiP collaboration prepare a Comprehensive Design Study.

During the last year I was UK PI for the CMS experiment at the CERN LHC. CMS and the LHC have not been operating for the last two years while undertaking maintenance and substantial improvements and operations began again in March 2015. Much of the year was devoted to commissioning the accelerator, which is now successfully providing collisions at almost twice the previous energy. The data soon led to early publications, studying angular distributions of particles. CMS commissioned a new Level-1 calorimeter trigger during 2015 based on ideas from Imperial, and is developing novel tracker detector modules using silicon microstrip sensors and a specialised front-end electronic integrated circuit, designed by Imperial and collaborators. The modules will select data to reconstruct online charged particle tracks emerging from p-p collisions, and pass information to the L1 trigger for the first time. This will improve the trigger, allowing CMS to be more selective in data preserved for full analysis, by associating high transverse momentum tracks with calorimeter and muon system information. A full size prototype module was demonstrated in a CERN test beam in November. We also carried out experiments on silicon crystal channeling in CERN proton and heavy ion beams.

I remain on Leave of Absence, promoting technologies derived from Particle Physics into a wider technical and commercial sphere. Our HEP-derived company deltaDOT (based on algorithms derived from vertex finding in b quark decays) has shown unique capability in antibody analysis and has been adopted by the NHS, and is used also in diagnosis for cardiovascular...
disease in humans and renal failure in animals. Real-time oil and water analytics and production allocation based on the same paradigm is proceeding in two GCC countries. Work pioneered by David Colling and me in HEP in the 1990s (working with Ecole Polytechnique, in the area of explosives detection through neutron activation γ de-excitation) has been reactivated, and in the aftermath of the Paris tragedy of 13th November 2015 is attracting considerable interest in the US, France and GCC.

Nucleon spin structure and Polarized Parton Densities.
A major controversy has raged in Particle Physics recently as to whether the angular momentum (AM) of a photon, and ‘a fortiori a gluon, can be split into physically meaningful, i.e. measurable, spin and orbital parts. A major review of the particle physics point of view was published in 2014, in collaboration with C. Lorcé. The combatants in this controversy seem, largely, to be unaware of the fact that Laser Physicists have been measuring the spin and orbital angular momentum of laser beams for decades! An attempt to reconcile the two points of view has been made. Publication (1).

Work on the long-term collaborative project, with Dubna and Sofia, of extracting the polarized parton densities and fragmentation functions from experiments on deep inelastic lepton-hadron reactions has continued with interesting results, especially concerning the data from the HERMES experiment. Publication (2). Also noteworthy has been the derivation of key tests for the correctness of published information on The Sivers, Boer-Mulders and Collins functions, which had been extracted from experimental data using non-trivial simplifying assumptions. Publication (3).


The neutrino is unique among the elementary particles as it has no conserved quantum numbers except, perhaps, a global lepton number. As it travels through space, the neutrino changes type, or flavor. This implies that neutrinos have a tiny mass, that lepton flavour is not conserved and that the Standard Model is incomplete. The neutrino has also shaped the history of the cosmos; perhaps removing the anti-matter created in the Big Bang and contributing to the creation of galaxies in a homogeneous Universe.

To measure the properties of the neutrino with sufficient precision requires novel neutrino sources; in particular, neutrino beams derived from the decay of muons, which can deliver measurements with of exquisite precision. The most important technological challenge that must be addressed before such a beam can be realised is the squeezing (“cooling”) of the muon beam into a space small enough for it to be accelerated. That is why we have taken the lead in the execution of the international Muon Ionization Cooling Experiment that will prove the principle of ionization cooling. Our legacy, we hope, will be a new technique for particle physics.


High Energy Physics

Dr Jaroslaw Pasternak

Jaroslaw Pasternak’s main area of scientific interest is related to muon accelerators and their applications in particle physics research, in particular to generation of high quality neutrino beams. He was focusing mainly on MICE experiment, which started taking data in its Step IV configuration in 2015. Jaroslaw continues to lead Imperial MICE group, which is currently the largest institute within the collaboration and leads MICE with Prof. K. Long as Spokesman. In parallel to the commissioning and data taking in Step IV, a significant effort is devoted to preparations for the final stage of MICE experiment - the Cooling Demonstration with RF re-acceleration to be operational in 2017-2018. He is also working with his RA Dr J-B. Lagrange on the applications of FFAG-type accelerators for novel neutrino beam production. He published 2 papers: one on MICE and another on older work for the Neutrino Factory design within IDS-NF project and several more are in preparation.


Dr Mitesh Patel

My research is primarily focused on the LHCb experiment at CERN’s Large Hadron Collider (LHC). I am particularly interested in the use of rare decay modes as probes for physics beyond the current “Standard Model” of particle physics.

I have focussed on investigating decays where we have observed significant discrepancies with respect to the Standard Model, such as $B^0 \rightarrow K_s \mu^+ \mu^-$. My research has developed new methods for studying this decay, as well as measuring related processes such as $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $B^0 \rightarrow \phi \mu^+ \mu^-$. These measurements constrain the properties of any new particles and therefore have implications for many new physics models.

I have also recently made a measurement of $B^0 \rightarrow D^*+\tau\nu$ and $B^0 \rightarrow D^*+\mu\nu$ decays that was previously considered impossible at a hadron collider like the LHC. The results are in agreement with those of two previous experiments but differ from the Standard Model prediction that electron, muon and tau particles should behave in the same way. I am working to make analogous measurements in a number of other decay modes.

Finally, I am developing the design of the proposed SHiP experiment at CERN. This experiment would search for new light particles that could help solve a number of problems of the Standard Model.

[1] Measurement of the ratio of branching fractions $B(B^0 \rightarrow D^*+\tau\nu)/ B(B^0 \rightarrow D^*+\mu\nu)$, R. Aaij et al., [LHCb Collaboration], Phys. Rev. Lett. 115 (2015) 11, 111803 (10.1103/PhysRevLett.115.111803)

[4] Angular analysis and differential branching fraction of the decay $B_0^\pm \rightarrow \phi \mu^+\nu$, R. Aaij et al., [LHCb Collaboration], JHEP 1509 (2015) 179 (10.1007/JHEP09(2015)179)

Dr Piero Antonio Posocco

The project I am involved in is aimed at designing, manufacturing and characterising a prototype of a plasma (Gabor) lens. This device will be tested in the end with a proton beam accelerated by the high-power laser system Cerberus at Imperial College. Once established the feasibility of this technology, the lens could be used as the primary device to focus laser-accelerated beams for in-vitro radiobiological studies with protons, thus expanding existing multi-disciplinary research on
My work on particle accelerators and their applications had two main focal points in 2015. I am principle investigator of the Front End Test Stand (FETS) project built at the Rutherford Appleton Laboratory. FETS is a generic project which aims to demonstrate the production, acceleration and clean chopping of a high power H- beam, as required for various future facilities. Beside Imperial responsible for the delivery of the main accelerator structure for FETS, a radio frequency quadrupole, I have established a collaboration between FETS and CERN on the subject of laser aided beam diagnostics. The principle was demonstrated at CERN’s new LINAC 4 at various beam energies in 2015.

The second major subject I am working on is the use of a Gabor plasma lens to capture and focus particle beams accelerated by the interaction of high power laser beams with matter. A lens has been built (the first such device in the UK) and preliminary tests have been performed in Surrey using a conventionally accelerated 1 MeV proton beam. Beam tests are scheduled at Imperial with the aim to demonstrate energy selection as required for medical applications in cancer therapy. This work is performed in collaboration with the Imperial Plasma physics group, the Medical and the Bioengineering Department.

My research concerns the fundamental nature of the neutrino. Within the area of neutrino physics, neutrinoless double beta decay (NDBD) - a rare, lepton-number violating, nuclear decay process – is of particular interest. The observation of neutrino oscillations demonstrated that neutrinos have mass; a consequence of this new, beyond the Standard Model physics led to renewed activity in NDBD experiments which provide the best 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.

I am a member of an international collaboration that is constructing an experiment, SuperNEMO, to search for NDBD. This year, the first components of the detector were installed in the Le Laboratoire Souterrain de Modane (LSM) in France, and it is planned to complete the first module in 2016 and then commence data-taking. The experiment is designed to search for NDBD as evidence for Majorana neutrino masses down to a level below 0.05eV (equivalent to a half-life of about 1026 years). 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.

Following delivery last year of our flight hardware for the European Space Agency LISAPathfinder mission, preparations for launch continued with development of software for ground station and subsequent data analysis. LisaPathfinder was successfully launched on 3rd December 2015. The nine month mission is a technology precursor for the ESA L3 mission in gravitational waves. In parallel to the LisaPathfinder flight program we have been working on a related technology for L3 supported by an ESA contract. This work was successfully completed and presented to ESA this year. 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. Involvement in direct dark matter searches has continued with 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. The LUX-ZEPLIN project, which I co-founded in 2008, has gone through an extensive design/R&D phase, selection of one of two next generation direct dark matter search projects in the US and funding approval in the UK (see H. Araujo).


My research has focused recently on preparing for the restart of the Large Hadron Collider (LHC) at CERN and analysing the data from the first run at its higher collision energy of 13 TeV in 2015. Together with colleagues from Imperial College, Bristol, Brussels and Rochester in the US, we have been searching the data taken by the CMS experiment for evidence of new particles predicted by the theory of Supersymmetry. So far no evidence has been found, but we have been able to set stringent limits on the allowed theoretical parameter space.

To fully benefit from the improved performance of the LHC, the CMS experiment must be upgraded. Working with colleagues from Bristol, STFC, France and the US my group is delivering an improved triggering system for the experiment. The new system was commissioned late in 2015 and will go live for data taking in 2016, benefiting our searches for new physics.

[1] A. Zabi et al., Triggering on electrons, jets and tau leptons with the CMS upgraded calorimeter trigger for the LHC RUN II, accepted by JINST.


Neutrino physics is one of the most exciting areas of current physics research, and this was recognised in 2015 through the awarding the USD 3M Fundamental Physics Breakthrough Prize, to myself and colleagues on the T2K neutrino oscillation experiment. I was also a laureate for this award for my work on the KamLAND experiment. I have worked on the T2K experiment since 2004, and in the past few years we have discovered that muon neutrinos can turn into electron neutrinos, which in turn unlocks a new set of possible measurements to search for matter-antimatter differences in neutrinos. This shapes our ongoing T2K work, our new participation in the Super-K experiment, and work towards the next-generation Hyper-K experiment.

I am also working on the COMET experiment, where we will make about 1018 muons, to see if some convert to an electron in the vicinity of an atomic nucleus. This cannot happen under physics as we understand it now—but is quite difficult to exclude when we try to extend this understanding—hence is an extremely sensitive indicator towards the next step in modelling...
High Energy Physics

Over the last 25 years I have concentrated on the physics and experimentation at CERN’s Large Hadron Collider and participated in all the phases of the experiment; from conception and design, through construction to the extraction of science. I was the Spokesperson of the CMS Collaboration for three years, from 2007, a period that included the start of collision data taking, and was its Deputy Spokesperson from 1993 to 2006. I pioneered some of the techniques used in CMS’ calorimeters that were crucial for the discovery of a Higgs boson announced by the CMS experiment in July 2012, along with the sister experiment ATLAS. My current work involves studies of the newly found Higgs boson, search for physics beyond the standard model of particle physics and the design of the upgrades of the CMS detector for very high luminosity LHC running that is due to start in mid-2020’s. I am pioneering a novel technique to replace CMS’ endcap calorimetry that uses silicon sensors and implements very fine lateral and longitudinal segmentation.


[2] CMS Collaboration, Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the standard model predictions using proton collisions at 7 and 8 TeV, Europhysics Journal C 75 (2015) 212


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: super-continuum 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 diode-pumped 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.

Programmable light
Building on our heritage of computer-based optical design, we utilise adaptive optics and structured illumination to manipulate optical wavefronts for applications ranging from ophthalmology to metrology of astronomical optics, exploiting segmented mirror and spatial light modulator technologies. For imaging we use structured illumination to realise wide-field optical sectioning (with Mark Neil’s spin-out company, Aurox Ltd) and adaptive optics techniques to measure and correct aberrated wavefronts, including for in vivo studies of the retina for ophthalmology. Non-imaging applications of programmable light include precision opto-genetics and optical tweezers.

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 are investigating and developing novel high power all-solid-state laser technologies and optical and nonlinear optical techniques. One large current programme of activity is on the development of lasers to be put into space for atmospheric remote sensing and Earth Observation. With on-going funding support from the European Space Agency (ESA) we have made breakthrough development of broadly wavelength-tunable (near infrared) diode-pumped Alexandrite laser technology offering new science and applications over existing technology. Previously we performed the world-first high power (multi-ten Watt) development of diode-pumped Alexandrite with broad wavelength tunability [ref. 1]. Building on this work we recently demonstrated the first short pulse, high pulse rate mode of this technology for altimetry/vegetation monitoring applications [ref 2]. The tunable laser technology is also being configured for other compact, high precision applications including biophotonics and quantum technologies. We have also implemented a versatile pulsed neodymium-doped vanadate solid-state laser source at 1064nm with independent control of pulse parameters suitable for industrial manufacturing applications [ref. 3]. The method uses a low power pulse controllable diode seed laser amplified to high power by novel ultrahigh gain solid-state amplifiers. We have also continued research of mid-IR laser generation near 3micron wavelength [ref 4].


Over the last year CD published work using autofluorescence spectroscopy and lifetime measurements to study the failing heart [1] and continued to lead an EPSRC funded project developing multiphoton microscopy techniques for clinical applications in collaboration with the University of Bath. Resulting papers include work towards clinical hand-held multiphoton microscopy with axial motion compensation [2], miniaturised multiphoton microscopes using bundles of single mode polarisation maintaining fibres and the use of negative curvature fibres for delivering ultrafast pulsed radiation for multiphoton microscopy. CD also continued to work on oblique plane microscopy, a type of light sheet microscope, which was applied to the study of calcium wave origins in isolated cardiac myocytes [3]. This work was featured in a news article on the Imperial webpage and in Microscopy and Analysis magazine. CD also continued to collaborate with colleagues in Bioengineering at Imperial and at King’s College London on super-resolution ultrasound imaging using microbubble contrast agents, and published the first in vivo demonstration of this technique [4] showing that it is capable of mapping the microvasculature and blood velocity in a mouse ear. This team has recently been awarded an EPSRC grant to continue this work.

Research

Photonics

In 2015 I published 12 papers working closely with Chris Dunsby, James McGinty and Mark Neil on the development and biomedical application of fluorescence-based technology. We have developed a novel high content analysis platform exploiting fluorescence lifetime imaging (FLIM) to readout protein interactions and have developed a fully open source platform supported by an EPSRC IAA award. We have also developed preclinical 3-D imaging technology for larval and adult zebrafish disease models including 3-D tracking of cell migration and global 3-D imaging of apoptosis in live zebrafish. With the MRC Clinical Sciences Centre, we have developed new super-resolved microscopy systems, uniquely combining structured illumination microscopy with FLIM and developing low cost STORM instrumentation, and have also initiated new optical approaches to mapping epigenetics. We are developing low cost 3-D imaging instruments for the Crick Institute where we are establishing a satellite laboratory. For clinical applications we have developed an adaptive optics based approach to realise ultracompact endoscopy with no distal components and single point fibre-optic probes for studies of heart disease and osteoarthritis. I co-chaired an international workshop in Washington, DC., to identify barriers to clinical translation of label-free optical technologies, from which I am co-writing a white paper.


Over the last year, my research activity has continued to bridge the interface between fundamental computational and applied nonlinear optics, including: soliton and dissipative soliton formation and propagation; parametric processes; Raman amplification; frequency comb and supercontinuum generation. Exploiting such processes, my work targets the development of high-energy, ultrashort pulse light sources covering regions of the UV, visible, near-IR and mid-IR for applications ranging from super-resolution optical microscopy to electron spectroscopy. Specifically, this has involved the development and demonstration of a watt-level average power picosecond source at 560 nm, and the design and implementation of a broadly tunable mid-infrared femtosecond source based on difference frequency generation in poled nonlinear crystals, developed in conjunction with the University of British Columbia.

I also continue to have a strong interest in the optical characterisation and application of low-dimensional nanomaterials, in particular two-dimensional (2d) crystals, such as transition metal dichalcogenides, for the development of advanced photonic and plasmonic devices. Through collaborative programs with the University of Cambridge.
and Nanjing University, China, I have published a number of papers investigating the unique optical properties of 2D layered semiconductors, including MoS2 and MoSe2, as well as a number of invited review papers summarizing their application in short-pulse laser technology.


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 temporally suspended. Novel metamaterial designs have also considered effects of optical axis orientation in hyperbolic media. 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.


This year has seen continued research in the key themes of programmable light and optical imaging. Projects using spatial light modulators to produce controllable optical traps for single cell analysis and micro-nano fluidics applications are coming to an end. These have been great interdisciplinary research opportunities with the Chemistry department at Imperial and other researchers based at Durham, Strathclyde and Aston universities, which have culminated in a slot in the prestigious 2015 Royal Society Summer Science Exhibition. Applications of spatial light modulators to projects in imaging and microscopy have been successful too this year within the photonics group with the construction of systems for imaging the orientation of single fluorescent emitters such as molecules and diamond colour centres, dynamic correction and control of light in multi-core fibre endoscopes (with PF, CD and CP) and for generation and control of focussed light beams in super-resolution microscopy. Other super-resolution microscopy projects include the improvement of our own STED and localisation system with the MRC CSC labs at the Hammersmith hospital (with PF and CD) and some particularly promising results on a new super-resolution imaging technique using spinning-disk structured illumination. New collaborations are starting with the centre for doctoral training in Neurotechnology and the Bioengineering department at imperial in optical imaging and stimulation techniques for optogenetics.


My research is in developing novel imaging technology, the main focus being biological and biomedical imaging. We have continued in our work applying adaptive optics and wavefront sensing techniques to the problem of microscopy with aberrating and scattering samples. In related work, we have also been applying adaptive optics technology for multi-photon endoscopy (with Paul French, Chris Dunsby and Mark Neil) to achieve imaging without the need for distal scanning optics. Another research direction is the development of Brillouin spectroscopic microscopy imaging (with Peter Török) and its application to the study of biomechanical properties of tissue. We are using the technique to image in 3-D at micron resolution the stiffness properties of the human cornea and its influence on the growth and differentiation of stem cells for regenerative medicine. This work is being carried out in collaboration with Che Connon of University of Newcastle.


Research

Roy Taylor’s research has been directed towards the development of wavelength, pulsewidth and repetition rate versatile laser sources for various application. The sources are based upon the concept of the master-oscillator power fibre amplifier (MOPFA) integrated with a fibre based nonlinear convertor. These compact and efficient single pass schemes can be readily power scaled, while the seeding of highly efficient fibre amplifiers in the MOPFA allows wavelength tunability and selection along with variation of the seed pulse width from picosecond to nanosecond and at variable and selectable repetition rates, primarily determined by the direct modulation schemes deployed. Followed by parametric mixing in integrated conventional as well as photonic crystal fibres allows extended wavelength tunability in the visible and near infra-red, with 662 nm being the shortest achieved to date. Pump sources and nonlinear fibres are being developed to extend this short wavelength limit. Shorter wavelengths have been achieved at multi-watt average powers using seeded fibre Raman based schemes followed by frequency doubling in fibre integrated poled crystal assemblies. Wavelength as short as 530 nm have been achieved with pulse widths from 50 ps – 5 ns and repetition rates from 10s MHz- 100s MHz at watts level average powers. Such systems can be applied to nonlinear microscopy. The techniques have currently been applied through difference frequency generation to give similar performance with extensive tunability in the mid infra-red, which is of importance in spectral fingerprinting.


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 Fusion Studies 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. These Z pinches generate high-speed ~100 km/s 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.

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.

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.

A 3D tomogram of a ~2mm cube of human bone imaged using laser driven betatron radiation.
A new interferometer for accurately measuring the low plasma densities found in mega-ampere switches has been developed (1), and is being extended to determine the ratio of neutral/ionised species. The interferometer will be fielded in upcoming MAGPIE experiments, where Thomson scattering diagnostics will also be fielded to provide important inputs to theory and MHD simulations of radiograph sources. 

Working with colleagues at the CAEP and AWE, the first high pressure physics experiments have been performed on the MACH facility, with copper, aluminium and silicon samples being driven to multi-GPa pressures (2). To measure macroscopic properties of these materials we have developed a fibre optic probe that monitors velocity in multiple directions simultaneously. Furthermore an X-pinch system is being optimised to provide hard X-ray probing of the materials microscopic state with X-ray diffraction (3) and absorption spectrometry being used to examine high pressure phase changes. 

With Sandia National Laboratory we are exploring using 3D convergent geometries to drive liquid deuterium to multi-GBar pressures; whilst with colleagues at CEA we are planning the first ever pulsed power driven HEDP experiments on a synchrotron, with the aim of directly measuring ultra-dense, high temperature plasmas in a collapsing plasma column. 


Our work concentrates on numerical modelling of high energy density physics relating to Inertial Confinement Fusion and magnetised Z-pinch plasmas. Recently we have been using our 3D radiation hydrodynamics model ‘Chimera’ to investigate physical processes related to indirect drive inertial confinement fusion on the National Ignition Facility. We are studying how structure of the ablation region in an ICF capsule is sensitive to the details of the material opacity; how three dimensional effects change the intrinsic growth of Rayleigh-Taylor instabilities and how the confinement of a fusion hotspot is altered in asymmetric implosions. Our analysis of the fusion hotspot relies on calculating the expected response from a range of neutron diagnostics on NIF [1]. Using our 3D MHD code, Gorgon, we are investigating similar processes in inertial fusion plasmas which are magnetically driven using pulsed power generators [2]. Recently, we have established that in MagLIF experiments (where the fusion fuel is compressed inside a metallic cylinder), material strength plays an important role in determining the extent of Rayleigh-Taylor growth [3]. We continue to use the models developed in fusion research for a range of other studies, including applications in space physics, laboratory astrophysics and fundamental high energy density physics [4]. 


Our work on dusty plasmas concentrates on the basic physics of dust-plasma interactions, and dust in tokamaks. We collaborate with John Allen (Oxford), Umberto deAngelis (Naples), and Alex Robinson (RAL). Here four topics...
are highlighted. Firstly, we have extended our previous work on the source-collector system to include electron emission [1]. This indicates that a potential well can form adjacent to the emitting surface, consistent with the postulated existence of a potential well which is a feature of the charging model used for emitting dust in our Tokamak dust transport code, DTOKS. Secondly, a new model of the charging of large dust grains has been proposed, also based, in part, on the source-collector work. Thirdly, we have studied the trapping of ions around dust grains through collisions, in the presheath/sheath region. Even grains much smaller than a Debye length can be entirely shielded by the orbiting population, completely altering their behaviour (e.g., their charge). Finally, we have developed the first theoretical model of the charging of non-spherical dust grains. This indicates that the conventional charging theory gives reasonable values of the grain potential for moderate departures from spherical shape, but not for significantly distorted grains.


We have continued our theoretical and computational work on ICF and HED plasmas, concentrating on development and use of our Vlasov-Fokker-Planck codes to study kinetic effects in electron transport self-consistently with magnetic field dynamics on both picosecond [1] and nanosecond timescales. We have performed the first calculations of ns laser propagation through pre-magnetized under-dense plasma, including beam diffraction and non-local transport. This shows Nernst inhibition of thermal beam channelling and the susceptibility to the magnetothermal instability [2]. In collaboration with colleagues at the University of Michigan, we have preformed the first VFP calculation of the B-field dynamics in an entire magnetized hohlraum, seeing significant kinetic modifications to bulk motion [3]. In collaboration with
the University of York and LLNL, with have made progress at validating and improving reduced non-local models for calculating laser hot-spots in NIF hohlraums. These capabilities were used to design and support a successful experiment led by Prof. Woolsey (York) on the ORION laser this year. Lastly, we commenced (i) upgrade of the hydro-package in our VFP codes to improve future applicability to direct-drive ICF and (ii) work on the national rad-hydrocode ODIN in conjunction with 3 other Universities.


My research group conducts experimental work at Imperial College’s MAGPIE pulsed power facility, concentrating on studies of high energy density plasmas and on development and implementation of advanced plasma diagnostics such as collective Thomson scattering, Faraday rotation and interferometry. We continued our work in the area of Laboratory Astrophysics: we investigated formation and stability of differentially rotated plasmas formed by ablation flows in wire arrays; characterised the structure of the interaction region formed at collisions of supersonic magnetised plasma flows in a magnetic reconnection geometry, observing pile-up of the magnetic field at the shock front; investigated development of cooling instabilities in bow shocks formed in the interaction of plasma jets with ambient medium, under conditions scalable to the dynamics of magnetised astrophysical jets.

We continued work on the physics of wire array z-pinches, focusing on measurements of collisionless interpenetration of counter-streaming ions and advection of magnetic field by the plasma flows, and on characterisation of the current switching mechanism in two-stage wire array z-pinches. We continue collaborations on this work with colleagues at Rochester, Cornell, Rice and Sorbonne Universities.


This year has seen us further develop laser wakefield accelerators and the electron and X-ray beams they produce so that they can be used in a range of applications. In collaboration with the faculty of medicine we have published work demonstrating that our X-ray source can be used to make detailed tomographic reconstructions of human bone samples [1]. In collaboration with Queen’s University Belfast we have shown that our electron beams can be used to produce neutral-jets of electron-positron plasma suitable for laboratory astrophysics experiments [2] and we have demonstrated a gamma-ray source with unprecedented peak brightness created by scattering an intense laser from one of our electron beams [3]. This year we have also performed experiments on the CLF’s Astra Gemini laser at the Rutherford to investigate Radiation Reaction effects (in collaboration with QUB, York and Strathclyde) and to use our X-rays to image rapidly evolving laser-driven shock (in collaboration with the Institute of Shock Physics).

Our studies of the wakefield acceleration process itself have continued, resulting in the first true snapshots of the structure of a wakefield [4] as well as experiments at RAL to investigate and control the properties of the electron beam.
Research

As part of the John Adams Institute, we continue to develop next-generation laser-driven particle accelerators. Collaborating with the IOQ Jena, we directly imaged the disturbance in the plasma due to a laser wakefield accelerator [1]. This was made possible by ‘freezing’ the motion of the relativistic structure with a probe pulse of duration down to ~5 fs. With QUB Belfast, we used our GeV wakefield electron source driven by the Gemini laser (at Rutherford Lab.) to produce copious numbers of positrons from a lead target. For an optimized length, the positron beam has densities comparable to its generating electron beam, leading to the demonstration of a high-density neutral electron–positron plasma [2]. We have also pioneered the use of the betatron x-ray emission by wakefield accelerated electrons. Recently, we demonstrated full 3D tomographic reconstruction of bone samples at microscopic (<50 μm) resolution [3]. At Brookhaven Laboratory, we were able to control the generation of narrow energy spread proton beams from shock acceleration. We improved on our previous ground-breaking experiments, by using a prepulse that spatially modified the density profile of a overdense gas jet for the laser to interact with [4].


Our work is theoretical and we develop new models of HED plasmas. We are also involved in the design and analysis of experiments to test the validity of those models. Our recent work has focussed on a fresh exploration of the interaction between charged particles in a plasma. We have extended the traditional description of transport properties of plasmas to the relativistic regime and also developed models to include all collisions between charged particles (usually these are restricted to glancing collisions). We have also looked in detail at collisions through numerical simulations of many charged particles and have discovered two previously unknown heating mechanisms whereby laser energy is transferred to the plasma. One mechanism involves inducing friction between the ions of a plasma which results in very rapid heating which we believe to be probably the fastest known heating rate of macroscopic material. We are now working on how to demonstrate that fast heating rate in a laser-plasma experiment.

My research focuses on developing and exploiting ultra-short and ultra-high-intensity lasers to create and probe exotic states of matter. This ranges from laboratory scale simulations of supernovas and plasma jets launched during star formation, through laser shocked materials similar to Jupiter’s core to the sub-femtosecond dynamics of laser irradiated optically levitated microtargets and nanometer scale “atomic clusters”. To underpin these 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 where it enables advanced plasma diagnostics such as Faraday rotation imaging of magnetic fields. This combination of pulsed power and lasers allows us to explore the complex behaviour of plasmas in which magnetic fields play a dominant role. Here we are beginning a new project to investigate turbulent magnetic field acceleration of cosmic rays with colleagues at Oxford. This year we are also starting a new project co-funded by the UK and US to develop and exploit mid-infrared lasers as the strong scaling of electron energy with laser wavelength will allow us to access much higher particle energies in the laboratory to drive new x-ray light sources.


My research focuses on studying astrophysical phenomena by the means of carefully scaled laboratory experiments, an emerging field known as Laboratory Plasma Astrophysics. I conduct experiments on different High-

Energy Density (HED) facilities such as the MAGPIE pulsed-power facility based in the Blackett Laboratory, with astrophysical applications ranging from the formation of jets from young stars and supersonic, magnetised plasma flows and shocks. I also perform experiments on world-class, high-power lasers looking at the physics of radiative shocks, which are prevalent in supernova remnants and accretion disks. I was principal investigator of experiments on the world-class Orion laser at AWE Aldermaston. Access to this facility was granted through a highly-competitive academic access proposal. In addition, I was co-PI on experiments performed at the PALS laser in Prague, Czech Republic. Both laser experiments are part of on-going collaborations with international researchers including Observatoire de Paris (France) and Universidad de las Palmas de Gran Canaria (Spain).

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 aid our understanding of 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. The new 2 Mega-Ampere current generator, MACH, has recently begun operations, demonstrating methods of tailoring the pressure drive onto an 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.
My research focuses on the extreme physical behaviour of condensed matter under the rapid and intense compressions that accompany certain natural and man-made processes. One area of particular interest is in understanding the limits of material strength under high velocity impact or high-power laser irradiation, 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 and often catastrophic conclusions. Within this area, I am presently studying the effect of bulk temperature and impurities on ultrafast elastoplasticity, new analytical methods for simulating true dislocation dynamics under dynamic loading, and the temperature dependence of dynamic fracture mechanisms.

Another important research thrust is the exploration of new X-ray probing techniques for sub-surface interrogation of shocked states. This past year my group performed the first demonstrations of single-bunch X-ray imaging of extreme dynamic states at the Diamond Light Source and ESRF synchrotrons, capturing single bunch X-ray phase contrast images of 3D printed metal lattices for tailored energy absorption, spall failure in magnesium foils, and compaction of astrophysical powders to understand asteroid formation.


The area of Shock Physics studies the effect of high-transient pressures in materials. Research areas include the development of well-calibrated diagnostic and loading platforms capturing data with nanosecond (or better) resolution. My research areas include (a) granular materials (b) polymers and biological materials and (c) energetic materials. Granular Materials are widely encountered and are used as mitigants against impact, sound and blast. We investigate the dynamics of projectile impact and develop shock tubes to study blast mitigation. The mechanical properties of polymer and biological materials are examined for the effect of damage. We have examined skin, trachea, and STEM cells over a wide range of loading conditions from quasi-static to blast and shock. This research is conducted with the Royal British Legion Centre for Blast Injury Studies to understand the immediate and long-term medical consequences of blast injury. Polymer studies have focused on the effect of small defect/flaws in polymer structures change the mechanical behaviour of the system with temperature and strain rate.

For energetic materials the research is to understand how such materials behave under impact, the output and how they interact with the environment, addressing the need to make such materials safer for transport and use.

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 use laser-cooled ions held in a Penning ion trap. We can cool an ion to the ground state of its motion, using optical sideband cooling, and have demonstrated an extremely low heating rate. Such a system can be used in applications such as quantum simulation. We also investigate the fascinating physics of “ion Coulomb crystals” which are formed when clouds of ions are laser cooled. We also work with colleagues at GSI Darmstadt to test the predictions of Quantum Electrodynamics (QED) using highly-charged ions in a trap.

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.
We have been recently exploring several directions of research, some of them completely new to our group. In the attosecond physics domain, we have predicted a new Auger-type process, ultrafast collective decay of double inner-valence holes in molecules that has been successfully measured by the Swedish group of R. Feifel and co-workers [1]. We have generalised our theory of electronic decay to triplet initial states relevant for Penning ionisation and collaborated with the leading experimental group of Ed Narevicius (Weizmann Institute, Israel) on Penning ionisation in ultracold collisions [2]. Moreover, we have for the first time explored the use of the modern dataflow computer architectures in first-principles many-body quantum mechanical computations. In collaboration with Wayne Luk (Computing) and Maxeler Technologies, we have successfully implemented the second-order perturbation theory (MP2) algorithm on dataflow engines, leading to ~50x acceleration factor over a single-core CPU [3]. Finally, we have used our recently developed B-spline ADC method to predict coherence of ionic state population in the course of molecular ionisation. This latter capability is crucial for the understanding of hole migration in photoionised molecules. and more are in progress.


My research deals with theoretical aspects of quantum information. A core goal is to separate classical components from genuinely quantum-mechanical components. Entanglement and quantum coherence are central aspects to such endeavours, and featured prominently in my work over the past year. In particular, a key focus has been the analysis of quantum coherence within quantum thermodynamics. For example, what does the second law of thermodynamics mean when a system is not macroscopic, or when the system displays coherence and/or entanglement? In work published in Nature Communications [3] we argued that a full treatment of irreversibility in such regimes cannot be based exclusively on free energy, but additional intrinsically quantum mechanical measures must be included in the accounting. We built on this with a Phys. Rev. X article [2] that explains the role that asymmetry under time-translation plays in thermodynamics.

Another highlight of the year involved the algorithmic notion of “randomness processing”, and its extension into quantum regimes. In another Nature Communications publication [1], we showed that quantum mechanics is provably more powerful than classical mechanics in this regard, and moreover provides dramatic speed-ups that could be implemented experimentally in the near future.

[1] Provably Quantum Advantage in Randomness Processing
H. Dale, D. Jennings, T. Rudolph
Nature Communications 6 8203 (2015)

[2] Quantum coherence, time-translation symmetry and thermodynamics
M. Lostaglio, K. Korzekwa, D. Jennings, T. Rudolph

[3] Description of quantum coherence in thermodynamic processes requires constraints beyond free energy
M. Lostaglio, D. Jennings, T. Rudolph
Nature Communications 6, 6383 (2015)

[4] Continuum tensor network field states, path integral representations and the encoding of spatial symmetries
D. Jennings, C. Brockt, J Haegeman, T. J. Osborne, F. Verstraete

The existence of quantum superposition states has inspired many paradoxes one of which is the Schrödinger’s cat paradox. Numerous attempts, to varying degrees of success, have been made to produce superposition states. In our collaboration with experimentalists in Florence [1], we consider a paradigm shift in this effort to more closely follow Schrödinger’s paradox. Examining it more carefully, we realize that the main ingredient of the story is not the cat inside the box, but rather the superposition of the two operations, namely ‘kill it’ or ‘leave it alive’. Rather than producing a specific state superposition, which has always been the way to investigate the paradox, we propose and experimentally superpose distinct quantum operations to produce any linear superposition of an arbitrary initial state and its most distinct state, its orthogonal. As in the paradox, our macroscopic operation is conditioned on detection of a microscopic system: the single photon. Maxwell’s demon is a thought experiment questioning the meaning of the second law of thermodynamics. We propose and implement the Maxwell’s demon experiments using a simple photonic setup and show how the information on the system plays a role in thermodynamics [2].


emission and transmission of X-rays”). Important recent results include the work reported in Nature Photonics on two-colour synchronised attosecond pulse generation and in Optica on measuring the photoelectron wavepacket emitted from non-monocrystalline surfaces. In the past year my personal research focus has been particularly on the development of the techniques of time-resolved X-ray spectroscopy and applications to the measurement of electronic and nuclear dynamics of matter following sudden photoexcitation. I highlight two areas in which we have made progress in this period: (a) development of HHG sources for attosecond pump-probe experiments where we have made advances on generation of isolated attosecond pulses and the development of a new beam-line for attosecond resolved X-ray absorption pump-probe studies [1], (b) experiments with X-ray FEL sources (LCLS in California and SACLA in Japan) measuring photoexcitation dynamics with sub-10 femtosecond temporal resolution [2][3][4].


In the last year we have been working on characterisation and control of quantum coherence. For decades we were used to the fact that interference phenomena require coherence properties, but beyond that qualitative relation, there was not rigorous connection. We have identified a relation that characterises the maximal contrast in an interference experiment that can be achieved with given coherence properties [1]. The decay of such quantum coherence is induced by interactions of a system with its environment. Describing such situations typically requires several approximations. As a result, one often obtains descriptions that are not in line with the probabilistic interpretation of quantum mechanics. We developed a framework that permits to test if a given model is such that all quantities that we interpret as probabilities can indeed not become negative [2]. Rather robust coherence properties are found in topologically protected systems. We developed a control mechanism that permits the clean implementation of such topological states in atoms stored in an optical lattice [3]. One of the most prominent applications of states with pronounced quantum coherence is the precise sensing of magnetic fields. We had developed control sequences that permit to substantially enhance the sensitivity of such sensors, and this year we could see our control sequences experimentally implemented in our collaboration with experimental partners from the TU Vienna [4].


description. With a theory collaborator, I have looked into methods of measuring the interactions in photon BEC, which are expected to be very weak, but nevertheless play a role in superfluid behaviour [2]. I also maintain interests in atomic quantum gases, for example studying two-time correlations in trapped BECs [3].


At present my interests are based around the following general questions:
- How much more powerful is quantum information, and where does this advantage fundamentally arise from? (e.g. [1]).
- How should thermodynamics be changed when we have very small environments, and our systems have quantum coherence? (e.g. [2]).
- How can we build an all-in-silicon, photonic quantum computer? (e.g. [3]). Although these seem reasonably disparate, in fact the mathematical tools and insights of quantum information science are used to tackle all three.

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

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

My research activity has two main strands: continuing to improve the apparatus using to measure the permanent electric dipole moment of the electron and developing techniques for direct laser cooling of simple polar molecules. The former has involved new combined radiofrequency-optical pumping techniques and the design and construction of thin film high voltage plates for reduced Johnston noise. The first results from the laser cooling experiments are summarized in [1]. The apparatus has been significantly upgraded over the last year with all solid-state laser system and has recently shown that CaF molecules can be slowed from 180 m/s to rest with frequency chirped laser light.

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 (i) 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. In collaboration with the TUV Austria we have demonstrated the ability to control, on the attosecond timescale, the electron quantum trajectories involved in the process of high harmonic generation [1]. This control was exercised using tailored high-intensity light fields produced by multi-colour laser field synthesis. We have shown the first time the generation of synchronised pulses at 20 eV and 90 eV for attosecond pump–probe experiments.” Nature Photonics 9:383 (2015)

My research involves experimental studies of trapped ions in a Penning trap. Our main efforts in the last year have been in using optical sideband cooling techniques to prepare an individual calcium ion in the quantum mechanical ground state of its motion in the trap and then to study its coherence properties. We are the first group to perform ground state cooling in a Penning trap and our measured heating rate is lower than all other measurements in ion traps [1]. We have also measured long coherence times in this system, which points to its suitability for applications in quantum information processing. We are making studies of ion Coulomb crystals and have demonstrated that we can understand and control the conformation of ion crystals in our trap [2]. Theoretical work carried out in my group has resulted in a recent proposal for the use of ions in a Penning trap for the demonstration of simple error-correcting protocols [3]. I am also collaborating with a group at GSI (Darmstadt) for a measurement of the ground state hyperfine splitting of highly-charged beryllium ions, which can give a test of QED in very high fields [4].


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 modeling. 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 that 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 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 instrument 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.
My research focuses primarily on measuring the Earth’s Radiation Budget, quantifying its variability at a variety of different spatial and temporal scales and analysing factors that influence this behaviour. This work uses a wide range of Earth Observation data in combination with in-situ and ground based measurements and relevant modelling tools. As PI for the Geostationary Earth Radiation Budget (GERB) instrument this year I have led work exploiting the data to provide the first estimate of the climatological radiative effect of mineral dust aerosol on the Top-of-Atmosphere over the Red Sea, linking this to the corresponding impact on the surface radiation budget and atmospheric heating. GERB-4, the last in the GERB series was successfully launched in July and preparations for the scientific release of a new ERB data product from the mission at a higher spatial resolution than is currently available are well in hand. I have continued to lead Imperial’s involvement in NASA’s CLARREO and NPL’s TRUTHS missions, designed to provide observations of spectrally resolved solar reflectance and, for CLARREO, emitted outgoing longwave radiation, with higher absolute accuracy than has previously been possible from space. The goal for both these missions is to act as in-orbit calibration standards for the Global Climate Observing System and reduce the uncertainty in key climate feedback processes.

I am also joint divisional director of the Earth Observation Data and Model evaluation section within the National Centre for Earth Observation (NCEO). My responsibilities include coordinating NCEO research efforts focused on the creation and exploitation of long-term climate quality datasets from space and EO activities centred on examining and quantifying links between the energy and the water cycles.


My research continues to focus on understanding the physics of magnetic reconnection. This plasma process lies at the heart of many solar, space and astrophysical plasma phenomena such as solar flares and geomagnetic storms. I am now analysing data from the new NASA Magnetospheric MultiScale mission, a flagship heliophysics mission which launched successfully in March 2015 and is making the best-ever observations of reconnection in the Earth’s magnetosphere. This significantly enhances our on-going work using other satellites such as Cluster, THEMIS and Wind where we have recently published new research showing:

- the nature of ion acceleration in reconnection jets in the Earth’s magnetotail;
- the nature of ion thermalization in the magnetotail;
- properties of reconnection in the solar wind. This work has been extended to other planets, in particular Saturn’s magnetic environment.

Using data from Cassini we showed for the first time the existence of magnetic reconnection in Saturn’s magnetotail where it enables the release of planetary material. This research is intimately related to the applied science of space weather. I lead Imperial’s participation in the FP7 project HELCATS, which is studying coronal mass ejections using STEREO. I am working with IC Business School to understand the economic impact of space weather, funded by UK Space Agency and in collaboration with the Met Office. I have also been collaborating with Airbus Defence and Space on the development of future space weather monitoring satellites, in particular the Carrington mission concept.

**References**


As a result my work focuses on a mix of analysis of magnetic field data from Cassini, planning for the Cassini end of mission orbits which will go closer to Saturn than any other spacecraft has gone, as well as ensuring that the magnetic field instrument which is presently being designed and built for the JUICE spacecraft mission will be able to achieve the science return we promised in our proposal.

For Cassini research we continue to gain a better understanding of the plasma processes occurring with Saturn’s magnetosphere as well as how this plasma interacts with the moon orbiting around Saturn. We are also focusing on gaining a better understanding of the planetary period oscillations which change with both season and hemisphere, this work will be critical for our end of mission science (September 2017) since we need to subtract these oscillations from the data in order to focus on the signal coming direct from Saturn’s interior. This will allow us to resolve the internal dynamo field at Saturn and hopefully finally resolve how long a day is on Saturn!
study investigated changes in atmospheric radiocarbon through the year 2100 resulting from different scenarios for fossil fuel use, and the potential impacts of atmospheric radiocarbon changes on various fields that use radiocarbon such as archaeology and ecology. The paper was cited widely in the news media. Other outreach activities include participation at the Imperial Fringe, and a Briefing Paper and a blog post for the Grantham Institute.

Our work to build the magnetometer instrument for the Solar Orbiter mission, due to launch in 2018, proceeds apace. During 2015 the instrument team, led by the Instrument Manager Helen O’Brien, undertook testing of our Engineering Model. The next 12 months will be critical, culminating in the delivery of the Flight Model in November 2016.

Our scientific focus is turning towards the inner solar system, where Solar Orbiter will explore. Working with and Junior Research Fellow Chris Chen, Lorenzo Matteini and STFC PhD student David Stansby, we are exploring kinetic and turbulent processes in the solar wind plasma, as well as the implications of short-lived jets of solar plasma whose origins remain unclear.


My research concerns planetary systems, focusing on the structure and dynamics of both planetary and moon magnetospheres. Assessments of how the fundamental process of magnetic reconnection operates at the boundary of both Saturn’s and Neptune’s magnetospheres has recently been reported. In the case of Saturn this has answered the long-standing question of whether the solar wind is capable of driving the planetary magnetosphere – generally not, except under very rare and extreme solar wind conditions. Work with international collaborators is ongoing, covering a range of topics, e.g., Jupiter’s mysterious transient auroral emissions.

Preparations for the European Space Agency’s first flagship planetary mission is well underway. The Jupiter Icy Moons Explorer (JUICE) mission will answer a broad range of science questions about the Jupiter system, and investigate Jupiter’s moon Ganymede – a potential habitat. I hold a multi-disciplinary role as co-lead of one of four science working groups, coordinating input from instrument teams in order to plan future operations when the spacecraft enters Jupiter orbit, and then Ganymede orbit. I have also taken up roles concerning exploration of Europa, Jupiter’s other moon of great interest, and concerning the planning of a future mission to either Uranus or Neptune in the outermost Solar System.


Focus of my work have been studies of the atmospheres of Venus, Saturn and Titan, while my PhD student Mehdi Ben Slama has been exploring the electro-magnetic signals produced by the internal oceans of Jupiter’s moons Ganymede and Europa. During June/July 2014 the Venus Express
spacecraft made flybys through Venus’ atmosphere down to 130 km altitude, deep enough for the atmospheric drag on the spacecraft to be detectable by on-board accelerometers. This aerobraking experiment which we led produced the first ever in-situ measurements of atmospheric densities on Venus near 75°N latitude and 130-140 km altitude. We detected a plethora of atmospheric waves, including planetary waves of 5-day period, unexpected at those altitudes (Müller-Wodarg et al., 2016). Our studies of Titan’s upper atmosphere focused on its large variability, including atmospheric waves, detected by the Cassini Ion and Neutral Mass Spectrometer (INMS). Simulations with our Titan General Circulation Model (GCM) successfully reproduced the INMS observations for the first time, illustrating that Titan’s upper atmosphere is forced primarily by its stratosphere and troposphere. Our Saturn GCM has contributed to analyses of Cassini UV occultation data (Koskinen et al., 2015) as well as determination of the influx of water from Saturn’s rings (Moore et al., 2015). Furthermore, we have made important progress on resolving the “energy crisis”, unexpectedly large temperatures observed in Saturn’s thermosphere. We find the key to resolving this decade-old problem to lie in wave-induced momentum drag which enables the global redistribution of energy from ionosphere-magnetosphere coupling. Much effort went into our preparations for the forthcoming Jupiter Icy Moon Explorer (JUICE) mission, in particular in context with the Radio and Plasma Wave Instrument (RPWI) which we co-lead with the Swedish Institute for Space Physics (IRF).


instability that is applicable to the very tenuous environment of comet 67P Churyumov-Gerasimenko a small, weakly out-gassing comet currently accompanied in its orbit by the European Space Agency’s comet chaser Rosetta. That work is linked to concepts pioneered by Matteini for understanding the behaviour of alpha particles in the solar wind turbulence. Ongoing collaborations with colleague Galand and post-doc Beth explored the electrodynamics of the highly-inhomogeneous ionisation region around 67P. Work has begun on NASA’s prime new mission, MMS, which consists of four spacecraft in close formation to study small-scale electron processes in the Earth’s magnetosphere. Currently on sabbatical at the MMS operations centre at LASP in Boulder, I have established a small team concentrating on the Earth’s bow shock, building on the key results obtained previously with post-doc Mitchell and longstanding experience with multi-spacecraft analysis dating from ESA’s Cluster mission.


Professor Ralf Toumi

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 tools for insurance and other sectors. Tropical cyclone research highlights are that we have demonstrated how they are affected by ocean colour (2) and how the ocean surface wave footprint increases rapidly with temperature (4).

[1] Broadbridge, Maria B.; Toumi, Ralf The deep circulation of the Faroe Shetland Channel: Opposing flows and topographic eddies JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS, 120, 9,5983 5996 2015


[4] Phibbs, Samuel; Toumi, Ralf Modeled dependence of wind and waves on ocean temperature in tropical cyclones GEOPHYSICAL RESEARCH LETTERS , 41, 20, 7383-7390, 2014

Dr Erik van Sebille

I joined the department in March 2015, in a joint appointment with the Grantham Institute. I am an oceanographer, studying how ocean currents heat, plankton and plastic material around the globe and what that means for climate and the environment. I am interested in how different parts of the ocean are connected on timescales of years to decades, and how large-scale transport patterns emerge from the chaotic and turbulent nature of the ocean circulation. I am also interested in how ocean currents shape ecosystems, in particular where marine life is most at risk to floating plastic litter. I am a member of the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), in which I have been co-writing a report, to be published in early 2016 on ‘Sources, fate and effects of micro-plastics in the marine environment’. I have received funding from EPSRC to scope out new ways to deal with Big Data, focussing on how to analyse pathways of water parcels within the next generation of petascale ocean circulation models. In 2015, I have published 15 peer-reviewed journal papers, 4 of which as first author, in journals including
Research

Proceedings of the National Academy of Sciences, Nature Communications (2x) and Global Change Biology. I have also done more than 50 interviews with international media including CNN, NBC, BBC, Sky News, New York Times, and the Guardian on ocean circulation and climate change.


The Composition-Climate team within SPAT 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 related work in the team investigates the variability of fire-generated pollution, its linkages to climate, and its impacts on human health (Voulgarakis et al., 2015a; 2015b). Our group is also developing the first interactive fire scheme for the Met Office’s global climate model (PhD student Stephane Mangeon), while we are also collaborating with teams at NASA on a variety of fire-related topics (e.g. Mangeon et al., 2015). A further focus of the team has been on understanding the role of aerosols in modulating global and regional climate (PhD student Kasoar et al., 2015), with an emphasis on Asia (PhD student Dilshad Shawk; collaborative project with IISc Bangalore). Also, ongoing work investigates the influence of clouds on pollutants in the atmosphere (PhD student Sunil Varma). Apostolos Voulgarakis, the leader of the team, is currently analysis lead for the international Chemistry-Climate Model Initiative (CCMI), member of the Scientific Steering Committee of the Precipitation Driver and Response Model Intercomparison Project (PDRMIP), and participant in the Fire Model Intercomparison Project (FireMIP).


Theoretical Physics

The research of the Theoretical Physics Group covers a wide range of areas bound together by the theme of fundamental questions in cosmology, gravity, particle physics, and quantum theory.

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
This past year I have finalised a method for the numerical calculation of the non-gaussian signature for general inflationary scenarios [1,2]. The aim of this research is to allow for the general time variation of slow-roll parameters when calculating the bispectrum, enabling more sensitive probes of the effective potential of inflation using future data. The calculations are technically challenging as a full mode-by-mode integration must be carried out. In parallel with this I implemented an alternative data-driven constraint on the landscape of inflationary models based on the Hamilton-Jacobi generation of inflationary trajectories [3]. The Hamilton-Jacobi approach allows us to generate viable inflationary solutions that are model independent, or rather, independent of any assumed potential. By parametrising the solutions via Hubble flow parameters we were able to obtain model independent constraints on the parameters and, in turn, relate these to allowed functional forms of the inflationary potential itself.

A highlight of this past year was the first flight of the Spider CMB polarisation telescope around Antarctica in December 2014. A large part of my research effort this year has been working on the analysis and interpretation of the resulting data. Spider will attempt to detect the faint signal of primordial gravitational waves. A detection of the primordial background through their B-mode CMB signature would have a profound effect on theoretical physics, confirming a crucial prediction of the simplest models of inflation and opening a new window on fundamental physics [4].

In recent work I also showed how the signature of parity violation in the CMB can be estimated using coordinate space based methods instead of previously considered harmonic methods. The fact that coordinate space is ideally suited to this task had been overlooked because the result is less intuitive. The methods pioneered in this work have opened a new line of research into non-standard cosmological effects.


In the causal set approach to quantum gravity spacetime is conjectured to be a discrete partial order. A major question is whether such a parsimonious structure can contain within itself enough information to recover an approximate continuum manifold. I provided further evidence that the answer to this is yes by discovering, with my collaborators, a family of causal set functions that correspond to the Gibbons Hawking York gravitational boundary term [1]. We also discovered that the Benincasa-Dowker causal set action, evaluated on a causal interval in flat spacetime, has a value that is equal to the area of the 2-sphere "joint" of the interval in Planck units. In other work I argued that the discreteness of spacetime could have implications for the understanding of the nature of time in physics [2]. I suggest that the reason there is no consensus on whether science adequately accounts for our experience of time is that we do not yet have a theory in which to describe those experiences. If spacetime is fundamentally discrete, the process of the coming into being of discrete atoms of spacetime could be the passage of time, providing an objective correlate for our conscious experience.

My recent work 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). If so, one should be able to derive the complicated symmetries of gravity from the simpler ones of Yang-Mills. Following on from our success in deriving the (at least) gravitational symmetries in this way we are now addressing the (at least) ones such as general coordinate invariance and local supersymmetry. In first approximation, these work too [1] and the challenge is show this exactly. A related question is the membrane origin of the global symmetries [2], which invokes the “double geometry” and “exceptional geometry” I introduced in 1989 and 1990. Two other areas of interest were the introduction of a supersymmetric extension of quantum mechanics called “superqubits” [4] and the nature of fundamental physical constants [3].


Please note that as well as being part of the Theoretical Physics group in Physics, I am also a member of two cross-disciplinary, inter-departmental groups/centres:- 1. Centre for Complexity Science 2. Social and Cultural Analytics Lab, Data Science Institute. My work looks at complexity, and in particular network structures, from theory to social science applications. My major interest is to understand how we should change the way we study networks when there is a strong constraint on the system. My temporal networks research is part of wider trend to consider networks embedded in spaces other than ordinary Euclidean space. I demonstrated how citation networks have a well-defined Minkowski space-time dimension (Clough & Evans 2016). For instance we found the hep-th archive (largely string theory) had a lower dimension than parts of arXiv.org. This suggests string theory is a much narrower field than other areas. My approach also led to the development of a new model for citation networks (Goldberg et al 2015). I had the chance to present my approach to citation networks at the major international conference of bibliometrics (Clough & Evans 2015). My continuing collaboration with an archaeologist looking at spatial networks led to my participation in a conference and contributing to a book covering all aspects of maritime network analysis, from ancient ships to modern container vessels (Rivers et al, 2015).


The AdS/CFT correspondence, which arose out of string theory, is a powerful theoretical tool which, quite remarkably, allows one to study strongly coupled quantum field theories using gravitational descriptions in higher spacetime dimensions. In recent years there has been a concerted effort to apply these ‘holographic’ techniques to illuminate vexing condensed matter systems such as high temperature superconductors and strange metal phases using novel black hole solutions, which are interesting in their own right.

A very important observable to study is the DC thermoelectric conductivity of a material. In a series of papers, culminating in [1]-[3], we proved that this physical observable can be calculated on the gravitational side, exactly, by solving the Navier-Stokes equations on the black hole horizon. This is a new connection between black holes and fluid dynamics that allows one to study transport of strongly coupled systems in a fundamentally new way and should have many implications in the field.


I continue my long-term programme on non-trivial temporal aspects of quantum theory, the Zeno effect and the emergence of classical behaviour from quantum theory. With three MSci students, I wrote a paper explaining in physically intuitive terms why the standard arrival time operator in quantum mechanics fails to be self-adjoint. We also offered a new, self-adjoint arrival time operator with the feature that it has a more obvious connection to measurements than the standard one. I also initiated a new programme of research on the Leggett-Garg inequalities, which concern the degree to which a single system measured sequentially in time can exhibit correlations beyond those expected on classical grounds, a temporal analogue of the Bell inequalities. In simple terms, the question of, “Is the moon there when no-one looks?”. I offered a new way of understanding such systems which makes use of quasi-probabilities analogous to the Wigner function. This work has attracted some interest from experimentalists, a possibility I intend to pursue.


During 2014-2015 Amihay Hanany published 7 research papers that cover various topics in supersymmetric gauge theories and in quiver gauge theories. Few notable projects are on:
I. the difficult problem of finding the Higgs branch of a 5d theory at infinite coupling
II. Brane Tilings and their extension to larger families of N=1 supersymmetry.
III. Coulomb branch formula for 3d N=2 theories
IV. The study of nilpotent orbits as moduli spaces of vacua for quiver gauge theories

I have continued my research programme into the geometry of string theory and M-theory, and in particular into double field theory, which I introduced in joint work with Zwiebach in a highly cited paper from 2009. 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 and a T-duality symmetry. This leads to physics and novel geometry in a doubled spacetime. I recently investigated the gauge symmetry of double field theory and found a new form for finite gauge transformations that reveals the geometric structure of the doubled space and the close relationship with generalised geometry. In work with my student Nipol Chaemjumrus, these results were generalised to Extended Field Theories, in which spacetime is further extended to incorporate U-duality symmetries.


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 Wrocław 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.


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 novel approach was found, and UV dimensional reduction and the power spectrum of vacuum fluctuations were examined in all of these theories and its variations, with highlights in [1]. An appraisal of the main findings resulted in an essay submitted to the Gravity Research Foundation competition [2], which received the second prize (out of 5 and many honourable mentions), behind Nobel Laureate Gerard ‘t Hooft, who coincidentally defended a similar thesis in his essay, starting from a totally different angle. I also finished and submitted for publication [3] the first instalment of the work on statistical evidence for cosmological theories, hoping to provide a more equitable judgment of the successes of inflation and the value of alternatives.

A key aim of my research is understanding the dynamics of the Higgs boson and other quantum fields in the very early universe. The properties of the Higgs boson make it particularly interesting for cosmology, with potentially observable consequences that may be used to probe fundamental physics at energy scales far beyond the reach of the LHC. By considering the dynamics of the Higgs field during and after inflation, I have been able to constrain the value of the last unknown parameter in the Standard Model, the coupling between the Higgs field and spacetime curvature. In today's Universe, curvature is so low that this parameter is almost impossible to measure, but it was very important in the highly curved early Universe.

I have also worked on magnetic monopoles, developing methods for calculating their properties from quantum field theory. This is important for the new MoEDAL experiment which is searching for them at the LHC.

A focus of my research during the 2014-15 period has been in two principal areas:

1. The localisation of gravity on a braneworld subsurface of spacetime with an infinite transverse space [1]. This work circumvented a purported 'no-go' theorem claiming to rule out an effective theory of massless gravity in such a system. This was achieved thanks to an asymptotic hyperbolic structure of spacetime which generates a mass gap between the massless lower dimensional graviton and the continuum of Kaluza-Klein massive gravity states. It also exploited a subtle asymptotic conformal invariance and corresponding self-adjointness features of the associated Schrödinger problem.

2. Spherically symmetric solutions in higher-derivative gravity. Essentially every approach to the quantisation of gravity involves quadratic curvature terms in the gravitational effective action. Finding spherically symmetric solutions to the resulting fourth-order field equations has been a challenge for many years, but was achieved in papers [2,3]. In addition to the classic Schwarzschild solution, a new branch of black-hole solutions was found, together with horizonless solutions that couple to shell distributional sources, and also 'wormholes' in topologically nontrivial spacetimes.

In addition, a review was written [4] of earlier work on the symmetry orbits of black-hole solutions to supergravity theories.


vectorial examples of AdS/CFT duality. We have shown that the one-loop partition function of such theories in flat and AdS space is trivial, suggesting their hidden simplicity. We also suggested general expressions for all Weyl anomaly coefficients in supersymmetric 6-dimensional superconformal theories.


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 the symmetry structure underlying M-theory. The central development was the discovery of a new extension of conventional Riemannian geometry, called “generalised” geometry, which unifies the massless string degrees of freedom and symmetries. This has important implications for a wide range of problems in string theory. In [1] I 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. In [2] we showed how the string corrections to heterotic supergravity could also be described using generalised geometry. In a preprint with Charles Strickland-Constable and André Coimbra, I introduced a new notion of “generalised special holonomy”, showing that it captured the geometry of generic minimally supersymmetric backgrounds. Finally in a preprint with Strickland-Constable and Kanghoon Lee we showed that a new class SO(8) gauged supergravity theories could not be realised in any conventional way as a truncation of string theory, although they could be realised as “non-geometrical” backgrounds, the physical meaning of which remains unclear.


During the period 2014-2015 my research has been focussed on understanding how black holes are encoded in the gauge theory at finite temperature. In fact we found rather surprisingly that a particular set of degrees of freedom in the gauge theory appear to naturally encode much of the behaviour of black holes. In the other direction I have started a new program of using geometric techniques to study the gravitational side of the correspondence and make inferences about strongly coupled gauge theory. In [3] I studied how the gravitational theory geometry is related to the low energy dynamics in the gauge theory. In [4] I introduced geometric tools to make very general statements about basic physical quantities in the gauge theory. This is an ongoing program with great potential for interesting physical results.

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/licensing 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 been 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 systems 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 Engi-
Technical Development, Intellectual Property and Commercial Interactions, the Blackett Laboratory Industry Club

neering (University of Osaka), the US Naval Research Laboratory and the Lawrence Livermore National Laboratory. We also host the Centre for Inertial Fusion Studies (CIIFS) 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 science 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 produced 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 funding, personnel exchange and equipment loan.

Quantum Optics and Laser Science
The Group applies cutting edge laser technology, quantum-enhanced technology and detailed numerical modeling 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 company investigating transparent conductive films for polymers. 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 Quantum 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 interdisciplinary and we work closely with industry. Direct support for research into high throughput and multidimensional fluorescence imaging, particularly fluorescence 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, manufacturing optical microscopy equipment. Our fibre laser programme addresses wavelength and pulse length versatile, all-fibre configurations primarily deploying MOPFA (Master Oscillator Power Fibre Amplifier) technology 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, established 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 generation satellite-based remote sensing for atmospheric and earth science addressing climate change, weather prediction 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 flow 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 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.

Physics and Corporate Partnerships 2015

The FoNS Corporate Partnerships team, Dr Becky Wilson and Dr Kay Penicud, have been working with the Department of Physics throughout 2015 to build partnerships with industry.

Corporate Partnerships organised the Imperial Space Lab Annual Conference in September 2015, which attracted over 200 people ranging from academia, industry and government. Physics was well represented, with Dr Gabrielle Thomas and Dr Peter Wass delivering presentations, and a number of PhD students exhibiting posters. The keynote presentation was given by Jonathan Firth, the Executive Vice President of Spaceport and Program Development at Virgin Galactic. The event has led to several follow up meetings with industry, and discussions on new collaborative projects are ongoing.

The Corporate Partnerships team worked with Professor Lesley Cohen to invite industry contacts to the PhD Symposium and arrange an Industry Lunch, enabling members of the Department to network with a number of industry contacts of Imperial. Further support has included working with Professor Kim on the EPSRC Quantum Training Hub bid, including securing Letters of Support.

The Corporate Partnerships team frequently promotes the research capabilities of the Department to a wide range of companies. In 2015, potential research collaborations involving members of the Department were discussed with partners including AWE, Qinetiq, Samsung, Dstl, BASF, Airbus Defence and Space, the Satellite Applications Catapult, the Centre for Process Innovation, Inmarsat, e2v, EDF, Solar Century, Evonik, Northrop Grumman, Lockheed Martin, National Physical Laboratory, Johnson Matthey, Shell, BP – and many more. These discussions have led to a number of new industry collaborations.

New initiatives planned for 2016 include the launch of a new training programme in working with external partners including those from industry, and a refresh of the defence and space mailing list managed by Corporate Partnerships, which aims to broaden the connections between a number of defence and space sector partners and academics across Imperial.
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 2015, 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.

2015 Industry Club members include: AWE, BP, Bloomberg, Electronic Arts National Physical Laboratory, Oxford Instruments, Qioptiq, RBS, Renishaw, TTP, Toshiba, Winton Capital.

Bespoke recruitment events were held in 2015 for Renishaw and Electronic Arts.
The Department has a dedicated Outreach Unit, managed by Senior Teaching Fellow Dr Mark Richards (Head of Physics Outreach), and employing two other full-time members of staff: Vinita Hassard (Outreach Coordinator and Ogden Science Officer), and Dr Simon Foster (Outreach Officer). 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.

In 2015 the department has undertaken numerous activities such as talks, workshops and interactive demonstrations with schools, local societies, teacher groups, charities, 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, the Cheltenham science festival, the Big Bang fair, Science Uncovered, and the Royal Society Summer Exhibition).

Engaging Young People

Insights Work Experience Programme:
In 2015, the department ran its flagship Insights work experience scheme for the fourth year. The scheme is designed for year 12 students in schools with little or no previous history of applying to Imperial; with the aim of widening access to such schools. Students on
Outreach

the scheme obtain a glimpse into research as well as experiencing the life of an undergraduate. We received over 350 applications for the 2015 insights scheme, and recruited a cohort of 20 students. The success of the scheme has now been replicated across several other departments including Electrical Engineering, Chemistry, and the National Heart and Lung Institute. All applications are now handled by College centrally, and it is expected that many other departments across Imperial will follow suite over the coming years.

Open Days:
The Department Open Days continue to be a great success, showcasing recent research, providing an insight into physics courses and examples of the many careers that can result from a physics degree. We welcomed approximately 1500 students in 2015.

Outreach activities 2015

International Year of Light – GoPhoton!

The year 2015 was designated by UN resolution the International Year of Light as a global celebration of the impact of light and photonics in our lives. The year fell at the conjunction of several anniversaries (e.g. 1015 Al-Hazen’s first book on optics, 1865 Maxwell’s equations, 1965 Kao’s work on optical fibres, etc.). The EU-funded GoPhoton! programme was conceived to deliver throughout 2015 a series of high-profile physics outreach events, aimed at audiences ranging from school children to entrepreneurs. The events included several presentations to the general public at the Science and Natural History Museums, a ‘Light-Late’ Fringe evening at Imperial, a Photonics Congress for 6th Formers, ‘The Future’s Bright’ meeting (for entrepreneurs and industry), two Open Days, and the creation of the ‘Light-Zone’ for the Imperial Festival over the weekend 9th-11th May. Of the 15,000 public visitors, around 2,500 attended the Light Zone. As well as numerous interactive optics-based displays (light painting, polarization, optical lie detector, laser projection microscope, solar cells, laser balloon popping, etc.) the Light Zone area hosted a 45-minute splash show including a science rapper, a laser harpist and a professionally choreographed display – the Maxwell Hip Hop – designed to illustrate key features of electromagnetic wave propagation through the medium of contemporary dance.

List of GoPhoton! Activities

19th February 2015 – Lit Up Fringe Festival, Imperial College - World of Polarization
20th March 2015 – Fresnel Lecture, GoPhoton! Art of Polarization, Royal Institute
22nd April 2015 – Photonics Open Evening, Blackett Lab
9th-11th May 2015 – The Photonics Splash, Imperial Festival, Imperial College
8th May 2015 – The Future’s Bright, Light Talks, Blackett Lab
27th May 2015 – Light In/Visibility, Art of Polarization at Light Lates, Science Museum
25th June 2015 – Physics Department Open Day (talks focusing on Photonics) Blackett Lab
25th September 2015 – Science Uncovered, Natural History Museum
21st November 2015 – Light and Dark matters, Light In/Visibility Art
Outreach highlights
Prof Terri Rudolph’s Inaugural lecture: Prof. Rudolph gave his inaugural lecture on 28th October 2014, but in the past year it has gone ‘viral’ and now has over 725,000 views on Youtube (https://www.youtube.com/watch?v=JKGZDhQoR9E) It's Imperial top ranking video and one of the most popular videos discussing Quantum theory on Youtube.

The CQD ‘Quantum Show’: Each year the new cohort of PhD students in the Controlled Quantum Dynamics (CQD) doctoral training centre put on a public show to explain the principles of Quantum mechanics. The aim is to get the students prepared for discussing the research with the public in the future, which is an important part of being a scientists. As part of this the students all receive training through their first term in the DTC and its hoped that after the show they will put their new found skills to use by undertaking additional talks whilst at Imperial.

This year’s show was in front of an audience of 200 people, from A level students to senior citizens!

Royal Institution lates: Dr Simon Foster took part in the ‘Gunpowder, Treason and Plot’ Ri lates event on Friday 6th November. Simon gave the main lecture on the history of Gunpowder in the iconic theatre to over 400 people. http://rigb.org/whats-on/events-2015/november/lates-gunpowder-treason-and-plot

Greenlight for girls: Greenlight for girls is an international organisation aimed at inspiring girls of all ages and backgrounds to undertake a career in the STEM subjects. Events have previously been held in the USA and Europe (which Imperial students and researchers have taken part in) and in September 2015 G4G held their UK launch at Imperial College. The event was organised by Jess Wade from the Centre for Plastic Electronics and more than 200 students aged 12-16 took part in the day. Not only were talks and workshops given by Imperial researchers and academics, but Jess also managed to get a whole host of external groups to come along and run activities, such as CISCO, The Royal Astronomical Society, INTEL, RSC, IET and Bletchley park even brought along one of their Enigma machines to let the students have a play with! The feedback was amazing and everyone took part was inspired by Jess and the day’s activities (NB Jess has the data and numbers). http://greenlightforgirls.org/g4g-dayimperial-college-london-2015

Women in Physics day: On April 22 2015 we hosted our annual event aimed at girls in years 10-11-12 under the ‘Go Photon’ heading. We had one hundred and fifty participants this year who were welcomed to the department by Dr Mark Richards and heard talks given by Prof Jenny Nelson on Organic Solar Cell research, Dr Marina Garland on the development of the Rossetta Mission, and Jess Wade on the PhD student journey. Juliet Pickering gave guidance on the admissions process to the department.


Tim Peake/Principia launch event: SPAT and Astrophysics both took part in the Principia launch event at the science museum to celebrate the launch of Time Peake to the International Space Station. The SPAT group took along a replica of the solar orbiter satellite that will be launched in 2018 to study the Sun and heliosphere and the Astrophysics took along the new Imperial Planetarium and wowed audiences with their research. In addition Dr Simon Foster undertook various media activities during the day to discuss the launch speaking on ITV news, CNN and Forces TV.
Science uncovered at the NHM:
This is the ‘European researchers night’ held annually at the NHM. Lot’s of groups took part, but with this year being the ‘international Year of Light’ the photonics group had a large display, with a variety of things on display. http://www3.imperial.ac.uk/newsandeventsggrp/imperialcollege/eventssummary/event_3-8-2015-10-19-34

Imperial Festival 2015: A variety of different groups took part in this year’s festival, with several having displays in the marquee. Also, as part of the ‘International Year of Light’ the photonics group took over the great hall and held a programme of inspiring activities. Vinita and Martin McCall will be able to advise more on this.

Pint of Science: The Theory and Simulation of Materials (TSM) group hosted the physics section of the Pint of Science event called ‘Atoms to Galaxies’. Pint of science is a science festival which takes place in pubs across the country, where scientists speak to members of the public in a less formal environment (a pub) to break down the barriers between scientists and the public. This year’s speakers included Toby Wiseman, Steven Schwartz, Arthur Turrell and Emily Drabek-Maunder from the Department of Physics. Pint of science has been identified by the Prime Minister as one of the ‘Points of Light’ https://www.pointsoflight.gov.uk/pint-of-science/

Duck Quacks Don’t Echo: Dr Simon Foster and Imperial alumni Maggie Aderin-Pocock are scientists on Sky One’s Science entertainment show Duck Quacks Don’t Echo, aired in September and October 2015. Weekly viewing figures were around 500,000 per show

Interrobang: Interrobang is a night of art, comedy and science, designed to provoke discussion and ideas. The October event took place around the topic of the climate coinciding with the UN conference on climate change being held in Paris. Dr Simon Foster spoke about the Sun’s influence on the climate, alongside international fashion designer Vivienne Westwood and writer, actress and comedian Sara Pascoe. http://omnibus-clapham.org/event/perception-festival-voice-interrobang-artcop21/

Girls science club: Beth Rice (postgraduate in Physics) runs a girls science club at the Baytree Centre in Brixton. The centre is an education and social inclusion charity for women and girls in the local area. The club is for primary aged children (6-11 years old) and each week the pupils undertake a different hands on experiment to teach them something about science or just how to think like a scientist.

List of Main Physics Outreach Activities

22nd April 2015 – Women in Physics, Blackett Lab (talks, demos, and departmental tours)
17th June 2015 – GCSE Open Day, Blackett Lab (talks, demos, and departmental tours)
18th June 2015 – UG Project Open Day, Blackett Lab (talks, demos, and tours)
24-25th June 2015 – Science & Engineering Open Days, Imperial College (talks, demos and tours)
19th September 2015 – Science & Engineering Open Day, Imperial College (*)
29th June-10th July 2015 – Insights Work Experience, Blackett Lab
School and Public Talks

Arttu Ranjante

12 Mar 2015, “Big Bang and Expanding Universe”, Nower Hill High School
29 Jun-5 Jul 2015, “Monopole Quest” exhibit at the Royal Society Summer Science Exhibition
3 Nov 2015, “Big Bang and Expanding Universe”, UTC Reading
5 Nov 2014, “Magnetic Monopoles”, Simon Langton Grammar School for Boys
26 Nov 2014, “What Does the Higgs Say?” The Bishop’s Stortford High School

Roberto Trotta

January 14th – Winchester Science Centre, Winchester
February 12th – Royal Institution, London [sold out]
March 16th – Airware, San Francisco [private event]
March 26th, The Oldest Light in the Universe, Imperial College London

Outreach

Imperial Horizons guest lecture, Imperial College London
Oct 2015, How big is space? Across RCA workshop, Data Science Institute, Imperial College London, Oct 2015

Other Events

20th October 2015- Science Centre at Barton Pevril College opened by Prof Joanna Haigh
Alumni gather to celebrate graduation milestones
Read the article by Jenn Bywater 30 June 2015


The Physics Class of 1965 gather with Imperial's fire engine mascot Jezebel to celebrate the 50th anniversary of their graduation

Former classmates gathered across South Kensington on Saturday 20 June to celebrate the milestone anniversaries of their graduation.

Touring a workshop with Paul Brown
Exploring dark matter in the inaugural Blackett Colloquium

On 24 October, more than 100 alumni and guests joined leading Imperial scientists to explore one of the biggest mysteries in physics, dark matter. Read the article by Jenn Bywater 29 October 2015 and watch the lecture at http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_27-10-2015-14-30-15

Welcoming guests to the event, Professor Jordan Nash (Head of the Department of Physics) explained that the new Blackett Colloquium lecture series would be an annual opportunity for alumni and members of the public to find out more about the Department’s work.

Dr Roberto Trotta (Senior Lecturer in Astrophysics) presented the evidence for dark matter coming from a variety of astrophysical and cosmological observations. He highlighted the need for a cross-disciplinary approach to the dark matter problem, arguing that a combination of all available experimental probes is much more powerful a tool to understand dark matter than any of them taken in isolation.

Dr Sarah Malik (researcher attached to the Large Hadron Collider Physics Centre) spoke about the collider approach to searching for dark matter, introducing the class of new subatomic particles that are considered good candidates for dark matter, and discussing the Large Hadron Collider at CERN.

Dr Henrique Araujo (experimental astroparticle physicist with the High Energy Physics group) explained how ‘direct search’ experiments are looking for galactic dark matter using very sensitive particle detectors installed in deep underground laboratories. He described two experiments, both of which use the liquid xenon technology which was partly pioneered at Imperial.

Following the presentations, guests were invited to the Physics Common Room for a champagne and canapé reception overlooking the South Kensington Campus and Royal Albert Hall, giving them an opportunity to meet the speakers and discuss their work further.

Alumnus Brian Smale (BSc Physics 1964) said: “To be able to discuss my strong amateur interest in cosmology with such learned researchers was both unexpected and rewarding and I will now be able to follow developments in this area without the uncertainties that concerned me previously” said Brian Smale (BSc Physics 1964). “It was a surreal experience to sit in that lecture theatre after more than 50 years, finding that it had not noticeably changed at all. I will never forget the quality of teaching that I enjoyed at Imperial, which laid a firm foundation for ways of thinking that helped me continually throughout my working life.”

Mr Peter Boldon (BSc Physics 1968, MSc Electrical and Electronic Engineering 1970) and Mrs Marilyn Boldon (BSc Physics 1968) said: “We’ve recently become inter-
ested in science again and especially Imperial. We often visit London to see our children so when we saw this event online we planned our trip around it."

Professor Nash had earlier suggested that although scientists are perhaps not as politically influential today as they were in Blackett’s time, Imperial’s science graduates, who spread out far beyond science into a wide network of influence, are the ones who really have the ability to influence the political world now.

Dr Roberto Trotta chatting to guests following his presentation

The opportunity to engage with alumni was as much appreciated by the presenters as by the guests. “I was delighted to have the opportunity to discuss the importance and relevance of such fundamental research for society”, said Dr Trotta. “This was a great way to connect with alumni, and it was fantastic to see their engagement with our work. I loved their well-informed and searching questions about the context of our research and why we should be leading on it.”

General relativity anniversary: a celebration with Imperial physicists

Imperial physicists led a huge celebration of Einstein’s ground-breaking theory of general relativity, which turns 100 this week.

100 years of general relativity
On the 23rd of November 2015, 700 people joined members of Imperial’s Theoretical Physics Group to celebrate the centenary of the theory of general relativity, which was discovered by Einstein in November 1915. Professor Fay Dowker gave a talk titled “Inner space, outer space, a meditation on General Relativity”. This was followed by a talk by Professor Jerome Gauntlett, the Head of the Theoretical Physics Group, titled “Black holes and the unity of physics”. The evening also included some introductory remarks from Professor Stephen Hawking who was originally due to talk, but had to cancel due to ill health.

A video of the talks can be found on youtube at https://www.youtube.com/watch?v=QLqBp0YC7I

and further discussion of the evenings events can be found in the article by Hayley Duning http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/newssummary/news_24-11-2015-12-11-43
In September, the Department was recognized with the Athena SWAN Silver award, which it has held since 2009, having been previously renewed in 2012. This award recognizes the continuing efforts of the Department in ensuring equality of opportunity, transparency in its procedures, and maintaining an environment that encourages all members of the community.

Two Juno Committee members were recognized with awards: Liz Elvidge, head of the Postdoctoral Development Centre, was awarded the Julia Higgins Medal, in recognition of her work with female postdocs and early career academics, and Jessica Wade, a postgraduate student in the Experimental Solid State group, won the IoP Early Career Physics Communicator Award for her wide-ranging activities, including school visits, setting up a Student Women in Physics Group at Imperial College, running an outreach lecture series at an east London school and serving on the Young Women’s Board of Women Into Science and Engineering (WISE).

Other key activities either initiated or supported by the Juno Committee are:

• The Committee produced a set of guidelines for the recruitment of academic staff that encourages women to apply to the Department and to improve the gender balance in the hiring of new academic staff. Some of the guidelines were already being implemented, but the Juno document provides a checklist for good practice at all stages of the hiring process, from ensuring that suitable female candidates are encouraged to apply, to recommendations for post-interview procedures.

• Following the formation of the Imperial College Student Women in Physics (IC student WiP) cohort in 2015, several student lunches and other events have been held, to encourage women to choose physics as an undergraduate degree and carry this enthusiasm into the academic world. Such activities are essential in addressing the “leaking pipeline” effect that sees diminishing number of women in physics from A-levels to academic appointments.

• The Committee has previous designed a new form for the Personal Review and Development Plan (PRDP). 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, rather than on past achievements. For some staff categories, this provides the main forum for an open discussion with a line manager or other senior staff member. The return rates this year across all staff categories. In the 2015 cycle, 95.5% of all staff completed their PRDP, indicating a widespread acceptance of the new form and procedures.

Juno Transparency and Opportunity Committee
http://www3.imperial.ac.uk/physics/staff/juno
To celebrate International Women’s Day (March 8th) the Imperial College Women in Physics (WiP) Cohort held a lunch to recognise quite how lucky we are to work with such exciting female academics, support staff, technicians and researchers. There are very few women working in STEM subjects (5.3% of women-in-work, vs. 31.3% of men) and even fewer in leadership roles. Only 11.6% of the highest paid academic roles and 10.7% of board directorships are held by women.1 Women make up 22% of the undergraduate and 15% of the postgraduate physics community. The lunch represented the launch of the WiP cohort. The cohort will organise a range of events to ensure women are inspired to choose physics as an undergraduate degree, explore as a postgraduate and carry this enthusiasm into the academic world.

Programme for WiP Academic Lunch

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>13:00-13:15</td>
<td>Arrive and get food</td>
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<tr>
<td>13:15-13:40</td>
<td>Focus Groups: Female Researchers and Why they Leave, How to have an impact, How to be assertive and confident, How to have presence, Boost your profile through networking, Manage your team and your boss</td>
</tr>
<tr>
<td>13:40-14:00</td>
<td>Presentation from PGs, Help for hosting first UG WiP Conference, Advertise WiP cohort to physics department, Open online WiP community webspace</td>
</tr>
<tr>
<td>14:00-14:15</td>
<td>Wrap up and feedback</td>
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</tbody>
</table>

The focus groups were a major success: informal discussion between postgraduates at different stages of their careers in different physics research groups, who would otherwise not have met. The attendees were asked a series of questions related to their experience of being a female scientist at Imperial. Questions ranged from “What would you like done to address gender awareness and the issues around women in science?”, to whether female postgraduate students felt they were “treated differently to their male colleagues”. The presentations were kept brief and text free. We discussed the motivation, the idea for the community, the events we were already organising and how to be involved. None of the events would be possible without the funding and support of the Graduate School. The Women in Physics cohort will have a committee of friendly postgraduate students. There will be a website where we will share internal and external events, resources and information on funding. There will be a structured mentoring system, Women in Physics Champions, each with a different set of expertise (for example, “how to have a family and complete your PhD”).

The aim of the event was to encourage interactions between the Masters and PhD level Women in Physics across every research group. Scientific research is demanding and competitive, and often women go days surrounded by only men. Despite how dated they are, the perceptions of sexism in the workplace that put so many young girls off studying STEM subjects are not entirely unfounded. The lunch attempted to attract more women to continue research beyond postgraduate level using a number of approaches:

- Positive female role models from diverse backgrounds: celebrating quite how lucky we are to be from such an international community
- Information on the range of different careers available
- Promote examples of how Imperial are making changes to the working environment to ensure that women (and women with families) are welcome and progress on merit
- Create a network which would offer advice and support

We are very grateful for all of the support (financially and emotionally!) provided by the graduate school at
all stages of our scientific careers. The responses to some of the focus group questions are shown below. Facts and Figures:

A short online survey was circulated online for feedback.

- The event was attended by over 70 members of the postgraduate community.
- The majority of attendees were PhD students in year 2.
- 100% of the people would like to attend more WiP events.
- 0% of people came with a friend and didn’t speak to anyone new.
- 80% of attendees only spoke to people they had never met.
- 35% had never been to another event celebrating Women in Science at Imperial College.
- 25% of attendees said they felt they were treated differently by their supervisor to their male colleagues.
- 25% of attendees are already signed up to attend another event organised by WiP committee (and funded by the graduate school).
- People praised Imperial College for: flexible working hours, supervision, societies/committee involvement and options for maternity leave.
- The WiP community think that mentoring and coaching (our ‘Champion’ scheme) is a great idea for addressing gender issues.
- They suggest courses on gender awareness and issues surrounding barriers to women in science be part of the graduate school program.
- 10 people signed up to be Women in Physics Champions.
- 3 people agreed to run a seminar on Barriers Facing Women in their Careers for UGs in years 3 & 4.
- 5 people agreed to help run a PGR UG open day for years 1 & 2.
Grants Awarded

**ASTRO**
Royal Astronomical Society
Dr Emma Chapman, Research Fellowship: Detecting and constraining the Epoch of Reionisation using foreground removal and state-of-the-art simulations £159,961

Science and Technology Facilities Council
Dr David Clements, Herschel Post Operations Support £112,325

**CMTH**
Research Council of Norway
Professor Kim Christensen, Numerical modelling of fires £69,396

Engineering & Physical Science Research Council
Professor Michael Finnis, Carbides for Future Fission Environments (CAFFE) £10,925

Office Of Naval Research Global
Dr Vincenzo Giannini (Co-I: Professor Stefan Maier), Localized phonon polariton resonances a highly efficient IR graphene plasmon launchers £54,999

Engineering & Physical Science Research Council
Dr Johannes Lischner, RS Fellow - EPSRC grant (2014): Ab initio many-body theory of plasmons in nanomaterials £162,448

**EXSS**
Commission of the European Communities
Dr Nikolaos Chastas, Horizon 2020 Marie Skłodowska-Curie Fellowship: Supersol - Solution processed low-dimensional oxide semiconducting structures and devices £144,781

Engineering & Physical Science Research Council
Professor Lesley Cohen, Tailoring of microstructural evolution in impregnated SOFC electrodes £129,566

Commission of the European Communities
Dr Emiliano Cortes, Horizon 2020 Marie Skłodowska-Curie Fellowship: HOTSPOT - Accessing hot-spots in plasmonic nanoantennas £135,893

EMRP / NPL
Dr Ned Ekins-Daukes, Research in Metrology for multi-junction solar cells £72,207

European Institute of Innovation and Technology
Dr Ned Ekins-Daukes, KIC SME Voucher: Solar monitor £31,705

Engineering & Physical Science Research Council
Dr Ned Ekins-Daukes (Co-I: Professor Stefan Maier), High Temperature, High Efficiency PV-Thermal Solar System £465,183

The Royal Society
Dr Ned Ekins-Daukes, Industry Fellowship: Near-Infrared Absorbers for High Efficiency Multi-Junction Solar Cells £141,259

SAMSUNG Electronics Co Ltd
Dr Ji-Seon Kim, High-Performance Organic Near-IR Photodetectors via Advanced Molecular Structure Control and Analysis £46,875

Engineering & Physical Science Research Council
Professor Stefan Maier, Impact Activities for Optical Fabrication and Imaging Facility for three-dimensional sub-micron designer materials for bioengineering and photonics £13,158

Commission of the European Communities
Dr Alex Mellor, Horizon 2020 Marie Skłodowska-Curie Fellowship: PVFIFTY - Towards a 50% efficient concentrator solar cell and a 40% efficient space solar cell £135,893

Engineering & Physical Science Research Council
Professor Jenny Nelson, SUPERGEN + £93,309

Engineering & Physical Science Research Council
Professor Jenny Nelson, Hysteresis and mesostability £151,793

Engineering & Physical Science Research Council
Professor Jenny Nelson, High resolution mapping of performance and degradation mechanisms in printable photovoltaic devices £1,130,570

Imperial College EPSRC Impact Acceleration Account
Dr Rupert Oulton, Pathways to Impact: Chromatic aberration sensing of lenses with Metal-Optics (ChASM-O) £32,086

Engineering & Physical Science Research Council
Dr Themistoklis Sidiropoulos, Doctoral Prize Fellowship £54,040

Commission of the European Communities
Dr Paul Stavrinou, ERC Proof of Concept (N Stingelin): Anti-reflection coating from solution-processable, high-refractive index inorganic/organic hybrid materials £26,062

Commission of the European Communities
Dr Paul Stavrinou, ITN: INFORM - Interfases in opto-electronic thin film multi-layer devices £238,888

Commission of the European Communities
Dr Kornelius Tetzner, Horizon 2020 Marie Skłodowska-Curie Fellowship: FlexChic - Flexible Complementary Hybrid Integrated Circuits £135,892
HEPH  
Science and Technology Facilities Council  
Dr Henrique Araujo, The LUX-ZEPLIN (LZ) Dark Matter Search  £2,503,518  

Science and Technology Facilities Council  
Dr David Colling, GridPP+  £384,773  

Science and Technology Facilities Council  
Dr David Colling, GridPP4 Hardware  £125,500  

Science and Technology Facilities Council  
Professor Paul Dauncey (Co-Is: Professor Gavin Davies, Professor Tejinder Virdee), Proof of Principle for CMS High-Granularity Calorimeter  £213,292  

Science and Technology Facilities Council  
Professor Paul Dauncey (Co-Is: Dr Henrique Araujo, Dr Oliver Buchmueller, Dr David Colling, Professor Gavin Davies, Professor Ulrik Egede, Professor Andrey Golutvin, Professor Geoff Hall, Professor Ed Hinds, Dr Jony Hudson, Professor Ken Long, Professor Jordan Nash, Dr Jaroslav Pasternak, Dr Mitesh Patel, Dr Jurgen Pozimski, Dr Ben Sauer, Dr Julia Sedgebeer, Dr Alex Tapper, Dr Mike Tarbutt, Dr Yoshi Uchida, Professor Tejinder Virdee, Dr Morgan Wascko), Consolidated Grant: The study of elementary particles and their interactions  £9,204,415  

Science and Technology Facilities Council  
Professor Paul Dauncey, Consolidated Grant: The study of elementary particles and their interactions - capital equipment  £145,067  

The Leverhulme Trust  
Professor Elliot Leader, Emeritus Fellowship  £12,560  

Imperial College STFC Impact Acceleration Account  
Professor Ken Long, Pathways to Impact: Generating Impact from the 2016 Neutrino conference  £7,500  

The Royal Society  
Dr Sarah Malik, University Research Fellowship: Where Particle Physics meets Cosmology: Searching for Dark Matter at the LHC  £595,957  

Science and Technology Facilities Council  
Dr Jurgen Pozimski, Secondment for FETS Research  £191,295  

Science and Technology Facilities Council  
Dr Jurgen Pozimski (Co-I: Dr Jaroslav Pasternak), FETS  £365,898  

Science and Technology Facilities Council  
Professor Tim Sumner, LISA Pathfinder - Mission Support 2  £216,783  

Commission of the European Communities  
Professor Tejinder Virdee, ERC Advanced Grant: Novel Calorimetry - Exploring the Terascale at LHC with Novel Highly Granular Calorimeters  £2,092,488  

PHOTONICS  
Biotechnology and Biological Sciences Research Council  
Professor Paul French (Co-I: Dr Chris Dunsby), High content analysis of 3-D cell cultures with multidimensional fluorescence imaging  £506,497  

Biotechnology and Biological Sciences Research Council  
Professor Paul French, Building a Next Generation Image Repository: Molecular Annotation and Cloudbased Data Processing and Analysis  £72,900  

The Royal Society  
Professor Paul French (Co-I: Dr James McGinty), Brian Mercer Feasibility Award  £30,000  

Imperial College BBSRC Impact Acceleration Account  
Dr James McGinty (Co-I: Professor Paul French), Pathways to Impact: Novel platform for 3-D optical mesoscopic imaging  £13,721  

Engineering & Physical Science Research Council  
Professor Roy Taylor, Tuneable, visible, integrated, fibre-based sources with selectable pulsewidth and repetition rate for biophotonic application  £293,020  

Imperial College EPSRC Impact Acceleration Account  
Professor Roy Taylor, Pathways to Impact: Fibre laser based visible sources  £55,230  

Imperial College EPSRC Impact Acceleration Account  
Professor Peter Torok, Pathways to Impact: Measuring tissue elasticity using Brillouin microscopy  £70,472  

Engineering & Physical Science Research Council  
Dr Robert Woodward, Doctoral Prize Fellowship  £49,792  

PLAS  
US Department of Energy via Cornell  
Dr Simon Nicholas Bland (Co-Is: Professor Jerry Chittenden, Professor Sergey Lebedev), Centre for Pulsed Power Driven High Energy Density Plasma Physics further funding  £156,588  

Engineering & Physical Science Research Council  
Professor Jerry Chittenden (Co-Is): Dr Robert Kingham, Professor Steven Rose), CCP Flagship: A radiation-hydrodynamics code for the UK laser-plasma community  £447,925  

AWE Plc  
Dr Daniel Eakins, PhD studentship support for Tom Ota: Enhancement of temperature diagnostics with application to dynamically compressed materials  £35,077  

US Department of Energy via Rochester  
Professor Sergey Lebedev (Co-Is: Professor Jerry Chittenden, Dr Simon Bland), Resolving the Issue: The Dynamics of Magnetized Astrophysical Jets through Pulsed Power HEDP Laboratory Studies further funding  £244,961  

Engineering & Physical Science Research Council  
Dr Stuart Mangles, Laser-Plasma Interactions at the Intensity Frontier: the Transition to the QED-Plasma Regime  £258,892
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<tr>
<th>Organization</th>
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<td>Office of Naval Research (USA)</td>
<td>Dr William Proud (Co-I: Dr Daniel Eakins), The effects of dynamic and pre-damage on heterogeneous materials</td>
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<td>Professor Steven Rose, Part-time PhD studentship for Daniel Burridge - Investigation into the Atomic physics of plasmas</td>
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<td>Professor Ed Hinds (Co-I: Dr Jony Hudson, Dr Ben Sauer, Dr Mike Tarbutt), Navigator Accelerometer Demonstrator</td>
<td>£3,866,489</td>
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<td>Professor Myungshik Kim, Wolfson Merit Award</td>
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<td>Professor Jon Marangos, ITN: HICONO - High-Intensity Coherent Nonlinear Optics</td>
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<td>Professor Jon Marangos (Co-I: Professor Misha Ivanov, Dr Stuart Mangles, Professor Zulfikar Najmudin, Professor Roland Smith; Professor John Tisch), MIR – MURI</td>
<td>£2,750,588</td>
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<td>Dr Mike Tarbutt (Co-I: Professor Ed Hinds, Dr Jony Hudson, Dr Ben Sauer), Magneto-optical trapping and sympathetic cooling of molecules</td>
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<td>Professor John Tisch, Pathways to Impact: Femtosecond Laser Pulse Compression System</td>
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<td>SPAT</td>
<td>Mr Chris Carr, Cluster FGM 2015-2016</td>
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<td>Met Office</td>
<td>Professor Ralf Tourni, A new regional atmosphere-ocean-wave coupled model of West Pacific Tropical Cyclones</td>
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Academic, Research and Support Staff

Outreach/Teaching
Dr Caroline Clewley - Teaching Fellow
Dr Mark Richards - Teaching Fellow
Dr Vijay Tymms - Teaching Fellow

Academic Leavers
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### Academic, Research and Support Staff

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**Research Associate Leavers 2014/15**

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- Dr Heykel Aouani
- Dr Emma Arbabzadah
- Dr Morteza Aslaminjed
- Dr Alexey Bak
- Dr Giovanni Barontini
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- Dr Peter Spencer
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- Dr George Swadling
- Dr Tommaso Tufarelli
- Dr Jeremy Turcaud
- Dr Arthur Turrell
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Research Support Staff

Experimental Solid State
Dr Xuhua Wang - CPE Glove Box Facility Officer

High Energy Physics
Dr Saad Mishal Hamid Alsari - Electrical Engineer
Mr Geoffrey Barber - Project Engineer
Dr Abdulkadir Farah – Computer System Support/Administrator
Mr Simon Fayer - Computing System Support/Administrator in Grid Computing
Dr Gregory Michiel Iles - Electronics Engineer
Dr Per Jonson – Senior Instrument Manager
Dr Andrew Rose - Electronic Engineer
Mr Trevor Edward Savidge - Project Engineer

Photons Group
Mr Ian Munro - Research Officer

Space & Atmospheric Physics
Dr Seyed Adeli – Instrument Engineer
Dr Leah-Nani Soledad Alconcel - Scientific Engineer
Dr Anthony Allen - Scientific Engineer
Dr Richard John Bantges - Scientific Engineer
Mr Maciej Bendyk – Instrumentation Engineer
Mr Patrick Brown - Senior Research Officer
Mr Emanuele Cupido – Instrument Manager
Mr Jose Dominguez-Mateos – Instrument Engineer
Dr Peter Fox – Instrument Calibration Engineer
Mr Stephen Kellock - Senior Research Officer
Mr Christoph Landorfer – Instrumentation Engineer
Ms Helen O’Brien - Research Officer
Mr Timothy Oddy - Spacecraft Operations Engineer
Dr Dr. J. C. Anglès-Action - Spacecraft Operations Engineer
Dr Adi Peter Slootweg - Research Officer
Mr Lawrence Soung-Yee – Instrumentation Engineer
Mr Karol Stephien – Instrument Mechanical Engineer
Mr Barry Whiteside – Instrumentation Engineer

Research Support Leavers in 2014/15
Dr Jonathan Fulcher – Data Acquisition System Computing Specialist
Mr Michael Huffman - Computing System Support/Administrator
Mr Stephen Johnson – Hypersonics & High Speed Impact Laboratory Supervisor
Mr Md Rashid – Software Developer
Mr Peter James Savage - Project Engineer
Dr James Spencer – Computational Science Support Specialist

Administrative and Support Staff

Head of Department’s Office
Kalvinder Chana - Senior Administrator
Linda Jones - Operations Manager for Physics
Caroline Jackson - Executive Assistant

Research Groups
Cluster Office (Astrophysics, Space & Atmospherics)
Mr Paul Grocott – Senior Group Administrator
Mrs Magdalena Vidler – Group Administrator

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

High Energy Physics Group
Paula Brown - Group Administrator
Paula Consiglio – Assistant Group Administrator

Institute of Shock Physics (ISP)
Ciara Mulholland - Senior Administrator for ISP

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

Plasma Physics
Aza Sabadosh - Temporary Senior Administrator

Theoretical Physics Group
Graziela De Nadai-Sowrey - Group Administrator

DTC
Ms Lisa Cheung – Administrative Assistant
Dr Simon Foster – Outreach Officer
Miss Miranda Smith – Senior Administrator to DTC

Miss Veena Dhulipala - DTC Administrator
Academic, Research and Support Staff

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

Undergraduate Office
Victor Urubusi – Examinations and Information Officer
Mery Fajardo - Admissions Administrator
Amira Hussain – Undergraduate Administrator and Year in Europe Coordinator
Derryck Stewart - Undergraduate Education Manager
Geetika Tewari – Undergraduate Administrator

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

Outreach
Ms Vinita Hassard – 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)
Kevin Ladhams (HEPH)
Alan Last (SPAT)
Stephen Maine
Giovanni Marinaro (QOLS)
Steven Nelson
Conor O’Donovan (QOLS)
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
Dr Sophie Armstrong-Brown - Programme Manager
Rachel Barker – Senior Group Administrator
Carol Barlow - Experiments Manager
Sandie Bemor - Group Administrator
Victoria Garland – Executive Assistant (maternity cover)
Anna Lal – Administrator
Alice Moore – Programme Manager
Bhavna Patel – Administrator
Ranjana Poudel - Common Room Assistant