International Student Research Project Opportunities (Summer 2018)

Academic coordinator for Exchange Programme: Dr. Ingo Mueller-Wodarg (i.mueller-wodarg@imperial.ac.uk)
Administrative coordinator for Exchange Programme: Laura Kington (l.kington@imperial.ac.uk)

Department of Physics website: http://imperial.ac.uk/physics

Supervisor(s)	**Project Description**
Prof. Amihay Hanany Theoretical Physics Group (a.hanany@imperial.ac.uk)	**Quiver Gauge Theories** There is a collection of projects in string theory research under the general topic of "quiver gauge theories". Past projects were done in the study of "brane tilings" and "orbifolds", but a general study in string theory is also possible. The work may involve theoretical, analytical, and/or computational studies, depending on the taste and choice of the student. Some of the projects involve combinatorial techniques as well as methods taken from number theory. Some other projects involve methods from representations of Lie algebras and algebraic geometry. The interested student needs to have a strong background in theoretical physics, but the projects are not restricted to a given year of study. The expectation from the student is to be well motivated and ready to solve problems which were not seen before, but using the tools acquired so far in their degree.
Prof. Richard Thompson Quantum Optics & Laser Science Group (r.thompson@imperial.ac.uk)	**Ion Traps and Laser Cooling** The student will work with Imperial graduate students on an experimental programme to trap and laser cool calcium ions in an ion trap and study their behaviour. We are performing experiments in a Penning trap studying the formation of ion Coulomb crystals as well as the coherence properties of individual ions cooled to the quantum mechanical ground state of their motion. The very low heating rates that we measure show the promise of this system for applications in quantum information studies. We are also currently building a new RF ion trap to extend this work using optimal control techniques to enhance our coherent control of the ions. The group also carries out some computer simulations of laser cooling of trapped ions. Please see our website at www.imperial.ac.uk/ion-trapping for more information on our projects. Experience: Students should be enthusiastic about experimental physics and should already have some experience of experimental work. Experience of building electronics devices is useful.
Prof. Ben Sauer Quantum Optics & Laser Science Group (ben.sauer@imperial.ac.uk)	**Lasers for cooling molecules and time reversal** This experimental project will take place in the Centre for Cold Matter (http://www.imperial.ac.uk/ccm). We have several projects underway to directly cool polar molecules with lasers. One of these projects aims to produce cold YbF molecules which will be used in an experiment to test time reversal symmetry. All of the experiments require very stable and precisely controlled laser frequencies. The aim of the summer project will be to investigate and improve the stability of our locking scheme, which involves a reference cavity stabilised to a HeNe laser.
Dr. Will Branford (w.branford@imperial.ac.uk) **Prof. Lesley Cohen** (l.cohen@imperial.ac.uk) Experimental Solid State Group	**Superconductivity, Magnetism and Transport in Semiconductors** We offer a variety of projects which vary from year to year based in the areas of superconductivity, magnetism and narrow gap semiconductors. The work usually involves cryogenics and training on large commercial pieces of apparatus such as magnetometers or electrical transport rigs. Experience: Preferably good experimental skills which means competence with software programs and confidence with handling experimental apparatus. Some of the experimental work is quite detailed. The work may also involve processing and analysis of data - working knowledge of first and second year physics helpful.
Prof Ulrich Egede High Energy Physics Group (u.egede@imperial.ac.uk)	**High Energy Physics data handling** High Energy Physics is at the leading edge of large scale data handling. One of the main challenges is to allow physicists to process PetaByte datasets distributed across the globe in a programmatic way that is efficient and easy to use. The tool Ganga (https://github.com/ganga-devs/ganga) provides a generic plug-in structure to allow for direct connections to the software and data structures used within specific High Energy Physics collaborations such as LHCb, LZ, SNO+ and T2K. Ganga is developed at Imperial and you will be part of the development team over the summer working on developing a new plugin. For this project, a keen interest in programming and experience with Python is required.

Dr. Morgan Wascko High Energy Physics Group (m.wascko@imperial.ac.uk)	**Neutrino Experiment R&D** The discovery of neutrino mass and flavour oscillation is the first confirmed observation of physics beyond the Standard Model. The T2K experiment in Japan is the world's flagship neutrino oscillation experiment, and has been approved for an upgrade in ~2022. One of the possible upgrade designs is a new type of detector called a high-pressure gas time projection chamber (HPTPC). This project is to work on a prototype HPTPC detector to test the technology for a future neutrino experiment and to make new measurements of particle interactions. This project can have two components, in any proportion; the first is hardware work to build and test the HPTPC prototype, and the second is computational/analysis work to study the physics capabilities of an HPTPC and analysis of data from the prototype. The student will develop an understanding of particle physics experiments, and/or modern data analysis techniques. No experience required.
Prof. Jeremy Chittenden (j.chittenden@imperial.ac.uk) **Dr. Brian Appelbe** (b.appelbe07@imperial.ac.uk) Plasma Physics Group	**Burning Plasmas in Inertial Confinement Fusion (ICF) Implosions** Ongoing experiments at the National Ignition Facility (NIF) aim to demonstrate controlled thermonuclear fusion by compressing deuterium-tritium capsules to a high temperature (~5 keV) and density (~10^31 m^-3). Nuclear reactions occurring in these hot plasmas release energy in the form of neutrons and alpha particles. The alpha particles can deposit their energy in the deuterium-tritium plasma through Coulomb collisions resulting in hotter plasma. If this alpha heating effect is significant then a burning plasma can be formed which results in a large energy yield (since the number of nuclear reactions increases exponentially with increasing temperature). In experiments carried out to date alpha heating has resulted in ~4 times greater energy yield. In order to further increase the yield, it is necessary to understand the physics of how alpha particles deposit their energy in the deuterium-tritium plasma. This is a kinetic process in which fast, non-thermal alphas move through a background plasma that is near Maxwellian. This project involves a computational study of ICF implosion & burn with a particular focus on the use of kinetic models for the alpha heating process. A main goal of this work will be to identify suitable diagnostic features of alpha heating so that researchers can improve their observations of experiments. Experimental work on this topic is carried out by researchers at MIT and the project should offer opportunity for collaboration with this group. Experience: Students should be interested in and enthusiastic about computational physics. Students will be able to use existing simulation codes and will be also given the opportunity to write their own.
Dr. Roberto Trotta Astrophysics Group (r.trotta@imperial.ac.uk)	**Improving the accuracy and precision of supernova type Ia as cosmological probes** Supernovae type Ia (SNIa) are a particular type of stellar explosion that have the important property of being almost standard candles -- ie, their luminosity is almost the same for all objects, and therefore can be used to measure distances in cosmology. SNIa were instrumental in establishing the accelerated expansion of the Universe (currently ascribed to an unknown form of energy, called dark energy) - a momentous discovery which was rewarded with the Nobel Prize for Physics 2011. One of the biggest mysteries in modern-day physics, the nature of dark energy remains currently unknown. Present and future SNIa observations are one of the most important tools that will help understanding dark energy better, in particular in order to determine whether or not its properties change with time. The number of SNIa observations is now in the several hundreds, and it is set to increase by over a factor of 10 in the next few years. Already today, our inferences about the nature of dark energy are being limited by poorly-understood systematic effects (such as the reddening and dimming introduced by dust, which can be confounded for the dimming due to the expansion of the Universe). This project will look at one of the frontiers of SNIa cosmology, namely the influence of the galactic environment in which the SNIa explodes on its observable properties. If SNIa's have different brightness in different environments, this could compromise or limit their usage as cosmological standard candles. Factors that will be considered are host galaxy mass, star formation rate, metallicity, stellar population age, spectral lines width, host morphology, location within the host. The project is well suited to a student with interests in computational methods, statistics, cosmology, and messy astrophysics.
Prof. Tim Horbury Space & Atmospheric Physics Group (t.horbury@imperial.ac.uk)	**Space weather: early warning at the Earth** As we increasingly rely on technology, so our society becomes more susceptible to space weather, the effect of the Sun on our local space environment. A major cause of space weather effects are coronal mass ejections (CMEs), discrete plasma structures ejected from the Sun at hundreds of km/s; when they arrive at the Earth, the interaction of their magnetic fields with that of the Earth can accelerate particles to high energies and drive large currents in the Earth. The magnetic fields in the upstream sheaths of CMEs can be a significant driver of space weather, but are poorly studied. In this project, which will involve data analysis with a smaller theoretical element, we will study these sheaths and test a new theory which aims to predict whether a CME will be damaging before it arrives at the Earth.

Dr. Florian Mintert Quantum Optics & Laser Science Group (f.mintert@imperial.ac.uk)	**Theory-blind quantum control** Quantum control allows us to development high-precision experiments or hardware for quantum information processing. Control for comparatively simple models can be developed based on theoretical models, but many physical systems are too complex to be modelled or simulated. Together with a team of several European partners we are working on techniques to design control based on experimental data only. One central aspect lies in the fact that quantum mechanics requires many repetitions of a measurement, before reliable conclusions can be drawn. Figuring out how we can use data based on a small number of iterations is an important step towards efficient control techniques. Together with the Imperial team and our partners, you would analyse and test different approaches for control based on scarce experimental data.
Prof. Roland A. Smith Plasma Physics Group (r.a.smith@imperial.ac.uk)	**Optical levitation of microtargets for ultra-high power laser experiments.** The interaction of ultra-intense lasers with a microtarget of order the laser wavelength (a micron or so) is a field pioneered by Imperial College. These targets are exciting for several reasons, their geometry results in large boosts to the laser electric field which enhances hot electron and x-ray generation and their perfectly isolated geometry creates a unique micro-laboratory to study ultra-high intensity laser physics. Our most recent experiments and simulations also show that we can use them to generate much more energetic MeV ion beams than "traditional" laser targets, and we are investigation how to harness this to underpin future ion-beam cancer therapy techniques. To enable these experiments we develop new optical levitation traps which work under vacuum and balance the force of gravity against photon momentum transfer from a continuous laser beam. This project could involve either experimental work to characterise and refine our trap systems, or numerical modelling in Python to better understand trap dynamics and help design new trap systems able to capture "exotic" objects such as microbubbles and chiral liquids, depending on the interests of the student.
Prof. John W.G. Tisch Quantum Optics and Laser Science Group (john.tisch@imperial.ac.uk)	**High Power Femtosecond Laser Pulse Compression for Attosecond Science** Femtosecond lasers, which generate light pulses of duration measured in femtoseconds, have had a revolutionary impact in industry and science. They have found widespread application in material processing, telecommunications, metrology and medicine, and have opened up new branches of science, including Femtochemistry – the study of femtosecond timescale chemical dynamics, a field that attracted the 1999 Nobel Prize in Chemistry – and Attoscience – which uses femtosecond laser pulses to generate even shorter X-ray pulses in the attosecond time domain. These, in turn, are transforming our understanding of the first moments in the electronic excitation of matter and leading to new approaches for optimising artificial light harvesting, molecular electronic devices and biomolecular analysis. While most of these applications benefit from the shortest possible laser pulse durations, there are fundamental limits to how short a pulse a laser can produce. For the high-power laser systems required for many applications, this limit is around 20-30 fs. A Hollow Fibre Pulse Compressor (HFPC) allows this limit to be reduced, opening up many new applications and experimental opportunities. An HFPC system is effectively an advanced optical system that uses nonlinear effects to compress laser pulses by factors of up to 10. Due to laser beam distortions and optical damage, current HFPC systems cannot handle input peak powers significantly above 50 GW. There is a growing scientific demand for HFPC systems that can operate reliably in the 50-500 GW range. For example, in the field of Attoscience, this power increase would translate directly into more intense attosecond X-ray pulses which would unlock many new scientific opportunities. This project will explore a number of strategies for increasing the power handling capability of HFPC systems. Students will gain hands-on experience in the field of ultrafast laser physics. This project is aimed at students with real enthusiasm for experimental work. The project is also likely to include computer data acquisition and modelling. Programming skills (e.g. Matlab, Python) are thus advantageous, but not essential.
Prof. John W.G. Tisch Quantum Optics and Laser Science Group (john.tisch@imperial.ac.uk)	**Femtosecond high-power laser field-synthesiser** Intense, ultrafast laser pulses provide a unique tool for measuring and controlling quantum electron dynamics in matter on the femtosecond and sub-femtosecond (attosecond) timescales. Recently, significant progress has been made in techniques to allow the shaping of ultrafast electric field waveforms by *coherent synthesis*. In this method, phase-coherent ultrafast sources of different wavelengths are combined with controllable delays (phases) and amplitudes to synthesise complex optical waveforms. These tailored fields have already been used to optimise soft x-ray generation from high harmonic generation and to measure for the first time the finite nonlinear response time of bound electrons on the attosecond timescale. In the future, synthesised waveforms are likely to lead to new spectroscopies and novel routes to the control of quantum system, including atoms, molecules and condensed phase systems, with relevance also to light-based electronics operating at petahertz rates. *(continues next page)*

	The student taking this project will join a small team working on developing such a field synthesiser in the AttosSecond Laboratory in the Physics Department. This synthesiser will be used for attosecond pulse generation and to study ultrafast dynamics in nanoplasmonic systems. While participating in a variety of aspects of the work, their particular sub-project will be to design and construct a computer-controlled feedback system to stabilise an optical interferometer to ensure the different field components (femtosecond laser pulses of different frequencies) are combined with the minimum timing jitter possible to ensure a stable synthesis. Students will gain hands-on experience in the field of ultrafast laser physics. This project is aimed at students with real enthusiasm for experimental work. The project is also likely to include computer data acquisition and modelling. Programming skills (e.g. Matlab, Python) are thus advantageous, but not essential.