UNIVERSITY OF BIRMINGHAM

Year 3 Group Studies

Group Study Leaders

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Year 3 Group Studies

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INTRODUCTION

Group Studies is a student-led, project-based activity that runs throughout the Spring Term. Groups of up to 20 students work collaboratively on a topic within one of the School's research groups. You will be given a project outline but will be expected to decide how to tackle the problem. As well as giving you the opportunity to study a topic in-depth, it also exposes you to the challenges and benefits of collaborative research. By their very nature, projects are open ended. How far you get will partly depend on how well organised you are as a Group. Everyone needs to know exactly what is expected of them and this means that there needs to be effective project management. The aim of this document is to give students a general overview of Group Studies and a brief description of each study area to accompany the introductory talks. It also provides an introduction to project management methodology and advice on how to get the most out of your Group Study.

ASSESSMENT

Group Studies is a 20-credit module and each student is expected to spend around 200 hrs working on this activity. Each student will earn an individual mark that will be made up of the following assessed components:

1. Management Plan (Group Mark) – 5%
2. Worksheet (Individual Mark) – 10%
3. Project Work (Individual Mark) – 20 %
4. Project Seminar (Sub-group Mark) – 10%
5. Project Report (Individual Mark) – 45%
6. Viva (Individual Mark) – 10%

In some cases the mark is an individual mark based on a student's own work, in others it is a whole group, or sub-group mark based on collaborative effort.

Deadlines for 2018

Management plan	12:00 Friday 1 February
Worksheet solutions	16:00 Monday 11 February
Peer review Personal statement	16:00 Thursday 21 March
Seminar slides	16:30 Friday 22 March
Individual vivas	Week 25-29 March
Final report Project notebook	16:00 Friday 29 March

Management Plan

As this is a student led activity, you will decide as a group how to break down the project into distinct areas and divide your team amongst the various tasks that you identify in your Management Plan. Someone will need to take overall responsibility for coordinating the project. The group may also wish to appoint sub-group leaders who will coordinate week-to-week work on specific areas of study within the project. Some guidance on Project Management is given later in this document.

Your Management Plan should explain how you will break down the task into manageable pieces and should identify milestones and deliverables for each of them. Review points should be built into the schedule to allow you to monitor progress against the milestones you have identified. The Project Manager will be expected to present a slide during the Project Seminar that compares the original project schedule to the schedule that was achieved and draw conclusions from the comparison.

The Management Plan assignment is a group activity that is set during the first week of term and the deadline for receipt of the Plan will be 12:00 on Friday of the third week of term.

Worksheet

The aim of the worksheet is to introduce some of the key physics concepts underpinning the study area. Group discussions on the general principles being explored are permissible, but solutions to the problems should be the student's own work.

The worksheet will be set during the first week of term and the deadline for receipt of solutions will be Monday of the fifth week of term.

Project Work

The mark for Project Work will be awarded for a combination of effort and achievement and will comprise an element of peer review. Students will be invited to rank the effort of colleagues within their sub-group, with whom they will have collaborated on a specific task. Staff will use the outcome of the peer review to inform the Project Work mark that is awarded to individual students. Discretionary marks are also available to reward those students who are deemed to have made an exceptional contribution to the Group Study.

Project Seminar

A group seminar will take place in the penultimate week of term. Each sub-group is expected to give a report and answer questions on their findings. A common mark will be awarded to students within each sub-group. Informal feedback will be given to students at the end of the seminar to help them prepare their final report. The Project Manager should give an overview and report on changes to the project schedule proposed in the Project Management Plan.

Project Report

Each student is expected to contribute directly to the project report. Their contribution should be clearly noted in the section heading. The page limit for the final report will depend on the size of your group, but around six pages of content per student is expected, including diagrams, but excluding references and appendices. There should be a separate introductory section to the whole report that places the work in context and should not exceed 5 pages in length. Each student should also submit a personal project notebook, which will be assessed along with their contribution to the report. The notebook should be a record of the day-to-day work done by the student. It should be kept up-to-date during the project.

Viva

Students will supply a short Personal Statement at the end of the project outlining their individual contributions. The viva will explore each student's individual contributions and their overall awareness of the underlying physics and wider implications of the project.

GUIDANCE ON EFFECTIVE PROJECT MANAGEMENT

This activity differs from any learning activity that students have done before by virtue of the fact that it is group-based and student led. Students typically work in groups of up to 20 students. The projects have a wide scope and, by their very nature, are open-ended. To get the most out of Group Studies, students need to work well together as a team. This does not happen automatically and requires a combination of good planning and effective project management.

All academic members of staff who hold research grants are required to have some competence in project management. This is to ensure that projects are delivered on time and within budget. In Group Studies there are no financial implications for non-delivery, but clearly an element of effective project management is needed to ensure that you will be able to deliver the best possible report at the end of the activity. Your report must be delivered on time, within the scope that has been defined for you and must meet the quality requirements of the staff assessing the project, your customer.

Milestones and Deliverables

There are various means to ensure that all group members contribute in the most efficient way toward the successful completion of the project. The first step is to break down the project into clearly defined areas. This should be done in such a way as to minimise overlap between the areas. In Project Management speak, this means having a well-defined Work Breakdown Structure. What this means in practice is defining a set of distinct Work Packages. Each Work Package should have a named person who is responsible for it. Work Packages should have well-defined inputs (if any) and outputs (also known as deliverables). Work Packages may be further divided into tasks, which are the responsibility of the sub-group of students assigned to work on that Work Package. Each task should be assigned to one or more members of the sub-group, so it is clear who is doing what.

As well as defining the tasks that need to be done, students need to estimate how long it will take to complete the tasks. This is especially important when one Work Package depends on the deliverables of another Work Package. Each deliverable should therefore have one or more clearly defined milestones. This will enable you, the Work Package leader and Project Manager to tell whether the project is going according to schedule. If not, more effort may be needed, or the Group may decide to reduce the scope of the project. It would be useful to build into your schedule one or two review points. These could be meetings when the Work Package leaders report on progress. You might like to invite the academic staff to attend these meetings and provide you with feedback.

Gantt chart

A graphical way to illustrate the stages of a project is through a Gantt chart. Each Work Package and/or task is represented by a horizontal bar that extends over some fraction of the length of the project. The abscissa covers the duration of the project, in this case the 8 weeks of term after you hand-in your Management Plan. A hypothetical Gantt chart created in Microsoft Excel is shown in Figure 1 below. It shows three Work Packages with different tasks, each with its own start and end date. Connected Work Packages are shown connected by arrows. I have also chosen to indicate two major Review Points to coincide with when the project moves from one phase into the next. Instructions on how to create a Gantt chart in Excel can be found online.

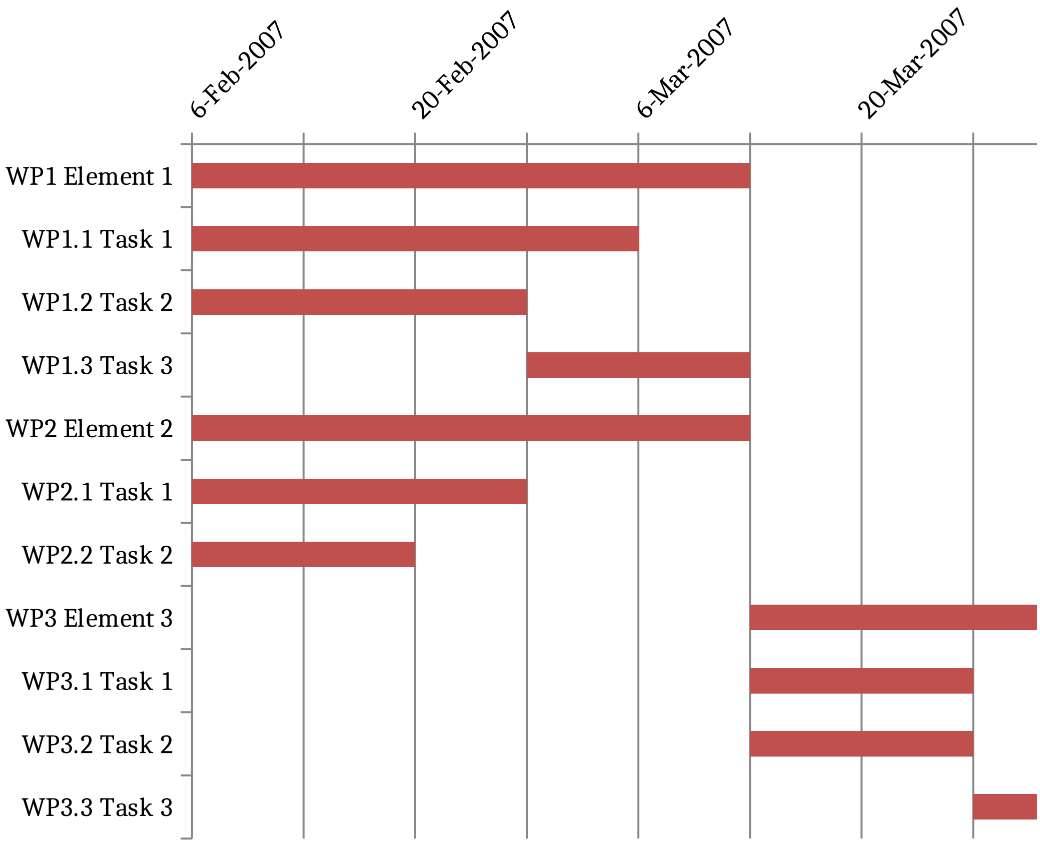

Figure 1. A hypothetical Gantt chart created in Microsoft Excel. Two Review Points are shown, one between dependent Work Packages WP1.2 and WP1.3 and one between the end of WPs1 and 2 and the start of WP3.

Reporting

The key to effective Project Management is good communication. You are encouraged to have regular Group meetings. There are timetabled slots for Group Studies to ensure that there are times when all students can meet together. You may request academic staff to attend some of your Group meetings. It is important to keep staff informed of your progress and problems. One of the responsibilities of the Project Manager might be to send a weekly status report in the form of an email to the staff responsible for your Group Study.

The role of Project Manager and Work Package Leader

The Project Manager and Work Package Leaders have responsibility to make sure everyone knows what is expected of them and to report when problems or setbacks occur. Remember that the staff consultants are available to help you, but students must decide when to call meetings. All meetings should be convened at a mutually convenient time.

Please note that the Project Manager and Work Package Leaders are expected to involve themselves in some of the tasks, not only to undertake a coordinating role. All students will be assessed on the contribution they make to the Group Study, regardless of whether or not they take on any coordinating role.

The role of academic staff and getting feedback

As this module is a student led activity you should not expect academic staff to tell you exactly what to do or how to organise yourselves. However, demonstrators are available to advise you and you should still seek regular feedback on your ideas and progress. You can get this feedback by involving the demonstrators in your deliberations and, although you cannot expect them to tell you exactly what to do, you can expect constructive criticism and pointers to things you may have missed that will help you, as a group, to achieve a better final outcome. You are strongly advised to inform the demonstrators when you hold significant meetings and make important decisions about the direction your project should take. You might also decide that one responsibility of the Project Manager is to send a weekly report on progress, perhaps by email, to the lead staff member responsible for your Group Study area.

GROUP STUDY AREAS

For 2016/17 there are ten Group Study areas:

1. Asteroseismology and Finding Planets
2. Atom Interferometry
3. Cold Atoms
4. Gravitational-Wave Astronomy
5. Medical Imaging
6. Nanoscale Physics
7. Particle Physics
8. Photonics
9. Radar and Remote Sensing
10. Robotics

A brief summary of each of the Group Study areas can be found in the following pages. Six Group Studies are lab-based, experimental projects and four are design studies, although there may be aspects of design and simulation in the lab-based projects too. Generally, students with a mixture of skills are needed in each of the Group Study areas, so keep an open mind when drawing up your prioritised list of study areas. All of them provide the opportunity to research a subject to greater depth than typically encountered in lectures.

Choosing a Group Study

Each Group Study can accommodate up to 10-18 students. As places are limited we cannot guarantee that students will get their first choice, or sometimes even their second choice. Students are therefore asked to rank all Group Study areas in priority order. The Head of Year will endeavour to distribute students in such a way as to give most students their first or second choice Group Study. Please note that Physics and Astrophysics (PaA) students have priority in the Asteroseismology and Finding Planets Group Study and Physics with Particle Physics and Cosmology Students (PwPPC) have priority on the Particle Physics Group Study.

Asteroseismology and Finding Planets

For several decades now, study of the interior of the Sun has been made possible by the technique of helioseismology – a technique pioneered in Birmingham. The measurement of the conditions in the solar interior is achieved by studying the surface manifestation of sound waves that are resonant within the body of the Sun. Recently, thanks to the CoRoT and *Kepler* space borne telescopes, such studies have now been extended to a wide range of stars (asteroseismology) thus giving real insights into the evolution of stars. Asteroseismology can be particularly powerful when it is applied to stars that are exoplanet hosts. It can provide the accurate and precise estimates of stellar properties that are needed to make robust inferences about the properties of the planets. Also, asteroseismic constraints on the age of stars are key contributors to the development of Galactic archaeology, which is the study of the formation and evolution of the Milky Way based on living fossils, i.e. stars.

The NASA Transiting Exoplanet Survey Satellite (TESS, launched in April 2018) will very soon (January 2019) deliver its first data to the scientific community. TESS is expected to discover thousands of short-period exoplanets in orbit around the brightest stars in the sky and to detect oscillation modes in hundreds of main-sequence and tens of thousands red-giant stars in the solar neighborhood.

However, one of the challenges related to the exploitation of TESS data is that the satellite will observe stars for significantly shorter periods of time compared e.g. to *Kepler*. This may limit our ability to measure precise and accurate oscillations modes and to subsequently model those stars and determine their fundamental properties.

This group will:

- investigate the robustness of the information that can be extracted from 30-d long datasets, by degrading *Kepler* data to TESS-like like curves,
- devise both a data-analysis and modelling procedure adapted to TESS data,
- apply such procedures to data from the TESS mission, which we expect receive in December/January, and hence participate to the scientific exploitation of such data.

Relevant review articles / links:
Asteroseismology of Solar-Type and Red-Giant Stars: http://arxiv.org/abs/1303.1957
Asteroseismology of red giants: From analysing light curves to estimating ages
https://arxiv.org/abs/1601.02802
Transiting Exoplanet Survey Satellite (TESS): http://tess.gsfc.nasa.gov

Staff: Dr Andrea Miglio, Dr Guy Davies, Dr Josefina Montalbán and Dr Warrick Ball.

Atom Interferometry

You might have heard the keywords "Quantum Technology", which is a hot topic nationally and internationally. In loose terms quantum technology describes any technology that harnesses the more spooky features of quantum mechanics, e.g. the possibility for a particle to be in several places or in several states at the same time or entanglement. Applications include quantum communications, quantum sensors, quantum metrology and quantum computation.

This group study is integrated into an actual interdisciplinary research project on quantum sensors led by the quantum matter group. We are developing ultra-precise gravity and gravity gradient sensors based on atom interferometry. An atom interferometer makes use of the possibility to simultaneously send an atom along two paths at different heights, i.e. in different parts of the gravitational potential. After recombination of these paths the atom will create a matterwave interference pattern, which allows reading out the gravitational acceleration or the gravity gradient, if using two such interferometers at different height. The sensitivity of these instruments is anticipated to be sufficient to detect the gravity signature of buried pipes, archaeological treasure, ground water, oil or minerals.

The group study will aim to implement a motional platform which would be used to operate the sensor in an application such as on a moving vehicle, and also use this to assess the impact of relevant noise sources upon the cold atoms source. This will involve learning about laser cooling and trapping, creating and optimising cold atoms clouds, integrating a cold atom system onto a motional platform formed by a hexapod and using this to study dynamic effects.

Staff: Dr Michael Holynski, Dr Alex Wilson, Mr Ben Stray, Mr Luuk Earl, and Dr Darren Holland.

Cold Atoms

By using laser light and magnetic traps, it is possible to cool a gas of atoms to the lowest temperatures in the universe, just a few billionth of a degrees above the absolute zero. At such temperatures, the wave-like behavior of matter becomes apparent and it is possible to observe fascinating phenomena like the onset of Bose-Einstein condensation and the superfluid-to-Mott insulator transition and to explore the regime of fully quantum-mechanical motion.

The first step to reach such temperatures is called Magneto Optical Trap (MOT), in which a combination of laser light and magnetic fields allows to trap and cool atoms down to a few microkelvin above the absolute zero. In this group study, you will be given the opportunity to build such system: the project will consist of setting up the lasers and locking them to atomic resonances, designing and implementing the optical system, building and characterizing the electromagnet and implement a control sequence using a microcontroller. The combination of all these elements will allow you to produce your own ultracold sample of Rubidium atoms and to characterize its properties.

The project will cover a large range of topics including optics and laser physics, electromagnetism, vacuum technology, electronics, mechanics, programming and, of course, atomic physics.

The work will be divided into four main tasks, each performed by a group of students. The first task will be to set-up and locking the cooling lasers. Because the frequency of the lasers has to be extremely well defined, the lasers will be locked to an atomic line with a Rubidium spectroscopy set-up. The second task consist in setting up the optics and acousto-optics to control the intensity and frequency of the cooling lasers. The third task will consist of arranging the laser beams and magnetic field coils around a vacuum chamber to realise a 3D cooling configuration. The fourth task will be to devise ways of measuring the number of trapped atoms and their temperature, and built simple electronics and computer control to pilot the experiment and realise these measurements.

Staff: Dr Giovanni Barontini, Dr Plamen Petrov

Gravitational-Wave Astronomy

One of the earliest predictions of the general theory of relativity has been the existence of gravitational waves: ripples in spacetime propagating at the speed of light and carrying with them information about rapidly accelerating masses. However, gravitational waves were directly observed for the first time by the Laser Interferometer Gravitational-wave Observatory (LIGO) only in September of 2015. Together with partners around the world, the Birmingham group has played a key role in building the LIGO instruments, analyzing the LIGO data, and interpreting the observational results.

The detection of gravitational waves from two merging black holes, each with a mass 30 times that of the Sun, ushered in a new era of gravitational-wave astronomy. This project will give you the opportunity to explore this new and exciting field.

The goals of this project are to search for gravitational waves in noisy data; to infer the properties of the sources from their gravitational-wave signature using sophisticated modern statistical techniques; to make predictions for how merging binary black holes, such as those observed by LIGO, could be formed; and to predict how often we expect to detect such sources in the future.

To be successful in this project, you do not need to be an astronomer, though some knowledge of astrophysics would be helpful. On the other hand, good programming skills and solid analytical ability will prove essential.

Staff: Prof Alberto Vecchio, Dr Christopher Berry, Dr John Veitch

Medical Imaging

This year the Medical Imaging Group Study will focus on the design, construction, testing, and image reconstruction of a Compton Camera. The project has been proposed by colleagues from the Medical Physics Department of the University Hospitals Birmingham NHS Foundation Trust who are particularly interested in the development of improved diagnostic imaging for medical applications. As an industry partner they will clearly have a genuine interest in the outcome of the project and will give you feedback on your accomplishments at your final presentation. This type of project gives you valuable experience of working in a professional environment, in addition to the experience of working as part of a larger research team.

Compton Cameras are imaging devices that use a position sensitive scattering detector and a separate energy detector to locate the position of an X-ray or gamma-ray emitting source. As you will know, the energy of a Compton scattered photon depends on the angle through which the photon is scattered. If this information is combined with the location of the scatter, the source is constrained to lie on the curved surface of a cone whose apex is the point of scatter. The axis of the cone is defined by the line between the point scatter and the point at which the scattered photon is detected. Successive measurements will result in multiple cones whose intersection reveals the location of the source.

Last year, the project developed along two distinct but interrelated strands: Experimental investigation into Compton Cameras and their components and software development to model the experimental work as well as analyse the experimental results.

This year, one sub-group might wish to perform a literature survey of existing Compton Cameras and build a simple Monte-Carlo computer model that can be used to investigate how the geometry of the camera, the position and energy resolution of the measurement determine the position resolution of the device.

Related to Task 1, a separate sub-group might like to develop a proof-of-principle Compton Camera using equipment available in the undergraduate third year Nuclear Laboratory. Some careful consideration will have to be given to the construction of the device, the data acquisition system and data analysis software. The model developed in Task 1, can be used to optimise the design of

a conceptual detector and provide a benchmark for the proof-of-principle device constructed in Task 2.
A further sub-group could investigate novel detection systems not regularly used in the labs, including, but not limited to: a pixilated scattering detector; the impact on detector sizes and exotic materials; changing the number of detectors, or using different readout electronics.

The development of complex reconstruction algorithms to demonstrate the viability the device designed and constructed by the other sub-groups is essential. This is both mathematically and computationally challenging, and, as such may require students from these backgrounds.

To be a success the project will require students with a variety of strengths from deep theoretical understanding or the problem, to excellent experimental skills, to writing complex computer programmes and reconstruction algorithms.

Staff: Prof David Parker, Dr Garry Tungate, Dr Tony Price, and Mr Stuart Pirrie

Nanoscale Physics

Nanoscale Physics investigates properties of structures smaller than 100 nm. At this scale the properties of materials change and might differ considerably from their bulk properties. There are various experimental methods available to observe nanoscale effects, some of them relatively new like the Scanning Tunnelling Microscope, Confocal Microscope and Atomic Force Microscope, while others are more traditional but may be equipped with modern technology that enables us to observe the very fine interactions frequently displayed by nanoscale materials. Arguably the most common methods are those investigating the optical properties of nanoscale materials and almost any lab or company that deals with nanoscale materials employs optical methods of some sophistication. This Group Study aims to introduce students to the ways of developing those optical methods to investigate novel physics at the nanoscale. These methods will be applied to the investigation of surface plasmons, one of the most exciting subjects in nanoscale physics.

This Group Study consists of two projects connected by the similarity of the experimental methods that will be used and the underlying fundamental physics. The desirable outcome of the study is the construction of a combined experiment for the investigation of surface plasmons by the members of both projects.

Project A: *Experimental set-up for investigation Surface Plasmons*
Surface plasmons can be viewed as an electromagnetic wave propagating at the interface between two dielectrics with opposite signs of their dielectric functions, for example glass/metal. The most exciting feature of the surface plasmon is an amplification of the electric field of the incoming light. This may be used for the detection of weak signals in optical spectroscopy. However, special methods are needed to excite the surface plasmon with light. The main aim of this project is to construct an experimental set-up that allows investigation of the surface plasmon. Students will be provided with the necessary theoretical and experimental background to enable them to complete the task. The bulk of the work is experimental, though it is expected that the students will be able to use theory to evaluate the experimental results.

Project B: *Experimental set-up for measurements of Faraday rotation*
Faraday rotation is the rotation of the plane of polarization when light propagates through transparent media subject to a magnetic field. In early

times it was used to demonstrate the electromagnetic nature of light while more recently it has been used in magneto-optical devices, for example optical isolators.

In the first stage of this study students learn about Faraday rotation by constructing an experiment from components available in the lab. The second stage involves the design and construction of a Faraday rotator and measurements of the effect in a cell of liquid materials. After this stage it is expected that students will attempt to measure the effect in nanoparticles suspended in a liquid, that is a nanoparticle colloidal solution.

Project A and Project B joint venture
Faraday rotation can be used to modulate the polarization state of light. Thus, the students from Project B can provide the students from Project A with a light source with a modulated state of polarization. The measurements of the surface plasmon can be repeated with this new source, greatly enhancing the resolution of the experiment.

Learning outcomes**:** resonators (electrical circuits and optical), polarization properties of light, interaction of light with media, magneto-optical effects – Faraday rotation, interaction of light with metal surfaces, surface plasmons, introduction to nanophotonics.

Skills: basic programming in Matlab and LabView, design of electric circuit resonators, understanding of basic optical components – polarizers, beam splitters, lenses, basic design of optical systems, lock-In detection techniques, automation of measurements.

Staff: Dr Andrey Kaplan

Particle Physics

Particle Physics is about challenging our understanding of the structure of matter and its relationship to the forces of nature at the most fundamental level possible. We collide very high-energy particles in accelerators, for example proton-proton collisions at the Large Hadron Collider (LHC), and use state-of-the-art detectors to measure the decay products from these collisions.

The observation of the Higgs boson, announced in 2012, is the highest profile discovery so far at the LHC. Since then much progress has been made to determine its properties, in order to establish whether it is the Higgs boson predicted by the Standard Model of Particle Physics. However, these measurements need to be made more precise and some of the less common Higgs decay modes have yet to be seen. Searches also continue at the LHC for exotic new particles or physical phenomena beyond those within the Standard Model, for example for signs of possible dark matter production and decay.

To pursue these investigations further, the LHC will be upgraded within the next decade, so that it can be operated at higher luminosity (i.e. rate of collision), with the goal of increasing the amount of data collected by a factor of ten. Beyond that, there is also a proposal to upgrade the LHC to collide proton beams at over twice the current centre-of-mass energy, to increase the potential for new physics discoveries.

The aim of this Group Studies project is to design detectors and to evaluate their physics potential for experiments at the high-energy LHC, in particular measurements of Higgs properties and searches for exotic particles. This will require you to consider the physics that can be carried out, the precision with which measurements can be made and the theoretical implications of these in terms of advancing the field. You will need to understand how particle detectors work and the associated technology required, and use these to determine the potential to reveal new physics.

You will work together in collaboration, but each student will need to become an expert in at least one aspect of the particle physics and also in one component of the detector (in much the same way that a team of particle physicists usually works).

The factors you will need to study are the underlying physics of both Standard Model and exotic processes, their main backgrounds and other possible limitations to measurements and discoveries. You should consider which particles you may expect to see and how they can be detected. This will require some understanding of how the proton beams are accelerated and brought into collision, and how the interactions are recorded. You will need to study simulated data for both the underlying physics processes and also for the passage of particles through detectors. The results of these physics analyses should be used to guide your design evaluations and decisions.

Staff: Dr Chris Hawkes, Dr Juraj Bracinik, Dr Jacob Kempster and Dr Evgueni Goudzovski

Photonics

The aim of this Group Study is to gain an insight into the physics and technology underlying long distance telecommunications. There is a substantial amount of enjoyable experimental work involved in this Group Study.

At present when we speak to someone on the other side of the Atlantic by telephone our conversations are encoded into changes in amplitude or frequency of electromagnetic radiation at a wavelength of around 1550 nm. These are then dispatched along fibre-optic waveguides that have been laid on the bed of the Atlantic Ocean. Clearly there are many challenges associated with such a scheme; for example, the signals need to be decoded satisfactorily avoiding an unacceptable loss of information. In addition the strength of the signals is attenuated with distance by various loss mechanisms in the fibres and thus the signals need to be boosted at intervals of a few km. However there is a need to make the communication link as efficient as possible by maximising the number of conversations that can be sent simultaneously down a single fibre. We can make a rough estimate of this number by assuming that the frequency width of one conversation is 1 kHz and that the frequency of the infrared radiation is about 200 THz. This gives a potential of some 2×10^{11} simultaneous conversations! Unfortunately, in order to take advantage of this possibility, we need to pick out each individual conversation with its own 'carrier' frequency with a resolution of 1 kHz in 200 THz! Further this has to be done independently on each side of the Atlantic. Clearly both the receiver and sender will have to use some sort of stable frequency standard as a reference. This is a current topic in telecommunication technology. One solution, which we examine in the Group Study, is the use of a frequency reference based on an atomic transition.

The final, but very ambitious goal of the project is shown in Figure 1 below. The laser has a wavelength of 1560 nm and its emission is split between a communication beam and another that is used to stabilise its wavelength using an absorption line of Rubidium. The EDFA is an Erbium doped fibre amplifier and the $LiNbO_3$ is a Lithium Niobate crystal that is used to double the frequency of the laser source.

One possibility is to split into three subgroups that could work on the following topics: one group will construct a laser whose frequency is 'locked' by feedback to one of the transitions around 780.2 nm in Rubidium. A second group will work on frequency-doubling the radiation from a telecom laser from 1560 to

780 nm, which can then be stabilised to the Rubidium cell. Finally a third group can investigate methods of sending information via laser light using frequency modulation techniques.

Figure 1. Schematic of a telecommunications system based upon the Rubidium frequency standard.

There is a large amount of physics involved in this project such as the non-linear optics involved in frequency doubling, the physics of the Rubidium atom (some of you may have come across this in the Photonics Lab), the physics of lasers, interaction of light with acousto-optic modulators, understanding of the propagation of beams with a Gaussian profile (simple laser beams), servo systems … etc. The aim of the study is to explore these physical ideas and techniques, to learn about them and to gain an understanding of them. These objectives can be achieved without necessarily reaching the final ambitious goal shown in figure 1!

Staff: Prof Shuang Zhang, Dr Vincent Boyer, Mr Andrew White

Radar and Remote Sensing

Passive Radar with Spaceborne Illuminators of Opportunity (IoO) for Maritime Targets Detection

Brief description:
The last decade has seen a surge of research dedicated to investigation of the Passive Coherent Location systems (PCL)[1] or Passive Radars for surveillance of the area and objects detection and tracking. In contrast to a conventional radar where the active transmitter and the receiver are collocated and the waveform and hardware are at the designer's control, PCL use transmitters of opportunity such as FM radio, DAB and DVB-T broadcasting stations and process reflections of such signals from objects in a surveillance area. For the ground or above ground surveillance such terrestrial sources of Electromagnetic Waves (EMW) emission are proven to be effective and there is an intensive research in this area with a large number of comprehensive publications. However, what if the surveillance area is far away from the reach of the signals from the terrestrial transmitter, such as ocean, remote mountains or polar areas? The solution is to use transmitting systems which provide global coverage, such as constellations of mobile communication satellites (Inmarsat, Iridium, GlobalStar, etc.) and/or global navigation satellites (GPS, Galileo, Glonass, etc.).

In contrast to PCL based on terrestrial Illuminators of Opportunity (IoO), passive radar with spaceborne IoOs is new area of research and the Microwave Integrated System Laboratory (**MISL**) is leading research group working in this area. You will be part of a research in this fascinating area of modern science where your skills in Physics and Mathematics are relevant.
It is assumed that the student groups will work in four thematic areas required to evaluate feasibility of PCL based on spaceborne IoOs, undertaking an appropriate mix of theoretical, modelling and signal processing tasks. In case of a smaller number of students, only three themes (1-3) will be considered. Two IoOs will be investigated in the project: **Inmarsat** Communication Satellite System (I-4 and I-5) and **Galileo** Global Navigation Satellite System. Involvement in this project means that you will also work with passive radar data acquired through dedicated experimental campaigns with our custom-built radar receivers.

Themes:

Investigation of the satellites systems and their emitted signals (Supervisors – MA for Galileo; MG for Inmarsat, CB – overview of PCL and available IoOs)

a) Satellite parameters, including the payload parameters, operational topology (beams, illuminated footprint, Look Angle Map**)** and system evolution.
b) Emitted (downlink) signals analysis (frequency allocation, channelization)
c) and computer modelling.
d) Emitted signals recording and pre-processing (synchronisation, etc.)
e) Comparison of simulated and experimental data.
f) Autocorrelation and Ambiguity functions of the signals.

1 "Bistatic Radar: Emerging Technology", M. Cherniakov (ed), Wiley, 2008, chapter 7, pp.247-311

System Structure and power budget analysis (MC, CB)

This theme considers whole PCL system parameters required for the proposed technology. These include:

a. PCL system topology (IoO – scatterer – receiver) and evaluation of bistatic parameters affecting the radar performance.
b. Power budget analysis using information from Theme 1.a (Transmission path length, attenuation for different Earth regions). This will inform specifications, G/T ratio and design of passive receiver.
c. Basic design and specifications of receiver to provide for the area surveillance and detection of the object of specified Radar Cross Section.
d. Analysis of maritime objects to be detected and bistatic Radar Cross Section estimation.

Signal processing: targets detection and trajectory estimation (Supervisors: MG for Inmarsat; MA for Galileo, CB). The students will be supplied with real radar data.

According to the system structure (see item 2) and the signal structure (see item 1) develop signal processing algorithms in MATLAB:

a) Coherent and non-coherent processing. Integration time.
b) Correlation of the Reference signal (Synchronization channel) with the Radar channel received signal, i.e. optimal signal processing.
c) The signal visualization in Doppler-Time domain.
d) Range-Doppler tracking and trajectory estimation

Maritime scenario simulation (Supervisors: MG,MA, CB, MC)

This theme deals with the modelling of the maritime scenario with single and multiple ships given their positions and trajectories with respect to passive receiver.

a) Synchronization signal modelling according to the information in sections 2 and 3 for both Galileo and Inmarsat.
b) Scenario setting using Google Earth coordinates. The radar channel signal will be modelled with estimated delay times, Doppler shifts, propagation losses and RCS (informed by 2(d)) added to synchronization channel.
c) The simulated scenario visualization in Doppler-Time domain informed by developments in section 3.

Overall project coordination: (MA)

Theme 1: Satellite as IoO: **MG**, MA, CB
Theme 2: System design: **MC**, CB,
Theme 3: Signal processing: **MA**, MG,CB
Theme 4. Maritime scenario simulation (CB, MG,MA,MC)

Staff: Dr. Mike Antoniou (MA)- Lead, Prof. Marina Gashinova (MG), Prof. Mike Cherniakov (MC), Prof. Chris Baker (CB).

Robotics

Teaching a humanoid robot how to use a swing

Similar to riding a bike, retaining and increasing a swinging motion on a swing is something we learn by trial-and-error. In doing so, we test and optimise a feedback strategy. This is in contrast to trying to gain the ability to pre-plan a timed sequence of motions, which would not succeed for these types of tasks. Only after having learned these skills can we observe ourselves performing them and analyse the underlying principles of the motions.

This group study explores the physical principles involved in using a swing, both in starting the motion from rest and keeping it going in a stationary mode. This insight is to be applied to enable a humanoid robot to use a swing. One of the main challenges of this group study is to manage the overall project and the different threads of the project proactively to ensure that available resources (such as students' time) are used efficiently.

The students will have available a NOA robot with programming suite, a swing specifically built for the robot, and simulation software (Webots7) for a virtual environment of mechanical constructs and the robot. Further equipment can be sourced or designed and built to meet the needs of the project. Examples would be cameras for video tracking, and mechanical realizations of simple model systems to verify numerical simulation code and explore feedback strategies.

The Robotics Group Study is intended to build on past achievements from year to year. Thus, the purpose of the students' project report is to summarise progress and newly gained insights and to provide a useful hands-on document for the following years.

As any other, this group study would benefit from a group of students encompassing a diverse set of individual interests, expertise and skills. In addition, it would be useful if expertise/aptitude in computer science, programming, numerical simulation, theoretical mechanics, and experimental physics were represented in the group.

Staff: Dr Wolfgang Theis, Dr Ken Elliott, and Dr M. Navarro-Cia