AS4010 Extragalactic Astronomy

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				
This module introduces the basic elements of extragalactic astronomy. This includes the morphological, structural and spectral properties of elliptical, spiral, quiescent and star-forming galaxies. We study how galaxy populations change from the distant galaxies in the early Universe into those observed in our local neighbourhood, including the coincident growth of super massive black holes at the centres of massive galaxies. Galaxy formation theory is introduced in relation to the growth of structure in a cold-dark matter Universe, and galaxy evolution in regions of high and low density is investigated. The module includes a look at modern instrumentation used in extragalactic astrophysics. Specialist lecturers from within the galaxy evolution research group will provide a direct link between material learnt in lectures and research currently being undertaken at the University of St Andrews. Students will engage in an assessed mini research project throughout the semester (computer based, in Python).				
Pre-requisite(s):	Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and pass MT2501 and pass MT2503			
Anti-requisite(s)	You cannot take this module if you take AS4022			
Learning and teaching methods of delivery:	**Weekly contact**: 1 or 2 x 1hr lectures x 10 weeks, 1 hr tutorial x 6 weeks, 1hr seminar x 3 weeks, 1hr computational hack session x 4 weeks			
Assessment pattern:	2-hour Written Examination = 80%, continual assessment (Computer Based Assignment) = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr R M Fernandes Tojeiro Reynolds			
Additional information from Schools:	**AS4010 - Extragalactic Astronomy** **Aims & Objectives** To be able to appreciate the various aspects of galaxy formation and evolution, and apply them to outcomes of modern extragalactic research activities. **Learning Outcomes** • be able to obtain galaxy properties from observational evidence • be able to describe the differences in galaxy populations and properties over the course of the Universe in terms of galaxy evolution • be able to describe the formation of galaxies in terms of observational cosmology • be able to apply basic physical principles to galaxy evolution and formation processes • be able to apply material covered in the lectures to current research activities in extragalactic astrophysics **Synopsis** Galaxy Observations: Spectral Energy Distributions and Star Formation Histories Galaxy Observations: Scaling Laws and Dynamics Observational Cosmology Galaxy Formation and Evolution Supermassive Black Holes and Active Galactic Nuclei **Additional information on continuous assessment etc.** Coursework involves a computational exercise based in Python (20%). **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4010.html **General Information**			

	Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS4011 The Physics of Nebulae and Stars 1

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				
This module introduces the physics of astrophysical plasmas, as found in stars and interstellar space, where interactions between matter and radiation play a dominant role. A variety of absorption, emission, and scattering processes are introduced to describe exchanges of energy and momentum, which link up in various contexts to control the state and motion of the matter, to regulate the flow of light through the matter, and to impress fingerprints on the emergent spectrum. The theory is developed in sufficient detail to illustrate how astronomers interpret observed spectra to infer physical properties of astrophysical plasmas. Applications are considered to photo-ionise nebulae, interstellar shocks, nova and supernova shells, accretion discs, quasar-absorption-line clouds, radio synchrotron jets, radio pulsars, and x-ray plasmas. Monte-Carlo computational techniques are introduced to model radiative transfer.				
Pre-requisite(s):	Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and (pass MT2001 or pass MT2501 and pass MT2503) and pass PH3081 or pass PH3082 or pass MT2003 or (pass MT2506 and pass MT2507)			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 10 weeks			
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr K Wood			
Additional information from Schools:	**AS4011 - The Physics of Nebulae and Stars 1** **Overview** The gas that lies between the stars takes many forms. From the dense, cold molecular clouds in which stars are conceived to the rarefied ionized plasma of HII regions, escaping photons carry information about their nature to distant parts of the Universe, a few of which contain astronomers. Astronomers unravel the nature of these gas clouds by catching photons whose last physical interaction was usually with an atom or ion in the cloud itself. The material with which the radiation last interacted imprints clues to its physical nature on this radiation. To find out the temperature, density, chemical abundance and ionization state of the cloud we must understand how matter behaves in a radiation field: how photons and inter-particle collisions can trigger transitions between different excitation and ionization states in atoms and molecules, and how these transitions create or destroy the photons that we eventually see. **Aims & Objectives** To present an introductory account of radiation transfer and its application to gaseous astrophysical systems, including • The definitions of the basic radiant quantities and the equation of radiation transfer. • The use of the Boltzmann and Saha equations to compute level populations and ionization equilibria - The Einstein relations and their role in computing line opacities and emissivities, • The Planck function and its properties,			

	• The various types of atomic and molecular line transitions and broadening mechanisms encountered in nebulae, • The application of these theories to molecular clouds, HII regions and planetary nebulae. **Learning Outcomes** By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and will be able to: • Define and use the basic radiant quantities such as specific intensity, mean intensity, flux and radiation pressure of a radiation field; • Differentiate and integrate the Planck function to obtain Wien's Law and the Stefan- Boltzmann Law, • Use the Boltzmann equation, the Saha equation and the Einstein relations to determine level populations and ionization balance both in and out of thermodynamic equilibrium, • Use the equation of radiative transfer to solve for simple geometries how the emergent intensity of a beam of radiation is modified by emitting and absorbing material along its path, • Define the photon mean free path and optical depth, and distinguish between optically thick and optically thin media, • Distinguish between radiatively and collisionally induced transitions, and state their importance in relation to the global energy balance of a body of gas, • Distinguish between natural, collisional and thermal broadening mechanisms in spectral lines, • State the importance of ionization fronts, use the jump conditions to distinguish between R- and D-type fronts, and understand their importance in the evolution of an HII region. • Distinguish between recombination-spectrum formation in Case A and Case B, and use Balmer-line fluxes and line ratios to determine total ionizing flux and interstellar extinction in Case B, • Use simple atomic theory to demonstrate the usefulness of transitions between low-lying levels of common collisionally-excited species as density and temperature diagnostics in emission-line nebulae, • Use radio brightness temperatures of a background source and foreground nebula to determine nebular temperature, • Distinguish the various types of transition for simple molecules, and recognise their importance as coolants in star-forming regions, • Understand basic principles behind Monte Carlo radiation transfer scattering codes including sampling for direction of emission, optical depths, and scattering angles, • Outline a Monte Carlo scattering code and develop Monte Carlo estimators for the intensity moments of the radiation field showing how they relate to formal definitions. **Synopsis** Definitions of basic radiant quantities. Opacity and emissivity. The equation of radiative transfer. Source function and optical depth. Black-body radiation and the diffusion approximation. Atomic and molecular processes: bound-bound, bound-free and free-free transitions, electron scattering, Boltzmann and Saha laws, the Einstein coefficients and their relation to emission and absorption coefficients and to blackbody radiation. Masers. Line-broadening mechanisms. Stromgren spheres, protoplanetary discs. Derivation of jump conditions across ionization fronts using conservation of mass, momentum and energy. Thermal equilibrium between ionization and cooling via photon escape in nebulae. Collisional cooling and detailed balance; hydrogen recombination spectrum in Case A and Case B; common line-ratio and radio diagnostics for nebular temperature and density. Rotational and vibrational spectra and selection

	rules in molecules. Monte Carlo radiation transfer, sampling from probability distributions, estimators for intensity moments of the radiation field, scattering codes. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The 25% continuous assessment is expected to take the form of writing Monte Carlo radiation transfer computer programs, building on what is taught in class. This homework will be issued around week 5 with a deadline around two weeks later. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4011.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS4012 The Physics of Nebulae and Stars 2

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

This module develops the physics of stellar interiors and atmospheres from the basic equations of stellar structure introduced in AS2001/AS2101 using the radiative transfer concepts developed in Nebulae and Stars I. Topics include: the equation of state that provides pressure support at the high temperatures and densities found in normal and white-dwarf stars; the interaction of radiation with matter, both in terms of radiation-pressure support in super-massive stars and in terms of the role of opacity in controlling the flow of energy from the stellar interior to the surface; the equation of radiative transfer and the effects of local temperatures, pressures and velocity fields on the continuum and line absorption profiles in the emergent spectrum. Computer-aided tutorial exercises illustrate the computational schemes that represent one of the triumphs of late twentieth-century physics, in their ability to predict the observable properties of a star from its radius and luminosity, which in turn are determined by its mass, age and chemical composition.

Pre-requisite(s):	Before taking this module you must pass AS4011
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr P Woitke
Additional information from Schools:	To be confirmed

AS4015 Gravitational and Accretion Physics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

This theoretical module is open to both physics and astrophysics students. It aims to explore the basics of gravitational dynamics and its application to systems ranging from planetary and stellar systems to clusters of galaxies. The dynamics responsible for the growth of super-massive black holes in galaxies and the accretion discs in stellar systems are also covered. Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Applications of these methods are made to several different astrophysical objects ranging from collisions in globular clusters to the presence of dark matter in the universe.

Pre-requisite(s):	Before taking this module you must pass PH2011 and pass PH2012 and pass MT2501 and pass MT2503 and (pass PH3081 or pass PH3082 or pass MT2506 and pass MT2507)
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr H Zhao
Additional information from Schools:	**AS4015 - Gravitational and Accretion Physics** **Aims & Objectives** To present an overview of the importance and relevance of gravitational process in astrophysics, including how gravity relates structures with kinematics and the long-term evolution of such structures due to gravitational interactions. The module also aims to provide a basic understanding of how astrophysical discs work and provide an insight into how compact astrophysical objects form and obtain their characteristic masses be they planets, stars or black holes. **Learning Outcomes** By the end of the module the student should be able to: Apply potential theory to gravitational systems. Relate kinematics to mass distributions in extended objects like clusters and galaxies. Determine how gravitational interactions drive the evolution of self-gravitating systems. Model the structures and evolution of astrophysical discs. Understand the statistical treatment of a large-N system Use the Jeans equations to determine mass distributions from observable properties. Model accretion processes and how these relate to the luminous Universe. **Synopsis** Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Applications of these methods are made to several different astrophysical objects ranging from collisions in globular clusters to the presence of dark matter in the universe. The physics of accretion and accretion discs is developed with emphasis on disc

	structures, accretion through the disc and the ability of discs to form smaller mass objects such as planets. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4015.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS4025 Observational Astrophysics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

This is an observational and laboratory-based module that introduces students to the hands-on practical aspects of planning observing programmes, conducting the observations and reducing and analysing the data. The exact topics covered may change annually depending on resource availability; examples include galaxy imaging and exoplanet transits. Sources of data may include telescopes at the University Observatory and/or international observatories. Students gain experience in observation, data analysis, the Linux operating system, standard astronomical software packages and modelling, and report writing

Pre-requisite(s):	Before taking this module you must (pass AS2001 or pass AS2101) and pass PH2011 and pass PH2012 and (pass MT2001 or pass 2 modules from {MT2501, MT2503})
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 3.5hr x 10 weeks supervised work
Assessment pattern:	Coursework = 100%
Re-assessment pattern:	No Re-assessment available - laboratory based
Module coordinator:	Professor A C Cameron
Additional information from Schools:	- **AS4025 - Observational Astrophysics** **Overview** Astrophysics is an observational, rather than an experimental, science. Nearly all the information that astronomers can gather about the Universe at large and the objects within it comes to us in the form of electromagnetic radiation. In this course students will gain an understanding of the observational work required for astronomical research. **Aims & Objectives** The aim of this module is to familiarise students with a wide range of observational techniques in astronomy and astrophysics. Students will gain practical experience in instrument building planning, documenting and conducting astronomical observations, data analysis, and report writing. **Learning Outcomes** By the end of the module, students should have a comprehensive knowledge of basic ground-based observational techniques and data-analysis methods and be able to:

	• Plan a set of observations. • Acquire optical images of various astronomical objects, including the necessary calibration data. • Perform photometry using standard astronomical software packages under the Linux operating system. • Carry out the basic reduction and advanced analysis of optical images. • Record and write up results in a professional manner. **Synopsis** This module provides an overview of the practical part of research in observational astronomy. Students learn how to plan observations with telescopes at the university observatory, followed by data reduction and analysis. The exact topics covered may change annually: examples include galaxy imaging, exoplanet transits and constructing and observing with radio telescopes. Further sources of data may be made available from international observatories. Students gain experience in observation, data analysis, the Linux operating system, standard astronomical software packages and modelling, and report writing. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can expect to commit about 14 hours a week to the module in weeks 1 to 11, including the scheduled afternoon. This module has two assessed assignments, which are likely to be due in weeks 5 and 11. This module is 100% continuously assessed. The continuous assessment is expected to take the form of formal writeups, one for each observing "lab," and lab book quiz(zes). The first writeup is a collaborative small-group report; the other report is written individually by each student. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as4025.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS5001 Advanced Data Analysis

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is intended for students in the final year of an MPhys or MSci programme involving the School, students on MSc Astrophysics, and students on EngD Photonics.			
Planned timetable:				

This module develops an understanding of basic concepts and offers practical experience with the techniques of quantitative data analysis. Beginning with fundamental concepts of probability theory and random variables, practical techniques are developed for using quantitative observational data to answer questions and test hypotheses about models of the physical world. The methods are illustrated by applications to the analysis of time series, imaging, spectroscopy, and tomography datasets. Students develop their computer programming skills, acquire a data analysis toolkit, and gain practical experience by analyzing real datasets.

Pre-requisite(s):	Familiarity with scientific programming language essential, for example through AS3013 or PH3080. Entry to an MPhys programme in the school or MSc Astrophysics.
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lectures x 5 weeks, 2 x 1hr office hours x 5 weeks, 1hr Q&A x 5 weeks
Assessment pattern:	Coursework = 100%
Re-assessment pattern:	No Re-assessment available - laboratory based
Module coordinator:	Professor K D Horne
Additional information from Schools:	**AS5001 - Advanced Data Analysis** **Overview** Astronomers and other physical scientists fit models to quantitative observational or experimental data in order to answer questions about the physical world. Data are always affected by measurement errors, leaving uncertainty in the answers to questions posed. Probability theory provides a precise language for discussing and expressing those uncertainties. Statistical data analysis provides practical tools for posing questions and teasing answers from the data. Analysis of real datasets is the best way to build expertise in quantitative data analysis. **Aims & Objectives** To develop an understanding of basic concepts and offer practical experience with the techniques of quantitative data analysis. **Learning Outcomes** By the end of the module, students should be comfortable with the concepts of probability theory and statistics, familiar with techniques for quantitative data analysis, and confident in their ability to tackle data analysis problems in physics & astronomy or wherever they may arise in their future work. **Synopsis** Beginning with fundamental concepts of probability theory and random variables, practical techniques are developed for using quantitative observational data to answer questions and test hypotheses about models of the physical world. The methods are illustrated by applications to the analysis of time series, imaging, spectroscopy, and tomography datasets. Students develop their computer programming skills, acquire a data analysis toolkit, and gain practical experience by analyzing real datasets. The module is assessed continuously on the basis of exercises and projects. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This module has two homework sets and two projects involving a mix of analytic work and computer analysis of datasets provided. Homework 1 issued at start of Week 1, due start of Week 4. Homework 2 issued at start of Week 4 due end of Week 6. Project 1 issued in Week 6, due at end of Week 9. Project 2 issued in Week 6, due at end of Week 11. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can expect to commit about 14 hours a week to the module in weeks 1 to 11, including the hours scheduled in lectures and for independent work on the assignments. Students are invited to use whatever programming tools or languages they deem to be most efficient for them in working on the assignments. MPhys students are reminded that if they choose multiple 'no-exam' modules then they will inevitably have a higher workload per week during weeks 1 to 11 than if they chose modules where some of the 150 hours was spent in the revision and exam weeks. **Recommended Books** Please view University online record:

	http://resourcelists.st-andrews.ac.uk/modules/as5001.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS5002 Magnetofluids and Space Plasmas

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is intended for students in the final year of an MPhys or MSci programme involving the School, and for those on the Astrophysics MSc			
Planned timetable:				
This module is aimed at both physics and astrophysics students with interests in the physics of plasmas. The interaction of a magnetic field with an ionized gas (or plasma) is fundamental to many problems in astrophysics, solar- terrestrial physics and efforts to harness fusion power using tokamaks. The syllabus comprises: Solar-like magnetic activity on other stars. The basic equations of magneto-hydrodynamics. Stellar coronae: X-ray properties and energetics of coronal loops. Energetics of magnetic field configurations. MHD waves and propagation of information. Solar and stellar dynamos: mean field models. Star formation: properties of magnetic cloud cores, magnetic support. Physics of accretion discs: transport of mass and angular momentum. Accretion on to compact objects and protostars. Rotation and magnetic fields in protostellar discs. Rotation distributions of young solar-type stars. Magnetic braking via a hot, magnetically channelled stellar wind.				
Pre-requisite(s):	Before taking this module you must pass 1 module from {PH3007, MT4510, MT4553} and pass 1 module from {AS3013, PH4030, PH3080, MT3802, MT4112}			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks			
Assessment pattern:	2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor M M Jardine			
Additional information from Schools:	**AS5002 - Magnetofluids and Space Plasmas** **Overview** The interaction of a magnetic field with an ionised gas (or plasma) is fundamental to many problems in astrophysics. Star formation in particular is heavily influenced by the magnetic fields of molecular clouds, and once stars form they can, if they posses a convective region, generate their own magnetic fields by dynamo activity. The behaviour of this magnetic field is at the heart of many of the most interesting observations of young stars and their accretion disks. This module is suitable for physics students as well as astronomers. PH4031 Fluids or MT4509 Fluid Dynamics are recommended as prior study. **Aims & Objectives** To present an account of the theory and observations of magnetic activity in solar-like stars, including an introduction to magnetohydrodynamics, the physics of heating stellar coronae to temperatures of 10^6K, the generation of stellar magnetic fields by dynamo action, the role of magnetic fields in star formation, the physics of accretion disks, stellar spin down by accretion disks and stellar winds. **Learning Outcomes** By the end of the module students should have an understanding of the physics of stellar magnetic fields as presented in the lectures and should be able to • Describe the main observational signatures of magnetic activity			

	• Use the magnetohydrodynamic equations describe the behaviour of simple magnetic field configurations • Give an account of the heating of stellar coronae and derive the scaling relations for pressure, temperature and length of magnetic loops • Describe the main observational features of solar and stellar dynamos and calculate the characteristics of a simple kinematic solution • Use the Virial theorem to explain the characteristics of magnetic support of molecular clouds and the onset of cloud collapse • Demonstrate the role of viscosity in accretion disks and determine the temperature profile of such a disk • Use torque balance in an accretion disk to explain stellar spin-down by star-disk coupling • Use conservation of mass and momentum to derive Parker's wind solution and describe the role of magnetic channelling in a rotating star • Determine the angular momentum loss rate for simple examples **Synopsis** Review of observations of stellar magnetic activity. Equations of magnetohydrodynamics (MHD) Heating of stellar coronae. Reconnection. Energetics of coronal loops and the role of rotation MHD waves and propagation of information. Solar and stellar dynamos (mean field models). Star formation: properties of magnetic cloud cores, magnetic support and the Virial theorem. Accretion disks: transport of mass and angular momentum, role of viscosity. Temperature profiles. Stellar spin down by magnetic star-disk coupling. Rotation distributions of young solar-type stars. Magnetic braking by stellar winds. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5002.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS5003 Contemporary Astrophysics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to MPhys Astrophysics or MSc Astrophysics students.			
Planned timetable:				
This module will provide an annual survey of the latest, most interesting, developments in astronomy and astrophysics at the research level. Emphasis will be placed upon the application of knowledge and expertise gained by students in their other modules to these current research topics.				
Pre-requisite(s):	For MPhys: before taking this module you must pass AS4010, AS4012, PH3061 and PH3081. For MSc: students must have substantial astronomy knowledge and skills.			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 7 weeks, 1hr workshop x 1 week, 1hr Q&A x 1 week			
Assessment pattern:	2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr H Zhao			
Additional information from Schools:	**AS5003 - Contemporary Astrophysics** **Overview**			

	Astrophysics is a constantly changing field in which new observations and theories are continually revising our knowledge and outlook. This course provides a view of research level astrophysics and the opportunity to apply the accumulated knowledge of the astrophysics degree to new problems. **Aims & Objectives** To introduce the students to research level astrophysics including several independent topics of current research. To use the knowledge base, applied to novel problems. To familiarise the students with the process of modelling physics in astrophysical contexts. **Learning Outcomes** The student will be able to use his/her accumulated knowledge and apply it to topics of current astrophysical research. Specifically, the student will be able to comprehend the primary concepts in research level astrophysics topics; formulate an approach to novel and unsolved problems; understand the different techniques and approaches used in various topics; make critical judgement of the merit of research papers in astrophysics. **Synopsis** This is a continually evolving module that introduces the student to two or three main topics of astrophysical research. Topics covered are selected by the teaching staff, and may include dynamics, gravitational lensing, general relativity, cosmological simulations, planet formation and young stellar objects, exoplanets, stellar activity, stellar and planetary atmospheres, interacting binaries, astrophysical discs, active galactic nuclei. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5003.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

AS5500 Research Skills in Astrophysics

SCOTCAT Credits:	30	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				

This module will provide the basic astrophysical background and will introduce students to the research skills needed for a career in astrophysics. The module consists of a series of introductory lectures and practicals on basic astrophysical concepts, followed by a tutorial-based system to introduce the skills of astrophysical research. These skills include the critical analysis of the scientific literature; presenting research topics and results to a scientific and general audience; a basic computational competence; and undertaking novel research in areas of current astrophysical interest, potentially including science education and public outreach. In Semester 1 students will attend weekly AS5500 meetings and work on research skills assignments. Students work 'half-time' on their project through semester 2. All students must meet weekly

with their project supervisor and attend the weekly AS5500 meetings. Most projects are based in research groups in the School, where students can benefit from peer support and informal interaction with academic supervisor and other members of research teams. It is expected that the 20 hours a week will be primarily in this environment.	
Pre-requisite(s):	Students must be registered on MSc Astrophysics.
Learning and teaching methods of delivery:	**Weekly contact**: S1: 1hr tutorial x 10 weeks, 3hr presentation session x 1 week, 1hr research seminars x 10 weeks. S2: 1hr tutorial x 10 weeks, 3hr presentation session x 1 week, 1hr research seminar x 10 weeks, 1hr supervisor meeting x 11 weeks
Assessment pattern:	Coursework = 100%
Re-assessment pattern:	Coursework = 100%
Module coordinator:	Dr A Weijmans
Additional information from Schools:	**AS5500 - Research Skills in Astrophysics** **Overview** This module prepares students for carrying out an astrophysical research project, by concentrating on research and communication skills. These skills feature in assignments that are continuously assessed over the course of the two semesters. The first semester concentrates on literature searches and comparisons, presentation skills and astrophysical background. The second semester features a small research project that the students will carry out under supervision of a staff member. This module contains both lectures, where concepts are introduced, and tutorial sessions where the students discuss the course content amongst themselves, under guidance of an experienced tutor. **Aims & Objectives** The module aims to provide students with the skills needed to successfully complete a research project in astrophysics, place their research into a broader context, and communicate their research and results to their colleagues. More specifically, this module focuses on the following skills: • use astrophysical knowledge to interpret literature and apply to research problems • find relevant information from literature and other sources, and critically evaluate and interpret this information • oral communication • written communication • time management and taking ownership of learning and research • applying acquired skills to a small research project **Learning Outcomes** At the end of this module, students should be able to • carry out an original research project, under supervision of an experienced researcher • critically evaluate their own knowledge, and identify the knowledge they need to acquire to carry out a scientific task or project • find information sources, extract relevant information, and critically evaluate, interpret and apply this information • present the results and broader context of their research project, both orally and on paper **Synopsis** Astrophysical background. Literature searching and interpretation. Selecting and presenting a research paper. Picking a research topic. Writing and presenting a literature review. Carrying out a research project, and writing a research report. **Additional information on continuous assessment etc.** Please note that the final details on continuous assessment will be communicated within the module. The assessment breakdown is expected to be Astrophysics take-home test — 5% Comparison of two research papers — 5%

	Oral presentation of research paper 10% Written literature review 25% Oral presentation of literature review 10% Written report on research project 40% Supervisor feedback on research project 5% **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5500.html **General Information** **Please also read the general information in the School's honours handbook which is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/**

AS5521 Observational Techniques in Astrophysics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				
This is a module that provides a complete overview of the practical part of research in observational astronomy. In the laboratory part, students learn how to plan observations with telescopes at the university observatory, followed by data reduction and analysis. The exact topics covered may change annually depending on resource availability; examples include galaxy imaging and exoplanet transits. The lecture part prepares the students for working with large-scale professional facilities and advanced observing techniques. The module includes optional observing training either with the James Gregory Telescopes in St Andrews, or with telescopes overseas. This training can be hands-on or remotely. Overall, students gain valuable experience in observation, data analysis, astronomical software, observing techniques, report and proposal writing.				
Pre-requisite(s):	Students must be registered for MSc Astrophysics.			
Co-requisite(s):	null			
Learning and teaching methods of delivery:	**Weekly contact**: Semester 1: 2 x 3.5hr supervised work x 10 weeks. Semester 2: 1hr interactive lecture x 10 weeks			
Assessment pattern:	Coursework = 100%			
Re-assessment pattern:	Coursework = 100%			
Module coordinator:	Dr A Scholz			
Additional information from Schools:	- **AS5521 - Observational Techniques in Astrophysics** **Overview** Astrophysics is an observational, rather than an experimental, science. Nearly all the information that astronomers can gather about the Universe at large and the objects within it, comes to us in the form of electromagnetic radiation. In this two-part course students will gain a comprehensive understanding of the observational work required for astronomical research. **Aims & Objectives** The aim of this module is to familiarise students with a wide range of observational techniques in astronomy and astrophysics, while allowing the pursuit of individual scientific interests. Students will gain theoretical knowledge and practical experience in instrument building, planning, documenting and conducting of astronomical observations, measurements, data analysis, proposal			

	writing and report writing. The module consists of a laboratory part in semester one and a lecture part in semester two, combined with telescope training. **Learning Outcomes** By the end of the module, students will have a comprehensive knowledge of astronomical observational facilities, observational techniques and data-analysis methods. They will be able to: • Write an observing proposal for advanced astronomical facilities. • Plan a set of observations, including scheduling, instrument setup, exposure times, lunar phase. • Operate optical telescopes competently. • Acquire optical images of various astronomical objects, including the necessary calibration data. • Carry out the basic reduction and advanced analysis of optical images. • Record and write up results in a professional manner. **Synopsis** This is a module that provides a complete overview of the practical part of research in observational astronomy. In the laboratory part, students learn how to plan observations with telescopes at the university observatory, followed by data reduction and analysis. The lecture part prepares the students for working with large-scale professional facilities and advanced observing techniques. Overall, students gain valuable experience in observation, data analysis, astronomical software, observing techniques, report and proposal writing. The observing training provides opportunities for taking data for research projects and is supervised by staff, and may be with local telescopes, with telescopes abroad, or remotely. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The laboratory part of the module has two assessed assignments (60% of the total mark). The lecture part has one assignment, a mock telescope proposal (40% of total mark). **Recommended Books** Please view University online record:

AS5522 Stellar Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				

This module develops the physics of stellar interiors and atmospheres from the basic equations of stellar structure and radiative transfer concepts developed in Nebulae and Stars I. Topics include: the equation of state that provides pressure support at the high temperatures and densities found in normal and white-dwarf stars; the interaction of radiation with matter, both in terms of radiation-pressure support in super-massive stars and in terms of the role of opacity in controlling the flow of energy from the stellar interior to the surface; the equation of radiative transfer and the effects of local temperatures, pressures and velocity fields on the continuum and line absorption profiles in the emergent spectrum. Computer-aided tutorial exercises illustrate the computational schemes that represent one of the triumphs of late twentieth-century physics, in their ability to predict the observable properties of a star from its radius and luminosity, which in turn are determined by its mass, age and chemical composition.

Pre-requisite(s):	Students must be registered for MSc Astrophysics.. Before taking this module you must pass AS4011 or equivalent from first degree.
Co-requisite(s):	null
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%
Re-assessment pattern:	Oral exam = 100%
Module coordinator:	Dr P Woitke
Additional information from Schools:	To be confirmed

AS5523 Gravitational Dynamics and Accretion Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				

This theoretical module explores the basics of gravitational dynamics and accretion physics and their application to systems such as circumstellar discs, stellar clusters to galaxies and clusters of galaxies. The module will provide students with the techniques to determine physical properties from observable quantities and to model the dynamics and evolutionary pathways of these systems. Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Accretion as a source of energy and mass growth will be explored with particular emphasis on models of viscous accretion discs. Applications of these methods are made to several different astrophysical objects including accretion discs in stellar systems, collisions in globular clusters, the growth of super-massive black holes, to the presence of dark matter in the universe.

Pre-requisite(s):	Students must be registered for MSc Astrophysics.
Co-requisite(s):	null
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures occasionally replaced by whole-group tutorials.
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%

Re-assessment pattern:	Oral re-assessment = 100%
Module coordinator:	Dr H Zhao
Additional information from Schools:	**AS5523 - Gravitational Dynamics and Accretion Physics** **Aims & Objectives** To present an overview of the importance and relevance of gravitational process in astrophysics, including how gravity relates structures with kinematics and the long-term evolution of such structures due to gravitational interactions. The module also aims to provide a basic understanding of how astrophysical discs work and provide an insight into how compact astrophysical objects form and obtain their characteristic masses be they planets, stars or black holes. **Learning Outcomes** By the end of the module the student should be able to: • Apply potential theory to gravitational systems. • Relate kinematics to mass distributions in extended objects like clusters and galaxies. • Determine how gravitational interactions drive the evolution of self-gravitating systems. • Model the structures and evolution of astrophysical discs. • Understand the statistical treatment of a large-N system. • Use the virial theorem to estimate global properties and evolutionary outcomes. • Use the Jeans equations to determine mass distributions from observable properties. • Model accretion processes and how these relate to the luminous Universe. **Synopsis** Starting from two-body motion and orbits under a central-force law, the module describes the calculation of extended potentials and their associated orbits. The use of the virial theorem and the statistical treatment of large numbers of self-gravitating bodies is then developed with application to stellar systems. Applications of these methods are made to several different astrophysical objects ranging from collisions in globular clusters to the presence of dark matter in the universe. The physics of accretion and accretion discs is developed with emphasis on disc structures, accretion through the disc and the ability of discs to form smaller mass objects such as planets. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5523.html **General Information**

AS5524 Astrophysical Fluid Dynamics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				
Fluid dynamics is the study of all things that 'flow', whether they are liquids or gases. The underlying concepts and techniques taught in this course are of wide ranging use, finding application in such diverse problems as the collision of galaxies, spacecraft re-entry into the Earth's atmosphere, or the structure and stability of fusion plasmas. Closer to home, the behaviour of fluid flows can readily be observed in rivers, on shorelines and in cloud formations. Fluid mechanics describes the types of flows that result from different forces (such as gravity). It explains how (and why) flows become supersonic and when they may become unstable. These basic principles can then be applied to a variety of problems. In addition to introducing the concepts of fluid dynamics, and describing their application, this course will provide the students with the opportunity to develop the numerical skills required for a computational approach to the problem. This project will account for 20% of the module grade, with the remaining 80% coming from the exam.				
Pre-requisite(s):	Registration on MSc Astrophysics.			
Co-requisite(s):	null			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures and some tutorials.			
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%			
Re-assessment pattern:	Oral re-assessment = 100%			
Module coordinator:	Professor C Helling			
Additional information from Schools:	**AS5524 - Astrophysical Fluid Dynamics** **Aims & Objectives** • To present an introduction to fluid dynamics, focusing particularly on the underlying physics including the use of conservation relations (mass, momentum, energy) to describe flows • a physical understanding of vorticity and its evolution in a flow • the role of viscosity and its effect on flows at boundaries • the use of conservation relations to describe the behaviour of fluids at a shock • the onset of simple instabilities **Learning Outcomes** By the end of the module students will have an understanding of the physics of fluid flow as presented in the lectures and will be able to: • apply conservation relations to determine the properties of given flow patterns • determine the vorticity of a flow and describe its behavior • use Bernoulli's equation to analyse simple flows - describe the role of viscosity and solve for simple ideal fluid flows • use the shock relations to relate fluid properties on each side of a shock • describe and calculate the onset of simple instabilities **Synopsis** Introduction of Lagrangian and Eulerian derivatives. Derivation of the vector form of the equations of conservation of mass, momentum and energy. Brief review of simple equations of state. Introduction of the concept of vorticity and the essentials of vorticity dynamics. Bernoulli's equation with simple examples. De Laval nozzle flow and transition to supersonic flow. Basic introduction to viscosity and its importance in boundary layers. Reynolds number. Sound waves and formation of shocks.			

	Conservation relations. Simple treatment of instabilities (convection, Rayleigh-Taylor, Kelvin-Helmholtz). **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/as5524.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

AS5599 Astrophysics Research Project (MSc)

SCOTCAT Credits:	60	SCQF level 11	**Semester**	Full Year
Academic year:	2021-2022			
Availability restrictions:	Available only to students on MSc Astrophysics.			
Planned timetable:				
The project aims to develop students' skills in searching the appropriate literature, in astrophysical theory or experimental and observational design, the evaluation and interpretation of data, and the presentation of a report. There is no specific syllabus for this module. Students taking the MSc Astrophysics degree select a project from a list of those available and are supervised by a member of the academic staff.				
Pre-requisite(s):	Registration on MSc Astrophysics. Some projects will need learning from specific modules - please contact potential supervisors.			
Co-requisite(s):	null			
Learning and teaching methods of delivery:	**Weekly contact**: 1hr peer group session x 11 weeks, 1hr supervisory meeting x 11 weeks, 1hr research seminar x 12 weeks			
Assessment pattern:	Coursework = 100%			
Module coordinator:	Professor M M Jardine			

PH4026 Signals and Information

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

This module gives an introduction to what are signals and information, and how they are measured and processed. It also covers the importance of coherent techniques such as frequency modulation and demodulation and phase sensitive detection. The first part of the module concentrates on information theory and the basics of measurement, with examples. Coherent signal processing is then discussed, including modulation/demodulation, frequency mixing and digital modulation. Data compression and reduction ideas are illustrated with real examples and multiplexing techniques are introduced. The module concludes with a discussion of basic antenna principles, link gain, and applications to radar.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr P A S Cruickshank
Additional information from Schools:	To be confirmed

PH4027 Optoelectronics and Nonlinear Optics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

This module provides an introduction to the basic physics underpinning optoelectronics and nonlinear optics, and its applications including displays and communications. The syllabus consists of: an overview of optoelectronic devices and systems; displays - types of display, liquid crystal displays, organic semiconductors and organic light-emitting diode (OLED) displays; nonlinear optics - propagation of light in anisotropic media, coupled wave equations; second harmonic generation; phase matching; and electro-optic modulators; fibres and telecommunications including modes of planar waveguides, factors limiting data transmission rates and detectors.

Pre-requisite(s):	Before taking this module you must (pass PH3081 or pass PH3082) or (pass MT2506 and pass MT2507) and pass PH3007
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Professor I D W Samuel
Additional information from Schools:	To be confirmed

PH4028 Advanced Quantum Mechanics: Concepts and Methods

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

This module builds on the material of PH3061 and PH3062 Quantum Mechanics 1 and 2 to present some of the important current and advanced topics in quantum mechanics. The mathematics of complex analysis is introduced to allow this to be used for relevant quantum mechanics problems. Scattering theory is developed using partial waves and Green's functions, leading to a discussion of quantum degenerate gases. Advanced topics in perturbation theory including WKB approximation for exploring differential equations. The density matrix formalism as the general state description in open quantum systems is presented; open system dynamics are described within the formalism of the density matrix master equation. Quantum information processing is covered, including concepts such as qubits, quantum entanglement and quantum teleportation.

Pre-requisite(s):	Before taking this module you must pass PH3061 and pass PH3062 and (pass PH3081 or pass PH3082) or (pass MT2003 or pass MT2506 and pass MT2507)
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr B W Lovett

Additional information from Schools:

PH4028 - Advanced Quantum Mechanics: Concepts and Methods

Aims & Objectives
The core idea of the course is to give a clear picture of the modern, 21st century quantum mechanics and to teach basic operational tools in this context. The module will include:

- Open quantum systems are covered with the use of density matrix formalism.
- Variational theory and WKB approximation.
- Entanglement and quantum information and their application.
- Quantum scattering.
- Complex analysis, importantly introducing the residue theorem which is then used in quantum scattering problems.

Learning Outcomes
By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and will be able to:

- classify and manipulate functions of a complex variable.
- use the residue theorem to perform real integrals.
- use scattering theory to solve quantum mechanical problems.
- Use variational theory and WKB approximation to solve quantum mechanical problems.
- use the density matrix as a representation of an open quantum system. Understand and be able to characterise whether a state is pure or mixed.
- understand the notion of quantum entanglement and its relationship to Bell's inequalities.
- understand sample problems in quantum information, for example, be able to demonstrate via simple calculations in Dirac notation and tensor products how quantum teleportation works.

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	Synopsis • complex analysis; Cauchy-Reimann conditions, Cauchy's integral theorem and formula; Laurent series, residue theorem and principal value. • scattering theory • variational theory. • WKB approximation. • density matrix. Purity of a state. • tensor product notation for multipartite states. • Bell's inequalities and entanglement. • quantum information processing. quantum bit (qubit). quantum teleportation. quantum key distribution. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph4028.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4031 Fluids

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				
This module provides an introduction to fluid dynamics, and addresses the underlying physics behind many everyday flows that we see around us. It starts from a derivation of the equations of hydrodynamics and introduces the concept of vorticity and the essentials of vorticity dynamics. The influence of viscosity and the formation of boundary layers is described with some straightforward examples. The effect of the compressibility of a fluid is introduced and applied to shock formation and to the conservation relations that describe flows through shocks. A simple treatment of waves and instabilities then allows a comparison between theory and readily-observed structures in clouds, rivers and shorelines.				
Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)			
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures and some tutorials.			
Assessment pattern:	2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor C Helling			
Additional information from Schools:	**PH4031 - Fluids** **Aims & Objectives**			

- To present an introduction to fluid dynamics, focusing particularly on the underlying physics including the use of conservation relations (mass, momentum, energy) to describe flows
- a physical understanding of vorticity and its evolution in a flow
- the role of viscosity and its effect on flows at boundaries
- the use of conservation relations to describe the behaviour of fluids at a shock
- the onset of simple instabilities

Learning Outcomes
By the end of the module students will have an understanding of the physics of fluid flow as presented in the lectures and will be able to:

- apply conservation relations to determine the properties of given flow patterns
- determine the vorticity of a flow and describe its behaviour
- use Bernoulli's equation to analyse simple flows - describe the role of viscosity and solve for simple ideal fluid flows
- use the shock relations to relate fluid properties on each side of a shock
- describe and calculate the onset of simple instabilities

Synopsis
Introduction of Lagrangian and Eulerian derivatives. Derivation of the vector form of the equations of conservation of mass, momentum and energy. Brief review of simple equations of state. Introduction of the concept of vorticity and the essentials of vorticity dynamics. Bernoulli's equation with simple examples. De Laval nozzle flow and transition to supersonic flow. Basic introduction to viscosity and its importance in boundary layers. Reynolds number. Sound waves and formation of shocks. Conservation relations. Simple treatment of instabilities (convection, Rayleigh-Taylor, Kelvin-Helmholtz).

Accreditation Matters
This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph4031.html

General Information
Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4032 Special Relativity and Fields

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

The module analyses classical fields in physics such as the electromagnetic field. Fields are natural ingredients of relativity, because they serve to communicate forces with a finite velocity (the speed of light). The module covers the tensor formalism of special relativity, relativistic dynamics, the Lorentz force, Maxwell's equations, retarded potentials, symmetries and conservation laws, and concludes with an outlook to general relativity.

Pre-requisite(s):	Before taking this module you must pass PH3007 and pass PH3081 and pass PH4038
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial x 10 weeks
Assessment pattern:	2-hour Written Examination = 75%, Coursework (assessed tutorial questions) = 25%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Professor N Korolkova
Additional information from Schools:	To be confirmed

PH4034 Principles of Lasers

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

This module presents a basic description of the main physical concepts upon which an understanding of laser materials, operations and applications can be based. The syllabus includes: basic concepts of energy-level manifolds in gain media, particularly in respect of population inversion and saturation effects; conditions for oscillator stability in laser resonator configurations and transverse and longitudinal cavity mode descriptions; single longitudinal mode operation for spectral purity and phase locking of longitudinal modes for the generation of periodic sequences of intense ultrashort pulses (i.e. laser modelocking); illustrations of line-narrowed and modelocked lasers and the origin and exploitability of intensity-induced nonlinear optical effects.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)
Anti-requisite(s)	You cannot take this module if you take PH5005
Learning and teaching methods of delivery:	**Weekly contact**: 3 lectures or tutorials.
Assessment pattern:	2-hour Written Examination = 90%, Coursework = 10%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr F E W Koenig
Additional information from Schools:	To be confirmed

PH4035 Principles of Optics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

This module formulates the main aspects of physics used in modern optics, lasers and optoelectronic systems. Topics covered include: polarised light and its manipulation, with descriptions in terms of Jones' vectors and matrices; Fresnel's equations for transmittance and reflectance at plane dielectric interfaces; reflection and transmission of multi-layer thin films plus their use in interference filters; interpretation of diffraction patterns in terms of Fourier theory; spatial filters; the theory and use of Fabry-Perot etalons; laser cavities and Gaussian beams.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lectures x 10 weeks, 1hr workshop x 10 weeks
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr F E W Koenig
Additional information from Schools:	To be confirmed

PH4036 Physics of Music

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

Musical instruments function according to the laws of physics contained in the wave equation. Wind instruments, the human voice and the acoustics of concert halls can be explained largely by considering waves in the air, but understanding drums, percussion, string instruments and even the ear itself involves studying the coupling of waves in various media. The concepts of pitch, loudness and tone are all readily explained in quantitative terms as are the techniques that musicians and instrument makers use to control them. The module includes a look at how digital audio of musical instrument sounds can be analysed and synthesised using a programming language such a Python.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082
Learning and teaching methods of delivery:	**Weekly contact**: 2 1hr lectures x 10 weeks, 1hr tutorial/workshop x 10 weeks
Assessment pattern:	Written examinations :80%. Continual assessment: 20%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr J A Kemp
Additional information from Schools:	**PH4036 - Physics of Music** **Aims & Objectives** To provide a detailed overview of the physics involved in the production, analysing and synthesizing of musical sounds. **Learning Outcomes** By the end of this module, students are expected to be able to: • Derive the wave equation in one, two and three dimensions.

- Know expressions for acoustic pressure and volume velocity for acoustic plane waves in free space and in cylindrical pipes.
- Derive the specific acoustic impedance in free space and the acoustic impedance in cylindrical pipes and the effect of boundary conditions such as side holes, branches and open or closed ends.
- Derive the Fourier series for sine waves, pulse waves, square waves and triangle waves and relate these to sound synthesis and the harmonic series and sound generation in real musical instruments.
- Describe beats, perception of roughness, pitch differences in cents and standard musical intervals from the perspective of the relationship between harmonic series, equal temperament and just intonation for standard musical intervals.
- Derive approximate frequencies of the formants of the vocal tract and describe the separate roles of the harmonic series and of the formants in forming vowel sounds.
- Derive the decibel values associated with spherical waves in free space, absorption of plane waves and diffuse sound fields in rooms.
- Develop skills in using computer programming in a language such as Python on digital audio and in report writing.

Synopsis
Beats, Fourier series. Discrete Fourier transform and using Python. Plucked, struck and bowed strings. Air damping. Vibrating membranes and plates. Wave equation in air. Transmission and reflection, losses and radiation. Standing waves, pipes, cross-section changes, side holes. The ear and perception of musical sound. Scales and temperament. Reverberation and architectural acoustics. Case studies on strings, drums, woodwind, brass, and voice. Synthesizing musical sound (additive, subtractive, FM, wave-table and physical modelling).

Accreditation Matters
This module may not contain material that is part of the IOP ‘Core of Physics’, but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP ‘Graduate Skill Base’.

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph4036.html

General Information
Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php

PH4038 Lagrangian and Hamiltonian Dynamics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	2
Academic year:	2021-2022			
Planned timetable:				

The module covers the foundations of classical mechanics as well as a number of applications in various areas. Starting from the principle of least action, the Lagrangian and Hamiltonian formulations of mechanics are introduced. The module explains the connection between symmetries and conservation laws and shows bridges between classical and quantum mechanics. Applications include the central force problem (orbits and scattering) and coupled oscillators.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507). In taking this module you will need a knowledge of vector calculus
Anti-requisite(s)	You cannot take this module if you take MT4507
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 lectures and some tutorials
Assessment pattern:	2-hour Written Examination = 75%, Coursework = 25%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr B H Braunecker

Additional information from Schools:

PH4038 - Lagrangian and Hamiltonian Dynamics

Aims & Objectives
To give students a solid grounding and sufficient training in Lagrangian and Hamiltonian techniques in classical mechanics and their applications, including

- the Principle of Least Action as the starting point of Lagrangian mechanics
- traditional applications of Lagrangian mechanics such as mechanical pendulums, planetary motion, collisions and some non-traditional ones
- appreciating the problem-solving power, generality and elegance of Lagrangian and Hamiltonian techniques
- understand the fundamental connection between symmetries and conservation laws (Noether theorem)

Learning Outcomes
By the end of the module, students will have a solid knowledge of the central concepts of Classical Mechanics and will have acquired and trained important problem-solving skills. They will be able to

- establish the Lagrangian, and to derive and solve the equations of motions for many systems subject to the Principle of Least Action
- calculate conserved quantities from symmetries
- calculate the Hamiltonian and establish Hamilton’s equations
- be familiar with canonical transformations and Hamilton-Jacobi theory
- understand the concept of phase space and the conservation of phase-space density (Liouville's theorem)
- acquire a deep knowledge of the Hamiltonian formalism that is crucial for the formulation and understanding of quantum mechanics

Synopsis
Review of Newtonian mechanics. Functionals and functional derivatives, Euler-Lagrange equations. Lagrangian, Principle of Least Action, symmetries and conservation laws: energy, momentum, angular momentum, centre of mass. Central forces and orbits, Kepler problem (planetary motion), scattering problems, Rutherford scattering. Hamiltonian formalism, canonical momenta, Hamilton’s equations, Poisson

	brackets, canonical transformations. Application to circuit electrodynamics, filters and transmission lines, classical field theory. Canonical mechanics: symmetries and conservation laws, Noether's theorem, Liouville's theorem, Hamilton-Jacobi formalism. **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This module is typically taken in JH by theoretical physicists, and in SH by those doing an MPhys in other degree programmes in the School. It is sufficiently core to the programmes that it is included in the summary of deadlines etc on the School's Students and Staff web pages. Five tutorial sheets will be issued over the semester in two week intervals. They contain questions that will deepen the understanding of the current topics in the lectures, and they are required to be handed in for marking. This accounts for 25% of the module mark. Tutorials take the form of 'whole class' tutorials (or are split into several sessions with parts of the class if social distancing is required) where the solutions and underlying physics and problem-solving strategies can be discussed. **Accreditation Matters** This module may not contain material that is part of the IOP 'Core of Physics', but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP 'Graduate Skill Base'. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph4038.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH4039 Introduction to Condensed Matter Physics

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

This module explores how the various thermal and electrical properties of solids are related to the nature and arrangement of their constituent atoms. For simplicity, emphasis is given to crystalline solids. The module covers: the quantum-mechanical description of electron motion in crystals; the origin of band gaps and insulating behaviour; the reciprocal lattice and the Brillouin zone, and their relationships to X-ray scattering measurements; the band structures and Fermi surfaces of simple tight-binding models; the Einstein and Debye models of phonons, and their thermodynamic properties; low-temperature transport properties of insulators and metals, including the Drude model; the physics of semiconductors, including doping and gating; the effect of electron-electron interactions, including a qualitative account of Mott insulators; examples of the fundamental theory applied to typical solids.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507) and (pass PH3061 or pass CH3712)
Co-requisite(s):	null
Learning and teaching methods of delivery:	**Weekly contact**: 3 x 1hr lecture x 10 weeks, 1hr workshop x 9 weeks, 1hr Q&A x 10 weeks
Assessment pattern:	2-hour Written Examination = 80%, Coursework = 20%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr C A Hooley
Additional information from Schools:	To be confirmed

PH4105 Physics Laboratory 2

SCOTCAT Credits:	15	SCQF level 10	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

The aims of the module are (i) to familiarise students with a wide variety of experimental techniques and equipment, and (ii) to instil an appreciation of the significance of experiments and their results. The module consists of sub-modules on topics such as low temperature solid state physics, optics, x-ray crystallography, and biophotonics.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507)
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 3.5hr laboratory x 10 weeks
Assessment pattern:	100% continual assessment.
Re-assessment pattern:	No Re-assessment available - laboratory based
Module coordinator:	Dr C F Rae
Additional information from Schools:	To be confirmed

PH5004 Quantum Field Theory

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				
This module presents an introductory account of the ideas of quantum field theory and of simple applications thereof, including quantization of classical field theories, second quantization of bosons and fermions, solving simple models using second quantization, path integral approach to quantum mechanics and its relation to classical action principles, field integrals for bosons and fermions, the relationship between path integral methods and second quantization, solving many-body quantum problems with mean-field theory, and applications of field theoretic methods to models of magnetism.				
Pre-requisite(s):	Before taking this module you must pass PH3012 and pass PH3061 and pass PH3062 and pass 1 module from {PH4038, MT4507} and pass 1 module from {PH4028, MT3503}			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 1hr lectures x 10 weeks, 1hr x 10 weeks tutorials and discussion sessions			
Assessment pattern:	2-hour Written Examination = 85%, Coursework = 15%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr J M J Keeling			
Additional information from Schools:	To be confirmed			

PH5005 Laser Physics and Design

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				
Quantitative treatment of laser physics including rate equations; transient/dynamic behaviour of laser oscillators including relaxation oscillations, Q-switching, cavity dumping and mode locking; single-frequency selection and frequency scanning, design analysis of optically-pumped solid state lasers; laser amplifiers; unstable optical resonators, geometric and diffraction treatments. An emphasis is placed on how understanding of the laser physics can be used to design useful laser systems.				
Pre-requisite(s):	Before taking this module you must pass PH3007 and pass PH3061 and pass PH3062			
Anti-requisite(s)	You cannot take this module if you take PH4034			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 10 weeks, 1hr workshop x 8 weeks, 1hr Q&A x 2 weeks			
Assessment pattern:	2.5-hour open-notes Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr B D Sinclair			
Additional information from Schools:	**PH5005 - Laser Physics and Design** **Overview** The course is designed to introduce the student to the classical treatment of laser physics providing the necessary quantitative techniques to permit design and prediction .A rate-equation model is used to model the laser system. In this course a			

	number of variations are explored with regard to their applicability and limitations. Learning is assisted through the incorporation into the course of animations and numerical modelling material. (The latter is the 'Psst' software, which may be downloaded free for personal use.) **Aims & Objectives** The course aims to develop a working knowledge and conceptual understanding of important topics in contemporary laser physics at a quantitative level. A key objective is to enable the student to undertake quantitative problem-solving relating to the design, performance and applications of lasers through thereby acquiring an ability to put such knowledge into practice by way of numerical calculations. The aim throughout is to provide a thorough grounding in basic principles and their application, so that by the end of the course the student will have acquired a range of essential skills and knowledge required by a practitioner of laser physics and engineering. Such knowledge of the basics will be of enduring value and relevance. It will enable the student to innovate, design and analyse laser devices and systems at a quantitative level. As well as developing the conceptual framework the course also aims to give a sound perspective of contemporary trends and developments in laser physics, particularly with regard to new schemes for the generation of coherent electromagnetic radiation and the associated devices. **Learning Outcomes** You will have acquired: • A conceptual understanding of the classical approach to laser physics, and a perspective of areas of • An ability through a thorough grounding in the rate equation and strong signal approaches to analyse quantitatively the steady-state and dynamical performance of important contemporary laser devices. • A comprehensive knowledge, including of recent developments, concerning: solid-state lasers (including diode-laser pumped devices), semiconductor lasers, fibre lasers, vibronic and other tuneable lasers, organic lasers, laser amplifiers, and newly emerging gain media. • An ability to both analyse quantitatively and to design such lasers. • A conceptual understanding of such important aspects of laser active media as linewidth determining processes, dispersive/gain properties, spatial and frequency hole-burning. • An ability to both describe quantitatively and analyse such effects. • A thorough grounding in the principles and design of laser resonators, particularly stable cavities. - An ability to analyse quantitatively and design such cavities by using matrix techniques. • Access to and familiarity with numerical modelling tools (including 'Psst') relating to many aspects of laser design and performance. **Synopsis** • Rate Equation Approach to Laser - Steady-State behaviour • Transient effects • Relaxation Oscillations • Q-switching • Diode-laser-pumped solid-state lasers • Optical Amplifier • Linear Gain Regime • Power Extraction • Dispersion & Gain in Laser • • Mode Effects • Review of Stable Optical Resonators • Matrix Techniques • Applications • Fibre Lasers

- Vibronic Lasers
- Tuning Techniques
- Linewidth Control
- Frequency Stabilisation
- Semiconductor Lasers
- Ultrafast lasers and diagnostic techniques

Additional information on continuous assessment etc.
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

The first part of the module looks at the key underlying ideas of laser physics. After an introduction we look at laser gain. We then turn our attention to laser modes, both longitudinal and transverse. There follows a treatment of time dependence in lasers, based on coupled rate equations, and taking in relaxation oscillations and Q-switching. The remainder of the module looks at how all these ideas can be applied to understand and design various laser systems. We look at a number of case studies. The module then covers ultrashort pulse lasers and semiconductor diode lasers. Tutorials provide a way to practice using these ideas and to discuss questions. A group-based laser design case study with associated feedback allows a more in-depth exploration of design of a particular last system.
Laser Design Case Study 20%
Open Notes Examination 80%

Recommended Books
Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5005.html

General Information
Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/

PH5011 General Relativity

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or as part of MSc Astrophysics.			
Planned timetable:				

This module covers: inertial frames, gravity, principle of equivalence, curvature of spacetime; basic techniques of tensor analysis; Riemannian spaces, metric tensor, raising and lowering of indices, Christoffel symbols, locally flat coordinates, covariant derivatives, geodesics, curvature tensor, Ricci tensor, Einstein tensor; fundamental postulates of general relativity: spacetime, geodesics, field equations, laws of physics in curved spacetime; distances, time intervals, speeds; reduction of equations of general relativity to Newtonian gravitational equations; Schwarzschild exterior solution, planetary motion, bending of light rays, time delays; observational tests of general relativity; Schwarzschild interior solution, gravitational collapse, black holes.

Pre-requisite(s):	Before taking this module you must pass PH3081 or pass PH3082 or (pass MT2506 and pass MT2507). Postgraduates: MSc Astrophysics students must discuss your prior learning with your adviser.
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lecture, 1 x 1hr workshop
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Dr M Dominik
Additional information from Schools:	**PH5011 - General Relativity** **Overview** The module provides an introduction to Einstein's theory of General Relativity. We lay the necessary grounds of differential geometry and tensor analysis with familiar concepts and non-relativistic mechanics before discussing the fundamental ideas behind Einstein's theory. We show how Newton's forces are being eliminated in favour of curvature of space-time, where matter and curvature are being related by Einstein's gravitational field equations. We find Schwarzschild's solution and discuss implications such as perihelion precession of planets, bending of light, gravitational redshift, time delay, black holes, and gravitational waves. Moreover, we show how General Relativity plays a role in current technology such as satellite navigation. **Aims & Objectives** The module should provide an introduction and applications to the theory of General Relativity, covering the following topics: • the "need" for General Relativity and its historic evolution - fundamental principles of General Relativity • the advanced mathematics required in order to apply the theory - derived predictions and their experimental tests • application of general relativity in science and technology **Learning Outcomes** Students are expected to be able to • understand the fundamental concepts of the theory of General Relativity • practice tensor analysis to describe physical phenomena in curved space-time - derive the equations of motion from a given metric tensor • compute the general-relativistic effects relevant to astronomy • compute the effects of general relativity in modern technology **Synopsis** Curvilinear coordinates: basis and coordinates, reciprocal basis, metric, vector fields, tensor fields, coordinate transformations, affine connection; Tensor analysis: covariant derivative, Riemann tensor, Einstein tensor; Classical mechanics (review): principle of stationary action, Hamilton's equations, Hamilton-Jacobi formalism; Mechanics in curved space: equations of motion, embedding, geodesics, stationary paths, conserved quantities, Hamilton-Jacobi equation; Special Relativity: Minkowski space, light cone, proper time, relativistic mechanics, energy-momentum tensor; General Relativity: principles, Einstein's field equations, cosmological constant, time and distance, synchronisation, Schwarzschild solution;

	Consequences: relativistic Kepler problem, bending of light, gravitational redshift, time delay, satellite navigation, black holes, cosmological redshift & Friedmann equations, Maxwell's equations in GR, gravitational waves. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5011.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5012 Quantum Optics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School			
Planned timetable:				
Quantum optics is the theory of light that unifies wave and particle optics. Quantum optics describes modern high-precision experiments that often probe the very fundamentals of quantum mechanics. The module introduces the quantisation of light, the concept of single light modes, the various quantum states of light and their description in phase space. The module considers the quantum effects of simple optical instruments and analyses two important fundamental experiments: quantum-state tomography and simultaneous measurements of position and momentum.				
Pre-requisite(s):	Before taking this module you must (pass PH3081 or pass PH3082 or pass MT2506 and pass MT2507) and pass PH3061 and pass PH3062 and pass PH4028			
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lecture x 10 weeks, 1hr tutorial x 10 weeks			
Assessment pattern:	2-hour Written Examination = 100%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Professor N Korolkova			
Additional information from Schools:	To be confirmed			

PH5015 Applications of Quantum Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or a postgraduate photonics programme.			
Planned timetable:				
Quantum physics is one of the most powerful theories in physics yet is at odds with our understanding of reality. In this module we show how laboratories around the world can prepare single atomic particles, ensembles of atoms, light and solid state systems in appropriate quantum states and observe their behaviour. The module includes studies of laser cooling, Bose-Einstein condensation, quantum dots and quantum computing. An emphasis throughout will be on how such quantum systems may actually turn into practical devices in the future. The module will include assessment based on tutorial work and a short presentation on a research topic.				
Learning and teaching methods of delivery:	**Weekly contact**: 2 x 1hr lectures x 10 weeks, 1hr tutorial/discussion session x 10 weeks, 3 hours student presentations			
Assessment pattern:	2-hour Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			
Module coordinator:	Dr D Cassettari			
Additional information from Schools:	To be confirmed			

PH5016 Biophotonics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or a postgraduate photonics programme.			
Planned timetable:				
The module will expose students to the exciting opportunities offered by applying photonics methods and technology to biomedical sensing and detection. A rudimentary biological background will be provided where needed. Topics include fluorescence microscopy and assays including time-resolved applications, optical tweezers for cell sorting and DNA manipulation, photodynamic therapy, optogenetics, lab-on-a-chip concepts and bio-MEMS. Two thirds of the module will be taught as lectures, including guest lectures by specialists, with the remaining third consisting of problem-solving exercises, such as writing a specific news piece on a research paper, assessed tutorial sheets and a presentation. A visit to a biomedical research laboratory using various photonics methods will also be arranged.				
Pre-requisite(s):	Before taking this module you must (pass 1 module from {PH3081, PH3082} or pass 2 modules from {MT2506, MT2507}) and pass 1 module from {PH4034, PH4035}. Pre-requisites are compulsory unless you are on a taught postgraduate programme.			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x1hr lectures x 10 weeks, 1hr tutorial x 10 weeks			
Assessment pattern:	2-hour Written Examination = 80%, Coursework (including presentation)= 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7			

<table>
<tr><td>Module coordinator:</td><td>Dr J C Penedo-Esteiro</td></tr>
<tr><td>Additional information from Schools:</td><td>
PH5016 - Biophotonics

Overview
The union of photonics and biotechnology presents some of the most exciting scientific and commercial prospects for the 21st century. Largely due to advances in microscopy and the invention of the laser in the 1960s, photonics has touched all aspects of our lives, ranging from home entertainment to optical telecommunications and data storage. Biophotonics is the fusion of photonics and biology that deals with the interaction between light and biological matter. Light is one of the primary tools in biology, and increasingly sophisticated optical instrumentation is used in biological detection and analysis as well as medical treatment.

Learning Outcomes
The key learning outcome is an appreciation for the wide range of photonics technologies that have important roles in the biomedical applications.
The students will therefore gain appreciation of the following:

Basic biological and biochemical concepts, such as the structure and function of cells, proteins and
Methods to investigate biological structures with spatial resolutions from angstroms to millimetres and with temporal resolutions from nanoseconds to seconds and beyond.
The nature of the interaction between biological materials (cells, tissue etc.) with light, such as scattering, absorption, fluorescence and Raman.
Optical instrumentation used in biomedical practice, especially for imaging.
Advanced light- based techniques such as single-molecule fluorescence, super-resolution methods, light-sheet microscopy, OCT and Raman Spectroscopy to provide multi-modal information.
Operation of biomedical detection systems such as assays and their detection limits.
Advanced optical techniques for mechanical manipulation of proteins and DNA such as optical tweezers and the added functionality and information provided by these methods.
An introduction to optogenetics and how to use light to control biological response, mostly in
Optical methods to measure forces exerted by cell during the cell life cycle.

Students will also gain transferable skills by developing some of the material themselves via critical study of research papers and materials, presentations and group work.

Synopsis
Imaging at different temporal and spatial scales from molecules to cells including optical coherence tomography, confocal and multiphoton imaging, and imaging beyond the diffraction limit. Overview of Microscopy and relevance for biological inspection. Basics of Cell and Molecular Biology, structure and function of biological structures and samples. Optical scattering, absorption and properties of fluorescent labels including small fluorophores, fluorescence proteins and quantum dots and their use in biological assays and biomedical sensing. New generation imaging methods including super-resolution techniques, light sheet microscopy and single-molecule technologies. Single-molecule DNA sequencing. Force-induced mechanical manipulation of biomolecules and cells using light. Operational principle of optical tweezers and its applications. Different types of beams, how they are generated and their applications. Interaction of light and tissue. Different types of light sources used
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	and their respective advantages and effects, including time-resolved methods/short-pulse lasers. Light as a stimulus in biological samples. Uses of light-sensitive ion channels in optogenetics. Overview of optical methods to measure forces exerted by cells. **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The coursework includes: 1 News and Views style paper: a 1200-word essay including one or two figures explaining a research paper and placing the topic and findings into context. A list of research papers to choose from will be provided. 2 A 15-20 min presentation on the same topic as the News & Views essay. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5016.html **General Information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5023 Monte Carlo Radiation Transport Techniques

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Normally only taken in the final year of an MPhys or MSci programme involving the School, or as part of MSc Astrophysics.			
Planned timetable:				
This module introduces the theory and practice behind Monte Carlo radiation transport codes for use in physics, astrophysics, atmospheric physics, and medical physics. Included in the module: recap of basic radiation transfer; techniques for sampling from probability distribution functions; a simple isotropic scattering code; computing the radiation field, pressure, temperature, and ionisation structure; programming skills required to write Monte Carlo codes; code speed-up techniques and parallel computing; three-dimensional codes. The module assessment will be 100% continuous assessment comprising homework questions and small projects where students will write their own and modify existing Monte Carlo codes.				
Pre-requisite(s):	Undergraduates: Before taking this module you must pass PH2012 and pass at least 1 module from {AS3013, PH3080, PH3081, PH3082}.. Postgraduates: MSc Astrophysics students must discuss their prior learning with their adviser			
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 5 weeks, 1hr tutorial x 5 weeks, 2hr computer session x 3 weeks.			
Assessment pattern:	Coursework (worksheets = 50%, 3-hour computing test = 25%, 1-hour Class Test = 25%) = 100%			
Re-assessment pattern:	No Re-assessment available - laboratory based			
Module coordinator:	Dr K Wood			

Additional information from Schools:	**PH5023 - Monte Carlo Radiation Transport Techniques** **Learning Outcomes** By the end of the lecture course students will have a comprehensive knowledge of Monte Carlo radiation transport techniques and applying them to write their own computer simulations for photon and neutron transport. • Use random numbers to sample events and processes from probability distribution functions • Understand and the structure of Monte Carlo radiation transfer codes for photon scattering and absorption • Understand the structure of Monte Carlo codes for neutron transport including absorption, scattering, and fission • Understand the concept of Monte Carlo detectors and estimators to determine physical quantities throughout a medium such as photon flux, fluence, radiation pressure • Understand variance reduction techniques to improve signal-to-noise in Monte Carlo simulations; forced first scattering, weighting techniques, Russian roulette, next-event estimators • Understand the structure of Monte Carlo codes for photon and neutron transport in three dimensional density structures • Understand the structure of Monte Carlo codes for neutron criticality calculations • Understand the important physical processes required for Monte Carlo simulations of light interacting with biological tissue, photobleaching, and photodynamic therapy • Be able to write Fortran programs and subroutines to sample from probability distribution functions, both analytic and tabulated • Be able to write Monte Carlo codes to simulate the transport of photons and neutrons in uniform density structures • Be able to adapt and modify a publicly available three dimensional Monte Carlo code for specific problems in photon transport **Synopsis** Recap of basic radiation transport processes; introduction to Monte Carlo techniques for sampling from probability distribution functions; outline a simple isotropic scattering computer code. Scattering phase functions (electrons, molecules, dust, biological tissue); techniques for computing internal intensity moments; radiation force and pressure calculations. Techniques for improving signal-to-noise in simulations; weighting schemes; error analysis. Applications of Monte Carlo techniques for medical physics including fluorescence spectroscopy, photobleaching, photodynamic therapy. Application of Monte Carlo techniques for neutron transport and criticality calculations. Monte Carlo radiative equilibrium calculations for gas and dust. Monte Carlo photoionisation calculations. Other applications: radiation transfer through clouds & atmospheric physics; relativistic scattering; polarisation; radiation-hydrodynamics; cosmic ray transport; neutron transport. Fortran coding skills: basic mathematical functions; if statements; do loops; functions and subroutines; random number generators; iterative techniques Parallelizing Monte Carlo codes. Lectures on using and modifying publicly available Monte Carlo codes for scattering, radiative equilibrium, and photoionisation. **Additional information on continuous assessment etc** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. This is a 15 credit module, so is expected to take 150 hours of study for the average student at this level. The module's work is finished by revision week, so students can

	expect to commit about 14 hours a week to the module in weeks 1 to 11, including the hours scheduled in lectures and in the computing cluster. MPhys students are reminded that if they choose multiple 'no-exam' modules then they will inevitably have a higher workload per week during weeks 1 to 11 than if they chose modules where some of the 150 hours was spent in the revision and exam weeks. **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5023.html **General Information** Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php.

PH5025 Nanophotonics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	Available only to students in a photonics taught postgraduate programme or the final year of an MPhys Honours Programme			
Planned timetable:				

Nanophotonics deals with structured materials on the nanoscale for the manipulation of light. Photonic crystals and plasmonic metamaterials are hot topics in contemporary photonics, and form part of the School's research programme. The properties of these materials can be designed to a significant extent via their structure. Many of the properties of these nanostructured materials can be understood from their dispersion diagram or optical band-structure, which is a core tool that will be explored in the module. Familiar concepts such as optical waveguides and cavities, multilayer mirrors and interference effects will be used to explain more complex features such as slow light propagation and high Q cavities in photonic crystal waveguides and supercontinuum generation in photonic crystal fibres. Propagating and localized plasmons will be explained and will include the novel effects of super-lensing and advanced phase control in metamaterials.

Pre-requisite(s):	Undergraduates: before taking this module you must take PH3061 and (take PH3081 or take PH3082) and (take PH4027 or take PH4034 or take PH4035). Postgraduates: students should be familiar with Maxwell's Equations of Electromagnetism in differential form.
Anti-requisite(s)	You cannot take this module if you take PH5183
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 1hr lectures x 10 weeks, 1hr workshop x 10 weeks
Assessment pattern:	2-hour Written Examination = 80%, Coursework = 20%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Module coordinator:	Professor A Di Falco
Additional information from Schools:	**PH5025 - Nanophotonics** **Learning Outcomes** Students will be able to: • Understand and design basic integrated optics devices, including waveguides and cavities • Use coupled mode theory in time domain to model the interaction of light in integrated devices • Understand the physics and application of photonic crystals, plasmonic nanostructures and metamaterials

	Synopsis Topics covered include: • Light propagation in optical waveguides and cavities • Coupled mode theory • Photonic crystals • Applications of photonic crystal technology • Optics of metals • Surface plasmon polaritons • Localised plasmons • Applications of nanoplasmonics • Metamaterials and applications **Additional information on continuous assessment etc.** The continuous assessment will be based on 3 assessed tutorials. The solutions will be discussed in dedicated lectures. **General information** Please also read the general information in the School's honours handbook that is available via https://www.st-andrews.ac.uk/physics-astronomy/students/ug/timetables-handbooks/.

PH5026 Supported Study Module

SCOTCAT Credits:	15	SCQF level 11	**Semester**	2
Academic year:	2021-2022			
Availability restrictions:	This module is only available by special permission of the Head of School. It is being provided to help with MPhys students in two different situations:- 1) Those who are on a reduced credit load and so may need to take 15 credits at level 5 in their penultimate year 2) Those who are unexpectedly in need of another 15 credits to be taken with their MPhys project in their final semester.			
Planned timetable:				

On rare occasions a student may need a level 5 module in semester two for their Physics or Astronomy MPhys degree programme, and this module may fulfil that need. This module is available only by special permission from the Head of School of Physics and Astronomy, and is expected to be taken rarely. This module is available only to students studying on an MPhys degree in Physics, Astrophysics, or Theoretical Physics. The topic and intended learning outcomes of this supported study module will be the same as that of one of the existing semester-one undergraduate level-five AS or PH modules that the School is in a position to offer at the time. Reading will be set weekly to cover the necessary content, and in many weeks tutorial sheets will be issued to be completed. This will be discussed in a weekly tutorial. There are no lectures.

Pre-requisite(s):	Before taking this module you must pass PH3061
Learning and teaching methods of delivery:	**Weekly contact**: 1 hour tutorial (11 weeks)
Assessment pattern:	2-hour Written Examination = 100%
Re-assessment pattern:	Oral Re-assessment, capped at grade 7
Additional information from Schools:	To be confirmed

PH5181 Photonics Laboratory 1

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Planned timetable:				

The photonics teaching laboratory gives training in the experimental photonics, and allows students the opportunity to explore photonics practically in a series of chosen open-ended investigations. Students use their knowledge and skills from the lecture modules, supplemented by additional reading, to investigate relevant photonic effects. Phase I involves work in small groups in introductory areas, then phase II allows primarily individual investigation of topics such as the second harmonic generation, optical parametric oscillation, erbium amplifiers, Nd lasers, optical tweezers, spectroscopy, remote sensing of speed, Brag reflectors, and holography.

Pre-requisite(s):	Admission pre-requisite

Learning and teaching methods of delivery:	**Weekly contact**: 3 x 3.5 hr in-person lab or direct lab prep
Assessment pattern:	Coursework = 100%
Re-assessment pattern:	No Re-Assessment available, lab-based module
Module coordinator:	Dr B D Sinclair
Additional information from Schools:	**PH5181 - Photonics Laboratory 1** **Aims & Objectives** • To give students training and experience in designing, carrying out, evaluating, and reporting on experimental aspects of photonics. • To provide an environment where students can explore aspects of photonics. **Learning Outcomes** • A deep knowledge of photonics • An improved ability to use experimental kit of relevance to photonics • An improved ability to plan and use experiment, computation, and reading to explore science • An improved ability to report and discuss aspects of experimental investigations and associated science • An improved ability in generic skills such as planning experiments, risk assessment, record keeping, data handling and evaluation, uncertainty analysis, drawing evidence-based conclusions. Identifying useful further work. **Synopsis** • Introduction • Work on exploring laser power and modes • Work on key aspects of experimental optics • Training in use of Matlab for mathematical modelling and exploration of photonics • Student-chosen individually-carried-out experimental investigations • Communication of outcomes through discussion, lab books **Pre-requisites** Admission to a Taught Postgraduate Photonics programme within the School **Anti-requisites** None **Assessment** Coursework = 100% **Additional information on continuous assessment etc.** Please see the MSc and EngD Handbook **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5181.html **General information** Please see information in the Handbook for CDT and MSc students in Photonics.

PH5192 Optical Imaging Concepts

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is limited to students registered on the EngD in Applied Photonics and the MSc in Photonics and Optoelectronic Devices.			
Planned timetable:				
This module aims to introduce the theory and applications of key imaging concepts that are in widespread use. The content includes on the underpinning side:- plane waves form Maxwell's equations, refractive index, polarisation, coherence, diffraction, Fourier optics, lenses and aberrations, optical instruments, point spread function. On the more system side the content includes material drawn from some of:-adaptive optics, multi-modal microscopies, super-resolution, optical coherence tomography, ghost and hyperspectral imaging and other contemporary imaging scenarios.				
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 10 weeks, 1hr workshop x 5 weeks, 1hr tutorial x 5 weeks			
Assessment pattern:	Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Practical (Oral) Examination = 100%			
Module coordinator:	Dr F E W Koenig			
Additional information from Schools:	To be confirmed			

PH5193 Laser Physics

SCOTCAT Credits:	15	SCQF level 11	**Semester**	1
Academic year:	2021-2022			
Availability restrictions:	This module is available only for those in the Engineering Doctorate in Applied Photonics and the MSc in Photonics and Optoelectronic Devices.			
Planned timetable:				
This module presents a description of the main physical concepts upon which an understanding of laser materials, operations, and applications can be based. These concepts include a treatment of light-matter interaction, absorption and refractive index, rate-equation theory of lasers, gain and its saturation, frequency selection and tuning in lasers, transient phenomena, resonator and beam optics, and the principles and techniques of ultrashort pulse generation and measurement.				
Learning and teaching methods of delivery:	**Weekly contact**: 2 or 3 x 1hr lectures x 10 weeks, 1hr tutorial x 4 weeks			
Assessment pattern:	2.5-hour Written Examination = 80%, Coursework = 20%			
Re-assessment pattern:	Oral Re-assessment, capped at grade 7 = 100%			
Module coordinator:	Dr B D Sinclair			

Additional information from Schools:	**PH5193 - Laser Physics** **Overview** The course is designed to introduce the student to the classical treatment of laser physics providing the necessary quantitative techniques to permit design and prediction .A rate-equation model is used to model the laser system. In this course a number of variations are explored with regard to their applicability and limitations. Learning is assisted through the incorporation into the course of animations and numerical modelling material. (The latter is the 'Psst' software, which may be downloaded free for personal use.) **Aims & Objectives** The course aims to develop a working knowledge and conceptual understanding of important topics in contemporary laser physics at a quantitative level. A key objective is to enable the student to undertake quantitative problem-solving relating to the design, performance and applications of lasers through thereby acquiring an ability to put such knowledge into practice by way of numerical calculations. The aim throughout is to provide a thorough grounding in basic principles and their application, so that by the end of the course the student will have acquired a range of essential skills and knowledge required by a practitioner of laser physics and engineering. Such knowledge of the basics will be of enduring value and relevance. It will enable the student to innovate, design and analyse laser devices and systems at a quantitative level. As well as developing the conceptual framework the course also aims to give a sound perspective of contemporary trends and developments in laser physics, particularly with regard to new schemes for the generation of coherent electromagnetic radiation and the associated devices. **Learning Outcomes** You will have acquired: • A conceptual understanding of the classical approach to laser physics, and a perspective of areas of • An ability through a thorough grounding in the rate equation and strong signal approaches to analyse quantitatively the steady-state and dynamical performance of important contemporary laser devices. • A comprehensive knowledge, including of recent developments, concerning: solid-state lasers (including diode-laser pumped devices), semiconductor lasers, fibre lasers, vibronic and other tuneable lasers, organic lasers, laser amplifiers, and newly emerging gain media. • An ability to both analyse quantitatively and to design such lasers. • A conceptual understanding of such important aspects of laser active media as linewidth determining processes, dispersive/gain properties, spatial and frequency hole-burning. • An ability to both describe quantitatively and analyse such effects. • A thorough grounding in the principles and design of laser resonators, particularly stable cavities. - An ability to analyse quantitatively and design such cavities by using matrix techniques. • Access to and familiarity with numerical modelling tools (including 'Psst') relating to many aspects of laser design and performance. **Synopsis** • Rate Equation Approach to Laser - Steady-State behaviour • Transient effects • Relaxation Oscillations • Q-switching • Diode-laser-pumped solid-state lasers • Optical Amplifier • Linear Gain Regime • Power Extraction • Dispersion & Gain in Laser •

	• Mode Effects • Review of Stable Optical Resonators • Matrix Techniques • Applications • Fibre Lasers • Vibronic Lasers • Tuning Techniques • Linewidth Control • Frequency Stabilisation • Semiconductor Lasers • Ultrafast lasers and diagnostic techniques **Additional information on continuous assessment etc.** Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment. The first part of the module looks at the key underlying ideas of laser physics. After an introduction we look at laser gain. We then turn our attention to laser modes, both longitudinal and transverse. There follows a treatment of time dependence in lasers, based on coupled rate equations, and taking in relaxation oscillations and Q-switching. The remainder of the module looks at how all these ideas can be applied to understand and design various laser systems. We look at a number of case studies. The module then covers ultrashort pulse lasers and semiconductor diode lasers. Tutorials provide a way to practice using these ideas and to discuss questions. A group-based laser design case study with associated feedback allows a more in-depth exploration of design of a particular last system. Laser Design Case Study 20% Open Notes Examination 80% **Recommended Books** Please view University online record: http://resourcelists.st-andrews.ac.uk/modules/ph5005.html **General Information** **Please also read the general information in the School's honours handbook that is available via st-andrews.ac.uk/physics/staff_students/timetables.php**