THE UNIVERSITY of ADELAIDE

DEPARTMENT OF PHYSICS

HONOURS PHYSICS 2019

This PDF file contains Coursework descriptions, followed by a Project listing.

THE UNIVERSITY *of* ADELAIDE

SUB CRUCE LUMEN

DEPARTMENT OF PHYSICS

HONOURS LECTURE MODULE DESCRIPTIONS

2019

Honours Courses

There are four courses that honours students enrol in for Physics Honours. These are

PHYSICS 4010 Advanced Physics A (lecture subjects)
PHYSICS 4015 Advanced Physics B (lecture subjects)
PHYSICS 4020A Honours Physics Project part A (semester 1)
PHYSICS 4020B Honours Physics Project part B (semester 2)

and each is worth 6 units. Within these courses, students take seven lecture modules, six of which are counted to PHYSICS 4010 and PHYSICS 4015, and one of which is part of PHYSICS 4020A. The lecture modules (one of which is actually a practical subject) that are offered within Physics are listed below. It is also possible to replace up to two of the modules listed below with level III lecture courses (Physics, Geophysics, Maths, Computer Science).

N.B. If you plan to take a level III course or a non-Physics course, please *do NOT enrol in it*! Enrol in the courses listed above, and your entry into the level III or non-Physics course will be handled informally by the honours coordinators of the relevant departments.

At the first or second honours meeting in early February, we will note your choice of lecture modules.

Lecture Module Descriptions

H-1 Advanced Astrophysics **(Hill/Rowell)** (S2)
H-2 Advanced Atmospheric Physics **(TBD)** (S2)
H-3 Electrodynamics **(Zanotti)** (S2)
H-4 Data Analysis and Modelling **(Rowell, Jackson)** (S1)
H-5 Gauge Field Theories **(Young)** (S2)
H-6 Differential Geometry & General Relativity **(White)** (S2)
H-7 Non-Linear Optics/ Photonics IV **(Veitch, Perrella, Sparkes, Luiten)** (S1)
H-8 Nuclear and Radiation Physics **(Santos/Bezak)** (S1)
H-9 Quantum Field Theory **(Young)** (S1)
H-10 Relativistic Quantum Mechanics & Particle Physics **(Thomas/Leinweber)** (S1)
H-11 Honours Electronics **(Veitch)** (S1)
H-12 Applications of Relativity **(Drake)** (S1)

Please note that certain courses have pre-requisites.
H-6, 9 & 10 require Advanced Dynamics and Relativity (level III Physics).
H-9 & 10 require Quantum Mechanics III.
H-9 requires H-10 concurrently.
H-5 requires H-9 & 10

H – COURSE DESCRIPTIONS

H-1

ADVANCED ASTROPHYSICS

Semester II

Lecturers

A/Profs Gary Hill, Gavin Rowell

Aim

This course aims to:

- Provide a detailed description of various aspects of high-energy astrophysics, both theoretical and observational.
- Provide solid fundamentals of radiative transfer in astrophysics
- Provide more detailed insight into the process of star formation, and the features of the interstellar medium.
- Describe in some detail radiation processes in high energy astrophysics, including synchrotron and inverse Compton.
- Describe special relativistic effects in astrophysical sources
- Introduce the experimental techniques and recent results in cosmic ray, gamma-ray and neutrino astrophysics, together with a theoretical background.
- Describe sources of high energy cosmic rays, gamma rays and neutrinos, e.g. supernovae and active galaxies, and discuss in detail the acceleration and production mechanisms for these messengers.
- Describe how a particle flux at the Earth can be calculated by integrating over the cosmological history of the Universe, taking into account the density and luminosity functions of the sources, and the effects of the expanding Universe.

Objectives

On completion of the course, students should:

- Have a detailed physical and mathematical understanding of a variety of astrophysical systems and processes, particularly in the area of high energy astrophysics
- Understand how high energy astrophysics experiments and observatories are addressing the open questions
- Have expertise in problem solving in the areas covered in lectures

Attributes

This course is intended to develop in students the following generic attributes:

- Skills of inquiry, objective criticism, logical thought and problem solving;
- To have a high order of numerical and analytical skills;
- The ability to communicate scientific information effectively;
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content (not necessarily in order below)

- Fundamentals of Radiative Transfer and scattering
- Interstellar Hydrogen, the Violent Interstellar Medium and Star Formation
- Cosmic Ray, Gamma-ray and Neutrino Observations and Techniques
- Sources of Cosmic Rays, Gamma-rays and neutrinos, and calculation of particle fluxes at Earth, including cosmological effects from the expanding Universe

- Radiation by Accelerated Charges
- Synchrotron and Inverse Compton Radiation
- Radio emission from particle showers – the Askaryan effect
- Cosmic Ray Diffusion in galactic magnetic fields
- Attenuation of cosmic rays and photons in the Universe (e.g. GZK cut off)
- Cosmic ray acceleration – the Fermi cloud theory, and diffuse shock acceleration

Structure

Two lectures per week. Tutorials arranged when needed.

Assessment

Written Examination	60-70%
Assignments	40-30%

References

Longair, M. *High Energy Astrophysics* vol 1 & 2
Rybicki,G. B. and Lightman, A. P. *Radiative Processes in Astrophysics*
Spitzer, L. *Physical Processes in the Interstellar Medium*
Shapiro, S. L. and Tuekolsky, S. A. *Black Holes, White Dwarfs and Neutron Stars*
Harwit, M. *Astrophysical Concepts*

Contact information

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H-2

ADVANCED ATMOSPHERIC PHYSICS

Semester II

Lecturer

TBD

Aim

This course aims to:

- Introduce the physics of planetary atmospheres and ionospheres, with special emphasis on the atmosphere and ionosphere of the Earth.
- To provide students with knowledge of the physical processes that govern the atmosphere.
- To provide students with knowledge of the processes that govern the formation of planetary ionospheres and radiowave propagation through weak plasmas.

Objectives

On completion of the course, students should:

- Have an understanding of the basics of atmospheres, including atmospheres in diffusive equilibrium.
- Understand the transfer of radiation through the atmosphere, including general solutions of the Radiative Transfer (Schwartzschild) equation.
- Understand the production and loss mechanisms that lead to formation of different atmospheric regions.
- Understand radiative properties of single lines and use for remote sensing from space.
- Understand the role of atmospheric waves in transporting momentum and how this affects the state of the atmosphere.
- Understand ionisation processes in planetary atmosphere and the production and loss mechanisms that influence the formation of different regions of the ionosphere
- Understand the propagation of radiowaves through weak plasmas and how this can be used to study the ionosphere.

Attributes

This course is intended to develop in students the following generic attributes:

- Skills of inquiry, objective criticism, logical thought and problem solving;
- A high order of numerical and analytical skills;
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

Introduction to Planetary Atmospheres (10%)

- Atmospheric composition, density and temperature
- Atmospheric thermodynamics and stability

Radiation and Radiative Transfer (25%)

- radiative transfer equation and solution
- heating rates
- radiative cooling to space approximation
- formation of the stratosphere
- heat conduction and the energy budget above 100 km
- remote sensing of atmospheres from space

Atmospheric Dynamics and the Role of Waves (45%)

- primitive equations for an atmosphere on a rotating planet
- Large scale motions for an atmosphere in radiative equilibrium
- vorticity and circulation
- the vorticity equation and potential vorticity
- Periodic motions and linear wave theory and solutions in a spherical atmosphere
- vertical propagation of planetary waves and their role in the energy budget of the middle atmosphere and the formation of the ozone hole
- vertical oscillations in a stratified fluid
- solutions of the primitive equations in a non-rotating, stratified fluid
- properties of atmospheric gravity waves
- Reynolds stresses and the transport of momentum by waves
- Wave-driven circulations of the atmosphere

Ionospheric Physics (20%)

- The ionosphere, formation and dissipation
- Propagation of radiowaves in a weak plasma with and without an external magnetic field
- Characteristic modes and ionospheric sounding

Structure

Two hours of lectures/tutorials per week.

Assessment

Written Examination	70%
Assignments	30%

References

Andrews, D. G. (2000): *An Introduction to Atmospheric Physics*, CUP.
Andrews, D. G. J. R. Holton and C. B. Leovy (1987): *Middle Atmosphere Dynamics*, Academic Press.
Houghton, J. (1977): *The Physics of Atmospheres*, CUP.
Holton, J. R. (1980): *An Introduction to Dynamic Meteorology*, Academic Press.

Contact information

General enquiries to the Honours coordinator, Bruce Dawson

H-3

ELECTRODYNAMICS

Semester II

Lecturer

A/Prof James Zanotti

Aim

This course aims to:

- Provide a more detailed insight into the solution of electrostatic problems through the use of Green's functions, and the Maxwell Stress tensor.
- Introduce the Inhomogeneous Wave Equations and retarded potentials.
- Introduce the calculation of radiation patterns from first principles, including both near field and radiation field components.
- Extend the treatment of wave propagation to conducting media, in particular metals, and thence to surface-plasmon-polariton solutions of Maxwell's equations.
- Introduce the implications of causality in electrodynamics, leading to a derivation of the Kramers-Kronig relations.
- Introduce metamaterials and negative refractive index.
- Review special relativity in electromagnetism, making the unification of electricity and magnetism explicit and deriving the electromagnetic field tensor.
- Introduce the Lienard-Wiechert potentials and use them to derive the radiation patterns from bremsstrahlung and synchrotron radiation.

Objectives

On completion of the course, students should:

- Have a detailed physical and mathematical understanding of a variety of electromagnetic phenomena.
- Have expertise in problem solving in the areas covered in lectures

Attributes

This course is intended to develop in students the following generic attributes:

- Skills of inquiry, objective criticism, logical thought and problem solving;
- To have a high order of numerical and analytical skills;
- The ability to communicate scientific information effectively;
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content (not necessarily in order below)

Electrostatics
- Green's function solution of Poisson's Eq'n
- Green's reciprocity theorem
- Maxwell Stress Tensor

Inhomogeneous wave equations
- Lorentz gauge
- Green's function solution
- Retarded potentials

Radiation
- Radiation from ideal dipole
- Near field and radiation fields
- Radiation from dipole antennae

- Multipole expansion and multipole radiation
- Reciprocity theorem

Propagation issues
- Drude model of metals
- Surface Plasmons
- Causality
- Kramers-Kronig relations
- Superluminal group & phase velocity
- Negative Index materials
- Metamaterials
- Negative refraction in periodic media

Relativity
- Review, four-vectors, Lorentz transform of fields
- Field Tensor
- Lienard-Wiechert potentials
- Bremsstrahlung
- Synchrotron radiation

If time permits, we will look at scattering and radiation reaction

Structure

Two lectures per week. Tutorials arranged when needed.

Assessment

Written Examination	70%
Assignments	30%

References

Intro to Electrodynamics DJ Griffiths; this is an excellent book that is well worth having. The course will go beyond its level of difficulty somewhat. The notation in the notes follows Griffiths.
Classical Electrodynamics JD Jackson; a very comprehensive text, at a fairly difficult level, but very well written. Eight copies of the second ed'n are available for borrowing from the Advanced Laboratory. N.B. this ed'n uses the Gaussian system of units, not SI.
Classical Electricity and Magnetism W Panofsky and M Philips. This is a classic text, perhaps slightly easier than Jackson, but also not as comprehensive. Very well written. Three copies of the second ed'n are available for borrowing from the Advanced Laboratory – see Adrian Giffen.
The Electromagnetic Field A Shadowitz; There should be a copy in the BSL. This has a good introduction to relativistic aspects of Electrodynamics.
Electromagnetic Fields and Waves P Lorrain and D Corson; A classic text that is in the BSL. Intermediate in level between Griffiths and Panofsky.

Contact information

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H-4

DATA ANALYSIS AND MODELLING
(formerly Fourier techniques and applications)

Semester I

Lecturer

A./Profs Gavin Rowell and Paul Jackson

Aim

This course aims to:

- Provide an understanding of how Fourier techniques can be used to solve problems in physics.
- Demonstrate how the Fourier transform provides an understanding of physical phenomena and links together many different fields
- Develop an understanding of how to use Monte-Carlo simulation techniques

Objectives

On completion of the course, students should:

- Understand how and when to apply Monte-Carlo techniques
- Develop proficiency with the package GEANT-4
- Develop confidence in solving problems in the spectral domain, including numerical solutions FT of data and applications to power spectra.
- Understand the relationship between how the instrument response function limits resolution and its relationship to convolution.
- Understand the relationship between the FTs and wave phenomena such as diffraction and scattering from three-dimensional objects.

Attributes

This course is intended to develop in students the following generic attributes:

- Ability to apply Fourier and Monte-Carlo techniques to the analysis of physical problems;
- Skills of inquiry, objective criticism, logical thought and problem solving;
- A high order of analytical skills;
- Scientific curiosity and the ability to continue learning independently;

Content

One-dimensional FT and applications, including convolution and wavelets (50%)

- Introduction to Fourier transforms of real variables, symmetry relations Application of Fourier Transforms to linear systems with emphasis on circuits, including transfer function and the impulse response
- Convolution in physical systems, including the Instrument Response
- Application of Modulation Rule and Shift Theorem in physical systems
- The Sampling Theorem and Aliasing
- Discrete Fourier transforms and the FFT
- Power spectra
- Wavelets and their use.
- Auto and Cross- correlation functions with discrete and continuous variables
- The Wiener-Khintchine Theorem
- The Hilbert Transform and applications.

Monte-Carlo techniques (50%)

- Introduction to random simulation

- Random number generators, and tests
- GEANT-4

Structure

Two hours of lectures per week plus tutorials as required

Assessment

Written Examination	70%
Assignments	30%

Texts

James, J. F., "*A Students Guide to Fourier Transforms*", CUP

References

Bracewell, R. N., *The Fourier Transform and its Applications*, McGraw-Hill
Champeny, D. C. *Fourier Transforms and their Physical Applications*, AP

Contact information

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A/Prof Paul Jackson
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H-5

GAUGE FIELD THEORIES

Semester II

Lecturer

A/Prof Ross Young

Aim

This course aims to:

Provide a working knowledge and understanding of the theory of particles and fields
To derive and understand particles and their interactions based on the concept of gauge invariance
Describe and understand the electromagnetic, electroweak and strong forces as gauge theories

Objectives

On completion of the course, students should:

Have an understanding of these fundamental interactions, their behaviours, features and dynamics as gauge theories
Have a good working knowledge of the elements of the Standard Model and perform calculations with them.
Understand the concepts and problems in current particle and nuclear physics
Gain specialised analytical skills and techniques necessary for gauge field theory calculations.

Attributes

This course is intended to develop in students the following generic attributes:

Ability to apply an understanding of the physical principles to the other areas;
Skills of inquiry, objective criticism, logical thought and problem solving;
A high order of analytical skills;
Scientific curiosity and the ability to continue learning independently;
An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

- Principles of Gauge Invariance
- Gauge invariance in Abelian gauge field theories
- Group theory in particle physics
- U(1) gauge group
- Internal symmetries
- Special unitary groups SU(n), SU(2)
- Gauge invariance in non-Abelian gauge field theories
- Gauge invariance and geometry
- Functional methods
- Path integral quantization and gauge theories
- Generating functional methods
- Non-Abelian gauge fields and the Fadeev-Popov method
- Massive gauge bosons: Spontaneous breaking of gauge symmetry
- Higgs mechanism
- Electroweak unification and the Standard Model
- Electroweak interactions

- CKM matrix
- Perturbation theory
- Regularization and renormalization procedure

Structure

Two hours of lectures per week.

Assessment

Assignments	100%

References

Mandl, F. and G. Shaw, Quantum Field Theory, (Revised edn, Wiley, 1993)
Aitchison, I. J. R. and A. J. G. Hey Gauge Theories in Particle Physics, (2nd edn, IoP, 1989)
Ryder, L. H. Quantum Field Theory, (2nd edn, CUP 1996)
Peskin, M E. and D. V. Schroeder Introduction to Quantum Field Theory, (Addison-Wesley 1995)
Itzykson and Zuber, Quantum Field Theory, (McGraw-Hill 1980)
Kaku, M. Quantum Field Theory: A Modern Introduction, (Oxford Univ. Press, 1993)
Muta, Quantum Chromodynamics,
Halzen, F. and A.D. Martin Quarks and Leptons, (Wiley and Sons,1984)
Bailin and Love, Introduction to Gauge Field Theory (IOP Publishing Ltd, Rev. Ed. 1993)
Ramond, P. Field Theory: a Modern Primer, (Addison-Wesley, 1990)
Huang, K. Quarks, Leptons and Gauge Theories, (World Scientific, 1992)

Contact information

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H-6

GENERAL RELATIVITY

Semester II

Lecturer

A/Prof Martin White

Aim

This course aims to:

- Explain the mathematical, physical and philosophical aspects of Einstein's theory of general relativity as the relativistic theory of gravity.

Objectives

On completion of the course, students should:

- Be able to do tensor calculus in curved Riemannian spacetimes.
- Understand that general relativity is a physical theory, in which gravitational effects are incorporated by making the four dimensional space-time of special relativity curved.
- Comprehend the motion of particles in a gravitational field as straight lines in a curved space and from that derive the geodesic equation of motion for particles in a gravitational field.
- Be able to calculate observable general relativistic effects such as the gravitational time dilation effects on the global positioning system (GPS), the bending of light by stars and the existence of black holes. Have an understanding of the standard model of cosmology with particular reference to the "Big Bang".

Attributes

This course is intended to develop in students the following generic attributes:

- Ability to apply an understanding of the physical principles and mathematics that underpins the relativistic theory of gravity.
- Skills of inquiry, objective criticism, logical thought and problem solving;
- A comprehensive understanding of tensor calculus and Riemannian geometry.
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content

Special Relativity - Review

- Minkowski space, Lorentz transformations
- Four-vectors and tensors
- Curvilinear coordinates
- World line, four-velocity and four momentum

Principle of Equivalence

- Inertial mass, active and passive gravitational mass
- Weak and strong equivalence principles
- Eotvos and Pound-Rebka experiments
- Gravity as a pseudoforce
- General covariance

Classical Field Theory

- Relativistic electrodynamics, four-current
- Lagrangian field theory

- Covariant derivative and Bianchi identity

Stress-Energy Tensor
- Relation to four-momentum and stress
- Perfect fluids and dust
- Canonical method, symmetry, result for electromagnetism
- Response of action to variation of metric tensor

Differential Geometry
- Manifolds, maps
- Tangent and co-tangent vectors
- Sylvester's law of inertia, vierbein field
- Type (p,q) tensors
- Forms and exterior derivatives

Curved Space-Time
- Covariant derivative on (p,q) tensors
- Normal coordinates for a local inertial frame
- Christoffel connection, torsion
- Parallel transport and geodesics
- Riemann curvature tensor

Einstein's Theory of Gravitation
- Bianchi identities, Ricci and Einstein tensors
- Einstein's equations
- Newtonian limit
- Cosmological constant
- Linearised gravity

Schwarzschild Metric
- Birkhoff's theorem
- Schwarzschild solution
- Black holes
- Killing vectors
- Deflection of light by Sun
- Precession of Mercury orbit

Introduction to Cosmology
- Friedman-Robertson-Walker metric
- Hubble constant: Universe closed, flat or open?
- Cosmic microwave background

Structure

Two hours of lectures/tutorials per week.

Assessment

Assignments	100%

Texts

Carroll, S., *Spacetime and Geometry – an Introduction to General Relativity,* Addison-Wesley, 2004.

References

Misner, C W, Thorne, K S, Wheeler, J A, *Gravitation*, Freeman, J A 1973.
Weinberg, S., *Gravitation and Cosmology*, John Wiley & Sons, 1972.
d'Inverno, R., *Introducing Einstein's Relativity,* OUP, 1992.
Hobson, MP, Efstathiou, G, Lasenby, A N, *General Relativity – an Introduction for Physicists,*CUP 2006.

Contact information

A/Prof Martin White

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H-7

NON-LINEAR OPTICS

Semester I

Lecturer

Prof Peter Veitch, Dr Chris Perrella, Dr Ben Sparkes, Prof Andre Luiten

Aim

This course gives students:

- In depth exposure to non-linear optics
- Experience in applying nonlinear optics to advanced lasers, and optical fiber systems
- Sufficient knowledge to pursue research in these fields.

Objectives

On completion of the course, students should:

- Have an understanding of detailed nonlinear optics theory.
- An appreciation and knowledge of how to use and apply it to practical laser systems
- A working knowledge of how to approach new problems in nonlinear optics and applications.

Attributes

This course is intended to develop in students the following generic attributes:

- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge and technology.
- Skills of inquiry, objective criticism, logical thought and problem solving;
- Higher order numerical and analytical skills.
- Scientific curiosity and the ability to continue learning independently.
- Experience in solving original problems using their acquired skills.

Content

- Introduction: Overview and review of nonlinear optics.
- Wave equation description of NLO: Second Harmonic Generation, phase matching,
- Second, Third and higher order
- Intensity dependent index of refraction, general tensor formulation of susceptibility.
- Nonlinear optical processes: intensity dependent index
- Semiconductor and molecular nonlinearities
- Inelastic nonlinear optical processes: Stimulated Raman, Brillouin etc.
- Optical Phase conjugation
- Nonlinear Fibre Optics: Fibre Fundamentals: overview of basic fibre concepts, types, properties and applications. Photonic Crystals: concepts, 1- 2- and 3-dimensional photonic crystals, Fibre Bragg Gratings
- Optical Glasses: concepts, optical and thermal properties, fabrication,
- Microstructured Fibres: guidance mechanisms, optical properties, fabrication and applications, Nonlinear fibre devices based on microstructured fibres: review of operation of a range of devices
- Thermonuclear laser fusion
- Quantum optics, quantum cryptography

Structure

Two hours of lectures/tutorials per week.

Assessment

Take-home midterm exam	30%
Take-home final exam	50%
Student seminar on relevant topic	20%

Texts

Class notes handed out

References

Milonni, P. and J. Eberly: *Lasers,* John Wiley & Sons, 1988
Ghatak A.K. and K. Thyagarajan: *Optical Electronics,* Cambridge 1989
Yariv, A.: *Optical Electronics*, Holt, Rinehart & Winston, 4th edition, 1991
Boyd, R.: *Nonlinear Optics,* Academic Press, 2003.
Butcher, P.N. and D. Cotter: *The Elements of Nonlinear Optics* Cambridge 1990
Agrawal, G.P.: *Nonlinear Fiber Optics* Academic Press 2001
Saleh & Teich: *Photonics*

Contact information

Prof Peter Veitch peter.veitch@adelaide.edu.au
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H-8

Nuclear and Radiation Physics

Semester I

Lecturer

Dr Alex Santos and Prof. Eva Bezak

Aim

This course aims to:

- Introduce radiation and nuclear physics from an experimental viewpoint, applied to environmental, medical and solid state physics.
- Show how nuclear and radiation physics are related to other physics disciplines – solid state, elementary particle physics, radiochemistry, astronomy.
- Demonstrate the influence of experimental techniques used (or developed) for nuclear physics purposes (logic circuits, gamma cameras, semiconductor detectors) on development of new technologies.

Objectives

On completion of the course, students should be able to:

- Identify the components of the nucleus and describe the systematic behaviour of stable nuclides;
- Describe the main features of the liquid drop and shell models of the nucleus, and discuss their achievements and deficiencies.
- Discuss radioactive decay and the models used to understand it;
- Describe and explain the parameters used to describe nuclear reactions;
- Describe and apply the concepts and theories which relate to the interactions of various forms of ionizing radiation, including X-rays, gamma rays, charged particles and neutrons with matter.
- Describe the principles involved in the detection and accurate measurement of radiation.
- Discuss some of the applications of radiation and nuclear physics to medical and environmental and material physics.

Attributes

This course is intended to develop in students the following generic attributes:

- Ability to apply an understanding of the physical principles that govern the interaction of photons and particles with matter
- Basic understanding of radiation safety issues and problems of radioactive waste disposal
- Ability to think from the experimental, technical and practical point of view
- Scientific curiosity and the ability to continue learning independently
- An appreciation of the central role of science in society and the close relationship between scientific research and many practical applications in our everyday lives that have resulted from this research.

Content

<u>Nuclear Physics (30%)</u>

- General properties of nuclei
- Stability, systematics, trans-uranic elements.
- Nuclear models, magic numbers
- Decay processes and half lives: fission, α and β-decay, electron capture
- Radioactive growth and decay, Bateman equations, laboratory generators
- Radioactive series

- Natural and artificial radioactivity, environmental problems, eg, radon, mining and waste disposal
- Radioisotope production
- Carbon dating, Accelerator Mass Spectrometry
- Theory of α , β and γ-decay, selection rules

Nuclear Reactions (20%)

- Interactions of neutrons with matter, neutron activation
- Applications of nuclear techniques (medical and solid state physics).

Radiation Physics (50%)

- General Properties of X-rays
- Generation of high energy Photons: X-ray apparatus, accelerators
- Tubes for imaging and therapy
- Fluorescent radiation, PIXE, monitoring bone lead levels
- Radiation measurements and units
- Interaction of Photons with Matter: photoelectric effect, Compton effect and pair production, Auger effect, Coherent (Rayleigh) scattering
- Energy transfer and deposition (absorption), build-up and KERMA
- Charged Particle Energy Losses
- Linear energy transfer (LET), stopping cross section, Bethe-Bloch formula
- Electron collision and radiation losses
- High-energy electron-photon showers, cosmic rays.

Structure

Two hours of lectures per week.

Assessment (to be Confirmed)

Written Examination (2 hours)	60%
Assignments	30%
Presentation	10%

Minimum requirements: Students must submit at least one assignment, take the examination and achieve an overall result of 50%.

Texts

Williams, W.S.C., *Nuclear and Particle Physics*, Oxford University Press, 1991.

Johns, H. E. and J. R. Cunningham, *The Physics of Radiology*, 4th Edition, CC Thomas: Springfield, 1983.

Evans, R. D., *The Atomic Nucleus*, McGraw Hill, 1955.

References

Lederer CM and V. S. Shirley, *Table of Isotopes*, 7th Edition, Wiley, 1978.

Burcham WE, and M. Jobes, *Nuclear and Particle Physics*, Longman, 1995.

Leo W. R., *Techniques for Nuclear and Particle Physics Experiments",* Springer-Verlag, 1994.

Khan F. M. and A. R. Potish., *The Physics of Radiation Therapy,* 3rd Edition, Williams and Wilkins, 2003.

Contact information

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H-9

QUANTUM FIELD THEORY

Semester I

Lecturer

A/Prof. Ross Young

Aims

This course aims to:

- Introduce students to field quantisation, scalar field theory and quantum electrodynamics.
- Develop calculational techniques in perturbation theory.
- Prepare students for Gauge Field Theory in semester II.

Objectives

On completion of the course, students should:

- understand field quantisation and the expansion of the scattering matrix;
- be able to carry out practical calculations based on Feynman diagrams.

Attributes

This course is intended to develop in students the following generic attributes:

- The capabilities of a professional theoretical physicist.
- An understanding of quantum theory at its most fundamental level; this is the basis of modern physics and therefore underlies most of the benefits to society from advanced technology.
- The ability to carry out advanced field-theoretic calculations, which involves the highest order of numerical and analytical skills and develops the ability to continue independent research.
- Enhanced scientific curiosity, objective criticism and an understanding of the close relationship between scientific research and the development of new knowledge.

Content

<u>Introduction</u>

- Review of four-vector notation.
- Why quantise fields? (a) t □ operator, so neither is $\boldsymbol{x}$; (b) causality; (c) photon field.
- Review point mechanics: Noether's theorem, Jacobi first integral, Hamiltonian.

<u>Classical Field Theory</u>

- Lagrangian (density), action, field equations of motion, equivalent Lagrangian.
- Real and complex scalar fields, 4-potential and Maxwell's equations, Schrödinger field.
- Stress-energy-momentum tensor and four-momentum, Hamiltonian (density).

<u>Field Quantisation</u>

- Dirac's quantum electrodynamics (1927).
- Free scalar field (real), 3-Fourier coefficients as ladder operators, particle number operators, Hamiltonian, zero-point energy and normal ordering, equal-time field commutators, complex scalar field.
- Heisenberg picture, space-time translations, ground state, invariantly normalized one-particle states, Fock space.

Invariant Functions

- Lorentz invariance and causality, Pauli-Jordan function, unordered free two-point function, boundary value of complex function, time-ordered functions, contour integrals and $i\epsilon$ prescriptions in momentum space.
- Feynman propagator, Green's function property and relation to canonical commutators.

Fermion Fields

- Replace commutators with anti-commutators; (Dirac equation, traces, polarization sums, etc., done concurrently in Relativistic Quantum Mechanics and Particle Physics); free fermion field and propagator, Lorentz properties.

Interacting Theories

- Local interactions: Yukawa, electromagnetic, ϕ^4, Mexican hat.
- Interaction picture, time-evolution operator, S-matrix, Green's functions.
- Contractions, Wick's theorem, Dyson-Wick expansion.
- Feynman diagrams and rules for ϕ^4 theory, position and momentum space, Green's functions and S-matrix.
- Feynman rules for complex scalar and Yukawa theories.

Introductory Quantum Electrodynamics

- Free photon field, gauge fixing (elementary), covariant gauges.
- Feynman rules.
- Polarisation sums.

Cross Sections and Decay Rates

- Wave packets for initial and final particles, mutual beam flux, sums over final states, identical particles, examples such as Compton scattering.

Structure

Two hours of lectures per week.

Assessment

Written Examination:	50%
Assignments:	50%

Texts

Peskin, M.E. and D.V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley 1995, Ch. 1-5.

References

Mandl, F. and G. Shaw, *Quantum Field Theory*, Wiley 1984.

Contact information

A/Prof. Ross Young ross.young@adelaide.edu.au
Phone 8313 3542 (internal: 33542)

H-10

RELATIVISTIC QUANTUM MECHANICS & PARTICLE PHYSICS

Semester I

Lecturer

Prof. Anthony Thomas and Prof. Derek Leinweber

Aim

This course aims to:

- Review the concepts that lead to the formulation of the Klein-Gordon and Dirac Equations.
- Highlight the deep connection between the Lorentz transformations of special relativity and the transformation properties of Dirac spinors and the adjoint spinor.
- Examine plane wave solutions, completeness relations and projection operators.
- Solve the relativistic Hydrogen atom and explore its fine structure.
- Introduce the Standard Model Interactions of Particle Physics, conservation laws and associated Feynman graphs for physical processes.

Objectives

On completion of the course, students should:

- Understand the founding principles of relativistic quantum mechanics.
- Have a working knowledge of Dirac gamma matrices and their role in the Lorentz transformations of Dirac Spinors.
- Be able to use projection operators to filter spin and positive/negative energy solutions.
- Appreciate the modern field-theoretic description of negative energy states.
- Be able to solve relativistic one-body problems for spin-0 and ½ particles.
- Identify particle interactions allowed by the Standard Model and describe the physical process by which they occur.

Attributes

This course is intended to develop in students the following generic attributes:

- To value the close relationship between scientific research and the development of new knowledge.
- An enthusiasm for, and enjoyment of, the ethos of science and the process of scientific investigation.
- Skills of inquiry, objective criticism, logical thought and problem solving;
- To have a high order of numerical and analytical skills;
- To possess scientific curiosity and the attitudes, knowledge and skills necessary for a commitment to life long learning;

Content

Relativistic Quantum Mechanics (75%)

- Klein Gordon Equation
- Problems with the Klein Gordon Equation
- Dirac Equation
- Probability Current
- Two-Spinor Decomposition
- Hole Theory and the Anti-Particle Wave Function
- Rotation Group O(3) and the Lorentz Group O(3;1)

- Review of Tensors
- Manipulating Exponentials of Operators
- Transforming Spinors: Vector and Spinor Lorentz Generators
- Lorentz Covariance of the Dirac Equation
- Adjoint Spinor
- Four-Current Density
- Parity
- Sixteen Gamma Matrices and associated Theorems for Gamma Matrices
- Natural Units
- Plane-Wave Solutions and their Lorentz Properties
- Completeness and Projectors
- Four-Spin
- Electromagnetic Coupling, Magnetic Moment and the Gyromagnetic ratio
- Charge Conjugation
- Klein-Gordon Atom
- Relativistic H Atom
- Corrections to Dirac Spectrum

<u>Particle Physics (25%)</u>

- Introduction to Standard Model Interactions
- Conservation of Charge, Baryon Number.
- Conservation of Lepton and Lepton Family Number.
- Quark Structure in Reactions.
- Strangeness, Parity, Charge Conjugation and G-Parity.
- Parity of the Pion.
- Quarks and Isospin.
- Constituent versus Current Quarks.
- Feynman Diagrams for Physical Processes

Structure

Two one-hour lectures per week.

Assessment

Written Examination	75%
Two Assignments	25%

Texts

Crewther, R., *Lecture Notes*: *Relativistic Quantum Mechanics* (2003)

References

Bjorken, J. D. and S. D. Drell, *Relativistic Quantum Mechanics*, Vol. I (1964)
Itzykson, C. and J.-B. Zuber, *Quantum Field Theory* (1980)

Contact information

Prof Derek Leinweber	derek.leinweber@adelaide.edu.au	8313 3423
Prof Anthony Thomas	anthony.thomas@adelaide.edu.au	8313 3547

H-11

HONOURS ELECTRONICS

Semester I

Lecturer

Professor Peter Veitch

Aim

This course provides an introduction to analogue and digital electronics used for signal conditioning, data acquisition and experiment control in experimental and applied physics. It includes applications of operational amplifiers, comparators, digital gates and flip-flops, astable and monostable multivibrators, digital to analog converters, analog to digital converters, and PIC (peripheral interface controller) chips.

Structure

One three-hour practical per week.

Assessment

Practical Examination	50%
Workbook assessment	50%

Texts

References

The Art of Electronics, *Horowitz and Hill.*

Contact information

Professor Peter Veitch peter.veitch@adelaide.edu.au
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H-12

APPLICATIONS OF RELATIVITY

Lecturers

Dr Sam Drake

Aim

The focus of this course is on teaching those aspects of relativity theory that are relevant to applied physics in the areas of signal processing, navigation, tracking, imagining, cartography and optimal path planning. All of the material is presented so that each new concept is demonstrated through practical examples. For each topic we will discuss a relativistic concept, derive the mathematics and give fully worked examples

Objectives

On completion of the course, students should:

- Understand how to construct and use space-time tensor equations to solve practical problems in applied physics
- Determine under what conditions relativistic effects such as time dilation and Einstein velocity addition are important
- Calculate the pseudo acceleration caused by coordinate transformations

Attributes

This course is intended to develop in students the following generic attributes:

- Skills of inquiry, objective criticism, logical thought and problem solving;
- To have a high order of numerical and analytical skills;
- The ability to communicate scientific information effectively;
- Scientific curiosity and the ability to continue learning independently;
- An appreciation of the central role of science in society and the close relationship between scientific research and the development of new knowledge

Content (not necessarily in order below)

Galilean Relativity

- Galilean transformation equations
- Principle of invariance
- The difference between phase and group velocity
- The Doppler effect for sound from the Galilean transformations

Lorentz transformations

- Derivation of the Lorentz transformations
- Consequences of the Lorentz transformations: The velocity addition formula, Angular aberration, time dilation, length contraction, lack of simultaneity
- The Doppler effect for light in a vacuum
- The relationship between causality and events inside or outside the light-cone
- The invariance of the Minkowski space-time interval under Lorentz transformations

Ring Laser Gyroscopes

- Beat frequency for the pedagogical RLG
- “Fresnel drag” for light in a medium

- Thomas procession (two Lorentz transformations produce a single Lorentz transformation and a rotation)

Tensors and the laws of physics

- Understand the difference between co and contra variant vectors
- Einstein summation convention
- The relationship between the metric tensor and the Jacobian matrices
- Know how to swap from tensor notation to linear algebra notation
- Understand how the Jacobian matrix can be used to calculate the error covariance matrix in different coordinate systems
- Derive the Doppler effect for light in a vacuum from the Lorentz transformations in tensor notation
- Express bias in tensor notation

Relativistic Dynamics

- Understand the Einstein velocity addition law is inconsistent with the conservation of Newtonian momentum
- $E^2 = p^2c^2+m^2c^4$
- Conservation of four momentum (energy-momentum) and how to use it to calculate
- Energy efficiencies
- Momentum of photons
- De Broglie wavelength
- Compton scattering

Relativistic Electromagnetism

- The speed of light in a vacuum from Maxwell's equations
- The Levi-Civita symbol and its use in Cross products, Curl, Grad curl etc
- The electromagnetic field tensor and its role in the Lorentz force on a charged particle in and EM field
- Rewriting Maxwell's equations as tensor equations
- Invariances of the EM tensor
- The transformation of the EM tensor using the Lorentz transformations
- Derivation of the Biot-Savart law from Lorentz transformations of a moving particle in an EM

Cartography and Tensor Algebra

- Derive expressions for the Euclidean distance of various map projections
- Express the distortions (angle, distance and area) for different cylindrical projections
- Use the distortion formula to calculate: the speed and heading as a function of change in latitude and longitude, the distance along a loxodrome between points on a sphere, the error in latitude and longitude for a given GPS error
- Calculate the distortive effects of projecting the WGS84 ellipsoid onto a sphere

Tracking in non-Cartesian coordinates

- Derive the Coriolis force by considering rotating basis vectors
- Express this derivative in terms of the Christoffel symbols
- Express the derivative of a vector with respect to proper time in terms of the derivative of the components and the Christoffel symbols
- In 2D polar coordinates calculate: The Christoffel symbols, Grad Phi
- Express the covariant derivative of a covariant vector in terms of the Christoffel symbols
- Appreciate that minimising the distance also leads to the geodesic equation

General Relativity and the Global positioning system

- Given the metric tensor for a weak gravitational field calculate the difference in proper time for a clock on Earth and one in circular orbit

Structure

Two one-hour lectures per week.

Assessment

Assignments	20%
Question sets	30%
End of semester open-book exam	50%

(Hurdle: to pass the course, students must score at least 40% in the exam)

References

The following book, papers and web sites are recommended:

- S. P. Drake, "Was Einstein an Engineer?", Proceedings of the IEEE, vol. 102, pp. 1870-1872, 2014.
- J. Wolfe. Einstein Light. Available: http://newt.phys.unsw.edu.au/einsteinlight/
- A. P. French, Special relativity. New York: Norton, 1968.
- B. F. Schutz, A first course in general relativity. Cambridge: Cambridge University Press, 1985.
- S. P. Drake, "The equivalence principle as a stepping stone form special to general relativity: A Socratic dialog," American Journal of Physics, vol. 74, pp. 22-25, 2006.
- S. P. Drake and K. Dogancay, "Some applications of tensor algebra to estimation theory," in Wireless Pervasive Computing, 2008. ISWPC 2008. 3rd International Symposium on, 2008, pp. 106-110.
- S. P. Drake, B. D. O. Anderson, and C. Yu, "Causal association of electromagnetic signals using the Cayley--Menger determinant," Applied Physics Letters, vol. 95, p. 034106, 2009

Contact information

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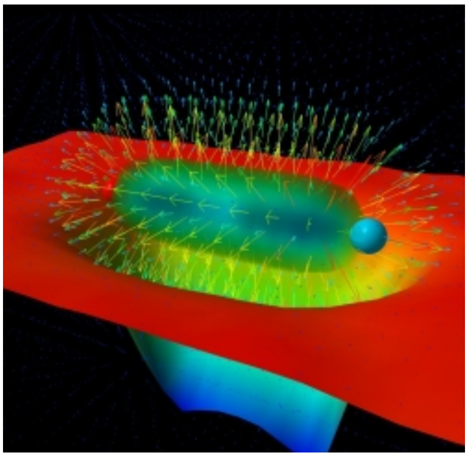
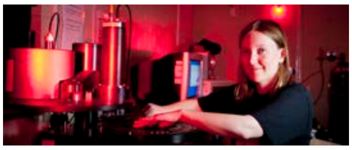
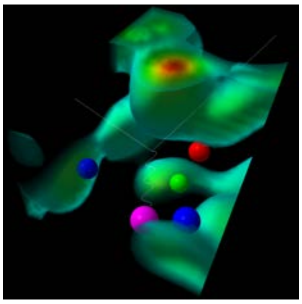
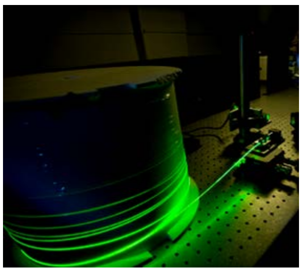
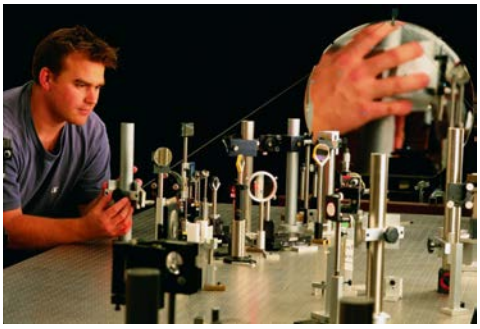
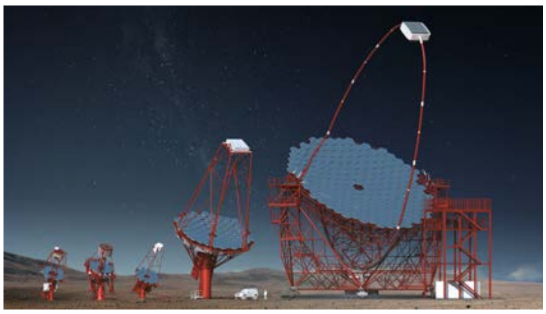
THE UNIVERSITY of ADELAIDE

DEPARTMENT OF PHYSICS
HONOURS PROJECTS – 2019



Honours Coordinator: Prof Bruce Dawson
Theoretical/Maths Physics Adviser: Assoc. Prof Ross Young
Medical Physics Adviser: Dr Alex Santos

P R O J E C T S

Guidelines for choosing a project.

In the process of selecting a research topic, begin by investigating offerings from at least two of the sections in this handbook. The sections broadly reflect the research groupings within Physics. You need to discuss specific projects with at least one of the supervisors named with each project.

It is also possible to undertake a project that is Physics by its nature but is offered outside of the Physics discipline. Such projects are usually not listed in this handbook. If you have a strong interest in such a project, you should discuss this with the Honours Coordinator to see if the project is suitable, and if appropriate supervision is possible.

You are to identify two projects to form your first and second choices. If there is more than one supervisor named, you will need to specify the principal supervisor - of your choice.

Choosing a project is not like an auction, or a fire sale, where the goods go either to the highest bidder or to the first comer. Final decisions on who does which project are not made until all students have indicated their preferences. This is done as early as possible in the academic year.

In several sections, specific projects are not listed, rather broad areas are given, and the actual projects are decided in consultation with your chosen supervisor. In the other sections, the projects are more specific and in the event that more than one student chooses a project, discussions will take place between the students, supervisors and the Honours Coordinator and decisions taken accordingly.

Once you have a project, you need to choose your principal supervisor and discuss with them the possible appointment of a co-supervisor(s). Having a co-supervisor is important, because there may be absences (foreseen or unforeseen) of the principal supervisor during the year, and you will then always have a source of advice. The Honours Coordinator can assist with these discussions.

It occasionally happens that a student discovers, after embarking upon it, that the project is unsuitable for them. Hopefully this realisation will happen (if it does happen) early in the year and a new project found. If you find that you are in this situation you should discuss this with the Honours Coordinator as soon as possible.

As part of your project you will be expected to present a twenty-minute talk to your fellow students and interested staff. This will happen in late August or September. Though compulsory, the talk is not actually assessed – its function is to make you assess your project and, especially, what you need to do to wrap up the project. You will also need to write a report (a short thesis) on what you accomplished in your project. This is assessed and will be due at the end of October. The remaining assessment takes the form of an interview in which you discuss the project with a panel of five academic staff members of Physics.

SECTION A - SPACE AND ATMOSPHERIC PHYSICS

(Supervisors: MacKinnon, Hamilton, Vincent, Reid, Younger, Dolman, Ward, Holdsworth, Harris, Cervera and Anderson)

A-1 Radar Rainfall Studies **(Dolman & Reid**)
A-2 Transient Weather Events **(Dolman, MacKinnon & Reid)**
A-3 Using satellite detections to monitor the ionosphere (**Holdsworth, MacKinnon & Dolman**)
A-4 GPS Measurements from Ground and Space **(Vincent & MacKinnon)**
A-5 Evolution of Interplanetary Dust Orbits (**Younger & MacKinnon**)
A-6 Radio Astronomy at 55 MHz **(MacKinnon, Rowell & Vincent)**
A-7 Active and Passive Measurement of Atmospheric Trace Gases **(Hamilton & Vincent)**
A-8 Cloud Microphysics **(Hamilton)**

SECTION B - HIGH ENERGY ASTROPHYSICS

(Supervisors: Dr Jose Bellido, E/Prof Roger Clay, Prof Bruce Dawson, Dr Sabrina Einecke, Assoc. Prof Gary Hill and Assoc. Prof Gavin Rowell)

B-1 Studying the Highest Energy Particles in Nature with the Pierre Auger Observatory **(Dawson, Bellido, Clay, Hill)**
B-2 Predicting the movement and development of cloud for dynamically scheduling astronomical observations **(Clay & Dawson)**
B-3 High-energy neutrino astronomy with the IceCube detector at the South Pole **(Hill)**
B-4 Study of Nature's Extreme Particle Accelerators at Tera-eV (10^{12} eV) Gamma-Ray Energies with HESS and Other Telescopes (**Rowell**)
B-5 Data Analysis, Machine Learning and High-Energy Gamma-Ray Astronomy (**Rowell, Einecke, Bellido**)

SECTION C - THEORETICAL PHYSICS

(Supervisors: Prof Derek Leinweber, Prof Anthony Thomas, Prof Tony Williams, Assoc. Prof Ross Young, Assoc. Prof James Zanotti, Dr Hrayr Matevosyan, Dr Rodney Crewther, Dr Ayse Kizilersu & Assoc. Prof Max Lohe)

C-1 Lattice Gauge Theory **(Kamleh, Leinweber, Williams, Young & Zanotti)**
C-2 Effective Field Theory **(Leinweber, Thomas & Young)**
C-3 Nuclear Theory **(Thomas)**
C-4 Models of Hadrons and Hadronic Interactions **(Matevosyan, Thomas & Zanotti)**
C-5 Quantum Field Theory **(Crewther, Thomas, Williams, Young & Zanotti)**
C-6 Complex Systems **(Kilzilersu, Leinweber, Lohe, Thomas & Williams)**
C-7 Theoretical High Energy Physics – **see section D2 of High Energy Physics**

SECTION D - HIGH ENERGY PHYSICS

(Supervisors: Prof Anthony Thomas, Prof Tony Williams, Assoc. Prof Ross Young, Assoc. Prof Paul Jackson & Assoc. Prof Martin White)

D-1 Experimental High Energy Physics **(Jackson, White)**
D-2 Theoretical High Energy Physics (**Thomas, White, Williams & Young)**
D-3 High Energy Physics Phenomenology **(Jackson, Thomas, White, Williams & Young)**

SECTION E - MEDICAL PHYSICS

(Supervisors: Santos, Penfold, Collins, Matyagin, Hickson)

E-1 Investigation of the use of Optical Photogrammetry in High Dose Rate Surface Brachytherapy **(Santos, Douglass)**
E-2 Validating a radionuclide method for radiation shielding verification in medical imaging departments **(Collins, Hickson and Matyagin)**
E-3 Small field dosimetry with beryllium oxide ceramic fibre optic dosimeters **(Santos)**
E-4 Characterization of the dosimetric properties of radiochromic films **(Santos)**

SECTION F - OPTICS & PHOTONICS

(Supervisors: E/Prof Jesper Munch, Prof Heike Ebendorff-Heidepriem, Prof Peter Veitch, Prof David Ottaway, Dr Stephen Warren-Smith, Dr Yinlan Ruan, Dr Erik Schartner, Dr Linh Nguyen, Prof. Robert McLaughlin, Dr Jiawen Li, Prof. Andre Luiten, A/Prof Martin O'Connor, Dr Fred Baynes, Dr Philip Light, Dr Chris Perrella, Dr Dan Brown, Dr Ben Sparkes, Dr Giuseppe Tettamanzi, Dr James Quach)

F-1 Aerial detection of Methane **(Ottaway, Veitch)**
F-2 Cloud Studies using high power eye-safe laser radar **(Ottaway, Veitch and Mackinnon)**
F-3 High-precision characterization of optics using Hartmann wavefront sensors **(Veitch)**
F-4 High Brightness Single Frequency Mid-Infrared Lasers **(Ottaway, Henderson-Sapir and Luiten)**
F-5 A New Class of Germanate Glass Microstructured Fibre Lasers **(Ebendorff-Heidepriem)**

F-6 Harnessing nanoparticles in glass optical fibres **(Ebendorff-Heidepriem)**
F-7 Nonlinear optics in optical waveguides: Can we control photons by photons? **(Luiten, Ebendorff-Heidepriem and Lohe)**
F-8 Novel Spectroscopic Analysis for Breath-based Diagnostics **(Luiten and White)**
F-9 Intelligent algorithms to detect blood flow with optical imaging **(McLaughlin, Li)**
F-10 3D printing of optical calibration objects for high resolution medical imaging **(McLaughlin, Li)**
F-11 Multiplexed extreme temperature sensing with fibres **(Ottaway, Warren-Smith and Shartner)**
F-12 Exploiting laser threshold for high sensitivity biochemical sensing **(Ottaway, Warren-Smith and Nguyen)**
F-13 Imaging Microstructured Optical Fibres **(Ottaway, Warren-Smith, Schartner)**
F-14 Optical Fibre Temperature Sensors for Heavy Industry Applications **(Ottaway, Warren-Smith, Schartner)**
F-15 Intelligent Infrared Imaging sensors using machine learning **(O'Connor)**
F-16 Micro-structured Optical Fibre for High Power Laser Beam Delivery **(O'Connor)**
F-17 Sensing & Spectroscopy **(Perrella, Luiten, Light, Sparkes, Tettamanzi)**
F-18 Quantum Atom-Fibre Photonics **(Perrella, Light, Luiten, Sparkes, Tettamanzi)**
F-19 Frequency Standards & Distribution **(O'Connor, Baynes, Light, Luiten, Sparkes, Tettamanzi)**
F-20 Quantum mechanical theory and experiment **(Quach, Tettamanzi)**

SECTION G - OZGRAV

(Supervisors: Prof David Ottaway, Prof Peter Veitch, Dr Dan Brown, Dr Sebastian Ng, Mr Huy Cao)

G-1 Advanced LIGO Detector Characterization and CW Astrophysics **(Ottaway, Brown)**
G-2 Computational Models of Lasers for Future Gravitational Wave Detectors **(Ottaway, Ng)**
G-3 Improving Fiber Laser Sources for Future Gravitational Wave Detectors **(Veitch, Ng)**
G-4 Characterizing the Directional Stability of Laser Sources for Future Gravitational Wave Detectors **(Veitch, Ng)**
G-5 Understanding Laser Beams (**Veitch, Ng, Cao)**
G-6 Mixed Digital and Analog Control of Advanced Lasers **(Ottaway, Ng)**
G-7 High-Precision Surface Metrology of Mirrors **(Veitch, Cao)**
G-8 Machine Learning Techniques for Advanced Gravitational Wave Detectors **(Brown, Ottaway)**
G-9 High Resolution 3D Scene Mapping Using Advanced GW Technology **(Ottaway, Brown)**

SECTION H - ENVIRONMENTAL LUMINESCENCE

(Supervisors: Nigel Spooner, Lee Arnold, David Ottaway, Heike Ebendorff-Heidepriem, Don Creighton.)

H-1 Geochronology:
H-2 Defence & National Security.
H-3 Mining and Mineral Processing

SECTION J - BIOPHYSICS

(Supervisors: Bronwyn Dolman and Iain Reid)

J-1 Modelling the Aussie Rules Football kick

SECTION K - SEMICONDUCTOR PHYSICS

(Supervisor: Dr David Huang (Chemistry))

K-1 Structure-property relationships in organic semiconductors

SECTION L - GEOPHYSICS

(Supervisors: Professor Sandy Steacy, Dr Thomas Reverso)

L-1 Coulomb stress models for earthquake interaction and forecasting

A – SPACE AND ATMOSPHERIC PHYSICS

(Iain Reid, Murray Hamilton, David Ottaway, Andrew MacKinnon, Robert Vincent, Bronwyn Dolman, Joel Younger, Stuart Anderson, Bruce Ward and David Holdsworth)

The atmosphere from ground to space is a complex system, combining the effects of fluid flows, radiative absorption and emission, chemistry, geomagnetism, plasma physics, and solar physics. The challenge of space and atmospheric physics is to understand the behaviour and origins of the physical processes which influence different regions of the atmosphere, producing the weather and climate that we experience. The Space and Atmospheric Physics Group is heavily involved in the development of new technologies to detect different atmospheric parameters, including winds, temperature, water vapour, cloud phase and plasma density. The equipment used for these measurements includes different types of radar and lidar systems, optical imagers, satellite observations, GPS receivers, and in-situ direct measurement sensors. The group also engages in numerical simulation and theoretical investigations to characterize the underlying physical processes, which can combine elements of signal analysis, electrodynamics, fluid mechanics, chemistry, statistical mechanics, and computational physics.

A-1: RADAR RAINFALL STUDIES

(Supervisors: Bronwyn Dolman and Iain Reid)

Scanning weather radars use empirical relationships to calculate rainfall rates from the measured returned power. These empirical relationships are updated in real time using the rain gauge network. Rain gauges can only provide surface information, however the actual rain rate can vary greatly during the descent from cloud to ground. Vertically pointing radars are capable of retrieving the rain rate throughout the vertical column from cloud to ground, and therefore offer additional information over rain gauges.

ATRAD Pty Ltd, an Adelaide based radar design and manufacturing company presently operates both UHF (~50 MHz) and VHF (~400 MHz) radars and have recently acquired an X-band (~10 GHz) radar system, typically only used as scanning radars. Using all of these radars together could enable un-precedent observations of vertical profiles of rainfall.

Depending on student's interest various projects, which could be hardware or data analysis focussed, using combinations of these systems are possible. These could include sensor fusion, radar deployment, comparison techniques, validation with Bureau of Meteorology's computational models, etc.

The project will be supported by ATRAD Pty Ltd, and provides an opportunity for the student to experience industry life.

A-2: TRANSIENT WEATHER EVENTS

(Supervisors: Bronwyn Dolman, Andrew MacKinnon and Iain Reid)

This project involves integrating data from multiple instruments to determine the origins of recurring and transient weather events in the Adelaide area. The Adelaide area includes a number of atmospheric sensors including multiple radars that measure wind speed and direction at different heights, surface weather stations, and balloon launching facilities, including an intense campaign of 136 launches in 2011. This provides an opportunity to study the sources of atmospheric waves and other meteorological phenomena in the Adelaide area and potentially compare these measurements to the Bureau of Meteorology's computational models. Related topics: extreme weather events, sensor fusion, atmospheric gravity waves and atmospheric tides.

A-3: USING SATELLITE DETECTIONS TO MONITOR THE IONOSPHERE

(Supervisors: David Holdsworth, Andrew MacKinnon and Bronwyn Dolman)

This project will refine satellite detection techniques using a large radar north of Adelaide to develop new ways to measure the amount of plasma in the upper atmosphere and compare the results with other methods. The Buckland Park stratosphere-troposphere (BPST) VHF radar is located 35 km North of Adelaide. The radar is typically used to measure stratosphere-troposphere winds and observed meteors in the upper atmosphere. Recently this radar has detected low-earth orbit (LEO) satellites at altitudes from 300 and 2000 km.

Ionospheric dispersion, which causes a delay in radar signal propagation between the ground and the satellite, results in an increase in the radar-measured distance to the satellite when compared with ephemeris information. The BPST satellite detections therefore potentially offer a new means of measuring Total Electron Content (TEC) at potentially significantly higher temporal resolution when compared with presently utilized GPS measurements.

A-4: GPS MEASUREMENTS FROM GROUND AND SPACE

(Supervisors: Andrew MacKinnon, Manuel Cervera and Robert Vincent)

Signals from the constellation of GPS (Global Positioning System) satellites are used for scientific research in areas other than the original purpose of accurate position location. Propagation of the two microwave signals transmitted from each satellite are determined by the refractive index of the atmosphere, which is in turn determined by the electron density in the ionosphere, the temperature profile of the atmosphere and, in the lowest part of the atmosphere, by water vapour. This project will use GPS measurements from dual-frequency GPS receivers to study variation in electron density in the ionosphere and atmospheric water vapour. The project will give the opportunity to carry out research in the rapidly changing field of GPS observations, which have wide application in atmospheric physics and meteorology. Measurements of GPS signals received on low-orbit micro satellites, such as the recently launched Australian Cube-satellites and COSMIC constellation (which provide a global perspective). Australia has a number of high-density GPS networks which could allow high spatial resolution measurements of both electron density and water vapour to be obtained.

A-5 EVOLUTION OF INTERPLANETARY DUST ORBITS

(Supervisors: Joel Younger and Andrew MacKinnon)

Computational modelling of the trajectories of small objects in orbits around stars enables a better understanding of the evolution of planetary systems and interplanetary dust. Streams of dust and small debris are generated in the solar system by sublimating comets, object collisions, and the influx of interstellar dust. Due to the complex interaction of solar radiation effects with dust grains, combined with gravitational effects, the orbits of dust particles change over time. These forces are well known and can be used to construct a numerical model of the orbits of interplanetary dust over long time periods, enabling a better understanding of the evolution of interplanetary dust and the estimation of the age of existing dust streams. Given recent advances in exoplanetary imaging, this can also be applied to interpret images of dust rings and discs around other stars. Opportunities exist to compare the results of numerical modelling with radar observations of meteor showers and spacecraft borne dust sensors to study the density and distribution of dust in the solar system.

A-6: RADIO ASTRONOMY AT 55 MHZ

(Supervisors: Andrew MacKinnon, David Holdsworth and Gavin Rowell)

A medium size antenna array operating at 55 MHz is presently being used at the Buckland Park field site (40 km North of Adelaide) as part of an atmospheric wind profiling radar. By running this radar in a purely receptive mode it effectively becomes a VHF radio telescope.

This purpose of this project would be to test the feasibility of using this array for Radio Astronomy. Sources to study might include the galactic centre, Jupiter and the Sun, aiming to detect any changes. It is also anticipated and hoped that these passive measurements could also be used to help calibrate the actual beam pattern of the entire array by observing astronomical radio sources as they move across the field of view of the array. Thus this project can explore the potential to monitor astrophysical sources. Students will gain experience in radio interferometry techniques which underpin major astronomy programmes in Australia such as the Square Kilometre Array (SKA).

A-7: ACTIVE AND PASSIVE MEASUREMENT OF ATMOSPHERIC TRACE GASES

(Supervisors: Murray Hamilton and Robert Vincent)

Water vapour and Methane are two important trace gases in the atmosphere; the first is the dominant greenhouse gas and the second perhaps the most topical, on account of the recent prominence of unconventional gas extraction. Knowledge of the spatial and temporal variability of each is crucial.

The routine measurements made around the world are too sparse and infrequent to properly capture this variability; in the case of water, for weather and climate modelling; and in the case of methane, for ascribing responsibility for the anthropogenic emissions.

This project could develop along a couple of paths; first is developing a lidar (active) that measures Raman-scattered light from water, and which will ultimately be deployed at Davis Station in Antarctica as part of a larger campaign to understand the influence of the Southern Ocean in the Earth's climate system. Second is to quantify methane leaks, based on a knowledge of the local atmospheric conditions and measured methane concentrations. This last project will suit a student who enjoys field work.

A-8: CLOUD MICROPHYSICS

(Supervisor: Murray Hamilton)

Clouds are unsurprisingly an integral part of the climate system, but perhaps surprisingly there are many puzzles regarding their formation and evolution. One such puzzle is around the presence of super-cooled liquid water (SLW) – why is there so much and why is it so persistent? One part of the world where there is more SLW than expected is the atmosphere over the Southern Ocean. This discrepancy is one of the most important sources of uncertainty in weather and climate models which predict the net heating/cooling of the earth, and whether water in clouds is liquid or solid has a large effect on the transport of radiative heat through the atmosphere.

We are addressing this question by developing balloon-borne optical instruments to measure the amount of liquid water, compared to ice, in a cloud, and where there is ice, to see what crystal form the ice particles adopt. There is quite a bit of work to do in characterising the instrument, both in balloon flights and fixed instruments on towers/masts. There will be opportunities to deploy the instruments in the field, and/or to analyse data from a deployment on the new CSIRO ship RV Investigator, and from Macquarie Is.

As a side note, a holographic microscope was developed (at U of A) to help in the characterisation of the above instrument. An interesting spinoff application is in characterising pollen for the pollen count warnings that some weather services offer to hay fever sufferers. There is also scope for a project to further develop this microscope.

B – HIGH ENERGY ASTROPHYSICS

(Jose Bellido, Roger Clay, Bruce Dawson, Sabrina Einecke, Gary Hill and Gavin Rowell)

http://physsci.adelaide.edu.au/astrophysics

B-1: STUDYING THE HIGHEST ENERGY PARTICLES IN NATURE WITH THE PIERRE AUGER OBSERVATORY

(Bruce Dawson, Jose Bellido, Roger Clay and Gary Hill)

The Pierre Auger Observatory in western Argentina has been built to detect giant cascades of particles created in our atmosphere by the highest energy particles known in the Universe. These ultra-high energy cosmic rays (protons and atomic nuclei), with energies up to 10^{20} eV, are thought to originate in the most extreme environments in the Universe. The Auger Observatory uses an array of particle detectors spread over 3000 square kilometres, in conjunction with 27 large optical telescopes, to measure and characterise the incoming cosmic rays - their arrival directions, energies and estimates of their mass. See www.auger.org. In 2017, Physics World nominated a result from the Observatory as one of the 10 physics breakthroughs of the year.

The University of Adelaide is a founding member of the Auger collaboration, with wide ranging responsibilities across the Observatory's mission. Projects will vary from year to year, and can be tailored to the interests and strengths of the student. They may include work on event reconstruction (finding the best way of converting raw data into the best estimates of cosmic ray directions, energy and mass); understanding the mass estimates in terms of contemporary particle interaction physics; testing hypotheses about cosmic ray sources by matching arrival directions with galaxy distributions of various types; or using infra-red cameras to characterise night-time cloud over the Observatory. Finally, the Observatory is embarking on a hardware upgrade to sharpen its ability to distinguish between cosmic rays of low and high mass (charge), and there will be projects dedicated to this. We encourage students to talk to us to find out what is new and topical.

B-2: PREDICTING THE MOVEMENT AND DEVELOPMENT OF CLOUD FOR DYNAMICALLY SCHEDULING ASTRONOMICAL OBSERVATIONS

(Roger Clay and Bruce Dawson)

Astronomical observatories employ a variety of techniques for detecting night-time cloud, including infra-red and visible cameras. The infra-red and visible wavebands are complementary, in that clouds radiate infra-red radiation but also block visible light from background stars. We use imaging infra-red cameras since techniques which search for sky without stars can be computationally slow and depend on a suitable spatial density of stars over the whole sky.

The Cherenkov Telescope Array (CTA) will be a major world observatory, based at two sites, to study gamma-rays from many selected interesting astronomical sources, and observing schedules will be optimised for a selection of sources each night. However, if there is some cloud, those schedules will require optimising to still observe as much as possible in directions away from the cloud, as the cloud develops and moves. This requires not only a knowledge of the present cloud locations but also a prediction of where cloud is likely to move over the following period of observations (minutes to hours). The purpose of this project is to develop software and procedures to assist with this dynamic observation scheduling, based on the current time series of cloud images. Cloud images are presently being recorded over Adelaide which will provide data for this investigation.

B-3: HIGH-ENERGY NEUTRINO ASTRONOMY WITH THE ICECUBE DETECTOR AT THE SOUTH POLE

(Gary Hill - gary.hill@adelaide.edu.au)

The IceCube detector is the world's largest high-energy particle detector. Instrumenting a cubic kilometre volume of the clear ice below the South Pole Station, Antarctica, this detector has many science goals, all of which may be explored as Honours projects. In 2018, IceCube led an international group of ground and space-based detectors in analysing data from a neutrino-gamma-ray coincident observation of the blazar TXS 0506+056 – showing that it is likely that this galaxy, located about 4 billion light years away, is a neutrino source, the first specific object identified in high energy neutrinos.

While the blazar TXS 0506+056 is the first identified source of neutrinos, we are yet to understand where the rest of the astrophysical neutrinos (around 1000 of the highest energy neutrinos of the entire sample, which is mostly lower energy background neutrinos made from cosmic ray interactions in the Earth's atmosphere) we see are coming from. We want to understand more about the sources, and how they make neutrinos. These neutrinos are most likely produced during the acceleration and interaction of the highest energy particles in nature, as we expect for TXS 0506+056. These locations could include the centres and jets of active galaxies, gamma-ray bursts, and supernovae. There is much work to be done in analysing the neutrino data, and determining which of these possible sources, or mixture of sources, and how they are distributed through the Universe, leads to the energies and locations across the sky that we actually see.

In addition to the primary study of the distant neutrino sources, there are other scientific goals of IceCube. The detector currently records thousands of atmospheric neutrinos each year, which are a beam for studying the boundaries of modern particle physics. Dark matter, the hypothesised missing 25% of the Universe, may be observable in IceCube as a signal resulting from neutralino capture and annihilation in the Sun and centre of the Earth (see also available projects for direct dark matter detection with SABRE under Experimental High Energy Physics). The detector is also a powerful low energy supernova neutrino detector.

Honours projects which would contribute to these IceCube science goals could cover many important areas e.g. understanding the nature of the neutrino source TXS 0506+056 and looking for more such sources, correlating the other full sky astrophysical neutrinos with other types of detections (cosmic rays, gamma rays), looking for structure in the neutrino sky, improving the energy and directional reconstruction of the neutrinos, and working on detector calibration, simulation and statistical analysis methods. Theoretical studies of potential neutrino sources are also possible as projects – understanding what we see at Earth depends on an understanding of the distribution of sources through the Universe, and we work on detailed calculations of source contributions, taking into account the cosmology of the Universe.

B-4: STUDY OF NATURE'S EXTREME PARTICLE ACCELERATORS AT TERA-EV (10^{12} EV) GAMMA-RAY ENERGIES WITH HESS AND OTHER TELESCOPES

(Gavin Rowell)

The High Energy Stereoscopic System (HESS) detects gamma-rays at TeV (10^{12} eV) energies and above, and has made significant contributions to our understanding of the high energy Universe. Over 100 sources of TeV gamma-ray emission have been discovered, most of them with HESS. The types of sources include shell-type supernova remnants, pulsar powered nebulae, compact X-ray binary systems, molecular clouds, radio galaxies and jet-powered active galaxies.

There are opportunities to study extended sources which may include supernova remnants, pulsar nebulae, star formation regions and also mysterious unidentified sources, as well as searching for transient/bursting sources in HESS data. These types of study can greatly help in addressing the origin of the gamma-ray emission as well as new information about the type of particles accelerated to extreme energies and where they are accelerated.

Comparison with images from other energies (radio, X-ray, low energy gamma-rays and neutrinos) may also be performed with a particular emphasis on radio data used to survey interstellar gas clouds (we use the Mopra radio telescope in Australia for this purpose).

Students will gain experience in data analysis algorithms using a variety of computer languages such as C, C++, Perl and Fortran within the Linux/Unix operating system as well as specific software packages dealing with astronomical images (such as miriad, ftools, ds9 etc.).

See these websites for more details:
http://www.physics.adelaide.edu.au/astrophysics/gpr/research.html
http://www.physics.adelaide.edu.au/astrophysics/MopraGam/
https://www.mpi-hd.mpg.de/hfm/HESS/

B-5: DATA ANALYSIS, MACHINE LEARNING AND HIGH-ENERGY GAMMA-RAY ASTRONOMY

(Gavin Rowell, Sabrina Einecke, Jose Bellido)

Gamma-ray astronomy studies the most energetic part of the electromagnetic spectrum and correspondingly requires large telescope systems and state-of-the-art analysis techniques. The Cherenkov Telescope Array (CTA) is the next-generation gamma-ray observatory and will play an important role to drive this research forward, marking the beginning of a new era of gamma-ray astronomy. CTA will exceed current experiments in a multitude of aspects: With more than 100 telescopes of 3 sizes at 2 locations equipped with state-of-the-art technologies, it will provide a new view of the sky at energies of up to 300 TeV. It measures Cherenkov radiation, emitted by extended air showers in the Earth's atmosphere that have been induced by gamma rays and protons. This indirect measurement requires advanced analysis techniques to derive the energy, direction and particle type of the incident primary. The branches Big Data and Data Mining are increasingly becoming an integral part in astroparticle physics – and thus also in CTA. Immense amounts of data need to be processed with the most modern and advanced techniques from machine learning, statistics and computer science, demanding close collaborations between the branches.

Various projects involve the investigation of CTA's performance using different analysis methods. Additional aspects of these studies will be to examine the performance at the highest gamma-ray energies >10 TeV, which are motivated by searching for the accelerators of the highest energetic cosmic rays in our Galaxy, and by improving the energy resolution of the telescopes for dark matter searches.

In this regard, some exemplary projects might be the following:

Signal Extraction Studies: One of the first steps within the data analysis pipeline is the extraction of the signal from a pixel's waveform, which can be defined by the charge and the arrival time. Simple algorithms are considering each pixel independently, while more advanced algorithms are also taking into account information from other pixels. In this way, the probability to extract e.g. photons from the night sky background can be reduced. The aim of this project is to study these algorithms by implementing those, adjusting the settings, and comparing them. Their capability can be studied e.g. dependent on the level of night sky background.

Image Cleaning Studies: Another first step within the data analysis pipeline comprises the cleaning of the camera image from pixels dominated by the night sky background. Simple algorithms select pixels above a specific threshold on the number of photons. More advanced algorithms are also taking into account the arrival time of the photons. The aim of this project is to study more advanced algorithms by implementing those, adjusting the settings, and comparing them. Their capability can be studied e.g. dependent on the level of night sky background or towards the highest energies.

Combination of Multiple Image Cleaning Algorithms: The cleaning of the camera image is a sensitive task, and different subsequent analysis steps might require different image cleaning algorithms or settings. The aim of this project is to apply multiple image cleaning algorithms, and derive a bulk of image parameters, which can be further combined to higher-level parameters. These parameters are perfectly suited for machine learning algorithms and have a great potential to optimise subsequent analysis steps.

Optimising the Data Analysis Chain for Specific Criteria: Often the data analysis methods are tuned towards an overall high performance. For specific analyses, other criteria might apply, such as the best-possible angular resolution or the

achievement of the highest energies. The aim of this project is to tune the data analysis methods for specific criteria, especially the optimisation of machine learning methods will be important.
Study of Truncated Shower Images: Depending on the properties of the shower and the observation, the shower image might not be fully contained in the camera. Often these events, which mostly feature the highest energies, are discarded. This project aims at the development of parameters and methods, such as machine learning, to reconstruct these events.
Studies of the Night Sky Background: The data analysis pipeline is tuned for a nominal level of night sky background. The aim of this project is to study how the standard settings of the pipeline perform under increased levels of night sky background and how the settings can be tuned without changing the default analysis algorithms.
Studies of Probabilistic Random Forests: Compared to standard Random Forests, probabilistic Random Forests can also consider the uncertainties of the input features and the label. The aim of this projects is to study the application of this new approach to gamma-ray data, e.g. to determine the particle type of the primary incident. As an alternative, probabilistic Random Forests can also be investigated by applying them to search for Active Galactic Nuclei in catalogues of gamma-ray sources.
Measuring the lateral distribution of air showers with CTA: The high resolution and large field of view of CTA may allow the study of the lateral distribution of the electromagnetic component of energetic air showers. Currently, the observation of cosmic rays relies on high-energy hadronic interaction models. However, it has been shown that these models are failing to reproduce the observations (for example, more muons are observed than predicted by the models). In this project we will simulate air showers and CTA detectors in order to evaluate the possibility of measuring their electromagnetic lateral distribution. If successful, we will compare the measured lateral distributions with the corresponding model predictions. The aim is to shed some light in the modelling of very-high-energy cosmic-ray air showers. This project overlaps with the Pierre Auger Observatory.

Students will gain practical experience with computer languages such as Python, the Linux/Unix operating system, as well as they will have access to high performance computers and machine learning techniques.

See these websites for more details:
http://www.cta-observatory.org/
http://www.physics.adelaide.edu.au/astrophysics/gpr/research.html

SECTION C - THEORETICAL PHYSICS

(Supervisors: Prof Derek Leinweber, Prof Anthony Thomas, Prof Tony Williams, Assoc. Prof Ross Young, Assoc. Prof James Zanotti, Dr Hrayr Matevosyan, Dr Rodney Crewther, Dr Ayse Kizilersu & Assoc. Prof Max Lohe)

The theoretical physics research activities described below cover a broad range of topics and are primarily carried out under the umbrella of the ARC Centre for the Subatomic Structure of Matter (CSSM).

C-1: LATTICE GAUGE THEORY

(Supervisors: Kamleh, Leinweber, Williams, Young, Zanotti)

Quantum Chromodynamics (QCD) describes the interactions between quarks and gluons as they compose particles such as the proton and neutron. Lattice gauge theory provides the only comprehensive method to extract, with controlled systematic errors, first-principles predictions from QCD for a wide range of observable phenomena. By discretising space-time onto a hypercubic lattice, we are able to directly study the properties of this highly non-perturbative theory. These numerical simulations are extremely challenging, requiring state of the art high performance computing techniques and the use of the world's fastest supercomputers.

Having such powerful tools on hand allows for the study of a variety of interesting phenomena relevant to international experimental efforts in particle and nuclear physics, such as excited state spectroscopy, hadronic interactions, probing the structure of the proton and other hadronic particles, hadronic decays, and the vacuum properties of QCD. In addition, visualizing the massive amounts of data created in lattice simulations provides deep insight into the fundamental mechanisms of QCD and hadron structure.

C-2: EFFECTIVE FIELD THEORY

(Supervisors: Leinweber, Thomas, Young)

Physicists around the world are focussed on revealing the phenomena emerging from the theory of Quantum Chromodynamics (QCD). QCD is the fundamental quantum field theory underlying the strong interaction. It explains the origin of 99% of the mass of the visible universe (the Higgs mechanism generates the other 1%).

At low energies, the quark and gluon fluctuations of QCD are frozen into "colourless" states called hadrons (eg. proton, neutron, pion etc.). Using these low-energy degrees of freedom and the symmetries of QCD, Effective Field Theories (EFTs) make it possible to derive model-independent properties of QCD.

Two common, and necessary, approximations made in lattice QCD simulations are the use of heavier-than-physical quark masses and the squeezing of the system into a finite volume. EFTs provide a robust framework for understanding the physical consequences of these approximations, and therefore provide the essential link between lattice simulation results and Nature. Here at Adelaide, we are developing innovative techniques which serve to guide and interpret research at international experimental facilities with a particular emphasis on: structure, resolving the distribution of quarks and gluons inside hadrons; and dynamics, underlying the excited state resonance spectrum of QCD.

C-3: NUCLEAR THEORY

(Supervisor: Thomas)

Traditionally the atomic nucleus has been regarded as a collection of bound protons and neutrons. However, with the discovery of quarks and a more fundamental theory of the strong interaction, namely Quantum Chromodynamics, it has become clear that the old view needs to be replaced. Indeed, the change of the properties of protons and neutrons in matter is the topic of a great deal of research effort around the world.

It seems likely that such changes may be critical to understanding the equation of state of dense matter and hence the properties of neutron stars. Having a quark-level understanding of dense matter will also be necessary in order to explore the phase transition to quark matter at high density and temperature. Finally, the nucleon-nucleon force itself also needs to be derived from the quark level.

C-4: MODELS OF HADRONS AND HADRONIC INTERACTIONS

(Supervisors: Matevosyan, Thomas, Zanotti)

While lattice QCD provides by far the best approach to the direct, numerical evaluation of hadronic properties. In parallel with these lattice calculations, there are important reasons for developing transparent models which can be used to aid the interpretation of lattice results, analyse experimental data and suggest new experiments. Ideally these models should incorporate, as far as possible, the known properties of QCD, including its symmetries. The model of Nambu and Jona-Lasinio (NJL), for example, provides a covariant framework which respects the chiral properties of QCD while allowing near analytic solutions for many problems.

We are especially interested in using models such as NJL, or even the MIT bag, to calculate hadron properties, to calculate reactions involving hadrons and to build quark models of atomic nuclei. Of particular topical interest, in the light of major experimental programs around the world, is the calculation of parton distribution functions (of nucleons, hyperons and nuclei), fragmentation functions, generalised parton distributions and novel phenomena such as the Collins and Sivers effects which promise insight into the orbital angular momentum of quarks within hadrons.

C-5: QUANTUM FIELD THEORY

(Supervisors: Crewther, Thomas, Williams, Young, Zanotti)

When quantum mechanics is mixed with relativity, position cannot be an operator, and it becomes necessary to quantise fields. Typically there are gauge fields (photon, gluon and the weak W,Z fields of the Standard Model, plus gravitons -- yet to be understood) and matter fields (lepton, quark and scalar fields such as the Higgs scalar boson). There are generalisations to higher symmetries such as grand unified theories and supersymmetry (see Section D2) and also to string theory. There are also non-polynomial field theories such as chiral Lagrangians. [Projects in string theory and quantum gravity are not suitable for honours projects and will not be offered].

Projects can be phenomenological or mathematical in character, and may include classical aspects like monopoles or toy models such as two-dimensional theories. The focus may be on technique - making calculations finite (renormalization and anomalies), giving particles mass (Higgs mechanism or dimensional transmutation), unifying interactions (higher symmetries) -- or data which is either hard to explain (weak hyperon decays, non-zero neutrino masses, the definition of angular momentum in a gauge theory, etc.) or requires precision theoretical calculation (radiative corrections, low-energy Standard Model tests).

C- 6: COMPLEX SYSTEMS

(Supervisors: Kizilersu, Leinweber, Lohe, Thomas, Williams)

Complex systems appear in diverse disciplines such as physics, economics, banking and finance, ecosystems, molecular biology, neuroscience, psychology and sociology.

Typically these systems are comprised of a large number of interconnected components which interact collectively, leading to emergent behaviour, such as self-organization, which is not apparent from the properties of the underlying components. As an example of complex systems in financial markets, there is considerable interest in developing a mathematical understanding of the dynamics of the order book, which records all bids to buy and sell on the stock market at the milli- to micro-second level.

Examples in physics are models in statistical mechanics, many body theory, dynamical systems, and in particular networked dynamical models in which a large number of nodes interact nonlinearly across a network which has various connectivity properties. Each node can behave classically, such as a harmonic oscillator or a chaotic system, or even as a quantum system. For certain models with suitable nonlinear interactions all nodes of the complex system can oscillate in synchrony to a common frequency, a remarkable phenomenon which has been extensively studied over the past decade. Dynamical complex systems are generally investigated by means of numerical computations, particularly for nontrivial network topologies, although there is scope for advanced theoretical and mathematical analysis.

C-7: THEORETICAL HIGH ENERGY PHYSICS
– SEE SECTION D2 OF SECTION D HIGH ENERGY PHYSICS

SECTION D: HIGH ENERGY PHYSICS

(Supervisors: Prof Anthony Thomas, Prof Tony Williams, Assoc. Prof Ross Young, Assoc. Prof Paul Jackson & Assoc. Prof Martin White)

The research activities of the High Energy Physics (HEP) group in the Department of Physics are largely carried out under the umbrella of the ARC Centre of Excellence for Particle Physics at the Terascale (CoEPP) of which Adelaide is one of four nodes (University of Adelaide, University of Melbourne, Monash University and the University of Sydney).

D-1: EXPERIMENTAL HIGH ENERGY PHYSICS

(Supervisors: Jackson, White)

ATLAS experiment at the CERN Large Hadron Collider in Geneva, Switzerland
We make precision measurements of the top quark and Higgs Boson and perform some of the most sensitive searches to physics beyond the Standard Model. You will get involved with the Adelaide team using the LHC data to constrain Beyond Standard Model theories (Supersymmetry, Dark Matter and beyond). You will probe the fundamental aspects of nature at the highest energies man has ever created. With the ATLAS experiment barely having collected 1% of the anticipated final dataset there is a huge scope of excitement - and discovery!

Belle II experiment at the KEKB Collider in Tsukuba, Japan
This year Belle II will commence preparation for first data where electron-positron collisions will produce pairs of B mesons. We use techniques to fully reconstruct B meson decays and then make measurements of rare decays. In earlier datasets three experiments have seen large disagreements with the Standard Model expectations and these measurements from Belle II will be the definitive statement on whether these studies point to cracks in the Standard Model.

ATLAS experiment Phase II Upgrade
From the 2020's and onwards the ATLAS experiment will be revolutionised to upgrade its capabilities. You will work with the Adelaide team to improve the readout technology of the all new charged particle silicon tracking chambers required to reconstruct particles passing through the inner detector from the high energy proton-proton collisions. There is also the possibility to work on new trigger software to allow the next generation of algorithms to function at a higher rate – and extract more physics!

SABRE experiment at the Stawell Underground Physics Laboratory (supervisors also Williams & Hill)
We are members of the SABRE (Sodium-iodide with Active Background REjection) Experiment under construction to be placed in the Stawell Underground Physics Laboratory, along with a sister experiment at the Gran Sasso Laboratory in Italy. We are in charge of the slow control system, involved with the detector readout and will be working on the physics data analysis. Preparation and involvement in all aspects of the experiment is possible, come and talk to us!

Simulation of Physics at the Circular Electron Positron Collider (CEPC)
One of the most exciting projects in the future of particle physics is that of a large scale 50-100km circular e+e- collider. Two proposals exist and we propose working on dedicated simulations for the proposed "Higgs Factory" in China a facility that will change the landscape of our understanding of Electroweak symmetry breaking on the Higgs Mechanism itself.

D-2: THEORETICAL HIGH ENERGY PHYSICS

(Supervisors: Thomas, White, Williams, Young)

It is an exciting time to be a physicist with the apparent recent discovery of the Higgs Boson as predicted by the Standard Model and with being on the verge of discovering a rich landscape of new physics Beyond the Standard Model (BSM): despite its success at explaining an enormously wide range of known physical phenomena, the current Standard Model describes only the behaviour of ordinary matter, which is a mere 4.6% of the universe's total mass-energy content! Dark Matter accounts for around 23% and Dark Energy accounts for the remaining 72% of the universe's mass-energy.
Evidence from gravitational lensing, galactic rotation curves and the cosmic microwave background radiation strongly suggests that approximately 23% of the universe's mass-energy and 83% of the mass is comprised of the mysterious quantity known as Dark Matter. There are many searches underway to probe the nature of this Dark Matter, both directly and indirectly, including cryogenic detectors buried deep beneath the ground.
In addition to the mysteries of Dark Matter and Dark Energy, there are extremely compelling reasons to believe that the Standard Model is not the complete story and that it must inevitably be extended to include BSM. The apparent unification of the electromagnetic, weak and strong forces at the scale of 10^16 GeV strongly argues for the existence of so-called Grand Unified Theories (GUTs), which include all three in a single unified model. In addition, the quantum effects of gravity can no longer be ignored at scales of 10^19 GeV (the Planck scale) and at such a scale we need to build a Theory of Everything that includes gravity.
The available projects include supersymmetry (SUSY), GUTs, dark matter, extra-dimensional models, composite Higgs models, and scale invariant theories. Projects will typically involve one of more of these concepts. The projects will involve building and studying predictions of models of BSM physics and will be most suited to students with either a theoretical interest or a combined theoretical plus computational interest.

D-3: HIGH ENERGY PHYSICS PHENOMENOLOGY

(Supervisors: Jackson, Thomas, White, Williams, Young)

Phenomenology is the interface between theoretical and experimental high energy physics. While there is some overlap with D2 above, the emphasis on these projects is in performing extensive and careful calculations of particle physics models so as to allow a direct comparison with experimentally measurable quantities. As explained above, the Standard Model (SM) cannot be the final answer and any theory of new physics should show up in lots of experiments including high-energy accelerator searches (such as the Large Hadron Collider and previous collider experiments), neutrino mass and mixing data, direct and indirect dark matter search experiments, low energy precision measurements, flavour physics, rare decays and in cosmology. The challenge of the phenomenologist is to calculate in detail the expected signals in each of these experiments, and to work out which new theories of physics are still viable given current measurements and which can be tested in new accelerators should they be constructed.

The Adelaide High Energy Physics group is heavily involved in the detailed phenomenology of supersymmetry (SUSY), including calculations in non-standard SUSY models, SUSY dark matter studies and the invention of new techniques for finding supersymmetric particles at the Large Hadron Collider. We also study the detailed observable phenomenological consequences of non-SUSY scenarios, including extra dimensional scenarios, effective dark matter models and general grand unified theories.

Finally, the Adelaide group is leading an international effort to take all current astrophysical and particle data to measure generic new theories of physics using state of the art computational techniques. We welcome applications from students wishing to do a combination of experimental, computational and theoretical work.

SECTION E - MEDICAL PHYSICS

(Supervisors: Santos, Douglass, Collins, Matyagin, Hickson)

Research in Medical Physics operates in collaboration with Medical Physicists working in hospitals around Adelaide. One of the strengths of the program is the opportunity it provides for students to work in a hospital environment and to gain insight into clinical procedures. An honours project in medical physics can provide an excellent introduction to the M.Phil. or to a Ph.D. in this field, and to a medical physics career. The program is coordinated by Dr Alex Santos and Dr Michael Douglass. Research in Radiotherapy Physics is carried out in the Department of Medical Physics at the Royal Adelaide Hospital. Projects in Medical Imaging Physics are available at both Flinders Medical Centre (Radiology) and the Royal Adelaide Hospital (Nuclear Medicine).

E-1: INVESTIGATION OF THE USE OF OPTICAL PHOTOGRAMMETRY IN HIGH DOSE RATE SURFACE BRACHYTHERAPY

(Supervisors: Santos and Douglass)

Brachytherapy is a type of treatment involving the use of radioactive elements to deliver a dose of radiation to a tumour. High dose rate brachytherapy (HDR) is used regularly to treat skin lesions at the Royal Adelaide Hospital. This procedure requires a plaster cast to be made of the patient's anatomical treatment site and then a wax mould is made. The mould contains plastic catheters which allows a radioactive source to pass through, allowing a dose of radiation to be delivered uniformly to the patient's skin.

There are several limitations associated with making this surface mould applicator including:

- The applicator is very fragile and is easily damaged sometimes resulting in a patient treatment being cancelled
- It is very time consuming to make a surface applicator by hand
- The patient must travel to the radiotherapy department several times during the planning stage before treatment begins (an inconvenience for rural patients)
- The shape of the applicator often doesn't conform well to the shape of the patient's skin resulting in poor dosimetric results

Optical photogrammetry has the potential to solve many of these problems. By photographing the patient's treatment site from multiple angles, a 3D model of the patient can be reconstructed. A highly conformal treatment applicator can then be designed virtually and 3D printed.

This project would suit a student with an interest and/or expertise in:

- Brachytherapy Treatments in Radiation Oncology
- Radiation Measurements
- Computer programming (preferably python)
- 3D Modelling /CAD
- 3D Printing

E-2: VALIDATING A RADIONUCLIDE METHOD FOR RADIATION SHIELDING VERIFICATION IN MEDICAL IMAGING DEPARTMENTS

(Supervisors: Collins, Hickson and Matyagin)

The proper design and installation of lead shielding is an important aspect of radiation safety in medical imaging departments. Comprehensive testing of new installations (such as in the new Royal Adelaide Hospital), to standards required under SA Radiation Regulations, are time-consuming and labour intensive. Various testing methods are available but the radionuclide method lends itself to future automation.

The aim of this project is to assist in the validation of a radionuclide NaI probe-based method that determines lead thickness and integrity using transmission data from a gamma-ray source (99mTc). The student will evaluate the various factors (detector characteristics, scatter, wall design etc.) that influence the accuracy and reproducibility of the method – using both experimental methods and Monte Carlo (EGSnrc) simulation. The basic simulation model will be provided, but will require further development/refinement. As such, the project is suited to students with an interest in computing.

E-3: SMALL FIELD DOSIMETRY WITH BERYLLIUM OXIDE CERAMIC FIBRE OPTIC DOSIMETERS

(Supervisor: Santos)

Radiation dose measurements in small fields is a challenging task for many detectors. Current practise generally requires the use of commercial radiation detectors with applied correction factors to account for their change in response when applied to small fields. Beryllium oxide (BeO) ceramics have an effective atomic number, z_{eff} ~7.1, closely matched to water, z_{eff} ~7.4. Therefore it is expected that there is little energy dependence and along with their small size, they may be a useful small field dosimeter with little to no correction factors necessary.

This project will involve Monte-Carlo simulations of the beryllium oxide (BeO) ceramic dosimeter to determine the expected dose deposition when exposed to small fields. Experimental measurements will then be performed at the Royal Adelaide Hospital and compared to other dosimetry systems.

E-4: CHARACTERIZATION OF THE DOSIMETRIC PROPERTIES OF RADIOCHROMIC FILMS

(Supervisor: Santos)

Radiochromic films are a self-developing, radiation sensitive film. Due to their self-developing and high spatial resolution, these films are being routinely utilised in the area of radiation oncology for the characterisation of radiation fields. There are various films designs in order to cater for the different applications and hence radiation sensitivities needed. While GafChromic EBT3 has been well characterised as a radiation dosimeter, data on the other dosimeters are lacking.

This project will involve Monte-Carlo simulations of the dose deposition within the different radiochromic film designs. Experimental measurements will then be performed at the Royal Adelaide Hospital to compare the different films to their expected response.

SECTION F - OPTICS & PHOTONICS

(Supervisors: Prof Heike Ebendorff-Heidepriem, Assoc Prof Murray Hamilton, E/Prof Jesper Munch, Prof David Ottaway, E/Prof Bob Vincent, Prof Peter Veitch, Dr Stephen Warren-Smith, Dr Yinlan Ruan, Dr Erik Schartner, Dr Linh Nguyen, Prof. Robert McLaughlin, Dr Jiawen Li, A/Prof Martin O'Connor, Prof. Andre Luiten, Dr. Fred Baynes, Dr. Chris Perrella, Dr. Phil Light, Dr Dan Brown, , Dr Ben Sparkes, Dr Giuseppe Tettamanzi, Dr James Quach)

Optics and photonics is an extremely active and well-funded area of research at the University of Adelaide. All of this research is conducted by Members of the Institute for Photonics and Advanced Sensing (IPAS). Projects span a broad range of areas, including laser physics, sensing and measurement, optical fibre research, advanced optical materials and biosensing. The honours projects listed below have been grouped into sub-classifications.

OPTICAL REMOTE SENSING

F-1: AERIAL DETECTION OF METHANE

(Supervisors: Prof David Ottaway, Prof Peter Veitch)

Methane is the dominant component of natural gas which has the lowest carbon footprint of any greenhouse gas so long as it is completely combusted. However un-burnt methane 'traps' significantly more infrared radiation per unit mass than does CO_2. Methane leaks also present a major safety hazard and a significant risk to infrastructure that carries in excess of a 1 trillion dollars of natural gas per annum. Hence, there is an urgent need for a method of cheaply and efficiently mapping pipeline infrastructure for leaks.

We are currently developing a new technology for the remote detection of methane using solid state lasers. These lidar systems will be flown on fixed-wing aircraft enabling a survey cost that is dramatically cheaper than any existing alternatives.

There are multiple projects offered in this area ranging from power scaling of lasers to enhancing the data product by developing new data analysis techniques for converting the methane concentration measurements to all important leak rates.

F-2: CLOUD STUDIES USING HIGH POWER EYE-SAFE LASER RADAR

(Supervisors: Prof. David Ottaway, Prof Peter Veitch and Assoc. Prof Andrew Mackinnon)

Improving our knowledge of clouds is critical to improving the accuracy of weather and climate models. Most laser based cloud detection systems operate using visible or near infrared wavelength. This severely limits the power that can used within eyesafe limits and prevents high resolution depth profiles of cloud structure from being obtained. As part of our aerial methane sensing we have recently demonstrated a cloud sensing laser radar that provides exquisite detail of cloud structure at very high temporal resolution.

This project will involve optimizing this laser radar and determining whether it can be used to detect sub-visual cirrus which is poorly understood and not well represented in climate models. Once automated this system can be run 24 hours per day in a campaign mode to gain some significant statistics on the formation of this cloud over Adelaide.

F-3: HIGH-PRECISION CHARACTERIZATION OF OPTICS USING HARTMANN WAVEFRONT SENSORS

(Supervisor: Prof Peter Veitch)

Accurate knowledge of optical parameters – e.g. focal lengths of lenses, curvatures of mirrors, etc. – is becoming increasingly important for a wide range of scientific and industrial applications, including mirrors in gravitational wave detectors, and in telescopes for optical and gamma-ray astronomy, and for use with aspheric and free-form optics for tailoring light-field distributions.

A variety of projects are available. They all aim to exploit the unprecedented accuracy and precision of Hartmann wavefront sensors and incorporate varying degrees of numerical simulation and hands-on experimental work.

LASERS AND NON LINEAR OPTICS

In a nonlinear fibre, light changes the properties of the material it is propagating in. As a result, it is possible to manipulate light using light, which opens up rich new physics and applications. The following projects are based on different aspects of nonlinearity in optical fibres.

F-4: HIGH BRIGHTNESS SINGLE FREQUENCY MID-INFRARED LASERS

(Supervisors: Prof David Ottaway, Dr Ori Henderson Sapir and Prof. Andre Luiten)

Frequency combs have enabled a revolution in spectroscopy, leading new applications ranging from atmospheric sensing of greenhouse gases through to medical diagnostics. Most of these demonstrations have occurred in the near infrared but significant gains can be achieved by converting these diagnostics to mid-infrared since absorption lines can be up to 2 orders of magnitude stronger. However, there are very few reported frequency combs in the mid-infrared.

In this project you will develop a high brightness single frequency source for pumping highly non-linear crystalline resonators for generating wide-band mid-infrared frequency combs. This will make use of a revolutionary dual-wavelength technique that recently allowed us to demonstrated the longest wavelength room temperature fibre laser.

F-5: A NEW CLASS OF GERMANATE GLASS MICROSTRUCTURED FIBRE LASERS

(Supervisor: Heike Ebendorff-Heidepriem)

While silica-based fibre lasers possess almost ideal laser characteristics, they cease to be transparent beyond 2µm. Germanate glasses are an appealing and as yet relatively unexplored choice for the fabrication of fiber lasers at longer wavelengths. The combination of good thermal properties, low phonon energy, and ability to be doped with high rare-earth concentrations make these glasses attractive for laser operation on untested laser transitions in the 2-3µm wavelength range. By taking advantage of the low temperature softening point of germanate glass, we have developed germanate glass extrusion methodologies. This approach enables the formation of unique microstructured geometries that cannot be made in any other way. This project will advance the fabrication and characterization of germanate fibres, conduct spectroscopic measurements of rare earth doped germanate glasses, and work towards demonstration of a microstructured germanate fibre laser.

F-6: HARNESSING NANOPARTICLES IN GLASS OPTICAL FIBRES

(Supervisor: Heike Ebendorff-Heidepriem)

The drivers for our work include the development of nonlinear fibre-based devices for all-optical data processing, switching and optical limiting. Our recent work on the development of a new theoretical model for nonlinear pulse propagation in highly nonlinear fibres, fabrication of the world's smallest core optical fibres, and experimental confirmation of our new theoretical model has attracted a lot of attention in science community. Within this project, we like to extend our new nonlinear model to include nonlinear polarisation. The project will include fabrication of subwavelength elliptical core fibres, which can be shown to have high nonlinear polarisation. Using the fabricated fibres, their nonlinear polarisation characteristics will be investigated experimentally and compared to those predicted by the model. The field of nonlinear processes in subwavelength waveguides is a new field of research in which our discipline plays a pioneering role.

F-7: NONLINEAR OPTICS IN OPTICAL WAVEGUIDES: CAN WE CONTROL PHOTONS BY PHOTONS?

(Supervisors: Andre Luiten, Heike Ebendorff-Heidepriem and Max Lohe)

Controlling photons by photons (nonlinear optics) is an exciting field in optics with applications in optical signal processing, quantum computing and sensing. At the University of Adelaide (Institute for Photonics and Advanced Sensing), we have the state of the art fabrication facilitiy to fabricate fibres with high nonlinearity. We are also one of the pioneers in the field of the theory of nonlinear processes in optical waveguides and collaborate with several international groups.

We offer a suite of Honours projects in the field of nonlinear optics in optical fibres. Depending on the background and the interest of students, each project can have different elements with different weighting of fabrication, theory/simulation and experiment. Some examples of projects are: Third and one-third harmonic generation in optical fibres, Development of highly nonlinear composite fibres, Nonlinear polarization switching in optical waveguides, Nonlinear pulse propagation in multimode-multicore fibres, Dispersion measurement in multimode fibres, Highly nonlinear optical fibres and cold atoms for nonlinear quantum applications, and Development of microstructured optical fibres for signal processing. The expertise of the supervisory team covers different elements for each project, providing extensive and efficient support for students.

Interested students will have a meeting with the supervisory team in which they can discuss the students' background and interest and possible projects.

OPTICS APPLICATIONS

F-8: NOVEL SPECTROSCOPIC ANALYSIS FOR BREATH-BASED DIAGNOSTICS

(Supervisors: Prof Andre Luiten and Dr Martin White)

We are funded to develop a new type of spectroscopic tool that can deliver broadband and high-resolution spectra of complex molecular mixtures. We are using this device to examine the exhaled breath so that we can potentially find evidence of undiagnosed disease based on the molecules that are present. The challenge of your project is to take these highly complex spectra, identify which molecules are present, and generate an estimate of the concentrations of each. Unfortunately, under atmospheric conditions there are subtle interactions between the molecules that slightly change the characteristic spectral fingerprint of each molecule - this means that simple nonlinear fitting or pattern matching algorithms do not work well. Using a variety of machine learning and Bayesian inference algorithms, you will create better and faster ways to extract the important data from the observations.

F-9: INTELLIGENT ALGORITHMS TO DETECT BLOOD FLOW WITH OPTICAL IMAGING

(Supervisors: Prof. Robert McLaughlin, Dr Jiawen Li)

Description: Optical coherence tomography (OCT) is a high resolution optical imaging technology, which is rapidly growing in importance in medical imaging. Our group has developed some of the world's smallest medical imaging probes, capable

of acquiring images deep within the body. One important use of this technology is to detect the presence of blood vessels during surgery. This project will develop sophisticated software algorithms to automatically detect blood vessels in OCT data. The project will require the student to gain a deep understanding of the physics underlying OCT imaging, and to implement algorithms in Matlab to detect blood vessels in real-world medical data.
Prerequisites: The student must have experience programming with Matlab and a strong background in mathematics and optics. Experience in other programming languages is also desirable.

F-10: 3D PRINTING OF OPTICAL CALIBRATION OBJECTS FOR HIGH RESOLUTION MEDICAL IMAGING

(Supervisors: Prof. Robert McLaughlin, Dr Jiawen Li)

Description: Our group develops highly novel imaging scanners that scan the body using optical coherence tomography. When developing and using these scanners in medical trials, it is important to regularly acquire scans of standardised, calibration objects. Examining the scans of these calibration objects allows us to rapidly identify when there are problems with the scanner. In this project, the student will first gain a deep understanding of the physics underlying optical coherence tomography to understand which aspects of the scanner are important to characterise. The student will then design a set of calibration objects that will allow us to easily assess the quality of the scanner. To fabricate the calibration objects, the student will use our recently-purchased Form2 SLA 3D printer from FormLabs, USA.
Prerequisites: The student must have a strong background in optics and photonics, and practical experience in building optical setups.

F-11: MULTIPLEXED EXTREME TEMPERATURE SENSING WITH FIBRES

(Supervisors: Prof David Ottaway, Dr Stephen Warren-Smith, Dr Erik Shartner)

The Institute for Photonics and Advanced Sensing (IPAS) has a significant program of research in developing extreme temperature sensors (up to 1300^{o}C) using microstructured optical fibres. These are typically made using fibre Bragg gratings, but there is a promising alternative that utilises interferometry between higher order modes in the fibre. However, multiplexing such sensors, which is a critical advantage of fibre sensing, has not yet been demonstrated.
In this project, you will have an opportunity to solve this critical problem using a microstructured optical fibre recently developed by IPAS. You will learn valuable knowledge and skills in optical fibre theory, fabrication, fibre handling (cleaving and splicing), and sensor fabrication and testing.

F-12: EXPLOITING LASER THRESHOLD FOR HIGH SENSITIVITY BIOCHEMICAL SENSING

(Supervisors: Prof David Ottaway, Dr Stephen Warren-Smith and Dr Linh Nguyen)

Microstructured optical fibres are a promising platform for biochemical sensing, offering small volume measurement and long interaction lengths. There is ongoing research at the Institute for Photonics and Advanced Sensing (IPAS) to further advance the sensitivity of these sensors to allow for single-particle, or even single molecule, detection.

This project aims to incorporate an exposed-core microstructured optical fibre into a fibre laser configuration. By finely tuning the in-line optical loss of the system the sensor can be operated very close to the laser threshold. Due to the high nonlinearity of the laser threshold process very sensitive measurements can be made on biochemical binding events via the evanescent field of the optical fibre. In this project you will learn important concepts on fibre and laser design, and experimental techniques on fibre handling (e.g. cleaving and splicing) and sensor development.

F-13: IMAGING MICROSTRUCTURED OPTICAL FIBRES

(Supervisors: Prof David Ottaway, Dr Stephen Warren-Smith, Dr Erik Schartner)

The Institute for Photonics and Advanced Sensing (IPAS) has a significant program of research in fabricating novel optical fibres for sensing and imaging applications. This includes fabrication equipment such as metal 3D printing, glass extruders, and fibre draw towers. IPAS has made recent progress is fabricating complex optical fibre structures by extruding glass through 3D printed dies.

In this project, you will have the opportunity to gain hands-on experience fabricating imaging fibres using our 3D printed dies. The ultimate aim is to fabricate imaging fibres that have unprecedented resolution for in-vivo imaging deep inside the body. You will also learn valuable knowledge and skills in optical fibre theory, fibre handling, and optical fibre characterisation.

F-14: OPTICAL FIBRE TEMPERATURE SENSORS FOR HEAVY INDUSTRY APPLICATIONS

(Supervisors: Prof David Ottaway, Dr Stephen Warren-Smith, Dr Erik Schartner)

The Institute for Photonics and Advanced Sensing (IPAS) has been working with international partners to develop high temperature sensors using microstructured optical fibres. These are fabricated using a femto-second laser ablation fibre Bragg grating, allowing them to survive to high temperatures up to 1300°C.

We are seeking a motivated and practical-orientated student to help us overcome challenges for applying our sensors in new and expanding applications. This includes implementing optical switching for parallel sensing and optical commutators for sensing rotating equipment. You will learn valuable knowledge and skills in optical fibre theory, sensor fabrication, LabVIEW, and sensor testing, while engaging in an active industry-based project involving real-world installations in challenging environments.

F-15: INTELLIGENT INFRARED IMAGING SENSORS USING MACHINE LEARNING

(Supervisor: A/Prof Martin O'Connor)

Machine Vision systems using visible cameras are used for Inspection and Automation in the Industrial and Defence sectors with a market value of $14 Billion USD. Learning algorithms can be trained to automatically detect features and even provide depth perception from 2-dimensional video data.

However, for many applications, infrared and thermal vision can see features and see-through obscurants where visible cameras cannot. Seeing through rain, smoke, fog, imaging the temperature of an object or the water content of food and crops are all scenarios where infrared vision outperforms visible.

The overall direction of this research program is to apply machine-learning techniques to emerging infrared imaging systems to solve current problems in industry. One project is to demonstrate passive ranging and augmented reality that can be used for military scenarios on Land and Sea. A second project is to investigate smart thermal imaging to assist medical operations. There will be interaction with local companies including BAE Systems. This project will involve the assembly and alignment of optical cameras and laser radars, recording video data and developing computer algorithms to demonstrate image enhancements. The student can have interest in either the infrared imaging sensor or the machine learning algorithm components or both.

F-16: MICRO-STRUCTURED OPTICAL FIBRE FOR HIGH POWER LASER BEAM DELIVERY

(Supervisor: A/Prof Martin O'Connor)

Mitsubishi Heavy Industries in Japan use powerful fibre lasers to cut and weld 40mm thick steel plates to manufactures large boilers for gas-fired power stations. However, they can't deliver the laser beam 100m across their factory to the weld site without degrading the power and beam quality.
This project will build on an existing partnership with Mitsubishi to model and fabricate micro-structured optical fibre with very large single-mode areas tailored for the delivery of kW-power laser beams. The project will involve some computer modelling work to understand laser beam guidance in optical fibres as well as assisting in various stages of fibre fabrication.

PRECISION MEASUREMENT

A defining feature of our technological society is a hunger for more accurate and precise measurement and sensing. Important real-world applications such as: The Global Positioning System (GPS), magnetic imaging, radar, optical fibre communications and even mobile phones, all rely on developing ever more accurate and precise measurements.
The Precision Measurement Group works to build instruments to meet this technological demand. We develop and extend measurement platforms of high value to fundamental physics: with an increasing focus on industrial, medical and defence contexts.

We have many projects available, and encourage interested students to meet with us and tour the lab. Please contact Andre Luiten (andre.luiten@adelaide.edu.au) to arrange a tour and meet with potential supervisors. A more in-depth summary of the research areas of the precision measurement group is presented below. We also encourage students to visit our website (https://www.adelaide.edu.au/ipas/research/nls/pmg-research/) for even more detail.

F-17: SENSING & SPECTROSCOPY

The optical frequency comb is a Nobel Prize winning innovation in laser technology that is poised to revolutionise spectroscopy. We use this massively parallel laser source to characterise atomic and molecular samples with unprecedented precision, accuracy, and speed. We also specialise in precision laser absorption and two-photon spectroscopy, both within conventional cells and fibre based architectures, with applications in fundamental physics, frequency standard development and quantum computing.

We are developing a program of high-precision sensing based on precision optical techniques using specialised lasers to probe crystalline-disc whispering gallery resonators, primarily for precision measurements of temperature, as well as all optical atomic magnetometers for precision magnetometry.

Example 1: Atom Trap Trace Analysis
Noble gas radio-isotopes are naturally occurring substances that can be used to study and date processes in natural systems. There are two key applications for noble gas radio-isotopes: the first is in dating, particularly in hydrology, where they allow dating in important age ranges outside those provided by traditional isotopes such as Carbon-14. Krypton-85 can measure ages in the scale of 1 year to decades, Argon-39 for 50 to 1000 years, while Krypton-81 can be used for ranges of 100 thousand to a million years. Applications for these tracers include groundwater movement, deep ocean currents, and studying old groundwater systems such as the Great Artesian Basin. The second major application arises because Krypton-85 is primarily produced by nuclear fuel reprocessing plants, and thus can be used to determine compliance to nuclear non-proliferation treaties.

Measuring these noble-gas radio-isotopes is difficult due to their extremely low abundance, as low as 1 part in 1000 trillion for the targeted applications. We are currently constructing a measurement system that uses the recently developed atom-trap trace analysis technique to count the rare radio-isotope atoms in a gas or water sample, as part of a new facility that will be made available to Australian and international environmental researchers.

This project will involve developing the laser cooling and trapping system required for our atom-trap trace analysis system, as well as optimisation of the overall excitation and detection system. There is room for multiple students to be involved in different aspects of the overall system, and although we are building an experimental apparatus, there is also the possibility for theoretical projects based on modelling the system so as to obtain enhanced performance.

Example 2: Molecular Spectroscopy for Disease Diagnosis
This project focusses on detecting biomarkers in the breath that can be used to diagnosis disease for which there are no other symptoms. We have built an innovative device to make these measurements. It consists of the Nobel Prize winning frequency comb (essentially millions of separate laser sources) together with a device that can split the light into its constituent laser colours and measure each power simultaneously. By comparing the spectrum before and after passing through the breath sample it is possible to garner quantitative knowledge on the concentration and nature of the chemicals. This project will focus on developing the apparatus to take the data while we offer a separate project (see project F10) that focusses on the data analysis that will enable chemical identification and concentration estimation.

Example 3: Primary thermometry using Doppler-broadened spectroscopy
The kelvin, the SI unit of thermodynamic temperature, has recently been redefined by fixing the Boltzmann constant to an exact value. This change now allows absolute determination of temperature through careful measurement of the width of Doppler-broadened absorption lines. Unlike many methods, this technique allows determination of temperature over a broad range. This project will improve the temperature uncertainly that we currently achieve in order obtain accuracy competitive with other primary thermometry techniques. The project will also develop a roust high-temperature cell that will allow application of the technique in difficult environments such as furnaces, where accurate temperature measurement is currently not possible.

F-18: QUANTUM ATOM-FIBRE PHOTONICS

The advent of micro-structured optical fibre has revolutionised methods for creating strong interactions between light and matter. Within our group we utilise both hollow-core fibre and exposed-core fibre to tailor and control light and matter interactions. This is achieved by confining light to small volumes, generating intense optical fields, while allowing an atomic vapour to be present within the same small volume.

We make use of this technology to guide cold atoms through fibre, implement both classical and quantum optical switches, perform optical quantum state storage and manipulation, and produce compact optical frequency standards.

Example 1: Quantum Optics with Cold Atoms
Strong atom-light interactions have been used to demonstrate many critical applications in quantum information science. Photons are excellent for relaying quantum information over large networks, while atoms can be used to process and store quantum information. We are developing a new platform based on laser-cooled atoms (cooled to just 10μK) loaded into hollow-core optical fibres, where we can obtain strong interaction of photons and atoms due to their excellent overlap within the fibre. This project will involve designing and implementing upgrades to our existing system to enhance performance. This includes cooling atoms to lower temperatures by implementing dynamic magnetic gradient control, and increasing atom density through implementation of a 'dark-spot' optical trap. This project will provide experience in optics, electronics, and software-development for control systems.

Example 2: Quantum Optics with Hot (Room-Temperature) Atoms
Alkali Metal Vapours have very convenient atomic structure that allows them to interact strongly with multiple lasers. This provides a platform for one light beam to switch the properties of another - a true optical switch. If it were possible to do this with just a single photon then one has the basis to a set of quantum gates that can be used to build a quantum computer. Unfortunately, the interaction strengths to date have been too weak to allow this: we are using a platform in which we trap the vapour inside the microscopic core of a special optical fibre. This potentially delivers a huge increase in interaction strength because of the confined dimensions and low loss of the fibre. Your project will explore the fundamental interactions of atoms confined within the optical fibre and attempt to find protocols that can deliver the means to move to the single photon level. Room temperature vapours offer convenience compared to the complexity of cold atoms as well as higher density. However, one would need to find ways to suppress the higher decoherence in the room temperature systems.

Example 3: Quantum State Storage and Manipulation
The ability to store and manipulate optical quantum information is crucial for delivering next-generation computing, protect privacy with absolutely-secure communications and provide ultra-precise measurement standards. The extreme atom-light interaction strengths within our Rubidium-filled hollow-core fibres provide the ideal environment for efficient storage and retrieval of photons. We are combining these with state-of-the-art quantum storage techniques to delivering a compact, robust and modular "quantum node". This node will integrate directly with current communications infrastructure, allowing for the creation of a quantum internet – the vital missing ingredient needed to overcome the experimental hurdles that are limiting the potential of current quantum technologies. This project will involve the design and construction of additional optical and electronic components required for novel quantum storage protocols in the warm and col atom-filled fibres. You will work on modelling, characterisation and optimising the various protocols using techniques such as light-assisted desorption and optical pumping of atoms.

F-19: FREQUENCY STANDARDS & DISTRIBUTION

We are developing optical and microwave sources having extremely high frequency stability for high impact experiments. We are also developing a fibre dissemination network to allow fast and precise frequency comparison between frequency standards within different laboratories. This can be extended to time dissemination over large scales for applications such as the square kilometre array (SKA) radio telescope.

Example 1: Development of next generation atomic clock for GPS

The global positioning system (GPS) triangulates a receiver's position using highly precise timing signals received from the GPS satellite constellation. To produce these timing signals, each satellite uses on-board atomic clocks as timing references. We are developing a new atomic clock that will have performance 10x – 100x more stable than current GPS timing signals based on lasers stabilised to a two-photon transition within a rubidium vapour. This clock will have applications in enhancing GPS receiver capabilities (faster GPS acquisition, reduced number of required satellites timing signals, and enhanced altitude determination). This project will involve non-linear spectroscopy, electronics, noise analysis and fibre optic laser delivery. The project will include characterising the performance of the clock and optimising the operational parameters and experimental components to enhance clock stability.

Example 2: Atom-by-Atom Construction of an Error-Free Environment for Single Electron Sources

Single-electron pumps based on few atomic impurities have recently been experimentally demonstrated. In these devices, the Coulomb potential of a few atoms can create a localised electron state with a large charging energy and considerable orbital level spacing's, enabling robust charge capturing processes even at relatively high temperatures (few K as opposed the few 10 mK of previous experiments). In this project, we will develop a simplified model describing the dynamics of these atomically precise electron pumps. This will be done by considering the loading, isolating and unloading of one electron at the time, with the goal of performance optimization.

Example 3: Toward Quantum-Limited Electrical Small Antennas.

Due to their high dynamical range, the linearity of their anti-peak voltage response, the natural inclusion of low noise amplification in the loop and the great sensitivity and larger bandwidth, arrays of Bi-Superconducting Quantum Interference Devices (BI-SQUIDs) are expected to be perfect system to be used in Electrical Small Antennas (ESA)s. However, the best possible arrangement for these arrays (parallel vs series) still needs to be investigated. By taking advantage of the Resistively and Capacitively shunted Junction (RCSJ) model, the electromagnetic evolution in time of these superconducting quantum elements can be studied by using simplified model and their main quantum features can be anticipated simply by using a limited number of linear differential equations. In this project, several arrays configurations will be investigated by using different modelling approaches, the final goal being to optimize future geometries that could be used for defence and for medical applications.

F-20: QUANTUM MECHANICAL THEORY AND EXPERIMENT

(Supervisors: Dr James Quach and Dr Giuseppe Tettamanzi)

Quantum mechanics is a branch of modern physics that deals with the very small: molecules, atoms, sub-atomic particles. The laws of quantum mechanics departs from the classical laws of physics in very fundamental ways. Because of this, things in the quantum mechanical realm can behave in very weird and wonderful ways. We explore and exploit the laws of quantum mechanics. Our goals are to better understand the nature of reality, and to use quantum mechanics to demonstrate novel behaviour and build better devices. We do this at both the fundamental theoretical level, and experimentally. We have projects in quantum gravity, quantum thermodynamics, quantum chaos, quantum biology, quantum computing, quantum sensing, quantum metrology, and nano-electronics. If you interested in doing an Honours project in one of these topics, please discuss with one of the supervisors.

and see
A-7 Active and Passive Measurement of Atmospheric Trace Gases **(Hamilton & Vincent)**
A-8 Cloud microphysics (**Hamilton**)

SECTION G – OZGRAV

(Supervisors: Prof David Ottaway, Prof Peter Veitch, Dr Dan Brown, Dr Sebastian Ng, Mr Huy Cao)

These projects are all part of the research program within the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), and include research towards upgrading the sensitivity of the current generation of detectors, analysing data from those detectors and the development of technology for future detectors. (http://www.ozgrav.org)

G-1: ADVANCED LIGO DETECTOR CHARACTERIZATION AND CW ASTROPHYSICS

(Supervisors: Prof David Ottaway and Dr Dan Brown)

The detection of Continuous-wave (CW) emission of gravitational waves from spinning neutron stars and other astrophysical bodies promises to reveal exciting new information on the structure of such objects. In this project you will have the opportunity to work on CW searches and advanced LIGO detector characterization as part of the OzGrav Centre of Excellence.

The Advanced LIGO project gravitational wave detector has one channel that detects gravitational waves and over 200,000 auxiliary channels that monitor critical aspects of the detector performance. Mining of these channels coupled with precise models of interferometer behaviour can provide critical information that can be fed back to the onsite commissioners. In this project you will work on a data analysis project in collaboration with either the LIGO detector characterization group or directly with the onsite commissioners.

G-2: COMPUTATIONAL MODELS OF LASERS FOR FUTURE GRAVITATIONAL WAVE DETECTORS

(Supervisors: Prof David Ottaway and Dr Sebastian Ng)

High brightness, low noise lasers are critical for the next generation of future of gravitational wave detectors. In all likelihood these lasers will be 2 μm fibre lasers. In this project you will adapt an advanced set of modeling tools to predict the performance of these lasers and help optimize the performance of 2 μm lasers we are developing.

G-3: IMPROVING FIBER LASER SOURCES FOR FUTURE GRAVITATIONAL WAVE DETECTORS

(Supervisors: Prof Peter Veitch, Dr Sebastian Ng)

Gravitational wave interferometers require ultra-stable lasers to achieve their ultimate sensitivity. Unfortunately, environmental effects degrade the performance of the laser. In this project you will join the team developing 2 μm fiber laser sources and investigate the isolation of the laser cavities from the environment. This could include the development of seismic actuation and sensing systems, the design of temperature control and isolation hardware and the investigation of liquid metal cooled fibre lasers.

G-4: CHARACTERIZING THE DIRECTIONAL STABILITY OF LASER SOURCES FOR FUTURE GRAVITATIONAL WAVE DETECTORS

(Supervisors: Prof Peter Veitch and Dr Sebastian Ng)

Gravitational wave interferometers require ultra-stable lasers to achieve their ultimate sensitivity. The stability of the "pointing" of the laser beam is of critical importance. In this project you will develop a new quadrant photodiode to measure the pointing stability of 2 μm lasers that we are developing for future detectors. It would suit students with an interest in electronics.

G-5: UNDERSTANDING LASER BEAMS

(Supervisors: Prof Peter Veitch, Dr Sebastian Ng and Mr Huy Cao)

Lasers are used in many high precision industries and research fields. Understanding the transverse intensity distribution and wavefront profile of the beams is critical for many applications. The increasingly diverse array of laser applications has resulted in a wider variety of laser wavelengths, challenging current diagnostic equipment. The goal of this project is to explore the use of new imaging arrays for laser beam profilers that can cover a wide range of wavelengths.

G-6: MIXED DIGITAL AND ANALOG CONTROL OF ADVANCED LASERS

(Supervisors: Prof David Ottaway, Dr Sebastian Ng)

The spectral control of lasers is crucial if they are to be used in applications ranging from gravitational wave detection through to the remote detection of leaks from gas pipelines. Field programmable gate arrays (FPGAs) offer a convenient platform to achieve this. However signal-to-noise arguments favour more traditional analog control methods particularly when high servo bandwidths are required. In this project you will explore the use of blended control strategies to optimize the performance of advanced lasers.

G-7: HIGH-PRECISION SURFACE METROLOGY OF MIRRORS

(Supervisors: Prof Peter Veitch and Mr Huy Cao)

High-precision and accurate measurement of the shape of reflective optics is key for a variety of applications, including GW detection and space-based imaging. In this project you will investigate the application of our Hartman wavefront sensor for characterizing both single element and segmented mirrors. This project may be done in collaboration with an external partner.

It may also include an investigation of "aperture stitching" for increasing the size of the mirror that can be measured – perhaps as a separate computational project.

G-8: MACHINE LEARNING TECHNIQUES FOR ADVANCED GRAVITATIONAL WAVE DETECTORS

(Supervisors: Dr Dan Brown and Prof David Ottaway)

The Advanced LIGO interferometers output a vast amount of data regarding their internal states. To further improve the sensitivity of these detectors we require new techniques to extract experimental parameters to control and diagnose issues within these complex experiments. Key to this effort is developing an understanding of how multiple degrees of freedom and experimental parameters interact with one another in these advanced interferometers.

This project will use advanced interferometer simulation software, developed by researchers at Adelaide, coupled with machine learning and Bayesian analysis methods to develop new techniques for extracting experimental parameters within gravitational wave interferometers. It would suit students with an interest in programming, data analysis techniques and machine learning.

G-9: HIGH RESOLUTION 3D SCENE MAPPING USING ADVANCED GW TECHNOLOGY

(Supervisors: Prof David Ottaway and Dr Dan Brown)

Recently we have developed a new type of camera called a phase camera. This camera operates on the principal of lock-in amplifier and has the potential to revolutionize ultra-high resolution 3D mapping. In this project you will explore this technology to understand its potential and limitations. This project will involve a mixture of numerical modeling, lab-based work and if things go really well, field trials.

H - ENVIRONMENTAL LUMINESCENCE

(Supervisors: Nigel Spooner, Lee Arnold, David Ottaway, Heike Ebendorff-Heidepriem, Don Creighton)

The Environmental Luminescence group studies a range of real-world problems requiring the detection of ultra-low levels of light, of relevance to Environmental Monitoring, Quaternary Geology, Archaeology, Palaeontology, Earth Sciences, and Defence and National Security. Our research interests lie both in the underlying physics and in the applications. The facilities are located in the Prescott Environmental Luminescence Laboratory in the state-of-the-art "The Braggs" building.

The use of luminescence for measurement of the radiation dose absorbed by natural minerals – an essential component in finding the age of artefacts and geological formations - is a core area of research for luminescence dosimetry and geochronology (Thermoluminescence and Optical Dating).
In collaboration with DSTO we have expanded our program to include the study of radiation absorption by artificial materials. This is a niche application for Forensic and Retrospective Dosimetry (population dose reconstruction) purposes following radiological events such as the Fukushima accident. We are also now developing a range of activities in the areas of real-time sensing of radiation and mineral species identification for mining and mineral processing.

H-1: Geochronology: Recently acquired luminescence readers enable the optical dating of individual grains of minerals, and the unique spectral and spatially-resolved capabilities at extremely low light levels of our "3D-TL" spectrometer and Photon-Counting Imaging System (PCIS) offer opportunities for R&D of new Geochronological techniques. These include methods exploiting spatial resolution to improve and extend the current single-quartz grain optical dating techniques by applying TL and OSL analysis to the same individual grains of grain arrays and for measurement of depth-dose profiles and surface studies, and time-resolved OSL analysis for mechanism investigations. These apparatus also enable photon-counting sensitivity to be applied using red and near-IR luminescence emissions, opening major new areas including the potential to increase the time range for TL dating and to broaden the suite of known environmental dosimeter materials.

H-2: Defence & National Security: TL and OSL dosimetry can reveal prior exposure to radiation after the ionising radiation sources or radioisotopes have been removed, i.e., in situations where it is not possible to obtain radiation dose data by any other means, such as in the clean-up phase following a radiological event. In these applications, luminescence complements "conventional" radiation detection methods: the radiation damage detected by luminescence in the aftermath of exposure to ionising radiation is closely analogous to a persistent fingerprint, and applications in which this capability fills a unique role include Retrospective Population Dosimetry following a radiological event or nuclear accident, and Forensic Analysis. However, luminescence dosimetry properties have been comprehensively studied for very few natural crystalline minerals, chosen for their potential for Geochronology, and a similarly small number of modern man-made materials. We conduct research programs both to discover new opportunistic dosimeter materials, both natural and artificial, and to extend the applicability of known dosimeter minerals.

H-3: Mining and Mineral Processing: We are currently developing focus on research for mining & mineral processing and material characterisation, in collaboration with the Institute for Mineral and Energy Resources. This includes the real-time monitoring of radiation fields and radionuclide detection using radiation-sensitive optical fibres, and creating novel fluorescence analysis techniques using our new facilities, notably a UV-IR Spectrofluorimeter/ OPA lasers for mineral identification and materials characterisation.
Project: *New tools for mapping radioactivity in metal ore*: Metal ores that have very low radioactivity can command a significant price premium on the global metal ore market. Therefore there is a strong economic driver to understand the distribution of radionuclides throughout metal ore samples to enable smart mining techniques to reduce the level of radionuclides in ores that are exported from Australia. A number of projects are available that will contribute to the development of new photonic tools required to allow the mapping of these radioactive isotopes, which can occur at the part per trillion level. This project is particularly suitable for students who are interested in applying their physics knowledge to an applied physics problem that is important to Australia.

We invite discussion with students interested in engaging in any of the wide range of projects enabled by the Environmental Luminescence group research activities.

J - BIOPHYSICS

(Supervisors: Bronwyn Dolman and Iain Reid)

J–1: Modelling the Aussie Rules Football kick

Simple physical systems such as spring-mass systems can be used to model muscle function, with the advantage of the governing laws of motion being well known. These simple models can then be used to examine how various muscles behave in different sporting settings, and under various regimes known to cause injury such as fatigue. This project will look at the function of a human leg when kicking an Australian Rules Football. Motion capture data is available, and will be used in conjunction with OpenSim, an open source musculoskeletal model and dynamical simulator. Following the lessons learned from the simulator, a simple model with well defined laws of motion will be designed to examine the function of kicking in Australian Rules Football.

K - SEMICONDUCTOR PHYSICS

(Supervisor: Dr David Huang, Department of Chemistry)

K-1: Structure-property relationships in organic semiconductors

Organic electronic devices, such as polymer solar cells and transistors, show promise as cheap and flexible alternatives to conventional silicon-based electronics. But organic devices are generally much less efficient than their inorganic counterparts. One of the main impediments to more rapid improvement and widespread adoption of organic semiconductor technologies is that device performance cannot easily be predicted from the chemical structure of the constituent molecules. Fundamentally, this is because organic semiconductor molecules are held together by weak non-covalent forces that result in significant structural disorder, which can have a substantial impact on device properties. The goal of this project is to develop a more predictive approach to controlling organic electronic device performance, in particular by exploiting the anisotropy of organic semiconductor molecules to manipulate the structure of organic semiconductor interfaces. This project will use statistical mechanics, quantum mechanics, and molecular dynamics and Monte Carlo simulations to investigate the self-assembly of organic semiconductor interfaces and the impact of the resulting interface structure (and the roles of disorder, dipolar anisotropy, and electron delocalisation) on electronic processes such as charge separation, transport, and recombination. Applications of this research include understanding efficient charge separation in organic solar cells and high charge-carrier mobilities in organic field-effect transistors.

L - GEOPHYSICS

(Supervisors: Professor Sandy Steacy, Dr Thomas Reverso)

(contact: sandy.steacy@adelaide.edu.au or thomas.reverso@adelaide.edu.au)

L-1 : Coulomb stress models for earthquake interaction and forecasting

Coulomb stress changes following moderate to large earthquakes affect the timing and location of subsequent events. For instance, stress changes from the 2010 Darfield earthquake triggered an earthquake 5 months later which badly damaged Christchuch. A range of projects are available to investigate various aspects of Coulomb triggering including the benefit of including fault information in Coulomb maps, the circumstances in which these stress changes trigger large events, and the extent to which they can be combined with statistical models to forecast earthquake rates.