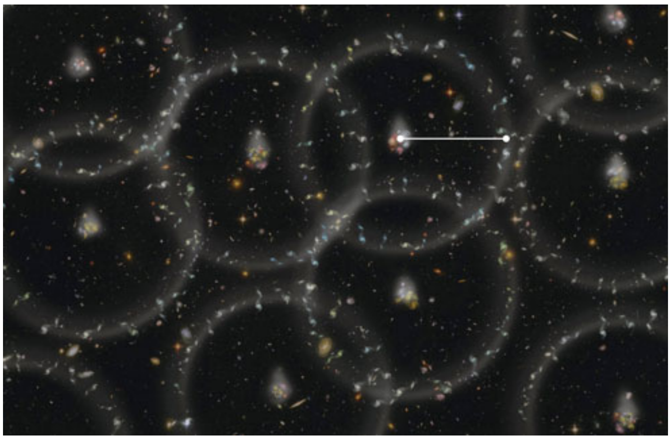
1. Probing Structure formation through Baryon Acoustic Oscillations from SKA - *observational project*
(Dr Yin-Zhe Ma)

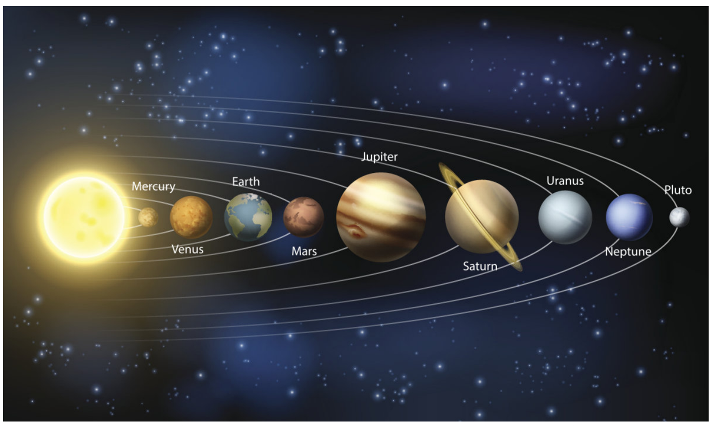


The student will start studying the problem of the detailed structure and formation of the cosmic microwave background, and the problem of structure formation in a more general sense (acoustic oscillations in the baryon-photon plasma, the notion of the sound horizon, super- and sub-horizon perturbations, the matter transfer function). Then the student should be able to run the CMB and matter transfer function code CAMB, with a variety of models. The student will be able to understand the output of the matter transfer function in terms of what it means for the cosmological parameters which were used as input for CAMB. We will provide the student with one of the existing datasets for the matter power spectrum (from, e.g., BOSS CMASS), and have the student study the chi- square distribution for a range of cosmological parameters. The student will simulate the HI intensity mapping data for the current MeerKAT and SKA experiment, and forecast the BAO measurement from MeerKAT and SKA-I.

Then we may go one step further, and have the student run an MCMC code to explore the cosmological parameter space with a real or simulated dataset.

Interested students should contact Dr Yin-Zhe Ma (ma@ukzn.ac.za).

2. Measuring the motion of our solar system with respect to the cosmic microwave background radiation - *observational project*
(Dr Yin-Zhe Ma)



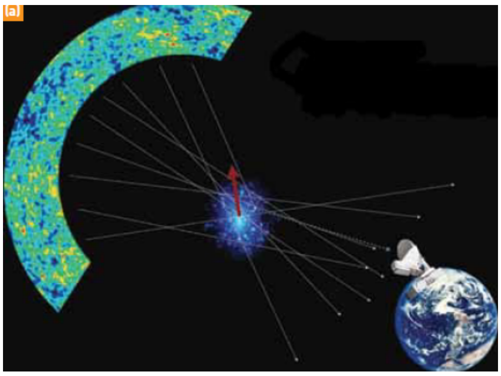
The cosmic microwave background (CMB) has a 3.4 mK dipole anisotropy which can naturally be explained as being due to the motion of the solar system with respect to the CMB rest frame . An interesting consistency check of this is to evaluate the solar system motion from peculiar velocity surveys.

Type-Ia supernovae luminosity measurements provide an accurate probe of peculiar velocities. Using observed correlations between SNe light curves, we can estimate the SNe absolute magnitudes and thus obtain accurate distance estimates to the SNe. Combined with spectroscopic measurements of the host galaxies' redshifts, this can be used to estimate the peculiar velocity of each SNe's host galaxy. The motion of the solar system will then show up as a dipole anisotropy in the SNe derived peculiar velocities. It is interesting to compare the estimates of the solar system motion from the SNe with those derived from the CMB. If they turn out to be inconsistent then it may be an indication that there is a significantly large intrinsic temperature dipole on the CMB surface of last scattering, which could be caused by a double inflation model for example.

In this study, we will use the state-of-the-art peculiar velocity field catalogue, named as CosmicFlow-2 catalogue, to calculate the speed of our solar system with respect to the CMB frame, by calculating the dipole anisotropy shown in the peculiar velocity field catalogue. This project will involve analytical and numerical modeling, as well as data analysis. The bulk of the work will be working with the catalogue on a computer. As such, a significant part of the project will be spent becoming comfortable in a high-level programming language like python or Fortran.

Interested students should contact Dr Yin-Zhe Ma (ma@ukzn.ac.za).

3. Studying the shape of dark matter halo with kinetic Sunyaev-Zeldovich effect - *observational project* (Dr Yin-Zhe Ma)



The kinetic Sunyaev-Zeldovich effect is the distortion of the black body spectrum of the cosmic microwave background radiation photons, which is produced by the re-scattering of the moving electron (left figure). The effect is proportional to the line-of-sight velocity of the galaxy cluster.

A recent study (Cunnama et al. 2009, MNRAS) shows that the velocity field of galaxy cluster is correlated with the elongation direction of the dark matter halo. Therefore, the elongation direction of each dark matter halo should be correlated with the measured kinetic Sunyaev-Zeldovich (kSZ) effect.

In this work, we will use two data sets to find such correlation signal. We will use the kSZ map produced from the Planck satellite, and the reconstructed tidal field catalogue from Slogan Digital Sky Survey. Then we will make a cross-correlation between the two and see how much signal is there. We will also do the same computation but with simulation and compare the results from simulation with real data. This study allows us to access how much baryons there are to source the kinetic Sunyaev-Zeldovich effect.

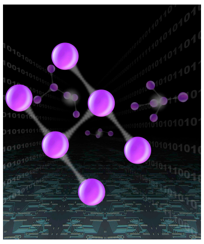
Interested students should contact Dr Yin-Zhe Ma (ma@ukzn.ac.za).

4. Quantum Teleportation of Multi-Dimensional Systems - *theory project* (Prof. Thomas Konrad)

We will investigate a new teleportation scheme with photons that can carry superpositions of many basis states (qudits). We want to quantify how far and with what fidelity we can teleport the photonic qudits. The study is devided into two honours projects: (i) model the central unit of teleportation - a non-linear optical process that creates entanglement between many optical modes. (ii) model the propagation of an entangled photon pair in turbulent air. Both projects contain modeling with Mathematica.

Interested students should contact Prof Thomas Konrad (konradt@ukzn.ac.za).

5. Quantum Optimization Algorithm - *theory project* (Prof. Thomas Konrad)



Quantum Computers promise unprecedented power of parallel processing. This project is to look at the possibility of using quantum parallelism in order to find the extrema of functions on a plane. We will review the literature and ideas developed by Prof Konrad in collaboration with Prof Hans Briegel from Austria.

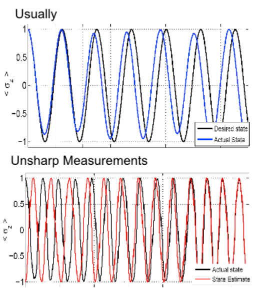
Interested students should contact Prof Thomas Konrad (konradt@ukzn.ac.za).

6. Quantum Computation with Classical Light III? - *experimental project* (Profs Andrew Forbes and Thomas Konrad)

Certain quantum information processing tasks (quantum walks) can be implemented using different degrees of freedom of laser pulses (for example polarization and orbital angular momentum). The project is to theoretically and experimentally check aspects of Grover's search algorithm that can amplify the probability of otherwise rarely occuring events. This is the third in a sequence of Honours projects, after the Deutsch Algorithm was successfully implemented and published, and aspects of the Deutsch-Jozsa Algorithm were studied in the framework of Honours projects in 2014 and 2015.

Interested students should contact Prof Thomas Konrad (konradt@ukzn.ac.za).

7. Towards a New Atomic Clock - *theory project* (Prof. Thomas Konrad)



The measurement and control of a single quantum system is tricky because of the sensitivity of quantum superpositions to the leakage of information to the outside. Particularly, if it comes to stabilizing dynamical processes, the usual sharp measurements disturb the system too much. As the example of a trapped ion oscillating in a microwave field we study methods to detect and control the microwave frequency by so-called unsharp measurements of the energy of the ion.

Interested students should contact Prof Thomas Konrad (konradt@ukzn.ac.za).

8. The Twin Paradox revisited - *theory project*
(Prof. Thomas Konrad)

The twin paradox in special relativity tells the story of a twin A who travels with a rocket at high speed to Alpha Centauri and finds his twin brother B after his return to be older than him. From B's point of view A left and returned but in A's rest frame B left and returned. So why should B be older and not A? The answer is because A accelerated to come back and B did not. We look at a new version of the story, where the state of A's clock is teleported back to B and thus A and B's clock's can be compared without a change of A's motional state. Which clock runs slower in this situation or are they still in sync?

Interested students should contact Prof Thomas Konrad (konradt@ukzn.ac.za).

9. Observational cosmology in the radio and/or microwave - *observational project*
(Dr Cynthia Chang and Prof Jonathan Sievers)

There are opportunities to work in observational cosmology using a variety of radio and microwave telescopes: HIRAX, HERA, SCI-HI, C-BASS, SPIDER. The range of work spans instrumentation development, field work (calibrations and observations), data analysis, and computational methods. The specific details of the project will be tailored to the student's interests. Programming experience (python preferred) is highly recommended but not required.

Interested students should contact Dr Cynthia Chang (cynthia@physicschick.com).

10. Finding the Biggest Things in the Universe - *observational project*
(Prof Jonathan Sievers)

Clusters of galaxies are the most massive gravitationally bound objects in the universe. Large ones can weigh as much as a thousand Milky Ways. Nevertheless, the seeds of their formation were planted in the first tiny fraction of a second after the Big Bang. As such, we can use clusters to learn about the birth of the universe, along with how it has grown with time. However, to be useful in studying cosmology, we need to measure the masses of clusters with as little systematic error as possible. The goal of this project is to use maps of the Cosmic Microwave Background (CMB) to find new clusters of galaxies and work on improving estimates of their masses.

The CMB is relic radiation from the Big Bang and gives us a snapshot of the universe when it was just 400,000 years old. Several experiments, such as the Planck Satellite and the Atacama Cosmology Telescope (ACT), have mapped the CMB over the sky with varying sensitivity and angular resolution. Clusters sit between us and the CMB, and leave a characteristic signature on the CMB. The large majority of the normal matter in clusters is not tied up in galaxies but instead is in the form of hot gas that fills the cluster. The cluster gas is many millions of degrees, while the CMB is 2.73 degrees above absolute zero. As the CMB photons pass through the gas, energy flows from hot to cold, and some of the cold CMB photons get a boost in energy. This boosting - the called the

Sunyaev-Zeldovich (SZ) effect - makes a characteristic signal in the CMB where clusters look bright at high frequency but show up as holes at low frequencies. Simulations predict that the SZ effect should be the most precise way of measuring cluster masses, but the field is still young (the first surveys with enough sensitivity and resolution to discover clusters through the SZ effect only appeared within the last 5 years). Both Planck and ACT have published catalogs of clusters but to date they have not been combined to search for clusters. This combination should be more powerful than either survey alone.

This project will start by taking publicly available Planck maps at different frequencies and splitting the cluster signal from other contaminating signals like radio sources, distant dusty galaxies, and the CMB itself. When this part of the pipeline has been checked against known results, the combined ACT and Planck maps will be searched for clusters. The benefits of this are twofold - first, clusters already discovered by ACT will get improved measurements, including of their masses, and second, the combination should be able to discover many clusters that each experiment individually missed. If time permits, the new combined SZ measurements will be used to help constrain models for the physics of clusters and measure basic parameters of the universe.

There will be a small analytic component to this project, but the bulk of the work will be working with the maps on a computer. As such, a significant part of the project will be spent becoming comfortable in a high-level programming language like python or Matlab.

Interested students should contact Prof. Jonathan Sievers (sieversj@ukzn.ac.za).

11. Can We Find the First Stars? - *experimental project* (Prof Jonathan Sievers)

We think we know that the first generation of stars lit up the universe when it was just a few hundred million years old. However, we have never directly seen these first stars, and what they looked like is still a mystery. One signal they leave is on the all-sky brightness of hydrogen. The rest frequency of hydrogen emission is 1.4 GHz, but the first stars were so early that the expansion of the universe has stretched out that light to around 100 MHz. You may recognize 100 MHz from places like your FM radio dial, and so searching for this signal is very difficult due to interference from radio stations and the like.

To get around the radio interference, experiments searching for the first stars need to be very far from people. A group at Carnegie-Mellon in the US deployed an experiment to an island nearly 200 km off the coast of Mexico, but found that even that far away the radio emission from the mainland covered the light from the first stars. Consequently, we teamed up with them to deploy an experiment to Marion Island, a small volcanic island half-way between South Africa and Antarctica. We are now fully funded to run an experiment at Marion, and we expect to send the first version this year. We have several projects appropriate for honours students, including working on hardware that will be deployed to Marion, working on electronic controls and data systems that will run an instrument left for the winter, and preparing analysis techniques for the data that we will collect. Students can train on data from the northern hemisphere experiment, and we expect the first data from Marion by the end of May. There may be an opportunity for students who work on the hardware/instrument software to deploy to Marion Island next year.

Interested students should contact Prof. Jonathan Sievers (sieversj@ukzn.ac.za).

12. HIRAX Analysis and Construction – *observational/experimental project*
(Prof Jonathan Sievers)

UKZN is building a new radio telescope to look at dark energy, a mysterious entity that is driving the expansion of the universe today. The first data are coming in now, and this project will let students get hands-on experience working with radio telescopes. There are a variety of possible project including:

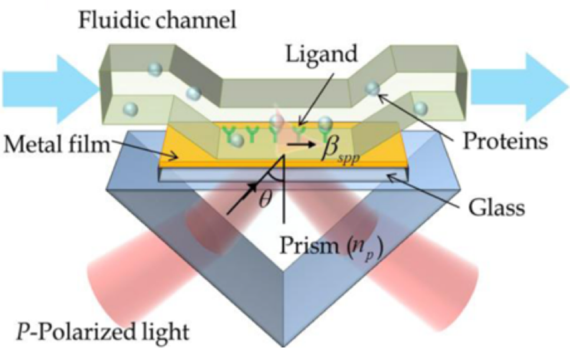
1) Look at the early data and make maps of the sky that will eventually lead to better understanding dark energy.

2) HIRAX will also search for Fast Radio Bursts, possibly the most enigmatic things in astronomy today. They flash very brightly for a thousandth of a second and then disappear. Students can help search early data for more bursts, or help develop code to search for them.

3) There are several experimental projects helping build HIRAX hardware available. No prior experience is needed as long as the student is interested in lab work. It is anticipated that the student(s) will also help deploy HIRAX hardware outside of Joburg, in the Karoo, and possibly in neighbouring countries.

Interested students should contact Prof. Jonathan Sievers (sieversj@ukzn.ac.za).

13. Plasmonic biosensing - *experimental project*
(Prof Mark Tame)



Surface Plasmon Resonance (SPR) is a phenomenon that occurs when the angle of incident light fully converts the field into surface plasmon waves that traverse the surface between a metal and dielectric material (glass). Variation in the dielectric material (i.e. changes in concentration of a substance or fluid) is directly detectable as changes in the angle at which SPR occurs; this gives rise to the ability to use SPR as a sensing technique, which has been achieved and made commercially viable successfully by the Swedish company Biacore from 1991. Commercial SPR instrumentation in use today however, are limited by the resolution they can achieve when measuring reflectivity. This limitation can be overcome by the study of the quantum nature of the light-material interaction in this equipment. In particular, the preparation of light in 'squeezed' states that make use of the uncertainty principle can enhance this resolution, as well as entangled 'multi-photon' states.

The project will involve designing and constructing a classical SPR biosensor that can measure chemical kinetics of drug interactions with enzymes and be used for drug development. If time permits, the project will explore techniques for enhancing the measurement resolution by using quantum states of light and achieve sensing capabilities beyond classical SPR biosensors.

Interested students should contact Prof. Mark Tame (tame@ukzn.ac.za).

14. Implementation of a BB84 protocol - *experimental project* (Prof Francesco Petruccione and Dr Yaseera Ismail)

The aim of this project is to implement a Quantum Key Distribution (QKD) scheme based on the implementation of the BB84 protocol.

Conventional encryption techniques is based on the difficulty of a mathematical construct to uphold the security of information however communication may be threatened by the rapid development of powerful systems. Quantum communication, or more specifically QKD, is based on a physical process of sharing a secure key for the encryption of sensitive data. QKD is implemented by transmitting single photons that are encoded through phase or polarisation, within a quantum channel that is either fibre or free-space.

The realisation of a QKD system is based on the implementation of an appropriate protocol for the encoding and decoding process. Bennet and Brassard demonstrated one of the most fundamental of protocols, known as BB84, based on encoding and decoding single photons by exploiting two types of polarisation basis, namely, the rectilinear and the diagonal basis. BB84 is known as a prepare-and-measure scheme since the transmitter, Alice, prepares the encoding and the receiver, Bob, measures the single photons received by randomly choosing from the aforementioned basis set.

This process leads to generation of a raw key which can undergo post-processing resulting a final key that can be utilised for encryption.

Objectives and Outcomes:

1. Establish a quantum link between to legitimate individuals.

2. Perform a BB84 protocol

3. Obtain a raw key from the encoded single photons transmitted through the quantum channel.

4. A comprehensive written report of the project and findings.

[1] Bennett C H, Brassard G. Quantum cryptography: public key distribution and coin tossing. In: In International Conference on Computers, Systems and Signal Processing,; 1984.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Yaseera Ismail (Ismaily@ukzn.ac.za).

15. Proving the existence of entanglement - *experimental project* (Prof Francesco Petruccione and Dr Yaseera Ismail)

The aim of this project is to verify the existence and quantify the quality of entanglement of a photon pair generation source.

The verification of entanglement lies in the violation of the CHSH inequality, which states that in local realistic theories the absolute value of a particular combination of correlations between two particles is bounded by 2, such that the violation is represented as follows:

$$S(\alpha,\alpha',\beta,\beta') = E[\alpha,\beta] - E[\alpha,\beta'] + E[\alpha',\beta] + E[\alpha',\beta'],$$

where α and α' and β and β' denote the local measurement settings of the two observers, each receiving one of the entangled particles. Here, a two-photon polarization entangled state will be used and the orientations of the measurement settings will be varied via polarisers placed in each arm of the source. The normalised expectation value for a fixed setting is given by

$$E[\alpha,\beta] = \frac{C(\alpha,\beta) - C(\alpha_\perp,\beta) - C(\alpha,\beta_\perp) + C(\alpha_\perp,\beta_\perp)}{C(\alpha,\beta) + C(\alpha_\perp,\beta) + C(\alpha,\beta_\perp) + C(\alpha_\perp,\beta_\perp)},$$

where $C(\alpha,\beta)$ denotes the coincidence count rate obtained for the combination of polariser settings (α,β). The statistical nature of the inequality requires that sufficiently long integration time for collecting the required coincidence rates. The quantum value of S should violate the inequality giving an ideal value of $2\sqrt{2}$, thus proving the existence of entanglement.

Objectives and Outcomes:

1. Set up the optical apparatus to verify entanglement of a photon generation source.
2. Gather data from the experimental setup to illustrate the existence of entanglement.
3. Vary parameters of the setup to understand what affects the quality of entanglement.
4. A comprehensive written report of the project and findings.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Yaseera Ismail (Ismaily@ukzn.ac.za).

16. Quantum state tomography of an entanglement source - *experimental project*
(Prof Francesco Petruccione and Dr Yaseera Ismail)

The aim of this project is to use quantum state tomography to characterize the quality of an entanglement source.

Quantum state tomography is the process of reconstructing the quantum state for a source of quantum systems by measurements on the systems coming from the source. Balanced homodyne tomography is a reliable technique of reconstructing quantum states in the optical domain. This technique combines the advantages of the high efficiencies of photodiodes in measuring the intensity or photon number of light, together with measuring the quantum features of light by a clever set-up called the homodyne tomography detector.

An entanglement source generates two photons in a certain quantum state. One of the photons, known as the idler, is used to trigger the detector. The other photon, the signal, is directed into the homodyne detector, in order to reconstruct its quantum state. Since the signal and idler photons are entangled, it is important to realize, that the optical mode of the signal state is created non-locally only when the trigger photon impinges the photodetector and is actually measured.

The measurement is reproduced a large number of times in order to develop a density matrix and the Wigner function. This gives rise to the quantum state of the photon.

Objectives and Outcomes:

1. Set up the optical apparatus to generate a quantum state tomography.
2. Gather data from the experimental setup to reproduce the quantum state tomography of the source.

3. Identify and vary the parameters of the setup to aim in improving the quality of the source.

4. A comprehensive written report of the project and findings.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Yaseera Ismail (Ismaily@ukzn.ac.za).

17. Propagation of hybrid-encoding states through simulated turbulence - *experimental project*
(Prof Francesco Petruccione and Dr Yaseera Ismail)

The aim of this project is to study the effects that simulated turbulence has on experimentally generated hybrid states containing higher dimensional states carrying orbital angular momentum and polarisation.

Quantum key distribution (QKD) is a physical process of sharing a secure key for the encryption of sensitive data. The implementation of QKD scheme is dependent upon a source of single photons that is appropriately encoded for the chosen quantum channel, either free- space or fibre. Encoding is implemented through polarisation or phase and recently as hybrid states whereby polarisation is coupled to phase. The phase component of the coupling is achieved through the generation of higher-dimensional states carrying orbital angular momentum (vortex beams).

Free-space QKD is challenged by the effects of atmospheric turbulence due to additional noise introduced to the system. Hence it is of relevance to study the effects that turbulence poses on overall efficiency of the system. In the case of hybrid encoding, the higher dimensional states are most prone to suffer the effects of the turbulence due to the breakdown of the phase.

For this study the hybrid states will be generated experimentally using an optical element known as q-plate which is also responsible to couple the phase to the polarisation. The simulated turbulence will be achieved by appropriately addressing a spatial light modulator with varying strengths of turbulence. The effects of the simulated turbulence on the hybrid states will be investigated.

Objectives and Outcomes:

1. Set up the optical apparatus to generate and couple phase to polarisation.

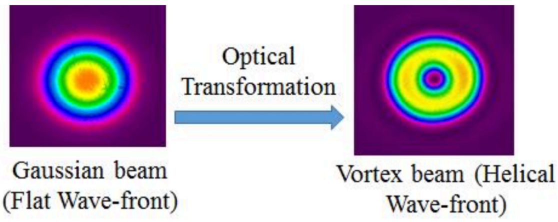
2. Simulate turbulence by appropriately addressing a spatial light modulator.

3. Gather data from the experimental setup to study the effects that the simulated turbulence has on the hybrid generated states.

4. A comprehensive written report of the project and findings.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Yaseera Ismail (Ismaily@ukzn.ac.za).

18. Modal decomposition of hybrid encoded states for Quantum Key Distribution - *experimental project*
(Prof Francesco Petruccione and Dr Yaseera Ismail)



The aim of this project is to perform a modal decomposition on hybrid-encoded states for Quantum Key Distribution.

One of the solutions to the Helmholtz equation, under paraxial approximation, is a Gaussian beam with a planar (flat) wave-front. These photons carry linear momentum however with an appropriate optical element linear momentum can be converted into orbital angular momentum resulting in a helical wave-front where by beam transforms from a Gaussian to a vortex beam as seen experimentally in the figure.

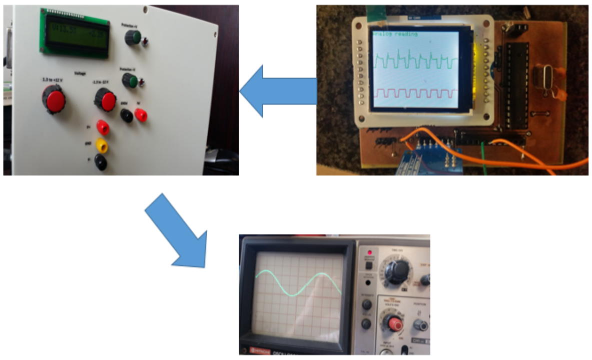
The advantage of higher dimensional states is the ability to perform dense coding for the application of quantum key distribution (QKD). QKD is based on a physical process of sharing a secure key for the encryption of sensitive data. Using polarisation only as a means of encoding restricts the encoding process to a bit of 1 or 0 however with higher dimensional states there is theoretically an infinite state space applicable for the encoding.

Performing a modal decomposition of a generated state provides information about the amount of orbital angular momentum carried by the photons. This process is useful for hybrid QKD systems that are designed to incorporate a free-space channel for the transmission and a fibre based system for the detection.

Objectives and Outcomes:
1. Set up the optical apparatus to generate a hybrid states carrying polarisation and OAM.
2. Gather data from the experimental setup by performing the modal decomposition
3. A comprehensive written report of the project and findings.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Yaseera Ismail (Ismaily@ukzn.ac.za).

19. Africhino laboratory tools - *experimental project* (Prof Francesco Petruccione and Dr Marco Mariola)



Many scientific experiments require the measurement of a physical quantity in form of electric signals in order to elaborate and control other processes. This research project aims to design a series of reliable, low-cost and open-source devices.

The devices will be integrated in a unique apparatus able to work as a classical personal computer or as an acquisition, elaboration and control system. In this work we intend to realise an Arduino based micro-controller board, generator functions and power control systems.

This project will give the candidate the necessary electronic design skills to be competitive in a world market and be self-sustaining in order to realize several electronic devices for their experiments as scientist.

Objective and Outcomes:

1. Design an Analog to Digital and Digital to Analog interface for an Open-Source Microcomputer.
2. Build a random generator function using the Direct Digital Synthesis.
3. Microcomputer interface for power systems control
4. A written report of the system comprensive for a physical experiment.

Interested students should contact Prof Francesco Petruccione (petruccione@ukzn.ac.za) or Dr Marco Mariola (MariolaM@ukzn.ac.za).

20. First steps in computational "Quantum Biology" - *theory project* (Dr Ilya Sinayskiy and Prof Francesco Petruccione)

The aim of this project is to familiarise the student with the Hierarchical Master Equation Approach - one of the main computational approaches in the newly emerging field of "quantum biology".

The student will learn the basics of the Theory of Open Quantum Systems, elements of quantum field theory and stochastic analysis. The student will learn about methods for the simulation of strongly interacting open quantum systems. For the computational part of the project, the student will learn methods of advanced programming in Mathematica or Python. The obtained results would be compared with known ones in the literature. Possibly, a publication could emerge from this project.

Interested students should contact Dr Ilya Sinayskiy (Sinayskiy@ukzn.ac.za) or Prof Francesco Petruccione (petruccione@ukzn.ac.za).

21. Many-body Computational Quantum Electrodynamics: Nonequilibrium Physics with Light - *theory project*
(Dr Ilya Sinayskiy and Prof Francesco Petruccione)

In this project, the student will learn about light-matter interacting systems and the basics of the phase transition physics. The student will learn fundamentals of the theory of open quantum systems and the ways to simulate them.

In the computation part of the project the student will write a program to numerically simulate the dynamics of a dissipative-driven spin-boson system. The student will explore different parameter regimes and numerical observe phase transition in such a system. The obtained results will be compared with known ones in the literature. Possibly, a publication could emerge from this project.

Interested students should contact Dr Ilya Sinayskiy (Sinayskiy@ukzn.ac.za) or Prof Francesco Petruccione (petruccione@ukzn.ac.za).

22. Open Quantum Walks - *theory project*
(Dr Ilya Sinayskiy and Prof Francesco Petruccione)

The aim of this project is to familiarise the student with open quantum walks (OQWs) and their properties. In particular, the student will focus on the microscopic derivation of particular OQWs and identify different behaviours of the "walker" with different thermodynamical parameters of the environment. Theoretical investigations would be illustrated by numerical simulations in Mathematica/Matlab packages.

Interested students should contact Dr Ilya Sinayskiy (Sinayskiy@ukzn.ac.za) or Prof Francesco Petruccione (petruccione@ukzn.ac.za).

23. Dissipative Quantum Computing with Open Quantum Walks - *theory project*
(Dr Ilya Sinayskiy and Prof Francesco Petruccione)

The aim of the project is to familiarise the student with concept of quantum computing, especially its dissipative formulation and the formalism of Open Quantum Walks (OQWs). The student will learn about OQW formulation of the dissipative quantum computing (DQC) model. As an example of the DQC with OQWs, some simple quantum computing algorithms would be considered and numerically simulated in Mathematica/Matlab packages.

Interested students should contact Dr Ilya Sinayskiy (Sinayskiy@ukzn.ac.za) or Prof Francesco Petruccione (petruccione@ukzn.ac.za).

24. Dissipative Dynamics of a Driven Qubit - *theory project*
(Dr Ilya Sinayskiy and Prof Francesco Petruccione)

In this project the student will study the dynamics of a qubit interacting with an external magnetic field and a dissipative environment. The interaction with the heat bath will be treated as weak and we will use the Born-Markov approximation, which is perfectly justified for many situations in quantum optics. We will assume that the qubit interacts with the precessing magnetic field. We will be interested in the dynamics of the coherence and occupation probability in the qubit subsystem (Mathematica/Matlab numerical simulations will be used).

Interested students should contact Dr Ilya Sinayskiy (Sinayskiy@ukzn.ac.za) or Prof Francesco Petruccione (petruccione@ukzn.ac.za).

25. An investigation of the presence of Pc5oscillations during TRINNI events - *observational project*
(Dr Zolile Mtumela and Dr Judy Stephenson)

Around 35 similar HF radars form an international network called SuperDARN (http://vt.superdarn.org/tiki-index.php) which routinely measure ionospheric convection. A unique “map potential” technique is used to produce global convection map for each hemisphere. This technique utilizes all existing radars ionospheric measurements of velocity with a spherical harmonic representation of the ionospheric electrostatic potential, to produce a map every 2 minutes.

In this study, we identify Trinni events, using ionospheric convection maps from the SuperDARN data in both hemispheres. Ionospheric convection patterns depend strongly on the orientation of the interplanetary magnetic field (IMF), often expressed in terms of IMF clock angle. The dominant driving mechanism is reconnection between the IMF and the geomagnetic field. Two intervals of likely TRINNI events for cases where the By-component was positive and negative will be presented and discussed. The assumption of a non-substorm interval will be justified by magnetometer and GOES satellite data, and the observations will be discussed in relation to magnetic reconnection in the magnetotail.

Brief background of Trinnis: During northward IMF, dayside reconnection can occur poleward of the cusps. In the case of purely northward IMF, reconnection happens between the Earth’s open magnetic field lines and the IMF, which leads to generation of lobe cell convection in the ionosphere and magnetosphere (Reiff and Burch, 1985). When the By component of the IMF is non-zero, reconnection can happen between the Earth’s closed magnetic field lines and the IMF on the equatorward side of the cusp (e.g. Nishida et al., 1998). This process creates merging-cell convection and is responsible for producing the flow bursts magnitude of which were measured by Senior et al., (2002) and Grocott et al. (2003). The particular phenomena discussed in detail by them were bursts of fast (~1000 m/s) westward auroral zone flow in the nightside ionosphere. These observations were made during extended intervals of modest dayside driving associated with a northward IMF. The flow bursts were assumed to be associated with the reconnection in the distant magnetotail as there were no signs of substorm activity registered by spacecrafts. These bursts of “tail reconnection during IMF northward non-substorm intervals” were then named TRINNIs.

This project would involve use of online tools on the SuperDARN website (vt.superdarn.org) to plot convection maps of SuperDARN data to flag possible TRINNI events. These solar wind data of these events must also be analysed to determine whether they fit the criterion. Once a few events have been isolated, preliminary investigations of these events will be carried out.

Interested students should contact Dr Zolile Mtumela (MtumelaZ@ukzn.ac.za) or Dr Judy Stephenson (Stephens@ukzn.ac.za).

26. An investigation of Pc5 pulsation events using SuperDARN and ground-based magnetometer data when IMF Bz is positive - *observational project*
(Dr Zolile Mtumela and Dr Judy Stephenson)

SuperDARN radars are coherent HF radars and so they receive reflections from field aligned irregularities in the ionosphere. Due to the fact that the ionosphere has finite conductivity, the motion of the field line can be seen in the back and forth movement of the plasma (seen as alternating blue (positive) and yellow (negative) velocity bands) in the Doppler velocity data of the radar. HF radar observations are of central importance here as they provide good spatial resolution of the resonances in very large field of view.

The Pc5 pulsation events can be monitored in the high-latitude ionosphere by SuperDARN and ground-based magnetometer array in CARISMA stations that are in the same range of magnetic latitude, when the interplanetary magnetic field of the solar wind is northward. These two instrument types complement each other. The line-of-sight Doppler velocities from the radar can be used to measure ULF oscillations in the F-region plasma flow associated with Pc5 field line resonance. Ultra low frequency (ULF) pulsations have been observed for many years in magnetometer data and are endemic within the magnetosphere. Spectral analysis of the Pc5 pulsations from SuperDARN and magnetometers has been performed. This will help in determining the characteristic features of pulsations during northward interplanetary magnetic field intervals.

This project will involve the candidate to investigate known TRINNI events. They will have to download the appropriate SuperDARN and magnetometer data for the events and perform Fourier analysis of them to determine the presence, or lack of, Pc5 pulsations. This will involve some basic programing and plotting using either Matlab, Python or IDL.

Interested students should contact Dr Zolile Mtumela (MtumelaZ@ukzn.ac.za) or Dr Judy Stephenson (Stephens@ukzn.ac.za).

27. Raman Spectral analysis of single walled carbon - *observational project*
(Dr Mathew Moodley)

In this topic, the vibrational properties of single-walled carbon nanotubes will be investigated using Raman spectroscopy. The information obtained will indicate the semi-conducting or metallic nature of the nanotube, its diameter and its defect concentration. The excitation laser wavelength on the detectable type of nanotubes will be investigated. (Raw experimental data already available).

Interested students should contact Dr Mathew Moodley (Moodleymk@ukzn.ac.za).

28. Photoluminescence spectra of single walled carbon nanotubes - *experimental project*
(Dr Mathew Moodley)

In this topic of research, the photoluminesce spectra of mixed single walled carbon nanotubes will be investigated. Such spectra gives us information on the electronic structure of material. In particular, its band gap energy. Furthermore, the diameters of the emitting nanotube material can be also obtained from the spectra. Such materials have applications advanced electronic devices.

Interested students should contact Dr Mathew Moodley (Moodleymk@ukzn.ac.za).

29. Pulsed laser CVD of novel 2D and 3D Materials - *experimental project*
(Dr Mathew Moodley)


Figure 1: Laser CVD apparatus

Be part of a revolution in making novel hybrid nanostructures of carbon, boron and silicon. Use the laser to make this material. Then, look under a high resolution electron microscope and discover new materials. Do what no other honours student has done before. Discover, write it up and publish it. Be famous.

Interested students should contact Dr Mathew Moodley (Moodleymk@ukzn.ac.za).

30. Pulsed laser Deposition of thin Films - *experimental project*
(Dr Mathew Moodley)

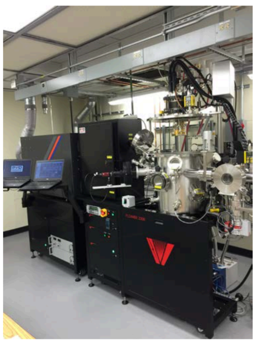


Figure 2: The new state of the art PLD/MBE 2300 system

A new state of the art instrument exceeding R9 million will be installed in the Physics department. The first of its kind in the Southern Hemisphere. With this instrument, one will be able to deposit thin film nanostructures of elemental and composite materials of unimaginable structural design. Your aim is to create a material with novel optical, electrical and magnetic properties for advanced applications. We will look at this material with an electron microscope, XRD, photoluminescence and other methods to study this material.

Interested students should contact Dr Mathew Moodley (Moodleymk@ukzn.ac.za).

31. Optical emission plasma spectroscopy - *experimental project* (Dr Mathew Moodley)

This project involves investigation laser induced plasmas. These plasmas are not ordinary ion and electron plasmas which you will study in the Honours plasma physics course. These are special plasmas containing elements such as carbon and catalysts. They are nucleating plasma. When the plasma cools, it forms self- assembled carbon nanotubes. You will used optical emission techniques to look at the optical spectra as a function of time and distance. You want to know when and how these super nanostructures grow. Cutting-edge science. Why is this important? Because no one knows, how these tubes grow and how they can be controlled. If you find out, you will be invited to the Swedish Academy of Sciences (Nobel Physics/Chemistry granting organization!!!)

Interested students should contact Dr Mathew Moodley (Moodleymk@ukzn.ac.za).

32. Plasma and classical mechanics - *theory projects* (Prof Richard Mace)

Students are encouraged to visit Prof. Mace if they have any plasma or classical mechanics related interests. Possible projects that are of mutual interest can then be discussed.

Interested students should contact Prof. Richard Mace (Macer@ukzn.ac.za).

Other projects are available, as presented in this meeting or already agreed on with supervisors. For many of the projects, bursaries are available. Please check with your potential supervisor.