# PHY3200: Physics Project

## Project Titles and Abstracts

## for

## Academic year 2020/2021

Dr Tony Apollaro

**Entanglement behaviour in the classical limit of spin systems**

Entanglement, a peculiar non-local correlation arising in quantum mechanics, is a fundamental resource in quantum information processing

[1]. Spin-1/2 systems have shown to exhibit highly entangled ground states [2]. In this project we want to evaluate the entanglement of two interacting spins when approaching the classical limit for spin systems, i.e., when the angular momentum of the spins tends to infinity

[2]. It will involve computational work and, depending on the outcome, could lead to a publication in a peer-reviewed journal.

[1] https://en.wikipedia.org/wiki/Quantum_Computation_and_Quantum_Information

[2] http://link.aps.org/doi/10.1103/PhysRevA.77.062314

[3] Lieb, Elliott H. The classical limit of quantum spin systems. Comm. Math. Phys. 31 (1973), no. 4, 327--340.

**Crossover between open systems dynamical regimes**

No quantum system can be considered perfectly isolated from its environment. When the interaction with an environment is taken into account, the quantum system's dynamics can be Markovian or non-Markovian [1]. Recently, my colleagues and I investigated the competition between a Markovian and a non-Markovian environment acting simultaneously on an open quantum system [2]. In this project, we will investigate the dynamics of multi-partite entanglement subject to Markovian and non-Markovian noise. It will involve computational work, possibly via the Quantum

Experience platform by IBM [3], and, depending on the outcome, could lead to a publication in a peer-reviewed journal.

[1]http://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780199213900.001.0001/acprof-9780199213900

[2] http://link.aps.org/doi/10.1103/PhysRevA.90.012310

[3] https://quantumexperience.ng.bluemix.net/qx

Dr Jackson Levi Said

**Testing Gravity Theories using recent Cosmological Observations**

Recent cosmological surveys have shown a growing observational tension between the early- and late-time Universe. This result was first noted to be statistically significant by the Planck collaboration which has since been boosted by the H0LiCOW collaboration results. One solution is to consider new observationally motivated cosmological models to alleviate this tension. While many theories exist in the literature, only some of physically motivated or observationally viable. This project will consist of considering a class of physically motivated new cosmological models which will then be contrasted against recent cosmological data. This will be achieved using Monte Python which is a Monte Carlo Markov Chain sampler that, more generally, uses several cosmological datasets to determine best fit parameters for modified theories of gravity and exotic particle physics theories in Python. The aim of the project will be to compare several cosmological models against each other and determine the best parameters of each.

Dr Alessio Magro

**Beam Packing Problem**

In almost 60 years of space activities, more than 7500 kg of space hardware was launched into space. Only a fraction of these objects is operational to date. The rest are commonly referred to as space debris and represent a risk to operational satellites and man-missions. As the number of objects increases, so does the risk of further catastrophic collisions. One of the latest space surveillance facilities in Europe is the BIRALES radar. BIRALES is a bistatic radar composed of a radio transmitter in Sardinia and the Medicina Northern Cross radio telescope near Bologna as the receiver part. The instrument uses a multi-beaming technique that generates several beams which cover the field of view (FoV) of the receiver. The arrangement of beams, or multi-pixel, is used to determine the trajectory of a high-velocity object crossing the FoV of the instrument.

This project will investigate the generation of an optimal multi-pixel taking into consideration the number of beams used, the area covered, degree of beam overlap and pointing deviation. Given the number of parameters, the use of evolutionary techniques, such as genetic algorithms can be investigated to find the optimal placement of these beams. The aim is to deploy an optimal solution for the beam configuration the operational BIRALES space surveillance radar.

Prospective students should be comfortable with programming, or willing to program, in Python or Matlab. The project will also involve some application of signal processing and machine learning techniques.

**Portable Radio Interferometer**

Co-Supervisor: Dr Louis Zammit Mangion

In recent years, the verification of large radio instruments has been achieved using inexpensive solutions that make use of Unmanned Aerial Vehicles (UAVs) as artificial sources. The position of the drone is usually obtained using a portable total station, or more recently, through accurate GNSS GPS. These studies combine the output signal from the antenna under test (AUT) with the position of the GPS at a final post-processing stage once the drone lands. This is often a time-consuming campaign where the drone has to be flown several times over the antenna.

Telemetry from the drone is generally transmitted to a ground station via a dedicated link. During a previous project (2019 - 2020) a custom data-link was constructed which used two RF transceivers, a monopole antenna as the transmitter and a FRactal Octagonal Ring element Array (FR-ORA) receiver as the receiver. The receiver can be reconfigured depending on the flight path of the UAVs, however, once a configuration is selected the individual elements of the array have the combined analogly.

The aim of this project is to digitise the signals of all antennas of the FR-ORA array such that all signal processing can be performed digitally or in software. This will involve the construction of analog as well as digital subsystems, as well as a computing device to control the system and process the digitised data. The solution should be portable (requiring minimal power) and scalable. Prospective students should also be comfortable with programming.

Dr Louis Zammit Mangion

**Ab-initio calculation of elastic constants**.

The program Wien2k has been used in past projects to calculate band structures and energies. By inducing a strain in the crystal (ie. Changing one or more dimension) and calculating the resulting energy, it is possible to deduce the corresponding elastic constant (s). In fact, third party scripts exist to perform this calculation automatically. The aim of this project is to validate the method using known materials and then apply it to other materials with potentially exotic elastic constants.

While the main program is a finished product, the project requires programming skills as the scripts that perform the calculation will need to be modified.

**Building a simple radio telescope**

Co-supervisor Dr. Andrea de Marco

A number of websites discuss home-made radio telescopes made by amateurs, and an article in IEEE Spectrum (October 2019) describes one such attempt using a home-built horn antenna and a PC TV tuner card as the radio front-end. The apparatus was reportedly able to detect the Doppler shift in the 21cm line due to galactic rotation.

The aim of this project is to design and build a similar system, starting with the simulation and design of the horn antenna and measuring the characteristics of the finished product. The project can then go on to investigate different possibilities for the radio front-end, either using a PC tuner as described in the article or assembling one using modular circuit elements. If time permits, two antennae can be connected in an interferometer arrangement to provide enhanced spatial resolution.

The project will involve a degree of mechanical and electronic construction as well as use of simulation and data-collection programs, however no programming skills should be needed.

Dr Joseph Caruana

**The effect of spirals on the evolution of galaxies**

Co-supervisors Prof Victor Debattista (UCLan), Mr Karl Fiteni (UM)

One way of understanding galaxy populations is through detailed study of our own Galaxy. Learning about the Milky Way's own evolution enables us to better understand the Universe at large. Such investigations entail running computer simulations which may then be compared to observational data. For this project, the student will analyse state-of-the-art simulations of spiral galaxies, and in particular will focus on and quantify the effect that these spirals have on a particular measured property, namely the action. The student will track this effect over time and produce maps of the change in action, which would lead to a better understanding of these systems. The student will also make use of data from the ESA Gaia spacecraft, a space observatory that is building the largest space catalogue of around 1 billion objects.

**The Night Sky Brightness on the Maltese Archipelago**

A night sky brightness (NSB) measurement programme commenced in 2017, resulting in the collection of a large amount of NSB data after surveying all of the three main islands with the aim of producing the first ever complete sky brightness map of our archipelago. Follow-up data was collected in the second and third years of this programme, focusing on resolution and zonal aspects. For this continuing monitoring programme, the student will compare all datasets taken over the four years, assess any variability in the measurements, and analyse any temporal variation in sky brightness over the Maltese islands. The student will be expected to record sky brightness measurements over the islands during night hours.

Prof Kristian Zarb Adami

**Machine Learning for Optical correction in large telescopes**

Aberrations introduced by the atmospheric turbulence in large telescopes are compensated using adaptive optics systems, where the use of deformable mirrors and multiple sensors relies on complex control systems. Recently, the development of larger scales of telescopes as the E-ELT or TMT has created a computational challenge due to the increasing complexity of the new adaptive optics systems. The Complex Atmospheric Reconstructor based on Machine Learning (CARMEN) is an algorithm based on artificial neural networks, designed to compensate the atmospheric turbulence. During recent years, the use of GPUs has been proved to be a great solution to speed up the learning process of neural networks, and different frameworks have been created to ease their development. The implementation of CARMEN in different Multi-GPU frameworks is presented in this paper, along with its development in a language originally developed for GPU, like CUDA. This implementation offers the best response for all the presented cases, although its advantage of using more than one GPU occurs only in large networks

**Automated drone calibration of radio arrays**

Over the past 2 years, we have successfully implemented a calibration method of radio arrays by using a radio source mounted on a drone. However, much of the work is still done manually with the data being analysed at a later date. This project will aim to automate the process such that, on user command, the drone will take-off, fly a pre-programmed flight, and return to base. During the flight, data will be continuously acquired by the array under test and the beam patterns plotted. This will give the user a real-time feeling of how the array is behaving and update the calibration coefficients of the system automatically.

Prof André Xuereb

**An optomechanical quantum simulator**

Late in 2018, a colleague and I proposed a new way to simulate quantum systems [1] using optomechanics [2], which is the study of how light interacts with the motion of very small, vibrating, mirrors. In that paper we suggested that our system could be used to explore quantum thermodynamics [3]. This project will pick up where our manuscript left off and demonstrate how to use our proposed system as a veritable quantum simulator, using ideas from optomechanics, non-equilibrium dynamics, and quantum control. It will involve computational work and, depending on the outcome of the project, could lead to a publication in a peer-reviewed journal.


[1] http://iopscience.iop.org/article/10.1088/1367-2630/aaca27/meta
[2] http://journals.aps.org/rmp/abstract/10.1103/RevModPhys.86.1391
[3] http://iopscience.iop.org/article/10.1088/1367-2630/17/3/035016/meta


**An (un)synchronised bunch**

A few years ago, my colleagues and I proposed a system [1,2] composed of many mechanical oscillators in a single optical cavity. We quickly realised that this idea could lead to much new physics, and there remain many unanswered questions. This project will look at one such question, regarding the issue of synchronisation and so-called chimera states [3]. These are fascinating states that occur in some systems composed of many oscillators, where some of the oscillators are synchronised with each other, but some are not. We will start off by looking at a model that realises these chimera states and then move to understand whether they can arise in the system discovered by us. This project will involve computational work. Depending on the results obtained, there it could lead to a publication in a peer-reviewed journal.


[1] https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.109.223601
[2] https://journals.aps.org/pra/abstract/10.1103/PhysRevA.88.053803
[3] https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.93.174102

Dr Andrea De Marco

**Autoencoder-Based Cleaning of Radio-Sky Images**

One of the challenges of detection of radio sources in radio sky images is accurate cleaning of the noisy background, including instrumentation effects in radio imaging pipelines. Many of the available source-detection algorithms rely on a rough approximation to image backgrounds based on a statistical sample of the pixels in an image. This background is then subtracted from the original image before source detection can be performed. In this project, the student will explore the use of unsupervised deep neural networks that can learn to encode a compressed representation of a source in a noisy background, building a cleaned-up reconstruction of the same source. Furthermore, standard source detection algorithms will be tested to compare rudimentary background estimators with autoencoder based ones to draw comparisons on the effect this has on the source detection algorithms.