CAS HONOURS PROJECT LIST 2025

Axion Dark Matter Detection

Supervisor: Dr Ben McAllister
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Project description: The nature of dark matter is one of the biggest mysteries in modern science – it makes up five sixths of the matter in the Universe, and is of unknown composition. It surrounds and passes through the Earth at all times. Axions are a hypothetical particle, and one of the leading candidates for dark matter. Swinburne is building a new axion detector to try and measure small effects induced by dark matter when it passes through the laboratory, and shed light on the mystery. The kind of experiment we are building is called an axion haloscope. The detector is being physically constructed and will be hosted at Swinburne – but work needs to be done on various aspects of the project, from detector characterisation, to control software and data analysis, including machine learning. This project could focus on any of these areas, tailored to fit the skills and interests of the student. There is room for multiple students, and you will be working in a small team with other researchers. You may be working with laboratory equipment, on code to control the experiment, or on a pipeline to acquire and tease through experimental data for hints of new physics using new data analysis techniques.

Testing the variability of fundamental constants with quasar spectra

Supervisor: Prof Michael Murphy
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Project description: Distant galaxies, seen in silhouette against bright, background quasars, imprint a characteristic pattern of absorption lines onto the quasar light as it travels to Earth. This pattern is determined by the fundamental constants of nature. Using spectra taken with the largest optical telescopes in the world (e.g. Keck and Subaru in Hawaii, VLT in Chile), this pattern can be compared with laboratory spectra to determine whether the fundamental constants were indeed the same in the distant, early universe as we measure them on Earth today. Several different avenues are available for exploration in this project. For example, one option is to analyse new spectra taken from the Keck and/or VLT with the aim of measuring the variability of the fine-structure constant (effectively, the strength of electromagnetism). Another option is to improve the methods used to make these exacting measurements so that we can make the best use of the existing telescopes, and the future 39-metre "Extremely Large Telescope" being built in Chile. These and a range of other possible options will be discussed with the candidate.

Further reading:

- Murphy M.T. et al., 2022, Astronomy & Astrophys, 658, A123 (arXiv:2112.05819)

Going with the flow: Using the motion of galaxies to measure the force of gravity!

Supervisors: Dr Ryan Turner, Prof Chris Blake
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Project description: Galaxies, the building blocks of the Universe, are not fixed in space but feel the gravitational tugs of the surrounding clusters and voids. By measuring these galaxy motions, we can test whether the laws of gravity on the scale of the Universe match the predictions of General Relativity. In this project we will use the latest database of galaxy motions, from the Dark Energy Spectroscopic Instrument, to measure the "pairwise velocity correlation" which quantifies how galaxies are pulled towards each other by gravity. We will then compare these measurements to theoretical predictions based on the growth rate of cosmic structure in General Relativity, and other models of gravity. This Project will allow you to develop research skills such as python coding, statistical analysis, handling large datasets, and reviewing the scientific literature.

How Do Exploding Stars Reshape Galaxy Evolution

Supervisor: A/Prof Deanne Fisher
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Project description: In starburst galaxies, clusters of supernovae explode in the disk, the combined energy and momentum pushes gas up out of the spiral galaxy and into the halo above the disk. This changes the properties of the galaxy, and is considered by most theories to be a linchpin that regulates the growth of galaxies. We view this as faint filaments of gas that extends above star forming galaxies. In this project we will study this gas. The physical properties of the gas directly relate to the physical models of how these large outflows of gas evolve and shape outflows. We will use data from the Keck 10m optical telescope and the VLT 8m telescope to study the outflowing gas. At Swinburne you will work in a team of other PhD students and postdocs, along with myself, and be part of an international team through regular meetings.

Further reading:

- Galactic Winds Dictating Galaxy Evolution – 20 min Lecture by L. Zscaechner https://www.youtube.com/watch?v=hqpLWgRMdw0
- How Feedback Shapes Galaxy Evolution – 1 hour lecture by Prof Christy Tremonti https://www.youtube.com/watch?v=ODZ_dfe2r7I

Famine, Feast or Future Fuel?

Supervisor: A/Prof Michelle Cluver
Contact: mcluver@swin.edu.au

Project description: Neutral, atomic hydrogen has fueled the stellar growth of galaxies (via its molecular phase) for over 13 billion years. As the SKA and its pathfinders reveal the amount and distribution of HI in and around galaxies across cosmic time, we must use this information to build our understanding of how galaxies evolve. A key first step is discerning between galaxies that lack (or are deficient in) HI and are therefore no longer forming stars, versus those with copious reservoirs of HI, but which are currently not forming stars efficiently. In the case of the latter, this gas may yet fuel star formation if the galaxy begins interacting with a neighbouring galaxy (as will be the case for the Milky Way and Andromeda). This project will make use of HI data from the AMIGA study of isolated galaxies, combined with high quality WISE mid-infrared measurements to develop a new calibration for determining the HI deficiency of galaxies.

Detecting the first gravitational wave signal from the explosion of massive stars

Supervisor: Dr Jade Powell
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Project description: Hundreds of gravitational-wave signals have now been discovered from the merger of binary neutron stars and black holes, but other sources of gravitational waves have not yet been discovered. Some of the most violent explosive events in the Universe are predicted to emit bursts of gravitational waves, and may result in the next big multi-messenger discovery. One of the most promising astrophysical sources of gravitational waves is a core-collapse supernova. In this project, you will help to develop a new search for gravitational waves from core-collapse supernovae, and apply this new search to real data from the LIGO-Virgo-KAGRA gravitational-wave observatories.

The Coalescence Rate of Neutron Star Binaries

Supervisor: Prof Matthew Bailes, Dr Simon Stevenson
Contact: mbailes@swin.edu.au

Project description: In our own galaxy, about a dozen neutron star pairs have been discovered that will coalesce in a spectacular fireball 100s to 1000s of million years from today. Upon coalescence, the neutron stars will emit a short burst of gravitational waves detectable by Advanced LIGO. In this Honours project the student will answer the question: Is the population of neutron star pairs in our own galaxy consistent with the observed merger rate from LIGO that observes millions of galaxies? This will be addressed by using supercomputer simulations of the neutron star population and comparing it with the results of pulsar surveys.

Exploring the realm of transients

Supervisor: Dr Anais Moller
Contact: amoller@swin.edu.au

Project description: Exploding stars and bursts of radiation, called *transients* due to their limited timespan, provide information on the extreme and fundamental physics of the Universe. In this project we will use the data from the largest transient survey in the world, the Vera C. Rubin Observatory LSST, detecting up to 10 million transients per night. We will use Fink broker to explore this data and study properties of different types of transients including supernovae as well as new types of transients. In this project you will develop coding and analysis skills to disentangle transients and their properties.

Further reading:

- Fink, a new generation of broker for the LSST community https://ui.adsabs.harvard.edu/abs/2021MNRAS.501.3272M/abstract

Clustering of Massive Quiescent Galaxies at $z > 3$

Supervisors: Professor Karl Glazebrook, Dr Themiya Nanayakkara, Dr Harry Chittenden, Dr Nancy Kawinwanichakij
Contact: kglazebrook@swin.edu.au

Project description: The population of massive (>~1E11 stellar mass) quiescent galaxies in the early universe (from z=3 now up to z~7) continues to puzzle observers and theorists. They must exist in massive halos of dark matter that are predicted to be rare at these early epochs. Some of them have extremely old stellar populations that only form just after the Big Bang (e.g. Glazebrook et al. 2024). New evidence has recently emerged from JWST spectroscopic redshifts that they are *clustered*, i.e. they commonly have neighbours at the same redshift nearby on the sky. Such clustering is an extremely important measurement as it provides additional information on the dark matter halo population that could host them,

In this honours project you will work with galaxy formation simulations, extract model quiescent populations, and compare the clustering with that observed. How often do we see nearby groupings at the same redshift in the simulations and how does that depend on dark matter halo mass? This comparison may lead to an understanding of these galaxies in the current cold dark matter paradigm, but there is the exciting possibility it may also point the way to a need for new dark matter physics. The honours student will be embedded in the JWST Australian Data Centre group (jadc.swin.edu.au) a group of ~ten scientists and PhD students at Swinburne studying the early Universe with JWST, providing extensive expert support in observations and simulations.

Further reading:

- Glazebrook et al. 2024 (Nature): https://ui.adsabs.harvard.edu/abs/2024Natur.628..277G/abstract
- Prof. Karl Glazebrook: https://experts.swinburne.edu.au/812-karl-glazebrook/about

Choose Your Own (Data-Intensive Space) Adventure

Supervisor: Prof Christopher Fluke
Contact: cfluke@swin.edu.au

Project description: Advanced Visualisation. Virtual Reality. Artificial Intelligence. Machine Learning. Human-Machine Teaming. Earth Observation. Space Domain Awareness. Space Systems. Augmented Human Performance. Cyber-Human Discovery Systems. Data-Intensive Space Applications. If any combination of these phrases captures your imagination, then this is your opportunity to co-create a customised Honours Project targeting augmented human-machine performance in the era of data-intensive space applications.

Further reading:

- Fluke, C.J., Hegarty, S.E., MacMahon, C.O.-M., 2020, "*Understanding the human in the design of cyber-human discovery systems for data-driven astronomy*", Astronomy & Computing, Vol 33, article id. 100423, see https://ui.adsabs.harvard.edu/abs/2020A%26C....3300423F/abstract

Searching for a pot of gold in pulsar timing array data sets using machine learning

Supervisor: A/Prof Ryan Shannon
Contact: rshannon@swin.edu.au

Project description: The Universe is permeated by low frequency gravitational waves, a fundamental property of Einstein's theory of general relativity. The gravitational waves are produced by supermassive black holes, billions of times more massive than the Sun. These gravitational waves are signatures of some of the most significant interactions in our Universe: the collisions of galaxies and the inspiral of the supermassive black holes at their core. We can detect these through observations of pulsars, ultra stable rotating neutron stars that can be used as cosmic clocks, which we refer to as a pulsar timing array. Recently the first compelling evidence for these gravitational waves was announced by pulsar timing arrays in Australia, Europe, and North America. Swinburne leads the MeerKAT Pulsar Timing Array, which will soon have the most sensitive array in the world. However, there exists other signals in the data from alternate astrophysical sources. This creates difficulties in detecting and characterising the gravitational waves. The current method for searching for these signals is particularly slow and computationally expensive, involving the sampling of hundreds of parameters simultaneously. Soon, as data sets get larger, this will no longer be a viable strategy. In this project, you will develop machine learning techniques to find and remove these processes. Machine learning has been shown to perform equally accurately in other areas of astronomy so the potential is immense. You will use state of the art tools and the best data in the world to create a novel technique that is sorely needed in the field.

Finding new radio pulsars in an extragalactic globular cluster using the MeerKAT telescope

Supervisor: Emma Carli
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Project description: Pulsars are “dead” collapsed stars that are amongst the most extreme objects of the Universe - they are the fastest spinning stars (usually, they undergo one complete revolution in less than a few seconds); they are the smallest and densest stars, with approximately the mass of our Sun contained in a radius of a few tens of kilometres; and they have the strongest stellar magnetic fields. Their lighthouse-like radio beams are observed as faint radio pulses from the Earth. While well over 3000 pulsars have been found in the Milky Way, our own galaxy, only about 40 extragalactic pulsars have been found due to their distance. In this project, you will use a dataset from the state-of-the-art South African radio telescope MeerKAT to search for some of the fastest-spinning and relativistic pulsars outside of our galaxy.

The first forming galaxies: where are they now?

Supervisor: A/Prof Edward Taylor
Contact: entaylor@swin.edu.au

Project description: One of the biggest puzzles in galaxy formation and evolution is the existence of very massive galaxies in the very early Universe. There are many aspects to this puzzle: it's a surprise that they can assemble so much mass so quickly; it's a surprise that something seems to have very suddenly cut off their star formation; it's doubly surprising that they seem to have sizes that are 1/10th the size of similarly massive galaxies in the present day Universe. The implication is that, in order to grow into the kinds of galaxies we see in local Universe, these galaxies have to grow considerably in size, but without growing very much in mass, and we don't really understand how this might be possible. The aim of this project is to use recently reanalysed archival data from a variety of sources (and across the entire Southern sky) to find the local Universe counterparts to these first forming galaxies. What we will do is take spectral velocity dispersion measurements, which are a measure of the gravitational potential at the centre of galaxies, as a way to make the evolutionary link between galaxy populations from the earliest times back to the here and now.

Galactic Outflows and Galaxy Quenching with the James Webb Space Telescope

Supervisor: Dr Rebecca Davies
Contact: rdavies@swin.edu.au

Project description: The James Webb Space Telescope has found many massive galaxies that formed all of their stars and died early in the Universe's history. Their rapid deaths may have been caused by galactic outflows, which are violent ejections of gas from galaxies triggered by accreting black holes and exploding stars. Outflows have enormous impacts on the galaxies they come from. They remove large amounts of hydrogen gas, depriving galaxies of fuel to form new stars. The student will use new state-of-the-art observations from the James Webb Space Telescope to investigate important open questions about outflows in the early Universe, with a range of possible topics such as: could outflows be responsible for shutting off star-formation in early massive galaxies? Is a black hole always needed to produce powerful outflows? Do radio jets contribute significantly to the total energy budget of outflows?

Searching for Off-peak Emission from Gamma-ray Pulsars

Supervisor: Dr Yuzhe (Robert) Song
Contact: yuzhesong@swin.edu.au

Project description: The recent release of the The Third Fermi Large Area Telescope Catalog of Gamma-ray Pulsars (3PC) has increased the number of detected gamma-ray pulsars to almost 300. This provides a good number of detected gamma-ray pulsars to study various topics related to gamma-ray emission mechanisms of pulsars. A recent study (https://ui.adsabs.harvard.edu/abs/2023MNRAS.524.5854S/abstract) indicates that pulsars might be emitting weak, isotropic gamma-ray emission. As a follow up to this study, this project is aiming to lay the foundation to search for this emission in detected gamma-ray pulsars when their rotational phase is off-peak. In this project, we will aim to perform the following tasks. We would first perform timing analysis of gamma-ray pulsars in 3PC using Tempo2 or PINT with existing timing solutions, and update them if necessary. We will then create an accessible table of on- and off-peak phases of each gamma-ray pulsar. We will then perform likelihood analysis on the off-peak phase of each individual pulsar.

Further reading:

- **3PC paper:** https://arxiv.org/abs/2307.11132 - this is an extremely good paper to understand the current state of observations of gamma-ray pulsars.
- **Fermi-LAT Data Analysis with Fermipy:** https://fermipy.readthedocs.io/en/latest/
- **Introduction to timing of gamma-ray pulsar:** https://ui.adsabs.harvard.edu/abs/2008A%26A...492..923S/abstract

Examining the Circumgalactic Medium Around Galaxies

Supervisor: A/Prof Glenn Kacprzak
Contact: gkacprzak@swin.edu.au

Project description: The circumgalactic medium (CGM) is the gaseous halo surrounding galaxies, playing a crucial role in galaxy evolution by regulating gas accretion and outflows. Despite its importance, the CGM remains poorly understood due to its diffuse nature and low density, making it challenging to detect and study. This project will involve analysing data from the Keck Telescope and other observatories to explore the physical properties of the CGM. You will use spectral line diagnostics to investigate the interactions between galaxies and their surrounding halos, focusing on how gas inflows and outflows impact galaxy growth and star formation. This work will help build a more complete understanding of how galaxies evolve over cosmic time.
You will develop skills in Python programming, data reduction, and visualisation while learning to work with astronomical datasets. The project may also involve comparing observations with theoretical models of the CGM, helping you gain a strong foundation in both observational and theoretical astrophysics.

Further reading:

- Tumlinson et al., 2017, *The Circumgalactic Medium*: https://arxiv.org/abs/1709.09180

Studying the Origins of Fast Radio Bursts through their Structure

Supervisor: Dr Joscha Jahns-Schindler
Contact: jjahnsschindler@swin.edu.au

Project description: Fast Radio Bursts (FRBs) are intense, brief flashes of radio waves originating from distant galaxies. First discovered in 2006, they have generated significant excitement due to their mysterious origin, which remains unresolved. Several emission mechanisms have been proposed, including synchrotron radiation and synchrotron maser emission. However, testing these models is challenging, as the few predictions they make are difficult to verify. A promising approach is to study the temporal evolution of FRB spectra. Many FRBs exhibit a downward drift in frequency during their brief duration, a phenomenon known as the "sad trombone effect". Several models for the sad trombone effect exist that provide a link between emission mechanisms and observations. Yet, none of these models have been directly applied to the available data. In this project, you will compare how well different emission models explain the observed FRB data. Specifically, you will focus on a small set of bright, publicly available FRBs observed with the FAST and Arecibo telescopes. The analysis will involve using MCMC fitting techniques in Python and a Bayesian framework to perform model comparisons.