CAS HONOURS PROJECT LIST 2024

Studying the companions of accreting neutron stars and black holes

Supervisor: Dr Simon Stevenson
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Project description: Neutron stars and black holes can accrete material from their companion stars, powering X-ray binary phases, and potentially spinning up the compact object, causing it to rotate rapidly. If the neutron star is a pulsar, this may be observed as a binary millisecond pulsar. In low-mass X-ray binaries, the companion star has a mass less than, or equal to the mass of the Sun. The orbit of the binary shrinks over time due to a combination of several processes, including mass lost during the mass transfer phase, energy emitted in the form of gravitational waves, and magnetic braking. The companion star can be potentially inflated by irradiation from the pulsar, or from energy deposited into the star through tides. You will perform detailed binary stellar evolution calculations using the one-dimensional stellar evolution code MESA to study the evolution of the companion star in accreting neutron star and black hole systems. You will compare your models to observed populations, including the binary millisecond pulsars (including black widow and redback binaries), accreting millisecond X-ray pulsars and low-mass X-ray binaries.

Further reading:

- Fragos and McClintock 2015, ApJ 800 17 'The origin of black hole spin in galactic low-mass X-ray binaries https://arxiv.org/abs/1408.2661

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. 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 the James Webb Space Telescope to Link Stars and Gas in Distant Galaxies

Supervisor: Dr Rebecca Davies
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Project description: Galaxies in the distant Universe are very different to those neighbouring our own Milky Way. Early galaxies have huge amounts of gas which they very rapidly convert into stars. Large groups of young massive stars glow very brightly, heating and ionizing the surrounding gas. The impact of these young stars on their surroundings depends on the properties of the radiation they produce: 'harder' radiation (with a larger fraction of high energy photons) results in more extreme ionization than 'softer' radiation (with a smaller fraction of high energy photons). Thanks to the James Webb Space Telescope (JWST), it is now possible (for the first time!) to directly measure both the properties of stellar populations and the ionization state of gas in distant galaxies. In this project, the student will use JWST data from the Blue Jay survey to investigate the link between stars and gas in galaxies at 'cosmic noon' (redshifts 2 – 3), approximately 10 billion years in the past. The student will work as part of a small international collabration and will develop skills in Python programming, data visualisation and statistical analysis.

Further reading:

- Steidel et al. 2016 (https://arxiv.org/pdf/1605.07186.pdf)
- Sanders et al. 2023 (https://arxiv.org/pdf/2301.06696.pdf)

Gravitational-wave data analysis with machine learning

Supervisor: Dr Shreejit Jadhav
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Project description: Since the detection of the first gravitational-wave (GW) signal by the twin LIGO detectors on 14th September 2015, the LIGO-Virgo detectors have observed over 90 events so far, firmly establishing the field of observational GW astronomy. Along with providing an excitingly new perspective to astrophysics, the field also poses unique challenges in data analysis and instrumentation. Although sources of all the past observations have been compact binary mergers, GW signals are expected to originate from a variety of other sources that can be observed by current ground-based detectors. Modelling of these sources must be done as accurately as possible for their detection from the noisy data recorded by the detectors. The noise transients in the data also demand careful characterization to avoid false positives. In this project, the student will study the basics of GW data analysis and subsequently develop the essential models for a unique set of GW sources, such as supernova explosions. The student will explore specialised deep learning techniques and / or statistical analysis in GW data analysis.

Detecting gravitational waves from core-collapse supernovae

Supervisor: Dr Jade Powell
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Project description: The first detections of gravitational waves were made during the last few years. The sources of those gravitational waves were binary neutron stars and black holes. Gravitational wave detectors are currently offline to improve their sensitivity for their next observing run. As the detectors become more sensitive, they may begin to detect gravitational waves from other sources. One of those potential sources is a nearby core-collapse supernova. Supernovae are a perfect multi-messenger source as they can be detected electromagnetically and in gravitational waves and neutrinos. A gravitational wave detection may tell us about the mechanism driving the explosion. In this project, you will develop data analysis techniques for the detection and parameter estimation of core-collapse supernovae in data from the LIGO and Virgo gravitational wave detectors.

Searching for Off-peak Emission from Gamma-ray Pulsars

Supervisor: Dr Yuzhe (Robert) Song
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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

Keeping an AI on the Sky

Supervisors: Dr Sara Webb, Prof Christopher Fluke, Prof Jeffery Cooke
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Project description: The sky is a very busy place, with exploding stars, merging galaxies and even hungry blackholes. Using Artificial Intelligence (AI) we've been able to mine large amounts of data looking for these astronomical phenomena, and now we're moving closer to the home using AI to map and track satellites around the Earth. By the year 2030 we expect to have over 60,000 satellites in orbit, over a 700% increase from today. With increased launches and deployment of satellites comes the risk of collisions and debris creation. Already we estimate there are over 100 trillion pieces of debris around the Earth. For astronomers, satellites and debris can severely impact our ability to do science. For the wider public, debris creates a risk of creating an unable low earth orbit in our lifetimes. By using large astronomical optical data sets, from the biggest astronomical cameras in the world, we can tackle two problems at once: 1) develop algorithms to quickly identify likely satellites/debris flashes for use in astronomy, and 2) catalogue the positions and time of satellite/debris detection for the use in space situational awareness. Both of these tasks can be aided by AI, and in this project, we'll investigate how to prepare current data for future AI models.

Investigating the effects of microgravity on the health of lactic acid producing bacteria for the production of yogurt in space

Supervisors: Dr Rebecca Allen, Dr Sara Webb and Dr Huseyin Sumer
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Project description: Microgravity aboard the International Space Station offers an extremely unique and interesting environment to investigate the biological, physical and chemical changes to science we've studied previously on Earth. One interesting result of decades of microgravity experimentation is that some bacterial strains thrive when under effective zero G. Another effect is found withoin astronauts and their gut bacteria health when in space. Our gut is comprised of a complex microbiome with trillions of bacteria working to process our food intake. With decreased health of the bacteria, or reduction in bacteria, the health of the entire body can be at risk. One way to replenish the gut is via eating probiotic foods such as yogurt. In this project you work with real returned space samples of bacterial strains grown in space to form yogurt and investigate how simulating microgravity here on Earth compares to the real deal. You'll work with microgravity wall simulators and earth analogs of the ISS experiment.

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 a new instrument being built on the VLT specifically for such work. These and other options will be discussed with the candidate.

Further reading:

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

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

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

Supervisors: Prof Chris Blake, Dr Ryan Turner
Contact: cblake@swin.edu.au

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 Sloan Digital Sky Survey, 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.

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

Supervisor: A/Prof Ryan Shannon
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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.

Battle of the Bulge: Connecting Galaxy Morphology and the Spatial Distribution of Star Formation

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

Project description: Galaxies in the nearby Universe allow us to study spatially-resolved star formation across large and diverse samples. This Project will use custom reprocessed imaging data from the WISE mid-infrared telescope to study a selected sample of (face-on) nearby galaxies to quantitatively measure the distribution of star formation across a wide range of galaxy morphologies. Using the latest stellar mass maps and star formation calibrations, we will be able to track how the efficiency of star formation varies across galaxies as a function of population type (bulge versus disk).

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 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 new data from the Galaxy And Mass Assembly (GAMA) survey 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.

What are we learning about dust with JWST?

Supervisor: Dr Themiya Nanayakkara, Dr Colin Jacobs, Prof Karl Glazebrook
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Project description: Within the first 1 year of JWST observations, we have obtained a lot of deep imaging and spectroscopic data. From these data we can for the time study emission lines from galaxies in the young Universe, some of which we could not reach from ground. In this project, you will use imaging and spectroscopic data obtained from JWST to study how the dust properties vary throughout cosmic time. By using imaging data from the Near Infra-Red Camera (NIRCam) you can start to make some preliminary estimates on the amount of dust based on how the colour of galaxies vary between different NIRCam filters. Then for a selected sample of these galaxies, you can go deeper by studying the spectroscopic data to explore what emission lines that trace the properties of dust tell about galaxies. Based on various indicators accessible at different times of the Universe, you will build up a picture of how dust properties may evolve with cosmic time in the Universe.

Exploring the realm of transients

Supervisor: Dr Anais Moller
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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. They create chemical elements, stars and galaxies. In this project we will use the data from one of the large transient surveys in the world, Zwicky Transient Facility, detecting up to 1 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. We will study their properties as they evolve over time. In this project you will develop coding, statistics and analysis skills to disentangle unique classes of 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
- Rapidly evolving transients https://ui.adsabs.harvard.edu/abs/2018MNRAS.481..894P/abstract