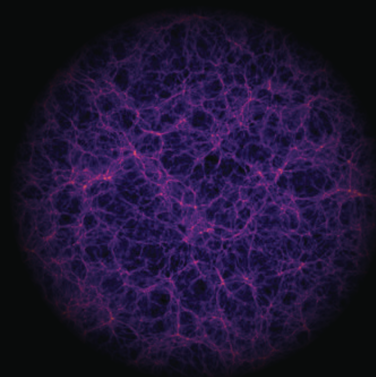
Astronomy PhD & MScR Projects at Durham

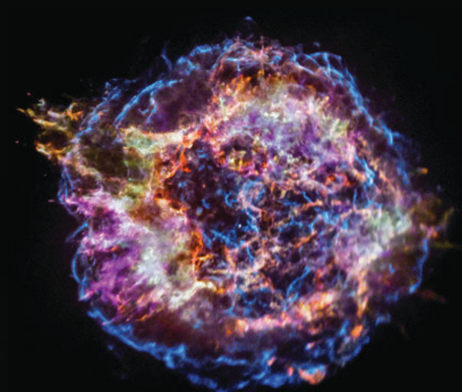
2024

Durham University

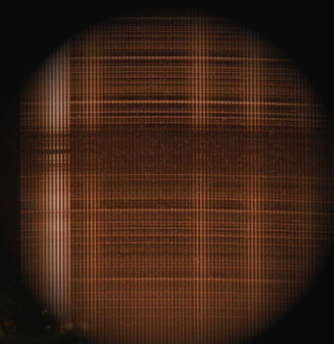
ICC



Durham Centre for Extragalactic Astronomy



CfAI



PHD & MSCR PROJECTS IN ASTRONOMY
FOR AUTUMN 2024 START

Introduction

List of STFC/RS/Durham funded PhD Projects

Bose: Fundamental Cosmology with Large Scale Structure

Cole: Beyond the Galaxy-Halo connection

Cooke: The Cosmological Lithium Problem

Eke: Simulations of Planetary Impacts

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Fragkoudi: Using galactic bar dynamics to probe the nature of dark matter

Jenkins: Using a Digital Twin of the Universe

Massey: Saving Euclid's Map of Dark Matter from Radiation Damage

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Oman: Gas Dynamics & Dark Matter in Dwarf Galaxies

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INTRODUCTION

Durham University is a UK-leading centre for astronomical research with world-class groups working in a wide range of fields covering the observational, theoretical and instrumentation aspects of astronomy. Durham has been ranked ranked Number One in Europe and sixth in the world for our research into Space Science (which covers research into astronomy and astrophysics) over the decade 2002–2012, according to Thomson Reuters. In 2014 we were ranked 5th in the world (1st in Europe) in terms of research impact in space sciences. The Clarivate Analytics Highly Cited Researchers 2018 list puts Durham's astronomers and cosmologists first in the UK, second in Europe and sixth in the world for the quality and influence of their research in space science.

There are 38 academic staff across the combined astronomy groups, with over 100 people involved in astronomy research, which includes postdocs, postgraduate students and support and technical staff. Our main areas of expertise are extragalactic astronomy and cosmology (observational and theoretical), advanced instrumentation, and high-energy astrophysics. Astronomy in Durham is split over three closely connected groups within the Physics Department and which are now all located to a large extent within the newly built Ogden Centre for Fundamental Physics. The three groups consists of the Centre for Advanced Instrumentation (CfAI), the Centre for Extragalactic Astronomy (CEA) and the Institute for Computational Cosmology (ICC).

We are seeking now graduate students to undertake research within our PhD and MSc by Research programmes, starting from October 2023. We particularly encourage applications from members of the community that are under-represented in physics.

Fully Funded PhD Studentship Options

This booklet outlines primarily PhD projects for which we can provide full funding (fees plus a stipend) over 4 years typically, but not exclusively. For those projects with funding associated, we provide brief details on the funding below.

Science and Technology Facilities Council (STFC) studentships. These up to 4-year long PhD studentships are available to any student meeting the qualification criteria thanks to financial backing from Durham University. We note that there are quotas on the number of international students that can be funded. We refer candidates to enjoy the clarity of the information and eligibility rules that applies to STFC studentships. We expect to offer at least 5 STFC-funded studentships this year, based on previous years STFC studentship allocations. According to the rules in place at the time of writing this could imply up to 2 international studentships.

Durham funded PhD studentship. We offer 1 Durham funded PhD studentship this year for a duration of 4 years.

Royal Society funded PhD studentship. This 4-year PhD studentship is open to students qualifying for home fees, i.e. UK students and/or students with settled status. We offer 1 Royal Society studentship this year.

Other PhD Studentship Options

We can offer an even broader range of PhD projects and supervisors for graduate students that have obtained their own funding or are in the process to apply for funding. For details of other potential projects and a full list of potential supervisors, please see the Postgraduate Opportunities link off of our web page. Some specific projects have been included in this booklet.

Two potential funding routes are provided by Durham University through the **Durham Doctoral Studentships (DDS)** and **China Scholarship Council (CSC)** schemes. The application deadline for DDS and CSC scholarships is such that nomination letters by staff based on the applicant's submitted material needs to be in place by typically at the end of December / start of January, for an autumn 2024 start. We note that by the deadline we need to have received reference letters in support of the application, something we request directly from the referees once an application has submitted, as well as relevant language certificates. Therefore we encourage interested graduate students to contact us well in advance of this deadline to ensure maximum success, as well as to explore other potential sources of funding. Hence we recommend DDS/CSC applications to be submitted by **early/mid December 2023** to receive full consideration.

Bell Burnell Graduate Scholarship Fund. The IOP and leading physicist Professor Dame Jocelyn Bell Burnell launched the Bell Burnell Graduate Scholarship Fund (BBGSF) to encourage greater diversity in physics. It is a scholarship fund to support full or part-time graduates who wish to study towards a doctorate in physics and are from groups that are currently under-represented in physics. As host university, Durham can put forward a maximum of two students for the Fund. To be considered, candidates needs to have applied and be nominated by a staff member by the internal physics deadline is early January (exact date TBC, but typically 2-3 weeks ahead of the BBGSF application deadline of January 19$^{\text{th}}$ 2024). Hence we recommend applicants interested to be considered for the *Bell Burnell Graduate Scholarship Fund* to submit their application by **early/mid December 2023** to receive full consideration.

In past years prospective PhD students have been successful in securing funding from various national and international funding bodies with support from academic staff in Durham, including *Van Mildert College Trust*, *Team Durham Graduate Programme*, *CONACYT* and *CONICET* PhD scholarships. For more details, please see the Postgraduate Opportunities link off of our web page.

PhD application process

PhD studentships are awarded on the basis of academic record and research aptitude, which are assessed via an on-line application and an interview (in person in Durham or remotely depending on the situation). We expect to interview shortlisted candidates for funded studentships from February through to mid-March (see our web-pages for up-to-date information regarding possible interview days and effective deadlines to meet).

We recommend you to indicate several projects for which you wish to be considered, or your general area of interest (simulations, observations, etc), to help us identify potential supervisors for the interview days. Your application is not expected to include an original research proposal, but rather to indicate which of the described projects you wish to pursue. In practice, these descriptions provide a starting point for each project; the ongoing direction of your research will adapt naturally over the course of study.

MSc by Research Studentship Options

We can offer an equally broad range of MSc by Research (MScR) projects and supervisors for graduate students that have their own funding. For details of other potential projects and a full list of potential supervisors, please see the Postgraduate Opportunities link off of our web page. Currently there is no guaranteed funding available for MScR projects, but for residents in England the UK government has a scheme to apply for post-graduate loans. For more specific details of the scheme, please consult the UK government webpages https://www.gov.uk/postgraduate-loan.

Arthur Browne Bursary 2024. The Bursary awards are based on academic merit and will be selected on a competitive basis, with one award per year expected. The University has directed that the funds (£6,000 for the academic year 2023/24 – amount for 2024/25 still TBC) are to be used towards fees and/or towards other course or living expenses (including research-based travel). Deadline for applications for the 2024 round will be announced in September 2024, with all eligible MScR students in Physics invited to submit a one page application for the Bursary.

Dowthwaite Scholarship 2024. This scholarship is based on academic merit and will be selected on a competitive basis, with one award per year expected. This scholarship is fully funded (i.e. stipend + home fees). Exact eligibility criteria and timescale still TBC. All eligible candidates will be informed about it in due course.

Follow the post-graduate opportunities link from our web site or contact our astronomy post-graduate administrator (Prof. Peder Norberg; peder.norberg@durham.ac.uk; Ogden Centre West 119) for further details.

FUNDAMENTAL COSMOLOGY WITH LARGE-SCALE STRUCTURE

Main Supervisor: Dr. Sownak Bose sownak.bose@durham.ac.uk
Office: Ogden Centre West 221
Funding: STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)

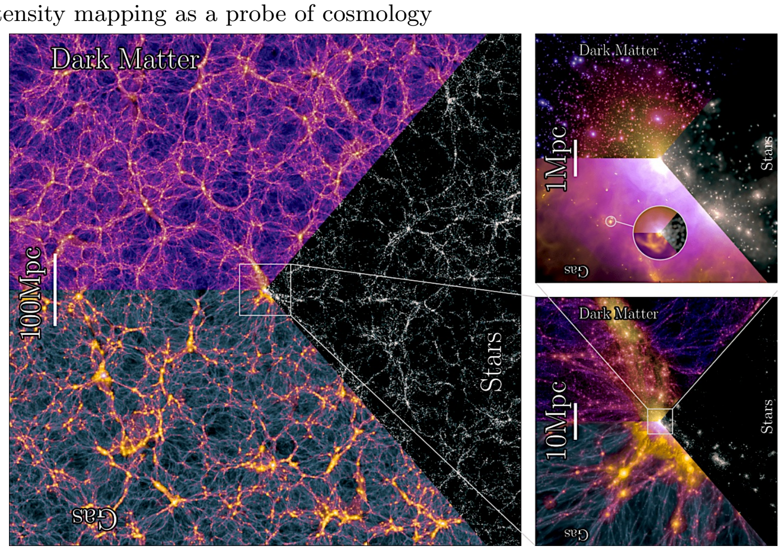
Description:

Cosmology is at the brink of a paradigm-defining decade. Several large-scale surveys of galaxies have been designed for the ultimate goal of answering open questions relating to the makeup and evolution of our cosmos: what is dark matter? Why does the Universe accelerate in its expansion? How do galaxies form? This requires a map of the large-scale structure of the Universe that exceeds far beyond what we have available to us at the moment, both in terms of volume and precision. The astronomy group at Durham is at the forefront of many of these activities, and has key leadership roles in programmes like the Dark Energy Sectroscopic Instrument (DESI) Survey, *Euclid*, the Square Kilometre Array (SKA) etc. To realise the full potential of these surveys, we need equally sophisticated, state-of-the-art cosmological simulations to act as the theoretical counterparts. This latter effort will be the focus of this PhD project. You will have the option of choosing from a number of potential avenues of investigation, including:

- Using state-of-the-art simulations of galaxy formation to understand the mapping between dark and luminous matter on cosmological scales;
- Performing radiation-hydrodynamics simulations to study the onset of the formation of the first stars and galaxies using intensity mapping;
- Development of semi-analytic methods and Machine Learning to create models based on more computationally expensive supercomputer simulations.

You will have the opportunity to work at the cutting edge of one of the most exciting fields of astrophysics and cosmology. This project is predominantly theoretical in nature, but making contact with observations will be a crucial objective. Working with other members of the group, as well as our international collaborators will, therefore, be encouraged. Experience in coding (Python, Julia, C/C++) and interest in programming generally is highly beneficial. You will also receive mentorship in research communication, both in conferences and in scientific publications.

References:
The MillenniumTNG simulations
Mapping dark and luminous matter
Intensity mapping as a probe of cosmology



The large-scale structure of the universe as predicted by the MillenniumTNG simulation. **Left panel***: projections of the dark matter (top), gas (bottom), and stars (right), distributed across more than 700 Mpc on a side. The* **bottom right** *and* **top right** *panels, respectively, show regions zoomed in successively by factors of 10 centred on a massive cluster in the simulation box, displaying the extraordinary dynamic range enabled by these simulations. Figure adapted from Pakmor et al. 2023.*

Notes:

BEYOND THE GALAXY-HALO CONNECTION

Main Supervisor: Prof Shaun Cole shaun.cole@durham.ac.uk
Office: Ogden Centre West 211
2nd Supervisor: Prof Peder Norberg peder.norberg@durham.ac.uk

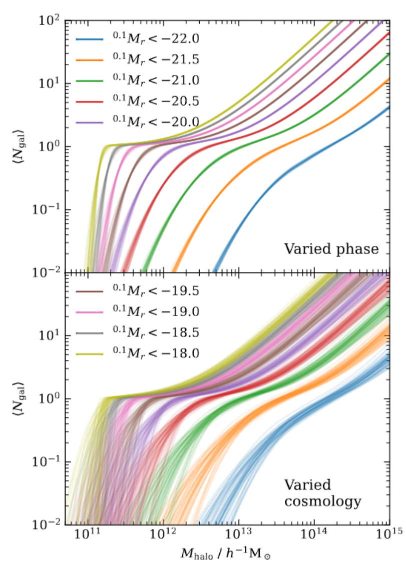
Funding: STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)

Description:

In this project, we will make use of both the latest generation of cosmological simulations of galaxy formation run on the COSMA supercomputers at the ICC and data from the unprecedentedly large DESI galaxy redshift survey. The DESI galaxy redshift survey which will be completed during the course of this project is an order of magnitude larger than previous surveys.

The connection between the dark matter cosmic web of voids, sheets, filaments, and knots produced in cosmological simulations and the large-scale galaxy distribution mapped in large galaxy redshift surveys has been made very successfully through statistical descriptions of the galaxy-halo connection. For instance, the Halo Occupation Distribution (HOD), which quantifies the mean number of galaxies of a given luminosity hosted by a halo of a given mass, has been well-constrained by fitting the clustering (2-point correlation function) of galaxies in the SDSS galaxy redshift survey (Zehavi ey al. 2011) and by early DESI data (see figure).

In this project, we will aim to go beyond this statistical connection between galaxies and dark matter and probe the way in which physical processes modelled in the simulations affect galaxy clustering. Using the Bright Galaxy Survey (BGS), which we have been involved in since its inception, we will be able to determine the galaxy 2-point correlation function with higher accuracy than ever before and also be able to explore more novel clustering statistics. In this way, we envisage being able to determine how galaxy properties not only depend on halo mass, but also on other parameters such as their formation history, internal structure, and local environment. Furthermore, by analysing the simulations, in which we have full knowledge of the formation history of each galaxy, we will seek explanations for the correlations we uncover and hence shed light on what processes are important in shaping the observed galaxy distribution.



Top: Best-fitting HODs of the 25 simulations with the same Planck cosmology, but with different random phases. Each line represents a single HOD fit. The HOD curves are highly consistent with one another for all the samples, with significant differences emerging only at the low mass tails. Bottom: Variation of the best-fit HODs for simulations with different cosmologies. Each line represents a single HOD fit. The HOD variation is larger than the case where cosmology is held constant as in the upper panel.
From Smith et al. (2023).

Notes:

THE COSMOLOGICAL LITHIUM PROBLEM

Main Supervisor:	Dr. Ryan Cooke	ryan.j.cooke@durham.ac.uk
Office:	Ogden Centre West 216	
Funding:	STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)	

Description:

Our current understanding of the Universe — both in terms of its contents and its evolution — is captured by a simple and elegant idea: The Standard Model of particle physics and cosmology. This model has triumphed over many alternatives, and observations to test this model have mostly strengthened this relatively simple description of the Universe. However, as part of this research, we are starting to notice possible cracks in the theory, brought to light by several tensions between the data and the models.

One of the main goals of this PhD project is to search for the nuclei that were made a few minutes after the Big Bang. These nuclei are referred to as the 'primordial' elements, and include hydrogen, helium, and lithium. Quite amazingly, the study of these primordial elements is the only experiment currently devised that simultaneously tests every known fundamental force: gravity, electromagnetism and the strong and weak nuclear forces. We can therefore use these 'primordial elements' to learn about the physics of the Universe just a few minutes after the Big Bang, and test the foundations of cosmology.

Previous work has searched the oldest stars in our Galaxy to measure the ratio of primordial lithium to hydrogen (Li/H). At present, such measures disagree significantly with the Standard Model, giving rise to a puzzle known as the 'Cosmological Lithium Problem'. After more than two decades of research, it still remains unclear if the observations need revision, or if this discrepancy requires new (presently unknown) physics beyond the Standard Model.

To solve this impasse, the PhD student assigned to this project will have the opportunity to:

- Produce a simulation of how Li/H is distributed in the Milky Way galaxy.
- Measure the Li/H ratio of gas clouds using data collected with the World's largest optical telescopes.
- Combine these two research goals and test the cosmological model.

This project will involve a roughly equal mix of theory, observation, and python programming.

Nature article presenting the detection of lithium in gas clouds
Review article on the Cosmological Lithium Problem

An image of a nearby galaxy, known as I Zwicky 18 – one of the most primitive environments known in the local Universe (Credit: HST/NASA/ESA).

Notes:

SIMULATIONS OF PLANETARY IMPACTS

Main Supervisor:	Dr. Vincent Eke	v.r.eke@durham.ac.uk
Office:	Ogden Centre West 215	
2^{nd} Supervisor:	Dr. Azi Fattahi	azadeh.fattahi-savadjani@durham.ac.uk
Funding:	STFC funding and other schemes (Bell Burnell, DDS, CSC, ...)	

Description:

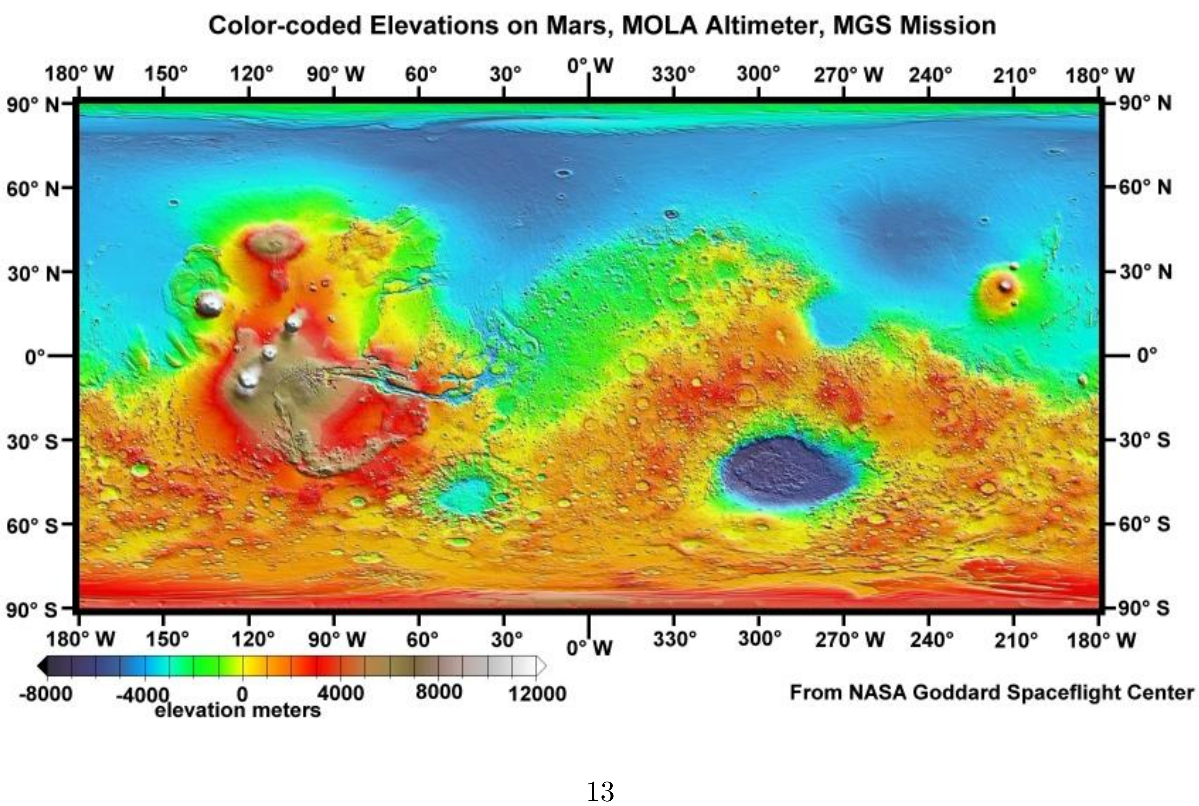
The early Solar System was a violent place where energetic collisions between planetesimals were rife. These impacts represent the most dramatic part of the planet formation process, an understanding of which is required to determine the frequency of exoplanets in habitable zones around other stars.

Observations of the current state of the Solar System provide abundant evidence of past giant impacts; e.g. the relatively large core of Mercury, the similar isotope ratios of the Earth and Moon, and the surprising rotation axis of Uranus. The Martian interior structure and crustal thickness has recently been studied using NASA's InSight mission, and JAXA's upcoming MMX mission will explore the Martian moons. Thus, a timely question is could the Martian dichotomy, whereby the northern hemisphere is typically much lower than the southern hemisphere, be connected with the presence of Phobos and Deimos?

One of the competing hypotheses to explain the Martian dichotomy is a large asteroid hitting the northern hemisphere at a grazing angle, removing some of the crust. An alternative hypothesis involves a south pole strike by a lunar-sized body, causing a hemispherical magma ocean that solidified to form the thicker crust in the south.

The detailed evolution of impacting systems can only be followed using numerical simulations. Durham's astronomy group is involved in running the world's largest numerical simulations in both planetary impacts and extragalactic astrophysics, and the ICC hosts a significant part of the national DiRAC supercomputer facility.

This project, which involves a collaboration with researchers at NASA Ames Research Center, will use the SWIFT state-of-the-art Smoothed Particle Hydrodynamics (SPH) code. While previous Martian impact simulations have used up to a million particles, we will improve the mass resolution by 2 orders of magnitude. With these superior numerical capabilities, we will be able to resolve the Martian crust as well as determining the internal structure of the resulting Mars and the satellite-forming debris disk with unprecedented detail.



Notes:

USING GALACTIC BAR DYNAMICS TO PROBE THE NATURE OF DARK MATTER

Main Supervisor: Dr. Francesca Fragkoudi francesca.fragkoudi@durham.ac.uk
Office: Ogden Centre West 127

Funding: Durham Funding and other funding schemes (DDS, CSC, ...)

Description:

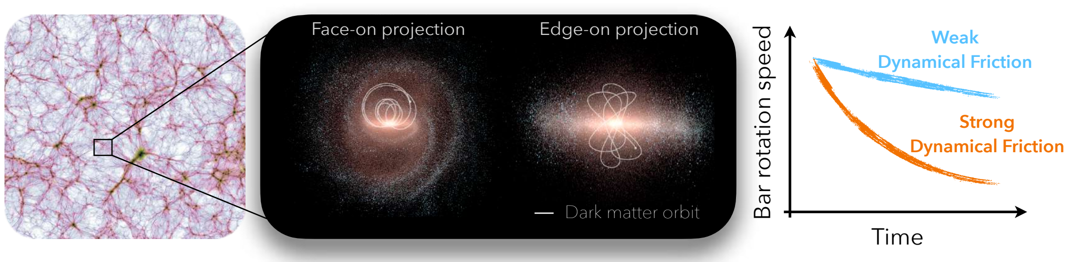
The nature of dark matter – the elusive substance making up 85% of the mass of the Universe and one of the pillars of the standard Lambda Cold Dark Matter (ΛCDM) cosmological model – remains a major unsolved mystery of modern physics. While its fundamental properties are as of yet unknown, its existence and properties can be inferred through its gravitational influence on normal (baryonic) matter. Dark matter interacts gravitationally with stars in spiral galaxies in two intriguing ways: i) it stabilises stellar discs against the formation of elongated, rotating structures, called galactic 'bars' (e.g. Ostriker & Peebles 1973) and, ii) when bars do form, dark matter inflicts a drag force on them, i.e. 'dynamical friction', causing them to slow down (e.g. Tremaine & Weinberg, 1984b). As these processes are mediated via resonant interactions between the bar and dark matter particles, the fraction of galaxies hosting bars, and the bar rotation speed itself, will be highly dependent on the existence and properties of dark matter (see Figure 1).

This PhD project will focus on using state-of-the-art models to shed light on the nature of dark matter via its effects on the stellar and gaseous dynamics of spiral galaxies, such as our own Milky Way. This is particularly timely as we are currently living in a golden era of galactic dynamics, thanks to exquisite data of the Milky Way and nearby galaxies from Gaia and ground-based spectroscopic surveys. We will use various models, such as state-of-the-art cosmological simulations in ΛCDM and alternative dark matter scenarios, as well as gas-dynamical models to answer questions in galactic dynamics such as:

- What are the distinguishing dynamical signatures between spiral arms and bars in the Milky Way from Gaia data?
- What are the signatures of the resonant interaction between dark matter and bars?
- How do these signatures depend on the nature of dark matter?
- How much dark matter is there in spiral galaxies (both low- and high-mass) in the local Universe?

The student involved in this project will have the opportunity to develop and work with cosmological simulations and/or gas-dynamical models, and compare these models to current and upcoming observational data.

Paper on bars in cosmological simulations
Paper on dynamical modelling of barred galaxies



Left and Middle: *Using cosmological simulations we can understand the connection between dark matter and the dynamical properties of barred spiral galaxies, such as the Milky Way.* Right: *Different dark matter scenarios will have distinct effects on the dynamical friction imparted on galactic bars.*

Notes:

DESIGN OPTIMISATION FOR THE MULTI CORE INTEGRAL FIELD UNIT

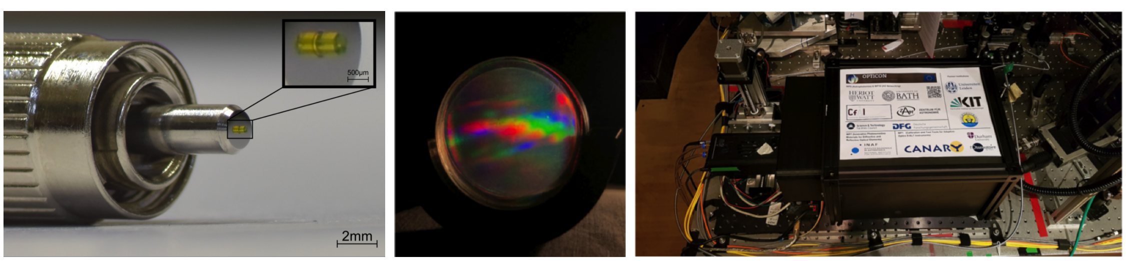
Main Supervisor:	Dr. Robert J. Harris	robert.j.harris@durham.ac.uk
Office:	Ogden Centre West 030	
2nd Supervisor:	Dr. Kieran O'Brien	kieran.s.obrien@durham.ac.uk
Funding:	STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)	

Description:

The Multi Core Integral Field Unit (MCIFU) is a modular pathfinder spectrograph for the Extremely Large Telecope Planetary Camera and Spectrograph (PCS). The science goal of PCS is characterise nearby exoplanets with sizes from sub-Neptune to Earth-size in the neighbourhood of the Sun and will require the most advanced astronomical instrumentation and techniques. PCS will combine eXtreme Adaptive Optics (XAO), coronagraphy and spectroscopy. The MCIFU (or the future variations) will enhance the capabilities of PCS, by provding spectroscopic capability, allowing us to probe deeper and looking for chemical makeup and biosignatures in the exoplanets' atmospheres.

In your PhD, you'll be joining the team developing the MCIFU instrument ready to test it in Chile in 2026. Along with Dr. Robert Harris and team in Durham, you'll interact with with international collaborators in the USA, Germany and Italy. Your tasks will include evaluating the system for future use in PCS and developing the hardware in the laboratory.

You'll also investigate how future technologies being developed by the group in Durham can be integrated into the MCIFU and eventually PCS. This could for instance be MKID detectors, which can resolve energy and hence reduce the need for bulk optics whilst also improving efficiency.



Images of the components of the original MCIFU system. Left) Two-photon Polymerised microlenses in yellow sit on a fiber ferrule. The lenses are roughly 400 um high, slightly larger than a human hair. Middle) A triple stacked volume phase holographic grating allowing high efficiency dispersion. Right) The original spectrograph system, sitting on the CANARY bench at the William Herschel Telescope in 2019. Your PhD will be to investigate how to take a small demonstrator and prepare it for use with the European Extremely Large telescope.

Notes:

USING A DIGITAL TWIN OF THE UNIVERSE TO LEARN ABOUT COSMOLOGY, DARK MATTER AND GALAXY FORMATION.

Main Supervisor:	Prof Adrian Jenkins	a.r.jenkins@durham.ac.uk
Office:	Ogden Centre West 217	
2nd Supervisor:	Prof Andrew Pontzen	
Funding:	STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)	

Description:

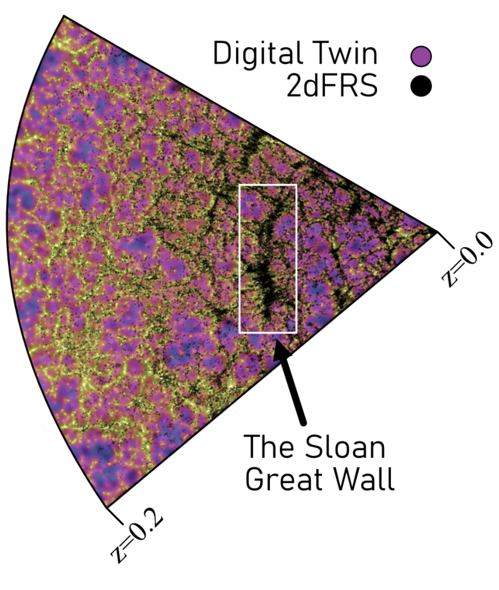
The central theme of this project is the exploitation of novel cosmological simulations that replicate the nearby universe to learn about cosmology, galaxy formation and the nature of dark matter. A 'digital twin' of the nearby universe can be used to answer scientific questions that directly relate to the particular structure we see around us. For example whether the local group lies within a region with an unusually large velocity with respect to the frame of the cosmic microwave background. It is only relatively recently, with the availability of sufficient computing power, that it has become possible to (re)construct the large-scale distribution of galaxies for galaxy redshift surveys such as 2dF (see figure below) and soon the SDSS and DESI surveys.

The reconstruction techniques take galaxy redshift surveys as an input. There are now state-of-the art cosmological galaxy formation simulations that are of similar size to the real surveys. Applying the reconstruction techniques to these simulations will help hone the reconstruction techniques themselves and will provide insights into how well galaxies trace the underlying dark mattter. There is potential to work on improving methods for constructing a digit twin for the region around the local group using distance estimates and other information for nearby galaxies.

The PhD student would join a Virgo Consortium project called 'Sibelius' involving staff, postdocs and students at Durham, Stockholm, Helsinki, Leiden and Paris.

References:

The Sibelius Dark simulation
The introductory paper for the Flamingo cosmological galaxy formation simulations
Outline of BORG Reconstruction technique
A study of nearby clusters and voids making use of the BORG reconstructions technique



A slice showing the present day dark matter density field evolved from the initial conditions inferred by the BORG algorithm. This is a low-resolution demonstration of the Digital Twin. Overplotted, in black, are the observed galaxy positions from the 2dF galaxy redshift survey. Credit: Stuart McAlpine and the Manticore project.

Notes:

SAVING EUCLID'S MAP OF DARK MATTER FROM RADIATION DAMAGE

Main Supervisor:	Prof. Richard Massey	r.j.massey@durham.ac.uk
Office:	Ogden Centre West 115	
Funding:	STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)	

Description:

ESA's Euclid mission launched in July 2023, and is now taking images of the whole sky from the quiet dark of Lagrange Point 2. Only it's not so quiet: above the protection of the Earth's atmosphere, high-energy radiation from the Sun bombards the most sensitive focal plane ever flown in space. An effect of the radiation damage, known as Charge Transfer Inefficiency, blurs all images. The shapes of distant galaxies appear distorted in a way that unfortunately mimics gravitational lensing: the primary effect that Euclid will use to map dark matter.

The goals are this project are to

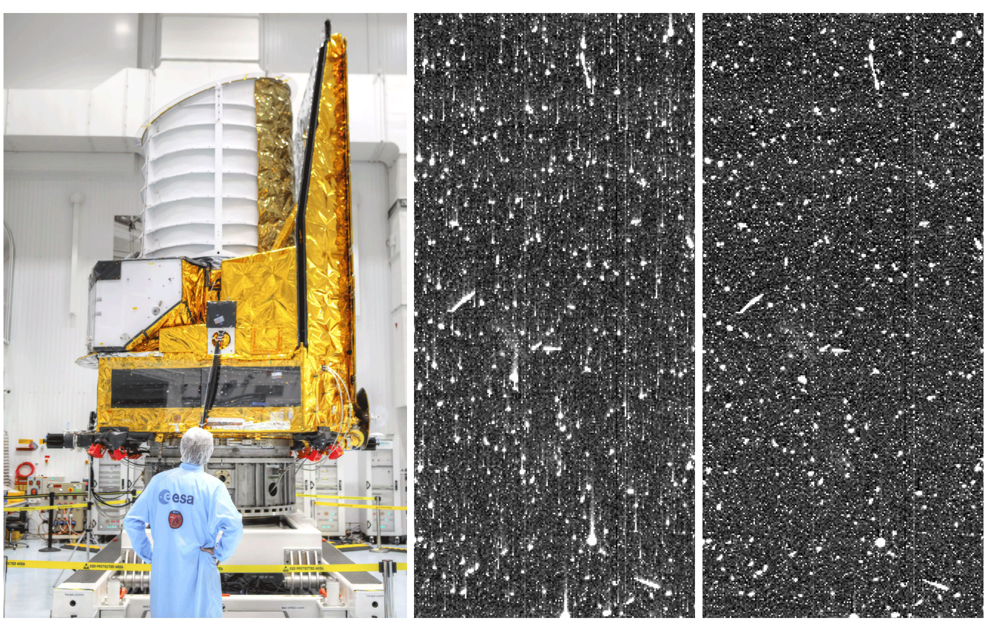
- model the effect of radiation damage on Euclid images, and its consequences for measurements of dark matter. For this task, Euclid will take several calibration images every day for five years. We will learn from them about the radiation environment in the Solar system, and what it does to CCD detectors – both are currently poorly understood. (Previous satellites have been damaged by radiation, but the Hubble Space Telescope was sheltered close to Earth, and Gaia flew during Solar Minimum.)
- correct every other image that Euclid takes. We will be working with the weak gravitational lensing measurement team to optimise the image post-processing, and make the best possible maps of dark matter.

This project will suit someone interested in image processing, distributed computing and very large data sets – as well as the nature of dark matter. It does not involve lab work. Euclid has already begun collecting in-orbit data for this project.

By the end of the PhD, Euclid's accumulated radiation dose is expected to have made Charge Transfer Inefficiency the dominant systematic effect standing between Euclid and dark matter science. So we need your help! And similar detectors are being built into future space telescopes, including NASA's Roman and IrOUv missions, so prospects for future extensions are high.

This project is offered as a PhD project, coinciding with the duration of the ESA Euclid mission.

Description of the software model of damaged CCDs (old but conveniently brief paper)
Additional engineering details about what causes the damage



Left: ESA's Euclid telescope safe and sound for the last time, just before launch this summer. Yes, it is made of gold!

Middle: Raw images from the Hubble Space Telescope are really showing its age. The vertical streaking is artificial, and caused by damage to the sensitive detectors, from high energy radiation in the harsh environment of space.

Right: By modelling radiation damage and its effect on images, it is possible to restore as-new performance during post-processing. Our correction process is currently applied to every image taken by Hubble. This project will try to understand and correct the effect on every image taken by Euclid.

Notes:

A NEW ERA OF ASTRONOMY WITH KINETIC INDUCTANCE DETECTORS

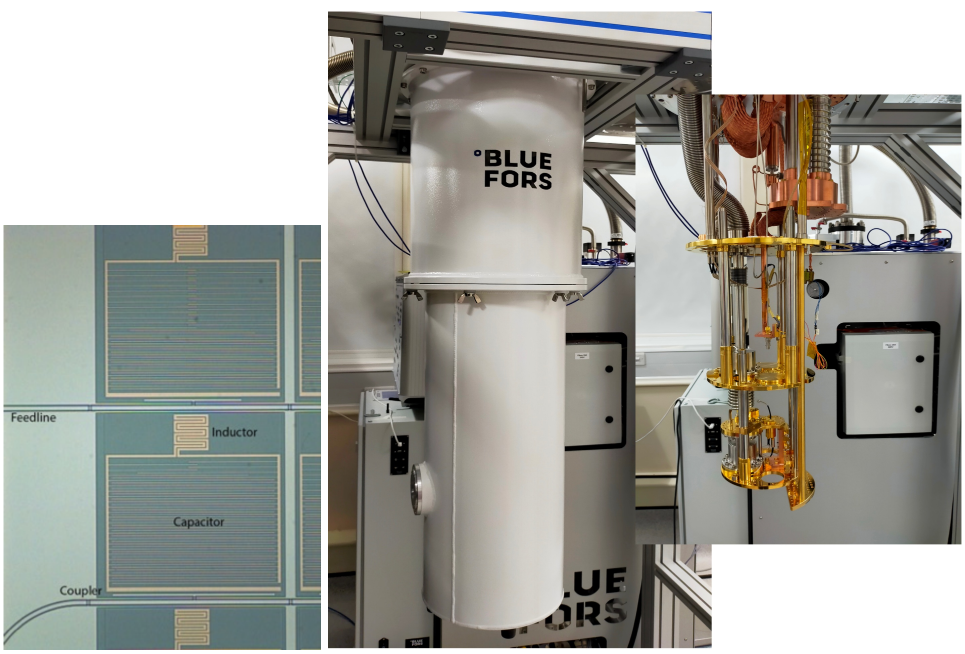
Main Supervisor:	Dr Kieran O'Brien	kieran.s.obrien@durham.ac.uk
Office:	Ogden Centre West 029	
2nd Supervisor:	Dr Robert J. Harris	robert.j.harris@durham.ac.uk
Funding:	STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)	

Description:

Many of the most important discoveries in astronomy over the last decades have been driven by technological advances that have enabled researchers to open up new avenues of research. This includes advances in telescope design, such as with the upcoming Extremely Large Telescope (ELT), modes of operation such as Adaptive Optics and perhaps most importantly, through developments in the detector technologies used, such as moving from photographic plates to electronic imaging. At Durham, we are part of a world-leading collaboration to develop and exploit Kinetic Inductance Detectors (KIDs) for optical and near-infrared astronomy. KIDs could potentially drive the next revolution in astronomy as they enable incredibly sensitive 3D spectroscopy. They are made from super-conducting materials that use the kinetic inductance effect to measure the energy of individual photons (to better than 10%) and their arrival time to better than 1 microsecond. By making arrays of 1000's of such detectors, we are able to open areas of research impossible with other technologies.

This project represents an exciting opportunity to join our team and be involved in a novel instrumentation project from an early stage. We are looking for a highly motivated student to work on instrument development in the Centre for Advanced Instrumentation. No prior knowledge of KIDs is expected and all necessary training will be given. The project would suit students interested in experimental physics from a wide range of backgrounds, including astronomy, low temperature physics, optics, and superconductivity. The exact focus of development could be chosen to match those interests, but potential areas include combining KIDs with photonic elements to explore a range of phenomena. Projects in each area could also include some observational astronomy alongside the instrumentation element.

Web pages: Durham KIDs homepage Homepage of Mazin Lab at UCSB
Introduction to KIDs: Introduction to KIDs by Ben Mazin
Example research paper: KIDspec paper



Far Left: Microscope image ($\sim 0.3 \times 0.5mm$) of pixels in a KID array, from Mazin Lab website. Centre and Right: photo of the KID development lab at Durham University.

Notes:

GAS DYNAMICS & DARK MATTER IN DWARF GALAXIES

Main Supervisor:	Dr Kyle Oman	kyle.a.oman@durham.ac.uk
Office:	Ogden Centre West 223	
Funding:	Royal Society and other funding schemes (Bell Burnell, DDS, CSC, ...)	

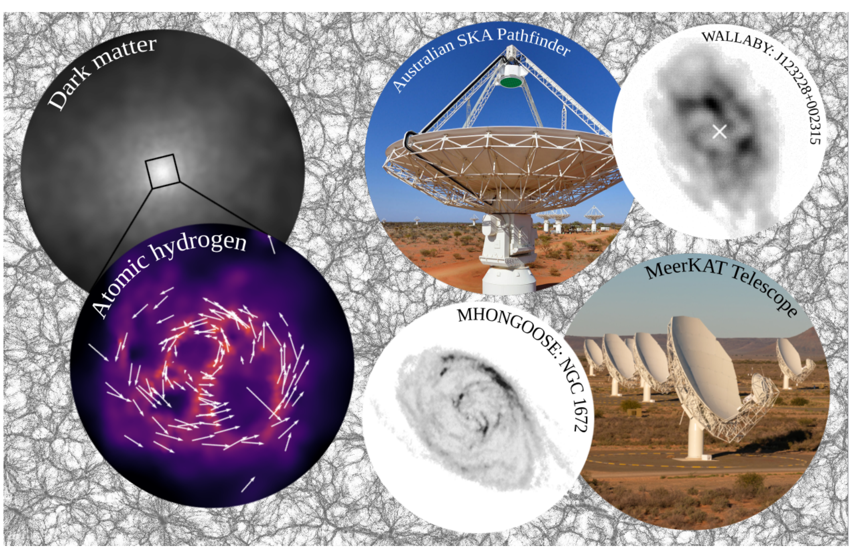
Description:

The lowest-mass, ‘dwarf’ galaxies have large dark-to-total matter ratios, making them excellent objects to study dark matter. In this studentship, you will use a combination of galaxy formation simulations and 21-cm radio observations of atomic hydrogen gas in dwarf galaxies to discriminate between candidates for the particle making up the dark matter.

The orbital speed of a particle in a gravitational field is dictated by the mass distribution within its orbit. Measurements of the orbital speed of stars or gas in galaxies as a function of orbital radius – rotation curves – therefore let us map out the total mass distribution in a galaxy. Subtracting an estimate of the visible mass distribution leaves the dark matter distribution. It is a generic prediction of the standard Λ cold dark matter cosmology that the centres of galaxies should have very high dark matter densities. The rotation curves of many dwarf galaxies, however, are consistent with much lower central densities. This is a long-standing discrepancy that could signal a need for additional dark-sector physics, such as a scattering interaction between dark matter particles, but could also be a symptom of limitations in our astrophysical theories of galaxy formation or our ability to model observational data to produce rotation curves.

Our group has recently obtained computing time for a large suite of simulations using the brand-new Colibre galaxy formation model that is ideally suited to make predictions for the gas dynamics in dwarf galaxies. We are also members of a new generation of 21-cm radio surveys at pathfinder observatories for the forthcoming Square Kilometer Array Observatory. This is a powerful combination that will allow you to make detailed theoretical predictions and test them against new datasets during your studentship. You may choose to focus on theory by learning to run and analyse your own simulations, or you could focus on modelling observations and developing new statistical methods. In either case, the question ‘how can we reliably identify those dwarf galaxies that tell us the most about dark matter?’ will help guide your project.

Link to further reading. | This studentship includes independent allowances for travel, equipment and skills development.



Left: A dark matter halo from the new Colibre galaxy formation simulations, with a zoom-in on the atomic gas of a dwarf galaxy embedded within it showing ordered rotation perturbed by bubbles inflated by supernova explosions. Upper right: The WALLABY survey at the Australian SKA Pathfinder is observing the atomic gas in half a million galaxies. Lower right: The MHONGOOSE survey combines very high sensitivity, spatial and spectral resolution in a survey atomic gas in 30 nearby galaxies.

Notes:

EXTREME APPETITES AND VIOLENT OUTBURSTS: THE PHENOMENOLOGY OF COMPACT OBJECTS IN NEARBY GALAXIES

Main Supervisor: Prof Tim Roberts t.p.roberts@durham.ac.uk
Office: Ogden Centre West 123

Funding: STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)

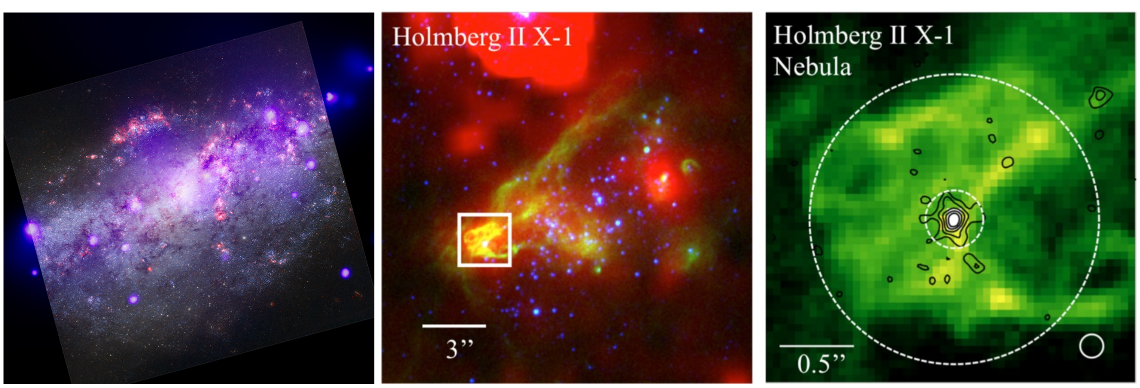
Description:

The sky is a spectacular sight when viewed in X-rays; it glows bright from the X-ray emission of super-heated gas close to the event horizons of many billions of black holes, reaching far back into cosmic history. Imprinted on that background our own Galaxy shines bright, lit up by its own populations of feeding black holes, neutron stars and white dwarfs, and the hot debris of stellar explosions. Over the last two decades we have been treated to an unprecedented view of these exotic phenomena from dedicated X-ray astronomy missions such as NASA's *Chandra* and ESA's *XMM-Newton* observatories, and smaller satellites such as *Swift*, *NuSTAR* and *eROSITA*. Together they continue to build up a wealth of data on the hot and violent regions of the Universe that shine bright in X-rays.

The PhD projects I am offering will make use of the unparalleled data now available to conduct studies of X-ray phenomena in the nearby Universe, focussing on the black holes and neutron stars in relatively nearby galaxies that we suspect to be the most rapacious accretors of material from companion stars, the *ultraluminous X-ray sources*, or ULXs. The projects will use both new and archival data, looking at X-rays and at complementary multi-wavelength data from across the whole electromagnetic spectrum, and will include the opportunity to exploit new ULX catalogues including one currently being constructed from the *eROSITA* all-sky survey. We will use these to address the most pressing issues in understanding ULXs and their effect on the wider universe. These could include, but are not limited to:

- Can we determine whether individual ULXs contain a neutron star or a black hole?
- What fraction of the ULX population overall is composed of neutron stars, and does this vary by environment?
- What are the physical mechanisms that permit neutron stars and black holes to reach the extreme accretion rates inferred for ULXs?
- What effect do ULXs have on their immediate environments (via radiative and/or mechanical feedback), and what are the implications of this method of feedback for the evolution of small galaxies throughout cosmic history?

Review paper on ULXs
Recent ULX catalogue drawn from three separate mission archives



Left: *Composite Hubble Space Telescope optical colour (red, green & blue) and Chandra X-ray (purple) image of the centre of the galaxy NGC 4490. Several of the brightest point X-ray sources in this galaxy are ULXs. Credit: NASA/CXC/SAO/STScI.* Centre and right: *Optical and IR images of the nebula powered by a ULX in the dwarf galaxy Holmberg II, seen in ionised hydrogen gas (green) in both panels (with the right panel a zoom of the centre). It also shows mid-IR emission in red (central panel) and near-IR contours (right panel), as well as starlight (blue, central panel). From Lau et al. (2019).*

Notes:

GRAVITATIONAL LENSING WITH HARMONI AT THE ELT

Main Supervisor: Dr Russell Smith russell.smith@durham.ac.uk

Office: Ogden Centre West 110

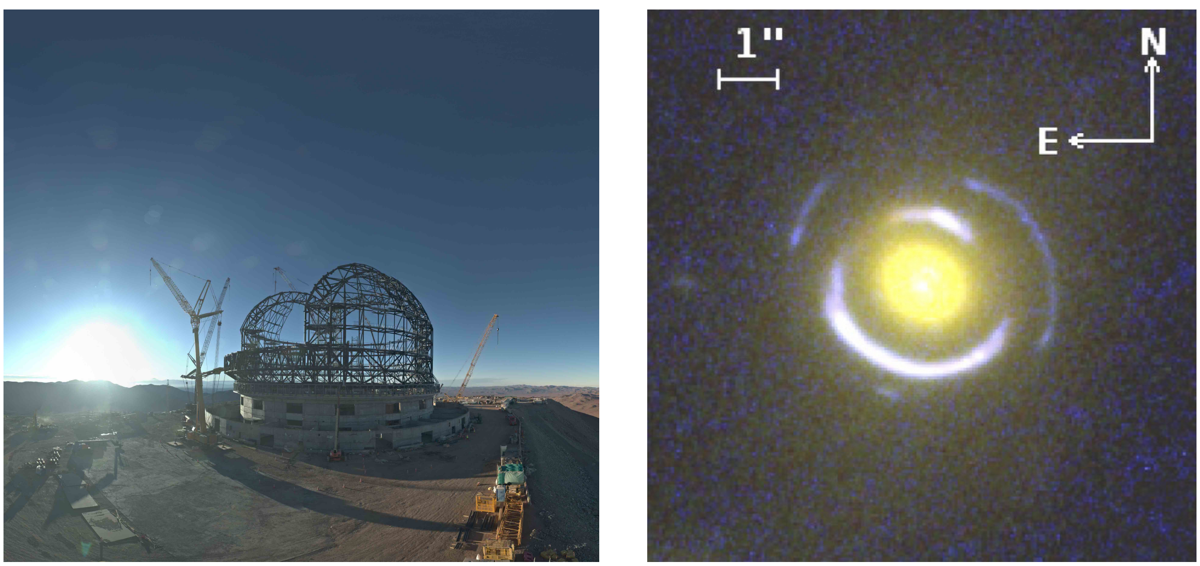
Funding: STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)

Description:

Strong gravitational lensing – the distortion and splitting of a background source image by the presence of a massive galaxy along the line of sight – has become an invaluable tool for probing the distribution of dark and luminous mass in and between galaxies, as well as testing for deviations from general relativity, and measuring the cosmological components of the Universe.

In this project, you will develop and analyse synthetic observations of lens systems as they will appear with the HARMONI Integral Field Unit (IFU) spectrograph on the 39m ESO Extremely Large Telescope (first light planned 2028). The goal is to evaluate and optimise strategies for observational campaigns centred on dark-matter substructure detection (e.g. Nightingale et al. 2022) and discovery of cosmologically-sensitive multi-plane lens systems (e.g. Collett & Smith 2020). You will use observations of local galaxies, and software for calculating the distorting effects of gravity, as well as the HARMONI instrument simulator, to generate realistic simulated datasets, for different observational configurations. Then armed with knowledge of the "truth" from which the simulations were constructed, you can determine what scientific questions can be tackled with observations from the real telescope, combined with state-of-the-art lens modelling software developed in Durham (PyAutoLens; Nightingale et al. (2021))

This project is an opportunity to help shape the first scientific exploitation of the new generation of giant telescopes, and to gain technical understanding of one of the leading astronomical facilities of the next decade. Durham is a full partner in the HARMONI instrument consortium, and is home to a wealth of local instrument expertise. There will also be opportunity for collaboration and visits with colleagues with similar interests in the HARMONI team at the University of Oxford.



Left: Construction of the 39m ESO ELT at Cerro Armazones, Chile, as of September 2023; (image: ESO). It may look different right now) Right: a double-source-plane strong lens, with two partial Einstein rings (blue) formed by background galaxies at different redshifts behind the lensing galaxy (yellow). With HARMONI at the ELT we will routinely discover more such systems, whose configurations can be used to probe the nature of dark energy.

Notes:

EXPLOITING NEW TECHNOLOGY TO ENHANCE GROUND-BASED ASTRONOMY

Main Supervisor: Dr Richard Wilson r.w.wilson@durham.ac.uk
Office: Rochester 325
2nd Supervisor: Dr James Osborn james.osborn@durham.ac.uk
Funding: STFC and other funding schemes (Bell Burnell, DDS, CSC, ...)

Description:

The aim of this studentship is to develop concepts and technologies to advance the capabilities of modern astronomical observatories by correcting for the detrimental effects of the Earth's atmosphere.

The student will engage with the development, deployment and exploitation of site-testing instrumentation at observatory sites, to improve our understanding of the effects of the Earth's atmosphere on astronomical observations. They will look to apply these results to improve the performance of adaptive optical and scintillation correction systems, or to the forecasting of optical turbulence conditions at observatory sites.

This work will be directly applicable to the next generation of giant telescopes, such as the 40 metre European Extremely Large Telescope in Chile - it will help them to reach their science goals including discovering extra-solar planets, understanding the formation of galaxies, and elucidating the nature of dark matter and dark energy.

The student will join the dynamic environment of the Centre for Advanced Instrumentation (CfAI), within the Physics Department at Durham University. The CfAI is a world leading research centre with a large and successful Astronomical Instrumentation group, including Adaptive Optics and Space Science technologies. The Adaptive Optics group has substantial experience in analysing atmospheric turbulence and the use of computer modelling of complex optical systems to design optical instrumentation to some of the world's premier astronomical observatories. The CfAI has also been at the cutting edge of space research for many years, producing key optical components for instruments on the James Webb Space Telescope and Earth observation satellites SENTINEL 4 and METimage.

The CfAI 0.5 metre turbulence monitoring telescope at Cerro Paranal, Chile. Home of the ESO Very Large Telescope (VLT) and nearby 40 metre European Extremely Large Telescope (ELT). Photo: tim Butterley.

Notes:

WHY ARE (SOME) QUASARS SPECIAL? TOWARDS AN UNDERSTANDING OF THE EVOLUTION OF QUASARS

Supervisor: Prof. David Alexander d.m.alexander@durham.ac.uk
Office: Ogden Centre West 119

Funding: DDS, CSC and other non-STFC funding schemes (Bell Burnell, ...)

Description:

Quasars are the most luminous subset of the overall population of Active Galactic Nuclei (AGN) and can be seen out to the edge of the observable Universe. They are powered by mass accretion onto a super-massive black hole, the same basic power source for all AGN, and are thought to have had a profound impact on the overall formation and evolution of galaxies. However, despite being discovered over half a century ago, we still have limited knowledge on how different subsets of the quasar population are related to each other; e.g., the connection between obscured and unobscured quasars.

The relationship between less powerful obscured and unobscured AGN appears to be due to the orientation of an optically and geometrically thick structure (often referred to as the "dusty torus") towards our line of sight. An AGN is observed to be obscured when the "torus" intercepts the line of sight while the AGN is unobscured when the "torus" is orientated away from the observer. This model is known as the "unified model of AGN" (see Netzer 2015 for a recent review). However, although referred to as a "unified model", we have recently found that this model does not apply to all quasars.

We have found that red quasars, a subset of the quasar population obscured by dust and gas, have fundamentally different radio and X-ray properties to normal quasars (Klindt et al. 2019; Fawcett et al. 2020, 2022, 2023; Rosario et al. 2020, 2021; Andonie et al. 2022). This evidence points towards red quasars being a phase (probably early in the life of a quasar) in the evolution of quasars rather than being normal quasars aligned away from our line of sight. However, although our results are clear and conclusive, we lack details about this phase such as the duration, whether it is episodic, and the trigger mechanism. The leading model for the evolution quasars is shown in the figure below.

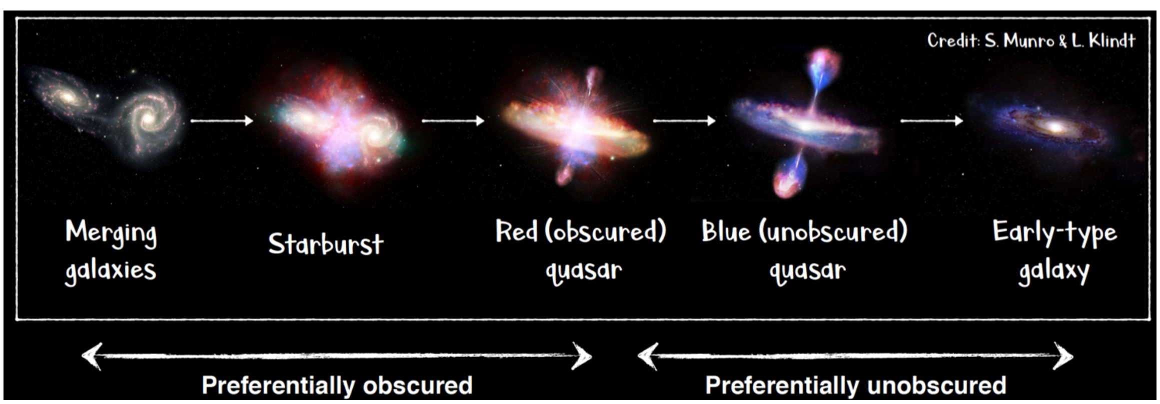


Figure: The leading evolutionary model for quasars. The sequence is triggered by huge amounts of gas inflow (potentially from a merger of two galaxies) which leads to a burst of dust-obscured star formation and a heavily buried (i.e., obscured) quasar. As the quasar ages it drives out energetic winds which blows away the obscuring dust, revealing a red quasar and then ultimately revealing an unobscured quasar (see Alexander & Hickox 2012 and Hickox & Alexander 2018 for reviews). Eventually the huge amount of energy formation and forms a "red and dead" early type galaxy. Schematic produced by S. Munro and L. Klindt.

I am looking for a student to extend our understanding of the evolution of quasars. This research will exploit our access to the Dark Energy Spectroscopic Instrument (DESI) survey (DESI collaboration et al. 2023; Alexander et al. 2023) and our soon-to-start AGN survey with the 4MOST instrument (Merloni et al. 2019). Each of these surveys will detect over 1 million quasars and AGN, pushing deeper than current surveys and extending to more extreme systems. You will undertake systematic analyses using a variety of multi-wavelength datasets to quantify the differences between normal, red, and fully obscured quasars. For example, utilising the previous Sloan Digital Sky Survey (SDSS) you will investigate how often quasars change from normal to red (and vice versa) over a decade-long timescale, providing key insight on whether the red-quasar phase is episodic and providing the first constraints on the duration of the red-quasar phase. You will also analyse deep multi-wavelength observations to measure the physical properties of fully obscured quasars to see how they are related to red and normal quasars.

Notes:

INTERPRETABLE EMULATION: MODELLING OUTSIDE THE BOX

Main Supervisor:	Prof. Carlton Baugh	c.m.baugh@durham.ac.uk
Office:	Ogden Centre West 122	
2^{nd} Supervisor:	Stefan Egan	Senior Engineer, Procter & Gamble
Funding:	STFC CASE (pending)	

Description:

Scientific models and experiments can be expensive to run. Often a large number of parameters need to be set to define a model, due to the complexity of the system being described and because we do not have a complete understanding of the processes involved and their interaction.

With many parameters to explore, using either a supercomputer simulation or running an experiment on a test facility, both of which are expensive, we need to find ways to explore the model parameter space thoroughly and quickly to find the best model.

This project looks at two approaches to find the best scientific models, called model optimization. The first is to devise a cheap mimic or surrogate calculation that replaces the expensive full simulation or experiment with a quick to evaluate model, using artificial intelligence techniques. The second is to look at a special form of the first step called symbolic regression. Artificial intelligence often acts as a black box to learn the connection between the values of input parameters and the target output, given enough examples. Typically, we have a system like a artificial neural network which produces an unseen, complex system of weights to make the transformation from input to output. Symbolic regression instead produces an equation. This gives us some insight into the process. Crucially, the equation, can, in principle be applied outside the range of the parameter space used to determine its form. This is called extrapolation.

The aim of this CASE studentship is to devise fast and accurate ways to mimic expensive scientific calculations or test experiments, and to test symbolic versions of these outside the original parameter space of the process.

This project will be useful for anyone who develops complex scientific models which are computationally expensive, or who has an experiment that can only be run for a small number of variations of control conditions. This wide applicability of the project outputs is evident from the very different natures of the two test test cases we have selected: galaxy formation and the drying of washing powder. Individually these processes involve very different challenges and require experts trained in completely different fields to approach them. Nevertheless, the underlying problems – a complex process which is explained by a model which requires many parameters to be set and for which simple equations do not currently exist – are in common.

An STFC CASE studentship has been applied for to use for this project. The CASE studentship is 3.5 years. The student will spend up to 18 months working at the Procter & Gamble Innovation Centre in Newcastle. Stefan Egan, Senior Engineer in Product Research & Development will co-supervise the project.

Relevant paper

Notes:

ACCURATE MAPPING OF DARK MATTER DISTRIBUTION IN GALAXY CLUSTERS

Main Supervisor:	Professor Mathilde Jauzac	mathilde.jauzac@durham.ac.uk
Office:	Ogden Centre West 126	
2nd Supervisor:	Dr Anna Niemiec	anna.niemiec@durham.ac.uk
Funding PhD:	DDS, CSC and other non-STFC funding schemes (Bell Burnell, ...)	
Funding MScR:	None defined.	

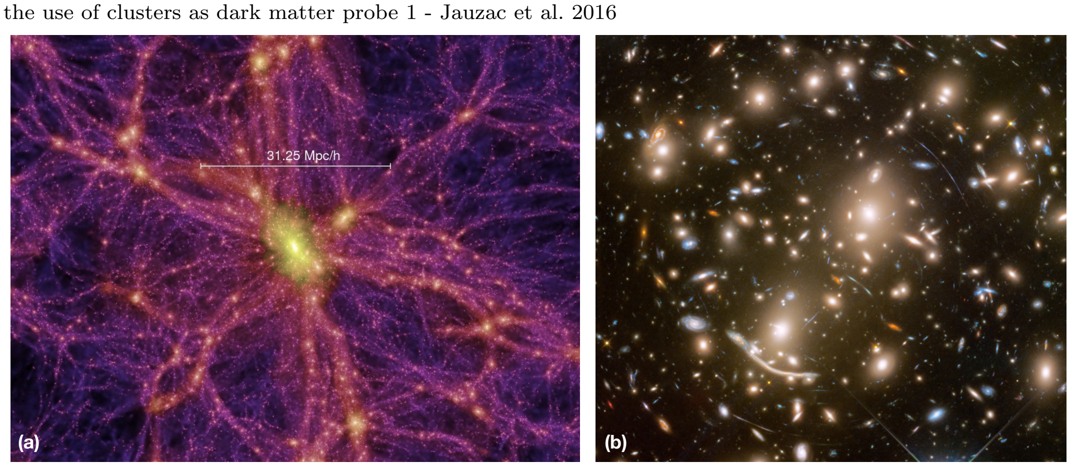
Description:

While easy to detect thanks to their different observational tracers (galaxies, X-ray gas), galaxy clusters are an important probe of the formation history of the Universe. Indeed, as the most massive gravitationally bound objects, they represent the latest stage to date of the hierarchical structure formation, and reside at the nodes of the cosmic web that fuels their growth. Adding to that, clusters are excellent laboratories for probing the physical mechanisms underlying the evolution of the Universe, and they are in particular a privileged location to study the nature of dark matter.

However, in order to use clusters as probes of these different processes, it is first essential to detect the different (sub)structures they are made of, and measure the distribution of matter within them. For the baryonic component of clusters (i.e gas and stars), this is done by combining multi-wavelength observations, from optical imaging tracing galaxy populations, to the hot gas emitting in the X-rays or interacting with the Cosmic Microwave Background (CMB) through the Sunyaev-Zeldovich (SZ) effect. The dark matter component is more elusive, and can for now only be detected indirectly. One way to do so, and a particularly powerful one, is gravitational lensing, that allows to probe a gravitational potential from the bending of passing light rays.

Our team is at the forefront of the study of galaxy clusters using gravitational lensing techniques (Jauzac et al. 2016, 2018). We have developed a new method to model galaxy clusters at all scales, using both strong and weak gravitational lensing constraints, and applied this new technique on very simple simulated clusters (Niemiec et al. 2020). We recently performed a first attempt at using it on real observational data (Niemiec et al. 2023) using very high quality observational data from the *Hubble Space Telescope* (*HST*) BUFFALO programme (Steinhardt et al. 2020). However, it is now important to perform detailed analyses on the different possible systematic errors that could affect these measurements. The goal of the proposed project is to use mock clusters to precisely calibrate our modeling methods. Through this project, the student will have the opportunity to deepen their understanding of the physics of gravitational lensing and galaxy clusters, as well as develop their coding skills. While initially designed for a MSc project, the analysis proposed can easily be broadened for a PhD.

Paper on the analysis of Abell 370 cluster - Niemiec et al. 2023
Paper on the new modeling method - Niemiec et al. 2020
Paper on the HST BUFFALO programme - Steinhardt et al. 2020
Paper on the use of clusters as dark matter probe 2 - Jauzac et al. 2018
Paper on the use of clusters as dark matter probe 1 - Jauzac et al. 2016



(a) *Giant galaxy cluster located at a node of the cosmic web, taken from the Millenium numerical simulation.* ***(b)*** *HST image of the cluster Abell 370. Strong gravitational lensing is visible in the form of giant elongated arcs.*

Notes:

THE INTERSTELLAR MEDIUM IN 3D

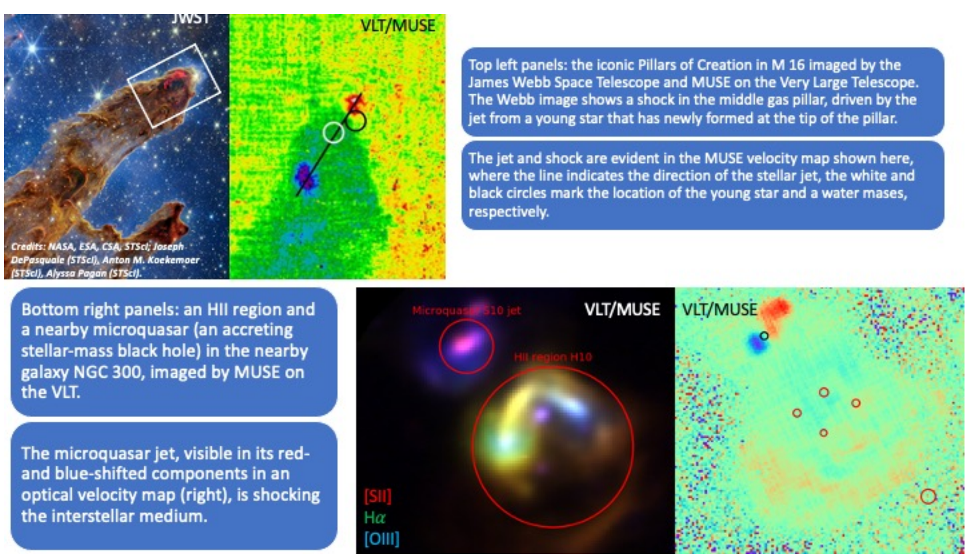
Main Supervisor:	Dr. Anna McLeod	anna.mcleod@durham.ac.uk
Office:	Ogden Centre West 120	
Funding:	DDS, CSC and other non-STFC funding schemes (Bell Burnell, ...)	

Description:

Shocks are a ubiquitous phenomenon observed in the Universe, occurring whenever gas is overrun and compressed by supersonic motions, such as supernovae shells, jets from accreting objects propagating through the interstellar medium (ISM), or collisions between molecular clouds, to name a few. Tracing shocks yields a crucial indicator of the structure and composition of the interstellar medium, needed to interpret observations and used as inputs for state-of-the-art simulations. In the optical wavelength regime, shocks are observed as low-energy level emission lines of the ionised gas, and pairs of emission line ratios have been used for decades (e.g. with so-called BPT diagrams) to distinguish between regions dominated by star formation and regions dominated by shocks or powerful active galactic nuclei (AGN). However, these kinds of diagnostics cannot distinguish between emission arising from shocks and emission arising from other non-stellar (e.g. AGN) activity. Moreover, the interpretation of BPT diagrams becomes highly non-trivial when applied to spatially-resolved observations, and optical observations alone do not capture the multi-phase nature of the ISM.

This project aims at using integral field spectroscopy data taken with the Very Large Telescope of a variety of different, spatially-resolved, astrophysical objects to develop a novel method to identify shocks. This method is new and unique, as it combines sets of emission line ratios together with emission line widths as a third dimension to trace shocks and distinguish them from photo-ionisation excitation, perfectly exploiting the spectro-photometric capability of spatially-resolved integral field data. The observations will then be compared to outputs from a series of shock and photo-ionisation models, therefore providing a valuable tool to interpret the observations as well as test different models. The developed methodology will then be deployed to novel multi-wavelength observations of the ISM, tracing shocks and photo-ionisation from the optical to the infrared in the Milky Way out to nearby galaxies using world-class facilities such as the Very Large Telescope, Keck, and James Webb. In this project you will learn to work at the forefront of both observations and modeling, you will write observing proposals to gather new data, and collaborate with an international team of experts in the field.

More about this topic:
Interstellar Shock Waves
A new diagnostic to separate line emission from star formation, shocks, and AGNs simultaneously in IFU data
Classification parameters for the emission-line spectra of extragalactic objects
Stellar Feedback and Resolved Stellar IFU Spectroscopy in the Nearby Spiral Galaxy NGC 300
SIGNALS: the Star formation, Ionized Gas, and Nebular Abundances Legacy Survey



Notes:

ACCURATE SEPARATION OF STAR FORMATION AND AGN ACTIVITY TO UNDERSTAND AGN FEEDBACK

Main Supervisor: Dr. Leah Morabito leah.k.morabito@durham.ac.uk
Office: Ogden Centre West 121

Funding: DDS, CSC and other non-STFC funding schemes (Bell Burnell, ...)

Description:

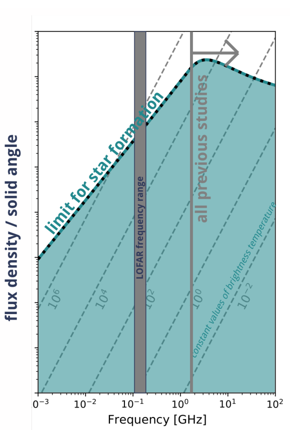
Observational evidence and cosmological simulations both agree that super-massive black holes co-evolve with their host galaxies, but we do not understand the details of this process. It is widely thought that most, if not all, super-massive black holes go through an active phase which can help regulate both their growth and also impact their host galaxy. When in this active phase, super-massive black holes are feeding on their host galaxy, which can provide the fuel to produce powerful outflows such as winds or jets, with observational signatures from X-rays to the radio. When we see these observational signatures, we call this an Active Galactic Nucleus (AGN).

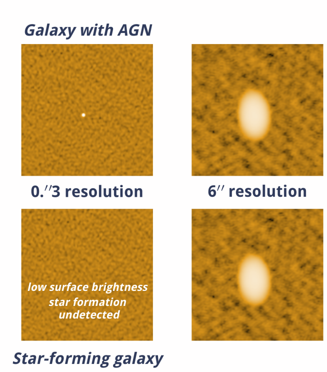
To understand how AGN can impact their host galaxies, we need to track both AGN activity and host galaxy growth. Galaxy growth is traced through star formation. An ideal way to track star formation is via radio observations, since radio waves penetrate dust and provide an orientation-free measurement of the star formation rate. However, AGN activity can also produce radio emission from jets, outflows, or coronal processes. The only way to distinguish between radio emission from AGN activity and radio emission from star formation is through high resolution radio observations. Recent advancements from the LOw Frequency ARray (LOFAR) show that it is possible to do this over a wide field of view (Morabito et al., 2022), but the separation of AGN activity and star formation is quite simple.

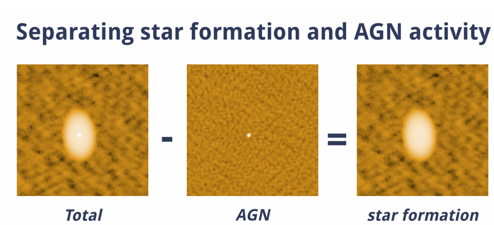
You will build a forward-modelling solution to the problem of separating star formation and AGN activity, by starting from first principles to create a model galaxy, using distributions of properties like size and star formation rate, that can be 'observed' with the addition of different levels of AGN luminosities. By comparing a suite of models with observed data, you will be able to place meaningful constraints on the radio emission from star formation and AGN activity. There are several exciting new datasets to work on, including high-resolution images of the Lockman Hole using LOFAR (Sweijen et al. 2022, and shortly the Boötes and ELAIS-N1 fields. The project will involve both creating simulations of mock galaxies, and working with observational data.

You will learn transferable skills such as dealing with large data sets, computing in a cluster environment, and how to translate physical laws into programming language.

More reading:
Paper 1: https://ui.adsabs.harvard.edu/abs/2022MNRAS.515.5758M/abstract
Paper 2: https://ui.adsabs.harvard.edu/abs/2013A%26A...556A...2V/abstract
Paper 3: https://ui.adsabs.harvard.edu/abs/2022NatAs...6..350S/abstract
Meet the team: https://lmorabit.github.io







Left: *High resolution radio observations picks out compact emission from AGN activity, while diffuse, low-surface brightness emission from star formation is not detected.* ***Above:*** *Using a combination of high and low resolution images, and some simple assumptions, we can estimate the emission from star formation by subtracting the AGN emission, providing simultaneous measurement of emission from both processes.*

A demonstration of the technique used in Morabito et al. (2022b) for identification of AGN and separation of radio emission from AGN and star formation.

Notes:

PROBING THE NATURE OF DARK MATTER USING FAINT (DWARF) GALAXIES

Main Supervisor: Dr Azadeh Fattahi azadeh.fattahi-savadjani@durham.ac.uk
Office: Ogden Centre West 222
Funding MScR: None defined.

Description:

According to our standard model of cosmology, 80& of the matter in the Universe is in the form of mysterious "dark matter", whose nature is one of the fundamental unknowns in model physics. Faint (dwarf) galaxies have proven to be excellent probes of the nature of dark matter since their mass is completely dominated by dark matter. Moreover, their properties have raised a number of challenges for our understanding of galaxy formation in the standard model of cosmology.

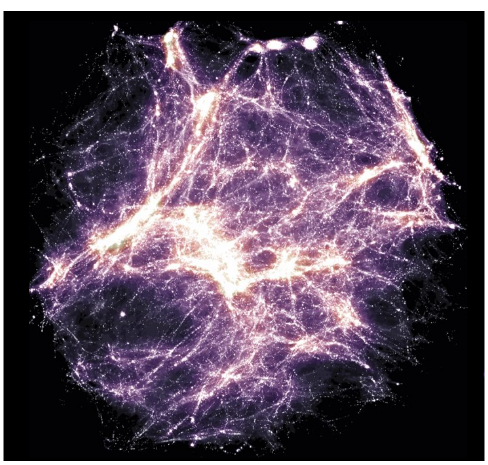
Our group has access to or have developed some of the most detailed cosmological galaxy formation simulations, which are necessary to address the challenges faced by the standard model of dark matter in explaining the properties of dwarf galaxies. The project(s) will involve analysing these world-leading simulations to study the formation and evolution of dwarf galaxies in their dark matter halos. You can choose to work on either of the following projects:

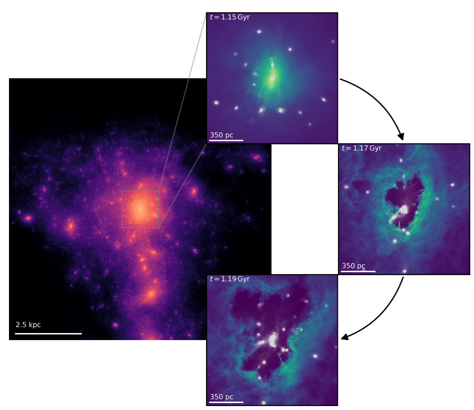
- Quantifying the dark matter content of dwarf galaxies in the Columba galaxy formation simulations. These simulation suite consists of a number of different volumes which includes dwarf galaxies in various environments. (see left-hand image below). These simulations are the state-of-the-art and currently running on super computers in Durham. The simulations with a resolution of around $10^4 M_\odot$ will yield a large number of dwarf galaxies, and ideal to look into population of dwarfs.

- Quantifying the effect of small dark matter halos merging with dwarf galaxies and forming "stellar halos" around them in the LYRA simulations, which are the highest resolution cosmological simulations of dwarf galaxies in the world. The simulations consists of 10 dwarf galaxies simulated at an unprecedented resolution of $4 M_\odot$ (see right-hand image bwlo).

Both of these projects rely on analysing large datasets from cosmological simulations. Hence, prior experience in a programming language (such as Python) is highly beneficial. Both projects will yield novel results, and will have the potential to be published in peer reviewed journals.

Review of dwarf galaxies in cosmological simulations
LYRA simulations





Left: Dark matter and gas distributions in one volume from the Columba set of cosmological hydrodynamical simulations. Each volume is roughly a sphere with a radius of 5Mpc. Right: Supernova explosion captured in a dwarf galaxy from the high resolution simulations of LYRA. The panel with a pink shade shows the dark matter distribution. Green and white in other panels show the gas and star distributions, respectively.

Notes:

3D PRINTED OPTICS FOR ASTRONOMY

Main Supervisor: Dr. Robert J. Harris robert.j.harris@durham.ac.uk
Office: Ogden Centre West 030
2nd Supervisor: Prof. Tim J. Morris t.j.morris@durham.ac.uk

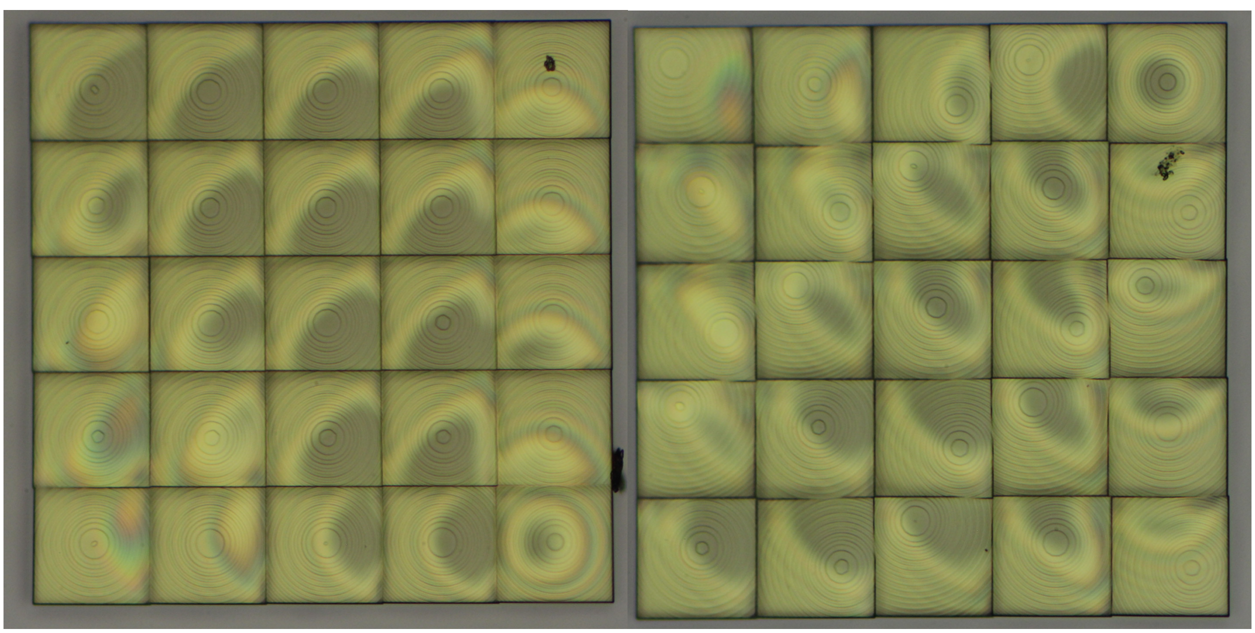
Funding MScR: None defined.

Description:

As we build new telescopes like the Extremely Large Telescope we need new materials and processes to meet the stringent requirements imposed on the instrumentation. This has led to old methods being re-examined and new ones developed. Two-photon polmerisation (2PP) is a 3D printing technique allowing creation of free-form structures at the same scale as the thickness of a human hair. The goal of this project is to design manufacture and test 2PP structures to enhance future astronomical instrumentation (e.g. 3D printed microlenses for tip-tilt sensing).

The project will begin with the modelling and characterisation of a dithered lenslet array designed to increase contrast between companions. You will become familiar with optical simulation tools, spend time in the laboratory developing the imaging setup and write and use analysis software to compare to the models and investigate the advantages of using the dithered design.

Should you have time, you will then use the skills you've learnt to design and fabricate your own optical reformatting system. You will test it with our laboratory spectrograph in preparations for tests at the telescope.



Images of normal and dithered lenslets, notice the discrete steps in the lenslets where the the printer has printed the structures. Left) You can see the centres of the lenslets in the centre of each square. Right) You can see the centre of the lenslet moves.

Notes:

BUILDING A TELESCOPE FIBER PICK-OFF FOR KIDSPEC

Main Supervisor: Dr Kieran O'Brien kieran.s.obrien@durham.ac.uk
Office: Ogden Centre West 029

Funding MScR: None defined.

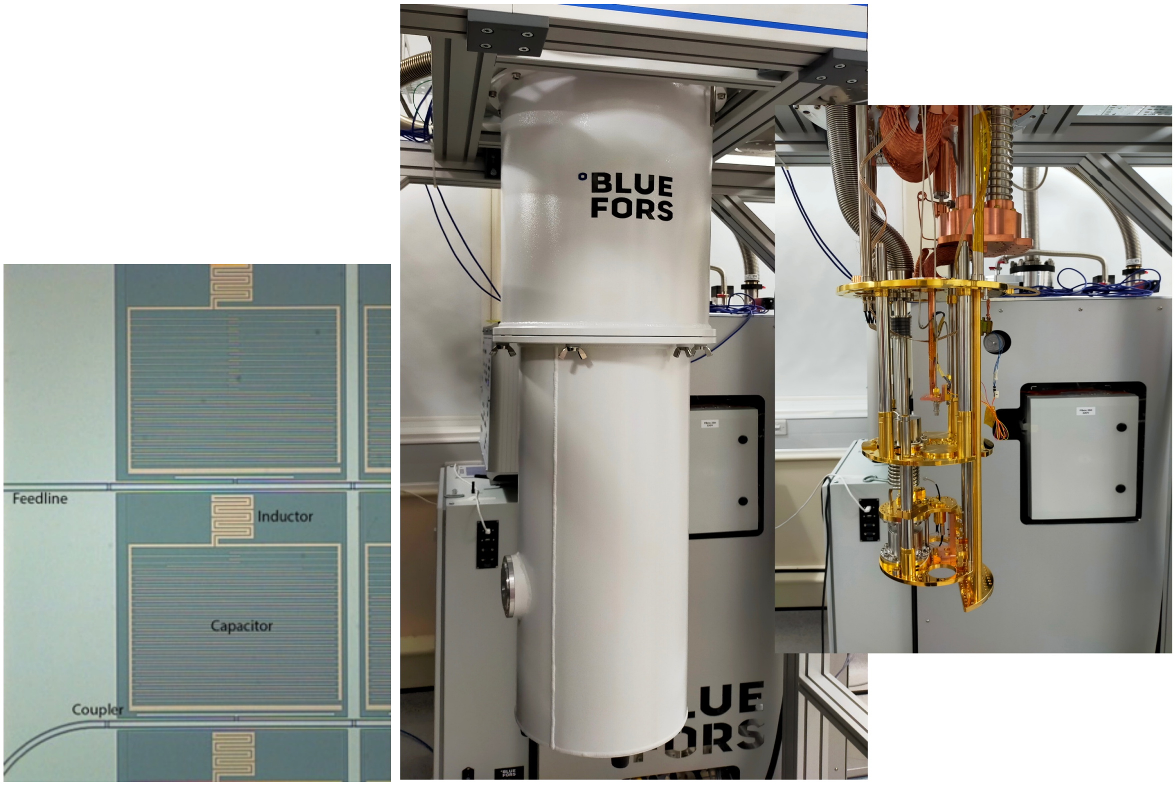
Description:

Many of the most important discoveries in astronomy over the last decades have been driven by technological advances that have enabled researchers to open up new avenues of research. This includes advances in telescope design, such as with the upcoming Extremely Large Telescope (ELT), modes of operation such as Adaptive Optics and perhaps most importantly, through developments in the detector technologies used, such as moving from photographic plates to electronic imaging. At Durham, we are part of a world-leading collaboration to develop and exploit Kinetic Inductance Detectors (KIDs) for optical and near-infrared astronomy. KIDs could potentially drive the next revolution in astronomy as they enable incredibly sensitive 3D spectroscopy. They are made from super-conducting materials that use the kinetic inductance effect to measure the energy of individual photons (to better than 10%) and their arrival time to better than 1 microsecond. By making arrays of 1000's of such detectors, we are able to open areas of research impossible with other technologies.

The first optical/IR KID camera was demonstrated in 2011 by a team from the University of California, led by Prof. Ben Mazin and including Dr. O'Brien. The photon counting capability and spectral resolution of a KID array is capable of making a unique contribution to a wide range of fields, including exoplanet science, time domain astronomy, gravitational wave follow-up and the high red-shift Universe.

This project represents an exciting opportunity to join our team and be involved in a novel instrumentation project from an early stage. We have built a demonstrator spectrograph and would like to use it with the telescopes here in Durham. We are looking for a highly motivated student to design and build the optical fiber interface between the telescope and the spectrograph. No prior knowledge of KIDs is expected and all necessary training will be given. The project would suit students from a wide range of backgrounds, including astronomy, optics, and detectors.

Web pages: Durham KIDs homepage Homepage of Mazin Lab at UCSB
Introduction to KIDs: Introduction to KIDs by Ben Mazin
Example research paper: KIDspec paper



Left, Microscope image (~ $0.3 \times 0.5mm$) of pixels in a KID array, from Mazin Lab website. Right, photo of the KID development lab at Durham University.

PROBING THE STELLAR CONTENT OF ELLIPTICAL GALAXIES USING POISSON FLUCTUATION SPECTROSCOPY

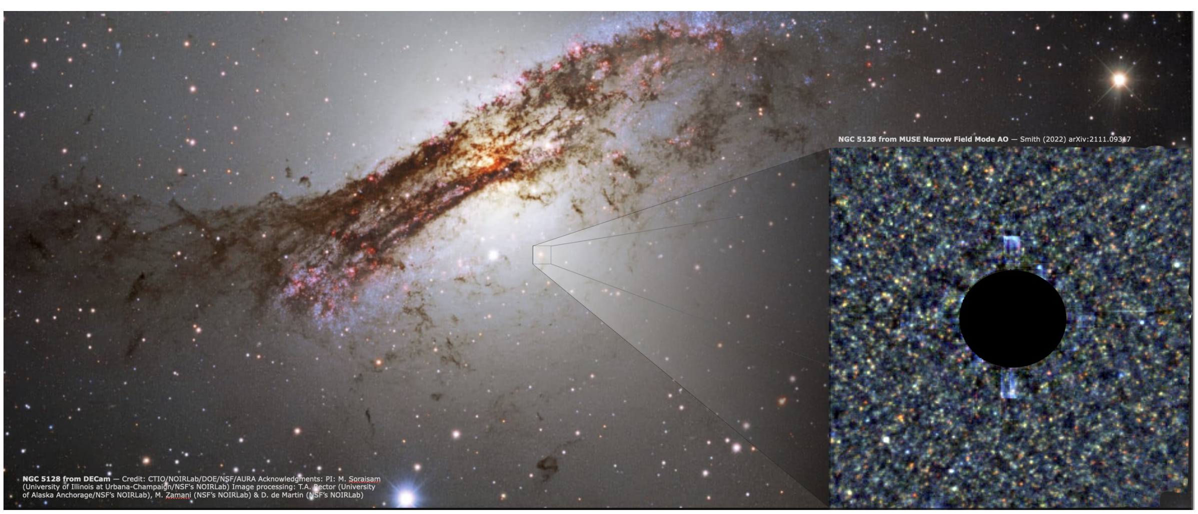
Main Supervisor:	Dr Russell Smith	russell.smith@durham.ac.uk
Office:	Ogden Centre West 110	
Funding MScR:	None defined.	

Description:

The goal of this project is to develop an innovative method for studying the brightest stars in elliptical galaxies, by analysing the statistical fluctuations in the spectra measured at different locations.

While most stars in external galaxies are individually faint, and present in huge numbers, the most luminous giants are individually bright, but much rarer. The small number of giant stars sampled by each pixel is subject to significant Poisson fluctuations; e.g. while on average we might see 10, some pixels will actually contain 12, or 7 or 15. As a result, the *spectrum* of the galaxy shows variations from pixel-to-pixel which carry the "fingerprints" of the giant stars, which can be extracted using statistical techniques like principal components analysis (PCA). Our recent work has explored this technique using "fake" data generated from an idealised model, and we have also proved that it works in practice, using optical VLT observations for a particularly nearby galaxy, where the fluctuations are easiest to measure (see Smith 2022, MNRAS, 509, 5737).

With the recent launch of the James Webb Space Telescope, and eventually with the next generation of giant ground-based telescopes like the ESO Extremely Large Telescope, we will be able to deploy this novel method in the cores of massive elliptical galaxies. Such observations will probe the origin of several puzzling discrepancies between models and observations for such galaxies. In this project you will help develop a suite of realistic synthetic datasets, tuned to the JWST and ELT characteristics, to determine what information can be retrieved from real data, and what observational configurations are most sensitive for what applications. The long term goal of this work is to develop a future programme of ELT observations with the HARMONI instrument, which Durham is involved in building.



A field of stars in the nearby peculiar galaxy NGC 5128 (top left), as seen in ground-based imaging (main) and with MUSE on the VLT in its high-resolution mode (inset). The brightest giant stars are visible in this image but too faint to obtain spectra for individually. A bright foreground star at the field centre is used for the adaptive optics correction. The detailed spectral information in the MUSE data (not shown here) can be harnessed by our Poisson-fluctuation spectroscopy technique to extract the ensemble-average properties of the cool giant stars. In this project, you will help develop the method for application to distant elliptical galaxies with the James Webb Space Telescope and/or the ESO Extremely Large Telescope.

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