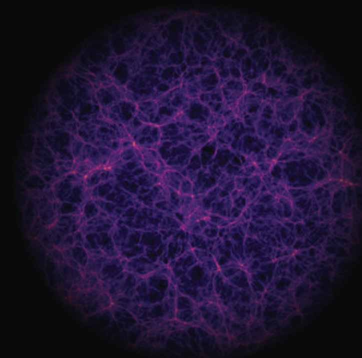
Astronomy PhD & MScR Projects at Durham

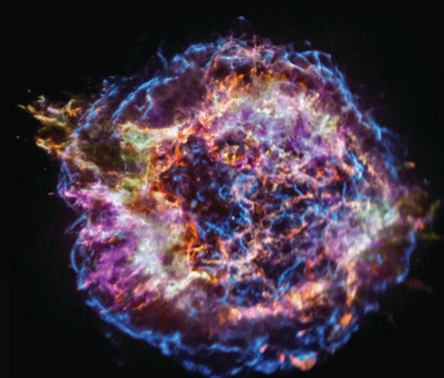
2026

ICC



Durham University

Durham Centre for Extragalactic Astronomy



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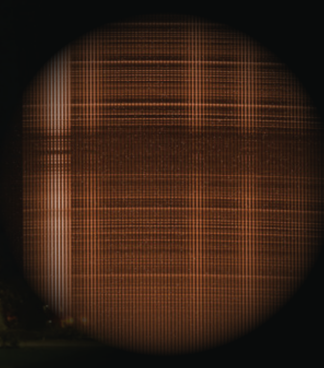


PHD & MSCR PROJECTS IN ASTRONOMY FOR AUTUMN 2026 START

Introduction

List of STFC/Durham funded PhD Projects

Bose: Fundamental Cosmology with Large-Scale Structure

Brown: Ultra High Energy Neutrino Astronomy with TRINITY

Brown: Improving the Accuracy of Drone Based Remote Sensing with Astronomical Instrumentation

Done: Understanding Emission from Black Hole Accretion Flows of Quasars across Cosmic Time

Li: Dark Energy and Gravity in the Era of EUCLID

Li: Dark Energy and Gravity: When Science Meets Supercomputing

Morabito: Do AGN Outflows Generate Radio Emission from Schocking the ISM?

Morabito: Finding Hidden Active Galactic Nuclei Using Novel Observational Modeling Methods

Morris: Multi-Wavelength Wavefront Sensing for Exoplanet Imaging

O'Brien: Developing Photon Counting Spectroscopy for Astronomy

Osborne: Atmospheric Impact Assessment of Space Activity

Osborne: Monitoring and Forecasting Atmospheric Turbulence

Pontzen: Accelerating Simulation Analysis

Pontzen: Non-Linear Gravitational Dynamics of Dark Matter

Pontzen: Comparing Observed and Simulated Dwarf Galaxies

Ren: Compact Terahertz Spectrometer Based on Metasurfaces

Scaringi: Hunting for Hostless Transients with BLACKGEM and RUBIN/LSST

Scaringi: Hunting Compact Binaries in the Southern Sky with BLACKGEM and RUBIN/LSST

Scaringi: Turning Noise into Signal: Using the LISA Foreground to Probe Galactic Binary Populations

Scaringi: Eavesdropping on Accretion Disks: Using TESS and PLATO to Unravel the Physics of Accretion

Swinbank: From the First Galaxies to the Milky-Way: the Role of Accretion, Star Formation and Feedback in Shaping Galaxies

Wilson: Characterising Atmospheric Turbulence for Ground Based Astronomy

List of additional PhD Projects that require applications for funding

Li: Numerical Relativity in the Realm of New Physics

McLeod: Hunting Cosmic Beasts: Detecting Wolf-Rayet Stars with IFU Spectroscopy

List of MScR Projects

Bose: Fundamental Cosmology with Large-Scale Structure

O'Brien: The Application of AI to Real-Time Photon Detection for Next Generation Large Scale MKID Arrays

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 the top institution 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 roughly 35 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 2026. 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 3.5 to 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 expect to offer up to 5-6 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 1-2 international studentships.

Durham funded PhD studentship. We offer up to two Durham funded PhD studentship this year for a duration of up to 4 years.

European Research Council (ERC) studentships. These 4-year PhD studentships are available to any student irrespective of domicile. We offer up to two ERC studentships 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 need to be in place typically by the end of December or start of January, for an autumn 2026 start. We note that by the deadline we need to have received reference letters in support of the application, as well as relevant language certificates. Therefore we encourage interested graduate students to contact us well in advance of this deadline to allow appropriate assessment, as well as to explore other potential sources of funding. Hence we recommend DDS/CSC applications to be submitted by **early/mid- December 2025** to receive full consideration.

Bell Burnell Graduate Scholarship Fund. The Institute of Physics (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 need to have applied and be nominated by a staff member by the internal physics deadline in early January. Hence we recommend applicants interested to be considered for the BBGSF to submit their application by **early/mid- December 2025** 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 the *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 late-January/early-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 web pages https://www.gov.uk/postgraduate-loan.

Follow the post-graduate opportunities link from our web site or contact our astronomy post-graduate coordinators, Prof. Ryan Cooke (ryan.j.cooke@durham.ac.uk) and Dr. Dimitri Gadotti (dimitri.a.gadotti@durham.ac.uk) 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 (PhD):	STFC and other funding schemes (Bell Burnell, CSC, DDS, Inlaks...)	
Funding (MScR):	None defined. Project is adaptable as an MScR project	

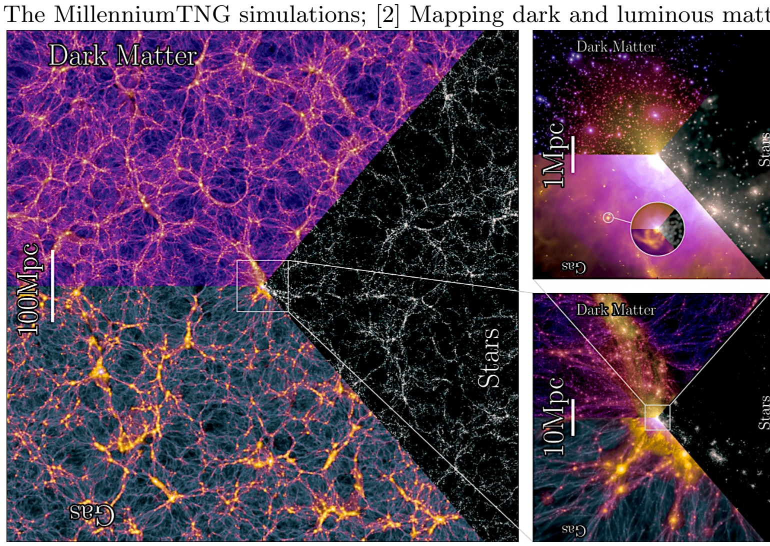
Description:

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;
- Development of semi-analytic methods and Machine Learning to create models based on more computationally expensive supercomputer simulations;
- Developing a cutting-edge cosmological inference framework that utilises the full information content of datasets at the field level, rather then using simple summary statistics.

You will have the opportunity to work at the forefront 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:
[1] The MillenniumTNG simulations; [2] Mapping dark and luminous matter; [3] Field-level inference in 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. Adapted from Pakmor et al. 2023.*

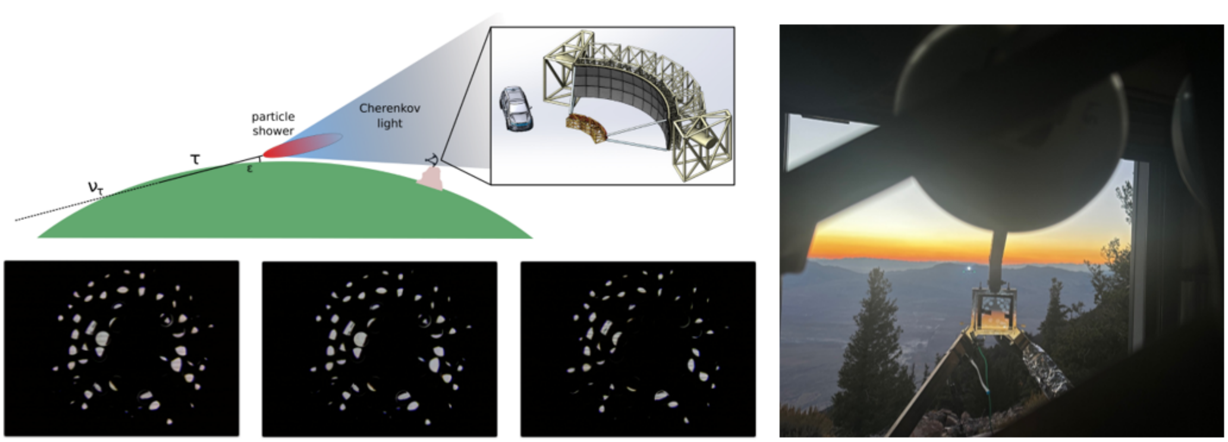
ULTRA HIGH ENERGY NEUTRINO ASTRONOMY WITH TRINITY

Main Supervisor: Dr. Anthony M. Brown anthony.brown@durham.ac.uk
Office: Ph125B
Funding: Durham, STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

The Trinity telescope is a new and unique approach to observing the neutrino Universe. Trinity will indirectly observe Ultra-High-Energy (UHE) tau neutrinos by detecting the Cherenkov radiation emitted by an upwards going air shower that appears out of the ground. This air shower is the result of a tau neutrino skim through the Earth's crust, interacting with matter to produce a tau particle, which decays as it comes out of the Earth. By placing a bespoke wide-field-of-view telescope on a mountain, and pointing it below the horizon, Trinity will observe these upwards travelling flashes of light (see Figure 1 below). Essentially, Trinity is translating expertise in gamma-ray astronomy to UHE neutrino astronomy, which allows us to minimise the observed background, whilst maximising the energy and angular resolution of the observations.

In your PhD, you'll be joining the Trinity collaboration, exploiting the Trinity demonstrator telescope to open up the UHE neutrino window to the Universe. Supervised by Dr Anthony Brown, and interacting closing with international collaborators in the USA, the PhD post will make significant contributions to several key operational aspects of Trinity. Your tasks will include developing new (drone-based) hardware to calibrate Trinity, quantifying the sensitivity of Trinity and interpreting Trinity observations to place sensitive flux limits on UHE neutrino emission from astrophysical sources.



Images outlining key aspects of the position. Top left: schematic outlining key components of Trinity's detection technique. Right: photo of drone-based light source illuminating the Trinity demonstrator telescope (for a variety of calibration requirements). Bottom left: first data of drone-based mirror alignment (September 2024).

IMPROVING THE ACCURACY OF DRONE BASED REMOTE SENSING WITH ASTRONOMICAL INSTRUMENTATION

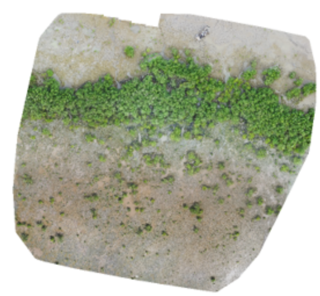
Main Supervisor: Dr. Anthony M. Brown anthony.brown@durham.ac.uk
Office: Ph125B
Funding: Durham, STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

The recent advances in UAV capability has given the remote sensing community a number of exciting possibilities. Unfortunately, in the context of plant ecology, the realization of this potential has focused on monitoring crop health where the species of plant is known. Furthermore, this monitoring is usually restricted to a small number of wavelengths, resulting in a noisy dataset that is not able to differentiate between plant species or identify pathogens. As such, UAVs have not realised their full potential in UAV-based remote sensing of plants. This unrealised potential also applies to other areas of UAV-based remote sensing such as atmospheric content where UAV technology affords us the possibility of mapping out temporal and spatial variations in atmospheric gas and dust content.

This PhD position will look to combine astronomical instrumentation, UAV technology and machine learning, with a sensor-fusion approach to improve remote sensing capability. To achieve this, your tasks will include developing new imaging capability to mount to UAVs, apply machine learning analysis to remote sensing data sets to improve remote sensing accuracy and conduct simulations to quantify the accuracy of the new remote sensing capability.





Left: image of UAV-based calibration system above a telescope array in Namibia. Centre: UAV imagery of a wheat field with different pathogens. Right: UAV-imagery of a mangrove forest in Suriname.

UNDERSTANDING EMISSION FROM BLACK HOLE ACCRETION FLOWS OF QUASARS ACROSS COSMIC TIME

Main Supervisor: Prof Chris Done chris.done@durham.ac.uk
Office: Ogden Centre West OCW132
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Black holes are the simplest possible objects, characterised only by mass and spin. We see them most easily via accretion, where the enormous gravitational potential energy released by the infalling material transforms these darkest objects in the Universe into the brightest. Hence there is another parameter which controls the observable appearance of an accreting black hole, namely the mass accretion rate, along with viewing angle for any non-spherical flow. Fundamentally, these parameters must determine the majority of the properties.

Standard disc models predict a spectrum peaking at $\sim 10^7$ K (X-ray temperatures) for the stellar mass black holes at high luminosities. These are observed, though there is generally an additional tail of emission to higher energies. However, scaling this up to the supermassive black holes in Quasars reveals significant differences. Their disc spectra should peak at lower temperatures, $\sim 10^5$ K, predicting a a very blue optical/UV continuum (red line in Fig 1a), but the data instead show a downturn in the UV emission which appears to connect to an upturn in the X-ray emission below 1 keV (the soft X-ray excess, magenta, Fig 1). This component is also intrinsically variable on timescales of weeks/months/years (see inset of Fig 1), unlike the standard disc models which predict variability on timescales of 10^4 years (Noda & Done 2018).

Instead, it can be phenomenologically modelled by modifying the disc structure, such that the gravitational energy is released in an accretion layer on the top of the disc, rather than the midplane as in the standard disc models (e.g. Kubota & Done 2018). Its physical nature is not well understood, but there are now data which show how its spectrum changes with mass accretion rate (Hagen, Done et al 2024, Noda & Done 2018). This project will use these as a basis for building more physical models of the accretion flow, which will enable us to understand the emission of Quasars across cosmic time, especially the new populations at high redshift discovered by the James Webb Space Telescope.

Hagen, Done et al 2024 MNRAS 543 2803 Kubota & Done 2018 MNRAS 480 1247
Noda & Done 2018 MNRAS 480 3898

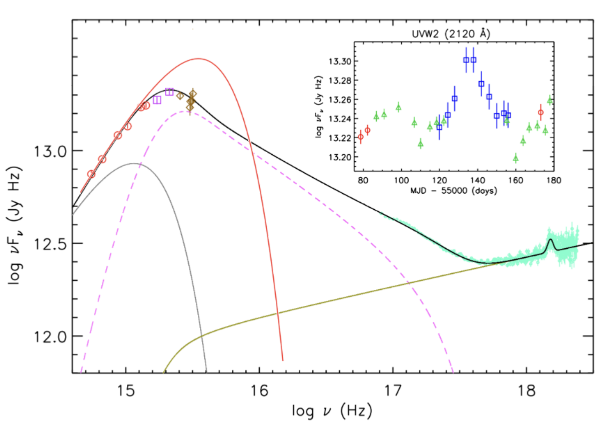


Fig 1: Typical Quasar accretion flow spectrum. The red line shows the prediction from a standard disk model. The data turn down before the predicted peak, but also extend into the soft X-ray bandpass above 10^{17} Hz forming a soft X-ray excess above the coronal power law (green). This can be fit with a warm Comptonised disc component (magenta). The inset shows how the UV at $\sim 10^{15}$ Hz varies on timescales of weeks.

DARK ENERGY AND GRAVITY IN THE ERA OF EUCLID

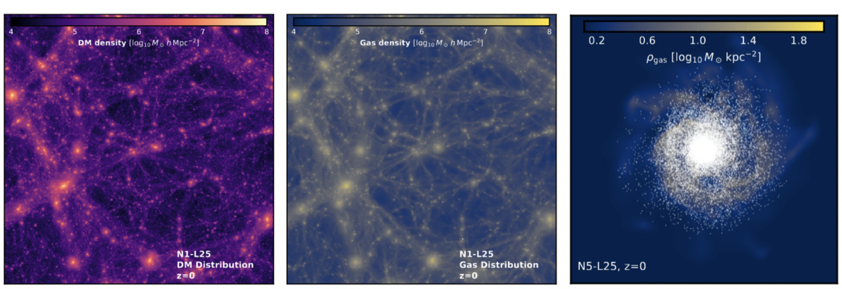
Main Supervisor:	Prof. Baojiu Li	baojiu.li@durham.ac.uk
Office:	Ogden Centre West 218	
2^{nd} Supervisor:	Prof. Carlton Baugh	c.m.baugh@durham.ac.uk
Funding:	ERC	

Description:

The European Space Agency's *Euclid* satellite, launched in 2023, is one of the most ambitious cosmological endeavours to explore the Universe, following a long history of successful telescopes that have defined the precision era of cosmology studies. By mapping the space distribution and time evolution of large-scale structures, it will shed light on the origin of the mysterious accelerated Hubble expansion, be it due to some unknown matter species (dark energy) or a new gravity theory beyond General Relativity. Euclid is currently undergoing its first data release, with projects supporting future data releases already being planned.

This PhD project is broadly designed to explore the scientific potential of *Euclid* to test models of dark energy and modified gravity (DEMG) models. It will closely align with the effort of Euclid's Theory Working Group, with the PhD student expected to be heavily involved therein. The overall objective is to carry out an unprecedentedly systematic and detailed test of DEMG models, based on a new scheme to parameterise these models that allows to, for the first time, fully explore the nonlinear regime of their predictions (Ref 1). Within this scope, possible directions include: explorations of *Euclid*'s data on galaxy clustering, weak gravitational lensing or clusters of galaxies to constrain models of new physics, improving our understanding of galaxy formation in the models through semi-analytic models or state-of-the-art hydrodynamical simulations, developing new summary statistics and cosmological probes to test models in general, or employing AI tools in the above aspects, or some mixture of the above possibilities. The student will learn both analytical and (super)computing skills from this project, as well as connections with observational data via model tests.

Reference 1: Systematic cosmological simulations of new physics 1
Reference 2: Systematic cosmological simulations of new physics 2
Reference 3: Systematic cosmological simulations of new physics 3
Reference 4: Galaxy formation simulations in modified gravity models 1
Reference 5: Galaxy formation simulations in modfiied gravity models 2
Reference 6: FORGE-A-BRIDGE: machine learning and gravity simulations



Galaxy formation simulation of a gravity model with a universe that is 5-dimensional, showing the distributions of dark matter (left), gas (middle) and stars (right; zoomed-in to a single galaxy).

DARK ENERGY AND GRAVITY: WHEN SCIENCE MEETS SUPERCOMPUTING

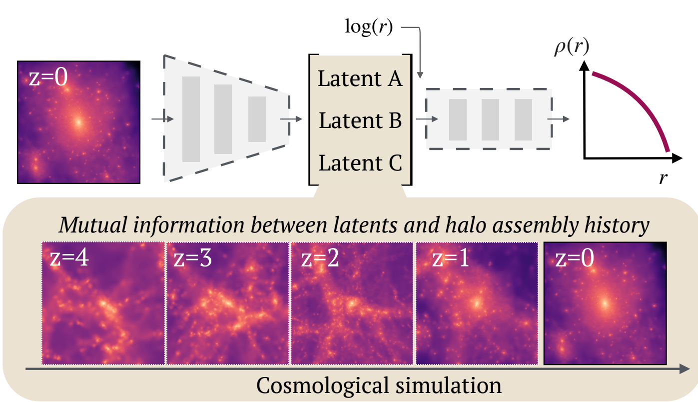
Main Supervisor:	Prof. Baojiu Li	baojiu.li@durham.ac.uk
Office:	Ogden Centre West 218	
2^{nd} Supervisor:	Prof. Andrew Pontzen	andrew.p.pontzen@durham.ac.uk
Funding:	ERC	

Description:

Computing plays a central role in the development of modern cosmology: it is through computer simulations that we can most accurately predict the evolution of the Universe and its large-scale structure, which contains rich information for building and refining our cosmological model. State-of-the-art cosmological simulations are quickly approaching the volume of the observable Universe, while also capturing the detailed interplay between key constituents of the universe such as neutrinos, dark matter and dark energy with the visible stars and gas. Dark matter, dark energy, and neutrinos are all invisible and involve physics that lies beyond current knowledge. By tracing these mysterious components' connection to visible structure in the universe, we can therefore extend our understanding in new directions.

However, large cosmological simulations are highly expensive, making them a privilege available only to a small number of groups around the world, including the ICC. Making most efficient use of computational resources allows for the best possible physics outcomes, while shrinking the environmental and financial costs. There have been growing efforts in developing more efficient methods, often based on artificial intelligence (AI), in recent years. Many of these studies use AI as a black box to increase efficiency. However, to increase simulations' predictive power, reliability and physics insight, there is urgent need to build more transparent, interpretable AI systems that may even be able to aid construct explanations for physical phenomena.

In this open-ended PhD project, the student will explore new ways to improve the efficiency of numerical simulations, enhance their utility in testing cosmological models, and work towards AI as a partner in advancing physics. Possible directions include: (i) applying machine learning (ML) to make predictions of key summary statistics with improved accuracy for models of new physics, and confront against observed data; (ii) going beyond summary statistics to make ML predictions at the field level; (iii) understanding how ML can forge a closer connection between cosmic structure formation—including galaxy formation—and fundamental physics, particularly dark matter, dark energy and gravity; (iv) exploring novel ways to build efficient simulations by augmenting traditional simulation methods with AI and analytical methods.



A neural network is trained to compress information about a simulated dark matter halo into a minimal representation, which can then be interpreted to yield physical insights about the growth of dark matter structures. From Lucie-Smith et al 2024.

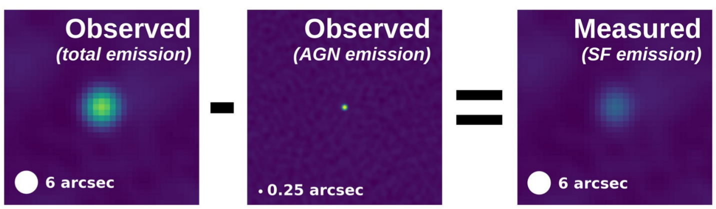
FINDING HIDDEN ACTIVE GALACTIC NUCLEI USING NOVEL OBSERVATIONAL MODELLING METHODS

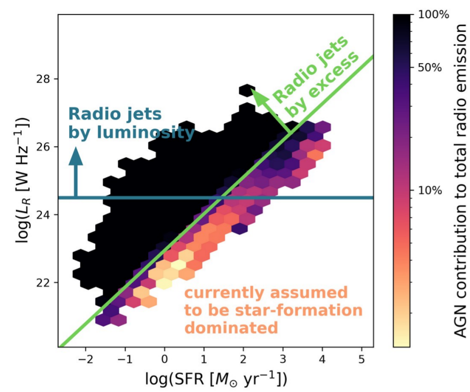
Main Supervisor: Prof. Leah Morabito leah.k.morabito@durham.ac.uk
Office: Ogden Centre West 121

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

Description:

Radio observations are an excellent way to trace activity from both star formation and activity from active galactic nuclei (AGN), which is necessary for understanding how they impact each other. All galaxies have some level of star formation, even if it is small. However, when galaxies host an AGN the question becomes: how do we know where the radio emission is coming from? In AGN which host powerful jets of relativistic plasma, it is easy to see these but most radio surveys don't have the resolution to identify smaller-scale jets. This limits our ability to simultaneously measure star formation and AGN activity. Recently, we have developed a method which uses the combination of high and low resolution possible with the LOw Frequency ARray (LOFAR) to cleanly separate and simultaneously measure radio emission from star formation and radio emission from AGN activity (Morabito et al. 2022). This has shown that there is ∼50% more radio emission due to AGN activity than previously thought (see figure below). However, the separation is still simplistic and does not provide meaningful uncertainties.





Above: Using LOFAR's ability to image the same data at different resolutions to separate the bright, compact radio emission from AGN activity and the radio emission from star formation. **Right:** Using this separation of radio emission between AGN activity and star formation, we can calculate the AGN contribution to the total radio emission. The figure shows radio luminosity as a function of star formation rate, and reveals that in the region currently assumed to be star-formation dominated, the AGN contribution is significant.

The aim of this project is to 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. The fundamentals of a code already exist, which means this project is ready to start on day one. We have several exciting new datasets to work on, including high-resolution images of the Lockman Hole (Sweijen et al. 2022), ELAIS-N1 (de Jong et al. 2024), and Boötes (Escott et al. submitted). Using this data, you will be able to answer questions like - where is this previously unknown radio emssion from AGN activity coming from? What kind of galaxies host it? What is its impact on star formation, and by extension, galaxy evolution?

From 2027 there will also be data from theLOFAR2.0 Ultra Deep Observation, which is a survey that will create the deepest ever radio image. You will have a chance to work on this survey, and collaborate on associated projects.

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:
A hidden Active Galactic Nuclei Population: https://arxiv.org/abs/2411.05069
Identifying AGN via brightness temperature with LOFAR: https://arxiv.org/abs/2207.13096
A decade of sub-arcsecond resolution imaging with LOFAR: https://arxiv.org/abs/2502.06946
Meet the team: https://lmorabit.github.io

DO AGN OUTFLOWS GENERATE RADIO EMISSION FROM SHOCKING THE ISM?

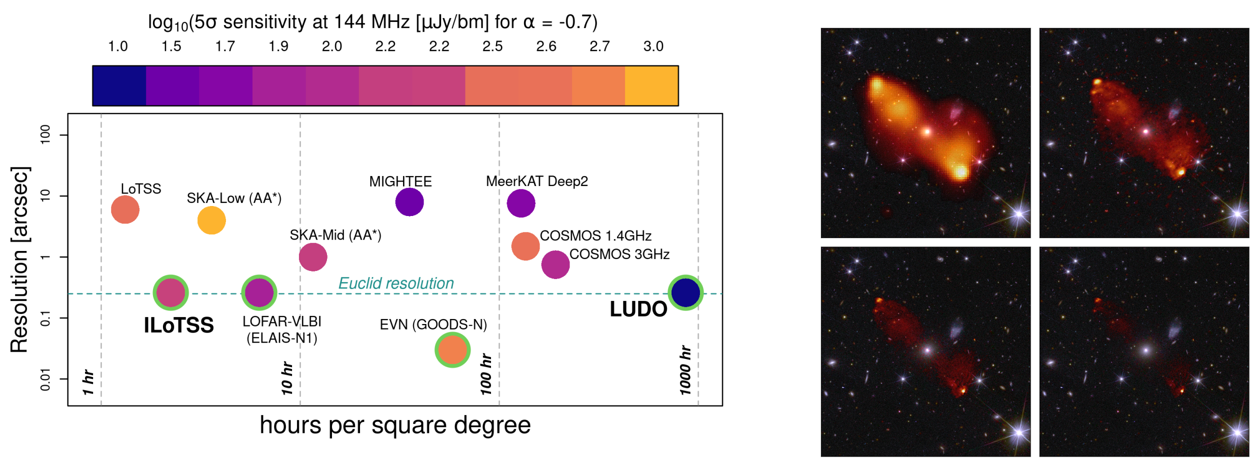
Main Supervisor: Prof. Leah Morabito leah.k.morabito@durham.ac.uk
Office: Ogden Centre West 121
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Active Galactic Nuclei (AGN) are actively accreting super-massive black holes which produce powerful outflows such as winds or jets, with observational signatures from X-rays to the radio. The winds can vary in strength and velocity, from colder and slower material to ultra-fast outflows. In the radio regime we see jets that range from galaxy scale to cluster scale, with a wide range of morphologies. There is growing evidence though that some of the radio emission may be related to winds and outflows driven by AGN - the question is, can we prove this? Understanding whether radio emission is tracing low-power jets or winds is important, as these couple to the interstellar medium (ISM) in very different ways, which has implications for how AGN are able to impact galaxy evolution.

With a wealth of new spectroscopic data from surveys like DESI, 4MOST, and Euclid, along with new cutting-edge high-resolution radio observations from telescopes like the LOw Frequency ARray (LOFAR), we have the opportunity to make progress in this area. The aim of this project is to look for correlations between radio emission and spectral lines which are indicative of shocked gas. We would expect a correlation if radio emission comes directly from winds shocking the ISM, whereas radio jets are more likely to simply punch through the ISM without leaving shock tracers in the gas.

In this project, you will first compile a spectroscopic dataset and measure the properties of spectral lines indicative of shocked gas. You will cross-match this with sub-arcsecond resolution LOFAR data to investigate their link to the radio emission. There will be opportunities to contribute to large international scientific collaborations, and learn radio data reduction for the upcoming LOFAR2.0 Ultra Deep Observation (LUDO), which will be the deepest ever radio survey, covering 3.7 deg^2 of the Euclid Deep Field North.



Left: A comparison of the resolution and sensitivity of different radio surveys, with the sensitivity all scaled to 144 MHz assuming a typical synchrotron spectrum. *Right:* LOFAR data, imaged at four different resolutions (orange; 6", 1.2", 0.6", and 0.3") overlaid on optical data from Euclid.

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. You will also have a chance to prepare proposals for telescope time and potentially go observing if the time is granted.

More reading:
Connecting radio emission to AGN wind properties with Broad Absorption Line Quasars https://arxiv.org/abs/2207.10102
A decade of sub-arcsecond resolution imaging with LOFAR: https://arxiv.org/abs/2502.06946
Meet the team: https://lmorabit.github.io

MULTI-WAVELENGTH WAVEFRONT SENSING FOR EXOPLANET IMAGING

Main Supervisor: Prof. Tim Morris t.j.morris@durham.ac.uk
Office: Ogden Centre West 027
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Most large telescopes make use of adaptive optics to overcome the blurring effects of atmospheric turbulence, allowing observations of the universe with exquisite spatial resolution. Adaptive optics observations have unlocked new science over the last two decades, enabling the characterisation of high-redshift galaxy kinematics, confirmed the existence of the super massive black hole at the center of our galaxy (winning the 2020 Nobel prize in Physics), and taking direct images of gas giants orbiting other stars. The next generation of extremely large telescopes with 30+ meter diameter primary mirrors coming online in the next decade and these telescopes all use adaptive optics. One of the driving science goals for these telescopes is to image exoplanets and characterise their surfaces and atmospheres. To meet this ambitious challenge we require research into new techniques, technologies, and instrumentation that will enhance adaptive optics system performance beyond what is currently possible.

One of the key pieces of technology within an adaptive optics system is the wavefront sensor, which measures the atmospheric phase aberrations several thousand times a second. The Pyramid wavefront sensor is at the heart of many high-performance adaptive optics systems, however it suffers from chromatic and non-linear effects that can affect measurements. The extremely large telescopes themselves also introduce complex wavefront aberrations that can be difficult to measure and control with existing Pyramid sensors. Recent research by Durham and collaborators has shown that by combining Pyramid wavefront sensor measurements at multiple wavelengths we can overcome many of these effects.

The goal of this project will be to develop an instrument that will provide the first on-sky demonstration of a multi-wavelength Pyramid wavefront sensor. The instrument will be installed on a 2-meter diameter telescope in Asiago (Italy) where an international team of young adaptive optics researchers and students are working on the development of a new adaptive optics testbed. No experience of optical instrumentation development is required for this PhD but you will need to have an interest in experimental physics and be willing to learn a wide range of transferrable skills such as optical design, data reduction, and adaptive optics simulation development. This is a rare opportunity to undertake research and development of a new technology and test it at a telescope. A successful demonstration of this technology in the next few years could result in it being adopted for use in the next generation of planet characterising instruments.

Image of the 39m Extremely Large Telescope under construction in Chile. Image ©European Southern Observatory

Kaspar, M. *et al*, *"PCS — A Roadmap for Exoearth Imaging with the ELT"*, *The Messenger* 182 (2021): 38–43.
Magniez, A. *"Polychromatic measurement of the wavefront for high-contrast imaging with an MKID-based Pyramid Wavefront Sensor"*, Durham University (2024)

DEVELOPING PHOTON COUNTING SPECTROSCOPY FOR ASTRONOMY

Main Supervisor:	Prof. Kieran O'Brien	kieran.s.obrien@durham.ac.uk
Office:	Ogden Centre West 029	
2nd Supervisor:	Dr. Simone Scaringi	simone.scaringi@durham.ac.uk
Funding:	STFC and other funding schemes (Bell Burnell, CSC, DDS...)	

Description:

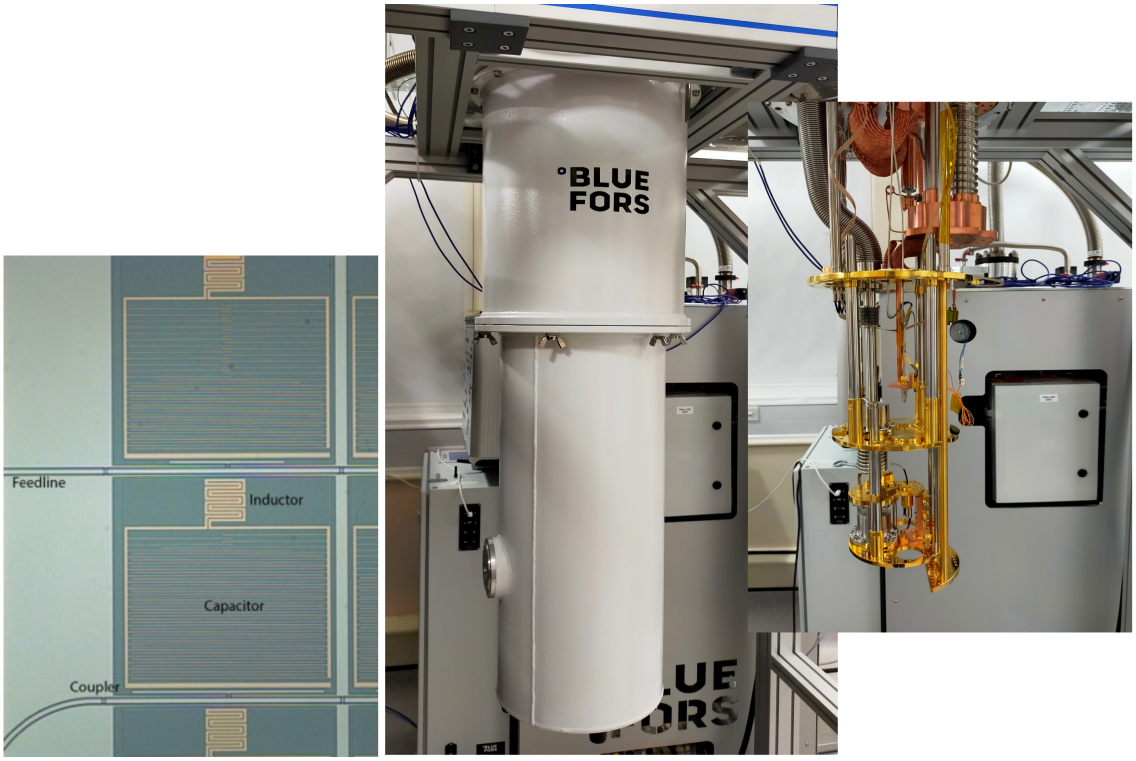
Many of the most important discoveries in astronomy over the last decades have been driven by technological advances that have enabled researchers to open up new avenues of research. This includes advances in telescope design, such as with the upcoming Extremely Large Telescope (ELT), modes of operation 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 by counting individual photons. They are made from super-conducting materials that use the kinetic inductance effect to measure the energy of a photon (to better than 10%) and its 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.

One such area is the field of time domain astronomy, this growing field includes the observations of the compact binary precursors of gravitational wave sources and the transiting exoplanets, among others. These objects show variability on timescales of milliseconds to hours and you will observe this variability spectroscopically to determine the fundamental properties of such systems.

This project represents an exciting opportunity to join our team of students a post-docs 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. Projects will include some observational astronomy alongside the instrument development.

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

ATMOSPHERIC IMPACT ASSESSMENT OF SPACE ACTIVITY

Main Supervisor:	Prof. James Osborn	james.osborn@durham.ac.uk
Office:	Ogden Centre West 026	
2nd Supervisor:	Dr. Fionagh Thomson	fionagh.thomson@durham.ac.uk
3rd Supervisor:	Prof. Richard Massey	r.j.massey@durham.ac.uk
Funding:	STFC and other funding schemes (Bell Burnell, CSC, DDS...)	

Description:

As of August 2025, over 12,600 active satellites orbit Earth, doubling since 2022. Expectations are for satellite populations to rise to 20-30,000 by 2030 and as many as 100,000 by 2050. Much of this growth is derived from the expansion of so-called mega-constellations, large networks of satellites delivering communications and other services around the world. Unlike traditional missions with long operational lifespans, these constellations introduce a high-throughput cycle of satellites entering and exiting the orbital environment to maintain network integrity and upgrade technology. Currently, 1 or 2 tracked objects re-enter the Earth's atmosphere every day, with this number set to increase significantly over the next decade. These launches and re-entries release soot and metallic particulates (e.g. aluminium oxide) into the upper atmosphere. These particles may influence climate dynamics by forming stratospheric clouds and accelerating ozone depletion, increasing UV exposure risks. Current data is sparse, relying on costly, infrequent (currently discontinued) missions (e.g. NOAA aircraft). Without long-term and scalable monitoring, climate models and policy decisions lack a reliable evidence base.

This programme will develop proof-of-concept technology demonstrators focused on one or both of the following approaches:

1. Develop and test a portable multi-spectral imaging/spectrographic systems capable of monitoring re-entry events in real time. These instruments will help determine the physical processes occurring during re-entry—specifically whether objects ablate, melt, or fragment, and how these behaviours vary with trajectory, composition, and structural design.

2. Balloon-borne sample return missions to collect and characterise particulates in the upper atmosphere, providing direct evidence of their physical and chemical properties.

The specific focus will be tailored to the candidate's background and interests, with flexibility to pursue either a single approach in depth or a comparative study across both. The project will include design, prototyping, and field validation phases.

This project is conducted in partnership with the University of Auckland, New Zealand, offering a unique opportunity to test instrumentation and collect data across both hemispheres. The collaboration supports joint field campaigns, shared access to facilities, and integration with complementary research in atmospheric science and space sustainability.

Durham University Space Research Centre: SPARC
Centre for Advanced Instrumentation: CfAI

Fig 1.: *PhD students observing a satellite from La Palma, Spain.*

MONITORING AND FORECASTING ATMOSPHERIC TURBULENCE

Main Supervisor: Prof. James Osborn james.osborn@durham.ac.uk
Office: Ogden Centre West 026
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Project Overview
Atmospheric turbulence is a critical limiting factor for ground-based optical systems, affecting image resolution in astronomy, signal fidelity in free-space optical communications, and tracking accuracy in space situational awareness (SSA). This PhD project aims to develop and apply advanced turbulence monitoring and forecasting tools to support these three domains, enhancing the performance and reliability of ground-based optical systems.

Research Objectives
1. Characterise atmospheric turbulence at key observatory and ground station sites using state-of-the-art instrumentation and data analysis techniques.
2. Develop and validate forecasting models, including data assimilation, for optical turbulence to support dynamic scheduling and adaptive system control in astronomy and communications.
3. Apply turbulence data to improve:
3a. Adaptive optics systems for large telescopes (e.g., VLT, ELT).
3b. Free-space optical communication links, including satellite-to-ground and inter-satellite systems.
3c. SSA systems for tracking and monitoring space debris and satellites.

Impact and Applications
This project will contribute to:
1. Improving image quality and photometric precision in ground-based astronomy.
2. Enhancing the reliability and bandwidth of optical communication systems.
3. Supporting SSA efforts by refining ground-based tracking capabilities.

The student will join CfAI's vibrant research environment, working alongside experts in adaptive optics, space instrumentation, and atmospheric physics. The project offers opportunities for international collaboration, fieldwork, and cross-sector impact.

Further Reading:
Durham University Space Research Centre: SPARC
Centre for Advanced Instrumentation: CfAI
Shack-Hartmann Image Motion Monitor SHIMM
Global turbulence Forecasting Forecasting

Fig 1.: *PhD student developing and testing atmospheric optical turbulence instrumentation on La Palma, Spain.*

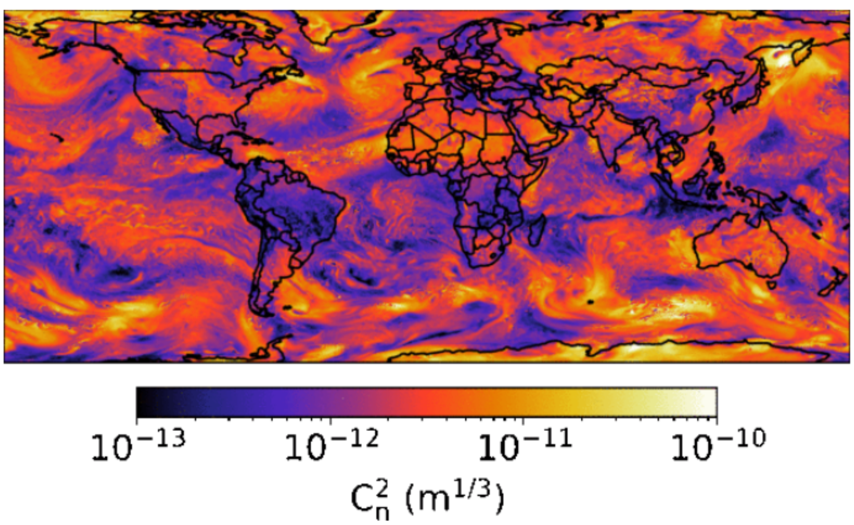


Fig 2.: *State of the Art turbulence forecast model developed at Durham. The colour indicates the strength of the atmospheric optical turbulence in units of the refractive index structure constant.*

ACCELERATING SIMULATION ANALYSIS

Main Supervisor: Prof Andrew Pontzen andrew.p.pontzen@durham.ac.uk
Office: Ogden Centre West OCW214
Funding: Durham, STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

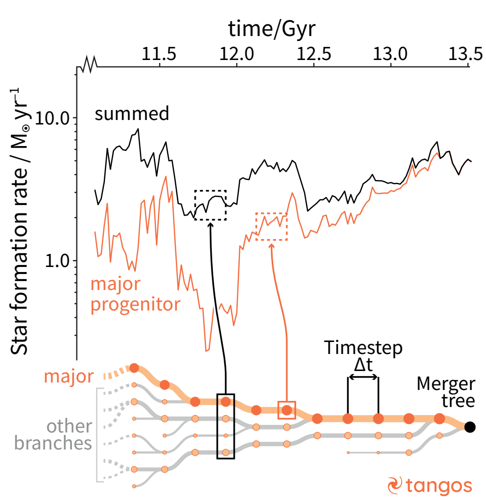
Simulations of the formation of structure in the universe are some of the most challenging computational problems known to humanity. By definition, they push the boundaries of hardware capabilities because the universe is so complex — there is no known limit to the amount of computer power or storage that can be usefully applied. However, astrophysicists often need to focus on science analyses without constantly fretting over technical details of the underlying large datasets.

Enabling this kind of work requires a full understanding of astrophysical questions and challenges, but also an enthusiasm for high-quality code making use of suitable cutting-edge technologies.

This PhD will dive into cutting-edge technologies in the context of simulation analysis, but its particular area of focus can be tailored to your interests. For example, it would be possible to focus on the use of advanced GPU hardware through technologies like WebGPU, the embedding of analysis inside user-friendly browser interfaces via WebAssembly, or the use of emerging database techniques including graph and NoSQL solutions. This project would be ideally suited to a student who would like to focus heavily on technology, while also becoming expert on the relevant aspects of astrophysical simulations to inform solutions that work for a wide variety of users, including the GMGalaxies team led by the supervisor.

Existing relevant software projects include:

topsy – GPU-accelerated visualisation of simulations
pynbody – scientific analysis of simulations
tangos – databases for querying simulations



Even relatively simple astrophysical queries such as 'give me the star formation rate over time from this simulated galaxy' can hide considerable algorithmic complexity, which becomes important for high-quality analyses of large simulation outputs. This illustration (from Pontzen & Tremmel 2018) breaks down some steps involved in retrieving star formation rates when a galaxy has formed from multiple progenitors. Improving reliable reconstructions of a galaxy's history using new database technologies is one possible topic of exploration, amongst many others such as GPU acceleration of scientific analysis.

NON-LINEAR GRAVITATIONAL DYNAMICS OF DARK MATTER

Main Supervisor: Prof Andrew Pontzen andrew.p.pontzen@durham.ac.uk
Office: Ogden Centre West OCW214
Funding: Durham, STFC and other funding schemes (Bell Burnell, CSC, DDS...)

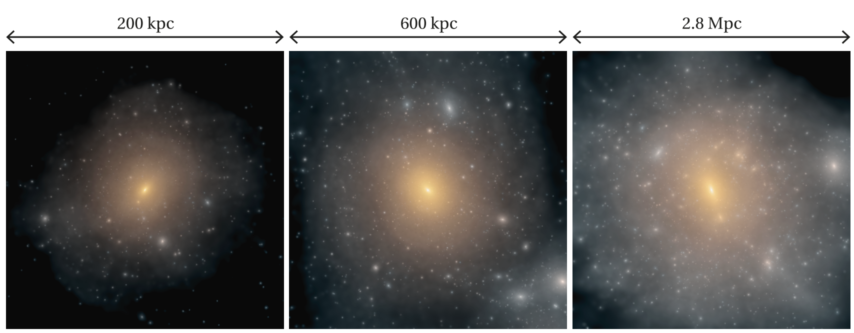
Description:

One of the major goals in cosmology and astrophysics today is to identify the nature of dark matter. In pursuit of this goal, it is essential to understand the dynamics of particles which interact through gravity alone; to a good approximation, dark matter must fall in this category, with any non-gravitational interactions being strongly subdominant. Major unresolved questions in this area include how and why dark matter structures reach an equilibrium bound state, and how these structures can then be altered by the gravitational action of supernovae and other sources of energy. Because gravity is a long-range force, normal thermodynamic arguments about the large-scale behaviour of dark matter fail spectacularly (the 'gravothermal catastrophe').

Sophisticated computer simulations provide considerable insight into how dark matter will behave in reality, but still leave crucial open questions. For example, while it has long been established that dark matter 'halos' that surround galaxies follow a characteristic density profile (specifically the 'Navarro-Frenk-White' profile), the physical reasons for this remain only partially understood. Lacking understanding in this area is both a fundamental shortcoming of current physics and a practical limitation for making robust predictions and comparisons with observations.

This project will involve analysing state-of-the-art simulations and pairing them with new techniques in dynamical analyses including insights from chaos theory. It requires a willingness to learn and develop new computational and mathematical techniques. There is considerable scope to tailor the project to your interests, and ultimately you will be an expert across techniques in computational and theoretical analyses, as well as in the observational properties of dwarf galaxies. There is also the opportunity to work with national and international collaborators (see the GMGalaxies website).

Example paper I: Conserved actions, maximum entropy and dark matter haloes
Example paper II: Milking the spherical cow – on aspherical dynamics in spherical coordinates
Example paper III: From particles to orbits: precise dark matter density profiles using dynamical information



The distribution of dark matter around galaxies is roughly independent of scale, but the exact way that a gravitational equilibrium is established remains only partially understood.

COMPARING OBSERVED AND SIMULATED DWARF GALAXIES

Joint Supervisors:	Prof Andrew Pontzen	andrew.p.pontzen@durham.ac.uk
	Dr Anna McLeod	anna.mcleod@durham.ac.uk
Office:	Ogden Centre West OCW214 / OCW120	

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

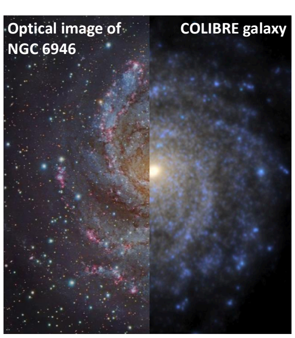
Description:

Dwarf galaxies are, as the name suggests, very small. While our Milky Way contains hundreds of billions of stars, dwarfs may contain only a few million, or even a few thousand. However they are of major importance to our understanding of the universe as a whole. First, because galaxies form 'hierarchically', today's large galaxies have assembled from dwarfs. Second, observations of surviving dwarf galaxies give us vital clues about the physics governing galaxy formation: they are relatively pristine remnants of the early universe, and moreover are sensitive indicators of the physics of dark matter.

This project will bring together breakthroughs in observational and computational studies of dwarf galaxies, to study their physical implications. On the observational side, astronomers have developed the ability to find very diffuse, very faint galaxies and study the individual stars within them. This allows for reconstructing detailed histories of when these tiny objects formed their stars. Integral field unit spectroscopy adds vital information on the movement of ionised gas, while radio observations can pinpoint the location and motion of cool neutral gas.

On the computational side, there has been immense progress in hardware speed coupled to an increasing sophistication of software designed to simulate galaxy formation. This has allowed individual stars, and the effects of energy from their radiation and supernovae, to be resolved within simulations of dwarf galaxies. However as yet comparisons between results from these new observational and computational facilities are only just getting underway. Making such comparisons poses its own challenges, which this project will tackle.

This project will involve analysing data from some of the world's largest telescopes (both ground- and space-based), making comparisons with cutting-edge numerical simulations. Depending on your interests, the work can be sculpted to focus more on the numerical or observational side. Either way, becoming expert in bridging data and numerics will provide you with a valuable astrophysics skill that is also highly transferrable into other sectors. The work will be co-supervised by Andrew Pontzen and Anna McCleod, who are experienced mentors with extensive international networks in the numerical and observational fields respectively.



Comparing simulated and observed galaxies is an essential way to make progress in understanding the universe. Here a comparison is made between spiral galaxies in COLIBRE. This project will have access to state-of-the-art simulations from the EDGE and COLIBRE collaborations, and will focus in on smaller dwarf galaxies.

Relevant computational papers:
EDGE-INFERNO: Simulating every observable star in faint dwarf galaxies and their consequences for resolved-star photometric surveys
EDGE: Predictable Scatter in the Stellar Mass–Halo Mass Relation of Dwarf Galaxies

Relevant observational papers:
Stellar Feedback and Resolved Stellar IFU Spectroscopy in the Nearby Spiral Galaxy NGC 300
Shaken, but not expelled: Gentle baryonic feedback from nearby starburst dwarf galaxies

COMPACT TERAHERTZ SPECTROMETER BASED ON METASURFACES

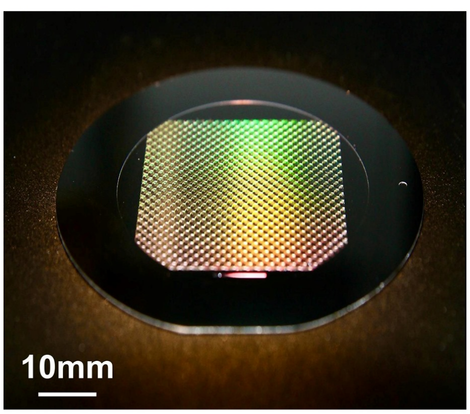
Supervisor: Dr. Yuan Ren yuan.ren@durham.ac.uk
Office: Ogden Centre West 023
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

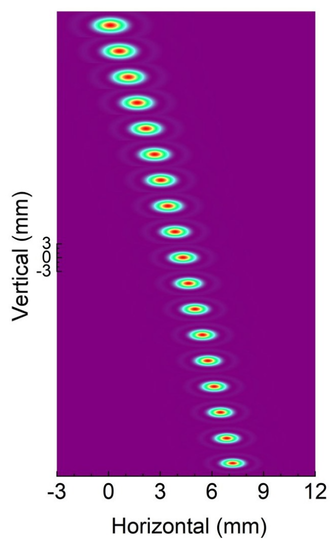
Description:

Terahertz (THz) spectroscopy holds significant importance owing to the abundance of molecular and atomic fingerprint lines within this frequency range. In astronomy, THz spectroscopy provides a powerful probe of rotational and vibrational transitions of molecules, offering insights into star and planet formation as well as the physical and chemical processes in galactic and interstellar environments.

Conventional THz spectrometers typically rely on multiple free-space optical elements or moving parts, which makes them bulky and challenge to integrate into compact systems. Metasurfaces - planar optical components composed of subwavelength nanostructures, have recently emerged as a powerful new approach for controlling the polarization, phase, and amplitude of light with unprecedented flexibility. These advances open the door to the design of highly compact and versatile spectroscopic instruments.

This PhD project will focus on the development of a proof-of-concept compact THz spectrometer based on metasurfaces. The project will span scales from designing and optimizing nanophotonics to integrating and characterizing a full spectrometer system. We are seeking a motivated candidate with a strong interest in experimental physics. Applicants from broad backgrounds, including astronomy, optics, electrical engineering are encouraged to apply.





Left: The image of the fabricated THz metasurface phase grating . *Right:* Intensity distribution of the miniaturized terahertz metasurface spectrometer.

More reading:
N. Yu and F. Capasso , Flat optics with designer metasurfaces, Nat. Mater. 2014; https://doi.org/10.1038/nmat3839
M. Faraji-Dana, et al, Compact folded metasurface spectrometer. Nat. Comm. 2018; https://doi.org/10.1038/s41467-018-06495-5
Y. Ren, et. al, Dual-wavelength terahertz two-dimensional phase gratings based on all dielectric metasurfaces, Appl. Phys. Lett. 2024; https://doi.org/10.1063/5.0187598

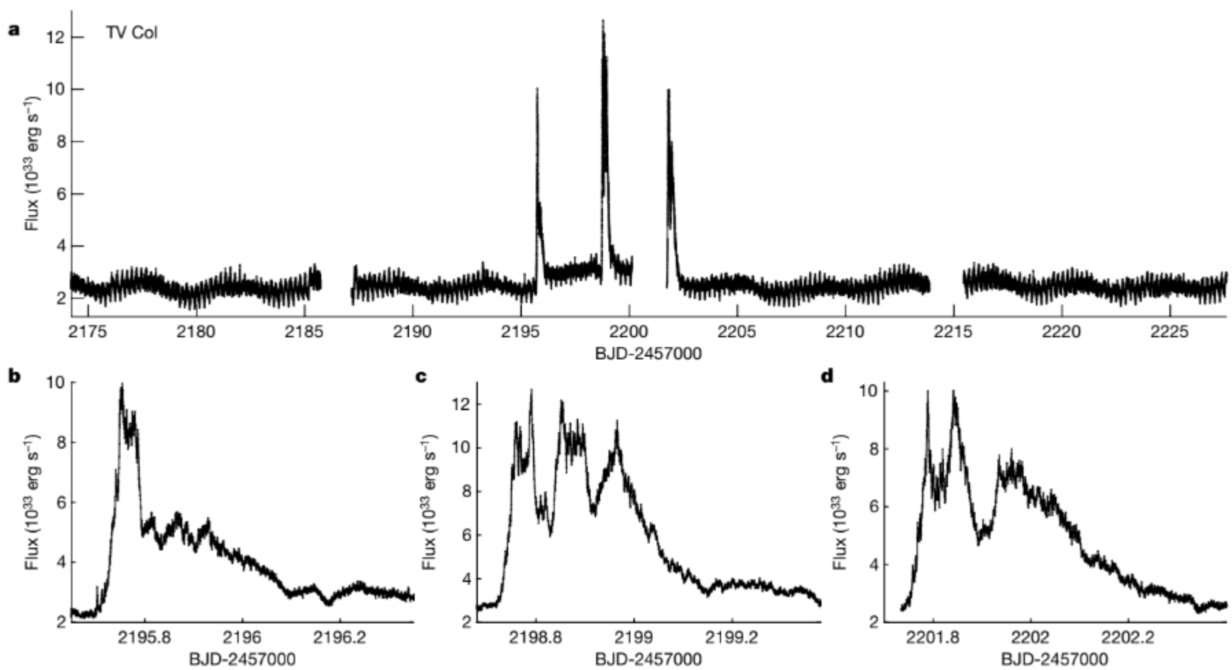
HUNTING FOR HOSTLESS TRANSIENTS WITH BLACKGEM AND RUBIN/LSST

Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
Office: Ogden Centre West 103
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

The BlackGEM telescope array and Rubin/LSST, both situated in Chile, are uniquely positioned to explore the dynamic southern sky with wide-field, high-cadence optical imaging. Among the most exciting prospects are the discovery of so-called "hostless" transients: short-lived flashes of light with no immediately identifiable host galaxy or stellar counterpart. These enigmatic events conceal some of the most exotic phenomena in astrophysics, from faint supernovae and outbursting compact binaries to the newly identified class of micronovae — optical bursts hypothesised to be the result of thermonuclear bursts localised to the magnetic poles of accreting white dwarfs.

This PhD project, will systematically identify and follow up such hostless events, developing strategies to rapidly cross-match candidates with Gaia and other catalogues, and to trigger fast spectroscopic observations. A key goal will be to uncover and characterise a statistically meaningful population of micronovae, probing their rates, energetics, and impact on white dwarf evolution, ultimately testing the thermonuclear explosion hypothesis. By combining real-time data analysis, machine-learning tools, and multi-wavelength follow-up, the project will open a new discovery space for faint and fast southern-sky transients.



TESS lightcurve of the accreting white dwarf TV Col showing three rapid (10 hour) bursts identified as micronovae. The rapid rise and short duration makes finding these events and following them up very challenging, but BlackGEM and Rubin/LSST should be able to discover these thanks to their optimised observing strategy to find and locate new transients.

More reading:
The BlackGEM telescope array I: Overview : https://arxiv.org/abs/2405.18923
Vera C. Rubin Observatory: https://www.lsst.org/
Localized thermonuclear bursts from accreting magnetic white dwarfs: https://www.nature.com/articles/s41586-022-04495-6
Simo's webpage: https://www.astro.dur.ac.uk/ simo/

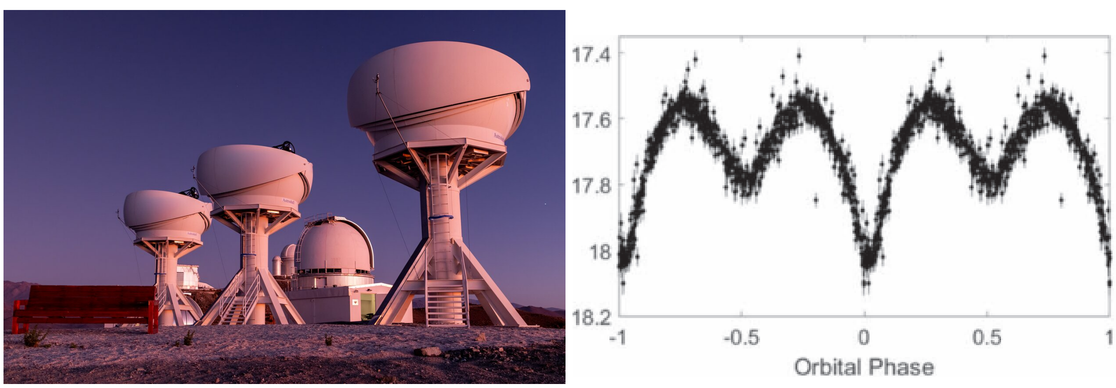
HUNTING COMPACT BINARIES IN THE SOUTHERN SKY WITH BLACKGEM AND RUBIN/LSST

Main Supervisor:	Dr. Simone Scaringi	simone.scaringi@durham.ac.uk
Office:	Ogden Centre West 103	
Funding:	STFC and other funding schemes (Bell Burnell, CSC, DDS...)	

Description:

The BlackGEM telescope array and Rubin/LSST are providing a new window into the time-variable southern sky, enabling systematic searches for compact binaries with short orbital periods. Systems such as cataclysmic variables (CVs), ultracompact binaries, and other white dwarf, neutron star, or black hole accretors are prime targets that will be discovered with these new facilities. Their optical variability, eruptive behavior, and distinctive light-curve signatures allow these time-domain surveys to reveal new members of these populations, many of which remain hidden in current catalogues. These discoveries will expand our understanding of how compact binaries form, evolve, and interact with their environments.

This PhD project will exploit both BlackGEM and LSST high-cadence imaging to detect and characterise short-period binaries, combining this with spectroscopic and multi-wavelength follow-up. By assembling and analysing a statistically significant sample, the project will provide new constraints on binary evolution pathways and the demographics of compact objects in the Galaxy. Given the large dataset from these time-domain surveys, building and identifying suitable candidates will most likley involve the use of machine learning techniques. The results are expected to inform predictions for the gravitational-wave population to be probed by *LISA*, helping to refine models of the Galactic foreground and improve our understanding of the astrophysical processes that shape compact binary evolution.



Left: The BlackGEM array situated at La Silla observatory in Chile *Right:* Phase-folded lightcurves of a compact binary with orbital period of 56.4 minutes recovered from the ZTF Survey (Burdge et al. 2020).

More reading:
The BlackGEM telescope array I: Overview : https://arxiv.org/abs/2405.18923
Vera C. Rubin Observatory: https://www.lsst.org/
A Systematic Search of Zwicky Transient Facility Data for Ultracompact Binary LISA detectable Gravitational-wave Sources: https://arxiv.org/abs/2009.02567
Simo's webpage: https://www.astro.dur.ac.uk/ simo/

TURNING NOISE INTO SIGNAL: USING THE LISA FOREGROUND TO PROBE GALACTIC BINARY POPULATIONS

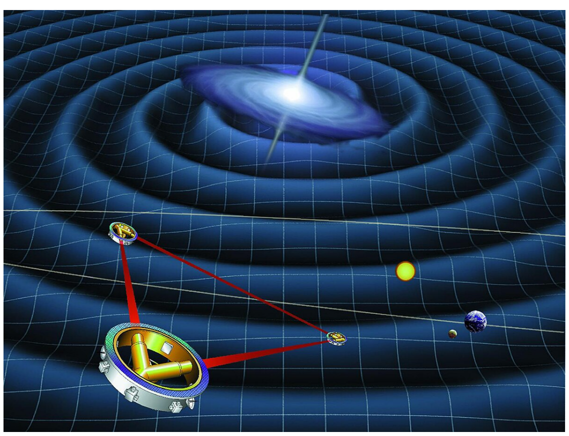
Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
Office: Ogden Centre West 103

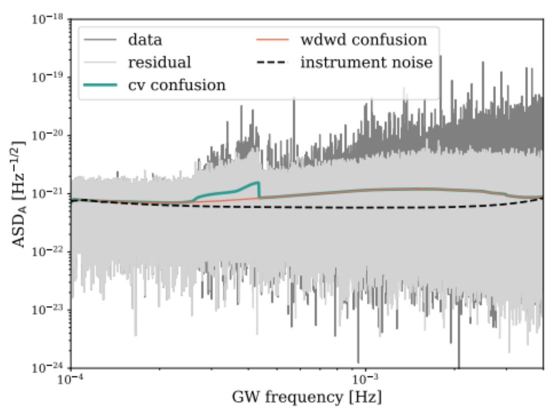
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Cataclysmic variables (CVs) and ultracompact binaries are expected to dominate the Galactic foreground in the LISA gravitational-wave band, yet their true space density and evolutionary pathways remain uncertain. Current population models predict a wide range of orbital period distributions and formation channels, leading to large uncertainties in the strength and shape of the unresolved GW background. This project will use synthetic Galactic populations of compact binaries — spanning different space densities, period distributions, and evolutionary prescriptions — to simulate their collective LISA signals and quantify the astrophysical information encoded in the excess foreground noise.

By systematically varying binary population inputs and mapping the resulting GW spectra, the project will establish how LISA's unresolved signal can be inverted to directly constrain space densities, evolutionary timescales, and binary formation channels. Particular emphasis will be placed on CVs and other short-period accretors, which are both key electromagnetic transients and major GW emitters. The outcome will be a new framework linking binary evolution and LISA observables — enabling us to transform the foreground "noise" into a powerful probe of the Galactic population of compact binaries.





Left: Artistic image showing a representation of the LISA interferometer. *Right:* Amplitude spectral density of simulated LISA data containing one realisation of the galactic population of white dwarf binaries and the 1kpc sample of Cataclysmic Variables after four years of observations. This project will expand this first study to explore how varying population parameters (e.g. space density) will alter the expected LISA signal.

More reading:
LISA Galactic binaries with astrometry from Gaia DR3 : https://arxiv.org/abs/2302.12719
Cataclysmic variables are a key population of gravitational wave sources for LISA : https://arxiv.org/pdf/2307.02553
LISA mission consortium: https://www.lisamission.org/
Simo's webpage: https://www.astro.dur.ac.uk/ simo/

EAVESDROPPING ON ACCRETION DISKS: USING TESS AND PLATO TO UNRAVEL THE PHYSICS OF ACCRETION

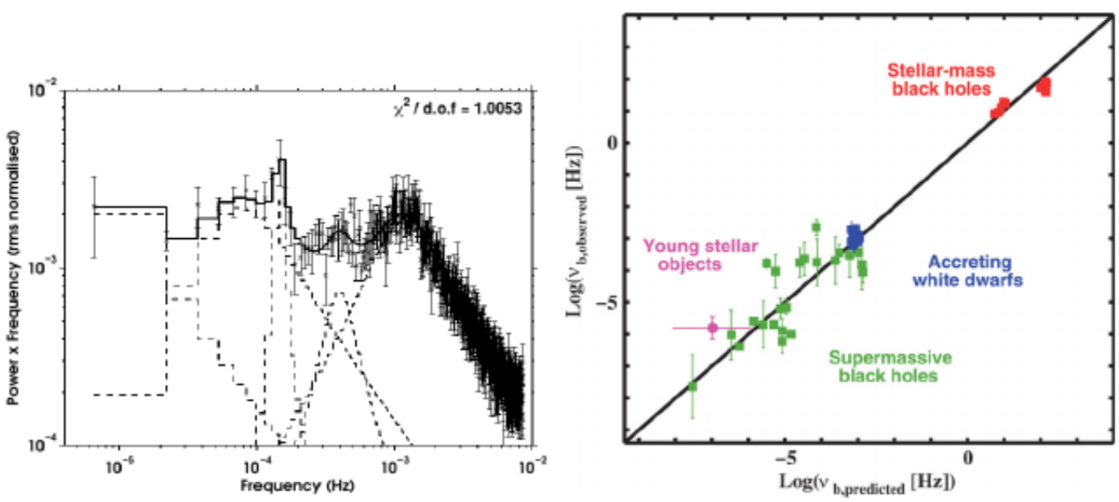
Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
Office: Ogden Centre West 103
Funding: STFC and other funding schemes (Bell Burnell, CSC, DDS...)

Description:

Accretion regulates the growth of most astrophysical objects: from star formation to supermassive black holes, from galaxy evolution to interacting binaries in our neighbourhood. It requires angular momentum loss, usually via accretion disks, which are found in young stellar objects (YSOs), compact binaries (WDs, NSs, BHs), and active galactic nuclei (AGN). Despite their ubiquity, disks are unstable: systems alternate between long quiescent states and short outbursts, during which most mass is accreted. Classical models (e.g. Pringle & Rees 1972) and more recent magnetohydrodynamics (e.g. Blaes & Balbus 1994) suggest common physical processes across all disks. Yet, the detailed physics of angular momentum transport, outbursts, and secular evolution remain poorly understood.

This project will focus on exploiting TESS and PLATO space-based observatories and use their provided variability data to apply timing tools to a large samples of accreting systems, focusing on white dwarfs. The goal will be to test whether accretion physics is indeed scale-invariant across mass and size scales using accreting white dwarfs as astrophysical laboratories. Key questions include:

- What viscous mechanisms drive inward propagation of matter?
- How does disk geometry depend on accretion rate?
- How do disks respond to different radiation environments?
- What are the long-term changes in mass transfer, especially in binaries?



Left: Power-spectral density (PSD) for the accreting white dwarf MV Lyrae Scaringi et al. (2012). The high-frequency break is common across accreting systems. *Right:* The accretion variability plane linking mass (M), radius (R), and accretion rate ($\dot{M}_{acc}$) to PSD breaks (ν_b) across scales Scaringi et al. (2015).

More reading:
TESS Science Support Center : https://heasarc.gsfc.nasa.gov/docs/tess/
PLATO mission: https://platomission.com/
Discovery of persistent quasi-periodic oscillations in accreting white dwarfs: a new link to X-ray binaries: https://arxiv.org/pdf/2410.01896
A physical model for the flickering variability in cataclysmic variables: https://arxiv.org/pdf/1311.6814

FROM THE FIRST GALAXIES TO THE MILKY-WAY: THE ROLE OF ACCRETION, STAR FORMATION AND FEEDBACK IN SHAPING GALAXIES

Supervisor: Prof. Mark Swinbank a.m.swinbank@durham.ac.uk
Office: Ogden Centre West 113

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

Description:

The cycling of baryons into galaxies, through their interstellar medium (ISM) and super massive mass black holes and then back out in to the circum-galactic medium are crucial processes in galaxy evolution. Numerical simulations that attempt to describe baryon cycling highlight the importance of accretion and cooling, and also of feedback from star formation and Active Galactic Nuclei (AGN). The coupling of energy to the ISM is particularly important as it governs the growth, chemical enrichment, and quenching of galaxies. Quantitative constraints on the sources exciting the gas and driving outflows, the momentum and energy transfer from radiation to the ISM, and the redistribution of gas and metals are vital at redshift (z)$\sim$ 1–3 since this is the epoch in which the growth and subsequent quenching of todays massive early type galaxies occurs.

In this project, we will primarily focus on constraining the cycling of baryons in and out of galaxies at high redshift using deep, multi-wavelength imaging and spectroscopy, leveraging major observational programs such as those with *James Webb Space Telescope (JWST)*, combined with new VLT MUSE- and KMOS- Large Programs. Our goals are to:

• map the large scale cosmic structures between galaxies to provide environmental constraints on gas flows for thousands of galaxies up to $z \sim 6$. This will trace gas accretion and interaction of galaxies with the cosmic web.

• Characterise outflows and feedback energetics for distant galaxies, combining VLT/MUSE data with resolved spectroscopy from the VLT/KMOS to study gas kinematics, ionization mechanisms, and feedback processes within the ISM of individual galaxies. We will quantify mass outflow rates, wind energetics, and the impact of star formation and AGN-driven outflows on galaxy evolution.

• Quantify the role of obscured star formation by correcting for dust-obscuration. We will refine estimates of stellar mass, star formation rates, and dust attenuation effects, ensuring an accurate interpretation of baryon cycling.

By integrating these observations, this study will provide unprecedented constraints on gas accretion, feedback, and the evolution of galaxies at cosmic noon.

This is an observationally-driven PhD project. The successful student will use a range of observational facilities, potentially including travel to Chile, Hawaii or Europe to obtain data for their thesis. The PhD will provide training in the reduction and analysis of imaging, integral field spectroscopy and interferometry (e.g. using *James Webb Space Telescope*, MUSE, KMOS and ALMA). We also expect to use our observations to test the theoretical models for galaxy formation being developed at Durham. In particular we will test whether the sub-grid recipes used to describe star formation and feedback that are calibrated at $z \sim 0$ in the models are applicable in the dense and rapidly evolving ISM of high redshift galaxies.

See also: http://www.astro.dur.ac.uk/~ams/kmos/ and http://www.astro.dur.ac.uk/~ams

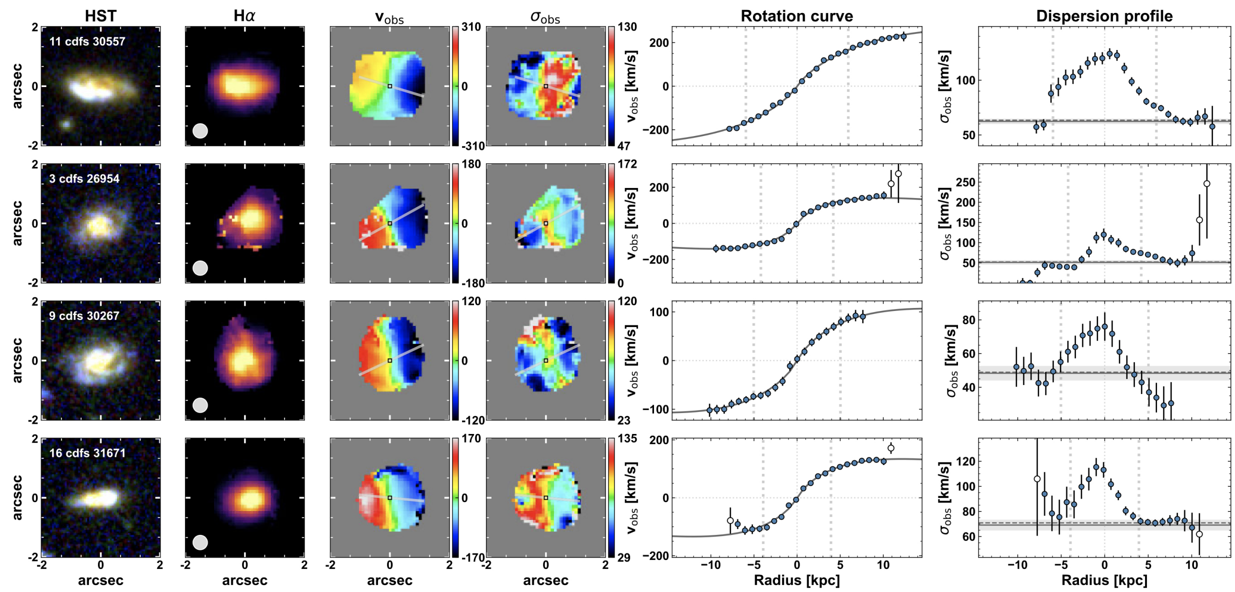


Fig. 1. Example images and dynamical maps of star-forming galaxies at $z \sim 1.5$ from our recent VLT/KMOS survey. For each galaxy, we show the *HST IJH*-colour image, the KMOS Hα line-of-sight velocity map, and the galaxy rotation curve, along with their one-dimensional dynamical profiles. We will exploit maps like these to measure the dynamics, rotation curves, and outflows, and combine these with maps of the large scale structure of the field from VLT/MUSE to quantify the role of accretion, dynamics and feedback in the baryon cycle.

CHARACTERISING ATMOSPHERIC TURBULENCE FOR GROUND BASED ASTRONOMY

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

Description:

The aim of this studentship is to develop new concepts and technology to characterise the effects of atmospheric turbulence for astronomy. The optical effects of atmospheric turbulence, known as 'seeing', are a major limitation for ground based optical astronomy. Seeing degrades the image resolution that can be achieved with large telescopes and adds noise to photometric measurements.

The student will engage with the development, deployment and exploitation of site testing instrumentation for international observatories, with the goal of improving our understanding of the effects of the Earth's atmosphere on astronomical observations. A particular emphasis of this project will be to develop compact systems for turbulence monitoring with fixed pointing, so that they do not rely complex and expensive telescope and observatory installations for their operation.

The work will be directly applicable to current large astronomical telescopes, as well as the next generation of giant telescopes such as the 40 metre European Extremely Large Telescope in Chile. The aim is to provide data to improve the performance of large telescopes, for example through the optimisation of adaptive optics correction systems, or the forecasting of optical turbulence conditions at observatory sites. It will help them to reach their science goals, including characterising extra-solar planets, understanding the formation of galaxies, and elucidating the nature of dark matter and dark energy. Optical turbulence monitors also have wider applications, for example in the development of technology for satellite free-space optical communications.

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. CfAI has extensive experience in analysing atmospheric turbulence and the use of computer modelling of complex optical systems to design optical instrumentation for some of the world's premier astronomical observatories.

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.

NUMERICAL RELATIVITY IN THE REALM OF NEW PHYSICS

Main Supervisor:	Prof. Baojiu Li	baojiu.li@durham.ac.uk
Office:	Ogden Centre West 218	
2nd Supervisor:	Prof. Tobias Weinzierl (CS)	tobias.weinzierl@durham.ac.uk
Funding:	Bell Burnell, CSC, DDS, or other	

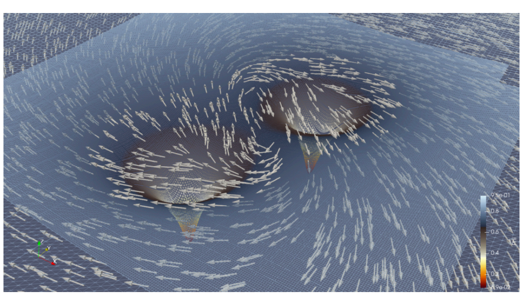
Description:

Numerical Relativity is the holy grail of computational physics. Yet, it took nearly a century after Einstein published General Relativity (GR) that long-term stable simulations of black holes became possible due to the highly nonlinear nature of the gravitational field equations. Since then, there have been huge progresses in this field, and interest has grown much stronger after the first gravitational wave (GW) detection less than a decade ago. Already, such detections have been used to shed light on the mysterious accelerated expansion of our Universe, ruling classes of gravity theories beyond GR.

With the advent of a new generation of GW detectors, GW cosmology will evolve into a mature subject in astronomy over the coming decades. In combination with numerical simulations, the data collected will allow people to test new theories of fundamental physics with unprecedented exquisiteness. However, even today, simulating the evolution of compact object systems such as black holes and neutron stars in various theories of gravity is still a big challenge.

In this project, the candidate will work on the scientific developments and applications of a new numerical relativity simulation code, ExaGRyPE, developed by a collaboration between the Physics and Computer Science departments at Durham University. There are a range of potential directions this project can lead to, including, but not restricted to, (i) the implementation and test of new physics models in the code (e.g. non-standard gravity), (ii) developing hydrodynamics modules that will enable simulations of complicated coupled multi-physics systems, or (iii) a reformulation of the underlying physical model in a higher-dimensional brane world—a simulation unfeasible with other codes in the field.

Reference: ExaGRyPE code paper



An ExaGRyPE simulation snapshot of two black holes in the process of merging. The colour map and the arrows show respectively two components (potential and shift vector) of the metric tensor, which describe the spacetime. Candidates will have the opportunity to collaborate with a larger group of code developers, and to acquire research software engineering skills. There is also the opportunity to use and learn high-performance computing skills such as GPU programming.

HUNTING COSMIC BEASTS: DETECTING WOLF–RAYET STARS IFU SPECTROSCOPY

Main Supervisor:	Dr. Anna McLeod	anna.mcleod@durham.ac.uk
Office:	Ogden Centre West 120	
Funding:	Bell Burnell, CSC, DDS, or other	

Description:

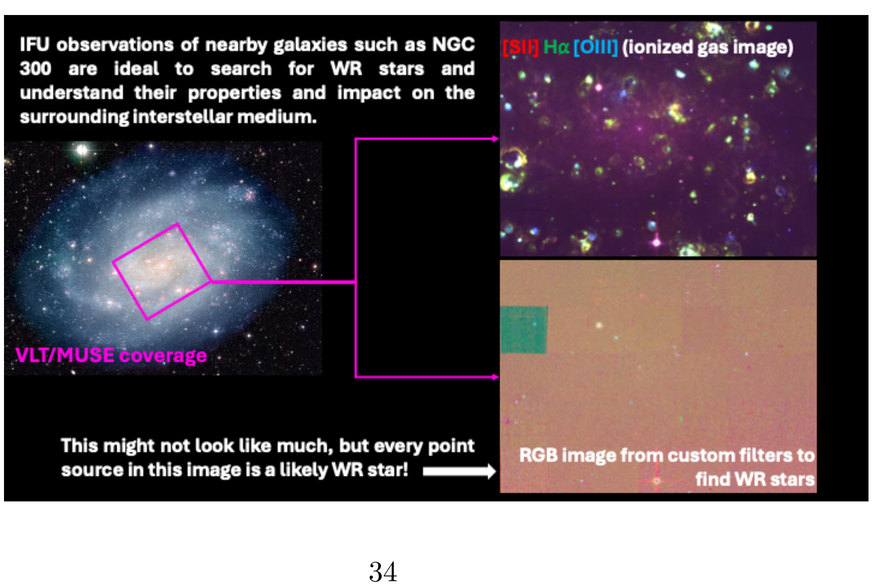
Wolf–Rayet (WR) stars are among the most extreme stars in the Universe: hot, massive, and violently shedding their outer layers in powerful winds. They are the immediate progenitors of many stripped-envelope supernovae and are thought to play a major role in driving the hard ionizing radiation that lights up star-forming galaxies near and far. Detecting and typing these stars is challenging, however, because their broad emission features are easily washed out when using only broadband imaging. This project turns that difficulty into an opportunity.

The first part of the PhD will harness cutting-edge integral field unit (IFU) spectroscopy — where every pixel is a spectrum — for entire nearby galaxies. From these data cubes, you will design and test synthetic narrow-, medium-, and broad-band filters to isolate the characteristic WR "bumps" around 4686 Å and 5808 Å. By comparing different filter setups, you will determine which combinations maximize the chances of finding WR stars even when only imaging (and no follow-up spectroscopy) is available. Because you start from IFU datacubes, you can validate your photometric detections directly with spectra, giving you a unique laboratory to test detection strategies, quantify completeness, and tune classification methods. The outcome is a powerful, community-ready "cookbook" for finding WRs in galaxies with nothing more than custom imaging.

Once you know where the WR stars are — and whether they are nitrogen-rich (WN), carbon-rich (WC), or rarer oxygen types (WO) — the project opens onto a wide range of science questions. How do WR demographics change with metallicity across galaxies? Do WR stars account for the hard ionizing radiation seen in nebular He II emission, or are other sources required? How do WR winds enrich and stir their local environment? And how do WR populations map onto predictions from binary versus single-star evolution models? With the IFU data in hand, you won't just detect the stars: you'll be able to place them in their galactic context, measure their local environments, and compare to models in unprecedented detail.

This PhD is ideal for a student who enjoys combining hands-on data science, observational astrophysics, and big-picture questions about stellar and galaxy evolution. You will develop transferable skills in spectral analysis, statistical methods, and Python-based data pipelines, while also contributing practical tools that can be used by the broader astronomical community. Along the way, you will be part of a growing effort to connect the life and death of massive stars with the galaxies they help to shape.

More about this topic: Wolf-Rayet stars in the Antennae unveiled by MUSE
The extended He II λ4686 emission in the extremely metal-poor galaxy SBS 0335 - 052E seen with MUSE
Physical Properties of Wolf-Rayet Stars



FUNDAMENTAL COSMOLOGY WITH LARGE-SCALE STRUCTURE

Main Supervisor:	Dr. Sownak Bose	sownak.bose@durham.ac.uk
Office:	Ogden Centre West 221	

Funding (PhD):	STFC and other funding schemes (Bell Burnell, CSC, DDS, Inlaks...)
Funding (MScR):	None defined. Project is adaptable as an MScR project

Description:

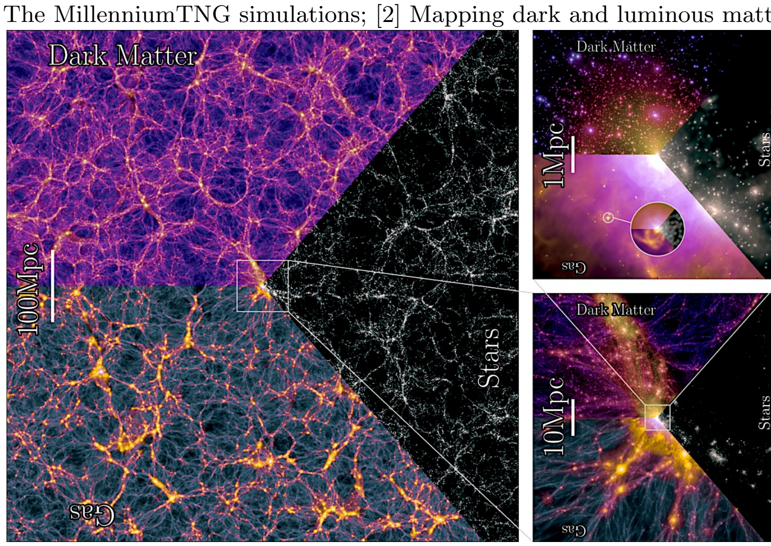
Cosmology is at the brink of a paradigm-defining decade. Several large-scale surveys of galaxies have been designed for the ultimate goal of answering open questions relating to the makeup and evolution of our cosmos: what is dark matter? Why does the Universe accelerate in its expansion? How do galaxies 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;
- Development of semi-analytic methods and Machine Learning to create models based on more computationally expensive supercomputer simulations;
- Developing a cutting-edge cosmological inference framework that utilises the full information content of datasets at the field level, rather then using simple summary statistics.

You will have the opportunity to work at the forefront 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:

[1] The MillenniumTNG simulations; [2] Mapping dark and luminous matter; [3] Field-level inference in 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. Adapted from Pakmor et al. 2023.*

THE APPLICATION OF AI TO REAL-TIME PHOTON DETECTION FOR NEXT GENERATION LARGE SCALE MKID ARRAYS

Main Supervisor:	Prof. Kieran O'Brien	kieran.s.obrien@durham.ac.uk
Office:	Ogden Centre West 029	
2^{nd} Supervisor:	Dr. Sofia Dimoudi	sofia.dimoudi@durham.ac.uk
Funding:	None defined	

Description:

MKIDs (Microwave Kinetic Inductance Detectors) is a type of superconducting photon detector that is capable, among others, of single photon detection with precise timing and energy information, and virtually no noise. These unique features, together with the capability of manufacturing vary large arrays, can provide significant advantages over traditional imaging detectors for scientific applications and beyond. While astronomical instrumentation is currently the main field that uses MKIDs, there is emerging interest for additional applications such as particle physics, THz imaging, biological imaging and more.

Image formation with an MKID array requires a series of processing steps in order to apply continuous detection of individual photon events in each streaming time series originating from an array element. With array sizes at the scale of 20000+ detector pixels, this can be a very challenging task to achieve in real time.

The main aim of this project is to study and experiment with the application of machine learning techniques to the problem of real-time image formation of MKIDs to enable optimal speed and quality for a range of applications, while focusing on Astronomical Adaptive Optics. This will include work in the requirements of the mathematical model of the MKID signal and the client application, and mapping to a machine learning framework with optimisation, as well as exploiting GPU hardware to optimise computing performance.

This project will take place in the MKID group in the Centre for Advanced Instrumentation. The group consists of a number of post-docs, PhD Students and is supported by specialist hardware and software engineers.