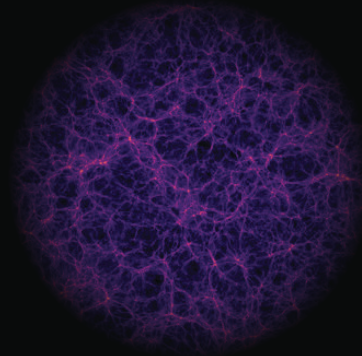


Astronomy PhD & MScR Projects at Durham

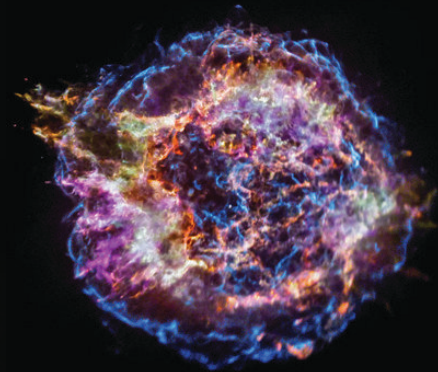
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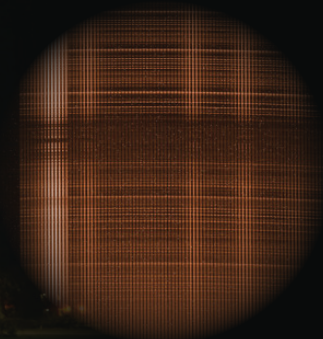
ICC



CEA Durham
Centre for
Extragalactic
Astronomy



CfAI



PHD & MSCR PROJECTS IN ASTRONOMY FOR AUTUMN 2027 START

Introduction

List of STFC/Durham funded PhD Projects

Alexander: Why are (some) Quasars Special? Towards an Understanding of the Evolution of Quasars
Brown: Improving the Accuracy of Drone Based Remote Sensing with Astronomical Instrumentation
Brown: Ultra High Energy Neutrino Astronomy with Trinity
Brown: Calibration Instrumentation for the Trinity Neutrino Telescope
Cooke: Big Bang Nucleosynthesis
Frenk: From the First Stars to the First Galaxies
Frenk: Cosmological Constraints on the Mass of the Neutrino
Gadotti: The Classical Bulge Problem
Greenwell: The Restless Nature of Growing Supermassive Black Holes
Ingram: Probing Black Holes and Neutron Stars with X-Ray Polarimetry-Timing
McLeod: Stellar Engines of Galaxy Evolution: Quantifying Feedback from Massive Stars
McLeod: Puffy Galaxies across Cosmic Time: Tracing Stellar Feedback from Cosmic Noon to Today
Oman: Gas Dynamics and Dark Matter in Dwarf Galaxies
Pontzen: Black Holes and Galaxies
Ren: Compact TeraHertz Spectrometer Based on Metasurfaces
Ren: Rydberg Atomic Receivers for Submillimetre Astronomy
Scaringi: Hunting for Hostless Transients with BlackGEM and Rubin/LSST
Scaringi: Hunting Compact Binaries in the Southern Sky with BlackGEM and Rubin/LSST
Scaringi: Eavesdropping on Accretion Disks: Using TESS and PLATO to Unravel the Physics of Accretion

List of additional PhD Projects that require applications for funding

Li: Numerical Relativity in the Realm of New Physics

List of MScR Projects

Smith: Probing the Stellar Content of Elliptical Galaxies with Fluctuation Spectroscopy
Smith: Modelling Dusty Gravitational Lenses

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 2027. 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 include up to 1-2 international studentships.

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

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 visit our web page.

A potential funding route is provided by the **China Scholarship Council (CSC)** scheme. The

application deadline for 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 2027 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 CSC applications to be submitted by **early December 2026** 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 December 2026** 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*, *CONICET*, and *SECIHTI* PhD scholarships.

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 visit 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 coordinator, Dr. Dimitri Gadotti (dimitri.a.gadotti@durham.ac.uk) for further details.

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

Supervisors:	Prof. David Alexander Dr. Claire Greenwell	d.m.alexander@durham.ac.uk claire.l.greenwell@durham.ac.uk
Offices:	Ogden Centre West 119 & 126	
Funding:	STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)	

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 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, 2024; Sargent et al. 2026). 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, the trigger mechanism, and the influence on the galaxy. The leading model for the evolution quasars is shown in the figure below.

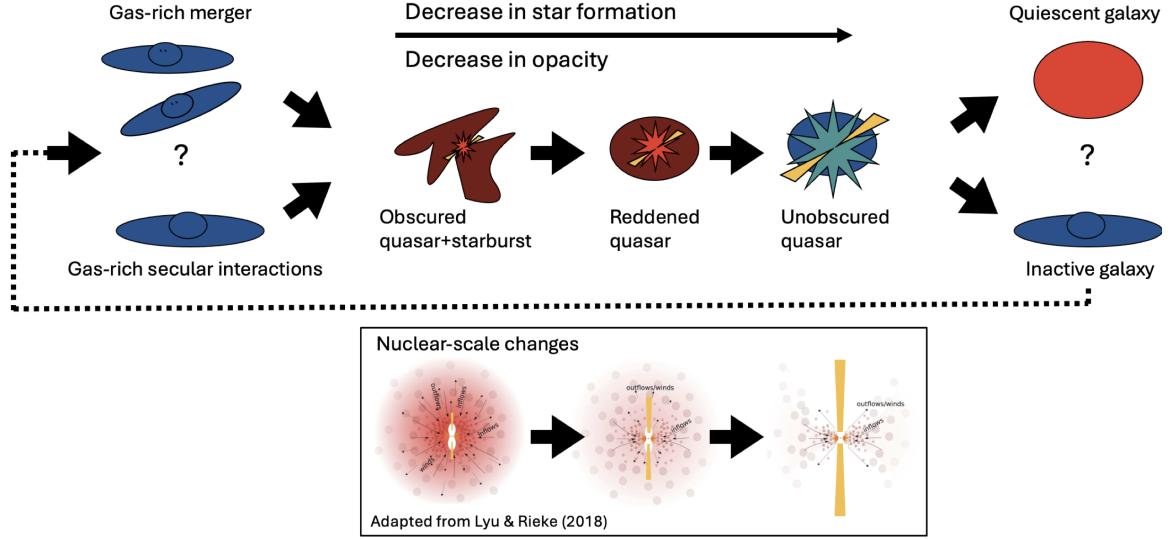


Figure: The leading evolutionary model for quasars. The sequence is triggered by huge amounts of gas inflow (potentially from galaxy mergers or interactions) which leads to a burst of dust-obscured star formation and a heavily buried (i.e., obscured) quasar. As the quasar ages it drives out energetic winds which blows away the obscuring dust, revealing a red quasar, followed by an unobscured quasar, and ultimately an inactive or quiescent galaxy. Schematic taken from Alexander et al., 2025.

We are looking for a student to extend our understanding of the evolution of quasars. This research will utilise our obscured infrared quasar survey with the 4MOST instrument (Merloni, Alexander et al. 2019; Andonie et al., 2025), which is starting its 5-year survey in late 2026, plus our access to the Dark Energy Spectroscopic Instrument (DESI) survey (DESI collaboration et al. 2026; Alexander et al. 2023). Each survey will detect over 1 million quasars, pushing deeper than previously achievable and providing an exceptional (and the first nearly complete) quasar census.

In this project you will be able to undertake systematic analyses using a variety of multi-wavelength datasets to quantify the differences between normal, red, and fully obscured quasars. You will have the opportunity to 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 be able to harness deep multi-wavelength observations to measure the physical properties of fully obscured quasars to see how they are related to red and normal quasars. You will be able to join and contribute to the DESI and 4MOST collaborations, and depending on the specific direction of your project may propose for further telescope time. You will also learn transferable skills including statistical data handling, programming, presenting your work, and working within large collaborations.

Main Supervisor: Dr. Anthony M. Brown anthony.brown@durham.ac.uk
Office: Ph125B
Funding: Durham, STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

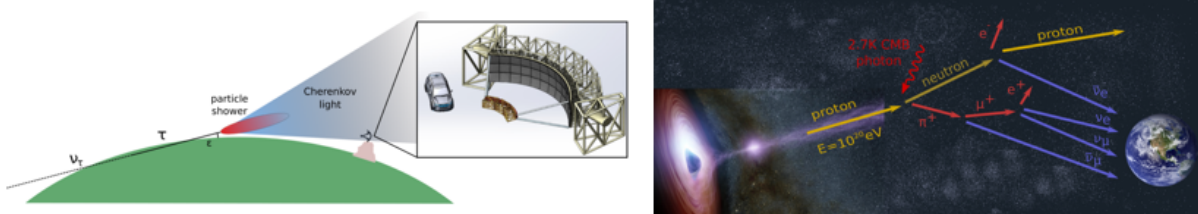
The recent advances in UAV capability has given the remote sensing community a number of exciting possibilities. Unfortunately, in the context of plant ecology, the realization of this potential has focused on monitoring crop health where the species of plant is known. Furthermore, this monitoring is 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.



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Main Supervisor: Dr. Anthony M. Brown anthony.brown@durham.ac.uk
Office: Ph125B
Funding: Durham, STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

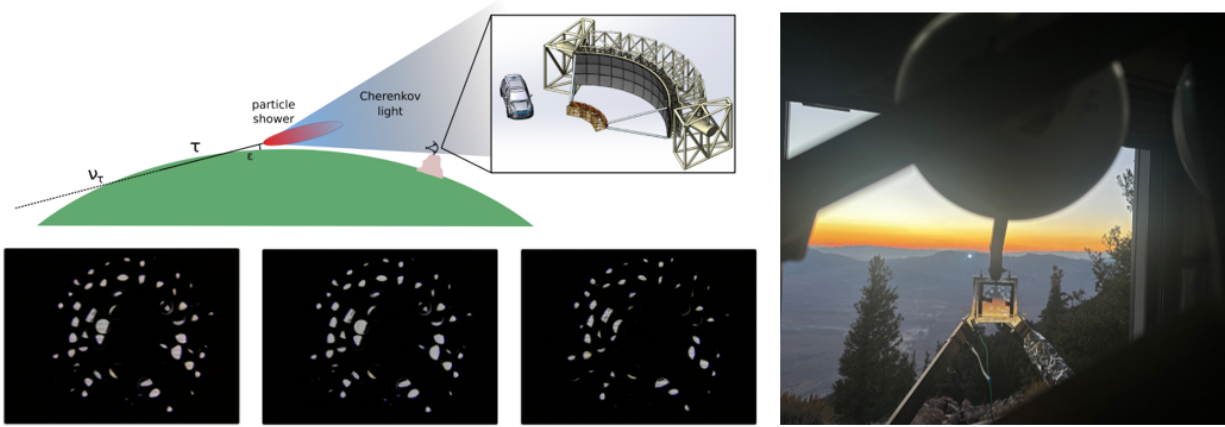
Your work will focus on developing and applying advanced simulations to quantify Trinity’s sensitivity and reconstruction accuracy, cleaning and analysing real observational data from the demonstrator, and investigating potential astrophysical sources of UHE neutrinos to interpret these observations. Through this combination of simulation, data analysis, and physical modelling, you will make substantive contributions to Trinity’s scientific output and its evolution toward a full-scale observatory.



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Main Supervisor: Dr. Anthony M. Brown anthony.brown@durham.ac.uk
Office: Ph125B
Funding: Durham, STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Your work will span three major calibration domains. You will design, refine, and operate the camera calibration system, enabling accurate gain, timing, and uniformity measurements across thousands of SiPM pixels. You will develop atmospheric-sensing techniques using controlled light beacons, characterising atmospheric transmission and its impact on Cherenkov signals in real time. And you will pioneer UAV-based mirror alignment, using airborne platforms to map optical throughput and verify the telescope's point-spread function with unprecedented flexibility. Through this combination of hardware development, field deployment, data analysis, and calibration modelling, you will make foundational contributions to Trinity's reliability and scientific readiness as it evolves toward a full-scale UHE neutrino observatory.



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).

BIG BANG NUCLEOSYNTHESIS

Main Supervisor: Prof. Ryan Cooke
Office: Ogden Centre West 216
Funding: Royal Society (4 years)

ryan.j.cooke@durham.ac.uk

Description:

Cosmology and particle physics are experiencing a golden age of discovery. This discovery period has enlightened us to a Universe that is filled with a mix of exotic components, most of which we do not fully understand. Nevertheless, this effort represents our best current physical description of the Universe, formally known as the Standard Model of particle physics and cosmology.

Currently, the earliest test of cosmology and particle physics is based on studying the lightest nuclides (hydrogen, deuterium, helium, and lithium), that were created during the first few minutes after the Big Bang. This process, which is referred to as Big Bang Nucleosynthesis (BBN; see Cooke et al. 2026a for a review), is a competition between the expansion rate of the Universe and the rate that the primordial nuclides were made.

This is a challenging PhD project that will deduce the primordial helium isotope ratio ($^3\text{He}/^4\text{He}$) for the first time, and provide a new test of cosmology. The PhD student assigned to this project will primarily use their computational skills to extract and analyse some of the most exquisite spectroscopic data ever recorded for astronomical purposes. There are three primary components to this project:

1. Technique development using data that are already available. The PhD student will analyse absorption lines in archival data to extract the physical properties of gas clouds where $^3\text{He}/^4\text{He}$ can be measured.
2. Develop new computational algorithms to analyse Milky Way gas clouds and measure their helium isotope ratio. This will be combined with Galactic Chemical Evolution models to infer the primordial $^3\text{He}/^4\text{He}$ ratio with ~ 10 percent precision (Cooke et al. 2022, 2026b).
3. Obtain spectroscopy of gamma ray burst (GRB) optical afterglows (see image) that intersect gas clouds where $^3\text{He}/^4\text{He}$ could be measured (see, for example, the GRB observed by Fynbo et al. 2014).



Artist's impression of a GRB afterglow. The bright white jet intersects nearby clouds of gas that imprint absorption features on the spectra of the GRB. These absorption lines allow us to count the relative number of ^3He and ^4He atoms that are in these gas clouds. GRBs that explode in near-pristine environments contain a signature of the ^3He and ^4He that were produced a few minutes after the Big Bang.

(Image credit: Soheb Mandhai)

FROM THE FIRST STARS TO THE FIRST GALAXIES

Main Supervisor:	Professor Sir Carlos Frenk	c.s.frenk@durham.ac.uk
Office:	Ogden Centre West 225	
2 nd Supervisor:	Professor Sownak Bose	sownak.bose@durham.ac.uk
Funding:	STFC	

Description:

One of the most exciting advances in cosmology of the past several years is the discovery by the James Webb Space Telescope (JWST) of very young galaxies, seen when the universe was only about 300 million years old (redshift $z = 14$). The primary JWST data consist of galaxy luminosity functions in the UV at redshifts $z = 10 - 14$. Several of the discovery papers claimed that the existence of such UV-bright galaxies poses a challenge to the standard model of cosmology, Λ CDM (where Λ stands for the cosmological constant and CDM for cold dark matter).

There are two complementary theoretical techniques to model galaxy formation: semi-analytic modelling and cosmological hydrodynamic simulations. The first consists of solving the relevant differential equations making simplifications such as spherical symmetry. The second solves similar equations in full generality. The ICC has pioneered both these techniques. Our semi-analytic model, GALFORM, developed over the past 25 years, is the state-of-the-art in the subject. The COLIBRE simulation project, currently being carried out in collaboration with colleagues at the University of Leiden, is the most sophisticated of its kind in the world. We have used both techniques to understand from a theoretical point of view the high-redshift JWST galaxies.

Predictions using GALFORM by ICC researchers (including the main supervisor of this project) for the galaxy UV luminosity functions at high redshift, made before the launch of JWST, turned out to match the data quite well, indicating that the early claims of a conflict with Λ CDM are misplaced. We have also recently studied the equivalent of the JWST galaxies in the COLIBRE simulations, with similar general conclusions. This project consists of investigating the origin and formation of the JWST galaxies. We know that the first stars in the universe formed at redshift $z > 20$. What happened between the formation of the first stars and the formation of the first galaxies? What are the relevant physical processes, involving dark and ordinary matter, that operated at those epochs? The student will be expected to use both GALFORM and COLIBRE for this project which will require modifying the codes to include pre-galactic physics and running and analysing the simulations.

Lu, Frenk et al. 2025. *A comparison of pre-existing Λ CDM predictions with the abundance of JWST galaxies at high redshift.*

Lu, Frenk et al. 2026. *The galaxy ultraviolet luminosity function from $z=7$ to 15 in the COLIBRE simulations.*

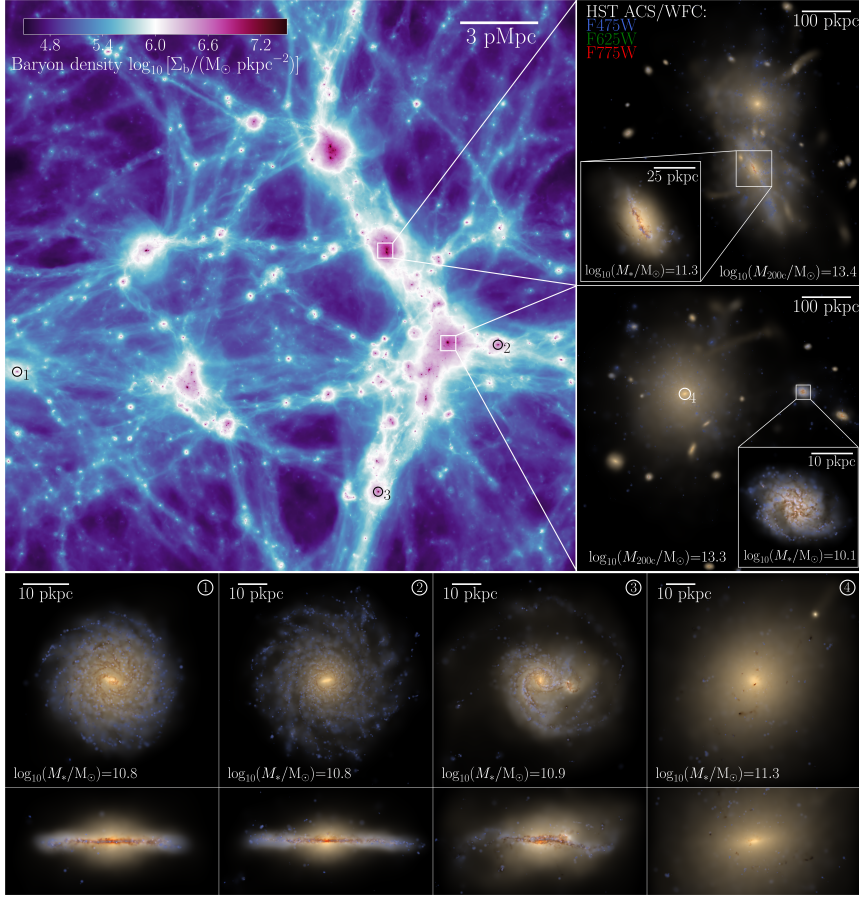


Image of the COLIBRE simulation. The top left panel shows a projection of the entire simulation with the colour encoding baryon surface density. The other panels zoom into different regions and show the stellar light in HST colours accounting for attenuation by dust. COLIBRE simultaneously models the large-scale cosmic web and the internal structure of galaxies.

COSMOLOGICAL CONSTRAINTS ON THE MASS OF THE NEUTRINO

Main Supervisor:	Professor Sir Carlos Frenk	c.s.frenk@durham.ac.uk
Office:	Ogden Centre West 225	
2 nd Supervisor:	Dr. Willem Elbers	willem.h.elbers@durham.ac.uk
3 rd Supervisor:	Professor Baojiu Li	baojiu.li@durham.ac.uk
4 th Supervisor:	Professor Adrian Jenkins	adrian.jenkins@durham.ac.uk
Funding:	Durham University Scholarship	

Description:

Various experiments have shown that neutrinos have a small mass. (The 2015 Nobel prize in Physics was awarded to Takaaki Kajita and Arthur B. McDonald for the discovery of neutrino oscillations, which demonstrate that neutrinos have a mass.) Thus, neutrinos are the only identified form of dark matter particles. As such, they affect the formation of cosmic structures such as galaxies and clusters. Cosmological diagnostics, particularly temperature fluctuations in the cosmic microwave background radiation and the large-scale clustering of galaxies, can be used to set an upper limit on the neutrino mass. The best current upper limit is about 0.1 eV and this implies that neutrinos contribute at most a few percent of the total dark mass in the Universe. The rest is very likely a cold dark matter particle. In the early universe neutrinos behaved like hot dark matter because when they emerged they moved at relativistic speeds. Their main effect is to modify the shape of the primordial spectrum of density perturbations on large scales. This is subsequently reflected in the galaxy distribution.

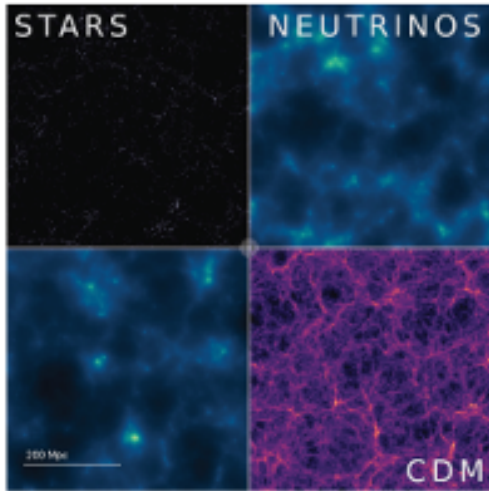
This project has two main goals. The first is to produce the best predictions to date of the effect of massive neutrinos on the large-scale distribution of galaxies at different cosmic epochs. Willem Elbers, a former PhD student, now a Research Fellow at Durham, and a co-supervisor of the project, has developed a novel technique that enables very large cosmological simulations with neutrinos to be carried out. For this project, the student will perform supercomputer simulations and will analyse them to follow the evolution of the dark matter and galaxies. These will be used to develop and test new statistics of the dark matter and galaxy distribution that are sensitive to the neutrino mass.

Armed with robust theoretical predictions, the second goal of the project is to apply the results to real data. The ICC is a partner in DESI, the “dark energy spectroscopic instrument” survey. This is an international venture that is carrying out the largest and most detailed survey of galaxies and quasars ever performed over a large range of cosmic epochs. DESI has already acquired more galaxy redshifts than all previous surveys combined and will continue to deliver exquisite data during the period of this project. Comparing the clustering pattern of galaxies in the DESI survey at different epochs with the simulation results will enable the student at least to set the best upper limits on the neutrino mass and, at best, to measure the neutrino mass. In either case, the project will have huge implications for particle physics and may reveal physics beyond the standard model.

Although this project is primarily astrophysical and cosmological, given its implications for particle physics, the supervisory team involves a particle physicist, Prof. Silvia Pascoli (Bologna University). The student will make use of the ICC’s large supercomputer (the “Cosmology Machine”), as well as resources provided by the “Virgo consortium”, Europe’s premier collaboration for cosmological simulations, which is based at the ICC.

Frenk, C. S. & White, S. D. M, 2012, Dark matter and cosmic structure, *Annalen der Physik*, vol. 524, 507

Elbers, W. et al., 2021: Negative neutrino masses as a mirage of dark energy



The distributions of stars, neutrinos, gas and cold dark matter in slice of a simulation of a large cosmological simulation carried out as part of Virgo's Flamingo project. Courtesy of Willem Elbers, ICC.

THE CLASSICAL BULGE PROBLEM

Main Supervisor: Dr. Dimitri Gadotti dimitri.a.gadotti@durham.ac.uk
Office: Ogden Centre West 102
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Description:

The textbook description of a spiral galaxy often depicts it as containing a central stellar spheroid, where stars are mostly moving in a random fashion, surrounded by a flat disc of stars that rotate more orderly around the galaxy centre. The central spheroid is often referred to as the ‘classical bulge’ (see figure below, left panel). In current models of galaxy formation and evolution, a classical bulge can be formed with the right combination of processes including star formation, stellar feedback, galaxy mergers, and AGN feedback from an accreting supermassive black hole.

However, recent observational studies on nearby galaxies have found that classical bulges are surprisingly scarce (see figure below, right panel; Gadotti et al. 2020; Bittner et al. 2020; Fraser-McKelvie et al. 2025). But such studies are based on relatively small and biased samples, so a robust assessment of the frequency of classical bulges in the nearby Universe is still lacking. **In this project, you will provide the astrophysical community with such an assessment.**

To do that, you will employ novel techniques, developed using the Imfit code (Erwin 2015) and a differential evolution algorithm, to perform photometric decompositions of galaxy images, from which the frequency of – and stellar mass content in – classical bulges can be obtained (Gadotti 2026). You will use images with exquisite quality from the Spitzer and Hubble Space Telescopes in infrared and optical passbands to provide robust answers based on a large unbiased sample of nearby galaxies. Finally, you will also employ the same techniques on images of simulated galaxies from state-of-the-art computer simulations to explore what physical processes lead to the formation of classical bulges.

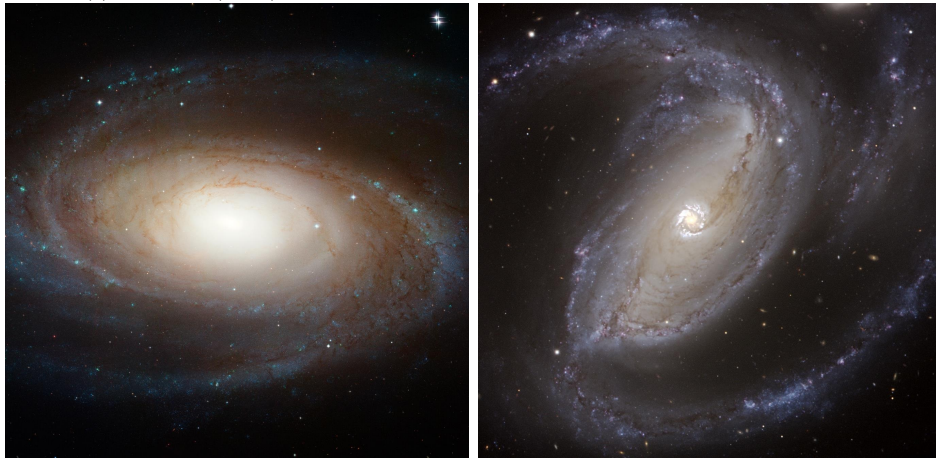
Bittner et al. 2020: <https://arxiv.org/abs/2009.01856>

Erwin 2015: <https://arxiv.org/abs/1408.1097>

Fraser-McKelvie et al. 2025: <https://arxiv.org/abs/2411.03430>

Gadotti et al. 2020: <https://arxiv.org/abs/2009.01852>

Gadotti 2026: <https://arxiv.org/abs/2511.13823>



M81 (left) and NGC 1097 (right) as imaged with the Hubble Space Telescope. M81 appears to host a central spheroid, i.e., a classical bulge, whereas the central region of NGC 1097 lacks such structure.

THE RESTLESS NATURE OF GROWING SUPERMASSIVE BLACK HOLES

Supervisors: Dr. Claire Greenwell claire.l.greenwell@durham.ac.uk
Prof. David Alexander d.m.alexander@durham.ac.uk

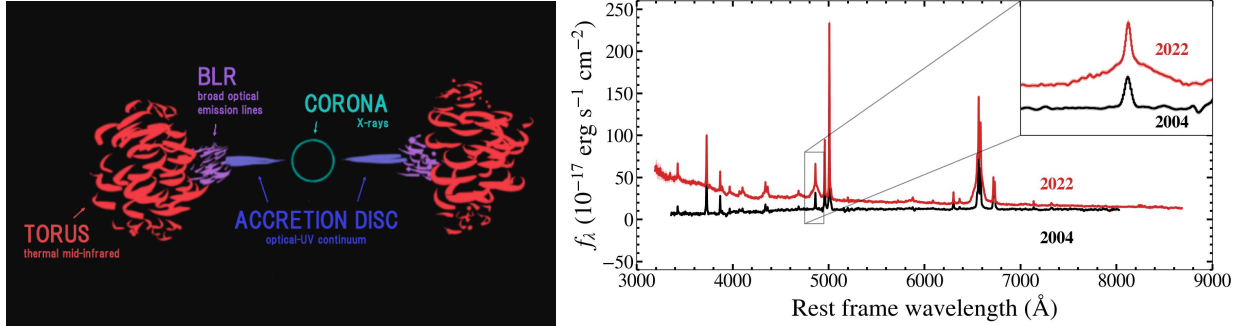
Offices: Ogden Centre West 126 & 119

Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Description:

Active Galactic Nuclei (AGN) are the subset of supermassive black holes that are rapidly accreting (e.g., Alexander et al., 2025). These are found at galaxy centres, in hugely diverse environments, producing luminous emission across most of the electro-magnetic spectrum. Large scale spectroscopic surveys are rapidly accelerating the number of observed AGN, opening up a new era of astronomy. For this project, we will look at AGN that have been observed multiple times and which show dramatic changes in properties: Changing-Look AGN (CLAGN; e.g. Ricci et al., 2023).

Previously, drastic differences in AGN properties were thought to be due to the geometry of their structure: Doppler broadened emission lines produced in the BLR (see left Figure) can be invisible or visible depending on whether the AGN is viewed through the obscuring torus or not. It was thought that significant changes in these properties should only happen on very long timescales. However, with the wealth of new optical spectroscopic data from SDSS and DESI we have shown that AGN can dramatically shift from Type 1 (large broad lines) to Type 2 (narrow lines only), or vice versa (see right Figure). The physics of this is thought to be related to changes in accretion processes, but is not well understood. These objects are key to our understanding of accretion physics.



Left: The central structure of an AGN. *Right:* Optical spectrum of the same object, taken ~ 18 years apart. The later observation shows a dramatic appearance of broad lines (both Greenwell et al., in prep.).

In this project, you will investigate the properties of these objects, beginning with the 561 CLAGN from the first DESI Data Release (Guo et al., 2024) and expanding to larger samples from later DESI Data Releases and the upcoming 4MOST survey (Andonie et al., 2025). This will be the largest homogenous samples to date, and you will investigate their population properties in a statistical way. There are different avenues available depending on interest (multi-wavelength data such as mid-infrared, radio, X-rays which trace different parts of the AGN system; see left Figure). Durham is an active member of the international DESI and 4MOST collaborations (both ground-breaking international projects), providing access to tools, expertise and optical spectra from each. You will have the opportunity to join and contribute to these collaborations, and depending on the direction of your project may propose for further telescope time. You

will learn transferable skills including statistical data handling, programming, presenting your work, and working within large collaborations.

As a supervisor, I am dedicated to supporting students in their wellbeing across the project and beyond. I have been involved in Inclusivity, Diversity, Equality and Accessibility efforts within the university, the DESI and 4MOST collaborations, and meetings I've organised. We will work together to find a working style that gets the best out of you. I am particularly interested in meeting students that this is also important to.

More reading:

[Moshe et al., 2014](#), [Ricci et al., 2023](#), [Zeltyn et al., 2024](#), [Guo et al., 2024](#), [Wang et al., 2025](#)

PROBING BLACK HOLES AND NEUTRON STARS WITH X-RAY POLARIMETRY-TIMING

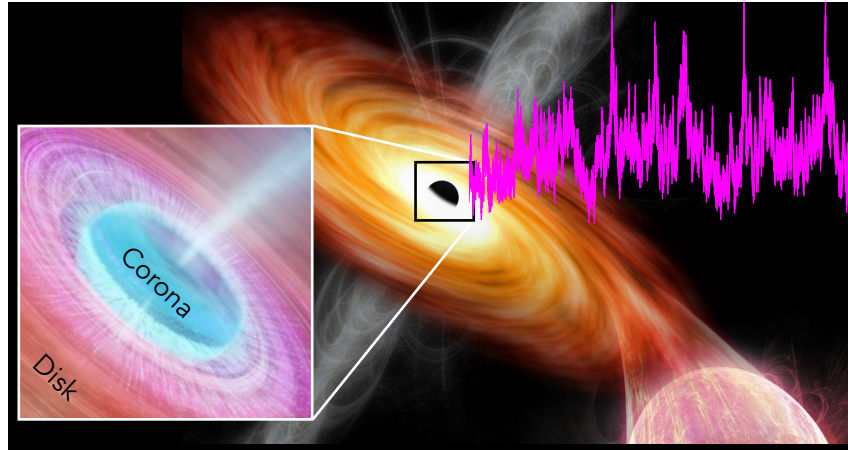
Main Supervisor: Dr. Adam Ingram adam.r.ingram@durham.ac.uk
Office: Ogden Centre West 122
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Description:

Stellar black holes and neutron stars, collectively known as compact objects, are the collapsed core left behind by a massive star at the end of its life. In an X-ray binary system, a compact object swallows gas from a luminous companion star in a process known as accretion. The inner regions of the accretion flow glow brightly in X-rays, illuminating the extreme region of strong gravity close to the compact object. However, interpreting the signal is difficult, because the X-ray emitting region is far too small to directly image (sub-nanoarcsecond scale), necessitating the use of sophisticated indirect mapping techniques.

The X-ray spectrum reveals that the accretion flow includes a thermal disk and a hot plasma known as the corona (see the figure), but it is insensitive to the shape and physical origin of the corona. This project will dig deeper by probing two other properties of the X-ray light: time-variability and polarization. Timing analysis exploits the rapid ($\sim 0.1 - 100$ s timescales) flickering that we see in the X-ray flux to make inferences about the accretion flow. Polarization of light is the predominant direction of oscillation of the electric field. The polarization degree (PD) is the extent to which different rays oscillate in the same direction, and the polarization angle (PA) defines the preferred direction. The 2021 launch of the Imaging X-ray Polarimetry Explorer (IXPE) revolutionized the study of X-ray binaries by being sensitive, for the first time, to X-ray polarization.

This project will continue my group's work to *combine* these two powerful diagnostics into X-ray polarimetry-timing, which is the study of rapid variability in the PD and PA. Polarimetry-timing is technically challenging, but we have developed a Fourier-domain technique (Ingram & Maccarone 2017; Ingram 2022). The technique is already working (Ewing et al 2025, 2026), but it has not yet been possible to make a firm detection of sub-second polarization variability due to low signal to noise. The aims for this project are to: 1) vastly increase the sensitivity of the technique by implementing a novel treatment of an instrumental effect known as deadtime, 2) search for polarization variability in new and archival IXPE observations and, 3) prepare for the 2030 launch of the enhanced X-ray Polarimetry and Timing mission (eXTP), which will hugely improve sensitivity. eXTP will be for polarimetry-timing what IXPE was for polarimetry, and this PhD project will provide the opportunity to play a central role in that revolution.



Schematic of a black hole X-ray binary system radiating a variable X-ray signal from close to the black hole.

STELLAR ENGINES OF GALAXY EVOLUTION: QUANTIFYING FEEDBACK FROM MASSIVE STARS

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

Description:

Galaxies are remarkably inefficient at forming stars: only a few percent of their available gas is converted into stars per orbital period. The leading explanation is stellar feedback, that is, the radiation, winds and supernovae of short-lived massive stars that heat, stir and reshape the interstellar medium. Yet how efficiently that energy and momentum actually couples to the surrounding gas remains a free parameter in almost every model of galaxy formation. This PhD will measure that coupling from first principles, by characterising the stars themselves.

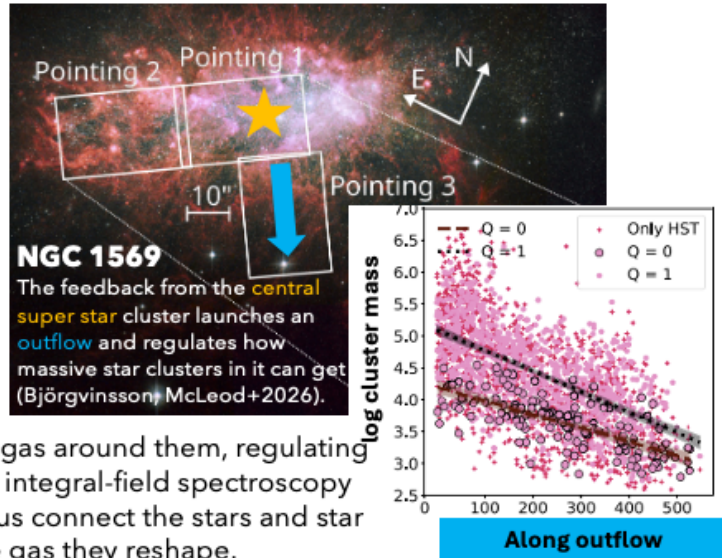
You will work with some of the world's most powerful facilities including JWST, HST, VLT/MUSE and ALMA, to characterise young massive stars and star clusters in nearby galaxies, and to connect them directly to the ionised gas they illuminate, shape, and disperse. The goal is an empirical census of the stellar energy and momentum injected into the interstellar medium, and of how that injection depends on galactic environment. Because individual stars cannot be resolved in distant galaxies, you will also develop the tools needed to interpret unresolved observations: testing stellar-population models against resolved data, and quantifying how inferred properties change when nearby galaxies are artificially “redshifted”. In doing so you will build the missing bridge between the physics of individual massive stars and the galaxies we observe across cosmic time. This is an observational project at the interface of stellar physics, the interstellar medium and galaxy evolution. You will gain experience with integral-field spectroscopy, multi-wavelength imaging, stellar population synthesis modelling and the analysis of large catalogues, working within international survey collaborations. The results will provide the empirical stellar feedback budget that galaxy evolution models currently lack.

McLeod et al. 2020, Stellar feedback and resolved stellar IFU spectroscopy in the nearby spiral galaxy NGC 300

McLeod et al. 2021, The impact of pre-supernova feedback and its dependence on environment

Rowland, McLeod et al. 2024, Pre-supernova stellar feedback in nearby starburst dwarf galaxies

Bjorgvinsson et al. 2026, Getting to know the star clusters in NGC 1569: Bayesian inference of stellar cluster properties in a dwarf starburst galaxy



Massive stars ionise and clear the gas around them, regulating further star formation. Combining integral-field spectroscopy with high-resolution imaging lets us connect the stars and star clusters that drive feedback to the gas they reshape.

PUFFY GALAXIES ACROSS COSMIC TIME: TRACING STELLAR FEEDBACK FROM COSMIC NOON TO TODAY

Main Supervisor: Dr. Anna McLeod anna.mcleod@durham.ac.uk
Office: Ogden Centre West 120
2nd Supervisor: Prof. Mark Swinbank a.m.swinbank@durham.ac.uk
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Description:

Massive stars do more than light up their surroundings: via what we call stellar feedback, they inject energy and momentum that can puff galaxy disks up against gravity. Different phases of the interstellar medium — ionised, atomic and molecular gas — respond differently to stellar feedback, so the relative thickness of each phase is a powerful, and still largely unexploited, diagnostic of how feedback actually works. This PhD will turn that idea into a quantitative measurement, from the nearby Universe out to the peak of cosmic star formation.

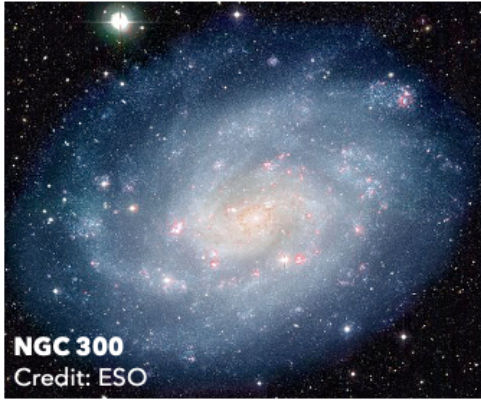
You will measure the vertical thickness of galaxy disks using a technique that does not require edge-on systems: the characteristic imprint left by disk thickness in the spatial structure of gas emission. Locally, you will apply this method to multi-wavelength maps of ionised, atomic and molecular gas in nearby galaxies, combining the results with measurements of the stellar energy injected into the disk to derive empirical feedback efficiencies. You will then extend the same diagnostic to large samples of galaxies at redshift $z \sim 1-2$, using Durham-led integral-field surveys and overlapping millimetre observations, recovering population-average disk thicknesses even where individual galaxies cannot be spatially resolved. The key scientific question is whether stellar feedback remains the dominant source of vertical support at cosmic noon, or whether gravity and accretion take over.

This is an observational, survey-driven project at the interface of nearby galaxy physics and high-redshift galaxy evolution. Co-supervised by Prof. Mark Swinbank, you will develop skills in spatial statistics, multi-wavelength data analysis and the interpretation of large galaxy samples. The results will provide a new empirical benchmark for cosmological simulations, and will position the work to exploit forthcoming SKA observations of atomic gas beyond the local Universe.

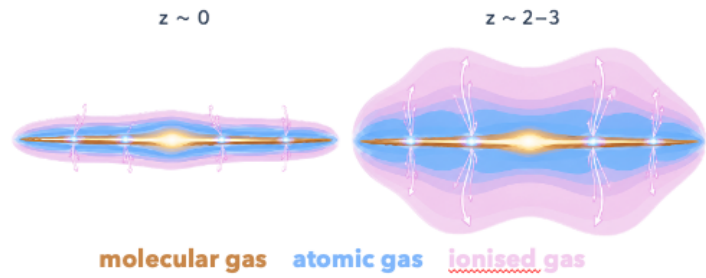
Elmegreen et al. 2025, An investigation of disk thickness in M51 from $H\alpha$, $Pa\alpha$, and mid-infrared power spectra

Stott et al. 2016, The KMOS Redshift One Spectroscopic Survey (KROSS): dynamical properties, gas and dark matter masses of $z \sim 1$ star-forming galaxies

Ostriker & Shetty 2011, Maximally star-forming galactic disks. I. Starburst regulation via feedback-regulated star formation



Star-forming galaxies like NGC 300 experience intense feedback from the massive stars that have formed in them. You will measure feedback in galaxies by determining how much their gas disks are “puffed up” by feedback.



GAS DYNAMICS & DARK MATTER IN DWARF GALAXIES

Main Supervisor: Dr. Kyle Oman
Office: Ogden Centre West 222
Funding: Royal Society (4 years)

kyle.a.oman@durham.ac.uk

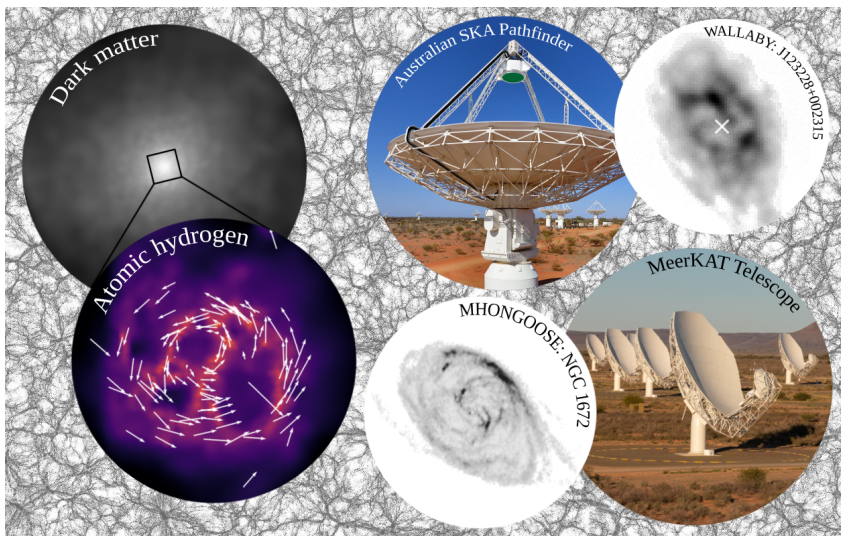
Description:

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 mass distribution within its orbit dictates the orbital speed of a particle in a gravitational field. 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 is working with the brand-new Colibre galaxy formation model that is ideally suited to predict the gas dynamics in dwarf galaxies. We are also members of the WALLABY, MHONGOOSE and MIGHTEE-HI 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 ‘what can dwarf galaxies reliably tell us about dark matter?’ will 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.

BLACK HOLES AND GALAXIES

Main Supervisor:	Prof. Andrew Pontzen	andrew.p.pontzen@durham.ac.uk
Office:	Ogden Centre West OCW225	
2 nd Supervisor:	Prof Christine Done	chris.done@durham.ac.uk
Funding:	STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)	

Description:

At the heart of almost every large galaxy sits a supermassive black hole, millions to billions of times the mass of our Sun. On galactic scales these black holes are astonishingly small. If the Milky Way were shrunk to the size of the Earth, its central black hole would be around the size of a grain of sand. Yet the evidence is overwhelming that these tiny objects shape their vast surroundings. The mass of a black hole is tightly linked to the properties of its host galaxy. The energy released as black holes grow seems to shut down star formation in the most massive galaxies, and it heats gas across galaxy clusters millions of light years across. How does something so small control something so large? This is one of the central open questions in astrophysics, and it matters well beyond galaxies. By pushing gas around, black holes reshape the distribution of matter in the universe. Understanding this "feedback" is now essential for extracting fundamental physics from surveys such as Euclid and Rubin/LSST.

The puzzle has recently become deeper. Measurements of the kinetic Sunyaev-Zel'dovich effect, which uses the cosmic microwave background as a backlight, suggest that black holes expel gas from galaxy groups more aggressively than our best simulations predict. The thermal Sunyaev-Zel'dovich power spectrum, a map-level census of hot gas, also hints at strong feedback. Yet the XRISM X-ray satellite has found that gas at the centres of clusters is surprisingly calm, with far gentler motions than the same simulations predict. How can feedback be both more violent and more gentle than we expect? The answer probably lies in the fact that each observation probes different masses, distances from the black hole, and cosmic epochs. Our recent work suggests there may be a fundamental limit on what black holes can achieve, which could provide a unifying thread.

In this project you will piece together this cosmic jigsaw. Depending on your interests, directions include:

- building physical models of how black holes reshape the gas around them as a function of mass and time, and testing them against state-of-the-art simulations such as FLAMINGO and COLIBRE, or improving the physics implemented within such simulations;
- predicting multiple observables from the same simulated universe, to establish which combinations of data can reveal how black holes really work;
- understanding how these predictions inform the interpretation of data from ACT, SPT, DESI, eROSITA, XRISM and the Simons Observatory.

This project would suit a student who enjoys physics and mathematics, likes coding (Python experience is helpful but not essential), and wants to work at the interface between theory, simulation and observation. You will join a lively group within the Institute for Computational Cosmology and work with national and international collaborators.

References:

- The limits of feedback from active galactic nuclei
- Cosmological feedback from a halo assembly perspective
- Comparing XRISM cluster velocity dispersions with predictions from cosmological simulations: are feedback models too ejective?
- Measurement of the full shape of the thermal Sunyaev–Zel’dovich power spectrum from SPT and *Herschel*-SPIRE

COMPACT TERAHERTZ SPECTROMETER BASED ON METASURFACES

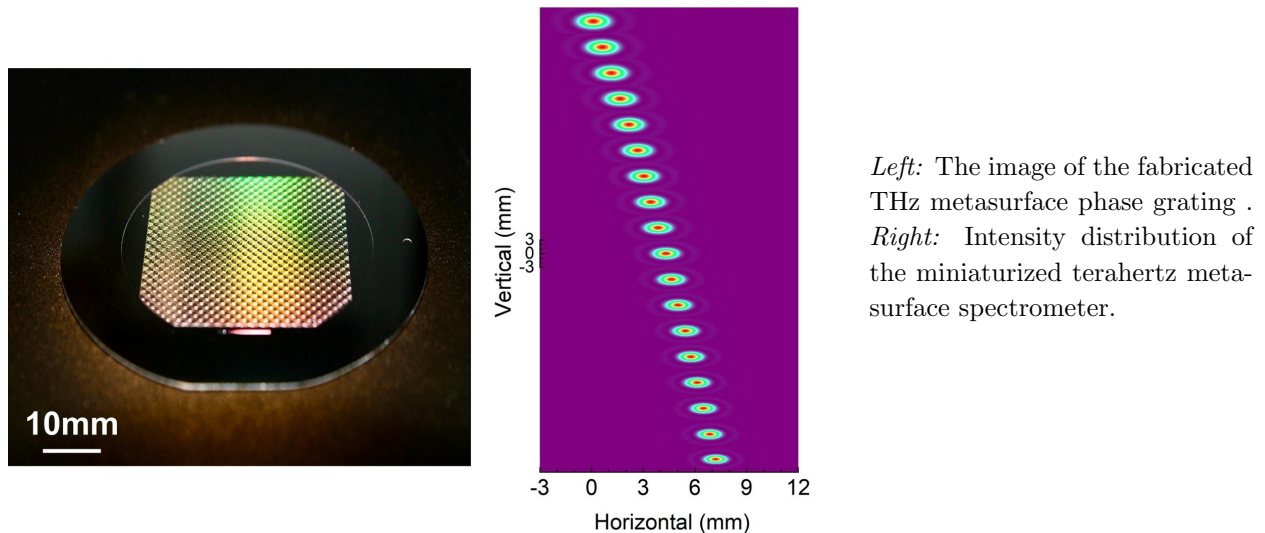
Supervisor: Dr. Yuan Ren yuan.ren@durham.ac.uk
Office: Ogden Centre West 023
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

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.



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>

RYDBERG ATOMIC RECEIVERS FOR SUBMILLIMETRE ASTRONOMY

Supervisor:	Dr. Yuan Ren	yuan.ren@durham.ac.uk
Office:	Ogden Centre West 023	
2 nd Supervisor:	Prof. Kevin Weatherill	k.j.weatherill@durham.ac.uk
Funding:	STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)	

Description:

The submillimetre and terahertz (THz) regime provides a powerful window on the cold universe, capturing thermal emission from interstellar dust and a wealth of molecular and atomic spectral lines. Observations at these wavelengths therefore provide key information on the physical and chemical conditions of the interstellar medium, and on the processes by which stars and galaxies form and evolve.

Rydberg atoms offer a new approach to electromagnetic-field detection in this regime. Highly excited atoms in a vapour cell interact strongly with an incident electromagnetic field, modifying their energy-level structure and optical response. The response can be tuned to different frequencies by selecting appropriate Rydberg transitions, covering a wide THz range, and offers a route to self-calibrated, SI-traceable measurements of electromagnetic fields.

This PhD project will explore the potential of Rydberg atomic sensing for submillimetre astronomy. The work will investigate key aspects of system performance through a combination of modelling, design and experimental characterisation, and assess its potential for future astronomical applications.

We are seeking a motivated candidate with a strong interest in experimental physics and instrumentation. Applicants from a broad range of backgrounds, including astronomy, quantum optics, atomic physics and electrical engineering, are encouraged to apply.

More reading:

C. G. Wade, et al, Real-Time Near-Field Terahertz Imaging with Atomic Optical Fluorescence, *Nature Photonics* 2017; <https://doi.org/10.1038/nphoton.2016.214>

S. Chen, et al, Terahertz electrometry via infrared spectroscopy of atomic vapor, *Optica* 2022; <https://doi.org/10.1364/OPTICA.456761>

W. Zhang, et al, Superconducting hot-electron bolometer mixers and their applications, *Superconductivity* 2022; <https://doi.org/10.1016/j.supcon.2022.100009>

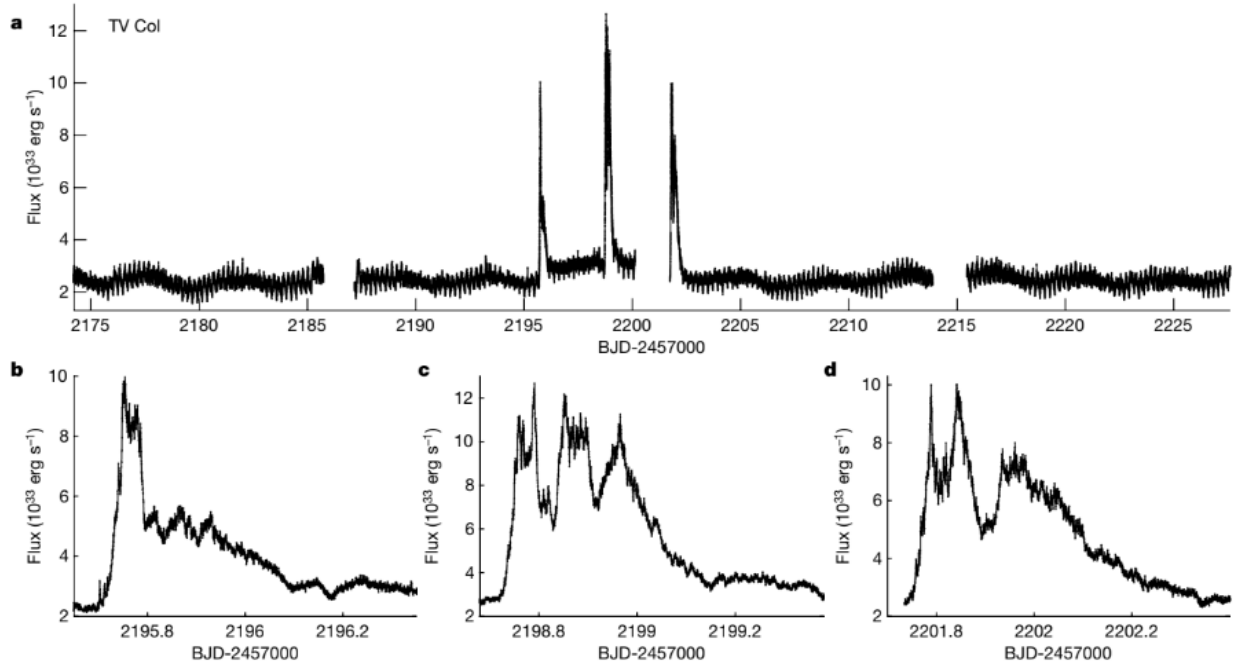
HUNTING FOR HOSTLESS TRANSIENTS WITH BLACKGEM AND RUBIN/LSST

Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
Office: Ogden Centre West 103
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

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 micromovae — 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 detected 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 micromovae, 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 micromovae. 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/>

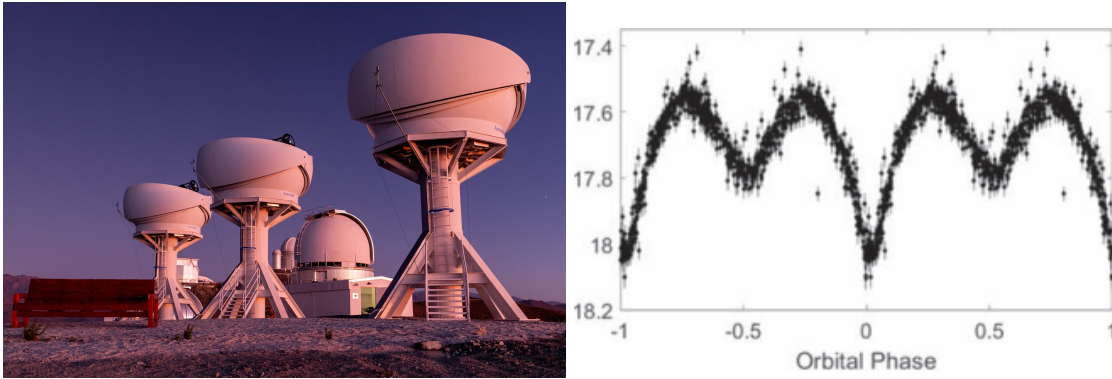
HUNTING COMPACT BINARIES IN THE SOUTHERN SKY WITH BLACKGEM AND RUBIN/LSST

Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
Office: Ogden Centre West 103
Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

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 behaviour, 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 likely 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/>

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

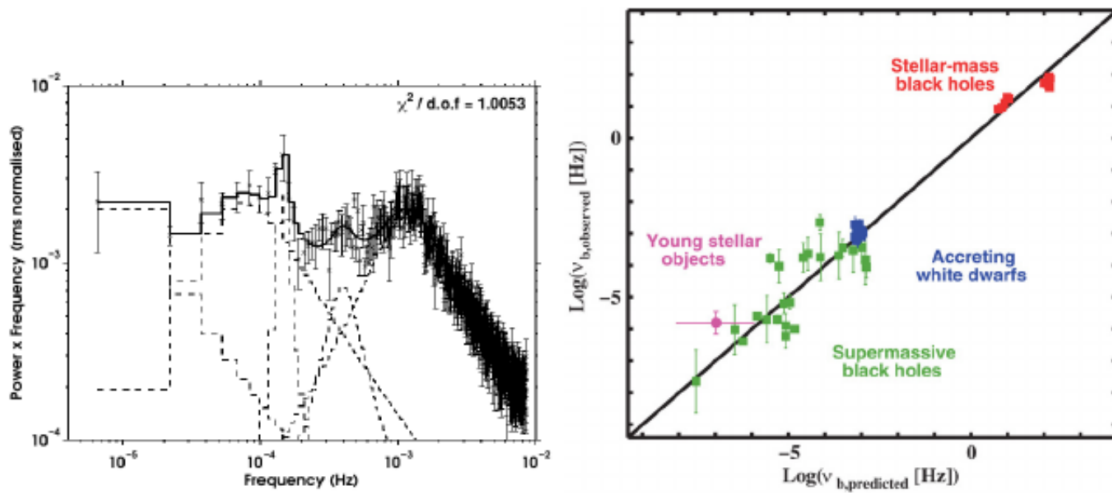
Main Supervisor: Dr. Simone Scaringi simone.scaringi@durham.ac.uk
 Office: Ogden Centre West 103
 Funding: STFC and non-STFC (e.g., CSC, Bell Burnell, etc.)

Description:

Accretion regulates the growth of most astrophysical objects: from star formation to supermassive black holes, from galaxy evolution to interacting binaries in our neighborhood. 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). Accretion 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 the 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>

NUMERICAL RELATIVITY IN THE REALM OF NEW PHYSICS

Main Supervisor:	Prof. Baojiu Li	baojiu.li@durham.ac.uk
Office:	Ogden Centre West 218	
2 nd Supervisor:	Prof. Tobias Weinzierl (CS)	tobias.weinzierl@durham.ac.uk
Funding:	Non-STFC (e.g., CSC, Bell Burnell, etc.)	

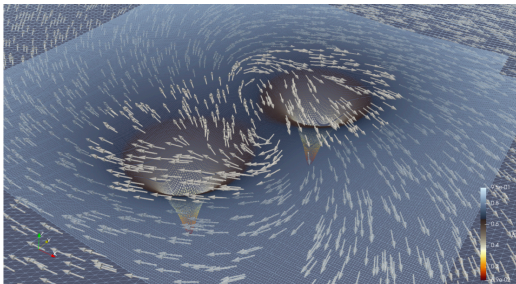
Description:

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.

PROBING THE STELLAR CONTENT OF ELLIPTICAL GALAXIES WITH FLUCTUATION SPECTROSCOPY

Main Supervisor: Dr. Russell Smith
Office: Ogden Centre West 110
Funding (MScR): None defined.

russell.smith@durham.ac.uk

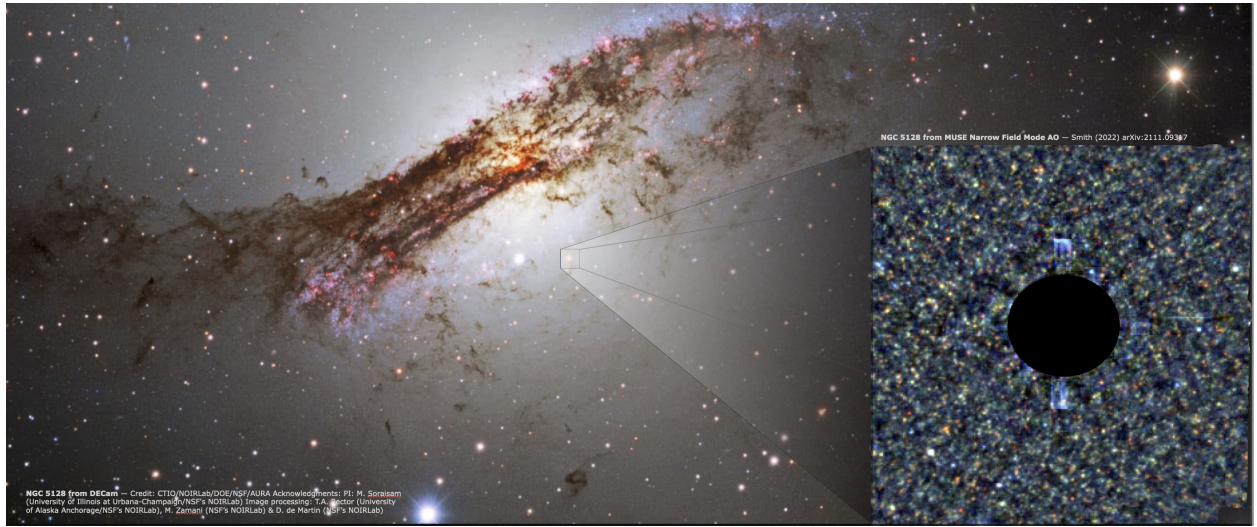
Description:

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 VLT optical observations for a particularly nearby galaxy, where the fluctuations are easiest to measure (see Smith 2022, MNRAS, 509, 5737). More recently, we applied the method to near-infrared data, revealing more exotic evolved stars including carbon stars and possible Mira-like variables (Smith & Gvozdenko 2026, arXiv:2605.21588). 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 contribute to developing the fluctuation spectroscopy method, either (1) improving the underlying modelling of the effect, or (2) analysing newly-acquired observational data, subject to telescope time allocation, or (3) generating and analysing “mock” observations mimicking the performance of ELT instruments, to inform future campaigns. The project is offered primarily for MScR study; a variant could be developed for a (non-STFC-funded) PhD project.



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 fluctuation spectroscopy technique to extract the ensemble-average properties of the cool giant stars, which cannot be accessed any other way.

MODELLING DUSTY GRAVITATIONAL LENSES

Main Supervisor: Dr. Russell Smith
Office: Ogden Centre West 110
Funding (MScR): None defined.

russell.smith@durham.ac.uk

Description:

Strong gravitational lensing occurs when the light from a distant object is deflected by the mass of an intervening galaxy, forming multiple highly-distorted images for the observer. Because the degree and form of the distortions depends on the mass distribution in the foreground object, and on the geometry of the Universe through which the rays propagate, lensing is exploited widely to measure the stellar and dark matter density profiles, explore the nature of dark matter, measure cosmological parameters, and test the theory of gravitation itself (see Shajib et al. 2024 for a full review).

In practice the analysis of gravitational lensing rests on modelling codes, such as PyAutolens (Nightingale et al. 2021, developed at Durham), which predict the appearance of the combined lens and source system in images, given a number of model parameters describing the intrinsic mass and light distribution. In general these codes assume that only effect of the foreground galaxy is through gravity. This is often justified. However in some important classes of object, such as galaxies with flattened disk-like components (example pictured below), dust in the lens galaxy can also impose complex extinction and reddening effects. In such cases, standard lens modelling methods fail completely, because the relative source flux in each pixel is not governed only by the geometric magnification, as they assume.

This project will explore methods for modelling dusty lenses, by combining (1) the techniques of pixel-based lens reconstruction in PyAutolens and (2) treatment of dust absorption using a radiative transfer code, e.g. SKIRT (Camps & Baes 2015). Although the dust acts as a flat (but non-uniform) absorbing screen for the background source, its effects on the lens galaxy depend on the distribution of stars and dust in three dimensions, e.g. the “near” side of a disk absorbs a light from a bulge component, but the far side does not. SKIRT accounts for such effects, but lensing codes treat each galaxy as a 2D projection of mass and light. The project will begin with a “simple” experiment of generating a fake dusty lens model self-consistently with SKIRT, using PyAutolens to impose lensing distortions on a background source, and applying the SKIRT attenuation map to produce a mock observation of a system perhaps resembling the one pictured below. The hard challenge is to invert that process, to find the model parameters which best reproduce the image, in a way that could be applied to real data. A fully self-consistent analysis is likely impractical, so you might start by exploring approximations or simplifications, testing their validity against the known answers of your simulated observation, and build from there towards greater complexity.

The eventual goal of this work is to open up the prospect of accurate lens modelling in edge-on disk systems, which promise novel constraints on the mass distributions in spiral galaxies and their dark halos (Dutton et al. 2013). A secondary goal is the use of the lensed source as a “self-calibrating” back-light with which to measure the dust attenuation properties of dust in distant galaxies unlike our own (Keel et al. 2023).



A disk and dusty gravitational lensing system, J1317-1405 (Lucey et al. 2018). In this image, the foreground galaxy is composed of an extended, flat and nearly edge-on, disk, and a bright central bulge. The near-circular Einstein ring around the bulge is formed by the gravitationally lensed galaxy far in the background. The colour differences around the ring are evidence for strong dust extinction effects, which contaminate the pixel values, causing standard lens-modelling techniques to fail.