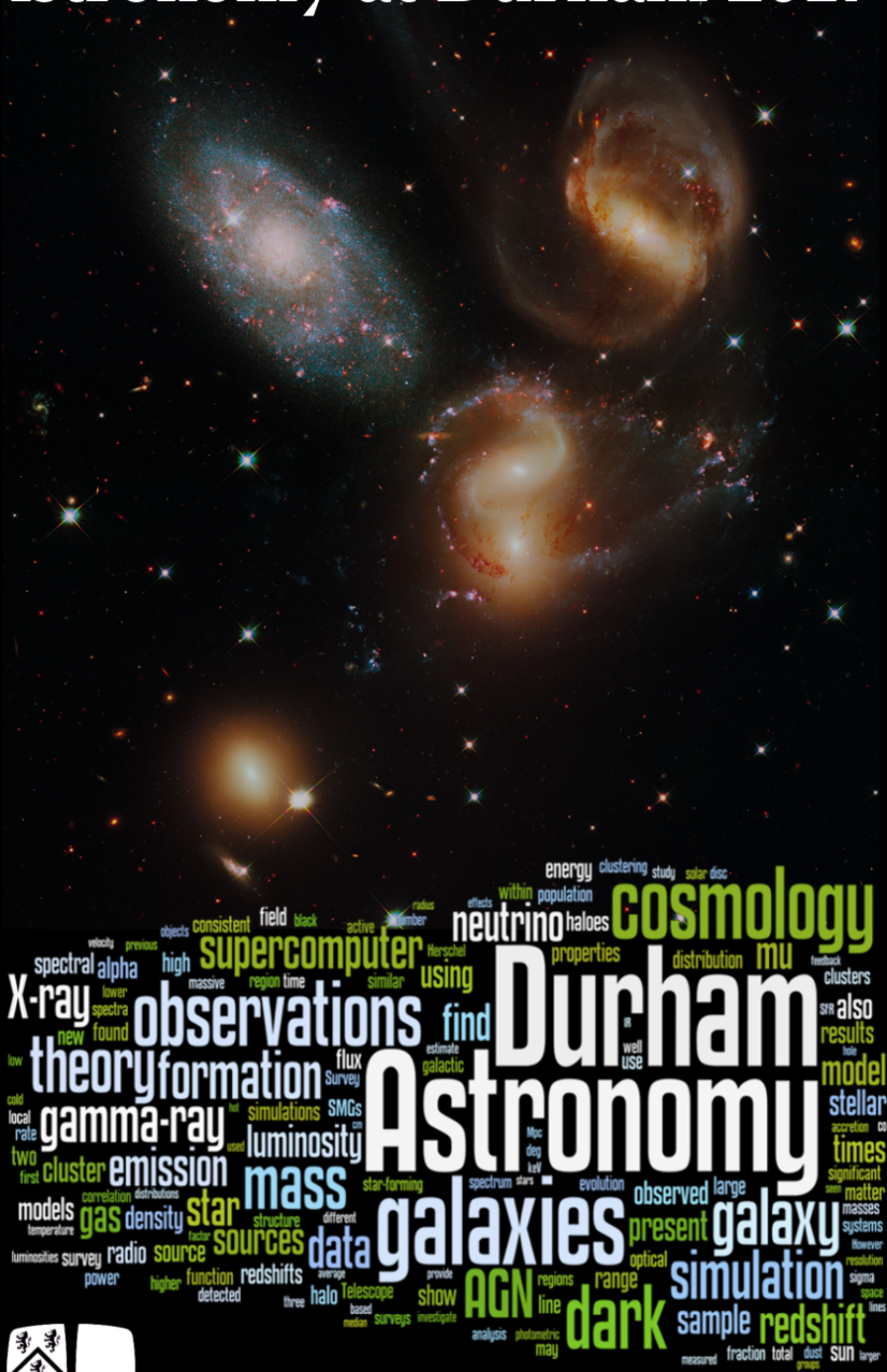
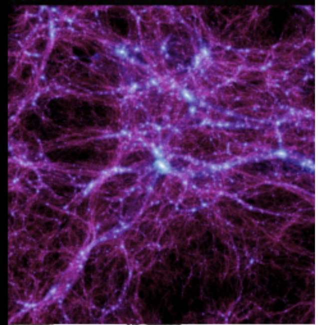
Fully Funded Studentships in Astronomy at Durham 2017





Durham University

FULLY FUNDED CDT STUDENTSHIPS IN ASTRONOMY FOR AUTUMN 2017 START
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INTRODUCTION

Durham University is a UK-leading centre for astronomical research with world-class groups working in a wide range of fields covering the observational, theoretical and instrumentation aspects of astronomy. Durham has been ranked ranked Number One in Europe and sixth in the world for our research into Space Science (which covers research into astronomy and astrophysics) over the decade 2002–2012, according to Thomson Reuters.

There are 31 academic staff across the combined astronomy groups, with over 100 postdocs, postgraduate students and support and technical staff involved in astronomy research. 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 all located to a large extent within the newly built Ogden Centre West. The three groups consists of the Centre for Advanced Instrumentation (CfAI), the Centre for Extragalactic Astronomy (CEA) and the Institute for Computational Cosmology (ICC).

In April 2017, Durham University was awarded 11 PhD studentships to set up a new Centre for Doctoral Training (CDT) in Data Intensive Science. These 4-year studentships are funded by STFC, the UK's research council for Astronomy and Particle Physics. The studentships will fully fund the PhD, providing a stipend for living expenses (14,553 for 2017/18, with no tax deductions to pay) and covering fees. **Up to half of these studentships are available for non-UK candidates from the EU.**

The CDT comprises the Institute for Computational Cosmology, the Institute for Particle Physics Phenomenology, the Centre for Extragalactic Astronomy and the Centre for Advanced Instrumentation and will be supported by industrial partners (including IBM and other large firms). The studentships are for four years and include a six month secondment at one of the industrial partners. CDT students will be equally well qualified to pursue a career in academia or industry after graduating.

Over the first six months of the programme, the CDT students will follow a combination of subject specific training and advanced training in computational methods, along with training in complementary skills. The research projects for CDT students recruited to the ICC and CEA will be drawn from our research programme which spans the running and analysis of large supercomputer simulations of the formation of cosmic structures and the preparation for and analysis of large galaxy surveys, such as DESI, Euclid and LSST (further details within the booklet).

The studentships will start in October 2017. Applications are invited following the instructions on: https://www.dur.ac.uk/physics/postgraduate/prospectivestudents/howtoapply. There is no deadline, but candidates are encouraged to apply as soon as possible.

Fully Funded CDT PhD Studentship

This booklet outlines PhD projects for which we can provide full funding (fees plus a stipend) over 4 years as part of the CDT. For other funded studentships see the standard PhD booklet, which also covers MScR options.

All 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 via remote access if necessary). Shortlisted candidates for STFC CDT studentship are being interviewed from mid-April until the positions are filled.

Follow the post-graduate opportunities link from our web site or contact our astronomy post-graduate administrator (Dr. Peder Norberg; peder.norberg@durham.ac.uk; Ogden Centre West 219) for further details. Further CDT specific information can be obtained from Carlton Baugh c.m.baugh@durham.ac.uk, while information about PhDs within the IPPP CDT can be obtained from Frank Krauss frank.krauss@durham.ac.uk.

MACHINE-LEARNING GALAXY-AGN CLASSIFICATION FOR THE NEXT GENERATION OF LARGE-AREA MULTI-WAVELENGTH SURVEYS

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Funding:	STFC CDT	

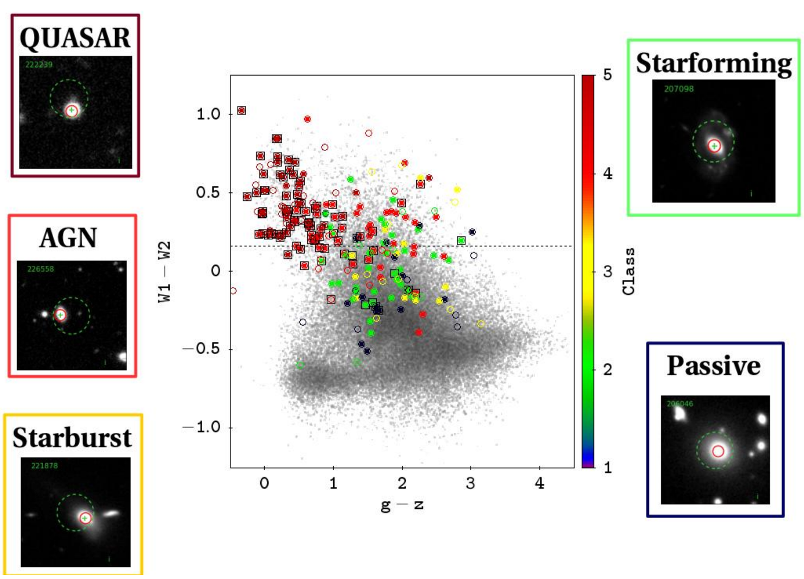
Description:

Extragalactic multiwavelength surveys planned for 2020+ are going to radically change they way we undertake astronomy. The Large Synoptic Survey Telescope (LSST) in the optical, Euclid in the near infrared, the Square Kilometer Array (SKA) in the radio and eROSITA in the X-rays are going to provide more than 10,000 deg^2 of superb quality multi-wavelength data with billions of detected sources: galaxies of all varieties, active galactic nuclei (AGN), including quasars, and stars. The full scientific exploitation of such datasets requires developing new skills in merging and mining this information.

The plot shows the application of a machine-learning classification technique (the Random Forest, RF, classifier; see Breiman 2001) for the X-ray detected sources from the 50 deg^2 XXL Survey (Fotopoulou et al., 2016), the largest sensitive X-ray survey currently undertaken. The RF classifier was trained based on the broad-band photometric data over the optical–near-IR waveband it was tuned to predict the optimal model (i.e., the various galaxy and AGN types). The classification agrees well with the expectation from source attributes that were not used during the training phase, such as the X-ray information (colored sample), and the presence of broad emission lines in the optical spectra (open squares). The power of this approach lies in the exploitation of a 200-dimension parameter space (based on the multi-wavelength input attributes) which cannot be explored with traditional methods. The extension of this work to identify a refined categorization of galaxies and the usage of state of the art classification algorithms (e.g., deep learning) will have profound implications in the science (and correspondingly the scientific break throughs) that can be undertaken in future surveys.

This project will focus on the classification of galaxies and AGN using currently available datasets drawn from the largest-area X-ray, optical, and near-IR data currently available: the XXL Survey (50 deg^2), SDSS, VISTA, HSC, and WISE. In particular, the first aim is the classification of each source in star/galaxy/AGN categories and the monitoring of changes in the classification as new data become available in the framework of LSST (a revolutionary deep large-area multi-band multi-epoch optical imaging survey). This monitoring will enable the study of the dynamic nature of the Universe which includes transient events and changing-look sources that can be further studied in detailed, e.g., with 4MOST optical spectroscopy.

Breiman, L. Machine Learning, 45, 5, (2001) Fotopoulou, S. et al., A&A, 592, 5 (2016)



Colour-colour diagram based on the WISE 3.6 μm (W1) and 4.5 μm near-IR bands and the g and z optical bands. The grey points correspond to optically detected systems and the coloured points correspond to the classification obtained from the RF for the X-ray sources: deep red - quasar, red - AGN, yellow - starburst galaxy, green - star-forming galaxy, blue - passive galaxy). The open squares indicate sources with broad emission lines detected in optical spectroscopy; i.e., indicating an optically identified quasar.

Notes:

COMPUTER VISUALISATION OF THE UNIVERSE

Main Supervisor:	Prof. Richard Bower	r.g.bower@durham.ac.uk
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2nd Supervisor:	Prof. Tom Theuns	
Funding:	STFC CDT	

Project Description:

Understanding how galaxies, such as the Milky-Way formed and evolved over the last 13.6 billion years is one of the biggest questions in extra-galactic astronomy. The processes which govern the formation of stars and galaxies (such as gravity, star-formation and super-novae driven winds, galaxy-galaxy mergers and the effects of active galactic nuclei) occur on timescales from millions- to billions- of years. Remarkably, the recent EAGLE simulation has now demonstrated that it is possible to match many of the properties of observed galaxies in a computer simulation. The goal of this project is to develop new visualisation tools that will allow us to properly understand the Universe that these simulations have created.

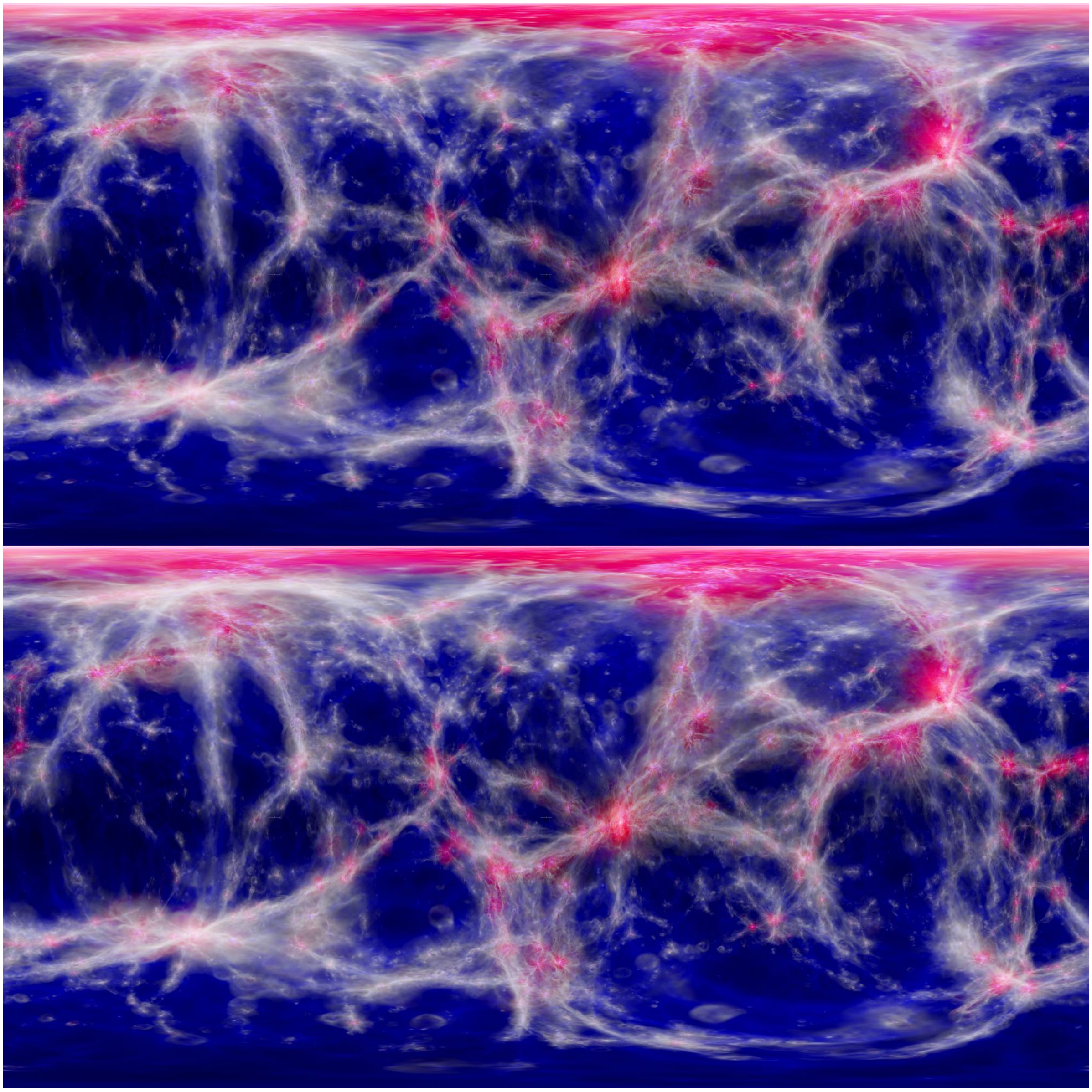
Over the course of the project, will develop visualisation tools that place the observe inside the Universe and allow them to explore just as if they were in a spacecraft, capable of faster than light speeds and time travel. The challenges for this programme stem from the resulting geometry and the volume of the data involved. We want the visualisation to work as a stereoscopic 360^o virtual reality, viewed from inside a high-spec Occulus Rift.

Currently, we are able to generate the required images, so that a predefined flight path can be explored. This process is extremely costly (in terms of computer time) at present since the programs that generate the image sequences are written in Python. However, they demonstrate the enormous potential of the approach. The student will tackle two challenges:

- to develop interactive ways of determining the flight-path, so that the most interesting and spectacular objects in the Universe can be quickly identified and explored. Ideally this process will involve interaction with the simulation database to select the most appropriate nearby objects and to connect them accordingly.
- to develop faster visualisation techniques. Current the entire simulation datafile must be read to generate each individual frame. This is inefficient: back ground objects change little, and the distant information could be largely reused across many frames, while foreground objects are rapidly updated. This work could benefit could greatly benefit from the on-the-fly data output being built into the SWIFT simulation code.

The benefits of these approaches have important applications beyond the cosmological computer simulations that the ICC undertakes, and the PhD student will work closely with industrial partners to champion this these developments across a wide range of scientific disciplines.

A few useful links are given below,
• The paper presenting the Eagle simulation, a good target for the visualisation approach that the student will develop. (http://adsabs.harvard.edu/abs/2015MNRAS.446..521S)
• A visualisation of the evolution of the Eagle Universe, developed for a Theatre production called entropy.
(https://drive.google.com/open?id=0B-7nssX3tkJHNzh1N3JsU2tuenM)
• An example space flight, illustrating the evolution of the Universe.
(https://drive.google.com/open?id=0B-7nssX3tkJHWFppLWFkSjB6SWM)



An all sky image of the Universe in its 2D representation. The image is created by raytracing on to the surface of a Riemann sphere, using two adjacent eyes to provide the stereoscopic effect. These images are then unwrapped to create the image pair shown in the figure. Viewed through the Oculus Rift the observer perceives themselves to be floating, or drifting in the Universe. The evolving structure of the Universe surround them and they can travel through the universe examining the physics of forming objects in detail.

Notes:

NEXT-GENERATION COMPUTER TECHNOLOGIES AND THEIR APPLICATIONS TO VIRTUAL UNIVERSES

Main Supervisor:	Prof. Richard Bower	r.g.bower@durham.ac.uk
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2nd Supervisor:	Dr. Robert Maskell (Intel Corp.)	robert.maskell@intel.com
Funding:	STFC CDT or STFC EPSRC CASE	

Description:

Recently our computer simulation group has begun a close collaboration with the Intel computer and processor manufacturer. The aim of the collaboration is to demonstrate novel computing technologies using cosmological computer simulations as a test-bed. This PhD position is a funded studentship, and will be jointly supervised by Robert Maskell, Intel's director of research. Hosted at the ICC, this is primarily a Computer Science PhD and will focus on computational aspects of cosmological simulations using the next-generation SWIFT computer code.

The next steps in cosmological modelling, simulating larger volumes at greater detail, require an order of magnitude increase in processing power or simulation efficiency. The SWIFT simulation code combines major improvements in algorithms (e.g. the fast multipole method and multiscale time-step hierarchy), highly scalable parallelisation (fine-grained task-based parallelism within nodes and asynchronous MPI communications between them) and SIMD vectorisation. The code delivers a factor ∼20x speed-up over current competing codes through our implementation of task-based parallelism and novel algorithms.

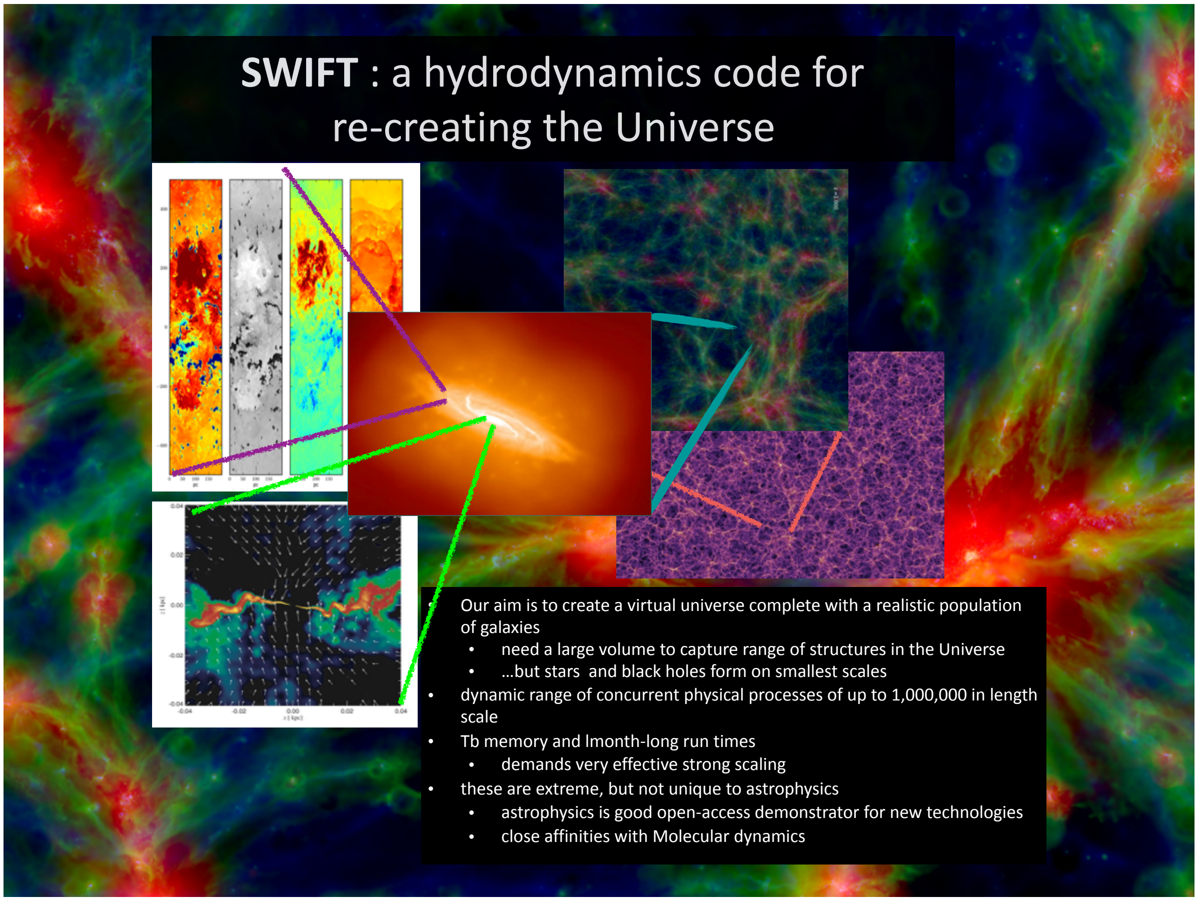
However, as the speed of the simulation rises, the bottleneck is quickly becoming the time it takes to output the simulation data and process it. Our solution to this "big data" problem is twofold: first, instead of writing a complete snapshot at fixed intervals, we write only the changing quantities of interest for particles whenever they experience sufficient change; and secondly, we stream this data into a continuous and incremental particle log on each node's local storage in parallel with the rest of the computation, thus avoiding IO latencies. In this way, output is generated piecewise, adapting to the speed of each particle's movement, and the output is committed to disk in the background during the computation without (a) stopping for I/O and (b) overloading the I/O sub-system.

The second strand to the solution is to minimise the data that is output and stored for long periods on conventional hard drives and to integrate post-processing tools within the simulation. Since most of the data products required for scientific analysis (e.g. the rate at which stars form in a galaxy or their masses) only evolve slowly over the course of a simulation this is an ideal oportunity to take advantage of new memory technologies. Instead of storing the ever-growing amount of raw data and painfully post-processing it, in-flight analysis enables us to only permanently store the particle log data for scientifically interesting regions, dramatically reducing the disk-space footprint of the simulation. Our solution will be based on Intel's 3D xPoint technology.

The benefits of these approaches have important applications beyond the cosmological computer simulations that the ICC undertakes, and the PhD student will work closely with Intel to champion this approach across a wide range of scientific disciplines.

A few useful links are given below:

- The SWIFT cosmological simulation code webpage: `www.swiftsim.com`
- The SWIFT cosmological simulation code repository: `https://gitlab.cosma.dur.ac.uk/swift/swiftsim`
- A presentation summarizing the state of SWIFT: `http://www.intel.com/content/www/us/en/events/hpcdevcon/parallel-programming-track.html#swift`
- Schaller M. et al., 2016, 'SWIFT: Using task-based parallelism, fully asynchronous communication, and graph partition-based domain decomposition for strong scaling on more than 100,000 cores, Proceedings of the PASC Conference, Lausanne, Switzerland (`https://arxiv.org/abs/1606.02738`)
- Gonnet P., Chalk A., Schaller M., 2016, 'QuickSched: Task-based parallelism with dependencies and conflicts `https://arxiv.org/abs/1601.05384`


SWIFT : a hydrodynamics code for re-creating the Universe
Our aim is to create a virtual universe complete with a realistic population of galaxies
need a large volume to capture range of structures in the Universe
...but stars and black holes form on smallest scales
dynamic range of concurrent physical processes of up to 1,000,000 in length scale
Tb memory and 1month-long run times
demands very effective strong scaling
these are extreme, but not unique to astrophysics
astrophysics is good open-access demonstrator for new technologies
close affinities with Molecular dynamics

Notes:

LINKING GALAXIES TO DARK MATTER

Supervisor:	Professor Shaun Cole	shaun.cole@durham.ac.uk
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Funding:	STFC CDT	

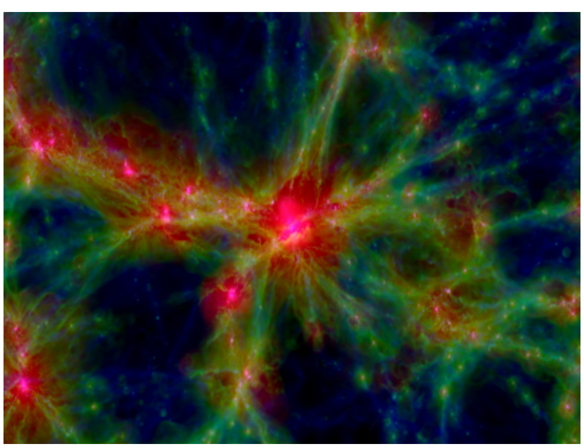
Description:

The central research themes at the Institute for Computational Cosmology (ICC) are exploring and constraining cosmological models and modelling and understanding galaxy formation. The projects that this PhD student will undertake will connect these two themes and also exploit the two main modelling techniques employed at the ICC – large super computer simulations and semi-analytic modelling.

A recent major undertaking for the ICC and its collaborators in the Virgo consortium has been the EAGLE galaxy formation simulation. A high resolution simulation of a 100 Mpc sized region of the Universe has been evolved over cosmic time from the near uniform initial conditions of the early universe to its present complex state (see Figure). The simulation incorporates the physics of the gravitational evolution of the Dark Matter distribution coupled to the hydrodynamical evolution of the baryonic gas and a sophisticated "sub-grid" model of star formation and feedback processes from supernovae (SNe) and active galactic nuclei (AGN). This direct simulation approach to modelling galaxy formation complements the GALFORM semi-analytic method that has been pioneered in Durham. In GALFORM the hierarchical merging history of the dark matter haloes is taken as a framework and then the processes of galaxy formation – gas shock heating and cooling, star formation and feedback – are treated using analytic models. The advantages of this second approach are that it is far faster to calculate, gives direct quantitative understanding of the physical processes and does not suffer from artificial resolution effects which are inevitable in numerical simulations. While its disadvantages are that it is only as good as the analytic models it utilizes and the approximations on which they are based.

We will aim to reproduce the properties of the galaxies in EAGLE, their positions, masses and ages, by using a semi-analytic model implemented in a dark matter only version of the EAGLE simulation. This will enable us to test and improve the analytic approximations in GALFORM and then predict how the properties of galaxies in the EAGLE simulation would change in response to altering the strength of various physical processes. From this we can learn about galaxy formation by determining how these processes need to be tuned or adapted to match a variety of observational data.

Frenk, C. S. & White, S. D. M, 2012, Dark matter and cosmic structure Annalen der Physik, vol. 524, 507
Sawala, T. et al. 2015, The APOSTLE simulations: solutions to the Local Group's cosmic puzzles, arXiv:1511.01098



A view of the large scale structure traced out by the distribution of gas and galaxies in the EAGLE simulation. The false colour indicates the gas temperature (red=hot). (Credit: Richard Bower and the Virgo Consortium)

One outcome of the above modelling will be a way of relating the galaxy distribution to the underlying dark matter distribution. This is of vital importance when modelling and interpreting galaxy clustering measurements from large surveys such as SDSS, GAMA and BOSS. The high precision data that is available from such surveys can constrain both cosmological parameters and galaxy formation models.

An initial project along these lines will exploit the SHAM (SubHalo Abundance Matching) ansatz which is a simpler way of relating dark matter to galaxies than a full semi-analytic or numerical model. It makes the extremely simplifying assumption that galaxy stellar mass is monotonically related to the mass of the dark matter (sub)halo that the galaxy forms within. We will be able to test this assumption with GALFORM and EAGLE, but already preliminary work shows that in certain regimes it can be very accurate. Hence we should be able to exploit this approach to deliver new constraints on cosmological parameters using existing measurements of galaxy clustering.

Notes:

USING LARGE DATASETS FROM ACCRETING NEUTRON STARS TO CONSTRAIN THE PHYSICS OF THE DENSEST MATTER

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Funding:	STFC CDT	

Description:

Neutron star cores have mean densities which are much higher than can be produced in current laboratory conditions, 2-8 times larger than the nuclear saturation density. They are also relatively cool and in equilibrium with both strong and weak force (unlike heavy ion collider experiments) and are neutron rich (unlike normal nuclei which are approximately symmetric in neutrons and protons). Thus they probe fundamental quantum chromodynamics in a regime which is not accessible on Earth The major observable of different potential QCD predictions is the radius of the neutron star of a given mass i.e. measuring M/R (e.g. Lattimer 2012). There are multiple ways to constrain this, but even the best current determinations have uncertainties of the order of 10-20% and each technique has its own set of caveats (see e.g. Miller & Lamb 2016).

One new way to constrain this is to look at the subset of neutron stars which are accreting from a companion. The RXTE satellite generated a huge X-ray database of observations accretion flows around neutron stars. Material from the binary companion star spirals down towards the neutron star, releasing an enourmous amount of gravitational potential energy. This can heat the infalling material up to extremenly high energies, so that it forms an intensely luminous X-ray emitting disc. This impacts onto the neutron star surface, producing even higher energy X-ray emission at a shock.

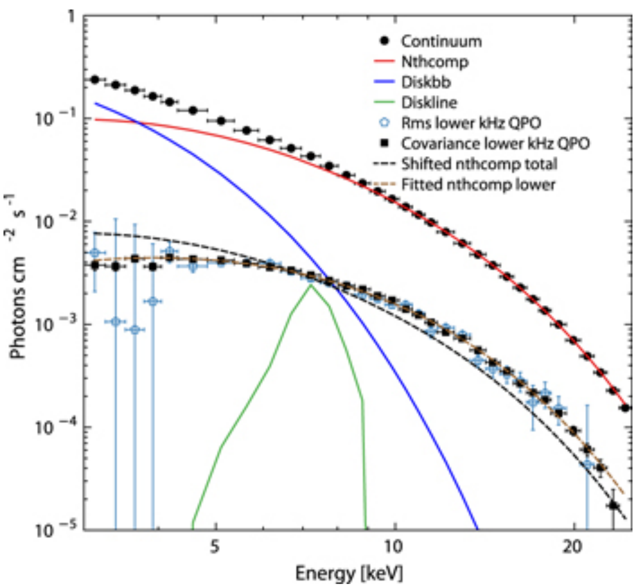
Similar accretion flows occur in black hole binary systems, the only difference being that the material slides smoothly through the disc down to the last stable circular orbit, where it then plunges silently down below the event horizon rather than forming a shock at the surface. The temperature and luminosity of the disc emission is routinely used to measure the size scale of the last stable circular orbit round the black hole (e.g. Done et al 2007).

There are two ways that the X-ray emission can be used to determine the size scale of a neutron star. Firstly, the temperature and luminosity of the disc can constrain its radius, similar to in black holes, but also the ratio of power dissipated between the disc and boundary layer is another diagnostic (Sibgatullen & Sunyaev 2000). The key issue is to disentangle the disc and boundary layer, as they merge together in the data. There are several ways to do this, firstly via using the best physically based models for the emitted spectra and secondly using the fast (sub-second) variability which is seen only in the boundary layer (see Fig 1). There are very new, sophisticated Fourier techniques which have been developed analyse variability which could be systematically applied to these data, which will extract out the spectrum of the fast variable component (Fig 1).

This PhD project would systematically go through the entire database of neutron star observations, and extract the spectra and higher order variability information for each object, resolving the short timescales on which the accretion flow evolves. The combined spectral-timing information can then be used to separate out the boundary layer from the accretion disc emission, and use the disc spectrum and ratio of disc to boundary layer luminosity to constrain the equation of state of ultradense material.

The broad title would be 'Mininig large X-ray databases to constrain the equation of state of ultradense material' but can expand out from this depending on the strengths and interests of the student.

Done et al 2007 Peille et al 2015 Revnivtsev & Gilfanov 2006 Sibgatullin & Sunyaev 2000



Neutron star spectrum showing the data (upper black points) decomposed into an accretion disc component (blue) and a boundary layer (red), together with some contribution (green) of reflection of the boundary layer from the accretion disc. The lower black and cyan points show the spectrum of the fast variability which picks out the shape of the boundary layer emission: Peille et al (2015)

Notes:

DATA-MINING FOR RARE OBJECTS IN IMAGING SURVEYS: PREPARING FOR LSST

Supervisor: Prof. Alastair Edge alastair.edge@durham.ac.uk
Office: Ogden Centre West 109

Funding: STFC CDT

Description:

We are about to enter an era of astronomy when we will have catalogued almost every star in the Milky Way and every massive galaxy in the Universe. The challenge of selecting a particular object or class of objects, such as the most distant quasars or lowest mass stars, requires us to develop new techniques to classify and categorise the hundreds of billions of objects we have detected.

Modern, machine-learning algorithms provide the tools to self-organise the results from large surveys into statistical groups. However, we must also apply our knowledge of the nature of stars and galaxies to ensure these algorithms deliver reliable identifications.

In anticipation of the Large Synoptic Survey Telescope, LSST, survey of the Southern Sky starting in 2021, we can use existing optical and near-infrared surveys to train different algorithms to classify objects into which type of star or galaxy they are, estimate their distance/redshift and determine a statistical confidence for these classifications. Once the initial classifications are made it will be possible to sift out the rarest objects and greatly speed up their follow-up.

The algorithms that use the natural similarity in observed properties to group certain classes of objects have uses in medicine, particle physics, genetics, national security and business so the skills learned in this project have a wide audience.

An artists impression of the LSST dome on Cerro Pachon, Chile.

Notes:

FINDING CRATERS THE EASY WAY

Main Supervisor:	Dr. Vincent Eke	v.r.eke@durham.ac.uk
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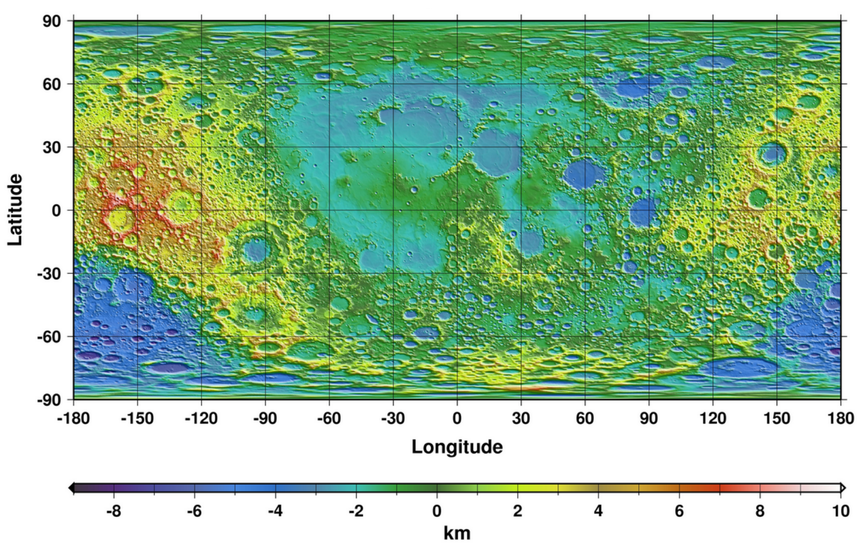
Funding:	STFC CDT	

Description:

The violent early history of Earth involved bombardment by asteroids and comets that are thought to have delivered the water that now comprises the oceans. Another consequence of this fusillade is the impact cratering on the surfaces of inner Solar System bodies. As younger surfaces are less cratered than older ones, crater number densities can teach us about the geological evolution of the bodies themselves as well as constraining models of impactor populations.

Crater counting has typically been performed by humans looking at remotely-sensed images of surfaces, and the ease with which craters are detected depends upon the relative position of the sun and the shapes of the shadows that it casts in the image. This is very time-consuming and the results lack repeatability, with different humans finding different craters. More recently, laser altimeters orbiting tha Moon, Mercury and Mars have provided well-sampled topographical measurements, offering an alternative type of data set from which to find craters.

The aim of this project is to develop and test automated algorithms for finding craters, in order to create crater catalogues for the Moon, Mercury and Mars.



The lunar Digital Elevation Model (DEM) constructed using measurements from the Lunar Orbiter Laser Altimeter (LOLA).

Notes:

THE MILKY WAY HALO IN 6 DIMENSIONS

Main Supervisor:	Prof. Carlos Frenk	c.s.frenk@durham.ac.uk
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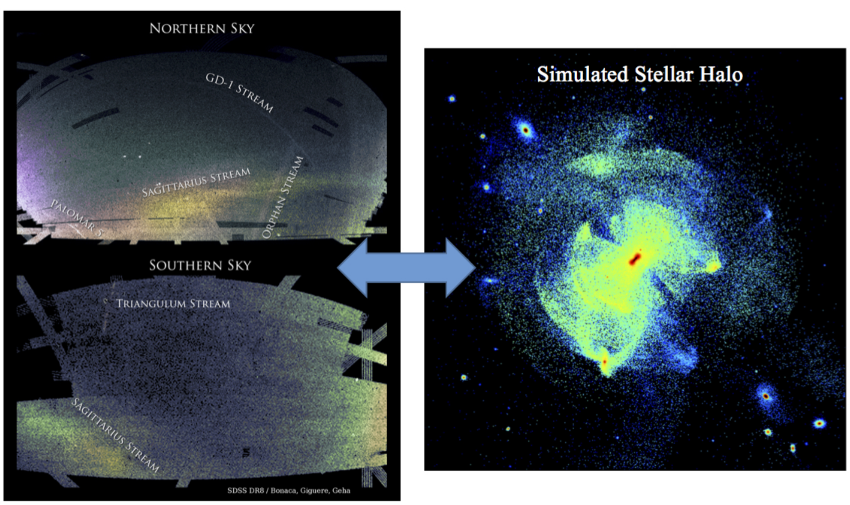
Funding:	STFC CDT	

Description:

The Milky Way (MW) galaxy is a cannibal; throughout its lifetime it devours hundreds of smaller "dwarf" galaxies. Observable memories of this voracious eating habit are splayed out in a vast stellar halo, which extends out to thousands of light years from the Galactic centre.

In the next decade, we will witness an explosion in the number of dedicated observational surveys of the MW halo. Our current observational view of the halo is, at best, limited to 4 dimensions — 3 positions, and 1 velocity component along the line-of-sight. However, we are now entering the era of "Galactic astrometry", where upcoming missions such as Gaia and the Large Synoptic Survey Telescope (LSST) will provide exquisite measurements of the transverse motions of halo stars. The addition of the transverse velocity components will transform our view of the halo into 6 dimensions. This game-changing 6D dataset will be essential in order to decipher the eating habits of our Galaxy. Furthermore, by tracing stellar streams in 6D we will be able to map the dark matter distribution of the Milky Way, and, potentially, uncover the nature of the dark matter particle.

This project will couple observational survey data with state-of-the-art models of galaxy formation in order to unravel the assembly history of the MW. Mock observations of simulated stellar halos will be developed that cater towards high-impact observational surveys such as Gaia and LSST. These mocks will be vital in order to exploit the exquisite observational data to its full potential, and will provide a testable theoretical framework that can be directly compared to observations. The student will use several different datasets to compare with the mocks, including the latest data releases from the Gaia mission (DR1 came out in September 2016, DR2 is due in Autumn 2017).



Left panel: A map of stars in the outer regions of the Milky Way Galaxy, derived from the Sloan Digital Sky Survey images. The colour indicates the distance of the stars, while the intensity indicates the density of stars on the sky. (Credit: Ana Bonaca). Right panel: The V-band surface brightness of a model stellar halo from the Aquarius simulations. (Credit: Andrew Cooper).

Notes:

PROBING THE PHYSICS OF THE INTERGALACTIC MEDIUM WITH HALF A MILLION QUASARS

Main Supervisor:	Dr. Michele Fumagalli	michele.fumagalli@durham.ac.uk
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Funding:	STFC CDT	

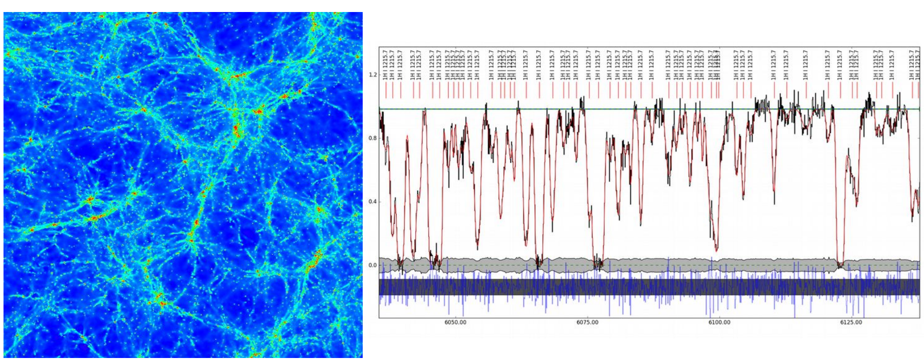
Description:

Within the current cosmological model, galaxies form at the intersection of an intricate web of dark matter and gas filaments which compose the intergalactic medium. This reservoir of cosmic hydrogen acts as the primary supply of fuel for the formation of stars in galaxies. Moreover, heavy elements produced by stars inside galaxies are constantly ejected from galaxies back into this cosmic web, which is continuously enriched with atoms heavier than hydrogen. Furthermore, the intergalactic medium is illuminated by the diffuse UV radiation that pervades the Universe, and is heated up to temperatures in excess of 10,000 K. Thus, the study of the physical properties of this intergalactic medium provides a gold-mine of information to tackle fundamental open questions in cosmology (such as the time evolution of the cosmic temperature), in galaxy formation (such as what regulates the supply of gas to sustain the growth of galaxies), and fundamental physics (such as the nature of dark matter).

Due to its very low density, the intergalactic medium can only be probed in absorption, using background light "bulbs" such as bright quasars to trace in silhouette the gas density, temperature and chemical composition of this cosmic gas. Traditionally, these studies have been performed using spectroscopic data at high-resolution from 8 meter telescopes, which so far have been limited to samples of hundreds of objects. We are now on the verge of true revolution for this type of studies, as in the next $\sim 5 - 10$ yrs large surveys such as WEAVE and DESI (both of which Durham University is a member in) will collect spectra for up to half a million quasars with sufficient resolution to probe the physics of the intergalactic medium.

The objective of this project is to develop the statistical framework within which we will be able to extract key information on the nature of our Universe and galaxy formation from this unprecedented dataset. This data-intensive project will, at first, involve the design and production of mock data for realisations of the full DESI and WEAVE surveys leveraging current observations and simulations of the intergalactic medium. Next, using these mock surveys, we will develop novel algorithms and statistical techniques to extract key quantities to constrain the evolution of the temperature of the Universe, the efficiency with which galaxies produce and eject heavy elements, and the nature of dark matter.

Find out more: Read about the DESI survey design. – Read about the WEAVE-QSO survey design. – Visit the DESI webpage. – Visit the WEAVE webpage.



(Left) The intergalactic medium as seen in a map of the gas density from a snapshot of the Eagle simulation, showing how matter is distributed in a net of filaments connecting galaxy halos, which is a distinctive prediction of the current ΛCMD cosmological model. The simulation box is 25 Mpc on a side, and the region shown is 5 Mpc on a side. *(Right)* High-resolution spectrum of a quasar (black), showing a plethora of absorption lines. By modelling these features (red), we can extract key information on the nature of the intergalactic medium.During this data-intensive project, we will generate mock realisations of the next generation of surveys which will provide us with a sample of half a million quasar spectra. We will further develop a new formalism to extract key observables to measure the evolution of the cosmic temperature, the role of gas in regulating the growth of galaxies, and the nature of dark matter.

Notes:

MODELLING DARK MATTER STRUCTURE DOWN TO THE SMALLEST SCALES.

Main Supervisor:	Prof Adrian Jenkins	A.R.Jenkins@durham.ac.uk
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Funding:	STFC CDT	

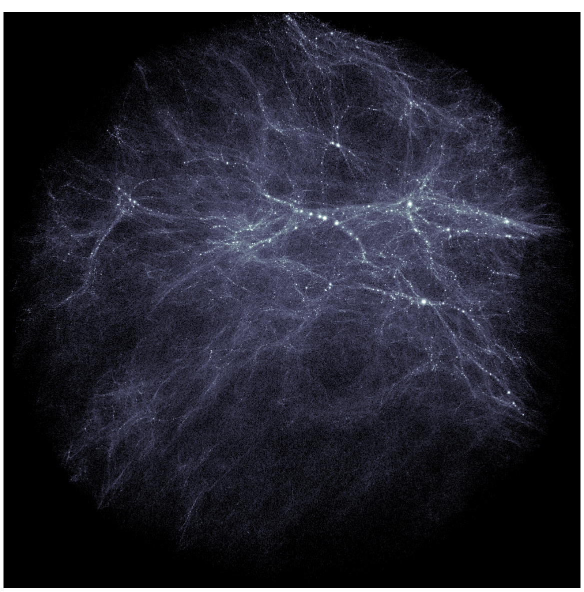
Description:

Background: The standard model of cosmology ΛCDM has just five fundamental parameters that determine the structure of the universe. Since the 1980s it has been possible to make precise predictions of the distribution of matter in a ΛCDM universe on the largest scales that we can observe. Exquisite measurements of the Cosmic Microwave Background, and of the clustering of galaxies and a range of other observations, have all proven to be consistent with ΛCDM, and ushered in the so-called era of 'precision cosmology' where parameters of the model, including the density of ordinary matter, and the density of the Cold Dark Matter can be predicted to a few percent accuracy. By contrast, making predictions for the ΛCDM model on the length scales of galaxies or smaller is much more challenging even for the dark matter, not least because structure formation is highly non-linear on these scales. However, recent developments in N-body methods, initial conditions, together with the availability of large local supercomputers, makes the time ripe to start exploring the realm of the smallest dark matter structures in their full cosmological setting.

The project: The goal of the project is to model the structure of the dark matter on the smallest scales for the ΛCDM model with particular emphasis on predicting the structure of the dark matter in the Galaxy around the Sun. This knowledge can then be used to infer, for example, the observational signatures of dark matter annihilation - a process that is expected to be most important in small clumps of dark matter with masses similar to the Earth.

There is a strong computational component to this project. The work will make extensive use of the COSMA supercomputing facility at Durham, which is part of the national DiRAC facility. COSMA will provide the resources needed to set up and run cosmological N-body simulations. There will also be opportunities develop new simulation methods to model how tidal fields affect dark matter substructures within galaxies. The project will produce substantial amounts of simulation data and one of the challenges will be to develop efficient and automatic ways of analysing the large volumes of simulation data.

Springel et al 2008, Prospects for detecting supersymmetric dark matter in the Galactic halo, Nature, 456, 73
Gao et al 2012, Where will supersymmetric dark matter first be seen?, MNRAS, 419, 1721



Visualisation of the output of an N-body simulation modelling dark matter in a ΛCDM universe at the present day in a low density region 100 kpc across. Even in this void region the dark matter is highly structured.

Notes:

UNDERSTANDING THE PHYSICS OF GALAXY FORMATION

Main Supervisor: Prof. Cedric Lacey cedric.lacey@durham.ac.uk
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Funding: STFC CDT

Description:

Understanding the physical processes that drive galaxy formation is a key problem in cosmology. At the Institute for Computational Cosmology (ICC), we pursue this goal using two different but complementary theoretical/computational approaches: large gas-dynamical simulations, and semi-analytical modelling. This PhD project will combine these two approaches.

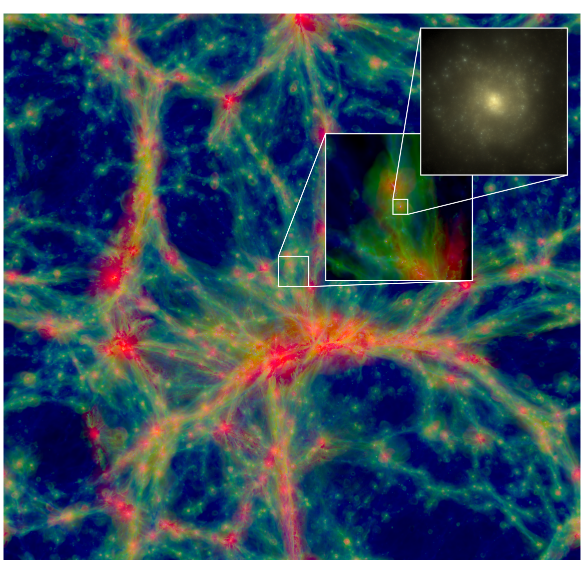
Galaxy formation is driven by the growth of structure in the dark matter forming dark matter halos, followed by shock heating and cooling of gas leading to accretion of gas onto galaxies, star formation, feedback from supernovae and AGN, and galaxy mergers and instabilities. Many aspects of the baryonic physics of galaxy formation remain poorly understood, including:

- how gas cooling is affected by filamentary accretion into halos
- how supernovae drive outflows from galaxies, and the fate of the outflowing gas
- the relative roles of galaxy mergers and dynamical instabilities in galaxy disks in forming galaxy spheroids, and the properties of these spheroids

This project will investigate one or more of these problems, by using a combination of cosmological gas-dynamical simulations (such as the EAGLE simulation run at the ICC, Schaye et al 2015) and semi-analytical modelling using the GALFORM code developed here (Lacey et al 2016). Gas-dynamical simulations provide a lot of detailed information, but produce very complex outputs, and are very expensive computationally. Semi-analytical models are much faster and more flexible, and can provide additional physical insight and understanding, as well as allowing a proper exploration of the effects of different parameters and assumptions in the models.

The project will involve analysing data from large numerical simulations, possibly also running additional numerical simulations, as well as modifying and running the GALFORM code.

Schaye, J. et al. 2015, The EAGLE project: simulating the evolution and assembly of galaxies and their environments
Lacey, C.G. et al. 2016, A unified multiwavelength model of galaxy formation



EAGLE cosmological simulation. Main panel shows gas density distribution in a 100 Mpc region, coloured from blue (cold) to red (hot). Gas flows into halos along filaments. It is heated by shocks on infall, and also by feedback from supernovae and active galactic nuclei, which drive outflows. Inset shows stellar distribution in disk galaxy formed in simulation. (Schaye et al 2015)

Notes:

SIMULATING AGN FEEDBACK

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3rd Supervisor:	Prof. Chris Done	chris.done@durham.ac.uk
Funding:	STFC CDT	

Description:

One of the most important discoveries of recent years is that massive galaxies in the nearby universe nearly all host supermassive black holes at their centres. These black holes grow by accreting gas, and in the process of doing so, they release enormous amounts of energy, and are visible as active galactic nuclei (AGN). This energy release is thought to have very important effects on galaxy formation and evolution, limiting the growth of galaxy masses by either expelling gas from galaxies or by preventing further gas from accreting into galaxies. These effects are known as *AGN feedback*.

AGN feedback is included in state-of-the-art numerical simulations of galaxy formation, such as the EAGLE simulation carried out at the ICC. However, current simulations implement AGN feedback in a very simple way, typically assuming that a fixed fraction of the rest mass energy accreted by the black hole is deposited as thermal energy in gas around the black hole. But in reality, AGN feedback is much more complicated, since AGN emit energy in the form of radiation, winds and relativistic jets, whose efficiencies depend strongly on the black hole mass, spin and accretion rate, and which interact with the host galaxy in different ways. However, thanks to both observational studies of AGN and numerical simulations of accretion disks around black holes, we are starting to understand what the efficiencies of these different modes of energy injection are.

The aim of this project is to develop new, more physically based subgrid models for AGN feedback by winds and jets and to implement them in the EAGLE cosmological gas-dynamical code. The improved code will then be used to carry out simulations to explore the effects of this more realistic modelling of feedback on galaxy formation.

Schaye, J. et al. 2015, *The EAGLE project: simulating the evolution and assembly of galaxies and their environments*, MNRAS 446, 521
Yuan, F & Narayan, R., 2014, *Hot Accretion Flows Around Black Holes*, ARAA 52, 529

Combined optical and radio image of the massive elliptical galaxy Centaurus A, showing the emerging radio jet. The radio emission is due to relativistic jets generated by an accreting massive black hole at the centre of the galaxy. The jets are thought to be heating the gas halo surrounding the galaxy.

Notes:

LARGE-SCALE STRUCTURE, NEUTRINOS AND THE ORIGIN OF THE ACCELERATED COSMIC EXPANSION

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Funding: STFC CDT

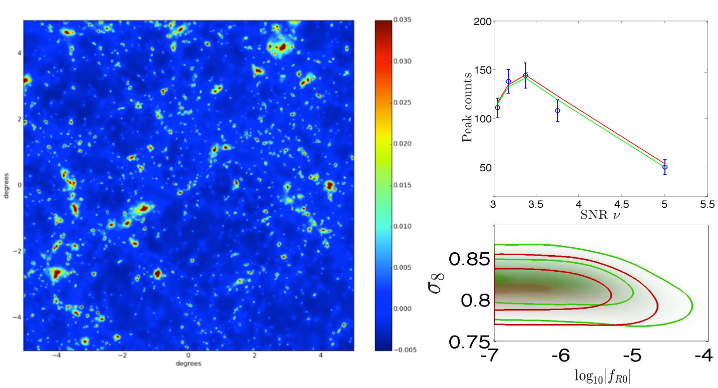
Description:

One of the most challenging questions in astrophysics, and indeed in the whole of modern physics, is the origin and nature of the accelerated cosmic expansion. This "cosmic acceleration" is unexpected in a universe filled with normal plus dark matter, with gravity described by Einstein's General Relativity. Although the standard ΛCDM model, which hypothesises that the acceleration is caused by a cosmological constant (Λ), is consistent with nearly all observational data collected over the past two decades, the extremely small and fine-tuned value of Λ required to match these observations makes it difficult to explain theoretically. It is usually suggested that the cosmic acceleration may be caused by either some new species of exotic matter, or a breakdown of General Relativity on large cosmic scales. Both indicate new physics beyond our current understanding. Studies in this area therefore open a new window to probe extensions to the standard model of fundamental physics, a prospect that has been the primary driver of various expensive multinational next-generation galaxy and cluster surveys such as eROSITA, DESI, Euclid and LSST. These observational projects will have greatly improved statistical power and precision, to finally allow us to the distinguish between and test the different theoretical possibilities.

One primary interest in the research group at Durham is to make accurate quantitative predictions of observables and test these against current and future survey data to constrain theoretical models. For this, one usually has to resort to large N-body and hydrodynamical simulations of cosmological volumes, which mimic the formation and evolution of large-scale structure in the Universe all the way down to galactic scales. This is a highly complicated physical process, which involves the intricate interplay between dark matter, baryons, photons, dark energy and the law of gravity. In addition, we now know that neutrinos are not massless but have nonzero mass, which means that their impact on the structure formation must be accurately modelled to avoid degeneracies or biased cosmological constraints. All these issues must be carefully investigated before future survey data can be used to make conclusions about new physics.

Up to 2 PhD studentships are offered to work on a wide range of related research topics, including (i) the construction and analyses of theoretical models for the cosmic acceleration, (ii) the development of numerical (e.g., simulation codes for dark energy and neutrinos) and analytical (e.g., semi-analytical galaxy formation) methods for large-scale structure formation, (iii) the predictions of cosmological observables, e.g., weak gravitational lensing, galaxy clustering, properties of galaxy clusters, as well as other novel probes, and (iv) the use of these predictions to test models against survey data. The actual research topic will depend on the students interest, but we will encourage and help the candidates to gain a comprehensive training in all important elements in modern cosmology – theories, simulations and data analyses – by working on more than one topic.

Relevant paper: Barreira A., Llinares C., Bose S., Li B., 2016, JCAP, 05, 001
Relevant paper: Liu X., Li B., et al. 2016, PRL, 117, 051101



Left: a map of lensing convergence field, which is essentially the line-of-sight projection of matter density field in a 5×5 deg^2 field-of-view, made using a new method described in Barreira et al. (2016). Red (blue) regions have higher (lower) densities than the cosmic mean. Maps like this contain rich information about the cosmological model. Upper Right: the number of peaks in the convergence map, which are proxies to the abundance of massive galaxy clusters, as a function of peak height, for two different models. Symbols with error bars are from current observations. Bottom Right: peak counts currently place the tightest constraints on non-ΛCDM cosmology (the horizontal axis is the parameter describing a very popular such model); Liu et al. (2016).

Notes:

CONSTRUCTION/EXPLOITATION OF THE NEXT GENERATION PECULIAR VELOCITY SURVEYS

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Description:

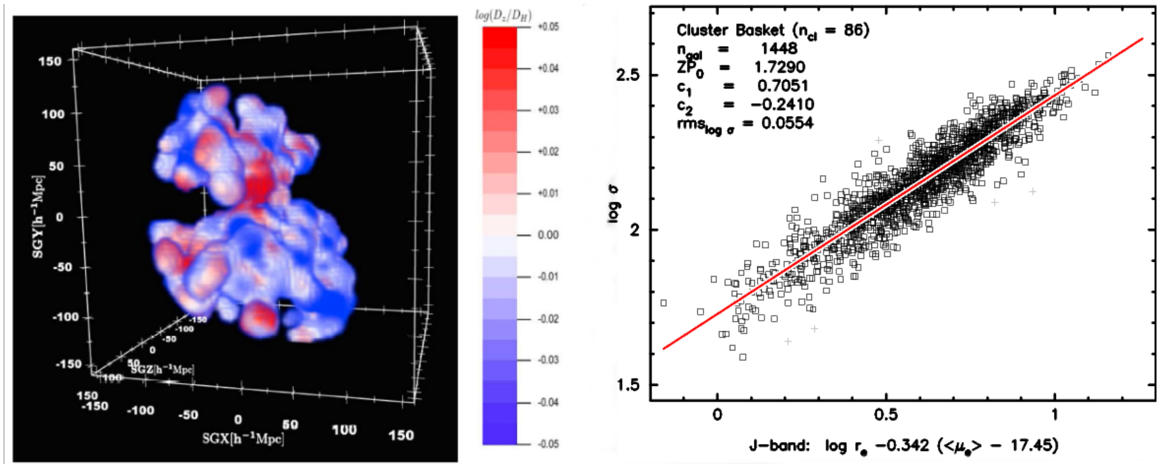
Peculiar velocities (v_{pec}) arise from inhomogeneities in the large-scale mass distribution and can be determined by accurate distance measurements (D) via $v_{pec} \approx cz - H_0 D$. While much progress has been made in mapping the local peculiar velocity field (see e.g. Springob et al 2014, Carrick et al. 2015), there are several key issues that are still poorly known, e.g. the precise source of the Local Group (LG) motion with respect to the CMB, the bulk flow amplitude at large scales which is a sensitive probe of matter density fluctuations. The quantity and accuracy of existing distance measurements restrict progress to provide robust answers to these fundamental questions.

The Taipan Galaxy Survey (de Cunha et al 2017) is a southern sky, multi-object spectroscopic survey, starting in early-2018, which will obtain redshifts for over a million galaxies and measure Fundamental Plane (FP) distances for $\sim$50 000 early-type galaxies within $z < 0.07$. The volume surveyed by Taipan will be 4× larger (with denser sampling and improved velocity precision) than the current state-of-the-art provided by 6dFGSv (Springob et al 2014). The statistical properties of the density and velocity fields, and their mutual consistency, will provide key tests of the cosmological model and independent measures of model parameters that cannot be determined from redshift surveys alone. Taipan combined with other planned peculiar velocity surveys will constraint $f\sigma_8$ at low-redshift, allow tests of modified gravity, and measure the local growth rate of large-scale structure (see Howlett et al. 2017).

As a PhD student you will join the Taipan peculiar velocity team and assist in all aspects of this survey which will include the data reduction and analysis, and exploitation of the results. Initially the work will involve the construction of a new homogeneous all-sky galaxy catalogue. As well as being used to refine the Taipan galaxy selection, this catalogue will be exploited to investigate to characterise the local cosmography, i.e. the local cosmic web (clusters, filaments, and voids) including a new assessment of the reality of the "Local Hole" (see Whitbourn & Shanks 2014).

A key aspect of the Taipan distance measurements will be the robust determination of FP photometric parameters (r_e and $\langle\mu_e\rangle$) and the linking to northern surveys like SDSS and the previous very sparse FP surveys (e.g. SMAC, ENEAR). A high level of reliability will be achieved by exploiting and inter-comparing existing high quality imaging surveys, i.e. `grizw` photometry north of Dec –30° from Pan-STARRS, the re-calibrated `ugriz` SDSS photometry, `JHK` 2MASS, $\mathtt{YJHK}_s$ VHS, `ugriz` VST ALTAS, Skymapper, DeCALs, etc. Multi-colour red sequence selection coupled with the $\sim 1''$ image quality will result in a very homogeneous *morphologically clean* FP dataset for $\sim$100 ,000 early-type galaxies over the entire sky within $z < 0.07$. This work will involve the enhancement and development of photometric data reduction pipelines. Using the derived FP and other parameters the characteristics of local early-type galaxy population will be investigated.

References:
6dFGSv survey, Springob et al 2014, *http://adsabs.harvard.edu/abs/2014MNRAS.445.2677S*
Taipan Galaxy Survey "White Paper", da Cunha et al 2017, *http://adsabs.harvard.edu/abs/2017arXiv170601246D*
"Cosmological forecasts", Howlett et al. 2017, *http://adsabs.harvard.edu/abs/2017MNRAS.464.2517H*
2M++ comparison, Carrick et al. 2015, *http://adsabs.harvard.edu/abs/2015MNRAS.450..317C*
The "Local Hole", Whitbourn & Shanks 2014, *http://adsabs.harvard.edu/abs/2014MNRAS.437.2146W*



Left: *The smoothed 6dFGSv peculiar velocity field in 3D, plotted on a grid in supergalactic cartesian coordinates, with grid-points colour-coded by the value of* $\Delta d = \log(D_z/D_H)$*, from Springob et al 2014.* **Right:** *The FP global fit for an all-sky set of rich clusters from Lucey et al 2018. This has been used to make a new robust determination of the bulk flow.*

Notes:

MINING LARGE GALAXY SURVEYS: FROM GALAXY EVOLUTION TO PROBING GRAVITY WITH LARGE SCALE STRUCTURE SURVEYS

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2nd Supervisor: one of Profs. Carlton Baugh, Shaun Cole, and/or Cedric Lacey

Funding: STFC CDT

Description:

Since SDSS, we work in the era of large spectroscopic surveys, in which millions to tens of millions of galaxies are targetted for spectroscopic follow-up. On the imaging side, we are in the era of hundreds of millions of objects, while with LSST planned for the mid-2020's, this endeavour will push us towards the billions of objects with multi-wavelength information.

In particular, Durham has a unique access to a series of world leading galaxy redshift surveys that are either on-going or planned to start before 2020, all ideally timed for exploitation during a 4 year PhD starting in autumn 2017:

a. DESI, the "Dark Energy Spectrocopic Survey Instrument" on the 4m Mayall telescope, is aimed at understanding the nature and evolution of dark energy and gravity by measuring up to 50 10^6 galaxy redshifts up to $z \sim 3.5$ over 14,000 deg^2. DESI begins its survey validations in early 2019, and will run for 5 years continuously from mid-2019.

b. MOONS, the "Multi-Object Optical and Near-infrared Spectrograph" on the 8m VLT, has as one of its extra-galactic aim to understand galaxy evolution at the epoch when star-formation was the most efficient, i.e. $1 \lesssim z \lesssim 2$. This is done by creating a GAMA-like survey over tens of square degrees. MOONS will be commissionned in mid-2019 and start a ~ 100 GTO night extra-galactic programme by end 2019, spanning several years.

c. PAUS, the "Probe of the Accelerating Universe Survey" on the 4m WHT, is aimed at mapping galaxy evolution within the large scale structure up to z 1 using high precision photometric redshifts, i.e. $\Delta z/(1+z) \lesssim 0.35\%$, with narrow band photometry. PAUS started acquiring data in 2016 and is aiming to cover $\sim$100 deg^2 by end 2018.

To analyse those galaxy surveys which are unique and world leading in terms of depth, area and space density sampled, new analysis tools, appropriate for each survey, need to be developped. For example for PAUS it will be critical to understand the photometric redshift success rate and associated completeness across the survey for any robust large scale structure analysis to take place. On the other hand for DESI, the statistical precision obtained with 50 10^6 redshifts require systematic effects in the imaging and spectroscopic data, as well as in the analysis pipeline, to be understood at the sub-percent level.

In parallel mock galaxy surveys, built from large N-body simulations, will be needed. Part of the PhD project will be to make them as realistic as possible for the specifications of each survey, so that the analysis pipeline can be properly tested and assessed. These mocks will be key in interpreting the results from those galaxy surveys.

MOONS, like its low redshift counterpart GAMA, is primarily a galaxy formation focused survey, hence ideally co-supervised by Prof. Lacey. On the other hand, Prof. Cole's key roles within DESI would make him the ideal co-supervisor for a DESI focused project, while Prof. Baugh would be naturally involved in a PAUS based project, building on his PAUS connections.

Hence a PhD project under the broad title "Mininig large galaxy surveys: from galaxy evolution to probing gravity with large scale structure surveys" can cover any of the areas above and will be suitably arranged for the selected candidate(s) to suit their interests and strengths, resulting in a set of different, but complementary project(s), that will be either more data or more simulation focused. The projects are likely to evolve during the course of the PhD to ensure the most relevant science goals are investigated and written up, resulting in a vibrant, active and novel PhD project.

VirgoDB database where mock surveys will be made publicly available
PAUCam Survey portalwhere PAUCam Survey operations are stored, while data is stored on CosmoHub.
GAMA survey portal with the basic GAMA survey introduction, a potential outline for science that will be done with MOONS (but at $z \sim 1$). Additional MOONS references: ASPCS paper SPIE paper.
DESI experiment part I and DESI experiment part II.

Notes:

LINKING THE PHYSICS OF THE INTERSTELLAR MEDIUM TO GALAXY FORMATION

Supervisors: Prof. Tom Theuns, Prof. Richard Bower & Dr. Michele Fumagalli
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Description:

It is well established that star formation is regulated by stellar feedback in galaxies like the Milky Way. However, the details of this process are poorly understood. Energy injection by supernovae plausible plays a major role, but stellar radiation affecting gas cooling and imparting momentum to gas and dust, pressure from cosmic rays, and tension from magnetic fields, may also be important. This lack of understanding limits the predictive power of all current models. At the dawn of the launch of the JWST space telescope that will probe star formation in the first galaxies, this is the right time to make a big effort in this subject.

Two recent opportunities promise big advances in this field in the coming years: (*i*) advances in instrumentation, in particular Integral Field Units (IFUs) on large telescopes (*e.g.* MUSE on VLT) - which will allow us to study the dynamics of the interstellar medium (ISM) in nearby and high redshift galaxies and (*ii*) a step-change in speeds of computers (*e.g.* INTEL's SKYLAKE chip) and tremendous advances in algorithms to exploit the many levels of parallelism in current and future CPU's (*e.g.* the SWIFT simulation code).

The successful candidate can shape their project together with the supervisors, to be more focussed on observations, simulations, or on the interface between them. All three are data intensive.

Observational strand: A census of metals and hydrogen around galaxies. To obtain statistical maps of the small-scale distribution of hydrogen and metals around distant galaxies, we have been awarded 55 orbits on the Hubble Space Telescope. We are currently observing 55 quasar pairs at redshift $z \sim 2.5$ that have the small angular separations needed to intersect the halo of galaxies with multiple sightlines. By correlating the spectral signatures of hydrogen and metals in these sightlines, we will measure the typical size of the dense gas clouds that populate the halo of high-redshift galaxies. We have also been awarded more than 200 hours to use the new instrument MUSE at VLT and the Hubble Space Telescope to measure the redshifts of galaxies near these dense gas clouds (see figure, left), to directly connect the gas seen in quasar spectra to the properties of galaxies measured in emission in the redshift range $z \sim 0.5 - 3.5$. In this PhD project, we will measure the kinematics and metallicity of the absorbing gas to put observational constraints on the typical velocities of inflows/outflows and on the mixing of metals in galaxy halos. We will also connect the halo gas properties to the star formation rates and masses of the galaxies detected in emission.

Simulation strand: exploiting and enhancing the SWIFT *simulation engine.* The SWIFT code is being developed in Durham in collaboration with Dr. P Gonnet (Google Switzerland) and INTEL. This open-source hydrodynamical code is designed to exploit the many levels of parallelism offered by current and future processors, using task-based parallelism. We are looking for a keen PhD student to add new physics to SWIFT (*e.g.* radiative transfer, or magneto-hydrodynamics) and set-up and run simulations on the interface between the interstellar, circum-galactic, and intergalactic gas. We aim to perform some of the most detailed simulations of this interface ever, using some of the largest computers available world-wide.

Observation-simulation interface strand. Whereas simulations provide physical values of gas properties (*e.g.* density, pressure, temperature, composition, ...) observations yield *spectra*. The translation from physical to observable properties is non-trivial. In this project we will develop methods to analyse very high resolution simulations that explicitly resolve the entrainment and mixing of gas clouds within galactic winds, and the interaction between inflows/outflows with the halo gas. By generating realistic mock spectra, we will perform detailed comparisons with observations to interpret the data and to guide the models. Such analysis tools are crucial if we want to take advantage of the data coming from new new instruments such as JWST - to interpret the nebular lines that probe the ISM in $z \sim 8$ galaxies, MUSE IFU observations - that probe the detailed interaction between hot and cold gas in galaxies, and the ALMA radio telescope - that will probe the cold and molecular gas and dust in galaxies.

A simulation of how energy injection by supernovae stirs the gas in a dwarf galaxy is illustrated by **this movie** of the gas density[1] in a column perpendicular to the galaxy's disc.

[1]dropbox link: `https://www.dropbox.com/s/zf1s5k8dnpprgie/density_dwarf_thin_L9.mp4?dl=0`

Notes:

THINKING OUTSIDE OF THE BOX

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Funding:	STFC	

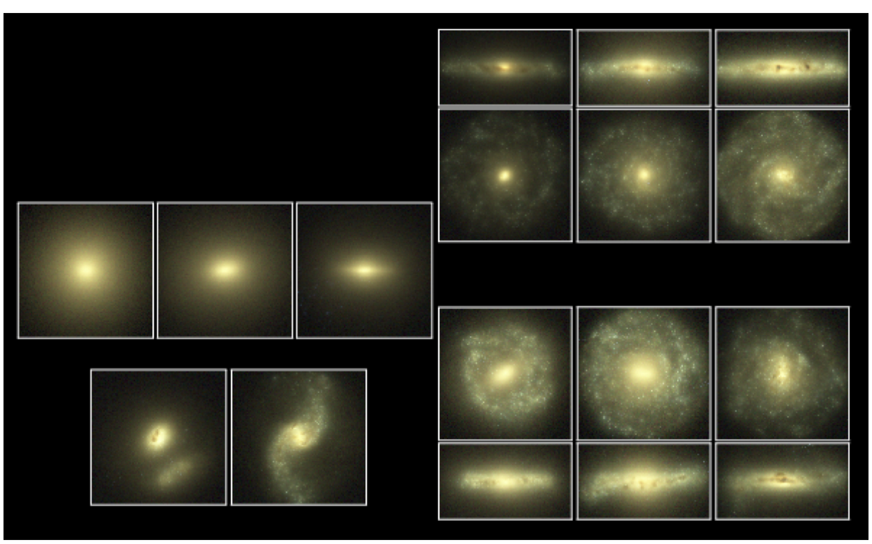
Description:

Cosmological simulations follow the formation of galaxies and clusters in periodic volumes. Finite computer resources then introduce a relation between numerical resolution and simulation volume, in the sense that large cosmological volumes can only be simulated at coarse resolution. As a consequence, current simulations struggle to keep-up with observational surveys, which study galaxies in detail in a volume that is much larger than can be simulated. This leads to a mismatch between data and simulations, not just in terms of statistics, but also in terms of which science can be done with the simulations. For example, current simulations cannot resolve galaxies in a volume that is large enough to study the baryon acoustic scale.

This project aims to overcome this limitation by thinking outside of the simulation box, based on three recent advances in computational cosmology. Firstly, we developed a scheme to generate cosmological initial conditions at any required resolution, in a computational volume of arbitrary size (Jenkins 2013). Secondly, we developed a scheme that can quickly decide which regions will need to be simulated at high resolution, given that they will interact with each other during the non-linear growth of structure (Monaco et al, 2013). Thirdly, we developed a new simulation engine called Swift, that can efficiently and accurately evolve a given set of initial conditions. The physics included in Swift is heavily based on the successful Eagle project (Schaye et al, 2015), which lead to the second most cited astronomy paper published in 2015.

Your task is to combine these three research strands into one easy to use simulation engine, and then perform the most impressive cosmological simulation of galaxy formation yet! Obviously, this project has a large computational and HPC base, but, forming the core of research at the ICC, there is a large number of other staff, students and postdocs, that work on related aspects that you can interact with. This also includes many of our international collaborators in the Netherlands, Germany, and elsewhere. The figure shows mock images of Eagle galaxies.

Jenkins A., MNRAS, 2013, 434; Monaco et al., MNRAS, 2013, 433; Link to a description of the Swift code; Schaye et al., 2015, MNRAS, 446, 521



Mock broad-band colour images of EAGLE *galaxies arranged in a Hubble diagram, from Schaye et al., 2015.*

Notes: