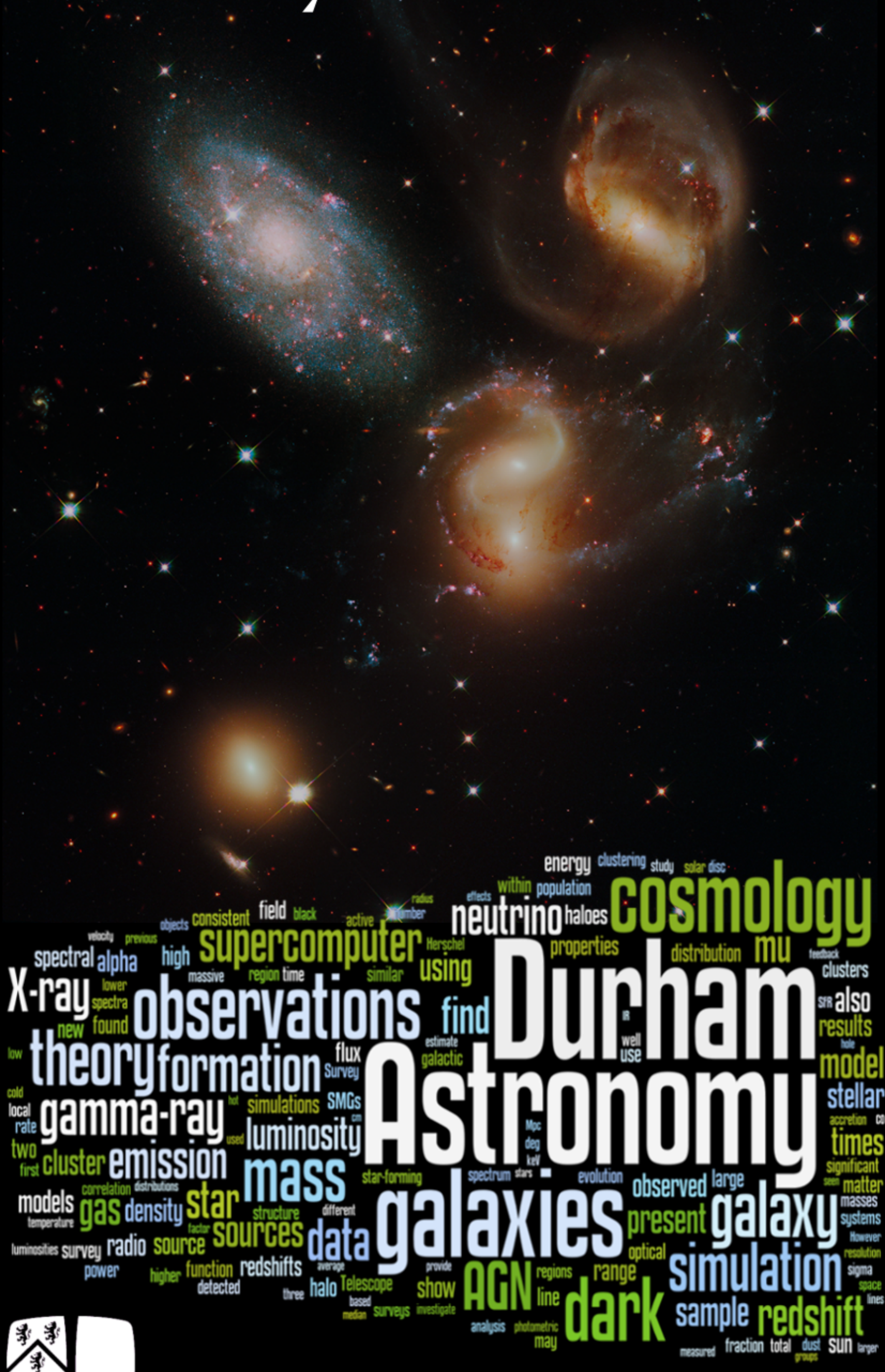
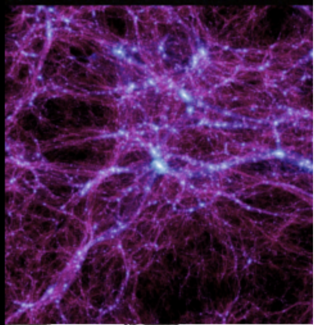
Fully Funded Studentships in Astronomy at Durham 2017





Durham University

FULLY FUNDED 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).

We are seeking now graduate students to undertake research within our PhD and MSc by Research programmes, starting from October 2017.

Fully Funded PhD Studentship Options

This booklet outlines PhD projects for which we can provide full funding (fees plus a stipend) over 3.5 years. We provide brief details on the funding below.

European Research Council (ERC) studentship. This 3.5 year PhD studentship is nominally available to graduate students from any country. We have 1 ERC studentship this year.

Science and Technology Facilities Council (STFC) studentships. These 3.5 year PhD studentships are only available to UK citizens and to EU nationals residing in the UK; see the STFC web site for more specific details regarding eligibility: http://www.stfc.ac.uk. We expect to offer about 6 STFC-funded studentships this year, based on previous years STFC allocations.

Engineering and Physical Sciences Research Council (EPSRC) Case studentship. This 3.5 year PhD studentship has the same eligibility criteria as the STFC studentships. We have 1 EPSRC Case studentship this year.

Royal Society funded PhD studentship. This 3.5 year PhD studentship has the same eligibility criteria as the STFC studentships. We have 1 Royal Society studentship this year.

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). We expect to interview shortlisted candidates for STFC studentship from mid-February through to mid-March.

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. For details of other potential projects and a full list of potential supervisors, please see the Postgraduate Opportunities link off of our web page

Two potential funding routes are provided by Durham University through the **Durham Doctoral Studentships (DDS)** and **China Scholarship Council (CSC)** schemes. The nominal application deadline for DDS/CSC applications are Monday January 16$^{\text{th}}$ 2017 for an autumn 2017 start. We encourage interested graduate students to contact us in advance of this deadline to ensure maximum success, as well as to explore other potential sources of funding. In the past year prospective PhD students have been successful in securing funding from various national and international fundings bodies with support from academic staff in Durham, including *Van Mildert College Trust* and *CONACYT* PhD scholarships. For more details, please see the Postgraduate Opportunities link off of our web page.

MSc by Research Studentship Options

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

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.

CREATING GALAXIES IN A VIRTUAL UNIVERSE

Main Supervisor:	Prof. Richard Bower	r.g.bower@durham.ac.uk
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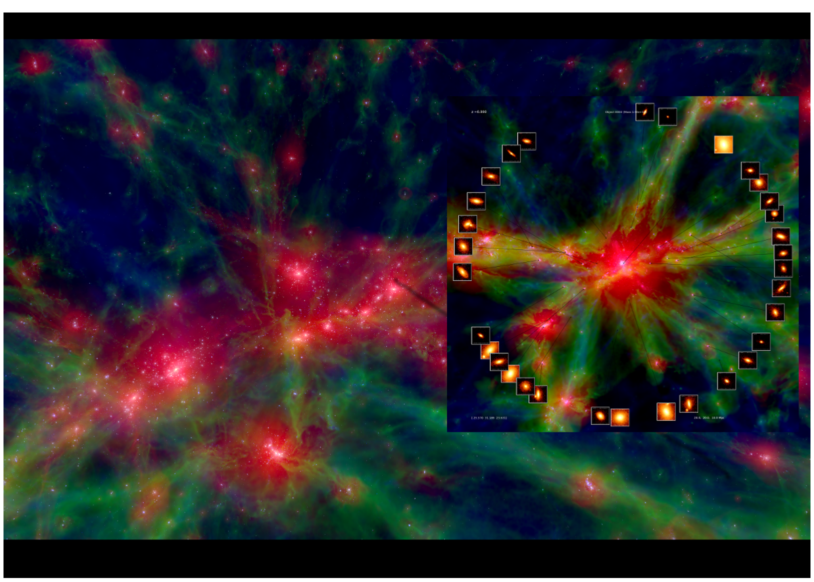
Funding:	STFC	

Description:

Imagine being able to create a virtual the Universe, complete with realistic galaxies and quasars, inside a computer. The EAGLE project aims to do exactly this. The first phase of the project make a ground-breaking step, creating a virtual Universe in which the masses and sizes of the galaxies formed compared well with observations. This creates a 'laboratory' with which we can experiment with galaxy formation, quantifying the roles of the physical processes such as gas cooling, metal enrichment and feedback from stars and black holes. The current EAGLE simulations are, however, limited in two respects. Firstly the simulations only marginally resolve galaxies, making it hard to reliably study the internal structure of the galaxies (such as their Hubble-type and morphology). Secondly the simulations have relatively small volume, sufficient to understand the average properties of galaxies, but not to understand the diversity of the galaxy population. A larger volume simulation would also break new grownd in using galaxies to test theoretical models for the growth of cosmic structure and to search for deviations from Einstein gravity. In this project, the student will join the Eagle team in advancing to the next level of realism and volume.

- Increasing the resolution of the simulations will allow us to understand the origin of galaxy's structural properties, such as Hubble's famous 'tuning-fork', and to identify the key processes that are involved in this. This will lead to a deeper understanding of the diversity of galaxy shapes and sizes; of the processes that regulate star formation and black hole growth. The aim of the project is to quantitatively compare the outputs of the simulation with observational programmes such as MANGA, SAMI and KROSS that measure the evolution of galaxy structure and dynamic over cosmic time, and to compare to galaxies seen through their gas content with ALMA and the future square kilometer radio telescope, SKA.
- Increasing the volume of the simulation will allows us to: (1) identify statistical samples of rare (and bright) objects this is critical since these are the only objects that can be detected in the distant Universe and to understand the origin of the diversity of galaxy properties; and (2) to trace the gravitational structure of the Universe on large scales galaxies, making it possible to test cosmological models and search for departures from Einsteins theory of gravity.

The student needs to have good computational skills, as the project will involve developing physics modules within the new SWIFT cosmological code, and good analytical and physics skills in order to understand the outcome of the simulations. A few useful links are given below.
• The Eagle Project pages (http://icc.dur.ac.uk/Eagle/)
• A paper summarising the first phase of the Eagle project (http://adsabs.harvard.edu/abs/2015MNRAS.446..521S)
• A first step towards understanding the diversity of galaxies (http://adsabs.harvard.edu/abs/2016arXiv160707445B)



The complex large-scale structure of the Universe as traced by dark matter, gas and galaxies. The upper half of the figure emphasises the gravitational structures built by the collapsing dark matter. These trap the diffuse gas (baryons) which is then able to cool and collapse to form stars. The lower half shows the diffuse baryons, with the colours reflecting the gas temperature (blue/cool to red/hot). Yellow/white colours highlight galaxies. Seen on this scale (100 Mpc across) galaxies appear almost point-like. The inset panel zooms in on the a single halo and shows some of the galaxies within it.

Notes:

NEXT-GENERATION COMPUTER TECHNOLOGIES AND THEIR APPLICATIONS TO VIRTUAL UNIVERSES

Main Supervisor:	Prof. Richard Bower	r.g.bower@durham.ac.uk
Office:	Ogden Centre West 216	
2nd Supervisor:	Dr. Robert Maskell (Intel Corp.)	robert.maskell@intel.com
Funding:	EPSRC CASE studentship	

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 CASE 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.

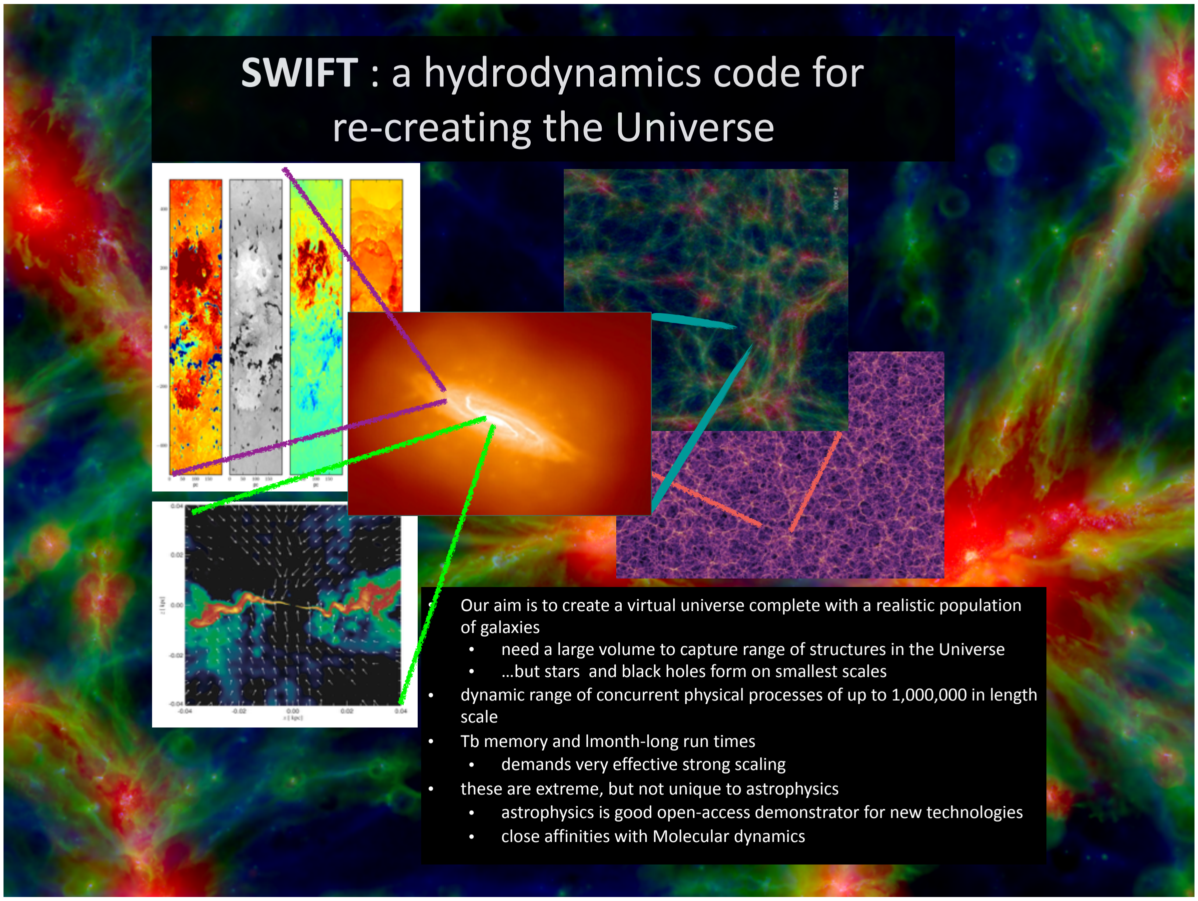
However, as the speed of the simulation rises, the bottleneck is quickly becoming the time it takes to output the simulation data and process it. Our solution to this "big data" problem is twofold: first, instead of writing a complete snapshot at fixed intervals, we write only the changing quantities 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 Intels 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 lmonth-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:

GAMMA RAY ASTRONOMY WITH THE CHERENKOV TELESCOPE ARRAY

Main Supervisor:	Prof Paula Chadwick	p.m.chadwick@durham.ac.uk
Office:	Rochester Building 125c	
2nd Supervisor:	Dr Anthony Brown	anthony.brown@durham.ac.uk
Funding:	STFC	

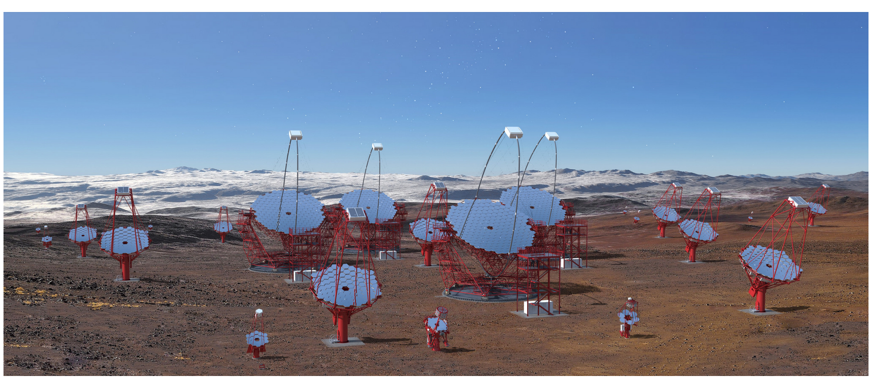
Description:

Over the last 10 years, very high energy (VHE) gamma ray astronomy has opened a new window on the extreme universe. The catalogue of known VHE-emitting objects has grown by an order of magnitude and includes many different classes of objects - supernova remnants, pulsars, binary star systems, star formation regions and active galaxies - while other objects remain a mystery. The VHE radiation from these systems is produced by non-thermal particle acceleration, but the mechanisms by which this occurs have not been established. Observations of the more distant objects provide us with a probe of the extragalactic background light, of intergalactic magnetic fields and even of the structure of space-time itself. VHE gamma rays may also be one of the ways in which we detect the presence of dark matter in the Universe.

However, we have really opened this new window only a little way, and so some 1200 scientists from 29 nations are joining together to create a new instrument: the Cherenkov Telescope Array (CTA). Consisting of a 100-telescope array in the southern hemisphere and a 50-telescope array in the north, CTA will have sensitivity around 10 times better than any gamma ray telescope now in operation, will cover 4 orders of magnitude in energy and have better angular resolution than anything we have built before. Prototyping of telescopes and instrumentation is well underway, and construction of the northern array on La Palma has already started.

As founder members of CTA, the Durham group is involved in many different aspects of the telescopes. Students can choose from a range of possible projects, including simulations of array performance, the development of new analysis algorithms, the design & testing of instrumentation and science studies in preparation for CTA (primarily using data from the Fermi Gamma-ray Space Telescope),. We are particularly involved in the construction of an innovative dual-mirror design for the small telescopes of the array. Students can expect to be involved in work on preliminary data from the prototype telescope in Paris and on the pre-production telescopes, which are expected to go on the final site of the southern array in Chile. Construction of these telescopes is expected to start in 2018, with the first data shortly thereafter.

CTA website: https://www.cta-observatory.org
Seeing the High-Energy Universe with the Cherenkov Telescope Array - The Science Explored with the CTA



Artist's impression of the Southern Cherenkov Telescope Array.

Notes:

LINKING GALAXIES TO DARK MATTER

Supervisor: Professor Shaun Cole shaun.cole@durham.ac.uk
Office: Ogden Centre West OCW211

Funding: STFC

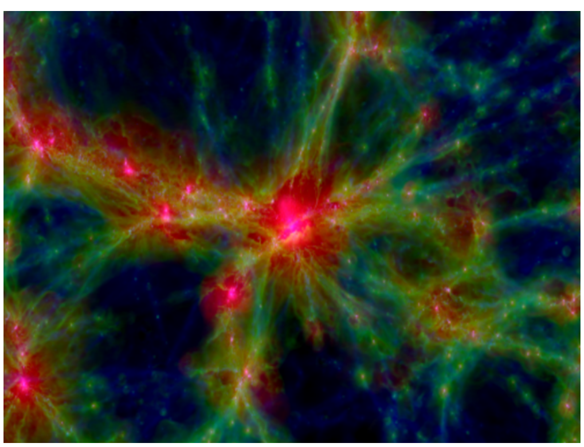
Description:

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:

THE FIRST STARS

Main Supervisor: Dr. Ryan Cooke ryan.j.cooke@durham.ac.uk
Office: Ogden Centre West 121
Funding: STFC (Royal Society TBC)

Description:

Less than one billion years after the Big Bang, the Universe was in a Cosmic 'Dark Ages' with no sources of light. During this time, primordial matter consisting of hydrogen and helium was being collected by gravity to make the first stars. This starlight brought an end to the Dark Ages, and heralded a new era of stars and galaxies. Aside from their starlight, the first stars played an important role in creating - for the first time - the elements of the periodic table besides hydrogen and helium. Unfortunately, the first stars are now extinct, and we are left in the dark about their most basic properties. That said, some of the most important characteristics of the first stars, such as their mass and how they died, can be inferred by finding the chemical elements they made during their lives.

To measure these elements, we must find galaxies that exclusively contain the elements from the first stars. The main aim of this project is to find these galaxies using spectra already available from the Sloan Digital Sky Survey. Once identified, the chemistry of these systems will be measured with high quality echelle spectroscopy. The chemistry of these galaxies will be compared to state-of-the-art models of nucleosynthesis to infer the typical masses and supernova explosion energy of the first stars. The galaxies that will be uncovered with this project are potentially the antecedents of the smallest and faintest galaxies in the Universe, and may also provide a window to study the properties of the first galaxies. This research is primarily an observational and data mining project.

Click here to see my research interests and click here for a list of relevant publications

An image of a nearby galaxy, known as I Zwicky 18 – one of the most pristine environments known in the local Universe (Credit: HST/NASA/ESA). The goal of this project is to discover the infant precursors of this galaxy, 10 billion years in the past. We will study these galaxies by using a technique called quasar absorption line spectroscopy to study their chemical makeup. This chemical information allows us to infer the properties of the stars that were responsible for the chemical enrichment.

Notes:

THE EATING HABITS OF THE MILKY WAY HALO

Main Supervisor: Dr. Alis Deason alis.j.deason@durham.ac.uk
Office: Ogden Centre West 224
2nd Supervisor: Prof. Carlos Frenk c.s.frenk@durham.ac.uk

Funding: STFC

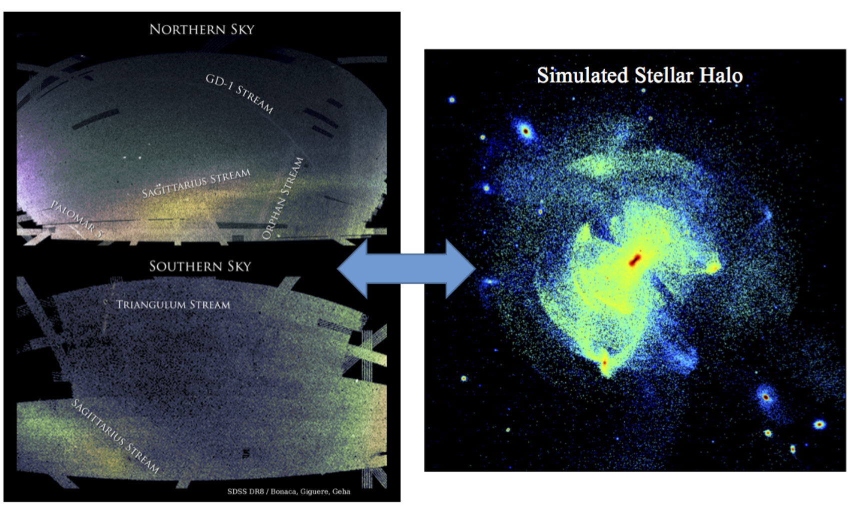
Description:

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.

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).

The project is intended to have both observational and theoretical elements, but the student can choose to focus more on one aspect if they wish.



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:

AGN FEEDBACK IN THE MOST MASSIVE CLUSTERS OF GALAXIES

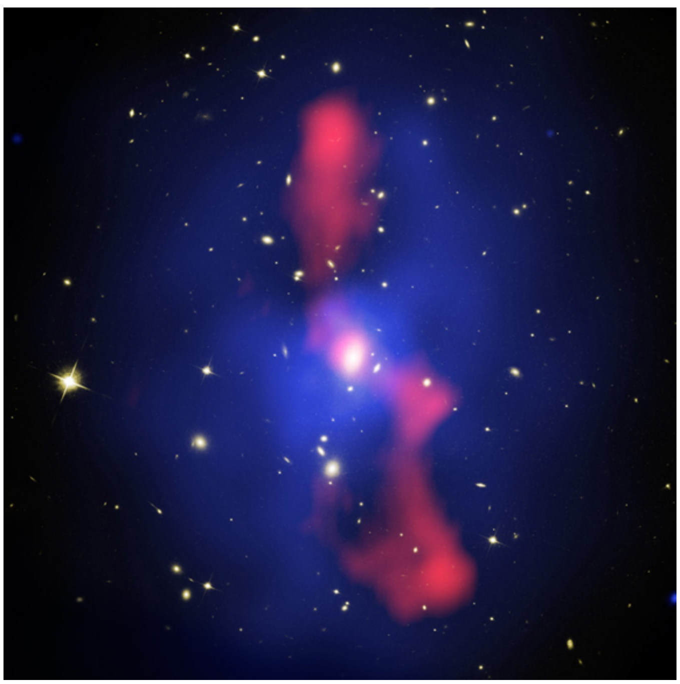
Main Supervisor: Prof. Alastair Edge alastair.edge@durham.ac.uk
Office: Ogden Centre West 109
Funding: STFC

Description:

Clusters of Galaxies are the most massive gravitationally bound systems known and their population and evolution are very closely related to Cosmological parameters. Recent panoramic surveys in the optical, near-infrared, radio and X-ray allow us to select the rarest, most massive clusters of galaxies out to high redshift ($z > 1.5$).

At the heart of these massive clusters is usually a single massive galaxy that dominates over all the other member galaxies of the cluster. These galaxies frequently host the most power AGN and this enhanced activity has a profound effect on the properties of the central galaxy and the cluster that surrounds it.

This project will use multi-frequency data from the radio to the gamma-ray regime to understand the life-cycle of the AGN in these galaxies and link it to the properties of the cluster as a whole. The project will use Jansky VLA, eMERLIN, ATCA and LOFAR radio data combined with VLT MUSE, Chandra, XMM-Newton, eROSITA and Fermi data. These data will allow us to link the AGN activity on short (i.e. decade) timescales to that on much longer ones (many millions of years).



A Chandra X-ray image of MS0735+74 ($z = 0.22$) with Chandra X-ray imaging (blue) with radio data from the VLA superimposed on it (red). Note the radio lobes fill "cavities" in the hot intracluster medium of the cluster. The expansion of these cavities mechanically heats the surrounding gas. The energy of required to create these cavities represented the most powerful, sustained event since the Big Bang.

Notes:

THE GAS CYCLE OF HIGH-REDSHIFT GALAXIES

Main Supervisor:	Dr Michele Fumagalli	michele.fumagalli@durham.ac.uk
Office:	Ogden Centre West 120	
Funding:	STFC	

Description:

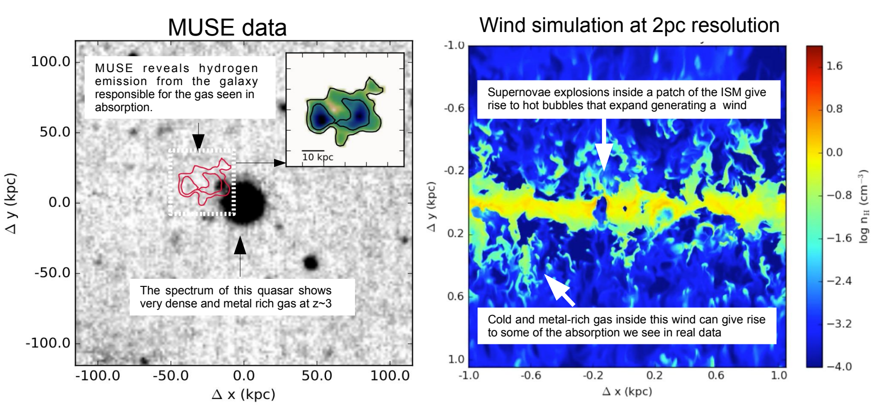
Galaxies continuously exchange gas between the interstellar medium (ISM), which is the dense material out of which stars form within galaxy disks, and the intergalactic medium (IGM), which is the more diffuse cosmic gas that pervades the universe. This gas exchange occurs within the circumgalactic medium (CGM), that is the gas around galaxies confined within the dark matter halos. The goal of this investigation is to understand how the baryon cycle in the CGM drives the evolution of galaxies from their infant stages of assembly, 10 billion years ago, to the more mature stages of their lives, today in the nearby universe. The proposed projects aim to address these fundamental and still open questions: how do galaxies get their gas? And how do galaxies spread the elements produced by stars in the universe?

I currently offer two PhD projects: the first one is primarily observational and based on spectroscopic data; the second one is primarily a theoretical project, based on the analysis and development of simulations. For students interested in a mix of theory and observations, it is possible to combine elements of both projects.

Project 1) 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.

Project 2) The CGM in high-resolution simulations Absorption spectroscopy in quasar spectra probes the distribution and kinematics of hydrogen and metals on very small scales, not exceeding a few parsecs. However, nearly all the simulations that have been used so far to model absorption lines have much lower resolution, at least two orders of magnitude below the scales probed in observations. Due to this fundamental mismatch of scales, comparisons between observations and simulations are limited to simple cumulative quantities, a fact that limits our ability to connect the observed gas clouds to the rich physics at work inside halos. As part of this PhD project, we will develop and analyse very high resolution simulations (see figure, right) that explicitly resolve the entrainment and mixing of gas clouds within galactic winds, and the interaction between inflows/outflows with the halo gas. By extracting realistic mock spectra from these simulations, we will perform detailed comparisons with observations to address outstanding questions on the origin of the metal-rich absorbers detected around high-redshift galaxies.

Read more about these projects here. Find out more on who I am and what I do (including recent publications) here.



Left: By combining spectroscopy in absorption against quasars with galaxy redshift surveys from MUSE and HST, this project will assemble the largest sample of high-redshift galaxies for which we can study the CGM (in absorption) as a function of the star-forming properties (in emission) of the host galaxies. Right: By comparing mock data from high-resolution simulations of the CGM with real data, this project will unveil the physical origin of the gas seen around high-redshift galaxies.

Notes:

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

Main Supervisor: Dr. Baojiu Li baojiu.li@durham.ac.uk
Office: Ogden Centre West 218
2nd Supervisor: Professor Carlton Baugh c.m.baugh@durham.ac.uk

Funding: STFC and/or ERC

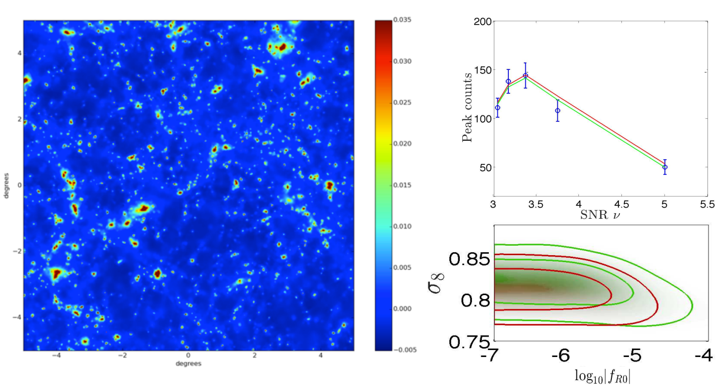
Description:

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:

THE RELATIONSHIP BETWEEN GAS AND GALAXIES

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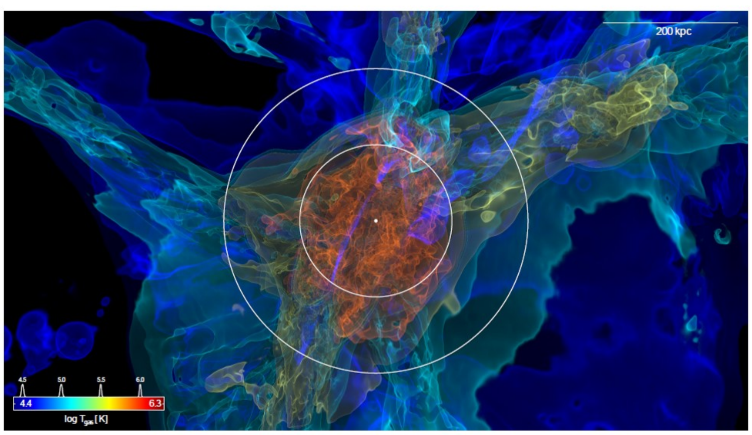
Description:

Possibly surprisingly, astronomers now think we understand the process by which matter collapsed gravitationally to form the large scale structure of the Universe. The surprise is due to the fact that we still do not know what makes up the 'dark matter' which dominates this collapse.

What is not yet understood is how the 'normal' matter then falls into these gravitational potential wells to form stars and galaxies. Initial theories for this suggested that essentially all of the gas in the Universe should have been converted into stars by the present day, while observations show that in fact only a tiny fraction of the gas has been converted. The answer to this conundrum is not yet fully understood, but has to include a large amount of 'feedback' where the formation of a first generation of stars generates shocks and winds that prevents the subsequent collapse of further gas into that gravitational potential well. Detailed numerical models including plausible feedback mechanisms such as supernovae and jets from super-massive black holes have now been created, but have not been tested by being compared with the real universe. We are proposing to make this comparison. To do this we need to measure the properties of the gas using a space based telescope (space based to allow observations in the ultra-violet where the low redshift gas properties can be measured), and also large ground based telescopes (where we can measure the distances to large samples of faint galaxies and the high redshift gas properties can be seen).

By combining the information about the gas and the galaxies in the real universe, and comparing the results with the outputs from state of the art models for the formation of galaxies, combining this for the entire observable history of the Universe, we hope to be able to confirm or rule out the proposed feedback mechanisms, and show that we understand why the Universe is still forming stars.



Caption *An example of the complex temperature structure around a redshift 2 galaxy. Red shows million degree gas, while blue shows 'cooler' photoionised gas (Nelson et al. 2016)*

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EXTREME STARBURSTS AT HIGH-REDSHIFT: WITNESSING THE FORMATION OF MASSIVE GALAXIES

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Funding:	STFC	

Description:

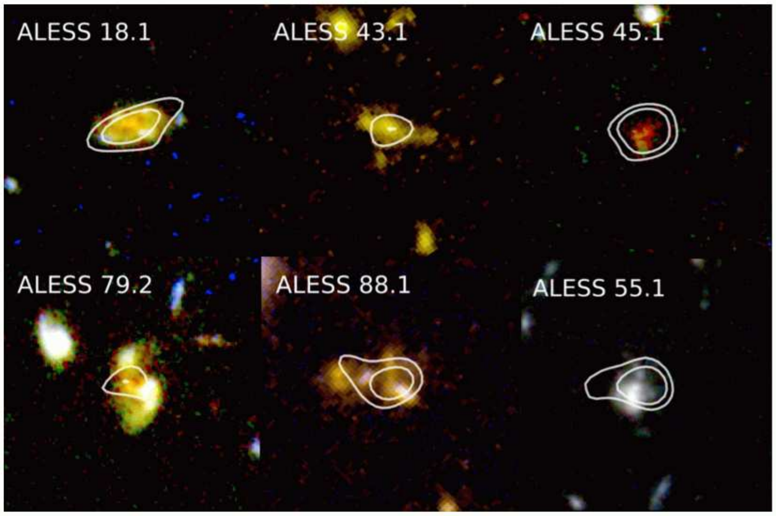
Many of the stars we see in todays massive galaxies formed between redshift, $z = 1$–3, corresponding to lookback times of 7–10 billion years. Galaxies at these early times were typically forming stars typically 10–30 $\times$ faster than average galaxies today. This period has therefore been herald as the "epoch of galaxy formation". The subsequent decline in the star-formation activity of galaxies over the last ~ 7 billion years since $z \sim 1$ appears to be driven by a reduction in the amount of cold molecular gas available within galaxies, as this material is converted into stars or heated and expelled from the galaxies.

Amongst high-redshift star-forming galaxies, the most active examples are converting their gas reservoirs into stars 100–1000 $\times$ faster than the Milky Way currently does. Such extreme rates of star formation are seen in less than one per cent of galaxies at the present day, but such active systems appear to be much more common in the early Universe. It has been suggested that up to half of all of the stars seen in local galaxies formed in these intense events at $z \sim 1$–3, making them a crucial phase for understanding galaxy formation.

Despite their high star-formation rates, this population of vigorous star-forming galaxies are some of the hardest to study. This is because a by-product of intense star formation is the creation of large amounts of dust, which forms in the atmospheres of massive stars during the later phases of their evolution and death. This dust absorbs the light from other young stars, making these galaxies very faint in the optical and ultra-violet wavebands which are typically used to survey the distant Universe. However, the dust grains which absorb this optical/ultra-violet light heat-up and subsequently re-emit the radiation in far-infrared and sub-millimetre wavebands. This emission makes these galaxies some of the most luminous far-infrared sources known, allowing us to pin-point the sites of immense starbursts early in the life of the Universe. The physical processes occuring within these galaxies will be very different to those which operate in the declining phase of "galaxy formation" since $z \sim 1$ and we need to understand and model these processes if we are to build a complete theory of galaxy formation and evolution.

To this end we are leading a survey campaign to study this enigmatic population of dusty starburst galaxies seen in the high-redshift Universe. These surveys combine tracers across a broad swathe of the electromagnetic spectrum, from the radio, sub-millimetre and far-infrared, through the mid- and near-infrared, into the optical, ultra-violet and out to X-rays. This multi-wavelength approach allows us to investigate the growth of this population through both their star formation, the growth in their stellar mass and the attendant decline in their gas content, as well as the accretion which occurs onto black holes within these systems. Our goal is to derive an empirical description of the evolution of the population of luminous, dusty starbursts and so to test their part in the formation of the massive, passive elliptical galaxies at the present-day, as well as links to the luminous Quasar population, whose activity also peaked at $z \sim 1$–3.

This is an observationally-driven PhD project and the successful student will be expected to use a range of observational facilities, including travel to Hawaii, Chile or Europe. The PhD will provide training in single sighle sub-mm observations with JCMT, interferometric data reduction and analysis, based on data from the JVLA and *e*-MERLIN radio interferometers and the Plateau de Bure and ALMA millimetre interferometers, as well as the exploitation of integral field spectroscopy (from KMOS and SINFONI on VLT) and wide-field imaging and spectroscopy. There will also be opportunities to relate the observational results to theoretical models being developed at Durham.



Hubble Space Telescope images of dusty starburst galaxies in the distant Universe. Overlayed on each of these are contours showing the sub-millimetre emission from these systems, as detected by the Atacama Large Millimeter Array (ALMA). ALMA is able to identify both the most active galaxies and indeed to pin-point those regions of vigorous star formation within these galaxies, even though these systems appear unremarkable in the optical and near-infrared. Our on-going studies with ALMA and other observatories seek to understand the cause of this intense activity in young galaxies at high redshifts and to test the link between this population and the formation of both elliptical galaxies and Quasars.

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