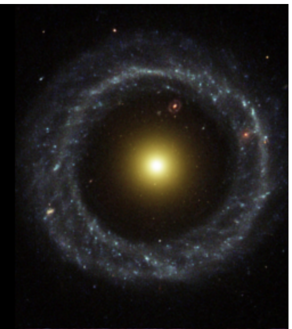
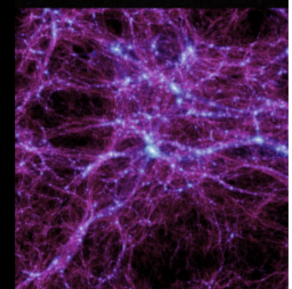
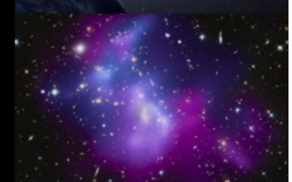
Fully Funded Studentships in Astronomy at Durham 2018







Durham University

FULLY FUNDED STUDENTSHIPS IN ASTRONOMY FOR AUTUMN 2018 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 people involved in astronomy research, whcih includes postdocs, postgraduate students and support and technical staff. Our main areas of expertise are extragalactic astronomy and cosmology (observational and theoretical), advanced instrumentation, and high-energy astrophysics. Astronomy in Durham is split over three closely connected groups within the Physics Department and which are now all located to a large extent within the newly built Ogden Centre for fundamental physics. The three groups consists of the Centre for Advanced Instrumentation (CfAI), the Centre for Extragalactic Astronomy (CEA) and the Institute for Computational Cosmology (ICC).

We are seeking now graduate students to undertake research within our PhD and MSc by Research programmes, starting from October 2018.

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 domiciled in the European Union (EU). We have 2 ERC studentship this year.

Science and Technology Facilities Council (STFC) studentships. These 3.5 year PhD studentships are only available to EU nationals domiciled 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 offer 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 (see our webpages for up-to-date information regarding possible interview days and effective deadlines to meet).

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 still to be confirmed, but nominally application should be submitted Tuesday January 16^{th} 2018 for an autumn 2018 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*, *CONACYT* and *CONICET* 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 broad range of MSc by Research (MScR) projects and supervisors for graduate students that have their own funding. For details of other potential projects and a full list of potential supervisors, please see the Postgraduate Opportunities link off of our web page Currently there is no 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.

ARE AGN SPECIAL? THE ENVIRONMENTAL DEPENDENCE AND GLOBAL IMPACT OF AGN ACTIVITY

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Funding:	STFC	

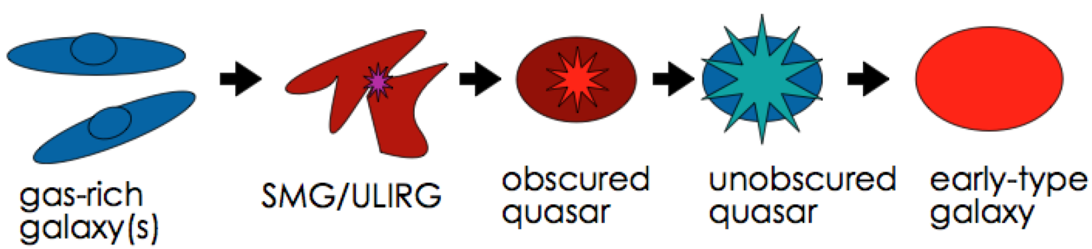
Description:

Powered by mass accretion onto super-massive black holes, Active Galactic Nuclei (AGN) are undoubtedly exotic phenomena. According to most theoretical models of galaxy formation, AGN have also had a profound impact on the way the Universe looks today. However, AGN activity is, in another sense, a common phenomenon: the finding that essentially all massive galaxies host a central super-massive black hole clearly indicates that these galaxies have all hosted AGN activity at some point during their lives. Are these AGN phases a special period in the lifetime of a galaxy that require specific environmental conditions or are they simply a random event that can occur at any time in any galaxy? Surprisingly, do not know the answer to this fundamental question, which is central to understanding AGN within the broader context of galaxy formation and evolution.

I am looking for a student to answer this fundamental question using state-of-the-art multi-wavelength observations over X-ray–radio wavelengths. A key challenge that must be overcome to answer this question is the construction of a (near) complete census of AGN activity, which requires the identification of AGN activity even in the presence of large amounts of obscuring gas and dust. This can be achieved from a combination of multi-wavelength observations, which provide a myriad of approaches to identify even the most heavily obscured AGN. This is a key step since there are hints that the most heavily obscured AGN reside in more dust-obscured host-galaxy environments than less obscured AGN. From this (near) complete census of AGN activity you will then measure the host galaxy and larger-scale environments in which the AGN resides to explore whether there are preferential environments that are conducive to AGN activity as a function of many key parameters (e.g., star formation rate, stellar mass, redshift, large-scale environment, obscuration, luminosity).

With this (near) complete census of AGN activity you will also be able to address another fundamental question: Are the differences between different types of AGN due to the orientation of a central obscuring structure or do they represent an evolutionary sequence? The figure below illustrates the most popular of these evolutionary models; in this figure "quasar" is used to indicate a luminous AGN. In this model the triggering of AGN activity is intiated by the merging of two gas-rich galaxies, which drive the gas into the central regions and fires up the AGN (i.e., due to gas accretion onto the central super-massive black hole). The extreme amount of gas driven into the central regions preferentially obscures the AGN from most sightlines (i.e., an example of how the environment can effect AGN activity). However, due to energetic outflows and winds from the AGN the gas is driven away from the central regions, eventually revealing an unobscured AGN.

The common wisdom is that the differences between obscured and unobscured AGN are due to the orientation of a central obscuring structure (commonly called the "obscuring dusty torus"; see Netzer 2015 for a recent review). However, we have recently discovered the first clear evidence for systematic differences in different types of quasars, which cannot be explained by the orientation of a dusty torus and argue for an evolutionary connection between different types of AGN. Your PhD research will build on these findings with more comprehensive analyses between the properties of obscured and unobscured AGN and may lead to the development of the evolutionary model for the AGN population.



One of the models that you will test in your PhD thesis. The general hypothesis is that galaxy major mergers drive gas towards the central regions of galaxies, iniating dust obscured star formation and AGN activity and obscuring the AGN from most sightlines (i.e., the obscured quasar phase). Due to energetic outflows and winds from the AGN the gas is driven away from the central regions eventually revealing an unobscured AGN (i.e., the unobscured quasar phase). Taken from Alexander & Hickox (2012).

Notes:

AI AND GALAXY FORMATION

Main Supervisor:	Prof. Carlton Baugh	c.m.baugh@durham.ac.uk
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Funding:	STFC CDT	

Description:

The aim of this PhD project is to investigate ways in which artificial intelligence techniques can be exploited to remove bottle necks in different aspects of galaxy formation modelling. Our current understanding of many of the processes which are thought to shape the formation and evolution of galaxies is rudimentary with the gaps in physical modelling plugged by parameters. Models often require many tens of parameters to be fully specified but not all of these turn out to be equally important for influencing the predictions of the model. One of the aims of this project is to remove the human "chi-by-eye" aspect of model definition and to make the process fully automated. The challenges to be overcome are:

- assessment of model sensitivity – which parameters are the most important ones to focus on and which can be set to fixed values?
- how can different datasets be used to constrain the model parameters when the errors may vary dramatically from one observation to another?
- is the model adequate to describe observations at different epochs?

Some previous attempts to automate model definition have used Monte Carlo Markov Chains (e.g. Henriques et al. 2013) and Bayesian methods (e.g. Bower et al. 2010).

A further application of AI is to connect intrinsic galaxy properties (stellar mass, star formation rate, the metallicity of the stars) to observable properties (e.g. the photometry or flux from the galaxy at different wavelengths or its spectrum). The AI approach can be trained using models like the one described above and then can be used to "mine" or extract intrinsic galaxy properties from observations.

Henriquez et al., 2013, MNRAS 431, 3373; http://adsabs.harvard.edu/abs/2013MNRAS.431.3373H
Bower et al., 2010, MNRAS 407, 2017; http://adsabs.harvard.edu/abs/2010MNRAS.407.2017B)

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:	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 $\sim$20x speed-up over current competing codes through our implementation of task-based parallelism and novel algorithms.

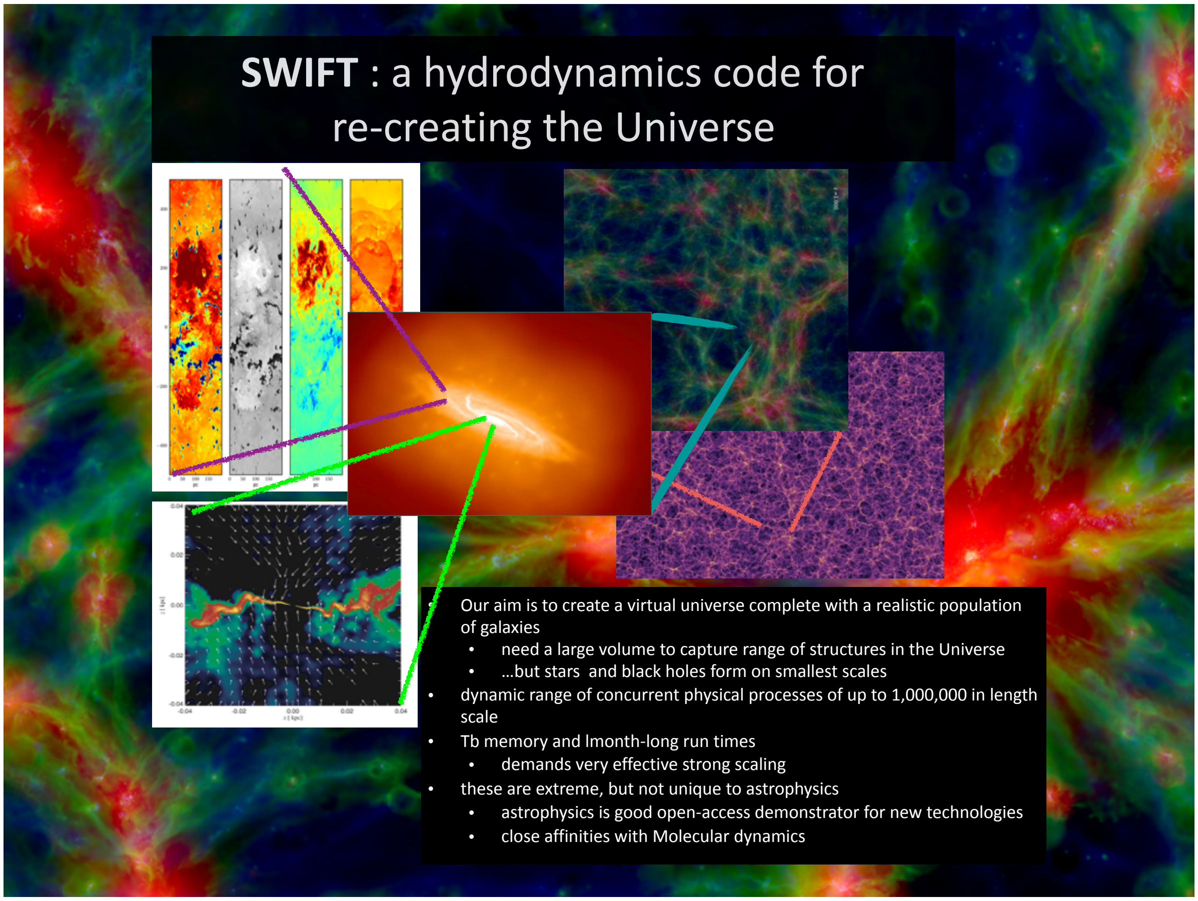
However, as the speed of the simulation rises, the bottleneck is quickly becoming the time it takes to output the simulation data and process it. Our solution to this "big data" problem is twofold: first, instead of writing a complete snapshot at fixed intervals, we write only the changing quantities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

EXTREME ENVIRONMENT ASTROPHYSICS: GAMMA-RAY ASTRONOMY AND THE CHERENKOV TELESCOPE ARRAY

Supervisor: Paula Chadwick p.m.chadwick@durham.ac.uk
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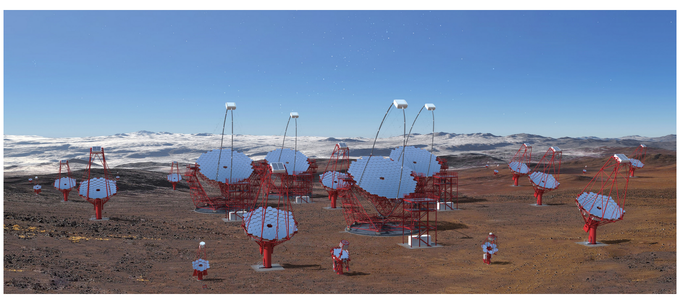
Funding: STFC

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 1350 scientists and engineers from 32 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 20-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 has already begun, and the construction of the array is expected to start in 2019, with 'first light' data from the seed array becoming available shortly thereafter.

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 science studies in preparation for CTA (primarily using data from the Fermi Gamma-ray Space Telescope), telescope calibration using drones, simulations of array performance, the development of new analysis algorithms and the design and testing of instrumentation. 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.



A computer-generated mock-up of the Cherenkov Telescope Array, CTA.

Notes:

THE DESI BRIGHT GALAXY SURVEY

Main Supervisor: Prof Shaun Cole Shaun.Cole@durham.ac.uk
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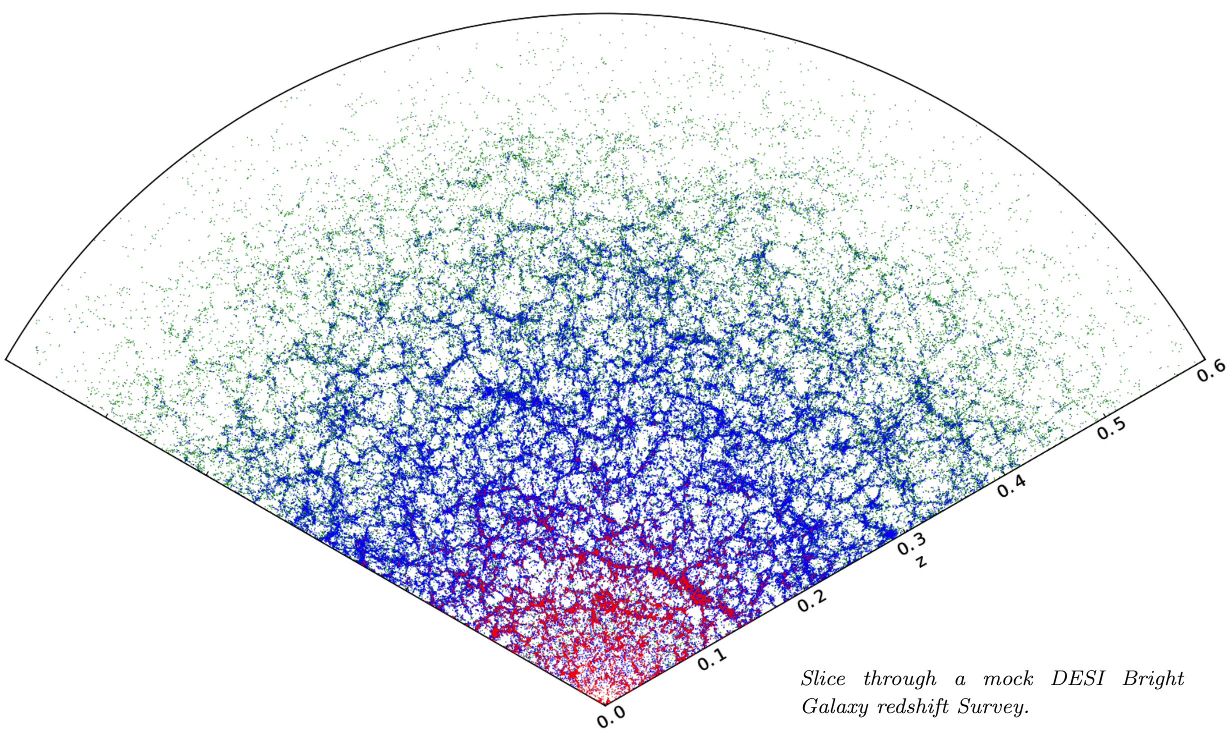
Funding: STFC

Description:

The 5000 fibre Dark Energy Spectrosopic Instrument (DESI) will start collecting millions of galaxy spectra in 2019. It will produce galaxy and quasar redshift catalogues containing tens of millions of objects. These will enable measurements of the large scale clustering of galaxies with unprecedentedly small statistical errors. In turn such measurements can be used to:

- Probe the nature of Dark Energy – Measuring the position of the Baryon Acoustic Oscillation (BAO) peak over a range of redshifts allows the past expansion history of the Universe to be mapped out and hence the evolution of the Dark Energy density to be inferred.
- Test modifications to Einstein's Gravity – Modified gravity models that explain the expansion history of the Universe without DE predict modifications to the rate at which structure grows. These can be detected via changes to the anisotropic clustering of galaxies in redshift space induced by the peculiar velocities of galaxies in forming structures.
- Test models of galaxy formation – The clustering of galaxies can be used to deduce their relation to DM. We can determine the mass of the DM haloes they inhabit how this depends on the properties of the galaxies (luminosity, colour, size ...) and varies with redshift.

However all this can only be achieved if systematic errors are smaller than the statistical errors. The challenge that we are rising to as we prepare for DESI is determining ways to identify systematic errors and devising strategies to allow their effects to be mitigated. Mock galaxy catalogues constructed from large cosmological N-body simulations will play an increasing role in this process.



Slice through a mock DESI Bright Galaxy redshift Survey.

We are preparing to run the Hyper-Millennium simulation – a Gpc simulation with over 10^{12} particles. The resolution of Hyper-Millennium will enable the merger histories of all the dark matter halos that host observable galaxies to be tracked. This enables semi-analytic galaxy formation models and other techniques to be used to populate the simulation with realistic galaxy populations.

Before this we already have very useful full DESI mocks based on the smaller ($\sim 10^{11}$ particle) Millennium XXL simulation.

These mocks and others generated by faster approximate methods are set to become an important part of establishing the credibility of DESI's main scientific results. They will be used in well controlled programmes of blind tests designed to reveal residual systematic errors. No one is going to believe that Dark Energy has a particular strange property or Einstein's gravity has to be modified if the data that appears to demand this could alternatively be explained by a systematic effect that has not been considered and quantified.

Possible projects include:

- Helping turn the Hyper-Millennium into DESI and Euclid mock catalogues. This could involve developing the GALFORM semi-analytic galaxy formation model to output the galaxy properties we need and tuning it to fit relevant observations, or developing more flexible empirical statistical models.
- Quantifying and mitigating known biases such as those due to the inability to place fibres on all objects. This requires that the fibre assignment is done in such a way that targeting probabilities can be determined with high precision.
- Developing and testing unbiased estimators for key statistics such as small scale redshift space distortions or void probabilities or void density profiles.
- Developing fast approximate mock creation methods to make large ensembles of mocks which in some cases will be necessary to verify that systematic errors are sub-dominant to the statistical errors.
- Setting up blind tests that will be used in analysis challenges in which others in the DESI (or Euclid) teams will try and correct results for various statistics without knowing the true parameters of the model they are analyzing.

DESI home page: http://desi.lbl.gov/

Notes:

SIMULATIONS OF PLANETARY IMPACTS

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

Description:

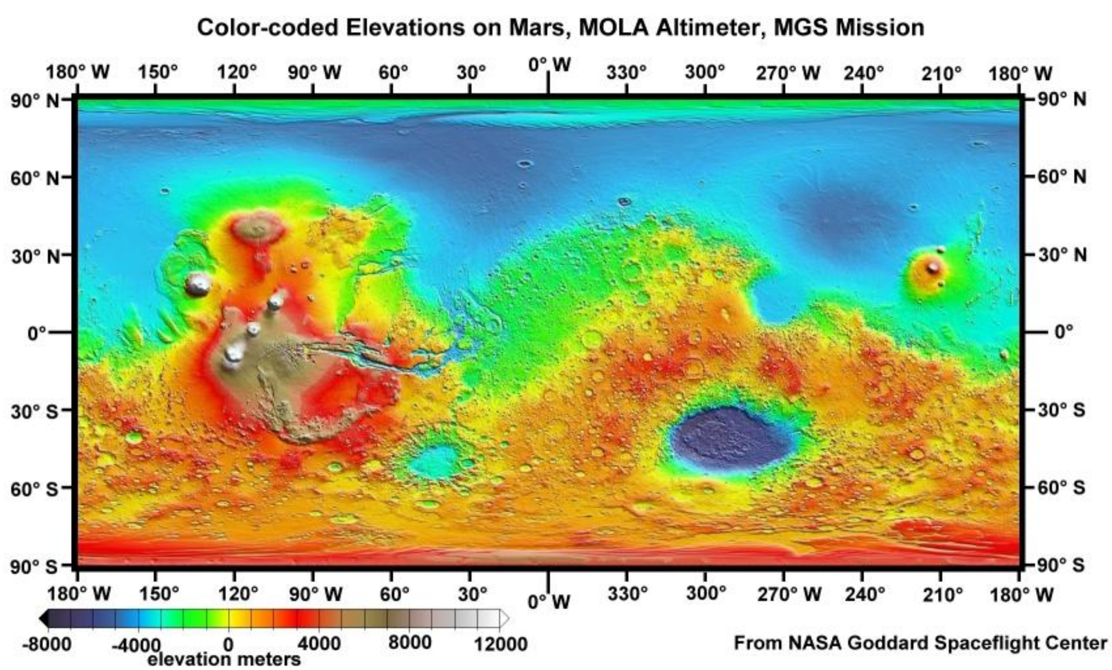
The early Solar System was a violent place where energetic collisions between planetesimals were rife. These impacts represent the most dramatic part of the planet formation process, an understanding of which is required to determine the frequency of exoplanets in habitable zones around other stars.

Observations of the current state of the Solar System provide abundant evidence of past giant impacts: the relatively large core of Mercury, the similar isotope ratios of the Earth and Moon, and the surprising rotation axis of Uranus. With the upcoming May 2018 launch of NASA's InSight lander to study the internal structure of Mars, a particularly timely question is what caused the Martian dichotomy, whereby the northern hemisphere is typically much lower than the southern hemisphere?

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

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

This project, which involves a collaboration with researchers at NASA Ames Research Center and Los Alamos National Laboratory, will use a state-of-the-art Smoothed Particle Hydrodynamics (SPH) code. While previous Martian impact simulations have used up to a million particles, we will improve the mass resolution by 2-3 orders of magnitude. With these superior numerical capabilities, we will be able to resolve the Martian crust as well as determining the internal structure of the resulting Mars with unprecedented detail. A variety of possible impacts will be investigated and the observable consequences will be inferred, in order to distinguish between competing theories about the formation of the Martian dichotomy.



The Martian Digital Elevation Model (DEM) constructed using measurements from the Mars Orbiter Laser Altimeter (MOLA), showing the dichotomy between northern and southern hemispheres.

Notes:

THE FRONTIER BETWEEN COSMOLOGY AND GALAXY FORMATION

Main Supervisor:	Prof Adrian Jenkins	a.r.jenkins@durham.ac.uk
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Funding:	STFC	

Description:

The development of the ΛCDM model is one of the most impressive advances in physics of the last thirty years. The Λ in ΛCDM refers to Einstein's cosmological constant, while CDM stands for "cold dark matter", a form of elementary particle that accounts for five sixths of the gravitating matter in the Universe. In ΛCDM all the structure we see today in the Universe arises from the gravitational amplification of small irregularities in the primordial energy density created by quantum processes during an early rapid expansion phase of the universe. This simple model, formulated in the 1980s can account for a wide range of observational data, from fluctuations in the temperature of the microwave background radiation to the large-scale distribution of galaxies. In spite of its spectacular successes, the foundations of the ΛCDM model are anything but solid because (i) there is no accepted physical basis for the cosmological constant and (ii) there is no direct evidence for the hypothesized cold dark matter particles. Furthermore, the model has yet to be tested convincingly on the scales of astronomical objects such as galaxies. Over the next decade there will be huge improvements in the quantity and quality of observational data particularly for the Milky way itself which allow new ways to test ΛCDM and to learn about the nature of dark matter and the physics of galaxy formation.

The project will involve running and analysing state-of-the-art simulations of the formation of individual galaxies and making comparisons with observational data. The ICC has its own large supercomputer (the "Cosmology Machine") as well as resources provided by the Virgo Consortium for cosmological simulations, Europe's premier collaboration in the subject.

The Virgo consortium has begun an ambitious programme of ultra-high resolution simulations of the formation of individual galaxies in a ΛCDM universe, with a goal of modelling galaxies at unprecedented numerical resolution. The timing of this programme, which is a collaboration including Durham, MPA Garching and HITS Heidelberg, is well suited for PhD projects starting in October 2018.

These simulations are extremely rich in detail and suitable for a wide range of possible PhD projects on topics such as probing the nature of dark matter through the properties of satellite galaxies, tidal and hydrodynamical stripping of satellite galaxies, the role of turbulence in the mixing of metals in the galaxy halo, and stellar dynamical modelling of the Milky Way galaxy.

This link gives an overview of the first completed set of simulations.

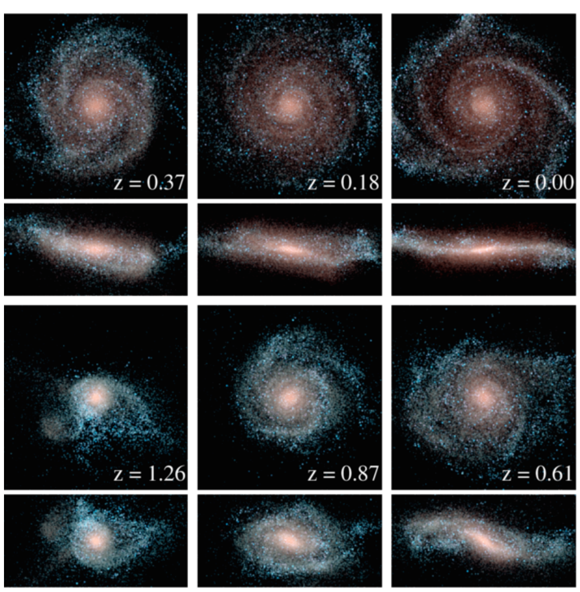

Image made from a simulated spiral galaxy created using the AREPO N-body/hydrodynamic code. This simulation shows the appearance of the galaxy over time from two perpendicular view points. This galaxy is one of set of 30 run jointly in Durham and in Heidelberg. Picture Credit: David Campbell)

Notes:

UNDERSTANDING THE PHYSICS OF GALAXY FORMATION

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

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.

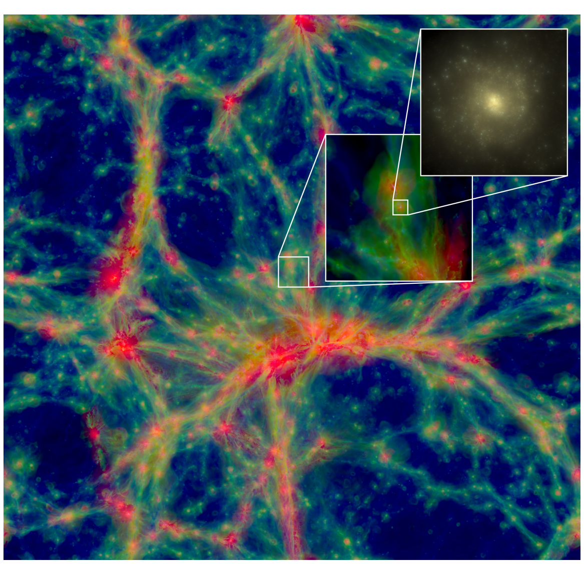
Galaxy formation is driven by the growth of structure in the dark matter forming dark matter halos, followed by shock heating and cooling of gas leading to accretion of gas onto galaxies, star formation, feedback from supernovae and AGN, and galaxy mergers and dynamical instabilities. Many aspects of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

- how gas cooling onto galaxies is affected by filamentary accretion into halos
- how supernovae drive outflows from galaxies, and the fate of the outflowing gas
- what are 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:

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

Main Supervisor:	Dr. Baojiu Li	baojiu.li@durham.ac.uk
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Funding:	ERC	

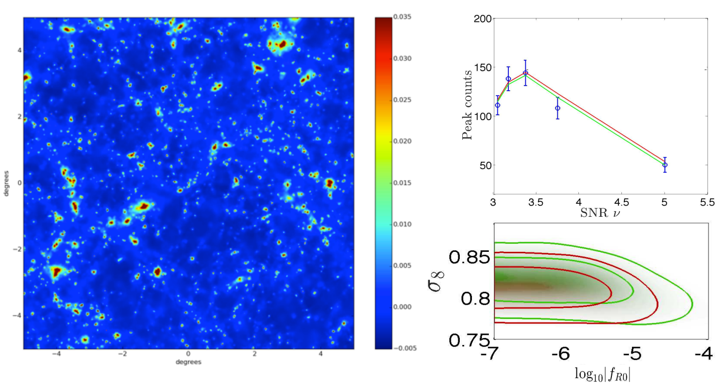
Description:

One of the most challenging questions in cosmology modern physics is the origin and nature of the accelerated Hubble 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, 4MOST and LSST. These observations 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 our group at Durham is to make accurate quantitative predictions of observables and confront these against current and future survey data to constrain theoretical models. For this, one 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. All these issues must be carefully investigated before future survey data can be used to make conclusions about new physics.

A PhD studentship, funded by European Research Council, may be 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 modified gravity) 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:

GRAVITATIONAL LENSING OBSERVATIONS WITH DURHAM'S SPACE TELESCOPE

Main Supervisor:	Dr. Richard Massey	r.j.massey@durham.ac.uk
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2nd Supervisor:	Prof. Alastair Edge	alastair.edge@durham.ac.uk
Funding:	Royal Society	

Description:

This project will exploit our exclusive access to Durham's new space telescope. We built the Superpressure Balloon-borne Imaging Telescope (SuperBIT) in collaboration with the University of Toronto. An innovative telescope concept, SuperBIT is raised above 99% of the Earth's atmosphere by a helium balloon the size of a football stadium. From the edge of space, SuperBIT gets a crystal clear view at optical and UV wavelengths. Test flights have already demonstrated $0.05''$ pointing stability, which is sufficient to enable Hubble Space Telescope-quality imaging; NASA are now funding the technology to take over when Hubble next fails. Joining with NASA's Jet Propulsion Laboratory and Princeton University, SuperBIT is now scheduled for a 3 month-long science flight in early 2019. This uses NASA's new balloon material technology to stay afloat 30 times longer than previously possible, and allow an ambitious survey of hundreds of gravitational lensing systems.

You will join a small, friendly team of < 20 people on both sides of the Atlantic. Occasional travel to collaborators and balloon launches in New Zealand or Texas will be required. Our primary responsibilities in Durham will be to optimise the observation schedule then scientifically analyse the imaging. Depending on your interest, possible areas of science focus include the nature of dark matter measured from small-scale substructure in galaxies that acts as strong gravitational lenses, or dark energy by precisely weighing hundreds of galaxy clusters via weak gravitational lensing. The small team means you can have a significant impact on the project. However, an open mind and hands-on attitude will required during flight campaigns, when everyone pitches in to brainstorm problems in areas from electronic to aeronautical engineering.

Video of a test-flight launch (and another)
SuperBIT project wiki pages & news
Informal paper summarising SuperBIT's recent development
Example of science case for possible strong lens study
An early study of weak lensing motivated in the same way as SuperBIT's cluster sample

SuperBIT ready for launch of a previous test flight from Timmins airfield in Northern Canada.

Notes:

THE RELATIONSHIP BETWEEN GAS AND GALAXIES

Main Supervisor: Prof. Simon Morris simon.morris@durham.ac.uk
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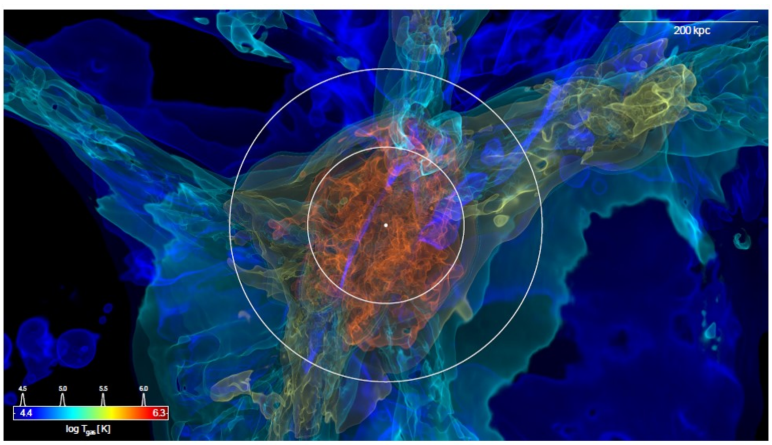
Funding: STFC

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.



Left: 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)

Notes:

VISIBLE AND NEAR INFRA-RED OBSERVATIONS OF VARIABILITY IN LOW MASS X-RAY BINARIES

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Funding: STFC

Description:

Low Mass X-ray binaries (LMXBs) are interacting binaries containing an compact object (a neutron star (NS) or black hole (BH)) with a mass of a few times that of the sun in an orbit with a low mass, sun-like object. The binary orbit is close enough that material is transferred into the potential well of the compact object forming an accretion disk, where it spirals inwards before being accreted onto the compact object or ejected in the form of a jet. The material radiates at wavelengths from radio through to hard X-rays and shows variability on timscales up to those equivalent to the last stable circular orbit around the compact object object (freq $\sim$ kHz). In recent years, the advent of X-ray satellites such as RXTE, XMM and most recently SUZAKU, have enabled the study of periodic (e.g. orbital motion), quasi-periodic (narrow peaks that wander in time) and aperiodic (broadband noise) variability in the X-ray lightcurves of these objects. This has opened our eyes to a rich phenomenology of sources. One of the most intriguing phenomena is the existence of different types of quasi-periodic oscillations (QPOs). These are features in the lightcurves that are periodic with a short coherence time and are thought to represent dynamical effects in the inner (hot) accretion flow. They are observed in a range of LMXBs, including persistent and transient sources, as well as in both BH and NS sources and much work is currently being undertaken to combine these different classes into a single scheme, enabling us to build a unified model for the emission mechanism.

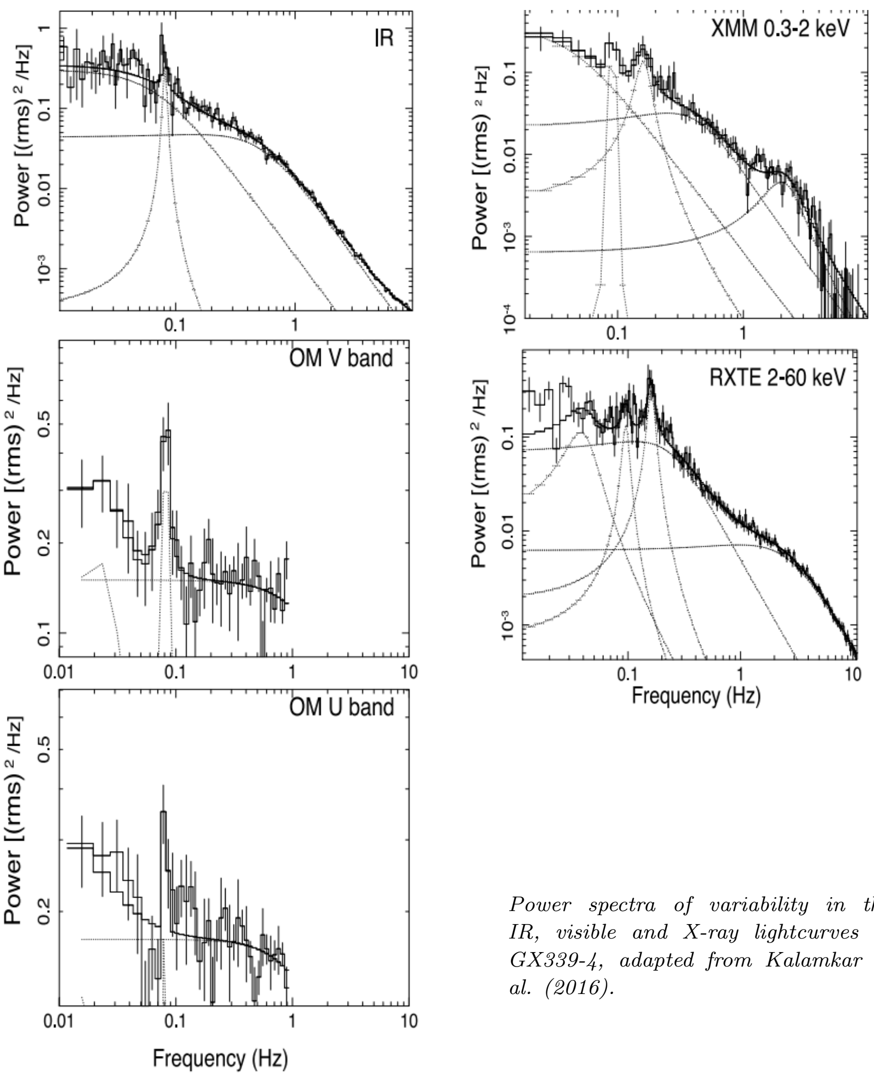
Recently, we have opened a new window for the study of QPOs with the observation of a so-called 'Type-C' QPO in the *visible* and *infra-red* lightcurves of the black-hole X-ray Binary GX339-4. The exact origin of this variability remains poorly understood, but it is believed to origininate in the inner accretion flow or the base of the jet.

The goal of this PhD is to search for and study the optical and near infrared counterparts to the X-ray QPOs to understand their formation and the emission process. We will use several avenues to explore this new region of parameter space, including;

1. Exploring archival multi-band photometric data on several persistent and transient systems in outburst to search for QPOs
2. Planning and executing new observations using instruments on 4-m and 8-m class telescopes
3. Exploiting unique high time-resolution spectroscopy from the next generation of energy-sensitive detectors being developed in our lab.

This work will be largely observationally based, with the opportunity to perform the your own observations and also exploit archival data. There is also the possiblity for an instrumentation aspect to the thesis based on the development of MKID-based instrumentation for high-time resolution astronomy.

Paper showing the visible and IR QPOs (Kalamkar et al. 2016)
Paper on the link between QPOs and accretion states in LMXBs (Motta et al. 2017)



Power spectra of variability in the IR, visible and X-ray lightcurves of GX339-4, adapted from Kalamkar et al. (2016).

Notes:

THE FORMATION AND EVOLUTION OF MASSIVE, GAS- AND DUST-RICH GALAXIES AT HIGH REDSHIFTS

Supervisor:	Ian Smail & Mark Swinbank	ian.smail@durham.ac.uk
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Funding:	STFC	

Description:

Our sun collapsed from a cold molecular gas cloud in the disk of the Milky Way around 4.5 billion years ago. However, many of the stars seen in galaxies today were formed at much earlier times, 7–10 billion years ago, corresponding to a redshift, z, of $z \sim 1$–3. Galaxies at these early times were forming stars typically 10–30 $\times$ faster than average galaxies today. This period has therefore been herald as the "epoch of galaxy formation" (or "Cosmic Noon"). Star-formation activity in galaxies has declined over the last ~ 7 billion years (since $z \sim 1$), apparently driven by a corresponding 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.

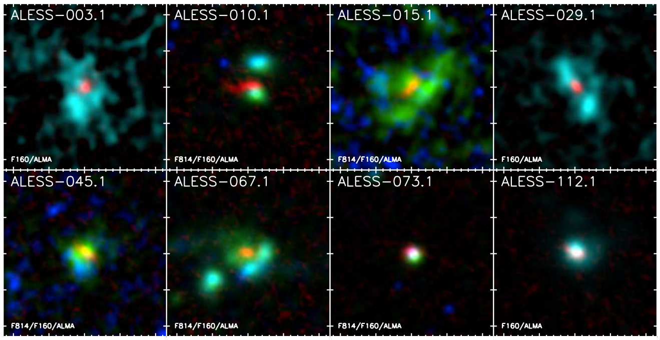
The most actively star forming galaxies at high redshift are converting their gas reservoirs into stars 100–1000 $\times$ faster than the Milky Way currently does. Such extreme rates of star formation are seen in less than one per cent of galaxies at the present day, but such active systems appear to 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 $z \sim 2$–4, making them a crucial phase for understanding galaxy formation.

Despite their high star-formation rates, this population of vigorous star-forming galaxies are in fact 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 that 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 the 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 may 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 robust theory of galaxy formation and evolution.

To this end we are undertaking a series of surveys to study this enigmatic population of dusty starburst galaxies. 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, galaxies at the present-day. We also wish to test links between these galaxies and the formation of clusters of galaxies and also the luminous Quasar population, whose activity also peaked at $z \sim 2$–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 to obtain data for their thesis. The PhD will provide training in interferometric data reduction and analysis, based on data from the JVLA and *e*-MERLIN radio interferometers and the Plateau de Bure NOEMA 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.

See also: http://www.astro.dur.ac.uk/∼irs and http://www.astro.dur.ac.uk/∼ams



Falsecolor images constructed from a combination of Hubble Space Telescope (HST) and Atacama Large Millimetre Array (ALMA) data for a selection of high-redshift starburst galaxies. The HST optical/near-infrared imaging is shown as the blue/green channels (which trace the light from less dust-obscured stars) and the ALMA submillimetre observations are the red channel (tracing the dustiest and most active regions of the galaxies). We see that asymmetric, morphologically complex stellar continuum emission appears to be largely uncorrelated with the sites of the significantly more compact dusty star formation. 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 massive galaxies and Quasars.

Notes:

THINKING OUTSIDE OF THE BOX

Main Supervisor:	Professor Tom Theuns	tom.theuns@durham.ac.uk
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Funding:	STFC	

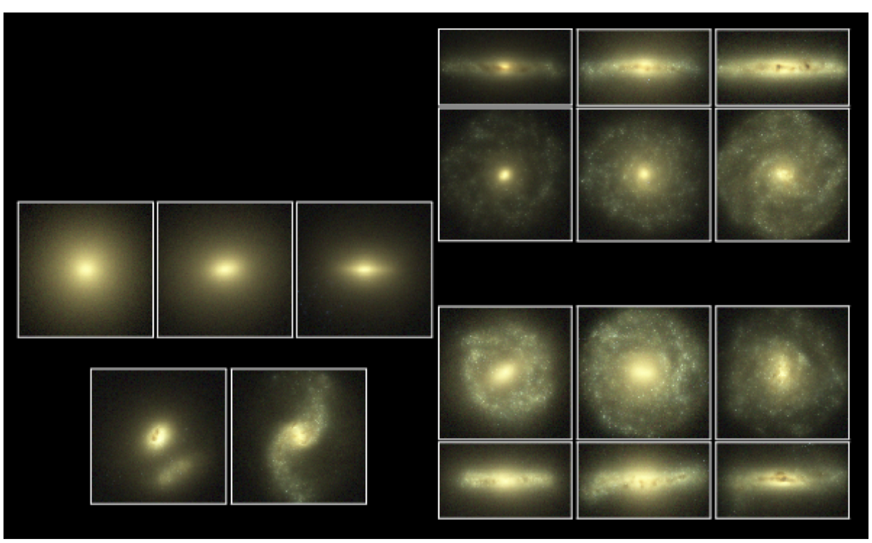
Description:

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. The aim of this project is to overcome this limitation using new techniques for creating initial conditions (Jenkins 2013, Monaco et al. 2013) that encode a particular survey geometry or survey strategy, and the use of the Swift simulation engine to evolve these initial conditions in time. This technical development should allow us to simulate at arbitrarily high resolution region in an arbitrarily large volume. We will use the successful galaxy formation scheme of the Eagle simulation described by Schaye (2015), which resulted in the second most cited astronomy paper published in 2015.

The newly developed scheme can be applied to a variety of problems that are currently impossible to simulate, such as the clustering of galaxies on the baryon-acoustic scale, or studying in detail galaxy formation as a function of environment. In the first instance we will apply the technique to the study of correlations in the properties of the intergalactic medium as probed in spectra of distant quasars. Such correlations provide powerful constraints on the physics of the intergalactic gas, but also on fundamental properties of the cosmos such as the nature of the dark energy, and fundamental physics such as neutrino masses, for example. The ultimate aim of this project is to provide simulation data to interpret the data to be collected by the Weave's QSO survey.

Obviously, this project has a large computational and HPC component, 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 and in Germany. There is also ample opportunity to become involved with the observational aspects of the survey.

Jenkins A., MNRAS, 2013, 434
Monaco et al., MNRAS, 2013, 433
Description of the Swift code
Schaye et al., 2015 Overview of the Weave project, with details on the QSO survey



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

Notes:

ACTIVE GALAXIES: THE X-RAY AND INFRARED CONNECTION

Main Supervisor:	Professor Martin Ward	martin.ward@durham.ac.uk
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2^{nd} Supervisor:	Professor David Alexander	d.m.alexander@durham.ac.uk
Funding:	STFC	

Description:

Active Galactic Nuclei (AGN), are sites of the most energetic processes, and correspondingly the most extreme physics, anywhere in the Universe. It has been known for more than half a century that the fundamental source of their extremely high luminosity, is accretion of material onto a supermassive black hole. However, it is only more recently that the importance of *outflows* has begun to be fully appreciated. This phenomenom can take several forms. One mode is via well collimated jets of very high velocity material, best observed at radio frequencies. These objects are called radio galaxies and radio-loud quasars. In terms of AGN, they make up the minority (10%), of the total population. The other mode involves slower, less well collimated winds, which may be present at some level in the majority of AGN. It is very important to understand the properties of this wind, since it will influence the relationship between the masses of the central black hole and the stellar bulges of their host galaxies. This, even though the winds are often seen best on very small physical scales, yet the galactic bulge extends out to kiloparsecs in size.

At Durham University we have been studying these winds for some time, using X-ray observations for the inner regions, and optical emission lines for the much larger scales. A significant fraction of AGN are obscured (depending on their distance and luminosity). This means that their inner regions are not observed directly, but rather they lie behind a shroud of dust and gas. To fully understand both the inner workings of AGN, and the influence of their local environment, we must study the properties, including outflows, in these obscured objects. It turns out that observations in both X-rays and infrared are best suited for this work. The X-rays penetrate the gas, and the infrared penetrates the dust. In this way the two techniques are complementary ways to study obscured AGN. In summary the aims of this project will be:

to quantify the energetics of the winds (its velocity and amount of material)

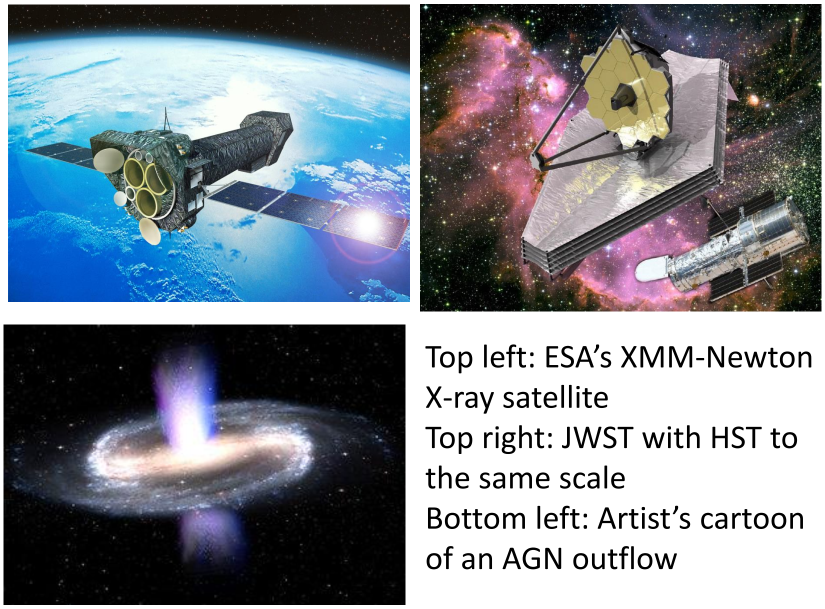
to measure black hole masses of obscured AGN, by means of infrared observations

to study the local environment of the AGN e.g. evidence for interactions, morphology and properties of the dust

Note: examples are shown of two of the most powerful X-ray XMM-Newton) and Infrared (JWST), facilities. Durham astronomers are major uses of the former, and expect to be so of the latter. Many other ground-based telescopes and satellites, as well as *big data* archives, will also be employed in the project.

This PhD project is observational in nature, but it will also involve modelling and understanding the connections between the principal components responsible for the emission in AGN. The supervisor (Ward) has many years of experience in working with X-ray and infrared data, and has successfully supervised 15 PhD students. He is currently chairman of the XMM-Newton X-ray satellite User's Committee, and is now a member of the Science Team of the mid-infrared instrument aboard the JWST. The project will build on,and extend, his recent PhD students' topics. There will be overlapping interests with other members of Durham's academic staff, such as Prof. Chris Done (X-ray models) and Prof. Dave Alexander (obscured AGN). The project is also likely to have links with existing collaborations with Brazilian and USA based astronomers, and will involve gaining experience using ground based telescopes in Chile and Hawaii.

Garcia-Bernete et al. MNRAS, 469,110,(2017)
Schartek,Jansen,Ward, AN, 338,354, (2017)



Two space missions...and a cartoon of an AGN

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