Durham University

May 2015

Newsletter

ICC - Institute for Computational Cosmology

Seeing the "big picture"

With this edition we are launching the Institute for Computational Cosmology Newsletter which aims to keep our members and friends up to date with our research, public engagement and other activities.

This inaugural issue is special for other reasons. We have recently started a fundraising campaign to support students and postdocs at the new premises for the Ogden Centre for fundamental Physics.

"The new Ogden Centre building by Libeskind is now fully funded with construction due to start in June and a projected opening date of Autumn 2016."

As many of you will know, we have been very fortunate to receive a substantial philanthropic donation from Sir Peter Ogden, a Physics alumnus and staunch supporter of the ICC and our sister institute, the IPPP. We are also very grateful to the Wolfson Foundation and to Durham University.

Our new building has been designed by the world-renowned architect, Daniel Libeskind, who is responsible for some of the most astounding modern buildings across the world, including the Jewish museum in Berlin, a breathtaking architectural masterpiece that blends history, tragedy and hope in a unique aesthetic.

The new Ogden Centre building by Libeskind is now fully funded with construction due to start in June and a projected opening date in Autumn 2016. It has taken several years to get here. The idea was born at a dinner with Sir Peter in London around 2011 when, recalling the experience of building the first Ogden Centre, Peter said: "Let's do it again!" So here we are today preparing for a new era in fundamental physics research at Durham University.

The Ogden Centre is now recognized as one of the premier institutions for research into cosmology, astronomy and particle physics in the world. Every year it attracts large numbers of the best aspiring young scientists from all over the world who want to come here to pursue PhDs or postdoctoral studies. Our fundraising campaign aims to raise funds for the most promising applicants to Durham.

The two Ogden institutes are very successful at attracting research grants from UK and EU agencies. However, funding for basic science in Europe, including the UK, is declining, gradually becoming insecure and unpredictable, thus threatening long-term projects. Support within the EU and the UK is increasingly targeted towards applied research of immediate economic relevance. At some level this "impact agenda" is understandable: the world is facing problems of unprecedented magnitude - climate change, food, water and energy scarcity and an ageing population whose solution will rely heavily on technology.

Yet, the history of science teaches us that technological innovation is invariably founded upon discoveries from basic scientific research into the fundamental principles of nature.

"The Ogden Centre is now recognized as one of the premier institutions for research into cosmology, astronomy and particle physics in the world."

By their very essence such discoveries are unpredictable. There is no way that William Lawrence Bragg could have dreamt that his quest to understand the nature of light in the early 1900s would have led to the discovery of X-ray diffraction and, four decades later, to the discovery of the double helix and ultimately of modern genetics. Who could have predicted that John Bardeen's research into the quantum theory of solids in the 1950s would have led to the invention of the transistor upon which all modern electronic devices, from mobile phones to computers, are based?

The lesson is clear: scientific discovery and the technological innovation to which it gives rise comes from individuals who are driven by a very basic human instinct to try to understand the world around us.

At the Ogden Centre we feel immensely priviledged to be able to dedicate our intellectual energy to uncovering how the Universe works, from its tiniest constituents - the elementary particles - to the largest stars and galaxies. But, as government funding priorities shift towards the search for short term solutions to practical, if admittedly important problems, pure science will increasingly come to rely on the philanthropy of individuals or institutions who are able to see the "bigger picture."

I hope that you will find this newsletter interesting and exciting. And that some of you, who are able to do so, will contribute through your support to our efforts to advance our knowledge about the Universe and, at the same time, train a new generation of scientists in the skills necessary to face the challenges of our world. Our fundraising campaign has got off to the best possible start with an early donation by a Durham physics alumnus who will be sponsoring a 4-year PhD studentship on astroparticle physics.

Privately funded postgraduate studentships need around £20,000 per year for a four year period:

If donated under a charitable giving arrangement the annual cost is reduced for the donor to £12,000, or £11,000 for a donor paying income tax at the highest rate. Perhaps you know a group of friends who might join with you to support a postgraduate student and help us in our search for the fundamental laws which govern our Universe. If so please contact Bruno van-Dyk at bruno.van-dyk@durham.ac.uk. ●

Carlos Frenk FRS, Director of the Institute for Computational Cosmology (ICC)

Contents

£3.35M Alumnus Donation

Photo: The donation is accepted outside St. Mary's College, Durham.

Plans for a new £10million landmark building to house Durham University's world-renowned Ogden Centre for Fundamental Physics took another step forward recently with the signing of a major gift agreement.

Physics alumnus and entrepreneur Sir Peter Ogden, Chairman of The Ogden Trust, recently attended a ceremony to finalise a £3.35 million donation towards the proposed new development.

Sir Peter has been a long-time supporter of physics research at Durham University and his Trust promotes the teaching and learning of the subject to schoolchildren and undergraduates who want to teach physics.

Sir Peter, who graduated from Durham in 1968 with a degree in Physics and a PhD in Theoretical Physics in 1971, lends his name to the original Ogden Centre for Fundamental Physics which opened in 2002 after being established by an earlier £2.2 million gift from The Ogden Trust.

The new building is now a top priority because of the rapid growth that has accompanied the academic success of the ICC and Institute for Particle Physics Phenomenology and will enable them to maintain their leading global positions in the decades ahead.

As well as the generous donation from The Ogden Trust, £1.5 million has been awarded by the Wolfson Foundation for the development.

Sir Peter Ogden said: "This is the largest single donation in The Ogden Trust's history, which indicates the importance of the relationship which it has developed with our physics department over the last decade.

The world-renowned architectural practice, Studio Daniel Libeskind (SDL), is designing the new building. SDL has designed many projects of global significance, including the Jewish Museum in Berlin and the master plan for Ground Zero in New York.

This new building and its facilities will attract the best students and researchers in cosmology and particle physics phenomenology from all over the world, and will enable Durham to lead international developments in these fields."

Photo: A mock up of the new project to be developed at the Mountjoy Site.

Prizes and Medals

Shaw Prize for Shaun Cole

Professor Shaun Cole, Deputy Director of Durham's Institute for Computational Cosmology, was awarded The Shaw Prize in Astronomy.
The award, shared with two other scientists, was made in recognition of Professor Cole's work on the 2df Galaxy Redshift Survey (2dFGRS) which conducted a study of 250,000 galaxies using the Anglo-Australian Telescope.
Reporting their findings in 2005, Professor Cole and his colleagues showed that baryon acoustic oscillations – sound waves that originated a few seconds after the Big Bang – could be used to measure distances in the Universe and the rate at which it is expanding.
Cole said: "The theory of baryon acoustic oscillations had already been predicted, but the work we did on 2dFGRS, and the work of our colleagues on the Sloan survey, confirmed that these soundwaves could be used as a yardstick to measure the expansion of the Universe. Today's award is a wonderful honour and has come as a tremendous surprise" ●

Proud sharers of the Shaw prize: Shaun Cole, John Peacock and Daniel Eisenstein

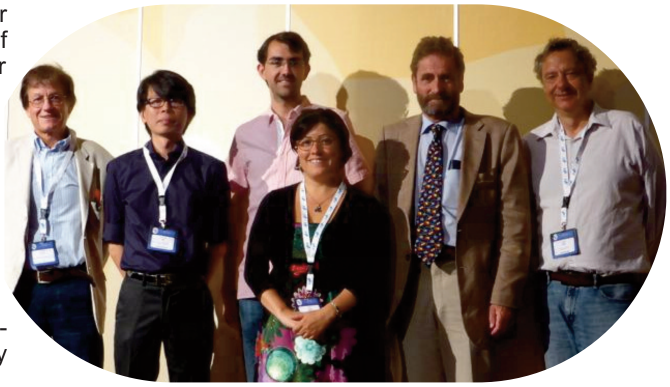
RAS Medal for Carlos Frenk

Carlos Frenk (r) receives his Gold Medal from Martin Barstow, president of the RAS

Professor Carlos Frenk, Ogden Professor of Fundamental Physics and Director of Durham's Institute for Computational Cosmology (ICC), received the Royal Astronomical Society's highest honour, the Gold Medal for Astronomy.
Frenk, who has co-authored more than 300 scientific papers and was elected a Fellow of the Royal Society in 2004, said: "It is, of course, a huge honour to be awarded a medal whose history goes back to 1824."To see my name listed alongside those of scientists whom I have admired all my life is a unique feeling.The gold medal is awarded 'in recognition of a lifetime's work'. Since I have spent most of my working life at Durham University, more than as a personal tribute, I see this as a recognition of the scientific contribution that my many collaborators at the Institute for Computational Cosmology, from PhD students to professors, and I have collectively made over the years." ●

MERAC Prize for Claudia Lagos

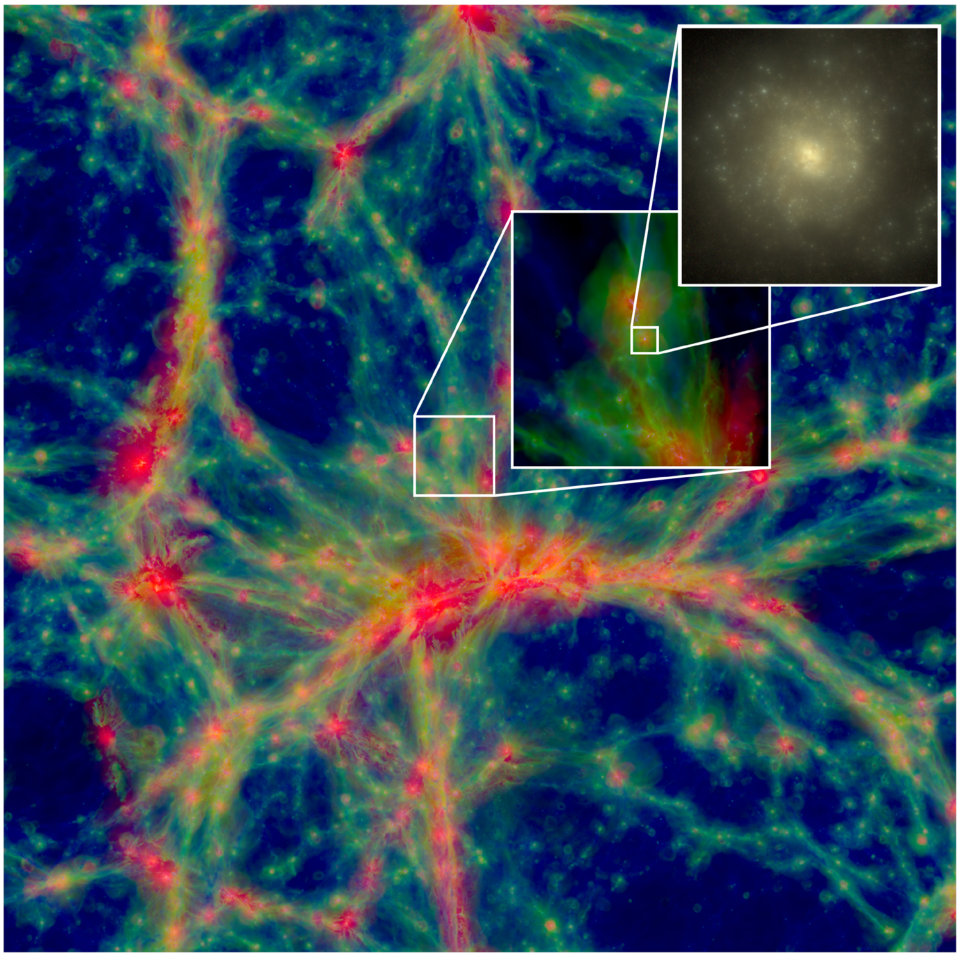
A 2014 MERAC Prize for the Best Doctoral Thesis inTheoretical Astrophysics was awarded to Dr. Claudia Lagos, ICC, for her thesis on the treatment of star formation and feedback in simulations of galaxy formation.
Lagos' PhD thesis focused on the galaxy formation model, GALFORM, which can implement essentially all existing theoretical models of star formation. Her work overhauls the two key processes at the centre of how galaxies are made: the formation of stars and the regulation of star formation following the injection of energy into the interstellar medium. These calculations represent the first real advances in these areas in over a decade. Lagos' work allows the physical predictions of the galaxy formation model, such as the content of the interstellar medium, to be confronted directly by observations from new major telescopes, such as the Atacama Large Millimetre Array (ALMA). ●



Claudia Lagos surrounded by MERAC prize laureates and prize committee

THE EAGLE

THE EAGLE HAS LANDED



EAGLE (Evolution and Assembly of GaLaxies and their Environments) is a simulation aimed at understanding how galaxies form and evolve. This computer calculation models the formation of structures in a cosmological volume, of over 300 million light-years across. This is large enough to contain 10,000 galaxies of the size of the Milky Way or bigger, enabling a comparison with the whole zoo of galaxies visible in the Universe.

The image to the left is a slice through the simulation volume, with the intergalactic gas colour coded from blue through green to red with increasing temperature. The hot gas has temperatures of over 100,000 Kelvin. The smaller images zoom into a galaxy like the Milky way, showing the gas halo that surrounds it.

EAGLE is a project of the Virgo Consortium for cosmological simulations, and is the latest and greatest in a long line of successes, including the Millenium simualtion which was first published in Nature in 2005.

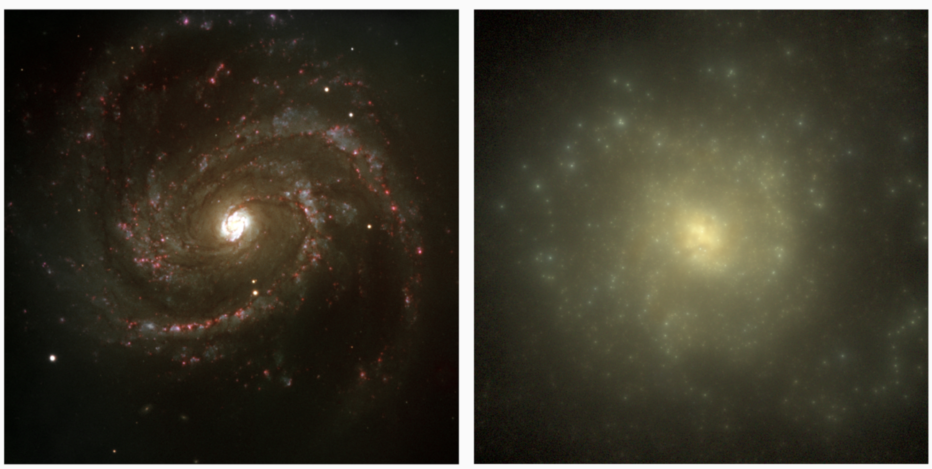
You can find more information and pictures on the website, http://icc.dur.ac.uk/Eagle.

IMAGING THE COSMOS

In EAGLE, we can look at very large and very small scales (cosmologically speaking), both with very high precision. In the examples to the right, we can see two galaxies - one from the real Universe and one from the EAGLE Universe.

Normally it would take billions of years for galaxies like those on the right to evolve However in simulations we can test our theories much quicker. We can view these billions of years in a matter of seconds, showing how these cosmological bodies interact, merge and eventually destroy each other often quite spectacularly.

Using EAGLE, we can try to replicate how the simulated galaxies would appear if we observed them by modelling the light emitted by stars and absorption by dust.



Left: Image of M100 taken on the ESO VLT by Dominique Naef, Eric Depagne and Chris Lidman in Chile.

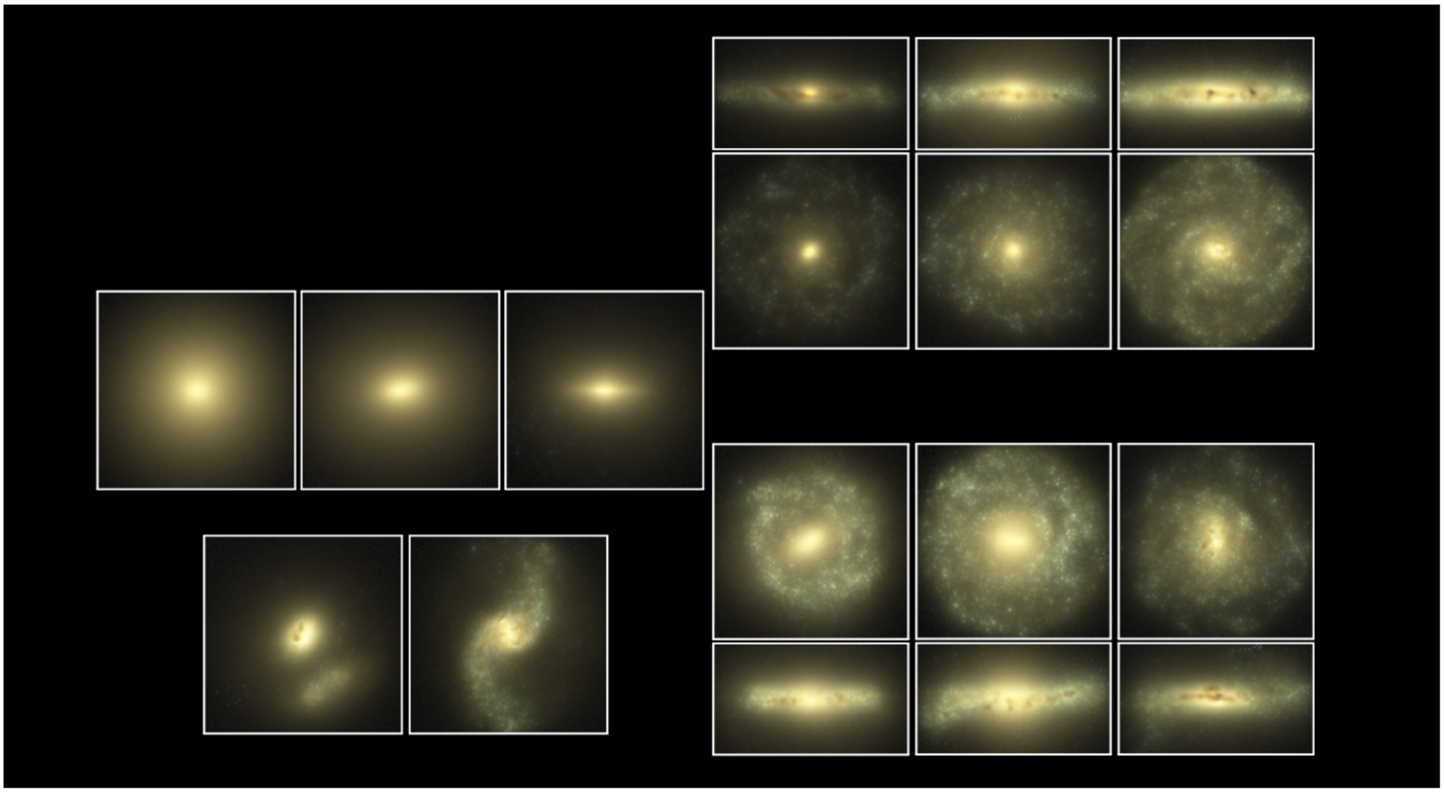
Right: Image of a typical spiral galaxy in EAGLE, imaged by James Trayford at Durham.

E PROJECT

The image below shows an assortment of EAGLE galaxies arranged into a Hubble tuning fork. The impressive resolution of EAGLE allows us to look at these galaxies in a detail that would not have been possible until recently, due to advancements in computing technology. On the left, there are 'early type' galaxies, which we now know are actually the oldest, a result of mergers which we can see happening in EAGLE. To have a look at these mergers in action, head over to our website. On the right, we have 'late type' galaxies, spirals which look similar to our own galaxy, the Milky Way. These are the galaxies that are formed initially, from dust and gas in the intergalactic medium - again, a process which EAGLE models well and we can view on human, rather than cosmic timescales.

Simulations like EAGLE allow us to see how dark matter affects these galaxies, and test our theories. Dark matter enables structures like galaxies to form, even while the Universe is expanding rapidly. Gas falling into these dark matter structures cools and forms stars like our Sun.

To create EAGLE, Durham has collaborated with a number of institutions, including Leiden University, PRACE, The European Research Council and The Ogden Trust. Working together with these organisations was key in making EAGLE the great success it has been, and will continue to be as extensive analysis takes place.



THE COSMIC COOKBOOK

By creating multiple simulations with different physical theories, physicists can, in principle, eliminate models that lead to a virtual universe different from ours. This process should then lead astronomers towards a better understanding of the physical processes at stake in galaxy formation.

The simulation starts when the Universe is still very uniform - no stars or galaxies had formed yet - with cosmological parameters motivated by observations by the Planck satellite of the cosmic microwave background radiation. Crucial parameters are the density of dark matter - which allows structures to grow, baryonic matter - the gas from which stars form, and the cosmological constant which is responsible for cosmic acceleration.

The Universe is then allowed to evolve according to the laws of Physics that we impose on it, including gravity and notably in EAGLE - hydrodynamics.

The EAGLE simulation is one of the largest cosmological hydrodynamical simulations ever, using nearly 7 billion particles to model the physics. It took more than one and a half months of computer time on 4000 cores of the DiRAC-2 supercomputer in Durham. It was performed with a greatly enhanced version of the public GADGET-2 simulation code. In EAGLE, we can achieve a resolution of 2000 light years, which lets us simulate the warm part of the gas within galaxies, and leads to the amazing pictures that you see. The simulation includes, among other things, cooling and heating of the gas, formation of stars, evolution of the stars as well as the usual dark matter.

This gives us a good representation of the physics in the real universe, making EAGLE the most realistic universe ever created inside a computer.

Research Highlights

Precision map of dark matter in far-off galaxy cluster

An international team of scientists, led by Durham University, created the map using observations from the NASA/European Space Agency (ESA) Hubble Space Telescope, with the research funded by The Leverhulme Trust.

The observations, from Hubble's Frontier Fields observing programme, enabled the researchers to map the amount and distribution of mass within the galaxy cluster – named MCS J0416.1–2403 – which is 4.5 billion light years from Earth.

When combined with the cosmic phenomenon known as strong gravitational lensing – where large clumps of mass act like lenses to magnify and bend light that travels past them from more distant objects - the astronomers were able to map the cluster mass distribution in unprecedented detail.

As the galaxies in the map are seen several times, this equates to almost 200 individual strongly lensed images across the frame. This detail allowed the team to calculate the distribution of visible and dark matter in the cluster and measure its mass with unprecedented precision.

They found that the cluster is 160 trillion times the mass of our Sun and modelled the total mass of the cluster to be 650,000 light years across, making the map the most precise ever produced.

Lead author Dr Mathilde Jauzac, said: "The depth of the data lets us see very faint objects and has allowed us to identify more strongly lensed galaxies than ever before.

Research team member Jean-Paul Kneib, of the École Polytechnique Fédérale de Lausanne, in Switzerland, said: "Although we've known how to map the mass of a cluster using strong lensing for more than twenty years, it's taken a long time to get telescopes that can make sufficiently deep and sharp observations, and for our models to become sophisticated enough for us to map, in such unprecedented detail, a system as complicated as MCS J0416.1–2403.

"Frontier Fields' observations and gravitational lensing techniques have opened up a way to very precisely characterise distant objects - in this case a cluster so far away that its light has taken four and a half billion years to reach us."

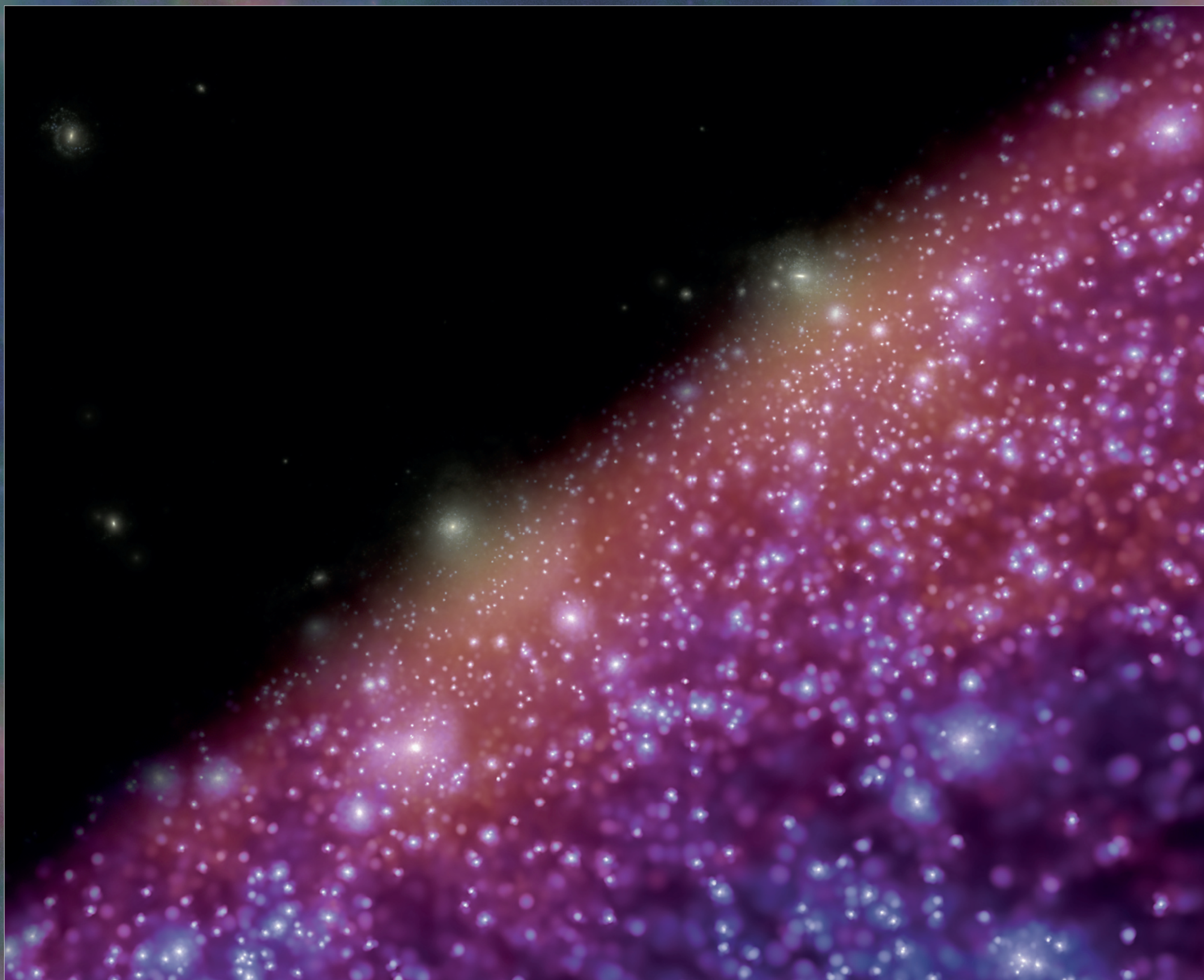
The researchers added that to get a full picture of the mass of the cluster they would need to include weak lensing measurements too.

The team will continue to study the cluster using ultra-deep Hubble imaging and detailed strong and weak lensing information to map the remaining parts of the cluster.

They will also take advantage of X-ray measurements of cluster gas and the stellar content in the cluster spectroscopic redshifts to map its contents and evaluate the respective contribution of dark matter, gas and stars to the cluster.

The researchers added that this would pave the way to understanding the history and evolution of this galaxy cluster.

“Cosmic own goal” another clue in hunt for dark matter



The hunt for dark matter has taken another step forward thanks to new supercomputer simulations showing the evolution of our “local Universe” from the Big Bang to the today.

Scientists believe clumps of dark matter, called halos that emerged from the early Universe trapped intergalactic gas and became the birthplaces of galaxies.

Cosmological theory predicts that our own cosmic neighbourhood should be teeming with millions of small halos, but only a few dozen small galaxies have been observed around the Milky Way.

Durham researchers believe their simulations answer this question, showing explicitly how and why millions of halos around our galaxy and neighbouring Andromeda failed to produce galaxies and became barren worlds. They say the gas that would have made the galaxy was sterilised by the heat from the first stars that formed in the Universe and was prevented from cooling and turning into stars.

However, a few halos managed to bypass this cosmic furnace by growing early and fast enough to hold on to their gas and form galaxies.

The work was funded by the UK's Science and Technology Facilities Council (STFC) and the European Research Council.

Lead researcher Dr Till Sawala, said the research was the first to simulate the evolution of our “Local Group” of galaxies, including the Milky Way, Andromeda, their satellites and several isolated small galaxies.

Dr Sawala said: “What we’ve seen in our simulations is a cosmic own goal. We already knew that the first generation of stars *emitted intense radiation*, heating intergalactic gas to temperatures hotter than the surface of the sun. After that, the gas is so hot that further star formation gets a lot more difficult, leaving halos with little chance to form galaxies.

“We were able to show that the cosmic heating was not simply a lottery with a few lucky winners. Instead, it was a rigorous selection process and only halos that grew fast enough were fit for galaxy formation.”

The close-up look at the Local Group is part of the larger EAGLE project currently being undertaken. To find out more, turn to the centre page.

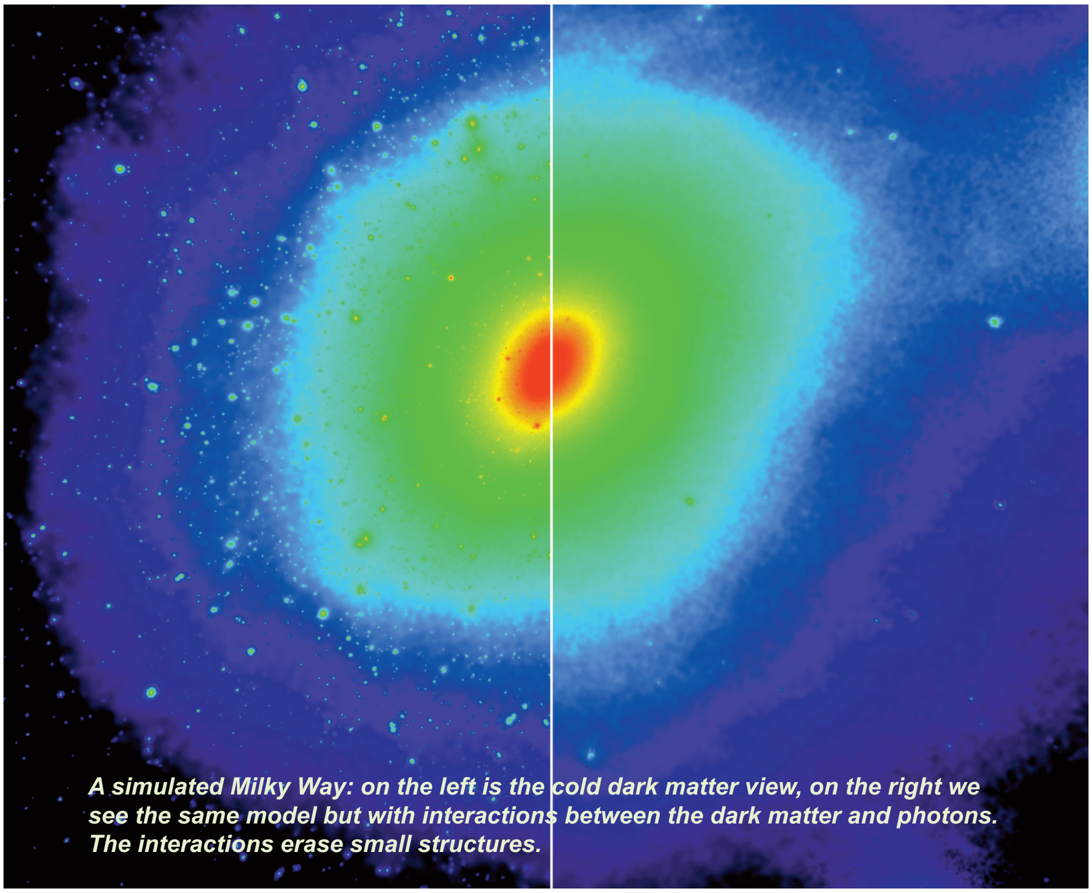
Scientists believe they have found a way to explain why there are not as many galaxies orbiting the Milky Way as expected. Computer simulations of the formation of our galaxy suggest that there should be many more, smaller galaxies around the Milky Way than are observed through telescopes.This has thrown doubt on the generally accepted theory of cold dark matter, a substance that scientists predict should allow for more galaxy formation around the Milky Way than is seen.

Interactive dark matter could explain Milky Way's missing satellite galaxies

Now cosmologists and particle physicists at the Institute for Computational Cosmology (ICC) and the Institute for Particle Physics Phenomenology (IPPP) at Durham University, working with colleagues at LAPTh College & University in France, think they have found a potential solution to the problem.

Writing in the journal Monthly Notices of the Royal Astronomical Society (MNRAS), the scientists suggest that dark matter particles, as well as feeling the force of gravity, could have interacted with photons and neutrinos in the young Universe, causing the dark matter to scatter.

Scientists think clumps of dark matter – or halos – that emerged from the early Universe, trapped the intergalactic gas needed to form stars and galaxies.



A simulated Milky Way: on the left is the cold dark matter view, on the right we see the same model but with interactions between the dark matter and photons. The interactions erase small structures.

Scattering the dark matter particles wipes out the structures that can trap gas, stopping more galaxies from forming around the Milky Way and reducing the number that should exist.

Lead author Dr Celine Boehm in the Institute for Particle Physics Phenomenology at Durham University said: "We don't know how strong these interactions should be, so this is where our simulations come in".

"By tuning the strength of the scattering of particles, we change the number of small galaxies, which lets us learn more about the physics of dark matter and how it might interact with other particles in the Universe. This is an example of how a cosmological measurement, in this case the number of galaxies orbiting the Milky Way, is affected by the microscopic scales of particle physics."

There are several theories about why there are not more galaxies orbiting the Milky Way, which include the idea that heat from the Universe's first stars sterilised the gas needed to form stars. The researchers say their current findings offer an alternative theory and could provide a novel technique to probe interactions between other particles and cold dark matter.

Co-author Professor Carlton Baugh, at the ICC, said: "Astronomers have long since reached the conclusion that most of the matter in the Universe consists of elementary particles known as dark matter."

"This model can explain how most of the Universe looks, except in our own backyard, where it fails miserably."

The model predicts that there should be many more small clumps of dark matter around our Milky Way than the visible satellites can observe.

"However, by using computer simulations to allow the dark matter to become a little more interactive with the rest of the material in the Universe, such as photons, we can give our cosmic neighbourhood a makeover and we see a remarkable reduction in the number of galaxies around us."

The calculations were carried out using the COSMA supercomputer at Durham University, which is part of the UK-wide DiRAC super-computing framework.

The work was funded by the Science and Technology Facilities Council and the European Union.

News and Outreach

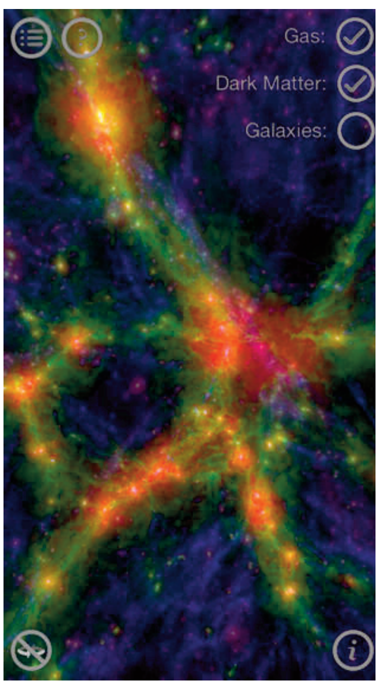
Physicist of the Year

Thirty-nine outstanding young physicists from the North East were rewarded for their dedication and enthusiasm for physics at Durham University's second Schools' Physicist of the Year event on Tuesday 24th June.

These exceptional Year 10 & Year 12 students were presented with their awards by Tim Simmons, CEO of the Ogden Trust, following nomination by their teachers. This year's winners were of an incredibly high standard with nominations for hard work and determination; being an active member of four extracurricular science clubs; and building, testing and installing a real-time directional lightning detector among many other things.

Over 200 people attended the celebration, with the students, their families and teachers taking part in hands-on activities provided by staff and students from Durham University's Physics Department including musical physics demos, programmable Lego robots and activities relating to the award-winning Cosmic Origins 3D film. ●

Cosmic App http://bit.ly/1uqXb7O



Have you ever wondered how the Universe changed from the Big Bang into the stars and galaxies?
Cosmic Universe allows you to view two numerical simulations of the formation of galaxies called "Millennium" and "Eagle". You find yourself in the centre of the simulated volume and you can look around you by rotating your iphone or ipad. It starts by developing a computer programme that encodes physical laws, such as gravity, and the behaviour of gases as described by the laws of hydrodynamics. This programme is then executed on a large super computer. The simulations in this app used a supercomputer in Germany, and the DiRAC supercomputer at the ICC. ●

The Infinite Monkey Cage, an award winning science/comedy chat on BBC radio 4 transported to Edinburgh Fringe in August. Carlos Frenk, director of the ICC, joined in the fun.

The Great North East Space & Engineering Expo at the Discovery Museum in Newcastle, organised by the Ashington Learning Partnership, attracted 360 pupils from all over the NE.

'Cosmology in Crisis' Exhibition of the ICC goes international: from our local 'Celebrate Science' in Durham to Stockholm and Thailand. The National Science and Technology Fair in Bangkok was attended by 1.2 million visitors.

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