Institution: University College London (UCL)

Unit of Assessment: 9 – Physics

Title of case study: Stimulating public interest in the dark side of the universe

1. Summary of the impact

Cosmologists at UCL – based in the Department of Physics and Astronomy and the Mullard Space Science Laboratory (MSSL) – conduct research into dark matter and dark energy through their involvement in a number of space missions and ground-based projects. This research has been shared with the public through a large number of talks, blogs, articles in the media, and television and radio programmes, stimulating significant public interest and discussion. Increased public understanding and interaction with the work was further achieved through a competition to improve mapping of dark matter. The research also influenced the creative practice of two artists, inspiring artworks that have been exhibited internationally and viewed by over 1 million people in total.

2. Underpinning research

Whilst we know the universe is accelerating, the cause of its acceleration is still unknown – is it dark energy, or could it be explained by modifying Einstein's theory of gravity? Another mystery is the nature of cold dark matter, a type of matter that is thought to account for a large part of the total mass of the universe, and the existence of which is inferred from the gravitational attraction of galaxies and stars. Cosmologists at UCL have been investigating these and other problems since 2004, when cosmology was established as a research area within the university. These researchers have played leadership roles in the following cutting-edge cosmology projects:

(i) The **Dark Energy Survey (DES)** has been UCL cosmology's 'flagship project'. The $40 million international DES is using a new wide-field camera, constructed in part at UCL, on the 4-metre Blanco telescope in Chile. The survey started in September 2013 and will map 300 million galaxies over five years. Its aim is to determine the nature of dark energy and what is causing the universe's acceleration. Contributions to the research by the UCL team since 2005 included building the optical corrector for the DES camera [1] and developing novel methods to derive galaxy distances from their colours by utilising artificial neural networks. UCL researchers also conducted studies of the feasibility of DES to characterise dark energy and dark matter – for example, that DES (combined with Planck) might measure neutrino mass for the first time [2].

(ii) Euclid is a European Space Agency (ESA) mission that is expected to launch in 2020. It will carry out spectroscopic measurements of tens of millions of galaxies with the aim of understanding the nature of dark matter and dark energy. Since 2006, UCL has been involved in the inception and creation of all aspects of the weak lensing science for Euclid. UCL has contributed and led scientifically on the development of weak lensing and photometric redshift methodology, on the creation of novel approaches for the mitigation and assessment of systematic effects [3], and in the survey design.

(iii) Planck – ESA's first mission to study the origins of the universe – surveyed the sky from 2009 to 2013. Contributions to Planck by UCL researchers [4, 5] included (a) the selection, calibration and testing of all the cold optical components of the High Frequency Instrument on board the Planck satellite; (b) development of innovative algorithms to constrain fundamental theories for the origin of structure in the universe; (c) methods to measure the global geometry and isotropy of the universe; and (d) methodology for the reconstruction of the mass distribution of the universe as traced by lensing of the cosmic microwave background (CMB). Cosmological research findings that are related to these UCL contributions include (a) the first detection by a single experiment of the deviation from scale-invariance of the primordial power spectrum, as predicted by the fundamental theory of the origin of cosmic structure called "inflation"; and (b) the first full sky map of where all the mass is in our universe.

(iv) The **LOFAR** array is the most sensitive radio telescope ever built in the low frequencies. A major goal of this telescope is to detect directly the Epoch of Reionisation, which is the time in the history of our universe when the first objects were born. The signal that arrives at the telescope from the Epoch of Reionisation is 10,000 times smaller than the contamination from our galaxy. UCL researchers have played a major role [6] since 2010 in building the techniques that separate these signals from each other and from the signal from extragalactic objects; they implemented an algorithm that performs foreground subtraction and introduced it in pipeline form so that other

members of the collaboration could use it.

Key UCL researchers: Ofer Lahav (Perren Chair of Astronomy 2004-present), Sarah Bridle (Reader in Astronomy 2004-2012), Jochen Weller (Lecturer 2005-2009), Filipe Abdalla (Lecturer in Astronomy 2005-present), Hiranya Peiris (Reader in Astronomy 2009-present), Tom Kitching (Lecturer 2012-present), Mark Cropper (Professor of Astrophysics 1988-present), Peter Doel (Reader in Astronomy 1998-present) and Giorgio Savini (Lecturer 2009-present).

While aspects of the impact clearly focus on UCL contributions, all four projects are international projects. They also involve other UK institutions, which share in the credit for the impact generated.

3. References to the research

[1] The impact of camera optical alignments on weak lensing measures for the Dark Energy Survey, M. Antonic et al. (incl. Bridle, Doel and Lahav), *MNRAS*, 431, 3291-3300 (2013) doi:10.1093/mnras/stt408

[2] Forecasting neutrino masses from galaxy clustering in the Dark Energy Survey combined with the *Planck* measurements, O. Lahav, A. Kiakotou, F.B. Abdalla and C. Blake, *MNRAS*, 405, 168-176 (2010) doi:10.1111/j.1365-2966.2010.16472.x

[3] Defining a weak lensing experiment in space, M. Cropper, H. Hoekstra, T. Kitching, R. Massey, J. Amiaux, L. Miller, Y. Mellier, J. Rhodes, B. Rowe, S. Pires, C. Saxton and R. Scaramella, *MNRAS*, 431, 3103-3126 (2013) doi:10.1093/mnras/stt384

[4] Planck 2013 results. XVI. Cosmological parameters, Planck collaboration (incl. Peiris) (2013) http://inspirehep.net/record/1224741

[5] Planck 2013 results. XXII. Constraints on inflation, Planck collaboration (incl. Peiris) (2013) http://inspirehep.net/record/1224747

[6] Foreground removal using FASTICA: a showcase of LOFAR-EoR, E. Chapman, F.B. Abdalla, G. Harker, V. Jelić, P. Labropoulos, S. Zaroubi, M.A. Brentjens, A.G. de Bruyn and L.V.E. Koopmans, *MNRAS*, 423, 2518-2532 (2012) doi:10.1111/j.1365-2966.2012.21065.x

References [2], [3] and [4] best indicate the quality of the underpinning research.

4. Details of the impact

UCL research into dark matter and dark energy has led to significant stimulation of public interest in these topics, achieved through a large number of public talks, online blogs, articles in the media, a BBC television programme and a public competition. It has also impacted upon two artists, influencing their creative practice and inspiring a number of their publicly exhibited artworks.

Public events: UCL cosmologists regularly deliver public talks based on their research. For example, dark energy work at UCL was the subject of talks by Ofer Lahav at the Royal Institution in June 2013 (attended by 300 people) and at Tate Britain (in March 2009), and a talk by Sarah Bridle at the British Astronomical Association (in 2008). Lahav also delivered a public UCL Lunch Hour Lecture (in November 2010), "Light and Darkness in the Accelerating Universe", which was subsequently uploaded to YouTube and had received almost 2,000 views as of 31 July 2013 [A]. Hiranya Peiris delivered a Space talk at Royal Greenwich Observatory in March 2013 and a talk at the British Interplanetary Society in July 2012, both of which were on her Planck research; a UCL Science Centre lecture to several hundred sixth formers and teachers in March 2012; and a talk to MPs and policymakers at the RCUK event "Impacts: people and skills" in 2010.

Peiris was also invited to present results from the Planck mission on the origin of the universe at CERN's first TEDx event, TEDxCERN, in May 2013. The event had a live audience of 600, as well as viewing parties at 27 international participating institutions that were attended by a total of 1,000 people, and 10,870 unique viewers who tuned into the webcast. Peiris's talk was subsequently posted on YouTube and had been viewed over 2,000 times as of 31 July 2013 [B].

Blogs: UCL cosmology research is regularly discussed in two blogs set up by members of staff: MSSL ASTRO, which was initiated by Tom Kitching in March 2013 on behalf of MSSL's Astrophysics Group; and Early Universe @UCL, which was set up by Peiris in May 2013 to highlight the Planck research. As of 31 July 2013, these blogs had received respectively around 2,000 views from 21 countries, and over 3,000 unique viewers with over 10,000 page hits.

Media coverage: Cosmology discoveries at UCL are regularly reported in press releases that attract a significant amount of attention from the media. For example, to accompany the first release of data from Planck, ESA published two press releases in March 2013 that featured work contributed by UCL researchers on the physics of the early universe, large-scale anomalies, and the weak gravitational lensing of the CMB. This work then received international press coverage in March 2013, with articles in the New York Times (NYT), the Financial Times, The Guardian, The Economist, and on the BBC's website. These articles stimulated much public interest and discussion about Planck and the CMB, as evidenced by the many comments posted online; for example, 451 and 345 comments followed the BBC [C] and NYT [D] articles respectively.

In February 2012, The Economist included both a feature article about UCL's DES work and an online video interview with Lahav about the research, which proved to be one of the most popular articles published that year. The interview sparked considerable in-depth discussion about dark energy by viewers, as evidenced by the detailed online comments [E]. The article also stimulated a significant amount of public interest in the topic, as described by the newspaper's Online Science Editor, who commented in August 2013: "The nature of dark energy remains one of the most perplexing mysteries in all of physics. Despite being abstruse and baffling, however, the topic sparks great public interest. Our three-page article about dark energy (which appeared both in our print edition and online […]), focusing on the ambitious Dark Energy Survey and its quest to understand the phenomenon, has been read a whopping 115,000 times since it first appeared in February 2012. That places it among the most popular pieces The Economist published in the whole of 2012, not just in its science section. It also secured 1,200 Facebook "likes" and was tweeted more than 400 times. An accompanying video interview with Professor Ofer Lahav has so far been viewed nearly 12,000 times. Astronomy, it seems, has not lost its ability to amaze and inspire." [F]

Television and radio: An episode of Dara Ó Briain's Science Club featured UCL researcher Filipe Abdalla talking about the LOFAR array and the challenges of pulling hard-to-detect cosmological information out of the data. The episode aired on BBC Two on 1 August 2013, with an audience of 1.22 million [G]. DES research at UCL was discussed on the BBC Radio 4 Today programme by Bridle, Lahav and Peter Doel in October 2011.

Public competition: In October 2012, UCL's Tom Kitching launched a public online competition through the company Kaggle, with the brief to develop algorithms to improve the mapping of dark matter using gravitational lensing. The competition was underpinned by UCL's research on weak lensing for the Euclid space mission. It ran for two months and attracted the attention of London-based Winton Capital Management, which contributed $20,000 of prize funds. The interesting problem posed by the challenge attracted 3,553 online entries from 353 teams of participants, and stimulated much discussion among entrants on the competition's forum about their solutions and dark matter [H]. The competition also received significant press attention, including articles in Time and Wired magazines, and was discussed in many blogs, including those written by the competition's winner and runner-up [I, J]. These participants' detailed posts about the competition and their solutions show that taking part increased their interest in and understanding of the topic.

Winton benefited from its involvement in the competition, using it to advertise its brand to the exact demographic in which it was interested in finding future employees; for example, it led to the company recruiting a new Senior Data Scientist in 2013. Winton's Recruitment Manager said: "Kaggle was a hugely successful venture for Winton. We expend huge amounts of money and time on identifying and trying to hire exceptional research scientists for our business. We only manage to hire 10-15 per year, though we interview several a week, and through the Kaggle competition we sourced two outstanding researchers, one a professor of statistics from Portugal, the other a postdoc physicist from California with a PhD from Harvard. The competition was great branding and even better it allowed us to help generate new physics research!" [K] The collaboration between UCL, Kaggle and Winton is continuing, with a new competition using Sloan Digital Sky Survey imaged galaxies soon to be launched.

Creative practice of artists: UCL research has influenced the creative practice of two artists, both of whom spent time in the Department of Physics and Astronomy as Artists-in-Residence and have created new art inspired by cosmology research carried out at UCL.

The first Artist-in-Residence worked within the department from 2010 to 2011. UCL research on dark matter, dark energy and DES inspired her to create a new body of artworks: 100 Billion Suns, As the World Turns, and History of Darkness. These works have been exhibited all over the world, in seven solo exhibitions and 21 group shows, including at Selfridges in London, the Museum of Contemporary Art in Sydney, Kettle's Yard in Cambridge, the Modern Art Museum of Fort Worth, The Art Institute of Chicago, Kunsthalle Wien, and Ingleby Gallery in Edinburgh. In total, the artworks have been viewed by over 1 million people. They also generated significant press coverage for the artist, including articles in Wired magazine, The Sunday Times Culture, Art Monthly, Observer New Review, AnOther Magazine, The Guardian and The Independent. She commented of her experience: "My time spent as Artist-in-Residence in the Department of Physics and Astronomy has been invaluable to my research and artistic output. […] The ideas I experienced in the department have inspired several more new works and will continue to do so for years to come." [L]

This artist has appeared in two films talking to Lahav about cosmology research at UCL. "All the Dead Stars" was made by Tate Britain in 2009 and "When Art Meets Astronomy" was made by UCL in 2011; as of 31 July 2013, these films had been viewed on YouTube by around 8,000 people [M] and around 6,000 people [N] respectively. Lahav also delivered talks at Tate Britain (in 2009) and the Whitstable Biennale (in 2010) on the connection between the department's research and the artist's work; these two talks were attended by a total of around 100 members of the public.

The second artist began her residency in 2011 and completed an artwork in February 2013 called "untitled - the dark energy survey". This artwork was directly inspired by the DES optical corrector constructed at UCL and took almost two years to produce. It is now on display at the University of London Observatory at Mill Hill, where it will be viewed by hundreds of visitors every year.

5. Sources to corroborate the impact

[A] UCL Lunch Hour Lecture on YouTube: http://bit.ly/1g5IDs3 – corroborates the number of views.

[B] TEDxCERN talk on YouTube: http://bit.ly/1foWOHv – corroborates the number of views.

[C] BBC online article about Planck: http://www.bbc.co.uk/news/science-environment-21866464 – the comments corroborate that public interest and discussion were stimulated.

[D] New York Times online article about Planck: http://nyti.ms/1gw7Sl3 – the comments corroborate that public interest and discussion were stimulated.

[E] The Economist video interview with Lahav: http://econ.st/19EoMgu – the comments following the video corroborate the stimulation of public discussion about dark energy.

[F] Supporting statement from Online Science Editor at The Economist – corroborates that the DES article and interview stimulated public interest in dark energy. Available on request.

[G] Supporting statement from a Series Producer at the BBC – corroborates the number of viewers in the audience for the episode of Dara Ó Briain's Science Club. Available on request.

[H] Public competition website: http://www.kaggle.com/c/DarkWorlds – corroborates the number of entries, and that significant discussion amongst participants was stimulated (on the forum page).

[I] Blog post by public competition winner: http://timsalimans.com/observing-dark-worlds/ – corroborates that understanding of, and interest in, science were increased.

[J] Blog post by public competition runner-up: http://homepages.inf.ed.ac.uk/imurray2/pub/12kaggle_dark/ – corroborates that understanding of, and interest in, science were increased.

[K] Supporting statement from Recruitment Manager at Winton Capital – corroborates the benefit of the public competition to Winton Capital, especially on their recruitment. Available on request.

[L] Supporting statement from Artist-in-Residence – corroborates the details of the exhibitions and that the UCL research had an impact on her work. Available on request.

[M] Tate Britain video on YouTube: http://bit.ly/1c8vZUf – corroborates the number of views.

[N] UCL "When Art Meets Astronomy" video on YouTube: http://bit.ly/1edv0Th – corroborates the number of views.