Institution: University of Sussex

Unit of Assessment: UoA 9 Physics

Title of case study: Research on fundamental physics inspires, entertains and stimulates the public

1. Summary of the impact

Large numbers of the public have been inspired and delighted by Sussex research on high-profile fundamental physics, through media coverage and cultural interpretation of this work, but also by participating in the process and contributing directly to further discoveries. Sussex research contributions to high-profile fundamental research include the Higgs boson discovery, which has had a phenomenal impact around the world, and the ESA's missions, XMM-Newton and Herschel, which appeal to an enduring curiosity and wonder about the nature of the universe. Our research underpins the pioneering Galaxy Zoo Project, which has enabled unprecedented engagement, providing a direct benefit to >200,000 participants who are directly contributing to active research, through one of the most high-profile examples of 'citizen science'. The cultural landscape has been enriched through, for example, a sell-out West-End theatre play and a music/art/science collaboration at a regional Arts Festival.

2. Underpinning research

The research underpinning this case study spans Astronomy and Particle Physics.

Observational astronomy

- Professor S. Oliver was Instrument Control Centre Scientist and a founding Associate Investigator on the ESA's Herschel SPIRE Instrument [see Section 3, R1]. He also leads the largest Herschel project, HerMES, which has discovered thousands of distant star-forming galaxies, providing important clues to understanding galaxy evolution. The XMM Cluster Survey [R2] – led by Dr A.K. Romer – analyses data from the XMM-Newton X-ray observatory in order to search for galaxy clusters. The number of clusters and their redshift distribution are sensitive to details in the cosmological models.

- The Sloan Digital Sky Survey (SDSS) is an international project systematically photographing the sky and cataloguing galaxies. Dr J. Loveday is one of only two UK astronomers awarded Sloan Digital Sky Survey (SDSS) 'builder' status [R3]. The 'builders' in SDSS are the individuals who have contributed two years or more of research effort to the project through writing software, building hardware, or leadership and fundraising. This research underpins the Galaxy Zoo Project which takes images of galaxies from the SDSS and enlists non-academic volunteers to classify them, to enable scientific studies of the morphologies of galaxies. Our research has subsequently used their contributions – e.g. the study of unusual red spiral galaxies undertaken by Dr A.K Romer and her group [R4]. This research was then discussed with 'citizens' in on-line forums, contributing to the citizen/academic dialogue and completing the citizen–science circle.

Discovery of the Higgs boson

The ATLAS experiment at CERN is one of two particle physics experiments at the high energy frontier. Sussex researchers Professor A. De Santo and Dr F. Salvatore participated in the discovery and characterisation of a new particle. This particle is consistent with the Standard Model Higgs boson [R5], thus achieving one of the primary goals of the LHC and tentatively completing the Standard Model (SM). The new particle now provides a testing ground for new (beyond SM) physics through precision studies of its branching fractions, angular decay distributions, and production in association with other particles, such as the top quark.

The neutron electric dipole moment

The search for the neutron's electric dipole moment (nEDM) [R6] tests theories of the origin of matter in the universe, and is a subtle probe of physics beyond the Standard Model. The CryoEDM experiment [R6] is led by Sussex researcher Professor P. Harris and provides the world's best nEDM upper limit. This rules out many scenarios of physics and constrains theoretical ideas for explaining the observed matter–antimatter asymmetry (i.e. the 'origin of matter') in the universe.

3. References to the research

R1 Griffin, M. *et al*. including Oliver, S., Roseboom, I., Savage, R., Smith, A. and Ward, R. (2010) 'The Herschel-SPIRE instrument and its in-flight performance', *Astronomy and Astrophysics*, 518(July/August), L3. DOI: 10.1051/0004-6361/201014519

R2 Romer, A.K., Viana, P.T.P., Liddle, A.R. and Mann, R.G. (2001) 'A serendipitous galaxy cluster survey with XMM: expected catalogue properties and scientific applications', *The Astrophysical Journal*, 547(2): 594–608.

R3 Abazjian, K.N. *et al*. including Loveday, J. (2009) 'The seventh data release of the Sloan Digital Sky Survey, *The Astrophysical Journal*, S182(2): S543–558.

R4 Masters, K., Mosleh, M. and Romer, A.K. *et al*. (2010) 'Galaxy Zoo: passive red spirals', *MNRAS*, 405(2): 783–799.

R5 ATLAS Collaboration – Aad, G. *et al*., including De Santo, S. (2012) 'Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC', *Physics Letters B*, 716(1): 1–29.

R6 Baker, C.A. *et al*., including Harris, P.G. (2006) 'An improved experimental limit on the electric dipole moment of the neutron', *Physics Review Letters*, 97(13): 131801 1–4.

Outputs R1, R3, R5 best indicate the quality of the underpinning research.

Outputs can be supplied by the University on request.

4. Details of the impact

Our physics and astronomy research has inspired, stimulated and entertained literally millions of people [see Section 5, C1–C6], and the discovery of the Higgs boson has generated exceptional interest around the world and challenged people's perceptions of the foundations of the universe. Our research has also contributed to a leading example of 'citizen science', changing the way in which science is conducted. Finally, our research inspires new artistic and cultural activities enriching the lives of many.

Inspiring and stimulating the general public through research on the fundamentals of the universe

The Herschel Space Observatory, and the SPIRE instrument in particular, have had a wide public reach because of their intrinsically awe-inspiring pictures and due to a highly proactive UK (including Sussex) engagement effort which has recorded 47million audience contacts [C1]. There have been at least 27 distinct press 'stories', producing many more press releases internationally. These press releases are routinely picked up by, for example, the BBC web pages [C2], because of their mass appeal to a ready audience [C3]. There have been extensive media appearances (including Oliver on *Sky at Night*, 6 April 2009 [C4] and HerMES featuring in the Radio 4 *Today* programme, 19 April 2013, average audience 6 million) and high-profile stands at major national

events like the Royal Society Summer Exhibition 2012 and the Big Bang Fair (2010, 2011, 2012, 2013).

Romer and Baskill recorded an audio slideshow [C5] covering the highlights from 10 years of the XMM-Newton observatory. In the piece, Romer describes the XMM-Newton images taken as part of her XMM cluster survey [see Section 3, R2]. The slideshow was accessed over 100,000 times from the BBC web site within the first day of availability alone [C5].

The Higgs boson's role in generating elementary particle masses has stimulated the public imagination and became the topic of popular science such as Leon Lederman's 1993 book *The God Particle*. Following the 4 July 2012 discovery, fundamental physics figured in public awareness in a way probably not seen since Eddington's 1919 confirmation of General Relativity, with front-page coverage in newspapers around the world, for example *The Wall Street Journal*, *The Times* and *The Independent.* In particular *The Guardian*, with its front-page headline 'Higgs was right', makes the direct comparison with the famous 1919 headline 'Einstein was right' [C6].

Inspiring people to contribute to scientific investigations and changing how science is done

Our research has underpinned the Galaxy Zoo Project [C7], which aims to address the scientific problem that, while the human eye is the best tool, the galaxies from SDSS were too numerous to be classified by professional astronomers. Galaxy Zoo enlists members of the public to classify galaxy images. One million SDSS images were made available via the Galaxy Zoo webpage http://www.galaxyzoo.org in July 2007. Within 24 hours of its launch, Galaxy Zoo received almost 70,000 classifications per hour. More than 100 million classifications were received by 2009, contributed by more than 200,000 people [C8] who are individually acknowledged on the web page. These classifications have led directly to some substantial new scientific findings – e.g. [R4]. A prime example is the discovery of a new class of galaxy, first noted by Galaxy Zoo volunteers [C9]. Given its groundbreaking character, Galaxy Zoo has been the subject of academic research into the motivations and benefits of the science to the volunteers. A study by Johns Hopkins researchers [C8] involved interviews with 22 volunteers and an analysis of online forum posts. The interviewees comprised people from many walks of life, including a judge, a theatre draftsperson, a chemist and an investment banker. According to the interview responses, motivations range from fun and interest in the beauty of the pictures to, importantly, the stretching of the imagination and the 'slight probability that I may point out the one object that will completely shock our current understanding about the universe' and the excitement of contributing to original scientific research. A desire to help (volunteerism) is also evident, as is a desire to meet people with the same interests. Galaxy Zoo is an influential pioneer in the field of 'citizen science', as discussed in the press, for example in a *Guardian* article [C10], spawning public engagement in other branches of science – The Zooniverse at https://www.zooniverse.org includes studies of cyclones, climate change and cancer data. It figures prominently in Michael Nielsen's book *Reinventing Discovery: The New Era of Networked Science*, which argues for an 'open science imperative' to reinvent discovery, which will 'help address our most critical human problems'.

Our science influencing artistic and cultural collaboration

We have been engaged as scientific consultants on various arts projects. A highlight was the well-received play 'Constellations', which premièred at the Royal Court, moved to the Duke of York's Theatre (West End, London, 2012 [C11]) and is expected to become a feature film. The lead character is an Astronomer from Sussex, the script specifically mentions the XCS survey [R2] and Romer and Liddle were the Chief Scientific Advisors. Herschel SPIRE influenced a scene in an episode of the Big Bang Theory! (April 2013), reaching 14–20 million viewers.

In 2009, Harris joined with the organisers of the Adur Festival, an Arts Festival in the South Coast region, and composer–performer Richard Durrant, to create a musically and visually accompanied lecture on the search for the neutron's EDM [R6] and its implications [C12]. The intention was for the audience to 'experience science in a completely new way' and so the music was written using notes generated by the experimental data [C12]. During a Q&A session, the sell-out audience was

'by all accounts, overwhelmed', with reactions ranging from struggling with the perceived 'anti-religious' implications of the research to a better understanding and affection for fundamental science [C12].

In conclusion Sussex physics research has changed the way the theatre–going public, the scientifically-engaged public and the general public appreciate aspects of fundamental physics and the scientific process, and has facilitated better engagement with scientific research, resulting in increased scientific literacy.

5. Sources to corroborate the impact

C1 The UK Herschel outreach site herschel.cf.ac.uk and our public events log bit.ly/1dilH3V

C2 Corroborated through a Commendation from BBC science correspondent, held by Sussex

C3 The four most recent Herschel BBC pages with URL and the number of times the page was accessed by BBC readers in the first 24 hours following publication: http://bbc.in/11TUikE (90,000); (http://bbc.in/10nH9vc (190,000); http://bbc.in/Ys2TIv (100,000); http://bbc.in/15roDu4 (125,000) – data from [C2]

C4 Oliver explaining far infrared astronomy in BBC's *Sky at Night* http://bbc.in/18o8iSR

C5 Audio slide show at http://news.bbc.co.uk/1/hi/sci/tech/8404574.stm; corroboration of the page hit number through Paul Kerley, BBC, held by Sussex

C6 The front page of *The Guardian*, 5 July 2012, http://bit.ly/124ef

C7 Lintott, C.J. *et al*. (2008) 'Galaxy Zoo: morphologies derived from visual inspection of galaxies from the Sloan Digital Sky Survey', *MNRAS*, 389(3): 1179–1189

C8 Raddick, M.J. *et al*. (2010) 'Galaxy Zoo: exploring the motivations of citizen science volunteers', *Astronomy Education Review*, 9(1): 010103

C9 Cardamone, C. *et al*. (2009) 'Galaxy Zoo green peas: discovery of a class of compact extremely star-forming galaxies', *MNRAS*, 399(3): 1191–1205.

C10 'Galaxy Zoo and the new dawn of citizen science', *The Guardian*, 18 March 2012, http://bit.ly/18od16N

C11 *New York Times*, 24 January 2012, http://nyti.ms/WeAqVK and *Financial Times*, 3 November 2012, http://on.ft.com/Y4RjQ8

C12 Corroborated through and quotes from testimonial by Richard Durrant, held by Sussex