Institution: The University of Manchester

Unit of Assessment: 9 (Physics)

Title of case study: Increased public understanding and economic impact arising from particle physics and cosmology research

Period when the underpinning research was undertaken: Jan 2000 – Dec 2016

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Richard Battye	Professor of Cosmology	2004 – present
Brian Cox	Professor of Particle Physics and Royal Society Professor of Public Engagement Royal Society Research Fellow	2008 – present 2005 – 2008
Richard Davis	Professor of Astrophysics	2004 - 2016
Clive Dickinson	Professor of Astrophysics	2009 - present
Jeffrey Forshaw	Professor of Particle Physics	2004 - present
Patrick Leahy	Senior Lecturer in Radio Astronomy	2004 - present
Althea Wilkinson	SKA SADT Consortium Project Manager	2004 - present

Period when the claimed impact occurred: August 2013 – July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research in particle physics and cosmology at The University of Manchester (UoM) has had a global impact. Research in particle physics has been crucial in establishing the global media impact of Brian Cox, which has increased public awareness and understanding of science, and generated significant economic impact. UoM research has contributed to the scientific success of the European Space Agency's Planck satellite project and to sharing that success with the general public. Brian Cox has engaged audiences of millions, especially through his world tour and popular book which feature and draw upon Planck data. This engagement has generated significant revenue in excess of [text removed for publication] and enabled people to understand, appreciate and enjoy science.

2. Underpinning research

Brian Cox's success as a research scientist underpins his media and public engagement success. His high academic standing makes him an authoritative voice and his specific expertise in particle physics regularly informs his media work. His success as a research scientist is evidenced by the following papers.

As part of the H1 collaboration, Cox led a novel measurement to probe the theory of strong interactions in the high-energy (diffractive) scattering regime **[1]**. The simulation of collision events in this regime was the focus of **[2]** and in **[3]**, Cox and Forshaw identified a new technique for identifying boosted massive particles. This has since developed into a sub-field of studying "boosted particles" through "jet substructure" and is being used to study the Higgs boson at the Large Hadron Collider. Largely as a result of this work, Cox became the leader of the "FP420" project to make the case for installing low-angle proton detectors at CERN **[4]**.

Work published by Davis *et al* **[5]** chronicles the design, construction and testing of the 30 and 44 GHz Front End Modules for the Low Frequency Instrument on the Planck satellite. This project, led by UoM, provided two of the satellite's nine frequency channels. The data collected from these modules was crucial for accurate foreground subtraction. In particular, the 30 GHz map was used as a tracer of galactic synchrotron emission in the cleaning of the large-angle polarization data crucial in determining the optical depth to reionization. Accurate knowledge of this quantity is necessary in determining cosmological parameters such as the age of the Universe. Both the 30 and 44 GHz maps are used in the fits to the large-angle temperature data. The cosmological analysis of the cleaned-up data, first published in **[6]**, provided the most accurate prediction of the age and composition of the Universe. Data collected by the Planck satellite has led to a new era of high-precision cosmology and allows scientists to study in detail the Universe shortly after the Big Bang and trace its evolution to the present time.

3. References to the research

[1] The H1 Collaboration. *Energy flow and rapidity gaps between jets in photoproduction at HERA. Eur. Phys. J. C* 24, (2002) 517. DOI: 10.1007/s10052-002-0988-9. Authors include nine UoM researchers, including **B.E. Cox.**

[2] **B.E. Cox and J.R. Forshaw**. *POMWIG: Herwig for diffractive interactions*, Computer Physics Communications 144 (2002) 104-110. DOI: 10.1016/S0010-4655(01)00467-2.

[3] J.M. Butterworth, **B.E. Cox, J.R. Forshaw**. *WW scattering at the CERN LHC* Phys. Rev. D 65 (2002) 096014. DOI: 10.1103/PhysRevD.65.096014. [330 citations, iNSPIRE database]

[4] M.G. Albrow et al. *The FP420 R & D Project: Higgs and New Physics with forward protons at the LHC, JINST* 4 (2009) T10001. DOI: 10.1088/1748-0221/4/10/T10001. **B. E. Cox** is the corresponding author and was co-spokesperson for the FP420 R&D project between 2004 and 2009. Authors include 24 UoM researchers [277 citations, iNSPIRE database]

[5] **R.J. Davis**, et al. *Design, development and verification of the 30 and 44 GHz front-end modules for the Planck Low Frequency Instrument* 2009 JINST 4 T12002. DOI:10.1088/1748-0221/4/12/T12002. Authors include 12 UoM researchers, including **A. Wilkinson**.

[6] The Planck Collaboration. *Planck 2015 results - XIII. Cosmological parameters.* Astronomy & Astrophysics, Volume 594 (2016) A13. DOI: 10.1051/0004-6361/201525830. Authors include nine UoM researchers, including **R. Battye**, **R.J. Davis, C. Dickinson, J.P. Leahy** and **A. Wilkinson**. [9082 citations, iNSPIRE database]

Reference **[6]** contains data that led to the Planck satellite team winning the $500k 2018 Gruber Prize in Cosmology for measurements leading "to the determination of cosmological parameters (matter content, geometry, and evolution of the universe) to unprecedented precision." Cox was awarded an OBE for services to science in 2010, the President's Medal from the Institute of Physics in 2012, The Royal Society Michael Faraday Prize in 2012 and was made The Royal Society Professor for Public Engagement in Science in 2016. Forshaw won the 2013 Institute of Physics Kelvin Medal.

4. Details of the impact

Context and pathway to impact

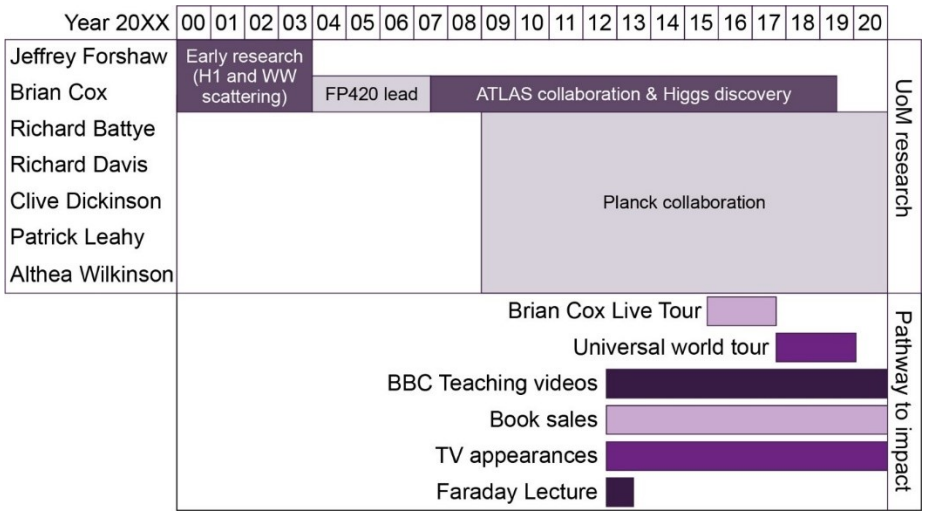
UoM has a long history of research in particle physics, including notably the Higgs boson discovery **[2, 3].** Cox's early public engagement work emerged in particle physics and cosmology, where astrophysics and particle physics meet. UoM research has led to Cox engaging the public in astronomy at Jodrell Bank Centre for Astrophysics, via programmes such as the BBC's Stargazing Live. The Chair of the Royal Society Public Engagement Committee verifies that, "*Brian Cox's research, conducted at The University of Manchester, has been critical in establishing his position as one of the world's leading science presenters. It was his BBC work on cosmology that really established him in the public consciousness. He set out to convey the excitement of particle-physics research, through the broadcast media, contributing significantly to public interest in, and understanding of, the search for the Higgs boson, and has gone on to popularise many other areas of science*"**[A].**

Cox's research, conducted at UoM **[**e.g. **1-4]**, has been critical in establishing his position as one of the world's leading science presenters. Through worldwide tours, popular science books, TV and radio work, Cox has engaged audiences in their millions. Cox has formed three registered companies (BCLive LLP, BCLiveUK Ltd, Apollo's Children Ltd) to manage these media and public engagement activities. His public engagement and service to science is recognised by his OBE and Royal Society professorship (see section 3).

The Planck project, in which UoM research played a crucial role **[5, 6],** directly inspired Cox and Forshaw to write their popular science book "Universal: a journey through the cosmos" and Cox to design a tour with a heavy focus on cosmology. Cox and Forshaw wrote this book with the primary goal of enabling a lay reader to understand some of the details of the Planck measurements and their importance. Armed with the book, Cox designed a tour with explicit

reference to the Planck data. The Universal book and tour would not have been possible, or would not have occurred in the same way, without the Planck data.

Links between UoM research and engagement activities that have led to impact are shown in the figure below.



Economic impact of book sales and live tours

'Universal: a journey through the cosmos' was published via Penguin Books in 2016. The total consumer market sales for this book in the UK were 30,307 copies in hardback (HB) and 30,261 copies in paperback (PB) as of September 2020, at a combined value of [text removed for publication] **[B].** Other books authored or co-authored by Cox and published since August 2013 are:

- The Planets (2019), [text removed for publication]
- Infinite Monkey Cage (2017), [text removed for publication]
- Forces of Nature (2016), [text removed for publication]
- Human Universe (2014), [text removed for publication]

As of September 2020, a total of 413,454 copies of these five books have been sold, generating [text removed for publication] **[B].** Note that several of these books have sold well in the USA and have been translated into >20 languages. Sales figures are for the UK only.

Within the REF impact period, Cox has delivered two tours:

- The Brian Cox Live tour, from 21/09/2016 - 26/05/2017, involving 55 shows in the UK and Ireland (debut, sell-out tour);
- Universal: Adventures in Space and Time, 7/02/2019 - 16/10/2019, involving 68 shows in Europe, USA, Canada, Asia, New Zealand and Australia.

The Brian Cox Live tour sold 158,589 tickets and set the Guinness world record for "most tickets sold for a science tour" **[C]**. Brian Cox also holds the Guinness world record for "most tickets sold for a science show" with 11,433 people attending his Universal tour date at The Arena Birmingham, UK on 23/02/2019, beating his previous record of 8,787 in attendance at the Brian Cox Live performance from the SSE Arena, Wembley, UK on 26/05/2017 **[C]**.

Profits for these tours are shown below **[D]:**

- Autumn / Winter 2016 UK Tour - [text removed for publication]
- May 2017 UK Tour - [text removed for publication]
- 2019 February UK / Ireland - [text removed for publication]
- 2019 Autumn UK/ Ireland – [text removed for publication]

The February and Autumn legs of the 2019 Universal Tour in the UK and Ireland generated ticket revenue of [text removed for publication] **[D].**

Export revenue reported through BCLive LLP, and image rights reported through Apollo's Children Ltd are provided below **[E]:**

- Australia Pacific 2014 - [text removed for publication]
- Australia Pacific 2016 - [text removed for publication]
- Australia Pacific 2017 - [text removed for publication]
- World Tour 2019 Australia / Pacific / USA / Canada - [text removed for publication]
- Overall profits from export revenue before tax (sum of the above) [text removed for publication]

Increased public understanding of cosmology through live tours

Beyond economic impact, engagement with audiences via these tours has increased knowledge and changed attitudes around cosmology.

A critical review of the Universal Tour in the Guardian describes how it has changed attitudes, "*by the time Cox concludes with "the planet is all we have, so let's treasure it", you're left in awe of the rarity and preciousness of humanity, the skies, our Earth, and the magic all around us*" **[Fi]**. A review in the Liverpool Echo describes the audience learning concepts relating to Planck data, "*Concepts such as the speed of light, black holes and the extraterrestrial seemed to be of particular interest to the audience in the Q&A, as we were taken to the edge of current understanding about the origin and evolution of our solar system and the universe*" **[Fii].**

A critical review of the earlier Brian Cox Live tour in the Yorkshire Evening Post shows audience enjoyment and learning, "*my jaw dropped and I sat hypnotised for the next two and a half hours but completely immersed with the knowledge that was pouring out of the professor's [Cox's] mouth"* **[Fiii].**

Reach of TV appearances

Cox has hosted eight TV series for the BBC and ABC since 2014: Human Universe, Space, Time & Videotape, Forces of Nature, The Entire Universe, Life of a Universe, The 21st Century Race for Space, The Planets and Stargazing Live.

The Planets was a five episode series which ran from 28/05/2019 - 25/06/2019, recording an average of 2,500,000 viewers each night. It was the top science series of 2019 for BBC2 in terms of viewing figures and outperformed the channel average for the 9pm Tuesday slot by [text removed for publication]. Notably, The Planets series had in excess of [text removed for publication] views in China.

Economic impact of media companies

Cox is Director of three companies which manage his public engagement activities **[G]:**

- BCLive LLP – [text removed for publication]
- BCLiveUK Ltd – [text removed for publication]
- Apollo's Children Ltd – [text removed for publication]

Reach and impact on teaching physics to UK secondary school children

BBC Head of Science states, "*Research conducted at the University of Manchester, through the engagement activity of Professor Brian Cox, has had a significant impact on teaching physics and astronomy to UK school children through BBC TV programmes and BBC educational videos.*

Professor Brian Cox has co-developed and presented educational resources for primary and secondary school students. Partly based on his research at the University Of Manchester, Professor Brain Cox has developed and presented 11 educational videos for physics key stage /GCSE and National 4, covering Wonders of the Universe. These educational videos have been viewed [text removed for publication] *times since the start of the financial year 20/21. Content is also available via BBC Bitesize for GCSE Physics (Single Science) including Professor Brian Cox explaining how we can analyse starlight using spectroscopy, which relates to UoM cosmology research. These videos have inspired a generation to learn about the universe and have been well received by teachers and students.*

During the Covid-19 pandemic, Professor Brian Cox delivered science lessons to 11-12 year old secondary school children while schools were closed, as part of the BBC's biggest online educational push in its history. 'Science with Prof Brian Cox' aired on 1st May 2020 and was requested [text removed for publication] *times since it was launched"* **[H].**

Impact on science policy and government investment in science

In direct response to the challenges Brian Cox posed at the Royal Society Faraday Lecture titled 'Making Britain the best place in the world to do science', David Willetts (Minister of State for Universities and Science, 2010-2014) stated at the Conservative Party Conference in September 2013 that, "*Our aim is for Britain to be the best place in the world to do science. That is the challenge Brian Cox has set and, Brian, we are up for that. But to achieve that we must invest long term and get the next generation doing science and engineering. That means girls as well as boys"* **[I].**

5. Sources to corroborate the impact

[A] Testimonial from Chair of the Royal Society Public Engagement Committee
[B] Total Consumer Market book sales figures, as of 30 September 2020
[C] Guinness World Record announcements for most tickets sold for a science tour (May 2017) and most tickets sold for a science show (June 2019)
[D] Ticket revenue and profits for Universal Tours, provided by BCLive LLP
[E] Non-UK touring income, from BCLive LLP
[F] Critical reviews and audience feedback from Universal Tour:
[Fi] The Guardian, 13 September 2019, LINK
[Fii] Liverpool Echo, 22 February 2019, LINK
[Fiii] Yorkshire Evening Post, 17 May 2017, LINK
[G] Company data from Endole for BCLive LLP, BCLiveUK Ltd and Apollo's Children
[H] Testimonial from Head of the BBC's Science Unit
[I] Transcript of David Willetts speech, Conservative Party Conference, September 2013