Institution: Cardiff University

Unit of Assessment: Physics (9)

Title of case study: Universe in the classroom: Transforming perceptions, teaching practice and public awareness of astronomy.

Period when the underpinning research was undertaken: 2001 – 2020

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:
Haley Gomez	Professor	2005 – present
Christopher North	Senior Lecturer	2008 – present
Matt Griffin	Professor	2001 – present
Peter Hargrave	Professor	2001 – present
Peter Ade	Professor	2001 – present
Stephen Eales	Professor	1994 – present
Mikako Matsuura	Senior Lecturer	2015 – present

Period when the claimed impact occurred: 2014 – 2020

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

1. Summary of the impact (indicative maximum 100 words)

Astronomy and astronomy instrumentation research at Cardiff provided new insights into the formation and evolution of stars, galaxies and the Universe. The research underpinned development of educational and public outreach resources; these enabled European-wide astronomy activities and inspired new interactive visualisations of astronomical observations with global reach, including the first 3D astrophysical exhibit in the Smithsonian. The Cardiff team also trained over 800 teachers, reaching over 10,000 school-age students and addressing gender perceptions around science. This innovative training programme led to changes in the Welsh Joint Education Committee (WJEC) AS and A-Level Physics curriculum.

2. Underpinning research (indicative maximum 500 words)

Researchers at Cardiff University have held leadership positions in instrumentation development and scientific exploitation of several major astronomical observatories. The Astronomy Instrumentation Group (AIG) made major contributions to space instrumentation programmes, including the Spectral and Photometric Imaging Receiver (SPIRE) on board ESA's *Herschel* space observatory (Griffin PI) **[3.1]** and the High Frequency Instrument (HFI) on board ESA's *Planck* satellite (Ade Co-I) **[3.2]**. They were also key partners in many ground-based and balloon-borne telescopes, including the Balloon-borne Large Aperture Submillimeter Telescope, BLAST (Hargrave Co-I) **[3.3]** and the SCUBA-2 camera on the James Clerk Maxwell Telescope (Ade Co-I) **[3.4]**.

These observatories and instruments have enabled an unprecedented view of the Universe, allowing researchers to peer into dust clouds to see stars forming and dying, trace cosmic dust back to the early Universe, and study the physics of the Big Bang. Cardiff astronomers, for example, led large collaborative projects, focusing on star formation and evolution, star death, space dust, galaxy formation and evolution, and investigations of the very early Universe. These projects resulted in over 200 peer-reviewed publications and include the *Herschel*-ATLAS survey (PI Eales), which produced unprecedented measurements of the dust and gas content of galaxies over cosmic history **[3.5]**.

Work by Gomez and Matsuura resolved the controversy about the origin of cosmic dust, one of the building blocks for life **[3.6]**, showing that supernovae are an important source of cosmic dust. Building on previous work, Gomez also analysed supernovae and stellar evolution from an infrared (dusty) viewpoint, which enabled the first 3D image of a supernova remnant **[3.7]**.

Cardiff's combined experience in developing astronomical instruments and exploiting the data from them underpinned the development of a range of educational and outreach tools that drew directly upon the research, including:

- ***Chromoscope***: a panoramic display of the sky as observed at different wavelengths, including data and results from *Herschel and Planck* **[3.1, 3.2, 3.3, 3.4, 3.5]**
- ***Star in a box***: interactive Hertzsprung-Russell diagram demonstrating the lifecycle of stars, developed by Cardiff and the Las Cumbres Observatory in Chile, and informed by work on supernovae and stellar evolution from an infrared viewpoint **[3.6, 3.7]**
- ***Messier Bingo:*** interactive game based on Messier objects **[3.5]**, created through a collaborative programme of research with Las Cumbres Observatory **[3.6]**

Cardiff research contributions have been recognised by The Royal Astronomical Society through several awards, including the 2014 Group Achievement Award for the *Herschel*-SPIRE instrument (Griffin, Ade, Hargrave), and individual medals and awards for work on *Herschel* (Griffin, Eales, Gomez, and Ade).

3. References to the research

[3.1] Griffin, M. J., et al., *The Herschel-SPIRE instrument and its in-flight performance*, Astronomy & Astrophysics, 518, L3, 2010. https://doi.org/10.1051/0004-6361/201014519 (1,477 citations)

[3.2] Ade, P. A. R., et al., *Planck 2015 results-XIII. cosmological parameters*. Astronomy & Astrophysics 594, A13, 2016. https://doi.org/10.1051/0004-6361/201525830 (5,553 citations)

[3.3] Pascale, E., et al., *The balloon-borne large aperture submillimeter telescope: BLAST*, Astrophysical Journal, 681, 400, 2008. https://doi.org/10.1086/588541 (128 citations)

[3.4] Holland, W. S. H., et al., *SCUBA-2: the 10,000 pixel bolometer camera on the James Clerk Maxwell Telescope*. Monthly Notices of the Royal Astronomical Society, 430, 2513, 2013. https://doi.org/10.1093/mnras/sts612 (325 citations)

[3.5] Eales, S. A., et al., *The Herschel ATLAS*, Publications of the Astronomical Society of the Pacific, 122, 499, 2010. https://doi.org/10.1086/653086 (404 citations)

[3.6] Gomez, H. L., et al., *A cool dust factory in the Crab Nebula: a Herschel study of the filaments*, Astrophysical Journal, 760, 76, 2012. https://doi.org/10.1088/0004-637X/760/1/96 (121 citations)

[3.7] DeLaney, T., et al, *The Three-dimensional Structure of Cassiopeia A*, Astrophysical Journal, 725, 2, 2038, 2010. https://doi.org/10.1088/0004-637X/725/2/2038 (95 citations)

4. Details of the impact (indicative maximum 750 words)

Cardiff's astronomy and instrumentation research achieved global news coverage and underpinned internationally used educational resources. Coupled with teacher training and interactive sessions, the Cardiff team promoted astronomy research across four key areas:

- Designed school resources and teacher training that challenged gender norms, and hosted European-wide school activities **(4.1)**
- Changed the WJEC AS & A-Level Physics curriculum and supported teachers with tools to teach multiwavelength astronomy at AS and A-Level **(4.2)**
- Developed new astronomy visualisation and outreach tools leading to new international public engagement **(4.3)**

- Conducted public outreach activities including workshops, talks, and media events promoting astrophysics, recognized by the award of an MBE for excellence in public engagement **(4.4)**

4.1 Designed school resources and teacher training

a. Supporting teachers and female role models in primary schools

In 2012, Wales scored lower than all other UK nations for Science (based on the Programme for International Student Assessment (PISA) evaluation). The country also had fewer than half the number of female physics academics compared to the UK average. To address this, the team developed the *Universe in the Classroom* (UitC) project, led by Gomez **[5.1]**, which was funded by the Welsh Government. The project targeted schools less likely to engage with science education, specifically those in rural areas, with more students in poverty, and lower educational attainment.

In 2014 and 2015, the UitC project trained 131 teachers across 99 Welsh primary schools. The training focused on theory and resources from Cardiff research, including the *Star in a box*, and interpretation of multiwavelength data demonstrated through the *Herschel* Space Observatory. A post-project survey of teachers indicated an increase in their confidence and ability to train pupils in physics and other sciences: 97% of teachers felt more confident when teaching science, and 94% used the Cardiff resources in their teaching delivery within six weeks of receiving them **[5.1]**.

The UitC project also trained 34 undergraduate and postgraduate students to be Stellar Role Models (STARS) using the same principles described above. The STARS delivered 21 workshops within disadvantaged and remote schools across Wales, engaging 871 primary students. A third of the STARS were female, an approach designed to challenge perceptions that scientists are more often male. After STARS workshops, students were asked to draw a 'typical' scientist. While children in general are more likely to draw a 'typical' scientist as male, after workshops hosted by female STARS both male and female students were more likely to draw a female scientist. Demonstrating the vital impact of positive role models, pupils with male teachers were 28% more likely to draw a female scientist after a female-led STARS workshop **[5.1]**.

b. Inspiring Science Education Project

Cardiff was the UK lead organisation in the €5M million EU-FP7 project Inspiring Science Education (ISE). Running between 2013 and 2016, the project was designed to bring astronomy research into schools to train and provide resources for teachers, working with 31 European partners.

In April and May 2016, Cardiff hosted the *2016 Observing Challenge;* this used the Las Cumbres Observatory network **[5.2a]** and involved more than 65 schools across Europe. Between March and June 2016, the team promoted *Messier Bingo*, an interactive game designed to locate and view objects captured by the Las Cumbres Observatory network. As part of the ISE platform, the *Messier Bingo* activity reached 21 schools across Europe with nearly 700 students taking part **[5.2a]**.

The ISE project highlighted Cardiff's outreach tools as exemplary "showcase" resources and promoted these to more teachers across Europe, including *Star in a box*, *Agent Exoplanet*, and *Chromoscope* **[5.2b]**. The ISE project website had 64,179 unique visitors by the end of July 2016. Over 5,700 teachers across Europe registered on the ISE programme in 2015, with 4,697 students using the online portal and 23,998 students reached in total **[5.2c]**. The Cardiff team hosted ISE events across the UK; these directly trained 149 teachers, delivered talks to 736 teachers, and involved 20 events reaching 1,470 pupils **[5.2d]**.

4.2 Changed the WJEC AS & A-Level Physics curriculum

In 2014 the exam board WJEC (including their subsidiary exam board Eduqas used across Great Britain) consulted Cardiff when revising their AS and A-Level Physics curriculum.

Encouraged by the availability of Cardiff educational resources for multiwavelength astronomy, in 2015 WJEC revised their AS and A-Level curriculums to include this topic **[5.3]**.

The revised WJEC and Eduqas Teaching Specification (which outlines all topics students are taught) now states that "*Learners should be able to demonstrate and apply their knowledge and understanding*" of multiwavelength methods **[5.4a]**. Between 2016 and 2019 there were 11,724 exam candidates across Great Britain who were taught multiwavelength astronomy within the new AS and A-Level Physics curriculum **[5.5]**.

The new curriculum was supported by a Teacher's Guide advising teachers to use Cardiff's resources such as *Chromoscope* and *Star in a box* **[5.4a]**. WJEC Subject Officer for Physics, Helen Francis, used Cardiff astronomy resources to train teachers on the new curriculum and reported that "*centres that are using the resource are very happy with its suitability*" and estimated that 50% of WJEC-sitting schools used Cardiff's educational resources **[5.3]**. Since 2014 Cardiff researchers have also trained over 1,600 teachers and PGCE students with these astronomy resources at over 30 events across the UK, including via partnerships at the Institute of Physics, National Space Centre, and Techniquest science discovery centre **[5.4b]**.

4.2 Inspired new astronomy visualisation and outreach tools

a. The *Chromoscope* platform

In 2009 Cardiff developed the *Chromoscope* interactive tool to display the sky as observed at different wavelengths, including data from *Herschel*. Between 2015 and 2019 *Chromoscope* received over 616,000 visits, 93% of which came from outside the UK **[5.6a]**. The tool has now been translated into 16 languages, and inspired other groups across the world to build their own astronomy outreach tools using Cardiff's framework. Examples include:

- **GLEAMoscope:** Launched in 2016, GLEAMoscope enabled visualisation of results from the GLEAM survey using low-frequency radio sky imaging. Developed by Dr Natasha Hurley-Walker of Curtin University, Australia, GLEAMoscope received global media coverage including the New York Times, Daily Mail, Business Insider, and featured on the BBC's *Sky at Night* **[5.6b]**. Dr Hurley-Walker reported that GLEAMoscope was used in "*hundreds*" of outreach events across Australia and inspired the creation of independent Android and virtual reality (VR) apps and planetarium shows, highlighting that "*Chromoscope has massively increased the impact of our research, and also helped us reach tens of thousands of people across the world*" **[5.6b]**.
- **Sloan Digital Sky Survey:** In January 2015, Johns Hopkins University used *Chromoscope* to show Sloan Digital Sky Survey images from Diffuse Interstellar Bands. Featured by the Daily Mail, Huffington Post, and Astronomy.com, the Sloan team confirmed the tool had over 10,000 visitors and is regularly used to teach astronomy at Johns Hopkins University **[5.6c]**
- **HOPS (H_2O Southern Galactic Plane Survey):** In 2017 the HOPS team at Macquarie University, Australia, launched a HOPS data viewing facility using *Chromoscope*. The HOPS team noted that "*Chromoscope has excelled as a presentation and outreach tool*" and that they are building a new online tool inspired by *Chromoscope* to visualise the HOPS data **[5.6d]**.

b. The Smithsonian's first 3D exhibit in astronomy

Gomez's research role in the analysis of the Cassiopeia-A supernova remnant **[3.6]** led to a collaboration with the Smithsonian Institute in the USA, who created an online and interactive 3D display of the supernova based on the research **[5.7]**. In November 2013 the Smithsonian launched their first 3D exhibit of items from across their entire catalogue, including the Cassiopeia-A supernova. NASA's Chandra X-Ray Center highlighted the display as the first ever supernova remnant to be modelled in 3D, and the only astronomical object featured in the Smithsonian's 3D exhibit **[5.8]**.

In November 2013 the Chandra X-Ray Center also designed and released a model of Cassiopeia A that can be 3D printed. The Smithsonian Institute reports that this 3D model was used across America including in schools and libraries, in STEM outreach programmes for

girls, and in exhibits for blind and visually impaired persons. It was also showcased to several US Senators, and the Secretary of the Smithsonian Institute **[5.7]**. Furthermore, in 2018 the Chandra X-Ray Center launched a virtual reality (VR) model of Cassiopeia-A described as "*the first of its kind*". The Center is now developing further 3D visualisations of astronomical models **[5.7]**.

4.4 Public outreach activities

Since 2014 Cardiff's astronomy researchers have appeared on national media, including *BBC News*, *BBC Radio*, *ITV News*, *The Telegraph*, and *The Independent*. The team's public astronomy talks reached over 11,000 people including the 2016 National Astronomy Meeting, the 2017 *New Scientist* Live festival, the 2016 Science Alive Festival in Hong Kong and the 2016 Cheltenham, Swansea, and Manchester Science Festivals.

As a result of over 100 school presentations, as well as activity workshops at the 2016 National Eisteddfod, the 2018 STEM Live event (National Museum of Wales), and several talks at the National Space Centre, over 8,900 pupils were directly informed of Cardiff's research **[5.8]**

The team's experience in developing public engagement activities from Cardiff astronomy research led to wider representation in many public-engagement-related committee and review roles including: Honorary Secretary of the Institute of Physics-Wales Committee; reviewers for STFC's Public Engagement schemes and evaluation framework; membership of the Institute of Physics UK Outreach & Public Engagement Advisory Group and Public Engagement grants panel; and invited talks at teacher education conferences in the USA and Greece. Gomez was awarded an MBE in the 2018 Queen's Birthday Honours for her "*services to astrophysics and astronomy and, in particular, for inspiring the next generation of physicists and astronomers by communicating her research to a wide audience*" **[5.9]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] *Universe in the Classroom* – Final Report.

[5.2] Collated Inspiring Science Education (ISE) reports: a) Cardiff ISE Activities; b) Cardiff Showcase items on ISE website; c) ISE Website and user statistics; d) Cardiff's ISE Events and workshops.

[5.3] Testimony: Helen Francis, Domain Leader - Mathematics and Science, Subject Officer – Physics, WJEC. Received 20 May 2020.

[5.4] Collated use of Cardiff resources for WJEC AS & A Level Physics: a) Excerpts from WJEC and Eduqas Teaching Specifications and supporting Teacher's Guides; b) Cardiff's teacher training events and workshops.

[5.5] Statistics on WJEC and Eduqas AS and A Level exam candidates between 2016 and 2019.

[5.6] Collated *Chromoscope* evidence, including a) Google Analytics of Chromoscope, and testimonies from; b) Dr Natasha Hurley-Walker (Curtin University); c) Dr Brice Ménard (Johns Hopkins University); d) Dr Cormac Purcell (Macquarie University).

[5.7] Collated reports and press releases of Smithsonian 3D exhibit of Cassopeia A: a) CAP #22, September 2017; b) Smithsonian Press release 13 November 2013; c) Chandra Observatory press release 27 December 2017.

[5.8] Collated Public engagement, Media, and School/Educational workshops sessions since August 2013.

[5.9] "Queen awards honours to RAS Fellows". Astronomy & Geophysics, Volume 59, Issue 4, August 2018, Page 4.7.