Institution: University of Southampton		
Unit of Assessment: 09 Physics		
Title of case study: 09-02 Astronomy with US: Creative Interventions with New Audiences		
Period when the underpinning research was undertaken: August 2010 – December 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:**
Betty Lanchester	Professor	October 1969 – September 2014
Mark Sullivan	Professor	October 2012 – present
Diego Altamirano	Principal Research Fellow	October 2013 – present
Daniel Whiter	Lecturer	January 2015 – present
Robert Fear	Associate Professor	October 2014 – present
Poshak Gandhi	Associate Professor	November 2014 – present
Michael Childress	Lecturer	September 2015 – August 2020
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

The University of Southampton *Astronomy with US* programme has engaged schools and communities in 117 countries with our research. Through 1,295 innovative activities, we have sparked a fascination in our research in space environment physics and time-domain astronomy, boosting scientific knowledge and skills in participants from a wide range of ages and socioeconomic backgrounds. Our overarching goal was to *reach communities who have been traditionally less likely to engage with science.* We successfully made astronomy accessible to the visually impaired, to women and girls, at new venues, at designated widening-participation schools, to home-educated children, and to communities in Latin America with a low science capital. We have interacted with over 49,000 people face-to-face through hands-on activities and more than 75,000 people online through interactive web activities and podcast downloads.

A flagship activity that has flourished through the Covid-19 pandemic is Aurora Zoo, an online Citizen Science project that has enabled more than 6,118 budding astronomers to analyse thousands of hours of aurora footage from the Arctic, leading to 205,930 classifications of 22,443 aurora images. This led to a research paper which included 5 members of the public as co-authors.

Overall, we have created a more scientifically aware cohort, whose opinions on scientists and appreciation of the importance of research has improved by 55-75%, while their knowledge of our research topics has increased by 80%. Perhaps most importantly for *us,* more than 80% were inspired to learn more about astronomy with proven enjoyment (4.25/5) of our activities.

2. Underpinning research

Our academic staff are leading researchers in different areas of time-domain astrophysics (Sullivan, Gandhi, Altamirano and Childress) and space environment physics (Fear, Whiter and formerly Lanchester). Our strengths lie in the study of magnetic fields in the solar system, the birth and evolution of the most extreme objects in the universe (black holes and neutron stars), and how their progenitors (supernovae) can be used to understand the evolution of our Universe.

Public engagement activities related to Space Environment Physics were inspired by our research on Earth and interplanetary magnetic fields. Paper [**3.1**] explores the relationship between “transpolar arcs”, which are bizarre auroral features known since the early days of Antarctic exploration, and the “cusp spot”, which is aurora formed by direct interaction between the solar wind and magnetosphere. The interaction between the two auroral forms indicates a fundamentally new mode of interaction between the solar wind and magnetosphere. [**3.2**] is the first paper that describes the ASK instrument (Auroral Structure and Kinetics) and the science that is possible with it. The ASK instrument is a narrow field auroral imager which observes structure within both auroral forms of the type discussed in [**3.1**]. ASK provides simultaneous images of aurora in 3 different spectral bands at sub-second resolution. These images provide the data for our Citizen Science project: Aurora Zoo [**G3**].

Public engagement activities related to Extreme Universe and Dark Energy were inspired by our research in "time-domain astronomy". Paper [**3.3**] shows that rapid optical flux variations from an accreting Galactic black-hole binary are delayed with respect to X-rays by about 0.1 seconds [**G1**]. This delayed signal is related to relativistic jet ejections, probing for the first time the "base of the jet", and suggesting that the jet structure and launching physics could potentially be unified under mass-invariant models. [**3.4**] answers a lingering question about the evolution of the accretion disk structure around black holes. [**3.5**] reports on the coherent timing analysis of the 182 Hz accreting millisecond X-ray pulsar, the most accurate natural clocks in the Universe. [**3.6**] and [**3.7**] report on detailed studies of supernovae (SNe Ia), and how they were used to constrain the origin and evolution of the Universe, and the nature of dark energy [**G1**,**G2**].

3. References to the research

3.1 "The interaction between transpolar arcs and cusp spots". Fear, R. C. et al. 2015, Geophysical Research Letters https://doi.org/10.1002/2015GL066194

3.2 "Morphology and dynamics of aurora at fine scale: first results from the ASK instrument". H. Dahlgren, N. Ivchenko, J. Sullivan, B. S. Lanchester, G. Marklund, and D. Whiter, 2008, Ann. Geophysicae https://doi.org/10.5194/angeo-26-1041-2008

3.3 "An elevation of 0.1 light-seconds for the optical jet base in an accreting Galactic black hole system" Gandhi et al 2017, Nat. Astronomy. https://doi.org/10.1038/s41550-017-0273-3

3.4 "The corona contracts in a black-hole transient". Kara, Steiner, Fabian, Cackett, Uttley, Remillard, Gendreau, Altamirano et al 2019, Nature. https://doi.org/10.1038/s41586-018-0803-x

3.5 "On the 2018 Outburst of the Accreting Millisecond X-Ray Pulsar Swift J1756.9-2508 As Seen with NICER". Bult, Altamirano et al., 2018, ApJ. https://doi.org/10.3847/1538-4357/aad5e5

3.6 "First Cosmology Results using Type Ia Supernovae from the Dark Energy Survey: Constraints on Cosmological Parameters", Abbott et al. (DES Collaboration. Childress and Sullivan are co-authors), 2019, ApJ Letters. https://doi.org/10.3847/2041-8213/ab04fa

3.7 "Improved cosmological constraints from a joint analysis of the SDSS-II and SNLS supernova samples", Betoule, M., K et al. (Sullivan is co-author), 2014, A&A. https://doi.org/10.1051/0004-6361/201423413

Selected key grants:

G1 STFC Consolidated Grant, ST/R000506/1, 'Astrophysics in Southampton', Knigge (PI), Sullivan, Childress, Gandhi, et al., 2018-21, GBP1.1m

G2 European Research Council, 615929, 'Supernovae: Physics and Cosmology in the Next Decade, Sullivan (PI), 2014-19, EUR2.0m

G3 NERC Fellowship, NE/S015167/1, 'How does the aurora hear the upper atmosphere?', GBP529,819, Whiter (PI), 2019-24

4. Details of the impact

The goal of the *Astronomy with US* (University of Southampton) programme is to engage a wide audience with our research, with a particular emphasis on audiences not reached via traditional activities. This required developing new strategies and methods. All our activities are monitored for their effectiveness, reach, and significance via evaluation sheets and analysing feedback and the level of engagement. Coordination of the programme is led by astronomy public engagement leader Dr Sadie Jones and public outreach and engagement leader Dr Pearl John who are both employed by the School of Physics & Astronomy.

4.1 Space Environment Physics Programme

4.1.1 *Aurora Zoo* (2019 – present): Aurora Zoo is an online Citizen Science project conceived by Lanchester and developed and tested by Whiter. It invites participants to classify data gathered from the Auroral Structure and Kinetics (ASK) camera in Svalbard, Norway [**3.2**]. ASK has been operational since 2007 and automatically captures data whenever it is dark; by 2019 it had accumulated thousands of hours of video footage of the aurora, most of which had never been looked at. While "event studies" into specific auroral events had been investigated in detail by the researchers, higher-level statistical studies on the ASK data were best sourced from *the crowd*.

Throughout 2019 and up until Covid-19 struck, Whiter's team used a beta version of Aurora Zoo as a face-to-face public engagement tool including at the Science Museum's '*Summer of Space'*,

Glastonbury Festival and *Light Up Poole! Digital Arts Festival*. 7,319 aurorae were classified across these events, with the team finding that people of all ages could produce valid and useful data while learning about aurora and enjoying themselves [**5.1**]. Initial results were presented in August 2019 to the research community at a leading astronomy conference in Finland [**5.2**].

In early 2020 a further set of computer-based (later virtual) workshops were run by Jones to introduce pupils up to key stage 5 to Aurora Zoo and demonstrate fieldwork from a January 2020 expedition to Svalbard [**5.3**]. 978 pupils across 9 events were engaged, leading to 6,545 classifications [**5.1**].

The full version of Aurora Zoo was launched online in April 2020 on the popular *Zooniverse* citizen science platform [**5.4**]. One of the key initial findings was the identification of rare *Fragmented Aurora-like Emission* from footage dating back to 22 December 2014. This led to our first collaborative paper with the 5 citizen scientists involved in the identification (3 women). The paper was submitted to ANGEO and published pre-review in December 2020 [**5.5**].

By 31 December 2020, 6,118 citizen scientists had made 205,930 classifications of 22,443 different aurora images, writing over 1,700 comments in Aurora Zoo public forums. These demonstrated an increased knowledge of aurorae and research skills such as: data interpretation; the importance of knowing the limitations of the instruments; identification of instrumental effects that could lead to misinterpretation of the data, and critical analysis of images. The 5 citizen scientist co-authors of the paper additionally gained valuable experience of the scientific publishing process. Aurora Zoo also inspired science fiction writer Rosie Oliver to include aurorae in her up-coming book. [**5.1**]

4.1.2 *Planeterrella* demonstrations (2017-2019): The Planeterrella is an interactive simulation using plasma and magnetic fields to mimic the interaction between the solar wind and magnetosphere in the formation of aurorae described by Fear [**3.1**]. A team of 8 researchers toured the Planeterrella to 54 local schools, several science and arts festivals (e.g. *Stargazing Live 2017* and *2018*, *World Science Week 2017* at Winchester Science Centre) and alternative venues.

Over 2017-2019 the team engaged 4,074 people face-to-face: 1,837 pupils and 60 teachers at 54 schools, and 2,177 members of the public at 23 events. Gender balance was a key aim of the programme, with 50% of students and 52% of the public being women or girls. 86% increase in knowledge of aurorae (compared to 77% for schools) with 69% showing an increase in their positive opinions about science and science careers (45% for schools). 78% of the public had an improved opinion of scientists (50% for schools) and 85% had a more positive opinion of the importance of auroral research (62% for schools) [**5.6**].

4.2 Engagement with the Extreme Universe and the Dark Energy Survey (DES)

4.2.1 The *Soton Astrodome* Mobile Planetarium (2014-2020): The Soton Astrodome is an advanced inflatable planetarium that allows up to 35 people to gain a fully immersive digital experience at any venue with 7x7m of floor space and 3.3m of height. Each 45 minute show includes an introduction by academics to themselves and their research, followed by animated content tailored to the audience. A Q&A session with the researchers concludes the show.

From January 2014 to March 2020, 28,571 people were engaged during 1,125 planetarium shows covering black holes [**3.3**, **3.4**], dark energy [**3.6**] and supernovae research [**3.7**]. Of that number, 8,128 were at public venues not usually used for science communication, including *Peppa Pig World* in the New Forest, and *City Art Gallery* and *Sea City Museum* in Southampton. 19,909 pupils and 534 teachers were engaged during 168 school visits to 87 schools. 30% of the schools were designated widening participation (WP), defined as those registering at least 17% of pupils entitled to free school meals. [**5.7**]

To gauge the significance of the shows for the pupils, 68 year-5 students from a local primary school fed back what they learned in a planetarium show in July 2019. Overall, 50% of students stated they had learned about aurora; stars and their life cycle; black holes; and/or galaxies**.** 14 Discovery level CREST Awards were earned by local home-educated students (aged 4-13 years). CREST is a British Science Association scheme to inspire young people and let them think and behave like scientists, with the awards being aligned to the national curriculum and providing a reward system for the students. Our CREST Awards went to those who took part in DES workshops, in total leading the pupils to make 5 films for the planetarium and 11 dark energy “research posters” based on our research [**3.6**, **3.7**] [**5.7**].

The shows also had an impact on teachers. Of 17 primary/secondary school teachers surveyed:

- 100% rated the shows 10/10 for enjoyment;
- 77% found the activities to be highly relevant to the school curriculum;
- 71% said that their astronomy knowledge had increased 'significantly'.

In response to the open-ended question '*what did you think of the show?*' teachers responded that we gave them enjoyable, inspiring experiences they would otherwise not have access to, as well as knowledge that they had passed on to their students. [**5.7**]

4.2.2 *Astro-sonification* for audiences with vision impairments (2019): In collaboration with visually impaired astronomer Dr Wanda Diaz-Merced (South Africa) and Dr Johanna Casado (Argentina), Gandhi developed sonification software that enables telescope data streams used in our black hole research [**3.3**, **3.4**] to be turned into sound using a variety of tones, instruments, tempos and notes. In 2019, Gandhi and Casado led a focus group with 4 members of a local visually impaired community organisation, *Southampton Sight*, to improve the software. The group reported an enjoyable experience (9/10) which raised their confidence and provided them new research skills (9/10): *"Taking part in this activity has really raised my self-confidence"; "I've encouraged other friends who are vision impaired to take part"; "I have learned a lot of new skills."* All were willing to engage with further projects with Southampton [**5.8**]. One of the participants wrote a *Southampton Sight* guest blog post, concluding that "*astronomy isn't the only science with complex data, so I think [Casado] may be opening up [a] whole new world for us. I hope [it] was as useful for her as it was fun for me*. [**5.9**]

4.2.3 *Spanish Speakers' engagement programme* (2018-2020): A goal of our programme was to engage with global communities with a lower science capital, for example no regional top-100 physics departments, where high-profile astronomy research may not be represented in local outreach activities. Altamirano engaged an international Spanish-speaking audience, recruited via a social media campaign, with black hole and neutron star research [**3.3**-**3.5**] in online engagements including remote talks for 345 pupils (57% girls) in 5 schools in Argentina, Mexico, Ecuador and Peru, and through podcasts (57,466 unique downloads from 105 countries, including broadcasts on local radio in Latin-America) of research lectures in Spanish [**5.10**]. In response to an online survey of 157 podcast listeners of the neutron star podcast, 99% of those who responded said they had learned something new and 95% indicated that they wanted to learn more by requesting an additional talk on black holes. Translated comments include "*I realised, within my human brain limitations, of the scales and magnitudes of a neutron star*"; "*Everything was very interesting, I love to understand what is happening out there. But the most impressive, which seems science fiction to me, is the scientific method*". Altamirano served as an astronomer role model for Latin American audiences, raising aspirations and confidence in those from marginalised groups: "*I never thought Latin Americans could become world-leading scientists."* (16-year-old pupil from a Peruvian secondary school after the Q&A session) [**5.10**]. The success of the first podcast was followed by a second together with an online sci-art competition based on our black hole research. We received 270 artwork entries from 165 amateur artists from 13 different countries. A selection of the artwork was used for a promotional campaign on Facebook that, together with direct interaction, attracted 808,000 unique users to the page, of which around 20,000 actively engaged with the posts (commenting/sharing with friends or groups). [**5.10**]

4.2.4 *AstroAirport* (2016): Funded by a STFC PE small award, in February half-term 2016, a team of four researchers staffed a stand in the departure lounge at Southampton Airport. The stand included demonstrations (e.g. Hoberman Spheres) to engage departure lounge passengers with the concept of exploding and collapsing stars [**3.5**]. 1,457 passengers engaged with our research. Of 59 survey respondents:

- 29% said *"this was the first science event they had ever attended"*;
- 92% of respondents learned something about our research;
- 100% could correctly say what a supernova was;
- 68% rated the engagement as 'extremely enjoyable'.

In a follow-up form one month later, 78% could recall what they had learned about our research and 89% said they had a more positive opinion of scientists as a result of the interaction [**5.11**].

4.2.5 *#SotonAstroArt* (2017-2020): Our award-winning Sci-Art project consists of activities connecting art and science and engaged 15,270 people with our DES/SN research [**3.6**]. Audiences included:

- 97 emerging artists, invited through social media and artist networks, and their audiences at 14 exhibitions (>300 people);
- 3,708 children and parents at arts workshops in festivals and community spaces (*Human Worlds Festival* 2017-2020, *The Photon Shop* 2019-2020, *Southampton Libraries* 2019), and 250 who received art activity packs during lockdown (2020);
- on-line audiences totalling 11,492 people (from 47 countries), including media and social media users, those who downloaded web-based resources, viewed videos, visited our websites and took part in our art competition;
- 446 professional astronomy/physics communicators from two conferences (2018) [**5.12**].

The impact of the project included an 11% change in perception of artists' understanding of their position in the Universe with 9% inspired to create new works and an 8% increased understanding of astrophysics concepts [see testimonials analysed in **5.12**]. Around 990 artworks were made at 13 family workshops leading to a 25% knowledge increase about supernova among participants. A highlight of the festival engagement was *The Photon Shop* at *Light Up Poole! Digital Arts Festival*, with an underserved community in a zone of socioeconomic deprivation. From ~2,000 visitors, we obtained feedback from 22 family groups: 75% agreed (45%), or strongly agreed (30%) that: "*I am more likely to study Physics or recommend studying Physics to a friend/family member*" as a result of visiting *The Photon Shop*. 95% stated a positive attitude change – they agreed (43%), or strongly agreed (52%) that *"It inspired me to find out more about Physics"* [**5.12**].

4.2.6 *Black Hole Talks* for schools and the public (2014-2020): Over 2014-2020, Altamirano and Jones, together with other astronomy staff members, delivered talks to 4,117 people (schools and the public) on compact objects and black holes, including research methods used in **3.3**, **3.4** and **3.5**. Curriculum-specific content included multiwavelength astronomy, radio interferometry and the importance of resolution.

534 evaluations were collected from 57 of the events at schools. Students reported a mean enjoyment of 4.1/5 and a 17% increase in their interest in black hole research. In addition, when asked to rate the amount that they had learned during the talk, 71% of GCSE students and 91% of A-level students surveyed increased their knowledge, and 77% of A-level students stated they were likely to do further reading on Black Hole research following the talk. Analysis of 730 evaluations from 16 public events led to similar results, with a mean enjoyment of 4.7/5, 31% increase of interest, and self-evaluation of learning of 4.1/5.

Overall, 59% of A-level students and 40% of the public displayed an advanced understanding of black hole concepts, such as the existence of astrophysical jets, and research-specific topics including how astrophysical jets are studied. [**5.13**]

5. Sources to corroborate the impact

5.1 Evaluation report: Aurora Zoo

5.2 19th International EISCAT Symposium conference abstract

5.3 Jones' talk on January 2020 Svalbard expedition, 3/12/2020 https://youtu.be/m5DCmVmDoK4

5.4 https://www.zooniverse.org/projects/dwhiter/aurora-zoo

5.5 Whiter et al., submitted December 2020 https://doi.org/10.5194/angeo-2020-95

5.6 Evaluation report: Planeterrella

5.7 Evaluation report: Soton Astrodome

5.8 Evaluation report: Astro-sonification

5.9 Southampton Sight blog post http://southamptonsight.org.uk/kates-blog/looking-at-stars-with-our-ears-making-astronomy-accessible-to-the-visually-impaired-community

5.10 Evaluation report: Spanish Speakers' engagement programme

5.11 Evaluation report: AstroAirport

5.12 Evaluation report: #SotonAstroArt

5.13 Evaluation report: Black Hole Talks