Institution: Keele University

Unit of Assessment: UoA9 Physics

Title of case study: The Stardome: enhancing science engagement and Science Capital with exoplanet research

Period when the underpinning research was undertaken: 2004 to 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:
Prof Coel Hellier	Professor	1994 - present
Prof Rob Jeffries	Professor	1995 - present
Prof Raphael Hirschi	Professor	2007 - present
Dr Pierre Maxted	Reader	2001 - present
Dr Barry Smalley	Senior Lecturer	1994 - present

Period when the claimed impact occurred: August 2013 to December 2020

Is this case study continued from a case study submitted in 2014? No

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

Keele University research on the discovery of transiting exoplanets has been developed into a successful and sustained programme of outreach for schools delivered through the "Stardome" – a mobile "exoplanetarium" that takes Keele's research directly into schools and colleges. This innovative science-communication programme has engaged more than 30,000 learners in the current REF period, many from disadvantaged communities. By raising awareness of exoplanetary science, it has enhanced science engagement and Science Capital, enthused children and teachers and has underpinned the teaching of Key Stage topics in the school curriculum relating to the Solar System. The impact of the Stardome has been recognised through the award of the 2015 Times Higher Education Award for the "Widening Participation or Outreach Initiative of the Year", while it now plays an important role in the externally funded, regional Higher Horizons+ widening-participation initiative.

2. Underpinning research (indicative maximum 500 words)

Following the discovery of the first known transiting exoplanet (Charbonneau et al. 2000), Keele University was one of the first UK groups to develop wide-area searches for transiting exoplanets. The WASP consortium (Wide-Area Search for Planets) got the Northern facility "SuperWASP" on-sky from 2004, followed by its Southern counterpart, the Keele-led WASP-South, from 2006. With the publication of the first Keele-led exoplanet discoveries (WASP-4b, Wilson et al. 2008; WASP-5b, Anderson et al. 2008; WASP-7b, Hellier et al. 2009) we quickly realised that here was science that appealed directly and readily to the interests of schoolchildren. Not only do they have an immediate fascination with space and planets (since, after all, they live on one), and are naturally curious about big questions such as life elsewhere in the galaxy, but basic questions such as "How big is it?", "What is the orbital period?", "How hot is it?", "Does it have an atmosphere?", "Could life exist there?", are questions that children can readily relate to. Thus, the WASP exoplanet discoveries provide a rare example of a topic that is both cutting-edge science but can also be assimilated by school children. For example, when WASP-18b was discovered, as the first-known planet with an orbital period of less than one day, and so producing the strongest star/planet tidal interaction of any known system, this was both of sufficient scientific interest to make the front cover of Nature (Hellier et al. 2009; [**3.1**]) but could also be described to schoolchildren as a planet so close to its star that its orbital period, its "year", is less than the time it takes Earth to spin once.

Such exoplanet discoveries could then be tied readily to Key Stage topics in the school curriculum about how our Solar System works (e.g., KS2 – year 5: Earth and Space), including the motions of the Moon and planets. Hence the Keele astrophysics group started its "Stardome" – a mobile planetarium that could take Keele's exoplanet science, *directly into* local schools and colleges. Activities related to Keele's exoplanet discoveries, and planet formation, could then be combined with a wider understanding of stars and their life cycles, tying in to Keele's research on star formation (e.g., Jeffries et al. 2001; [**3.5**]), and on the origin of the chemical elements and the death of massive stars (e.g., Pignatari et al. 2011; [**3.6**]).

The Keele-led WASP-South has gone on to be the most successful of the ground-based transit surveys. Together with our collaborators and our Northern-counterpart survey (principally, the Universities of St. Andrews, Warwick, Leicester and Queen's University Belfast; with follow-up collaborations with the Geneva Observatory, Observatory de Haute Provence, and the University of Liege group who operate the TRAPPIST photometer), we have now discovered nearly 200 gas-giant exoplanets (with the announcement of WASP-192b in 2020). Since 2000 there have been over 100 Keele-led, refereed-journal papers about exoplanets, principally announcements of the WASP exoplanet discoveries, and another 100 Keele-led, refereed papers about the formation and life cycles of stars. Notable exoplanet discoveries from the Keele-led WASP-South survey, that can translate directly into Stardome presentations, include: WASP-8b (Queloz et al. 2010; [**3.2**]), the first hot-Jupiter found in a highly eccentric orbit; WASP-17b (Anderson et al. 2010; [**3.3**]), the first hot-Jupiter found in a retrograde orbit; WASP-18b (Hellier et al. 2009; [**3.1**]), with the strongest star-planet tidal interaction; WASP-19b (Hebb et al. 2010), the hot-Jupiter with the shortest-known orbital period; WASP-30b (Anderson et al. 2010), the first known transiting brown dwarf; WASP-43b (Hellier et al. 2011; [**3.4**]), the closest-orbiting hot-Jupiter; WASP-47b (Hellier et al. 2012), the first hot Jupiter found with small, rocky companion planets; WASP-76b (West et al. 2013), a planet that has rain of droplets of iron; WASP-80b (Triaud et al. 2013), the first hot-Jupiter found transiting a red-dwarf star; WASP-96b (Hellier et al. 2013), the first planet shown to have clear skies; WASP-121b (Delrez et al. 2015), distorted by its star's gravity into an egg shape; WASP-166b (Hellier et al. 2018), the lowest-mass of the WASP planets, and WASP-189 (Anderson et al. 2018), the brightest star known to be transited by a hot-Jupiter planet.

3. References to the research (indicative maximum of six references)

Example papers are:

3.1 Hellier, C. et al. (2009) Nature, Volume 460, Issue 7259, 1098, An *orbital period of 0.94 days for the hot-Jupiter planet WASP-18b (*166 citations. Citation data are taken from NASA ADS).
3.2. Queloz, D. et al. (2010) Astronomy and Astrophysics, Volume 517, L1, 4. *WASP-8b: a retrograde transiting planet in a multiple system (*105 citations).
3.3 Anderson, D. R. et al. (2010) The Astrophysical Journal, Volume 709, 159, WASP*-17b: An Ultra-Low-Density Planet in a Probable Retrograde Orbit (*146 citations).
3.4 Hellier, C. et al. (2011) Astronomy & Astrophysics, Volume 535, L7, 5, *WASP-43b: the closest-orbiting hot Jupiter (99* citations).
3.5 Jeffries, R. D., Thurston, M. R. & Hambly, N. C. (2001). Astronomy and Astrophysics, Volume 375, 863-889 Photometry *and membership for low mass stars in the young open cluster NGC* 2516 (92 citations).
3.6 Pignatari, M. et al. (2011), Astrophysical Journal Letters, Volume 687, L95 *The s-Process in Massive Stars at Low Metallicity: The Effect of Primary 14N from Fast Rotating* Stars (120 citations).

Keele's exoplanet and stellar research was supported by STFC grants to Keele:
2006: £971,000, "Stellar Astrophysics at Keele".
2008: £440,000, "Project support for the Wide Area Search for Planets".
2009: £1485,000, "Astrophysics at Keele".
2011: £34,000, "Project support for WASP (Supplement)".
2012: £1049,000, "Astrophysics at Keele".
2015: £1167,000, "Astrophysics at Keele".

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

Keele's "Stardome" is a mobile planetarium specifically designed to take cutting-edge research directly into local schools and colleges (**5.8**). Presentations pitched at school children are custom created by Keele academics. The presentations tie Keele's exoplanet discoveries to Key Stage topics in the school curriculum about how our Solar System works, including discussion of the motions of the Moon and planets, and ideas about heat, light, and atmospheres, and also aspects of life sciences and evolutionary biology. The Stardome is a 360-degree fully immersive, multi-sensory, inflatable planetarium that can be taken into schools and other venues, and which seats a class of children in one go. A typical 45-minute Stardome session (of which there are usually 5-8 in a school day) begins with blasting off into space, followed by a tour of the objects within the Solar System, before exploring a selection of WASP extra-solar planets (examples listed in Sections 2 and 3 above), discussing how they were discovered, their orbits, size, masses and compositions, and their potential to support life.

Stardome visits are focused on areas of high socio-economic deprivation, with academic staff, assisted by Keele undergraduate students, delivering a multimedia experience to inspire and enthuse children, teachers and future outreach practitioners alike. During the REF period (August 2013 to December 2020) more than 30,000 school children and 500 teachers from over 140 schools have benefited from sessions in the Stardome (**5.1**).

The Stardome originated from a 2011 "Science in Society" grant from the STFC ("An Exoplanetarium for Schools", PI Prof Rob Jeffries, £6850), combined with funding from the Keele alumni fund. From there the programme expanded to involve the National Network for Collaborative Outreach (NNCO), Harper Adams University, the University of Wolverhampton and Staffordshire University. In 2016, the Ogden Trust funded an Outreach Officer, Scott Walker, who expanded the delivery of Stardome sessions, while the Higher Horizons+ collaboration (part of the government-funded Uni Connect Programme), further invested in and extended the Stardome's outreach activities from 2017. In recent years the reach of the Stardome has expanded to areas including Lancashire, Gloucestershire and Herefordshire. The development and delivery of Stardome sessions has benefited from the continued close involvement of astrophysics academic staff and PhD students (e.g., Prof Jeffries has delivered more than 50 Stardome days in schools during this REF period). More than 30 Keele students, including those from other disciplines, have been trained in Stardome delivery and as student ambassadors, with a number of them deciding to embark on a career in teaching as a result.

Reaching New Audiences

From the outset, a key aim of the Stardome programme was to address the limited engagement of local young people with STEM subjects and Higher Education (HE). The Stardome, as part of Higher Horizons+ Uni Connect programme, focuses upon areas with an unexplained gap in Higher Education participation. This supports the people component of the Industrial Strategy white paper (p. 97, Industrial Strategy: Building a Britain fit for the future, BEIS, 2017). Communities in Keele's local environment of Stoke-on-Trent are under-represented within higher education, with only 15.5% of Stoke's population having a HE qualification compared to the national average of 27.4% (UK census, 2011), while 60% of adults have a reading age of under 11 (Stoke.gov, 2016). Across Stoke-on-Trent and the North West of England, 43 schools in the most socio-economically disadvantaged areas, according to Indices of Deprivation data, have engaged with the Stardome (**5.1**). In total, over the REF period, the Stardome programme has interacted with 144 schools, over 500 teachers, over 30,000 children, and numerous other community groups and events. Dozens of schools have arranged repeat visits, for example Burnwood Community Primary School (Stoke-on-Trent, 59.6% free school meals) and Grace Academy Darlaston (Walsall, 58.0% free school meals) (**5.1**).

Importantly, the Stardome also reaches audiences with learning difficulties who would often struggle to access space and exoplanet research. Sessions were delivered at all the local SEN (special education needs) schools. A manager at Caudwell Children relayed the following comment from a parent of a child attending a Stardome session "We had a fabulous time thank

you so much. [….] has come home super inspired. He loved the whole experience, I think because it was so immersive in the dome and to have the guided talk from someone who had so much knowledge and enthusiasm really added to it." (**5.2**) It is also clear that the fully immersive environment plays a key role in supporting the young people's engagement with the material "My class were so engaged and inspired by this session […..] It has genuinely improved their engagement" (**5.3**).

The impact of the Stardome has been acknowledged at a national level through it being awarded the 2015 Times Higher Education Award for 'Widening Participation or Outreach Initiative of the Year' (**5.4**). The judges reported the project made excellent use of "astronomy as a gateway into physics" and show-cased "the work of a university to a wider group of people" (**5.4**).

Widening access to Higher Education

The Stardome has made an important contribution in increasing the most socio-economically disadvantaged learners enrolling at Keele with the university performing 7.2% above its benchmark in 2018/19 (**5.6**). Evaluations, completed by 4316 children immediately after participating in a Stardome session, show that 70% had learned what an exoplanet is, 79% were, as a result, more interested in science. The evaluation also found that 50% of young people aged 14 and over were then considering studying a science subject at University (**5.7**). Higher Horizons+ believe that the Stardome programme, particularly with its extension in Birmingham, has widened participation not just at Keele University, but across the Higher Education (HE) sector (**5.5**).

Enhancing Science Capital

The science capital teaching approach [see Godec, S, King, H, Archer, L, (2017) The Science Capital Teaching Approach: engaging students with science, promoting social justice. London: University College London] has been adopted by the Stardome programme and is designed to enable audiences to find more meaning and relevance in science and, as a result, engage more with the subject. As described by a teacher, the Stardome brings "the stars into the classroom ... [and] is what really fires their imagination and gives them that enthusiasm to go on to become future scientists" (**5.8**).

The impact on teachers has been confirmed by post-event surveys carried out in 2016-2019 (**5.3**). Of 81 respondents, 75 said they were "very satisfied" with the Stardome experience. The reactions of teachers included "Absolutely amazing experience for the children and adults. We were blown away"; "The children, and staff, thoroughly enjoyed the space dome and were completely in awe of the whole experience"; "The amount of enthusiasm generated from the Stardome across the school was phenomenal..."; "It was BRILLIANT! I was in awe and so were the children! Scott [former PhD student from the school of Chemical and Physical Sciences and now Ogden Trust Outreach Officer who delivered more than 100 Stardome days] was so knowledgeable and engaging", and many more. Success can also be judged by repeat requests for Stardome visits to schools. 79/81 said they would book the Stardome again (**5.3**) and many did. A teacher from Blythe Bridge High school commented, "We have used the Stardome for the last 6 years as part of the Year 5 Physics Festival. The knowledge & understanding the students get from this opportunity are first class".

100% of the teachers surveyed said they thought that children had benefited from the Stardome sessions (**5.3**) with comments such as "Fantastic resource and children learnt a lot.". 65% of them identified specific topics that the children learnt something new about. These include exoplanets (and the search for them), Goldilocks Zone (life needing water), evolution of life, alien life, life forms, stars, planets and their moons. Several teachers said they learnt something new too, which gives them more in-depth knowledge and confidence about teaching this topic to children. In another post-event survey asking 24 teachers in 2019-2020 whether the pupils were more interested in STEM subjects since taking part in the Stardome session, 83% of the teachers answered yes (**5.9**). Comments from teachers include: "Greater enthusiasm for science", "Children including planets names in their work and conversations" and "Children went home to research questions generated from the Stardome."

The Stardome's long-term impact upon learning is clear from longitudinal teacher surveys, which are undertaken a minimum of 12 months post event, reporting an enhanced student self-efficacy, confidence, and willingness to engage in their learning (**5.5**). In addition, the Stardome programme provides the gateway for teachers, particularly those in primary schools who are typically non-science specialists, to develop a professional physics network.

Overall, the Stardome provided the children and staff with a memorable and exciting experience. More importantly, the Stardome successfully consolidated and extended children's knowledge of space, inspiring them to find out more about the topic and STEM subjects in general.

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

5.1 Stardome summary table of visitor engagements

5.2 Organizational and individual endorsements of Stardome

5.3 Post-event educator evaluations of the Stardome collected by the Ogden Trust (2016 - 2019)

5.4 Times Higher Award (2015) programme: https://www.timeshighereducation.com/news/times-higher-education-awards-2015-results-announced

5.5 Head of Higher Horizons+ testimonial

5.6 HESA data (2015 - 2019) Widening participation: UK Performance Indicators

5.7 Immediate post event student evaluation of Stardome (2013 - 2020)

5.8 Public engagement video including teacher and pupil testimonial (*download also held within Keele's repository*)

5.9 Post-event survey of teachers (2019-2020)