Institution: Keele University		
Unit of Assessment: UoA9 Physics		
Title of case study: Worldwide impact of exoplanet science underpinned by the discovery of the WASP extrasolar planets.		
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
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? N		

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

Exoplanet science has burst into the public sphere, with few scientific topics connecting as readily to an interested public. Google alerts show the worldwide media writing about exoplanets every day. Much of this derives from the WASP exoplanets discovered by Keele, which are often the best planets to study. During the REF period the worldwide media have produced over 2000 articles talking about a WASP exoplanet. Major organisations (NASA, ESA, ESO) regularly put out press releases about Keele-discovered WASP exoplanets, repeatedly resulting in widespread dissemination. During 2019 a "Google alert" about WASP exoplanets triggered on 95 different days. Third-party content creators regularly expound on WASP exoplanets to large audiences. Writers across the world are writing about exoplanet science based on exoplanets discovered by the Keele-led WASP-South survey.

2. Underpinning research (indicative maximum 500 words)

Ours is the first generation to know that almost all the stars in the night sky are orbited by planetary systems. The public interest in exoplanets is huge. A Google alert for “exoplanets” news items triggers nearly every day, usually with multiple items. The exoplanets that are best for detailed study are the transiting exoplanets (enabling masses, radii, densities and hence estimates of compositions) orbiting bright host stars (enabling atmospheric characterisation). A large fraction of these are the WASP exoplanets discovered by Keele.

The WASP project (Wide Angle Search for Planets) has now found 192 exoplanets transiting bright stars ($V < 13$), making it the most successful of the ground-based transit surveys. While NASA’s TESS satellite looks for small, rocky planets, WASP has already found most of the gas giants that are most favourable for further study. Of the 100 best exoplanets for atmospheric characterisation (bright host stars; large transit depths; large atmospheric scale-heights) half are WASP discoveries. Half of the gas giants targeted for atmospheric characterisation by the *Hubble Space Telescope* are WASP planets. The $10-billion *James Webb Space Telescope* (launch 2021) was built to characterise exoplanet atmospheres as one of four major science themes. Seven of the twelve transiting exoplanets chosen for its *Early Release Science* program are WASP planets.

WASP is a collaboration between: (1) Keele University, who built and operated the WASP-South transit-search camera array, and led planet discovery in the Southern Hemisphere, (2) Queen’s University Belfast and the University of Warwick, who ran the Northern counterpart, SuperWASP-North, (3) St. Andrews University, who were responsible for some of the WASP software, and (4) the follow-up teams (for which Keele/WASP-South collaborated with the Geneva Observatory team led by Didier Queloz, who operated the Euler/CORALIE spectrograph, and the University of Liege with their TRAPPIST photometer).

The Keele-led WASP-South has discovered 119 exoplanets, plus a further 39 in the equatorial strip jointly with WASP-North (while 34 WASP planets are Northern finds). Keele is the lead WASP institute for the Southern planets, but we are also co-authors and co-discoverers on all the Northern finds, having contributed software, data analysis and expertise. Keele University has lead-authored more discovery papers for exoplanets transiting bright stars ($V < 12$) than any institute worldwide; and many WASP-South planets (WASP-17b, WASP-18b, WASP-19b, WASP-

43b, the WASP-47 system, WASP-96b, WASP-103b, WASP-107b, WASP-121b, WASP-189b, etc.) are among the most important exoplanets for ongoing detailed study.

From 2007 (discovery of WASP-1b) to 2020 (WASP-192b), the WASP project has produced 170 refereed papers that have been cited over 8000 times (data from NASA's ADS). Such is the interest in studying WASP planets, however, that by far the majority of papers about WASP planets are now by other research teams worldwide: there have now been 630 refereed papers about WASP planets, cited over 20,000 times (ADS data).

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

Keele academics (Hellier, Maxted, Smalley) have authored 170 refereed-journal papers related to WASP (2006 to 2020), now cited over 8000 times. Examples include:

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, data from ADS).
Queloz, D. et al (2010) Astronomy and Astrophysics, Volume 517, L1, 4. *WASP-8b: a retrograde transiting planet in a multiple system (*105 citations).
Anderson, D. R. et al (2010) The Astrophysical Journal, Volume 709, 159, WASP-*17b: An Ultra-Low-Density Planet in a Probable Retrograde Orbit (*147 citations).
Triaud, A. et al (2010) Astronomy and Astrophysics, Volume 524, A25, 22*, Spin-orbit angle measurements for six southern transiting planets. New insights into the dynamical origins of hot Jupiters* (352 citations).
Hellier, C. et al (2011) Astronomy & Astrophysics, Volume 535, L7, 5, *WASP-43b: the closest-orbiting hot Jupiter (*100 citations).
Hellier, C. et al (2012) Monthly Notices of the Royal Astron. Soc, Vol 426, 739, Seven *transiting hot Jupiters from WASP-South, Euler and TRAPPIST: WASP-47b, WASP-55b, WASP-61b, WASP-62b, WASP-63b, WASP-66b and WASP-67b* (100 citations).
WASP-South was supported by 6 STFC grants to Keele (all PI Hellier) including:
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)

The discovery of the WASP exoplanets has led to a profusion of studies of those planets, resulting in widespread and sustained media activity reporting exoplanet science, and thus impact on the public in many countries worldwide. Some of this media activity originates from Keele's own press releases, but, as the WASP exoplanets get studied by astronomers worldwide, most WASP-related media activity is now originated by others, featuring exoplanet science that was underpinned by Keele's research in the sense that the discovery of a planet is the starting point for all subsequent study of that planet.

A **Google alert** for media activity mentioning a WASP exoplanet triggered on 95 different days in 2019 and 92 different days in 2020, with each such trigger typically reporting multiple media items [1]. Thus, major media outlets are writing articles featuring a WASP exoplanet at an average rate of once a day. This level of interest has been rising over the REF period (2014 totalled Goggle-alert triggers on 21 different days).

The fact that exoplanets are designated after the discovery team means that one can readily link media activity to the underpinning discovery, and thus the extensive third-party dissemination and outreach related to on-going study of the WASP exoplanets qualifies as REF impact deriving from the WASP discovery programme (while, in addition to the media activity featuring specific WASP planets, there is also a great deal of generic media content grouping the WASP exoplanets with those from other teams, an example being a NASA video celebrating the discovery of 4000 exoplanets, with 493,000 views [2]).

A NASA Tweet about exoplanet WASP-12b (@NASA has 26 million followers) gained 3700 "retweets" and 9100 "likes" in 24 hours [3], and led to a multimedia presentation on NASA's outreach site (comments included: "*That's amazing!", "I wish we had more budget allocated to NASA*", "*This is a nuts exoplanet*" and "*I wish NASA had a third of the military's funding. Imagine the possibilities!*"). Similarly, a NASA Tweet about WASP-39b gained 1700 retweets and 6500 likes ("*Wonderful … Love learning new things!*"). Another NASA Tweet of a video featuring a *Hubble* observation of WASP-107b has had 280,000 views with 3200 retweets and 10,700 likes (comment: "*Awesome, thanks Hubble!*"). A NASA Tweet about WASP-121b had 600 retweets and 1600 "likes". Remarkably, in a recent Twitter search for "@NASAHubble exoplanet", 8 of the top 15 Tweets were about a WASP planet. The impact goes well beyond the English language; as just one example, a Tweet about WASP-76b in the Thai language gained 4000 retweets [3].

YouTube videos [4] by third-party content creators can reach wide audiences (we mention here only videos exceeding a million views). A video from 2015, "10 strangest planets", featuring WASP-12b & WASP-17b, has had 17,400,000 views with 233,000 "likes" and 30,600 comments ("*this is the first video that got me into astronomy and anything space related*"); a second video from 2015, also featuring WASP-12b & WASP-17b has had 8,400,000 views with 114,000 likes and 12,400 comments ("*I wonder if species from other planets are asking themselves whether there is life on Earth?*"). A 2017 video featuring a "virtual reality" tour of WASP-121b has had 12,000,000 views with 175,000 likes and 5000 comments ("*what if aliens are different and don't need water or oxygen?*"). A 2017 video featuring the WASP ringed planet has had 1,200,000 views. A 2018 video featuring a WASP planet has had 3,400,000 views with 38,000 likes and 3000 comments ("*How do they know this if the planets are so far away? What kinds of telescope do they use?*"). A recent video featuring WASP-12b has had 1,230,000 views in less than 5 months ("*I'm learning more watching these in quarantine than actually going to school*"). Again, the impact extends beyond the English-speaking world, with Spanish-language videos on the "strangest planets" theme (and featuring a WASP planet), having had views of 4,225,000 (2017 video), 3,830,000 (2015 video), 3,880,000 (2016 video), 1,768,000 (2017 video) and 1,320,000 (2020 video), where a total of 258,000 "likes" and 16,800 comments show engagement. A 2017 Russian-language video featuring WASP-43b has had 5,100,000 views (114,000 likes & 3700 comments). There are similar videos featuring at least one WASP planet, each with views in the range 1 million to 4 million (and totalling over 12,000 "comments"), in French, Portuguese, Chinese, Indonesian & Japanese.

Press releases about WASP planets are documented on our WASP outreach website (https://wasp-planets.net/ now averaging a hundred "hits" a day, and supported by a @WASPplanets Twitter account)**.** Press releases from NASA, ESA, ESO & *Nature* usually gain worldwide attention. For example, an ESA press release about WASP-189b (being the "first science results'' from the CHEOPS satellite; Sept 2020) resulted (from a Google search) in 50 English-language articles in the UK, USA, Canada and Australia, and also articles in German (Germany, Austria), French (France, Belgium, Switzerland), Italian, Spanish, Portuguese (Portugal, Brazil), Dutch, Finnish, Slovakian, Hungarian, Greek, Polish, Russian, Latvian, Turkish, Persian, Korean, Indonesian, Vietnamese and Chinese.

Another typical example was a press release [5] in March 2020 by ESO in conjunction with *Nature* about observations of WASP-76b with the new ESPRESSO spectrograph on the VLT. The WASP-South planet WASP-76b is an ultra-hot Jupiter whose discovery we announced in 2013. The ESPRESSO observations revealed that iron in WASP-76b's atmosphere is vapourised on the hot day-side of the planet, to condense on the cooler night-side, thus falling as "iron rain" at dusk. A day after the press release, Google searches showed coverage on 54 English-language news websites (including, in the UK, coverage on BBC News, and in the Guardian, Independent, The Times, Telegraph, Sun, Daily Mail, Express, Metro, plus, in the US, CNN, Newsweek, Fox News, NBC News, plus media in Ottawa, Canberra, etc). In addition, there were 22 articles in the Spanish media, 12 in French, 11 in German, 8 in Chinese, 7 in Dutch, and over 30 in 11 other languages. Twitter activity by accounts with millions of followers (@BBCNews, @nature, etc) and many others then led to over 5000 Tweets and Retweets mentioning WASP-76b. Indeed, after press reports of "raining metal", a heavy-metal band adopted the name "WASP-76b" [5a].

We track **media activity** using Google alerts (documenting it on our wasp-planets.net website). Listing only press releases taken up by major media outlets, bursts of media activity within the REF period include (each with coverage on typically 50 news and science websites worldwide, often in multiple languages): “Subtle signs of water on hazy worlds” WASP-12b, WASP-17b, WASP-19b (NASA/STSci/ESA), “X-ray view of WASP-18b” (NASA/GSFC), “Cousin planets of WASP-94” (Geneva/ESO), “Changing face of WASP-43b” (NASA/STSci/ESA), “Giant ring system” around WASP exoplanet (Leiden Obs), “Sunscreen layer in WASP-33b” (NASA/GSFC), “Cloudy days on exoplanets” (NASA/JPL), “Stratosphere of WASP-121b” (NASA), “Nature vs nurture” WASP-67b & HAT-P-38b (NASA), “WASP-12b: blistering, pitch-black planet” (NASA), “Titanium oxide in WASP-19b” (ESO/VLT), “Smothering stratosphere of WASP-18b” (NASA/GSFC/JPL), “Spectrum of WASP-39b” (NASA JPL, Hubble/ESA), “WASP-104b darker than charcoal” (New Scientist), “Hubble detects helium in … WASP-107b” (Nature, NASA/STSci/ESA), “Clear skies of WASP-96b” (Nature/Exeter), “Metals in atmosphere of WASP-127b” (Cambridge/IAC), “Water destroyed then reborn”, WASP-103b, WASP-121b (NASA JPL/Hubble/Spitzer), “Aluminium oxide in WASP-33b” (IAC), “Metals streaming from WASP-121b” (NASA/STSci), “Sapphires and rubies in the sky”, WASP-47e (Universities of Cambridge & Zurich), “Helium in WASP-69b” (IAC/Exeter), “Dark sides of exoplanets” (McGill Univ; 7 of 12 planets studied were WASP), “Yellow skies of WASP-79b” (NASA/Hubble/Johns Hopkins), “Water common in exoplanets” (Cambridge University; 11 of 19 planets studied were WASP), and “WASP-12b orbital decay” (Princeton).

The greatest coverage for a third-party press release was for a 2015 NASA/Hubble press release on the presence of water in the atmospheres of 10 planets (6 of them WASP planets) that resulted in coverage on 162 news websites [6]. The greatest coverage of all was for a 2014 press release by ourselves, on the discovery of WASP-142b (by Tom Wagg during a “work experience’’ week), that resulted in coverage on 650 media websites worldwide (205 in English, including BBC News, ITV News, CNN, TIME, The Telegraph, The Guardian, The Independent, The Washington Post, Toronto Star, etc. plus 59 in German, 48 in Spanish, 106 in Russian, 30 in Chinese, 23 in French, 20 in Italian, and a hundred more in several hundred in over 12 other languages), plus TV features (see below) and live Radio interviews across the world including CNN in the US, the Canadian Broadcasting Corporation, Colombian National Radio, Australian Broadcasting Company, and RTE Ireland [7].

The above compilation shows that institutions worldwide are disseminating exoplanet science underpinned by Keele’s exoplanet discoveries. Over the full REF period there have been over 2000 media articles mentioning a WASP exoplanet on websites of sufficient standing to be picked up by a “Google alert” (English-language only). While half of these articles were reactions to press releases, the other half were journalists writing about WASP exoplanets even without the prompt of WASP-specific press releases. Thanks to the NASA publicity machine and others, much of the overall dissemination about exoplanets that has now seeped into public awareness has been based on WASP-discovered planets.

UK TV coverage featuring WASP exoplanets includes the BBC2 "*Horizon: Secrets of the Solar System*" (3rd March 2015; audience 2.03 million), containing a 14-min segment about WASP-84b and a segment on retrograde planets based on WASP-17b. The discovery of WASP-142b featured on BBC1 Midlands Today (11th June 2015; 600,000 viewers), BBC1 Breakfast (14th June 2015; 3 million viewers) and Sky News (14th June 2015; 500,000 viewers). The BBC2 “Horizon” programme, “*The Wildest Weather in the Universe*" (24th Oct 2016; audience 2 million), featured WASP-33b as "hottest known planet", and discussed possible rain of "liquid rubies" on WASP-12b. In addition, BBC4's *Sky at Night* (16th Feb 2017; audience 600,000) featured WASP as a successful hunter for exoplanets, while in Nov 2019 the naming of WASP-13b featured on national BBC1, ITV and Sky news.

Non-academic **books** explicitly featuring WASP exoplanets includes the popular-level books “*How do you find an exoplanet?”* (John Asher Johnson, Princeton, 2015), “*The Planet Factory: Exoplanets and the Search for a Second Earth*” (Elizabeth Tasker, Bloomsbury Sigma, 2017) and

the children's book "*Exploring Exoplanets*" (Searchlight Books, 2015) [8]. Universities are increasingly teaching undergraduates about exoplanets and textbooks (e.g. "Exoplanets", Haswell, Cambridge University Press) feature WASP planets extensively.

Naming the WASP planets: In 2019 the International Astronomical Union launched a worldwide public-outreach competition in which the youth of each nation named an exoplanet. Twenty countries were allocated a WASP planet [9]. In each country, schools and youth groups, involving tens of thousands of children, talked about that exoplanet and suggested a name, often a name from local traditions, giving an ongoing link between their culture and cutting-edge science. In the UK a 17-page activity booklet for schools was produced by UCLan about the UK's allocated planet, WASP-13b. A total of 515 school and Scout groups proposed a name. 15,000 then voted, choosing the Manx Gaelic "Gloas" and "Cruinlagh" for the star and the planet [10] (a teacher reported the "mind-blowing" effect of naming a planet on her class). Similar campaigns were conducted in the 19 other countries naming a WASP planet (Aruba, Bulgaria, Costa Rica, Dominican Republic, Guatemala, Ivory Coast, Jordan, Malawi, Mauritius, Morocco, Panama, Philippines, Serbia, Slovenia, South Africa, Tanzania, Thailand, Togo and Turkey).

The fact that so much third-party outreach activity is about exoplanets that were discovered by Keele, with writers and content creators choosing to talk about WASP exoplanets as exemplars of exoplanet science, shows the worldwide impact of Keele's exoplanet discovery research.

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

[1] Google alert for "WASP" combined with "planet" or "exoplanet" (English-language only).
[2] https://apod.nasa.gov/apod/ap190710.html [Note: all viewing stats as at 31/12/2020].
[3] Tweets mentioned include: https://twitter.com/NASA/status/909183628688658432
https://twitter.com/NASA/status/969724768881664003
https://twitter.com/NASAHubble/status/1121051785358204928
https://twitter.com/NASAHubble/status/892794853783941120
https://twitter.com/kornkt/status/1238024720605253633
[4] Videos featuring WASP planets include: (English language):
https://www.youtube.com/watch?v=6KZ1kvIUFrU
https://www.youtube.com/watch?v=0FsQ-v8Tec4
https://www.youtube.com/watch?v=qhLExhpXX0E
https://www.youtube.com/watch?v=9UB3FrT5SAY
https://www.youtube.com/watch?v=w4LIkhudFVQ
https://www.youtube.com/watch?v=p6QDgXA-vIE
(Spanish language): https://www.youtube.com/watch?v=CSfYetZRde8
https://www.youtube.com/watch?v=7XbAnc-f1_8
https://www.youtube.com/watch?v=tnp0R9nSQPg
https://www.youtube.com/watch?v=7mgojZkY4-M
https://www.youtube.com/watch?v=czat5ycUGO8
(Russian): https://www.youtube.com/watch?v=WgXeLyCk2Ko
(Other languages): https://www.youtube.com/watch?v=qLD7hwGhzE0;
https://www.youtube.com/watch?v=DjilWlReHQ0;
https://www.youtube.com/watch?v=HVcEdYkPIVQ;
https://www.youtube.com/watch?v=0SSu1pRyhgY
https://www.youtube.com/watch?v=q8OvlXWIZY0
[5] https://www.eso.org/public/news/eso2005/ and see https://wasp-76b.com/
[6] https://esahubble.org/news/heic1524/
[7] https://wasp-planets.net/2015/06/10/15-yr-old-work-experience-schoolboy-discovers-a-new-planet/
[8] Book ISBNs are: 9780691156811, 9781472917720 & 9780761378785
[9] http://www.nameexoworlds.iau.org/ https://wasp-planets.net/naming/
[10] https://www.bbc.co.uk/news/world-europe-isle-of-man-50823652
A download of all YouTube videos held within Keele's repository