Institution: University of Glasgow (UofG)

Unit of Assessment: UoA 9 Physics

Title of case study: Translating the significance of gravitational wave research for a global audience

Period when the underpinning research was undertaken: 1971–present

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:
Sir James Hough	Research Professor, Natural Philosophy	1972–present
Sheila Rowan	Chair, Natural Philosophy	1994–present
Kenneth Strain	Professor, Physics	1995–present
Graham Woan	Professor, Astrophysics	1996–present
Martin Hendry	Professor, Gravitational Astrophysics and Cosmology	1996–present
Ik Siong Heng	Professor, Physics and Astronomy	2006–present
Giles Hammond	Professor, Physics and Astronomy	2007–present

Period when the claimed impact occurred: 2013–present

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

1. Summary of the impact

September 2015 saw the first-ever direct detection of gravitational waves, vindicating Einstein's century-old Theory of Relativity and opening an entirely new window on the universe. The significance of the discovery could have been inaccessible to most non-scientists. However, UofG physicists in the Institute for Gravitational Research, who developed the thread-like mirror suspensions critical to the first detection, have embedded public engagement in their research practice for many years. Prof Hendry's ongoing leadership role in the global communication of gravitational wave discoveries, on behalf of a thousand-strong international team, has resulted in an international, sustained and wide-reaching stimulation of public interest and understanding in the new field of gravitational wave astronomy.

2. Underpinning research

The detection of gravitational waves requires instrumentation of unprecedented sensitivity, capable of detecting changes in the curvature of spacetime, equivalent to displacements less than a million millionth the width of a hair. Between 2010 and 2015, the twin Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors were upgraded to their Advanced configuration and achieved this remarkable sensitivity. In September 2015, LIGO made the first direct detection of gravitational waves from GW150914, the merger of two black holes more than a billion light years distant — a discovery that was awarded the 2017 Nobel Prize for Physics and which has opened an entirely new observational window on the cosmos.

Since the European detector, Virgo, joined LIGO in 2017, over 50 further confirmed or candidate gravitational-wave detections have followed. These include: GW170817, a binary neutron star collision that was the first event observed in both gravity and light, and GW190521, the first detection of an intermediate-mass black hole. These discoveries have brought spectacular new insights to many fundamental questions in physics: from the cosmic

expansion rate and the speed of gravity to the origin of black holes and the equation of state of ultra-dense matter.

Research undertaken by scientists in UofG's Institute for Gravitational Research (IGR) has been pivotal to LIGO's remarkable scientific achievements — as a direct result of the key leadership roles played by IGR staff in the development, construction and operation of the Advanced LIGO detectors, and in analysing and interpreting the signals which they have detected.

- **Hough**, **Rowan**, **Strain** and **Hammond** have made seminal contributions to the Advanced LIGO upgrades — with **Strain** the overall PI for the Advanced LIGO UK project [3.1]. **Hough** and **Rowan** were instrumental in the design and development of the quasi-monolithic silica suspension concept, firstly in the UK/German GEO600 detector [3.2] and then in Advanced LIGO. **Hammond** led significant elements of the installation and characterisation of the final quadruple suspensions at both LIGO detectors [3.1]. In his 2017 Nobel lecture, Nobel Laureate Barish identified the monolithic suspensions "led by Glasgow" as essential to the detection of gravitational waves.
- **Woan**, **Hendry** and **Heng** have made significant contributions to LIGO Virgo analysis methodology which have underpinned the gravitational-wave detections. **Woan** was instrumental in bringing Bayesian inference techniques to gravitational-wave data analysis, and these methods have become the standard approach adopted in our detection pipelines [refs 3.3, 3.4]. **Heng** leads methods that search for generic transients, or 'bursts', and co-chaired the LIGO Virgo Burst group at the time of the GW150914 detection [3.5]. **Hendry** led the peculiar velocity analysis for the first-ever standard siren determination of the Hubble constant, which measures the cosmic expansion rate, using GW17817 [3.6].

The significance of UofG's research achievements has been recognised by the award of multiple honours and prizes to IGR staff, including a Knighthood and the Royal Society Bakerian Medal to **Hough**, the Institute of Physics Hoyle Medal to **Rowan** and the Special Breakthrough Prize in Fundamental Physics and the Royal Society of Edinburgh President's Medal to all IGR staff. This strong research background positioned UofG to lead LIGO's outreach programme.

3. References to the research (* = best indicators of quality)

1. "GW150914: The Advanced LIGO Detectors in the Era of First Discoveries", Phys. Rev. Lett. 116 (2016) 131103. doi:10.1103/PhysRevLett.116.131103
2. "Advanced techniques in GEO 600", Classical and Quantum Gravity, 31, Issue 22 (2014) 224002. doi:10.1088/0264-9381/31/22/224002
3. "Observation of Gravitational Waves from a Binary Black Hole Merger", Phys. Rev. Lett. 116 (2016) 061102. doi:10.1103/PhysRevLett.116.061102 *
4. "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral", Phys. Rev. Lett. 119 (2017) 161101. doi:10.1103/PhysRevLett.119.161101*
5. "Observing gravitational-wave transient GW150914 with minimal assumptions" Phys. Rev. D. 93 (2015), 122004. doi:10.1103/PhysRevD.93.122004
6. "A gravitational-wave standard siren measurement of the Hubble constant", Nature, 551 (2017), 7678 pp 85–88. doi:10.1038/nature24471 *

4. Details of the impact

UofG research underpins a rich environment for public engagement

UofG's Institute for Gravitational Research (IGR) has embedded public engagement in its practice, with its *'rich scientific environment*' [5.1] acting as a foundation for a vibrant outreach programme, long before the acceleration of activity following the first gravitational waves detection announcement (February 2016). Since August 2013, IGR researchers have supported the delivery of ~3,000 public events (in 27 countries) including: multiple TEDx talks and webinars [5.2]; exhibits and keynote talks at the Royal Society Summer Science Exhibition, London (2016 and 2017) and the USA National Science & Engineering Festival [5.3 page 5] (2014, 2016, 2018); >70 school visits by Hendry alone [5.4]; and 18 Science Festivals [5.4] (including European Astrofest, Cheltenham, Glasgow and Oman Science Festivals, India National Science Day, NewScientist Live, Edinburgh International Science and Book Festivals). The number of people reached is difficult to determine due to variability in recording methods, but at the very least, this runs to many tens of thousands. Engagement levels at these events have been consistently high, with an improved public understanding of gravitational research arising as a result. For example, at the Royal Society Summer Science Exhibition, post-exhibition surveys indicated that 70% of respondents said their knowledge of gravitational waves increased [5.5].

The LIGO Scientific Collaboration's (LSC) Education and Public Outreach (EPO) Group was founded in 2008 [5.1]. UofG's Hendry has been a key member since its inception. When the first detection was observed, *'Martin was already playing a leading role in coordinating and supporting our global program of informal education activities*' [5.1]. Based on this and the public engagement expertise at UofG, UofG was selected as the informal communications lead in announcing the discovery. Subsequently, Hendry was asked to Chair the EPO Group, and was invited to chair the newly formed "Communications and Education" Division of the LSC, and to join the LSC's Management Team.

Creating and supporting a base for widespread understanding

Hendry has led the provision of 113 LIGO *Science Summaries* since August 2013 — a key component of LIGO's public outreach to journalists and non-specialists [5.6a]. Hendry maintains editorial oversight and is a key author. These *Science Summaries* are *'short, non-technical articles written to accompany every [LIGO] collaboration publication'* [5.1].

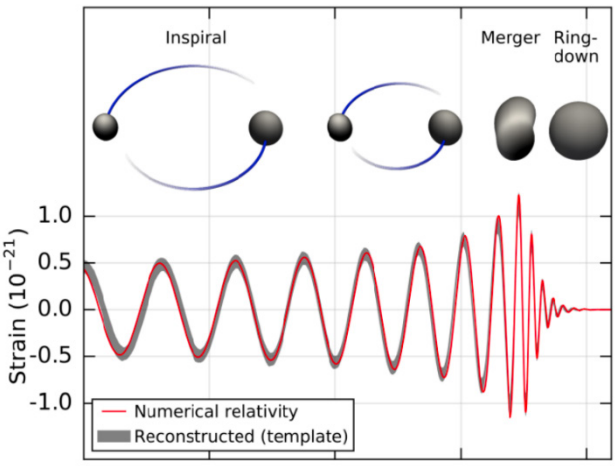

*Figure from '**Observation of Gravitational Waves from a Binary Black Hole Merger**' Science Summary (11/02/16), showing key results detected from a merger in a distant galaxy more than one billion light years from the Earth. Results correspond with the three stages of a black hole merger - the **inspiral**, as the two black holes approach each other; the **merger** as the black holes join together and the subsequent **ringdown**, as the single black hole that has newly formed briefly oscillates before settling down* [5.6b].

Science Summaries are published in 21 languages and have increased public understanding of gravitational waves, directly assisting journalists in their communications. '*LIGO has done a fabulous job publicising their work and explaining the concepts to the public and to journalists like myself as well. Martin Hendry specifically has helped me ensure that my reporting on LIGO's discoveries is factually correct*' — Journalist, Science News [5.7]. By explaining research and the significance of results in lay language, Hendry created a base for understanding that has changed how journalists report — "*Martin's work meant that I could assume that the general public was working from a higher level of knowledge about black holes and gravitational waves when each new discovery was announced…. given that gravitational waves are an extremely difficult concept for the lay person to grasp, Martin and his colleagues have done sterling work to help the public understand what they are."* — ex-BBC Scotland Science correspondent [5.8].

With the first detection, Hendry and LIGO sought to emphasise its significance to the world beyond the scientific community. A YouGov poll in February 2016 asked how much, if at all, the discovery mattered [5.9]. Overall, 34% of respondents felt it mattered 'a great deal' or 'a fair amount'. However, for those aged 18-24, this rose to 50%. With Hendry, UofG designed content specific to each social media channel, particularly focused on continuing engagement with younger audiences. This was translated to WeChat for Chinese audiences, resulting in UofG's best-ever WeChat engagement, with 46,716 views and 4,086 reposts.

Hendry designed the hugely successful strategy to use social media to direct the public to the latest news while allowing direct engagement with LIGO researchers. The video explaining the significance of gravitational waves and UofG's contribution, posted on UofG's Facebook, registered the highest-ever engagement levels (2.2 million people vs an average reach for UofG posts of 46,900 people). UofG's Twitter announcement of the first-ever detection of black holes appeared in >503,000 Twitter feeds (vs a UofG average of 20,800) and was retweeted 1,300 times (vs a UofG average of 16).

Creative public engagement: translating physics using the arts

UofG researchers have crossed boundaries to demonstrate science, including:

- A collaboration between Professor Hammond and Glasgow School of Art students to produce the Halo Harp, an interactive musical instrument inspired by LIGO technology, which became an open-source project for schools [5.10].
- Performances at Glasgow Science Festivals: *'Peake into Space: Cosmic Cabaret'* was inspired by conversations between UofG physicists and artists; and *Chasing the Waves* was presented to 576 school pupils in areas of multiple deprivation with low rates of higher education progression. >80% of pupils attending had little/no prior knowledge of gravitational waves and 75% had never attended a science show. UofG researchers fact-checked the science and participated in audience Q&As. Afterwards, a majority of pupils felt more interested in science and half expressed a new interest in STEM careers.

Feedback to such Glasgow Science Festival events included:

From pupils —*'It makes me feel more confident that if I were to travel round the world then I could say: we're from Glasgow and we've discovered great things'* [5.11 page 1].

From teachers — *'Beneficial for our pupils to see that fellow Scottish students and scientists are part of very important research involving the "workings" of our universe. Very inspirational'* [5.11 page 1].
From the public — '*You got someone who knew relatively little about science to be interested in what seems to be a truly vital discovery – thanks!'* [5.11 page 2].

Chasing the Waves was shortlisted for the Times Higher Award and won the Herald Higher Education Award for Outstanding Contribution to the Local Community (2017).

5. Sources to corroborate the impact

5.1. Testimonial letter from LIGO Scientific Collaboration spokesperson 2017–2019, head of MIT LIGO group and later head of Advanced LIGO Project
5.2. TED talks 'Theme: From Exploration to Innovation' listing https://www.ted.com/tedx/events/18373
5.3. National Science Foundation (US) article "NSF hosts 26 hands-on exhibits at largest U.S. science and engineering festival" https://www.nsf.gov/news/news_summ.jsp?cntn_id=138292
5.4. Institute of Gravitational Research (IGR) Public engagement activity summary
5.5. Royal Society 2017 Summer Science Exhibition Feedback
5.6. LIGO Science Summaries
(a) General overview - https://www.ligo.org/science/outreach.php
(b) Observation of Gravitational Waves from a Binary Black Hole Merger' Science Summary (11/02/16) - https://www.ligo.org/science/Publication-GW150914/index.php
5.7. Science News Correspondent feedback
5.8. Ex-BBC Scotland Science Correspondent feedback
5.9. YouGov UK survey: https://yougov.co.uk/opi/surveys/results/#/survey/b8db9270-d173-11e5-a405-005056900127
5.10. Halo Harp: An Open-Source Project for Schools (Project information on the STEM Central in Motion blog hosted by Education Scotland on the schools network, Glow). https://blogs.glowscotland.org.uk/glowblogs/STEMcentralinmotion/2015/10/21/halo-harp-an-open-source-project-for-schools/
5.11. Chasing the Waves evaluation report/collated feedback from Glasgow Science Festival