Institution: Queen Mary University of London		
Unit of Assessment: 9		
Title of case study: Cassini probe images of Saturn create new cultural artefacts and increase public engagement		
Period when the underpinning research was undertaken: 2004 – 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:**
Prof. Carl Murray	Professor of Mathematics and Astronomy	Sep 1982 – present
Period when the claimed impact occurred: 08/13 – present		
Is this case study continued from a case study submitted in 2014? N		

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

Prof. Murray held a pivotal role in the imaging team for NASA's Cassini-Huygens probe mission to Saturn, with direct responsibility for over 48,000 novel images and collective responsibility for all images. As the only UK member of this team, Murray acted as the UK's Cassini probe expert for both the scientific and mainstream media, directly enabling the production of accurate and engaging multimedia output that was distributed to hundreds of millions of people. His images and expertise facilitated the creation of new cultural artefacts across art, music, science communication and entertainment; increased public awareness and understanding of science; and sparked discussion and debate. This is evidenced by the greater use of online learning resources during critical phases of the mission and increased participation and engagement across news and social media.

2. Underpinning research (indicative maximum 500 words)

The solar system is the only system of planets to which we can send spacecraft for in situ observations and even sampling. This establishes a series of benchmarks, which can be used for comparisons with unreachable exoplanets. The detailed exploration of the planets of the solar system entails placing spacecraft in orbit about the planets and studying them in detail for long periods of time. This had already happened for Mercury, Venus, Earth, Mars and Jupiter, so Saturn, the second largest planet in the solar system, was the next target. Saturn is unique in terms of the size and intricacy of its spectacular ring system. What we can learn about the rings and the adjacent moons can help us to understand how planets form and evolve.

Prof. Carl Murray has a body of work on celestial mechanics and examining Saturn's outermost F ring, one of the most active rings in the Solar System. Murray helped to determine that this ring's active nature is caused by interactions with other bodies and has characterised these interactions by studying one of Saturn's inner moons, Prometheus. Murray's work revealed how Prometheus creates distinctive 'streamer-channels' in the F ring, a small scattering of objects that orbit within the ring's vicinity, and how these objects collide with the F ring to trigger spectacular 'mini jets' of debris [3.1, 3.2]. Thus, he was uniquely placed to join the Cassini team to investigate (i) ring dynamics, particularly the peculiar twisted, braided F ring of Saturn and (ii) natural satellite dynamics, particularly the gravitational interaction of moons with each other and the ring system. Cassini was the first spacecraft to study the Saturn system in situ.

Together with its smaller *Huygens* lander, the Cassini probe reached Saturn in 2004 and spent 13 years orbiting the ringed planet before intentionally crashing into it in September 2017 (a mission phase known as the Grand Finale [3.3]). Cassini performed 162 targeted fly-bys of Saturn's moons. Some of these moons, including Enceladus and Titan, are thought to be habitable and therefore promising places to search for microbial extra-terrestrial life. Cassini's imaging team was responsible for co-designing the mission's digital cameras, handling image capture and analysis, and planning the sequencing and gathering of data. Murray acted as the UK's sole representative for a Target Working Team at NASA's Jet Propulsion Laboratory, responsible for approving relevant requests for observational time. Post-approval, Murray advised and guided teams on factors such as filter use, gain, and exposure time, and organised conflict-free observing schedules (working with postdoctoral researcher Mike Evans).

Murray's study of ring dynamics, along with the images he planned and obtained using Cassini, led him to discover an exotic object in Saturn's A ring in 2013, which he nicknamed Peggy, after his mother-in-law [3.4]. Murray subsequently led a campaign to monitor and obtain higher-resolution observations of this object, thought to be a young satellite in the process of escaping from the ring system or breaking up. One of the last images Cassini ever took targeted Peggy as it sat in the outermost part of Saturn's rings.

Our knowledge of Saturn's moons and their habitability has advanced due to Murray's work with the Paris Observatory, in which Cassini data were used to verify and update models of satellite orbits [3.5]. The work proved conclusively that tidal dissipation in the Saturn system – the conversion of orbital energy to heat in celestial bodies, and a key mechanism in the orbital evolution of planetary satellites – had been drastically underestimated. This provided a ready explanation for the existence of liquid water beneath the surface of Enceladus, from which Murray and the Cassini imaging team spotted an erupting plume of ice particles for the first time in 2005 [3.6].

Murray's wider expertise in celestial mechanics and planetary ring systems enabled him to explain and contextualise the images from the Cassini mission in a way that inspired and connected with journalists and creators (across art, music, and culture) with no scientific background, resulting in an array of uniquely engaging new artefacts and output.

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

[3.1] Attree, N. O., Murray, C. D., Cooper, N. J., & G. A. (2012). Williams. Detection of low-velocity collisions in Saturn's F Ring. *Astrophysical Journal Letters*, *755*(2). doi:10.1088/2041-8205/755/2/L27

[3.2] Attree, N. O., Murray, C. D., Williams, G. A., & Cooper, N. J. (2014). A survey of low-velocity collisional features in Saturn's F Ring. *ICARUS,* 227:56-66. 10.1016/j.icarus.2013.09.008

[3.3] Tiscareno, M. S., Nicholson, P. D., Cuzzi, J. N., Spilker, L. J., Murray, C. D. et. al. (2019). Close-range remote sensing of Saturn's rings during Cassini's ring-grazing orbits and Grand Finale. *Science*, *364* (6445). doi: 10.1126/science.aau1017

[3.4] Murray, C. D., Cooper, N. J., et. al. (2014). The discovery and dynamical evolution of an object at the outer edge of Saturn's A ring. *ICARUS,* 236:165-168. 10.1016/j.icarus.2014.03.024

[3.5] Lainey, V., et. al. *(*2017*).* New constraints on Saturn's interior from Cassini astrometric data*.* *ICARUS*, *281*, 286-296. 10.1016/j.icarus.2016.07.014

[3.6] Porco, C.C., Helfenstein, P., Thomas, P.C., Ingersoll, A.P., Wisdom, J., West, R., Neukum, G., Denk, T., Wagner, R., Roatsch, T., Kieffer, S., Turtle, E., McEwen, A., Johnson, T.V., Rathbun, J., Veverka, J., Wilson, D., Perry, J., Spitale, J., Brahic, A., Burns, J. A., DelGenio, A. D., Dones, L., Murray, C. D., Squyres, S. (2006). Cassini observes the active south pole of Enceladus*. Science, 311* (5766), 1393–1401. 10.1126/science.1123013

Evidence of the quality of the research:

[EQR. 1] PI, C.D. Murray. (April 2017 – March 2021). Solar and Planetary Research [ST/P000622/1]. *STFC*. Research Grant. GBP762,625.

[EQR. 2] PI, R. Nelson. (April 2015 – March 2019). Astronomy Research at Queen Mary 2015-2018 [ST/M001202/1]. *STFC*. Research Grant. GBP1,237,643

[EQR. 3] PI, D. Burgess. (April 2012 – March 2016). Astronomy Research at Queen Mary 2012 – 2015 [ST/J001546/1]. *STFC*. Research Grant. GBP1,632,102

[EQR. 4] PI. C Murray. (April 2008 – March 2011). Dynamics of Saturn's F Ring and Satellites [ST/F002696/1]. *STFC*. Research Grant. GBP315,785

[EQR. 5] PI, C Murray. (April 2011 – March 2012). Ring-satellite interactions and orbital evolution in the Saturn system [ST/I001581/1]. *STFC*. Research Grant. GBP354,067

[EQR. 6] PI, C Murray. (April 2006 – March 2010). Cassini imaging centre [GR/L40670]. *STFC*. GBP587,270.

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

As a prominent member of the Cassini probe imaging team, Murray "has joint credit for all images taken by Cassini's cameras," says Cassini Project Scientist Linda Spilker of NASA's Jet Propulsion Laboratory, who was responsible for the mission's scientific goals [5.1]. "He was directly responsible for designing 12% of the more than 400,000 images taken by Cassini." These include those relating to Saturn's ring system, and to the Grand Finale [3.1]. These images are now ubiquitous throughout popular culture.

Driving engaging journalism through iconic images and unique UK-based expertise

Murray's expertise and scientific outputs enabled the production of new media content that would not have been possible otherwise. Murray was Cassini's UK scientific representative and labelled "the only UK-based Cassini imaging expert" by BBC Science Correspondent Jonathan Amos [5.2], regularly acting as a personable and authoritative interviewee to facilitate new journalistic output. "I cannot illustrate my stories about Saturn without using Cassini images. Murray's knowledgeable explanations and insight have enabled me to enhance the presentation of the images with a high level of scientific accuracy," corroborates Mr. Amos, who covered the discovery of Peggy (an object spotted in Saturn's rings by Murray, and nicknamed after Murray's mother-in-law). Mr Amos continues, "This would not be possible without Murray's involvement. Murray's research allows us to convey high quality science, with the type of human-interest angle that draws people in" [5.2].

Rebecca Morelle, the Global Science Correspondent for BBC News (which reaches 487 million people per week across its television, radio and online formats), seconds Amos' comments, also calling Cassini's Grand Finale "the scientific highlight of 2017" and going on to say that "We frequently interview Prof. Murray when putting together pieces about Cassini, Saturn and planetary science. His passion and ability to translate complicated science into something the general public will understand make him stand out. His research expertise brought stories to life and enabled me to provide exciting, informative content in a way that would not be possible without his contribution" [5.3]. Murray continually facilitated wider engagement with his work and Cassini via 23 radio and television appearances from November 2013 onwards, further enabling the creation of original content by platforms reaching a potential weekly audience of hundreds of millions [ie BBC World News (weekly audience: 112,000,000), BBC News (weekly audience: 468,200,000), BBC World Service (weekly audience: 279,000,000), BBC Radio Scotland (weekly audience: 825,000), Radio 4's Today Programme (weekly audience: 7,170,000), BBC One O'Clock News, BBC Radio 4's Inside Science, ITV 6 O'Clock News, ITV's Good Morning Britain, and Channel 5 News]. Specific comments on these news media directly reference Murray's involvement and impact: "Not just NASA, ESA (European Space Agency) too. UK's Dr Murray as one of the lead scientists. Fantastic work and amazing results" and "Peggy! Brilliant. Well spotted Sir! The universe is so fascinating. Every day more amazing things are discovered" [5.4].

Influencing creative practice and enabling unique creative output

As emphasised by Jonathan Amos, Cassini's images – which required Murray's expertise and instrumentation co-design to obtain – brought a "step change" and "have rapidly become the new standard" for visuals of Saturn [5.2]. The images have inspired artists and musicians to create new artefacts:

The 'Cassini's Journey' painting series by Makiko Nakamura (John Martin Gallery, London, May 2019) is based on Murray's images [5.5]. An illustration of water geysers on Enceladus is included in the 2020 Royal Mail stamp collection "Visions of the Universe". The illustration is on a 65p 2nd class stamp. This collection credits Cassini's cameras, which Murray played a key role in developing and maintaining, for revealing the geysers, and highlights the fact that a British astronomer contributed to the discovery (otherwise, the geysers would not have been featured) [5.6].

Additionally, Murray collaborated with composer Yazz Ahmed on a piece featuring spiky broken chords and arrhythmic explorations inspired by Cassini images of hexagonal features on Saturn's surface. This formed part of a suite commemorating 100 years of Holst's 'The Planets'. 'The Planets' is a seven-movement orchestral suite in which each movement is named after a planet of

the solar system, inspired by astrology and Roman mythology rather than astronomy. Ahmed, mentored by Murray and using Cassini data was tasked with writing a new movement for the suite, this time informed by astronomy and physics. The suite was performed by the Ligeti Quartet on a frequently sold-out UK planetarium tour in a show that the *Guardian* called "dizzying and smartly staged" in its four-star review [5.7]. A total of 6 performances were given to a total audience of approximately 650 people. Ahmed reports that "the beauty of Murray's work, and his detailed explanations of how Saturn actually works, allowed me to create a unique piece that really does represent the astronomy involved. I could not have done this without his involvement." Furthermore, the "fascinating and productive" process of collaborating with Murray led Ahmed to develop a new strand to her creative practice: "The success of the resulting piece has furthered my interest in collaborating with scientists. Following the success of Saturn, I accepted a commission by the Open University to create a piece inspired by the Moon." [5.8]

Murray's Cassini images have been used to create new products capable of inspiring, engaging, educating, and entertaining the public:

- A 2015 YouTube video entitled "11 Years of Cassini Saturn Photos in 3 hrs 48 min," created by Jon Keegan of the Wall Street Journal using Murray's research and 341,805 Cassini images, has been viewed over 3,500,000 times. The video has attracted over 1,800 comments and 13,000 likes.
- A dedicated Horizon documentary on Saturn was produced based on Cassini's findings. The average Horizon viewership is approximately 1,700,000. In 2018, the documentary was nominated for a Sir Arthur Clarke Award 'for a highly engaging documentary showcasing the story of this fascinating mission and its discoveries. This is a "must watch", receiving praise not only from those with an active interest in space, but also those who wouldn't normally engage with space' [5.9].
- The images were used in Amazon Prime's 'The Grand Tour' to illustrate the 'space age design' of the featured Aston Martin. The series attracts a viewership of approximately 1,500,000.
- Cassini images regularly featured in Prof. Brian Cox's record-breaking sell-out international stage show 'Brian Cox Live' to show the fragility of the Earth, a mere speck as viewed from Saturn. Annually, Cox performs to over 150,000 people.
- The images are also included in at least 68 prominent stock image collections (such as Alamy, Reuters, Getty Images and National Geographic).

Inspiring and informing the public thus driving participation in discussion and debate about astronomy research

Murray's images, including 'The Day the Earth Smiled' (Figure 1), named Cassini's "most iconic image mosaic" by Cassini Project Scientist Linda Spilker [5.1], have become the go-to representations of Saturn in popular culture. An analysis of 5,645 posts from the social media site Reddit shows that 18% of all image posts on Saturn cite Cassini [5.4].

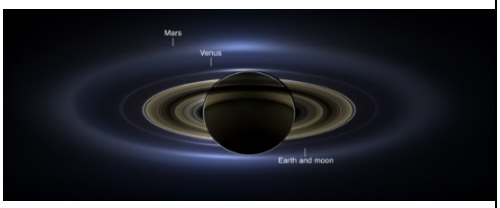

Figure 1: The Day the Earth smiled. Reprinted from NASA, Cassini. *NASA. Copyright [2013] by NASA.*

Cassini images have inspired and informed the public and driven participation in debate and discussion about astronomy:

- Page views for Wikipedia's pages on Saturn spiked by a factor of over 9 during the Grand Finale as the engagement with widespread media coverage of Cassini drove audiences to seek out further information.
- On Twitter, there were over 287,000 retweets relating to "Saturn Cassini" in 2017, 9.5 times higher than the mean in the preceding three years.
- New posts related to Cassini on Reddit, a community discussion site with 330,000,000 users, peaked in 2017 coinciding with the mission Grand Finale. The posts with the most "upvotes" conveyed inspiration and wonder (eg "amazing" and "pictures don't even look real") and indicated informed discussion and sharing of information among the public (multiple posts with >10,000 upvotes and >1,000 comments).

- Cassini science has also driven a sustained increase in engagement with Saturn-related content, with weekly posts increasing from a baseline of 200 to 800 after the peak in 2017.
- Cassini science has informed discussions in communities outside of typical science channels. The top 20 sub-groups for discussions about Cassini on Reddit include nine focused on general photography and general interest posts. In 2019–2020 there has been an average of five posts a week, even on advanced topics such as the moon Enceladus.

- An analysis of 12,300 YouTube comments on Cassini videos reveals debate over topics such as (i) the nature and structure of Saturn's rings (one of Murray's specialisms), (ii) why the Cassini mission flew into Saturn and the proof that it did so and (iii) the quality and nature of the images and instruments. Murray's research and images, present in every video, form crucial reference points in these discussions. Example comments include "Saturn has moons between its rings that produce ripples in the rings through gravity...interesting!"; "How did they video it being destroyed?" and "Cassini's speed is the reason these particular photos are only in greyscale and low resolution on this pass*".*

Thus, through his co-production of Cassini images and wider expertise in Saturn's system and celestial mechanics, Murray has directly driven the creation of new cultural artefacts and engaging journalistic output, and increased public engagement and debate.

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

[5.1] L Spilker. Cassini Project Scientist. *California Institute of Technology* (testimonial letter, 20 May, 2020). [Corroborator 1]

[5.2] J Amos. Science Correspondent. *BBC News* (testimonial letter, 19 May 2020). [Corroborator 2]

[5.3] R Morelle. Global Science Correspondent. *BBC News* (testimonial letter, 15 May 2020). [Corroborator 3]

[5.4] Phillips, A. E., Sajonia-Coburgo-Gotha, B., & White, C. (2021). What happened, and who cared? Evidencing research engagement retrospectively (QMUL-PH-21-14). https://arxiv.org/abs/2103.06778

[5.5] John Martin Gallery. Makiko Nakamura: Cassini's Journey. https://www.jmlondon.com/exhibitions/cassinis-journey/. 25 November 2020.

[5.6] Collect GB Stamps (2020, 11 February). *Visions of the Universe*. https://www.collectgbstamps.co.uk/explore/issues/?issue=22913. 25 November 2020.

[5.7] J Lewis (2018, 1 October). *The Planets 2018_Ligeti Quartet review _ Holst orbits into the modern age.* Guardian. https://www.theguardian.com/music/2018/oct/01/the-planets-2018-ligeti-quartet-review. 20 October 2020.

[5.8] Y Ahmed. Composer. *Freelancer* (testimonial letter, 21 July 2020).

[5.9] BBC Horizon (2018). Space Achievement - Media, broadcast and written. *Sir Arthur Clarke Awards*. The Sir Arthur Clarke Awards recognise and reward those individuals and teams that have made notable or outstanding achievements in, or contributions to, all space activities in the past year. https://www.bis-space.com/2018/10/07/21144/the-2018-sir-arthur-clarke-awards-finalists-announced.