Institution: University of Surrey

Unit of Assessment: 9 Physics

Title of case study: Inspiring and Enhancing Public Understanding of Physics

Period when the underpinning research was undertaken: 2000 - 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:
Professor Jim Al-Khalili FRS	Professor of Physics and Professor of Public Engagement in Science	1991 – present

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 (indicative maximum 100 words)

The research carried out by Al-Khalili in nuclear physics, quantum physics and quantum biology has informed and inspired his hugely successful and impactful work in communicating and disseminating physics, and science more broadly, to wider society. He has achieved this through his popular science books, such as the influential *Life on the Edge: The Coming of Age of Quantum Biology*, as well as his numerous television documentaries and regular radio programme, *The Life Scientific*. His efforts have had an impact on millions of people around the world – such as teachers as far away as India and Argentina using his documentaries in classrooms – and have played a part in generating the resurgence of interest in physics in popular culture.

2. Underpinning research (indicative maximum 500 words)

Al-Khalili has over 30 years of experience of research in theoretical nuclear physics and has published >80 papers in peer reviewed journals in the field. But for the past two decades, he has gradually developed his research in the emerging field of quantum biology **[R1]**.

Together with Surrey colleagues he has investigated the importance of quantum tunnelling in DNA by first running computational simulations to map the energy surface of the hydrogen bonds holding DNA together and then solving the quantum master equation for so-called open quantum systems to study the effects of the cellular environment on the tunnelling rate **[R2, R3]**. He has also led research into the study of quantum decoherence and the impact this can have on the persistence of quantum effects within living cells **[R4]**. Together with McFadden, he set up the world's first Doctoral Training Centre (DTC) in quantum biology at Surrey through a £1m Leverhulme Trust grant in 2017. This has enabled him to collaborate with colleagues across different disciplines at Surrey, such as J. McFadden (molecular biology), A. Rocco (statistical physics and open quantum systems) and M. Sacchi (computational chemistry). Together with these colleagues and his PhD students funded on the Leverhulme DTC, he is currently working on a range of projects, such as the impact of the dynamics of non-Markovian open quantum systems on the thermodynamical properties of matter, the role of environmental (coloured) noise on quantum dynamics, the investigation of novel entropy functions characterising non-ordinary statistical mechanics and the analysis of the off-equilibrium fluctuation-dissipation theorem. These foundational problems on quantum mechanics are of potential interest in quantum computing and quantum information theory and have applications across a range of quantum technologies. In 2020, he set up a Quantum Foundations Centre.

While building his research in quantum biology, Al-Khalili has continued active research in nuclear reaction theory and is currently studying the role of three-body nuclear forces in reactions of astrophysical interest, such as (d,p) transfer reactions. Together with N. Timofeyuk and STFC research student M. Dinmore, he recently published work on this topic **[R5].**

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

[R1] "Environment-induced dephasing versus von Neumann measurements in proton tunneling", A.D. Godbeer, **J.S. Al-Khalili**, and P.D. Stevenson, Phys. Rev. A 90 (2014). DOI: 10.1103/PhysRevA.90.012102

[R2] "Modelling proton tunnelling in the adenine–thymine base pair", A.D. Godbeer, **J.S. Al-Khalili** and P.D. Stevenson, Phys. Chem. Chem. Phys. 17 (2015) 13034-13044. DOI: https://doi.org/10.1039/C5CP00472A

[R3] "Origins of Quantum Biology", J. McFadden and **J.S. Al-Khalili**, Proc. R. Soc. A 474:20180674 (2018) DOI: 10.1098/rspa.2018.0674

[R4] "Effects of an induced three-body force in the incident channel of (d,p) reactions", M.J. Dinmore, N.K. Timofeyuk, **J.S. Al-Khalili**, and R.C. Johnson, Phys. Rev. C 99, (2019) 064612. DOI: 10.1103/PhysRevC.99.064612

[R5] "Three-nucleon force contribution to the deuteron channel in (d,p) reactions", N.K. Timofeyuk, M.J. Dinmore, and **J.S. Al-Khalili**, Phys. Rev. C 102, (2020) 064616 DOI: 10.1103/PhysRevC.102.064616

Funding:

2017 Leverhulme Doctoral Scholarships Grant, £1,050,000, for Quantum Biology Doctoral Training Centre, DS-2017-079 (J. McFadden & J. Al-Khalili appointed as joint heads of Centre).

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

Having already forged an international research reputation for his contributions in theoretical nuclear physics, Al-Khalili has now also established himself as one of the world's leading and best-known science communicators. His research in quantum mechanics underpinned much of the contents of his best-selling popular science books, *Quantum: A Guide for the Perplexed* (2004), *Life on the Edge: the coming of age of quantum biology* (2015) and *The World According to Physics* (2020). To date, his thirteen books (eight of which were published in the assessment period) have sold over 250,000 copies in the English language alone and have been translated into 24 languages.

Over the assessment period, his research in the new interdisciplinary field of quantum biology has underpinned much of his public engagement activities which, in turn, have had a significant impact through his books, articles in the media **[S1]**, radio **[S2, S9]** and television **[S3, S4]** documentaries, schools talks **[S5]** and public lectures. It is the impact of this research, particularly through his broad public engagement work, that is highlighted here. As part of the schools lecture series Science Live, he has discussed his research in quantum biology to thousands of A-level students. Daniel Powell, director of Science Live says: "*the lectures [Al-Khalili] has given at Science Live have been seen by approximately 120,000 students, the vast majority (112,000) of whom have been Years 10 and 11 (GCSE age) and some of whom (8,000) have been Years 12 and 13 (A-level students)*" **[S5]**. In 2015, Al-Khalili gave a TEDGlobal talk at the Royal Institution ("How quantum biology might explain life's biggest secrets") in which he focused on his research into the nature of quantum tunnelling in DNA. The TED website shows that the talk has so far been viewed 2.4 million times and has a transcript in 29 languages.

The same year (2015) saw the publication of the first general interest book on quantum biology, *Life on the Edge: the coming of age of quantum biology* (2015) which Al-Khalili co-authored with

his University of Surrey research collaborator, the molecular geneticist, Professor Johnjoe McFadden. Sales figures, as at October 2020, stood at 49,000 copies in the English language **[S6]**. The book was shortlisted for the Royal Society Winton Book Prize in 2015 **[S6]** and received favourable reviews in science publications and the media **[S6]**. Within a year of publication, the book had been translated into 16 languages.

In June 2016, Al-Khalili was awarded the Inaugural Stephen Hawking Medal for Science Communication **[S7]** having been chosen by Hawking personally, together with an international panel of judges, including cosmonaut Sergey Leonov, Richard Dawkins and Brian May. His citation reads: *"for his treatment of complex physics concepts through science documentaries"*. Hawking was quoted as saying that it was Al-Khalili's 2015, 2-part BBC4 documentary, *The Secrets of Quantum Physics*, and episode 2 in particular on quantum biology, which most impressed **[S7]**. It was in this episode that Al-Khalili expounded upon his research on proton tunnelling in DNA **[R2]**.

In 2014, Al-Khalili was chosen as one of EPSRC's ten RISE Leaders in science and engineering. In the past six years he has received seven honorary degrees from UK universities (including York and St Andrews) and in 2018 he was elected a fellow of the Royal Society on the strength of both his research and his wider public engagement and science communication efforts.

During this assessment period, Al-Khalili has established himself as one of the world's best-known science broadcasters, with over 30 hours of television during the assessment period, with his documentaries attracting a total viewing figure of over 20 million since 2013 in the UK alone **[S4]**, and subsequently aired in many countries around the world. Many of his documentary series, such as *Chemistry: A Volatile History* and *Shock and Awe: The Story of Electricity* (BBC4, 2010) continue to be used by teachers in classrooms as far afield as Australia and Argentina. He received a 2013 Grierson Trust nominal for *Order and Disorder: The Story of Energy* (BBC4, 2012). BBC4 editor Cassian Harrison states: *"Professor Al-Khalili has a natural ability to communicate complex principles and theories in contemporary physics in a friendly and accessible way, prompting the viewer to look at the world with a different and renewed appreciation. His knowledge and research make him a trusted authority in the eyes of the viewer and have contributed to the success of the programmes. Jim is established as one of BBC4's principal scientific presenters. Audience Appreciation Indexes for Jim's programmes have an average of 84 against an BBC average of 65, and feedback from viewers is universally positive"* **[S3]**.

For many people, Al-Khalili is best known as the presenter of BBC Radio 4's long-running programme, *The Life Scientific* **[S8]**, which attracts over two million listeners in the UK each week **[S2]** for the 24 weeks of the year that it is broadcast. Since it was first broadcast in 2011, he has interviewed over 200 scientists, including nine Nobel Prize winners, four presidents of the Royal Society and three Government chief scientific advisors. Instrumental in his success in bringing out the best of his guests is his own track record and standing as a research scientist **[S2]**. BBC Radio 4 controller Gwyn Williams states: *"Al-Khalili is vital as both a presenter and a practicing scientist… It is hard to overstate the impact he and his Radio 4 programmes will have had on audiences… His own research gives him an understanding of what is involved in a life in science [and] his research allows him to ask deeper, more authoritative questions"* **[S2]**. In early 2019, the tables were turned in the programme as he himself was interviewed, by the broadcaster Adam Rutherford in which he spoke about his research career in nuclear physics and quantum biology **[S8]**.

The impact of Al-Khalili's contribution to promoting and communicating science is well-illustrated by the part he has played in the surge in interest in studying physics at UK universities over the past few years **[S9]**, which has led to, on average, a doubling of the undergraduate physics cohort at the University of Surrey during the assessment period over the average of the equivalent

previous seven years. His research in quantum biology, in particular, has generated much excitement and enthusiasm in wider society and is encouraging a generation of future scientists to think about interdisciplinary research. Professor Paul Hardaker, Chief Executive of the IOP says: *"Jim has trailblazed public engagement and communication in science. … He has opened doors and provided opportunities for us to have conversations and connect with the public in a way that we as an organisation would have otherwise found more difficult to do on our own…It is directly thanks to people like Jim that the scientific landscape has changed to one where we, as scientists, can effectively engage with the public to the benefit of both."* **[S9]**

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

[S1] A selection of The Guardian articles: https://www.theguardian.com/profile/jimalkhalili

[S2] Testimonial letter from Gwyneth Williams, controller of Radio 4 is available (also contains listener figures).

[S3] Testimonial letter from Cassian Harrison, editor of BBC4 (contains viewing figures).

[S4] Al-Khalili's TV documentaries are also available on YouTube and have received a total of over 30 million views worldwide at the end of December 2020 (https://www.youtube.com/results?search_query=jim+al-khalili&sp=CAM%253D).

[S5] Testimonial letter from Daniel Powell, Director of Science Live.

[S6] Impact of the book, *Life on the Edge:*

- Email from Larry Finlay (MD of Transworld books) contains a breakdown of sales figures;
- Royal Society Winston Prize for Science Books (2015) https://royalsociety.org/grants-schemes-awards/book-prizes/science-book-prize/2015/;
- Book reviews: Financial Times: https://www.ft.com/content/0c6e53be-643d-11e4-b219-00144feabdc0, Physics World magazine: https://physicsworld.com/a/bringing-the-quantum-to-life/, The Guardian: https://www.theguardian.com/books/2014/dec/14/life-on-the-edge-jim-al-khalili-review-weird-world-of-quantum-biology

[S7] Guardian article on announcement of Hawking medal: https://www.theguardian.com/science/2016/jun/16/winners-of-inaugural-stephen-hawking-medal-announced-hans-zimmer-jim-al-khalili-particle-fever and Video of Stephen Hawking announcement: https://www.youtube.com/watch?v=6PLrxRSceFU

[S8] *The Life Scientific* Programme website: https://www.bbc.co.uk/programmes/b015sqc7. Over 230 episodes have been broadcast of which 169 were broadcast during the assessment period.

[S9] Testimonial letter from Professor Paul Hacker, Chief Executive of the Institute of Physics