Professor Stephen Hawking: an appreciation by Lord Rees

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ABSTRACT. In this paper, the Astronomer Royal and former Master of Trinity College, Lord Martin Rees, pays tribute to Professor Stephan Hawking, reminiscing the significant events of his life. The focal point of the essay is Hawking's manifestation of willpower and determination in face of the deadly disease he was diagnosed with at the age of 22. Amongst some of the most significant achievements, Rees mentions Stephen's 'eureka moment', namely when he unexpectedly discovered a link between gravity and quantum theory, predicting that black holes would not be completely black, but that they would radiate in a distinctive way. According to Hawking, this radiation is only significant for black holes because they are less massive than stars – and none of these have been found. 'Hawking radiation' theory had very deep implications for mathematical physics and one of the main achievements of string theory has been to corroborate his idea.

KEYWORDS: *Black holes, breakthrough prize, cosmology, hawking radiation, space, time, universe*

The Astronomer Royal and former Master of Trinity College, Lord Martin Rees, pays tribute to Professor Stephen Hawking, 1942-2018.

Soon after I enrolled as a graduate student at Cambridge University in 1964, I encountered a fellow student, two years ahead of me in his studies; he was unsteady on his feet and spoke with great difficulty. This was Stephen Hawking. He had recently been diagnosed with a degenerative disease, and it was thought that he might not survive long enough even to finish his PhD. But, amazingly, he lived on to the age of 76. Even mere survival would have been a medical marvel, but of course he didn't just survive. He became one of the most famous scientists in the world – acclaimed as a world-leading researcher in mathematical physics, for his best-selling books about space, time and the cosmos, and for his astonishing triumph over adversity.

Astronomers are used to large numbers. But few numbers could be as large as the odds I'd have given, back in 1964 when Stephen received his 'death sentence', against witnessing this uniquely inspiring crescendo of achievement sustained for more than 50 years. Few, if any, of Einstein's successors have done more to deepen our insights into gravity, space and time.
Stephen went to school in St Albans, near London, and then to Oxford University. He was, by all accounts, a 'laid back' undergraduate, but his brilliance nonetheless earned him a first class degree in physics, and an 'entry ticket' to a research career in Cambridge. Within a few years of the onset of his disease, he was wheelchair-bound, and his speech was an indistinct croak that could only be interpreted by those who knew him. But in other respects fortune had favoured him. He married a family friend, Jane Wilde, who provided a supportive home life for him and their three children, Robert, Lucy and Tim.

The 1960s were an exciting period in astronomy and cosmology: this was the decade when evidence began to emerge for black holes and the big bang. In Cambridge, Stephen joined a lively research group. It was headed by Dennis Sciama, an enthusiastic and effective mentor who urged him to focus on the new mathematical concepts being developed by Roger Penrose, then at London University, which were initiating a renaissance in the study of Einstein's theory of general relativity. Stephen mastered Penrose's techniques and quickly came up with a succession of insights into the nature of black holes (then a very new idea), along with new arguments that our universe had expanded from a 'big bang'. The latter work was done jointly with George Ellis, another of Sciama's students, with whom Stephen wrote a monograph entitled The Large-Scale Structure of Space-Time. Especially important was the realization that the area of a black hole's horizon (the 'one-way membranes' that shroud the interior of black holes, and from within which nothing can escape) could never decrease. The analogy with entropy (a measure of disorder, that likewise can never decrease) was developed further by the late Israeli theorist Jacob Bekenstein. In the subsequent decades, the observational support for these ideas has strengthened – most spectacularly with the 2016 announcement of the detection of gravitational waves from colliding black holes.

Stephen was elected to the Royal Society, Britain's main scientific academy, at the exceptionally early age of 32. He was by then so frail that most of us suspected that he could scale no further heights. But, for Stephen, this was still just the beginning. He worked in the same building as I did. I would often push his wheelchair into his office, and he would ask me to open an abstruse book on quantum theory – the science of atoms, not a subject that had hitherto much interested him. He would sit hunched motionless for hours – he couldn't even turn the pages without help. I wondered what was going through his mind, and if his powers were failing. But within a year he came up with his best-ever idea – encapsulated in an equation that he said he wanted on his memorial stone.

The great advances in science generally involve discovering a link between phenomena that seemed hitherto conceptually unconnected: for instance, Isaac Newton famously realised that the force making an apple fall was the same as the force that held the moon and planets in their orbits. Stephen's 'eureka moment' revealed a profound and unexpected link between gravity and quantum theory: he predicted that black holes would not be completely black, but would radiate in a characteristic way. Bekenstein's concept that black holes had 'entropy' was more than just an analogy. This radiation is only significant for black holes much less massive than stars – and none of these have been found. However 'Hawking radiation' had very deep implications for mathematical physics – indeed one of the main achievements of string theory has been to corroborate his idea. It is still the focus of theoretical interest – a topic of debate and controversy more than 40 years after his discovery. Indeed the Harvard theorist, Andrew Strominger (with whom Stephen recently collaborated) said that this paper had caused 'more sleepless nights among theoretical physicists than any paper in history'. The key issue is whether information that is seemingly lost when objects fall into a black hole is in principle recoverable from the radiation when it evaporates. If it is not, this violates a deeply believed general physical principle. In 2013 he was one of the early winners of the Breakthrough Prize, worth US$3 million, which was intended to recognize theoretical work.

Cambridge was Stephen's base throughout his career, and he became a familiar figure navigating his wheelchair around the city's streets. By the end of the 1970s, he had advanced to one of the most distinguished posts in the University – the Lucasian Professorship of Mathematics, once held by Newton himself. He held this chair with distinction for 30 years; but reached the retiring age in 2009 and thereafter held a special research professorship. He travelled widely: he was a specially frequent visitor at Caltech, in Pasadena, California; and at Texas A and M University. He continued to seek new links between the very large (the cosmos) and the very small (atoms and quantum theory) and to gain deeper insights into the very beginning of our universe – addressing questions like 'was our big bang the only one?' He had a remarkable ability to figure things out in his head. But latterly he worked with students and colleagues who would write a formula on a blackboard; he would stare at it, and say whether he agreed with it, and perhaps what should come next.

In 1987, Stephen contracted pneumonia. He had to undergo a tracheotomy, which removed even the limited powers of speech he then possessed. It had been more than 10 years since he could write, or even use a keyboard. Without speech, the only way he could communicate was by directing his eye towards one of the letters of the alphabet on a big board in front of him.

But he was saved by technology. He still had the use of one hand; and a computer, controlled by a single lever, allowed him to spell out sentences. These were then declaimed by a speech synthesiser, with the androidal American accent that has thereafter become his trademark. His lectures were, of course, pre-prepared, but conversation remained a struggle. Each word involved several presses of the lever, so even a sentence took several minutes. He learnt to economise with words. His comments were aphoristic or oracular, but often infused with wit. In his later years, he became too weak to control this machine effectively, even via facial muscles or eye movements, and his communication – to his immense frustration – became even slower.

At the time of his tracheotomy operation, he had a rough draft of a book, which he'd hoped would describe his ideas to a wide readership and earn something for his two eldest children, who were then of college age. On his recovery from pneumonia, he resumed work with the help of an editor. When the US edition of *A Brief History of Time* appeared, the printers made some errors (a picture was upside down), and the publishers tried to recall the stock. To their amazement, all copies had already been sold. This was the first inkling that the book was destined for runaway success – four years on best-seller lists around the world.

The feature film *The Theory of Everything* (where he was superbly impersonated by Eddie

Redmayne, in an Oscar-winning performance), portrayed the human story behind his struggle. It surpassed most biopics in representing the main characters so well that they themselves were happy with the portrayal (even though it understandably omitted and conflated key episodes in his scientific life). Even before this film, his life and work had featured in movies. In an excellent TV docudrama made in 2004, he was played by Benedict Cumberbatch. (And in 2012 Cumberbatch spoke his words in a four-part documentary *The Grand Design* made for the Discovery TV Channel).

Why did he become such a 'cult figure'? The concept of an imprisoned mind roaming the cosmos plainly grabbed people's imagination. If he had achieved equal distinction in (say) genetics rather than cosmology, his triumph of intellect against adversity probably wouldn't have achieved the same resonance with a worldwide public.

The *Theory of Everything* conveyed with sensitivity how the need for support (first from a succession of students, but later requiring a team of nurses) strained his marriage to breaking point, especially when augmented by the pressure of his growing celebrity. Jane's book, on which the film is based chronicles the 25 years during which, with amazing dedication, she underpinned his family life and his career.

This is where the film ends. But it left us only half way through Stephen's adult life. After the split with Jane, Stephen married, in 1995, Elaine Mason, who had been one of his nurses, and whose former husband had designed Stephen's speech synthesiser. But this partnership broke up within a decade. He was sustained, then and thereafter by a team of helpers and personal assistants, as well as his family. His daughter Lucy has written books for children with her father as co-author. His later theories were described and beautifully illustrated in other books such as *Our Universe in a Nutshell* and *The Grand Design*. These weren't bought by quite as many people as his first book – but probably more readers got to the end of them.

The success of *A Brief History of Time* catapulted Stephen to international stardom. He featured in numerous TV programmes; his lectures filled the Albert Hall, and similar venues in the US and Japan. He featured in Star Trek and The Simpsons, and in numerous TV documentaries, as well as advertisements. He lectured at Clinton's White House; he was back there more recently when President Obama presented him with the US Medal of Freedom, a very rare honour for any foreigner – and of course just one of the many awards he accumulated over his career (including Companion of Honour from the UK). In the summer of 2012, he reached perhaps his largest-ever audience when he had a star role at the opening ceremony of the London Paralympics.

His 60th birthday celebrations, in January 2002, were a memorable occasion for all of us. Hundreds of leading scientists came from all over the world to honour and celebrate Stephen's discoveries, and to spend a week discussing the latest theories on space, time and the cosmos. But the celebrations weren't just scientific – that wouldn't have been Stephen's style. Stephen was surrounded by his children and grandchildren; there was music and singing; there were 'celebrities' in attendance. And when the week's events were all over, he celebrated with a trip in a hot air balloon.

It was amazing enough that Stephen reached the age of 60; few of us then thought that he would survive 16 more years. His 70th birthday was again marked by an international gathering of scientists in Cambridge, and also with some razzmatazz. So was his 75th birthday, though now shared by several million people via a live-stream on the internet. He was in these last years plainly weakening. But he was still able to 'deliver' entertaining (and sometimes rather moving) lectures via his speech synthesiser and with the aid of skilfully prepared visuals.

Stephen continued, right until his last decade, to co-author technical papers, and speak at premier international conferences – doubly remarkable in a subject where even healthy researchers tend to peak at an early age. Specially influential were his contributions to 'cosmic inflation' – a theory that many believe describes the ultra-early phases of our expanding universe. A key issue is to understand the primordial seeds which eventually develop into galaxies. He proposed (as, independently, did the Russian theorist Viatcheslav Mukhanov) that these were quantum fluctuations – somewhat analogous to those involved in 'Hawking radiation' from black holes. He hosted an important meeting in 1982 where such ideas were thoroughly discussed. Subsequently, particularly with James Hartle and Thomas Hertog, he made further steps towards linking the two great theories of 20th century physics: the quantum theory of the micro-world and Einstein's theory of gravity and space-time.

He continued to be an inveterate traveller – despite attempts to curb this as his respiration weakened. This wasn't just to lecture. For instance, on a visit to Canada he was undeterred by having to go two miles down a mine-shaft to visit an underground laboratory where famous and delicate experiments had been done. And on a later trip, only a last-minute health setback prevented him from going to the Galapagos. All these travels – and indeed his everyday working life – involved an entourage of assistants and nurses. His fame, and the allure of his public appearances, gave him the resources for nursing care, and protected him against the 'does he take sugar?' type of indignity that the disabled often suffer.

Stephen was far from being the archetype unworldly or nerdish scientist – his personality remained amazingly unwrapped by his frustrations and handicaps. As well as his extensive travels, he enjoyed trips to theatre or opera. He had robust common sense, and was ready to express forceful political opinions. However, a downside of his iconic status was that that his comments attracted exaggerated attention even on topics where he had no special expertise – for instance philosophy, or the dangers from aliens or from intelligent machines. And he was sometimes involved in media events where his 'script' was written by the promoters of causes about which he may have been ambivalent.

But there was absolutely no gainsaying his lifelong commitment to campaigns for the disabled, and (just in the last few months) in support of the NHS – to which he acknowledged he owed so much. He was always, at the personal level, sensitive to the misfortunes of others. He recorded that, when in hospital soon after his illness was first diagnosed, his depression was lifted when he compared his lot with a boy in the next bed who was dying of leukaemia. And he was firmly aligned with other political campaigns and causes. When he visited Israel, he insisted on going also to the West Bank. Newspapers in 2006 showed remarkable pictures of him, in his wheelchair, surrounded by fascinated and curious crowds in Ramallah.

Even more astonishing are the pictures of him 'floating' in the NASA aircraft (the 'vomit comet') that allows passengers to experience weightlessness – he was manifestly overjoyed at escaping, albeit briefly, the clutches of the gravitational force he'd studied for decades and which had so cruelly imprisoned his body.

Tragedy struck Stephen Hawking when he was only 22. He was diagnosed with a deadly disease, and his expectations dropped to zero. He himself said that everything that happened since then was a bonus. And what a triumph his life has been. His name will live in the annals of science; millions have had their cosmic horizons widened by his best-selling books; and even more, around the world, have been inspired by a unique example of achievement against all the odds – a manifestation of amazing willpower and determination.