THE UNIVERSE OF STEPHEN HAWKING

[Opening Words]

What I have done is to show that it is possible for the way the universe began to be determined by the laws of science. In that case, it would not be necessary to appeal to God to decide how the universe began. This doesn't prove that there is no God, only that God is not necessary.

Der Spiegel (17 October 1988)

Even if there is only one possible unified theory, it is just a set of rules and equations. What is it that breathes fire into the equations and makes a universe for them to describe? The usual approach of science of constructing a mathematical model cannot answer the questions of why there should be a universe for the model to describe. Why does the universe go to all the bother of existing?

A Brief History of Time (1988)

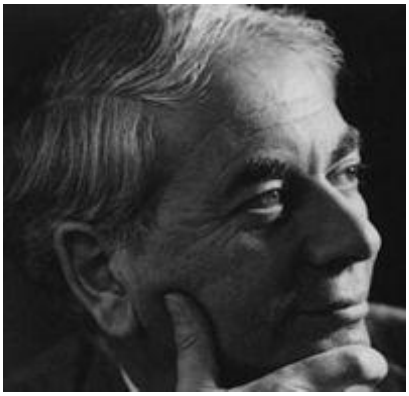
Stephen William Hawking was born in Oxford on 08 January 1942, the 300th anniversary of the death of Galileo. He later wrote that Oxford was one of the two safest places in the UK at the time. Apparently, the British and German governments had agreed not to bomb each other's top university towns – Cambridge and Oxford in return for Göttingen and Heidelberg.

His parents, Dr. Frank and Isobel Hawking, were both Oxford graduates – his mother was one of that university's first female graduates. Hawking's father was a research biologist specializing in tropical diseases and his mother is only described as a political activist.

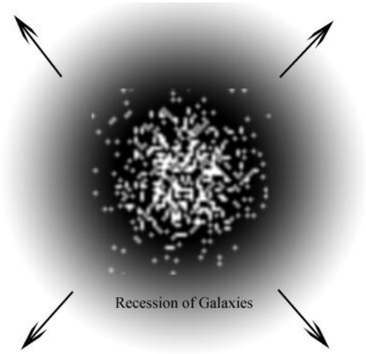
The family moved to St. Albans in Herfordshire when Frank became Head of Parasitology at the National Institute for Medical Research. Hawking attended the famous St. Albans School, where he was a good, but not exceptional, student. It was there that he developed a passion for mathematics, and now one of the school's four houses is named after him, as is an extracurricular series of science lectures.

Hawking's father wanted him to attend University College, Oxford, which did not offer a Mathematics major. Consequently, he studied natural science and majored in Physics. He had so little difficulty with any of his studies that he didn't work very hard and his final examination results were on the borderline of First and Second Class Honours. That necessitated an oral examination in which his genius was immediately recognised by the academic panel.

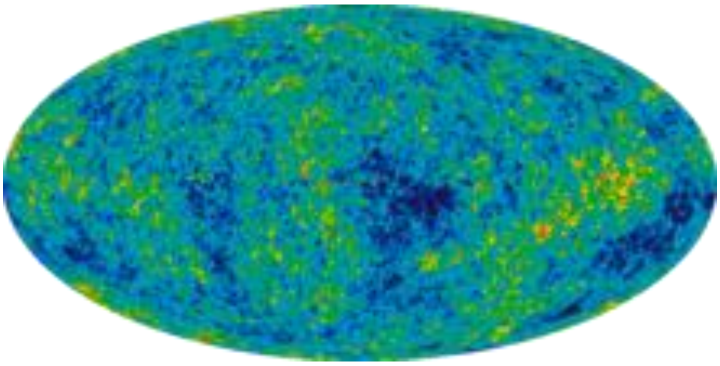
Hawking proceeded to a post-graduate studies at Trinity Hall, Cambridge, in 1962. It was there that the first symptoms of motor neurone disease became apparent, so his first two years were undistinguished. However, his condition then stabilized and he continued working on his PhD with the help of his tutor, Dr. Dennis Sciama, graduating in 1965.



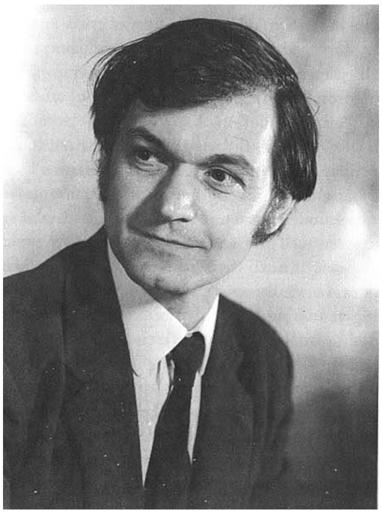
Dennis William Sciama had earned his PhD at Cambridge under the tutelage of the legendary quantum physicist, Paul Dirac. His work extended from radio and X-ray astronomy to quasars and anisotropies in the Cosmic Microwave Background radiation. Shortly before his death in 1999, he was working on a particulate model of dark matter.



In 1948, Fred Hoyle, Thomas Gold and Hermann Bondi had proposed a steady-state universe in which the expansion was compensated for by the spontaneous creation of new matter. Quite unlike Einstein's model of a universe that neither expanded nor contracted, this theory maintained a uniform density of matter and allowed the formation of new galaxies in the spaces produced by the expansion. Thus, the appearance of the visible universe did not change over time.

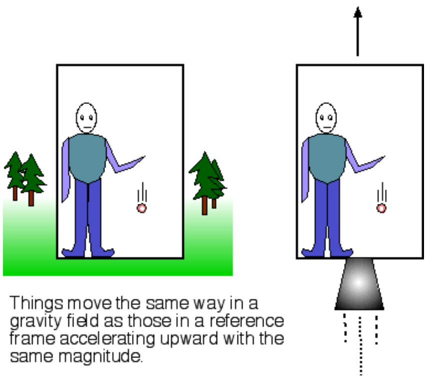


In the early 1960s, this theory had wider support than the 'Big Bang' model, in which the entire Universe originated from a primordial explosion. Pivotal evidence for the latter explanation emerged in 1964 with the discovery of the Cosmic Microwave Background radiation by two American radio astronomers, Arno Penzias and Robert Wilson. Thought of as 'the afterglow of the Big Bang', these microwaves are actually primordial gamma rays whose wavelengths were hugely distended by the expansion of space-time.



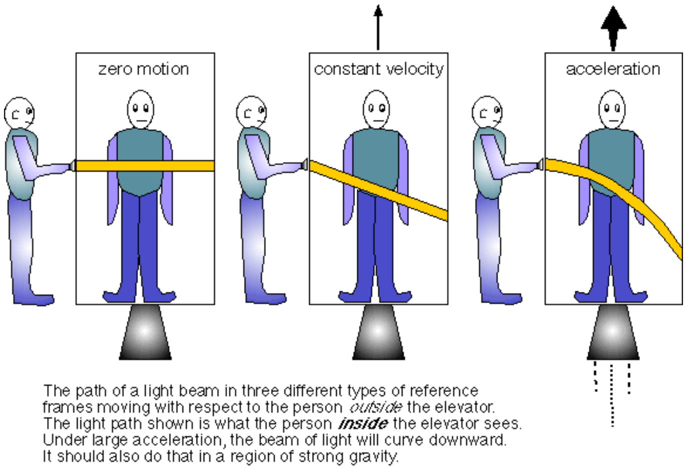
At the time, the initial conditions of the Universe were only thought of as tiny, incredibly dense and fantastically hot. In his PhD thesis, Hawking argued that, if a sufficiently massive star can collapse to form a ‘singularity’, then so could such an entity explode outward. This argument drew on Albert Einstein’s General Theory of Relativity and work on singularities by the mathematical physicist, Roger Penrose, who was also at Cambridge (though he got his PhD in 1958). Penrose and Hawking would be collaborators in future years.

Also in 1965, Hawking married Jane Wilde, a language student. They had three children but the marriage ended in 1990.

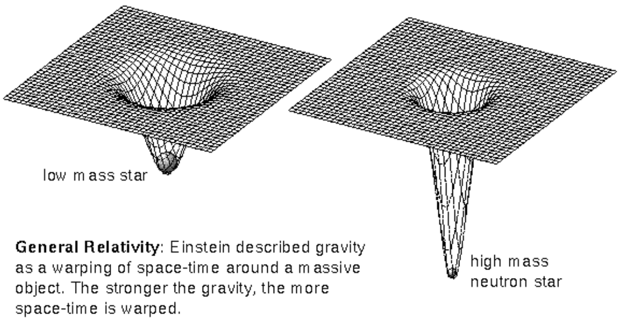


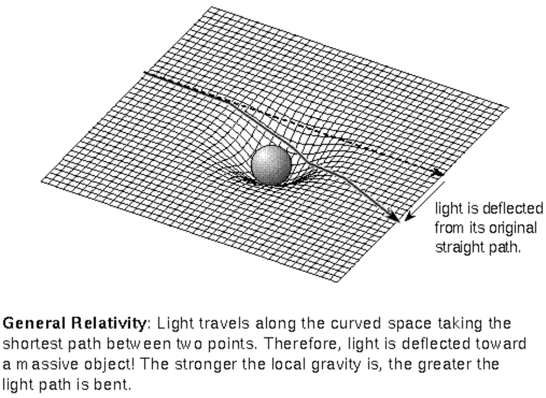
Things move the same way in a gravity field as those in a reference frame accelerating upward with the same magnitude.

So, what are these singularities? By way of background, Einstein’s Special Theory of Relativity dealt only with frames of reference moving at high but constant velocities relative to each other. In his later General Relativity, he considered accelerating frames of reference and concluded that being stationary in a gravitational field with no information coming from outside would be indistinguishable to being in a frame that was being accelerated.

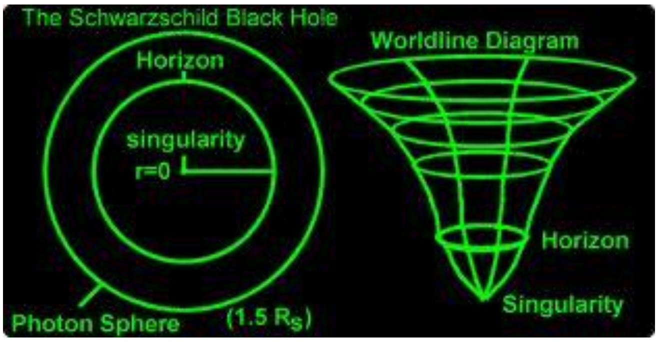


This, in turn, meant that rays of light must bend in a gravitational field in the same way as they would in the accelerating frame of reference. Because the speed of light is constant and the curved path is longer than a straight path, the passage of time must slow down in the vicinity of a gravitating mass.





That led Einstein to conceive of gravitation not as a force but as a distortion of space-time caused by the presence of mass. The configuration of that distortion is called a ‘gravity well’. The bending of starlight in the Sun’s gravitational field was confirmed by Arthur Eddington while observing a solar eclipse in 1919.



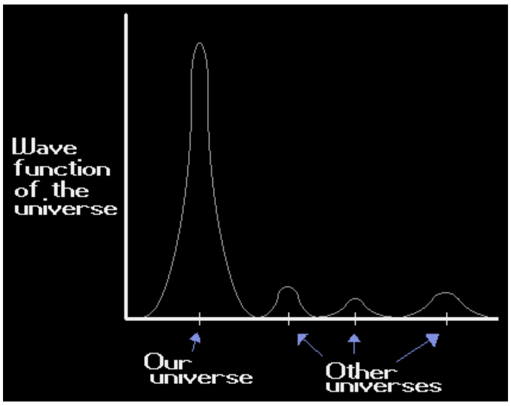
As soon as the General Theory was published in 1915, the German astronomer, Karl Schwartzschild, calculated the radius for a uniform sphere of given mass at which the escape velocity would be the speed of light. For that to happen, the Sun's radius would have to be 3 km and the Earth's would be a mere 9 mm. If a massive body is even smaller than that, the Schwartzschild radius constitutes an 'event horizon' – not merely a 'point of no return' for anything that comes any closer but also a discontinuity in space-time that prevents inside events from being observed from the outside. Later work identified a photon sphere of outer radius 1.5 times the Schwartzschild radius, within which entering photons will be captured in unstable circular paths.

Hawking needed a wheelchair from 1969 but his work with Penrose continued as they investigated different forms of gravitational singularities that could inhabit 'black holes'. That term was coined by the American physicist, John Wheeler, in 1967 after the discovery of neutron stars raised the possibility that singularities were not just mathematical curiosities – matter might indeed be compressible to virtually infinite density. Working with Brandon Carter of Australia, Werner Israel of South Africa and D.C. Robinson, Hawking found support for Wheeler's theorem that any black hole could be fully described by just three properties: mass, angular momentum (an expression of rotation) and electric charge.

With Carter and James Bardeen of the US, Hawking developed the Four Laws of Black Hole Mechanics, analogous to the laws of thermodynamics, in 1974. In the same year, he calculated that black holes should thermally create and emit subatomic particles, an effect that became known as Bekenstein-Hawking radiation, until they exhaust their energy and evaporate. (The Israeli physicist, Jakob Bekenstein, had made a less specific suggestion two years earlier, which Hawking had initially set out to refute.)

1974 was a seminal year for Hawking, as he was elected one of the youngest Fellows of the Royal Society and then accepted a visiting professorship at the California Institute of Technology in Pasadena. He has spent a month there every year since 1992. In 1975, he produced his first book, a highly technical work titled *The Large Scale Structure of Space-Time* (1975).

Unfortunately, by that time, he was unable to feed himself or get out of bed. His speech became slurred to the point that he could be understood only by people who knew him well. This did not prevent him from appearing in popular television documentaries, as his ideas were widely talked about in public circles. In 1979, he was made the Lucasian Professor of Mathematics at Cambridge, a post he held for 30 years until his retirement in 2009. (That prized position had also been held by Sir Isaac Newton and Paul Dirac.) During a visit to the European Centre for Nuclear Research (CERN) in Geneva in 1985, Hawking contracted pneumonia and needed an emergency tracheotomy. That cost him what remained of his speaking ability, so a keypad-operated voice synthesiser was built for him in Cambridge.



Not surprisingly, Hawking was in the forefront of the quest for a ‘Grand Unified Theory’ that would reconcile general relativity with quantum mechanics. In 1983, he corresponded with James Hartle at the University of Chicago’s Fermilab and the two produced a wave function for the initial conditions of the Universe. Just as the complete probability wave equations for individual particles have components for the ‘virtual particles’ they may become, the Hartle-Hawking formula indicates high probability for the Universe we have but also small chances for universes who physical laws are different. The resulting model was of a Universe with no boundaries and apparently ‘closed’ (i.e., finite in volume), but Hawking later determined that an ‘open’ Universe was also possible.

Still very much a public figure, Hawking turned to writing books for lay readers. *A Brief History of Time* came out in 1988 and stayed on the British *Sunday Times* best-seller list for a record 237 weeks. Some 25 million copies were sold in 40 languages. Hawking then wrote *The Universe in a Nutshell* in 2001 and co-authored *A Briefer History of Time* in 2005 with Leonard Mlodinow, an American physicist who had also written screenplays for *Star Trek: The Next Generation*.

In 1997, Hawking and his old Caltech friend, Kip Thorne (centre), made a public bet with John Preskill (left), also of Caltech, over the ‘black hole information paradox’. Thorne and Hawking argued, that since general relativity does not allow black holes to radiate and lose information, the mass-energy and information in Hawking radiation must be new and does not originate from inside the black hole’s event horizon. Since this contradicted the quantum concept of microcausality, quantum mechanics would need to be rewritten. Preskill argued the opposite, that since quantum mechanics suggests that the information emitted by a black hole relates to information that fell in at an earlier time, the view of black holes given by general relativity must be modified in some way. The winner of the bet was to receive an encyclopedia of the loser's choice. In 2004, Hawking conceded the bet, saying that he now believed that event horizons leak information when they fluctuate. Hawking gave Preskill a copy of an encyclopedia on baseball but Thorne still considers the matter to be undecided.

Hawking has won more medals and honours over the years than time permits to mention. Starting with the Eddington Medal of the Royal Astronomical Society (1975) and the Hughes Medal of the Royal Society of London (1976), he then received the royal honours of Commander of the Order of the British Empire (1982) and Companion of Honour (1989). He also received the Albert Einstein Medal from Switzerland, the Wolf Prize in Physics from Israel (1988) and the Lilienfeld Prize from the American Physical Society (1999). In 2009, Barack Obama presented him with the Presidential Medal of Freedom, the highest civilian honour in the United States.

Hawking had needed full-time care from 1985 onwards. He separated from his wife, Jane, in 1990 and married his personal care assistant, Elaine Mason, in 1995. They were divorced in 2006, which enabled him to reconcile with his children. Jane published a memoir, *Music to Move the Stars*, about their marriage and its breakdown, which was revised in 2010 as: *Travelling to Infinity, My Life with Stephen*. Hawking co-authored four children's books with his daughter, Lucy. With titles like George and the Big Bang, you can guess what they were like.

So, the man who once feared he wouldn't live long enough to finish his PhD thesis is now 70 years of age. While he is no longer the Lucasian Professor, Hawking is still the Research Director of Cambridge's Centre for Theoretical Cosmology. Now few of his former students and collaborators have gone on to do distinguished work in their various fields. We need to honour his brilliant achievements, his sheer determination and, perhaps most importantly, his commitment to science and progress.

[Closing Words]

For millions of years, mankind lived just like the animals. Then something happened which unleashed the power of our imagination. We learned to talk and we learned to listen. Speech has allowed the communication of ideas, enabling human beings to work together to build the impossible. Mankind's greatest achievements have come about by talking, and its greatest failures by not talking. *It doesn't have to be like this.* Our greatest hopes could become reality in the future. With the technology at our disposal, the possibilities are unbounded. All we need to do is make sure we keep talking.

British Telecom advertisement (1993), part of which was used in Pink Floyd's *Keep Talking* (1994).