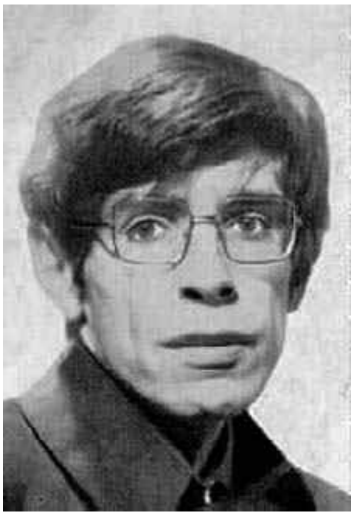
MATEMÁTICOS ACTUALES

# Stephen William Hawking, en la historia del tiempo

Stephen Hawking fue uno de los físicos teóricos más importantes del mundo, famoso por su trabajo sobre los agujeros negros.



Los padres de Stephen Hawking vivían en Londres, donde su padre estaba realizando una investigación en medicina. Sin embargo, Londres fue un lugar peligroso durante la Segunda Guerra Mundial y la madre de Stephen fue enviada a la ciudad más segura de Oxford, donde nació Stephen. La familia pronto volvió a estar unida y vivió en Highgate, al norte de Londres, donde Stephen comenzó sus estudios.

En 1950, el padre de Stephen se trasladó al Instituto de Investigación Médica en Mill Hill. La familia se mudó a St Albans para que el viaje a Mill Hill fuera más fácil. Stephen asistió a la escuela secundaria para niñas de St Albans (que tomó niños hasta la edad de 10 años). Cuando fue mayor asistió a la escuela de St Albans, pero su padre quería que tomara el examen de beca para ir a la escuela pública de Westminster. Sin embargo, Stephen estaba enfermo en el momento de los exámenes y permaneció en la escuela de St Albans, a la que había asistido desde los 11 años. Stephen escribe en [Referencia 2]:

> *Allí obtuve una educación tan buena, si no mejor, como la que hubiera tenido en Westminster. Nunca he descubierto que mi falta de agrado social haya sido un obstáculo.*

Hawking quería especializarse en matemáticas en sus últimos años en la escuela, donde su profesor de matemáticas lo había inspirado a estudiar la materia. Sin embargo, el padre de Hawking estaba fuertemente en contra de la idea y Hawking fue persuadido de hacer de la química su materia principal de la escuela. Parte del razonamiento de su padre era que quería que Hawking fuera a University College, Oxford, la universidad a la que él mismo había asistido, y que la universidad no tenía un compañero de matemáticas.

En marzo de 1959 Hawking tomó los exámenes de becas con el objetivo de estudiar ciencias naturales en Oxford. Recibió una exposición, a pesar de sentir que se había desempeñado mal, y en el University College se especializó en física en su título de ciencias naturales. Acaba de obtener un título de Primera Clase en 1962 y en [Referencia 1] explica cómo la actitud de la época funcionó en su contra:

> *La actitud predominante en Oxford en ese momento era muy anti-trabajo. Se suponía que debías ser brillante sin esfuerzo, o aceptar tus limitaciones y obtener un título de cuarta clase. Trabajar duro para obtener una mejor clase de título se consideraba la marca de un hombre gris, el peor epíteto en el vocabulario de Oxford.*

De Oxford, Hawking se mudó a Cambridge para dedicarse a la investigación en relatividad general y cosmología, un área difícil para alguien con poca formación matemática. Hawking se había dado cuenta de que se estaba volviendo bastante torpe durante su último año en Oxford y, cuando regresó a casa para la Navidad de 1962 al final de su primer período en Cambridge, su madre lo convenció de que acudiera a un médico.

A principios de 1963 pasó dos semanas sometiéndose a pruebas en el hospital y le diagnosticaron una enfermedad de la neurona motora (enfermedad de Lou Gehrig). Su condición se deterioró rápidamente y los médicos predijeron que no viviría lo suficiente para completar su doctorado. Sin embargo, Hawking escribe:

> *... aunque había una nube sobre mi futuro, descubrí para mi sorpresa que estaba disfrutando de la vida en el presente más que antes. Comencé a avanzar con mi investigación ...*

La razón por la que progresó su investigación fue que conoció a una chica con la que quería casarse y se dio cuenta de que tenía que completar su doctorado para conseguir un trabajo, así que:

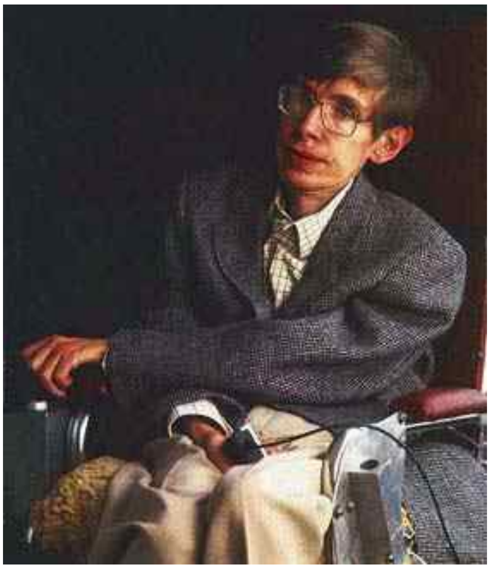
> *... Entonces comencé a trabajar por primera vez en mi vida. Para mi sorpresa, descubrí que me gustaba.*

Después de completar su doctorado en 1966, Hawking obtuvo una beca en Gonville and Caius College, Cambridge. Al principio, su puesto fue el de investigador, pero luego se convirtió en profesor en Gonville and Caius College. En 1973 dejó el Instituto de Astronomía y se incorporó al Departamento de Matemática Aplicada y Física Teórica de Cambridge. Se convirtió en profesor de Física Gravitacional en Cambridge en 1977. En 1979, Hawking fue nombrado Profesor Lucasiano de Matemáticas en Cambridge. El hombre nacido 300 años después de la muerte de Galileo ahora ocupaba la cátedra de Newton en Cambridge.

Entre 1965 y 1970 Hawking trabajó en singularidades en la teoría de la relatividad general ideando nuevas técnicas matemáticas para estudiar esta área de la cosmología. Gran parte de su trabajo en esta área se realizó en colaboración con

Roger Penrose quien, en ese momento, estaba en Birkbeck College, Londres. A partir de 1970, Hawking comenzó a aplicar sus ideas anteriores al estudio de los agujeros negros.

Continuando con este trabajo sobre los agujeros negros, Hawking descubrió en 1970 una propiedad notable. Usando la teoría cuántica y la relatividad general, pudo demostrar que los agujeros negros pueden emitir radiación. Su éxito al demostrar esto le hizo trabajar desde ese momento en la combinación de la teoría de la relatividad general con la teoría cuántica. En 1971, Hawking investigó la creación del Universo y predijo que, después del Big Bang, muchos objetos eran tan pesados como $10^9$ toneladas, pero solo se habría creado el tamaño de un protón. Estos mini agujeros negros tienen una gran atracción gravitacional gobernada por la relatividad general, mientras que las leyes de la mecánica cuántica pueden, asimismo, aplicarse a estos objetos.



Otro logro notable de Hawking al usar estas técnicas fue su "propuesta sin límites" hecha en 1983 con Jim Hartle de Santa Bárbara. Hawking explica que esto significaría:

> *... que tanto el tiempo como el espacio son finitos en extensión, pero no tienen ningún límite o borde. ... no habría singularidades, y las leyes de la ciencia se mantendrían en todas partes, incluso al comienzo del universo.*

En 1982, Hawking decidió escribir un libro popular sobre cosmología. En 1984 había elaborado un primer borrador de *Breve historia del tiempo*. Sin embargo, Hawking iba a sufrir otra enfermedad:

> *Estuve en Ginebra, en el CERN, el gran acelerador de partículas, en el verano de 1985. ... Cogí una neumonía y me llevaron de urgencia al hospital. El hospital de Ginebra le sugirió a mi esposa que no valía la pena mantener encendida la máquina de soporte vital. Pero ella no aceptaba nada de eso. Me llevaron en avión de regreso al Hospital Addenbrooke en Cambridge, donde un cirujano llamado Roger Gray realizó una traqueotomía. Esa operación me salvó la vida pero me quitó la voz.*

Hawking recibió un sistema informático que le permitía tener una voz electrónica. Fue con estas dificultades que revisó el borrador de *Una breve historia del tiempo* que se publicó en 1988. El libro rompió récords de ventas de una manera que hubiera sido difícil de predecir. En mayo de 1995 había estado en la lista de los más vendidos del Sunday Times durante 237 semanas, rompiendo el récord anterior de 184 semanas. Esta hazaña está registrada en el Libro Guinness de los Récords de 1998. También consta el hecho de que la edición de bolsillo se publicó el 6 de abril de 1995 y alcanzó el número uno de los más vendidos en 3 días. En abril de 1993 había 40 ediciones de tapa dura de *A Brief History of Time* en los Estados Unidos y 39 ediciones de tapa dura en el Reino Unido.

En 2002 Hawking publicó *Sobre los hombros de gigantes. Las grandes obras de la física y la astronomía*. Este libro, que él mismo editó, contiene reimpresiones de ediciones casi completas de: Copérnico, Sobre la revolución de las esferas celestiales (1543); Galileo, Diálogos sobre dos nuevas ciencias (1638); Kepler, Armonía del mundo (libro cinco) (1618); Newton, Principia (1687); y siete artículos sobre relatividad de Einstein. Cada obra está precedida por un comentario de Hawking. También del 7 al 10 de enero de 2002 se llevó a cabo un taller y un simposio en Cambridge para celebrar el 60 aniversario de Hawking. El procedimiento se publicó en 2003 y James T Liu escribe en una reseña:

> *Si bien muchos físicos, cosmólogos y astrónomos destacados han hecho contribuciones importantes al estudio de la gravedad cuántica y la cosmología, el impacto de las contribuciones de Stephen Hawking al campo realmente se destaca. Aunque su trabajo sobre la termodinámica de los agujeros negros es quizás el más conocido, Hawking también ha hecho importantes contribuciones al estudio de los teoremas de singularidad en la relatividad general, la unicidad de los agujeros negros, los campos cuánticos en los espaciotiempos curvos, la gravedad cuántica euclidiana, la función de onda del universo. y muchas otras áreas también. Además de su propio trabajo, Hawking se ha desempeñado como asesor y mentor de un grupo notable de estudiantes. Además, sería difícil imaginar reunir una lista de investigadores que trabajen en cosmología cuántica sin incluir a un gran número de estudiantes y colegas cercanos de Hawking. Así, el grupo que se reunió en el CMS en Cambridge en honor a su 60 cumpleaños incluye a algunos de los principales teóricos en el campo.*

En 2005, Hawking publicó *La pérdida de información en los agujeros negros*, en la que propuso una solución a la paradoja de la pérdida de información. Ese mismo año se publicó *Los agujeros negros y la paradoja de la información*, que es la transcripción de la famosa charla que pronunció Hawking en la XVII Conferencia Internacional sobre Relatividad General y Gravitación en Dublín en 2004. En 2007 publicó *Dios creó los números enteros. Los avances matemáticos que cambiaron la historia*. Esta es otra antología editada por Hawking que contiene selecciones de los escritos de veintiún matemáticos. Para cada matemático da una breve biografía y pone la selección en su contexto matemático.

Por supuesto, Hawking ha recibido, y sigue recibiendo, una gran cantidad de honores por sus notables logros. Fue elegido miembro de la Royal Society en 1974, siendo uno de sus miembros más jóvenes. En 1975 fue galardonado con la Medalla Eddington, en 1976 recibió la Medalla Hughes de la Royal Society, en 1979 recibió la Medalla Albert Einstein, en 1982 fue nombrado Comandante de la orden del Imperio Británico por la Reina, en 1985 recibió el Medalla de Oro de la Real Sociedad Astronómica, y en 1986 fue elegido miembro de la Pontificia Academia de Ciencias. Continuó recibiendo importantes distinciones como el prestigioso Premio Wolf de Física en 1988. Al año siguiente recibió los Premios Príncipe de Asturias en Concordia y también fue nombrado Compañero de Honor. En 1999 recibió el premio Julius Edgar Lilienfeld de la American Physical Society:

> *... por la audacia y la creatividad en la física gravitacional, mejor ilustrada por la predicción de que los agujeros negros deberían emitir radiación de cuerpo negro y evaporarse, y por el regalo especial de hacer que las ideas abstractas sean accesibles y emocionantes para expertos, generalistas y el público por igual.*

En 2003 Hawking recibió el premio Michelson Morley de la Case Western Reserve University y en 2006 la medalla Copley de la Royal Society. Este último premio, anunciado el 24 de agosto de 2006, fue entregado a Hawking el 30 de noviembre de 2006 en el Día del Aniversario anual de la Sociedad, que conmemora la fundación de la Sociedad en 1660. Este fue el 275º aniversario de la Medalla Copley y el premio a Hawking fue marcado de una manera única. La medalla que recibió había sido llevada por el astronauta británico Piers Sellers en una misión del Transbordador Espacial a la Estación Espacial Internacional. Martin Rees, presidente de la Royal Society, dijo:

> *Stephen Hawking ha contribuido tanto como cualquiera desde Einstein a nuestra comprensión de la gravedad. Esta medalla es un reconocimiento digno de una asombrosa carrera investigadora que abarca más de 40 años.*

Piers Sellers dijo:

> *Stephen Hawking es un héroe definitivo para todos los que participamos en la exploración del Cosmos. Su contribución a la ciencia es única y sirve de inspiración continua para toda persona pensante. Fue un honor para la tripulación de la misión STS-121 llevar su medalla al espacio. Creemos que esto es particularmente apropiado ya que Stephen ha dedicado su vida a pensar en el Universo más grande.*

En respuesta, Hawking dijo:

> *Esta es una medalla muy distinguida. Fue otorgado a Darwin, Einstein y Crick. Me siento honrado de estar en su compañía.*


Basado en el artículo de JJ O'Connor y EF Robertson
http://www-history.mcs.st-and.ac.uk/Biographies/Hawking.html
casanchi.com

**Referencias:**


1. Biography in *Encyclopaedia Britannica.* http://www.britannica.com/biography/Stephen-W-Hawking
2. S Hawking, *Black Holes and Baby Universes and Other Essays* (London, 1993).


**Referencias cruzadas:**

History Topics: A history of time: 20th century time

---

Ideas about time have changed dramatically in the $20^{th}$ century. At the beginning of the century time was viewed as Newton's universal, absolute, mathematical time. There had been remarkable progress towards more and more accurate measurement and at the beginning of the century pendulum clocks had been perfected to the extent that they recorded time to an accuracy of less than \large\frac{1}{100}\normalsize1001 of a second error in a day.

We begin our consideration of the $20^{th}$ century revolution in understanding time by first looking at those who began to question Newton's absolute time in the latter part of the $19^{th}$ century. In 1870 Carl Neumann questioned Newton's law of inertia. He considered a universe in which there was only one particle and asked what Newton's law of inertia meant in such circumstances. How did one know if the particle was moving in a straight line when there was no other reference point. He then introduced the idea of an inertial clock. If a particle is known to not be acted on by any forces then its motion can be used as an inertial clock. Equal time intervals would correspond to equal distances moved by the particle. However, how can we tell that a particle is not subject to forces?

P G Tait answered Carl Neumann's problem of the inertial clock in 1883 and in doing so he essentially showed that Newton's absolute space was an unnecessary concept, for he could create an absolute space framework. He did assume that positions of particles in different places could be measured at the same instant so he in effect used absolute time to define absolute space.

Mach published a history of mechanics in 1883. In it he argued strongly against Newton's idea of absolute space and absolute time. Newton argued that inertial motion was relative to absolute space but instead Mach argued that inertial motion was relative to the average of all the mass in the universe. As far as time was concerned Mach wrote:
*It is utterly beyond our power to measure the changes of things by time. Quite the contrary, time is an abstraction, at which we arrive by means of the changes of things.*
So according to Mach time is change and only relative distances are significant.

In 1898 Poincaré wrote a paper in which he asked two highly significant questions about time. Is it meaningful to say that one second today is equal to one second tomorrow? Is it meaningful to say that two events which are separated in space occurred at the same time? We should not give the impression that nobody before Poincaré had thought of these questions for these ideas had been discussed. However, it is certainly fair to say that Poincaré pointed to the problems much more clearly than anyone had before. The first of Poincaré's questions still has not received a satisfactory answer but the second of his questions was answered by Einstein only a few years after Poincaré's paper.

In 1902 Poincaré wrote another paper relevant to our topic. In this he asked what information is required to predict the future. By this he was thinking about Laplace's realisation that Newton's laws completely determined the future if the position, mass and movement of every particle were known. Laplace was, of course, right, but Newton on the other hand had based his theory on absolute space and absolute time and the positions and velocities of the particles were given with respect to this absolute coordinate system. Poincaré, however, was thinking in a relativistic manner and asked what information was needed if all that one were given were relative quantities. If, for example, the universe consisted of exactly three particles and all that were known were the relative velocities, what then?

Although Poincaré was thinking deeply about relativity before Einstein, it was the latter who made the final breakthrough. Einstein decided that time was the whole key to understanding the universe, see [14]. He wrote:
*My solution was really for the very concept of time, that is, that time is not absolutely defined but there is an inseparable connection between time and the velocity of light.*
The impact of the special theory of relativity on the understanding of time was enormous. The foundations on which the theory is based are remarkably simple. Einstein required the laws of physics to be the same for any two observers moving at a constant speed, that is not acted on by forces, and also that the speed of light is independent of the speed of its source. Looked at another way he assumed that there was no absolute space and time, but that the laws were the same in any inertial frame. Suppose we have two observers A*A* and B*B* in different inertial frames, that is each is travelling at a constant velocity not acted on by any forces. Each of A*A* and B*B* has a master clock which we can think of as the time in their particular inertial frame and clocks in A*A*'s inertial frame can be synchronised. Similarly clocks in B*B*'s inertial frame can be synchronised. The amazing consequence is that two events which are simultaneous in A*A*'s frame will not appear simultaneous in B*B*'s frame. These results, although experimentally verifiable, still seem counter-intuitive to people.

There were other remarkable effects on time with special relativity. Time was affected by velocity. A body travelling close to the velocity of light experiences time dilation. What does this mean? We must think about this statement clearly for, with no absolute space to measure velocity against, how can a body move at close to the velocity of light? Let us be more precise. If two bodies A*A* and B*B* are moving apart at close to the velocity of light then someone sitting on A*A* would experience time normally, and someone sitting on B*B* would also experience time normally. However, if someone sitting on A*A* could view a clock on B*B* then it would appear to run very slowly, and similarly if someone sitting on B*B* could view a clock on A*A* then it would appear to run very slowly.

These results have now been verified experimentally but we should pause for a moment to think about certain problems which remain. What does the phrase "experience time normally" mean? Does a clock running slowly mean that time is running slowly? We still do not know what time is and we are identifying it with something determined by a clock, either some device or our biological clock. All we can say on this point is that all types of clocks appear to agree on time dilation and if we cannot identify time with clocks then we need a major new idea which is still totally missing.

On 21 September 1908 Minkowski began his famous lecture at the University of Cologne with these words:
*The views of space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.*
He also said:
*Nobody has ever noticed a place except at a time, or a time except at a place.*
Weyl quickly understood the new notion that Minkowski put forward. He wrote:
*The scene of action of reality is ... a four-dimensional world in which space and time are linked together indissolubly. However deep the chasm that separates the intuitive nature of space from that of time in our experience, nothing of this qualitative difference enters into the objective world which physics endeavours to chrystalise out of direct experience. It is a four dimensional continuum, which is neither "space" nor "time".*
Before we move on from special relativity, we must consider one aspect which seems particularly difficult in Minkowski's 4-dimensional space-time, and indeed in any version of relativity. Since time is only meaningful for a single observer, with different observers at different places having their own local times, what does "now" mean. Einstein believed that this was a human concept which was not meaningful in the mathematical description of the universe. Rudolf Carnap reported Einstein's views:
*Einstein said that the problem of the "now" worried him seriously. He explained that the experience of the "now" means something special for people, something essentially different from the past and future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation.*

In fact Einstein wrote:-
*... there is something essential about the "now" which is outside the realm of science.*
In fact all relativity seems to have done is to make us realise that time is a much more difficult concept than Newton's absolute time. However it has made no contribution to answering the fundamental question "what is time?".

General relativity incorporated gravitation into the space-time theory. This had some further remarkable implications for time. Not only was time affected by velocity, as special relativity showed, but time was also affected by a massive body. The Earth is a massive body but not massive enough to have a large effect on the passage of time. In fact a clock on the surface of the Earth will run more slowly than a clock which is not subjected to gravitational forces. The amount is very small however, and our Earth clock will loose about \large\frac{1}{1000000000}\normalsize10000000001 of a second in an hour. In fact the difference in the rate at which clocks run at the top of a high building compared with at the bottom has now been measured. As we mentioned the gravitation of the Earth is small compared with some astronomical objects such as neutron stars. Such objects consist of atoms which have collapsed under the force of gravity. The time dilation at the surface of a neutron star is very significant, and a clock there would run 20% slower than on the surface of the Earth. The ultimate in gravitation occurs with a black hole and with such an object gravity is so strong that time effectively stops.

We have already talked about experiments capable of detecting time differences of \large\frac{1}{1000000000}\normalsize10000000001 of a second in an hour. We began this article by noting that at the beginning of the 20$^{th}$ century time could be measured to an accuracy of around \large\frac{1}{1000}\normalsize10001 of a second in an hour. This was achieved with a nearly free pendulum clock. We should now look at the revolution in clocks that occurred.

The free pendulum is one which is completely free from mechanical tasks, such as being part of the driving mechanism of the clock, that would stop it from being completely regular. R J Rudd introduced a genuine free pendulum clock in 1898, then W H Shortt introduced a clock with two pendulums in 1921. One pendulum was a true free pendulum, the other was part of the driving mechanism of the clock. In 1928 a totally new type of clock was built by W A Marrison at Bell Laboratories, namely the quartz crystal clock. These are widely used today and are mechanical devices which utilise the fact that a quartz crystal vibrates at a standard frequency in an electric field.

In 1949 the National Bureau of Standards in the United States built the first atomic clock, using ammonia. In around 1960 the cesium atom was in use in atomic clocks. The accuracy was such that by 1967 the second was changed from its original astronomical definition as a fraction of a day, to a definition where the second was given as 9,192,631,770 oscillations of the cesium atom's resonant frequency. By 1993 the National Institute of Standards and Technology in the United States had built an atomic clock accurate to five parts in 10^{15}1015.

Let us now look at another revolution in time which took place in the 20$^{th}$ century with the discovery of quantum mechanics, see [10]. It is really impossible in an article such as this to cover all aspects of time in relation to quantum theory but we will look at one or two issues to gain a feeling for their relation. The first point to note is that quantum theory was developed within the absolute time scenario of Newton.

Heisenberg discovered the Uncertainty Principle in 1927. This states, in its best known form, that there is a lower limit to the product of the uncertainty in a particle's position and the uncertainty in its momentum so that the more accurately one is able to measure the position of a particle, the more uncertainty there is in the knowledge of its momentum. Even in this form it has a direct consequence for aspects of time we have already discussed, for it means that Laplace's realisation that Newton's laws meant that the future was completely determined by the present would not extend to quantum theory. In practice, predicting the future from Newton's laws was impossible but theoretically it could be done. However the Uncertainty Principle meant that it was not theoretically possible to know the present with the arbitrary degree of accuracy needed to predict the future.

The Uncertainty Principle also connects other pairs of quantities in the same way. For example the uncertainty in the energy of a particle and the time at which this energy is measured cannot both be determined to an arbitrary degree of accuracy. The more precisely one determines the time at which the energy is measured, the less accurately one can know that energy. Einstein was deeply unhappy about the Uncertainty Principle for it meant that the world could never be described with complete accuracy and he felt that it should not be so. He devised a number of thought experiments to try to disprove the Uncertainty Principle and posed them as challenges to Niels Bohr. The most famous one was the clock in the box which Einstein presented at the 1930 Solvay Conference in Brussels. Before we describe it, however, we should stress that the Uncertainty Principle is not about practical problems of measurement but about theoretical uncertainty. The point of Einstein's "clock in the box" thought experiment was to argue a theoretical case. The fact that it would be impossible in practice to carry out the experiment is not relevant.

Einstein's "clock in the box" consists of a box suspended from a spring. The box contains a clock which operates a shutter. There is a scale beside the box and a pointer attached to the box to measure its height. Clearly if the box has a weight added the spring stretches and the pointer comes down the scale. Similarly if the box becomes lighter then the spring will lift the box up and the pointer will move up the scale. The experiment as proposed by Einstein was to open the shutter for a very brief period and allow one particle to escape. We can fix the time of the escape as accurately as we want by having the shutter open for as short a period as we want. But, claimed Einstein, we can measure the energy of the particle as accurately as we want for its energy is determined by its mass and so we measure the mass by attaching a weight to the bottom of the box to bring the pointer back to its original position. The clever feature was that the time and the energy were calculated independently.

At first the "clock in the box" worried Bohr, but he soon realised how the Uncertainty Principle operated in this case. To weigh the particle one must measure the position of the pointer at rest on the scale. But deciding the pointer is at rest and measuring its position are subject to the Uncertainty Principle. The more accurately we determine that the pointer is at rest, the less accurate will be our determination of its position. There is a second uncertainty in this experiment. If we cannot measure the height of the box to arbitrary precision, we cannot measure the height of the clock inside the box with arbitrary precision, so we do not know the rate of the clock with arbitrary precision (by Einstein's own general relativity results).

In the "clock in the box" thought experiment we have seen how relativity and quantum theory begin to interact. Several early attempts to bring the two theories together revolved round the problem of time. Milne developed a complex theory of cosmology, attempting to unify relativity and quantum theory, that included a non-constant value for $G$, which we know as the gravitational constant. In order to account for this, Milne actually developed two separate time scales: kinematic time $t$ and Newtonian time $\tau$. The two time scales were related by the following relation:

$$\tau = \log(t/t_{0}) + t_{0}$$

where $t_{0}$ is the present epoch. For us, $t$ is always equal to $t_{0}$ and thus $G$ was reduced to a constant. The result for Milne's cosmology was a stationary universe with an infinite past age which, of course, acted as a precursor to the steady-state theory. It also meant that there were an infinite number of particles in the universe, a result Milne felt was untestable. Milne interpreted this as meaning there were two "realities" each following a different time scale and that any questions dealing with "reality" were scientifically illegitimate.

Dirac tackled a similar problem in his development of his Large Numbers Hypothesis. He was forced to initially create two time scales, much like Milne, one being atomic and the other being global (Newtonian). Atomic time was supposed to describe radioactive decay while global time would be applied to large-scale phenomena. Dirac was forced into this conclusion based on results of the Large Numbers Hypothesis that threw off age calculations of the Moon and Sun. He also had a changing value for $G$, though his decreased while Milne's increased. Dirac later abandoned the dual time scale idea.

There are ways that quantum theory time appears to contradict relativity time, and this is worrying. The idea was first put forward by Einstein, together with Nathan Rosen and Boris Podolsky in 1935 and it is known by the initials of its proposers as the EPR experiment. It relies on the fact that a quantum event sometimes creates a pair of particles with complementary properties - for example they must have opposite spins. In quantum theory the particle will have the properties of both possible states until we measure it when it collapses into one of the two states. However, when we measure one particle and it collapses into one state, the other particle must instantly have the complementary property. Einstein firmly believed that no information could be transmitted faster than the speed of light, and saw this as an objection to quantum theory. The EPR experiment in this form, however, did not seem possible to test.

John Bell sharpened the EPR experiment in the 1960s by devising a way to check that the particles had all possible states until tested. The classical theory (or a common sense theory) would say that the two particles had definite states when created, it was just that we do not know what they are until we test one of them. Bell discovered "Bell's inequalities" which would hold in the classical case. If such an experiment could be carried out it would verify whether the particles only chose their state when tested but at the time Bell proposed his version the experiment was beyond existing experimental techniques. In the early 1980s Alain Aspect successfully carried out the experiment at Orsay in Paris. He showed that Bell's inequalities were violated and so the quantum interpretation held rather than the classical one. The implications are, however, that when one particle is tested and chooses a particular state, its partner must chose the complementary state at the same instant. This violates the basic principle of relativity that no information can be transmitted faster than the speed of light. The implications for "time" are still not fully understood.

An interpretation of quantum theory put forward by Hugh Everett in 1957 is the many worlds interpretation. In this the universe splits into two every time a quantum event is forced to choose between two states. What is the effect of this theory on time? In [3] Deutsch supports the many worlds interpretation and argues against the idea that time is flowing from past to present to future. His argument against this is that to measure how the present moves forward one would need a second "time" against which to measure the progress our standard time. Again to measure this second time's flow one would need a third time and so on. Deutsch presents a universe consisting of snapshots, rather than a continuous progression with the flowing of time.

Other ideas consider that instead of space-time being four dimensional, there are many more dimensions. Such theories attempt to unify all the theories of physics under a single mathematical framework. In such high dimensional spaces time travel seems a possibility but we will not look at this possibility in this essay. It is, however, reasonable to ask if there is more than one time dimension. What would it mean if we lived in a universe where time was two dimensional?

Hawking has presented some ideas concerning imaginary time; see for example [7] and [4]. He writes in [7] about a model for time/size of universe as a sphere:
*... with the distance from the North Pole representing imaginary time and the size of the circle of constant distance from the North Pole representing the spatial size of the universe. The universe starts at the North Pole as a single point. As one moves south, the circles of latitude at constant distance from the North Pole get bigger, corresponding to the universe expanding with imaginary time. ... Even though the universe would have zero size at the North and South Poles, these points would not be singularities. ... The laws of science will hold at them ... The history in real time, however, will look very different...*
After describing the real time appearance as beginning in a singularity he then wonders which is the "real" time:
*This might suggest that the so-called imaginary time is really the real time, and that what we call real time is just a figment of our imaginations. In real time, the universe has a beginning and an end in singularities that form a boundary to space-time and at which the laws of science break down. But in imaginary time, there are no singularities or boundaries. so maybe what we call imaginary time is more basic, and what we call real time is just an idea we invent to help us describe what we think the universe is really like.*
Penrose, in [6], takes a different approach but reaches similar conclusions about our perception of time:
*The temporal ordering that we 'appear' to perceive is, I am claiming, something that we impose upon our perceptions in order to make sense of them in relation to the uniform forward time-progression of an external physical reality.*
Time is a fascinating topic and new ideas are continually being put forward. It is still perhaps the most mysterious property of the universe.

---

1. History Topics: The development of the 'black hole' concept
2. Black holes as we understand them today have faced a lot of opposition since the conception of the idea, even from those who worked extensively on them. Initially based solely in the workings of mathematics and the imagination, they have since become a widely celebrated and heavily studied, serious area of science.
3. NASA defines a black hole to be
4. *"a place in space where gravity pulls so much that even light can not get out."*[1]
5. Thus to consider the origins of the development of the black hole concept, the understanding of gravity, and also of light, must be considered.
6. The publication of Isaac Newton's *Philosophiæ Naturalis Principia Mathematica* in **1687** set out his ideas on the notion of gravity, outlining his law of universal gravitation. This law states that every body attracts every other body by a force acting along the line connecting their centres of gravity. This force is directly proportional to the product of the two masses, and inversely proportional to the square of the distance separating their centres of gravity.
7. Written mathematically, this Law states that
8. $F = (G*m_1*m_2)/(r^2)$
9. where $F$ is the gravitational force acting between the two objects with masses $m_1$ and $m_2$ (in kilograms). The distance between the centre of gravity of each of the masses is denoted $r$, and $G$ is the universal gravitational constant, with value around $6.674\times10^{-11}$ N m$^2$ kg$^{-2}$.
10. With the fundamentals of gravity in tow, John Michell, having previously studied twin stars, in **1784** went on to propose the idea that there could exist a body sufficiently massive that even light could not escape.
11. At the time it was understood, largely because of Newton's promotion of the idea, that light consisted of particles (or corpuscles) that were projected from a source, and thus acted like any other projectile, i.e. could vary in speed. Therefore, it was believed that gravity could act on light accordingly, and, if a body was massive enough, its gravitational pull could prevent light from leaving a star to reach an observer's eye.
12. It was John Michell who first suggested the existence of such a physical body in his letter to Henry Cavendish, published in November 1784 in the Philosophical Transactions of the Royal Society of London. Michell referred to these objects as "dark stars"[2]. Earlier in the 18$^{th}$ century, English astronomer James Bradley had given a value for the speed of light: he'd calculated that it travelled at 301,000,000 m s$^{-1}$ (rather close to today's c = 299,792,458 m s$^{-1}$). Michell considered the reduction of the speed of the light particles from a given star in order to calculate its mass. He understood the concept of escape velocity (minimum initial velocity required to escape from a body's gravitational pull), thus questioned how massive a star would have to be for its escape velocity to be greater than the speed of light.
13. Michell's simplistic calculations assumed that the density of a "dark star" would be the same as that of the Sun, and concluded that such a body could form if the diameter of a star was greater than 500 times[3] that of the Sun making the escape velocity at the surface greater than the speed of light. Michell also noted that in order to detect these non-radiating bodies, one would have to observe the gravitational effects on nearby bodies (this is still a method used today).
14. However, at the time, it was not known that light travelled at a constant speed, as would be shown by Albert Einstein later. Thus the erroneous thought of light slowing down and falling back to the star's surface was not faced with objection. The notion of a black hole didn't really take off though

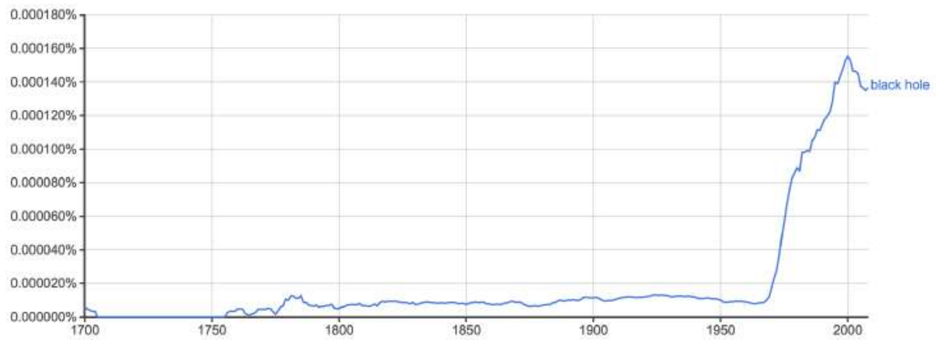
either; black holes were yet to enter their phase of popularity, and Michell's work went quite unnoticed until it resurfaced in the 1970s.

15. Furthermore, with the growing approval of light's wave-like nature, initialised by Robert Hooke and Christiaan Huygens in the late 17th century and progressed by Thomas Young in the early 19th century, it was unclear how gravity could influence light if it were a wave rather than a particle. Michell's idea lost popularity with the gain in that of light-waves.
16. Another mathematical 'proof' was however offered independently of Michell by Pierre-Simon Laplace in 1799 also in favour of what Michell had proposed, but with different conclusions on the ratios of density and size. Like Michell, Laplace was working with the assumption that light was formed of projectable particles. Moreover, his proof was only provided upon the insistence of German astronomer F.X. von Zach, who wanted more than the brief quantitative reasoning that was given in Laplace's original 1796 paper *Exposition du Système du Monde*. There is even some debate as to whether or not Laplace believed in black holes. In subsequent editions of *Système du Monde*, he removed his 'invisible-star' theory, and never mentioned it again. Perhaps he lost interest, or perhaps he too bought in to the light-as-a-wave theory, thus dispelling that current notion of a black hole.
17. Both Laplace and Michell were working with inadequate laws of light. They were also both wrong in their predictions of what stellar black holes were like.
18. *"They both went for the 'big star' option. But this was wrong. The black holes that have been found are all very small in size and very high in density."*[3]
19. Modern relativity rejects Michell's notion of light shooting directly from a surface, slowing due to gravity, and falling back again. This is because it's now understood that the speed of light remains constant in empty space, thus cannot slow down and stop in the conventional sense that a normal projectile can.
20. Little new was offered for the next century that would further the development of the concept of the black hole, and it would take some revolutionary thinking the restart its progression.
21. Einstein's Theory of General Relativity, published **1915**, regarded space and time as a curved four-dimensional object. No longer should space and time be considered absolute, but relative depending upon the observer's frame of reference. He argued this by postulating a constant velocity of light, regardless of an observer's frame of reference.
22. A constant velocity of light implies a relative time and space: suppose person 1 was on a train travelling 100 km $h^{-1}$ and they threw a ball vertically upward, let it drop, and caught it. In their frame of reference (on the train), the ball appears to have no horizontal velocity, i.e. it travels at 0 km $h^{-1}$ horizontally. Let person 2 not be on the train, rather, beside the track. Suppose they can see the ball and track its motion. Then from their frame of reference, the ball appears to move at a horizontal velocity of 100 km $h^{-1}$.
23. The difference between a ball and light, is that Einstein said light would always, no matter what frame of reference the observers were in, measure at the same velocity: *c*. With the train analogy, the difference in measured velocities of the ball from the two frames of reference is 100 km $h^{-1}$, however, with light, there is can be no difference in measurement, even if it were measured from a frame of reference travelling at almost the speed of light. Therefore, since velocity equals distance divided by time, if velocity is constant, distance and time must vary depending upon the frame of reference. In other words, distance and time are relative.
24. Rather than a force, Einstein viewed gravity as a warping of time and space. General relativity says that massive bodies bend the space around them,

causing objects to deviate from the straight line path they would have travelled with no forces acting upon them. This is often depicted as a mass sitting on a rubber sheet, thus stretching the center downwards. The greater the mass, the further down the rubber sheet is depressed. With a black hole, a sort of sink is formed on this rubber sheet due to the black hole's immense mass.

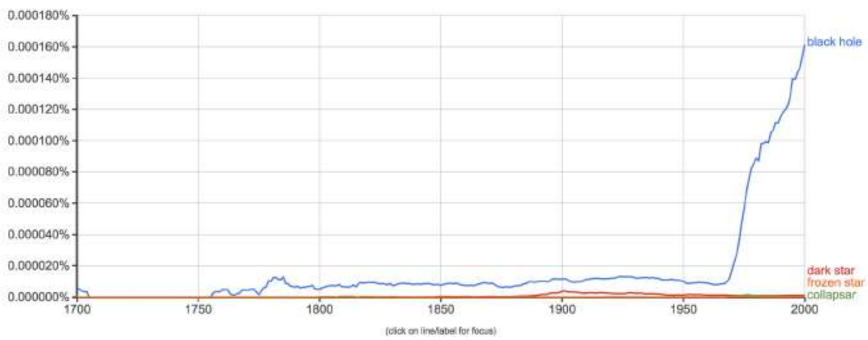
25. However, much like many before, and many after, who worked on the physics behind black holes, Laplace and Hawking included, Einstein doubted the existence of such a physical body being possible, due to the requirement of the physical existence of a singularity. While his formulae allowed for their existence, he did not believe that nature would. This was not uncommon of the time and to give the actual existence of black hole much serious consideration was dangerous for a scientist's career[4].
26. Einstein presented his general relativity with ten field equations that describe the impact of gravity in a curved space-time. While addressing the issue of Mercury's shifting perihelion, he was only able to give an approximate solution to his equations. It may then have come as a pleasant surprise to Einstein when only a month after the publication of his theory, he received a letter from German physicist Karl Schwarzschild with his exact solution to the field equations. Einstein wrote back in 1916:
27. *"I have read your paper with the utmost interest. I had not expected that one could formulate the exact solution of the problem in such a simple way. I liked very much your mathematical treatment of the subject. Next Thursday I shall present the work to the Academy with a few words of explanation."*[5]
28. Within his solution, Schwarzschild introduced what would become known as the *Schwarzschild radius*, the radius defining the event horizon of a black hole. It is given by the equation $r_s = (2*G*M)/(c^2)$ where $r_s$ is the *Schwarzschild radius*, $G$ is the universal gravitational constant, $M$ is the mass of the of the body (in kilograms), and $c$ is the speed of light.
29. Schwarzschild believed that the outward pressure exerted as matter was squeezed into a singularity would be sufficient to prevent a black hole actually forming. He reported that this problem of the formation of a black hole was
30. *"clearly not physically meaningful."*[6]
31. Despite all the mathematical theory that had been developed for centuries prior, it wouldn't be until after the mid-20th century that the possibility of a black hole's existence was generally accepted.
32. The debate over black holes' existence flared up between Indian American astrophysicist, then student of Cambridge University, Subrahmanyan Chandrasekhar, and English astronomer Arthur Eddington in the **1930s**.
33. Chandrasekhar had calculated that a white dwarf much heavier than the Sun couldn't exist, and that it would undergo a collapse into a singularity with infinite density. On 11th January 1935, with Eddington's apparent approval, Chandrasekhar was to deliver his results to a meeting of the Royal Astronomical Society in London. Little did he know, Eddington had prepared his own talk, and would give it directly following Chandrasekhar's.
34. Eddington belittled Chandrasekhar's argument, declaring that due to its solely mathematical basis, it had no bearing on the physical universe. How could something so large as a star effectively disappear? He upheld the view that white dwarfs could not totally collapse. Though Eddington's case was fairly unsubstantiated, the Briton's reputation prevented anyone from daring to openly disagree with him. Even Chandrasekhar was not given the chance to respond to Eddington's retort.
35. Their rivalry on the matter continued for some years. At a meeting in Paris in 1939, Eddington maintained his disapproval of Chandrasekhar's ideas,

despite the quiet, growing support for Chandrasekhar from the likes of Bohr, Pauli and Dirac. By this stage, it was widely believed that Eddington misunderstood the problem, thus he became largely ignored on this topic. At the meeting, Eddington claimed that there was no experimental test that could determine which of the two notions was correct, which was a valid point, but with astronomer and white dwarf expert Gerard Kuiper on hand to immediately refer to his work supporting Chandrasekhar, Eddington reluctantly apologised for hurting Chandrasekhar, but still refused to bow to his theory. Eddington's reluctance to accept what Chandrasekhar put forward supposedly had racial and sexuality-repressive undertones, as well as stemming from the fact that Chandrasekhar's argument's acceptance would totally discredit what Eddington had been claiming for many years. No doubt an element of pride was present.

36. This condemnation of Chandrasekhar's suggestions by such an esteemed figure as Eddington possibly delayed the development of the black hole concept by decades. No-one followed up the claims made by Chandrasekhar, and the Indian himself turned to other fields, leaving Cambridge, where he felt his life and career had been harassed by racism, for Chicago. However, Canadian physicist Werner Israel, who studied in depth the scientific temper of these times, rejects this, claiming that Eddington's support would have made little difference to the sway of public opinion of Chandrasekhar's theory. Regardless, it wouldn't be until 1983 that Chandrasekhar would be awarded for his work on white dwarfs, with the Nobel Prize.
37. Black holes hadn't even received their universal title until the 1960s. Previously known as 'darks stars', 'collapsars' and 'gravitationally completely collapsed objects'[a] to name a few terms, the expression 'black hole' is popularly attributed to physicist John Wheeler, who admitted the term was offered to him by an audience member of one of his lectures in 1967. The use of the words 'black hole' had previously been used in 1963 at an astrophysics conference in Dallas, as claimed[7] by science writer Marcia Bartusiak. Wheeler perhaps was merely the first with the scientific authority to use the phrase, hence its popularity took off and credit is often given to him. Just based on Google's Ngram viewer it can be seen that the use of the words 'black hole' in publications seemingly increased dramatically in and after the 1960s.
38. 

[8]
39. Chandrasekhar never opted to speculate what would happen to a star of sufficient mass, i.e. exceeding what would become known as the *Chandrasekhar limit*. This did not stop others from doing so however. Within two years of the discovery of the neutron by James Chadwick in 1932, German and Swiss astronomers respectively Walter Baade and Fritz Zwicky proposed the existence of the neutron star. Whilst studying the cause of supernovae, they concluded that during such explosions, ordinary stars are turned into stars consisting of extremely closely packed neutrons, hence their name neutron star. A supernova can occur when a white dwarf in a binary star system essentially steals matter from its partner, gaining too much mass. Its core temperature rises enough to cause runaway nuclear fusion. Similar conclusions on neutron stars were also made by Russian scientist Lev Davidovich Landau.

40. What's important is that at the time, a neutron star would be the densest object in the universe. Since their existence was treated with the same hesitation as with that of black holes, their observation would certainly help sway opinion over the possibility of the physical existence of black holes.
41. Moreover, just as Chandrasekhar had predicted an upper limit for white dwarfs, **1939** saw a paper in *Physical Review* by American theoretical physicist J. Robert Oppenheimer and his graduate student at University of California, Berkley, George Volkoff, in which they predicted an equivalent constraint on neutron stars. They did not however know what would occur if a star's mass passed this boundary.
42. Following up this research, this time with a different graduate student, Hartland Snyder, Oppenheimer determined that if a star's core was more massive than two or three solar masses, then the stellar remnant would neither become a white dwarf nor a neutron star. They calculated that the star would continue to contract indefinitely. Mathematically, they yielded singularities, the stuff of nightmares for physicists.
43. Though in this publication Oppenheimer and Snyder had offered the first modern description of black holes, the paper came out on 1st September 1939, the day of Germany's invasion of Poland triggering the start of the Second World War, and thus the paper received little attention.
44. At this time, very few astronomers were ready to believe that such strange objects could exist in the real world. Even Einstein attempted to prove the impossibility of their existence in his paper published in 1939[b], only a month after Oppenheimer and Snyder's. Though, Einstein had not even read Oppenheimer-Snyder, and his paper was considered as one of his worst. Stuck with the past's way of thinking, and with the teaching of relativity confined to the mathematics' departments rather than the physics' (or banned in total as throughout the Third Reich), most astronomers almost did not want such objects to be possible. It certainly helped their cause that there had yet to be any observations of neutrons stars, let alone of black holes.
45. Thus the work of British astronomer Jocelyn Bell can be considered important in the black hole concept's development. In **1967**, she, along with radio astronomer Antony Hewish, picked up radio pulses from an unknown source. Initially dubbed LGM-1 (for "Little Green Men 1", since they considered the source could be an extraterrestrial civilisation), it was later found to be a rapidly rotating neutron star - the first observational evidence that neutron stars existed. Most of the known neutron stars have been found by detecting their regularly emitted radio pulses.
46. It was around this time that the tide was turning toward general acceptance of the possible existence of bodies such as black holes. Again using Google's Ngram viewer, when compared to other names used before 'black hole' was popularised, it can be inferred that worldwide acceptance of the concept of a black hole really only took off after the 1960s, since that was the first time any of the terms used for the concept became frequently used in publications.




[9] [c]

47. More and more time and study was put into black holes, including those of British theoretical physicist Stephen Hawking. By the end of the 1960s, both Werner Israel and British mathematician Roger Penrose with John Wheeler had helped revolutionise the study of black holes.
48. Israel, using general relativity, showed that non-rotating black holes had to be very simple; they were perfectly spherical, their size depended upon their mass only, and any two such black holes with the same mass must be identical. He, and many others, believed that the only way a black hole, which had to be perfectly spherical,

could form was if it was created from the collapse of a perfectly spherical object. Thus any real star, which would never be perfectly spherical, would only ever collapse to form a naked singularity.

49. Penrose and Wheeler however argued that due to the rapid movements involved in a star's collapse, the gravitational waves given off would make it ever more and more spherical until it settled to a stationary state, where it would be perfectly spherical. It was this viewpoint that won out in the end, thanks also to similar supporting work from others. It became accepted that any black hole could be completely described with three properties: its mass, angular momentum, and electrical charge.
50. In 1970, Hawking, using quantum theory and general relativity, was able to show that black holes *can* actually emit radiation, giving a theoretical argument for their existence in **1974**. This is the prediction for what is now know as *Hawking Radiation*. By radiating, black holes conserve entropy, solving the incompatibility problem with the second law of thermodynamics. This added to the argument for their physical existence.
51. According to quantum physics, particle-antiparticle pairs are constantly being produced throughout the universe. What happens in nearly every case is that they almost instantly annihilate with each other, releasing energy into the universe. Hawking postulated that were such a particle pair to form near a black hole's event horizon, then before given the chance to annihilate, one of the pair could be dragged toward the black hole's singularity, while the other escapes. It is in this form that black holes are said to radiate. This challenges what general relativity says about nothing being able to escape from the clutches of a black hole. Moreover, Hawking stated that since a black hole radiates in such a manner, it shrinks, evaporating until it vanishes.
52. Naturally, as with most discoveries in this field, *Hawking Radiation* poses yet more unanswered questions. If a black hole shrinks, what happens to the information that was put into it? This leads to the information paradox since quantum mechanics says information cannot be deleted.
53. Despite all the doubt throughout the many years of work on black holes, the likelihood of their physical reality is almost certain. What is now widely accepted[10] as the first discovered black hole, *Cygnus X-1* was first 'seen' in 1964, and was generally recognised as a black hole by the **1990s**. It was the subject of a bet in 1974 between Hawking and American theoretical physicist Kip Thorne, which Hawking conceded in 1990, admitting that *Cygnus X-1* was indeed in all likelihood a black hole, based on the sufficient observational data they had.
54. Further support has been offered by the Hubble Space Telescope (HST) not just in verifying black holes' existence, but also in backing up claims made since the 1960s regarding galaxies each containing a supermassive black hole at their centre. Launched in 1990, the HST has allowed astronomers to conclude that black holes are probably common to the centres of all galaxies.
55. One of the latest observational discoveries in this field has come from the LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo Scientific Collaboration. Observed on 14th September 2015, the Collaboration announced on 11th February **2016** that they had made the first observational discovery of gravitational waves (disturbances in the curvature of space-time generated by accelerated masses). They had emerged from a collision of two black holes. This offered the first observational evidence for the existence of binary black hole systems. In 2017, Kip Thorne was one of three (Thorne, Barry Barish, Rainer Weiss) to receive the Nobel Prize for contribution to the detection of gravitational waves.
56. It is still unclear how singularities apply in reality. This poses the question over the limit of mathematics' ability to fully model nature. Alternatively, singularities imply that we have yet to develop a complete description of the universe and its workings: it may be that some of the notions we take as firm truths are just not quite correct.
57. The concept of a black hole has overcome a great deal of resistance to get to the point of acceptance it enjoys today. With its conceptual development, a large number of scientists have made their name bringing what was initially just a mathematical concept, ridiculed for its lack of physical meaning, into the forefront as one of astronomy's most exciting realities studied, questioning long held beliefs of the workings of the universe. Resistance was futile; black holes are inescapable.