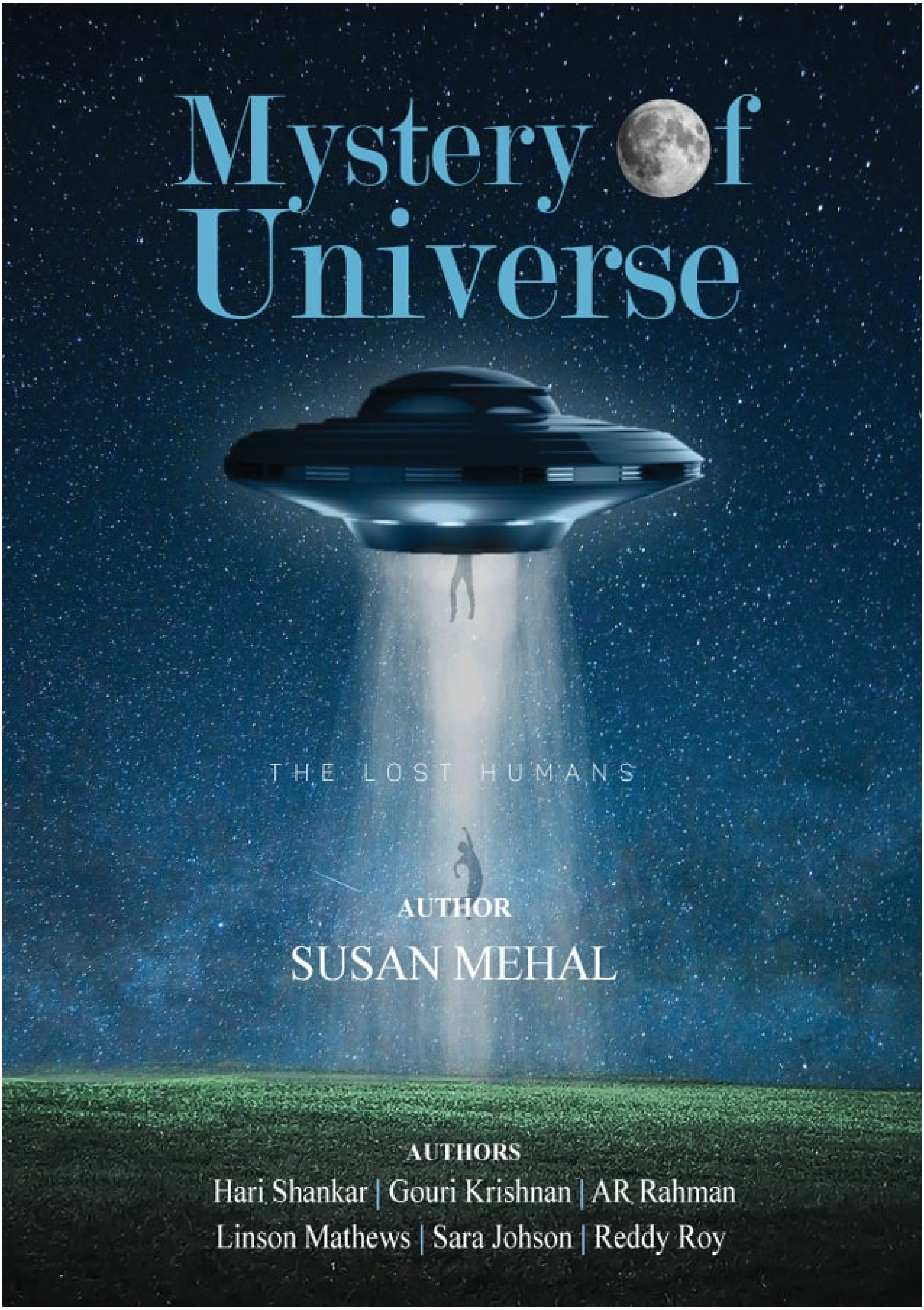


Mystery of Universe

THE LOST HUMANS

AUTHOR

SUSAN MEHAL

AUTHORS

Hari Shankar | Gouri Krishnan | AR Rahman
Linson Mathews | Sara Johson | Reddy Roy

This is

Mystery of Universe

Engaging storybook-style descriptions that explain key discoveries about the universe. More to Explore Once you've discovered The Mysteries of the Universe, dive into the companion titles from this series from DK Books!

Written by:

Ahmed

Nahla

Mohamed

Table of Contents

Chapters

Book Intro

Written by:

Ahmed

THIS VOLUME CONTAINS a collection of pieces that I wrote over the period 1976 to 1992. They range from autobiographical sketches through the philosophy of science to attempts to explain the excitement I feel about science and the universe. The volume concludes with the transcript of a Desert Island Discs program on which I appeared. This is a peculiarly British institution in which the guest is asked to imagine himself or herself cast away on a desert island and is invited to choose eight records with which to while away the time until rescued. Fortunately, I didn't have too long to wait before returning to civilization. Because these pieces were written over a period of sixteen years, they reflect the state of my knowledge at the time, which I hope has increased over the years. I have therefore given the date and occasion for which each was composed. As each was meant to be self-contained, there is inevitably a certain amount of repetition. I have tried to reduce it, but some remains. A number of the pieces in this volume were designed to be spoken. My voice used to be so slurred that I had to give lectures and seminars through another person, usually one of my research students who could understand me or who read a text I had written. However, in 1985 I had an operation that removed my powers of speech altogether. For a time I was without any means of communication. Eventually I was equipped with a computer system and a remarkably good speech synthesizer. To my surprise, I found I could be a successful public speaker, addressing large audiences. I enjoy explaining science and answering questions. I'm sure I have a lot to learn about how to do it better, but I hope I'm improving. You can judge for yourselves whether I am by reading these pages. I do not agree with the view that the universe is a mystery, something that one can have intuition about but never fully analyze or comprehend. I feel that this view does not do justice to the scientific revolution that was started almost four hundred years ago by Galileo and carried on by Newton. They showed that at least some areas of the universe do not behave in an arbitrary manner but are governed by precise mathematical laws.

Over the years since then, we have extended the work of Galileo and Newton to almost every area of the universe. We now have mathematical laws that govern everything we normally experience. It is a measure of our success that we now have to spend billions of dollars to build giant machines to accelerate particles to such high energy that we don't yet know what will happen when they collide. These very high particle energies don't occur in normal situations on earth, so it might seem academic and unnecessary to spend large sums on studying them. But they would have occurred in the early universe, so we must find out what happens at these energies if we are to understand how we and the universe began. There is still a great deal that we don't know or understand about the universe. But the remarkable progress we have made, particularly in the last hundred years, should encourage us to believe that a complete understanding may not be beyond our powers. We may not be forever doomed to grope in the dark. We may break through to a complete theory of the universe. In that case, we would indeed be Masters of the Universe. The scientific articles in this volume were written in the belief that the universe is governed by an order that we can perceive partially now and that we may understand fully in the not-too-distant future. It may be that this hope is just a mirage; there may be no ultimate theory, and even if there is, we may not find it. But it is surely better to strive for a complete understanding than to despair of the human mind.

Chapter 1

A BRIEF HISTORY OF A BRIEF HISTORY

Written by:

Nahla

Chapter 1

A BRIEF HISTORY OF A BRIEF HISTORY

A BRIEF HISTORY OF A BRIEF HISTORY*

I AM STILL RATHER taken aback by the reception given to my book, A Brief History of Time. It has been on The New York Times best-seller list for thirty-seven weeks and on The Sunday Times of London list for twenty-eight weeks. (It was published later in Britain than in the United States.) It is being translated into twenty languages (twenty-one if you count American as different from English). This was much more than I expected when I first had the idea in 1982 of writing a popular book about the universe. My intention was partly to earn money to pay my daughter's school fees. (In fact, by the time the book actually appeared, she was in her last year of school.) But the main reason was that I wanted to explain how far I felt we had come in our understanding of the universe: how we might be near finding a complete theory that would describe the universe and everything in it. If I were going to spend the time and effort to write a book, I wanted it to get to as many people as possible. My previous technical books had been published by Cambridge University Press. That publisher had done a good job, but I didn't feel that it would really be geared to the sort of mass market that I wanted to reach. I therefore contacted a literary agent, Al Zuckerman, who had been introduced to me as the brother-in-law of a colleague. I gave him a draft of the first chapter and explained that I wanted it to be the sort of book that would sell in airport book stalls. He told me there was no chance of that. It might sell well to academics and students, but a book like that couldn't break into Jeffrey Archer territory. I gave Zuckerman a first draft of the book in 1984. He sent it to several publishers and recommended that I accept an offer from Norton, a fairly upmarket American book firm. But I decided instead to take an offer from Bantam Books, a publisher more oriented toward the popular market. Though Bantam had not specialized in publishing science books, their books were widely available in airport book stalls. That they accepted my book was probably because of the interest in it taken by one of their editors, Peter Guzzardi. He took his job very seriously and made me rewrite the book to make it understandable to nonscientists like himself Each time I sent him a rewritten chapter, he sent back a long list of objections and questions he wanted me to clarify. At times I thought the process would never end. But he was right: It is a much better book as a result. Shortly after I accepted Bantam's offer, I got pneumonia. I had to have a tracheostomy operation that removed my voice. For a time I could communicate only by raising my eyebrows when someone pointed to letters on a card. It would have been quite impossible to finish the book but for the computer program I had been given. It was a bit slow, but then I think slowly, so it suited me quite well. With it I almost completely rewrote my first draft in response to Guzzardi's urgings. I was helped in this revision by one of my students, Brian Whitt. I had been very impressed by Jacob Bronowski's television series, The Ascent of Man. (Such a sexist title would not be allowed today.) It gave a feeling for the achievement of the human race in developing from primitive savages only fifteen thousand years ago to our present state. I wanted to convey a similar feeling for our progress toward a complete understanding of the laws that govern the universe. I was sure that nearly everyone was interested in how the universe operates, but most people cannot follow mathematical equations—I don't care much for equations myself. This is partly because it is difficult for me to write them down but mainly because I don't have an intuitive feeling for equations. Instead, I think in pictorial terms, and my aim in the book was to describe these mental images in words, with the help of familiar analogies and a few diagrams. In this way, I hoped that most people would be able to share in the excitement and feeling of achievement in the remarkable progress that has been made in physics in the last twenty-five years. Still, even if one avoids mathematics, some of the ideas are unfamiliar and difficult to explain. This posed a problem: Should I try to explain them and risk people being confused, or should I gloss over the difficulties? Some unfamiliar concepts, such as the fact that observers moving at different velocities measure different time intervals between the same pair of events, were not essential to the picture I wanted to draw. Therefore I felt I could just mention them but not go into depth. But other difficult ideas were basic to what I wanted to get across. There were two such concepts in particular that I felt I had to include. One was the so-called sum over histories. This is the idea that there is not just a single history for the universe. Rather, there is a collection of every possible history for the universe, and all these histories are equally real (whatever that may mean). The other idea, which is necessary to make mathematical sense of the sum over histories, is "imaginary time." With hindsight, I now feel that I should have put more effort into explaining these two very difficult concepts, particularly imaginary time, which seems to be the thing in the book with which people have the most trouble. However, it is not really necessary to understand exactly what imaginary time is—just that it is different from what we call real time. When the book was nearing publication, a scientist who was sent an advance copy to review for Nature magazine was appalled to find it full of errors, with misplaced and erroneously labeled photographs and diagrams. He called Bantam, who were equally appalled and decided that same day to recall and scrap the entire printing. They spent three intense weeks correcting and rechecking the entire book, and it was ready in time to be in the bookstores by the April publication date. By then, Time magazine had published a profile of me. Even so, the editors were taken by surprise by the demand. The book is in its seventeenth printing in America and its tenth in Britain.* Why did so many people buy it? It is difficult for me to be sure that I'm objective, so I think I will go by what other people said. I found most of the reviews, although favorable, rather unilluminating. They tended to follow the formula: Stephen Hawking has Lou Gehrig's disease (in American reviews), or motor neurone disease (in British reviews). He is confined to a wheelchair, cannot speak, and can only move x number of fingers (where x seems to vary from one to three, according to which inaccurate article the reviewer read about me). Yet he has written this book about the biggest question of all: Where did we come from and where are we going? The answer that Hawking proposes is that the universe is neither created nor destroyed: It just is. In order to formulate this idea, Hawking introduces the concept of imaginary time, which I (the reviewer) find a little hard to follow. Still, if Hawking is right and we do find a complete unified theory, we shall really know the mind of God. (In the proof stage I nearly cut the last sentence in the book, which was that we would know the mind of God. Had I done so, the sales might have been halved.) Rather more perceptive (I felt) was an article in The Independent, a London newspaper, which said that even a serious scientific book like A Brief History of Time could become, a cult book My wife was horrified, but I was rather flattered to have my book compared to Zen and the Art of Motorcycle Maintenance. I hope, like Zen, that it gives people the feeling that they need not be cut off from the great intellectual and philosophical questions. Undoubtedly, the human interest story of how I have managed to be a theoretical physicist despite my disability has helped. But those who bought the book from the human interest angle may have been disappointed because it contains only a couple of references to my condition. The book was intended as a history of the universe, not of me. This has not prevented accusations that Bantam shamefully exploited my illness and that I cooperated with this by allowing my picture to appear on the cover. In fact, under my contract I had no control over the cover. I did, however, manage to persuade Bantam to use a better photograph on the British edition than the miserable and out-of-date photo used on the American edition. Bantam will not change the American cover, however, because it says that the American public now identifies that with the book. It has also been suggested that people buy the book because they have read reviews of it or because it is on the best-seller list, but they don’t read it; they just have it in the bookcase or on the coffee table, thereby getting credit for having it without taking the effort of having to understand it. I am sure this happens, but I don’t know that it is any more so than for most other serious books, including the Bible and Shakespeare. On the other hand, I know that at least some people must have read it because each day I get a pile of letters about my book, many asking questions or making detailed comments that indicate that they have read it, even if they do not understand all of it. I also get stopped by strangers on the street who tell me how much they enjoyed it. Of course, I am more easily identified and more distinctive, if not distinguished, than most authors. But the frequency with which I receive such public congratulations (to the great embarrassment of my nine-year-old son) seems to indicate that at least a proportion of those who buy the book actually do read it. People now ask me what I am going to do next. I feel I can hardly write a sequel to A Brief History of Time. What would I call it? A Longer History of Time? Beyond the End of Time? Son of Time? My agent has suggested that I allow a film to be made about my life. But neither I nor my family would have any self-respect left if we let ourselves be portrayed by actors.

The same would be true to a lesser extent if I allowed and helped someone to write my life. Of course, I cannot stop someone from writing my life independently, as long as it is not libelous, but I try to put them off by saying I’m considering writing my autobiography. Maybe I will. But I’m in no hurry. I have a lot of science that I want to do first.

* This essay was originally published in December 1988 as an article in The Independent. A Brief History of Time remained on The New York Times best-seller list for fifty-three weeks; and in Britain, as of February 1993, it had been on The Sunday Times of London list for 205 weeks (At week 184, it went into the Guinness Book of Records for achieving the most appearances on this list.) The number of translated editions is now thirty-three. * By April 1993, it was in its fortieth hardcover and nineteenth paperback printing in the United States, and its thirty-ninth hardcover printing in Britain.

Chapter 2

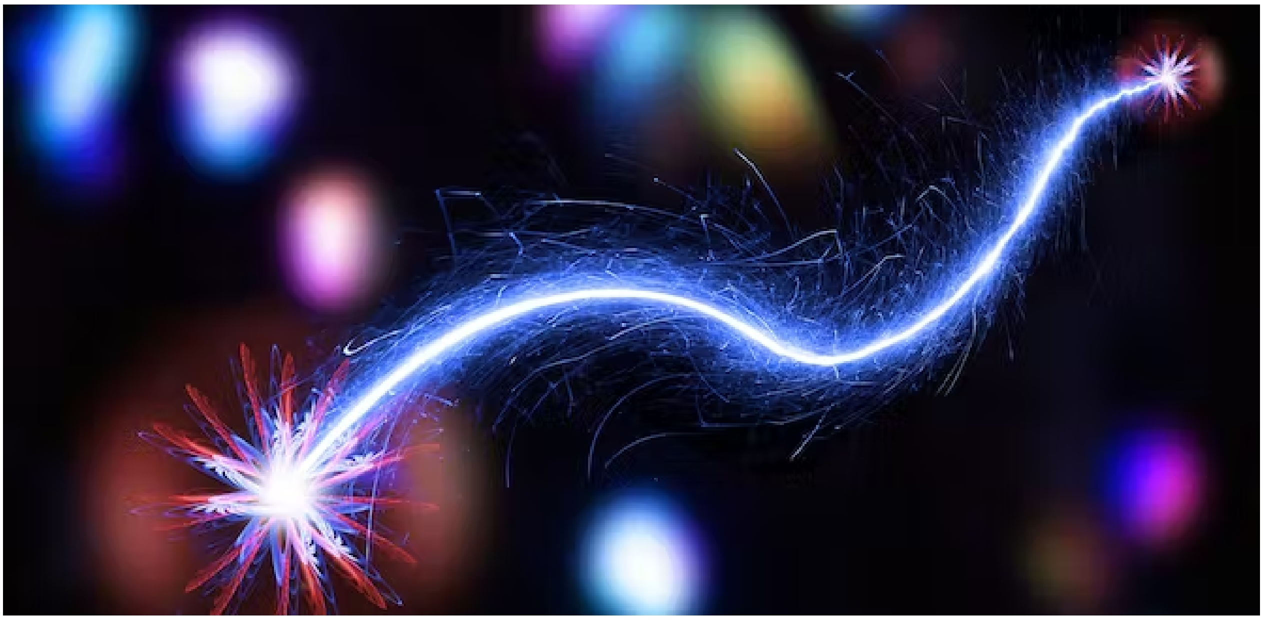
IS THE END IN SIGHT FOR THEORETICAL PHYSICS?

Written by:

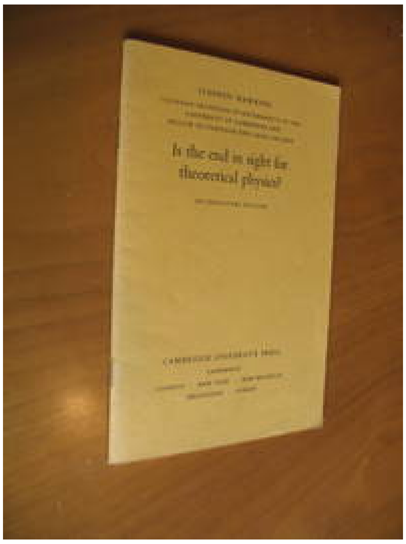
Mohamed

Chapter 2

IS THE END IN SIGHT FOR THEORETICAL PHYSICS?



IN THESE PAGES I want to discuss the possibility that the goal of theoretical physics might be achieved in the not-too-distant future: say, by the end of the century. By this I mean that we might have a complete, consistent, and unified theory of the physical interactions that would describe all possible observations. Of course, one has to be very cautious about making such predictions. We have thought that we were on the brink of the final synthesis at least twice before. At the beginning of the century it was believed that everything could be understood in terms of continuum mechanics. All that was needed was to measure a certain number of coefficients of elasticity, viscosity, conductivity, etc. This hope was shattered by the discovery of atomic structure and quantum mechanics. Again, in the late 1920s Max Born told a group of scientists visiting Göttingen that "physics, as we know it, will be over in six months." This was shortly after the discovery by Paul Dirac, a previous holder of the Lucasian Chair, of the Dirac equation, which governs the behavior of the electron. It was expected that a similar equation would govern the proton, the only other supposedly elementary particle known at that time. However, the discovery of the neutron and of nuclear forces disappointed those hopes. We now know in fact that neither the proton nor the neutron is elementary but that they are made up of smaller particles. Nevertheless, we have made a lot of progress in recent years, and as I shall describe, there are some grounds for cautious optimism that we may see a complete theory within the lifetime of some of those reading these pages. Even if we do achieve a complete unified theory, we shall not be able to make detailed predictions in any but the simplest situations. For example, we already know the physical laws that govern everything that we experience in everyday life. As Dirac pointed out, his equation was the basis of "most of physics and all of chemistry." However, we have been able to solve the equation only for the very simplest system, the hydrogen atom, consisting of one proton and one electron. For more complicated atoms with more electrons, let alone for molecules with more than one nucleus, we have to resort to approximations and intuitive guesses of doubtful validity. For macroscopic systems consisting of 10 particles or so, we have to use statistical methods and abandon any pretense of solving the equations exactly. Although in principle we know the equations that govern the whole of biology, we have not been able to reduce the study of human behavior to a branch of applied mathematics. What would we mean by a complete and unified theory of physics? Our attempts at modeling physical reality normally consist of two parts: 1. A set of local laws that are obeyed by the various physical quantities. These are usually formulated in terms of differential equations. 2. Sets of boundary conditions that tell us the state of some regions of the universe at a certain time and what effects propagate into it subsequently from the rest of the universe. Many people would claim that the role of science is confined to the first of these and that theoretical physics will have achieved its goal when we have obtained a complete set of local physical laws. They would regard the question of the initial conditions for the universe as belonging to the realm of metaphysics or religion. In a way, this attitude is similar to that of those who in earlier centuries discouraged scientific investigation by saying that all natural phenomena were the work of God and should not be inquired into. I think that the initial conditions of the universe are as suitable a subject for scientific study and theory as are the local physical laws. We shall not have a complete theory until we can do more than merely say that "things are as they are because they were as they were.” The question of the uniqueness of the initial conditions is closely related to that of the arbitrariness of the local physical laws: One would not regard a theory as complete if it contained a number of adjustable parameters such as masses or coupling constants that could be given any values one liked. In fact, it seems that neither the initial conditions nor the values of the parameters in the theory are arbitrary but that they are somehow chosen or picked out very carefully. For example, if the proton-neutron mass difference were not about twice the mass of the electron, one would not obtain the couple of hundred or so stable nucleides that make up the elements and are the basis of chemistry and biology. Similarly, if the gravitational mass of the proton were significantly different, one would not have had stars in which these nucleides could have been built up, and if the initial expansion of the universe had been slightly smaller or slightly greater, the universe would either have collapsed before such stars could have evolved or would have expanded so rapidly that stars would never have been formed by gravitational condensation. Indeed, some people have gone so far as to elevate these restrictions on the initial conditions and the parameters to the status of a principle, the anthropic principle which can be paraphrased as, “Things are as they are because we are.” According to one version of the principle, there is a very large number of different, separate universes with different values of the physical parameters and different initial conditions. Most of these universes will not provide the right conditions for the development of the complicated structures needed for intelligent life. Only in a small number, with conditions and parameters like our own universe, will it be possible for intelligent life to develop and to ask the question, “Why is the universe as we observe it?” The answer, of course, is that if it were otherwise, there would not be anyone to ask the question. The anthropic principle does provide some sort of explanation of many of the remarkable numerical relations that are observed between the values of different physical parameters. However, it is not completely satisfactory; one cannot help feeling that there is some deeper explanation. Also, it cannot account for all the regions of the universe. For example, our solar system is certainly a prerequisite for our existence, as is an earlier generation of nearby stars in which heavy elements could have been formed by nuclear synthesis. It might even be that the whole of our galaxy was required. But there does not seem any necessity for other galaxies to exist, let alone the million million or so of them that we see distributed roughly uniformly throughout the observable universe. This largescale homogeneity of the universe makes it very difficult to believe that the structure of the universe is determined by anything so peripheral as some complicated molecular structures on a minor planet orbiting a very average star in the outer suburbs of a fairly typical spiral galaxy. If we are not going to appeal to the anthropic principle, we need some unifying theory to account for the initial conditions of the universe and the values of the various physical parameters. However, it is too difficult to think up a complete theory of everything all at one go (though this does not seem to stop some people; I get two or three unified theories in the mail each week). What we do instead is to look for partial theories that will describe situations in which certain interactions can be ignored or approximated in a simple manner. We first divide the material content of the universe into two parts: “matter,” particles such as quarks, electrons, muons, etc., and “interactions,” such as gravity, electromagnetism, etc. The matter particles are described by fields of one-halfinteger spin and obey the Pauli exclusion principle, which prevents more than one particle of a given kind from being in the same state. This is the reason we can have solid bodies that do not collapse to a point or radiate away to infinity. The matter principles are divided into two groups: the hadrons, which are composed of quarks; and the leptons, which comprise the remainder. The interactions are divided phenomenologically into four categories. In order of strength, they are: the strong nuclear forces, which interact only with hadrons; electromagnetism, which interacts with charged hadrons and leptons; the weak nuclear forces, which interact with all hadrons and leptons; and finally, the weakest by far, gravity, which interacts with everything. The interactions are represented by integer-spin fields that do not obey the Pauli exclusion principle. This means they can have many particles in the same state. In the case of electromagnetism and gravity, the interactions are also long-range, which means that the fields produced by a large number of matter particles can all add up to give a field that can be detected on a macroscopic scale. For these reasons, they were the first to have theories developed for them: gravity by Newton in the seventeenth century, and electromagnetism by Maxwell in the nineteenth century. However, these theories were basically incompatible because the Newtonian theory was invariant if the whole system was given any uniform velocity, whereas the Maxwell theory defined a preferred velocity—the speed of light. In the end, it turned out to be the Newtonian theory of gravity that had to be modified to make it compatible with the invariance properties of the Maxwell theory. This was achieved by Einstein’s general theory of relativity, which was formulated in 1915. The general relativity theory of gravity and the Maxwell theory of electrodynamics were what are called classical theories; that is, they involved quantities that were continuously variable and that could, in principle at least, be measured to arbitrary accuracy. However, a problem arose when one tried to use such theories to construct a model of the atom. It had been discovered that the atom consisted of a small, positively charged nucleus surrounded by a cloud of negatively charged electrons. The natural assumption was that the electrons were in orbit around the nucleus as the earth is in orbit around the sun. But the classical theory predicted that the electrons would radiate electromagnetic waves. These waves would carry away energy and would cause the electrons to spiral into the nucleus, producing the collapse of the atom. This problem was overcome by what is undoubtedly the greatest achievement in theoretical physics in this century: the discovery of the quantum theory. The basic postulate of this is the Heisenberg uncertainty principle, which states that certain pairs of quantities, such as the position and momentum of a particle, cannot be measured simultaneously with arbitrary accuracy. In the case of the atom, this meant that in its lowest energy state the electron could not be at rest in the nucleus because, in that case, its position would be exactly defined (at the nucleus) and its velocity would also be exactly defined (to be zero). Instead, both position and velocity would have to be smeared out with some probability distribution around the nucleus. In this state the electron could not radiate energy in the form of electromagnetic waves because there would be no lower energy state for it to go to. In the 1920s and 1930s quantum mechanics was applied with great success to systems such as atoms or molecules, which have only a finite number of degrees of freedom. Difficulties arose, however, when people tried to apply it to the electromagnetic field, which has an infinite number of degrees of freedom, roughly speaking two for each point of space-time. One can regard these degrees of freedom as oscillators, each with its own position and momentum. The oscillators cannot be at rest because then they would have exactly defined positions and momenta. Instead, each oscillator must have some minimum amount of what are called zero-point fluctuations and a nonzero energy. The energies of all the infinite number of degrees of freedom would cause the apparent mass and charge of the electron to become infinite. A procedure called renormalization was developed to overcome this difficulty in the late 1940s. It consisted of the rather arbitrary subtraction of certain infinite quantities to leave finite remainders. In the case of electrodynamics, it was necessary to make two such infinite subtractions, one for the mass and the other for the charge of the electron. This renormalization procedure has never been put on a very firm conceptual or mathematical basis, but it has worked quite well in practice. Its great success was the prediction of a small displacement, the Lamb shift, in some lines in the spectrum of atomic hydrogen. However, it is not very satisfactory from the point of view of attempts to construct a complete theory because it does not make any predictions of the values of the finite remainders left after making infinite subtractions. Thus, we would have to fall back on the anthropic principle to explain why the electron has the mass and charge that it does.



Chapter 3

THE QUANTUM MECHANICS OF BLACK HOLES

Written by:

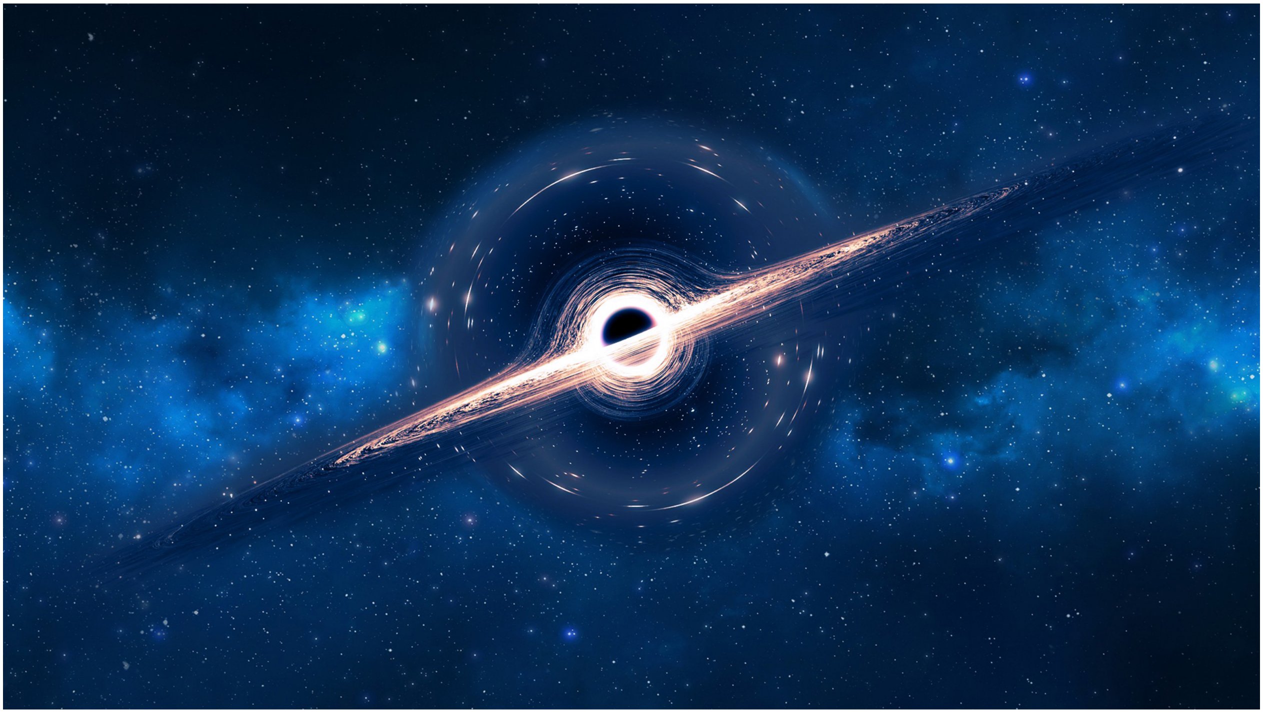
Mohamed

Chapter 3

THE QUANTUM MECHANICS OF BLACK HOLES

THE QUANTUM MECHANICS OF BLACK HOLES

THE FIRST THIRTY years of this century saw the emergence of three theories that radically altered man's view of physics and of reality itself. Physicists are still trying to explore their implications and to fit them together. The three theories are the special theory of relativity (1905), the general theory of relativity (1915), and the theory of quantum mechanics (c. 1926). Albert Einstein was largely responsible for the first, was entirely responsible for the second, and played a major role in the development of the third. Yet Einstein never accepted quantum mechanics because of its element of chance and uncertainty. His feelings were summed up in his oft-quoted statement "God does not play dice." Most physicists, however, readily accepted both special relativity and quantum mechanics because they described effects that could be directly observed. General relativity, on the other hand, was largely ignored because it seemed too complicated mathematically, was not testable in the laboratory, and was a purely classical theory that did not seem compatible with quantum mechanics. Thus, general relativity remained in the doldrums for nearly fifty years. The great extension of astronomical observations that began early in the 1960s brought about a revival of interest in the classical theory of general relativity because it seemed that many of the new phenomena that were being discovered, such as quasars, pulsars, and compact X-ray sources, indicated the existence of very strong gravitational fields—fields that could be described only by general relativity. Quasars are starlike objects that must be many times brighter than entire galaxies if they are as distant as the reddening of their spectra indicates; pulsars are the rapidly blinking remnants of supernova explosions, believed to be ultradense neutron stars; compact X-ray sources, revealed by instruments aboard space vehicles, may also be neutron stars or may be hypothetical objects of still higher density, namely black holes. One of the problems facing physicists who sought to apply general relativity to these newly discovered or hypothetical objects was to make it compatible with quantum mechanics. Within the past few years there have been developments that give rise to the hope that before too long we shall have a fully consistent quantum theory of gravity, one that will agree with general relativity for macroscopic objects and will, one hopes, be free of the mathematical infinities that have long bedeviled other quantum field theories. These developments have to do with certain recently discovered quantum effects associated with black holes, which provide a remarkable connection between black holes and the laws of thermodynamics. Let me describe briefly how a black hole might be created. Imagine a star with a mass ten times that of the sun. During most of its lifetime of about a billion years, the star will generate heat at its center by converting hydrogen into helium. The energy released will create sufficient pressure to support the star against its own gravity, giving rise to an object with a radius about five times the radius of the sun. The escape velocity from the surface of such a star would be about a thousand kilometers per second. That is to say, an object fired vertically upward from the surface of the star with a velocity of less than a thousand kilometers per second would be dragged back by the gravitational field of the star and would return to the surface, whereas an object with a velocity greater than that would escape to infinity. When the star had exhausted its nuclear fuel, there would be nothing to maintain the outward pressure, and the star would begin to collapse because of its own gravity. As the star shrank, the gravitational field at the surface would become stronger and the escape velocity would increase. By the time the radius had got down to thirty kilometers, the escape velocity would have increased to 300,000 kilometers per second, the velocity of light. After that time any light emitted from the star would not be able to escape to infinity but would be dragged back by the gravitational field. According to the special theory of relativity, nothing can travel faster than light, so that if light cannot escape, nothing else can either. The result would be a black hole: a region of space-time from which it is not possible to escape to infinity. The boundary of the black hole is called the event horizon. It corresponds to a wave front of light from the star that just fails to escape to infinity but remains hovering at the Schwarzschild radius: $2 GM/\sqrt{c}$, where G is Newton’s constant of gravity, M is the mass of the star, and c is the velocity of light. For a star of about ten solar masses, the Schwarzschild radius is about thirty kilometers. There is now fairly good observational evidence to suggest that black holes of about this size exist in double-star systems such as the X-ray source known as Cygnus X-I. There might also be quite a number of very much smaller black holes scattered around the universe, formed not by the collapse of stars but by the collapse of highly compressed regions in the hot, dense medium that is believed to have existed shortly after the big bang in which the universe originated. Such “primordial” black holes are of greatest interest for the quantum effects I shall describe here. A black hole weighing a billion tons (about the mass of a mountain) would have a radius of about 10 -13 centimeter (the size of a neutron or a proton). It could be in orbit either around the sun or around the center of the galaxy. The first hint that there might be a connection between black holes and thermodynamics came with the mathematical discovery in 1970 that the surface area of the event horizon, the boundary of a black hole, has the property that it always increases when additional matter or radiation falls into the black hole. Moreover, if two black holes collide and merge to form a single black hole, the area of the event horizon around the resulting black hole is greater than the sum of the areas of the event horizons around the original black holes. These properties suggest that there is a resemblance between the area of the event horizon of a black hole and the concept of entropy in thermodynamics. Entropy can be regarded as a measure of the disorder of a system or, equivalently, as a lack of knowledge of its precise state. The famous second law of thermodynamics says that entropy always increases with time. The analogy between the properties of black holes and the laws of thermodynamics has been extended by James M. Bardeen of the University of Washington, Brandon Carter, who is now at the Meudon Observatory, and me. The first law of thermodynamics says that a small change in the entropy of a system is accompanied by a proportional change in the energy of the system. The factor of proportionality is called the temperature of the system. Bardeen, Carter, and I found a similar law relating to the change in mass of a black hole to a change in the area of the event horizon. Here the factor of proportionality involves a quantity called the surface gravity, which is a measure of the strength of the gravitational field at the event horizon. If one accepts that the area of the event horizon is analogous to entropy, then it would seem that the surface gravity is analogous to temperature. The resemblance is strengthened by the fact that the surface gravity turns out to be the same at all points on the event horizon, just as the temperature is the same everywhere in a body at thermal equilibrium. Although there is clearly a similarity between entropy and the area of the event horizon, it was not obvious to us how the area could be identified as the entropy of a black hole. What would be meant by the entropy of a black hole? The crucial suggestion was made in 1972 by Jacob D. Bekenstein, who was then a graduate student at Princeton University and is now at the University of the Negev in Israel. It goes like this. When a black hole is created by gravitational collapse, it rapidly settles down to a stationary state that is characterized by only three parameters: the mass, the angular momentum, and the electric charge. Apart from these three properties the black hole preserves no other details of the object that collapsed. This conclusion, known as the theorem "A black hole has no hair," was proved by the combined work of Carter, Werner Israel of the University of Alberta, David C. Robinson of King's College, London, and me. The no-hair theorem implies that a large amount of information is lost in a gravitational collapse. For example, the final black-hole state is independent of whether the body that collapsed was composed of matter or antimatter, and whether it was spherical or highly irregular in shape. In other words, a black hole of a given mass, angular momentum, and electric charge could have been formed by the collapse of any one of a large number of different configurations of matter. Indeed, if quantum effects are neglected, the number of configurations would be infinite, since the black hole could have been formed by the collapse of a cloud of an indefinitely large number of particles of indefinitely low mass. The uncertainty principle of quantum mechanics implies, however, that a particle of mass m behaves like a wave of wavelength h/mc, where h is Planck's constant (the small number 6.62 X 10 -27 erg-second) and c is the velocity of light. In order for a cloud of particles to be able to collapse to form a black hole, it would seem necessary for this wavelength to be smaller than the size of the black hole that would be formed. It therefore appears that the number of configurations that could form a black hole of a given mass, angular momentum, and electric charge, although very large, may be finite. Bekenstein suggested that one could interpret the logarithm of this number as the entropy of a black hole. The logarithm of the number would be a measure of the amount of information that was irretrievably lost during the collapse through the event horizon when a black hole was created. The apparently fatal flaw in Bekenstein's suggestion was that if a black hole has a finite entropy that is proportional to the area of its event horizon, it also ought to have a finite temperature, which would be proportional to its surface gravity. This would imply that a black hole could be in equilibrium with thermal radiation at some temperature other than zero. Yet according to classical concepts no such equilibrium is possible, since the black hole would absorb any thermal radiation that fell on it but by definition would not be able to emit anything in return. This paradox remained until early 1974, when I was investigating what the behavior of matter in the vicinity of a black hole would be according to quantum mechanics. To my great surprise, I found that the black hole seemed to emit particles at a steady rate. Like everyone else at that time, I accepted the dictum that a black hole could not emit anything. I therefore put quite a lot of effort into trying to get rid of this embarrassing effect. It refused to go away, so that in the end I had to accept it. What finally convinced me that it was a real physical process was that the outgoing particles have a spectrum that is precisely thermal; the black hole creates and emits particles just as if it were an ordinary hot body with a temperature that is proportional to the surface gravity and inversely proportional to the mass. This made Bekenstein's suggestion that a black hole had a finite entropy fully consistent, since it implied that a black hole could be in thermal equilibrium at some finite temperature other than zero.

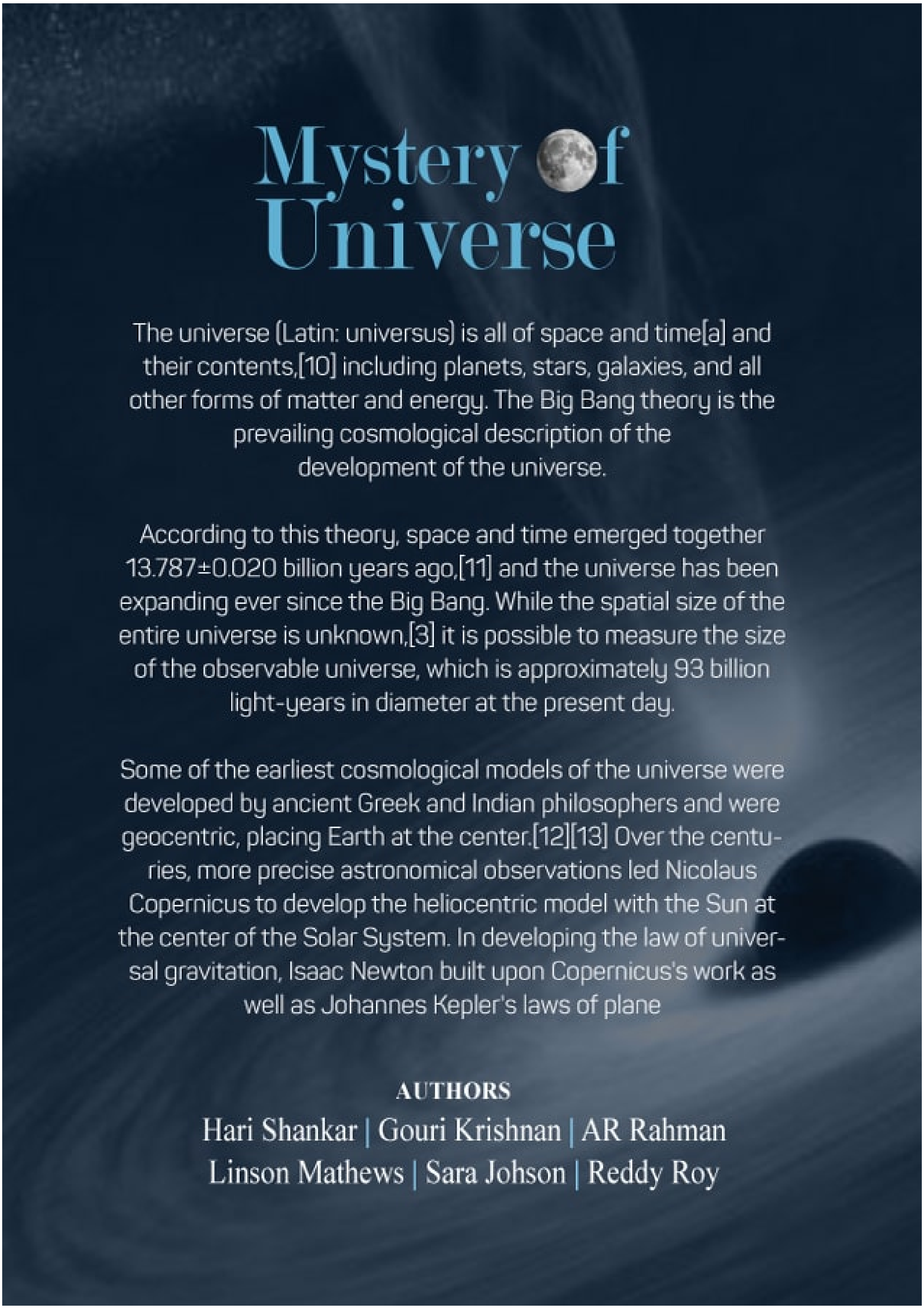


Since that time, the mathematical evidence that black holes can emit thermally has been confirmed by a number of other people with various different approaches. One way to understand the emission is as follows. Quantum mechanics implies that the whole of space is filled with pairs of “virtual” particles and antiparticles that are constantly materializing in pairs, separating, and then coming together again and annihilating each other. These particles are called virtual because, unlike “real” particles, they cannot be observed directly with a particle detector. Their indirect effects can nonetheless be measured, and their existence has been confirmed by a small shift (the “Lamb shift”) they produce in the spectrum of light from excited hydrogen atoms. Now, in the presence of a black hole one member of a pair of virtual particles may fall into the hole, leaving the other member without a partner with which to annihilate. The forsaken particle or antiparticle may fall into the black hole after its partner, but it may also escape to infinity, where it appears to be radiation emitted by the black hole. Another way of looking at the process is to regard the member of the pair of particles that falls into the black hole—the antiparticle, say—as being really a particle that is traveling backward in time. Thus, the antiparticle falling into the black hole can be regarded as a particle coming out of the black hole but traveling backward in time. When the particle reaches the point at which the particle-antiparticle pair originally materialized, it is scattered by the gravitational field so that it travels forward in time. Quantum mechanics therefore allows a particle to escape from inside a black hole, something that is not allowed in classical mechanics. There are, however, many other situations in atomic and nuclear physics where there is some kind of barrier that particles should not be able to penetrate on classical principles but that they are able to tunnel through on quantum-mechanical principles. The thickness of the barrier around a black hole is proportional to the size of the black hole. This means that very few particles can escape from a black hole as large as the one hypothesized to exist in Cygnus X-I, but that particles can leak very rapidly out of smaller black holes. Detailed calculations show that the emitted particles have a thermal spectrum corresponding to a temperature that increases rapidly as the mass of the black hole decreases. For a black hole with a mass of the sun, the temperature is only about a ten-millionth of a degree above absolute zero. The thermal radiation leaving a black hole with that temperature would be completely swamped by the general background of radiation in the universe. On the other hand, a black hole with a mass of only a billion tons—that is, a primordial black hole, roughly the size of a proton—would have a temperature of some 120 billion degrees Kelvin, which corresponds to an energy of some ten million electron volts. At such a temperature a black hole would be able to create electron-positron pairs and particles of zero mass, such as photons, neutrinos, and gravitons (the presumed carriers of gravitational energy). A primordial black hole would release energy at the rate of 6,000 megawatts, equivalent to the output of six large nuclear power plants. As a black hole emits particles, its mass and size steadily decrease. This makes it easier for more particles to tunnel out, and so the emission will continue at an ever-increasing rate until eventually the black hole radiates itself out of existence. In the long run, every black hole in the universe will evaporate in this way. For large black holes, however, the time it will take is very long indeed; a black hole with the mass of the sun will last for about 10 66 years. On the other hand, a primordial black hole should have almost completely evaporated in the ten billion years that have elapsed since the big bang, the beginning of the universe as we know it. Such black holes should now be emitting hard gamma rays with an energy of about 100 million electron volts. Calculations made by Don N. Page, then of the California Institute of Technology, and me, based on measurements of the cosmic background of gamma radiation made by the satellite SAS-2, show that the average density of primordial black holes in the universe must be less than about two hundred per cubic light-year. The local density in our galaxy could be a million times higher than this figure if primordial black holes were concentrated in the "halo" of galaxies—the thin cloud of rapidly moving stars in which each galaxy is embedded—rather than being uniformly distributed throughout the universe. This would imply that the primordial black hole closest to the earth is probably at least as far away as the planet Pluto. The final stage of the evaporation of a black hole would proceed so rapidly that it would end in a tremendous explosion. How powerful this explosion would be would depend on how many different species of elementary particles there are. If, as is now widely believed, all particles are made up of perhaps six different varieties of quarks, the final explosion would have an energy equivalent to about ten million one-megaton hydrogen bombs. On the other hand, an alternative theory put forward by R. Hagedorn of CERN, the European Organization for Nuclear Research in Geneva, argues that there is an infinite number of elementary particles of higher and higher mass. As a black hole got smaller and hotter, it would emit a larger and larger number of different species of particles and would produce an explosion perhaps 100,000 times more powerful than the one calculated on the quark hypothesis. Hence the observation of a black-hole explosion would provide very important information on elementary particle physics, information that might not be available any other way.

https://www.youtube.com/watch?v=WxAK2laJKc0

A black-hole explosion would produce a massive outpouring of high-energy gamma rays. Although they might be observed by gamma-ray detectors on satellites or balloons, it would be difficult to fly a detector large enough to have a reasonable chance of intercepting a significant number of gamma-ray photons from one explosion. One possibility would be to employ a space shuttle to build a large gamma-ray detector in orbit. An easier and much cheaper alternative would be to let the earth's upper atmosphere serve as a detector. A high-energy gamma ray plunging into the atmosphere will create a shower of electronpositron pairs, which initially will be traveling through the atmosphere faster than light can. (Light is slowed down by interactions with the air molecules.) Thus the electrons and positrons will set up a kind of sonic boom, or shock wave, in the electromagnetic field. Such a shock wave, called Cerenkov radiation, could be detected from the ground as a flash of visible light. A preliminary experiment by Neil A. Porter and Trevor C. Weekes of University College, Dublin, indicates that if black holes explode the way Hagedorn's theory predicts, there are fewer than two black-hole explosions per cubic light-year per century in our region of the galaxy. This would imply that the density of primordial black holes is less than 100 million per cubic light-year. It should be possible to greatly increase the sensitivity of such observations. Even if they do not yield any positive evidence of primordial black holes, they will be very valuable. By placing a low upper limit on the density of such black holes, the observations will indicate that the early universe must have been very smooth and nonturbulent. The big bang resembles a black-hole explosion but on a vastly larger scale. One therefore hopes that an understanding of how black holes create particles will lead to a similar understanding of how the big bang created everything in the universe. In a black hole, matter collapses and is lost forever, but new matter is created in its place. It may therefore be that there was an earlier phase of the universe in which matter collapsed, to be re-created in the big bang. If the matter that collapses to form a black hole has a net electric charge, the resulting black hole will carry the same charge. This means that the black hole will tend to attract those members of the virtual particle-antiparticle pairs that have the opposite charge and repel those that have a like charge. The black hole will therefore preferentially emit particles with a charge of the same sign as itself and so will rapidly lose its charge. Similarly, if the collapsing matter has a net angular momentum, the resulting black hole will be rotating and will preferentially emit particles that carry away its angular momentum. The reason a black hole "remembers" the electric charge, angular momentum, and mass of the matter that collapsed and "forgets" everything else is that these three quantities are coupled to long-range fields: in the case of charge the electromagnetic field, and in the case of angular momentum and mass the gravitational field. Experiments by Robert H. Dicke of Princeton University and Vladimir Braginsky of Moscow State University have indicated that there is no long-range field associated with the quantum property designated baryon number. (Baryons are the class of particles including the proton and the neutron.) Hence, a black hole formed out of the collapse of a collection of baryons would forget its baryon number and radiate equal quantities of baryons and antibaryons. Therefore, when the black hole disappeared, it would violate one of the most cherished laws of particle physics, the law of baryon conservation. Although Bekenstein's hypothesis that black holes have a finite entropy requires for its consistency that black holes should radiate thermally, at first it seems a complete miracle that the detailed quantum-mechanical calculations of particle creation should give rise to emission with a thermal spectrum. The explanation is that the emitted particles tunnel out of the black hole from a region of which an external observer has no knowledge other than its mass, angular momentum, and electric charge. This means that all combinations or configurations of emitted particles that have the same energy, angular momentum, and electric charge are equally probable. Indeed, it is possible that the black hole could emit a television set or the works of Proust in ten leatherbound volumes, but the number of configurations of particles that correspond to these exotic possibilities is vanishingly small. By far the largest number of configurations correspond to emission with a spectrum that is nearly thermal. The emission from black holes has an added degree of uncertainty, or unpredictability, over and above that normally associated with quantum mechanics. In classical mechanics one can predict the results of measuring both the position and the velocity of a particle. In quantum mechanics the uncertainty principle says that only one of these measurements can be predicted; the observer can predict the result of measuring either the position or the velocity but not both. Alternatively, he can predict the result of measuring one combination of position and velocity. Thus, the observer's ability to make definite predictions is in effect cut in half. With black holes the situation is even worse. Since the particles emitted by a black hole come from a region of which the observer has very limited knowledge, he cannot definitely predict the position or the velocity of a particle or any combination of the two; all he can predict is the probabilities that certain particles will be emitted. It therefore seems that Einstein was doubly wrong when he said, “God does not play dice.” Consideration of particle emission from black holes would seem to suggest that God not only plays dice but also sometimes throws them where they cannot be seen.

*An article published in Scientific American in January 1977.



Mystery of Universe

The universe (Latin: universus) is all of space and time[a] and their contents,[10] including planets, stars, galaxies, and all other forms of matter and energy. The Big Bang theory is the prevailing cosmological description of the development of the universe.

According to this theory, space and time emerged together 13.787±0.020 billion years ago,[11] and the universe has been expanding ever since the Big Bang. While the spatial size of the entire universe is unknown,[3] it is possible to measure the size of the observable universe, which is approximately 93 billion light-years in diameter at the present day.

Some of the earliest cosmological models of the universe were developed by ancient Greek and Indian philosophers and were geocentric, placing Earth at the center.[12][13] Over the centuries, more precise astronomical observations led Nicolaus Copernicus to develop the heliocentric model with the Sun at the center of the Solar System. In developing the law of universal gravitation, Isaac Newton built upon Copernicus's work as well as Johannes Kepler's laws of plane

AUTHORS

Hari Shankar | Gouri Krishnan | AR Rahman
Linson Mathews | Sara Johson | Reddy Roy