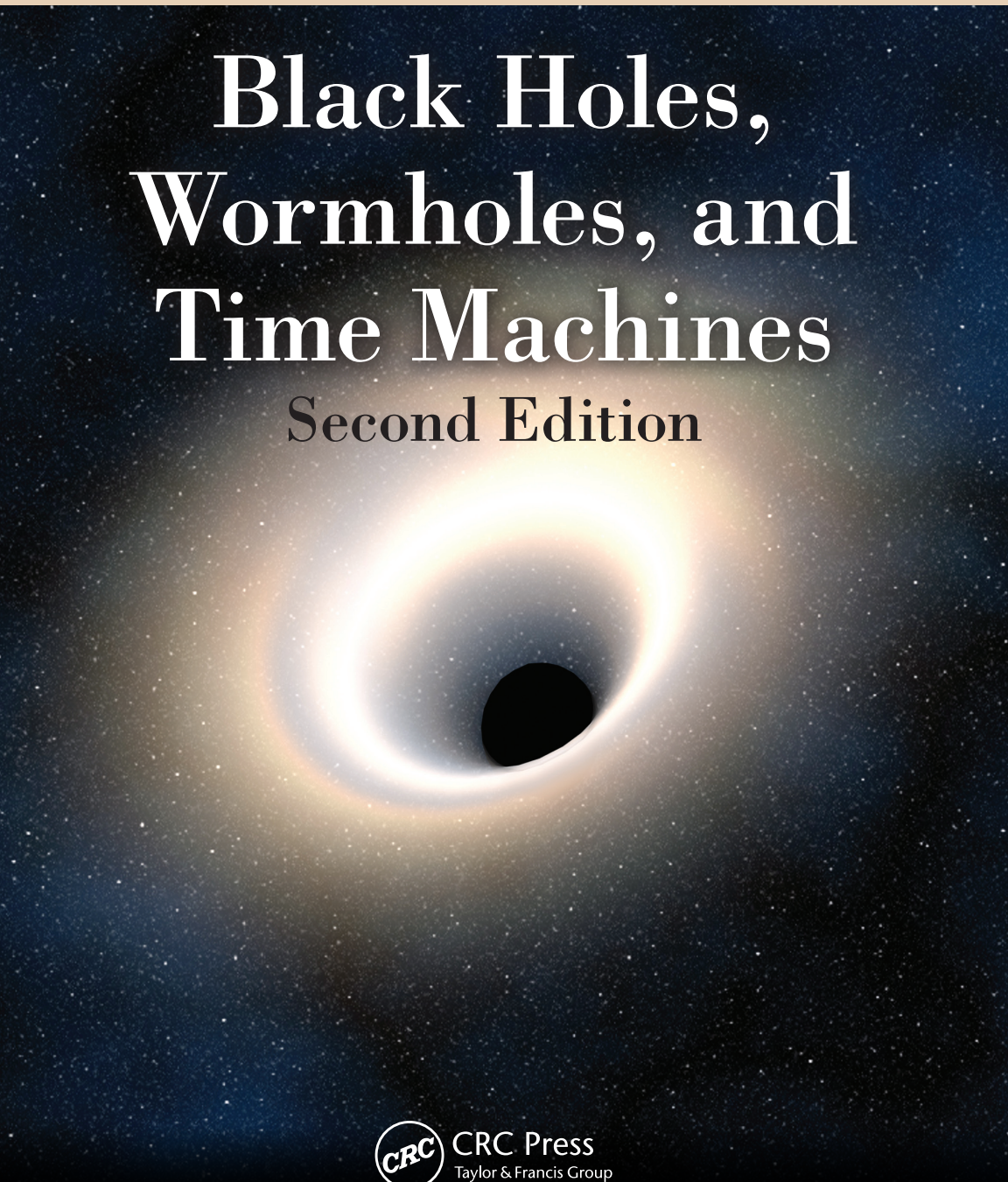
Jim Al-Khalili

Black Holes, Wormholes, and Time Machines

Second Edition



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To Julie, David, and Kate

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Preface

Over the past few years there has been an explosion in the number of books and television programmes popularizing current scientific ideas and theories and making them accessible to a wider audience. So is there any need for this, yet another book on a subject that has received more attention than most: the nature of space and time and the origin of our Universe? The other day, I was looking through the website of a large Internet book club. Under the category of science and nature, I searched for all books with the word 'time' in their title. I found 29! Of course, Stephen Hawking's *Brief History of Time* is the best known of these, but there were many others with titles like *About Time*, *The Birth of Time*, *The Edge of Time*, *The River of Time*, and so on. It seems that questioning the nature of time at a fundamental level is the 'in' topic at the moment. What was most surprising for me was to see that many of those 29 titles had been published *since* I began writing this book.

Established science writers such as Paul Davies, John Gribbin, and Richard Dawkins were an inspiration to me as an undergraduate in the mid-1980s. But they were preaching to the converted. At best, they were aimed at the 'intelligent layperson', whoever that is supposed to be. My ambition has therefore been to write a book at a more basic level, which would explain some of the ideas and theories of modern physics for *anyone* to understand, provided of course that they are interested enough to pick up such a book in the first place. I have also tried to make it a little more fun, aiming (probably without much success) for a sort of Stephen Hawking-meets-Terry Pratchett.

Many scientists would argue that difficult subjects such as Einstein's theories of relativity can only be 'dumbed down' so much before reaching a level where the explanations are no longer correct. I hate that term: dumbed down. It sounds so patronizing. And while it is flattering to be considered by society to be more intelligent than everyone else, scientists are just people who have spent many years being trained to understand the relevant jargon, abstract concepts, and mathematical formulae. The hard part is to translate these into words and ideas that someone without their training can appreciate.

Because of the way this book developed, it has been written with a teenage audience in mind. However, it is aimed as well at anyone who finds its title fascinating or intriguing. It does not matter if you have not picked up a science book since you were fifteen.

So how *did* this book come about? Well, about three years ago, the then head of my physics department at the University of Surrey, Bill Gelletly, suggested that

I should give, as one of a series of lectures to first year undergraduates covering a range of general interest topics in modern physics, a lecture on 'wormholes'. Such a topic is certainly not part of a traditional undergraduate degree course in physics. In fact, fans of the TV series *Star Trek: Deep Space Nine* are probably better informed about wormholes than your average physicist. Anyway, I thought it would be fun, and proceeded to do some background reading in preparation for the lecture. On the day, I was surprised to find in the audience many students not in the course, as well as postdoctoral researchers and members of staff. There seemed to be something magical about the title.

Each year, my department sends out a list of speakers from among its academic staff and lecture titles to local schools and colleges. This is mainly as publicity for the department in the hope that these lectures might play a part in our recruitment drive to attract new students. I offered my 'wormholes' talk as one of these. Such was its success, I was asked by the Institute of Physics to be the 1998 Schools Lecturer. This involved the substantially greater commitment of having to travel around the country giving the lecture to 14–16-year-olds, with audiences of several hundred at a time. And, having put a significant amount of preparation into this performance, I found that I had accumulated far too much fascinating material to cram into a one-hour lecture and decided to put it all down in a book.

I have tried as much as possible to be up to date. In fact, when the manuscript came back to me from the publishers for final corrections and changes, I had to completely revise the chapter on cosmology. Because of recent astronomical discoveries, many of the ideas about the size and shape of the Universe had changed during the few short months since I had written that chapter.

Jim Al-Khalili
Portsmouth, England, July 1999

About the second edition

It is now twelve years since this book was first published, so when its current publishers, Taylor and Francis, asked me if I would like to make any changes or additions, I leapt at the chance. After all, while we have not had another Einstein come along and change the face of physics during the first decade of the new millennium, there have still been a sufficient number of new ideas and discoveries to at least warrant lengthening some of the chapters in this book. Most of the book remains exactly as it was, but I have taken the liberty of bringing some of the stories (big) bang up to date.

Jim Al-Khalili
Portsmouth, England, May 2011

Acknowledgments

Looking back over the second half of 1998, when the bulk of the book was written, I realise that I owe my greatest debt of gratitude to my wife, Julie, and my children, David and Kate, for putting up with me. Since I could not allow my writing to interfere with my full-time research work, it had to be done at home during the evenings and the weekends. I am also indebted to the following friends, family, and colleagues for kindly reading through the manuscript and making so many constructive comments and suggestions: Julie Al-Khalili, Reya Al-Khalili, Richard Wilson, Johnjoe MacFadden, Greg Knowles, Simon Doran, James Christley, Ray Mackintosh, John Miller, and James Curry. I am sure that errors still remain, for which I hold sole responsibility. I must also thank Bill Gelletly for making the suggestion that got the whole project started, Kate Jones for some constructive lunch-time discussions on entropy, Youcef Nedjadi for clarifying some aspects of free will, Matt Visser for filling me in on some of the latest ideas about wormholes, Brian Stedeford for useful insights into the work of Lewis Carroll, Phil Palmer for clarifying a number of points in cosmology, James Malone for kindly providing the computer-generated image of a wormhole for the book cover, and finally my commissioning editor at Institute of Physics Publishing, Michael Taylor, for all his help and support.

About the author

Jim Al-Khalili is a theoretical physicist, author and broadcaster. He is currently professor of physics at the University of Surrey, where he still teaches undergraduate courses. He also holds the first Surrey University chair in the public engagement in science and is an executive vice president of the British Science Association. As a broadcaster, he is a regular presenter of science documentaries on television and radio. He was awarded the Royal Society Michael Faraday Prize for science communication in 2007 and an OBE, for services to science, in 2008. He received his PhD in theoretical nuclear physics in 1989 and has since published widely in this field. His other books include *Quantum: A Guide for the Perplexed, Nucleus: A Trip in the Heart of Matter* and *Pathfinders: The Golden Age of Arabic Science*. He is married, has two children, and lives in Southsea in Hampshire.

Introduction

Exciting Times

"The time has come" the Walrus said,

"to talk of many things" . . .

Lewis Carroll
Through the Looking Glass

. . . of atoms, stars and galaxies,

and what a black hole means;

and whether Einstein's space can bend

enough to construct time machines.

This book is meant for all those people—which is pretty much everyone I know—who are curious about such exotic-sounding concepts as black holes, space warps, the Big Bang, time travel, and parallel universes. In writing the book I have asked myself whether complete non-experts can learn a little about some of the ideas of modern physics without feeling the urge to check that their IQ is up to the task before embarking.

The subject matter of the book has been covered elsewhere at many different levels. At the very top is the advanced text or monograph for the practitioner in the field. This is the sorcerer's spell book, decipherable only by the privileged few. Then comes the textbook aimed at the university physics student. It too contains some spells, but nothing very powerful. Below that comes the top end of the popular science market. Such books are aimed at the non-scientist in that they contain little or no mathematics. However, they invariably appeal only to those who are either a) other scientists or b) fans of such books already, who have invariably read similar books on the subject.

So, when writing this book I have made every effort to cut out as much scientific jargon as possible. Popular science writers are, on the whole, becoming highly adept these days at explaining complex concepts using everyday words. But every now and then we will let slip a 'Jargonese' word which to us is so obvious we forget that it does not carry the same meaning for everyone.

Short or long ten minutes?

One summer, when I was about ten or eleven, I became fascinated with the concept of time. Where did it come from? Did we invent it or has it always been around? Does the future already exist somewhere? Is the past still being acted out? Deep questions for a kid. But, before you mistake me for a child prodigy, let me share with you what my idea of time travel was. I knew that on the other side of the world, somewhere in the middle of the Pacific Ocean, was an invisible line running from the North Pole to the South Pole which divided the world into Today and Yesterday! If a ship was anchored across this line, then on one end of the ship it could be 9:00 on Tuesday morning and at the other end 10:00 on Monday morning. Surely this was a clear example of time travel, just by walking a few yards along the deck!

OK, I knew there was something fishy going on and I remember one evening my father explaining to me that time zones around the world are only a human invention. For instance if it is decreed that at midnight in New York it is already 5:00 a.m. in London, this is just our way of making sure that, as the Earth spins and different countries face towards the sun, the hours of daylight are roughly the same for everyone, if not at the same time. I followed all of this, sort of, but felt disappointed. Surely there was more to the concept of 'time' than that, something more mysterious. I had this theory about time flowing at different rates depending on my mood. Clocks definitely slowed down towards the end of school lessons and, as my birthday approached, the weeks and days almost ground to a halt.

Now it is the turn of my own children to come to these conclusions. If I tell them they have ten more minutes before they have to put their toys away, they are quite serious when they ask whether it is a short, medium, or long ten minutes. Anyway, who can argue against the simple observation that, for a child, time goes by very slowly. One year is an extremely long time for five-year-olds since it makes up a fifth of their life, but the older we get the faster the years seem to flash by: can you believe it is Christmas again already! or, has it really been three years since I was last here? and so on.

Deep down we feel we *know* that time flows at a steady rate. When asked how fast time flows, the scientists' usual glib response is to say that it is at a rate of one second per second. In our culture we believe that, no matter how subjective we feel about the passage of time, there is a cosmic clock that marks off the seconds, minutes, hours, days, and years everywhere in the Universe relentlessly and inexorably and there is nothing we can do to change it.

Or is there? Does such cosmic time really exist anyway? Modern physics has shown that it doesn't. Don't worry, there is very strong evidence to support this. In fact, before I go any further let me say that we now know with absolute certainty that *time travel to the future is possible*. Scientists have successfully carried out many experiments that have tested this and proven beyond any doubt that it is possible. If you are in any doubt about this amazing, maybe even startling, piece of information then this is not due to any *X-Files*-type government cover-up but rather because you have not done a course in special relativity. All will be revealed, I hope, in this book.

Common sense

It is probably fair to say that most people are not exactly on best buddy terms with Einstein's theories of relativity (yes, there are two of them). So I am never surprised by the response I get when I tell my non-scientist friends that nothing can go faster than light. 'How do you know?' they say. 'Just because scientists haven't found anything that can go faster than light, that doesn't mean that you won't one day have to eat your words. You should be more open minded to other possibilities that just may not have occurred to you. Imagine showing a television to an isolated tribe in the deepest Amazon which has never seen one before,' and so on. I am not in the least bothered by this response because it is exactly the attitude I would like the reader of this book to have. Namely, being open minded and having the ability to accept a new worldview even if it flies against everything you thought you were sure about, or what you would call simple common sense.

Albert Einstein was once quoted as saying that common sense is just the prejudices we acquire by the age of eighteen. So, for the Amazonian tribe which has never seen a television before, it would go against their common sense that such a box could speak to them and show them a whole world inside it. (OK, I am assuming that they have electricity there and a power point!) But I am sure you would agree that after we had spent enough time with this tribe explaining radio waves and modern electronics and all the other things that go into making a television work, then they would grudgingly have to adjust their worldview so that this new information no longer went against their common sense.

At the beginning of the twentieth century, several new scientific theories were developed and proven to be, so far anyway, correct. Between them they are responsible for almost the whole of modern science and technology. The fact that we have digital watches, computers, televisions, microwaves, CD players, and just about every other modern appliance is testimony to the fact that these theories are, if not the whole story, pretty much true in the way they describe the world around us. The theories in question are relativity and quantum mechanics. I should explain that a successful theory is one which can predict what would happen under certain circumstances: If I do *this*, then according to my theory *that* will happen. If I carry out an experiment and find that the theory's predictions were correct, then this is evidence in support of the theory. But a theory is not the same as a law.

The law of gravity says that all objects in the Universe are attracted to each other by a force that depends on how massive they are and how far apart they are. This is not open to doubt, and while we know that it needs to be modified when we are dealing with extremely massive objects such as black holes, we trust it completely when it comes to describing the way falling objects behave on Earth. However, a theory is only good as long as a better one doesn't come along and disprove it. We can never prove a theory, only disprove it, and a successful theory is one that stands the test of time. Contrary to the view of many non-scientists, most scientists would like nothing better than to prove a scientific theory wrong, the more respectable the better. So, since theories such as quantum mechanics and Einstein's relativity have lasted for most of this century despite the constant efforts of physicists to prove them wrong or at least find loopholes and weaknesses, we have to admit that they are probably right, or at least on the right track.