Can we change the past?

The surprising answer to this question can be found in the final chapters of this book.

Examining both the history of the study of time, from the classical Greeks through to the present day, and presenting in detail the modern state of physical research on the subject, this book is a superb overview of a fascinating subject.

The figures who have helped to shape our views on time are presented as real people, in the context of their own times and struggles: from Socrates' troubles in Athens, to the experiences of physicists under the old Soviet Union. In addition Novikov details his personal experiences with great Russian and Western physicists, such as Sakharov, Zeldovich, Rees and Hawking, and his travels in the West before the fall of the Iron Curtain.

Details of the modern theories in fields such as the possibility of time machines, anomalous flows of time (at black or white holes) and the possible source of the River of Time are described with authority and clarity. These are areas in which Novikov is himself a leading researcher.

Accessible to all, the engaging style and wonderful illustrations make this book hugely enjoyable to read.

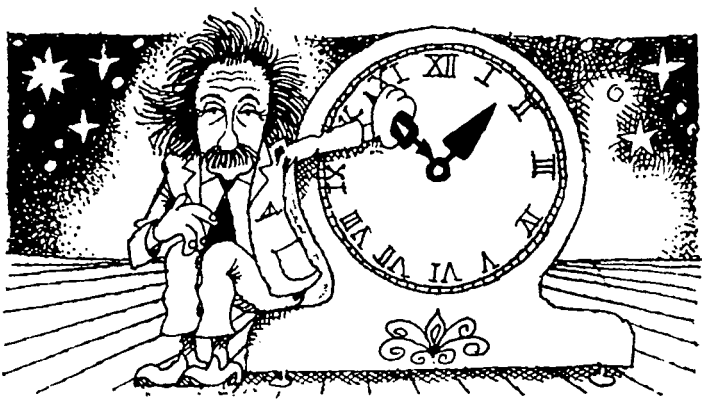
Igor Novikov is Professor of Astrophysics at Copenhagen University, and Director of the Theoretical Astrophysics Centre, also in Copenhagen. He is the author of 15 books, six of which have been translated into English, and numerous technical papers and popular articles.

His previous books include *Evolution of the Universe, Black Holes and the Universe* and a biography of Hubble, all published in English by Cambridge University Press.

The River of Time

Igor D. Novikov

Translated from the Russian by Vitaly Kisin



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Cover illustration: Time warp. Computer illustration depicting a warped pocket watch against a multi-coloured background. This could be used to illustrate one of the concepts of Einstein's Theory of Special Relativity – that time is not absolute but depends on the relative motion of the observer and that which is being observed. Einstein later showed that time and space are different dimensions of the same thing – spacetime – which could be warped by gravitational fields. Science fiction writers often use the concept of warped spacetime to allow travel at speeds above that of light – something expressly prohibited by Einstein's theories. Credit: Mehau Kulyk/Science Photo Library

To my children,
Elena and Dmitri,
who have longer than myself
to flow down
the river of time

I tell myself that like water
time flows between one's fingers
onto the sand that slowly cools,
and through the sand it seeps into nowhere...

and if Styx is indeed a river
that separates two worlds so far apart
then its flow is lost among millennia.

Still, we know a river that has no bottom
one whose banks do not restrain its flow...
a moment comes when human names sink into it.

Its waters are transparent and dark,
they fill up everyone and everything,
one can discern them between lines and hear them in music.

One wades into this river only once,
is banned from ever finding the mysterious source
where Time is fast asleep, curled in a tight cocoon
on the rocky bosom of Eternity.

Marina Katys

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Preface to the Russian edition

The person to whom I owe my fate was my grandmother. My parents were not there to take part in bringing me up, so my first consciously made steps in life grew from her love and care. Once she found for me an exciting book: *Brer Rabbit's Adventures*, translated into Russian. I learnt to read with this book. It was my grandmother again who bought for me, on a flea-market, my first popular book about science. It was a very difficult time, the Second World War was raging and the family was evacuated to the town of Krasnokamsk on the Volga. People thought about food first, books were very secondary. But my grandmother – mind you, she had no education whatsoever – felt, perhaps, that food for thought was just as necessary for kids as food for the stomach. The book that she bought (or swapped?) was marvelous; I will never forget it. It was *Children's Encyclopaedia*, a pre-1917 book, with wonderful color prints. As far as I can remember, their quality was far superior to the often smeared and bleak illustrations that I find nowadays in some editions of books that I write.

That book had a chapter about astronomy. Browsing for the first time through the volume (as for any other kid, this was the first thing to do with a new book), I was amazed by a drawing of a gigantic fountain of fire, with a small globe of our Earth alongside.

I learnt later that it was a solar protuberance, and that the Earth was placed there for comparison. The image was so grandiose that I was in absolute awe. I was impressed by the majestic scale of natural processes which were much grander than anything that my childish imagination could conjure up.

Truly, that print proved to be auspicious for me. It was enigmatic, baffling and mysteriously attractive. I very quickly read everything it contained about astronomy, and then all the other chapters. Some sections on world history were quite interesting, but nothing could compare with astronomy! The depths of cosmic space, the vortices on the Sun, and the possibility of life on Mars captured my inquisitiveness, my imagination and my love. I think that the mysterious phenomena of the Universe were the fount of all these feelings. I knew they were for life. 'The light of the first love is in each of us.'

Life can display so much, it is so multifaceted and wonderful, but it can also be terrible. I lived with my grandmother because my father, who occupied a responsible position in the People's Commissariat for Transportation, was arrested in 1937 and 'died in prison' (according to an official acknowledgement, that is; in 'their' parlance, this stands for 'was executed'), while my mother was deported to exile. Both were completely cleared of all accusations ('rehabilitated', in Soviet parlance) in the 1950s. Nevertheless, I did not know and still do not know of anything more wonderful than striving to learn the mysteries of the Universe. What I mean is not an abstract longing, not a lazy 'philosophizing' about the meaning of existence (I understood quite early that this was nonsense and, often, a manifestation of laziness and self-admiration caused by each wiggle of one's thought) but hard and happy work.

From early childhood I grew more and more certain that the best way to stimulate the development of the mind and of its creative potential is to strike a spark of unstoppable inquisitiveness into the

mysteries that nature is hiding. True inquisitiveness will lead one further, make one seek and toil, even if he or she never becomes a scientist.

Later I read a great many science-popularizing books. Frankly, their number was much tinier then than now but... most of them were quite good! I learnt very soon that one needs to know an awful lot if one wishes to really accomplish anything in science. The fire of inquisitiveness was burning in me, so nothing could ever stop me. Furthermore, years of studying, of overcoming small but gradually more difficult obstacles, were rewarded with constantly growing delight.

Why am I telling all this?

I do it to illustrate two ideas with my own fate. Firstly, it is extremely important to imbue a person with a bona fide scientific thirst for knowledge, which later will become this person's driving force. It is not essential that he or she actually becomes a professional scientist. A love of science, a comprehension of its foundations, an admiration of the discoveries that unravel the most profound secrets of nature are as necessary to any person as an all-round cultural and aesthetic education. Our contemporaries cannot live without music, or paintings, or books. A life without appreciation of the achievements of science, which comes up with answers to the most profound whys and hows that we ask of nature, is equally unacceptable. A well-known physics theorist in the USSR, Vitaly Ginzburg has said this about the theory of relativity – one of the most perfect physical theories of our time: it incites 'a feeling... akin to what one feels looking at the most outstanding masterpieces in painting, sculpture or architecture'.

I will also cite a Soviet philosopher Boris Kuznetsov discussing the art and science of ancient Greece as the unifying elements of human culture: 'it speaks... of life uninterrupted, of new impressions, feelings and thoughts that are still inspired by Venus of Milo

or Nike of Samothrace. In the same vein, we perceive the immortality of Plato's *Dialogues* or Aristotle's *Physics*.'

Secondly, to become a physicist or astronomer and really participate in scientific progress, one has to master the entire body of knowledge in the field one has chosen. Dilettantism has no place here. Science of today is incredibly complex and its mathematical equipment is so abstract and abstruse that the non-initiated simply could not fathom the degree of complexity of the whole. Actual work in science demands that you become an expert in applying the mathematical tools. Your knowledge of contemporary mathematics and related fields must be profound. This is the only level of expertise that allows one to reach the essence of subjects studied in physics and astronomy.

For a number of reasons, this level is not open to just anyone wishing to climb to it. Only a few become physicists, quite a few only handle mathematics within a high school course. Does it mean that any opportunity to admire the awesome achievements of physics is forever closed for these people, that it is impossible to find out about the science which penetrates the mystery of how matter is structured at its deepest levels and at the same time discovers the quanta of time and space?

Of course it does not, and one can describe the achievements of physics clearly and correctly to anyone interested, even without resorting to arithmetic. It means, however, that one should not try to explain all the details and difficulties in calculations and all the logical relations that lead to drawing the conclusions. The strategy must be different: one must try to create a shining image of a phenomenon, to make the reader form an idea of what the physicists attempt to achieve. These images can be understood without mathematics and can be admired and applauded. Remember, however, that if you are not a professional, not a physicist, do not entertain the illusion that having read a popular physics book you may be

able to offer a 'hypothesis' that would solve the difficulties outlined in the book. Nothing good will come of it. An image is definitely not 'her majesty physics'. To offer a useful hypothesis, one has to become professional; however, everyone can enjoy an image drawn by a professional.

By way of comparison, I can say that I love music passionately but that God did not grant me a musical ear. I will never write music, nor reproduce even an elementary tune. I do enjoy listening to music written by (talented) professionals and performed by equally professional (also talented) individuals, and will continue to do so.

People who cannot draw or paint at all, do enjoy paintings, those who could not write a novel enjoy reading novels.

It is my firm belief that a similar situation holds for attempts to make science understood by the non-scientist. The author's goal must be to create a strong, impressive image.

I will try to describe in the subsequent chapters the achievements of physics that I dearly love.

This is a book about time, or rather, about scientists' attempts to understand what time is. The reader can be expected to ask, with full justification, whether there should exist a science of time. Isn't time something that anyone understands? What can one study about time?

I propose that you try to give a definition of what time is; I believe you won't be able to do it. Saint Augustine (354–430 AD) wrote: 'I know perfectly well what time is, as long as I do not think about it. But once I start thinking hard – I feel at a loss and do not know any more what time is.'†

Is it not true that anyone attempting to find an answer to this question feels a similar confusion? When we begin thinking about

† Translated from the version in Russian.

the nature of time, we tend to feel that this is an irresistible flow into which all events are embedded. Millennia of human experience seem to have proved that time flows at an unchanging pace. Apparently, it cannot be slowed down or accelerated. What is even more certain is that it cannot be turned back. For a long time, the notion of time remained a mere intuitive feeling and the object of abstract philosophical exercises.

In the first years of the 20th century it became clear that time *can* be influenced! For example, very fast motion slows down the pace of time. Next it was found that time flow is also affected by the gravitational field. An inseparable relation was discovered between time and the properties of space. This was the birth and the beginning of the rapid development of what we may call the physics of time (and space). Discoveries have been made recently in elementary particle physics and in astronomy, which greatly advanced our knowledge of the fascinating properties of time and may have brought closer the solution of the puzzles involved (for instance: why is a chain of events invariably one-dimensional but does not have, say, a 'width' and 'height' to which we are used in our three-dimensional space?; what was there before our Universe emerged? etc.).

The current stage in physics is characterized by a new and powerful breakthrough in our understanding of the structure of matter. In the first decades of the 20th century, physicists succeeded in unraveling the structure of atoms and in finding the main features of the interaction between atomic particles. Now physics studies quarks, which are subnuclear particles, and penetrates deeper and deeper into the microscopic world. All this progress is connected most closely with understanding the nature of time.

The book describes how the thinkers before us defined time and how the discoveries were made which showed that we may influence the flow of time. It describes how time flows in specific regions of the Universe, how it slows down in the neighborhood of neutron

stars, how time is stopped in black holes and 'splashes over the brim' in white holes, how time may 'convert' into space and vice versa.

The properties of time are especially interesting at the first moments of the explosion which started the creation of our Universe; this was the period when time existed in the form of distinct time quanta.

The properties of time in superhigh-energy physics are important for science in general and for future technologies. Some very recent publications indicate that it might be possible to design a time machine which would allow time travel into the past.

The book also describes people who created the physics of time and who are doing further research in it now. It seems to happen too often that the great thinkers of the past or the distinguished contemporary scientists exist for the reading public only as abstract names mentioned in textbook and non-textbook publications, all written in a dry and very unemotional style. The images of these individuals are hardly associated with flesh-and-blood people, their interests, passions and contradictions. When I speak in this book about the scientific creativity of these scientists, I try also to find features and events that describe them as real human beings. On the other hand, it was never my intention to give their detailed biographies or to list their scientific achievements.

The book is aimed at readers interested in the history of scientific ideas, in the puzzles facing contemporary science, and in the personalities of scientists themselves, especially those physicists that I have had the pleasure and honor of meeting and working with. I do not assume that a reader has any special knowledge beyond the simplest course of high-school physics.

The reader will find that I chose a personalized style of presentation, especially when outlining studies in which I participated myself or when describing my meetings with physicists and

astronomers. I quote in this connection Professor Vitaly Ginzburg, who had said this about one section of his scientific paper:

> It is not customary to use 'I' and 'me' in the scientific literature, especially in the Russian language. The same is mostly true for the science popularizing literature, so that the author has been referring to himself above only as 'we' or 'us' or was using other turns of speech suitable for such occasions. It would be difficult and even strange, however, to keep to this style in this specific section of the paper, since it is to a large extent autobiographical... I hope, therefore, that several personal pronouns will not produce intense negative response among the readers.

I hope that neither will my readers judge me too harshly for this 'immodest' presentation of my personal thoughts and my impressions.†

To write this book, I had to draw in places from my earlier popular physics and astrophysics books; some of them were written in collaboration with other people, to whom I express my gratitude.

The book cites a considerable number of quotations. Quite often, these are little known pronouncements of outstanding scientists of the past, as well as our contemporaries. I firmly believe that only the exact words of these illustrious personalities can bring to the reader their thoughts (and quite often their feelings as well). The great Russian poet Aleksander Pushkin said: 'To follow the reasoning of a great personality is a most captivating and gratifying subject' *(Arap Petra Velikogo* [Peter the Great's Moor]).

I. D. Novikov
Moscow

† *Remark for the English translation:* This self-justification may sound strange to an English reader. As far as I can see, authors of science-popularizing books have no qualms in using the pronouns 'I', 'me' or 'myself' when appropriate. This is not the case, however, for Russian literature.

Preface to the English edition

I began preparations to publish this book in English at the end of 1991; for a number of reasons, this stage stretched to several years. An oriental adage says: 'Hours tick away, days run away but years fly away.' These words are a reflection of our subjective perception of time intervals in the past, of what we remember of them. For most people, the feeling of the flight of time is considerably intensified when one turns in one's mind's eye to larger and larger blocks of time which one has lived through. I distinctly feel now that it was virtually yesterday that I was writing this book, even though several years separate me from those days and so much has happened and so much has changed. In that period, I began working in a new place, as astrophysics professor of Copenhagen University. My native country, the former USSR, the former enormous empire, broke into pieces and is trying, in untold hardship for its peoples, to claw its way out of the frightening historical abyss into which it had been plunged. Even though I continue to head the Department of Theoretical Astrophysics of the Petr Lebedev Physics Institute in Moscow, my settled life beyond the borders of my native land, in a very different world, has definitely changed my perception of life, although to a considerably lesser

degree than I could have predicted. It involves my attitude to this book as well.

My recollections of childhood days that are found in the preface to the Russian edition are likely to be more understandable to the Western reader if I now add several strokes to this description; I do think that these are rather typical for my generation in Russia. I have mentioned already in the preface that my father fell victim to Stalin's regime when I was two years old. I do not remember anything about him. My mother, arrested and exiled, ultimately returned from the Gulag areas but was not allowed to live in Moscow. She secretly visited my elder brother and me in a tiny 'communal' (multi-family) three-room flat occupied by my stepfather, my grandmother, my brother's wife and the family of my aunt (four people, including my cousin suffering from tuberculosis). My mother was terribly tormented by the utterly unexplainable and meaningless persecutions of Stalin's system. Not only was she, a very beautiful young woman, snatched out of life in the 1930s and thrown into the hell of Gulag prisons but, later, she was constantly trying to comprehend – and failing to – 'What was it for? What have I done?' Constantly remembering how my father had been arrested and then herself, she got so terrified in the nights by a noise or a knock on the door that she would throw herself under the bed, with a hysterical, barely audible yell: 'They've come... they've come to take me!'. My brother and I were marked with this invisible brand of 'children of an enemy of the people'. Those who were never branded with this secret, destructive, caused-by-nothing label which put you beyond the pale of law and society could not be expected to grasp the weight of this load.

I need to remark that nobody in the family ever displayed any hate towards the reigning political system or even betrayed a critical discussion of it, at any rate in the presence of children. Perhaps, the adults suffered so much grief that they shielded their

young from the reality. I think now that I simply had no idea that other ways of life, other surroundings were at all possible, and thus could not suffer 'excessively'. I regarded even our utter poverty as something that was to be taken for granted. When my stepfather died, leaving mother and me to live alone, our monthly budget was about 600 roubles, the price of lunch in a student canteen being 8–10 roubles. My brother would help as much as he could: he began to work. But it was very little: he had his own family to feed on an engineer's salary, which was quite modest in the USSR.

My early passion with the mysteries of the Universe was invariably encouraged by my relatives. I would switch to a different world which was far removed from the all-pervasive tragedies of my country (so I was hardly conscious of them), to the world of pure truths devoid of the contradictions of our day-to-day existence; I fell in love with the logic of relations between these pure truths. This may have been too deep a devotion, since, from the earliest moments that I can recollect about my childhood and youth, I was absolutely sure that the most important and deeply loved truths about space, time and the Universe had at last (and only recently!) been understood and established as final. I did not discern (or tried not to notice) the obvious discrepancy: my attitude meant that the millennia-old history of science had timed the discovery of the most important knowledge about the world almost to the day of my birth. Having become a scientist, I had to fight in myself this extremely harmful and unproductive attitude of a person who believes that he knows – or can find – the ultimate truth. In fact, such beliefs are dangerous, and not only in science but in life as well.

These were therefore the psychological surroundings in which grew my love of Knowledge, which I perceived as the love of the Grandiose, Mysterious (especially Mysterious) and Eternal.

The science of astronomy existed in my country in the rigid,

draconian reality warped by Stalin and his henchmen. Officially, all science was classified into two groups: the 'progressive, the-only-true, *our* Marxist science' and the 'decaying, on-the-brink-of-bankruptcy, *their* capitalist science'. Today in Russia, as always in the West, this sounds as a flat hoary joke. The reality was far from a joke, it enforced a form of existence on science. The theory of an expanding Universe was banned. My future professor and advisor Abram Leonidovich Zelmanov, a cosmologist, one of the creators of the mathematical apparatus of today's science of the Universe, was fired, together with some other leading scientists, from his job at the Shternberg Astronomical Institute in Moscow: both for his research in cosmology and for being a Jew. I vividly remember how, still very young, I pounced impatiently on a fresh issue of the recently organized *Referativny Zhurnal* for abstracts of the latest papers on cosmology in foreign journals, only to be stunned by a cliché at the end of each one of them: 'The author (or authors) shares the views of the bourgeois theory of expanding Universe'.

In our country of that time, scientists had to think – first and foremost – about survival, at the same time doing the job they were devoted to. It is a marvel, perhaps, that in such an atmosphere the science of the Universe did not degenerate in the country; in fact, it even produced exceptionally good results. I tend more and more to the opinion that the 'double burden' on the shoulders of our experts, in some way stimulated a successful quest for new knowledge. It made them work with quadrupled effort and yield.

As a tentative proof of the possibility of such a response to crushing calamity, I turn to a contemporary genius in astronomy and physics: Stephen Hawking of Cambridge University in England. Hawking has been crippled by a frightful disease and confined to a wheelchair; with time, he has virtually lost all control over his muscles and finally lost speech. His intellect and his sense of

humor, however, were getting stronger and sharper. As one of my colleagues put it, Hawking was transferred to a different life dimension and there achieved outstanding results in science.

I do regard myself as an expert in, among other fields, the physics of time; hence, it is impossible to forget, in a book about time, to mention some moments of my personal experience of 'floating' in time, of being carried by time flow and its vortices through the middle and end of the 20th century.

Any person who devotes enough thought to the meaning of 'being' comes, sooner or later, to query the very hypothesis of 'climbing on the banks of the River of Time', of liberating oneself from its majestic flow, of stopping and, so to speak, looking at the essence of what is happening.

The query will cease to appear so strange if one remembers that we are indeed able to stop traveling through space and 'come to rest'. Why then are we unable to do this in time? Or are we?

However, I jump ahead of the story here – more of that later in the book.

The book has been substantially revised for the English edition. Some passages, which seemed to overload the presentation, have been dropped. On the other hand, I have added new material, mostly dealing with further progress in the analysis of the possibilities of creating a time machine, paragraphs outlining some of my discussions with colleagues in Russia and in the West, and much more.

To conclude this 'second' preface, I wish to add several words to the comparison, offered in the 'first' preface, between art, on the one hand, and talking about science, on the other.

One can rather crudely divide painting into, say, realistic and abstract. Both types of painting stimulate feelings and thoughts in the viewer (profound feelings and thoughts if the paintings are truly great). However, abstract art requires that the viewer partic-

ipate in the process of creation of a painting, that he 'think further' and 'feel further' into what the painter has presented. Realistic painting generates very different associations stemming from the comprehensive visual images that the painter has completed to perfection.

I believe that a story about science (my story, anyway) is closer to realistic than to abstract painting. I do not exclude that one could write about science in the 'abstract-art' style, inviting the reader, who is not an expert in the field, to join in drawing the conclusions. The fantasies and dreams of a non-expert reader may then carry him or her too far astray. This might be interesting, may even be desirable (I might try and write something like this some day) but this would definitely *not* give a picture of the current status of a science. Science is not a dream but a reality, often very useful, a practical and necessary reality. I do not forget, of course, that without a dream, one can never achieve important results in science.

For the English edition I added a few new illustrations partly using the characters of the illustrations in the Russian edition.

And last but not least: in recent years during the preparation of the English version of the book, in addition to my duties as a Professor of the Astronomical Observatory of Copenhagen University, I also worked as Director of the Theoretical Astrophysics Center of the Danish National Research Foundation. Both institutions supported and encouraged me in my work, and I thank them very much for that.

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Copenhagen