Black Holes and Time Warps: Einstein's Outrageous Legacy

by Kip Thorne

Reviewed by John Preskill

It is dangerous to ask a scientist to review a book on science that is intended for a lay audience, particularly if the subject of the book is close to the reviewer's own specialty, as in this case. So I may not be the best qualified to judge how effectively this book reaches its intended readers. Nevertheless, I can say with confidence that Kip Thorne's account of the "outrageous" consequences of the general theory of relativity is one of the best popularizations of science that I have read. It is surely the best by far of the many popular books on relativity theory.

An essential part of the appeal of the book is its subject, for the general theory of relativity is arguably the very greatest triumph of the human intellect, and nothing better illustrates the profound beauty of the natural laws that govern the universe. Thorne brings a unique set of qualifications to the demanding task of explaining relativity to the lay person. First, few active researchers can match his deep grasp of the relevant science. Second, he is a gifted teacher whose pedagogical skills have been well honed by guiding a generation of Caltech students through the subtleties of relativity. Third, he writes prose that is lucid and absorbing. Finally, he has an insider's view of the exciting developments, stretching back to the early 60's, that are the focus of most of the book.

Rarely has a world class scientist shown such devotion in the preparation of a non-technical book; Thorne worked on the manuscript, on and off, for some 15 years. It traces the history of relativity theory from its origins in the early 20th century and documents the subsequent struggle to understand the theory and its implications. Though Thorne is not a historian, he recounts this history with meticulous attention to detail. In particular, he conducted taped interviews with 47 scientists who were directly involved in the developments that he describes. For the earlier history, he relies more heavily on secondary sources, but he has also studied many of the original research articles. (In the case of Einstein's papers, it was necessary for Thorne to read many of them in Russian, because he does not read German and they have never been translated into English.) The sources are well documented in the notes at the back of the book.

The book is non-technical in the sense that it contains no equations (aside from a few in the notes). This is not to say that it is easy reading. A reader unfamiliar with the material will need to work hard to fully absorb the nearly 600 pages. But that dedicated reader will be amply rewarded. This book contains the real stuff; Thorne has resisted to a remarkable extent the temptation to water down the scientific content for the sake of ease of presentation. The reader who takes the trouble to master this book will have achieved a grasp of many subtle and elusive concepts. Sadly, the same cannot be said of most science writing, and certainly cannot be said of most popular accounts of relativity theory. Considering Thorne's high standard of scientific accuracy, the book is amazingly readable.

There is much more here than a remarkably lucid description of the science. A very important part of what makes the book enjoyable are the portrayals of many fascinating personalities. Perhaps the three most interesting are John Wheeler, the American theoretical physicist who was Thorne's mentor and who coined the term "black hole" in 1967, Stephen Hawking, the British theorist whose brilliant contributions to the theory of black holes in the early 70's are vividly related here, and Yakov Borisovich Zel'dovich, the Soviet astrophysicist. I especially enjoyed the account of the career of Zel'dovich, who was a key figure in the design of the Soviet hydrogen bomb, and then funneled his enormous energy and intellect into astrophysics beginning in the late 50's. By 1964, he had built the strongest theoretical astrophysics team in the world. Thorne's many contacts with Zel'dovich and other Soviet physicists have enabled him to offer intriguing insights into the contrast between the Soviet and American style of doing science.

While captivating figures such as Zel'dovich add spice to the book, the real main character is the truly outrageous black hole, the central topic of 8 of the 14 chapters (and also of a long prologue). One of the most outrageous features of a black hole is that no other macroscopic object has so simple a structure; a black hole is composed of nothing but pure warped spacetime. And a black hole surrounded by empty space is an essentially unique object; once its mass and rate of rotation are known, its structure is completely determined. (In John Wheeler's apt phrase, "A black hole has no hair.") Equally outrageous is the black hole's appetite for destruction: astronauts that foolishly enter a black hole can never escape; rather they will be inextricably drawn to a"singularity" where their bodies will be torn apart by enormous gravitational forces.

Thorne chronicles the evolution of the concept of the black hole, from abstract mathematical idealization to concrete physical object. The astronomer Karl Schwarzschild first discovered what we now call a black hole as a mathematical solution to Einstein's gravitational field equation (while he was serving in the German army on the Russian front during World War I). But for decades, most physicists stubbornly resisted the preposterous implications of Schwarzschild's solution. This included Einstein himself, who wrote a regrettable (and quite incorrect) paper in 1939 arguing that black holes cannot exist. Not until the 1960's did the black hole concept firmly take hold in the community of physicists and astronomers. Thorne nostalgically recounts how the "golden age" of black hole research opened up around 1964 as the first hints emerged that black holes have no hair. The golden age lasted some ten years. During this period came, among other things, the discoveries that black holes can spin and vibrate, and that they can exchange energy with the matter that surrounds them. (Many of Thorne's own students made fundamental contributions during this period.) These insights ushered in a new discipline, "relativistic astrophysics," and led to the (presumed) detection of black holes by astronomers and experimental physicists as X-ray emitting binary star systems, and as quasars emitting extraordinarily powerful radio signals.

Of particular interest to the Caltech community is the chapter of the book concerning gravitational wave detection and the LIGO project. Gravitational waves are ripples in the geometry of spacetime that are expected to be copiously created in rare cataclysmic astronomical events, such as a collision of two black holes. These waves are exceedingly difficult to detect because the events that produce strong signals typically occur only at great distances from us. LIGO (for Laser Interferometer Gravitational-Wave Observatory) is an ambitious effort by a joint Caltech/MIT team to construct a facility that, it is hoped, will directly detect gravitational waves for the very first time. The apparatus must be extraordinarily sensitive, and although construction of LIGO has now begun, the success of the enterprise is still far from assured.

It was Thorne himself who proposed in 1976 that Caltech initiate a program aimed at detection of gravitational waves, and he recalls here his own struggle at that time to evaluate the risk and potential payoff of such a program. He also recounts the sometimes painful evolution of the project from the freewheeling style of its early days to the much more regimented style that became necessary as it neared the construction stage. Thorne is at his best contemplating the scientific potential of LIGO; his passion for the prospect of viewing the universe in an entirely new way shines through in this chapter.

The most outrageous implications of general relativity are the subject of the final chapter of the book, which is called "Wormholes and Time Machines." The topic here is more speculative than in the earlier chapters, and is described more from Thorne's own personal perspective. I suspect that some readers will also find it to be the most interesting chapter, as it offers a glimpse of the cutting edge of current research on an intrinsically fascinating topic.

Thorne recalls how Carl Sagan prevailed upon him to invent a system of interstellar transport for the novel *Contact*. Thorne suggested wormholes. A wormhole is a "short circuit" in space that connects distantly separated points, and enables someone who travels through it to reach a remote location virtually instantaneously. Sagan's request inspired Thorne and his students to investigate whether an "arbitrarily advanced civilization" could in principle create such wormholes. (This remains an open question.) Thinking about wormholes eventually led Thorne to the startling insight that a wormhole can be turned into a time machine by moving one end of a wormhole in an appropriate way. This subtle trick is explained here in detail and with exceptional clarity. There follows a sober and careful discussion of the implications. Thorne concludes that whether time machines can exist is really a question about the (still poorly understood) laws that govern quantum gravity. He reports that his own gut feeling is that the laws of physics forbid time machines–but we still don't know for sure.

During the 30 or so years of Kip Thorne's scientific career, the study of gravitational physics has been radically transformed. In the early 60's, general relativity was widely perceived (with some justification) as a beautiful but highly abstract and complicated theory that made very little contact with the real world. Since then, advances in technology and in theoretical understanding have changed that perception forever. Today, observational astronomers and experimental physicists routinely seek and find evidence for black holes in binary star systems and at the center of galaxies. To a great extent, this book is the story of how this transformation took place, as seen by a central participant. Above all, it is a story of human reason at its best, following the tortuous path toward undertanding of the deepest truths.

I believe that many Caltech students, faculty, and alumni will enjoy this book. A dedicated reader will learn a great deal of physics. But even if some readers don't have the patience to absorb the details of all of the arguments, they will still delight in the insights into the scientific process, the vivid anecdotes, and the sense of adventure inherent in the difficult struggle to grasp the fundamental laws of Nature.