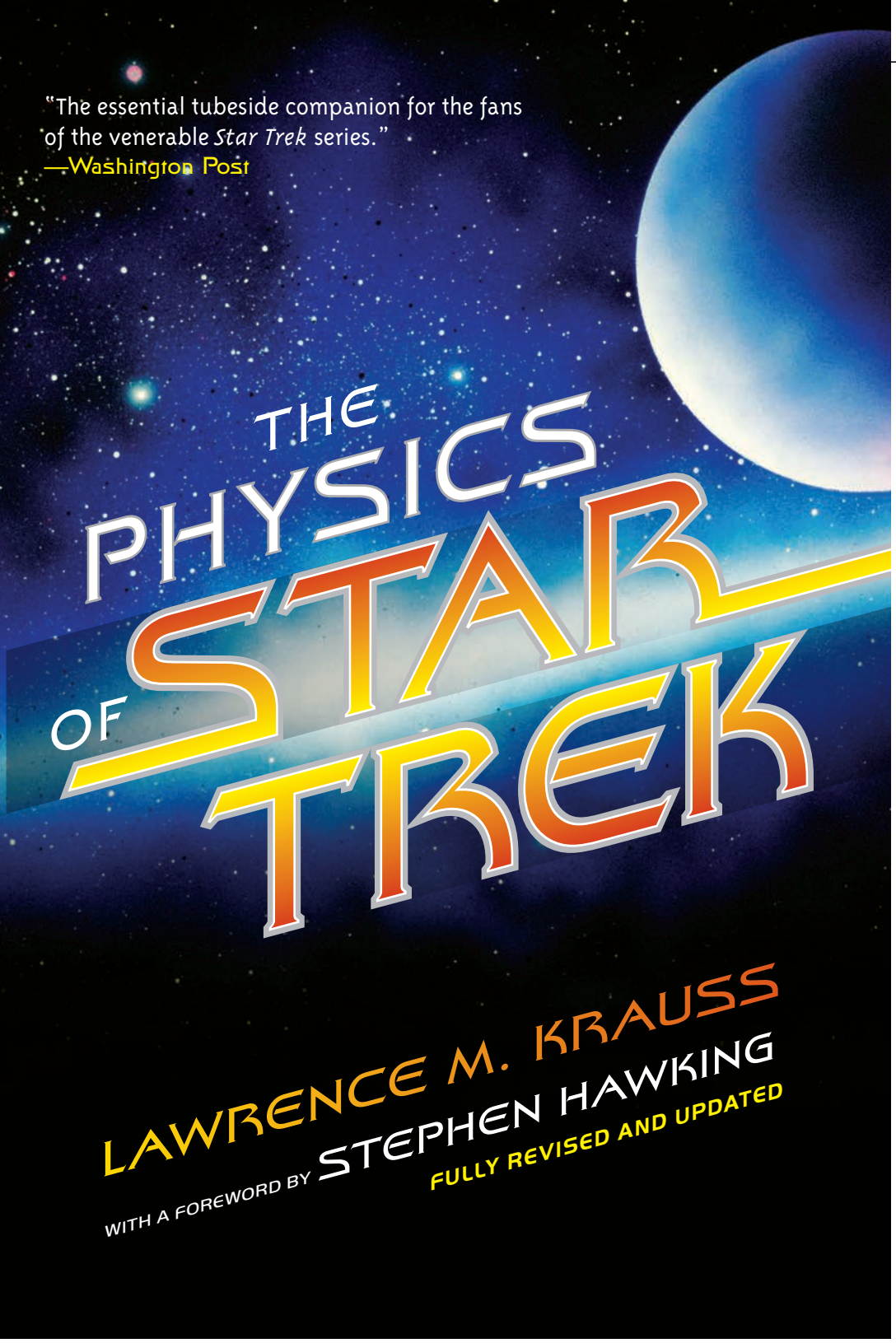
"The essential tubeside companion for the fans of the venerable *Star Trek* series."
—Washington Post
THE PHYSICS OF STAR TREK
LAWRENCE M. KRAUSS
WITH A FOREWORD BY STEPHEN HAWKING
FULLY REVISED AND UPDATED

THE PHYSICS OF STAR TREK

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To my family

"But I canna change the laws of physics, Captain!"

(Scotty, to Kirk, innumerable times)

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FOREWORD

Stephen Hawking

I was very pleased that Data decided to call Newton, Einstein, and me for a game of poker aboard the *Enterprise*. Here was my chance to turn the tables on the two great men of gravity, particularly Einstein, who didn't believe in chance or in God playing dice. Unfortunately, I never collected my winnings because the game had to be abandoned on account of a red alert. I contacted Paramount studios afterward to cash in my chips, but they didn't know the exchange rate.

Science fiction like Star Trek is not only good fun but it also serves a serious purpose, that of expanding the human imagination. We may not yet be able to boldly go where no man (or woman) has gone before, but at least we can do it in the mind. We can explore how the human spirit might respond to future developments in science and we can speculate on what those developments might be. There is a two-way trade between science fiction and science. Science

fiction suggests ideas that scientists incorporate into their theories, but sometimes science turns up notions that are stranger than any science fiction. Black holes are an example, greatly assisted by the inspired name that the physicist John Archibald Wheeler gave them. Had they continued with their original names of "frozen stars" or "gravitationally completely collapsed objects," there wouldn't have been half so much written about them.

One thing that Star Trek and other science fiction have focused attention on is travel faster than light. Indeed, it is absolutely essential to Star Trek's story line. If the *Enterprise* were restricted to flying just under the speed of light, it might seem to the crew that the round trip to the center of the galaxy took only a few years, but 80,000 years would have elapsed on Earth before the spaceship's return. So much for going back to see your family!

Fortunately, Einstein's general theory of relativity allows the possibility for a way around this difficulty: one might be able to warp spacetime and create a shortcut between the places one wanted to visit. Although there are problems of negative energy, it seems that such warping might be within our capabilities in the future. There has not been much serious scientific research along these lines, however, partly, I think, because it sounds too much like science fiction. One of the consequences of rapid interstellar travel would be that one could also travel back in time. Imagine the outcry about the waste of taxpayers' money if it were known that the National Science Foundation were supporting research

on time travel. For this reason, scientists working in this field have to disguise their real interest by using technical terms like “closed timelike curves” that are code for time travel. Nevertheless, today’s science fiction is often tomorrow’s science fact. The physics that underlies Star Trek is surely worth investigating. To confine our attention to terrestrial matters would be to limit the human spirit.

PREFACE

Why the physics of Star Trek? Gene Roddenberry's creation is, after all, science fiction, not science fact. Many of the technical wonders in the series therefore inevitably rest on notions that may be ill defined or otherwise at odds with our current understanding of the universe. I did not want to write a book that ended up merely outlining where the Star Trek writers went wrong.

Yet I found that I could not get the idea of this book out of my head. I confess that it was really the transporter that seduced me. Thinking about the challenges that would have to be faced in devising such a fictional technology forces one to ponder topics ranging from computers and the information superhighway to particle physics, quantum mechanics, nuclear energy, telescope building, biological complexity, and even the possible existence of the human soul! Compound this with ideas such as warped space and time travel and the whole subject became irresistible.

I soon realized that what made this so fascinating to me was akin to what keeps drawing fans to Star Trek today, almost

thirty years after the series first aired. This is, as the omnipotent Star Trek prankster Q put it, "charting the unknown possibilities of existence." And, as I am sure Q would have agreed, it is even good fun to imagine them.

As Stephen Hawking states in the foreword to this book, science fiction like Star Trek helps expand the human imagination. Indeed, exploring the infinite possibilities the future holds—including a world where humanity has overcome its myopic international and racial tensions and ventured out to explore the universe in peace—is part of the continuing wonder of Star Trek. And, as I see this as central to the continuing wonder of modern physics, it is these possibilities that I have chosen to concentrate on here.

Based on an informal survey I carried out while walking around my university campus the other day, the number of people in the United States who would not recognize the phrase "Beam me up, Scotty" is roughly comparable to the number of people who have never heard of ketchup. When we consider that the Smithsonian Institution's exhibition on the starship *Enterprise* was the most popular display in their Air and Space Museum—more popular than the real spacecraft there—I think it is clear that Star Trek is a natural vehicle for many people's curiosity about the universe. What better context to introduce some of the more remarkable ideas at the forefront of today's physics and the threshold of tomorrow's? I hope you find the ride as enjoyable as I have.

Live long and prosper.

PREFACE TO THE REVISED EDITION

When I first sat down to write *The Physics of Star Trek* almost 13 years ago I had no idea how significantly it would change my life, nor of the impact it might have on trekkers and non-trekkers alike. I was mostly hoping that following its publication a mob of angry fans wouldn't lynch me and that my physics colleagues would still talk to me.

Needless to say, these worries proved to be ill-founded. Indeed the immediate and overwhelming reaction on all counts was the opposite of what I had expected. One of the first letters I received after the book appeared was from a fan who said, "I had been waiting for 20 years to read a Star Trek book in the Science Fact section of a bookstore!" And when I began to lecture on this subject I met 7- and 8-year-olds with dog-eared copies of the book who had great questions to ask. And my colleagues turned out to be largely thrilled that a physics book could actually be a popular bestseller. And lo and behold, the

book appeared to create a new genre of "The Science of . . ." books. First, books titled *The _____ of Star Trek* began to appear by the dozens, followed quickly by books with titles like *The Physics of Christmas* and *The Science of Harry Potter*.

And I even got to stand at the helm of the *Enterprise* at Paramount, even if I didn't get to join a poker game with Einstein, and I filmed a TV documentary with Captain Kirk himself, and hung out with the likes of Commander Riker and Quark.

Shortly after the book appeared I was asked for a sequel, and the request has been repeated numerous times over the years, but I decided I had said everything I wanted to say on this subject. Well, almost everything I had to say. In the intervening years, not only has Star Trek continued, but the world of science has as well, and I daresay the latter may have progressed far more than the former. In an effort to bring the science in the book up to date I decided to review the material from cover to cover, adding new information when necessary, and removing arguments when nature has shown them to be incorrect.

Of course, in the process, I couldn't resist adding some new Star Trek connections and even a few new bloopers, one related to me by a 5-year-old at a lecture I gave, and one by a member of the crew of the *Enterprise*. I have tried hard to preserve the character of the original book, much of which has happily survived unscathed. In the end, I hope readers con-

tinue to enjoy the discussions and come away a bit more enamored with the amazing fact that, as remarkable as the Star Trek Universe may be, the real universe keeps providing surprises that are both grander and stranger than anything human screenwriters may come up with.

Lawrence M. Krauss
Cleveland, Ohio 2007

SECTION ONE

A COSMIC POKER GAME

In which the physics of inertial dampers and tractor beams paves the way for time travel, warp speed, deflector shields, wormholes, and other spacetime oddities

1

Newton Antes

"No matter where you go, there you are."

—From a plaque on the starship *Excelsior*, in *Star Trek VI: The Undiscovered Country*, presumably borrowed from *The Adventures of Buckaroo Banzai*

You are at the helm of the starship *Defiant* (*NCC–1764*), currently in orbit around the planet Iconia, near the Neutral Zone. Your mission: to rendezvous with a nearby supply vessel at the other end of this solar system in order to pick up components to repair faulty transporter primary energizing coils. There is no need to achieve warp speeds; you direct the impulse drive to be set at full power for leisurely half-light-speed travel, which should bring you to your destination in a few hours, giving you time to bring the captain's log up to date. However, as you begin to pull out of orbit, you feel an intense pressure in your chest. Your hands are leaden, and you are glued to your seat. Your mouth is fixed in an evil-looking grimace, your eyes feel like they are about