Preface

My father showed me a comet through his binoculars after dinner one day when I was 6. I saw it suspended in space, hung among the stars of the Big Dipper, a white, ghostly wisp from somewhere distant. I knew the planets moved around the Sun. I had heard about comets. But to actually *see* one was breathtaking, different. It was not a picture. It was *there*. It was silent and mysterious, seemingly from another time. Years later, when I was a middle-school student in Florida, our school librarian displayed a copy of Newton's *Principia* prominently on a stand in the library. It was laid open to some pages of intriguing, complex-looking geometrical drawings, including a dramatic illustration of a comet. I had no real comprehension of the strange book's contents, but was drawn to flipping through its pages every time I passed by it. In there, I had been told, was the first real explanation of how things in the sky moved. I later learned how the riches in that book, first published in the late 1680s, really did open the door to understanding celestial phenomena. It was a revelation to discover that things I saw in the sky could be known in a completely new way, through the language of mathematics.

The universe we inhabit can be known on many levels even to those who have never seen a country-dark sky. No words can adequately convey the ethereal majesty of comet Hale-Bopp's twin tails seen from the pitch-dark skies of Haleakala, in Maui, but the mathematics of its motion are also fascinating and beautiful, and last well beyond the actual experience. The motions of the bodies in our solar system are a phenomenon of a more abstract kind, most accessible through the figures and operations of mathematics. One can try to describe the movements of the celestial bodies in language, and many have written wonderfully poetic descriptions of heavenly phenomena. But to begin to understand how it all *works*, one needs to penetrate into the core of things, into masses, forces, and accelerations, which describe quantitatively how bodies affect each other even over staggeringly huge distances. It is not widely appreciated that with modest familiarity with the tools of high-school mathematics, one may gain surprisingly clear insight into the mysteries of celestial motions. It is a deep and rich world of sublime, subtle relationships. Some of them, like Kepler's Harmonic Law, are especially beautiful, echoing the harmonies in the physical world. With the language of mathematics, one can more deeply appreciate the workings of creation in a way unknown to those who do not take the trouble to learn it. After a while, the relatively few key equations become as familiar as old friends. And one does not have to take anyone else's word for how it all fits together: it *does*. One can see for oneself how gravity works and bodies move by doing the manipulations and the calculations. It is the next best thing to being there!

It is one purpose of this book to convey the power of simple mathematics to tell fundamental things about nature. Many people, for example, know the tides are caused by the pull of the Moon and to a lesser extent the Sun. But very few can explain exactly how and why that happens. Fewer still can calculate the actual pulls of the Moon and Sun on the oceans. The book attempts to show this with simple tools. The book endeavors to cross disciplines to provide context – history, astronomy, physics and mathematics – and effort has been made to explain things frequently passed over or taken for granted in other books. It does not purport to be a comprehensive textbook or tome on every aspect of classical celestial mechanics. Rather, it samples key areas of interest and invites further inquiry. The emphasis is on intuitive appreciation rather than rigor. The book hopefully will lead readers to investigate the fundamentals of mass and motion on their own, and to puzzle through the problems that Newton and others faced in trying to make sense of why things move as they do. It is also hoped that the book will encourage a sense of wonder at the beauty of the physical world and an appreciation of the brilliant minds who struggled to comprehend and express it in almost equally beautiful mathematics.

The focus of the book is Newton's, rather than Einstein's, gravity. In other words, it deals with classical mechanics, which originated in the seventeenth century and which remains the basis for the core problems of celestial mechanics today. It therefore does not treat the curved spacetime of Einstein's General Theory of Relativity. There is nothing in the book about the behavior of masses at relativistic speeds, black hole physics, or other aspects of Einstein's geometrical view of gravity.

The book has three main characteristics that define it:

First, it concentrates strongly on the historical development of the mathematics and science of orbital motion, beginning with Galileo, Huygens, Kepler, and Newton, each of whom is prominently represented. Quotes and problems from Galileo's *Dialogs Concerning Two New Sciences*, Huygens's *The Pendulum Clock*, and particularly Newton's *Principia* should help the reader get a little bit inside the minds of those thinkers and see the problems as they saw them, and experience their concise and typically eloquent writing.

Second, it is problem based: it uses concrete, hopefully interesting problems and case studies to teach and illustrate. This method is critical for a hands-on understanding of this topic. Many of the problems use actual historical data, and results are compared with those obtained using modern data and methods. To underscore the relevancy of the original thinking on these issues, modern problems dealing with near Earth asteroids, NASA missions, and newly discovered dwarf planets are set next to historical problems that deal with the same mathematical or physical principles. Emphasis is on problems with dramatic interest and power of illustration.

Third, its mathematics is the simplest possible. The math is generally at the high-school or early college level (algebra and the most basic geometry and a little trigonometry), with detailed explanations of the methods needed to solve the problems and understand the concepts. Calculus is the standard method for presenting this subject in most textbooks, and it produces quick, concise results. But it does not necessarily follow that calculus is needed for those results, or that a calculus-based presentation is the most intuitive vehicle for a beginner learning the fundamentals. I use methods and derivations that have appeared to be the most intuitively comprehensible, with stress on practical application. The surprise is how deeply one can dive with only the most basic mathematics and an intuitive grasp of the physics. This having been said, certain fundamental pre-calculus concepts involving limits introduced by Newton in his *Principia* are dealt with in this book, and should help one who has not had calculus get a foothold on the subject.

I wish to acknowledge two people who were the guiding lights for me in working on this book. The first is my father, who, when he was alive, always encouraged my interest in science, even to the point of driving me on my birthdays when I was a young boy to any observatory of my choice in the West. The other is my wife, Kathy, whose has given total support for this project even as it emerged from preparing casual collections of class notes to the far greater and more taxing commitment of a book. I am also very grateful for her editorial good judgment on the random questions that I would pose to her.

I also wish to thank the editors at Springer for their excellent editorial suggestions that have helped add clarity in many places in the book.

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