PREFACE

Our book, *Welcome to the Universe: An Astrophysical Tour*, grew out of an introductory survey course in astrophysics that Neil deGrasse Tyson, J. Richard Gott, and I team-taught for a number of years at Princeton University. The course is meant for nonscience majors, but we designed it to be a quantitative course. With mathematics no more complicated than high-school algebra and some basic laws of physics (which we cover in the book), we can understand how we know that the Big Bang occurred 14 billion years ago, and that a thimbleful of white dwarf material has as much mass as five elephants. Our goal was not simply that our students be told about the wonders of the universe, but that they learn the tools to understand *how* we know what we know. We aimed to empower our students to apply quantitative and physical reasoning to their everyday lives, to understand the basis behind the very real issues that face us as citizens of the world.

In mathematics, physics, and indeed astronomy, equations give us a way to realize, and understand, the relationship between concepts that we may not have previously known were connected. Newton's law of gravity connects the force on a dropped pencil to the mass and radius of the Earth. Planck's radiation law gives us a relationship between the temperature and size of a star and its luminosity. And Einstein's famous formula, $E = mc^2$, tells us that energy E and mass m are intimately related, and that in a fundamental sense, they are two aspects of a common phenomenon, called "mass-energy."

Welcome to the Universe was not written as a textbook per se, but rather was meant to be read as you read any book for pleasure, albeit perhaps with a pad of paper by your side if you want to follow along with some of the calculations. However, the book *can* be used in a classroom setting, perhaps in conjunction with a more traditional textbook. It is also ideal for use in a "flipped" classroom, where the lectures are on videos and the teacher works with groups of students on solving problems in class. We thus make this volume of problems available, which ask you, the reader and student, to grapple directly with the quantitative and conceptual aspects of the subject. Almost all the problems here were used in this course and other courses we have taught at the same level. These problems range from the fairly easy to the challenging, but they all require no mathematics beyond high-school algebra. The problems are not just exercises in applying astronomical formulas but are designed to give insight into specific astrophysical problems. We hope that in the process of solving these problems, you will gain both some facility in the quantitative techniques of our field and also experience that "ah-ha" moment, when you measure the expansion rate of the universe from direct observations, or repeat the calculation astronomers did when neutrinos were first discovered that had been emitted from a supernova 150,000 light-years away.

We have put the solutions to these problems in the back of the book. We encourage you to attempt these problems first before looking at the solutions. But you will see that the solutions go into quite a bit of pedagogical detail, and they often give additional insights and background material that goes beyond the initial problem. Even if you are able to solve a problem fully on your own, you are likely to gain new insights by reading the solutions. Of course, an easy and fun way to read this book is to read each problem and its solution together, to see the answers and the techniques to solve each problem revealed.

Many of these problems can be used as is in a classroom setting, or as inspiration for similar problems that the teacher or professor can devise. We are rather fond of multi-part problems that build on one another, but these can be reduced considerably as the instructor finds appropriate. The underlying concepts do sometimes repeat in these exercises. For example, we have many problems exploring the range of densities in the universe, from the black hole limits set by our lack of understanding of quantum gravity (yes, you can calculate such a thing using just high-school algebra) to the incredibly low density of the universe as a whole. We encouraged our students to explain their answers in full (i.e., in words) in their homework, to demonstrate that they understood the context and content of what they were doing and were not simply plugging into a formula. Each instructor will need to find the appropriate balance of English and mathematics for their students. In that spirit, there are some more qualitative questions, as well as essay questions throughout the book.

This problem book starts with some general musing and advice on problem-solving skills and tools. We assume that you are familiar with scientific notation, the way we write the really large and really small numbers that come up so often in our subject. The problems are ordered according to the chapter structure of *Welcome to the Universe*, giving you guidance on which problems to attempt as you read the book. In a separate section following the problems, we tabulate some of the most useful numbers and equations used throughout these problems (and a few that are not); you should take these as given in these problems, unless we direct you otherwise. One of the themes throughout is that algebra is often easier than arithmetic, and in these problems we put a lot of emphasis on algebraic techniques to simplify problems before plugging in numbers. Many of these problems require answers to "astronomical accuracy" (i.e., to a rough precision only), and we demonstrate a style of calculator-free arithmetic that can quickly and accurately get you to the answer.

We thank all those who have contributed to these problems. Our colleagues Chris Chyba, Joe Patterson, Anatoly Spitkovsky, Jenny Greene, and David Spergel have used many of these problems in teaching the Princeton introductory astronomy course and have helped us refine them. Chris Chyba contributed a number of the problems here; we mark them as such. Jeremy Goodman, David Spergel, Vera Gluscevic, and Mariangela Lisanti gave helpful comments and insights on several problems. We worked with a significant number of teaching assistants, both graduate and undergraduate, who helped refine the solutions and did the lion's share of grading homework assignments and exams. We thank our wonderful editor Ingrid Gnerlich

for her continuing faith in this book and for all her support. But most of all, we thank the thousands of students who have taken our course at Princeton, who continue to inspire us with their energy, their curiosity, and their insightful questions.

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