INTRODUCTION TO HIGH-ENERGY ASTROPHYSICS

High-energy astrophysics covers cosmic phenomena that occur under the most extreme physical conditions. It explores the most violent events in the Universe: the explosion of stars, matter falling into black holes, and gamma-ray bursts – the most luminous explosions since the Big Bang. Driven by a wealth of new observations, the last decade has seen a large leap forward in our understanding of these phenomena.

Exploring modern topics of high-energy astrophysics, such as supernovae, neutron stars, compact binary systems, gamma-ray bursts, and active galactic nuclei, this textbook is ideal for undergraduate students of high-energy astrophysics. It is a self-contained, up-to-date overview of this exciting field of research. Assuming a familiarity with basic physics, it introduces relevant concepts, such as gas dynamics and radiation processes, in an instructive way. An extended appendix gives an overview of some of the most important high-energy astrophysics instruments, and each chapter ends with exercises.

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Preface

What is high-energy astrophysics? The term is customarily used for a large set of different astrophysical phenomena that in some sense involve "high" energies. In some cases, the detected particles, for example, cosmic or gamma rays, are of particularly high energy. In other cases, for example, in radio astronomy, the detected photons may be of low energy but are produced by very energetic electrons. Admittedly, the definition of high-energy astrophysics is vague and imprecise. In fact, almost every astrophysical object features aspects that involve high energies. Typically, high-energy astrophysics revolves around phenomena that involve physics under the most extreme conditions. The matter in the center of a neutron star, for example, is much denser than that in an atomic nucleus. Active galactic nuclei harbor black holes at their centers, with masses a billion times greater than the mass of the Sun. Such supermassive black holes accelerate jets to velocities greater than 99% of the speed of light and display a variety of special relativistic effects. These are just two examples of the kinds of objects that we describe in this book.

The past decade has been a very exciting time for high-energy astrophysics. New instruments, such as X-ray and gamma-ray observatories, have revolutionized our view of the high-energy universe. Some mysteries have been solved; many new ones have arisen. The novel views of many high-energy phenomena that have come about in the past few years should quickly enter the classroom, which is one of the prime motivations behind the writing of this book. Although in recent years words such as *supernovae* and *black holes* have become familiar and ubiquitous, even in the nonscientific realm, these intriguing and glamorous constituents of our universe are frequently under-represented in university physics education. In this book, we wish to convey the fascination that arises from studying the physics of these extraordinary phenomena.

The field of high-energy astrophysics has become so vast that it is impossible to give a proper introduction to all its subdisciplines. In this spirit, we also have to remark that inevitably some interesting fields had to be left out. For this introductory text, we have chosen five areas of focus: supernovae, neutron stars, compact binaries, gamma-ray bursts, and active galactic nuclei.

We suggest two ways of using this book in a university course. First, one can go through this book front to back, starting with the physics chapters on special relativity and gas and radiation processes. Then, armed with the necessary physical gadgetry, the reader can dive into the colorful physical phenomena of high-energy astrophysics introduced in Chapters 4–8.

An alternative route would be to start right away with the astrophysics and cover the physical groundwork as one goes along. Here, we would recommend sticking to the order of Chapters 4–8, although other permutations are certainly possible. For this second route, in each chapter we have given plenty of cross-references to the relevant foundation chapters where the student can read up on the necessary physics. The latter approach may be more suitable for a graduate course, where students may be expected to have covered much of Chapters 1–3 anyway, whereas the former approach may be more suited for an undergraduate course. In any case, we are always happy to receive feedback on how this book is being employed in teaching.

For this undergraduate text, we generously borrowed from existing books and published articles. Little is in a strict sense original work. Only rarely do we credit the originators of the various theories and models that we describe in this book, and only sometimes do we depict the often tortuous ways in which certain astrophysical paradigms have come into being. We felt that a proper, historical referencing of the many topics covered in this book would disrupt the flow of the text and be of only limited use to the student. Instead, we give suggestions for further reading at the end of every chapter.

Finally, one word about the sore subject of units. Although most undergraduate courses in physics will use SI units, in astrophysics the most common set of units remains the cgs system. Therefore, we stick to cgs units in this book. Moreover, in various places we use additional units that are particularly helpful such as, for example, the parsec as a unit of distance, the electron volt as a unit of energy, and the solar mass as a unit of mass. These units are defined where used.

Many people have helped us. Thanks go to Matthias Hoeft, Matthias Liebendörfer, Elke Roediger, and Aurora Simionescu for proofreading the often half-finished bits of this book. Particular thanks go to Eva Stueeken and Daniel Price. Finally, we thank the Max-Planck Institut für Astrophysik in Garching for its hospitality.