

Preface

Space exploration engendered enormous progress in astronomy and astrophysics. Astronomy was no longer limited by observations in the very narrow optical window accessible from the Earth's surface; instead, space observations in all wavelengths of the electromagnetic spectrum, from the shortest gamma rays to radio waves, opened unique opportunities to carry out astronomical observations and delicate measurements of distant objects beyond the shroud of our atmosphere. This, in turn, allowed us to view our space environment in unprecedented detail and essentially opened up our universe. Astrophysics is a powerful tool for obtaining deep insights into the universe, revealing and interpreting the physical mechanisms and physicochemical processes underlying the astronomical objects and phenomena that we observe with modern science.

This book is addressed to laymen who would like to obtain more insights into our space environment—which stretch from home planet Earth well beyond the solar system to the edge of the universe (which is associated with its origin). The book will also be useful to students who are interested in space and astronomy. The author invites all to join him for this fascinating journey.

The book has its origins in the International Space University (ISU) program.

The International Space University was founded in 1987 as the new world educational body to teach space science and applications. The first session was held in 1988 and I joined this facility a year later. This involvement became a significant part of my personal career. For a quarter of a century I delivered lectures and/or lecture courses on physics and astrophysics to the ISU students, mainly at the summer sessions in different parts of the world. Throughout these years I chaired or co-chaired Space Physical Sciences Department and/or team projects and actively participated in the major ISU events. In 1991 I served as Dean of Faculty. I have been elected several terms in the Academic Council, served a few years in the Board of Trustees, and contributed to the format development of the ISU Master of Space Sciences program and permanent campus selection for which Strasbourg became the place. I benefited from close relationships with student communities and faculty involved in the ISU programs and preserved close and warm relationship with the ISU alumni and colleagues all over the world.

Certainly, my lecture courses were refined from session to session throughout the years running together with an experience I gained on how to teach in the very specific ISU environment different from what I used to pursue with my university lecture courses in Russia and USA. In this case, the bottom line was the necessity to accommodate the **I**nterdisciplinary, **I**ntercultural, and **I**nternational (3**I**) approach ISU accepts as the basic philosophy, and therefore to satisfy both professionals (say, specialized in physics or at least in engineering) and non-professionals (say, specialized in policy and law or in social sciences) having different background and cultural roots. These were my lessons learned which I took from the students' response and appreciation. Anyway, based on this multiyear experience, I compiled a lecture set, mainly in electronic/slides format I used in my presentations at the core lectures curriculum. ISU faculty and my colleague Joe Pelton (one of those who supported three MIT graduate students—ISU founders John Hawley, Peter Diamandis, and Bob Richards—with their idea) suggested me to collect and edit the material and prepare the written version of the lecture course on space physics and astronomy and publish it as a short book of the special series covering the ISU program and even extended. The title suggested *The Fundamentals of Modern Astrophysics: A Survey of the Cosmos from the Home Planet to Space Frontiers* fully corresponds to the idea and the book contents.

I should confess that the work on the manuscript turned out not as easy as I initially thought, and required me to apply more efforts to incorporate both fundamentals and modern views in the fast progressing field rather than to simply collect my lectures. Moreover, the contents are broader and include more details not covered in the lectures. I attempted to combine a strict approach and accuracy with accessibility of understanding when discussing quite complicated topics to give an opportunity to comprehend the main sense and, at the same time, to keep it interesting. I therefore essentially avoided mathematics and used simple formulas only when they promote a better understanding of the described physical phenomena. At the same time, I tried to keep the main definitions and to give a brief history of great advancement in the discussed fields, when it seemed appropriate. Many important breakthroughs accomplished by ground based astronomical facilities and space born instruments are addressed and some of them are reviewed in more detail.

The book consists of 11 chapters and basically covers all the main fields/branches in contemporary astrophysics.

Naturally, we start with the space environment closest to our home planet Earth: the solar system, a very confined place in boundless outer space. The solar system is discussed in the first four chapters. In Chap. 1, the general properties of the solar system are described as well as its family members—terrestrial and giant planets, their satellites (moons) and rings, and the numerous small bodies, including asteroids, comets, meteoroids, and interplanetary dust. A special focus is given to the remarkable dynamical properties of the solar system bodies, including orbital and rotational motion, different types of resonances, and small body migration with implications for the planets' evolution.

Chapter 2 is dedicated to the terrestrial (inner) planets (Mercury, Venus, Earth, and Mars), which occupy the region closest to the Sun and are composed of rock.

The manifold features of their surface landforms, geology, and interiors, and their main atmospheric properties are discussed. The core of the chapter is our Earth—the planet uniquely possessing life—and its natural satellite, the Moon. The completely different natural conditions of our neighbor planets Venus and Mars serve as two extreme models of the Earth's evolution. The problems of evolution of Venus and Mars are specifically addressed.

In Chap. 3, the gaseous and icy giant planets (Jupiter, Saturn, Uranus, and Neptune) with their numerous satellites and rings are discussed, including their interiors, structure, and composition, their general patterns of atmospheric dynamics, and their common features of formation and evolution. The unique nature and properties of their numerous satellites and rings are especially emphasized, and in particular the Galilean satellites of Jupiter, Europa, and Ganymede, and the Saturnian satellites Titan and Enceladus as potential abodes for biota.

Chapter 4 deals with the properties of a vast family of small bodies: the asteroids and comets, which are primarily located in the main asteroid belt and the Kuiper belt and in the Oort cloud, respectively, as well as smaller size bodies—meteoroids and interstellar dust. These small bodies are of particular interest first of all as the remnant bodies of which the solar system originated, which therefore preserve in their composition the most pristine matter. Examples of such matter are the various classes of meteorites, which are regarded as fragments of the collisional processes of asteroids. Catastrophic collisions are emphasized as being responsible for the dramatic changes of planetary environments throughout the history of the solar system.

Chapter 5 focuses on the properties of our star—the Sun—and its plasma environment called the heliosphere. The composition, structure, and peculiarities of the main zones of the Sun are outlined with an emphasis on the photosphere, chromosphere, and corona. The generation of the solar wind and its properties, the 11-year solar activity cycle and related events, as well as the different phenomena caused by disturbances in the chromosphere and corona are discussed. This is followed by an overview of the structure of the heliosphere expanding to the solar system outer boundary where plasma interaction with the interstellar medium occurs, including important phenomena within the heliosphere such as the solar wind interactions with the planets and small bodies. Particular attention is given to the Earth's upper atmosphere and magnetosphere, which protect the biosphere from harmful electromagnetic and corpuscular solar radiation.

From the solar system we move further away to the other stars filling the night skies. They are the most familiar example of the fascinating beauty of our space environment and vast universe. Chapter 6 discusses stars—their complex nature and their lifetimes from birth to ultimate death. Special attention is given to the evolution of stars with different masses by tracing them in the Hertzsprung-Russell diagram and reviewing nuclear fusion as an energy source. The final stages of a star's lifetime are specifically addressed, including the red giants/white dwarfs for low mass stars, and the neutron stars/black holes left behind after high mass stellar supernovae explosions. The fascinating properties of black holes are discussed in terms of relativistic physics and general relativity effects.

Stars harbor planets, and hence it is natural to address the common processes of star-disk-planetary system formation, the peculiarities of the physicochemical mechanisms involved, and the subsequent system evolution. Chapter 7 discusses extrasolar planets, whose discovery ranks among the greatest breakthroughs in astrophysics. The study of extrasolar planets (or exoplanets) has become a “hot topic” of modern science. The different discovery techniques for exoplanets and their unusual properties, such as the hot massive super-Jupiters responsible for peculiar exoplanetary system configurations completely different from that of our solar system, are discussed. Recent findings on Earth-type and especially Earth-like planets manifested a great progress in the field and opened new horizons in planetary science. The continuous search for Earth-like planets in the years to come is highlighted as a challenging goal of both astrophysics and astrobiology.

In Chap. 8, the general problems of the origin and evolution of planetary systems (and in particular, the solar system) are considered based on the fundamental concepts of star-planet genesis including important theoretical and observational constraints. This field of astrophysics is called planetary cosmogony. Basically, the scenario includes a sequence of events beginning with protoplanetary gas-dust accretion disc around a solar-type star formation from a primordial protoplanetary nebula, follow-up processes of its fragmentation into original dusty-gaseous clusters, and collisional interactions of these clusters leading eventually to intermediate solid bodies (planetesimals) and, ultimately, planets and a planetary system.

As a logical extension of this topic, we address the potential origin of life on a planet located in the so-called habitable zone in a star’s vicinity, where suitable climatic conditions could be set up and supported. In Chap. 9, we briefly discuss these intriguing problems dealing with another interdisciplinary hot topic of modern science: astrobiology. This field is rooted in an astrophysics and biology synergy and is intimately related to planetary sciences, particularly planetary systems formation and evolution. Astrobiology is also closely linked to basic philosophical concepts.

In Chap. 10 we discuss our space environment at large, beginning from our home—the solar system and our own Milky Way galaxy—and reaching to the extreme boundaries of the universe filled with stars and galaxies. The hierarchical system of the revealed structures of progressively growing size, the clusters and superclusters of galaxies forming the cosmic web, is regarded as the remnant of density fluctuations in matter condensing out of the expanding universe after its origin associated with the Big Bang scenario.

Finally, Chap. 11 addresses the problem of cosmology: the study of the origin, evolution, and ultimate fate of the universe. The Big Bang model of the universe’s origin and evidence in its support are thoroughly discussed. The supporting factors include the continuing observed expansion of the universe according to Hubble’s law; detection of the cosmic background microwave (CMB) radiation at 2.7 K, which is addressed as the remnant of the original explosion; and the present abundance of light elements (hydrogen, deuterium, helium, and lithium) which were synthesized soon after the explosion. Scenarios of the ultimate fate of the universe are based on its total estimated mass with the involvement of dark matter and dark

energy, the latter being considered an analog of Einstein's cosmological constant now associated with anti-gravity force and the monstrous vacuum energy. It is emphasized that modern cosmology is viewed as the synergy of micro- and macro-physics and is intimately related to the physics of elementary particles and the four fundamental interactions in nature: strong, weak, electromagnetic, and gravitational, with involvement of the idea of supersymmetry unifying the constants of these interactions under very high energy. Our current understanding of both the early and evolving universe is based on the Standard Model (most recently supported by the Higgs boson discovery) and Superstring (M) theory, the latter underlying the diversity of elementary particles, quantum mechanics, and gravity and integrating the nature of matter. Modern theory assumes that an infinite multitude of universes exists, our own being one of them. The Multiverse concept also assumes that universes are continually born and decay and that they may be coupled through worm holes along a hidden dimension and to hyperspace.

Basically, these 11 chapters contain most essential things known in modern astrophysics. They briefly summarize the main concepts in the field and prospects for future theoretical and experimental studies. I attempted to discuss these topics in as accessible a way as possible, and this is why no special mathematical treatment and particular references were involved. For those who would like to know more and wish to pursue an in-depth study of these topics, a list of Additional Reading is attached.

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