Preface

The high energy part of the electromagnetic spectrum and the domain of cosmic rays, neutrinos, gravitational waves, dark matter are the most recent additions to multimessenger astronomy, the world of astroparticle physics. Since high energy astrophysics involves both photons and particle probes, there is a natural splitting of observational techniques into different astronomies: X-ray, gamma ray, with cosmic rays, neutrinos, gravitational waves. Astroparticle physics is an observational science, that uses instrumentation whose elements have been originally conceived for physics at accelerators or designs new detectors for the search of rare events. The astroparticle instrumentation is built and tested in the laboratory by the astronomers. Thus astroparticle students must undergo a double training, in experimental physics and in observational astronomy. The practical information the students need is split into different places: detectors are described in high energy experimental textbooks, telescopes in high energy astrophysics textbooks, and the most recent advances are found in specialized literature. The book aims to present the instrumentation and the techniques of high energy observational astrophysics and the guidelines to plan, execute, and analyze the observations. This textbook is based on several years of teaching the courses of Astrophysical Techniques to graduate students at the University of Pisa who are specializing in astrophysics. The field of high energy astrophysics is rapidly evolving, as shown by the recent discovery of gravitational waves. The textbook is a snapshot of the current status of the art of observational technologies and presents their foreseen evolution. The textbook starts with radiation–matter interactions and discusses their impact on the design of detectors. Detectors are first presented, since they are the building blocks of the advanced instrumentation described later. The word telescope acquires a new meaning, compared to the optical domain: the telescope can use grazing incidence or be a collimator or be a combination of different instruments. The following chapters present the different astronomies that belong to high energy astrophysics, starting with the high energy region of electromagnetic spectrum and presenting astrophysics with cosmic rays, neutrinos, gravitational waves, and the searches for dark matter. Each chapter contains the orders of magnitude of the signals to be detected to link instrumentation to the astrophysics context.

The book is divided into different parts. The first part introduces the fundamentals of the field. Chapter 1 discusses the information carriers, the high energy photons, and the particle probes: cosmic rays, neutrinos, gravitational waves, dark matter; the observational windows and their constraints on the observatory site are discussed. Chapter 2 presents the radiation–matter interactions of charged particles and photons, the fundamentals tools to design the detectors. Chapter 3 discusses the interactions of the information carriers with the media encountered during the travel to the observer, that determine the observational horizons: surprisingly, more energetic particles are not necessarily able to travel longer distances. After the journey in space, high energy photons and particles encounter the terrestrial atmosphere, that acts as a large-volume calorimeter, allowing the detection of the particle showers they produce with ground-based arrays. The second part of the book describes the world of detectors. Chapter 4 presents the general characteristics of detectors; detectors for high energy particles often have intrinsic resolution capability. The single detectors are the building blocks of the astroparticle instrumentation discussed later. Chapter 5 discusses the properties of the detectors based on ionization in gases and liquids: ionization chambers, proportional counters, Geiger counters, multi-wire proportional chambers, drift chambers, liquid ionization detectors. Chapter 6 describes the scintillation detectors, materials that produce small amounts of light when hit by radiation; the light emitted by scintillators is collected by photomultiplier tubes. Chapter 7 presents the detectors based on ionization in solid-state materials, that provide imaging and spectroscopic capabilities within small volumes. Chapter 8 deals with Cherenkov and transition radiation detectors, used for particle identification. Chapter 9 discusses the calorimeters for measuring the energy of particles through their absorption in a material. Chapter 10 is a revisitation of the detectors described before from the point of view of the measurement of physical observables of photons and particles, in view of integrating them into complex instruments. The third part of the book describes the instrumentation for the different domains of high energy astrophysics. Chapter 11 deals with X-ray astronomy, performed with space-based observatories; the telescopes are based on grazing incidence or, at high energies, on collimators or coded aperture masks. Chapter 12 discusses gamma-ray astronomy and the different techniques to observe the low energy side (up to tens GeV) with space-based observatories and the high energy side (above some tens GeV) with ground-based arrays. Chapter 13 discusses the astronomy based on cosmic rays, a combination of space-based observatories at low energies and of ground-based arrays at high energies. The instrumentation used in gamma and cosmic ray investigations shows close similarities with the instrumentation at particle accelerators. Chapter 14 presents neutrino astronomy and the techniques to detect neutrinos with different energies. Chapter 15 presents the youngest astronomy, gravitational wave astronomy, which was born during the writing of this book. The different techniques used for the search of gravitational waves and the interferometers that achieved the first detection are discussed. Chapter 16 addresses the dark side of the Universe, the searches for dark matter, both direct and indirect, and the dark energy. Chapter 17 discusses the topic of observing in high energy astrophysics, with a discussion of the signal-to-noise

ratio and the techniques of data analysis for the different astronomies discussed in the previous chapters. Chapter 18 discusses high energy astrophysics as a part of the multiwavelength and multimessenger astrophysics. The Web links to instrumentation are provided in the related chapters. Reference monographs are listed at the end of each chapter.

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