COSMIC RAYS AND PARTICLE PHYSICS

Fully updated for the second edition, this book introduces the growing and dynamic field of particle astrophysics. It provides an overview of high-energy nuclei, photons, and neutrinos, including their origins, their propagation in the cosmos, their detection at Earth, and their relation to each other. Coverage is expanded to include new content on high energy physics, the propagation of protons and nuclei in cosmic background radiation, neutrino astronomy, high-energy and ultra-high-energy cosmic rays, sources and acceleration mechanisms, and atmospheric muons and neutrinos. Readers are able to master the fundamentals of particle astrophysics within the context of the most recent developments in the field. This book will benefit graduate students and established researchers alike, equipping them with the knowledge and tools needed to design and interpret their own experiments and, ultimately, to address a number of questions concerning the nature and origins of cosmic particles that have arisen in recent research.

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Preface to the first edition

The connection between cosmic rays and particle physics has experienced a renewal of interest in the past decade. Large detectors, deep underground, sample groups of coincident cosmic ray muons and study atmospheric neutrinos while searching for proton decay, monopoles, neutrino oscillations, etc. Detector arrays at the surface measure atmospheric cascades in the effort to identify sources of the most energetic naturally occurring particles. This book is an introduction to the phenomenology and theoretical background of this field of particle astrophysics. The book is directed to graduate students and researchers, both experimentalists and theorists, with an interest in this growing interdisciplinary field.

The book is divided into an introductory section and three main parts. The two introductory chapters give a brief background of cosmic ray physics and particle physics. Chapters 5 through 8 concern cosmic rays in the atmosphere – hadrons, photons, muons and neutrinos. The second major part (chapters 9–13) is about propagation, acceleration and origin of cosmic rays in the galaxy. Air showers and related topics are the subject of the last four chapters.

I am grateful to many colleagues at Bartol and elsewhere for discussions which have helped me learn about aspects of the field. I thank Alan Watson, Raymond Protheroe, Paolo Lipari, Francis Halzen, David Seckel, Todor Stanev, Floyd Stecker and Carl Fichtel for reading various chapters and offering helpful suggestions.

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Preface to the second edition

Interest and activity in particle astrophysics has continued to grow. It has now been 25 years since publication of the first edition. A new edition is long overdue, but nevertheless well-motivated in view of the growth of the field and several important discoveries in the interim. The discoveries include flavor oscillations in atmospheric and solar neutrinos, the cutoff of the spectrum of ultra-high-energy cosmic rays, TeV gamma rays from supernova remnants in the Galaxy and from distant active galaxies, an unexpected excess of positrons at high energy (but not of anti-protons) and, most recently, high-energy astrophysical neutrinos.

The discoveries are the result of major investments in the development of new instruments: the major underground experiments, Super-Kamiokande, SNO and Borexino; the giant air shower arrays, Auger and Telescope Array; the imaging atmospheric Cherenkov telescopes VERITAS, H.E.S.S. and MAGIC, and the Fermi Satellite; the particle spectrometers in space, PAMELA and AMS-02, along with balloon-borne detectors ATIC and CREAM; and the neutrino telescopes AMANDA and Baikal, ANTARES and IceCube.

Corresponding developments on the side of particle physics stem from the colliding beam machines at DESY, Fermilab and CERN. These have provided measurements of parton distribution functions over an unprecedented kinematic range, the discovery of the top quark and, most recently, the discovery of the Higgs boson. The LHC is now running at a center of mass energy equivalent to 10^{17} eV in the lab, well above the knee in the cosmic ray spectrum.

All of the discoveries mentioned have given rise to new questions that stimulate continuing interest in particle astrophysics. In writing this expanded edition, we have kept the basic structure of the first edition while adding chapters on new topics stimulated by some of these open questions. Topics of the new chapters include neutrino oscillations, propagation of ultra-high energy cosmic rays in the cosmic microwave background, sources of the highest energy cosmic rays and neutrino

astronomy. The chapters on atmospheric muons and neutrinos, and those on acceleration and propagation of cosmic rays, go into greater depth and focus on new results. Most important are the two chapters on particle physics, which are completely new, and are intended to bring the latest results from high-energy physics to bear on cosmic ray physics.

We are grateful to many colleagues who, in one way or another, helped us to understand and explain the material in this book.