

Cambridge University Press

978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and Cosmology

Peter Meszaros

Frontmatter

[More information](#)

The High Energy Universe

Ultra-High Energy Events in Astrophysics and Cosmology

In the last two decades, cosmology, particle physics, high energy astrophysics, and gravitational physics have become increasingly interwoven. The intense activity taking place at the intersection of these disciplines is constantly progressing, with the advent of major cosmic ray, neutrino, gamma-ray, and gravitational wave observatories for studying cosmic sources, along with the construction of particle physics experiments using beams and signals of cosmic origin.

This book provides an up-to-date overview of the recent advances and potential future developments in this area, discussing both the main theoretical ideas and experimental results. It conveys the challenges, but also the excitement associated with this field. Written in a concise yet accessible style, explaining technical details with examples drawn from everyday life, it will be suitable for undergraduate and graduate students, as well as for other readers interested in the subject. Color versions of a selection of the figures are available at www.cambridge.org/9780521517003.

PÉTER MÉSZÁROS is Eberly Chair of Astronomy & Astrophysics and Professor of Physics at the Pennsylvania State University, where he is also Director of the Center of Particle Astrophysics. His main research interests are high energy astrophysics and cosmology. He has been a co-recipient of the Rossi Prize of the American Astronomical Society and the First Prize of the Gravity Research Foundation. He is a member of the American Academy of Arts and Sciences and the Hungarian Academy of Sciences.

Cambridge University Press

978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and Cosmology

Peter Meszaros

Frontmatter

[More information](#)

The High Energy Universe

Ultra-High Energy Events in Astrophysics and Cosmology

PÉTER MÉSZÁROS

Pennsylvania State University



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press

978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and Cosmology

Peter Meszaros

Frontmatter

[More information](#)

CAMBRIDGE UNIVERSITY PRESS

Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo, Mexico City

Cambridge University Press

The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org

Information on this title: www.cambridge.org/9780521517003

© P. Mészáros 2010

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without the written
permission of Cambridge University Press.

First published 2010

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

ISBN 978-0-521-51700-3 Hardback

Additional resources for this publication at www.cambridge.org/9780521517003

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party internet websites referred to in
this publication, and does not guarantee that any content on such websites is,
or will remain, accurate or appropriate.

Cambridge University Press
978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and
Cosmology
Peter Meszaros
Frontmatter
[More information](#)

Deborahnak, Andornak

Cambridge University Press

978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and Cosmology

Peter Meszaros

Frontmatter

[More information](#)

Contents

Preface page x

1 Introduction 1

- 1.1 The dark and the light 1
- 1.2 Where the fires burn 2
- 1.3 The vast dark sea 5
- 1.4 The great beyond 6
- 1.5 The next steps 8

2 The nuts and bolts of the Universe 11

- 2.1 The building blocks: elementary particles 11
- 2.2 The forces: three easy pieces and a harder one 17
- 2.3 Beyond the Standard Model 28
- 2.4 Into the soup 29

3 Cosmology 31

- 3.1 The dynamics of the Universe 31
- 3.2 The primordial fireball: a particle cauldron 38
- 3.3 Into the unknown: the GUT and Planck eras 42
- 3.4 Inflation, dark energy and dark matter 43

4 Cosmic structure formation 46

- 4.1 The perturbed Universe 46
- 4.2 Large scale structure formation 48
- 4.3 Stars: the Universe's worker bees 55
- 4.4 Stellar and galactic concentrates 57
- 4.5 Black hole characteristics 60
- 4.6 Black hole astrophysics 64

viii Contents

- 5 Active galaxies 67**
 - 5.1 What makes a galaxy “active”? 67
 - 5.2 MBH masses, masers and distances 69
 - 5.3 An AGN garden, classified 74
 - 5.4 Extreme AGNs 80
- 6 Stellar cataclysms 83**
 - 6.1 Stellar high energy sources 83
 - 6.2 White dwarfs and thermonuclear supernovae 84
 - 6.3 Core collapse supernovae 87
 - 6.4 Neutron stars and pulsars 92
 - 6.5 Accreting X-ray binaries 94
 - 6.6 Millisecond pulsars 95
 - 6.7 Magnetars 96
 - 6.8 Stellar black holes 98
 - 6.9 Micro-quasars: neutron stars or black holes? 100
- 7 Gamma-ray bursts 103**
 - 7.1 What are gamma-ray bursts? 103
 - 7.2 Phenomenology of gamma-ray bursts 105
 - 7.3 The GRB prompt radiation 109
 - 7.4 GRB progenitors 112
 - 7.5 GRB afterglows 115
 - 7.6 Cosmological uses of GRBs 118
 - 7.7 Very high energy gamma-rays 118
 - 7.8 Non-photonic emission 121
 - 7.9 Wider impact of GRB multi-channel studies 122
- 8 GeV and TeV gamma-rays 124**
 - 8.1 Importance of the GeV–TeV range 124
 - 8.2 Galactic GeV–TeV sources 124
 - 8.3 Extragalactic sources 128
 - 8.4 Detectability of GeV–TeV sources 132
 - 8.5 GeV and TeV detection techniques 136
- 9 Gravitational waves 140**
 - 9.1 Ripples in space-time 140
 - 9.2 Astrophysical sources of gravitational waves 143
 - 9.3 Stellar binary GW sources 145
 - 9.4 Galaxies as gravitational wave sources 149
 - 9.5 Gravitational wave detectors 151

10 Cosmic rays 154

- 10.1 Particles from Heaven 154
- 10.2 Ultra-high energy cosmic rays 158
- 10.3 Cosmic-ray observational techniques 162

11 Neutrinos 166

- 11.1 The elusive neutrinos 166
- 11.2 Stellar and supernova neutrinos 168
- 11.3 Atmospheric neutrinos 170
- 11.4 VHE astrophysical neutrinos 171
- 11.5 Cosmogenic neutrinos 175
- 11.6 Neutrino detectors 176

12 Dark dreams, Higgs and beyond 180

- 12.1 Dark matter 180
- 12.2 Indirect astrophysical WIMP searches 181
- 12.3 Direct WIMP searches 183
- 12.4 Axions 186
- 12.5 Dark energy 186
- 12.6 Beyond the Standard Model at the LHC 188
- 12.7 Underground astrophysics and particle physics 191

Epilogue 194

References 196
Glossary 199
Index 206

Cambridge University Press

978-0-521-51700-3 - The High Energy Universe: Ultra-High Energy Events in Astrophysics and Cosmology

Peter Meszaros

Frontmatter

[More information](#)

Preface

This book provides an overview of topics in high energy, particle and gravitational astrophysics, aimed mainly at interested undergraduates and other readers with only a modest science background. Mathematics and equations have been kept to a minimum, emphasizing instead the main concepts by means of everyday examples where possible. I have tried to cover and discuss in some detail all the major areas in these topics where significant advances are being made or are expected in the near future, with discussions of the main theoretical ideas and descriptions of the principal experimental techniques and their results.

Cosmology, particle physics, high energy astrophysics and gravitational physics have, in the last two decades, become increasingly closely meshed, and it has become clear that thinking and experimenting within the isolated confines of each of these disciplines is no longer possible. The multi-channel approach to investigating nature has long been practiced in high energy accelerators involving the strong, the weak and the electromagnetic interactions, whereas astrophysics has long been possible only using electromagnetic signals. This situation, however, is rapidly changing, with the advent of major cosmic-ray, neutrino and gravitational wave observatories for studying cosmic sources, and the building of particle physics experiments using beams and signals of cosmic origin. At the same time, theoretical physics has increasingly concentrated efforts in attempts to unify gravity with the other three forces into an ultimate theory involving all four. The intense activity in these fields is beginning to open new vistas onto the Universe and our understanding of Nature's working on the very small and very large scales. In this book I have sought to convey not only the facts but also the challenges and the excitement in this quest.

I have been fortunate in my collaborators working in these fields and, at my own university, in having colleagues active in the various areas discussed

here. Among the latter, I am grateful to Irina Mocioiou, Yuexing Li, Niel Brandt, Michael Eracleous, Derek Fox, Abe Falcone, L. Sam Finn, Paul Sommers, Douglas Cowen and Stephane Coutu for providing me feedback and advice on individual chapters. I am also grateful to my wife Deborah for suggestions on improving the readability of the manuscript. Any remaining errors are my own.

Understanding our cosmic environment and its immense displays of power is somewhat akin to experiencing a major storm at sea. One feels awe at its vastness and violence, and also the desire to understand, as far as possible, how it works and what causes it. I hope that this book will help its readers participate in this experience.