

Contents

| | |
|--|-----------|
| <i>List of contributors</i> | page xii |
| <i>Preface</i> | xvii |
| <i>Acknowledgements</i> | xx |
| <i>List of symbols and abbreviations</i> | xxi |
| Part I Dark matter in cosmology | 1 |
| 1 Particle dark matter <i>G. Bertone and J. Silk</i> | 3 |
| 1.1 Introduction | 3 |
| 1.2 The baryon budget | 4 |
| 1.3 The case for cold dark matter: good news and bad news | 5 |
| 1.4 Portrait of a suspect | 7 |
| 1.5 Observing cold dark matter | 10 |
| 1.6 The future | 12 |
| 2 Simulations of cold dark matter haloes <i>B. Moore and J. Diemand</i> | 14 |
| 2.1 From cold collapse to hierarchical clustering – a brief history | 14 |
| 2.2 Results from collisionless simulations | 17 |
| 2.3 Predictions for direct and indirect detection experiments | 34 |
| 3 Milky Way satellites <i>J. Bullock, M. Kaplinghat and L. Strigari</i> | 38 |
| 3.1 Satellite galaxies | 38 |
| 3.2 Streams | 46 |
| 3.3 Central profiles and the nature of dark matter | 48 |
| 3.4 Indirect detection of dark matter from Milky Way satellites | 51 |
| 3.5 Future prospects | 55 |

| | | | |
|----------------|---|--------------------------|------------|
| 4 | Gravitational lensing and dark matter | <i>Y. Mellier</i> | 56 |
| 4.1 | Introduction | | 56 |
| 4.2 | Gravitational lensing theory | | 57 |
| 4.3 | Evidence for dark matter from strong lenses | | 63 |
| 4.4 | Cold dark matter confronted to gravitational lenses | | 65 |
| 4.5 | Hot dark matter: limits on neutrino masses from lensing | | 77 |
| 4.6 | Dark matter or modified gravity? | | 78 |
| 4.7 | Conclusion and outlook | | 80 |
| 5 | Dark matter at the centres of galaxies | <i>D. Merritt</i> | 83 |
| 5.1 | Phenomenology of galactic nuclei | | 83 |
| 5.2 | Dark matter models | | 86 |
| 5.3 | Dark matter in collisionless nuclei | | 88 |
| 5.4 | Dark matter in collisional nuclei | | 92 |
| 5.5 | The Galactic centre | | 94 |
| 5.6 | Dwarf spheroidal galaxies | | 97 |
| 6 | Modified gravity as an alternative to dark matter | | |
| | <i>J. D. Bekenstein</i> | | 99 |
| 6.1 | Missing mass in galaxies and clusters of galaxies | | 99 |
| 6.2 | The MOND scheme | | 102 |
| 6.3 | Modified gravity theory for MOND | | 105 |
| 6.4 | TeV \bar{S} and other relativistic MOND theories | | 109 |
| 6.5 | Gravitational lenses and cosmology in TeV \bar{S} | | 112 |
| Part II | Candidates | | 119 |
| 7 | DM production mechanisms | <i>G. Gelmini</i> | |
| | and <i>P. Gondolo</i> | | 121 |
| 7.1 | Dark matter particles: relics from the pre-BBN era | | 121 |
| 7.2 | Thermal production in the standard cosmology | | 123 |
| 7.3 | Non-thermal production in the standard cosmology | | 130 |
| 7.4 | Thermal and non-thermal production in non-standard cosmologies | | 133 |
| 8 | Supersymmetric dark matter candidates | <i>J. Ellis</i> | |
| | and <i>K. A. Olive</i> | | 142 |
| 8.1 | Motivations | | 142 |
| 8.2 | The MSSM and R -parity | | 144 |
| 8.3 | Possible supersymmetric dark matter candidates | | 147 |
| 8.4 | Renormalization-group equations and electroweak symmetry breaking | | 151 |
| 8.5 | The CMSSM | | 153 |

| | | |
|-----------------|--|-----|
| 8.6 | mSUGRA | 159 |
| 8.7 | Other possibilities | 161 |
| 8.8 | Summary | 162 |
| 9 | Dark matter at the electroweak scale: | |
| | non-supersymmetric candidates <i>G. Servant</i> | 164 |
| 9.1 | New symmetries at the TeV scale and dark matter | 166 |
| 9.2 | Dark matter from extra dimensions: Kaluza–Klein DM | 167 |
| 9.3 | Little Higgs dark matter | 182 |
| 9.4 | Dark matter in technicolour and composite Higgs theories | 183 |
| 9.5 | Mirror dark matter | 183 |
| 9.6 | ‘Minimal’ approaches | 184 |
| 9.7 | WIMPonium | 188 |
| 9.8 | Connecting dark matter and the baryon asymmetry | 188 |
| 9.9 | Conclusion | 189 |
| 10 | Non-WIMP candidates <i>J. L. Feng</i> | 190 |
| 10.1 | Motivations | 190 |
| 10.2 | SuperWIMP dark matter | 191 |
| 10.3 | WIMPless dark matter | 198 |
| 11 | Axions <i>P. Sikivie</i> | 204 |
| 11.1 | Introduction | 204 |
| 11.2 | Axion production in the early Universe | 208 |
| 11.3 | Relic density and primordial velocity dispersion | 219 |
| 11.4 | Axion miniclusters | 222 |
| 11.5 | Axion isocurvature perturbations | 224 |
| 12 | Sterile neutrinos <i>M. Shaposhnikov</i> | 228 |
| 12.1 | Particle physics motivation | 228 |
| 12.2 | Cosmological and astrophysical constraints on sterile neutrino dark matter | 232 |
| 12.3 | Sterile neutrino production in the early Universe | 239 |
| 12.4 | Conclusions | 247 |
| Part III | Collider searches | 249 |
| 13 | SUSY searches at the LHC <i>T. Plehn and G. Polesello</i> | 251 |
| 13.1 | Discovery channels | 252 |
| 13.2 | LHC measurements | 255 |
| 13.3 | Parameter extraction | 264 |
| 13.4 | Dark matter and the LHC | 274 |
| 13.5 | Outlook | 275 |

| | | |
|--|--|-----|
| 14 Supersymmetric dark matter at colliders | <i>M. Battaglia and M. E. Peskin</i> | 276 |
| 14.1 | Introduction | 276 |
| 14.2 | Questions for the collider experiments | 279 |
| 14.3 | Dark matter at hadron colliders | 285 |
| 14.4 | Dark matter at lepton colliders | 293 |
| 14.5 | Collider measurements and astrophysical questions | 303 |
| 15 Extra dimensions at the LHC | <i>K. Kong, K. Matchev and G. Servant</i> | 306 |
| 15.1 | Flat extra dimensions (UED) | 306 |
| 15.2 | Warped extra dimensions | 311 |
| 15.3 | SUSY–UED discrimination at the LHC | 317 |
| 16 SUSY tools | <i>F. Boudjema, J. Edsjö and P. Gondolo</i> | 325 |
| 16.1 | Annihilation cross-section and the relic density | 326 |
| 16.2 | Direct detection | 331 |
| 16.3 | Indirect detection | 334 |
| 16.4 | Exploring the parameter space | 338 |
| 16.5 | Interface with collider and precision measurements codes | 340 |
| Part IV | Direct detection | 345 |
| 17 Direct detection of WIMPs | <i>D. G. Cerdeño and A. M. Green</i> | 347 |
| 17.1 | Introduction | 347 |
| 17.2 | Event rate | 347 |
| 17.3 | Astrophysics input | 353 |
| 17.4 | Signals | 356 |
| 17.5 | Particle physics input | 362 |
| 18 Annual modulation signature with large mass highly radiopure NaI(Tl) | <i>R. Bernabei and P. Belli</i> | 370 |
| 18.1 | The annual modulation signature and the target material | 370 |
| 18.2 | The DAMA/NaI and DAMA/LIBRA experiments | 373 |
| 18.3 | The model-independent results | 374 |
| 18.4 | The corollary quests for the candidate particle(s) | 379 |
| 18.5 | Comparison with other activities | 380 |
| 18.6 | Future perspectives | 381 |

| | | |
|--|---|-----|
| 19 Particle dark matter and the DAMA/NaI and DAMA/ LIBRA annual modulation effect | <i>N. Fornengo</i> | 383 |
| 19.1 | The DAMA annual modulation effect | 383 |
| 19.2 | Supersymmetric candidates | 386 |
| 19.3 | Additional candidates | 389 |
| 20 Cryogenic detectors | <i>G. Gerbier and J. Gascon</i> | 391 |
| 20.1 | Introduction | 391 |
| 20.2 | Principles of operation of solid state cryogenic detectors | 392 |
| 20.3 | Single parameter detectors | 398 |
| 20.4 | Ionization phonon bolometers | 401 |
| 20.5 | Scintillation phonon bolometers | 404 |
| 20.6 | MACHe3 | 409 |
| 20.7 | Prospects for 1 ton detectors | 410 |
| 21 Liquid noble gases | <i>E. Aprile and L. Baudis</i> | 413 |
| 21.1 | Noble liquids for dark matter detection | 413 |
| 21.2 | Two-phase XeTPCs: XENON, ZEPLIN and LUX | 420 |
| 21.3 | Two-phase ArTPCs: WArP and ArDM | 428 |
| 21.4 | Single-phase detectors: XMASS, DEAP/CLEAN | 432 |
| 22 Directional detectors | <i>N. Spooner</i> | 437 |
| 22.1 | Direct dark matter detection technologies and directionality | 437 |
| 22.2 | The directional signature and statistics | 438 |
| 22.3 | Directional detector concepts | 440 |
| 22.4 | Gas detector physics – diffusion and straggling | 442 |
| 22.5 | TPC gamma background rejection and energy threshold | 447 |
| 22.6 | TPC neutron background rejection, solar neutrinos and radon | 450 |
| 22.7 | Electronic noise and other background | 452 |
| 22.8 | WIMP detection and directional sensitivity in practice | 452 |
| 22.9 | Head–tail recoil discrimination, theory and experiment | 456 |
| 22.10 | Experimental status and readout technology | 457 |
| 22.11 | Scale-up and a future WIMP telescope | 463 |
| 23 Axion searches | <i>S. Asztalos</i> | 467 |
| 23.1 | Constraints on axion properties | 468 |
| 23.2 | Conclusions | 487 |

| | |
|---|-----|
| Part V Indirect detection and astrophysical constraints | 489 |
| 24 Gamma-rays <i>L. Bergström and G. Bertone</i> | 491 |
| 24.1 Annihilation | 491 |
| 24.2 Decaying dark matter | 496 |
| 24.3 Galactic centre | 497 |
| 24.4 Substructures | 499 |
| 24.5 The extragalactic signal | 504 |
| 24.6 Connection between antimatter and gamma-ray signal | 505 |
| 25 High-energy neutrinos from WIMP annihilations in the Sun <i>F. Halzen and D. Hooper</i> | 507 |
| 25.1 Searching for dark matter with neutrinos | 507 |
| 25.2 The capture and annihilation of WIMPs in the Sun | 509 |
| 25.3 The neutrino spectrum | 511 |
| 25.4 Neutrino telescopes | 513 |
| 25.5 The case of neutralino dark matter | 516 |
| 25.6 The case of Kaluza–Klein dark matter | 518 |
| 26 Indirect dark matter detection with cosmic antimatter <i>P. Salati, F. Donato and N. Fornengo</i> | 521 |
| 26.1 Production of antimatter in the Galaxy | 521 |
| 26.2 Propagation of antinuclei in the Galaxy | 521 |
| 26.3 Antiprotons in cosmic rays | 524 |
| 26.4 Antideuterons in cosmic rays | 532 |
| 26.5 Positrons in cosmic rays | 537 |
| 26.6 Conclusions | 546 |
| 27 Multi-wavelength studies <i>S. Profumo and P. Ullio</i> | 547 |
| 27.1 Introduction | 547 |
| 27.2 The multi-wavelength approach and galaxy clusters | 556 |
| 27.3 The multi-wavelength approach and dwarf galaxies | 559 |
| 27.4 The multi-wavelength approach and the Milky Way | 561 |
| 27.5 Radio observations | 563 |
| 27.6 Conclusions and overview | 564 |
| 28 Particle dark matter and Big Bang nucleosynthesis <i>K. Jedamzik and M. Pospelov</i> | 565 |
| 28.1 Introduction | 565 |
| 28.2 Standard BBN theory | 567 |
| 28.3 Observed light element abundances | 569 |
| 28.4 Cascade nucleosynthesis from energy injection | 573 |
| 28.5 Residual DM annihilation during BBN | 576 |

| | | |
|-----------|--|------------|
| 28.6 | Catalysed BBN (CBBN) | 579 |
| 28.7 | DM production during BBN: NLSP→LSP example | 583 |
| 29 | Dark matter and stars <i>G. Bertone</i> | 586 |
| 29.1 | DM capture and annihilation in stars | 587 |
| 29.2 | The Earth and other planets | 589 |
| 29.3 | Main-sequence stars | 591 |
| 29.4 | Compact objects | 593 |
| 29.5 | Pop III stars | 599 |
| | <i>References</i> | 602 |
| | <i>Index</i> | 736 |