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Axions

Theory, Cosmology, and Experimental Searches

 Springer

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Emilio Zavattini, born on March 14th, 1927, in Rimini, Italy, distinguished physicist and source of many fertile ideas in our field, passed away on January 9th, 2007.

He will be remembered by all those who had the privilege of working with him, especially the younger generation researchers, for his keen insights and for his ability to critically question all ideas, including his own. This was a peculiar tract of his style which rendered him unique. While holding discussions with him, one was never afraid of expressing a scientific opinion, however trivial or unfounded, and he would always correct mistakes without causing embarrassment.

His early work in the field of strong and weak interactions, especially using muons, conducted at CERN and at other institutions worldwide, represents an outstanding achievement in physics. His deep interest in the structure of vacuum began with the spectroscopy of muonic atoms and led him to formulate the ideas at the basis of current searches for nonlinear effects in Maxwell's equations due to vacuum polarization, and for other new interactions at low energy scales.

This quest is still open and is being carried out today by a growing community of physicists. Many of the members of this community have been trained by him and all remember him fondly for all that he had been able to give.

Preface

Axion physics started in 1977 when Roberto Peccei and Helen Quinn proposed their solution to the strong CP problem by postulating a new $U(1)$ symmetry. The strong CP problem is a “blemish” of the standard model of particle physics which is one of the most profound and successful theories in modern physics that has been verified by numerous experiments to very high accuracy. Associated with the Peccei-Quinn symmetry is a light and weakly-interacting particle that was named by Frank Wilczek based on experience from day-to-day life: *I named them after a laundry detergent, since they clean up a problem with an axial current* (Frank Wilczek, Nobel lecture 2004). So far the axion has remained elusive for over 30 years of intensive research, and none of the axion searches, based on either astrophysical observations or pure laboratory based experiments, was able to yield a positive signature for the axion or an axion-like particle.

The motivation of this book is to provide a starting point for graduate students and senior scientists in the field of axions and axion-like particles. We give a broad overview on the theoretical motivation of axions and axion-like particles, their implication for cosmology and astrophysics, their role as a well-motivated dark-matter candidate, and experimental axion searches. Most of this book is based on lectures given at the 1st Joint ILIAS-CERN-CAST axion training in Geneva at CERN in November 2005. Of course, the experiments and theoretical works are by far too numerous to be completely covered in a volume of lecture notes like this.

We are indebted to many people who have contributed directly or indirectly to finalize this book and to make the axion lecture series possible. Our special thanks go to the lecturers who have delivered stimulating written versions of their presentations and who have helped patiently during the preparation of the final text. We are grateful to our colleagues of the CAST collaboration and numerous helpers whose assistance was crucial, especially for the organization of the lecture series and for the day-to-day running of the meeting. We owe special thanks to Konstantin Zioutas for his support, who right from the conception of the first idea was convinced that the time was ripe for a lecture series on axion-related physics.

We thank the network on direct dark matter detection of the ILIAS integrating activity of the European Union (contract number: RII3-CT-2003-506222) for support and CERN for hosting the meeting.

Kingston, Darmstadt, München,
February 2007

*Berta Beltrán, Markus Kuster, and
Georg Raffelt*

Contents

Part I Axion Theory

1 The Strong CP Problem and Axions

| | |
|---|----|
| <i>Roberto D. Peccei</i> | 3 |
| 1.1 The $U(1)_A$ Problem and Its Resolution | 3 |
| 1.2 Approaches to the Strong CP Problem | 6 |
| 1.3 $U(1)_{PQ}$ and Axions | 7 |
| 1.4 Axion Dynamics | 9 |
| 1.5 Invisible Axion Models | 12 |
| 1.6 Concluding Remarks | 15 |
| References | 15 |

2 Axion Cosmology

| | |
|--|----|
| <i>Pierre Sikivie</i> | 19 |
| 2.1 Thermal Axions | 20 |
| 2.2 Axion Field Evolution | 23 |
| 2.3 The Domain-Wall Problem | 32 |
| 2.4 Cold Axions | 36 |
| 2.5 Axion Miniclusters | 42 |
| 2.6 Axion Isocurvature Perturbations | 44 |
| References | 47 |

3 Astrophysical Axion Bounds

| | |
|--|----|
| <i>Georg G. Raffelt</i> | 51 |
| 3.1 Introduction | 51 |
| 3.2 Axion Interactions | 52 |
| 3.3 The Sun as an Axion Source | 54 |
| 3.4 Globular-Cluster Stars | 57 |
| 3.5 White-Dwarf Cooling | 59 |
| 3.6 Supernova 1987A | 60 |
| 3.7 Conclusions | 64 |
| References | 66 |

4 Axions and Large Extra Dimensions

Biljana Lakić, Raul Horvat and Milica Krčmar 73

4.1 Introduction on Extra Dimensions 73

4.2 Axions in Large Extra Dimensions 75

4.3 CAST as a Probe of Large Extra Dimensions 78

4.4 Conclusion 81

References 82

5 Axions and Their Relatives

Eduard Massó 83

5.1 The Axion 83

5.2 The Axion Relatives 85

5.3 Searching for ALPs 87

5.4 Is it Possible to Evade the Astrophysical Constraints? 89

5.5 ALPs as Dark Matter 90

5.6 Conclusion 91

References 92

Part II Observations and Experiments

6 Magnetic and Electric Dipole Moments in Storage Rings

Yannis K. Semertzidis 97

6.1 Dipole Moment Experiments in Storage Rings 97

6.2 Muon $g-2$ 99

6.3 Electric Dipole Moments 105

References 112

7 Photon-Axion Conversion in Intergalactic Magnetic Fields and Cosmological Consequences

Alessandro Mirizzi, Georg G. Raffelt and Pasquale D. Serpico 115

7.1 Introduction 115

7.2 Photon-Axion Conversion 116

7.3 Photon-Axion Conversion and Supernova Dimming 119

7.4 CMB Constraints 125

7.5 QSO Constraints 127

7.6 Constraints from Angular Diameter Distance 128

7.7 Conclusions 130

Appendix A: A Photon-Axion Conversion in a Random Background ... 131

References 132

8 Microwave Cavity Searches

Gianpaolo Carosi and Karl van Bibber 135

8.1 Dark Matter and the Axion 135

8.2 Principles of Microwave Cavity Experiments 138

8.3 Technical Implementation 140

8.4 Data Analysis 147
 8.5 Results 148
 8.6 Future Developments 149
 8.7 Summary and Conclusions 154
 References 155

**9 Recent Results from the PVLAS Experiment
 on the Magnetized Vacuum**

Giovanni Cantatore and the PVLAS Collaboration 157
 9.1 Introduction 157
 9.2 Aim and Measurement Principle of PVLAS 159
 9.3 PVLAS Apparatus 170
 9.4 Results 174
 9.5 Discussion 184
 9.6 Conclusions 192
 Note Added in Proof 193
 References 194

**10 Axion Searches in the Past, at Present,
 and in the Near Future**

*Rémy Battesti, Berta Beltrán, Hooman Davoudiasl, Markus Kuster,
 Pierre Pagnat, Raoul Rabadán, Andreas Ringwald, Neil Spooner,
 and Konstantin Zioutas* 199
 10.1 Searches for Dark Matter Axions 199
 10.2 Solar Axions Searches 201
 10.3 Searches for Laser Induced Axions 213
 10.4 Search for Kaluza-Klein Axions with TPCs 226
 10.5 Collider Bounds on Scalars and Pseudoscalars 231
 10.6 Summary and Outlook 233
 References 234

Acronyms and Abbreviations 239

Index 243