Maurizio Gasperini

Gravity, Strings and Particles

A Journey Into the Unknown

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To my Mother
with my deepest gratitude

Preface

This book grew out of conversations I had with a good friend of mine (Pier Paolo Casalboni, also known as "*Slim*"). During the summer vacations, while tanning on the beach in Cesenatico, he often asks me to tell him the latest news and the most peculiar ideas concerning my work as theoretical physicist.

In this book I will talk of physics addressing to readers who do not necessarily have a specific background in this field, but are nevertheless interested in discovering the novelty, the originality, and the possible weird implications of some amazing ideas used by modern physics of fundamental interactions. I will avoid introducing mathematical expressions as much as possible, trying to convey ideas rather than explaining formulas. Also, I will leave aside the cautious attitude typical of the academic style, following sometimes my excitement and my personal feelings concerning the topics under discussion.

We can say that this is a book of popular science, but of a rather unconventional type, as the emphasis is not only on what is known but also—and mainly—on what is still unknown. Indeed, many parts of the book are devoted to introduce and illustrate fundamental theoretical models and results which are potentially highly relevant to a deeper understanding of Nature, but still waiting to be directly confirmed (or disproved) by experimental observations. From this point of view the book may be of some interest also to professional physicists, working or not in the field of fundamental interactions.

I should explain, finally, the reason why the book is focused on the three topics mentioned in the title: gravity, strings, and particles. Why these three topics? What brings them together, selecting them among many other important issues of modern physical research?

It is known that there are many important links among them: for instance, as we shall see, the fact that a unified description of all elementary matter particles and all forces, including gravity, can be consistently achieved only within a model based on strings.

However, my choice is mainly motivated by the widespread belief that only a joint study of high-energy models of gravity, strings, and particles may help us to shed light on what seems to be (to me, at least) one of the biggest and most fascinating mysteries of modern science: besides time and three spatial dimensions, are there other dimensions in our Universe? If yes, how many are they?

Cesena, Italy Maurizio Gasperini
February 2013

Notations

For a maximum simplification of the (very few) equations presented in this book I will always adopt the so-called natural system of units, where both the light velocity c and the Planck constant $\hbar$ are set equal to one.

With this choice of units mass and energy have the same physical dimensions, energy has dimensions of the inverse of a length, and energy density has dimensions of an inverse length to the fourth power.

We will often use, as a typical reference distance, the Planck length L_P defined (in the above units) by $L_P = \sqrt{G}$, where G is Newton's gravitational constant; we will also use, as a typical reference energy, the Planck mass M_P defined by $M_P = 1/L_P$.

We will usually express distances in centimeters (abbreviated as cm); energies in electron volts (abbreviated as eV), or billions of electron volts (abbreviated as GeV), or thousands of GeV (abbreviated as TeV). Sometimes we will use for the distances also the light year, roughly equivalent to 0.9×10^{18} cm. Finally, we will express temperatures in Kelvin degrees, remembering that one Kelvin degree (with the Boltzmann constant set equal to one) corresponds to 8.6×10^{-5} eV.

In the above units the Planck length is given by:

$$L_P \simeq 1.61 \times 10^{-33}\,\text{cm},$$

the Planck mass is given by:

$$M_P \simeq 1.22 \times 10^{19}\,\text{GeV},$$

and the Hubble radius L_H, which controls the size of the portion of space directly accessible to our observation, is presently given by:

$$L_H \simeq 1.28 \times 10^{28}\,\text{cm}.$$

Other scales of energy and distance, possibly relevant to the topics of this book, will be introduced and discussed whenever necessary.

Contents

Chapter 1
Prologue: Inside the Energy Walls of Our "Cradle"

We often say that the physics of "small distances" is equivalent to the physics of "high energies." This is indeed true, as a direct consequence of the celebrated Heisenberg's principle (or uncertainty principle) stating that, in order to explore (and measure) smaller and smaller distances, we need probes with higher and higher momenta, namely with larger and larger kinetic energies. According to the uncertainty principle, in particular, the required energy E turns out to be inversely proportional to the considered distance d, so that E tends to infinity when the distance d goes to zero.

Even in the case of very large distances, however, we are unavoidably lead to the high-energy regime. This basically occurs for two reasons: one reason, of accidental type, is related to the expansion of our Universe; the other reason, of more fundamental nature, is related to the fact that all information and signals (of all types) are characterized by a finite speed of propagation.

According to this second (important) property of Nature, in fact, looking "far away in space" also means looking "back in time," because the signals we receive from more and more distant sources have been emitted at increasingly remote epochs. If a galaxy is millions of light-years away from Earth, for instance, its light has been traveling for millions of years to get to us, and the information it can provide is referred to the epoch when the light left the galaxy—namely, to millions of years ago.[1]

Because of the expansion of our Universe, on the other hand, looking back in time implies considering epochs in which matter and radiation were concentrated in increasingly smaller volumes of space, so that the temperature and the kinetic energy of their elementary components were higher and higher. Hence, the more remote is the signal which reaches us, the greater is the energy scale corresponding to the emission epoch.

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[1]The famous *Andromeda Galaxy*, whose picture is also used as a desktop background in recent versions of Mac computers, is one of the nearest galaxies, and is approximately 2.5 million light-years away from Earth (corresponding to a distance of about 2.4×10^{19} km).

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