PREMISE

# A STROLL ALONG THE BEACH

We are obsessed with ourselves. We study *our* history, *our* psychology, *our* literature, *our* gods. Much of what we know concerns ourselves, as if we humans were the most important thing in the universe. I think I love physics because it opens a window and lets us gaze into the distance. It's a breath of fresh air.

The view from this window is astonishing. We have learned much about the universe, recognizing our previous errors. We thought Earth was flat; or motionless at the centre of the universe. We thought the universe was small and never changing. We thought man was a race apart, with no relationships with other animals. We have learned of the existence of quarks, black holes, particles of light, waves of space and the extraordinary molecular architecture of every cell in our body. Humanity is like a child growing up, amazed to discover that there is a world beyond his playing field, and that that world is immense, full of mysteries and ideas different from those he grew up with. The more we learn about our world, the greater our amazement at its beauty and variety.

But the more we discover, the more we realise that what we don't know is far more than what we know. We build more powerful telescopes, and we find new, strange and unexpected skies. We study smaller and smaller particles of matter, and discover deeper and deeper structures. Today we see back almost as far as the big bang, the explosion that gave birth to the visible universe 14 billion years ago, but we are already glimpsing something that took place even earlier. We have learned that space curves, and now we suspect that curved space is made up of vibrating quantum grains.

Our knowledge of the elementary ways of the world continues to expand. If we put together everything we have learned about the physical world during the twentieth century, evidence points to something profoundly different from the notions of matter and energy, space and time we were taught at school. It points to an elementary structure generated by a swarming of quantum events, where time and space no longer rule. Quanta of fields generate space, time, matter and light, exchanging information. Reality is a network of granular events, linked by probabilistic dynamics; space, time, matter and energy dissolve in a cloud of probability.

This bizarre new world is emerging slowly from the study of quantum gravity, the main open quest in fundamental physics. The challenge is to bring coherence to what we have learned of the world through the two major twentieth century discoveries in physics: general relativity and quantum theory. This book is dedicated to quantum gravity and the strange world that the effort to find this theory is revealing.

The book describes the state of the art of the research: what we know, what we are learning, and what we think we are beginning to understand today of the elementary nature of things. It starts very early in history, with the distant origins of some of the key concepts that allow us today to organize our understanding of the world. It describes in some detail the two great discoveries of the twentieth century, Einstein's theory of general relativity and quantum mechanics, bringing the core of their physical content into focus. It describes the representation of the world that is emerging from the research on quantum gravity, and the most recent evidence from Nature, such as the confirmation of the standard cosmological model obtained with the Planck satellite and the non-observation of the supersymmetric particles that many expected to observe at the CERN laboratory in Geneva in 2013. It discusses the consequences of these theories: the granular structure of space, the eclipse of time at small scale, the physics of the big

bang, the origin of the heat of black holes, and what might be the role of information at the basis of physics.

In a famous allegory that Plato recounts in Book VII of the *Republic*, people are chained in the depths of a dark cavern; they only see shadows of statues projected onto the walls by a fire behind them; to them, that is reality. One of them is released, leaves the cavern and emerges into the sunlight. At first he is blinded by the light; his eyes are not used to such brilliance. When his sight returns, he is able to see the wonders that surround him; he returns to his companions and tells them what he has seen, but they have difficulty in believing him. We all live in the depths of a cavern, bound by chains of ignorance and prejudice; our senses are weak and we only see shadows. We want to see further, but this confuses us, we are not accustomed to the effort. But we try. This is what science is about. Scientific thinking explores the world and re-designs it; it offers us novel images that little by little become more distinct, and teaches us to see more clearly. Science is a continuous exploration of new forms of thought. Its strength is its visionary capacity to demolish preconceived ideas, reveal new realities and construct new and more effective images of the world in which we live. It is an adventure that rests on our accumulated knowledge, but it is driven by change. Look further. The world is immense, iridescent; we want to go out and see it. We are immersed in its mystery and beauty; there are hills in the distance and beyond them new territories still to be explored. The uncertainty of our knowledge, our own precariousness, suspended as we are over the abyss of the immensity of what we don't know, does not make our short life meaningless: it makes it precious.

For me this is an adventure into a marvellous world; I have written this book to share this enchantment, particularly with the reader who knows little to nothing of physics but is interested in knowing what we understand of the world today, what we don't understand, and where we are going. I hope to communicate the breath-taking beauty of the panorama of reality that is visible from where we are today. I also have my colleagues in mind, the companions of adventure scattered to the four corners of the globe, and the young scientists who are thinking of walking this road. I have tried to sketch a general outline of the structure of the physical world, seen in the light of both the theory of relativity and of quantum mechanics, and my current view of how they can merge. This book is not meant just to make the subject more accessible to the general public, it is also intended to articulate a coherent point of view in a field of research where sometimes technicalities hide the overall picture. Science is made up of experiments, hypotheses, equations, calculations and lengthy discussions; but these are the tools of the trade, as musical instruments are for musicians. When all is said and done, what matters in music is the music; what matters in science is the understanding of the world that science can offer. It is not necessary to understand Copernicus' complicated calculations to grasp the significance of the discovery that the Earth turns around the Sun, nor to understand the complex discussions in Darwin's book to grasp the importance of the discovery that all living beings on the planet have the same ancestors. Science is understanding the world from a continually widening point of view.

In this book I describe the state of the art of the research regarding this new world view as I understand it today; I try to bring the essential interactions and logical connections into focus and I try to explain this as I would to a colleague and friend who, during a stroll along the beach on a gentle summer evening asks: "But as you see it, how do things actually are?"