

Preface

This Springer Brief emerged from meetings of Working Group 1 (WG1) of the European Cooperation in Science and Technology (COST) action MP0905 “Black Holes in a Violent Universe” which started in 2010. WG1 (chaired by X.C.) is devoted to the study of quantum effects in black hole physics. The term “quantum black holes” (in the title of both the Working Group and this book) refers to black holes for which quantum effects are physically significant. This is a very broad field, ranging from primordial black holes to ones which have mass close to the Planck scale (defined below). Quantum black holes are fascinating objects as they offer a connection between general relativity and quantum mechanics. The most celebrated quantum effect associated with black holes is Hawking radiation. Another important challenge is to understand when black holes form and in particular when the collision of two particles at very high energy will form a black hole. These are some of the *raison d’êtres* of our Working Group.

Quantum effects are significant for primordial black holes, which could play a very important cosmological role and even be a source of dark matter. Furthermore, one of most important developments in particle physics of the last 20 years has been the realisation that the Planck scale at which quantum gravitational effects become important could be much lower than the traditional value of 10^{19} GeV. Indeed, if there are more than four dimensions in nature, it could potentially be within reach of the CERN Large Hadron Collider (LHC). This idea has triggered significant research which has furthered our understanding of quantum black holes. While so far there is no hint of black holes at the LHC, the data have set some of the tightest limits to date on the Planck scale. Furthermore, the possibility of creating Planckian quantum black holes at colliders was a motivation for ground-breaking theoretical studies of black hole production and decay mechanisms.

In WG1 we have been fortunate to bring together experts in the field of quantum black holes. It was thus the perfect opportunity to review the state of the art of the field. This book is the result of interactions among the members of this working group. Our aim is to have a general introduction to the topic, describing in some detail the theoretical advances that have taken place since the 1970s while being less rigorous in the more speculative parts. In particular, for low-scale

quantum gravity black holes, we have not described the current experimental limits in detail as these are evolving constantly as the LHC data grow. Note that we define “quantum black holes” as the ones for which quantum effects are important, although the term is sometimes used more restrictively, to refer to holes for which quantum gravitational effects are important.

We hope that this book will be useful to researchers, advanced undergraduate and graduate students. We assume some familiarity with general relativity, quantum theory and particle physics at the undergraduate level. Throughout this book we use the space-time signature $(-, +, \dots, +)$. At various points in this book, we will use relativistic units in which both Newton’s gravitational constant G and the speed of light c are equal to unity, as well as electromagnetic Gaussian units in which the Coulomb force constant $(4\pi\epsilon_0)^{-1} = 1$. In our discussion of black hole thermodynamics we will also set the reduced Planck’s constant $\hbar$ and the Boltzmann constant k_B equal to one. Using the constants G , $\hbar$ and c , we can construct a fundamental length-scale $L_P = \sqrt{\hbar G/c^3} \approx 1.6 \times 10^{-35}$ m, mass-scale $M_P = \sqrt{\hbar c/G} \approx 2.2 \times 10^{-8}$ kg $\approx 1.2 \times 10^{19}$ GeV/ c^2 and time-scale $t_P = \sqrt{\hbar G/c^5} \approx 5.4 \times 10^{-44}$ s. These are known as the Planck scales and quantities are given in these units when we use relativistic units. When we discuss space-times with more than four dimensions, we denote the number of space-time dimensions by $d = n + 4$, with n being the number of “extra” dimensions. We use the notation $M_\odot$ to denote the mass of the Sun ($\approx 2 \times 10^{30}$ kg), which is a useful mass-scale for astrophysical objects.

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