Preface

It fills me with a sense of joy and humility to present this book on the eve of the centenary year of the publication of Albert Einstein's General Theory of Relativity. When general relativity arrived, it acquired an aura of mystery with its sophisticated view of space, time and gravitational phenomena. From the early phase when primary elaboration of the theory was mathematical in nature, it has evolved into a phase where it is being confronted by ever sophisticated experiments and has been successful so far. Students often get attracted to the theory and want to know what is there yet to be done. The book is envisaged as an attempt to familiarise the students and prospective researchers with the basic features of the theory and offer a perspective on its more advance features.

There are many excellent text books from the classics by Misner-Thorne-Wheeler, Weinberg and Wald to the more recent ones by Sean Carroll, James Hartle and Thanu Padmanabhan, with differing styles and emphasis and there are excellent review articles on front line topics. The idea here is to combine the 'Text Book' and 'The Review'. Thus, I have tried to adopt the pedagogical style of a text book but avoiding its emphasis on detailed treatments and at the same time, tried to present the essential ideas and just enough background material needed to appreciate the issues and current research.

There is also a conscious effort to emphasize the physical ideas and motivations, contrasting the mathematical idealizations which are important in appreciating the scope and limitations of the theory. Consequently, requisite mathematical background of differential geometry is summarised in the last chapter while the main text emphasizes the physical aspects.

The first five chapters, usually form the core of an introductory course on General Relativity (GR) and constitute the 'Basics' part of the book. The first chapter traces Einstein's arguments and informally motivates the mathematical model for space-time. In the second chapter, we first discuss the basic physical quantities related to space-time measurements and their relation to a metric in an arbitrary coordinate system. This is followed by examples of space-times corresponding to different types of gravitational fields. Some of these are revisited subsequently for further elaboration. Chapter 3 discusses adaptation of dynamics in a Riemannian geometry framework while the next chapter presents the Einstein Equation together with its elementary properties. The

fifth chapter discusses different phenomena either predicted by GR or influenced by GR. This also contains the classic tests of general relativity.

The 'Beyond' part of the book, takes a look at some of the more sophisticated features of GR. The chapter six discusses the physical requirements of a well defined deterministic framework for non-gravitational dynamics and the constraints it puts on the global structure of space-times. Surprisingly, the singular features seen in physically motivated examples, turn out to have more general presence. The structure of the physically acceptable space-times is such that if certain conditions - such as complete gravitational collapse or everywhere expanding universe - are realised in nature, then the space-time will necessarily have regions where GR will cease to be applicable.

Not all physical situations are as grim. There are physical bodies of finite extent and it becomes necessary to look at the space-time geometry far away from them. This is especially relevant in the context of energy being carried away in the form of gravitational waves. Chapter seven discusses the characterization of the appropriate asymptotic space-times.

In the next three chapters, we revisit black holes, gravitational waves and cosmological space-times. Apart from considering the general definition of black holes, we motivate and discuss their quasi-local generalization in terms of the trapping, isolated and dynamical horizons. In the second look at gravitational waves, we trace the issues that were involved in settling the 'reality' of gravitational waves and briefly discuss the basic features of the challenge involved in their direct detection. The cosmological space-times are discussed primarily to get a glimpse of the possible nature of the space-like singularities.

The chapter eleven discusses the evolutionary interpretation for the class of globally hyperbolic space-times and reviews the initial value formulation. This forms a basis for numerical relativity presented in the next chapter. The Hamiltonian formulation paves a way for canonical quantization of gravity. While the book is focussed on the classical general relativity, introductory summaries of the main approaches to a quantum theory of gravity are included in the chapter thirteen. An alternative view of emergent gravity is also briefly mentioned.

There are many topics which should have found a place in the book, but could not be included for different reasons. These are listed in the fourteenth chapter together with some concluding remarks. The final chapter contains a summary of the requisite differential geometry and some of the results used in the main text.

The best efforts are never enough when it comes to avoiding errors. I hope to have an 'errata' link available on my homepage.

It is time now to acknowledge my debts. My understanding and appreciation of GR has been been shaped by several influences over several years which are hard to demarcate. Nevertheless, I must mention Naresh Dadhich and thank him for the numerous

discussions and his generous encouragement. Within the context of this book, I would like to acknowledge critical feedback from my former teacher, Arvind Kumar on an earlier draft of chapter 2 and my former student Alok Laddha for his comments on chapter 7. I would also like to thank Thanu Padmanabhan for his help on the emergent gravity view and Sudipta Sarkar for a discussion on Jacobson's work. I must not forget the students of my Institute who had taken my courses on GR and those from other places from India who had taken short term courses on various occasions under the SERC Schools in Theoretical High Energy Physics (India). The book has grown out of the various lecture notes. I thank them all. I thank my friend and colleague, Gautam Menon for proof reading and suggestions. There are times of meeting deadlines where responsibilities get shuffled and prioritised. This cannot be done without support from the family. I thank Nisha, Aditya, and my parents for it.

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