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Elements of Cosmological Thermodynamics

Springer

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Dedicated to my parents
Aditya Saha & Manasi Saha
and to my beloved brother
Soumyadeep (Piku)

Foreword

This book is well equipped to serve as a nice introductory text to the application of horizon thermodynamics in the context of Cosmology. The implications of modified and generalized Hawking temperatures in the formulation of cosmological thermodynamics are carefully explained. The book also discusses various drawbacks within this research field and lists some open issues for the readers to deal with. I hope their endeavours will enrich this research field as well as open up new frontiers for future generations to work with.

Kolkata, India
December 2017

Subenoy Chakraborty

Preface

The study of cosmological horizons has gained much attention in recent literature. Consequently, the thermodynamics of horizons or, more precisely, cosmological thermodynamics (gravitational thermodynamics is also used sometimes) has become a very popular research field and is emerging very rapidly. The apparent reason for this popularity is the discovery of the intimate relationship between gravity and the laws of thermodynamics which resulted in the establishment of the laws of black hole thermodynamics. Attempts were then undertaken to generalize these laws in the context of Cosmology. Nowadays, cosmological models, which, in addition to passing the observational tests, are consistent with the laws of thermodynamics, particularly the first law, the generalized second law and thermodynamic equilibrium, are more acceptable as compared to those which only pass the observational tests.

This book in the SpringerBriefs Series in Physics serves as a concise introduction to the vibrant research field of cosmological thermodynamics. The first two chapters focus entirely on establishing the basic features of relativistic cosmology and equilibrium thermodynamics respectively. The third chapter discusses the origin and provides a brief history of cosmological thermodynamics and also explains how this particular field of research was gradually developed from the mathematical point of view. In this regard, the modified and generalized forms of the Hawking temperature are introduced and their implications explained. The next three chapters discuss its application in determining the thermodynamic viability of certain well-known and widely accepted cosmological models, particularly, the flat, homogeneous and isotropic Friedmann–Lemaitre–Robertson–Walker model, the isotropic but inhomogeneous Lemaitre–Tolman–Bondi model, and the gravitationally induced adiabatic particle creation model. The work described in this book (in Chaps. 4–6) is the result of research undertaken while I was a Ph.D. student under the able supervision of Prof. S. Chakraborty at the Department of Mathematics of Jadavpur University and later a Postdoctoral Fellow under the mentorship of Prof. N. Banerjee at the Department of Physical Sciences of Indian Institute of Science Education and Research (IISER), Kolkata.

The book is most suitable for graduate level students and researchers who have a basic understanding of Differential Geometry. Some familiarity with General Relativity will prove useful but is not necessary. A brief overview of the important and relevant concepts of Cosmology and Thermodynamics in the first two chapters of the book enables even the first year undergraduate students in Applied Mathematics, Physics, as well as allied subjects to gain some insights into this field. The final chapter of this book enlists few (of many) shortcomings in this field and also outlines prospective open issues which may impart a sense of challenge into the mind of the reader. I sincerely hope that the lucid language used throughout the book and the rich bibliography at the end of each chapter will be identified as important assets by the readers and at least a few of them will be inspired to find new directions of research in this field.

This book has been checked several times with extreme care to free it from all discrepancies and typos. Even then the vigilant readers may find mistakes and several portions of this book may seem to be unwarranted or irrelevant. I take sole responsibility for these errors which may have resulted from my inadequate knowledge in the subject or escaped my notice. Any comments or suggestions for improvement are welcome and should be directed to my email id subhajit1729@gmail.com.

Kolkata, India Subhajit Saha
December 2017

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I begin by offering my heartfelt thanks and warmest regards to my Ph.D. thesis supervisor Prof. Subenoy Chakraborty without whose guidance, support, understanding, patience and professionalism, this book would not exist. I am also indebted to him for agreeing to write a foreword to this book. I also thank *Kakima* (Mrs. Archana Chakraborty) for her delicious cuisines and warm hospitality, and Sumanta for his support and academic help occasionally. I extend my sincere gratitude to the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune for their vibrant Visiting Program as well as their extensive research facilities and warm hospitality which helped in writing down a significant part of this book. I should specially mention the role of IUCAA library which helped in checking the manuscript of this book for plagiarism through their URKUND anti-plagiarism software. I also wish to thank my friends and fellow researchers, particularly Abdulla, Abhijit, Saugata, Sujoy *da* and Sunandan *da* as well as my colleagues at Panihati Mahavidyalaya (where I am presently teaching) for their constant support and encouragement. I also express my indebtedness to my high school physics tutor Mrs. Rita Neogi and her family for their well wishes and deep concern for my well-being. For discussion or clarification on certain topics within the subject, I thank Profs. Narayan Banerjee, Christian Corda, Diego Pavon, Stefano Viaggiu, Alexis Helou and Valerio Faraoni. I am also grateful to Herma and Liesbeth (of Springer) for their prompt help with my technical queries during the writing of this book. Special thanks are also due to Mr. Subodh Kumar and Ms. Komala Jaishankar for their extensive help extended during the pre-production stage. Above all, I express my deepest gratitude and indebtedness to my parents and my beloved brother for their sacrifices, well wishes, encouragement, mental support and utmost love and care.

About the Book

Based on the author's own work and results obtained by renowned cosmologists across the globe, this short book provides a concise introduction to the relatively new research field of cosmological thermodynamics. Starting with a brief overview of basic cosmology and thermodynamics, this text gives an interesting account of the application of horizon thermodynamics to the homogeneous and isotropic Friedmann-Lemaitre-Robertson-Walker model, the inhomogeneous Lemaitre-Tolman-Bondi model, and the gravitationally induced adiabatic particle creation scenario. Both seasoned and new researchers in this field will appreciate the lucid presentation and the rich bibliography.

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About the Author

Dr. Subhajit Saha is an Assistant Professor of Mathematics at Panihati Mahavidyalaya, a West Bengal Govt. aided college in Sodepur, India. He is actively engaged in research in the field of Cosmological Thermodynamics and is currently exploring its applications in the gravitationally induced particle creation scenario as well as other areas of Theoretical Cosmology. He obtained his PhD degree from Jadavpur University in 2015. He worked in the field of "Horizon Thermodynamics with Modified Hawking Temperature" under the supervision of Prof. Subenoy Chakraborty. Prior to that, he obtained his B.Sc. in Mathematics and M.Sc. in Applied Mathematics from Jadavpur University in 2009 and 2011 respectively. He was awarded the prestigious National Postdoctoral Fellowship by the Science and Engineering Research Board of the Govt. of India in 2016. He pursued postdoctoral research at Indian Institute of Science Education and Research (IISER) Kolkata under the mentorship of Prof. Narayan Banerjee. Dr. Saha has published around 25 articles in peer-reviewed international journals, several of them in reputed journals published by Springer, Elsevier, World Scientific, and the American Physical Society. He is a Life Member of the Indian Association for General Relativity and Gravitation and a Member of the International Astrostatistics Association.