The Grip of Gravity

The Quest to Understand the Laws of Motion and Gravitation

Gravity is the most enigmatic of all known forces of nature. It controls everything, from ocean tides to the expansion of the Universe. The search for the laws of motion and gravitation started over two thousand years ago. The reader is taken on an exciting journey through the subsequent centuries, identifying the blind alleys, profound insights and flashes of inspiration that have punctuated this search. Despite the fantastic progress that has been made, the true nature of gravity is still a mystery and the book attempts to show how the current developments in string theory (perhaps the 'Theory of Everything') may lead to a new and radical interpretation of gravity. This book describes the fundamental concepts and developments, and the experiments, both performed and planned, to increase our understanding of gravity and the natural phenomena in which gravity is the principal player.

PRABHAKAR GONDHALEKAR is an astrophysicist with major research interest in the interstellar medium and active galactic nuclei. He was formerly head of the Space Astronomy Group at the Rutherford Appleton Laboratory.

PRABHAKAR GONDHALEKAR

The Grip of Gravity

The Quest to Understand the Laws of Motion and Gravitation

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521803168

First published 2001
This digitally printed first paperback version 2005

A catalogue record for this publication is available from the British Library

Library of Congress Cataloguing in Publication data

Gondhalekar, Prabhakar, 1942–
The grip of gravity: the quest to understand the laws of motion and gravitation /
Prabhakar Gondhalekar.
p. cm.
Includes bibliographical references and index.
ISBN 0 521 80316 0
1. Gravitation – History. 2. Motion – History. I. Title.
QC178.G56 2001
531´.14–dc21 00-065149

ISBN-13 978-0-521-80316-8 hardback
ISBN-10 0-521-80316-0 hardback

ISBN-13 978-0-521-01867-8 paperback
ISBN-10 0-521-01867-6 paperback

Contents

Preface

Our world is ruled by two sets of laws: the laws of gravity and the laws of quantum mechanics. The laws of gravity describe the large structures in the universe such as the Earth, the solar system, stars, galaxies and the universe itself. These laws allow us to predict the path and motion of spacecraft and asteroids and also the evolution of the universe. The laws of quantum mechanics, on the other hand, describe the very small structures such as molecules, atoms and subatomic particles. They enable us to understand the three subatomic forces, lasers, CD players and nuclear weapons. One of the great puzzles of the twentieth century is that these two sets of laws, each employing a different set of mathematics and each making astonishingly accurate predictions in its own regime, should be so profoundly different and incompatible.

Quantum mechanics is a child of the twentieth century. Its origins can be traced back to the year 1900, when Planck proposed the particle nature of electromagnetic radiation to explain the black-body spectrum. The character of the laws of motion and the laws of gravity, on the other hand, has unfolded over a considerably longer period. Today, the concepts of mass, force and gravity are very familiar, but they are also deeply mysterious and are intimately linked to our understanding of motion. Historically motion was perhaps the first natural phenomenon to be investigated scientifically. Over two thousand years ago, the Greek philosopher Aristotle made the first attempt to make the concept of motion more precise. Unfortunately he coupled this with his doubtful astronomical views and separated the motion of the celestial bodies from the free fall of objects on Earth. This separation impeded the understanding of the laws of motion and the development of ideas of universal gravitation until the middle ages. The study of motion or mechanics was also the first 'science' to be developed in the modern period starting with Isaac Newton in the seventeenth century. The internal beauty and elegance of Newton's work and its early success in accounting in quantitative detail for the motion of the Moon, and of other planets, had enormous influence on philosophical thought and provided impetus for systematic development of science in the twentieth century. By introducing the concept of universal gravitation Newton swept aside the separation of celestial and terrestrial motions which had been assumed for the previous two thousand years. The concepts of space, time and relativity enter naturally into the study of motion. Newton assumed absolute and independent space and time without actually using these concepts in the application of his mechanical principles. Two centuries after Newton the question of absolute motion arose again, this time in connection with electrodynamics. It was Albert Einstein's great genius to accept, finally, that there was no such thing as absolute and independent space and time. This simple but revolutionary admission led Einstein to his now famous equation $E = mc^2$.

Gravity has a strong grip on human imagination, and Newton and Einstein dominate the development of gravitational theory. Newton's classical theory held sway for two hundred years. At the beginning of the twentieth century it was realised that Newton's theory does not describe the motion of bodies in a strong gravitational field or bodies that move close to the speed of light. In his theory of general relativity Einstein reinterpreted the concept of gravity. He showed that gravity could be described in terms of the geometry of space-time. Einstein's field theory of gravitation predicts only small departures from Newtonian theory except in circumstances of extreme gravitational fields or high speeds. But the major significance of Einstein's theory is its radical conceptual departure from classical theory and its implications for the future development of scientific thought.

Normally, the laws of gravitation and quantum mechanics operate completely independently, but in situations of extremely high gravitational attraction like the surface of a black hole or on extremely small length scales like the point of origin of the universe, the two sets of laws come together. In these situations the two sets of laws act together in ways which we still do not understand. It now seems likely that the theory of general relativity leads to an approximation of the true nature of gravity; the true form will only be found in the synthesis of general relativity and quantum theory or the theory of quantum gravity. It is astonishing that three hundred years after Newton and one hundred years after Einstein the quest for gravity still continues.

In this book I have traced the gradual unfolding of our understanding of the laws of motion and universal gravitation and the associated concepts of space, time and relativity. This unfolding has taken a long time (and is still continuing) and many fascinating personalities have been involved in the process. Experimental verification has played an essential part in our understanding of these laws and a number of challenging experiments are planned to deepen that understanding. Gravity has fashioned our universe and the story of gravity would not be complete without a brief review of the astronomical processes in which gravity is a major player.

This book is intended for both nonspecialists and students of science. For science students and teachers, I hope this book will expose part of the foundation of modern physics. For nonspecialists, I hope that by describing the evolution of this major theme in science, I have given a feel for the long road that has, we believe, led us to the brink of the "theory of everything".

Many people have helped me to write this book: Barry Kellett, David Giaretta and George Hanoun helped with various aspects of word processing and text preparation. David Pike read the first draft of the book with great care and generously bandaged the wounds I had inflicted on the English language. Francis Everitt read the manuscript closely, and I am grateful for his detailed comments on a number of aspects of this book. I particularly appreciate his comments on the historical details

and the latest technical information, on the proposed space experiments to test the theory of gravitation, which he provided. Jayant Narlikar also offered valuable comments on a number of topics in the book. Awinash Gondhalekar reviewed the near-complete manuscript: inclusion of his comments and observations on all aspects of this book has considerably enhanced this presentation. I would like to thank Lindsay Nightingale, who read the final version of this book with great care; her comments and questions were very helpful in 'making the science clear' at a number of points in the book. Lastly I would like to thank the editorial and production teams of Cambridge University Press. Any errors and omissions are, of course, entirely my responsibility.

Finally, I would like to thank my wife Jane for her unwavering support.

Prabhakar M. Gondhalekar