GRAVITY'S FATAL ATTRACTION

Black Holes in the Universe

Second edition

Richly illustrated with the images from observatories on the ground and in space, and computer simulations, this book shows how black holes were discovered, and discusses our current understanding of their role in cosmic evolution.

This second edition covers new discoveries made in the past decade, including definitive proof of a black hole at the center of the Milky Way, evidence that the expansion of the Universe is accelerating, and the new appreciation of the connection between black holes and galaxy formation. There are entirely new chapters on gamma-ray bursts and cosmic feedback.

Begelman and Rees blend theoretical arguments with observational results to demonstrate how both have contributed to the subject. Clear, explanatory illustrations and photographs reveal the strange and amazing workings of our Universe. The engaging style makes this book suitable for introductory undergraduate courses, amateur astronomers, and all readers interested in astronomy and physics.

Mitchell Begelman is Chairman of the Department of Astrophysical and Planetary Sciences and Fellow of JILA, at the University of Colorado at Boulder. He has won several awards, including the Guggenheim Fellowship, Sloan Research Fellowship, and the American Astronomical Society Warner Prize.

Martin Rees is Professor of Cosmology and Astrophysics and Master of Trinity College at Cambridge University, and Astronomer Royal. He is a winner of the Gold Medal of the Royal Astronomical Society and other awards. He has written several books for a general readership.

The authors are leading authorities on the astrophysics of black holes, and were key players in establishing the existence of black holes and their role in cosmic phenomena.

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Second edition

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Preface to the Second Edition

As early as 1967 black holes were creeping into public consciousness. On the television program *Star Trek*, Captain Kirk and the crew of the starship *Enterprise* were caught in the gravitational field of an "uncharted black star" and were propelled backward in time. Astronomers then had no clue whether black holes were real or just theoreticians' constructs. Certainly no serious evidence of their reality existed, and few would have guessed that they would soon become the object of intense astronomical study. Until the 1970s, the black hole was still a novel concept, studied by specialists in Einstein's general theory of relativity. And that theory itself (though already several decades old) had only tentative empirical support. Gravity, one of the fundamental forces of nature, was still poorly understood.

Thanks to a technological revolution in observational astronomy – new detectors and mirror designs in optical telescopes, radio telescopes that offer far sharper images than even the best optical instruments, and observations made from space, revealing the sky at infrared, ultraviolet, X-ray, and gamma-ray wavelengths – we are now confident that there are millions of black holes in every galaxy. Each of these holes is the remnant of an ordinary star several times more massive than the Sun. More remarkably, giant black holes, weighing as much as millions (or even billions) of suns, lurk in the centers of most galaxies. The most energetic phenomena in the Universe – quasars, and jets a million light-years long erupting from the centers of galaxies – are powered by black holes. The same phenomena, in miniature, are energized by the smaller holes within our own Galaxy.

This book describes the extraordinary ways in which black holes make their presence known. We discuss the designs and accidents through which they were discovered, and how far we have come toward understanding their relationship to other structures in the cosmos. Every advance in technology has disclosed an assortment of dazzling, unexpected phenomena. Some of these phenomena, like "gravitational lenses," are well understood and are being co-opted as tools in the search for black holes and other forms of "dark matter"; others, such as gamma-ray bursts, remain poorly understood. In between lies a range of phenomena for which understanding is substantial but incomplete: the processes and flow patterns around black holes; how the first ones formed; and the two-way interactions between supermassive holes and their "host" galaxies. And new questions for the future are constantly arising. Can gravitational waves from merging black holes be detected? How much could black holes contribute to the "dark matter" in the Universe? Could microscopic holes exist – the size of an atomic nucleus but the weight of a mountain? As the Universe evolves, what is the ultimate fate of matter "swallowed" by black holes?

As theorists in a profession heavily dominated (and rightly so) by observers, we demand empirical proof that black holes exist, and that they have the properties predicted by Einstein's theory. Is there a "smoking gun" that removes all doubt of their existence, or of their ubiquity at the level we claim? When the first edition of the book appeared (in 1995) there were still some doubts. But the evidence has strengthened tremendously since then, and our understanding of the role of black holes in the Universe has deepened as well. In this completely new edition we have substantially rewritten several chapters and included much new material. There are new chapters on gamma-ray bursts and cosmic feedback. Images, from observations and simulations alike, have been updated throughout. These advances are owed to new and more sensitive instruments and to vastly more powerful computers than were available in the 1990s.

Black holes are an important feature of our cosmic environment. We are beginning to understand the exotic ways they manifest themselves, and how astronomical observations can probe their immediate surroundings.

These cosmic "fireworks," spectacular as they are, may ultimately prove to be of greatest value as stepping-stones to even more profound knowledge. Shrouded from view, deep inside black holes, lurk mysteries that will not be understood without a unification of Einstein's theory of gravity with the other great "pillar" of twentieth-century physics, the quantum theory. Such new insights, when they are achieved, may change our view of the nature of time, and of our entire Universe. The strong new evidence that black holes indeed exist strengthens the motivation for this fundamental quest.

Research in astrophysics is, for us, an intensely interactive activity. Many observers have generously discussed their latest work with us; we have also benefited from other theorists who have special knowledge and expertise that we lack. We especially acknowledge all we have learned from Roger Blandford, a frequent collaborator throughout the last thirty years. We are fortunate to have, among our immediate colleagues, leading authorities such as Andrew Fabian, Stephen Hawking, Donald Lynden-Bell and Richard McCray. We are grateful to them, and to our many other collaborators. We are also grateful to many colleagues who took the time to prepare illustrations – often of results "hot off the press," or even prepublication.

We have been especially fortunate in our publisher and editors – Jonathan Cobb, Susan Moran and Nancy Brooks of Freeman helped with the first edition. And we remain grateful to Colin Norman, Joseph Silk, and Virginia Trimble for offering helpful comments on that edition.

Preface to the Second Edition

We are grateful to our respective staffs – especially Judith Moss in Cambridge and Elaine Verdill and her colleagues in Boulder – for keeping the three-way exchange of text and pictures running smoothly during those (more or less) preinternet days. During the preparation of this new edition, we have been helped and encouraged by Simon Mitton and Vince Higgs at Cambridge University Press. We are also grateful to Lindsay Barnes, Laura Clark and Chris Miller for editorial assistance with both text and pictures; and to Phil Armitage, Davide Lazzati and Chris Reynolds for valuable advice on the updates.

