THE KERR SPACETIME

Rotating Black Holes in General Relativity

Rotating black holes, as described by the Kerr spacetime, are the key to understanding the most violent and energetic phenomena in the Universe, from the core collapse of massive supernova explosions producing powerful bursts of gamma rays, to supermassive black hole engines that power quasars and other active galactic nuclei.

This book is a unique, comprehensive overview of the Kerr spacetime, with original contributions and historical accounts from researchers who have pioneered the theory and observation of black holes, and Roy Kerr's own description of his 1963 discovery. It covers all aspects of rotating black holes, from mathematical relativity to astrophysical applications and observations, and current theoretical frontiers. This book provides an excellent introduction and survey of the Kerr spacetime for researchers and graduate students across the spectrum of observational and theoretical astrophysics, general relativity and high-energy physics.

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Foreword

It is an amazing fact that there are roughly 10^{20} rotating black holes in the observable universe, and that the spacetime near each of them is, to a very good approximation, given by an exact solution of Einstein's vacuum field equations discovered in 1963 by Roy Kerr. The Kerr spacetime is a defining feature of modern astrophysics. It is becoming increasingly important as the basis for understanding astrophysical processes from core collapse supernovae which produce gamma-ray bursts while forming black holes to the supermassive black hole engines that power quasars. These processes are the most violent and energetic phenomena in the universe since the Big Bang, and the key to understanding them is the Kerr geometry.

Yet the man behind this remarkable solution has remained somewhat enigmatic. When one of the contributors to this book heard that a conference was to be held to celebrate Roy's 70th birthday in 2004, he was suprised to learn that Roy was still alive! The idea of such a conference was suggested to me by another of my former teachers, Brian Wybourne, shortly before Brian passed away late in 2003. This book, which contains the invited lectures of the 2004 *Kerr Fest*, is the lasting result.

As someone who took courses from Roy at the University of Canterbury, one personal anecdote is in order. Roy amused his students with his laid back style and laconic humour, while always impressing upon us how to see quickly to the point in complex calculations, to back-track and fix our mistakes. He was also disdainful of needless bureaucracy, and took it as a badge of honour that he was the last person to deliver his exam scripts to the university Registry for printing. "I can't see why the Registry always want the exams so early," he complained. "In Texas we just used to write the exams on the board. Look, don't worry about the exam. I just rehash the old questions from past years."

In one lecture that year, after filling a blackboard with calculations that weren't getting closer to the expected solution, Roy wrote

$$\cdots = \text{ mess}$$

"Look, at this point I think I'd go off to the pub", he sighed. Standing back to look at the board for a minute, he enlightened us further. "Ah, I screwed up a factor of ct in the second line... I can't be bothered doing all that again. Just take down a note: *The stupid bastard screwed up the ct*."

When we came to sit the exam for that course, some last minute rushing in its preparation became evident. The questions may just have been "rehashed", but when one put the values in, the algebra rapidly became very formidable, for question after question. One student left halfway through in an obvious state of distress. While wrestling with one particular question, which two pages of algebra made me suspect was actually not analytically soluble, the value of Roy's teaching became clear in a flash of inspiration. "$\cdots =$ mess", I wrote, "I can't be bothered solving this equation, but if I was to proceed here is the method I would use:... "

This anecdote not only illustrates the fun we had as Roy's students, but serves as a useful analogy for the state of understanding in 1963 about the problem of solving Einstein's equations for the exterior field of a rotating mass. After some decades of work the consensus of the experts was that the problem equalled a "mess", which most general relativists had given up on. The status of "black holes" as possible physical objects in the universe was also disputed. The term "black hole" itself had yet to be coined by Wheeler in 1967. Despite the work of Oppenheimer and Snyder on gravitational collapse in 1939, and the eventual understanding of the properties of the horizon in Schwarzschild's 1916 solution, everyone knew that realistic bodies rotated. Thus back in 1963 it was still a possibility that the Schwarzschild horizon was a mathematical curiosity, which might not survive the perturbation of adding angular momentum. Roy's solution changed all that. He established black holes as possible entities in the physical universe, and recent decades of many astrophysical observations have confirmed that nature has made good use of them.

Roy's brilliance in achieving what nobody had for decades, by pen and paper before the days of algebraic computing, was really a consequence of his insights into dealing with "messes". He understood deeply the importance of simplifying symmetry principles, of differential and integral constraints, and how to quickly sort out the relevant degrees of freedom from the irrelevant ones. The Kerr solution is a monumental legacy to Roy's incisive insight.

David Wiltshire

Preface

The book is organized into three parts.

- *General relativity.* Wherein the contributors discuss the classical physics of rotating black holes. There is an orientational overview of the Kerr spacetime, followed by Roy Kerr's own account of its discovery, twistorial applications, constants of the motion, the uniqueness theorems and visualization of the Kerr geometry.
- *Astrophysics*. Observational evidence for rotating black holes, supermassive black holes, merger and collapse.
- *Quantum gravity.* Theoretical frontiers, black hole entropy and quantum physics, higher dimensional black strings and black rings.

The contributions encompass by and large the invited lectures of the *Kerr Fest: a Symposium on Black Holes in Astrophysics, General Relativity and Quantum Gravity*, held at Roy Kerr's home institution, the University of Canterbury, in Christchurch, New Zealand, in August 2004 to celebrate Roy's 70th birthday a few months beforehand on 16 May. As one of the original speakers, Zoltan Perjés, sadly passed away a few months after the Symposium, one of Roy's former colleagues who was unable to attend the Symposium, Roger Penrose, kindly agreed to submit an article in his place.

As appendices, we also reprint Roy Kerr's renowned *Physical Review Letter* of 1963, at less than two pages, stunning in its impact and brevity, along with his conference proceeding article presented at the *First Texas Symposium on Relativistic Astrophysics* in December 1963, in which the black hole property of the solution was first described.

There should be something in this book for almost everyone – there are relatively few books one can turn to to get significant coverage of the Kerr spacetime, and most of the relevant material is scattered around the scientific literature in small bits and pieces. We hope that this book will serve as a coherent starting point for those interested in more technical details, and as a broad overview for those who are interested in the current state of play.

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January 2008

Roy Patrick Kerr, 2007.

Illustrations