CANONICAL GRAVITY AND APPLICATIONS

Canonical methods are a powerful mathematical tool within the field of gravitational research, both theoretical and observational, and have contributed to a number of recent developments in physics. Providing mathematical foundations as well as physical applications, this is the first systematic explanation of canonical methods in gravity. The book discusses the mathematical and geometrical notions underlying canonical tools, highlighting their applications in all aspects of gravitational research, from advanced mathematical foundations to modern applications in cosmology and black-hole physics. The main canonical formulations, including the Arnowitt–Deser–Misner (ADM) formalism and Ashtekar variables, are derived and discussed.

Ideal for both graduate students and researchers, this book provides a link between standard introductions to general relativity and advanced expositions of black hole physics, theoretical cosmology, or quantum gravity.

Martin Bojowald is an Associate Professor at the Institute for Gravitation and the Cosmos, Pennsylvania State University. He pioneered loop quantum cosmology, a field in which his research continues to focus.
CANONICAL GRAVITY AND APPLICATIONS

Cosmology, black holes, quantum gravity

MARTIN BOJOWALD
Institute for Gravitation and the Cosmos
The Pennsylvania State University
## Contents

1 Introduction ........................................... 1
2 Isotropic cosmology: a prelude ....................... 4
   2.1 Equations of motion .............................. 5
   2.2 Matter parameters .............................. 8
   2.3 Energy conditions .............................. 10
   2.4 Singularities ................................... 11
   2.5 Linear perturbations ............................ 12
3 Hamiltonian formulation of general relativity ... 17
   3.1 Constrained systems ............................ 18
   3.2 Geometry of hypersurfaces ...................... 40
   3.3 ADM formulation of general relativity ......... 50
   3.4 Initial-value problem ............................ 72
   3.5 First-order formulations and Ashtekar variables 82
   3.6 Canonical matter systems ....................... 98
4 Model systems and perturbations ..................... 113
   4.1 Bianchi models ................................ 113
   4.2 Symmetry ....................................... 129
   4.3 Spherical symmetry ............................. 147
   4.4 Linearized gravity ............................. 163
5 Global and asymptotic properties .................... 184
   5.1 Geodesic congruences ........................... 185
   5.2 Trapped surfaces ................................ 198
   5.3 Asymptotic infinity ............................. 203
   5.4 Matching of solutions ........................... 217
   5.5 Horizons ........................................ 235
6 Quantum gravity ....................................... 248
   6.1 Constrained quantization and background independence 249
   6.2 Quantum cosmology ............................. 258
Contents

6.3 Quantum black holes 271
6.4 The status of canonical quantum gravity 273
Appendix A: Some mathematical methods 274
References 289
Index 300