Relativistic Cosmology

Cosmology has been transformed by dramatic progress in high-precision observations and theoretical modelling. This book surveys key developments and open issues for graduate students and researchers. Using a relativistic geometric approach, it focuses on the general concepts and relations that underpin the standard model of the Universe.

Part 1 covers foundations of relativistic cosmology, whilst Part 2 develops the dynamical and observational relations for all models of the Universe based on general relativity. Part 3 focuses on the standard model of cosmology, including inflation, dark matter, dark energy, perturbation theory, the cosmic microwave background, structure formation and gravitational lensing. It also examines modified gravity and inhomogeneity as possible alternatives to dark energy. Anisotropic and inhomogeneous models are described in Part 4, and Part 5 reviews deeper issues, such as quantum cosmology, the start of the universe and the multiverse proposal. Colour versions of some figures are available at www.cambridge.org/9780521381154.

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Preface

This book provides a survey of modern cosmology emphasizing the relativistic approach. It is shaped by a number of guiding principles.

- **Adopt a geometric approach** Cosmology is crucially based in spacetime geometry, because the dominant force shaping the universe is gravity; and the best classical theory of gravity we have is Einstein's general theory of relativity, which is at heart a geometric theory. One should therefore explore the spacetime geometry of cosmological models as a key feature of cosmology.
- **Move from general to special** One can best understand the rather special models most used in cosmology by understanding relationships which hold in general, in all spacetimes, rather than by only considering special high symmetry cases. The properties of these solutions are then seen as specialized cases of general relations.
- **Explore geometric as well as matter degrees of freedom** As well as exploring matter degrees of freedom in cosmology, one should examine the geometric degrees of freedom. This applies in particular in examining the possible explanations of the apparent acceleration of the expansion of the universe in recent times.
- **Determine exact properties and solutions where possible** Because of the nonlinearity of the Einstein field equations, approximate solutions may omit important aspects of what occurs in the full theory. Realistic solutions will necessarily involve approximation methods, but we aim where possible to develop exact relations that are true generically, on the one hand, and exact solutions of the field equations that are of cosmological interest, on the other.
- **Explore the degree of generality or speciality of models** A key theme in recent cosmological writing is the idea of 'fine tuning', and it is typically taken to be bad if a universe model is rather special. One can, however, only explore the degree of speciality of specific models by embedding them in a larger context of geometrically and physically more general models.
- **Clearly relate theory to testability** Because of the special nature of cosmology, theory runs into the limits of the possibility of observational testing. One should therefore pursue all possible observational consistency checks, and be wary of claiming theories as scientific when they may not in principle be testable observationally.
- **Focus on physical and cosmological relevance** The physics proposed should be plausibly integrated into the rest of physics, where it is not directly testable; and the cosmological models proposed should be observationally testable, and be relevant to the astronomical situation we see around us.

- **Search for enduring rather than ephemeral aspects** We have attempted to focus on issues that appear to be of more fundamental importance, and therefore will not fade away, but will continue to be of importance in cosmological studies in the long term, as opposed to ephemeral topics that come and go.

Part 1 presents the foundations of relativistic cosmology. Part 2 is a comprehensive discussion of the dynamical and observational relations that are valid in all models of the universe based on general relativity. In particular, we analyse to what extent the geometry of spacetime can be determined from observations on the past light-cone. The standard Friedmann–Lemaître–Robertson–Walker (FLRW) universes are discussed in depth in Part 3, covering both the background and perturbed models. We present the theory of perturbations in both the standard coordinate-based and the 1+3 covariant approaches, and then apply the theory to inflation, the cosmic microwave background, structure formation and gravitational lensing. We review the key unsolved issue of the apparent acceleration of the expansion of the universe, covering dark energy models and modified gravity models. Then we look at alternative explanations in terms of large scale inhomogeneity or small scale inhomogeneity.

Anisotropic homogeneous (Gödel, Kantowski-Sachs and Bianchi) and inhomogeneous universes (including the Szekeres models) are the focus of Part 4, giving the larger context of the family of possible models that contains the standard FLRW models as a special case. In all cases the relation of the models to astronomical observations is a central feature of the presentation.

The text concludes in Part 5 with a brief review of some of the deeper issues underlying all cosmological models. This includes quantum gravity and the start of the universe, the relation between local physics and cosmology, why the universe is so special that it allows intelligent life to exist, and the issue of testability of proposals such as the multiverse.

The text is at an advanced level; it presumes a basic knowledge of general relativity (e.g. as in the recent introductory texts of Carroll (2004), Stephani (2004), Hobson, Efstathiou and Lasenby (2006) and Schutz (2009)) and of the broad nature of cosmology and cosmological observations (e.g. as in the recent introductory books of Harrison (2000), Ferreira (2007) and Silk (2008)). However, we provide a self-contained, although brief, survey of Riemannian geometry, general relativity and observations.

Our approach is similar to that of our previous reviews, Ellis (1971a, 1973), MacCallum (1973, 1979), Ellis and van Elst (1999a) and Tsagas, Challinor and Maartens (2008), and it builds on foundations laid by Eisenhart (1924), Synge (1937), Heckmann and Schucking (1962), Ehlers (1961), Trümper (1962, and unpublished), Hawking (1966) and Kristian and Sachs (1966). This approach differs from the approach in the excellent recent texts by Peacock (1999), Dodelson (2003), Mukhanov (2005), Weinberg (2008), Durrer (2008), Lyth and Liddle (2009) and Peter and Uzan (2009), in that we emphasize a covariant and geometrical approach to curved spacetimes and where possible consider general geometries instead of restricting considerations to the FLRW geometries that underlie the standard models of cosmology.

A further feature of our presentation is that although it is solidly grounded in relativity theory, we recognize the usefulness of Newtonian cosmological models and calculations. We detail how the Newtonian limit follows from the relativistic theory in situations of cosmological interest, and make clear when Newtonian calculations give a good approximation to the results of the relativistic theory and when they do not.

It is not possible to cover all of modern cosmology in depth in one book. We present a summary of present cosmological observations and of modern astrophysical understanding of cosmology, drawing out their implications for the theoretical models of the universe, but we often refer to other texts for in-depth coverage of particular topics. We are relatively complete in the theory of relativistic cosmological models, but even here the literature is so vast that we are obliged to refer to other texts for fuller details. In particular, the very extensive discussions of spatially homogeneous cosmologies and of inhomogeneous cosmologies in the books by Wainwright and Ellis (1997), Krasiński (1997), and Bolejko *et al*. (2010) complement and extend our much shorter summaries of those topics in Part 4. Our guiding aim is to present a coherent core of theory that is not too ephemeral, i.e. that in our opinion will remain significant even when some present theories and observations have fallen away. Only the passage of time will tell how good our judgement has been.

We have given numerical values for the key cosmological parameters, but these should be interpreted only as indicative approximations. The values and their error bars change as observations develop, so that no book can give definitive values. Furthermore, there are inherent limitations to parameter values and error bars – which depend on the particular observations used, on the assumptions made in reducing the observational data, on the chosen theoretical model needed to interpret the observations, and on the type of statistical analysis used.

In the text we have two kinds of interventions apart from the usual apparatus of footnotes and references: namely, exercises and problems. The *Exercises* enable the reader to develop and test his or her understanding of the main material; we believe we know the answers to all the exercises, or at least where the answer is given in the literature (in which case an appropriate reference is provided). By contrast, the *Problems* are unsolved questions whose solution would be of some interest, or in some cases would be a major contribution to our understanding.

We are grateful to numerous people who have played an important role in developing our understanding of cosmology: we cannot name them all (though most of their names will be found in the reference list at the end), but we would particularly like to thank John Barrow, Bruce Bassett, Hermann Bondi,[1] Marco Bruni, Anthony Challinor, Chris Clarkson, Peter Coles, Rob Crittenden, Peter Dunsby, Ruth Durrer, Jürgen Ehlers,[1] Henk van Elst, Pedro Ferreira, Stephen Hawking, Charles Hellaby, Kazuya Koyama, Julien Larena, David Matravers, Charles Misner, Jeff Murugan, Bob Nichol, Roger Penrose, Felix Pirani, Alan Rendall, Wolfgang Rindler, Tony Rothman, Rainer Sachs, Varun Sahni, Misao Sasaki, Bernd Schmidt, Engelbert Schucking, Dennis Sciama,[1] Stephen Siklos, John Stewart, Bill Stoeger,

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Cosmology - Cosmology - Relativistic cosmologies: To derive his 1917 cosmological model, Einstein made three assumptions that lay outside the scope of his equations. The first was to suppose that the universe is homogeneous and isotropic in the large (i.e., the same everywhere on average at any instant in time), an assumption that the English astrophysicist Edward A. Milne later elevated to an entire philosophical outlook by naming it the cosmological principle. Relativistic Astrophysics and Cosmology offers a succinct and self-contained treatment of general Physical Foundations of Cosmology. 442 PagesÂ·2006Â·2.56 MBÂ·7,486 Downloads. PHYSICAL FOUNDATIONS OF COSMOLOGY Inï¬‚ationary cosmology has been developed over the last 20 years Physic Relativistic Astrophysics and Cosmology - A Primer. 295 PagesÂ·2007Â·14.87 MBÂ·763 Downloads.Â Table of contents page iii 1. Special Relativity. 10. 1.1. Motivation. 10. 1.2. The postulates General Relativity, Bla View Relativistic cosmology Research Papers on Academia.edu for free.Â Origen's Cosmology and Ontology of Time constitute a major catalyst and a massive transformation in the development of Christian doctrine. The author challenges the widespread impression about this theology being bowled head over heels by its encounter with Platonism, Gnosticism, or Neoplatonism, and casts new light on Origen's grasp of the relation between Hellenism, Hebrew thought and Christianity.