The Cosmic Century

A History of Astrophysics and Cosmology

The twentieth century witnessed the emergence of the disciplines of astrophysics and cosmology, from subjects which scarcely existed to two of the most exciting and demanding areas of contemporary scientific inquiry. There has never been a century in which fundamental ideas about the nature of our Universe and its contents have changed so dramatically. This book reviews the historical development of all the key areas of modern astrophysics, linking the strands together to show how advances have led to the extraordinarily rich panorama of modern astrophysics and cosmology. While many of the great discoveries were derived from pioneering observations, the emphasis is upon the development of theoretical concepts and how they came to be accepted. These advances have led astrophysicists and cosmologists to ask some of the deepest questions about the nature of our Universe and to stretch our ability to address them by advanced observation to the very limit. This is a fantastic story, and one that would have defied the imaginations of even the greatest story-tellers.

MALCOLM LONGAIR completed his Ph.D. in the Radio Astronomy Group of the Cavendish Laboratory, University of Cambridge, in 1967. From 1968 to 1969 he was a Royal Society Exchange Visitor to the Lebedev Institute, Moscow. He has been an exchange visitor to the USSR Space Research Institute on six subsequent occasions and has held visiting professorships at institutes and observatories throughout the USA. From 1980 to 1990, he held the joint posts of Astronomer Royal for Scotland, Regius Professor of Astronomy at the University of Edinburgh and Director of the Royal Observatory, Edinburgh. He has been Head of the Cavendish Laboratory, Cambridge since 1997, and was made a CBE in the 2000 Millennium Honours list. Longair's primary research interests are in the fields of high-energy astrophysics and astrophysical cosmology. He has published 15 books and over 250 journal articles on his research work.

For
Deborah

Reviews of *The Cosmic Century*:

Malcolm Longair has written a very timely book, directed toward students, researchers, and lecturers; I enjoyed experiencing all three roles while reading it. It is a lucid and in-depth presentation of the subject and introduces topics at various levels of complexity. . . Longair's style very effectively engages the reader in the story of this wonderful adventure of the human mind.

Riccardo Giacconi, *Physics Today*

Longair emphasizes the development of theoretical concepts over the observations that they were based on, and brings the discussion up to date with the emergence of 21st-century precision cosmology.

Physics World

I can envisage this book being useful to physicists from other areas of specialization, who would like an overview of astrophysics and cosmology, or for workers in one of these areas who want to broaden their horizons. It could also be a text for graduate students in astronomy, astrophysics or astrophysical cosmology, who want a synoptic overview of these areas. [The book] clearly separates speculation from well-established theory. . . a sound work that will be well appreciated.

George Ellis, *Nature Physics*

Little of astrophysics and cosmology escapes the gaze of Longair . . . Readers, especially those already familiar with many of the topics, will enjoy his prose. Certainly all graduate students in the field should read this book. And anyone interested in the history of science would enjoy it as bedside reading if they were willing to skip the equations.

Jay M. Pasachoff, *Nature*

Longair has woven a masterful tapestry of these exciting times and the scientists who drove them. In doing so he creates the perfect backdrop against which to describe the rapid progress that took place in the last third of the century. The book is written in a clear, concise manner at a level suitable for undergraduates . . . with its exhaustive bibliography and careful indexing, this excellent book is destined to be come an important and familiar resource.

D. E. Hogg, *Choice*

It is fresh, authoritative, thorough, and insightful . . . the understanding and appreciation of the scientific methodology leaps from every page . . . This book is superbly written, well referenced, fully illustrated, and beautifully produced. It will become a classic. Buy it, read it, and improve yourself.

David W. Hughes, *The Observatory*

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A History of Astrophysics and Cosmology

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Preface

How this book came about

The origin of this book was a request by the late Brian Pippard to contribute a survey of astrophysics and cosmology in the twentieth century to the three-volume work that he edited with Laurie Brown and the late Abraham Pais, *Twentieth Century Physics* (Bristol: Institute of Physics Publishing and New York: American Institute of Physics Press, 1995). This turned out to be a considerable undertaking, my first draft far exceeding the required page limit. By drastic editing, I reduced the text to about half its original length and the survey appeared in that form as Chapter 23 of the third volume.

I was reluctant to abandon all the important material which had to be excised from the published survey and was delighted that the Institute of Physics agreed to my approaching Cambridge University Press about publishing the full version. The Press were keen to take on the project, with some further expansion of the text and, in particular, with a number of explanatory supplements to chapters where a little simple mathematics can make the arguments more convincing for the enthusiast. I have also made liberal use of references to my other books, where I have already given treatments of topics covered in this book. The result has been a complete rethink of the whole project and an expansion of the text by a factor of five as compared with the original published version.

As when I was writing my book, *Theoretical Concepts in Physics*, 2nd edn (Cambridge: Cambridge University Press, 2003), I have learned so much during the preparation of this book that I wish I had known when I was learning these subjects. The historical material provides real *physical* insight into the intellectual infrastructure of astrophysics and cosmology, and it is saddening that it is not more easily accessible to the student, researcher and lecturer. Even worse, in many cases, the folk-tales of astrophysics and cosmology have acquired mythical status, which do not necessarily coincide with how many of the great insights came about.

The original sub-title of the book was to be *A History of Twentieth Century Astrophysics and Cosmology*, reflecting its origin as a chapter of *Twentieth Century Physics*. As pointed out by the CUP editors, the story runs right up to 2005 and furthermore astrophysics and cosmology in their modern physics-related guises scarcely existed before 1900. Therefore, it seemed much more appropriate to drop the words 'Twentieth Century' from the subtitle.

Warnings and apologies

The magnitude of the task I set myself only became apparent once I was well into the writing of the final text. It is folly to pretend to completeness, or to hope to make reference to all

the important contributions of so many distinguished colleagues. Therefore, I have had to be selective and am only too aware of the limitations of what is published here. Even worse, I do not believe it is possible to write a wholly objective history of as complex a field as the development of astrophysical and cosmological understanding over the twentieth century. I have tried to be fair in my assessments of what is of lasting importance, but this is bound to be a subjective process.

Equally significant is the fact that I am one of the lucky generation who began research in the early 1960s when the whole astrophysical and cosmological landscape changed forever from one dominated by optical astronomy to one of multi-wavelength astronomy in which quite different types of astrophysics began to dominate much of the scene. The influx of physicists into astrophysics from that time onwards has been one of the most important features of this story and I write from that perspective. One of the most revealing aspects of the story told in this book is the close link between developments in physics and their impact upon astrophysics and cosmology, and *vice versa*, and the fact that this symbiosis has been at the heart of these disciplines from the beginning. I find it revealing that the author index of this book includes references to large numbers of physicists as well as to astrophysicists and cosmologists.

Although the author index includes about 1000 individuals, I am aware that it omits many who have made important contributions, sometimes simply because they were not the first author on the paper. The problem of attributing credit to individuals has become very much more difficult during the last few decades of the twentieth century when many of the key papers can involve tens or hundreds of authors. This reflects the fact that many of the large space- and ground-based projects can now involve very large numbers of individuals, and so the credit should go to the project team rather than to individual scientists. I have made value judgements about whom to credit in these cases, often giving up and simply giving the detailed authorship in the bibliography. I hope my colleagues will understand the impossibility of doing justice to everyone involved.

I am bound to repeat the disclaimer that I am not a professional historian, and far less a philosopher, of science. My objectives in this book are astrophysical and cosmological, specifically to track the intellectual history of the development of astrophysics and cosmology through what has been one of the most extraordinary centuries in the history of scientific endeavour. Therefore, this is not a history of astronomy *per se*, but astronomy viewed through the mirror of physical understanding. Numerous controversial topics will be treated in this history, but my approach has been to concentrate upon the astrophysical and cosmological issues rather than the more sensational aspects of the story.

Secondary literature

There is an enormous wealth of fascinating material on the history of twentieth-century astrophysics and cosmology which I have had to condense into a modest space. In the references, I have given complete bibliographical citations to all the original articles discussed. In preparing this book, I have found the following volumes particularly helpful:

Bernstein, J. and Feinberg, G. (1986). *Cosmological Constants: Papers in Modern Cosmology* (New York: Columbia University Press). This volume includes translations of many of the seminal papers in cosmology.

Bertotti, B., Balbinot, R., Bergia, S. and Messina, A., eds (1990). *Modern Cosmology in Retrospect* (Cambridge: Cambridge University Press).

Bondi, H. (1960). *Cosmology*, 2nd edn (Cambridge: Cambridge University Press).

Gillespie, C. C., ed. (1981). *Dictionary of Scientific Biography* (New York: Charles Scribner's Sons).

Gingerich, O., ed. (1984). *The General History of Astronomy, Vol. 4. Astrophysics and Twentieth-Century Astronomy to 1950: Part A* (Cambridge: Cambridge University Press).

Harrison, E. (2001). *Cosmology: The Science of the Universe* (Cambridge: Cambridge University Press).

Hearnshaw, J. B. (1986). *The Analysis of Starlight: One Hundred and Fifty Years of Astronomical Spectroscopy* (Cambridge: Cambridge University Press).

Hearnshaw, J. B. (1996). *The Measurement of Starlight: Two Centuries of Astronomical Photometry* (Cambridge: Cambridge University Press).

Kragh, H. (1996). *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton: Princeton University Press).

Lang, K. R. and Gingerich, O., eds (1979). *A Source Book in Astronomy and Astrophysics, 1900–1975* (Cambridge, Massachusetts: Harvard University Press). This volume contains reprints of and brief historical introductions to many of the original articles published between 1900 and 1975 referred to in this survey. All the articles are translated into English.

Learner, R. (1981). *Astronomy through the Telescope* (London: Evans Brothers Limited).

Leverington, D. (1996). *A History of Astronomy from 1890 to the Present* (Berlin: Springer-Verlag).

Martínez, V. J., Trimble, V. and Pons-Bordeía, M. J., eds (2001). *Historical Development of Modern Cosmology*, ASP Conference Series, vol. 252 (San Francisco: ASP).

North, J. D. (1965). *The Measure of the Universe* (Oxford: Clarendon Press).

A key resource for all aspects of astrophysics and cosmology is the series entitled *Annual Review of Astronomy and Astrophysics*, which first appeared in 1963. These reviews are authoritative and represent understanding at the year of the review. The more recent volumes include autobiographical essays by a number of the key personalities who appear in this book. For many topics, I have given references to authoritative books and reviews in the Notes to each chapter.

I have also assumed some familiarity with astronomical terminology. For more details of the terminology and reviews of many areas of astronomy, the following can be recommended:

Nicholson, I. (1999). *Unfolding our Universe* (Cambridge: Cambridge University Press). This is an elementary text, but it includes a large amount of useful background material on all aspects of astronomy.

Maran, S. P., ed. (1992). *The Astronomy and Astrophysics Encyclopedia* (New York: Van Nostrand Reinhold, and Cambridge: Cambridge University Press).

Murdin, P., ed. (2001). *Encyclopaedia of Astronomy and Astrophysics* (4 vols) (Bristol and Philadelphia: Institute of Physics Publishing, and London, New York and Tokyo: Nature Publishing Group).

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The stimulus for looking deeper into the history of the technology of modern astrophysics and cosmology was provided by the invitation to participate in the excellent Valencia conference organised by Vicent Martínez, Virginia Trimble and Maria-Jesus Pons-Bordeía entitled *Historical Development of Modern Cosmology*. Michael Hoskin kindly reviewed the contents of my paper for that meeting. The invitation by Wendy Freedman to celebrate the centenary of the foundation of the Carnegie Observatories by providing a brief history of twentieth-century cosmology for the symposium *Measuring and Modelling the Universe* also contributed to the enrichment of the present text.

Special thanks are due to Leon Mestel and John Faulkner for their help with the history of the understanding of stellar evolution. I have picked the brains of countless colleagues on the contents of this book – my apologies if I cannot record them all. I also thank many colleagues for allowing me to quote their birth years in the main text – I hope colleagues of all ages will take encouragement from the wide range of ages at which individuals have made seminal contributions to astrophysics and cosmology.

Special thanks are also due to David Green for his help in customising the CUP LaTeX macros to format the book just as I wanted it to appear in its published form.

Particular thanks are due to the following whose help was invaluable in tracking down many of the obscurer references which have been consulted: Judith Andrews, for her help in tracking down many of the old references referred to in the bibliography, and the birth and death years of the individuals mentioned in the text; Gillian Wotherspoon and Nevenka Huntic of the Rayleigh Library of the Cavendish Laboratory, for help in finding old books and journals; Mark Hurn, librarian at the Institute of Astronomy, for his help in tracking down many old astronomical journals held in the Institute's splendid library; the librarians

at the Gordon and Betty Moore Library, the Cambridge University Library and the Royal Observatory, Edinburgh, for their assistance. Judith Andrews also deserves special thanks for acting as my secretary for the last eight years and for defending me from the excessive demands of management of the Laboratory so that this book could be completed in a reasonable time.

As ever, it is an enormous pleasure to dedicate this book to Deborah, whose love and support mean so much more than can be adequately expressed in words.

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World Scientific Publishers (Figs 14.11, 14.15(a), 14.16)
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Zeitschrift für Astrophysik (Fig. 3.5)