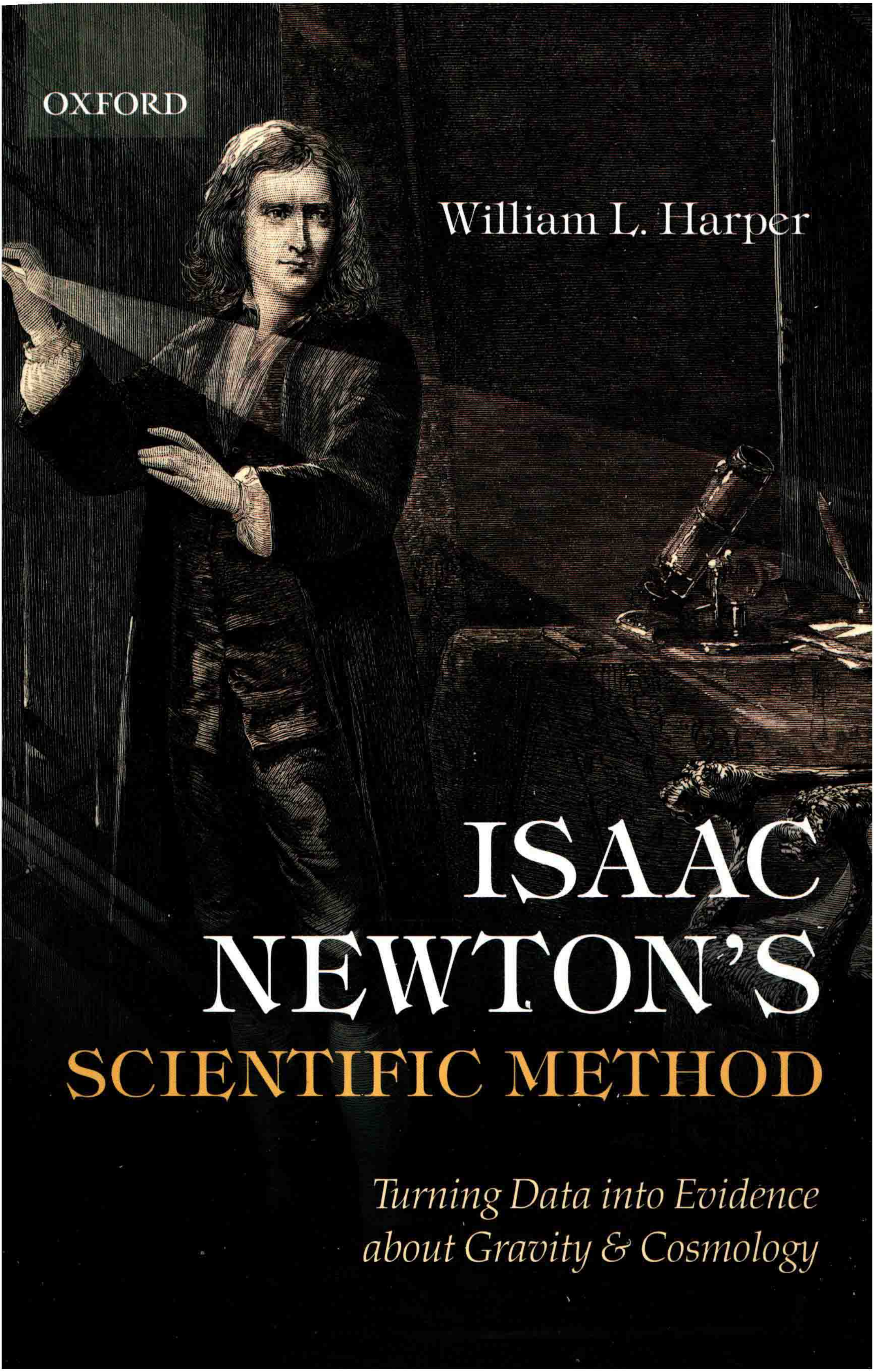

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William L. Harper

ISAAC NEWTON'S SCIENTIFIC METHOD

Turning Data into Evidence about Gravity & Cosmology

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Great Clarendon Street, Oxford ox2 6dp

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide in

Oxford New York

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Kuala Lumpur Madrid Melbourne Mexico City Nairobi
New Delhi Shanghai Taipei Toronto

With offices in

Argentina Austria Brazil Chile Czech Republic France Greece
Guatemala Hungary Italy Japan Poland Portugal Singapore
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Published in the United States
by Oxford University Press Inc., New York

First published 2011

British Library Cataloguing in Publication Data
Data available

Library of Congress Cataloging in Publication Data
Data available

Typeset by SPI Publisher Services, Pondicherry, India
Printed in Great Britain
on acid-free paper by
MPG Books Group, Bodmin and King's Lynn

ISBN 978–0–19–957040–9

10 9 8 7 6 5 4 3 2 1

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Turning Data into Evidence about Gravity and Cosmology

This book is dedicated to the memory of my father,
LEONARD ANDREW HARPER
and
to the memory of my mother,
SOPHIA RATOWSKI HARPER

Preface

The title of this book uses the modern term "scientific method" to refer to the methodology for investigating nature argued for and applied in Newton's argument for universal gravity. I use this modern term, rather than Newton's term "experimental philosophy" for his method of doing natural philosophy, to make salient the main theme I will be arguing for. I will argue that Newton's rich method of turning data into evidence was central to the transformation of natural philosophy into natural science and continues to inform the practice of that science today.

Newton's argument for universal gravity exemplifies a method that adds features which can significantly enrich the basic hypothetico-deductive (H-D) model that informed much of philosophy of science in the last century. On this familiar H-D model, hypothesized principles are tested by experimental verification of observable consequences drawn from them. Empirical success is limited to accurate prediction of observable phenomena. Such success is counted as confirmation taken to legitimate increases in probability. We shall see that Newton's inferences from phenomena realize an ideal of empirical success that is richer than prediction. To achieve this richer sort of empirical success a theory needs, not only to accurately predict the phenomena it purports to explain, but also, to have those phenomena accurately measure the parameters which explain them. Newton's method aims to turn theoretical questions into ones which can be empirically answered by measurement from phenomena. Propositions inferred from phenomena are provisionally accepted as guides to further research. Newton employs *theory-mediated* measurements to turn data into far more informative evidence than can be achieved by hypothetico-deductive confirmation alone.

On his method, deviations from the model developed so far count as new *theory-mediated* phenomena to be exploited as carrying information to aid in developing a more accurate successor. This methodology, guided by its richer ideal of empirical success, supports a conception of scientific progress that does not require construing it as progress toward Laplace's ideal limit of a final theory of everything. This methodology of progress through successively more accurate revisions is not threatened by Larry Laudan's argument against convergent realism. We shall see that, contrary to a famous quotation from Thomas Kuhn, Newton's method endorses the radical theoretical transformation from his theory to Einstein's. We shall also see that this rich empirical method of Newton's is strikingly realized in the development and application of testing frameworks for relativistic theories of gravity. Finally, we shall see that this rich methodology of Newton's appears to be at work in cosmology today. It appears that it was realizations of Newton's ideal of empirical success as convergent agreeing measurements of parameters by diverse phenomena that turned dark energy from a wild hypothesis into an accepted background assumption that guides further empirical research into the large-scale structure and development of our universe.

This book is directed to philosophers of science and students studying it. It is also directed to physical scientists and their students. Practicing scientists may well be able to profit from this book. Almost universally, scientists describe the role of evidence in their science as though it were just an application of hypothetico-deductive confirmation. This is so even when, as I try to show in the context of General Relativity and its empirical evidence, the practice of their science exemplifies Newton's richer and more effective method of turning data into evidence. This book is also directed to historians of science and their students. I hope it can suggest how studying the role of evidence can usefully contribute toward understanding the history of radical theory change.

I have found that attention to the details of calculations and proofs of theorems offered by Newton in support of his inferences helped me understand their role in affording empirical support for the propositions inferred as outcomes of *theory-mediated* measurements. I have also found attention to historical details about data available to Newton instructive. I have found historical episodes, such as Römer's use of eclipses of a moon of Jupiter's to measure a finite speed of light and the observation enterprise of Pound and Bradley initiated by Newton to obtain more precise measurements of the orbits of Jupiter's moons, both informative and fascinating. I have, however, attempted to relegate such details of proofs, calculations, and specialized historical background to appendixes so that readers who do not share my fascination for such details can follow the main argument without getting bogged down.

I have, however, included a fairly detailed account of data cited by Newton in support of his phenomena in chapter 2 and of his argument in chapters 3 through 8. Readers interested in Newton's main lessons on scientific method can focus on chapter 1, section IV of chapter 3, sections II.2–IV of chapter 4, and chapters 7, 9, and 10. They would also profit from the specifically labeled sections on method in the other chapters, without costing them very much extra time and effort to master details. The details offered in the other sections of these chapters, and the other chapters, do strongly reinforce these lessons on method and their historical context. I hope they will be of considerable interest to the growing number of very good philosophers of science, who are now taking a great interest in the details of Newton's work on gravity and method and in how these details can illuminate scientific method today.

In my effort to show how Newton's argument can illuminate scientific method today, I have appealed to modern least-squares assessments of estimates of parameter values. I argue that Newton's moon-test inference holds up by our standards today. Student's *t*-95% confidence parameter estimates illustrate the basic agreement achieved in the moon-test in Newton's initial version, and in the different published editions, of his *Principia*. Gauss's least-squares method of combining estimates of differing accuracy affords insight into how the agreement of the cruder moon-test estimates of the strength of terrestrial gravity adds empirical support to the much sharper estimates from pendulums. The cruder agreeing moon-test estimates are irrelevant to small differences from the pendulum estimates, but they afford additional empirical support for resisting large differences. This increased resistance to large differences – an increased resiliency – is an important empirical advantage afforded by agreeing measurements from diverse phenomena.

Some Acknowledgements

I want to thank my wife, Susan Pepper. Without her generous support I would not have been able to finish this long project. My daughter Kathryn May Harper and my sister Vicki Lynn Harper have also provided much appreciated support and encouragement.

A great many people have contributed to assist my efforts over the more than twenty years I have worked on this project. The historian of science Curtis Wilson and the philosophers of science Howard Stein and George Smith have been my chief role models and have offered very much appreciated critical comments on early versions of several chapters. I also thank George for his permission to use his very informative phrase "Turning data into evidence" in the title of this book.

My colleague Wayne Myrvold has been responsible for a great many improvements, as his very insightful criticisms over quite a few years have led me to deeper understanding of important issues I have tried to come to grips with. This book is part of a project supported by a joint research grant awarded to Wayne and me. Gordon Fleming and Abner Shimony, both of whom are physicists as well as philosophers of science, have offered very much appreciated encouragement and guidance. I especially thank Gordon for his careful reading and critical comments on chapters 1, 9, and 10. Gordon's emphasis on the value of diagrams was reinforced by my reading of Simon Singh's book *Big Bang: The Origin of the Universe* as a role model suggested by my lawyer Anthony H. Little. I also want to thank North Davis, a physician and a fellow mountain hiker, who kindly read and sent comments on an early version of my introductory chapter.

My colleagues Robert Batterman, Chris Smeenk, John Nicholas, and Robert DiSalle have also contributed much appreciated critical comments and important guidance. The historical background section in chapter 1 benefited from very much appreciated help by the late James MacLachlan. The comments by referees and by Eric Schliesser have led to substantial improvements, for which I thank them.

This work on Newton's scientific method has benefited from students and colleagues who participated in my graduate seminars on Newton and method. These included over the years four two-term interdisciplinary seminars on gravitation in Newton and Einstein. These were jointly listed in and taught by faculty from Physics and Astronomy, Applied Mathematics and Philosophy. I want especially to thank Shree Ram Valluri, from Applied Mathematics, who convinced me to help initiate these valuable learning experiences. He has also helped me understand details of many of the calculations and is the developer of the extension of Newton's precession theorem to eccentric orbits. I also want to thank Rob Corless, another participant in the gravitation seminars from Applied Mathematics, for checking derivations.

My treatment of Newton's method at work in cosmology today owes much to Dylan Gault who, in December 2009, completed his thesis on cosmology as a case study of scientific method. Wayne Myrvold and I were co-supervisors.

This book has also benefited from questions and comments raised at the many talks I have given over the years on Newton's method. I want, particularly, to thank Kent Staley, who presented very insightful comments on my paper at the Henle conference in March 2010.

I want to thank my research assistant Soumi Ghosh. She developed diagrams, converted my WordPerfect documents to Word, acquired permissions, and put the whole thing together. Without her talent, dedication, effort, and good judgment this project might never have resulted in this book. In the last drive to format the manuscript she was ably assisted by Emerson Doyle. Their work was supported by the joint research grant awarded to Wayne Myrvold and me. I am grateful to Wayne and the Social Sciences and Humanities Research Council of Canada for this support. Soumi's work reading page proofs was supported by the Rotman Institute of Philosophy at the University of Western Ontario. I am very grateful for their funding support and their much appreciated support in work space, resources help and encouragement in my project for engaging the role of evidence in science.

I want to thank Peter Momtchiloff for encouraging me to publish with Oxford University Press, selecting the excellent initial readers, guiding me through the initial revisions, and convincing me to turn endnotes into footnotes. Daniel Bourner, the production editor, kept us on track and helped to resolve difficult problems about notation. Eleanor Collins was responsible for the excellent cover design. Sarah Cheeseman skillfully guided the transformation to page proofs, including the transformation of my long endnotes into footnotes. Soumi Ghosh helped me proofread and assemble the corrections for the page proofs. Erik Curiel was an excellent, careful proofreader for chapters 1–3, 6, and 8. Howard Emmens was the expert proofreader who used all the queries and my responses to produce the final version for printing. I am very grageful for all their efforts. This book is much better than it would have been without all their help.

Abbreviations

Corresp.	Newton, I. (1959–1977). *The Correspondence of Isaac Newton*. Turnbull, H.W. (ed., vols. I–III), Scott, J.F. (ed., vol. IV), Hall, A.R. and Tilling, L. (eds., vols. V–VII). Cambridge: Cambridge University Press.
C&W	Cohen, I.B. and Whitman, A. (trans.) (1999). *Isaac Newton, The Principia, Mathematical Principles of Natural Philosophy: A New Translation*. Los Angeles: University of California Press.
ESAA	Seidelmann, P.K. (ed.) (1992). *Explanatory Supplement to the Astronomical Almanac*. Mill Valley: University Science Books.
GHA 2A	Taton, R. and Wilson, C. (1989). *The General History of Astronomy, vol. 2, Planetary Astronomy from the Renaissance to the Rise of Astrophysics, Part A: Tycho Brahe to Newton*. Cambridge: Cambridge University Press.
GHA 2B	Taton, R. and Wilson, C. (1995). *The General History of Astronomy, vol. 2, Planetary Astronomy from the Renaissance to the Rise of Astrophysics, Part B: The Eighteenth and Nineteenth Centuries*. Cambridge: Cambridge University Press.
Huygens 1690	Huygens, C. *Discourse on the Cause of Gravity*. Bailey, K. (trans.), Bailey, K. and Smith, G.E. (ann.), manuscript.
Kepler 1992	Kepler, J. (1992). *New Astronomy*. Donahue, W.H. (trans.). Cambridge: Cambridge University Press.
Math Papers	Whiteside, D.T. (ed.) (1967–81). *The Mathematical Papers of Isaac Newton*, 8 vols. Cambridge: Cambridge University Press.

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