ASTRONOMY AND ASTROPHYSICS LIBRARY

R. N. Wilson

Reflecting Telescope Optics I

Basic Design Theory and its Historical Development

Second Edition
With 238 Figures

Springer

Raymond N. Wilson
Waaler Str. 29
85296 Rohrbach, Germany

Cover picture: Karl Schwarzschild, surrounded by, from left to right, Marin Mersenne, René Descartes, James Gregory, William Herschel, Ludwig von Seidel, George Ritchey, Henri Chrétien, Bernhard Schmidt.
(From various sources acknowledged in the book.)

Library of Congress Control Number: 2004041321

ISSN 0941-7834

Second corrected printing.

ISBN 978-3-540-40106-7 Second Edition Springer Berlin Heidelberg New York
ISBN 3-540-58964-3 First Edition Springer Berlin Heidelberg New York

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

Typesetting and production: LE-TEX Jelonek, Schmidt & Vöckler GbR, Leipzig
Cover design: *design & production* GmbH, Heidelberg

Printed on acid-free paper SPIN: 11971481 55/3180/YL - 5 4 3 2 1 0

To the memory of

Karl Schwarzschild

(1873–1916)

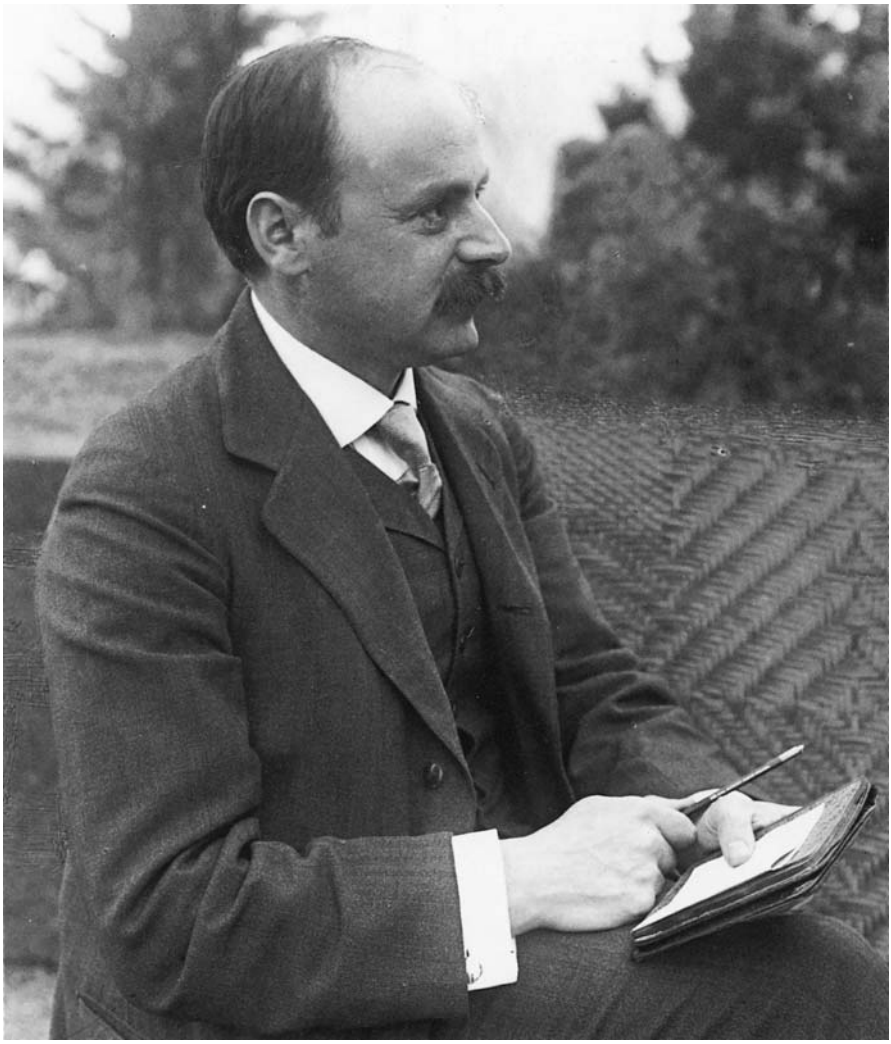
who developed the first complete aberration theory of reflecting telescopes

To the memory of

Harold Hopkins

(1918–1994)

a great physicist, teacher and friend,
who revealed to me the beauty and power of aberration theory



Karl Schwarzschild ca. 1908 (courtesy Martin Schwarzschild)

Preface to the 2nd edition

A corrected reprint of the first edition appeared in 2000. It was a requirement that the pagination remain unaltered, but nevertheless, apart from minor and format corrections on 17 pages, a number of corrections or additions of substance could be incorporated. These included minor corrections to Figs. 1.3 b) and 2.8 and to the text of Fig. 5.18. The most important change of all was probably the complete revision of the historical treatment of Cassegrain in the Portrait Gallery, due to the superb research of Baranne and Launay on his identity, published in 1997. Additions of substance were text on pages 21, 323 and 487 (Portrait Gallery – Mersenne) and corrections on pages 117 (y^2 to y^4), 174 (concerning the scale of Fig. 3.37), 263 (Fig. 3.96 instead of 3.97 in the text), 341 (sign in the text equation below Eq. (4.36)), Table 5.2 (concerning UKIRT), Table A.15 (first symbol), pages 505 (Ref. 3.71) and 531 (Brown and Cassegrain). Several of these errors were pointed out by readers, to whom I express my gratitude.

The present 2nd edition contains all the material of the first edition, unchanged apart from some further corrections, but with 25 pages more of additional explanations or new material, including 5 new figures (2 in Chap. 4, 2 in Chap. 5 and 1 following the Portrait Gallery). Significant text additions are on pages 1–2, 22, 43–46, 63, 85–86, 86–87, 117, 120–122, 126, 129–130, 131–132, 214, 222–223, 232–233, 262, 269, 278–279, 281, 324, 328, 370–372, 402–404, 426–429, 433–435, 500–501. The most important of these are the following: pages 43–46 with the correction to Eq. (2.53) and the extensive justification of the definition of m_2 in Eq. (2.55) – due to a most fruitful correspondence with Dr. Dan Schroeder, for which I express here my grateful thanks; pages 120–122 where the mathematical argument has been completely reformulated; pages 232–233 and 278–279 where the remarkable new analytical procedure of Rakich and Rumsey for setting up 3- or 4-mirror telescope solutions is briefly discussed; pages 370–372 with the new prime-focus corrector due to Bernard Delabre of ESO including a new "Spot-Diagram" in the same standard format used in the first edition; pages 402–404 with a description of the new Linear ADC-corrector used in the ESO VLT; pages 426–429 with the historical print of the casting of the blank of the Melbourne reflector – kindly supplied by Peter Hingley, librarian of the RAS, to whom my grateful thanks; pages 435–436 with a historic photo of Ritchey at his

60 cm telescope and pages 500–501 with the historic group photo of the ISU Meeting at Mt. Wilson in 1910. The latter two photos, previously unknown in the astronomical community, were kindly supplied by Dr. Don Osterbrock, to whom I express my grateful thanks. I consider the above three historic print/photos to be a major enrichment of the book.

A change hopefully made correctly throughout the book is the spelling of the name "Abbe" *without* an acute accent on the "e". This error was pointed out by a reviewer in an Irish journal and has been confirmed by a former colleague of mine at Carl Zeiss. Abbe himself *pronounced* his name in later life (as virtually everyone does today, also in Germany) as though there were an accent, but he apparently never wrote it that way!

Apart from the valuable help from outside sources, acknowledged above or in the text, I also owe a great debt of gratitude to a number of ESO colleagues: Uta Grothkopf and Angelika Treumann of the ESO library, for their admirable service in literature procurement, particularly concerning historical aspects of Petzval's work; Bernard Delabre for information on his P.F. corrector; Gero Rupprecht for information on the ESO Linear ADC system; Philippe Dierickx for help with the setting-up of the new Spot Diagram (Fig. 4.18); Ed Janssen for completing this Spot Diagram, for the new figure of the LADC (Fig. 4.36) and corrections to two existing figures (see above); Stephane Guisard for pointing out two errors; and, above all, Lothar Noethe for many discussions and suggestions arising from his detailed knowledge of the book – I sometimes think he knows parts of it better than I know them myself! My deep thanks are again due to my wife Anne, who always serves as my "Delphic Oracle" on the English language; to Springer-Verlag for the admirable cooperation in all respects, also to Uwe Matrisch of the firm LE-TeX in Leipzig for excellent work in setting up the final form of this edition; and to the management of ESO for their invaluable general support.

I hope, of course, that this second edition will be often reprinted. Minor corrections, hopefully few, can then be made. But I am virtually certain that I shall not produce a third edition. Unlike the matter of RTO II, the theory of RTO I is, I believe, largely complete. Innovations may be made with minor modifications of known solutions for centered systems or with new "Schiefspiegler" with several mirrors. But radically new optical design solutions seem unlikely. Revolutionary progress is more likely in the domain of RTO II or in aspects not treated there, such as interferometry.

July 2003 *Ray N. Wilson*

Preface

The development of telescope optics is a fascinating story. Until this century, the optical theory of reflecting telescopes was essentially limited to the Cartesian treatment of axial imagery. In 1905, Karl Schwarzschild initiated a revolution by applying third order (Seidel) theory to the field imagery of 2-mirror telescopes. Since then, the whole gamut of possible telescope systems has been invented, analysed and, in many cases, tried out in practice.

Over all its history, the optical development of the telescope has also depended on *technical* inventions, above all in mirror materials, glasses, support systems and means of achieving high reflectivity. Over the last 30 years, developments have been particularly spectacular, above all in manufacture and test techniques and generally in enhancing the image quality available.

When I started this work in 1988 there was little literature in book form available on telescope optics. Two of the best were in German: "Die Fernrohre und Entfernungsmesser" by König-Köhler (1959) and the monograph on "Teleskope" by K. Bahner in "Handbuch der Physik", Vol. XXIX, which appeared in 1967. A major part of this latter work was devoted to a condensed, but excellent exposition of the theory of telescope optics. Inevitably, more modern technical developments which have since assumed great importance could not be included; furthermore, the fact that it was written in German has reduced its impact and dissemination to a limited section of the interested community.

In 1987, "Astronomical Optics" by D. J. Schroeder appeared. Harland Epps kindly drew my attention to this excellent book in 1988 and I reflected then whether scope for a further work on the subject still existed. I finally concluded that it did: Schroeder's book covers a much wider field, since "astronomical" optics includes the broad subject of astronomical instruments, whereas my intention was (and remains) only the comprehensive coverage of the optics of the *reflecting* telescope, in the broadest interpretation of that term. Furthermore, Schroeder's work emerged more from the university orbit and includes much basic optical theory addressed to graduate students who need, and can profit from, the whole physics background.

The aim of the present book is different from Schroeder's. It is addressed primarily to specialists in the field, both in the astronomical community itself and in the industries concerned, although I hope it may also be useful to stu-

dents. Consequently, subjects such as practical alignment and test techniques, as well as maintenance aspects, occupy a significant part. Nevertheless, there are inevitably major overlap areas with both Bahner's and Schroeder's books which the informed reader will recognise. This overlap, involving repetitions in a somewhat different context, is unavoidable for a complete presentation.

Bahner's book included sections on achromatic objectives for refracting telescopes, astrographic objectives and oculars. No such material is included in this book. The refractor as such and the optical design of oculars are only of historical interest in large telescope optics and are only mentioned in this context. Of course, refracting *elements* still play an important role in wide-field telescopes, field correctors and focal reducers, and these are dealt with in Chapters 3 and 4. In general, mirrors supply the optical power while refracting elements have only the subordinate but important role of improving the imagery.

I favour the morphological approach with a strong emphasis on the historical background of the subject. In this sense, Chapter 5 is to be seen as essential background for understanding the current situation in telescope optics. For the background of the general theory of optical aberrations and diffraction, the reader is referred to specialist books in the field of optics. Only the essential consequences of Gaussian optics, third order theory and diffraction theory are given: the emphasis is on a complete treatment of the *application* to reflecting telescope optics.

At the suggestion of the publisher, the work has been split into two volumes. The first volume deals with the historical development (but there is no claim to completeness as a history of telescope optics - that would be a separate work) and the theory of reflecting telescope optics, including that of the refracting corrector elements. The second volume deals with technical aspects and modern developments in general. Although there is considerable cross-referencing between the volumes, the split is a logical one, since each volume has its own entity.

Every attempt has been made to give complete references to the international literature. It is hoped that the work will be useful, apart from its own content, as a "source book" of the subject.

While I was writing the book, three further works on the subject were published: "Telescope Optics" by Rutten and van Venrooij (1988), "Astrooptik" by Laux (1993) and "Reflective Optics" by Korsch (1991). The first two are primarily destined for amateurs, but have equally great value for professionals. As with the works of Bahner and Schroeder, there is considerable overlap with my material and I have referred to them liberally in my text. I only became aware of Korsch's work when my own text was finished, but again there is inevitably considerable overlap of treatment. However, not only the content and aim of these five works, all admirable, are very different, but also their styles. In this sense, I feel confirmed in my own enterprise.

Chapter 3 of Vol. I, dealing with the aberration theory of reflecting telescopes, is the longest and certainly one of the most important in the whole work. It is in this area that there is the greatest overlap with the above books. However, an illustration of the major, and legitimate, differences in presentation is the data given on the optical quality of systems discussed. Spot-diagrams are the commonest way of representing the quality according to geometrical optics. Rutten-van Venrooij and Laux give virtually complete spot-diagram analyses of the systems they discuss, a very valuable feature. To keep Vol. I within reasonable bounds, I have preferred to limit myself to chosen examples, intended to illustrate with spot-diagrams the key points of the development. Some of these are taken from the literature; but most of those in Chapter 3 (and a few in Chapter 4) have been optimized by Bernard Delabre of ESO from starting systems I set up from the basic theory, or with minor modifications emerging from the calculations. I am deeply grateful for this major contribution to the work.

I owe a great debt of gratitude to many specialist members of the astronomical community and associated industrial concerns, particularly Carl Zeiss (Oberkochen) and REOSC (Paris), who have generously supplied information. This debt extends, too, to many ESO colleagues. Above all, I am grateful to the ESO management for supporting the project and for extensive help in establishing the final text. In the detailed work, I wish to thank specifically, as well as Bernard Delabre mentioned above, Marion Beelen, Samantha Milligan, Baxter Aitken (who has not only played a major role in the text-processing but also kindly read through the entire work), Ed Janssen (who drew and formatted the figures) and Hans-Hermann Heyer for much hard work and enthusiastic support. My gratitude is also due to Richard West for general encouragement and support. Finally, I thank the publisher, Springer-Verlag, for excellent cooperation, and, last but by no means least, my wife Anne, for much help with the text and, above all, for patience throughout the whole task.

D-85296 Rohrbach
January 1996

Ray N. Wilson

Contents