

A Practical Guide to Lightcurve Photometry and Analysis

Brian D. Warner

A Practical Guide to Lightcurve Photometry and Analysis

Foreword by Alan W. Harris

 Springer

Brian D. Warner
Minor Planet Observer
17995 Bakers Farm Road
Colorado Springs, Colorado 80908
U.S.A.
brian@minorplanetobserver.com

Library of Congress Control Number: 2005933716

ISBN-10: 0-387-29365-5

ISBN-13: 978-0387-29365-3

Printed on acid-free paper.

© 2006 Springer Science+Business Media, Inc.

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer Science+Business Media, Inc., 233 Spring Street, New York, NY 10013, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden.

The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

Printed in the United States of America. (EB)

9 8 7 6 5 4 3 2 1

springer.com

Foreword

It is a pleasure and an honor to offer a few words of forward to Brian Warner's guide to photometry. In his preface, he makes a considerable point about amateurs and professionals, and those who dare or deign to step across the line supposedly dividing the two. Here I would like to make a few observations about the two monikers, and suggest that there is not, or at least should not be, a distinction between "amateur" and "professional." In preparing these remarks I referred to *Webster's New Collegiate Dictionary* (1960 edition; not so new anymore, but that was when my collegiate experience began):

am´a-teur, *n.* [F., fr. L. *amator* lover, fr. *amare* to love.] 1. One who cultivates a particular pursuit, study, or science, from taste, without pursuing it professionally; also, a dabbler. 2. In sports and esp. athletics, one who is not rated as a professional.

Well... a "dabbler" eh? "not rated as a professional"? No wonder we have an identity problem here. Somehow in my youth as an amateur astronomer I missed this connotation of the term. To me, the meaning of the term amateur was dominated by its root, "to love," that is, one who does what he does out of love of the subject, not for remuneration (to the extent one can get away with that). In that context, most "professional" astronomers I know are also "amateurs": they love what they are doing and choose the profession primarily for that reason, not how much money they could earn. Indeed, I have often advised students that if they are smart enough to eke out a living in astronomy they are smart enough to get rich quick in some other field, thereby freeing themselves a bit later in life to become a "gentleman astronomer."

This brings me to another perspective on "amateur" versus "professional." Most folks need to earn a living somehow, so almost every "amateur" astronomer is a "professional" at something else. And curiously, most of us who call ourselves "professional" astronomers are amateurs in other fields that are essential to our pursuits. This basic fact of life further blurs the distinction between amateur and professional, in any field. Indeed, my own graduate training is as a theoretician. I have never taken a single course in observational astronomy. So as an observer, I'm one of you, an amateur, self-taught in my own backyard. Another conspicuous example is computer programming. "The other Brian Warner," author of this book, is a professional when it comes to software development, and writing for that matter, talents many of my "professional" astronomer colleagues sorely lack. A result of this is that there are software packages out there, written by professional software writers for the amateur community that are far more powerful, efficient

and user-friendly than their "pro" counterparts. The people who wrote them may be "amateur" astronomers, but they are highly professional in their computer skills. Amateurs now have at their disposal computer tools for telescope pointing, focusing, data taking, and reduction that far surpass what is in use at most professional observatories. You'll find several such packages mentioned and described in this book.

I'll now turn to a bit of history. In the late 1990's, my colleague Ted Bowell and I noted that there was a dearth of activity among American amateur astronomers in minor planet (asteroid) observing, compared to various overseas observers, notably in Japan and Italy. Ted had just been to an amateur meeting in Italy and was favorably impressed by their organization and activities. We decided to organize a meeting of amateurs and professionals engaged in asteroid observations to try to stimulate interest in the amateur community in the United States. The meeting was hosted at Lowell Observatory in Flagstaff, AZ, 23–24 April, 1999. I think we were successful in stimulating interest.

During the meeting, it became apparent, to me at least, that a key to amateur participation was the availability of understandable and user-friendly computer tools. At that time, amateur participation in asteroid work was mainly in astrometry, aided by the program *Astrometrica*, written by Herbert Raab of Linz, Austria. This program allowed amateurs to do positional astrometry on asteroids in a friendly environment without having to understand fully every detail of the process (*n.b.*, this is not the same as "in a state of ignorance"!). At the time of the Flagstaff meeting, I commented that in order to get amateurs involved in photometric observations of asteroids, what was needed was a *Photometrica* program.

In the years since that time, *Photometrica*, admittedly not by that name, has been written, in fact in several versions, as cited in this book. One is Warner's own *Canopus* program, and this book serves as a companion for observers who want to learn the game of asteroid or variable star photometry, using either *Canopus* or one of the several other options mentioned in the book. I think with the development of these user-friendly programs, and now with the publication of this book, CCD (charge-coupled device) photometry for amateurs has come of age, and I look forward to the contributions that will inevitably follow.

Alan W. Harris*
La Canada, CA
August 2003

*There is also another Alan Harris (also engaged in asteroid research, in Berlin, Germany). In this case we are both Alan William Harris, so a middle initial doesn't differentiate. I refuse to identify him as "the other" Alan Harris, as I think neither should suffer a diminutive term. The same goes for Brian Warner.

Preface

Pardon the “D” in the author’s name on the cover (it stands for “Dale” by the way). I’m the *other* Brian Warner. The *real* Brian Warner is the famous and distinguished one. He’s the author of *High Speed Photometry* and *Cataclysmic Variable Stars*. There yet is another Brian Warner. He goes by the stage name of Marilyn Manson. I’ve received some very strange phone calls late at night from some of Manson’s fans. “No, I’m the *other* Brian Warner.” The disappointment at the other end was nearly devastating. So, I use the “D” to make sure it’s clear who I am and so that you won’t think I’ll break out into song at any moment.

The real Brian Warner and I do have something more in common than our names: a deep interest in lightcurves. My interest is not so much in cataclysmic variables but asteroids and eclipsing binaries. When I was in junior high school, I had hopes of being a professional astronomer someday and specializing in close contact binaries. Many years have passed and I’m not a professional astronomer. However, I do still occasionally observe eclipsing binaries as a nearly full-time “gentleman astronomer.”

My first efforts in asteroid lightcurves began in the 1970s when I worked with the late Terry Schmidt at his Tiara Observatory in South Park, CO (yes — *the* South Park). It was my great fortune to leave my small telescope out on the porch on a day he was walking around the new neighborhood. He spotted the scope and knocked on the door. That started a 25-year friendship with Terry as my astronomy mentor. One of my three asteroid discoveries, 34398 Terryschmidt, is named in his honor.

I was pleasantly surprised at the popularity of the first edition of the *Practical Guide*, and so I want thank everyone, the reviewers especially, who embraced the book. As with any book on a complex topic meant for the reader with a beginner to intermediate technical understanding of the topic, the first edition covered some things in less detail than it might have and certainly left many things out. That’s what second editions are for: to keep the material fresh, fill in gaps from the first edition, and tell of new ways to approach old problems. These are goals for this second edition in addition to, of course, being a recruiting tool to bring more people into the exciting field of photometry and lightcurve analysis.

Since the first edition, I’ve developed and learned of what I believe are easier and more straightforward methods for reducing data, the process that is probably the biggest “monster” the beginning photometrists encounters, or at least fears. Those methods are presented in this second edition in lieu of those from the first. I could include both sets but that would increase the size of the book beyond what the editors would allow and, more important, would serve more to confuse than help the reader. The original methods follow those described in other well-known

texts such as Arne Henden and Ron Kaitchuck's *Astronomical Photometry*, which should be on the shelf of any photometrist, no matter what level.

Along with changes in the reduction methods come those to the observing guidelines. The second edition has streamlined those so that you can go to the telescope with a much clearer game plan and so concentrate more on getting data of your target than on wondering if you're doing the right thing in the right way. You'll still find information about analyzing lightcurves, asteroid and eclipsing binary – after all, the title does include “Analysis.”

You'll also get some more insight about measuring images; in particular, how aperture sizes affect data. When trying to reach a higher level of work, you need to understand some of the finer details – without necessarily having to know the math or hard theory involved – so that you can use your software to the best of its ability. As I noted in the first edition, never trust a computer. Just because it gives you an answer doesn't mean you shouldn't question it. The more you know about what's involved in getting good data, the better a scientist you will be.

I'll keep this brief, so before I conclude, I want to thank Alan Harris, Arne Henden, Richard Binzel, and Petr Pravec again for their continuing support. I also want to thank Robert Buchheim and Richard Miles. Both have contributed enormously to my understanding of photometry's “dark side” and alternate methods. Their knowledge and generosity made this second edition far more complete than it might have been otherwise.

A number of people read the revised manuscript, trying to make sure that the material was both clear and accurate. They were Richard Binzel, Robert Buchheim, Robert Stephens, Robert Koff, Jerry Foote, and Greg Crawford. My thanks to them for finding the glaring errors. Any that remain are solely my responsibility.

Thanks to John Watson of Springer for taking the proposal for a second edition to the editorial board for its approval as well as his suggestions. Thanks also to Dr. Harry Bloom and Christopher Coughlin, also of Springer, for taking on the task of dealing with a writer who was forever the frustration of his English teachers. Without them, there would have been no second edition.

This one's for Margaret, too.

Brian D. Warner
Palmer Divide Observatory
July 2005

Contents

GETTING STARTED	1
1.1 What Is Lightcurve Photometry?.....	3
1.2 What Lies Ahead.....	4
TARGETS OF OPPORTUNITY.....	7
2.1 Asteroids	7
2.2 Variable Stars.....	12
2.3 Eclipsing Binary Lightcurve Characteristics.....	15
2.4 Cataclysmic Variables.....	17
2.5 Cepheids.....	18
2.6 Long Period (Mira) Variables	18
2.7 Semi-Regular Variables	18
2.8 Other Targets	19
2.9 Summary.....	20
PHOTOMETRY FUNDAMENTALS.....	21
3.1 A Little Bit of History.....	21
3.2 The First Color-Based Systems.....	22
3.3 The Johnson–Cousins Standard	23
3.4 Setting the Standard	24
3.5 Seeing Red	24
3.6 CCDs and Standard Magnitudes	24
3.7 Landolt Standards	25
3.8 Henden Sequences	26
THE PHOTOMETRY PRIMER.....	27
4.1 Instrumental Versus Standard Magnitudes.....	27
4.2 Air Mass.....	28
4.3 Extinction.....	29
4.4 Transforms and Nightly Zero-Points.....	31
4.5 Differential Versus All-Sky Photometry.....	32
4.6 Seeing and Scintillation.....	35
4.7 Matching Pixel Size to Seeing	36
4.8 Bias Frames.....	36
4.9 Dark Frames.....	37
4.10 Flat Fields.....	37

- 4.11 Photometry Apertures and Annuluses.....41
- 4.12 Reporting Errors.....46

- PHOTOMETRIC REDUCTIONS47**
 - 5.1 The Different Path.....48
 - 5.2 The Differential Formula49
 - 5.3 Clear to Visual Conversions.....50
 - 5.4 First-Order Extinctions – Are They Really Necessary?50
 - 5.5 The Same Color Index52
 - 5.6 Transforms First.....53
 - 5.7 Finding Transforms53
 - 5.8 The Hidden Transforms56
 - 5.9 First-Order Extinction57
 - 5.10 Finding First-Order Extinction (Modified Hardie)59
 - 5.11 A Variation on the Modified Hardie method61
 - 5.12 Finding First-Order Extinction (Comp Star).....62
 - 5.13 Comparison and Target Standard Color Index Values.....63
 - 5.14 Find the Color Indices of the Comparisons and Target.....64
 - 5.15 The Comparison Star Standard Magnitudes.....66
 - 5.16 Finding the Comparison Star Standard Magnitudes.....67
 - 5.17 Target Standard Magnitudes68
 - 5.18 Finding the Standard Magnitudes of the Target.....68
 - 5.19 The Different Path’s End71
 - 5.20 A Minimalist Approach71
 - 5.21 Using the Minimalist Approach for Standard Magnitudes.....72

- SECOND ORDER EXTINCTION.....77**
 - 6.1 Deriving a Single-Color Approach77
 - 6.2 The Slope of Slopes Method.....78
 - 6.3 When Is the Second-Order Term Applied?.....80
 - 6.4 Summary.....81

- TELESCOPES AND CAMERAS.....83**
 - 7.1 The Telescope83
 - 7.2 The CCD Camera.....87
 - 7.3 Digital and Web Cameras95
 - 7.4 Filter Wheels.....96
 - 7.5 Guiding Considerations.....97

- IMAGING AND PHOTOMETRY SOFTWARE99**
 - 8.1 Image Acquisition Software.....99
 - 8.2 Specific Features.....100
 - 8.3 Photometry Software.....102

8.4	Conforming to Accepted Standards	106
8.5	Manual Versus Automated Measuring.....	109
COLLECTING PHOTONS		111
9.1	The First Step – Getting the Right Time	111
9.2	Planning the Observing Program	112
9.3	Selecting Targets.....	113
9.4	General Considerations	114
9.5	Asteroids	115
9.6	Variable Stars.....	117
9.7	The Observing Run	118
9.8	Measuring Images	120
9.9	From Image to Data	123
9.10	The Hands-On Approach for Measuring Images	125
9.11	Checking the Comparison Stars	129
9.12	The Automated Approach to Measuring Images	130
ANALYZING THE DATA		133
10.1	The Quality of Data.....	133
PERIOD ANALYSIS.....		137
11.1	About Merging Data and Setting Zero-Points.....	137
11.2	A Simple Start.....	139
11.3	To What Precision.....	142
11.4	Refining the Search Process.....	143
11.5	The Amplitude of the Lightcurve.....	144
11.6	Aliases in Depth.....	145
11.7	Plotting the Half-Period	149
11.8	A Specific Alias Example	150
11.9	The Case of 3155 Lee	151
11.10	Period Analysis on a Spreadsheet.....	152
11.11	From Lightcurve to Shape.....	157
BUILDING STAR SYSTEMS		161
12.1	Getting Started	161
12.2	Binary Maker	164
12.3	The Many Possibilities.....	166
12.4	The Effects of Changing the Inclination	166
12.5	The Effects of Temperature Changes in the Primary	168
12.6	The Effects of Temperature Changes in the Secondary	169
12.7	The Effects of Changing the Mass Ratio	171
12.8	The Effects of Gravity/Limb Darkening and Reflection.....	172

PUBLISHING YOUR DATA AND RESULTS.....	173
13.1 Confirm Before You Publish	173
13.2 Asteroids	175
13.3 Variable Stars.....	176
13.4 Learn by Association	177
BIBLIOGRAPHY	181
GLOSSARY	187
APPENDIX A: CONSTELLATION NAMES.....	203
APPENDIX B: TRANSFORMS EXAMPLE	205
Example Transforms Data	205
The Spreadsheet.....	206
The Hidden Transforms	208
APPENDIX C: FIRST-ORDER (HARDIE) EXAMPLE.....	211
The Data.....	211
The Spreadsheet.....	213
APPENDIX D: FIRST-ORDER (COMP) EXAMPLE.....	217
The Data.....	217
The Spreadsheet.....	217
APPENDIX E: STANDARD COLOR INDICES.....	219
The Data.....	219
The Spreadsheet.....	219
APPENDIX F: COMPARISON STANDARD MAGNITUDES	223
The Data.....	223
The Spreadsheet.....	224
APPENDIX G: TARGET STANDARD MAGNITUDES	227
The Data.....	227
The Spreadsheet.....	228

APPENDIX H: LANDOLT/GRAHAM STANDARD FIELDS.....231

APPENDIX I: HENDEN CHARTS253

APPENDIX J: HIPPARCOS BLUE-RED PAIRS.....285
Steps used to produce the List.....285
Hipparcos Blue-Red Pairs287

APPENDIX K: SDSS BLUE-RED PAIRS.....291

INDEX295