

Understanding Variable Stars

Variable stars are those that change brightness. Their variability may be due to geometric processes such as rotation, or eclipse by a companion star, or physical processes such as vibration, flares, or cataclysmic explosions. In each case, variable stars provide unique information about the properties of stars, and the processes that go on within them.

This book provides a concise overview of variable stars, including a historical perspective, an introduction to stars in general, the techniques for discovering and studying variable stars, and a description of the main types of variable stars. It ends with short reflections about the connection between the study of variable stars, and research, education, amateur astronomy, and public interest in astronomy. This book is intended for anyone with some background knowledge of astronomy, but is especially suitable for undergraduate students and experienced amateur astronomers who can contribute to our understanding of these important stars.

JOHN R. PERCY is a Professor of Astronomy and Astrophysics at the University of Toronto, based at the University of Toronto in Mississauga (UTM). His research interests include variable stars and stellar evolution, and he has published over 200 research papers in these fields. He is also active in science education (especially astronomy) at all levels, throughout the world. His education interests and experiences include: teaching development at the university level, development of astronomy curriculum for Ontario schools, development of resources for educators, pre-service and in-service teacher education, lifelong learning, public science literacy, the roles of science centres and planetariums, the role of skilled amateurs in research and education, high school and undergraduate student research projects, international astronomy education and development, and multicultural astronomy. He is Director of the undergraduate Science Education program, and the Early Teacher Program at UTM, and is cross-appointed to the Ontario Institute for Studies in Education.

He has served as President of the Royal Astronomical Society of Canada, the Royal Canadian Institute, the American Association of Variable Star Observers, the International Astronomical Union Commissions on Variable Stars, and on Astronomical Education, and of the Astronomical Society of the Pacific. He was recently the recipient of the Royal Canadian Institute's Sandford Fleming Medal for contributions to public awareness and appreciation of science and technology, the U of T School of Continuing Studies' Citation for Exceptional Commitment and Achievement in adult learning, and the Distinguished Educator Award of the Ontario Institute for Studies in Education. In 1999, he was elected a fellow of the American Association for the Advancement of Science. In 2003, he received the University of Toronto's Northrop Frye Award for exemplary linkage of teaching and research. His most recent book, co-edited with Jay M. Pasachoff, is *Teaching and Learning Astronomy* (Cambridge University Press, 2005).

Cambridge University Press
978-0-521-23253-1 - Understanding Variable Stars
John R. Percy
Frontmatter
[More information](#)

Understanding Variable Stars

JOHN R. PERCY

University of Toronto, Toronto, Ontario, Canada



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-0-521-23253-1 - Understanding Variable Stars
John R. Percy
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS

Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press

The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org

Information on this title: www.cambridge.org/9780521232531

© J. Percy 2007

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2007

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

ISBN 978-0-521-23253-1 hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.



Janet Akyüz Mattei (1943–2004) (Photo by Michael Mattei, courtesy of the AAVSO.)

This book is dedicated to the memory of my colleague and friend Dr Janet Akyüz Mattei (1943–2004). She was born in Bodrum, Turkey, and educated at Brandeis University (BA 1965), University of Virginia (MS 1972), and Ege University, Turkey (MS 1970, Ph.D. 1982). She served as Director of the American Association of Variable Star Observers for 30 years, from 1973 until her death. She led the AAVSO through a period of unprecedented growth, in the volume of data submitted by observers and requested by professional astronomers, and in the diversity and complexity of research projects supported. The AAVSO became internationally respected for its treasury of data and information, and for its international network of volunteer observers. She won a dozen major awards in countries around the world. She served in scientific and educational organizations and committees at every level, up to the International Astronomical Union. As a professional astronomer, she was an expert on cataclysmic variables and Mira stars, as well as on the general topic of amateur-professional collaboration – an area in which she made a profound contribution in many ways, and many places. But Janet was more than a scientist and administrator. She was a teacher, with an infectious enthusiasm for astronomy – and wildflowers. She was a diplomat and a leader, an exemplary human being, and a dear friend of every amateur or professional astronomer or educator she worked with. I had the pleasure of working with her on many projects, notably *Hands-On Astrophysics*. My interests in variable stars, and their role in science and education, have been indelibly affected by my 30 years of collaboration and friendship with Janet. I know that she has left a similar mark on hundreds of others, worldwide.

John R. Percy

Contents

List of Boxes x
List of Figures xi
List of Tables xvii
Preface xviii

1 History and development 1
1.1 Tycho’s and Kepler’s stars 2
1.2 The beginnings of modern astronomy 3
1.3 Systematic visual observations 4
1.4 The photographic revolution 6
1.5 Spectroscopy 6
1.6 Classification and explanation 7
1.7 Photoelectric photometry: the electronic revolution 8
1.8 Consolidation 8
1.9 The modern age 9
1.10 Variable stars: the present status 12

2 Stars 14
2.1 Positions 14
2.2 Binary and multiple stars 15
2.3 Star clusters 17
2.4 Galaxies 18
2.5 Motions of the stars 21
2.6 Apparent magnitude 22
2.7 Distance 23
2.8 Absolute magnitude and luminosity 24
2.9 Stellar masses 25
2.10 Spectra 26
2.11 Colour 27
2.12 Temperature 28
2.13 Diameter 31

viii Contents

- 2.14 Composition 32
- 2.15 Rotation 33
- 2.16 Radial velocity 34
- 2.17 The Hertzsprung–Russell (H–R) diagram 36
- 2.18 Star structure 38
- 2.19 Star formation 39
- 2.20 Star evolution 43
- 2.21 Star death 45

- 3 Variable stars 48**
 - 3.1 Magnitude and Julian Date 49
 - 3.2 Measurement of variable stars 50
 - 3.3 Discovery and observation 55
 - 3.4 Analysis of variable star data 61
 - 3.5 Classification 71
 - 3.6 Certification 74
 - 3.7 Nomenclature 74
 - 3.8 Bibliography 76

- 4 Rotating variable stars 81**
 - 4.1 The spotted sun 82
 - 4.2 Sunlike stars 84
 - 4.3 FK Comae stars 88
 - 4.4 RS Canum Venaticorum stars 88
 - 4.5 BY Draconis stars 91
 - 4.6 Peculiar A (Ap) stars 92
 - 4.7 Pulsars 96

- 5 Eclipsing variable stars 103**
 - 5.1 Overview 103
 - 5.2 Ellipsoidal variable stars 106
 - 5.3 Classification of eclipsing variables 107
 - 5.4 Analysis of eclipsing variables 111
 - 5.5 Detached eclipsing variables 118
 - 5.6 Semi-detached binaries 121
 - 5.7 W Ursae Majoris stars – contact binaries 122
 - 5.8 Symbiotic binary systems 124
 - 5.9 VV Cephei stars 126
 - 5.10 X-ray binaries 128
 - 5.11 The evolution of binary systems 132
 - 5.12 Transiting exoplanets 133

- 6 Pulsating variable stars 136**
 - 6.1 Pulsation modes 136
 - 6.2 Pulsation mechanisms 138
 - 6.3 Modelling stellar pulsation 139

6.4	Non-linear effects	140
6.5	The instability strip(s)	141
6.6	Helioseismology: pulsations of the sun	145
6.7	Asteroseismology	145
6.8	Classical Cepheid variable stars	147
6.9	Population II Cepheids (W Virginis stars)	161
6.10	RV Tauri variables	167
6.11	RR Lyrae stars	173
6.12	Delta Scuti stars	182
6.13	Rapidly oscillating peculiar A (roAp) stars	190
6.14	Pulsating degenerate stars	192
6.15	Beta Cephei (Beta Canis Majoris) stars	195
6.16	Pulsating red giants (PRGs)	203
6.17	Red supergiant (SRc) variables	217
7	Eruptive variable stars	224
7.1	Flare stars	224
7.2	Cataclysmic variables	228
7.3	Supernovae	255
7.4	Gamma-ray bursters	270
7.5	Active Galactic Nuclei (AGN)	272
8	Pre-main-sequence variable stars	278
8.1	T Tauri stars	279
8.2	FU Orionis stars	289
8.3	Herbig-Haro objects	291
8.4	Herbig Ae and Be stars	291
8.5	Putting it all together	292
9	Miscellaneous variable stars	296
9.1	Be stars – Gamma Cassiopeiae variables	296
9.2	Wolf-Rayet stars	301
9.3	Hypergiant variable stars	304
9.4	R Coronae Borealis (RCB) stars	312
10	Epilogue	319
10.1	Variable stars and astronomical research	319
10.2	Variable stars and amateur astronomy	320
10.3	Variable stars and science education	324
10.4	Variable stars and the general public	327
	<i>Appendix: Acronyms</i>	330
	<i>References</i>	332
	<i>Resources</i>	342
	<i>Index</i>	344

Boxes

3.1 MOST Satellite (Microvariability and Oscillations of Stars) 79
4.1 Star sample – IM Pegasi 90
4.2 Star sample – ϵ Ursae Majoris (a peculiar A star) 97
5.1 Star sample – Algol (β Persei) 120
5.2 Star sample – β Lyrae 125
5.3 Star sample – (ϵ Aurigae) 129
6.1 Star sample – Polaris 162
6.2 Star sample – RU Camelopardalis 169
6.3 Star sample – PG Virginis 188
6.4 Star sample – DO Eridani 193
6.5 Star sample – PG 1159–035=GW Virginis 197
6.6 Star sample – BW Vulpeculae 206
6.7 Star sample – Mira 219
6.8 Star sample Betelgeuse 221
7.1 Star sample – Nova Cygni 1992 237
7.2 Star sample – Supernova 1987A 268
7.3 Star sample – V838 Monocerotis 275
8.1 Star sample – T Tauri 294
9.1 Star sample – γ Cassiopeiae 302
9.2 Star sample – η Carinae 309

Figures

- 2.1 A visual binary star system Krüger 60, in Cepheus 16
- 2.2 The globular cluster M14, showing a Population II Cepheid variable star at maximum (left) and minimum (right) brightness 18
- 2.3 Cepheid variable stars discovered by E.P. Hubble (the numbered stars) in the nearby spiral galaxy M33 20
- 2.4 The proper motion is the annual angular (apparent) motion of a star across the sky 21
- 2.5 The passbands of the visual (UBV) and infrared filters (RIJHKL) in the UBV photometric system (lower panel), compared with the spectrum of the sun (lower panel), and the transparency of the earth's atmosphere (upper panel) 23
- 2.6 Parallax is the apparent change in the position of a star on the sky, as the earth revolves around the sun 24
- 2.7 Spectra of six stars of different types: η U Ma (B3V), α Cyg (A2Ia), β Cas (F2III-V), μ Cas (G0V), γ Cep (K1IV), and α Ori (M2Iab) 27
- 2.8 Photographs of spectra of main sequence stars of various types, from B0 to M8e 30
- 2.9 The principle of the Doppler effect 34
- 2.10 Radial velocity variations of BW Vul, a β Cephei pulsating star 35
- 2.11 Schematic Hertzsprung–Russell diagram, showing the locations of various types of stars 37
- 2.12 A 'model' of the interior of a 15 solar-mass star 40
- 2.13 HST image of a forming star 42
- 2.14 Evolution tracks on the H–R diagram, for stars with masses ranging from 0.8 to 120 times that of the sun, and chemical composition appropriate for that of our galaxy 44
- 3.1 A chart for making visual observations of a variable star, ρ Cas 51
- 3.2 A photoelectric photometer 53
- 3.3 A CCD chip 54
- 3.4 The light curve of the pulsating red giant EU Del on a 5000-day scale (left) showing the slow variability of the star, and on a 200-day scale (right) showing the 63-day period of the star 63

xii List of Figures

- 3.5 The power spectrum of the measurements of EU Del 65
- 3.6 The self-correlation diagram of the measurements of EU Del 67
- 3.7 Wavelet plot for the variable star R Dor 68
- 3.8 ($O - C$) diagrams for two RR Lyrae stars in the globular cluster M5 70
- 3.9 Graph showing the Eddington–Plakidis analysis for random cycle-to-cycle fluctuations in period, for four RV Tauri stars 71
- 3.10 The *Microvariability and Oscillations of STars* (MOST) satellite, and the Project Scientist Jaymie Matthews, in the ‘clean room’ of the Institute for Aerospace Studies, University of Toronto 78
- 4.1 A white-light image of the sun, showing sunspots 83
- 4.2 The sunspot cycle: the changing number of sunspots with time 85
- 4.3 For the young sun-like star HD63433: the V light curve during one season (top), the period analysis using phase-dispersion minimization (middle), and the phase curve using the period 6.46 ± 0.01 days 87
- 4.4 Light curve and schematic model of RS CVn, with the sun drawn to scale 89
- 4.5 The spectra of three Ap stars, of different types: Si (silicon), SiSrCr (silicon-strontium-chromium), and HgMn (mercury-manganese) 93
- 4.6 The variations in brightness, in the Stromgren uvby system, for the Ap star HD 24712 (HR 1217, DO Eri) 94
- 4.7 A map of the distribution of the chemical elements and the magnetic field on the surface of the Ap star α^2 CVn, derived from high-resolution spectropolarimetry 96
- 4.8 First observation of radio pulses from a pulsar, CP1919, by Jocelyn Bell and Anthony Hewish 98
- 4.9 Probing the mysterious heart of the Crab Nebula, the tattered remains of an exploding star, astronomers have found this object to be even more dynamic than previously understood 99
- 4.10 The periods of pulsars, plotted against the rate of period change 101
- 5.1 Schematic picture of a simple eclipsing binary, and its light curve 104
- 5.2 Light curve of the ellipsoidal variable ψ Ori 108
- 5.3 The Lagrangian surfaces around a pair of stars in mutual orbit 109
- 5.4 Schematic view of mass transfer from one component to the other 111
- 5.5 Light and velocity curves for AI Phe, a ‘clean’ eclipsing binary 119
- 5.6 Light curves of Algol at different wavelengths 120
- 5.7 (O-C) diagram for Algol, showing changes in period, due to mass transfer 122
- 5.8 Light curve (upper left), line profiles showing two stellar components (lower left) and calculated model (right) for the W UMa star AW UMa, with the very low mass ratio 0.078 [the mass ratio is the ratio of the masses of the two components] 123
- 5.9 Artist’s conception of β Lyr, by Alexandra Kalasova, based on Harmanec (2002) 125
- 5.10 Spectrum of two symbiotic binary stars, CI Cyg and AG Dra 127

- 5.11 Spectrum variations of ζ Aur, a VV Cep star, as the hot star emerges from behind the cool star 128
- 5.12 Light curve of ϵ Aur during the 1982–1984 eclipse 129
- 5.13 Model of ϵ Aur, based on the light curve in figure 5.12 130
- 5.14 Light curve of HD 209458, showing the effect of the transit of an exo-planet 134
- 6.1 Illustration of non-radial pulsation modes 137
- 6.2 Diagram showing the zones in an unstable star which convert radiant energy into kinetic energy, and *vice versa*, in a model of a pulsating RR Lyrae star, expressed as the fractional energy production (positive) or dissipation (negative) per period 142
- 6.3 The location of various types of pulsating star on the H–R diagram 143
- 6.4 Evolution tracks on the H–R diagram, showing the changes which take place in a star as it evolves 144
- 6.5 Frequency diagram for pulsational p-modes excited in the sun 146
- 6.6 The magnitude, temperature (deduced from the colour), radius (deduced from the magnitude and temperature), and radial velocity of the prototype Cepheid δ Cep 148
- 6.7 Variations of amplitude and phase of maximum seen in the light curve of a typical Cepheid as a function of increasing wavelength (UBVR_{IJK} filters in the Johnson system) 150
- 6.8 Light and colour curves of three Cepheids with different periods 151
- 6.9 The Petersen diagram for double-mode Cepheids in the LMC (diamonds) and in our galaxy (crosses) 153
- 6.10 The period–luminosity relation for Cepheid pulsating variables 159
- 6.11 The V light amplitude of Polaris, as a function of time 162
- 6.12 One interpretation of the (O – C) diagram of Polaris 163
- 6.13 The position of Population II Cepheids, including BL Her, W Vir, and RV Tau variables, on the H–R diagram 165
- 6.14 The observed photoelectric magnitudes of maxima (open circles) and minima (filled circles) of RU Cam after the sudden decrease in amplitude in 1966 169
- 6.15 The continuous spectrum of RV Tau in the visible and IR 171
- 6.16 The 8-year light curve of the RV Tauri star U Mon, based on visual observations from the AAVSO International Database 172
- 6.17 The 60-year light curve of the RV Tauri star U Mon, based on visual measurements from the AAVSO International Database 173
- 6.18 Synthetic horizontal branch model for the globular cluster M3 with some horizontal branch models ($Y = 0.20$, $Z = 0.0004$) shown 174
- 6.19 Light curves for a selection of RR Lyrae variables in the metal-rich globular cluster M107 (NGC 6171) 175
- 6.20 The position of δ Scuti stars and γ Doradus stars in the H–R diagram 185
- 6.21 The complex light curve of FG Vir, obtained from the 2002 Delta Scuti Network campaign 188

xiv List of Figures

- 6.22 The power spectrum of FG Vir, obtained from the data in the previous figure 189
- 6.23 Schematic model of a roAp star 191
- 6.24 The B light curve (top) and velocity curve (middle) of the roAp star DO Eri 192
- 6.25 The position of ZZ Ceti stars and other degenerate pulsating stars in the H-R diagram 196
- 6.26 The complex light curve of PG1159-035., as determined from the central six days of a *Whole Earth Telescope* campaign 197
- 6.27 The power spectrum of the complete set of measurements of PG1159-035 from the WET campaign 198
- 6.28 The relationship between the light amplitude of β Cep and wavelength 199
- 6.29 The positions of β Cephei stars (various symbols), slowly pulsating B stars (SPB: open circles), and δ Scuti stars (x) in the H-R diagram 201
- 6.30 The absorption-line profile variations of ϵ Per 202
- 6.31 The (O-C) diagram for BW Vul, covering 100000 cycles 206
- 6.32 Light curves of several small-amplitude pulsating red giants 207
- 6.33 The light curve of the semi-regular pulsating red giant Z UMa, based on measurements from the AAVSO International Database 208
- 6.34 Variable red giants in the Large Magellanic Cloud, plotted in an apparent K magnitude *versus* log(period) graph 209
- 6.35 The 1978–2004 light curve of Mira, based on visual measurements from the AAVSO International Database 210
- 6.36 The spectra of four pulsating red giants 213
- 6.37 Radius *versus* time for selected layers (solid lines) in the atmosphere of a Mira star, based on theoretical models by Bowen (1988) 216
- 6.38 ‘Lemming’ diagram for Mira stars 218
- 6.39 HST image of Mira and its hot companion 220
- 6.40 HST image of Betelgeuse, showing the size of the star as compared with the size of the Earth’s orbit. 221
- 7.1 A flare on the fainter component of the visual binary star system Krüger 60 225
- 7.2 A flare on YY Gem, the companion of Castor 225
- 7.3 The generic model of a cataclysmic variable 228
- 7.4 The light curve of the Nova Cyg 1975 (V1500 Cyg), based on visual measurements from the AAVSO International Database 230
- 7.5 A schematic light curve of a nova, showing various features which might be found 231
- 7.6 The light curve of the CV U Gem, showing the eclipse of the hot spot, and the brightening when the hot spot is most easily seen 233
- 7.7 The recurrent nova T Pyxidis, showing discrete clouds of ejected material 236
- 7.8 The light curve of RS Oph, a recurrent nova, from 1957 to 1991, based on visual measurements from the AAVSO International Database 238

- 7.9 The light curve of SS Cyg, the prototype U Gem type of dwarf nova, based on visual observations from the AAVSO International Database 239
- 7.10 The light curve of SU UMa, based on visual observations from the AAVSO International Database 241
- 7.11 Simultaneous AAVSO, Extreme Ultraviolet Explorer, and Rossi X-Ray Timing Explorer observations of SS Cyg through outburst 244
- 7.12 The light curve of the polar AM Her, based on visual observations from the AAVSO International Database 246
- 7.13 A schematic model for a polar 247
- 7.14 The distribution of the orbital periods of CVs, showing the long-period cutoff at about 10 hours, the period gap between 2 and 3 hours, and the low-period cutoff at about 80 minutes 250
- 7.15 The light curve of AX Per, based on visual observations from the AAVSO International Database 254
- 7.16 Light curves of a large number of supernovae in the *gri* photometric system, discovered by the CFHT Supernova Legacy Survey 259
- 7.17 The light curves of several Type Ia supernovae (top) 262
- 7.18 Spectra of Types Ia, Ib, Ic, and II supernovae, near maximum light 264
- 7.19 Discovery images of SN 1987A 268
- 7.20 HST image of SN 1987A, showing the development of 'hot spots' in a ring of previously ejected material around the supernova, as a result of interaction with debris ejected in the supernova explosion 269
- 7.21 Model of a GRB. GRBs are not completely understood, but the most likely model involves a massive rotating star which collapses at the end of its life 271
- 7.22 Afterglow of the GRB 010222, imaged by amateur astronomer Gary Billings, Calgary, on 22 February 2001 272
- 7.23 Model of an active galactic nucleus (AGN) 273
- 7.24 Light curves of the two images of the gravitationally lensed quasar SBS1520+530 A and B, and of a comparison star S4. A and B are each images of the quasar, and their variability is that of the quasar 274
- 7.25 Light curve of V838 Mon, based on visual observations from the AAVSO International Database 275
- 7.26 Hubble Space Telescope image of V838 Mon 276
- 8.1 Spectra of T Tauri stars 280
- 8.2 The position, in the H-R diagram, of a sample of T Tauri stars in the Taurus-Auriga molecular cloud complex 281
- 8.3 Light curve of the T Tauri star DK Tau 282
- 8.4 Spectroscopic variations in the T Tauri star η Cha 11 285
- 8.5 Schematic model of a T Tauri star 288
- 8.6 The photographic (small points) or B (large points) light curve of FU Ori through 1976 289
- 8.7 Light curve of T Tau over 15000 days, based on visual measurements from the AAVSO International Database 294

xvi List of Figures

- 9.1 Spectrum variations in the UV NV lines of HD 58978 (FY CMa), a Be star 297
- 9.2 Long-term light curve of CX Dra, a Be star 298
- 9.3 Short-term light curve of α And, a Be star, obtained by the *Hipparcos* satellite, in the *Hipparcos* photometric band 299
- 9.4 Short-term spectroscopic variations of π Aqr, a Be star 300
- 9.5 Spectra of two WR stars, HD 192163 which is of WN type, and HD 193793 which is of WC type 302
- 9.6 Location of hypergiants and WR stars on the H-R diagram 304
- 9.7 Light curve of WR123 (HD177230), a WR star, obtained by the MOST satellite 305
- 9.8 Top: the average full range of brightness variation for supergiants; a few extreme 'hypergiants' are marked 306
- 9.9 The photometric V-magnitude variations of P Cyg, obtained with a robotic telescope 307
- 9.10 The HeI λ 3965 and H I λ 3835 lines in the spectrum of P Cyg, and their variation with time (the Julian Dates are marked) 308
- 9.11 Long-term light curve of η Car, showing the great eruption in the 19th century, the subsequent fading, and the more recent recovery, as the obscuring material disperses 310
- 9.12 The light curve of ρ Cas (filled symbols, top) compared to the radial velocity curve (dotted line, bottom) 312
- 9.13 The light curve of RY Sgr from 1991 to 2003 315
- 9.14 Spectrum and model for an R CrB star 316

Tables

4.1 Bright and/or interesting rotating variable stars 83
5.1 Bright and/or interesting eclipsing variable stars 105
5.2 Bright and/or interesting ellipsoidal variables 107
6.1 Bright and/or interesting Cepheid variable stars 160
6.2 Bright and/or interesting pulsating red giants and supergiants 168
6.3 Bright and/or interesting Beta Cephei and related stars 204
6.4 Bright and/or interesting pulsating red giants and supergiants 212
7.1 Bright and/or interesting cataclysmic and related variable stars 240
7.2 Bright and/or interesting symbiotic stars 254
8.1 Bright and/or interesting pre-main-sequence stars 292
9.1 Notable R Coronae Borealis stars 313

Preface

The roots of this book go back over forty years. As an undergraduate in 1960, I was exposed to the variable star research at the David Dunlap Observatory of the University of Toronto. Mentors such as Don Fernie, Jack Heard, and Helen Sawyer Hogg brought the field to life. As a graduate student, I sampled both theory (with Pierre Demarque) and observation (with Don Fernie). Then I was fortunate to obtain a faculty position at the University of Toronto's brand-new Erindale Campus in Mississauga, west of Toronto. I was concerned with teaching, supervising students, and building a new university campus.

My research continued, and my graduate teaching responsibility was a course on variable stars. This book evolved from that course. The 1970s were in many ways the 'golden age' of variable stars at the University of Toronto. A dozen graduate students undertook M.Sc. and/or Ph.D. theses on variable stars. The David Dunlap Observatory, being a 'local' observatory under our control, enabled both large-scale surveys, and long-term studies to be carried out – both of which are almost impossible at modern-day national observatories. The observatory was equipped with both a 1.88m spectroscopic telescope, and 0.6m and 0.5m photometric telescopes, and many of these thesis projects combined these techniques in a very effective way. I learned much from these graduate students, and owe much to my colleagues, including a succession of Directors of the David Dunlap Observatory – who were also Chairs of the Department of Astronomy and Astrophysics.

My urge to write a book on variable stars developed around 1980. I had become active in the American Association of Variable Star Observers. I had also begun to concentrate on the supervision of undergraduate research projects on the observation and analysis of variable stars. There was a need for a textbook suitable for high-level amateur astronomers, as well as for graduate and undergraduate students. There was an excellent book in German by Cuno Hoffmeister *et al.*, but,

by the time it was translated into English by Storm Dunlop, it was becoming out of date.

At that point, I acquired two potential co-authors – Janet Mattei and Lee Anne Willson. Janet was a professional astronomer who was overseeing the remarkable growth of the AAVSO as it entered the space age. Lee Anne, like me, worked in a university setting, and was deeply involved with the AAVSO as well as with students. Lee Anne actually spent a year in Toronto, at the newly established Canadian Institute for Theoretical Astrophysics at the University of Toronto. As I looked back, twenty years later, I realized that we had *almost* finished an excellent book! But we had become distracted. I edited conference proceedings on *The Study of Variable Stars using Small Telescopes*, and co-edited *Variable Star Research: An International Perspective* with Janet and with Christiaan Sterken, as well as proceedings of astronomy education conferences. To some extent, the ‘book bug’ was out of my system.

But by the twenty-first century, there still remained a need for a book on variable stars, and here it is. Unfortunately (or fortunately), the field of variable stars has changed drastically since 1984. The spirit of the Mattei–Percy–Willson book remains, but little of the substance. At my own university, as with most others in North America, graduate students’ interest in stars has been replaced by interest in extragalactic astronomy and cosmology, so it has been many years since I offered my graduate course on variable stars. My knowledge of the field, at the graduate level, is no longer comprehensive. But you cannot understand galaxies if you cannot understand stars! And variable stars, of course, are the tools by which we understand the age and distance scale of the universe, as well as the structure and evolution of the stars.

One of the problems in writing this book is to decide what to include and what to leave out. On the one hand, there are thousands of pages of details which could have been included. On the other hand, I recognize that there is a wealth of good print and on-line material on variable stars which is already available, including on the AAVSO’s website. And I admit that this book reflects my own research interests – perhaps more than it should. I hope, however, that it establishes the ‘big picture’ of variable stars, and gives the reader background and context for further learning about this ever-exciting field.

I thank the many individuals who have contributed to this book, in various ways, in addition to the late Janet Mattei and Lee Anne Wilson who got things started.

Several of my colleagues have kindly read through specific chapters, and contributed useful comments: Johannes Andersen, Christine M. Clement, William Herbst, John B. Lester, Geraldine J. Peters, Aleks Scholz, Matthew Templeton,

xx Preface

David G. Turner, Marten van Kerkwijk, Elizabeth Waagen, and Thomas R. Williams. Special thanks to Andy Howell, Slavek Rucinski, and Michael Shara for reading and commenting on substantial sections where my expertise was limited. Any errors or deficiencies in this book, however, are strictly my own.

Other colleagues have contributed illustrations: Tim Bedding, Jocelyn Bell Burnell, Gary Billings, Christine M. Clement, Peter Cottrell and Ljiljana Skuljan, Alex Filippenko and Tom Matheson, Gilles Fontaine, Doug Gies, Richard O. Gray, Gerald Handler, Arne Henden, Gregory W. Henry, Bill Herbst, Andy Howell and the CFHT Supernova Legacy Project, Alexandra Kalasova and Petr Harmanec, Laszko Kiss, S. Lefebvre and Tony Moffat, Michael Mattei, Stefan Mochnacki and Slavek Rucinski, Arto Oksanen, Optec Inc., Geraldine Peters, Mercedes Richards, Michael Shara, Aleks Scholz, and David Turner.

I thank them and all those others who have given me permission to use figures from their publications. This includes the editors of the journals from which many of the figures are taken. And I thank all those others who I might have forgotten.

The AAVSO Headquarters staff have been extremely helpful, not only in supplying illustrations for this book, but in so many other aspects of my research and education work. Arne Henden, Matthew Templeton, Elizabeth Waagen, and the late Janet Mattei – to whom this book is dedicated – are the most visible of the names. I also thank the AAVSO observers, without whom there would be no AAVSO, and without whom my research would have been much more difficult – or impossible. Thanks especially to Howard Landis who contributed, in so many ways, to the success of the AAVSO photoelectric photometry program.

I thank my research collaborators Peter Cottrell, Don Fernie, Petr Harmanec, Greg Henry, Bill Herbst, Christiaan Sterken, Endre Zsoldos and others, and my dozens of students – mostly undergraduates and outstanding senior high school students in the University of Toronto Mentorship Program. Their work is highlighted in several parts of this book, and has been an inspiration to me.

I thank the Natural Sciences and Engineering Research Council of Canada for supporting my research, and NSERC Canada and the Ontario Work-Study Program for supporting many of my undergraduate research students.

Three decades ago, Simon Mitton introduced me to Cambridge University Press, and I am proud to have them as publisher of “my book.” Special thanks to editors Jeanette Alfoldi, Lindsay Barnes, Vince Higgs, Jacqueline Garget, Sally Thomas, and especially to copy editor Anne Rix for her careful work.

Joseph B. Wilson and especially Byron Desnoyers Winmill have also provided careful, editorial help, especially in mastering the intricacies of Cambridge style

and formatting. I thank them, both for this and for their patience in dealing with my usually disorganized approach!

Finally, I thank my wife Maire and our daughter Carol for their inspiration, patience, and love. I have certainly benefitted from their examples as scholars, authors, teachers, and mentors. I hope that some of the joy of variable star astronomy, its organizations and people, has rubbed off on them.