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).

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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

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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,

David G. Turner, Marten van Kirkwijk, 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. Lefebre 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.