The study of cataclysmic variables – interacting binary stars containing a white dwarf accreting from an orbiting companion – is undergoing an exciting renaissance, as it embraces observations at all wavelengths. Cataclysmic variables allow, in particular, the direct and detailed study of equilibrium and non-equilibrium accretion discs; in turn this also helps in our understanding of X-ray binaries, black holes and active galactic nuclei. This timely volume provides the first comprehensive survey of cataclysmic variable stars, integrating theory and observation into a single, synthesized text.

An introductory chapter gives the historical background of studies of cataclysmic variables. The author then goes on to give an up-to-date review of both the observations (at all wavelengths, and over all time scales) and the theories and models of the structures and accretion processes believed to be involved. A very detailed bibliography is also provided to guide the reader to pertinent primary literature. Altogether this volume offers graduate students a single-volume introductory text while providing researchers with a timely reference on cataclysmic variable stars.

Cataclysmic Variable Stars

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CATACLYSMIC VARIABLE STARS

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The stars that have most glory, have no rest.

Samuel Daniel. *History of the Civil War.*

To Harry Ward and Harold (Sid) Slatter, inspiring teachers in formative years.

Contents

Preface

The history of cataclysmic variable star research mirrors the objects themselves: periods of relative inactivity punctuated by heightened or even explosive advances. Until about 1970 each resurgence of interest was a result of a distinct technological advance. In the past two decades the technological improvements have been almost continuous and the interest in cataclysmic variables has burgeoned from the realization that they have so much to offer. Not only are they of interest per se, exhibiting a challenging range of exotic phenomena covering the electromagnetic spectrum from radio waves to TeV gamma rays, and time scales from fractions of a second to millions of years, they are important for their relevance to other exciting areas of astrophysics.

For example, it has become evident that accretion discs are one of the most commonly occurring structures – probably all stars form from disc-like configurations, with material left over to provide planetary systems. A large fraction of binary stars form accretion discs at some stage of their evolution. Accretion discs are important in X-ray binaries – matter accreting onto neutron stars or black holes. Entire galaxies are initially gaseous discs, and most may develop central discs intermittently that fuel their active nuclei.

But it is in cataclysmic variables (CVs) that accretion discs are observed to best advantage – quasi-stable discs, unstable discs and transformations between them. In dwarf novae during outburst, or in nova-like variables in their high state, the light is dominated by emission from discs – and being almost two-dimensional their observed properties are strongly affected by the viewing angle. All are close double stars, and those with eclipses present unrivalled opportunities for determining spatially resolved physical structures. The CVs provide test beds for theories of accretion discs that may then be extended to more energetic regimes.

The instabilities in discs result in release of gravitational potential energy, observed as dwarf novae. Ultimately, the accumulation of hydrogen-rich material on the surfaces of the white dwarf primaries results in a thermonuclear runaway, observed as a classical or recurrent nova. These furnish unique opportunities to test models of non-equilibrium nuclear reactions, of hydrodynamics of expanding shells, of common envelope binaries and of radiation-driven stellar winds.

An added dimension appears in the effects of magnetic fields – either in providing viscosity in the accretion discs of nominally non-magnetic systems, or in the modification or total prevention of discs in systems whose primaries have field strengths in the range 10^5–10^8G. Among these are many of the most readily observed

celestial X-ray sources, and optically they show strongly variable linear and circular polarization.

Understanding of the evolution of CVs is still in its infancy. The physical processes involved include magnetic braking by stellar winds, angular momentum loss through emission of gravitational radiation, mass loss through nova eruptions, common envelope evolution, and complexities caused by the occurrence of large magnetic fields in the primaries of some systems.

CVs provide unusual opportunities for amateur astronomers to make valuable contributions. Their very unpredictability and their apparent brightness during outburst has ensured that they have had a high priority among amateurs, with the result that almost continuous light curves over many decades are available for a few dozen systems. Understanding of the underlying physical processes is only now becoming sufficient to enable these light curves to be analysed in meaningful ways.

There have been many review articles and conference proceedings on CVs, and there are books devoted to the theory and observation of accretion discs, but this is the first book to introduce and review the topic of CVs in its entirety, seen through the eyes of one author. It is intended that the book shall do duty at a number of levels: it may serve as a graduate text, giving an in-depth overview of one area of interacting binaries; it will give mature researchers in adjunct disciplines a means of making contact with current issues in this exciting field; it will give the community of amateur variable star observers some insight into the importance of their labours from the professional viewpoint; and it should serve the CV community itself by providing a moderately comprehensive overview into which they can fit their often more specialized knowledge. These specialists will no doubt be at least as interested in what I have not found room for as in how I have represented their own contributions. Not all of the latter have stood the test of time; the selection that I have made inevitably is a personal choice, including some judgement of what is unlikely to be of lasting value. If this provokes further investigation I shall be satisfied in the investment of time given to what has become in my mind 'the bloody book' (after 'These bloody mathematics that rule our lives': Albert Camus, *The Plague*).

A number of simple conventions have been adopted in this book: discs *outburst* and novae *erupt*; the *amplitude* of a periodic signal is half the range of the modulation (incorrectly called 'semi-amplitude' by some authors); the mass donor is called the *secondary* star, even in those rare instances where it is more massive than the mass receiver; compact forms are used for multiple repeated types (NL for nova-like) but, to avoid possible confusion with other symbols, no distinction is made between singular and plural for terms with latinate plurals (DN for both dwarf nova and dwarf novae).

References are extensive but not exhaustive. However, areas of topicality are more comprehensively referenced in order to give the researcher rapid access to the current literature (e.g., accretion disc simulations, magnetic CVs, superhump phenomena).

Over the past 25 years I have benefitted greatly from personal contacts with the expertise and enthusiasm of the international CV community. For discussions and advice specifically related to the writing of this book I am especially grateful to J. Cannizzo, F. Meyer, E. Meyer-Hofmeister, D. O'Donoghue and D. Wickramasinghe. J. Faulkner, R.P. Kraft and D.N. Lin provided financial support, hospitality and amusement during a three month sabbatical at Santa Cruz in 1990, as did F. Meyer, E.

Meyer-Hofmeister and H. Ritter for three months at Garching in 1992 and D. Wickramasinghe for one month at Canberra in 1993. These short sabbaticals were also aided by travel funds from an Ernest Oppenheimer Travelling Fellowship, from the University of Cape Town and from the Foundation for Research Development. The last named has been largely responsible for funding my research into CVs over the past decade.

J. Cannizzo kindly computed Figure 3.31 and M. Harrop-Allin kindly prepared Figure 9.11. Typing of the manuscript through its many evolutionary stages has been in the care of Penny Dobbie, whose patience in dealing with recalcitrant software, inadequate hardware and a demanding author deserve mention in the annals of sainthood. Penny was guided out of some of the software problems by generous help from Jacqui King.

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