A cataclysmic key programme for SALT†

Brian Warner*

The study of cataclysmic variable stars has a long history in South Africa. A brief overview of this history is followed by indications of where the new Southern African Large Telescope (SALT) is likely to make major contributions to this research field. There are about 60 staff and students in the SALT Consortium, who work on interacting binaries containing compact components. Most of these people work on cataclysmic variable stars, with the remainder researching neutron star and black hole binary pairs. This group will use a significant amount of SALT observing time. I look at some of the collective and individual topics that SALT will be able to address.

Introduction

The study of cataclysmic variables (CVs), novae and dwarf novae in particular, has deep roots in South Africa. Major contributions to the long-term light curves have been made by amateur astronomers since early in the twentieth century. Overbeek[1] points out that over 750 000 observations of the magnitudes of variable stars have been made by about 100 amateurs in southern Africa.

A fine example of amateur/professional collaboration was set by the discovery and subsequent study of Nova Pictoris in 1925. This nova was discovered by a Mr R. Watson, a telegrapher in Beaufort West, on his way to work early one morning. He was an amateur astronomer who had made one of the many independent discoveries of Nova Aquilae in 1918. Watson telegraphed the Royal Observatory in Cape Town, which enabled the then director, Harold Spencer Jones, to obtain spectra on the rise of the nova, and eventually to produce one of the most comprehensive studies ever made of the evolution of the spectrum of a nova.[2]

The earliest detection of rapid variations in brightness in a southern CV was made by David Thackeray and his colleagues[3] in 1949 at the Radcliffe Observatory in Pretoria. They noticed irregular variations in brightness on time scales of minutes in VV Puppis. This star is now known to be polarized and a strongly magnetic CV, one of the first of the 'polars' to be recognized.

Although high-time-resolution astronomical photometry was partly pioneered in South Africa by David Evans in the 1950s, in his study of lunar occultations (for details see ref. 4), no use of it was made to investigate variable stars. It was not until 1972 that application of pulse-counting high-speed photometry was introduced in South Africa by R. E. Nather. He and the author had been observing CVs in the northern hemisphere (from the McDonald Observatory at the University of Texas (UT)) for four years before the latter's move to Cape Town‡. Since 1972, the study of CVs has been a major research field at the University of Cape Town (UCT). And since the mid-1970s the importance of the field has increased with the realization of the connections between CVs and other areas of astrophysics.

It is through CVs in particular that the study of accretion discs is most readily pursued. Accretion discs exist throughout the Universe – around black holes in Active Galactic Nuclei, around young stars in the process of formation, and in interacting binaries (in which mass is transferred from one component to the other), especially those containing degenerate accretors. The latter comprise white dwarfs, which are observed in CVs and Symbiotic stars, and neutron star and black hole accretors that constitute X-ray binaries.

Reference 5 gives an overview of the importance of CVs both in their own right and to other areas of astrophysics. Since that review was published, results from the Chandra/XMM X-Ray satellite have shown that there are many bright stellar X-ray sources in globular clusters, including those in M31 and other nearby galaxies, and that most of these are CVs and low-mass X-ray binaries. Furthermore, the dynamical evolution of globular clusters and other dense stellar aggregates is largely determined by the population of these gravitationally tightly bound interacting binaries, which is further reason to understand them as fully as possible.

SALT

The telescope

Some background to the construction of the Southern African Large Telescope (SALT) at Sutherland and its initial instrumentation has recently been given by Buckley, Charles and O'Donoghue.[6] At an early stage, the decision made by the South African government to support such a project was influenced by a number of factors, including (a) the long history of world-class astronomical research in the country (starting in 1828 with the first observations made at the Royal Observatory, Cape of Good Hope[7,8]), (b) a very good site with existing infrastructure at a unique longitude in the southern hemisphere, and (c) a comparatively small but internationally high-profile group of optical astrophysicists [the successor to the Royal Observatory, the South African Astronomical Observatory (SAAO), from 1972 to 2000 published about 1800 research articles; the Department of Astronomy at the University of Cape Town, over the same period, produced about 600 articles].

The SALT Consortium

The importance of the observation and interpretation of accretion discs and interacting binaries is seen in the large number of individuals, within the SALT Consortium, who are actively engaged or have direct interests in such studies. The consortium was assembled from groups who wished to have access to a large telescope. There was no particular bias towards the observers of interacting binaries, yet there are at least 40 such staff members§ of the various institutions, to which may be added a

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‡This was not the first of the connections between the universities of Texas and Cape Town. A. P. Fairall received his PhD degree from UT and moved to UCT in 1970; P. A.T. Wild, then in the Physics Department at UCT, spent a year as McDonald Fellow at UT during 1969/70. Prior to these, D.S. Evans, then deputy director of the Cape Observatory, had spent a year as visiting professor at UT in 1966 and moved there permanently in 1968. In the mid-1970s, W. van Citters, J.T. McGraw and D. Kurtz, who had been postgraduate students at UT during the author's tenure there, spent a year or more at UCT. The origin of the UT/UCT interacting binary dates from those years. The fact that UT and UCT now have access to similar large telescopes is probably not unconnected with these early interchanges.

*Department of Astronomy, University of Cape Town, Private Bag, Rondebosch 7701, South Africa. E-mail: warner@physci.uct.ac.za

§These include: Thorstensen (Dartmouth); Clemens (North Carolina); Gallagher, Orio (Wisconsin); Beuermann, Hessman, Reinsch (Göttingen); Smak, Olech, Sarna, Mikolajewska, Schwarzenberg-Czerny (Warsaw); Evans, Hellier (Keele); Hassal, Bromage (Central Lancashire); Haswell, Norton, Kolb, Barnard, Willems, Roche (Open University); Coe, Haigh, Kaiser, Knigge, Morales, Sanzana (Southampton); Charles, Buckley, Potter, Romero, O'Donoghue, Still (SAAO); Warner, Woudt (UCT); Koen (Western Cape); Meintjies (Free State); de Jager, Raubenheimer (North-West).

corps of students, bringing the total population to about 60. There are representatives from almost all the participating institutions, and the implication is that SALT will be a major contributor to future observations of interacting binaries in our and neighbouring galaxies. There could be advantage in some of the observational programmes being coordinated among the SALT observers, and indeed more widely in SALT/HET north/south joint programmes. If SALT is to include key programmes in the structure of its observational planning, then one on CVs and related objects is appropriate.

Examples of CV research programmes

The Hobby-Eberly Telescope (HET), the forerunner of SALT, was originally conceived as a spectroscopic survey telescope, and had the temporary initialism 'SST'. Although broadened in concept and instrumentation to include detailed study of individual objects, both SALT and HET remain powerful survey instruments for faint objects.

General spectroscopic survey

There are nearly 1300 CVs in the Downes *et al.* catalogue.[9] Because they are concentrated towards the Galactic centre, more than half of the CVs lie in the southern hemisphere. About 37% of the total do not have any observed spectra. There are probably ~200 of these poorly observed CVs that are bright enough to be within reach (on the sky and in brightness) of SALT. A complete spectroscopic survey of *all* CVs observable with the low-resolution spectrograph on SALT is justifiable: it would provide a unique, homogeneous data base from which a new classification scheme could emerge, and in particular any unusual spectra could lead to discoveries of new types of CVs. This and the photometric survey that is being undertaken at Sutherland with existing telescopes[10–15] will reveal the most valuable CVs for intensive study with SALT, which will provide exciting projects for research staff and students for some years to come.

CVs in the Magellanic Clouds

The study of erupting novae in the Magellanic Clouds and other neighbouring galaxies is an obvious project for SALT and will supplement what is already being achieved at other observatories. Old novae decay in brightness to post-eruption quiescent values reaching as bright as absolute magnitude $M_v \sim +1$; there is a spread of brightness because the apparent luminosity of a disc-dominated CV depends on its orbital inclination – the face-on discs are the brightest.[16] Most of the historical novae in the Large Magellanic Cloud (LMC) have been rediscovered from their blue colours and variability;[17] many more (of prehistoric eruption date) will be found among the nova-like variables that still await discovery. Moderate amounts of high-time-resolution photometry should be obtained for these brighter CVs, leading to the first determination of their orbital period distribution in an external galaxy—and one with a metal content differing from our Galaxy's.

A new area of research will be opened by the regular availability of modest amounts of observing time. The far southerly declination of the Magellanic Clouds makes them optimal systems for observation by SALT. The brightest M_vs of CVs are at $\sim +1$; these occur for the system of highest mass transfer rate and are nova-likes (which include the old novae) and outbursting dwarf novae (DN).[18] In the LMC the brightest DN in outburst would therefore be expected to reach $M_v \sim 19½$, and indeed the first survey of outbursting DN has produced six probable detections in the apparent magnitude range ~19.2–22.5 (Shara, Hinkley & Zurek:[19] hereafter SHZ). The survey was carried out with the Cerro Tololo Inter-American Observatory's 4-metre reflector (in Chile) on alternate nights over an 11-night baseline, with a total search area of 0.38 deg.^{2} The observed light curves resemble those of DN, but there are doubts remaining about their classification, which could easily be removed by observing repeat outbursts of these same objects.

SHZ point out that an extra stellar magnitude of sensitivity and an improvement in spatial resolution should lead to the discovery of thousands of DN in the Magellanic Clouds. SALT will deliver these requirements, and if it is possible to obtain approximately one hour per night of observational time over a baseline of two months or so during peak Magellanic Cloud observing season, interesting results should be obtained. SHZ estimate an areal density of 10^4 DN deg^{-2} in the LMC, so the 8′ circular field of the principal CCD photometer, SALTICAM, should contain ~140 DN. Even if only a small fraction prove detectable, it will provide a useful sample which will lead to the first reliable luminosity function and outburst frequency distribution of DN. If the candidates are noticed on the CCD frame within a day or two of observation, spectroscopic follow-up (which should be possible to at least 23rd magnitude) can give confirmation of the CV nature of the object.

Even if only one LMC field is selected for detailed study, there can be considerable spin-off. Additional multicolour observations and high-speed photometry of the field should lead to the discovery of non-erupting CVs (the nova-likes). The data set, consisting of daily snapshots and some higher time resolution photometry, will provide an opportunity for detecting variable stars of types other than CVs. The stacked data will give a general purpose deep field into and beyond the LMC.

A similar project could be carried out for the SMC, in which no CVs other than a small number of erupting novae have yet been observed.

Photometric and polarimetric surveys

The quite short observational windows that SALT provides over much of the sky are very suitable for snapshot and 'video clip' observations of CVs – which will also lead to the discovery of the most interesting objects. A general polarimetric survey will reveal the more strongly magnetic CVs (polars and some of the intermediate polars); an hour's worth each of photometry at ~20 s time resolution on CVs chosen (from spectroscopic evidence) for their low mass transfer rate will reveal more of the new class of CVs (which we designate the CV/ZZ stars) where the white dwarf primary is a ZZ Cet star (i.e. pulsating in non-radial modes).[20] Similar sampling by high-speed photometry of faint CVs in general will uncover more magnetic CVs with ultra-short rotation periods (i.e. less than about 10 min). The more examples of all of these that we have, the closer we will come to understanding them.

Targeted observations

The wide variety of instrumentation available on SALT will deliver greater signal-to-noise ratio for all of the observational techniques that have become standard procedures in CV studies, and will allow application of those techniques to fainter objects. There is a revealed truth in CV research: no two CVs are alike. The reason is that not only are there so many parameters that determine the physical behaviour and appearance of CVs, many of these parameters have a large dynamic range. Even masses and mass ratios have a substantial range – masses range from ~0.02–1.0 $M_\odot$ (solar masses) for the secondary star components and ~0.2–1.4 $M_\odot$ for the primaries; orbital periods cover the range ~10 min–100 yr (the upper end being Symbiotic stars);

orbital separations range over ~0.1–5000 solar radii; rates of mass transfer ($\dot{M}$) of 0–10^{-7} $M_\odot$ per year; magnetic fields of the primaries from 0–10^8 G; and compositions from standard solar through hydrogen-deficient to pure helium. Then there are the magnetic fields and cycles that occur in the secondaries, which lead to differing long-term behaviours of mass transfer rate, and the length of time since the last nova eruption, which determines the surface temperature of the primary and the effect of irradiation of the secondary by the hot primary. Finally, the observed photometric and spectroscopic behaviour of a CV depends quite sensitively on its orbital inclination.

The result of this mix of influences is that understanding the physics involved in CVs has depended both on detailed studies of individual CVs and on the general properties of the various subclasses of CV. In particular, studies of extreme examples have provided the clues to the behaviour of the more normal objects. To take just one example: many of the strongest X-ray sources in the sky are CVs, and this was just becoming recognized in the mid-1970s when the first strongly optically polarized CV was found (AM Her in 1976[21]), showing the presence of a strong magnetic field, and implying magnetically controlled accretion onto the primary. Although most CVs are X-ray sources, the strongest are those in which magnetic fields control and concentrate the transferring mass onto small regions of the primary. Subsequent to the discovery of these polars and intermediate polars, more subtle signatures of magnetic fields on the primaries have been recognized, for example, the short-period brightness oscillations known as dwarf nova oscillations (DNOs) and quasi-periodic oscillations (QPOs), which are interpreted as effects of magnetically controlled accretion.[22]

Figure 1 is a Fourier transform spectrum of the light curve of Z Chamaeleontis during outburst, showing the presence of a strong DNO and QPO. The amplitudes of DNOs are often so low that they are detectable only through Fourier analysis.

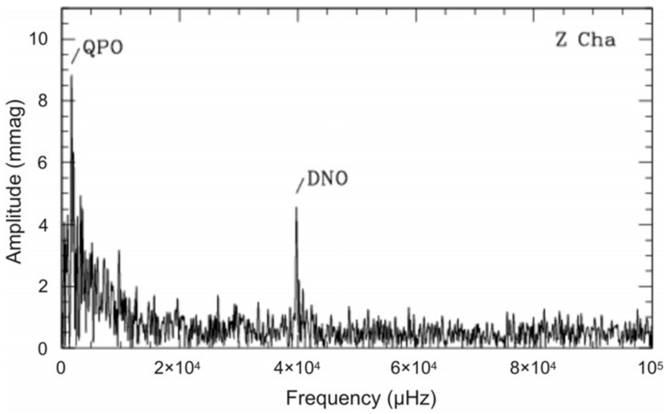

Fig. 1. Fourier amplitude spectrum of ~1.5 h of light curve of the dwarf nova Z Cha during outbursts on 6 February 2000. The ordinate axis is amplitude measured in millimagnitudes.

The importance of detailed observational studies of individual CVs, especially the more extreme objects, is therefore clear. SALT will provide the means by which rapid progress should be possible, though because of the limitations on continuous observation, not all aspects will be able to be covered. It should also be remembered that in CVs there are some areas of research where larger telescopes do not necessarily provide better signal-to-noise ratios—if the intrinsic flickering in a CV dominates the signal, then lower photon noise, atmospheric scintillation and instrument noise components mean only that the flickering is seen with better fidelity.

An abundance of photons enables higher resolution to be achieved—higher spectral resolution and higher time resolution, and a combination of both. I will give some examples of where these can advance current research.

High-time-resolution spectroscopy

The short time scales of variations in CVs naturally demand high time resolution. High-speed photometry has long given valuable insight into the structures of CVs, but only in recent years has it been supplemented with spectroscopy having adequate time resolution. For example, I expect Doppler tomography of CVs (see chapter 2 of ref. 18) to be a major application of SALT

I have already mentioned the flickering that occurs in CVs; this appears on time scales from sub-second to tens of minutes. From eclipse analyses of CVs possessing accretion discs it is found that the flickering comes from two regions (which differ in relative importance in different objects)—(a) the stream impact region of the accretion disc, which leads to supersonic shocks and the formation of a 'bright spot', and (b) the disc itself, especially the inner regions near to the primary. Flickering from the bright spot is reasonably well understood as the effect of unstable shocks in turbulent gas flow, but the nature of disc flickering is speculative. A probable explanation is that it is the result of processes similar to those acting in the photosphere and chromosphere of the Sun, namely, magnetic loops and prominences rising out of the disc and releasing their magnetic energy as flares. Whether this can account for the entire range of time scales, and their frequency distribution, is not known.

With sufficient time resolution it will be possible to examine the evolution of emission line profiles accompanying the flares and flickers. If their sources are compact regions on the disc, then the Keplerian periods and differential shearing of the sources will be detectable in the lines. In principle it should be possible to correlate lifetimes with position in the disc. The results may well assist in the interpretation of similar solar phenomena.

This is an 8-m-class telescope project, and the first attempts to observe and analyse such observations have been already been made with the European Southern Observatory's VLT.[23] Because the time scales are so short, obtaining only tens of minutes of spectral data is sufficient for analysis, but the observations need to be made on a range of CV types. This is a project ideally suited to SALT.

Apart from the stochastic flickering, time-resolved spectroscopy at adequate signal-to-noise ratios of the DNOs and QPOs in emission lines (that accompany the continuum modulations mentioned above) will extend what has been done[24] so far only for DNOs in the eclipsing dwarf nova V2051 Oph. This is, elucidate further the nature of the supposed rotating beam of radiation that is processed by the accretion disc and excites the emitting gas above it. Again, 'video clips' of the kind that SALT will be able to deliver are adequate for this work.

Polars show quasi-periodic modulations of brightness at typically a few herz that are ascribed to oscillations in the accretion column.[25,26] Whether there are accompanying modulations in emission lines is not known, but SALT should be able to investigate this, and it might even be possible to perform echo mapping as the modulated continuum emission excites the different components at different distances within the system. Just having higher time resolution in continuum observations will help to investigate the claim that there are many simultaneous excitations of separate accretion columns, each with its own resonance frequency.[27] This is an area of research that has been neglected in recent years because of the inability to make progress with small telescopes.

Another area of research (and one that we have been pursuing in Cape Town) is the study of the shortest-period interacting binaries. These are the AM CVn stars, which contain a pair of helium white dwarfs. Only fourteen definite AM CVn stars are known, plus two controversial objects,[28] four of which were discovered from observations made at Sutherland. It is therefore a local speciality, and one that is particularly appropriate for SALT to be used on — the orbital periods of the southern AM CVn stars range from 10 to 33 minutes and most are faint or have faint states, making time-resolved spectroscopy a large-telescope necessity. This is a particularly interesting area of research because the AM CVn stars should be prominent sources of gravitational radiation, and are of importance as possible progenitors of Type Ia supernovae (the standard candles of the accelerating universe).

High-time-resolution photometry

Eclipse profiles in CVs, in low-$\dot{M}$ accretion disc systems and especially in polars, frequently show large changes in brightness on time scales of only tens of seconds. These will be better resolved and at higher signal-to-noise ratios (with the caveat mentioned above of limitations set by system flickering) by use of SALT. The first example of eclipses in a polar, observed with SALT, is given in the review by Buckley, Charles and O'Donoghue.[6]

The improvement in observation of DNOs with SALT, compared with the best that we have previously achieved, is shown in Fig. 2, where two ~26-s oscillations in the star VW Hyi near the ends of its outbursts are shown. The lower panel is from a photometric run made with the 1.0-m reflector at Sutherland on 16 June 1984; the upper panel is a small extract from a photometric run made with the SALTICAM photometer on the same star on 9 December 2005. In the former each plotted point results from integrating all the visible light from the star for 2 seconds; the latter records the signal integrated for 0.11 seconds through an ultraviolet filter. Although, from a purely statistical point of view, the 26-s modulation is merely over-sampled by the larger telescope, the greatly improved time resolution with good signal-to-noise ratio will enable a search for much higher frequency and/or lower amplitude signals, even short-lived ones.

The general availability of time series photometry at considerably higher time resolution than hitherto carries the exciting possibility that, as is common in the progress of science, new technology will reveal new phenomena. To give an example (not necessarily a prophecy), radial oscillations of white dwarfs have not yet been observed; their periods would be in the range 1–5 s. It is generally understood that, as it requires more energy to excite radial than non-radial modes, it is the latter (as mentioned above) that are excited in isolated white dwarfs (that is, the ZZ Cet stars). But in a CV/ZZ star the rain of accreting gas may excite radial modes—and these would not necessarily be confined to a narrow 'instability' strip because the excitation mechanism comes from outside and is less dependent on positive feedback from within the white dwarf. A search at high time resolution of CVs in which the white dwarf is seen prominently in the spectrum seems worthwhile. This should included polars, and although their large magnetic fields may prevent the transverse motions characteristic of non-radial oscillations, low amplitude radial oscillations might be possible. In the case of polars the observations need to be confined to those times when the system is in a state of low $\dot{M}$, or perhaps for those systems where the accretion pole is occulted by the primary for part of the orbital cycle, so that radiation from the accretion column does not overwhelm that from the surface of the white dwarf. Again, the faintness of polars in these lower luminosity states requires SALT to provide sufficient photons at high (~0.1 s) time resolution. And in general, for all CVs that descend into states of low $\dot{M}$, thus becoming most difficult to observe just when they are at their most interesting, SALT will be a valuable asset.

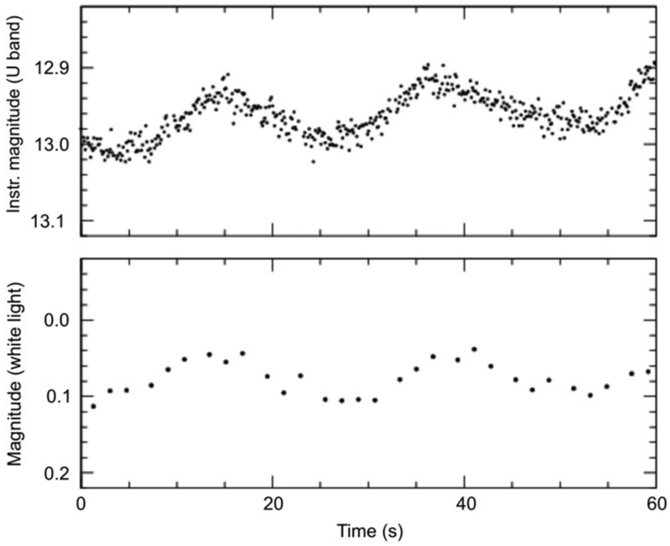

Fig. 2. Short sections of light curves of the dwarf nova VW Hyi in outburst, as observed by SALT (upper panel) and a 1-m telescope (lower panel).

The above remarks can be generalized to include high-time-resolution polarimetry and spectropolarimetry. As SALTICAM has been the first usable instrument on SALT, it is worth noting that the short time scale brightness variations inherent in CVs—especially AM CVn stars, eclipsing polars, DNOs and CV/ZZ stars—provide good opportunities for producing interesting science rapidly in the start-up phase of SALT.

High-resolution spectroscopy

The intermediate and high-resolution spectrographs on SALT will provide spectra at resolutions not normally available to CV studies. The relatively short observational windows (less than the orbital period of a typical CV) put some restrictions on what can be done, and it is not clear that in such broad-line sources higher resolution has much advantage, but this is another arena in which a preliminary investigative programme may reveal unsuspected aspects of CVs. If nothing else, for the most distant CVs the strengths of interstellar lines will be useful as distance indicators!

Time-critical observations

Many studies of binary stars require observations to be made at specific times. In the case of eclipsing systems, where it may be important to obtain spectra or photometry during ingress or egress, there are usually opportunities available at accurately predictable times. But interacting binaries in general, and CVs in particular, sometimes require observations to be made with target of opportunity (ToO) time. For example, the very unpredictability of dwarf nova outbursts is one of their aspects that makes them challenging and interesting. More observations are required, for instance, suitable for studying the structures of the heating and cooling waves that traverse accretion discs during the rise and fall, respectively, of dwarf nova outbursts. Improved photometric and spectroscopic observations of the DNOs and QPOs in dwarf novae are required — but it is rarely the case that advance notice of more than a day or two is available. In some cases it may be that only when monitoring with a small telescope shows that a particular behaviour is under way that access to SALT might be called for. It is important, therefore, that a certain amount of ToO time be available on SALT for those of us studying CVs.

Conclusions

There are opportunities for collaborative work on CVs within the SALT Consortium, which may be extended in some cases to become SALT/HET 'all sky' studies. Further extension to include outside groups, especially theoreticians, may happen. Long-term, low-time-resolution studies, and short bursts of high-time-resolution observation, are well suited to SALT's special properties. ToO studies with short lead times are important for such unpredictable systems as CVs.

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1. Overbeek M.D. (1995). Amateur astronomy in South Africa. *Astrophys. Space Sci.* **230**, 479–493.
2. Spencer Jones H. (1931). The spectrum of Nova Pictoris. *Annals of the Cape Observatory* **10**, Part 9.
3. Thackeray A.D., Wesselink A.J. and Oosterhoff P.Th. (1950). Additional observations and improved ephemeris of VV Puppis. *Bull. Astr. Inst. Netherlands* **11**, 193–199.
4. Warner B. (1988). *High Speed Astronomical Photometry.* Cambridge University Press, Cambridge.
5. Warner B. (2000). Cataclysmic variables. *Publ. Astr. Soc. Pacific* **112**, 1523–1525.
6. Buckley D.A.H., Charles P.A. and O'Donoghue D. (2005). Science with the Southern African Large Telescope. *S. Afr. J. Sci.* **101**, 531–535.
7. Warner B. (1978). *Astronomers at the Royal Observatory, Cape of Good Hope.* Balkema, Cape Town.
8. Warner B. (1995). *Royal Observatory Cape of Good Hope, 1820–1831: The Founding of a Colonial Observatory.* Kluwer Academic, Dordrecht.
9. Downes R.A., Webbink R.F., Shara M.M., Ritter H., Ulrich K. and Duerbeck H.W. (2001). A catalog and atlas of cataclysmic variables: the living edition. *Publ. Astr. Soc. Pacific* **113**, 764–768.
10. Woudt P.A. and Warner B. (2001). High-speed photometry of faint cataclysmic variables – I. V359 Cen, XZ Eri, HY Lup, V351 Pup, V630 Sgr, YY Tel, CQ Vel and CE-315. *Mon. Not. Roy. Astr. Soc.* **328**, 159–166.
11. Woudt P.A. and Warner B. (2002). High-speed photometry of faint cataclysmic variables – II. RS Car, V365 Car, V436 Car, AP Cru, RR Cha, BI Ori, CM Phe and V522 Sgr. *Mon. Not. Roy. Astr. Soc.* **335**, 44–52.
12. Woudt P.A. and Warner B. (2003). High-speed photometry of faint cataclysmic variables – III. V842 Cen, BY Cir, DD Cir, TV Crv, V655 CrA, CP Cru, V794 Oph, V992 Sco, EU Sct and V373 Sct. *Mon. Not. Roy. Astr. Soc.* **340**, 1011–1019.
13. Woudt P.A. and Warner B. (2006). Dwarf nova oscillations and quasi-periodic oscillations in cataclysmic variables – IV. Observations of frequency doubling and tripling in VW Hyi. *Mon. Not. Roy. Astr. Soc.* **367**, 1562–1576.
14. Woudt P.A., Warner B. and Pretorius M.L. (2004). High-speed photometry of faint cataclysmic variables – IV. V356 Aql, Aqr1, FIRST J1023+0038, Halpha 0242-2802, GI Mon, AO Oct, V972 Oph, SDSS 0155+00, SDSS 0233+00, SDSS 1240-01, SDSS 1556-00, SDSS 2050-05, FH Ser. *Mon. Not. Roy. Astr. Soc.* **351**, 1015–1025.
15. Woudt P. A., Warner B. and Spark M. (2005). High-speed photometry of faint cataclysmic variables – V. V433 Ara, OQ Car, V591 Cen, V1039 Cen, Cal 86 (Dor), UY Mic, LB 9963 (Oct), V367 Peg, Sgr (MACHO peculiar variable), RX J0403+044 (Tau), V382 Vel and SY Vol. *Mon. Not. Roy. Astr. Soc.* **364**, 107–116.
16. Warner B. (1986). Accretion disc inclinations and absolute magnitudes of classical nova remnants. *Mon. Not. Roy. Astr. Soc.* **222**, 11–18.
17. Shara M.M., Hinkley S. and Zurek D.R. (2003). Erupting dwarf novae in the Large Magellanic Cloud. *Astron. J.* **126**, 2887–2895.
18. Warner B. (1995). *Cataclysmic Variable Stars.* Cambridge University Press, Cambridge.
19. Cited in ref. 17.
20. Warner B. and Woudt P.A. (2004). Pulsating white dwarfs in cataclysmic variables: the marriage of ZZ Cet and dwarf nova. *Astr. Soc. Pacific, Conf. Series* **310**, 382–386.
21. Tapia S. (1977). Discovery of a magnetic compact star in the AM Herculis/3U 1809+50 system. *Astrophys. J. Lett.* **212**, 125–129.
22. Warner B. and Woudt P.A. (2002). Dwarf nova oscillations and quasi-periodic oscillations in cataclysmic variables – II. A low-inertia magnetic accretor model. *Mon. Not. Roy. Astr.* Soc. **335**, 84–98.
23. Hoffman B., Hessman F.V. and Reinsch K. (2002). Kepler tomography of the accretion disk in V436 Centauri. *Astr. Soc. Pacific Conf. Ser.* **261**, 485–486.
24. Steeghs D., O'Brien K., Horne K., Gomer R. and Oke J.B. (2001). Emission-line oscillations in the dwarf nova V2051 Ophiuchi. *Mon. Not. Roy. Astr. Soc.* **323**, 484–496.
25. Larsson S. (1992). Rapid optical variability in the AM Herculis object V834 Centauri. I – Quasi-periodic oscillations. *Astron. Astrophys.* **265**, 133–143.
26. Imamura J N. (1984). Comparison of the X-ray observations of the AM Herculis objects to theory. *Astrophys. J.* **285**, 223–231.
27. Ramseyer T.F., Robinson E.L., Zhang E., Wood J.H. and Stiening R.F. (1993). A survey for QPOs in AM Herculis stars and a detailed study of the QPOs in AN Ursae Majoris. *Mon. Not. Roy. Astr. Soc.* **260**, 209–220.
28. Woudt P.A. and Warner B. (2003). The new AM CVn star in Hydra. *Mon. Not. Roy. Astr. Soc.* **345**, 1266–1270.