Twenty-Eight Years of CV Results With the AAVSO

Paula Szkody
Anjum S. Mukadam
Department of Astronomy, University of Washington, Seattle, WA 98195; email correspondence should be sent to szkody@astro.washington.edu

Boris T. Gaensicke
Department of Physics, University of Warwick, Coventry CV4 7AL, England

Janet A. Mattei
Arne A. Henden
Mike Simonsen
Matthew R. Templeton
Elizabeth O. Waagen
Gary Walker
AAVSO, 49 Bay State Road, Cambridge, MA 02138

Edward M. Sion
Department of Astronomy and Astrophysics, Villanova University, Villanova, PA 19085

Steve B. Howell
NASA Ames Research Center, Moffett Field, CA 94035

Dean Townsley
Department of Physics and Astronomy, University of Alabama, Tuscalosa, AL 35487

Presented at the 100th Annual Meeting of the AAVSO, October 7, 2011; received November 22, 2011; accepted November 29, 2011

Abstract Working with AAVSO data and AAVSO staff on cataclysmic variables since the 1980s resulted in twenty-nine papers from 1984 to 2011. The early work began with characterization of optical light curves of various dwarf novae and novalikes, then moved into coordination of optical observations with satellites (IUE, EUVE, XMM, Chandra, HST, GALEX) to explore the ultraviolet and X-ray regimes of disk systems versus those containing magnetic white dwarfs. The major advances in the field that were derived from these results are summarized, ending with the recent results on the cooling of the white dwarfs and the return of pulsations in GW Lib and V455 And following their 2007 outbursts, and on the spectra of the two peculiar Z Cam systems IW And and V513 Cas.

1. Introduction

A Centennial is a time for looking back and pondering the progress that has been made and remembering the people responsible for that progress. After finishing my Ph.D. in 1975 in the field of cataclysmic variables (CVs), I was eager to pursue new objects and new ways of doing things. Having met Janet Mattei at a CV meeting, I was introduced to the AAVSO and its archives and observers who had their own telescopes. Thus began a collaboration that has continued to the present time. A brief summary of twenty-eight years of data, highlighting my personal results from twenty-nine papers that used AAVSO data is given below. This summary is divided into the eras of its two directors during that period of time, and ends with results on the ongoing projects of observing the accreting, pulsating white dwarfs in CVs and spectral observations of two peculiar Z Cam stars. The CV types that will be discussed include typical systems containing accretion disks, the systems containing highly magnetic (B > 10MG) white dwarfs termed Polars, and the subset of Low Accretion Rate Polars termed LARPs.

2. The Janet era: 1984–2004

The hot topics in the 1980s were centered on the cause of dwarf novae outbursts and the observed UV delay from the optical during the rise to outburst, the differences in outburst cycles for different objects, and the differences between theoretical predictions and observations of the boundary layer (the area where the accetion disk meets the white dwarf surface). The tools to explore these issues included the International Ultraviolet Explorer (IUE), used for ultraviolet spectra, and ROSAT and EXOSAT for the X-ray regimes. To lay the groundwork on outbursts, the large AAVSO data archive on dwarf novae was used to measure the outbursts of twenty-one well-studied dwarf novae. The rise, maximum, decline, and total outburst duration were measured and correlated with various properties (Szkody and Mattei 1984). These first studies showed a correlation of outburst duration with orbital period, as well as a bifurcated pattern of outbursts for some systems like SS Cyg. While this work provided a framework for theoreticians, only bright systems were well-observed. Since that time, it was discovered that the faint WZ Sge systems or Tremendous Outburst Amplitude Dwarf novae (TOADs; Howell, Szkody, and Cannizzo 1995) are the shortest orbital period systems but have the longest outbursts (as they only show superoutbursts which last weeks). The early work for the 1984 paper also showed some intriguing behavior apparent in Z Cam: a rising quiescent magnitude in the outbursts preceding a standstill. Some of this odd behavior is now being pursued in the Z CamPaign of Mike Simonsen (Simonsen 2011). The 1983 outburst of GK Per was well-followed and compared to past outbursts in 1975 and 1991 (Szkody *et al.* 1985) to reveal long outburst durations (50–60 days) with a high excitation emission spectrum present at ouburst. This object was then identified as an intermediate polar when the white dwarf spin was found in X-rays (Watson *et al.* 1985).

To explain dwarf novae outbursts in general as well as the peculiar outbursts of some CVs, theorists presented models for accretion disk instabilities or mass transfer instabilities. These theories had to explain the 1/2- to 1-day delay in the ultraviolet outburst compared to the optical as well as the change (or lack of change) in the accretion disk during quiescence. While several satellite campaigns used AAVSO light curves to study the delay on outburst rise, my work concentrated on the quiescent interval. Using AAVSO light curves to phase IUE data to the outburst cycle for fifteen systems, we found that the majority showed decreasing UV fluxes after optical quiescence began (Szkody *et al.* 1991). This result was contrary to the expectations for the popular theory of accretion disk instability and was a puzzle until later work showed that white dwarfs cool after outburst (Godon *et al.* 2006) and thus, the UV follows this cooling as a flux decrease.

The AAVSO light curves of systems after superoutburst also provided fodder for theorists. The photometry of AL Com after its 1995 outburst (Howell *et al.* 1996) showed a dip similar to WZ Sge that was modeled with a cooling front passing through the disk, while the orbital light curves showed the first harmonic as well as the orbital period. This was among the first indications of the common property of disks in very short orbital period systems that is indicative of a thickening of the disk at the stream impact point as well as on the opposite side of the disk. Other topics in the 1990s moved toward identifying the underlying stars in the fainter, short period systems where the disk contribution is minimal, and understanding the effects of the outburst and accretion on the white dwarf. The observed lack of the predicted boundary layer also remained a problem for CVs at this time. With the start of Hubble Space Telescope (HST), the Extreme Ultraviolet Explorer (EUVE), and Chandra X-ray observations, the probe of the white dwarf and the boundary layer could go much deeper and to different wavelength regimes than previously possible.

With the aid of the AAVSO light curves, HST was used to catch dwarf novae at outburst and quiescence, as well as to follow the effects of the outburst on the white dwarf. The HST spectra of U Gem at outburst (Sion *et al.* 1997) showed a peculiar emission profile in the wings of HeII, indicating a chromospheric structure of the disk. EUVE spectra at outburst (Long *et al.* 1996) revealed the boundary layer of U Gem for the first time, showing it to be at a temperature of 140,000K, and with a size comparable to the white dwarf. The orbit-resolved spectra revealed the presence of a wind, with emission far from the orbital plane. The HST spectra obtained at several times during a quiescent interval showed that the white dwarf cooled after heating by the outburst (Sion *et al.* 1998). Details on the interplay of the various wavelength regions was provided by an intensive campaign with RXTE, ROSAT, IUE, and optical throughout the 45-day supercycle of V1159 Ori (Szkody *et al.* 1999). The results from this compilation showed an inverse correlation between the optical and UV light curves and those from X-ray, as well as the presence of a wind during outbursts, while model fits to the UV data showed a standard disk model did not fit the observed data.

3. The Arne era: 2005 (2002)–present

Collaboration with Arne Henden began in 2002, a few years before he became Director in 2005. The hot topics of the new millenia included the general population of CVs, Polars, and a new area of pulsating white dwarfs in CVs. The Sloan Digital Sky Survey (SDSS) took center stage in the optical, while the Far Ultraviolet Spectroscopic Explorer (FUSE) and the Galaxy Evolution Explorer (GALEX) provided data in the UV and XMM was added to the X-ray scene.

The first HST data on the low state of the Polar EF Eri showed a unique spectrum with a large dip near 1600 Å, and a large amplitude modulation throughout the orbit (Szkody *et al.* 2010b). These data could be interpreted with either a cool white dwarf (the dip being a quasi-molecular hydrogen feature apparent in cool white dwarfs) and the modulation due to the viewing of a hot spot on the white dwarf throughout the orbit, or with two cyclotron components due to different magnetic fields. XMM data on the eclipsing polar SDSSJ0155+00 delineated a viewing geometry that allowed observation of the accretion flow through the base of the accretion funnel, leading to estimates for the physical parameters of these areas (Schmidt *et al.* 2005).

Work with the SDSS spectral database led to the identification of 285 CVs, resulting in eight papers in a series in the *Astronomical Journal* (*AJ*) (see Szkody *et al.* 2011 which includes previous papers in the series). These new CVs probed to fainter magnitudes and larger distances than previous surveys. Followup observations conducted by Arne and other AAVSO members, using the U.S. Naval Observatory (USNO) telescope as well as telescopes around the world, led to the ultimate identification of orbital periods of over 100 of the new objects. These results changed the picture of the orbital period distribution of CVs, bringing the observed periods much closer to the theoretical population models and showing that the previous results were largely due to selection effects (Gaensicke *et al.* 2009). Two surprising results also emerged from these SDSS results: the identification of a likely large population of LARPs and the presence of several pulsating, accreting white dwarfs among the SDSS objects. Followup XMM observations of the LARPs SDSS1553+55 (MQ Dra) and SDSS1324+03 showed low X-ray temperatures and luminosities, implying the source of X-rays was the M dwarf secondary, not the accretion shock (Szkody *et al.* 2004).

Followup HST spectra of the pulsating white dwarfs in CVs revealed a much hotter instability strip for these systems than the hydrogen-atmosphere non-accreting white dwarf pulsators (Szkody *et al.* 2010a) and the presence of increased amplitudes of pulsation in the UV compared to the optical regions. The outbursts of two of these pulsators (GW Lib and V455 And) in 2007 allowed the unique opportunity to follow these two systems as the white dwarf, heated by the outburst and moved out of its instability strip, cooled and resumed pulsations (Bullock *et al.* 2011). AAVSO data outlined the outburst and provided the required ground coverage to determine that the observed fluxes would not harm the HST observations. While the optical magnitudes were within a few tenths of a magnitude of the quiescent brightness by years 2010 and 2011, the temperatures determined from the UV spectra were still elevated. At years three and four after outburst, GW Lib was 3700K and 1300K hotter than quiescence, while V455 And was 600K and 200K hotter. In both objects, shorter periodicities than at quiescence (interpreted as the return of pulsations) are apparent in the UV by year three after outburst. Continued observations of these two objects will provide clues as to the mass accreted during the outburst and the amount of heating of the interior of the white dwarf.

Another ongoing project stems from the Z CamPaign (Simonsen 2011) which resulted in the identification of two peculiar Z Cam stars (IW And and V513 Cas). These systems show brightenings to an outburst following a standstill, in contrast to the usual behaviour of decline to quiescence following a standstill. Spectral observations of IW And and V513 Cas combined with the AAVSO photometry of these two systems throughout the various states of outburst, standstill, and quiescence are being used to study the accretion rates during these states. The available data so far show IW And has a traditional change from Balmer emission at quiescence to absorption at outburst, while V513 Cas shows emission cores flanked by broad absorption at quiescence and an unusual strength of high excitation HeII emission during outburst.

4. Conclusions

The past twenty-eight years has shown some large changes in understanding of CVs due in large part to the coverage of outbursts and optical states provided by the AAVSO observers and archive. The long term records of outbursts and the simultaneous determination of optical states during spacecraft observations at other wavelengths have been a vital part of the research undertaken. With the continued help of AAVSO observers, these advances into the understanding of accretion disks, magnetic white dwarfs, pulsating white dwarfs, and the makeup of the CV population will continue for the next twenty-eight years.

5. Acknowledgements

The many observers of the AAVSO that contributed to all the scientific work described here are gratefully acknowledged. This work was funded by

NSF grant AST1009734 and NASA grants HST-GO-1163.01-A, HST-GO-11639-01A, and HST-GO-12231.01A from the Space Telescope Science Institute which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS 5-26555.

References

Bullock, E., *et al.* 2011, *Astron. J.*, **141**, 84.
Gaensicke, B. T., *et al.* 2009, *Mon. Not. Roy. Astron. Soc.*, **397**, 2170.
Godon, P., Sion, E. M., Cheng, F., Long, K. S., Gaensicke, B. T., and Szkody, P. 2006, *Astrophys. J.*, **642**, 1018.
Howell, S. B., De Young, J., Mattei, J. A., Foster, G., Szkody, P., Cannizzo, J. K., Walker, G., and Fierce, E. 1996, *Astron. J.*, **111**, 2367.
Howell, S. B., Szkody, P., and Cannizzo, J. K. 1995, *Astrophys. J.*, **439**, 337.
Long, K. S., Mauche, C. W., Raymond, J. C., Szkody, P., and Mattei, J. 1996, *Astrophys. J.*, **469**, 841.
Schmidt, G. D., *et al.* 2005, *Astrophys. J.*, **620**, 422.
Simonsen, M. 2011, *J. Amer. Assoc. Var. Star Obs.*, **39**, 66.
Sion, E. M., Cheng, F. H., Szkody, P., Sparks, W., Gaensicke, B., Huang, M., and Mattei, J. 1998, *Astrophys. J.*, **496**, 449.
Sion, E. M., *et al.* 1997, *Astrophys. J.*, **483**, 907.
Szkody, P., Mateo, M., and Mattei, J. 1985, *Publ. Astron. Soc. Pacific*, **97**, 264.
Szkody, P., and Mattei, J. 1984, *Publ. Astron. Soc. Pacific*, **96**, 988.
Szkody, P., Stablein, C., Mattei, J. A., and Waagen, E. O. 1991, *Astrophys. J., Suppl Ser.*, **76**, 359.
Szkody, P., *et al.* 1999, *Astrophys. J.*, **521**, 362.
Szkody, P., *et al.* 2004, *Astron. J.*, **128**, 2443.
Szkody, P., *et al.* 2010a, *Astrophys. J.*, **710**, 64.
Szkody, P., *et al.* 2010b, *Astrophys. J.*, **716**, 1531.
Szkody, P., *et al.* 2011, *Astron. J.*, **142**, 181.
Watson, M. G., King, A. R., and Osborne, J. 1985, *Mon. Not. Roy. Astron. Soc.*, **217**, 917.