Twenty Years of Work with Janet Mattei on Cataclysmic Variables

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Abstract Janet Mattei and the AAVSO International Database have had a large impact on the field of cataclysmic variables, especially in the areas of outburst light curves of dwarf novae and ground-based support of space observations. A summary of some of the major results from AAVSO data during the last 20 years are presented.

1. Introduction

Since the 1980s, Janet Mattei and the AAVSO have been instrumental in the advances occurring in the understanding of the accretion that occurs in cataclysmic variables (CVs)—close binary systems with mass transfer from a late main sequence secondary to the white dwarf primary. In the 1980s, the importance of the magnetic field of the white dwarf was just beginning to emerge. The main topics of concern were the cause of dwarf novae outbursts, the delay time between the optical and UV outburst, the differences in outburst cycles among different types of systems, and the nature of the boundary layer where the accretion disk meets the white dwarf. To gather information on these problems, the knowledge from the ground was matched to incoming data from the available space toys in the ultraviolet (IUE) and X-ray (ROSAT, EXOSAT, Ginga). Coming up in the 1990s would be HST, EUVE, RXTE, ASCA, followed by FUSE and Chandra. This is a brief review of some of the main areas of interest to Janet and her contributions to the field of cataclysmic variables using the resources of the AAVSO observers and the resulting data. Since it is a review based on my own viewpoint, it is only a glimpse of all the results that have emerged, and perusal of the ADS will give a clearer picture of all the work that was accomplished.

2. The cause of dwarf novae outbursts—SS Cygni

As one of the brightest CVs, SS Cygni was one of the most studied by Janet and AAVSO observers. The first AAVSO monograph published (Mattei *et al.* 1985) detailed all the outbursts observed for this object from its discovery in 1896 to 1985. This and its supplements (Mattei *et al.* 1991, 1996) provided a grand summary of the variation in outbursts in a single dwarf nova and created the impetus for several studies of the lengths of time between narrow and wide outbursts, the shape of the outburst, and so on, that could be interpreted as evidence for the disk instability model as opposed to the mass transfer model. Some of the most productive results came from collaborations with John Cannizzo (Cannizzo and Mattei 1998) in which the shapes and delays could be understood within the context of the disk instability model as outbursts which moved from large to small disk radii (outside-in) or from small to large disk radii (inside-out).

Because of its brightness and relatively frequent outbursts, SS Cyg was also extensively observed with every UV and X-ray satellite. Major advances were produced using Target of Opportunity (TOO) programs on the satellites, where notification of the beginning of outburst by the AAVSO produced the trigger that started the satellite observations. This usually involved very close monitoring and many phone calls on short notice, especially to learn about the rise times of the outburst in different wavelengths. A real breakthrough occurred with simultaneous observations using the EUVE and RXTE satellites along with the AAVSO optical (Mattei *et al.* 2000). These data detailed very clearly the one-day delay between the optical rise to outburst and the increase of the X-ray and EUV light, and the unusual behavior of the hard X-rays, first rising with the optical, then plummeting to near zero for most of the outburst. The results confirmed a theoretical picture of material flowing from the disk (optical) to the white dwarf (X-ray) and the boundary layer changing from a low-density thermal bremsstrahlung region to an optically-thick zone radiating as a black body in the temperature regime of the EUV as the accretion rate increased during the outburst.

3. The differences in outburst cycles

The vast records of the AAVSO database provided opportunities for study of many dwarf novae, and Janet was very interested in having these records utilized. One of the first studies of a variety of outbursts came from a detailed study of 21 dwarf novae (Szkody and Mattei 1984). This study debunked an idea that all systems with orbital periods less than 4 hours should have bi-modal distributions of outbursts with long and short outbursts. It also explored correlations between durations of outbursts, rise, decline, and quiescent intervals with physical parameters of the CV systems such as orbital period and mass. The results confirmed a clear relation between orbital period and length of outburst, rise and decline times, enabling predictions of orbital periods from observed outbursts. A strong correlation of outburst width with rise and decline times was also apparent. An interesting point made by Janet in this study was the change in quiescent levels preceding standstills in Z Cam, a relation that has not yet been understood in detail.

GK Per was one of the systems that revealed the great range of dwarf novae behavior. *AAVSO Monograph 13* (Mattei *et al.* 1998), summarized the long term light curve from 1963 through 1995. The good coverage of the infrequent (several years) but long (1–2 month duration) and low amplitude (2–3 magnitude) outbursts led to spectroscopic and satellite data that revealed the high excitation nature of the outburst, and a pulsed spin period at 351 seconds that was consistent with an accreting magnetic white dwarf (Szkody *et al.* 1985; Watson *et al.* 1985). Stimulated by these light curves, theorists computed models that included GK Per among disk instability outbursts (Kim *et al.* 1992).

4. Finding the boundary layer—U Gem

Another favorite object among AAVSO observers was the prototype dwarf nova U Gem, the subject of *AAVSO Monograph 2* (Mattei *et al.* 1987). As with SS Cyg, the available observation records of outburst history and brightness made it suitable for space observations, and U Gem became a good candidate for the detection of a boundary layer. AAVSO data provided during HST observations of U Gem confirmed that the UV spectra were obtained while U Gem was in outburst (Sion *et al.* 1997). The unusual line shapes (double-peaked emission lines with low velocity central absorption) implied either an origin in photoionized material above the disk plane with a thickened outer disk absorbing the boundary layer radiation, or a wind. Further details were provided by a TOO triggered (by AAVSO observations on Christmas) in order to obtain EUVE observations during an outburst. The highly successful program caught the developing boundary layer, and conducted observations throughout several orbits during the outburst. The results (Long *et al.* 1996) provided the first clear determination of the size and temperature of the boundary layer in U Gem, and further evidence for an outflowing wind at outburst. Broad dips in the EUV and X-ray near the phases when the mass transfer stream was viewed provided supporting evidence that some material can be located far above the orbital plane.

5. Revealing the white dwarf—quiescent studies

Besides catching outbursts, AAVSO monitoring was essential to avoid outbursts of bright systems (which would destroy some of the detectors on board HST) and also to study CVs during quiescence, especially those systems where the accretion rates were so low that the underlying stars could be detected. In these systems, the white dwarf could be monitored to study the effect of outbursts on heating of the white dwarf. One of the first systems that could be used in this way was U Gem, as it has a relatively long quiescence interval following an outburst. Again, HST spectra were crucial for the determination that U Gem had a white dwarf of 30,000K that was heated to 40,000K by a dwarf nova outburst (Sion *et al.* 1998). In addition, these spectra revealed that U Gem was a slow rotator (not spun up very much by its accretion) and had a composition that included metals (from its mass transfer from the secondary). Studies such as this have stimulated theoretical ideas on accretion, and have produced models for the evolution and past history of close binaries that included common envelope phases and repeating novae with thermonuclear runaways to explain the observed composition and angular momentum.

6. Acknowledgements

I represent many in the CV community in gratefully acknowledging Janet's legacy to our field. This includes her coordination of alerts for Targets of Opportunity and general monitoring for space observations, her leadership in establishing an online database that could be used to identify light curves of CVs during spectroscopic or satellite observations, her alerts of new phenomena occurring in erupting variables, and her promotion of fruitful interaction between amateurs and professionals that led to new discoveries and understanding of the accretion process. We remember that she was always cheerfully willing to help, even at odd hours and during vacation time. While Janet and I published 12 papers together, I remember her for much more than her scientific work. Her enthusiasm for astronomy and life in general energized every campaign and made every shared dinner a memorable experience. We will all sadly miss a valued colleague and a dear friend.

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