Dwarf Nova Outbursts – The First Hours

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The triggering of the outbursts of dwarf novae is believed to be an instability in the accretion disk surrounding the white dwarf. It has become clear that at least some outbursts are preceded by small changes in the emission lines or in the continuum level. This paper reviews what is known about these changes and discusses their potential importance.

Keywords: Dwarf Novae

1 Introduction

Dwarf novae (DNe) are characterized by outbursts of 3-5 mags at intervals of weeks to years. Figure 1 shows two views of AR And separated by less than 24 hours. Most of what we know of the light curve behavior of DNe comes from amateur astronomers making visual observations. An example can be seen in Figure 2 which is a portion of a light curve of the dwarf nova SS Cyg gathered by the American Association of Variable Star Observers (AAVSO).

Spectroscopic studies have shown that DNe are binary systems with orbital periods of a few hours. A dwarf nova (DN) consists of a white dwarf star with a red dwarf companion. The white dwarf is accreting matter from its companion. This matter has too much angular momentum to fall on the white dwarf directly but instead forms an accretion disk. The disk is the site of the DN outbursts. Even in quiescence the optical spectrum is usually dominated by the accretion disk. A blue continuum comes from the dense central disk while strong H emission lines arise in the outer disk or in a corona above and below the disk plane. In high inclination systems the emission lines are double-peaked due to the Doppler separation of the line emission coming from the approaching and receding sides of the disk.

2 Dwarf Nova Outburst Models

Historically, there have been two models used to explain the accretion disk outbursts in DNe (Cannizzo and Kaitchuck 1992). The modulated mass-transfer model (MT) involves an instability in the atmosphere of the donor star which triggers cyclic episodes of mass transfer. The release of gravitational potential energy of the matter falling through the accretion disk and onto the white dwarf is the source of the outburst. In the disk instability model (DI) the outburst is also due to the release of gravitational energy, but the source of the modulation is an instability in the disk.

In the DI model the disk is assumed to be (very nearly) Keplerian and heated by gas viscosity. Gas spirals inward and angular momentum is transferred outward (Pringle 1981). The outbursts are usually modeled as a thermal instability (Smak 1983). In any disk annulus thermal equilibrium requires that the temperature increases with surface density, i.e. higher temperature requires greater viscous heating which is expected at a higher surface density. This temperature-surface density relationship exists as long as the opacity varies slowly with temperature. In regions of partial H ionization the opacity varies as T^{10}. In such a region an upward temperature perturbation will cause opacity to increase significantly, reducing radiative cooling, and further increase temperature. A downward temperature perturbation will reduce opacity, increasing radiative cooling, dropping the temperature even further. If the region is perturbed to either the cool state or the hot state, partial ionization is removed and thermal stability is achieved. However, in neither case can the stability be maintained. In the hot state, viscosity is strong and transfers matter inward faster than it is arriving from outer annuli. This reduces surface density and temperature until the cool state is reached. In the cool state, the viscosity is lower and the transfer of mass from the outer regions cause the surface density, and hence the temperature, to rise. The region cycles between hot states and cool states. In the hot state the entire disk is heated by the release of matter that accumulated in the unstable zone during the cool state. This cyclic storage and release of transferred matter is the source of DN outbursts.

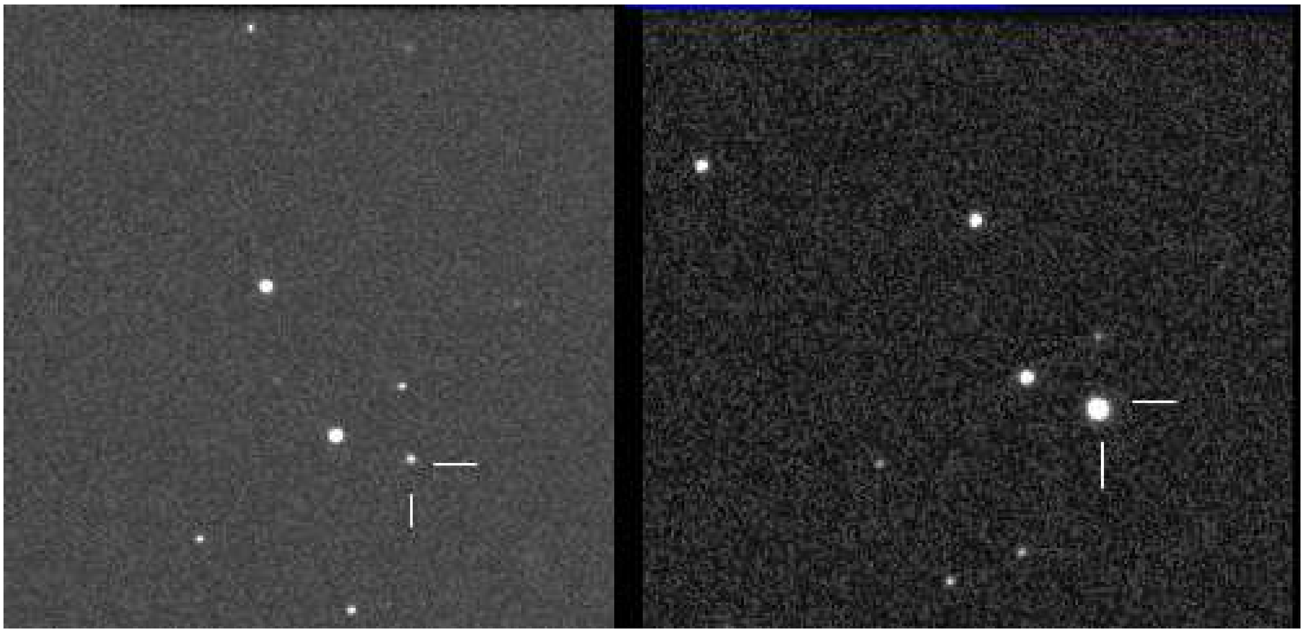

Fig. 1: Two images of AR And separated by 24 hours.

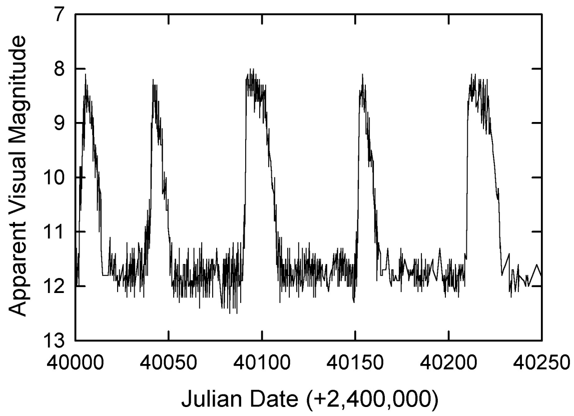

Fig. 2: The AAVSO light curve of SS Cyg.

The DI model has been successful in explaining the overall characteristics of DN light curves. But the model requires confirmation and constraints from observations at key stages of DN outbursts.

3 Observations of the Early Stages of Outbursts

For several years there has been growing evidence that DN outbursts are preceded by observable changes. In his book on cataclysmic variable stars (Warner 1995), Brian Warner says that early outburst observations are "clearly of great potential in revealing more about the triggering of DN outbursts." They are also of value for testing and developing the disk outburst theory. For any given DN the interval between outburst is not constant so the exact time of an outburst is unpredictable. This has made observations of specific phases of outburst difficult. We have been successful in collecting observations of some of the early stages of dwarf nova outbursts. There appear to be details in the early outburst stages that do not fit the DI model in its simplest form. There have been reports of small brightenings that precede the outbursts. These are at a level that would escape detection by most visual observers. Clarke et al. (1986) observed a $0^{\mathrm{m}}.1$ brightening in SS Cyg about 24 hours before outburst. We have observed a similar brightening in HL CMa (Mansperger et al. 1994) and RX And (Kaitchuck et al. 1988).

Figure 3 shows the outburst observations of RX And from the AAVSO. There is a slight rise in the light level on November 16, 1985, which preceded the main outburst on November 17. Given the scatter in the visual data this minor rise in light level could easily be dismissed as observational error. However, Figure 4 shows our photometrically calibrated spectra from those same nights (Kaitchuck et al. 1988). It too shows a rise of about $0^{\mathrm{m}}.1$. Also, the emission line wings decreased in strength during the night prior to the outburst. This could indicate a loss of line emission from inner regions of the disk that are heating and/or becoming optically thick.

However, these pre-outburst behaviors are not universal among DNe. In TW Vir the emission lines

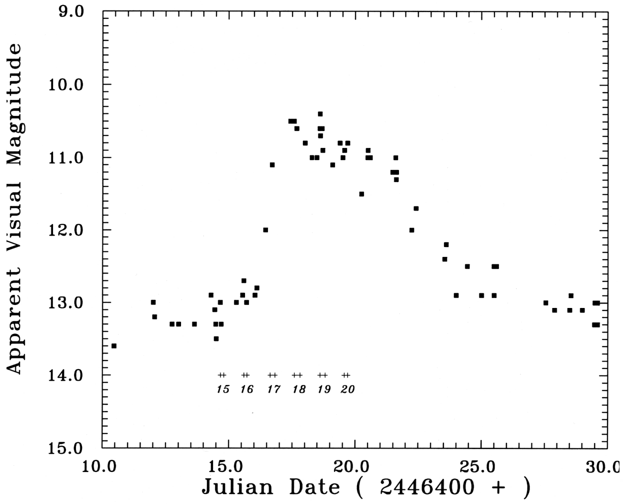

Fig. 3: The AAVSO light curve of the December 1985 RX And outburst.

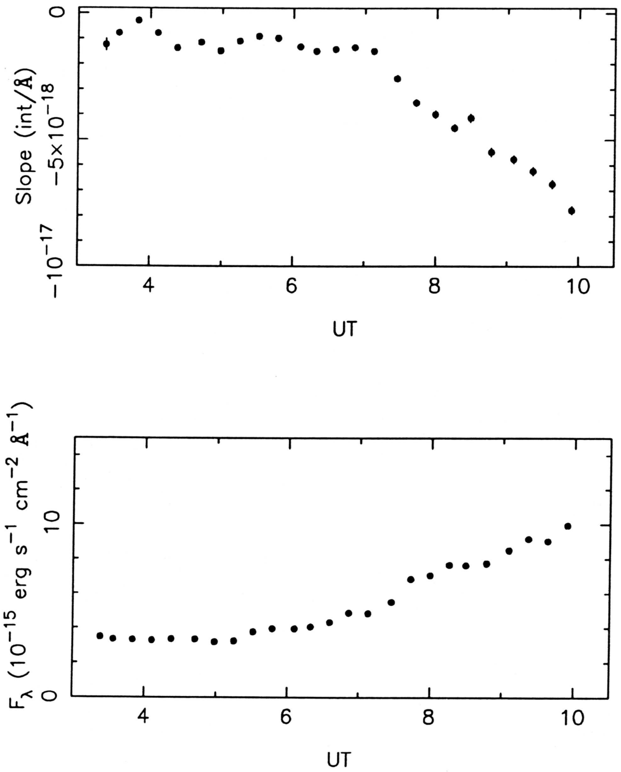

Fig. 5: The change in flux and continuum slope during the rise to outburst of TW Vir, March 1989.

weakened 24 hours before an outburst (Mansperger and Kaitchuck 1990) but the line widths were unchanged. As Figure 5 illustrates, the continuum slope abruptly increased at the start of the outburst. This indicates a significant temperature change in just a few minutes. An attempt was made to model this data using a modified DI model by Mineshige (Mineshige 1988). This model actually predicts a pre-outburst brightening. The model did reproduce the observed pattern of change in the continuum slope but not the changes in the continuum flux.

More recently, we observed AR And in its rise to outburst. The data consist of B, V, R, I photometry (CCD). Figure 6 shows the V flux versus time. A few hours prior to outburst maximum the rate of the flux increase abruptly changed. This is a detail that is not recorded by the noisier (and usually sparser) visual observations.

Color-color plots show that AR And in outburst matches a black body fairly well, about as good as main sequence stars. However, during the decline two nights later it does not. For DNe near maximum

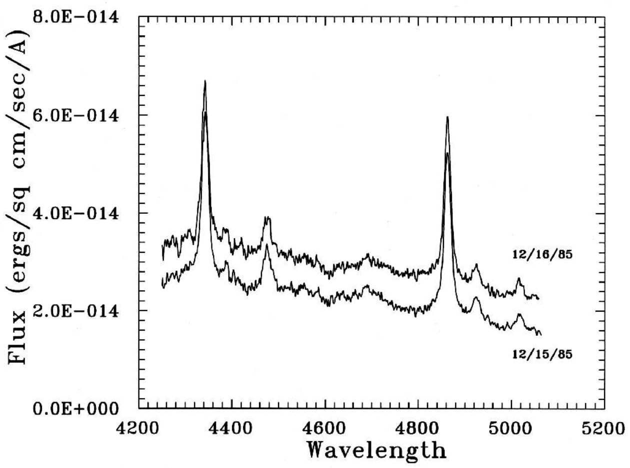

Fig. 4: Mean spectra of RX And December 15 and 16 1985.

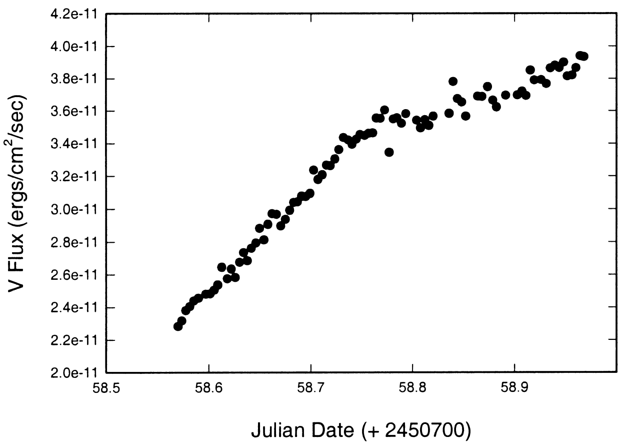

Fig. 6: The change in flux during the rise to outburst of AR And, November 1997.

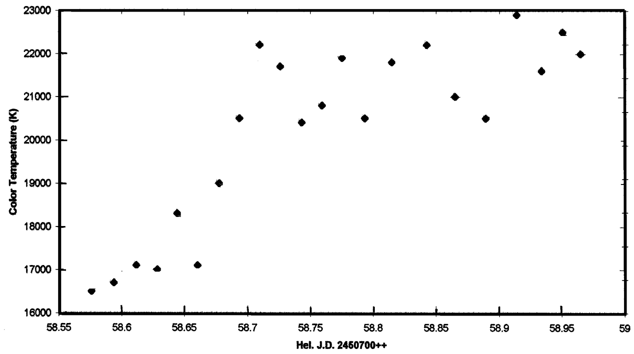

Fig. 7: The disk temperature versus time during the November 1997 outburst of AR And.

outburst and early decline the flux generally matches the optically thick steady-state disk models, i.e., F $\sim$ λ^{α} with α = -2.3 (Pringle 1981). From our observations of AR And α ranged from -2.9 to -3.2 on the rise to maximum and -1.9 in decline. The color temperatures were found during the rise to maximum light by assuming the disk radiated as a single blackbody. Figure 7 shows the results. The temperature increased from 17000 to 22000 K in a single night.

The observed flux is proportional to the product of the black body intensity and the emitting surface area. By using the observed color temperatures at two times the outburst, the ratios of areas were found. These ratios refer to emitting areas, and do not necessarily indicate actual changes in the disk radius. The emitting area was larger in outburst compared to quiescence the night before. The surface area increased by about 40% in the I filter and about 100% in the other filters. If the emitting regions were circular there was about a 40% radius increase in V and R and about an 18% radius increase in I. During the actual rise to outburst the emitting areas were fairly constant. Better fits to the observed flux distributions were found using a disk model with 500 annuli whose temperatures changed as a power law of radius. For a steady-state disk the exponent is expected to be -0.75. The best fit to our observations was with an exponent of -0.9. The average disk temperature (weighted by the surface area of each annulus) during the outburst ranged from 11000 K to 15000 K.

4 Summary

At least some DN outbursts are preceded by changes in the continuum level, emission line strengths and widths. However, very few outbursts have been observed in these early stages. We can not yet characterize the full range of behavior. The precursor activity is not always the same and may not always occur. The disk temperature and the light curve slope can change abruptly, sometimes in just a few minutes.

Further observations can lead to a full characterization of pre-outburst behavior. This may lead to a better understanding of where and how the outburst begins in the accretion disks. This will test and better constrain the DI model.

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