Cataclysmic Variable Stars

Modern Astronomy in Motion

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1. Introduction.

Cataclysmic variable stars (CVs) are binary star systems containing a low-mass main sequence secondary and a white dwarf primary star. Due to the proximity of the stars to each other, the secondary star is distorted into a tear-drop shape. This also results in mass-transfer between the secondary star and the primary. As the mass flows toward the primary star, it forms an accretion disk around the white dwarf which results in a very dynamic system. To add to the dynamics of these systems, some CV systems undergo quasi-periodic outbursts. In all CV systems, the distance is so great that the stars themselves are nearly invisible in telescopes so the accretion disk is the source of most of the light visible from earth. CVs include systems such as novae, dwarf novae, polars, and intermediate polars.

Figure 1. Artist rendition of a cataclysmic variable star system, in this case, a dwarf-nova system. Image permission courtesy of Mark A. Garlick.

Figure 2. Artist rendition of a polar. The magnetic field of the white-dwarf totally prevents the formation of an accretion disk. Instead, the magnetic field redirects all of the incoming gas toward the magnetic poles of the white dwarf. Image permission courtesy of Mark A. Garlick.

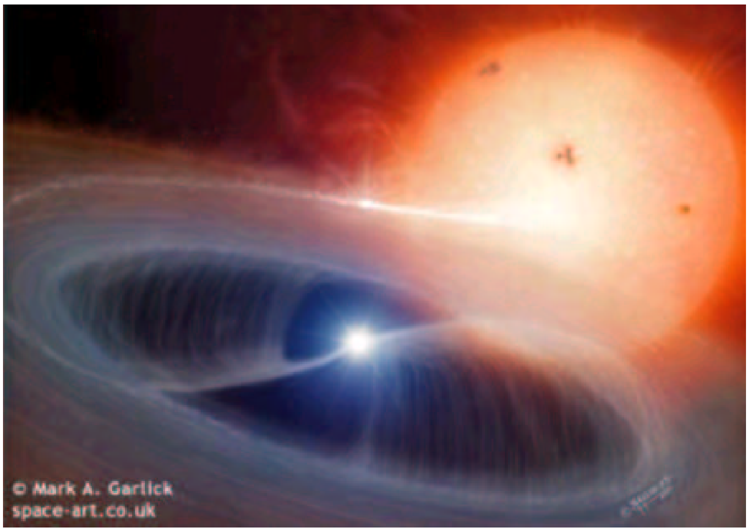

Figure 3. Artist rendition of an intermediate polar. The magnetic field of the white-dwarf prevents the formation of a complete accretion disk. Instead, the magnetic field redirects some of the incoming gas toward the magnetic poles of the white dwarf. Image permission courtesy of Mark A. Garlick.

Figure 4. Artist rendition of the view from a hypothetical planet in orbit around a CV system. Not only are CVs a worthy object of scientific study, but the visual imagery they can bring to mind provide a wonderful subject for planetarium use. Image permission courtesy of Mark A. Garlick.

CVs are an excellent example of how modern technology has been instrumental in solving some of the puzzles provided by these star systems. Astronomers are able to use tools such as photometry and spectroscopy to extract an amazing amount of information from an object that can only be seen as a point of light even in the largest telescopes. The use of these tools combined with the dynamics of these systems make CVs an attractive example of what modern astronomers do.

Most of what we know about CV systems is due to the fact that there is always some kind of motion in progress. In cataclysmic variables, a red dwarf is transferring matter onto a white dwarf. The matter transfer results in the formation of an accretion disk around the primary star. Due to conservation of angular momentum, the matter is unable to fall directly onto the surface of the white dwarf. Angular momentum carries the gas stream in the direction of the orbit of the secondary star while at the same time, falling toward the primary. Viscosity causes the gas to spread out forming an accretion disk. As gas continues to fall towards the primary, it impacts the edge of the accretion disk where it is slowed down. The loss in energy resulting from the decrease in speed manifests itself in a "hot-spot".

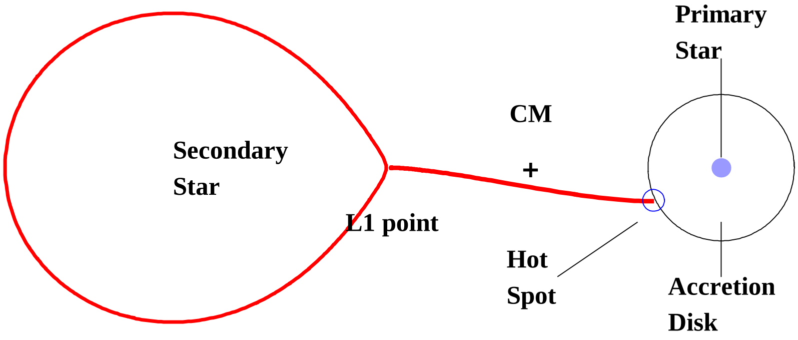

Figure 5. Diagram of a typical dwarf-nova system. The diagram shows gas leaving the surface of the secondary star at the first Lagrange point (L1). As the gas impacts the accretion disk, it heats up creating a hot-spot. Graphic created using *Mathematica* 4.2.

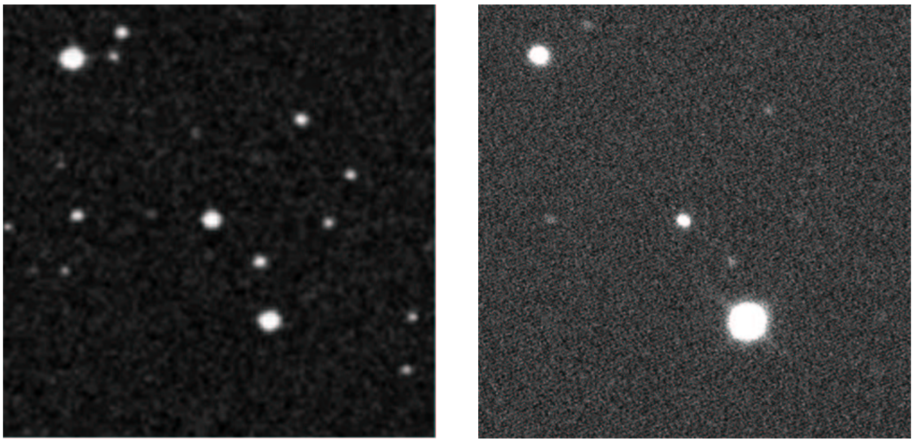

Figure 6. Dwarf novae are a subclass of CVs which show quasi-periodic outbursts of 1 to 5 magnitudes. Outbursts are the result of two possible occurrences: the sudden transfer of matter from the secondary star or an instability in the accretion disk. These images show a CV (U Gem) before and during an outburst. U Gem is the lowest bright star in both images. The first image is from the online Digital Sky Survey and the second image was a short exposure taken using a CCD camera and the 31" NURO telescope, part of Lowell Observatory.

2. Light Curves.

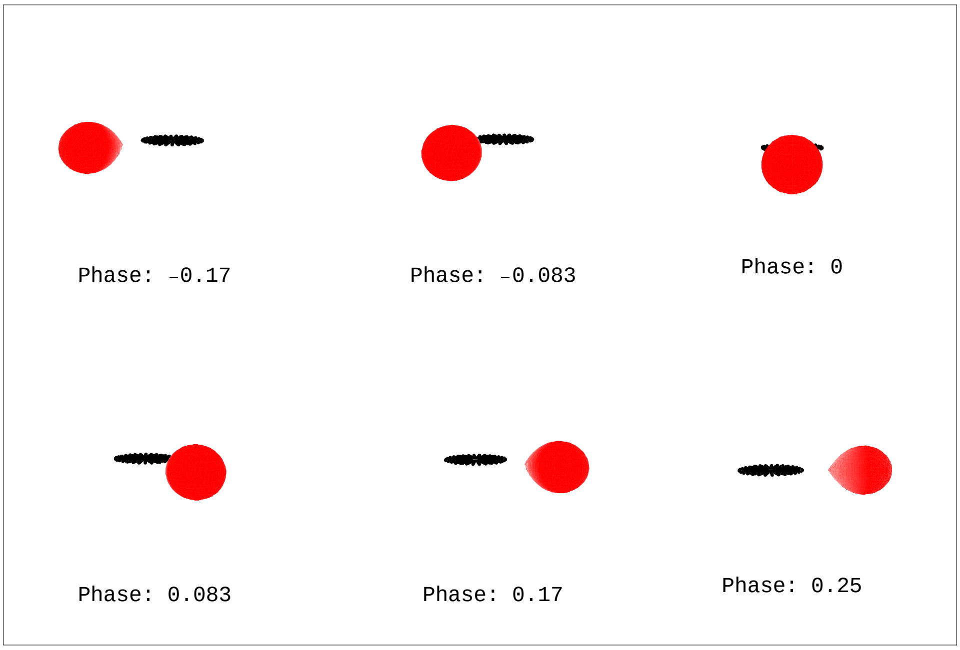

Figure 7. Some CV systems are inclined in such a way that an eclipse occurs. In such a case, the CV revolves around the center-of-mass of the system, and during eclipse, the light from the accretion disk is blocked by the secondary star. Since most of the visible light originates from the disk, this results in a dramatic decrease in the light observed from earth. If brightness is plotted versus time, a light curve can be generated. Graphic created using *Mathematica* 4.2.

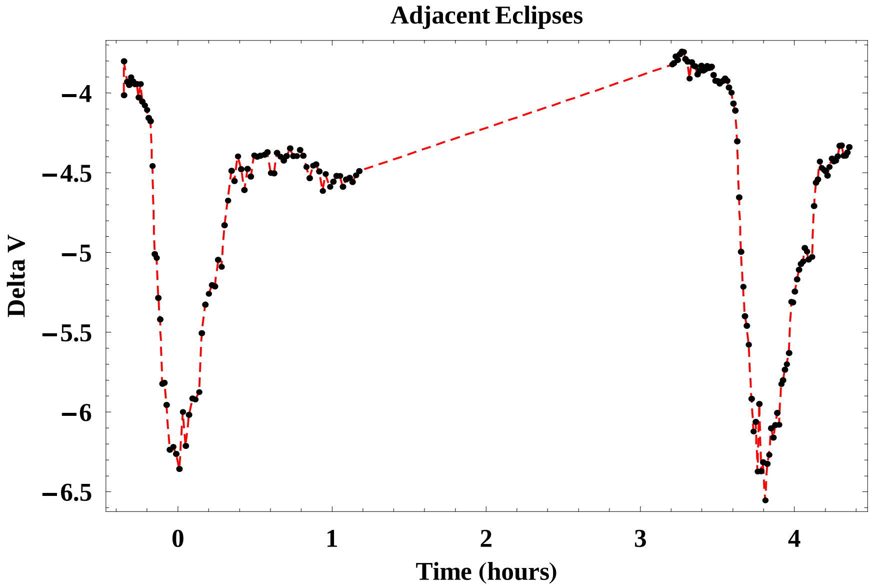

Figure 8. CCD photometry can be used to determine the orbital periods of CV systems. The light curve above shows two adjacent eclipses approximately 3.8 hours apart, which reveals the orbital period of this CV to be about 3.8 hours. The above graph has some data points missing. Even though the data points are missing, it is evident that between the end of one eclipse and the onset of the next eclipse, there is a brightening of the system. This brightening actually begins just before the second eclipse and is due to the line-of-sight view of the hot-spot. Graphic created using *Mathematica* 4.2.

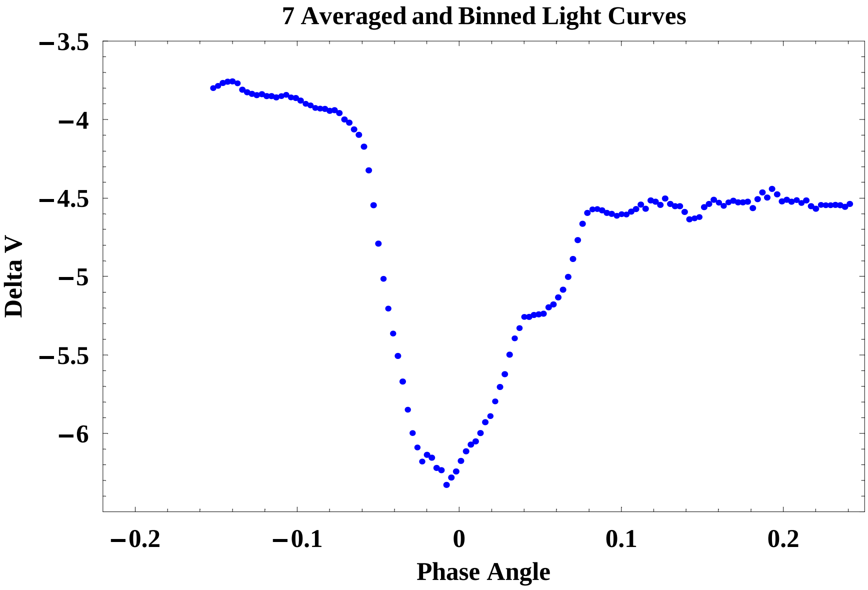

Figure 9. Computers can average several light curves to reveal the structure of the eclipses. Sudden changes in the shape of a light curve may indicate that a prominent feature has just been eclipsed or has just emerged from the eclipse. The locations of these features is an important piece of information that can be used to determine some of the physical parameters of eclipsing CV systems. These contact points can help establish the geometry of the system. Graphic created using *Mathematica* 4.2.

3. Spectrum.

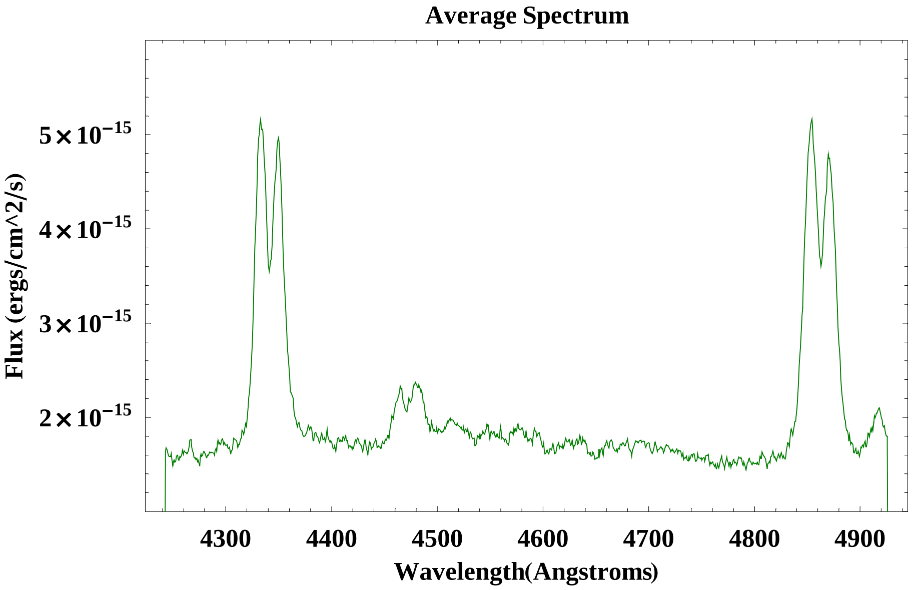

Figure 10. Spectroscopic observations reveal double-peaked emission lines which hint at the presence of a rotating disk of hot gas. Analysis tools such as this were the primary means of determining that CV systems actually involved accretion disks. Graphic created using *Mathematica* 4.2.

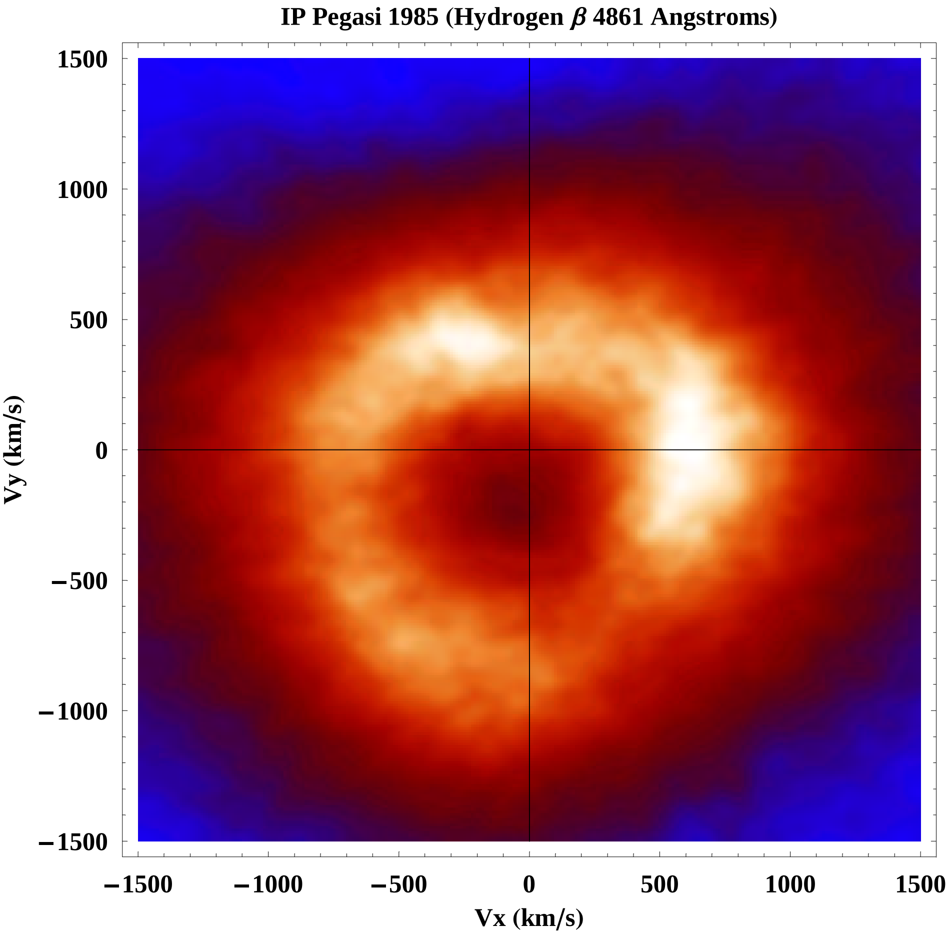

Figure 11. Doppler tomography can construct "images" of these systems from their spectra even though the distance makes it impossible to resolve them in a normal telescope. The images are in velocity-space rather than normal X-Y space so understanding the image requires a fair amount of practice. The image that is created shows the distribution of light across the face of the accretion disk. Tomograms generated for other CV systems may show details such as the gas stream and the heated face of the secondary star. Graphic created using *Mathematica* 4.2.

4. For More information.

The information presented here is only a small amount of the available information on these systems. The information presented here is similar to information that is available freely on the web and in some cases, the information shown here came from the web. Here is a list of resources that may prove useful.

The artwork presented in the introduction is part of a collection of space related artwork by Mark A. Garlick. You can find more images online at his webpage: http://space-art.co.uk

Images of starfields can be found by searching the online Digital Sky Survey by object name: http://archive.stsci.edu/cgi-bin/dss_form

Light curves for many CV systems can be obtained from the American Association of Variable Star Observers (AAVSO): http://www.aavso.org/

An atlas of doppler tomograms for various CV systems can be found in a journal submission:

R.H.Kaitchuck, E.M.Schlegel, R.K.Honeycutt, T.R.Marsh, K.Horne, J.C.White II, and C.S.Mansperger, "An Atlas of Doppler Emission Line Tomography of Cataclysmic Variable Stars". ApJS, 93, 519. Erratum: ApJS, 98, 367 (1994).

The data plotted in this presentation is data collected by the author and Dr.Ronald H.Kaitchuck in the case of the photometry and by Dr.Ronald H.Kaithcuck in the case of the spectral data.

Mathematica 4.2 was used to generate all of the non-artistic graphics from actual data. More information on *Mathematica* can be found on the Wolfram Research, Inc. website: http://www.wolfram.com