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MODELING THE DIVERSE FUV SPECTRA OF DISK-DOMINATED CATACLYSMIC VARIABLES

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RESUMEN

Los espectros de *FUSE* y *HST* de novas enanas en explosiones y de variables semejantes a novas presentan un amplio rango de características. En unos cuantos sistemas existen señales obvias de un viento rápido en la forma de los perfiles de OVI semejantes a P-Cygni y de otros iones en relativamente altos estados de ionización. Pero estos casos son raros. Son más comunes los sistemas con espectros FUV que presentan una compleja mezcla de líneas de alto y bajo estado de ionización. Se describen intentos para reproducir los espectros utilizando el código de Monte Carlo de transferencia radiativa, desarrollado para modelar vientos bicónicos en sistemas de disco.

ABSTRACT

The *FUSE* and *HST* spectra of dwarf novae in outburst and of nova-like variables exhibit a wide range of characteristics. In a few systems, there are obvious signatures of a fast wind in the form of P-Cygni-like profiles of OVI and other relatively high ionization state ions. But this is rare. More common are systems with FUV spectra showing a complex mixture of high and low ionization state lines. Here we describe attempts to reproduce the spectra using a Monte Carlo radiative transfer code developed to model bi-conical winds in disk systems.

Key Words: **ACCRETION, ACCRETION DISKS — BINARIES: CLOSE — NOVAE, CATACLYSMIC VARIABLES — STARS: MASS LOSS**

Since the original *IUE* studies of cataclysmic variables, it has been clear that nova-like variables and dwarf nova in outbursts drive winds (Heap et al. 1978; Greenstein & Oke 1982; Cordova & Mason 1982). The evidence for winds is found in P-Cygni-like profiles of C IV and other strong resonance lines in many systems, and in blue-shifted centroids of the same lines in many others. The blue-edge velocities in systems, such as IX Vel and V3885 Sgr (Hartley et al. 2002) are 2000-5000 $\mathrm{km\,s^{-1}}$. In high-inclination systems, the resonance lines are seen primarily in emission. Time-resolved studies of the line shapes show rotational effects (Mason et al. 1995), leading to qualitative picture of the wind in terms a fast bipolar flow originating from the inner disk. A good description of the wind has been very difficult to develop. Furthermore, many the disk-dominated cataclysmic variables observed with *FUSE* show lines with arising from low velocity, relatively low ionization state transitions,presumably arising from material further out from in the disk whose origin is still poorly understood (See, e.g. Froning et al. 2001).

In an attempt to develop a better understanding of the structure of the outflow that develops around the disk of nova-like variables and of dwarf novae in outburst, we have developed a Monte Carlo radiative transfer code to simulate the UV and FUV spectra assuming an axially symmetric wind flow (Long & Knigge 2002). Unlike Shlosman & Vitello (1993) and Knigge et al.,(1995), who concentrated solely on modeling individual lines, usually C IV, our goal is to simulate the entire spectrum. The code, Python, invokes a Sobolev approximation with escape probabilities to follow photons through the wind. We do not attempt to calculate self-consistently the flow, by for example, calculating the radiative pressure, and modifying the flow. Instead, the wind geometry and flow are defined using the prescriptions of Shlosman & Vitello (1993) or Knigge et al., (1995). All cosmically-abundant elements are included. Sources of radiation include the disk, the white dwarf, the boundary layer (modeled as an additional source located at the white dwarf), and the wind itself.

Simulated spectra generated with Python resemble those observed with *FUSE, HST*, and other space-borne observatories. Most of the transitions that are commonly seen in CVs are seen in the models with about the correct line strengths. In addition, the simulated spectra also indicate all of the basic characteristics that one would expect as system pa-

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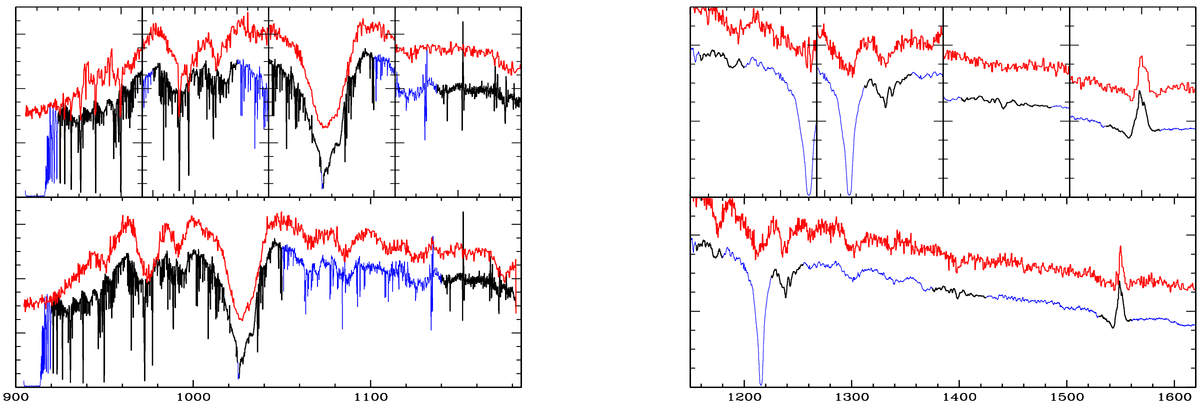

Fig. 1. Example of a fit to the FUSE (left) and *HST*/GHRS (right) spectra of SS Cygni in outburst. The upper panels show fits to individual regions of the spectra. The lower panels are consolidated fits to the *FUSE* and *HST* spectra. For clarity, the models are shown displaced above the data. The best-fit models in the two cases are similar, but not identical.

rameters are changed: a transition from pure absorption to pure emission as the inclination is increased, a progression towards higher ionization state lines as $\dot{m}_{disk}$ is increased or $\dot{m}_{wind}$ is decreased, and the proper rotational effects in line profiles as eclipses are simulated.

We are currently beginning an effort to construct large grids of models in an attempt to determine to what degree the wind prescriptions built into the code can reproduce the spectra of specific CVs in a quantitative sense. As one would expect, it is relatively easy to fit individual lines, especially the strong resonance lines.

Our most encouraging results are obtained on lower inclination systems. For example, as shown in Fig. 1, we are able to fit both *FUSE* (900-1185 Å) and *HST*/GHRS (1150-1640 Å) spectra fairly well with a single wind model for each. The wind prescriptions that fit best at present require $\dot{m}_{wind}$ or 0.01-0.1 $\dot{m}_{disk}$ with a hint that the lower value is closer to the norm. They also favor relatively long acceleration lengths, as was found by Shlosman et al., (1996) and by Knigge & Drew(1997) in their attempts to model C IV in a number of CVs.

Others systems, particularly, those which are observed at high inclination, such as WZ Sge and UX UMa, are more problematic. This is in part because it is very difficult to fit both the high ionization lines that participate in the fast outflow and the low ionization lines that do not.

However, it is not yet evident that we have explored all of the relevant portions of parameter space, and so it is not yet clear how well we will do in the end. Ideally, we will find that a group of models in a restricted range of parameters fit the spectra of a variety of disks and winds. This would allow one to place real physical limits on the nature of the winds in disk-dominated cataclysmic variables.

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