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# The accretion and spreading of matter on white dwarfs ☆

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## Abstract

For a slowly rotating non-magnetized white dwarf the accretion disk extends all the way to the star. At the interface between the accretion disk and the star, the matter moves through a boundary layer (BL) and then spreads toward the poles as new matter continuously piles up behind it. We have solved the 3d compressible Navier–Stokes equations on an axisymmetric grid to determine the structure of this BL for different accretion rates (states). The high states show a spreading BL which sets off a gravity wave in the surface matter. The accretion flow moves supersonically over the cusp making it susceptible to the rapid development of gravity wave and/or Kelvin–Helmholtz instabilities. This BL is optically thick and extends more than 30° to either side of the disk plane after 3/4 of a Keplerian rotation period ($t_K = 19$ s). The low states also show a spreading BL, but here the accretion flow does not set off gravity waves and it is optically thin.

*Keywords:* Accretion; Accretion disks; Binaries:close; Novae; Cataclysmic variables; White dwarfs

## Contents

## 1. Introduction

Cataclysmic variables (CV) is an interesting class of close binary stars comprising a hot white dwarf (WD) and a relatively lower mass red dwarf star filling its Roche lobe (Warner, 1995). In such systems hydrogen-rich matter from the red dwarf exits through the inner Lagrange point and flows toward the white dwarf, where the matter proceeds to form an accretion disk around the white dwarf due to the excess angular momentum originating from the orbital motion of the binary (Prendergast and Burbidge, 1968).

In the disk, turbulence (Shakura and Sunyaev, 1973) and magnetic fields (Balbus et al., 1994) dissipate potential

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energy and cause the matter to lose angular momentum. As a result the disk matter slowly falls inward toward the white dwarf (Pringle, 1981). If the WD is non-magnetic, the accretion disk extends all the way to the surface. Only half of the entire accretion luminosity, $L_{\rm acc} = GM_*\dot{m}/R_*$, is emitted in the disk, since the matter is still moving at a roughly Keplerian velocity, $v_{\rm K} \approx \sqrt{GM_*/R_*}$, before it is ultimately accreted (Lynden-Bell and Pringle, 1974). The kinetic energy must therefore be converted into other forms of energy in order for the matter to come into co-rotation with the surface of the WD (Pringle, 1981). This occurs in a comparably small (on the size of a disk scale height) boundary layer (BL) near the star.

Since the BL is much smaller than the disk itself and each radiates equal amounts of energy, the disk emits mainly in the optical and near UV, whereas the BL emits in the far UV and in soft X-rays. However, since the kinetic energy may also be converted into winds, WD rotation or heating, the details of the emitted spectrum depends on the detailed structure of the BL. Therefore the structure of the BL is important to understand both to make the observational interpretations between the different components of the spectrum which is important in the study of dwarf novae and in the general interpretation of observational data, but also because it determines how the accreted matter ultimately distributes itself in the envelope of the WD, which is important for classical novae. Before such a detailed analysis of the radiative transfer in conjunction with the hydrodynamics can be undertaken, it is important to understand the dynamical processes that lead to the formation of the BL. We focus on such a dynamical study in this paper leaving a radiation-hydrodynamical study for later.

Dwarf novae are a subclass of CVs in which a thermal instability in the accretion disk causes an increase in the matter transfer rate through the disk and thus an increase in the rate of gravitational energy release (Cannizzo, 1988). This in turn causes a 2–5 mag increase in the disk luminosity and consequently in the BL luminosity. The BL may react in various ways due to enhanced accretion and detailed studies are required to determine its response (Fisker and Balsara, 2005).

Another CV subclass is the classical nova. A classical nova obtains, when enough hydrogen-rich rich material has been accumulated in the envelope to reach the ignition point at the e-degenerate base of the envelope. The resulting thermonuclear runaway ejects part or all of the envelope. The initial CNO composition of the burning material should be strongly enhanced compared to the accreted material to account for composition of the observed ejecta (Starrfield et al., 1972). Several mechanisms have been suggested for this CNO enhancement (see José, 2005, and references therein). They can be roughly divided into pre-burst mixing between accreted material and the underlying CO rich WD (Kippenhahn and Thomas, 1978; MacDonald, 1983; Rosner et al., 2001; Alexakis et al., 2004) by accretion driving instabilities or mixing with the underlying material when the convective zone of the thermonuclear runaway extends deep enough to dredge up CO material (Starrfield et al., 1972; Glasner et al., 1997).

The BL has typically been solved in a model where the averaging of the vertical structure which is employed in accretion disk studies (Shakura and Sunyaev, 1973) has been extrapolated to the surface. This reduces the description of the BL to a one dimensional problem in the radial direction (Pringle, 1981; Meyer and Meyer-Hofmeister, 1982; Popham and Narayan, 1995; Collins et al., 1998). However, this assumption is not necessarily correct since the BL may spread out (Ferland et al., 1982). These calculations were complimented with an analytic treatment of the meridional direction which showed that BL could spread and cover a significant part of the WD (Piro and Bildsten, 2004).

Recognizing the multi-dimensionality of the problem several authors have attacked the problem directly using numerically methods culminating in simulations which included flux-limited radiative transport (Robertson and Frank, 1986; Kley and Hensler, 1987; Kley, 1989; Kley, 1991). However, as these simulations predated those of (Piro and Bildsten, 2004) their setup did not include sufficient resolution in the radial and meridional planes to capture the dynamics and structure of the BL.

In this paper we set out to calculate the dynamical structure of the BL with sufficient numerical resolution to capture the dynamical evolution of the accretion flow and its interaction with the stellar surface (see Fisker and Balsara, 2005). Our model is presented in Section 2 and results are given in Section 3.

## 2. Computational model

The source of the angular momentum transport in the BL, which is responsible for transporting matter through the disk, is a combination of magnetic fields and turbulence. However, an a priori prescription, in particular in the BL, is a source of disagreement (see Popham and Narayan, 1995, and references therein). Instead the efficiency of the angular momentum transport can be parametrized with a coefficient, $\alpha$ so that $\nu = \alpha c_{\rm s} H$, where $\nu$ is the kinematic viscosity coefficient, $c_{\rm s}$ is the sound speed and $H$ is the vertical disk scale height (Shakura and Sunyaev, 1973). Describing the angular momentum transport with a simple viscosity coefficient means that the dynamics follows the Navier–Stokes equations. Here the Navier–Stokes equations as given by Mihalas and Mihalas (1984) are solved in spherical coordinates $(r, \theta, \phi)$ on an axisymmetric mesh with 384 ratioed zones in the radial direction and 128 ratioed zones in the meridional range spanning 0°–30° from the disk plane – same as Fisker and Balsara (2005). Symmetry across the disk plane is assumed. This allows a doubling of the zone resolution at the same CPU-cost.

This allows us to resolve a pressure scale height in the radial direction and a disk scale height in the meridional