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# Constraints of Winds from Accretion Disks

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**Abstract.** The structure of an accretion disk illuminated by X-rays is investigated. For high values of X-ray heating no static disk solution was found, while for low values of heating a corona was formed above the disk. In the high X-ray illumination case the only possible wind solution is the supersonic solution meaning the evaporation of the disk. Only a very narrow range of X- ray heating and critical point height yield the proper wind solution that agrees with the disk solution. Finally, a self-consistent model of accretion disk and a wind is presented.

## 1. Introduction

Illumination can affect the disk in various ways. First, illumination contributes directly to the heating of the interior of the disk and as a consequences changes the entire vertical structure of the disk. The thermal balance of the optically thin regions is very delicate. Hence, we expect that even small amounts of additional heating can have a large effect on the disk atmosphere, including the production of a "chromosphere" (Mineshige and Wood 1991), a corona and a wind (Begelman and McKee 1983).

None of the previouse treatments tried to solve the disk-wind problem self-consistently. The purpose of this paper is to derive self-consistent solutions of the hydrostatic disk structure and the dynamic wind above it. In this paper we concentrate on disks around white-dwarfs.

## 2. The physical model and basic assumption

### 2.1. *The disk model*

The hydrostatic part of the present model follows the basic model by Shaviv and Wehrse (1991) for more details see also Idan and Shaviv (1996). The energy input per unit time and mass in this work, is produced both by viscous dissipation, convection and heating. The behavior of the X-ray flux with depth is assumed to be controlled by:

$$\frac{\partial Q_x}{\partial z}(z) = -\kappa_x \rho Q_x \tag{1}$$

where $Q_x$ is the incoming X ray flux at a radius R of the accretion disk and at $z_0$ the disk height, and is an input parameter. Here we ignore the X ray flux



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entering from the opposite side of the disk, as well as the wavelength dependence of the X-rays. $\tau_x$ is the optical depth for extinction of X-rays, namely

$$\tau_x = \int_{z_0}^{z} \rho \kappa_x^{abs} dz \tag{2}$$

where $\kappa_x$ was taken from -NIST Standard Reference Database 8, "X-ray and Gamma-ray attenuation coefficients and cross sections database", version 2.0 Program written by M.J. Berger. In order to simplify the calculation, we assume that the X-rays may be treated as monochromatic and define a mean monochromatic absorption coefficient by:

$$< \kappa > = \frac{\int \kappa(E) f(E) dE}{\int f(E) dE} = \kappa(E = E_x = 2Kev). \tag{3}$$

The assumption that goes into eq. (1) implies that all the absorbed X-rays are converted into heat. It maybe an upper bound for the formation of a wind (see below).

### 2.2. *The wind model*

We assume a simple plane geometry. Obviously this assumption breaks down as the wind moves outward and a full 3D treatment is needed. However, we will discuss only the domain between the disk and the first critical point. We assume, and later justify a posteriori, that the height of the critical point is sufficiently low so as not to invalidate our assumption about the geometry.

The basic wind equations are the continuity equation, the momentum equation and the energy equation (Idan and Shaviv 1996). Due to the complexity of the problem, we assume L.T.E. and we are aware of the crudeness of this assumption. Our solution will only be an upper limit to the wind solution.

The independent variables in the wind model are : The height of the critical point, $z_{crit}$, where we assume a priori that the denominator and numerator vanish, the temperature at $z_{crit}$, and the illumination flux at $z_{crit}$. We assume that the X rays are absorbed and the attenuation of the X-ray flux at depth z follows equation (1). Scattering and reflection of X-rays are ignored in the present treatment.

Once we choose these independent variables, we can calculate the density and the mass loss at $z_{crit}$ and integrate downward (and outward if required). When the velocity drops below $10^{-3}$ of the local speed of sound we switch to the hydrostatic code and proceed to calculate the static disk structure. The thermodynamic quantities are assumed to be continuous through the point where the switch from hydrodynamic to hydrostatics takes place.

## 3. Results

### 3.1. The illuminated disk without a wind - The formation of a corona

We first demonstrate the effect of heating on a steady state disk without assuming a wind. The runs of the temperature and density for various heating rates are shown in figures 1. The incident fluxes are the fluxes at the height

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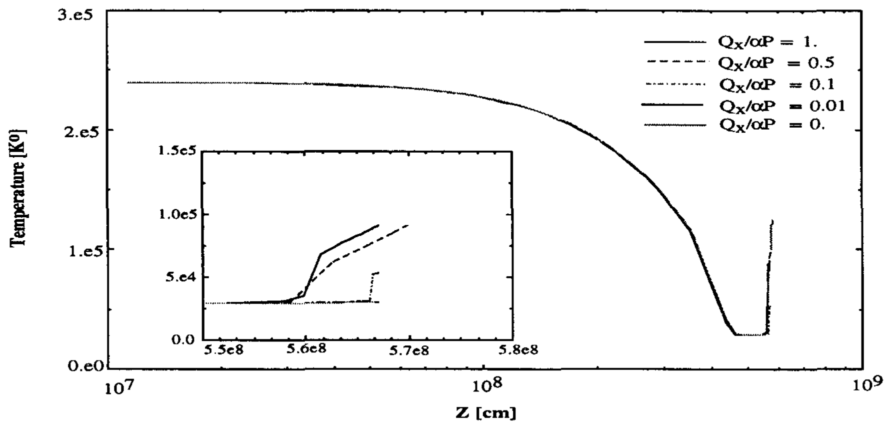


Figure 1. The temperature profile as function of height for various rates of illumination. $\dot{m}_{acc} = 1.6 \times 10^{-10} M_{\odot} yr^{-1}$ and $R_{disk} = 10 R_{wd}$

where the optical depth of the disk is $10^{-4}$ and the pressure is $10^{-4} dyn cm^{-2}$. When illumination is included the disk height increases with the increase in the amount of heating. However, the change in the disk height is only a few percent, in complete agreement with the results of Meyer and Meyer-Hofmeister (1982). But when the heating flux - $Q_x$ - is of the order of 10% of $\alpha P$, where $\alpha P$ is the local heating due to the viscosity, a corona is formed above the disk and it governs the upper part of the disk. As a result, the disk height -which before the appearance of the corona increased with heating - starts to decrease as the heating continues to grow. Once a hot corona is established above a cool atmosphere, heat conduction downward becomes important. At the bottom of the atmosphere, where the temperature is low, the heat conduction is inefficient and the emissivity of the matter is too low to radiate away the accumulating energy. If the density in the corona is too low it can not radiate all the energy and the density increases. Therefore, the corona "digs" itself downward till the layer where all the energy can be radiated away and a stationary state is reached. If the heating due to illumination is higher then the heating due to viscosity – no static disk solution was found, obviously.

For the entire range of parameters explored here ($10^{-5} \alpha P < Q_x < \alpha P$), the consistent corona-disk model yields an optically thin corona and hence the structure of the inner disk is practically unaffected.

### 3.2. The wind structure

We start our investigation of the wind structure with a parameter study in case of a disk with $\dot{m}_{acc} = 1.6 \times 10^{-10} M_{\odot} yr^{-1}$. However, in this section we investigate only the structure of the wind and the conditions for its existence and ignore the requirement for a self consistent wind-disk solution. Even without the condition of self consistency with a disk, a wind solution exists only for certain combinations of $z_{crit}$ and $Q_x$ (at $z = z_{crit}$). In figure 2a we see how

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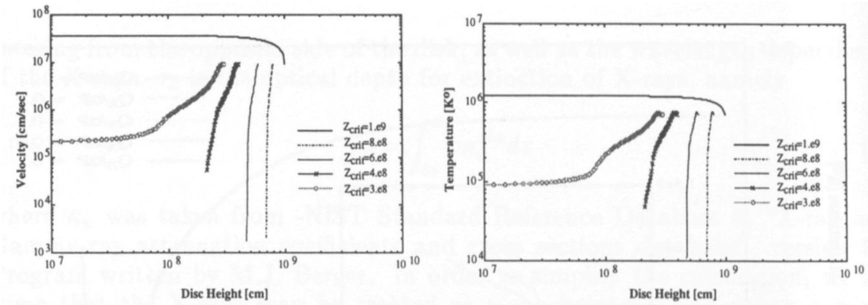


Figure 2. The wind velocity and temperature profiles for a constant $\dot{m}_{wind} = 5 \times 10^{-12} M_{\odot} yr^{-1}$ and different $z_{crit}$. The accretion rate is $1.6 \times 10^{-10} M_{\odot} yr^{-1}$ and $R_{disk} = 10 R_{wd}$.

the value of the pair $(z_{crit}, Q_x)$ affects the wind - for a constant wind mass loss of $\dot{m}_{wind} = 5 \times 10^{-12} M_{\odot} yr^{-1}$. The values of $\dot{m}_{wind}$ given here are for a ring with $\Delta R_{disk} = 5 \times 10^8 cm$ which is a typical size of a ring in a full disk model. The wind solution is very sensitive to the height of the critical point. Actually, the critical point must be placed within a very narrow parameter range. In the particular case shown here, a height of $10^9 cm > z_{crit} > 5 \times 10^8 cm$ leads to a very steep solution for the velocity. These solutions for the wind are good wind solutions. It is however, not clear to what extent the height of the disk will 'fit in'. On the contrary, we can expect that only one disk model will 'fit in' and in this way at least narrow the range of the wind parameters. For $z_{crit} \geq 10^9 cm$ there is no subsonic solution and the velocity increases monotonically as the disk is approached. For $z_{crit} < 4 \times 10^8 cm$, the wind velocity never approaches zero. A given combination of $z_{crit}$ and $Q_x$ does not necessarily yield the prescribed wind mass loss. Moreover, there is not necessarily a wind solution for every pair! Figure 2b shows the run of the temperature for the corresponding cases. We summarize our results in figure 3, where we plotted in the $\dot{m}_{wind} - z_{crit}$ plane the final results for the different rings. As a rule, as we move closer to the WD the mass loss in the wind decreases!

## 3.3. Wind and disk

We next calculate the hydrodynamic structure of the wind and the hydrostatic structure of the disk self consistently with one another. In figure 4a, and 4b, we plot the density, temperature and the velocity as function of height for $\dot{m}_{acc} = 1.6 \times 10^{-10} M_{\odot} yr^{-1}$. The initial height (the height of the critical point) was $7.5 \times 10^8 cm$. The corresponding wind mass loss is $\dot{m}_{wind} = 5 \times 10^{-13} M_{\odot} yr^{-1}$

Note that as the velocity vanishes the slope of the curve increases very much while the sound velocity hardly changes. For this reason the exact value of the Mach number at which the switch between the wind and the disk is made is unimportant, provided it falls in the region where the slope $dv/dz$ is sufficiently high.

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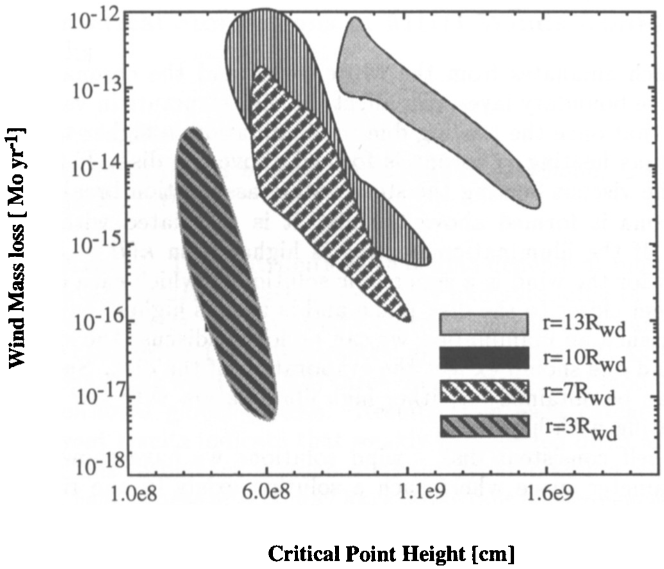


Figure 3. The domain in the figure depict proper wind mass loss as function of $z_{crit}$ where a self consistent wind and disk model exist for different $R_{disk}$

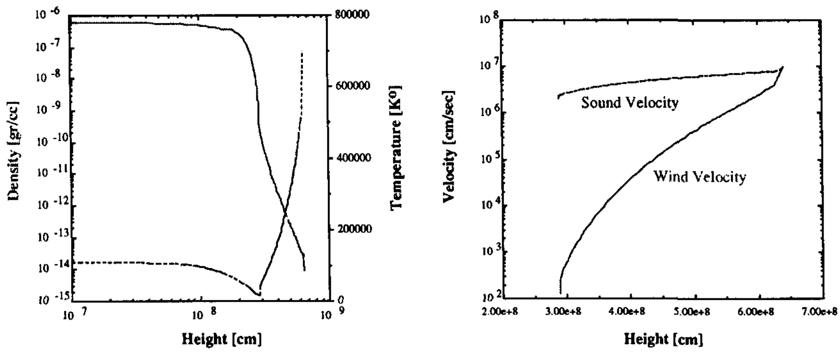


Figure 4. The temperature, density velocity profiles as function of height for a proper self-consistent wind and disk model where $R_{disk} = 10R_{wd}$. $\dot{m}_{acc} = 1.6 \times 10^{-10} M_{\odot} yr^{-1}$ and $z_{crit} = 7.5 \times 10^{8} cm$. The wind mass loss is $5 \times 10^{-13} M_{\odot} yr^{-1}$.

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## 4. Conclusions

Illumination which emanates from the white dwarf and the corona above the white dwarf or the boundary layer, can affect the disk structure in various ways. We have shown that once the heating due to illumination is higher then 10% of the internal viscous heating, a corona is formed above the disk. If the heating is higher then the viscous heating the steady state assumption breaks down.

Once a corona is formed above the disk it is associated with mass loss through winds. If the illumination heating is higher then $\kappa(B - J)$ the only possible solution for the wind is a supersonic solution in which case the velocity increases as we get closer to the disk plane and is always higher then the speed of sound. Under such an illumination we can no longer discuss the steady state disk and wind and one should expect the evaporation of the disk. Such a supersonic solution can be obtained for either high illumination with low $z_{crit}$ or low illumination heating with high $z_{crit}$.

As for the self consistent disk - wind solutions we have shown that the area in the parameter space where such a solution exists in one ring, is very narrow. In the case of a ring in an accretion disk ($R_{disk} = 10R_{wd}$) with $\dot{m}_{acc} = 1.6 \times 10^{-10} M_{\odot} yr^{-1}$ and $z_{crit} = 7.5 \times 10^{8} cm$ - the matching wind solution has a mass loss rate of $\dot{m}_{wind} = 5 \times 10^{-13} M_{\odot} yr^{-1}$. If we assume that this is a typical number per ring and multiply it by the total area of the disk we obtain that the wind mass loss from the entire disk is few times $10^{-12} M_{\odot} yr^{-1}$ (which is only few percent of the $\dot{m}_{acc}$), a number frequently quoted from the observations.

However, the most important conclusion of the present work is that wind solutions exist only for a very narrow range of parameters or wind mass losses. The gratifying result is that this mass loss is within the range of the numbers quoted as wind mass loss from accretion disks (Hoare and Drew 1993).

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