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A study of accretion disk wind emission

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Abstract. Accretion disk wind has been the most accepted scenario to explain the strong emission lines and the P Cyg profiles detected in the ultraviolet spectra of non-magnetic cataclysmic variables (CV's). Due to the main characteristics of line profiles, it is commonly accepted that those winds are radiatively driven. Here, we present an alternative method to study the disk-wind that takes into account the structure of whole system (disk+wind), as well as the interface between the disk photosphere and wind. We calculated a set of 1D NLTE atmosphere wind models with a consistent velocity wind profile, and map them into a 2D model including a 3D velocity field. The synthetic spectrum is calculated by exactly solving the radiative transfer equation throughout the inner disk, interface region and wind, taking into account the Doppler shifts for each step. We found a modeled line profile behavior according with the observed one. We also found dependences between line profiles and disk parameters. When tested with UV data for two nova-like systems, the models shows a good agreement. However, we found a lack a flux for high ionization lines. It is possible that it is due to the influence of the inner disk radiation on the outer wind regions.

Key words. Stars: accretion disk – Stars: atmospheres – Stars: wind – Stars: cataclysmic variables

1. Introduction

The mass transfer in non-magnetic cataclysmic variables (CVs) are done through an accretion disk. The most luminous disks are present in "*nova-like*" and "*dwarf novae*" in outburst. The ultraviolet (UV) spectra of these kind of CVs show features that would evidence mass loss through a wind (e.g. Cordova & Mason 1982, 1985). The wind driving mechanism is still unknown. However, it is most accepted that these winds are radiatively line-driven. Other mechanisms have been proposed, such as magnetically driven winds (e.g. Blandford & Payne 1982), but a lack of more accurate estimates of mass loss, ionization structure and collimation, makes hard to know which mechanism (or mechanisms) is actually working.

Hydrodynamic models of line-driven disk wind predict strong rotating, axi-symmetrical geometry and different degrees of collimation (e.g. Proga et al. 1998, 1999; Pereyra et al. 2000). These models bears mass loss rates ($\dot{M}_w$) ~1-10% of accretion rate ($\dot{M}_a$). Also, in order to limit the basics wind parameters,

Send offprint requests to: R. E. Puebla kinematic models have been developed to get their synthetic spectra and confront them with data (e.g. Vitello & Shlosman 1993; Knigge et al. 1995). Recently, some improvements have been done on these kind of models, specially using Monte-Carlo methods, to calculate the wind temperature and ionization structure (Long & Knigge 2002; Noebauer et al. 2010). Even so, it is still difficult to find a set of wind parameters that could reproduce the spectral characteristics (lines + continuum) in a wide spectral range (Long 2006).

Here, we present a brief review of an alternative method that was recently developted by our group (Puebla et al. 2011). Our approximation tries to reduce the free parameter space calculating the mass loss rate through a set of one-dimensional hydrodynamic models. Wind atmosphere models are calculated using the velocity profiles thus calculated, and the spectrum is obtained to compare with data. Below, we show the method and the first comparisons with UV data from two high orbital inclination "*nova-like*" CVs: RW Tri and V347 Pup (Puebla et al. 2011).

2. The disk-wind model

In order to analyze the disk-wind interaction and their emission in UV, we developed a model that try to reproduce the kinematic behavior that would have a such as system. We divided the disk in a set of concentric atmospheres. Each of these atmospheres is composed by an internal disk structure, the photosphere itself and a wind that extends up to a height equal to disk radius. All of these structures are calculated in the vertical sense. Those structures so calculated are then placed together to form a two-dimensional structure of disk plus wind. The recipe ingredients of the model as well as the walking road to obtain the spectrum is described below.

2.1. The CMFGEN disk wind atmospheres

Each disk-wind atmosphere is calculated using the code CMFGEN (Hillier & Miller 1998). This code was originally developted to study the OB star winds. It calculates the structure of a stellar atmosphere with wind solving the radiative transfer, radiative equilibrium and the rate equations in non local thermal equilibrium (NLTE), in the co-moving frame (CMF). The code details and how it works can be found in some of previous publications (e.g. Hillier 1990; Hillier & Miller 1998; Hillier & Lanz 2001; Hillier 2003). In the case of our approximation, the structure of each atmosphere is calculated as follows.

The first step is to calculate an accretion disk atmosphere through the method developted by Wade & Hubeny (1998). We take the density structure from this model to obtain a velocity profile through the mass loss and continuity equation. This velocity field is then matched with a velocity wind profile calculated from Euler equation taking into account the physical condition of the disk environment in vertical sense (variable gravity, variable radiation flux and wind expansion) (Puebla et al. 2011).

The second step is to calculate the wind structure (electron temperature, atomic level population, radiation field, etc.), the emissivity and opacity for an extensive frequency grid in CMF. This atmosphere models are calculated using CMFGEN with a plane parallel geometry. The input model are the local effective temperature and mass loss.

Finally, this set of models are interpolated within a two-dimensional and finer grid. Thus, for each frequency, we make 2D maps for the emissivity, opacity and then the source function in co-moving frame, as well as for electron density and radiation field.

The left panel of figure 1 shows the temperature structure for an atmosphere model with a T_{eff}=2.6×10^4 K from a ring of a disk with M_{WD}=0.6 M$_\odot$ and an accretion rate, $\dot{M}_a$=5×10^{-9} M$_\odot$ yr^{-1}. The right panel shows the ionization structure for oxygen for the same atmosphere. Both figures are focused on photosphere-wind interface. The figure shows a strong ionization structure variation in the interface region, close to the minimum temperature. This behavior is reproduced in all atmosphere models through the disk.

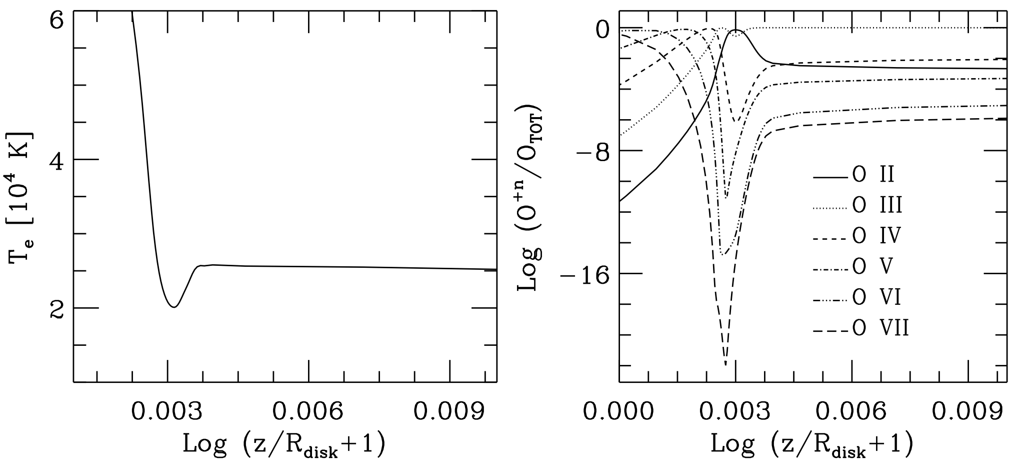

Fig. 1. Temperature (left panel) and oxygen ionization structure (right panel) for a disk-wind atmosphere corresponding to a disk with m_{WD}=0.6 $M_\odot$ and accretion rate $\dot{M}_a$=5×10^{-9} $M_\odot$ yr^{-1}. The base model is on r_o =3.8×10^9 cm with T_{eff}=2.6×10^4 K.

2.2. Spectral synthesis

The spectral synthesis method is based on the 2D code by Busche & Hillier (2005). We adapted this code to disk plus wind geometry. In addition to vertical velocity, we included azimuthal and radial velocity components. The spectrum is calculated using a new grid of impact parameters and for each of them, a regular net of azimuthal points taking into account the projection of disk and wind on the sky. For each point the radiation is transfered through the disk and wind using the source function in CMF, which is re-calculated in the observer frame using the Doppler shift caused by the 3D velocity field in the observer direction.

3. Results

3.1. The model behavior

We calculated synthetic spectra in order to study their behavior with different disk parameters as accretion rate, orbital inclination and white dwarf mass. The main characteristics are listed as follows:

- Accretion rate directly affects the wind temperature. This cause a strong dependence of relative intensity of lines on $\dot{M}_a$. Thus, high $\dot{M}_a$ bears stronger lines for higher ionized species (C IV, N V) than low ionized species lines (C III, Si III). Also, when accretion rate is higher the mass loss increases, which leads to deeper absorption profiles when $\dot{M}_a$ rises.
- When varying the orbital inclination, we found a behavior consistent with observations. It is spected due to geometry model, however we found some emission features some lines, as Si IV, that are not observed. This effect is caused by the *cylindrical-like* geometry of atmosphere models.
- We used disk models with the same temperature, but different white dwarf masses (M_{WD}). We found that the M_{WD} changes the size of ejecting wind region. Thus, lower M_{WD}, higher this region, and then more material are ejected. This bears deeper absorption line profiles, specially for low orbital inclination systems.

3.2. Application on RW Tri and V347 Pup

We confronted the models with UV data from archive IUE and HST archive for "*nova-like*" CVs RW Tri and V347 Pup, respectively. These systems have high orbital inclination

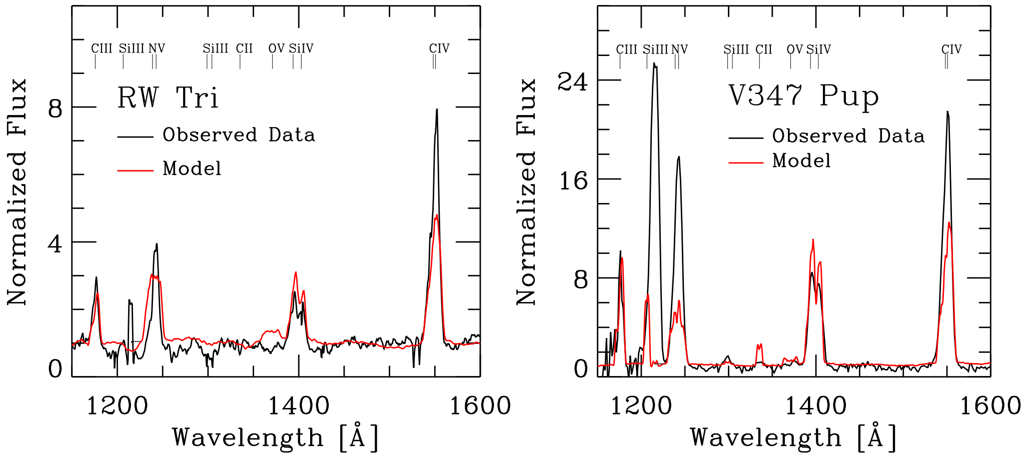

Fig. 2. UV data (black lines) for RW Tri (left panel) and V347 Pup (right panel) with the corresponding best models (red lines). These models was calculated using physical parameters close to those found in literature. The mass loss rates are 8.2×10^{-11} $M_{\odot}$ yr^{-1} and 8.1×10^{-11} $M_{\odot}$ yr^{-1} respectively (Puebla et al. 2011).

and present strong emission lines, specially for N v, C iii, C iv and Si iv.

Figure 2 shows the best models and the UV data for both systems. The left panel corresponds to RW Tri, and the right one to V347 Pup. These systems have similar physical parameters, except for orbital inclination (70° for RW Tri and 80° for V347 Pup), and their spectra also are. As it is shown by figure, we found a good agreement for C iii and Si iv lines. On the other hand, for high ionization lines, N v and C iv, a lack of flux is evident.

The formation line regions strongly depend on the ionization structure of wind. This structure depends on disk luminosity (more directly on M_{WD} and $\dot{M}_a$), and its temperature radial distribution. Our models use the standard temperature radial distribution (Shakura & Sunyaev 1973). Hence, our models bears wind structures that follow the corresponding from original 1D atmosphere models in the vertical sense. The ionization structure of each wind point is only influenced by the disk temperature just below, but not by rest of disk radiation. Due to this, the outer (and upper) wind regions do not see the inner disk radiation. That is the reason why high ionization regions are little in our models, and the reason why this kind of lines are not strong enough.

In the case of low ionization lines our models bears formation regions compatible with the strength of line observed for two systems. These regions are mainly located on the outer wind, and close to the cooler disk surface.

Recently works using Monte-Carlo methods have shown that the inner disk radiation could influence remote wind areas, and would produce stronger higher ionization emission lines (Noebauer et al. 2010). This could evidence that a treatment 2D of the structure is necessary in the analysis of accretion disk winds emission.

4. Conclusions

We developed an alternative method to study the accretion disk plus wind emission. This method is based on stellar winds atmospheres structures calculated using modified codes commonly used for hot stars.

The temperature and ionization structure reflect the "*cylindrical*" nature of the set of models. Our model reproduce the main observed trends of line profiles observed in the UV spectra for luminous non-magnetic CVs.

When compared with observations, our models bear acceptable linen profiles for the main lines of UV for high orbital inclination systems. However, it was found a lack of flux for high ionization lines. It could be due to the influence of the inner disk or the "*boundary layer*" radiation on the outer wind region needs to be taken account.

5. Discussion

DMITRY BISIKALO: What is the physical mechanism of wind acceleration up to 5000 km s^{-1}?

RAUL PUEBLA: The wind is accelerated radiatively by lines. We used the Abbott (1980) approximation, with α values between 0.5 and 0.9. The k value equal to 0.6. With these parameters it is possible to accelerate the wind up to 5000 km s^{-1} in the upper branch of solutions.

LINDA SCHMIDTOBREICK: Can the winds that you get become strong enough to suppress the accretion?

RAUL PUEBLA: Our wind models bears mass loss rates up to ~5 % of accretion rates in disk. These values are low enough to maintain a steady disk accretion.

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