The Disk Wind Contribution to the Optical Spectra of Cataclysmic Variables

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ABSTRACT

High-State non-magnetic Cataclysmic Variable systems (CVs) exhibit strong emission in Hydrogen & Helium optical recombination lines. Here we present results obtained by encorporating a macro atom treatment into our Monte Carlo radiative transfer code originally used to model UV resonance lines in CVs, Python . Our benchmark CV model is capable of producing all of the notable optical lines (e.g. He II 4686, Hα, He I), as well as enchanced emission in the Ly-α and He II 1640 UV lines. In addition, the improved treatment of recombination means that the bound-free continuum emission is sufficient to mask the so-called 'Balmer jump' photoabsorption edge, suggesting a potential solution to a longstanding problem.

1. Introduction

Introduction to CVs, Cv modeling, UV spectra and optical spectra.

2. A Biconical Wind CV Model

What motivates this model. Literature.

2.1. Description of Model: Geometry and Kinematics

– Velocity law, kinematics, etc.

– Refer to figure 2

– define velocity law: As in LK02, we follow the prescription of SV93 in both our fundamental biconical wind model and velocity law. The poloidal velocity, v_l, along a streamline in our model is given by

$$v_l = v_0 + [v_\infty(r_0) - v_0] \frac{(l/R_v)^\alpha}{(l/R_v)^\alpha + 1}, \tag{1}$$

where l is distance measured along a poloidal streamline. This power-law velocity profile was adopted by SV93 in order to give a continuous variation in the derivative of the velocity and a ralistic spread of Doppler-shifted frequencies in the outer portion of the wind ($l > R_v$). We have similar requirements.

2.2. Photon Sources

Identify the photon sources in the model.

2.2.1. Disk Treatment

How we treat the disk and why. Refer to LK02, Kurucz, Wade, Murray and Chiang.

2.2.2. Boundary Layer

Whether we include one, why why not, referring to He II and ionization.

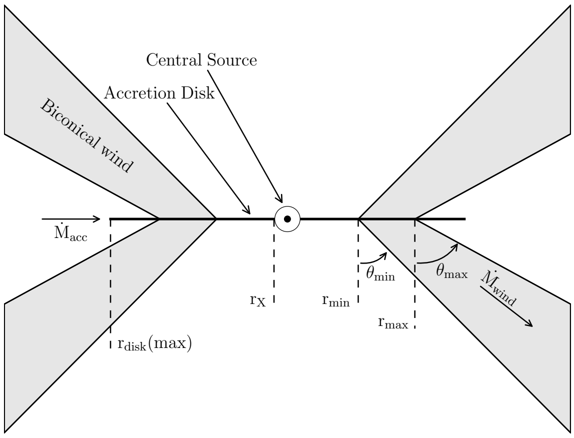

Fig. 1.— Cartoon illustrating the three broad classes of sightline discussed in the text.

Free Parameters	Value
M_{WD}	$0.8 M_{\odot}$
$\dot{M}_{acc}$	$3.16 \times 10^{-9}\ M_{\odot} yr^{-1}$
$\dot{M}_{wind}$	$3.16 \times 10^{-8}\ M_{\odot} yr^{-1}$
r_{min}	$4 R_{WD}$
r_{max}	$12 R_{WD}$
θ_{min}	$20.0°$
θ_{max}	$65.0°$
λ	0
v_{∞}	$3 v_{esc}$
R_v	7×10^{11}cm
α	1.5

Table 1: Wind geometry parameters used in the benchmark CV model.

3. Radiative Transfer & Code Validation

Introduction and description of Python.

- Brief, mainly referring to LK02 and H13.

- Give a little history to the code. How it improves on e.g. SV93.

3.1. Ionization scheme

Description of ML93 ionization scheme and motivation for using it.

- First, the SED can be approximated well by a Blackbody due to the absence of an X-ray source, and therefore the blackbody treament is appropriate;

- Second, this provides continuity from LK02 and allows us to do a like-for-like comparison

- Here we follow LK02 in using the ionization scheme presented by Mazzali & Lucy (1993), who specifically present the formula

$$\frac{n_{j+1}n_e}{n_j} = W[\xi + W(1-\xi)] \left(\frac{T_e}{T_R}\right)^{1/2} \left(\frac{n_{j+1}n_e}{n_j}\right)^*_{T_R}, \tag{2}$$

which, in principle, accounts for ionizations from and recombinations to all levels of an ion.

3.2. Macro-atoms

Description of macro atom and why they are so important. Describe the interplay between macro atoms and simple ions.

3.3. Atomic Data

Description of atomic data used (that is different from H13).

- Clearly identify and cite sources.

- Discuss any limitations and what motivated the level choices in particular (i.e. why do we split up he I but not He II, l-mixing, etc).

3.4. Code Validation and Testing

3.4.1. Non-LTE Level Populations

Discussion of how we tested the macro atom scheme

- Figure 2 Case A and B comparisons with Seaton 1959.

– I'd possibly also like to include a Helium test w/ ChiantiPy or similar

– or maybe TARDIS?

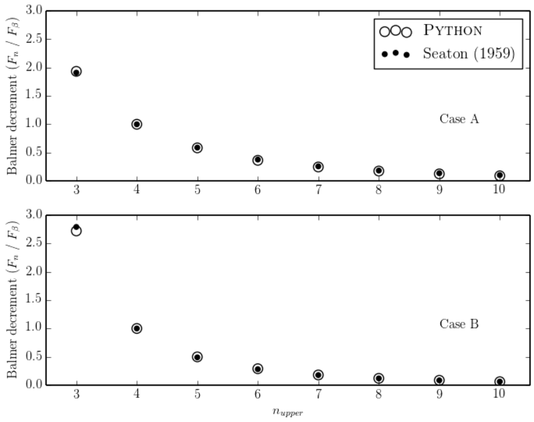

Fig. 2.— Case A & B comparison between S59 and Python at 10000K and 20000K

3.4.2. Ionization

How ML93 + macro atom hybrid ionization has been tested.

– Description of past tests: TARDIS, LK02 v Cloudy, NSH v Cloudy.

– My own cloudy test with Hydrogen and Helium?

– Refer to ionization state sections.

– Show in Figure 3- Ion fractions of Helium, Carbon, Oxygen?

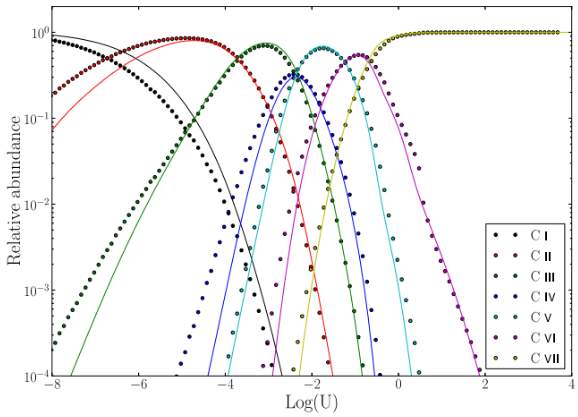

Fig. 3.— CLOUDY TEST. Show three panel figure showing Carbon, Helium and Oxygen.

4. Results

4.1. Synthetic Spectra

Present the spectra with a brief description, .

4.2. Ionization State

Present the ionization state with wind plots showing dominant ions.

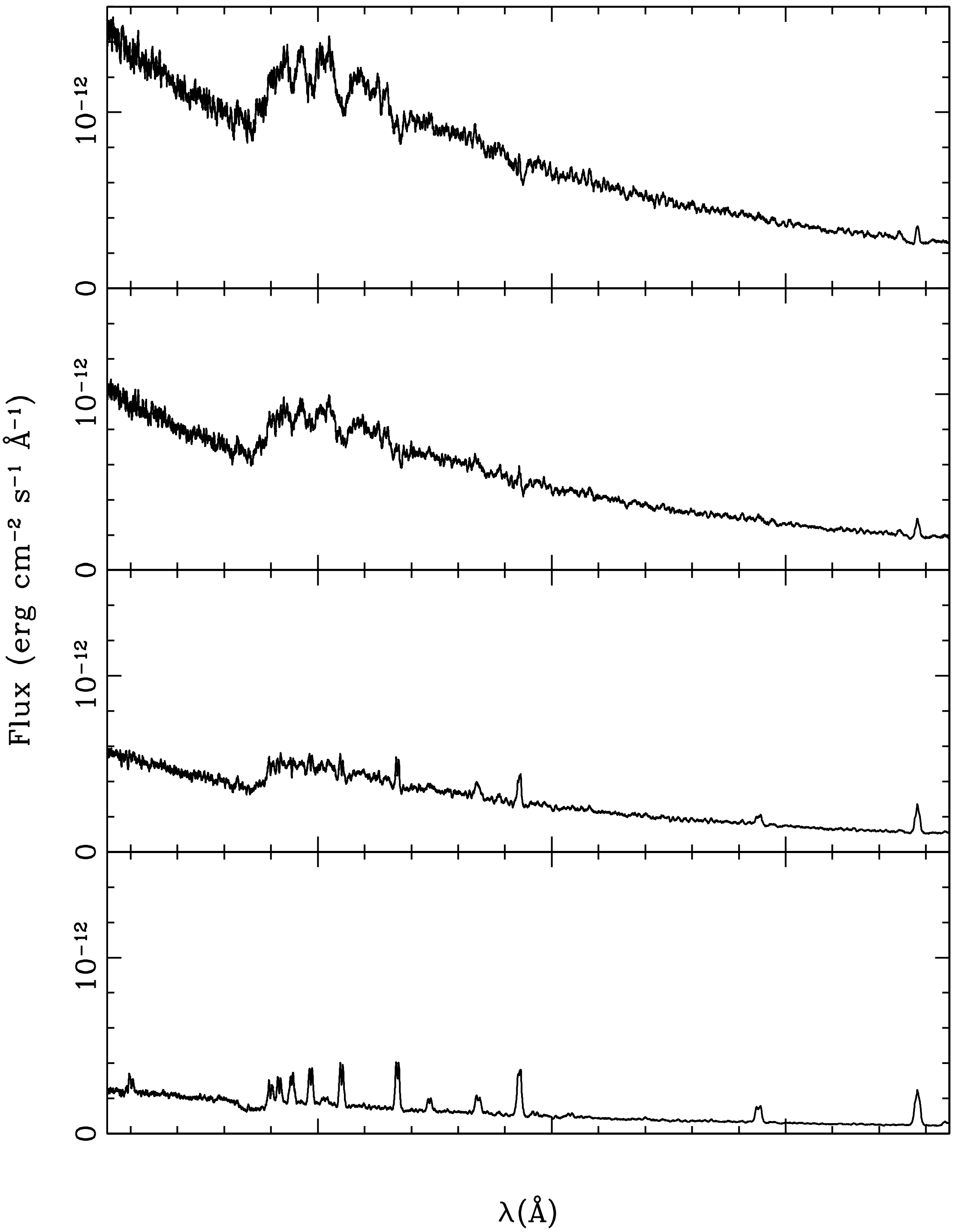

Fig. 4.— Synthetic Spectra computed for sightlines of 22.5, 25, 62.5 and 80 degrees.

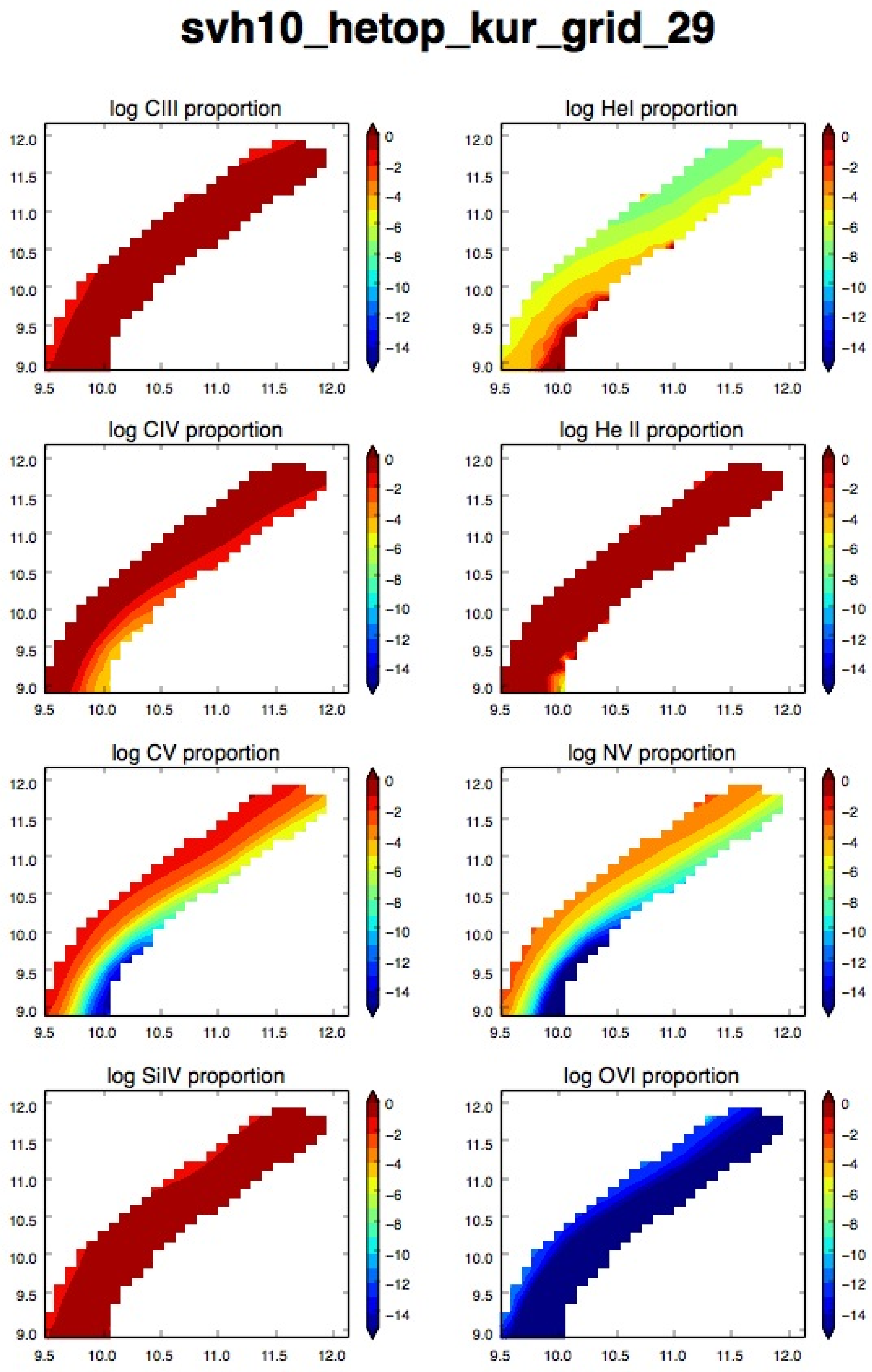

Fig. 5.— Synthetic Spectra computed for sightlines of 22.5, 25, 62.5 and 80 degrees.

5. Discussion of Results

5.1. The Balmer Series

– A main result: that we are able to produce the Balmer lines. Comparison to old model without macro atoms?

– How this changes with inclination

– Comparison to literature

– trends along the series, strengths and double v single peaked emission

5.2. The Balmer Jump

– A main result: that we are able to fill in the Balmer jump with the recombination continuum from the wind

– How this changes with inclination

– Comparison to literature

– Discussion of disk atmosphere treatment and its effect.

5.3. Helium Lines

Discussion of Helium lines in the spectrum.

– He II 4686, He II 1640 strengths

– Make the prediction that if 4686 is strong we might expect strong He II 3202 5-¿3.

– Discuss why it wouldn't have been seen yet (spectral coverage)

– Helium I lines

5.4. UV Resonance Lines

Compare spectra to LK02 and other models. Are the spectral features preserved, has anything significant changed. Lyman alpha?

5.4.1. OVI and the Auger effect

– Why it is important

– how it could be implemented.

6. Comparison with Data

Here we compare Python to real data. Hopefully from e.g. a high inclination nova like with a number of features which are similar. Discuss the similarities and differences and why.

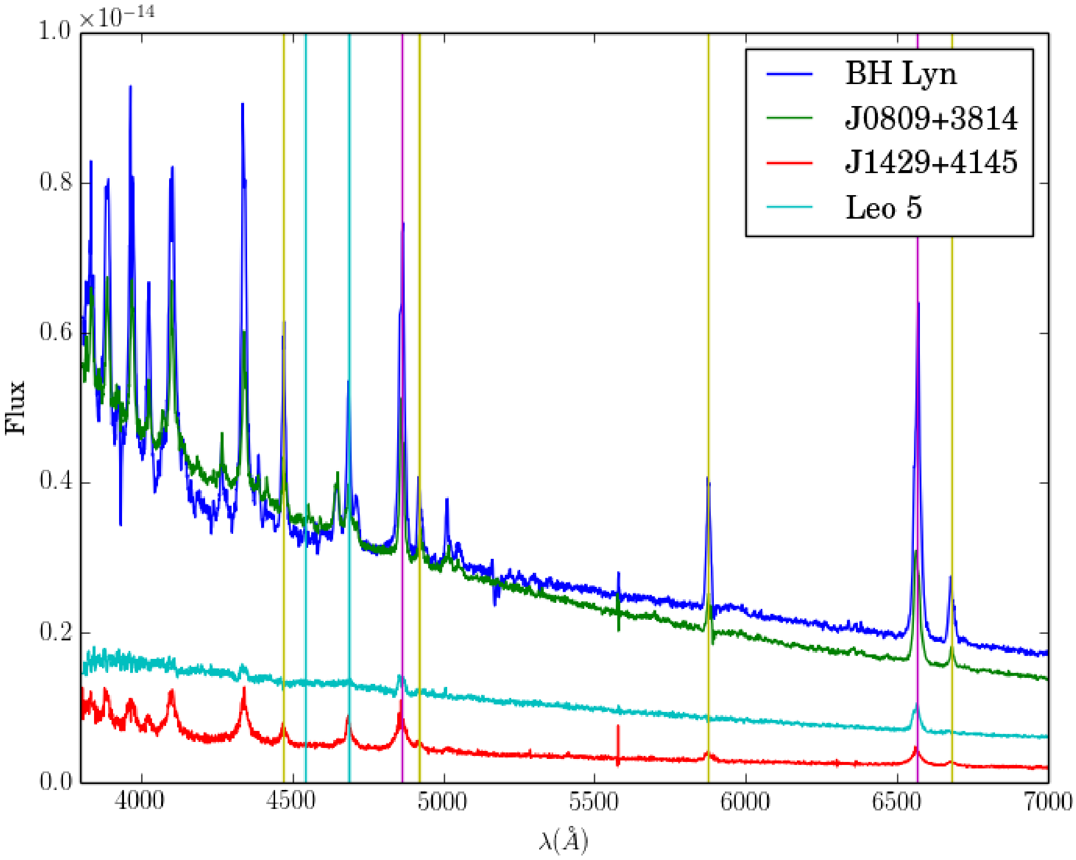

Fig. 6.— Comparison between our benchmark model viewed at xx degrees with the non-magnetic Nova Like UX UMa.

7. Conclusions and Future Work

7.1. Future Work

In addition to this project, we plan to apply the macro atom scheme to QSOs in order to build on the work of Higginbottom et al. (2013), in which a benchmark biconical disk wind model was presented. In particular, we hope that the macro-atom scheme will enable the model to produce significant Lyman-α emission, as is observed in QSOs.

Acknowledgements