

# Phase-dependent effects on X-ray emission of magnetic cataclysmic variables



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## Abstract

The X-ray emission in magnetic cataclysmic variables is mainly due to an optically thin bremsstrahlung from the post-shock region. The observed flux of some systems shows variations along the orbital motion, which can be explained by phase-dependent absorption and/or occultation of the emitting regions. Two emitting regions can also play a role on these modulations. In this work, we explore these phase-dependent effects on the continuum emission of mCVs using CYCLOPS-X. This code calculates these effects self-consistently with the 3D geometry of the accretion column, limited by the lines of a dipolar magnetic field.

## 1. Introduction

- Magnetic cataclysmic variables (mCVs) are a class of the cataclysmic variables where the accreted material is channelled by the magnetic field of a white dwarf (WD) forming an accretion column (e. g. Cropper, 1990, SSR, 54, 195).
- The flux from mCVs is phase-dependent (see Figure 1). This can be explained by partial/total self-eclipses and/or absorption by the accretion stream. The existence of two accreting regions can also modulate the observed emission from mCVs.

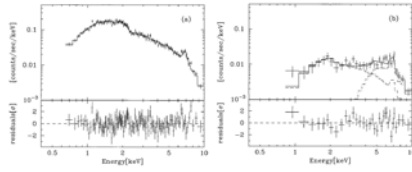


Figure 1: Phase resolved spectroscopy of the polar CP Tuc. Extracted from Misaki et al. (1996, ApJ, 470, 53).

- The absorption of the post-shock region varies along the orbital revolution due the complex geometry of the accretion stream. Moreover, in one given orbital phase, the accretion stream can cover partially the post-shock region. An ad-hoc representation of these effects is presented by Done & Magdziarz (1998, MNRAS, 298, 737).
- Here, we present a self-consistent 3D representation of the accretion stream including bremsstrahlung emission of the post-shock region and absorption by the pre-shock portion of the column. The code includes by construction effects due to occultation and two emitting regions.

## 2. CYCLOPS-X

- CYCLOPS-X (Silva et al. 2011, arXiv:1101.5568) is an extension to X-ray wavelengths of a 3D code aimed to model the optical and infrared emission of polars (Costa & Rodrigues 2009, MNRAS, 398, 240).
- The post-shock region in CYCLOPS-X is a 3D multitemperature and multidensity structure geometrically defined by a dipolar magnetic field. Please see the complete list of parameters of a model in Costa & Rodrigues (2009).
- The photoelectric absorption by the pre-shock region is also considered. To represent this absorption, we adopt the cross-sections of Balucinska-Church & McCammon (1992, ApJ, 400, 699). The photo-absorption from the interstellar medium can also be considered.

## 3. Parameters used in the figures

In the following figures, we used the parameters listed in Table 1 and the radial temperature and density profiles shown in Figure 2.

Table 1: Parameters used in the figures.

Parameters	Absorption	Self-eclipse	Two regions
$i$ , deg	33.0	40.0	80.0
$\beta$ , deg	18.0	68.0	50.0
$\Delta_{long}$ , deg	21.0	49.0	29.0
$\Delta_R$	0.3	0.30	0.3
$h_{spot}$ , $R_1$	0.22	0.22	0.22
$B$ , MG	20.0	20.0	20
$b_{lat}$ , deg	74.0	45.0	50.0
$b_{long}$ , deg	90.0	360.0	360.0
$T_{max}$ , keV	21.0	21.0	11.0/71.0
$N_{el}^{max}$ , $cm^{-3}$ (log)	14.6	14.6	14.6

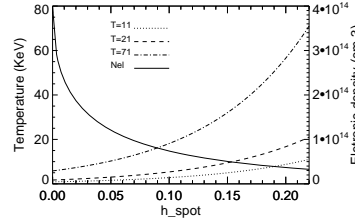


Figure 2: Temperature and density profiles used in the figures.

## 4. Absorption effects

Figures 3 and 4 show light curves and spectra of models with different column densities in the pre-shock region. No interstellar absorption is considered. As expected, Fig. 4 shows that the absorption due to the pre-shock region saturates. For larger densities, this saturation occurs at larger energies. This saturation results from the partial covering of the emitting region by the pre-shock region (Fig. 5). It is proportional to the post-shock area occulted by the pre-shock region. Hence, this effect depends on the geometry of the system and can only be properly accounted in a correct 3D representation of the system (Fig. 6). This "absorption saturated" spectrum is similar to the faint phase spectrum of CP Tuc shown in Figure 1 (right). The difference in low energies can be corrected by including the interstellar absorption.

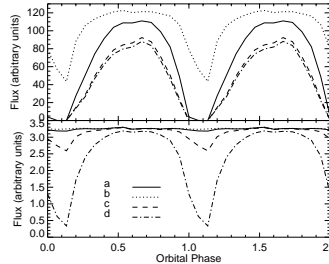


Figure 3: X-ray light curves for different densities;  $a = 3.3 \cdot 10^{10} \text{ cm}^{-2}$ ;  $b = 3.3 \cdot 10^9 \text{ cm}^{-2}$ ;  $c = 3.3 \cdot 10^{11} \text{ cm}^{-2}$ ;  $d = 3.3 \cdot 10^{12} \text{ cm}^{-2}$ .

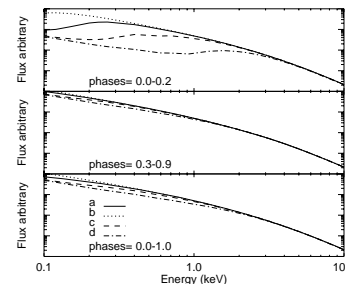


Figure 4: X-ray spectra of the models presented in Figure 3.



Figure 5: Images of the accretion stream in 12 spin phases along the WD rotation for model c.

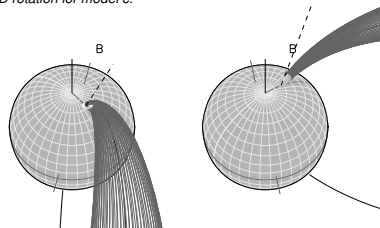


Figure 6: Observer view of the system in spin phases 0.125 (left) and 0.35 (right).

## 5. Occultation effects

In Figure 7, we can observe the modulation in X-ray light curves generated by self-eclipse. There are three possible configurations as a function of the inclination: no eclipse ( $i=10^\circ$ ), partial eclipse ( $i=40^\circ$ ), and total eclipse ( $i=90^\circ$ ). For

this geometry, the changes in the shape of the spectra from phase to phase are negligible.

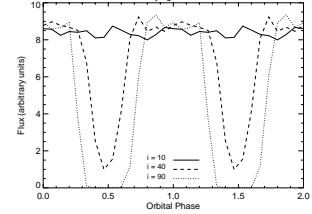


Figure 7: X-ray light curves for self-eclipse configuration.

## 6. Two regions effects

We now turn to the effects of a two-pole geometry with different temperatures. Figure 8 shows that due to occultation effects each region is not seen during all the spin revolution, which is also illustrated by Fig. 9. The different temperatures result in phase-dependent spectra (Fig. 10).

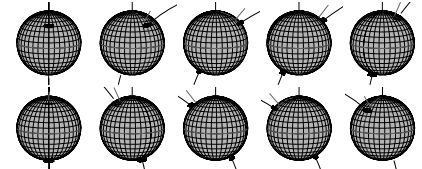


Figure 8: Observer view of a system with two visible emitting regions in 10 spin phases.

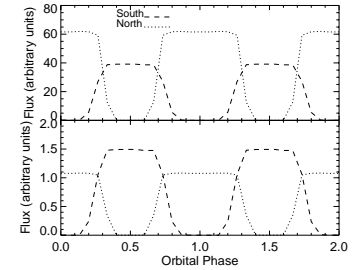


Figure 9: (Upper panel) X-ray light curves in 0.1 keV for north ( $T=11 \text{ keV}$ ) and south ( $T=71 \text{ keV}$ ) post-shock regions. (Bottom panel) Same as upper panel for 1 keV.

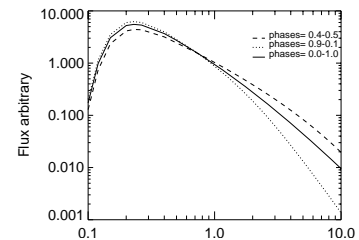


Figure 10: X-ray light curves of the model presented in Figure 9.

## 7. Conclusions

We present a new code to study the X-ray emission from magnetic cataclysmic variables: CYCLOPS-X. Presently, it includes one or two post-shock regions emitting by bremsstrahlung. They are located in the footpoints of an accretion column defined by the magnetic field lines. An improvement relative to previous works is that CYCLOPS-X has a self-consistent approach of the geometric dependent effects such as (1) the occultation of the post-shock region behind the white-dwarf limb and (2) the absorption of the pre-shock region. An effect to emphasize is the change of the spectra shape due to the saturation of the absorption.