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.

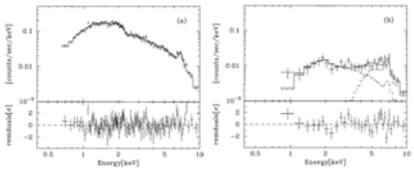

Figure 1: *Phase resolved spectroscopy of the polar CP Tuc. Extracted from Misaki et. al. (1996, ApJ, 470, 53).*

- 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 bremssthralung emission of the post-shock region and **absorption** by the pre-shock portion of the column. The code includes by constrution 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
β, deg	18.0	68.0	50.0
Δ_{long}, deg	21.0	49.0	29.0
Δ_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

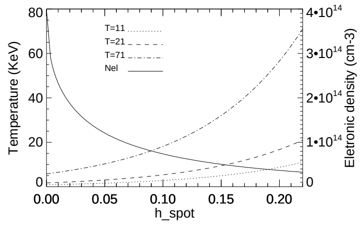

Figure 2: *Temperature and density profiles used in the figures.*

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, the denser the region, the larger the absorption. However, 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 satured" 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.

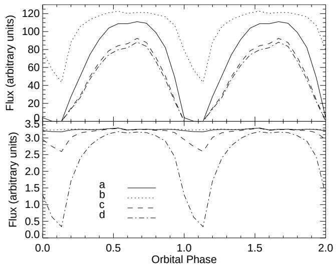

Figure 3: *X-ray light curves for different densities; a =* $3.3\ 10^{10}$ *cm*$^{-3}$*; b =* $3.3\ 10^{9}$ *cm*$^{-3}$*; c =* $3.3\ 10^{11}$ *cm*$^{-3}$*; d =* $3.3\ 10^{12}$ *cm*$^{-3}$*.*

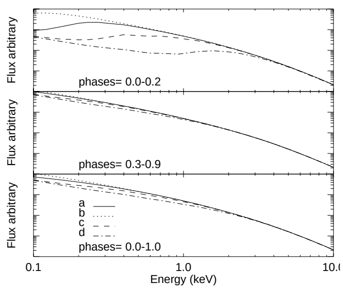

Figure 4: *X-ray spectra of the models presented in Figure 3.*

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

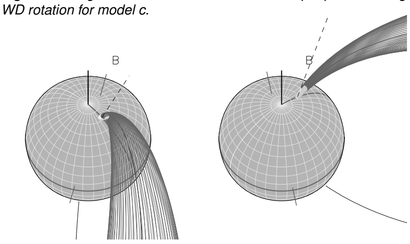

Figure 6: *Observer view of the system in spin phases 0.125 (left) and 0.35 (right).*

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^o), partial eclipse (i=40^o), and total eclipse (i=90^o). For this geometry, the changes in the shape of the spectra from phase to phase are negligible.

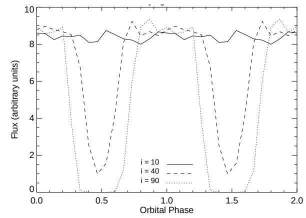

Figure 7: *X-ray light curves for self-eclipse configuration.*

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).

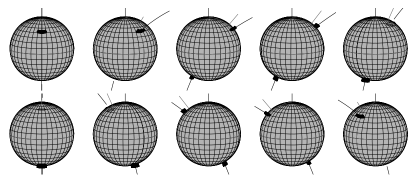

Figure 8: *Observer view of a system with two visible emitting regions in 10 spin phases.*

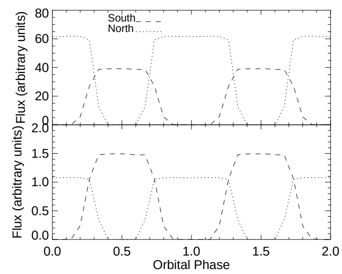

Figure 9: *(Upper panel) X-ray light curves in 0.1 keV for north (T=11 keV) and south (T=71 keV) post-shock regions. (Bottom panel) Same as upper panel for 1 keV.*

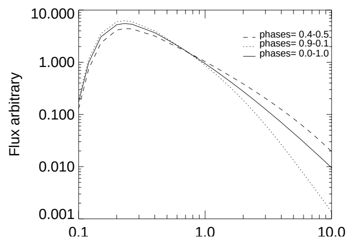

Figure 10: *X-ray light curves of the model presented in Figure 9.*

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 bremssthralung. 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.

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