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# X-RAY SPECTRUM FROM THE ACCRETION COLUMNS OF MAGNETIC WHITE DWARFS

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RESUMEN. Se estudia un modelo general de la columna de acreción en enanas blancas magnéticas (e.g., como en las binarias tipo AM Herculis que consiste de cinco regiones: 1) una región de choque; 2) una región de prechoque calentada sobre la región (1); 3) una región de prechoque enfriada sobre la región (2); 4) un halo circundante, y 5) la superficie de la enana blanca. Encontramos: a) que el ancho del pico de hierro es ∿ 0.8 KeV y relativamente insensible a la profundidad óptica tranversa de Thomson; b) si el halo existe, es muy delgado o tiene muy baja densidad, y c) la profundidad óptica transversa de Thompson es ∿ 0.6.

ABSTRACT: We study a general model of the accretion column of magnetic white dwarfs (e.g. as in AM Herculis binaries) consisting of five regions: 1) a shocked region; 2) a heated preshocked region above region (1); 3) a cool preshocked region above region (2); 4) a surrounding halo; and 5) the surface of the white dwarf. We find: a) the width of the iron peak is ∿ 0.8 keV and relatively insensitive to the transverse Thomson optical depth; b) if a halo exists it is very thin or has a very low density; and c) the transverse Thomson optical depth ∿ 0.6.

*Key words:* STARS-ACCRETION — STARS-WHITE DWARF

## I. INTRODUCTION

AM Her binaries is a subclass of cataclysmic variables in which the white dwarf has a magnetic field strong enough to lock the white dwarf to the companion star. The magnetic field channels the accretion flow to the magnetic polar caps of the white dwarf where the gas passes through a strong shock and the accretion energy is released.

Recent data indicate that there may be cool unshocked material surrounding columns in AM Herculis systems, in particular, the data of Wickramasinghe et al. (1987a, 1987b) indicate that the accretion halo of E1405-451 is optically thick to the Zeeman $\pi$ component of $H\alpha$.

A high temperature ($T > 10 \mathrm{keV}/k_B$) is argued for the optical emission region in AM Herculis binaries by Wickramasinghe and Meggett (1982, 1985). The required height, H, of the emission region is very small, $H \sim 10^5$ cm (compared to the radius of the white dwarf $\sim 10^9$ cm).

Canalle and Opher (1988) found good agreement with the width and height of the observed cyclotron lines of VV Puppis using a height $H \sim 4 \times 10^7$ cm, a magnetic field B (Gauss): $7.4 < \log B < 7.5$, and temperatures $0.2 < T < 2.5 \mathrm{keV}/k_B$. In another study, Canalle and Opher (1989) found again that a relatively low temperature $T < 5.5 \mathrm{keV}/k_B$ can explain well the spectrum of ST LMi.

In the present study, from the observed X-ray spectrum of AM Herculis of Rothschild et al. (1981), we try to answer the following questions: 1) "What is the thickness and density of the surrounding halo of the accretion column?"; 2) "What is the transverse Thomson optical depth of the accretion column?"; and 3) "What is the origin of the observed iron line peak of ∿ 0.8 keV?".

## II. CALCULATIONS

We studied the following general model of the accretion column: Above a low shocked region (1) of temperature $T = 30$ keV/$k_B$, there is an extended region (2) of temperature $T = 5$ keV/$k_B$, above which is a cool region (3). Surrounding the accretion column regions (1) - (3) there is a cool halo (region (4)). The surface of the white dwarf is designated as region (5).

In Canalle and Opher (1988, 1989) we suggested that the extended region (2) of temperature $T \sim 5$ keV/$k_B$ occurred after the shock due to rapid cooling. We here suggest that region (2) is above the shock region and exists due to preheating. We suggest that this preheating is due to Alfvén waves. After the shock there exists a turbulent region which certainly produces turbulent Alfvén waves. The Alfvén velocity is greater than the infall velocity; the Alfvén waves can thus conduct energy out of the shocked region and heat the infalling matter. For example, using the generic values of a magnetic field $\log B \sim 7.5$ and a density $\log n \sim 17$, an Alfvén velocity on the order of a tenth of the velocity of light is obtained which is a hundred times greater than the infall velocity.

The standard parameters for the regions (1) - (5) studied were: $n_1 = 4\, n_2$, $n_2 = 4\, n_4$; $n_3 = n_2$; $\log n_1 = 16 - 17$; $T_1 = 30$ keV/$k_B$; $T_2 = 5$ keV/$k_B$; $\log H_1 = 6.7$; $\log H_2 = 7.7$; $\log R_1 = 7.7$; and $\log R_4 = 8$ (where $R_1 = R_2 = R_3$ is the radius of the accretion column of regions (1) - (3), and $R_4$ is the radius of the cool halo (region (4)).

The elements were divided into four groups. The groups used, and the log of the relative abundances of the elements, were:

Group (I): H(0), He(-1.0)
Group (II): C(-3.4), N(-4.0), O(-3.1), Ne (-4.0)
Group (III): Mg(-4.5), Si(-4.5), S(-4.7)
Group (IV): Fe(-4.4)

In region (1) groups (I)-(IV) are completely ionized; in region (2) only groups I and II are ionized; and in region (3) and (4) only group (I) is ionized. In region (5) we assumed that none of the groups are ionized and has a density $n_5 \gg n_1$. Using e.g., $\log n_5 = 4 \log n_1$ or $\log n_5 = 5 \log n_1$ did not change the results.

We followed the Monte Carlo calculation of Felsteiner and Opher (1976). About $10^6$ photons are uniformly produced throughout regions (1) and (2). The photons are produced in the form of bremsstrahlung and thermal line spectra and are allowed to Compton scatter from all regions (1) - (5). Every photon is followed until it leaves the outside border of the accretion column ($R_4$), or is absorbed. If it is absorbed, we take into account K-shell X-ray fluorescence, as discussed in Felsteiner and Opher (1976).

## III. DISCUSSION AND CONCLUSIONS

The parameters used in our standard model are comparable to those used by others, for example, Imamura and Durisen (1983). Using the commonly used definition for f as the ratio of the cross sectional area of the accretion column to the surface area of the white dwarf, our standard model has $\log f = -3.2$. This can be compared with model 2 of Imamura and Durisen (1983) where $\log f = -3.0$. Also in their model 2 we have $\log H_1 = 7.4$ and $\log n_1 = 16.5$, which can be compared with our $\log H_1 = 6.7$ and $\log n_1 = 16 - 17$.

Swank et al. (1984) assumed Thomson scattering from cold electrons and just studied the Fe $K_\alpha$ line. In our calculation we used the exact Klein-Nishima formula modified to take into account the motion of the free hot electrons, allowing the photons not only to lose energy but also to gain energy. We also took into account the Fe $K_\beta$ line which has an intensity $\sim 1/6$ that of the Fe $K_\alpha$ line. The presence of both Fe $K_\alpha$ and Fe $K_\beta$ lines gives an intrinsic width to the iron peak. Thermal iron lines also contribute to the intrinsic width, where we used the results of Mewe et al. (1985) for the thermal lines. The intrinsic width is of course broadened by Compton scattering.

We compared our results with the observed spectra of AM Herculis of Rothschild et al. (1981). A finite density of the halo severely decreases the spectrum below the iron peak, due to absorption by the halo. This is not found in the observed spectrum (which remains high). This means that if a halo exists it has a very low density, or is very thin. Varying the density $n_1$, the resultant spectrum obtained closest to the observed spectrum had $\log n_1 \sim 16.3$. This corresponds to $\log (n_1 R_1) \sim 24.0$ and a transverse Thomson optical depth $\sim 0.6$. The width of the iron line peak obtained was $\sim 0.8$ keV, in agreement with the observations of Rothschild et al. (1981). The width is primarily due to the intrinsic width of the iron peak due to the $K_\alpha$, $K_\beta$ and thermal lines (which contrasts with the results of Swank et al. (1984) who attributed the width $\sim 0.8$ keV primarilly to Thomson scattering).

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## EFERENCES

analle, J.B.G., and Opher, R. 1988, Astr. and Ap., 189, 325
analle, J.B.G., and Opher, R. 1989, Astr. and Ap., 219, 334
elsteiner, J., and Opher , R. 1976, Astr. and Ap., 46, 189
mamura, J.N., and Durisen, R.H. 1983, Ap. J., 268, 291
ewe, R., Lemen, J.R., and van den Oord, G.H.J. 1985, Astron. Ap. Suppl., 65, 511
ickramasinghe, D.T., and Meggitt, S.M.A. 1982, M.N.R.A.S., 198, 975
ickramasinghe, D.T., and Meggitt, S.M.A. 1985, M.N.R.A.S., 214, 605
ickramasinghe, D.T., Tuohy, I.R., and Visvanathan, N. 1987a, Ap. Space Sci., 131, 601
ickramasinghe, D.T., Tuohy, I.R., and Visvanathan, N. 1987b, Ap. J., 318, 326

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