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White Dwarf Masses in magnetic CVs: Multi-temperature Fits to *Ginga* data

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Abstract. We have used the hard X-ray spectrum obtained from *Ginga* to determine the mass of the white dwarf primary star in 13 magnetic CV systems. Our model for the spectral fit includes the temperature and density structure in the post-shock accretion flow, taking into account the additional cooling of the cyclotron radiation. We obtain good fits to the data, and we compare our derived masses to those determined by other means.

1. Introduction

The mass of the white dwarf is one of the fundamental parameters in Cataclysmic Variable (CV) systems, strongly influencing the accretion process and therefore the emission from these interacting binaries. It is also an important constraint on the evolutionary models of interacting binaries (for example de Kool 1992).

One of the methods of measuring the white dwarf mass is to make use of the spectrum of the keV X-rays emitted from the accreting white dwarfs (Rothschild et al. 1981, Kylafis & Lamb 1982, Ishida 1991). The basis of the method is that the temperature of the accretion shock depends on the white dwarf mass and radius. For typical white dwarf parameters, $kT_s \sim 20$ keV. More massive white dwarfs have smaller radii, so the corresponding shock temperatures are higher. A higher shock temperature implies a hotter post-shock region, and hence a harder X-ray spectrum. By fitting model spectra to the observed spectrum the temperature and therefore the white dwarf mass can be deduced.

It has been recognised that the observed X-ray spectra are, however, determined by emission contributed from the *entire* post-shock region, which is a cooling (principally by bremsstrahlung emission) column of plasma below the accretion shock, stratified in temperature and density (Aizu 1973). For the

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strongly magnetic mCVs, the AM Her systems, the effects of cyclotron cooling must also be included.

2. The Model

We have used the closed integral solution of Wu (1994) to determine the temperature and density of the post-shock region. Although the structure accretion region is complex (for example, Lamb 1995), the hard X-ray emission is likely to emanate from a core of high specific accretion rate. The complicating effects of absorption and of density inhomogeneities are less significant for the shape of the spectrum at energies above ~ 2 keV. We have therefore chosen to model the accretion region as a cylindrical structure, vertically stratified. We have then calculated the emission from each stratum using the MEKAL optically thin plasma code (Mewe et al. 1995). The integration scheme is a simple summation.

In Figure 1 we compare the spectrum from a single temperature plasma at the shock temperature T_s (case a), that from a stratified shock with only bremsstrahlung cooling (case b), and that from a stratified shock with both bremsstrahlung and cyclotron cooling (case c). In each case the mass of the white dwarf is $0.6M_\odot$, the local accretion rate is 1 g/cm^2/sec, the radius of the column is 10^8 cm and the metallicity is solar. In the last case the magnetic field B = 40MG. The distance assumed is 100pc. The spectrum progressively steepens from case a to c.

Beardmore et al. (1995) found it necessary to include a reflection component in their model fits to *Ginga* AM Her spectra. We have therefore included in our model the Compton reflection from the surface of the white dwarf, using the analytic approximation given in van Teeseling et al. (1996), corrected for viewing angle effects. In addition, we have included a warm (partially ionised) absorber above the post-shock flow, by modifying the ABSORI routine (Zdziarski & Magdziarz 1996, Done et al. 1992) in the XSPEC X-ray fitting code (Arnaud 1996) to accept the multi-temperature emission from the post-shock flow as the photoionising flux. The full model was integrated into XSPEC to perform the fits to the data.

3. Fits to the Data

We have chosen to use *Ginga* data for the model fits, mainly because of its sensitivity over wide energy band ($\sim 1.7-20$ keV) and the availability of a significant body of mCV observations. Data were extracted for 5 AM Her systems and 8 Intermediate Polars from the UK *Ginga* public data archive in Leicester.

We show in table 1 the hydrogen column of the absorber, the iron abundance relative to the solar iron abundance, the goodness of the fit and 2 mass estimates: one where we assumed no reflection and one where we did. In the reflection case, we calculated the viewing angle of the accretion region when this was possible, using estimates of the inclination and dipole offset in Cropper (1990). When this angle was not known, we assumed a viewing angle of 0° (giving maximum reflection), so the best fit mass estimate lies between these two values.

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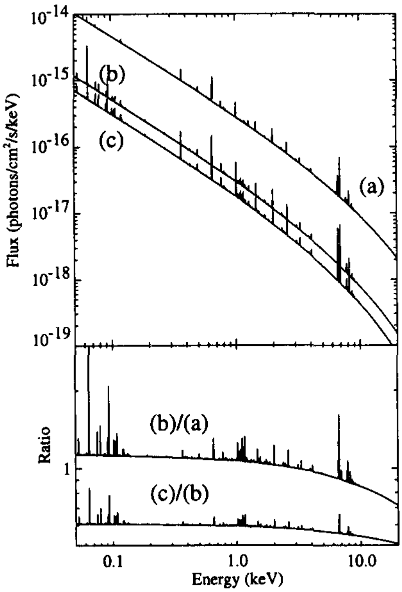

Figure 1. Upper plot: The spectrum from a single temperature plasma (at the shock temperature T_s (case a) (displaced vertically by a factor 10 for clarity), that from a stratified shock with only bremsstrahlung cooling (case b), and that from a stratified shock with both bremsstrahlung and cyclotron cooling (case c). Lower plot: Ratios of case (b) to (a), and of case (c) to (b).

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Source	N_H 10^{22} cm^{-2}	Iron rel solar	M_{wd} ($M_\odot$) ($M_\odot$) no reflection	χ^2 (dof)	M_{wd} ($M_\odot$) ($M_\odot$) with reflection	χ^2 (dof)
AM Her	24–33	0.4	0.82 (0.78–0.85)	0.75 (101)	0.75 (0.69–0.79)	0.74 (100)
EF Eri	0.3	0.4	0.63 (0.59–0.65)	0.95 (21)	0.63 (0.59–0.67)	0.93 (21)
BY Cam	28	0.4	0.73 (0.65–1.08)	1.35 (23)	0.68 (0.62–1.01)	1.36 (22)
V834 Cen	20	1.0 (fix)	0.46 (0.37–0.69)	0.76 (22)	0.46 (0.38–0.71)	0.56 (21)
QQ Vul	1.0	1.0 (fix)	1.03 (>0.66)	1.29 (23)	1.02 (>0.68)	1.18 (22)
EX Hya	4.0	0.6	0.37 (0.35–0.38)	1.18 (25)	0.37 (0.36–0.38)	1.26 (24)
AO Psc	13.6	0.5	0.46 (0.42–0.50)	0.95 (21)	0.48 (0.43–0.55)	1.08 (25)
FO Aqr	12.3–16.5	0.3	0.89 (0.76–1.12)	0.78 (48)	0.83 (0.71–0.99)	0.77 (47)
TV Col	15.8	1.4	1.06 (0.88–1.30)	1.13 (21)	0.98 (0.79–1.16)	1.09 (21)
BG CMi	19.1	0.6	0.97 (0.85–1.10)	0.65 (17)	0.88 (0.78–1.02)	0.66 (17)
TX Col	0.6	0.3	0.37 (0.33–0.41)	1.39 (25)	0.36 (0.32–0.40)	1.35 (25)
PQ Gem	3.4	1.0 (fix)	1.07 (0.91–1.23)	1.02 (16)	0.96 (0.83–1.12)	1.06 (16)
AE Aqr	1	1.0 (fix)	0.43 (0.29–0.65)	0.80 (19)	0.43 (0.29–0.65)	0.80 (19)

Table 1. The best fit parameters to the *Ginga* data using the modified warm absorber and the multi-temperature bremsstrahlung model. The following parameters are shown: the hydrogen column density of the warm absorber (N_H), the iron abundance, the mass of the white dwarf (M_{wd}) both including a contribution from reflection of the surface of the white dwarf and without. The range in the white dwarf mass is at the 90% confidence range. For AM Her and FO Aqr we simultaneously fitted more than one spin resolved data sets with N_H being allowed to vary.

The white dwarf masses of mCVs have been measured by several workers (Mukai & Charles 1987, Ishida 1991, Fujimoto & Ishida 1995, Hellier et al. 1996). There are noticable discrepancies between those results and ours, mainly due to different assumptions being used by different groups in deriving their mass estimates. In particular, Ishida (1991) assumes a single temperature bremsstrahlung at the shock temperature, so that his mass estimates (based on the same data as here) are lower limits.

We have compared the mass spectrum derived in this work with the mass spectra of Webbink (1990) (with both magnetic and non-magnetic systems aggregated) and Bergeron et al. (1992). The isolated white dwarf distribution is peaked at $M_\odot \sim 0.6$, whereas the distribution of the mass of white dwarfs in CV system is extended to higher masses. Our mass compilation is too small to be useful to draw any strong conclusions, but we note that the mean mass of the sample is lower than that of Webbink (1990), and is consistent with a bimodal distribution as suggested by the evolutionary models (de Kool 1992).

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Discussion

P. Stockman: Can you show the effects of the warm absorbers and discuss what GINGA data can tell us about them?

M. Cropper: The warm absorbers have marginal effect in the GINGA passband so the ionisation parameter is not well determined.

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