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LETTER

Letter to the Editor

The close DAO+dM binary RE J0720−318: a stratified white dwarf with a thin H layer and a possible circumbinary disk

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Abstract. We have analysed the EUVE spectrum of the DAO white dwarf RE J0720−318. In contrast to the optical spectrum, which can only be fitted with a homogeneously mixed H+He atmosphere, we find the EUVE spectrum can only be matched with a stratified structure. The H layer mass of $3\times10^{-14}M_\odot$ is a factor of $\sim$10 below upper limits from previous EUVE observations of white dwarfs. In addition, we detect an unprecedented HeI/HI ratio of $\sim$1 for the absorbing column along the line of sight, implying an H ionization fraction >90% if all this material resides in the local ISM. We suggest that, since this is a close pre-CV binary system, most of the helium probably lies within the immediate vicinity of the star, possibly in the form of a circumbinary disk left over from the common envelope (CE) phase. These results have important implications for our understanding of the evolutionary status of DAO white dwarfs in particular, and for post-CE binaries in general.

Key words: binaries:close–stars:individual:RE J0720−318–stars:abundances–stars:evolution–white dwarfs

1. Introduction

Close binary systems comprising a white dwarf plus a main sequence companion are thought to have evolved via a phase of common envelope evolution (e.g. Paczynski 1976), and are the progenitors of cataclysmic variables (e.g. de Kool 1992). Only a few of these systems have been studied in detail, e.g. Feige 24 (DA+dM, Thorstensen et al. 1978) and V471 Tauri (DA+K2V, Nelson and Young 1970). A full understanding of the properties of the system and the individual stars is vital to our understanding of their evolutionary status and for theoretical models of close binary evolution.

DAO white dwarfs are a small, peculiar class of degenerate objects whose evolution is not well understood. They have hybrid spectra showing both hydrogen and helium lines, in particular a weak HeII feature in the optical at 4686Å, and lie in the temperature range 50,000-70,000K. Originally it was thought that DAOs represented white dwarfs crossing between the helium-rich cooling sequence (DO stars) and the hydrogen-rich sequence (DAs), arising from DOs by gravitational settling of helium and upward diffusion of hydrogen in the atmosphere to form an overlying hydrogen layer, leading eventually to the DAs. The absence of any known DAs above 70,000K and the gap in the helium cooling sequence between 30,000-45,000K supported this idea. If this interpretation was correct, they should have chemically stratified atmospheres.

Two discoveries undermined this hypothesis. Firstly, a very hot DA was found (RE J1738+665, Barstow et al. 1994), providing a possible missing link between hydrogen-rich Planetary Nebula Nucleii (PNN) and the DA cooling sequence, and avoiding the need to invoke evolution through the helium channel first. Secondly, Bergeron et al. (1994) showed that almost all DAOs had homogeneously mixed rather than layered atmospheres. It now appears that the label 'DAO' covers a diverse array of objects. Bergeron et al. identified at least five subclasses, the largest of which appears to be a group of low mass stars ($M<0.48M_\odot$) which are the direct descendants of hydrogen-rich subdwarfs, having evolved from the Extended Horizontal Branch (EHB). However, at least one of these objects has been shown to be a double degenerate (Feige 55, Holberg et al. 1995). Other subclasses include higher mass stars consistent with post-AGB evolution, and a stratified star that could still represent a transitional state on the cooling sequence. The classification of the very high mass white dwarf GD50 as a DAO from its EUV spectrum has further confused the picture, since this star may well be the result of a white dwarf merger (Vennes et al. 1996). The origin of the helium in each of these subgroups could be different.

Excluding GD50, three DAO stars have been detected in the extreme ultraviolet (EUV) - RE J1016-053 (Tweedy et al. 1993), RE J2013+400 (Barstow et al. 1995a) and RE J0720-

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Table 1. White dwarf parameters (from optical fit)

Parameter	Value	1σ limits
Temp. (K)	53630	52400−54525
log g	7.64	7.54−7.74
log He/H	-3.56	-3.43−-3.70
M ($M_{\odot}$)	0.55	±0.03

318 (Barstow et al. 1995b, Vennes and Thorstensen 1994). All three lie in close, post-common envelope binaries with cool red dwarf companions, have masses consistent with post-AGB evolution, and represent the fifth of Bergeron et al.'s DAO subgroups. Burleigh and Barstow (1995) showed that the failure to detect any further DAOs in the EUV was either because the stars lay in high interstellar hydrogen column directions, or because these hot objects must have substantial quantities of elements heavier than He levitated in their atmospheres, providing the opacity to block any EUV flux. In addition, given that DAs outnumber DAOs by about a hundred to one in white dwarf catalogues (e.g. McCook and Sion 1987), and there are about 110 DAs identified in the ROSAT Wide Field Camera (WFC) survey (e.g. Pye et al. 1995), we should not necessarily expect to see any further examples in the EUV.

The optical spectrum of RE J0720−318 (Figure 1) clearly shows the distinctive HeII absorption feature at 4686Å, which can only be fitted with a homogeneous H+He atmospheric stucture. From modelling this spectrum, Barstow et al. (1995b) derive the white dwarf parameters T_{eff}, log g and log He/H given in Table 1. The binary nature of the system is easily recognized from the variable narrow emission lines in the cores of the Balmer absorption dips. These arise from reprocessing of the EUV radiation from the white dwarf on the surface of the red dwarf companion. RE J0720−318 has the lowest helium abundance of any of the DAOs studied by Bergeron et al. (1994) and Burleigh and Barstow (1995). Tweedy et al. (1993) and Barstow et al. 1995b) speculate that the helium in these stars may result from accretion from the stellar wind of the M dwarf companion.

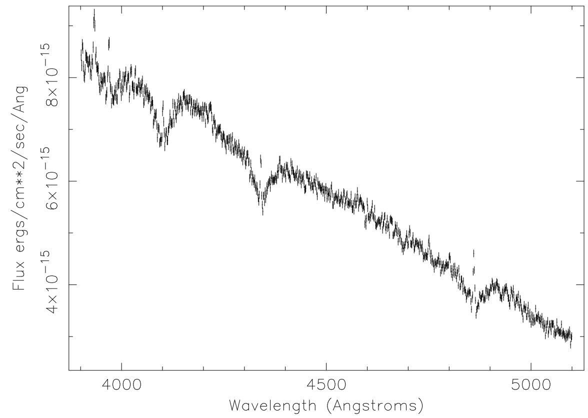

Fig. 1. Co-added optical spectrum of RE J0720−318, showing the weak HeII 4686Å feature and the characteristic narrow emission lines

2. EUVE and IUE Observations and data reduction

RE J0720−318 was observed by EUVE in 'dither' mode between 1995 December 16-20, and was detected in all three wavebands with exposure times of 122,459s (SW, 70−190Å), 121,067s (MW, 140−380Å) and 112,861s (LW, 280−760Å). The dither mode consists of a series of pointings slightly offset in different directions from the nominal source position. Systematic variations in the EUVE detector efficiency originally limited the signal-to-noise that could be achieved to ≈5. By using the dither mode to average out flat field variations, a substantial fraction of this fixed pattern noise can be removed. This technique has improved the S/N of the dithered spectrum of HZ43 by around a factor 4 (Dupuis et al. 1995, Barstow, Holberg and Koester 1995). Therefore, to take any residual fixed pattern noise into account, we quadratically add a 5% systematic to the statistical errors on the data. We have extracted the spectra from the images ourselves, using standard IRAF procedures. Our general reduction techniques are described in more detail in our earlier work (e.g. Barstow, Holberg and Koester 1994).

Two low resolution IUE SWP spectra (SWP54496 and SWP54497, exposure = 40 minutes each) were obtained by us on 1995 April 24. These have been extracted and calibrated with the NEWSIPS processing, which gives an absolute error on each data point, and then co-added to improve the overall signal-to-noise (Figure 2).

We have also included the ROSAT PSPC soft band (0.1-0.4keV) X-ray count rate (0.455 counts/sec) in our analysis (Fleming et al. 1996). Significantly, RE J0720−318 was not detected in the PSPC hard (0.4-2.4keV) band. We can assume, therefore, that the vast majority of the EUV and soft X-ray flux comes from the white dwarf alone, and that the red dwarf companion is not active.

3. Analysis and Results

We have fitted a set of fully line blanketed stratified and homogeneous H+He models, computed by Koester (1991), to the far-UV and EUV data, using the XSPEC spectral fitting programme. We have described the detailed use of XSPEC for analysis of optical, UV and EUV data in several previous publications (e.g. Barstow, Holberg and Koester 1994). The stratified model assumes plane parallel geometry with a thin H layer overlying a helium atmosphere, under LTE conditions. The H layer mass is covered in the approximate range $10^{-16} > M_{H\odot} > 10^{-11}$. The second model structure assumes a homogeneous distribution of H+He, also under LTE conditions, in the range $-8 >$ log He/H> -2. When comparing the IUE and EUVE data sets with the models, we utilise the V magnitude (V=14.87±0.04) as a normalisation point, calculated by Barstow et al. (1995b) to account for the contribution by the red dwarf companion.

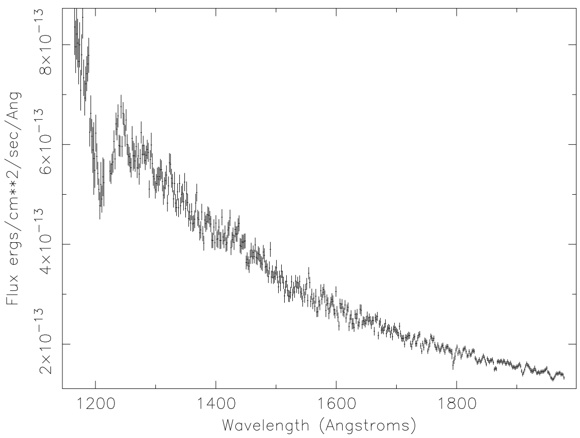

Fig. 2. Co-added IUE SWP Spectrum of RE J0720−318. Note the absence of any weak HeII absorption feature at 1640Å

3.1. Far-UV data

The co-added low resolution IUE SWP spectrum (Figure 2) clearly shows no evidence for weak HeII absorption at 1640Å or any other heavy element features. This is in contrast to far-UV spectra of the similar system RE J1016−053. Tweedy et al. (1993) report weak HeII and CIV absorption lines in this star at 1640Å and 1549Å respectively, and Barstow et al. (1995a) also report a CIV 1549Å feature in the other ROSAT pre-CV DAO/dM binary RE J2013+400. However, they do not see a HeII line at 1640Å. The upper limit to the helium content of RE J2013+400 from the IUE spectrum is log He/H=-2.5, entirely consistent with the optical data.

For RE J0720−318, assuming a homogeneous model structure and fitting the optically derived T and log g, we find that the helium content implied from a fit to the optical data (log He/H=-3.56) can easily be hidden within the general scatter of the data points around 1640Å in the IUE spectrum. Indeed, a helium line would only be visible above the noise for log He/H>-2.5.

3.2. The EUVE spectrum

The entire EUVE spectrum is shown in Figures 3 and 4. The most striking feature is the saturated HeI absorption edge at 504Å, dominating the long wavelength spectrum. Nothing like this has ever been seen in any other EUVE spectra of white dwarfs (e.g. Dupuis et al. 1995, Barstow, Dobbie and Holberg 1996). In fitting the EUVE spectrum and the PSPC data point, we utilise the optically determined T and log g (Barstow et al. 1995b, see Table 1), and allow these only to vary between their 1σ confidence limits. Figure 3 shows the best fit using a homogeneous model. Although the HeI 504Å edge is well matched, the predicted HeII edge at 228Å and the short wavelength continuum do not match the observed fluxes.

The best fit stratified model is shown in Figure 4. All the major features are accurately reproduced, in particular the HeII series of absorption dips converging on 228Å, the 206Å feature,

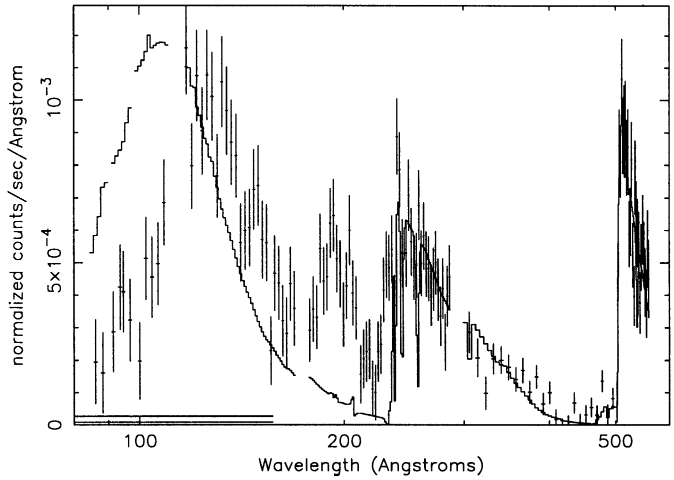

Fig. 3. EUVE spectrum of RE J0720−318 with the best fit homogeneous model (every 2nd data point has been removed for clarity)

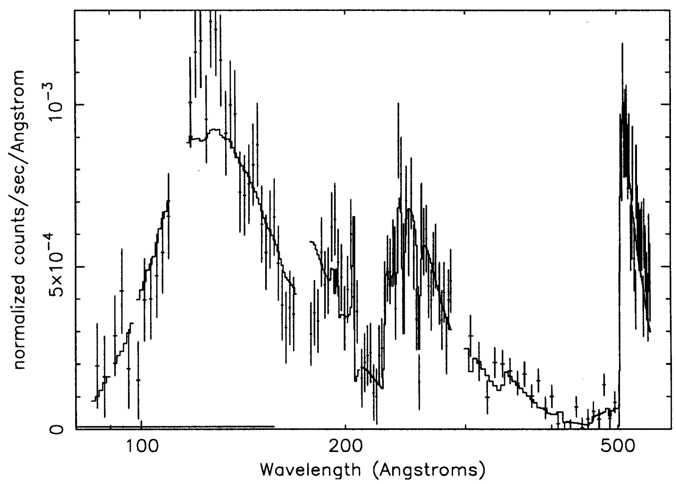

Fig. 4. EUVE spectrum of RE J0720−318 with the best fit stratified model (every 2nd data point has been removed for clarity)

Table 2. Interstellar H and He column densities and H layer mass derived from the best fit stratified model

Parameter	Value	1σ limits
N_H	2.30×10^{18}	$2.25-2.36\times10^{18}$
N_{HeI}	1.44×10^{18}	$1.41-1.47\times10^{18}$
N_{HeII}	9.78×10^{17}	$8.58-10.03\times10^{18}$
M_H	$3.07\times10^{-14}M_\odot$	$2.93-3.21\times10^{-14}M_\odot$

the sw spectrum and the HeI 504Å edge. The best fit parameters are listed in Table 2.

4. Discussion

The EUVE spectrum of RE J0720−318 has yielded three important results. Firstly, in contrast to the optical spectrum, which can only be matched with a mixed H+He model structure, we have shown that the EUV spectrum can only be reproduced by a stratified atmosphere. Secondly, we find the white dwarf has an unexpectedly thin H layer, $3\times10^{-14}M_{\odot}$. Finally, there appears, compared with HI, to be an unusually high line-of-sight interstellar helium column density to the system (see Table 2). The implied hydrogen ionization fraction, assuming a cosmic He/H ratio, is 90%, and the helium ionization fraction is 40%.

The failure to model the EUVE spectrum with a homogeneous atmosphere confirms the result of Barstow et al. (1995b), who could not match the ROSAT WFC and PSPC data points with a mixed H/He structure. These authors also failed to fit the ROSAT data with a stratified model. However, the EUVE spectrum reveals line of sight absorbing material with a HeI/HI ratio far removed from the canonical (cosmic) value of 0.1 originally assumed, and an additional HeII component not previously taken into account. We have now shown that the EUV and soft X-ray data can indeed be matched by a stratified model, although this model cannot reproduce the HeII 4686Å feature in the optical region. This has important implications for our understanding of the white dwarf's structure and evolution, and for the binary itself.

Since the EUV radiation originates from hotter, deeper layers of the white dwarf atmosphere, the underlying structure of the star must be stratified. The helium present in the optical spectrum may reside on the surface of the white dwarf in a thin mixed layer. This would suggest that the helium is being accreted from the red dwarf companion via a stellar wind, and is not intrinsic to the white dwarf itself.

The hydrogen layer mass derived from the stratified fit is the lowest found for any white dwarf from EUVE spectra (Barstow, Dobbie and Holberg 1996). If this had been an isolated star it would probably have evolved into a normal DA, but as it is in a close binary system the thin H layer may well be the result of mass transfer between the two components during an earlier common envelope phase. Thereafter it is possible for any moderate mass loss to bring some of the underlying helium to the surface, giving the optical HeII 4686Å line. However, analysis of the fit to the medium waveband spectrum (Figure 4) clearly shows that while the HeII series coverging on 228Å is photospheric in origin, the edge itself must be due to cooler interstellar or possibly circumstellar material.

The HeI/HI ratio of $\sim$1 is, by around a factor ten, the highest measured in any direction in the sky from EUVE data (e.g. Barstow, Dobbie and Holberg 1996). This is so high that, taken together with the $\sim$90% hydrogen ionization fraction (also the highest measured from EUVE data), we must question whether the absorbing gas lies in the local interstellar medium between ourselves and RE J0720−318, or if in fact this gas lies in the vicinity of the binary system.

It is possible that most of the helium resides in the RE J0720−318 system itself, in the form of a circumbinary gas. Recent theoretical studies of CE evolution by Terman and Taam (1996) suggest that circumbinary disks are likely to form in post-CE systems. The spiral-in process decelerates so rapidly in the final stages of CE evolution that material in the immediate vicinity of the binary cores is not expected to be ejected from the system. Instead, this forms a disk in the orbital plane of the binary (since studies show that ejection of the CE mainly takes place in this direction). It should be noted that Barstow et al . (1995b) find evidence to suggest the orbital inclination of the binary may be as high as 85°, and thus it is possible that we are seeing the system through an optically-thin disk. The presence of this disk may affect the orbital evolution of the detached pre-CV, as is known to occur in pre-main sequence stars, through tidal and resonant interaction between the binary and disk. Processes such as gravitational radiation and magnetic braking have often been discussed as mechanisms in the evolution of pre-CV binaries, but thus far the effect of a circumbinary disk has been generally overlooked. The possible detection of such a disk in a post-CE system therefore has profound implication for our understanding of the formation and evolution of close binaries.

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