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Temperatures and Chemical Abundances of Accreting White Dwarfs in Cataclysmic Binaries

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Abstract

We present new results on surface temperatures, and chemical abundances of accreting white dwarfs (WD) in cataclysmic and symbiotic binaries. The S-Type symbiotic system RW Hydrae contains an accreting WD with a surface temperature of 160,000 K and little evidence for the presence of an accretion disk. The presence of accreted heavy elements in CV WD atmospheres suggests either dredgeup of metals in the white dwarf from the effects of ongoing dwarf nova episodes or contamination of the Roche lobe-filling donors by repeated past nova explosions. We report on the first detection of the nuclide Argon in the photosphere of an accreting white dwarf by Godon et al. (2017).

1 Introduction

The chemical abundances of white dwarfs in cataclysmic variables have been derived largely from high quality HST and FUSE spectra. The observed metal lines are fitted with rotationally broadened theoretical line profiles. However, for the most part, the S/N is not high enough to determine reliable individual abundances. Moreover, the reliability of the chemical abundances could be compromised by underlying emission, an upper disk atmosphere (curtain), circumstellar, interstellar absorption and variations of absorption features with orbital phase.

The most telling characteristic of the abundances is their sub-solar metallicity values. If the replacement time of the accreted atmosphere is shorter than the diffusion timescales of the accreted ions, then the surface abundances would tend to reflect the composition of the infalling matter from the donor star. There is no reason to expect the secondary mass donor stars to have sub-solar metallicity. Rather, one expects that effects of diffusion are responsible for these abundances. At temperatures below 20,000 K, radiative forces levitation of the ions is unimportant. The problem is that in order for accretion-diffusion equilibrium to govern the surface abundances, the accretion rate must be low enough to permit accretion-diffusion equilibrium, otherwise, the accretion timescale is too short and the abundances tell us nothing about diffusion. The continually changing and unsettled atmosphere of a CV white dwarf where other forms of mixing and spreading of accreted matter are likely involved presents a challenging theoretical problem.

In this paper, we discuss the N/C abundance anomaly and the possible origins of suprasolar heavy element abundances in the accreted atmospheres of CV white dwarfs.

2 The Accreting White Dwarf in RW Hydrae

The S-type symbiotic system RW Hydrae (=HD 117970) has a primary component classified as a M2 III red giant. The inclination of RW Hya is high, just sufficient for the system to undergo eclipses while the orbital period is 370.2 days (Merrill 1950; Kenyon & Mikolajewska 1995). Published estimates of the white dwarf mass range extend from 0.3 to 0.6 $M_\odot$. We take the distance to the system from the GAIA database. The results of our model fitting analysis of the FUSE spectrum is shown in Fig.1. We obtained that the FUSE spectrum is dominated by a low gravity (log(g)=6.5) hot ($T = 160,000$ K) WD. For a $0.4 M_\odot$ mass, the WD has a radius of $0.065 R_\odot$.

3 CV White Dwarf Chemical Abundances

The analysis of CV WD metal abundances and their implications represents a new frontier in CV WD research. The principal objective is to determine the abundances of accreted metals for a statistically significiant large sample of CVs with exposed WDs. This will deepen our insights into the evolution of CVs, the CV WDs' thermonuclear history and the N/C anomaly.

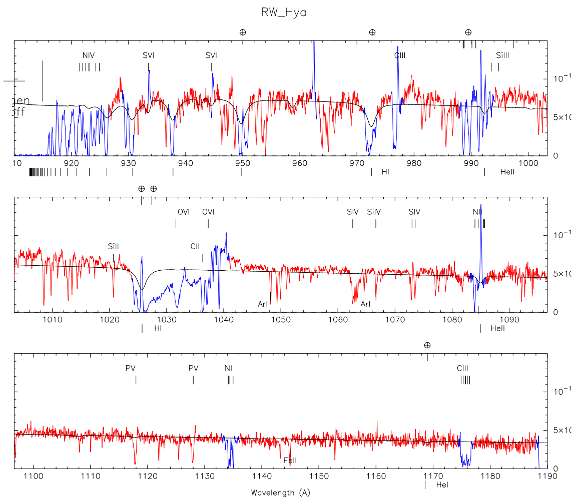

Figure 1: A single temperature hot NLTE WD model fit for a low mass WD to the dereddened FUSE spectrum of RW Hya with a best fit corresponding to a white dwarf with a surface temperature of 160,000 K and log(g) = 6.5. Assuming a mass of $0.4M_{\odot}$ with a radius of $0.065R_{\odot}$ yields a scale factor-derived distance of 811 pc, confirming that a low mass white dwarf with its larger radius, and a very high temperature gives a distance to RW Hya which is within the error bars of the GAIA distance.

Does the N/C abundance anomaly arise from (1) a formerly more massive secondary donor star (capable of CNO burning) having been peeled away by mass transfer down to its CNO-processed core or (2) does it originate in the white dwarf itself due to explosive CNO burning associated with nova explosions or possibly by dredgeup and mixing in consequence of a dwarf nova outburst?

About 10% of the CVs manifest the N/C anomaly (Gänsicke 2018). If it originated in the donor, then the donor had to be more massive than its present value to sustain hot CNO burning. This could be the case if the CVs with the N/C anomaly are the descendants of the supersoft X-ray binaries, where the formerly more massive donor star in the system undergoes thermal timescale mass transfer (TTMT) at a high rate, thus driving steady thermonuclear burning on the white dwarf in equilibrium with the accretion supply rate. This builds up the mass of the WD accompanied by the rapid accumulation of helium ash, thus blocking the enhanced C needed to power the fast nova outburst. This scenario is one of the most promising progenitor channels for producing SN Ia (e.g. Di Stefano 2010; Hachisu et al. 2010).

Sion and Sparks (2014) on the other hand have shown that at least for the fraction of CVs that reveal the N/C anomaly, the origin of the CNO processed abundances lies with the white dwarf which subsequently contaminated the secondary donor star with the ejecta of many past repeated nova explosions and are transferring this material back to the white dwarf. The central temperatures of any formerly more massive secondary stars in CVs undergoing hydrostatic CNO burning are far too low to produce these suprasolar abundances. This research may provide clues for the single degenerate CO core pathway to SN Ia from the highest mass number nuclides detected in suprasolar abundances.

4 Explosive Thermonuclear Burning and the Chemical Abundances of CV White Dwarfs

HST and FUSE spectra of the exposed white dwarf in the dwarf nova U Gem also exhibits a rich array of absorption features due to metals (Sion et al. 1998, Long & Gilliland 1999, Godon et al. 2017). CVs reveal a high N/C anomaly (Gänsicke 2018) where the highly non-solar abundances of N and C are inferred qualitatively from the N v/C iv emission line intensity ratios revealed from their accretion disks or accretion columns of magnetic accretors (Gänsicke et al. 2003) The N/C abundance anomaly (strong N v 1240/weak or absent C iv 1550) is the hallmark of CNO processing.

There are only 5 systems (all dwarf novae) in which the N/C anomaly and/or the detection of suprasolar heavy element abundances are manifested by FUV photospheric absorption line spectra of CV White Dwarfs exposed during dwarf nova quiescence (VW Hyi, U Gem; Sion et al. 1995, 1997, 2001; Long and Gilliland 1999, BW Scl, SW UMa, BC UMa, Gänsicke et al. 2005). All five CV WDs have suprasolar abundances of nuclides like Al, P, with atomic masses A > 20. The derived abundances (relative to solar values) from absorption line profile fitting of the HST spectra of VW Hyi are Al 3, Si 0.3, C 0.3, N 3.0, Al 2.0, P 20-900, and Mn 50 (Sion et al. 2001). For U Gem, the white dwarf surface abundances are C 0.3 - 0.35, N 35 - 41, Si 1.4 - 6, Al 6.6 - 20 (Sion et al.1998, Long et al.2006; Godon et al. 2017). In three SU UMa-type CVs with exposed WDs, BW Scl, SW UMa and BC UMa, the detected photospheric features reveal aluminum abundances of 3.0 ± 0.8, 1.7 ± 0.5, and 2.0 ± 0.5, respectively (Gänsicke et al. 2005).

In a series of HST COS observations of U Gem following one of its dwarf nova outbursts, we obtained a sequence of high quality, phase resolved spectra with which to study any variations in the chemical abundances following the outburst (Godon et al. 2017). This study confirmed earlier abundance determina-

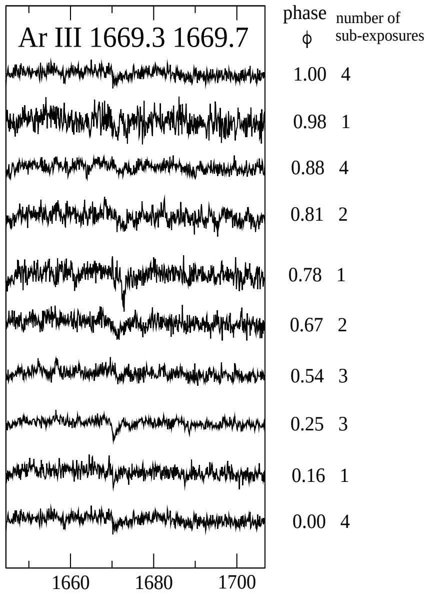

Figure 2: The HST/COS exposures of U Gem displayed as a function of the binary orbital phase ϕ in the wavelength region near 1670 Å. The phase is indicated on the right together with the number of sub-exposures that were co-added for each orbital phase. For a high gravity ∼40,000 K WD photosphere, the line near 1670 Å corresponds to Ar III (1669.3 & 1669.7). The absorption lines are deeper near orbital phase 0.75 and 0.25 due to the stream overflowing the disk (from Godon et al. 2017).

tions but no strong evidence of abundance variations as a function of time since the dwarf nova outburst could be detected. However, to our surprise, Argon (Ar III ~ 1669.5Å) was detected with an abundance of at least 20 times solar. The formation of Ar III is almost certainly in the WD photosphere but the abundance determinations are complicated by orbital phase dependent variations due to gas streamimg that extends above the disk plane (Godon et al. 2017). The Ar III absorption feature is shown in Fig.2.

The actual abundance could be much higher because Godon et al.(2017) capped the supra-solar abundance of any nuclide at 20 times solar. This is the first detection of photospheric Argon in any CV white dwarf. The detection of this nuclide may suggest that the white dwarf in U Gem has an ONeMg core. The interpretation and implications of this identification will be presented elsewhere.

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