

A possible solution to the Lyman/Balmer line problem in hot DA white dwarfs

S. P. Preval,¹ M. A. Barstow,¹ N. R. Badnell², J. B. Holberg³ and I. Hubeny⁴

¹*Department of Physics and Astronomy, University of Leicester, University Road, Leicester, LE1 7RH, UK; sp267@le.ac.uk, mab@le.ac.uk*

²*Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK; badnell@phys.strath.ac.uk*

³*Lunar and Planetary Laboratory, Sonnett Space Sciences Bld, University of Arizona, Tucson, AZ 85721, USA; holberg@argus.lpl.arizona.edu*

⁴*Steward Observatory, University of Arizona, 933 N. Cherry Ave, Tucson, AZ 85721, USA; hubeny@as.arizona.edu*

Abstract. Arguably, the best method for determining the effective temperature (T_{eff}) and surface gravity ($\log g$) of a DA white dwarf is by fitting the Hydrogen Lyman and Balmer absorption features. However, as has been shown for white dwarfs with $T_{\text{eff}} > 50,000\text{K}$, the calculated value from the Lyman and Balmer lines are discrepant, which worsens with increasing temperature. Many different solutions have been suggested, ranging from the input physics used to calculate the models, to interstellar reddening. We will focus on the former, and consider three variables. The first is the atomic data used, namely the number of transitions included in line blanketing treatments and the photoionization cross sections. The second is the Stark broadening treatment used to synthesise the Lyman and Balmer line profiles, namely the calculations performed by Lemke (1997) and Tremblay & Bergeron (2009). Finally, the third is the atmospheric content. The model grids are calculated with a pure H composition, and a metal polluted composition using the abundances of Preval et al. (2013). We present the preliminary results of our analysis, whereby we have determined the T_{eff} for a small selection of white dwarfs. We plan to extend our analysis by allowing metallicity to vary in future model grids.

1. Introduction

An accurate knowledge of T_{eff} and $\log g$ allows us to deduce many aspects of a white dwarf's evolution. Currently, the best way of determining both of these quantities is by fitting a calculated model atmosphere to either the hydrogen Lyman or Balmer line absorption series (Holberg et al. 1986). This is not without its drawbacks, however, as the shape of the Lyman/Balmer absorption features is also dependent upon the metal species present in the atmosphere. Therefore, inaccurate atomic data used to calculate model atmospheres may also result in an inaccurate determination of the T_{eff} and $\log g$.

Current calculations of Lyman/Balmer line profiles also utilise pre-calculated Stark broadening tables to reduce calculation time. As with the atomic data, if the broadening

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tables are not accurate enough, then this will also propagate errors to the determined T_{eff} and $\log g$.

In an analysis by Barstow et al. (2001), the authors measured T_{eff} and $\log g$ for a sample of DA white dwarfs that had data in the Lyman/Balmer line regions from ORFEUS, HUT, and the Far Ultraviolet Spectroscopic Explorer (FUSE) in the UV, and ground based telescopes in the optical. It was shown that the T_{eff} determined from the Lyman/Balmer line series disagreed for several white dwarfs, however, this was regarded as being due to systematics present in the observational data. An improved study by Barstow et al. (2003a) considered a larger data set where all UV data originated from FUSE. A uniform pipeline was developed and applied to the UV data in an attempt to reduce any systematics present. The determined Lyman/Balmer T_{eff} up to $\sim 50,000\text{K}$ was found to be in agreement for both series, however, a statistically significant discrepancy became apparent for stars with T_{eff} greater than this. This discrepancy has affectionately been dubbed "The Lyman/Balmer line problem".

In this proceeding, we present preliminary results from our study of the Lyman/Balmer line problem in hot DA white dwarfs. We approach the problem from three perspectives. The first is the opacity used to calculate model atmospheres. This involves using atomic data from the Kurucz (1992) (Ku92 hereafter) and the Kurucz (2011) (Ku11 hereafter) data releases. The Ku92 release contains $\sim 10^6$ and $\sim 10^8$ Fe/Ni iv-vi transitions respectively. The second is the broadening tables used to synthesise the Lyman/Balmer line profiles. Two of these tables are investigated, one calculated by Lemke (1997), and another from Tremblay & Bergeron (2009). The third is the composition of the atmosphere. We calculate model atmospheres with a pure hydrogen composition, and a metal polluted composition.

2. Observations

Seven white dwarfs are chosen that have been observed both in the UV and optical wavebands. All of these bar WD1254+233 (GD153) are thought to be polluted with metals. Two of these stars, namely WD0501+527 (G191-B2B), and WD1254+233, are calibration standards (Bohlin & Gilliland 2004) and have well measured T_{eff} . The remaining five, WD0229-481, WD0556-375, WD0621-376, WD1738+669, and WD2211495 have been observed to have $T_{\text{eff}} > 50,000\text{K}$, and have exhibited the

Lyman/Balmer problem. The UV data for each of these stars is taken from FUSE observations. Where possible, FUSE datasets taken using the LWRS aperture are used as flux losses due to source drift are minimised. Stars with multiple datasets are coadded to improve the signal to noise. The full list of datasets used in this analysis will be included in a future publication.

Optical observations are taken from several sources. In the case of WD0501+527 and WD1254+233, coadded G430L observations from the Space Telescope Imaging Spectrometer (STIS) aboard the Hubble Space Telescope are used. For the remaining five stars, objects with declinations $> 0^\circ$ were observed by the Steward Observatory, while objects with declinations $< 0^\circ$ were observed by the South African Astronomical Observatory. Full details on the optical observations are given in Marsh et al. (1997).

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3. Model atmosphere calculations

Model atmospheres used in this study are calculated using *tlusty* (Hubeny 1988) version 201, and are synthesised with *synspec* version 49 (Hubeny & Lanz 2011). Each grid is calculated with T_{eff} ranging from 35,000 to 100,000K in steps of 2,500K, and $\log g$ from 6.5 to 9.5 in steps of 0.25 dex. It has been shown by Barstow et al. (1998) that the inclusion of heavy metals in model atmospheres will affect the determined T_{eff} . This result is investigated in this study by including two atmospheric compositions. The first is a pure hydrogen composition, and the second is a metal polluted composition using the abundances from Preval et al. (2013), with $\text{C}/\text{H}=1.72 \times 10^{-7}$, $\text{N}/\text{H}=2.16 \times 10^{-7}$, $\text{O}/\text{H}=4.12 \times 10^{-7}$, $\text{Al}/\text{H}=1.60 \times 10^{-7}$, $\text{Si}/\text{H}=3.68 \times 10^{-7}$, $\text{P}/\text{H}=1.64 \times 10^{-8}$, $\text{S}/\text{H}=1.71 \times 10^{-7}$, $\text{Fe}/\text{H}=1.83 \times 10^{-6}$, and $\text{Ni}/\text{H}=1.01 \times 10^{-6}$ as number fractions.

Tremblay & Bergeron (2009) calculated new Stark broadening tables, including additional sources of opacity not accounted for in Lemke (1997)'s tables. As the line shapes of the Lyman/Balmer series are affected by T_{eff} , $\log g$, and the broadening treatment, it is imperative to calculate the synthetic profiles as accurately as possible. To assess the effects of using either the Lemke (1997) and the Tremblay & Bergeron (2009) calculations, all model grids are synthesised using either of these broadening tables in turn.

The completeness of the atomic data supplied to model atmosphere can be inferred to have an effect upon the determined T_{eff} . Radiative levitation calculations by Chayer et al. (1995) were found to be dependent upon the number of transitions included in the calculation. We investigate this possibility by calculating the metal polluted model atmospheres using either the Ku92 dataset, or the Ku11 dataset. The difference between these datasets is the number of energy levels and transitions available for the ions Fe/Ni iv-vi. Ku92 is supplemented with photoionization (PI) cross sections calculated by the Opacity Project for Fe iv-vi, while Ni iv-vi is supplemented with PI data calculated using an hydrogenic approximation. The Ku11 data is not accompanied by PI cross section data. We therefore calculated this data using the atomic collision package

autostructure (Badnell 1986, 1997, 2011). Full details of this calculation will be provided in a future publication.

4. Results/Discussion

As expected, the largest Lyman/Balmer line discrepancies occur when pure H grids are used to measure T_{eff} . Curiously, however, in the case of WD1254+233, which is known to be a pure H atmosphere star, the discrepancy between the Lyman/Balmer line T_{eff} is not affected by the metal content, but is resolved upon using the Lemke (1997) broadening tables. In the case of the metal rich stars, the discrepancies between the Lyman/Balmer T_{eff} are greatly reduced when using a metal polluted model grid, and are improved further when these grids are synthesised using the Tremblay & Bergeron (2009) tables. In Figure 1, we have plotted the measured T_{eff} using the Lyman/Balmer lines for the different types of model grid used. We have also tabulated the T_{eff} determinations in Table 1. Interestingly, the use of Kull data in model atmosphere calculations does not appear to have any noticeable effect upon the determined T_{eff} , regardless of the Stark broadening table employed. It is for this reason we have omitted the Kull results from Figure 1. The next step to try and improve the agreement between the Lyman/Balmer is to allow variations in the metal abundances. This will be done by

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calculating a set of model grids for different multiples of the G191-B2B abundances used in this proceeding. We also plan to include more stars in our sample.

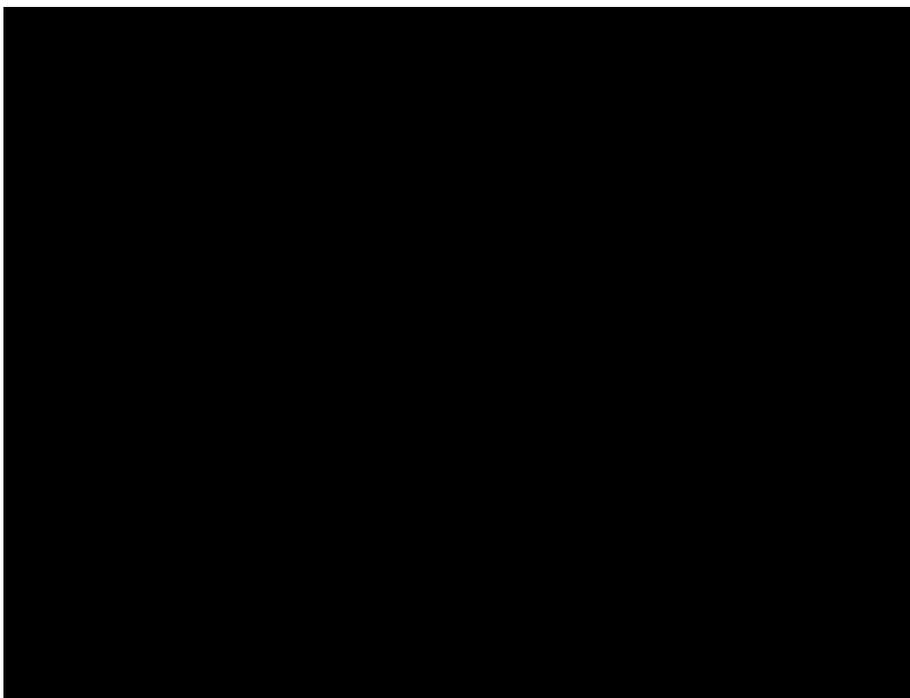


Figure 1. Plot of Lyman T_{eff} vs Balmer T_{eff} determined for the seven white dwarfs. The upper two panels are for models synthesised using the Tremblay tables, and the bottom two are for models synthesised with the Lemke tables. The two panels on the left are for pure H atmospheres, and the two panels on the right are for a metal polluted atmosphere using the Ku92 data release with Opacity Project cross sections. The straight line is for equal Lyman/Balmer T_{eff} .

5. Conclusion

We have presented a preliminary report on our investigation into the Lyman/Balmer line problem from the perspective of the opacity used to calculate the model atmosphere, the Stark broadening tables used to synthesise the Lyman/Balmer line profiles, and the composition of the atmosphere specified in the model. The choice of atomic data, either Ku92 or Ku11 is inconsequential, and the largest improvement is observed when using the Tremblay tables with metal polluted atmospheres.

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Table 1. T_{eff} determinations from seven white dwarfs in K. For each white dwarf, the upper row corresponds to Lyman line measurements, while the lower row corresponds to Balmer line measurements.

WD name	Lemke			Tremblay		
	Pure H	Ku92	Ku11	Pure H	Ku92	Ku11
WD0229-481	59,116 \pm 585599	55,600 \pm 485467	55,670 \pm 487467	60,596 \pm 621594	56,843 \pm 540514	56,914 \pm 5405
	60,227 \pm 18851779	58,206 \pm 18071677	58,143 \pm 18061658	62,173 \pm 19951807	59,922 \pm 19601721	59,929 \pm 1907
WD0501+527	62,863 \pm 166168	58,754 \pm 145143	58,769 \pm 143141	63,973 \pm 179177	59,671 \pm 154152	59,693 \pm 1531
	60,165 \pm 383381	57,919 \pm 366370	57,888 \pm 365369	62,658 \pm 412402	60,113 \pm 390377	60,102 \pm 3883
WD0556-375	70,383 \pm 14011304	65,114 \pm 11061103	65,001 \pm 10991072	70,823 \pm 14241341	65,463 \pm 11281099	65,344 \pm 1123
	63,691 \pm 23042083	61,173 \pm 21902189	61,127 \pm 21792177	65,902 \pm 23592217	62,986 \pm 23012102	62,956 \pm 2278
WD0621-376	70,268 \pm 489481	65,142 \pm 384393	64,988 \pm 380389	73,740 \pm 444426	67,716 \pm 361369	67,601 \pm 3523
	59,731 \pm 16101470	58,277 \pm 15941513	58,285 \pm 16231518	61,650 \pm 16501560	59,994 \pm 16801523	60,036 \pm 1680
WD1254+233	38,908 \pm 6356	38,256 \pm 5149	38,332 \pm 5349	39,418 \pm 6665	38,680 \pm 5554	38,773 \pm 5756
	38,669 \pm 146140	38,083 \pm 131126	38,151 \pm 133127	40,511 \pm 144142	39,595 \pm 132133	39,686 \pm 1341
WD1738+669	87,689 \pm 917918	79,264 \pm 771748	78,870 \pm 755730	92,624 \pm 700894	82,960 \pm 753748	82,440 \pm 7187
	79,280 \pm 20372024	75,923 \pm 20252040	75,701 \pm 20751956	82,625 \pm 21662049	78,956 \pm 21262014	78,763 \pm 2093
WD2211-495	73,767 \pm 334329	68,067 \pm 279280	67,900 \pm 272273	74,470 \pm 345333	68,513 \pm 306295	68,341 \pm 2972
	68,429 \pm 24172232	66,720 \pm 24802244	66,228 \pm 24682245	70,767 \pm 23842300	68,408 \pm 25162291	68,409 \pm 2418

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