Helium at white dwarf photospheric conditions: preliminary laboratory results

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Abstract. We present preliminary results of an experimental study exploring helium at photospheric conditions of white dwarf stars. These data were collected at Sandia National Laboratories’ Z-machine, the largest x-ray source on earth. Our helium results could have many applications ranging from validating current DB white dwarf model atmospheres to providing accurate He pressure shifts at varying temperatures and densities. In a much broader context, these helium data can be used to guide theoretical developments in new continuum-lowering models for two-electron atoms. We also discuss future applications of our updated experimental design, which enables us to sample a greater range of densities, temperatures, and gas compositions.

1. Introduction

White dwarfs (WDs) represent the endpoint of stellar evolution for roughly 97% of all stars (Kepler et al. 2016b). These stellar remnants can be further subcategorized into DAs, which have hydrogen-dominated atmospheres, DBs, whose atmospheres are dominated by helium, and more exotic species such as DQs, which exhibit atmospheres almost completely dominated by carbon (Sion et al. 1983).

Due to their relative physical simplicity, compact size, high mass, and observability in most parts of the electromagnetic spectrum, WD stars have served as laboratories for many different areas of astronomy and physics. They have been used as galactic and cosmic chronometers (e.g., Winget et al. 1987; Gianninas et al. 2015), as a tool for deriving initial-final stellar mass relations (e.g., Cummings et al. 2015, 2016), as a site to study the compositions of extrasolar planets (e.g., Zuckerman et al. 2007; Farihi et al. 2014), and as a gravitational-field source to constrain our understanding of general relativity (Onofrio & Wegner 2014). Additionally, we can use WDs to examine aspects of electroweak theory (Winget et al. 2004), as well as our understanding of crystallization in dense Coulomb plasmas (Winget et al. 2009).

For the purposes outlined above, accurate effective temperature ($T_{\text{eff}}$) and surface gravity ($\log g$) values of these stars are needed. Using the so-called spectroscopic method, which involves fitting a model atmosphere to an observed stellar spectrum (see Bergeron et al. 1992, Tremblay & Bergeron 2009, and Koester 2010 for more details),
observers have derived these parameters for over 30,000 WDs. While this method has been proven to be very precise (e.g., $\delta T_{\text{eff}}/T_{\text{eff}} \sim 5\%$, $\delta \log g/\log g \sim 1\%$), its accuracy is questionable. Several studies (Falcon et al. 2010, 2012; Barstow et al. 2005) have shown that $\log g$ values derived using this spectroscopic method do not agree with those derived from other, independent methods. Falcon et al. (2013) developed an experimental platform at Sandia National Laboratories’ Z-machine to address these $\log g$ discrepancies by verifying H-Balmer spectral line profiles at temperatures and densities applicable to DA WD photospheres. Advances in our understanding of hydrogen line-shape formation have resulted from these experimental efforts (e.g., Gomez et al. 2016). Here, we present preliminary experimental results, which attempt to address similar problems in DB WDs (Falcon et al. 2012; Koester & Kepler 2015).

2. Experimental setup/results

The fundamentals of our experimental platform are described in Falcon et al. (2013), and further details about Sandia’s Z-machine as well as our experimental collaboration are given in Rochau et al. (2014). In Fig. 1, we show data collected during an experiment containing a H/He gas mixture. The addition of hydrogen allowed us to use the resulting H$\beta$ line to obtain plasma temperatures and densities (Falcon et al. 2015), which, for the shown experiment, are consistent with conditions found in DB WD photospheres.

![Figure 1](image-url)  

**Figure 1.** Time-resolved spectrum of an experiment containing a mixture of hydrogen and helium. Major features are identified in the text.

In Fig. 1, we identify several prominent emission (bright yellow) and absorption (dark red/black) features. The timing impulse, labeled ‘1’ in that figure, enables us to determine the beginning of our experiment, while the two very bright laser lines at
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4579 Å and 5435 Å (labeled as ‘4’) serve as wavelength references. The timing comb, identified as ‘7’, is used to time-resolve our experimental data. The absorption features of our experimental gas are labeled ‘2’ for the H\(_\gamma\) line, ‘3’ for the H\(_\beta\) line, ‘5’ for the He I feature at 5015 Å, and ‘6’ for the 5875 Å He I line. The extracted spectra for three different time steps are shown in Fig. 2, where we can clearly see the presence of all the features indicated in Fig. 1.

Figure 2. Spectra extracted at varying time steps. The two laser lines (‘3’ in Fig. 1) and the timing impulse/comb (‘1’ and ‘6’ in Fig. 1) have been removed for clarity. Major hydrogen and helium spectral features are identified in the plot. The shown spectra have been offset for clarity.

3. Conclusions/Future work

We have presented preliminary experimental data aimed at addressing persistent difficulties in model atmospheres for DB WDs. Our results, which are presented in Sec. 2, show that we are able to reach DB WD photospheric conditions and thereby explore the problems laid out in Falcon et al. (2012) and Koester & Kepler (2015). The advent of the discovery of hot DQ WDs (Dufour et al. 2008) and uncertainties in their model atmospheres (Dufour et al. 2011) have already guided the way for future experiments. In fact, we recently performed experiments with a significantly altered experimental platform, and a preliminary analysis of the resulting data shows that we are able to capture relevant atomic species and spectral lines. Furthermore, an experiment that can validate pure oxygen model atmospheres (Kepler et al. 2016a) will be developed soon.

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