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A new analysis of spectral line shapes in white dwarf atmospheres

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Abstract. We present an analysis of hydrogen Balmer line shapes observed in two white dwarf spectra. One spectrum presents singlet lines while the second one presents lines with a triplet structure. The latter is a feature of the presence of a strong magnetic field. Using both Stark and Zeeman effects, we infer the density and the magnetic field. Our line shape calculations employ a computer simulation technique. The radiative transfer is accounted for through a one-dimensional slab model.

1. Introduction

Studies of white dwarf atmospheres have shown that the majority of white dwarfs have an atmosphere of pure hydrogen as a result of gravitational setting, which removes helium and heavier elements from the atmosphere and moves them towards inner layers [1,2]. These atmospheres can be considered as hydrogen plasmas, which are similar to some that can be created in laboratory experiments. Such white dwarfs are classified as being of the DA type due to the strong hydrogen absorption lines they present. The electron density in a white dwarf atmosphere is high enough (up to 10^{17} cm^{-3}, and higher) so that the line shapes are dominated by Stark broadening and, hence, can serve as a probe of the electron density N_e. Triplet lines, which are visible in some DA white dwarf spectra, are the result of the Zeeman effect. The line splitting is proportional to the magnetic field B and, hence, provides a direct estimate of magnetic field. In this work, we give an illustration of the method by focusing on two white dwarf spectra exhibiting Balmer series absorption lines.

2. Line shape analysis

The spectra shown in Fig. 1 exhibit very clean absorption lines in the Balmer series, which indicates the presence of hydrogen in the atmosphere. Furthermore, the Zeeman triplet structure visible in Fig. 1(b) indicates the presence of a strong magnetic field in the atmosphere. An order-of-magnitude estimate for the plasma density can be obtained from line broadening analysis. Assume, for the sake of simplicity, a homogeneous plasma absorbing continuum Planckian radiation of intensity I_0 coming from the star inner part. The outgoing radiation intensity I at the vicinity of a given atomic line is given by

$$I = I_0 \exp(-\kappa L), \tag{1}$$

where κ denotes the extinction coefficient [3] and L is the slab size. Figure 2 shows a plot of the quantity $-\ln(I/I_0)$, which is proportional to the extinction coefficient. Only Hα is shown here. Its spectrum can be described using standard line broadening modeling techniques involving the Fourier transform of the atomic dipole autocorrelation function [4]. The result of such a technique is shown in the figure. A computer simulation method accounting for Stark broadening [5] has been used. In the calculation, the ions are assumed to move in a cubic box with periodic boundary conditions, while the electrons are described using a collision operator (see [5] for more details). The broadening due to neutral species is also retained through a collision operator model accounting for resonant (C_3) and van der Waals (C_6) interactions; formulas from [6,7] have been used. Good agreement with the observed spectrum has been obtained by setting a value of 6×10^{17} cm^{-3} for the electron density in the simulation. In the calculation, we have assumed equal plasma and atomic densities, but we note that the spectrum is not very sensitive to the atomic density since the Stark broadening is dominant factor here. In the same way, it is also not very sensitive to temperature; here, we have assumed a value of 1 eV for the temperature of charged and neutral species, which corresponds to the effective temperature inferred from the continuum background.

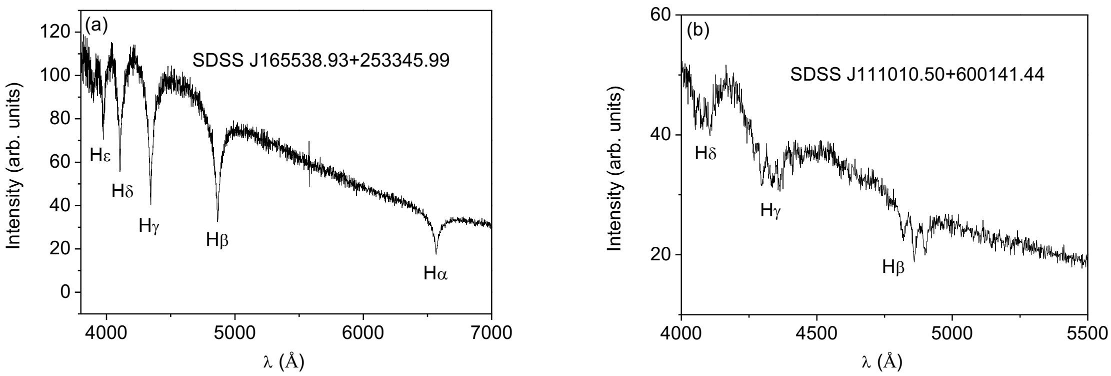

Figure 1 – Plot of two white dwarf spectra obtained from the Sloan Digital Sky Survey database (SDSS, www.sdss.org). The absorption lines correspond to the Balmer series, which indicates the presence of hydrogen in the atmosphere. The Zeeman triplet structure visible in (b) is due to the presence of a strong magnetic field in the atmosphere.

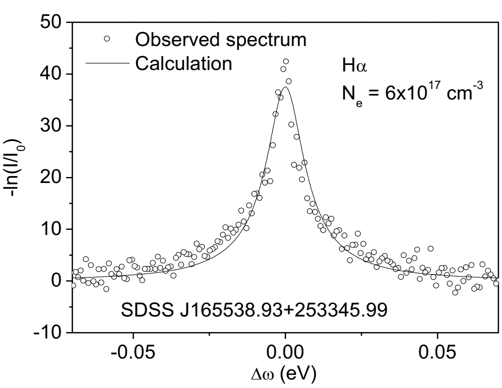

Figure 2 – Calculations of the Hα line profile accounting for Stark broadening have been carried out. Good agreement with the observed spectrum is obtained if one sets a plasma density value of 6×10^{17} cm^{-3}. This falls in the typical range expected in white dwarf stellar atmospheres.

Figure 3 shows a plot of the second white dwarf spectrum (from Fig. 1b) near Hβ. The separation between the Zeeman components is of the order of 40 Å, which yields a magnetic field value of 360 T.

A similar order-of-magnitude value was obtained in previous analyses [8,9]. We did not obtain a reasonable estimate of the plasma density from line shape adjustment because of noise. New analyses are presently underway.

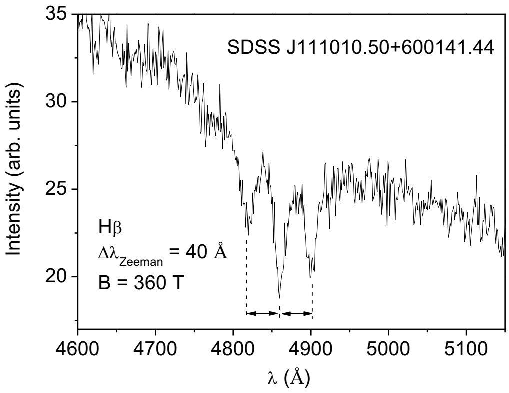

Figure 3 – Plot of the Hβ line spectrum in a magnetized white dwarf atmosphere. The separation between components is proportional to the magnetic field and, hence, can serve as a diagnostic. Here, a value of 360 T has been inferred from the spectrum.

3. Conclusion

An analysis of the lines observed in a star spectrum provides information on the chemical species present in the atmosphere and on the plasma parameters. In complement to previous works [10], we have analyzed two white dwarf spectra exhibiting strong absorption lines in the Balmer series. Information on the plasma density has been inferred from Stark broadening analysis. Information on the magnetic field in the atmosphere has also been inferred, using the separation between Zeeman components. An improvement of the model, which accounts for plasma non-homogeneity, is presently ongoing. It will involve collisional-radiative calculations coupled to line transfer simulations. Specific issues such as plasma self-emission will be addressed. At very strong magnetic field values, the quadratic (diamagnetic) Zeeman effect becomes important and must be included in line shape calculations. Preliminary calculations in [10] have indicated a noticeable alteration of the triplet. More elaborate Stark-Zeeman calculations will require specific adaptations of the atomic physics, e.g., involving the coupling between states with different principal quantum numbers.

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