A study of the Lyman-α line profile in helium-atmosphere white dwarfs
Cynthia Genest-Beaulieu* & Pierre Bergeron
Université de Montréal, *genest@astro.umontreal.ca

The hydrogen abundances in helium-atmosphere (DBA) white dwarfs determined from optical or UV spectra have been reported to differ significantly in some studies. We revisit this problem and present a theoretical investigation of the Lyman-α line profile using model atmospheres and synthetic spectra calculated with both homogeneous and stratified chemical compositions. We also discuss the different broadening mechanisms of the Lyman-α line in DBA white dwarfs.

The current situation

The study of white dwarfs relies heavily on the determination of their atmospheric parameters, which are the effective temperature ($T_\text{eff}$), the surface gravity (log g) and, in the present case, the hydrogen abundance (log N(H)/N(He)). To determine those quantities, we compare the observed spectrum of an object to a grid of synthetic spectra obtained from model atmospheres (see Fig. 1). The accuracy of the atmospheric parameters determined this way depends greatly on the physics included in the model atmosphere.

Chemically stratified atmospheres

Fig 4: Observed optical depth ($\tau$) as a function of wavelength ($\lambda$) of W01425+540, using chemically homogeneous model atmospheres. Both observed and synthetic spectra are first normalized. Then, the effective temperature ($T_\text{eff}$) and surface gravity (log g) are determined. The hydrogen abundance is finally constrained from the Hydrogen line (see insert). We then proceed in an iterative fashion, with agreement between those quantities is found. As shown, the optical spectrum is reproduced very well by those models.

Fig 5: Abundance profile as a function of the Rosseland optical depth obtained for a chemically stratified model atmosphere with log N(H)/N(He) = −4.25 (in the connection zone, red line). This profile was obtained by fixing the hydrogen abundance in the connection zone, and then the diffusion approximation. Vennes et al., 1986, was used to calculate the abundance profile as a function of depth in the radiative zone of the atmosphere (black line).

Effect on optical spectra

Fig 6: Effect of the chemical stratification in the atmosphere on the observed Lyman-α line. Chemically homogeneous (red) and stratified (blue) models were calculated for Teff = 14 510 K, log g = 7.97 and log N(H)/N(He) = −4.25 (constant throughout the atmosphere for homogeneous, constant only in the connection zone for stratified). As can be seen, the stratification of the atmosphere badly has an effect on the predicted line, even though the hydrogen abundance has increased significantly (see Fig 3).

Conclusions

- The atmosphere parameters obtained from a fit to the ultraviolet spectrum differ significantly from what is inferred from the optical spectroscopic fit.
- The stratification of the atmosphere alone does not improve the situation since the added hydrogen causes the pressure to drop significantly, rendering the pressure broadening less efficient.
- The addition of neutral helium broadening on the wings of the Lyman-α line does improve the predicted line shape as well as the overall agreement of the UV/optical fit, but because of Lyman-α is not well reproduced. This might be due to the treatment of neutral helium broadening used for this line, which is only valid in the wings and not in the core.
- It might be able to achieve a better agreement between the Lyman-α and optical regions of the spectrum by including convection overshoot in our calculations, a hypothesis that remains to be explored more thoroughly.

References


Fig 7: Pressure as a function of depth of the homogeneous (red) and stratified (blue) models. The addition of hydrogen in the stratified model causes the pressure to drop by a significant amount as we approach the surface. Lower pressure means that pressure broadening (e.g. Stark broadening) is weaker. This explains why the Lyman-α line is reproduced by the stratified model in Fig. 6 is not as broad as anticipated.

Fig 8: Effect of the inclusion of line broadening by neutral helium in a chemically homogeneous model, as prescribed in Koester & Wolff, 1986. & Koester. The predicted line is now broader (open), but we are still far from the actual observed line. The white dwarf studied in Koester & Wolff is cooler ($T_\text{eff}$=7500 K) than W01425+540. Their Line list was complete from 1000 Å to 6500 Å, so they used the dissociation limit of the radiative theory, which is valid for most of the line. Since our line is saturated only to λ=10 Å, we might need to include a transition to the treatment model that treat the broadening by neutral helium in the core of the line.

Fig 9: Effect of the inclusion of the line broadening by neutral helium in a chemically stratified atmosphere. As can be seen, the overall line is better reproduced by the stratified model including the helium broadening (magenta), especially regarding the far wings and the asymmetry of the line. The core of the line is still not quite broad enough, and the line is only slightly asymmetrical. However, this effect can be caused by the approximation used in the treatment of neutral helium broadening.

Fig 10: Comparison of the observed optical spectrum of W01425+540 (black, normalized) with models with normalized homogeneous (top) and stratified (bottom). Synthetic spectra for the atmospheric parameters inferred from the optical fit (see Fig. 1). Although the stratified model offers a considerable improvement of the predicted line shape (see Fig. 9, magenta line), the predicted hydrogen line in the optical region is too strong. The bottom spectrum also shows that it is possible to roughly reproduce the observed optical and UV (see insert) spectrum, by using a cooler ($T_\text{eff}$=13 500 K) stratified model containing less hydrogen (N(H)/N(He)~4.80), but see Fig. 11.

Fig 11: Energy distribution of W01425+540 (ugriz photometry, black dots). Also shown are the synthetic spectra of the stratified models of Fig. 10, scaled to W01425+540’s distance (56 pc, Bergeron et al., 2013). Insert: Predicted Lyman-α line for both stratified models, normalized at 1275 Å. Even though the stratified model at Teff = 13 500 K (green) can roughly reproduce both the observed optical and UV spectra, the energy distribution is not consistent with the observed photometry of this object. This means that W01425+540’s effective temperature must be around 14 500 K (magenta).

Wing broadening by neutral He

The chemically stratified model with neutral helium broadening offers an improvement of the predicted Lyman-α lines, but the predicted hydrogen lines in the optical are too strong. The current code starts the stratification as soon as the atmosphere becomes radiative. If there were convective overshoot, the stratification could begin higher in the atmosphere, meaning that the hydrogen abundance would be overestimated in the atmosphere of our current models. Since, as suggested in Fig. 4, the optical hydrogen lines are formed deeper in the atmosphere than Lyman-α, a stratified model including convective overshoot may help solve the discrepancy between the optical and UV spectra.

Convective overshoot?

Fig 12: Example of abundance profile that would simulate convective overshoot (blue line). Also shown is the abundance profile shown in Fig. 5, where no convective overshoot was considered (black line). The connection zone is represented by the thick red line. The convective overshoot is simulated artificially by starting the stratification at a higher (arbitrary) layer in the atmosphere. Such models are currently being computed.