A Spectroscopic Study of Deneb (α Lyrae)

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Abstract

This paper describes an investigation into what can be learned about the physical properties of the blue-white star Deneb (α Lyrae) from both low (150 lines/mm) and high (2400 lines/mm) resolution spectra, based on the simple model that the star is a rotating, uniformly emitting oblate spheroid with a photosphere that is a single layer in thermal equilibrium.

Deneb is a hot A2 Ia super giant star that has evolved away from the main sequence. The aim of this work was to test the ability of a simple stellar model to predict the Hydrogen absorption line profiles in Deneb's spectrum. The measured line profile at H_γ was modelled and predictions of the line profiles at H_β and H_α computed. It was found that the agreement between measurement and model was good at H_β but there appeared to be additional non-equilibrium effects at play at H_α.

The thickness and pressure of Deneb's photosphere was computed as a function of an, as yet to be determined, impact parameter.

1. Introduction

Deneb (α lyr) is classed as a A2 Ia star i.e. a hot (A2) super giant (Ia) star that has exhausted its supply of Hydrogen in its core and has evolved away from the main sequence and is believed to be in the process of expanding into a red super giant and will likely go supernova in a few million years. It has a strong solar wind, losing mass at a rate of 0.8 millionth solar masses per year.

The aim of this work was to test the ability of a simple stellar model to predict the Hydrogen line profiles in Deneb's spectrum.

The stellar model used was that of a, solid body, rotating, uniformly emitting oblate spheroid with a photosphere that is a single layer in thermal equilibrium. It is also assumed that the observed absorption lines are formed solely within this photosphere.

Using this model an effective "black body" temperature can be deduced from low resolution (150 lines/mm) spectra provided proper calibration is performed to correct the continuum spectrum for instrument response and atmospheric absorption. High resolution (2400 lines/mm) investigations of individual line shapes can then be used to determine other model parameters for example, a "Lorentzian Half Width" (which is related to pressure due to particle collisions in the photosphere) and the star's speed of rotation.

The theory and computer programs used in this study have been previously described in an earlier study of the blue component of Albireo (β Cyg).

2.0 Low Resolution Spectra

Figure 1 shows a low resolution (150 lines/mm) spectrum of Deneb, this spectrum was fully calibrated for instrument response and atmospheric absorption using a library reference spectrum. In the figure the Hydrogen α, β and γ line positions have been indicated.

Figure 1: 150 l/mm spectrum of Deneb

Low resolution data can be used to obtain an estimate for the effective temperature of a star. It is simply necessary to divide the spectrum by the particular "Planck wavelength curve" that results in the flattest resultant spectrum. This process yields a temperature estimate of 11250K for Deneb. Figure 2 shows the flattened spectrum of Deneb after division by the appropriate Planck curve. The shape of this curve indicates that the star is well represented by a "black body" spectrum as the background level is quite flat.

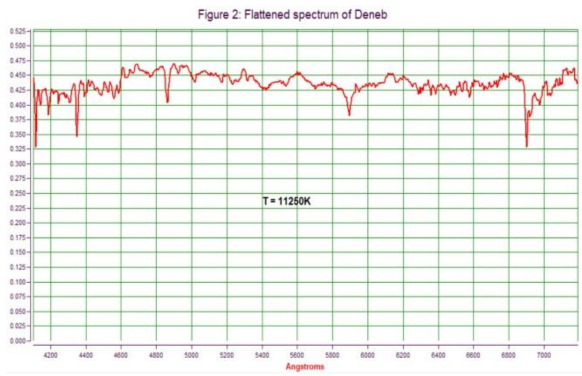


Figure 2: Flattened spectrum of Deneb

3.0 High Resolution Spectra

High resolution (2400 line/mm) spectra captured at H_γ, H_β and H_α wavelengths are shown in figures 3, 4 and 5 respectively the profiles are typical of a low pressure photoshpere i.e. a small FWHM, but note that the H_α profile appears to be unusual in that H_α would normally be expected to be the strongest of the Balmer series. Clearly there is more than just photospheric absorption occurring.

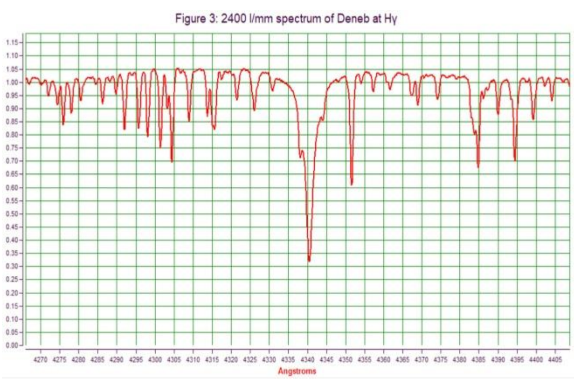


Figure 3: 2400 l/mm spectrum of Deneb at Hγ

Figure 4: 2400 l/mm spectrun of Deneb at Hβ

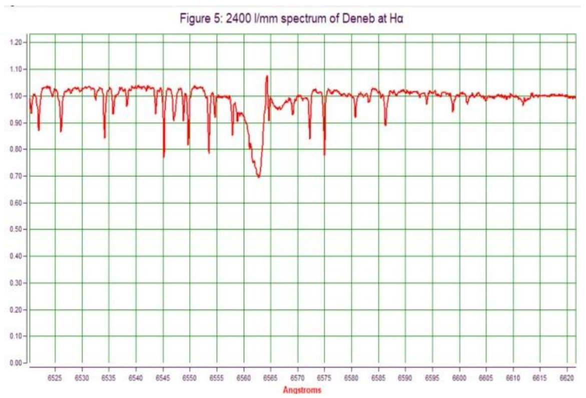


Figure 5: 2400 l/mm spectrum of Deneb at Hα

I will choose to model the star using the H_γ profile due to the anomalous appearance of the profile at H_α.

3.1 H_γ line analysis

For the H_γ absorption line the central wavelength was determined, based on equal areas each side of centre, to be 4340.61A whilst the minimum profile intensity value $A_\beta(\lambda_\beta)$ for the normalized absorption line was found to be 0.323. The measured profile was transformed to an equivalent normalized emission line prior to modelling, the resultant modelled absorption line is shown in figure 6.

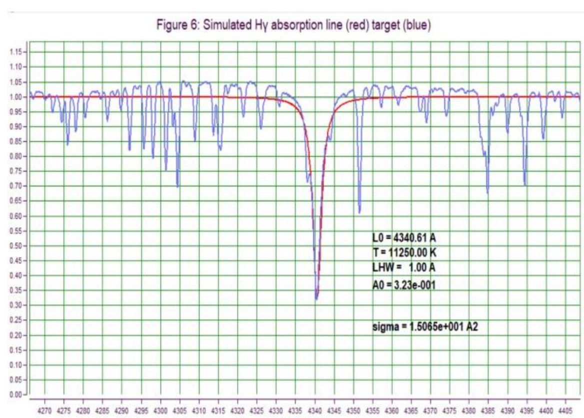


Figure 6: Simulated Hy absorption line (red) target (blue)

Parameters of the stellar model displayed are:-

- L0: the central wavelength in Angstrom
- T: the photosphere temperature in Kelvin
- LHW: the Lorentzian Half-width in Angstrom
- A0: this is the intensity of the absorption line at the central wavelength.

Also displayed is the calculated photon capture cross-section (sigma) in units of square Angstroms.

It was assumed that rotation was insignificant for this star so the maximum surface velocity was set to zero.

3.2 H_β and H_α line synthesis

The custom software was then used to compute the expected absorption lines at H_β and H_α wavelengths. The result for H_β is depicted in figure 7 however, before presenting the result for H_α we need to consider carefully, due to the unusual shape of the measured line, the wavelength at which to calculate a line.

The measured centre wavelength at H_γ corresponds to a Doppler shift $(\Delta\lambda/\lambda)$ of 2.5e-4 whilst at H_β the measured Doppler shift is 4.1e-4. We will assume an average value of 3.3e-4 for the H_α line which corresponds to a wavelength of 6566.84A implying the star is receding from us at a velocity of approximately 1.0e2 kms^{-1}. Figure 8 depicts the result for H_α using this wavelength.

The agreement between the model and measurement at H_β is good whilst that at H_α needs more consideration.

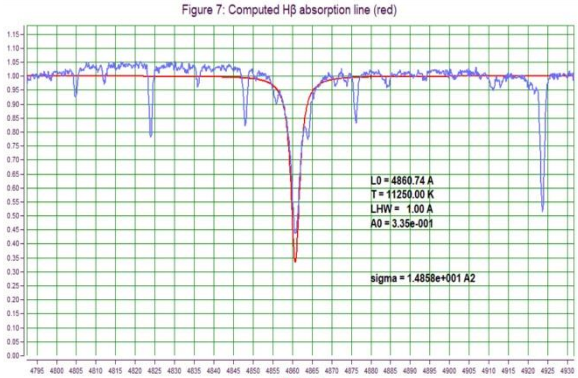


Figure 7: Computed Hβ absorption line (red)

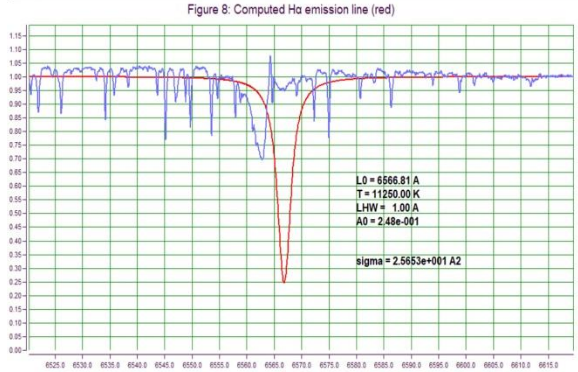


Figure 8: Computed Hα emission line (red)

If we divide the measured H_α profile by the calculated profile we obtain the profile displayed in Figure 9. This looks like a typical line profile from an out-flowing wind. Deneb is a hot super giant star that has evolved away from the main sequence and therefore this is clear evidence of the star shedding some of it's outer layers into the surrounding space. This mechanism may also contribute to the small difference between the measured and calculated profiles at H_β.

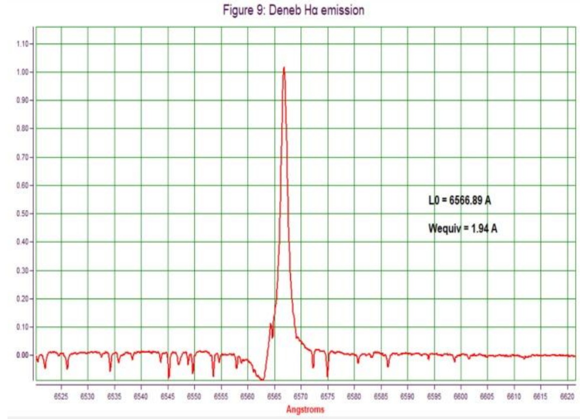
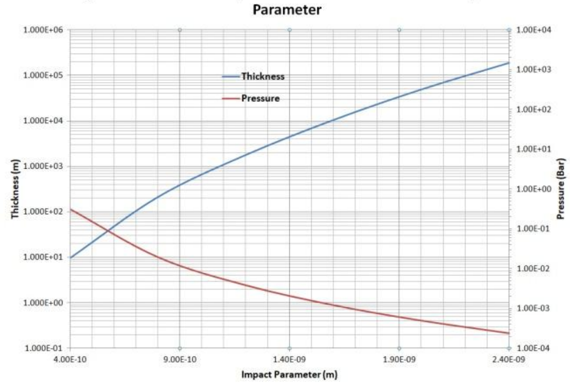


Figure 9: Deneb Hα emission

3.3 Photosphere Pressure and Thickness

When modelling the absorption at H_γ the custom software also calculates the thickness and pressure of the photosphere given a value for an "inpact parameter". Multiple runs were performed to yield the data displayed in figure 10 where Deneb's predicted photosphere pressure and thickness is displayed as a function of this impact parameter.

Figure 10: Deneb Photosphere Thickness and Pressure vs Impact Parameter



When (if) I am able to calculate the appropriate values for stellar impact parameters I will publish predictions for the pressure and thickness of all the stellar photospheres I have measured.

4.0 Conclusions

A spectroscopic study of Deneb (α Lyrae) has been performed to determine physical properties of the star. It has been found that:-

- The authors simple photosphere model works well
- The approximate temperature of Deneb's photosphere is 11250K.
- The Lorentzian half width is 1A
- No stellar rotation is discernable
- Deneb is shedding matter via a stellar wind which is distorting the normal absorption line at $H_{\alpha.}$