A Spectroscopic Study of Deneb (α Lyrae)

Kenneth R Whight

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 line profiles in Deneb's spectrum. It was found that the agreement between measurement and model was reasonably good but could be improved if the radiation distribution was assumed to vary from that of a perfect "black body".

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 "mean free path" between 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.

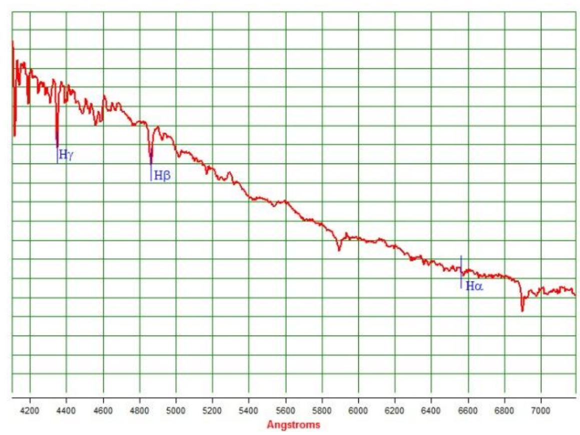

Figure 1: 150 l/mm spectrum of Deneb

Figure 2: Flattened line 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 10600K for Deneb but note that the error in temperature increases for hot stars as the peak of emission is well into the UV region of the spectrum so the resulting temperature estimate is very sensitive to small calibration errors in the measured spectrum. Luckily line profiles themselves are most sensitive to pressure effects thought the relative strengths of a line series is dependent on temperature. It is possible to input any desired temperature into high resolution simulations so the "best fit" can be obtained.

Figure 2 shows the flattened spectrum of Deneb after division by the appropriate Planck curve. The shape of this curve indicates that there may be some deviation from a perfect "black body" spectrum as the background level is not completely flat.

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.

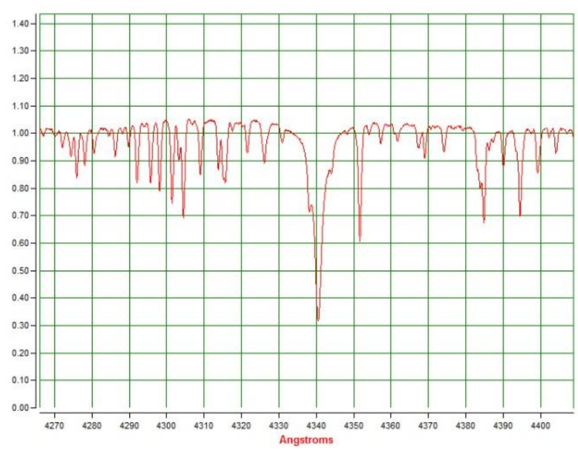

Figure 3: 2400 l/mm spectrum of Deneb at H_γ

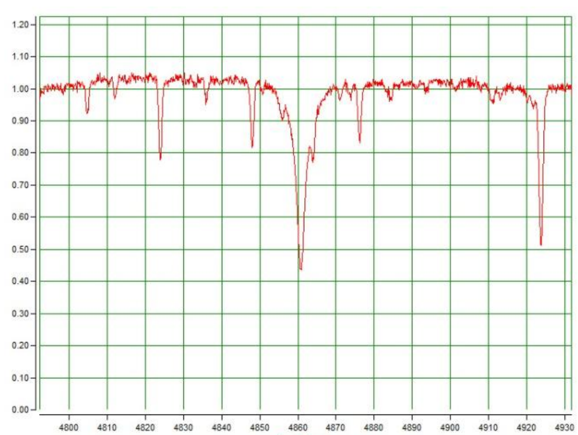

Figure 4: 2400 l/mm spectrum of Deneb at H_β

The profiles are typical of a low pressure photoshpere i.e. a small FWHM, but note that the H_α profile appears to be distorted on the red side of the peak absorption. This distortion will be returned to at the end of this study.

I will choose to model the star using the H_β profile simply because as the temperature of the target star reduces the H_γ profile becomes weaker.

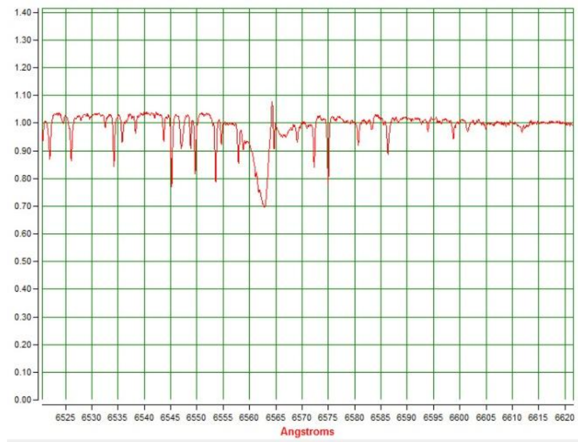

Figure 5: 2400 l/mm spectrum of Deneb at H_α

3.1 H_β line analysis

For the H_β absorption line the central wavelength was determined, based on equal areas each side of centre, to be 4860.72A whilst the minimum profile intensity value $A_\beta(\lambda_\beta)$ for the normalized absorption line was found to be 0.438. This value will be required when predicting other absorption lines in the hydrogen Balmer series. The measured profile was transformed to an equivalent normalized emission line prior to modelling, the result of which is shown in figure 6.

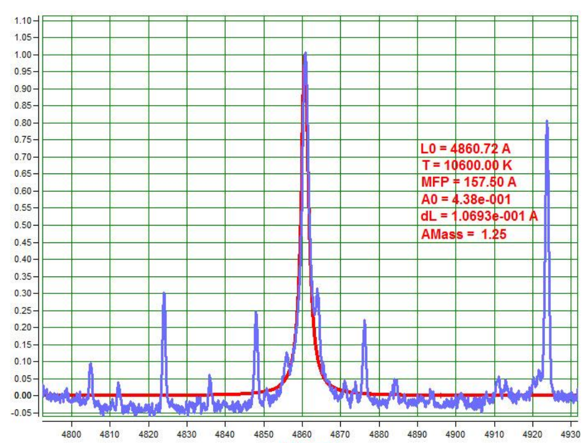

Figure 6: Simulated H_β emission line (purple) target (red)

Parameters of the stellar model displayed are:-

- L0: the central wavelength in Angstrom
- T: the photosphere temperature in Kelvin
- MFP: the particle mean free path in Angstrom
- v: the maximum surface velocity of the star as a proportion of c.
- Ob: the Oblateness of the star i.e. equatorial radius divided by polar radius (Ob $\geq$ 1).
- Theta: the viewing angle in radians above the stellar equator.
- dL: this is the $d\lambda$ value at the central wavelength.
- AMass: I assume the effective atomic mass of the atoms is 1.75 (75% H and 25% He) a different figure can be input to the simulations if preferred.

It was assumed that rotation was insignificant for this star so the maximum surface velocity was set to zero. All non-zero parameter values appear as labels in the RSpec displayed spectra as can be seen in Figure 6.

3.2 H_γ and H_α line synthesis

The custom software can be used to compute the expected absorption lines at H_γ and H_α wavelengths. The result is depicted in figures 7 and 8 respectively together with the measured line profiles.

The agreement between the model and measurement could be better, the absorption at H_γ is underestimated whilst that at H_α is overestimated.

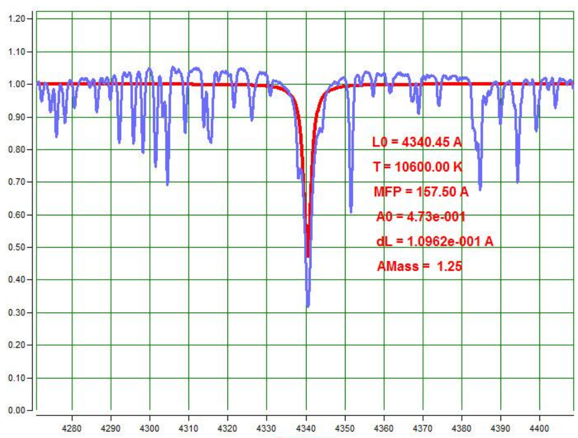

Figure 7: Computed H_γ absorption line (red) $A_\gamma(\lambda_\gamma)$ = 0.473

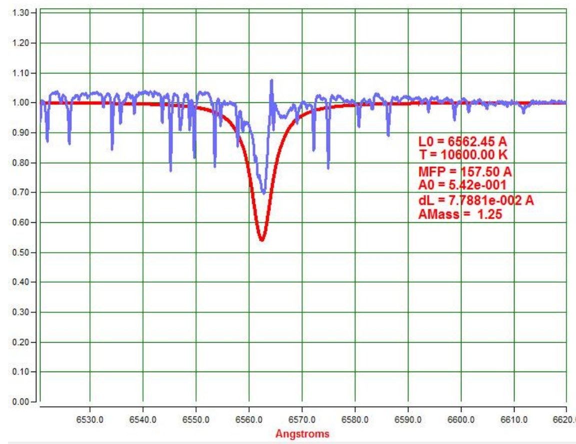

Figure 8: Computed H_α absorption line (red) $A_\alpha(\lambda_\alpha)$ = 0.542

It is possible that the lacklustre agreement, when compared to the AlbireoB modelling results, is due to the star not approximating a "black body" particularly well as indicated in figure 2. Alternatively the temperature estimate is wrong. In an attempt to allow for these possibilities the model has been adapted so that the incident radiation temperature can be different from the photosphere matter temperature. Thus the equation relating line strengths (derived in the Albireo B report) i.e. :-

$$A_\alpha(\lambda_\alpha) = A_\beta(\lambda_\beta)^{\frac{P(T,\lambda_\alpha)d\lambda_\alpha}{P(T,\lambda_\beta)d\lambda_\beta} exp\left[\frac{hc}{kT}\left(\frac{1}{\lambda_\beta}-\frac{1}{\lambda_\alpha}\right)\right]} \quad (1)$$

becomes:-

$$A_\alpha(\lambda_\alpha) = A_\beta(\lambda_\beta)^{A_p\frac{P(T,\lambda_\alpha)d\lambda_\alpha}{P(T,\lambda_\beta)d\lambda_\beta} exp\left[\frac{hc}{kT}\left(\frac{1}{\lambda_\beta}-\frac{1}{\lambda_\alpha}\right)\right]} \quad (2)$$

where A_p is an "absorption pre-factor" which can be used to adjust the relative strengths of two lines in the incident continuum.

By this means a perfect fit for the depth of the absorption lines at H_γ and H_α wavelengths can be obtained as shown in figures 9 and 10.

Whilst this "adjustment" procedure may seem a dubious exercise it is important to realise that it is really the lines shapes that matter and these seem to be predicted remarkably well by the simple model. The procedure will be put on a firmer footing in my next report on the analysis of the stars Vega and Sirius.

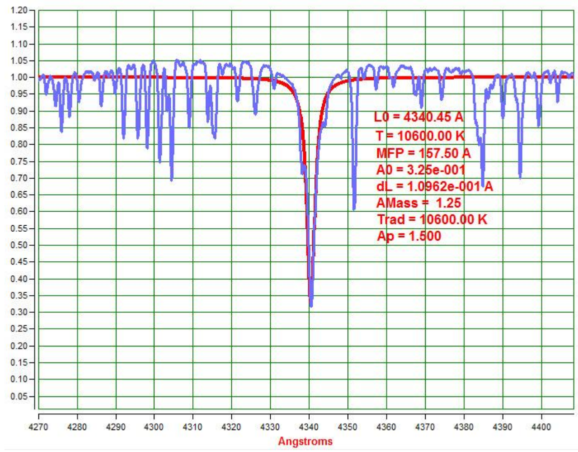

Figure 9: Computed H_γ absorption line (red) $A_\gamma(\lambda_\gamma)$ = 0.325

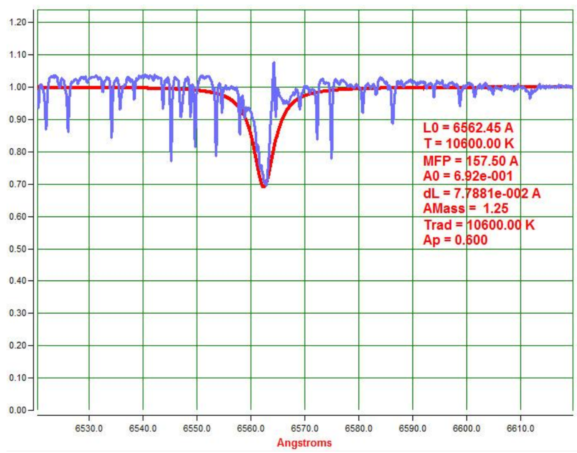

Figure 10: Computed H_α absorption line (red) $A_\alpha(\lambda_\alpha)$ = 0.542

As mentioned earlier in this document, there appears to be a distortion to the redside of the H_α absorption line. Dividing the measured line by the modelled line we get the curve displayed in figure 11.

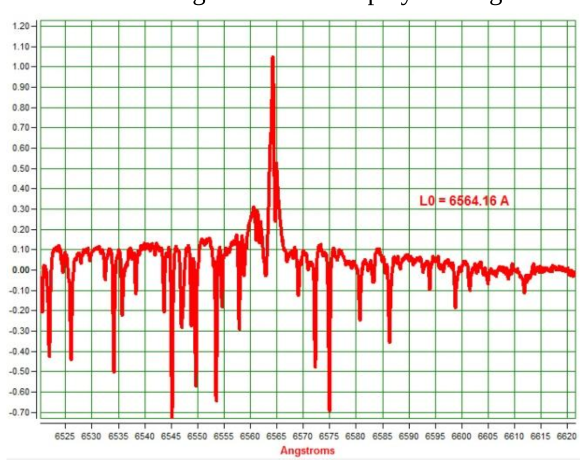

Figure 11: Computed H_α absorption line (red) $A_\alpha(\lambda_\alpha)$ = 0.542

This curve looks like a red-shifted H_α emission line, shifted by 1.71A, I believe this is a permanent feature and results from a fast stellar wind that produces a "line of sight" blue-shifted absorption line which is superimposed onto an emission line from the transverse flowing stellar wind.

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 approximate temperature of the star's photosphere is 10600K.
- The mean free particle path in the photosphere is approximately 157.5A.
- Rotation is not significant.
- To get the best agreement between the model and measurement the star's continuum spectrum must be allow to deviate from that of a true "black body".