# A Spectroscopic Study of Deneb (α Lyrae)

*Kenneth R Whight 20/01/2023*

**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 $H_\gamma$ was modelled and predictions of the line profiles at $H_\beta$ and $H_\alpha$ computed. It was found that the agreement between measurement and model was good at $H_\beta$ but there appeared to be additional non-equilibrium effects at play at $H_\alpha$.

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, rotating solid body, 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 earlier studies of the Sun (via reflection spectrs off Europa) and the blue component of Albireo (β Cyg).

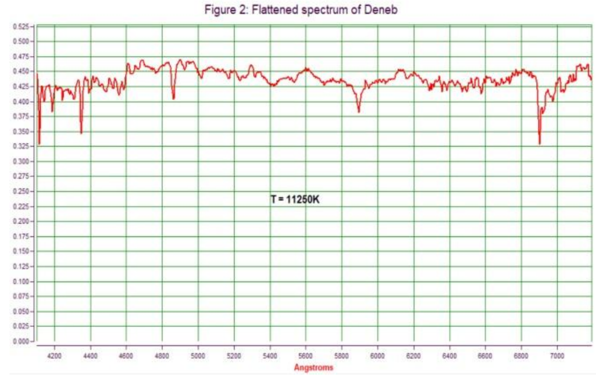

Figure 1: 150 l/mm spectrum of Deneb

## 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.

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 $H_\gamma$, $H_\beta$ and $H_\alpha$ 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 $H_\alpha$ profile appears to be unusual in that $H_\alpha$ would normally be expected to be the strongest of the Balmer series. Clearly there is more than just photospheric absorption occurring.

I will choose to model the star using the $H_\gamma$ profile due to the anomalous appearance of the profile at $H_\alpha$.

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

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

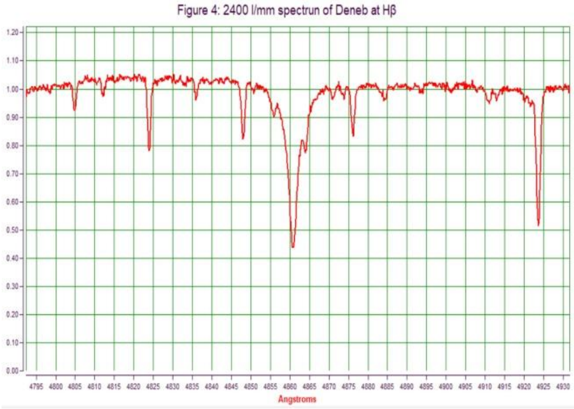



Figure 5: 2400 l/mm spectrum of Deneb at Hα


## 3.1 $H_\gamma$ line analysis

For the $H_\gamma$ 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.

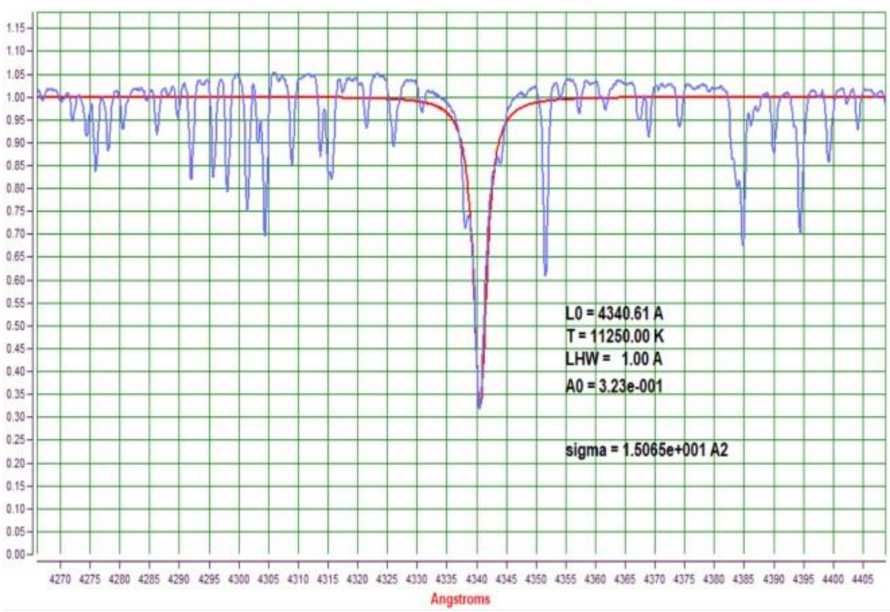
Parameters of the stellar model displayed are:-

- 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.

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

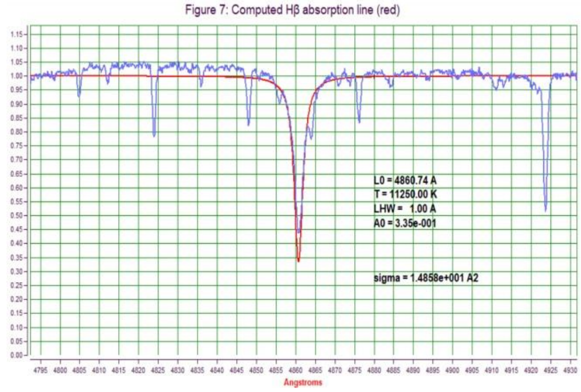



### 3.2 $H_\beta$ and $H_\alpha$ line synthesis

The custom software was then used to compute the expected absorption lines at $H_\beta$ and $H_\alpha$ wavelengths.

The result of modelling at $H_\beta$ is depicted in figure 7. The agreement between the model and measurement is seen to be quite good. The shape is well reproduced but there exists a small difference of 0.103 between the predicted and measured amplitude. This discrepancy will be discussed later.

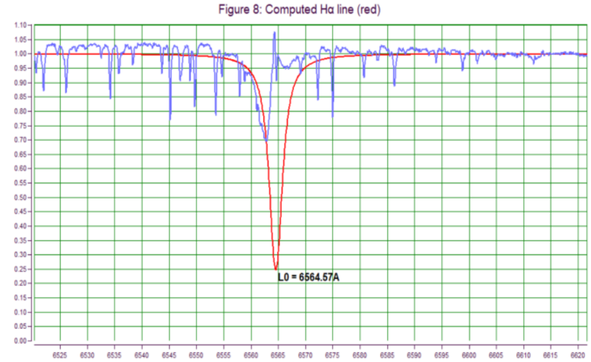
Figure 7: Computed Hβ absorption line (red)




Before attempting ro model at $H_\alpha$ we need to consider carefully, due to the unusual shape of the measured line, the wavelength at which to calculate the star's absorption line.

Deneb is known to be approaching us at a speed of 4.5 km $s^{-1}$ therefore it's $H_\alpha$ line should peak at 6564.57 A. Figure 8 depicts the modelling result at $H_\alpha$ using this wavelength.

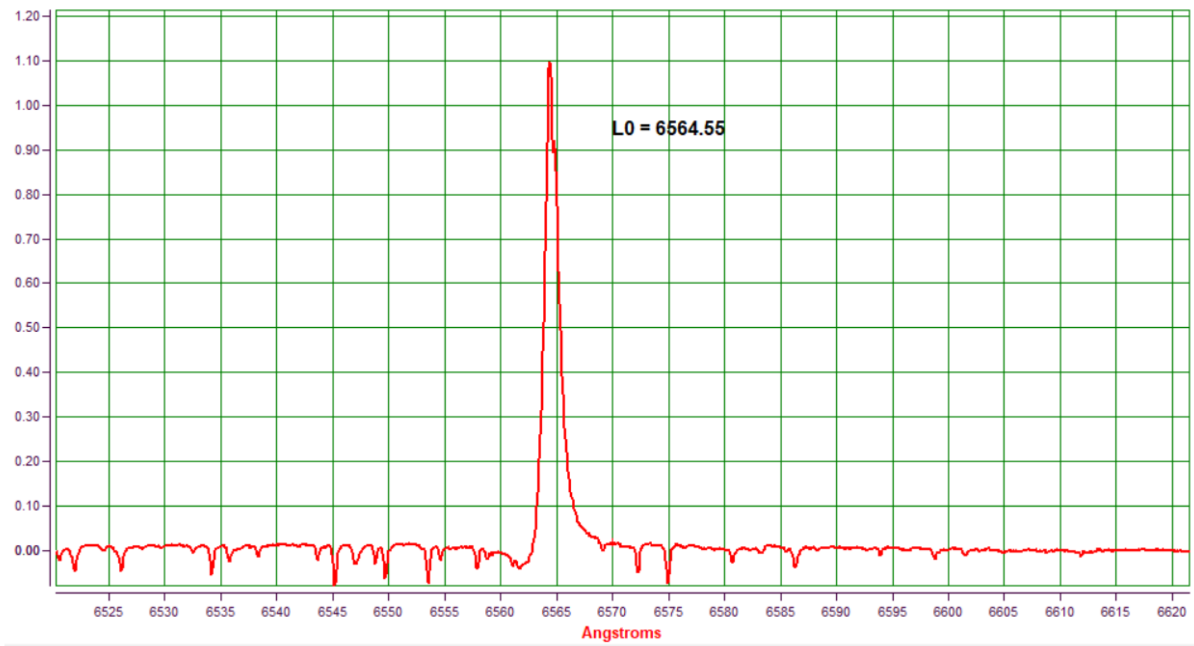
Figure 8: Computed Hα line (red)




If we divide the measured $H_\alpha$ 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 in that there is a hint of blue shifted absorption together with strong emission from the ejected material.

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 $H_\beta$.

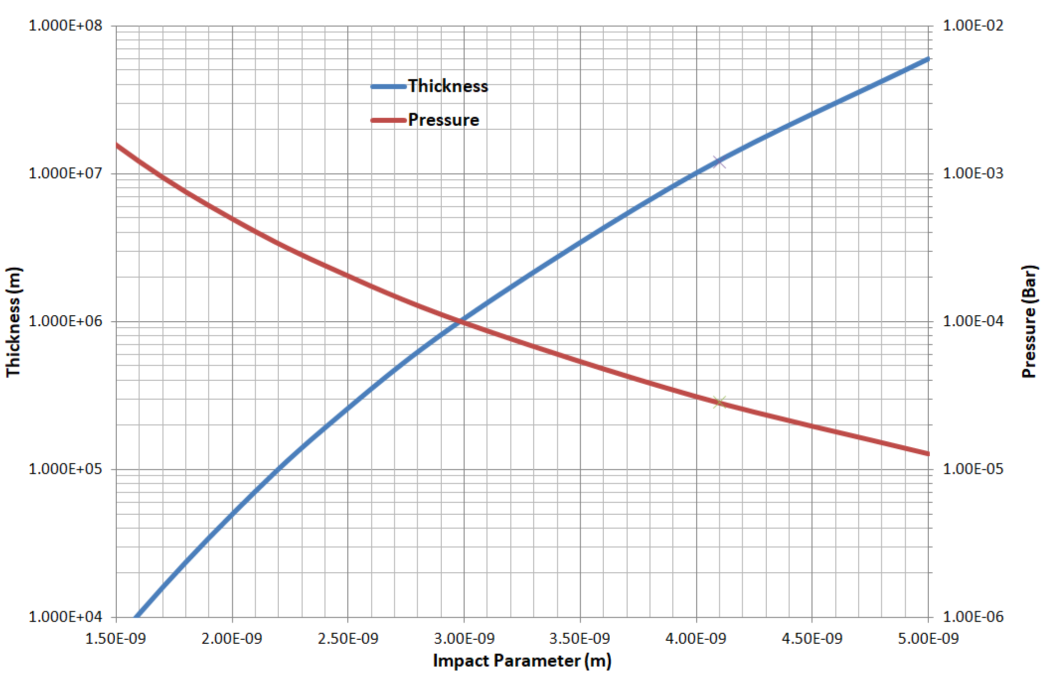
The peak wavelength depicted in Figure 9 corresponds to a maximum intensity outflow speed, relative to the star, of approximately 1 km $s^{-1}$.




### 3.3 Photosphere Pressure and Thickness

When modelling the absorption at $H_\gamma$ the custom software also calculates the thickness and pressure of the photosphere given a value for an "impact 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.

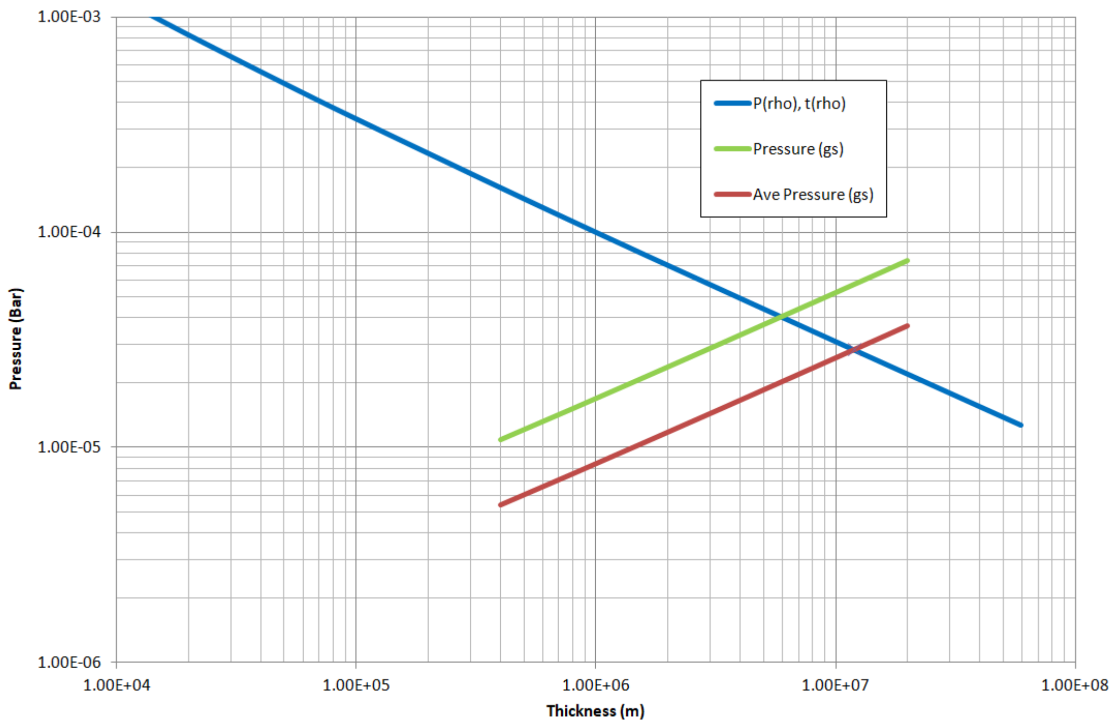
**Figure 10: Photosphere Thickness and Pressure vs Impact Parameter**



As for previous stars studied by the author[1] (Sun, Albireo B, Vega), its is also possible to estimate the pressure of Deneb's photosphere as a function of it's thickness given a value for it's surface gravity and the column density of atoms in the Balmer series ground state. This column density is calculated by the author's software in the process of modelling a stars absorption line profiles and the surface gravity is known to be gs = 12.59 m $s^{-2}$.

Given this value of surface gravity, Figure 11 shows the result of calculating the photosphere pressure as a function of photosphere thickness. This figure also shows the parameterised (by the impact parameter) curve of pressure vs thickness derived from the data displayed in Figure 10. Taking the average pressure as a half of the base pressure, as calculated from surface gravity, the intersection of these two functions yield an estimate of 2.85e-5 Bar, 1.2e4 km and 4.1e-9 m for the pressure, thickness and impact parameter appropriate to Deneb's photosphere.

**Figure 11: Photosphere Thickness vs Pressure**




## 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 appears to work well.
- The approximate temperature of Deneb's photosphere is 11250K.
- The Lorentzian half width is 1A
- No stellar rotation is discernible
- Deneb is shedding matter via a stellar wind which is distorting the normal absorption line at $H_{\alpha}$.
- The photosphere pressure is calculated to be 2.85e-5 Bar.
- The photosphere thickness is calculated to be 1.2e4 km.
- The pressure related impact parameter is calculated to be 4.1e-9 m.

## 5.0 References


1. www.thewhightstuff.co.uk