A Spectroscopic Study of Vega (α Lyrae) and Sirius (α Canis Majoris)

Kenneth R Whight 11/01/2022

Abstract

This paper describes an investigation into what can be learned about the physical properties of the White star Vega (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.

The aim of this work was to test the ability of this simple stellar model to predict the Hydrogen line profiles in Vega's spectrum and to estimate the pressure and thickness of its photosphere.

High resolution spectra of Sirius (α Canis Majoris) are remarkably similar to those obtained for Vega so the results of studying Vega are assumed to apply equally well to Sirius.

1. Introduction

Vega (α Lyr) is classed as a A0 V star i.e. a hot (A0) main sequence (V) star that is rotating rapidly but is being viewed from within 5° of its pole so that the effects of rotation on its spectra should be negligible. Sirius (α CMa) is a similarly classed star whose spectra are remarkably similar to those of Vega, however it is not recorded as a fast rotator. I shall use the similarity of the spectra to assert that the results of modelling Vega apply equally well to Sirius.

The aim of this work was to test the ability of a simple stellar model to predict the Hydrogen line profiles in Vega’s spectrum and to estimate the pressure and thickness of its photosphere.

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, the “Lorentzian Half Width” of pressure induced line broadening and, if appropriate, the star's speed of rotation.

The theory, methods and computer programs used in this study have been previously described in earlier studies of the Sun[1] (via reflection spectra off of Europa) and the blue component of Albireo[2] (β Cyg) that are published on my website www.thewhightstuff.co.uk.

2 Low Resolution Spectra

Figure 1: 150 l/mm spectrum of Vega

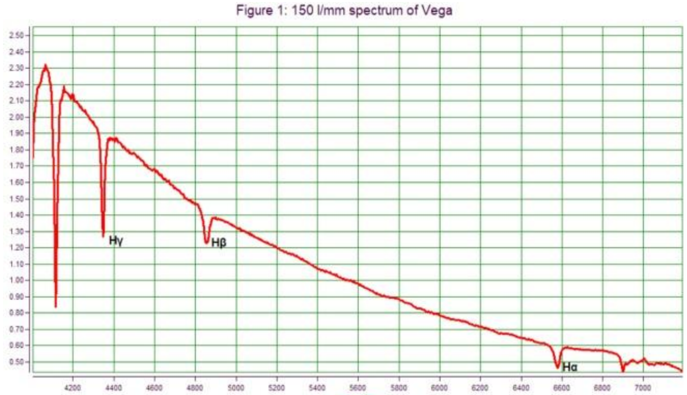
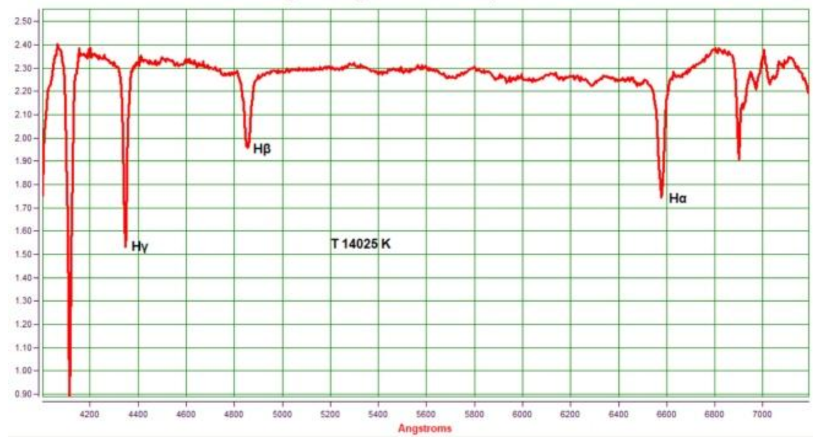


Figure 1 shows a low resolution (150 lines/mm) spectrum of Vega, this spectrum was fully calibrated for instrument response and atmospheric absorption using a library reference spectrum. In the figure the Hydrogen α, β and γ line positions have been indicated.

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. Figure 2 shows the optimal flattened spectrum of Vega after division by a 14025K Planck curve.

However it is worth noting that significant errors can result for hot stars as the peak of emission is well into the UV region of the spectrum so the resulting temperature is very sensitive to small "errors" in the measured spectrum. Luckily line profiles are most sensitive to pressure effects and not temperature. I have used the temperature suggested by the low resolution measurements in my simulations.

Figure 2: Vega Flattened Line Spectrum



3.0 High Resolution Spectra

High resolution (2400 line/mm) spectra, of both Vega and Sirius, taken at H_γ, H_β and H_α wavelengths are shown in figures 3, 4 and 5 respectively, apart from small differences in position, due to Doppler effects, or experimental error, they are remarkably similar.

Figure 3: 2400 l/mm Hγ Vega Sirius Comparison

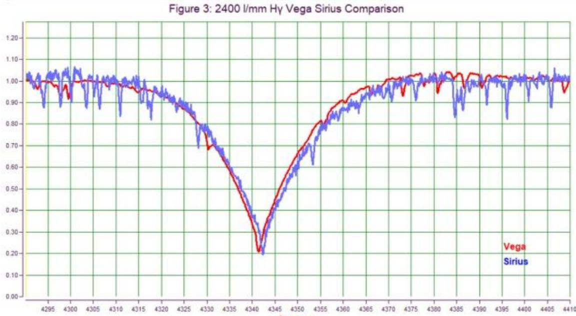
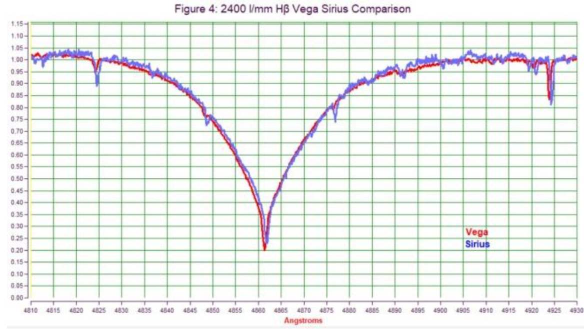
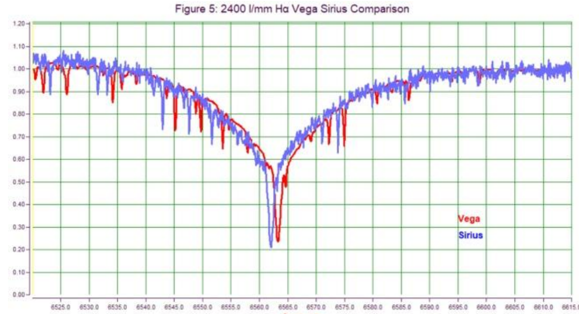


Figure 4: 2400 l/mm Hβ Vega Sirius Comparison



All lines appear to show evidence of a "spike" that seems to emerge out of the broader body of the line as we progress from H_γ to H_α via H_β. The line shapes are not as "rounded" as seen in my earlier studies of the Sun and AlbireoB. There is the possibility that this could be due to a non-uniformity in the emission across the disk of the star (www.star-facts.com) or the result of the photosphere having two distinct layers. These possibilities will be investigated in a subsequent paper.

Figure 5: 2400 l/mm Hα Vega Sirius Comparison



In this paper I will model Vega on the same basis as my work on the Sun and Albireo B, i.e. having a photosphere that is a single layer in thermal equilibrium.

3.1 Single Layer Model

For the H_β absorption line the central wavelength was determined, based on equal areas each side of centre, to be 4861.47A. The absorption profile was then modelled assuming the absorption line amplitude at the line centre $A_\beta(\lambda_\beta) = 0.204$, the result of which is shown in figure 6.

In this figure it can be seen that a compromise has had to be made between fitting the shape of the "core" and the "wings" of the profile. Important parameter values appear as labels in the RSpec displayed spectra.

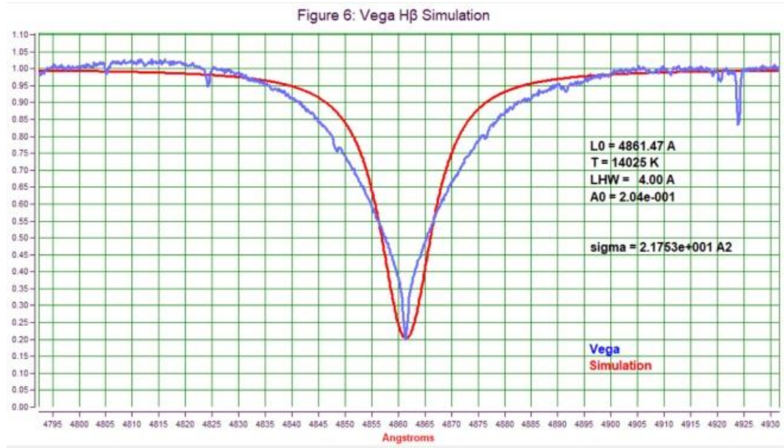


Figure 6: Vega Hβ Simulation

Subsequent prediction of the H_γ and H_α absorption lines, using the method described in my previous reports yield the results depicted in figures 7 and 8.

In these figures it can be seen that the model predictions are very good with regard to the amplitude of each line however there is an obvious difference in shape between the modelled and measured profiles. It is to be hoped that, although the line profile shapes were not very well reproduced, the calculations provide a reasonable estimate for the thickness and average pressure of Vega's photosphere.

Figure 9 shows the result of calculations of the thickness and pressure of Vega's photosphere as a function of the impact parameter ρ.

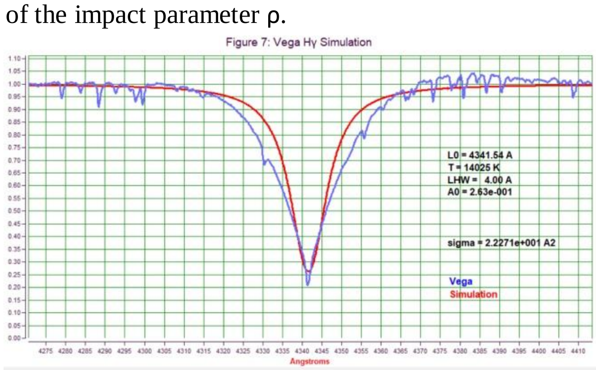


Figure 7: Vega Hγ Simulation

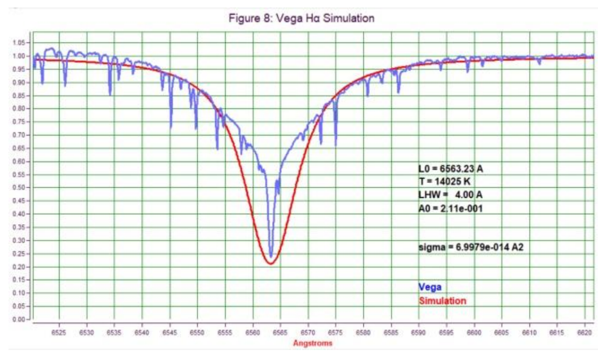


Figure 8: Vega Hα Simulation

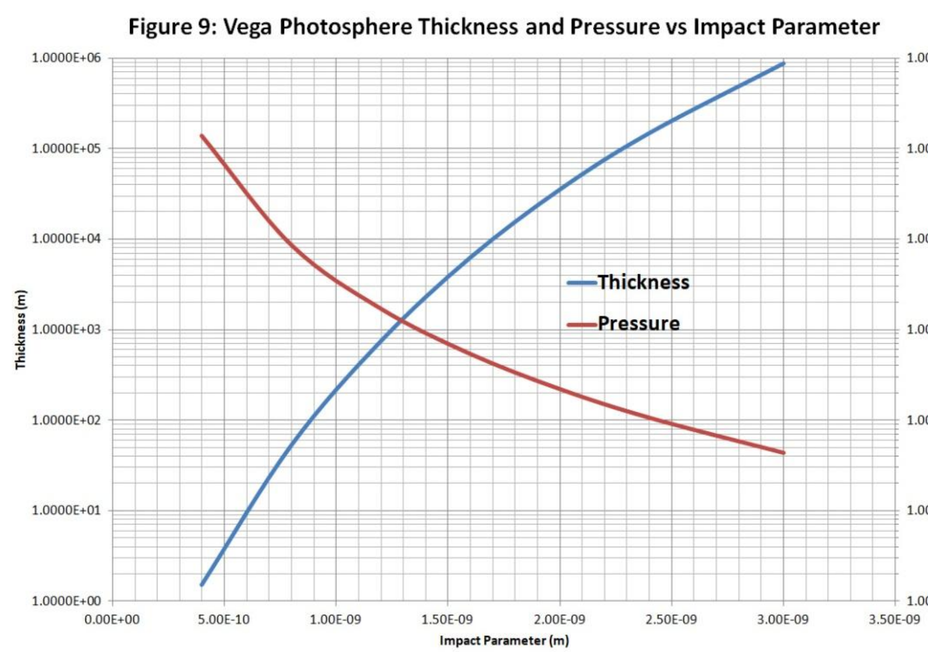
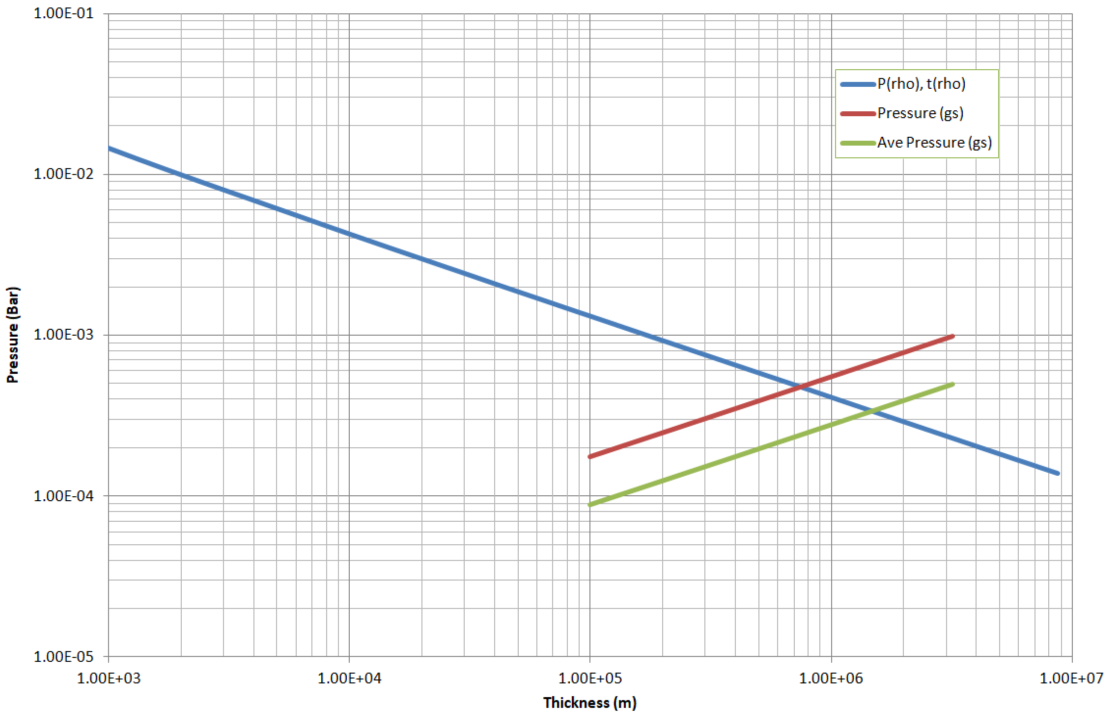


Figure 9: Vega Photosphere Thickness and Pressure vs Impact Parameter

As verified in the study of the Solar photosphere[1], we can also use known values of stellar surface gravity to estimate photosphere pressure as a function of thickness given the value for the column density of neutral atoms in the Balmer ground state (N2t).

Figure 10: Vega Photosphere Pressure vs Thickness



A plot of these independent functions of pressure vs thickness is displayed in figure 16 given that Vega's surface gravity is 126 ms^{-2} and, as calculated by the simulation software, N2t = $7.2585e^{20}$ m^{-2}. In this figure we have plotted two surface gravity curves, the red curve assumes the pressure at the base of the photosphere whilst the green curve assumes half this base pressure as a better equivalent to the impact parameter derived pressure[3]. The intersection of the blue and green curves in figure 10 implies a photosphere thickness of 1450km and a pressure of 3.36e-4 Bar.

4.0 Discussion

The single layer model has proven reasonably successful in modelling other stars e.g. the Sun[1] and Albireo B[2], with regard to both amplitude and line profile shape when known complicating factors (Albireo B's decreation disc) are allowed for. However for Vega, whilst line amplitudes are well reproduced the shape of the line profiles are not well reproduced. It is not obvious what process could yield such line shapes but failure of the assumption that the photosphere is a uniformity emitting oblate spheroid is a prime candidate. The possibility that the photosphere is not a single layer but has two broadly distinct layers is another possibility and there may well be others. I intend to investigate further in the future to see if the discrepancy can be accounted for,

5.0 Conclusions

A spectroscopic study of Vega (α Lyrae) and, by implication, Sirius (α Canis Majoris) has been performed to determine physical properties of these star's. It has been found that:-

- The relative amplitude of the hydrogen Balmer line series are well reproduced by the simple model however the line profiles are not well modelled by a uniform single layer photosphere.
- The photosphere temperature is 14025K.

- The photosphere thickness is 1450km.
- The photosphere pressure is 3.36e-4 Bar.

6.0 References

1. www.thewhightstuff.co.uk Astrospectroscopy Projects Europa pdf

2. www.thewhightstuff.co.uk Astrospectroscopy Projects AlbireoB pdf