A Spectroscopic Study of Altair (α Aql)

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Abstract

This paper describes an investigation into what can be learned about the physical properties of the White star Altair (α Aql) 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. Altair is a hot A7 IV-V rapidly rotating star.

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

1. Introduction

Altair (α Aql) is classed as a A7 IV-V star i.e. a hot (A7) sub-giant/main-sequence (IV-V) star that is rotating rapidly with an equatorial surface velocity of $9.53 \times 10^{-4}c$ (Wikipedia). As a result the star is oblate with an equatorial to polar radius ratio of 1.245 and the polar axis is inclined at $6o^{o}$ to the line of sight (Wikipedia). Figure 1, which was copied from the Wikipedia page, is a representation of the star.

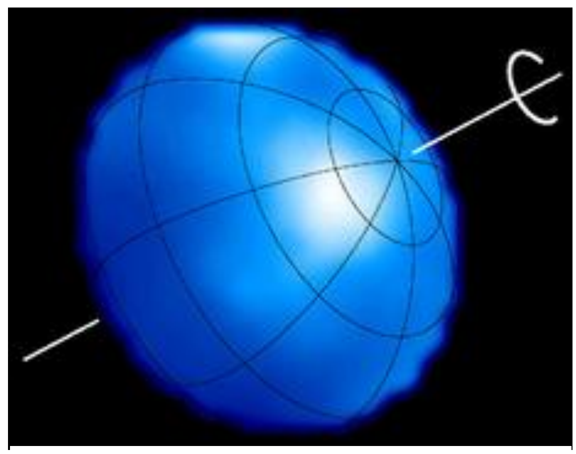


Figure 1: False color image of the rapidly rotating star Altair, made with the MIRC imager on the CHARA array on Mt. Wilson.

The aim of this work was to test the ability of a simple stellar model to predict the Hydrogen line profiles in Altair's spectrum and to determine the pressure and thickness of the star's photosphere. The stellar model used will be that of a solid body (oblate spheroid), rotating and emitting uniformly through a photosphere that is a single layer in thermal equilibrium.

As temperature has a relatively small effect on line profiles, certainly for high pressure dwarf stars, I will assume a uniform temperature over the star. 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.

The theory and computer programs used in this study have been previously described in earlier studies of the Sun and other stars[1].

1.1 Low Resolution Spectra

Figure 2 shows a low resolution (150 lines/mm) spectrum of Altair, 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 9550K for Altair. Figure 3 shows the flattened spectrum of Altair after division by the appropriate Planck curve.

Figure 2: 150 l/mm spectrum of Altair

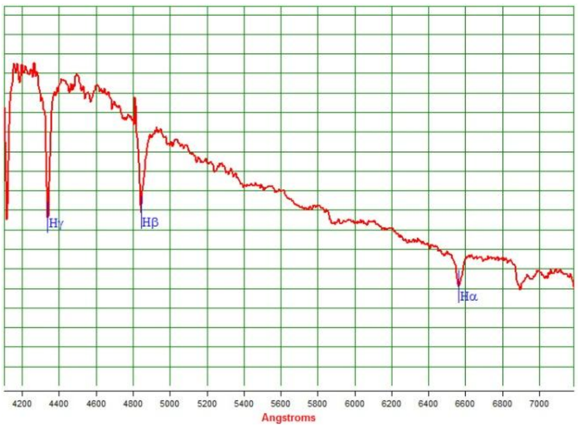
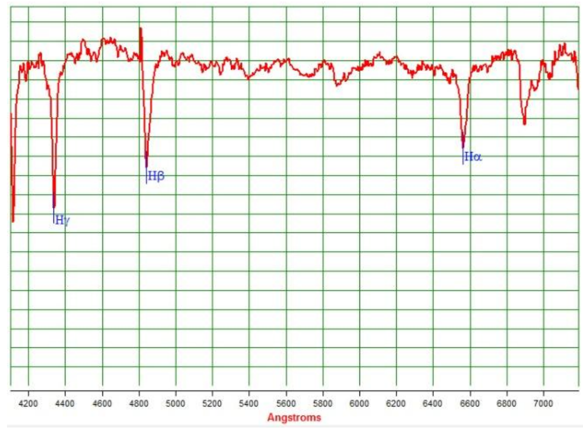


Figure 3: Flattened line spectrum of Altair.



1.2 High Resolution Spectra

High resolution (2400 line/mm) spectra taken at H_γ, H_β and H_α wavelengths are shown in figures 4, 5 and 6 respectively. I have chosen to model the H_γ absorption line using the values for the oblateness (ob), equatorial surface velocity (vrot) and viewing angle (theta) stated in the Wikipedia entry, this leaves just the Lorentezian Half-Width (LHW) as a free fitting parameter.

Figure 4: 2400 l/mm spectrum of Altair at Hγ

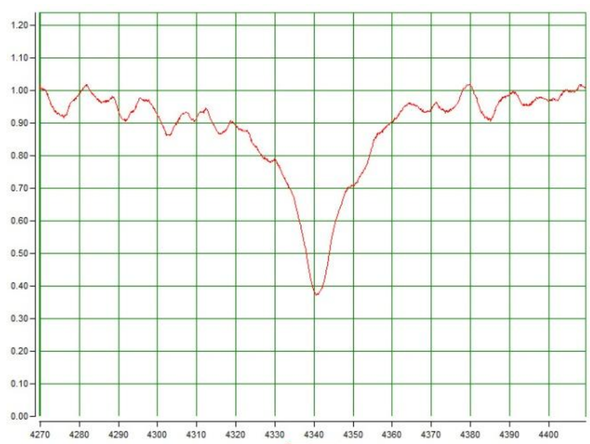
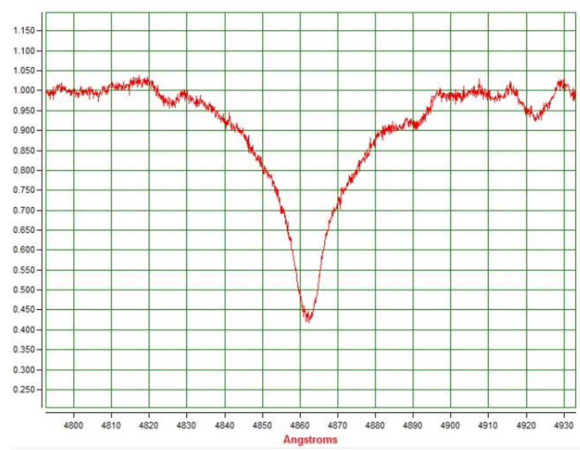


Figure 5: 2400 l/mm spectrum of Altair at H_β



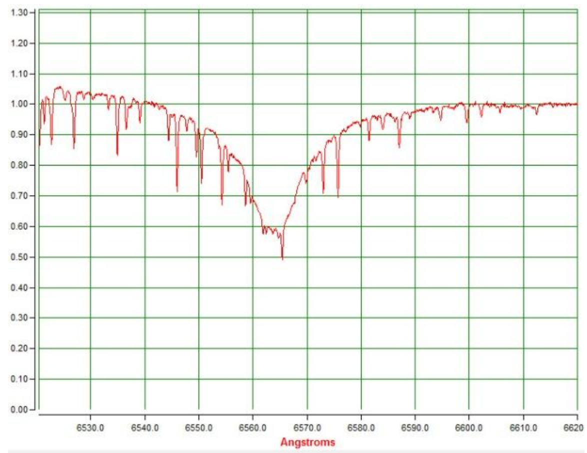
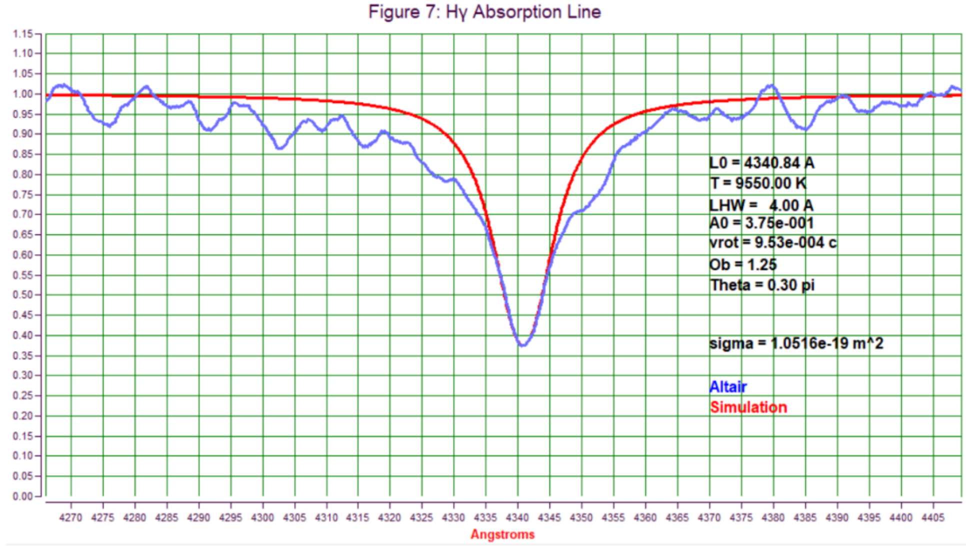


Figure 6: 2400 l/mm spectrum of Altair at H_α

1.3 H_γ line analysis

For the H_γ absorption line the continuum gradient was automatically removed, using my software, and the central wavelength determined, based on equal areas each side of centre. The $A_\gamma(\lambda_\gamma)$ value (Intensity at the absorption line centre A0) was 0.375 Simulations were performed, adjusting the parameter LHW, to achieve a good fit to this profile and the result is depicted in figure 7.

Figure 7: Hγ Absorption Line



It can be seen that, with LHW = 4.0A, a good fit is achieved in the core of the line but there appears to be some extra emission in the "wings" that is not reproduced by the model. All the parameters used to obtain this fit are displayed in the figure as is the calculated photon capture cross-section 'sigma'.

1.4 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 results are depicted in figures 8 and 9 respectively (red curves) together with the measured line profiles (blue curves). The wavelength (L0), profile amplitude (A0) and photon capture cross-section (sigma) values appear as labels in these figures. All other model parameters are as listed in Figure 7.

Whilst the fit is quite good, considering the simplicity of the mosel, at H_β we are again seeing significant additional emission compared to the thermal equilibrium expectation at H_α. Excess H_α emission was seen in the study of Albireo B and it is possible that the same mechanism is at play here. Both stars are rapidly rotating so a bulging equator may result in excess emission from the equatorial regions.

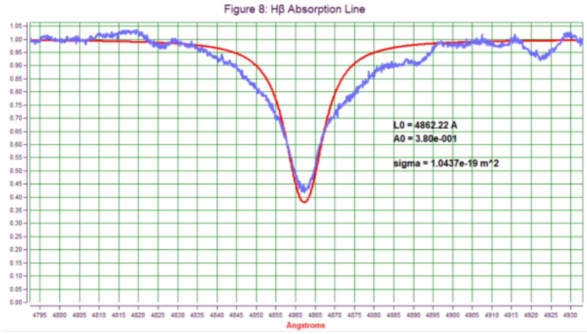


Figure 8: Hβ Absorption Line

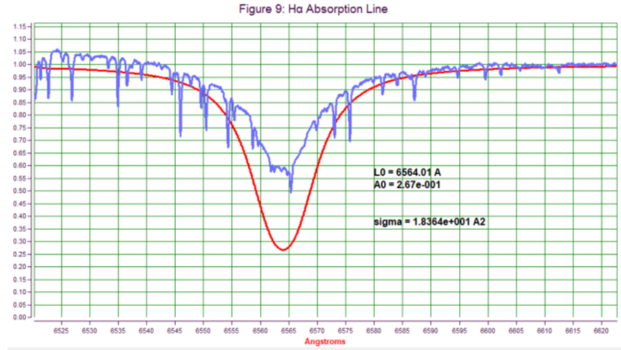
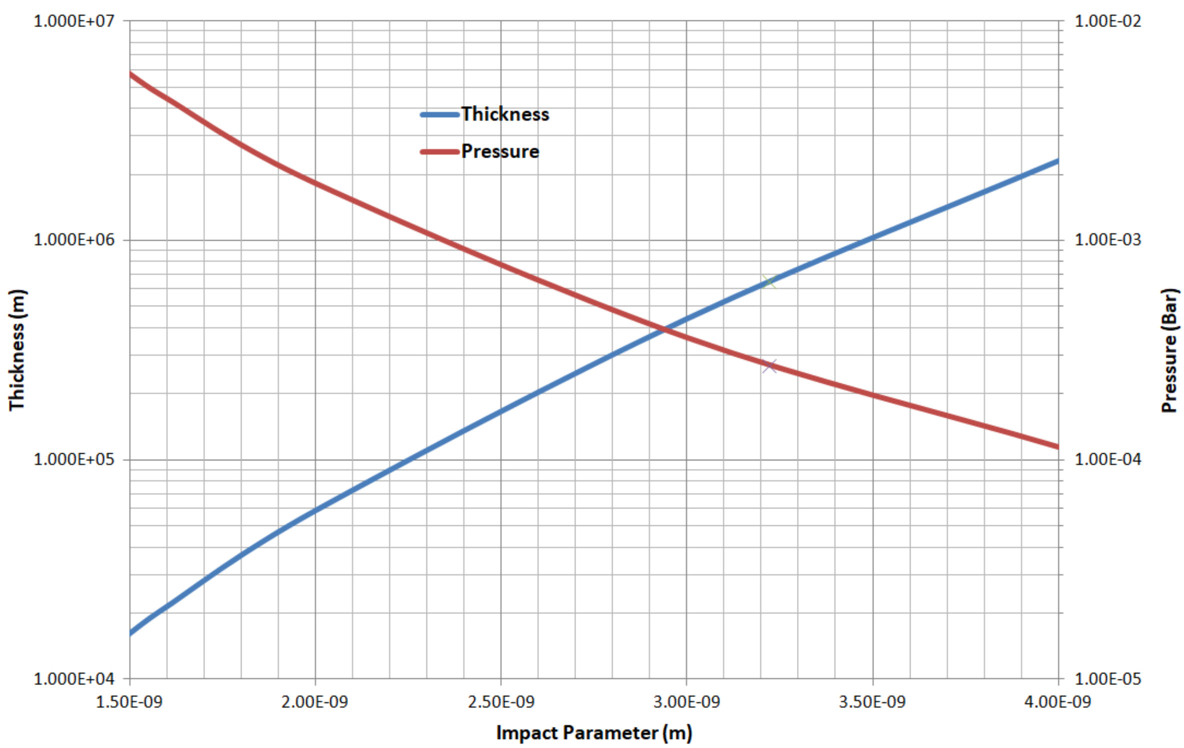


Figure 9: Hα Absorption Line

1.5 Photosphere Pressure and Thickness

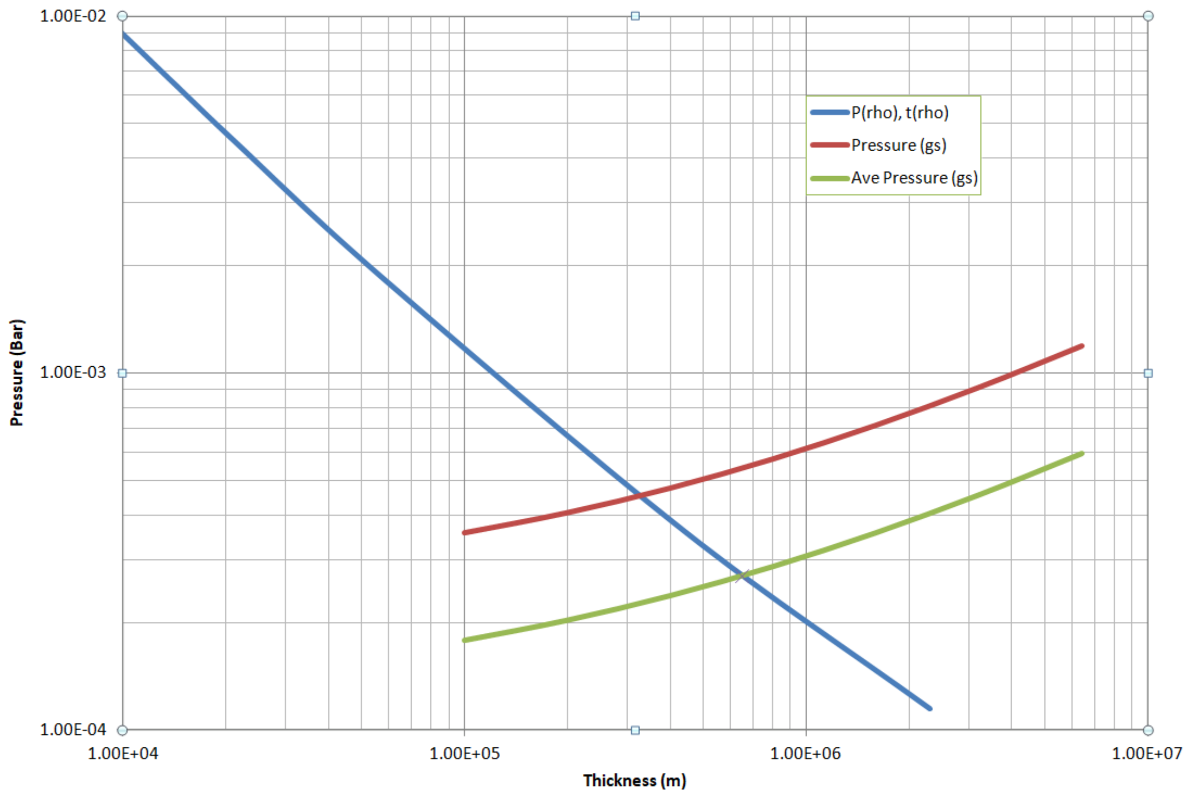
The analysis of the H_γ absorption line also yielded a value of 9.6753×10^{20} m^2 for the column density of atoms in the n=2 principle quantum state. This value is split by the custom software into predictions of the pressure and thickness of Altair's photosphere as a function of the impact parameter 'imp'. The result is displayed in figure 10.

Figure 10: Altair Photosphere Thickness and Pressure vs Impact Parameter



As for previous stars studied by the author[1] (Sun, Albireo B, Vega, Deneb), its is also possible to estimate the pressure of Altair's photosphere as a function of it's thickness given a value for it's surface gravity and the previously mentioned column density of atoms in the Balmer series ground state. The surface gravity is known to be gs = 195 m s^{-2} and Figure 11 shows the result of calculating the photosphere pressure as a function of photosphere thickness given this value. Also shown in this figure is 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 2.7e-4 Bar, 6.5e2 km and 3.22e-9 m for the pressure, thickness and impact parameter appropriate to Altairs's photosphere.

Figure 11: Altair Photosphere Pressure vs Thickness



2. Discussion

Rotation effects can be expected to compromise the assumption of a uniformly emitting spheroid. This fact has been used to propose, as in the case of Albireo B, that the equatorial bulge allows for some additional H_β and H_α emission with the dynamical properties of the star. If this mechanism is valid then the bulge must be less optically thick for Altair as some emission at H_β is seen whereas it was absent in the case of Albireo B at H_β. Such a mechanism would seem to be consistent with the fact that Albireo B is spinning off a decreation disk whilst Altair is not.

Allowing for the proposed addition equatorial emission, a good fit using the known parameter values of oblateness, rotational velocity and viewing elevation was obtained with just the Lorentzian half-width parameter left to adjust. The fit was particularly good at H_α where the additional wing absorption seen at H_γ and H_β was not present. Why this should be the case is not known.

3. Conclusions

A spectroscopic study of Altair (α Aql) has been performed to determine physical properties of the star. My analysis suggests the following properties for the star:-

- The approximate temperature of the star's photosphere is 9550K.
- The pressure Lorentzian half width is 4.0A.
- The maximum surface speed due to rotation is $9.53\text{x}10^{-4}$c
- the Oblateness factor for the star is 1.245.
- We are viewing the star a 0.3π from its equator.
- Some excess emission, possibly from an equatorial bulge, is present at the H_α wavelength.

- Altair's photosphere has a pressure and thickness of approximately 2.7e-4 Bar and 650 km respectively.
- The appropriate pressure Lorentzian impact parameter is 3.22e-9

4. References

1. www.thewhightstuff.co.uk