Analysing High Resolution Spectra from AlbireoB

K.R. Whight (www.thewhightstuff.co.uk)

Introduction

This document represents a step by step guide to analysing high resolution (2400 l/mm) spectra of the Hα , Hβ and Hγ regions of AlbireoB's spectrum using the software I have produced (PROFILE). It also represents a user guide to that software.

I assume that the reader has previously read the document "Stellar Temperature" and used my software (PLANCK) to obtain a temperature estimate of 17625K for AlbireoB. I also assume that the reader uses RSpec software for all "standard" processing of spectral data. PROFILE will work with any spectral data presented in two column .dat format but, in that case it creates a *filename.*par file to store parameters input to and calculated by the software which must accompany the .dat file at all times for PROFILE to work properly. If the user is using RSpec then this data will be written to the *filename.*ini file and displayed as a label on opening the *filename.*dat file in RSpec.

A flowchart representing the operation of PROFILE is shown at the end of this document. Given *filename*.dat is the original input file containing the fully calibrated measured line profile the following processed .dat files contain:-

- *filename*_F is the (continuum =1.0) flattened spectrum.
- *filename*_Ref is the equivalent emission line spectrum (continuum = 0.0).
- *filename*_T is the modelled temperature broadened emission line spectrum (continuum = 0.0).
- *filename*_TP is the modelled temperature and pressure broadened emission line spectrum (continuum = 0.0).
- *filename*_TPR is the modelled temperature , pressure and rotation (if required) broadened emission line spectrum (continuum = 0.0).
- *filename*_TP(R)A is the temperature , pressure and, where required, rotation broadened absorption line spectrum(continuum = 1.0)

Note these files are accompanied by .ini or .par files according to whether RSpec is or is not being used. If RSpec is not being used the PROFILE automatically creates the initial *filename*.par file when first run.

The software also creates a *filename_xxx_model* file that records the input parameters so that the model run can be repeated without having to re-type the inputs. When such a *_model* file is detected the software gives the option to use it as input or to ignore it, the file can be edited prior to a run to ease the input burden when trialling different parameter sets.

Modelling AlbireoB

We will model the Hγ profile as this was the only line that did not appear to have an emission component originating from the star's known decreation disk. The physical nature of the star will then be inferred from the result of comparing predicted absorption and measured Hγ profiles.

Profiles at Hβ and Hα will then be computed and used to separate the stellar absorption and disk emission components.

Figures 1, 2 and 3 respectively show the Hγ , Hβ and Hα line profiles to be analysed.

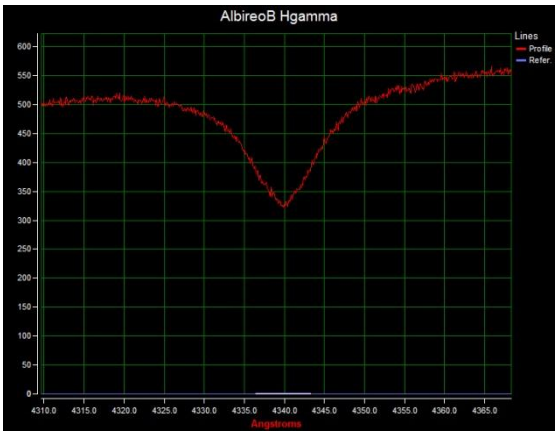

Figure 1: 2400 l/mm spectrum of AlbireoB at H_γ

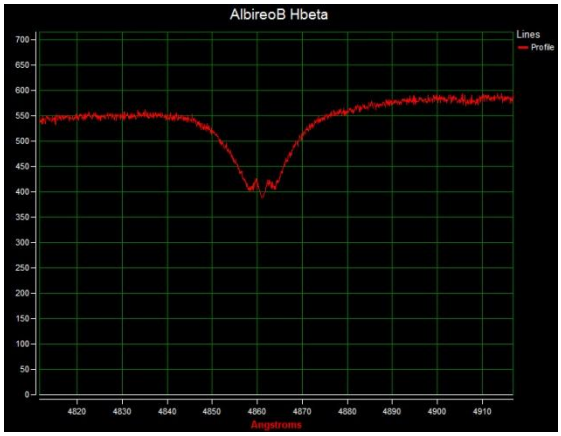

Figure 2: 2400 l/mm spectrum of AlbireoB at H_β

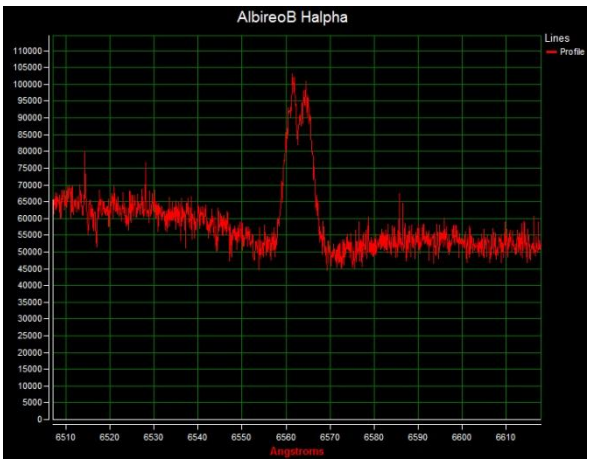

Figure 5: 2400 l/mm spectrum of AlbireoB at H_α

H_γ line analysis

Double click the "Spectra" shortcut Icon and use the browse button to select the file "AlbireoBHg" in the Library\AlbireoB\Lmm2400\Hgam folder included with the released software, then click the Profile button. A command prompt window should popup asking if you want the profile centre wavelength to be calculated or if you want to specify a centre wavelength. Once this question has been answered the software will output a *filename*_F.dat file (in this case AlbireoB_F.dat) containing the "flattened" spectrum and a *filename*_Ref.dat file containing the "equivalent emission line" profile.

Note the flattening process infers a linear gradient from the first and last 5% of profile data so the profile should be trimmed so that these regions are representative of the continuum. Note also that if the input file has an accompanying RSpec .ini file then a file *filename*_F.ini and *filename*_Ref.ini will also have been written which will contain relevant parameter values, input to and derived from, the spectra expressed as labels. Non RSpec users will find files *filename*.par, *filename*_F.par and *filename*_Ref.par produced containing the equivalent parameter values. Figure 4 illustrates this process the window depicted in figure 4 is closed by typing any key and <return>.

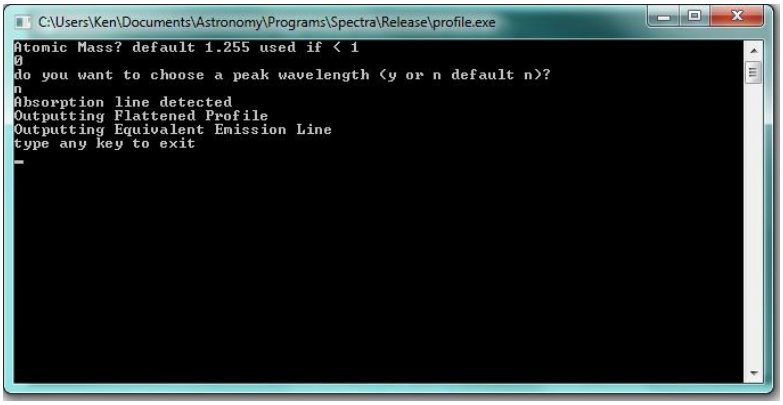

Figure 4, Producing a "Flattened" absorption profile and an "Equivalent Emission Line" profile'

Modelling the star at Hγ

The modelling process involves using PROFILE to predict emission line profiles as a convolution of temperature, pressure and rotation effects and then comparing them to the *filename*_Ref profile modifying the parameters until a good fit is achieved.

As can be seen from the flow chart at the end of this document the initial starting point for a simulation is the *filename*_Ref.dat (in this case AlbireoBHg_Ref .dat) file but subsequently you can jump in at any point. For example, if you are happy with the temperature and pressure but wish to modify the rotation parameters then you can select *filename*_TP.dat as the input file.

Figure 5 shows the, RSpec displayed, result of the modelling process. Note that parameter values for the modelled line appear as labels in this figure as RSpec is being used.

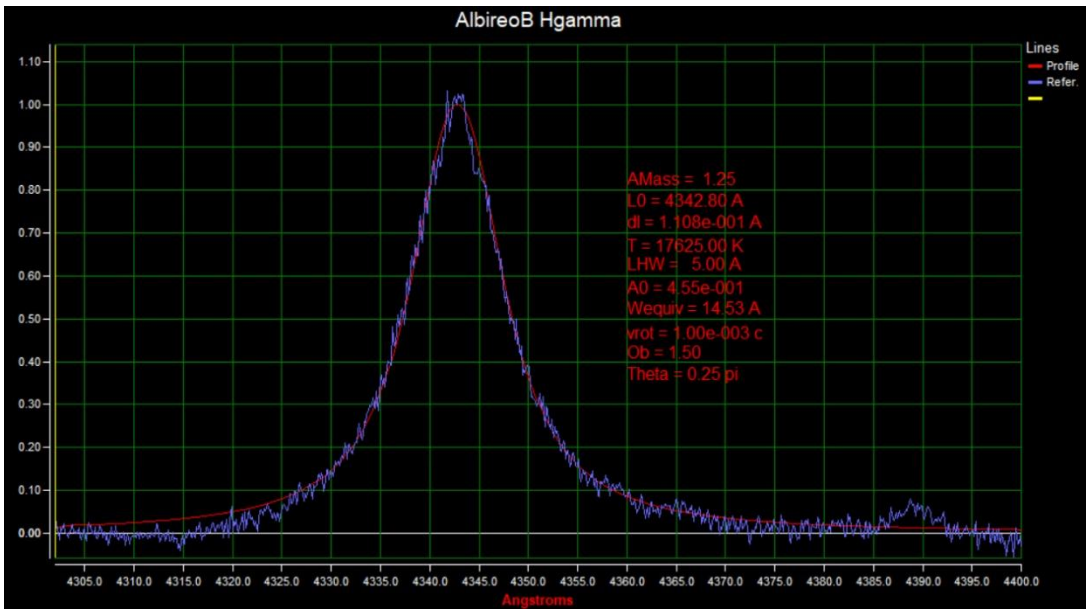

Figure 5: Simulated H_γ emission line (red) target (blue)

Figure 6 displays a "straight through" run of PROFILE with the final parameter set as input. As before, the window (depicted in figure 6) is closed by typing any key and <return>.

```
Model data file detected
do you want to use this file (y/n derault n)
y
do you want to choose a peak wavelength (y or n default n)?
n
Atomic Mass? default 1.255 used if < 1
0.000000e+000
Temperature for convolution (K)?
1.762500e+004
Pressure Lorentzian Half Width (A)?
5.000000e+000
Rotational velocity (fraction of c)?
1.000000e-003
Rotating Spheriode (s) or Kepler Disk (d)? default (s)
1
Oblatness factor (Requ/Rpol)?
5.000000e-001
Viewing angle (relative to equator) as a fraction of pi 0 <= theta <= pi/2?
2.500000e-001
Output an Absorption line? (y or n default n)?
n
type any key to exit
```

The time taken to complete the run depicted in Figure 6 is of the order of ten seconds on a modern (2020) laptop computer with approximately 750 wavelength bins spanning the spectrum, the run time increases with the number of bins. Note that a file *filename*_Ref_Model existed and was chosen as the source for the required inputs.

Figure 6: Complete run of PROFILE

We can now run PROFILE again, on the just generated *filename*_TPR file, to generate the predicted absorption line and compute interesting properties of the photosphere. Model parameter data is displayed from the stored labels and we will now answer 'y' (yes) to the question "Output an Absorption line?". This process is depicted in Figure 7.

```
Atomic Mass number 1.250
Centre Wavelength 4.342800e+003(A)
Temperature for convolution 1.762500e+004(K)
Pressure Lorentzian Half Width 5.000000e+000 (A)
Rotational velocity (fraction of c) 1.000000e-003
Oblatness factor (Requ/Rpol) 5.000000e-001
Viewing angle (relative to equator) as a fraction of pi 2.500000e-001
Output an Absorption line? (y or n default n)?
y
Amplitude at centre wavelength known (y or n default n)?
y
Required amplitude at centre wavelength?
0.455
Use a calcuated Impact Parameter y/n?
y
Dipole seperation as a fraction of the Bohr radius (range 0 to 1.0)? Default 0.5
0.25
impact parameter converged after 22 iterations
Nit = 6.112840e+021, NII = 3.829347e+021
Amplitude (A0) at lambda0 = 4.550000e-001
type any key to exit
```

The program asks if the amplitude of the absorption is known, we know the Hγ line depth so answer ‘y’ (yes) and then supply the appropriate value 0.455.

Subsequent questions gather information that allows the pressure and thickness of the photosphere to be estimated.

Figure 7: Complete run of PROFILE

The theory behind this estimation process is described in the documents “AlbireoB” and “Theory” available on my website.

Simulating the Hβ and Hα Absorption profiles

It is now necessary to run PROFILE on the files AlbireoBHb.dat and AlbireoBHa.dat to produce the *filename*_F and *filename*_Ref files. In both cases respond to the questions as for the Hγ case, see Figure 4. This process prepares both measured profiles for modelling and determines the central wavelengths.

```
n
Atomic Mass? default 1.255 used if < 1
0.000000e+000
Temperature for convolution (K)?
1.762500e+004
Pressure Lorentzian Half Width (A)?
5.000000e+000
Rotational velocity (fraction of c)?
1.000000e-003
Rotating Spheriode (s) or Kepler Disk (d)? default (s)
s
Oblatness factor (Requ/Rpol)?
1.500000e+000
Viewing angle (relative to equator) as a fraction of pi 0 <= theta <= pi/2?
2.500000e-001
Output an Absorption line? (y or n default n)?
y
Amplitude at centre wavelength known (y or n default n)?
n
Wavelength of modelled line?
4342.8
A0 for modelled line?
0.455
dlambda0 of modelled line?
0.1108
Wequiv for modelled equivalent emission line?
14.53
Amplitude (A0) at lambda0 = 4.241695e-001
type any key to exit
```

We can now run PROFILE again, on the just generated *filename*_Ref file, and input the desired model parameters when requested. Alternatively we can copy the Hγ *filename*_Ref_Model file to the appropriate Hβ and Hα *filename*_Ref _Model files to save typing. Either way we will answer 'y' (yes) to the question "Output an Absorption line?". This process is depicted in Figure 8 for the case of Hβ, Note that additional questions are asked now that an absorption profile is being computed.

Figure 8: Complete run of PROFILE to produce the expected Hβ Absorption profile

The additional questions are:-

1. Amplitude at centre wavelength known? In this case we are attempting to predict the Hβ absorption from the Hγ line model hence the response is 'n' (no).
2. Wavelength of modelled line? We modelled the Hγ line so the value 4342.64 was entered, see parameters displayed in Figures 7.
3. A0 for modelled line? enter the amplitude of the modelled Hγ absorption line at the its centre wavelength i.e. the value 0.455, see parameters displayed in Figure 7.
4. dLambda for modelled line? this is the Hγ bin width, the value 0.1108 was entered, see parameters displayed in Figure 7.

The program then displays the computed value of A0 for the Hβ line, outputs the profile data and then invites you to close the window by typing any key and <return>. A comparison of the predicted (AlbireoBHb_TPRA) and flattened measured (AlbireoBHb_F) absorption profile is depicted in Figure 9 for Hβ. This same process can now be repeated to predict the expected absorption line profile at Hα and the result is shown in figure 10. As can be seen the predicted profile at Hβ , where emission is minimal, matches the absorption wings pretty well. At Hα , where emission is dominant it is more difficult to judge the accuracy of the predicted absorption line. It is assumed that disk emission accounts for the departures from predictions in the core of the lines.

AlbireoB's disk emission at Hβ and Hα is revealed by dividing the flattened measured profiles (*filename*_F profiles) by the modelled profiles depicted in figures 9 and 10 respectively, this is achieved in RSpec using the Maths on two series functionality. The resulting disk profiles should be saved as DiskHb and DiskHa and their labels should be blanked if using RSpec, if not using RSpec do not produce a corresponding .par file.

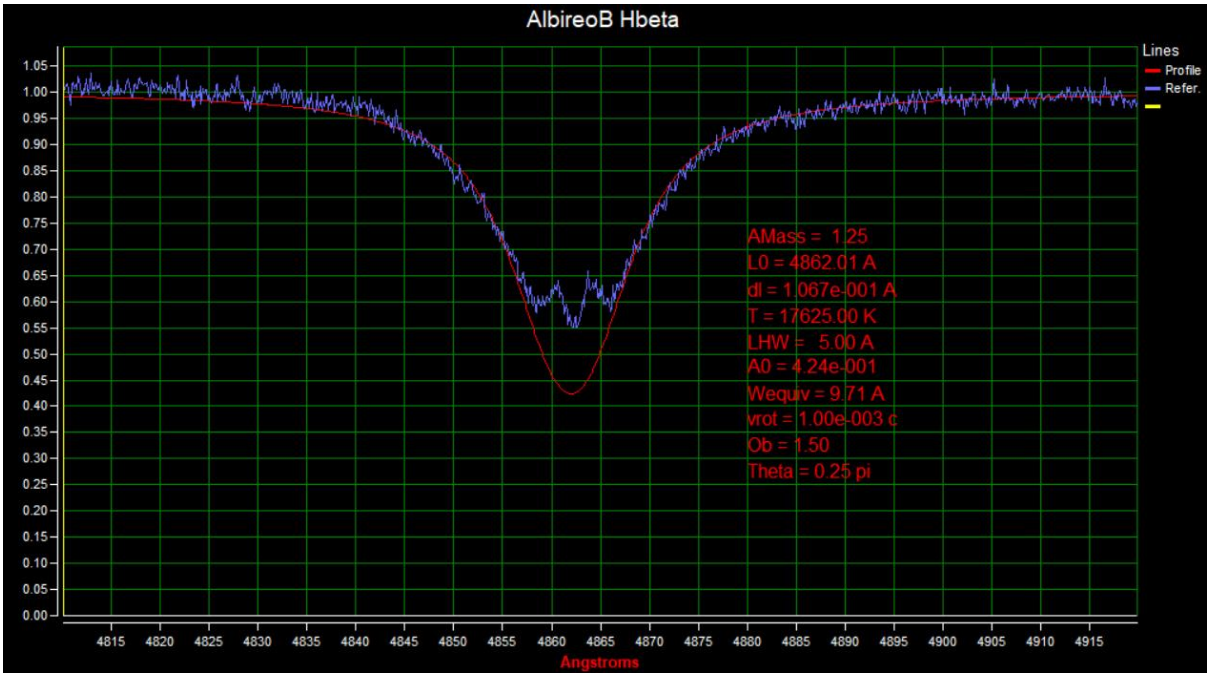

Figure 9: Model/Measurement comparison at Hβ

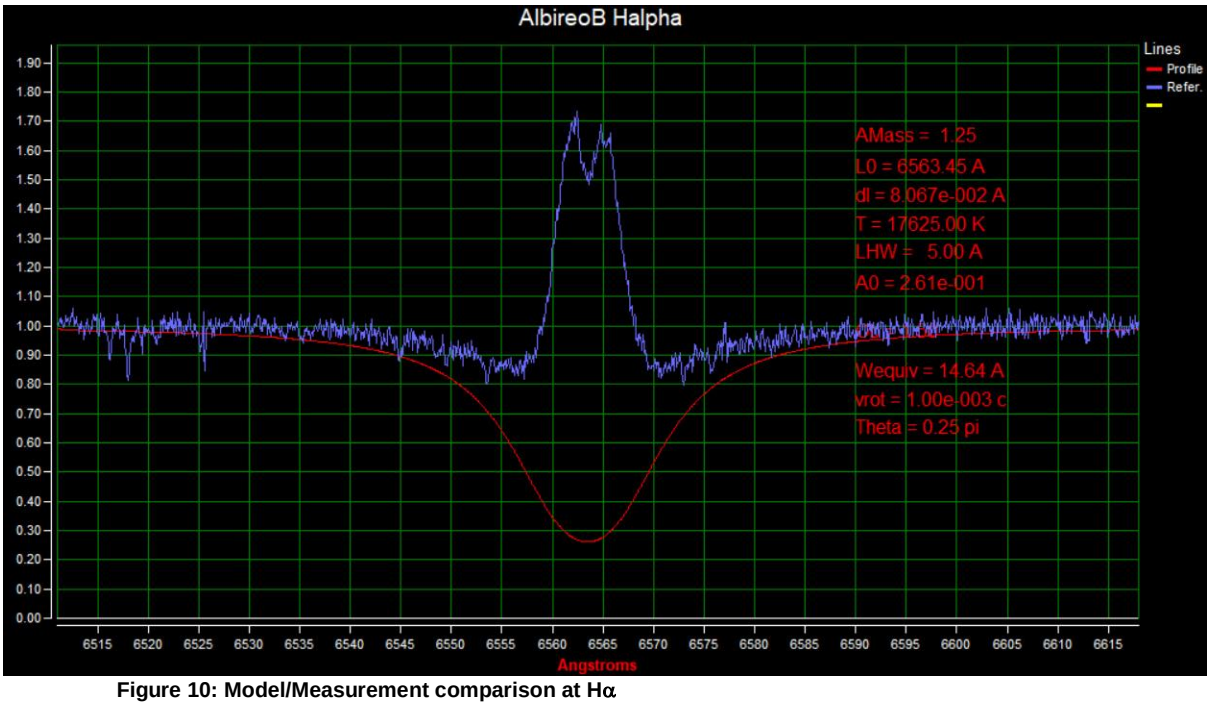

Figure 10: Model/Measurement comparison at Hα

Run PROFILE on both disk data files to produce *filename*_F files the profiles contained in these files are displayed in Figure11.

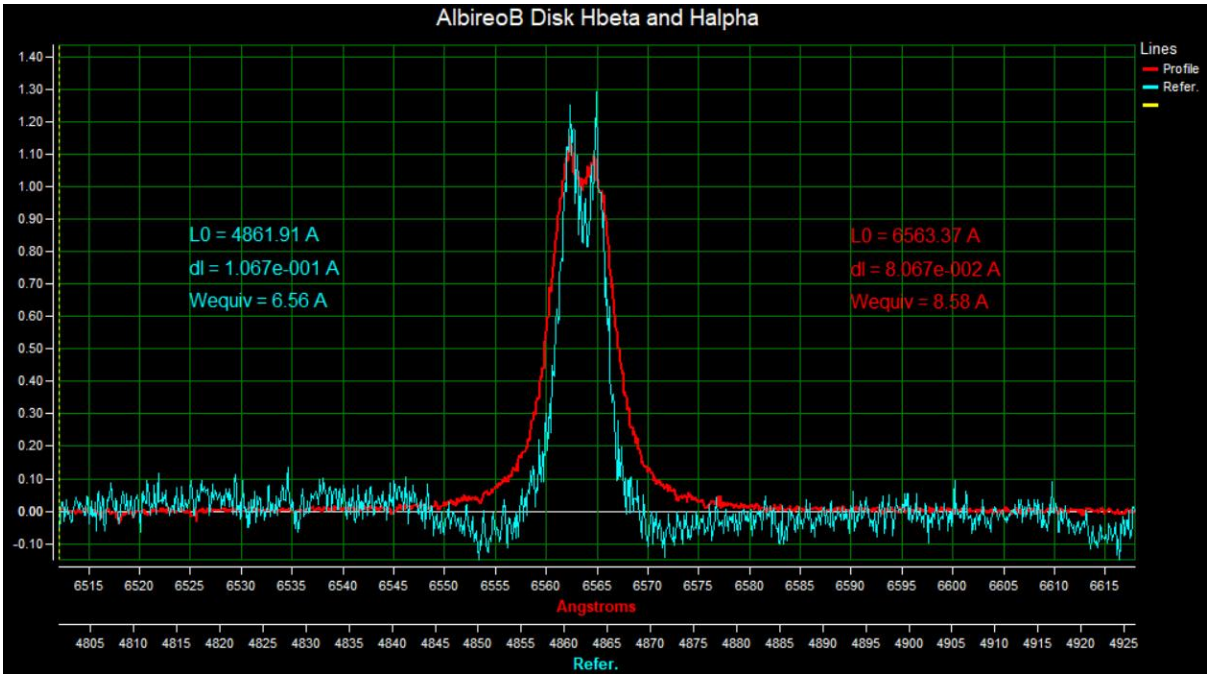

Figure 11: Overlay of Hβ and Hα disk profiles

Modelling AlbireoB's disk

The modelling of AlbireoB's rotating disk proceeds in a similar way to AlbireoB's absorption lines except that there will be no need now to convert any simulated emission line into an absorption line.

The software can treat the disk as a very oblate (ob > 5.0) spheroid or a circular Kepler orbit disk. This topic will be further illustrated and discussed in a subsequent document.

PROFILE Flowchart