

Stellar Temperature

KR Whight

Planck's distribution law for the energy flux of radiation emitted from a black body at temperature T per unit area per unit time, as a function of wavelength, is:-

$$P(\lambda) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\left(\exp\left(\frac{hc}{\lambda kT}\right) - 1\right)} \quad (1)$$

where:- λ is wavelength, h Planck's constant, k Boltzmann's constant, c the speed of light, and T is the temperature of the black body in Kelvin. The units of $P(\lambda)$ are Watts per square meter per unit wavelength.

The amplitude, as a function of wavelength, of measured spectra are proportional to the flux collected in each pixel bin, so when comparing to the Planck function (1) we first need to divide by the bin wavelength width to get the units correct.

Note: given a value of T , for relatively long wavelengths

$$P(\lambda) \approx \frac{2\pi hc^2}{\lambda^5} \frac{1}{\left(1 + \frac{hc}{\lambda kT}\right) - 1} = \frac{2\pi ckT}{\lambda^4} \quad (2)$$

A single main sequence star is a good approximation to a black body and its spectrum comprises a continuum given by equation (1) upon which dark absorption lines are superposed. The continuum emission peaks at a value determined by the stellar temperature, peak emission moves to shorter wavelengths as the temperature rises. At wavelengths much longer than the peak wavelength the continuum can be approximated by (2).

The aim of my program "planck.exe" is to divide out the continuum spectrum, leaving just the "flattened" absorption spectrum and in the process obtain a value for T - the effective temperature of the star. The input to the program is the star's fully calibrated spectrum, the calibration must correct for instrument response and atmospheric absorption and in the process converts the raw measured spectrum into spectral energy as a function of wavelength. Success at obtaining an effective temperature will obviously depend on how well the calibration is performed and how well the star approximates a black body.

The program also outputs a B-V value (difference in magnitude of the star as viewed through a "blue" and "visual" filter with well defined bandpasses). A B-V value does not depend on the star being a black body and so is a more universal (pun intended!) stellar property, it does still require a good calibration however. To calculate a B-V value the calibrated input spectrum (not the flattened output spectrum) is multiplied by B and V filter functions and integrated over the B and V filter bandpasses. Then B-V is computed from:-

$$B - V = 2.5 \log_{10} \left(\frac{v}{b} \right) + zp$$

where b and v are the result of the B and V filter integrations respectively, zp is a “Zero Point” calibration parameter.

To determine zp (appropriated to a given observing setup) it is necessary to determine the B-V value of a calibration star with a known B-V value. In this calibration process zp is set to zero and a B-V value computed for the calibration star. The difference between the calibration star’s true B-V and the calculated B-V becomes the value of zp suitable for use in analysing other spectra from the same observing session i.e.:-

$$zp = (B - V)_{true} - (B - V)_{measured}$$

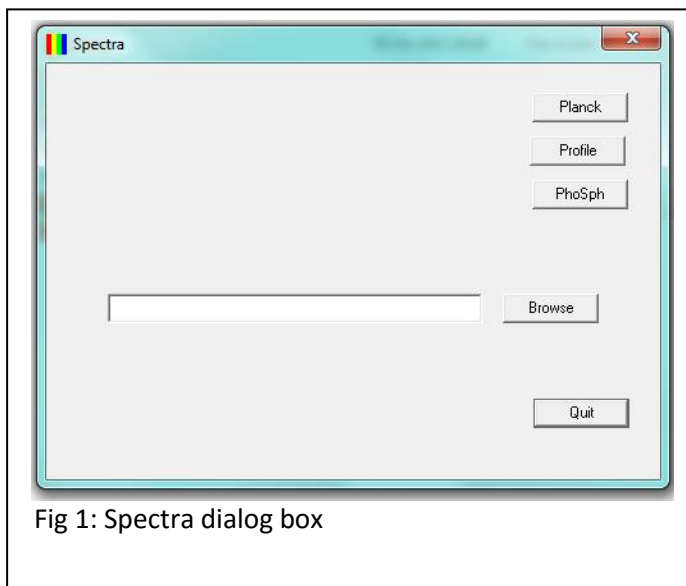


Fig 1: Spectra dialog box

Planck.exe is a simple Win32 command prompt program written in C, a (more user friendly) C++ dialog box launcher program spectra.exe is used to run planck.exe on chosen spectra. Spectra.exe, planck.exe and the accompanying program Profile.exe must be copied into the same folder in order to work properly. Place a shortcut to spectra.exe on the desktop then on double-clicking this shortcut a dialog box as shown in fig1 should be seen.

Clicking the Browse button allows a fully calibrated RSpec data file to be

chosen, planck.exe will be run on the chosen file when the “Planck” button is clicked.

When planck.exe runs, a console window pops up (fig 2) and the user is required to enter relevant information on request.

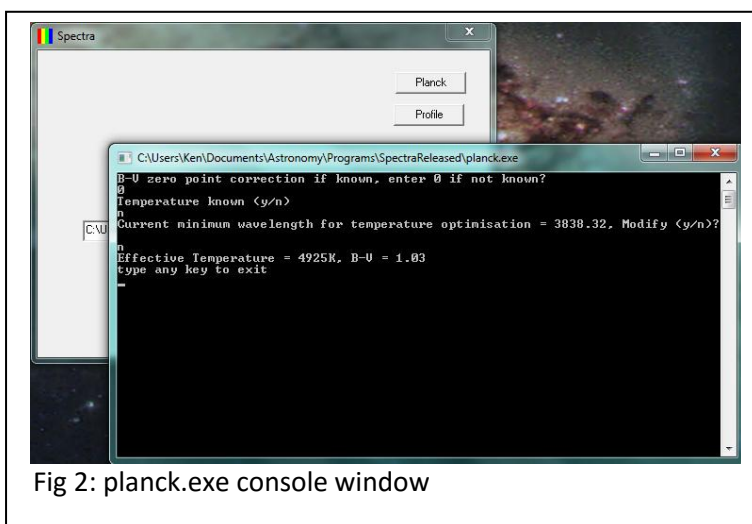


Fig 2: planck.exe console window

There is the option to reduce the wavelength range over which the effective temperature is computed, this sometimes gives a better result for cooler stars (G, K or M) where the shorter wavelength part of the spectrum can be very dependent on the quality of the spectrum calibration. Respond to the request for input by typing Y (to modify the displayed minimum value) or N (to keep the full range,

N is the default) and press *Return*. If Y is input then a new value for the minimum wavelength requested.

A value for the “Zero Point” B-V parameter will also be requested enter the value if known or enter 0.0 if a calibration is being performed as described earlier.

On completion an effective temperature (if found) and B-V value is displayed. Note O and B stars will not generally yield an effective temperature as the peak emission wavelength is well into the UV and so the continuum spectra of these hot stars are indistinguishable. A failure to determine an effective temperature message is displayed in these cases and the spectrum is flattened using (2). Other error messages may also be displayed if the program fails.

Finally to close the planck.exe console window type any character into window and press “return”. The Spectra dialog box can then be used to analyse another spectrum or the “quit” button pressed to exit the dialog box program.

Planck.exe does not alter the input files but writes three new output files to the same directory as the input files:-

“filename”T. dat,

“filename”T.ini

“filename”_err.dat.

Where “filename” is the name of the RSpec .dat file selected on clicking the “Browse” button.

Both the .dat files are viewable in RSpec. “filename”T.dat and “filename”T.ini allow RSpec to display the flattened spectrum (original spectrum divided by the planck spectrum using equation (1) or (2) as appropriate to the stellar temperature). The calculated effective temperature (if determined) and B-V values are displayed in the modified title, see figures 3 and 4. I used a star type A7v spectrum

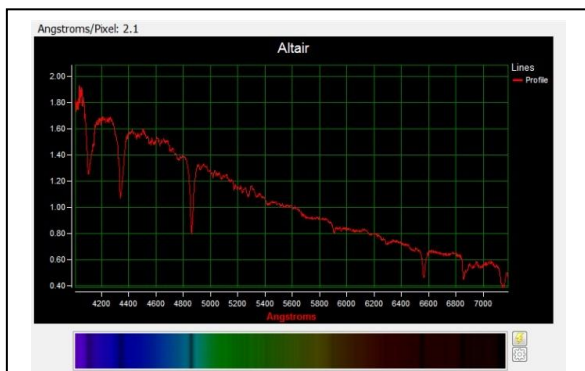


Fig 3: Calibrated Altair Input Spectrum

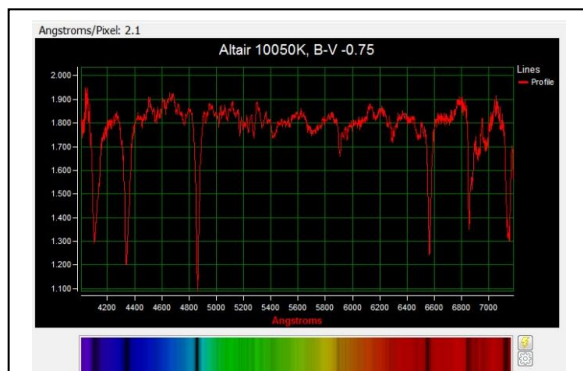


Fig 4: Flattened Altair Output Spectrum

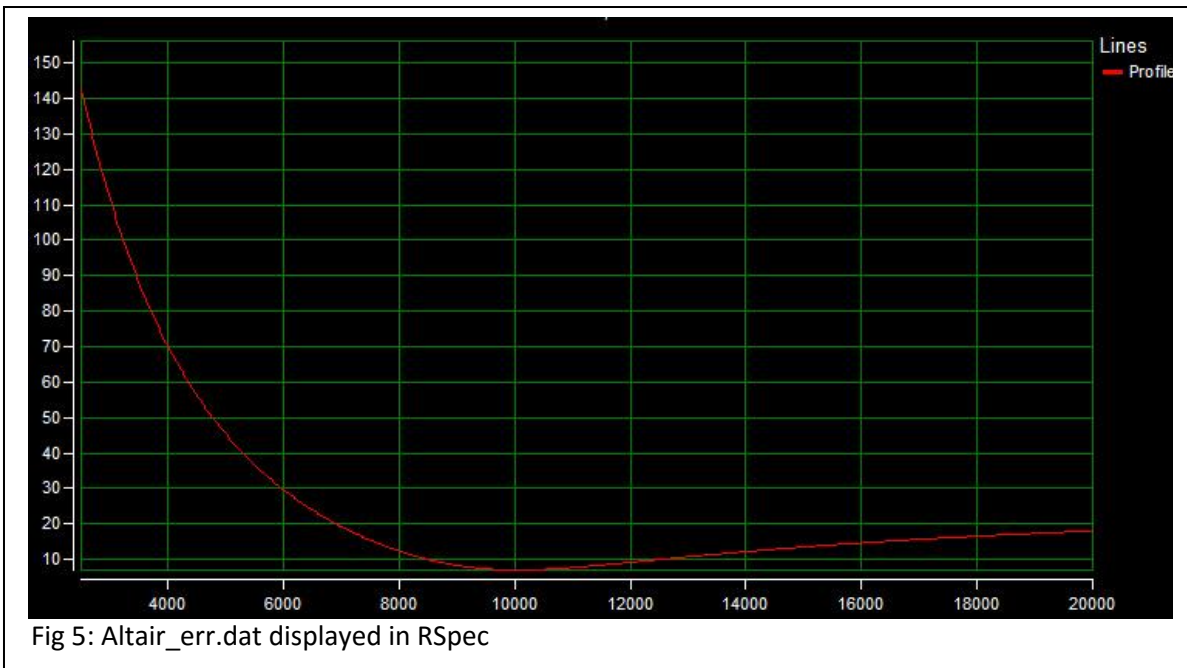
from the RSpec library to obtain the calibrated spectrum shown in fig 3.

Figure 5 illustrates the process for calculating the optimal effective temperature, the input spectrum is divided by planck curves of successively higher temperatures in steps of 25K over the range 2500K to 20000K. At each temperature point the resultant spectrum is analysed by computing an average

intensity and a root mean square deviation from this average. The RMS deviation is plotted as a function of temperature in figure 5.

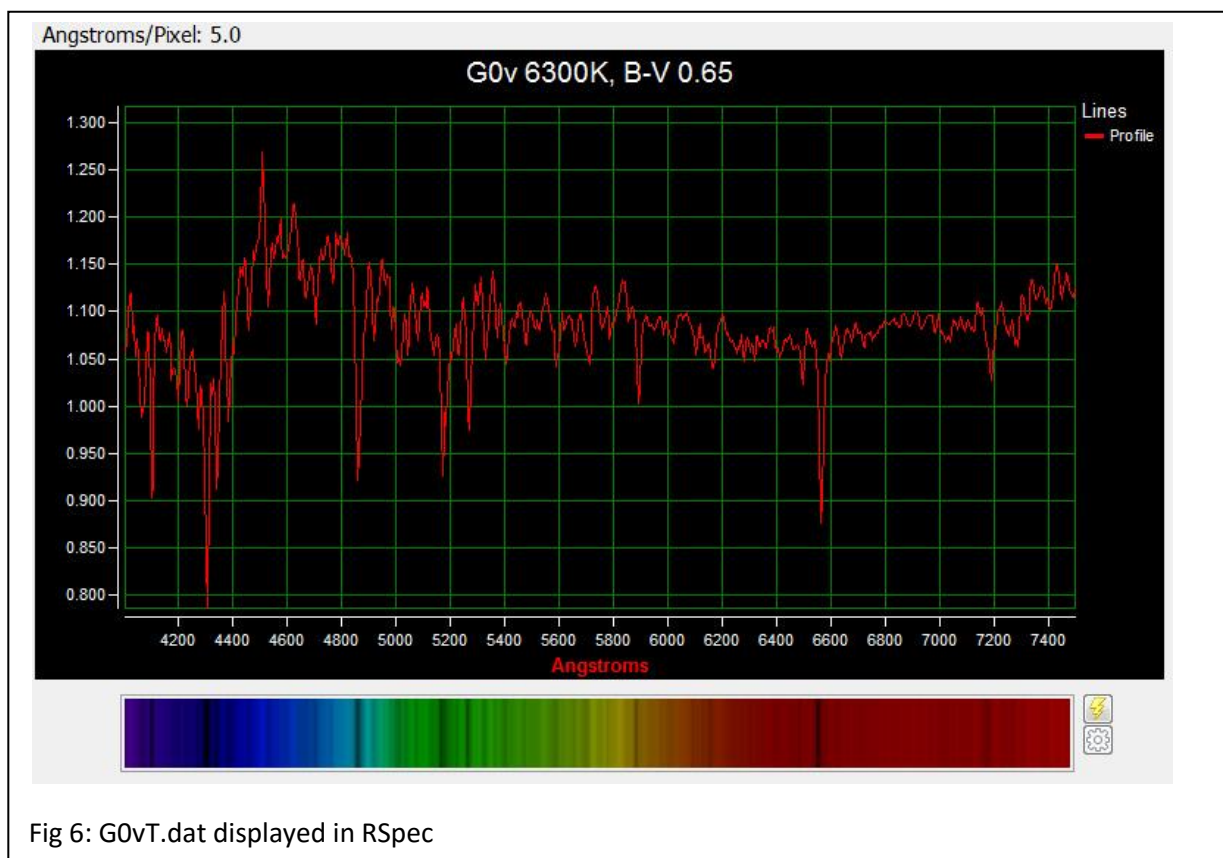
The effective temperature is determined by the temperature position of the minimum in the value of the RMS deviation.

Note that the minimum is very broad for Type A stars indicating an insensitivity of the flattening process to temperature, this problem is related to the lack of data at short UV wavelengths which also results in the inability of this method to determine an effective temperature for O and B stars.



Only by including data on intensity at shorter wavelengths could accuracy be improved if indeed the target star continued to be a good black body radiator at these wavelengths.

Figure 6 shows the flattened spectrum of a G0v star for which the wavelength range (in the



flattening process) was restricted to wavelengths above 4000 Angstroms. In this case the flattening process is much more sensitive to temperature (as depicted in figure 7) and therefore leads to a more accurate value for the effective temperature.



Fig 7: G0v_err.dat displayed in RSpec