**ChromaStar lab 5: The “Balmer thermometer” and MK spectral class**

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**Level:** Second year University

**Purpose:** To become familiar with the ChromaStar web application for modelling stellar atmospheres and spectra. To investigate the variation with *T*eff of the absolute *strength* of the Balmer series of spectral lines arising from the *i=2* atomic energy level of H I, and to relate it to the variation with *T*eff of the Morgan-Keenan (MK) spectral class of B through F stars, and to the variation in a star’s *colour*.

**Background:** TheMorgan-Keenan (MK) spectral classes (main classes OBAFGKM(LTY)) are known to correlate with a star’s effective temperature, *T*eff. For stars of class B, A, and F, the H I Balmer lines are one of the important spectral classification diagnostics, peaking in strength at spectral class A0 (by *definition* of class “A0”!). That is, the Balmer lines become weaker as spectral class differs from A0, either toward B stars (*ie.* toward classes “earlier” than A0) or toward F stars (*ie.* toward classes “later” than A0).

**Apparatus:**

The ChromaStar stellar atmospheric modelling WWW application: (www.ap.smu.ca/OpenStars/)

**Initial set-up:**

Make sure you are starting with a fresh ‘reload’ of ChromaStar so that all the input parameters have their default values (among other things, the stellar parameters will default to *solar* values - if you think that some values are not reverting to default, try clearing your browser’s history with all optional data types checked, and ‘reload’ again).

In the “Input:” section, in the “stellar parameter” panel at the top, take note of the *T*eff control. *Note* that you can change *T*eff over a large range quickly by moving the circular slider, *and* you can also set the value precisely by entering it in the central text box. You’ll need to use the control both ways.

Note the “MODEL” button and the banner with alphanumeric output just above the graphical displays. On the right, this banner echoes back the values of the input parameters for the model that ChromaStar *last finished* computing. After hitting the “MODEL” button, you will know that ChromaStar has finished computing a new model when you see your updated parameters reflected in this banner.

Open the optional input panel titled “Show/hide samples” – you’ll be working with the top row of radio buttons labeled with the identities of important standard stars of well-defined MK spectral class. *Caution:* Do *not* select any of these radio buttons yet!

In the “Output:” section note the image near the top labeled “Visual spectrum” – this simulates a *direct image* of a stellar spectrum in the visible band as recorded with a colour-sensitive detector, and it has approximately the spectral resolution (*R=λ/Δλ*) and inverse linear dispersion required for MK spectral classification. Note that certain spectral lines are visible – in particular those that correspond to spectral classes around G2 – the Sun’s class. Note the line identification labels bracketing the spectrum, and find the ones labeled as “H I” followed by a Greek letter – these are the Balmer lines that you will looking for and you should be able to find *labels* for the first four lines in the series (H I *α*, H I *β*, H I *γ*, H I *δ*, corresponding to transitions to the *j=3*, *4*, *5*, and *6* energy levels, respectively). *Note* – you may not be able to see all the corresponding lines themselves in the spectrum – they are too weak in the Sun!

*Important tips*:

1. The H I *γ* and *δ* lines are crowded with other lines that may or may not show up at any given *T*eff – it will help to realize that the nearby He I lines only show up in the hottest stars (*T*eff > 20000 K), and even then, only *very* weakly!, and the Fe I lines only show up in stars of spectral class F and “later” (*T*eff < 7500 K). The Ca I 4227 line needs to be distinguished very carefully from H I *δ*. Line IDs are always center-justified over or under the corresponding line.
2. ii) You will find it helpful to use your WWW browser’s “zoom” feature to *magnify* this image (Cntrl +/- in Windows).

Take note of the colour image of the star labeled “White light disk”, and of the Johnson *B-V* photometric colour index where it is reported in the alphanumeric output banner. The value of the colour index quantifies the colour that appears to the eye in the image.

**Procedure:**

1. Through trial modelling with different input *T*eff values, estimate the *largest* value of *T*eff for which *all* the Balmer series lines are still just visible as judged from the “Visual spectrum” display (*ie.* what is the lowest *T*eff value among *hot* stars for which *all* Balmer lines are barely visible). In your report, give both the value of *T*eff and an estimate of its *uncertainty*, *ΔT*eff. Also, note the colour of the star in the “White light disk” display, and report the value of the *B-V* color index for the model with your reported value of *T*eff.
2. Use the same procedure at step 2) to estimate the *smallest* value of *T*eff for which *all* the Balmer series lines (not just H*α*) are still just visible (*ie.* what is the *highest* *T*eff value among *cool* stars for which all Balmer lines are barely visible). In your report, give both the value of *T*eff and an estimate of its *uncertainty*, *ΔT*eff. Also, note the colour of the star in the “White light disk” display, and report the value of the *B-V* color index for the model with your reported value of *T*eff.
3. Through trial modelling with different input *T*eff values, estimate the value of *T*eff at which the Balmer lines reach *maximum strength* as judged from the “Visual spectrum” display. This will be tricky – the lines have a broad strength maximum as a function of *T*eff – it will be *important* here to report an *uncertainty*, *ΔT*eff, as well as a *T*eff value itself.

*Tip*: *Note* that you have already bracketed the *T*eff value you’re looking for her in steps 1) and 2). Also, note the colour of the star in the “White light disk” display, and report the value of the *B-V* color index for the model with your reported value of *T*eff. For this step, also report the uncertainty in colour, *ΔB-V*, corresponding to *ΔT*eff.

**Only proceed to the Analysis once you’ve completed this step.**

**Analysis & Discussion:**

1. In the “samples” input panel, check the radio button labeled “Vega”. Hit the “Model” button – ChromaStar is now modeling this star. You should *confirm* this: In the “stellar” panel the value of *T*eff should now be 9550 K, the value of log *g* should be 3.95, and the value of the metal content should now be -0.5. *Caution*: If you “reload” the ChromaStar page for any reason at this point in the procedure, the Vega “sample” star will become deselected, and you will have to select it again!
2. Vega is an MK *classification standard* - it *defines* the A0 spectral class in the MK system – and, by *definition*, A0 stars have the strongest Balmer lines. Therefore, stars of *T*eff *approximately* equal to 9550 K have the strongest Balmer lines, and we can take this as the *accepted value*. Does your derived value of *T*eff from step 3) agree, *to within your uncertainty*, *ΔT*eff, with the accepted value? (You may need to dust off your 1st year physics lab skills when it comes to the meaning of “agreement”!). *Note* that you *will* ***not*** *lose marks* if your result does not agree with the accepted one, but you *will lose marks* if your statement is not supported by the values of the accepted *T*eff, your derived *T*eff, and your *ΔT*eff!
3. Recall that Vega is the fundamental *photometric* calibration standard in the Johnson system as well. Therefore, by definition, the calibrated *B-V* value of Vega is 0.0. Does your derived value of *B-V* value from step 3) agree, *to within your uncertainty*, with the accepted value? All the tips and admonitions in step 2) also apply here!