COLOURS IN ASTRONOMY

Project Report

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APPARENT MAGNITUDE

Before talking about the colours, first we define the apparent magnitudes of stars.

Apparent magnitude (m) is a measure of the brightness of a star or other astronomical object observed from the Earth. An object's apparent magnitude depends on its intrinsic luminosity, its distance from Earth, and any extinction of the object's light caused by interstellar dust along the line of sight to the observer. The formula for calculating the apparent magnitude is:

$$m = -2.5\log\left(\frac{F_x}{F_{vega}}\right)$$

Hence we can clearly see that the magnitude scale is reverse logarithmic: the brighter an object is, the lower its magnitude. An object that is measured to be 5 magnitudes higher than another object is 100 times dimmer. Consequently, a difference of 1.0 in magnitude corresponds to a brightness ratio of 5√100, or about 2.512.

If we wish to calculate the apparent magnitude of a star we are observing, we first have to account for the differences in our telescope. We have to take a set of calibration images that measure the standard star in our instrumental system. This usually requires calibration of the differing atmospheric transmission between the observations of the standard and science images, which changes with zenith angle and sky conditions. But we can estimate by calculating the transmission constant by comparing a nearby standard star to an established catalogue.

$$c = m_{std} - m_{ins}$$

And then use this constant to calculate the apparent magnitude of a star we are observing.

$$m_{std} = c + m_{ins}$$

COLOUR OF A STAR

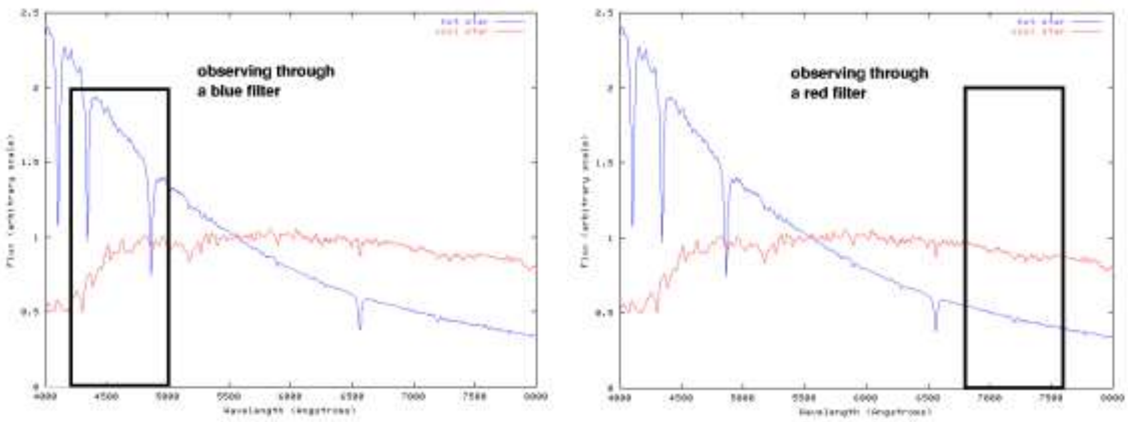
While we observe a star, there is only so much a scientist can do while the limited time he/she is sitting in front of the telescope. So ancient astronomers began to record the observations of 'photographic plates'. Similar to modern techniques, they had photographic plates for particular colours- BVR standing for blue, visible and red. These are measured the peak wavelength of 4400Å and 5500Å and 7000Å and have an error of 1000Å,900Å and 2200Å respectively, meaning that they can measure. In simple terms, we can measure the blue-magnitude of a star using a blue filter.

Astronomical colour is not simple 'blue', or 'red'. We define astronomical colour as *the difference between the magnitude of a star in one passband and the magnitude of the same star in a different passband.*

The most common is the UBV photometric system, also called the Johnson system (or Johnson-Morgan system), which is wide band, and usually employed for classifying stars according to their colours. The letters U, B, and V stand for ultraviolet, blue, and visual magnitudes, which are measured for a star; two subtractions are then performed in a specific order to classify it in the system. We can also include R and I (UBVRI) for red and infrared wavelengths.

We use this technique to save effort and time. It takes a lot of time and effort to acquire the spectrum of a star-which can give us better information about the star. In order to measure the spectrum of a star, one must disperse its light via a prism or grating. Spreading the light out over a detector shows how much appears at each wavelength … but it also provides much less light at each spot on the detector. That means that exposure times for spectra are much, much longer than exposure times of equivalent signal-to-noise for images.

So, we take the UBVRI values. But why do we subtract them? Because otherwise we run into a problem. Some stars are brighter in particular filters! If we plot the temperatures and saw that:



For the hot star, the star appears brighter in B filter and cold star appears brighter in V filter. Thus, we have defined arbitrary values for the U, B, V, R, I values of the star Vega, which also serves as the basis for measurement of apparent magnitude.

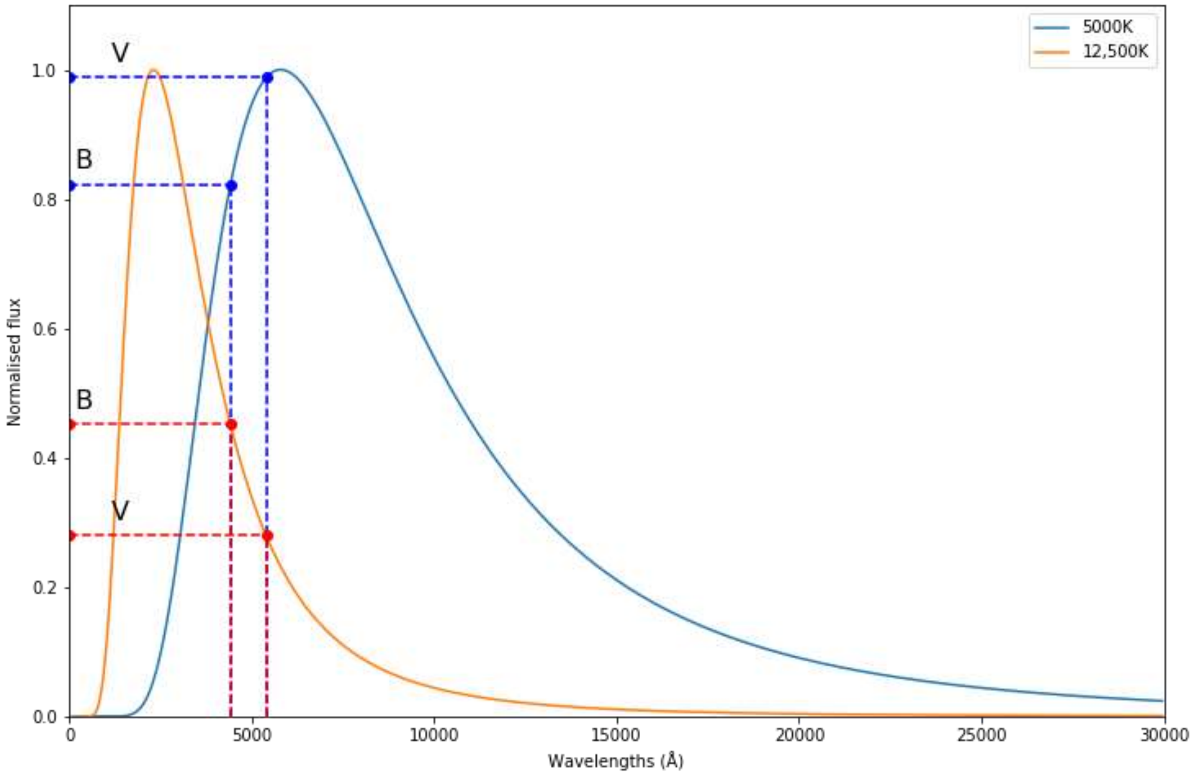
We can then compare the star as being 'bluer' or 'redder' than the standard star Vega and can estimate the temperature as well.

COLOUR AND TEMPERATURE

The colour of a star is primarily a function of its effective temperature. A star is approximately a perfect black body. As a blackbody gets hotter, its colour changes.

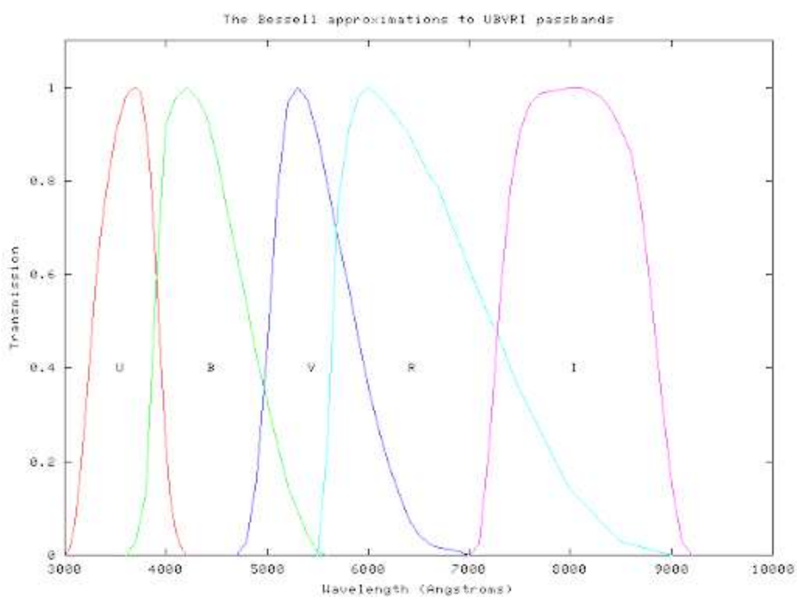
The colour that we see is usually an additive combination of the emissions from each wavelength. Hot stars appear blue because most energy is emitted in the bluer parts of the spectrum. There is little emission in the blue parts of the spectrum for cool stars - they appear red. We can see the same in the following plot as well which uses the formula:

$$F_\lambda = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{\left(e^{\frac{hc}{\lambda kT}} - 1\right)}$$



	U	B	V	R	I
λ	3650	4400	5500	7000	9000
Δλ	700	1000	900	2200	2400

We can estimate the passbands using the following normalised graph:



The UBVRI passbands are called broadband because they span wide swaths of wavelengths. The spectral resolution of the passbands is small:

$$\text{spectral resolution} = \frac{central\ wavelength}{width\ of\ passband} \cong 5$$

For some applications, astronomers use filters which transmit a much smaller range of wavelengths; a common filter used to measure light emitted by hydrogen atoms is centred at 6563 Angstroms and roughly 20 Angstroms wide:

$$\text{spectral resolution} = \frac{6563\text{Å}}{20\text{Å}}$$

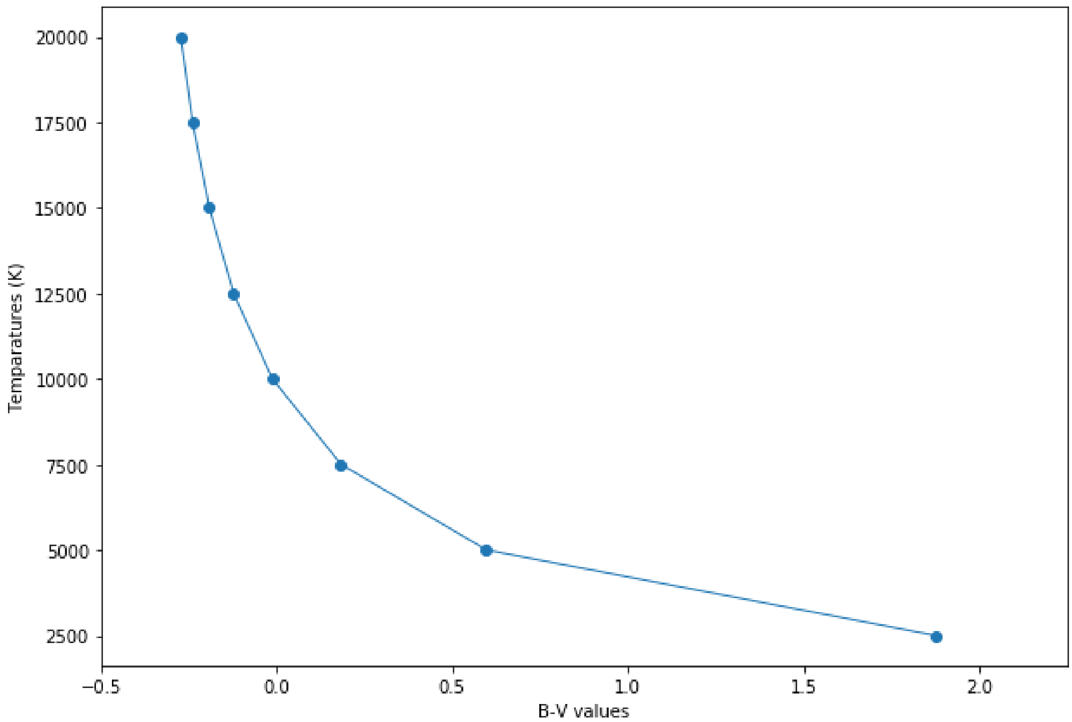
A narrowband filter like this requires much longer exposure times to build up the same signal as a broadband filter. Since telescope time is so precious, astronomers tend to use broadband systems. That's one reason for the popularity of the UBVRI system.

Estimate temperature using B-V values

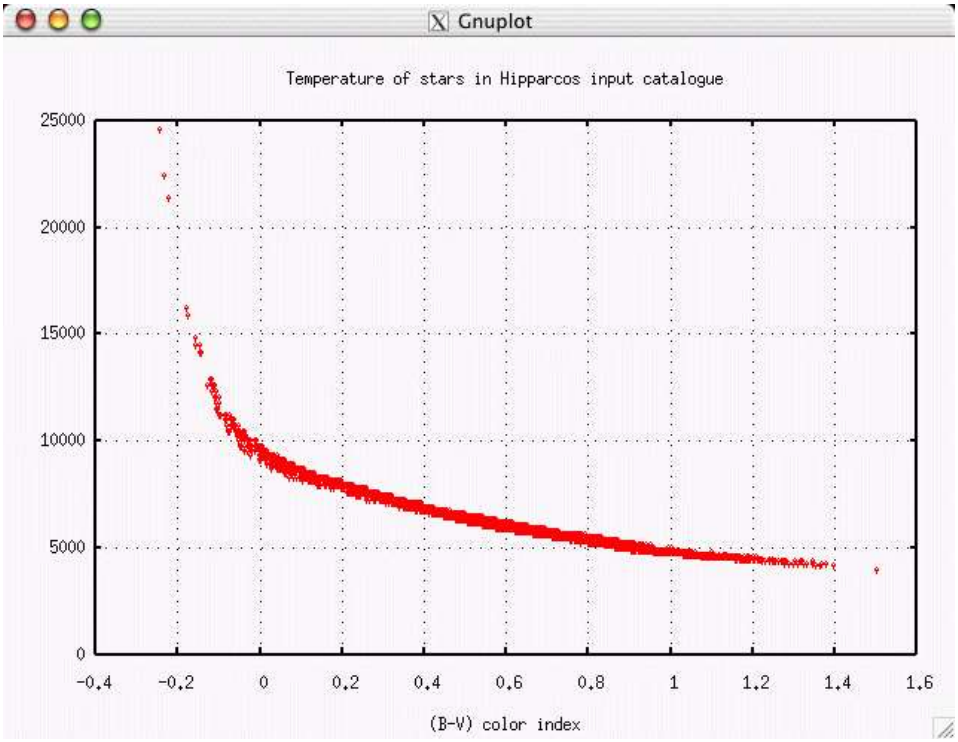
If we plot the B-V values for various temperatures, we will get a graph similar to shown. We will use the formula:

$$B - V = -2.5\log\left(\frac{F_B}{F_V}\frac{F_V^{vega}}{F_B^{vega}}\right)$$

To get the plot:



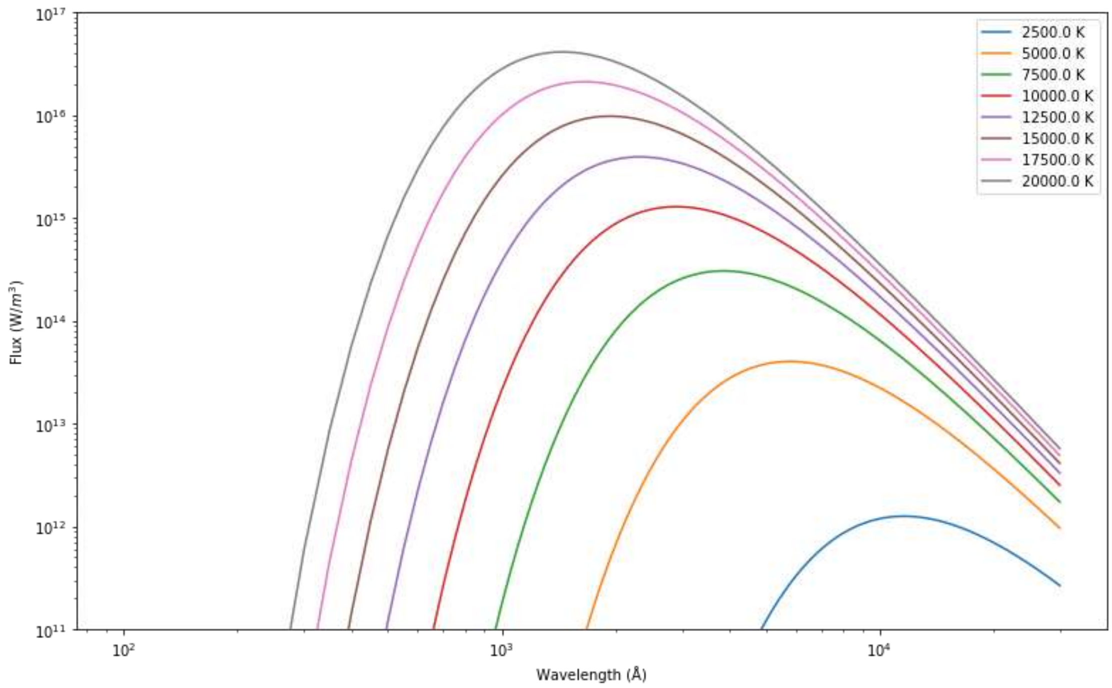
We can compare to the real data from Hipparcos input catalogue.



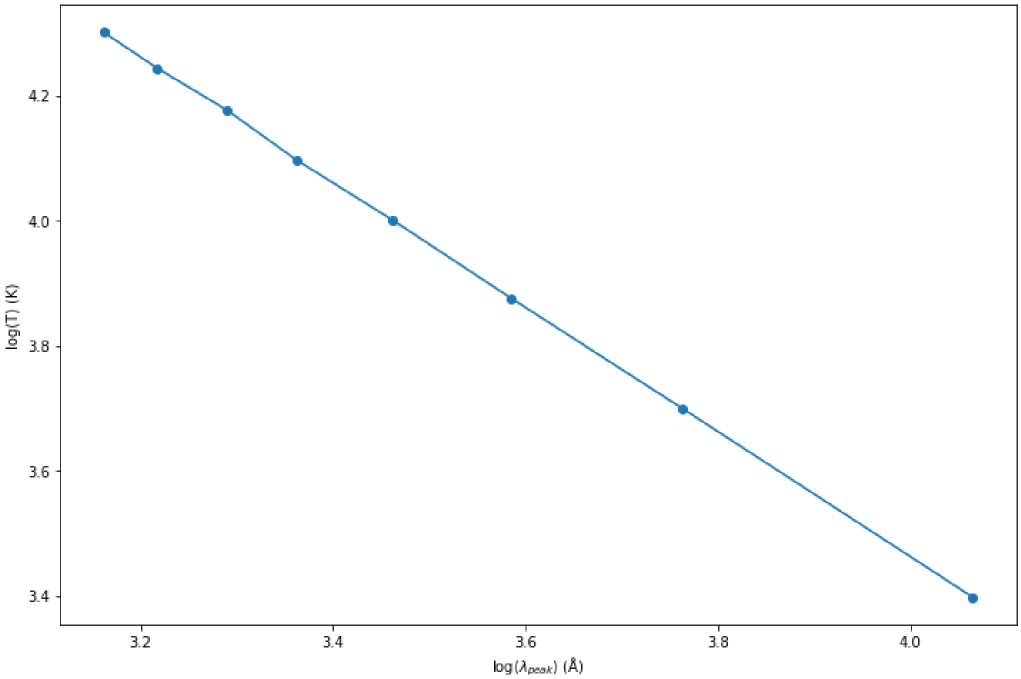
This is a very close match and hence we have also used the graph to roughly calculate the temperatures of Spica and Antares using their B-V values.

Temperature using Wien's Law

The curves show that hotter stars give off more thermal radiation. The curves also show that the peak wavelength of the thermal radiation moves to shorter wavelengths as the temperature increases.



By plotting the peak wavelengths and temperatures we observe that it follows a straight line and we can calculate the Wien's constant which is the constant product of temperature and peak wavelength.



RESULTS

We calculated the temperatures of Spica and Antares using their B-V values:

Spica:

- B-V value $= 1.83$
- Calculated temperature $= 12700.0\ K$
- Actual temperature $= 18000K$

Antares:

- B-V value $= -0.13$
- Calculated temperature $= 2500.0\ K$
- Actual temperature $= 3400K$

We calculated the Wien's constant and used it to calculate temperature of sun and pole star from their p eak wavelengths.

Wien's constant:

- Calculated value $= 2.895\ x\ 10^{-3}\ mK$
- Standard Value $= 2.867\ x\ 10^{-3}\ mK$
- Error % $= 0.97\%$

Sun:

- $\lambda_{peak} = 5300$Å
- Calculated temperature $= 5461.54$ K
- Actual temperature $= 5778K$

Pole Star:

- $\lambda_{peak} = 3500Å$
- Calculated temperature $= 8270.33$ K
- Actual temperature $= 6015K$

In the end we showed the image of the same galaxy: Messier32 in three filters and saw that it was brighter in R filter.

References/citations:

http://spiff.rit.edu/classes/phys440/lectures/color/color.html
http://spiff.rit.edu/classes/phys373/lectures/colors/colors.html#blink
https://en.wikipedia.org/wiki/Photometric_system