Colour in Astronomy

-----------Project Report:

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B.Tech.: Mechanical

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1.Introduction:

Colour in Astronomy, is a simple numerical expression that determines the color of an object, which in the case of a star gives its temperature. The smaller the color index, the more blue (or hotter) the object is. Conversely, the larger the color index, the more red (or cooler) the object is. This is a consequence of the logarithmic magnitude scale, in which brighter objects have smaller (more negative) magnitudes than dimmer ones. For comparison, the yellowish Sun has a B–V index of 0.656 ± 0.005, whereas the bluish Rigel has a B–V of −0.03 (its B magnitude is 0.09 and its V magnitude is 0.12, B–V = −0.03). Traditionally, the color index uses Vega as a zero point.

2. Objective:

Explain what colour means in an astronomical context and its relationship with the temperature of a star. Learn how to create colour-colour diagrams and how to use these diagrams to distinguish between different types of objects and introduce Wein's Displacement Law.

3. Contents:

1. Apparent magnitudes
2. Colour of a star
3. Colour and Temperature

3.1 Apparent magnitudes

The first step is to obtain instrumental and absolute BVR magnitudes. This is accomplished by observing at least one standard star with known magnitudes on the standard system along with our night's data and using it to determine the transformation equations. Often the standard star is not in science images, so 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.

However, there is an easier way if one has a standard star in the science images. In this case we can skip the atmospheric corrections, and go right to the transformation equations.

We can calculate the transformation constant C, simply as:

secondary standard: C = mst_d – min_s

and then apply it to the target: mst_d = C + min_s

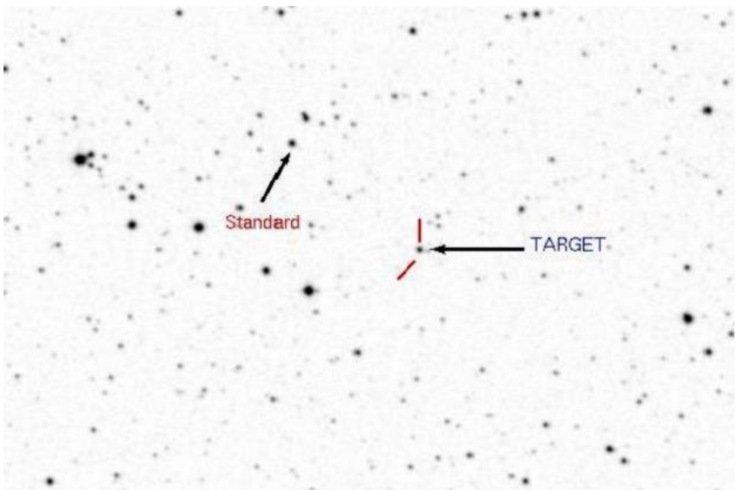


Fig. 1. Field of view showing the target and secondary standard.

Hence, we obtain the apparent BVR magnitudes for your programme stars.

3.2 Colour of star

The photo shows the open cluster M50. The variety of colours of the stars is obvious. Open clusters typically contain hundreds of stars, many of which are bright, young, and blue. In fact, most of the bright blue stars in the above picture belong to M50, but most of the dimmer, red stars do not. M50 lies about 3000 light-years from Earth and is about 20 light years across.

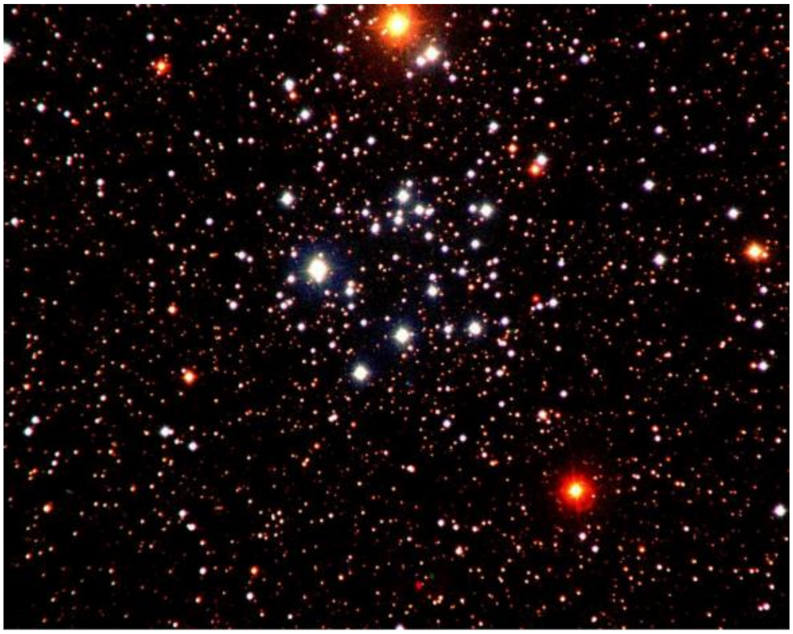


Fig. 2. Open cluster M50. Credit and Copyright: S. Kohle, T. Credner et al.

Magnitude is a number that measures the brightness of a star or galaxy. In magnitude, higher numbers correspond to fainter objects, lower numbers to brighter objects; the very brightest objects have negative magnitudes.

We measure the amount of light or flux in a restricted wavelength band. This can be done by letting the incoming beam of light go through a filter. The filters work by blocking out light at all wavelengths except those around the wavelength they are designed to see. Rather than just have one apparent magnitude, m measured across the entire visible spectrum we can use a filter to restrict the incoming light to a narrow waveband. If, for instance, we use a filter that only allows light in the blue part of the spectrum, we can measure a star's blue apparent magnitude, B.

Colour is defined as the difference between the magnitude of a star in one filter and the magnitude of the same star in a different filter.

The physical property that magnitude actually measures is:
radiant flux - the amount of light that arrives in a given area on Earth in a given time.
Magnitude is a logarithmic quantity.
A magnitude m=4 star emits 2.51 times as much light as a magnitude m=5 star. This allows you to define colour in terms of the amount of light given off by a star. Colour is a difference in magnitudes.

B-V is the difference between a star's blue magnitude and the same star's green magnitude.
Since magnitude is defined as
$m = -2.5 \log (Fx/ Fvega)$,
where Fx is the observed flux in the band x,
Fvega is the flux of the star Vega.
The star Vega, in the constellation of Lyra is used as a reference in the magnitude system. Vega has the arbitrary definition of zero magnitude at all wavelengths

U=B=V=R=I=0

This does not mean that Vega show the same brightness through all filters. It is an arbitrary decision taken by the astronomers who have agreed on taking Vega as the zero point for the magnitude scale.

3.3 Colour and Temperature

The colour of a star is primarily a function of its effective temperature. A star approximates the behavior of a black body radiator. As a blackbody gets hotter, its colour changes.

If we were to heat a solid bar, it would first emit radiation in the infrared region. Further heating would see it glow a dull reddish colour. With more heating it could eventually glow orange, yellow, white and eventually blue-hot. Ultimately if it were hot enough a black body emits most of its energy in the ultraviolet region. 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.

3.3.1 Blackbody Energy Distribution Curve

The radiated power of a blackbody using the Power Density Planck law:

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

$h = 6.626 \times 10^{-34}$ joule s

$k = 1.381 \times 10^{-23}$ joule K^{-1}

$c = 2.998 \times 10^{8}$ m s^{-1}

ʎ should be in meters.

F(ʎ) is in units of watts/m3.

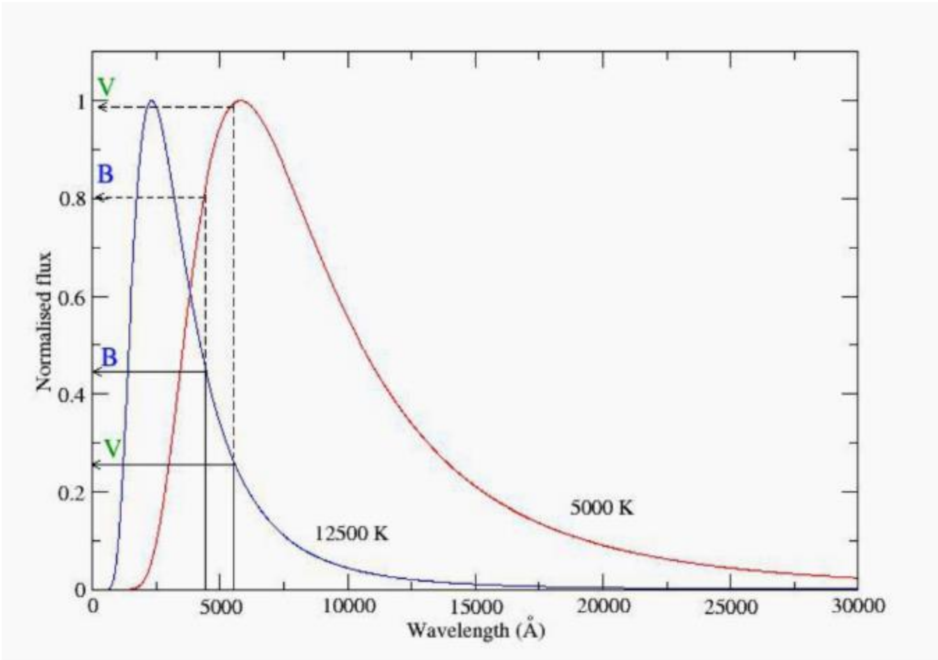


Fig. 3. Comparison of the B-V colour for a 'hot' and a 'cold' star.

The blue curve represents the 12,500 K star. It emits more energy in the B waveband than in the V waveband.
This means that it is brighter in B than in V, therefore its apparent magnitude B will be lower than apparent magnitude V.
The colour Index is B – V,
so for this star it will be < 0, that is, negative.

The red curve represents the 5000 K star, for this B-V is positive.

In terms of flux:

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

Graph we plotted using formula:

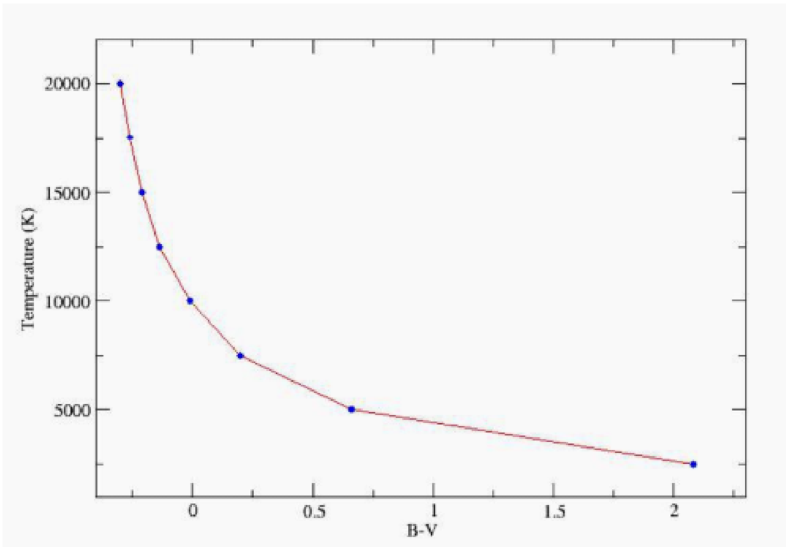
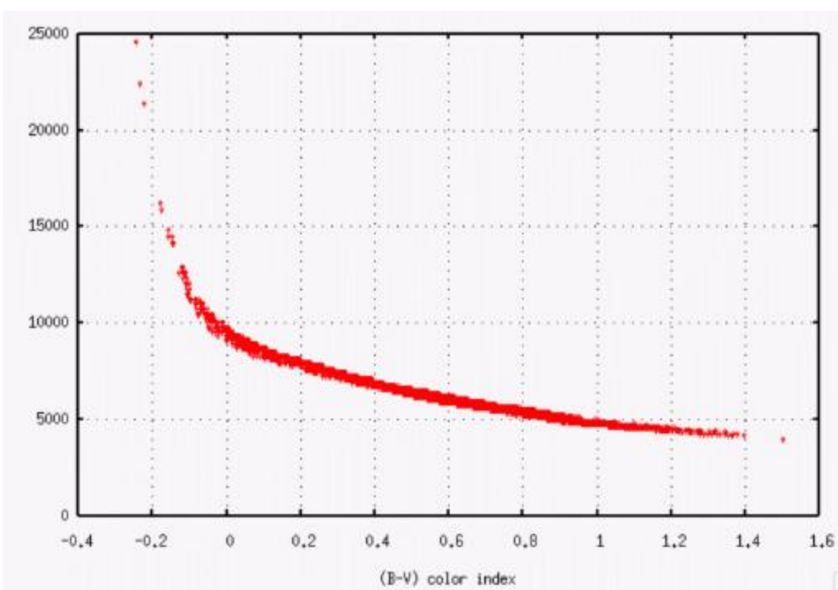


Fig. 4. Relationship between colour and temperature obtained from the blackbody theoretical curves.

Actual graph using real data:



Spica has (B-V) =-0.13 and Antares (B-V) =1.83. We can deduce approximately the temperatures: 3000 K for Antares and 12300 K for Spica. The real temperatures of Antares and Spica are 3400 K and 18000 K, respectively.

The main reason for the discrepancy in the temperature is that only the peak wavelength has been used to derive the B and V magnitudes, without taking into account the transmission curves of each filter.

Another reason why we obtain lower temperatures is that the Interstellar space is not a perfect vacuum. The interstellar medium (ISM) comprises cold neutral gas (H I at ≈ 70 K), warm neutral gas (H I at 6,000 K) and hot ionized plasma (H II at 106K) primarily located in the plane of the galaxy in the spiral arms. Cosmic dust is made up of small grains of silicates, iron, carbon, frozen water and ammonia ice 0.1 to 0.01 microns (μm) in size. Although this cosmic dust only makes up 1% of the mass of the ISM, it absorbs and scatters light from stars. This means that light from a distant star is reduced in intensity so that the star appears dimmer than it would be if there was no intervening material.

3.3.2 Using the blackbody curves obtained, annotate the wavelength at which the flux is maximum.

Thermal radiation is emitted by stars. 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.

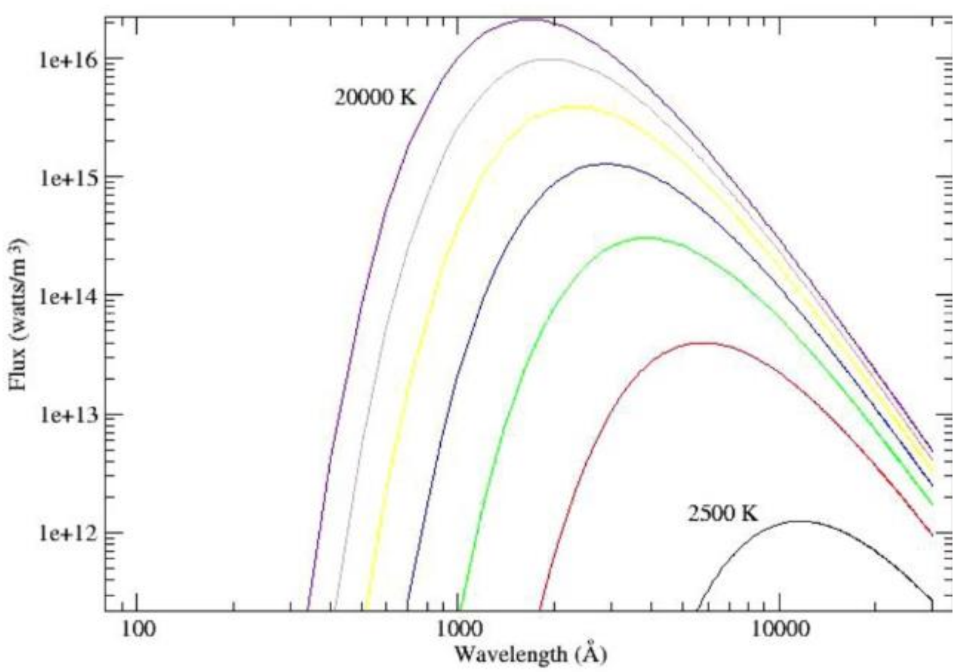


Fig. 7. Blackbody curves for thermal bodies at different temperatures.

4. Temperature and Peak Wavelength (Wien's law):

Wien's Law tells us that objects of different temperature emit spectra that peak at different wavelengths.

• Hotter objects emit most of their radiation at shorter wavelengths; hence they will appear to be bluer.

• Cooler objects emit most of their radiation at longer wavelengths; hence they will appear to be redder.

Furthermore, at any wavelength, a hotter object radiates more (is more luminous) than a cooler one. This could be understood this by the size of the area that encloses each curve.

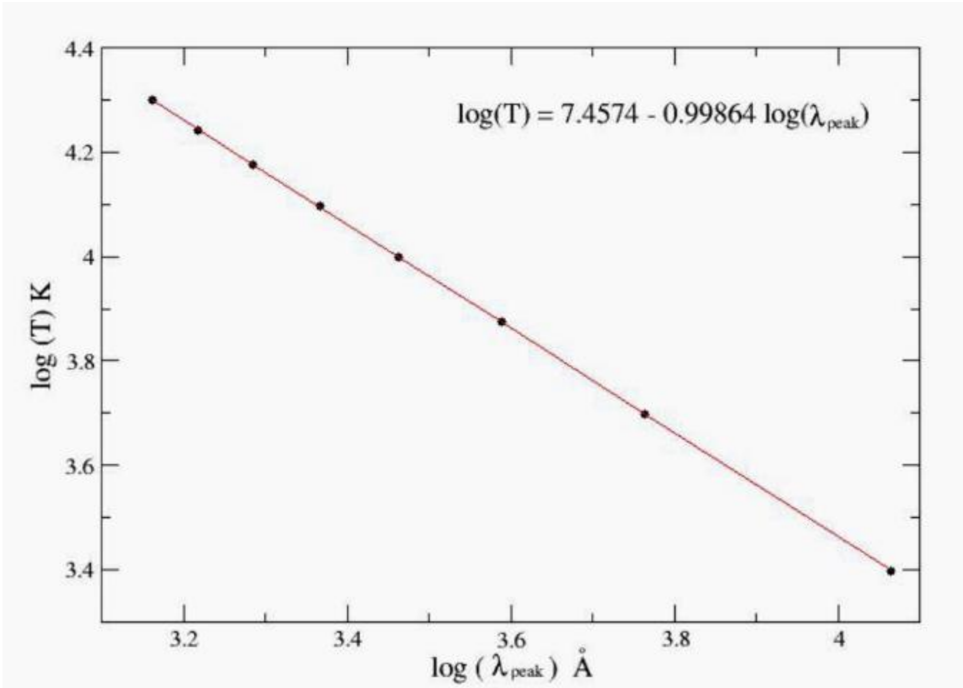


Fig. 8. Temperature as a function of the peak wavelength.

The best-fit is

Log (T K) =7.4574-0.9986 log (ʎpeak Å)

Thus, ʎpeak T = 107.4574 = 28668171.9 Å K

The Wien's constant in units of the International System that we find from our data is

2.867 x 10-3 m K

which can be compared with the carefully measured relationship between temperature and peak wavelength of thermal radiation

ʎpeak T = 2.897 x 10 -3 m K,

where ʎpeak is measured in meters and T is measured in Kelvin.

5. Calculations:

5.1 Spica and Antares:

Spica is the brightest star in the constellation of Virgo and one of the brightest stars in the night-time sky. Spica has a colour of B-V=-0.13. Antares, the brightest star in Scorpius, has B-V=1.83.

In terms of radiant flux, a colour index can be expressed as
B-V = -2.5 log (Fblue) + 2,5 log (Fgreen), which is equal to
2.5log (Fblue/Fgreen).

So, if a star has a B-V colour of -0.13, then
log (Fblue/Fgreen) = +0.13/2.5,
which, by the definition of log, means that
(Fblue/Fgreen) = 10(0.13/2.5) = 1.13

In other words, a star with B-V = -0.13 emits 1.13 times as much blue-wavelength light as green-wavelength light.
For Antares, (Fblue/Fgreen) = 0.18 or (Fgreen/Fblue) = 5.4
Antares emits 5.4 times more green light than blue light.

By definition for Vega, (Fblue/Fgreen) = 1
For Spica , (Fblue/Fgreen) > 1
For Antares , (Fblue/Fgreen) < 1

Therefore, since Spica emits more blue light than Vega it will appear bluer than Vega. Antares, on the other hand, will appear redder than Vega.

5.2 Sun's average temperature:

The Sun's peak wavelength is 5300 Angstroms. Convert this length to meters.

1 meter = 1010 Angstroms
5300 Angstroms (1 m/ 1010 Angstroms) = 5.3 x (10^ (-7)) m.

Insert this length into the peak wavelength equation:

λpeak T = 2.897 x (10^ (-3)) m K.
To get: (5.3 x (10^ (-7)) m) T = 2.897 x (10^ (-3)) m K.

Now, solve for T:
T = (2.897 x (10^ (-3)) m K) / (5.3 x (10^ (-7)) m) = 5460 K

6.Results.

1. Creation of color diagrams using python.
2. Use these diagrams to distinguish between different types of objects such as temperature of stars from their B-V.
3. Blackbody Energy Distribution Curve
4. Wein's Displacement Law and its application, and hence calculation of average temperature of sun and polar star.