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Stellar temperature inferred from blackbody radiation

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Abstract. We measured the temperature of a sample of stars by fitting their spectra with the Planck's curve. Then, knowing the color indexes, we were able to verify that this sample obeys the color-temperature relation.

1. Introduction

Through our research we achieved the following goal: analyzing the color-temperature diagram of a sample of 60 stars we verified that there is a linear relation; then we applied the derived relation to a larger sample of 10^5 stars to obtain their temperature. The color index of a star is the difference between two magnitudes obtained with two different photometric filters. We used the *ugriz* photometric system. The equation of the color-temperature relation we needed to verify is:

$$y = ax + b \tag{1}$$

where y is the color index and x is the reciprocal of the temperature, $\frac{1}{T}$. A black body is a theoretical object which absorbs 100% of the incident radiation. Therefore, it does not reflect any radiation and it appears completely black. A black body emits a continuum spectrum, with some energy at all wavelengths, which depends only on the body's temperature, not on its shape or material. The radiation it emits is called blackbody radiation.

2. Observational Data

We used a sample of 5000 stars, whose spectra were downloaded from the public archive of the Sloan Digital Sky Survey (SDSS). SDSS is a survey that provides images and spectra covering more than a quarter of the sky and a tridimensional map containing about one million galaxies and 120 thousands quasars. SDSS used a 2.5 m telescope, at the Apache Point Observatory in New Mexico. For the photometric survey, five filters were used; each filter can select only a specific range of the electromagnetic spectrum. The five filters, u, g, r, i, z, and their average wavelengths are:

u	g	r	i	z
3551 Å	4686 Å	6165 Å	7481 Å	8931 Å

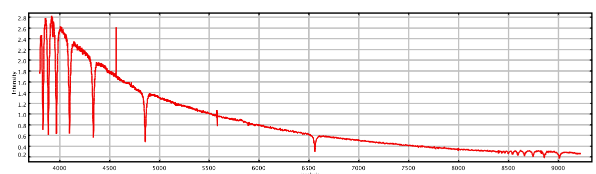

Fig. 1. Spectrum of the star SDSS J152518.55+381749.

Object	SDSS J152518.55+381749
Right Ascension	15:25:18
Declination	+38:17:49

3. Work description

We put the data of the 5000 stars previously selected, with a maximum value of the PSF g-band magnitude of 19 mag, in a table. The table contained the values of the magnitudes of the g, r, and u filters. We used them to create the values of the $g - r$ and $u - g$ color indexes, calculating the differences between the magnitude of the g and r filters and the magnitude of the u and g filters, respectively. Then, we built a color−color diagram, putting the $g - r$ color index on the abscissa axis and the $u - g$ color index on the ordinate axis. We selected 60 stars out of the 5000, taken from different parts of the diagram, which correspond to different temperatures. We used the software IRAF (Image Reduction and Analysis Facility) to extract and process the spectra of the 60 stars. Then, we normalized the spectra, that is, the intensity of each spectrum was normalized to 1 at wavelength $\lambda_0 = 5500$ Å, in order to be able to compare them with the normalized Planck function (Fig. 2).

$$B(\lambda, T) = \frac{\lambda_0^5 \left[\exp\left(\frac{1.439\times10^8}{\lambda_0 T}\right) - 1\right]}{\lambda^5 \left[\exp\left(\frac{1.439\times10^8}{\lambda T}\right) - 1\right]} \text{ erg cm}^{-3}\text{ sec}^{-1} \qquad (2)$$

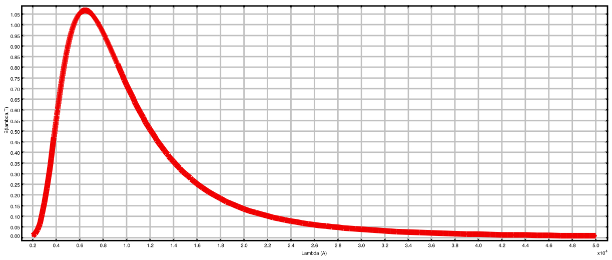

Fig. 2. Blackbody spectrum (Planck function).

We included the values of the wavelength and the intensity of the normalized spectra in a TOPCAT table and then, we calculated the corresponding maximum blackbody intensity for each star. After that, we built two superposed graphs: the former was the spectrum of the star and the latter was the blackbody spectrum, with the wavelength of the star on the abscissa axis and the blackbody intensity on the ordinate axis. We compared the two graphs, modifying the temperature of the blackbody until its curve reached the best fit, trying to find the best approximation (Figg. 3, 4, 5). We built a table with the data of the 60 stars obtained from the archive, in which we added the temperatures found by our fit. Then, we matched this table with the previously constructed one in which we recorded the data of the 5000 stars. We calculated the following values, adding two new columns to the resulting table:

1. $g - r$
2. $\frac{1}{T}$

We prepared the final plot by using TOPCAT, inserting these data respectively in the x- and y-axis. We obtained a distribution of points, each of them identifying a star, on the graph. We modeled the data with a linear regression, i.e., by fitting a linear function (Fig. 6). We found the line that best fits the distribution of data. We obtained a correlation coefficient r = 0.93, which is very close to 1, therefore we can consider the fit good. The equation of the regression line is:

$$g - r = \frac{m}{T} + c \qquad (3)$$

m=7988 c=-0.84.

Then, we calculated the temperature of a sample of 10^5 stars, using the previously-derived values. We used the relation:

$$T = \frac{m}{(g - r) - c} \qquad (4)$$

O	B	A	F
$3 \cdot 10^4$-$6 \cdot 10^4$ K	10^4-$3 \cdot 10^4$ K	7500-10^4	6000-7500
G	K	M	
5000-6000 K	3500-5000 K	<3500	

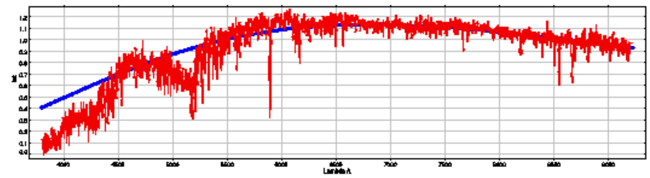

Fig. 3. Comparison between the star spectrum (red line) and the blackbody curve at 4250 K (blue line).

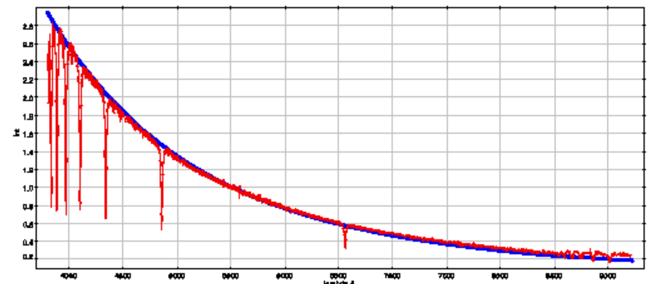

Fig. 4. Comparison between the star spectrum (red line) and the blackbody curve at 18500 K (blue line).

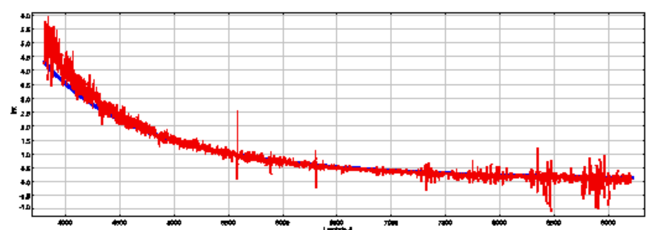

Fig. 5. Comparison between the star spectrum (red line) and the blackbody curve at 250000 K (blue line).

4. Results

We verified that the sample of stars obeys the color-temperature relation and derived the regression line. We built a histogram (Fig. 7), to show the distribution of the temperatures of the stars. It is evident that most of the stars in the sample, about the 76%, have temperatures between 3000 K and 10000 K. We can generalize that within the Galaxy it is possible to find the same distribution of temperatures. The greatest part of the stars belongs to the A, F, G, and K spectral classes.

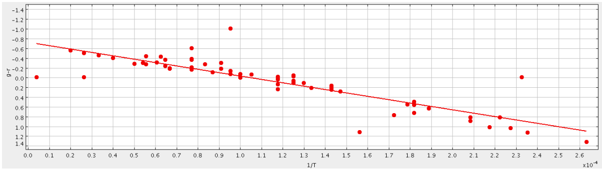

Fig. 6. $g - r$ color index as a function of T^{-1}. The continuous line shows our best fit with a linear regression.

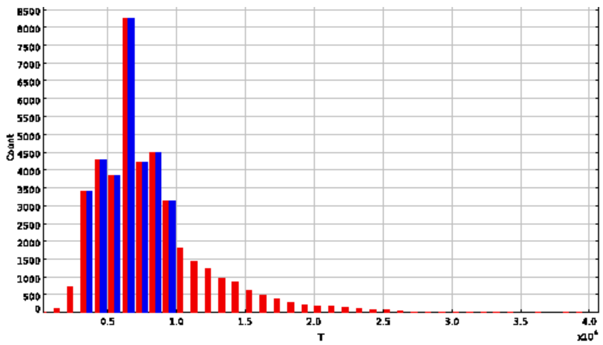

Fig. 7. Histogram showing the distribution of the temperatures of the stars. In blue the stars with temperatures between 3000 K and 10000 K.

References

Sloan Digital Sky Survey:http://www.sdss.org/
http://phet.colorado.edu/en/simulation/blackbody-spectrum