Photoelectric Photometry of the Pleiades

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Abstract

*The distance to the Pleiades' star cluster has been determine muassuring the apparent magnitude (for blue and visual filters) by means of a photometer using the program CLEA, and obtaining a value of $D = 125 \pm 14$ pc $= 406 \pm 47$ ly. To this aim, the Hertzsprung-Russell (**H-R**) diagram for the Pleiades star cluster has been compared with the (**H-R**) diagram of known main sequence stars, observing also the main sequence of the Pleiades cluster.*

1. Introduction

Stars are continuously emitting energy which could be express in terms of its luminosity ($L = \frac{\mathrm{d}E}{\mathrm{d}t}$) or its flux ($F = \frac{L}{area}$). The apparent magnitud m of a certain star, at unknown distance, is express in therms of the ratio of its flux F over a reference flux F_* by the equation 1.

$$m = -2.5log_{10}\left(\frac{F}{F_*}\right) \tag{1}$$

As well, the absolute magnitud M is defined as the apparent magnitud of the star if it were at a distance of 10 pc. By this way, the absolute magnitud relate the apparent magnitud to the distancefrom the earth to the star. this relation is called the distance modulus $m - M$.

$$m - M = 5log_{10}(D_{(pc)}) - 5 \tag{2}$$

Distance modulus expression were D is the distance to the star en parsec. from this equation, an expression for the distance D in function of its apparent and absolute magnitude can be obtained.

$$D = 10^{\frac{m-M}{5}+1} \tag{3}$$

Due to both magnitudes give information about the flux of stars, and therefore its energy, it could be used to determine the state of the star. One of the ways used to represent it is the Hertzsprung-Russell (**H-R**) diagram.

In a Hertzsprung-Russell (**H-R**) diagram the absolute magnitud M of a certain star cluster are plot as function of the spectral type ("Color index") which are related with the temperature of the star. In those types of diagram is posiblle to observe some defined regions which indicate the state of the star.

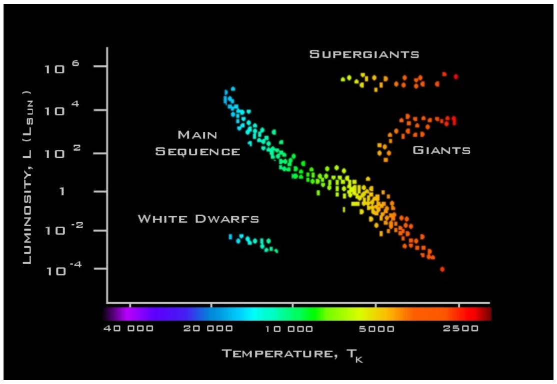

Figure 1: *Hertzsprung-Russell (**H-R**) diagram with four differents states of the stars: White Dwarfs, Main sequence, Giants and Super Giants. [1]*

In Figure 1 an Hertzsprung-Russell (**H-R**) diagram is shown with four different regions corresponding to the evolutionary state of the star. The White Dwarf, in the left botton part of the diagram,the oldest with lowest luminosity but high temperature; Red Gigants and Supergigants, at top right; high luminosity and low temperature; and the Main sequence, the long diagonal line, where the stars spend most of their time.

2. Methods

In this experiment the CLEA program *Photoelectric Photometry of the Pleiades* has been used to record the apparent magnitudes of 24 stars on the region of the Pleiades star cluster.

This program allows to simulate the real procedure to take meassures in a real telescope, been necessary to request for bigger telescopes havin limit number of measuresfor each. For that reason meassures have been taken with three differents telescopes with diameters of 0.4, 1 and 4 meters.

Once in the control panel, the corresponding star of study have been located by its coordinates archived in the program. The control panel allows to track the star in order to not lose it. This tracking is necessary due to, although the movement of the star is negligible form the earth, the earth is also rotating so the image of the star will move from east to west i opposite direction of the rotation move.

Before measure the apparent magnitude of the star by the photometer is necessary to measure the background, by measure the sky, in order to minimaze the noise. This must be done for each filter in each telescope.

After tracking the star and the sky noise has been measured, one of the posible filter (B, for blue, and V, for visual) has been selected and the measure started. The measure is made by means of integrations (number of times a measure is repeated) so it is necesary to select the wanted integrations and the duration of each integration. This selection is done trying to mantaing the signal noise, or S/N ratio, in 100. If this value is shown to increase or decrese, integrations or time should be change.

Once the apparent magnitude in one of the filters is recorded, the filter is changed and the apparent magnitude measured again. Then, change the localization to another star and repeat the process.

3. Results

The apparent visual and blue magnitude (m_V and m_B respectivily) of 24 differents stars on the region of the Pleiades star cluster have been measured using the CLEA program *Photoelectric Photometry of the Pleiades*. All the data obtained at the laboratory are shown in Table 4, in Appendix B.

In Figure 2 the apparent visual magnitud, m_V, and the color index, $m_B - m_V$, are plotted in a Hertzsprung-Russell (**H-R**) diagram showing the main sequence of the stars.

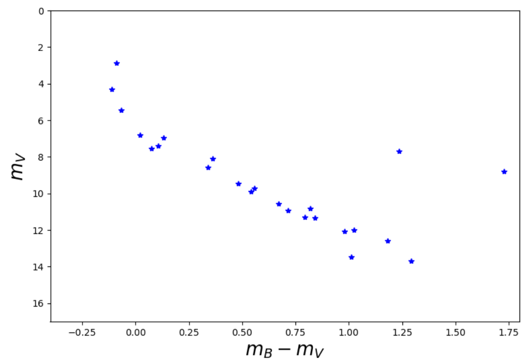

Figure 2: *(**H-R**) diagram of apparent visual magnitud m_V of 24 differents stars on the region of the Pleiades star cluster as function of their color index $m_B - m_V$.*

On the other hand, the absolute visual magnitude, M_V, of known main sequence stars, as well as the color index, $M_B - M_V$; are known [2] and appear in Table 3, in Appendix A.

In Figure 3 the absolute magnitude , M_V, and the color index, $M_B - M_V$, of the known main sequence stars [2], are plotted in a (**H-R**) diagram, showing again the main sequence of the stars.

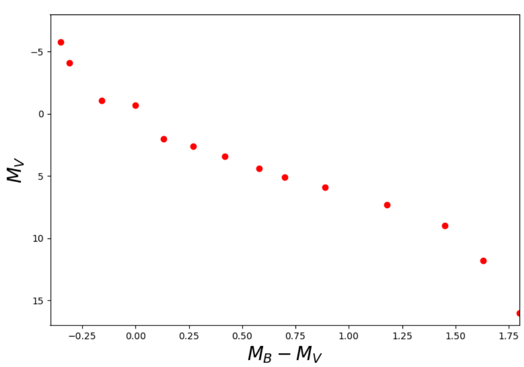

Figure 3: *(**H-R**) diagram of absolute visual magnitud M_V of known main sequence stars as function of their color index $M_B - M_V$.*

In order to compare both magnitudes, M_V and m_V, they have been plotted in a same (**H-R**) diagram. However, due to some of the experimental values of the apparent visual magnitude m_V at the edges of the diagram could be out the main sequence, only some values of both magnitudes at the $B - V$ [1] middle zone have been plotted.

Table 1 shows the values used in order to obtain the linear regression to determine the distance D.

$M_B - M_V$	M_V	$m_B - m_V$	m_V
0.27	2.6	0.482	9.47
0.42	3.4	0.795	11.3
0.58	4.4	0.339	8.581
0.7	5.1	0.558	9.702
0.89	5.9	1.011	13.459
1.18	7.3	0.671	10.552
1.45	9.0	0.98	12.054
		1.025	12.007
		0.361	8.109
		0.541	9.897
		1.182	12.601
		1.291	13.689
		0.715	10.928
		0.818	10.821
		0.842	11.351

Table 1: *Values at the $B - V$ middle zoneused to obtain the difference $m_V - M_V$. Two first columns corresponds to known main sequence stars. The other two columns corresponds to stars on the region of the Pleiades star cluster.*

In Figure 4 both visual apparent (m_V) and absolute (M_V) magnitudes have been plotted in a (**H-R**) diagram as a function of their color index ($B - V^1$). Only stars at the the $B - V^1$ middle zone are plotted.

[1] B and V represent the corresponding magnitude for blue (B) or visual (V)

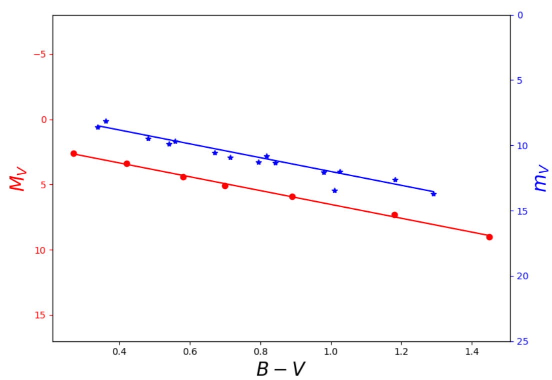

Figure 4: *Visual apparent (m_V, blue stars) and absolute (M_V, red dots) magnitudes as a function of their color index ($B-V$[1]). Y-axis range are different for both magnitudes been $[17, -8]$ for M_V and $[25, 0]$ for m_V. Both adjust have been done by a linear regression.*

The linear regression done allow to obtain slopes and intercepts for both magnitudes. This values appear in Table 2.

	Slope	Intercept
m_V	5.3 ± 0.3	6.7 ± 0.2
M_V	5.30 ± 0.12	1.23 ± 0.11

Table 2: *Slopes and intercepts for both magnitudes with their standard deviation [C].*

Both slopes are shown to be equal, which means both adjust are paralel each other. Thus the difference between both magnitudes' adjust must be the same for whatever color index value. The difference $m_V - M_V$ is going to be obtained by means of intercepts values which correspond to a star with color index $B-V=0$.

$$m_V^{intercept} - M_V^{intercept} = 5.5 \pm 0.3 \tag{4}$$

Once the difference has been determined, the distance D, in parsec, can be calculate by equation 3. The value of D in light years has been obtained taking into account that 1 pc = 3.26156 ly.

$$D = 125 \pm 14 \text{ pc} = 406 \pm 47 \text{ ly} \tag{5}$$

4. Conclussions

Three different telescopes with diameters of 0.4, 1 and 4 meters have been used in order to meassure the apparent magnitude of 24 stars on the region of the Pleiades star cluster by means of a photometer with two filters, blue filter m_B and visual filter m_V, been able to obtain their color index and, therefore, a (**H-R**) diagram.

From that diagram, it has been possible to determine that almost all the stars measured are in the main sequence. There are two stars ($N2230-00985$ and $N2230-02192$) that differ above the main sequence coulding be two Red Giants according to the diagram of the Figure 1. As well, the star $N2230-01554$ differs below the main sequence coulding be a White Dwarf.

The index color ($B-V$) of the (**H-R**) gives information about the range of emision of stars, and therefore, its temperature. The hottest star would emites in the blue range with the lowest color index ($B-V$) value. By this terms and according to the diagram 2, the hottest star meassured is $N2230-01585$ with an color index $B-v=-0.11$. On the other hand, the apparent visual magnitude m_V is related by equation 1 with the luminosity. Lower apparent magnitud means higher luminosity, so for stars of Table 4 in the diagram 2 the brightest star is $N2230-02202$.

Once linear regression of both magnitudes in the (**H-R**) diagram have been done is possible to obtain the absolute or apparent magnitude for whatever star from its color index $B-V$ by the adjust equation given by the slope and the intercept. By this way, the absolute and apparent magnitud can be calculated for the

Sun (type $G2$ and $B - V = 0.62$) if it were in the Pleiades cluster.

Comparing those values with absolute magnitud of known main sequence stars, the distance to the Pleiades star cluster has been obtained with a final value of $D = 406 \pm 47$ ly. This value is compatible and very similiar which the obtained in In 1958 by *H.L. Johnson* and *R.I. Mitchell* of 410ly. The discrepancy between both values is about less than 1%.

$$\begin{aligned} M_V &= 5.30 \cdot (0.62) + 1.23 = 4.516 \\ m_V &= 5.3 \cdot (0.62) + 6.7 = 9.986 \end{aligned} \tag{6}$$

References

[1] Kathryn Hadley Ph.D. Hertzsprung russell diagram. `http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z13.html`. Accessed: Friday 27$^{\text{th}}$ April, 2018.

[2] Contemporary Laboratory Experiences in Astronomy. Photoelectric Photometry of the Pleiades: Student manual. A Manual to Accompany Software for the Introductory Astronomy Lab Exercise Document SM 2: Version 1.

[3] `https://github.com/Jaimedgp/Practicas-de-Laboratorio/tree/master/Astronomy/Pleiades/CalcScript.py`.

A. Given Data of the Absolute Magnitud

M_V	$M_B - M_V$
-5.8	-0.35
-4.1	-0.31
-1.1	-0.16
-0.7	0.0
2.0	0.13
2.6	0.27
3.4	0.42
4.4	0.58
5.1	0.7
5.9	0.89
7.3	1.18
9.0	1.45
11.8	1.63
16.0	1.8

Table 3: *Given values for visual absolute magnitude M_V and color index $M_B - M_V$ of main sequence stars [2].*

B. Raw Data Obtained in the Laboratory

Object-ID	RA	Dec	B	V
N2230-01442	3h41m18.0s	$23^o58'00''$	10.539	8.81
N2230-00478	3h42m55.1s	$24^o29'36''$	9.952	9.47
N2230-00526	3h44m06.6s	$24^o20'12''$	12.095	11.3
N2230-00306	3h45m06.5s	$24^o15'50''$	8.92	8.581
N2230-01585	3h45m12.5s	$24^o28'02''$	4.18	4.29
N2230-00156	3h45m40.2s	$24^o37'39''$	10.26	9.702
N2230-01554	3h45m42.4s	$25^o03'26''$	14.47	13.459
N2230-00319	3h45m43.2s	$24^o16'13''$	11.223	10.552
N2230-00990	3h45m48.4s	$24^o52'43''$	13.034	12.054
N2230-01908	3h46m27.3s	$24^o15'18''$	7.51	7.404
N2230-02089	3h46m27.8s	$23^o35'35''$	13.032	12.007
N2230-01621	3h46m34.2s	$23^o37'27''$	8.47	8.109
N2230-01627	3h46m50.5s	$23^o14'22''$	10.438	9.897
N2230-02081	3h46m59.3s	$24^o31'12''$	6.83	6.81
N2230-01820	3h47m01.4s	$24^o22'24''$	13.783	12.601
N2230-02202	3h47m29.1s	$24^o06'18''$	2.78	2.87
N2230-02192	3h47m36.9s	$23^o36'34''$	8.942	7.707
N2230-02091	3h47m50.8s	$24^o40'45''$	14.98	13.689
N2230-02449	3h48m13.4s	$25^o05'56''$	11.643	10.928
N2230-02207	3h48m20.8s	$23^o25'16''$	5.367	5.434
N2230-01601	3h48m30.1s	$24^o20'44''$	7.078	6.948
N2230-01175	3h49m07.5s	$24^o00'40''$	11.639	10.821
N2230-01127	3h49m25.1s	$23^o47'42''$	12.193	11.351
N2230-00985	3h49m56.6s	$24^o20'56''$	7.629	7.554

Table 4: *Raw data obtained in the laboratory using the CLEA program Photoelectric Photometry of the Pleiades. Three first columns with the Id of each star (*Object-ID*) and their coordenates (*RA *and* Dec*) are used in order to locate the star. The two last columns are the apparent magnitudes of each star meassured by the photometer with the blue filter* B *and the visual filter* V*.*

C. All The Calculus

All the calculus done in the report, including linear regressions, graphs, and errors propagation have been done using a script wrote by the student in python and available in [3].