Colour-Magnitude Diagram Practical Report

TD Msweli
(MSWTSH005)

07 August 2020

Contents

List of Figures

1 Introduction

A Colour-magnitude diagram is a representation of the relationship between the magnitude and the colour index of stars in a cluster(compared to the H-R diagram which is used for individual stars.). The Colour-magnitude diagram has a lot of significance in so much as it gives information about the star cluster including it's distance from the observer(Brill, 3013) . The aim of this project is to make a Colour-magnitude diagram of the NGC 3532 star cluster. Images in two filters will be reduced and aligned before photometry is done, from here, instrumental magnitudes will be calculated and used along with the absolute magnitudes of the stars to come up with a general function for the total sample of stars being observed, this general function will then be manipulated to calculate the color index and the magnitudes of the different stars. Ultimately, a Color-magnitude diagram will be drawn and used to find the age and the distance to the NGC3532 star cluster.

Figure 1: An image of the NGC3532 star cluster(source: Fred Herrmann, Astronomy)

2 Method

Using two images(1 B-filter image and 1 V-filter image) that have already been reduced(Yotti, 2020), These images were aligned using astroImageJ software; an image sequence of the two images was opened and the Align stack using WCS or apertures function was used to do the aligning with a *radius of object aperture=7, an inner radius of background annulus=17 and an outer radius of background annulus=27.* To continue the aligning process, 4 stars were selected and the aligning process was finished having produced two aligned images(Yotti, 2020). To build an equatorial coordinate system into the two FITS files, the images were uploaded to the (http://nova.astrometry.net) site and the two images were downloaded having a coordinate system built in. The next step was to do aperture photometry on the two images. To do this, the images were opened in an image sequence in AstroImageJ and using the recommended buttons and an *innermost circle= 5 ,middle circle= 12 and the outermost circle= 17* as these were convenient to use in order to prevent flux from neighboring stars. Photometry was done on a number of 50 stars and data containing the Right Ascension, Declination and Source-Sky was retrieved. The next step was to convert the source-sky flux of each star into an instrumental magnitude using the formula: $m = -2.5log(\frac{N}{t})$, where N is the source-sky flux, m is the instrumental magnitude and t is the exposure time of each image. After this values of the instuental magnitudes $b$and$v$ were recorded. The next step was to chose 20 stars and find their standard magnitudes, the 20 stars were chosen and their coordinates were uploaded to the SIMBAD database to retrieve the standard magnitudes in both filters. Using the Standard magnitudes and the instrumental magnitudes of the 20 stars, the following equations($B - V = C_{bv} + \mu_{bv}(b - v)$ and $V - v = C_v + \epsilon(B - V)$) were represented graphically to produce the values of C_{bv}, μ_{bv}, C_v and ϵ (using a vpython programme to do least squares fitting)(Yotti, 2020). The two equations were now used to calculate the $B - V$ and V values for all the stars using the values retrieved from the linear leastsquares graph. Using the equations: $(B - V)_0 = (B - V) - E(B - V)$, where E is the fixed color excess value= 0.1 and $(B - V)_0$ is the intrinsic color index and $V_0 = v - A_v$, where V_0 is the V intrinsic magnitude and A_v is the V-band extinction in magnitudes= $3.1E(B - V)$, the extinction correlated color index values and V-magnitude values were all produced for each star. A color magnitude diagram was then plotted with the y axis(V_0) in reverse in order to indicate increasing brightness since a star's brightness is inversely related to it's magnitude. The next step was to plot a color magnitude graph using the isochrone models given in order to calculate the distance to the star, this was done by shifting the graph along the y axis(V_0) in order to match the main sequences of the two graphs. Stars with the same color index were picked and the formula ($m - M = 5log(d) - 5$ were m is the apparent magnitude, M is the absolute magnitude and d is the distance between the star and the observer in parsecs.) was used to calculate the distance to the star. The final step was to find the age of the star cluster, this was done by comparing the isochrone models and finding out which one was relatively similar to the data of the star cluster, in this way an appropriate age for the star cluster was determined.

3 Data and Results

3.1 Alignining and doing photometry

TableA: Figures used to align the two images in the stack aligner window.

radius of object aperture	7
inner radius of background annulus	17
outer radius of background annulus	27

TableB: Figures used to do photometry in the multi aperture measurements window.

radius of object aperture	5
inner radius of background annulus	12
outer radius of background annulus	17

3.2 Converting sky counts into Extinction-Correlated Standard Magnitudes

TableC: Showing The Source-Sky, RA and Dec of the Stars

Star	B-RA	B-DEC	B-Source-Sky	V-RA	V-DEC	V-Source-Sky
T1	11.103541	-58.737986	175356.170374	11.103541	-58.737992	321931.207779
C2	11.087969	-58.783726	173175.776766	11.087972	-58.783743	301924.529925
C3	11.092475	-58.730481	120514.945416	11.092478	-58.730492	216551.769348
C4	11.095132	-58.836221	130123.425236	11.095132	-58.836235	236262.871260
C5	11.094627	-58.731372	145069.542904	11.094630	-58.731383	267050.506798
C6	11.102203	-58.892275	194081.605887	11.102199	-58.892274	334616.965162
C7	11.103661	-58.844041	262564.648080	11.103659	-58.844042	480746.803780
C8	11.103719	-58.810368	129439.981098	11.103718	-58.810371	232643.523232
C9	11.108091	-58.805146	108023.655752	11.108089	-58.805142	219571.295152
C10	11.110379	-58.860773	69737.497408	11.110374	-58.860759	124301.779459
C11	11.106511	-58.695100	82806.146817	11.106512	-58.695104	150111.771534
C12	11.109986	-58.744094	349221.652960	11.109985	-58.744094	590856.726580
C13	11.113763	-58.742207	150221.607522	11.113761	-58.742202	265072.026556
C14	11.114246	-58.706764	160494.304934	11.114245	-58.706762	283399.099946
C15	11.115201	-58.793439	493561.673341	11.115196	-58.793426	796241.260297
C16	11.098203	-58.662618	194996.918643	11.098205	-58.662624	318166.459988
C17	11.098531	-58.675299	100265.488169	11.098533	-58.675306	178980.454777
C18	11.102070	-58.638395	167067.175389	11.102072	-58.638400	295451.123948
C19	11.095999	-58.677618	125477.311258	11.096002	-58.677624	415010.083551
C20	11.081964	-58.749633	239631.477752	11.081968	-58.749647	418428.117283
C21	11.076062	-58.694453	187312.501912	11.076067	-58.694454	595844.724127
C22	11.083323	-58.831202	48841.891147	11.083326	-58.831226	90583.689654
C23	11.086988	-58.842399	90447.109847	11.086990	-58.842421	160330.311478
C24	11.081729	-58.551718	297687.910019	11.081731	-58.551691	480628.711144
C25	11.082321	-58.665898	209415.947796	11.082325	-58.665898	364044.935468
C26	11.084232	-58.685650	64894.84108	11.084236	-58.685655	120390.238811
C27	11.088591	-58.676835	67021.468697	11.088595	-58.676840	120005.102726
C28	11.099637	-58.724925	191022.099682	11.099638	-58.724934	617943.791150
C29	11.097477	-58.731186	86444.236667	11.097479	-58.731196	160093.340170
C30	11.090667	-58.922119	37233.537569	11.090666	-58.922138	70729.305052
C31	11.119907	-58.907496	221910.006157	11.119896	-58.907450	384050.302767
C32	11.107598	-58.762888	105152.199615	11.107597	-58.762889	202656.357251
C33	11.085535	-58.779307	81742.723020	11.085539	-58.779325	148735.807039

TableC: Showing The Source-Sky, RA and Dec of The Stars(continued)

C34	11.082776	-58.794878	211323.447492	11.082780	-58.794898	375896.285978
C35	11.096706	-58.831098	102715.407475	11.096706	-58.831110	192356.739965
C36	11.094584	-58.597766	49986.420751	11.094586	-58.597764	92888.949778
C37	11.072027	-58.768891	235684.423406	11.072032	-58.768906	411704.883679
C38	11.076661	-58.755795	198195.151164	11.076665	-58.755809	664529.861497
C39	11.080587	-58.717726	102639.852338	11.080591	-58.717735	504005.477691
C40	11.070201	-58.728462	196654.741142	11.070205	-58.728467	523566.736529
C41	11.085508	-58.859981	65998.719515	11.085510	-58.860006	119369.604913
C42	11.096955	-58.541548	93828.700727	11.096957	-58.541541	164496.717882
C43	11.082882	-59.018277	365226.746485	11.082879	-59.018312	641558.460654
C44	11.085260	-59.016406	111200.951213	11.085257	-59.016436	198640.050587
C45	11.093308	-58.769334	111376.216096	11.093310	-58.769347	203505.839151
C46	11.099056	-58.692493	84978.731456	11.099058	-58.692500	155477.886595
C47	11.097068	-58.703367	64493.652822	11.097070	-58.703375	120467.250642
C48	11.077573	-58.685307	98020.614638	11.077577	-58.685307	173385.558605
C49	11.095134	-58.963337	39276.189705	11.095130	-58.963347	73484.760908
C50	11.077007	-58.730654	54031.026670	11.077011	-58.730663	100219.147635

exposure time for b filter = $15 seconds$
exposure time for v filter = $15 seconds$

$$m = -2.5log(\frac{N}{t})$$

, where N is the Source-Sky for an image with a respective filter.
Using the data in TableC and the equation above, the result is the data in TableD.

TableD: The Instrumental Magnitudes of The Stars in The b and v Filters.

Star	b	v
T1	-10.1696	-10.8292
C2	-10.1560	-10.7595
C3	-9.7624	-10.3987
C4	-9.8457	-10.4933
C5	-9.9637	-10.6263
C6	-10.2797	-10.8711
C7	-10.6079	-11.2646
C8	-9.8399	-10.4765
C9	-9.6436	-10.4137
C10	-9.1684	-9.7960
C11	-9.3549	-10.0008
C12	-10.9175	-11.4885
C13	-10.0016	-10.6182
C14	-10.0734	-10.6908
C15	-11.2931	-11.8124
C16	-10.2848	-10.8164
C17	-9.5627	-10.1978
C18	-10.1170	-10.7360
C19	-9.8062	-11.1049
C20	-10.5086	-11.1138
C21	-10.2412	-11.4976
C22	-8.7818	-9.4524
C23	-9.4508	-10.0723
C24	-10.7442	-11.2643
C25	-10.3623	-10.9627
C26	-9.0903	-9.7613
C27	-9.1253	-9.7578
C28	-10.2625	-11.5371
C29	-9.4016	-10.0707
C30	-8.4871	-9.1838
C31	-10.4252	-11.0207
C32	-9.6143	-10.3267
C33	-9.3409	-9.9908
C34	-10.3721	-10.9974
C35	-9.5889	-10.2700

Star	b	v
C43	-10.9661	-11.5779
C36	-8.8069	-9.4797
C37	-10.4906	-11.0962
C38	-10.3025	-11.6160
C39	-9.5881	-11.3159
C40	-10.2940	-11.3572
C41	-9.1086	-9.7520
C42	-9.4906	-10.1002
C44	-9.6750	-10.3049
C45	-9.6768	-10.3312
C46	-9.3830	-10.0390
C47	-9.0836	-9.7619
C48	-9.5380	-10.1573
C49	-8.5451	-9.2253
C50	-8.8914	-9.5621

TableE: Data From the SIMBAD Database Showing The Stars and Their Respective Standard Magnitudes.

No.	Object	MagB	MagV
1	T1	8.561	8.469
2	C3	8.919	8.910
3	C4	8.893	8.809
4	C9	8.958	8.778
5	C11	9.374	9.273
6	C14	8.635	8.614
7	C15	7.395	7.358
8	C17	9.149	9.14
9	C20	8.169	8.167
10	C22	9.885	9.792
11	C24	7.874	7.992
12	C26	9.621	9.525
13	C30	10.240	10.110
14	C31	8.248	8.262
15	C33	9.377	9.317
16	C38	8.651	7.624
17	C44	9.014	8.949
18	C45	9.031	8.952
19	C47	9.639	9.555
20	C49	10.191	10.082

The following equations were used to construct linear fits depicted in figures GraphA and GraphB.

$$\begin{aligned} B - V &= C_{bv} + \mu_{bv}(b - v) \\ V - v &= C_v + \epsilon(B - V) \end{aligned}$$

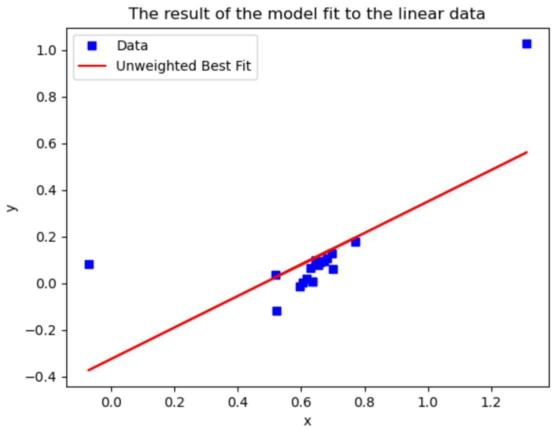

Figure 2: GraphA, The linear graph of B-V versus b-v (y=B-V, x= b-v).

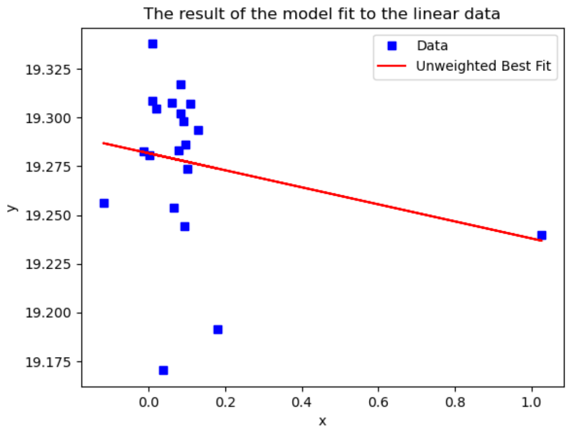

Figure 3: GraphB,The linear graph of V-v versus B-V (y=V-v, x=B-V).

The results are the following:

$$C_{bv} = -0.32 \pm 0.11$$
$$\mu_{bv} = 0.67 \pm 0.16$$
$$C_v = 19.28 \pm 0.01$$
$$\epsilon = -0.04 \pm 0.04$$

To correct for extinction and reddening, the following equations were used:

$(B - V)_0 = (B - V) - E(B - V)$,where E=0.1.

$V_0 = V - A_v$,Where $A_v = R_v E(B - V)$ and $R_v = 3.1$

TableF: The data of the magnitude(V_0) versus Color Index$(B-V)_0$.

Star	$(B-V)_0$	V_0
T1	0.10974185720999974	8.408143061085003
C2	0.07592746841999995	8.490954801170002
C3	0.0956901464009994	8.844110975288503
C4	0.10250278854300049	8.746877254455502
C5	0.11151337533300061	8.6103783173705
C6	0.06861959684999996	8.382172861225
C7	0.10799033517000063	7.9734408885449999
C8	0.09581370471900075	8.766289187831498
C9	0.17639546379300047	8.7976910040805
C10	0.09039906380699914	9.448879591519503
C11	0.10146590351099932	9.239732307523502
C12	0.056284387650000774	7.769634317024999
C13	0.08379697419000032	8.629230687815001
C14	0.08426030129999999	8.55646408505
C15	0.025112652389999417	7.457850418515003
C16	0.03253467185999974	8.45093978761
C17	0.09498660760800073	9.045274893708001
C18	0.08524873287000032	8.510861744995003
C19	0.4951363656239996	7.982528498924
C20	0.07693106543999971	8.136258363440003
C21	0.46961875152000043	7.599765885520001
C22	0.11639823371100005	9.782337152223501
C23	0.08679606885900018	9.173935033221502
C24	0.02563313787000033	8.005735427495003
C25	0.07401895533	8.288555510704999
C26	0.11658451186800012	9.473411536718002
C27	0.09337605189300047	9.4859159559305
C28	0.48062205431999966	7.555947143320002
C29	0.11546311397399982	9.164392657899
C30	0.13208762377799976	10.044862260753002
C31	0.07110342017999968	8.23160653993
C32	0.14154986781900006	8.8982803991815
C33	0.10389939804899942	9.2487839905365
C34	0.08905642461000016	8.247925005985003
C35	0.12275125900200001	8.962223029277002
C36	0.11768635809000015	9.754551098964999

TableF: The data of the magnitude(V_0) versus Color Index$(B-V)_0$(continued)

Star	$(B-V)_0$	V_0
C37	0.07719962354999943	8.153741024175
C38	0.50407286904	7.46791356204
C39	0.7538622488730002	7.670971357660501
C40	0.35309094317999995	7.78548488543
C41	0.0999675570509997	9.4891174848135O2
C42	0.07956096612300023	9.1488946742855
C43	0.08084554245000022	7.670697626825
C44	0.09182716257599957	8.939350536776002
C45	0.10664000712000067	8.90731484612
C46	0.10750526267400021	9.199248977849
C47	0.12106317497400008	9.470975527399002
C48	0.08540096866200078	9.089484352186998
C49	0.12214241412299981	10.007235106285503
C50	0.11647353333599957	9.672556123036001

3.3 Plotting The Color-Magnitude Diagram

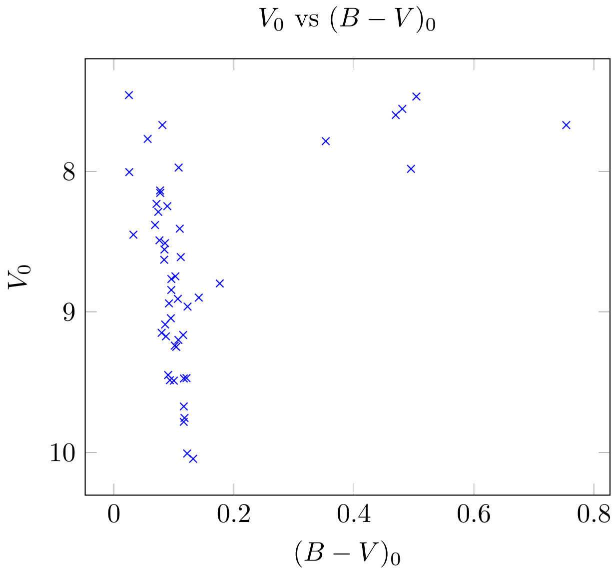

Figure 4: GraphC,The color-magnitude diagram of star cluster NGC3532.

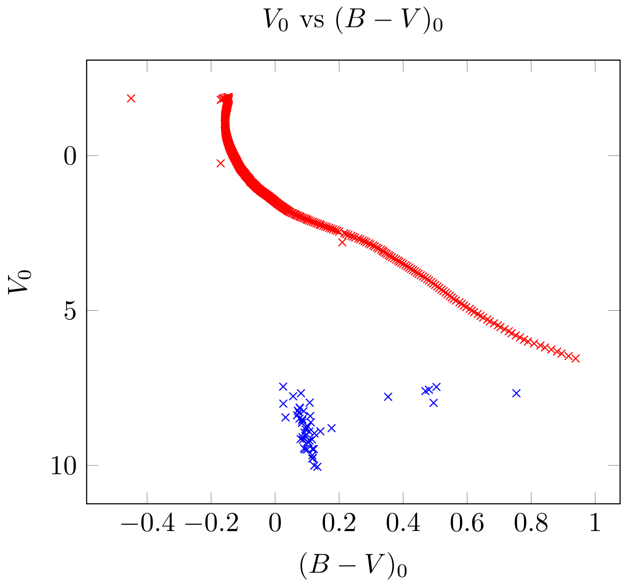

Figure 5: GraphD,The color-magnitude diagram of star cluster NGC3532 compared to an isochrone model.

If the isochrone graph is translated along the y-axis its main sequence overlaps with the main sequence of the colour-magnitude diagram of NGC3532.
Using the formula: $m - M = 5log(d) - 5$, the distance (d) can be calculated in parsecs.
Star coordinates on data of the magnitude(V_0) versus Color Index$(B-V)_0 = ((B-V)_0; V_0)$
From isochrone model: $(0.140; 2.221)$
From CMD(NGC3532: $(0.141; 8.898)$

$$\begin{aligned} m - M &= 5log(d) - 5 \\ 8.898 - 2.221 &= 5log(d) - 5 \\ d &= 10^{(\frac{8.898-2.221+5}{5})} \\ d &= 216.47pc \end{aligned}$$

3.4 Determining The Age of The Cluster.

The age model that best represents the CMD of the NGC3532 Star Cluster is the 10^{10} age model which is represented below.

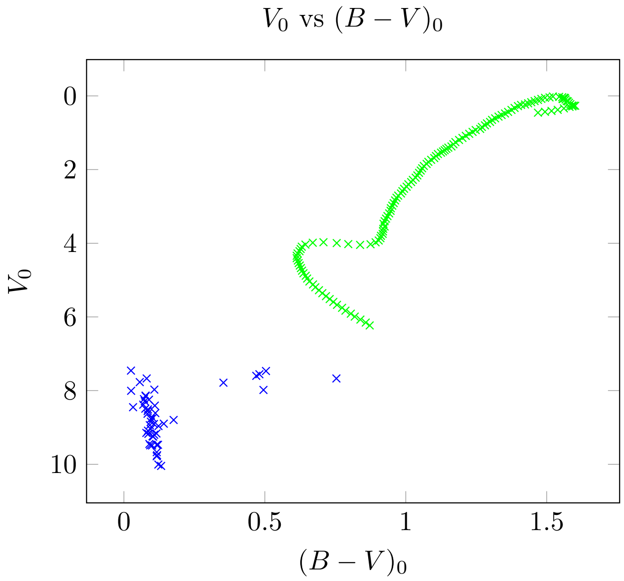

Figure 6: GraphE,The color-magnitude diagram of star cluster NGC3532 compared to an age model.

NGC3532 Star Cluster age=10^{10}

4 Analysis and Discussion

The results of this project were produced in the following manner: After photometry was done on the two images, one taken with a b filter and one taken with a v filter, the results of the stars' Right Ascension, Declination and Source-sky in the two filters were recorded in Table C on page 5 and page 6. Using the equation: $m = -2.5log(\frac{N}{t})$, the Source-Sky values and the exposure times used while taking the images ,recorded on page 6, were used to calculate the instrumental magnitudes of all the stars. (only the Source-sky data in the b filter was used to calculate the instrumental magnitudes). The instruental magnitudes were recorded in TableD on page 7. On page 8, in TableE, the data of the 20 stars that were chosen, the coordinates from TableC were uploaded to the SIMBAD Database to retrieve the standard magnitudes of the 20 stars. The next step was to produce an equation to find the standard magnitudes of the rest of the stars and this was done by using the equations on page 8, specificly: $B - V = C_{bv} + \mu_{bv}(b - v)$ and $V - v = C_v + \epsilon(B - V)$. The two graphs, GraphA and GraphB were a result of plotting the equations and from these plots, the values of C_{bv}, μ_{bv}, C_v and ϵ were produced. The two equations were now ready to be used to calculate the standard magnitudes of all the stars. The equation used to correct for extinction and reddenning on page 9 was also used in a program to calculate the Extinction corrected magnitudes and color indices. In TableF on page 10, the values of the Magnitudes(V_0) and Color indices($(B - V_0)$) are recorded and used to plot the Color-Magnitude Diagram of the NGC3532 Star Cluster on page 12. On page 13, in GraphD, the Color-Magnitude Diagram of NGC3532 is compared to an isochrone of the age 10^8. The Color-Magnitude Diagram's main sequence overlaps the isochrone's main sequence if the isochrone model is translated along the y-axis. Therefore, the Distance(d) is calculated using two stars from the isochrone model and the Color-Magnitude diagrm. The Distance modulus formula is used to calculate the Distance in parsecs on page 13. On page 14, the age of the cluster is determined by comparing the cluster to an isochrone model of the age 10^{10}, since this model was the most similar to the CMD of NGC3532 in that stars leave the main sequence shorter down the main sequence line.

5 Conclusion

The findings are as follows:

$$\begin{aligned} d &= 216.47pc \\ Age &= 10^{10} years \end{aligned}$$

To improve the project, a bigger sample of stars is imperative, this is realised on the Color-Magnitude Diagram of the NGC3532 Star Cluster on this report on page 12 as the main sequence is short and it is not quite clear when the stars leave the main sequence.

6 References

_Brett Yotti, AST2003H Observational Project,The Color-Magnitude Diagram, 2020.

_Michael H. Brill, Datacolor, Lawrenceville, NJ, USA, Color-Magnitude Diagrams, page 1, 3013.